Modified Level II Streambed-Scour Analysis for Structure I-74-32-4946 Crossing Sugar Creek in Montgomery County, Indiana

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

Prepared in cooperation with the
INDIANA DEPARTMENT OF TRANSPORTATION

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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

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

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-74-32-4946 on Interstate 74 crossing Sugar Creek in Montgomery County, Indiana, are presented. The site is near the town of Crawfordsville in the central part of Montgomery 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 13.0 feet for the modeled discharge of 30,000 cubic feet per second and approximately 15.1 feet for the modeled discharge of 41,900 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-74-32-4946.

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 Crawfordsville in the central part of Montgomery County. The drainage area for the site is approximately 414 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 wooded.

Within the immediate vicinity of the bridge, Sugar Creek has a channel-bed slope of approximately 0.000802 ft/ft. The channel-bed material is gravel, and the channel banks consist of silt-clay. At the time of the Level I site visit on June 25, 1991, the banks were observed to have 40 to 80 percent woody vegetative cover; the field report noted that the banks were experiencing fluvial erosion with some mass wasting.

The Interstate 74 crossing of Sugar Creek is a 392-ft-long, multi-lane bridge consisting of five spans supported by concrete and steel piers and sloping concrete 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, 1963) 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-74-32-4946 crossing Sugar Creek in Montgomery 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 30,000 cubic feet per second							
1	21+62	672	0	13.0	13.0	665.5	653.1
2	22+50	671	0	13.0	13.0	663.4	653.1
3	23+23	666	0	13.0	13.0	663.5	653.1
4	24+08	672	0	13.0	13.0	666.1	653.1
Modeled discharge is 41,900 cubic feet per second							
1	21+62	672	0	15.1	15.1	665.5	651.0
2	22+50	671	0	15.1	15.1	663.4	651.0
3	23+23	666	0	15.1	15.1	663.5	651.0
4	24+08	672	0	15.1	15.1	666.1	651.0

[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, 21+62, represents a point 2,162 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 (666.1 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, 1963, Bridge plans Interstate Route 74: Bridge File I-74-32-4946.

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-74 OVER SUGAR CREEK          I-74-32-4946
T2          COUNTY MONTGOMERY              QUAD CRAWFORDSVILLE
T3          11-18-96                       R L Miller
SI          0
Q            30000  41900
SK           .000802  .000802
XS   EXIT    0   45
GR         1127 750  1309 700  1365 690  1838 680  2136 677
GR         2162 677  2166 675  2171 671  2173 670  2174 669
GR         2184 668  2213 667  2236 666  2251 666  2284 667
GR         2299 668  2304 669  2310 672  2323 675  2331 678
GR         2350 678  2372 677  2389 677  2395 677  2403 677
GR         2426 678  2429 679  2430 680  2437 685  2446 690
GR         2455 695  2461 700  2470 705  2480 708  2485 709
GR         2489 710  2498 715  2509 716  2560 716  2579 715
GR         2794 710  3025 720  3129 720  3332 720  3545 730
GR         4410 740
N               .100   .034  .100
SA                  2162  2199
XS   FULLV   393 45
GR         1127 750  1309 700  1365 690  1838 680  2136 677
GR         2162 677  2166 675  2171 671  2173 670  2174 669
GR         2184 668  2213 667  2236 666  2251 666  2284 667
GR         2299 668  2304 669  2310 672  2323 675  2331 678
GR         2350 678  2372 677  2389 677  2395 677  2403 677
GR         2426 678  2429 679  2430 680  2437 685  2446 690
GR         2455 695  2461 700  2470 705  2480 708  2485 709
GR         2489 710  2498 715  2509 716  2560 716  2579 715
GR         2794 710  3025 720  3129 720  3332 720  3545 730
GR         4410 740
N               .100   .034  .100
SA                  2162  2199
BR   BRDGE  393    695.7   45
GR         2093 0699.3  2094 0697.9  2096 0697.8  2148 0676.5
GR         2153 0676.5  2163 0671.9  2255 0671.0  2258 0668.6
GR         2264 0666.2  2279 0666.8  2299 0666.8  2316 0666.1
GR         2329 0665.9  2345 0667.1  2360 0667.4  2376 0667.4
GR         2383 0668.5  2389 0671.6  2426 0671.9  2432 0674.6
GR         2442 0674.6  2479 0690.1  2481 0690.1  2482 0691.6
GR         2417 0692.1  2367 0692.8  2285 0694.1  2192 0696.2
GR         2119 0698.5  2093 0699.3
N            .034
PD          666  2  1
PD          672  2  2
PD          672  8  3
CD           3      120   2   690
DC 0 BRDGE 2255  2389  2342  2461  *  8
DP         2093 2482  2  *  *  1.0  2.5  1.1
DP         2093 2482  2  *  *  1.0  2.5  1.1
DP         2093 2482  2  *  *  1.0  2.5  1.1
DP         2093 2482  2  *  *  1.0  2.5  1.1
XS   APPR    906
GR         1702 750  1736 750  1851 750  1979 700  2076 690
GR         2142 690  2199 688  2203 687  2205 686  2209 685
```

WSPRO INPUT FILE

```
GR          2211 684   2214 681   2215 680   2222 675   2226 674
GR          2236 674   2250 675   2258 676   2342 676   2352 675
GR          2356 670   2357 669   2360 668   2362 667   2437 667
GR          2440 670   2446 675   2458 676   2461 677   2473 677
GR          2483 677   2486 678   2492 679   2496 680   2500 681
GR          2504 682   2522 682   2540 681   2557 680   2752 690
GR          2840 710   3174 720   3597 730   4020 740
N                .100     .034     .100
SA                   2342   2461
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/ 6/97  7:33 am     Version V050196
           Input File: 4946.dat       Output File: 4946.LST
   *-------------------------------------------------------------*
T1          I-74 OVER SUGAR CREEK          I-74-32-4946
T2          COUNTY MONTGOMERY              QUAD CRAWFORDSVILLE
T3          11-18-96                       R L MILLER
SI          0
Q            30000  41900

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

SK           .000802  .000802

   ************************  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-74 OVER SUGAR CREEK          I-74-32-4946
          COUNTY MONTGOMERY              QUAD CRAWFORDSVILLE
              11-18-96                       R L MILLER

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

XS   EXIT   0   45
GR         1127 750  1309 700  1365 690  1838 680  2136 677
GR         2162 677  2166 675  2171 671  2173 670  2174 669
GR         2184 668  2213 667  2236 666  2251 666  2284 667
GR         2299 668  2304 669  2310 672  2323 675  2331 678
GR         2350 678  2372 677  2389 677  2395 677  2403 677
GR         2426 678  2429 679  2430 680  2437 685  2446 690
GR         2455 695  2461 700  2470 705  2480 708  2485 709
GR         2489 710  2498 715  2509 716  2560 716  2579 715
GR         2794 710  3025 720  3129 720  3332 720  3545 730
GR         4410 740
N               .100   .034  .100
SA                 2162  2199

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

                     X,Y-coordinates (46 pairs)
    X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
```

WSPRO OUTPUT

1127.000	750.000	1309.000	700.000	1365.000	690.000
1838.000	680.000	2136.000	677.000	2162.000	677.000
2166.000	675.000	2171.000	671.000	2173.000	670.000
2174.000	669.000	2184.000	668.000	2213.000	667.000
2236.000	666.000	2251.000	666.000	2284.000	667.000
2299.000	668.000	2304.000	669.000	2310.000	672.000
2323.000	675.000	2331.000	678.000	2350.000	678.000
2372.000	677.000	2389.000	677.000	2395.000	677.000
2403.000	677.000	2426.000	678.000	2429.000	679.000
2430.000	680.000	2437.000	685.000	2446.000	690.000
2455.000	695.000	2461.000	700.000	2470.000	705.000
2480.000	708.000	2485.000	709.000	2489.000	710.000
2498.000	715.000	2509.000	716.000	2560.000	716.000
2579.000	715.000	2794.000	710.000	3025.000	720.000
3129.000	720.000	3332.000	720.000	3545.000	730.000
4410.000	740.000				

Minimum and Maximum X,Y-coordinates

Minimum X-Station:	1127.000	(associated Y-Elevation:	750.000)
Maximum X-Station:	4410.000	(associated Y-Elevation:	740.000)
Minimum Y-Elevation:	666.000	(associated X-Station:	2251.000)
Maximum Y-Elevation:	750.000	(associated X-Station:	1127.000)

X-coordinates & Horizontal Breakpoints Translated by Skew Angle

X Input	X Skewed	X Input	X Skewed	X Input	X Skewed
1127.000	1456.212	1309.000	1584.905	1365.000	1624.503
1838.000	1958.965	2136.000	2169.683	2162.000	2188.067
2166.000	2190.896	2171.000	2194.431	2173.000	2195.846
2174.000	2196.553	2184.000	2203.624	2213.000	2224.130
2236.000	2240.393	2251.000	2251.000	2284.000	2274.334
2299.000	2284.941	2304.000	2288.477	2310.000	2292.719
2323.000	2301.912	2331.000	2307.569	2350.000	2321.004
2372.000	2336.560	2389.000	2348.581	2395.000	2352.823
2403.000	2358.480	2426.000	2374.744	2429.000	2376.865
2430.000	2377.572	2437.000	2382.522	2446.000	2388.886
2455.000	2395.250	2461.000	2399.492	2470.000	2405.856
2480.000	2412.927	2485.000	2416.463	2489.000	2419.292
2498.000	2425.655	2509.000	2433.434	2560.000	2469.496
2579.000	2482.931	2794.000	2634.959	3025.000	2798.301
3129.000	2871.840	3332.000	3015.382	3545.000	3165.996
4410.000	3777.644				

Roughness Data (3 SubAreas)

SubArea	Roughness Coefficient	Horizontal Breakpoint
1	.100	---
	---	2188.067
2	.034	---
	---	2214.230
3	.100	---

WSPRO OUTPUT

```
------- ---------- ---------

      *-------------------------------------------------*
      *      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-74 OVER SUGAR CREEK        I-74-32-4946
       COUNTY MONTGOMERY            QUAD CRAWFORDSVILLE
           11-18-96                     R L MILLER

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

XS   FULLV   393 45
GR        1127 750  1309 700  1365 690  1838 680  2136 677
GR        2162 677  2166 675  2171 671  2173 670  2174 669
GR        2184 668  2213 667  2236 666  2251 666  2284 667
GR        2299 668  2304 669  2310 672  2323 675  2331 678
GR        2350 678  2372 677  2389 677  2395 677  2403 677
GR        2426 678  2429 679  2430 680  2437 685  2446 690
GR        2455 695  2461 700  2470 705  2480 708  2485 709
GR        2489 710  2498 715  2509 716  2560 716  2579 715
GR        2794 710  3025 720  3129 720  3332 720  3545 730
GR        4410 740
N              .100   .034  .100
SA                2162  2199

 ***   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:      393.   Cross-Section Skew:  45.0   Error Code   0
 Valley Slope:   .00000    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (46 pairs)
    X          Y          X          Y          X          Y
---------- ---------- ---------- ---------- ---------- ----------
  1127.000   750.000    1309.000   700.000    1365.000   690.000
  1838.000   680.000    2136.000   677.000    2162.000   677.000
  2166.000   675.000    2171.000   671.000    2173.000   670.000
  2174.000   669.000    2184.000   668.000    2213.000   667.000
  2236.000   666.000    2251.000   666.000    2284.000   667.000
  2299.000   668.000    2304.000   669.000    2310.000   672.000
  2323.000   675.000    2331.000   678.000    2350.000   678.000
  2372.000   677.000    2389.000   677.000    2395.000   677.000
  2403.000   677.000    2426.000   678.000    2429.000   679.000
  2430.000   680.000    2437.000   685.000    2446.000   690.000
```

WSPRO OUTPUT

2455.000	695.000	2461.000	700.000	2470.000	705.000
2480.000	708.000	2485.000	709.000	2489.000	710.000
2498.000	715.000	2509.000	716.000	2560.000	716.000
2579.000	715.000	2794.000	710.000	3025.000	720.000
3129.000	720.000	3332.000	720.000	3545.000	730.000
4410.000	740.000				

Minimum and Maximum X,Y-coordinates

Minimum X-Station:	1127.000	(associated Y-Elevation:	750.000)
Maximum X-Station:	4410.000	(associated Y-Elevation:	740.000)
Minimum Y-Elevation:	666.000	(associated X-Station:	2251.000)
Maximum Y-Elevation:	750.000	(associated X-Station:	1127.000)

X-coordinates & Horizontal Breakpoints Translated by Skew Angle

X Input	X Skewed	X Input	X Skewed	X Input	X Skewed
1127.000	1456.212	1309.000	1584.905	1365.000	1624.503
1838.000	1958.965	2136.000	2169.683	2162.000	2188.067
2166.000	2190.896	2171.000	2194.431	2173.000	2195.846
2174.000	2196.553	2184.000	2203.624	2213.000	2224.130
2236.000	2240.393	2251.000	2251.000	2284.000	2274.334
2299.000	2284.941	2304.000	2288.477	2310.000	2292.719
2323.000	2301.912	2331.000	2307.569	2350.000	2321.004
2372.000	2336.560	2389.000	2348.581	2395.000	2352.823
2403.000	2358.480	2426.000	2374.744	2429.000	2376.865
2430.000	2377.572	2437.000	2382.522	2446.000	2388.886
2455.000	2395.250	2461.000	2399.492	2470.000	2405.856
2480.000	2412.927	2485.000	2416.463	2489.000	2419.292
2498.000	2425.655	2509.000	2433.434	2560.000	2469.496
2579.000	2482.931	2794.000	2634.959	3025.000	2798.301
3129.000	2871.840	3332.000	3015.382	3545.000	3165.996
4410.000	3777.644				

Roughness Data (3 SubAreas)

SubArea	Roughness Coefficient	Horizontal Breakpoint
1	.100	---
	---	2188.067
2	.034	---
	---	2214.230
3	.100	---

--
* 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

WSPRO OUTPUT

```
*-------------------------------------------------------------*
          I-74 OVER SUGAR CREEK        I-74-32-4946
        COUNTY MONTGOMERY             QUAD CRAWFORDSVILLE
            11-18-96                     R L MILLER

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

BR   BRDGE  393    695.7   45
GR        2093 0699.3  2094 0697.9  2096 0697.8  2148 0676.5
GR        2153 0676.5  2163 0671.9  2255 0671.0  2258 0668.6
GR        2264 0666.2  2279 0666.8  2299 0666.8  2316 0666.1
GR        2329 0665.9  2345 0667.1  2360 0667.4  2376 0667.4
GR        2383 0668.5  2389 0671.6  2426 0671.9  2432 0674.6
GR        2442 0674.6  2479 0690.1  2481 0690.1  2482 0691.6
GR        2417 0692.1  2367 0692.8  2285 0694.1  2192 0696.2
GR        2119 0698.5  2093 0699.3
N           .034
PD         666  2  1
PD         672  2  2
PD         672  8  3
CD          3      120   2   690

 ***   Completed Reading Data Associated With Header Record BRDGE   ***
 ***   Storing Bridge Data In Temporary File As Record Number  3    ***

 ***              Data Summary For Bridge Record BRDGE              ***
 SRD Location:      393.   Cross-Section Skew:  45.0   Error Code   0
 Valley Slope:  *******    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (30 pairs)
    X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
  2093.000    699.300      2094.000    697.900      2096.000    697.800
  2148.000    676.500      2153.000    676.500      2163.000    671.900
  2255.000    671.000      2258.000    668.600      2264.000    666.200
  2279.000    666.800      2299.000    666.800      2316.000    666.100
  2329.000    665.900      2345.000    667.100      2360.000    667.400
  2376.000    667.400      2383.000    668.500      2389.000    671.600
  2426.000    671.900      2432.000    674.600      2442.000    674.600
  2479.000    690.100      2481.000    690.100      2482.000    691.600
  2417.000    692.100      2367.000    692.800      2285.000    694.100
  2192.000    696.200      2119.000    698.500      2093.000    699.300
----------  ----------   ----------  ----------   ----------  ----------

                Minimum and Maximum X,Y-coordinates
  Minimum X-Station:    2093.000  ( associated Y-Elevation:  699.300 )
  Maximum X-Station:    2482.000  ( associated Y-Elevation:  691.600 )
  Minimum Y-Elevation:   665.900  ( associated X-Station:   2329.000 )
  Maximum Y-Elevation:   699.300  ( associated X-Station:   2093.000 )

     X-coordinates & Horizontal Breakpoints Translated by Skew Angle
```

WSPRO OUTPUT

X Input	X Skewed	X Input	X Skewed	X Input	X Skewed
2093.000	2162.123	2094.000	2162.830	2096.000	2164.244
2148.000	2201.014	2153.000	2204.549	2163.000	2211.620
2255.000	2276.674	2258.000	2278.795	2264.000	2283.038
2279.000	2293.645	2299.000	2307.787	2316.000	2319.808
2329.000	2329.000	2345.000	2340.314	2360.000	2350.920
2376.000	2362.234	2383.000	2367.184	2389.000	2371.427
2426.000	2397.589	2432.000	2401.832	2442.000	2408.903
2479.000	2435.066	2481.000	2436.480	2482.000	2437.187
2417.000	2391.225	2367.000	2355.870	2285.000	2297.887
2192.000	2232.126	2119.000	2180.508	2093.000	2162.123

Roughness Data (1 SubAreas)

SubArea	Roughness Coefficient	Horizontal Breakpoint
1	.034	---

Discharge coefficient parameters

BRType	BRWdth	EMBSS	EMBElv	UserCD
3	120.000	2.00	690.000	**********

Pressure flow elevations

AVBCEL	PFElev
*********	695.700

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	666.000	2.000	1
2	672.000	2.000	2
3	672.000	8.000	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-74 OVER SUGAR CREEK I-74-32-4946
COUNTY MONTGOMERY QUAD CRAWFORDSVILLE

WSPRO OUTPUT

```
             11-18-96                          R L MILLER
DC 0 BRDGE 2255  2389  2342  2461  *  8
DP         2093 2482  2  *  *  1.0  2.5  1.1
DP         2093 2482  2  *  *  1.0  2.5  1.1
DP         2093 2482  2  *  *  1.0  2.5  1.1
DP         2093 2482  2  *  *  1.0  2.5  1.1

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

XS   APPR    906
GR         1702 750  1736 750  1851 750  1979 700  2076 690
GR         2142 690  2199 688  2203 687  2205 686  2209 685
GR         2211 684  2214 681  2215 680  2222 675  2226 674
GR         2236 674  2250 675  2258 676  2342 676  2352 675
GR         2356 670  2357 669  2360 668  2362 667  2437 667
GR         2440 670  2446 675  2458 676  2461 677  2473 677
GR         2483 677  2486 678  2492 679  2496 680  2500 681
GR         2504 682  2522 682  2540 681  2557 680  2752 690
GR         2840 710  3174 720  3597 730  4020 740
N               .100   .034   .100
SA                 2342  2461

 ***   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:      906.   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 (44 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
  1702.000     750.000     1736.000     750.000     1851.000     750.000
  1979.000     700.000     2076.000     690.000     2142.000     690.000
  2199.000     688.000     2203.000     687.000     2205.000     686.000
  2209.000     685.000     2211.000     684.000     2214.000     681.000
  2215.000     680.000     2222.000     675.000     2226.000     674.000
  2236.000     674.000     2250.000     675.000     2258.000     676.000
  2342.000     676.000     2352.000     675.000     2356.000     670.000
  2357.000     669.000     2360.000     668.000     2362.000     667.000
  2437.000     667.000     2440.000     670.000     2446.000     675.000
  2458.000     676.000     2461.000     677.000     2473.000     677.000
  2483.000     677.000     2486.000     678.000     2492.000     679.000
  2496.000     680.000     2500.000     681.000     2504.000     682.000
  2522.000     682.000     2540.000     681.000     2557.000     680.000
  2752.000     690.000     2840.000     710.000     3174.000     720.000
  3597.000     730.000     4020.000     740.000
----------  ----------   ----------  ----------   ----------  ----------

                Minimum and Maximum X,Y-coordinates
  Minimum X-Station:    1702.000  ( associated Y-Elevation:  750.000 )
```

WSPRO OUTPUT

```
Maximum X-Station:     4020.000  ( associated Y-Elevation:  740.000 )
Minimum Y-Elevation:    667.000  ( associated X-Station:   2437.000 )
Maximum Y-Elevation:    750.000  ( associated X-Station:   1702.000 )

                  Roughness Data (  3 SubAreas )
                          Roughness   Horizontal
                SubArea  Coefficient  Breakpoint
                -------  -----------  ----------
                   1         .100        ---
                             ---       2342.000
                   2         .034        ---
                             ---       2461.000
                   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-74 OVER SUGAR CREEK        I-74-32-4946
          COUNTY MONTGOMERY             QUAD CRAWFORDSVILLE
              11-18-96                      R L MILLER
 EX

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

          Reach       Water Surface   Friction
    #   Discharge       Elevation      Slope          Flow Regime
   --   ---------    -------------   --------   --------------------
    1    30000.00       ********        .0008        Sub-Critical
    2    41900.00       ********        .0008        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-74 OVER SUGAR CREEK        I-74-32-4946
```

WSPRO OUTPUT

COUNTY MONTGOMERY QUAD CRAWFORDSVILLE
11-18-96 R L MILLER

	WSEL / EGEL / CRWS	VHD / HF / HO	Q / V / FR #	AREA / K / SF	SRDL / FLEN / ALPHA	LEW / REW / ERR
Section: EXIT	690.486	.349	30000.000	11598.740	*********	1362.276
Header Type: XS	690.836	******	2.586	1058490.00	*********	2446.875
SRD: .000	682.183	******	.256	******	3.358	******
Section: FULLV	690.817	.324	30000.000	11957.950	393.000	1360.423
Header Type: FV	691.141	.303	2.509	1103986.00	393.000	2447.471
SRD: 393.000	682.183	.000	.243	.0008	3.312	.003

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

Section: APPR	690.875	.976	30000.000	6944.611	513.000	2067.510
Header Type: AS	691.851	.385	4.320	1087030.00	513.000	2755.851
SRD: 906.000	681.713	.326	.440	.0007	3.362	-.001

<<< 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	690.836	.314	30000.000	6751.959	393.000	2113.002
Header Type: BR	691.149	.313	4.443	2014262.00	393.000	2481.490
SRD: 393.000	676.804	.000	.185	******	1.022	.001

Specific Bridge Information	C	P/A	PFELEV	BLEN	XLAB	XRAB
Bridge Type 3 Flow Type 1						
Pier/Pile Code 0	.9894	.024	695.700	********	********	********

	WSEL / EGEL / CRWS	VHD / HF / HO	Q / V / FR #	AREA / K / SF	SRDL / FLEN / ALPHA	LEW / REW / ERR
Section: APPR	690.519	1.040	30000.000	6700.149	393.000	2070.967
Header Type: AS	691.559	.381	4.478	1046424.00	472.164	2754.283
SRD: 906.000	681.713	.028	.460	.0007	3.335	-.002

Approach Section APPR Flow Contraction Information

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
.465	.000	1065888.0	2209.566	2578.051	690.519

WSPRO OUTPUT

```
                <<< 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-74 OVER SUGAR CREEK        I-74-32-4946
        COUNTY MONTGOMERY             QUAD CRAWFORDSVILLE
            11-18-96                      R L MILLER

                    WSEL     VHD       Q         AREA      SRDL      LEW
                    EGEL      HF       V           K        FLEN      REW
                    CRWS      HO      FR #        SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: EXIT       693.325   .380  41900.000  14707.420 *********  1346.379
Header Type: XS     693.705 ******      2.849 1478138.00 *********  2451.985
SRD:       .000     683.906 ******       .239     ******     3.010     ******

Section: FULLV      693.655   .358  41900.000  15072.590   393.000  1344.531
Header Type: FV     694.013   .305      2.780 1531110.00   393.000  2452.579
SRD:    393.000     683.906   .000       .229      .0008     2.977      .003

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

Section: APPR       693.640  1.209  41900.000   8901.213   513.000  2040.697
Header Type: AS     694.849   .411      4.707 1429649.00   513.000  2768.014
SRD:    906.000     684.363   .426       .444      .0008     3.509     -.001

       <<< 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      693.549   .503  41900.000   7589.102   393.000  2106.379
Header Type: BR     694.052   .347      5.521 1910609.00   393.000  2482.000
SRD:    393.000     678.577   .000       .267     ******     1.062      .001

Specific Bridge Information   C      P/A   PFELEV    BLEN      XLAB      XRAB
Bridge Type 3   Flow Type 1 ------ ----- -------- -------- -------- --------
Pier/Pile Code  0             .9705  .024  695.700 ******** ******** ********
------------------------- ------ ----- -------- -------- -------- --------

                    WSEL     VHD       Q         AREA      SRDL      LEW
                    EGEL      HF       V           K        FLEN      REW
                    CRWS      HO      FR #        SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: APPR       693.291  1.276  41900.000   8648.627   393.000  2044.077
```

WSPRO OUTPUT

```
Header Type: AS    694.567   .454      4.845 1383777.00   481.338  2766.481
SRD:    906.000    684.363   .061       .462       .0008     3.496     -.003

            Approach Section APPR  Flow Contraction Information
           M( G )   M( K )     KQ       XLKQ     XRKQ     OTEL
          -------- -------- --------- -------- -------- --------
              .483     .028 1345389.0 2231.320 2606.938  693.291
          -------- -------- --------- -------- -------- --------

              <<< 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-74 OVER SUGAR CREEK        I-74-32-4946
           COUNTY MONTGOMERY            QUAD CRAWFORDSVILLE
               11-18-96                     R L MILLER

  ***  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):  8.000
             *---------------------------------------------*

     Scour      -- Flow --          -- Width --         --- X-Limits ---
 #   Depth  Contract Approach  Contract Approach  Side   Contract Approach
--   ------ --------- --------- -------- --------  ------ -------- --------
 1  -5.535 16996.440 23258.800  126.000  119.000  Left:  2255.000 2342.000
    ..... Approach Channel Depth:   21.141 .....  Right: 2389.000 2461.000
*  Negative Scour Depth Encountered - Check If Variables Are Reasonable  *

 2  -6.032 22378.920 30165.580  126.000  119.000  Left:  2255.000 2342.000
    ..... Approach Channel Depth:   23.913 .....  Right: 2389.000 2461.000
*  Negative Scour Depth Encountered - Check If Variables Are Reasonable  *
--   ------ --------- --------- -------- --------  ------ -------- --------


    ************************ 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-74 OVER SUGAR CREEK        I-74-32-4946
           COUNTY MONTGOMERY            QUAD CRAWFORDSVILLE
               11-18-96                     R L MILLER

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

                    Constants and Input Variables
```

WSPRO OUTPUT

Pier Width: 2.000

Pier Shape Factor	(K1): 1.00
Flow Angle of Attack Factor	(K2): 2.50
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	12.98	30000.000	690.864	24.964	5.336	.188	2093.000	2482.000
2	15.06	41900.000	693.609	27.709	7.298	.244	2093.000	2482.000

********** 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-74 OVER SUGAR CREEK I-74-32-4946
COUNTY MONTGOMERY QUAD CRAWFORDSVILLE
11-18-96 R L MILLER

*** 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): 2.50
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	12.98	30000.000	690.864	24.964	5.336	.188	2093.000	2482.000
2	15.06	41900.000	693.609	27.709	7.298	.244	2093.000	2482.000

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

WSPRO OUTPUT

```
*-------------------------------------------------------------*
          I-74 OVER SUGAR CREEK        I-74-32-4946
        COUNTY MONTGOMERY            QUAD CRAWFORDSVILLE
            11-18-96                     R L MILLER

     ***  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):   2.50
                    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   12.98  30000.000  690.864 24.964   5.336     .188   2093.000  2482.000
 2   15.06  41900.000  693.609 27.709   7.298     .244   2093.000  2482.000
--   ----- ---------- -------- ------ -------- -------- --------- ---------


************************  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-74 OVER SUGAR CREEK        I-74-32-4946
        COUNTY MONTGOMERY            QUAD CRAWFORDSVILLE
            11-18-96                     R L MILLER

     ***  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):   2.50
                    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   12.98  30000.000  690.864 24.964   5.336     .188   2093.000  2482.000
```

WSPRO OUTPUT

```
 2    15.06  41900.000  693.609 27.709   7.298      .244   2093.000  2482.000
--    ----- ---------- -------- ------ -------- -------- --------- ---------

  ER

   ****************** Normal end of WSPRO execution. *****************
   *************** Elapsed Time:   0 Minutes  9 Seconds  **************
```