LEVEL II SCOUR ANALYSIS FOR BRIDGE 29 (READTH00510029) on TOWN HIGHWAY 51, crossing MILL BROOK, READING, VERMONT

Open-File Report 98-402

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 RONDA L. BURNS and MATTHEW A. WEBER

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

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

For additional information
write to:

District Chief
U.S. Geological Survey
361 Commerce Way
Pembroke, NH 03275-3718

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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 29 (READTH00510029) ON TOWN HIGHWAY 51, CROSSING MILL BROOK, READING, VERMONT

By **Ronda L. Burns and Matthew A. Weber**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure READTH00510029 on Town Highway 51 crossing Mill Brook, Reading, 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 culvert, 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 New England Upland section of the New England physiographic province in eastern Vermont. The 9.56-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is pasture upstream of the culvert and on the left bank downstream, while the immediate banks are tree or shrub covered. The downstream right bank is forested.

In the study area, Mill Brook has a sinuous channel with a slope of approximately 0.008 ft/ft, an average channel top width of 45 ft and an average bank height of 3 ft. The channel bed material is mainly gravel with a median grain size (D_{50}) of 77.5 mm (0.254 ft). The geomorphic assessment at the time of the Level I site visit on March 29, 1995 and Level II site visit on July 29, 1996, indicated that the reach was laterally unstable. There are cut-banks upstream and downstream of the culvert and heavy fluvial erosion on the downstream banks.

The Town Highway 51 crossing of Mill Brook is a 27-ft-long, one-lane structure consisting of a 25-foot span, steel, multi-plate arch culvert (Vermont Agency of Transportation, written communication, March 8, 1995). The opening length of the structure parallel to the culvert face is 24.7 ft. The channel is skewed approximately 30 degrees to the opening while the computed opening-skew-to-roadway is 20 degrees.

A scour hole 3.0 ft deeper than the mean thalweg depth was observed along the upstream end of the left side of the culvert during the Level I assessment. The only scour protection measure at the site was type-2 stone fill (less than 36 inches diameter) at the upstream and downstream corners of the culvert along the embankment. 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 0.5 ft. The worst-case contraction scour occurred at the incipient roadway-overtopping discharge, which was less than the 100-year discharge. Left abutment scour ranged from 5.3 to 11.3 ft. Right abutment scour ranged from 12.9 to 19.2 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 culvert 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.

Plymouth, VT. Quadrangle, 1:24,000, 1966
Photoinspected 1983

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 READTH00510029 ***Stream*** Mill Brook

County Windsor ***Road*** TH 51 ***District*** 4

Description of Bridge

Bridge length 27 ***ft*** ***Bridge width*** -- ***ft*** ***Max span length*** 25 ***ft***

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

Abutment type N/A ***Embankment type*** Sloping

Stone fill on abutment? No ***Date of inspection*** 3/29/95

Description of stone fill Type-2, at the upstream and downstream ends of the culvert on the embankment.

The culvert is a multi-plate corrugated steel pipe arch with concrete footings. There is a 3 ft deep scour hole along the upstream left side of the culvert.

Yes

Is bridge skewed to flood flow according to There ***survey?*** 30 ***Angle*** Yes

is a moderate channel bend in the upstream reach. The scour hole has developed in the location where the flow impacts the upstream left side of the culvert.

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	3/29/95	0	0
Level II	7/29/96	0	0

Potential for debris Moderate. Some debris was caught at the upstream face of the culvert on 3/29/95.

Describe any features near or at the bridge that may affect flow (include observation date) None as of 7/29/96.

Description of the Geomorphic Setting

General topography The channel is located in a high relief valley with a wide flood plain on the left.

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

Date of inspection 3/29/95

DS left: Steep channel bank to a wide flood plain and the VT 106 roadway

DS right: Steep valley wall

US left: Steep channel bank to a wide flood plain and the VT 106 roadway

US right: Moderately sloping channel bank to a steep valley wall

Description of the Channel

Average top width 45 *ft* ***Average depth*** 3 *ft*

Predominant bed material Sand/Gravel ***Bank material*** Silt/Sand/Gravel

Sinuous with semi-alluvial channel boundaries and irregular point and lateral bars.

3/29/95

Vegetative co Trees and brush with grass on the flood plain

DS left: Trees and brush

DS right: Shrubs and brush with grass on the flood plain

US left: Shrubs and brush with grass on the overbank

US right:

Do banks appear stable? No

If not, describe location and type of instability and date of observation. Cut-banks were observed upstream and downstream of the culvert on 3/29/95. There is heavy fluvial erosion with mass wasting on the banks downstream of the culvert.

Describe any obstructions in channel and date of observation. Several trees were across the channel in the downstream reach as of 3/29/95 and 7/29/96.

Hydrology

Drainage area 9.56 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

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

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

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

USGS gage description --

USGS gage number --

Gage drainage area -- ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 2,500 ***ft³/s*** ***Q500*** 3,580 ***ft³/s***

The 100- and 500-year discharges are based on flood frequency estimates available from the VTAOT database (written communication, May 1995) for bridge number 25 in Reading. Bridge number 25 crosses Mill Brook upstream of this site and has a drainage area of 9.54 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 Subtract 8.8 ft from the USGS arbitrary survey datum to obtain the VTAOT plans' datum.

Description of reference marks used to determine USGS datum. RM1 is a nail in telephone pole #170-1 on the downstream left bank, 50 ft from the culvert (elev. 494.65 ft, arbitrary survey datum). RM2 is a bolt on top of the culvert at the downstream end near the center (elev. 492.78 ft, arbitrary survey datum). RM3 is a bolt on top of the culvert at the upstream end to the left of center (elev. 493.27 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	-22	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Culvert section
RDWAY	21	1	Road Grade section
APPRO	67	2	Modelled Approach section (Templated from APTEM)
APTEM	80	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 0.060, and overbank "n" values ranged from 0.041 to 0.050.

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 0.0083 ft/ft, which was estimated from thalweg points surveyed downstream of the culvert.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.0041 ft/ft) to establish the modelled approach section (APPRO), one culvert length upstream of the upstream face as recommended by Shearman and others (1986). This location provides a consistent method for determining scour variables.

For this site, the culvert geometry was modified to create an "equivalent" bridge opening having the same area as the culvert. Bridge routines were then used to approximate the culvert flow with road overflow.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.9 ***ft***
Average low steel elevation 493.3 ***ft***

100-year discharge 2,500 ***ft³/s***
Water-surface elevation in bridge opening 493.3 ***ft***
Road overtopping? Yes ***Discharge over road*** 1,110 ***ft³/s***
Area of flow in bridge opening 166 ***ft²***
Average velocity in bridge opening 8.3 ***ft/s***
Maximum WSPRO tube velocity at bridge 10.9 ***ft/s***

Water-surface elevation at Approach section with bridge 495.0
Water-surface elevation at Approach section without bridge 491.2
Amount of backwater caused by bridge 3.8 ***ft***

500-year discharge 3,580 ***ft³/s***
Water-surface elevation in bridge opening 493.3 ***ft***
Road overtopping? Yes ***Discharge over road*** 2,050 ***ft³/s***
Area of flow in bridge opening 166 ***ft²***
Average velocity in bridge opening 9.2 ***ft/s***
Maximum WSPRO tube velocity at bridge 12.1 ***ft/s***

Water-surface elevation at Approach section with bridge 495.7
Water-surface elevation at Approach section without bridge 492.1
Amount of backwater caused by bridge 3.6 ***ft***

Incipient overtopping discharge 1,000 ***ft³/s***
Water-surface elevation in bridge opening 488.2 ***ft***
Area of flow in bridge opening 88 ***ft²***
Average velocity in bridge opening 11.4 ***ft/s***
Maximum WSPRO tube velocity at bridge 14.9 ***ft/s***

Water-surface elevation at Approach section with bridge 493.2
Water-surface elevation at Approach section without bridge 490.1
Amount of backwater caused by bridge 3.1 ***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 20). At this site, the 100- and 500-year discharges resulted in unsubmerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Thus, contraction scour for these discharges was computed by use of the Chang equation (Richardson and Davis, 1995, p. 145-146).

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). Results from these computations are presented in appendix F. Furthermore, for those discharges which resulted in unsubmerged orifice flow, contraction scour was computed by substituting estimates for the depth of flow at the culvert outlet in the contraction scour equations. Results with respect to these substitutions are provided in appendix F.

Abutment scour for the right abutment 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 at the left abutment was computed by use of the HIRE equation (Richardson and Davis, 1995, p. 49, equation 29) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. The variables used by the HIRE abutment-scour equation are defined the same as those defined for the Froehlich abutment-scour equation.

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	0.0	0.0	0.5
Depth to armoring	6.1	9.3	N/A
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	9.5	11.3	5.3
Right abutment	17.1	19.2	12.9
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	2.0	2.2	1.6
Right abutment	2.0	2.2	1.6
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

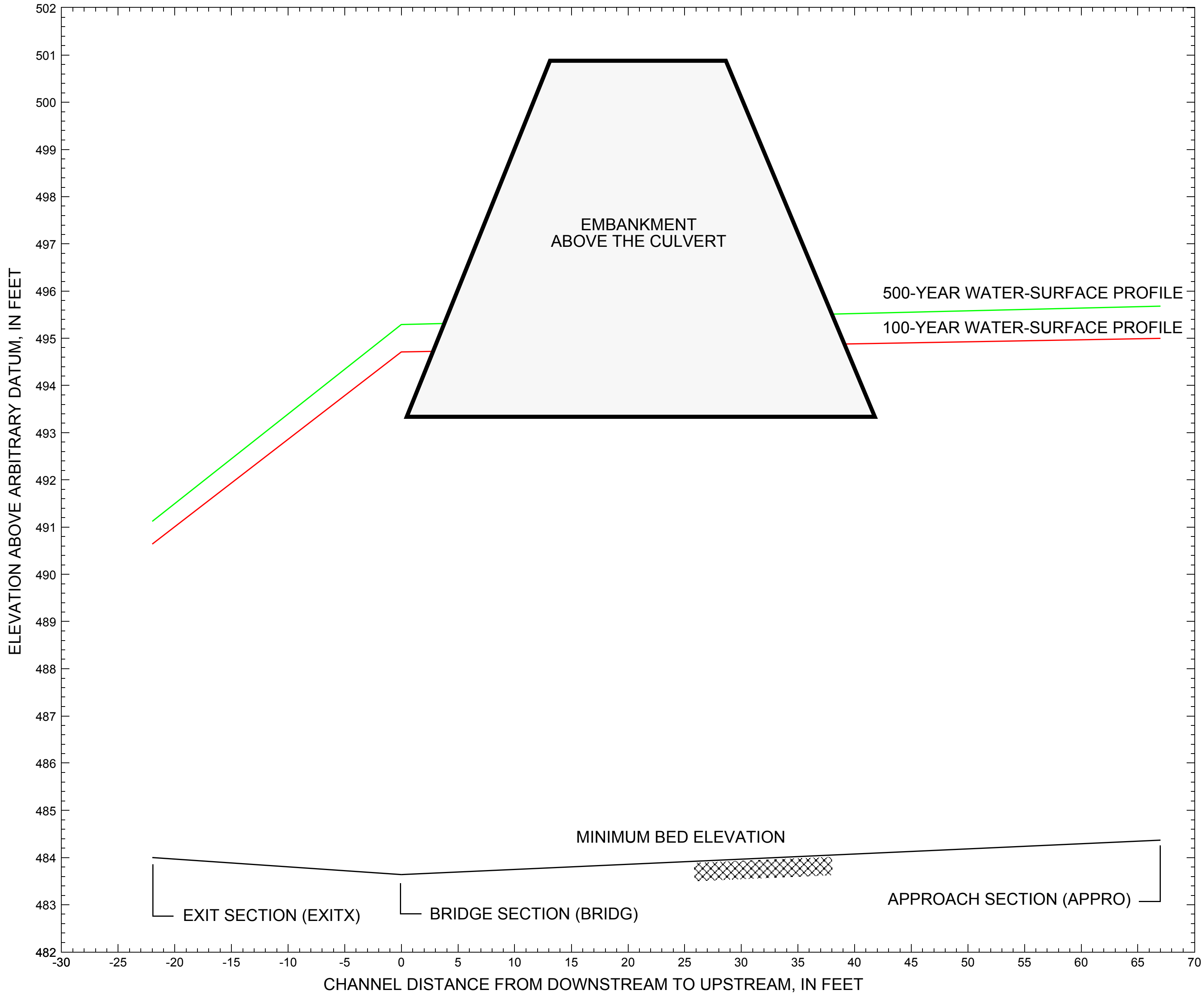

Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, Vermont.

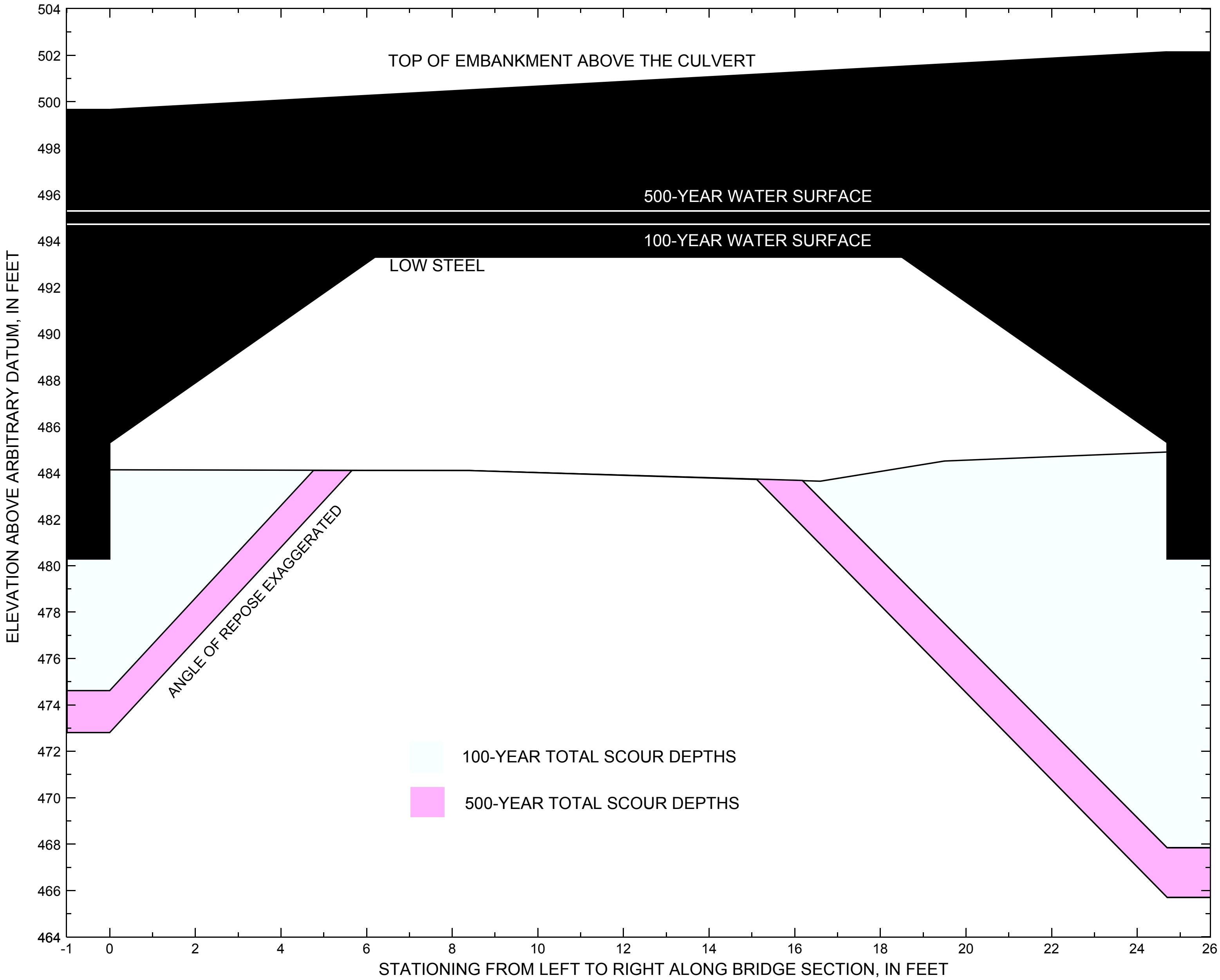

Figure 8. Scour elevations for the 100- and 500-year discharges at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, 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 2,500 cubic-feet per second											
Left abutment	0.0	--	493.3	480.3	484.1	0.0	9.5	--	9.5	474.6	-5.7
Right abutment	24.7	--	493.3	480.3	484.9	0.0	17.1	--	17.1	467.8	-12.5

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, 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 3,580 cubic-feet per second											
Left abutment	0.0	--	493.3	480.3	484.1	0.0	11.3	--	11.3	472.8	-7.5
Right abutment	24.7	--	493.3	480.3	484.9	0.0	19.2	--	19.2	465.7	-14.6

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

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U.S. Geological Survey, 1972, Cavendish, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Photoinspected 1983, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File read029.wsp
T2        Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
T3        TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           2500.0   3580.0   1000.0
SK          0.0083   0.0083   0.0083
*
XS   EXITX    -22           0.
GR         -290.9, 510.00   -290.9, 491.87   -282.3, 490.20   -116.1, 490.04
GR          -97.1, 488.14      0.0, 489.68      4.2, 486.07      7.5, 484.86
GR           11.0, 484.45     14.8, 484.17     18.2, 484.00     27.2, 484.44
GR           28.7, 484.84     38.1, 485.62     70.3, 512.27    159.3, 517.55
*
N           0.041        0.057
SA                   0.0
*
XS   FULLV      0  * * *   0.0045
*
*             SRD    LSEL      SKEW
BR   BRIDG     0   493.30      20.0
GR            0.0, 485.29      0.0, 484.13      8.4, 484.10
GR           16.6, 483.64     19.5, 484.51     24.7, 484.90     24.7, 485.31
GR           18.5, 493.30      6.2, 493.30      0.0, 485.29
*
*          BRTYPE  BRWDTH  EMBSS  EMBELV
CD           2       42.0    1.9  500.91
N           0.040
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     21      17.5     2
* GR          -498.2, 495.30   -304.4, 492.80
GR         -304.0, 510.00   -304.0, 494.08   -234.0, 493.15   -115.0, 493.69
GR          -53.5, 496.07      0.0, 499.66     28.1, 502.15     91.3, 509.28
GR          157.5, 518.13    275.7, 542.61
*
XT   APTEM     80           0.
GR         -304.0, 510.00
GR         -304.0, 494.08   -108.2, 491.52    -33.3, 490.41      0.0, 491.07
GR            2.4, 487.73      8.4, 485.08     10.9, 484.51     17.3, 484.42
GR           28.1, 485.20     35.7, 486.95     53.1, 488.76     84.2, 493.62
GR          112.1, 504.54    148.1, 510.74
*
AS   APPRO     67  * * *  0.0041
GT
N           0.045     0.060      0.050
SA                0.0       35.7
*
HP 1 BRIDG  493.30 1 493.30
HP 2 BRIDG  493.30 * * 1370
HP 1 BRIDG  490.92 1 490.92
HP 2 RDWAY  494.71 * * 1105
HP 1 APPRO  495.00 1 495.00
HP 2 APPRO  495.00 * * 2500
*
HP 1 BRIDG  493.30 1 493.30
HP 2 BRIDG  493.30 * * 1524
HP 1 BRIDG  491.37 1 491.37
HP 2 RDWAY  495.29 * * 2047
HP 1 APPRO  495.68 1 495.68
HP 2 APPRO  495.68 * * 3580
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

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       U.S. Geological Survey WSPRO Input File read029.wsp
       Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
       TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
          *** RUN DATE & TIME: 03-16-98  10:59

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     166.   12566.    -1.    57.                          0.
  493.30          166.   12566.    -1.    57.  1.00     0.    25.      0.

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

        WSEL     LEW     REW    AREA        K        Q    VEL
      493.30     0.0    24.7   165.7   12566.    1370.   8.27

X STA.        0.0         5.3         6.3         7.0         7.8         8.5
  A(I)             23.1         7.7         6.3         6.6         6.4
  V(I)             2.97        8.84       10.91       10.39       10.70

X STA.        8.5         9.3        10.0        10.8        11.5        12.3
  A(I)              6.6         6.5         6.5         6.7         6.7
  V(I)            10.31       10.46       10.58       10.29       10.24

X STA.       12.3        13.0        13.8        14.5        15.2        15.9
  A(I)              6.6         6.6         6.5         6.5         6.4
  V(I)            10.41       10.37       10.57       10.58       10.68

X STA.       15.9        16.6        17.3        18.1        18.9        24.7
  A(I)              6.5         6.4         6.6         7.0        23.6
  V(I)            10.58       10.72       10.43        9.81        2.90

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     134.   11403.    15.    39.                       2272.
  490.92          134.   11403.    15.    39.  1.00     0.    25.   2272.

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      21.

        WSEL     LEW     REW    AREA        K        Q    VEL
      494.71  -304.0   -88.6   243.6    9591.    1105.   4.54

X STA.     -304.0      -280.9      -267.9      -257.9      -249.4      -241.7
  A(I)             18.1        13.3        11.8        11.1        10.7
  V(I)             3.05        4.16        4.70        4.97        5.16

X STA.     -241.7      -234.8      -228.2      -221.4      -214.2      -207.0
  A(I)             10.4        10.3        10.3        10.7        10.5
  V(I)             5.31        5.38        5.36        5.16        5.28

X STA.     -207.0      -199.7      -192.0      -183.9      -175.5      -166.7
  A(I)             10.3        10.7        11.0        11.0        11.2
  V(I)             5.36        5.16        5.04        5.03        4.92

X STA.     -166.7      -157.5      -147.4      -137.1      -125.6       -88.6
  A(I)             11.5        11.9        11.9        12.5        24.5
  V(I)             4.82        4.64        4.65        4.41        2.25

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      67.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     891.   60294.   304.   305.                       8657.
            2     338.   35820.    36.    38.                       5895.
            3     248.   20704.    52.    53.                       3069.
  495.00         1477.  116818.   392.   396.  1.13  -304.    88.  15329.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      67.

        WSEL     LEW     REW    AREA        K        Q    VEL
      495.00  -304.0    87.9  1476.8  116818.    2500.   1.69

X STA.     -304.0      -188.6      -152.9      -125.3      -102.4       -82.8
  A(I)            199.3        97.0        86.4        79.2        74.0
  V(I)             0.63        1.29        1.45        1.58        1.69

X STA.      -82.8       -65.6       -49.9       -35.4       -21.5        -5.7
  A(I)             69.3        67.1        65.4        63.3        67.1
  V(I)             1.80        1.86        1.91        1.98        1.86

X STA.       -5.7         6.8        12.3        17.1        21.9        26.9
  A(I)             73.0        55.5        50.9        50.9        50.2
  V(I)             1.71        2.25        2.46        2.46        2.49

X STA.       26.9        32.6        39.0        46.1        54.6        87.9
  A(I)             53.7        52.9        52.3        55.7       113.5
  V(I)             2.33        2.36        2.39        2.24        1.10
```

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     U.S. Geological Survey WSPRO Input File read029.wsp
     Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
     TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
        *** RUN DATE & TIME: 03-16-98  10:59

 CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
          1     166.   12566.    -1.    57.                          0.
493.30          166.   12566.    -1.    57.  1.00     0.    25.      0.

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

     WSEL     LEW     REW    AREA        K        Q    VEL
   493.30     0.0    24.7   165.7   12566.    1524.   9.20

X STA.        0.0         5.3         6.3         7.0         7.8         8.5
  A(I)             23.1         7.7         6.3         6.6         6.4
  V(I)             3.31        9.84       12.13       11.56       11.90

X STA.        8.5         9.3        10.0        10.8        11.5        12.3
  A(I)              6.6         6.5         6.5         6.7         6.7
  V(I)            11.47       11.64       11.77       11.44       11.39

X STA.       12.3        13.0        13.8        14.5        15.2        15.9
  A(I)              6.6         6.6         6.5         6.5         6.4
  V(I)            11.58       11.53       11.75       11.77       11.88

X STA.       15.9        16.6        17.3        18.1        18.9        24.7
  A(I)              6.5         6.4         6.6         7.0        23.6
  V(I)            11.77       11.92       11.60       10.91        3.23

 CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
          1     141.   12126.    14.    40.                       2498.
491.37          141.   12126.    14.    40.  1.00     0.    25.   2498.

 VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      21.

     WSEL     LEW     REW    AREA        K        Q    VEL
   495.29  -304.0   -73.7   372.9   18614.    2047.   5.49

X STA.     -304.0      -286.4      -273.8      -262.9      -253.5      -244.9
  A(I)             23.4        19.2        18.3        17.0        16.6
  V(I)             4.37        5.32        5.58        6.01        6.16

X STA.     -244.9      -237.0      -229.3      -221.6      -213.7      -205.8
  A(I)             16.3        16.3        16.2        16.3        16.0
  V(I)             6.29        6.27        6.31        6.27        6.38

X STA.     -205.8      -197.9      -189.5      -181.0      -172.0      -162.5
  A(I)             15.7        16.4        16.4        16.9        17.4
  V(I)             6.50        6.23        6.25        6.07        5.89

X STA.     -162.5      -153.1      -142.7      -132.4      -121.1       -73.7
  A(I)             17.0        18.1        17.6        18.6        43.0
  V(I)             6.02        5.65        5.82        5.51        2.38

 CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      67.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
          1    1098.   85240.   304.   306.                      11837.
          2     362.   40213.    36.    38.                       6541.
          3     284.   25367.    54.    55.                       3701.
495.68         1744.  150820.   394.   399.  1.07  -304.    90.  20092.

 VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      67.

     WSEL     LEW     REW    AREA        K        Q    VEL
   495.68  -304.0    89.6  1743.9  150820.    3580.   2.05

X STA.     -304.0      -218.0      -178.9      -149.4      -124.5      -102.8
  A(I)            190.6       118.6       102.6        95.7        89.8
  V(I)             0.94        1.51        1.74        1.87        1.99

X STA.     -102.8       -83.8       -66.3       -50.3       -35.7       -21.7
  A(I)             84.3        82.2        79.4        75.2        73.5
  V(I)             2.12        2.18        2.25        2.38        2.43

X STA.      -21.7        -5.3         7.5        13.5        19.1        24.7
  A(I)             80.8        86.3        66.5        62.8        61.7
  V(I)             2.22        2.07        2.69        2.85        2.90

X STA.       24.7        30.9        38.4        46.0        55.7        89.6
  A(I)             64.4        68.3        62.2        69.5       129.4
  V(I)             2.78        2.62        2.88        2.57        1.38
```

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        U.S. Geological Survey WSPRO Input File read029.wsp
        Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
        TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
           *** RUN DATE & TIME: 03-16-98  11:13

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

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      88.    6394.    19.    32.                        1071.
   488.20           88.    6394.    19.    32.  1.00     0.    25.   1071.

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       488.20     0.0    24.7    87.8    6394.    1000.  11.39

X STA.         0.0        4.1        5.0        5.9        6.8        7.7
  A(I)            12.7        3.5        3.4        3.5        3.5
  V(I)            3.94      14.27      14.57      14.39      14.46

X STA.         7.7        8.6        9.5       10.4       11.3       12.2
  A(I)             3.5        3.5        3.5        3.5        3.5
  V(I)           14.36      14.28      14.30      14.29      14.13

X STA.        12.2       13.0       13.9       14.7       15.5       16.3
  A(I)             3.5        3.4        3.5        3.4        3.4
  V(I)           14.22      14.51      14.47      14.70      14.89

X STA.        16.3       17.1       18.0       18.9       20.0       24.7
  A(I)             3.4        3.5        3.6        3.6       12.5
  V(I)           14.56      14.45      13.99      13.79       4.01

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      67.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     365.   16029.   239.   239.                        2560.
             2     273.   25088.    36.    38.                        4278.
             3     158.   10603.    46.    46.                        1655.
   493.18          796.   51720.   321.   324.  1.33  -239.    82.   6159.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      67.

         WSEL     LEW     REW    AREA        K        Q    VEL
       493.18  -239.2    81.7   795.5   51720.    1000.   1.26

X STA.      -239.2      -92.6      -70.1      -52.0      -36.5      -22.2
  A(I)           140.7       47.5       43.9       41.0       39.3
  V(I)            0.36       1.05       1.14       1.22       1.27

X STA.       -22.2       -4.2        7.3       10.5       13.4       16.1
  A(I)            43.4       51.1       26.4       24.9       23.5
  V(I)            1.15       0.98       1.89       2.01       2.13

X STA.        16.1       18.9       21.9       24.9       28.1       31.7
  A(I)            24.7       25.7       25.5       26.1       27.5
  V(I)            2.02       1.94       1.96       1.92       1.82

X STA.        31.7       36.1       40.5       45.6       51.7       81.7
  A(I)            29.4       26.4       28.0       30.3       70.3
  V(I)            1.70       1.89       1.79       1.65       0.71
```

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        U.S. Geological Survey WSPRO Input File read029.wsp
        Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
        TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
           *** RUN DATE & TIME: 03-16-98  10:59

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

EXITX:XS   ****** -285.     514.  0.51 *****  491.15  490.04   2500.  490.64
      -22. ******    44.   27430.  1.39 ***** *******    0.81    4.86

FULLV:FV      22.  -285.     572.  0.39  0.16  491.31 *******   2500.  490.92
        0.    22.    44.   31467.  1.31  0.00   -0.01    0.67    4.37
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.08     491.18     491.07
 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   490.42     510.69    0.50
 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   490.42     510.69     491.07
 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPRO"     KRATIO =  0.64

APPRO:AS      67.   -89.     320.  1.18  0.66  492.36  491.07   2500.  491.18
       67.    67.    69.   20037.  1.24  0.39    0.00    1.08    7.82
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   501.76       0.00     491.38     493.15
 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   491.36     494.86     494.95     493.30
 ===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      22.     0.     166.  1.06 *****  494.36  488.94   1370.  493.30
        0. ******    25.   12566.  1.00 ***** *******    0.56    8.27

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       2. ****   5.  0.460  0.000  493.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
   RDWAY:RG      21.    50.  0.02  0.05  495.03   -0.01   1105.  494.71

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   1105.   215.  -304.   -89.   1.6   1.1   5.3   4.5   1.4   3.0
   RT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****

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

APPRO:AS      25.  -304.    1476.  0.05  0.08  495.05  491.07   2500.  495.00
       67.    31.    88.  116720.  1.13  1.01   -0.01    0.16    1.69

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

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K      AREA     VEL    WSEL
   EXITX:XS     -22.  -285.    44.   2500.   27430.     514.    4.86  490.64
   FULLV:FV       0.  -285.    44.   2500.   31467.     572.    4.37  490.92
   BRIDG:BR       0.     0.    25.   1370.   12566.     166.    8.27  493.30
   RDWAY:RG      21.******* 1105.    1105.*********       0.    2.00  494.71
   APPRO:AS      67.  -304.    88.   2500.  116720.    1476.    1.69  495.00

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  ***********************

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXITX:XS    490.04    0.81  484.00  517.55************  0.51  491.15  490.64
   FULLV:FV  ********    0.67  484.10  517.65  0.16  0.00  0.39  491.31  490.92
   BRIDG:BR    488.94    0.56  483.64  493.30************  1.06  494.36  493.30
   RDWAY:RG  ***************  493.15  542.61  0.02******  0.05  495.03  494.71
   APPRO:AS    491.07    0.16  484.37  510.69  0.08  1.01  0.05  495.05  495.00
```
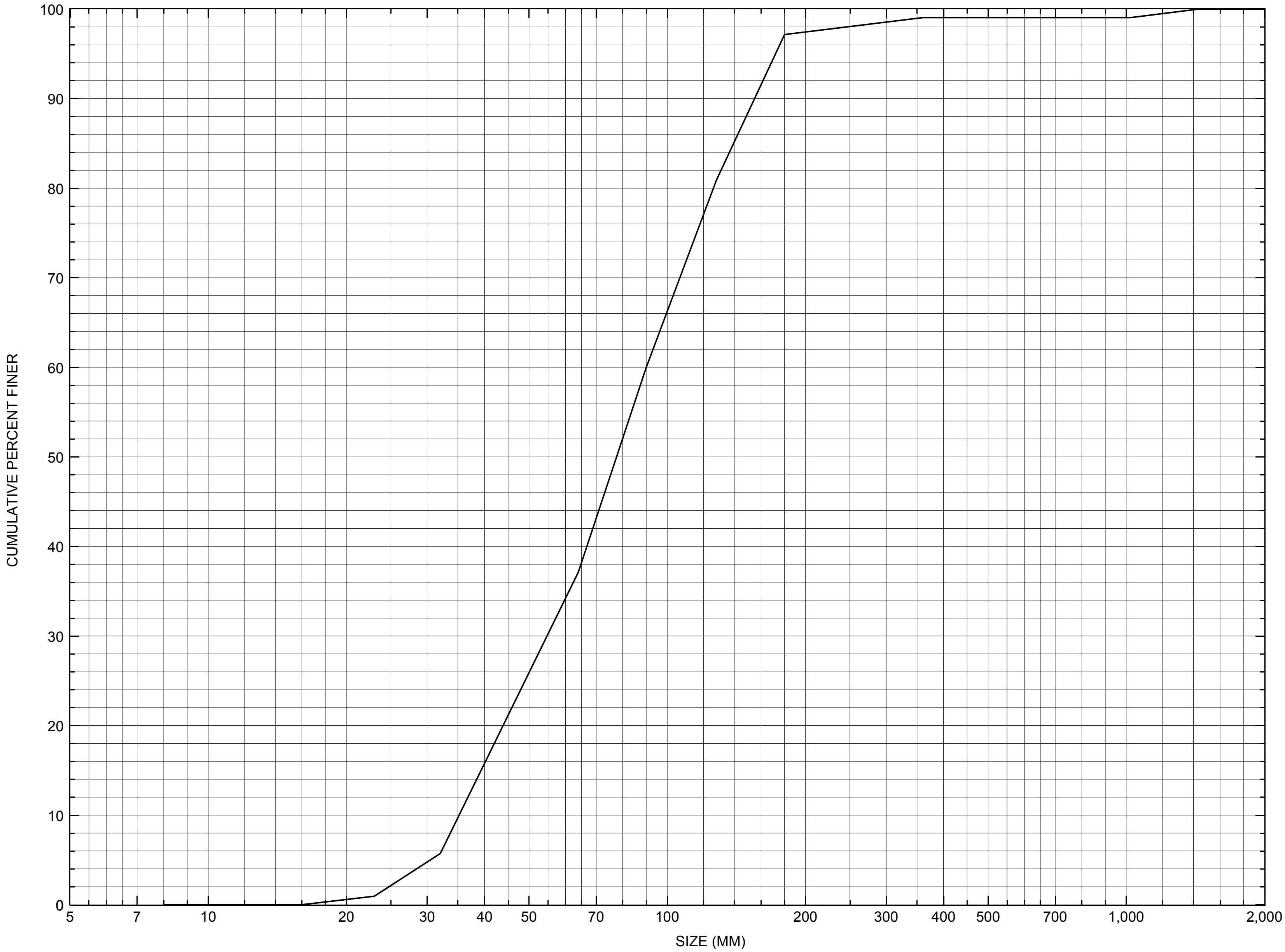

WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File read029.wsp
        Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
        TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
           *** RUN DATE & TIME: 03-16-98  10:59

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

EXITX:XS   ******  -287.     671.  0.53 *****  491.65  490.89   3580.  491.12
      -22. ******    45.   39287.  1.21 ***** *******    0.73    5.33

FULLV:FV      22.  -288.     721.  0.45  0.16  491.82 *******   3580.  491.37
        0.    22.    45.   43504.  1.17  0.00    0.00    0.64    4.97
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.33     491.52     492.08
 ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   490.87     510.69    0.50
 ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   490.87     510.69     492.08
 ===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 =   492.08     510.69     492.08

APPRO:AS      67.  -155.     492.  1.11 *****  493.19  492.08   3580.  492.08
       67.    67.    75.   30672.  1.35 ***** *******    1.02    7.28
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===210 QUESTIONABLE CRITICAL-FLOW SOLUTION.
                   SECID “BRIDG”     Q,CRWS =  3580.00     493.30
 ===230 REJECTED FLOW CLASS 1 SOLUTION.
              WS1,WSSD,WS3 =   509.50       0.00     493.30
                      CRWS =   492.08   ********     493.30
                      YMAX =   510.69   ********     493.30
 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                   WS,QBO,QRD =   496.62         0.      3580.
 ===280 REJECTED FLOW CLASS 4 SOLUTION.
 ===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      22.     0.     166.  1.32 *****  494.62  489.30   1524.  493.30
        0. ******    25.   12566.  1.00 ***** *******    0.63    9.20

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       2. ****   5.  0.481  0.000  493.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      21.    50.  0.03  0.07  495.72    0.00   2047.  495.29

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   2047.   230.  -304.   -74.   2.1   1.6   6.5   5.5   2.0   3.0
   RT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****

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

APPRO:AS      25.  -304.    1743.  0.07  0.11  495.75  492.08   3580.  495.68
       67.    32.    90.  150665.  1.07  0.00    0.00    0.18    2.05

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********
                       <<<<<END OF BRIDGE COMPUTATIONS>>>>>

   FIRST USER DEFINED TABLE.
     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS     -22.  -287.    45.   3580.   39287.     671.    5.33  491.12
    FULLV:FV       0.  -288.    45.   3580.   43504.     721.    4.97  491.37
    BRIDG:BR       0.     0.    25.   1524.   12566.     166.    9.20  493.30
    RDWAY:RG      21.******* 2047.   2047.*********       0.    2.00  495.29
    APPRO:AS      67.  -304.    90.   3580.  150665.    1743.    2.05  495.68

  SECOND USER DEFINED TABLE.
     XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
    EXITX:XS    490.89    0.73  484.00  517.55************  0.53  491.65  491.12
    FULLV:FV  ********    0.64  484.10  517.65  0.16  0.00  0.45  491.82  491.37
    BRIDG:BR    489.30    0.63  483.64  493.30************  1.32  494.62  493.30
    RDWAY:RG  ****************  493.15  542.61  0.03******  0.07  495.72  495.29
    APPRO:AS    492.08    0.18  484.37  510.69  0.11  0.00  0.07  495.75  495.68
```

```
        U.S. Geological Survey WSPRO Input File read029.wsp
        Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
        TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
           *** RUN DATE & TIME: 03-16-98  11:13

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

EXITX:XS   ******     0.     172.  0.53 *****  489.85  487.68   1000.  489.33
      -22. ******    43.   10971.  1.00 ***** *******    0.51    5.82

FULLV:FV      22.     0.     177.  0.50  0.18  490.04 *******   1000.  489.54
        0.    22.    43.   11445.  1.00  0.00    0.01    0.49    5.65
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      67.     1.     210.  0.38  0.45  490.49 *******   1000.  490.11
       67.    67.    62.   12932.  1.07  0.00    0.00    0.47    4.76
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   493.18       0.00     488.20     493.15

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

            <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

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

BRIDG:BR      22.     0.      88.  2.96  0.31  491.16  488.03   1000.  488.20
        0.    22.    25.    6391.  1.47  0.99   -0.01    1.13   11.39

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       2. ****   4.  0.826 ******  493.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      21.        <<<<<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      25.  -239.     796.  0.03  0.09  493.21  488.40   1000.  493.18
       67.    30.    82.   51732.  1.33  1.97    0.02    0.16    1.26

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.598  0.600   20523.     9.    34. ********

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -22.     0.    43.   1000.   10971.     172.    5.82  489.33
   FULLV:FV       0.     0.    43.   1000.   11445.     177.    5.65  489.54
   BRIDG:BR       0.     0.    25.   1000.    6391.      88.   11.39  488.20
   RDWAY:RG      21.**************      0.       0.       0.    2.00********
   APPRO:AS      67.  -239.    82.   1000.   51732.     796.    1.26  493.18

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       9.    34.   20523.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    487.68    0.51  484.00  517.55************  0.53  489.85  489.33
   FULLV:FV  ********    0.49  484.10  517.65  0.18  0.00  0.50  490.04  489.54
   BRIDG:BR    488.03    1.13  483.64  493.30  0.31  0.99  2.96  491.16  488.20
   RDWAY:RG  ****************  493.15  542.61  0.02******  0.03  493.20********
   APPRO:AS    488.40    0.16  484.37  510.69  0.09  1.97  0.03  493.21  493.18
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C: Bed material particle size distribution for a pebble count in the channel approach of structure READTH00510029, in Reading, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number READTH00510029

General Location Descriptive

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

Date (MM/DD/YY) 03 / 08 / 95

Highway District Number (I - 2; nn) 04

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

Town (FIPS place code; I - 4; nnnnn) 58375

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

Waterway (I - 6) MILL BROOK

Road Name (I - 7): -

Route Number TH051

Vicinity (I - 9) 0.06 MI TO JCT W VT106

Topographic Map Cavendish

Hydrologic Unit Code: 01080104

Latitude (I - 16; nnnn.n) 43292

Longitude (i - 17; nnnnn.n) 72332

Select Federal Inventory Codes

FHWA Structure Number (I - 8) 10141400291414

Maintenance responsibility (I - 21; nn) 03

Maximum span length (I - 48; nnnn) 0025

Year built (I - 27; YYYY) 1963

Structure length (I - 49; nnnnnn) 000027

Average daily traffic, ADT (I - 29; nnnnnn) 000040

Deck Width (I - 52; nn.n) 000

Year of ADT (I - 30; YY) 91

Channel & Protection (I - 61; n) 6

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

Waterway adequacy (I - 71; n) 7

Operational status (I - 41; X) A

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

Structure type (I - 43; nnn) 319

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) 9.0

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

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

Comments:

The structural inspection report of 9/10/93 indicates the structure is a multi-plate arch culvert. Both concrete abutment footings are exposed at the surface. At the upstream end of the left abutment footing there is a deep scour hole. The footing at the left abutment may be slightly undermined. There is large boulder fill in this area for protection. The waterway is noted as “somewhat poorly aligned” with the structure. The flow is directed into the upstream end of the left abutment and then deflected into the downstream end of the right abutment. The streambed material is composed of mainly stone and gravel. There is a point bar noted on the left bank just downstream of the structure. Road embankment erosion and settlement are indicated in the report as not evident. The culvert has mitered openings.

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: Stones and gravel

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)* 9.56 mi^2 Lake/pond/swamp area 0.01 mi^2
Watershed storage *(ST)* 0.1 %
Bridge site elevation 940 ft Headwater elevation 2290 ft
Main channel length 5.53 mi
10% channel length elevation 980 ft 85% channel length elevation 1880 ft
Main channel slope *(S)* 227.61 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? Y *If no, type ctrl-n pl* Date issued for construction *(MM / YYYY)*: 04 / 1963

Project Number TF 7/1962 Minimum channel bed elevation: 475.5

Low superstructure elevation: USLAB 477.12 DSLAB 476.52 USRAB 477.04 DSRAB 476.44

Benchmark location description:

BM#1, Spike in root of an 18 inch elm tree, located about 75 feet right bankward from the right abutment on the roadway and about 15 feet from the roadway centerline upstream, elevation 500.0 feet.

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

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

If 1: Footing Thickness 5.0 Footing bottom elevation: 471.79*

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? Y *If no, type ctrl-n bi* Number of borings taken: 4

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

Briefly describe material at foundation bottom elevation or around piles:

The footings are set in a dense to very dense sand with some gravel and silt.

Comments:

The low superstructure elevations given are for the tops of the concrete footings. The plans showed the channel was to be excavated and leveled at 476.1 ft at the upstream end and 475.5 ft at the downstream end with a 1% grade or slope.

***The upstream footing bottom elevation is 472.09 ft and the downstream end is at an elevation of 471.48 ft.**

Cross-sectional Data

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

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

Comments: **Upstream arch face channel cross section. *Point of contact where the steel arch meets the concrete footing.**

Station	-12.5	-12.5	-7.5	+2.5	+5.5	+12.5	+12.5	-	-	-	-
Feature	footing bottom	LCL*	-	-	-	LCR*	footing bottom	-	-	-	-
Low chord elevation		476.6	-	-	-	476.6		-	-	-	-
Bed elevation	472	475.3	474.7	475.5	476.0	476.0	472.0	-	-	-	-
Low chord to bed	-	-	-	-	-	-	-	-	-	-	-

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

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

Comments: **Downstream arch face channel cross section. *Point of contact where the steel arch meets the concrete footing.**

Station	-12.5	-12.5	+2.5	+12.5	+12.5	-	-	-	-	-	-
Feature	footing bottom	LCL*	-	LCR*	footing bottom	-	-	-	-	-	-
Low chord elevation		476.2	-	476.2		-	-	-	-	-	-
Bed elevation	471.5	475.7	475.6	475.5	471.5	-	-	-	-	-	-
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: MS Date: 6/26/97
Computerized by: MS Date: 6/26/97
Reviewd by: RLB Date: 3/30/98

Structure Number READTH00510029

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* M. WEBER Date *(MM/DD/YY)* 3 / 29 / 1995
2. Highway District Number 04 Mile marker 000000
County WINDSOR (027) Town READING (58375)
Waterway *(I - 6)* MILL BROOK Road Name AGONY HILL ROAD
Route Number TH051 Hydrologic Unit Code: 01080104
3. Descriptive comments:
This structure is a multi-plate arch culvert. It is located 0.06 miles from the junction with VT 106.

B. Bridge Deck Observations

4. Surface cover... LBUS 4 RBUS 4 LBDS 4 RBDS 6 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 1 DS 2 *(**1**- pool; **2**- riffle)*
6. Bridge structure type 7 *(**1**- single span; **2**- multiple span; **3**- single arch; **4**- multiple arch; **5**- cylindrical culvert; **6**- box culvert; or **7**- other)*
7. Bridge length 27 *(feet)* Span length 25 *(feet)* Bridge width -- *(feet)*

Road approach to bridge:

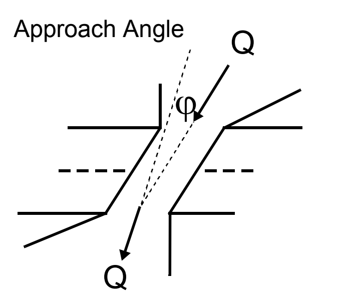
8. LB 1 RB 2 *(**0** even, **1**- lower, **2**- higher)*
9. LB 2 RB 2 *(**1**- Paved, **2**- Not paved)*
10. Embankment slope (*run / rise in feet / foot*):
US left -- US right --

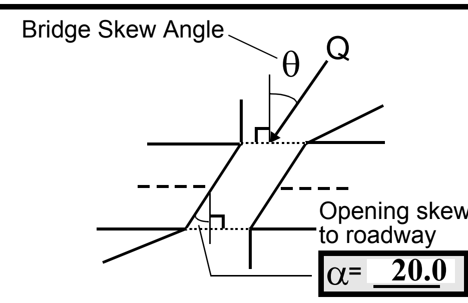
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	0	-	1	2
RBUS	0	-	0	0
RBDS	0	-	0	0
LBDS	0	-	0	0

*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: 15 16. Bridge skew: 30



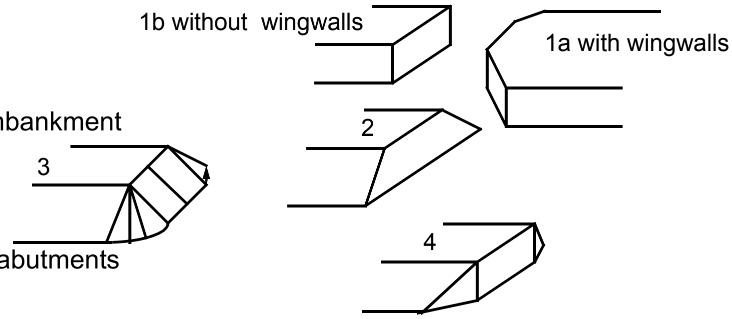


17. Channel impact zone 1: Exist? Y *(Y or N)*
Where? LB *(LB, RB)* Severity 2
Range? 5 feet US *(US, UB, DS)* to 50 feet US
Channel impact zone 2: Exist? Y *(Y or N)*
Where? RB *(LB, RB)* Severity 3
Range? 75 feet DS *(US, UB, DS)* to 100 feet DS

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

18. Bridge Type: 2

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 immediate banks US are shrub and brushland, with pasture on the overbanks. On the RBUS, there is a house about 150 feet from the culvert with some trees between the pasture and this house. The immediate banks DS have trees and the RBDS is forested with a house about 150 feet from the culvert.
6. The structure is described as a "multi-plate arch culvert" accoriding to the historical form.
7. The measured culvert width is 24 feet at the bottom; 27 feet including footing widths. The top length is 40.5 feet and the bottom length is 60.5 feet. The roadway width is 17.5 feet, of which 14 feet is dirt road and the rest is the narrow shoulders.
15 and 16. The ambient channel meanders. The approach and skew angles were taken using estimates of bank full flow immediately US and DS of the culvert. VTAOT lists no opening skew to roadway, but it was measured at 20 degrees.
17. The US impact is at the US left culvert corner. There is a cut bank here and some of the stones set on the US left side of the culvert have slumped.

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
33.0	3.5			1.5	2	1	23	235	2	3

23. Bank width 50.0 24. Channel width 10.0 25. Thalweg depth 35.5 29. Bed Material 32

30 .Bank protection type: LB 0 RB 0 31. 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*

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

27. The bank material is sand and gravel with occasional boulders on the RB.
29. The bed material is gravel and sand.
All US distances are measured from the US culvert face, which is about 12 feet US from the US edge of the road and about 10 feet DS of the US right and left culvert ends.

33. Point/Side bar present? **Y** (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: **40** 35. Mid-bar width: **7**

36. Point bar extent: **0** feet **US** (US, UB) to **70** feet **US** (US, UB, DS) positioned **80** %LB to **100** %RB

37. Material: **2**

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

Point bar material is sand and gravel. Some shrubs are growing on the bar.

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

41. Mid-bank distance: **5** 42. Cut bank extent: **5** feet **US** (US, UB) to **50** feet **US** (US, UB, DS)

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

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

The greatest damage is up against the stone embankment on the left side of the culvert. Some stones have slumped.

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.):

Local scour exists at the upstream end of the culvert. The upstream left culvert footing is threatened.

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)		57 Angle (BF)		61. Material (BF)		62. Erosion (BF)	
LB	RB	LB	RB	LB	RB	LB	RB
25.5		0.5		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.):

3

The culvert is a corrugated, galvanized steel arch with stone fill around the arch perimeter, including the sides above the concrete footings.

63. The bed material is sand in the US scoured area and gravel and sand elsewhere.

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

67. Debris Potential 1____ (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:

1

There is a large bank failure DS with trees lying in the stream. There are some small sticks at the US right culvert corner, but nothing substantial. The stream meanders in a wide floodplain and although the US reach is a riffle, the culvert is not in the uplands. Lateral movement could cause trees to fall into the stream. The culvert will block some of the bank full flow and the low sides may trap debris.

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		-	50	2	2	3	4.5	90.0
RABUT	3/1	15	50			2	2	-

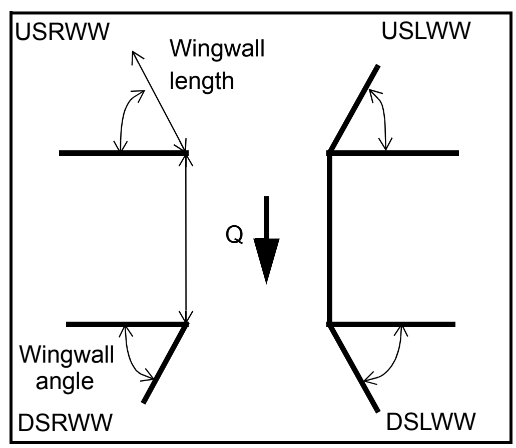
Pushed: LB or RB *Toe Location (Loc.): 0- even, 1- set back, 2- protrudes*
Scour cond.: 0- not evident; 1- evident (comment); 2- footing exposed; 3-undermined footing; 4- piling exposed; 5- settled; 6- failed
Materials: *1*- Concrete; *2*- Stone masonry or drywall; *3*- steel or metal; *4*- wood

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

1
2
3/1
There is a scour hole at the US face; maximum scour is 3 feet deep (4 feet total water depth) at 5 feet US. The scour extends 15 feet US to 10 feet under the culvert and is a maximum of 13 feet wide at 0 feet US.
77. The material of the abutments (sides of the culvert) is corrugated, galvanized steel and concrete footings. The thalweg moves from the scour hole at the US left culvert corner to follow the right culvert footing.

80. Wingwalls:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						24.7	
USRWW:	N		-		-	1.0	
DSLWW:	-		-		N	61.0	
DSRWW:	-		-		-	61.0	



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	-	-	N	-	-	-	2	1
Condition	N	-	-	-	-	-	4	4
Extent	-	-	-	-	-	2	2	-

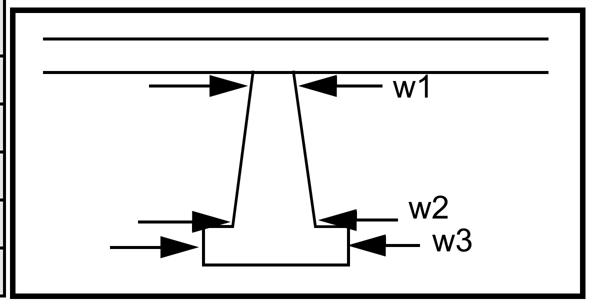
Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other

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 is	the	fill is	the	LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP
87. Type	stone	cul-	not	cul-	1- Solid pier, 2- column, 3- bent
88. Material	fill at	vert	in	vert	1- Wood; 2- concrete; 3- metal; 4- stone
89. Shape	the	on	the	wher	1- Round; 2- Square; 3- Pointed
90. Inclined?	upst	the	chan	e the	Y- yes; N- no
91. Attack ∠ (BF)	ream	left	nel,	cul-	
92. Pushed	and	and	but	vert	LB or RB
93. Length (feet)	-	-	-	-	
94. # of piles	dow	right	is	meet	
95. Cross-members	nstre	sides	piled	s the	0- none; 1- laterals; 2- diagonals; 3- both
96. Scour Condition	am	.	on	bank	0- not evident; 1- evident (comment); 2- footing exposed; 3- piling exposed; 4- undermined footing; 5- settled; 6- failed
97. Scour depth	ends	This	top	. In	
98. Exposure depth	of	stone	of	addi-	

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

tion, there is some stone fill in the channel at the upstream left end of the culvert. The stone fill in that area has slumped from channel erosion.

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 - 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? - (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 4_____ Width 1_____ Depth: 1_____ Positioned 3____ %LB to 3____ %RB

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

3
0
0
-

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

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

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

Confluence comments (eg. confluence name):

both banks DS, especially on the right bank, exposing clay with gravel bank material. Where bank wasting is not occurring, the banks are silty. The bed material is gravel except in the scour hole downstream where clay

F. Geomorphic Channel Assessment

107. Stage of reach evolution wit____

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)*:

h gravel is exposed. Downstream measurements are made from the DS face of the culvert, which is 12 feet DS of the DS edge of the road and 10 feet US of the DS culvert corners.

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: READTH00510029 Town: READING
Road Number: TH 51 County: WINDSOR
Stream: MILL BROOK

Initials RLB Date: 3/16/98 Checked: EMB

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	2500	3580	1000
Main Channel Area, ft2	338	362	273
Left overbank area, ft2	891	1098	365
Right overbank area, ft2	248	284	158
Top width main channel, ft	36	36	36
Top width L overbank, ft	304	304	239
Top width R overbank, ft	52	54	46
D50 of channel, ft	0.2544	0.2544	0.2544
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	9.4	10.1	7.6
y1, average depth, LOB, ft	2.9	3.6	1.5
y1, average depth, ROB, ft	4.8	5.3	3.4
Total conveyance, approach	116818	150820	51720
Conveyance, main channel	35820	40213	25088
Conveyance, LOB	60294	85240	16029
Conveyance, ROB	20704	25367	10603
Percent discrepancy, conveyance	0.0000	0.0000	0.0000
Qm, discharge, MC, cfs	766.6	954.5	485.1
Ql, discharge, LOB, cfs	1290.3	2023.3	309.9
Qr, discharge, ROB, cfs	443.1	602.1	205.0
Vm, mean velocity MC, ft/s	2.3	2.6	1.8
Vl, mean velocity, LOB, ft/s	1.4	1.8	0.8
Vr, mean velocity, ROB, ft/s	1.8	2.1	1.3
Vc-m, crit. velocity, MC, ft/s	10.3	10.4	10.0
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	2500	3580	1000
(Q) discharge thru bridge, cfs	1370	1524	1000
Main channel conveyance	12566	12566	6394
Total conveyance	12566	12566	6394
Q2, bridge MC discharge,cfs	1370	1524	1000
Main channel area, ft2	166	166	88
Main channel width (normal), ft	23.2	23.2	23.2
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	23.2	23.2	23.2
y_bridge (avg. depth at br.), ft	7.14	7.14	3.78
Dm, median (1.25*D50), ft	0.318	0.318	0.318
y2, depth in contraction,ft	5.66	6.20	4.32
ys, scour depth (y2-ybridge), ft	-1.48	-0.94	**0.54**

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	2500	3580	1000
Q, thru bridge MC, cfs	1370	1524	1000
Vc, critical velocity, ft/s	10.32	10.44	9.96
Va, velocity MC approach, ft/s	2.27	2.64	1.78
Main channel width (normal), ft	23.2	23.2	23.2
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	23.2	23.2	23.2
qbr, unit discharge, ft2/s	59.1	65.7	43.1
Area of full opening, ft2	165.7	165.7	87.8
Hb, depth of full opening, ft	7.14	7.14	3.78
Fr, Froude number, bridge MC	0.56	0.63	0
Cf, Fr correction factor (<=1.0)	1.00	1.00	0.00
**Area at downstream face, ft2	134	141	N/A
**Hb, depth at downstream face, ft	5.78	6.08	N/A
**Fr, Froude number at DS face	0.75	0.77	ERR
**Cf, for downstream face (<=1.0)	1.00	1.00	N/A
Elevation of Low Steel, ft	493.3	493.3	0

Elevation of Bed, ft	486.16	486.16	-3.78
Elevation of Approach, ft	495	495.68	0
Friction loss, approach, ft	0.08	0.11	0
Elevation of WS immediately US, ft	494.92	495.57	0.00
ya, depth immediately US, ft	8.76	9.41	3.78
Mean elevation of deck, ft	500.91	500.91	0
w, depth of overflow, ft (>=0)	0.00	0.00	0.00
Cc, vert contrac correction (<=1.0)	0.95	0.93	1.00
**Cc, for downstream face (<=1.0)	0.889587	0.88258	ERR
Ys, scour w/Chang equation, ft	**-1.12**	**-0.38**	N/A
Ys, scour w/Umbrell equation, ft	-3.27	-2.62	N/A

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

**Ys, scour w/Chang equation, ft	0.66	1.05	N/A
**Ys, scour w/Umbrell equation, ft	-1.90	-1.55	ERR

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	5.66	6.20	4.32
WSEL at downstream face, ft	490.92	491.37	--
Depth at downstream face, ft	5.78	6.08	N/A
Ys, depth of scour (Laursen), ft	-0.11	0.13	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)

(Federal Highway Administration, 1993)

Downstream bridge face property	100-yr	500-yr	Other Q
Q, discharge thru bridge MC, cfs	1370	1524	1000
Main channel area (DS), ft2	134	141	87.8
Main channel width (normal), ft	23.2	23.2	23.2
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	23.2	23.2	23.2
D90, ft	0.5081	0.5081	0.5081
D95, ft	0.5645	0.5645	0.5645
Dc, critical grain size, ft	0.4333	0.4744	0.6431
Pc, Decimal percent coarser than Dc	0.176	0.133	0.026
Depth to armoring, ft	**6.09**	**9.28**	**N/A**

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	2500	3580	1000	2500	3580	1000
a', abut.length blocking flow, ft	234.8	234.8	240	63.9	65.6	57.7

Ae, area of blocked flow ft2	618.12	703.14	378.02	357.22	401.51	245.65
Qe, discharge blocked abut.,cfs	--	--	321.74	697.5	917.38	365
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	1.45	1.84	0.85	1.95	2.28	1.49
ya, depth of f/p flow, ft	2.63	2.99	1.58	5.59	6.12	4.26
--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	70	70	70	110	110	110
K2	0.97	0.97	0.97	1.03	1.03	1.03
Fr, froude number f/p flow	0.148	0.170	0.120	0.146	0.163	0.127
ys, scour depth, ft	15.07	17.56	9.80	**17.05**	**19.19**	**12.89**

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)	234.8	234.8	240	63.9	65.6	57.7
y1 (depth f/p flow, ft)	2.63	2.99	1.58	5.59	6.12	4.26
a'/y1	89.19	78.41	152.37	11.43	10.72	13.55
Skew correction (p. 49, fig. 16)	0.93	0.93	0.93	1.04	1.04	1.04
Froude no. f/p flow	0.15	0.17	0.12	0.15	0.16	0.13
Ys w/ corr. factor K1/0.55:						
vertical	**9.51**	**11.32**	**5.30**	ERR	ERR	ERR
vertical w/ ww's	7.80	9.29	4.35	ERR	ERR	ERR
spill-through	5.23	6.23	2.92	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	0.75	0.77	1.13	0.75	0.77	1.13
y, depth of flow in bridge, ft	5.78	6.08	3.78	5.78	6.08	3.78
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	**2.01**	**2.23**	ERR	**2.01**	**2.23**	ERR
Fr>0.8 (vertical abut.)	ERR	ERR	**1.64**	ERR	ERR	**1.64**