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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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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO Member Bodies). The work of developing International Standards is carried out through ISO Technical Committees. Every Member Body interested in a subject for which a Technical Committee has been set up has the right to be represented on that Committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

Prior to 1972, the results of the work of the Technical Committees were published as ISO Recommendations; these documents are now in the process of being transformed into International Standards. As part of this process, International Standard ISO 1100 replaces ISO Recommendation R 1100-1969, drawn up by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels.*

The Member Bodies of the following countries approved the Recommendation :

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	

The Member Body of the following country expressed disapproval of the Recommendation on technical grounds :

Canada

Printed in Switzerland

CONTENTS

Liquid flow measurement in open channels – Establishment and operation of a gauging-station and determination of the stage-discharge relation

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies methods for 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 International Standards. This International Standard 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 International Standard 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 International Standard (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 REFERENCES

ISO 555, *Liquid flow measurement in open channels – Dilution methods for measurement of steady flow – Constant-rate injection method.*

ISO 748, *Liquid flow measurement in open channels – Velocity-area methods.*

ISO 772, *Liquid flow measurement in open channels – Vocabulary and symbols.*

ISO 1438, *Liquid flow measurement in open channels using thin-plate weir and venturi flumes.*[1]

3 DEFINITIONS

For the purposes 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 seconds, and metres or feet.

5 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 shall be made by one of the accepted methods.

6 CHOICE OF SITE

6.1 Preliminary survey

A preliminary survey shall 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.

6.2 Selection of site

The site selected shall 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

1) At present at the stage of draft.

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 International Standards for the measurement of liquid flow in open channels.[1)]

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 shall be calibrated separately by discharge measurement.

6.2.1 *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 shall not be any variable backwater effect.

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

a) The site shall be sensitive, i.e. a significant change in discharge, even for the lowest discharges, shall 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 shall 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.

b) Sites where weed growth is prevalent shall be avoided.

c) There shall be no vortices, dead water or other abnormalities in flow.

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

7 DESIGN AND CONSTRUCTION OF A GAUGING-STATION

7.1 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 International Standards dealing with single-discharge measurement[1)], and in 6.2 of this International Standard, 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 shall be sufficient to make any observational error negligible relative to the fall of level between the two gauges. Further, there shall be no additions to the discharge, or withdrawals from it, between the two gauges.

7.2 Devices for measurement of stage

7.2.1 *Reference gauge*

The reference gauge shall be a vertical gauge or an inclined gauge. The markings shall 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 shall be respectively below and above the lowest and highest anticipated water-levels.

The reference gauge shall be securely fixed to an immovable and rigid support in the stream and shall be correlated to a fixed bench-mark by precise levelling to the national datum. It shall 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 shall 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 shall be taken to incorporate such extreme values as may be required for the purpose of the station. Possible deepening of the bed shall also be taken into account.

1) See ISO 555, ISO 748, and ISO 1438.

7.2.1.1 Vertical gauge

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

7.2.1.2 Inclined gauge

The inclined gauge shall 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.

7.2.2 *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 shall be installed inside the float-well to serve as a check.

7.2.2.1 Stilling-well

The stilling-well for the accommodation of the float of the float-operated recorder shall meet the following requirements.

a) It shall 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 shall be provided at various stages.

c) Joints with any inlet pipe shall be watertight.

d) The dimensions of the inlet pipe(s) or of the channel shall 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 shall be fitted in the inlet pipe to damp out oscillation.

7.2.2.2 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 shall 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 shall be provided to discharge the pressure take-off, if necessary.

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

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

7.2.2.3 Requirements of the recorder

The recorder shall either provide a continuous graphical record of the changing water-level or 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 must know the effects so that he may correct them if necessary.

In the case of a recorder giving a graphical chart, the chart sheet shall be positively located on the drum. The scales chosen for time and stage will depend on the characteristics of the river, and shall be such that reading 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 shall be as short and direct as possible and there shall be no contact between any moving part of the mechanism and any fixed part of the structure.

The clock mechanism shall maintain accurate time.

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

Precautions shall 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.

7.3 Procedure for observation of gauges

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

8 SURVEY OF STATION – GENERAL REQUIREMENTS

After a gauging-station has been constructed, a definitive survey shall be made.

The definitive survey shall 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, shall also be made of the elevations and relative positions taken at the time of the definitive survey.

9 CALIBRATION OF STATION

9.1 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.

9.1.1 *Measurement of discharge for calibration (rating)*

The discharge shall be measured in accordance with the relevant International Standards[1]. Errors may also be estimated on the basis of those International Standards.

The survey of the site shall be carried out in greater detail than in the case of single-discharge measurements. Special attention shall 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.

9.1.2 *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 shall be checked periodically

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

b) by direct measurement of dimensions to verify stability.

9.2 Construction of stage-discharge curve and rating table

9.2.1 *Single-gauge station*

9.2.1.1 STAGE-DISCHARGE CURVE – STABLE CHANNELS

Discharges shall be plotted as abscissae against the corresponding stages as ordinates and the stage-discharge curve shall be drawn smoothly through the points as plotted. The stage used in plotting shall be the mean stage during the period of discharge measurement.

The curve shall 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 A.5.3 of Annex A).

The spacing of the measurements shall be closer at the lower end of the range and the drawing of the curve shall be checked by one of the methods described in Annex A. Where observations are made at rising and falling stages, they shall be indicated by suitable symbols, and there shall 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.

9.2.1.2 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 shall be plotted as abscissae against the corresponding stages as ordinates and each point labelled in chronological order. The lie of the points shall be examined for shifts in control with reference to their chronological order. Smooth curves shall 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.

9.2.1.3 METHODS OF TESTING STAGE-DISCHARGE CURVES

The curves shall invariably express the stage-discharge relation objectively and shall therefore be tested for absence from bias and goodness of fit in the periods

1) See ISO 555, ISO 748, and ISO 1438.

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 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 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 shall, 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, 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, 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, A.5.6.2).

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

9.2.1.4 RATING-TABLE

A rating-table shall 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.

9.2.2 *Twin-gauge stations*

9.2.2.1 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.

9.2.2.2 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.

9.3 Verification of the stage-discharge relationship

If the procedure recommended in 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 shall 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.

If a particular change of the stage-discharge curve can be attributed to any definable incident in the history of the station, the new curve should be regarded as having applied from the time of that incident.

Methods of checking the consistency of gaugings are described in Annex A.

For unstable channels, a fresh set of discharge measurements shall be made each water-year and new curves drawn corresponding to periods of no change in control.

10 OPERATION OF GAUGING-STATION AND COMPILATION OF RECORDS

10.1 Operation of gauging-station

Provision should be made to ensure that the station is maintained in full operating order at all times. All instruments shall be in working order and conform to relevant standards and shall be properly and regularly calibrated.

10.2 Compilation of records

The records shall be regularly compiled.

When water-level fluctuates during the period of a day, the discharge may be evaluated from a sufficient number of points to enable the mean daily discharges to be computed. When the value of the difference between the instantaneous discharges at the highest and lowest stages in a day divided by the lowest instantaneous discharge of the same day exceeds 20 %, a discharge hydrograph shall be plotted. The ordinates taken shall be sufficient to define the flow conditions of the day. The total volume of the discharge shall be obtained from the area under the hydrograph for the day and the mean rate of discharge shall be obtained by dividing the total volume by the time.

Quantities derived from extrapolation of the stage-discharge curve shall be indicated by the letter "e" and the limits beyond which extrapolation has taken place shall be defined and indicated in an appropriate note accompanying the data. The discharges which have been estimated by interpolation due to failure of the recorder or lack of observer's readings shall be indicated by the letter "i".

The accuracy (number of decimals) of the figures published shall not exceed the accuracy with which they have been determined. The day of record shall extend from a fixed time in the morning on one day to the same time on the next day, quantities measured for that period being credited to the day on which the record started.

10.3 Extrapolation of the stage-discharge curve

Extrapolation of the stage-discharge curve shall be avoided. Whether it is permissible in a given case, and to what extent, depends on the accuracy of the curve (number of observations, natural scatter) and on the characteristics of the channel (see section A.6 of Annex A).

11 OBSERVATION ERROR AND RELIABILITY OF THE STAGE-DISCHARGE CURVE

The stage-discharge curve obtained from the observations gives the mean relationship between the stage and the discharge. The ideal stage-discharge curve would be obtained if measurements were made without errors of observation and where the control remained constant. All points would then fall exactly on the curve. Since these ideal conditions are unattainable in practice, there will be deviations of observations from the curve. These deviations of the measured discharges from the curve give, within limits of the reliability of the curve, an estimate of the observational error. The reliability of the mean curve and of the deviations of the measured discharges from the discharges estimated from the curve may generally be assessed by one or more of the concepts of "Standard error of the mean (the stage-discharge curve)", "Acceptance limits of the observations", and "Confidence limits of the mean stage-discharge curve", as indicated in the following clauses.

11.1 Standard error of the stage-discharge curve

From the points that have been used to determine the stage-discharge curve, all or a certain number shall be chosen, well spaced along the curve. For observations within small intervals of the stage of the selected points taken as the central value, the *standard deviation* from the curve, s_D (i.e. the square root of the mean of the squares of the residuals of the discharge figures from the curve) shall be computed. The intervals shall be selected so that

a) there are a sufficient number of observations in each interval;

b) the error of observation in each interval could be considered as independent of discharge.

The *standard error* of the mean (the stage-discharge curve) is

$$s_E = \frac{s_D}{\sqrt{m}} \qquad \ldots (1)$$

where

m is the number of observations used to determine the stage-discharge curve;

s_D is the standard deviation.

The standard error s_E is usually expressed as a percentage of the estimated discharge from the stage-discharge curve. It is to be noted that the standard error is worked out only for the range over which the control remains invariant.

Where the standard deviation s_D cannot be computed because the number of observations is too small, the value of s_D may be taken to equal X_Q, i.e. the *percentage standard error* of the single discharge measurement in accordance with ISO 748.

NOTE — All calculations of standard deviations are strictly applicable only if care has been taken to randomize the systematic errors by interchanging, as often as possible, the instruments used for the measurements and by changing the observer.

11.2 "Acceptance limits" of the stage-discharge observations

A pair of curves, one on each side of the stage-discharge curve at a distance of twice the *standard deviation,* are called the "control curves" and define the *95 % acceptance limits* of the discharges at the corresponding stages.

On average, in nineteen out of every twenty measurements, results should be within these limits. Any points lying far outside (say, beyond three times the standard deviation) can be regarded as the result of faulty measurement, except in those cases where two or more consecutive points, either chronologically or over a range of stage, appear to be well on one side of one of the limits. Where this occurs, a change of the stage-discharge curve is probable, which means that the calibration of the station has to be repeated, or a different stage-discharge curve is required owing to a shift in control.

Usually, the two postulates made for a valid estimate of the standard deviation in 11.1 are not available; that is, there are not a sufficient number of observations over small intervals of stage and the errors are known to be porportional to discharge over a range having the same control. Therefore, a pooled estimate of the percentage standard deviation may be worked out from the individual percentage deviations of discharge

(i.e. $\frac{\text{observed discharge} - \text{estimated discharge}}{\text{estimated discharge}} \times 100\ \%$),

taking all the observations together. From this overall percentage standard deviation, the "95 % acceptance limit" may be drawn over the entire range of control.

11.3 95 % confidence limits of the mean (the stage-discharge curve)

Where the pair of curves are drawn to pass through points at a distance of twice the *standard error* s_E of the mean (the stage-discharge curve) (NOT at twice the standard deviation of the observations) on either side of the stage-discharge curve, the pair of curves are called the *95 % confidence limits* of the curve, and the error should be regarded as representative for the corresponding region of the stage-discharge curve.

These limits define the band-width for which there is a probability of 95 % that the true curve lies within these limits.

11.4 Alternative method of determining "acceptance limits of observations" and "confidence limits of the stage-discharge curve"

Another method of determining the "acceptance limits" for discharges and the "confidence limits of the mean (stage-discharge curve)" is to plot the data on log-log paper. The discharges are taken along the abscissae and the stages (referred to datum G_0 for nil discharge – see A.5.10 of Annex A) along the ordinates. The plotted points within the range having the same control will generally fall on a straight line. The "acceptance limits" based on the standard deviation and the "confidence limits" based on the standard error of the mean shall be worked out from the horizontal distances of the observed points from this line.

ANNEX A

DESIGN, CONSTRUCTION AND OPERATION OF A GAUGING-STATION

A.1 PRELIMINARY SURVEY

The topographic survey shall include a plan of the site indicating the width of the water-surface at a stated level, the edges of the natural banks of the channel(s), the line of any definite discontinuity of the slope of these banks and the toe and crest of any artificial floodbank. All obstructions in the channel(s) or floodway shall be indicated. A longitudinal section of the channel shall be drawn extending from below a control, where this exists, to the upstream limits of the reach, showing the level of the deepest part of the bed and water-surface gradients at low and high stages. Cross-sections shall be surveyed in the proposed measuring-section and upstream and downstream of this section. At least five cross-sections shall be taken in a measuring-reach or two cross-sections above a measuring-section and the same below that point, covering a minimum distance equal to one bank-full width of the channel in each direction. The control section should be defined, wherever possible, by surveying a close grid of spot-levels over the area or by a sufficient number of cross-sections. All cross-sections shall be taken normal to the direction of flow and should be extended through the floodway to an elevation well above the highest anticipated stage of flood. The spacing of levels or soundings shall be close enough to reveal any abrupt change in the contour of the channel. The bed shall be carefully examined for the presence of rocks or boulders between the cross-sections, particularly in the vicinity of a measuring-section.

Where velocities are to be measured by a current-meter, exploratory measurements of velocities shall be made in the proposed measuring-section and in the cross-sections immediately upstream and downstream. When possible, the method of velocity distribution should be used for these measurements. When floats are to be used for velocity measurements, trial runs of floats shall be closely spread across the width of the channel to ensure that any abnormality of flow will be detected. These measurements shall be repeated at more than one value of discharge.

A.2 DESIGN OF STATION

The design of the station shall be based on the features disclosed by the preliminary survey.

The control section which determines the water stages at low flows at the gauging-point shall be situated at the downstream end of the measuring-reach, and the operating cross-section nearest to the control (i.e. the measuring-section in the case of current-meter measurement or the terminal section in the case of any other method) shall be sufficiently remote from it to avoid any distortion of flow which might occur in that vicinity, but close enough to ensure that a variable stage-discharge relation will not be introduced through the effect of wind or weed growth in the channel.

Higher flows are usually controlled by the general characteristics of the channel for a considerable distance downstream.

The reference gauge and the recorder shall be located as closely as possible to the measuring-section in the case of a current-meter station, or near the mid-point of the measuring-reach in the case of any other method of measurement.

The important requirements specified as necessary for a suitable gauging-site shall be naturally present, for example a sufficient length of reasonably straight and regular channel free from variable backwater. Where other desirable features are not present, conditions may be improved to some extent by rectification work.

The loss of water from the main channel by spillage can be avoided by constructing floodbanks to confine the flow in a defined floodway. This, however, can only be done for small channels.

It is advisable to protect unstable banks and such protection shall, in the case of current-meter measuring-sections, extend upstream and downstream from the section a distance equal to at least one-fourth the bank-full width of the channel in each direction or, in the case of float measurement, throughout the whole of the measuring-reach.

Instability of the bed may sometimes be corrected by introducing an "artificial control" (see below), which may also serve to improve the stage-discharge relationship (sensitivity), or to create sufficient depth in the measuring-section for instruments to be effectively used. Occasionally, it may be possible to eliminate variable backwater effect by introducing an artificial control.

An "artificial control" is a structure built for the reasons given above. It may be a low dam, or a contraction similar to a flume. The structure is seldom designed to function as a control throughout the entire range of stage. Each "artificial control" structure shall be designed in accordance with the conditions at the site where it is to be built. In the design of controls, the following four major points shall be borne in mind :

a) the shape of the structure shall permit the passage of water without creating undesirable disturbances in the channel above or below the control;