LEVEL II SCOUR ANALYSIS FOR BRIDGE 54 (LUDLTH03560054) on TOWN HIGHWAY 356, crossing JEWELL BROOK LUDLOW, VERMONT

Open-File Report 98-92

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

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

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By SUSAN A. WILLOUGHBY and MICHAEL A. IVANOFF

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Pembroke, New Hampshire

1998

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

U.S. GEOLOGICAL SURVEY
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CONTENTS

FIGURES

TABLES

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

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

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

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.

LEVEL II SCOUR ANALYSIS FOR BRIDGE 54 (LUDLTH03560054) ON TOWN HIGHWAY 356, CROSSING JEWELL BROOK, LUDLOW, VERMONT

By **Susan A. Willoughby and Michael A. Ivanoff**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure LUDLTH03560054 on Town Highway 356 crossing Jewell Brook, Ludlow, 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 (Federal Highway Administration, 1993). Results of a Level I scour investigation also are included in appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the bridge, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in appendix D.

The site is in the Green Mountain section of the New England physiographic province in south central Vermont. The 10.3 -mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover upstream of the bridge is forest and trees with a road along the left bank; there is a road and a house on the right bank. Downstream of the bridge, there are trees along the immediate banks, houses on the left side, and a road and houses along the right side.

In the study area, the Jewell Brook has an incised, straight channel with a slope of approximately 0.017 ft/ft, an average channel top width of 56 ft and an average bank height of 6 ft. The channel bed material ranges from gravel to boulders with a median grain size (D_{50}) of 88.0 mm (0.289 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 12, 1995, indicated that the reach was stable.

The Town Highway 356 crossing of Jewell Brook is a 41-ft-long, two-lane concrete bridge consisting of five 37-foot rolled steel stringers (Vermont Agency of Transportation, written communication, March 20, 1995). The opening length of the structure parallel to the bridge face is 33 ft. The bridge is supported by vertical, concrete abutments with wingwalls; both abutments and wingwalls are faced with laid up stone. The channel is normal to the opening with a computed opening-skew-to-roadway of 0 degrees.

A scour hole 0.5 ft deeper than the mean thalweg depth was observed along the left abutment and downstream left wingwall during the Level I assessment. The only scour protection measure at the site was type-2 stone fill (less than 36 inches diameter) along the entire base length of the downstream right wingwall, and along both banks up and downstream. Additional details describing conditions at the site are included in the Level II Summary and appendices D and E.

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

Contraction scour for all modelled flows ranged from 0 to 1.0 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 6.2 to 13.8 ft. The worst-case abutment scour 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 Davis, 1995, p. 46). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.

Ludlow, VT. Quadrangle, 1:24,000, 1971

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 LUDLTH03560054 ***Stream*** Jewell Brook

County Windsor ***Road*** TH356 ***District*** 3

Description of Bridge

Bridge length 41 ***ft*** ***Bridge width*** 23.1 ***ft*** ***Max span length*** 37 ***ft***

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

Abutment type Vertical, concrete ***Embankment type*** Sloping

Stone fill on abutment? No ***Date of inspection*** 10/12/95

Description of stone fill Type-2, along the downstream right wingwall.

Brief description of piers/abutments Abutments and wingwalls are concrete. The left abutment is undermined for about 1.5 feet along the channel with a 0.3 foot penetration.

Is bridge skewed to flood flow according to No ***survey?*** No ***Angle*** -

Is bridge located on a bend in channel? If so, describe (mild, moderate, severe)

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	10/12/95	0	0
Level II	10/12/95	0	0

Potential for debris Low. The stream channel widens near the bridge, allowing debris flow.

Describe any features near or at the bridge that may affect flow (include observation date) None, 10/12/95.

Description of the Geomorphic Setting

General topography The channel is located within a moderate relief valley with a narrow flood plain on both sides.

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

Date of inspection 10/12/95

DS left: Steep channel bank to a mildly sloping overbank

DS right: Steep channel bank to a moderately sloping overbank and floodplain

US left: Steep channel bank to mildly sloping overbank

US right: Steep channel bank to mildly sloping overbank and floodplain

Description of the Channel

Average top width 56 ft ***Average depth*** 6.0 ft

Predominant bed material Gravel/Cobbles ***Bank material*** Gravel/Cobbles

Perennial and straight with random width variations and non-alluvial channel boundaries.

10/12/95

Vegetative co Brush and grass with small trees along the immediate bank.

DS left: Brush and very small trees along immediate bank, then lawns and houses.

DS right: Trees and brush on the immediate bank with forest beyond.

US left: Small trees and brush with stone fill near edge of water.

US right:

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

The assessment of 10/12/95 noted no obstructions in channel.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 10.3 ***mi***^{2}

Percentage of drainage area in physiographic provinces: (approximate)

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

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: There are houses on the upstream right overbank area and both downstream overbank areas.

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

USGS gage description --

USGS gage number --

Gage drainage area -- ***mi***^{2}

Is there a lake/p No

Calculated Discharges

Q100 1,770 ***ft***^{3}***/s*** ***Q500*** 2,400 ***ft***^{3}***/s***

The 100- and 500-year discharges are based on a drainage-area relationship [(10.3/7.3)exp 0.67] with estimates available from the VTAOT database for bridge number 98I in Ludlow (written communication 5/95). Bridge number 98I crosses Jewell Brook upstream of this site and has a drainage area of 7.3 square miles. The 100- and 500-year discharge values are within the range of flood frequency curves computed by use of several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887)

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 a concrete curb at the downstream end of the left abutment at the corner of the bridge deck (elev. 500.59 ft, arbitrary survey datum). RM2 is a chiseled X on top of a concrete curb at the downstream end of the right abutment at the corner of the bridge deck (elev. 500.67 ft, arbitrary survey datum). RM3 is a nail placed 5 feet up from the base of a telephone pole located on the upstream right bank, 50 ft from the right abutment and 75 ft upstream, on the corner of Andover St. and Pond St. (507.29 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT2	-35	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXIT2)
BRIDG	0	1	Bridge section
RDWAY	7	1	Road Grade section
APPR2	47	2	Modelled Approach section (Templated from APTEM)
APTEM	56	1	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 analyses reported herein reflect conditions existing at the site at the time of the study. Furthermore, in the development of the model it was necessary to assume no accumulation of debris or ice at the site. Results of the hydraulic model are presented in the Bridge Hydraulic Summary, appendix B, and figure 7.

Channel roughness factors (Manning's "n") used in the hydraulic model were estimated using field inspections at each cross section following the general guidelines described by Arcement and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.040 to 0.070, and overbank "n" values ranged from 0.045 to 0.050.

Normal depth at the exit 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 0.017 ft/ft which was estimated from the appropriate topographic map (U.S. Geological Survey, 1971).

The surveyed approach section (APTEM) was moved along the approach channel slope (0.008 ft/ft) to establish the modelled approach section (APPR2), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This location also provides a consistent method for determining scour variables.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.6 *ft*
Average low steel elevation 497.3 *ft*

100-year discharge 1,770 *ft³/s*
Water-surface elevation in bridge opening 497.4 *ft*
Road overtopping? No *Discharge over road* - *ft³/s*
Area of flow in bridge opening 208 *ft²*
Average velocity in bridge opening 8.5 *ft/s*
Maximum WSPRO tube velocity at bridge 9.6 *ft/s*

Water-surface elevation at Approach section with bridge 499.1
Water-surface elevation at Approach section without bridge 497.8
Amount of backwater caused by bridge 1.3 *ft*

500-year discharge 2,400 *ft³/s*
Water-surface elevation in bridge opening 497.4 *ft*
Road overtopping? Yes *Discharge over road* 161 *ft³/s*
Area of flow in bridge opening 208 *ft²*
Average velocity in bridge opening 10.8 *ft/s*
Maximum WSPRO tube velocity at bridge 12.2 */s*

Water-surface elevation at Approach section with bridge 500.0
Water-surface elevation at Approach section without bridge 498.9
Amount of backwater caused by bridge 1.1 *ft*

Incipient overtopping discharge 1,660 *ft³/s*
Water-surface elevation in bridge opening 495.4 *ft*
Area of flow in bridge opening 147 *ft²*
Average velocity in bridge opening 11.3 *ft/s*
Maximum WSPRO tube velocity at bridge 13.2 *ft/s*

Water-surface elevation at Approach section with bridge 497.5
Water-surface elevation at Approach section without bridge 497.6
Amount of backwater caused by bridge N/A *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 Davis, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analyses for the 100- and 500-year discharges are presented in tables 1 and 2 and the scour depths are shown graphically in figure 8.

Contraction scour for the incipient roadway-overtopping discharge was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20a). The 100- and 500-year discharges resulted in an orifice flow solution. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Thus, for these discharges contraction scour was computed by use of the Chang pressure-flow scour equation (Richardson and Davis, 1995, p. 144-146). The streambed armoring depths computed suggest that armoring will not limit the depth of contraction scour.

For comparison, estimates of contraction scour also were computed for the discharges resulting in orifice flow by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144). Results of these computations are presented in appendix F. Furthermore, for the 100-year discharge, which resulted in unsubmerged orifice flow, contraction scour was computed by substituting an estimate for the depth of flow at the downstream bridge face in the contraction scour equations. Results with respect to this substitution also are provided in appendix F.

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

Scour Results

Contraction scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(Scour depths in feet)		
Main channel			
Live-bed scour	--	--	--
Clear-water scour	0	1.0	0.3
Depth to armoring	5.3	8.0	15.0
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	11.9	13.8	11.0
Right abutment	7.0–	7.3-	6.2-
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(D_{50} in feet)		
Abutments:			
Left abutment	1.2	2.3	1.8
Right abutment	1.8	2.3	1.8
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

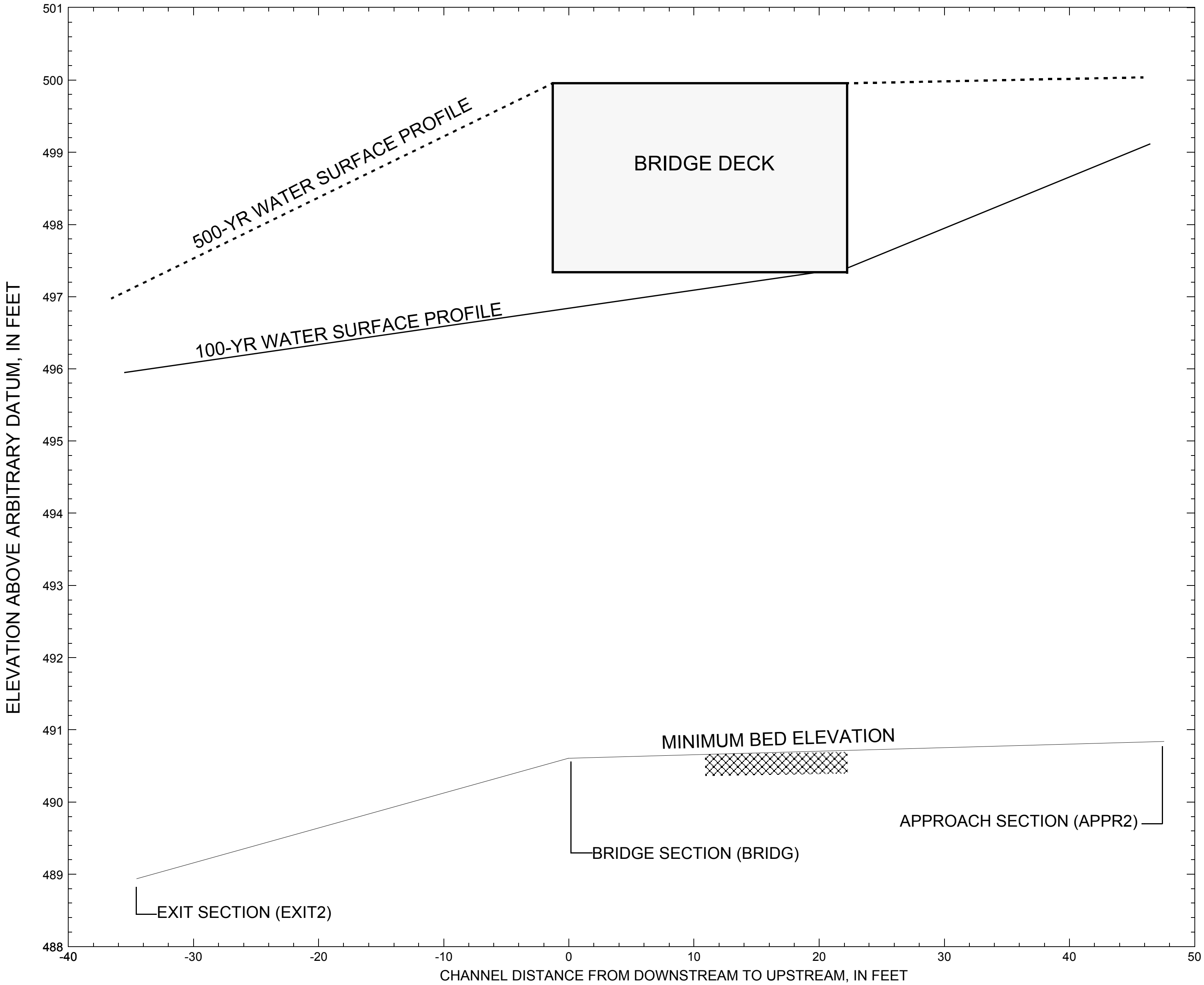

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure LUDLTH03560054 on Town Highway 356, crossing Jewell Brook, Ludlow, Vermont.

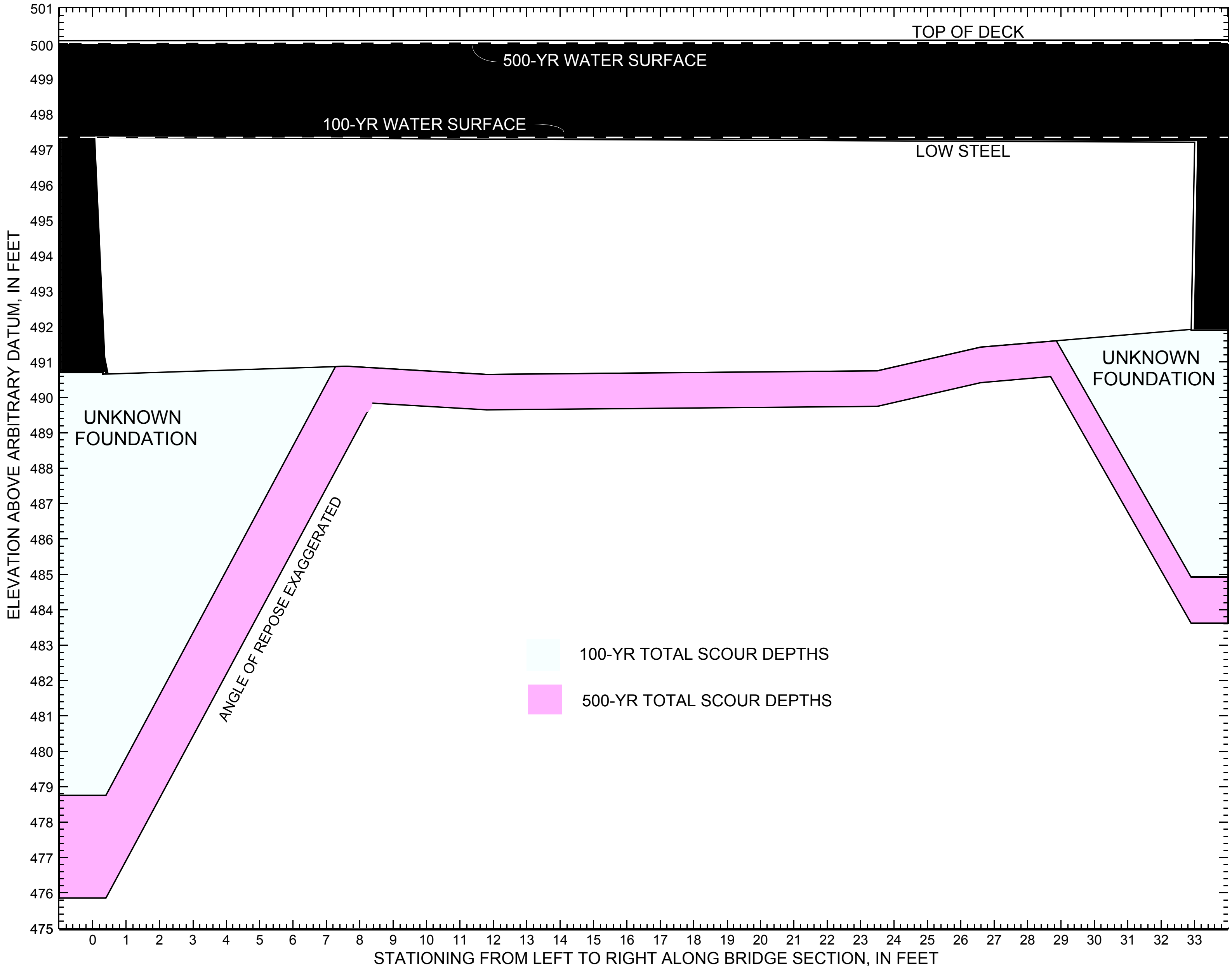

Figure 8. Scour elevations for the 100- and 500-yr discharges at structure LUDLTH03560054 on Town Highway 356, crossing Jewell Brook, Ludlow, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-yr discharge at structure LUDLTH03560054 on Town Highway 356, crossing Jewell Brook, Ludlow, 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 1,770 cubic-feet per second											
Left abutment	0.0	---	497.3	--	490.7	0	11.9	--	11.9	478.8	--
Right abutment	33.0	---	497.2	--	491.9	0	7.0	--	7.0	484.9	--

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-yr discharge at structure LUDLTH03560054 on Town Highway 356, crossing Jewell Brook, Ludlow, 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 2,400 cubic-feet per second											
Left abutment	0.0	---	497.3	--	490.7	1.0	13.8	--	14.8	475.9	--
Right abutment	33.0	---	497.2	--	491.9	1.0	7.3	--	8.3	483.6	--

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, 1971, Ludlow, 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        U.S. Geological Survey WSPRO Input File ludl054.wsp
T2        Hydraulic analysis for structure LUDLTH03560054   Date: 19-NOV-97
T3        TH 356 CROSSING JEWELL BROOK IN LUDLOW, VERMONT                SAW
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           1770.0   2400.0   1660.0
SK          0.017   0.017   0.017
*
XS   EXIT2    -35
*
GR           -6.8, 497.02      0.0, 494.01
GR            5.9, 490.71     11.6, 489.81     13.0, 489.43     18.8, 488.95
GR           23.1, 489.39     27.5, 489.58     29.0, 490.03     31.0, 490.71
GR           36.9, 492.11     46.8, 497.45     70.1, 499.51
*           120.1, 498.97    145.9, 498.53
*
N           0.050        0.065        0.045
SA                  -6.8         46.8
*
XS   FULLV      0  * * *   0.0297
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0    497.28       0.0
GR            0.0, 497.35      0.3, 491.11      0.4, 490.66      7.6, 490.88
GR           11.8, 490.65     23.5, 490.75     26.6, 491.42     32.9, 491.92
GR           33.0, 497.21      0.0, 497.35
*
*         BRTYPE  BRWDTH       WWANGL    WWWID
CD            1      28.1 * *     70.0      5.6
N           0.040
*
*             SRD    EMBWID   IPAVE
XR   RDWAY      7      23.1     1
GR         -130.3, 514.44   -112.0, 505.19    -84.7, 499.5    -67.8, 499.5
GR          -37.9, 499.5     -4.3, 500.65      0.0, 500.6     15.0, 500.49
GR           36.5, 500.49
GR           94.4, 500.17    122.0, 500.09    141.4, 500.42
GR          160.4, 504.92    161.3, 507.36    169.1, 509.00    207.4, 525.10
*
*           EXPECTED SRD =   47 AT ONE BR. LENGTH BUT COMPUTED SRD =   56
*
XT   APTEM     56
GR          -83.3, 517.69    -56.4, 502.56    -19.1, 501.65    -17.8, 501.11
GR           -7.4, 493.59     -1.9, 492.42      0.0, 491.99      0.4, 491.84
GR            4.0, 491.29      8.9, 491.18     12.9, 490.91     20.2, 491.15
GR           23.1, 491.50     25.9, 491.99     29.9, 492.70     40.2, 499.25
GR           58.4, 500.40     84.7, 501.22    109.4, 501.53    116.2, 501.95
GR          126.4, 507.80    147.4, 520.31
*
AS   APPR2   47 * * * 0.008
GT
N           0.045        0.070        0.045
SA                 -17.8         40.2
*
HP 1 BRIDG  497.35 1 497.35
HP 2 BRIDG  497.35 * * 1770
HP 1 BRIDG  496.48 1 496.48
HP 1 APPR2  499.07 1 499.07
HP 2 APPR2  499.07 * * 1770
*
HP 1 BRIDG  497.35 1 497.35
HP 2 BRIDG  497.35 * * 2239
HP 2 RDWAY  500.02 * * 161
HP 1 APPR2  500.02 1 500.02
HP 2 APPR2  500.02 * * 2400
*
HP 1 BRIDG  495.44 1 495.44
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
   T1        U.S. Geological Survey WSPRO Input File ludl054.wsp
   T2        Hydraulic analysis for structure LUDLTH03560054   Date: 19-NOV-97
   T3        TH 356 CROSSING JEWELL BROOK IN LUDLOW, VERMONT                  SAW

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

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      208     14902      0     78                            0
    497.35           208     14902      0     78  1.00      0     33        0

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

          WSEL     LEW     REW    AREA        K        Q    VEL
        497.35     0.0    33.0   207.6   14902.    1770.   8.53

 X STA.        0.0        2.6        4.2        5.8        7.3        8.8
   A(I)            16.2       10.9       10.0        9.9        9.4
   V(I)            5.47       8.14       8.83       8.95       9.37

 X STA.        8.8       10.2       11.6       13.0       14.4       15.8
   A(I)             9.5        9.2        9.3        9.2        9.2
   V(I)            9.30       9.60       9.47       9.61       9.64

 X STA.       15.8       17.2       18.6       20.1       21.5       23.0
   A(I)             9.3        9.3        9.4        9.3        9.6
   V(I)            9.52       9.54       9.46       9.56       9.18

 X STA.       23.0       24.4       26.1       27.9       30.0       33.0
   A(I)             9.5       10.3       10.4       11.5       16.1
   V(I)            9.27       8.56       8.49       7.69       5.50
1
      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      181     17612     33     43                         2412
    496.48           181     17612     33     43  1.00      0     33     2412
1
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR2;  SRD =      47.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              2      332     22313     55     59                         4623
    499.07           332     22313     55     59  1.00    -14     40     4623
1
      VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR2;  SRD =      47.

          WSEL     LEW     REW    AREA        K        Q    VEL
        499.07   -15.1    40.0   332.0   22313.    1770.   5.33

 X STA.      -15.1       -6.1       -3.1       -0.5        1.6        3.6
   A(I)            28.5       18.8       17.2       15.9       15.2
   V(I)            3.11       4.72       5.14       5.55       5.82

 X STA.        3.6        5.5        7.3        9.0       10.8       12.5
   A(I)            14.7       14.2       13.8       14.0       13.8
   V(I)            6.04       6.23       6.41       6.31       6.42

 X STA.       12.5       14.2       15.8       17.5       19.3       21.1
   A(I)            13.8       13.7       13.8       14.2       14.5
   V(I)            6.40       6.44       6.41       6.25       6.08

 X STA.       21.1       23.1       25.2       27.6       30.5       40.0
   A(I)            15.1       15.5       17.1       18.9       29.2
   V(I)            5.86       5.70       5.18       4.68       3.03
1
   *
```

WSPRO OUTPUT FILE (continued)

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

       WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
               1      208     14902     0     78                            0
     497.35           208     14902     0     78  1.00      0     33        0

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

           WSEL     LEW     REW    AREA        K        Q    VEL
         497.35     0.0    33.0   207.6   14902.    2239.  10.79

  X STA.         0.0        2.6        4.2        5.8        7.3        8.8
    A(I)            16.2       10.9       10.0        9.9        9.4
    V(I)            6.92      10.30      11.17      11.32      11.86

  X STA.         8.8       10.2       11.6       13.0       14.4       15.8
    A(I)             9.5        9.2        9.3        9.2        9.2
    V(I)           11.76      12.15      11.99      12.16      12.19

  X STA.        15.8       17.2       18.6       20.1       21.5       23.0
    A(I)             9.3        9.3        9.4        9.3        9.6
    V(I)           12.04      12.07      11.96      12.09      11.61

  X STA.        23.0       24.4       26.1       27.9       30.0       33.0
    A(I)             9.5       10.3       10.4       11.5       16.1
    V(I)           11.73      10.82      10.75       9.73       6.96

      VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       7.

           WSEL     LEW     REW    AREA        K        Q    VEL
         500.02   -87.2   -22.7    28.9     505.     161.   5.56

  X STA.       -87.2      -82.8      -80.2      -77.7      -75.1      -72.6
    A(I)             1.6        1.4        1.3        1.3        1.3
    V(I)            4.93       5.94       6.07       6.00       6.18

  X STA.       -72.6      -70.0      -67.4      -64.9      -62.4      -59.8
    A(I)             1.3        1.3        1.3        1.3        1.3
    V(I)            5.97       6.09       6.18       6.04       6.04

  X STA.       -59.8      -57.2      -54.7      -52.0      -49.4      -46.8
    A(I)             1.3        1.3        1.4        1.4        1.4
    V(I)            6.01       6.01       5.94       5.87       5.85

  X STA.       -46.8      -44.1      -41.3      -38.4      -34.9      -22.7
    A(I)             1.4        1.4        1.5        1.7        2.5
    V(I)            5.72       5.64       5.29       4.83       3.18

      CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR2;  SRD =      47.

       WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
               2      385     28004    57     61                         5700
               3        6       104    13     13                           21
     500.02           391     28108    70     74  1.02    -15     54     5194

      VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR2;  SRD =      47.

           WSEL     LEW     REW    AREA        K        Q    VEL
         500.02   -16.4    53.5   390.7   28108.    2400.   6.14

  X STA.       -16.4       -6.7       -3.4       -0.8        1.4        3.6
    A(I)            33.8       22.9       20.3       18.2       18.2
    V(I)            3.55       5.24       5.92       6.59       6.59

  X STA.         3.6        5.5        7.3        9.2       11.0       12.8
    A(I)            16.8       16.7       16.6       16.2       15.9
    V(I)            7.15       7.20       7.24       7.39       7.53

  X STA.        12.8       14.5       16.3       18.1       19.9       21.8
    A(I)            16.2       16.1       16.2       16.3       16.9
    V(I)            7.42       7.47       7.43       7.38       7.10

  X STA.        21.8       23.8       26.1       28.5       31.7       53.5
    A(I)            17.5       18.5       19.3       22.7       35.7
    V(I)            6.85       6.50       6.20       5.30       3.36
1
   *
```

WSPRO OUTPUT FILE (continued)

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

     WSEL  SA#    AREA        K  TOPW  WETP  ALPH    LEW    REW     QCR
             1     147    12843    33    41                        1764
   495.44          147    12843    33    41  1.00      0     33    1764

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       495.44     0.1    33.0   147.0   12843.    1660.  11.29

 X STA.         0.1        2.8        4.5        6.1        7.6        9.0
   A(I)            12.5        7.8        7.3        6.7        6.8
   V(I)            6.64      10.65      11.33      12.30      12.26

 X STA.         9.0       10.4       11.8       13.1       14.4       15.8
   A(I)             6.5        6.4        6.4        6.3        6.3
   V(I)           12.75      12.91      12.99      13.17      13.20

 X STA.        15.8       17.1       18.4       19.8       21.2       22.6
   A(I)             6.3        6.3        6.4        6.6        6.5
   V(I)           13.10      13.13      13.01      12.61      12.79

 X STA.        22.6       24.0       25.6       27.4       29.6       33.0
   A(I)             6.8        7.1        7.4        8.4       12.1
   V(I)           12.26      11.64      11.19       9.92       6.83

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR2;  SRD =      47.

     WSEL  SA#    AREA        K  TOPW  WETP  ALPH    LEW    REW     QCR
             2     248    14687    50    53                        3123
   497.48          248    14687    50    53  1.00    -12     38    3123

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR2;  SRD =      47.

         WSEL     LEW     REW    AREA        K        Q    VEL
       497.48   -12.9    37.5   248.1   14687.    1660.   6.69

 X STA.       -12.9       -5.1       -2.1        0.3        2.4        4.2
   A(I)            20.4       14.5       12.9       12.0       11.3
   V(I)            4.07       5.73       6.44       6.90       7.38

 X STA.         4.2        6.0        7.7        9.3       10.9       12.5
   A(I)            11.1       10.7       10.7       10.4       10.5
   V(I)            7.49       7.72       7.75       8.01       7.88

 X STA.        12.5       14.1       15.7       17.3       18.9       20.6
   A(I)            10.4       10.3       10.4       10.6       10.9
   V(I)            7.98       8.03       8.00       7.80       7.60

 X STA.        20.6       22.4       24.4       26.6       29.3       37.5
   A(I)            11.3       12.0       12.4       14.0       21.3
   V(I)            7.32       6.94       6.70       5.95       3.90
1
   *
   EX
```

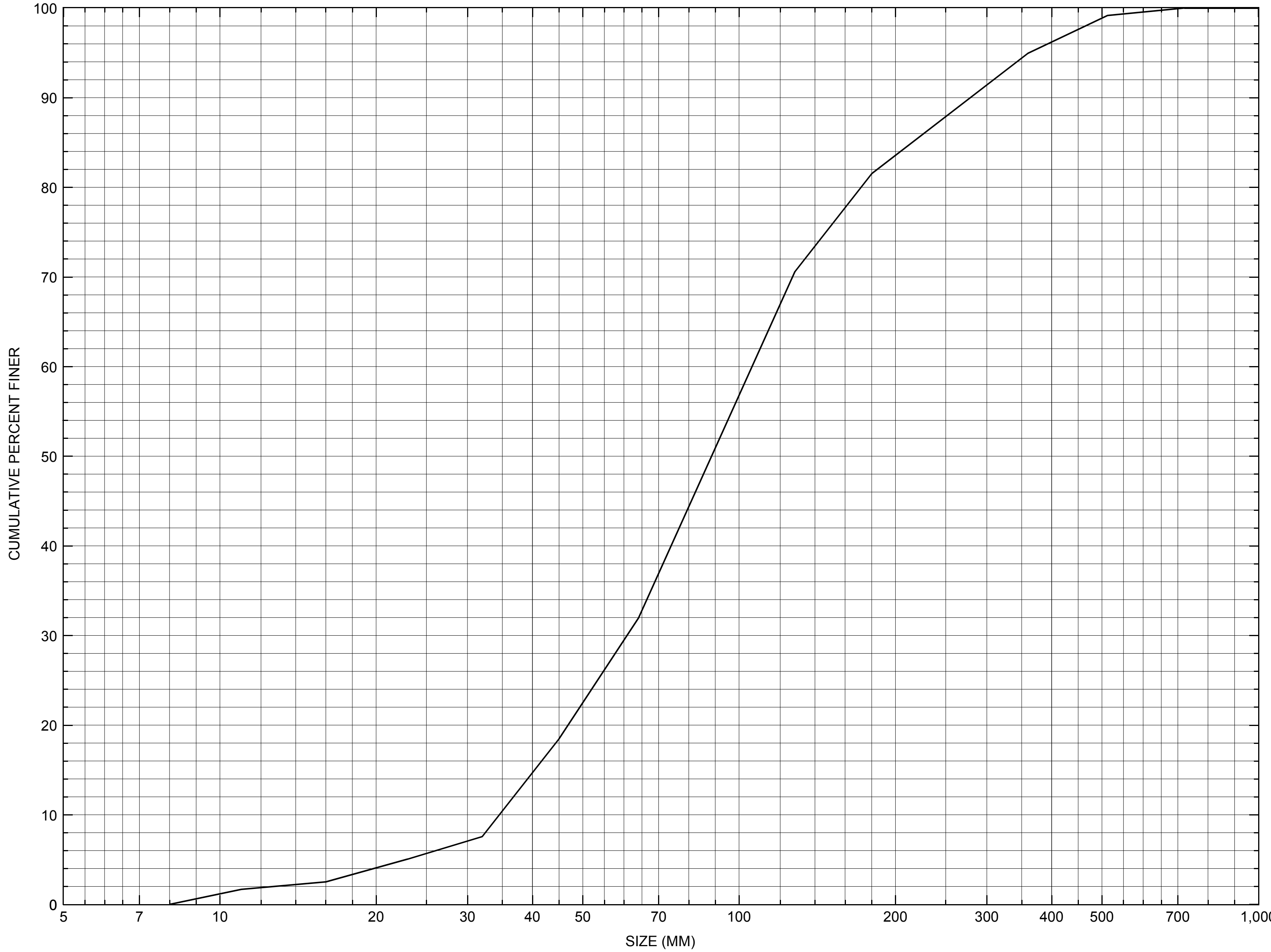
```
       U.S. Geological Survey WSPRO Input File ludl054.wsp
        Hydraulic analysis for structure LUDLTH03560054   Date: 19-NOV-97
        TH 356 CROSSING JEWELL BROOK IN LUDLOW, VERMONT                  SAW
           *** RUN DATE & TIME: 12-02-97  17:05

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

EXIT2:XS   ******     -3      222  0.99 *****  496.89  494.56    1770  495.90
       -34 ******     44    13569  1.00 ***** *******    0.66    7.98

FULLV:FV       35     -2      200  1.22  0.69  497.69 *******    1770  496.48
         0     35     43    11753  1.00  0.11    0.01    0.75    8.84
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR2:AS       47    -12      263  0.71  0.79  498.47 *******    1770  497.77
        47     47     38    15958  1.00  0.00   -0.01    0.52    6.74
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   495.59     497.46     497.76     497.28

 ===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       35      0      208  1.12 *****  498.47  495.44    1761  497.35
         0 ******     33    14902  1.00 ***** *******    0.60    8.48

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.464  0.000  497.28 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       7.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPR2:AS       19    -14      332  0.44  0.19  499.52  495.73    1770  499.07
        47     20     40    22331  1.00  0.48    0.00    0.38    5.33

   FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW      Q        K     AREA     VEL    WSEL
   EXIT2:XS     -35.    -4.    44.   1770.   13569.     222.    7.98  495.90
   FULLV:FV      0.     -3.    43.   1770.   11753.     200.    8.84  496.48
   BRIDG:BR      0.      0.    33.   1761.   14902.     208.    8.48  497.35
   RDWAY:RG      7.**************      0.*********       0.    1.00********
   APPR2:AS     47.   -15.    40.   1770.   22331.     332.    5.33  499.07

  SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF     HO   VHD      EGL    WSEL
   EXIT2:XS    494.56    0.66  488.95  499.51************  0.99  496.89  495.90
   FULLV:FV  ********    0.75  489.99  500.55  0.69  0.11  1.22  497.69  496.48
   BRIDG:BR    495.44    0.60  490.65  497.35************  1.12  498.47  497.35
   RDWAY:RG  ****************  499.50  525.10************  0.31  500.37********
   APPR2:AS    495.73    0.38  490.84  520.24  0.19  0.48  0.44  499.52  499.07
```

```
U.S. Geological Survey WSPRO Input File ludl054.wsp
        Hydraulic analysis for structure LUDLTH03560054   Date: 19-NOV-97
        TH 356 CROSSING JEWELL BROOK IN LUDLOW, VERMONT                  SAW
           *** RUN DATE & TIME: 12-02-97  17:05

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

EXIT2:XS   ******     -6      276  1.17 *****  498.15  495.49    2400  496.98
       -34 ******     46    18401  1.00 ***** *******    0.67    8.68

FULLV:FV       35     -5      252  1.41  0.68  498.96 *******    2400  497.54
         0     35     45    16165  1.00  0.12    0.00    0.75    9.53
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR2:AS       47    -14      321  0.87  0.79  499.74 *******    2400  498.87
        47     47     40    21258  1.00  0.00   -0.01    0.54    7.48
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   497.54      497.28
            <<<<<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       35      0      208  1.81 *****  499.16  496.22    2239  497.35
         0 ******     33    14902  1.00 ***** *******    0.76   10.79

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  497.28 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
   RDWAY:RG       7.    24.  0.17  0.60  500.45    0.00    161.  500.02

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    161.    65.   -87.   -23.   0.5   0.5   4.3   5.5   0.9   3.1
   RT:      0.    28.    94.   122.   0.3   0.2   3.6   6.1   0.6   3.0

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

APPR2:AS       19    -15      391  0.60  0.26  500.62  496.59    2400  500.02
        47     20     54    28134  1.02  0.48    0.00    0.46    6.14

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT2:XS     -35.    -7.    46.   2400.   18401.     276.    8.68  496.98
   FULLV:FV       0.    -6.    45.   2400.   16165.     252.    9.53  497.54
   BRIDG:BR       0.     0.    33.   2239.   14902.     208.   10.79  497.35
   RDWAY:RG       7.*******   161.    161.       0.       0.    1.00  500.02
   APPR2:AS      47.   -16.    54.   2400.   28134.     391.    6.14  500.02

  SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXIT2:XS    495.49    0.67  488.95  499.51************  1.17  498.15  496.98
   FULLV:FV  ********    0.75  489.99  500.55  0.68  0.12  1.41  498.96  497.54
   BRIDG:BR    496.22    0.76  490.65  497.35************  1.81  499.16  497.35
   RDWAY:RG  ****************  499.50  525.10  0.17******  0.60  500.45  500.02
   APPR2:AS    496.59    0.46  490.84  520.24  0.26  0.48  0.60  500.62  500.02
```

```
 U.S. Geological Survey WSPRO Input File ludl054.wsp
        Hydraulic analysis for structure LUDLTH03560054   Date: 19-NOV-97
        TH 356 CROSSING JEWELL BROOK IN LUDLOW, VERMONT                 SAW
           *** RUN DATE & TIME: 12-02-97  17:05

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

 EXIT2:XS   ******     -3      212  0.95 ***** 496.64  494.37    1660  495.69
       -34 ******     44    12726  1.00 ***** *******    0.65    7.83

 FULLV:FV       35     -2      191  1.18  0.69  497.45 *******    1660  496.27
         0      35     43    10987  1.00  0.11    0.01    0.75    8.70
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPR2:AS       47    -12      252  0.68  0.79  498.23 *******    1660  497.56
        47      47     38    15015  1.00  0.00    0.00    0.52    6.59
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
            <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

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

 BRIDG:BR       35      0      147  1.99  0.59  497.42  495.27    1660  495.44
         0      35     33    12832  1.00  0.19   -0.01    0.94   11.30

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   1.  1.000 ******  497.28 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
    RDWAY:RG       7.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

 APPR2:AS       19    -12      248  0.70  0.29  498.18  495.55    1660  497.48
        47      20     38    14679  1.00  0.47    0.02    0.53    6.69

FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXIT2:XS     -35.    -4.    44.   1660.   12726.     212.    7.83  495.69
    FULLV:FV       0.    -3.    43.   1660.   10987.     191.    8.70  496.27
    BRIDG:BR       0.     0.    33.   1660.   12832.     147.   11.30  495.44
    RDWAY:RG       7.**************      0.******************    1.00********
    APPR2:AS      47.   -13.    38.   1660.   14679.     248.    6.69  497.48

  SECOND USER DEFINED TABLE.

     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
    EXIT2:XS    494.37    0.65  488.95  499.51************  0.95  496.64  495.69
    FULLV:FV  ********    0.75  489.99  500.55  0.69  0.11  1.18  497.45  496.27
    BRIDG:BR    495.27    0.94  490.65  497.35  0.59  0.19  1.99  497.42  495.44
    RDWAY:RG  ****************  499.50  525.10**********************************
    APPR2:AS    495.55    0.53  490.84  520.24  0.29  0.47  0.70  498.18  497.48
   ER
1  NORMAL  END  OF  WSPRO  EXECUTION.
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure LUDLTH03560054, in Ludlow, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number LUDLTH03560054

General Location Descriptive

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

Date *(MM/DD/YY)* 03 / 20 / 95

Highway District Number *(I - 2; nn)* 03

County *(FIPS county code; I - 3; nnn)* 027

Town *(FIPS place code; I - 4; nnnnn)* 41200

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

Waterway *(I - 6)* JEWELL BROOK

Road Name *(I - 7):* -

Route Number TH356

Vicinity *(I - 9)* 0.01 MI TO JCT W CL1 TH2

Topographic Map Ludlow

Hydrologic Unit Code: 01080106

Latitude *(I - 16; nnnn.n)* 43236

Longitude *(i - 17; nnnnn.n)* 72423

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 10141000541410

Maintenance responsibility *(I - 21; nn)* 03

Maximum span length *(I - 48; nnnn)* 0037

Year built *(I - 27; YYYY)* 1937

Structure length *(I - 49; nnnnnn)* 000041

Average daily traffic, ADT *(I - 29; nnnnnn)* 000600

Deck Width *(I - 52; nn.n)* 231

Year of ADT *(I - 30; YY)* 93

Channel & Protection *(I - 61; n)* 5

Opening skew to Roadway *(I - 34; nn)* 10

Waterway adequacy *(I - 71; n)* 6

Operational status *(I - 41; X)* A

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

Structure type *(I - 43; nnn)* 302

Year Reconstructed *(I - 106)* 0000

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

Clear span (*nnn.n ft*) -

Number of spans *(I - 45; nnn)* 001

Vertical clearance from streambed (*nnn.n ft*) 006.0

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

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

Comments:

The structural inspection report of 6/14/93 indicates the structure is a steel stringer type bridge with a concrete deck. The abutment walls and wingwalls are reported as concrete faced “laid-up” stone walls. Overall the abutment and wingwall concrete has surface spalling and random cracking. One of the right abutment’s wingwalls is noted as having a settlement crack. There also is a settlement crack on the right abutment wall and on the left abutment wall. Yet another is noted as a diagonal crack in one of the wing-walls of the left abutment and may have resulted in a small section of concrete facing spalling off the wall at the bottom right corner. **(Continued, page 32)**

Bridge Hydrologic Data

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

Terrain character: -

Stream character & type: -

Streambed material: -

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

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

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

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

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

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

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

Describe any significant site conditions upstream or downstream that may influence the stream's stage: -

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

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

Water Surface Elevation Estimates for Existing Structure:

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

Long term stream bed changes: -

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

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

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

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

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

Clear span (*ft*): - Clear Height (*ft*): - Full Waterway (*ft^2*): -

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

Comments:

Some natural stone fill protection is noted as visible along the upstream and downstream banks. The report indicates no footings were seen at the surface but noted some voids where the left abutment wall has been undermined with scour measured at 1 to 1.5 feet in the channel along the abutment.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **10.31** mi^2 Lake/pond/swamp area **0.07** mi^2

Watershed storage *(ST)* **0.7** %

Bridge site elevation **1020** ft Headwater elevation **3343** ft

Main channel length **4.57** mi

10% channel length elevation **1080** ft 85% channel length elevation **2200** ft

Main channel slope *(S)* **327.13** ft / mi

Watershed Precipitation Data

Average site precipitation - in Average headwater precipitation - in

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

Average seasonal snowfall *(Sn)* - ft

Bridge Plan Data

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

Project Number -　　Minimum channel bed elevation: -

Low superstructure elevation: USLAB - DSLAB - USRAB - DSRAB -

Benchmark location description:

NO BENCHMARK INFORMATION

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

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

If 1: Footing Thickness -　　Footing bottom elevation: -

If 2: Pile Type: - (*1-Wood; 2-Steel or metal; 3-Concrete*)　　Approximate pile driven length: -

If 3: Footing bottom elevation: -

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

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

Briefly describe material at foundation bottom elevation or around piles:

NO FOUNDATION MATERIAL INFORMATION

Comments:

NO PLANS.

Cross-sectional Data

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

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

Comments: **The elevation and station coordinates are in feet. The sketch that the low chord to bed length and station distances were recorded on was dated 6/17/93. The elevation coordinates were lined up with the system surveyed for this report by the low chord points.**

Station	0	17	26	37	-	-	-	-	-	-	-
Feature	LAB	-	-	RAB	-	-	-	-	-	-	-
Low chord elevation	497.35	497.28	497.25	497.21	-	-	-	-	-	-	-
Bed elevation	490.45	490.68	490.75	491.91	-	-	-	-	-	-	-
Low chord to bed	6.9	6.6	6.5	5.3	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low chord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low chord to bed	-	-	-	-	-	-	-	-	-	-	-

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

Comments: -
-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low chord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low chord to bed	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low chord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low chord to bed	-	-	-	-	-	-	-	-	-	-	-

APPENDIX E:

LEVEL I DATA FORM

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

Qa/Qc Check by: **CG** Date: **1/24/96**

Computerized by: **CG** Date: **2/2/96**

Reviewd by: **SAW** Date: **12/16/97**

Structure Number **LUDLTH03560054**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **M. Ivanoff** Date *(MM/DD/YY)* **10** / **12** / 19**95**
2. Highway District Number **03** Mile marker **0**
   County **Windsor (027)** Town **Ludlow (41200)**
   Waterway *(I - 6)* **Jewel Brook** Road Name **Pond Street**
   Route Number **TH 356** Hydrologic Unit Code: **01080106**
3. Descriptive comments:
   This site is located 0.01 miles from the junction with town highway 2.

B. Bridge Deck Observations

4. Surface cover... LBUS **6** RBUS **2** LBDS **2** RBDS **2** Overall **2**
   *(2b us,ds,lb,rb: **1**- Urban; **2**- Suburban; **3**- Row crops; **4**- Pasture; **5**- Shrub- and brushland; **6**- Forest; **7**- Wetland)*
5. Ambient water surface... US **2** UB **2** DS **2** *(**1**- pool; **2**- riffle)*
6. Bridge structure type **1** *(**1**- single span; **2**- multiple span; **3**- single arch; **4**- multiple arch; **5**- cylindrical culvert; **6**- box culvert; or **7**- other)*
7. Bridge length **41.0** *(feet)* Span length **37.0** *(feet)* Bridge width **23.1** *(feet)*

Road approach to bridge:

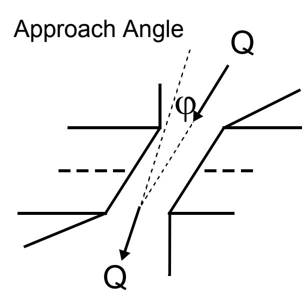
8. LB **0** RB **0** *(**0** even, **1**- lower, **2**- higher)*
9. LB **1** RB **1** *(**1**- Paved, **2**- Not paved)*
10. Embankment slope (*run / rise in feet / foot*):
    US left **0.0:1** US right **0.0:1**

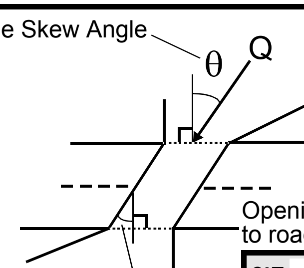
	Protection			
	11.Type	12.Cond.	13.Erosion	14.Severity
LBUS	0	-	0	0
RBUS	2	1	3	3
RBDS	2	1	2	1
LBDS	5	1	0	0

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

Channel approach to bridge (BF):

15. Angle of approach: **0** 16. Bridge skew: **0**





α= **0.0**

17. Channel impact zone 1: Exist? **Y** *(Y or N)*
    Where? **LB** *(LB, RB)* Severity **2**
    Range? **10** feet **US** *(US, UB, DS)* to **0** feet **DS**
    Channel impact zone 2: Exist? **N** *(Y or N)*
    Where? **-** *(LB, RB)* Severity **-**
    Range? **-** feet **-** *(US, UB, DS)* to **-** feet **-**

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

18. Bridge Type: **1a**

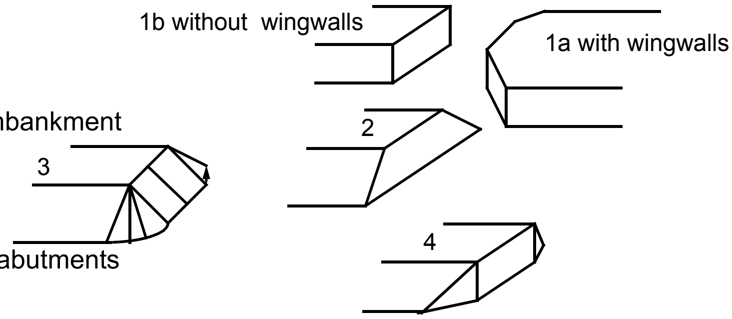
1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

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

3- Spill through abutments

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



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

7. All measurements are the same as on the historical form. There is a clear span of 32.5 feet.
14. The RBUS laid up stone wall is in good condition. The concrete facing of the wingwall has spalled off. Moderate road wash is occurring at the base of upstream right curbing.

C. Upstream Channel Assessment

20. SRD	21. Bank height (BF) LB	21. Bank height (BF) RB	22. Bank angle (BF) LB	22. Bank angle (BF) RB	26. % Veg. cover (BF) LB	26. % Veg. cover (BF) RB	27. Bank material (BF) LB	27. Bank material (BF) RB	28. Bank erosion (BF) LB	28. Bank erosion (BF) RB
32.5	7.5			6.5	3	3	345	345	0	0

23. Bank width **35.0** 24. Channel width **30.0** 25. Thalweg depth **58.5** 29. Bed Material **345**

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

SRD - Section ref. dist. to US face *% Vegetation (Veg) cover: **1**- 0 to 25%; **2**- 26 to 50%; **3**- 51 to 75%; **4**- 76 to 100%*
*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*
*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*
*Bank protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*

32. Comments (bank material variation, minor inflows, protection extent, etc.):
27. The bank material is composed of gravel, cobble and boulder.
29. The bed material is composed of gravel, cobble and boulder.
30. Native stone fill lines both banks beyond 200 feet upstream. A railroad bridge pier is high on the right bank (100 to 126 feet upstream). There is large boulder fill between the pier and the stream bed.

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

36. Point bar extent: - feet - (US, UB) to - feet - (US, UB, DS) positioned - %LB to - %RB

37. Material: -

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

NO POINT BARS

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

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

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

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

NO CUT BANKS

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

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

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

NO CHANNEL SCOUR

49. Are there major confluences? **N** (Y or if N type ctrl-n mc) 50. How many? -

51. Confluence 1: Distance - 52. Enters on - (LB or RB) 53. Type - (**1**- perennial; **2**- ephemeral)

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

54. Confluence comments (eg. confluence name):

NO MAJOR CONFLUENCES

A concrete culvert 3.5 ft in diameter drains into the stream 151 feet upstream on the right bank.

D. Under Bridge Channel Assessment

55. Channel restraint (BF)? LB **2** RB (**1**- natural bank; **2**- abutment; **3**- artificial levee)

56. Height (BF)		57 Angle (BF)		61. Material (BF)		62. Erosion (BF)	
LB	RB	LB	RB	LB	RB	LB	RB
37.5		1.0		2	7	7	-

58. Bank width (BF) - 59. Channel width (Amb) - 60. Thalweg depth (Amb) **90.0** 63. Bed Material -

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

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

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

345

63. The bed material is composed of gravel, cobble and boulder.

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

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

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

70. Debris and Ice Comments:

1

Stream channel widens near the bridge, allowing debris flow.

Abutments	71. Attack ∠(BF)	72. Slope ∠ (Qmax)	73. Toe loc. (BF)	74. Scour Condition	75. Scour depth	76. Exposure depth	77. Material	78. Length
LABUT		**0**	**90**	**2**	**1**	**0.5**	**0**	**90.0**
RABUT	**1**	**0**	**90**			**2**	**0**	**33.0**

Pushed: LB or RB *Toe Location (Loc.): 0- even, 1- set back, 2- protrudes*
Scour cond.: 0- not evident; 1- evident (comment); 2- footing exposed; 3-undermined footing; 4- piling exposed; 5- settled; 6- failed
Materials: *1*- Concrete; *2*- Stone masonry or drywall; *3*- steel or metal; *4*- wood

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

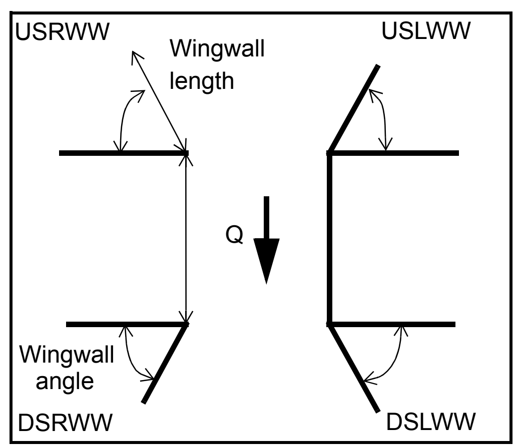
0
0
1

74. The left abutment has a void in the concrete at the corner junction with the wingwall. The void has a maximum penetration of 0.8 feet. There is also a 1.5 feet long void with 0.3 feet penetration 5 feet under the bridge from the upstream face. The right abutment appears to have two settlement cracks starting under the last two steel beams. The structural inspection report of 6/14/93 noted that the left abutment was undermined 1 to 1.5 feet along the channel.

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						**33.0**	
USRWW:	**Y**		**1**		**0**	**0.5**	
DSLWW:	**0**		**0**		**Y**	**16.0**	
DSRWW:	**1/2**		**1**		**0**	**13.0**	

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



82. **Bank / Bridge Protection**:

Location	USLWW	USRWW	LABUT	RABUT	LB	RB	DSLWW	DSRWW
Type	**0**	**1**	**Y**	**0**	**-**	**-**	**-**	**-**
Condition	**Y**	**0.5**	**1**	**0**	**-**	**-**	**-**	**-**
Extent	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**-**

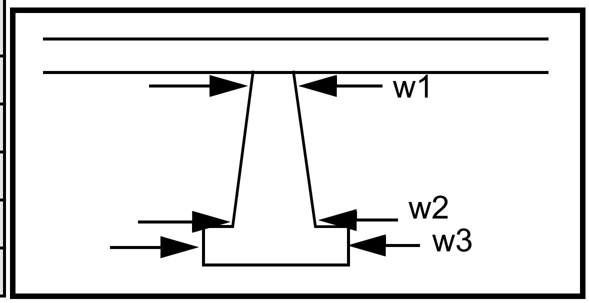
Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other

83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):
-
-
-
-
-
0
-
-
2
1
1

Piers:

84. Are there piers? **80.** *(Y or if N type ctrl-n pr)*

85. Pier no.	width (w) feet			elevation (e) feet		
	w1	w2	w3	e@w1	e@w2	e@w3
Pier 1				65.0	20.5	75.0
Pier 2	9.0			40.0	17.5	70.0
Pier 3	3.5	-	-	-	-	-
Pier 4	-	-	-	-	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	The	remove	am left	junc-	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	upst	d	wing	tion	***1**- Solid pier, **2**- column, **3**- bent*
88. Material	ream	expo	wall	with	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	right	sing	has a	the	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	wing	the	void	abut	*Y- yes; N- no*
91. Attack ∠ (BF)	wall	laid	alon	ment	
92. Pushed	con-	up	g the	to 2	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles	crete	stone	wall	feet	
95. Cross-members	fac-	wall.	from	dow	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	ing	The	the	nstre	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	has	dow	cor-	am.	
98. Exposure depth	been	nstre	ner	Ther	

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

e is 0.5 feet of penetration.
The downstream right wingwall has a settlement crack running down it. The wingwall has a rough end with upright timbers at the downstream end.

N

E. Downstream Channel Assessment

100.

SRD	Bank height (BF) LB	Bank height (BF) RB	Bank angle (BF) LB	Bank angle (BF) RB	% Veg. cover (BF) LB	% Veg. cover (BF) RB	Bank material (BF) LB	Bank material (BF) RB	Bank erosion (BF) LB	Bank erosion (BF) RB
-	-			-	-	-	-	-	-	-

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

Bank protection type (Qmax): LB - RB - Bank protection condition: LB - RB -

SRD - Section ref. dist. to US face *% Vegetation (Veg) cover: **1**- 0 to 25%; **2**- 26 to 50%; **3**- 51 to 75%; **4**- 76 to 100%*
*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*
*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*
*Bank protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*

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

101. Is a drop structure present? - *(Y or N, if N type ctrl-n ds)* 102. Distance: - feet
103. Drop: - feet 104. Structure material: - *(**1**- steel sheet pile; **2**- wood pile; **3**- concrete; **4**- other)*
105. Drop structure comments (eg. downstream scour depth):
-
-
-
-
-
-

106. Point/Side bar present? - (Y or N. if N type ctrl-n pb) Mid-bar distance: - Mid-bar width: -

Point bar extent: - feet - (US, UB, DS) to - feet - (US, UB, DS) positioned - %LB to - %RB

Material: -

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

-
-
-
-

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

Cut bank extent: RS feet ____ (US, UB, DS) to ____ feet ____ (US, UB, DS)

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

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

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

Scour dimensions: Length 3 Width 435 Depth: 435 Positioned 0 %LB to 0 %RB

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

345
2
2
1

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

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

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

Confluence comments (eg. confluence name):

e fill lining the banks. The fill extends over 200 feet downstream.
The downstream bank material is composed of cobble, gravel and boulder.

F. Geomorphic Channel Assessment

107. Stage of reach evolution Th

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

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

e downstream bed material is composed of gravel, cobble, and boulder.

109. G. Plan View Sketch

- N

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

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number: LUDLTH03560054 Town: LUDLOW
Road Number: TH356 County: WINDSOR
Stream: JEWELL BROOK

Initials SAW Date: 12/2/97 Checked: MAI

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

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

Approach Section

Characteristic	100 yr	500 yr	Q incipient
Total discharge, cfs	1770	2400	1660
Main Channel Area, ft2	332	385	248
Left overbank area, ft2	0	0	0
Right overbank area, ft2	0	6	0
Top width main channel, ft	55	57	50
Top width L overbank, ft	0	0	0
Top width R overbank, ft	0	13	0
D50 of channel, ft	0.28878	0.28878	0.28878
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	6.0	6.8	5.0
y1, average depth, LOB, ft	ERR	ERR	ERR
y1, average depth, ROB, ft	ERR	0.5	ERR
Total conveyance, approach	22313	28108	14687
Conveyance, main channel	22313	28004	14687
Conveyance, LOB	0	0	0
Conveyance, ROB	0	104	0
Percent discrepancy, conveyance	0.0000	0.0000	0.0000
Qm, discharge, MC, cfs	1770.0	2391.1	1660.0
Ql, discharge, LOB, cfs	0.0	0.0	0.0
Qr, discharge, ROB, cfs	0.0	8.9	0.0
Vm, mean velocity MC, ft/s	5.3	6.2	6.7
Vl, mean velocity, LOB, ft/s	ERR	ERR	ERR
Vr, mean velocity, ROB, ft/s	ERR	1.5	ERR
Vc-m, crit. velocity, MC, ft/s	10.0	10.2	9.7
Vc-l, crit. velocity, LOB, ft/s	ERR	ERR	ERR
Vc-r, crit. velocity, ROB, ft/s	ERR	ERR	ERR

Results

Live-bed(1) or Clear-Water(0) Contraction Scour?			
Main Channel	0	0	0
Left Overbank	N/A	N/A	N/A
Right Overbank	N/A	N/A	N/A

Clear Water Contraction Scour in MAIN CHANNEL

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

Bridge Section	Q100	Q500	Other Q
(Q) total discharge, cfs	1770	2400	1660
(Q) discharge thru bridge, cfs	1761	2239	1660
Main channel conveyance	14902	14902	12843
Total conveyance	14902	14902	12843
Q2, bridge MC discharge,cfs	1761	2239	1660
Main channel area, ft2	208	208	147
Main channel width (normal), ft	33.0	33.0	33.0
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	33	33	33
y_bridge (avg. depth at br.), ft	6.30	6.30	4.45
Dm, median (1.25*D50), ft	0.360975	0.360975	0.360975
y2, depth in contraction,ft	5.01	6.15	4.76
ys, scour depth (y2-ybridge), ft	-1.30	-0.15	**0.30**

Pressure Flow Scour (contraction scour for orifice flow conditions)

Chang pressure flow equation   Hb+Ys=Cq*qbr/Vc
Cq=1/Cf*Cc   Cf=1.5*Fr^0.43 (<=1)   Cc=SQRT[0.10(Hb/(ya-w)-0.56)]+0.79 (<=1)
Umbrell pressure flow equation
(Hb+Ys)/ya=1.1021*[(1-w/ya)*(Va/Vc)]^0.6031
(Richardson and other, 1995, p. 144-146)

	Q100	Q500	OtherQ
Q, total, cfs	1770	2400	1660
Q, thru bridge MC, cfs	1761	2239	1660
Vc, critical velocity, ft/s	10.00	10.19	9.68
Va, velocity MC approach, ft/s	5.33	6.21	6.69
Main channel width (normal), ft	33.0	33.0	33.0
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	33.0	33.0	33.0
qbr, unit discharge, ft2/s	53.4	67.8	50.3
Area of full opening, ft2	208.0	208.0	147.0
Hb, depth of full opening, ft	6.30	6.30	4.45
Fr, Froude number, bridge MC	0.6	0.76	0.0
Cf, Fr correction factor (<=1.0)	1.00	1.00	1.00
**Area at downstream face, ft2	181	N/A	N/A
**Hb, depth at downstream face, ft	5.48	N/A	N/A
**Fr, Froude number at DS face	0.73	ERR	ERR

**Cf, for downstream face (<=1.0)	1.00	N/A	N/A
Elevation of Low Steel, ft	497.28	497.28	0.0
Elevation of Bed, ft	490.98	490.98	0.0
Elevation of Approach, ft	499.07	500.02	0.0
Friction loss, approach, ft	0.19	0.26	0.0
Elevation of WS immediately US, ft	498.88	499.76	0.0
ya, depth immediately US, ft	7.90	8.78	0.0
Mean elevation of deck, ft	500.57	500.57	0.0
w, depth of overflow, ft (>=0)	0.00	0.00	0.00
Cc, vert contrac correction (<=1.0)	0.94	0.92	1.00
**Cc, for downstream face (<=1.0)	0.905766	ERR	ERR
Ys, scour w/Chang equation, ft	**-0.65**	**0.97**	N/A
Ys, scour w/Umbrell equation, ft	-0.34	0.88	0.0

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

**Ys, scour w/Chang equation, ft	0.41	N/A	N/A
**Ys, scour w/Umbrell equation, ft	0.48	N/A	N/A

In UNsubmerged orifice flow, an adjusted scour depth using the Laursen equation results and the estimated downstream bridge face properties can also be computed (ys=y2-ybridgeDS)

y2, from Laursen's equation, ft	5.01	6.15	4.76
WSEL at downstream face, ft	496.48	--	--
Depth at downstream face, ft	5.48	N/A	N/A
Ys, depth of scour (Laursen), ft	-0.48	N/A	N/A

Armoring

Dc=[(1.94*V^2)/(5.75*log(12.27*y/D90))^2]/[0.03*(165-62.4)]

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

Downstream bridge face property	100-yr	500-yr	Other Q
Q, discharge thru bridge MC, cfs	1761	2239	1660
Main channel area (DS), ft2	181	208	147
Main channel width (normal), ft	33.0	33	32.9
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	33.0	33.0	33.0
D90, ft	0.9185	0.9185	0.9185
D95, ft	1.1853	1.1853	1.1853
Dc, critical grain size, ft	0.5188	0.5959	0.7708
Pc, Decimal percent coarser than Dc	0.226	0.183	0.134
Depth to armoring, ft	**5.33**	**7.98**	**14.98**

Abutment Scour

Froehlich's Abutment Scour

Ys/Y1 = 2.27*K1*K2*(a'/Y1)^0.43*Fr1^0.61+1

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

	Left Abutment			Right Abutment		
Characteristic	100 yr Q	500 yr Q	Other Q	100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	1770	2400	1660	1770	2400	1660
a', abut.length blocking flow, ft	15.1	16.4	13.0	7	20.5	4.5
Ae, area of blocked flow ft2	68.29	83.62	46.7	21.52	33.57	11.95
Qe, discharge blocked abut.,cfs	286.57	403.64	242.1	65.21	112.84	45.55

(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)

Ve, (Qe/Ae), ft/s	4.20	4.83	5.15	3.03	3.36	3.81
ya, depth of f/p flow, ft	4.52	5.10	3.57	3.07	1.64	2.60

--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)

K1	0.82	0.82	0.82	0.82	0.82	0.82

--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)

theta	90	90	90	90	90	90
K2	1.00	1.00	1.00	1.00	1.00	1.00
Fr, froude number f/p flow	0.348	0.377	0.481	0.305	0.463	0.417
ys, scour depth, ft	**11.94**	**13.75**	**11.04**	**7.02**	**7.29**	**6.24**

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

a'(abut length blocked, ft)	15.1	16.4	12.8	7	20.5	4.6
y1 (depth f/p flow, ft)	4.52	5.10	3.57	3.07	1.64	2.60
a'/y1	3.34	3.22	3.59	2.28	12.52	1.77
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.35	0.38	0.48	0.30	0.46	0.42
Ys w/ corr. factor K1/0.55:						
vertical	ERR	ERR	ERR	ERR	ERR	ERR
vertical w/ ww's	ERR	ERR	ERR	ERR	ERR	ERR
spill-through	ERR	ERR	ERR	ERR	ERR	ERR

Abutment riprap Sizing

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

Characteristic	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	0.73	0.76	0.94	0.6	0.76	0.94
y, depth of flow in bridge, ft	5.48	6.30	4.45	5.48	6.30	4.45
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	**1.22**	**2.25**	ERR	**1.81**	**2.25**	ERR
Fr>0.8 (vertical abut.)	ERR	ERR	**1.83**	ERR	ERR	**1.83**