LEVEL II SCOUR ANALYSIS FOR BRIDGE 1 (CANATH00010001) on TOWN HIGHWAY 1, crossing HALLS STREAM, CANAAN, VERMONT

U.S. Geological Survey
Open-File Report 96-640

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

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By Erick M. Boehmler

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Pembroke, New Hampshire

1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Slope		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Area		
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Velocity and Flow		
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

OTHER ABBREVIATIONS

BF	bank full	LWW	left wingwall
cfs	cubic feet per second	MC	main channel
D_{50}	median diameter of bed material	RAB	right abutment
DS	downstream	RABUT	face of right abutment
elev.	elevation	RB	right bank
f/p	flood plain	ROB	right overbank
ft^2	square feet	RWW	right wingwall
ft/ft	feet per foot	TH	town highway
JCT	junction	UB	under bridge
LAB	left abutment	US	upstream
LABUT	face of left abutment	USGS	United States Geological Survey
LB	left bank	VTAOT	Vermont Agency of Transportation
LOB	left overbank	WSPRO	water-surface profile model

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 1 (CANATH00010001) ON TOWN HIGHWAY 1, CROSSING HALLS STREAM, CANAAN, VERMONT

By **Erick M. Boehmler**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure CANATH00010001 on town highway 1 crossing Halls Stream, Canaan, 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 (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study 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 can be found in Appendix D.

The site is in the White Mountain section of the New England physiographic province of northeastern Vermont in the town of Canaan. The 89.5-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks have tree, shrub and brush, and grass vegetation coverage.

In the study area, Halls Stream has a sinuous channel with a slope of approx-imately 0.0012 ft/ft, an average channel top width of 109 ft and an average channel depth of 4 ft. The predominant channel bed materials are sand and gravel (D_{50} is 5.03 mm or 0.0165 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 27, 1994, indicated that the reach was laterally unstable. The lateral instability was evident due to a wide point-bar and cut-banks with undermining of bank material, slumping, fallen bank vegetation evident in the upstream channel.

The town highway 1 crossing of Halls Stream is a 99-ft-long, two-lane bridge consisting of one 33-foot and two 31-foot concrete T-beam spans (Vermont Agency of Transportation, written communication, August 5, 1994). The bridge is supported by vertical, concrete abutments with spill-through embankments in front of each abutment wall. The channel is skewed approximately 10 degrees to the opening while the opening-skew-to-roadway is zero degrees.

There are two piers in the channel at this site. Field notes and the channel survey at the bridge indicate that the streambed elevation is higher on the downstream right sides of each pier and lower on the downstream left sides. This asymmetrical streambed condition suggests a flow attack angle may influence scour on each pier. Furthermore, field observations suggest that the flow attack angle is higher for the right pier (pier 2) than the left pier (pier 1).

The scour protection measures at the site were type-2 stone fill (less than 36 inches diameter) on both upstream banks and both downstream road embankments. Type-3 stone fill (less than 48 inches diameter) was found on the spill-through slopes of each abutment and both downstream banks. The stone fill protection on the spill-through embankment of the right abutment was noted as slumped with some of the fill material evident in the channel immediately downstream of the bridge. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1995). 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 8.0 to 8.8 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 8.9 to 17.3 ft. The worst-case abutment scour occurred at the 500-year discharge. For the two piers, scour ranged from 11.1 to 15.8. The worst-case pier scour occurred for pier2 at the incipient overtopping discharge. 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 others, 1995, p. 47). 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.

Monadnock Mountain, VT, Lovering Mountain, NH and Pittsburg, NH Quadrangles, 1989, 1:24,000.

NORTH

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 CANATH00010001 ***Stream*** Halls Stream

County Essex ***Road*** TH 1 ***District*** 9

Description of Bridge

Bridge length 99 ***ft*** ***Bridge width*** 23.3 ***ft*** ***Max span length*** 33 ***ft***

Alignment of bridge to road (on curve or straight) Curve

Abutment type Spill-through ***Embankment type*** Sloping

Stone fill on abutment? Yes ***Date of inspection*** 10/27/94

Description of stone fill Type-3 on the spill-through abutment slopes and the downstream banks. Type-2 on the upstream banks and downstream road embankments. Type-1 on pier2.

Abutments and piers are concrete. There are remnant scour holes up to two feet deep noted around both piers.

Brief description of piers/abutments

Y

Is bridge skewed to flood flow according to There ***survey?*** ***Angle*** 10 Y

is a mild channel bend in the upstream reach.

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

	Date of inspection	*Percent of channel blocked horizontally*	*Percent of channel blocked vertically*
Level I	10/27/94	0	0
Level II	10/27/94	0	0

Potential for debris Moderate. There is a lumber yard on the right overbank US and alot of vegetation on the banks of a long-term laterally unstable channel.

Describe any features near or at the bridge that may affect flow (include observation date) Halls stream enters the Connecticut River immediately downstream of this site. 10/27/94.

Description of the Geomorphic Setting

General topography The stream is located in a moderate relief valley setting with a flat to slightly irregular flood plain and moderately sloped valley walls.

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

Date of inspection 10/27/94

DS left: Steep road embankment to the TH 1 road surface.

DS right: Steep channel bank to a gradually sloped overbank.

US left: Moderately sloped channel bank to irregular flood plain.

US right: Steep channel bank to a narrow overbank.

Description of the Channel

Average top width 109 *ft* ***Average depth*** 4 *ft*

Predominant bed material Sand / Gravel ***Bank material*** Silt / Clay

Perennial and sinuous with alluvial channel boundaries.

10/27/94

Vegetative co (Right bank of Connecticut River) Brush with a few trees.

DS left: Grass

DS right: Trees with shrubs and brush.

US left: Grass with a few trees.

US right:

Do banks appear stable? N ***If not, describe location and type of instability and date of observation.***

The upstream reach bends left on approach to the bridge with a cut-bank developing on the right bank and a large sand and gravel point bar on the left bank. 10/27/94.

None evident on 10/27/94.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 89.5 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province/section	***Percent of drainage area***
New England / White Mountain	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: There are houses and a lumber yard along the right bank side.

Is there a USGS gage on the stream of interest? Yes

USGS gage description Halls Stream near E. Herefore, Quebec

USGS gage number 01129300 (Discontinued)

Gage drainage area 85 ***mi²***

Is there a lake/p Yes

Halls Stream enters the Connecticut River about 50 feet downstream of this site.

Calculated Discharges

Q100 6,320 ***ft³/s*** ***Q500*** 7,650 ***ft³/s***

The 100- and 500-year discharges are based on a log-pearson-type3 flood frequency analysis of gaged peak discharge records from 1963 through 1992 (Interagency Advisory Committee on Water Data, 1982).

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 Subtract 397.4 feet from USGS survey to obtain VTAOT plans datum.

Description of reference marks used to determine USGS datum. RM1 is the center point of a chiseled “X” in a chiseled square on top of the US end of the left abutment concrete (elev. 500.36 ft, arbitrary survey datum). RM2 is a brass tablet set in the concrete curb on the downstream side near mid-span of the bridge engraved with “The Supreme Court of the United States” (elev. 500.10 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-95	2	Exit section (Templated from APTEM)
FULLV	0	2	Downstream Full-valley section (Templated from APTEM)
BRIDG	0	1	Bridge section
RDWAY	14	1	Road Grade section
APTEM	111	1	Approach section as surveyed (Used as a template)
APPRO	124	2	Modelled Approach section (Templated from APTEM)

[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 modelling of the reach. Channel "n" values for the reach ranged from 0.035 to 0.040, and overbank "n" values were 0.085.

Halls Stream enters the Connecticut River just downstream of this site. Although the timing of peak discharges on Halls Stream and the Connecticut River above the confluence may be coincident, normal depth at the exit section (EXITX) was assumed as the starting water surface. This depth was computed by use of the slope-conveyance method outlined in the user's manual for WSPRO (Shearman, 1990). The slope used was 0.0012 ft/ft, which was estimated from surveyed thalweg points between the approach (APTEM) and bridge (BRIDG) sections.

The APTEM section was moved along the approach channel slope (0.0012 ft/ft) to establish the modelled approach (APPRO), full-valley (FULLV) and EXITX sections. The APPRO section was set at one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

The modelled 500-year discharges resulted in roadway overtopping. The incipient overtopping discharge was 6,550 cfs.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.5 ***ft***
Average low steel elevation 496.4 ***ft***

100-year discharge 6,320 ***ft^3/s***
Water-surface elevation in bridge opening 492.9 ***ft***
Road overtopping? N ***Discharge over road*** 0 ***ft^3/s***
Area of flow in bridge opening 597 ***ft^2***
Average velocity in bridge opening 10.6 ***ft/s***
Maximum WSPRO tube velocity at bridge 12.7 ***ft/s***

Water-surface elevation at Approach section with bridge 496.1 ***ft***
Water-surface elevation at Approach section without bridge 493.7 ***ft***
Amount of backwater caused by bridge 2.4 ***ft***

500-year discharge 7,650 ***ft^3/s***
Water-surface elevation in bridge opening 496.4 ***ft***
Road overtopping? Y ***Discharge over road*** 966 ***ft^3/s***
Area of flow in bridge opening 854 ***ft^2***
Average velocity in bridge opening 7.8 ***ft/s***
Maximum WSPRO tube velocity at bridge 8.3 ***ft/s***

Water-surface elevation at Approach section with bridge 497.7 ***ft***
Water-surface elevation at Approach section without bridge 494.3 ***ft***
Amount of backwater caused by bridge 3.4 ***ft***

Incipient overtopping discharge 6,550 ***ft^3/s***
Water-surface elevation in bridge opening 492.9 ***ft***
Area of flow in bridge opening 604 ***ft^2***
Average velocity in bridge opening 10.9 ***ft/s***
Maximum WSPRO tube velocity at bridge 13.0 ***ft/s***

Water-surface elevation at Approach section with bridge 496.3 ***ft***
Water-surface elevation at Approach section without bridge 493.8 ***ft***
Amount of backwater caused by bridge 2.5 ***ft***

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 others, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analysis are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

Contraction scour was computed by use of Laursen's clear-water contraction scour equation (Richardson and others, 1995, p. 32, equation 20) for the 100-year and incipient road overtopping discharge. The 500-year discharge 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 and Richardson and others, 1995, p. 145-146). The results of Laursen's clear-water contraction scour for the 500-year event were also computed and included in appendix F.

Pier scour was computed by use of a modified equation developed at Colorado State University (Richardson and others, 1995, p. 36, equation 21) for all discharges modeled. Variables for the pier scour equation include pier length, pier width, average depth and maximum velocity (for the froude number) immediately upstream of the bridge, and four correction factors for pier shape, flow attack angle, streambed-form, and streambed armoring. Although the ratios of scour depth to pier width for each pier at this site exceeds the maximum ratio of 2.4 indicated for round-nose piers aligned with the flow direction (Richardson and others, 1995, p. 36), field observations of the streambed around the piers suggest that there is a flow attack angle on each pier. Therefore, scour depths computed from the equation were assumed to provide a better estimate of the maximum scour depth potential at each pier. In this report, piers are presented as pier 1 and pier 2 for the left and right piers at this site respectively.

Abutment scour for the right abutment at all modelled discharges was computed by use of the Froehlich equation (Richardson and others, 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 at the left abutment was computed by use of the HIRE equation (Richardson and others, 1995, p. 49, equation 29) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. The variables used by the HIRE abutment-scour equation are defined the same as those defined for the Froehlich abutment-scour equation.

Because the influence of scour processes on the spill-through embankment material is uncertain, the scour depth at the vertical concrete abutment walls is unknown. Therefore, the variables for the abutment scour equations applied were computed including the width of the spill-through embankments. The total scour depths were applied for the entire spill-through embankment below the elevation at the toe of each embankment, as shown in figure 8.

Scour Results

Contraction scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(Scour depths in feet)		
Main channel			
Live-bed scour	--	--	--
Clear-water scour	8.0	8.8	8.4
Depth to armoring	--	--	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	8.9	10.4	9.3
Right abutment	15.8	17.3	16.1
Pier scour			
Pier 1	12.6	11.1	12.8
Pier 2	15.6	13.8	15.8
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(D_{50} in feet)		
Abutments:			
Left abutment	2.6	1.1	2.6
Right abutment	2.6	1.1	2.6
Piers:			
Pier 1	1.7	0.9	1.7
Pier 2	1.7	0.9	1.7
	--	--	--

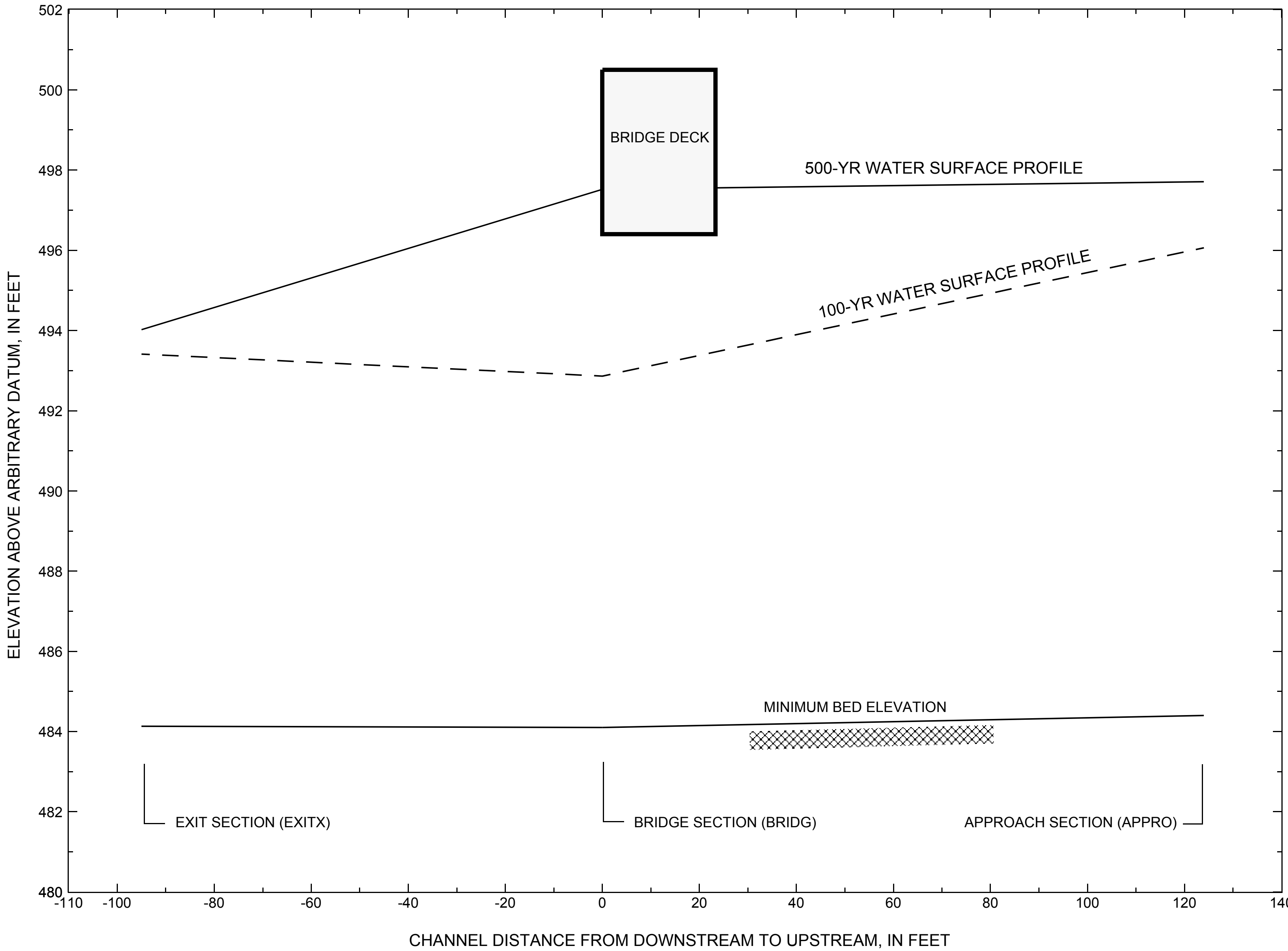

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure CANATH00010001 on town highway 1, crossing Halls Stream, Canaan, Vermont.

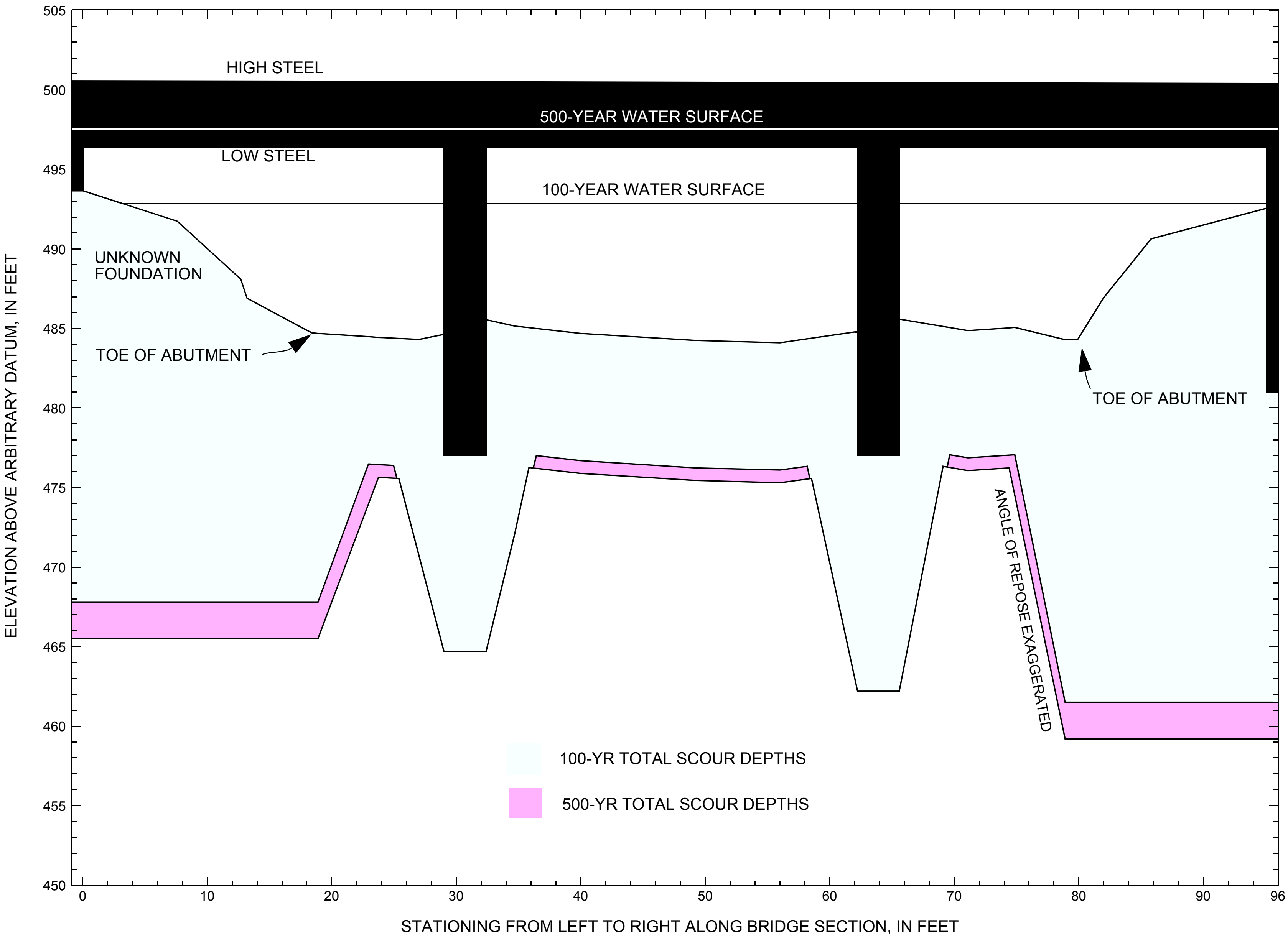

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure CANATH00010001 on town highway 1, crossing Halls Stream, Canaan, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure CANATH00010001 on Town Highway 1, crossing Halls Stream, Canaan, Vermont.
[VTAOT, Vermont Agency of Transportation; --,no data]

Description	Station[1]	VTAOT Bridge Seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 6,320 cubic-feet per second											
Left abutment wall	0.0	99.0	496.4	--	493.7	--	--	--	--	--	--
Left abutment toe	18.4	--	--	--	484.7	8.0	8.9	--	16.9	467.8	--
Pier 1	30.7	--	--	477	484.6	8.0	--	12.6	20.6	464.0	-13
Pier 2	63.9	--	--	477	484.8	8.0	--	15.6	23.6	461.2	-16
Right abutment toe	79.4	--	--	--	485.3	8.0	15.8	--	23.8	461.5	--
Right abutment wall	95.1	99.1	496.4	481	492.6	--	--	--	--	--	--

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 CANATH00010001 on Town Highway 1, crossing Halls Stream, Canaan, Vermont.
[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station[1]	VTAOT Bridge Seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 7,650 cubic-feet per second											
Left abutment wall	0.0	99.0	496.4	--	493.7	--	--	--	--	--	--
Left abutment toe	18.4	--	--	--	484.7	8.8	10.4	--	19.2	465.5	--
Pier 1	30.7	--	--	477	484.6	8.8	--	11.1	19.9	464.7	-12
Pier 2	63.9	--	--	477	484.8	8.8	--	13.8	22.6	462.2	-15
Right abutment toe	79.4	--	--	--	485.3	8.8	17.3	--	26.15	459.2	--
Right abutment wall	95.1	99.1	496.4	481	492.6	--	--	--	--	--	--

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

SELECTED REFERENCES

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Brown, S.A. and Clyde, E.S., 1989, Design of riprap revetment: Federal Highway Administration Hydraulic Engineering Circular No. 11, Publication FHWA-IP-89-016, 156 p.

Federal Emergency Management Agency, March 1980, Flood Insurance Study, Town of Canaan, Essex County, Vermont: Washington, D.C., 20 p.

Froehlich, D.C., 1989, Local scour at bridge abutments *in* Ports, M.A., ed., Hydraulic Engineering--Proceedings of the 1989 National Conference on Hydraulic Engineering: New York, American Society of Civil Engineers, p. 13-18.

Hayes, D.C.,1993, Site selection and collection of bridge-scour data in Delaware, Maryland, and Virginia: U.S. Geological Survey Water-Resources Investigation Report 93-4017, 23 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: U.S. Geological Survey, Bulletin 17B of the Hydrology Subcommittee, 190 p.

Lagasse, P.F., Schall, J.D., Johnson, F., Richardson, E.V., Chang, F., 1995, Stream Stability at Highway Structures: Federal Highway Administration Hydraulic Engineering Circular No. 20, Publication FHWA-IP-90-014, 144 p.

Laursen, E.M., 1960, Scour at bridge crossings: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 86, no. HY2, p. 39-53.

Richardson, E.V. and Davis, S.R., 1995, Evaluating scour at bridges: Federal Highway Administration Hydraulic Engineering Circular No. 18, Publication FHWA-IP-90-017, 204 p.

Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment: Federal Highway Administration Publication FHWA-HI-90-016.

Ritter, D.F., 1984, Process Geomorphology: W.C. Brown Co., Debuque, Iowa, 603 p.

Shearman, J.O., 1990, User's manual for WSPRO--a computer model for water surface profile computations: Federal Highway Administration Publication FHWA-IP-89-027, 187 p.

Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model; research report: Federal Highway Administration Publication FHWA-RD-86-108, 112 p.

U.S. Department of Transportation, 1993, Stream stability and scour at highway bridges, Participant Workbook: Federal Highway Administration Publication FHWA HI-91-011.

U.S. Geological Survey, 1989, Monadnock Mountain, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Aerial photographs, 1984, Contour interval, 20 feet, Scale 1:24,000.

U.S. Geological Survey, 1989, Lovering Mountain, New Hampshire 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Aerial photographs, 1984, Contour interval, 20 feet Scale 1:24,000.

U.S. Geological Survey, 1989, Pittsburg, New Hampshire 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Aerial photographs, 1984, Contour interval, 20 feet Scale 1:24,000.

Canada Department of Energy, Mines, and Resources, Surveys and Mapping Branch, 1980, Coaticook, Quebec, Canada 15 by 30 Minute quadrangle map: Aerial photographs, 1978, Contour interval, 25 feet, Scale 1:50,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

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T1        U.S. Geological Survey WSPRO Input File cana001.wsp
T2        Hydraulic analysis for structure CANATH00010001   Date: 23-APR-96
T3        Town Highway 1 Bridge Crossing Halls Stream, Canaan, VT            EMB
Q           6320.0,   7650.0,   6550.0
SK          0.0012,   0.0012,   0.0012
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XT   APTEM    111
GR         -491.0, 496.40   -418.0, 491.00   -136.4, 490.81    -90.5, 490.06
GR          -75.3, 489.41    -26.4, 490.26     -6.3, 491.30     -3.7, 490.44
GR           -2.4, 486.76      0.0, 485.81     11.9, 486.16     21.3, 486.83
GR           46.8, 487.39     66.1, 486.96     80.7, 485.87     90.2, 484.52
GR           97.9, 484.38    104.6, 484.90    110.3, 486.23    110.6, 486.98
GR          111.4, 488.59    115.5, 489.72    136.3, 490.31    148.5, 498.02
GR          164.2, 499.75
*
XS   EXITX    -95  *  *  *  0.0012
GT
N             0.085        0.035
SA                   -6.3
*
XS   FULLV      0  * * *   0.0012
GT
N             0.085        0.035
SA                   -6.3
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0    496.40       0.0
GR            0.0, 496.41      0.0, 493.66      7.6, 491.73     12.7, 488.09
GR           13.2, 486.89     18.4, 484.72     24.1, 484.42     27.0, 484.31
GR           28.9, 484.61     32.4, 485.55     34.7, 485.15     40.0, 484.69
GR           49.2, 484.24     56.0, 484.10     62.0, 484.78     65.5, 485.60
GR           71.1, 484.87     79.4, 485.30     82.0, 486.94     85.8, 490.63
GR           95.1, 492.56     95.1, 496.39      0.0, 496.41
*
*         BRTYPE  BRWDTH    EMBSS   EMBELV
CD           3      28.5      3.6    499.5
PW 0         484.61, 3.6     484.78, 7.2      496.40, 6.2
N           0.040
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     14      23.3     1
GR         -492.1, 496.40   -419.2, 496.25   -330.7, 496.72   -262.4, 497.17
GR         -163.4, 498.45    -97.2, 499.30    -37.1, 500.09      0.0, 500.57
GR            0.1, 501.14     32.2, 501.48     65.3, 501.55     98.4, 501.30
GR           98.5, 500.40    137.2, 500.79    204.1, 501.93
*
AS   APPRO    124  * * *  0.0012
GT
N           0.085        0.035
SA                  -6.3
*
HP 1 BRIDG  492.86 1  492.86
HP 2 BRIDG  492.86 * *  6320
HP 2 BRIDG  493.15 * *  6320
HP 1 APPRO  496.06 1  496.06
HP 2 APPRO  496.06 * *  6320
*
HP 1 BRIDG  496.41 1  496.41
HP 2 BRIDG  496.41 * *  6668
HP 2 RDWAY  497.52 * *   966
HP 1 APPRO  497.71 1  497.71
HP 2 APPRO  497.71 * *  7650
*
HP 1 BRIDG  492.93 1  492.93
HP 2 BRIDG  492.93 * *  6550
HP 2 BRIDG  493.23 * *  6550
HP 1 APPRO  496.32 1  496.32
HP 2 APPRO  496.32 * *  6550
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

```
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
             1      597     74505    92     97                         8633
   492.86           597     74505    92     97  1.00      3     95     8633

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       492.86     3.2    95.1   597.1   74505.    6320.  10.59
X STA.        3.2       17.6       21.4       24.8       28.0       31.4
  A(I)            50.2       31.6       28.3       27.2       27.0
  V(I)            6.29      10.00      11.17      11.60      11.70

X STA.       31.4       35.1       38.4       41.6       44.6       47.6
  A(I)            27.6       26.3       25.8       25.5       25.2
  V(I)           11.44      12.03      12.24      12.37      12.54

X STA.       47.6       50.5       53.4       56.3       59.3       62.6
  A(I)            25.1       25.3       24.9       25.8       26.9
  V(I)           12.57      12.47      12.68      12.23      11.76

X STA.       62.6       66.3       70.2       73.9       78.2       95.1
  A(I)            28.1       29.6       29.3       33.3       53.8
  V(I)           11.24      10.67      10.78       9.49       5.88

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       493.15     2.0    95.1   623.9   79373.    6320.  10.13
X STA.        2.0       17.4       21.4       24.8       28.1       31.5
  A(I)            53.3       34.1       29.5       28.4       28.8
  V(I)            5.93       9.27      10.71      11.13      10.99

X STA.       31.5       35.2       38.6       41.8       44.8       47.8
  A(I)            28.8       27.4       26.9       26.2       26.6
  V(I)           10.97      11.53      11.76      12.08      11.88

X STA.       47.8       50.8       53.7       56.6       59.6       62.9
  A(I)            26.2       26.4       25.9       26.8       27.9
  V(I)           12.07      11.97      12.19      11.79      11.34

X STA.       62.9       66.8       70.5       74.3       78.7       95.1
  A(I)            29.9       29.6       31.4       34.7       55.1
  V(I)           10.55      10.67      10.06       9.11       5.73

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
     WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
             1     2382    121466   480    480                        30116
             2     1313    229127   152    158                        21927
   496.06          3695    350593   632    638  2.31   -485    145    33370

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
         WSEL     LEW     REW    AREA        K        Q    VEL
       496.06  -486.2   145.4  3695.3  350593.    6320.   1.71
X STA.     -486.2     -368.0     -298.7     -232.6     -167.9     -105.6
  A(I)           424.9      353.8      340.0      336.3      333.3
  V(I)            0.74       0.89       0.93       0.94       0.95

X STA.     -105.6      -57.1       -3.5        7.0       16.4       26.5
  A(I)           302.3      305.9      103.3       92.9       93.1
  V(I)            1.05       1.03       3.06       3.40       3.39

X STA.       26.5       37.2       48.3       59.3       69.8       79.2
  A(I)            96.2       96.7       97.0       95.2       92.0
  V(I)            3.28       3.27       3.26       3.32       3.43

X STA.       79.2       87.9       95.4      103.5      116.1      145.4
  A(I)            91.4       86.7       93.5      113.5      147.5
  V(I)            3.46       3.64       3.38       2.78       2.14
```

```
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      932     96294      0    202                            0
   496.41           932     96294      0    202  1.00      0     95        0

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
             WSEL     LEW     REW    AREA        K        Q    VEL
           496.41     0.0    95.1   932.5   96294.    6668.   7.15
X STA.        0.0       14.3       19.0       22.9       26.5       30.0
  A(I)            76.1       51.9       45.5       43.6       41.9
  V(I)            4.38       6.42       7.32       7.64       7.96

X STA.       30.0       34.0       37.7       41.2       44.6       48.0
  A(I)            43.7       42.4       41.4       40.2       40.7
  V(I)            7.63       7.87       8.06       8.30       8.19

X STA.       48.0       51.3       54.6       57.9       61.4       65.1
  A(I)            40.1       40.4       40.8       41.0       42.4
  V(I)            8.31       8.26       8.17       8.13       7.86

X STA.       65.1       69.1       73.0       77.1       81.9       95.1
  A(I)            43.5       44.7       46.3       51.0       74.9
  V(I)            7.66       7.47       7.20       6.53       4.45

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      14.
        WSEL     LEW     REW    AREA        K        Q    VEL
      497.52  -492.1  -235.3   222.7    3541.     966.   4.34
X STA.     -492.1     -483.3     -475.2     -467.1     -459.2     -451.7
  A(I)            10.0        9.3        9.4        9.3        9.0
  V(I)            4.85       5.21       5.13       5.22       5.34

X STA.     -451.7     -444.1     -436.6     -429.1     -421.7     -414.2
  A(I)             9.2        9.1        9.3        9.3        9.4
  V(I)            5.24       5.28       5.17       5.17       5.16

X STA.     -414.2     -406.3     -397.8     -388.5     -378.5     -367.3
  A(I)             9.7       10.0       10.5       10.9       11.5
  V(I)            4.95       4.83       4.62       4.44       4.22

X STA.     -367.3     -354.7     -340.3     -322.8     -298.9     -235.3
  A(I)            12.1       12.8       14.0       16.0       21.9
  V(I)            4.00       3.76       3.44       3.02       2.20

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1     3181    195043    485    486                        46242
             2     1566    303205    154    161                        28301
   497.71          4747    498248    639    648  2.20   -490    148    49438

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
        WSEL     LEW     REW    AREA        K        Q    VEL
      497.71  -491.0   148.0  4746.6  498248.    7650.   1.61
X STA.     -491.0     -385.4     -325.3     -266.1     -206.0     -149.7
  A(I)           510.3      404.5      401.2      410.2      385.8
  V(I)            0.75       0.95       0.95       0.93       0.99

X STA.     -149.7      -94.3      -50.0       -1.4        8.9       19.1
  A(I)           395.8      354.0      360.0      120.4      116.6
  V(I)            0.97       1.08       1.06       3.18       3.28

X STA.       19.1       30.3       41.8       53.7       65.2       76.2
  A(I)           120.6      121.5      123.3      122.0      120.9
  V(I)            3.17       3.15       3.10       3.13       3.16

X STA.       76.2       85.8       94.6      103.9      117.8      148.0
  A(I)           115.0      115.4      122.0      142.4      184.7
  V(I)            3.33       3.32       3.14       2.69       2.07
```

```
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      604     75667     92     98                        8760
  492.93           604     75667     92     98  1.00      3     95     8760

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
      492.93     2.9    95.1   603.5   75667.    6550.  10.85
X STA.        2.9        17.6        21.4        24.8        28.0        31.5
  A(I)            51.3        31.9        28.6        27.5        27.9
  V(I)            6.39       10.26       11.47       11.91       11.76

X STA.       31.5        35.1        38.5        41.6        44.7        47.6
  A(I)            27.8        26.4        26.0        25.7        25.3
  V(I)           11.79       12.39       12.61       12.75       12.93

X STA.       47.6        50.6        53.5        56.4        59.4        62.7
  A(I)            25.5        25.7        25.3        26.2        27.2
  V(I)           12.85       12.75       12.97       12.52       12.04

X STA.       62.7        66.5        70.3        74.1        78.4        95.1
  A(I)            28.5        29.3        30.5        33.7        53.4
  V(I)           11.51       11.19       10.73        9.71        6.13

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
      493.23     1.7    95.1   631.4   80741.    6550.  10.37
X STA.        1.7        17.4        21.4        24.9        28.1        31.6
  A(I)            54.5        34.5        29.9        28.7        29.1
  V(I)            6.01        9.49       10.97       11.40       11.26

X STA.       31.6        35.3        38.6        41.8        44.9        47.9
  A(I)            29.2        27.7        27.2        26.5        26.9
  V(I)           11.22       11.80       12.04       12.37       12.16

X STA.       47.9        50.8        53.7        56.7        59.7        63.0
  A(I)            26.2        26.4        26.9        27.1        28.2
  V(I)           12.50       12.40       12.19       12.09       11.63

X STA.       63.0        66.9        70.6        74.5        78.7        95.1
  A(I)            30.3        30.1        31.8        34.0        56.2
  V(I)           10.81       10.90       10.30        9.63        5.82

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW      QCR
            1     2507    131651    483    484                       32403
            2     1353    240233    152    159                       22892
  496.32          3860    371884    635    642  2.30   -489    146    35594

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
        WSEL     LEW     REW    AREA        K        Q    VEL
      496.32  -489.7   145.8  3860.0  371884.    6550.   1.70
X STA.     -489.7      -369.0      -302.7      -238.7      -174.7      -112.2
  A(I)           451.0       355.0       346.3       348.3       347.9
  V(I)            0.73        0.92        0.95        0.94        0.94

X STA.     -112.2       -63.8       -12.2         5.7        15.2        25.4
  A(I)           309.4       318.7       138.1        97.0        97.4
  V(I)            1.06        1.03        2.37        3.38        3.36

X STA.       25.4        36.0        47.3        58.4        69.1        78.7
  A(I)            98.3       101.9       100.2       100.3        95.1
  V(I)            3.33        3.21        3.27        3.27        3.44

X STA.       78.7        87.4        95.4       103.6       116.6       145.8
  A(I)            94.1        93.1        97.1       118.9       151.8
  V(I)            3.48        3.52        3.37        2.75        2.16
```

WSPRO OUTPUT FILE (continued)

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+++ BEGINNING PROFILE CALCULATIONS --   3

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******   -453     2230  0.30 *****  493.71  491.22    6320  493.41
       -94 ******    142   182375  2.38 ***** *******    0.40    2.83

FULLV:FV       95   -453     2238  0.30  0.11  493.83 *******    6320  493.54
         0     95    142   183116  2.38  0.00    0.01    0.40    2.82
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>


APPRO:AS      124   -453     2244  0.29  0.15  493.99 *******    6320  493.70
       124    124    142   183785  2.38  0.00    0.01    0.39    2.82
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

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

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

BRIDG:BR       95      3      597  2.84  0.28  495.70  491.87    6320  492.86
         0     95     95    74433  1.63  1.71    0.00    0.94   10.59

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       3.   0.   1.  0.784  0.094  496.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      14.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

APPRO:AS       96   -485     3697  0.10  0.18  496.17  491.48    6320  496.06
       124    116    145   350867  2.31  0.29    0.01    0.19    1.71

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.841  0.548  158048.    -5.    87.   496.03

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.
   XSID:CODE    SRD    LEW    REW       Q        K      AREA     VEL    WSEL
   EXITX:XS     -95.  -454.   142.   6320.  182375.    2230.    2.83  493.41
   FULLV:FV       0.  -454.   142.   6320.  183116.    2238.    2.82  493.54
   BRIDG:BR       0.     3.    95.   6320.   74433.     597.   10.59  492.86
   RDWAY:RG      14.**************      0.******************    1.00********
   APPRO:AS     124.  -486.   145.   6320.  350867.    3697.    1.71  496.06

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      -5.    87.  158048.

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    491.22    0.40  484.13  499.50************  0.30  493.71  493.41
   FULLV:FV  ********    0.40  484.25  499.62  0.11  0.00  0.30  493.83  493.54
   BRIDG:BR    491.87    0.94  484.10  496.41  0.28  1.71  2.84  495.70  492.86
   RDWAY:RG  ****************  496.25  501.93**********************************
   APPRO:AS    491.48    0.19  484.40  499.77  0.18  0.29  0.10  496.17  496.06
```
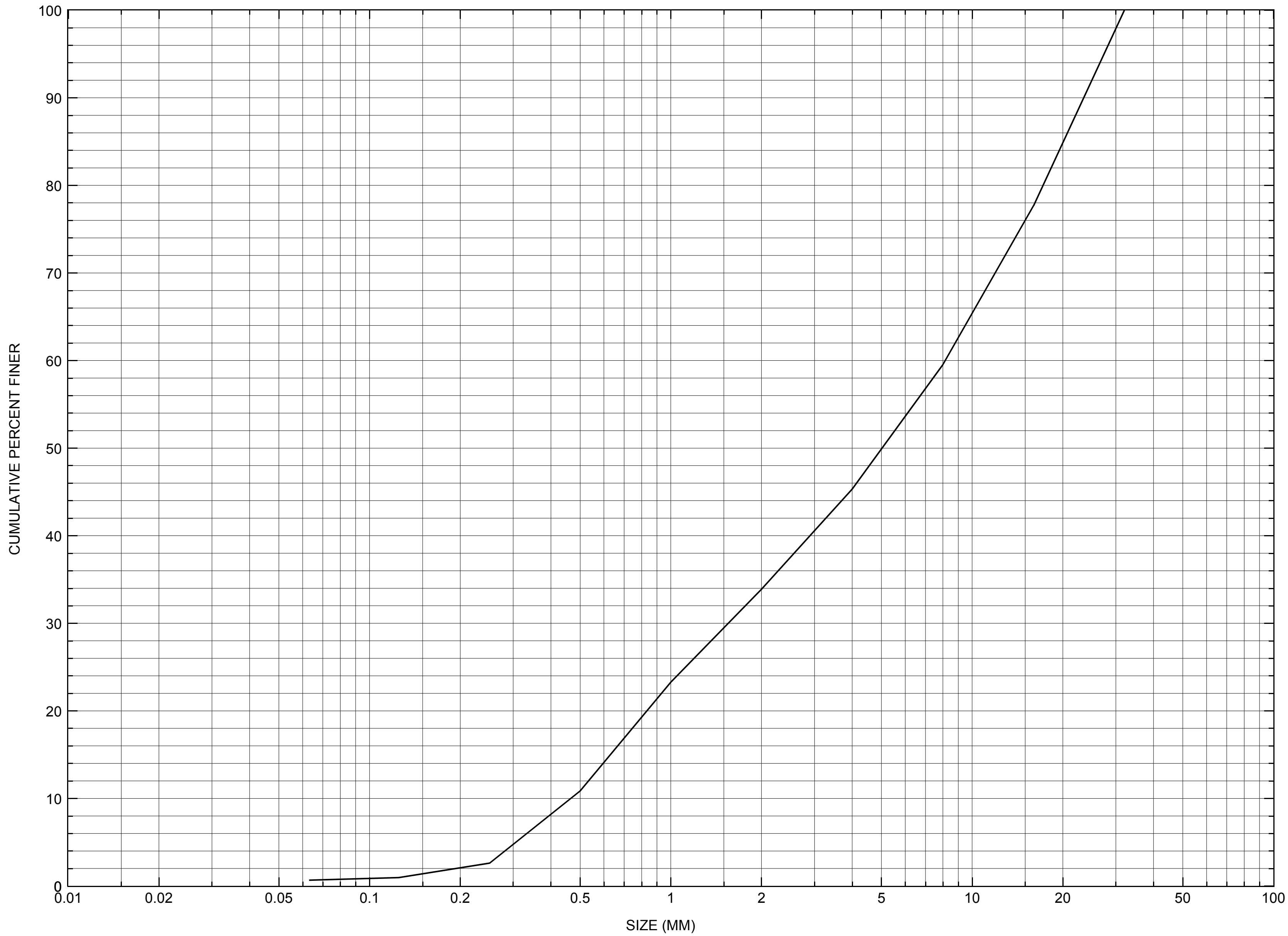

```
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS      Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******   -461     2598  0.32 *****  494.34  491.64    7650  494.02
       -94 ******    143   220696  2.37 ***** *******    0.39    2.94

FULLV:FV       95   -461     2606  0.32  0.11  494.47 *******    7650  494.15
         0     95    143   221523  2.37  0.00    0.01    0.38    2.94
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      124   -462     2613  0.32  0.15  494.63 *******    7650  494.31
       124    124    143   222271  2.37  0.00    0.01    0.38    2.93
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   497.62       0.00     493.25     496.25

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   493.53     496.94     497.11     496.40

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

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

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS      Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

BRIDG:BR       95      0      854  0.95 *****  497.36  492.14    6668  496.41
         0 ******     95    96294  1.00 ***** *******    0.46    7.81

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       3.   0.   5.  0.406  0.085  496.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
   RDWAY:RG      14.   101.  0.02  0.09  497.78    0.00    966.  497.52

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    966.   257.  -492.  -235.   1.3   0.9   5.0   4.3   1.1   3.1
   RT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****

===140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
                              WSEL,YLT,YRT =   497.71      496.4      499.8
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS      Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

APPRO:AS       96   -490     4750  0.09  0.13  497.80  491.91    7650  497.71
       124    118    148   498702  2.20  0.27    0.00    0.15    1.61

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.
   XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -95.  -462.   143.   7650.  220696.    2598.    2.94  494.02
   FULLV:FV       0.  -462.   143.   7650.  221523.    2606.    2.94  494.15
   BRIDG:BR       0.     0.    95.   6668.   96294.     854.    7.81  496.41
   RDWAY:RG      14.*******   966.    966.*********       0.    1.00  497.52
   APPRO:AS     124.  -491.   148.   7650.  498702.    4750.    1.61  497.71

 SECOND USER DEFINED TABLE.
   XSID:CODE    CRWS     FR#    YMIN    YMAX     HF    HO   VHD     EGL    WSEL
   EXITX:XS    491.64    0.39  484.13  499.50************  0.32  494.34  494.02
   FULLV:FV  ********    0.38  484.25  499.62  0.11  0.00  0.32  494.47  494.15
   BRIDG:BR    492.14    0.46  484.10  496.41************  0.95  497.36  496.41
   RDWAY:RG  ****************  496.25  501.93  0.02******  0.09  497.78  497.52
   APPRO:AS    491.91    0.15  484.40  499.77  0.13  0.27  0.09  497.80  497.71
```

WSPRO OUTPUT FILE (continued)

```
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******   -454     2296  0.30 *****  493.82  491.29    6550  493.52
       -94 ******    142   189020  2.38 ***** *******    0.40    2.85

FULLV:FV       95   -455     2304  0.30  0.11  493.95 *******    6550  493.65
         0     95    142   189777  2.38  0.00    0.01    0.39    2.84
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      124   -455     2310  0.30  0.15  494.10 *******    6550  493.81
       124    124    142   190459  2.38  0.00    0.01    0.39    2.84
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   496.32       0.00     492.93     496.25

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

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

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

BRIDG:BR       95      3      604  3.02  0.28  495.95  492.06    6550  492.93
         0     95     95    75681  1.65  1.84    0.00    0.96   10.85

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       3.   0.   4.  0.779  0.094  496.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      14.         <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

APPRO:AS       96   -489     3862  0.10  0.18  496.43  491.55    6550  496.32
       124    117    146   372076  2.30  0.30    0.01    0.18    1.70

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.841  0.558  163783.    -6.    86. ********

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.
   XSID:CODE    SRD    LEW    REW      Q        K     AREA     VEL    WSEL
   EXITX:XS     -95.  -455.   142.   6550.  189020.    2296.    2.85  493.52
   FULLV:FV       0.  -456.   142.   6550.  189777.    2304.    2.84  493.65
   BRIDG:BR       0.     3.    95.   6550.   75681.     604.   10.85  492.93
   RDWAY:RG      14.**************      0.       0.       0.    1.00********
   APPRO:AS     124.  -490.   146.   6550.  372076.    3862.    1.70  496.32

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      -6.    86.  163783.

 SECOND USER DEFINED TABLE.
   XSID:CODE    CRWS     FR#   YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    491.29    0.40  484.13  499.50************  0.30  493.82  493.52
   FULLV:FV  ********    0.39  484.25  499.62  0.11  0.00  0.30  493.95  493.65
   BRIDG:BR    492.06    0.96  484.10  496.41  0.28  1.84  3.02  495.95  492.93
   RDWAY:RG  ****************  496.25  501.93  0.03******  0.10  496.38********
   APPRO:AS    491.55    0.18  484.40  499.77  0.18  0.30  0.10  496.43  496.32
```

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for channel sample taken at the approach cross-section of structure CANATH00010001, in Canaan, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number CANATH0010001

General Location Descriptive

Data collected by (First Initial, Full last name) E. BOEHMLER

Date (MM/DD/YY) 08 / 05 / 94

Highway District Number (I - 2; nn) 09

County (FIPS county code; I - 3; nnn) 009

Town (FIPS place code; I - 4; nnnnn) 11800

Mile marker (I - 11; nnn.nnn) 000000

Waterway (I - 6) HALLS STREAM

Road Name (I - 7): -

Route Number TH001

Vicinity (I - 9) 0.15 MI TO JCT W VT25

Topographic Map Monadnock.Mtn

Hydrologic Unit Code: 01080101

Latitude (I - 16; nnnn.n) 45006

Longitude (i - 17; nnnnn.n) 71304

Select Federal Inventory Codes

FHWA Structure Number (I - 8) 10050600010506

Maintenance responsibility (I - 21; nn) 03

Maximum span length (I - 48; nnnn) 0033

Year built (I - 27; YYYY) 1931

Structure length (I - 49; nnnnnn) 000099

Average daily traffic, ADT (I - 29; nnnnnn) 000240

Deck Width (I - 52; nn.n) 233

Year of ADT (I - 30; YY) 91

Channel & Protection (I - 61; n) 5

Opening skew to Roadway (I - 34; nn) 00

Waterway adequacy (I - 71; n) 6

Operational status (I - 41; X) A

Underwater Inspection Frequency (I - 92B; XYY) N

Structure type (I - 43; nnn) 104

Year Reconstructed (I - 106) 1961

Approach span structure type (I - 44; nnn) 000

Clear span (nnn.n ft) -

Number of spans (I - 45; nnn) 003

Vertical clearance from streambed (nnn.n ft) 012.0

Number of approach spans (I - 46; nnnn) 0000

Waterway of full opening (nnn.n ft^2) -

Comments:

Structural inspection report of 6/23/93 indicates a 3-span concrete T-beam bridge. The report notes heavy concrete spalling with reinforcement rods exposed at the right abutment and right wingwall. The footings are not exposed and no settlement is apparent. Heavy channel scour is indicated particularly at the upstream ends of the piers. Minor embankment erosion was noted. The channel alignment is straight into the bridge crossing. Riprap coverage is good. No point bars are noted. Debris pile-up is noted particularly around the piers.

Bridge Hydrologic Data

Is there hydrologic data available? **N** *if No, type ctrl-n h* VTAOT Drainage area *(mi^2)*: -

Terrain character: -

Stream character & type: -

Streambed material: **Coarse gravel with boulders and stones**

Discharge Data *(cfs)*: $Q_{2.33}$ - Q_{10} - Q_{25} -

Q_{50} - Q_{100} - Q_{500} -

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

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

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

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: **Bridge is just upstream from the Hall stream confluence with the Connecticut River which may increase backwater at and upstream of this bridge site.**

Watershed storage area (*in percent*): - %

The watershed storage area is: - (*1-mainly at the headwaters; 2- uniformly distributed; 3-immediatly upstream oi the site*)

Water Surface Elevation Estimates for Existing Structure:

Peak discharge frequency	$Q_{2.33}$	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Water surface elevation (*ft*)	-	-	-	-	-
Velocity (*ft / sec*)	-	-	-	-	-

Long term stream bed changes: -

Is the roadway overtopped below the Q_{100}? (*Yes, No, Unknown*): **U** Frequency: -

Relief Elevation (*ft*): - Discharge over roadway at Q_{100} (ft^3*/ 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 (ft^2): -

Downstream distance (*miles*): - Town: - Year Built: -
Highway No. : - Structure No. : - Structure Type: -
Clear span (*ft*): - Clear Height (*ft*): - Full Waterway (ft^2): -

Comments:

-

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **89.52** mi^2 Lake and pond area **0.41** mi^2

Watershed storage *(ST)* **0.5** %

Bridge site elevation **1070** ft Headwater elevation **2000** ft

Main channel length **25.16** mi

10% channel length elevation **1100** ft 85% channel length elevation **1600** ft

Main channel slope *(S)* **26.49** ft / mi

Watershed Precipitation Data

Average site precipitation ______ in Average headwater precipitation ______ in

Maximum 2yr-24hr precipitation event *(I24,2)* ______ in

Average seasonal snowfall *(Sn)* ______ ft

Bridge Plan Data

Are plans available? **Y** *If no, type ctrl-n pl* Date issued for construction *(MM / YYYY)*: **06** / **1931**

Project Number **SA 11 - 1931** Minimum channel bed elevation: **85.0**

Low superstructure elevation: USLAB **100.45** DSLAB **98.95** USRAB **100.55** DSRAB **99.05**

Benchmark location description:

BM#1, spike in 10 inch maple, stationing 6+57, 14 feet right, elevation 100.00. The maple tree is 130 feet from left abutment on right bank of the Connecticut River upstream of bridge and confluence, 4 feet from right side of roadway going north.

Reference Point (*MSL, Arbitrary, Other*): **Arbitrary** Datum (*NAD27, NAD83, Other*): **Arbitrary**

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

If 1: Footing Thickness **2.0** Footing bottom elevation: **84.0***

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: **1** (*1-regolith, 2-bedrock, 3-unknown*)

Briefly describe material at foundation bottom elevation or around piles:

Material at foundations was determined at time of excavation for abutments and piers. The material is noted as sand and gravel with a little clay.

Comments:

***Footing bottom elevation is available for the right abutment only at 84.11 feet. Two piers of the bridge were set with a bottom elevation of 80.0 and a spread footing thickness of 2.0 feet. The low chord elevations at both piers is about 99.**

Cross-sectional Data

Is cross-sectional data available? N *If no, type ctrl-n xs*

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

Comments: **NO CROSS SECTION INFORMATION**

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

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

Comments: **NO CROSS SECTION INFORMATION**

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

APPENDIX E:

LEVEL I DATA FORM

U. S. Geological Survey
Bridge Field Data Collection and Processing Form

Qa/Qc Check by: **MAW** Date: **1/20/95**

Computerized by: **EMB** Date: **1/20/95**

Reviewd by: **EMB** Date: **4/22/96**

Structure Number **CANATH00010001**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **E. BOEHMLER** Date *(MM/DD/YY)* **10** / **27** / 19**94**

2. Highway District Number **09** Mile marker **-**

County **ESSEX (009)** Town **CANAAN (11800)**

Waterway *(I - 6)* **HALLS STREAM** Road Name **-**

Route Number **TH01** Hydrologic Unit Code: **01080101**

3. Descriptive comments:

The structure is a concrete T-beam type bridge located about 0.15 miles from the intersection of TH01 with VT253, at the center of Beecher Falls village.

B. Bridge Deck Observations

4. Surface cover... LBUS **6** RBUS **2** LBDS **5** RBDS **2** Overall **2**
*(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 **1** UB **1** DS **1** *(**1**- pool; **2**- riffle)*

6. Bridge structure type **2** *(**1**- single span; **2**- multiple span; **3**- single arch; **4**- multiple arch; **5**- cylindrical culvert; **6**- box culvert; or **7**- other)*

7. Bridge length **99.0** *(feet)* Span length **33.0** *(feet)* Bridge width **23.3** *(feet)*

Road approach to bridge:

8. LB **0** RB **1** *(**0** even, **1**- lower, **2**- higher)*

9. LB **1** RB **1** *(**1**- Paved, **2**- Not paved)*

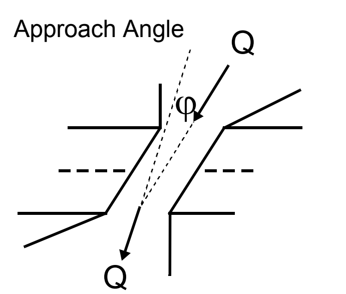
10. Embankment slope (*run / rise in feet / foot*):
US left **2.3:1** US right **5.0:1**

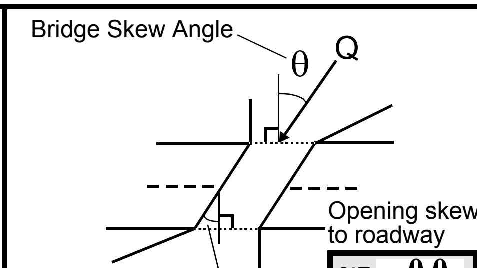
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	0	-	0	0
RBUS	0	-	0	0
RBDS	2	1	2	1
LBDS	2	1	2	1

*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: **30** 16. Bridge skew: **10**





α= **0.0**

17. Channel impact zone 1: Exist? **Y** *(Y or N)*
Where? **RB** *(LB, RB)* Severity **1**
Range? **75** feet **US** *(US, UB, DS)* to **33** feet **US**

Channel impact zone 2: Exist? **Y** *(Y or N)*
Where? **RB** *(LB, RB)* Severity **2**
Range? **30** feet **DS** *(US, UB, DS)* to **100** feet **DS**

*Impact Severity: **0**- none to very slight; **1**- Slight; **2**- Moderate; **3**- Severe*

18. Level II Bridge Type: **3**

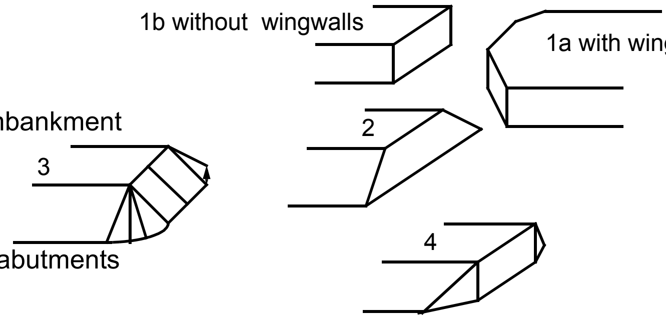
1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

2- Vertical abutments and wingwalls, sloping embankment
Wingwalls perpendicular to abut. face

3- Spill through abutments

4- Sloping embankment, vertical wingwalls and abutments
Wingwall angle less than 90°.



19. Bridge Deck Comments (surface cover variations, measured bridge and span lengths, bridge type variations, approach overflow width, etc.)

Surface cover on the right bank upstream is suburban predominantly with a grass lawn, a house, a lumber yard, and a small plot of trees. The coverage on the upstream left bank is all trees, thickly intergrown. Surface cover on the left bank downstream is the roadway approach to the left abutment and downstream of it is the Connecticut River waterway. The downstream right bank surface cover is suburban with a house and lawn. Measured bridge dimensions are the same as those indicated on the historical form. Erosion indicated on the downstream left bank road approach is due to bank cutting by the Connecticut River where the bank here is the road approach embankment. In addition, there is some minor roadwash erosion apparent behind the left abutment on the downstream left road embankment. Impact zone 2 indicated actually is the impact of the Connecticut River on the right bank 20 feet downstream of the Halls Stream confluence. This downstream right bank area is slightly affected by roadwash. The downstream left bank road approach protection is spotty and intergrown with tall grass and other brush. This is most apparent from the downstream face of the bridge to about 30 feet along the left road embankment.

C. Upstream Channel Assessment

20. SRD	21. Bank height (BF) LB	21. Bank height (BF) RB	22. Bank angle (BF) LB	22. Bank angle (BF) RB	26. % Veg. cover (BF) LB	26. % Veg. cover (BF) RB	27. Bank material (BF) LB	27. Bank material (BF) RB	28. Bank erosion (BF) LB	28. Bank erosion (BF) RB
91.5	**5.5**			**3.5**	**2**	**2**	**1**	**1**	**1**	**2**

23. Bank width **35.0** 24. Channel width **35.0** 25. Thalweg depth **122.0** 29. Bed Material **23**

30 .Bank protection type: LB **2** RB **2** 31. Bank protection condition: LB **1** RB **1**

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*

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

Bank and bed material is sand mainly with silt & clay and fine to medium size gravel. Two minor inflows (storm-drainage pipes) are present entering on the right bank about 130 feet upstream and on the right bank nearly 200 feet downstream. The protection on the banks is restricted to the area of 30 feet upstream to the abutments on both banks. In addition, the right bank is protected from about 190 to greater than 300 feet upstream with no protection present between 30 and 190 feet upstream. the left bank has no additional protection beyond 30 feet upstream. Generally, where protection is found upstream, it is in good condition.

33. Point/Side bar present? **Y** (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: **88** 35. Mid-bar width: **35**

36. Point bar extent: **300** feet **US** (US, UB) to **39** feet **US** (US, UB, DS) positioned **10** %LB to **60** %RB

37. Material: **3**

38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):

The point bar is an island type feature here. With slightly higher water levels flow would proceed also along the left bank side of the point bar. It has some grass growing only at the very highest area of the bar and makes up about 15% of the point bar area. The remaining area is unvegetated, loose gravel that probably moves around frequently.

39. Is a cut-bank present? **Y** (Y or if N type ctrl-n cb) 40. Where? **RB** (LB or RB)

41. Mid-bank distance: **120** 42. Cut bank extent: **190** feet **US** (US, UB) to **50** feet **US** (US, UB, DS)

43. Bank damage: **2** (1- eroded and/or creep; 2- slip failure; 3- block failure)

44. Cut bank comments (eg. additional cut banks, protection condition, etc.):

Beyond 190 feet upstream a cut bank is protected by type-2 stone fill. The cut bank is only slightly apparent with some undercutting and slip failures of bank material. During higher flows when flow runs along the left bank side of the bar, a cut bank is developing and is mainly visible from 150 to about 30 feet upstream of the left abutment where the stone fill protection ends.

45. Is channel scour present? **N** (Y or if N type ctrl-n cs) 46. Mid-scour distance: **-**

47. Scour dimensions: Length **-** Width **-** Depth : **-** Position **-** %LB to **-** %RB

48. Scour comments (eg. additional scour areas, local scouring process, etc.):

NO CHANNEL SCOUR

49. Are there major confluences? _____ (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** RB _____ (1- natural bank; 2- abutment; 3- artificial levee)

56. Height (BF) LB	56. Height (BF) RB	57 Angle (BF) LB	57 Angle (BF) RB	61. Material (BF) LB	61. Material (BF) RB	62. Erosion (BF) LB	62. Erosion (BF) RB
113.0		**2.5**		**2**	**7**	**7**	**-**

58. Bank width (BF) **-** 59. Channel width (Amb) **-** 60. Thalweg depth (Amb) **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.):

32

There is some large stone fill in the channel under the bridge, roughly class 1 or 2, embedded in the sand and gravel bed material. The bed material under the bridge is the same predominantly as that found on the streambed upstream.

65. **Debris and Ice** Is there debris accumulation? ____ *(Y or N)* 66. Where? N ____ *(1- Upstream; 2- At bridge; 3- Both)*

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

69. Is there evidence of ice build-up? 3 ____ *(Y or N)* Ice Blockage Potential N ____ *(1- Low; 2- Moderate; 3- High)*

70. Debris and Ice Comments:

3

The low stream gradient and existence of piers in the channel and a point bar upstream make this bridge a likely site for debris and ice to accumulate. There is alot of vegetation on the banks and a laterally unstable channel in addition to a lumber yard on the right over-bank upstream, which makes the potential for debris moderate.

Abutments	71. Attack ∠(BF)	72. Slope ∠ (Qmax)	73. Toe loc. (BF)	74. Scour Condition	75. Scour depth	76. Exposure depth	77. Material	78. Length
LABUT		0	35	2	1	0	0	90.0
RABUT	1	10	40			2	1	95.0

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

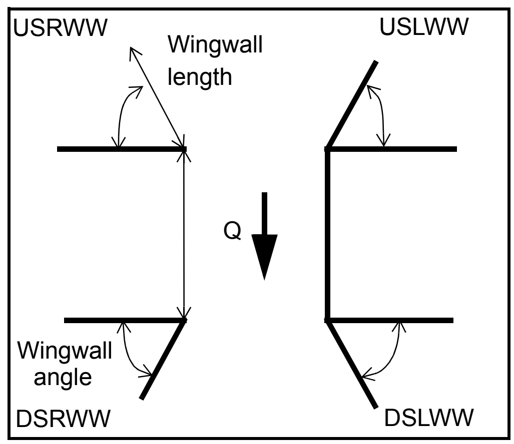
79. Abutment comments (eg. undermined penetration, unusual scour processes, debris, etc.):

0
0
1

The abutments are the spill-through type with class 3 protection on each abutment slope. Fill between the rip-rap has eroded to the extent that it has washed down off each slope exposing the top of the concrete piles of each the abutments. The riprap has slumped and some stones have eroded away from the slopes. Only the tops of piles are exposed, the remainder is well protected by the spill-through slopes and protection on them. The scour process occurring at each abutment is only slight at the worst. The attack angle above gives a general angle of the channel toward the abutment face but does not reflect the angle of flow attack on the abutment in this case as flow from the overbank area is funneled by the bridge opening such that flow largely runs

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:	arou		nd		the	69.0	
USRWW:	flow		thro		ugh	2.5	
DSLWW:	abut		ment		slope	29.0	
DSRWW:	.					28.0	



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

82. **Bank / Bridge Protection**:

Location	USLWW	USRWW	LABUT	RABUT	LB	RB	DSLWW	DSRWW
Type	N	-	-	-	0	N	-	-
Condition	-	-	0	N	-	-	-	-
Extent	0	N	-	-	-	0	0	0

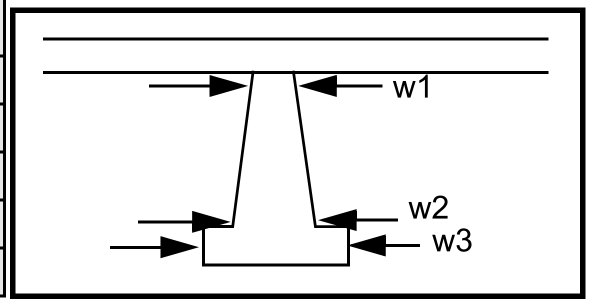
Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other

83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):
-
-
3
2
1
3
3
1
-
-
-

Piers:

84. Are there piers? _-_ *(Y or if N type ctrl-n pr)*

85. Pier no.	width (w) feet			elevation (e) feet		
	w1	w2	w3	e@w1	e@w2	e@w3
Pier 1	-	-	-	-	-	-
Pier 2	-	3.0	3.6	-	496.5	485.0
Pier 3	0.0	3.2	3.6	0.0	496.5	485.0
Pier 4	0.0	-	-	0.0	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	-	boul-	have	een	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	-	ders	slum	the	***1**- Solid pier, **2**- column, **3**- bent*
88. Material	0	form	ped	boul-	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	-	the	sligh	ders	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	-	abut	tly	has	*Y- yes; N- no*
91. Attack ∠ (BF)	0	ment	and/	erod	
92. Pushed	-	flow	or	ed	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles	-	thro	fill	such	
95. Cross-members	Larg	ugh	mate	that	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	e	type	rial	the	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	gran	slope	once	bot-	
98. Exposure depth	ite	sand	betw	tom	

99. Pier comments (eg. undermined penetration, protection and protection extent, unusual scour processes, etc.):

of the concrete abutment walls are exposed. The riprap on the right abutment appears to have at least slumped down off from the right abutment wall as the top of the riprap boulders sits lower on the wall than on the left abutment wall. Some boulders have rolled off the slope and into the channel under span 3 and are not protecting effectively the concrete right abutment wall. The fill behind the right abutment wall has begun to erode from the abutment slope.

E. Downstream Channel Assessment

100.

SRD	Bank height (BF) LB	Bank height (BF) RB	Bank angle (BF) LB	Bank angle (BF) RB	% Veg. cover (BF) LB	% Veg. cover (BF) RB	Bank material (BF) LB	Bank material (BF) RB	Bank erosion (BF) LB	Bank erosion (BF) RB
-	-			-	Y	MC	L	1	2	1

Bank width (BF) - Channel width (Amb) 25.0 Thalweg depth (Amb) 26.1 Bed Material N

Bank protection type (Qmax): LB 5 RB LB Bank protection condition: LB 1 RB 0

*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.):

1
2.0
0.0
MCR
1
2
1
N
10
LB
1
0
1
2.0
0.0

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

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

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

-
-
-
-
-
-

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: -

Point or side bar comments (Circle Point or Side; note additional bars, material variation, status, etc.):

-
-
-
-

Is a cut-bank present? - (Y or if N type ctrl-n cb) Where? - (LB or RB) Mid-bank distance: The

Cut bank extent: re is feet hea (US, UB, DS) to vy feet con (US, UB, DS)

Bank damage: cre (**1**- eroded and/or creep; **2**- slip failure; **3**- block failure)

Cut bank comments (eg. additional cut banks, protection condition, etc.):

te spalling from the base of each pier to about 3 to 4 feet up each pier wall with "re-bar" exposed. Wood used to make the concrete forms are visible on the streambed surface at the base of each pier. Type-1 stone fill is placed around entire circumference of pier 2. None is evident on pier 1. A local scour hole has developed around each pier. Around pier 1, the hole is evident as the bed drops from 1 foot deep at 5 feet upstream of the

Is channel scour present? pie (Y or if N type ctrl-n cs) Mid-scour distance: r to 3

Scour dimensions: Length feet Width deep Depth: at Positioned the %LB to nos %RB

Scour comments (eg. additional scour areas, local scouring process, etc.):

e of the pier. The deepest part of the channel runs along the left bank side of pier 2. The riprap at the nose of pier 2 has eroded away or slumped, settling deeper into the material in the hole. The hole is 4 feet deep at the nose compared to 2 feet deep elsewhere upstream and around the hole. The footings of both piers at their noses are detectable by rangepole covered by a one to two inch sediment layer.

Are there major confluences? (Y or if N type ctrl-n mc) How many? 1

Confluence 1: Distance 1 Enters on 1 (LB or RB) Type 7 (**1**- perennial; **2**- ephemeral)

Confluence 2: Distance 0 Enters on 0 (LB or RB) Type - (**1**- perennial; **2**- ephemeral)

Confluence comments (eg. confluence name):

3
3

F. Geomorphic Channel Assessment

107. Stage of reach evolution 1

1- *Constructed*
2- *Stable*
3- *Aggraded*
4- *Degraded*
5- *Laterally unstable*
6- *Vertically and laterally unstable*

108. Evolution comments *(Channel evolution not considering bridge effects; See HEC-20, Figure 1 for geomorphic descriptors)*:

1

The banks of halls stream end about 20 feet downstream of the bridge as the stream flows into the Connecticut river there. The banks are protected to the confluence on the left bank and beyond the point of the confluence on the right bank. The downstream right bank protection has covered completely the bank material making an assessment of it impossible. The streambed drops quickly to a depth greater than wadable downstream, which made an adequate assessment of the material impossible. A best bed material estimate might be the same as that indicated upstream. There is a small storm drainage pipe entering on the right bank at the confluence. Velocities are swift through the bridge but then slow at the confluence. The Connecticut River then proceeds over a riffle about 250 feet downstream of the bridge. The bank and channel width shown above were taken from that computed for the under bridge section. A downstream cross section was not surveyed. Therefore, the bank heights and angles and the thalweg depth indicated here are estimates and were not computed.

109. G. Plan View Sketch

-

point bar (pb)	debris	flow (Q →)	stone wall
cut-bank (cb)	rip rap or stone fill	cross-section	other wall
scour hole		ambient channel	

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number:	CANATH00010001	Town:	Canaan
Road Number:	TH 1	County:	Essex
Stream:	Hall's Stream		

Initials EMB   Date: 10/4/96 Checked:

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

Critical Velocity of Bed Material (converted to English units)
Vc=11.21*y1^0.1667*D50^0.33 with Ss=2.65
(Richardson and others, 1995, p. 28, eq. 16)

Approach Section

Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	6320	7650	6550
Main Channel Area, ft2	1313	1566	1353
Left overbank area, ft2	2382	3181	2507
Right overbank area, ft2	0	0	0
Top width main channel, ft	151.7	154.3	152.1
Top width L overbank, ft	479.8	484.7	483.4
Top width R overbank, ft	0	0	0
D50 of channel, ft	0.0165	0.0165	0.0165
D50 left overbank, ft	0	0	0
D50 right overbank, ft	0	0	0
y1, average depth, MC, ft	8.7	10.1	8.9
y1, average depth, LOB, ft	5.0	6.6	5.2
y1, average depth, ROB, ft	ERR	ERR	ERR
Total conveyance, approach	350593	498248	371884
Conveyance, main channel	229127	303205	240233
Conveyance, LOB	121466	195043	131651
Conveyance, ROB	0	0	0
Percent discrepancy, conveyance	0.0000	0.0000	0.0000
Qm, discharge, MC, cfs	4130.4	4655.3	4231.2
Ql, discharge, LOB, cfs	2189.6	2994.7	2318.8
Qr, discharge, ROB, cfs	0.0	0.0	0.0
Vm, mean velocity MC, ft/s	3.1	3.0	3.1
Vl, mean velocity, LOB, ft/s	0.9	0.9	0.9
Vr, mean velocity, ROB, ft/s	ERR	ERR	ERR
Vc-m, crit. velocity, MC, ft/s	4.1	4.2	4.1
Vc-l, crit. velocity, LOB, ft/s	0.0	0.0	0.0
Vc-r, crit. velocity, ROB, ft/s	N/A	N/A	N/A

Results

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

Main Channel	0	0	0

ARMORING

D90	0.0769	0.0769	0.0769
D95	0.0899	0.0899	0.0899
Critical grain size,Dc, ft	0.2348	0.1167	0.2456
Decimal-percent coarser than Dc	N/A	N/A	N/A
Depth to armoring,ft	N/A	N/A	N/A

Clear Water Contraction Scour in MAIN CHANNEL

y2 = (Q2^2/(131*Dm^(2/3)*W2^2))^(3/7)   Converted to English Units
ys=y2-y_bridge
(Richardson and others, 1995, p. 32, eq. 20, 20a)

Approach Section	Q100	Q500	Qother
Main channel Area, ft2	1313	1566	1353
Main channel width, ft	151.7	154.3	152.1
y1, main channel depth, ft	8.66	10.15	8.90
Bridge Section			
(Q) total discharge, cfs	6320	7650	6550
(Q) discharge thru bridge, cfs	6320	6668	6550
Main channel conveyance	74505	96294	75667
Total conveyance	74505	96294	75667
Q2, bridge MC discharge,cfs	6320	6668	6550
Main channel area, ft2	597	854	604
Main channel width (skewed), ft	91.9	95.1	92.2
Cum. width of piers in MC, ft	6.7	6.7	6.7
W, adjusted width, ft	85.2	88.4	85.5
y_bridge (avg. depth at br.), ft	7.01	9.66	7.07
Dm, median (1.25*D50), ft	0.020625	0.020625	0.020625
y2, depth in contraction,ft	15.04	15.26	15.46
ys, scour depth (y2-ybridge), ft	8.03	5.60	8.39

Pressure Flow Scour (contraction scour for orifice flow conditions)

Hb+Ys=Cq*qbr/Vc   Cq=1/Cf*Cc   Cf=1.5*Fr^0.43 (<=1)
Chang Equation   Cc=SQRT[0.10(Hb/(ya-w)-0.56)]+0.79 (<=1)
(Richarson and others, 1995, p. 145-146)

	Q100	Q500	OtherQ
Q, total, cfs	6320	7650	6550
Q, thru bridge, cfs	6320	6668	6550
Total Conveyance, bridge	74505	96294	75667
Main channel(MC) conveyance, bridge	74505	96294	75667
Q, thru bridge MC, cfs	6320	6668	6550
Vc, critical velocity, ft/s	4.09	4.20	4.11
Vc, critical velocity, m/s	1.25	1.28	1.25
Main channel width (skewed), ft	91.9	95.1	92.2
Cum. width of piers in MC, ft	6.7	6.7	6.7
W, adjusted width, ft	85.2	88.4	85.5
qbr, unit discharge, ft^2/s	74.2	75.4	76.6
qbr, unit discharge, m^2/s	6.9	7.0	7.1
Area of full opening, ft^2	597.1	854.0	604.4
Hb, depth of full opening, ft	7.01	9.66	7.07
Hb, depth of full opening, m	2.14	2.94	2.15
Fr, Froude number, bridge MC	0.94	0.46	0.96
Cf, Fr correction factor (<=1.0)	1.00	1.00	1.00
Elevation of Low Steel, ft	0	496.4	0
Elevation of Bed, ft	-7.01	486.74	-7.07
Elevation of Approach, ft	0	497.71	0
Friction loss, approach, ft	0	0.13	0
Elevation of WS immediately US, ft	0.00	497.58	0.00
ya, depth immediately US, ft	7.01	10.84	7.07
ya, depth immediately US, m	2.14	3.30	2.15
Mean elevation of deck, ft	0	501.37	0
w, depth of overflow, ft (>=0)	0.00	0.00	0.00
Cc, vert contrac correction (<=1.0)	1.00	0.97	1.00
Ys, depth of scour, ft	N/A	8.82	N/A

Comparison of Chang and Laursen results (for unsubmerged orifice flow)

y2, from Laursen’s equation, ft	0	15.25888	0
Full valley WSEL, ft	0	494.15	0
Full valley depth, ft	7.008216	7.410633	7.069006
Ys, depth of scour (y2-yfullv), ft	0	7.848244	0

Abutment Scour

Froehlich's Abutment Scour
Ys/Y1 = 2.27*K1*K2*(a'/Y1)^0.43*Fr1^0.61+1
(Richardson and others, 1995, p. 48, eq. 28)

Characteristic	Left Abutment 100 yr Q	500 yr Q	Other Q	Right Abutment 100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	6320	7650	6550	6320	7650	6550
a', abut.length blocking flow, ft	497	500.2	500.3	58.1	60.7	58.5
Ae, area of blocked flow ft2	2537.36	3122.93	2664.73	447.5	544.83	461.98
Qe, discharge blocked abut.,cfs	2655.74	--	2788.92	1285.79	1464.8	1313.76
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	1.05	1.03	1.05	2.87	2.69	2.84
ya, depth of f/p flow, ft	5.11	6.24	5.33	7.70	8.98	7.90
--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthrough)						
K1	0.55	0.55	0.55	0.55	0.55	0.55
--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)						
theta	90	90	90	90	90	90
K2	1.00	1.00	1.00	1.00	1.00	1.00
Fr, froude number f/p flow	0.082	0.070	0.080	0.182	0.158	0.178
ys, scour depth, ft	15.01	16.38	15.37	15.82	17.25	16.05

HIRE equation (a'/ya > 25)
ys = 4*Fr^0.33*y1*K/0.55
(Richardson and others, 1995, p. 49, eq. 29)

a'(abut length blocked, ft)	497	500.2	500.3	58.1	60.7	58.5
y1 (depth f/p flow, ft)	5.11	6.24	5.33	7.70	8.98	7.90
a'/y1	97.35	80.12	93.93	7.54	6.76	7.41
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.08	0.07	0.08	0.18	0.16	0.18
Ys w/ corr. factor K1/0.55:						
vertical	16.24	18.88	16.83	ERR	ERR	ERR
vertical w/ ww's	13.32	15.48	13.80	ERR	ERR	ERR
spill-through	8.93	10.38	9.25	ERR	ERR	ERR

Abutment riprap Sizing

Isbash Relationship
D50=y*K*Fr^2/(Ss-1) and D50=y*K*(Fr^2)^0.14/(Ss-1)
(Richardson and others, 1995, p112, eq. 81,82)

Characteristic	Q100	Q500	Qother			
Fr, Froude Number	0.94	0.46	0.96	0.94	0.46	0.96
(Fr from the characteristic V and y in contracted section--mc, bridge section)						
y, depth of flow in bridge, ft	7.01	9.66	7.07	7.01	9.66	7.07
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (spillthrough abut.)	ERR	1.10	ERR	ERR	1.10	ERR
Fr>0.8 (spillthrough abut.)	2.55	ERR	2.58	2.55	ERR	2.58

Pier Scour (both live-bed and clear water scour)

ys/y1=2.0*K1*K2*K3*K4*(a/y1)^0.65*Fr1^0.43
(Richardson and others, 1995, p. 36, eq. 21)

K1, corr. factor for pier nose shape
Sharp nose, 0.9; round nose, cylinder, or cylinder grp., 1.0; square nose, 1.1

K2, corr. factor attack angle (see Table 3, p 37)
K2=[cos(attackangle)+L/a*sin(attackangle)]^0.65

K3, corr. factor for bed condition
Clear-water, plane bed, antidune, 1.1; med. dunes, 1.1-1.2 (see Tab.4,p37)

K4, corr. factor for armoring (the following equations are in Si units)
K4=[1-0.89*(1-Vr)^2]^0.5
Vr=(V1-Vi)/(Vc90-Vi)
V1=0.645*((D50/a)^0.053)*Vc50
Vc=6.19*(y^1/6)*(Dc^1/3)

Note for round nose piers:
ys<=2.4 times the pier width (a) for Fr<=0.8
ys<=3.0 times the pier width (a) for Fr>0.8

Pier 1	Q100	Q500	Qother	
Pier stationing, ft	30.7	30.7	30.7	
Area of WSPRO flow tube, ft2	25.9	40.2	26.2	
Skewed width of flow tube, ft	2.9	3.4	2.9	
y1, pier approach depth, ft	8.93	11.82	9.03	
y1 in meters	2.722	3.604	2.754	
V1, pier approach velocity, ft/s	12.19	8.33	12.5	
a, pier width, ft	3.35	3.35	3.35	
L, pier length, ft	26	26	26	
Fr1, Froude number at pier	0.719	0.427	0.733	
Pier attack angle, degrees	5	5	5	
K1, shape factor	1	1	1	
K2, attack factor	1.40	1.40	1.40	
K3, bed condition factor	1.1	1.1	1.1	
D50, ft	0.0665	0.0665	0.0665	0.0165
D50, m	0.020268	0.020268	0.020268	
D90, ft	0.134	0.134	0.134	0.0769
D90, m	0.040841	0.040841	0.040841	
Vc50,critical velocity(D50),m/s	1.994	2.090	1.998	
Vc90,critical velocity(D90),m/s	2.519	2.639	2.524	
Vi,incipient velocity,m/s	1.045	1.095	1.047	
Vr, velocity ratio	1.812	0.935	1.871	
K4, armor factor	0.00	0.00	0.00	
ys, scour depth (K4 applicable) ft	0.00	0.00	0.00	
ys, scour depth (K4 not applied)ft	12.59	11.10	12.75	

Pier 2	Q100	Q500	Qother
Pier stationing, ft	63.9	63.9	63.9
Area of WSPRO flow tube, ft2	25.9	40.2	26.2
Skewed width of flow tube, ft	2.9	3.4	2.9
y1, pier approach depth, ft	8.93	11.82	9.03
y1 in meters	2.722	3.604	2.754
V1, pier approach velocity, ft/s	12.19	8.33	12.5
a, pier width, ft	3.35	3.35	3.35
L, pier length, ft	26	26	26
Fr1, Froude number at pier	0.719	0.427	0.733
Pier attack angle, degrees	10	10	10
K1, shape factor	1	1	1
K2, attack factor	1.73	1.73	1.73
K3, bed condition factor	1.1	1.1	1.1
D50, ft	0.0665	0.0665	0.0665
D50, m	0.020268	0.020268	0.020268
D90, ft	0.134	0.134	0.134
D90, m	0.040841	0.040841	0.040841
Vc50,critical velocity(D50),m/s	1.994	2.090	1.998
Vc90,critical velocity(D90),m/s	2.519	2.639	2.524
Vi,incipient velocity,m/s	1.045	1.095	1.047
Vr, velocity ratio	1.812	0.935	1.871
K4, armor factor	0.00	0.00	0.00
ys, scour depth, (K4 applicable) ft	0.00	0.00	0.00
ys, scour depth, (K4 not applied)ft	15.63	13.78	15.82

D50=0.692(K*V)^2/(Ss-1)*2*g
(Richardson and others, 1995, p.115, eq. 83)

Pier-shape coefficient (K), round nose, 1.5; square nose, 1.7
Characteristic avg. channel velocity, V, (Q/A):
(Mult. by 0.9 for bankward piers in a straight, uniform reach,
up to 1.7 for a pier in main current of flow around a bend)

Pier 1	Q100	Q500	Qother
K, pier shape coeff.	1.5	1.5	1.5
V, char. aver. velocity, ft/s	10.6	7.81	10.8
D50, median stone diameter, ft	1.65	0.89	1.71

Pier 2			
K, pier shape coeff.	1.5	1.5	1.5
V, char. aver. velocity, ft/s	10.6	7.81	10.8
D50, median stone diameter, ft	1.65	0.89	1.71