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Flood Control and Drainage Structures

Course Number: CE-02-710

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Module 4: Bridges

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** bridge openings for hydraulic adequacy and backwater impacts in urban channels.
- **Calculate** total backwater using energy conservation principles and relevant coefficients.
- **Select** appropriate abutment shapes and pier incremental coefficients to optimize hydraulic performance.

Executive Summary: Sizing bridge openings is a paramount engineering task for urban channels. Proper design requires balancing structural economics with hydraulic gradient analyses to ensure backwater effects do not exceed 6 to 12 inches and that flow characteristics—particularly in supercritical regimes—remain stable to prevent excessive scour or deposition.

Sizing bridge openings is of paramount importance as improperly designed bridges in urban channels lead to excessive scour, deposition, or a failure to carry design flows. Several primary references should be used for bridge hydraulic studies and river stability analysis, including FHWA HDS No. 1, Richardson (1988), and AASHTO Volume 7.



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.



Basic Criteria

Bridge openings must be designed to minimize effects on flow characteristics while maintaining consistency with good bridge design and economics.

- **Supercritical Flow Constraints:** In lined channels, the bridge should not affect the flow at all; there must be no projections into the design water prism that could create a hydraulic jump or standing waves.
- **Velocity Considerations:** Choose openings that maintain permissible velocities; velocities exceeding these limits require special protection of the bottom and banks.

Design Approach

The planning method for bridge openings must include water surface profiles and hydraulic gradient analyses of the channel for major storm runoff.

- **Backwater Limits:** Once the 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 6 to 12 inches.
- **Supercritical Flow Clearance:** The clear bridge opening should permit flow to pass under unimpeded and unchanged in cross section.

Bridge Opening Freeboard

Freeboard—the distance between the design flow water surface and the bottom of the bridge deck—varies by case.

- **Debris full Consideration:** Expected debris must receive full consideration when setting freeboard.
- **Standard Recommendations:** In larger waterways where large floating debris is likely, consider at least a 3-foot freeboard during a 100-year flood.
- **Zero Freeboard:** Bridges securely anchored to foundations and designed to withstand dynamic forces may, in some cases, be designed without freeboard.

Hydraulic Analysis

Hydraulic engineering has a greater impact on bridge cost than structural design because it determines the overall length of the bridge. While FHWA HY-4 or HEC-RAS are acceptable, the assessment approach below is standard.

Expression for Backwater

A practical expression for backwater is formulated by applying the principle of conservation of energy between Section 1 (maximum backwater upstream) and Section 4 (reestablished normal stage downstream). This is valid for subcritical flow in reasonably uniform channels.

Equation HS-23:

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

Where:

- **h*** = total backwater (ft)
- **K*** = total backwater coefficient
- **α1** = kinetic energy coefficient
- **An2** = gross water area in constriction measured below normal stage (ft²)
- **Vn2** = average velocity in constriction or Q/An2 (ft/sec)
- **A4** = water area at Section 4 where normal stage is reestablished (ft²)
- **A1** = total water area at Section 1 including that produced by the backwater (ft²)
- **g** = acceleration of gravity (32.2 ft/sec²)

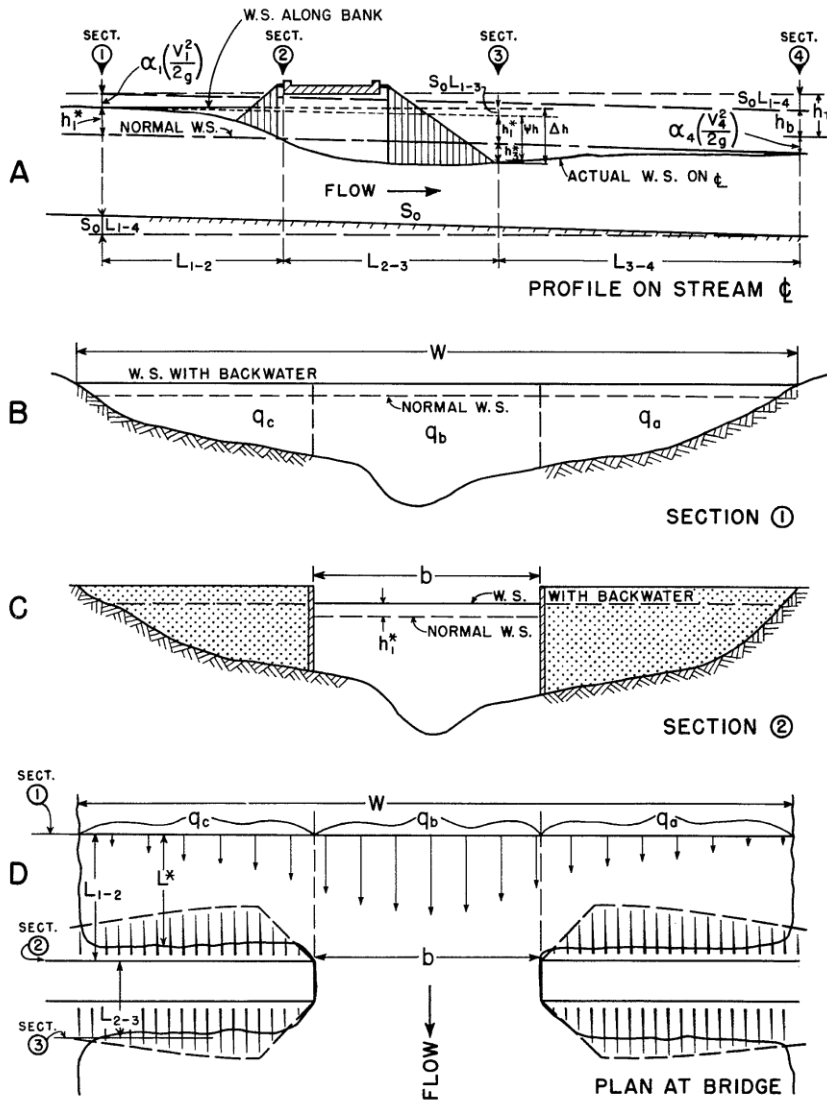


Figure HS-21. Normal Bridge Crossing Designation

Calculation Note: To permit the designer to recognize cases where the kinetic energy term (the second part of Equation HS-23) may be ignored, use the following guides: $M > 0.7$, $Vn^2 < 7$ ft/sec, and the first term result is < 0.5 ft.

Backwater Coefficient

The experimental value of the overall backwater coefficient (K^*) varies based on stream constriction (M), abutment type, piers, eccentricity, and skew. It consists of a base curve coefficient (K_b) plus incremental coefficients for these factors.

Effect of M and Abutment Shape (Base Curves)

Base curve coefficients (K_b) apply to normal crossings for specific abutment shapes.

- **Wingwall Abutments:** K_b increases with channel constriction. Lower curves on the chart represent better hydraulic shapes.
- **Spill-through Abutments:** The coefficient is little affected by embankment slope.

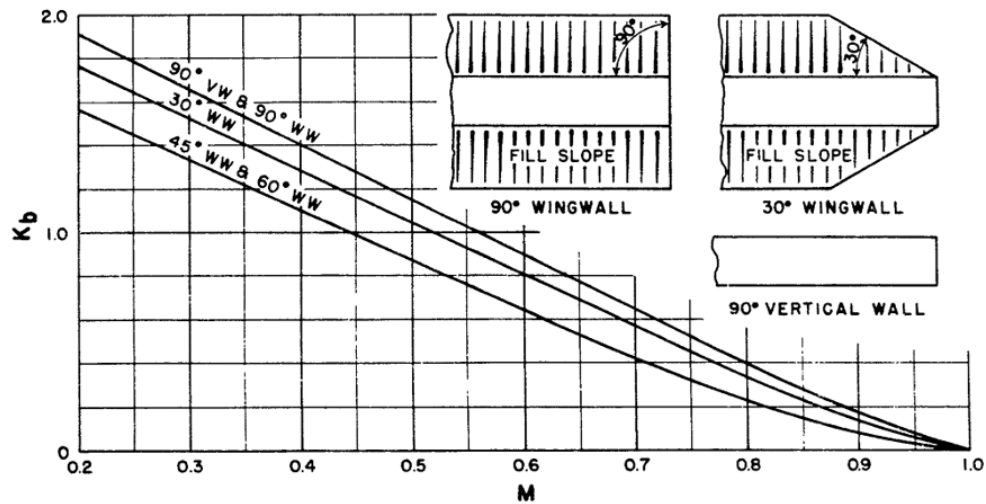


Figure HS-22. Base Curves for Wingwall Abutments

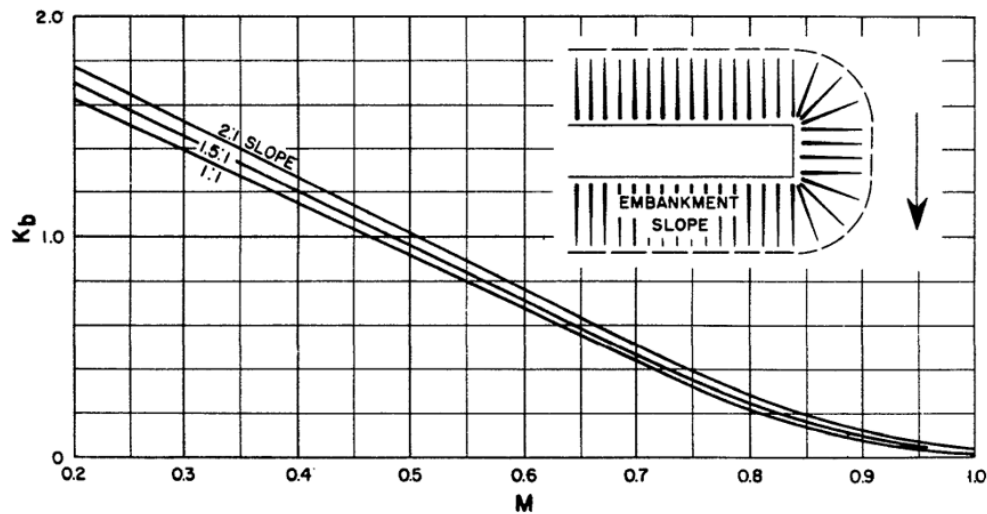


Figure HS-23. Base Curves for Spillthrough Abutments



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