CHAPTER 7
BRIDGE HYDRAULICS

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Synopsis

General design criteria for frequency, high water, clearances, average velocity, relief openings, spur dikes, and structural design and alterations are presented, as well as procedures for water surface profile calculations. Key references for information on bridge hydraulics are the WSPRO (HY-7) computer program research report (USDOT, FHWA, 1986), the HEC-RAS computer user's manual, hydraulic reference manual and applications guide (U.S. Army Corps of Engineers, 1998), and HDS-1 (USDOT, FHWA, 1978).

7.1 Design Criteria

Each bridge requires development of site-specific design criteria that will meet the needs of the specific crossing. Standard bridge design criteria are presented below.

7.1.1 Return Period

The peak discharge design return period for bridges with spans of 20 feet or greater, as specified in Volume 1, Section 6.7, shall be the 100-year storm event. The design shall comply with flood plain/floodway encroachment criteria from Volume 1. Because the risks and requirements for each bridge are unique, site-specific factors may affect the selection of an appropriate design return period.

7.1.2 High Water

The design high water at a bridge location establishes the minimum elevation for the approach embankments, which ensures the integrity of the roadway base and pavement. Design high water is not necessarily the highest water of record or the water surface elevation of the design flood, but instead is determined by good judgment based on frequency, duration, area drained, and the outfall condition. Arriving at an elevation to which the water has risen in the past can be helpful, but determining the frequency and duration associated with that observed high water is often difficult.

7.1.3 Clearances

Low member and horizontal bridge clearance requirements should consider the site-specific potential for plugging by debris and the need for passage of boat traffic. The method for establishing design values should be clearly documented.

A method used by the St. Paul District of the U.S. Army Corps of Engineers (1985) to evaluate plugging potential is included in Table 7-1. The Table leads the designer through a consideration of various aspects of bridge plugging to select a high, medium, or low potential for plugging. After selecting the plugging potential, bridges are designed with area reduction percentages as follows:

1. Low potential—5 to 10 percent

2. Medium potential—15 to 20 percent

3. High potential—25 to 30 percent

In general, a 50 percent area reduction would be an absolute maximum to be considered. The design engineer is ultimately responsible for making a proper evaluation that considers site-specific conditions.

<u>Vertical Clearance</u>

Unless a regulatory agency has established higher values, the following minimum vertical clearances are recommended:

1. To allow debris to pass without causing damage, recommended minimum clearance between design flood stage and the low member of the bridge should be:

    a. Interstate highways—3 feet

    b. High use or essential highways--2 to 3 feet

    c. Other highways—1 to 2 feet

2. For crossings subject to small boat traffic, recommended minimum clearance should be:

    a. Rivers and streams--6-foot clearance above mean annual flood stage

    b. Across lakes or canals--6-foot clearance above prevailing water elevation

<u>Horizontal Clearance</u>

Horizontal clearance should be adequate to minimize encroachment and adverse backwater conditions caused by a flow constriction (see Section 7.2). If costs are not substantially higher, bridges are preferred to multi-barreled culverts. Except for perpendicular crossings, horizontal clearance does not equal span distance. The span is measured center to center from piers, while horizontal clearance is a projected area that varies with the angle of the crossing.

The projected length is generally taken as the perpendicular distance between the closest bridge substructure or the fender system.

7.1.4 Average Velocity

The average velocity is generally considered when the capacity of a bridge opening is being evaluated; localized velocities may become significant, however, if the potential for scour exists. The applicability of using an average velocity diminishes when significant differences occur across the flow area in terms of roughness and flow depth. Consideration should be given to the use of riprap or bank protection on fill slopes when the maximum allowable velocities specified in Chapter 3 are exceeded for the soil type and conditions encountered.

7.1.5 Relief Openings

When the flow distribution in the approach channel at flood stage is over a broad area (in unconfined or flood plain channels) and the placement of approach embankments will cause extensive encroachment, consideration should be given to the use of relief openings in addition to the main channel bridge. The relief openings are usually located at a less defined channel away from the main channel. This secondary channel is often at an elevation higher than the normal flow in the main channel.

Relief openings can reduce scour at the main bridge and can reduce backwater. They should be designed to carry a specific discharge, if possible, since they are susceptible to scour hazards. These openings should be located and designed so they will not "invite" the main river to flow through them and thereby leave the main opening to convey less than the planned amount of flood. Procedures for evaluating relief opening requirements are described in Chapter 4 of the WSPRO (HY-7) computer program documentation (USDOT, FHWA, 1986).

7.1.6 Spur Dikes

Most bridge abutments in Davidson County are set in bedrock. However, where approach embankments encroach on wide flood plains and constrict the normal flow, special attention should be given to scour in the vicinity of bridge abutments. A typical spur dike, as shown in Figure 7-1, provides a structural method for reducing the gradient and velocity along the embankment by moving the mixing action of the merging flow away from the abutment to the upstream end of the dike. Before a spur dike is selected as a bridge component, regulatory constraints on fill in flood plains should be considered.

The three principal considerations for proportioning a spur dike are shape, height, and length. A dike shaped in the form of a quarter of an ellipse, with a ratio of the major (length) to the minor (offset) axis of 2.5:1, is recommended (USDOT, FHWA, HDS-1, 1978). The spur dike height should be based on the design high water level. It should have sufficient height and freeboard to avoid overtopping and be protected from wave action. Unless dikes are constructed entirely of stone or earth dikes are properly armored with graded stone facing, they can be severely damaged or completely destroyed by overtopping.

The length of a spur dike can be determined using procedures presented in HDS-1 (USDOT, FHWA, 1978). In general, the length of a spur dike should be increased with an increase in flood plain discharge, with an increase in velocity under the bridge, or with both. At the recommended minimum length of 100 feet or more, curvilinear flow is directed around the end of the dike, to merge with the main channel flow and establish a straight course downriver before reaching the bridge abutment.

7.1.7 Structural Design

Bridges are to be designed in accordance with the latest edition of AASHTO Specifications for Highway Bridges. The bridge shall be designed to resist the hydraulic force produced by a 100-year storm.

7.1.8 Structural Alterations

Under some conditions, existing bridges may be retained or modified (widened or lengthened) when a roadway is upgraded. When such alterations are designed, the level of effort should be consistent with that required for a new structure. When a bridge is being widened, special attention should be placed on evaluating vertical clearance, new pier losses, and deck drainage.

7.2 Water Surface Profile Calculations

The procedure for performing water surface profile calculations at bridges should be consistent with the needs of the project. When changes to elevations and regulatory floodways presented on a Flood Insurance Rate Map or Floodway Maps are evaluated, consistent procedures should be used. This generally involves using the program and values of the original Flood Study to evaluate changes for approval.

Two commonly used water surface profile computer programs are HEC-RAS and SWMM EXTRAN block. The HEC-RAS computer program, developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center (1998), and SWMM 4.3 was developed by the U.S. Environmental Protection Agency (Huber, 1992; Roesner 1994) and is well suited for performing the water surface profile computations associated with most bridges. They are recommended for most projects, particularly if bridge hydraulic requirements are not significant.

7.3 Construction and Maintenance Considerations

An important step in the design process involves identifying whether special provisions are warranted to properly construct or maintain proposed facilities. Typical problems encountered with bridges include excessive scour at the entrance toe of a main channel embankment, collection of debris and sedimentation in one or more bridge openings under low or normal flow conditions, and improper handling of bridge deck runoff on the overbank area of a channel. As repairing many problems at bridges can require a lengthy regulatory process, these problems should be considered during design to minimize maintenance requirements.

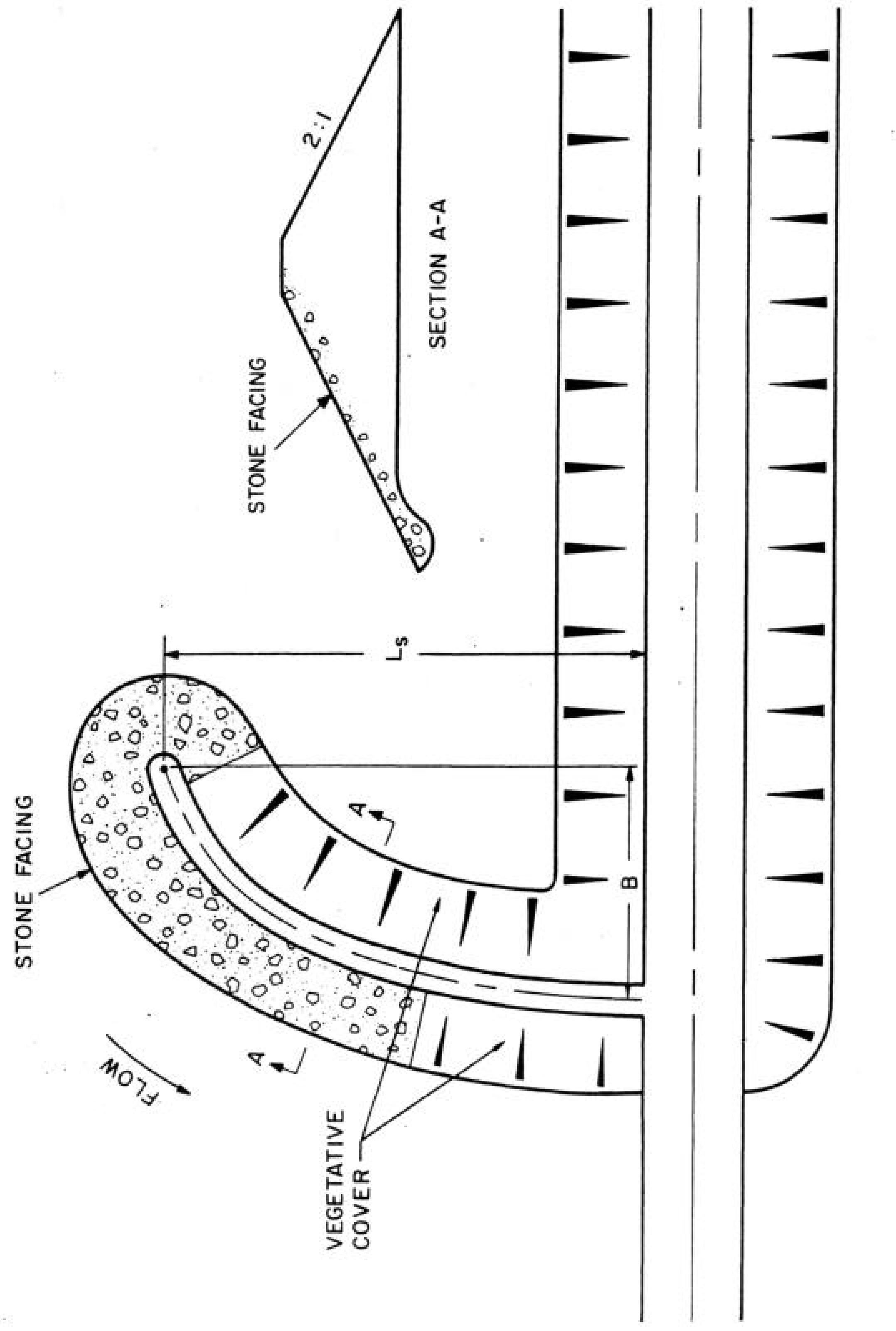
Table 7-1
EXAMPLE TABULATION SHEET FOR EVALUATING BRIDGE PLUGGING POTENTIAL

No.	Item	Associated Level of Risk: Low	Associated Level of Risk: High	Risk Level Used: Low	Risk Level Used: Medium	Risk Level Used: High
1.	Distance between piers or abutments	>100 ft	<10 ft			
2.	Number of openings greater than 30-100 feet	>2	1			
3.	Low chord elevation clearance to water	>3 ft	<3 ft			
4.	Depth of flow below low chord member	>20 ft	<10 ft			
5.	Bridge is perched and overbanks carry flows	Yes	No			
6.	Potential source of debris	Little Debris	Heavy Debris			
7.	Ability of channel to transport debris through bridge	1 to 4 fps	>5 fps			
8.	Upstream structures such as bridges that can prevent debris from being transported	1 or more	None			
9.	Past history of plugging or experiences with similar structures under similar circumstances	None	Some			
10.	Potential for actions to remove the debris using cranes, etc.	Great	Slight			
11.	Type of stream with regard to the rate of rise	Slow	Fast			
12.	Percentage of the flow area obstructed by the bridge deck	<5%	>10%			
13.	Impact upstream of bridge if plugging occurred	Minor Damage	Heavy Damage, Loss of Life			

Other Considerations:

Recommendations:

Reference: U.S. Army Corps of Engineers, St. Paul District, Engineering Division (June 1985).



Reference: USDOT, FHWA, HDS-1 (1978).

Figure 7-1
Plan and Cross Section of Spur Dike