Bridges

Introduction

This document offers three aids in bridge design:

- HDS-1 Empirical Loss Method
- risk assessment forms and
- single-opening backwater calculations.

HDS-1 Empirical Loss Method

Equation C-1 predicts the bridge backwater, h_1, based on the principle of conservation of energy between the point of maximum backwater upstream from the bridge, Section 4, and a point downstream from the bridge at which normal stage has been reestablished, Section 1 (see Figure C-1).

$$h_1 = \frac{K \alpha_2 V_{n2}^2}{2g} + \alpha_1 \left[\left(\frac{A_{n2}}{A_4} \right)^2 - \left(\frac{A_{n2}}{A_1} \right)^2 \right] \frac{V_{n2}^2}{2g}$$

Equation C-1

where:

h_1=total backwater (m)
K=total backwater coefficient
α_1, α_2=kinetic energy correction coefficients (as described below)
A_{n2}=gross water area in constriction measured below normal stage (m^2)
V_{n2}=average velocity in constriction (m/s)
A_4=water area at section 4 where normal stage is reestablished (m^2)
A_1=total water area at section 1, including that produced by the backwater (m^2)

Figure C-1: Section Locations for Bridge Backwater Calculation

The next subsections deal with these HDS-1 Empirical Loss topics:

- Empirical Loss equation applications
- kinetic energy correction coefficient determination
- use of computer programs
- total backwater coefficient

Empirical Loss Equation Applications

The equation is applicable if the following apply:

- The channel is essentially straight in the vicinity of the bridge.
- The cross-sectional area of the stream is fairly uniform.
- The gradient of the stream bottom is approximately constant between Sections 1 and 4.
- The flow is free to contract and expand.
- There is no appreciable scour in the constriction.
- The flow is in the subcritical range.

Kinetic Energy Correction Coefficient Determination

You can determine the kinetic energy correction coefficient, α_1, with Equation C-2.

$$\alpha_1 = \frac{\left(q\,v^2\right)}{Q\,V_1^2}$$

Equation C-2

where:

v=average velocity in a subsection of Section 1 (m/s)
q=discharge in same subsection (m^3/s)
Q=total discharge in stream (m^3/s)
V_1=average velocity in stream at Section 1 (m/s)
$= \frac{Q}{A_1}$

You can estimate the kinetic energy coefficient at the constriction, α_2, by using Figure C-2 with α_1 from Equation C-3, and by using the bridge opening ratio, M.

$$M = \frac{Q_b}{Q_t}$$

Equation C-3

where:

M=bridge opening ratio
Q_b=discharge of subchannel coincident with bridge opening at Section 1 (m^3/s)
Q_t=total channel discharge at Section 1 (m^3/s)

Figure C-2: Aid for Estimating α_2

Use of Computer Programs

Suitable application of Equation C-1 requires an iterative process since A_1 depends on the backwater, h_1. This warrants the use of a computer program to determine the variables. Therefore, for most bridge design scenarios, the department recommends using computer programs for backwater calculations. For initial estimates during planning or for validation of existing bridges or widening projects, you may use Equation C-4 which is an abbreviation of Equation C-1.

$$h_1 = K \alpha_2 \frac{V_{n2}^2}{2g}$$

Equation C-4

Total Backwater Coefficient

Then, apply resulting backwater at Section 1. Large backwater heads, as calculated using Equation C-4, may indicate the need to use Equation C-1 or computer methods. You can derive the total backwater coefficient (K), for use in Equations C-1 and C-4, by using Equation C-5:

$$K = K_b + \Delta K_p + \Delta K_s + \Delta K_e$$

Equation C-5

where:

K_b=base constriction coefficient (see Figure C-4)

ΔK_p=pier coefficient (from Figure C-5) = $\sigma \cdot \Delta K$

Equation C-6

ΔK_s=skew coefficient (see Figure C-6)

ΔK_e=eccentricity coefficient (see Figure C-7)

The ratio of the water area occupied by the piers to the gross water area of the constriction, J, is used to determine ΔK in Figure C-5.

$$J = \frac{A_p}{A_{n2}}$$

Equation C-7

where:

A_{n2}=gross water area based on normal water surface (m^2)

Note: Use projected bridge length normal to flow for skew crossings

A_p=total projected area of piers normal to flow (m^2)

$$= {}^{N} W_p \, h_{n2}$$

where:

W_p=width of pier normal to flow (m), as shown in Figure C-3

h_{n2}=height of pier exposed to flow (m)

Figure C-3: Pier Widths for Normal and Skew Crossings

Figure C-4: Backwater Coefficient Base, K_b *(subcritical flow)*

Figure C-5: Backwater Coefficient for Piers, ΔK_p

Figure C-6: Backwater Coefficient for Skew, ΔK_s

Figure C-7: Eccentricity Backwater Coefficient, ΔK_e

Risk Assessment Forms

The next subsections contains forms you may use to perform a risk assessment for determining a reasonable design frequency for

- new location bridges
- bridge replacements
- bridge widening

The following forms are provided in this appendix:

- economic and risk assessment for bridge class structures
- worksheet for annual risk costs.

Single-Opening Backwater Calculation

A proposed bridge widening for an existing channel crossing is shown in Figure C-1. Using a design discharge of 469.43 m^3/s and average estimated water surface slope of 0.00049 m/m, a channel analysis yields a water surface elevation of 25.8 m. Cross-section areas, wetted perimeters, and values of Manning's n are given in the table below. The roadway is supported by two cylindrical piers having a total projected area normal to the flow of 5.4 m^2 and is to be widened to 12.5 m. The stream is essentially straight, the cross-section relatively constant in the vicinity of the bridge, and the crossing is normal to the general direction of flow. Determine the backwater for the given discharge.

Table C-1. Given Cross Section Information

Under the conditions stated, it is permissible to assume that the cross-sectional area of the stream at Section 1 is the same as that at the bridge. The following table shows the computed conveyances, discharges, and velocities for each subsection of the unconstricted channel section at the bridge site.

Table C-2. Calculations for Cross Sections

From the preceding table, the discharge in Section B and the velocity at Section 1 are computed as follows:

$$Q_b = 22.10 + 322.07 + 46.92 = 391.09\ \text{m}^3/\text{s}$$

$$V_1 = \frac{Q}{A_{tot}} = \frac{469.43}{435.3} = 1.08\ \text{m / s}$$

The kinetic energy coefficient, α_1, is calculated

$$\alpha_1 = \frac{\sum | qv^2 |}{QV_1^2} = \frac{1027.00}{469.43\ (1.08)^2} = 1.88$$

The factor M is the ratio of that portion of the discharge approaching the bridge in width “b” to the total discharge:

$$M = \frac{Q_b}{Q_{tot}} = \frac{391.09}{469.43} = 0.83$$

Using Figure C-2 with $\alpha_1 = 1.88$ and $M = 0.83$, the value of α_2 is estimated as 1.74.

Using Figure C-4, the base curve coefficient is $K_b = 0.23$ for a bridge waterway of 49 m.

The incremental coefficient (ΔK_p) for two solid piers is determined as follows. The gross water area under the bridge for normal stage (A_{n2}) is 268.3 m^2, and the area obstructed by the piers (A_p) is 5.4 m^2. Therefore,

$$J = \frac{A_p}{A_{n2}} = \frac{5.4}{268.3} = 0.020$$

Using Figure C-5 (first graph) with J = 0.020 for solid piers, the reading from the ordinate is $\Delta K = 0.05$. This value is for M = 1.0 and must be adjusted for M= 0.83. Figure C-5 (second graph) is used to determine the correction factor σ as 0.96. The incremental pier backwater coefficient, ΔK_p, is calculated as 0.05 with Equation A8-6.

The overall backwater coefficient (since there is no skew or eccentricity) is determined with Equation C-5:

$$K = K_b + \Delta K_p = 0.23 + 0.05 = 0.28$$

The through-bridge velocity is found with the Continuity Equation:

$$V_{n2} = \frac{Q}{A_{n2}} = \frac{469.43}{268.3} = 1.75 \text{ m / s}$$

Using Equation C-4, the approximate backwater is calculated as follows:

$$h = K\,\alpha_2\,\frac{V_{n2}^2}{2g} = 0.28 \cdot 1.74 \frac{(1.75)^2}{2\,(9.81)} = 0.076 \text{ m}$$

Using Equation C-5 and substituting values for the difference in kinetic energy between Sections 4 and 1 where A_4=435.3 m^2, A_{n2}=268.3 m^2, and A_1=435.3+0.076(160)=447.5 m^2,

$$h_1 = 0.076 + 1.88 \left[\left| \frac{268.3}{435.3} \right|^{2} - \left(\frac{268.3}{447.5} \right)^{2} \right| \frac{(1.75)^2}{2\,(9.81)} = 0.082$$

For bridge widening projects or preliminary estimations, the small difference (0.006 m) may not have warranted the effort required to derive the variables required for Equation C-1.