FDM 13-20-1 Design Methods

June 19, 2013

1.1 Definition

A bridge is defined as a structure having a span of more than 20 feet from face to face of abutments or end bents, measured along the center line of the roadway. This definition also applies to box culverts (measured from inside face of outer cells) and multiple pipes (measured from outer face of outer pipes provided the clear distance between adjacent pipes is less than half the diameter of the smaller contiguous pipe).

The region is required to submit a Structure Survey Report and a Hydraulic Report for each bridge structure. For more information regarding Structure Survey Reports, refer to FDM 3-20-30. Reporting procedures are provided in Chapter 6 and Chapter 8, respectively, of the WisDOT Bridge Manual.

1.2 Type of Flow

The three types of flow that may be encountered in bridge design (see Attachment 1.1, Detail B) are labeled as Type **I** flow (subcritical), Type **II** flow (passes through critical), and Type **III** flow (critical). The symbols in this attachment are defined as follows:

h_l*=total backwater or rise above normal stage at Section 1

N.W.S.=normal water surface

S_O=slope of channel bottom or normal water surface

y_x=depth of flow at Section X

y_n=normal depth of flow in model

y_{xc}=critical depth at Section X

W.S.=water surface

Most of the streams in Wisconsin exhibit flat gradients and hence Type **I**, or subcritical flow, is normally encountered.

1.3 Methods

Normally, determining the required waterway areas for minor drainage structures is performed by the region staff through the hydrological/hydraulic analysis of the site with the aid of region-collected data. The Bureau of Structures (BOS) is responsible for the hydraulic/hydrologic analysis of bridges and box culverts they design while consultants perform this function for structures they design.

Due to economics, most bridges are not designed to span the entire floodway that occurs at a specified flood flow. Instead, only a part of the floodway is spanned, thus producing a constriction. The loss of energy produced by this constriction must be balanced by a rise in the upstream water surface. This rise, denoted by h_1* in Attachment 1.1, is called the backwater. The backwater of a bridge is defined as the upstream water surface rise above normal stage of the natural stream. The designer should determine the impact of the backwater on the floodplain as described in FDM 13-10-1.

Bridge design involves determining the waterway area, location, and configuration that will produce a backwater equal to or less than some specified value. This goal may be achieved by a number of methods. Three of the most common ways to accomplish the calculation of bridge and culvert hydraulics are:

1. WSPRO, Water-Surface Profiles, (HY-7)
2. Hydraulic Design of Highway Culverts, (HDS-5 & HY-8)
3. Water Surface Profiles, (HEC-2) & (HEC-RAS)

1.3.1 WSPRO, Water-Surface Profiles (HY-7)

FHWA and WisDOT endorse and employ this design methodology in the majority of its stream crossing bridges. WSPRO is a computer model developed by the U.S. Geologic Survey for the computation of water surface profiles using a one-dimensional step-backwater approach. Profile computations for free-surface flow through bridges are based on relatively recent developments in bridge backwater analysis and recognize the influence of bridge geometry variations. The model has the ability to compute subcritical as well as supercritical profiles. Pressure flow situations are computed using FHWA techniques. Embankment overtopping flows, in conjunction with either free-surface or pressure flow through the bridge, can be computed. WSPRO is also capable of computing profiles at stream crossings with multiple openings including culverts.

Updates to the WSPRO program will include metric input and output as well as scour analysis routines that are based on the FHWA Hydraulic Engineering Circular No. 18 "Evaluating Scour at Bridges." References for user include:

1. J.O. Sherman, W. H. Hirby, V.R. Schneider, H. N. Flippo, "Bridge Waterways Analysis Model: Research Report," Federal Highway Administration Report No. FHWA/RD-86/108.
2. J.O. Sherman, "Users Manual for WSPRO, A Computer Model for Water-Surface Profile Computations," Federal Highway Administration Report No. FHWA-SA-98-080.
3. “Hydraulics,” Bridge Manual, State of Wisconsin, Department of Transportation, Chapter 8.

1.3.2 Hydraulic Design of Highway Culverts, (HDS-5 & HY-8)

HY-8 is a comprehensive culvert design program that includes analysis and design capabilities for conventional culvert, culverts with improved inlets, energy dissipators, multiple culvert analysis, storage-routing techniques, and hydrologic analysis. The program offers the user a wide range of alternate drainage structure shapes for analysis that include circular, box, elliptical, pipe-arch, and user defined. The user has a choice of materials that include steel, concrete, and aluminum. The program also offers a variety of options to define the tail-water elevation.

The HY-8 methodology is based on the application of three Federal Highway Administration publications: "Hydraulic Design of Highway Culverts (HDS No.5)" dated September 2001, "Hydraulic Design of Energy Dissipators for Culverts and Channels (HEC No. 14)," and "Hydrology (HEC No. 19)."

References for users include:

1. Ginsberg, Abigail, "HY-8 Culvert Analysis Microcomputer Program Applications Guide", Federal Highway Administration Report FHWA-EPD-87-101.
2. "Hydraulic Design of Highway Culverts (HDS No. 5),” Federal Highway Administration Report No. FHWA-NHI-01-020.
3. "Hydraulic Design of Energy Dissipators for Culverts and Channels (HEC No. 14),”Federal Highway Administration Report No. FHWA-NHI-06-086.
4. "Hydrology" (HEC No. 19), Federal Highway Administration Report No. FHWA-IP-84-15.

1.3.3 Water Surface Profiles, HEC-2 and HEC-RAS

HEC-2 and the update HEC-RAS are step-backwater programs similar to the WSPRO program. The U.S. Army Corps of Engineers developed and maintains this model. The program is intended for calculating water surface profiles for steady gradually varied flow in natural or man-made channels. Both subcritical and flow profiles can be calculated. The effects of various obstructions such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computation. The computational procedure is based on the solution of the one-dimensional energy equation with energy losses due to friction evaluated with Mannings Equation. This computational procedure is generally known as the standard step method.

This program is most frequently and historically used in the development of flood profiles and floodway delineation for use in flood insurance studies as part of the National Flood Insurance Program.

References for users include:

1. "HEC-2 Water Surface Profiles Users Manual,” Computer Program 723-X6-L202A, Hydraulic Engineering Center, Davis, CA. May 1991.

1.4 Additional Literature

For designs involving local scour, overflow sections, and spur dikes, the designer is referred to the following:

1. HDS #1, "Hydraulics of Bridge Waterways," U.S. Department of Transportation, FHWA, 1978.
2. "Hydraulics," Bridge Design Manual, State of Wisconsin, Department of Transportation, Chapter 8.

LIST OF ATTACHMENTS