Flood Control and Drainage Structures

Course Number: CE-02-710

PDH: 2

Approved for: AK, AL, AR, DE, FL, GA, IA, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WI, WV, and WY

State Board Approvals

Florida Provider # 0009553 License #868
Indiana Continuing Education Provider #CE21800088
Maryland Approved Provider of Continuing Professional Competency
New Jersey Professional Competency Approval #24GP00025600
North Carolina Approved Sponsor #S-0695
NYSED Sponsor #274

How Our Written Courses Work

This document is the course text. You may review this material at your leisure before or after you purchase the course.
After the course has been purchased, review the technical material and then complete the quiz at your convenience.
A Certificate of Completion is available once you pass the exam (70% or greater).
If a passing grade is not obtained, you may take the quiz as many times as necessary until a passing grade is obtained).
If you have any questions or technical difficulties, please call (508) 298-4787 or email us at admin@PDH Pro.com.

Bridges

There are extensive manuals on bridges that are available and should be used in bridge hydraulic studies and river stability analysis. Some of the best include:

1. *Hydraulics of Bridge Waterways* Hydraulic Design Series No. 1 (FHWA 1978). This is a good basic reference.

2. *Highway in the River Environment* (Richardson 1988 draft with appendices and 1974). This is particularly good for hydraulics, geomorphology, scour, and degradation.

3. *Design Manual for Engineering Analysis of Fluvial Systems for the Arizona Department of Water Resources* (LSA 1985). This is a prime reference on hydraulics and the three-level sediment transport analysis, with examples.

Photograph HS-14—A stable channel at bridges is important and includes caring for the stream downstream of the bridge as shown here on Cherry Creek.

4. *Hydraulic Analysis Location and Design of Bridges* Volume 7 (AASHTO 1987). This is a good overview document.

5. *Technical Advisory on Scour at Bridges* (FHWA 1988). This presents information similar to references 2, 3, and 4 above, but in a workbook format, and perhaps oversimplified.

Bridges are required across nearly all open urban channels sooner or later and, therefore, sizing the bridge openings is of paramount importance. Open channels with improperly designed bridges will either have excessive scour or deposition or not be able to carry the design flow.

4.0 Basic Criteria

Bridge openings should be designed to have as little effect on the flow characteristics as reasonable, consistent with good bridge design and economics. However, in regard to supercritical flow with a lined channel, the bridge should not affect the flow at all—that is, there should be no projections into the design water prism that could create a hydraulic jump or flow instability in form of reflecting and standing waves.

4.0.1 Design Approach

The method of planning for bridge openings must include water surface profiles and hydraulic gradient analyses of the channel for the major storm runoff. Once this hydraulic gradient is established without the bridge, the maximum reasonable effect on the channel flow by the bridge should be determined. In urban cases this should not exceed a backwater effect of more than 6 to 12 inches.

Velocities through the bridge and downstream of the bridge must receive consideration in choosing the bridge opening. Velocities exceeding those permissible will require special protection of the bottom and banks.

For supercritical flow, the clear bridge opening should permit the flow to pass under unimpeded and unchanged in cross section.

4.0.2 Bridge Opening Freeboard

The distance between the design flow water surface and the bottom of the bridge deck will vary from case to case. However, the debris that may be expected must receive full consideration in setting the freeboard. Freeboard may vary from several feet to minus several feet. There are no general rules. Each case must be studied separately. In larger waterways, streams and on rivers where large floating debris is likely, at least a 3-foot freeboard during a 100-year flood should be considered.

Bridges that are securely anchored to foundations and designed to withstand the dynamic forces of the flowing water might, in some cases, be designed without freeboard.

4.1 Hydraulic Analysis

The hydraulic analysis procedures described below are suitable, although alternative methods such as FHWA HY-4 or HEC-RAS are acceptable, as well.

The design of a bridge opening generally determines the overall length of the bridge. The length affects the final cost of the bridge. The hydraulic engineering in the design of bridges has more impact on the bridge cost than does the structural design. Good hydraulic engineering is necessary for good bridge design (FHWA 1978, Richardson 1974 and 1988).

The reader is referred to *Hydraulics of Bridge Waterways* (U.S. Bureau of Public Roads 1978) for more guidance on the preliminary assessment approach described below. In working with bridge openings, the designer may use the designation shown in Figure HS-21.

4.1.1 Expression for Backwater

A practical expression for backwater has been formulated by applying the principle of conservation of energy between the point of maximum backwater upstream from the bridge and a point downstream from the bridge at which normal stage has been reestablished, as shown in Sections 1 and 4, respectively, of Figure HS-21. The expression is reasonably valid if the channel in the vicinity of the bridge is reasonably uniform, the gradient of the bottom is approximately constant between Sections 1 and 4, there is no appreciable erosion of the bed in the constriction due to scour, and the flow is subcritical.

The expression for computation of backwater upstream from a bridge constricting the flow is as follows:

$$h_1^* = (K^*)\left(\frac{(V_{n2})^2}{2g}\right) + \propto 1\left[\left(\frac{A_{n2}}{A_4}\right)^2 - \left(\frac{A_{n2}}{A_1}\right)^2\right]\frac{V_{n2}^{\;2}}{2g} \qquad \text{(HS-23)}$$

in which:

h_1^* = total backwater (ft)

K^* = total backwater coefficient

$\propto 1 = \dfrac{qv^2}{QV_1^2}$ = kinetic energy coefficient

A_{n2} = gross water area in constriction measured below normal stage (ft^2)

V_{n2} = average velocity in constriction or Q/A_{n2} (ft/sec). The velocity V_{n2} is not an actual measurable velocity but represents a reference velocity readily computed for both model and field structures.

A_4 = water area at Section 4 where normal stage is reestablished (ft^2)

A_1 = total water area at Section 1 including that produced by the backwater (ft^2)

g = acceleration of gravity (32.2 ft/sec^2)

To compute backwater by Equation HS-23, it is necessary to obtain the approximate value of h^*_1 by using the first part of the equation:

$$h_1^* = (K^*)\left(\frac{V_{n2}^2}{2g}\right) \qquad \text{(HS-24)}$$

The value of A_1 in the second part of Equation HS-23, which depends on h^*_1, can then be determined.

This part of the expression represents the difference in kinetic energy between Sections 4 and 1, expressed in terms of the velocity head $\frac{V_{n2}^2}{2g}$. Equation HS-24 may appear cumbersome, but it was set up as shown to permit omission of the second part when the difference in kinetic energy between Sections 4 and 1 is small enough to be insignificant in the final result.

To permit the designer to readily recognize cases in which the kinetic energy term may be ignored, the following guides are provided:

$M > 0.7$, where M = bridge opening ratio

$V_{n2} < 7$ ft/sec

$(K^*)\left(\frac{V_{n2}^2}{2g}\right) < 0.5$ ft

If values meet all three conditions, the backwater obtained from Equation HS-24 can be considered sufficiently accurate. Should one or more of the values not meet the conditions set forth, it is advisable to use Equation HS-23 in its entirety. The use of the guides is further demonstrated in the examples given in FHWA (1978) that should be used in all bridge design work.

4.1.2 Backwater Coefficient

The value of the overall backwater coefficient K^*, which was determined experimentally, varies with:

1. Stream constriction as measured by bridge opening ratio, M.
2. Type of bridge abutment: wingwall, spill through, etc.
3. Number, size, shape, and orientation of piers in the constriction.
4. Eccentricity, or asymmetric position of bridge with the floodplains.
5. Skew (bridge crosses floodplain at other than 90 degree angle).

The overall backwater coefficient K^* consists of a base curve coefficient, K_b, to which are added incremental coefficients to account for the effect of piers, eccentricity, and skew. The value of K^* is primarily dependent on the degree of constriction of the flow but also changes to a limited degree with the other factors.

4.1.3 Effect of M and Abutment Shape (Base Curves)

Figure HS-22 shows the base curve for backwater coefficient, K_b, plotted with respect to the opening ratio, M, for several wingwall abutments and a vertical wall type. Note how the coefficient K_b increases with