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Liquid flow measurement in open channels — Slope-area method

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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 1070 replaces ISO Recommendation R 1070-1969, 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 :

Argentina	Greece	Netherlands
Australia	India	Romania
Belgium	Ireland	Spain
Canada	Israel	Switzerland
Egypt, Arab Rep. of	Italy	Thailand
France	Japan	United Kingdom
Germany	Korea, Rep. of	

The Member Bodies of the following countries expressed disapproval of the Recommendation on technical grounds :

Czechoslovakia
U.S.A.

Printed in Switzerland

Liquid flow measurement in open channels – Slope-area method

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies the method of determining the slope and area of cross-section of the stream, and of computing the discharge therefrom. The method provides an approximate estimate of the discharge in somewhat special conditions in the stream and is used when estimation of discharge by more accurate methods, like the velocity-area methods, is not possible. The slope-area method can be used with some degree of accuracy in channels with stable boundaries such as rock (or very cohesive clay) bed and sides, and in channels with relatively coarse bed material; this method may also be used in other cases such as alluvial channels including channels with defined spills or non-uniform channel sections, subject to the acceptance of larger errors involved in the selection of the value of the Manning's coefficient n or Chezy's coefficient C. It is, however, not desirable to use this method in the case of very large channels or channels with very flat slopes of high sediment concentration or channels with significant curvature.

This International Standard deals only with ad hoc measurements of discharge and should not be employed for establishing rating-curves. Although the accuracy of results from applying the slope-area method is less than that from applying the velocity-area methods, it is sometimes necessary to use the slope-area method to define the extreme high-stage end of rating-curves because the magnitude of extremely rare floods is such that other methods of measuring discharge cannot be used.

2 REFERENCES

ISO 748, *Liquid flow measurement in open channels by velocity-area methods.*

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

ISO 1100, *Liquid flow measurement in open channels – Establishment and operation of a gauging-station and determination of the stage-discharge relation.*

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 seconds and metres (or feet).

5 PRINCIPLE OF THE METHOD OF MEASUREMENT

A measuring-reach is chosen for which the mean area of cross-section of the stream is determined and the surface slope of the flowing water in that reach is measured. The mean velocity is then established by using known empirical formulae which relate the velocity to the hydraulic mean depth, the surface slope corrected for kinetic energy of the flowing water and the characteristics of the bed and bed material. The discharge is computed as the product of the mean velocity and the mean area of cross-section of the stream.

6 SELECTION AND DEMARCATION OF SITE

6.1 Initial survey of site

It is desirable that approximate measurements of widths, depths and surface slopes should be made in a preliminary survey to decide on the suitability of a site conforming, as far as possible, with the conditions given in 6.2 and 6.3. It is intended that these measurements should only serve as a guide.

6.2 Selection of site

6.2.1 The accuracy of the determination of discharge by the slope-area method is increased if the river-banks and bed are reasonably stable and the river-reach fairly straight and uniform in section and free from obstructions and disturbances.

6.2.2 The length of the reach depends upon river slopes at very low stages and flood stages. The slope shall be such that the surface fall in the length of the reach used at each site is at least ten times the expected error in "measurement of fall".

6.2.3 The flow in the reach shall be free from significant disturbances due to the effect of tributaries joining upstream or downstream or of any structure. The reach shall be one in which no substantial expansion occurs.

6.2.4 The orientation of the reach shall be such that the direction of the flow is as closely as possible normal to that of the prevailing wind.

6.2.5 The flow in the channel shall, as far as possible, be contained within its banks at all stages at which this method is used, as otherwise the overflow would have to be separately measured.

6.2.6 The site shall not be unduly exposed to wind.

6.2.7 The site shall be easily accessible at all times.

6.3 Demarcation of site

The site, after selection, shall be provided with means for the demarcation of the cross-section and for the determination of the stage.

The position of each cross-section normal to the general direction of flow shall be defined on the two banks by clearly visible and readily identifiable markers.

6.4 Changes occurring after the selection of the site

If, after the site has been selected, changes occur which do not comply with the above requirements, steps shall be taken to rectify the changes to make it conform to these requirements. If this is not possible, another site shall be selected.

7 DEVICES FOR MEASUREMENT OF SLOPE

7.1 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.

7.1.1 *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.

7.1.2 *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 Liquid-level recorder[1)]

This is particularly useful where large fluctuations of discharge occur during short intervals as in the case of hill torrents and flashy rivers. It may consist of a recorder operated by a float, or of a pneumatic recorder. The float-operated recorder shall be installed above a vertical stilling-well communicating with the channel. The pneumatic recorder may be installed at a distance in a place in which both access and use are easy. It is essential, however, to combine the recorder always with a reference gauge, placed near the point of measurement of the recorder.

7.3 Crest-stage gauge

This is suitable for use where only the peak level attained during each flood has to be determined. Peak discharges can be calculated from two such gauges installed in a reach of the river, provided the time-lag in the reach can be taken as nil.

8 PROCEDURE FOR INSTALLING GAUGES AND MAKING OBSERVATIONS

8.1 Installation

Gauges shall be installed, on both banks of the river, at not fewer than three cross-sections, making a total of at least six gauges. The gauge data shall be related to a standard system of levels.

8.2 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 a complete oscillation, whichever is longer, and the maximum and minimum readings taken and averaged.

8.3 Recording

Information regarding the date, time, weather conditions, direction of wind, current, etc., shall be recorded before the commencement of operations.

All gauges shall be observed at suitable intervals and readings recorded throughout the period of measurement including initial and terminal readings.

9 COMPUTATION OF SURFACE SLOPE

9.1 Computation of slope from gauges

Slope is computed from the gauge observations at either end of the reach, the intermediate gauge(s) being used to confirm that the slope is uniform throughout the reach. The gauges shall be read to the smallest marking on the

1) For detailed provisions regarding stilling-well, recorder, etc., reference should be made to clauses 7.2.2 and A.3 of ISO 1100.

gauge which is generally 2 mm on the metric gauge (0.01 ft on gauges marked with FPS units) and shall be steady when observed.

NOTE — When accurate gauges do not exist or have been destroyed, and when no other method can be employed, a rough estimate of the slope during the peak stage can be made by means of flood-marks on the banks. Several dependable highwater flood-marks for each bank shall be used in determining the water-level.

10 AREA OF CROSS-SECTION OF THE STREAM AND ITS WETTED PERIMETER

10.1 Number of cross-sections

In the reach selected, a minimum of three cross-sections is generally desirable. These shall be clearly marked on the banks by means of masonry pillars or easily identifiable markers. If, for any reason, it is not possible to measure more than one cross-section, the central one only may be observed.

10.2 Measurement of cross-sections

These cross-sections shall be measured for each discharge observation at, or as near as possible to, the time at which the gauge observations are made. It is often impossible to measure the cross-section during flood and, therefore, to this extent, an error may be introduced owing to an unobserved and temporary change in cross-sections. If, however, the side is inerodable, it will be sufficient to observe the cross-sections before and after the floods.

The method of measurement of the cross-sectional area shall be in accordance with section 6 of ISO 748.

10.3 Determination of mean area of cross-section of stream

If the reach is substantially uniform and there are insignificant differences in the cross-sectional areas, A_1, $A_2 \ldots A_m$, determined in accordance with 10.2 at the chosen cross-sections, the mean area of cross-section of stream $\bar{A}$ may be taken as

$$\bar{A} = \frac{A_1 + 2A_2 + \ldots 2A_{m-1} + A_m}{2(m-1)}$$

10.4 Determination of wetted perimeter

For each chosen cross-section, the area of which is measured in accordance with 10.2, the corresponding wetted perimeter shall be determined and if the wetted perimeters are P_1, $P_2 \ldots P_m$ respectively, then the mean wetted perimeter $\bar{P}$ may be taken as

$$\bar{P} = \frac{P_1 + 2P_2 + \ldots 2P_{m-1} + P_m}{2(m-1)}$$

11 VELOCITY OF STREAM

11.1 Evaluation of velocity

The mean velocity between two cross-sections ($A_0 \neq A_1$, see Figure) when the flow is not significantly different from steady flow, using Manning's formula, will be

$$\bar{v} = \frac{R_h^{2/3} S^{1/2}}{n} \text{ (in SI units)}$$

$$\bar{v} = \frac{1{,}5\, R_h^{2/3} S^{1/2}}{n} \text{ (in FPS units)}$$

where

$\bar{v}$ is the mean velocity;

R_h is the hydraulic mean depth;

n is the Manning's coefficient of rugosity having a value given in 11.2;

S is the slope corrected for the kinetic energy difference at the two ends, namely,

$$\frac{z_1 - z_0 + \left(\frac{v_1^2}{2g} - \frac{v_0^2}{2g}\right)}{L}$$

The reach shall as far as possible be uniform. If no uniform reach is available, the reach should preferably be converging rather than diverging to facilitate an appropriate correction for change in kinetic energy. However, if the reach is expanding, then the slope correction would include some allowance for eddy loss as well as the correction for the change in kinetic energy between the ends.

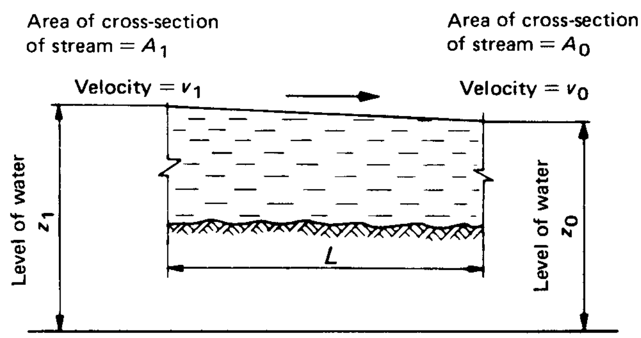

FIGURE — **Longitudinal section of the reach**

The mean velocity for the same conditions as above, using Chezy's formula, will be

$$\bar{v} = C\sqrt{R_h S}$$

where C is Chezy's coefficient and $\bar{v}$, R_h and S are as defined above in the case of Manning's formula.

11.2 Values of Manning's coefficient n and Chezy's coefficient C

Where a reasonable value of rugosity coefficient can be extrapolated from discharge measurements taken by a more accurate method, for example current-meter method or float method and slope observations, at lower stages, the highest of which is as close as possible to the stage measured, the values so obtained may be used provided there are no changes in the channel characteristics. The accuracy of this extrapolated coefficient decreases as the difference between the measured stage and the highest of the lower stages increases.

In the absence of measured data, the values given in Table I of the Appendix may be assumed for open channels with relatively coarse bed material and not characterized by bed formations.

In the case of alluvial open channels with other than corase bed material and in the case of open channels having vegetations, clay and rocky banks, etc., the values given in Table 2 of the Appendix may be used as a guide.

12 COMPUTATION OF DISCHARGE

The discharge shall be calculated by multiplying the mean velocity obtained from 11.1 by the mean area of the cross-section of the stream obtained from 10.3.

In case the cross-sectional area of the stream is not uniform in the reach, the use of average values for the area A, wetted perimeter P, and hydraulic mean depth R_h will not yield correct results; in such cases, the conveyance factor for each part of the section is evaluated and added to get the conveyance factor for the whole section and then the geometric mean of the conveyance factors at the two end sections gives the conveyance factor for the reach.

In the case of a composite section, the values of the rugosity coefficient over different portions of the section are likely to be different. The section shall be split into relatively homogeneous segments and the velocities and discharges for these segments calculated separately and added.

13 ERRORS

The accuracy of the measurement depends on the correct determination of slope and of the coefficient of rugosity. The coefficient is likely to change with varying stages of floods. If no experimental determination has been made, considerable experience is necessary in choosing the correct value of the rugosity coefficient to be assumed.

An error will also be introduced if the chosen areas of the cross-sections of the stream are not approximately equal.

APPENDIX

VALUES OF COEFFICIENTS n AND C FOR OPEN CHANNELS

Tables I and 2 indicate the coefficients which may be used subject to the following observations :

1 The data given for the coefficients in the following tables are not comprehensive and should be used *only as a guide*; appreciable error will be introduced when R_h is small and the size of the bed material is large.

2 In the following tables, the values of C are in SI units; they have to be multiplied by 1,811 for conversion to FPS units.

3 Chezy's and Manning's coefficients in the following tables are inter-related for the bed conditions mentioned therein. With the use of Nikuradse's coefficient, the bed conditions may be defined more explicitly, but further research is required before its general acceptance.

4 It is advantageous to determine the range of roughness on natural channels by measurement and to record the actually verified coefficients photographically on colour, stereo slides, for guidance in the selection of coefficients for a reach under survey. Proper values may thus be selected by visual comparison.

TABLE 1 – **Coefficients for channels with relatively coarse bed material and not characterized by bed formations**

Type of bed material	Size of bed material mm	Manning's coefficient n	Chezy's coefficient C			
			R_h = 1 m	R_h = 2,5 m	R_h = 5 m	R_h = 10 m
Gravel	4 to 8	0,019 to 0,020	53 to 50	61 to 58	69 to 65	77 to 73
	8 to 20	0,020 to 0,022	50 to 45	58 to 53	65 to 59	73 to 67
	20 to 60	0,022 to 0,027	45 to 37	53 to 43	59 to 48	67 to 54
Pebbles and shingle	60 to 110	0,027 to 0,030	37 to 33	43 to 39	48 to 44	54 to 49
	110 to 250	0,030 to 0,035	33 to 29	39 to 33	44 to 37	49 to 42

TABLE 2 – **Coefficients for channels other than those with coarse bed material**

Type of channel and description	**Manning's coefficient *n***	**Chezy's coefficient *C*** $R_h = 1$ m	$R_h = 2{,}5$ m	$R_h = 5$ m	$R_h = 10$ m
A. Excavated or dredged					
a) Earth, straight and uniform					
1 Clean, recently completed	0,016 to 0,020	63 to 50	72 to 58	81 to 65	91 to 73
2 Clean, after weathering	0,018 to 0,025	55 to 40	64 to 46	72 to 52	81 to 59
3 With short grass, few weeds	0,022 to 0,033	45 to 30	53 to 35	59 to 40	67 to 44
b) Rock cuts					
1 Smooth and uniform	0,025 to 0,040	40 to 25	46 to 29	52 to 33	59 to 37
2 Jagged and irregular	0,035 to 0,050	29 to 20	33 to 23	37 to 26	42 to 29
B. Natural streams					
B.1 *Minor streams*					
(top width at flood stage less than 30 m (100 ft))					
a) Streams on plains Clean, straight, full stage, no rifts or deep pools	0,025 to 0,033	40 to 30	46 to 35	52 to 40	59 to 44
B.2 *Flood plains*					
a) Pasture, no brush					
1 Short grass	0,025 to 0,035	40 to 29	46 to 33	52 to 37	59 to 42
2 High grass	0,030 to 0,050	33 to 20	39 to 23	44 to 26	49 to 29
b) Cultivated areas					
1 No crop	0,020 to 0,040	50 to 25	58 to 29	65 to 33	73 to 37
2 Mature row crops	0,025 to 0,045	40 to 22	46 to 26	52 to 29	59 to 33
3 Mature field crops	0,030 to 0,050	33 to 20	39 to 23	44 to 26	49 to 29
c) Brush					
1 Scattered brush, heavy weeds	0,035 to 0,070	29 to 14	33 to 17	37 to 19	42 to 21
2 Light brush and trees (without foliage)	0,035 to 0,060	29 to 17	33 to 19	37 to 22	42 to 24
3 Light brush and trees (with foliage)	0,040 to 0,080	25 to 12	29 to 14	33 to 16	37 to 18
4 Medium to dense brush (without foliage)	0,045 to 0,110	22 to 9	26 to 10.5	29 to 12	33 to 13
5 Medium to dense brush (with foliage)	0,070 to 0,160	14 to 6.5	17 to 7.5	19 to 8	21 to 9
d) Trees					
1 Cleared land with tree stumps, no sprouts	0,030 to 0,050	33 to 20	39 to 23	44 to 26	49 to 29
2 Same as above, but with heavy growth of sprouts	0,050 to 0,080	20 to 12	23 to 14	26 to 16	29 to 18
3 Heavy stand of timber, a few felled trees, little undergrowth, flood-stage below branches	0,080 to 0,120	12 to 8.5	14 to 9.5	16 to 11	18 to 12
4 Same as above, but with flood-stage reaching branches	0,100 to 0,160	10 to 6.5	12 to 7.5	13 to 8	15 to 9
5 Dense willows, in mid-summer	0,110 to 0,200	9 to 5	10.5 to 6	12 to 6.5	13 to 7.5