LEVEL II SCOUR ANALYSIS FOR BRIDGE 25 (ANDOTH00230025) on TOWN HIGHWAY 23, crossing the ANDOVER BRANCH, ANDOVER, VERMONT

U.S. Geological Survey
Open-File Report 97-372

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 25 (ANDOTH00230025) on TOWN HIGHWAY 23, crossing the ANDOVER BRANCH, ANDOVER, VERMONT

By ROBERT H. FLYNN AND RONDA L. BURNS

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Pembroke, New Hampshire

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

U.S. GEOLOGICAL SURVEY
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Denver, CO 80225-0286

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Velocity and Flow	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

OTHER ABBREVIATIONS

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

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

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

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 25 (ANDOTH00230025) ON TOWN HIGHWAY 23, CROSSING THE ANDOVER BRANCH, ANDOVER, VERMONT

By **Robert H. Flynn and Ronda L. Burns**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure ANDOTH00230025 on Town Highway 23 crossing the Andover Branch, Andover, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). Results of a Level I scour investigation also are included in Appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the bridge, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in Appendix D.

The site is in the Green Mountain section of the New England physiographic province in south-central Vermont. The 6.74-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is pasture on the right overbank and forest on the left overbank while the immediate banks, both upstream and downstream, are forested.

In the study area, the Andover Branch has an incised, sinuous channel with a slope of approximately 0.02 ft/ft, an average channel top width of 55 ft and an average bank height of 9 ft. The channel bed material ranges from gravel to boulder with a median grain size (D_{50}) of 78.4 mm (0.257 ft). The geomorphic assessment at the time of the Level I and Level II site visit on August 27, 1996, indicated that the reach was stable.

The Town Highway 23 crossing of the Andover Branch is a 25-ft-long, two-lane structure consisting of a multi-plate corrugated steel arch culvert with concrete footings (Vermont Agency of Transportation, written communication, March 29, 1995). The culvert is mitered at the inlet and outlet. The channel is skewed approximately zero degrees to the opening while the opening-skew-to-roadway is zero degrees.

The footings are exposed approximately 1.25 ft, with the exception of the downstream end of the right footing which is exposed approximately 0.5 ft. The only scour protection measure at the site was type-2 stone fill (less than 36 inches diameter) along the upstream left bank. 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 others, 1995). 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 modelled flows ranged from 1.6 to 2.8 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 10.0 to 11.7 ft along the left footing and from 11.8 to 16.7 along the right footing. The worst-case abutment scour occurred at the 500-year discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and others, 1995, p. 47). 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.

Andover, 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 ANDOTH00230025 ***Stream*** Andover Branch

County Windsor ***Road*** TH23 ***District*** 2

Description of Bridge

Bridge length 25 ***ft*** ***Bridge width*** 24 ***ft*** ***Max span length*** 23 ***ft***

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

Abutment type Steel arch culvert ***Embankment type*** Sloping

Stone fill on abutment? No ***Date of inspection*** 8/27/96

Description of stone fill Type-2, along the upstream left bank. No stone fill along concrete footings.

.

Brief description of piers/abutments Structure is a multi-plate steel arch culvert with concrete footings.

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

There is a mild channel bend in the upstream and downstream reach but, the bends are greater than 100 feet away from the site..

Debris accumulation on bridge at time of Level I or Level II site visit:

	Date of inspection	*Percent of channel blocked horizontally*	*Percent of channel blocked vertically*
Level I	8/27/96	0	0
Level II	8/27/96	0	0

Potential for debris Moderate. There is some debris caught along the upstream and downstream banks.

Describe any features near or at the bridge that may affect flow (include observation date) There is a point bar, noted on 8/27/96, along the upstream right bank and along the downstream end of the right footing.

Description of the Geomorphic Setting

General topography The channel is located in a moderate relief valley setting with a narrow to slightly irregular flood plain and steep valley walls on both sides.

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

Date of inspection 8/27/96

DS left: Moderately sloped channel bank to the valley wall.

DS right: Moderately sloped channel bank to a narrow overbank.

US left: Moderately sloped channel bank to the valley wall.

US right: Moderately sloped channel bank to a narrow overbank.

Description of the Channel

Average top width 55 ***ft*** ***Average depth*** 9 ***ft***

Predominant bed material Cobbles ***Bank material*** Sand to Boulders

Sinuous but stable with semi-alluvial channel boundaries and a narrow flood plain.

8/27/96

Vegetative co Trees and brush.

DS left: Trees and brush.

DS right: Trees and brush.

US left: Trees and brush.

US right:

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

The assessment of 8/27/96 noted side bars along the upstream right bank and downstream end of the right footing.

Describe any obstructions in channel and date of observation.

In addition, some debris is caught on trees and boulders along the upstream channel banks.

Hydrology

Drainage area 6.74 ***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 1,730 ***ft³/s*** ***Q500*** 2,500 ***ft³/s***

The 100- and 500-year discharges are based on flood frequency estimates available from the VTAOT database. These values were selected due to the central tendency of the discharge frequency curve with others which were computed by use of empirical relationships and graphically extrapolated to the 500-year discharge (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887).

Description of the Water-Surface Profile Model (WSPRO) Analysis

Datum for WSPRO analysis (USGS survey, sea level, VTAOT plans) USGS survey

Datum tie between USGS survey and VTAOT plans None

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on top of a boulder located 10 ft upstream from the upstream left bank end of the guard rail (elev. 505.15 ft, arbitrary survey datum). RM2 is a nail located 6 ft above the ground in the west side of a 1.0 ft diameter tree on the downstream right overbank approximately 20 ft east of the edge of road and 50 ft north of the centerline of the culvert (elev. 494.55 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	-16	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	29	1	Road Grade section
APTEM	64	1	Approach section as surveyed (Used as a template)
APPRO	78	2	Modelled Approach section (Templated from APTEM)

[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. For all modelled flows, the bridge was also modelled as a culvert for comparison to the bridge routines. Results of the culvert routines yielded similar upstream water surface elevations as those computed by WSPRO. The culvert routines indicated that normal depths are 4.1 to 5.6 feet above critical depths within the constriction and it is assumed that convergence to this normal depth is possible within the structure.

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 0.040 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 0.018 ft/ft, which was estimated from the topographic map (U.S. Geological Survey, 1971).

The surveyed approach section (APTEM) was moved along the approach channel slope (0.014 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This location also provides a consistent method for determining scour variables.

For the 100- and 500-year discharge, WSPRO assumes critical depth at the bridge section. Supercritical models were developed for these discharges. After analyzing both the supercritical and subcritical profiles for each discharge, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumptions of critical depth at the bridge are satisfactory solutions.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.9 *ft*
Average low steel elevation 497.2 *ft*

100-year discharge 1,730 *ft³/s*
Water-surface elevation in bridge opening 489.3 *ft*
Road overtopping? No *Discharge over road* - *ft³/s*
Area of flow in bridge opening 124 *ft²*
Average velocity in bridge opening 13.9 *ft/s*
Maximum WSPRO tube velocity at bridge 17.0 *ft/s*

Water-surface elevation at Approach section with bridge 493.6
Water-surface elevation at Approach section without bridge 490.9
Amount of backwater caused by bridge 2.7 *ft*

500-year discharge 2,500 *ft³/s*
Water-surface elevation in bridge opening 490.9 *ft*
Road overtopping? No *Discharge over road* - *ft³/s*
Area of flow in bridge opening 157 *ft²*
Average velocity in bridge opening 16.0 *ft/s*
Maximum WSPRO tube velocity at bridge 20.2 *ft/s*

Water-surface elevation at Approach section with bridge 497.8
Water-surface elevation at Approach section without bridge 492.2
Amount of backwater caused by bridge 5.6 *ft*

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

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

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

Scour depths were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analysis are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1995, p. 32, equation 20). The 100- and 500-year discharge models resulted in free-surface flow through the bridge with no road overflow. In this case, the 500-year discharge model resulted in the worst case contraction scour.

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

Scour Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	--	--
Clear-water scour	1.6	2.8	--
Depth to armoring	N/A N/	A --	--
Left overbank	--	--	--
Right overbank	--	--	10.0

Local scour:			
Abutment scour	11.7	--	11.8
Left abutment	16.7–	---	---
Right abutment			
Pier scour	--	--	--
Pier 1	--	--	--
Pier 2	--	--	2.4
Pier 3			

Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:	3.1	--	2.4
Left abutment	3.1	--	--
Right abutment	--	--	--
Piers:	--	--	--
Pier 1	--	--	
Pier 2			

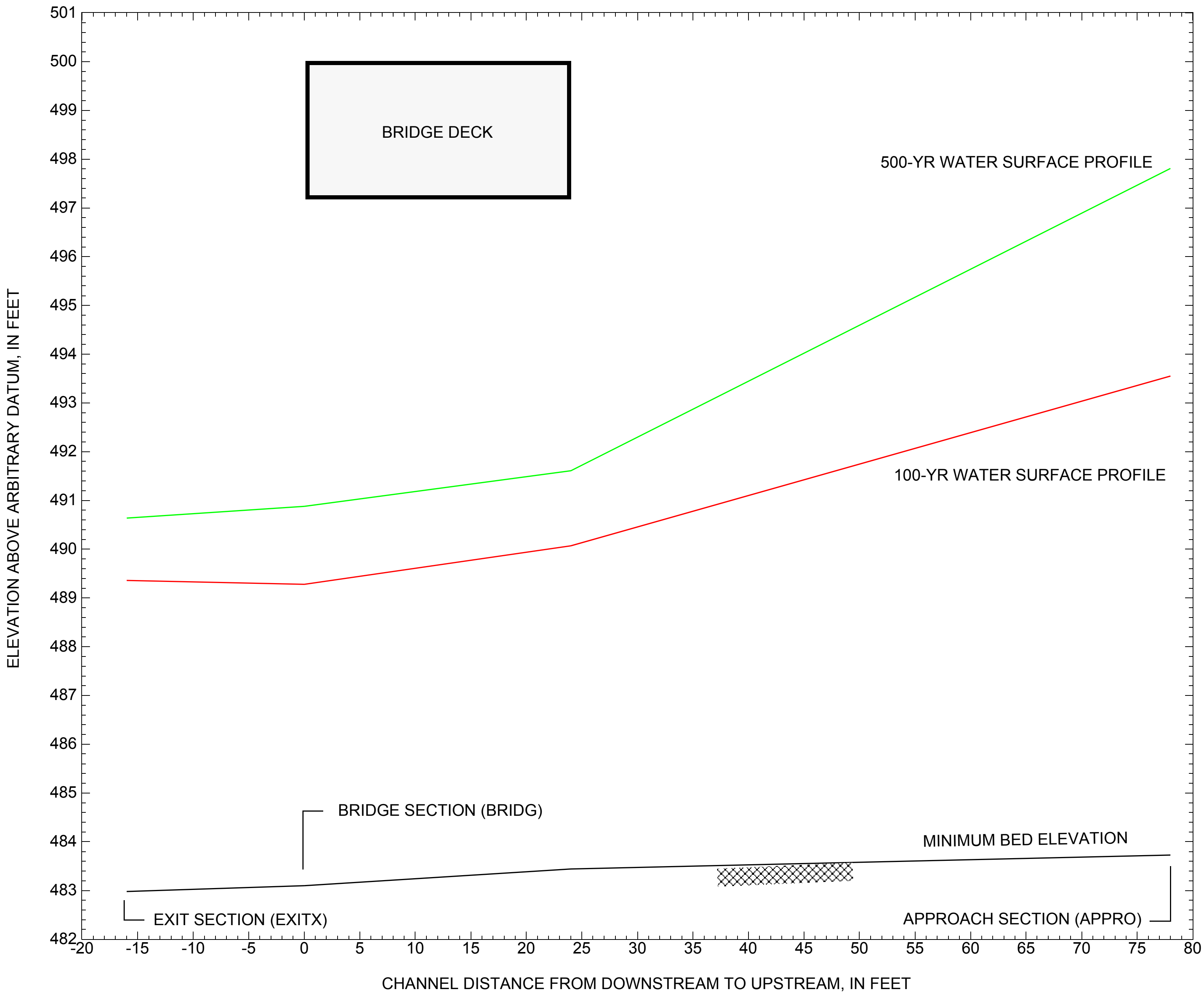

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure ANDOTH00230025 on Town Highway 23, crossing Andover Branch, Andover, Vermont.

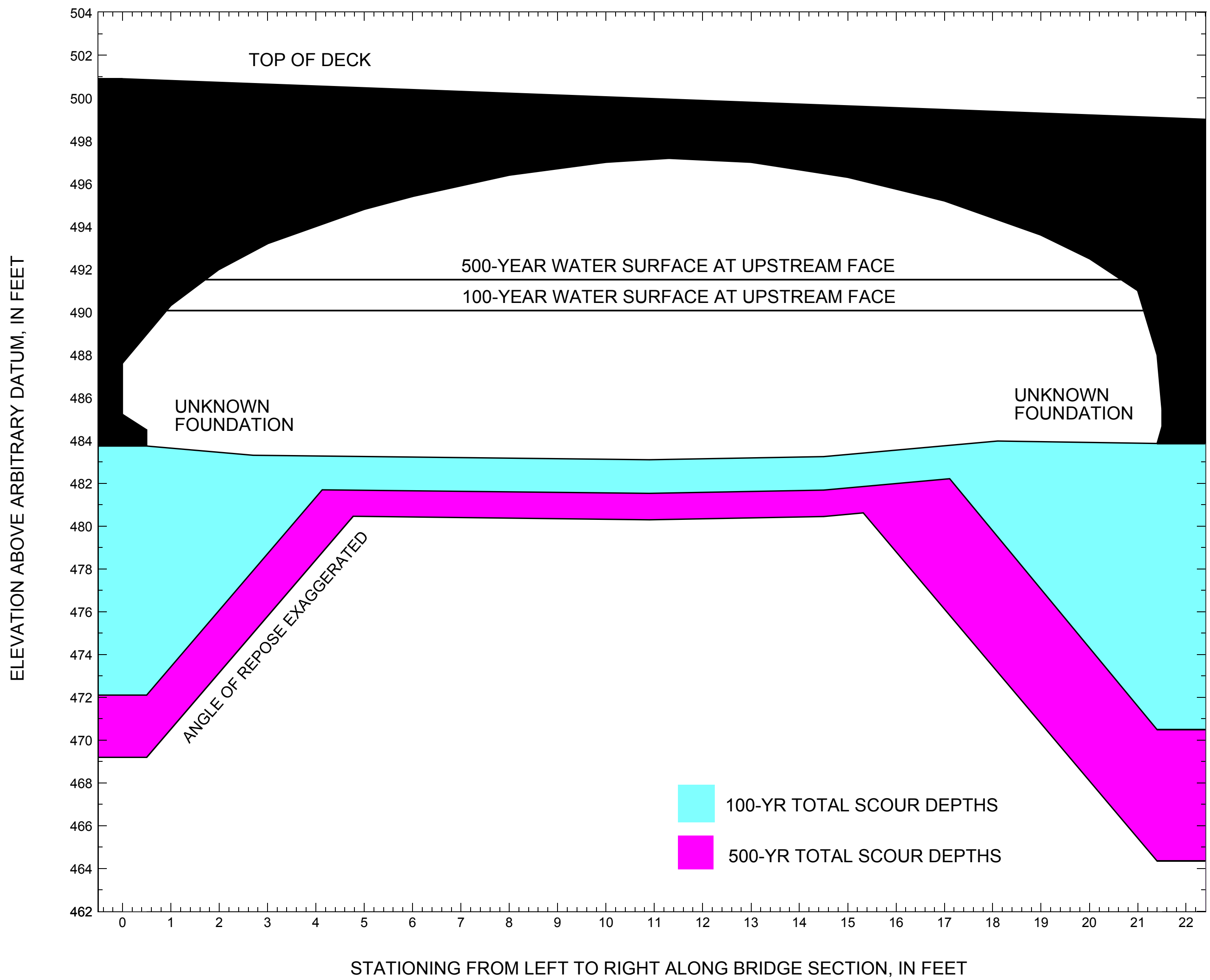

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure ANDOTH00230025 on Town Highway 23, crossing Andover Branch, Andover, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure ANDOTH00230025 on Town Highway 23, crossing Andover Branch, Andover, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 1,730 cubic-feet per second											
Left abutment	0.5	--	--	--	483.7	1.6	10.0	--	11.6	472.1	--
Right abutment	21.4	--	--	--	483.9	1.6	11.8	--	13.4	470.5	--

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 ANDOTH00230025 on Town Highway 23, crossing Andover Branch, Andover, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 2,500 cubic-feet per second											
Left abutment	0.5	--	--	--	483.7	2.8	11.7	--	14.5	469.2	--
Right abutment	21.4	--	--	--	483.9	2.8	16.7	--	19.5	464.4	--

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

SELECTED REFERENCES

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Benson, M. A., 1962, Factors Influencing the Occurrence of Floods in a Humid Region of Diverse Terrain: U.S. Geological Survey Water-Supply Paper 1580-B, 64 p.

Brown, S.A. and Clyde, E.S., 1989, Design of riprap revetment: Federal Highway Administration Hydraulic Engineering Circular No. 11, Publication FHWA-IP-89-016, 156 p.

Federal Highway Administration, 1983, Runoff estimates for small watersheds and development of sound design: Federal Highway Administration Report FHWA-RD-77-158.

Federal Highway Administration, 1993, Stream Stability and Scour at Highway Bridges: Participant Workbook: Federal Highway Administration Report FHWA-HI-91-011.

Froehlich, D.C., 1989, Local scour at bridge abutments *in* Ports, M.A., ed., Hydraulic Engineering--Proceedings of the 1989 National Conference on Hydraulic Engineering: New York, American Society of Civil Engineers, p. 13-18.

Hayes, D.C.,1993, Site selection and collection of bridge-scour data in Delaware, Maryland, and Virginia: U.S. Geological Survey Water-Resources Investigation Report 93-4017, 23 p.

Johnson, C.G. and Tasker, G.D.,1974, Progress report on flood magnitude and frequency of Vermont streams: U.S. Geological Survey Open-File Report 74-130, 37 p.

Lagasse, P.F., Schall, J.D., Johnson, F., Richardson, E.V., Chang, F., 1995, Stream Stability at Highway Structures: Federal Highway Administration Hydraulic Engineering Circular No. 20, Publication FHWA-IP-90-014, 144 p.

Laursen, E.M., 1960, Scour at bridge crossings: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 86, no. HY2, p. 39-53.

Potter, W. D., 1957a, Peak rates of runoff in the Adirondack, White Mountains, and Maine woods area, Bureau of Public Roads

Potter, W. D., 1957b, Peak rates of runoff in the New England Hill and Lowland area, Bureau of Public Roads

Richardson, E.V. and Davis, S.R., 1995, Evaluating scour at bridges: Federal Highway Administration Hydraulic Engineering Circular No. 18, Publication FHWA-IP-90-017, 204 p.

Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment: Federal Highway Administration Publication FHWA-HI-90-016.

Ritter, D.F., 1984, Process Geomorphology: W.C. Brown Co., Debuque, Iowa, 603 p.

Shearman, J.O., 1990, User's manual for WSPRO--a computer model for water surface profile computations: Federal Highway Administration Publication FHWA-IP-89-027, 187 p.

Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model; research report: Federal Highway Administration Publication FHWA-RD-86-108, 112 p.

Talbot, A.N., 1887, The determination of water-way for bridges and culverts.

U.S. Department of Transportation, 1993, Stream stability and scour at highway bridges, Participant Workbook: Federal Highway Administration Publication FHWA HI-91-011.

U.S. Geological Survey, 1971, Andover, 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 (continued)

```
T1        U.S. Geological Survey WSPRO Input File ando025.wsp
T2        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
T3        Bridge #25 over Andover Branch, Andover, VT. RHF
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           1730.0   2500.0
SK          0.018    0.018
*
XS   EXITX   -16             0.
GR         -169.9, 521.88    -77.2, 507.94    -44.3, 503.73    -21.2, 498.89
GR          -16.2, 494.02     -4.9, 486.06     -1.6, 485.23      0.0, 483.90
GR            3.6, 482.98     10.5, 483.12     18.0, 483.67     19.5, 483.86
GR           22.8, 484.27     28.8, 485.84     41.1, 494.11    180.6, 493.60
GR          197.9, 498.12    211.7, 503.43
*
N           0.050        0.060        0.050
SA                 -16.2         41.1
*
*
XS   FULLV      0  * * *   0.0071
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0     497.18    0.0
GR            0.0, 485.22      0.5, 484.49      0.5, 483.74       2.7, 483.31
GR           10.9, 483.10     14.5, 483.25     18.1, 483.98      21.4, 483.86
GR           21.5, 484.66     21.5, 485.46
GR           21.4, 488.00     21.0, 491.00     20.0, 492.5       19.0, 493.60
GR           18.0, 494.40     17.0, 495.20     15.0, 496.3       13.0, 497.0
GR           11.3, 497.18     10.0, 497.00      8.0, 496.4        6.0, 495.4
GR            5.0, 494.8       4.0, 494.0       3.0, 493.2        2.0, 492.0
GR            1.0, 490.3       0.0, 487.6       0.0, 485.22
*
*         BRTYPE  BRWDTH  EMBSS   EMBELV
CD           2     23.9    1.2    497.2
N           0.040
*
*
*             SRD    EMBWID   IPAVE
XR   RDWAY    29      21.8     2
GR         -316.0, 542.08   -138.8, 519.75    -23.2, 503.43      0.0, 500.90
GR           22.7, 498.98     87.3, 495.43    246.3, 504.61    270.5, 502.36
*
*
XT   APTEM   64
GR         -258.8, 533.83    -82.0, 509.90    -57.2, 507.52    -36.2, 505.45
GR          -16.4, 496.67      0.0, 485.32      2.1, 484.53     13.2, 484.27
GR           15.5, 483.88     17.4, 483.74     19.2, 483.73     19.9, 484.26
GR           22.7, 484.77     35.6, 493.81    173.7, 495.21    187.3, 508.40
*
AS   APPRO   78 * * * 0.014
GT
N           0.040        0.060        0.040
SA                 -16.4         35.6
*
HP 1 BRIDG   489.28 1 489.28
HP 2 BRIDG   489.28 * * 1730
HP 1 APPRO   493.55 1 493.55
HP 2 APPRO   493.55 * * 1730
*
HP 1 BRIDG   490.88 1 490.88
HP 2 BRIDG   490.88 * * 2500
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

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

        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     124.   11984.    21.    30.                        1734.
   489.28          124.   11984.    21.    30.  1.00     0.    22.   1734.

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       489.28     0.0    21.5   124.4   11984.    1730.  13.91

X STA.        0.0        2.0        3.1        4.1        5.0        5.8
  A(I)           10.2        6.3        5.9        5.5        5.3
  V(I)           8.45      13.64      14.70      15.72      16.38

X STA.        5.8        6.7        7.6        8.4        9.2       10.1
  A(I)            5.2        5.2        5.1        5.1        5.1
  V(I)          16.68      16.68      16.84      16.98      16.92

X STA.       10.1       10.9       11.7       12.6       13.5       14.4
  A(I)            5.2        5.1        5.4        5.4        5.5
  V(I)          16.79      16.81      16.14      16.06      15.59

X STA.       14.4       15.4       16.5       17.7       19.1       21.5
  A(I)            5.8        6.2        6.7        7.5       12.6
  V(I)          14.88      14.02      12.87      11.51       6.88



    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      78.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             2     304.   24493.    47.    52.                        4416.
   493.55          304.   24493.    47.    52.  1.00   -12.    35.   4416.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      78.

         WSEL     LEW     REW    AREA        K        Q    VEL
       493.55   -11.6    34.9   304.4   24493.    1730.   5.68

X STA.      -11.6       -2.7        0.0        1.8        3.4        5.0
  A(I)           27.6       18.7       15.7       14.0       13.6
  V(I)           3.13       4.64       5.51       6.19       6.35

X STA.        5.0        6.4        7.8        9.2       10.6       12.0
  A(I)           12.9       12.8       12.4       12.3       12.4
  V(I)           6.69       6.75       6.95       7.01       6.98

X STA.       12.0       13.3       14.7       16.0       17.3       18.6
  A(I)           12.2       12.4       12.4       12.5       12.7
  V(I)           7.10       6.98       6.99       6.93       6.81

X STA.       18.6       20.0       21.6       23.4       26.1       34.9
  A(I)           13.7       14.1       15.3       18.9       27.7
  V(I)           6.31       6.11       5.66       4.57       3.12
```

```
        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     157.  16395.    20.    33.                        2508.
   490.88          157.  16395.    20.    33.  1.00     0.    22.   2508.

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       490.88     0.0    21.5   156.7   16395.    2500.  15.96

X STA.        0.0        2.3        3.4        4.4        5.3        6.2
  A(I)            14.4        8.5        7.5        7.0        6.5
  V(I)            8.70      14.78      16.65      17.95      19.28

X STA.        6.2        7.1        7.9        8.7        9.5       10.3
  A(I)             6.6        6.2        6.3        6.2        6.2
  V(I)           18.92      20.18      19.96      20.15      20.09

X STA.       10.3       11.1       11.9       12.7       13.6       14.5
  A(I)             6.2        6.2        6.5        6.5        6.7
  V(I)           20.03      20.07      19.25      19.13      18.54

X STA.       14.5       15.4       16.4       17.6       19.0       21.5
  A(I)             7.1        7.6        8.4        9.4       16.7
  V(I)           17.64      16.48      14.97      13.30       7.47



    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      78.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       1.      21.     2.     2.                           4.
             2     518.  54833.    52.    59.                        9272.
             3     432.  33810.   141.   142.                        4292.
   497.81          950.  88664.   195.   203.  1.07   -19.   176.  11543.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      78.

         WSEL     LEW     REW    AREA        K        Q    VEL
       497.81   -18.5   176.2   950.5   88664.    2500.   2.63

X STA.      -18.5       -3.7        0.5        3.6        6.5        9.1
  A(I)            69.1       47.0       40.0       37.6       35.1
  V(I)            1.81       2.66       3.12       3.32       3.56

X STA.        9.1       11.7       14.3       16.8       19.2       21.9
  A(I)            34.5       34.6       34.2       33.2       36.1
  V(I)            3.62       3.61       3.65       3.76       3.47

X STA.       21.9       25.2       30.4       43.7       57.7       72.9
  A(I)            39.8       48.7       59.5       51.1       53.0
  V(I)            3.14       2.57       2.10       2.45       2.36

X STA.       72.9       88.8      106.7      126.2      148.5      176.2
  A(I)            53.3       56.7       58.4       61.7       66.9
  V(I)            2.35       2.20       2.14       2.03       1.87
```

```
        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31

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

EXITX:XS   ******   -10.     198.  1.19 *****  490.54  488.37   1730.  489.36
      -16. ******    34.   12883.  1.00 ***** *******    0.72    8.74

FULLV:FV      16.   -10.     211.  1.04  0.26  490.81 *******   1730.  489.77
        0.    16.    34.   14132.  1.00  0.00    0.01    0.66    8.19
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      78.    -8.     193.  1.26  1.27  492.19 *******   1730.  490.94
       78.    78.    31.   12983.  1.00  0.11    0.00    0.71    8.98
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                   SECID "BRIDG"     Q,CRWS =    1730.     489.28

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

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

BRIDG:BR      16.     0.     124.  3.43 *****  492.70  489.28   1730.  489.28
        0.    16.    22.   11974.  1.14 ***** *******    1.07   13.92

     TYPE PPCD FLOW      C     P/A    LSEL   BLEN   XLAB   XRAB
       2. ****   1.  0.938 ******  497.18 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      29.        <<<<<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      54.   -12.     304.  0.50  0.56  494.05  489.77   1730.  493.55
       78.    55.    35.   24494.  1.00  0.79    0.00    0.39    5.68

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.449  0.152   20771.     2.    23.   493.27

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V090192            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K      AREA     VEL    WSEL
   EXITX:XS     -16.   -10.    34.   1730.   12883.     198.    8.74  489.36
   FULLV:FV       0.   -10.    34.   1730.   14132.     211.    8.19  489.77
   BRIDG:BR       0.     0.    22.   1730.   11974.     124.   13.92  489.28
   RDWAY:RG      29.**************      0.*****************     2.00********
   APPRO:AS      78.   -12.    35.   1730.   24494.     304.    5.68  493.55

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       2.    23.   20771.

        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    488.37    0.72  482.98  521.88************  1.19  490.54  489.36
   FULLV:FV  ********    0.66  483.09  521.99  0.26  0.00  1.04  490.81  489.77
   BRIDG:BR    489.28    1.07  483.10  497.18************  3.43  492.70  489.28
   RDWAY:RG  ****************  495.43  542.08**********************************
   APPRO:AS    489.77    0.39  483.93  534.03  0.56  0.79  0.50  494.05  493.55
```

WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31

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

 EXITX:XS   ******   -11.     256.  1.48 *****  492.12  489.51   2500.  490.64
      -16. ******    36.   18620.  1.00 ***** *******    0.74    9.76

 FULLV:FV      16.   -12.     272.  1.32  0.27  492.39 *******   2500.  491.07
        0.    16.    36.   20212.  1.00  0.00    0.01    0.68    9.21
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPRO:AS      78.   -10.     246.  1.60  1.32  493.85 *******   2500.  492.25
       78.    78.    33.   18271.  1.00  0.14    0.00    0.75   10.16
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
  ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   497.81       0.00     490.88     495.43
  ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
  ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                   WS,QBO,QRD =   500.64         0.      2500.
  ===280 REJECTED FLOW CLASS 4 SOLUTION.
  ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.
  ===250 INSUFFICIENT HEAD FOR PRESSURE FLOW.
                        YU/Z,WSIU,WS = 1.10     498.30     498.40
  ===270 REJECTED 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      16.     0.     157.  6.07  0.33  496.96  483.30   2500.  490.88
        0.    16.    22.   16400.  1.53  1.56    0.00    1.23   15.96

     TYPE PPCD FLOW       C     P/A    LSEL   BLEN   XLAB   XRAB
       2. ****   1.  0.807 ******  497.18 ****** ****** ******

    XSID:CODE     SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      29.        <<<<<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      54.   -19.     950.  0.11  0.24  497.92  491.05   2500.  497.81
       78.    55.   176.   88652.  1.07  0.73    0.00    0.22    2.63

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.498  0.554   39540.     2.    23.   497.76

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31
   FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -16.   -11.    36.   2500.   18620.     256.    9.76  490.64
   FULLV:FV       0.   -12.    36.   2500.   20212.     272.    9.21  491.07
   BRIDG:BR       0.     0.    22.   2500.   16400.     157.   15.96  490.88
   RDWAY:RG      29.**************      0.       0.*********    2.00********
   APPRO:AS      78.   -19.   176.   2500.   88652.     950.    2.63  497.81

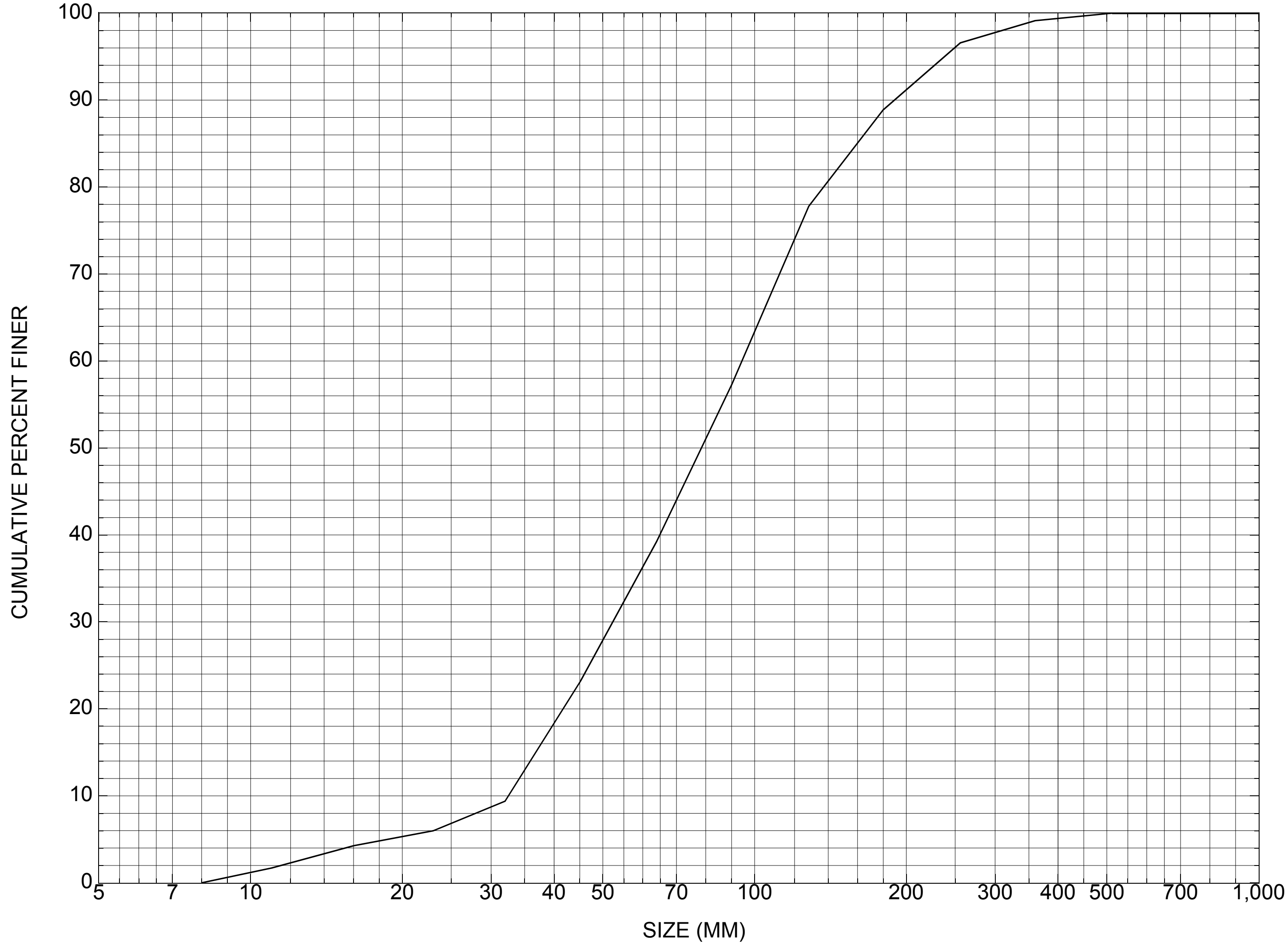
    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       2.    23.   39540.

        U.S. Geological Survey WSPRO Input File ando025.wsp
        Hydraulic analysis for structure ANDOTH00230025   Date: 04-MAR-97
        Bridge #25 over Andover Branch, Andover, VT. RHF
           *** RUN DATE & TIME: 04-10-97  09:31
  SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    489.51    0.74  482.98  521.88************  1.48  492.12  490.64
   FULLV:FV  ********    0.68  483.09  521.99  0.27  0.00  1.32  492.39  491.07
   BRIDG:BR    483.30    1.23  483.10  497.18  0.33  1.56  6.07  496.96  490.88
   RDWAY:RG  ****************  495.43  542.08************  0.09  498.46********
   APPRO:AS    491.05    0.22  483.93  534.03  0.24  0.73  0.11  497.92  497.81
   ER
1  NORMAL  END  OF  WSPRO  EXECUTION.
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure ANDOTH00230025, in Andover, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number ANDOTH00230025

General Location Descriptive

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

Date *(MM/DD/YY)* 03 / 29 / 95

Highway District Number *(I - 2; nn)* 02

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

Town *(FIPS place code; I - 4; nnnnn)* 01300

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

Waterway *(I - 6)* ANDOVER BRANCH

Road Name *(I - 7):* -

Route Number TH023

Vicinity *(I - 9)* 0.1 MI TO JCT W CL2 TH1

Topographic Map Andover

Hydrologic Unit Code: 01080107

Latitude *(I - 16; nnnn.n)* 43168

Longitude *(i - 17; nnnnn.n)* 72418

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 10140100251401

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

Maximum span length *(I - 48; nnnn)* 0023

Year built *(I - 27; YYYY)* 1962

Structure length *(I - 49; nnnnnn)* 000025

Average daily traffic, ADT *(I - 29; nnnnnn)* 000120

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

Year of ADT *(I - 30; YY)* 91

Channel & Protection *(I - 61; n)* 7

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*) 012.8

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

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

Comments:

The structural inspection report of 9/22/93 indicates the structure is a multi-plate steel arch type culvert. The concrete footings are exposed on both right and left and are reported in fairly good condition with no cracks or leaks. The waterway passes nearly straight through the crossing. The streambed consists of stone and gravel. Both ends of the arch have mitered sections. The report indicates that the north side (left side, looking downstream) mitered sections deflect inward excessively, restricting the waterway opening.

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)* 6.74 mi^2

Lake and pond area 0.01 mi^2

Watershed storage *(ST)* 0.1 %

Bridge site elevation 1120 ft

Headwater elevation 2860 ft

Main channel length 4.25 mi

10% channel length elevation 1180 ft

85% channel length elevation 2100 ft

Main channel slope *(S)* 288.70 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 cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

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

Comments: **NO CROSS SECTION INFORMATION**

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

APPENDIX E:

LEVEL I DATA FORM

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

Qa/Qc Check by: **EW** Date: **9/24/96**
Computerized by: **EW** Date: **9/25/96**
Reviewd by: **RF** Date: **4/09/97**

Structure Number **ANDOTH00230025**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **R. BURNS** Date *(MM/DD/YY)* **08** / **27** / 19**96**

2. Highway District Number **02** Mile marker **000000**

County **Windsor (027)** Town **Andover (01300)**

Waterway *(I - 6)* **Andover Branch** Road Name **Pettengill Road**

Route Number **TH023** Hydrologic Unit Code: **01080107**

3. Descriptive comments:

This structure is located 0.1 miles from the junction with CL2 TH1.

B. Bridge Deck Observations

4. Surface cover... LBUS **6** RBUS **4** LBDS **6** RBDS **4** Overall **6**
*(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 **3** *(**1**- single span; **2**- multiple span; **3**- single arch; **4**- multiple arch; **5**- cylindrical culvert; **6**- box culvert; or **7**- other)*

7. Bridge length **25** *(feet)* Span length **23** *(feet)* Bridge width **24** *(feet)*

Road approach to bridge:

8. LB **2** RB **1** *(**0** even, **1**- lower, **2**- higher)*

9. LB **2** RB **2** *(**1**- Paved, **2**- Not paved)*

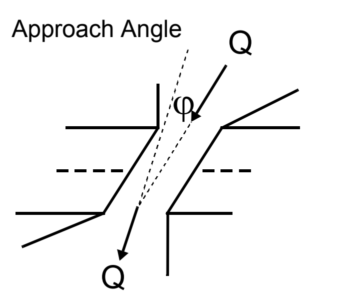
10. Embankment slope (*run / rise in feet / foot*):
US left **1.2:1** US right **1.2:1**

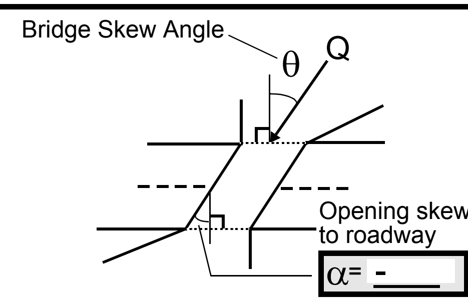
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	0	-	2	1
RBUS	0	-	0	-
RBDS	0	-	0	-
LBDS	0	-	0	-

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

Channel approach to bridge (BF):

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





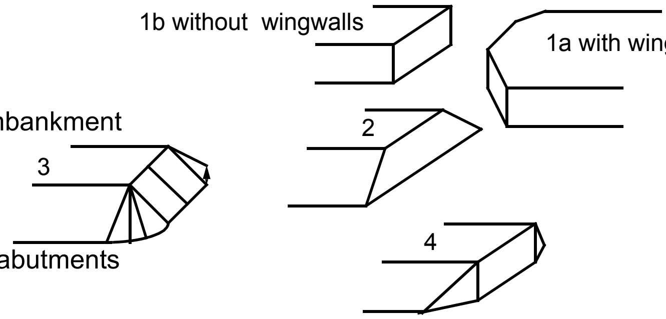
17. Channel impact zone 1: Exist? **Y** *(Y or N)*
Where? **LB** *(LB, RB)* Severity **1**
Range? **130** feet **US** *(US, UB, DS)* to **115** feet **US**

Channel impact zone 2: Exist? **Y** *(Y or N)*
Where? **LB** *(LB, RB)* Severity **1**
Range? **100** feet **DS** *(US, UB, DS)* to **120** 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 perpendicular 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 are all forested. On the upstream and downstream right banks, the surface cover is mowed grass beyond the tops of banks. On the left bank there is a saw mill with a gravel yard.

6. The bridge is a multi-plate steel arch type culvert.

7. Measured bridge width between the outside of guardrails = 21.8 feet.

11. There is placed protection on the top and sides of the arch, but it does not extend much beyond the bridge width to act as road embankment protection.

18. The structure is a multi-plate steel arch culvert with a mitered inlet and outlet similar to wingwalls perpendicular to an abutment face.

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
64.0	**11.5**			**9.0**	**4**	**3**	**543**	**432**	**1**	**1**

23. Bank width **35.0** 24. Channel width **35.0** 25. Thalweg depth **52.0** 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.):

30. There is some natural protection along the left bank from the culvert face to 68 feet upstream. The stone fill on the exterior of the arch and mitered ends extends 20 feet beyond the end of the culvert on the left bank.

The mitered sections on the upstream and downstream ends of the left side of the arch have been deflected in toward the stream. The deflection is greater at the inlet end of the arch.

33. Point/Side bar present? Y (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: 86 35. Mid-bar width: 18

36. Point bar extent: 138 feet US (US, UB) to 60 feet US (US, UB, DS) positioned 50 %LB to 100 %RB

37. Material: 432

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

The point bar is not vegetated.

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: 75 42. Cut bank extent: 97 feet US (US, UB) to 67 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.):

-

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	56. Height (BF) RB	57 Angle (BF) LB	57 Angle (BF) RB	61. Material (BF) LB	61. Material (BF) RB	62. Erosion (BF) LB	62. Erosion (BF) RB
22.5		0.5		2	7	7	-

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

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

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

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

435

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:

2

Debris is caught along the banks upstream and downstream.

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		**5**	**110**	**2**	**2**	**0**	**1.25**	**90.0**
RABUT	**3**	**-**	**110**			**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.):

0

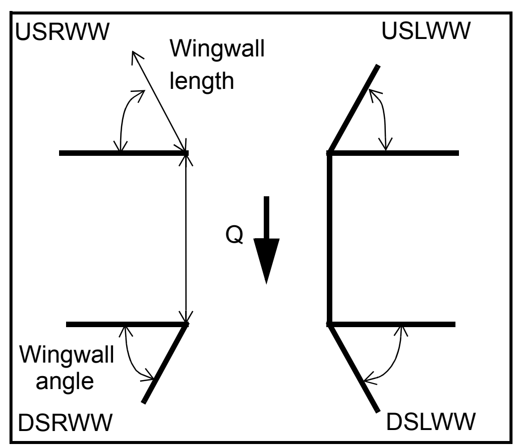
1.25

3

The abutments are corrugated steel with a wave length of 0.5 feet. The footings are concrete. The RABUT footing is exposed 1.25 feet at the upstream end but only 0.5 feet at the downstream end due to a side bar. The LABUT footing is exposed 1.25 feet along the entire base length.

80. **Wingwalls**:

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



*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**	-	-	-	-	-
Condition	**N**	-	-	-	-	-	-	-
Extent	-	-	-	-	-	**0**	**0**	-

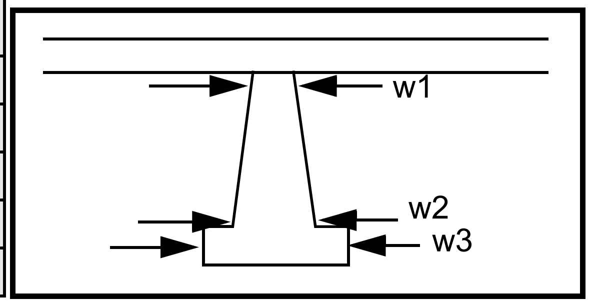
*Bank / Bridge protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank / Bridge protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*
*Protection extent: **1**- entire base length; **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? __-__ *(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)		-	-	-	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type		-	-	-	***1**- Solid pier, **2**- column, **3**- bent*
88. Material		-	-	-	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape		-	-	-	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?		-	-	-	*Y- yes; N- no*
91. Attack ∠ (BF)		-	-	-	
92. Pushed		-	-	-	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles		-	-	-	
95. Cross-members		-	-	-	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition		-	-	-	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	N	-	-	-	
98. Exposure depth	-	-	-	-	

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
-	-			-	-	NO	PIE	RS		

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

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

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

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

4
3
423
23
1
1
435
0
0
-
-
From 91 feet downstream to 210 feet downstream, there is a mid-channel bar positioned 40% LB to 85% RB. It is composed of gravel, cobbles, boulders and is vegetated. There is cut-bank along the left bank parallel to

101. Is a drop structure present? **th** *(Y or N, if N type ctrl-n ds)* 102. Distance: - feet

103. Drop: - feet 104. Structure material: **e** *(**1**- steel sheet pile; **2**- wood pile; **3**- concrete; **4**- other)*

105. Drop structure comments (eg. downstream scour depth):
mid-channel bar.

As with the upstream end, the mitered section on the downstream end of the left side of the arch has been deflected in toward the stream although, not as severely as at the upstream end.

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 **N** %LB to **-** %RB

Material: **NO**

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

DROP STRUCTURE

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

Cut bank extent: **38** feet **10** *(US, UB, DS)* to **16** feet **UB** *(US, UB, DS)*

Bank damage: **70** *(**1**- eroded and/or creep; **2**- slip failure; **3**- block failure)*

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

DS
75
100
342

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

Scour dimensions: Length **point** Width **bar** Depth: **is** Positioned **veg** %LB to **etat** %RB

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

ed over approximately 80% of its' surface area.

Are there major confluences? **N** *(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 **-** *(**1**- perennial; **2**- ephemeral)*

Confluence comments (eg. confluence name):

NO CUT BANKS

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)*:

N
-
-
-
-
-
-
NO CHANNEL SCOUR

Y

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: ANDOTH00230025 Town: Andover
Road Number: TH23 County: Windsor
Stream: Andover Branch

Initials RHF Date: 3/11/97 Checked: EB

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

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

Approach Section

Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	1730	2500	0
Main Channel Area, ft2	304.6	518	0
Left overbank area, ft2	0	1	0
Right overbank area, ft2	0	432	0
Top width main channel, ft	47	52	0
Top width L overbank, ft	0	2	0
Top width R overbank, ft	0	141	0
D50 of channel, ft	0.2572	0.2572	0
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	6.5	10.0	ERR
y1, average depth, LOB, ft	ERR	0.5	ERR
y1, average depth, ROB, ft	ERR	3.1	ERR
Total conveyance, approach	24522	88818	0
Conveyance, main channel	24522	54885	0
Conveyance, LOB	0	22	0
Conveyance, ROB	0	33911	0
Percent discrepancy, conveyance	0.0000	0.0000	ERR
Qm, discharge, MC, cfs	1730.0	1544.9	ERR
Ql, discharge, LOB, cfs	0.0	0.6	ERR
Qr, discharge, ROB, cfs	0.0	954.5	ERR
Vm, mean velocity MC, ft/s	5.7	3.0	ERR
Vl, mean velocity, LOB, ft/s	ERR	0.6	ERR
Vr, mean velocity, ROB, ft/s	ERR	2.2	ERR
Vc-m, crit. velocity, MC, ft/s	9.7	10.5	N/A
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	N/A
Left Overbank	N/A	N/A	N/A
Right Overbank	N/A	N/A	N/A

ARMORING

D90	0.6214	0.6214	0
D95	0.7812	0.7812	0
Critical grain size,Dc, ft	0.8706	1.0418	ERR
Decimal-percent coarser than Dc	0.0315	0.018	0
Depth to armoring,ft	N/A	N/A	ERR

Clear Water Contraction Scour in MAIN CHANNEL

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

Approach Section	Q100	Q500	Qother
Main channel Area, ft2	304.6	518	0
Main channel width, ft	47	52	0
y1, main channel depth, ft	6.48	9.96	ERR

Bridge Section			
(Q) total discharge, cfs	1730	2500	0
(Q) discharge thru bridge, cfs	1730	2500	0
Main channel conveyance	11984	16395	0
Total conveyance	11984	16395	0
Q2, bridge MC discharge,cfs	1730	2500	ERR
Main channel area, ft2	124	157	0
Main channel width (skewed), ft	21.5	21.5	0.0
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	21.5	21.5	0
y_bridge (avg. depth at br.), ft	5.79	7.29	ERR
Dm, median (1.25*D50), ft	0.3215	0.3215	0
y2, depth in contraction,ft	7.36	10.09	ERR
ys, scour depth (y2-ybridge), ft	1.57	2.80	N/A

Abutment Scour
Froehlich’s Abutment Scour
Ys/Y1 = 2.27*K1*K2*(a’/Y1)^0.43*Fr1^0.61+1
(Richardson and others, 1995, p. 48, eq. 28)

	Left Abutment			Right Abutment		
Characteristic	100 yr Q	500 yr Q	Other Q	100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	1730	2500	0	1730	2500	0
a’, abut.length blocking flow, ft	11.6	18.5	0	13.5	154.7	0
Ae, area of blocked flow ft2	46.3	110.7	0	62.8	555.9	0
Qe, discharge blocked abut.,cfs	173	235.1	0	264.9	1272.3	0
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	3.74	2.12	ERR	4.22	2.29	ERR
ya, depth of f/p flow, ft	3.99	5.98	ERR	4.65	3.59	ERR
--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)						
K1	0.82	0.82	0.82	0.82	0.82	0.82
--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)						
theta	90	90	90	90	90	90
K2	1.00	1.00	1.00	1.00	1.00	1.00

Fr, froude number f/p flow	0.330	0.153	ERR	0.345	0.213	ERR
ys, scour depth, ft	9.96	11.74	N/A	11.80	16.71	N/A

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

a'(abut length blocked, ft)	11.6	18.5	0	13.5	154.7	0
y1 (depth f/p flow, ft)	3.99	5.98	ERR	4.65	3.59	ERR
a'/y1	2.91	3.09	ERR	2.90	43.05	ERR
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.33	0.15	N/A	0.34	0.21	N/A
Ys w/ corr. factor K1/0.55:						
vertical	ERR	ERR	ERR	ERR	15.68	ERR
vertical w/ ww's	ERR	ERR	ERR	ERR	12.86	ERR
spill-through	ERR	ERR	ERR	ERR	8.63	ERR

Abutment riprap Sizing

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

Characteristic	Q100	Q500	Qother	Q100	Q500	Qother
Fr, Froude Number	1	1	0	1	1	0
(Fr from the characteristic V and y in contracted section--mc, bridge section)						
y, depth of flow in bridge, ft	5.79	7.29	0.00	5.79	7.29	0.00
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	ERR	ERR	0.00	ERR	ERR	0.00
Fr>0.8 (vertical abut.)	2.42	3.05	ERR	2.42	3.05	ERR
Fr<=0.8 (spillthrough abut.)	ERR	ERR	0.00	ERR	ERR	0.00
Fr>0.8 (spillthrough abut.)	2.14	2.69	ERR	2.14	2.69	ERR