LEVEL II SCOUR ANALYSIS FOR BRIDGE 26 (CRAFTH00250026) on TOWN HIGHWAY 25, crossing the BLACK RIVER, CRAFTSBURY, VERMONT

U.S. Geological Survey
Open-File Report 96-155

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

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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 26 (CRAFTH00250026) ON TOWN HIGHWAY 25, 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 CRAFTH00250026 on town highway 25 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 37.8-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the flood plains are pasture and the banks have no woody vegetation coverage.

In the study area, the Black River is not incised, has a sinuous channel with a slope of approximately 0.0004 ft/ft, an average channel top width of 32 ft, and an average channel depth of 4 ft. The predominant channel bed material is sand (D_{50} is 0.802 mm or 0.00263 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 6, 1994, indicated that the reach was laterally unstable.

The town highway 25 crossing of the Black River is a 42-ft-long, one-lane bridge consisting of one 40-foot clear-span steel stringer type structure with a timber deck (Vermont Agency of Transportation, written commun., August 4, 1994). The bridge is supported by concrete-capped, granite-block abutments with wingwalls (except for the downstream side of the left abutment). The channel is skewed to the opening by approximately 20 degrees and there is no opening-skew-to-roadway.

A scour hole 5 ft deeper than the mean thalweg depth was observed centered at 50 ft upstream of the bridge during the Level I assessment. There is sparse type-2 stone fill along the right abutment and right wingwalls. 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 CRAFTH00250026 ***Stream*** Black River

County Orleans ***Road*** TH025 ***District*** 09

Description of Bridge

Bridge length 42 ***ft*** ***Bridge width*** 22.6 ***ft*** ***Max span length*** 40 ***ft***

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

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

Stone fill on abutment? Y ***Date of inspection*** 10/6/94

Description of stone fill Type-2 along right abutment and wingwalls

Abutments are concrete-capped granite block type.

Y

Is bridge skewed to flood flow according to There ***survey?*** 20 ***Angle*** Y

is a moderate channel bend at the bridge site.

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	10/6/94	0	0
Level II	10/6/94	--	--

Potential for debris Low.

Describe any features near or at the bridge that may affect flow (include observation date) None--10/6/94.

Description of the Geomorphic Setting

General topography The channel is located within a 2,000 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 10/6/94

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 32 *ft*

Average depth 3.5 *ft*

Predominant bed material Sand

Bank material Sand

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

10/6/94

Vegetative co Pasture land

DS left: Pasture land

DS right: Pasture land

US left: Pasture land

US right: N

Do banks appear stable? The US LB and the DS RB are affected by significant cut banks; both cut banks have severe erosion with block failure of bank material. There is also significant channel widening immediately US of the bridge.

date of observation.

The assessment of 10/6/94 noted no channel obstructions

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 37.8 ***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:***

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 N

Calculated Discharges

Q100 2,320 ***ft³/s*** ***Q500*** 2,680 ***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 None

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on top of concrete curb at DS LABUT (elev. 501.37 ft, arbitrary datum). RM2 is a chiseled X in granite on top of block at US RWW (elev. 501.33 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]Cross-section	Section Reference Distance (SRD) in feet	[2]Cross-section development	Comments
EXIT	-42.5	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXIT)
BRDG	0	1	Bridge section
RD	11	1	Road Grade section
APPR	112.2	1	Surveyed approach section
APPRO	57.9	2	Moved approach to one bridge length distance

[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 0.039 to 0.044, and overbank "n" values ranged from 0.032 to 0.062.

Normal depth at the exit section (EXIT) 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 modeled 500-year discharge overtops the left roadway embankment but not the bridge deck.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.4 *ft*
Average low steel elevation 497.2 *ft*

100-year discharge 2,320 *ft^3/s*
Water-surface elevation in bridge opening 495.2 *ft*
Road overtopping? N *Discharge over road* -- *s*
Area of flow in bridge opening 230 *ft^2*
Average velocity in bridge opening 10.1 *ft/s*
Maximum WSPRO tube velocity at bridge 12.6 *ft/s*

Water-surface elevation at Approach section with bridge 497.2
Water-surface elevation at Approach section without bridge 495.6
Amount of backwater caused by bridge 1.6 *t*

500-year discharge 2,680 *ft^3/s*
Water-surface elevation in bridge opening 497.2 *ft*
Road overtopping? Y *Discharge over road* 243 */s*
Area of flow in bridge opening 300 *ft^2*
Average velocity in bridge opening 8.0 *ft/s*
Maximum WSPRO tube velocity at bridge 9.6 */s*

Water-surface elevation at Approach section with bridge 498.5
Water-surface elevation at Approach section without bridge 495.8
Amount of backwater caused by bridge 2.7

Incipient overtopping discharge 2,350 *ft^3/s*
Water-surface elevation in bridge opening 495.3 *ft*
Area of flow in bridge opening 231 *ft^2*
Average velocity in bridge opening 10.2 *ft/s*
Maximum WSPRO tube velocity at bridge 12.7 *ft/s*

Water-surface elevation at Approach section with bridge 497.3
Water-surface elevation at Approach section without bridge 495.6
Amount of backwater caused by bridge 1.7 *t*

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 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). Therefore, contraction scour for the 500-year discharge was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). The results of Laursen's clear-water contraction scour for the 500-year event are also shown in appendix F. Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) for the 100-year and incipient road-overflow discharges. For contraction scour computations using the Laursen's equation, 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 model resulted in the worst case contraction scour with a scour depth of 21.8 ft.

Scour at both abutments, for all modelled discharges, was computed by use of the HIRE equation (Richardson and others, 1993, p. 50, equation 25) because 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. 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.

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	17.2	21.8	17.4
Depth to armoring	N/A	N/A	N/A
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	8.3	9.3	8.3
Right abutment	10.3	11.9	10.4
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	2.1	1.3	2.1
Right abutment	2.1	1.3	2.1
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

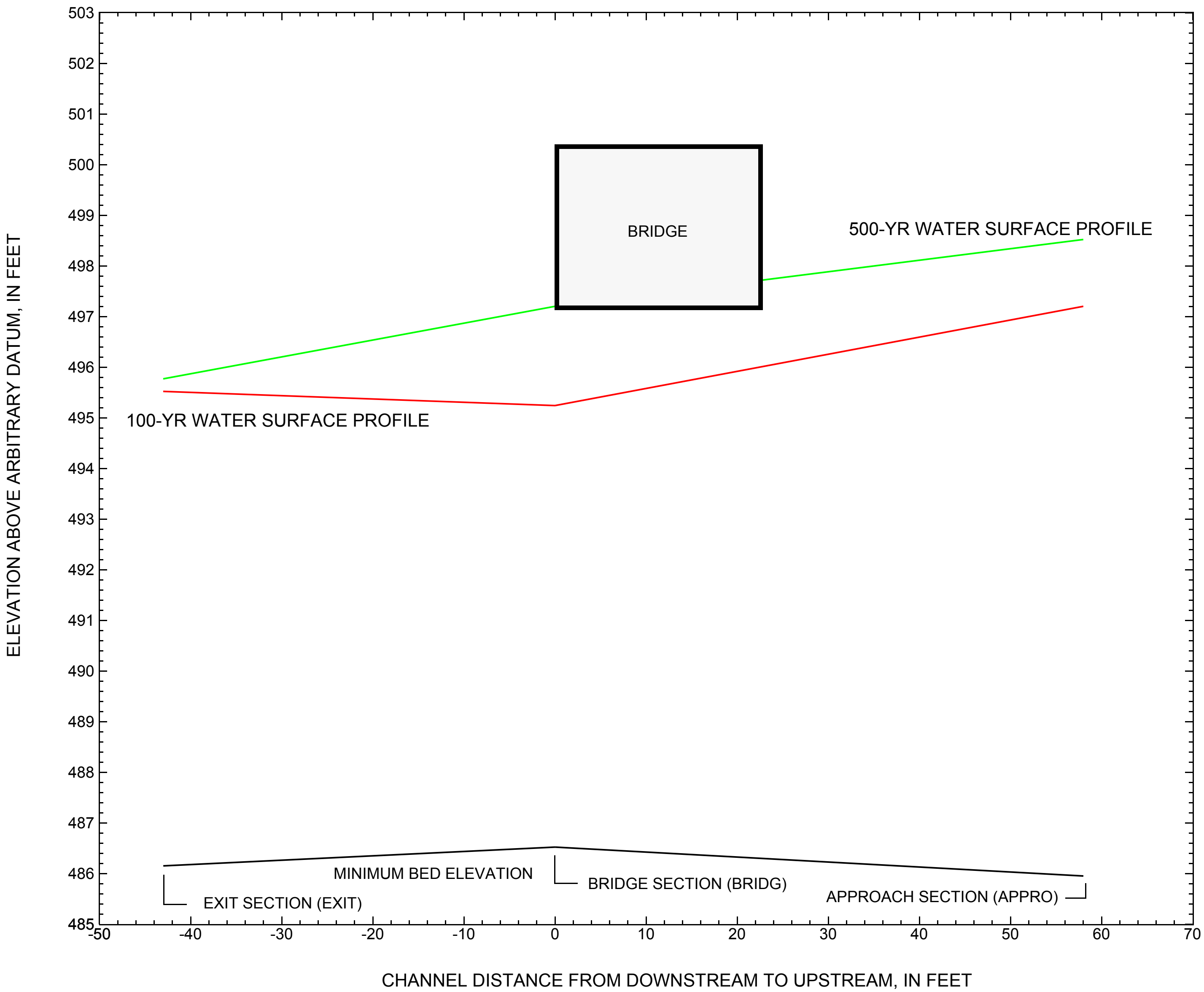

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure CRAFTH00250026 on town highway 25, crossing the Black River, Craftsbury, Vermont.

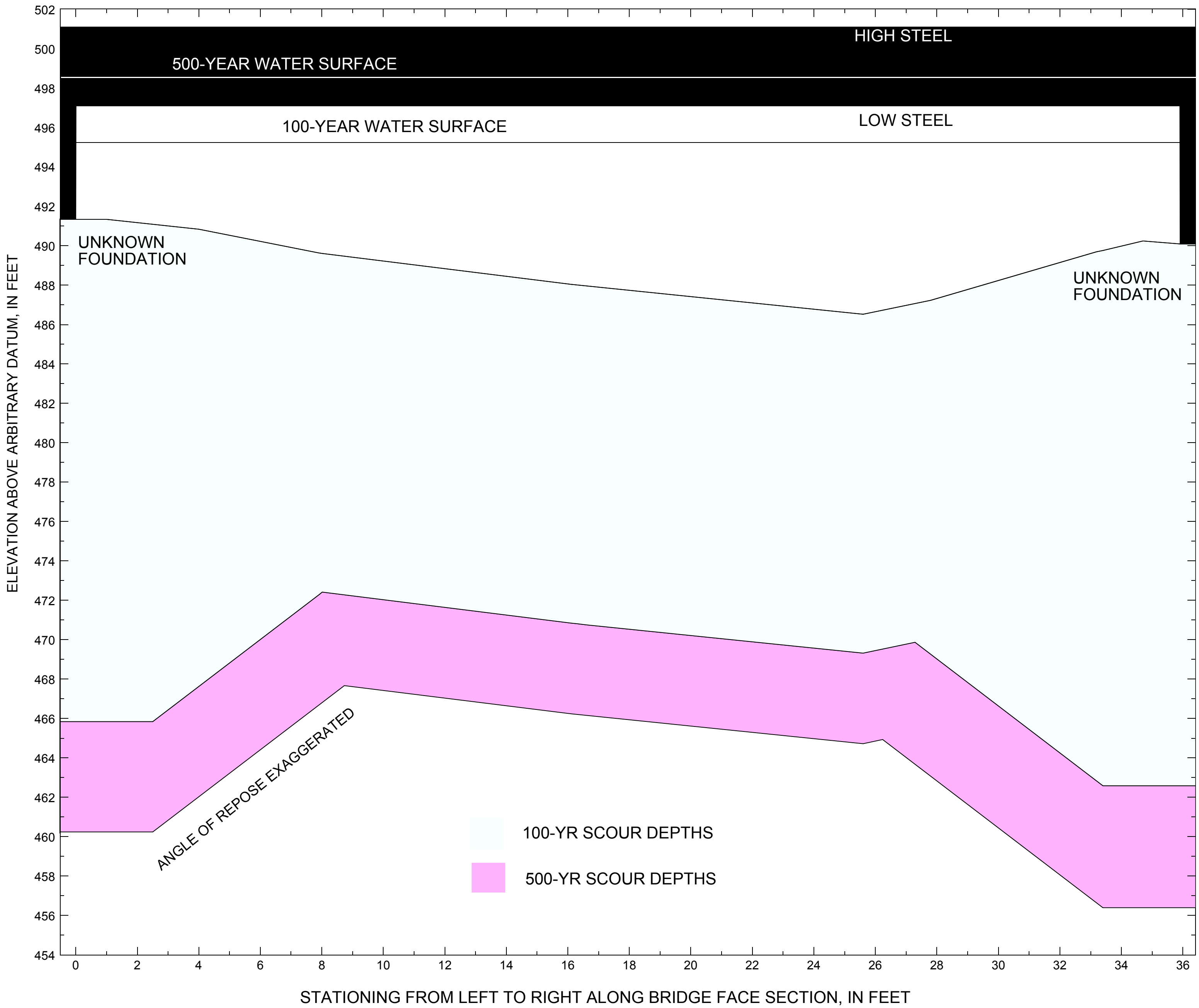

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure CRAFTH00250026 on town highway 25, crossing the Black River, Craftsbury, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure CRAFTH00250026 on Town Highway 25, crossing the Black River, Craftsbury, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord 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 2,320 cubic-feet per second											
Left abutment	0.0	--	497.2	--	491.3	17.2	8.3	--	25.5	465.8	--
Right abutment	35.9	--	497.2	--	490.1	17.2	10.3	--	27.5	462.6	--

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 CRAFTH00250026 on Town Highway 25, crossing the Black River, Craftsbury, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord 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 2,680 cubic-feet per second											
Left abutment	0.0	--	497.2	--	491.3	21.8	9.3	--	31.1	460.2	--
Right abutment	35.9	--	497.2	--	490.1	21.8	11.9	--	33.7	456.4	--

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

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U.S. Geological Survey, 1986, Albany, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Map, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File craf026.wsp
T2        Hydraulic analysis for structure CRAFTH00250026   Date: 31-JAN-96
T3        Craftsbury bridge 26 crossing the Black River...JDA...01/31/96
Q          2320,     2680,    2350
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   EXIT       -42.5        0.
GR         -639.5, 510.97   -563.9, 503.40   -450.4, 499.11   -403.3, 495.57
GR         -308.4, 493.89   -132.0, 492.23    -16.0, 494.65      0.0, 493.43
GR            3.1, 489.66      7.2, 486.55     11.1, 487.06     15.5, 486.72
GR           29.9, 486.15     36.7, 489.39     38.6, 493.03     88.2, 492.73
GR          159.3, 492.39    205.1, 493.14    291.2, 498.40    343.0, 499.99
GR          399.9, 504.90    426.8, 508.99
*
N           0.032        0.044        0.062
SA                   0.0         38.6
*
XS   FULLV       0  * * *   0.0004
*
*              SRD     LSEL    XSSKEW
BR   BRDG       0     497.2       0.0
GR            0.0, 497.17      1.0, 491.34      4.0, 490.84      7.9, 489.63
GR           16.1, 488.04     25.6, 486.52     27.8, 487.23     33.2, 489.69
GR           34.7, 490.24     35.9, 490.09     35.9, 497.20      0.0, 497.17
*
*         BRTYPE  BRWDTH        WWANGL    WWWID
CD           1      31.6 * *     48.8      8.4
N           0.039
*
*              SRD    EMBWID   IPAVE
XR   RD         11      22.6     2
GR         -681.1, 503.64   -126.1, 497.24      0.0, 500.38      0.0, 501.05
GR           42.1, 501.07     42.1, 500.40    152.0, 498.43    312.1, 498.89
GR          443.1, 501.26    524.9, 502.69
*
XT   APPR      112.2         0.
GR         -588.5, 509.31   -540.3, 504.72   -468.0, 497.73   -433.1, 497.00
GR         -391.0, 493.58   -310.9, 493.08   -200.9, 493.03   -124.4, 493.42
GR            5.8, 493.20      9.1, 489.38     10.8, 487.63     14.4, 485.97
GR           22.9, 488.23     27.9, 488.78     29.0, 489.50     30.1, 492.71
GR          125.3, 493.23    184.1, 491.71    307.4, 492.01    459.3, 492.97
GR          542.8, 503.5
*
AS   APPRO    57.9
GT            -0.022
N           0.032        0.044        0.032
SA                   5.8         30.1
*
HP 1 BRDG   495.24 1 495.24
HP 2 BRDG   495.24 * * 2320
```

```
HP 1 APPRO  497.20 1 497.20
HP 2 APPRO  497.20 * * 2320
*
HP 1 BRDG   497.20 1 497.20
HP 2 BRDG   497.20 * * 2404
HP 2 RD     498.31 * * 243
HP 1 APPRO  498.52 1 498.52
HP 2 APPRO  498.52 * * 2680
*
HP 1 BRDG   495.25 1 495.25
HP 2 BRDG   495.25 * * 2350
HP 1 APPRO  497.25 1 497.25
HP 2 APPRO  497.25 * * 2350
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V090192            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File craf026.wsp
        Hydraulic analysis for structure CRAFTH00250026   Date: 31-JAN-96
        Craftsbury bridge 26 crossing the Black River...JDA...01/31/96
           *** RUN DATE & TIME: 02-20-96  15:45
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRDG ;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     230.   26055.    36.    45.                       3328.
   495.24          230.   26055.    36.    45.  1.00     0.    36.   3328.
1
  HP 2 BRDG   495.24 * * 2320
1
    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRDG ;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       495.24     0.3    35.9   230.4   26055.    2320.  10.07

 X STA.         0.3        5.3        8.0       10.1       11.9       13.5
  A(I)             19.8       14.1       12.0       11.4       10.7
  V(I)             5.85       8.25       9.65      10.18      10.83

 X STA.        13.5       15.1       16.5       17.8       19.1       20.3
  A(I)             10.5       10.2        9.6        9.7        9.4
  V(I)            11.08      11.40      12.09      11.94      12.39

 X STA.        20.3       21.5       22.6       23.7       24.8       25.9
  A(I)              9.3        9.2        9.4        9.3        9.5
  V(I)            12.48      12.58      12.41      12.47      12.22

 X STA.        25.9       27.1       28.4       30.0       32.0       35.9
  A(I)             10.1       10.4       11.7       13.2       21.0
  V(I)            11.50      11.15       9.88       8.79       5.52
1
  HP 1 APPRO  497.20 1 497.20
1
    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      58.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1    1668.  186066.   450.   450.                      18229.
             2     217.   27526.    24.    30.                       3684.
             3    2136.  275503.   463.   463.                      26033.
   497.20         4021.  489095.   937.   943.  1.01  -444.   493.  46929.
1
  HP 2 APPRO  497.20 * * 2320
    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      58.

         WSEL     LEW     REW    AREA        K        Q    VEL
       497.20  -443.7   493.0  4020.7  489095.    2320.   0.58

 X STA.      -443.7     -339.9     -288.1     -238.2     -188.5     -135.6
  A(I)            276.7      212.0      207.9      207.5      211.2
  V(I)             0.42       0.55       0.56       0.56       0.55

 X STA.      -135.6      -79.8      -26.1       15.3       41.3       87.8
  A(I)            214.4      210.5      209.0      186.0      200.9
  V(I)             0.54       0.55       0.56       0.62       0.58

 X STA.        87.8      137.4      176.0      207.3      239.2      271.5
  A(I)            203.9      185.5      170.9      173.1      172.5
  V(I)             0.57       0.63       0.68       0.67       0.67

 X STA.       271.5      305.6      341.2      378.7      421.8      493.0
  A(I)            178.9      182.2      183.0      199.1      235.7
  V(I)             0.65       0.64       0.63       0.58       0.49
1
  *
  HP 1 BRDG   497.20 1 497.20
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRDG ;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     300.   26544.     0.    85.                          0.
   497.20          300.   26544.     0.    85.  1.00     0.    36.      0.
1
```

```
   HP 2 BRDG   497.20 * * 2404
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRDG ;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        497.20     0.0    35.9   299.9   26544.    2404.   8.01

 X STA.         0.0        4.5        7.1        9.2       11.1       12.8
   A(I)            24.6       17.6       16.1       14.9       14.6
   V(I)            4.88       6.85       7.46       8.08       8.23

 X STA.        12.8       14.4       15.9       17.3       18.7       20.1
   A(I)            13.7       13.6       13.1       13.2       12.7
   V(I)            8.78       8.82       9.19       9.11       9.48

 X STA.        20.1       21.3       22.6       23.8       25.0       26.2
   A(I)            12.6       12.5       12.6       12.5       12.7
   V(I)            9.53       9.64       9.53       9.60       9.47

 X STA.        26.2       27.5       28.9       30.5       32.5       35.9
   A(I)            13.1       13.8       14.9       16.5       24.7
   V(I)            9.19       8.69       8.09       7.28       4.87
1
   HP 2 RD     498.31 * * 243
     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RD   ;  SRD =      11.

          WSEL     LEW     REW    AREA        K        Q    VEL
        498.31  -218.9   -83.1    72.6    2229.     243.   3.35

 X STA.      -218.9     -183.3     -172.6     -165.2     -159.1     -154.1
   A(I)             7.3        5.1        4.3        3.9        3.6
   V(I)            1.66       2.40       2.84       3.08       3.35

 X STA.      -154.1     -149.8     -145.9     -142.4     -139.1     -136.1
   A(I)             3.3        3.2        3.1        2.9        2.9
   V(I)            3.66       3.84       3.97       4.13       4.23

 X STA.      -136.1     -133.2     -130.4     -127.8     -125.3     -122.5
   A(I)             2.8        2.7        2.7        2.7        2.8
   V(I)            4.32       4.45       4.44       4.53       4.35

 X STA.      -122.5     -119.4     -115.7     -111.2     -104.8      -83.1
   A(I)             2.9        3.1        3.5        3.9        5.9
   V(I)            4.13       3.88       3.52       3.09       2.07
1
   HP 1 APPRO  498.52 1 498.52
1     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      58.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1    2290.  301271.   482.   482.                       28326.
              2     249.   34631.    24.    30.                        4529.
              3    2754.  414518.   473.   474.                       37689.
    498.52         5293.  750420.   980.   986.  1.01  -476.   503.  69374.
1
   HP 2 APPRO  498.52 * * 2680
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      58.

          WSEL     LEW     REW    AREA        K        Q    VEL
        498.52  -476.4   503.5  5293.4  750420.    2680.   0.51

 X STA.      -476.4     -351.1     -297.6     -247.9     -199.7     -150.0
   A(I)           384.4      287.1      272.4      265.1      267.2
   V(I)            0.35       0.47       0.49       0.51       0.50

 X STA.      -150.0      -97.8      -46.0        3.9       32.3       76.7
   A(I)           269.9      269.9      264.0      272.5      253.0
   V(I)            0.50       0.50       0.51       0.49       0.53

 X STA.        76.7      124.8      167.3      201.3      234.7      269.3
   A(I)           262.0      248.3      228.8      224.9      230.7
   V(I)            0.51       0.54       0.59       0.60       0.58

 X STA.       269.3      304.9      342.3      381.6      425.1      503.5
   A(I)           234.7      240.1      243.2      258.1      317.2
   V(I)            0.57       0.56       0.55       0.52       0.42
1
   *
```

WSPRO OUTPUT FILE (continued)

```
   HP 1 BRDG   495.25 1 495.25
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRDG ;  SRD =       0.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     231.   26115.    36.    45.                        3336.
    495.25          231.   26115.    36.    45.  1.00     0.    36.   3336.
1
   HP 2 BRDG   495.25 * * 2350
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRDG ;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        495.25     0.3    35.9   230.8   26115.    2350.  10.18

 X STA.         0.3        5.3        7.9       10.1       11.9       13.5
   A(I)            19.9       13.8       12.4       11.4       10.7
   V(I)            5.91       8.54       9.50      10.29      10.95

 X STA.        13.5       15.1       16.5       17.8       19.1       20.3
   A(I)            10.5       10.2        9.6        9.7        9.4
   V(I)           11.21      11.53      12.23      12.08      12.53

 X STA.        20.3       21.5       22.6       23.7       24.8       25.9
   A(I)             9.3        9.2        9.4        9.3        9.5
   V(I)           12.62      12.73      12.55      12.62      12.36

 X STA.        25.9       27.1       28.4       30.0       32.0       35.9
   A(I)            10.1       10.4       11.8       13.2       21.1
   V(I)           11.63      11.28      10.00       8.89       5.58
1
   HP 1 APPRO  497.25 1 497.25
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      58.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1    1690.  189603.   452.   452.                       18550.
              2     218.   27783.    24.    30.                        3715.
              3    2159.  280336.   463.   464.                       26446.
    497.25         4068.  497722.   940.   946.  1.01  -446.   493.  47677.
1
   HP 2 APPRO  497.25 * * 2350
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      58.

          WSEL     LEW     REW    AREA        K        Q    VEL
        497.25  -446.1   493.4  4067.6  497722.    2350.   0.58

 X STA.      -446.1     -339.9     -286.5     -236.9     -188.9     -136.1
   A(I)           282.0      221.2      209.1      203.3      213.6
   V(I)            0.42       0.53       0.56       0.58       0.55

 X STA.      -136.1      -80.3      -26.7       15.0       41.4       87.0
   A(I)           216.8      212.8      210.8      190.5      199.2
   V(I)            0.54       0.55       0.56       0.62       0.59

 X STA.        87.0      137.0      175.9      207.4      238.9      272.1
   A(I)           208.0      188.6      173.8      171.9      179.3
   V(I)            0.56       0.62       0.68       0.68       0.66

 X STA.       272.1      305.4      341.2      378.8      422.0      493.4
   A(I)           176.6      184.5      185.4      201.9      238.4
   V(I)            0.67       0.64       0.63       0.58       0.49
1
 +++ BEGINNING PROFILE CALCULATIONS --   3
  XSID:CODE   SRDL    LEW     AREA    VHD     HF     EGL    CRWS       Q    WSEL
        SRD   FLEN    REW        K  ALPH     HO     ERR     FR#     VEL

 EXIT :XS   ******  -400.    1592.  0.05 *****  495.56  493.59   2320.  495.52
       -43. ******   244.  115995.  1.46 ***** *******    0.20    1.46

 FULLV:FV      43.  -400.    1592.  0.05  0.02  495.58 *******   2320.  495.53
         0.    43.   244.  116061.  1.46  0.00    0.00    0.20    1.46
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                              "APPRO"     KRATIO =  2.04

 APPRO:AS      58.  -416.    2541.  0.01  0.01  495.59 *******   2320.  495.58
        58.    58.   480.  236283.  1.03  0.00    0.00    0.10    0.91
```

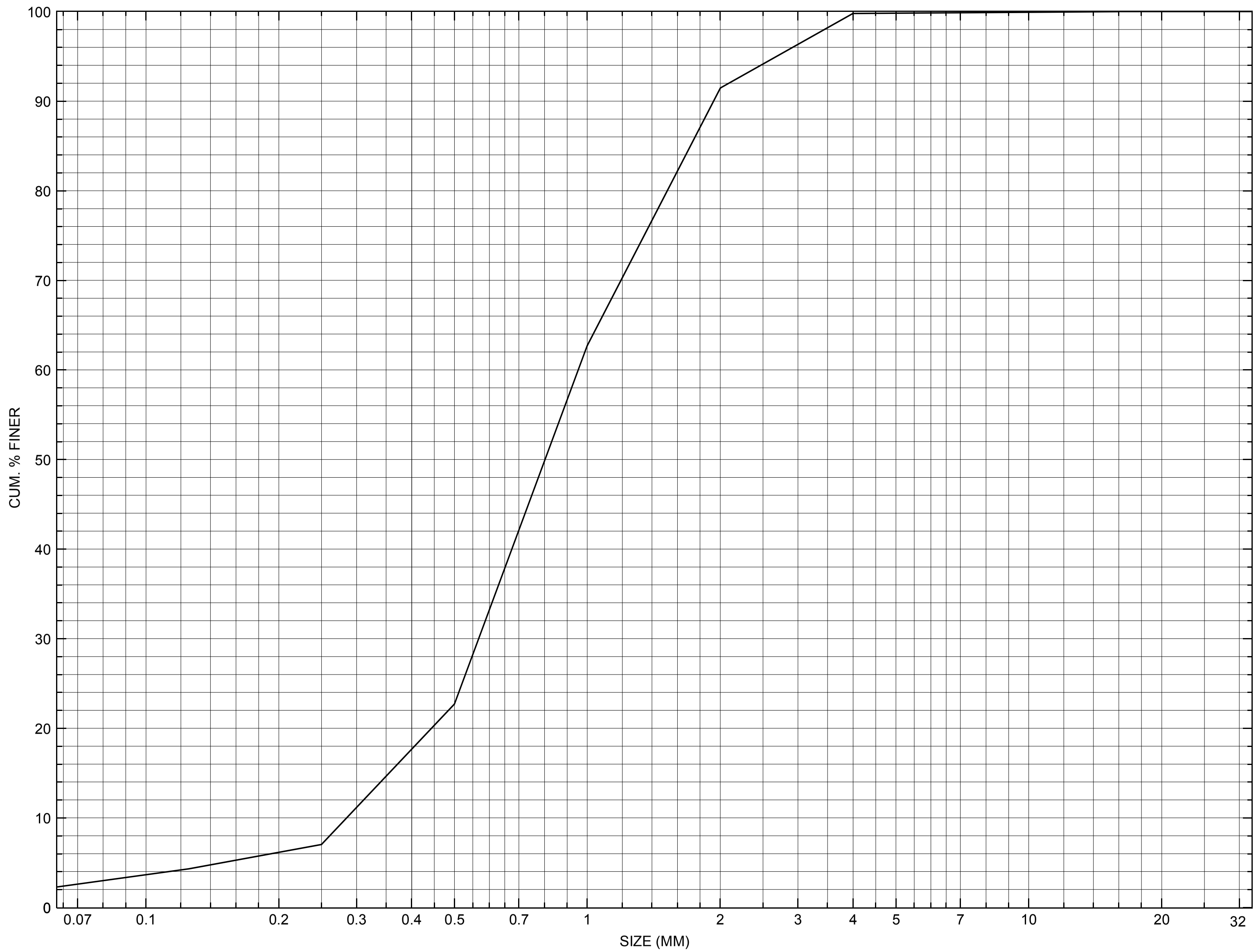
```
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

            <<<<<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

BRDG :BR      43.     0.     230.  1.66  0.11  496.90  493.85   2320.  495.24
        0.    43.    36.   26038.  1.06  1.22    0.00    0.72   10.07

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  0.974 ******  497.20 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RD   :RG      11.        <<<<<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      26.  -444.    4020.  0.01  0.05  497.20  493.34   2320.  497.20
       58.    81.   493.  488911.  1.01  0.25    0.00    0.05    0.58

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.960  0.965   17198.    95.   131.   497.20

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

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT :XS     -43.  -400.   244.   2320.  115995.    1592.    1.46  495.52
   FULLV:FV       0.  -400.   244.   2320.  116061.    1592.    1.46  495.53
   BRDG :BR       0.     0.    36.   2320.   26038.     230.   10.07  495.24
   RD   :RG      11.**************      0.*****************    2.00********
   APPRO:AS      58.  -444.   493.   2320.  488911.    4020.    0.58  497.20

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      95.   131.   17198.
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT :XS    493.59    0.20  486.15  510.97************  0.05  495.56  495.52
   FULLV:FV  ********    0.20  486.17  510.99  0.02  0.00  0.05  495.58  495.53
   BRDG :BR    493.85    0.72  486.52  497.20  0.11  1.22  1.66  496.90  495.24
   RD   :RG  ****************  497.24  503.64**********************************
   APPRO:AS    493.34    0.05  485.95  509.29  0.05  0.25  0.01  497.20  497.20
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXIT :XS   ******  -406.    1757.  0.05 *****  495.82  493.78   2680.  495.77
      -43. ******   248.  133935.  1.40 ***** *******    0.19    1.53

FULLV:FV      43.  -406.    1758.  0.05  0.02  495.84 *******   2680.  495.79
        0.    43.   248.  134029.  1.40  0.00    0.00    0.19    1.52
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           “APPRO”     KRATIO =  2.02

APPRO:AS      58.  -419.    2771.  0.01  0.01  495.85 *******   2680.  495.83
       58.    58.   482.  271157.  1.03  0.00    0.00    0.10    0.97
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   497.77       0.00     495.42     497.24

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   495.44     497.70     497.75     497.20

 ===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
```

```
 BRDG :BR      43.      0.     300.  1.00 *****  498.20  493.97   2404.  497.20
         0. ******    36.   26544.  1.00 ***** *******    0.49    8.01

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   5.  0.427 ******  497.20 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
    RD   :RG      11.    35.  0.00  0.00  498.53   -0.01    243.  498.31

              Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
    LT:    243.   136.  -219.   -83.   1.1   0.5   3.6   3.3   0.8   2.8
    RT:      0.    16.   150.   165.   0.0   0.0   2.0  18.3   0.3   2.6

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

 APPRO:AS      26.  -476.    5295.  0.00  0.03  498.53  493.46   2680.  498.52
        58.    82.   504.  750892.  1.01  0.30   -0.01    0.04    0.51
   FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXIT :XS     -43.  -406.   248.   2680.  133935.    1757.    1.53  495.77
    FULLV:FV       0.  -406.   248.   2680.  134029.    1758.    1.52  495.79
    BRDG :BR       0.     0.    36.   2404.   26544.     300.    8.01  497.20
    RD   :RG      11.*******   243.    243.*********       0.    2.00  498.31
    APPRO:AS      58.  -476.   504.   2680.  750892.    5295.    0.51  498.52

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

     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD     EGL    WSEL
    EXIT :XS    493.78    0.19  486.15  510.97************  0.05  495.82  495.77
    FULLV:FV  ********    0.19  486.17  510.99  0.02  0.00  0.05  495.84  495.79
    BRDG :BR    493.97    0.49  486.52  497.20************  1.00  498.20  497.20
    RD   :RG  ****************  497.24  503.64  0.00******  0.00  498.53  498.31
    APPRO:AS    493.46    0.04  485.95  509.29  0.03  0.30  0.00  498.53  498.52
1
  XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS      Q    WSEL
        SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

 EXIT :XS   ******  -402.    1607.  0.05 *****  495.59  493.61   2350.  495.54
       -43. ******   244.  117495.  1.46 ***** *******    0.20    1.46

 FULLV:FV      43.  -402.    1607.  0.05  0.02  495.61 *******   2350.  495.56
         0.    43.   244.  117564.  1.45  0.00    0.00    0.20    1.46
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                               "APPRO"     KRATIO =  2.04

 APPRO:AS      58.  -416.    2562.  0.01  0.01  495.62 *******   2350.  495.60
        58.    58.   480.  239361.  1.03  0.00    0.00    0.10    0.92
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
            WS1,WSSD,WS3,RGMIN =   497.25       0.00     495.25     497.24

  ===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

 BRDG :BR      43.      0.     231.  1.69  0.11  496.95  493.89   2350.  495.25
         0.    43.    36.   26140.  1.05  1.24    0.00    0.72   10.18

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   4.  0.976 ******  497.20 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
    RD   :RG      11.    35.  0.00  0.01  497.27    0.00      0.  497.26

              Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
```

```
   LT:      0.     3.  -128.  -125.   0.0   0.0   0.5   0.4   0.0   2.5
   RT:      0.    27.   148.   175.   0.1   0.0   2.1  11.8   0.3   2.6

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

APPRO:AS      26.  -446.    4065.  0.01  0.05  497.25  493.37   2350.  497.25
       58.    82.   493.  497262.  1.01  0.26    0.00    0.05    0.58

      M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     0.960  0.965   17547.    95.   130. ********
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT :XS     -43.  -402.   244.   2350.  117495.    1607.    1.46  495.54
   FULLV:FV       0.  -402.   244.   2350.  117564.    1607.    1.46  495.56
   BRDG :BR       0.     0.    36.   2350.   26140.     231.   10.18  495.25
   RD   :RG      11.*******     0.      0.*********       0.    2.00  497.26
   APPRO:AS      58.  -446.   493.   2350.  497262.    4065.    0.58  497.25

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      95.   130.   17547.
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXIT :XS    493.61    0.20  486.15  510.97************  0.05  495.59  495.54
   FULLV:FV  ********    0.20  486.17  510.99  0.02  0.00  0.05  495.61  495.56
   BRDG :BR    493.89    0.72  486.52  497.20  0.11  1.24  1.69  496.95  495.25
   RD   :RG  ****************  497.24  503.64  0.00******  0.01  497.27  497.26
   APPRO:AS    493.37    0.05  485.95  509.29  0.05  0.26  0.01  497.25  497.25
  ER

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 CRAFTH00250026, in Craftsbury, Vermont.

APPENDIX D:

HISTORICAL DATA FORM