LEVEL II SCOUR ANALYSIS FOR
BRIDGE 16 (STRATH00180016) on
TOWN HIGHWAY 18, crossing the
WEST BRANCH
OMPOMPANOOSUC RIVER,
STRAFFORD, VERMONT

U.S. Geological Survey
Open-File Report 98-024

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION
U.S. Department of the Interior
U.S. Geological Survey

LEVEL II SCOUR ANALYSIS FOR BRIDGE 16 (STRATH00180016) on TOWN HIGHWAY 18, crossing the WEST BRANCH OMPOMPANOOSUC RIVER, STRAFFORD, VERMONT

By LORA K. STRIKER AND MICHAEL A. IVANOFF

U.S. Geological Survey
Open-File Report 98-024

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

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

Copies of this report may be
purchased from:

U.S. Geological Survey
Branch of Information Services
Open-File Reports Unit
Box 25286
Denver, CO 80225-0286

CONTENTS

Conversion Factors, Abbreviations, and Vertical Datum	iv
Introduction and Summary of Results	1
Level II summary	7
Description of Bridge	7
Description of the Geomorphic Setting.....	8
Description of the Channel.....	8
Hydrology.....	9
Calculated Discharges	9
Description of the Water-Surface Profile Model (WSPRO) Analysis	10
Cross-Sections Used in WSPRO Analysis.....	10
Data and Assumptions Used in WSPRO Model	11
Bridge Hydraulics Summary	12
Scour Analysis Summary	13
Special Conditions or Assumptions Made in Scour Analysis.....	13
Scour Results.....	14
Riprap Sizing.....	14
Selected References	18
Appendices:	
A. WSPRO input file.....	19
B. WSPRO output file.....	22
C. Bed-material particle-size distribution	29
D. Historical data form.....	31
E. Level I data form.....	37
F. Scour computations.....	47

FIGURES

1. Map showing location of study area on USGS 1:24,000 scale map	3
2. Map showing location of study area on Vermont Agency of Transportation town highway map	4
3. Structure STRATH00180016 viewed from upstream (October 19, 1995).....	5
4. Downstream channel viewed from structure STRATH00180016 (October 19, 1995).	5
5. Upstream channel viewed from structure STRATH00180016 (October 19, 1995).	6
6. StructureSTRATH00180016 viewed from downstream (October 19, 1995).	6
7. Water-surface profiles for the 100- and 500-year discharges at structure STRATH00180016 on Town Highway 18, crossing the West Branch Ompompanoosuc River Strafford, Vermont.	15
8. Scour elevations for the 100- and 500-year discharges at structure STRATH00180016 on Town Highway 18, crossing the West Branch Ompompanoosuc River Strafford, Vermont.	16

TABLES

1. Remaining footing/pile depth at abutments for the 100-year discharge at structure STRATH00180016 on Town Highway 18, crossing the West Branch Ompompanoosuc River Strafford, Vermont	17
2. Remaining footing/pile depth at abutments for the 500-year discharge at structure STRATH00180016 on Town Highway 18, crossing the West Branch Ompompanoosuc River Strafford, Vermont	17

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	VT AOT	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 16 (STRATH00180016) ON TOWN HIGHWAY 18, CROSSING THE WEST BRANCH OMPOMPANOOSUC RIVER, STRAFFORD, VERMONT

By Lora K. Striker and Michael A. Ivanoff

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure STRATH00180016 on Town Highway 18 crossing the West Branch Ompompanoosuc River, Strafford, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (Federal Highway Administration, 1993). Results of a Level I scour investigation also are included in appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the bridge, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in appendix D.

The site is in the New England Upland section of the New England physiographic province in east-central Vermont. The 6.28-mi² drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is predominantly forest. Surface cover on the upstream right bank is shrub and brushland.

In the study area, the West Branch Ompompanoosuc River has an incised, sinuous channel with a slope of approximately 0.03 ft/ft, an average channel top width of 32 ft and an average bank height of 3 ft. The channel bed material ranges from gravel to boulder with a median grain size (D_{50}) of 64.5 mm (0.212 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 19, 1995, indicated that the reach was stable.

The Town Highway 18 crossing of the West Branch Ompompanoosuc River is a 35-ft-long, one-lane bridge consisting of two 11-foot rail-road stringer spans with a timber deck (Vermont Agency of Transportation, written communication, March 23, 1995). The opening length of the structure parallel to the bridge face is 21.6 ft. The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 0 degrees to the opening while the computed opening-skew-to-roadway is 5 degrees.

Although there was no channel scour observed during the Level I assessment, the left abutment footing was exposed 1.0 ft and the right abutment footing was exposed 0.5 ft. Scour protection measures at the site include: type-2 stone fill (less than 36 inches diameter) along the upstream left and right banks, along the entire base length of the upstream left and right wingwalls, left and right abutments, downstream left and right wingwalls, and downstream left and right banks. 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). 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 was 0.0 ft. Abutment scour ranged from 3.4 to 7.5 ft. The worst-case abutment scour occurred at the 500-year discharge. Pier scour ranged from 2.1 to 2.2 ft. The worst case pier scour occurred at the incipient-overtopping discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

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

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

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 STRATH00180016 **Stream** West Branch Ompompanoosuc River
County Orange **Road** TH 18 **District** 4

Description of Bridge

Bridge length	<u>35</u>	ft	Bridge width	<u>14.0</u>	ft	Max span length	<u>11</u>	ft
Alignment of bridge to road (on curve or straight)				<u>Curve</u>				
Abutment type				<u>Vertical, concrete</u>				
Embankment type				<u>Sloping; Near Vertical</u>				
Stone fill on abutment?				<u>Yes</u>				
Date of inspection				<u>10/19/95</u>				
Description of stone fill				<u>Type-2, along the entire base length of the upstream left and right</u>				
<u>wingwalls, left and right abutments, and downstream left and right wingwalls.</u>								

Abutments and wingwalls are concrete. The pier has square wooden piles with a concrete footing.

	No	0
<i>Is bridge skewed to flood flow according to No. 1 survey?</i>	<i>Angle</i>	

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

	<i>Date of inspection</i>	<i>Percent of channel blocked horizontally</i>	<i>Percent of channel blocked vertically</i>
<i>Level I</i>	10/19/95	0	0
<i>Level II</i>	Moderate. Although the natural bank material protects trees from falling into the channel, the debris potential is moderate due to the timber pier.		
<i>Potential for debris</i>			

None as of 10/19/95.

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

Description of the Geomorphic Setting

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

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

Date of inspection 10/19/95

DS left: Steep channel bank to irregular overbank and steep valley wall

DS right: Steep channel bank to narrow flood plain and steep valley wall

US left: Steep channel bank to irregular overbank and steep valley wall

US right: Steep channel bank to narrow flood plain and steep valley wall

Description of the Channel

Average top width	<u>32</u>	Average depth	<u>3</u>
	<u>Cobble[#]</u>		<u>Cobble/Boulder[#]</u>

Predominant bed material **Bank material** Perennial, sinuous, incised, and stable channel with non-alluvial channel boundaries.

10/19/95

Vegetative cover Small trees and short grass

DS left: Small trees and short grass

DS right: Small trees and short grass

US left: Small trees and short grass

US right: Yes

Do banks appear stable? - Yes, no, or if not, describe location and type of instability and

date of observation.

None as of 10/19/95.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 6.3 **mi²**

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province/section	Percent of drainage area
<u>New England/New England Upland</u>	<u>100</u>

Is drainage area considered rural or urban? Rural **Describe any significant urbanization:** -

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

USGS gage description --

USGS gage number --

Gage drainage area -- **mi²** No

Is there a lake/p -

Calculated Discharges

<u>1,400</u>	<u>1,900</u>
Q₁₀₀	Q₅₀₀
ft³/s	ft³/s

The 10-, 25-, 50-, and 100-year discharges were

taken from the VTAOT database (Vermont Agency of Transportation, written communication, May 1995) and extrapolated to the 500-year event. The VTAOT discharges fall within a range defined by several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887).

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

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

Datum tie between USGS survey and VTAOT plans None

Description of reference marks used to determine USGS datum. RM1 is a chiseled X at the US end of the left abutment (elev. 498.76 ft, arbitrary survey datum). RM2 is a chiseled X at the DS end of the right abutment (elev. 499.65 ft, arbitrary survey datum). RM3 is a nail 6.5 ft from the ground in telephone pole #2311804/12, 95 ft upstream and 30 ft left from the center of the left abutment (elev. 507.29, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

¹ <i>Cross-section</i>	<i>Section Reference Distance (SRD) in feet</i>	² <i>Cross-section development</i>	<i>Comments</i>
EXIT1	-144	3	Exit section (overbanks modified from EXIT2)
EXIT2	-23	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXIT2)
BRIDG	0	1	Bridge section
RDWAY	7	1	Road Grade section
APPRO	34	2	Approach section as surveyed (Used as a template)

¹ For location of cross-sections see plan-view sketch included with Level I field form, Appendix E.
For more detail on how cross-sections were developed see WSPRO input file.

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). The 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 0.050 to 0.060, and overbank "n" values ranged from 0.041 to 0.065.

Normal depth at the exit section (EXIT1) was assumed as the starting water surface for the incipient-overtopping discharge model. 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 0.0290 ft/ft, which was estimated from the topographic map (U.S. Geological Survey, 1981). Critical depth at the exit section (EXIT1) was assumed as the starting water surface elevation for the 100- and 500-year discharge. The computed normal depths were within 0.3 ft of critical depth by use of the slope-conveyance method. Therefore, the critical water surface was assumed to be a satisfactory starting water surface for the 100- and 500-year discharge models.

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

Bridge Hydraulics Summary

Average bridge embankment elevation 500.0 *ft*
Average low steel elevation 499.0 *ft*

100-year discharge 1,400 *ft³/s*
Water-surface elevation in bridge opening 499.1 *ft*
Road overtopping? Yes *Discharge over road* 649 *ft³/s*
Area of flow in bridge opening 101 *ft²*
Average velocity in bridge opening 7.1 *ft/s*
Maximum WSPRO tube velocity at bridge 8.3 *ft/s*

Water-surface elevation at Approach section with bridge 500.1
Water-surface elevation at Approach section without bridge 499.6
Amount of backwater caused by bridge 0.5 *ft*

500-year discharge 1,900 *ft³/s*
Water-surface elevation in bridge opening 499.1 *ft*
Road overtopping? Yes *Discharge over road* 1,150 *ft³/s*
Area of flow in bridge opening 101 *ft²*
Average velocity in bridge opening 7.2 *ft/s*
Maximum WSPRO tube velocity at bridge 8.4 *ft/s*

Water-surface elevation at Approach section with bridge 500.6
Water-surface elevation at Approach section without bridge 500.2
Amount of backwater caused by bridge 0.4 *ft*

Incipient overtopping discharge 520 *ft³/s*
Water-surface elevation in bridge opening 497.4 *ft*
Area of flow in bridge opening 71 *ft²*
Average velocity in bridge opening 7.4 *ft/s*
Maximum WSPRO tube velocity at bridge 9.3 *ft/s*

Water-surface elevation at Approach section with bridge 498.3
Water-surface elevation at Approach section without bridge 498.0
Amount of backwater caused by bridge 0.3 *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 analysis for the 100- and 500-year discharges are presented in tables 1 and 2 and figure 8.

Contraction scour for the 100-year, 500-year, and incipient roadway-overtopping discharges 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 submerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Thus, contraction scour for these discharges was computed by use of the Chang equation (Richardson and Davis, 1995, p. 145-146). The streambed armoring depths computed suggest that armoring will not limit the depth of contraction scour.

For comparison, estimates of contraction scour for the discharges resulting in orifice flow were also computed by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144) and presented in appendix F.

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

Pier scour was computed by use of an equation based on the Colorado State University equation (Richardson and Davis, 1995, p. 36, eq. 21). Variables for the equation include: pier length, pier width, approach velocity and correction factors for pier shape, flow attack angle, streambed condition, streambed armoring, and average depth and maximum velocity (for the froude number) immediately upstream of the bridge.

Scour Results

<i>Contraction scour:</i>	<i>100-yr discharge</i>	<i>500-yr discharge</i>	<i>Incipient overtopping discharge</i>
	<i>(Scour depths in feet)</i>		

Main channel

<i>Live-bed scour</i>	--	--	--
	<hr/>	<hr/>	<hr/>
<i>Clear-water scour</i>	0.0	0.0	0.0
	<hr/>	<hr/>	<hr/>
<i>Depth to armoring</i>	1.5	1.6	3.0
	<hr/>	<hr/>	<hr/>
<i>Left overbank</i>	--	--	--
	<hr/>	<hr/>	<hr/>
<i>Right overbank</i>	--	--	--
	<hr/>	<hr/>	<hr/>

Local scour:

<i>Abutment scour</i>	6.2	5.7	3.4
	<hr/>	<hr/>	<hr/>
<i>Left abutment</i>	7.2	7.5	4.9
	<hr/>	<hr/>	<hr/>
<i>Right abutment</i>	--	--	--
	<hr/>	<hr/>	<hr/>
<i>Pier scour</i>	2.1	2.1	2.2
	<hr/>	<hr/>	<hr/>
<i>Pier 1</i>	--	--	--
	<hr/>	<hr/>	<hr/>
<i>Pier 2</i>	--	--	--
	<hr/>	<hr/>	<hr/>
<i>Pier 3</i>	--	--	--
	<hr/>	<hr/>	<hr/>

Riprap Sizing

	<i>100-yr discharge</i>	<i>500-yr discharge</i>	<i>Incipient overtopping discharge</i>
	<i>(D₅₀ in feet)</i>		
<i>Abutments:</i>	1.2	1.7	1.7
	<hr/>	<hr/>	<hr/>
<i>Left abutment</i>	1.2	1.7	1.7
	<hr/>	<hr/>	<hr/>
<i>Right abutment</i>	1.3	1.3	1.6
	<hr/>	<hr/>	<hr/>
<i>Piers:</i>	--	--	--
	<hr/>	<hr/>	<hr/>
<i>Pier 1</i>	--	--	--
	<hr/>	<hr/>	<hr/>
<i>Pier 2</i>	--	--	--
	<hr/>	<hr/>	<hr/>

Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure STRATH00180016 on Town Highway 18, crossing the West Branch Ompompanoosuc River, Strafford, Vermont.

Figure 8. Scour elevations for the 100- and 500-year discharges at structure STRATH00180016 on Town Highway 18, crossing West Branch Ompompanoosuc River, Strafford, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure STRATH00180016 on Town Highway 18, crossing the West Branch Ompompanoosuc River, Strafford, 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 1,400 cubic-feet per second											
Left abutment	0.0	--	499.1	--	494.2	0.0	6.2	--	6.2	488.0	--
pier	11.5	--	499.1		493.8	0.0	--	2.1	2.1	491.7	--
Right abutment	21.6	--	499.0	--	494.9	0.0	7.2	--	7.2	487.7	--

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 STRATH00180016 on Town Highway 18, crossing the West Branch Ompompanoosuc River, Strafford, Vermont.

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

Description	Station ¹	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation ² (feet)	Bottom of footing elevation ² (feet)	Channel elevation at abutment/pier ² (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour ² (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 1,900 cubic-feet per second											
Left abutment	0.0	--	499.1	--	494.2	0.0	5.7	--	5.7	488.5	--
pier	11.5	--	499.1		493.8	0.0	--	2.2	2.2	491.6	--
Right abutment	21.6	--	499.0	--	494.9	0.0	7.5	--	7.5	487.4	--

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.
- Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: U.S. Geological Survey, Bulletin 17B of the Hydrology Subcommittee, 190 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. Geological Survey, 1981, Chelsea, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```

T1      U.S. Geological Survey WSPRO Input File stra016.wsp
T2      Hydraulic analysis for structure STRATH00180016   Date: 21-MAR-97
T3      TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
*
J3      6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q        1400.0    1900.0
SK       0.0290    0.0290
*
*      Incipient Model at discharge of 520 cfs modelled with vertical
*      wall at station -4.0 because the flow does not get over the top
*      of bank.
*
XS      EXIT1  -144
GR      -129.9, 512.07    -82.6, 496.30    -58.3, 496.98
GR      -45.6, 495.91    -30.3, 495.69    -4.0, 497.02
GR      0.0, 495.86      1.6, 493.17      7.7, 493.12      12.2, 493.07
GR      17.3, 493.30     24.3, 492.75     27.5, 492.52     29.8, 491.95
GR      31.0, 492.74     34.0, 493.14     34.3, 493.79     44.1, 498.21
GR      54.4, 499.11     158.9, 500.92     216.6, 511.58
*
N        0.050          0.060          0.065
SA       -4.0          44.1
*
XS      EXIT2  -23
GR      -129.9, 515.24    -82.6, 499.47    -58.3, 497.89    -45.6, 495.95
GR      -30.3, 496.60    -18.9, 496.82    -4.0, 497.93      0.0, 496.77
GR      4.4, 494.19      5.7, 494.12      7.5, 493.68     10.5, 493.67
GR      14.3, 493.52     19.1, 493.69     22.1, 493.82     23.9, 494.11
GR      29.1, 494.32     35.6, 497.85     44.1, 499.12     54.4, 500.02
GR      158.9, 501.83     216.6, 512.49
*
N        0.041          0.060          0.065
SA       -4.0          35.6
*
XS      FULLLV    0 * * *    0.0031
*
*      SRD      LSEL      XSSKEW
BR      BRIDG    0    499.04    5.0
GR      0.0, 499.08      0.1, 495.28      0.6, 495.33      0.6, 494.18
GR      2.5, 494.36      3.8, 493.76      7.2, 493.63     10.3, 493.92
GR      12.6, 493.76     14.6, 493.89     17.3, 494.44     20.8, 494.89
GR      20.9, 495.29     21.5, 495.33     21.6, 499.00     0.0, 499.08
*
*      BRTYPE  BRWDTH      WWANGL      WWWID
CD        1      17.5 * *      85.6      0.4
PW      493.8, 2.0 494.62, 2.0 494.62, 0.6 499.04, 0.6 499.04, 0.0
N        0.050
*
*      SRD      EMBWID    IPAVE
XR      RDWAY    7      14.0      2
GR      -104.6, 509.39    -81.9, 501.36    -65.4, 499.91    -50.1, 498.37
GR      -43.8, 496.9      -40.4, 497.10    -24.8, 497.94    -5.7, 499.78
GR      0.0, 499.98      21.8, 499.95     27.5, 499.81     59.6, 500.36
GR      97.4, 501.24     137.7, 501.20    150.4, 501.92    184.1, 507.41
*
AS      APPRO    34          0.
GR      -134.5, 519.91    -102.0, 505.81    -80.1, 501.08    -55.9, 500.97
GR      -39.3, 498.63     -33.3, 497.77    -16.8, 498.22     -7.5, 498.30
GR      0.0, 498.16      4.5, 494.48      7.2, 493.88      9.3, 493.65
GR      12.9, 493.66     16.4, 493.93     17.6, 494.42     21.7, 495.85
GR      22.6, 495.86     28.4, 499.14     54.4, 499.79     73.0, 500.54
GR      109.6, 501.58     135.5, 501.63    159.1, 503.08    181.9, 507.51
*
N        0.050          0.055          0.060
SA       0.0          28.4
*
HP 1 BRIDG    499.08 1 499.08

```

WSPRO INPUT FILE (continued)

```

HP 2 BRIDG  499.08 * * 752
HP 2 RDWAY  499.97 * * 649
HP 1 APPRO  500.11 1 500.11
HP 2 APPRO  500.11 * * 1400
*
HP 1 BRIDG  499.08 1 499.08
HP 2 BRIDG  499.08 * * 762
HP 2 RDWAY  500.49 * * 1153
HP 1 APPRO  500.63 1 500.63
HP 2 APPRO  500.63 * * 1900
*
T1          U.S. Geological Survey WSPRO Input File testio.wsp
T2          Hydraulic analysis for structure STRATH00180016   Date: 21-MAR-97
T3          TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
*
J3          6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           520.0
SK          0.0290
*
XS  EXIT1  -144
GR          -4.1, 500.00      -4.0, 497.02
GR          0.0, 495.86       1.6, 493.17      7.7, 493.12      12.2, 493.07
GR          17.3, 493.30      24.3, 492.75      27.5, 492.52      29.8, 491.95
GR          31.0, 492.74      34.0, 493.14      34.3, 493.79      44.1, 498.21
GR          54.4, 499.11      158.9, 500.92      216.6, 511.58
*
N           0.060           0.065
SA          44.1
*
XS  EXIT2  -23
*          -129.9, 515.24      -82.6, 499.47      -58.3, 497.89      -45.6, 495.95
*          -30.3, 496.60      -18.9, 496.82
GR          -4.1, 500.00      -4.0, 497.93      0.0, 496.77
GR          4.4, 494.19       5.7, 494.12      7.5, 493.68      10.5, 493.67
GR          14.3, 493.52      19.1, 493.69      22.1, 493.82      23.9, 494.11
GR          29.1, 494.32      35.6, 497.85      44.1, 499.12      54.4, 500.02
GR          158.9, 501.83      216.6, 512.49
*
N           0.060           0.065
SA          35.6
*
XS  FULLV  0 * * * 0.0031
*
*          SRD      LSEL      XSSKEW
BR  BRIDG  0      499.04      5.0
GR          0.0, 499.08      0.1, 495.28      0.6, 495.33      0.6, 494.18
GR          2.5, 494.36      3.8, 493.76      7.2, 493.63      10.3, 493.92
GR          12.6, 493.76      14.6, 493.89      17.3, 494.44      20.8, 494.89
GR          20.9, 495.29      21.5, 495.33      21.6, 499.00      0.0, 499.08
*
*          BRTYPE  BRWDTH      WWANGL      WWWID
CD          1      17.5 * *      85.6      0.4
PW          493.8, 2.0 494.62, 2.0 494.62, 0.6 499.04, 0.6 499.04, 0.0
N           0.050
*
*          SRD      EMBWID      IPAVE
XR  RDWAY  7      14.0      2
*          -104.6, 509.39      -81.9, 501.36      -65.4, 499.91      -50.1, 498.37
*          -43.8, 496.9      -40.4, 497.10      -24.8, 497.94      -5.7, 499.78
GR          0.0, 501.00
GR          0.0, 499.98      21.8, 499.95      27.5, 499.81      59.6, 500.36
GR          97.4, 501.24      137.7, 501.20      150.4, 501.92      184.1, 507.41
*
AS  APPRO  34      0.
*          -134.5, 519.91      -102.0, 505.81      -80.1, 501.08      -55.9, 500.97
*          -39.3, 498.63      -33.3, 497.77      -16.8, 498.22
GR          -7.6, 502.00      -7.5, 498.30

```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

U.S. Geological Survey WSPRO Input File stra016.wsp
 Hydraulic analysis for structure STRATH00180016 Date: 21-MAR-97
 TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
 *** RUN DATE & TIME: 10-17-97 14:40
 CROSS-SECTION PROPERTIES: ISEQ = 4; SECID = BRIDG; SRD = 0.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	105	5026	0	52				0
499.08		105	5026	0	52	1.00	0	22	0

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = BRIDG; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
499.08	0.0	21.6	105.4	5026.	752.	7.14
X STA.	0.0	2.0	3.2	4.2	5.1	6.0
A(I)	8.7	5.8	5.2	4.9	4.8	
V(I)	4.31	6.48	7.17	7.74	7.80	
X STA.	6.0	6.9	7.7	8.6	9.5	10.4
A(I)	4.6	4.6	4.6	4.6	4.6	
V(I)	8.25	8.25	8.15	8.09	8.22	
X STA.	10.4	11.3	12.1	13.0	13.9	14.9
A(I)	4.6	4.6	4.6	4.6	4.9	
V(I)	8.18	8.09	8.21	8.15	7.73	
X STA.	14.9	15.8	16.9	18.1	19.4	21.6
A(I)	4.9	5.1	5.3	5.9	8.4	
V(I)	7.69	7.35	7.03	6.38	4.46	

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = RDWAY; SRD = 7.

WSEL	LEW	REW	AREA	K	Q	VEL
499.97	-66.1	36.8	98.9	4751.	649.	6.56
X STA.	-66.1	-52.6	-48.7	-46.5	-44.8	-43.4
A(I)	9.1	6.0	4.9	4.5	4.0	
V(I)	3.57	5.38	6.63	7.18	8.07	
X STA.	-43.4	-42.1	-40.8	-39.5	-38.1	-36.8
A(I)	3.9	3.8	3.7	3.9	3.8	
V(I)	8.27	8.50	8.71	8.42	8.65	
X STA.	-36.8	-35.3	-33.8	-32.2	-30.4	-28.6
A(I)	3.8	3.9	4.0	4.1	4.2	
V(I)	8.52	8.25	8.12	7.87	7.66	
X STA.	-28.6	-26.5	-24.2	-21.3	-17.2	36.8
A(I)	4.5	4.7	5.2	6.2	10.5	
V(I)	7.14	6.83	6.25	5.26	3.09	

CROSS-SECTION PROPERTIES: ISEQ = 6; SECID = APPRO; SRD = 34.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	85	3640	50	50				635
	2	138	10143	28	31				1730
	3	18	294	34	34				75
500.11		242	14076	112	115	1.28	-49	62	1777

VELOCITY DISTRIBUTION: ISEQ = 6; SECID = APPRO; SRD = 34.

WSEL	LEW	REW	AREA	K	Q	VEL
500.11	-49.8	62.3	241.7	14076.	1400.	5.79
X STA.	-49.8	-32.5	-25.6	-18.2	-9.8	-1.4
A(I)	21.2	15.3	15.0	15.7	15.6	
V(I)	3.30	4.59	4.67	4.46	4.50	
X STA.	-1.4	3.6	5.4	6.8	8.1	9.4
A(I)	14.9	10.0	8.6	8.3	7.9	
V(I)	4.70	7.02	8.13	8.47	8.81	
X STA.	9.4	10.6	11.9	13.1	14.4	15.7
A(I)	8.0	8.0	8.0	8.1	8.4	
V(I)	8.79	8.79	8.70	8.67	8.37	
X STA.	15.7	17.2	18.9	21.0	23.9	62.3
A(I)	8.9	9.4	10.4	11.9	28.2	
V(I)	7.87	7.41	6.74	5.88	2.48	

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File stra016.wsp
 Hydraulic analysis for structure STRATH00180016 Date: 21-MAR-97
 TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
 *** RUN DATE & TIME: 10-17-97 14:40
 CROSS-SECTION PROPERTIES: ISEQ = 4; SECID = BRIDG; SRD = 0.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	105	5026	0	52				0
499.08		105	5026	0	52	1.00	0	22	0

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = BRIDG; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
499.08	0.0	21.6	105.4	5026.	762.	7.23
X STA.	0.0	2.0	3.2	4.2	5.1	6.0
A(I)	8.7	5.8	5.2	4.9	4.8	
V(I)	4.37	6.57	7.27	7.84	7.91	
X STA.	6.0	6.9	7.7	8.6	9.5	10.4
A(I)	4.6	4.6	4.6	4.6	4.6	
V(I)	8.36	8.36	8.26	8.20	8.33	
X STA.	10.4	11.3	12.1	13.0	13.9	14.9
A(I)	4.6	4.6	4.6	4.6	4.9	
V(I)	8.29	8.20	8.32	8.26	7.83	
X STA.	14.9	15.8	16.9	18.1	19.4	21.6
A(I)	4.9	5.1	5.3	5.9	8.4	
V(I)	7.79	7.45	7.12	6.47	4.51	

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = RDWAY; SRD = 7.

WSEL	LEW	REW	AREA	K	Q	VEL
500.49	-72.0	65.2	161.6	7805.	1153.	7.13
X STA.	-72.0	-54.9	-50.2	-47.2	-45.0	-43.3
A(I)	13.6	8.8	7.4	6.8	5.9	
V(I)	4.24	6.54	7.84	8.49	9.70	
X STA.	-43.3	-41.6	-40.0	-38.3	-36.6	-34.8
A(I)	5.8	5.6	5.5	5.6	5.6	
V(I)	9.98	10.29	10.54	10.38	10.36	
X STA.	-34.8	-33.0	-31.0	-29.0	-26.8	-24.5
A(I)	5.6	5.7	5.8	6.0	6.1	
V(I)	10.36	10.07	9.94	9.68	9.46	
X STA.	-24.5	-21.7	-18.2	-13.3	2.7	65.2
A(I)	6.6	7.3	8.2	13.0	26.9	
V(I)	8.73	7.89	7.05	4.43	2.14	

CROSS-SECTION PROPERTIES: ISEQ = 6; SECID = APPRO; SRD = 34.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	112	5472	53	54				923
	2	153	12013	28	31				2015
	3	39	849	48	48				201
500.63		304	18333	130	132	1.31	-52	76	2308

VELOCITY DISTRIBUTION: ISEQ = 6; SECID = APPRO; SRD = 34.

WSEL	LEW	REW	AREA	K	Q	VEL
500.63	-53.5	76.2	304.4	18333.	1900.	6.24
X STA.	-53.5	-34.5	-28.0	-21.4	-14.4	-6.9
A(I)	25.5	17.9	17.4	17.1	17.6	
V(I)	3.72	5.29	5.45	5.56	5.39	
X STA.	-6.9	0.2	4.1	5.9	7.5	8.9
A(I)	17.3	16.4	11.3	10.3	10.0	
V(I)	5.48	5.79	8.44	9.24	9.51	
X STA.	8.9	10.3	11.7	13.1	14.6	16.1
A(I)	9.7	9.7	9.8	10.1	10.3	
V(I)	9.77	9.76	9.66	9.44	9.26	
X STA.	16.1	17.8	19.8	22.4	27.3	76.2
A(I)	11.0	11.6	13.2	17.0	41.0	
V(I)	8.65	8.22	7.17	5.58	2.31	

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File testio.wsp
 Hydraulic analysis for structure STRATH00180016 Date: 21-MAR-97
 TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
 *** RUN DATE & TIME: 12-12-97 15:17
 CROSS-SECTION PROPERTIES: ISEQ = 4; SECID = BRIDG; SRD = 0.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	71.	3983.	21.	27.				730.
497.43		71.	3983.	21.	27.	1.00	0.	22.	730.

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = BRIDG; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
497.43	0.0	21.6	70.8	3983.	520.	7.35
X STA.	0.0	3.1	4.0	4.8	5.5	6.3
A(I)	9.1	3.1	2.8	2.9	2.8	
V(I)	2.85	8.47	9.27	9.01	9.13	
X STA.	6.3	7.1	7.8	8.6	9.4	10.3
A(I)	2.9	2.8	2.9	3.0	3.0	
V(I)	9.03	9.13	8.89	8.69	8.61	
X STA.	10.3	11.1	12.0	12.8	13.6	14.4
A(I)	2.9	3.0	3.0	2.9	3.0	
V(I)	8.83	8.69	8.76	9.04	8.72	
X STA.	14.4	15.3	16.2	17.2	18.3	21.6
A(I)	3.0	3.0	3.2	3.3	8.2	
V(I)	8.76	8.57	8.17	7.87	3.19	

CROSS-SECTION PROPERTIES: ISEQ = 6; SECID = APPRO; SRD = 34.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	87.	4293.	33.	36.				802.
498.28		87.	4293.	33.	36.	1.00	-6.	27.	802.

VELOCITY DISTRIBUTION: ISEQ = 6; SECID = APPRO; SRD = 34.

WSEL	LEW	REW	AREA	K	Q	VEL
498.28	-6.4	26.9	87.3	4293.	520.	5.96
X STA.	-6.4	6.9	7.6	8.2	8.9	9.6
A(I)	18.8	3.0	3.1	3.1	3.0	
V(I)	1.38	8.64	8.40	8.46	8.59	
X STA.	9.6	10.3	10.9	11.6	12.3	12.9
A(I)	3.1	3.1	3.1	3.2	3.0	
V(I)	8.28	8.45	8.39	8.23	8.76	
X STA.	12.9	13.6	14.4	15.1	15.9	16.7
A(I)	3.2	3.4	3.4	3.3	3.4	
V(I)	8.06	7.67	7.65	7.82	7.74	
X STA.	16.7	17.5	18.5	19.6	20.9	26.9
A(I)	3.5	3.6	3.7	4.0	9.3	
V(I)	7.41	7.32	7.09	6.42	2.79	

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = BRIDG; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
497.73	0.0	21.6	77.2	4538.	520.	6.73
X STA.	0.0	3.2	4.0	4.8	5.6	6.3
A(I)	10.2	3.2	3.1	3.1	3.1	
V(I)	2.55	8.05	8.27	8.34	8.46	
X STA.	6.3	7.1	7.9	8.7	9.5	10.3
A(I)	3.1	3.2	3.1	3.2	3.2	
V(I)	8.36	8.20	8.33	8.12	8.03	
X STA.	10.3	11.2	12.0	12.8	13.6	14.5
A(I)	3.3	3.1	3.2	3.2	3.2	
V(I)	7.88	8.26	8.08	8.18	8.20	
X STA.	14.5	15.3	16.2	17.3	18.4	21.6
A(I)	3.2	3.3	3.5	3.5	9.1	
V(I)	8.07	7.86	7.46	7.38	2.87	

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File stra016.wsp
Hydraulic analysis for structure STRATH00180016 Date: 21-MAR-97
TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
*** RUN DATE & TIME: 10-17-97 14:40

===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1": USED WSI = CRWS.
WSI,CRWS = 496.85 497.13

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXIT1:XS	*****	-84	218	0.78	*****	497.91	497.13	1400	497.13
-143	*****	42	9922	1.22	*****	*****	0.95	6.42	

===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
"EXIT2" KRATIO = 1.72

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXIT2:XS	121	-74	295	0.36	1.40	499.31	*****	1400	498.95
-22	121	43	17094	1.04	0.00	0.00	0.54	4.75	
FULLV:FV	23	-75	309	0.33	0.14	499.47	*****	1400	499.14
0	23	44	18208	1.04	0.00	0.01	0.51	4.54	

<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

===110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.

WSLIM1,WSLIM2,DELTAY = 498.64 519.91 0.50

===115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.

WSLIM1,WSLIM2,CRWS = 498.64 519.91 499.56

===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 = 499.56 519.91 499.56

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	34	-45	185	1.10	*****	500.66	499.56	1400	499.56
34	34	45	10390	1.23	*****	*****	1.04	7.58	

<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.

WS3N,LSEL = 499.14 499.04

<<<<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	23	0	101	0.86	*****	499.94	497.64	752	499.08
0	*****	22	5026	1.00	*****	*****	0.61	7.44	

TYPE	PPCD	FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	0.	6.	0.800	0.041	499.04	*****	*****	*****

XSID:CODE	SRDL	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RDWAY:RG	7.	20.	0.20	0.67	500.58	0.00	649.	499.97

	Q	WLEN	LEW	REW	DMAX	DAVG	VMAX	VAVG	HAVG	CAVG
LT:	625.	65.	-65.	0.	3.1	1.5	6.8	6.4	2.1	3.1
RT:	24.	15.	22.	37.	0.2	0.1	3.4	19.3	0.7	2.7

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	17	-49	242	0.67	0.30	500.78	499.56	1400	500.11
34	18	62	14069	1.28	0.00	0.00	0.79	5.80	

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

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

FIRST USER DEFINED TABLE.

XSID:CODE	SRDL	LEW	REW	Q	K	AREA	VEL	WSEL
EXIT1:XS	-144.	-85.	42.	1400.	9922.	218.	6.42	497.13
EXIT2:XS	-23.	-75.	43.	1400.	17094.	295.	4.75	498.95
FULLV:FV	0.	-76.	44.	1400.	18208.	309.	4.54	499.14
BRIDG:BR	0.	0.	22.	752.	5026.	101.	7.44	499.08
RDWAY:RG	7.	*****	625.	649.	*****	0.	2.00	499.97
APPRO:AS	34.	-50.	62.	1400.	14069.	242.	5.80	500.11

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXIT1:XS	497.13	0.95	491.95	512.07	*****	*****	0.78	497.91	497.13
EXIT2:XS	*****	0.54	493.52	515.24	1.40	0.00	0.36	499.31	498.95
FULLV:FV	*****	0.51	493.59	515.31	0.14	0.00	0.33	499.47	499.14
BRIDG:BR	497.64	0.61	493.63	499.08	*****	*****	0.86	499.94	499.08
RDWAY:RG	*****	*****	496.90	509.39	0.20	*****	0.67	500.58	499.97
APPRO:AS	499.56	0.79	493.65	519.91	0.30	0.00	0.67	500.78	500.11

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File stra016.wsp
 Hydraulic analysis for structure STRATH00180016 Date: 21-MAR-97
 TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
 *** RUN DATE & TIME: 10-17-97 14:40

===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1": USED WSI = CRWS.
 WSI,CRWS = 497.29 497.51

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXIT1:XS	*****	-85	266	0.92	*****	498.43	497.51	1900	497.51
-143	*****	43	12878	1.17	*****	*****	0.95	7.13	

===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
 "EXIT2" KRATIO = 1.76

EXIT2:XS	121	-82	361	0.45	1.50	499.93	*****	1900	499.48
-22	121	48	22632	1.04	0.00	0.00	0.57	5.26	
FULLV:FV	23	-82	378	0.41	0.15	500.09	*****	1900	499.68
0	23	50	24247	1.04	0.00	0.01	0.54	5.03	

<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

===110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.

WSLIM1,WSLIM2,DELTAY = 499.18 519.91 0.50

===115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.

WSLIM1,WSLIM2,CRWS = 499.18 519.91 500.18

===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 = 500.18 519.91 500.18

APPRO:AS	34	-49	249	1.16	*****	501.34	500.18	1900	500.18
34	34	64	14578	1.29	*****	*****	1.03	7.62	

<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.

WS3N,LSEL = 499.68 499.04

<<<<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	23	0	101	0.88	*****	499.96	497.65	762	499.08
0	*****	22	5026	1.00	*****	*****	0.61	7.54	

TYPE	PPCD	FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	0.	6.	0.800	0.041	499.04	*****	*****	*****

XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RDWAY:RG	7.	20.	0.21	0.80	501.21	0.01	1153.	500.49

	Q	WLEN	LEW	REW	DMAX	DAVG	VMAX	VAVG	HAVG	CAVG
LT:	972.	82.	-72.	10.	3.6	1.7	7.4	7.0	2.4	3.2
RT:	181.	49.	10.	60.	0.7	0.5	4.7	8.0	1.2	2.9

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	17	-52	304	0.80	0.37	501.43	500.18	1900	500.63
34	19	76	18332	1.31	0.00	0.01	0.82	6.24	

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
EXIT1:XS	-144.	-86.	43.	1900.	12878.	266.	7.13	497.51
EXIT2:XS	-23.	-83.	48.	1900.	22632.	361.	5.26	499.48
FULLV:FV	0.	-83.	50.	1900.	24247.	378.	5.03	499.68
BRIDG:BR	0.	0.	22.	762.	5026.	101.	7.54	499.08
RDWAY:RG	7.	*****	972.	1153.	*****	*****	2.00	500.49
APPRO:AS	34.	-53.	76.	1900.	18332.	304.	6.24	500.63

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXIT1:XS	497.51	0.95	491.95	512.07	*****	*****	0.92	498.43	497.51
EXIT2:XS	*****	0.57	493.52	515.24	1.50	0.00	0.45	499.93	499.48
FULLV:FV	*****	0.54	493.59	515.31	0.15	0.00	0.41	500.09	499.68
BRIDG:BR	497.65	0.61	493.63	499.08	*****	*****	0.88	499.96	499.08
RDWAY:RG	*****	*****	496.90	509.39	0.21	*****	0.80	501.21	500.49
APPRO:AS	500.18	0.82	493.65	519.91	0.37	0.00	0.80	501.43	500.63

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File testio.wsp
 Hydraulic analysis for structure STRATH00180016 Date: 21-MAR-97
 TH 18 crosses W Br Ompompanoosuc River at junction with TH 07
 *** RUN DATE & TIME: 12-12-97 15:17

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXIT1:XS	*****	0.	78.	0.69	*****	495.93	494.95	520.	495.23
-144.	*****	38.	3052.	1.00	*****	*****	0.81	6.67	

===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
 "EXIT2" KRATIO = 1.80

EXIT2:XS	121.	-3.	111.	0.34	1.95	497.88	*****	520.	497.54
-23.	121.	35.	5503.	1.00	0.00	0.00	0.48	4.68	

FULLV:FV	23.	-3.	117.	0.31	0.19	498.08	*****	520.	497.77
0.	23.	35.	5933.	1.00	0.00	0.01	0.45	4.43	

<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

APPRO:AS	34.	0.	79.	0.68	0.37	498.65	*****	520.	497.97
34.	34.	26.	4214.	1.00	0.19	0.02	0.67	6.61	

<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

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

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
BRIDG:BR	23.	0.	71.	0.84	0.28	498.27	496.88	520.	497.43
0.	23.	22.	3991.	1.00	0.11	0.00	0.71	7.34	

TYPE	PCPD	FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	0.	1.	1.000	0.047	499.04	*****	*****	*****

XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RDWAY:RG	7.							

<<<<EMBANKMENT IS NOT OVERTOPPED>>>>

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	17.	-7.	87.	0.55	0.27	498.83	497.16	520.	498.28
34.	17.	27.	4288.	1.00	0.30	0.01	0.65	5.95	

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
0.175	0.000	5155.	2.	23.	497.99

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

FIRST USER DEFINED TABLE.

XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXIT1:XS	-144.	0.	38.	520.	3052.	78.	6.67	495.23
EXIT2:XS	-23.	-3.	35.	520.	5503.	111.	4.68	497.54
FULLV:FV	0.	-3.	35.	520.	5933.	117.	4.43	497.77
BRIDG:BR	0.	0.	22.	520.	3991.	71.	7.34	497.43
RDWAY:RG	7.	*****		0.	*****		2.00	*****
APPRO:AS	34.	-7.	27.	520.	4288.	87.	5.95	498.28

XSID:CODE	XLKQ	XRKQ	KQ
APPRO:AS	2.	23.	5155.

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXIT1:XS	494.95	0.81	491.95	511.58	*****		0.69	495.93	495.23
EXIT2:XS	*****	0.48	493.52	512.49	1.95	0.00	0.34	497.88	497.54
FULLV:FV	*****	0.45	493.59	512.56	0.19	0.00	0.31	498.08	497.77
BRIDG:BR	496.88	0.71	493.63	499.08	0.28	0.11	0.84	498.27	497.43
RDWAY:RG	*****		499.81	507.41	*****				
APPRO:AS	497.16	0.65	493.65	507.51	0.27	0.30	0.55	498.83	498.28

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION

Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure STRATH00180016, in Strafford, Vermont.

APPENDIX D:
HISTORICAL DATA FORM

Structure Number STRATH00180016

General Location Descriptive

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

Date (MM/DD/YY) 03 / 23 / 95

Highway District Number (I - 2; nn) 04

County (FIPS county code; I - 3; nnn) 017

Town (FIPS place code; I - 4; nnnnn) 70675

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

Waterway (I - 6) West Branch Ompompanoosuc River

Road Name (I - 7): -

Route Number TH018

Vicinity (I - 9) @ JCT W CL3 TH7

Topographic Map Chelsea

Hydrologic Unit Code: 01080103

Latitude (I - 16; nnnn.n) 43540

Longitude (I - 17; nnnnn.n) 72235

Select Federal Inventory Codes

FHWA Structure Number (I - 8) 10091000160910

Maintenance responsibility (I - 21; nn) 03

Maximum span length (I - 48; nnnn) 0011

Year built (I - 27; YYYY) 1991

Structure length (I - 49; nnnnnn) 000035

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

Deck Width (I - 52; nn.n) 140

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) B

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

Structure type (I - 43; nnn) 402

Year Reconstructed (I - 106) 0000

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

Clear span (nnn.n ft) -

Number of spans (I - 45; nnn) 002

Vertical clearance from streambed (nnn.n ft) 005.0

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

Waterway of full opening (nnn.n ft²) -

Comments:

The structural inspection report dated 6/13/94 indicates the structure is a two span railroad rail stringer type bridge with a timber deck. The abutments are concrete and reported in "like new" condition. The footings of each abutment are indicated as exposed at the surface but are not undermined. Each abutment has stone fill protection in front of the wall. The pier consists of a concrete footing on four pressure treated timber columns with diagonal pressure treated wooden plank bracing. Overall the pier (bent) is noted in fairly good condition. The streambed material is reported as consisting of stone and gravel with a few randomly distributed boulders. (Continued, page 34)

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 of 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:

Channel scour is noted as not evident. Minor bank erosion is mentioned. Furthermore, debris accumulation is noted as minor. The riprap mentioned in the report is noted as natural stone and boulders.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area (*DA*) 6.28 mi² Lake/pond/swamp area 0 mi²
Watershed storage (*ST*) 0 %
Bridge site elevation 1140 ft Headwater elevation 2380 ft
Main channel length 4.94 mi
10% channel length elevation 1120 ft 85% channel length elevation 2040 ft
Main channel slope (*S*) 248.31 ft / mi

Watershed Precipitation Data

Average site precipitation - _____ in Average headwater precipitation - _____ in
Maximum 2yr-24hr precipitation event (*I*(24,2)) - _____ 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:

There is no benchmark information available.

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:

There is no foundation material information available.

Comments:

There are no bridge plans available.

Cross-sectional Data

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

Source (FEMA, VTAOT, Other)? -

Comments: **There is no cross-section information available.**

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: **There is no cross-section information available.**

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

Qa/Qc Check by: RB Date: 4/9/96

Computerized by: RB Date: 4/9/96

Reviewed by: LKS Date: 12/12/97

Structure Number STRATH00180016

A. General Location Descriptive

1. Data collected by (First Initial, Full last name) M. IVANOFF Date (MM/DD/YY) 10 / 19 / 1995
2. Highway District Number 04 Mile marker 0
- County Orange (0170) Town Strafford (70675)
- Waterway (I - 6) West Branch Ompompanoosuc River Road Name -
- Route Number TH018 Hydrologic Unit Code: 01080103
3. Descriptive comments:
The bridge is located at the junction of TH 17 and TH 18.

B. Bridge Deck Observations

4. Surface cover... LBUS 6 RBUS 5 LBDS 6 RBDS 6 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 2 (1- pool; 2- riffle)
6. Bridge structure type 2 (1- single span; 2- multiple span; 3- single arch; 4- multiple arch; 5- cylindrical culvert; 6- box culvert; or 7- other)
7. Bridge length 35 (feet) Span length 11 (feet) Bridge width 14 (feet)

Road approach to bridge:

8. LB 1 RB 0 (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	<u>0</u>	<u>-</u>	<u>0</u>	<u>0</u>
RBUS	<u>0</u>	<u>-</u>	<u>0</u>	<u>0</u>
RBDS	<u>0</u>	<u>-</u>	<u>0</u>	<u>0</u>
LBDS	<u>0</u>	<u>-</u>	<u>0</u>	<u>0</u>

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? N (Y or N)

Where? - (LB, RB) Severity -

Range? - feet - (US, UB, DS) to - feet -

Channel impact zone 2: Exist? N (Y or N)

Where? - (LB, RB) Severity -

Range? - feet - (US, UB, DS) to - feet -

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

18. Bridge Type: 1a

1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

2- Vertical abutments and wingwalls, sloping embankment
Wingwalls 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.)

7. Bridge dimensions are from the VTAOT files. The measured bridge length is 35.4 ft and the bridge span is 21.6 ft. The left span opening from the abutment to the pier is 10 ft.

C. Upstream Channel Assessment

21. Bank height (BF)		22. Bank angle (BF)		26. % Veg. cover (BF)		27. Bank material (BF)		28. Bank erosion (BF)	
20. SRD	LB	RB	LB	RB	LB	RB	LB	RB	LB
<u>20.0</u>	<u>3.5</u>			<u>3.5</u>	<u>3</u>	<u>3</u>	<u>435</u>	<u>435</u>	<u>0</u>
23. Bank width <u>40.0</u>		24. Channel width <u>30.0</u>		25. Thalweg depth <u>28.5</u>		29. Bed Material <u>4356</u>			
30. Bank protection type: LB <u>2</u> RB <u>2</u>		31. Bank protection condition: LB <u>1</u> RB <u>1</u>							

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. The bank protection is natural bank material that extends beyond 300 ft upstream.

There is bedrock control 108 to 180 ft upstream along the left bank and channel.

33. Point/Side bar present? N (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: - 35. Mid-bar width: -
 36. Point bar extent: - feet - (US, UB) to - feet - (US, UB, DS) positioned - %LB to - %RB
 37. Material: -
 38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):
There are no pointbars upstream at this site.

39. Is a cut-bank present? N (Y or if N type ctrl-n cb) 40. Where? - (LB or RB)
 41. Mid-bank distance: - 42. Cut bank extent: - feet - (US, UB) to - feet - (US, UB, DS)
 43. Bank damage: - (1- eroded and/or creep; 2- slip failure; 3- block failure)
 44. Cut bank comments (eg. additional cut banks, protection condition, etc.):
There are no cut-banks upstream at this site.

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.):
There is no channel scour upstream at this site.

49. Are there major confluences? Y (Y or if N type ctrl-n mc) 50. How many? 1
 51. Confluence 1: Distance 208 52. Enters on LB (LB or RB) 53. Type 1 (1- perennial; 2- ephemeral)
 Confluence 2: Distance - Enters on - (LB or RB) Type - (1- perennial; 2- ephemeral)
 54. Confluence comments (eg. confluence name):
 -

D. Under Bridge Channel Assessment

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

56. Height (BF)

LB RB

18.0

57 Angle (BF)

LB RB

1.0

61. Material (BF)

LB RB

2

7

62. Erosion (BF)

LB RB

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? N (1- Upstream; 2- At bridge; 3- Both)
67. Debris Potential - ____ (1- Low; 2- Moderate; 3- High) 68. Capture Efficiency 1 (1- Low; 2- Moderate; 3- High)
69. Is there evidence of ice build-up? 2 (Y or N) Ice Blockage Potential N (1- Low; 2- Moderate; 3- High)
70. Debris and Ice Comments:

2

There are trees along the banks but native stones offer protection. The capture efficiency of the bridge is increased because of the timber pier.

<u>Abutments</u>	71. Attack ∠(BF)	72. Slope (Qmax)	73. Toe loc. (BF)	74. Scour Condition	75. Scour depth	76. Exposure depth	77. Material	78. Length
LABUT		0	90	2	2	0	1	90.0
RABUT	1	0	90			2	2	21.5

Pushed: LB or RB

Toe Location (Loc.): 0- even, 1- set back, 2- protrudes

Scour cond.: 0- not evident; 1- evident (comment); 2- footing exposed; 3- undermined footing; 4- piling exposed;
5- settled; 6- failed

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

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

0

0.5

1

The maximum exposure of 1.2 ft along the left abutment is at the downstream junction between the corner of the abutment and wingwall.

The maximum exposure of 0.7 ft along the right abutment is at the downstream junction between the corner of the abutment and wingwall.

80. Wingwalls:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?
USLWW:	_____	_____	_____	_____	_____
USRWW:	<u>Y</u>	_____	<u>1</u>	_____	<u>2</u>
DSLWW:	<u>0</u>	_____	<u>1</u>	_____	<u>Y</u>
DSRWW:	<u>1</u>	_____	<u>2</u>	_____	<u>0</u>

81. Angle? Length?

21.5

1.0

13.0

14.0

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	<u>0.5</u>	<u>2</u>	<u>Y</u>	<u>0</u>	<u>1</u>	<u>1</u>	<u>1</u>	<u>3</u>
Condition	<u>Y</u>	<u>0</u>	<u>1</u>	<u>1.0</u>	<u>1</u>	<u>1</u>	<u>1</u>	<u>1</u>
Extent	<u>1</u>	<u>1.5</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	-

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.):

-
-
-
-
2
1
1
2
3
1

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		3.0	5.0	90.0	85.0	75.0
Pier 2	3.5	5.0	499	85.0	0.6	0.6
Pier 3	494.6	494.3	-	2	-	-
Pier 4	-	-	-	-	-	-

Level 1 Pier Descr.	1	2	3	4
86. Location (BF)		M	-	-
87. Type		3	-	-
88. Material		1	-	-
89. Shape		2	-	-
90. Inclined?		N	-	-
91. Attack $\angle$ (BF)		0	-	-
92. Pushed		-	-	-
93. Length (feet)	-	-	-	-
94. # of piles		UNK	-	-
95. Cross-members		2	-	-
96. Scour Condition		2	-	-
97. Scour depth	Y	0	-	-
98. Exposure depth	MC	0.8	-	-

LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP

1- Solid pier, 2- column, 3- bent

1- Wood; 2- concrete; 3- metal; 4- stone

1- Round; 2- Square; 3- Pointed

Y- yes; N- no

LB or RB

0- none; 1- laterals; 2- diagonals; 3- both

0- not evident; 1- evident (comment);
2- footing exposed; 3- piling exposed;
4- undermined footing; 5- settled; 6- failed

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

-
-
-
-
-
-
-
-
-
-

E. Downstream Channel Assessment

100.

SRD	Bank height (BF)		Bank angle (BF)		% Veg. cover (BF)		Bank material (BF)		Bank erosion (BF)				
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB			
-	-	-	-	-	-	-	The	pier	con-	sists			
Bank width (BF)		-	Channel width (Amb)		-	Thalweg depth (Amb)		-	Bed Material of 4				
Bank protection type (Qmax):			LB	ver-	RB	tica	Bank protection condition:			LB	l	RB	pres

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.):

sure treated timbers with 3 diagonal bents set on a pointed concrete footing. The footing is exposed 0.8 feet along the left side with the stream flowing around both sides.

4
4
435
45
1

101. Is a drop structure present? 1 (Y or N, if N type ctrl-n ds)

102. Distance: - feet

103. Drop: - feet

104. Structure material: 435 (1- steel sheet pile; 2- wood pile; 3- concrete; 4- other)

105. Drop structure comments (eg. downstream scour depth):

6
2
2
1
1

Placed stones extend 15 ft along both banks with native stones extending beyond 300 ft downstream on both

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

Point bar extent: e is a feet bed (US, UB, DS) to rock feet con (US, UB, DS) positioned tro %LB to lat %RB

Material: 140

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

to 168 ft downstream. Further steps extend to 230 ft downstream with approximately a 20 ft drop.

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

Cut bank extent: _____ 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.):

N

-

There is no drop structure downstream at this site.

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

Scour dimensions: Length _____ Width _____ Depth: _____ Positioned N %LB to - %RB

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

-

-

-

-

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

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

Confluence 2: Distance re Enters on are (LB or RB) Type no (1- perennial; 2- ephemeral)

Confluence comments (eg. confluence name):

pointbars downstream at this site.

F. Geomorphic Channel Assessment

107. Stage of reach evolution _____

1- Constructed

2- Stable

3- Aggraded

4- Degraded

5- Laterally unstable

6- Vertically and laterally unstable

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

Y
LB
40
15
DS
75
DS
1
-

109. G. Plan View Sketch

- N

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number: STRATH00180016 Town: STRAFFORD
 Road Number: TH 18 County: ORANGE
 Stream: W. BR. OMPOMPANOOSUC RIVER

Initials LKS Date: 08/21/97 Checked: EMB

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

Critical Velocity of Bed Material (converted to English units)
 $V_c = 11.21 \cdot y_1^{0.1667} \cdot D_{50}^{0.33}$ with $S_s = 2.65$
 (Richardson and Davis, 1995, p. 28, eq. 16)

Approach Section

Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	1400	1900	520
Main Channel Area, ft ²	138	153	87
Left overbank area, ft ²	85	112	0
Right overbank area, ft ²	18	39	0
Top width main channel, ft	28	28	33
Top width L overbank, ft	50	53	0
Top width R overbank, ft	34	48	0
D50 of channel, ft	0.2115	0.2115	0.2115
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y ₁ , average depth, MC, ft	4.9	5.5	2.6
y ₁ , average depth, LOB, ft	1.7	2.1	ERR
y ₁ , average depth, ROB, ft	0.5	0.8	ERR
Total conveyance, approach	14076	18333	4293
Conveyance, main channel	10143	12013	4293
Conveyance, LOB	3640	5472	0
Conveyance, ROB	294	849	0
Percent discrepancy, conveyance	-0.0071	-0.0055	0.0000
Q _m , discharge, MC, cfs	1008.8	1245.0	520.0
Q _l , discharge, LOB, cfs	362.0	567.1	0.0
Q _r , discharge, ROB, cfs	29.2	88.0	0.0
V _m , mean velocity MC, ft/s	7.3	8.1	6.0
V _l , mean velocity, LOB, ft/s	4.3	5.1	ERR
V _r , mean velocity, ROB, ft/s	1.6	2.3	ERR
V _{c-m} , crit. velocity, MC, ft/s	8.7	8.9	7.9
V _{c-l} , crit. velocity, LOB, ft/s	ERR	ERR	ERR
V _{c-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

$y_2 = (Q_2^2 / (131 * D_m^{(2/3)} * W_2^2))^{(3/7)}$ Converted to English Units
 $y_s = y_2 - y_{\text{bridge}}$
 (Richardson and Davis, 1995, p. 32, eq. 20, 20a)

Bridge Section	Q100	Q500	Other Q
(Q) total discharge, cfs	1400	1900	520
(Q) discharge thru bridge, cfs	752	762	520
Main channel conveyance	5026	5026	3983
Total conveyance	5026	5026	3983
Q2, bridge MC discharge, cfs	752	762	520
Main channel area, ft ²	102	102	69
Main channel width (normal), ft	21.5	21.5	21.5
Cum. width of piers in MC, ft	0.6	0.6	0.6
W, adjusted width, ft	20.9	20.9	20.9
y _{bridge} (avg. depth at br.), ft	4.88	4.88	3.30
D _m , median (1.25*D ₅₀), ft	0.264375	0.264375	0.264375
y ₂ , depth in contraction, ft	3.90	3.95	2.85
y _s , scour depth (y ₂ -y _{bridge}), ft	-0.98	-0.93	-0.46

Armoring

$D_c = [(1.94 * V^2) / (5.75 * \log(12.27 * y / D_{90}))^2] / [0.03 * (165 - 62.4)]$
 Depth to Armoring = $3 * (1 / P_c - 1)$
 (Federal Highway Administration, 1993)

Downstream bridge face property	100-yr	500-yr	Other Q
Q, discharge thru bridge MC, cfs	752	762	520
Main channel area (DS), ft ²	102	102	69
Main channel width (normal), ft	21.5	21.5	21.5
Cum. width of piers, ft	0.6	0.6	0.6
Adj. main channel width, ft	20.9	20.9	20.9
D ₉₀ , ft	0.6498	0.6498	0.6498
D ₉₅ , ft	0.8727	0.8727	0.8727
D _c , critical grain size, ft	0.2685	0.2757	0.3361
P _c , Decimal percent coarser than D _c	0.355	0.339	0.251
Depth to armoring, ft	1.46	1.61	3.01

Pressure Flow Scour (contraction scour for orifice flow conditions)

Chang pressure flow equation $H_b + Y_s = C_q * q_{br} / V_c$
 $C_q = 1 / C_f * C_c$ $C_f = 1.5 * Fr^{0.43}$ (≤ 1) $C_c = \text{SQRT}[0.10 (H_b / (y_a - w) - 0.56)] + 0.79$ (≤ 1)
 Umbrell pressure flow equation
 $(H_b + Y_s) / y_a = 1.1021 * [(1 - w / y_a) * (V_a / V_c)]^{0.6031}$
 (Richardson and other, 1995, p. 144-146)

	Q100	Q500	OtherQ
Q, total, cfs	1400	1900	520
Q, thru bridge MC, cfs	752	762	520
Vc, critical velocity, ft/s	8.71	8.86	7.85
Va, velocity MC approach, ft/s	7.31	8.14	5.98
Main channel width (normal), ft	21.5	21.5	21.5
Cum. width of piers in MC, ft	0.6	0.6	0.6
W, adjusted width, ft	20.9	20.9	20.9
qbr, unit discharge, ft ² /s	36.0	36.5	24.9
Area of full opening, ft ²	102.0	102.0	69.0
Hb, depth of full opening, ft	4.88	4.88	3.30
Fr, Froude number, bridge MC	0.61	0.61	0
Cf, Fr correction factor (≤ 1.0)	1.00	1.00	0.00
**Area at downstream face, ft ²	N/A	N/A	N/A
**Hb, depth at downstream face, ft	N/A	N/A	N/A
**Fr, Froude number at DS face	ERR	ERR	ERR
**Cf, for downstream face (≤ 1.0)	N/A	N/A	N/A
Elevation of Low Steel, ft	499.04	499.04	0
Elevation of Bed, ft	494.16	494.16	-3.30
Elevation of Approach, ft	500.11	500.63	0
Friction loss, approach, ft	0.3	0.37	0
Elevation of WS immediately US, ft	499.81	500.26	0.00
ya, depth immediately US, ft	5.65	6.10	3.30
Mean elevation of deck, ft	499.97	499.97	0
w, depth of overflow, ft (≥ 0)	0.00	0.29	0.00
Cc, vert contrac correction (≤ 1.0)	0.96	0.96	1.00
**Cc, for downstream face (≤ 1.0)	ERR	ERR	ERR
Ys, scour w/Chang equation, ft	-0.60	-0.58	N/A
Ys, scour w/Umbrell equation, ft	0.72	1.32	N/A

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

**Ys, scour w/Chang equation, ft N/A N/A N/A

**Ys, scour w/Umbrell equation, ft N/A N/A 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 ($y_s = y_2 - y_{\text{bridgeDS}}$)

y2, from Laursen's equation, ft	3.90	3.95	2.85
WSEL at downstream face, ft	--	--	--
Depth at downstream face, ft	N/A	N/A	N/A
Ys, depth of scour (Laursen), ft	N/A	N/A	N/A

Abutment Scour

Froehlich's Abutment Scour

$Y_s/Y_1 = 2.27 \cdot K_1 \cdot K_2 \cdot (a'/Y_1)^{0.43} \cdot Fr_1^{0.61+1}$
(Richardson and Davis, 1995, p. 48, eq. 28)

Characteristic	Left Abutment			Right Abutment		
	100 yr Q	500 yr Q	Other Q	100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	1400	1900	520	1400	1900	520
a', abut.length blocking flow, ft	49.8	53.5	6.4	40.8	54.7	5.4
Ae, area of blocked flow ft ²	32.78	27.27	5.83	35.08	43.76	8.05
Qe, discharge blocked abut., cfs	--	--	14.86	--	--	31.47
(If using Qtotal_overbank to obtain Ve, le						
Ve, (Qe/Ae), ft/s	4.25	5.05	2.55	3.36	3.56	3.91
ya, depth of f/p flow, ft	0.66	0.51	0.91	0.86	0.80	1.49
--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	85	85	85	95	95	95
K2	0.99	0.99	0.99	1.01	1.01	1.01
Fr, froude number f/p flow	0.567	0.614	0.471	0.614	0.587	0.564
ys, scour depth, ft	6.19	5.68	3.37	7.15	7.47	4.92

HIRE equation ($a'/y_a > 25$)

$y_s = 4 \cdot Fr^{0.33} \cdot y_1 \cdot K / 0.55$

(Richardson and Davis, 1995, p. 49, eq. 29)

a' (abut length blocked, ft)	49.8	53.5	6.4	40.8	54.7	5.4
y1 (depth f/p flow, ft)	0.66	0.51	0.91	0.86	0.80	1.49
a'/y1	75.66	104.96	7.03	47.45	68.38	3.62
Skew correction (p. 49, fig. 16)	0.98	0.98	0.98	1.01	1.01	1.01
Froude no. f/p flow	0.57	0.61	0.47	0.61	0.59	0.56
Ys w/ corr. factor K1/0.55:						
vertical	3.90	3.10	ERR	5.38	4.93	ERR
vertical w/ ww's	3.20	2.54	ERR	4.41	4.05	ERR
spill-through	2.15	1.71	ERR	2.96	2.71	ERR

Abutment riprap Sizing

Isbash Relationship

$$D50 = y * K * Fr^2 / (Ss - 1) \text{ and } D50 = y * K * (Fr^2)^{0.14} / (Ss - 1)$$

(Richardson and Davis, 1995, p112, eq. 81,82)

Characteristic	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	0.63	0.62	0.95	0.63	0.62	0.95
y, depth of flow in bridge, ft	4.90	7.14	4.09	4.90	7.14	4.09
Median Stone Diameter for riprap at: left abutment						right abutment, ft
Fr<=0.8 (vertical abut.)	1.20	1.70	ERR	1.20	1.70	ERR
Fr>0.8 (vertical abut.)	ERR	ERR	1.69	ERR	ERR	1.69

Pier Scour

$$y_s / y_1 = 2.0 * K_1 * K_2 * K_3 * K_4 * (a / y_1)^{0.65} * Fr_1^{0.43}$$

(Richardson and Davis, 1995, p. 36, eq. 21)

K1, corr. factor for pier nose shape

Sharp nose, 0.9; round nose, cylinder, or cylinder grp., 1.0; square nose, 1.1

K2, corr. factor attack angle (see Table 3, p 37)

$$K_2 = [\cos(\text{attackangle}) + L/a * \sin(\text{attackangle})]^{0.65}$$

K3, corr. factor for bed condition

Clear-water, plane bed, antidune, 1.1; med. dunes, 1.1-1.2 (see Tab.4,p37)

K4, corr. factor for armoring (the following equations are in Si units)

$$K_4 = [1 - 0.89 * (1 - V_r)^2]^{0.5}$$

$$V_r = (V_1 - V_i) / (V_{c90} - V_i)$$

$$V_1 = 0.645 * ((D50/a)^{0.053}) * V_{c50}$$

$$V_c = 6.19 * (y^{1/6}) * (D_c^{1/3})$$

Note for round nose piers:

$y_s \leq 2.4$ times the pier width (a) for $Fr \leq 0.8$

$y_s \leq 3.0$ times the pier width (a) for $Fr > 0.8$

Pier 1	Q100	Q500	Qother
Pier stationing, ft	10.8	10.8	10.8
Area of WSPRO flow tube, ft ²	4.6	4.6	3.1
Skewed width of flow tube, ft	0.797	0.897	0.697
y1, pier approach depth, ft	5.77	5.13	4.45
y1 in meters	1.759	1.563	1.356
V1, pier approach velocity, ft/s	8.25	8.36	8.46
a, pier width, ft	0.6	0.6	0.6
L, pier length, ft	10.6	10.6	10.6
Fr1, Froude number at pier	0.605	0.651	0.707
Pier attack angle, degrees	0	0	0
K1, shape factor	1.1	1.1	1.1
K2, attack factor	1.00	1.00	1.00
K3, bed condition factor	1.1	1.1	1.1
D50, ft	0.2115	0.2115	0.2115
D50, m	0.064462	0.064462	0.064462
D90, ft	0.6498	0.6498	0.6498
D90, m	0.198049	0.198049	0.198049
Vc50,critical velocity(D50),m/s	2.727	2.674	2.611
Vc90,critical velocity(D90),m/s	3.964	3.887	3.796
Vi,incipient velocity,m/s	1.664	1.632	1.594
Vr, velocity ratio	0.370	0.406	0.447
K4, armor factor	0.80	0.83	0.85
ys, scour depth (K4 applicable) ft	2.08	2.12	2.15
ys, scour depth (K4 not applied)ft	ERR	ERR	ERR

Pier rip-rap sizing

$D50 = 0.692 (K \cdot V)^2 / (Ss - 1) \cdot 2 \cdot g$
 (Richardson and Davis, 1995, p.115, eq. 83)

Pier-shape coefficient (K), round nose, 1.5; square nose, 1.7
 Characteristic avg. channel velocity, V, (Q/A):
 (Mult. by 0.9 for bankward piers in a straight, uniform reach,
 up to 1.7 for a pier in main current of flow around a bend)

Pier 1	Q100	Q500	Qother
K, pier shape coeff.	1.7	1.7	1.7
V, velocity on pier, ft/s	8.25	8.4	9.3
D50, median stone diameter, ft	1.28	1.33	1.63