Designation: D5388 – 21

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

This standard is issued under the fixed designation D5388; 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 standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1129 Terminology Relating to Water

D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water

D3858 Test Method for Open-Channel Flow Measurement of Water by Velocity-Area Method

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this standard, refer to Terminology D1129.

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), n*—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:

$$\alpha = \frac{\sum \frac{k_i^{\,3}}{a_i^{\,2}}}{\frac{K_T^{\,3}}{A_T^{\,2}}} \tag{1}$$

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), n*—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:

$$K = \frac{1.49}{n} AR^{2/3} \tag{2}$$

3.2.3 *cross-section area (A), n*—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 multiplied by the width between stations of the cross section.

3.2.4 *cross sections (numbered consecutively in downstream order), n*—representative portions 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

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

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

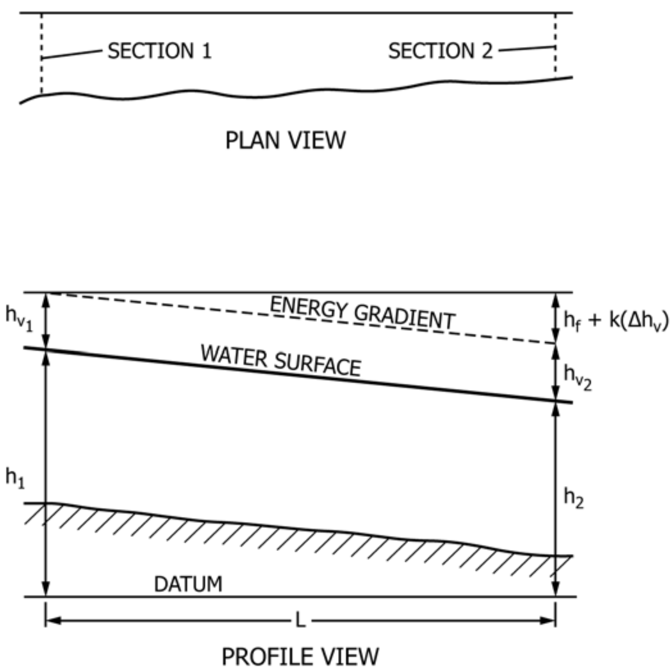

FIG. 1 Definition Sketch of Step-Backwater Reach

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), n*—a value is computed by multiplying the change in velocity head through the reach by a coefficient. For an expanding reach:

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

and for a contracting reach:

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

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), n*—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), n*—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), n*—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), n*—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, n*—the 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) (n), n*—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), n*—the square of the average velocity divided by twice the acceleration due to gravity measured in ft(m) and computed 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:

$$h_1 = h_2 + h_{v_2} + hf + ho - h_{v_1} \quad (10)$$

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 D3858). 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 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.

5.1.2 To develop a rating curve, plot stage versus discharge for several discharges and their computed stages on a rating curve together with direct current-meter measurements.

6. Interferences

6.1 The cross sections selected are typical and representative of the reach half way to each adjacent cross section. If there are abrupt changes between adjacent cross sections, the results could be suspect. The ratio of the conveyance to the conveyance at an adjacent cross section is within 0.7 and 1.4.

6.2 Care must be taken in selecting the water-surface elevation for the downstream cross section. The elevation is too high if it reflects backwater at the upstream cross section and too low if it would be in super-critical flow. A good rule of thumb is to select a stage so that the conveyance of the downstream cross section is approximately equal to the conveyance of the upstream-most cross section.

6.3 The only way to be certain that the water-surface elevation is not too high or too low or that the reach is sufficiently long enough or that enough cross sections are used, or all of the above, is to use the converging profile method. In this method, several profiles are developed using a range of starting water-surface elevations. The slope of the profiles from the higher starting elevations increases as you move in an upstream direction. The slope of the profiles from the lower starting elevations decreases as you move in an upstream direction. At some distance upstream, the profiles will converge.

6.4 A minimum of about ten cross sections are needed to develop a smooth backwater curve.

7. Apparatus

7.1 The equipment generally used for a "transit-stadia" survey is recommended. An engineer's transit, a self-leveling level with azimuth circle, newer equipment using electronic circuitry, or other advanced surveying instruments may be used. Standard level rods, a telescoping 25-ft (7.62-m) level rod, rod levels, head levels, steel and metallic tapes, tag lines (small wires with markers fixed at known spacings), vividly colored flagging, survey stakes, a camera (preferably stereo) with built-in light meter with color film, and ample note paper are necessary items.

7.2 Additional equipment that may expedite a survey includes axes, machetes, a boat with oars and motor, hip boots, waders, rain gear, sounding equipment, and two-way radios.

7.3 Safety equipment includes life jackets, first aid kit, drinking water, and pocket knives.

8. Sampling

8.1 Sampling as defined in Terminology D1129 is not applicable in this test method.

9. Calibration

9.1 Check the surveying instruments, levels, transits, etc. adjustments before each use, and possibly daily when in continuous use, or after some occurrence that may have affected the adjustment.

9.2 The standard check is the *two-peg* or *double-peg* test. If the error is over 0.03 ft in 100 ft (0.009 m in 30.4 m), adjust instrument. The two-peg test and how to adjust the instrument are described in many surveying textbooks and in instructions provided by the manufacturer. Refer to manufacturer's manual for the electronic instruments.

9.3 If the *reciprocal leveling* technique is used in the survey, it is the equivalent of the two-peg test between each of the two successive hubs.

9.4 Check sectional and telescoping level rods visually at frequent intervals to be sure sections are not separated. A proper fit at each joint can be quickly checked by measurements across the joint with a steel tape.

9.5 Check all field notes of the transit-stadia survey before proceeding with the computations.

10. Procedure

10.1 Selection of a reach of channel is the first and probably the most important step to obtain reliable results. Ideal reaches rarely exist; thus the various elements in a reach must be evaluated and compromises made so the best reach available is selected. This test method requires the reach to be much longer than a reach using the slope-area test method.

10.2 Select a reach of the channel that is as uniform as possible. minimize changes in channel conveyance between sections as much as possible. Avoid abrupt changes in channel shape because of uncertainties regarding the value of the expansion/contraction loss coefficient and the friction losses in the reach.

10.3 A reach with flow confined to a roughly trapezoidal channel is desirable because roughness coefficients have been determined for such shapes. However, compound channels,