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LIQUID FLOW MEASUREMENT IN OPEN CHANNELS

ESTABLISHMENT AND OPERATION OF A GAUGING STATION AND DETERMINATION OF THE STAGE-DISCHARGE RELATION

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BRIEF HISTORY

The ISO Recommendation R 1100, *Liquid flow measurement in open channels – Establishment and operation of a gauging station and determination of the stage-discharge relation,* was drawn up by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels,* the Secretariat of which is held by the Indian Standards Institution (ISI).

Work on this question led to the adoption of a Draft ISO Recommendation.

In December 1966, this Draft ISO Recommendation (No. 1071) was circulated to all the ISO Member Bodies for enquiry. It was approved, subject to a few modifications of an editorial nature, by the following Member Bodies :

Australia	Ireland	South Africa, Rep. of
Belgium	Israel	Switzerland
Brazil	Italy	Thailand
Chile	Japan	Turkey
Czechoslovakia	Korea, Rep. of	United Kingdom
France	Netherlands	U.S.A.
Germany	Portugal	
India	Romania	

One Member Body opposed the approval of the Draft :

Canada

The Draft ISO Recommendation was then submitted by correspondence to the ISO Council, which decided, in July 1969, to accept it as an ISO RECOMMENDATION.

CONTENTS

ISO Recommendation | R 1100 | July 1969

LIQUID FLOW MEASUREMENT IN OPEN CHANNELS

ESTABLISHMENT AND OPERATION OF A GAUGING STATION AND DETERMINATION OF THE STAGE-DISCHARGE RELATION

1. SCOPE

This ISO Recommendation deals with the continuous measurement of water level, the determination of the stage-discharge relation by correlating water levels to discharges and the compilation of records of flow at a gauging station. It also deals with the establishment and operation of the gauging station on a river or open channel.

Single-discharge measurements may be made by any of the accepted methods of measurement of liquid flow in open channels in accordance with the relevant ISO Recommendations*. This ISO Recommendation covers only such additional requirements as are necessitated by its wider scope.

Open channels have been grouped into stable and unstable types as the characteristic stage-discharge curves of the two are different.

This ISO Recommendation does not cover cases such as those encountered

(*a*) during floods when flow conditions are suddenly or rapidly varying due to abrupt flood waves;

(*b*) during periods when flow conditions are significantly impeded by the formation or presence of ice.

An Annex is included covering design and practice to assist compliance with this ISO Recommendation (Annex A); it also gives relevant statistical tests and procedures for construction of stage-discharge curves.

Further Annexes deal with the correction for discharge in unsteady flow (Annex B) and the family of curves giving the stage-discharge relation (Annex C).

2. DEFINITIONS

For the purposes of this ISO Recommendation, the definitions given in ISO Recommendation R 772, *Vocabulary of terms and symbols used in connection with the measurement of liquid flow with a free surface*, apply.

3. UNITS OF MEASUREMENT

The units of measurement used in this ISO Recommendation are seconds, and metres or feet.

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* See the following ISO Recommendations :

- ISO Recommendation R 555, *Liquid flow measurement in open channels – Dilution methods for measurement of steady flow – Part I – Constant rate injection method;*
- ISO Recommendation R 748, *Liquid flow measurement in open channels by velocity area methods*;
- ISO Recommendation R . . ., *Liquid flow measurement in open channels using thin plate weir and venturi flumes* (at present, Draft ISO Recommendation No. 1438).

4. PRINCIPLE OF THE METHOD OF MEASUREMENT

The principle of the method is to establish a unique relation between the discharge of a channel and either the water level in the section of a stream or the readings of water levels at each end of a reach. Knowledge of this stage-discharge relation will enable the discharge to be determined by simple measurement of the level, during the operating period of the station.

To establish this relation, it is necessary to carry out at the selected site a sufficient number of measurements of the discharge and the corresponding stage simultaneously. Each discharge measurement should be made by one of the accepted methods.

5. CHOICE OF SITE

5.1 Preliminary survey

A preliminary survey should be made to ensure that the physical and hydraulic features of the proposed site conform to the requirements for the application of the methods of flow measurement which it is intended to use.

5.2 Selection of site

The site selected should be such that it is possible to measure the whole range and all types of flow which may be encountered or which it is required to measure. The whole range of measurement, referred to one reference gauge, may be made at a single section, or, for certain ranges of discharge, at two or more sections. Similarly, different methods of measurement may be employed for separate parts of the range, the particular conditions relative to each of the methods of measurement being specified in the relevant ISO Recommendations for the measurement of liquid flow in open channels.*

Either single or twin gauge stations may be employed, depending upon conditions, but the former should be preferred.

The operation of a single gauge station depends upon the assumption that the elevation of the free surface is a substantially unique function of the discharge. In the case of stations affected by hysteresis, the rise and fall should be calibrated separately by discharge measurement.

5.2.1 *At a single gauge station*

(*a*) It is desirable to select a site where the relationship between stage and discharge is substantially consistent and stable. However, this may not be possible on all alluvial rivers. For such rivers, the stage-discharge relation is generally applicable only for the period for which it has been determined.

(*b*) There should not be any variable backwater effect.

5.2.2 *At any gauging station (with single or twin gauges)*

(*a*) The site should be sensitive, i.e. a significant change in discharge, even for the lowest discharges, should be accompanied by

- a significant change in stage in the case of a single gauge station;
- a significant change in stage (at one or other of the gauges) and in fall (between the two gauges) in the case of a twin gauge station.

Otherwise, small errors in stage readings during calibration in a non-sensitive station can result in large errors in the discharges indicated by the curve.

A comparison should be made between the change in discharge and the corresponding minimum change in stage to ensure that the sensitivity of the station is sufficient for the purpose for which the measurements are required.

* ISO Recommendations R 555 and R 748, and Draft ISO Recommendation No. 1438.

(*b*) Sites where weed growth is prevalent should be avoided.

(*c*) There should be no vortices, dead water or other abnormalities in flow.

(*d*) Access to the site at all stages and at all times should be available as far as possible.

6. DESIGN AND CONSTRUCTION OF A GAUGING STATION

6.1 General

A gauging station consists of one or more natural or artificial measuring cross-sections (weir or flume), and a reference gauge.

In cases where a general system of river gauges is in existence, it is not absolutely necessary that the position of the measuring cross-section should coincide with the position of the gauge, provided that the discharge is equal in both places for all stages. In all other cases, it is advisable to install the gauge in, or very near to, the chosen cross-section.

Where a desirable site satisfies some but not all of the requirements stated in the relevant ISO Recommendations dealing with single-discharge measurement*, and in clause 5.2 of this ISO Recommendation, it may be made to do so by appropriate modifications (see Annex A). In general this will only be feasible for smaller rivers.

In the case of a twin gauge station, the length of the reach should be sufficient to make any observational error negligible relative to the fall of level between the two gauges. Further, there should be no additions to the discharge, or withdrawals from it, between the two gauges.

6.2 Devices for measurement of stage

6.2.1 *Reference gauge.* The reference gauge should be a vertical gauge or an inclined gauge. The markings should be clear and sufficiently accurate for the purpose for which the measurements are required. The lowest marking and the highest marking on the reference gauge should be respectively below and above the lowest and highest anticipated water levels.

The reference gauge should be securely fixed to an immovable and rigid support in the stream and should be correlated to a fixed bench-mark by precise levelling to the national datum. It should have a stilling arrangement, wherever necessary, so that the water level can be read accurately.

Where a continuous record of water levels is required, a water-level recorder should be installed. It is essential, however, to combine such a recorder always with a normal river gauge, placed near the point of measurement of the recorder. In other cases a normal river gauge will suffice.

NOTE. – When possible, an estimate of extreme values should be made by statistical analysis. Care should be taken to incorporate such extreme values as may be required for the purpose of the station. Possible deepening of the bed should also be taken into account.

6.2.1.1 VERTICAL GAUGE. This staff gauge should be truly vertical. It should be of such a shape as not to cause any noticeable heading up of flow.

6.2.1.2 INCLINED GAUGE. The inclined gauge should fit closely and be solidly anchored to the slope of the natural bank of the water-course. It may be calibrated on the site by precise levelling.

6.2.2 *Continuous liquid level recorder.* This may consist of a recorder operated by a float in a stilling well communicating with the channel or a pneumatic recorder or other device. It is essential, however, to combine such a recorder always with a reference gauge, placed near the point of measurement of the recorder. In the case of the float-actuated recorder, an additional gauge should be installed inside the float-well to serve as a check.

* See ISO Recommendations R 555 and R 748, and Draft ISO Recommendation No. 1438.

6.2.2.1 STILLING WELL. The stilling well for the accommodation of the float of the float-operated recorder should meet the following requirements.

(*a*) It should be vertical and have sufficient height and depth to allow the float to rise and fall over the full range of water levels.

(*b*) In water courses with widely fluctuating silt content (i.e. densities), inlet pipes should be provided at various stages.

(*c*) Joints with any inlet pipes should be watertight.

(*d*) The dimensions of the inlet pipe(s) or of the channel should be large enough for the water level in the well to follow the rise and fall of stage without delay, and also to prevent clogging due to sediment.

(*e*) If the stage cannot be read on the chart with sufficient accuracy because of short period wave effect, a constriction should be fitted in the inlet pipe to damp out oscillation.

6.2.2.2 THE PNEUMATIC RECORDER

(*a*) This recorder measures the stage by means of the pressure exerted on a take-off which is immersed and solidly fixed at a known elevation.

(*b*) The recorder should have a source of compressed gas (air or nitrogen) and a device for adjusting the air flow in the form "bubble to bubble".

(*c*) A device for driving away the gas should be provided to discharge the pressure take-off, if necessary.

(*d*) The pipe connecting the manometer to the pressure take-off should have a length less than the limit fixed by the manufacturer. It should not have low points running the risk of accumulating the condensates of the gas.

(*e*) The device for measuring the pressure should be sufficiently sensitive and accurate. In case a manometer with a liquid stopper is used, the density of this liquid at various temperatures should be eventually taken into account and the manufacturer should indicate the value of the errors.

6.2.2.3 REQUIREMENTS OF THE RECORDER. The recorder either should provide a continuous graphical record of the changing water level or should register the water levels digitally at suitably close intervals of time.

The recorded results will depend directly upon the changing water levels. If they are affected by other phenomena (damping of the stilling well of the float-operated recorder, loss of head due to the gas flow or the liquid stopper of the manometer, in a pneumatic recorder) the user should know the effects so that he may correct them if necessary.

In the case of a recorder giving a graphical chart, the chart sheet should be positively located on the drum. The scales chosen for time and stage will depend on the characteristics of the river, and should be such that readings can be made with a degree of accuracy sufficient to show the different phases of the hydrograph.

Any mechanical linkage connecting parts of the recorder should be as short and direct as possible and there should be no contact between any moving part of the mechanism and any fixed part of the structure.

The clock mechanism should maintain accurate time.

The recorder should be placed out of danger of flooding and be protected against the elements and interference by unauthorized persons.

Precautions should be taken against the occurrence of errors in records due to

(*a*) lag of the stylus behind the movement of the float;

(*b*) change in the submergence of the float in the water;

(*c*) submergence of the counterweight and the float line.

6.3 Procedure for observation of gauges

The gauge should be read from such a position as to avoid all parallax errors. The gauge should be observed continuously for a minimum period of 2 minutes or the period of complete oscillation, whichever is longer, and the maximum and minimum readings taken and averaged.

7. SURVEY OF STATION – GENERAL REQUIREMENTS

After a gauging station has been constructed a definitive survey should be made.

The definitive survey should include the accurate determination of the elevations and relative positions of reference gauges and inlet zeros, the survey of inlet pipes or channel inverts, base of stilling well in the case of a float-operated recorder, the fixation of the pressure take-off and tightness of the gas pipes and of all parts under pressure in the case of a pneumatic recorder, cross-section markers and any other key points or significant features of the site.

A periodic check, at least once a year, and on every occasion the gauge is changed, should also be made of the elevations and relative positions taken at the time of the definitive survey.

8. CALIBRATION OF STATION

8.1 General

The object of a gauging station is to obtain a knowledge of the discharge of a river or open channel. Once the stage-discharge curve is available, the discharge will be known by reading the gauge or recorder. The operations necessary to obtain this relationship are called the calibration (rating) of the station.

8.1.1 *Measurement of discharge for calibration (rating).* The discharge should be measured in accordance with the relevant ISO Recommendations*. Errors may also be estimated on the basis of those ISO Recommendations.

The survey of the site should be carried out in greater detail than in the case of single discharge measurements. Special attention should be given to the likelihood of changes in the channel that may affect the stage-discharge curve.

NOTES

1. Very few rivers have absolutely stable characteristics. The calibration, therefore, cannot be carried out once and for all, but has to be repeated as frequently as required by the rate of change in the stage-discharge curve. It is recommended that measurements at the stages which do not frequently occur should be made as often as possible.
2. In the case of an unstable river the stage-discharge relationship changes more frequently, especially following floods. Discharge observations have therefore to be made at more frequent intervals during these periods.

8.1.2 *Notches, weirs and flumes.* In the case of notches, weirs and flumes the operation recommended above would not normally be necessary because the stage-discharge relationship may have been determined by laboratory experiments. However, their operation should be checked periodically

(*a*) by discharge measurements to ensure that the assumed rating applies and that they actually account for all the flow passing the section;

(*b*) by direct measurement of dimensions to verify stability.

* See ISO Recommendations R 555 and R 748, and Draft ISO Recommendation No. 1438.

8.2 Construction of stage-discharge curve and rating table

8.2.1 *Single gauge station*

8.2.1.1 STAGE-DISCHARGE CURVE – STABLE CHANNELS. Discharges should be plotted as abscissae against the corresponding stages as ordinates and the stage-discharge curve should be drawn smoothly through the points as plotted. The stage used in plotting should be the mean stage during the period of discharge measurement.

The curve should be defined by a sufficient number of measurements suitably distributed throughout the whole range of water levels, each preferably made at steady stage. The number of measurements to define the curve will depend on the range to be covered, the shape of the stage-discharge curve and the desired accuracy (see clause A.5.3 of Annex A).

The spacing of the measurements should be closer at the lower end of the range and the drawing of the curve should be checked by one of the methods described in Annex A. Where observations are made at rising and falling stages, they should be indicated by suitable symbols, and there should be about the same number of each at corresponding steps in order to establish the suitable mean curve.

In order to have at least one measurement at or near the peak discharge, it is desirable to increase the frequency of measurements when the gradient of the hydrograph is becoming significantly flatter at or near the peak.

8.2.1.2 STAGE-DISCHARGE CURVE – UNSTABLE CHANNELS. In the case of unstable channels, the stage-discharge relationship does not remain stable and frequent changes in "control" occur during and after flood periods. Also in the case of unstable channels, the particular stage-discharge relations prevailing over the different periods are required for the estimation of discharges from stage records for the periods for which no discharge measurements are available. The discharges for the water year should be plotted as abscissae against the corresponding stages as ordinates and each point labelled in chronological order. The lie of the points should be examined for shifts in control with reference to their chronological order. Smooth curves should be drawn separately for each period having no shift in control. Thus, there may be more than one curve within the rising and falling phases of the same water year for an unstable channel subject to silting and scouring.

8.2.1.3 METHODS OF TESTING STAGE-DISCHARGE CURVES. The curves should invariably express the stage-discharge relation objectively and should therefore be tested for absence from bias and goodness of fit in the periods between shifts of control, and for the shifts in control. Methods for locating shifts in control in the stage-discharge curves due either to physical changes in the channel features or to changes occurring in course of time are also indicated in clause A.5.8 of Annex A.

For stable channels, where the control is uniform and remains unchanged, it may be possible to fit a mathematical curve. This may be done as explained in clause A.5.10 of Annex A. More frequently, even in a stable channel, where the curve has to be drawn by visual estimation for example, when the section is not uniform, the tests described for unstable channels become equally necessary.

In the case of natural unstable channels, different controls come into operation at different stages in different years, so that not only are the curves for the rising and falling stages different from each other and from year to year, but there are also inflexions and discontinuities due to shifts in control within a stage. The inordinate labour involved in fitting the high-degree composite curves rules them out in practice. The best-fitting rising and falling curves have, therefore, to be drawn by visual estimation and should, therefore, be tested for absence from bias and for goodness of fit, separately for the individual portions between shifts in control.

For absence from bias, there are two tests. In one, the curve is tested to satisfy the basic requirement that a significantly equal number of points are expected to lie above and below an unbiassed curve so that the deviations are not more than those due to chance fluctuations (Test 1, clause A.5.6.1). In the other, the condition that the algebraic sum of the percentage deviations of the observed discharges from an unbiassed curve should not be significantly different from zero is tested by comparing the mean of the percentage deviations with the standard error (Test 3, clause A.5.6.3).

For goodness of fit, a test is applied to check that a sign change in deviations (i.e. observed value minus expected value from the curve) is as likely as a non-change of sign. This test also helps in detecting shifts in control at different stages (Test 2, clause A.5.6.2).

The above-mentioned tests are described in detail in clause A.5.6 of Annex A with examples illustrating their application.

8.2.1.4 RATING TABLE. A rating table should be prepared from the stage-discharge curve, or from the equation of the curve, showing the discharges corresponding to stages in ascending order, and with intervals corresponding to the desired accuracy of reading.

8.2.2 *Twin gauge stations*

8.2.2.1 STAGE-DISCHARGE CURVE. The establishment of a single gauge station is impossible in all cases where the flow in the reach of the river is controlled by conditions existing in another reach (upstream or downstream), if the latter vary owing to natural causes (rise in water level of tributary, obstruction, etc.), or owing to artificial causes (moving flood gates of navigational dams, hydro-electric schemes, etc.). It is, however, possible to obtain a measurement of flow with two gauges placed in the same reach by the slope discharge method. For all pairs of values of levels z_0 and z_1 read off each of the scales, there is a single corresponding value of discharge Q, provided that the topography and roughness of the bed have not changed in the reach between the scales.

The plotting of the stage-discharge observations with the value of fall against each observation will reveal whether the relationship is affected by variable slope at all stages, or is affected only when the fall reduces below a particular value. In the absence of any channel control, the discharge would be affected by the fall at all times, and the correction is applied as indicated in the constant fall method covered in Annex C. When the discharge is affected only when the fall reduces below a particular value, the normal fall method is applied, which is also given in Annex C.

8.2.2.2 RATING TABLE. The complexity of the relationship generally makes it difficult to prepare a rating table and it is recommended that the values be obtained from the relevant graphs.

8.3 Verification of the stage-discharge relationship

If the procedure recommended in clause A.5.1 is followed, no actual verification is needed. When, after one or more years, a sufficient number of observations is available for the whole range of discharges, the curve should be drawn. By repeating the procedure it will be possible after a certain period to draw a new curve. When shift is thus detected in an unstable channel, a new curve is drawn which serves as a norm during the period until another shift is detected. Each curve is the calibration curve which serves as the norm during the next period of observations. By comparing successive curves and noting the deviations, it is possible to determine the necessary frequency of observations for the future, and the lengths of the periods during which a certain stage-discharge curve may be regarded as reliable.

In cases where the regularity of observations needed for the method described above cannot be realized, the following method of verification is recommended. The stage-discharge curve relationship should be checked by discharge measurements from time to time at a low stage and at a medium or high stage, and always during and after major floods. If a significant departure from the previously established stage-discharge curve is found, further checks should be made. If the difference is confirmed, sufficient discharge measurements should be made to define the area in which the stage-discharge relationship has altered and a new stage-discharge curve should be drawn.