LEVEL II SCOUR ANALYSIS FOR BRIDGE 51 (RANDTH00SC0051) on SCHOOL STREET, crossing THAYER BROOK, RANDOLPH, VERMONT

U.S. Geological Survey
Open-File Report 96-240

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

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By SCOTT A. OLSON

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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 51 (RANDTH00SC0051) ON SCHOOL STREET, CROSSING THAYER BROOK, RANDOLPH, VERMONT

***By* Scott A. Olson**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure RANDTH00SC0051 on School Street crossing Thayer Brook, Randolph, 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 Green Mountain physiographic division of central Vermont in the town of Randolph. The 5.30-mi^2 drainage area is a predominantly rural basin. In the vicinity of the study site, the left and right banks are forested with residences on the left overbanks.

In the study area, Thayer Brook has a sinuous channel with a slope of approximately 0.03 ft/ft, an average channel top width of 36 ft and an average channel depth of 3 ft. The predominant channel bed materials are gravel and cobble (D_{50} is 58.2 mm or 0.191 ft). The geomorphic assessment at the time of the Level I site visits on August 4, 1994 and December 8, 1994, indicated that the reach was stable.

The School Street crossing of Thayer Brook is a 39-ft-long, two-lane bridge consisting of one 35-foot concrete span (Vermont Agency of Transportation, written commun., August 2, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. Type-2 stone fill (less than 36 inches diameter) along the downstream left bank was the only existing protection. The approach channel is skewed approximately 45 degrees to the bridge face; the opening-skew-to-roadway is also 45 degrees. Additional details describing conditions at the site are included in the Level II Summary, Appendix D, and Appendix E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). 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 1.0 to 2.2 ft. with the worst-case scenario occurring at the 500-year discharge. Abutment scour ranged from 6.2 to 12.0 ft. The worst-case abutment scour also occurred at the 500-year 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, 1993, p. 48). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection measures, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein, based on the consideration of additional contributing factors and experienced engineering judgement.

Randolph VT. Quadrangle, 1:24,000, 1981

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 RANDTH00SC0051 ***Stream*** Thayer Brook

County Orange ***Road*** TH00SC ***District*** 04

Description of Bridge

Bridge length 39 ***ft*** ***Bridge width*** 23.1 ***ft*** ***Max span length*** 35 ***ft***

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

Abutment type vertical ***Embankment type*** sloping

Stone fill on abutment? no ***Date of inspection*** 08/04/94 and 12/08/94

Description of stone fill Type-2 in good condition protects the downstream left bank.

Abutments and wingwalls are vertical and constructed of concrete.

Y 45

Is bridge skewed to flood flow according to N ***survey?*** ***Angle***

Opening skew to roadway is also 45 degrees.

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	8/4/94 and 12/8/94	0	0
Level II	08/09/94	-	-

Potential for debris Moderate

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

There is a large piece of concrete debris, probably the old bridge deck, in the middle of the stream bed about 40 feet downstream of the bridge.

Description of the Geomorphic Setting

General topography The bridge crosses a high gradient upland stream with no flood plains in a moderate relief valley.

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

Date of inspection 8/4/94 and 12/8/94

DS left: Steep high channel bank to mild sloping overbank.

DS right: Steep valley wall intersected by roadway.

US left: Steep high channel bank to mild sloping overbank.

US right: Steep valley wall.

Description of the Channel

Average top width 36 ***ft*** ***Average depth*** 3 ***ft***

Predominant bed material gravel and cobble ***Bank material*** gravel/cobble

Incised upland stream with only slight sinuosity.

8/4/ and 12/8/94

Vegetative co Forested; residence on overbank.

DS left: Forested.

DS right: Forested; residence on overbank.

US left: Forested.

US right: Y

Do banks appear stable? 8/4/94 and 12/8/94. ***If not, describe location and type of instability and date of observation.***

There is a large piece of concrete roughly 15 feet by 15 feet in the channel about 40 feet downstream of the bridge. It is believed to be the old bridge deck. August 4, 1994 and December 8, 1994.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 5.30 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
Green Mountain Prov.	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: None. Area is mostly forested high-elevation headwater drainage.

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

USGS gage description

USGS gage number

Gage drainage area ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 1,080 ***ft³/s*** ***Q500*** 1,840 ***ft³/s***

The Q100 was based upon a drainage area relationship [(5.3/3.5) to the 0.7 power] with a site on Thayer Brook with discharge data available from VTAOT (VTAOT, oral communitcation, March 17, 1995). The site had a drainage area of 3.5 square miles. Q500 was estimated by multiplying the Q100 by 1.7 (Richardson and others, 1983).

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 Not applicable.

Description of reference marks used to determine USGS datum. RM1 is a chiseled square on the top of the downstream end of the left abutment (elev. 516.57 feet, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT2	-20	1	Downstream section
EXIT	0	1	Exit section
SVEX	1	5	Exit section without the concrete debris mid-channel (used as a template for the full valley section only).
FV	40	2	Downstream Full-valley section (Templated from SVEX)
BRIDG	40	1	Bridge section
APPR	110	1	Modelled Approach section (Templated from SURVA)
SURVA	130	2	Approach section as surveyed (Used as a template)

[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 analysis 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, Jr. and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. The channel "n" value used for the reach was 0.065. Overbank "n" values ranged from 0.053 to 0.100.

Normal depth at the downstream section, EXIT2, 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 0.031 ft/ft which was determined from surveyed thalweg points downstream of the bridge.

The surveyed approach section (SURVA) was moved along the approach channel slope (0.026 ft/ft) to establish the modelled approach section (APPR), 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.

For the 100- and 500-year discharges, WSPRO assumes critical depth at the bridge section. Further analysis, in which the water surface is shown to pass through critical depth in the constriction, suggests the critical depth assumption at the bridge section is a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 516.0 *ft*
Average low steel elevation 513.6 *ft*

100-year discharge 1,080 *ft³/s*
Water-surface elevation in bridge opening 504.6 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 97.2 *ft²*
Average velocity in bridge opening 11.1 *ft/s*
Maximum WSPRO tube velocity at bridge 13.1 *ft/s*

Water-surface elevation at Approach section with bridge 508.4
Water-surface elevation at Approach section without bridge 506.7
Amount of backwater caused by bridge 1.7 *ft*

500-year discharge 1,840 *ft³/s*
Water-surface elevation in bridge opening 506.2 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 138 *ft²*
Average velocity in bridge opening 13.3 *ft/s*
Maximum WSPRO tube velocity at bridge 16.1 *ft/s*

Water-surface elevation at Approach section with bridge 510.7
Water-surface elevation at Approach section without bridge 508.0
Amount of backwater caused by bridge 2.7

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

Water-surface elevation at Approach section with bridge ______
Water-surface elevation at Approach section without bridge ______
Amount of backwater caused by bridge ______ *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.

Contraction scour for the 100-yr and 500-yr discharges were computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18,19). 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.

Depths to armoring were 22 feet and 38 feet for the 100-yr and 500-yr discharges, respectively. These high values indicate that armoring would not limit the amount of contraction scour.

Abutment scour was computed by the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). Parameters for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

Scour Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	--	--
Clear-water scour	1.0	2.2	--
Depth to armoring	22.4	38.2	--
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	9.1	12.0	--
Right abutment	6.2	8.4	--
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	1.6	2.3	--
Right abutment	1.6	2.3	--
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

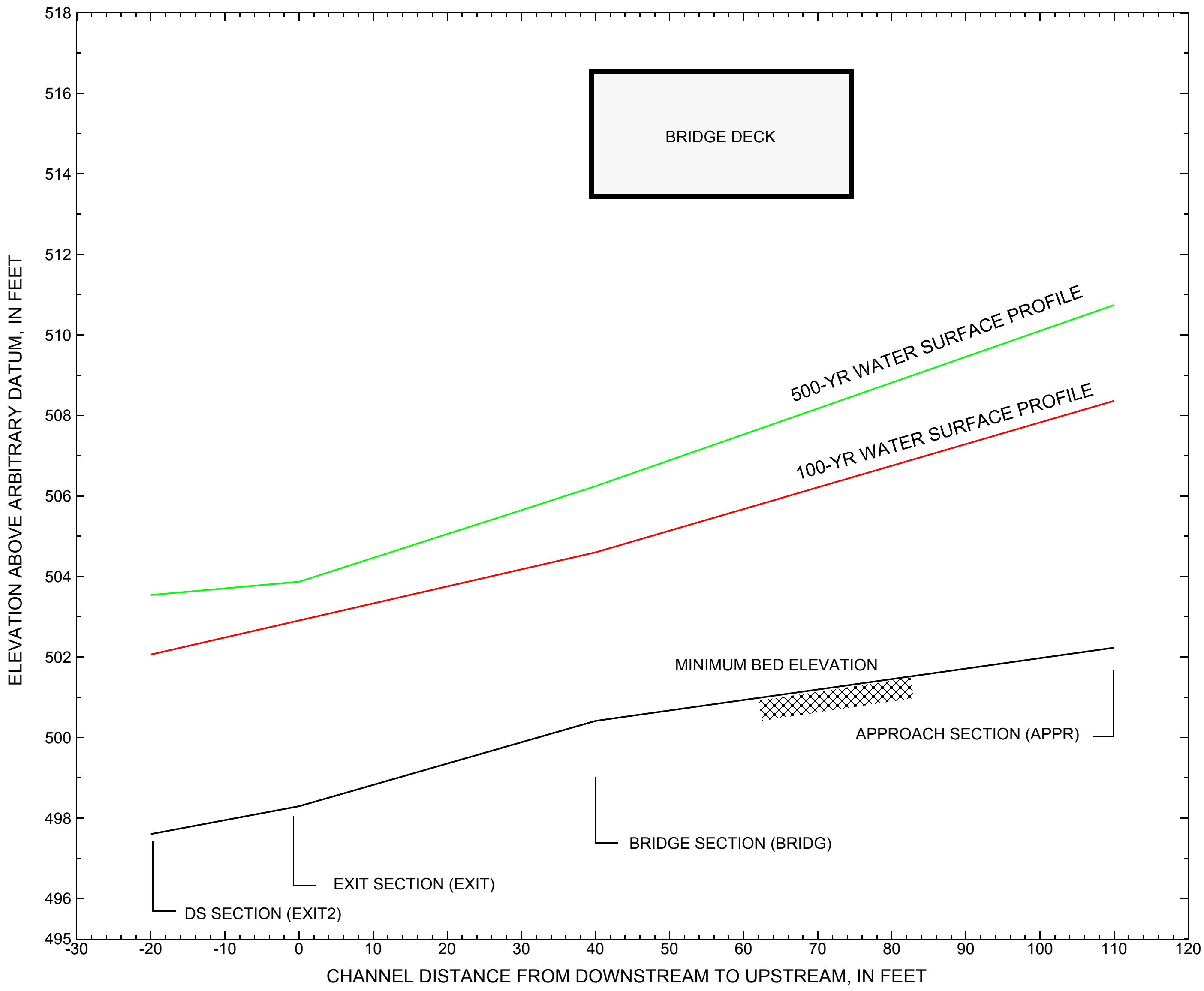

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure RANDTH00SC0051 on School Street, crossing Thayer Brook, Randolph, Vermont.

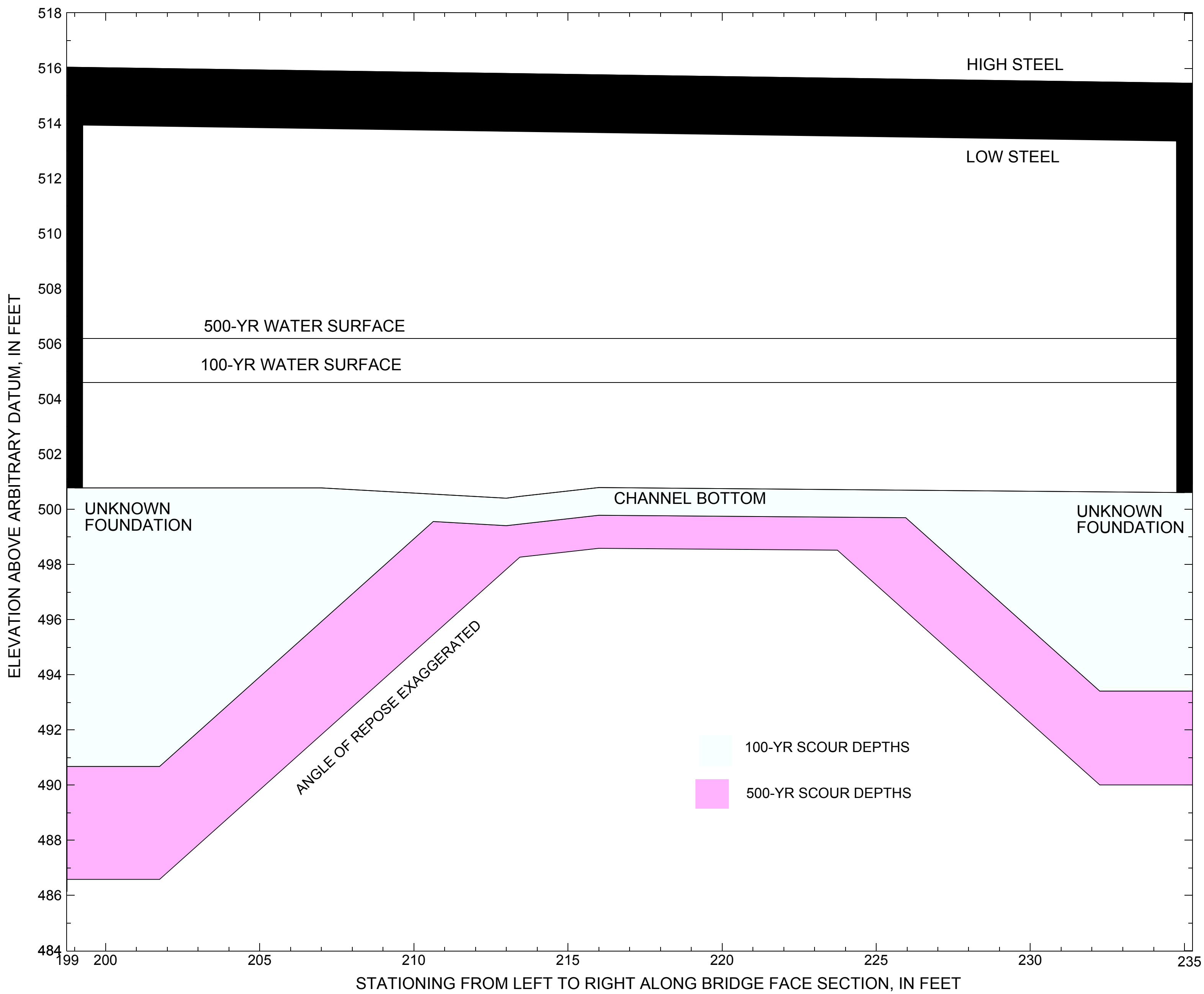

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure RANDTH00SC0051 on School Street, crossing Thayer Brook, Randolph, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure RANDTH00SC0051 on School Street, crossing Thayer Brook, Randolph, 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 1,080 cubic-feet per second											
Left abutment	199	--	514.1	--	500.8	1.0	9.1	--	10.1	490.7	--
Right abutment	235	--	513.2	--	500.6	1.0	6.2	--	7.2	493.4	--

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 RANDTH00SC0051 on School Street, crossing Thayer Brook, Randolph, 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 1,840 cubic-feet per second											
Left abutment	199	--	514.1	--	500.8	2.2	12.0	--	14.2	486.6	--
Right abutment	235	--	513.2	--	500.6	2.2	8.4	--	10.6	490.0	--

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, 1981, Randolph, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1            HYDRAULIC ANALYSIS
T2            Randolph, VT BRIDGE #051
T3            USGS  BOW,NH   03/21/95
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q              1080  1840
SK             0.031 0.031
*
XS   EXIT2     -20
GR          57.,  513        77.,  502.6
GR          197., 502.6      200., 501.6      202., 498.9      205., 497.9
GR          208., 498.4      213.5,497.6      220., 498.0      228., 498.63
GR          237., 501.3      257., 515
N              0.1       0.065
SA                   200
*
XS   EXIT       0
GR          181., 512.86     184., 510.03     191., 503.52     200., 501.69
GR          204., 499.68     207., 498.76     210., 498.34     215., 498.29
GR          215., 499.64     225., 499.96     226., 498.50     228., 498.38
GR          230., 498.50     231., 499.29     235., 500.06     237., 499.19
GR          241., 502.94     255., 514.57
N            0.065
*
*           The following template section is the same as the exit section
*           except that the large block of concrete that was in the
*           stream is removed from the middle of the section.  The section
*           without the block is the one to be propagated up to the
*           downstream bridge face
*
XT   SVEX       1
GR          181., 512.86     184., 510.03     191., 503.52     200., 501.69
GR          204., 499.68     207., 498.76     210., 498.34     215., 498.29
GR          226., 498.50     228., 498.38
GR          230., 498.50     231., 499.29     235., 500.06     237., 499.19
GR          241., 502.94     255., 514.57
*
XS   FV        40
GT           2.1
N            0.065
*
BR   BRIDG    40   513.5  45
GR          199., 514.07     200., 500.78     207., 500.78     213., 500.41
GR          216., 500.79     235., 500.61     235., 513.17     199., 514.07
N           0.065
CD          1  23.1  *  *  42.5  14.4
*
XT   SURVA    130
GR          189., 516.29     195., 514.24     198., 510.80     200., 507.13
GR          203., 505.08     204., 502.75     210., 502.95     223., 502.81
GR          232., 503.01     233., 505.93     252., 516.97
*
AS   APPR      110
GT             -.52
N              0.053      0.065
SA                  195
*
HP 1 APPR      508.36 1 508.36
HP 2 APPR      508.36 * * 1080
HP 1 BRIDG     504.60 1 504.60
HP 2 BRIDG     504.60 * * 1080
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
          HYDRAULIC ANALYSIS
          Randolph, VT BRIDGE #051
          USGS  BOW,NH   03/21/95
         *** RUN DATE & TIME: 09-27-95  11:53
    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =     110.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             2     194.   11751.    39.    45.                        2453.
   508.36          194.   11751.    39.    45.  1.00   199.   238.   2453.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =     110.
         WSEL     LEW     REW    AREA        K        Q    VEL
       508.36   199.0   238.1   193.9   11751.    1080.   5.57

X STA.       199.0      204.5      206.2      207.7      209.2      210.7
  A(I)           17.0       10.6        9.1        9.0        8.5
  V(I)           3.17       5.10       5.94       6.02       6.34

X STA.       210.7      212.1      213.5      214.9      216.2      217.6
  A(I)            8.5        8.3        8.2        8.1        8.2
  V(I)           6.35       6.51       6.58       6.64       6.62

X STA.       217.6      218.9      220.3      221.7      223.0      224.4
  A(I)            8.2        8.2        8.3        8.4        8.4
  V(I)           6.62       6.60       6.51       6.41       6.39

X STA.       224.4      225.9      227.5      229.1      230.9      238.1
  A(I)            8.8        9.2        9.6       11.1       18.1
  V(I)           6.12       5.84       5.61       4.85       2.99

    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =      40.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      97.    4612.    25.    33.                        1088.
   504.60           97.    4612.    25.    33.  1.00   200.   235.   1088.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =      40.
         WSEL     LEW     REW    AREA        K        Q    VEL
       504.60   199.7   235.0    97.2    4612.    1080.  11.11

X STA.       199.7      202.9      204.9      206.7      208.3      209.9
  A(I)            8.3        5.2        4.9        4.5        4.4
  V(I)           6.47      10.47      11.09      11.90      12.22

X STA.       209.9      211.4      212.8      214.3      215.8      217.3
  A(I)            4.3        4.1        4.2        4.2        4.2
  V(I)          12.53      13.11      12.86      12.89      12.87

X STA.       217.3      218.9      220.5      222.0      223.6      225.2
  A(I)            4.3        4.3        4.2        4.3        4.4
  V(I)          12.68      12.63      12.88      12.63      12.34

X STA.       225.2      226.7      228.4      230.1      232.0      235.0
  A(I)            4.4        4.5        4.9        5.1        8.5
  V(I)          12.37      11.87      11.08      10.56       6.32

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =     110.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             2     293.   21123.    45.    53.                        4269.
   510.74          293.   21123.    45.    53.  1.00   198.   242.   4269.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =     110.
         WSEL     LEW     REW    AREA        K        Q    VEL
       510.74   197.6   242.2   293.3   21123.    1840.   6.27

X STA.       197.6      203.8      205.8      207.4      209.0      210.6
  A(I)           26.1       16.6       13.8       13.2       12.8
  V(I)           3.53       5.53       6.66       6.96       7.16

X STA.       210.6      212.0      213.5      215.0      216.4      217.8
  A(I)           12.2       12.4       12.0       11.9       11.9
  V(I)           7.52       7.42       7.66       7.73       7.72

X STA.       217.8      219.2      220.7      222.1      223.6      225.1
  A(I)           12.1       12.1       12.3       12.4       12.7
  V(I)           7.62       7.61       7.51       7.40       7.22

X STA.       225.1      226.7      228.3      230.1      232.4      242.2
  A(I)           13.1       13.7       15.2       18.2       28.4
  V(I)           7.03       6.71       6.04       5.07       3.24

    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =      40.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     138.    7778.    25.    36.                        1842.
   506.24          138.    7778.    25.    36.  1.00   200.   235.   1842.
```

WSPRO OUTPUT FILE (continued)

```
    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =      40.
         WSEL     LEW     REW    AREA        K        Q    VEL
       506.24   199.6   235.0   138.2    7778.    1840.  13.32

X STA.       199.6      203.1      205.1      206.9      208.5      210.0
  A(I)            12.6        7.7        7.0        6.3        6.0
  V(I)            7.32      11.88      13.10      14.50      15.35

X STA.       210.0      211.5      212.9      214.3      215.8      217.3
  A(I)             6.0        5.8        5.7        5.9        5.7
  V(I)           15.43      15.74      16.13      15.70      16.01

X STA.       217.3      218.8      220.3      221.8      223.3      224.9
  A(I)             5.8        5.8        5.9        5.8        6.1
  V(I)           15.95      15.90      15.68      15.76      15.05

X STA.       224.9      226.4      228.0      229.8      231.8      235.0
  A(I)             6.1        6.2        6.9        7.8       12.9
  V(I)           14.97      14.72      13.32      11.79       7.14

            HYDRAULIC ANALYSIS
            Randolph, VT BRIDGE #051
            USGS  BOW,NH   03/21/95
           *** RUN DATE & TIME: 09-27-95  11:53

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

EXIT2:XS   ******   199.     126.  1.15 *****  503.21  501.67   1080.  502.06
      -20. ******   238.    6132.  1.00 ***** *******    0.85    8.58

EXIT :XS      20.   194.     143.  0.88  0.59  503.79 *******   1080.  502.91
        0.    20.   241.    6465.  1.00  0.00    0.00    0.76    7.54

 ===125 FR# EXCEEDS FNTEST AT SECID “FV   “:  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.96     504.10     504.01

 ===110 WSEL NOT FOUND AT SECID “FV   “:  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   502.41     516.67    0.50

 ===115 WSEL NOT FOUND AT SECID “FV   “:  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   502.41     516.67     504.01

FV   :FV      40.   199.     117.  1.32  1.39  505.40  504.01   1080.  504.09
       40.    40.   240.    5186.  1.00  0.22    0.00    0.97    9.21
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>
APPR :AS      70.   200.     133.  1.03  2.33  507.74 *******   1080.  506.71
      110.    70.   235.    6759.  1.00  0.00    0.01    0.74    8.15
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                   SECID “BRIDG”     Q,CRWS =    1080.      504.60

            <<<<<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      40.   200.      97.  1.93 *****  506.52  504.60   1080.  504.60
       40.    40.   235.    4603.  1.00 ***** *******    0.99   11.13

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  513.50 ****** ****** ******

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

APPR :AS      47.   199.     194.  0.48  1.05  508.85  505.94   1080.  508.36
      110.    49.   238.   11766.  1.00  1.27   -0.01    0.44    5.56

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.001  0.000   12465.   200.   235.   507.97

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

  FIRST USER DEFINED TABLE.
    XSID:CODE     SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT2:XS      -20.   199.   238.   1080.    6132.     126.    8.58  502.06
   EXIT :XS        0.   194.   241.   1080.    6465.     143.    7.54  502.91
   FV   :FV       40.   199.   240.   1080.    5186.     117.    9.21  504.09
   BRIDG:BR       40.   200.   235.   1080.    4603.      97.   11.13  504.60
   APPR :AS      110.   199.   238.   1080.   11766.     194.    5.56  508.36
```

WSPRO OUTPUT FILE (continued)

```
SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT2:XS    501.67    0.85  497.60  515.00************  1.15  503.21  502.06
   EXIT :XS  ********    0.76  498.29  514.57  0.59  0.00  0.88  503.79  502.91
   FV   :FV    504.01    0.97  500.39  516.67  1.39  0.22  1.32  505.40  504.09
   BRIDG:BR    504.60    0.99  500.41  514.07************  1.93  506.52  504.60
   APPR :AS    505.94    0.44  502.23  516.45  1.05  1.27  0.48  508.85  508.36

            HYDRAULIC ANALYSIS
            Randolph, VT BRIDGE #051
            USGS  BOW,NH   03/21/95
           *** RUN DATE & TIME: 09-27-95  11:53

 ===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT2":  USED WSI = CRWS.
                              WSI,CRWS =    503.17     503.54

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

EXIT2:XS   ******    75.     302.  1.02 *****  504.57  503.54   1840.  503.54
      -20. ******   240.   12794.  1.78 ***** *******    1.06    6.09

 ===125 FR# EXCEEDS FNTEST AT SECID "EXIT ":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80     0.89     503.85     503.55

 ===110 WSEL NOT FOUND AT SECID "EXIT ":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   503.04     514.57    0.50

 ===115 WSEL NOT FOUND AT SECID "EXIT ":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   503.04     514.57     503.55

EXIT :XS      20.   191.     191.  1.44  0.54  505.31  503.55   1840.  503.87
        0.    20.   242.    9803.  1.00  0.21    0.00    0.88    9.64

 ===125 FR# EXCEEDS FNTEST AT SECID "FV   ":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80     1.01     505.27     505.32

 ===110 WSEL NOT FOUND AT SECID "FV   ":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   503.37     516.67    0.50

 ===115 WSEL NOT FOUND AT SECID "FV   ":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   503.37     516.67     505.32

 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
             ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "FV   "
                  WSBEG,WSEND,CRWS =   505.32     516.67     505.32

FV   :FV      40.   192.     173.  1.76 *****  507.08  505.32   1840.  505.32
       40.    40.   241.    8853.  1.00 ***** *******    1.00   10.64
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPR ":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80     0.83     507.99     507.38

 ===110 WSEL NOT FOUND AT SECID "APPR ":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   504.82     516.45    0.50

 ===115 WSEL NOT FOUND AT SECID "APPR ":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   504.82     516.45     507.38

APPR :AS      70.   199.     180.  1.63  2.54  509.62  507.38   1840.  507.99
      110.    70.   237.   10528.  1.00  0.00    0.00    0.83   10.24
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                  SECID "BRIDG"     Q,CRWS =    1840.     506.24

            <<<<<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      40.   200.     138.  2.76 *****  509.00  506.24   1840.  506.24
       40.    40.   235.    7772.  1.00 ***** *******    1.00   13.32

     TYPE PPCD FLOW      C     P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  513.50 ****** ****** ******

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

APPR :AS      47.   198.     293.  0.61  1.06  511.35  507.38   1840.  510.74
      110.    51.   242.   21119.  1.00  1.29    0.02    0.43    6.27

       M(G)   M(K)        KQ   XLKQ   XRKQ    OTEL
      0.075  0.000   22659.   200.   235.   510.38
```

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

FIRST USER DEFINED TABLE.

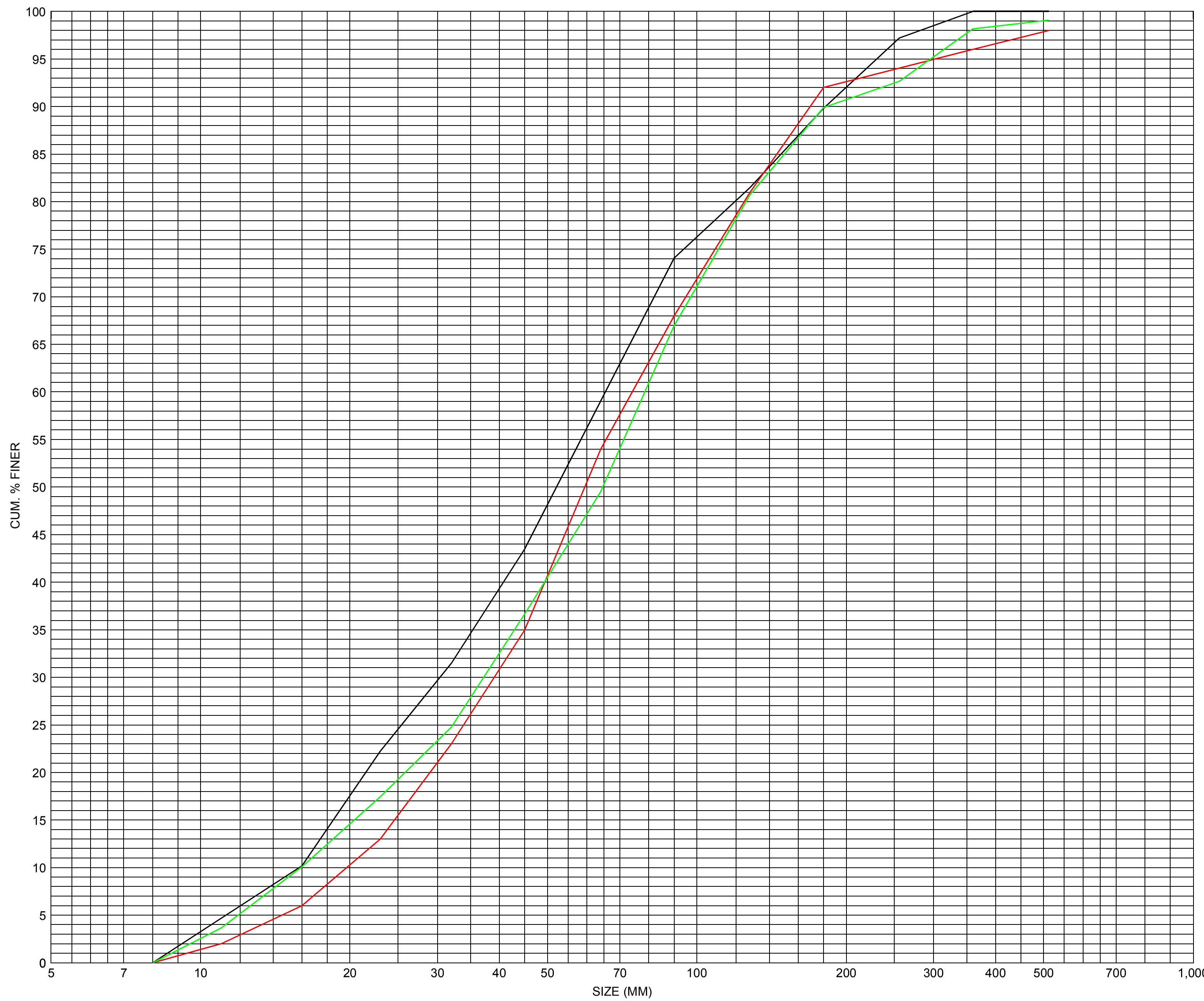
XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXIT2:XS	-20.	75.	240.	1840.	12794.	302.	6.09	503.54
EXIT :XS	0.	191.	242.	1840.	9803.	191.	9.64	503.87
FV :FV	40.	192.	241.	1840.	8853.	173.	10.64	505.32
BRIDG:BR	40.	200.	235.	1840.	7772.	138.	13.32	506.24
APPR :AS	110.	198.	242.	1840.	21119.	293.	6.27	510.74

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXIT2:XS	503.54	1.06	497.60	515.00	******	******	1.02	504.57	503.54
EXIT :XS	503.55	0.88	498.29	514.57	0.54	0.21	1.44	505.31	503.87
FV :FV	505.32	1.00	500.39	516.67	******	******	1.76	507.08	505.32
BRIDG:BR	506.24	1.00	500.41	514.07	******	******	2.76	509.00	506.24
APPR :AS	507.38	0.43	502.23	516.45	1.06	1.29	0.61	511.35	510.74

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure RANDTH00SC0051, in Randolph, Vermont.

APPENDIX D:

HISTORICAL DATA FORM