LEVEL II SCOUR ANALYSIS FOR BRIDGE 28 (WORCTH00200028) on TOWN HIGHWAY 20, crossing MINISTER BROOK, WORCESTER, VERMONT

Open-File Report 98-526

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION

U.S. Department of the Interior
U.S. Geological Survey

USGS
science for a changing world
LEVEL II SCOUR ANALYSIS FOR BRIDGE 28 (WORCTH00200028) on TOWN HIGHWAY 20, crossing MINISTER BROOK, WORCESTER, VERMONT

By ERICK M. BOEHMLER AND ROBERT H. FLYNN

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Pembroke, New Hampshire
1998
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

<table>
<thead>
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<th>Multiply</th>
<th>By</th>
<th>To obtain</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>inch (in.)</td>
<td>25.4</td>
<td>millimeter (mm)</td>
</tr>
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<td>meter (m)</td>
</tr>
<tr>
<td>mile (mi)</td>
<td>1.609</td>
<td>kilometer (km)</td>
</tr>
<tr>
<td><strong>Slope</strong></td>
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<td></td>
</tr>
<tr>
<td>foot per mile (ft/mi)</td>
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<td>meter per kilometer (m/km)</td>
</tr>
<tr>
<td><strong>Area</strong></td>
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<td></td>
</tr>
<tr>
<td>square mile (mi²)</td>
<td>2.590</td>
<td>square kilometer (km²)</td>
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<tr>
<td><strong>Volume</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cubic foot (ft³)</td>
<td>0.02832</td>
<td>cubic meter (m³)</td>
</tr>
<tr>
<td><strong>Velocity and Flow</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>foot per second (ft/s)</td>
<td>0.3048</td>
<td>meter per second (m/s)</td>
</tr>
<tr>
<td>cubic foot per second (ft³/s)</td>
<td>0.02832</td>
<td>cubic meter per second (m³/s)</td>
</tr>
<tr>
<td>cubic foot per second per square mile</td>
<td>0.01093</td>
<td>cubic meter per second per square kilometer [(m³/s)/km²]</td>
</tr>
<tr>
<td>[(ft³/s)/mi²]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**OTHER ABBREVIATIONS**

- BF: bank full
- LWW: left wingwall
- cfs: cubic feet per second
- Max: maximum
- D₅₀: median diameter of bed material
- MC: main channel
- DS: downstream
- RAB: right abutment
- elev.: elevation
- RABUT: face of right abutment
- f/p: flood plain
- RB: right bank
- ft²: square feet
- ROB: right overbank
- ft/ft: feet per foot
- RWW: right wingwall
- FEMA: Federal Emergency Management Agency
- TH: town highway
- FHWA: Federal Highway Administration
- US: upstream
- JCT: junction
- USGS: United States Geological Survey
- LAB: left abutment
- VTAOT: Vermont Agency of Transportation
- LB: left bank
- WSPRO: water-surface profile model
- LOB: left overbank
- yr: year

In this report, the words “right” and “left” refer to directions that would be reported by an observer facing downstream.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.
LEVEL II SCOUR ANALYSIS FOR BRIDGE 28 (WORCTH00200028) ON TOWN HIGHWAY 20, CROSSING MINISTER BROOK, WORCESTER, VERMONT

By Erick M. Boehmler and Robert H. Flynn

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure WORCTH00200028 on Town Highway 20 crossing Minister Brook, Worcester, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (FHWA, 1993). Results of a Level I scour investigation also are included in appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the bridge, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in appendix D.

The site is in the New England Upland section of the New England physiographic province in north-central Vermont. The 4.68-mi² drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is forest except for the right bank upstream. Surface cover on the right bank upstream consists of pasture beyond a narrow strip of trees along the brook.

In the study area, Minister Brook has an incised, sinuous channel with a slope of approximately 0.08 ft/ft, an average channel top width of 37 ft and an average bank height of 4 ft. The channel bed material ranges from sand to boulders with a median grain size \(D_{50}\) of 103 mm (0.337 ft). The geomorphic assessment at the time of the Level I and Level II site visit on July 17, 1996, indicated that the reach was stable.

The Town Highway 20 crossing of Minister Brook is a 30-ft-long, one-lane bridge consisting of one 27-foot steel-beam span (Vermont Agency of Transportation, written communication, October 13, 1995). The opening length of the structure parallel to the bridge face is 22.8 ft. The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 20 degrees to the opening while the opening-skew-to-roadway is zero degrees.
A scour hole 1.0 ft deeper than the mean thalweg depth was observed at the downstream end of the left abutment and along the left bank from 35 feet upstream to the bridge during the Level I assessment. Scour protection measures at the site included type-1 (less than 12 inches diameter) and type-2 (less than 36 inches diameter) stone fill. Type-1 stone fill was observed along the right abutment, the right wingwalls, and discontinuously along the upstream right bank. Type-2 stone fill was observed along the left abutment, the left wingwalls, the left bank upstream, and the left and right banks downstream. Additional details describing conditions at the site are included in the Level II Summary and appendices D and E.

Scour depths and recommended rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and Davis, 1995) for the 100- and 500-year discharges. In addition, the incipient roadway-overtopping discharge was determined and analyzed as another potential worst-case scour scenario. Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.0 to 0.1 ft. The worst-case contraction scour occurred at the 100-year discharge. Abutment scour ranged from 3.3 to 6.1 ft. The worst-case abutment scour occurred at the 100-year discharge for the left abutment and at the 500-year discharge for the right abutment. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results.” Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and Davis, 1995, p. 46). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.
Figure 1. Location of study area on USGS 1:24,000 scale map.
Figure 2. Location of study area on Vermont Agency of Transportation town highway map.
LEVEL II SUMMARY

Structure Number: WORCTH00200028  Stream: Minister Brook

County: Washington  Road: TH 20  District: 6

Description of Bridge

<table>
<thead>
<tr>
<th>Bridge length</th>
<th>ft</th>
<th>Bridge width</th>
<th>ft</th>
<th>Max span length</th>
<th>ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td></td>
<td>15.9</td>
<td></td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

Alignment of bridge to road (on curve or straight): Straight

Abutment type: Vertical, concrete

Embankment type: Sloping

Stone fill on abutment?: Yes

Date of inspection: 7/17/96

Description of stone fill: Type-1 along the right abutment and right wingwalls upstream and downstream and type-2 along the left abutment and the left wingwalls upstream and downstream.

Abutments and wingwalls are concrete. There is a one foot deep scour hole along the downstream end of the left abutment. The footings of the right and left abutments are exposed one-half to one foot.

Yes

Is bridge skewed to flood flow according to Level I survey? Yes

Angle

Is bridge skewed to flood flow according to Level II survey? Yes

Debris accumulation on bridge at time of Level I or Level II site visit:

<table>
<thead>
<tr>
<th>Date of inspection</th>
<th>Percent of channel blocked horizontally</th>
<th>Percent of channel blocked vertically</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/17/96</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Level I: 7/17/96

Level II: High. Some debris was observed lodged along the left abutment and there is significant tree cover along the upstream banks.

Potential for debris

None were observed on 7/17/96.

Describe any features near or at the bridge that may affect flow (include observation date):

---
Description of the Geomorphic Setting

General topography: The channel is located in a moderate relief valley with narrow flood plains and steep valley walls.

Geomorphic conditions at bridge site: downstream (DS), upstream (US)

Date of inspection: 7/17/96

DS left: Steep channel bank to a moderately sloped overbank
DS right: Steep channel bank and valley wall
US left: Steep channel bank and valley wall
US right: Steep channel bank and a moderately sloped overbank

Description of the Channel

Average top width: 37 ft
Cobbles / Boulders: 4
Average depth: ft
Cobbles / Boulders: Perennial but flashy, sinuous, and locally anabranched with semi-alluvial channel boundaries.

Predominant bed material: Cobbles / Boulders
Bank material: Perennial but flashy, sinuous, and locally anabranched with semi-alluvial channel boundaries.

Date of inspection: 7/17/96

Vegetative cover on channel banks near bridge:

DS left: Trees
DS right: Trees
US left: Trees and grass
US right: Trees and grass on the overbank

Do banks appear stable? Yes

Date of observation:

None were observed on 7/17/96

Describe any obstructions in channel and date of observation.

7/17/96
Hydrology

**Drainage area** \[4.68 \text{ mi}^2\]

**Percentage of drainage area in physiographic provinces: (approximate)**

<table>
<thead>
<tr>
<th>Physiographic province/section</th>
<th>Percent of drainage area</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England / New England Upland</td>
<td>100</td>
</tr>
</tbody>
</table>

Is drainage area considered rural or urban? **Rural**

Describe any significant urbanization: 

Is there a USGS gage on the stream of interest? **No**

**USGS gage description** 

**USGS gage number** 

**Gage drainage area** \[\text{mi}^2\] **No**

Is there a lake/pond that will significantly affect hydrology/hydraulics? **No**

**Calculated Discharges**

<table>
<thead>
<tr>
<th>(Q_{100})</th>
<th>(Q_{500})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,160 (\text{ft}^3/\text{s})</td>
<td>1,760 (\text{ft}^3/\text{s})</td>
</tr>
</tbody>
</table>

The 100- and 500-year discharges are based on a drainage area relationship \[4.68/(8.3)^{0.67}\] with flood frequency estimates available from the Flood Insurance Study for the Town of Worcester (FEMA, 1977) for Minister Brook at the confluence with the North Branch Winooski River. The drainage area above the confluence is 8.3 square miles. These drainage area adjusted discharges were within a range defined by flood frequency curves derived from several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887). Each curve was extended graphically to the 500-year event.
Description of the Water-Surface Profile Model (WSPRO) Analysis

Datum for WSPRO analysis (USGS survey, sea level, VTAOT plans)  
USGS survey

Datum tie between USGS survey and VTAOT plans  
None

Description of reference marks used to determine USGS datum.  
RM1 is a chiseled X on top of the upstream end of the left abutment (elev. 500.22 ft, arbitrary survey datum). RM2 is a chiseled X on top of the downstream end of the right abutment (elev. 500.24 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

<table>
<thead>
<tr>
<th>1 Cross-section</th>
<th>2 Section Reference Distance (SRD) in feet</th>
<th>2 Cross-section development</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXIT1</td>
<td>-67</td>
<td>2</td>
<td>Initial conditions section (Templated from EXTEM)</td>
</tr>
<tr>
<td>EXITX</td>
<td>-23</td>
<td>2</td>
<td>Exit Section</td>
</tr>
<tr>
<td>EXTEM</td>
<td>-23</td>
<td>1</td>
<td>Exit Section as surveyed (Used as a template)</td>
</tr>
<tr>
<td>FULLV</td>
<td>0</td>
<td>2</td>
<td>Downstream Full-valley section (Templated from EXTEM)</td>
</tr>
<tr>
<td>BRIDG</td>
<td>0</td>
<td>1</td>
<td>Bridge section</td>
</tr>
<tr>
<td>RDWAY</td>
<td>10</td>
<td>1</td>
<td>Road Grade section</td>
</tr>
<tr>
<td>APPR1</td>
<td>40</td>
<td>1</td>
<td>Approach section</td>
</tr>
</tbody>
</table>

1 For location of cross-sections see plan-view sketch included with Level I field form, appendix E. For more detail on how cross-sections were developed see WSPRO input file.
Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration’s WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). The analyses reported herein reflect conditions existing at the site at the time of the study. Furthermore, in the development of the model it was necessary to assume no accumulation of debris or ice at the site. Results of the hydraulic model are presented in the Bridge Hydraulic Summary, appendix B, and figure 7.

Channel roughness factors (Manning’s “n”) used in the hydraulic model were estimated using field inspections at each cross section following the general guidelines described by Arcement and Schneider (1989). Final adjustments to the values were made during the modeling of the reach. Channel “n” values for the reach ranged from 0.043 to 0.070, and overbank “n” values ranged from 0.047 to 0.075.

Critical depth at the downstream-most section (EXIT1) was assumed as the starting water surface. Normal depth was computed by use of the slope-conveyance method outlined in the user’s manual for WSPRO (Shearman, 1990). The slope used was 0.0765 ft/ft, which was estimated from thalweg points surveyed downstream. The normal water surface was within 0.7 feet of the critical water surface for each discharge modeled. Thus, the critical water surface was assumed to be a satisfactory starting water surface.

The approach section (APPR1) was surveyed one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This location provides a consistent method for determining scour variables.

Culvert routines provided with WSPRO are not fully integrated. Therefore, it was necessary to develop individual ratings for the culvert and bridge to model this multiple-opening situation. The ratings were combined to determine the quantity of the total discharge diverted from the bridge through the culvert. The combined ratings indicate the culvert diverts 250 cfs, 430 cfs, and 330 cfs of the total discharge for the 100-year, 500-year, and incipient roadway-overtopping peak discharges respectively. Each discharge modeled at the bridge was reduced by the flow through the culvert for the model provided in appendices A and B.

For the 100-year discharge, WSPRO assumes critical depth at the bridge section. A supercritical model was developed for this discharge. After analyzing both the supercritical and subcritical profiles, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumption of critical depth at the bridge is satisfactory solutions.
### Bridge Hydraulics Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Average bridge embankment elevation</td>
<td>500.7 ft</td>
</tr>
<tr>
<td>Average low steel elevation</td>
<td>498.7 ft</td>
</tr>
<tr>
<td>100-year discharge</td>
<td>1,160 ft³/s</td>
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<tr>
<td>Water-surface elevation in bridge opening</td>
<td>495.6 ft</td>
</tr>
<tr>
<td>Road overtopping?</td>
<td>No</td>
</tr>
<tr>
<td>Discharge over road</td>
<td>-- ft³/s</td>
</tr>
<tr>
<td>Area of flow in bridge opening</td>
<td>84 ft²</td>
</tr>
<tr>
<td>Average velocity in bridge opening</td>
<td>10.9 ft/s</td>
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<tr>
<td>Maximum WSPRO tube velocity at bridge</td>
<td>13.5 ft/s</td>
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<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>498.1 ft</td>
</tr>
<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>496.5 ft</td>
</tr>
<tr>
<td>Amount of backwater caused by bridge</td>
<td>1.6 ft</td>
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<tr>
<td>500-year discharge</td>
<td>1,760 ft³/s</td>
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<tr>
<td>Water-surface elevation in bridge opening</td>
<td>498.7 ft</td>
</tr>
<tr>
<td>Road overtopping?</td>
<td>Yes</td>
</tr>
<tr>
<td>Discharge over road</td>
<td>76 ft³/s</td>
</tr>
<tr>
<td>Area of flow in bridge opening</td>
<td>155 ft²</td>
</tr>
<tr>
<td>Average velocity in bridge opening</td>
<td>8.6 ft/s</td>
</tr>
<tr>
<td>Maximum WSPRO tube velocity at bridge</td>
<td>10.4 ft/s</td>
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<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>500.6 ft</td>
</tr>
<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>497.1 ft</td>
</tr>
<tr>
<td>Amount of backwater caused by bridge</td>
<td>3.5 ft</td>
</tr>
<tr>
<td>Incipient overtopping discharge</td>
<td>1,540 ft³/s</td>
</tr>
<tr>
<td>Water-surface elevation in bridge opening</td>
<td>498.7 ft</td>
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<tr>
<td>Area of flow in bridge opening</td>
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<td>Average velocity in bridge opening</td>
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<td>Maximum WSPRO tube velocity at bridge</td>
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<td>Water-surface elevation at Approach section with bridge</td>
<td>500.1 ft</td>
</tr>
<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>496.9 ft</td>
</tr>
<tr>
<td>Amount of backwater caused by bridge</td>
<td>3.2 ft</td>
</tr>
</tbody>
</table>
Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

Scour depths were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and Davis, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analyses for the 100- and 500-year discharges are presented in tables 1 and 2 and the scour depths are shown graphically in figure 8.

Contraction scour for the 100-year discharge was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20). At this site, the 500-year and incipient-overtopping discharges resulted in unsubmerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Thus, contraction scour for these discharges was computed by use of the Chang equation (Richardson and Davis, 1995, p. 145-146). The streambed armoring depths computed suggest that armoring will not limit the depth of contraction scour.

For comparison, contraction scour for the discharges resulting in orifice flow also was computed by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144). Furthermore, for the 500-year and incipient-overtopping discharges, contraction scour was computed by substituting estimates for the depth of flow at the downstream bridge face in the contraction scour equations. Results with respect to these alternative computations are provided in appendix F.

Abutment scour was computed by use of the Froehlich equation (Richardson and Davis, 1995, p. 48, equation 28). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.
### Scour Results

<table>
<thead>
<tr>
<th>Contraction scour:</th>
<th>100-year discharge</th>
<th>500-year discharge</th>
<th>Incipient overtopping discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Scour depths in feet)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Main channel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live-bed scour</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Clear-water scour</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Depth to armoring</td>
<td>12.4(^\text{-})</td>
<td>44.5(^\text{-})</td>
<td>36.5(^\text{-})</td>
</tr>
<tr>
<td>Left overbank</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Right overbank</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Local scour:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abutment scour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left abutment</td>
<td>6.1</td>
<td>5.6</td>
<td>5.8</td>
</tr>
<tr>
<td>Right abutment</td>
<td>3.3(^\text{-})</td>
<td>5.0(^\text{-})</td>
<td>4.1(^\text{-})</td>
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<tr>
<td>Pier scour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 1</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pier 2</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pier 3</td>
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### Riprap Sizing

<table>
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<th>100-year discharge</th>
<th>500-year discharge</th>
<th>Incipient overtopping discharge</th>
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<td>((D_{50}) in feet)</td>
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<td>Abutments:</td>
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<tr>
<td>Left abutment</td>
<td>1.5</td>
<td>1.8</td>
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<tr>
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<td>1.5</td>
<td>1.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Piers:</td>
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<td></td>
<td></td>
</tr>
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<td>Pier 1</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pier 2</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, Vermont.
Figure 8. Scour elevations for the 100- and 500-year discharges at structure WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, Vermont.
Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, Vermont. [VTAOT, Vermont Agency of Transportation; --, no data]

<table>
<thead>
<tr>
<th>Description</th>
<th>Station$^1$</th>
<th>VTAOT minimum low-chord elevation (feet)</th>
<th>Surveyed minimum low-chord elevation$^2$ (feet)</th>
<th>Bottom of footing/pile elevation$^2$ (feet)</th>
<th>Channel elevation at abutment/ pier$^2$ (feet)</th>
<th>Contraction scour depth (feet)</th>
<th>Abutment scour depth (feet)</th>
<th>Pier scour depth (feet)</th>
<th>Depth of total scour (feet)</th>
<th>Elevation of scour$^2$ (feet)</th>
<th>Remaining footing/pile depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left abutment</td>
<td>0.0</td>
<td>--</td>
<td>498.7</td>
<td>--</td>
<td>492.0</td>
<td>0.1</td>
<td>6.1</td>
<td>--</td>
<td>6.2</td>
<td>485.8</td>
<td>--</td>
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<tr>
<td>Right abutment</td>
<td>22.8</td>
<td>--</td>
<td>498.7</td>
<td>--</td>
<td>493.0</td>
<td>0.1</td>
<td>3.3</td>
<td>--</td>
<td>3.4</td>
<td>489.6</td>
<td>--</td>
</tr>
</tbody>
</table>

1. Measured along the face of the most constricting side of the bridge.
2. Arbitrary datum for this study.

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, Vermont. [VTAOT, Vermont Agency of Transportation; --, no data]

<table>
<thead>
<tr>
<th>Description</th>
<th>Station$^1$</th>
<th>VTAOT minimum low-chord elevation (feet)</th>
<th>Surveyed minimum low-chord elevation$^2$ (feet)</th>
<th>Bottom of footing/pile elevation$^2$ (feet)</th>
<th>Channel elevation at abutment/ pier$^2$ (feet)</th>
<th>Contraction scour depth (feet)</th>
<th>Abutment scour depth (feet)</th>
<th>Pier scour depth (feet)</th>
<th>Depth of total scour (feet)</th>
<th>Elevation of scour$^2$ (feet)</th>
<th>Remaining footing/pile depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left abutment</td>
<td>0.0</td>
<td>--</td>
<td>498.7</td>
<td>--</td>
<td>492.0</td>
<td>0.0</td>
<td>5.6</td>
<td>--</td>
<td>5.6</td>
<td>486.4</td>
<td>--</td>
</tr>
<tr>
<td>Right abutment</td>
<td>22.8</td>
<td>--</td>
<td>498.7</td>
<td>--</td>
<td>493.0</td>
<td>0.0</td>
<td>5.0</td>
<td>--</td>
<td>5.0</td>
<td>488.0</td>
<td>--</td>
</tr>
</tbody>
</table>

1. Measured along the face of the most constricting side of the bridge.
2. Arbitrary datum for this study.
SELECTED REFERENCES


Potter, W. D., 1957a, Peak rates of runoff in the Adirondack, White Mountains, and Maine woods area, Bureau of Public Roads


Talbot, A.N., 1887, The determination of water-way for bridges and culverts.

APPENDIX A:

WSPRO INPUT FILE
WSPRO INPUT FILE

T1       U.S. Geological Survey WSPRO Input File worc028.1.wsp
T2       Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
T3       Town Highway 20 over Minister Brook, Worcester, VT
*        J3       6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*        Q       910.0
*        WS      492.28
*        XT      EXTEM    -23
GR       -111.4, 502.13 -76.8, 494.83 -35.5, 494.85 -8.5, 494.54
GR       -2.4, 492.36  0.0, 491.16   3.6, 491.17   8.8, 490.90
GR       14.0, 491.32  20.6, 491.15  25.6, 491.23  27.7, 492.18
GR       32.8, 494.39  33.0, 502.13
*        XS      EXIT1    -67  * * *  0.0385
GT       0.067        0.070
SA       -8.5
*        XS      EXITX    -23  * * *  0.0385
GT       *        XS      FULLV      0  * * *   0.0276
GT       *        SRD      LSEL     XSSKEW
BR       BRIDG     0    498.68       0.0
GR       0.0, 498.67  0.0, 492.76   1.2, 492.75
GR       1.4, 491.97  3.2, 491.68   7.0, 491.51  12.8, 491.52
GR       15.4, 491.54 20.3, 492.45  21.5, 493.02  21.6, 493.26
GR       22.8, 493.31 22.8, 498.70  0.0, 498.67
*        SRD      EMBWID   IPAVE
XR       RDWAY     10      15.9     2
GR       -216.3, 508.06 -168.0, 505.50 -77.1, 501.15 -25.1, 500.48
GR       -1.9, 500.18  -1.9, 500.69  0.0, 500.69   23.0, 500.72
GR       24.9, 500.72  25.0, 500.07  67.8, 500.11  73.4, 500.09
GR       117.5, 501.35 177.5, 504.64 238.0, 509.69
*        SRD      LSEL     XSSKEW
BR       BRIDG     0    495.56       1
GR       0.0, 495.56  0.0, 495.56
GR       9.1, 491.82  12.8, 491.99  15.9, 493.02  17.4, 493.89
GR       23.6, 497.73 31.2, 498.68  46.4, 498.14  55.3, 497.24
GR       61.8, 492.43 65.5, 492.06  68.4, 492.07  70.1, 491.91
GR       71.6, 492.09 76.7, 497.19 126.9, 501.25 138.2, 504.44
GR       216.4, 507.84
*        AS       APPR1     40
GR       -100.9, 513.40 -72.7, 509.90 -59.5, 504.69 -26.1, 499.58
GR       -9.3, 500.20  0.0, 493.93   2.2, 492.25   6.3, 492.01
GR       9.1, 491.82  12.8, 491.99  15.9, 493.02  17.4, 493.89
GR       23.6, 497.73 31.2, 498.68  46.4, 498.14  55.3, 497.24
GR       61.8, 492.43 65.5, 492.06  68.4, 492.07  70.1, 491.91
GR       71.6, 492.09 76.7, 497.19 126.9, 501.25 138.2, 504.44
GR       216.4, 507.84
*        N        0.067        0.060   0.047
SA       -9.3        76.7
*        HP       1 BRIDG 495.56 1 495.56
HP       2 BRIDG 495.56 * * 910
HP       1 APPR1 498.07 1 498.07
HP       2 APPR1 498.07 * * 1160
*
T1        U.S. Geological Survey WSPRO Input File worc028.2.wsp
T2        Hydraulic analysis for structure WORCTH00200028 Date: 17-JUL-97
T3        Town Highway 20 over Minister Brook, Worcester, VT

J1         * * 0.005
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
Q          1760.0 1540.0
W          491.15  490.92

XT  EXTEM  -23
GR         -111.4, 502.13   -76.8, 494.83   -35.5, 494.85   -8.5, 494.54
GR          -2.4, 492.36    0.0, 491.16    3.6, 491.17    8.8, 490.90
GR          14.0, 491.32   20.6, 491.15   25.6, 491.23   27.7, 492.18
GR          32.8, 494.39   33.0, 502.13
*          70.8, 488.67   73.1, 488.08   76.5, 488.50   88.3, 489.58
*          97.0, 494.39   106.6, 498.36   122.7, 498.25

XS  EXIT1  -67 * * *  0.0385
GT          N         0.067        0.070       0.075       0.070
SA          -8.5        32.8        59.4

XS  EXITX  -23 * * *  0.0385
GT          *

XS  FULLV  0 * * *   0.0276

BR  BRIDG  0  498.68  1 498.70
GR          0.0, 498.67   0.0, 492.76   1.2, 492.75
GR          1.4, 491.97   3.2, 491.68   7.0, 491.51   12.8, 491.52
GR          15.4, 491.54  20.3, 492.45  21.5, 493.02  21.6, 493.26
GR          22.8, 493.31  22.8, 498.70   0.0, 498.67

BR  BRIDGE 498.68 498.70
BR  BRIDGE 496.17 496.17
BR  RDWAY 500.56 500.56
BR  APPR1 500.58 500.58

BR  BRIDGE 498.70 498.70
BR  BRIDGE 498.70 498.70
BR  BRIDGE 495.93 495.93
BR  APPR1 500.12 500.12
BR  APPR1 500.12 500.12

EX
APPENDIX B:

WSPRO OUTPUT FILE
**CROSS-SECTION PROPERTIES:**  ISEQ = 4;  SECID = BRIDG;  SRD = 0.

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<th>SA#</th>
<th>AREA</th>
<th>K</th>
<th>TOPW</th>
<th>WETP</th>
<th>ALPH</th>
<th>LEW</th>
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**VELOCITY DISTRIBUTION:**  ISEQ = 4;  SECID = BRIDG;  SRD = 0.

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<td>V(I)</td>
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**CROSS-SECTION PROPERTIES:**  ISEQ = 6;  SECID = APPR1;  SRD = 40.

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<td>A(I)</td>
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<td>V(I)</td>
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WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File worc028.2.wsp
Hydraulic analysis for structure WORCTH00200028 Date: 17-JUL-97
Town Highway 20 over Minister Brook, Worcester, VT

CROSS-SECTION PROPERTIES:  ISEQ = 4;  SECID = BRIDG;  SRD = 0.

WSEL  SA#  AREA     K TOPW  WETP  ALPH  LEW REW  QCR
1     155.  10334.  0.  58.  0.00   498.70

VELOCITY DISTRIBUTION:  ISEQ = 4;  SECID = BRIDG;  SRD = 0.

WSEL  LEW  REN  AREA  K Q VEL
498.70  23.   0.70

X STA.  A(I)  V(I)
0.0     18.4  3.62
2.9     6.5  10.17
3.8     6.5  10.32
4.7     6.6  10.14
5.6     6.6  10.14

CROSS-SECTION PROPERTIES:  ISEQ = 5;  SECID = RDWAY;  SRD = 10.

WSEL  SA#  AREA     K TOPW  WETP  ALPH  LEW REW  QCR
1     500.56  32.2  346.  76.  2.36

VELOCITY DISTRIBUTION:  ISEQ = 5;  SECID = RDWAY;  SRD = 10.

WSEL  LEW  REN  AREA  K Q VEL
500.56  118.6  518.8

X STA.  A(I)  V(I)
-31.3    48.7  1.81
-9.8     19.8  4.44
-4.0     18.4  4.78
26.8     18.7  4.70
29.5     18.3  4.80
32.2

CROSS-SECTION PROPERTIES:  ISEQ = 6;  SECID = APPR1;  SRD = 40.

WSEL  SA#  AREA     K TOPW  WETP  ALPH  LEW REW  QCR
1     500.58  312.  33225.  1760.  3.39

VELOCITY DISTRIBUTION:  ISEQ = 6;  SECID = APPR1;  SRD = 40.

WSEL  LEW  REN  AREA  K Q VEL
500.58  118.6  518.8

X STA.  A(I)  V(I)
-32.6    48.7  1.81
-0.2     19.8  4.44
-2.7     18.4  4.78
4.9      18.7  4.70
7.1      18.3  4.80
9.2

CROSS-SECTION PROPERTIES:  ISEQ = 6;  SECID = APPR1;  SRD = 40.
CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
1      155.   10334.     0.    58.                          0.
498.70           155.   10334.     0.    58.  1.00     0.    23.      0.

VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

WSEL     LEW     REW    AREA        K        Q    VEL
498.70     0.0    22.8   154.8   10334.    1210.   7.82

X STA.         0.0        2.9        3.8        4.7        5.6        6.6
A(I)             18.4        6.5        6.6        6.6        6.6
V(I)            3.29        9.24        9.38        9.22        9.21

X STA.           6.6        7.5        8.4        9.3        10.2        11.1
A(I)             6.4        6.6        6.6        6.6        6.6

X STA.          11.1       12.1       13.0       13.9       14.8       15.7
A(I)             6.6        6.6        6.5        6.6        6.5
V(I)            9.12        9.12        9.34        9.20        9.27

X STA.          15.7       16.7       17.6       18.7       19.7       22.8
A(I)             6.7        6.6        6.8        6.9        17.7
V(I)            9.07        9.18        8.84        9.23        9.23

CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = APPR1;  SRD =      40.

WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
1       5.      45.    18.    18.                         14.
2     393.   25415.    86.    94.                       4776.
3      53.    2166.    36.    36.                        365.
500.12          451.   27626.   140.   148.  1.06   -30.   113.   4462.

VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPR1;  SRD =      40.

WSEL     LEW     REW    AREA        K        Q    VEL
500.12   -29.6    112.9   451.3  27626.    1540.   3.41

X STA.          29.6       0.7       2.9       5.0       7.0       9.0
A(I)            37.8       16.7       16.6       16.2       16.1
V(I)            2.04       4.61       4.64       4.76       4.79

X STA.           9.0       10.9       13.0       15.3       18.1       22.6
A(I)            16.3       16.8       17.4       19.1       19.7
V(I)            4.71       4.58       4.43       4.03       3.91

X STA.          22.6      56.6       60.6       63.0       65.1       67.2
A(I)            69.1      21.3       17.7       16.7       16.8
V(I)            1.11       3.61       4.34       4.60       4.58

X STA.          67.2      69.2       71.2       73.9       81.2      112.9
A(I)            16.5      15.8       19.1       24.6       40.7
V(I)            4.66      4.86       4.03       3.13       1.89
WS PRO OUTPUT FILE (continued)

--- 015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1": USED WSI = CRWS.

--- 125 FR# EXCEEDS FNTEST AT SECID "EXIT1": TRIALS CONTINUED.

--- 110 WSEL NOT FOUND AT SECID "EXIT1": REDUCED DELTAY.

--- 115 WSEL NOT FOUND AT SECID "EXIT1": USED WSMIN = CRWS.

--- 125 FR# EXCEEDS FNTEST AT SECID "FULLV": TRIALS CONTINUED.

--- 110 WSEL NOT FOUND AT SECID "FULLV": REDUCED DELTAY.

--- 115 WSEL NOT FOUND AT SECID "FULLV": USED WSMIN = CRWS.

--- 285 CRITICAL WATER-SURFACE ELEVATION A _ S _ U _ M _ E _ D !!!!!

--- 285 CRITICAL WATER-SURFACE ELEVATION A _ S _ U _ M _ E _ D !!!!!

--- RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

--- FIRST USER DEFINED TABLE.
---015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1": USED WSI = CRWS.
WSI,CRWS = 491.15 493.84

XSID:CODE  SRDL  LEW  AREA  VHD  HF  EQL  CRWS  Q  WSEL  SRD  FLEN  REW  K  ALPH  HO  ERR  FR#  VEL
EXIT1:X... -80.  0.94  494.78  493.84  493.84  493.84
-67.  1.29  1.01  6.83

---125 FR# EXCEEDS FNTTEST AT SECID "EXITX": TRIALS CONTINUED.
FNTTEST,FR#,WSEL,CRWS = 0.80 1.42 495.13 495.54

---110 WSEL NOT FOUND AT SECID "EXITX": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY = 493.34 502.13 0.50

---115 WSEL NOT FOUND AT SECID "EXITX": USED WSMIN = CRWS.
WSLIM1,WSLIM2,CRWS = 493.34 502.13 495.54

---130 CRITICAL WATER-SURFACE ELEVATION A S S U M E D !!!!! ENERG... WSBEG,WSEND,CRWS = 495.54 502.13 495.54

EXITX:X... -80.  0.94  494.78  493.84  493.84  493.84

---125 FR# EXCEEDS FNTTEST AT SECID "FULLV": TRIALS CONTINUED.
FNTTEST,FR#,WSEL,CRWS = 0.80 1.03 496.15 496.17

---110 WSEL NOT FOUND AT SECID "FULLV": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY = 495.04 502.76 0.50

---115 WSEL NOT FOUND AT SECID "FULLV": USED WSMIN = CRWS.
WSLIM1,WSLIM2,CRWS = 495.04 502.76 496.17

---130 CRITICAL WATER-SURFACE ELEVATION A S S U M E D !!!!! ENERG... WSBEG,WSEND,CRWS = 496.17 502.76 496.17

FULLV:FV... -80.  0.94  497.11  496.17  496.17  496.17

<<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

---220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
WS3,WS11,WS1,WS1 = 496.82 499.75 499.94 498.68

---245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

<<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

---FIRST USER DEFINED TABLE.
XSID:CODE  CRWS  FR#  YMIN  YMAX  HF  HO  VHD  EQL  WSEL
EXIT1:X... 493.84  1.01  498.23  500.44  0.94  494.78  493.84
EXITX:X... 495.54  1.01  490.90  502.13  0.94  496.47  495.54
FULLV:FV  496.17  1.01  491.53  502.76  0.94  497.11  496.17
BRIDG:BR  496.63  0.58  491.51  498.70  1.15  499.85  498.70
RDWAY:RG  500.07  509.69  0.04  500.56

---SECOND USER DEFINED TABLE.
WSPRO OUTPUT FILE (continued)

---015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1": USED WSI = CRWS.

---125 PR# EXCEEDS FNTEST AT SECID "EXITX": TRIALS CONTINUED.

---110 WSEL NOT FOUND AT SECID "EXITX": REDUCED DELTAY.

---115 WSEL NOT FOUND AT SECID "EXITX": USED WSMIN = CRWS.

---130 CRITICAL WATER-SURFACE ELEVATION A_S_S_U_M_E_D !!!!!

ENERGY EQUATION N_O_T B_A_L_A_N_C_E_D AT SECID "EXITX"

---220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.

---245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

FIRST USER DEFINED TABLE.

SECOND USER DEFINED TABLE.
APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION
Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure WORCTH00200028, in Worcester, Vermont.
APPENDIX D:
HISTORICAL DATA FORM
According to the structural inspection report dated 7/14/95, the structure has a wooden deck with wood post guard rails and the superstructure consists of 5 I-beam stringers. Minor cracks are noted on the abutments and wingwalls. No footings are exposed and no undermining is noted. Channel scour is described as normal. The boulder-lined embankments show signs of past flooding. A bar consisting of mainly boulders is noted at the right abutment and debris is minor. Stone fill is noted as good around the abutments. Hydraulic adequacy is described as possibly narrow. The abutments are laid-up river boulders with concrete caps. The inspection report dated 10/18/93 states that the (continued on page 34)
Bridge Hydrologic Data

Is there hydrologic data available? **Y** if No, type ctrl-n h  
VTAOT Drainage area (mi²): **4.96**

Terrain character: **Hilly to mountainous, mostly forested**

Stream character & type: -

Streambed material: -

Discharge Data (cfs):

<table>
<thead>
<tr>
<th>Qn</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.33</td>
<td>400</td>
</tr>
<tr>
<td>10</td>
<td>800</td>
</tr>
<tr>
<td>25</td>
<td>1080</td>
</tr>
<tr>
<td>50</td>
<td>1280</td>
</tr>
<tr>
<td>100</td>
<td>1480</td>
</tr>
<tr>
<td>500</td>
<td>-</td>
</tr>
</tbody>
</table>

Record flood date (MM/DD/YY): - / - / -  
Water surface elevation (ft): -

Estimated Discharge (cfs): -  
Velocity at Q = (ft/s): -

Ice conditions (Heavy, Moderate, Light): -  
Debris (Heavy, Moderate, Light): -

The stage increases to maximum highwater elevation (Rapidly, Not rapidly): -

The stream response is (Flashy, Not flashy): -

Describe any significant site conditions upstream or downstream that may influence the stream’s stage: This hydraulic report is for the combined flow through structures 24 and 28, from a 1979 report. Bridge 24 is an overflow for bridge 28. Until 1979, bridge 24 was a 16.5 by 8 ft bridge. It was washed out in a flood. Currently, it is a 4 ft corrugated, galvanized metal pipe. Bridge 28 is on the main channel and bridge 24 is on an overflow/side channel.

Watershed storage area (in percent): -%

The watershed storage area is: -  
1-mainly at the headwaters; 2-uniformly distributed; 3-immediately upstream of the site

Water Surface Elevation Estimates for Existing Structure:

<table>
<thead>
<tr>
<th>Peak discharge frequency</th>
<th>Q2.33</th>
<th>Q10</th>
<th>Q25</th>
<th>Q50</th>
<th>Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water surface elevation (ft)</td>
<td>-</td>
<td>485.7</td>
<td>486.4</td>
<td>486.8</td>
<td>487.1</td>
</tr>
<tr>
<td>Velocity (ft/sec)</td>
<td>487.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Long term stream bed changes: -

Is the roadway overtopped below the Q100? (Yes, No, Unknown): **U**  
Frequency: -

Relief Elevation (ft): -  
Discharge over roadway at Q100 (ft³/sec): -

Are there other structures nearby? (Yes, No, Unknown): **U**  
If No or Unknown, type ctrl-n os

Upstream distance (miles): -  
Town: -  
Year Built: -

Highway No.: -  
Structure No.: -  
Structure Type: -

Clear span (ft): -  
Clear Height (ft): -  
Full Waterway (ft²): -
Downstream distance (miles): _______ Town: ___________ Year Built: 1960
Highway No.: TH 21 Structure No.: 26 Structure Type: steel beam
Clear span (ft): 19 Clear Height (ft): 7 Full Waterway (ft²): 133

Comments:
left abutment, in general, appears to be quite unstable.

Water surface elevations above are design elevations for a proposed 15 x 6 foot bridge to replace existing bridge 24.
Notes in hydraulics folder indicate a WSPRO analysis was done on this bridge in 1979.

---

USGS Watershed Data

Watershed Hydrographic Data

<table>
<thead>
<tr>
<th>Drainage area (DA)</th>
<th>4.68 mi²</th>
<th>Lake/pond/swamp area</th>
<th>0 mi²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed storage (ST)</td>
<td>0 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridge site elevation</td>
<td>1180 ft</td>
<td>Headwater elevation</td>
<td>3642 ft</td>
</tr>
<tr>
<td>Main channel length</td>
<td>3.53 mi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% channel length elevation</td>
<td>1300 ft</td>
<td>85% channel length elevation</td>
<td>2640 ft</td>
</tr>
<tr>
<td>Main channel slope (S)</td>
<td>506.13 ft / mi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Watershed Precipitation Data

Average site precipitation __________ in Average headwater precipitation __________ in
Maximum 2yr-24hr precipitation event (I24,2) __________ in
Average seasonal snowfall (Sn) __________ ft
Reference Point (MSL, Arbitrary, Other): ___________ Datum (NAD27, NAD83, Other): ___________

Foundation Type: 4 (1-Spreadfooting; 2-Pile; 3- Gravity; 4-Unknown)

If 1: Footing Thickness _______ Footing bottom elevation: _______
If 2: Pile Type: _____ (1-Wood; 2-Steel or metal; 3-Concrete) Approximate pile driven length: _______
If 3: Footing bottom elevation: _______

Is boring information available? N If no, type ctrl-n bi Number of borings taken: _______

Foundation Material Type: 3 (1-regolith, 2-bedrock, 3-unknown)

Briefly describe material at foundation bottom elevation or around piles:
No foundation material information was available.

Comments:
No plans.
Cross-sectional Data

Is cross-sectional data available? **Y**

Source *(FEMA, VTAOT, Other)*? **VTAOT**

Comments: This cross section is the upstream face. The low chord elevations are from the survey log done for this report on 7/17/96. The low chord to bed length data are from the sketch attached to a bridge inspection report dated 10/18/93.

<table>
<thead>
<tr>
<th>Station</th>
<th>Low chord elevation</th>
<th>Bed elevation</th>
<th>Low chord to bed</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>498.7</td>
<td>492.8</td>
<td>5.9</td>
</tr>
<tr>
<td>3</td>
<td>498.7</td>
<td>491.9</td>
<td>6.8</td>
</tr>
<tr>
<td>8</td>
<td>498.7</td>
<td>492.9</td>
<td>5.8</td>
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<tr>
<td>13</td>
<td>498.8</td>
<td>493.7</td>
<td>4.0</td>
</tr>
<tr>
<td>24</td>
<td>498.8</td>
<td>494.8</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station</th>
<th>Feature</th>
<th>Low chord elevation</th>
<th>Bed elevation</th>
<th>Low chord to bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station</th>
<th>Feature</th>
<th>Low chord elevation</th>
<th>Bed elevation</th>
<th>Low chord to bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source *(FEMA, VTAOT, Other)*? 

Comments:
APPENDIX E:

LEVEL I DATA FORM
A. General Location Descriptive

1. Data collected by (First Initial, Full last name) **R. FLYNN** Date (MM/DD/YY) 07 / 17 / 1996
2. Highway District Number **06**
   County **WASHINGTON** (023)
   Waterway (I - 6) **Minister Brook**
   Route Number **TH 20**
3. Descriptive comments:
   This bridge is located 0.1 mile from the junction with TH 3.

B. Bridge Deck Observations

4. Surface cover... LBUS **6** RBUS **4** LBDS **6** RBDS **6** Overall **6**
   (2b us,ds,lb,rb: 1- Urban; 2- Suburban; 3- Row crops; 4- Pasture; 5- Shrub- and brushland; 6- Forest; 7- Wetland)
5. Ambient water surface...US **2** UB **2** DS **2** (1- pool; 2- riffle)
6. Bridge structure type **1** ( 1- single span; 2- multiple span; 3- single arch; 4- multiple arch; 5- cylindrical culvert; 6- box culvert; or 7- other)
7. Bridge length **30** (feet) Span length **27** (feet) Bridge width **15.9** (feet)

Road approach to bridge:
8. LB **2** RB **2** ( 0 even, 1- lower, 2- higher)
9. LB **2** RB **2** ( 1- Paved, 2- Not paved)
10. Embankment slope (run / rise in feet / foot):
    US left -- US right --

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LBUS</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>RBUS</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>RBDS</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>LBDS</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Bank protection types: 0- none; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Erosion: 0 - none; 1- channel erosion; 2- road wash; 3- both; 4- other
Erosion Severity: 0 - none; 1- slight; 2- moderate; 3- severe

Channel approach to bridge (BF):
15. Angle of approach: **40**
16. Bridge skew: **20**

17. Channel impact zone 1:
   Where? **LB** (LB, RB) Severity **1**
   Range? **5** feet US (US, UB, DS) to **30** feet US
   Exist? **Y** (Y or N)

18. Channel impact zone 2:
   Where? **LB** (LB, RB) Severity **0**
   Range? **5** feet DS (US, UB, DS) to **30** feet DS
   Exist? **Y** (Y or N)

Impact Severity: 0- none to very slight; 1- Slight; 2- Moderate; 3- Severe
This is a new bridge. According to the right bank landowner, it was constructed in 1994. The deck is 2 by 8 inch wood beams, which have been placed with the 2 inch side facing up and down and the length in the direction of flow. The bridge has 4 by 4 inch wooden curbs and guardrails both US and DS. Wingwalls have an angle less than 90 degrees, but the ends of the wingwalls do not go below low chord. A 6 ft culvert is located on the right bank about 46 ft from the right abutment. The stream is divided between these two structures with most of the flow going through the bridge. There is no scour along the channel with the culvert.

4. There is a strip of trees along the immediate bank then a horse pasture and barn on the upstream right bank.

5. The water is pooled at the US bridge face and is riffled upstream from the upstream face.

7. The bridge dimensions provided on the previous page are from the VTAOT files. The bridge length, span length, and bridge width measured were 27.2, 23.2, and 16.1 ft respectively.
33. Point/Side bar present? N (Y or N, if N type ctrl-n pb) 34. Mid-bar distance: __________ 35. Mid-bar width: __________
36. Point bar extent: _____ feet _____ (US, UB) to _____ feet _____ (US, UB, DS) positioned _____ %LB to _____ %RB
37. Material: __________
38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):
NO POINT BARS

39. Is a cut-bank present? N (Y or if N type ctrl-n cb) 40. Where? _____ (LB or RB)
41. Mid-bank distance: __________ 42. Cut bank extent: _____ feet _____ (US, UB) to _____ feet _____ (US, UB, DS)
43. Bank damage: _____ (1- eroded and/or creep; 2- slip failure; 3- block failure)
44. Cut bank comments (eg. additional cut banks, protection condition, etc.):
NO CUT BANKS

45. Is channel scour present? Y (Y or if N type ctrl-n cs) 46. Mid-scour distance: 18
47. Scour dimensions: Length 35 Width 5 Depth : 1 Position 0 %LB to 50 %RB
48. Scour comments (eg. additional scour areas, local scouring process, etc.):
Scour is from the US bridge face to 35 ft US.

49. Are there major confluences? N (Y or if N type ctrl-n mc) 50. How many? __________
51. Confluence 1: Distance _____ 52. Enters on _____ (LB or RB) 53. Type _____ (1- perennial; 2- ephemeral)
Confluence 2: Distance _____ Enters on _____ (LB or RB) Type _____ (1- perennial; 2- ephemeral)
54. Confluence comments (eg. confluence name):
NO MAJOR CONFLUENCES

D. Under Bridge Channel Assessment
55. Channel restraint (BF)? LB 2 _____ (1- natural bank; 2- abutment; 3- artificial levee)
56. Height (BF) 57 Angle (BF) 61. Material (BF) 62. Erosion (BF)
LB RB LB RB LB RB
17.5 2.0 2 7 7 -
58. Bank width (BF) - 59. Channel width - 60. Thalweg depth 90.0 63. Bed Material -

Bed and bank Material: 0- organics; 1- silt / clay, < 1/16mm; 2- sand, 1/16 - 2mm; 3- gravel, 2 - 64mm; 4- cobble, 64 - 256mm;
5- boulder, > 256mm; 6- bedrock; 7- manmade

Bank Erosion: 0- not evident; 1- light fluvial; 2- moderate fluvial; 3- heavy fluvial / mass wasting

64. Comments (bank material variation, minor inflows, protection extent, etc.):
4532
63. The bed material under the bridge is primarily cobbles and gravel at the US end of the right abutment and cobbles and boulders in mid-channel and along the left abutment.
65. **Debris and Ice**  Is there debris accumulation? ____ (Y or N)  
66. Where? Y ____ (1- Upstream; 2- At bridge; 3- Both)

67. **Debris Potential** 3 ____ (1- Low; 2- Moderate; 3- High)

68. **Capture Efficiency** 3 ____ (1- Low; 2- Moderate; 3- High)

69. Is there evidence of ice build-up? 3 ____ (Y or N)

70. **Debris and Ice Comments:**

1

67. There are trees and brush on the US banks and at the left abutment.
68. Large rocks and steep slopes US make the capture efficiency high.

<table>
<thead>
<tr>
<th>Abutments</th>
<th>71. Attack (BF)</th>
<th>72. Slope &lt;br&gt;Q&lt;sup&gt;max&lt;/sup&gt;</th>
<th>73. Toe loc. (BF)</th>
<th>74. Scour Condition &lt;br&gt;Location</th>
<th>75. Scour Depth &lt;br&gt;Material</th>
<th>76. Exposure depth &lt;br&gt;Length</th>
<th>77. Material</th>
<th>78. Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>LABUT</td>
<td>40</td>
<td>90</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
<td>90.0</td>
<td></td>
</tr>
<tr>
<td>RABUT</td>
<td>1</td>
<td>0</td>
<td>90</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>23.0</td>
<td></td>
</tr>
</tbody>
</table>

**Pushed:** LB or RB  
**Toe Location (Loc.):** 0- even; 1- set back; 2- protrudes

**Scour cond.:** 0- not evident; 1- evident (comment); 2- footing exposed; 3- undermined footing; 4- piling exposed; 5- settled; 6- failed

**Materials:** 1- Concrete; 2- Stone masonry or drywall; 3- steel or metal; 4- wood

79. Abutment comments (eg. undermined penetration, unusual scour processes, debris, etc.):

0  
0.5

1

Protection along both abutment footings is in good condition. Scour is evident at the DS end of the left abutment. The left abutment footing is exposed 1 ft at the DS end and 0.5 ft at the US end. The right abutment footing is exposed 0.5 ft at the DS end.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>USLWW:</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>23.0</td>
<td>____</td>
</tr>
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<td>USRWW:</td>
<td>Y</td>
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<td>____</td>
<td>____</td>
<td>0</td>
<td>1.5</td>
<td>____</td>
</tr>
<tr>
<td>DSLWW:</td>
<td>-</td>
<td>-</td>
<td>____</td>
<td>____</td>
<td>Y</td>
<td>19.5</td>
<td>____</td>
</tr>
<tr>
<td>DSRWW:</td>
<td>1</td>
<td>0</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>19.5</td>
<td>____</td>
</tr>
</tbody>
</table>

**Wingwall materials:** 1- Concrete; 2- Stone masonry or drywall; 3- steel or metal; 4- wood

**81. Wingwall Location:**

82. **Bank / Bridge Protection:**

<table>
<thead>
<tr>
<th>Location</th>
<th>USLWW</th>
<th>USRWW</th>
<th>LABUT</th>
<th>RABUT</th>
<th>LB</th>
<th>RB</th>
<th>DSLWW</th>
<th>DSRWW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>-</td>
<td>2</td>
<td>Y</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Condition</td>
<td>Y</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Extent</td>
<td>1</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

**Bank / Bridge protection types:** 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee

**Bank / Bridge protection conditions:** 1- good; 2- slumped; 3- eroded; 4- failed

**Protection extent:** 1- entire base length; 2- US end; 3- DS end; 4- other
83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):
- - - - - - - - - -
2 1 1 1 1 1

Piers:
84. Are there piers? 82. (Y or if N type ctrl-n pr)

<table>
<thead>
<tr>
<th>Pier no.</th>
<th>width (w) feet</th>
<th>elevation (e) feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w1</td>
<td>w2</td>
</tr>
<tr>
<td>Pier 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Level 1 Pier Descr. 1 2 3 4
86. Location (BF) The e it . -
87. Type DS meet -
88. Material left s the -
89. Shape wing dow -
90. Inclined? wall nstre -
91. Attack \(\angle\) (BF) foot- am -
92. Pushed ing is end -
93. Length (feet) - - - -
94. # of piles expo of -
95. Cross-members sed the -
96. Scour Condition most left -
97. Scour depth ly abut -
98. Exposure depth wher ment N -
E. Downstream Channel Assessment

<table>
<thead>
<tr>
<th>SRD</th>
<th>Bank height (BF)</th>
<th>Bank angle (BF)</th>
<th>% Veg. cover (BF)</th>
<th>Bank material (BF)</th>
<th>Bank erosion (BF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LB RB</td>
<td>LB RB</td>
<td>LB RB</td>
<td>LB RB</td>
<td>LB RB</td>
</tr>
</tbody>
</table>

Bank width (BF) - Channel width - Thalweg depth - Bed Material -

<table>
<thead>
<tr>
<th>Bank protection type (Qmax):</th>
<th>LB</th>
<th>RB</th>
<th>Bank protection condition:</th>
<th>LB</th>
<th>RB</th>
</tr>
</thead>
</table>

SRD - Section ref. dist. to US face % Vegetation (Veg) cover: 1-0 to 25%; 2-26 to 50%; 3-51 to 75%; 4-76 to 100%

Bed and bank Material: 0-organics; 1-silt/clay, < 1/16mm; 2-sand, 1/16 - 2mm; 3-gravel, 2 - 64mm; 4-cobble, 64 - 256mm; 5-boulder, > 256mm; 6-bedrock; 7-manmade

Bank Erosion: 0-not evident; 1-light fluvial; 2-moderate fluvial; 3-heavy fluvial/mass wasting

Bank protection types: 0-absent; 1-< 12 inches; 2-< 36 inches; 3-< 48 inches; 4-< 60 inches; 5-wall/artificial levee

Bank protection conditions: 1-good; 2-slumped; 3-eroded; 4-failed

Comments (eg. bank material variation, minor inflows, protection extent, etc.):

101. Is a drop structure present?  N  (Y or N, if N type ctrl-n ds)  102. Distance: ______ feet

103. Drop: ______ feet  104. Structure material:  O  (1-steel sheet pile; 2-wood pile; 3-concrete; 4-other)

105. Drop structure comments (eg. downstream scour depth):

PIERS
106. **Point/Side bar present?**  (Y or N, if N type ctrl-n pb) Mid-bar distance: _____ Mid-bar width: _____
Point bar extent: _____ feet (US, UB, DS) to _____ feet (US, UB, DS) positioned %LB to %RB
Material: 2
Point or side bar comments (Circle Point or Side; note additional bars, material variation, status, etc.):

107. **Stage of reach evolution**
   1- Constructed
   2- Stable
   3- Aggraded
   4- Degraded
   5- Laterally unstable
   6- Vertically and laterally unstable

---

The there is a large amount of debris on the left and right banks. The protection along the banks extends to 100 ft DS.
108. Evolution comments (Channel evolution not considering bridge effects; See HEC-20, Figure 1 for geomorphic descriptors):

NO POINT BARS
APPENDIX F:

SCOUR COMPUTATIONS
### SCOUR COMPUTATIONS

Structure Number: WORCTH00200028  
Town: Worcester

Road Number: TH 20  
County: Washington

Stream: Minister Brook

Initials EMB  
Date: 7/2/98  
Checked: RLB

#### Analysis of contraction scour, live-bed or clear water?

Critical Velocity of Bed Material (converted to English units)

\[
V_c = 11.21 \cdot y^1.0167 \cdot D_{50}^{0.333} \text{ with } S_s = 2.65
\]

(Richardson and Davis, 1995, p. 28, eq. 16)

#### Approach Section

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>100 yr</th>
<th>500 yr</th>
<th>other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total discharge, cfs</td>
<td>1160</td>
<td>1760</td>
<td>1540</td>
</tr>
<tr>
<td>Main Channel Area, ft&lt;sup&gt;2&lt;/sup&gt;</td>
<td>227</td>
<td>433</td>
<td>393</td>
</tr>
<tr>
<td>Left overbank area, ft&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Right overbank area, ft&lt;sup&gt;2&lt;/sup&gt;</td>
<td>5</td>
<td>71</td>
<td>53</td>
</tr>
<tr>
<td>Top width main channel, ft</td>
<td>62</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>Top width L overbank, ft</td>
<td>0</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td>Top width R overbank, ft</td>
<td>11</td>
<td>42</td>
<td>36</td>
</tr>
<tr>
<td>D&lt;sub&gt;50&lt;/sub&gt; of channel, ft</td>
<td>0.337</td>
<td>0.337</td>
<td>0.337</td>
</tr>
<tr>
<td>D&lt;sub&gt;50&lt;/sub&gt; left overbank, ft</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>D&lt;sub&gt;50&lt;/sub&gt; right overbank, ft</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>y&lt;sub&gt;1&lt;/sub&gt;, average depth, MC, ft</td>
<td>3.7</td>
<td>5.0</td>
<td>4.6</td>
</tr>
<tr>
<td>y&lt;sub&gt;1&lt;/sub&gt;, average depth, LOB, ft</td>
<td>ERR</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>y&lt;sub&gt;1&lt;/sub&gt;, average depth, ROB, ft</td>
<td>0.5</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Total conveyance, approach</td>
<td>12536</td>
<td>33225</td>
<td>27626</td>
</tr>
<tr>
<td>Conveyance, main channel</td>
<td>12449</td>
<td>29786</td>
<td>25415</td>
</tr>
<tr>
<td>Conveyance, LOB</td>
<td>0</td>
<td>244</td>
<td>45</td>
</tr>
<tr>
<td>Conveyance, ROB</td>
<td>88</td>
<td>3195</td>
<td>2166</td>
</tr>
<tr>
<td>Percent discrepancy, conveyance</td>
<td>-0.0080</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Q&lt;sub&gt;m&lt;/sub&gt;, discharge, MC, cfs</td>
<td>1151.9</td>
<td>1577.8</td>
<td>1416.7</td>
</tr>
<tr>
<td>Q&lt;sub&gt;L&lt;/sub&gt;, discharge, LOB, cfs</td>
<td>0.0</td>
<td>12.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Q&lt;sub&gt;r&lt;/sub&gt;, discharge, ROB, cfs</td>
<td>8.1</td>
<td>169.2</td>
<td>120.7</td>
</tr>
<tr>
<td>V&lt;sub&gt;m&lt;/sub&gt;, mean velocity MC, ft/s</td>
<td>5.1</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>V&lt;sub&gt;L&lt;/sub&gt;, mean velocity, LOB, ft/s</td>
<td>ERR</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>V&lt;sub&gt;r&lt;/sub&gt;, mean velocity, ROB, ft/s</td>
<td>1.6</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>V&lt;sub&gt;c&lt;/sub&gt;-&lt;sub&gt;m&lt;/sub&gt;, crit. velocity, MC, ft/s</td>
<td>9.7</td>
<td>10.2</td>
<td>10.0</td>
</tr>
<tr>
<td>V&lt;sub&gt;c&lt;/sub&gt;-&lt;sub&gt;L&lt;/sub&gt;, crit. velocity, LOB, ft/s</td>
<td>ERR</td>
<td>ERR</td>
<td>ERR</td>
</tr>
<tr>
<td>V&lt;sub&gt;c&lt;/sub&gt;-&lt;sub&gt;r&lt;/sub&gt;, crit. velocity, ROB, ft/s</td>
<td>ERR</td>
<td>ERR</td>
<td>ERR</td>
</tr>
</tbody>
</table>

#### Results

| Live-bed(1) or Clear-Water(0) Contraction Scour? | 0 | 0 | 0 |

**Armoring**

\[
D_c = \left[\frac{(1.94 \cdot V^2)}{(5.75 \cdot \log(12.27 \cdot y/D_{90}))^2}\right] \cdot \left[0.03 \cdot (165 - 62.4)\right]
\]

Depth to Armoring=3*(1/Pc-1)

(Federal Highway Administration, 1993)

Downstream bridge face property

<table>
<thead>
<tr>
<th>100-yr</th>
<th>500-yr</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q, discharge thru bridge MC, cfs</td>
<td>910</td>
<td>1331</td>
</tr>
<tr>
<td>Main channel area (DS), ft&lt;sup&gt;2&lt;/sup&gt;</td>
<td>83.6</td>
<td>97</td>
</tr>
<tr>
<td>Main channel width (normal), ft</td>
<td>22.8</td>
<td>22.8</td>
</tr>
<tr>
<td>Cum. width of piers, ft</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Adj. main channel width, ft</td>
<td>22.8</td>
<td>22.8</td>
</tr>
<tr>
<td>D&lt;sub&gt;90&lt;/sub&gt;, ft</td>
<td>1.3302</td>
<td>1.3302</td>
</tr>
<tr>
<td>D&lt;sub&gt;95&lt;/sub&gt;, ft</td>
<td>1.6687</td>
<td>1.6687</td>
</tr>
<tr>
<td>Dc, critical grain size, ft</td>
<td>0.9659</td>
<td>1.4131</td>
</tr>
<tr>
<td>Pc, Decimal percent coarser than Dc</td>
<td>0.189</td>
<td>0.087</td>
</tr>
</tbody>
</table>

Depth to armoring, ft | 12.43  | 44.49   | 36.49   |
Clear Water Contraction Scour in MAIN CHANNEL

\[ y_2 = \left( \frac{Q_2^2}{(131 \times D_m^{2/3} \times W_2^2)} \right)^{3/7} \]  

Converted to English Units

\[ y_s = y_2 - y_{bridge} \]

(Richardson and Davis, 1995, p. 32, eq. 20, 20a)

<table>
<thead>
<tr>
<th>Bridge Section</th>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q) total discharge, cfs</td>
<td>1160</td>
<td>1760</td>
<td>1540</td>
</tr>
<tr>
<td>(Q) discharge thru bridge, cfs</td>
<td>910</td>
<td>1331</td>
<td>1210</td>
</tr>
<tr>
<td>Main channel conveyance</td>
<td>5883</td>
<td>10334</td>
<td>10334</td>
</tr>
<tr>
<td>Total conveyance</td>
<td>5883</td>
<td>10334</td>
<td>10334</td>
</tr>
<tr>
<td>Q2, bridge MC discharge, cfs</td>
<td>910</td>
<td>1331</td>
<td>1210</td>
</tr>
<tr>
<td>Main channel area, ft2</td>
<td>84</td>
<td>155</td>
<td>155</td>
</tr>
<tr>
<td>Main channel width (normal), ft</td>
<td>22.8</td>
<td>22.8</td>
<td>22.8</td>
</tr>
<tr>
<td>Cum. width of piers in MC, ft</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>W, adjusted width, ft</td>
<td>22.8</td>
<td>22.8</td>
<td>22.8</td>
</tr>
<tr>
<td>y_{bridge} (avg. depth at br.), ft</td>
<td>3.67</td>
<td>6.79</td>
<td>6.79</td>
</tr>
<tr>
<td>Dm, median (1.25*D50), ft</td>
<td>0.42125</td>
<td>0.42125</td>
<td>0.42125</td>
</tr>
<tr>
<td>y2, depth in contraction, ft</td>
<td>3.73</td>
<td>5.17</td>
<td>4.77</td>
</tr>
</tbody>
</table>

\[ y_s = y_2 - y_{bridge} \]

Pressure Flow Scour (contraction scour for orifice flow conditions)

Chang pressure flow equation

\[ H_b + Y_s = C_q \cdot q_{br}/V_c \]

\[ C_q = \frac{1}{C_f \cdot C_c} \quad C_f = 1.5 \cdot F_r^{0.43} \quad (\leq 1) \]

\[ C_c = \sqrt{0.10 \left[ \frac{H_b}{(y_a - w)} - 0.56 \right] + 0.79} \quad (\leq 1) \]

Umbrell pressure flow equation

\[ \frac{(H_b + Y_s)}{y_a} = 1.1021 \left[ (1 - w/y_a) \cdot \frac{V_a}{V_c} \right]^{0.6031} \]

(Richardson and Davis, 1995, p. 144-146)

<table>
<thead>
<tr>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q, total, cfs</td>
<td>1160</td>
<td>1760</td>
</tr>
<tr>
<td>Q, thru bridge MC, cfs</td>
<td>910</td>
<td>1331</td>
</tr>
<tr>
<td>Vc, critical velocity, ft/s</td>
<td>9.68</td>
<td>10.21</td>
</tr>
<tr>
<td>Va, velocity MC approach, ft/s</td>
<td>5.07</td>
<td>3.64</td>
</tr>
<tr>
<td>Cum. width of piers in MC, ft</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>W, adjusted width, ft</td>
<td>22.8</td>
<td>22.8</td>
</tr>
<tr>
<td>q_{br}, unit discharge, ft2/s</td>
<td>39.9</td>
<td>58.4</td>
</tr>
<tr>
<td>Area of full opening, ft2</td>
<td>83.6</td>
<td>154.8</td>
</tr>
<tr>
<td>Hb, depth of full opening, ft</td>
<td>3.67</td>
<td>6.79</td>
</tr>
<tr>
<td>Fr, Froude number, bridge MC</td>
<td>0</td>
<td>0.58</td>
</tr>
<tr>
<td>Cf, Fr correction factor (\leq 1.0)</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>**Area at downstream face, ft2</td>
<td>N/A</td>
<td>97</td>
</tr>
<tr>
<td>**Hb, depth at downstream face, ft</td>
<td>ERR</td>
<td>4.25</td>
</tr>
<tr>
<td>**Fr, Froude number at DS face</td>
<td>1.17</td>
<td>1.15</td>
</tr>
<tr>
<td>**Cf, for downstream face (\leq 1.0)</td>
<td>N/A</td>
<td>1.00</td>
</tr>
<tr>
<td>Elevation of Low Steel, ft</td>
<td>498.68</td>
<td>498.68</td>
</tr>
<tr>
<td>Elevation of Bed, ft</td>
<td>495.01</td>
<td>491.89</td>
</tr>
<tr>
<td>Elevation of Approach, ft</td>
<td>0</td>
<td>500.58</td>
</tr>
<tr>
<td>Friction loss, approach, ft</td>
<td>0</td>
<td>0.12</td>
</tr>
<tr>
<td>Elevation of WS immediately US, ft</td>
<td>0.00</td>
<td>500.46</td>
</tr>
<tr>
<td>ya, depth immediately US, ft</td>
<td>-495.01</td>
<td>8.57</td>
</tr>
<tr>
<td>Mean elevation of deck, ft</td>
<td>500.7</td>
<td>500.7</td>
</tr>
<tr>
<td>w, depth of overflow, ft (\geq 0)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cc, vert contrac correction (\leq 1.0)</td>
<td>0.94</td>
<td>0.96</td>
</tr>
<tr>
<td>**Cc, for downstream face (\leq 1.0)</td>
<td>ERR</td>
<td>0.79</td>
</tr>
<tr>
<td>Ys, scour w/Chang equation, ft</td>
<td>N/A</td>
<td>-0.72</td>
</tr>
<tr>
<td>Ys, scour w/Umbrell equation, ft</td>
<td>N/A</td>
<td>-1.72</td>
</tr>
</tbody>
</table>

** = for UNSubmerged orifice flow using estimated downstream bridge face properties.

**Ys, scour w/Chang equation, ft | N/A | 2.98 | 2.65 |

** = for UNSubmerged orifice flow, an adjusted scour depth using the Laursen equation results and the estimated downstream bridge face properties can also be computed (ys=y_2-y_{bridge DS})

\[ y_2, \text{ from Laursen's equation, ft} \quad 3.73 \quad 5.17 \quad 4.77 \]
\[ \text{WSEL at downstream face, ft} \quad 496.63 \quad 496.33 \]
\[ \text{Depth at downstream face, ft} \quad N/A \quad 4.25 \quad 4.04 \]
\[ \text{Ys, depth of scour (Laursen), ft} \quad N/A \quad 0.92 \quad 0.73 \]
**Abutment Scour**

Floehlich's Abutment Scour

\[ Y_s/Y_1 = 2.27*K_1*K_2*(a'/Y_1)^0.43*Fr_1^0.61+1 \]

(Richardson and Davis, 1995, p. 48, eq. 28)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Left Abutment</th>
<th>Right Abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Qt), total discharge, cfs</td>
<td>1160</td>
<td>1760</td>
</tr>
<tr>
<td>a', abut. length blocking flow, ft</td>
<td>6.1</td>
<td>32.6</td>
</tr>
<tr>
<td>Ae, area of blocked flow ft2</td>
<td>15.7</td>
<td>42.7</td>
</tr>
<tr>
<td>Qe, discharge blocked abut., cfs</td>
<td>47.8</td>
<td>--</td>
</tr>
<tr>
<td>Ve, (Qe/Ae), ft/s</td>
<td>3.04</td>
<td>1.81</td>
</tr>
<tr>
<td>ya, depth of f/p flow, ft</td>
<td>2.57</td>
<td>1.31</td>
</tr>
<tr>
<td>a'/y1</td>
<td>2.37</td>
<td>24.89</td>
</tr>
<tr>
<td>K1</td>
<td>0.82</td>
<td>0.82</td>
</tr>
<tr>
<td>theta</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Fr, froude number f/p flow</td>
<td>0.334</td>
<td>0.261</td>
</tr>
<tr>
<td>ys, scour depth, ft</td>
<td>6.13</td>
<td>5.59</td>
</tr>
</tbody>
</table>

HIRE equation (a'/ya > 25)

\[ ys = 4*Fr^0.33*y_1*K/0.55 \]

(Richardson and Davis, 1995, p. 49, eq. 29)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fr, Froude Number</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>y, depth of flow in bridge, ft</td>
<td>3.67</td>
<td>4.25</td>
<td>4.04</td>
<td>3.67</td>
<td>4.25</td>
<td>4.04</td>
</tr>
</tbody>
</table>

Abutment riprap Sizing

Isbash Relationship

\[ D_{50} = y*K*Fr^2/(Ss-1) \] and \[ D_{50} = y*K*(Fr^2)^{0.14}/(Ss-1) \]

(Richardson and Davis, 1995, p112, eq. 81, 82)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fr, Froude Number</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>y, depth of flow in bridge, ft</td>
<td>3.67</td>
<td>4.25</td>
<td>4.04</td>
<td>3.67</td>
<td>4.25</td>
<td>4.04</td>
</tr>
</tbody>
</table>

Median Stone Diameter for riprap at:

| Fr <= 0.8 (vertical abut.) | ERR  | ERR  | ERR  | ERR  | ERR  |
|Fr > 0.8 (vertical abut.)  | 1.53  | 1.78  | 1.69  | 1.53  | 1.78  | 1.69  |

50