LEVEL II SCOUR ANALYSIS FOR BRIDGE 22 (CRAFTH00180022) on TOWN HIGHWAY 18, crossing the BLACK RIVER, CRAFTSBURY, VERMONT

U.S. Geological Survey
Open-File Report 96-158

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

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By JOSEPH D. AYOTTE

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Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
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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 22 (CRAFTH00180022) ON TOWN HIGHWAY 18, CROSSING THE BLACK RIVER, CRAFTSBURY, VERMONT

***By* Joseph D. Ayotte**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure CRAFTH00180022 on town highway 18 crossing the Black River, Craftsbury, 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, available from 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 New England Upland physiographic province of north-central Vermont in the town of Craftsbury. The 41.6-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks and floodplains are pasture and have no woody vegetation coverage.

In the study area, the Black River is not incised, has a meandering channel with a slope of approximately 0.0004 ft/ft, an average channel top width of 66 ft, and an average channel depth of 3 ft. The predominant channel bed material is sand (D_{50} is 0.148 mm or 0.000487 ft). The geomorphic assessment at the time of the Level I and Level II site visit on June 13, 1995, indicated that the reach was laterally unstable.

The town highway 18 crossing of the Black River is a 60-ft-long, one-lane bridge consisting of one 55-foot clear-span riveted through-girder type structure with a timber deck (Vermont Agency of Transportation, written commun., August 3, 1994). The bridge is supported by concrete abutments with no wingwalls. The bridge skew is approximately 5 degrees and there is no opening-skew-to-roadway.

A scour hole 3 ft deeper than the mean thalweg depth was observed 35 ft downstream of the bridge during the Level I assessment. There is also approximately 2 ft of channel scour upstream of the bridge. There is type-one (less than 12 in diameter) protection on both abutments that may act, in part, as spill-through abutments; the material however is partially made up of the remnants of older log-cribbing abutments, when the bridge length was significantly less than the current structure. 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, 1993). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The scour analysis results are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

Albany, VT. Quadrangle, 1:24,000, 1986

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 CRAFTH00180022 ***Stream*** Black River

County Orleans ***Road*** TH018 ***District*** 09

Description of Bridge

Bridge length 60 ***ft*** ***Bridge width*** 14.8 ***ft*** ***Max span length*** 55 ***ft***

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

Abutment type Vertical ***Embankment type*** Sloping

Stone fill on abutment? Yes ***Date of inspection*** 6/13/95

Description of stone fill Mostly type-1, sloping from abutment toward the channel, also partially comprised of remnant log-cribbing from abutments of previous structure, near the toe of the stone fill.

Brief description of piers/abutments Abutments are concrete; older log-cribbing abutment remants are still in place. Stone fill is sloped up to concrete abutments.

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 5

There is a mild channel bend in the downstream reach. A scour hole has developed 35 ft downstream of the bridge.

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	6/13/95	0	0
Level II	6/13/95	--	--

Potential for debris Low.

Describe any features near or at the bridge that may affect flow (include observation date) None--6/13/95.

Description of the Geomorphic Setting

General topography The channel is located within a 1,000 foot-wide, flat to slightly irregular flood plain with steep valley walls on both sides.

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

Date of inspection 6/13/95

DS left: Wide flood plain to steep valley wall

DS right: Wide flood plain to steep valley wall

US left: Wide flood plain to steep valley wall

US right: Wide flood plain to steep valley wall

Description of the Channel

Average top width 66 ***ft*** ***Average depth*** 3 ***ft***

Predominant bed material Sand ***Bank material*** Sand

Sinuous, laterally unstable with alluvial channel boundaries and a wide flood plain.

6/13/95

Vegetative co

Pasture land

DS left: Pasture land

DS right: Pasture land

US left: Pasture land

US right: N

Do banks appear stable? ***If not, describe location and type of instability and date of observation.*** The US RB and the DS LB are affected by significant cut banks; the DS cut bank has minor erosion of bank material. The US cut bank is noted as more than minor erosion. There is also significant channel widening immediately DS of the bridge.

The assessment of

6/13/95 noted no channel obstructions

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 41.6 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
New England Upland	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization:*** None

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

USGS gage description Black River at Coventry

USGS gage number 04296000

Gage drainage area 122 ***mi²***

Is there a lake/p No --

Calculated Discharges

Q100 2,440 ***ft³/s*** ***Q500*** 2,810 ***ft³/s***

The 100- and 500-year discharges are based on a drainage area relationship with the above mentioned gage using an exponent of 0.5. The exponent was derived using data at the gage and data from Craftsbury bridge 23. From the VTAOT data base, the 100-year discharge is estimated to be 2100 cubic feet per second and the drainage area is 30.9 square miles (VTAOT, written commun. May, 1995). At the gage (04296000) the 100-year discharge is estimated to be 4,080 cubic feet per second.

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 0.1 from USGS survey to obtain VTAOT datum

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on top of concrete bridge seat at streamward corner, DS end of Left abutment (elev. 504.27 ft, arbitrary datum). RM2 is a chiseled X on top of concrete bridge seat at streamward corner, US end of right abutment (elev. 503.01 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT1	-77	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXIT1)
BRIDG	0	1	Bridge section
RDWAY	9	1	Road Grade section
SURVA	93	1	Surveyed approach section
APPRO	71	2	Modelled Approach section (Templated from SURVA)

[1] For location of cross-sections see plan-view plot 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). 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, Jr. and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.04 to 0.58, and overbank "n" values ranged from 0.05 to 0.065.

Normal depth at the exit section (EXIT1) 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 0.0004 ft/ft which was estimated from the topographic map (U.S. Geological Survey, 1986).

The exit section is comprised of overbank points surveyed at the indicated section reference distance and channel points from several hundred feet downstream with no elevation adjustment. These points were used because the exit channel was overdeepened by as much as 3 ft from scour.

The modeled 100- and 500-year discharges overtop the right roadway embankment but not the bridge deck.

Bridge Hydraulics Summary

Average bridge embankment elevation 509.2 *ft*
Average low steel elevation 504.1 *ft*

100-year discharge 2440 *ft³/s*
Water-surface elevation in bridge opening 504.7 *ft*
Road overtopping? Y *Discharge over road* 315 *ft³/s*
Area of flow in bridge opening 348.9 *ft²*
Average velocity in bridge opening 6.0 *ft/s*
Maximum WSPRO tube velocity at bridge 7.6 *ft/s*

Water-surface elevation at Approach section with bridge 504.9
Water-surface elevation at Approach section without bridge 503.1
Amount of backwater caused by bridge 1.8 *ft*

500-year discharge 2810 *ft³/s*
Water-surface elevation in bridge opening 504.7 *ft*
Road overtopping? Y *Discharge over road* 457 *ft³/s*
Area of flow in bridge opening 349 *ft²*
Average velocity in bridge opening 6.7 *ft/s*
Maximum WSPRO tube velocity at bridge 8.5 *ft/s*

Water-surface elevation at Approach section with bridge 505.1
Water-surface elevation at Approach section without bridge 503.5
Amount of backwater caused by bridge 1.6

Incipient overtopping discharge 1780 *ft³/s*
Water-surface elevation in bridge opening 501.9 *ft*
Area of flow in bridge opening 239 *ft²*
Average velocity in bridge opening 7.4 *ft/s*
Maximum WSPRO tube velocity at bridge 9.5 *ft/s*

Water-surface elevation at Approach section with bridge 503.7
Water-surface elevation at Approach section without bridge 502.3
Amount of backwater caused by bridge 1.4 *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, 1993). 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.

The 100-year and 500-year 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). Therefore, contraction scour for these two discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). For the incipient road over-flow discharge, contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18). The results of Laursen's clear-water contraction scour for the 100-yerar and 500-year events were also computed and can be found in appendix F. For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour. In this case, the 500-year discharge model resulted in the worst case contraction scour with a scour depth of 28.5 ft.

Scour at the left and right abutments, for all modelled discharges, was computed by use of the HIRE equation (Richardson and others, 1993, p. 50, equation 25). The HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. Variables for the HIRE equation include the Froude number of the flow approaching the embankments and the depth of flow approaching the embankment less any roadway overtopping

Since the bed material is a fine sand, there is no potential for armoring.

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	24.5	28.5	19.0
Depth to armoring	N/A	N/A	N/A
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour			
Left abutment	13.0	13.8	10.5
Right abutment	14.3	15.0	12.6
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	0.7	0.9	1.7
Right abutment	0.7	0.9	1.7
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

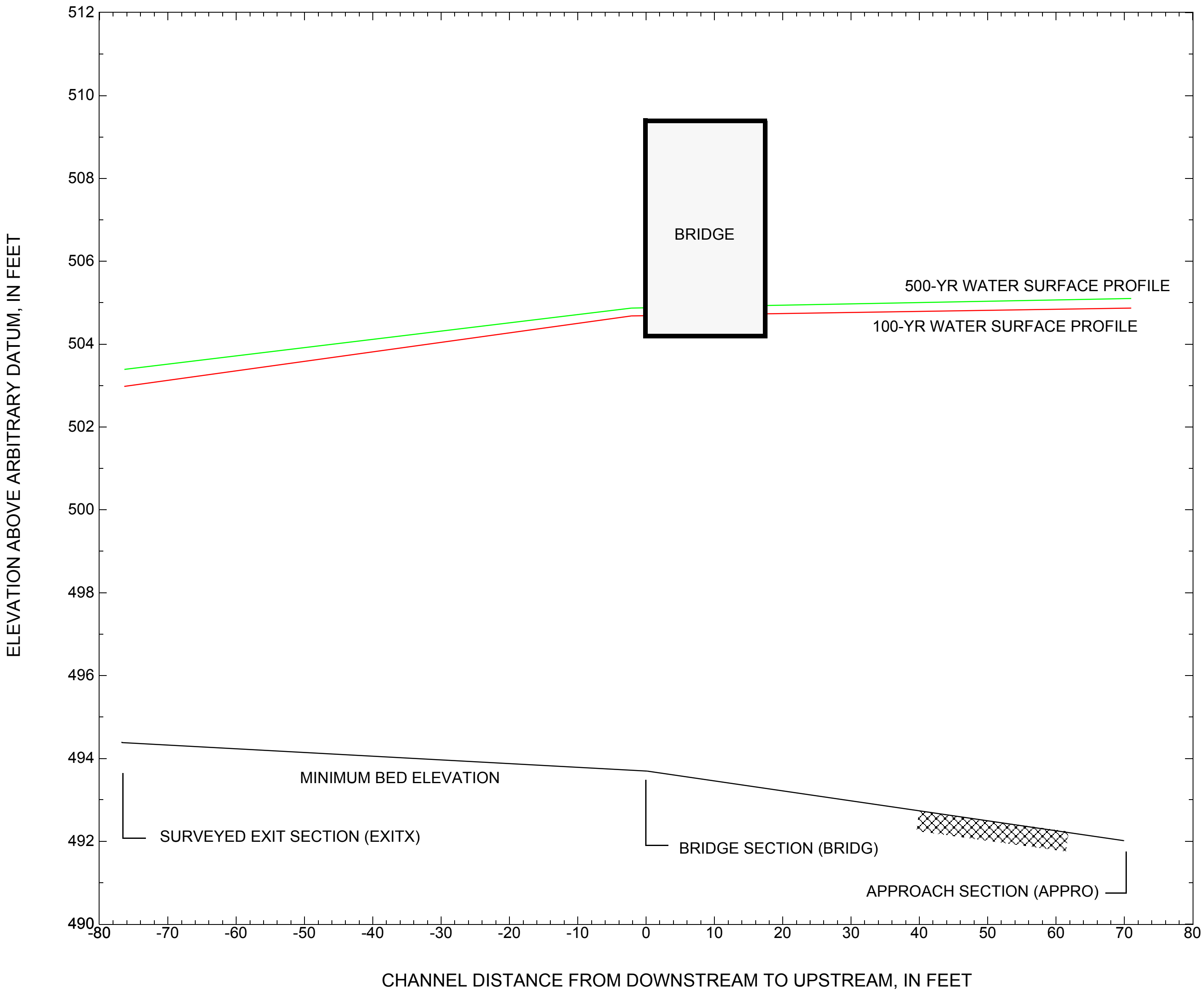

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure CRAFTH00180022 on town highway 18, crossing the Black River, Craftsbury, Vermont.

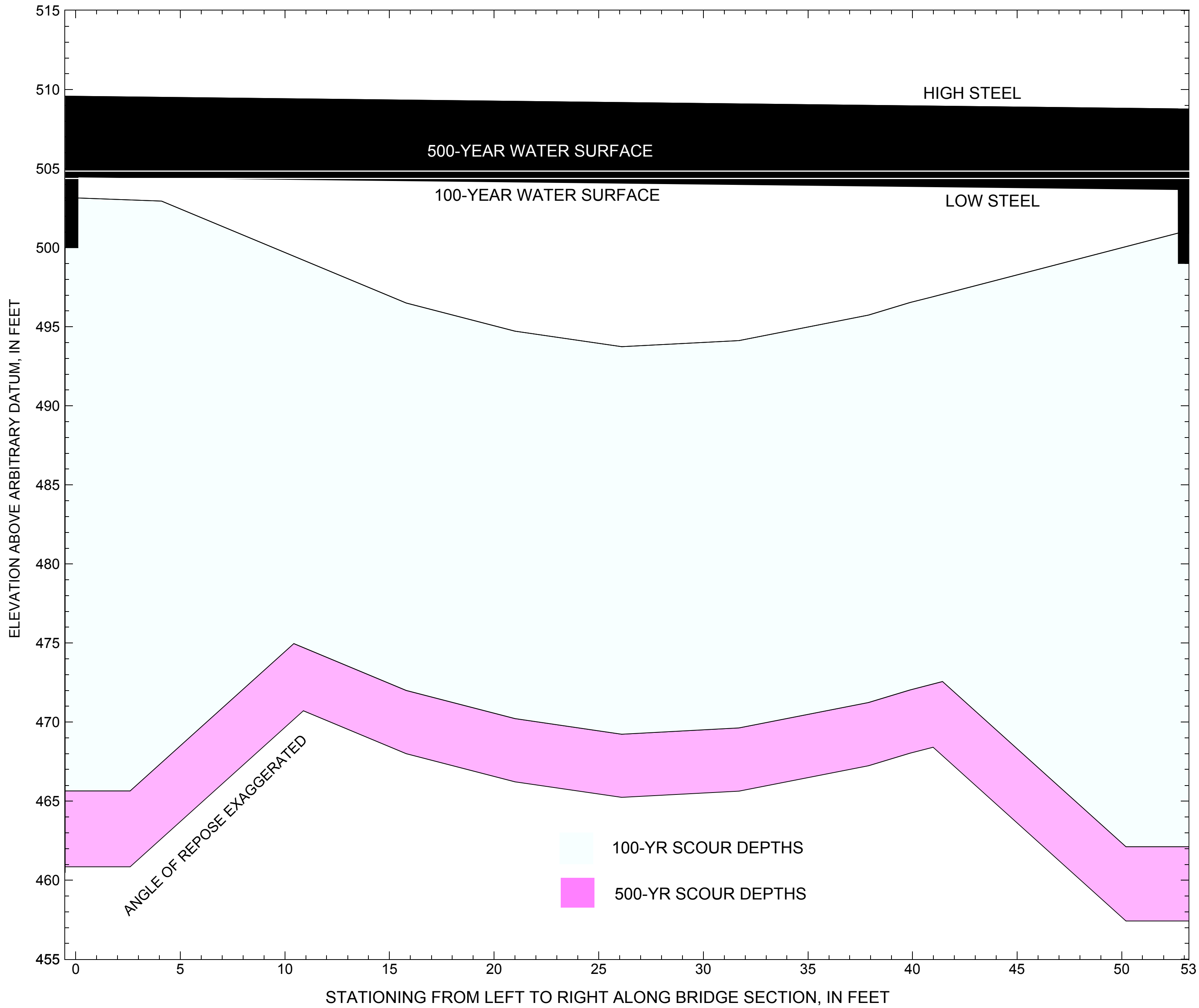

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure CRAFTH00180022 on town highway 18, crossing the Black River, Craftsbury, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure CRAFTH00180022 on Town Highway 18, crossing the Black River, Craftsbury, Vermont.

[VTAOT, Vermont Agency of Transportation; --,no data]

Description	Station[1]	VTAOT top of abutment elevation (feet)	Surveyed top of abutment 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 2,440 cubic-feet per second											
Left abutment	0.0	507.49	504.68	500.1	503.2	24.5	13.0	--	37.5	465.7	-34
Right abutment	52.7	506.11	506.32	499.1	500.9	24.5	14.3	--	38.8	462.1	-37

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 CRAFTH00180022 on Town Highway 18, crossing the Black River, Craftsbury, Vermont.

[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station[1]	VTAOT top of abutment elevation (feet)	Surveyed top of abutment 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 2,810 cubic-feet per second											
Left abutment	0.0	507.49	504.68	500.1	503.2	28.5	13.8	--	42.3	460.9	-39
Right abutment	52.7	506.11	506.32	499.1	500.9	28.5	15.0	--	43.5	457.4	-42

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

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APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File craf022.wsp
T2        Hydraulic analysis for structure crafth00180022   Date: 21-FEB-96
T3        craftsbury bridge 22 crossing black river,    JDA
Q           2440.0   2810.0   1780
SK          0.0004   0.0004   0.0004
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXIT1   -77
GR         -201.7, 511.98   -160.4, 509.14   -107.8, 508.55    -90.0, 507.14
GR          -56.8, 500.38    -38.3, 500.22    -24.7, 499.93    -13.2, 499.62
GR           -6.3, 496.59     -5.7, 495.15      7.0, 494.85     16.6, 494.76
GR           26.1, 494.36     28.9, 495.00     40.6, 496.51     47.7, 498.78
GR           47.7, 499.80     72.1, 498.85    250.6, 499.14    317.2, 502.32
GR          386.7, 509.67
*
N           0.050        0.040        0.060
SA                -13.2        47.7
*
XS   FULLV       0  * * *   0.0004
*
*            (US bridge face moved w/o correction to DS face)
*            SRD     LSEL    XSSKEW
BR   BRIDG      0    504.12       0.0
GR            0.0, 504.68      0.1, 503.15      4.1, 502.95     15.8, 496.54
GR           21.0, 494.72     26.1, 493.74     31.7, 494.13     37.9, 495.74
GR           39.9, 496.54     52.6, 500.92     52.7, 503.57      0.0, 504.68
*
*         BRTYPE  BRWDTH
CD             1      17.9
N           0.055
*
*            SRD    EMBWID   IPAVE
XR   RDWAY       9      14.8      2
GR         -196.9, 512.99   -169.2, 511.46   -105.6, 509.80     -2.4, 508.34
GR            0.0, 509.73      0.3, 509.79     52.5, 508.69     52.9, 508.62
GR           55.0, 507.19     61.1, 506.28    116.5, 504.50    159.6, 503.66
GR          209.0, 503.82    295.7, 505.68    374.1, 509.04
*
XT   SURVA      93           0.
GR         -302.7, 513.79   -272.1, 511.62   -171.2, 502.95   -136.8, 502.28
GR         -117.7, 502.10    -78.7, 497.87    -14.3, 498.36    -11.1, 497.20
GR            8.9, 496.56     12.5, 495.79     15.3, 494.08     18.4, 493.40
GR           31.1, 492.00     36.7, 493.15     40.8, 495.73     46.5, 496.57
GR           54.3, 496.86     55.2, 497.89     55.5, 497.83     74.3, 499.21
GR          169.9, 498.70    214.4, 498.95    223.7, 499.38    260.5, 500.89
GR          347.5, 509.59
*
AS   APPRO      71
GT            -.009
N           0.065        0.058        0.055
SA                -14.3        74.3
```

```
*
*
*
HP 1 BRIDG   504.68 1 504.68
HP 2 BRIDG   504.68 * * 2080
HP 2 RDWAY   504.68 * * 315
HP 1 APPRO   504.87 1 504.87
HP 2 APPRO   504.87 * * 2440
*
HP 1 BRIDG   504.68 1 504.68
HP 2 BRIDG   504.68 * * 2334
HP 2 RDWAY   504.87 * * 457
HP 1 APPRO   505.10 1 505.10
HP 2 APPRO   505.10 * * 2810
*
HP 1 BRIDG   501.94 1 501.94
HP 2 BRIDG   501.94 * * 1780
HP 1 APPRO   503.71 1 503.71
HP 2 APPRO   503.71 * * 1780
*
EX
ER
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APPENDIX B:

WSPRO OUTPUT FILE

```
        U.S. Geological Survey WSPRO Input File craf022.wsp
        Hydraulic analysis for structure crafth00180022   Date: 21-FEB-96
        craftsbury bridge 22 crossing black river,    JDA
           *** RUN DATE & TIME: 02-22-96  10:42
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     349.   20097.     0.   113.                           0.
   504.68          349.   20097.     0.   113.  1.00     0.    53.      0.
1
  HP 2 BRIDG   504.68 * * 2080
1
    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       504.68     0.0    52.7   348.9   20097.    2080.   5.96

 X STA.         0.0       11.4       15.0       17.3       19.3       21.0
   A(I)            32.7       22.7       18.7       16.8       16.0
   V(I)            3.18       4.57       5.55       6.19       6.49

 X STA.        21.0       22.6       24.1       25.5       26.8       28.2
   A(I)            15.1       14.7       14.3       13.9       13.8
   V(I)            6.89       7.07       7.26       7.47       7.53

 X STA.        28.2       29.6       30.9       32.4       33.9       35.6
   A(I)            13.9       13.8       14.2       14.4       15.1
   V(I)            7.46       7.55       7.32       7.23       6.89

 X STA.        35.6       37.4       39.5       42.1       45.6       52.7
   A(I)            15.7       16.8       17.8       20.7       27.6
   V(I)            6.63       6.19       5.85       5.01       3.77
1
  HP 2 RDWAY   504.68 * * 315
1
    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       9.

         WSEL     LEW     REW    AREA        K        Q    VEL
       504.68   110.9   249.1    90.0    1680.     315.   3.50

 X STA.       110.9      136.0      144.2      150.3      155.0      159.1
   A(I)             7.7        5.2        4.7        4.2        4.0
   V(I)            2.04       3.01       3.34       3.75       3.95

 X STA.       159.1      162.8      166.6      170.3      174.1      177.9
   A(I)             3.7        3.8        3.7        3.7        3.7
   V(I)            4.23       4.15       4.27       4.22       4.28

 X STA.       177.9      181.8      185.8      189.9      194.1      198.6
   A(I)             3.7        3.8        3.8        3.9        4.0
   V(I)            4.27       4.19       4.12       4.06       3.94

 X STA.       198.6      203.2      208.2      213.8      221.8      249.1
   A(I)             4.1        4.3        4.6        5.4        8.0
   V(I)            3.83       3.64       3.44       2.91       1.98
  HP 1 APPRO   504.87 1 504.87
CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      71.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     777.   47314.   179.   180.                        9184.
             2     785.   84768.    89.    91.                       13250.
             3    1143.   91148.   226.   226.                       14584.
   504.87         2705.  223231.   494.   497.  1.15  -194.   300.  33531.
1
  HP 2 APPRO   504.87 * * 2440

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      71.

         WSEL     LEW     REW    AREA        K        Q    VEL
       504.87  -193.6   300.4  2705.0  223231.    2440.   0.90

 X STA.      -193.6      -90.2      -65.3      -42.5      -19.9       -2.7
   A(I)           268.2      166.9      155.4      150.5      124.4
   V(I)            0.45       0.73       0.78       0.81       0.98

 X STA.        -2.7       10.4       19.8       26.9       33.7       42.8
   A(I)           107.5       96.6       86.4       85.8       96.0
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   V(I)             1.14       1.26       1.41       1.42       1.27

 X STA.        42.8       56.8       78.0      100.6      122.4      143.7
   A(I)            113.8      131.5      130.0      127.8      127.4
   V(I)             1.07       0.93       0.94       0.95       0.96

 X STA.       143.7      164.7      185.9      207.8      234.0      300.4
   A(I)            127.7      130.5      132.1      146.5      199.8
   V(I)             0.96       0.93       0.92       0.83       0.61
1
   *

   HP 1 BRIDG   504.68 1 504.68


     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     349.   20097.     0.   113.                          0.
    504.68          349.   20097.     0.   113.  1.00     0.    53.      0.
1
   HP 2 BRIDG   504.68 * * 2334
1
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        504.68     0.0    52.7   348.9   20097.    2334.   6.69

 X STA.         0.0       11.4       15.0       17.3       19.3       21.0
   A(I)             32.7       22.7       18.7       16.8       16.0
   V(I)             3.57       5.13       6.23       6.94       7.28

 X STA.        21.0       22.6       24.1       25.5       26.8       28.2
   A(I)             15.1       14.7       14.3       13.9       13.8
   V(I)             7.73       7.93       8.14       8.38       8.45

 X STA.        28.2       29.6       30.9       32.4       33.9       35.6
   A(I)             13.9       13.8       14.2       14.4       15.1
   V(I)             8.37       8.47       8.22       8.12       7.73

 X STA.        35.6       37.4       39.5       42.1       45.6       52.7
   A(I)             15.7       16.8       17.8       20.7       27.6
   V(I)             7.44       6.95       6.56       5.63       4.23
1
   HP 2 RDWAY   504.87 * * 457
1
     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       9.

          WSEL     LEW     REW    AREA        K        Q    VEL
        504.87   105.0   257.9   117.7    2454.     457.   3.88

 X STA.       105.0      131.5      140.7      147.4      152.7      157.4
   A(I)              9.9        7.0        6.1        5.5        5.2
   V(I)             2.32       3.29       3.77       4.16       4.42

 X STA.       157.4      161.5      165.6      169.6      173.7      177.9
   A(I)              5.0        4.8        4.8        4.8        4.8
   V(I)             4.58       4.74       4.77       4.71       4.77

 X STA.       177.9      182.1      186.4      190.8      195.5      200.2
   A(I)              4.9        4.8        5.0        5.2        5.1
   V(I)             4.70       4.75       4.60       4.43       4.46

 X STA.       200.2      205.3      210.7      217.3      226.4      257.9
   A(I)              5.4        5.6        6.2        7.0       10.7
   V(I)             4.25       4.05       3.66       3.24       2.13
1
   HP 1 APPRO   505.10 1 505.10
1
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      71.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     819.   51097.   182.   182.                       9857.
              2     805.   88469.    89.    91.                      13769.
              3    1195.   97537.   228.   229.                      15517.
    505.10         2819.  237103.   499.   502.  1.14  -196.   303.  35566.
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1
   HP 2 APPRO   505.10 * * 2810
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      71.

          WSEL     LEW     REW    AREA        K        Q    VEL
        505.10  -196.3   302.7  2819.2  237103.    2810.   1.00

 X STA.      -196.3      -93.3      -66.6      -43.8      -21.3       -3.6
   A(I)           274.4      181.2      160.8      154.9      131.1
   V(I)            0.51       0.78       0.87       0.91       1.07

 X STA.        -3.6        9.6       19.4       26.9       33.9       43.4
   A(I)           110.7      101.4       91.9       89.6      102.5
   V(I)            1.27       1.39       1.53       1.57       1.37

 X STA.        43.4       58.0       79.4      101.7      123.6      144.5
   A(I)           119.7      135.6      133.4      133.7      130.1
   V(I)            1.17       1.04       1.05       1.05       1.08

 X STA.       144.5      165.5      186.7      208.7      234.8      302.7
   A(I)           132.7      135.5      137.2      151.9      210.8
   V(I)            1.06       1.04       1.02       0.92       0.67
1
   *
   HP 1 BRIDG   501.94 1 501.94
1     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     239.   18284.    47.    51.                        3076.
    501.94          239.   18284.    47.    51.  1.00     6.    53.   3076.
1
   HP 2 BRIDG   501.94 * * 1780

     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        501.94     5.9    52.6   239.4   18284.    1780.   7.44

 X STA.         5.9       14.7       17.4       19.4       21.0       22.4
   A(I)            21.2       14.3       12.5       11.1       10.5
   V(I)            4.20       6.23       7.10       8.04       8.44

 X STA.        22.4       23.7       25.0       26.1       27.3       28.4
   A(I)            10.1        9.9        9.5        9.4        9.3
   V(I)            8.82       9.00       9.41       9.45       9.54

 X STA.        28.4       29.6       30.8       32.1       33.4       34.9
   A(I)             9.5        9.4        9.7       10.3       10.5
   V(I)            9.37       9.47       9.15       8.67       8.50

 X STA.        34.9       36.5       38.3       40.8       44.0       52.6
   A(I)            10.9       11.7       13.3       14.9       21.4
   V(I)            8.20       7.59       6.68       5.96       4.16
1
   HP 1 APPRO   503.71 1 503.71
1
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      71.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     577.   30348.   166.   166.                        6109.
              2     682.   67082.    89.    91.                       10734.
              3     887.   61930.   214.   215.                       10244.
    503.71         2146.  159361.   469.   472.  1.18  -180.   289.  24009.
1
   HP 2 APPRO   503.71 * * 1780
1     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      71.

          WSEL     LEW     REW    AREA        K        Q    VEL
        503.71  -180.1   288.8  2146.5  159361.    1780.   0.83

 X STA.      -180.1      -78.9      -54.9      -32.8      -11.1        2.0
   A(I)           214.9      138.5      123.4      119.6       87.6
   V(I)            0.41       0.64       0.72       0.74       1.02

 X STA.         2.0       13.4       20.7       26.9       32.6       39.4
   A(I)            83.3       72.4       67.1       65.6       72.1
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   V(I)             1.07       1.23       1.33       1.36       1.23

 X STA.        39.4       50.8       68.5       92.6      115.1      137.2
   A(I)             85.0      102.2      110.8      104.8      106.0
   V(I)             1.05       0.87       0.80       0.85       0.84

 X STA.       137.2      158.7      179.4      201.6      226.5      288.8
   A(I)            105.0      103.7      108.7      115.6      160.1
   V(I)             0.85       0.86       0.82       0.77       0.56
1
   *
   EX
 +++ BEGINNING PROFILE CALCULATIONS --   3
  XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
        SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

 EXIT1:XS   ******   -70.    1539.  0.07 *****  503.05  499.92   2440.  502.98
      -77. ******   323.  121984.  1.69 ***** *******    0.18    1.59

 FULLV:FV      77.   -70.    1540.  0.07  0.03  503.08 *******   2440.  503.02
        0.    77.   323.  122105.  1.69  0.00    0.00    0.18    1.58
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPRO:AS      71.  -173.    1854.  0.03  0.03  503.11 *******   2440.  503.08
       71.    71.   282.  128789.  1.20  0.00    0.00    0.13    1.32
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
            WS1,WSSD,WS3,RGMIN =   505.10       0.00     502.67     503.66

  ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

  ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
            WS3,WSIU,WS1,LSEL =   502.92     504.72     504.79     504.12

  ===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      77.     0.     349.  0.55 *****  505.23  500.64   2080.  504.68
        0. ******    53.   20097.  1.00 ***** *******    0.41    5.96

     TYPE PPCD FLOW       C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****    5.  0.372  0.000  504.12 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.    56.  0.01  0.01  504.88   -0.02    315.  504.68

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****
   RT:    315.   138.   111.   249.   1.0   0.7   4.0   3.5   0.9   2.9

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

 APPRO:AS      53.  -194.    2707.  0.01  0.08  504.89  499.23   2440.  504.87
       71.    71.   300.  223514.  1.15  0.15   -0.02    0.07    0.90

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********

                      <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
   FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT1:XS     -77.   -70.   323.   2440.  121984.    1539.    1.59  502.98
   FULLV:FV       0.   -70.   323.   2440.  122105.    1540.    1.58  503.02
   BRIDG:BR       0.     0.    53.   2080.   20097.     349.    5.96  504.68
   RDWAY:RG       9.*******     0.    315.       0.*********    2.00  504.68
   APPRO:AS      71.  -194.   300.   2440.  223514.    2707.    0.90  504.87

    XSID:CODE   XLKQ   XRKQ       KQ
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   APPRO:AS  **********************
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT1:XS    499.92    0.18  494.36  511.98************  0.07  503.05  502.98
   FULLV:FV  ********    0.18  494.39  512.01  0.03  0.00  0.07  503.08  503.02
   BRIDG:BR    500.64    0.41  493.74  504.68************  0.55  505.23  504.68
   RDWAY:RG  ****************  503.66  512.99  0.01******  0.01  504.88  504.68
   APPRO:AS    499.23    0.07  491.99  513.78  0.08  0.15  0.01  504.89  504.87
1
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXIT1:XS   ******   -72.    1702.  0.07 *****  503.46  500.13   2810.  503.39
      -77. ******   327.  140370.  1.64 ***** *******    0.18    1.65

FULLV:FV      77.   -72.    1703.  0.07  0.03  503.50 *******   2810.  503.43
        0.    77.   327.  140502.  1.64  0.00    0.00    0.18    1.65
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      71.  -178.    2043.  0.03  0.03  503.52 *******   2810.  503.49
       71.    71.   287.  148272.  1.19  0.00    0.00    0.13    1.38
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   505.81       0.00     503.03     503.66

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   503.50     505.16     505.23     504.12

 ===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      77.     0.     349.  0.70 *****  505.38  501.01   2334.  504.68
        0. ******    53.   20097.  1.00 ***** *******    0.46    6.69

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****    5.  0.406  0.000  504.12 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.    56.  0.01  0.02  505.11   -0.01    457.  504.87

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****
   RT:    457.   153.   105.   258.   1.2   0.8   4.4   3.9   1.0   2.9

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

APPRO:AS      53.  -196.    2820.  0.02  0.10  505.12  499.42   2810.  505.10
       71.    71.   303.  237176.  1.14  0.13   -0.01    0.08    1.00

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********

                      <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT1:XS     -77.    -72.   327.   2810.  140370.    1702.    1.65  503.39
   FULLV:FV       0.    -72.   327.   2810.  140502.    1703.    1.65  503.43
   BRIDG:BR       0.      0.    53.   2334.   20097.     349.    6.69  504.68
   RDWAY:RG       9.*******     0.    457.       0.*********    2.00  504.87
   APPRO:AS      71.  -196.   303.   2810.  237176.    2820.    1.00  505.10

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  **********************
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
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    EXIT1:XS    500.13    0.18  494.36  511.98************  0.07  503.46  503.39
    FULLV:FV  ********    0.18  494.39  512.01  0.03  0.00  0.07  503.50  503.43
    BRIDG:BR    501.01    0.46  493.74  504.68************  0.70  505.38  504.68
    RDWAY:RG  ****************  503.66  512.99  0.01******  0.02  505.11  504.87
    APPRO:AS    499.42    0.08  491.99  513.78  0.10  0.13  0.02  505.12  505.10
1
  XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS      Q    WSEL
        SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

 EXIT1:XS   ******   -66.    1220.  0.06 *****  502.22  498.62   1780.  502.16
      -77. ******   314.   88924.  1.82 ***** *******    0.19    1.46

 FULLV:FV      77.   -66.    1221.  0.06  0.03  502.25 *******   1780.  502.19
        0.    77.   314.   89027.  1.82  0.00    0.00    0.19    1.46
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPRO:AS      71.  -134.    1494.  0.03  0.03  502.28 *******   1780.  502.25
       71.    71.   274.   96496.  1.20  0.00    0.00    0.12    1.19
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
            WS1,WSSD,WS3,RGMIN =   503.71       0.00     501.94     503.66

  ===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      77.     6.     239.  1.54  0.15  503.48  500.15   1780.  501.94
        0.    77.    53.   18270.  1.79  1.11    0.00    0.77    7.44

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   4.  0.748 ******  504.12 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
    RDWAY:RG       9.    56.  0.01  0.01  503.71    0.00      0.  503.70

              Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
    LT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****
    RT:      0.    14.   158.   171.   0.0   0.0   0.6   0.6   0.0   2.5

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

 APPRO:AS      53.  -180.    2145.  0.01  0.08  503.72  498.42   1780.  503.71
       71.    69.   289.  159248.  1.18  0.17    0.00    0.07    0.83

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.885  0.710   46186.    11.    58. ********

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
   FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXIT1:XS     -77.   -66.   314.   1780.   88924.    1220.    1.46  502.16
    FULLV:FV       0.   -66.   314.   1780.   89027.    1221.    1.46  502.19
    BRIDG:BR       0.     6.    53.   1780.   18270.     239.    7.44  501.94
    RDWAY:RG       9.*******     0.      0.       0.*********    2.00  503.70
    APPRO:AS      71.  -180.   289.   1780.  159248.    2145.    0.83  503.71

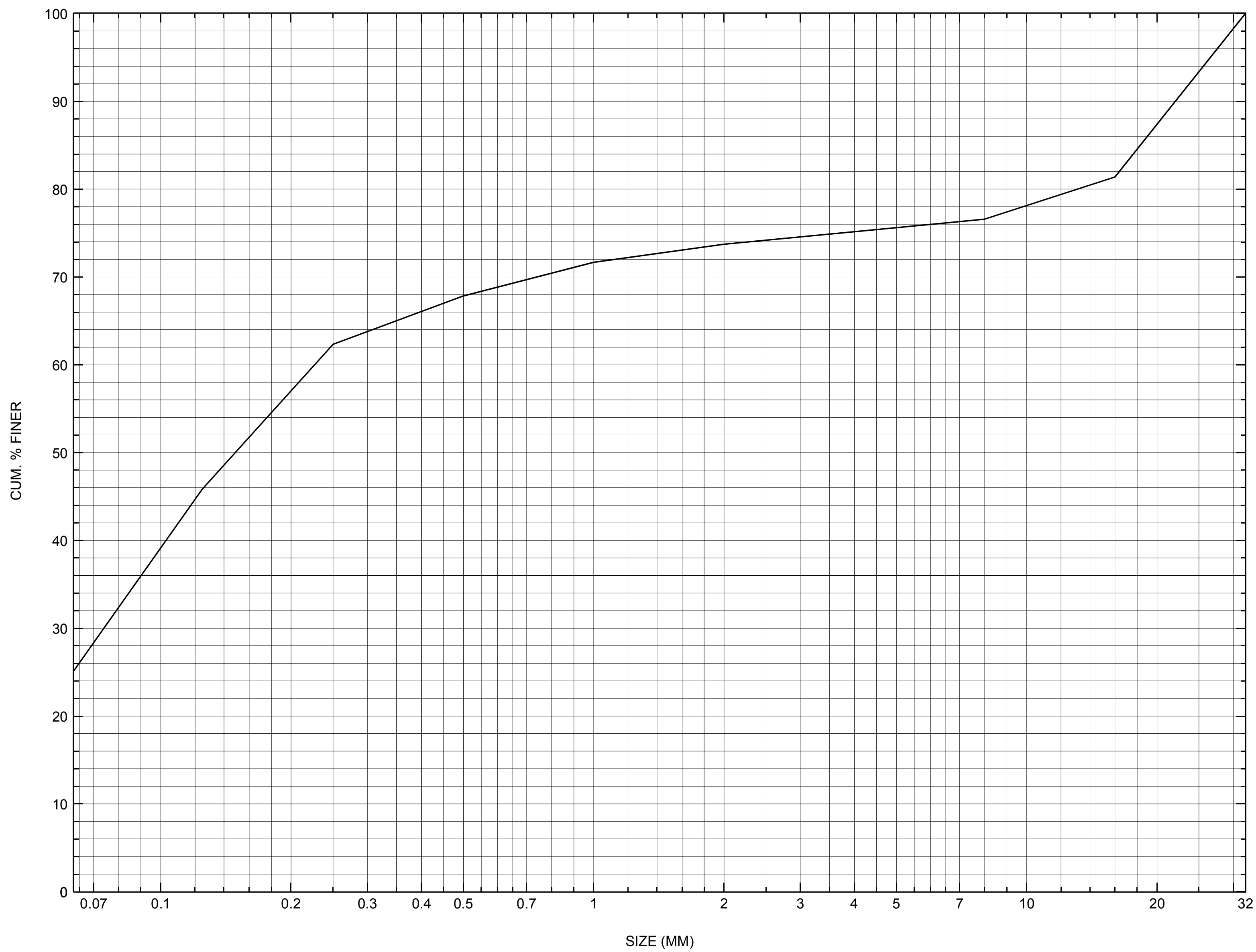
     XSID:CODE   XLKQ   XRKQ       KQ
    APPRO:AS      11.    58.   46186.

  SECOND USER DEFINED TABLE.

     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
    EXIT1:XS    498.62    0.19  494.36  511.98************  0.06  502.22  502.16
    FULLV:FV  ********    0.19  494.39  512.01  0.03  0.00  0.06  502.25  502.19
    BRIDG:BR    500.15    0.77  493.74  504.68  0.15  1.11  1.54  503.48  501.94
    RDWAY:RG  ****************  503.66  512.99  0.01******  0.01  503.71  503.70
    APPRO:AS    498.42    0.07  491.99  513.78  0.08  0.17  0.01  503.72  503.71
      END OF FILE ON PRIMARY INPUT UNIT  55
1  NORMAL  END  OF  WSPRO  EXECUTION.
```

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for fine-bed bulk sample at the approach cross-section for structure CRAFTH00180022, in Craftsbury, Vermont.

APPENDIX D:

HISTORICAL DATA FORM