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Standard Test Method for Indirect Measurements of Discharge by Step-Backwater Method [1]

This standard is issued under the fixed designation D 5388; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the computation of discharge of water in open channels or streams using representative cross-sectional characteristics, the water-surface elevation of the upstream-most cross section, and coefficients of channel roughness as input to gradually-varied flow computations.[2]

1.2 This test method produces an indirect measurement of the discharge for one flow event, usually a specific flood. The computed discharge may be used to define a point on the stage-discharge relation.

1.3 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Terminology Relating to Water[3]

D 2777 Practice for Determination of Precision and Bias of Applicable Methods of Committee D-19 on Water [3]

D 3858 Practice for Open-Channel Flow Measurement of Water by Velocity-Area Methods [3]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

NOTE—Several of the following terms are illustrated in Fig. 1.

3.2.1 *alpha* (α)—a dimensionless velocity-head coefficient that represents the ratio of the true velocity head to the velocity head computed on the basis of the mean velocity. It is assumed equal to unity if the cross section is not subdivided. For subdivided sections, α is computed as follows:

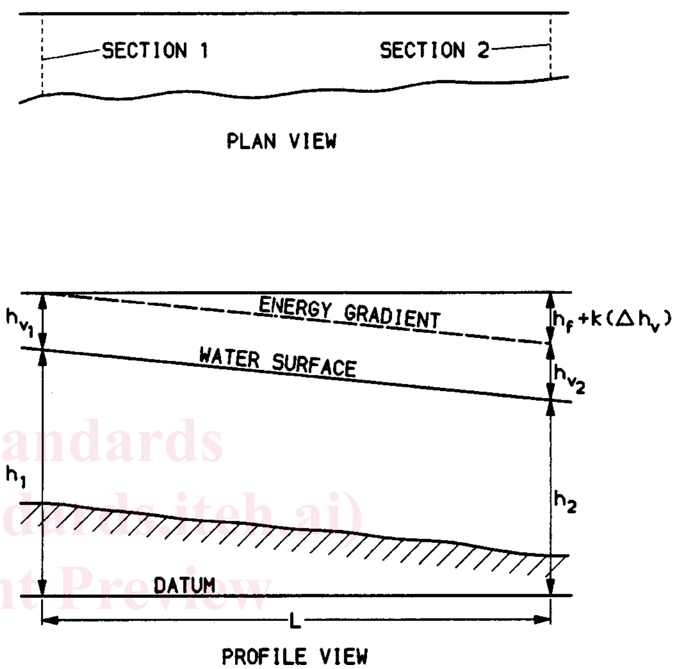

FIG. 1 Definition Sketch of Step-Backwater Reach

$$\alpha = \frac{\Sigma \frac{k_i^{3}}{a_i^{2}}}{\frac{K_T^{3}}{A_T^{2}}} \quad (1)$$

where:

k and a = the conveyance and area of the subsection indicated by the subscript i, and

K and A = the conveyance and area of the total cross section indicated by the subscript T.

3.2.2 *conveyance* (K)—a measure of the carrying capacity of a channel without regard to slope and has dimensions of cubic feet per second. Conveyance is computed as follows:

$$K = \frac{1.49}{n} AR^{2/3} \quad (2)$$

3.2.3 *cross-section area* (A)—the area at the water below the water-surface elevation that it computed. The area is computed as the summation of the products of mean depth

[1] This test method is under the jurisdiction of ASTM Committee D-19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

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[2] Barnes, H. H., Jr., "Roughness Characteristics of Natural Streams," *U.S. Geological Survey Water Supply Paper 1849*, 1967.

[3] *Annual Book of ASTM Standards*, Vol 11.01.

multiplied by the width between stations of the cross section.

3.2.4 *cross sections (numbered consecutively in downstream order)*—representative of a reach and channel and are positioned as nearly as possible at right angles to the direction of flow. They must be defined by coordinates of horizontal distance and ground elevation. Sufficient ground points must be obtained so that straight-line connection of the coordinates will adequately describe the cross-section geometry.

3.2.5 *expansion or contraction loss (ho)*—in the reach is computed by multiplying the change in velocity head through the reach by a coefficient. For an expanding reach:

$$ho = Ke(h_{v_1} - h_{v_2}) \tag{3}$$

and for a contracting reach:

$$ho = Kc(h_{v_2} - h_{v_1}) \tag{4}$$

where:
h_v = velocity head at the respective section, and
Ke and Kc = coefficients.

3.2.5.1 *Discussion*—The values of the coefficients can range from zero for ideal transitions to 1.0 for *Ke* and 0.5 for *Kc* for abrupt changes.

3.2.6 *fall* (Δh)—the drop in the water surface, in ft (m), computed as the difference in the water-surface elevation at adjacent cross sections (see Fig. 1):

$$\Delta h = h_1 - h_2 \tag{5}$$

3.2.7 *friction loss* (h_f)—the loss due to boundary friction in the reach and is computed as follows:

$$h_f = \frac{L\,Q^2}{K_1\,K_2} \tag{6}$$

where:
L = length of reach, feet (metres), and
K = conveyance at the respective section.

3.2.8 *Froude number (F)*—an index to the state of flow in the channel. In a prismatic channel, the flow is tranquil or subcritical if the Froude number is less than unity and a rapid or supercritical if it is greater than unity. The Froude number is computed as follows:

$$F = \frac{V}{\sqrt{gdm}} \tag{7}$$

where:
V = the mean velocity, ft/s (m/s),
dm = the mean depth in the cross section, feet, and
g = the acceleration of gravity, ft/s/s (m/s/s).

3.2.9 *hydraulic radius (R)*—defined as the area of a cross section or subsection divided by the corresponding wetted perimeter. The wetted perimeter is the distance along the ground surface of a cross section or subsection.

3.2.10 *Manning's equation*—Manning's equation for computing discharge for gradually-varied flow is:

$$Q = \frac{1.49}{n} A\,R^{2/3}\,S_f^{\,1/2} \tag{8}$$

where:
Q = discharge, ft^3/s (m^3/s),
n = Manning's roughness coefficient,
A = cross-section area, ft^2(m^2),
R = hydraulic radius, ft, (m), and
S_f = friction slope, ft/ft (m/m).

3.2.11 *roughness coefficient (n)*—or Manning's *n* is used in the Manning equation. Roughness coefficient or Manning's *n* is a measure of the resistance to flow in a channel. The factors that influence the magnitude of the resistance to flow include the character of the bed material, cross-section irregularities, depth of flow, vegetation, and channel alignment. A reasonable evaluation of the resistance to flow in a channel depends on the experience of the person selecting the coefficient and reference to texts and reports that contain values for similar stream and flow conditions (see 10.3).

3.2.12 *velocity head* (h_v)—in ft(m), compute velocity head as follows:

$$h_v = \frac{\alpha V^2}{2g} \tag{9}$$

where:
α = velocity-head coefficient,
V = the mean velocity in the cross section, ft/s (m/s), and
g = the acceleration of gravity, ft/s/s (m/s/s).

4. Summary of Test Method

4.1 The step-backwater test method is used to indirectly determine the discharge through a reach of channel. The step-backwater test method needs only one high-water elevation and that being at the upstream most cross section. A field survey is made to define cross sections of the stream and determine distances between them. These data are used to compute selected properties of the section. The information is used along with Manning's *n* to compute the change in water-surface elevation between cross sections. For one-dimensional and steady flow the following equation is written for the sketch shown in Fig. 1:

$$h_1 = h_2 + h_{v_2} + hf + ho - h_{v_1} \tag{10}$$

where:
h = elevation of the water surface above a common datum at the respective sections,
hf = the loss due to boundary friction in the reach, and
ho = the energy loss due to deceleration or acceleration of the flow (in the downstream direction) in an expanding or contracting reach.

5. Significance and Use

5.1 This test method is particularly useful for determining the discharge when it cannot be measured directly (such as during high flow conditions) by some type of current meter to obtain velocities and with sounding weights to determine the cross section (refer to Test Method D 3858). This test method requires only one high-water elevation, unlike the slope-area test method that requires numerous high-water marks to define the fall in the reach. It can be used to determine a stage-discharge relation without needing data from several high-water events.

5.1.1 The user is encouraged to verify the theoretical stage-discharge relation with direct current-meter measurements when possible.