Modified Level II Streambed-Scour Analysis for Structure I-164-7-6973 Crossing Bluegrass Creek in Vanderburgh County, Indiana

By JOHN T. WILSON, BRET A. ROBINSON, DAVID C. VOELKER, and ROBERT L. MILLER

Prepared in cooperation with the
INDIANA DEPARTMENT OF TRANSPORTATION

U.S. GEOLOGICAL SURVEY
Open-File Report 97-331

Indianapolis, Indiana
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
Water Resources Division
5957 Lakeside Boulevard
Indianapolis, IN 46278-1996

Copies of this report can be purchased from:
U.S. Geological Survey
Branch of Information Services
Box 25286
Federal Center
Denver, CO 80225

CONTENTS

Tables

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square foot (ft^2)	929.0	square centimeter
feet per second (ft/s)	0.3048	meters per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Abbreviations used in this report:

D_{50}	median diameter of bed material
Q100	100-year discharge
FEMA	Federal Emergency Management Agency
HEC	Hydraulic Engineering Circular
IDNR	Indiana Department of Natural Resources
INDOT	Indiana Department of Transportation
USGS	U. S. Geological Survey
WSPRO	Water Surface PROfile model

Modified Level II Streambed-Scour Analysis for Structure I-164-7-6973 Crossing Bluegrass Creek in Vanderburgh County, Indiana

By John T. Wilson, Bret A. Robinson, David C. Voelker, *and* Robert L. Miller

ABSTRACT

Level II scour evaluations follow a process in which hydrologic, hydraulic, and sediment-transport data are evaluated to calculate the depth of scour that may result when a given discharge is routed through a bridge opening. The results of the modified Level II analysis for structure I-164-7-6973 on Interstate 164 crossing Bluegrass Creek in Vanderburgh County, Indiana, are presented. The site is near the town of Daylight in the northeastern part of Vanderburgh County. Scour depths were computed with the Water Surface PROfile model, version V050196, which incorporates the scour-calculation procedures outlined in Hydraulic Engineering Circular No. 18. Total scour depths at the piers were approximately 13.1 feet for the modeled discharge of 4,440 cubic feet per second and approximately 18.7 feet for the modeled discharge of 6,220 cubic feet per second.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the Indiana Department of Transportation (INDOT), is conducting Level II scour analyses at a number of bridges throughout Indiana. This report describes the methods applied and the modeling results for bridge I-164-7-6973.

Background and Scope

Level I scour assessment is a process where a large number of bridges are studied as a group. Assessments usually are made by evaluating a combination of geomorphic, hydrologic, and bridge-characteristic data. The results help investigators determine which bridges appear to be most likely to experience streambed-scour problems and which bridges appear to be relatively immune to problems brought on by streambed scour (for example, bridges built on bedrock).

When applied correctly, Level I scour assessments provide an investigator with information to identify those bridges that appear to be relatively safe and those bridges that fall into higher risk categories.

Level II scour evaluations describe the process for an investigator to apply a model to a bridge site and calculate the potential depth of scour that may result from a given flood event. Level II analyses involve the application of basic hydrologic, hydraulic, and sediment-transport engineering concepts and may include an evaluation of flood history, channel hydraulic conditions (for example, water-surface profile analysis), and basic sediment-transport analyses such as scour calculations (Lagasse and others, 1995).

The methods and model outlined in Hydraulic Engineering Circular (HEC) No. 18 (Richardson and Davis, 1995) formulate the basis for Level II scour evaluations. Methods used in this study for Level II scour evaluations are a modification of the HEC-18 standards. These modifications were made to comply with the methodology requested by INDOT (Merril Dougherty, Indiana Department of Transportation, oral commun., 1996). Descriptions of the specific modifications are given in the "Evaluation Methods" section of this report.

This report presents the methods followed for modeling, special considerations for this study site, and the input for and the output from the Water Surface PROfile (WSPRO) model.

Site Description

The study site is located near the town of Daylight in the northeastern part of Vanderburgh County. The drainage area for the site is approximately 35.3 mi^2 (Merril Dougherty, Indiana Department of Transportation, written commun., 1997). The predominant land use in the basin is agricultural; in the immediate vicinity of the bridge, the land is predominantly pasture land.

Within the immediate vicinity of the bridge, Bluegrass Creek has a channel-bed slope of approximately 0.00075 ft/ft. The channel-bed material is silt-clay, and the channel banks consist of silt-clay. At the time of the Level I site visit on March 4, 1992, the banks were observed to have 5 to 25 percent woody vegetative cover; the field report noted that the banks were experiencing fluvial erosion.

The Interstate 164 crossing of Bluegrass Creek is a 163-ft-long, multi-lane bridge consisting of three spans supported by concrete and steel piers and sloping riprap-covered spill-through abutments. Additional details describing conditions at the site are included in the Level I data base (Hopkins and Robinson, unpub. data, 1997). Photographs of the site, taken at the time of the Level I site visit, are archived at the USGS office in Indianapolis.

EVALUATION METHODS

The methods described in this section apply to a number of bridge sites in Indiana being evaluated for scour and outline the procedures requested by INDOT for these modified Level II scour analyses. The principal modification requested by INDOT was that the input data to the model come from or be estimated from existing data sources; no additional field data were collected. Actual methods used in the scour evaluation at this particular bridge site use the most applicable method possible, given the data available.

To determine drainage area, either published values found in Hoggatt (1975) or USGS 7.5-minute topographic maps with Hoggatt's original drainage-area delineations were used. Where there are no published data, drainage-area segments measured from the maps produced by Hoggatt were either subtracted from downstream sites or added to upstream sites published by Hoggatt (1975).

In Indiana, flood discharges are coordinated by agreement among State and Federal agencies. At sites where flood discharges officially are coordinated among State and Federal agencies in Indiana, the coordinated 100-year discharge (Q100) was modeled. INDOT also provided an additional flood discharge for these coordinated sites in excess of the Q100 to be modeled.

If a flood discharge was not coordinated, the USGS examined Federal Emergency Management Agency (FEMA) studies for Q100 determinations. Where FEMA studies did not produce a Q100, the USGS contacted IDNR for an estimated Q100 in the vicinity of the site being studied. If IDNR did not have a Q100, data from nearby USGS streamflow-gaging stations were analyzed with nearby and similar drainage basins that have been coordinated. At sites having no coordinated discharge data, the two discharges used in the model were 1) the approximated Q100 and 2) a discharge equal to 1.7 times the approximated Q100.

Most of the cross-section and bridge-opening geometry data were taken from the bridge plans (Indiana State Highway Commission, 1985) provided by INDOT. Bridge plans are presumed to be representative of current conditions at the site. To determine the cross-section geometry, a line was drawn on the bridge plans parallel to the bridge stationing and approximately one bridge width from the bridge. For sites where the bridge plans did not extend far enough laterally for collection of all cross-section data required for WSPRO model analysis, additional data were collected from 7.5-minute topographic maps.

The roadway and embankment profile was taken from the bridge and highway plans for those sites where roadway overtopping was expected. The INDOT bridge plans and 7.5-minute topographic maps were used as a guide, based on the water-surface elevations calculated by the WSPRO model, to determine if roadway overtopping might occur.

Roughness values (n-values) for the main channel were estimated by viewing photographs archived from the Level I scour assessments. The n-values for the overbanks were assigned on the basis of the surface-cover data summarized in the Level I data base (Hopkins and Robinson, unpub. data, 1997). From those data, the following roughness values were assigned to the surface-cover categories: urban—0.050, suburban—0.035, row crop—0.045, pasture—0.035, brush—0.120, forest—0.100, and wetland (any area covered by standing water)—0.100. The n-values for the overbanks were adjusted if the Level I photographs provided sufficient detail to warrant an adjustment.

WSPRO version V050196 was used to model flow through the study site. Starting water-surface elevation was obtained with a slope-conveyance computation. The channel-bed slope in the immediate vicinity of the bridge was estimated from the 7.5-minute topographic map and was used as the slope of the energy grade line for this computation.

WSPRO version V050196 includes a field that allows the input of up to four scour-adjustment factors (K1 to K4). For this modeling, the default value for K4 (bed armoring) was chosen. For scour-adjustment factors K1 and K2 (pier-nose shape and angle of attack, respectively), input values were determined by evaluating the data archived in the Level I data base (Hopkins and Robinson, unpub. data, 1997). For the K3 factor (bed forms), a value of 1.1 was applied in all cases.

In some cases, piers set on the overbanks are constructed with footings that are higher in elevation than pier footings in the main channel. In these situations, if the channel position changes, the piers that were initially constructed on the overbank may become part of the main channel. Therefore, to evaluate total potential scour, the model results obtained for contraction scour and deepest local scour in the main channel were added and applied to all piers in the bridge opening. This methodology allowed for an evaluation of potential undermining of pier supports in the event that future channel movement placed overbank piers in the main channel.

Where bridge pairs have a continuous abutment or fill between the bridges that does not allow expansion of flow, the bridge pair was modeled as one bridge. Sites with discontinuous abutments, allowing expansion between the bridges, were modeled as two separate bridges. In those cases, a valley cross section was measured between the bridges and used as the approach section for the downstream bridge and as the exit section for the upstream bridge.

At sites with no embankment to function as a weir or at sites where the tailwater drowns out the embankment, a composite bridge and road section was used to compute flow. Those sites were computed with friction-loss equations rather than with a bridge routine.

Total scour is taken as the sum of local scour plus contraction scour. If the model predicted negative contraction scour (aggradation), the contraction-scour value was assumed to be zero in determining the total scour depth (table 1). This assumption was made so that a negative contraction scour would not mask the potentially detrimental effects of local scour at a pier. No abutment scour evaluations were made in this study.

Table 1. Cumulative scour depths for the modeled discharges at structure I-164-7-6973 crossing Bluegrass Creek in Vanderburgh County, Indiana

Pier number[1]	Stationing from bridge plans[2]	Initial bed-elevation at pier (feet)	Main-channel contraction scour depth (feet)	Local scour depth (feet)	Worst-case total-scour depth[3] (feet)	Bottom elevation of pier (feet)	Worst-case bed elevation after scour[4] (feet)
Modeled discharge[5] is 4,440 cubic feet per second							
1	105+73	366	3.3	9.8	13.1	358.3	350.1
2	106+26	365	3.3	9.8	13.1	358.3	350.1
Modeled discharge is 6,220 cubic feet per second							
1	105+73	366	7.8	10.9	18.7	358.3	344.5
2	106+26	365	7.8	10.9	18.7	358.3	344.5

[1]Pier numbers were assigned from left to right as shown on the bridge plans.

[2]Stationing is the center line of the pier as determined from the bridge plans. Stationing from bridge plan, 105+73, represents a point 10,573 feet from an arbitrary starting location referenced on the bridge plans.

[3]Worst-case total-scour depths are generated by summing the calculated contraction-scour depth with the worst case of local scour.

[4]Worst-case bed elevation is computed by subtracting the worst-case total-scour depth from the lowest initial bed elevation in the bridge opening (363.2 feet).

[5]Coordinated discharge.

SPECIAL CONSIDERATIONS

Model runs indicate the water-surface elevation at the bridge is lower than the low-steel elevation for the modeled discharges. Therefore, there should be no pressure flow through the bridge opening for the discharges modeled.

RESULTS

Scour depths were computed with a version of WSPRO (Larry Arneson, Federal Highway Administration, written commun., 1996) modified from Shearman (1990). This version of WSPRO includes scour calculations in the model output. Scour depths were calculated assuming an infinite depth of material that could erode and a homogeneous particle-size distribution. The results of the scour analysis are presented in table 1; a complete input file and output results are presented in the appendix.

REFERENCES

Hoggatt, R.E., 1975, Drainage areas of Indiana streams: U.S. Geological Survey, Water Resources Division, 231 p.

Indiana State Highway Commission, 1985, Bridge plans Interstate Route 164: Bridge File I-164-7-6973.

Lagasse, P.F.; Schall, J.D.; Johnson, F.; Richardson, E.V.; and Chang, F., 1995, Stream stability at highway structures (2d ed.): Federal Highway Administration, Hydraulic Engineering Circular No. 20, Publication FHWA-IP-90-014, 144 p.

Richardson, E.V., and Davis, S.R., 1995, Evaluating scour at bridges (3d ed.): Federal Highway Administration, Hydraulic Engineering Circular No. 18, Publication FHWA-IP-90-017, 204 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, 177 p.

APPENDIX

WSPRO INPUT FILE

```
T1          I-164 OVER BLUEGRASS CREEK    I164-7-6973
T2          COUNTY: VANDERBURGH           QUAD: DAYLIGHT 194C
T3          7-31-97                       JOHN T. WILSON
Q           4440     6220
SK          .00075   .00075
XS   EXIT   0    23
GR          9750 380   10241 376   10537 374   10548 364   10576 364
GR         10590 374   10611 376   10621 378   10647 378   10656 376
GR         10774 376   10799 378   10848 380
N          .045        .036        .045
SA               10537       10590
XS   FULLV  155    23
BR   BRDGE  155    389.0    23
*          ***BRIDGE DECK SKEWED 23 DEGREES (FROM BRIDGE PLANS)***
GR         10522 389.0   10522 388.2   10525 388.2   10576 364.9   10582 364.8
GR         10584 363.9   10584 363.5   10587 363.2   10594 364.0   10610 364.9
GR         10624 364.9   10674 388.3   10677 388.2   10677 389.0   10522 389.0
N          .036
PD         365.3    2.0    1
PD         365.8    2.0    2
PD         365.8    4.0    3
CD         3     140     3     391
DC 0 BRDGE  10548  10651  10612  10661  *  4
*           ***DC LIMITS AT BRIDGE ARE LEW AND REW FOR Q1***
*           BXL      BXR      PW    *  *  K1   K2     K3
DP          10522    10677    2.0   *  *  1    2.0    1.1
DP          10522    10677    2.0   *  *  1    2.0    1.1
*           ***DP CARDS USE WHOLE BRIDGE OPENING FOR BXL/BXR***
*           ***NO PIERS IN MAIN CHANNEL***
XS   APPR  450
*          ***SECTION IS ADJUSTED FOR 23 DEGREES OF SKEW***
GR          9793 380   10189 376   10397 374   10413 372   10469 372   10554 374
GR         10612 374   10623 364   10648 364   10661 374   10706 376   10715 378
GR         10744 378   10761 378   10811 380   10811 385
N          .045        .036        .045
SA               10612       10661
HP 2 BRDGE  377.7  *  377.7    4440
HP 2 BRDGE  378.8  *  378.8    6220
EX
ER
```

WSPRO OUTPUT

```
   ************************  W S P R O  ***************************
      Federal Highway Administration  -  U. S. Geological Survey
            Model for Water-Surface Profile Computations.
         Run Date & Time:  8/ 4/97  2:13 pm      Version V050196
          Input File: bluegras.dat   Output File: bluegras.LST
   *-------------------------------------------------------------*
T1          I-164 OVER BLUEGRASS CREEK    I164-7-6973
T2          COUNTY: VANDERBURGH           QUAD: DAYLIGHT 194C
T3          7-31-97                       JOHN T. WILSON
Q           4440    6220

 ***   Processing Flow Data; Placing Information into Sequence  1   ***

SK          .00075  .00075

   ************************  W S P R O  ***************************
      Federal Highway Administration  -  U. S. Geological Survey
            Model for Water-Surface Profile Computations.
           Input Units: English  /  Output Units: English
   *-------------------------------------------------------------*
             I-164 OVER BLUEGRASS CREEK   I164-7-6973
          COUNTY: VANDERBURGH           QUAD: DAYLIGHT 194C
            7-31-97                       JOHN T. WILSON

         *-----------------------------------------------*
         *      Starting To Process Header Record EXIT   *
         *-----------------------------------------------*

XS   EXIT  0   23
GR          9750 380  10241 376  10537 374  10548 364  10576 364
GR         10590 374  10611 376  10621 378  10647 378  10656 376
GR         10774 376  10799 378  10848 380
N          .045       .036       .045
SA               10537      10590

 ***   Completed Reading Data Associated With Header Record EXIT    ***
 ***  Storing X-Section Data In Temporary File As Record Number  1  ***

 ***              Data Summary For Header Record EXIT              ***
 SRD Location:        0.   Cross-Section Skew:  23.0   Error Code   0
 Valley Slope:   .00000    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (13 pairs)
    X          Y            X          Y            X          Y
----------  ----------   ----------  ----------   ----------  ----------
 9750.000     380.000    10241.000     376.000    10537.000     374.000
10548.000     364.000    10576.000     364.000    10590.000     374.000
10611.000     376.000    10621.000     378.000    10647.000     378.000
10656.000     376.000    10774.000     376.000    10799.000     378.000
10848.000     380.000
----------  ----------   ----------  ----------   ----------  ----------
```

WSPRO OUTPUT

```
                Minimum and Maximum X,Y-coordinates
  Minimum X-Station:    9750.000  ( associated Y-Elevation:  380.000 )
  Maximum X-Station:   10848.000  ( associated Y-Elevation:  380.000 )
  Minimum Y-Elevation:   364.000  ( associated X-Station:  10576.000 )
  Maximum Y-Elevation:   380.000  ( associated X-Station:   9750.000 )

     X-coordinates & Horizontal Breakpoints Translated by Skew Angle
  X Input    X Skewed      X Input    X Skewed      X Input    X Skewed
---------- ----------    ---------- ----------    ---------- ----------
  9750.000   9815.663     10241.000  10267.630     10537.000  10540.100
 10548.000  10550.230     10576.000  10576.000     10590.000  10588.890
 10611.000  10608.220     10621.000  10617.420     10647.000  10641.360
 10656.000  10649.640     10774.000  10758.260     10799.000  10781.270
 10848.000  10826.380
---------- ----------    ---------- ----------    ---------- ----------

                   Roughness Data (  3 SubAreas )
                            Roughness   Horizontal
                  SubArea  Coefficient  Breakpoint
                  -------  -----------  ----------
                     1         .045        ---
                                ---       ********
                     2         .036        ---
                                ---       ********
                     3         .045        ---
                  -------  -----------  ----------

         *-----------------------------------------------------*
         *      Finished Processing Header Record EXIT         *
         *-----------------------------------------------------*

   ************************* W S P R O ****************************
      Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
           Input Units: English  /  Output Units: English
   *-------------------------------------------------------------*
              I-164 OVER BLUEGRASS CREEK   I164-7-6973
           COUNTY: VANDERBURGH           QUAD: DAYLIGHT 194C
             7-31-97                       JOHN T. WILSON

         *-----------------------------------------------------*
         *      Starting To Process Header Record FULLV        *
         *-----------------------------------------------------*

XS   FULLV  155   23

 ***   Completed Reading Data Associated With Header Record FULLV   ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  2  ***

 ***              Data Summary For Header Record FULLV              ***
 SRD Location:      155.   Cross-Section Skew:  23.0   Error Code   0
 Valley Slope:   .00000    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00
```

WSPRO OUTPUT

X,Y-coordinates (13 pairs)

X	Y	X	Y	X	Y
9750.000	380.000	10241.000	376.000	10537.000	374.000
10548.000	364.000	10576.000	364.000	10590.000	374.000
10611.000	376.000	10621.000	378.000	10647.000	378.000
10656.000	376.000	10774.000	376.000	10799.000	378.000
10848.000	380.000				

Minimum and Maximum X,Y-coordinates

Minimum X-Station:	9750.000	(associated Y-Elevation:	380.000)
Maximum X-Station:	10848.000	(associated Y-Elevation:	380.000)
Minimum Y-Elevation:	364.000	(associated X-Station:	10576.000)
Maximum Y-Elevation:	380.000	(associated X-Station:	9750.000)

X-coordinates & Horizontal Breakpoints Translated by Skew Angle

X Input	X Skewed	X Input	X Skewed	X Input	X Skewed
9750.000	9815.663	10241.000	10267.630	10537.000	10540.100
10548.000	10550.230	10576.000	10576.000	10590.000	10588.890
10611.000	10608.220	10621.000	10617.420	10647.000	10641.360
10656.000	10649.640	10774.000	10758.260	10799.000	10781.270
10848.000	10826.380				

Roughness Data (3 SubAreas)

SubArea	Roughness Coefficient	Horizontal Breakpoint
1	.045	---
	---	********
2	.036	---
	---	********
3	.045	---

---
* Finished Processing Header Record FULLV *

********** W S P R O **********
Federal Highway Administration - U. S. Geological Survey
Model for Water-Surface Profile Computations.
Input Units: English / Output Units: English

I-164 OVER BLUEGRASS CREEK I164-7-6973
COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C
7-31-97 JOHN T. WILSON

---
* Starting To Process Header Record BRDGE *

WSPRO OUTPUT

```
BR   BRDGE  155    389.0    23
GR         10522 389.0  10522 388.2  10525 388.2  10576 364.9  10582 364.8
GR         10584 363.9  10584 363.5  10587 363.2  10594 364.0  10610 364.9
GR         10624 364.9  10674 388.3  10677 388.2  10677 389.0  10522 389.0
N          .036
PD         365.3   2.0   1
PD         365.8   2.0   2
PD         365.8   4.0   3
CD         3    140    3    391

   ***   Completed Reading Data Associated With Header Record BRDGE   ***
+++072 NOTICE:  X-coordinate # 2 increased to eliminate vertical segment.
+++072 NOTICE:  X-coordinate # 7 increased to eliminate vertical segment.
+++072 NOTICE:  X-coordinate #14 increased to eliminate vertical segment.
   ***   Storing Bridge Data In Temporary File As Record Number  3    ***

   ***              Data Summary For Bridge Record BRDGE              ***
   SRD Location:      155.   Cross-Section Skew:  23.0   Error Code   0
   Valley Slope:  *******    Averaging Conveyance By Geometric Mean.
   Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                      X,Y-coordinates (15 pairs)
      X          Y          X          Y          X          Y
 ----------  ----------  ----------  ----------  ----------  ----------
  10522.000     389.000    10522.100     388.200    10525.000     388.200
  10576.000     364.900    10582.000     364.800    10584.000     363.900
  10584.100     363.500    10587.000     363.200    10594.000     364.000
  10610.000     364.900    10624.000     364.900    10674.000     388.300
  10677.000     388.200    10677.100     389.000    10522.000     389.000
 ----------  ----------  ----------  ----------  ----------  ----------

                  Minimum and Maximum X,Y-coordinates
   Minimum X-Station:   10522.000  ( associated Y-Elevation:  389.000 )
   Maximum X-Station:   10677.100  ( associated Y-Elevation:  389.000 )
   Minimum Y-Elevation:   363.200  ( associated X-Station:  10587.000 )
   Maximum Y-Elevation:   389.000  ( associated X-Station:  10522.000 )

       X-coordinates & Horizontal Breakpoints Translated by Skew Angle
    X Input    X Skewed      X Input    X Skewed      X Input    X Skewed
 ----------  ----------  ----------  ----------  ----------  ----------
  10522.000   10527.170    10522.100   10527.260    10525.000   10529.930
  10576.000   10576.870    10582.000   10582.400    10584.000   10584.240
  10584.100   10584.330    10587.000   10587.000    10594.000   10593.440
  10610.000   10608.170    10624.000   10621.060    10674.000   10667.080
  10677.000   10669.850    10677.100   10669.940    10522.000   10527.170
 ----------  ----------  ----------  ----------  ----------  ----------

                    Roughness Data (  1 SubAreas )
                           Roughness   Horizontal
                  SubArea  Coefficient  Breakpoint
                  -------  -----------  ----------
                     1         .036         ---
                  -------  -----------  ----------
```

WSPRO OUTPUT

```
                Discharge coefficient parameters
             BRType   BRWdth   EMBSS   EMBElv    UserCD
               3      140.000   3.00   391.000 **********

                    Pressure flow elements
                       AVBCEL     PFElev
                    *********    389.000

                      Abutment Parameters
      ABSLPL  ABSLPR   XTOELT    YTOELT    XTOERT    YTOERT
    ******* ******* ********* ********* ********* *********


                      Pier/Pile Data (  3 Group(s) )
                    Code Indicates Bridge Uses Piers
                     Group  Elevation  Gross Width  Number
                    ------  ---------  -----------  ------
                       1      365.300      2.000       1
                       2      365.800      2.000       2
                       3      365.800      4.000       3
                    ------  ---------  -----------  ------

          *-------------------------------------------------*
          *      Finished Processing Header Record BRDGE    *
          *-------------------------------------------------*

    ************************  W S P R O  ***************************
       Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
            Input Units: English  /  Output Units: English
    *-------------------------------------------------------------*
               I-164 OVER BLUEGRASS CREEK   I164-7-6973
            COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
              7-31-97                      JOHN T. WILSON
  DC 0 BRDGE  10548  10651  10612  10661  *  4
  DP         10522   10677   2.0  *  *  1   2.0   1.1
  DP         10522   10677   2.0  *  *  1   2.0   1.1

          *-------------------------------------------------*
          *      Starting To Process Header Record APPR     *
          *-------------------------------------------------*

  XS   APPR  450
  GR          9793 380  10189 376  10397 374  10413 372  10469 372  10554 374
  GR         10612 374  10623 364  10648 364  10661 374  10706 376  10715 378
  GR         10744 378  10761 378  10811 380  10811 385
  N          .045       .036       .045
  SA               10612      10661

   ***   Completed Reading Data Associated With Header Record APPR    ***
+++072 NOTICE:  X-coordinate #16 increased to eliminate vertical segment.
   ***  Storing X-Section Data In Temporary File As Record Number  4  ***
```

WSPRO OUTPUT

```
***              Data Summary For Header Record APPR                ***
SRD Location:      450.   Cross-Section Skew:     .0   Error Code    0
Valley Slope:   .00000    Averaging Conveyance By Geometric Mean.
Energy Loss Coefficients ->   Expansion:   .50   Contraction:    .00

                    X,Y-coordinates (16 pairs)
     X          Y          X          Y          X          Y
----------  ----------  ----------  ----------  ----------  ----------
 9793.000     380.000    10189.000     376.000    10397.000     374.000
10413.000     372.000    10469.000     372.000    10554.000     374.000
10612.000     374.000    10623.000     364.000    10648.000     364.000
10661.000     374.000    10706.000     376.000    10715.000     378.000
10744.000     378.000    10761.000     378.000    10811.000     380.000
10811.100     385.000
----------  ----------  ----------  ----------  ----------  ----------

                 Minimum and Maximum X,Y-coordinates
 Minimum X-Station:    9793.000  ( associated Y-Elevation:  380.000 )
 Maximum X-Station:   10811.100  ( associated Y-Elevation:  385.000 )
 Minimum Y-Elevation:   364.000  ( associated X-Station:  10648.000 )
 Maximum Y-Elevation:   385.000  ( associated X-Station:  10811.100 )

                   Roughness Data (  3 SubAreas )
                            Roughness   Horizontal
                   SubArea  Coefficient  Breakpoint
                   -------  -----------  ----------
                      1         .045        ---
                                ---       ********
                      2         .036        ---
                                ---       ********
                      3         .045        ---
                   -------  -----------  ----------

Bridge datum projection(s):  XREFLT  XREFRT  FDSTLT  FDSTRT
                            ******* ******* ******* *******

          *-------------------------------------------------*
          *      Finished Processing Header Record APPR     *
          *-------------------------------------------------*

    ************************  W S P R O  ***************************
       Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
           Input Units: English  /  Output Units: English
    *-----------------------------------------------------------*
              I-164 OVER BLUEGRASS CREEK   I164-7-6973
            COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
              7-31-97                      JOHN T. WILSON
  HP 2 BRDGE  377.7  *  377.7   4440
  HP 2 BRDGE  378.8  *  378.8   6220
  EX
```

WSPRO OUTPUT

```
      *=================================================*
      *     Summary of Boundary Condition Information    *
      *=================================================*

        Reach      Water Surface   Friction
 #   Discharge      Elevation       Slope          Flow Regime
--   ---------    -------------   --------   --------------------
 1     4440.00      ********         .0007        Sub-Critical
 2     6220.00      ********         .0007        Sub-Critical
--   ---------    -------------   --------   --------------------

      *=================================================*
      *        Beginning  2 Profile Calculation(s)      *
      *=================================================*


************************* W S P R O ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
         Input Units: English  /  Output Units: English
*-------------------------------------------------------------*
           I-164 OVER BLUEGRASS CREEK   I164-7-6973
         COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
           7-31-97                      JOHN T. WILSON

                  WSEL     VHD       Q         AREA      SRDL      LEW
                  EGEL      HF       V           K        FLEN      REW
                  CRWS      HO      FR #        SF       ALPHA      ERR
                --------- ------ ---------- ---------- --------- ---------
Section: EXIT      377.431   .292   4440.000   1674.664 ********* 10065.320
Header Type: XS    377.724 ******      2.651  161998.20 ********* 10791.890
SRD:       .000    372.111 ******       .493     ******     2.675    ******

Section: FULLV     377.576   .261   4440.000   1776.783   155.000 10047.560
Header Type: FV    377.837   .110      2.499  170718.80   155.000 10793.700
SRD:    155.000    372.111   .000       .458      .0007     2.686      .003

       <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS AT SECID "APPR ".
      KRATIO:  1.41

Section: APPR      377.877   .100   4440.000   2516.636   295.000 10003.190
Header Type: AS    377.977   .142      1.764  240046.20   295.000 10714.450
SRD:    450.000    373.705   .000       .238      .0005     2.069     -.002

       <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

        <<< The Following Data Reflect The "Constricted" Profile >>>
          <<< Beginning Bridge/Culvert Hydraulic Computations >>>
```

WSPRO OUTPUT

	WSEL EGEL CRWS	VHD HF HO	Q V FR #	AREA K SF	SRDL FLEN ALPHA	LEW REW ERR
Section: BRDGE	377.534	.349	4440.000	973.954	155.000	10548.350
Header Type: BR	377.883	.159	4.559	173325.40	155.000	10651.000
SRD: 155.000	370.639	.000	.271	******	1.080	-.008

Specific Bridge Information	C	P/A	PFELEV	BLEN	XLAB	XRAB
Bridge Type 3 Flow Type 1						
Pier/Pile Code 0	.9621	.049	389.000	********	********	********

	WSEL EGEL CRWS	VHD HF HO	Q V FR #	AREA K SF	SRDL FLEN ALPHA	LEW REW ERR
Section: APPR	378.037	.093	4440.000	2633.659	155.000	9987.326
Header Type: AS	378.130	.118	1.686	249520.20	177.564	10761.930
SRD: 450.000	373.705	.130	.234	.0005	2.112	-.005

Approach Section APPR Flow Contraction Information

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
.855	.525	118648.7	********	********	378.037

<<< End of Bridge Hydraulics Computations >>>

********** W S P R O **********
Federal Highway Administration - U. S. Geological Survey
Model for Water-Surface Profile Computations.
Input Units: English / Output Units: English

I-164 OVER BLUEGRASS CREEK I164-7-6973
COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C
7-31-97 JOHN T. WILSON

	WSEL EGEL CRWS	VHD HF HO	Q V FR #	AREA K SF	SRDL FLEN ALPHA	LEW REW ERR
Section: EXIT	378.392	.276	6220.000	2419.685	*********	9947.397
Header Type: XS	378.668	******	2.571	227079.00	*********	10808.600
SRD: .000	375.777	******	.443	******	2.686	******
Section: FULLV	378.537	.247	6220.000	2546.638	155.000	9929.524
Header Type: FV	378.784	.110	2.442	239037.00	155.000	10812.170
SRD: 155.000	375.777	.000	.414	.0007	2.661	.006

<<< The Preceding Data Reflect The "Unconstricted" Profile >>>

WSPRO OUTPUT

```
Section: APPR      378.818   .112   6220.000   3276.399   295.000  9910.013
Header Type: AS    378.931   .150      1.898  318418.10   295.000 10781.450
SRD:    450.000    375.161   .000       .244       .0005     2.006     -.004

       <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

        <<< The Following Data Reflect The "Constricted" Profile >>>
          <<< Beginning Bridge/Culvert Hydraulic Computations >>>


                    WSEL     VHD       Q          AREA       SRDL       LEW
                    EGEL      HF       V            K        FLEN       REW
                    CRWS      HO      FR #         SF        ALPHA      ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: BRDGE     378.595   .581   6220.000   1085.344   155.000 10546.020
Header Type: BR    379.176   .394      5.731  201412.20   155.000 10653.260
SRD:    155.000    372.022   .115       .339     ******     1.138      .002

Specific Bridge Information   C      P/A   PFELEV    BLEN      XLAB      XRAB
Bridge Type 3   Flow Type 1 ------ ----- -------- -------- -------- --------
Pier/Pile Code  0            .9376  .048  389.000 ******** ******** ********
--------------------------- ------ ----- -------- -------- -------- --------

                    WSEL     VHD       Q          AREA       SRDL       LEW
                    EGEL      HF       V            K        FLEN       REW
                    CRWS      HO      FR #         SF        ALPHA      ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: APPR      379.551   .074   6220.000   3948.323   155.000  9837.461
Header Type: AS    379.625   .265      1.575  394817.70   180.861 10799.770
SRD:    450.000    375.161   .184       .189       .0005     1.907      .006

          Approach Section APPR  Flow Contraction Information
          M( G )   M( K )     KQ        XLKQ      XRKQ      OTEL
         -------- -------- --------- -------- -------- --------
             .877     .830   67105.7 ******** ********  379.551
         -------- -------- --------- -------- -------- --------

            <<< End of Bridge Hydraulics Computations >>>


   ************************  W S P R O  ***************************
      Federal Highway Administration  -  U. S. Geological Survey
            Model for Water-Surface Profile Computations.
           Input Units: English  /  Output Units: English
   *-----------------------------------------------------------*
             I-164 OVER BLUEGRASS CREEK   I164-7-6973
          COUNTY: VANDERBURGH            QUAD: DAYLIGHT 194C
            7-31-97                        JOHN T. WILSON
```

WSPRO OUTPUT

```
   ***     Beginning Velocity Distribution For Header Record BRDGE     ***
           SRD Location:    155.000       Header Record Number  3

        Water Surface Elevation:    377.700              Element # 1
        Flow:    4440.000   Velocity:  4.48  Hydraulic Depth:   9.588
        Cross-Section Area:    991.07         Conveyance:   177571.10
           Bank Stations ->  Left:  10547.980   Right:  10651.350

X STA.     10548.0    10567.6    10573.4    10577.4    10581.0    10584.5
  A( I )              87.7       59.6       50.0       45.9       46.4
  V( I )              2.53       3.73       4.44       4.84       4.79
  D( I )              4.48      10.28      12.41      12.85      13.32

X STA.     10584.5    10587.4    10590.2    10593.2    10596.1    10599.2
  A( I )              42.1       40.8       40.9       40.4       41.1
  V( I )              5.27       5.44       5.43       5.50       5.40
  D( I )             14.38      14.29      13.96      13.67      13.50

X STA.     10599.2    10602.2    10605.3    10608.6    10611.9    10615.3
  A( I )              40.6       41.3       42.0       42.0       43.5
  V( I )              5.47       5.37       5.28       5.29       5.11
  D( I )             13.32      13.15      12.97      12.82      12.80

X STA.     10615.3    10618.7    10622.3    10626.3    10632.0    10651.4
  A( I )              44.0       46.3       50.4       58.6       87.8
  V( I )              5.05       4.80       4.41       3.79       2.53
  D( I )             12.80      12.80      12.48      10.38       4.53

      ************************  W S P R O  ***************************
         Federal Highway Administration  -  U. S. Geological Survey
               Model for Water-Surface Profile Computations.
              Input Units: English  /  Output Units: English
      *-------------------------------------------------------------*
                  I-164 OVER BLUEGRASS CREEK   I164-7-6973
              COUNTY: VANDERBURGH            QUAD: DAYLIGHT 194C
                7-31-97                        JOHN T. WILSON

   ***     Beginning Velocity Distribution For Header Record BRDGE     ***
           SRD Location:    155.000       Header Record Number  3

        Water Surface Elevation:    378.800              Element # 1
        Flow:    6220.000   Velocity:  5.62  Hydraulic Depth:  10.242
        Cross-Section Area:   1107.39         Conveyance:   207095.10
           Bank Stations ->  Left:  10545.580   Right:  10653.700

X STA.     10545.6    10566.3    10572.5    10576.8    10580.5    10584.0
  A( I )              98.3       67.1       56.7       51.3       50.1
  V( I )              3.16       4.63       5.49       6.06       6.21
  D( I )              4.74      10.89      13.24      13.94      14.24

X STA.     10584.0    10587.1    10590.0    10593.0    10596.1    10599.2
  A( I )              47.8       45.4       45.6       45.7       45.1
  V( I )              6.51       6.85       6.82       6.81       6.89
  D( I )             15.44      15.42      15.08      14.78      14.59
```

WSPRO OUTPUT

X STA.	10599.2	10602.3	10605.6	10608.9	10612.3	10615.7
A(I)		45.1	46.0	46.8	46.8	47.4
V(I)		6.89	6.76	6.64	6.64	6.56
D(I)		14.42	14.24	14.06	13.91	13.90

X STA.	10615.7	10619.3	10623.0	10627.2	10633.3	10653.7
A(I)		50.1	51.7	55.3	67.3	97.7
V(I)		6.20	6.02	5.62	4.62	3.18
D(I)		13.90	13.90	13.34	10.99	4.78

********** W S P R O **********
Federal Highway Administration - U. S. Geological Survey
Model for Water-Surface Profile Computations.
Input Units: English / Output Units: English

I-164 OVER BLUEGRASS CREEK I164-7-6973
COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C
7-31-97 JOHN T. WILSON

*** Live-Bed Contraction Scour Calculations for Header Record BRDGE ***

Constants and Input Variables

Bed Material Transport Mode Factor (k1): .64
Total Pier Width Value (Pw): 4.000

#	Scour Depth	-- Flow -- Contract	Approach	-- Width -- Contract	Approach	Side	--- X-Limits --- Contract	Approach
1	3.310	4440.000	1947.640	99.000	49.000	Left:	********	********
	..... Approach Channel Depth:	11.588				Right:	********	********
2	7.811	6220.000	2115.898	99.000	49.000	Left:	********	********
	..... Approach Channel Depth:	13.102				Right:	********	********

********** W S P R O **********
Federal Highway Administration - U. S. Geological Survey
Model for Water-Surface Profile Computations.
Input Units: English / Output Units: English

I-164 OVER BLUEGRASS CREEK I164-7-6973
COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C
7-31-97 JOHN T. WILSON

*** Pier Scour Calculations for Header Record BRDGE ***

WSPRO OUTPUT

Constants and Input Variables

Pier Width: 2.000

Pier Shape Factor	(K1):	1.00
Flow Angle of Attack Factor	(K2):	2.00
Bed Condition Factor	(K3):	1.10
Bed Material Factor	(K4):	1.00
Velocity Multiplier	(VM):	1.00
Depth Multiplier	(YM):	1.00

#	Scour Depth	Flow	WSE	Depth	Velocity	Froude #	X-Stations Left	X-Stations Right
1	9.79	4440.000	377.663	14.463	5.520	.256	10522.000	10677.000
2	10.91	6220.000	378.779	15.579	6.940	.310	10522.000	10677.000

********** W S P R O **********
Federal Highway Administration - U. S. Geological Survey
Model for Water-Surface Profile Computations.
Input Units: English / Output Units: English

I-164 OVER BLUEGRASS CREEK I164-7-6973
COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C
7-31-97 JOHN T. WILSON

*** Pier Scour Calculations for Header Record BRDGE ***

Constants and Input Variables

Pier Width: 2.000

Pier Shape Factor	(K1):	1.00
Flow Angle of Attack Factor	(K2):	2.00
Bed Condition Factor	(K3):	1.10
Bed Material Factor	(K4):	1.00
Velocity Multiplier	(VM):	1.00
Depth Multiplier	(YM):	1.00

#	Scour Depth	Flow	WSE	Depth	Velocity	Froude #	X-Stations Left	X-Stations Right
1	9.79	4440.000	377.663	14.463	5.520	.256	10522.000	10677.000
2	10.91	6220.000	378.779	15.579	6.940	.310	10522.000	10677.000

ER

********** Normal end of WSPRO execution. **********
********** Elapsed Time: 0 Minutes 53 Seconds **********