LEVEL II SCOUR ANALYSIS FOR BRIDGE 43 (CHELTH00460043) on TOWN HIGHWAY 46, crossing JAIL BROOK, CHELSEA, VERMONT

U.S. Geological Survey
Open-File Report 97-386

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 43 (CHELTH00460043) on TOWN HIGHWAY 46, crossing JAIL BROOK, CHELSEA, VERMONT

By SCOTT A. OLSON

U.S. Geological Survey
Open-File Report 97-386

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

Pembroke, New Hampshire

1997

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

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, 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

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
References.....	18
Appendixes:	
A. WSPRO input file.....	19
B. WSPRO output file.....	21
C. Bed-material particle-size distribution	26
D. Historical data form.....	28
E. Level I data form.....	34
F. Scour computations.....	44

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 CHELTH00460043 viewed from upstream (November 18, 1994).....	5
4. Downstream channel viewed from structure CHELTH00460043 (November 18, 1994).	5
5. Upstream channel viewed from structure CHELTH00460043 (November 18, 1994).	6
6. Structure CHELTH00460043 viewed from downstream (November 18, 1994).....	6
7. Water-surface profiles for the 100- and 500-year discharges at structure CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, Vermont.	15
8. Scour elevations for the 100- and 500-year discharges at structure CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, Vermont.	16

TABLES

1. Remaining footing/pile depth at abutments for the 100-year discharge at structure CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, Vermont.....	17
2. Remaining footing/pile depth at abutments for the 500-year discharge at structure CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, 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 43 (CHELTH00460043) ON TOWN HIGHWAY 46, CROSSING JAIL BROOK, CHELSEA, VERMONT

By Scott A. Olson

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure CHELTH00460043 on Town Highway 46 crossing Jail Brook, Chelsea, 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 New England Upland section of the New England physiographic province in central Vermont. The 4.68-mi² drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is best described as suburban with homes, lawns, and a few trees.

In the study area, Jail Brook has an incised, straight channel with a slope of approximately 0.02 ft/ft, an average channel top width of 32 ft and an average bank height of 6 ft. The channel bed material ranges from coarse sand to boulder with a median grain size (D_{50}) of 43.0 mm (0.141 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 18, 1994, indicated that the reach was stable.

The Town Highway 46 crossing of Jail Brook is a 27-ft-long, two-lane bridge consisting of one 23-foot concrete span (Vermont Agency of Transportation, written communication, August 25, 1994). The opening length of the structure parallel to the bridge face is 22.8 ft. The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately zero degrees to the opening and the opening-skew-to-roadway is also zero degrees.

Channel scour was not observed. However, the left abutment footing was exposed one foot. Scour countermeasures at the site consisted of type-2 stone fill (less than 36 inches diameter) on the banks and road embankments upstream and downstream of the bridge. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and recommended rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and 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 all modelled flows ranged from 1.1 to 1.2 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 5.0 to 6.5 ft at the left abutment and 4.7 to 6.2 ft at the right abutment. 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.

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 CHELTH00460043 **Stream** Jail Brook
County Orange **Road** TH46 **District** 4

Description of Bridge

Bridge length 27 **ft** **Bridge width** 26.2 **ft** **Max span length** 23 **ft**
Alignment of bridge to road (on curve or straight) Straight
Abutment type Vertical, concrete **Embankment type** None
Stone fill on abutment? No **Date of inspection** 11/18/94
Description of stone fill Type-2, along the banks upstream and downstream of the bridge.

Abutments and wingwalls are concrete. The left abutment footing is exposed 1.0 ft.

N

--

Is bridge skewed to flood flow according to N **survey?** Angle
11/18/94
<10%

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

	<u>Date of inspection</u> <u><10%</u>	<u>Percent of channel</u> <u>blocked horizontally</u>	<u>Percent of channel</u> <u>blocked vertically</u>
Level I	<u><10%</u>	<u>Moderate</u>	<u>e. There</u>
Level II	<u>is some debris caught on the channel bar at the downstream bridge</u>		
Potential for debris	<u>face.</u>		

November 18, 1994. Homes have been built directly on the edge of the channel.

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

Description of the Geomorphic Setting

General topography The channel is located within a narrow, flat valley with steep valley walls.
Just downstream of the site, the stream enters the flood plain of the White River.

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

Date of inspection 11/18/94

DS left: Steep channel bank to a narrow terrace.

DS right: Steep channel bank to a narrow terrace.

US left: Steep channel bank to a narrow terrace.

US right: Steep channel bank to a narrow terrace.

Description of the Channel

Average top width	<u>32</u>	Average depth	<u>6</u>
	<u>#</u> Cobbles/Boulders		<u>#</u> Cobbles/Boulders
Predominant bed material		Bank material	<u>Straight and stable</u>

with alluvial and constructed channel boundaries and a narrow flood plain.

11/18/94

Vegetative cover Lawns and homes with a few trees on the immediate channel bank.

DS left: Lawns and homes with a few trees on the immediate channel bank.

DS right: Lawns and homes with a few trees on the immediate channel bank.

US left: Lawns and homes with a few trees on the immediate channel bank.

US right: Y

Do banks appear stable? - yes, no, or other location and type of instability and
date of observation.

The assessment of 11/
18/94 noted a channel bar at the downstream bridge face. There is some debris caught on the bar.
Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 4.68 **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:** The site is located in the village of Chelsea. However, the drainage is considered rural.

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 ond

Calculated Discharges			
<u>920</u>		<u>1,450</u>	
Q₁₀₀	ft³/s	Q₅₀₀	ft³/s

The 100- and 500-year discharges are taken directly from the flood insurance study model (Dewberry and Davis, written communication, March 10, 1994). The selected discharges are within a range defined by flood frequency curves determined from 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 square on the upstream left corner of the concrete bridge deck (elev. 99.50 ft, arbitrary survey datum). RM2 is a chiseled square on downstream right corner of the concrete bridge deck (elev. 99.65 ft, 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>
EXITX	-46	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	14	1	Road Grade section
APPRO	54	1	Approach section

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

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). The analyses reported herein reflect conditions existing at the site at the time of the study. Furthermore, in the development of the model it was necessary to assume no accumulation of debris or ice at the site. Results of the hydraulic model are presented in the Bridge Hydraulic Summary, Appendix B, and figure 7.

Channel roughness factors (Manning's "n") used in the hydraulic model were estimated using field inspections at each cross section following the general guidelines described by Arcement and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.050 to 0.065, and overbank "n" values ranged from 0.045 to 0.075.

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 0.022 ft/ft. This was the 100-year water-surface profile slope immediately downstream of the bridge in the Flood Insurance Study for the Town of Chelsea (Federal Emergency Management Agency, 1980).

The approach section (APPRO) was surveyed 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 discharges, 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 99.7 *ft*
Average low steel elevation 98.2 *ft*

100-year discharge 920 *ft³/s*
Water-surface elevation in bridge opening 94.4 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 83.2 *ft²*
Average velocity in bridge opening 11.1 *ft/s*
Maximum WSPRO tube velocity at bridge 13.1 *ft/s*

Water-surface elevation at Approach section with bridge 97.0
Water-surface elevation at Approach section without bridge 95.9
Amount of backwater caused by bridge 1.1 *ft*

500-year discharge 1,450 *ft³/s*
Water-surface elevation in bridge opening 95.8 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 113 *ft²*
Average velocity in bridge opening 12.8 *ft/s*
Maximum WSPRO tube velocity at bridge 15.6 *ft/s*

Water-surface elevation at Approach section with bridge 98.8
Water-surface elevation at Approach section without bridge 97.3
Amount of backwater caused by bridge 1.5 *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 Laursen's live-bed contraction scour equation (Richardson and others, 1995, p. 30, equation 17). Contraction scour results are provided in Appendix F and shown in Figure 8.

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

<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>		
<i>Main channel</i>			
<i>Live-bed scour</i>	1.1	1.2	--
<i>Clear-water scour</i>	--	--	--
<i>Depth to armoring</i>	18.2	27.2	--
<i>Left overbank</i>	--	--	--
<i>Right overbank</i>	--	--	--
<i>Local scour:</i>			
<i>Abutment scour</i>	5.0	6.5	--
<i>Left abutment</i>	4.7	6.2	--
<i>Right abutment</i>			
<i>Pier scour</i>	--	--	--
<i>Pier 1</i>	--	--	--
<i>Pier 2</i>	--	--	--
<i>Pier 3</i>			

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>	1.6	2.1	--
<i>Left abutment</i>	1.6	2.1	--
<i>Right abutment</i>	--	--	--
<i>Piers:</i>	--	--	--
<i>Pier 1</i>	--	--	--
<i>Pier 2</i>

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, Vermont.

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, 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 920 cubic-feet per second											
Left abutment	0.0	--	98.1	--	90.3	1.1	5.0	--	6.1	84.2	--
Right abutment	22.8	--	98.3	--	89.9	1.1	4.7	--	5.8	84.1	--

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 CHELTH00460043 on Town Highway 46, crossing Jail Brook, Chelsea, 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 1,450 cubic-feet per second											
Left abutment	0.0	--	98.1	--	90.3	1.2	6.5	--	7.7	82.6	--
Right abutment	22.8	--	98.3	--	89.9	1.2	6.2	--	7.4	82.5	--

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.
- Federal Emergency Management Agency, 1980, Flood Insurance Study, Town of Chelsea, Orange County, Vermont: Washington, D.C., February 1980.
- 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. 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, 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 chel043.wsp
T2      Hydraulic analysis for structure CHELTH00460043   Date: 01-MAY-96
T3      Hydraulic Analysis for Chelsea bridge 43 over the Jail Brook by SAO
Q        920      1450
SK       0.022    0.022
*
J3       6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS      EXITX      -46
GR       -63.3,   96.68   -36.7,   95.79   -2.4,   94.00   0.0,   92.93
GR        2.4,   90.82    5.1,   89.32    6.5,   88.95    6.8,   88.62
GR        7.4,   87.89    8.9,   87.82   14.5,   88.11   18.6,   88.26
GR       20.2,   88.65   24.3,   90.81   29.9,   93.99   40.0,   94.89
GR       71.1,   95.59  104.1,   97.34
N        0.075      0.065      0.075
SA              -2.4      29.9
*
XS      FULLV      0 * * * 0.022
N        0.045      0.065      0.045
SA              -2.4      29.9
*
BR      BRIDG      0  98.21
GR        0.0,   98.14    0.9,   91.50    2.1,   91.51    2.3,   90.29
GR        3.4,   90.47    9.8,   90.66   16.6,   90.52   20.5,   89.96
GR       21.0,   89.93   21.1,   90.26   22.0,   90.30   22.0,   90.65
GR       22.8,   98.29    0.0,   98.14
CD        1 35.4 * * 80 1.4
N        0.050
*
XR      RDWAY      14 26
GR       -60.0, 105      -60.0, 99.84    0.0,   99.65   23.3,   99.68
GR       89.5, 99.82
*
AS      APPRO      54
GR       -54.7, 100.76   -6.6,   99.54   -2.9,   97.82   -2.6,   94.45
GR        0.0,   93.43    4.0,   91.65    4.5,   91.13    9.3,   91.04
GR       12.5,   91.58   17.0,   92.28   19.0,   93.16   19.9,   96.68
GR       23.7,   98.56   32.5,   99.90   79.0, 102.42
N        0.055      0.065      0.045
SA              -6.6      23.7
*
HP 1 BRIDG 94.41 1 94.41
HP 2 BRIDG 94.41 * * 920
HP 1 APPRO 97.04 1 97.04
HP 2 APPRO 97.04 * * 920
*
HP 1 BRIDG 95.78 1 95.78
HP 2 BRIDG 95.78 * * 1450
HP 1 APPRO 98.77 1 98.77
HP 2 APPRO 98.77 * * 1450
*
EX
ER

```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

U.S. Geological Survey WSPRO Input File chel043.wsp
 Hydraulic analysis for structure CHELTH00460043 Date: 01-MAY-96
 Hydraulic Analysis for Chelsea bridge 43 over the Jail Brook by SAO

CROSS-SECTION PROPERTIES: ISEQ = 3; SECID = BRIDG; SRD = 0.
 WSEL SA# AREA K TOPW WETP ALPH LEW REW QCR
 94.41 1 83. 4945. 22. 30. 1.00 1. 22. 920.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRIDG; SRD = 0.
 WSEL LEW REW AREA K Q VEL
 94.41 0.5 22.4 83.2 4945. 920. 11.06
 X STA. 0.5 3.0 4.2 5.2 6.2 7.2
 A(I) 7.5 4.7 4.0 3.9 3.8
 V(I) 6.17 9.78 11.40 11.85 12.11
 X STA. 7.2 8.1 9.1 10.1 11.0 11.9
 A(I) 3.7 3.6 3.6 3.6 3.5
 V(I) 12.47 12.81 12.80 12.73 13.07
 X STA. 11.9 12.9 13.8 14.7 15.7 16.6
 A(I) 3.6 3.6 3.5 3.6 3.6
 V(I) 12.89 12.83 13.07 12.80 12.80
 X STA. 16.6 17.5 18.4 19.4 20.4 22.4
 A(I) 3.7 3.7 4.1 4.5 7.4
 V(I) 12.39 12.30 11.32 10.24 6.20

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPRO; SRD = 54.
 WSEL SA# AREA K TOPW WETP ALPH LEW REW QCR
 97.04 2 110. 6013. 23. 30. 1.00 -3. 21. 1348.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPRO; SRD = 54.
 WSEL LEW REW AREA K Q VEL
 97.04 -2.8 20.6 109.8 6013. 920. 8.38
 X STA. -2.8 0.4 1.9 3.2 4.2 5.1
 A(I) 9.7 6.5 5.9 5.3 5.1
 V(I) 4.76 7.04 7.85 8.64 9.07
 X STA. 5.1 5.8 6.6 7.3 8.1 8.8
 A(I) 4.6 4.6 4.4 4.4 4.4
 V(I) 9.98 10.08 10.40 10.50 10.47
 X STA. 8.8 9.5 10.3 11.1 11.9 12.8
 A(I) 4.3 4.4 4.6 4.6 4.8
 V(I) 10.58 10.42 9.98 9.94 9.67
 X STA. 12.8 13.7 14.7 15.8 17.1 20.6
 A(I) 4.9 5.3 5.5 6.4 10.1
 V(I) 9.41 8.74 8.38 7.13 4.55

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File chel043.wsp
 Hydraulic analysis for structure CHELTH00460043 Date: 01-MAY-96
 Hydraulic Analysis for Chelsea bridge 43 over the Jail Brook by SAO

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

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	113.	7808.	22.	32.				1453.
95.78		113.	7808.	22.	32.	1.00	0.	23.	1453.

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

	WSEL	LEW	REW	AREA	K	Q	VEL
	95.78	0.3	22.5	113.4	7808.	1450.	12.79
X STA.		0.3	2.9	4.1		5.2	6.2
A(I)		10.7	6.4		5.7	5.2	5.0
V(I)		6.78	11.25		12.78	13.81	14.52
X STA.	7.2		8.1		9.0	10.0	10.9
A(I)		4.9	4.8		4.7	4.7	4.7
V(I)		14.92	15.06		15.34	15.51	15.45
X STA.	11.8		12.7		13.6	14.5	15.4
A(I)		4.7	4.7		4.8	4.7	4.8
V(I)		15.55	15.49		15.26	15.32	14.97
X STA.	16.3		17.3		18.2	19.2	20.3
A(I)		5.0	5.2		5.7	6.1	10.9
V(I)		14.52	13.97		12.76	11.89	6.64

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPRO; SRD = 54.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	2	154.	9311.	29.	36.				2034.
	3	0.	1.	1.	1.				0.
98.77		155.	9312.	30.	38.	1.00	-5.	25.	1988.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPRO; SRD = 54.

	WSEL	LEW	REW	AREA	K	Q	VEL
	98.77	-4.9	25.1	154.5	9312.	1450.	9.38
X STA.		-4.9	0.1	1.7		3.0	4.0
A(I)		14.9	9.3		7.9	7.4	6.9
V(I)		4.88	7.78		9.16	9.79	10.49
X STA.	5.0		5.8		6.6	7.4	8.2
A(I)		6.4	6.1		6.1	6.0	6.0
V(I)		11.27	11.84		11.97	12.09	12.07
X STA.	8.9		9.7		10.5	11.3	12.2
A(I)		5.9	6.0		6.1	6.3	6.5
V(I)		12.20	12.01		11.85	11.48	11.12
X STA.	13.1		14.1		15.1	16.3	17.7
A(I)		6.7	7.3		7.7	9.3	15.6
V(I)		10.76	9.94		9.46	7.83	4.64

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File chel043.wsp
Hydraulic analysis for structure CHELTH00460043 Date: 01-MAY-96
Hydraulic Analysis for Chelsea bridge 43 over the Jail Brook by SAO

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXITX:XS	*****	-1.	118.	0.95	*****	94.53	92.58	920.	93.58
-46.	*****	29.	6197.	1.00	*****	*****	0.70	7.82	
FULLV:FV	46.	-1.	118.	0.94	1.01	95.55	*****	920.	94.60
0.	46.	29.	6224.	1.00	0.00	0.01	0.70	7.79	
===125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.									
FNTEST,FR#,WSEL,CRWS = 0.80 0.99 95.93 95.90									
===110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.									
WSLIM1,WSLIM2,DELTAY = 94.10 102.42 0.50									
===115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.									
WSLIM1,WSLIM2,CRWS = 94.10 102.42 95.90									
===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.									
"APPRO" KRATIO = 0.66									
APPRO:AS	54.	-3.	84.	1.85	1.77	97.77	95.90	920.	95.93
54.	54.	20.	4138.	1.00	0.45	0.00	0.99	10.90	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									
===285 CRITICAL WATER-SURFACE ELEVATION A _ S _ S _ U _ M _ E _ D !!!!!									
SECID "BRIDG" Q,CRWS = 920. 94.41									

<<<<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	46.	1.	83.	1.90	*****	96.31	94.41	920.	94.41
0.	46.	22.	4947.	1.00	*****	*****	1.00	11.06	
TYPE PPCD FLOW C P/A LSEL BLEN XLAB XRAB									
1. **** 1. 1.000 ***** 98.21 ***** ***** *****									
XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL	
RDWAY:RG	14.		<<<<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	19.	-3.	110.	1.09	0.61	98.13	95.90	920.	97.04
54.	21.	21.	6019.	1.00	1.22	0.02	0.68	8.37	
M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL				
0.022	0.000	6703.	-2.	19.	96.38				

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

FIRST USER DEFINED TABLE.

XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXITX:XS	-46.	-1.	29.	920.	6197.	118.	7.82	93.58
FULLV:FV	0.	-1.	29.	920.	6224.	118.	7.79	94.60
BRIDG:BR	0.	1.	22.	920.	4947.	83.	11.06	94.41
RDWAY:RG	14.	*****		0.	*****		1.00	*****
APPRO:AS	54.	-3.	21.	920.	6019.	110.	8.37	97.04

XSID:CODE	XLKQ	XRKQ	KQ
APPRO:AS	-2.	19.	6703.

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXITX:XS	92.58	0.70	87.82	97.34	*****		0.95	94.53	93.58
FULLV:FV	*****	0.70	88.83	98.35	1.01	0.00	0.94	95.55	94.60
BRIDG:BR	94.41	1.00	89.93	98.29	*****		1.90	96.31	94.41
RDWAY:RG	*****		99.65	105.00	*****				
APPRO:AS	95.90	0.68	91.04	102.42	0.61	1.22	1.09	98.13	97.04

WSPRO OUTPUT FILE (continued)

U.S. Geological Survey WSPRO Input File chel043.wsp
Hydraulic analysis for structure CHELTH00460043 Date: 01-MAY-96
Hydraulic Analysis for Chelsea bridge 43 over the Jail Brook by SAO

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXITX:XS	*****	-18.	167.	1.28	*****	96.09	93.90	1450.	94.80
-46.	*****	39.	9768.	1.09	*****	*****	0.93	8.69	

===125 FR# EXCEEDS FNTEST AT SECID "FULLV": TRIALS CONTINUED.
FNTEST,FR#,WSEL,CRWS = 0.80 0.92 95.87 94.91

===110 WSEL NOT FOUND AT SECID "FULLV": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY = 94.30 98.35 0.50

===115 WSEL NOT FOUND AT SECID "FULLV": USED WSMIN = CRWS.
WSLIM1,WSLIM2,CRWS = 94.30 98.35 94.91

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
FULLV:FV	46.	-19.	170.	1.22	0.99	97.09	94.91	1450.	95.86
0.	46.	40.	10027.	1.08	0.00	0.01	0.92	8.55	

===125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.
FNTEST,FR#,WSEL,CRWS = 0.80 1.09 96.99 97.30

===110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY = 95.36 102.42 0.50

===115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.
WSLIM1,WSLIM2,CRWS = 95.36 102.42 97.30

===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 = 97.30 102.42 97.30

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	54.	-3.	116.	2.43	*****	99.73	97.30	1450.	97.30
54.	54.	21.	6472.	1.00	*****	*****	1.00	12.49	

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

===285 CRITICAL WATER-SURFACE ELEVATION A _ S _ S _ U _ M _ E _ D _ ! ! ! ! !
SECID "BRIDG" Q,CRWS = 1450. 95.78

<<<<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	46.	0.	113.	2.55	*****	98.32	95.78	1450.	95.78
0.	46.	23.	7805.	1.00	*****	*****	1.00	12.79	

TYPE	PCPD FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	****	1.	1.000	*****	98.21	*****	*****

XSID:CODE	SRDL	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RDWAY:RG	14.							
			<<<<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	19.	-5.	155.	1.37	0.60	100.14	97.30	1450.	98.77
54.	21.	25.	9318.	1.00	1.22	0.01	0.73	9.38	

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
0.074	0.000	10788.	-3.	20.	98.09

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

FIRST USER DEFINED TABLE.

XSID:CODE	SRDL	LEW	REW	Q	K	AREA	VEL	WSEL
EXITX:XS	-46.	-18.	39.	1450.	9768.	167.	8.69	94.80
FULLV:FV	0.	-19.	40.	1450.	10027.	170.	8.55	95.86
BRIDG:BR	0.	0.	23.	1450.	7805.	113.	12.79	95.78
RDWAY:RG	14.	*****		0.	*****		1.00	*****
APPRO:AS	54.	-5.	25.	1450.	9318.	155.	9.38	98.77

XSID:CODE	XLKQ	XRKQ	KQ
APPRO:AS	-3.	20.	10788.

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXITX:XS	93.90	0.93	87.82	97.34	*****		1.28	96.09	94.80
FULLV:FV	94.91	0.92	88.83	98.35	0.99	0.00	1.22	97.09	95.86
BRIDG:BR	95.78	1.00	89.93	98.29	*****		2.55	98.32	95.78
RDWAY:RG	*****		99.65	105.00	*****		*****	*****	*****
APPRO:AS	97.30	0.73	91.04	102.42	0.60	1.22	1.37	100.14	98.77

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION

Appendix C. Bed material particle-size distribution for three pebble count transects in the channel approach of structure CHELTH00460043, in Chelsea, Vermont.

APPENDIX D:
HISTORICAL DATA FORM

Structure Number CHELTH00460043

General Location Descriptive

Data collected by (First Initial, Full last name) M. IVANOFF

Date (MM/DD/YY) 08 / 25 / 94

Highway District Number (I - 2; nn) 04

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

Town (FIPS place code; I - 4; nnnnn) 13525

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

Waterway (I - 6) JAIL BRANCH

Road Name (I - 7): -

Route Number TH046

Vicinity (I - 9) AT JCT TH 46 + VT 113

Topographic Map Chelsea

Hydrologic Unit Code: 01080105

Latitude (I - 16; nnnn.n) 43593

Longitude (I - 17; nnnnn.n) 72267

Select Federal Inventory Codes

FHWA Structure Number (I - 8) 10090400430904

Maintenance responsibility (I - 21; nn) 03

Maximum span length (I - 48; nnnn) 0023

Year built (I - 27; YYYY) 1964

Structure length (I - 49; nnnnnn) 000027

Average daily traffic, ADT (I - 29; nnnnnn) 000050

Deck Width (I - 52; nn.n) 262

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) 101

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) 007.0

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

Waterway of full opening (nnn.n ft²) -

Comments:

Structural report of 9/24/93 indicates a concrete slab type bridge. The junction with 113 is just behind the right abutment. Both concrete abutment stems and wings are relatively clean with minor spalling at the upstream wing of the left abutment. The left abutment footing is exposed for the entire length. The streambed at the upstream end of the left abutment is 6 inches below the top of the footing and the downstream end is 18 inches below the top of footing. No apparent undermining. The stream has a straight alignment to the bridge. The stream bed consist of stone and boulder with a few gravel deposits. Minor embankment erosion and drift/vegetation near the downstream fascia. (continued on page 31)

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: Stone boulders with a few gravel deposits

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:

Stone fill is natural stone and boulder. The bridge has a paved road approach with flat embankments.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area (*DA*) 4.68 mi² Lake/pond/swamp area 0 mi²
Watershed storage (*ST*) 0 %
Bridge site elevation 840 ft Headwater elevation 1980 ft
Main channel length 4.08 mi
10% channel length elevation 970 ft 85% channel length elevation 1650 ft
Main channel slope (*S*) 222.67 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:

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? *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? Y *If no, type ctrl-n xs*

Source (FEMA, VTAOT, Other)? VTAOT

Note: some cross sections are available for channel.

Comments:

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)? FEMA

Comments: **Flood Insurance Study model.**

Station	127	140	153								
Feature	LAB		RAB								
Low cord elevation	834.1		834.1								
Bed elevation	825.9	825.9	825.9								
Low cord to bed length	8.2		8.2								

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

APPENDIX E:

LEVEL I DATA FORM

Qa/Qc Check by: MAI Date: 2/3/95

Computerized by: MAI Date: 3/15/95

Reviewed by: SAO Date: 5/20/95

Structure Number CHELTH00460043

A. General Location Descriptive

1. Data collected by (First Initial, Full last name) D. SONG Date (MM/DD/YY) 11 / 18 / 1994
2. Highway District Number 04 Mile marker 0
- County ORANGE (017) Town CHELSEA (13525)
- Waterway (I - 6) JAIL BRANCH Road Name -
- Route Number TH046 Hydrologic Unit Code: 01080105
3. Descriptive comments:
At the junction of TH 46 and VT 113.

B. Bridge Deck Observations

4. Surface cover... LBUS 2 RBUS 2 LBDS 2 RBDS 2 Overall 2
(2b us,ds,lb,rb: 1- Urban; 2- Suburban; 3- Row crops; 4- Pasture; 5- Shrub- and brushland; 6- Forest; 7- Wetland)
5. Ambient water surface... US 2 UB 2 DS 2 (1- pool; 2- riffle)
6. Bridge structure type 1 (1- single span; 2- multiple span; 3- single arch; 4- multiple arch; 5- cylindrical culvert; 6- box culvert; or 7- other)
7. Bridge length 27 (feet) Span length 23 (feet) Bridge width 26.2 (feet)

Road approach to bridge:

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

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

10. Embankment slope (run / rise in feet / foot):

US left -- US right --

	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	<u>2</u>	<u>1</u>	<u>0</u>	<u>-</u>
RBUS	<u>2</u>	<u>1</u>	<u>1</u>	<u>1</u>
RBDS	<u>2</u>	<u>1</u>	<u>0</u>	<u>-</u>
LBDS	<u>2</u>	<u>1</u>	<u>2</u>	<u>1</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 parallel to abut. face

3- Spill through abutments

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

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

7. Measured bridge length: 28, clear span: 22.8, and width: 26 feet.

11. Protection consists of boulders on the top of or at the ends of wingwalls.

Channel is straight throughout the reach; banks have been protected and built-up both upstream and downstream.

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	RB	
<u>27.5</u>	<u>8.0</u>			<u>6.5</u>	<u>2</u>	<u>1</u>	<u>541</u>	<u>541</u>	<u>1</u>	<u>1</u>	
23. Bank width		<u>35.0</u>	24. Channel width		<u>45.0</u>	25. Thalweg depth		<u>30.5</u>	29. Bed Material		<u>453</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.):

27. Banks are covered by stone fill (boulders). There is some localized slumping of the stone fill material.

30. Protection extends beyond 200 ft. upstream of the bridge.

Numerous drainage pipes (minor) into the 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.):
NO POINT BARS
A small bar comprised of pebbles and gravel exists at low flow on the right bank.

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

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 (1- natural bank; 2- abutment; 3- artificial levee)

56. Height (BF)		57 Angle (BF)	
LB	RB	LB	RB
<u>13.0</u>		<u>0.5</u>	

61. Material (BF)		62. Erosion (BF)	
LB	RB	LB	RB
<u>2</u>	<u>7</u>	<u>7</u>	-

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

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

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

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

453

63. Bed material ranges from coarse sand to boulder.

65. **Debris and Ice** Is there debris accumulation? ____ (Y or N) 66. Where? Y (1- Upstream; 2- At bridge; 3- Both)
 67. Debris Potential 2 (1- Low; 2- Moderate; 3- High) 68. Capture Efficiency 2 (1- Low; 2- Moderate; 3- High)
 69. Is there evidence of ice build-up? 1 (Y or N) Ice Blockage Potential N (1- Low; 2- Moderate; 3- High)
 70. Debris and Ice Comments:

1

67. Some accumulation of debris on channel bar at downstream face of the bridge.

<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	23.0

Pushed: LB or RB

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

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

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

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

0

0

1

74. RABUT: Only the top of the footing is exposed, level with the channel; the footing is lower (about 1 ft.) than the left abutment footing.

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>.5</u>	_____	<u>Y</u>
DSRWW:	<u>1</u>	_____	<u>0</u>	_____	<u>0</u>

81.	Angle?	Length?
	<u>23.0</u>	_____
	<u>0.5</u>	_____
	<u>28.0</u>	_____
	<u>28.0</u>	_____

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

82. Bank / Bridge Protection:

Location	USLWW	USRWW	LABUT	RABUT	LB	RB	DSLWW	DSRWW
Type	0	2	Y	0	-	1	-	-
Condition	Y	0	1	0	-	2	-	-
Extent	1	1	2	0	2	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.):

-
-
-
-
2
1
2
1
1
2

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		7.0	8.0	85.0	75.0	80.0
Pier 2	8.0	8.0	-	85.0	-	-
Pier 3	-	-	-	-	-	-
Pier 4	-	-	-	-	-	-

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

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
-	-		-		-	NO	PIE	RS		
Bank width (BF)		-	Channel width		-	Thalweg depth		-	Bed Material	
Bank protection type (Qmax):		LB		RB		Bank protection condition:		LB		RB

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

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

1
1
541
541
0
1
453
2
2
2
1

Bed material ranges from course sand to boulder.

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

102. Distance: - feet

103. Drop: - feet

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

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

protection extends beyond 200 ft. downstream of the bridge. The left bank protection has localized slumping about 30 ft. downstream, exposing the bank.

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: 5 feet 18 (US, UB, DS) to 5 feet UB (US, UB, DS)

Bank damage: 15 (1- eroded and/or creep; 2- slip failure; 3- block failure)

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

DS

5

80

4

Is channel scour present? Thi (Y or if N type ctrl-n cs) Mid-scour distance: s is a

Scour dimensions: Length bar Width at Depth: the Positioned do %LB to wns %RB

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

ream bridge face in the center of the channel.

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

N

109. G. Plan View Sketch

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

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number: CHELTH00460043 Town: CHELSEA
 Road Number: TH46 County: ORANGE
 Stream: JAIL BROOK

Initials SAO Date: 5/20/97 Checked: ECW

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

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

Approach Section

Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	920	1450	0
Main Channel Area, ft ²	110	154	0
Left overbank area, ft ²	0	0	0
Right overbank area, ft ²	0	1	0
Top width main channel, ft	23.4	28.6	0
Top width L overbank, ft	0	0	0
Top width R overbank, ft	0	1.4	0
D50 of channel, ft	0.141	0.141	0
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
 y ₁ , average depth, MC, ft	 4.7	 5.4	 N/A
y ₁ , average depth, LOB, ft	N/A	N/A	N/A
y ₁ , average depth, ROB, ft	N/A	0.7	N/A
 Total conveyance, approach	 6013	 9312	 0
Conveyance, main channel	6013	9311	0
Conveyance, LOB	0	0	0
Conveyance, ROB	0	1	0
Percent discrepancy, conveyance	0.0000	0.0000	N/A
Q _m , discharge, MC, cfs	920.0	1449.8	N/A
Q _l , discharge, LOB, cfs	0.0	0.0	N/A
Q _r , discharge, ROB, cfs	0.0	0.2	N/A
 V _m , mean velocity MC, ft/s	 8.4	 9.4	 N/A
V _l , mean velocity, LOB, ft/s	N/A	N/A	N/A
V _r , mean velocity, ROB, ft/s	N/A	0.2	N/A
V _{c-m} , crit. velocity, MC, ft/s	7.6	7.7	N/A
V _{c-l} , crit. velocity, LOB, ft/s	N/A	N/A	N/A
V _{c-r} , crit. velocity, ROB, ft/s	N/A	N/A	N/A

Results

Live-bed(1) or Clear-Water(0) Contraction Scour?

Main Channel	1	1	N/A
Left Overbank	N/A	N/A	N/A
Right Overbank	N/A	N/A	N/A

Live-Bed Contraction Scour

Laursen's Live Bed Contraction Scour

$$y_2/y_1 = (Q_2/Q_1)^{(6/7)} * (W_1/W_2)^{(k_1)}$$

$$y_s = y_2 - y_{\text{bridge}}$$

(Richardson and others, 1995, p. 30, eq. 17 and 18)

Characteristic	Approach			Bridge		
	100 yr	500 yr	Other Q	100 yr	500 yr	Other Q
Q1, discharge, cfs	920	1450	0	920	1450	0
Total conveyance	6013	9312	0	4945	7808	0
Main channel conveyance	6013	9311	0	4945	7808	0
Main channel discharge	920	1450	N/A	920	1450	N/A
Area - main channel, ft ²	110	154	0	83.2	113	0
(W1) channel width, ft	23.4	28.6	0	21.9	22.2	0
(Wp) cumulative pier width, ft	0	0	0	0	0	0
W1, adjusted bottom width(ft)	23.4	28.6	0	21.9	22.2	0
D50, ft	0.141	0.141	0.141			
w, fall velocity, ft/s (p. 32)	3.1	3.1	0			
y, ave. depth flow, ft	4.70	5.38	N/A	3.80	5.09	N/A
S1, slope EGL	0.041	0.049	0			
P, wetted perimeter, MC, ft	30	36	0			
R, hydraulic Radius, ft	3.667	4.278	N/A			
V*, shear velocity, ft/s	2.200	2.598	N/A			
V*/w	0.710	0.838	N/A			
Bed transport coeff., k1, (0.59 if V*/w<0.5; 0.64 if .5<V*/w<2; 0.69 if V*/w>2.0 p. 33)						
k1	0.64	0.64	0			
y2,depth in contraction, ft	4.90	6.33	N/A			
ys, scour depth, ft (y2-y_bridge)	1.11	1.24	N/A			

Armoring

$$D_c = [(1.94 * V^2) / (5.75 * \log(12.27 * y / D_{90}))^2] / [0.03 * (165 - 62.4)]$$

$$\text{Depth to Armoring} = 3 * (1 / P_c - 1)$$

(Federal Highway Administration, 1993)

Downstream bridge face property	100-yr	500-yr	Other Q
Q, discharge thru bridge MC, cfs	920	1450	N/A
Main channel area (DS), ft ²	83.2	113	0
Main channel width (normal), ft	21.9	22.2	0.0
Cum. width of piers, ft	0.0	0.0	0.0

Adj. main channel width, ft	21.9	22.2	0.0
D90, ft	0.8560	0.8560	0.0000
D95, ft	1.1480	1.1480	0.0000
Dc, critical grain size, ft	0.7734	0.9043	N/A
Pc, Decimal percent coarser than Dc	0.113	0.091	0.000
Depth to armor, ft	18.21	27.23	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 others, 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	920	1450	0	920	1450	0
a', abut.length blocking flow, ft	0.8	2.7	0	0.7	5.1	0
Ae, area of blocked flow ft ²	2.4	8.1	0	2	10.8	0
Qe, discharge blocked abut., cfs	11.5	39.2	0	9.2	50	0
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	4.79	4.84	N/A	4.60	4.63	N/A
ya, depth of f/p flow, ft	3.00	3.00	N/A	2.86	2.12	N/A
--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	0.488	0.492	N/A	0.480	0.561	N/A
ys, scour depth, ft	5.04	6.46	N/A	4.71	6.16	N/A
HIRE equation (a'/ya > 25)						
$y_s = 4 \cdot Fr^{0.33} \cdot y_1 \cdot K / 0.55$						
(Richardson and others, 1995, p. 49, eq. 29)						
a' (abut length blocked, ft)	0.8	2.7	0	0.7	5.1	0
y1 (depth f/p flow, ft)	3.00	3.00	N/A	2.86	2.12	N/A
a'/y1	0.27	0.90	N/A	0.25	2.41	N/A
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.49	0.49	N/A	0.48	0.56	N/A
Ys w/ corr. factor K1/0.55:						
vertical	N/A	N/A	N/A	N/A	N/A	N/A
vertical w/ ww's	N/A	N/A	N/A	N/A	N/A	N/A

spill-through	N/A	N/A	N/A	N/A	N/A	N/A
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)						
Downstream bridge face property	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	1	1	0	1	1	0
y, depth of flow in bridge, ft	3.80	5.09	0.00	3.80	5.09	0.00
Median Stone Diameter for riprap at: left abutment				right abutment, ft		
Fr<=0.8 (vertical abut.)	N/A	N/A	0.00	N/A	N/A	0.00
Fr>0.8 (vertical abut.)	1.59	2.13	N/A	1.59	2.13	N/A
Fr<=0.8 (spillthrough abut.)	N/A	N/A	0.00	N/A	N/A	0.00
Fr>0.8 (spillthrough abut.)	1.40	1.88	N/A	1.40	1.88	N/A