Modified Level II Streambed-Scour Analysis for Structure I-164-10-6971 Crossing Pigeon Creek in Vanderburgh County, Indiana

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

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INDIANA DEPARTMENT OF TRANSPORTATION

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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-164-10-6971 Crossing Pigeon 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-164-10-6971 on Interstate 164 crossing Pigeon Creek in Vanderburgh County, Indiana, are presented. The site is near the town of Stevenson and is in the eastern 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 10.6 feet for the modeled discharge of 12,700 cubic feet per second and approximately 13.1 feet for the modeled discharge of 17,400 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-164-10-6971.

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 Stevenson and is in the eastern part of Vanderburgh County. The drainage area for the site is approximately 260 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, Pigeon Creek has a channel-bed slope of approximately 0.00022 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 60 to 65 percent woody vegetative cover; the field report noted that the banks were experiencing fluvial erosion.

The Interstate 164 crossing of Pigeon Creek is a 275-ft-long, multi-lane bridge consisting of four 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, 1984) 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-164-10-6971 crossing Pigeon Creek in Vanderburgh County, Indiana

[--, no value]

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 12,700 cubic feet per second							
1	996+28	366	4.9	5.7	10.6	348.0	342.9
2	997+05	367	4.9	5.7	10.6	348.0	342.9
3	997+80	367	4.9	5.7	10.6	361.9	342.9
Modeled discharge is 17,400 cubic feet per second							
1	996+28	366	6.9	6.2	13.1	348.0	340.4
2	997+05	367	6.9	6.2	13.1	348.0	340.4
3	997+80	367	6.9	6.2	13.1	361.9	340.4

[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, 996+28, represents a point 99,628 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 (353.5 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, 1984, Bridge plans Interstate Route 164: Bridge File I-164-10-6971.

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 PIGEON CREEK      I164-10-6971
T2          COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
T3          7-31-97                      JOHN T. WILSON
Q           12700   17400
SK          .00022  .00022
XS   EXIT  0   12
*          GR 9286 382  9305 380  9318 378  9328 376  9339 374  9349 372
*          GR 9374 372  9388 374  9415 376  9428 378  9445 380  9473 382
GR         9570 385
GR         9571 382  9578 380  9592 378  9609 376  9614 374  9617 372
GR         9624 370  9634 368  9637 366  9645 364  9656 362  9667 360
GR         9711 362  9716 364  9730 366  9817 368  9848 368  9878 366
GR         9936 366  10050 368  10092 370  10139 372  10450 380
N            .032       .100
SA                9730
XS   FULLV  272
BR   BRDGE  272   387.8  12
*          ***BRIDGE DECK SKEWED 12 DEGREES (FROM BRIDGE PLANS)***
GR         9567 387.8  9567 387.0  9570 387.0  9607 367.1  9633 365.9
GR         9646 356.7  9649 355.3  9658 353.2  9662 355.2  9680 355.1
GR         9700 367.1  9797 367.2  9836 386.9  9836 386.9  9839 386.9
GR         9839 388.0  9567 387.8
N          .035        .032        .035
SA               9633        9700
PD         366.2   2.2   1
PD         367.0   2.2   2
PD         367.0   6.6   3
CD         3    134    2    390
DC 0 BRDGE  9633  9700  9594  9673  *  0
*           ***TOP OF BANKS USED FOR DC LIMITS***
*           BXL      BXR      PW    *  *  K1  K2  K3
DP          9567     9839     2.2   *  *  1   1   1.1
DP          9567     9839     2.2   *  *  1   1   1.1
DP          9567     9839     2.2   *  *  1   1   1.1
*           ***DP CARDS USE WHOLE BRIDGE OPENING FOR BXL/BXR***
*           ***NO PIERS IN MAIN CHANNEL***
XS   APPR  678
GR        9328 390  9329 382  9517 382  9524 380  9537 378  9543 376
GR        9547 374  9553 372  9557 370  9567 368  9594 366  9599 360
GR        9653 362  9660 364  9673 366  9807 368  9949 368  9965 368
GR        10450 380
N         .100      .032      .100
SA             9517      9673
HP 2 BRDGE  379.6  *  379.6   12700
HP 2 BRDGE  381.9  *  381.9   17400
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:  7/31/97  3:24 pm      Version V050196
          Input File: pigeon.dat     Output File: pigeon.LST
   *-------------------------------------------------------------*
T1          I-164 OVER PIGEON CREEK      I164-10-6971
T2          COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
T3          7-31-97                      JOHN T. WILSON
Q           12700   17400

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

SK          .00022  .00022

   ************************  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 PIGEON CREEK      I164-10-6971
          COUNTY: VANDERBURGH           QUAD: DAYLIGHT 194C
             7-31-97                       JOHN T. WILSON

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

XS   EXIT  0   12
GR         9570 385
GR         9571 382  9578 380  9592 378  9609 376  9614 374  9617 372
GR         9624 370  9634 368  9637 366  9645 364  9656 362  9667 360
GR         9711 362  9716 364  9730 366  9817 368  9848 368  9878 366
GR         9936 366  10050 368  10092 370  10139 372  10450 380
N            .032      .100
SA                9730

 ***   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:  12.0   Error Code   0
 Valley Slope:   .00000    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00
```

WSPRO OUTPUT

X,Y-coordinates (24 pairs)

X	Y	X	Y	X	Y
9570.000	385.000	9571.000	382.000	9578.000	380.000
9592.000	378.000	9609.000	376.000	9614.000	374.000
9617.000	372.000	9624.000	370.000	9634.000	368.000
9637.000	366.000	9645.000	364.000	9656.000	362.000
9667.000	360.000	9711.000	362.000	9716.000	364.000
9730.000	366.000	9817.000	368.000	9848.000	368.000
9878.000	366.000	9936.000	366.000	10050.000	368.000
10092.000	370.000	10139.000	372.000	10450.000	380.000

Minimum and Maximum X,Y-coordinates

Minimum X-Station: 9570.000 (associated Y-Elevation: 385.000)
Maximum X-Station: 10450.000 (associated Y-Elevation: 380.000)
Minimum Y-Elevation: 360.000 (associated X-Station: 9667.000)
Maximum Y-Elevation: 385.000 (associated X-Station: 9570.000)

X-coordinates & Horizontal Breakpoints Translated by Skew Angle

X Input	X Skewed	X Input	X Skewed	X Input	X Skewed
9570.000	9572.120	9571.000	9573.098	9578.000	9579.945
9592.000	9593.639	9609.000	9610.268	9614.000	9615.158
9617.000	9618.093	9624.000	9624.939	9634.000	9634.721
9637.000	9637.655	9645.000	9645.480	9656.000	9656.240
9667.000	9667.000	9711.000	9710.038	9716.000	9714.930
9730.000	9728.623	9817.000	9813.722	9848.000	9844.045
9878.000	9873.389	9936.000	9930.122	10050.000	10041.630
10092.000	10082.710	10139.000	10128.690	10450.000	10432.890

Roughness Data (2 SubAreas)

SubArea	Roughness Coefficient	Horizontal Breakpoint
1	.032	---
	---	9728.623
2	.100	---

---
* 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 PIGEON CREEK I164-10-6971
COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C
7-31-97 JOHN T. WILSON

WSPRO OUTPUT

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

XS   FULLV  272

 ***   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:      272.   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 (24 pairs)
    X          Y             X          Y             X          Y
---------- ----------   ---------- ----------   ---------- ----------
 9570.000    385.000     9571.000    382.000     9578.000    380.000
 9592.000    378.000     9609.000    376.000     9614.000    374.000
 9617.000    372.000     9624.000    370.000     9634.000    368.000
 9637.000    366.000     9645.000    364.000     9656.000    362.000
 9667.000    360.000     9711.000    362.000     9716.000    364.000
 9730.000    366.000     9817.000    368.000     9848.000    368.000
 9878.000    366.000     9936.000    366.000    10050.000    368.000
10092.000    370.000    10139.000    372.000    10450.000    380.000
---------- ----------   ---------- ----------   ---------- ----------

                Minimum and Maximum X,Y-coordinates
 Minimum X-Station:    9570.000  ( associated Y-Elevation:  385.000 )
 Maximum X-Station:   10450.000  ( associated Y-Elevation:  380.000 )
 Minimum Y-Elevation:   360.000  ( associated X-Station:   9667.000 )
 Maximum Y-Elevation:   385.000  ( associated X-Station:   9570.000 )

                  Roughness Data (  2 SubAreas )
                         Roughness   Horizontal
                SubArea  Coefficient  Breakpoint
                -------  -----------  ----------
                   1         .032        ---
                             ---       9730.000
                   2         .100        ---
                -------  -----------  ----------

         *-------------------------------------------------*
         *      Finished Processing Header Record FULLV    *
         *-------------------------------------------------*
```

WSPRO OUTPUT

```
************************ 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 PIGEON CREEK      I164-10-6971
        COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
           7-31-97                      JOHN T. WILSON

        *-------------------------------------------------*
        *      Starting To Process Header Record BRDGE    *
        *-------------------------------------------------*

BR   BRDGE  272   387.8  12
GR        9567 387.8  9567 387.0  9570 387.0  9607 367.1  9633 365.9
GR        9646 356.7  9649 355.3  9658 353.2  9662 355.2  9680 355.1
GR        9700 367.1  9797 367.2  9836 386.9  9836 386.9  9839 386.9
GR        9839 388.0  9567 387.8
N         .035        .032        .035
SA              9633        9700
PD        366.2   2.2   1
PD        367.0   2.2   2
PD        367.0   6.6   3
CD        3    134    2    390

  ***   Completed Reading Data Associated With Header Record BRDGE   ***
+++072 NOTICE:  X-coordinate # 2 increased to eliminate vertical segment.
+++072 NOTICE:  X-coordinate #14 increased to eliminate vertical segment.
+++072 NOTICE:  X-coordinate #16 increased to eliminate vertical segment.
  ***   Storing Bridge Data In Temporary File As Record Number  3    ***

  ***              Data Summary For Bridge Record BRDGE              ***
  SRD Location:      272.   Cross-Section Skew:  12.0   Error Code   0
  Valley Slope:  *******    Averaging Conveyance By Geometric Mean.
  Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (17 pairs)
     X          Y          X          Y          X          Y
----------  ----------  ----------  ----------  ----------  ----------
  9567.000    387.800     9567.100    387.000     9570.000    387.000
  9607.000    367.100     9633.000    365.900     9646.000    356.700
  9649.000    355.300     9658.000    353.200     9662.000    355.200
  9680.000    355.100     9700.000    367.100     9797.000    367.200
  9836.000    386.900     9836.100    386.900     9839.000    386.900
  9839.100    388.000     9567.000    387.800
----------  ----------  ----------  ----------  ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:    9567.000  ( associated Y-Elevation:  387.800 )
  Maximum X-Station:    9839.100  ( associated Y-Elevation:  388.000 )
  Minimum Y-Elevation:   353.200  ( associated X-Station:   9658.000 )
  Maximum Y-Elevation:   388.000  ( associated X-Station:   9839.100 )
```

WSPRO OUTPUT

X-coordinates & Horizontal Breakpoints Translated by Skew Angle

X Input	X Skewed	X Input	X Skewed	X Input	X Skewed
9567.000	9568.988	9567.100	9569.086	9570.000	9571.923
9607.000	9608.114	9633.000	9633.546	9646.000	9646.263
9649.000	9649.196	9658.000	9658.000	9662.000	9661.912
9680.000	9679.520	9700.000	9699.082	9797.000	9793.963
9836.000	9832.110	9836.100	9832.208	9839.000	9835.045
9839.100	9835.143	9567.000	9568.988		

Roughness Data (3 SubAreas)

SubArea	Roughness Coefficient	Horizontal Breakpoint
1	.035	---
	---	9633.546
2	.032	---
	---	9699.082
3	.035	---

Discharge coefficient parameters

BRType	BRWdth	EMBSS	EMBElv	UserCD
3	134.000	2.00	390.000	**********

Pressure flow elevations

AVBCEL	PFElev
*********	387.800

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	366.200	2.200	1
2	367.000	2.200	2
3	367.000	6.600	3

--
* Finished Processing Header Record BRDGE *
--

WSPRO OUTPUT

```
   ************************  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 PIGEON CREEK      I164-10-6971
           COUNTY: VANDERBURGH           QUAD: DAYLIGHT 194C
              7-31-97                       JOHN T. WILSON
DC 0 BRDGE  9633  9700  9594  9673  *  0
DP          9567    9839    2.2  *  *  1   1   1.1
DP          9567    9839    2.2  *  *  1   1   1.1
DP          9567    9839    2.2  *  *  1   1   1.1

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

XS   APPR  678
GR         9328 390  9329 382  9517 382  9524 380  9537 378  9543 376
GR         9547 374  9553 372  9557 370  9567 368  9594 366  9599 360
GR         9653 362  9660 364  9673 366  9807 368  9949 368  9965 368
GR         10450 380
N          .100      .032      .100
SA              9517      9673

 ***   Completed Reading Data Associated With Header Record APPR    ***
 ***  Storing X-Section Data In Temporary File As Record Number  4  ***

 ***              Data Summary For Header Record APPR              ***
 SRD Location:      678.   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 (19 pairs)
     X          Y            X          Y            X          Y
----------  ----------   ----------  ----------   ----------  ----------
  9328.000     390.000     9329.000     382.000     9517.000     382.000
  9524.000     380.000     9537.000     378.000     9543.000     376.000
  9547.000     374.000     9553.000     372.000     9557.000     370.000
  9567.000     368.000     9594.000     366.000     9599.000     360.000
  9653.000     362.000     9660.000     364.000     9673.000     366.000
  9807.000     368.000     9949.000     368.000     9965.000     368.000
 10450.000     380.000
----------  ----------   ----------  ----------   ----------  ----------

                  Minimum and Maximum X,Y-coordinates
  Minimum X-Station:    9328.000  ( associated Y-Elevation:  390.000 )
  Maximum X-Station:   10450.000  ( associated Y-Elevation:  380.000 )
  Minimum Y-Elevation:   360.000  ( associated X-Station:   9599.000 )
  Maximum Y-Elevation:   390.000  ( associated X-Station:   9328.000 )
```

WSPRO OUTPUT

```
                    Roughness Data (  3 SubAreas )
                             Roughness   Horizontal
                   SubArea  Coefficient  Breakpoint
                   -------  -----------  ----------
                      1         .100        ---
                                ---       9517.000
                      2         .032        ---
                                ---       9673.000
                      3         .100        ---
                   -------  -----------  ----------

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 PIGEON CREEK     I164-10-6971
           COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
              7-31-97                      JOHN T. WILSON
  HP 2 BRDGE  379.6  *  379.6   12700
  HP 2 BRDGE  381.9  *  381.9   17400
  EX

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

            Reach      Water Surface   Friction
     #    Discharge      Elevation      Slope         Flow Regime
    --    ---------    -------------   --------   --------------------
     1     12700.00      ********        .0002        Sub-Critical
     2     17400.00      ********        .0002        Sub-Critical
    --    ---------    -------------   --------   --------------------

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

WSPRO OUTPUT

```
************************* 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 PIGEON CREEK      I164-10-6971
         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	379.625	.126	12700.000	7962.207	*********	9580.625
Header Type: XS	379.751	******	1.595	855502.50	*********	10435.420
SRD: .000	370.219	******	.165	******	3.188	******
Section: FULLV	379.689	.124	12700.000	8016.903	272.000	9580.178
Header Type: FV	379.813	.059	1.584	862349.40	272.000	10437.900
SRD: 272.000	370.219	.000	.163	.0002	3.185	.003

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

Section: APPR	379.776	.121	12700.000	8357.127	406.000	9525.453
Header Type: AS	379.898	.085	1.520	896346.40	406.000	10440.960
SRD: 678.000	370.670	.000	.163	.0002	3.376	.000

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

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

	WSEL EGEL CRWS	VHD HF HO	Q V FR #	AREA K SF	SRDL FLEN ALPHA	LEW REW ERR
Section: BRDGE	379.615	.280	12700.000	3297.909	272.000	9583.730
Header Type: BR	379.895	.077	3.851	863997.90	272.000	9821.579
SRD: 272.000	369.584	.067	.201	******	1.213	-.002

Specific Bridge Information	C	P/A	PFELEV	BLEN	XLAB	XRAB
Bridge Type 3 Flow Type 1	------	-----	--------	--------	--------	--------
Pier/Pile Code 0	.9080	.026	387.800	********	********	********

	WSEL EGEL CRWS	VHD HF HO	Q V FR #	AREA K SF	SRDL FLEN ALPHA	LEW REW ERR
Section: APPR	379.892	.118	12700.000	8463.099	272.000	9524.703
Header Type: AS	380.010	.080	1.501	909428.30	298.355	10445.630
SRD: 678.000	370.670	.035	.160	.0002	3.370	.003

WSPRO OUTPUT

Approach Section APPR Flow Contraction Information

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
.740	.271	663052.3	9566.487	9804.344	379.892

<<< 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 PIGEON CREEK I164-10-6971
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	381.965	.139	17400.000	10005.800	*********	9571.124
Header Type: XS	382.103	******	1.739	1172349.00	*********	10450.000
SRD: .000	371.329	******	.156	******	2.952	******
Section: FULLV	382.028	.137	17400.000	10061.270	272.000	9570.991
Header Type: FV	382.165	.059	1.729	1181949.00	272.000	10450.000
SRD: 272.000	371.329	.000	.155	.0002	2.947	.002

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

Section: APPR	382.118	.132	17400.000	10554.280	406.000	9328.985
Header Type: AS	382.250	.085	1.649	1230404.00	406.000	10450.000
SRD: 678.000	371.802	.000	.167	.0002	3.112	.000

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

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

	WSEL / EGEL / CRWS	VHD / HF / HO	Q / V / FR #	AREA / K / SF	SRDL / FLEN / ALPHA	LEW / REW / ERR
Section: BRDGE	381.908	.417	17400.000	3853.407	272.000	9579.467
Header Type: BR	382.325	.083	4.515	1080896.00	272.000	9826.118
SRD: 272.000	371.126	.139	.231	******	1.314	-.004

Specific Bridge Information	C	P/A	PFELEV	BLEN	XLAB	XRAB
Bridge Type 3 Flow Type 1	------	-----	--------	--------	--------	--------
Pier/Pile Code 0	.8724	.026	387.800	********	********	********

WSPRO OUTPUT

	WSEL	VHD	Q	AREA	SRDL	LEW
	EGEL	HF	V	K	FLEN	REW
	CRWS	HO	FR #	SF	ALPHA	ERR
Section: APPR	382.324	.126	17400.000	10785.580	272.000	9328.959
Header Type: AS	382.451	.085	1.613	1264829.00	301.391	10450.000
SRD: 678.000	371.802	.041	.162	.0002	3.120	.006

Approach Section APPR Flow Contraction Information

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
.780	.330	847280.1	9569.225	9815.893	382.324

<<< 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 PIGEON CREEK I164-10-6971
COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C
7-31-97 JOHN T. WILSON

*** Beginning Velocity Distribution For Header Record BRDGE ***
SRD Location: 272.000 Header Record Number 3

Water Surface Elevation: 379.600 Element # 1
Flow: 12700.000 Velocity: 3.86 Hydraulic Depth: 13.854
Cross-Section Area: 3294.26 Conveyance: 862624.40
Bank Stations -> Left: 9583.759 Right: 9821.548

X STA.	9583.8	9616.8	9631.5	9641.8	9647.9	9652.8
A(I)		269.5	195.5	169.1	133.6	119.7
V(I)		2.36	3.25	3.75	4.75	5.30
D(I)		8.17	13.29	16.35	22.02	24.58
X STA.	9652.8	9657.1	9661.6	9666.3	9671.0	9675.6
A(I)		112.3	114.7	114.8	113.6	113.7
V(I)		5.65	5.53	5.53	5.59	5.59
D(I)		25.69	25.66	24.42	24.44	24.46
X STA.	9675.6	9680.3	9686.1	9694.6	9708.9	9724.1
A(I)		115.0	132.0	154.7	187.8	189.2
V(I)		5.52	4.81	4.10	3.38	3.36
D(I)		24.48	22.57	18.27	13.10	12.48
X STA.	9724.1	9739.6	9755.1	9770.8	9787.3	9821.5
A(I)		193.3	193.4	194.1	206.0	272.0
V(I)		3.29	3.28	3.27	3.08	2.33
D(I)		12.47	12.45	12.44	12.42	7.95

WSPRO OUTPUT

```
************************ 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 PIGEON CREEK     I164-10-6971
        COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
           7-31-97                      JOHN T. WILSON

***    Beginning Velocity Distribution For Header Record BRDGE    ***
       SRD Location:    272.000       Header Record Number  3

     Water Surface Elevation:    381.900              Element # 1
     Flow:   17400.000   Velocity:  4.52  Hydraulic Depth:  15.616
     Cross-Section Area:   3851.32         Conveyance:  1080054.00
        Bank Stations -> Left:   9579.482   Right:   9826.102

X STA.      9579.5     9614.6     9629.2     9640.5     9647.3     9652.5
  A( I )             317.1      227.1      199.1      162.9      137.0
  V( I )              2.74       3.83       4.37       5.34       6.35
  D( I )              9.04      15.49      17.73      23.69      26.75

X STA.      9652.5     9657.3     9662.3     9667.1     9672.1     9677.1
  A( I )             134.8      137.9      130.6      133.8      133.9
  V( I )              6.45       6.31       6.66       6.50       6.50
  D( I )             27.97      27.78      26.71      26.74      26.77

X STA.      9677.1     9682.5     9689.6     9700.6     9715.1     9729.3
  A( I )             141.3      164.4      195.0      214.8      210.9
  V( I )              6.16       5.29       4.46       4.05       4.12
  D( I )             26.45      23.18      17.77      14.79      14.78

X STA.      9729.3     9744.0     9759.0     9774.2     9790.0     9826.1
  A( I )             215.8      221.6      223.3      233.6      316.4
  V( I )              4.03       3.93       3.90       3.72       2.75
  D( I )             14.76      14.75      14.73      14.72       8.77

************************ 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 PIGEON CREEK     I164-10-6971
        COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
           7-31-97                      JOHN T. WILSON
```

WSPRO OUTPUT

*** 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):	.000

#	Scour Depth	-- Flow -- Contract	Approach	-- Width -- Contract	Approach	--- X-Limits --- Side	Contract	Approach
1	4.862	7172.545	6124.180	67.000	79.000	Left:	9633.000	9594.000
	..... Approach Channel Depth:	17.930				Right:	9700.000	9673.000
2	6.918	9291.045	7457.910	67.000	79.000	Left:	9633.000	9594.000
	..... Approach Channel Depth:	20.362				Right:	9700.000	9673.000

********** 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 PIGEON CREEK I164-10-6971

COUNTY: VANDERBURGH QUAD: DAYLIGHT 194C

7-31-97 JOHN T. WILSON

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

Constants and Input Variables

Pier Width: 2.200

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

#	Scour Depth	---- Localized Hydraulic Properties ---- Flow	WSE	Depth	Velocity	Froude #	-- X-Stations -- Left	Right
1	5.70	12700.000	379.650	26.450	5.629	.193	9567.000	9839.000
2	6.18	17400.000	381.949	28.749	6.620	.218	9567.000	9839.000

WSPRO OUTPUT

```
************************* 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 PIGEON CREEK      I164-10-6971
       COUNTY: VANDERBURGH           QUAD: DAYLIGHT 194C
          7-31-97                       JOHN T. WILSON

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

                  Constants and Input Variables

                       Pier Width:   2.200
             *-----------------------------------------*
               Pier Shape Factor            (K1):   1.00
               Flow Angle of Attack Factor  (K2):   1.00
               Bed Condition Factor         (K3):   1.10
               Bed Material Factor          (K4):   1.00
               Velocity Multiplier          (VM):   1.00
               Depth Multiplier             (YM):   1.00
             *-----------------------------------------*
```

#	Scour Depth	Localized Hydraulic Properties — Flow	WSE	Depth	Velocity	Froude #	X-Stations — Left	Right
1	5.70	12700.000	379.650	26.450	5.629	.193	9567.000	9839.000
2	6.18	17400.000	381.949	28.749	6.620	.218	9567.000	9839.000

WSPRO OUTPUT

```
************************ 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 PIGEON CREEK      I164-10-6971
       COUNTY: VANDERBURGH          QUAD: DAYLIGHT 194C
          7-31-97                      JOHN T. WILSON

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

                  Constants and Input Variables

                      Pier Width:   2.200
             *----------------------------------------*
               Pier Shape Factor            (K1):   1.00
               Flow Angle of Attack Factor  (K2):   1.00
               Bed Condition Factor         (K3):   1.10
               Bed Material Factor          (K4):   1.00
               Velocity Multiplier          (VM):   1.00
               Depth Multiplier             (YM):   1.00
             *----------------------------------------*
```

	Scour	Localized Hydraulic Properties				X-Stations	
#	Depth	Flow	WSE	Depth	Velocity	Froude #	Left	Right
1	5.70	12700.000	379.650	26.450	5.629	.193	9567.000	9839.000
2	6.18	17400.000	381.949	28.749	6.620	.218	9567.000	9839.000

```
  ER

   ****************** Normal end of WSPRO execution. *****************
   *************** Elapsed Time:   1 Minutes 18 Seconds **************
```