

Methods of measurement of
**Liquid flow in open
channels —**

Part 3: Stream flow measurement —

Part 3D: Moving-boat method

[ISO title: Measurement of liquid flow in open channels —
Moving-boat method]

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This British Standard, having been prepared under the direction of the Industrial-process Measurement and Control Standards Committee, was published under the authority of the Executive Board and comes into effect on 31 October 1980

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National foreword

This British Standard has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee and is identical with ISO 4369:1979 “*Measurement of liquid flow in open channels — Moving-boat method*” published by the International Organization for Standardization (ISO).

Terminology and conventions. The text of the International Standard has been approved as suitable for publication, without deviation, as a British Standard. Some terminology and certain conventions are not identical with those used in British Standards; attention is especially drawn to the following.

The comma has been used throughout as a decimal marker. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Wherever the words “International Standard” appear, referring to this standard, they should be read as “British Standard”.

Since the publication of ISO 4369, ISO 5168 has been published. Footnote 1 on page 1 therefore no longer applies.

Cross-references

International Standard	Corresponding British Standard
	BS 3680 <i>Methods of measurement of liquid flow in open channels</i>
ISO 772:1978	Part 1:1979 <i>Vocabulary and symbols</i> (Technically equivalent)
ISO 748:1979	Part 3:1980 <i>Stream flow measurement</i> Part 3A:1980 <i>Velocity-area methods</i> (Identical)
ISO 5168:1979	BS 5844:1980 <i>Measurement of fluid flow: estimation of uncertainty of a flow-rate measurement</i> (Identical)

The related standard for ISO 3454:1975 is BS 3680-8B:1973.

The Technical Committee has reviewed the provisions of ISO 4366:1979, for which there is no corresponding British Standard, and has decided that they are acceptable for use in conjunction with this standard.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 30, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope and field of application

This International Standard specifies methods for measuring discharge in large rivers and estuaries by the moving-boat technique. In the following sections procedures applicable to this method and the general requirements of equipment are covered. A complete facsimile example of computation of a moving boat measurement is given in the annexes.

2 References

- ISO 748, *Liquid flow measurement in open channels — Velocity area methods*.
 ISO 772, *Liquid flow measurement in open channels — Vocabulary and symbols*.
 ISO 3454, *Liquid flow measurement in open channels — Sounding and suspension equipment*.
 ISO 4366, *Liquid flow measurement in open channels — Echo sounders*.
 ISO 5168, *Calculation of the uncertainty of a measurement of flowrate*¹⁾.

3 Definitions

For the purpose of this International Standard the definitions given in ISO 772 apply.

4 Units of measurement

The units of measurement used in this International Standard are SI units.

5 General

Frequently, on large rivers and estuaries, conventional methods of measuring discharge by current meters are difficult and involve costly and tedious procedures.

This is particularly true at remote sites where no facilities exist, or during floods when facilities may be inundated or inaccessible.

In those cases where unsteady flow conditions require that measurement be made as rapidly as possible, the moving-boat technique is applicable. It requires no fixed facilities and it lends itself to the use of alternate sites.

The moving-boat technique uses a velocity-area method of determining discharge. The technique requires that the following information be obtained:

- a) location of observation points across the stream with reference to the distance from an initial point;
- b) stream depth, d , at each observation point;
- c) stream velocity, v , perpendicular to the cross section at each observation point.

The principal difference between a conventional measurement and the moving-boat measurement is in the method of data collection. The mean velocity in the segments of a cross-section of the stream in the case of a conventional technique is determined by point velocities or an integrated mean velocity in the vertical. The moving-boat technique measures the velocity over the width of a segment by suspending the current meter at a constant depth during the traverse of the boat across the stream. The measured velocity and the additional information of the depth sounding gives the required data for determining the discharge.

6 Principle of the moving-boat method

The moving-boat measurement is made by traversing the stream along a preselected path that is generally normal to the streamflow (see Figure 1). During the traverse an echo sounder records the geometry of the cross-section and a continuously operating current meter senses the combined stream and boat velocities. A third set of data needed is obtained either by measuring at intervals the angle between the current meter, which aligns itself in a direction parallel to the movement of the water past it, and the preselected path or by measuring the distance to a fixed point on the bank.

The velocity measurement observed at each of the observation points in the cross-section (v_v in Figure 2) is the velocity of water past the current meter resulting from both stream flow and boat movement. It is the vector sum of the velocity of water with respect to the stream bed (v) and the velocity of the boat with respect to the stream bed (v_b).

¹⁾ At present at the stage of draft.

The sampling data recorded at each observation point provide the necessary information to determine the velocity of the stream. There are two methods to obtain this velocity, referred to as method 1 and method 2. Method 1 consists of measuring the angle α between the selected path of the boat and a vertical vane which aligns itself in a direction parallel to the movement of the water past it. An angle indicator attached to the vane assembly indicates angle α .

Method 2 consists of measuring the distance from the observation points to a fixed point on the bank from which the width of the traversed segment can be determined along with the simultaneous measurement of time. From these data, the velocity component of the boat, v_b , can be computed and by means of the measurement of total velocity, v_v , the velocity component, v , of the stream perpendicular to the selected boat path is determined.

The reading from the rate indicator unit in pulses per second is used in conjunction with a calibration table to obtain the vector magnitude v_v .

Normally, data are collected at 30 or 40 observation points in the cross-section for each run. Where practicable, automatic and simultaneous readings of all required parameters may be recorded.

6.1 Determination of stream velocity

By method 1 the stream velocity v , perpendicular to the boat path (true course) at each observation point 1, 2, 3, . . . , can be determined from the relationship

$$v = v_v \sin \alpha \quad \dots (1)$$

The solution of equation (1) yields an answer which represents that component of the stream velocity which is perpendicular to the true course even though the direction of flow may not be perpendicular.

By method 2 the stream velocity can be determined from

$$v = \sqrt{v_v^2 - v_b^2} \quad \dots (2)$$

where v_b is obtained from

$$v_b = \frac{l_i - l_{(i-1)}}{t_i} \quad \dots (3)$$

(see Figure 3)

where

i is the observation point order;

l_i is the distance from observation point i to a fixed point on the bank;

t_i is the time required to traverse the width of a segment.

6.2 Determination of distance between observation points

From the vector diagram, (see Figure 2) it can be seen that

$$\Delta l_b = \int v_v \cos \alpha \, dt \quad \dots (4)$$

where Δl_b is the distance which the boat has travelled along the true course between two consecutive observation points, provided the stream velocity is perpendicular to the path.

Where the velocity is not perpendicular, an adjustment is required as explained in 10.3.

If it is assumed that α is approximately uniform over the relatively short distance which makes up any one increment, then it may be treated as a constant.

Therefore applying method 1, equation (4) becomes

$$\Delta l_b \approx \cos \alpha \int v_v \, dt \quad \dots (5)$$

Now

$$\int v_v dt = \Delta l_v$$

where Δl_v is the relative distance through the water between two consecutive observation points as represented by the output from the rate indicator and counter.

Therefore for the i th relative distance

$$\Delta l_{b_i} \approx \Delta l_{v_i} \cos \alpha_i \quad \dots (6)$$

the total width, B , of the cross sectional area is

$$B = \sum_{i=1}^{i=m} \Delta l_{b_i} \approx \sum_{i=1}^{i=m} \Delta l_{v_i} \cos \alpha_i \quad \dots (7)$$

If method 2 is applied, then the width of the interval between observation points should be computed as the difference between successive distance measurements from a fixed point on one of the banks as shown in equation (3).

6.3 Determination of stream depth

The stream depth at each observation point should be obtained by adding the transducer depth to the depth from the echo sounder chart, unless the transducer is set to read total depth.

7 Limitations

The method is normally employed on rivers over 300 m wide and over 2 m in depth.

The minimum width which is required depends on the number of segments into which the cross-section is divided and the minimum time to pass these segments to obtain a sufficiently accurate measurement.

The number of segments should be at least 25.

The width to be taken for each segment depends on the accuracy with which the velocity in each segment can be measured. The interval between two observation points should be sufficient to allow the observer to read the instruments and record the results. The minimum speed of the boat should be such as to ensure that the boat may traverse the section in a straight line. For the best results this speed should be of the same order as the velocity of the stream.

The river should be of sufficient depth to allow for the draught of the boat and the requirement of easy manoeuvring during the traverse of the cross-section. Shallow locations may cause damage to the instruments as the current meter and/or vane extend about 1 m below the boat.

The stream should not have an under-current, as can be the case in tidal-flow, where the direction is opposite to the flow in which the velocity is measured. In such cases the velocity distribution in the vertical is unknown and the mean velocity cannot be satisfactorily correlated to the measured velocity.

During the time that the boat traverses the stream the discharge should not change to such an extent that an unreliable measurement is obtained. For unsteady flow conditions on tidal streams, it will normally be desirable not to average the results from a series of runs, but rather to keep them separate so as to better define the discharge cycle (see Figure 4).

8 Equipment

8.1 General

The equipment required is similar no matter which of the two methods is used (see clause 6).

Essentials of the equipment required for both methods are given below. A more detailed description of the equipment is dealt with in Annex A.

8.2 Boat

An easily manoeuvrable boat which is sufficiently stable for the stream in which it is to be used is required.

8.3 Vane and angle indicator (method 1)

A vane with indicating mechanism should be mounted on a suitable part of the boat, generally the bow. The angle between the direction of the vane and the true course of the boat should be indicated on a dial by the pointer mounted in line with the vane. A sighting device attached to the free swivelling dial provides a means of aligning the index point on the dial with the true course. The dial should be calibrated in degrees (from 0 to 90°) on both sides of its index point.

8.4 Current meter

The current meter should preferably be a component propeller type with a body which should be, in the case of method 1, adapted for mounting on the leading edge of the vane. If method 2 is applied, the current meter with its sounding weight should be suspended on a cable from the boat. The requirements for this suspension equipment should conform to ISO 3454 on sounding and suspension equipment.

8.5 Pulse rate indicator and counter

The revolutions of the current meter are transmitted as electrical pulses which should be displayed on a counter or converted via an electronic assembly to a velocity display.

In the first case, the pulses are converted to velocity by the use of a current meter rating table.

If method 1 is applied, the counting unit should have provision to preset the number of electronically counted pulses. An audible signal is generated when the preset number is reached and the echo sounder chart is automatically marked. The counter should automatically reset itself before repeating the process. A sketch and description of the rate indicator and counter are given in Figure 5.

8.6 Distance measurement (method 2)

To locate the observation points in the cross-section, the distance should be measured from each point to a fixed position on the embankment. The distance measurement can be performed optically for example by a range finder or by electronic equipment (for example a radiolog).

The distance measuring device should have a (relay) connection with the echo sounder so that at each observation point a vertical line marking can be triggered on the sounder stripchart (automatically or by hand).

8.7 Echo sounder

A (portable) echo sounder should be used to provide a continuous stripchart of the depth profile of the cross-section between the two floats. The echo sounder should have the facility of a relay connection with the rate indicator and counter or the distance meter to trigger vertical line markings on the sounder chart at each observation point. The echo sounder should conform to ISO 4366.

9 Measurement procedures

Procedures for a moving-boat measurement should include selection and preparation of a suitable measuring site, preparation and assembly of the equipment used for the measurement and a selection of settings for the instruments used to collect the data.

9.1 Selection of the site

The measuring site should be selected so that substantially uniform flow can be expected. This means that streamlines are as parallel as possible and that the bed shows no sharp discontinuities.

9.2 Preparation of the site

Some preparation of the site is required prior to starting a series of moving-boat measurements.

9.2.1 A path for the boat to travel should be selected which is as nearly perpendicular to the flow direction as possible. This path should be marked by two clearly visible range markers placed on each bank. The colour of these markers should contrast sharply with the background. Spacing between the markers is dependent upon the length of the path. Approximately 30 m of spacing is required for each 300 m of path length.

9.2.2 Anchored floats to mark the beginning and ending points of the measurement should be placed in the stream 12 to 15 m from each shore along the selected path (see Figure 1). In making a traverse, this distance is needed for manoeuvring the boat when entering or leaving the path. The floats should be placed so that the depth of water in their vicinity is always greater than 1 m (vane or current meter depth).

It is preferable to offset the floats about 3 to 6 m upstream of the line of the boat path in order that they do not interfere with the approaching boat.

9.2.3 The width of the stream may be measured by triangulation, stadia or other methods and the exact locations of the floats determined. The distance of the floats to the edge of the water should be measured (for example with a tape measure), and should be noted in the main part of the measurement notes for use in the computation of the measurement. When method 1 is used it is desirable to have permanent cross-section markers so that the true width may be conveniently computed by measuring from the markers to the water's edge. (If method 2 is used the distance between the markers should be checked each time a measurement is made thus providing a calibration check on the distance measuring device).

9.3 Function of the crew members

Three experienced crew members are usually necessary for making a moving-boat discharge measurement. For method 1 they include a boat operator, an angle observer and a notekeeper; for method 2 a boat operator, an observer for the pulses of the current meter, who is also notekeeper, and a distance observer. Before crew members begin making discharge measurements by the moving-boat method it is important that they develop a high degree of proficiency in all aspects of the technique.

A short description of the function of the crew members follows below. A more detailed description is given in Annex A.

- a) The notekeeper should be the person responsible for both the preparation and execution of the measurement. He should also report the results of the measured data (see Annex B).
- b) The boat operator should be familiar with the measuring site and should take care that the boat remains on line as nearly as possible throughout the traverse of the cross-section.
- c) The angle observer (method 1) should read the angle formed by the vane with respect to the true course and report the result to the notekeeper.
- d) The distance observer (method 2) should read the distance to one of the markers on the bank using optical or electronic equipment. He should mark the observation points on the stripchart of the echo sounder if this is done manually.

If automatic, simultaneous recording is used the number of crew members may be reduced to two.

10 Computation of discharge

10.1 General

Theoretically the discharge is given by

$$Q = A \int v(x,y) \, dx dy$$

where

- Q is the true discharge;
- A is the cross-sectional area;
- $v(x,y)$ is the velocity field over width and depth.

In practice the integral is usually approximated by the summation

$$Q_m = \sum_{i=1}^{i=m} b_i d_i \bar{v}_i \quad \dots (8)$$

where

- Q_m is the calculated discharge;
- b_i is the width of the i th segment;
- d_i is the depth of the i th segment;
- $\bar{v}_i$ is the mean velocity in the i th segment;
- m is the number of segments.

The stream discharge is then the summation of the products of the segment areas of the stream cross-section and their respective mean velocities.

The moving-boat measurement utilizes the mid-section method of computing discharge. This method assumes that the mean velocity at the middle of each segment represents the mean velocity in the segment. The area extends laterally from half the distance from the preceding meter location to half the distance to the following and vertically from the water surface to the sounded bed (see ISO 748).

10.2 Method of computation

In Figure 3, a definition sketch of the midsection method has been superimposed over a facsimile of a cross-section profile from an echo sounder chart. The cross-section is defined by depths at locations 1, 2, 3, . . . , n , which were marked during the measurement on the echo-sounder chart.

According to the midsection method, the partial discharge is computed for any section at location i as

$$q_i = v_i \left[\frac{l_{(i+1)} - l_{(i-1)}}{2} \right] d_i \quad \dots (9)$$

where

- q_i is the unadjusted discharge through section i ;
- v_i is the sampled velocity at location i ;
- $l_{(i-1)}$ is the distance from initial point to the preceding location;
- $l_{(i+1)}$ is the distance from initial point to the next location;
- d_i is the depth of water at location i .

The stream velocity should be determined for location i either by equation (1) when method 1 is applied or by equation (2) for method 2. For further details see Table 1 and Table 2, where a complete measurement has been computed for method 1 and method 2 respectively.

The distance from the initial point (marker on the bank) to the observation point where the data are collected is the summation of the cumulative distance from the meter locations to the float, the distance from the float to the edge of the water and the distance from the edge of the water to the marker (see Figure 3). These last two distances are measured separately for each bank. The distances are defined as follows:

l_1 = distance from initial point (marker) to edge of water

$l_2 = l_1 + \text{measured distance to float from edge of water}$

$l_3 = l_2 + \Delta l_{b_3}$

$l_4 = l_3 + \Delta l_{b_4}$

$l_{(n-1)} = l_{(n-2)} + \Delta l_{b_{(n-1)}}$

$l_n = l_{(n-1)} + \text{measured distance from float to edge of water}$

$l_{(n+1)} = l_n + \text{distance to final point (marker)}$

In the above, Δl_{b_i} is the distance from the meter location to the preceding one as determined according to method 1.

For method 2 the distances l_i to the marker are measured directly. Each of the segment widths represents the distance that extends laterally from half the distance from the preceding meter location ($i-1$) to half the distance to the next, ($i+1$). For example the width of the segment i equals

$$b_i = \frac{l_{(i+1)} - l_{(i-1)}}{2} \quad \dots (10)$$

The stream depth at each measuring point in the cross-section is obtained by adding the transducer depth to each of the depth readings recorded on the echo sounder chart at the sampling locations.

Depending on the apparatus used, this addition can be done automatically.

The individual segment areas are obtained by multiplying the width as obtained from equation (10), by the depth at the measuring point.

The incremental areas are then summed to provide the total unadjusted area for the measurement.

According to equation (9), the (unadjusted) discharge through one of the segments is obtained by multiplying the unadjusted area and the measured velocity at the observation point. These values should be summed to provide the total (unadjusted) discharge for the measurement. The brackets refer to method 1.

10.3 Correction for width in the case of oblique flow (method 1)

10.3.1 General

There may be circumstances when a measurement site must be chosen in which the flow is not normal to the cross-section. Then if method 1 is applied, the width of the segments should be computed from the relationship expressed by equation (6).

$$\Delta l_{b_i} \approx l_{v_i} \Delta \cos \alpha_i$$

This equation is based on the assumption that a right triangle relationship exists between the velocity vectors involved.

If the flow is not normal to the cross-section, this situation does not exist and the use of the equation can result in a computed width that is too large or too small, depending on whether the vector quantity representing the oblique flow has a component that is opposed to, or in the direction of, that of the boat (see Figure 6).

Where method 2 is applied, no correction for width is needed as the distances are measured directly.

The component of the flow normal to the cross-section is not influenced by the boat velocity component as long as the boat path is parallel to the cross-section.

To compensate for minor deviations of the direction of flow or the deviations between the boat path and the cross-section, an equal number of runs should be taken in both directions. See Figure 7 a) and Figure 7 b).

10.3.2 Computation of the correction for width (method 1)

Ideally the correction for error in the computed width would be applied to that particular increment in the cross-section where the error occurred.

However in practice only the overall width is directly measured and thus is available for comparison with the computed quantities. Therefore, if the sum of the computed incremental widths does not equal the measured width of the cross-section, correction should be made by adjusting each increment proportionately.

The moving-boat method uses the relationship between the measured and computed widths of the cross-section to determine a width/area adjustment factor. To obtain this factor, the measured width of the cross-section is divided by its computed width, that is

$$k_B = \frac{B_m}{B_c} \quad \dots (11)$$

where

- k_B is the width-area adjustment factor;
- B_m is the measured width of cross-section;
- B_c is the computed width of cross-section.

The factor is then used to adjust both total area and total discharge of the measurement as if the width error had been evenly distributed on a percentage basis across each width increment of the cross-section.

See Table 1, for an example of an application of a width-area adjustment factor.