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Determination of Water Discharge

Chapter X of Meteorologiya, Gidrologiya i Gidrometriya, M. L. Leyvikov; Moscow: 1949, pages 283-342.

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[Note: Refer to original book for the figures.]

CHAPTER X

DETERMINATION OF WATER DISCHARGE

Methods of determining water discharge in open channels (rivers and canals) and at hydrotechnical constructions are rather numerous. They can be divided into the following groups.

1. Methods of determining discharge by measuring velocities of flow and the cross-sectional area of a current.

2. Methods of determining discharge by admixtures.

3. Methods of determining discharge by measuring elements contained in hydraulic formulas such as: level; head of flow over weirs, through orifices etc.; cross-sectional area; longitudinal slope.

4. Methods of direct measurement of water discharge.

5. Indirect methods of computing water discharge by hydrotorical formulas.

Methods of the first group include measuring discharge by means of floats, current meters, bathotachymeters, dynamometers; to the methods of the second group belong the chemical, thermal, and colorimetric determinations; the hydraulic formulas are applied in measuring discharge at weirs, hydrometric flumes, etc.; to the same group belongs the "hydraulic" method of determining discharge by formula (56).

Methods of the first group find the widest use since they are universal and can be applied to currents of any size and kind. Other methods of determining discharge are limited in their application, depending on various conditions. Indirect methods of determining discharge are employed mainly for computation of mean and characteristic discharges.

22. [illegible] OF VELOCITIES OF FLOW OF WATER

Distribution of Velocities of Flow throughout a Cross Section

At different points of a cross section, velocities of flow are not the same. The closer to the bottom and to the banks, the lower the velocity. In open channels, the maximum current velocity is found in the middle of the river, at the surface, or at a short distance beneath the surface of the water. In winter, under a frozen surface, velocity is greater below the water's surface than in summer.

When velocities of flow are measured at different depths along the same vertical line of the cross section, these velocities decrease toward the bottom. The change of velocity with depth may be graphically shown by diagrams of velocities in vertical lines of a river's cross section. These diagrams are drawn in the following way: on the vertical coordinate, depths are plotted at which measurements of velocities were taken; along horizontal lines drawn through these points measured velocities are plotted; the ends of the horizontal segments are connected by a smooth curve (Figure 78). Since the velocity at the very bottom of the current cannot be determined directly by aid of existing hydrometrical devices, the bottom velocity is determined through extrapolation of the diagram (that is, through prolongation of the velocity curve down to the bottom). This applies also to the velocity at the very surface of the water when it is measured with instruments which must be submerged in water.

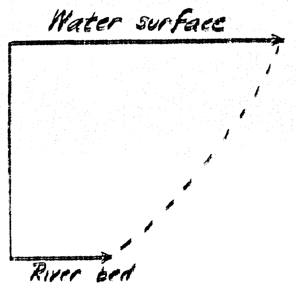


Figure 71. Velocity Diagram Along a Vertical in an Open Channel

A velocity diagram for a current covered with ice differs from the velocity diagram for open currents; under ice cover velocities decrease not only toward the bottom but toward the under surface of the ice as well (Figure 72).

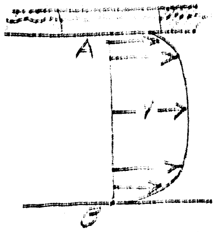


Figure 72. Velocity Diagram Along a Vertical Under Ice Cover

Besides diagrams of velocities in vertical lines, diagrams of velocities along horizontal lines of a river's cross section may be drawn. To do so, on the horizontal line representing the river's width, velocities are plotted as measured at the given depth, and the ends of segments thus obtained are connected by a broken line or a smooth curve (Figure 80). One diagram is drawn for each depth to be depicted.

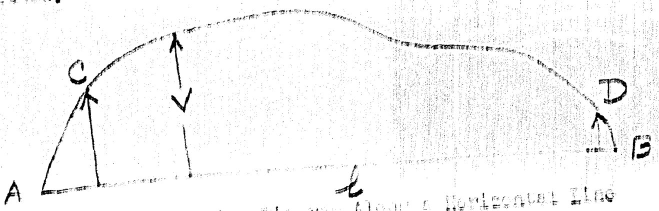


Figure 80. Velocity Diagram Along a Horizontal Line

Equal Velocity Lines

Distribution of velocities throughout the cross section may be graphically shown by drawing equal velocity lines. Drawing these lines is based on distribution data of velocities along different vertical lines of the cross section. Figure 81 illustrates distribution of equal velocity lines in the channel and on the floodlands of an open river; Figure 82 shows these lines for a river covered with ice. Equal velocity lines make it easy to find the direction of the dynamic axis of a river (that is, the maximum velocity line) as well as the influence on the velocity distribution wielded by the roughness of the river's bed, by the channel's configuration, and by the ice cover.

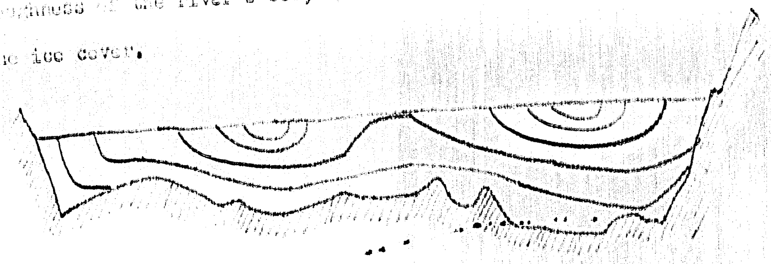


Figure 81. Equal Velocity Lines in an Open River

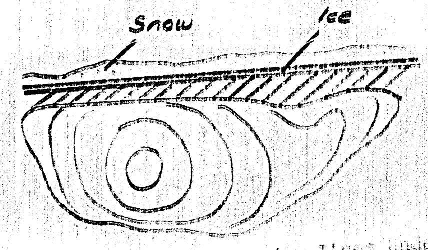


Figure 82. Equal Velocity Lines under Cover

Mean Velocity of Flow in the Vertical

For computing water discharge by measured velocities, it is necessary to know the mean velocity of flow in different verticals. This allows the determination of partial discharges for areas adjoining the verticals. By adding up partial discharges, the amount of the total discharge in the whole of the cross sectional area is then obtained.

The mean velocity in a vertical is the arithmetical mean of velocities at all points of the vertical.

For determination of the mean velocity in a vertical, it is sufficient to measure velocities at the following five points: (1) at the surface; (2) at 0.2H; (3) at 0.6H; (4) at 0.8H from the surface; and (5) at the bottom. H here means the full depth along the given vertical.

With the five-point method, the mean velocity in a vertical is computed by using the equation:

$$v_{mean} = \frac{v_{surf.} + 3v_{0.2H} + 3v_{0.6H} + 2v_{0.8H} + v_{bot.}}{10} \qquad (82)$$

Satisfactory results are also obtained with the three-point method by using the equation:

$$v_{mean} = \frac{v_{0.2H} + 2v_{0.6H} + v_{0.8H}}{4}, \qquad (83)$$

or with the two-point method by using the equation:

$$v_{mean} = \frac{v_{0.2H} + v_{0.8H}}{2}, \qquad (84)$$

where v_{mean} is the mean velocity in the vertical;

$v_{0.2H}$; $v_{0.6H}$; $v_{0.8H}$ are velocities at respective points of depth beneath the surface;

$v_{surf.}$ is the velocity on the surface;

v_{bot} is the velocity near the bottom.

Numerous observations have shown that the velocity at a point which is 0.6 of the total depth (0.6H) is approximately the mean velocity in the vertical, that is,

$$v_{mean} = v_{0.6H} \qquad (85)$$

This evidence is of great practical importance, since to determine the mean velocity in a vertical it is sufficient to measure velocity at only one point. For example, at a 1.5 meter depth the mean velocity in the vertical may be approximated by one measurement at a point 0.9 meter beneath the water surface.

Since determination of the surface velocity can usually be carried out most easily, correlation between the surface velocity and the mean velocity in the vertical is of much interest. In general this correlation is expressed by the equation:

$$v_{mean} = K\, v_{surf} \,. \qquad (86)$$

where v_{mean} and v_{surf} are the mean and the surface velocities respectively;

K is a coefficient which is usually estimated at 0.85, and according to different investigations may vary from 0.76 to 0.92.

Equations (82) through (86) for mean velocity refer to an open channel. In an ice-covered channel, equation (84) is to be recommended as well as the following equations:

$$v_{mean} = \frac{v_{surf.} + 2v_{0.2H} + 2v_{0.4H} + 2v_{0.6H} + 2v_{0.8H} + v_{bot.}}{10}, \qquad (87)$$

$$v_{mean} = 0.85\, v_{0.6H} \qquad (88)$$

or

$$v_{mean} = 0.85\, v_{0.4H} \qquad (89)$$

54. MEASUREMENT OF DISCHARGE WITH FLOATS

Determination of water discharge with floats consists of measuring velocities of a cross-sectional area by means of floats and soundings. There are two kinds of floats: surface and submerged; the former give the surface velocity; the latter the velocity at the given depth of the vertical.

Measurement of Velocities with Surface Floats

Surface floats for measuring velocities usually are made of wooden discs cut from dry logs. Diameter of the discs ranges from 10 to 25 centimeters; their thickness from 5 to [illegible] centimeters. For visibility, floats are painted white or bright red; sometimes they are provided with small flags. Observations with floats must be made only in calm, windless weather. In order to decrease the influence of even a slight wind on the float's movement, the float must project above the surface as little as possible.

The method of determining flow velocities with floats consists of the following: along each of the observation lines (the main as well as the upper and lower auxiliary observation lines), three stakes are fixed, two of them on the side of the river from where floats are to be observed, and one on the opposite side. Above the upper observation line one more auxiliary observation line is fixed; this is called the starting line. The distance between the starting and the upper observation lines must be such that the float will accelerate to the velocity of the current before it crosses the upper observation line; the swifter the current the greater this distance must be. Usually it ranges from 5 to 20 meters. The distance between the upper and the lower observation lines must be chosen so that at its maximum speed the float will cover that distance within 25 or 30 seconds.

After the observation lines have been fixed, soundings are taken along them (with the exception of the starting line). It is important that the width of the river and the depths along all three lines be approximately the same, since velocity measured with floats refers not to the observation lines but to the whole reach between them, which has to be, therefore, as uniform as possible.

After soundings have been completed, floats are put into action. The distance between the upper and the lower observation lines as well as the time of a float's transit between these lines being known, the mean velocity of the float's movement may be computed by using the equation

$$v = \frac{L}{t}, \qquad (90)$$

where v is the mean velocity of flow in meters per second conventionally referred to that point of the main observation line which the float was passing;

L is the distance between the upper and the lower observation lines;

t is the time in seconds of the float's passage from the upper to the lower lines.

Measurement of velocities by means of floats is performed by several observers. With a small river, especially when spanned by a cable or rope, two observers will suffice, one of them to release floats at the starting line, and the other to observe their course by walking down the bank ahead of them and recording with a stop watch the times and points at which the floats pass the three observation lines. With wide rivers, four or five observers are necessary, one of them to release floats from a boat at the starting line, another (by aid of a cable or by taking bearings) to note the points and the rest of the crew to signal the moment at which the floats pass the lines.

Float movement is influenced by various factors: velocity and direction of the wind; shape of the float, its weight, its depth of immersion, etc. Therefore, at each of the given release points, several floats are set free; the points at which they pass the line is determined [illegible] their distances from the banks. When a float is retarded at the banks or passes the observation line unobserved, it is disregarded and another float is released in its place.

When floats are released, they are distributed as evenly as possible across the width of the river, [illegible] or points of current [illegible] cross sectional deflections, and at the river bends. [illegible] nearest level-mark point.

Computation of Float Discharges

Flow velocities measured with surface floats represent [illegible] surface velocities at respective points, or verticals, of the main observation line. Water discharges computed from velocities measured by floats are called float discharges.

Computation of float water discharges is effected in the following way. A drawing is made of the river's cross section along the observation line for the stage level at the time velocities were being measured (Figure 83). On the water-level line are [illegible] verticals; [illegible] these [illegible] the surface points [illegible] velocity [illegible] are plotted on [illegible] values of corresponding [illegible] so obtained are connected [illegible] scale [illegible] by a broken line, which is then replaced by a smooth curve running through most of the points or in close proximity to them. Since [illegible] velocities are equal to zero, the curve is closed at the ends of the horizontal line representing the water level. A smooth curve with upward bulge obtained in this way is called the velocity curve. The vertical lines representing the [illegible] (sounding verticals) are then extended upward until [illegible] the velocity curve. In Figure 83 are drawn, as an example, [illegible] points a [illegible] the lines ad and be [illegible] b [illegible] By drawing a vertical line [illegible] the distance between the [illegible] abvg. [illegible] velocity for the partial area [illegible] multiplying the value of the area abvg by the mean velocity [illegible] partial water discharge for the given partial area [illegible] The same kind of computation is done for the adjoining partial area, and so on. By adding up all the partial discharges, the total discharge through the cross sectional area is obtained.

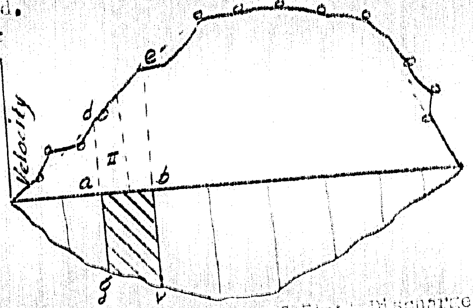


Figure 83. Computation of Float Discharges

I —— Velocity measured by floats

- - - Finally assumed velocities

II Mean velocity for area abvg

The discharge obtained in this way is called fictitious, since surface velocities of flow are always higher than mean velocities in the vertical. To determine the actual discharge, the fictitious discharge is multiplied by a conversion coefficient [illegible] mean velocity, based on the equation [illegible]

$$Q=KQ' \qquad (11)$$

where Q is the actual discharge;
Q' is the fictitious discharge;
K is the conversion coefficient (usually taken as 0.85).

Where possible, a series of measurements [illegible] velocities [illegible] the actual value of the coefficient K under given conditions is computed.

Determination of Float Discharge by Maximum Surface Velocity

On small rivers with a swift current (on mountain rivers) as well as in cases when work has to be done within a short time [illegible], measurements are confined to determining the maximum surface velocity. For this purpose, from 5 to 10 floats are cast into the middle of a river. The two floats covering the distance in the shortest time are used in computation, provided the difference between their times of passage does not exceed 10 percent. The mean time of these two floats is taken to be the maximum surface velocity of the current.

To convert from the maximum surface velocity to the mean velocity through the whole cross sectional area, coefficient K_0 is used; its value is determined by use of empirical formulas. Of these formulas, the following one is employed most often:

$$K_0 = \frac{v_{max} + 2.354}{v_{max} + 3.129} \qquad (92)$$

where v_{max} is the maximum surface velocity in meters per second.

With the method described there is no need to determine the points at which floats pass the observation line, and consequently no necessity to span the stream by cable.

Computation of discharge in simplified case. This value can be obtained by multiplying the area of the cross section by the mean velocity for the whole cross section (which is equal to $v_{mean} = K_0 v_{max}$).

Submerged Floats

Floats used to measure the velocity of flow at a given depth are called submerged floats. A submerged float consists of two parts -- one surface float and a second one connected to the first by a rope or light cable and submerged to the desired depth (Figure 6h). Submersion depth is considered to be the length of the rope or cable; rope length can be changed so as to take measurements at any given depth; usually it is fixed at 0.6H of the vertical in which velocity is being measured. This makes it possible to obtain immediately the mean velocity in a vertical. Best results are obtained with so-called double floats consisting of two parts of equal weight and volume (Figure 6h, 6e and 6f).

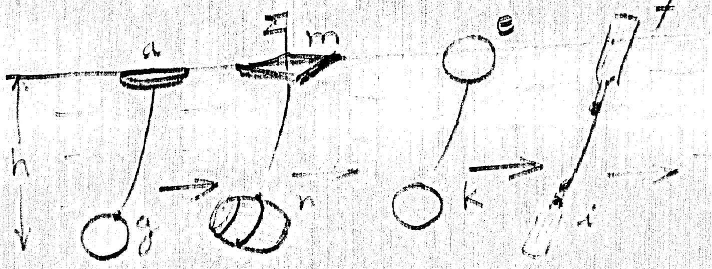


Figure [illegible]. Subsurface Floats

To determine velocity at the submersion depth of a double float, a regular surface float is released first and followed by a double subsurface float submerged to 0.6H depth. Measurement of velocity of subsurface floats is carried out by the usual means. Velocity of a double subsurface float equals the arithmetical mean of the surface and the submerged float velocities, that is,

$$v_{dbl} = \frac{v_{surf} + v_{subm}}{2} \qquad (93)$$

where v_{dbl}, v_{surf}, and v_{subm} are velocities of the double, the surface, and the submerged floats respectively.

From equation (93) we have:

$$v_{subm} = 2v_{dbl} - v_{surf} \qquad (93a)$$

Since the submerged portion of the double float was at 0.6H depth, we may write $v_{subm} = v_{0.6H} = v_{mean}$.

Value of the mean velocity in a vertical having been computed by aid of equation (93a), partial discharges for different adjoining partial cross sectional areas may be obtained, and subsequently, the total discharge for the whole cross section may be found.

Integrating floats

If a small wooden ball be attached by a thread to a rope running through a ring at the bottom end of a wooden pole or spar, and if the pole or spar is lowered to the river bottom and the rope pulled, the thread will break and the ball will be released and simultaneously moving downstream and to the surface. Since its course passes through all the different depths of the current, the ball attains a velocity equal to the mean velocity of the flow in the respective vertical. The time between the moment of the ball's release and that of its emersion being known, the mean velocity in a vertical may be computed by use of the equation:

$$v_{mean} = \frac{L}{t}, \qquad (94)$$

where L is the distance between the point of the float's submersion and the point of its emersion;

t is the time from the moment of the float's release at the bottom to its appearance on the surface.

Emerging floats just described are termed integrating floats.

Let us assume that, in still water, an integrating float travels from a depth h to the surface with a speed v_0. In the time t, which the float took to emerge on the surface, it would have covered, in still water, a distance $h = v_0 t$, from which $t = \frac{h}{v_0}$. After substituting in equation (94) the expression $\frac{h}{v_0}$ for t, we have:

$$v_{mean} = \frac{L \cdot v_0}{h}, \qquad (95)$$

in which L has the same meaning as in equation (94);

v_0 represents the velocity of emersion from a depth h in still water;

h is the depth from which the float emerged from still water when the velocity of emersion was measured.

Thus, if the velocity of emersion from still water and the depth from which that emersion took place have been determined beforehand for a given integrating float, it is not necessary to make any measurements of time while working with such a float. It is sufficient to measure only the distance L over which the float is carried downstream by the current.

Computation of water discharge by velocities measured with an integrating float is effected in the same way as that by velocities measured with a double subsurface float.

General Remarks on Measurements of Water Discharge by Means of Floats

Measurements of water discharge by means of floats do not require the use of complicated devices, thus permitting this method to be employed under any circumstances. Provided that certain rules and procedures are followed, the float method may produce sufficiently exact data. Float discharge computed for small and swift currents on the same basis of the maximum surface velocity may result in an error not exceeding 10 to 15 percent of the actual discharge. Accuracy of determination of discharges by means of surface floats generally lies within 8 to 15 percent; with integrating floats -- within 5 to 8 percent.

Subsurface floats are seldom used. Integrating floats may be employed for measurements of very low velocities of flow.

25. MEASURING DISCHARGE WITH CURRENT METERS

The current meter is the most accurate and most widely used device for measuring velocities of flow of water. The operation principle of the current meter consists of the following: If a horizontal shaft which can rotate on a stationary bearing be provided with attached vanes like those with windmills or of spiral form, and such a contrivance put in a stream so that the current will exert angular pressure on vane surfaces, the vanes will begin to rotate with some velocity. The rotation speed of such a shaft with attached vanes depends on the velocity of the current. Revolving speed of the vanes may be used for measuring the velocity of a current, hence the designation current meters.

Construction of Current Meters

A current meter (Figure (5)) consists of three principal parts: vanes, or blades, A ; body, or housing, B with a computing mechanism; and tail C .

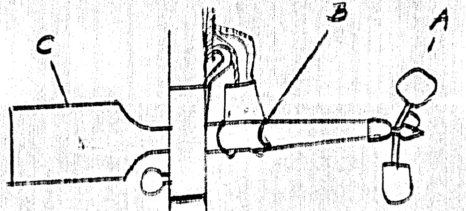


Figure 12. [illegible] Current Meter

Vanes of the current meter consist of spirally bent blades which are attached to the shaft by spokes or directly to the hub.

Size of vanes varies from 4 or 5 to 30 centimeters in diameter. Vanes of larger size revolve more smoothly than those of smaller diameters. However, they are inconvenient for use in smaller rivers and for measuring velocities at points close to the surface or to the bottom. Vanes are detachable, and with some types of current meters are interchangeable.

At the front, on the vane side, the shaft of the current meter pivots against ball bearings in order to reduce friction; for the same reason, the shaft is made as long as possible.

The principal requirement for constructing the body of a current meter is that its shape should be streamlined so that it will disturb as little as possible the natural flow of water in which the current meter is immersed. The body of the current meter serves to house the ball bearing, the revolution counter, and other mechanisms.

As a means of determining the revolving speed of the current

meter vanes, a contact device is employed (Figure 66) whose working principle consists of the following. Near the shaft pivot, a worm gear g connects the shaft with a cog-wheel Z. This wheel is provided with several pins a. As the wheel rotates, each of these pins alternately makes contact with the lever b which closes the electric circuit supplied to the body of the current meter from a dry battery. Closing the circuit activates a signalling contrivance (electric bell, lamp, telephone). By counting the signals representing a definite number of revolutions of the vanes, and by noting with a stop watch the number of seconds between signals, it is possible to compute the number of revolutions of the vanes per second. For each current meter, the correlation between the velocity of flow and the revolutions per second [illegible] known; thus, from the number of revolutions of a current meter, the velocity of flow can be computed. Sometimes an automatic revolution counter or a recorder device is wired into the circuit; in such a case no direct counting of the revolutions is necessary in order to measure velocity.

Figure 66. Contact Device of a Current Meter

By varying the number of pins on the wheel Z, it is possible to secure contacts after any desired number of revolutions of the shaft (of the vanes).

Besides the contact device just described, some other types of it are in use (for instance, in form of a mercury drop rolling within a small revolving drum).

The complete contact device is usually hermetically sealed within an oil-filled chamber to protect the contacts from oxidation. If work is carried out in clean water -- free of mud or dissolved salts -- the contact device can be left exposed.

To maintain the current meter at the desired depth, two methods may be employed: the current meter is either fixed to a pole, that is, to a metal measuring rod that rests against the river bottom, or is hung from a cable.

When used on a pole, the current meter is provided with a hole between body and tail through which the pole is passed and made secure with a set screw; on a cable, current meters are held fast by 2 contrivances in the form of hooks: one above, from which the meter hangs, and another below, to which a bob is attached for the purpose of preventing the device from being shunted aside by the current. Some types of current meters can be used both ways, that is, fixed to a pole or hung from a cable. Such meters are called universal current meters. An intermediate type between the thrust-pole and the cable types is a current meter which is permanently fixed to the lower end of the pole and moved with it up and down in the water.

When a thrust pole is employed, the current meter is fixed at the desired depth by means of set screws; large thrust-pole current meters are held at necessary depths with a cable or a rope.

The lower end of the thrust pole is provided with a round or cross-shape bottom plate to prevent the pole from sinking into the river bed (Figure 67).

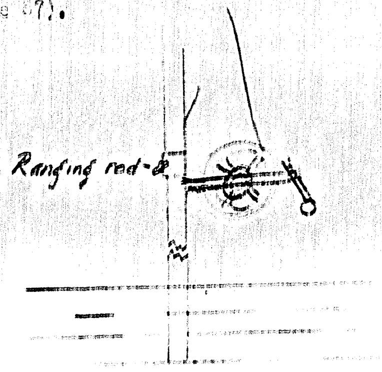


Figure 67. Thrust Pole With Bottom Plate, Depth Indicator, and Ranging Rod

To avoid frequent withdrawal of the current meter for readjusting it to varying depths, a device called a winch is sometimes used. At the top of the pole, a pulley is attached through which a cable of 2 or 3 millimeters in diameter is passed. One end of the cable is connected to the current meter; the current meter can be lifted by means of a small windlass, or gradually lowered by releasing the cable. To facilitate sure movement of the current meter along the pole, the latter is provided with a guide rail, and the body of the meter is grooved to fit the track. The drum frequently carries an indicator dial graduated so as to show the immersion depth of the meter. The reading of depths is effected in the following way: after the pole is set up, the current meter is brought into such a position that its axis lies on the water surface; then the hands are set at zero so that as the meter is lowered the depth of immersion can be read directly from the dial. Such a dial is called the depth indicator. In the absence of such an indicator, the required immersion depth of a current meter can be read directly from the cable by marking it at the necessary intervals.

Sounding poles are provided with a protruding guide or ranging rod which allows the horizontal axis of the current meter to be set in the desired direction (perpendicular to the observation line). The ranging rod consists of a short horizontal tube whose axis is perpendicular to that of the current meter. To set up the current meter correctly, the ranging rod must coincide with the observation line.

Suspension poles are fastened to the observation platform (bridge, pontoon) by means of dowels or grips. For use in lowering and lifting the suspension pole with an attached current meter, a light windlass is used (Figure 88).

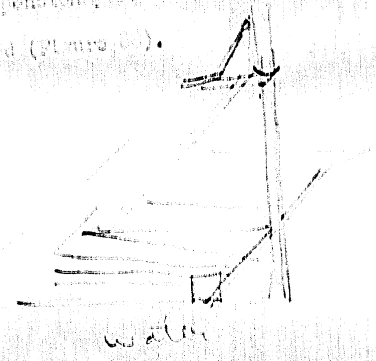


Figure 88. Current Meter on a Suspension Pole

Operating the pole becomes difficult at depths over 3 meters; in these instances, the current meter is lowered by means of a cable. Lowering and raising a current meter by use of a cable can be carried out either by hand (with very light current meters) or by means of a special winch with a depth indicator (Figure 89). Since the bob must be fixed at a distance not less than 0.3 or 0.4 meters from the body of the current meter, current meters cannot be conveniently lowered by cable to considerable depths. However, there are types of cable-held current meters which are prevented from drifting by use of a special slanting cable that eliminates the necessity of bobs.

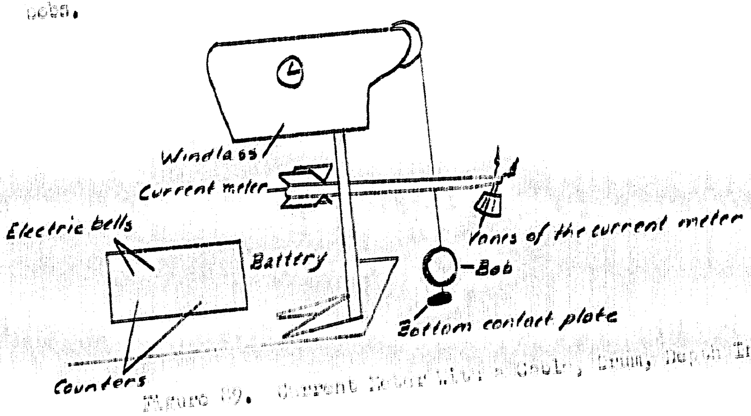


Figure 89. Current Meter with a Cable, Drum, Depth Indicator, and Revolution Counter

The tail part of the current meter represents a guiding device which keeps the meter headed into the current. The tail part usually consists of a vertical plate screwed to the housing of the meter.

All the essential parts of the current meter (vanes, housing, and tail) are made of a non-oxidizing metal.

Equipment for a Current Meter

For the operation of current meters, certain additional equipment is necessary. The above described holding contrivances (poles, cables), a stop watch, and electrical apparatus must be included with the equipment of an electric-signal current meter.

A stop watch is a pocket watch with a big second hand. Most widely used stop watches have dials graduated by 0.2 seconds from 0 to 60 seconds. Minutes are read from an additional small dial.

Stop watches must be regularly checked.

The electrical equipment of a current meter consists of batteries, cable, and signaling devices.

In operating the current meters, batteries of dry or semi-dry cells are employed. The battery and bell (whistle, telephone) are kept in a small box.

In signaling devices, insulated wires are used which are sheathed together in an especially constructed cable or remain loose (which is less convenient). A double cable consisting of two separately insulated strands enclosed in a joint insulation is usually employed. In cable-held current meters, a four-wire cable of 7.5 millimeters in diameter is also used, and functions simultaneously as a support for holding the meter. One-strand cables of about [illegible] millimeters in diameter are also in use. The cable must be checked before using. This is done by the usual method of checking electric wiring. Non-insulated cables or poles serve as return wires.

Of the signaling devices, the telephone has the advantage of being operable with low current; this is especially important in case of open contact, since the latter is quickly oxidized by a high current. Telephones get out of order less frequently than electric bells.

Instead of electric bells, electric revolution counters are sometimes employed in current meters.

One of the last developments in water current meters is the chronograph (Figure 90), which registers the revolving speed of the meter simultaneously with registering the time. This device is employed only in minute and precise research.

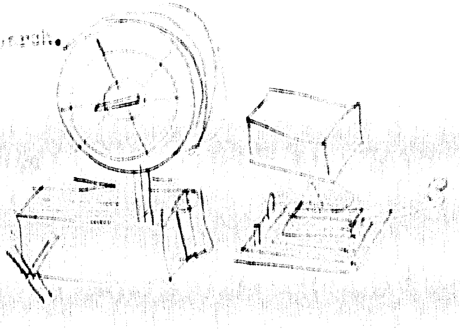


Figure 90. Chronograph

Types of Current Meters

There are many different systems of current meters. On the whole, they can be divided into two groups: (1) those with horizontal shafts, and (2) those with vertical shafts.

The general construction principles of current meters with vanes revolving on a horizontal shaft have been described above.

In the USSR, of current meters with horizontal shafts most widely used, are the Zhestovskiy's current meter, the LAGU current meter, and others.

The Soviet current meter of the Zhestovskiy model (Figure 91) has a light, compact shape. A special feature of this current meter is the completely water-tight insulation of the contact device (chamber) and the ball bearings which are placed within the inner housing 1 of the hub of the screw-vane 21 and set on the common shaft firmly fixed within the body of the meter. The housing 1 is filled with vaseline oil.

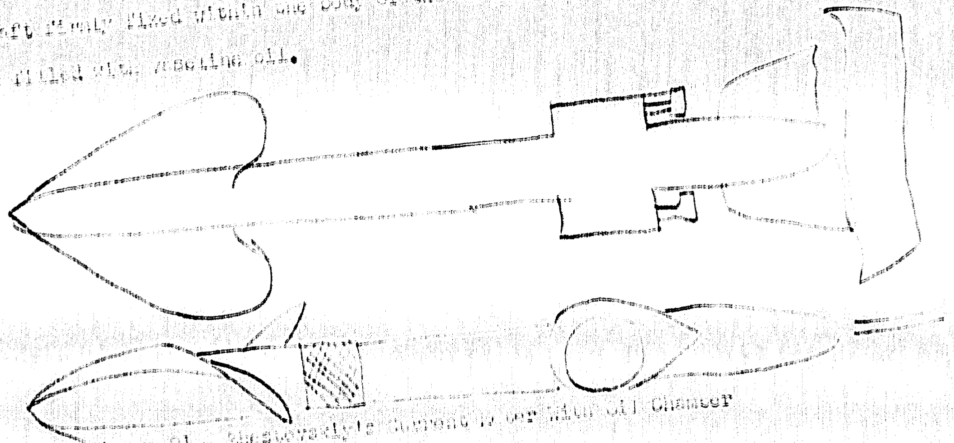


Figure 91. Electrolytic Current Meter with Oil Chamber

The chamber is supplied with electric current through the terminal 2 which is insulated from the meter body by an ebonite bushing 3; the current then enters the receptacle plug 4, which also has ebonite insulation 5. Into the socket 4 is inserted with slight friction, the plug 6, which, in its turn, is insulated from the shaft 7 by the ebonite bushing 8. The shaft 7 has a drilled bore through which a thin copper rod 9 connects the socket 6 with the contact chamber 10; one end of the rod is fixed in the ebonite bushing 11 and has a drilled hole for driving the screw 12, which clamps the contact spring in form of a thin silver wire 13. The free ring of the spring glides over the ebonite roller 14, which has its axle 15 aligned with the cogwheel 16. The cogwheel has 20 teeth and a contact pin 17, whose free end rests on the rim of the roller 14. This type of construction provides for one contact after each 20 revolutions of the vane 21; these signals are transmitted to the channel 18 via the inner worm thread 17 of the detachable ring 19, which is tightly inserted into the cylindrical sleeve 20. The latter is fastened to the vane by means of the coupling 22. The shaft 1 rotates in the tail bushing 23.

The Ott type current meter is universal; it has a set of vanes: for low and for high velocities; it can be used conveniently on small and on large rivers, in muddy and in clear water, and at various current velocities.

One disadvantage of this current meter is the complexity of its construction, which calls for extreme care in handling.

Of other current meters with horizontal shafts, the [illegible] model (developed [illegible] hydrometric service) as well as current meters manufactured by the [illegible] Institute of Hydraulic Engineering and [illegible] ([illegible]) are worth mentioning.

The LAGI current meter (Figure 22) is universal. It consists of a body, a vane with shaft, a contact device, and a tail. The vanes of the current meter are of a detachable screw type; they rotate together with the shaft, which is mounted on a ball thrust bearing.

Figure 22. LAGI Current Meter

The [illegible] meter has a cast brass housing with a narrow cylindrical front part 1, where the shaft with vanes is fixed. The terminals 8 and 9 are situated on the upper part of the housing, the first of them being insulated from the housing by means of the ebonite bushing 10. The lower part of the terminal 9 has the shape of a screw 12 and enters from above the contact chamber 14. On the screw 12, the nut [illegible] silver portion [illegible]. The contact chamber contains a plate [illegible], on which the shaft [illegible] of the contact cogwheel [illegible] is fastened; the cogwheel has [illegible] teeth and the contact pin [illegible].

The contact chamber 14, which is enclosed with metal sheathing, [illegible] is not hermetically sealed.

[illegible] the current meter is dismantled, the front part [illegible] is inserted into a special socket [illegible]

Because [illegible] the IAW current meter cannot be used in [illegible]. The meter is employed for current velocities over 0.[illegible] meters per second.

The [illegible] Institute of Hydraulic Engineering and [illegible] manufactured small current meters with open contacts (so-called "pocket" meters, handy for preliminary research). A special feature of these current meters consists in protective ribs and a metal ring which shield the vanes (Figure 93), as well as in signaling after each 50 revolutions.

Figure 93. Current Meter [illegible]

Of Soviet current meters with vertical shafts, the most widely used are those manufactured by the Central Asiatic Irrigation Research Institute SANIIRI (formerly the Institute of Water Resources -- IVKh) [illegible] current meters. The peculiarity of these meters is that they can be employed in [illegible] as well as in very muddy water; [illegible] rivers.

The IVKh meter consists of three parts: the head, the frame, and the tail (Figure 94). The head portion represents a bell-like frame 1 with two vertical orifices 2 for inserting the vertical shaft, which is screwed together from two parts: the upper 3 and the lower 4. Between the upper two points, the horizontal frame [illegible] 5 is [illegible]; this frame bears a small turbine (rotor) with six funnel-shaped vanes 6, which perform the same function as the vanes in current meters with horizontal shafts.

Figure 94. IVKh Current Meter

The lower portion of the shaft has a depression at the bottom in form of a small tipped bushing 1 of hard steel step bearing 3 [illegible] with this bearing, the shaft rests on the stationary [illegible] of the steel supporting pin 2. The latter is screwed into the [illegible] 10, which is fixed to the bushing 11 by means of the screw 11. [illegible] 11 is inserted into the orifice 2. To prevent the pin 2 from bearing away, the shaft of the turbine can be raised a little above the pin. This is effected by unscrewing the coupling 12 from the bushing 7 which has a left thread on its outer surface.

The upper part of the turbine is fastened with the screw 12 and continues in the worm gear 14 which is placed within the contact chamber 15 and geared to the cogwheel 17, which has 20 teeth and one or more contact pins. The terminal 16 is insulated by the ebonite bushing 19 [illegible] and the silver contact spring 20. A non-insulated terminal 23 is placed in the rear portion of the frame. The contact chamber is protected from above by the head 21, which has a screw thread and is provided with a leather pad.

The IVKh current meters are universal.

In recent years, wide use has been made in the USSR of Bakhirev's current meter which is an improvement of the IVKh meter. A special feature of Bakhirev's current meter consists in the fact that its ball thrust bearing and contacts are insulated. Bakhirev's current meter is noted for its length of service without the need for overhauling. The chamber of [illegible]'s current meter must be kept filled with oil.

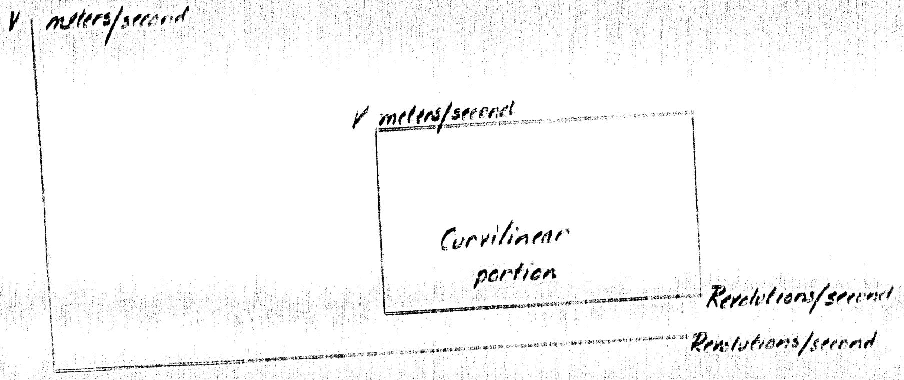
Rating of Current Meters

In order to use a current meter for measuring the current velocity, it is necessary to know the relation between the revolutions per second and the velocity of the current. This relation is obtained in a special test termed "rating." Because in manufacturing current meters it is impossible to secure absolutely identical characteristics regarding the working conditions and the friction of the operating parts, each meter must be rated individually before putting it into [illegible]. Current meters must also be rated periodically because the bearings can wear out with long service, and the relation between the rotation speed of the vanes and the flow velocity of water can change.

In establishing a rating, the meter is moved through still water at different velocities and the rotation speed of the vanes at each velocity is determined; this operation is repeated for a number of velocities, from the lower (starting with 0.01 meters per second) to the upper velocities for which the device in question was constructed (usually up to 3 or 4 meters per second).

If the revolutions per second of a current meter be plotted along the horizontal axis, and the corresponding velocities along the vertical axis of a graph, the smooth curve connecting the plotted points will graphically represent the relation between these data. Such a line is called a rating curve. By aid of this curve, the rotation speed of the vanes being known, the velocity

[illegible]



[illegible]

[illegible] 1.5 meters per second); above these values the curves [illegible] into straight lines. In Figure [illegible], the curvilinear portion [illegible] per second is shown [illegible] on a larger scale. Rating curves have a curvilinear portion [illegible] the current is not [illegible]

[illegible] mechanism, [illegible] and other rotating parts. To make the current meter revolve, some minimal current velocity is necessary, which is called the starting velocity, or the sensitiveness, of the meter. The value of the starting velocity is shown on the rating curve by the segment of the vertical axis between the origin of coordinates and the intersection of the axis with the curve. During further increase in velocity, the resistant forces continue for some time to noticeably affect the rotation of the vanes; but gradually this influence decreases and finally becomes quite inconsiderable; this reduction results in the straightening of the curve from a given velocity whose value is quite definite for each particular current meter. For current meters of the same type (and of the same size), the sensitiveness and the velocities at which the rating curve becomes a straight line approach each other but never coincide completely. The curvilinear portion of the rating curve may be substituted for by a corresponding segment of broken line.

Most often, the rating curve is [illegible] represented in form of a curve and in the form of equations which are called current meter equations. To each current meter, there usually are two such equations: one for low velocity and the other for the rest of velocities. Current meter equations have the following form:

$$a)\quad v = an + \sqrt{bn^2 + v_0^2}\,, \tag{96}$$

$$b)\quad v = v_0 + \kappa n, \tag{97}$$

$$c)\quad v = \kappa n. \tag{98}$$

where v is current velocity in meters per second;

n is revolutions per second of the vanes;

a, b and κ are constant coefficients of the current meter;

v_0 is starting velocity.

From current meter equations (96) and (97) it can easily be seen that, when $n=0$, the value of $v=v_0$, that is, the starting velocity.

The simplest current meter equation $v=kn$ applies only to the upper [illegible] of [illegible] when $n=0$, the velocity ob- [illegible] which is impossible even with [illegible] current [illegible].

[illegible] current meter equation it is easy to draw up a rating scale; this is simpler to use than a graph or an equation. A portion of a rating table is shown below; it was set up in conformity with the rating curve of the current meter equations (Figure [illegible]).

TABLE 32

RATING TABLE PATTERN

[illegible] per second (Integers and Tenths)	Revolutions per second (hundredths)									
	0	1	2	3	4	5	6	7	8	9
0.10	0.108	0.112	0.117	0.122	0.125	0.130	0.134	0.136	0.143	0.147
0.20	[illegible]	0.156	0.167	0.173	0.180	0.186	0.192	0.199	0.206	0.212
and so on										

In Table 32, each column corresponds to a certain number of hundredths of revolutions per second. Thus, the velocity for 0.23 revolutions per second is to be found at the intersection of the line 0.2 and the column 3. In our case, it equals 0.173 meters per second.

Rating of current meters is made in special rating basins. There are two types of rating basins with rectilinear and with circular motion of current meters. The first type is found more often because it provides more exact data. In the USSR there are several rating basins of different types.

Figure [illegible]. Rating Basin

Artificial as well as natural channels and reservoirs may be used as rating basins. Rerating of a current meter is recommended after each 30 to 50 discharge measurements. The muddier the water in which the meter is employed, the oftener the meter must be rated. If the meter has been seriously damaged, or has received a blow or concussion without visible damage, it must be immediately rerated.

Each current meter must be always accompanied by a rating certificate indicating data [illegible] by the rating laboratory (basin); number and type of the meter; date of its latest rating; whether it was rated before or after overhauling; the equations of the rating curve.

Current Meter Specifications

Each current meter must meet the following requirements:

a. The starting velocity of the meter must be as low as possible. The best current meters are those whose starting velocities do not exceed 0.03 meters per second. The current meters most widely used in the USSR have the following sensitiveness characteristics: Zhestovskiy's model, 0.05 to 0.06 meters per second; IVKh and Bakhirev's, 0.06 to 0.07 meters per second; LAGU model, 0.12 to 0.15 meters per second.

b. The meter must be sturdy: the bearings must be of high durability, that is, not wear out during long use; the vanes should not easily bend from blows which may occur during the work in water; the contacts must not wear through or burn out.

c. The mechanism must be protected against soiling and oxidation. Insulation of the electric contacts is particularly important.

d. The shape and the size of the current meter must cause as little disturbance as possible of the current flow; this can be achieved by good streamlining.

e. Important characteristics of a current meter are simplicity of construction, portability, and moderate weight.

f. Other things being equal, the universality of current meters is preferable.

Maintenance of Current Meters

The current meter is an intricate instrument and demands delicate handling. It is especially important to protect the vanes and the shaft of the meter from damage because bending of these parts of the instrument distorts the measurement data.

Immediately after use, the current meter must be taken apart and cleaned. Special attention must be paid to cleaning the spring contacts and parts exposed to oxidation. If the ball bearings of a meter are made of steel, they must/ be removed after use, and stored separately after being greased with bone or vaseline (but not vegetable) oil; before assembling, the balls are wiped dry if the meter is soon to be used, or left slightly greased if the current meter is put away for a considerable time.

When working in the open in winter, the current meter might happen to get coated with ice; such coating must not be removed by striking or scraping, or by any other forcible manner. Removal of ice from a current meter can be effected by placing it in warm water. One of the ways of preventing the current meter from freezing consists of pouring salt water over it immediately after it has been taken out of water.

Usually, the current meter is stored in a box with separate sockets for its protruding parts. In transit, the current meter must be protected against concussions, [illegible], or [illegible].

Use and maintenance of the current meter should be entrusted only to a person well acquainted with its construction.

Measurements of Velocities with Current Meter

Work with a current meter essentially implies measurements of flow velocity at different points of a river's cross-section. The construction principle of the current meter, allowing the meter to be lowered to different depths by means of a pole or a cable, makes it most convenient to take alternate measurements along each of the chosen vertical lines, called velocity verticals.

Velocity verticals are chosen along the width of the river at points of a sharp change of the bottom. The velocity verticals are chosen according to sounding data of the cross section. If the section is smooth and symmetrical, the verticals are distributed evenly [illegible] throughout the width of the river. With the [illegible] of the cross section [illegible] irregular profile, the velocity verticals [illegible] [illegible] [illegible] The number of velocity verticals to be chosen depends on the width of the river bed (Table 33).

Table 33

[illegible]

Width of river bed (in meters)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	over 1000
Number of velocity verticals	3	5	7	9	11	13	15-17

For determination of water discharge on very wide rivers or in time of flood, the number of velocity verticals must be increased.

If the velocity verticals do not coincide with sounding verticals, soundings must be taken at the velocity verticals also.

At each vertical, velocities are determined at several points in order to obtain a more or less accurate value of the mean velocity for the whole vertical. Usually, this is done by aid of known relations between the mean velocity in a vertical and velocities at its different points.

For open channels, the five-point method (at the surface;

[illegible] [illegible]), the three-point (0.2H; 0.6H; 0.8H) [illegible] [illegible] [illegible] two-point [illegible] and (0.6H), one-point (0.2H and 0.8H) [illegible] [illegible] results are [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] verticals [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible].

An ordinary measurement of velocities is carried out through [illegible] [illegible] [illegible] it is expedient to employ [illegible] [illegible] [illegible] 0.2H; 0.6H; 0.8H and [illegible] [illegible] [illegible] the mean velocity over the [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible] (H) of the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] (0.2H and 0.8H) [illegible] [illegible] [illegible] (0.6H), or [illegible] the one-point [illegible] measurement of velocity [illegible] [illegible] [illegible] is considered equal to the mean velocity in the vertical under ice cover and in absence of [illegible].

Observations have shown that at any point of a river's [illegible] flow velocities constantly change, both increasing and decreasing [illegible] considerably by [illegible] percent from the average value. This phenomenon is called pulsation. The degree of pulsation is higher at the bottom than at the surface and higher at the banks than in the middle of the river. Because of pulsation, time of velocity measurements must be increased at any particular point of a velocity vertical. The closer the point to the bottom or the bank, the longer must be [illegible] velocity measurement at any [illegible] at least 2 minutes; at point approximately [illegible] to at least 2 [illegible] minutes; at 0.2 [illegible] at least 2 minutes, [illegible] observation time must [illegible] 1 minute.

As an [illegible] for the [illegible] velocities, not at the same point [illegible] number of revolutions of the meter may be [illegible] as follows:

At the velocity (meters per second)	0.2-0.5	0.5-1.0	1.0-1.5	Over 1.5
Revolutions not less than	[illegible]	150-200	250-300	300-350

On rivers with strong currents, the time of using the current meter at one point of a vertical may be decreased, provided the number of revolutions is not below 200.

The order of operations in working with a current meter on [illegible] is as follows: [illegible] with recording the time of [illegible] water level at the nearest level-mark point (or along the observation line); then two soundings are taken in the given velocity vertical; with no considerable discrepancies in sounding data, the depth is considered equal to the arithmetical mean of the two soundings; after this the fractions of the obtained depths (depending on the method employed) are computed, and the current meter is set first at the surface, and then at the other computed point of the vertical.

Special Features of Velocity Measurements with a Current Meter Under Ice Cover

[illegible] ice [illegible], [illegible] current meter [illegible]. In case of long winter sessions, heated booths on runners are used.

The immediate measurement of velocities with a current meter under the cover, although generally similar to that in open channels, presents some differences with the [illegible] pulsation [illegible] in a vertical under the influence of the ice cover.

The duration of measurement at points of a vertical under the [illegible] cover [illegible] creates pulsation conditions similar to those at the river bottom. Therefore, observation time at each point must be not less than [illegible] minutes (instead of [illegible] minutes as with an open channel) and, at the under surface of the ice cover, not less than [illegible] minutes (instead of [illegible] minutes).

In case of wide discrepancies in time readings for the same number of revolutions, the length of each observation must be increased.

The depths in a vertical under ice cover must be measured from the under surface of the ice (if the water level coincides with it). For such measurements, it is necessary to determine to that part of the cross sectional area is filled with sludge. If this extent exceeds 20 percent, a different observation line must be taken.

Field Work: Procedure, Computation of Discharge Through Determination of Velocities with Current Meter

The field work preceding the computation of actual discharge through determination of velocities by means of a current meter comprises: measuring the water level along the observation line and at the nearest stationary level-mark point; soundings along the observation line (along the sounding and the velocity verticals); and determination of velocities at the chosen points.

Prior to a discharge measurement, the following entries must be made in the form (or in the notebook): date of measurement; location of the observation line and of the nearest level-mark point; description of measuring conditions (weather, wind); condition of the river bed; data about the current meter (type, model, number of revolutions within the interval between the contacts); water level mark immediately before commencement of measurements.

When soundings are taken, distances of the sounding and the velocity verticals are entered, as well as soundings of the verticals. Thereupon, lowering depths of the axis of the current meter (0.2H; 0.6H; etc.) are computed (preferably, from tables).

In velocity measurements, the number of revolutions of the current meter's vanes as well as the stop watch readings are entered.

Computation of Discharge from Velocities Determined with Current Meters

To the usual methods of computation of discharge measured with the current meter using: the analytical, the graph-analytical, the [illegible], and the simplified analytical methods.

In the analytical method, the discharge is determined by way of computations. In general, this method consists in the following.

Determination is effected of each [illegible] cross sectional area delimited by adjacent velocity verticals. For that purpose, areas between sounding verticals contained in the cross sectional area between each pair of velocity verticals are computed and summed up. The velocity verticals are, in this case, the extreme sounding verticals for the given cross sectional area.

Mean velocities are then found for each separate velocity vertical by one of empirical equations (depending on the number of points at which velocity measurements were carried out) and arithmetical means of mean velocities for each pair of adjacent velocity verticals are computed. At the river banks, the velocities are considered equal to zero. By multiplying the values of areas between velocity verticals by the corresponding arithmetical means of mean velocities, partial discharges for each cross sectional sub-area are obtained. Summing up the partial discharges yields the total discharge in the cross sectional area.

The sequence of computations in the analytical method of determination of discharge by means of a current meter is illustrated in Appendix 4. All the hydraulic elements of a river obtained by way of computations (discharge Q ; cross sectional area Ω ; width of the river B ; maximum depth H_{max} ; maximum velocity v_{max} ; mean velocity in the cross section $v_{mean} = \frac{Q}{\Omega}$, as well as the number of showing the velocity verticals and the number of points at which velocities have been measured, are entered on the first page of the form. Besides, the mean depth $H_{mean} = \frac{\Omega}{B}$; wetted perimeter P; the hydraulic radius $R = \frac{\Omega}{P}$; and the [illegible] I [illegible] are determined.

The grapho-analytical method of computing water discharges consists in the following.

A drawing is made of the river's cross section on which location of the velocity verticals is shown (Figure 97). Above the horizontal line representing the water surface, opposite each of the velocity verticals, segments (ordinates) are plotted on the established scale; these represent the mean velocities along the verticals. The upper ends of the ordinates are connected by a smooth curve, which is called the velocity curve (v_{mean}). Beneath the drawing of the cross section, three columns are set up for the sake of convenience /in form of horizontal lines; one for depth recording (h); another for mean velocities (v_{mean}); and the third for values of elemental discharges (q)./

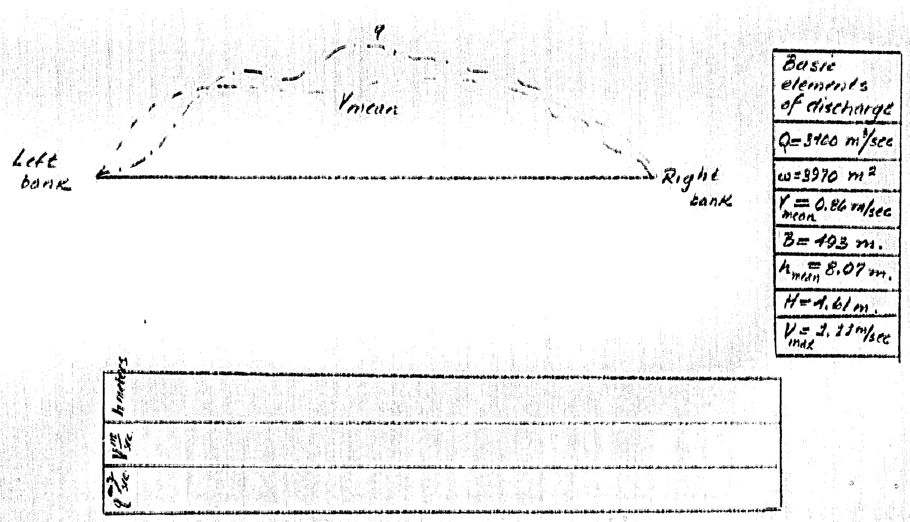


Figure 97. Computation of Discharge by the Grapho-analytical Method

the depths are measured at equal intervals; it is desirable to ascertain depths at 10 points on small rivers and up to [illegible] in big ones. If during the measurements verticals have been [illegible] ones. [illegible] [illegible], [illegible] [illegible] [illegible] [illegible] interpolation between adjacent sounding verticals. [illegible] [illegible] [illegible] intervals; [illegible] [illegible] the length of each interval at 10 meters, the width of the river being 120 meters.

The mean velocities, which are entered in the second row of [illegible] [illegible] [illegible], [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] v_{max} [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]).

The values of the mean velocities [illegible] obtained by the [illegible] [illegible] [illegible] [illegible] values of the elementary discharges per [illegible] each of the areas [illegible] sub-area [illegible] [illegible] [illegible] [illegible] [illegible] each vertical [illegible] [illegible] [illegible] [illegible] [illegible]. In our case, the [illegible] width of a sub-area is 10 meters; [illegible], [illegible] [illegible] of any vertical, a half sub-area is [illegible], its width [illegible] by 2 [illegible] [illegible] [illegible] discharge value for each sub-area, [illegible] [illegible] [illegible] [illegible] [illegible] discharges of all the sub-areas. However, since the intervals between verticals are equal, it is possible to simplify the computations by summing up all the elementary discharges q (obtaining Σq) and subsequently multiplying the sum by the width of a sub-area (in our case, by 10).

The q values are plotted to scale above the horizontal line of the water surface, and the upper points subsequently connected by a smooth curve. This curve, called the elemental discharge curve, [illegible] a profile similar to that of the cross [illegible] case, [illegible] computations [illegible] [illegible].

In the graphic-analytical method of computing discharge, the values of the mean velocities in verticals are determined preliminarily from velocity diagrams. For this purpose, each diagram is subdivided into a series of bars of equal width except the last one [illegible] which is [illegible] of the remainder of the vertical's depth.

The mean velocity along the vertical is then computed [illegible] median lines of all the bars if the last bar is of the same width as all the others; otherwise, the median line of the last bar is multiplied by the ratio between its width and the width of each of the other bars, and the product is added to the sum of the median lines of all the other bars, after which the obtained value is divided by the total number of bars. In other words, the mean velocity is found in the method described by aid of the equation:

$$v_{mean} = \frac{v_1 + v_2 + \ldots + v_n \cdot \frac{h_n}{h}}{n}, \qquad (92)$$

where v_{mean} is the mean velocity in the vertical;

$v_1, v_2 \ldots$ are the median lines (velocities) of the particular bars;

h is the width of the bars (the same for all of them except the last one);

h_n is the width of the last bar;

n is the number of bars.

Thus, the graphic-analytical method makes it possible to determine the water discharge by using a graphic representation of the [illegible] sections and velocities [illegible] and performing certain very simple computations.

In the graphomechanical method of discharge computation, in contrast to the graphic-analytical method, the discharge is not determined through summing up the partial discharges but by [illegible] computation, [illegible], of the area [illegible] free line and the elemental discharge curve. For this purpose the drawing is prepared in the same [illegible] as for the graphic-analytical method; [illegible], the mean velocities along verticals are found by way of determining the areas of velocity diagrams and subsequently dividing these areas by the corresponding depth of the vertical.

For each type of diagram, the so-called planimeter coefficient is established. For this purpose, a square with a side, for instance, of 5 centimeters is drawn and is encompassed by the planimeter for several times. The value of each point of graduation will depend on the scale established for drawing the graphs. Let us suppose that for the velocity diagrams, the following scales were taken: for velocities, 0.2 meters per second for one centimeter; for depths, 2 meters for one centimeter. Then the area of the encompassed square will amount to $(5 \times 0.2) \times (5 \times 2) = 10$ square meters per second, and the value of one point of the planimeter, or the planimeter coefficient will be $K=\frac{10}{n}$ [illegible] square [illegible] represent (here n is the [illegible] planimeter [illegible] [illegible] square).

[illegible] it is [illegible] partial discharge. [illegible] will be affected by [illegible] the value [illegible] number of points.

The accuracy of determining discharge by the graph-analytical method depends on the care exercised in drawing the graph and in [illegible] the errors, [illegible] with the planimeter [illegible]; [illegible] measurement must be repeated.

[illegible] in other situations; it is [illegible] used in order to check discharges computed by the analytical or the graph-analytical method.

The simplified analytical method of water discharge computation consists in consecutive computation of partial discharges [illegible] between velocity verticals [illegible] between them. In this case, the mean velocities [illegible] are computed by taking the arithmetical mean of mean velocities of two adjacent verticals. Instead of the described method, a more complicated manner of computation is also employed in which the computed velocity is that of the given vertical, the corresponding area being extended to both sides up to half the distance between the given and the adjacent verticals.

[illegible] river bed, [illegible]

[illegible]

[illegible] measurements of [illegible], a [illegible] tachymeter [illegible]. A tachymeter (Figure 98) [illegible]

[illegible]

Figure 98. [illegible]

Figure 99. Setting a Lithotachymeter

[illegible] considerably [illegible] systems. The bathotachymeter [illegible] in the [illegible] thus [illegible] total section. Prior to lowering, [illegible] is screwed out of the bathotachymeter, after which the device is lowered into the water with the tip set in the direction of the current. Then, simultaneously with starting the stop watch, the [illegible] is quickly [illegible] which turns the pipe against the current, [illegible] the bulb. When the bulb is filled to [illegible] (usually [illegible] is turned through a quick movement of 180 degrees. The device is then taken out and the volume of water in the bulb is measured by means of a graduate (sometimes the volume is computed from the weight of the water, the weight being determined by means of a spring balance or [illegible]). By dividing the volume W of the water in the bulb by the time t, read from the stop watch, the water influx per second is obtained; after which by aid of a rating curve or equation, flow velocity is determined.

As with current meters, bathotachymeters are rated in rating basins, the only difference being that, instead of the number of revolutions per second, in rating a bathotachymeter, the water influx per second is determined. For each bathotachymeter the nozzle, [illegible] (or equations) the [illegible]; [illegible] for the pipe within the nozzle, the other for the pipe than the nozzle.

Since the bathotachymeter is a device which [illegible] calibrated for determining velocity at any point in a vertical, [illegible] mean velocity [illegible] getting distance from velocities measured with a [illegible] are taken the same as [illegible] the current meter.

The bathotachymeter, in contrast to the current meter, can be used for measuring velocities at several points simultaneously. For [illegible] is immersed, fixed at a pole to desired depths, the simultaneously [illegible] the water. [illegible] taken from the water [illegible], the [illegible] allows immediate determination of the mean velocity in the vertical. This method of discharge determination is called the summary method. In the summary method, it is possible to measure the water from each bathotachymeter separately; in such a case, the summary method is not at all different from the regular point method. However, it [illegible] leads to more exact results because of simultaneous measurement of the velocities at all points in a vertical.

The bathotachymeter has the advantage of being simply constructed, is portable, needs no special care, and is easily handled. As a shortcoming, however, it must be mentioned that it cannot be used in water at freezing temperature since under such conditions the influx orifice of the bathotachymeter is narrowed by the [illegible] communication [illegible] around it and the rating curve does not apply. Besides, in [illegible] from a boat and at consider- [illegible] [illegible] [illegible] unsatisfactory [illegible] observation line; [illegible] deviations of the device, as little as 5 degrees, lead to an error in velocity [illegible] percent.

Usually, the [illegible] may be used in preliminary surveys for approximate determination of water discharges.

21. Measurement of Velocities with Hydrometers

Hydrometers comprise a rather numerous group of devices [illegible] for determining [illegible] water pressure. The [illegible] devices [illegible] only a historical significance. Of devices of the [illegible] type [illegible] for velocity measurements, the best known is the hydrometric tube, consisting of a tube bent at right angles and open at both ends (Figure 100).

Figure 100. Hydrometric Tube

The tube is immersed to the desired depth so that its shorter end is horizontally directed against the current, the other end being vertical. Under the pressure of the current, the water level in the tube rises above that in the river or stream. The height (rise, that is, the height) of the water column h above the surface of the stream depends on the flow velocity, which may be determined by the known hydraulic equation:

$$v = \varphi\sqrt{2gh}, \text{ or } v = \mu\sqrt{h}, \qquad (10)$$

where v is the velocity at a point at the desired depth, in meters per second;

g is the gravitational acceleration, equal to 9.81 meters per second] per second;

h is the rise of water in the tube, in meters;

φ is a coefficient determined by rating each tube;

$\mu = \varphi\sqrt{2g}$.

[illegible] is determined by rating the instrument, it is necessary to measure only the height of the water column h. Therefore, for more accurate reading of h, a small [illegible] rod is employed which is lowered into the pipe by means of a float.

Hydrometric tubes may successfully be employed for measuring velocities in narrow streams of water; in water-conducting flumes of hydroelectric power plants; on overflow surfaces of water-raising dams; in very narrow river beds. The tubes are used mostly in laboratory work. At the present time they are almost out of use on rivers and canals because they indicate momentary velocity regardless of pulsation; consequently, to obtain mean velocity at a point, 30 to 60 observations must be made. Furthermore, rating of tubes is very complicated and they cannot be used in very deep water or at very low velocities.

Computing discharge from data obtained with the hydrometric [illegible] can be effected by the very procedures used with current meter [illegible] meters.

[illegible] [illegible] discharge [illegible] can be satisfactorily obtained.

10. [illegible] OF DISCHARGE [illegible]

[illegible]

[illegible]

[illegible] generally by relating the calculated [illegible] during which [illegible] stage [illegible] during the measurement of discharge, stage variations do not exceed the permissible error, the discharge thus measured is regarded as related to the representative stage level computed as the arithmetical mean of stage readings during the measurement period. If the stage variations are very small or the measurement [illegible] it is sufficient that stage readings be taken at the beginning and end of the observations. However, if the stage varies considerably or the discharge measurements take a long time, the representative (effective) level to which the measured discharge must be related is determined in a more complicated way.

Figure 101. Computation of Representative Mean Level Mark

[illegible] in each gauge [illegible] of the following, [illegible] the cross section (Figure 101), following verticals are drawn; the distances between the verticals [illegible] vertical lines [illegible] [illegible] = ω [illegible] [illegible] the values ω by the mean velocity along the corresponding vertical [illegible] lines, [illegible] of partial [illegible] $\omega_1 v_1, \omega_2 v_2 \ldots$, etc., are obtained. [illegible] $h_1, h_2 \ldots$, etc., the corresponding [illegible] is determined with the equation:

$$H_m = \frac{\omega_1 v_1 h_1 + \omega_2 v_2 h_2 + \ldots + \omega_n v_n h_n}{\omega_1 v_1 + \omega_2 v_2 + \ldots + \omega_n v_n} \qquad ([illegible])$$

Record of Discharge Measurements

All of the discharge measurements are entered in a special record form. Besides the value of each discharge measured, the date and place of the measurement, stage at which the discharge [illegible], mean velocity, [illegible] are also entered in the record. In Appendix 5, a sample record is given of discharges computed from the cross-sectional area and the velocities. The resulting data entered in the record are taken from the measurement and discharge computation forms.

A record of measured discharges makes for better evaluation of all elements obtained from field measurements and water discharge [illegible].

[illegible]

[illegible]

[illegible].

[illegible].

[illegible].

[illegible].

[illegible] river where the discharge is to be measured, a constant discharge is released of a table-salt solution or any other solution of some harmless and easily soluble matter. Further downstream where full intermixture of the solution with the water of the current has by that time taken place, water is sampled to determine the degree of concentration ([illegible]) of the solution released in it. Let us suppose then, Q is the discharge sought, q is the solution discharge, K_1 is the strength or concentration degree of the released solution, and K_2 is the solution's concentration in the water sample taken from the river. Then, obviously, there must exist the equation $Q \cdot K_2 = q \cdot K_1$.

[illegible]

$$Q = \frac{q \cdot K_1}{K_2}.$$

[illegible]

[illegible] K_0. [illegible]

$$Q = \frac{q \cdot K_1}{K_2 - K_0}.$$

[illegible]

Concentration of the salt solution is determined either by chemical analysis (for example, by titrating with silver nitrate), or electrically with the Kohlrausch bridge. The latter method is based on the fact that a change in concentration influences the electric resistance of the solution (resistance decreasing as the concentration increases). This method may be employed on the spot and provides very exact data. It must be kept in mind, however, that

[illegible]

[illegible] depth. [illegible]

[illegible] recent.

A serious [illegible] consists in the difficulty of transporting large drums and considerable quantities of salt, especially in mountain regions. Besides, methods of determining concentration in weak solutions are still rather complicated and unreliable. On the other hand, this method can be employed where the current meter cannot be used, or where it provides inaccurate data.

[illegible]

[illegible] not sufficiently known. [illegible] of dependence [illegible] in a solution.

[illegible] method is based on [illegible] the current [illegible]

The [illegible] method of [illegible]sation.

Measuring discharges by [illegible] methods is seldom done. [illegible], due to some quite obvious advantages compared with [illegible] determination, it is possible to expect [illegible] application (especially [illegible]).

60. MEASUREMENT OF WATER DISCHARGE BY WEIRS

The method of measuring water discharge by weirs is one of the most widely employed. It is successfully used in natural as well as in artificial currents. On big rivers and canals, the weir method is applicable if their currents are blocked by constructions with water-discharging facilities, and if these constructions is not [illegible] any noticeable seepage either at the [illegible] the structures. [illegible] con- [illegible] (weirs, [illegible] canals), [illegible] water discharge is possible.

Determination of Water Discharge by Dam Weirs

The following three frequent cases of discharge determination are [illegible].

1. Water passes the dam's spillway when the shutters are completely removed. Water discharge is determined in this case by aid of general hydraulic equations for a [illegible] submerged suppressed weir.

2. Water passes the spillway partially closed by shutters over which water is flowing. Water discharge is then determined by aid of equations for a rectangular sharp-crested weir.

3. Water passes beneath the shutters of the spillway. In this case, discharge is computed by the [illegible] equation for water discharge from a wall orifice.

For each of these cases, the respective equations and values of their empirical coefficients are treated in detail in textbooks of hydraulics.

Below are given only a few of such equations in order to show, for several instances, the type and sequence of operations in determining water discharge by means of weirs at existing con-

[illegible].

[illegible]

[illegible] is expressed in

the following form:

$$Q = mb\sqrt{2g}\,H_0^{3/2}, \qquad (13)$$

where Q is the discharge given in cubic meters per second;

m is the coefficient of the weir discharge depending

on the conditions under which the water flows

[illegible]

[illegible]

b is the width of the weir in meters;

g is the acceleration of gravity equal to 9.81

meters per second per second;

from which

$$\sqrt{2g} = \sqrt{19.62} = 4.43.$$

$$H_0 = H + \frac{v^2}{2g},$$

where H is the depth of the water above the weir (head), in meters; and

v is the mean velocity of the water before the weir (velocity of approach) in meters per second.

In order to [illegible] weir, it is necessary to [illegible] measure [illegible] the weir must be [illegible]; [illegible] [illegible] [illegible] [illegible] the water [illegible] from the spillway (before the curvature of the surface) and the level of the surface of the spillway; [illegible] [illegible] [illegible] the curvature of the surface.

[illegible]

[illegible] submerged suppressed weir:

$$Q = \varphi b h \sqrt{2g(H_0 - h)},\qquad (1[illegible])$$

where φ is the velocity coefficient computed from [illegible] tables;

h is the depth of the water on the spillway in figure;

Q, b, H_0 and $2g$ have the same meaning as above.

In all cases, [illegible] are determined in the same way as for an unsubmerged suppressed weir. The value of h is [illegible] and

[redacted] [illegible] the level of the water on the spillway and the level of the spillway's surface.

Weir with Sharp Crest, Unsubmerged

The discharge over an unsubmerged weir with a narrow crest is determined by aid of the formula:

$$Q = m_0 b\sqrt{2g}\, H^{3/2} \tag{105}$$

where m_0 [illegible] coefficient of the weir, [illegible] takes into account the velocity of approach, [illegible] is determined by aid of the equation:

$$m_0 = \left(0.405 + \frac{0.003}{H}\right)\left[1 + 0.55\left(\frac{H}{H+p}\right)^2\right] \tag{106}$$

In which H (as in the basic formula) represents the head above the edge of the weir, and [illegible] [illegible].

In calculating the discharge over a sharp-crested weir the coefficient [illegible] is determined in the same way as in the preceding formula, [illegible] values of H and p are observed [illegible]: the first -- as the difference between the level of water before the weir and the level of the upstream edge of the crest; the latter -- as the difference between the level of the upstream edge of the crest and [illegible] level [illegible] above the crest.

Unsubmerged Orifice

The discharge through an unsubmerged orifice is determined by aid of the formula:

$$Q = \varphi \epsilon b a\sqrt{2g(H_0 - \epsilon a)}, \tag{107}$$

ϵ [illegible]

[illegible];

a [illegible]

[illegible];

Q, q, b, H_0 and $2q$ [illegible]

[illegible], b [illegible] a [illegible]:

[illegible] H_0 [illegible]

[illegible].

Submerged Orifice

For a submerged orifice, the discharge formula reads thus:

$$Q = \mu b a \sqrt{2g(H_0 - h_z)}, \qquad (102)$$

where μ is the coefficient of discharge through orifice computed from reference table;

h_z depth of the water immediately behind the plate;

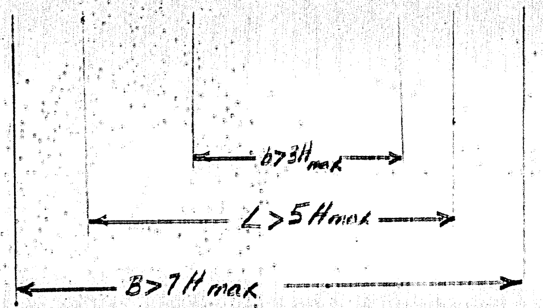
Q, b, a, H_0 and $2g$ have the same meaning as above.

The ways of determining b, a, and H_0 are known from the preceding. The value of h_z is obtained by leveling of the water level immediately behind the plate and of the spillway's surface in the same place.

Determination of Discharge by Means of Weirs in Small Currents

To the most widely used types of weirs employed for measuring small water discharges belong the trapezoidal, the rectangular, and the triangular weirs.

The trapezoidal weir, with downward contraction (Figure 102) consists of a metal or wooden plate with a trapezoidal notch. The notch is cut along the perimeter of an isosceles trapezoid with the smaller base at the bottom and with an inclination of the side slopes of 1 : 4 ($\tan \alpha = 0.25$, or $\alpha = 14°$).



[illegible]. Trapezoidal Weir (With Downward Contraction)

The edge of the weir must rise above the bottom of the discharge channel by not less than the value of the maximum head H_{max}. The length of the weir's edge must be 3 or 4 times more than the maximum head.

The trapezoidal weir with the 1 : 4 inclination of the side slopes has the important advantage that the discharge coefficient m of its discharge formula does not practically depend on the head value H and is equal to 0.42, on which account the discharge computation formula acquires, in this case, the following form (in meters):

$$Q = 4.43\, mbH^{3/2} = 4.43 \times 0.42\, bH^{3/2} = 1.86\, bH^{3/2} \quad (109)$$

Equation (109) shows that, for the weir described, the discharge is in direct proportion to the length of the edge of the weir.

Tests have established that equation (109) remains correct for the following inclination angles α depending on the length of the crest:

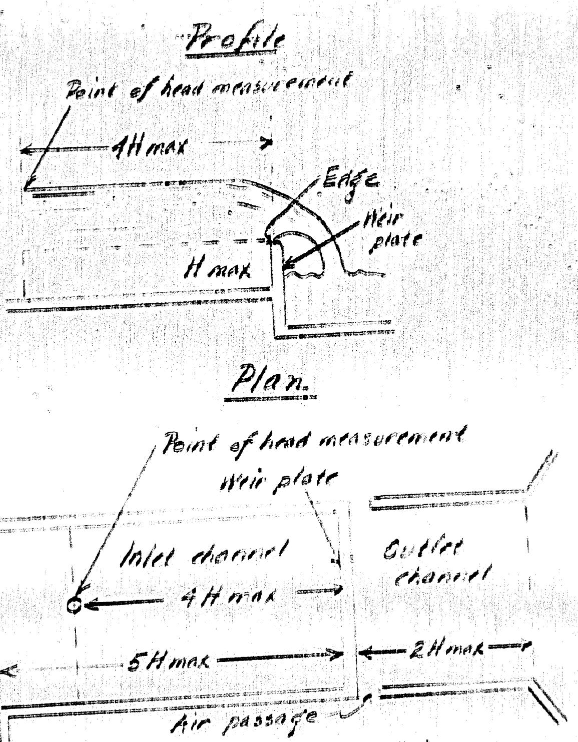
Length of Crest (mm):	152.4	304.8	609.6	914.4	from 0.9 to 2.7 meters at heads of 76 to 609 millimeters
Angle α	13°15'	13°25'	13°45'	14°	14°30'

The weir is installed at the end of a damping basin from one and a half to three times as wide as the overflowing stream. In such cases, the contraction of the stream at the crest and on the sides is complete, and the velocity of approach to the weir may be neglected.

The minimum recommended head at the weir is not less than 0.5 meters; the maximum head up to 1.0 meter.

Computations of discharge at the trapezoidal weir are facilitated by special charts giving the value of discharge in relation to the head value H, for the length of the crest b=1.0 meter (Appendix 6). To obtain the discharge value at the weir, it is necessary to measure the height of the head only, for which purpose a stationary depth gage is installed.

The rectangular weir (Figure 103) has a rectangular notch whose horizontal edge must rise above the bed of the channel by not less than the value of the maximum head; in cases when the latter is less than 0.2 meters, the edge must rise above the bed of the channel by not less than 0.2 meters.


Profile

Plan.

Figure 101. Rectangular Weir

The rectangular weir is installed in an approach channel with
rectangular cross section, The channel being seven to eight times
as long as the height of the maximum head. The walls of the ap-
proach channel must be flat, vertical, and parallel; the bottom of
the channel must be horizontal. The crest of the weir is set at a
distance not less than the fivefold maximum head from the entrance
cross section of the channel. The width of the channel and the
width of the overflowing steam must be the same. The channel
walls are provided with holes for passage of air under the stream.

The minimum head that ensures sufficiently exact results
is equal to 0.025 meters. The permissible maximum head amounts
to 1.25 meters. By strict adherence to rules of installation of
rectangular weirs, the error in determining water discharge may be

reduced to 1 per cent.

The discharge of water passing over a rectangular unsubmerged weir is computed by aid of formula (105).

The triangular weir (Figure 104) has a notch in the form of an isosceles right triangle with the vertex of the right angle turned down. The bisector of the right angle of a triangular weir in operation must be strictly vertical.

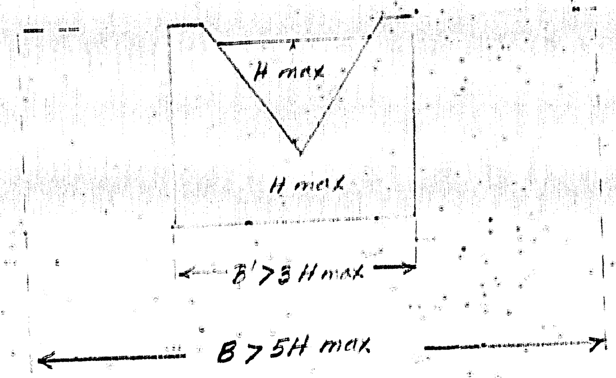


Figure 104. Triangular Weir

The discharge over a triangular weir is determined by aid of the formula: (110

$$Q = 1.343 H^{2.47}$$

The minimum head that ensures sufficiently exact determination of discharge value equals 0.05 meters; the permissible maximum head may not exceed 1.0 meter.

The triangular weir is installed at the outflow end of a basin which must be at least five times as wide as the maximum head value.

The triangular weir being properly installed and the head carefully measured, very exact data (with an error not over 2 per cent) may be obtained.

Temporary and Stationary Weirs

Depending on practical conditions of discharge measurement, temporary or stationary weirs may be installed. Temporary weirs are installed either in form of portable metal plates (of about 1 to 2 millimeter width) with notches of definite shapes, or [illegible] wooden plates with [illegible] notches. [illegible] weir [illegible] the [illegible] and the slopes of the canal or brook [illegible] lateral [illegible] plate acquiring a proper position.

To prevent escape of water under the plate [illegible] is attached to the plate and covers the bottom and slopes, [illegible] with earth or [illegible] point, measurements are carried out regularly, but continuous blocking of the channel is undesirable (for instance, [illegible] of the channel is very low, which [illegible] of the [illegible]), the walls and the bottom of the channel may be [illegible] lined flush with small wooden or concrete beams having special grooves for installation of the portable plate for the duration of intended measurements.

Stationary weirs are often constructed in the form of concrete, stone, or wooden (matchboard) walls.

Measurement of discharges by stationary weirs is widely employed on mountain streams, characterized by [illegible] bot-

toms, irregular beds, and swift currents.

[illegible]

[illegible] discharge by weirs with sharp crests, [illegible]

must be observed in installation and use of weirs:

a. [illegible]

over the weir; [illegible] the side of the [illegible] cannot be prevented, [illegible]

[illegible]

b. [illegible] of the approach channel [illegible]

c. the weir crest must be horizontal and installed [illegible] and perpendicular to the general direction of the current above the weir; the axis of the current must [illegible] the weir into two symmetrical parts;

d. It is necessary to insure free admission of air under [illegible] the [illegible] level below the weir.

e. the edge of the weir crest must be sharp, not thicker than 1 or 2 millimeters, the sharp surface of the edge facing upstream (figure 105);

f. determination of the head must be done by checking water-level marks not immediately at the edge of the weir crest but from 1 to 2 meters upstream, the distance being, in no case, less than [illegible] the maximum head;

g, [illegible] and foreign matter in front of the weir [illegible] over the weir depends on the elevation of the edge of the [illegible] bottom in front of the weir;

h, the crest of the rectangular and of the trapezoidal weir must be installed strictly horizontally, and, in case of the triangular weir, the condition that the axis of symmetry of the notch [illegible] vertical.

Figure 102. Sketch of a Stream Flowing Over a Sharp-crested Weir with [illegible]; the Position of the Sharp Edge of the Crest.

Checking accuracy of installation of small weirs is done by two vertical scales set equidistantly from the edges of the notch, the origin (zero) of the scales being exactly at the same altitude with the crest line of the trapezoidal and the rectangular weir or with the horizontal line running through the vertex of the triangular weir.

If the weir is installed correctly, the readings of both scales at the level of the overflowing water will be the same.

At large weirs stationary marks may be installed instead of gauges (to the right and to the left of the notch) so that, at a correct position of the weir, the elevation of these marks above the crest will be the same, and so that the line connecting them will be perpendicular to the vertical axis of symmetry of the notch. As such marks, protruding pins are employed, on which level rods or levels may be placed.

61. [illegible]

For measuring water discharges of small natural currents, and particularly of irrigation canals, [illegible] measuring flumes.

[illegible]

Parshall's hydrometric flume has the following construction (Figure [illegible]). Its main part consists of the throat which has vertical, strictly parallel side walls and a flat floor sloped in the direction of the current. Before the throat lies the inlet section of the flume with a horizontal floor, and below the throat the outlet section with a floor sloped reversely (against the current).

The inlet and the outlet sections have strictly vertical side walls and are funnel-shaped in the plan: the first is wider at the entrance and gradually narrowing towards the throat; the latter, on the contrary, widens in the direction from the throat towards the outlet.

The line where the floor of the trough bends, that is, the line at which the horizontal floor of the inlet portion joins

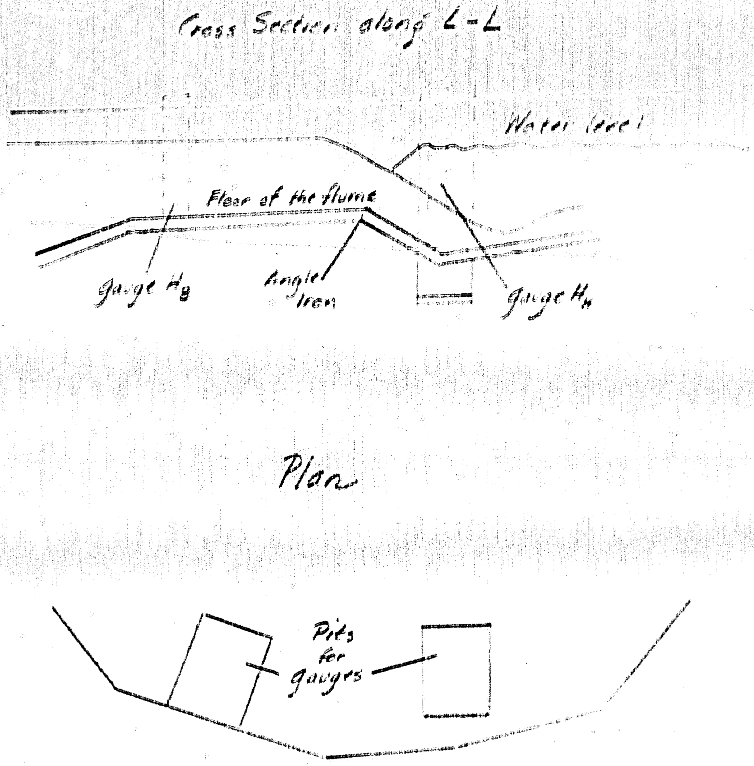


Figure 106. Parshall's Hydrometric Flume.

grade. [illegible] and as straight and horizontal, in order to ensure the correct [illegible]. [illegible]

[illegible]

Construction of [illegible] the [illegible] of the canal [illegible]

[illegible] with the [illegible]

edge of the [illegible] into the [illegible] of the canal. The [illegible]

[illegible] the [illegible] consist of two [illegible] and [illegible] in [illegible]

The bottom and the slopes of the canal above and below the flume are reinforced in order to protect them from washout. For this purpose, stone, revetment, fascines, wire mesh filled with cobblestones, etc. are used. The higher the discharge through the flume, the more reliable must be the reinforcement. [redacted] [illegible] wall A. [illegible] of the flume. [illegible] the inner walls of the [illegible], that is, on [illegible] the flume. [illegible] value [illegible] coefficients of [illegible] is checked by means of a [illegible] instrument.

The value of the water discharge directed through the flume is determined from the depths H_u and H_l that is, from the readings of the upper and the lower depth gages in the damping pits, as well as from the width W by aid of appropriate formulas. For quick practical computation of the dis-

[illegible]

[illegible]

$B = 0.5 W + 1.20$ meters
$D = 1.2 W + 0.48$ "
$C = W + 0.30$ "

[illegible] flume, of the discharge [illegible]

[illegible] the [illegible]

$F = 0.6$ meters

[illegible]

$G = 0.92$ meters

The side walls of the inlet section [illegible] of the flume [illegible] of 11 degrees [illegible] side walls of the outlet section — [illegible] minutes.

The height of the side walls is fixed, depending on the maximum possible depth E of water in the channel, so that the walls of the flume rise above the maximum water level in front of the flume by 0.1 to 0.15 meters. For discharges up to 3

[illegible] in question. [illegible] In each case, [illegible] (of the highest stage must be determined) [illegible] ha have ever taken place along the particular reach under observation, [illegible] of [illegible].

[illegible] stage be obtained by way of leveling. Since a straight slope varies in connection with changes in water level, it is necessary, if possible, to determine the [illegible] to [illegible], therefore, in leveling, [illegible] of water [illegible]. However, if the marks have [illegible] indirectly, the [illegible] [illegible] records, [illegible].

[illegible] results, [illegible] exact values of coefficients of roughness, [illegible] consecutive (or separate) [illegible] for any level mark [illegible] stage [illegible] of the river. Besides, with this method, there is no [illegible] of carrying out the [illegible] work of [illegible] and the [illegible] of the [illegible] stages.

[illegible]

$$\rho = \frac{w_1 + w_2 + \dots + w_n}{t_1 + t_2 + \dots + t_n}$$

(b-a) in case of considerable discharges, it is possible to build [illegible] form of a [illegible] and [illegible] area of the [illegible] dis- [illegible] by hand.

[illegible] of the channels [illegible] being filled up, and the stream, at that point, substantially [illegible] under the [illegible] stream.

[illegible] of water collected in a receptacle is determined by [illegible]. [illegible] necessary to use a [illegible] measuring vessel.

Direct measurements of water discharge are sometimes performed for the purpose of establishing [illegible]