Modified Level II Streambed-Scour Analysis for Structure I-69-16-5324 Crossing Fosters Branch in Madison County, Indiana

By 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	United States Geological Survey
WSPRO	Water Surface PROfile model

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By 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-69-16-5324 on Interstate 69 crossing Fosters Branch in Madison County, Indiana, are presented. The site is near the town of Ingalls in the southwestern part of Madison 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 8.0 feet for the modeled discharge of 1,600 cubic feet per second and approximately 12.8 feet for the modeled discharge of 2,720 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-69-16-5324.

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 Ingalls in the southwestern part of Madison County. The drainage area for the site is approximately 15.1 mi^2 (estimated using Hoggatt, 1975, and USGS 7.5-minute topographic data). The predominant land use in the basin is agricultural; in the immediate vicinity of the bridge, the land is predominantly agricultural.

Within the immediate vicinity of the bridge, Fosters Branch has a channel-bed slope of approximately 0.0022 ft/ft. The channel-bed material is sandy silt/clay, and the channel banks consist of sandy silt/clay. At the time of the Level I site visit on August 1, 1994, the banks were observed to have 0 to 25 percent woody vegetative cover; and the field report noted that the banks were experiencing some fluvial erosion.

The Interstate 69 crossing of Fosters Branch is a 96-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 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, 1964) 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-69-16-5324 crossing Fosters Branch in Madison 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 1,600 cubic feet per second							
1	933+15	837	3.9	4.1	8.0	829.4	827.4
2	933+55	837	3.9	4.1	8.0	830.0	827.4
Modeled discharge is 2,720 cubic feet per second							
1	933+15	837	8.1	4.7	12.8	829.4	822.6
2	933+55	837	8.1	4.7	12.8	830.0	822.6

[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, 933+15, represents a point 93,315 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 (835.4 feet).

[5] Not a 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, 1964, Bridge plans Interstate Route 69: Bridge File I-69-16-5324.

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-69 Over Foster Branch          I69-16-5324
T2        County: Madison                  Quad: Ingalls 112 B
T3        11-18-96                         Bret A. Robinson
SI        0
Q         1600 2720
SK        .0022 .0022
XS   EXIT 0 0
GR        92758 870  93006 860  93058 850  93177 840  93215 840  93251 835
GR        93266 834.7  93280 835  93314 840  93395 840  93526 850  93601 860
GR        94006 870
N         .045 .034 .045
SA        93210 93320
XS   FULLV 100 0
GR        92758 870  93006 860  93058 850  93177 840  93215 840  93251 835
GR        93266 834.7  93280 835  93314 840  93395 840  93526 850  93601 860
GR        94006 870
N         .045 .034 .045
SA        93210 93320
BR   BRDGE 100 848 0
GR       93292 0848.7  93292 0848.1  93295 0847.8  93325 0835.1  93354 0835.2
GR        93383 0847.6  93385 0847.7  93385 0848.3  93292 0848.7
N         .034
PD        837 3 1
CD        3 150 2 846
DC 0 BRDGE 93313 93365 93375 93470 * 3
*         LPierEdge RPierEdge PierWdth * * K1 K2 K3(1.1)
DP        93292 93385 1.5 * * 1 1 1.1
DP        93292 93385 1.5 * * 1 1 1.1
XS   APPR 350 0
GR        92911 870  93222 860  93300 850  93371 840  93406 835  93421 834.7
GR        93434 835  93469 840  93635 840  93659 850  93722 860
GR        94089 870
N         .100 .034 .100
SA        93400 93440
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  0:56 pm     Version V050196
          Input File: 5324.dat       Output File: 5324.LST
   *-------------------------------------------------------------*
T1         I-69 OVER FOSTER BRANCH            I69-16-5324
T2         COUNTY: MADISON                    QUAD: INGALLS 112 B
T3         11-18-96                           BRET A. ROBINSON
SI         0
Q          1600 2720

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

SK         .0022 .0022

   ************************  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-69 OVER FOSTER BRANCH            I69-16-5324
       COUNTY: MADISON                    QUAD: INGALLS 112 B
         11-18-96                           BRET A. ROBINSON

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

XS   EXIT 0 0
GR         92758 870  93006 860  93058 850  93177 840  93215 840  93251 835
GR         93266 834.7  93280 835  93314 840  93395 840  93526 850  93601
860
GR         94006 870
N          .045 .034 .045
SA         93210 93320

 ***   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:    .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
----------  ----------  ----------  ----------  ----------  ----------
 92758.000     870.000    93006.000     860.000    93058.000     850.000
 93177.000     840.000    93215.000     840.000    93251.000     835.000
 93266.000     834.700    93280.000     835.000    93314.000     840.000
 93395.000     840.000    93526.000     850.000    93601.000     860.000
 94006.000     870.000
----------  ----------  ----------  ----------  ----------  ----------
```

WSPRO OUTPUT

```
                Minimum and Maximum X,Y-coordinates
  Minimum X-Station:   92758.000  ( associated Y-Elevation:  870.000 )
  Maximum X-Station:   94006.000  ( associated Y-Elevation:  870.000 )
  Minimum Y-Elevation:   834.700  ( associated X-Station:  93266.000 )
  Maximum Y-Elevation:   870.000  ( associated X-Station:  92758.000 )

                  Roughness Data (  3 SubAreas )
                          Roughness   Horizontal
                SubArea  Coefficient  Breakpoint
                -------  -----------  ----------
                   1         .045        ---
                             ---        ********
                   2         .034        ---
                             ---        ********
                   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-69 OVER FOSTER BRANCH            I69-16-5324
       COUNTY: MADISON                    QUAD: INGALLS 112 B
         11-18-96                           BRET A. ROBINSON

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

  XS   FULLV 100 0
  GR        92758 870  93006 860  93058 850  93177 840  93215 840  93251 835
  GR        93266 834.7  93280 835  93314 840  93395 840  93526 850  93601
860
  GR        94006 870
  N         .045 .034 .045
  SA        93210 93320

   ***   Completed Reading Data Associated With Header Record FULLV   ***
   ***  Storing X-Section Data In Temporary File As Record Number  2  ***

   ***               Data Summary For Header Record FULLV              ***
   SRD Location:      100.   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 (13 pairs)
      X          Y            X          Y            X          Y
  ----------  ----------   ----------  ----------   ----------  ----------
```

WSPRO OUTPUT

```
  92758.000     870.000    93006.000     860.000    93058.000     850.000
  93177.000     840.000    93215.000     840.000    93251.000     835.000
  93266.000     834.700    93280.000     835.000    93314.000     840.000
  93395.000     840.000    93526.000     850.000    93601.000     860.000
  94006.000     870.000
 ----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
   Minimum X-Station:   92758.000  ( associated Y-Elevation:  870.000 )
   Maximum X-Station:   94006.000  ( associated Y-Elevation:  870.000 )
   Minimum Y-Elevation:   834.700  ( associated X-Station:  93266.000 )
   Maximum Y-Elevation:   870.000  ( associated X-Station:  92758.000 )

                    Roughness Data (  3 SubAreas )
                            Roughness   Horizontal
                  SubArea  Coefficient  Breakpoint
                  -------  -----------  ----------
                     1         .045        ---
                               ---       ********
                     2         .034        ---
                               ---       ********
                     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-69 OVER FOSTER BRANCH           I69-16-5324
        COUNTY: MADISON                   QUAD: INGALLS 112 B
          11-18-96                          BRET A. ROBINSON

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

   BR   BRDGE 100 848 0
   GR        93292 0848.7  93292 0848.1  93295 0847.8  93325 0835.1  93354
0835.2
   GR        93383 0847.6  93385 0847.7  93385 0848.3  93292 0848.7
   N         .034
   PD        837 3 1
   CD        3 150 2 846

    ***   Completed Reading Data Associated With Header Record BRDGE   ***
 +++072 NOTICE:  X-coordinate # 2 increased to eliminate vertical segment.
 +++072 NOTICE:  X-coordinate # 8 increased to eliminate vertical segment.
    ***   Storing Bridge Data In Temporary File As Record Number  3    ***
```

WSPRO OUTPUT

```
***              Data Summary For Bridge Record BRDGE                ***
SRD Location:      100.   Cross-Section Skew:    .0   Error Code   0
Valley Slope:  *******    Averaging Conveyance By Geometric Mean.
Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates ( 9 pairs)
    X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
93292.000     848.700    93292.100     848.100    93295.000     847.800
93325.000     835.100    93354.000     835.200    93383.000     847.600
93385.000     847.700    93385.100     848.300    93292.000     848.700
----------  ----------   ----------  ----------   ----------  ----------

                Minimum and Maximum X,Y-coordinates
 Minimum X-Station:   93292.000  ( associated Y-Elevation:  848.700 )
 Maximum X-Station:   93385.100  ( associated Y-Elevation:  848.300 )
 Minimum Y-Elevation:   835.100  ( associated X-Station:  93325.000 )
 Maximum Y-Elevation:   848.700  ( associated X-Station:  93292.000 )

                  Roughness Data (  1 SubAreas )
                           Roughness   Horizontal
                  SubArea  Coefficient  Breakpoint
                  -------  -----------  ----------
                     1         .034        ---
                  -------  -----------  ----------

                  Discharge coefficient parameters
               BRType   BRWdth    EMBSS    EMBElv     UserCD
                 3      150.000   2.00    846.000 **********

                     Pressure flow elevations
                        AVBCEL      PFElev
                     *********     848.000

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


                  Pier/Pile Data (  1 Group(s) )
                 Code Indicates Bridge Uses Piers
                Group  Elevation  Gross Width  Number
               ------  ---------  -----------  ------
                  1      837.000      3.000       1
               ------  ---------  -----------  ------

        *-------------------------------------------------*
        *      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
```

WSPRO OUTPUT

```
   *-------------------------------------------------------------*
          I-69 OVER FOSTER BRANCH            I69-16-5324
        COUNTY: MADISON                    QUAD: INGALLS 112 B
          11-18-96                           BRET A. ROBINSON
   DC 0 BRDGE 93313 93365 93375 93470 * 3
   DP         93292 93385 1.5 * * 1 1 1.1
   DP         93292 93385 1.5 * * 1 1 1.1

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

   XS   APPR 350 0
   GR         92911 870  93222 860  93300 850  93371 840  93406 835  93421
834.7
   GR         93434 835  93469 840  93635 840  93659 850  93722 860
   GR         94089 870
   N          .100 .034 .100
   SA         93400 93440

    ***   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:      350.   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 (12 pairs)
        X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
 92911.000     870.000    93222.000     860.000    93300.000     850.000
 93371.000     840.000    93406.000     835.000    93421.000     834.700
 93434.000     835.000    93469.000     840.000    93635.000     840.000
 93659.000     850.000    93722.000     860.000    94089.000     870.000
----------  ----------   ----------  ----------   ----------  ----------

                    Minimum and Maximum X,Y-coordinates
     Minimum X-Station:   92911.000  ( associated Y-Elevation:  870.000 )
     Maximum X-Station:   94089.000  ( associated Y-Elevation:  870.000 )
     Minimum Y-Elevation:   834.700  ( associated X-Station:  93421.000 )
     Maximum Y-Elevation:   870.000  ( associated X-Station:  92911.000 )

                       Roughness Data (  3 SubAreas )
                              Roughness   Horizontal
                    SubArea  Coefficient  Breakpoint
                    -------  -----------  ----------
                       1         .100        ---
                                 ---       ********
                       2         .034        ---
                                 ---       ********
                       3         .100        ---
                    -------  -----------  ----------
```

WSPRO OUTPUT

```
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-69 OVER FOSTER BRANCH            I69-16-5324
        COUNTY: MADISON                    QUAD: INGALLS 112 B
          11-18-96                           BRET A. ROBINSON
 EX

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

            Reach       Water Surface   Friction
     #    Discharge       Elevation       Slope          Flow Regime
    --    ---------     -------------   --------   --------------------
     1      1600.00       ********         .0022         Sub-Critical
     2      2720.00       ********         .0022         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-69 OVER FOSTER BRANCH            I69-16-5324
        COUNTY: MADISON                    QUAD: INGALLS 112 B
          11-18-96                           BRET A. ROBINSON

                      WSEL     VHD        Q          AREA       SRDL       LEW
                      EGEL      HF        V            K         FLEN       REW
                      CRWS      HO     FR #           SF        ALPHA      ERR
                    --------- ------ ---------- ---------- --------- ---------
 Section: EXIT       840.275   .305   1600.000    385.182 ********* 93173.730
 Header Type: XS     840.580 ******      4.154   34087.96 ********* 93398.600
 SRD:        .000    838.380 ******       .597     ******     1.137    ******

 Section: FULLV      840.517   .250   1600.000    440.307   100.000 93170.850
 Header Type: FV     840.766   .192      3.634   39197.02   100.000 93401.770
 SRD:     100.000    838.380   .000       .512      .0019     1.216     -.005
```

WSPRO OUTPUT

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

Section: APPR	840.837	.447	1600.000	543.487	250.000	93365.050
Header Type: AS	841.284	.421	2.944	38764.05	250.000	93637.010
SRD: 350.000	838.661	.099	.669	.0017	3.319	-.002

<<< 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	840.203	.936	1600.000	206.549	100.000	93312.950
Header Type: BR	841.139	.360	7.746	21859.17	100.000	93365.700
SRD: 100.000	839.293	.198	.691	******	1.003	-.002

Specific Bridge Information	C	P/A	PFELEV	BLEN	XLAB	XRAB
Bridge Type 3 Flow Type 1						
Pier/Pile Code 0	.9984	.047	848.000	********	********	********

	WSEL	VHD	Q	AREA	SRDL	LEW
	EGEL	HF	V	K	FLEN	REW
	CRWS	HO	FR #	SF	ALPHA	ERR
Section: APPR	842.157	.189	1600.000	910.623	100.000	93355.690
Header Type: AS	842.346	.280	1.757	63535.57	144.515	93640.170
SRD: 350.000	838.661	.928	.344	.0017	3.938	.007

Approach Section APPR Flow Contraction Information

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
.801	.218	49595.2	********	********	842.157

<<< 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-69 OVER FOSTER BRANCH I69-16-5324
COUNTY: MADISON QUAD: INGALLS 112 B
11-18-96 BRET A. ROBINSON

	WSEL	VHD	Q	AREA	SRDL	LEW
	EGEL	HF	V	K	FLEN	REW
	CRWS	HO	FR #	SF	ALPHA	ERR

WSPRO OUTPUT

```
                  --------- ------ ---------- ---------- --------- ---------
Section: EXIT       841.257   .402   2720.000    618.192 ********* 93162.040
Header Type: XS     841.659 ******      4.400   57984.69 ********* 93411.470
SRD:        .000    839.503 ******       .570     ******     1.336    ******

Section: FULLV      841.503   .337   2720.000    680.293   100.000 93159.110
Header Type: FV     841.840   .196      3.998   65204.49   100.000 93414.700
SRD:     100.000    839.503   .000       .503      .0020     1.355     -.015

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

Section: APPR       841.837   .662   2720.000    820.135   250.000 93357.960
Header Type: AS     842.499   .499      3.317   56873.79   250.000 93639.410
SRD:     350.000    840.737   .163       .674      .0020     3.873     -.002

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

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

===210 QUESTIONABLE CRITICAL-FLOW SOLUTION AT SECID "BRDGE".
       Q, CRWS:     2720.00     840.83


                     WSEL    VHD       Q         AREA      SRDL      LEW
                     EGEL     HF       V           K        FLEN      REW
                     CRWS     HO      FR #        SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: BRDGE      840.834  2.251   2720.000    240.798   100.000 93311.450
Header Type: BR     843.085 ******     11.296   27172.29   100.000 93367.180
SRD:     100.000    840.834 ******      1.021     ******     1.135    ******

Specific Bridge Information   C      P/A   PFELEV    BLEN      XLAB      XRAB
Bridge Type 3   Flow Type 1 ------ ----- -------- -------- -------- --------
Pier/Pile Code  0             .9388  .048  848.000 ******** ******** ********
--------------------------- ------ ----- -------- -------- -------- --------

                     WSEL    VHD       Q         AREA      SRDL      LEW
                     EGEL     HF       V           K        FLEN      REW
                     CRWS     HO      FR #        SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: APPR       844.929   .148   2720.000   1735.831   100.000 93336.010
Header Type: AS     845.077   .311      1.567  137299.20   148.917 93646.830
SRD:     350.000    840.737  1.681       .230      .0020     3.879      .006

          Approach Section APPR  Flow Contraction Information
          M( G )    M( K )      KQ        XLKQ      XRKQ      OTEL
          -------- -------- --------- -------- -------- --------
             .791     .360   87717.3 ******** ********  844.929
          -------- -------- --------- -------- -------- --------

             <<< End of Bridge Hydraulics Computations >>>
```

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-69 OVER FOSTER BRANCH          I69-16-5324
    COUNTY: MADISON                  QUAD: INGALLS 112 B
      11-18-96                        BRET A. ROBINSON

 ***  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):  3.000
            *-----------------------------------------------*

    Scour     -- Flow --          -- Width --        --- X-Limits ---
 #  Depth  Contract Approach  Contract Approach  Side   Contract Approach
--  ------ --------- --------- -------- --------  ------ -------- --------
 1  3.941  1600.000  1395.693   49.000   95.000  Left:  ******** ********
    ..... Approach Channel Depth:    5.505 .....  Right: ******** ********
 2  8.148  2720.000  2000.194   49.000   95.000  Left:  ******** ********
    ..... Approach Channel Depth:    8.277 .....  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-69 OVER FOSTER BRANCH          I69-16-5324
    COUNTY: MADISON                  QUAD: INGALLS 112 B
      11-18-96                        BRET A. ROBINSON

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

                  Constants and Input Variables

                       Pier Width:   1.500
            *-----------------------------------------*
              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   4.08  1600.000  841.131  6.031   7.343     .527  93292.000 93385.000
```

WSPRO OUTPUT

2	4.71	2720.000	842.515	7.415	9.642	.624	93292.000	93385.000

```
     ************************* 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-69 OVER FOSTER BRANCH              I69-16-5324
        COUNTY: MADISON                     QUAD: INGALLS 112 B
          11-18-96                            BRET A. ROBINSON

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

                        Constants and Input Variables

                              Pier Width:   1.500
                    *-----------------------------------------*
                      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	4.08	1600.000	841.131	6.031	7.343	.527	93292.000	93385.000
2	4.71	2720.000	842.515	7.415	9.642	.624	93292.000	93385.000

```
  ER

   ****************** Normal end of WSPRO execution. *****************
   *************** Elapsed Time:   0 Minutes  3 Seconds **************
```