LEVEL II SCOUR ANALYSIS FOR BRIDGE 31 (LUDLTH00460031) on TOWN HIGHWAY 46, crossing JEWELL BROOK, LUDLOW, VERMONT

Open-File Report 98-376

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

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

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By MICHAEL A. IVANOFF AND ERICK M. BOEHMLER

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Pembroke, New Hampshire

1998

U.S. DEPARTMENT OF THE INTERIOR
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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	Max	maximum
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 31 (LUDLTH00460031) ON TOWN HIGHWAY 46, CROSSING JEWELL BROOK, LUDLOW, VERMONT

By Michael A. Ivanoff and Erick M. Boehmler

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure LUDLTH00460031 on Town Highway 46 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 (FHWA, 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 central Vermont. The 7.29-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is pasture along the right bank while the immediate banks are covered by trees. The surface cover along the left bank is forest.

In the study area, Jewell Brook has an incised, sinuous channel with a slope of approximately 0.02 ft/ft, an average channel top width of 53 ft and an average bank height of 8 ft. The channel bed material ranges from gravel to boulder with a median grain size (D_{50}) of 123 mm (0.403 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 46 crossing of Jewell Brook is a 31-ft-long, one-lane bridge consisting of one 29-foot prestressed concrete slab span (Vermont Agency of Transportation, written communication, March 20, 1995). The opening length of the structure parallel to the bridge face is 27.9 ft. The bridge is supported by vertical, concrete abutments. The channel is skewed zero degrees to the opening and the opening-skew-to-roadway is also zero degrees.

The left abutment was undermined 0.5 ft deep along the downstream end. The only scour protection measure at the site was type-2 stone fill (less than 36 inches diameter) along the left bank upstream and downstream of the bridge. Additional details describing conditions at the site are included in the Level II Summary and appendices D and E.

Scour depths and 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 0.0 to 0.1 ft. The worst-case contraction scour occurred at the 100-year discharge. Abutment scour ranged from 5.1 to 13.6 ft. The worst-case abutment scour occurred at the incipient roadway-overtopping discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and 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 LUDLTH00460031 ***Stream*** Jewell Brook

County Windsor ***Road*** TH 46 ***District*** 3

Description of Bridge

Bridge length 31 ***ft*** ***Bridge width*** 16.0 ***ft*** ***Max span length*** 29 ***ft***

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

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 left bank upstream and downstream of the bridge. There are a few boulders at the downstream end of the left abutment.

Abutments are concrete. The left abutment is undermined 0.5 ft deep along the downstream end. The right abutment leans streamward, 0.5 ft from the vertical, at the upstream top end.

No --

Is bridge skewed to flood flow according to No ***survey?*** ***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 Moderate. There is some debris caught on boulders and trees leaning over the channel upstream.

Describe any features near or at the bridge that may affect flow (include observation date) There were a few large boulders at the upstream end of the right abutment as of 10/12/95.

Description of the Geomorphic Setting

General topography The channel is located within a high relief valley with a narrow flood plain.

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

Date of inspection 10/12/95

DS left: Steep channel bank to State Route 100 and the valley wall.

DS right: Steep channel bank to a narrow flood plain

US left: Steep channel bank to State Route 100 and the valley wall

US right: Steep channel bank to a narrow flood plain

Description of the Channel

Average top width 53 ***ft*** ***Average depth*** 8 ***ft***

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

Perennial and sinuous with semi-alluvial channel boundaries and narrow point bars.

10/12/95

Vegetative co Trees and brush with VT 100 along the bank

DS left: Trees and brush along the bank with grass on the flood plain

DS right: Trees and brush with VT 100 along the bank

US left: Trees and brush along the bank with grass on the flood plain

US right: Yes

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

None observed as of 10/12/95.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 7.29 ***mi²***

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***: None

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 1,400 ***ft³/s*** ***Q500*** 1,900 ***ft³/s***

The 100- and 500-year discharges are based on the flood frequency estimates available from the VTAOT database (written communication, May 1995) for bridge number 98I in Ludlow. Bridge number 98I crosses Jewell Brook downstream of this site and has a drainage area of 7.3 square miles. These values were within a range defined by flood frequency curves derived from several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887). Each curve was extended graphically to the 500-year event.

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 the upstream end of the left abutment knee wall (elev. 494.78 ft, arbitrary survey datum). RM2 is a chiseled X in a chiseled square on top of the downstream end of the right abutment knee wall (elev. 494.16 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]Cross-section	*Section Reference Distance (SRD) in feet*	*[2]Cross-section development*	*Comments*
EXITX	-28	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	8	1	Road Grade section
APPRO	49	1	Approach section

[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 0.045 to 0.050, and an overbank "n" value of 0.035.

Normal depth at the exit section (EXITX) was assumed as the starting water surface. This depth was computed by use of the slope-conveyance method outlined in the user's manual for WSPRO (Shearman, 1990). The slope used was 0.0178 ft/ft, which was estimated from thalweg points surveyed downstream of the bridge.

The approach section (APPRO) was surveyed one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This location provides a consistent method for determining scour variables.

For the 100-year discharge, WSPRO assumes critical depth at the bridge section. A supercritical model was developed for this discharge. After analyzing the supercritical and subcritical profiles for the 100-year discharge, it was assumed that the water surface profile passes through critical depth within the bridge opening. Thus, the assumption of critical depth at the bridge is a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.0 *ft*
Average low steel elevation 498.0 *ft*

100-year discharge 1,400 *ft^3/s*
Water-surface elevation in bridge opening 495.7 *ft*
Road overtopping? No *Discharge over road* -- *ft^3/s*
Area of flow in bridge opening 119 *ft^2*
Average velocity in bridge opening 11.8 *ft/s*
Maximum WSPRO tube velocity at bridge 16.0 *ft/s*

Water-surface elevation at Approach section with bridge 498.1
Water-surface elevation at Approach section without bridge 495.8
Amount of backwater caused by bridge 2.3 *ft*

500-year discharge 1,900 *ft^3/s*
Water-surface elevation in bridge opening 498.0 *ft*
Road overtopping? Yes *Discharge over road* 285 *ft^3/s*
Area of flow in bridge opening 180 *ft^2*
Average velocity in bridge opening 8.8 *ft/s*
Maximum WSPRO tube velocity at bridge 17.7 *ft/s*

Water-surface elevation at Approach section with bridge 500.0
Water-surface elevation at Approach section without bridge 496.7
Amount of backwater caused by bridge 3.3 *ft*

Incipient overtopping discharge 1,550 *ft^3/s*
Water-surface elevation in bridge opening 498.2 *ft*
Area of flow in bridge opening 181 *ft^2*
Average velocity in bridge opening 8.6 *ft/s*
Maximum WSPRO tube velocity at bridge 10.9 *ft/s*

Water-surface elevation at Approach section with bridge 499.8
Water-surface elevation at Approach section without bridge 496.1
Amount of backwater caused by bridge 3.7 *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 100-year discharge was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20). At this site, the 500-year and incipient roadway-overtopping discharges resulted in unsubmerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Thus, contraction scour for these discharges was computed by use of the Chang equation (Richardson and Davis, 1995, p. 145-146). The streambed armoring depths computed suggest that armoring will not limit the depth of contraction scour.

For comparison, contraction scour for the discharges resulting in orifice flow also was computed by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144). Furthermore, for the 500-year and incipient roadway-overtopping discharges, which resulted in unsubmerged orifice flow, contraction scour was computed by substituting estimates for the depth of flow at the downstream bridge face in the contraction scour equations. Results with respect to these alternative contraction scour estimates 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-year discharge*	*500-year discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	--	--
Clear-water scour	0.1	0.0	0.0
Depth to armoring	12.5	13.7	14.2
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	6.4	5.1	7.3
Right abutment	12.4	11.2	13.6
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Riprap Sizing

	100-year discharge	*500-year discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	1.8	2.0	1.9
Right abutment	1.8	2.0	1.9
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

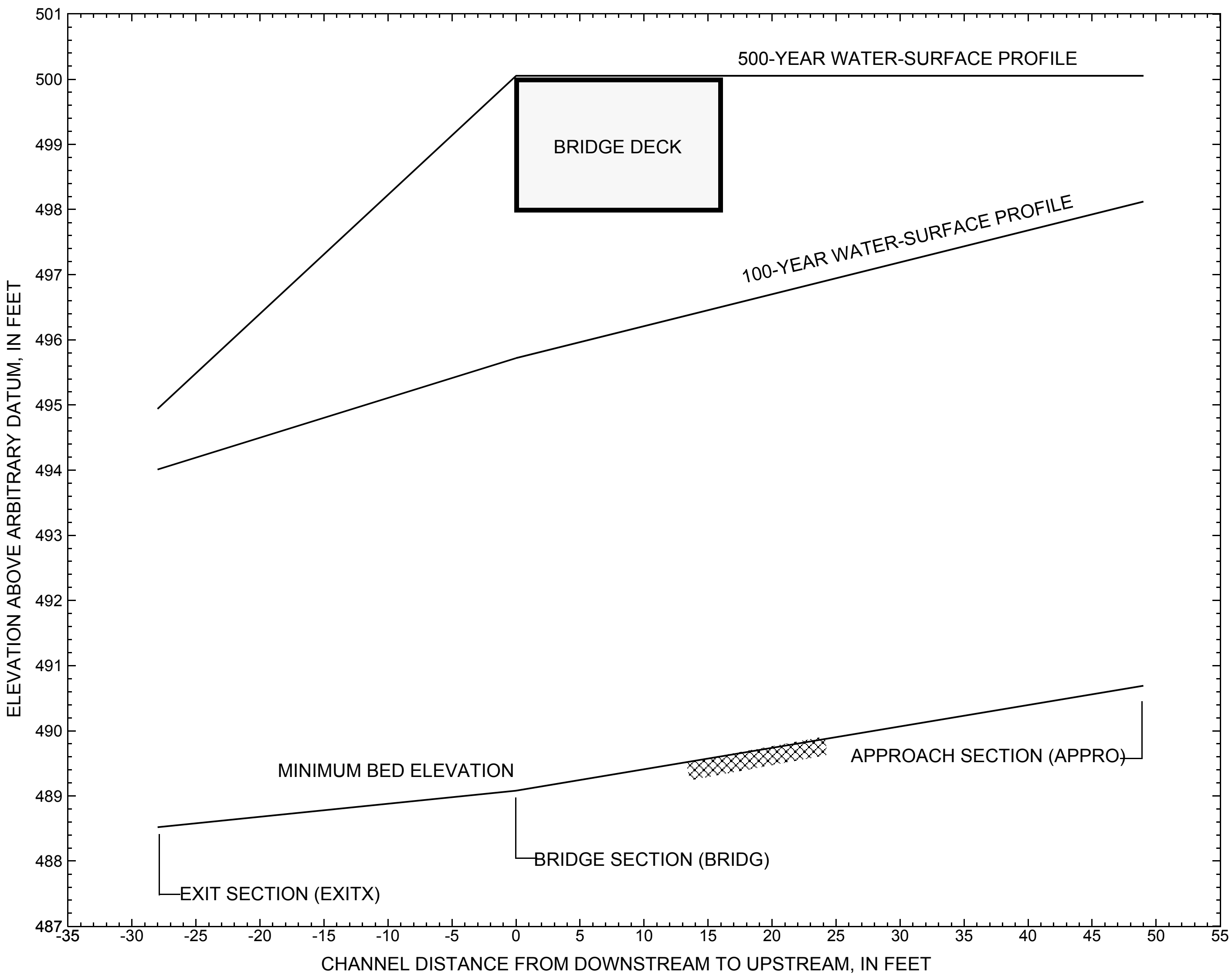

Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure LUDLTH00460031 on Town Highway 46, crossing Jewell Brook, Ludlow, Vermont.

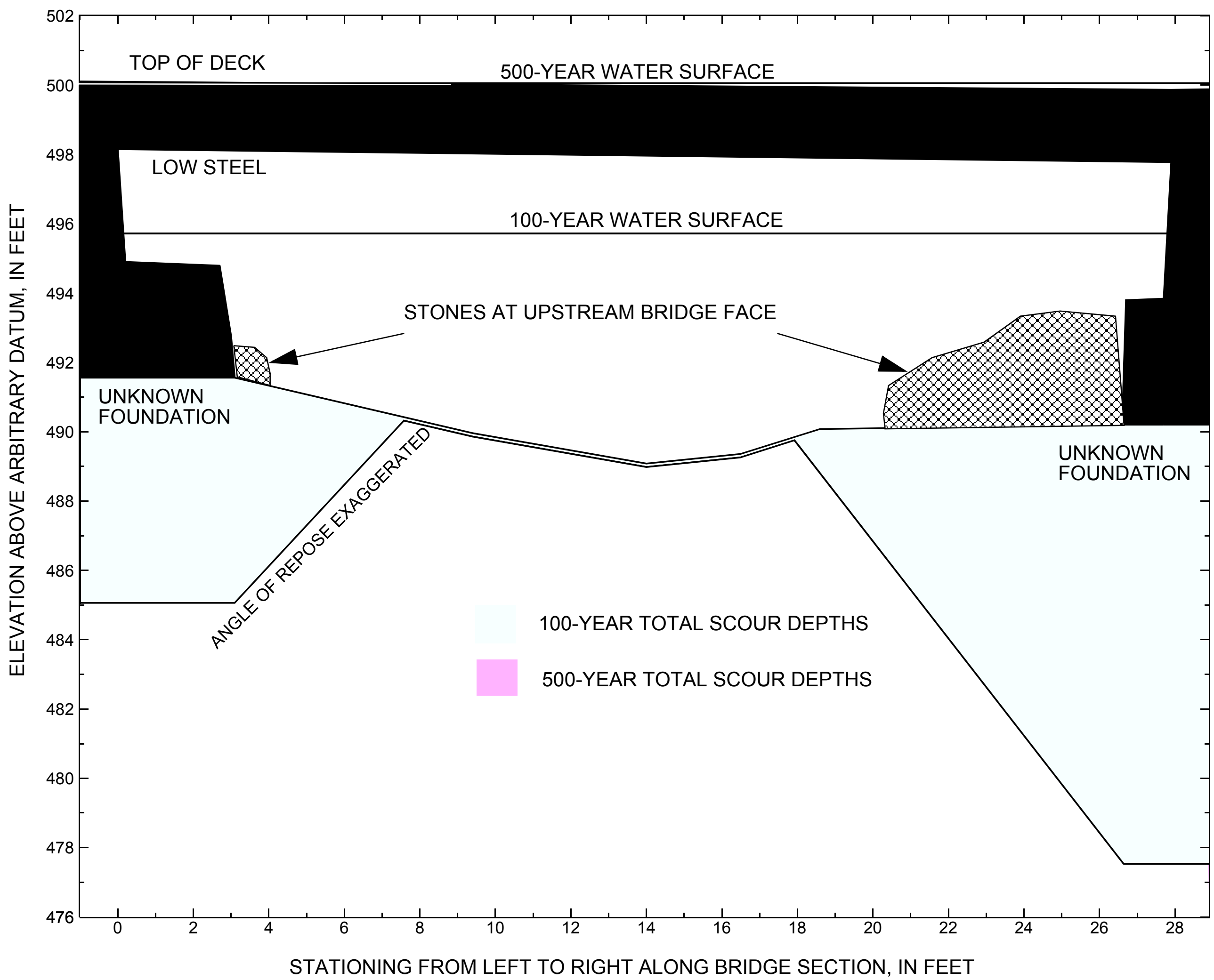

Figure 8. Scour elevations for the 100- and 500-year discharges at structure LUDLTH00460031 on Town Highway 46, crossing Jewell Brook, Ludlow, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure LUDLTH00460031 on Town Highway 46, 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/pile 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-year discharge is 1,400 cubic-feet per second											
Left abutment	0.0	--	498.2	--	491.6	0.1	6.4	--	6.5	485.1	--
Right abutment	27.9	--	497.8	--	490.1	0.1	12.4	--	12.5	477.6	--

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure LUDLTH00460031 on Town Highway 46, 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/pile 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-year discharge is 1,900 cubic-feet per second											
Left abutment	0.0	--	498.2	--	491.6	0.0	5.1	--	5.1	486.5	--
Right abutment	27.9	--	497.8	--	490.1	0.0	11.2	--	11.2	478.9	--

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 ludl031.wsp
T2        Hydraulic analysis for structure LUDLTH00460031   Date: 27-FEB-98
T3        Bridge 31 on Town Highway 46 over Jewell Brook Ludlow, VT   by MAI
*               * * This file was generated by AWISPP v2.5 * *
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           1400.0    1900.0   1550.0
SK          0.0178    0.0178   0.0178
*
XS   EXITX    -28
GR          -59.0, 512.86    -42.6, 497.96    -14.6, 499.01     -6.0, 498.60
GR            0.0, 491.88      3.8, 489.99      6.0, 489.56      7.5, 488.90
GR           14.2, 488.52     19.6, 488.81     22.0, 489.48     25.5, 489.92
GR           31.1, 493.48     41.4, 497.24     97.3, 497.68    145.1, 495.73
GR          210.2, 499.33    288.0, 499.68    330.1, 507.78
N           0.045        0.035
SA                  41.4
*
XS   FULLV      0  * * *   0.0193
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0    497.96       0.0
GR            0.0, 498.15      0.2, 494.90      2.7, 494.79      3.0, 492.75
GR            3.9, 491.56      9.4, 489.96     14.0, 489.08     16.5, 489.36
GR           18.6, 490.08     21.8, 492.62     26.7, 493.80     27.7, 493.84
GR           27.9, 497.78      0.0, 498.15
*
*         BRTYPE  BRWDTH
CD           1      15.9
N           0.045
*
*             SRD    EMBWID   IPAVE
XR   RDWAY      8      16.0     1
GR          -62.4, 514.53      -43.1, 498.93    -15.5, 499.79
GR            0.0, 500.10       27.2, 499.87    124.3, 499.55
GR          166.7, 500.13      292.1, 503.63    333.2, 507.51    351.9, 508.33
* Flow was forced to remain w/in the channel during incipient roadway-
* overtopping discharge by removing stationing -44.4 on the left overbank
AS   APPRO     49
GR          -68.8, 512.03    -44.4, 499.92    -18.3, 500.20
GR           -8.8, 499.46      0.0, 495.57      4.3, 492.79
GR            7.7, 491.92     15.4, 490.69     20.7, 491.77     24.3, 491.33
GR           28.1, 492.10     32.6, 492.58     38.0, 495.51     50.1, 500.57
GR          244.4, 501.82    283.5, 502.56    331.1, 508.32    352.4, 508.82
* The following coordinate was removed because flow remains within the channel
* below the top of right bank at 500.57 ft;   128.9, 499.54
N           0.050        0.035
SA                  50.1
*
HP 1 BRIDG  495.72 1 495.72
HP 2 BRIDG  495.72 * * 1400
HP 1 APPRO  498.12 1 498.12
HP 2 APPRO  498.12 * * 1400
*
HP 1 BRIDG  497.96 1 497.96
HP 2 BRIDG  497.96 * * 1588
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. Geological Survey WSPRO Input File ludl031.wsp
        Hydraulic analysis for structure LUDLTH00460031   Date: 27-FEB-98
        Bridge 31 on Town Highway 46 over Jewell Brook Ludlow, VT   by MAI
           *** RUN DATE & TIME: 03-23-98  15:45
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     119.    9067.    28.    34.                        1400.
   495.72          119.    9067.    28.    34.  1.00     0.    28.   1400.


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

         WSEL     LEW     REW    AREA        K        Q    VEL
       495.72     0.1    27.8   118.9    9067.    1400.  11.77

X STA.         0.1        6.5        7.5        8.4        9.2       10.0
  A(I)            17.9        4.9        4.7        4.6        4.6
  V(I)            3.91      14.24      14.81      15.30      15.19

X STA.        10.0       10.8       11.5       12.2       12.9       13.6
  A(I)             4.6        4.5        4.5        4.5        4.6
  V(I)           15.37      15.56      15.73      15.57      15.25

X STA.        13.6       14.3       15.0       15.7       16.4       17.1
  A(I)             4.5        4.4        4.4        4.5        4.4
  V(I)           15.63      15.73      15.73      15.72      15.98

X STA.        17.1       17.8       18.6       19.6       21.1       27.8
  A(I)             4.5        4.6        5.4        6.2       16.7
  V(I)           15.41      15.19      12.95      11.31       4.20

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      49.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     237.   19155.    50.    53.                        2928.
   498.12          237.   19155.    50.    53.  1.00    -6.    44.   2928.


    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      49.

         WSEL     LEW     REW    AREA        K        Q    VEL
       498.12    -5.8    44.2   237.0   19155.    1400.   5.91

X STA.        -5.8        5.5        7.3        8.8       10.3       11.7
  A(I)            30.9       10.2        9.7        9.6        9.5
  V(I)            2.26       6.84       7.22       7.28       7.40

X STA.        11.7       13.0       14.3       15.6       16.9       18.3
  A(I)             9.3        9.4        9.3        9.4        9.6
  V(I)            7.53       7.45       7.54       7.44       7.26

X STA.        18.3       19.7       21.3       22.7       24.2       25.6
  A(I)             9.7        9.9        9.5        9.5        9.5
  V(I)            7.22       7.07       7.37       7.37       7.36

X STA.        25.6       27.1       28.7       30.4       32.2       44.2
  A(I)             9.7        9.9       10.0       10.2       32.2
  V(I)            7.25       7.07       6.99       6.86       2.17
```

```
        U.S. Geological Survey WSPRO Input File ludl031.wsp
        Hydraulic analysis for structure LUDLTH00460031   Date: 27-FEB-98
        Bridge 31 on Town Highway 46 over Jewell Brook Ludlow, VT   by MAI
           *** RUN DATE & TIME: 03-23-98  15:45
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     180.   13642.    14.    52.                         3619.
   497.96          180.   13642.    14.    52.  1.00     0.    28.   3619.

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       497.96     0.0    27.9   179.9   13642.    1588.   8.83

X STA.         0.0        4.7        5.7        6.6        7.5        8.4
  A(I)            19.6        6.7        6.6        6.6        6.6
  V(I)            4.04       11.89      12.01      12.12      12.07

X STA.         8.4        9.2       10.0       10.9       11.7       12.3
  A(I)             6.7        6.7        6.7        6.7        5.6
  V(I)           11.91      11.94      11.78      11.86      14.08

X STA.        12.3       12.9       13.5       14.1       15.0       15.8
  A(I)             4.5        5.7        5.6        7.2        7.6
  V(I)           17.71      14.03      14.17      10.99      10.43

X STA.        15.8       16.8       17.7       18.9       20.5       27.9
  A(I)             8.0        8.1        8.9       11.3       34.6
  V(I)            9.89       9.85       8.94       7.03       2.29

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

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     130.   10322.    28.    35.                         1593.
   496.11          130.   10322.    28.    35.  1.00     0.    28.   1593.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.05   -44.5   160.9    65.6    1219.     285.   4.35

X STA.       -44.5      -41.3      -38.5      -35.3      -31.4      -26.1
  A(I)             2.8        2.8        2.9        3.2        3.6
  V(I)            5.16       5.04       4.86       4.41       4.00

X STA.       -26.1      -15.6       42.7       57.2       68.2       77.1
  A(I)             4.5        6.8        3.7        3.3        2.9
  V(I)            3.19       2.09       3.85       4.35       4.88

X STA.        77.1       85.0       92.3       98.9      105.1      110.7
  A(I)             2.8        2.8        2.7        2.6        2.5
  V(I)            5.01       5.14       5.28       5.46       5.66

X STA.       110.7      116.0      121.2      126.0      131.7      160.9
  A(I)             2.5        2.5        2.4        2.5        5.8
  V(I)            5.77       5.73       6.06       5.65       2.46

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      49.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     345.   26908.    78.    81.                         4125.
   500.05          345.   26908.    78.    81.  1.00   -45.    49.   4125.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      49.

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.05   -44.7    48.9   344.9   26908.    1900.   5.51

X STA.       -44.7        9.2       10.6       11.9       13.1       14.4
  A(I)            89.1       11.5       11.4       11.4       11.3
  V(I)            1.07       8.30       8.33       8.33       8.39

X STA.        14.4       15.6       16.8       18.1       19.5       20.7
  A(I)            11.0       11.5       11.7       11.9       10.2
  V(I)            8.61       8.28       8.11       7.97       9.31

X STA.        20.7       22.1       23.7       25.2       26.8       28.4
  A(I)            11.6       13.4       13.4       13.1       13.1
  V(I)            8.18       7.07       7.09       7.24       7.26

X STA.        28.4       30.1       31.8       33.6       36.0       48.9
  A(I)            12.9       13.2       13.3       15.0       34.8
  V(I)            7.39       7.18       7.15       6.35       2.73
```

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      U.S. Geological Survey WSPRO Input File ludl031.wsp
      Hydraulic analysis for structure LUDLTH00460031   Date: 27-FEB-98
      Bridge 31 on Town Highway 46 over Jewell Brook Ludlow, VT   by MAI
         *** RUN DATE & TIME: 03-23-98  15:34
  CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

   WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
           1     181.   11720.     0.    66.                          0.
 498.15          181.   11720.     0.    66.  1.00     0.    28.      0.


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

       WSEL     LEW     REW    AREA        K        Q    VEL
     498.15     0.0    27.9   181.3   11720.    1550.   8.55

X STA.        0.0        5.1        6.2        7.3        8.3        9.2
  A(I)            23.4        7.8        7.7        7.4        7.4
  V(I)            3.31       9.87      10.03      10.45      10.40

X STA.        9.2       10.1       11.0       11.8       12.7       13.5
  A(I)             7.4        7.1        7.2        7.3        7.2
  V(I)           10.50      10.84      10.78      10.55      10.70

X STA.       13.5       14.3       15.1       16.0       16.8       17.7
  A(I)             7.1        7.1        7.1        7.2        7.3
  V(I)           10.85      10.93      10.93      10.71      10.66

X STA.       17.7       18.6       19.7       21.1       23.0       27.9
  A(I)             7.3        8.0        9.1        9.9       21.1
  V(I)           10.67       9.71       8.56       7.84       3.68

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

   WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
           1     127.    9964.    28.    35.                       1538.
 496.00          127.    9964.    28.    35.  1.00     0.    28.   1538.

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      49.

   WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
           1     329.   30119.    57.    61.                       4484.
 499.83          329.   30119.    57.    61.  1.00    -9.    48.   4484.


  VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      49.

       WSEL     LEW     REW    AREA        K        Q    VEL
     499.83    -8.8    48.3   329.2   30119.    1550.   4.71

X STA.       -8.8        4.2        6.1        7.8        9.5       11.1
  A(I)            43.7       14.1       13.3       13.3       13.0
  V(I)            1.77       5.49       5.81       5.82       5.95

X STA.       11.1       12.5       14.0       15.4       16.9       18.4
  A(I)            12.8       12.9       12.7       13.0       13.4
  V(I)            6.06       6.02       6.10       5.97       5.80

X STA.       18.4       20.0       21.6       23.2       24.7       26.3
  A(I)            13.0       13.5       13.0       12.9       13.3
  V(I)            5.94       5.75       5.97       6.00       5.83

X STA.       26.3       28.0       29.7       31.5       33.5       48.3
  A(I)            13.0       13.2       13.8       13.9       47.4
  V(I)            5.95       5.89       5.62       5.56       1.64
```

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       U.S. Geological Survey WSPRO Input File ludl031.wsp
        Hydraulic analysis for structure LUDLTH00460031   Date: 27-FEB-98
        Bridge 31 on Town Highway 46 over Jewell Brook Ludlow, VT   by MAI
           *** RUN DATE & TIME: 03-23-98  15:45

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

EXITX:XS   ******    -2.     135.  1.68 *****  495.69  493.79   1400.  494.01
      -28. ******    33.   10493.  1.00 ***** *******    0.93   10.40

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.94     494.51     494.33

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   493.51     513.40    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   493.51     513.40     494.33

FULLV:FV      28.    -2.     133.  1.73  0.51  496.22  494.33   1400.  494.49
        0.    28.    32.   10282.  1.00  0.03    0.00    0.95   10.55
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.10     495.56     495.81

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   493.99     512.03    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   493.99     512.03     495.81

 ===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 "APPRO"
                WSBEG,WSEND,CRWS =   495.81     512.03     495.81

APPRO:AS      49.    -1.     134.  1.70 *****  497.51  495.81   1400.  495.81
       49.    49.    39.    8748.  1.00 ***** *******    1.00   10.44
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                  SECID "BRIDG"     Q,CRWS =    1400.     495.72

            <<<<<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      28.     0.     119.  2.16 *****  497.88  495.72   1400.  495.72
        0.    28.    28.    9061.  1.00 ***** *******    1.00   11.78

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  497.96 ****** ****** ******

   XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
  RDWAY:RG       8.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS      33.    -6.     237.  0.54  0.40  498.66  495.81   1400.  498.12
       49.    36.    44.   19130.  1.00  0.38   -0.01    0.48    5.91

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.364  0.042   18353.     5.    33.   497.94

  FIRST USER DEFINED TABLE.

   XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
  EXITX:XS     -28.    -2.    33.   1400.   10493.     135.   10.40  494.01
  FULLV:FV       0.    -2.    32.   1400.   10282.     133.   10.55  494.49
  BRIDG:BR       0.     0.    28.   1400.    9061.     119.   11.78  495.72
  RDWAY:RG       8.**************      0.*****************     1.00********
  APPRO:AS      49.    -6.    44.   1400.   19130.     237.    5.91  498.12

   XSID:CODE   XLKQ   XRKQ       KQ
  APPRO:AS       5.    33.   18353.
 SECOND USER DEFINED TABLE.

   XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
  EXITX:XS    493.79    0.93  488.52  512.86************  1.68  495.69  494.01
  FULLV:FV    494.33    0.95  489.06  513.40  0.51  0.03  1.73  496.22  494.49
  BRIDG:BR    495.72    1.00  489.08  498.15************  2.16  497.88  495.72
  RDWAY:RG  ****************  498.93  514.53********************************
  APPRO:AS    495.81    0.48  490.69  512.03  0.40  0.38  0.54  498.66  498.12
```
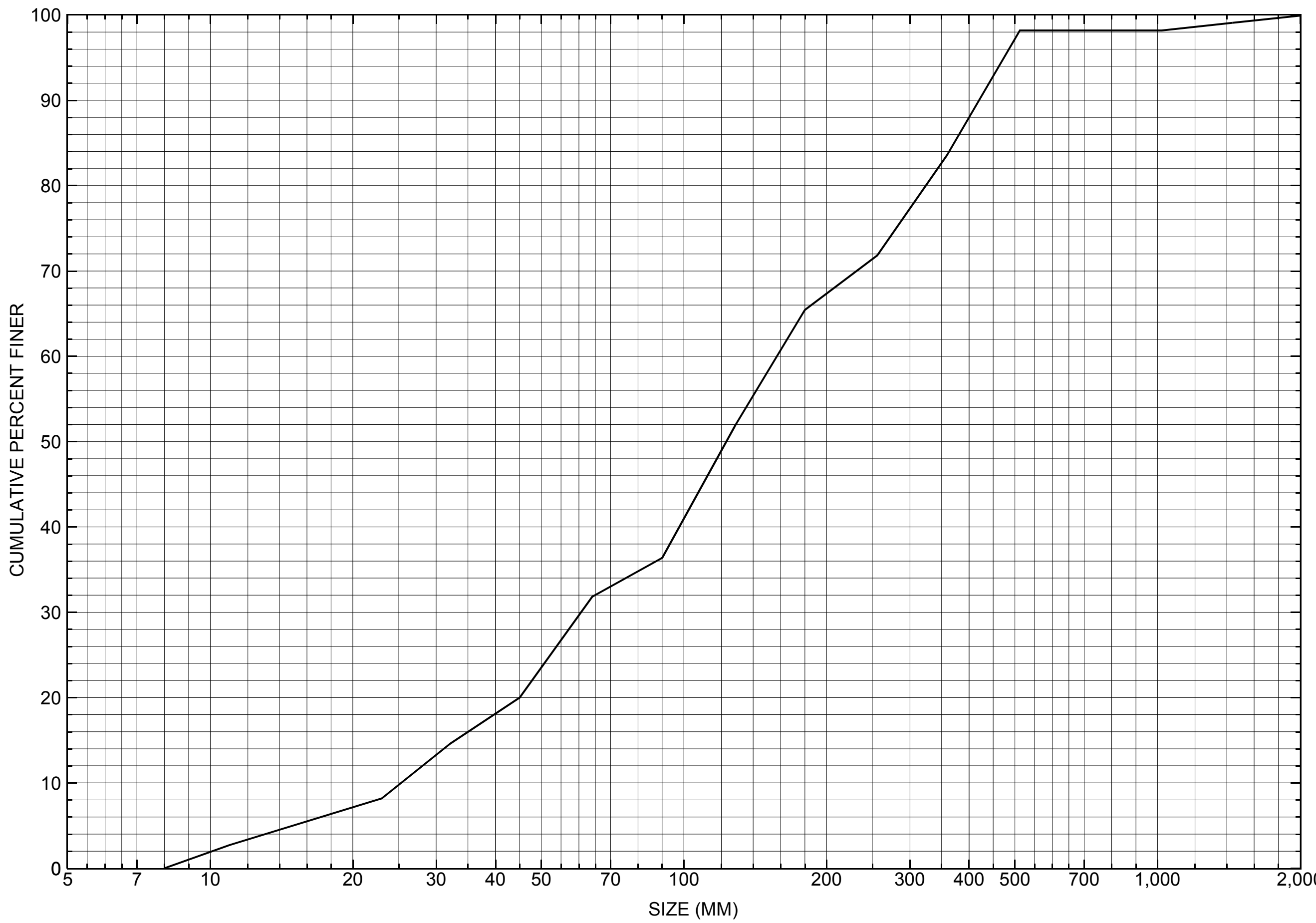

```
      U.S. Geological Survey WSPRO Input File ludl031.wsp
      Hydraulic analysis for structure LUDLTH00460031   Date: 27-FEB-98
      Bridge 31 on Town Highway 46 over Jewell Brook Ludlow, VT   by MAI
         *** RUN DATE & TIME: 03-23-98  15:45

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

EXITX:XS   ******    -3.     168.  1.98 *****  496.92  494.72   1900.  494.94
      -28. ******    35.   14227.  1.00 ***** *******    0.94   11.29
 ===125 FR# EXCEEDS FNTEST AT SECID “FULLV”:  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    0.95     495.44     495.26
 ===110 WSEL NOT FOUND AT SECID “FULLV”:  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   494.44     513.40    0.50
 ===115 WSEL NOT FOUND AT SECID “FULLV”:  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   494.44     513.40     495.26

FULLV:FV      28.    -3.     166.  2.03  0.51  497.46  495.26   1900.  495.43
        0.    28.    35.   13983.  1.00  0.03    0.00    0.96   11.43
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>
 ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    1.07     496.48     496.66
 ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   494.93     512.03    0.50
 ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   494.93     512.03     496.66
 ===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 “APPRO”
                 WSBEG,WSEND,CRWS =   496.66     512.03     496.66

APPRO:AS      49.    -2.     169.  1.96 *****  498.63  496.66   1900.  496.66
       49.    49.    41.   12054.  1.00 ***** *******    1.00   11.24
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
         WS1,WSSD,WS3,RGMIN =   499.51       0.00     496.69     498.93
 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                 WS,QBO,QRD =   501.56         0.      1900.
 ===280 REJECTED FLOW CLASS 4 SOLUTION.
 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.
 ===265 ROAD OVERFLOW APPEARS EXCESSIVE.
                 QRD,QRDMAX,RATIO =     285.       212.    1.35

            <<<<<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      28.     0.     180.  1.21 *****  499.17  496.11   1588.  497.96
        0. ******    28.   13642.  1.00 ***** *******    0.61    8.83

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.470 ******  497.96 ****** ****** ******

   XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
  RDWAY:RG       8.    33.  0.16  0.47  500.36   -0.01    285.  500.05

            Q    WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
  LT:     87.     29.   -44.   -16.   1.1   0.7   4.5   4.4   1.0   3.0
  RT:    199.    134.    27.   161.   0.5   0.3   3.6   4.7   0.6   3.0

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

APPRO:AS      33.   -45.     345.  0.47  0.30  500.52  496.66   1900.  500.05
       49.    35.    49.   26929.  1.00  0.00   -0.01    0.46    5.51

  FIRST USER DEFINED TABLE.

   XSID:CODE    SRD    LEW    REW       Q        K      AREA     VEL   WSEL
  EXITX:XS     -28.    -3.    35.   1900.   14227.     168.   11.29  494.94
  FULLV:FV       0.    -3.    35.   1900.   13983.     166.   11.43  495.43
  BRIDG:BR       0.     0.    28.   1588.   13642.     180.    8.83  497.96
  RDWAY:RG       8.*******    87.    285.*********       0.    1.00  500.05
  APPRO:AS      49.   -45.    49.   1900.   26929.     345.    5.51  500.05

 SECOND USER DEFINED TABLE.

   XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD     EGL    WSEL
  EXITX:XS     494.72    0.94  488.52  512.86************  1.98  496.92  494.94
  FULLV:FV     495.26    0.96  489.06  513.40  0.51  0.03  2.03  497.46  495.43
  BRIDG:BR     496.11    0.61  489.08  498.15************  1.21  499.17  497.96
  RDWAY:RG  ****************  498.93  514.53  0.16******  0.47  500.36  500.05
  APPRO:AS     496.66    0.46  490.69  512.03  0.30  0.00  0.47  500.52  500.05
      U.S. Geological Survey WSPRO Input File ludl031.wsp
```

```
       Hydraulic analysis for structure LUDLTH00460031   Date: 27-FEB-98
       Bridge 31 on Town Highway 46 over Jewell Brook Ludlow, VT   by MAI
          *** RUN DATE & TIME: 03-23-98  15:34

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

EXITX:XS   ******    -2.     145.  1.78 *****  496.08  494.10   1550.  494.31
      -28. ******    33.   11615.  1.00 ***** *******    0.93   10.69

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.94     494.81     494.64

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   493.81     513.40    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   493.81     513.40     494.64

FULLV:FV      28.    -2.     143.  1.83  0.51  496.62  494.64   1550.  494.79
        0.    28.    33.   11390.  1.00  0.03    0.00    0.95   10.84
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.09     495.85     496.09

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   494.29     508.82    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   494.29     508.82     496.09

 ===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 "APPRO"
                  WSBEG,WSEND,CRWS =   496.09     508.82     496.09

APPRO:AS      49.    -1.     145.  1.77 *****  497.86  496.09   1550.  496.09
       49.    49.    39.    9757.  1.00 ***** *******    1.00   10.68
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   496.03     498.15     498.54     497.96

 ===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      28.     0.     181.  1.12 *****  499.27  496.00   1538.  498.15
        0. ******    28.   11748.  1.00 ***** *******    0.59    8.48

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.463  0.000  497.96 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF    VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

===140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
                              WSEL,YLT,YRT =   499.83      499.5      508.8

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

APPRO:AS      33.    -9.     329.  0.35  0.24  500.17  496.09   1550.  499.83
       49.    36.    48.   30093.  1.00  0.38   -0.01    0.35    4.71

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -28.    -2.    33.   1550.   11615.     145.   10.69  494.31
   FULLV:FV       0.    -2.    33.   1550.   11390.     143.   10.84  494.79
   BRIDG:BR       0.     0.    28.   1538.   11748.     181.    8.48  498.15
   RDWAY:RG       8.**************      0.       0.       0.    1.00********
   APPRO:AS      49.    -9.    48.   1550.   30093.     329.    4.71  499.83

 SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS     494.10    0.93  488.52  512.86************  1.78  496.08  494.31
   FULLV:FV     494.64    0.95  489.06  513.40  0.51  0.03  1.83  496.62  494.79
   BRIDG:BR     496.00    0.59  489.08  498.15************  1.12  499.27  498.15
   RDWAY:RG   ****************  499.87  508.33************  0.33  500.24********
   APPRO:AS     496.09    0.35  490.69  508.82  0.24  0.38  0.35  500.17  499.83
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure LUDLTH00460031, in Ludlow, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number LUDLTH00460031

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)* 41275

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

Waterway *(I - 6)* JEWELL BROOK

Road Name *(I - 7):* -

Route Number TH046

Vicinity *(I - 9)* @ JCT W VT100

Topographic Map Ludlow

Hydrologic Unit Code: 01080106

Latitude *(I - 16; nnnn.n)* 43231

Longitude *(i - 17; nnnnn.n)* 72426

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 10141000311410

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

Maximum span length *(I - 48; nnnn)* 0029

Year built *(I - 27; YYYY)* 1973

Structure length *(I - 49; nnnnnn)* 000031

Average daily traffic, ADT *(I - 29; nnnnnn)* 000020

Deck Width *(I - 52; nn.n)* 160

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

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

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

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

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

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

Structure type *(I - 43; nnn)* 501

Year Reconstructed *(I - 106)* 1989

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*) 008.5

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

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

Comments:

The structural inspection report of 7/5/93 indicates the structure is a prestressed concrete slab type bridge. The abutment walls are concrete with concrete "knee walls". The knee wall on the left abutment is about 30 inches wide and the downstream half of it is undermined about 0.5 ft with up to a foot of penetration. The right abutment wall appears to have rotated forward about 0.5 ft on the upstream end and possibly a couple inches on the downstream. A small sand and gravel point bar is noted along the right abutment wall blocking about one third of the channel. A few boulders are noted present in front of the left abutment wall and around the ends of both abutments. Boulder fill also is noted along the left bank upstream and downstream of the bridge.

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:

-

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **7.29** mi^2

Lake/pond/swamp area **0.05** mi^2

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

Bridge site elevation **1140** ft

Headwater elevation **3343** ft

Main channel length **3.82** mi

10% channel length elevation **1200** ft

85% channel length elevation **2280** ft

Main channel slope *(S)* **376.67** 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? N *If no, type ctrl-n xs*

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

Comments: **NO CROSS SECTION INFORMATION**

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

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

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

Comments: **NO CROSS SECTION INFORMATION**

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: MAI Date: 11/24/95
Computerized by: MAI Date: 11/24/95
Reviewd by: MAI Date: 3/25/98

Structure Number LUDLTH00460031

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* E. Boehmler Date *(MM/DD/YY)* 10 / 12 / 1995
2. Highway District Number 03 Mile marker 0
County Windsor (027) Town Ludlow (41275)
Waterway *(I - 6)* Jewell Brook Road Name Clark Drive
Route Number TH 46 Hydrologic Unit Code: 01080106
3. Descriptive comments:
The bridge is at the junction with VT 100.

B. Bridge Deck Observations

4. Surface cover... LBUS 6 RBUS 4 LBDS 6 RBDS 4 Overall 4
*(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 1 *(**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 31.0 *(feet)* Span length 29.0 *(feet)* Bridge width 16.0 *(feet)*

Road approach to bridge:

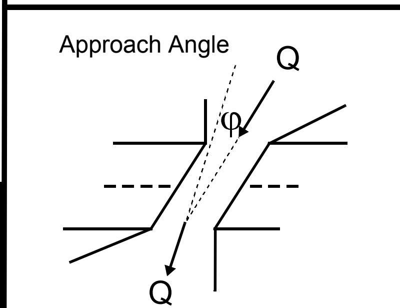
8. LB 0 RB 0 *(**0** even, **1**- lower, **2**- higher)*
9. LB 1 RB 2 *(**1**- Paved, **2**- Not paved)*
10. Embankment slope (*run / rise in feet / foot*):
US left -- US right --

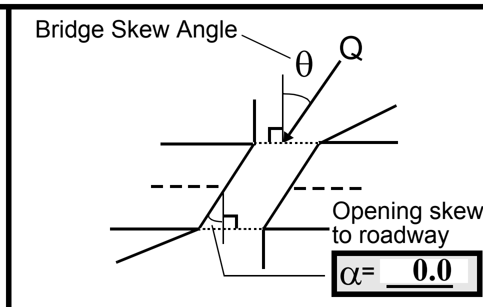
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	2	1	0	0
RBUS	2	2	1	2
RBDS	3	1	0	0
LBDS	3	1	0	0

*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: 10 16. Bridge skew: 0





17. Channel impact zone 1: Exist? Y *(Y or N)*
Where? RB *(LB, RB)* Severity 1
Range? 60 feet US *(US, UB, DS)* to 0 feet US
Channel impact zone 2: Exist? Y *(Y or N)*
Where? LB *(LB, RB)* Severity 1
Range? 8 feet UB *(US, UB, DS)* to 25 feet DS

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

18. Bridge Type: **1b**

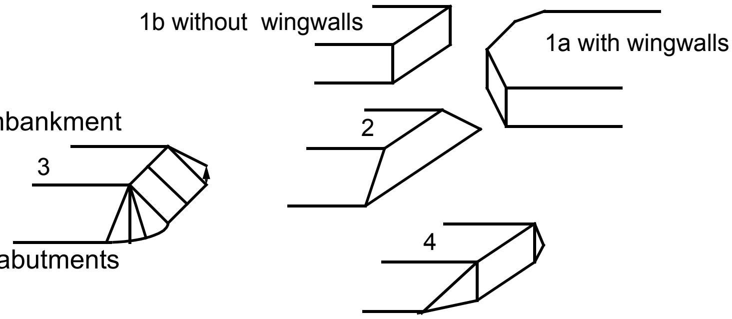
1a- Vertical abutments with wingwalls

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.)

4. The left overbank is forested with VT 100 on the top of bank; trees and shrubs are on the high and immediate stream banks. Trees line the right bank of the channel with pasture (grass) beyond and then forest about 500 ft from the bank. The upstream right bank has a driveway, house, and lawn.

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
33.5	**6.5**			**8.0**	**3**	**4**	**7**	**435**	**1**	**0**

23. Bank width **25.0** 24. Channel width **25.0** 25. Thalweg depth **59.0** 29. Bed Material **453**

30 .Bank protection type: LB **2** RB **0** 31. Bank protection condition: LB **1** 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*

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

27. The left bank between 0 and 135 ft US is protected with stone fill and functions as the road embankment of VT 100. Beyond 135 ft US the left bank consists of cobbles, boulders, and gravel.
The US channel consists of a series of short riffled and pooled zones, with the riffle areas 0.5 ft and pools 1.5 ft maximum depth. Some of the pooled areas are formed by scour behind large boulders, particularly along the sides of the channel. The left bank is impacted moderately between 85 ft and 115 ft upstream.

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

D. Under Bridge Channel Assessment

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

56. Height (BF) LB	RB	57 Angle (BF) LB	RB	61. Material (BF) LB	RB	62. Erosion (BF) LB	RB
28.5		0.0		2	7	7	-

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

435

The channel under the bridge is riffled, but flattens compared to the section from 0 to 60 ft US.

There is a fine to medium gravel and sand side bar along the right abutment under the bridge.

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

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

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

70. Debris and Ice Comments:

2

There are a lot of trees on the banks. The banks are stable with only a few localized areas of erosion. The US channel shifts from the right to left bank to pass through the bridge. There is a potential for debris and ice to pile up just US of the bridge on the right bank side. There is some debris deposited along the impact zone on the US right bank and some trees leaning over the channel, but no major accumulation.

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		10	90	2	3	0	4.5	90.0
RABUT	1	0	90			2	5	28.0

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

3.0

1

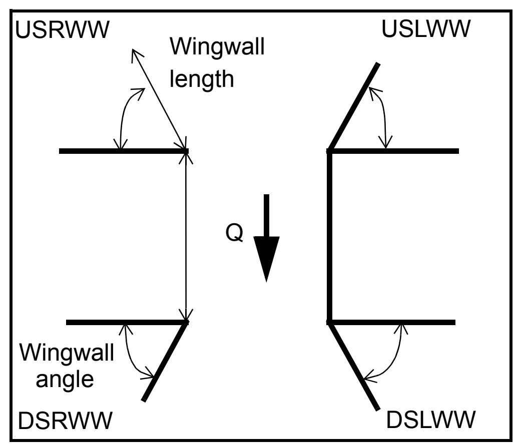
74. LABUT: undermined along the DS half of the kneewall. Maximum undermined depth is 0.5 ft below the wall with a maximum penetration of 1.0 ft. The boulders along the left abutment are sitting between 2 and 4 ft away from the wall, which may cause more erosion than they will prevent.

RABUT: the abutment wall and kneewall have settled slightly. The wall has rotated such that the front top of the wall leans slightly streamward at the US end. The boulders at the US end of the kneewall create turbulence even during low stream flows.

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						28.0	
USRWW:	N		-		0	0.5	
DSLWW:	-		-		N	16.0	
DSRWW:	-		0		-	16.0	

*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	N	-	-	-	-	-
Condition	N	-	-	-	-	-	-	-
Extent	-	-	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*

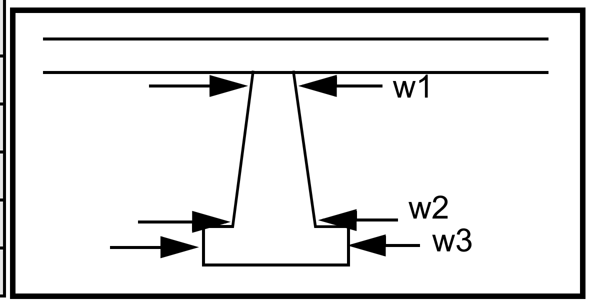
*Protection extent: **1**- entire base length; **2**- US end; **3**- DS end; **4**- other*

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

Piers:

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

85. Pier no.	width (w) feet			elevation (e) feet		
	w1	w2	w3	e@w1	e@w2	e@w3
Pier 1	-	-	-	-	-	-
Pier 2	-	-	-	-	-	-
Pier 3	-	-	-	-	-	-
Pier 4	-	-	-	-	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	ere are	stone	slump	-	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	a few	fill at	ed.	-	***1**- Solid pier, **2**- column, **3**- bent*
88. Material	boul-	the		-	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	ders	upst		-	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	in	ream		-	*Y- yes; N- no*
91. Attack ∠ (BF)	front	end		-	
92. Pushed	of	of		-	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles	the	the		-	
95. Cross-members	left	right		-	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	abut	abut		-	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	ment	ment		-	
98. Exposure depth	. The	has	N	-	

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

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

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

Point bar extent: ______ feet **2** ____ *(US, UB, DS)* to **2** ______ feet **7** ____ *(US, UB, DS)* positioned **435** %LB to **1** ____ %RB

Material: **1** ____

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

453
2
0
1

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

Cut bank extent: **bank** feet **is** ____ *(US, UB, DS)* to **pro-** ____ feet **tect** ____ *(US, UB, DS)*

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

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

with boulder and cobble fill from 0 to over 150 ft DS, as the stream bank is also the road embankment for VT 100.

The right bank material consists of native boulders and cobble with stone fill. The boulders serve as natural protection.

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

Scour dimensions: Length **some** ____ Width **light** ____ Depth: **ero-** ____ Positioned **sio** ____ %LB to **n of** ____ %RB

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

both banks.

The DS channel is pooled and flatter than just US of the bridge. This pooled portion extends from 5 to 30 ft DS. The channel gradient steepens between 30 to 70 ft DS and then flattens a bit again.

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

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

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

Confluence comments (eg. confluence name):

-

NO DROP STRUCTURE

F. Geomorphic Channel Assessment

107. Stage of reach evolution ____

***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)*:

Y
0
6
14
UB
3
DS
75
100

109. G. Plan View Sketch

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

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number:	LUDLTH00460031	Town:	Ludlow
Road Number:	TH 46	County:	Windsor
Stream:	Jewell Brook		

Initials MAI Date: 03/23/98 Checked: ECW

I. 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 Davis, 1995, p. 28, eq. 16)

Approach Section

Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	1400	1900	1550
Main Channel Area, ft2	237	345	329
Left overbank area, ft2	0	0	0
Right overbank area, ft2	0	0	0
Top width main channel, ft	50	78	57
Top width L overbank, ft	0	0	0
Top width R overbank, ft	0	0	0
D50 of channel, ft	0.4029	0.4029	0.4029
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	4.7	4.4	5.8
y1, average depth, LOB, ft	ERR	ERR	ERR
y1, average depth, ROB, ft	ERR	ERR	ERR
Total conveyance, approach	19155	26908	30119
Conveyance, main channel	19155	26908	30119
Conveyance, LOB	0	0	0
Conveyance, ROB	0	0	0
Percent discrepancy, conveyance	0.0000	0.0000	0.0000
Qm, discharge, MC, cfs	1400.0	1900.0	1550.0
Ql, discharge, LOB, cfs	0.0	0.0	0.0
Qr, discharge, ROB, cfs	0.0	0.0	0.0
Vm, mean velocity MC, ft/s	5.9	5.5	4.7
Vl, mean velocity, LOB, ft/s	ERR	ERR	ERR
Vr, mean velocity, ROB, ft/s	ERR	ERR	ERR
Vc-m, crit. velocity, MC, ft/s	10.7	10.6	11.1
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 Davis, 1995, p. 32, eq. 20, 20a)
```

Bridge Section	Q100	Q500	Other Q
(Q) total discharge, cfs	1400	1900	1550
(Q) discharge thru bridge, cfs	1400	1588	1550
Main channel conveyance	9067	13642	11720
Total conveyance	9067	13642	11720
Q2, bridge MC discharge,cfs	1400	1588	1550
Main channel area, ft2	119	180	181
Main channel width (normal), ft	27.7	27.9	27.9
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	27.7	27.9	27.9
y_bridge (avg. depth at br.), ft	4.29	6.45	6.50
Dm, median (1.25*D50), ft	0.503625	0.503625	0.503625
y2, depth in contraction,ft	4.34	4.81	4.71
ys, scour depth (y2-ybridge), ft	**0.052**	-1.64	-1.79

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 Davis, 1995, p. 144-146)
```

	Q100	Q500	OtherQ
Q, total, cfs	1400	1900	1550
Q, thru bridge MC, cfs	1400	1588	1550
Vc, critical velocity, ft/s	10.73	10.61	11.09
Va, velocity MC approach, ft/s	5.91	5.51	4.71
Main channel width (normal), ft	27.7	27.9	27.9
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	27.7	27.9	27.9
qbr, unit discharge, ft2/s	50.5	56.9	55.6
Area of full opening, ft2	118.9	179.9	181.3
Hb, depth of full opening, ft	4.29	6.45	6.50
Fr, Froude number, bridge MC	0	0.61	0.59
Cf, Fr correction factor (<=1.0)	0.00	1.00	1.00
**Area at downstream face, ft2	N/A	130	127
**Hb, depth at downstream face, ft	N/A	4.66	4.55
**Fr, Froude number at DS face	ERR	1.00	1.01
**Cf, for downstream face (<=1.0)	N/A	1.00	1.00

Elevation of Low Steel, ft	497.96	497.96	497.96
Elevation of Bed, ft	493.67	491.51	491.46
Elevation of Approach, ft	0	500.05	499.83
Friction loss, approach, ft	0	0.3	0.24
Elevation of WS immediately US, ft	0.00	499.75	499.59
ya, depth immediately US, ft	-493.67	8.24	8.13
Mean elevation of deck, ft	499.98	499.98	499.98
w, depth of overflow, ft (>=0)	0.00	0.00	0.00
Cc, vert contrac correction (<=1.0)	ERR	0.94	0.94
**Cc, for downstream face (<=1.0)	ERR	0.813682	0.791467
Ys, scour w/Chang equation, ft	N/A	**-0.74**	**-1.20**
Ys, scour w/Umbrell equation, ft	N/A	-0.33	-1.15

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

**Ys, scour w/Chang equation, ft	N/A	1.93	1.78
**Ys, scour w/Umbrell equation, ft	ERR	1.45	0.79

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	4.34	4.81	4.71
WSEL at downstream face, ft	--	496.11	496.00
Depth at downstream face, ft	N/A	4.66	4.55
Ys, depth of scour (Laursen), ft	N/A	0.15	0.16

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)

(Federal Highway Administration, 1993)

Downstream bridge face property	100-yr	500-yr	Other Q
Q, discharge thru bridge MC, cfs	1400	1588	1550
Main channel area (DS), ft2	118.9	130	127
Main channel width (normal), ft	27.7	27.9	27.9
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	27.7	27.9	27.9
D90, ft	1.3779	1.3779	1.3779
D95, ft	1.5552	1.5552	1.5552
Dc, critical grain size, ft	1.0556	1.0866	1.0984
Pc, Decimal percent coarser than Dc	0.203	0.193	0.189
Depth to armoring, ft	**12.46**	**13.67**	**14.16**

Abutment Scour

Froehlich's Abutment Scour

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

(Richardson and Davis, 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	1400	1900	1550	1400	1900	1550
a', abut.length blocking flow, ft	5.9	44.7	8.8	16.4	21	20.4
Ae, area of blocked flow ft2	16.13	52.27	29.58	57.97	52.56	89.06
Qe, discharge blocked abut.,cfs	36.55	--	52.46	249.38	--	314.56
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	2.27	1.07	1.77	4.30	5.41	3.53

ya, depth of f/p flow, ft	2.73	1.17	3.36	3.53	2.50	4.37

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

K1	1	1	1	1	1	1

--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	0.242	0.146	0.170	0.403	0.452	0.298
ys, scour depth, ft	**6.37**	**5.10**	**7.28**	**12.45**	**11.24**	**13.55**

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

a'(abut length blocked, ft)	5.9	44.7	8.8	16.4	21	20.4
y1 (depth f/p flow, ft)	2.73	1.17	3.36	3.53	2.50	4.37
a'/y1	2.16	38.23	2.62	4.64	8.39	4.67
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.24	0.15	0.17	0.40	0.45	0.30
Ys w/ corr. factor K1/0.55:						
vertical	ERR	4.51	ERR	ERR	ERR	ERR
vertical w/ ww's	ERR	3.70	ERR	ERR	ERR	ERR
spill-through	ERR	2.48	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 Davis, 1995, p112, eq. 81,82)

Characteristic	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	1	1	1	1	1	1
y, depth of flow in bridge, ft	4.29	4.66	4.55	4.29	4.66	4.55
Median Stone Diameter for riprap at: left abutment				right abutment, ft		
Fr<=0.8 (vertical abut.)	ERR	ERR	ERR	ERR	ERR	ERR
Fr>0.8 (vertical abut.)	**1.79**	**1.95**	**1.90**	**1.79**	**1.95**	**1.90**