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# A STUDY OF ANGLE OF ATTACK AT BRIDGES AND THE PREFES PROGRAM

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Lawrence, Kansas

December 1996

## K-TRAN

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**15. Supplementary Notes**


**16. Abstract**

This report includes descriptions of three computer programs developed to enable practicing engineers to make use of the two-dimensional finite element model FESWMS-2DH for the analysis of scour at single opening bridges. Multiple opening bridges could be analyzed one opening at a time after using WSPRO to determine the division of flow for each opening. The executable versions of the programs are available. The program descriptions are as follows:

PREFES is a preprocessor for FESWMS-2DH which is described in detail in the report. The program PREFES creates the finite element grid input file and various other files required to run FESWMS-2DH. It is designed to create close to the maximum allowable number of finite element nodes with the greatest node density through the bridge opening. This results in very precise flow modeling by FESWMS-2DH. Reliable estimates of angle of attack, velocity magnitude and approach depth can be obtained for scour calculations. The input file for PREFES is quite similar to a WSPRO input file. This input file contains WSPRO cross-sectional data as well as several other parameter "cards" containing instructions for the FESWMS-2DH model.

POSTFES is a BETA-version postprocessor for FESWMS-2DH. The program uses one of the FESWMS-2DH output files, NODE.OUT, to generate a table of variables used for pier scour calculations. The table gives flow depth, resultant velocity magnitude and angle of attack as functions of stationing across the bridge opening. The program could be expanded to perform actual scour calculations for pier, abutment or other conctaction.

WSPROFES is a BETA-version "pre-pre-processor". It transforms a standard WSPRO input file into the input needed for the PREFES program. It enables the use of FESWMS-2DH without manually creating an input file for PREFES. This program has been successfully tested on several WSPRO input files, however it is considered a BETA-version program.


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**FINAL REPORT**

**Project No. K-TRAN: KU-94-5**

Prepared for
**Kansas Department of Transportation**

by

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**December 1996**

## PREFACE

This research project was funded by the Kansas Department of Transportation K-TRAN research program. The Kansas Transportation Research and New-Developments (K-TRAN) Research Program is an ongoing, cooperative and comprehensive research program addressing transportation needs of the State of Kansas utilizing academic and research resources from the Kansas Department of Transportation, Kansas State University and the University of Kansas. The projects included in the research program are jointly developed by transportation professionals in KDOT and the universities.

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# OVERVIEW OF PROGRAMS

This report includes descriptions of three computer programs developed to enable practicing engineers to make use of the two-dimensional finite element model FESWMS-2DH for the analysis of scour at single opening bridges. (Multiple opening bridges could be analyzed one opening at a time after using WSPRO to determine the division of flow for each opening.) The executable versions of the programs are included on the enclosed floppy disk together with example files and the FESWMS-2DH programs. The program descriptions are as follows

*PREFES is a preprocessor for FESWMS-2DH which is described in detail in the report. The program PREFES creates the finite element grid input file and various other input files required to run FESWMS-2DH. It is designed to create close to the maximum allowable number of finite element nodes with the greatest node density through the bridge opening. This results in very precise flow modeling by FESWMS-2DH. Consequently, reliable estimates of angle of attack, velocity magnitude and approach depth can be obtained for scour calculations. The input file for PREFES is a file quite similar to a WSPRO input file. This input file contains WSPRO cross-sectional data as well as several other parameter "cards" containing instructions for the FESWMS-2DH model.*

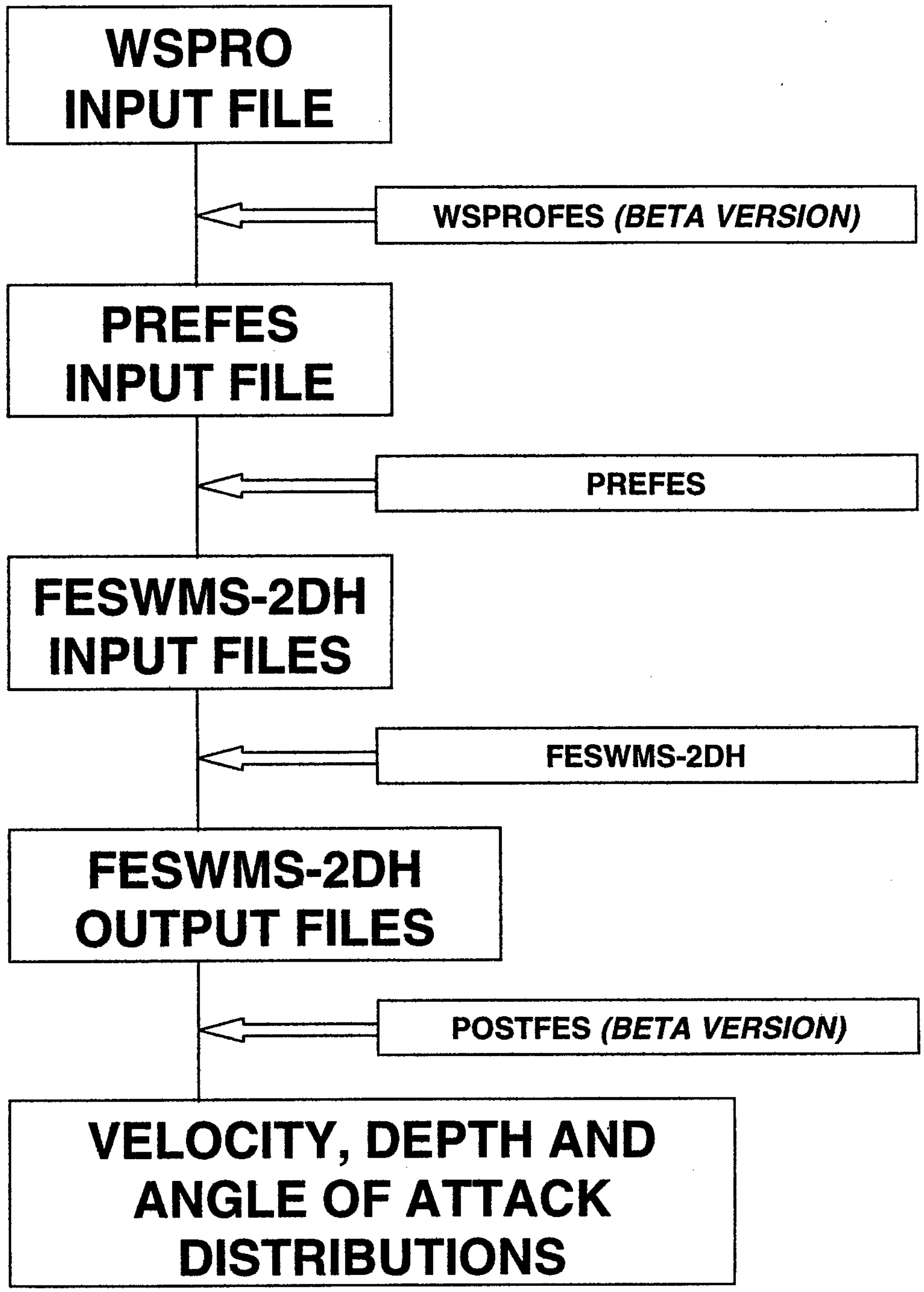
*POSTFES is a BETA-version postprocessor for FESWMS-2DH. At this time the program uses one of the FESWMS-2DH output files, NODE.OUT, to generate a table of variables used for pier scour calculations. The table gives flow depth, resultant velocity magnitude and angle of attack as functions of stationing across the bridge opening. The program could easily be expanded to perform actual scour calculations for pier, abutment and contraction scour.*

*WSPROFES is a BETA-version "pre-pre-processor." Essentially, it transforms a standard WSPRO input file into the input file needed for the PREFES program described above. It enables the use of FESWMS-2DH without manually creating an input file for PREFES. Although this program has been successfully tested on several WSPRO input files, it is considered a BETA-version program.*

A flowchart illustrating the sequence in which the programs described above are to be used in analyzing bridges using FESWMS-2DH is presented below. (See Chapt. 8 for details on program execution.) The execution times are about 1, 2, 10 to 30 and 1 minute, respectively, for WSPROFES, PREFES, FESWMS-2DH and POSTFES. The execution time for FESWMS-2DH is strongly dependent on the type of PC used. Pentium machines are recommended but 486's with 8MB of ram will run the program.

The WSPRO example represented by input file E8.DAT in the scour manual entitled Bridge Scour Analysis Using WSPRO in Vol. II of the KDOT Bridge Manual is used for illustration of the procedure above. This bridge was a real bridge with 7 piers, skewed at 30 degrees to the main river channel. (Details are found in the KDOT Bridge Manual.) The WSPRO input file E8.DAT is shown in Table 1. Table 2 shows the file E8.IN created by WSPROFES using E8.DAT as the input file. Tables 3, 4 and 5 show the files DINMOD.DAT, ANOMOD.DAT, FLOMOD.DAT and GRID.DAT created by PREFES using E8.IN as the input file. The plot files for the finite element grid, the ground surface contours, and the velocity vectors as generated by FWSWMS-2DH are shown in Figure 1. Table 6 presents the transverse distribution of resultant velocity, angle of attack and depth of flow as generated by POSTFES using as input the FESWMS-2DH output file, NODE.OUT. The tabular data in this file could be imported into a spreadsheet and used to perform detailed scour calculations based on a true two-dimensional model – FESWMS-2DH. As discussed in Chapter 1 of the report, studies of actual bridge scour conditions show that angle of attack plays a vital role in determining a bridge's susceptibility to scour. WSPRO simply does accurately model angle of attack.

# PROGRAMS


WSPRO INPUT FILE
WSPROFES (BETA VERSION)
PREFES INPUT FILE
PREFES
FESWMS-2DH INPUT FILES
FESWMS-2DH
FESWMS-2DH OUTPUT FILES
POSTFES (BETA VERSION)
VELOCITY, DEPTH AND ANGLE OF ATTACK DISTRIBUTIONS

# TABLE 1. WSPRO Input File E8.DAT

```
T1         NATURAL CHANNEL WITHOUT CONTRACTION SCOUR
T2         EXAMPLE 8
T3         50-YEAR CASE A
J1         0.5   0.01   0.001
Q          28200
WS         565.90
*            (Add 1000 Ft. to all Elevations)
XS    A-A      8500
*            STA.     ELEV     STA.     ELEV     STA.     ELEV     STA.     ELEV
GR           0        575      300      565      700      560      900      559
GR           1200     558      1250     556      1275     551      1300     550
GR           1400     551      1450     558      1600     561      1900     565
GR           2200     568      2500     575
N             .055       .045       .035      .045      .055
SA                  700       1200       1450       1900
*
XS    B-B         9400
*            STA.     ELEV     STA.     ELEV     STA.     ELEV     STA.     ELEV
GR              0     575      200      567      400      564      600      562
GR            800     561      1100     560.5    1200     560      1250     557
GR           1275     553      1300     552      1350     552.5    1400     553
GR           1425     556      1450     560      1650     563      1900     566
GR           2150     569      2500     575
SA                 600      1250      1425      1650
*
XS    EXIT        10000
*            STA.     ELEV     STA.     ELEV     STA.     ELEV     STA.     ELEV
GR             00     575      200      568      300      566      450      564
GR            600     563      900      560      1000     559.5    1030     558
GR           1060     554      1100     553      1150     553      1250     554
GR           1275     556      1300     557      1450     559      1500     559
GR           1700     562      2000     566      2200     569      2500     575
SA                 600      1060      1250      1450
*
XS    FULLV        10600  -30
*            STA.     ELEV     STA.     ELEV     STA.     ELEV     STA.     ELEV
GR             00     575      200      567      400      564      600      563
GR            800     563      900      562      1000     562      1015     562
GR           1050     562      1100     560      1120     561      1140     560
GR           1170     555      1200     554      1250     555      1300     555
GR           1350     560      1400     561      1450     562      1480     563
GR           1503     563      1518     563      1700     563      1900     564
GR           2200     567      2500     575
SA            800     1140     1350     1700
*
BR    BRIDG      10600    569      -30
*            STA.     ELEV     STA.     ELEV     STA.     ELEV     STA.     ELEV
GR           1000     569      1015     562      1050     562      1100     560
GR           1120     561      1140     560      1170     555      1200     554
GR           1250     555      1300     555      1350     560      1400     561
GR           1450     562      1480     563      1503     563      1518     569
GR           1000     569
N             .045       .035       .045
SA                 1140      1350
PW         554.5  3  555     3   555     6    557.8  6    557.8  9    561     9
PW         561   15  562    15   562    18    562.7 18    562.7 21    564.5  21
PW         564.5 24.5  569  24.5
CD              3        44       3      572.8
*
XR    ROAD      10622      44        *        *       30
*          STA.  ELEV    STA.   ELEV    STA.   ELEV    STA.   ELEV    STA.   ELEV
*          ACTUAL ROAD DATA
*             00   575     50    569     300    570     500    572.0   700    572.5
*           800    572.7   900    572.8   1600   572.8   1700   572.8   1800   572.7
*           1900   572.6   2000   572.4   2100   572.2   2200   572     2300   571.9
*           2450   571.9   2500   575
*          ASSUMED ROAD DATA (ONLY 1000 FT OF WEIR FLOW)
GR          759    575     759    572.8   1759   572.8   1759   575
N            .03
*
AS    APPRO      12000
*          STA.  ELEV    STA.   ELEV    STA.   ELEV    STA.   ELEV    STA.   ELEV
GR           00    575     300    569     600    566     700    565     800    563
GR          850    562     900    561     950    560     1000   558     1050   556
GR         1100    555     1140   555     1200   556     1250   558     1300   560
GR         1350    561     1500   563     1518   563     1700   565     1900   567
GR         2200    569     2400   573     2500   575
SA                 700     950       1300      1518
*
HP 2 BRIDG        566.03       0     566.03    28200
HP 2 APPRO        568.68       0     568.68    28200
HP 1 BRIDG        566.03       0     566.03    28200
HP 1 APPRO        568.68       0     568.68    28200
EX
ER
```

# TABLE 2. Input File E8.IN Generated by WSPROFES to be Used as Input File for PREFES Program

```
T1         NATURAL CHANNEL WITHOUT CONTRACTION SCOUR
T2         EXAMPLE 8
T3         50-YEAR CASE A
*
NET            13000      3000       0.50       0.50       5.00       5.00
TYP       1    0.060      4.000      0.050      7.000
TYP       2    0.050      5.000      0.040      8.000
TYP       3    0.040      6.000      0.030      9.000
*
Q         28200
WS        565.90
*
*
XS   A-A      8500.         0.0    1200       1450        14     1    1
GR   0       575       300         565        700        560          900        559
GR   1200    558       1250        556        1275       551          1300       550
GR   1400    551       1450        558        1600       561          1900       565
GR   2200    568       2500        575
NR             5
PT      1          2          3          2          1
SA     700       1200       1450       1900
*
XS   B-B      9400.         0.0    1250       1425        18     1    1
GR   0       575       200         567        400        564          600        562
GR   800     561       1100        560.5      1200       560          1250       557
GR   1275    553       1300        552        1350       552.5        1400       553
GR   1425    556       1450        560        1650       563          1900       566
GR   2150    569       2500        575
NR             5
PT      1          2          3          2          1
SA     600       1250       1425       1650
*
XS   EXIT    10000.         0.0    1060       1250        20     1    1
GR   00      575       200         568        300        566          450        564
GR   600     563       900         560        1000       559.5        1030       558
GR   1060    554       1100        553        1150       553          1250       554
GR   1275    556       1300        557        1450       559          1500       559
GR   1700    562       2000        566        2200       569          2500       575
NR             5
PT      1          2          3          2          1
SA     600       1060       1250       1450
*
XS   FULLV   10599.       -30.0    1140       1350        26     1    1
GR   00      575       200         567        400        564          600        563
GR   800     563       900         562        1000       562          1015       562
GR   1050    562       1100        560        1120       561          1140       560
GR   1170    555       1200        554        1250       555          1300       555
GR   1350    560       1400        561        1450       562          1480       563
GR   1503    563       1518        563        1700       563          1900       564
GR   2200    567       2500        575
NR             5
PT      1          2          3          2          1
SA     800       1140       1350       1700
*
BR   BRIDG   10600.       569.0 -30.0 44.0  0.0  1140       1350       16     0      0
GR   1000    569       1015        562        1050       562          1100       560
GR   1120    561       1140        560        1170       555          1200       554
GR   1250    555       1300        555        1350       560          1400       561
GR   1450    562       1480        563        1503       563          1518       569
NR             3
PT      2          3          2
SA    1140       1350
*
XS   FULLU   10651.       -30.0    1140       1350        26     1    1
GR   00      575       200         567        400        564          600        563
GR   800     563       900         562        1000       562          1015       562
GR   1050    562       1100        560        1120       561          1140       560
GR   1170    555       1200        554        1250       555          1300       555
GR   1350    560       1400        561        1450       562          1480       563
GR   1503    563       1518        563        1700       563          1900       564
GR   2200    567       2500        575
NR             5
PT      1          2          3          2          1
SA     800       1140       1350       1700
*
AS   APPRO   12000.         0.0    950        1300        23     1    1
GR   00      575       300         569        600        566          700        565
GR   800     563       850         562        900        561          950        560
GR   1000    558       1050        556        1100       555          1140       555
GR   1200    556       1250        558        1300       560          1350       561
GR   1500    563       1518        563        1700       565          1900       567
GR   2200    569       2400        573        2500       575
NR             5
PT      1          2          3          2          1
SA     700        950       1300       1518
ER
```

# TABLE 3. DINMOD.DAT and ANOMOD.DAT Created by PREFES as Input Files for FESWMS-2DH

**DINMOD.DAT**

```
SWMS                 1         1
        NATURAL CHANNEL WITHOUT CONTRACTION SCOUR
    3    3    1    0    0    0    1    0
PLOT
        EXAMPLE 8
    0    2
      0.14       0.07      0.105      0.105        2.0
 12000.000  2500.000       .000       .000    500.000    482.247    180.000

LAST
```

**ANOMOD.DAT**

```
SWMS                  1          1                                         0
0
    0    1    1    0    0    0
VECT                                                                       0
0
             Flow velocity field
    1    0
        20          0          1              250.000     60.281
      .140       .070
 12000.000  2500.000       .000       .000    500.000    482.247    180.000
ISOL                                                                       0
0
             Water surface contour
    1    2    1
         0    570.90        .20
      .140       .070
 12000.000  2500.000       .000       .000    500.000    482.247    180.000
ISOL                                                                       0
0
             Velocity contour
    1    3    1
         0    180.00        .50
      .140       .070
 12000.000  2500.000       .000       .000    500.000    482.247    180.000
LAST
```

# TABLE 4. FLOMOD.DAT Created by PREFES as Input File for FESWMS-2DH

```
SWMS                1           1
          NATURAL CHANNEL WITHOUT CONTRACTION SCOUR
    0    3    0    0    0    0    0    1    1    0    1
    1    0    1    1    0    0   98   99
         1         0         0        10        .000         .000         .000         .670
  565.900       .000

PROP
         1      .060     4.000       .050      7.000                          1       .6000
         2      .050     5.000       .040      8.000                          1       .6000
         3      .040     6.000       .030      9.000                          1       .6000

QSEC
         1   28200.00
12009120101201112012120131201412015120161201712018120191202012021120221202312024
12025120261202712028120291203012031120321203312034120351203612037120381203912040
12041120421204312044120451204612047120481204912050120511205212053120541205512056
12057120581205912060120611206212063120641206512066120671206812069120701207112072
120731207412075120761207712078120791208012081120821208312084120851208612087    -1

ZSEC
         1   565.900                      2
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32
   33   34   35   36   37   38   39   40   41   42   43   44   45   46   47   48
   49   50   51   52   53   54   55   56   57   58   59   60   61   62   63   64
   65   66   67   68   69   70   71   72   73   74   75   76   77   78   79   -1

FLUX
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32
   33   34   35   36   37   38   39   40   41   42   43   44   45   46   47   48
   49   50   51   52   53   54   55   56   57   58   59   60   61   62   63   64
   65   66   67   68   69   70   71   72   73   74   75   76   77   78   79   -1
 7601 7602 7603 7604 7605 7606 7607 7608 7609 7610 7611 7612 7613 7614 7615 7616
 7617 7618 7619 7620 7621 7622 7623 7624 7625 7626 7627 7628 7629 7630 7631 7632
 7633 7634 7635 7636 7637 7638 7639   -1
12009120101201112012120131201412015120161201712018120191202012021120221202312024
12025120261202712028120291203012031120321203312034120351203612037120381203912040
12041120421204312044120451204612047120481204912050120511205212053120541205512056
12057120581205912060120611206212063120641206512066120671206812069120701207112072
120731207412075120761207712078120791208012081120821208312084120851208612087    -1

LAST
```

# TABLE 5. GRID.DAT Created by PREFES as Input File for FESWMS-2DH

**GRID.DAT**

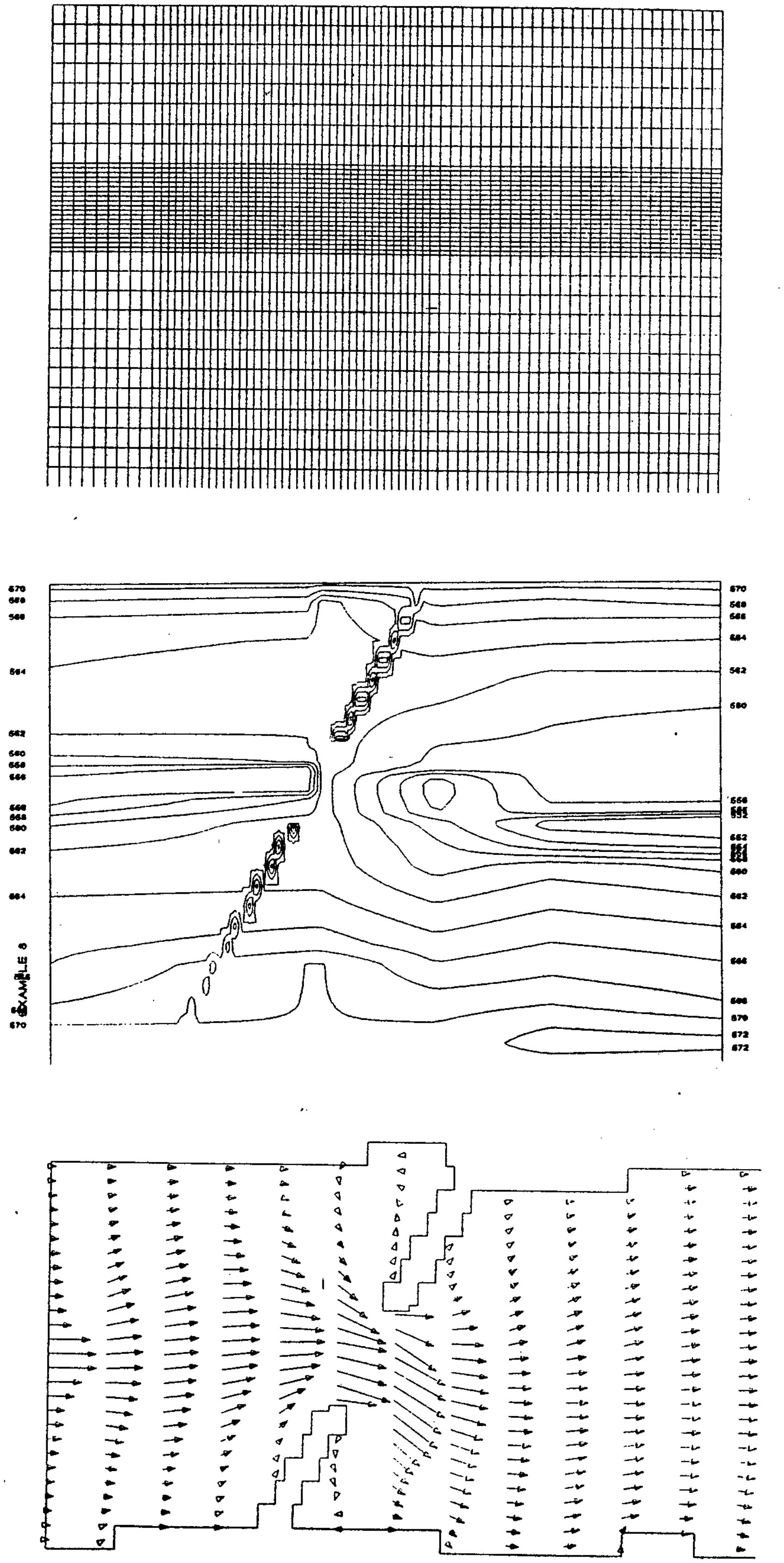
```
12087        2964
    1  8500.000     88.767   570.900        .000
    2  8500.000    137.346   570.422        .000
    3  8500.000    185.924   568.802        .000
    4  8500.000    234.503   567.183        .000
    5  8500.000    283.082   565.564        .000
    6  8500.000    331.660   564.604        .000
    7  8500.000    380.239   563.997        .000
    8  8500.000    428.818   563.390        .000
    9  8500.000    477.396   562.783        .000
    :       :          :         :             :
    :       :          :         :             :
12078 12000.000  2055.485   566.555        .000
12079 12000.000  2104.875   567.049        .000
12080 12000.000  2154.266   567.543        .000
12081 12000.000  2203.657   568.073        .000
12082 12000.000  2253.047   569.061        .000
12083 12000.000  2302.438   570.049        .000
12084 12000.000  2351.828   570.049        .000
12085 12000.000  2401.219   570.049        .000
12086 12000.000  2450.609   570.049        .000
12087 12000.000  2500.000   570.900        .000
  1    1   80  159  160  161   82    3    2   81     1
  2    3   82  161  162  163   84    5    4   83     1
  3    5   84  163  164  165   86    7    6   85     1
  4    7   86  165  166  167   88    9    8   87     1
  5    9   88  167  168  169   90   11   10   89     1
  6   11   90  169  170  171   92   13   12   91     2
  7   13   92  171  172  173   94   15   14   93     2
  8   15   94  173  174  175   96   17   16   95     2
  9   17   96  175  176  177   98   19   18   97     2
 10   19   98  177  178  179  100   21   20   99     2
 11   21  100  179  180  181  102   23   22  101     2
 12   23  102  181  182  183  104   25   24  103     2
 13   25  104  183  184  185  106   27   26  105     2
  :    :    :    :    :    :    :    :    :    :     :
  :    :    :    :    :    :    :    :    :    :     :
2958119151199412073120741207511996119171191611995     1
2959119171199612075120761207711998119191191811997     1
2960119191199812077120781207912000119211192011999     1
2961119211200012079120801208112002119231192212001     1
2962119231200212081120821208312004119251192412003     1
2963119251200412083120841208512006119271192612005     1
2964119271200612085120861208712008119291192812007     1
```

**Figure 1. FESWMS-2DH Plots of (a) Finite Element Grid, (b) Ground Elevation Contour Map and (c) Velocity Vectors**

(a)

(b)

(c)



# TABLE 6. Results from POSTFES for Flow Through Bridge Opening

| Node No. | Station(ft) | V(ft/s) | Beta(deg) | Depth(ft) |
|---|---|---|---|---|
| 6811 | 1000.01 | 4.457 | 90.00 | 3.13 |
| 6812 | 1013.63 | 4.174 | 90.00 | 3.13 |
| 6892 | 1027.27 | 8.567 | 45.00 | 3.04 |
| 6893 | 1040.89 | 8.579 | 45.00 | 3.04 |
| 6894 | 1054.53 | 8.187 | 42.11 | 3.05 |
| 6974 | 1068.16 | 7.805 | 41.11 | 2.95 |
| 6975 | 1081.79 | 7.487 | 38.22 | 2.96 |
| 6976 | 1095.42 | 7.260 | 35.87 | 2.96 |
| 7056 | 1109.06 | 8.095 | 25.17 | 3.68 |
| 7057 | 1122.68 | 8.016 | 22.50 | 3.72 |
| 7058 | 1136.32 | 7.891 | 18.45 | 3.76 |
| 7138 | 1149.94 | 10.857 | 9.94 | 5.76 |
| 7139 | 1163.58 | 10.417 | 10.10 | 6.96 |
| 7140 | 1177.21 | 10.150 | 11.42 | 7.48 |
| 7220 | 1190.84 | 8.194 | 15.11 | 9.79 |
| 7221 | 1204.47 | 8.216 | 17.55 | 9.77 |
| 7301 | 1218.11 | 7.855 | 19.64 | 11.54 |
| 7302 | 1231.73 | 8.032 | 21.80 | 11.27 |
| 7303 | 1245.37 | 8.275 | 23.71 | 11.00 |
| 7383 | 1259.01 | 8.598 | 22.42 | 10.96 |
| 7384 | 1272.63 | 8.815 | 23.01 | 10.92 |
| 7385 | 1286.27 | 9.052 | 23.55 | 10.92 |
| 7465 | 1299.89 | 9.222 | 21.11 | 10.92 |
| 7466 | 1313.53 | 9.505 | 22.70 | 9.61 |
| 7467 | 1327.16 | 9.979 | 25.30 | 8.31 |
| 7547 | 1340.79 | 10.049 | 23.39 | 7.21 |
| 7548 | 1354.42 | 10.531 | 24.61 | 6.07 |
| 7628 | 1368.06 | 10.071 | 20.17 | 5.87 |
| 7629 | 1381.68 | 10.169 | 19.35 | 5.60 |
| 7630 | 1395.32 | 10.111 | 18.08 | 5.32 |
| 7710 | 1408.94 | 8.872 | 12.38 | 5.10 |
| 7711 | 1422.58 | 8.447 | 10.95 | 4.81 |
| 7712 | 1436.22 | 7.873 | 9.36 | 4.52 |
| 7792 | 1449.84 | 6.376 | 3.36 | 4.20 |
| 7793 | 1463.48 | 5.478 | .01 | 3.83 |
| 7794 | 1477.11 | 4.369 | -6.39 | 3.54 |
| 7874 | 1490.74 | 2.655 | -18.65 | 3.29 |
| 7875 | 1504.37 | 1.470 | -26.02 | 3.26 |
| 7876 | 1518.01 | .864 | .00 | 3.22 |

# A Study of Angle of Attack at Bridges


## ABSTRACT

A technical advisory mandate was issued by the Federal Highway Administration (FHWA) September 16, 1988, which stated "*every bridge over a scourable stream, whether existing or under design, should be evaluated as to its vulnerability to floods....*" The ramifications of this mandate were substantial since 86% of 577,000 bridges in the National Bridge Inventory are over water. Furthermore, although scour is the leading cause of bridge damage and failure, the state-of-the-art in bridge scour estimation had been virtually the same since the mid 1950's. Consequently, a flurry of activity has existed in the area of bridge scour since the mandate came down.

Numerous studies have shown that many important bridge scour parameters are very difficult to tie down. One-dimensional hydraulic models such as HEC-2 provide no information about angle of attack. WSPRO uses a stream-tube analysis from the approach section to the bridge opening that one might term quasi-two-dimensional. However, the straight stream tubes are not representative of the double-curved streamlines actually observed in the laboratory and field for flow through contractions.

This study considers angle of attack of flow through bridge openings. The principal objective of the study is to provide a methodology that will enable engineers to predict the angle of attack for flow through bridge openings without resorting to physical modeling techniques. The finite element model FESWMS-2DH would appear to be the ideal answer. The program was developed by the U.S. Geological Survey in cooperation with FHWA to provide a tool for the analysis of open channel

flow in regions where flow distribution is important and the assumption of one-dimensional flow is not adequate.

Testing of FESWMS-2DH at KU indicated that it would be unlikely that many practicing engineers would have the time to devote to using the comprehensive program. Consequently, this study attempted to do the following:

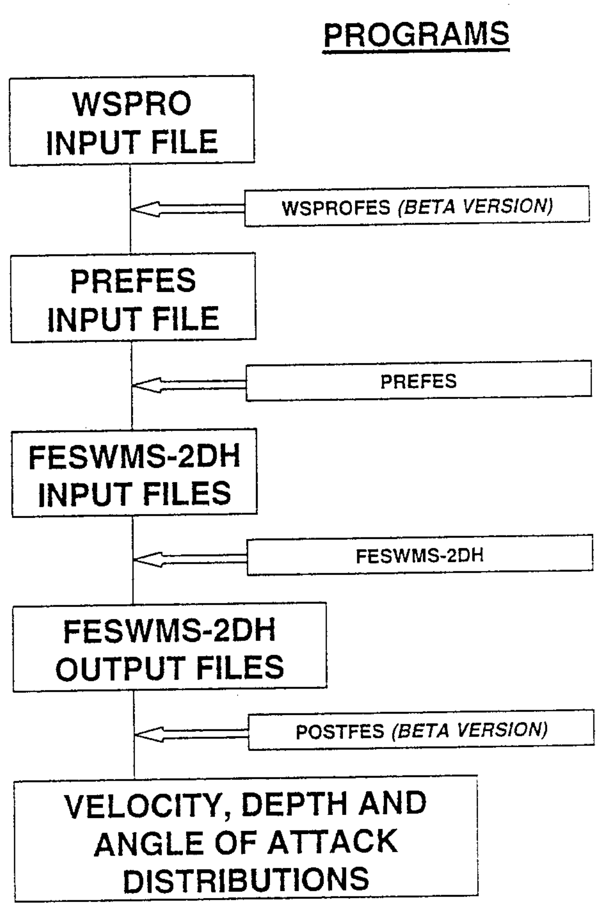
Part 1 -- Review and summarize other research examining pier scour at bridge piers and the effect of flow angle of attack.

Part 2 -- Compare laboratory angle of attack measurements with FESWMS-2DH computations of angle of attack for hydraulically similar conditions at a bridge opening. In other words, test the ability of FESWMS-2DH to simulate an actual two-dimensional flow field.

Part 3 -- Develop pre-processor and post-processor computer programs to create the input files required by FESWMS-2DH from a simple input file containing WSPRO-type input data and generate final output file containing the variable values for bridge scour analysis. (Also, a program has recently been developed to convert an actual WSPRO input file into the input file required by the FESWMS-2DH pre-processor.)

This study concludes that the angle of attack as computed from the FESWMS-2DH analysis is consistent with the angle of attack as observed in the laboratory for hydraulically similar conditions. Additionally, the main computer program presented within this study, PREFES, has been established as a proficient tool to create the input files necessary to run FESWMS-2DH.

The work reported was originally presented by Deanna Sereno in April, 1996, as an M.S. thesis. The program has since been modified and the name has been changed from CONVERT to PREFES. Also, a "pre-pre-processor" called WSPROFES and a post-processor called POSTFES were created. Both are considered BETA-version programs! WSPROFES is a program created to convert a standard WSPRO input file into the input file required to run PREFES. The POSTFES program uses a FESWMS-2DH output file to generate velocity magnitude, angle of attack and flow depth distributions for the bridge opening. This program could and should be expanded to actually calculate pier, abutment and contraction scour depths directly from the FESWMS-2DH output. More details on these two programs are given in Chapter 8. The flowchart below shows how the battery of programs are applied.



# A Study of Angle of Attack at Bridges

## Part 1 -- Pier Scour at Bridge Piers and the Effect of Angle of Attack

# A Study of Angle of Attack at Bridges

## Part 2 -- Determination of Angle of Attack at a Channel Constriction using a Physical Model and FESWMS-2DH

# A Study of Angle of Attack at Bridges

## Part 3 -- PREFES User's Manual

# A Study of Angle of Attack at Bridges

## Part 3 -- PREFES User's Manual

## Part 3 -- PREFES User's Manual

# Part 1 -- Pier Scour at Bridge Piers and the Effect of Angle of Attack

## 1.0 Introduction

Since the technical advisory mandate was issued by the Federal Highway Administration (FHWA) September 16, 1988, stating "*every bridge over a scourable stream, whether existing or under design, should be evaluated as to its vulnerability to floods....*", activity in the professional community has flourished in the research of bridge scour. Many papers and journals have been published regarding findings in theoretical study, in the laboratory, and in the field. Countless equations, theoretical and empirical, have surfaced for the estimation of bridge scour.

This section reviews the fundamentals of pier scour. The factors effecting pier scour are examined using the results of previous studies, and the recommended method of determining pier scour is presented. The influence of angle of attack is well documented in case studies.

## 2.0 Phenomena of Pier Scour

### 2.1 Process of Pier Scour

The basic mechanism causing local scour at piers is the formation of vortices which locally increase the erosive capacity of the water. These vortices, resulting from the pileup of water on the upstream face and subsequent acceleration of the flow around the nose of the pier, are termed horseshoe vortices. Additionally, vertical vortices formed downstream of the pier are referred to as wake vortices.[13]

The action of the vortex removes bed materials away from the base region. If the transport rate of sediment away form the local region is greater than the transport rate into the region, a scour hole develops. As the depth of scour is increased, the strength of the vortices decreases, thus reducing the transport rate away from the region and eventually leading to an equilibrium scour depth. The formation of this phenomena is illustrated in Figure 2.1.[13]

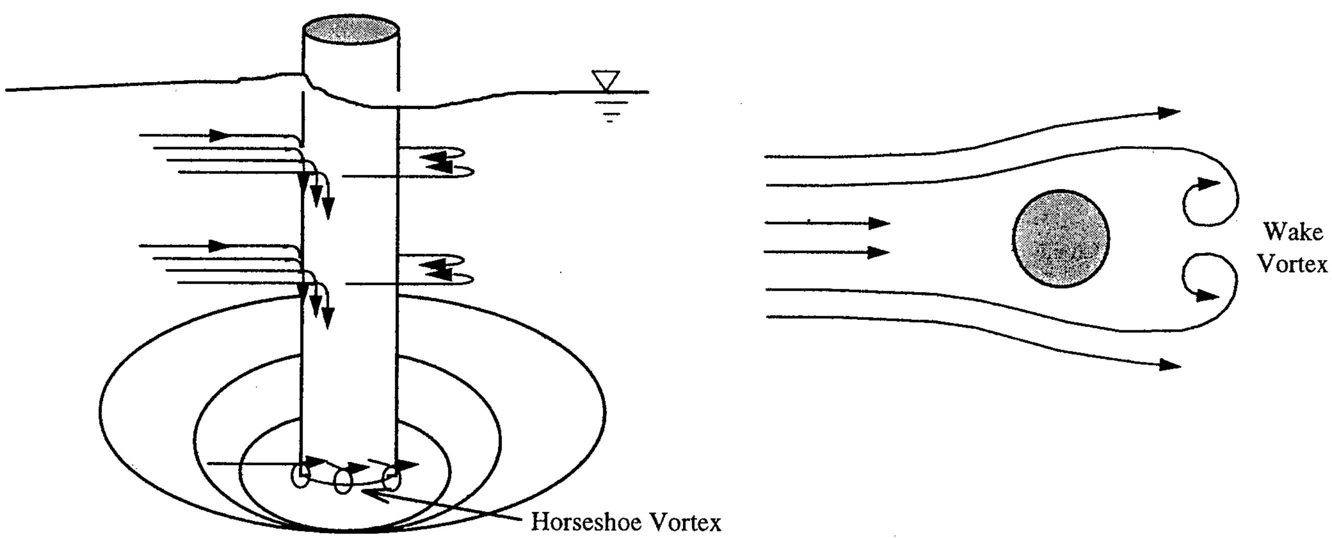



Figure 2.1 -- Schematic Representation of Scour at a Cylindrical Pier

### 2.2 Factors Affecting Pier Scour

Many factors affect the magnitude of pier scour, including:

1) Pier Width and Pier Shape
2) Skew of the Pier to the Approach Flow and Pier Length
3) Flow Velocity and Depth
4) Bed Material Characteristics and Bed Transport Characteristics

These factors are discussed in detail below:

2.2.1 Pier Width and Pier Shape

As the width of the pier increases, the potential scour depth increases. Since the width of each pier effectively reduces the cross-sectional area of flow, the velocity through the bridge increases to maintain continuity. The increase in the velocity allows for greater potential of scour. The relation between pier scour (Ys) and pier width (a) is shown in Figure 2.2. The curve in this diagram is a locally weighted, smooth sample (LOWESS) curve drawn through moving median values. This data set, from the bridge scour database of the National Scour Study, indicates that the effect of pier width on depth of scour is significant for widths greater than about 1.7 feet.[7]

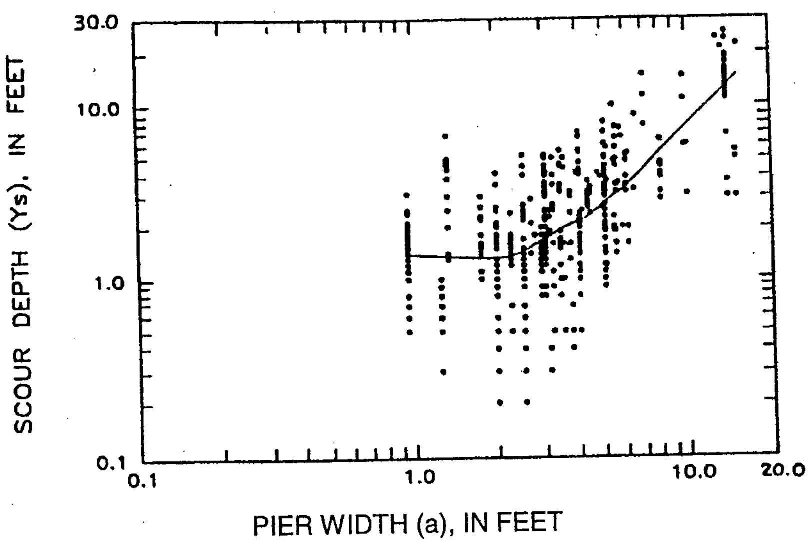



Figure 2.2 --- Relation Between Pier Width (a) and Scour Depth (Ys)

The shape of both the nose and the end of the pier also has a significant effect on the depth of local scour. Streamlining the nose of the pier will reduce the strength of the horseshoe vortices; while, streamlining the downstream end of the pier will reduce the strength of the wake vortices.[13]

2.2.2 Skew of the Pier to the Approach Flow and Pier Length

The skew of the pier to the approach flow, also referred to as angle of attack, in conjunction with the length of the pier, has a large effect on the depth of scour. Laursen and Toch (1956) illustrated that a large angle of attack can drastically increase scour depth . For example, the scour depth at a rectangular pier with aspect ratio of 10 tripled with an angle of attack of 30 degrees as opposed to the scour at the same pier directly aligned with the approach flow.[8]

The length of a pier only affects the scour depth when the pier is **not** directly aligned with the flow. For instance, for a pier directly aligned with the approach flow, increasing the length of the pier has no effect on the depth of scour; however, for a pier not in alignment with the approach flow, doubling the length of the pier will increase the scour depth by thirty-three percent (33%).[13]

### 2.2.3 Flow Velocity and Depth

As the flow velocity increases, the strength of the vortices increases, thus the scour depth increases. This relation is illustrated in Figure 2.3, where the influence of pier width is removed by comparing the dimensionless variables. It should be noted that this data set, also taken from the bridge scour database of the National Scour Study, indicates that if the flow velocity is greater than the critical velocity for incipient motion ($V_1 > V_c$), the flow velocity may have a negligible effect on scour depth.[7]

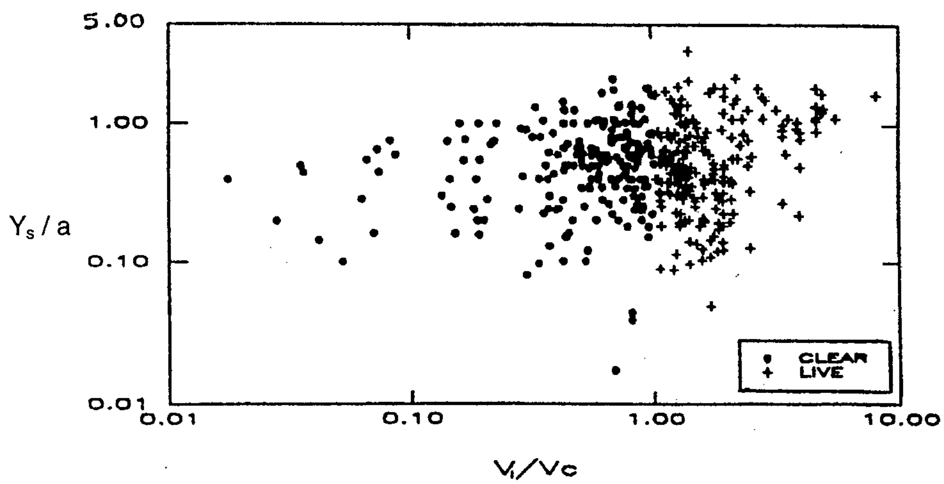



Figure 2.3 -- Relation Between Ratios of Local Approach Velocity ($V_1$) to Critical Incipient Motion Velocity ($V_c$) and Scour Depth ($Y_s$) to Pier Width (a) for clear-water and live-bed Scour Conditions.

The influence of flow depth on the depth of local scour is evident in Figure 2.4. In this analysis, flow depth ($Y_1$) and scour depth ($Y_s$) are each divided by the pier width to eliminate the bias. The lower curve is a LOWESS curve for the data. The upper curve is the result of the local pier scour prediction equation recommended in HEC-18 (FHWA, 1993)[13] with a Froude number of 0.22, the median Froude number of the data set. Although the HEC-18 equation appears to consistently over-predict the scour depth attributed to the flow depth, the slopes of these lines compare very well for this relation.[7]

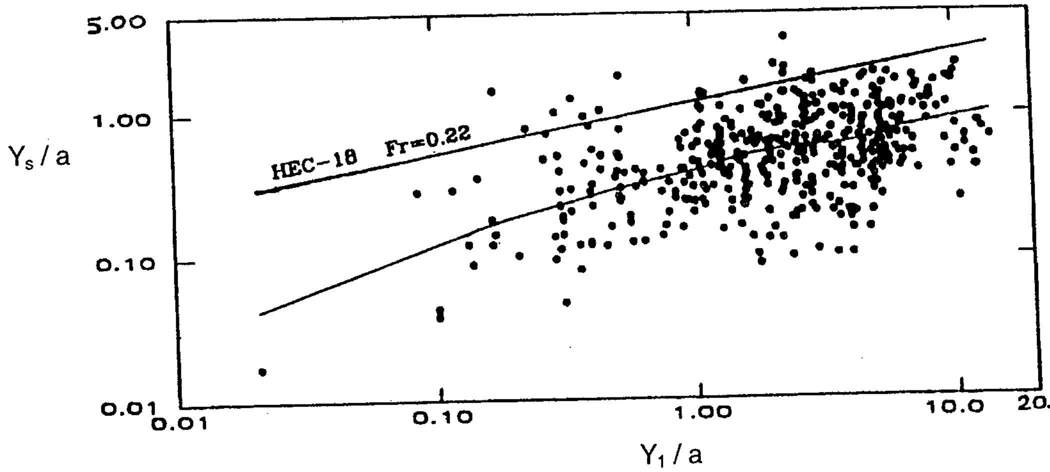



Figure 2.4 -- Relation Between Ratios of Flow Depth ($Y_1$) to Pier Width (a) and Scour Depth ($Y_s$) to Pier Width (a).

### 2.2.4 Bed Material Characteristics and Bed Transport Characteristics

The bed material can dictate the rate at which scour will occur. As expected, loose granular soils are easily moved by flow, cohesive soils require a higher velocity for motion, and cemented soils have the slowest rate of erosion. However, the ultimate scour depth can be equally deep in any soil.

Bed Transport Characteristics for scour can be classified in two categories. If bed material is being transported to the area of scour from an upstream location, the condition is referred to as live-bed scour. On the other hand, if the sediment load in the approach flow is light, it is referred to as clear-water scour. [13]

## 2.3 Methods of Determining Pier Scour

Scour has long been known to be a cause of bridge failures over waterways. A wealth of research has been conducted which has culminated in the publication of numerous methods for predicting bridge scour.

In 1983, many of the more common methods were compared and evaluated (Jones, 1983). These methods include those presented by Laursen (1960), Neill (1969), Shen et al. (1969), Richardson et al. (1975) - termed "CSU" equation, and Jain and Fischer (1979). The results of this comparison appear in Figures 2.5 and 2.6.

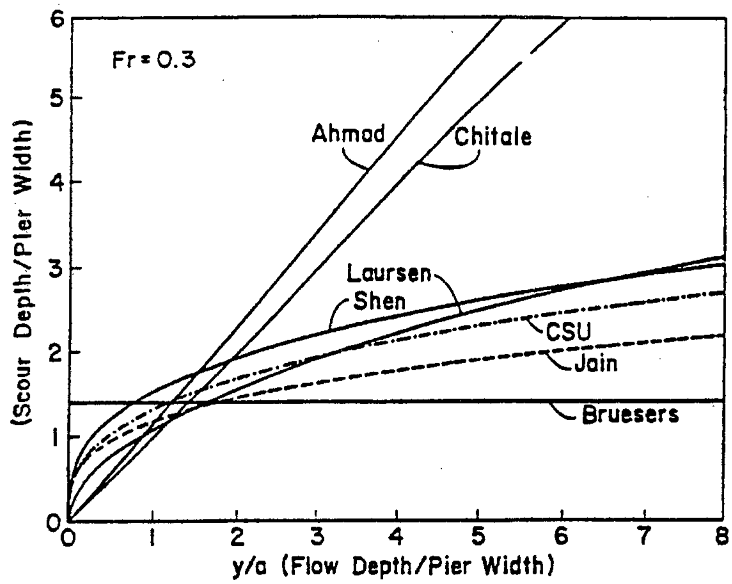



Figure 2.5 -- Comparison of Scour Formulas for Variable Depth Ratios (Fr = 0.3)

Since some of the equations include velocity as a variable, often in the form of the Froude number, the first comparison utilizes a constant Froude number of 0.3 to compare the equations.

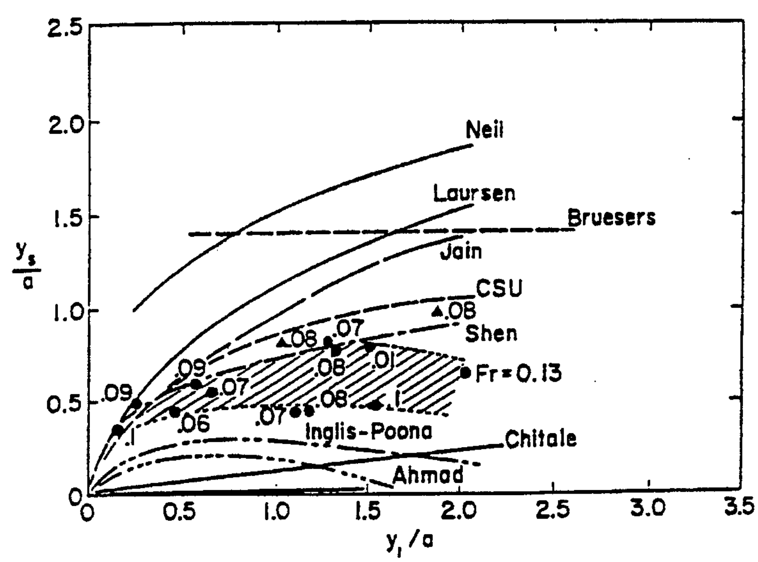



Figure 2.6 -- Comparison of Scour Formulas with Field Scour Measurements

In Figure 2.6, it is evident that the CSU equation encompasses all of the available field data. Additionally, it yields lower scour depths than Jain's, Laursen's and Neill's equations.

The recent abundance of failures has triggered a more detailed look at scour prediction. The Federal Highway Administration, who sponsored much of this research, presented the recommended method for determination of pier scour depth in HEC-18 (Richardson et al, 1993).[13] This equation is a modified version of Colorado State University's (CSU) equation originally developed in 1975.

$$y_s / a = 2 K_1 K_2 K_3 K_4 (y_1 / a)^{0.35} Fr_1^{0.43}$$

where:

$y_s$ = Scour depth, ft
$y_1$ = Flow depth directly upstream of the pier, ft
$K_1$ = Correction Factor, pier nose shape
$K_2$ = Correction Factor, angle of attack and pier length
$K_3$ = Correction Factor, bed condition
$K_4$ = Correction Factor, bed material size and critical velocity
$a$ = Pier width, ft
$Fr_1$ = Froude Number directly upstream (dependent upon approach velocity, $V_1$)

This equation and its use are described in detail in HEC-18. It is presented here to indicate the variables which affect scour depth at piers.

## 3.0 Alignment of Piers with the Approach Flow (Angle of Attack)

### 3.1 Sensitivity Analysis of Variables Within the Pier Scour Equation

For many years, engineers have recognized that the alignment of the piers with the approach flow has significant influence on the depth of scour. In recent years, the extent of this influence has been investigated and documented.

#### 3.1.1 "Sensitivity Analysis of Bridge Scour Equations" (Glenn, 1993) [3]

An informal sensitivity analysis of the variables contained in the recommended scour equations presented in HEC-18 was conducted and presented in the paper listed above. The results of this analysis with regard to pier scour are repeated in Table 3.1.

| Variable | | Sensitivity Index | Relative Sensitivity |
|---|---|---|---|
| Name | Description | (Si) | (Sr) |
| $y_1$ | Flow Depth Directly Upstream of Pier | 0.10 | 0.18 |
| $V_1$ | Velocity Directly Upstream of Pier | 0.35 | 0.61 |
| a | Pier Width | 0.57 | 1.00 |
| L | Pier Length | 0.33 | 0.58 |
| $\Theta$ | Skew Angle of Pier to Approach Flow | 0.33 | 0.58 |

Table 3.1 -- Results of Sensitivity Analysis on the modified CSU Pier Scour Equation

The magnitude of the sensitivity index serves as an indicator as to the sensitivity of the equation with regard to a particular variable. A sensitivity index greater than one (1) signifies that an incremental change in the variable produces a larger change in the result; on the other hand, if the sensitivity index less than one, an incremental change in the variable triggers a smaller change in the result.

The relative sensitivity is obtained by dividing the sensitivity index of each variable by the largest sensitivity index.

#### 3.1.2 "Bridge Scour Analysis in New Jersey: Which Scour Factors Matter Most?" (Anella and Oliger, 1993) [1]

A second study was performed to correlate the scour susceptibility of bridges with observable characteristics (Anella and Oliger, 1993). This analysis was designed to review 148 bridges in Burlington County, New Jersey and give each a scour sufficiency rating (SSR), from 0 to 100 percent, reflecting the bridge's potential to avoid or resist scour damage. The formula to determine the SSR was based on a weighted group of scour factors:

- Type of Foundation (35%)
- Bridge Characteristics (15%)
- Collapse Vulnerability (10%)
- Waterway Characteristics (15%)
- History of scour (25%)

The SSR was subsequently used to group the bridges into three priority categories to determine which bridges would be further investigated in Phase II of this study. "Of the 148 structures, five (3.4%) were ranked as priority one, the highest category, requiring rigorous investigation in Stage II. Sixty structures (40.5%) received a priority two ranking, also requiring them to be evaluated in Stage II."

Upon further review of the factors leading priority one and priority two structures to be ranked as susceptible, it was discovered that the most influential component of the bridge characteristics is the angle of attack of the flood flow. **Of the structures receiving a ranking of priority one or two, 72.3% had an angle of attack greater than 10 degrees.**

## 3.2 Examples of Significance of Pier Alignment

The following case studies demonstrate the influence of the pier alignment.

### 3.2.1 "Local Scour at Bridge Piers in Alberta - Case History" (Humphries, 1994)[4]

The following in an exert from this paper which was presented at the 1994 ASCE National Conference on Hydraulic Engineering in San Francisco, California.

> The Oldman river has a mobile gravel bed and, over the years, progressive channel migration has increased the skew angle under the Brocket bridge. A combination of scour surveys, aerial photographs, stream flow data and inspection records dating back over the life of the bridge offers the opportunity to follow the development of a scour hole at the pier due to the increase in flow angle of attack.
>
> In 1954 the bridge was built square to the river. The north bank upstream of the bridge is actively eroding redirecting the flow under the bridge. By 1992 the low flow was skewed by 50 degrees to the pier. A 45 m long guidebank was built in 1968 to protect the north abutment and in 1975 the Oldman river experienced an extreme flood. The flood flow generated a 4 m deep scour hole adjacent to the guidebank but no significant pier scour was measured. Between 1975 and 1983 the skew angle increased from 25 to 49 degrees and a 1.2 m deep scour hole developed by the nose and north side of the pier. In 1987 this hole was 3 m deep and the bottom of the hole was only 0.3 m above the bottom of the pier footing. The skew angle had increased to 45 degrees. . . . Between 1975 and 1987 the Oldman river did not experience a flow any greater than a 1 in 7 year flood.

The author goes on to conclude that the increased angle of attack of the flow at the pier is the primary cause of the deep scour hole.

3.2.2 "Estimating Bridge Scour in New York From Historical U.S. Geological Survey Streamflow Measurements" (Butch, 1993)[2]

This paper, presented at the 1993 ASCE Hydraulic Engineering Conference, summarizes the estimated scour measurements at 31 bridges in New York State by the New York State Department of Transportation. Included in the presentation is a detailed summary of the scour at State Route 23 over the Otselie River in Cortland County. The streambed elevation for various years is illustrated in Figure 3.1.

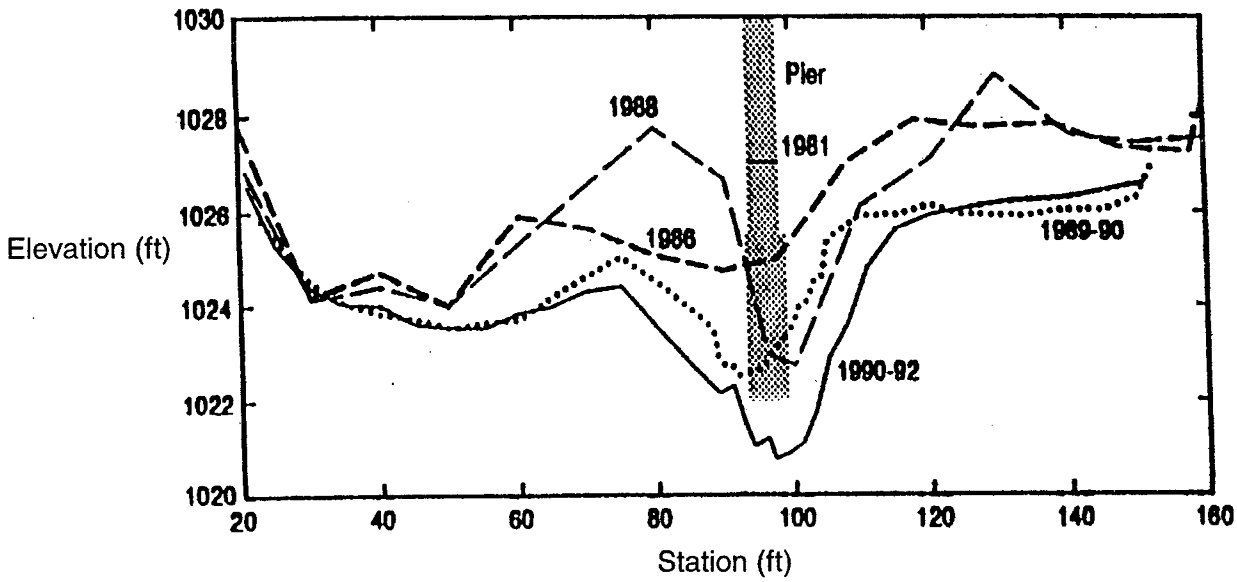



Figure 3.1 -- History of Scour (1981-92) at Otselic River, A. State Rt. 23

High flows in 1983, 1988, and 1990 produced a 6.1 foot scour hole around the pier partially exposing concrete pilings. Streambed measurements taken on October 24, 1992 indicate a 2.1 foot increase in the depth of the scour hole since 1990. It is pertinent to note that each high flow had a recurrence interval less than 10 years.

The author concludes that a 30 degree angle of attack between the approach flow and the pier increased "the tendency of the streambed to scour and extended the entire length of the pier".

## 3.3 Method of Determining Angle of Attack

Through the studies presented in the first two sections of this chapter,

- with the dimensionless sensitivity analysis enumerating the contribution of angle of attack to the scouring process, and

- with the inspection of numerous, highly scour-susceptible bridges revealing that a nearly three-fourths have a significant angle of attack, and finally

- with the infinite number of case studies that could be presented where angle of attack is one of the primary causes of local scour,

it is apparent that the angle of attack plays a vital role in determining the amount of local scour.

However, many of the flow analysis tools currently used in the profession today are simple, one-dimensional models. A popular method of determining angle of attack is the use of WSPRO's streamtube approach. This method is only pseudo-two-dimensional and, in many instances, will vary greatly from the actual angle of attack.

Fortunately, as computer speed increases and storage space becomes less expensive, more realistic flow analysis models are surfacing. Using the finite element and finite difference approaches, two- and three- dimensional models are being developed and are rapidly proving their worth.

### 3.3.1 Comparison of One- and Two- Dimensional Hydraulic Analysis

A dual analysis was performed for a proposed bridge over the Ohio River and approach roadways across the floodplain spanning from Indiana to Kentucky. (Ports, Turner, and Froehlich, 1993). [10] During the conceptual and preliminary design, a hydraulic evaluation using WSPRO was completed to determine the potential scour. However, for the final design of the project, the Kentucky Department of Highways determined that a two-dimension hydraulic analysis would be completed. The two-dimensional model chosen is FHWA's **F**inite **E**lement **S**urface-**W**ater **M**odeling **S**ystem - Two-Dimensional Flow in a Horizontal Plane (FESWMS).

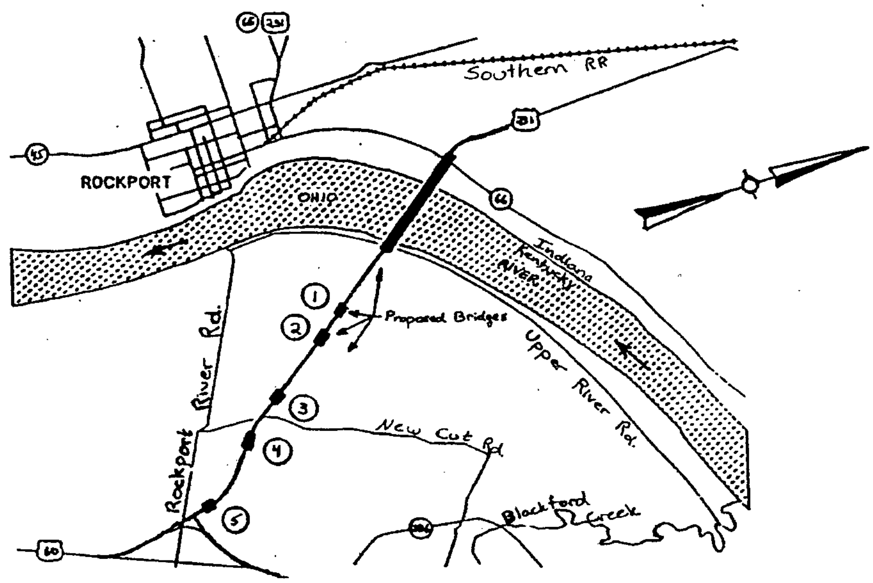



Figure 3.2 -- Location Map for Comparison of One - and Two - Dimensional Analyses

For estimation of pier scour, the modified CSU equation was employed to the results of each of the above analyses. It should be noted that no angle of attack is calculated in WSPRO; therefore, a maximum and a minimum angle are assumed from the streamtube configuration.

The results of both analyses and their affects on the predicted pier scour depths for two of the piers are repeated below. [10]

| | | FESWMS Results | WSPRO Results (maximum) | WSPRO Results (minimum) |
|---|---|---|---|---|
| Pier 1, Station 876 + 05 | | | | |
| | Skew Angle | 35° | 15° | 10° |
| | Effective Pier Width, ft | 31 | 15.9 | 11.8 |
| | Pier Length, ft | 51.8 | 51.8 | 51.8 |
| | Velocity, fps | 2.9 | 2.9 | 2.9 |
| | Flow Depth, ft | 9 | 9 | 9 |
| | Froude Number | 0.17 | 0.17 | 0.17 |
| | Scour Depth, ft | 20 | 13 | 11 |
| Pier 2, Station 877 + 30 | | | | |
| | Skew Angle | 35° | 15° | 10° |
| | Effective Pier Width, ft | 31 | 15.9 | 11.8 |
| | Pier Length, ft | 51.8 | 51.8 | 51.8 |
| | Velocity, fps | 3.3 | 2.9 | 2.9 |
| | Flow Depth, ft | 9 | 9 | 9 |
| | Froude Number | 0.19 | 0.17 | 0.17 |
| | Scour Depth, ft | 21 | 13 | 11 |

The paper summarizes the analysis as follows:
"In summary, the two-dimensional hydraulic analysis provides significantly improved estimates of velocity magnitude, direction of flow, and flow distribution for complex flow conditions around bends, through contractions and through multiple openings. As discussed, these flow characteristics are essential for the estimation of potential bridge scour." [10]

### 3.3.2 Further Evaluation of Two-Dimensional Flow Modeling

In Part 2 of this paper, a physical model is used to evaluate the results of a finite element model in determining pier alignment.

In Part 3 of this paper, a computer program is presented which facilitates the use of a finite element model. Additionally, within this section, three examples are provided to illustrate the use of the program and results.

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13. Richardson, E.V., Harrison, L.J., Richardson, J.R., and Davis, S.R. (1993). "Evaluating Scour at Bridges." FHWA, Hydraulic Engineering Circular No. 18, 2nd Ed., Pub. FHWA-IP-90-017, Washington, D.C.

14. Shen, H.S., Schneider, V.R., and Karake, S. (1969). "Local Scour Around Bridge Piers." Journal of Hydraulic Engineering, American Society of Civil Engineers, 95(6).

## Part 2 -- Determination of Angle of Attack at a Channel Constriction using a Physical Model and FESWMS-2DH

### 1.0 Introduction

A physical model of a constriction in a rectangular channel was used to evaluate the results from a FESWMS-2DH analysis of a hydraulically similar channel constriction. The laboratory flume is 1-ft wide, 40-ft long and is connected to a 10-cfs capacity constant head tank with a recirculating water supply system. Although it is a tilting flume, all experiments were performed with the flume bed horizontal. A downstream overflow weir was used to set the tailwater depth downstream from the constriction.

To maintain realistic dimensions in the finite element model, a prototype channel 200-ft wide is assumed. The geometric scale factor for construction of the laboratory model is, therefore 100:1. Velocity and discharge similitude are based on the Froude number.

## 2.0 Characteristics of the Prototype

### 2.1 Channel Characteristics

The prototype for this comparison is a simple rectangular channel with a base width of 200 feet. An abrupt constriction restricts the flow to 60 % of its original width for a length of 40 feet. The slope through this reach of the channel is 0.02 %, and the Manning's roughness coefficient is 0.03.

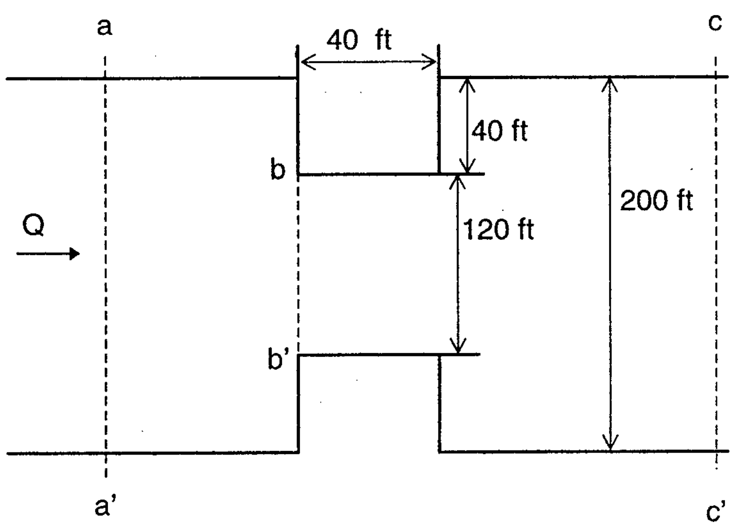



Figure 2.1 - Plan View of Prototype

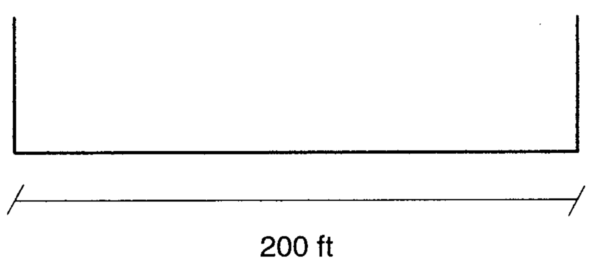



Figure 2.2 -- Cross-Sections a-a' and c-c'

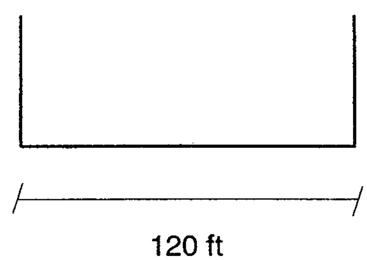



Figure 2.3 -- Cross-Section b-b'

### 2.2 Flow Characteristics

At the downstream section (c-c'), the flow depth is 10 feet and the flow rate is 25,800 cubic feet per second.

## 3.0 Physical Model

### 3.1 Channel Characteristics

The physical model was developed in a glass-walled flume at the University of Kansas, Lawrence, Kansas. The flume has a constant width of 1 foot and a continuously variable slope. A constant head tank approximately 30 feet above the flume is used to keep the flow constant for steady-state conditions. An overflow weir was used to control tailwater depth.

A 1:100 scale of the prototype was constructed as shown below:
Note that this represents a half-width of the prototype.

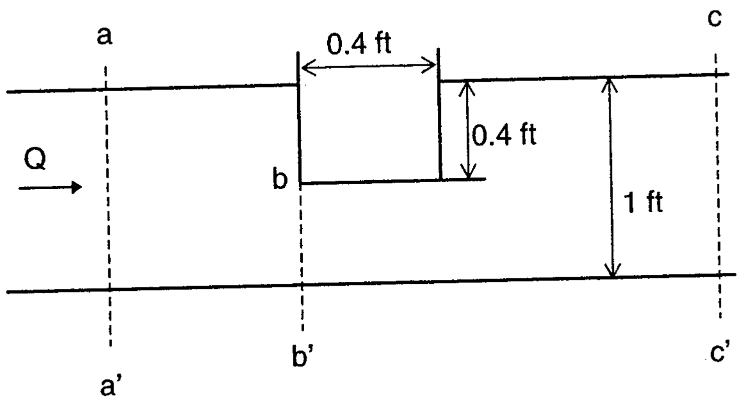



Figure 3.1 - Plan View of Model

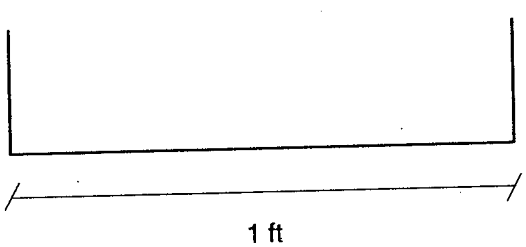



Figure 3.2 -- Cross-Sections a-a' and c-c'

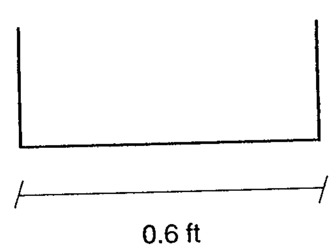



Figure 3.3 -- Cross-Section b-b'

3.2 Flow Characteristics

The flume flow rate was measured as 0.129 cfs using a mercury manometer at a venturi section prior to entrance into the flume. Quality-control measures were taken by checking this flow against the integrated velocity distribution within the flume, obtained from a pitot tube connected to a differential pressure transducer at 60 % depth at 1/10th-foot intervals at two upstream cross-sections.

The flow depth was measured at sections a-a', b-b', and c-c' with a depth gage equipped with a vernier scale calibrated to one-one thousandths (1/1000) centimeters. These depths were later used in the calibration of the finite element model.

3.3 Determination of Direction of Flow

3.3.1 Method

To measure the direction of flow in the vicinity of the constriction, free-rotating flags were spaced at one-tenth (1/10th) foot intervals. A template calibrated to five degrees was placed at the base of the flume for each flag.

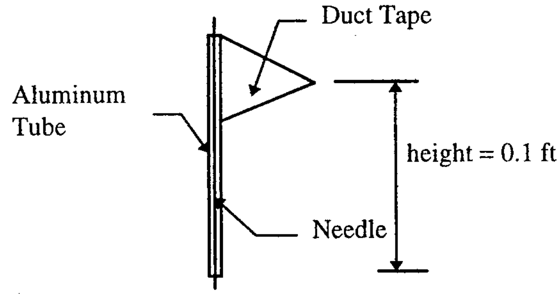



Figure 3.4 -- Free-Rotating Flag

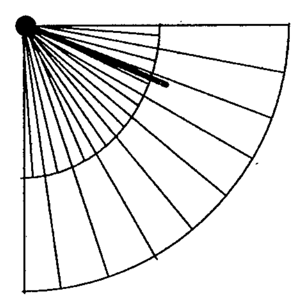


Figure 3.5 -- Plan View of Flag with Template

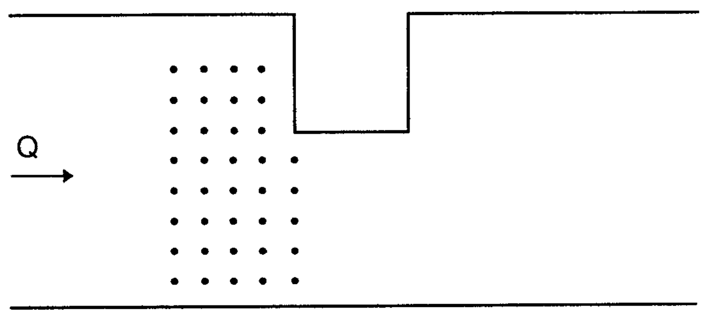


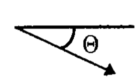

Figure 3.6 -- Locations of Flags

### 3.3.2 Results

The angle of attack for the channel constriction was measured at each of the locations shown in Figure 3.6 with the flag-template device depicted in Figure 3.5. The results for each location are illustrated below. The transverse distribution of angle of attack will be presented later.

| Distance from Left Bank of Channel (feet) \ Distance Upstream from Channel Constriction (feet) | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 |
|---|---|---|---|---|---|
| 0.2 | 10-20 | 10-25 | 20 | 49 | |
| 0.3 | 15 | 20 | 35 | 45 | |
| 0.4 | 12-17 | 25 | 30 | 40 | |
| 0.5 | 15 | 20 | 22 | 25 | 17-20 |
| 0.6 | 10-15 | 15 | 16 | 20 | 10-15 |
| 0.7 | 9 | 9 | 10 | 10-13 | 10 |
| 0.8 | 5 | 5 | 7 | 8 | 5-8 |
| 0.9 | 3 | 3 | 3 | 3 | 5 |

Figure 3.7 -- Angle of Attack (degrees)



## 4.0 Finite Element Model

The finite element model utilized in this analysis is **F**inite **E**lement **S**urface **W**ater **M**odeling **S**ystem (FESWMS). Developed by the Federal Highway Administration, FESWMS offers the capability to analyze flow in open channels two-dimensionally within a horizontal plane, for both steady and unsteady flow.

### 4.1 Channel Characteristics

The geometry of the channel is as described for the prototype in section 2.1. A simple rectangular channel with a base width of 200 feet undergoes an abrupt constriction restricting the flow to 60 % of its original width for a length 40 feet. The slope through this reach of the channel is 0.02 %, and the Manning's roughness coefficient is 0.03.

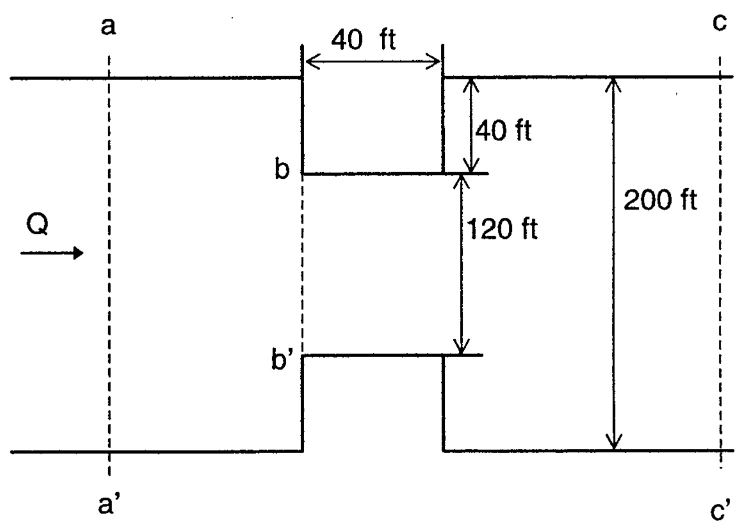



Figure 4.1 - Plan View of Finite Element Model

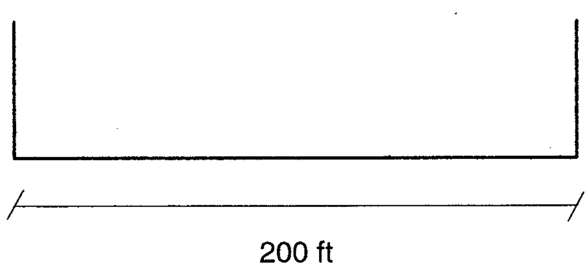



Figure 4.2 -- Cross-Sections a-a' and c-c'

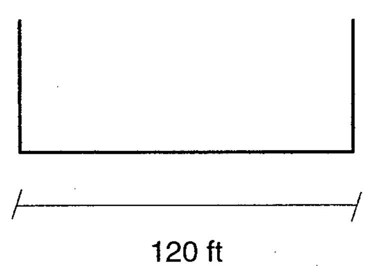



Figure 4.3 -- Cross-Section b-b'

## 4.2 Flow Characteristics

At the downstream section (c-c'), the flow depth is 10 feet and the flow rate is 25,800 cubic feet per second.

## 4.3 Model Development

The network for the channel consists of nine-node rectangular elements of length and width 10 and 10 feet, respectively. A diagram of the network appears in Figure 4.4.

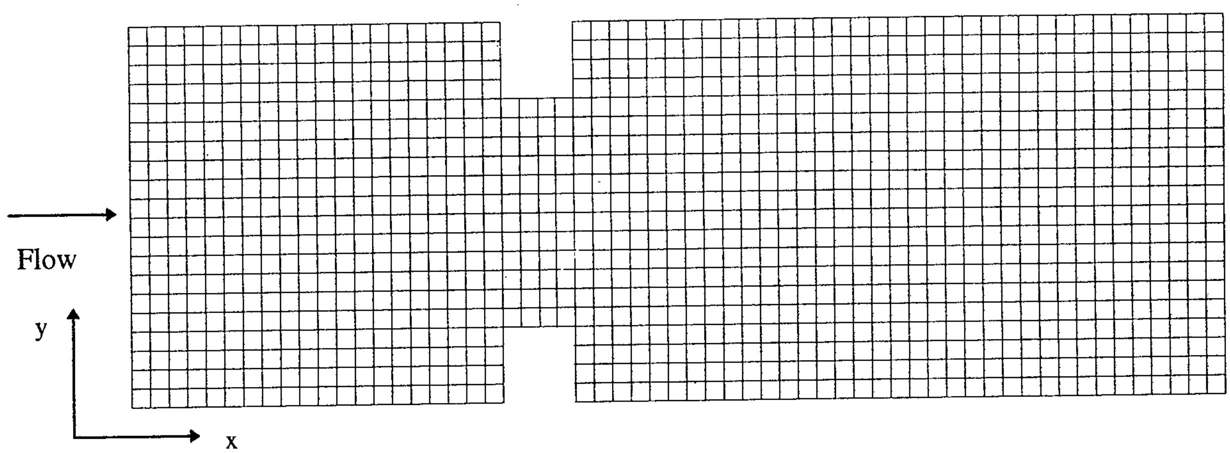


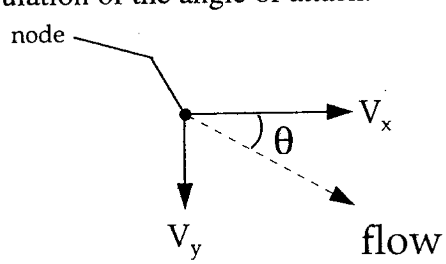

Figure 4.4 -- Network Grid Developed for Use in Two-Dimensional Model

## 4.4 Determination of Direction of Flow

### 4.4.1 Method

The angle of attack is not directly computed in FESWMS. However, the flow analysis module within FESWMS (FLOMOD) creates an ASCII file containing all results. The information available in this file includes (for each node) the depth of flow, the velocity in the x-direction, and the velocity in the y-direction.

As shown in Figure 4.4, the model was defined so that the x-direction is along the direction of flow. This technique, suitable for straight channels, allows for easy calculation of the angle of attack.




$$\theta = \tan^{-1}\left(\frac{-V_y}{V_x}\right)$$

Figure 4.5 -- Angle of Attack Using FESWMS-2DH

### 4.4.2 Results

The angle of attack can be calculated, as shown above, at any node location. For ease of comparison with the physical model, angle of attack in the finite element model is calculated at the corresponding locations of the flags in the physical model.

To facilitate viewing of these results, the angles of attack are plotted in Figure 4.6. In this graph, cross-sections at ten (10) foot intervals upstream of the convergence are examined. Note: the left bank is at x = 0; the centerline of the channel is at x = 100; the left bank constricts to x = 40.

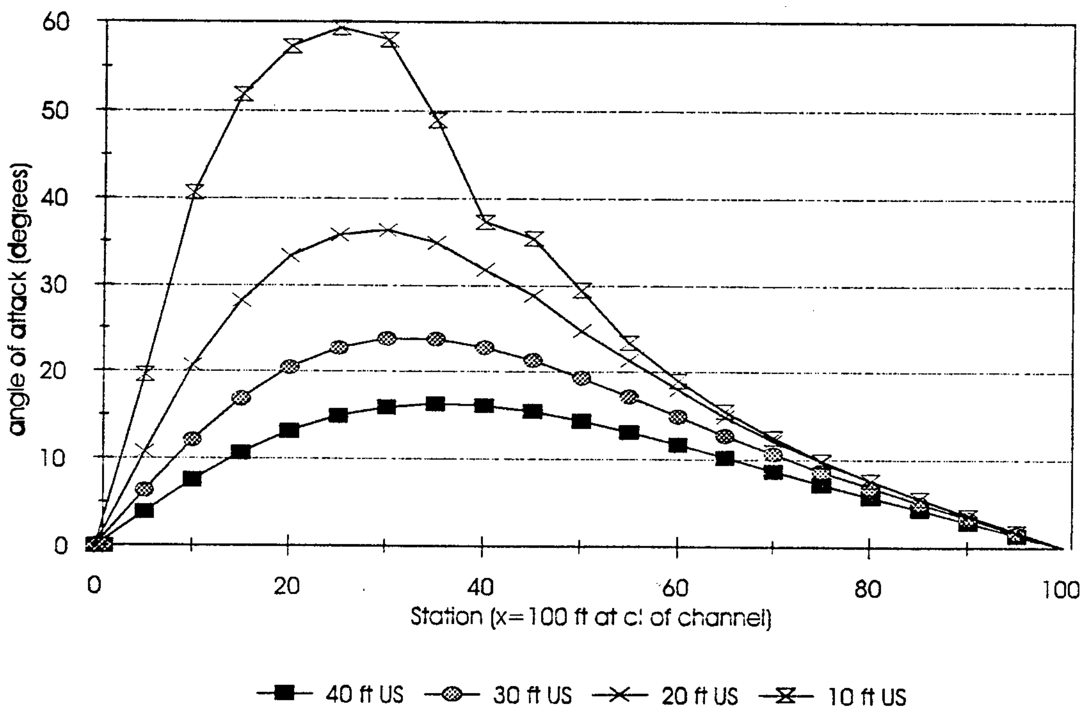



Figure 4.6 -- Angle of Attack at Cross-Sections Prior to the Channel Constriction for FESWMS-2DH

For a complete view of the flow field, the velocity vectors are plotted at 15 foot intervals throughout the channel (Figure 4.7). This is a sample of output from FESWMS-2DH.

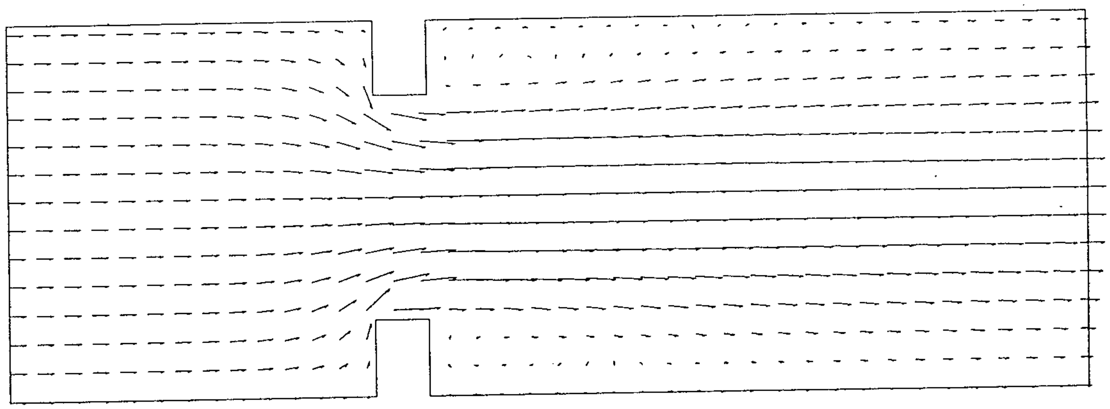


Figure 4.7 -- Velocity Vectors Resulting from FESWMS Analysis

## 5.0 Comparison of Direction of Flow between Physical Model and Finite Element Model

Figures 5.1a and 5.1b illustrate a collective view of all the data from both the physical model and the finite element model.

| Distance from Left Bank of Channel (feet) | Distance Upstream from Channel Constriction (feet): 0.4 | 0.3 | 0.2 | 0.1 | 0.0 |
|---|---|---|---|---|---|
| 0.2 | 10-20 | 10-25 | 20 | 49 | |
| 0.3 | 15 | 20 | 35 | 45 | |
| 0.4 | 12-17 | 25 | 30 | 40 | |
| 0.5 | 15 | 20 | 22 | 25 | 17-20 |
| 0.6 | 10-15 | 15 | 16 | 20 | 10-15 |
| 0.7 | 9 | 9 | 10 | 10-13 | 10 |
| 0.8 | 5 | 5 | 7 | 8 | 5-8 |
| 0.9 | 3 | 3 | 3 | 3 | 5 |

Figure 5.1a -- Physical Model Results
Angle of Attack (degrees)

| Distance from Left Bank of Channel (feet) | Distance Upstream from Channel Constriction (feet): 40 | 30 | 20 | 10 | 0 |
|---|---|---|---|---|---|
| 20 | 13 | 20 | 33 | 57 | |
| 30 | 16 | 24 | 35 | 58 | |
| 40 | 16 | 23.5 | 32 | 37 | |
| 50 | 14.5 | 19.5 | 25 | 30 | 29 |
| 60 | 11.5 | 15 | 18 | 20 | 16 |
| 70 | 9 | 10.5 | 12.5 | 12 | 11 |
| 80 | 6 | 7 | 8 | 8 | 8 |
| 90 | 3 | 3.5 | 3.5 | 3.5 | 4 |

Figure 5.1b -- Finite Element Model Results
Angle of Attack (degrees)

Figures 5.2a through 5.2e illustrate a comparison at each cross-section where measurements were taken on the physical model. The stationing is representative of the prototype. For each graph, the following key applies:

—■—FESWMS | Physical Model

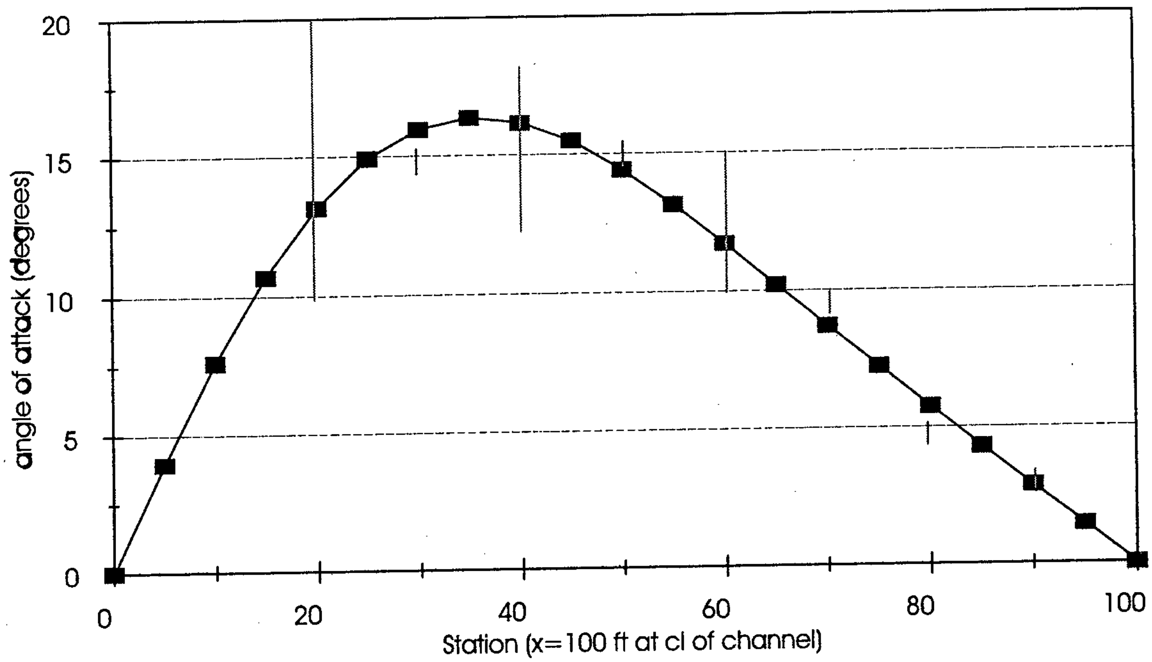



Figure 5.2a -- Angle of Attack Comparison (40 ft US of bridge opening)

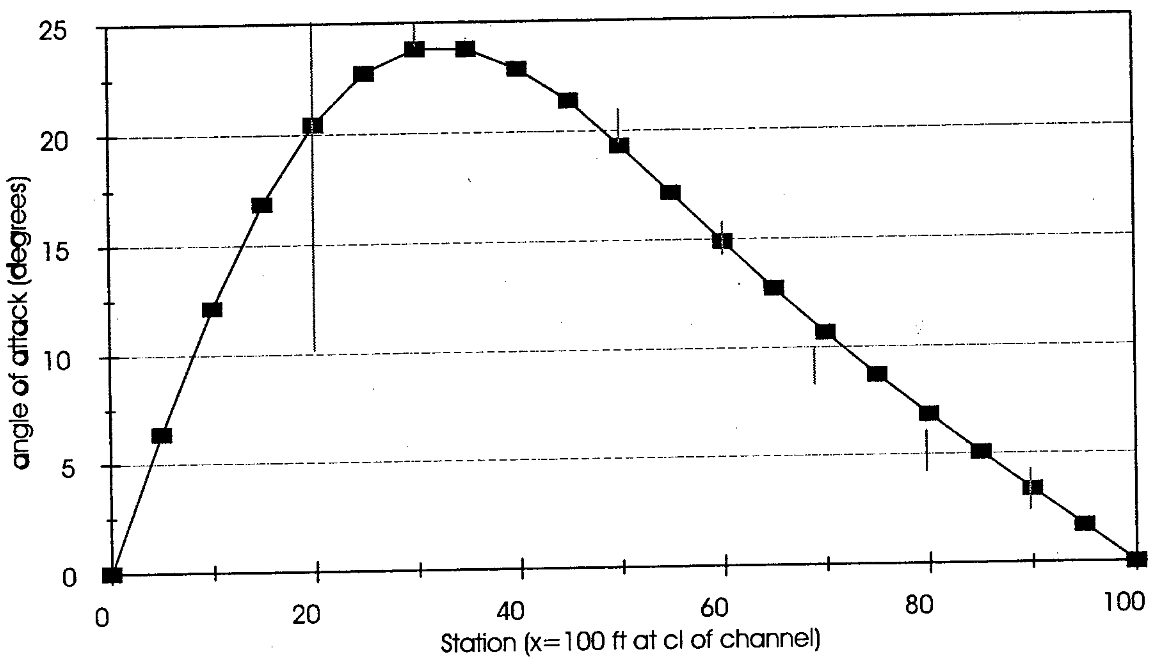



Figure 5.2b -- Angle of Attack Comparison (30 ft US of bridge opening)

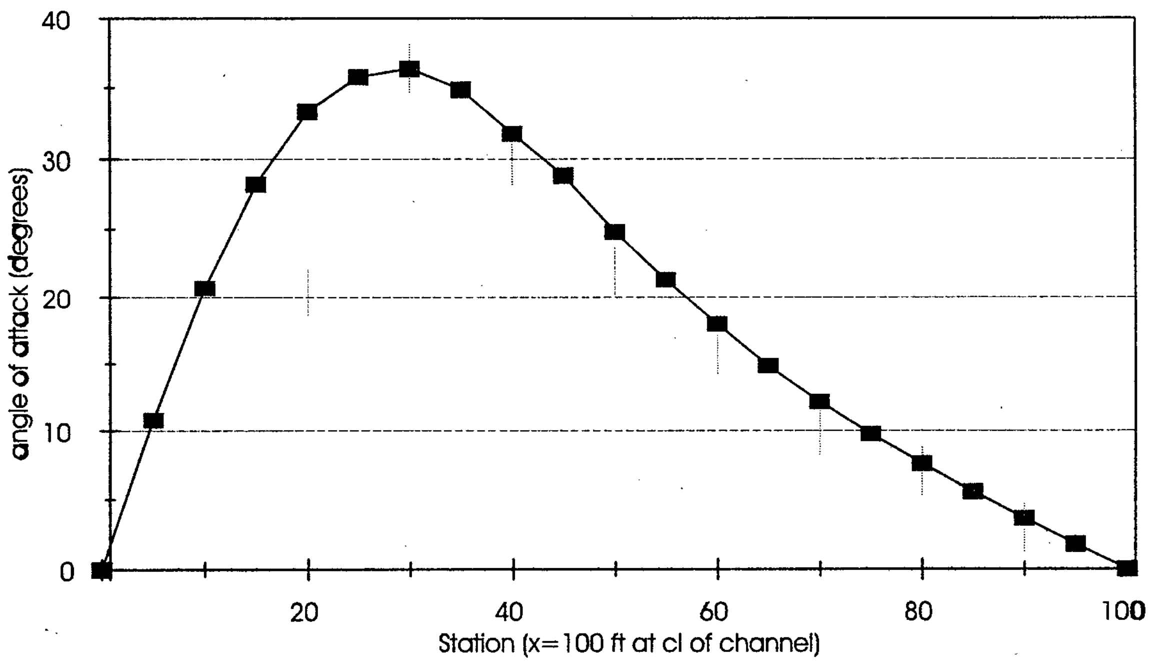



Figure 5.2c -- Angle of Attack Comparison (20 ft US of bridge opening)

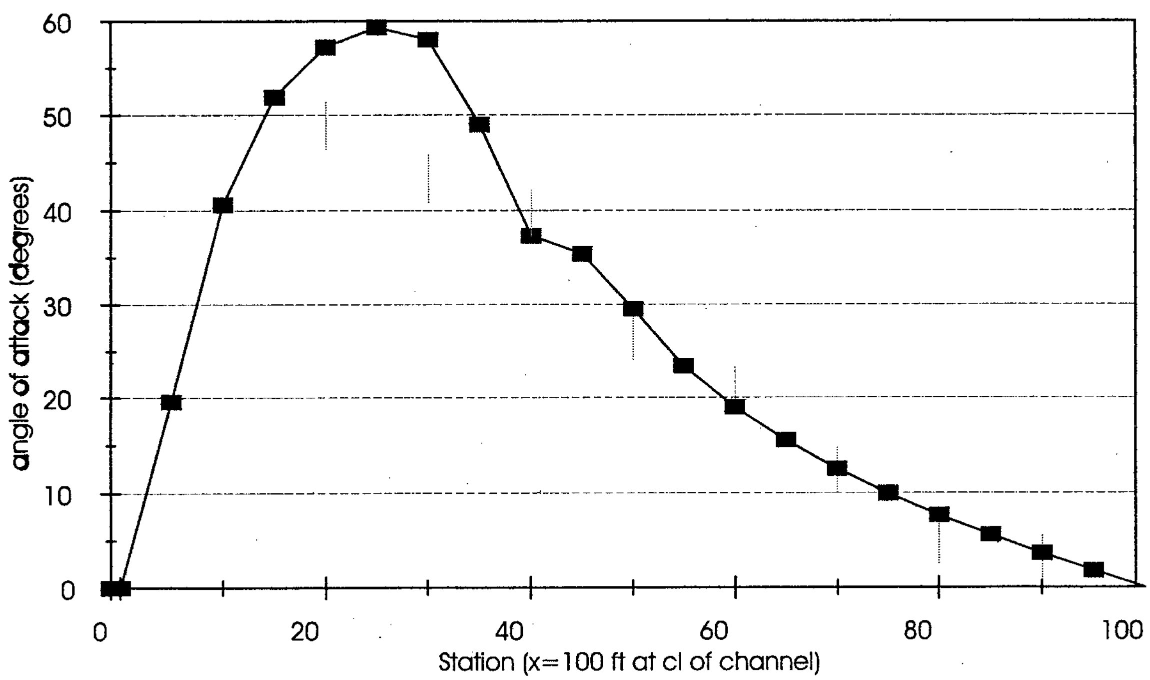



Figure 5.2d -- Angle of Attack Comparison (10 ft US of bridge opening)

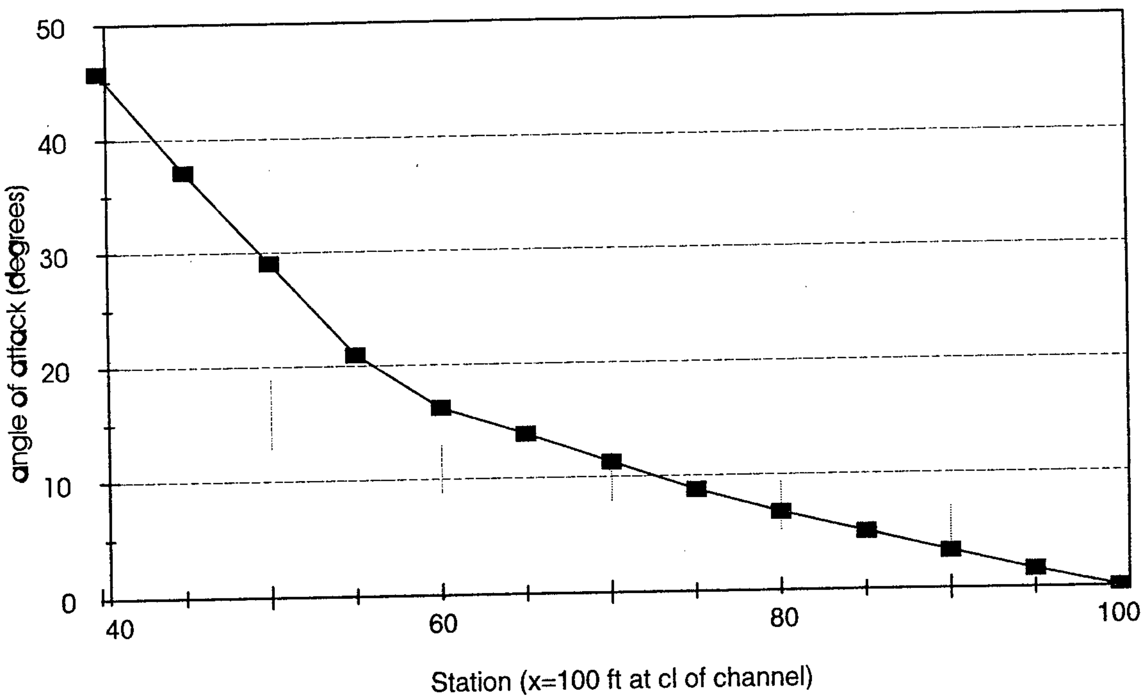



Figure 5.2e -- Angle of Attack Comparison (at the bridge opening)

In comparing the results of the physical model to the results of FESWMS-2DH, the overall trend seems good. Some large variations occur just upstream of the bridge in the overbank; however, this area is the dead zone. The extremely low velocities in the dead zone cause suspect reliability in the physical model reading. In the region of interest, the results of the comparison are satisfactory.

## 1.0 Introduction

### 1.1 Need for a Two Dimensional Flow Analysis Tool

Recent interest in scour at bridges has created a need to determine actual two-dimensional flow fields through bridge openings. Pier scour is dramatically affected by the angle of attack of the approach flow. Therefore, it is highly desirable to be able to determine the velocity vector field in the vicinity of bridge openings.

Most hydraulic analyses of bridges are currently performed by either HEC-2 or WSPRO. HEC-2 offers nothing and WSPRO offers little in the way of true velocity vectors since HEC-2 is a purely one-dimensional model and WSPRO is one-dimensional except from the approach section to the bridge where a stream-tube model is used. Consequently, in order to predict the angle of attack of the approach flow across a bridge opening, a two-dimensional flow model is needed. A finite element package developed by the Federal Highway Administration, **F**inite **E**lement **S**urface-**W**ater **M**odeling **S**ystem: Two(**2**)-**D**imensional Flow in a **H**orizontal Plane (FESWMS-2DH) offers the capability to analyze two-dimensional flow in open channels with consideration of culverts, piers, weirs, and wind effects for both steady and unsteady flow.

The problem inherent in using FESWMS-2DH is the complicated nature of the program. While the program is user friendly, coding for analysis by a two-dimensional flow model is not. The typical potential user may not be able to devote the time necessary to accurately model bridge sites using FESWMS-2DH.

This study entailed developing a program (PREFES) that creates, from an input file containing WSPRO cross-sectional data, the input files necessary to run FESWMS-2DH.

### 1.2 Benefit of Using PREFES

The program PREFES creates the finite element grid and various other input files for FESWMS-2DH from an input file quite similar to a WSPRO input file. This input file contains WSPRO cross-sectional data as well as several other parameter "cards" containing instructions for the FESWMS-2DH model.

Figure 1.1 shows a plan view of four cross sections that could be used for a WSPRO run. Figure 1.2 depicts one of the cross sections with "survey data", either actually surveyed or taken from a contour map. The property type zones refer to the roughness parameters for different regions such as overbank and main channel reaches. Essentially, PREFES overlays a finite element grid on the cross sections (Figure 1.1) and uses interpolation schemes to assign elevation and property type values to each node in the finite element network. This is illustrated in Figure 1.3.

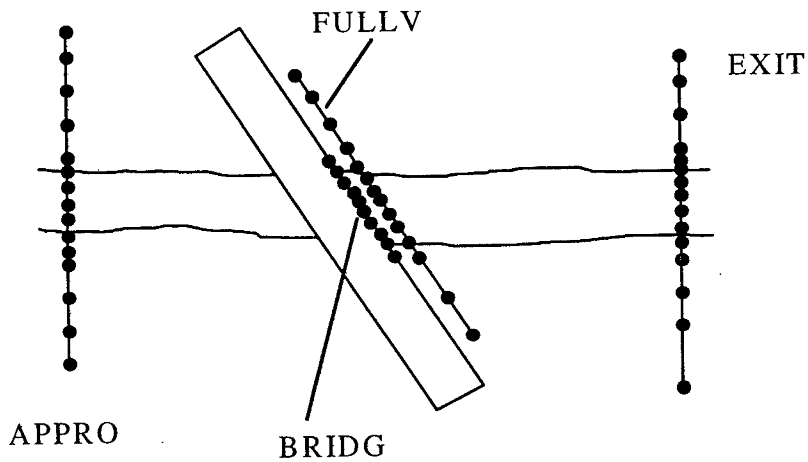



Figure 1.1 -- Plan View of Channel Reach

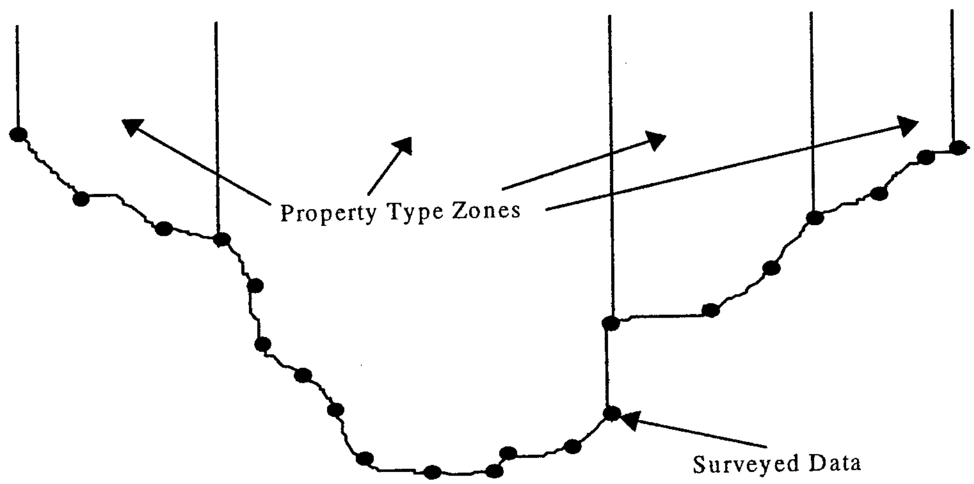



Figure 1.2 -- Elevation View of One Cross-Section

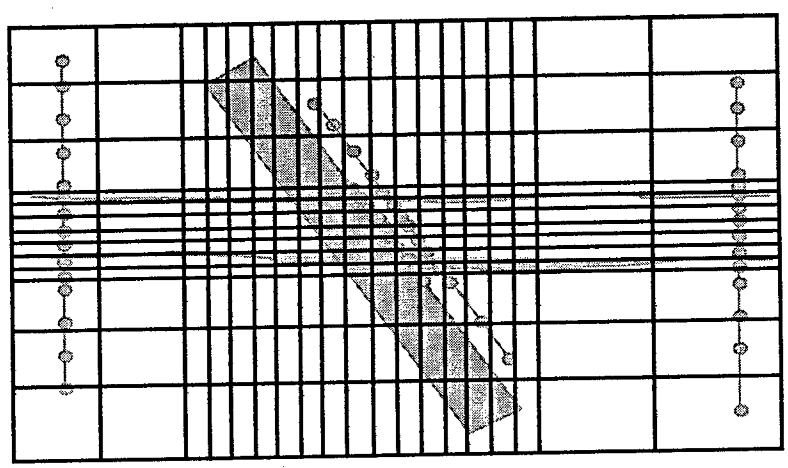


Figure 1.3 -- Network Overlay

In addition to the network, PREFES develops default files which may serve as the input files for FESWMS-2DH.

## 1.3 Before Using PREFES

PREFES was developed for use on microcomputers running under the MS-DOS, or compatible, operating system. The files which PREFES creates can be utilized by FESWMS-2DH version 2 or higher.

### 1.3.1 System Requirements

At least 570 kilobytes of free RAM (random access memory) is needed to run PREFES. Additionally, an 8087/80287/80387 math coprocessor is also required.

### 1.3.2 Files Included

| | |
|---|---|
| PREFES.exe | program executable |
| ex1 | input file for example 1 |
| ex2 | input file for example 2 |
| ex3 | input file for example 3 |

The program executable file should be placed in a directory which is contained in the PATH (in the autoexec.bat file). NOTE: If you modify your PATH statement, you will need to restart your computer before the changes will take effect. For further information on the PATH statement, see a DOS reference manual.

When running FESWMS-2DH, all related project files must be contained in the same directory. It is strongly suggested that each of the input files provided on this diskette be placed in isolated directories to create unique FESWMS projects.

For instance,
Assuming the FESWMS files are installed using the defaults on the installation diskette, the directory structure is as follows:

| | |
|---|---|
| C:\ FESWMS\PROGRAMS\ | All Program Files |
| C:\ FESWMS \ALEX\ | Example Alex Project Files |
| C:\ FESWMS \BEND90\ | Example Bend90 Project Files |
| C:\ FESWMS \ISLAND\ | Example Island Project Files |
| C:\ FESWMS \CONTRARY\ | Example Contrary Project Files |

In this situation, it is suggested to create a directory named EX1 under FESWMS and place the input file "ex1" in the directory.

| | |
|---|---|
| C:\FESWMS\EX1\ | ex1 |

Using this structure, when running PREFES from the C:\FESWMS\EX1\ directory and using ex1 as the input file, all necessary FESWMS input files for the ex1 example will be created in the C:\FESWMS\EX1\ directory.

## 2.0 Overview of Grid Development

### 2.1 Information Contained in the Input File for PREFES

The structure and contents of the Input File is similar to one used for WSPRO and is examined in detail in Chapter 3. The general information needed for the Input File is given below.

#### 2.1.1 Program Control Information (used in developing the network)

Maximum number of node points (allowed in version of
Maximum number of elements FESWMS-2DH)

Fraction of total elements along a section perpendicular to flow that are contained in main channel
Fraction of total elements along a section parallel to flow that are contained in the bridge reaches

#### 2.1.2 Property Type

Channel Roughness Variation by depth

#### 2.1.3 Flow Characteristics

Discharge into an Open Boundary
Water Surface Elevation at an Open Boundary

#### 2.1.4 Channel Characteristics

Cross-Section Geometry

location with reference to an arbitrary datum downstream
angle of skew
number of station-elevation (GR) points
stations and elevations for known points
left bank and right bank stations

additional for bridges:

bridge width
low-steel elevation

Property Type for Sub-areas of each Cross-Section

## 2.2 Cross-Section Alignment

In order to simulate curved river reaches, PREFES requires a common horizontal datum for all cross-sections. And all cross-section's ground elevation data need to have the same datum.

Figure 2.1 illustrates a general river reach with several cross-sections including APPROACH section, EXIT section , BRIDGE section , and other general sections.

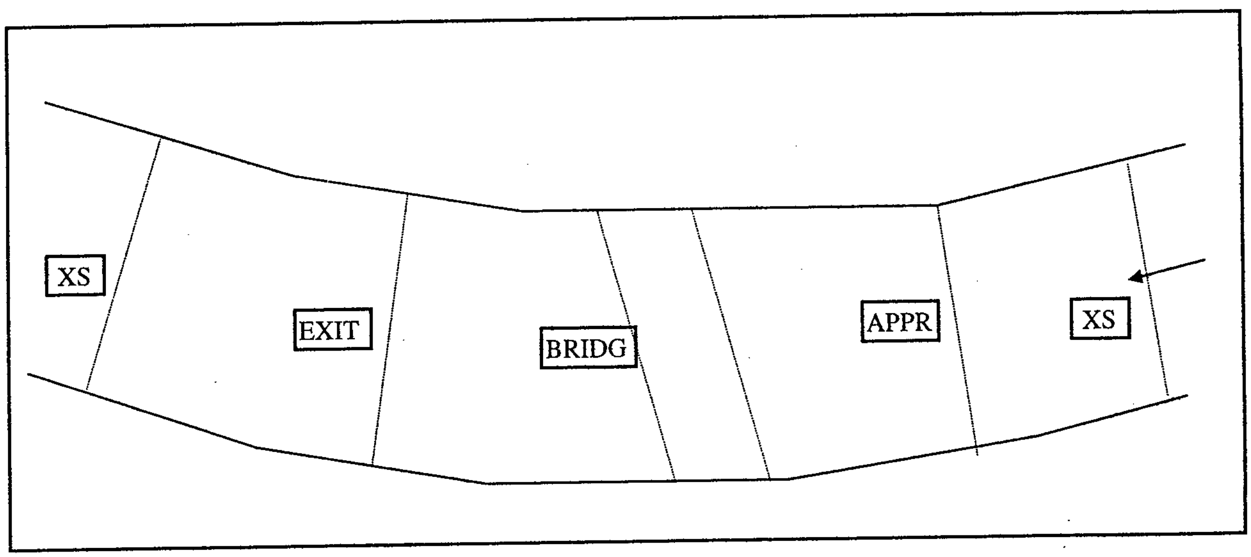



Figure 2.1 --Planview of the River Reach

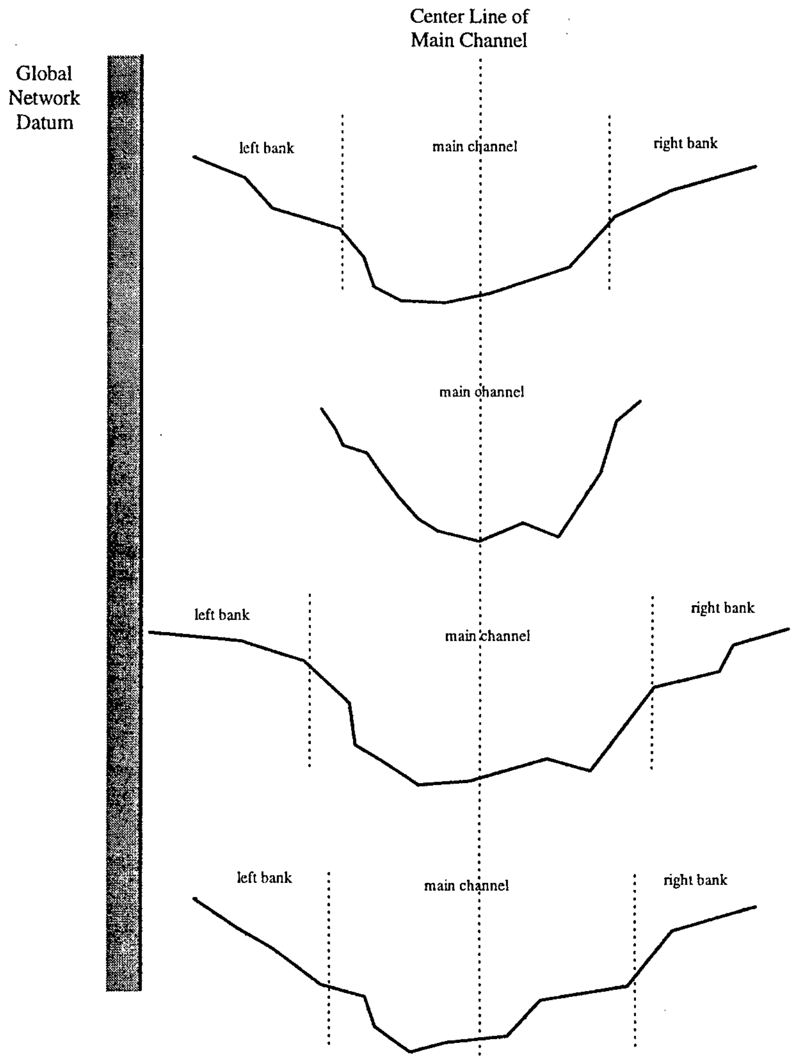



Figure 2.2 -- River Cross Sections

Figure 2.2 shows that all of the cross-section share a common global network datum in order to model curved stream reaches.

## 2.3 Grid Size Determination

PREFES creates a rectangular grid with nine-node rectangular elements. The length of the grid is the distance from the furthest downstream section to the furthest upstream section (accounting for any skew). The width of the grid is the distance from the left-most known ground elevation point to the right-most known ground elevation point. Note: "left" and "right" are defined as looking downstream.

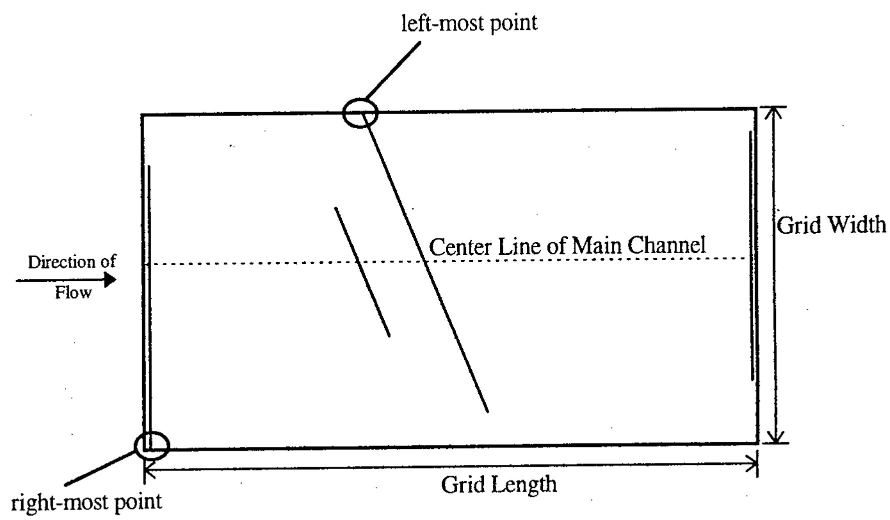



Figure 2.3 -- Grid Size Determination by Location of Shifted Cross-Sections

The accuracy of the finite element method increases as the fineness of the grid increases. For this reason, it is best to use as many elements as the finite element package allows and to space the elements closest in regions of greater differential or in regions where accelerations are expected to be largest.

The number of elements within the grid created by PREFES depends on the maximum number of elements and the maximum number of nodes entered in the Input File. It is recommended that the user set these values as the maximums specified in the user's manual for the version of FESWMS-2DH.

With the anticipation that the larger fluctuations in velocity and water surface elevation will occur in the main channel and in the immediate vicinity of the bridge, PREFES allows the spacing of the elements in these ranges to be manipulated. The spacing of the elements can be affected by specifying the fraction of elements in the main channel and the fraction of elements at the bridges.

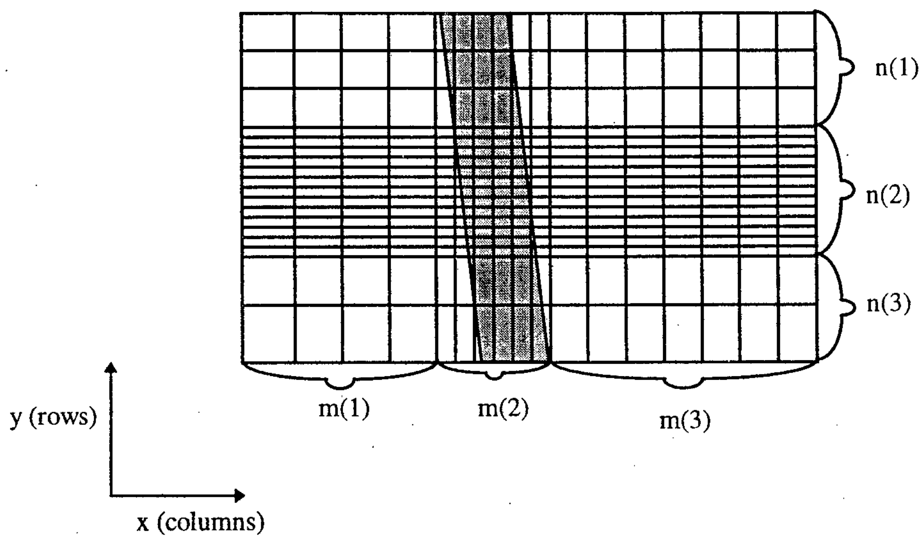



Figure 2.4 -- Spacing of Elements

Range of elements:

y- direction is divided into three ranges.

The first range is for the left overbank, the second range is for the main channel, and the third range is for the right overbank.

x-direction is divided into three ranges.

The first range extends from the upstream-most cross-section to the upstream face of the bridge (accounting for skew). The bridge has a range of elements for its width (accounting for skew) in the x-direction. The final range extends from the downstream face of the bridge to the downstream-most cross-section.

Referring to the sketch above,

where n(i) is the number of rows in the y-direction in the $i^{th}$ range
m(i) is the number of columns in the x-direction in the $i^{th}$ reach

$$\text{Fraction of elements in the main channel} = \frac{n(2)}{[n(1) + n(2) + n(3)]}$$

$$\text{Fraction of elements in the bridge reach} = \frac{m(2)}{[m(1) + m(2) + m(3)]}$$

## 2.4 Estimating Ground Elevations Outside of a Cross-Section's Surveyed Limits

Since surveyed cross-sectional data may not cover the entire flood width, it may be necessary to estimate ground elevations outside the actual survey limits for the shorter surveyed cross-sections. (PREFES will use ground elevations no more than 5 ft higher than the computed water surface elevation in order to maximize grid density in the finite element model.) PREFES allows three methods for dealing with cross sections for which the water surface elevation exceeds the elevation data. They are:

### 2.4.1 Linear Interpolation

This method linearly interpolates the ground elevation outside the limits for the cross-section by extrapolating a line created by the two known points adjacent to the limit.

### 2.4.2 Vertical Wall

This method places a vertical wall outside the limits for the cross-section. For sections not designated as bridges, the height of the vertical wall can be entered on the Network Card of the input file. For bridge sections, the vertical wall extends to the low-steel elevation.

### 2.4.3 Using Road Data (for Bridge Sections only)

This method uses the road data as ground elevations outside the bridge limits. If the road data does not extend to the grid boundaries, one of the two previous methods is used to estimate additional points.

## 2.5 Ground Elevation Interpolation

Once all cross-section elevation data has been extended to the limits of the grid, interpolation for each node within the grid can begin. This is accomplished in two steps. First, elevations are determined at specific spacing intervals within each cross-section (2.5.1). Second, elevations are interpolated between cross-sections at every node point (2.5.2).

### 2.5.1 Interpolation Determined by Node Spacing along each Cross-Section

The ground elevations at the node spacing in the y-direction along each cross-section is determined by linear interpolation of the survey data.

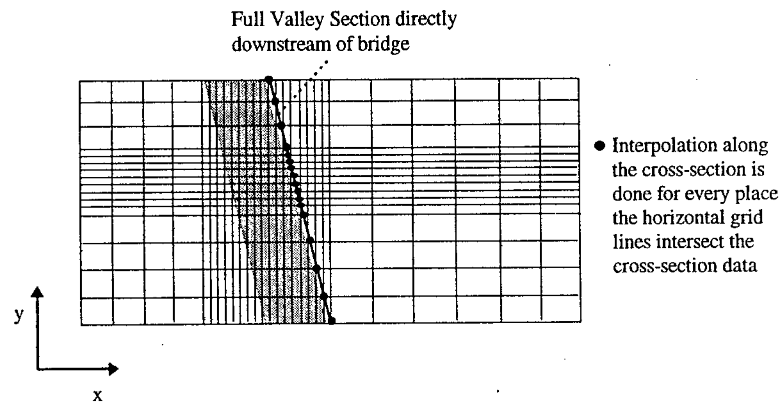



Figure 2.5 -- Interpolation Along Each Cross-Section

### 2.5.2 Interpolation at Every Node (between cross-sections)

The ground elevations at every node are determined by interpolating in the x-direction between cross-sections.

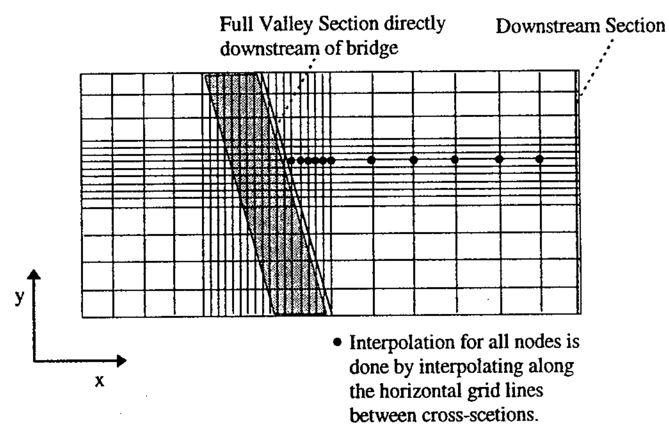



Figure 2.6 -- Interpolation Between Cross-Sections

**Important:** Since node points are linearly interpolated between sections, it is important that the input cross-sections accurately represent the ground surface in the area between them. This becomes important most often around bridges. **A full-valley section upstream, as well as downstream, of the bridge is necessary.** For the bridge itself, PREFES copies the bridge section one bridge width upstream of the given location. (Note: the WSPRO BRIDGE section is at the downstream bridge face.)

## 2.6 Ceiling Elevation Determination

The ceiling elevations are determined using the low steel elevations for the bridge data. Any node points which fall on or between the bridge section and its fabricated replica will have a ceiling elevation of the low steel elevation.

## 2.7 Property Type Determination

Since the property type (Manning's roughness coefficient variation) for a range in the cross-section is a label for a given set of characteristics, the values cannot be interpolated. Rather, the property type for each node is assigned by its position between cross-sections.

## 2.8 Additional Considerations

### 2.8.1 Bridge Piers

PREFES does not address the consideration of bridge piers. The effect of the piers can be modeled three ways. Each requires the user to edit the files which PREFES creates.

#### 2.8.1.1 Physical Obstructions Method

Bridge Piers can be coded as actual obstructions to flow by altering the Grid.dat file after PREFES creates it. By setting the ground elevations at pier locations equal to the road elevation, islands of no flow regions are created. However, the results of this approach are unproven.

#### 2.8.1.2 Effective Roughness Method

A theoretical solution to this problem is addressed by considering the effect of drag force due to the piers. Essentially, this approach includes additional shear stress to account for pier drag force.

The drag force equation is given by:

$$\mathbf{F_D = C_D A_p \rho V^2 / 2} \qquad \textbf{(2-1)}$$

where $C_D$ is the coefficient of drag
$A_p$ is the frontal area of the pier(s)
$\rho$ is the density of the fluid
$V$ is the undisturbed velocity of the fluid (i.e. without the obstruction)

And the wall shear stress due to friction is given by:

$$F_\tau = \tau P_w L = \gamma R S_f P_w L = \gamma(A/P_w) S_f P_w L$$

then $F_\tau = \gamma A S_f L$

where $\tau$ is the wall shear stress
$R$ is the hydraulic radius
$S_f$ is the friction slope
$P_w$ is the wetted perimeter and
$L$ is the length of the reach

Using Manning's equation: (English units)
$Q = 1.49/n * R^{(2/3)} * A * S_f^{(1/2)}$
where $A$ is the cross-sectional area and
$n$ is Manning's resistance coefficient

$$S_f = [(Q * n)/1.49]^2 * P_w^{(4/3)} / A^{(10/3)}$$

Substituting:

$$F_\tau = \gamma * A * [(Q*n)/1.49]^2 / P_w^{(4/3)} / A^{(10/3)} * L$$

$$\mathbf{F_\tau = \gamma*(Q^2*n^2/2.22)*L*P_w^{(4/3)}/A^{(7/3)}} \qquad \textbf{(2-2)}$$

Therefore, the total force exerted on the water in the reach of the bridge is:

$$F = F_\tau + F_D$$

Assuming this total force is all do to wall shear, an effective Manning's resistance coefficient can be found:

$$F = \gamma * (Q^2 * n_{eff}^2/2.22)*L*P_w^{(4/3)}/A^{(7/3)} = F_\tau + F_D$$

Substituting equations 2-1 and 2-2 gives:

$$\gamma*(Q^2*n_{eff}^2/2.22)*L*P_w^{(4/3)}/A^{(7/3)} = \gamma*(Q^2*n^2/2.22)*L*P_w^{(4/3)}/A^{(7/3)} + C_D A_p \rho V^2 / 2$$

Thus:

$$\mathbf{n_{eff} = [n^2 + .0345 *(C_D A_p/L)*(A^{(1/3)}/Pw^{(4/3)})]^{(1/2)}} \qquad \textbf{(2-3)}$$

The effective Manning's resistant coefficient can then be used by PREFES, and thus FESWMS-2DH, to analyze the flow. It should be noted that since the drag force depends on the frontal area of the piers, it also depends on the angle of attack as the flow approaches the piers. Since the angle of attack simultaneously depends on the effective roughness, a number of iterations will need to be performed to achieve convergence.

It is recommended that an initial estimate of angle of attack be made to determine the frontal area of the piers and thus an effective roughness. This value should be entered in the input file and PREFES and FESWMS-2DH should both be run. By examining the results of FESWMS-2DH, the actual angle of attack, which corresponds to the effective roughness given, can be calculated. Then a new frontal pier width and corresponding effective roughness can be determined. This method should be repeated until the angle of attack no longer changes.

#### 2.8.1.3 PIER Record Method

FESWMS-2DH utilizes a PIER record which can be added to the Flomod.dat input file which PREFES creates. For information on this method, see the FESWMS-2DH manual.

### 2.8.2 Limitations

PREFES creates only the necessary files with certain defaults (see Section 4.0) for FESWMS-2DH to be run. The development of the finite element network can be a tremendous reduction in man-hours. However, it is not the intention to limit the capabilities of FESWMS-2DH.

PREFES creates the network so that the elements and nodes are numbered in an orderly fashion for ease of identification. This feature allows the user to alter any node or element data within the Grid.dat file easily.

The remaining files (Dinmod.dat, Flomod.dat, Anomod.dat) can be changed within FESWMS-2DH to allow for many special considerations. The default values can be changed and additional records can be added to these files to allow for weir flow, wind influence, special boundary conditions, etc.. It is recommended that all these options be studied in the FESWMS-2DH manual to determine their applicability to the project.

## 3.0 Input File Organization

The input file for PREFES is quite similar to a WSPRO input file. It contains WSPRO cross-sectional data as well as several other parameter "cards" containing instructions for the FESWMS-2DH model. An example input file follows:

```
T1   Example 1
T2   Left Bank Constriction, with skewed bridged
*
NET        9000            .5
TYP   1   0.05     6   0.040     10
TYP   2   0.04     6   0.035     10
TYP   3   0.06     6   0.050     10
TYP   4   0.03     7
*
Q         7500
WS          38
*
XS   EXIT    1000     0     95     157  11   1   1
GR    0     38     25    35.2    40     30    42.5     28
GR   57.5   25.2   110    16     140     16   147.   17.6
GR   152.    24    157.    36    162.    40
NR       3
PT    3     2     4
SA       65    105
*
XS   FVD     1246    -28    113     178  13   1   1
GR    0    45.1   28.3   42.9   79.2   31.5   82.1   27.9
GR   88.9   26.1   113.   20.0   135.   18.0   158.   18.0
GR   167.   20.0   172.   31.5   175.   39.2   178.   45.1
GR   186.   45.1
NR       3
PT    1     2     4
SA       30     80
*
BR   BR     1247     55 -28  50 1.5    113     178  12   0   0
GR   113.   45.3   114.   22.6   124.   20.3   138.   19.4
GR   152.   19.4   161.   20.3   167.   22.6   169.   26.2
GR   172.   31.7   175.   39.4   178.   45.3   186.   45.3
NR       1
PT    4
*
XS   FVU     1300    -28    113     178  13   1   1
GR    0    45.3   28.3   43.0   79.2   31.7   82.1   28.0
GR   88.9   26.2   113.   22.6   135.   20.3   158.   20.3
GR   167.   24.0   172.   31.7   175.   39.4   178.   45.3
GR   186.   45.3
NR       3
PT    1     2     4
SA       27     80
*
AS   app    1700     0     90     157  13   1   1
GR    0     40     25     38     50     32     75     30
GR   100   23.2    120    22     125   21.5   142.   22.2
GR   147.  23.2    152.    28    155   34.8   157.    40
GR   165    40
NR       4
PT    3     1     2     4
SA       25     50    100
*
ER
```

## 3.1 Record Format

Information is input by means of a formatted text input file.
This file can be created/edited several ways:

1) DOS editor
2) word processor which allows a 'TEXT ONLY' save option
3) spreadsheet/database which either allows a 'TEXT ONLY' save option or will create a print/export file as 'TEXT ONLY'
4) HEC editor
5) FESWMS-2DH editor

## 3.2 Variable Types

Variables will either be alphanumeric (A), integer (I), or real (R).

Alphanumeric variables are read into the program as character string and therefore do not need to be formatted specifically.

Integer variables must be right justified in the range provided.

Real variables must either be right justified in the range provided or must contain a decimal point.

## 3.3 Record Descriptions (see following pages)

3.3.1 Title Records:

| **T1** | **T1 Record** | **T1** |
|---|---|---|

**Purpose:** Specifying a title given to the plots of the network and ground elevations created by running the DINMOD module in FESWMS-2DH.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-80 | A | title1 |

**Definition of Variables:**

recid Record Identifier -- 'T1'

title1 any alphanumeric combination

| **T2** | **T2 Record** | **T2** |
|---|---|---|

**Purpose:** Specifying a title given to the plot of the velocity vectors and the plot of the water surface elevations created by running the ANOMOD module in FESWMS-2DH.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-80 | A | title2 |

**Definition of Variables:**

recid Record Identifier -- 'T2'

title2 any alphanumeric combination

3.3.2 Program Control Record:

| NET | NET Record | NET |
|---|---|---|

**Purpose:** Specifying variables that help determine the size of the network.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-3 | A | recid |
| 4-10 | | blank |
| 11-20 | R | NODELIM |
| 21-30 | R | ELEMLIM |
| 31-40 | R | MCPCNT |
| 41-50 | R | BRPCNT |

**Definition of Variables:**

recid Record Identifier -- 'NET'

NODELIM The maximum number of nodes in the network. (Default = 13,000)
ELEMLIM The maximum number of elements in the network. (Default = 4,000)

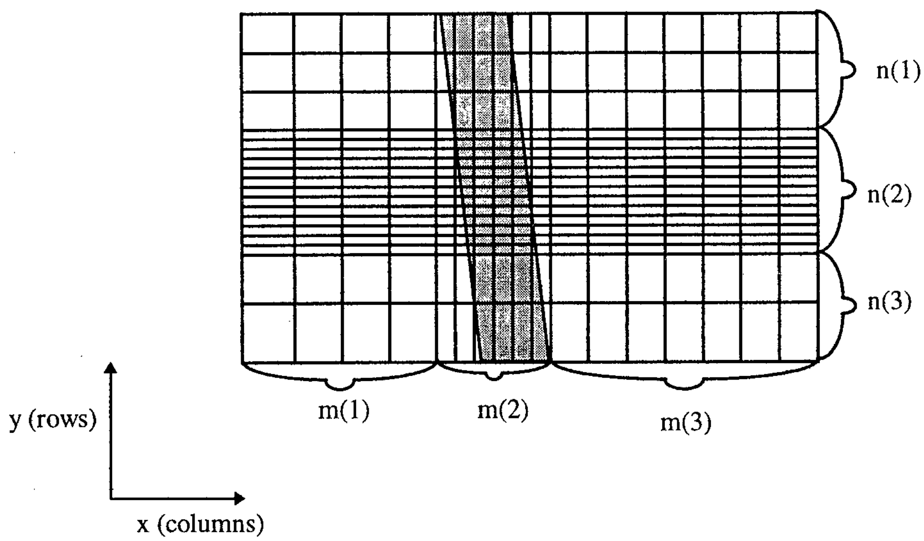
MCPCNT The ratio of the number of elements in the main channel to the total number of elements perpendicular to the flow. (Default = 0.60)

BRPCNT The ratio of the number of elements in the bridge reach to the total number of elements perpendicular to the flow. (Default = 0.40)

Referring to the sketch below,
where n(i) is the number of rows in the y-direction in the $i^{th}$ range
m(i) is the number of columns in the x-direction in the $i^{th}$ reach
i is the reach number

MCPCNT = n(2) / [n(1) + n(2) +n(3)]

BRPCNT = m(2) / [m(1) + m(2) +m(3)]




Range of elements:

y- direction is divided into three ranges.

The first range is for the left overbank, the second range is for the main channel, and the third range is for the right overbank.

x-direction is divided into three reaches.

One reach extends from the downstream-most cross-section to the downstream face of the bridge.
The bridge has a reach of elements for its width (accounting for skew) in the x-direction.
One reach extends from the upstream-most cross-section to the upstream face of the bridge.

3.3.3 Property Type Records:

**TYP** **TYP Record** **TYP**

**Purpose:** Specifying the property types and their roughness characteristics.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-3 | A | recid |
| 4-5 | | blank |
| 6-10 | I | PTYP |
| 11-20 | R | BN(ptyp) |
| 21-30 | R | BD(ptyp) |
| 31-40 | R | TN(ptyp) |
| 41-50 | R | TD(ptyp) |

**Definition of Variables:**

recid Record Identifier -- 'TYP'

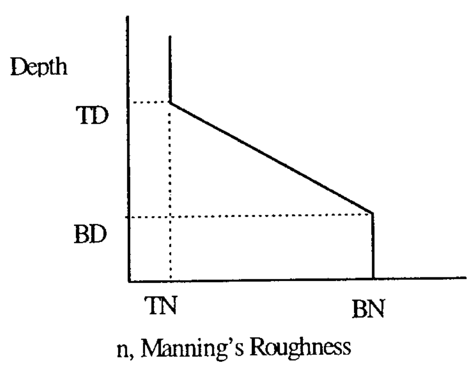
PTYP An integer label indicating that the following roughness characteristics correspond to any location with this label.

BN(ptyp) The Manning roughness coefficient exemplified in the channel for all water depths lower than BD(ptyp).

BD(ptyp) The water depth below which the channel roughness is BN(ptyp)

TN(ptyp) The Manning roughness coefficient exemplified in the channel for all water depths above than TD(ptyp).

TD(ptyp) The water depth above which the channel roughness is TN(ptyp)




The roughness coefficient between the depths of BD(ptyp) and TD(ptyp) is linearly interpolated as shown.

**If no values are entered for TN(ptyp) and TD(ptyp), the roughness is assumed to be constant, BN(ptyp) for all depths.**

3.3.4 Flow Characteristic Records:

| Q | Q Record | Q |
|---|---|---|

**Purpose:** Specifying the discharge at the upstream section of the network.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1 | A | recid |
| 2-9 | | blank |
| 10-20 | R | Q |

**Definition of Variables:**

recid Record Identifier -- 'Q'

Q Discharge entering the upstream boundary of the network

| WS | WS Record | WS |
|---|---|---|

**Purpose:** Specifying the water surface elevation at the downstream section of the network.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-9 | | blank |
| 10-20 | R | WS |

**Definition of Variables:**

recid Record Identifier -- 'WS'

WS Water surface elevation at the downstream boundary of the network

3.3.5 Cross-Section Definition Records:

## AS — AS Record — AS

**Purpose:** Specifying cross-section information for the approach section before a bridge.
**Note: PREFES treats this the same as an XS record**

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-5 | | blank |
| 6-10 | A | SECID(sec) |
| 11-20 | R | SRD(sec) |
| 21-30 | R | SKEW(sec) |
| 31-40 | R | LBY(sec) |
| 41-50 | R | RBY(sec) |
| 51-55 | I | NPT(sec) |
| 56-60 | I | LEND(sec) |
| 61-65 | I | REND(sec) |

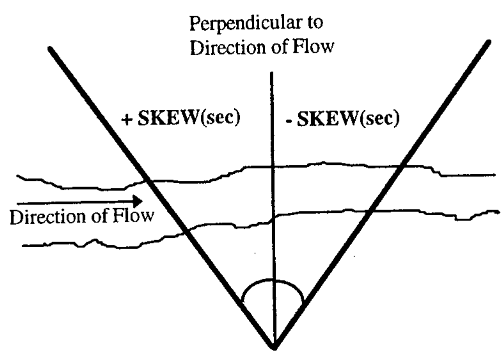
**Definition of Variables:**

recid Record Identifier -- 'AS'

SECID(sec) An alphanumeric string to identify the cross-section. Not utilized by PREFES or FESWMS-2DH.

SRD(sec) The section reference distance. The distance from an arbitrary downstream point to the centerline of the main channel of this section.

SKEW(sec) The angle of skew for this section. Positive and Negative defined below:

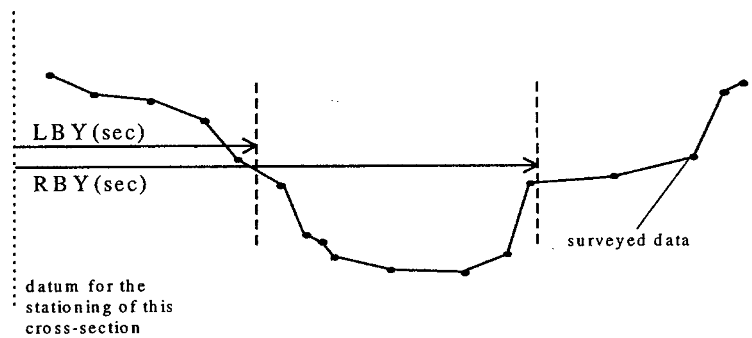


| AS | AS Record (continued) | AS |
|---|---|---|

LBY(sec) The station of the left bank for this cross-section.

RBY(sec) The station of the right bank for this cross-section.

Note: The stations for the left and right banks do **not** need to correspond to stations of known ground elevation data (entered on GR records.)




Elevation of the Approach Section, Looking Downstream

NPT(sec) Number of points used to define the cross-section geometry.

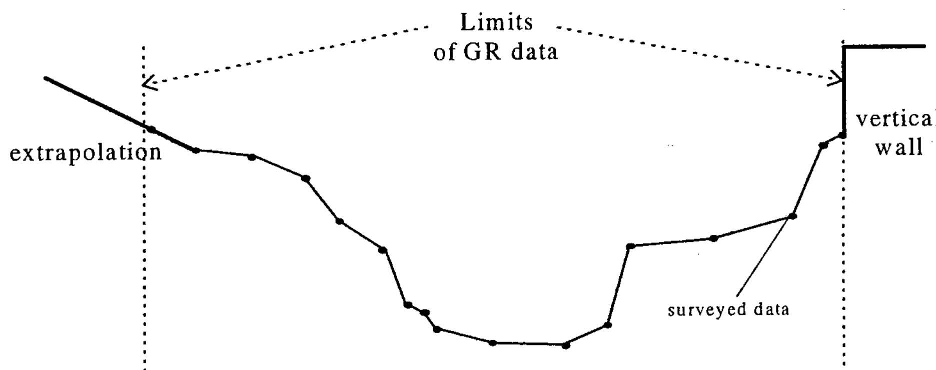
AS **AS Record (continued)** AS

LEND(sec) Indicators specifying the method used to estimate the elevations
REND(sec) for stations in the cross-section that are outside the limits.

Possible Values:

0 -- a vertical wall is placed outside the actual surveyed limits

1 -- any points outside of station limits will be linearly extrapolated using the two points of the cross-section immediately next to the limit



**BR** **BR Record** **BR**

**Purpose:** Specifying cross-section information for a bridge section.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-5 | | blank |
| 6-10 | A | SECID(sec) |
| 11-20 | R | SRD(sec) |
| 21-30 | R | LSEL(sec) |
| 31-35 | R | SKEW(sec) |
| 36-40 | R | BRWIDTH(sec) |
| 41-45 | R | BRDROP(sec) (NO LONGER USED!!) |
| 46-55 | R | LBY(sec) |
| 56-65 | R | RBY(sec) |
| 66-70 | I | NPT(sec) |
| 71-75 | I | LEND(sec) |
| 76-80 | I | REND(sec) |

**Definition of Variables:**

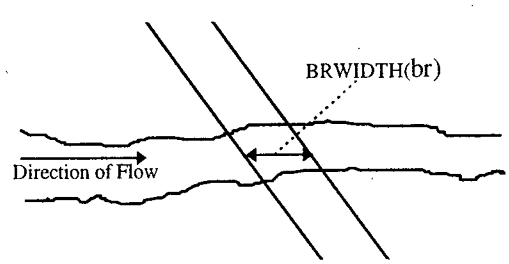
recid Record Identifier -- 'BR'

SECID(sec) An alphanumeric string to identify the cross-section. Not utilized by PREFES or FESWMS-2DH.

SRD(sec) The section reference distance. The distance from an arbitrary downstream point to the centerline of the main channel of this section.

LSEL(sec) Low-steel elevation of the bridge. This is used as the ceiling elevation for all nodes that fall at the location of the bridge.

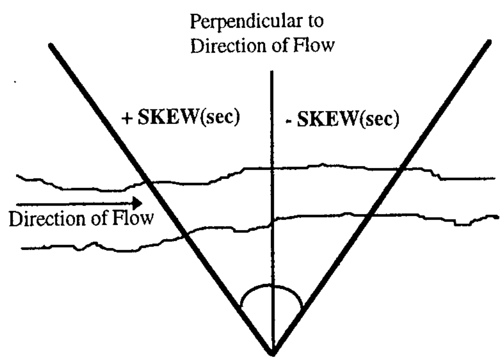
BRWIDTH(sec) Width of the bridge measured in the direction of flow.



**BR** | **BR Record (continued)** | **BR**

BRDROP(sec) The drop in elevation through the bridge. A positive value denotes a "drop" -- i.e. the elevation at the downstream side is lower than the elevation at the upstream side of the bridge for a given station. (THIS VARIABLE IS NO LONGER USED)

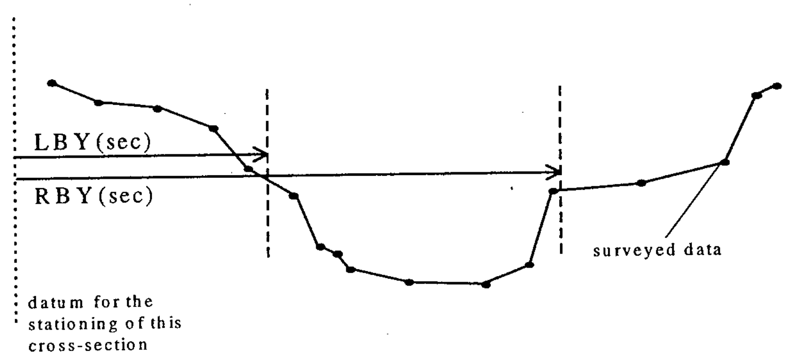
SKEW(sec) The angle of skew for this section. Positive and Negative defined below:




LBY(sec) The station of the left bank for this cross-section.

RBY(sec) The station of the right bank for this cross-section.

Note: The stations for the left and right banks do **not** need to correspond to stations of known ground elevation data (entered on GR records.)




Elevation of the Approach Section, Looking Downstream

**BR** **BR Record (continued)** **BR**

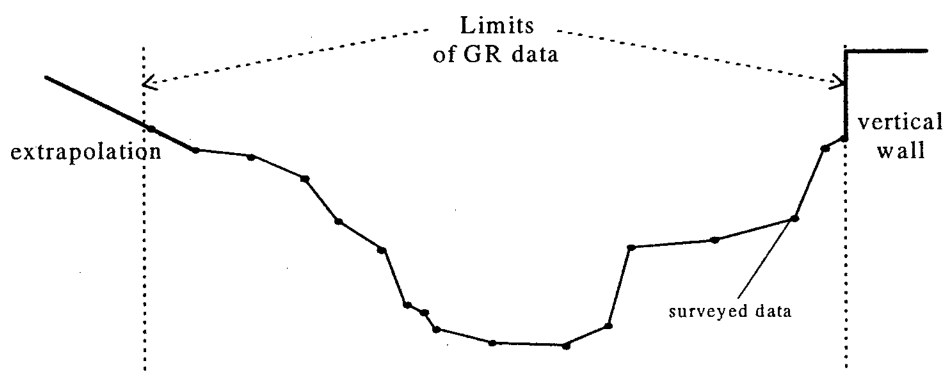
NPT(sec) Number of points used to define the cross-section geometry.

LEND(sec) Indicators specifying the method used to estimate the elevations
REND(sec) for stations in the cross-section that are outside the limits.

Possible Values:

0 -- a vertical wall extending to the low-steel elevation is placed outside the limits.

1 -- any points outside station limits will be linearly extrapolated using the two points of the cross-section immediately next to the limit.



| XR | XR Record | XR |
|---|---|---|

**Purpose:** Specifying cross-section information for the road.

**Note: This section is only valid if it follows a bridge section.**

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-5 | | blank |
| 6-10 | A | SECID(sec) |
| 11-20 | R | SRD(sec) |
| 21-30 | R | RDTOBR(sec) |
| 31-40 | I | NPT(sec) |

**Definition of Variables:**

| | |
|---|---|
| recid | Record Identifier -- 'XR' |
| SECID(sec) | An alphanumeric string to identify the cross-section. Not utilized by PREFES or FESWMS-2DH. |
| SRD(sec) | The section reference distance. The distance from an arbitrary downstream point to the centerline of the main channel of this section. |
| RDTOBR(sec) | The horizontal distance, measured along the cross-section stationing, from the datum for the road stationing to the first point of the bridge ground elevation data. |
| NPT(sec) | Number of points used to define the cross-section geometry. |

**Note: Road section is only used to establish ground elevations outside the bridge opening. No weir flow information is utilized.**

| XS | XS Record | XS |
|---|---|---|

**Purpose:** Specifying cross-section information for general sections.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-5 | | blank |
| 6-10 | A | SECID(sec) |
| 11-20 | R | SRD(sec) |
| 21-30 | R | SKEW(sec) |
| 31-40 | R | LBY(sec) |
| 41-50 | R | RBY(sec) |
| 51-55 | I | NPT(sec) |
| 56-60 | I | LEND(sec) |
| 61-65 | I | REND(sec) |

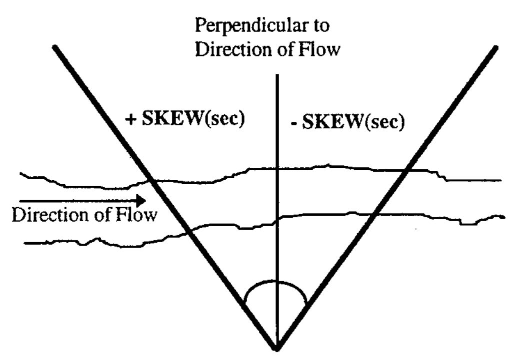
**Definition of Variables:**

recid Record Identifier -- 'XS'

SECID(sec) An alphanumeric string to identify the cross-section. Not utilized by PREFES or FESWMS-2DH.

SRD(sec) The section reference distance. The distance from an arbitrary downstream point to the centerline of the main channel of this section.

SKEW(sec) The angle of skew for this section. Positive and Negative defined below:

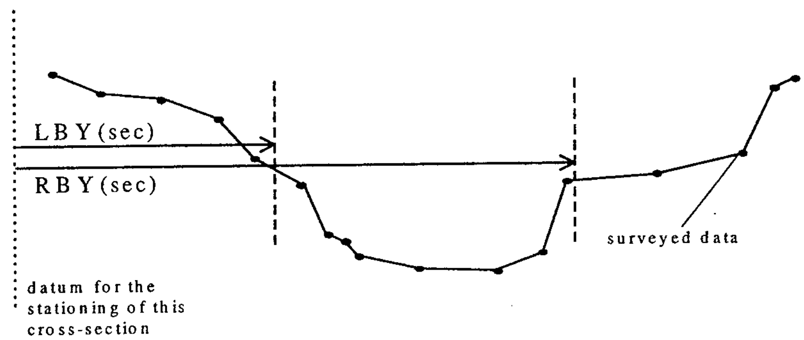


| XS | XS Record (continued) | XS |
|---|---|---|

LBY(sec) The station of the left bank for this cross-section.

RBY(sec) The station of the right bank for this cross-section.

Note: The stations for the left and right banks do **not** need to correspond to stations of known ground elevation data (entered on GR records.)




Elevation of the Approach Section, Looking Downstream

NPT(sec) Number of points used to define the cross-section geometry.

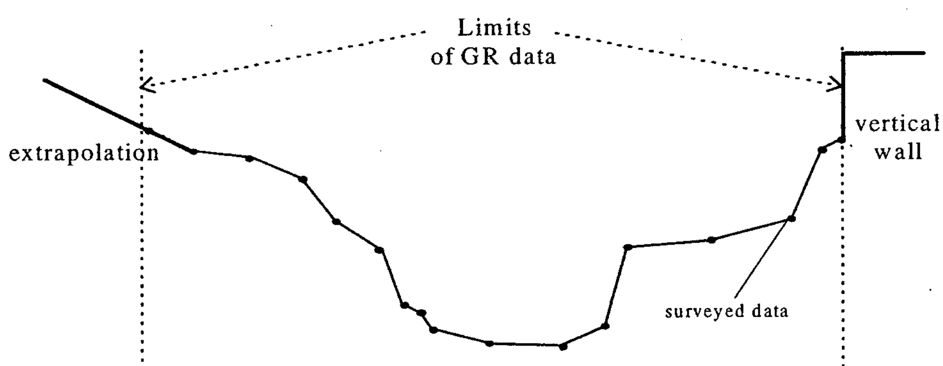
**XS** **XS Record (continued)** **XS**

LEND(sec) REND(sec) Indicators specifying the method used to estimate the elevations for stations in the cross-section that are outside the limits.

Possible Values:

0 -- a vertical is placed outside the actually surveyed limits

1 -- any points outside station limits will be linearly extrapolated using the two points of the cross-section immediately next to the limit.



| XT | XT Record | XT |
|---|---|---|

**Purpose:** Specifying template cross-section information.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-5 | | blank |
| 6-10 | A | SECID(sec) |
| 11-20 | I | NPT(sec) |

**Definition of Variables:**

recid  Record Identifier -- 'XS'

SECID(sec) An alphanumeric string to identify the cross-section. Not utilized by PREFES or FESWMS-2DH.

NPT(sec) Number of points used to define the cross-section geometry.

3.3.6 Cross-Section Geometry Records:

| GR | GR Record | GR |
|---|---|---|

**Purpose:** Specifying the ground elevations for each of the cross-sections,

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3 | | blank |
| 4-10 | R | ST(sec,pt) |
| 11-20 | R | ELEV(sec,pt) |
| 21-30 | R | ST(sec,pt) |
| 31-40 | R | ELEV(sec,pt) |
| 41-50 | R | ST(sec,pt) |
| 51-60 | R | ELEV(sec,pt) |
| 61-70 | R | ST(sec,pt) |
| 71-80 | R | ELEV(sec,pt) |

**Definition of Variables:**

recid Record Identifier -- 'GR'

ST(sec,pt) The station of the known point on the cross-section with reference to its individual section datum.

ELEV(sec,pt) The ground surface elevation of the known point on the cross-section.

| GT | GT Record | GT |
|---|---|---|

**Purpose:** Specifying any alterations to the template section for this fabricated cross-section.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-10 | | blank |
| 11-20 | R | ELRISE(sec) |
| 21-30 | R | YLIML(sec) |
| 31-40 | R | YLIMR(sec) |
| 41-50 | R | SCALE(sec) |
| 51-60 | R | YORIG(sec) |

**Definition of Variables:**

recid    Record Identifier -- 'GT'

ELRISE(sec)    The vertical distance added to the ground elevations of the template section.

YLIML(sec)    The left-most station of the template section to be retained.

YLIMR(sec)    The right-most station of the template section to be retained.

SCALE(sec)    Scale factor used to expand or contract the template section.

YORIG(sec)    Station in the template that is held constant when the SCALE factor is used.

3.3.7 Cross-Section Property Range Records (See 3.3.3 Property Type Record) :

| **NR** | **NR Record** | **NR** |
|---|---|---|

**Purpose:** Specifying the number of property ranges for this cross-section.

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-10 | | blank |
| 11-15 | I | NPROPR(sec) |

**Definition of Variables:**

recid Record Identifier -- 'NR'

NPROPR(sec) Number of property ranges (must be between 1 and 8)

| **PT** | **PT Record** | **PT** |
|---|---|---|

**Purpose:** Specifying the property type code for each property range

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-5 | | blank |
| 6-10 | I | PTYP(sec,1) |
| 11-20 | I | PTYP(sec,2) |
| 21-30 | I | PTYP(sec,3) |
| 31-40 | I | PTYP(sec,4) |
| 41-50 | I | PTYP(sec,5) |
| 51-60 | I | PTYP(sec,6) |
| 61-70 | I | PTYP(sec,7) |
| 71-80 | I | PTYP(sec,8) |

**Definition of Variables:**

recid Record Identifier -- 'PT'

PTYP(sec,prange) The property type for the property range.
(range location is specified using the SA record.)

**SA** **SA Record** **SA**

**Purpose:** Specifying the right-most station for the property range (prange).

Note: The program automatically assumes that the right-most station of the last property range (prange) is the right-most GR point. Therefore, the maximum numbr of YSA's is seven (7).

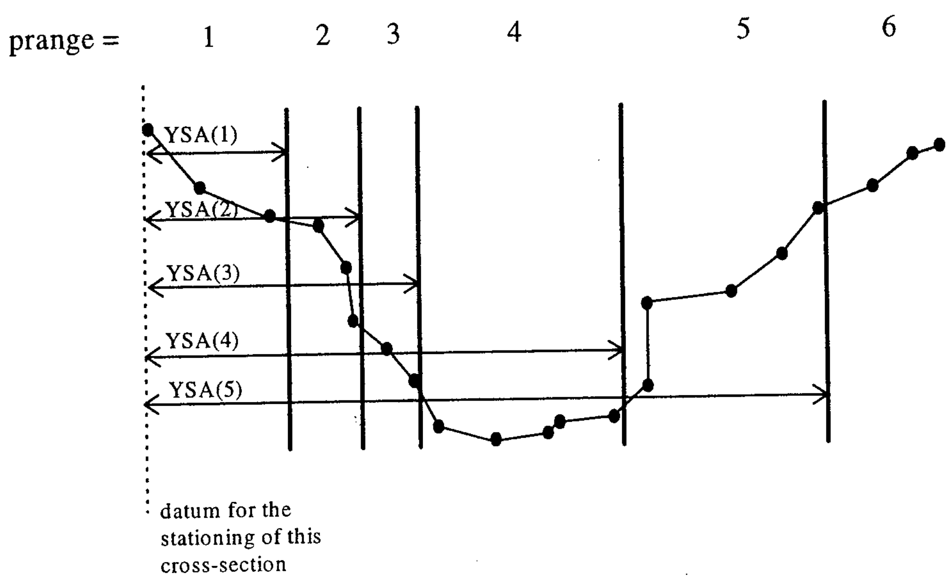
**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |
| 3-5 | | blank |
| 6-15 | R | YSA(sec,1) |
| 16-25 | R | YSA(sec,2) |
| 26-35 | R | YSA(sec,3) |
| 36-45 | R | YSA(sec,4) |
| 46-55 | R | YSA(sec,5) |
| 56-65 | R | YSA(sec,6) |
| 66-65 | R | YSA(sec,7) |

**Definition of Variables:**

recid Record Identifier -- 'YSA'

YSA(sec,prange) The right-most station for the property range.



3.3.8 End of Input File Record:

| **ER** | **ER Record** | **ER** |
|---|---|---|

**Purpose:** Used to indicate the end of the input file

**Format:**

| Columns | Type | Contents |
|---|---|---|
| 1-2 | A | recid |

**Definition of Variables:**

recid Record Identifier -- 'ER'

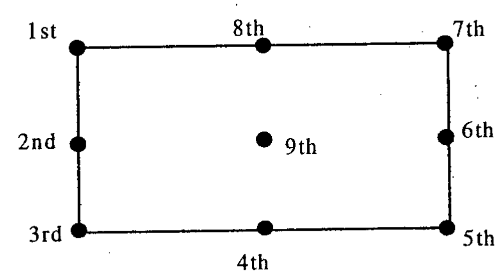
## 4.0 Description of Output

### 4.1 Grid.dat

This file contains the physical network utilized in FESWMS-2DH. It consists of the node and element data as follows:

For each rectangular element:

- list of the nine nodes which define the element
  (eight nodes on the element boundary going counter-clockwise and one node at the center of the element)

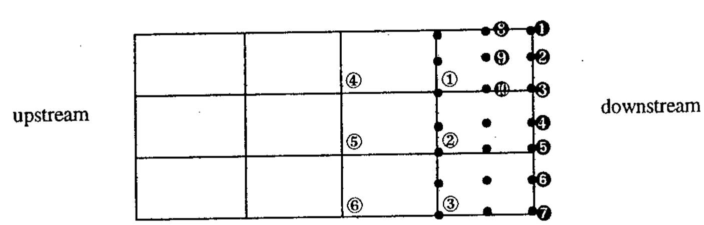



- property type code for the element

For each node:

- x-coordinate
- y-coordinate
- ground elevation
- ceiling elevation

The nodes and elements are numbered starting at the downstream-most and left-most location (see Figure 4.1). The nodes are numbered at each element corner, element mid-side, and element center by stepping down as shown. When the right-most side is reached the next node to be numbered is one half-element upstream at the left-most location. The element numbering follows a similar path from left-most to right-most then moving one element upstream.




① ELEMENT NUMBER

❶ NODE NUMBER

Figure 4.1 -- Numbering Sequence, Simplified Network

4.2 Dinmod.dat

This file is the input file to run the DINMOD module in FESWMS-2DH. PREFES creates this file as a template file. The defaults may easily be changed in the FESWMS-2DH editor to customize for the project.

The defaults are set for DINMOD to do the following:

(1) perform a geometric check of the network
(2) create two (2) plots, sized to fit the monitor screen with water flowing from left to right
    (a) network (with property codes in each element)
    (b) ground elevation contours

The purpose of each default is described in the FESWMS-2DH manual:

| SWMS Record: | PLOT Record: |
|---|---|
| WIDE = 1 | PTITLE = title2* |
| SCREEN = 1 | IPLTN = 0 |
| JTITLE = title1* | IPLTE = 2 |
| IPRNT = 3 | HTT = 0.14 |
| IPLOT = 3 | HTN = 0.07 |
| ICHEK = 1 | HTE = 0.105 |
| IAUTO = 0 | CVINC = 0 |
| IREFN = 0 | XLOWER = maximum SRD(sec)* |
| IRESQ = 0 | |
| IGIN = 1 | YLOWER = grid width |
| IGOUT = 0 | XOFFSET = 0 |
| | YOFFSET = 0 |
| | XSCALE = grid length/7 |
| | YSCALE = grid width/5 |
| | ROTATE = 180 |

* These variables are input values from the Input File used by PREFES and described in Chapter 3.

## 4.3 Flomod.dat

This file is the input file to run the FLOMOD module in FESWMS-2DH. PREFES creates this file as a template file. The defaults may easily be changed in the FESWMS-2DH editor to customize for the project.

The purpose of each default is described in the FESWMS-2DH:

SWMS Record:
- WIDE = 1
- SCREEN = 1
- JTITLE = title1*
- IDRUN = 0
- IPRNT = 3
- IUNIT = 0
- IWIND = 0
- IFRIC = 0
- ISLIP = 0
- IHINT = 0
- INORM = 1
- IONOFF = 1
- ISAVE = 0
- NPVMIN = 1
- IGRID = 1
- INITC = 0
- ISOUT = 1
- IRSRC = 1
- IBCIN = 0
- IWDIN = 0
- ILCOF = 98
- IUCOF = 99
- NITS = 1
- NITD = 0
- NUPV = 0
- NITP = 1
- TSTRT = 0
- TMAX = 0
- DELT = 0
- THETA = 0.67
- WSEL = WS*
- OMEGA = 0

QSEC Record:
- XSQ = Q*
- LXSQN(K) = a list of node numbers that create the most upstream boundary

ZSEC Record:
- IXSZ = 1
- XSZ1(IXSZ) = WS*
- IBCZ(IXSZ) = 2
- LXSZN(K) = a list of node numbers that create the most downstream boundary

FLUX Record:
- LFLUXN(K) = lists of numbers representing different cross-sections at which the flow is determined. (These are used to verify continuity and check convergence of finite element solution)

PROP Record:
- M = PTYPE*
- LPROPS(1,M) = BN(PTYPE)*
- LPROPS(2,M) = BD(PTYPE)*
- LPROPS(3,M) = TN(PTYPE)*
- LPROPS(4,M) = TD(PTYPE)*
- LPROPS(6,M) = 1

**Note: The default set for LPROPS(6,M) is unrealistic. The actual value should be 0.0. However, in many instances, FESWMS-2DH requires a base eddy viscosity to begin calculations from a "cold" start. Once the model has converged, this variable should be changed to 0.0 and the model should be re-run.**

- LPROPS(7,M) = 0.6

* These variables are input values from the Input File used by PREFES and described in Chapter 3.

## 4.4 Anomod.dat

This file is the input file to run the ANOMOD module in FESWMS-2DH. PREFES creates this file as a template file. The defaults may easily be changed in the FESWMS-2DH editor to customize for the project.

The purpose of each default is described in the FESWMS-2DH:

SWMS Record:
- WIDE = 1
- SCREEN = 1
- TFIRST = 0
- TLAST = 0
- IPRNT = 0
- IGRID = 1
- IFLOW = 1
- GRIDB = 0
- IFLOWB = 0
- IUNITS = 0

VECT Record:
- NEWPLT = 0
- PTITLE = title2*
- IPLTV = 1
- IPLTS = 0
- VSCALE = 50
- PGRIDX = grid length/45
- PGRIDY = grid width/45
- HTT = 0.14
- HTN = 0.07
- XLOWER = maximum SRD(sec)*
- YLOWER = grid width
- XOFFSET = 0
- YOFFSET = 0
- XSCALE = grid length/7
- YSCALE = grid width/5
- ROTATE = 180

ISOL Record:
- NEWPLT = 0
- PTITLE = title2*
- IPLTC = 1
- ICVAL = 2
- NDECV = 1
- CVMIN = 0
- HTT = 0.14
- HTN = 0.07
- HTC = 0.105
- XLOWER = maximum SRD(sec)*
- YLOWER = grid width
- XOFFSET = 0
- YOFFSET = 0
- XSCALE = grid length/7
- YSCALE = grid width/5
- ROTATE = 180

ISOL Record:
- NEWPLT = 0
- PTITLE = title2*
- IPLTC = 1
- ICVAL = 3
- NDECV = 1
- CVMIN = 0
- HTT = 0.14
- HTN = 0.07
- HTC = 0.105
- XLOWER = maximum SRD(sec)*
- YLOWER = grid width
- XOFFSET = 0
- YOFFSET = 0
- XSCALE = grid length/7
- YSCALE = grid width/5
- ROTATE = 180

* These variables are input values from the Input File used by PREFES and described in Chapter 3.

## 5.0 Helpful Hints for Running FESWMS-2DH

This chapter is designed to introduce the user to FESWMS-2DH by looking at some common uses, concerns, and problems. This chapter in not intended to be a substitute for the FESWMS-2DH User's Manual.

### 5.1 Input files for FESWMS-2DH

#### 5.1.1 Utilizing the output from PREFES

PREFES creates four files intended for use as input files for FESWMS-2DH: Grid.dat, Dinmod.dat, Flomod.dat, and Anomod.dat (see Chapter 4). Since these files are structured in a format readable by FESWMS-2DH, no modification is necessary prior to running the finite element program. However, if desired, these files can be modified within FESWMS-2DH to customize for the project.

#### 5.1.2 Editing the input files within FESWMS-2DH

To edit the input files within FESWMS-2DH, the user can select Edit from the File menu or select Edit within the appropriate Module menu. For instance, to edit Dinmod.dat, the user should be in the DINMOD Module. FESWMS-2DH allows for two methods of editing files: a data file editor and a full-screen editor.

The data file editor is only available from within the Module menus. This editor "walks" the user through the editing process. Short definitions for each variable are provided, and the current value is listed as the "Default". If the FESWMS-2DH User's Manual is not readily available, this editor can be used as a quick reference.

The full-screen editor operates similar to many text editors. It allows the user to view the entire input file and make changes within that format. Due to the record format, caution is required to insure the values are in the appropriate ranges. It is necessary to keep the FESWMS-2DH User's Manual at hand to reference the location and definition of all variables. Since no pull-down menu is available, the help screen within this editor can be very useful. Additionally, a listing of short-cut keys is provided in Table 5.1.

## Table 5.1 -- Short-Cut Keys for Use in FESWMS's Full Screen Editor

```
+-------------------- Cursor Movement Commands --------------------+
  Function                   Single Key Multiple Keys
  ========================== ========== ==========================
  Move left one character    <Left>     <Ctrl-S>
  Move right one character   <Right>    <Ctrl-D>
  Move left one word         --         <Ctrl-Left> or <Ctrl-A>
  Move right one word        --         <Ctrl-Right> or <Ctrl-F>
  Move to next tab stop      <Tab>      <Ctrl-I>
  Move to beginning of line  <Home>     <Ctrl-Q><S>
  Move to end of line        <End>      <Ctrl-Q><D>
  Move up one line           <Up>       <Ctrl-E>
  Move down one line         <Down      <Ctrl-X>
  Scroll up one line         --         <Ctrl-W>
  Scroll down one line       --         <Ctrl-Z>
  Scroll up one page         <PgUp>     <Ctrl-R>
  Scroll down one page       <PgDn>     <Ctrl-C>
  Move to top of window      --         <Ctrl-Home> or <Ctrl-Q><E>
  Move to bottom of window   --         <Ctrl-End> or <Ctrl-Q><X>
  Move to beginning of file  --         <Ctrl-PgUp> or <Ctrl-Q><R>
  Move to end of file        --         <Ctrl-PgDn> or <Ctrl-Q><C>
  Move to a specified line   --         <Ctrl-J><L>
+------------------------------------------------------------------+

+------------------- Insert and Delete Commands -------------------+
  Function                   Single Key Multiple Keys
  ========================== ========== ==========================
  Delete current character   <Del>      <Ctrl-G>
  Delete character to left   <Bksp>     <Ctrl-H> or <Ctrl-Bksp>
  Delete current line        --         <Ctrl-Y>
  Delete to end of line      --         <Ctrl-Q><Y>
  Delete word to right       --         <Ctrl-T>
  Start a new line           <Enter>    <Ctrl-M>
  Insert a new line above    --         <Ctrl-N>
+------------------------------------------------------------------+

+------------------------- File Commands --------------------------+
  Function                   Single Key Multiple Keys
  ========================== ========== ==========================
  Save file                  <F2>       <Ctrl-K><S>
  Load a new file            <F3>       <Ctrl-K><L>
  Quit editing; do not save  --         <Ctrl-K><Q>
  Save file and load new one --         <Ctrl-K><D>
  Save file under a new name --         <Ctrl-K><N>
  Save file then quit        <F10>      <Ctrl-K><X>
+------------------------------------------------------------------+

+------------------------- Block Commands -------------------------+
  Function                   Single Key Multiple Keys
  ========================== ========== ==========================
  Mark start of block        <F7>       <Ctrl-K><B>
  Mark end of block          <F8>       <Ctrl-K><K>
  Mark current word as block --         <Ctrl-K><T>
  Jump to start of block     --         <Ctrl-Q><B>
  Jump to end of block       --         <Ctrl-Q><K>
  Copy the marked block      --         <Ctrl-K><C>
  Move the marked block      --         <Ctrl-K><V>
  Delete the marked block    --         <Ctrl-K><Y>
  Read a file and mark it    --         <Ctrl-K><R>
  Write marked block         --         <Ctrl-K><W>
  Print marked block         --         <Ctrl-K><P>
+------------------------------------------------------------------+

+--------------- Text Search and Replace Commands -----------------+
  Function                   Single Key Multiple Keys
  ========================== ========== ==========================
  Find a text string         --         <Ctrl-Q><F>
  Find and replace a string  --         <Ctrl-Q><A>
  Repeat last find/replace   --         <Ctrl-L>
```

```
+-------------------------------------------------------------------+

+---------------------- Text Marker Commands ----------------------+
  Function                  Single Key Multiple Keys
  ========================= ========== ==========================
  Set text marker           --         <Ctrl-K><#>; # = 0..9
  Jump to text marker       --         <Ctrl-Q><#>; # = 0..9
  Toggle text marker display --        <Ctrl-K><M>
  Jump to previous position --         <Ctrl-Q><P>
+-------------------------------------------------------------------+

+------------ Mode Toggles and Option Setting Commands ------------+
  Function                  Single Key Multiple Keys
  ========================= ========== ==========================
  Toggle insert mode        <Ins>      <Ctrl-V>
  Toggle auto-indent mode   --         <Ctrl-O><I>
  Toggle line word-wrap     --         <Ctrl-O><W>
  Set uniform tab stops     --         <Ctrl-O><T>
  Set new right margin      --         <Ctrl-O><R>
+-------------------------------------------------------------------+

+--------------------- Miscellaneous Commands ---------------------+
  Function                  Single Key Multiple Keys
  ========================= ========== ==========================
  Restore original line     --         <Ctrl-Q><L>
  Center the line           --         <Ctrl-O><C>
+-------------------------------------------------------------------+
```

## 5.2 Running the DINMOD Module

The DINMOD Module is a data input module designed to create a physical network which will be utilized by the flow module (FLOMOD). Since PREFES creates a network file (Grid.dat), it is not necessary to run this module. However, DINMOD also performs a geometric check on the network and creates graphs which can also be helpful in checking the network. Therefore, it is recommended that DINMOD always be run prior to the flow analysis (FLOMOD).

### 5.2.1 Altering Dinmod.dat

The input file for DINMOD (Dinmod.dat), as created in PREFES, is designed to perform a geometric check of the network, create a plot of the network with the property type printed in the centroid of each element, and create a plot of the ground elevation contours.

Although DINMOD is capable of many other functions, none of these are discussed in this manual. It is recommended that the user consult the FESWMS-2DH User's Manual for all the capabilities of this module.

The default values for the plots are set so the plots will be useful as a quick check of the network. The plots are sized to fit a computer monitor and are rotated so the flow of the river will be from left to right. These defaults can easily be changed using one of the editors discussed above. Additionally, property types are printed at the centroid of each element. This selection may be changed to print either the node numbers or the element numbers; however, since the plot is sized so small, these values may be over-crowded and more difficult to read. The titles for the plots, as defined in the PREFES input file, can also be changed using the editors.

### 5.2.2 Inspecting the Results of DINMOD

#### 5.2.2.1 Dinmod.prt

Dinmod.prt is a text file created by the DINMOD Module which contains the results of the run. Any errors found during the geometric check will be listed here. This file can be viewed by selecting Browse under the DINMOD Module menu.

#### 5.2.2.2 Plots

The two plots created by DINMOD can be very useful in detecting network errors. On the network plot, the user should look for oddly shaped elements. If no changes have been made to the network since its creation in PREFES, all elements should be rectangular. Examining the plot of ground elevation contours for irregularities is perhaps the easiest method for detecting any errors in the cross-section ground elevation data and errors in the extrapolation keys entered on the Input File for PREFES.

## 5.3 Running the FLOMOD Module

FLOMOD is the Flow Analysis Module. It is within this module that the vertically-integrated equations of continuity and momentum are solved to obtain depth-averaged velocities and flow depths at the node locations.

### 5.3.1 Altering Flomod.dat

The input file for FLOMOD (Flomod.dat), as created in PREFES, is designed to run one (1) Newtonian iteration towards the solution using the default flow parameters listed in Chapter 4. It is recommended that these parameters and their defaults be studied for the applicability to the project and changed if necessary using one of the editors described above.

The most common defaults which the user may need or wish to change are in the SWMS and PROP records.

INITC is a key which indicates whether (INITC=1) or not (INITC=0) an Initial Condition data file (Init.dat) is to be read. This file includes initial values of x-velocity, y-velocity, and depth for each node. When running FESWMS-2DH from a cold start, where only a downstream elevation and a flow rate is known, this value should be 0. However, if initial conditions are known, the user can create a file Init.dat. Generally, this file is used when the output from a previous run is used as the input for the current run, in which case Flow.dat (created during the execution of FLOMOD) should be copied into Init.dat. Typical situations when the user may wish to do this include: (1) if the previous run did not converge and more iterations are required, or (2) if the value of a variable has changed slightly and the user feels that the output from a previous run is a sufficient starting place to begin the iterations for the current run. (see LPROPS(6,M) below)

IRSRC is a key which specifies whether (IRSRC=1) or not (IRSRC=0) a Restart-Recovery file is written after every iteration. This value is initially set to one (1). This feature is very advantageous if the user is running numerous iterations and the possibility of computer failure is not unrealistic.

ISLIP is a key which defines the frictional characteristics of the solid boundaries. The boundaries can exhibit zero flow (no slip), tangential flow with no tangential shear (slip), or tangential flow with tangential wall shear (semi-slip).

NITS dictates the number and type of iterations to be performed for a steady-state solution. This value is initially set for one Newtonian solution. It is recommended that FLOMOD initially be run for just one iteration to allow the user the opportunity to detect any errors prior to completing the analysis.

NITP dictates how many iterations are skipped between printing output to Flomod.dat. This variable is initially set at zero since only one iteration is to be performed. However, if many iterations are performed, the user may wish to limit the frequency at which results are written to file.

LPROPS(6,M) is the turbulence model base kinematic coefficient of the eddy viscosity. The initial value is set to 1.0. However, for water, this value should be 0.0. The variable is set to 1.0 initially as a method for trouble shooting. In many instances, setting the base kinematic viscosity to 0.0 initially causes errors in the results or prevents the analysis from being completed entirely. For instance a run-time error of "518 All fully-assembled equations have a zero diagonal coefficient. Contents of IHED are as follows: " can be caused by too low of a kinematic viscosity. Also, if the flow analysis yields velocity vectors which radiate at large magnitude from a specific area (this is overtly obvious examining the velocity vector plot where these regions will resemble a donut), increasing LPROPS(6,M) may alleviate the problem. Since the correct value for the base kinematic viscosity is 0.0, it is recommended that this variable be changed to 0.0 for the final analysis. A typical method for trouble shooting the symptoms mentioned above is (1) give LPROPS(6,M) an arbitrarily high value, thus circumventing any errors, for a set number of iterations, preferably getting close to convergence, (2) reduce the value and rerun FLOMOD (this requires changing INITC and copying the output file (Flow.dat) to an initial condition file (Init.dat), (3) repeat until the value of LPROPS(6,M) is reduced to 0.0

### 5.3.2 Inspecting the results of FLOMOD

The results of the flow analysis are printed to Flomod.prt and Flow.dat.

#### 5.3.2.1 Convergence of the Solution

With all finite element analysis, the solution can only be reached through a series of iterations. FESWMS-2DH presents the user with options as to the type of iteration and the number to be performed (see NITS in the FESWMS-2DH User's Manual). Summaries are printed in Flomod.prt which will allow the user to determine if the solution has converged:

(1) "Convergence Parameters" within Flomod.prt lists the maximum change and average change in x-velocity, y-velocity, and depth and at which nodes these changes occur.

(2) "Element Change of Status Report" within Flomod.prt lists all elements which changed status in the most recent iteration, i.e. turned on/off. It should be noted that for an element to be dry, only one node of the element must be dry. Therefore, a small fluctuation in water surface elevation may change the status of the elements.

#### 5.3.2.2 Evaluating the Results Once the Solution has Converged

Flomod.prt summarizes the results of the flow analysis. Different results can be calculated and printed in this file such as the continuity norms, the Froude numbers, or the energy head at every node. These results can be important in determining if the model is running properly.

Flow.dat is a listing of the node number, x-velocity, y-velocity, and depth. This file is used by ANOMOD to create plots. However, it can also be helpful to the user if further analysis is required, for instance if the angle of attack for a pier is of concern. A typical method of extracting data from Flow.dat follows:

(1) Determine what node number are of interest. This can be done by examining the Grid.dat file for the nodes whose x-coordinate (SRD

as defined in Chapter 3) and the y-coordinate (distance from the left-most point to node) are within the range of interest.

(2) Extract the information for those nodes. This can be done by using a text editor capable of editing large files to delete the lines of node numbers which are not of interest and save the data under a different name.

(3) Import the information into a spreadsheet for further calculations.

Note: If the Flow.dat file is small or if the spreadsheet application is capable of handling large files, step 2 may not be necessary.

Perhaps the easiest method for reviewing the results of the flow modeling is to run the analysis module (ANOMOD).

## 5.4 Running the ANOMOD Module

The ANOMOD Module is a post-analysis module which utilizes the results of the flow analysis to generate plots for evaluation.

### 5.4.1 Altering Anomod.dat

The input file for ANOMOD (Anomod.dat), as created in PREFES, is designed to create three plots. The first plot is of the velocity vectors.

The default values for the plots are set so the plots will be useful as a quick check of the flow analysis. The plots are sized to fit a computer monitor and are rotated so the flow of the river will be from left to right. These defaults can easily be changed using one of the editors discussed above. The titles for the plots, as defined in the PREFES input file, can also be changed using the editors.

### 5.4.2 Inspecting the Results of ANOMOD

The plots generated by ANOMOD may assist in the error-checking process. For instance, the velocity vector plot may contain "donut" shapes. This feature is an indication that the convergence must first be approached with an abnormally high base kinematic coefficient of the eddy viscosity (see LPROPS(6,M) in 5.3.1).

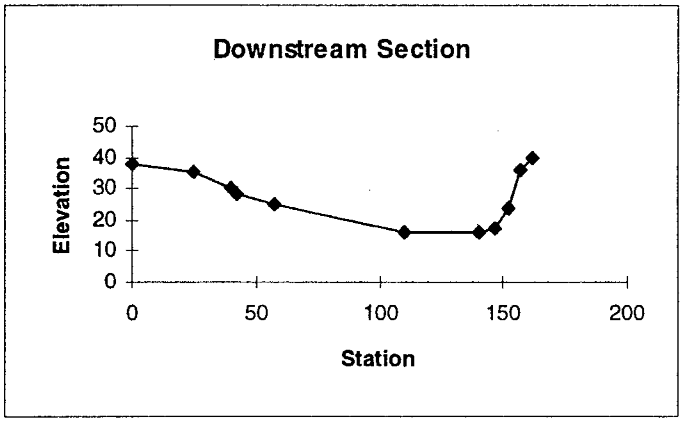
Not all errors and/or problems in the analysis will be so readily apparent. However, it is suggested that each plot be examined to determine if the results are logical.

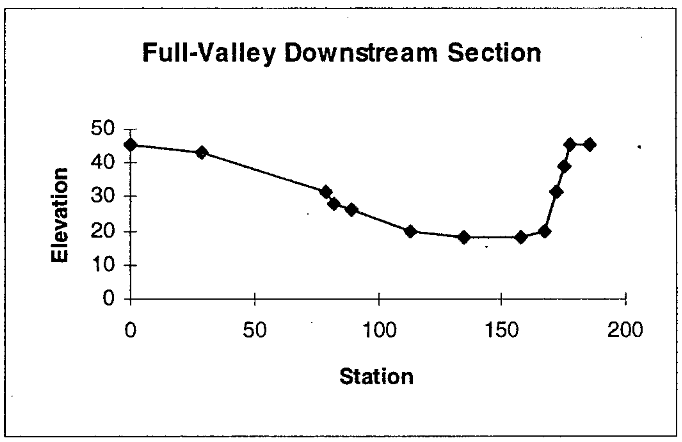
# 6.0 Examples

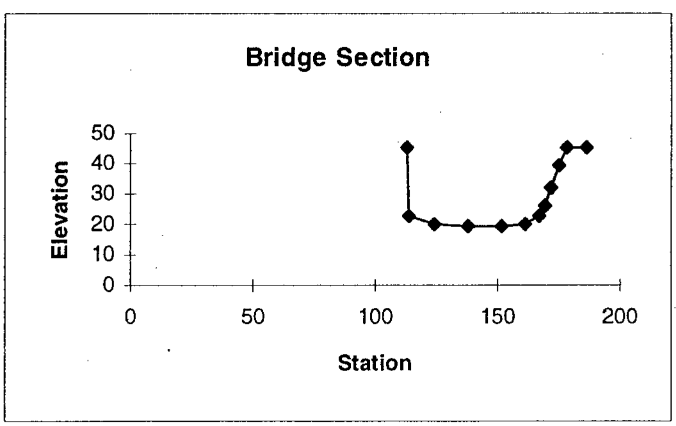
## 6.1 Example 1 -- Left Bank Constriction With a Skewed Bridge

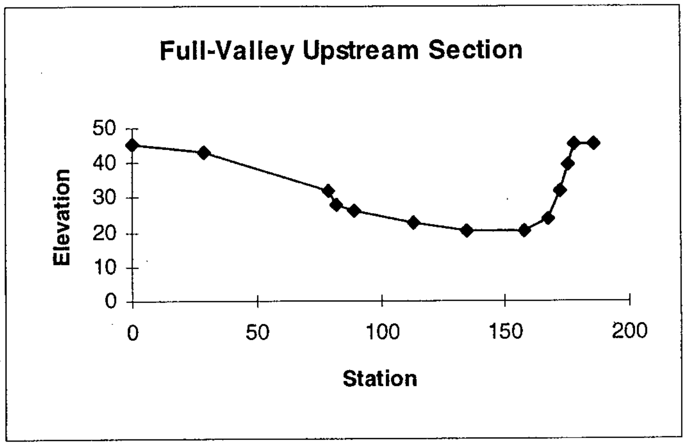
### 6.1.1 Problem Description

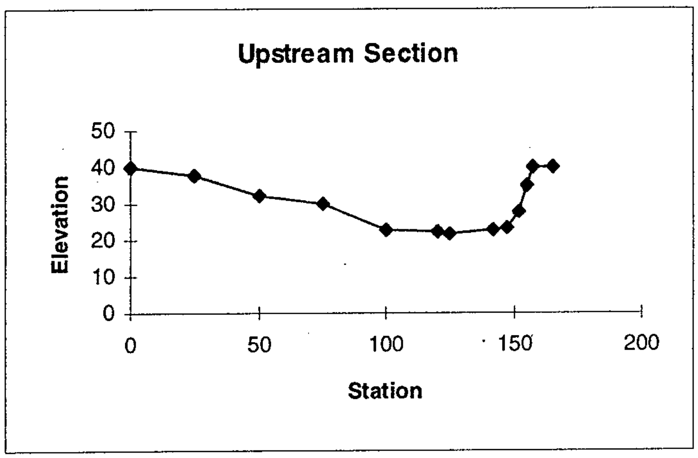
This channel has a gradually sloping left bank and a very steep right bank. The bridge section is skewed such that the left channel is towards downstream (negative skew).






### 6.1.2 Input File for PREFES (ex1)

```
T1    Example 1
T2    Left Bank Constriction, with skewed bridge
*
NET             9000               .5                  2         4
TYP      1      0.05         6   0.040        10
TYP      2      0.04         6   0.035        10
TYP      3      0.06         6   0.050        10
TYP      4      0.03         7
*
Q               7500
WS                38
*
XS    EXIT      1000         0      95       157   11    1     1
GR       0        38        25    35.2        40        30       42.5       28
GR    57.5      25.2       110      16       140        16       147.       17.6
GR    152.        24      157.      36      162.        40
NR            3
PT       3         2         4
SA           65       105
*
XS    FVD       1246       -28     113       178   13    1     1
GR       0      45.1      28.3    42.9      79.2      31.5       82.1       27.9
GR    88.9      26.1      113.    20.0      135.      18.0       158.       18.0
GR    167.      20.0      172.    31.5      175.      39.2       178.       45.1
GR    186.      45.1
NR            3
PT       1         2         4
SA           30        80
*
BR    BR        1247        55  -28   50  1.5    113        178   12    0    0
GR    113.      45.3      114.    22.6      124.      20.3       138.       19.4
GR    152.      19.4      161.    20.3      167.      22.6       169.       26.2
GR    172.      31.7      175.    39.4      178.      45.3       186.       45.3
NR            1
```

```
PT      4
*
XS    FVU       1300      -28       113       178   13    1     1
GR      0       45.3      28.3      43.0      79.2        31.7       82.1       28.0
GR    88.9      26.2      113.      22.6      135.        20.3       158.       20.3
GR    167.      24.0      172.      31.7      175.        39.4       178.       45.3
GR    186.      45.3
NR          3
PT      1         2         4
SA          27        80
*
AS    app       1700       0         90       157   13    1     1
GR      0        40        25        38        50          32         75         30
GR    100       23.2      120        22       125         21.5       142.       22.2
GR    147.      23.2      152.       28       155         34.8       157.        40
GR    165        40
NR          4
PT      3         1         2         4
SA          25        50       100
*
ER
```

### 6.1.3 Output from PREFES

#### 6.1.3.1 Grid.dat

```
10800      2627
          1  1000.000     0.000    38.277     0.000
          2  1000.000     2.793    37.964     0.000
          3  1000.000     5.586    37.651     0.000
          4  1000.000     8.380    37.338     0.000
          5  1000.000    11.173    37.025     0.000
          6  1000.000    13.966    36.712     0.000
          7  1000.000    16.759    36.399     0.000
          8  1000.000    19.552    36.087     0.000
.
.
.
     10796     0.000   158.443     0.000     0.000
     10797     0.000   160.206     0.000     0.000
     10798     0.000   161.969     0.000     0.000
     10799     0.000   165.969     0.000     0.000
     10800     0.000   169.969     0.000     0.000
    1    1   76  151  152  153   78    3    2   77    3
    2    3   78  153  154  155   80    5    4   79    3
    3    5   80  155  156  157   82    7    6   81    3
    4    7   82  157  158  159   84    9    8   83    3
    5    9   84  159  160  161   86   11   10   85    3
.
.
.
 262510569106441071910720107211064610571105701064 5    4
 26261057110646107211072210723106481057310572106 47    4
 26271057310648107231072410725106501057510574106 49    4
```

#### 6.1.3.2 Dinmod.dat

```
SWMS                 1         1
   Example 1
    3    3    1    0    0    0    1    0
PLOT
   Left Bank Constriction, with skewed bridge
    0    2
      0.14       0.07      0.105      0.105
  1700.000    169.969      0.000      0.000     87.961     33.994    180.000
LAST
```

### 6.1.3.3 Flomod.dat

```
SWMS                   1         1

   Example 1
   0    3    0    0    0    2    0    1    1    0    1
   1    1    1    1    0    0   98   99
       20         0         0        20      .000      .000      .000      .670
   38.000      .000      .000      .000      .000 .000E+00      .000      .000
     .000      .000  .000E+00      .000      .000      .000     .0000
PROP
        1     0.050     6.000     0.040    10.000                 0.0    0.6000
        2     0.040     6.000     0.035    10.000                 0.0    0.6000
        3     0.060     6.000     0.050    10.000                 0.0    0.6000
        4     0.030     7.000     0.000     0.000                 0.0    0.6000
QSEC
        1   7500.00
1065110652106531065410655106561065710658106591066010661106621066310664106651066
1066710668106691067010671106721067310674106751067610677106781067910680106811068
1068310684106851068610687106881068910690106911069210693106941069510696106971069
1069910700107011070210703107041070510706107071070810709107101071110712107131071
107151071610717107181071910720107211072210723107241072510725   -1    0    0    0    0
ZSEC
        1    38.000                        2
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32
   33   34   35   36   37   38   39   40   41   42   43   44   45   46   47   48
   49   50   51   52   53   54   55   56   57   58   59   60   61   62   63   64
   65   66   67   68   69   70   71   72   73   74   75   -1    0    0    0    0
FLUX
 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966
 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982
 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998
 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025   -1    0    0    0    0
 4201 4202 4203 4204 4205 4206 4207 4208 4209 4210 4211 4212 4213 4214 4215 4216
 4217 4218 4219 4220 4221 4222 4223 4224 4225 4226 4227 4228 4229 4230 4231 4232
 4233 4234 4235 4236 4237 4238 4239 4240 4241 4242 4243 4244 4245 4246 4247 4248
 4249 4250 4251 4252 4253 4254 4255 4256 4257 4258 4259 4260 4261 4262 4263 4264
 4265 4266 4267 4268 4269 4270 4271 4272 4273 4274 4275   -1    0    0    0    0
 7501 7502 7503 7504 7505 7506 7507 7508 7509 7510 7511 7512 7513 7514 7515 7516
 7517 7518 7519 7520 7521 7522 7523 7524 7525 7526 7527 7528 7529 7530 7531 7532
 7533 7534 7535 7536 7537 7538 7539 7540 7541 7542 7543 7544 7545 7546 7547 7548
 7549 7550 7551 7552 7553 7554 7555 7556 7557 7558 7559 7560 7561 7562 7563 7564
 7565 7566 7567 7568 7569 7570 7571 7572 7573 7574 7575   -1    0    0    0    0
LAST
```

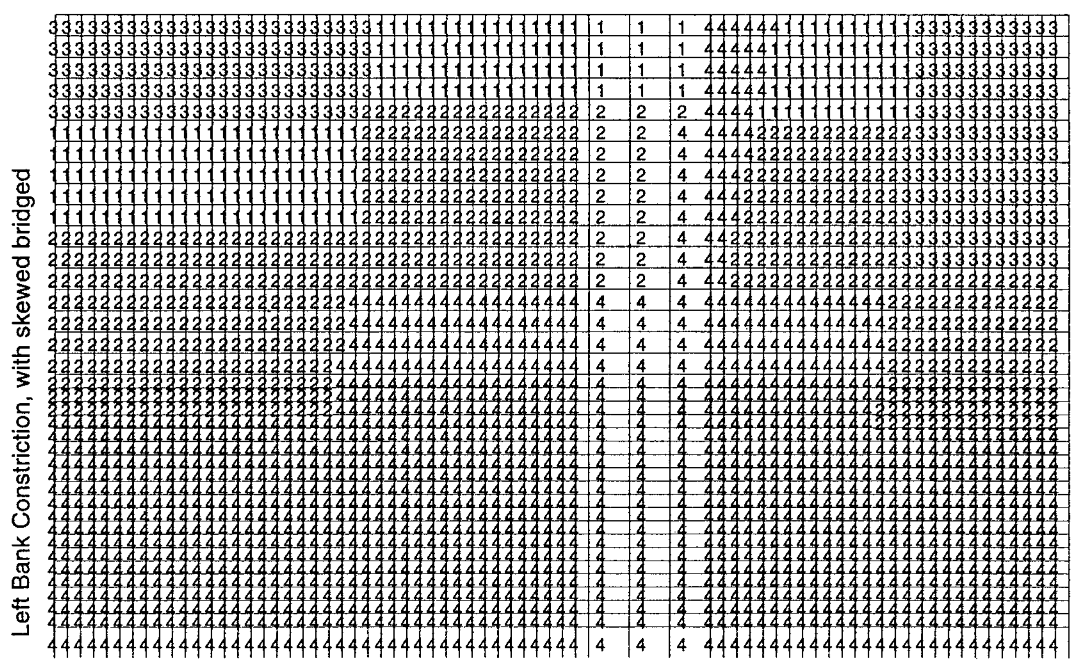
Note: The numbers shaded above vary from the actual PREFES output file (flomod.dat). The results presented in section 6.1.4 were computed the using two FESWMS runs: (1) the first run was completed with the original flomod.dat file with the exception that the number of initial full-Newtonian iterations (NITS=10) was changed to 10 and semi-slip conditions were applied to solid boundaries (ISLIP=2). (2) the second run utilized the output from the first run (flow.dat) as an initial condition file (init.dat) (INIT=1), corrected the base kinematic eddy viscosity to 0 (LPROPS(6,M)=0), and computed another 20 initial full-Newtonian iterations (NITS=20). For explanation of this method see sections 4.3 and 5.3.

#### 6.1.3.4 Anomod.dat

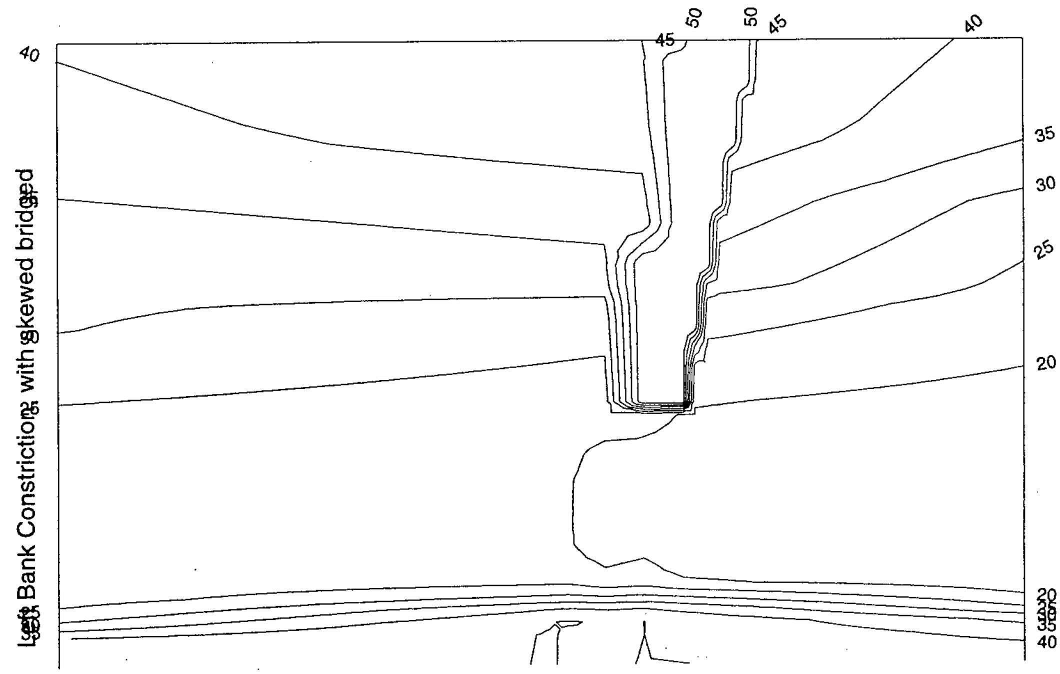
```
SWMS                 1         1                                    0
0
    0    1    1    0    0    0

VECT                 0
0
   Left Bank Constriction, with skewed bridge
    1    0
        50           0         1            43.981     4.249
     0.140      0.070
  1700.000    169.969      0.000      0.000     87.961    33.994   180.000

ISOL                 0
0
   Left Bank Constriction, with skewed bridge
    1    2    1
         0      48.00       0.20
     0.140      0.070
  1700.000    169.969      0.000      0.000     87.961    33.994   180.000

ISOL                 0
0
   Left Bank Constriction, with skewed bridge
    1    3    1
         0     180.00       1.00
     0.140      0.070
  1700.000    169.969      0.000      0.000     87.961    33.994   180.000
LAST
```

### 6.1.4 FESWMS-2DH Output

#### 6.1.4.1 Plot of Network

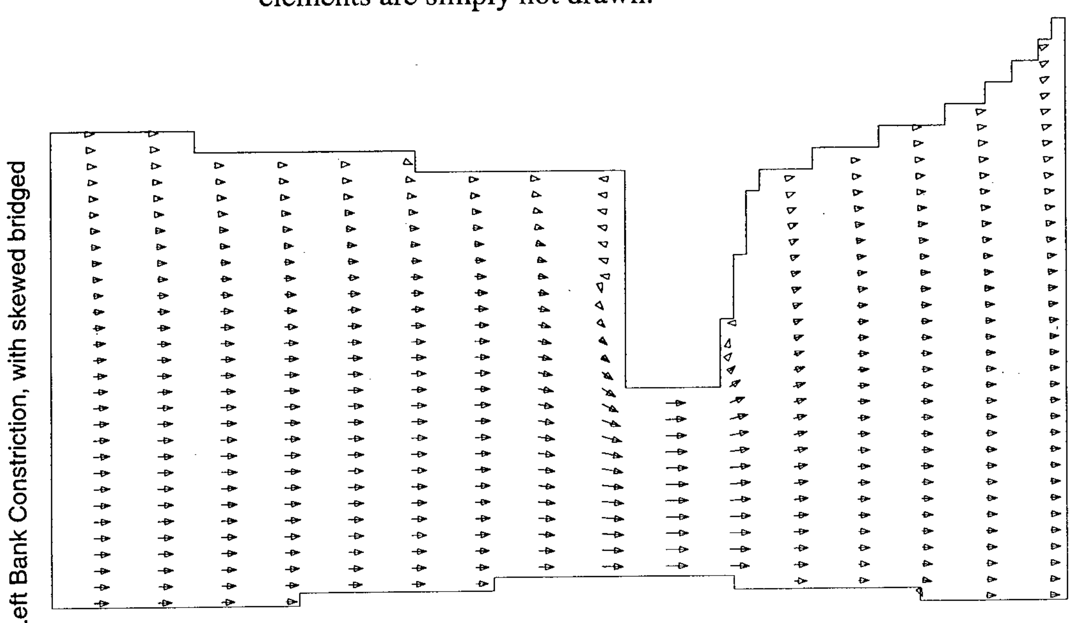


6.1.4.2 Plot of Ground Elevation

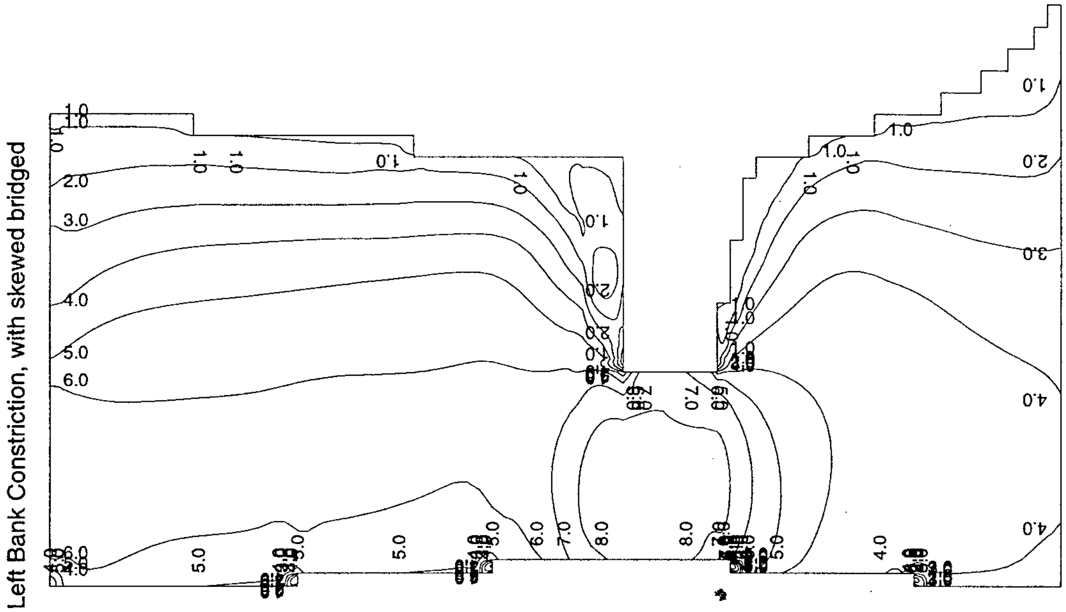



6.1.4.3 Plot of Velocity Vectors

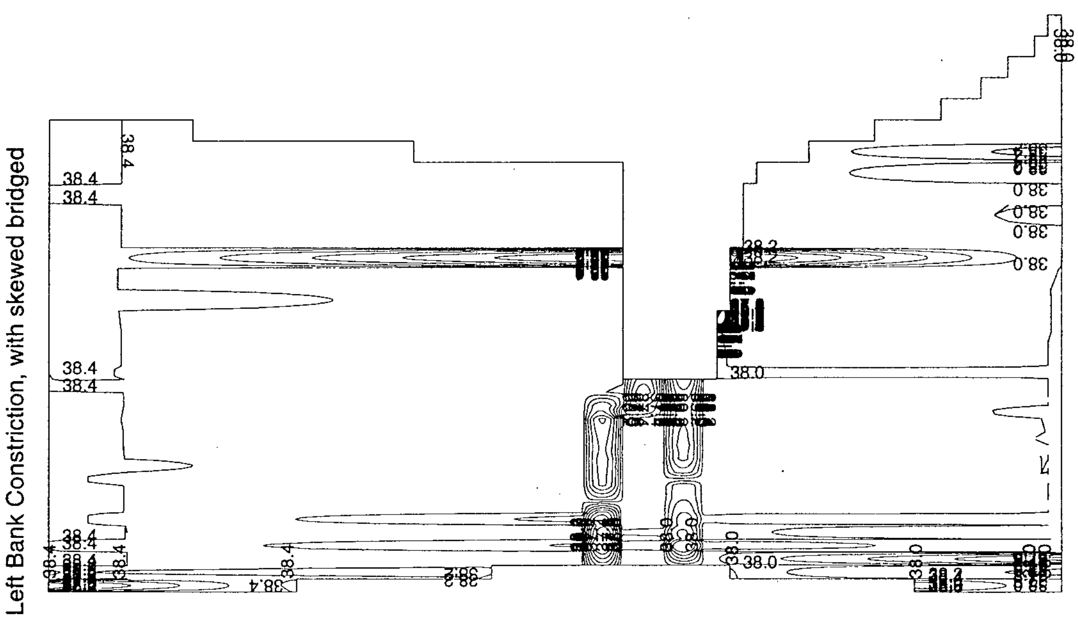
Note: The rough edges surrounding the channel are due to the inherent nature of a rectangular finite element grid. If one node of the element is dry, the element experiences no flow. The no flow elements are simply not drawn.



6.1.4.4 Plot of Velocity Isolines



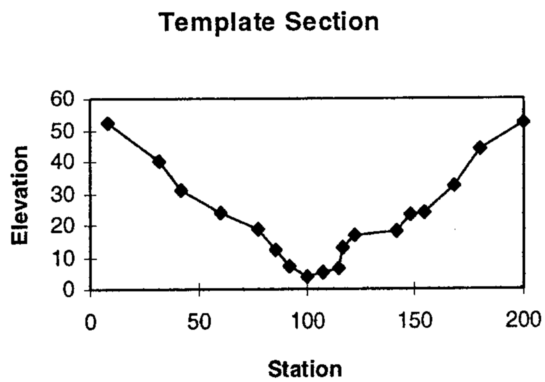

6.1.4.5 Plot of Water Surface Elevation Isolines



## 6.2 Example 2 -- Natural Channel Without Bridge Pier Consideration

### 6.2.1 Problem Description

With the use of a template section, a simple channel is developed.




| Station | Elevation |
|---|---|
| 8.0 | 52.0 |
| 32.0 | 40.0 |
| 42.0 | 31.0 |
| 60.0 | 24.0 |
| 78.0 | 19.0 |
| 86.0 | 12.0 |
| 92.0 | 7.0 |
| 100.0 | 4.0 |
| 108.0 | 5.0 |
| 114.8 | 6.6 |
| 117.2 | 12.8 |
| 122.0 | 17.0 |
| 142.0 | 18.0 |
| 148.0 | 23.4 |
| 154.0 | 24.0 |
| 168.0 | 32.0 |
| 180.0 | 44.0 |
| 200.0 | 52.0 |

The template section is used to fabricate five cross-sections:

- Upstream Section
- Full-Valley Upstream Section
- Bridge Section (located at the downstream end of the contraction)
- Full-Valley Downstream Section
- Downstream Section

Upstream Section:
scale = 1
elrise = 1.14
limits = full

Full-Valley Section,
upstream of bridge:
scale = 1
elrise = .475
limits = full

Bridge Section:
scale = .85
elrise = .40
yliml = 75
ylimr = 125

Full-Valley Section,
downstream of bridge:
scale = .9
elrise = .38
limits = full

Downstream Section:
scale = 1
elrise = 0
limits = full

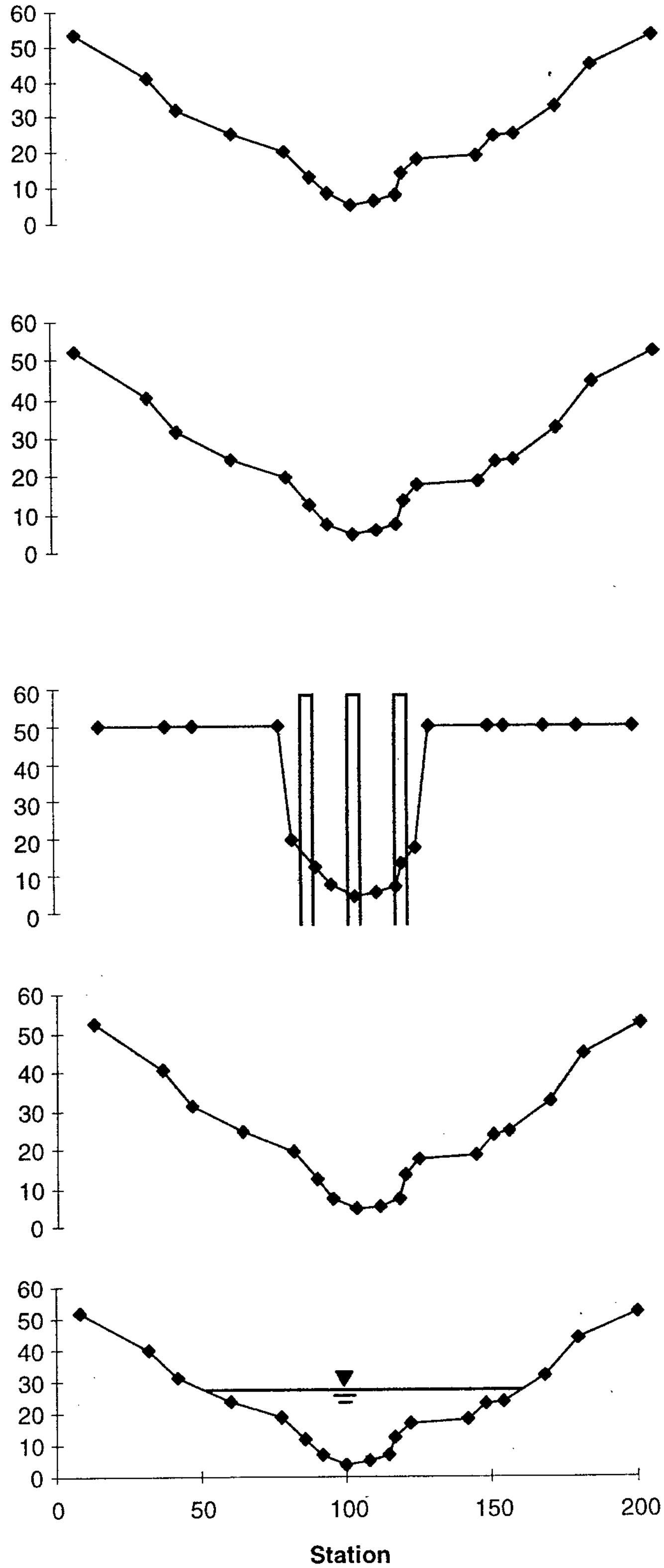



Figure 6.2 -- Cross-Section Elevations

### 6.2.2 Input File for PREFES (EX2)

```
T1    Example 2
T2    Simple Channel from Template, No Consideration of Piers
NET            10000        0       0.6       0.4        2         2
Q              10000
WS                28
*
TYP      1     0.050        6
TYP      2     0.030        6
*
XT                18
GR       8        52       32        40        42        31        60        24
GR      78        19       86        12        92         7       100         4
GR     108         5    114.8       6.6     117.2      12.8       122        17
GR     142        18      148      23.4       154        24       168        32
GR     180        44      200        52
*
XS     DS       1000        0        75       125   18    1    1
GT                 0        0       200         1       100
NR            3
PT       1         2        1
SA           75       125
*
XS     FV       1200        0        75       125   18    1    1
GT              0.38        0       200       0.9       100
NR            3
PT       1         2        1
SA           75       125
*
BR     BR       1201       40    0   44  .02        80        120   18    0    0
GT               0.4       75       125      0.85       100
NR            1
PT       2
*
XR     RD       1201        0         4
GR       0        50       70        50       130        50       180        50
*
XS     FVU      1250        0        75       125   18    1    1
GT             0.475        0       200         1       100
NR            3
PT       1         2        1
SA           75       125
*
XS     US       1600        0        75       125   18    1    1
GT              1.14        0       200         1       100
NR            3
PT       1         2        1
SA           80       120
*
ER
```

## 6.2.3 Output from PREFES

### 6.2.3.1 Grid.dat

```
12000       2923
             1  1000.000      0.000     52.000      0.000
             2  1000.000      5.357     49.991      0.000
             3  1000.000     10.714     47.982      0.000
             4  1000.000     16.071     45.973      0.000
             5  1000.000     21.429     43.964      0.000
             6  1000.000     26.786     41.955      0.000
             7  1000.000     32.143     39.871      0.000
             8  1000.000     37.500     35.050      0.000
.
.
.
1    1   76  151  152  153   78    3    2   77    1
    2    3   78  153  154  155   80    5    4   79    1
    3    5   80  155  156  157   82    7    6   81    1
    4    7   82  157  158  159   84    9    8   83    1
    5    9   84  159  160  161   86   11   10   85    1
    6   11   86  161  162  163   88   13   12   87    1
    7   13   88  163  164  165   90   15   14   89    1
.
.
.
```

### 6.2.3.2 Dinmod.dat

```
SWMS                 1          1
  Example 2
    3    3    1    0    0    0    1    0
PLOT
  Simple Channel from Template, No Consideration of Piers
    0    2
     0.14      0.07      0.105      0.105
  1600.000   200.000     0.000      0.000      79.429     40.000
180.000

LAST
```

### 6.2.3.3 Flomod.dat

```
SWMS              1          1
  Example 2
    0    3    0    0    0    2    0    1    1    0    1
    1    1    1    1    0    0   98   99
        20         0         0        10       .000       .000       .000       .670
    28.000      .000      .000      .000       .000   .000E+00       .000       .000
      .000      .000  .000E+00      .000       .000       .000      .0000
PROP
         1     0.050     6.000     0.000      0.000                  0.0     0.6000
         2     0.030     6.000     0.000      0.000                  0.0     0.6000
QSEC
         1  10000.00

1185111852118531185411855118561185711858118591186011861118621186311864118651186
1186711868118691187011871118721187311874118751187611877118781187911880118811882
1188311884118851188611887118881188911890118911189211893118941189511896118971189
1189911900119011190211903119041190511906119071190811909119101191111912119131191
11915119161191711918119191192011921119221192311924119 25       -1    0    0    0    0

ZSEC
         1    28.000                      2
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32
   33   34   35   36   37   38   39   40   41   42   43   44   45   46   47   48
   49   50   51   52   53   54   55   56   57   58   59   60   61   62   63   64
   65   66   67   68   69   70   71   72   73   74   75   -1    0    0    0    0
FLUX
 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116
 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132
 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148
```

```
2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164
2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175   -1    0    0    0    0
4351 4352 4353 4354 4355 4356 4357 4358 4359 4360 4361 4362 4363 4364 4365 4366
4367 4368 4369 4370 4371 4372 4373 4374 4375 4376 4377 4378 4379 4380 4381 4382
4383 4384 4385 4386 4387 4388 4389 4390 4391 4392 4393 4394 4395 4396 4397 4398
4399 4400 4401 4402 4403 4404 4405 4406 4407 4408 4409 4410 4411 4412 4413 4414
4415 4416 4417 4418 4419 4420 4421 4422 4423 4424 4425   -1    0    0    0    0
8101 8102 8103 8104 8105 8106 8107 8108 8109 8110 8111 8112 8113 8114 8115 8116
8117 8118 8119 8120 8121 8122 8123 8124 8125 8126 8127 8128 8129 8130 8131 8132
8133 8134 8135 8136 8137 8138 8139 8140 8141 8142 8143 8144 8145 8146 8147 8148
8149 8150 8151 8152 8153 8154 8155 8156 8157 8158 8159 8160 8161 8162 8163 8164
8165 8166 8167 8168 8169 8170 8171 8172 8173 8174 8175   -1    0    0    0    0
LAST
```

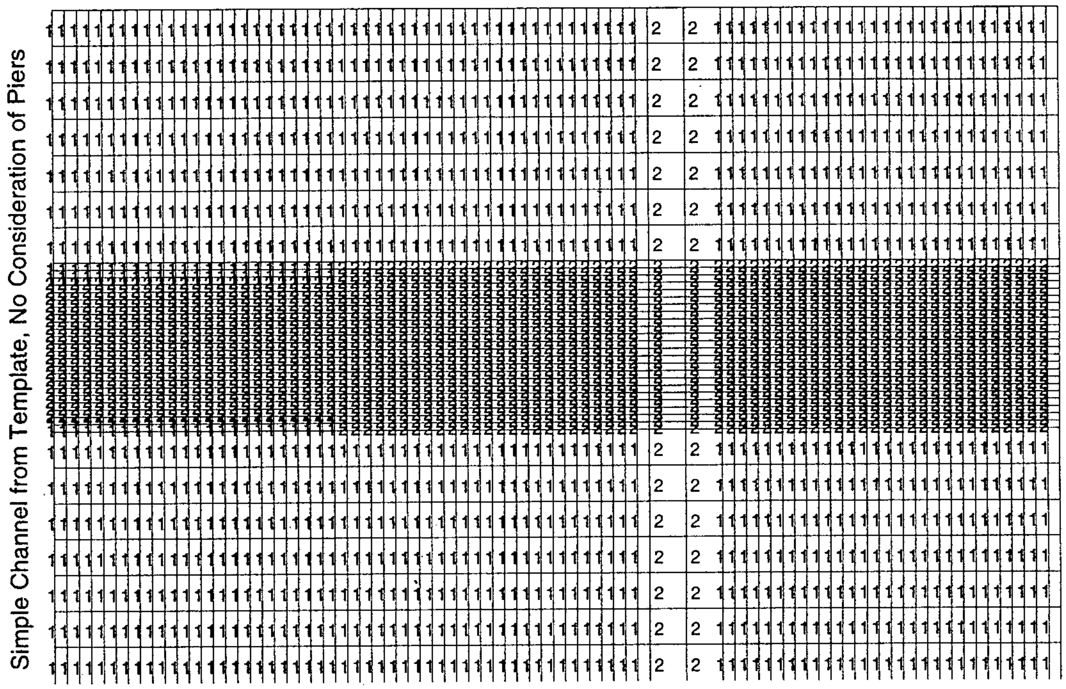
Note: The numbers shaded above vary from the actual PREFES output file (Flomod.dat). The results presented in section 6.1.4 were computed the using two FESWMS runs: (1) the first run was completed with the original Flomod.dat file with the exception that the number of initial full-Newtonian iterations (NITS=10) was changed to 10 and semi-slip conditions were applied to solid boundaries (ISLIP=2). (2) the second run utilized the output from the first run (Flow.dat) as an initial condition file (Init.dat) (INIT=1), corrected the base kinematic eddy viscosity to 0 (LPROPS(6,M)=0), and computed another 20 initial full-Newtonian iterations (NITS=20). For explanation of this method see sections 4.3 and 5.3.

### 6.2.3.4 Anomod.dat

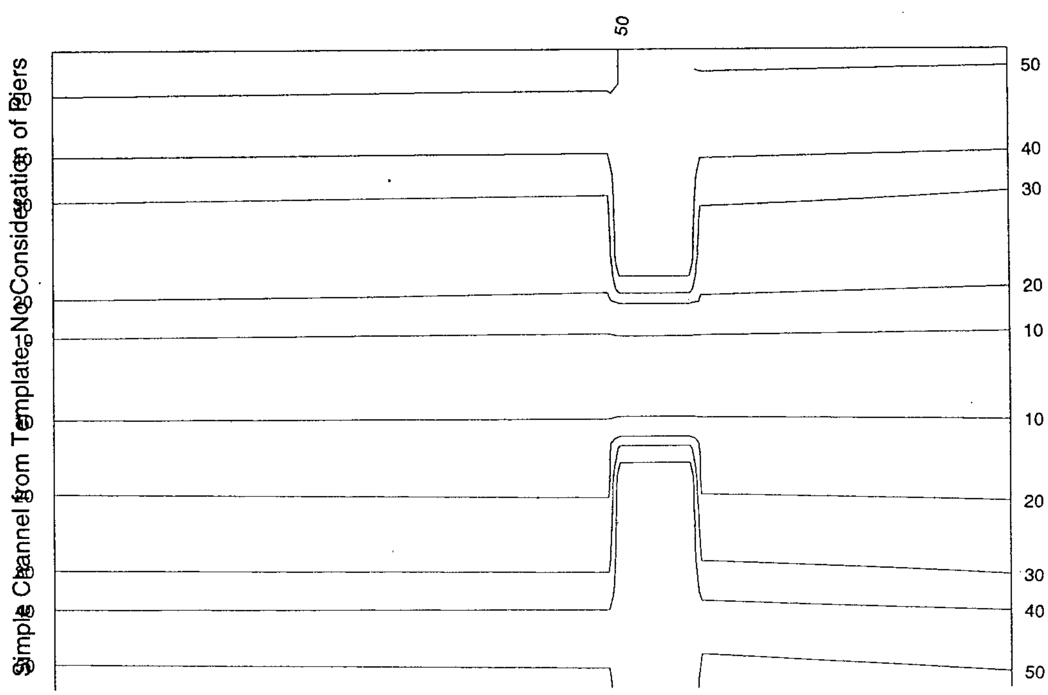
```
SWMS             1        1                                         0          0
   0    1    1   0    0   0
VECT             0                                                             0
  Simple Channel from Template, No Consideration of Piers
   1    0
       50        0        1            39.714     5.000
   0.140     0.070
 1600.000  200.000     0.000     0.000    79.429    40.000   180.000
ISOL             0                                                             0
  Simple Channel from Template, No Consideration of Piers
   1    2    1
        0     38.00     0.20
   0.140     0.070
 1600.000  200.000     0.000     0.000    79.429    40.000   180.000
ISOL             0                                                             0
  Simple Channel from Template, No Consideration of Piers
   1    3    1
        0    180.00     2.00
   0.140     0.070
 1600.000  200.000     0.000     0.000    79.429    40.000   180.000
LAST
```

### 6.2.4 Output from FESWMS

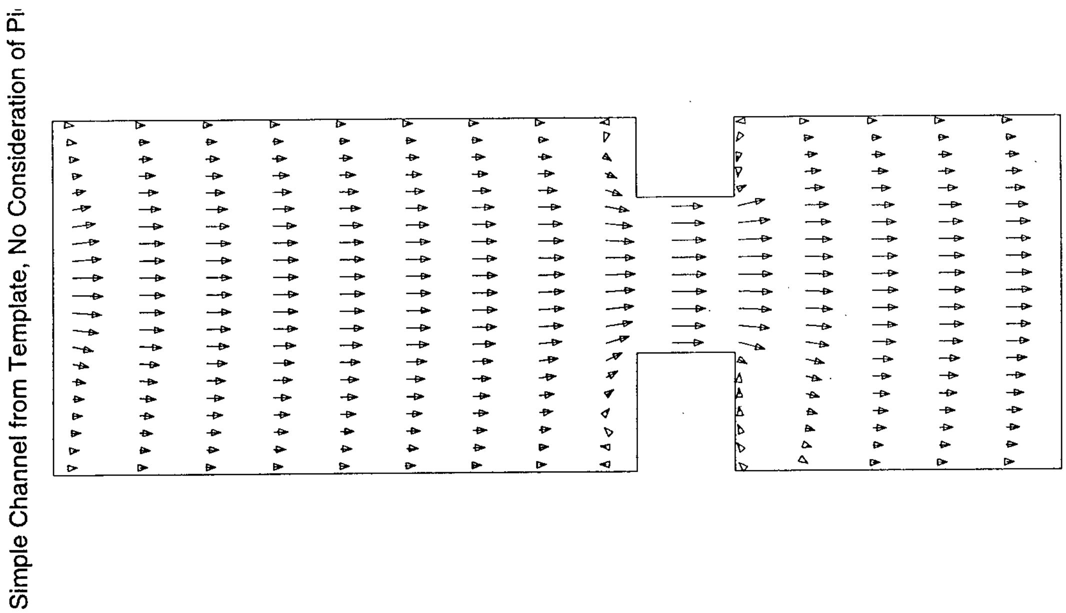
#### 6.2.4.1 Plot of Network



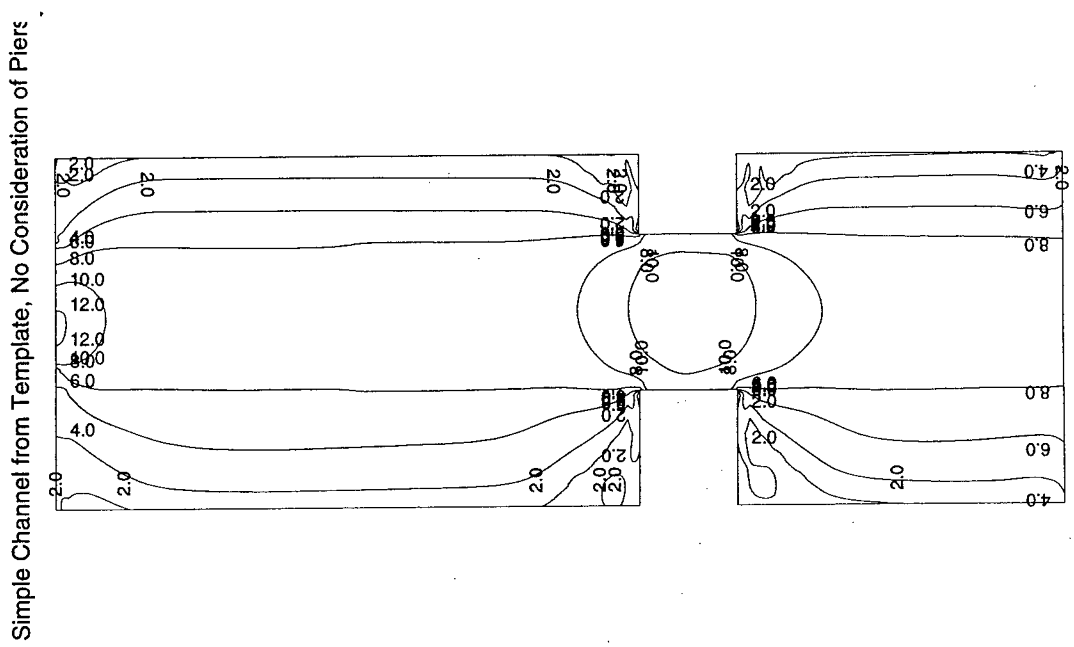

#### 6.2.4.2 Plot of Ground Elevation



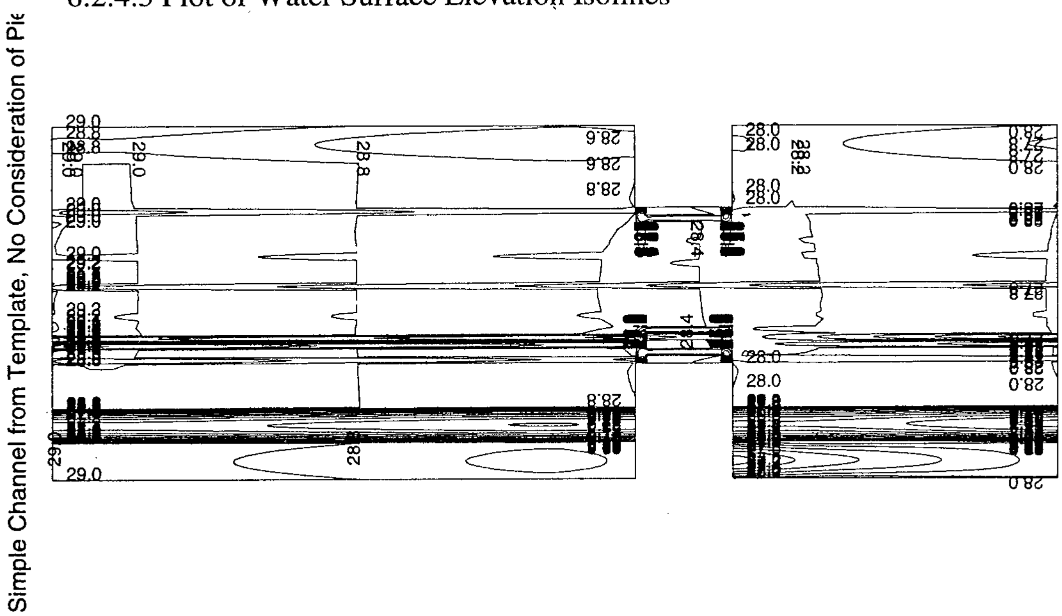
6.2.4.3 Plot of Velocity Vectors




6.2.4.4 Plot of Velocity Isolines



6.2.4.5 Plot of Water Surface Elevation Isolines



## 6.3 Example 3 -- Natural Channel With Bridge Pier Consideration

### 6.3.1 Problem Description

Same as Example 2, except the bridge has piers in the line of flow.

Three lines of three piers each. The piers are four (4) foot in diameter and are spaced as shown:

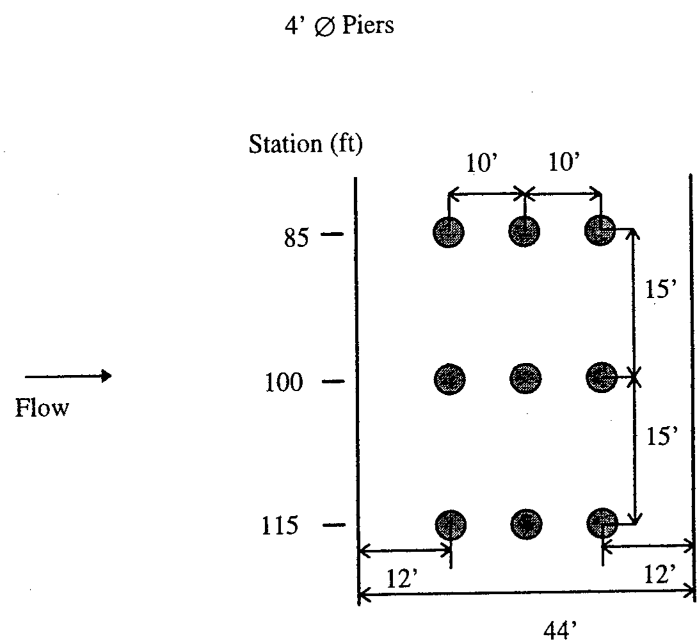



Figure 6.1 -- Plan View of Bridge Piers

The introduction of piers into the flow affects the velocity and depth in the vicinity of the bridge. To account for this effect, we will use the method of determining an equivalent channel roughness. (See section 2.8)

In determining the effective Manning's resistance coefficient, it will be necessary to examine the flow characteristics at various locations at/near the bridge. FESWMS determines the depth-averaged velocity and flow depth at each node in grid.dat. For this reason, a pictorial representation of the network as defined by PREFES and listed in grid.dat is presented in Figure 5.2.

Note: Since the physical geometry of the channel bed is identical to that of Example 2, the location of the nodes and elements as defined in grid.dat in Example 2, will remain the same for this problem.

The element numbers are *font* and the node numbers are *font*. To prevent the figure from becoming cluttered, not all nodes and elements are labeled. For more information on the numbering scheme, see section 4.1.

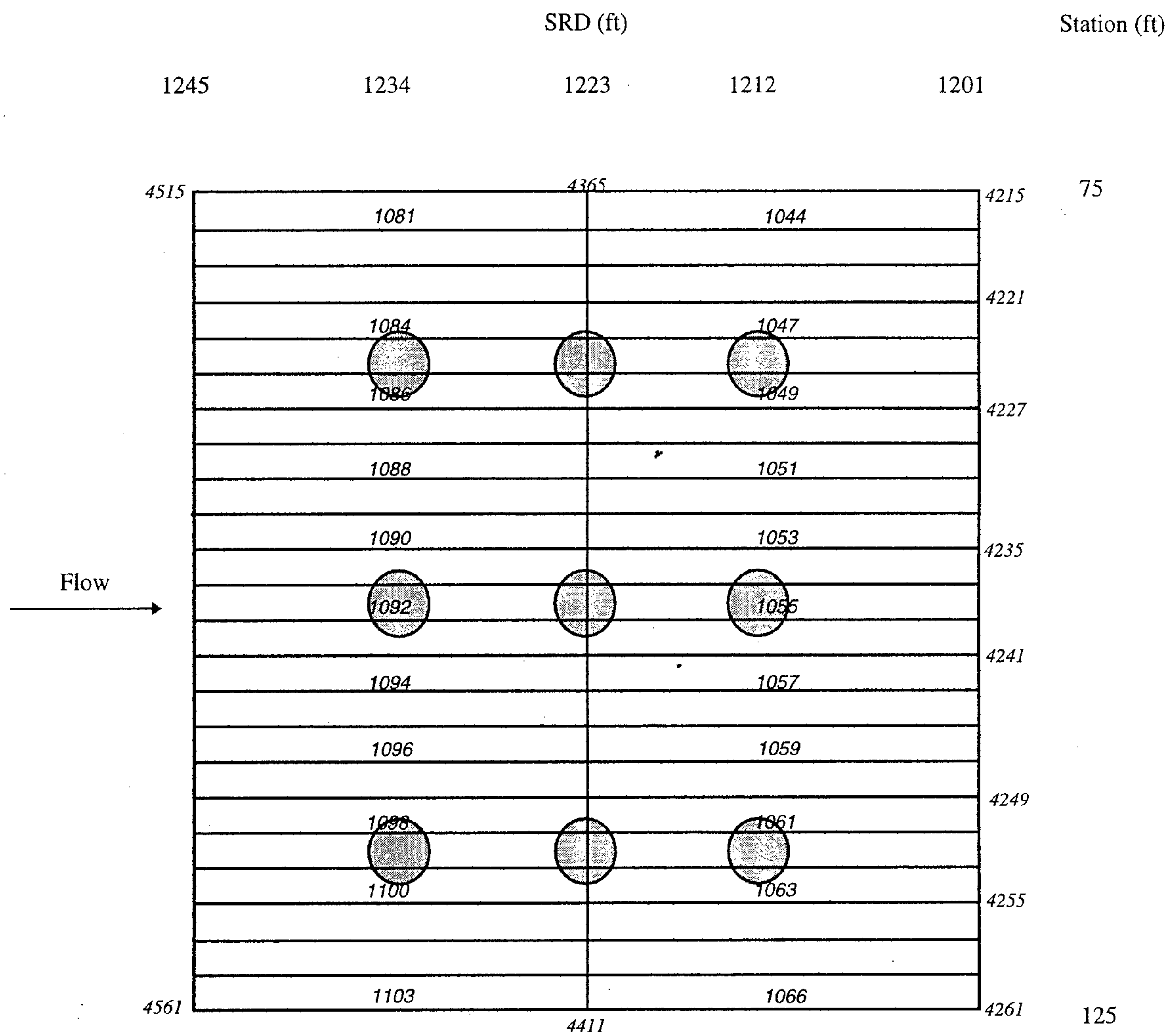



Figure 6.2 -- Pictorial Representation of Bridge Section
Contained in Grid.dat

### 6.3.2 Determining the Effective Manning's Resistance Coefficient

Traveling through this reach, the water is affected by two main forces, the shear force due to the bed and the drag force due to the piers. These forces affect the approach flow conditions (depth, angle of attack, velocity, etc). FESWMS applies the shear force in the model; however, unless a PIER record is added to Flomod.dat, the effects of the drag force are not seen. (The results of such an analysis are presented in Example 2.)

In determining the effective Manning's Resistance Coefficient, where

total force = total drag force + total shear force = effective shear force,

(Here, the effective shear force is used to determine an effective channel roughness.)

two techniques are available:

(a) The drag force that the piers exert on the water can be modeled by distributing the shear force along the entire channel reach, thus increasing Manning's Resistance Coefficient (n) at all locations within the reach.

(b) The drag force that the piers exert on the water can be modeled by distributing the shear force <u>only</u> to those elements in each pier block.

Both techniques will be presented here and compared to determine the effect on the approach flow.

First, it is necessary to calculate the total force exerted on the water through the bridge reach ($F = F_\tau + F_D$)

As seen in section 2.8.1.2, the drag force equation is given by:

$$\mathbf{F_D = C_D\, A_p\, \rho\, V^2 / 2} \qquad \textbf{(2-1)}$$

where $C_D$ is the coefficient of drag
$A_p$ is the frontal area of the pier(s)
$\rho$ is the density of the fluid
V is the undisturbed velocity of the fluid
(i.e. without the obstruction)

ant the shear force is calculated by:

$$\mathbf{F_\tau = \gamma*(Q^2*n^2/2.22)*L*P_w^{(4/3)}/A^{(7/3)}} \qquad \textbf{(2-2)}$$

where $\gamma$ is unit weight ($lb/ft^3$)
Q is the flow (cfs)
A is the cross-section area ($ft^2$)
$P_w$ is the wetted perimeter (ft) and
L is the length of the reach (ft)

Note that $F_D$ requires the free-stream velocity of the water (as if the piers are not there). This velocity can be obtained from the results of Example 2 where the effect of the piers was ignored. Additionally, the frontal area of the piers is required. For this example the depth of Example 2 will be used to find this value.

$F_\tau$ is the stress that the bed exerts without regard to the piers. For these variables, Example 2 results will be utilized.

The calculations for determining the effective roughness for (a) and (b) are presented in sections 6.3.2.1 and 6.3.2.2 respectively. All data is extracted from the output of the FESWMS model run of Example 2 (Flow.dat). A comparison of the flow characteristics for examples 2, 3a, and 3b is presented in section 6.3.3.

6.3.2.1 Increasing Channel Roughness Throughout the Bridge Section

Table 6.1 lists the results of all nodes in the bridge section for Example 2

| | | | | | | | Calculated Values | |
|---|---|---|---|---|---|---|---|---|
| Node | x Coord (ft) | y Coord (ft) | Ground Elevation (ft) | x Velocity (fps) | y Velocity (fps) | Depth (ft) | Angle of Attack (deg) | Resultant Velocity (fps) |
| 4217 | 1201.000 | 77.174 | 27.252 | -10.146 | 0.000 | 1.060 | 0.000 | 10.146 |
| 4218 | 1201.000 | 78.261 | 23.805 | -10.922 | -0.442 | 4.549 | -2.292 | 10.931 |
| 4219 | 1201.000 | 79.348 | 20.358 | -11.257 | -0.411 | 8.038 | -2.063 | 11.265 |
| 4220 | 1201.000 | 80.435 | 18.658 | -11.492 | -0.322 | 9.392 | -1.604 | 11.497 |
| 4221 | 1201.000 | 81.522 | 17.629 | -11.702 | -0.284 | 10.746 | -1.375 | 11.705 |
| 4222 | 1201.000 | 82.609 | 16.601 | -11.888 | -0.267 | 11.773 | -1.261 | 11.891 |
| 4223 | 1201.000 | 83.696 | 15.573 | -12.052 | -0.250 | 12.801 | -1.203 | 12.055 |
| 4224 | 1201.000 | 84.783 | 14.545 | -12.195 | -0.236 | 13.826 | -1.089 | 12.197 |
| 4225 | 1201.000 | 85.870 | 13.517 | -12.316 | -0.226 | 14.851 | -1.031 | 12.318 |
| 4226 | 1201.000 | 86.957 | 12.488 | -12.420 | -0.217 | 15.856 | -0.974 | 12.422 |
| 4227 | 1201.000 | 88.044 | 11.505 | -12.508 | -0.208 | 16.861 | -0.974 | 12.510 |
| 4228 | 1201.000 | 89.130 | 10.526 | -12.582 | -0.198 | 17.839 | -0.917 | 12.584 |
| 4229 | 1201.000 | 90.217 | 9.546 | -12.644 | -0.187 | 18.818 | -0.859 | 12.645 |
| 4230 | 1201.000 | 91.304 | 8.567 | -12.696 | -0.177 | 19.796 | -0.802 | 12.697 |
| 4231 | 1201.000 | 92.391 | 7.588 | -12.738 | -0.167 | 20.774 | -0.745 | 12.739 |
| 4232 | 1201.000 | 93.478 | 7.044 | -12.772 | -0.157 | 21.266 | -0.688 | 12.773 |
| 4233 | 1201.000 | 94.565 | 6.603 | -12.798 | -0.147 | 21.758 | -0.630 | 12.799 |
| 4234 | 1201.000 | 95.652 | 6.163 | -12.817 | -0.135 | 22.199 | -0.630 | 12.818 |
| 4235 | 1201.000 | 96.739 | 5.722 | -12.828 | -0.123 | 22.640 | -0.573 | 12.829 |
| 4236 | 1201.000 | 97.826 | 5.281 | -12.834 | -0.110 | 23.081 | -0.516 | 12.834 |
| 4237 | 1201.000 | 98.913 | 4.841 | -12.833 | -0.098 | 23.522 | -0.458 | 12.833 |
| 4238 | 1201.000 | 100.000 | 4.400 | -12.827 | -0.085 | 23.669 | -0.401 | 12.827 |
| 4239 | 1201.000 | 101.087 | 4.547 | -12.814 | -0.073 | 23.816 | -0.344 | 12.814 |
| 4240 | 1201.000 | 102.174 | 4.694 | -12.796 | -0.062 | 23.670 | -0.286 | 12.796 |
| 4241 | 1201.000 | 103.261 | 4.841 | -12.771 | -0.050 | 23.524 | -0.229 | 12.771 |
| 4242 | 1201.000 | 104.348 | 4.988 | -12.740 | -0.038 | 23.379 | -0.172 | 12.740 |
| 4243 | 1201.000 | 105.435 | 5.134 | -12.702 | -0.026 | 23.234 | -0.115 | 12.702 |
| 4244 | 1201.000 | 106.522 | 5.281 | -12.656 | -0.013 | 23.076 | -0.057 | 12.656 |
| 4245 | 1201.000 | 107.609 | 5.453 | -12.604 | 0.000 | 22.918 | 0.000 | 12.604 |
| 4246 | 1201.000 | 108.696 | 5.730 | -12.544 | 0.013 | 22.644 | 0.057 | 12.544 |
| 4247 | 1201.000 | 109.783 | 6.006 | -12.475 | 0.026 | 22.369 | 0.115 | 12.475 |
| 4248 | 1201.000 | 110.870 | 6.283 | -12.398 | 0.041 | 22.096 | 0.172 | 12.398 |
| 4249 | 1201.000 | 111.957 | 6.559 | -12.312 | 0.059 | 21.823 | 0.286 | 12.312 |
| 4250 | 1201.000 | 113.044 | 6.836 | -12.215 | 0.073 | 20.983 | 0.344 | 12.215 |
| 4251 | 1201.000 | 114.131 | 8.230 | -12.108 | 0.077 | 20.143 | 0.344 | 12.108 |
| 4252 | 1201.000 | 115.218 | 11.266 | -11.986 | 0.081 | 17.479 | 0.401 | 11.986 |
| 4253 | 1201.000 | 116.304 | 13.573 | -11.844 | 0.098 | 14.815 | 0.458 | 11.844 |
| 4254 | 1201.000 | 117.391 | 14.601 | -11.681 | 0.127 | 13.789 | 0.630 | 11.682 |
| 4255 | 1201.000 | 118.478 | 15.630 | -11.502 | 0.162 | 12.763 | 0.802 | 11.503 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4256 | 1201.000 | 119.565 | 16.658 | -11.309 | 0.212 | 11.372 | 1.089 | 11.311 |
| 4257 | 1201.000 | 120.652 | 18.421 | -11.103 | 0.293 | 9.981 | 1.490 | 11.107 |
| 4258 | 1201.000 | 121.739 | 22.093 | -10.856 | 0.320 | 6.267 | 1.662 | 10.861 |
| 4259 | 1201.000 | 122.826 | 25.765 | -10.365 | 0.000 | 2.553 | 0.000 | 10.365 |
| 4292 | 1212.000 | 77.174 | 27.247 | -10.273 | 0.000 | 1.120 | 0.000 | 10.273 |
| 4293 | 1212.000 | 78.261 | 23.800 | -10.981 | -0.148 | 4.588 | -0.745 | 10.982 |
| 4294 | 1212.000 | 79.348 | 20.353 | -11.346 | -0.126 | 8.055 | -0.630 | 11.347 |
| 4295 | 1212.000 | 80.435 | 18.653 | -11.580 | -0.083 | 9.415 | -0.401 | 11.580 |
| 4296 | 1212.000 | 81.522 | 17.624 | -11.774 | -0.064 | 10.775 | -0.286 | 11.774 |
| 4297 | 1212.000 | 82.609 | 16.596 | -11.939 | -0.055 | 11.803 | -0.286 | 11.939 |
| 4298 | 1212.000 | 83.696 | 15.568 | -12.082 | -0.048 | 12.831 | -0.229 | 12.082 |
| 4299 | 1212.000 | 84.783 | 14.540 | -12.208 | -0.045 | 13.858 | -0.229 | 12.208 |
| 4300 | 1212.000 | 85.870 | 13.512 | -12.319 | -0.044 | 14.885 | -0.229 | 12.319 |
| 4301 | 1212.000 | 86.957 | 12.483 | -12.415 | -0.046 | 15.890 | -0.229 | 12.415 |
| 4302 | 1212.000 | 88.044 | 11.500 | -12.498 | -0.048 | 16.896 | -0.229 | 12.498 |
| 4303 | 1212.000 | 89.130 | 10.521 | -12.571 | -0.051 | 17.875 | -0.229 | 12.571 |
| 4304 | 1212.000 | 90.217 | 9.541 | -12.633 | -0.055 | 18.854 | -0.229 | 12.633 |
| 4305 | 1212.000 | 91.304 | 8.562 | -12.686 | -0.058 | 19.833 | -0.286 | 12.686 |
| 4306 | 1212.000 | 92.391 | 7.583 | -12.730 | -0.062 | 20.811 | -0.286 | 12.730 |
| 4307 | 1212.000 | 93.478 | 7.039 | -12.766 | -0.065 | 21.304 | -0.286 | 12.766 |
| 4308 | 1212.000 | 94.565 | 6.598 | -12.794 | -0.069 | 21.796 | -0.286 | 12.794 |
| 4309 | 1212.000 | 95.652 | 6.158 | -12.816 | -0.072 | 22.237 | -0.344 | 12.816 |
| 4310 | 1212.000 | 96.739 | 5.717 | -12.832 | -0.076 | 22.678 | -0.344 | 12.832 |
| 4311 | 1212.000 | 97.826 | 5.276 | -12.841 | -0.078 | 23.118 | -0.344 | 12.841 |
| 4312 | 1212.000 | 98.913 | 4.836 | -12.844 | -0.081 | 23.559 | -0.344 | 12.844 |
| 4313 | 1212.000 | 100.000 | 4.395 | -12.841 | -0.084 | 23.706 | -0.401 | 12.841 |
| 4314 | 1212.000 | 101.087 | 4.542 | -12.833 | -0.087 | 23.853 | -0.401 | 12.833 |
| 4315 | 1212.000 | 102.174 | 4.689 | -12.818 | -0.089 | 23.707 | -0.401 | 12.818 |
| 4316 | 1212.000 | 103.261 | 4.836 | -12.798 | -0.092 | 23.560 | -0.401 | 12.798 |
| 4317 | 1212.000 | 104.348 | 4.983 | -12.772 | -0.094 | 23.414 | -0.401 | 12.772 |
| 4318 | 1212.000 | 105.435 | 5.129 | -12.740 | -0.096 | 23.269 | -0.458 | 12.740 |
| 4319 | 1212.000 | 106.522 | 5.276 | -12.702 | -0.097 | 23.110 | -0.458 | 12.702 |
| 4320 | 1212.000 | 107.609 | 5.448 | -12.659 | -0.098 | 22.951 | -0.458 | 12.659 |
| 4321 | 1212.000 | 108.696 | 5.725 | -12.610 | -0.097 | 22.676 | -0.458 | 12.610 |
| 4322 | 1212.000 | 109.783 | 6.001 | -12.556 | -0.096 | 22.400 | -0.458 | 12.556 |
| 4323 | 1212.000 | 110.870 | 6.278 | -12.496 | -0.092 | 22.125 | -0.401 | 12.496 |
| 4324 | 1212.000 | 111.957 | 6.554 | -12.432 | -0.087 | 21.850 | -0.401 | 12.432 |
| 4325 | 1212.000 | 113.044 | 6.831 | -12.362 | -0.082 | 21.012 | -0.401 | 12.362 |
| 4326 | 1212.000 | 114.131 | 8.225 | -12.284 | -0.080 | 20.175 | -0.401 | 12.284 |
| 4327 | 1212.000 | 115.218 | 11.261 | -12.194 | -0.079 | 17.505 | -0.344 | 12.194 |
| 4328 | 1212.000 | 116.304 | 13.568 | -12.084 | -0.073 | 14.835 | -0.344 | 12.084 |
| 4329 | 1212.000 | 117.391 | 14.596 | -11.956 | -0.061 | 13.809 | -0.286 | 11.956 |
| 4330 | 1212.000 | 118.478 | 15.625 | -11.816 | -0.040 | 12.783 | -0.172 | 11.816 |
| 4331 | 1212.000 | 119.565 | 16.653 | -11.659 | -0.008 | 11.389 | -0.057 | 11.659 |
| 4332 | 1212.000 | 120.652 | 18.416 | -11.478 | 0.038 | 9.996 | 0.172 | 11.478 |
| 4333 | 1212.000 | 121.739 | 22.088 | -11.224 | 0.069 | 6.303 | 0.344 | 11.224 |
| 4334 | 1212.000 | 122.826 | 25.760 | -10.800 | 0.000 | 2.611 | 0.000 | 10.800 |
| 4367 | 1223.000 | 77.174 | 27.242 | -10.392 | 0.000 | 1.181 | 0.000 | 10.392 |
| 4368 | 1223.000 | 78.261 | 23.795 | -11.112 | -0.006 | 4.627 | -0.057 | 11.112 |
| 4369 | 1223.000 | 79.348 | 20.348 | -11.447 | -0.010 | 8.073 | -0.057 | 11.447 |
| 4370 | 1223.000 | 80.435 | 18.648 | -11.665 | -0.011 | 9.439 | -0.057 | 11.665 |
| 4371 | 1223.000 | 81.522 | 17.619 | -11.848 | -0.009 | 10.804 | -0.057 | 11.848 |
| 4372 | 1223.000 | 82.609 | 16.591 | -12.003 | -0.005 | 11.833 | 0.000 | 12.003 |
| 4373 | 1223.000 | 83.696 | 15.563 | -12.137 | -0.003 | 12.861 | 0.000 | 12.137 |
| 4374 | 1223.000 | 84.783 | 14.535 | -12.252 | -0.001 | 13.889 | 0.000 | 12.252 |
| 4375 | 1223.000 | 85.870 | 13.507 | -12.351 | 0.001 | 14.918 | 0.000 | 12.351 |
| 4376 | 1223.000 | 86.957 | 12.478 | -12.437 | 0.002 | 15.924 | 0.000 | 12.437 |
| 4377 | 1223.000 | 88.044 | 11.495 | -12.510 | 0.003 | 16.930 | 0.000 | 12.510 |
| 4378 | 1223.000 | 89.130 | 10.516 | -12.574 | 0.004 | 17.910 | 0.000 | 12.574 |
| 4379 | 1223.000 | 90.217 | 9.536 | -12.628 | 0.004 | 18.890 | 0.000 | 12.628 |
| 4380 | 1223.000 | 91.304 | 8.557 | -12.674 | 0.004 | 19.870 | 0.000 | 12.674 |
| 4381 | 1223.000 | 92.391 | 7.578 | -12.712 | 0.005 | 20.849 | 0.000 | 12.712 |
| 4382 | 1223.000 | 93.478 | 7.034 | -12.744 | 0.006 | 21.342 | 0.000 | 12.744 |
| 4383 | 1223.000 | 94.565 | 6.593 | -12.770 | 0.007 | 21.835 | 0.057 | 12.770 |
| 4384 | 1223.000 | 95.652 | 6.153 | -12.790 | 0.007 | 22.275 | 0.057 | 12.790 |
| 4385 | 1223.000 | 96.739 | 5.712 | -12.804 | 0.007 | 22.716 | 0.057 | 12.804 |
| 4386 | 1223.000 | 97.826 | 5.271 | -12.813 | 0.007 | 23.156 | 0.057 | 12.813 |
| 4387 | 1223.000 | 98.913 | 4.831 | -12.817 | 0.007 | 23.597 | 0.057 | 12.817 |
| 4388 | 1223.000 | 100.000 | 4.390 | -12.815 | 0.007 | 23.744 | 0.057 | 12.815 |
| 4389 | 1223.000 | 101.087 | 4.537 | -12.809 | 0.007 | 23.891 | 0.057 | 12.809 |
| 4390 | 1223.000 | 102.174 | 4.684 | -12.798 | 0.008 | 23.744 | 0.057 | 12.798 |
| 4391 | 1223.000 | 103.261 | 4.831 | -12.782 | 0.008 | 23.597 | 0.057 | 12.782 |
| 4392 | 1223.000 | 104.348 | 4.978 | -12.761 | 0.008 | 23.450 | 0.057 | 12.761 |
| 4393 | 1223.000 | 105.435 | 5.124 | -12.736 | 0.008 | 23.303 | 0.057 | 12.736 |
| 4394 | 1223.000 | 106.522 | 5.271 | -12.705 | 0.009 | 23.144 | 0.057 | 12.705 |
| 4395 | 1223.000 | 107.609 | 5.443 | -12.670 | 0.009 | 22.984 | 0.057 | 12.670 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4396 | 1223.000 | 108.696 | 5.720 | -12.631 | 0.010 | 22.707 | 0.057 | 12.631 |
| 4397 | 1223.000 | 109.783 | 5.996 | -12.588 | 0.011 | 22.431 | 0.057 | 12.588 |
| 4398 | 1223.000 | 110.870 | 6.273 | -12.540 | 0.012 | 22.154 | 0.057 | 12.540 |
| 4399 | 1223.000 | 111.957 | 6.549 | -12.489 | 0.014 | 21.877 | 0.057 | 12.489 |
| 4400 | 1223.000 | 113.044 | 6.826 | -12.432 | 0.016 | 21.042 | 0.057 | 12.432 |
| 4401 | 1223.000 | 114.131 | 8.220 | -12.370 | 0.019 | 20.206 | 0.115 | 12.370 |
| 4402 | 1223.000 | 115.218 | 11.256 | -12.296 | 0.021 | 17.530 | 0.115 | 12.296 |
| 4403 | 1223.000 | 116.304 | 13.563 | -12.203 | 0.015 | 14.855 | 0.057 | 12.203 |
| 4404 | 1223.000 | 117.391 | 14.591 | -12.091 | 0.006 | 13.829 | 0.000 | 12.091 |
| 4405 | 1223.000 | 118.478 | 15.620 | -11.964 | 0.003 | 12.803 | 0.000 | 11.964 |
| 4406 | 1223.000 | 119.565 | 16.648 | -11.818 | 0.003 | 11.406 | 0.000 | 11.818 |
| 4407 | 1223.000 | 120.652 | 18.411 | -11.650 | 0.001 | 10.010 | 0.000 | 11.650 |
| 4408 | 1223.000 | 121.739 | 22.083 | -11.418 | -0.002 | 6.339 | 0.000 | 11.418 |
| 4409 | 1223.000 | 122.826 | 25.755 | -10.973 | 0.000 | 2.669 | 0.000 | 10.973 |
| 4442 | 1234.000 | 77.174 | 27.237 | -10.381 | 0.000 | 1.258 | 0.000 | 10.381 |
| 4443 | 1234.000 | 78.261 | 23.790 | -11.054 | 0.191 | 4.683 | 0.974 | 11.056 |
| 4444 | 1234.000 | 79.348 | 20.343 | -11.406 | 0.181 | 8.108 | 0.917 | 11.407 |
| 4445 | 1234.000 | 80.435 | 18.643 | -11.630 | 0.141 | 9.478 | 0.688 | 11.631 |
| 4446 | 1234.000 | 81.522 | 17.614 | -11.813 | 0.124 | 10.847 | 0.573 | 11.814 |
| 4447 | 1234.000 | 82.609 | 16.586 | -11.966 | 0.118 | 11.875 | 0.573 | 11.967 |
| 4448 | 1234.000 | 83.696 | 15.558 | -12.098 | 0.112 | 12.903 | 0.516 | 12.099 |
| 4449 | 1234.000 | 84.783 | 14.530 | -12.213 | 0.109 | 13.931 | 0.516 | 12.213 |
| 4450 | 1234.000 | 85.870 | 13.502 | -12.313 | 0.107 | 14.960 | 0.516 | 12.313 |
| 4451 | 1234.000 | 86.957 | 12.473 | -12.399 | 0.107 | 15.966 | 0.516 | 12.399 |
| 4452 | 1234.000 | 88.044 | 11.490 | -12.474 | 0.107 | 16.972 | 0.516 | 12.474 |
| 4453 | 1234.000 | 89.130 | 10.511 | -12.539 | 0.108 | 17.952 | 0.516 | 12.539 |
| 4454 | 1234.000 | 90.217 | 9.531 | -12.594 | 0.107 | 18.931 | 0.458 | 12.594 |
| 4455 | 1234.000 | 91.304 | 8.552 | -12.641 | 0.107 | 19.909 | 0.458 | 12.641 |
| 4456 | 1234.000 | 92.391 | 7.573 | -12.680 | 0.106 | 20.888 | 0.458 | 12.680 |
| 4457 | 1234.000 | 93.478 | 7.029 | -12.712 | 0.105 | 21.381 | 0.458 | 12.712 |
| 4458 | 1234.000 | 94.565 | 6.588 | -12.738 | 0.104 | 21.873 | 0.458 | 12.738 |
| 4459 | 1234.000 | 95.652 | 6.148 | -12.757 | 0.103 | 22.313 | 0.458 | 12.757 |
| 4460 | 1234.000 | 96.739 | 5.707 | -12.770 | 0.102 | 22.753 | 0.458 | 12.770 |
| 4461 | 1234.000 | 97.826 | 5.266 | -12.778 | 0.100 | 23.193 | 0.458 | 12.778 |
| 4462 | 1234.000 | 98.913 | 4.826 | -12.780 | 0.098 | 23.634 | 0.458 | 12.780 |
| 4463 | 1234.000 | 100.000 | 4.385 | -12.777 | 0.096 | 23.780 | 0.458 | 12.777 |
| 4464 | 1234.000 | 101.087 | 4.532 | -12.769 | 0.094 | 23.927 | 0.401 | 12.769 |
| 4465 | 1234.000 | 102.174 | 4.679 | -12.755 | 0.092 | 23.780 | 0.401 | 12.755 |
| 4466 | 1234.000 | 103.261 | 4.826 | -12.736 | 0.090 | 23.633 | 0.401 | 12.736 |
| 4467 | 1234.000 | 104.348 | 4.973 | -12.711 | 0.088 | 23.485 | 0.401 | 12.711 |
| 4468 | 1234.000 | 105.435 | 5.119 | -12.681 | 0.085 | 23.338 | 0.401 | 12.681 |
| 4469 | 1234.000 | 106.522 | 5.266 | -12.645 | 0.081 | 23.178 | 0.344 | 12.645 |
| 4470 | 1234.000 | 107.609 | 5.438 | -12.605 | 0.077 | 23.018 | 0.344 | 12.605 |
| 4471 | 1234.000 | 108.696 | 5.715 | -12.559 | 0.072 | 22.740 | 0.344 | 12.559 |
| 4472 | 1234.000 | 109.783 | 5.991 | -12.509 | 0.066 | 22.463 | 0.286 | 12.509 |
| 4473 | 1234.000 | 110.870 | 6.268 | -12.453 | 0.058 | 22.185 | 0.286 | 12.453 |
| 4474 | 1234.000 | 111.957 | 6.544 | -12.394 | 0.048 | 21.907 | 0.229 | 12.394 |
| 4475 | 1234.000 | 113.044 | 6.821 | -12.329 | 0.037 | 21.073 | 0.172 | 12.329 |
| 4476 | 1234.000 | 114.131 | 8.215 | -12.258 | 0.028 | 20.239 | 0.115 | 12.258 |
| 4477 | 1234.000 | 115.218 | 11.251 | -12.178 | 0.022 | 17.571 | 0.115 | 12.178 |
| 4478 | 1234.000 | 116.304 | 13.558 | -12.082 | 0.020 | 14.902 | 0.115 | 12.082 |
| 4479 | 1234.000 | 117.391 | 14.586 | -11.968 | 0.016 | 13.870 | 0.057 | 11.968 |
| 4480 | 1234.000 | 118.478 | 15.615 | -11.839 | 0.001 | 12.837 | 0.000 | 11.839 |
| 4481 | 1234.000 | 119.565 | 16.643 | -11.692 | -0.027 | 11.439 | -0.115 | 11.692 |
| 4482 | 1234.000 | 120.652 | 18.406 | -11.519 | -0.071 | 10.041 | -0.344 | 11.519 |
| 4483 | 1234.000 | 121.739 | 22.078 | -11.273 | -0.094 | 6.390 | -0.458 | 11.273 |
| 4484 | 1234.000 | 122.826 | 25.750 | -10.865 | 0.000 | 2.739 | 0.000 | 10.865 |
| 4517 | 1245.000 | 77.174 | 27.232 | -10.071 | 0.000 | 1.335 | 0.000 | 10.071 |
| 4518 | 1245.000 | 78.261 | 23.785 | -10.796 | 0.488 | 4.739 | 2.578 | 10.807 |
| 4519 | 1245.000 | 79.348 | 20.338 | -11.111 | 0.478 | 8.144 | 2.464 | 11.121 |
| 4520 | 1245.000 | 80.435 | 18.638 | -11.339 | 0.403 | 9.517 | 2.063 | 11.346 |
| 4521 | 1245.000 | 81.522 | 17.609 | -11.544 | 0.375 | 10.890 | 1.833 | 11.550 |
| 4522 | 1245.000 | 82.609 | 16.581 | -11.727 | 0.365 | 11.917 | 1.776 | 11.733 |
| 4523 | 1245.000 | 83.696 | 15.553 | -11.888 | 0.355 | 12.945 | 1.719 | 11.893 |
| 4524 | 1245.000 | 84.783 | 14.525 | -12.029 | 0.345 | 13.974 | 1.662 | 12.034 |
| 4525 | 1245.000 | 85.870 | 13.497 | -12.150 | 0.336 | 15.003 | 1.604 | 12.155 |
| 4526 | 1245.000 | 86.957 | 12.468 | -12.253 | 0.327 | 16.008 | 1.547 | 12.257 |
| 4527 | 1245.000 | 88.044 | 11.485 | -12.340 | 0.316 | 17.014 | 1.490 | 12.344 |
| 4528 | 1245.000 | 89.130 | 10.506 | -12.414 | 0.302 | 17.993 | 1.375 | 12.418 |
| 4529 | 1245.000 | 90.217 | 9.526 | -12.476 | 0.287 | 18.972 | 1.318 | 12.479 |
| 4530 | 1245.000 | 91.304 | 8.547 | -12.527 | 0.270 | 19.949 | 1.261 | 12.530 |
| 4531 | 1245.000 | 92.391 | 7.568 | -12.569 | 0.250 | 20.927 | 1.146 | 12.571 |
| 4532 | 1245.000 | 93.478 | 7.024 | -12.603 | 0.229 | 21.419 | 1.031 | 12.605 |
| 4533 | 1245.000 | 94.565 | 6.583 | -12.629 | 0.208 | 21.912 | 0.917 | 12.631 |
| 4534 | 1245.000 | 95.652 | 6.143 | -12.648 | 0.186 | 22.351 | 0.859 | 12.649 |
| 4535 | 1245.000 | 96.739 | 5.702 | -12.661 | 0.163 | 22.791 | 0.745 | 12.662 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4536 | 1245.000 | 97.826 | 5.261 | -12.667 | 0.139 | 23.231 | 0.630 | 12.668 |
| 4537 | 1245.000 | 98.913 | 4.821 | -12.666 | 0.116 | 23.670 | 0.516 | 12.667 |
| 4538 | 1245.000 | 100.000 | 4.380 | -12.660 | 0.092 | 23.817 | 0.401 | 12.660 |
| 4539 | 1245.000 | 101.087 | 4.527 | -12.648 | 0.069 | 23.964 | 0.286 | 12.648 |
| 4540 | 1245.000 | 102.174 | 4.674 | -12.630 | 0.046 | 23.816 | 0.229 | 12.630 |
| 4541 | 1245.000 | 103.261 | 4.821 | -12.606 | 0.023 | 23.669 | 0.115 | 12.606 |
| 4542 | 1245.000 | 104.348 | 4.968 | -12.576 | 0.000 | 23.521 | 0.000 | 12.576 |
| 4543 | 1245.000 | 105.435 | 5.114 | -12.538 | -0.023 | 23.373 | -0.115 | 12.538 |
| 4544 | 1245.000 | 106.522 | 5.261 | -12.494 | -0.047 | 23.212 | -0.229 | 12.494 |
| 4545 | 1245.000 | 107.609 | 5.433 | -12.442 | -0.071 | 23.051 | -0.344 | 12.442 |
| 4546 | 1245.000 | 108.696 | 5.710 | -12.383 | -0.096 | 22.773 | -0.458 | 12.383 |
| 4547 | 1245.000 | 109.783 | 5.986 | -12.315 | -0.121 | 22.495 | -0.573 | 12.316 |
| 4548 | 1245.000 | 110.870 | 6.263 | -12.238 | -0.147 | 22.216 | -0.688 | 12.239 |
| 4549 | 1245.000 | 111.957 | 6.539 | -12.153 | -0.175 | 21.937 | -0.802 | 12.154 |
| 4550 | 1245.000 | 113.044 | 6.816 | -12.057 | -0.202 | 21.104 | -0.974 | 12.059 |
| 4551 | 1245.000 | 114.131 | 8.210 | -11.950 | -0.225 | 20.271 | -1.089 | 11.952 |
| 4552 | 1245.000 | 115.218 | 11.246 | -11.830 | -0.236 | 17.611 | -1.146 | 11.832 |
| 4553 | 1245.000 | 116.304 | 13.553 | -11.688 | -0.225 | 14.950 | -1.089 | 11.690 |
| 4554 | 1245.000 | 117.391 | 14.581 | -11.526 | -0.210 | 13.911 | -1.031 | 11.528 |
| 4555 | 1245.000 | 118.478 | 15.610 | -11.349 | -0.221 | 12.871 | -1.089 | 11.351 |
| 4556 | 1245.000 | 119.565 | 16.638 | -11.158 | -0.259 | 11.471 | -1.318 | 11.161 |
| 4557 | 1245.000 | 120.652 | 18.401 | -10.957 | -0.326 | 10.071 | -1.719 | 10.962 |
| 4558 | 1245.000 | 121.739 | 22.073 | -10.717 | -0.338 | 6.440 | -1.833 | 10.722 |
| 4559 | 1245.000 | 122.826 | 25.745 | -10.243 | 0.000 | 2.809 | 0.000 | 10.243 |
| Average | | | | | | 17.228 | 12.195 | |

Force Due to Drag

| | | |
|---|---|---|
| $C_D$ | 1.000 | |
| $A_p$ | 206.738 | ft2 |
| p | 4.920 | lb s2 / ft4 |
| $V^2/2$ | 74.357 | ft2/s2 |
| **F (drag)** | **75632** | **lb** |

Force Due to Bed Shear

| | | |
|---|---|---|
| Q | 10000 | ft3 / s |
| n | 0.030 | |
| L | 45.000 | ft |
| $P_w$ | 94.456 | ft(approx) |
| A | 820.019 | ft2 |
| **F (shear)** | **7780** | **lb** |

**Effective F (shear) 83412 lb**
**Effective n 0.066**

6.3.2.2 Increasing Channel Roughness Only at the Pier Elements

Figure 6.3 illustrates the elements which will be effected.

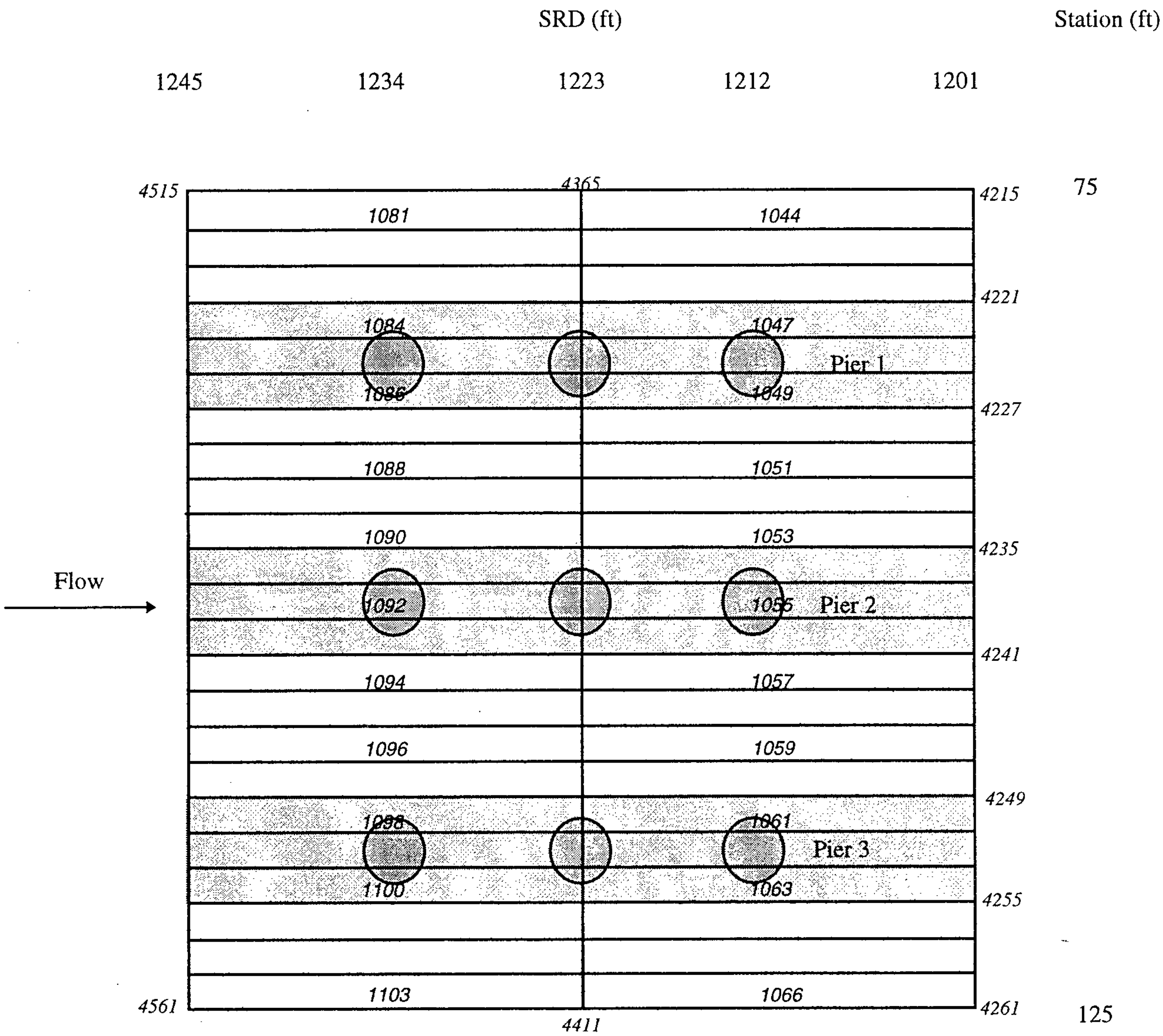



Figure 6.3 -- Pictorial Representation of the Elements Subjected to an Effectively Higher Manning's Resistance due to Drag Force.

Tables 6.2a - 6.2c lists the results of all nodes at each shaded Pier section for Example 2.

**Table 6.2a -- Pier 1 Area**

| Node | x Coord (ft) | y Coord (ft) | Ground Elevation (ft) | x Velocity (fps) | y Velocity (fps) | Depth (ft) | Angle of Attack (deg) | Resultant Velocity (fps) |
|---|---|---|---|---|---|---|---|---|
| 4221 | 1201.000 | 81.522 | 17.629 | -11.702 | -0.284 | 10.746 | -1.375 | 11.705 |
| 4222 | 1201.000 | 82.609 | 16.601 | -11.888 | -0.267 | 11.773 | -1.261 | 11.891 |
| 4223 | 1201.000 | 83.696 | 15.573 | -12.052 | -0.250 | 12.801 | -1.203 | 12.055 |
| 4224 | 1201.000 | 84.783 | 14.545 | -12.195 | -0.236 | 13.826 | -1.089 | 12.197 |
| 4225 | 1201.000 | 85.870 | 13.517 | -12.316 | -0.226 | 14.851 | -1.031 | 12.318 |
| 4226 | 1201.000 | 86.957 | 12.488 | -12.420 | -0.217 | 15.856 | -0.974 | 12.422 |
| 4227 | 1201.000 | 88.044 | 11.505 | -12.508 | -0.208 | 16.861 | -0.974 | 12.510 |
| 4296 | 1212.000 | 81.522 | 17.624 | -11.774 | -0.064 | 10.775 | -0.286 | 11.774 |
| 4297 | 1212.000 | 82.609 | 16.596 | -11.939 | -0.055 | 11.803 | -0.286 | 11.939 |
| 4298 | 1212.000 | 83.696 | 15.568 | -12.082 | -0.048 | 12.831 | -0.229 | 12.082 |
| 4299 | 1212.000 | 84.783 | 14.540 | -12.208 | -0.045 | 13.858 | -0.229 | 12.208 |
| 4300 | 1212.000 | 85.870 | 13.512 | -12.319 | -0.044 | 14.885 | -0.229 | 12.319 |
| 4301 | 1212.000 | 86.957 | 12.483 | -12.415 | -0.046 | 15.890 | -0.229 | 12.415 |
| 4302 | 1212.000 | 88.044 | 11.500 | -12.498 | -0.048 | 16.896 | -0.229 | 12.498 |
| 4371 | 1223.000 | 81.522 | 17.619 | -11.848 | -0.009 | 10.804 | -0.057 | 11.848 |
| 4372 | 1223.000 | 82.609 | 16.591 | -12.003 | -0.005 | 11.833 | 0.000 | 12.003 |
| 4373 | 1223.000 | 83.696 | 15.563 | -12.137 | -0.003 | 12.861 | 0.000 | 12.137 |
| 4374 | 1223.000 | 84.783 | 14.535 | -12.252 | -0.001 | 13.889 | 0.000 | 12.252 |
| 4375 | 1223.000 | 85.870 | 13.507 | -12.351 | 0.001 | 14.918 | 0.000 | 12.351 |
| 4376 | 1223.000 | 86.957 | 12.478 | -12.437 | 0.002 | 15.924 | 0.000 | 12.437 |
| 4377 | 1223.000 | 88.044 | 11.495 | -12.510 | 0.003 | 16.930 | 0.000 | 12.510 |
| 4446 | 1234.000 | 81.522 | 17.614 | -11.813 | 0.124 | 10.847 | 0.573 | 11.814 |
| 4447 | 1234.000 | 82.609 | 16.586 | -11.966 | 0.118 | 11.875 | 0.573 | 11.967 |
| 4448 | 1234.000 | 83.696 | 15.558 | -12.098 | 0.112 | 12.903 | 0.516 | 12.099 |
| 4449 | 1234.000 | 84.783 | 14.530 | -12.213 | 0.109 | 13.931 | 0.516 | 12.213 |
| 4450 | 1234.000 | 85.870 | 13.502 | -12.313 | 0.107 | 14.960 | 0.516 | 12.313 |
| 4451 | 1234.000 | 86.957 | 12.473 | -12.399 | 0.107 | 15.966 | 0.516 | 12.399 |
| 4452 | 1234.000 | 88.044 | 11.490 | -12.474 | 0.107 | 16.972 | 0.516 | 12.474 |
| 4521 | 1245.000 | 81.522 | 17.609 | -11.544 | 0.375 | 10.890 | 1.833 | 11.550 |
| 4522 | 1245.000 | 82.609 | 16.581 | -11.727 | 0.365 | 11.917 | 1.776 | 11.733 |
| 4523 | 1245.000 | 83.696 | 15.553 | -11.888 | 0.355 | 12.945 | 1.719 | 11.893 |
| 4524 | 1245.000 | 84.783 | 14.525 | -12.029 | 0.345 | 13.974 | 1.662 | 12.034 |
| 4525 | 1245.000 | 85.870 | 13.497 | -12.150 | 0.336 | 15.003 | 1.604 | 12.155 |
| 4526 | 1245.000 | 86.957 | 12.468 | -12.253 | 0.327 | 16.008 | 1.547 | 12.257 |
| 4527 | 1245.000 | 88.044 | 11.485 | -12.340 | 0.316 | 17.014 | 1.490 | 12.344 |
| Average | | | | | | 13.886 | 0.162 | 12.146 |

Force Due to Drag

| | | |
|---|---|---|
| CD | 1.000 | |
| Ap | 55.545 | ft2 |
| p | 4.9201b | s2 / ft4 |
| V2 / 2 | 73.765 | ft2/s2 |
| F (drag) | 20158 | lb |

Force Due to Bed Shear

| | | |
|---|---|---|
| Q | 1100 | ft3 / s |
| n | 0.030 | |
| L | 45.000 | ft |
| Pw | 6.522 | ft |
| A | 90.566 | ft2 |
| F (shear) | 456 | lb |

**Effective F (shear) 20614 lb**
**Effective n 0.129**

**Table 6.2b -- Pier 2 Area**

| Node | x Coord (ft) | y Coord (ft) | Ground Elevation (ft) | x Velocity (fps) | y Velocity (fps) | Depth (ft) | Angle of Attack (deg) | Resultant Velocity (fps) |
|---|---|---|---|---|---|---|---|---|
| 4235 | 1201.000 | 96.739 | 5.722 | -12.828 | -0.123 | 22.640 | -0.573 | 12.829 |
| 4236 | 1201.000 | 97.826 | 5.281 | -12.834 | -0.110 | 23.081 | -0.516 | 12.834 |
| 4237 | 1201.000 | 98.913 | 4.841 | -12.833 | -0.098 | 23.522 | -0.458 | 12.833 |
| 4238 | 1201.000 | 100.000 | 4.400 | -12.827 | -0.085 | 23.669 | -0.401 | 12.827 |
| 4239 | 1201.000 | 101.087 | 4.547 | -12.814 | -0.073 | 23.816 | -0.344 | 12.814 |
| 4240 | 1201.000 | 102.174 | 4.694 | -12.796 | -0.062 | 23.670 | -0.286 | 12.796 |
| 4241 | 1201.000 | 103.261 | 4.841 | -12.771 | -0.050 | 23.524 | -0.229 | 12.771 |
| 4310 | 1212.000 | 96.739 | 5.717 | -12.832 | -0.076 | 22.678 | -0.344 | 12.832 |
| 4311 | 1212.000 | 97.826 | 5.276 | -12.841 | -0.078 | 23.118 | -0.344 | 12.841 |
| 4312 | 1212.000 | 98.913 | 4.836 | -12.844 | -0.081 | 23.559 | -0.344 | 12.844 |
| 4313 | 1212.000 | 100.000 | 4.395 | -12.841 | -0.084 | 23.706 | -0.401 | 12.841 |
| 4314 | 1212.000 | 101.087 | 4.542 | -12.833 | -0.087 | 23.853 | -0.401 | 12.833 |
| 4315 | 1212.000 | 102.174 | 4.689 | -12.818 | -0.089 | 23.707 | -0.401 | 12.818 |
| 4316 | 1212.000 | 103.261 | 4.836 | -12.798 | -0.092 | 23.560 | -0.401 | 12.798 |
| 4385 | 1223.000 | 96.739 | 5.712 | -12.804 | 0.007 | 22.716 | 0.057 | 12.804 |
| 4386 | 1223.000 | 97.826 | 5.271 | -12.813 | 0.007 | 23.156 | 0.057 | 12.813 |
| 4387 | 1223.000 | 98.913 | 4.831 | -12.817 | 0.007 | 23.597 | 0.057 | 12.817 |
| 4388 | 1223.000 | 100.000 | 4.390 | -12.815 | 0.007 | 23.744 | 0.057 | 12.815 |
| 4389 | 1223.000 | 101.087 | 4.537 | -12.809 | 0.007 | 23.891 | 0.057 | 12.809 |
| 4390 | 1223.000 | 102.174 | 4.684 | -12.798 | 0.008 | 23.744 | 0.057 | 12.798 |
| 4391 | 1223.000 | 103.261 | 4.831 | -12.782 | 0.008 | 23.597 | 0.057 | 12.782 |
| 4460 | 1234.000 | 96.739 | 5.707 | -12.770 | 0.102 | 22.753 | 0.458 | 12.770 |
| 4461 | 1234.000 | 97.826 | 5.266 | -12.778 | 0.100 | 23.193 | 0.458 | 12.778 |
| 4462 | 1234.000 | 98.913 | 4.826 | -12.780 | 0.098 | 23.634 | 0.458 | 12.780 |
| 4463 | 1234.000 | 100.000 | 4.385 | -12.777 | 0.096 | 23.780 | 0.458 | 12.777 |
| 4464 | 1234.000 | 101.087 | 4.532 | -12.769 | 0.094 | 23.927 | 0.401 | 12.769 |
| 4465 | 1234.000 | 102.174 | 4.679 | -12.755 | 0.092 | 23.780 | 0.401 | 12.755 |
| 4466 | 1234.000 | 103.261 | 4.826 | -12.736 | 0.090 | 23.633 | 0.401 | 12.736 |
| 4535 | 1245.000 | 96.739 | 5.702 | -12.661 | 0.163 | 22.791 | 0.745 | 12.662 |
| 4536 | 1245.000 | 97.826 | 5.261 | -12.667 | 0.139 | 23.231 | 0.630 | 12.668 |
| 4537 | 1245.000 | 98.913 | 4.821 | -12.666 | 0.116 | 23.670 | 0.516 | 12.667 |
| 4538 | 1245.000 | 100.000 | 4.380 | -12.660 | 0.092 | 23.817 | 0.401 | 12.660 |
| 4539 | 1245.000 | 101.087 | 4.527 | -12.648 | 0.069 | 23.964 | 0.286 | 12.648 |
| 4540 | 1245.000 | 102.174 | 4.674 | -12.630 | 0.046 | 23.816 | 0.229 | 12.630 |
| 4541 | 1245.000 | 103.261 | 4.821 | -12.606 | 0.023 | 23.669 | 0.115 | 12.606 |
| Average | | | | | | 23.492 | 0.026 | 12.773 |

Force Due to Drag

| | | |
|---|---|---|
| $C_D$ | 1.000 | |
| $A_p$ | 93.966 | ft2 |
| p | 4.9201 | lb s2 / ft4 |
| $V^2$ / 2 | 81.575 | ft2/s2 |
| F (drag) | 37713 | lb |

Force Due to Bed Shear

| | | |
|---|---|---|
| Q | 1957 | ft3 / s |
| n | 0.030 | |
| L | 45.000 | ft |
| $P_w$ | 6.522 | ft |
| A | 153.212 | ft2 |
| F (shear) | 423 | lb |

**Effective F (shear) 38136 lb**
**Effective n 0.180**

**Table 6.2c -- Pier 3 Area**

Node x Coord y Coord Ground Elevation x Velocity y Velocity Depth
Angle of Attack Resultant Velocity
(ft) (ft) (ft) (fps) (fps) (ft) (deg) (fps)

| Node | x Coord (ft) | y Coord (ft) | Ground Elevation (ft) | x Velocity (fps) | y Velocity (fps) | Depth (ft) | Angle of Attack (deg) | Resultant Velocity (fps) |
|---|---|---|---|---|---|---|---|---|
| 4249 | 1201.000 | 111.957 | 6.559 | -12.312 | 0.059 | 21.823 | 0.286 | 12.312 |
| 4250 | 1201.000 | 113.044 | 6.836 | -12.215 | 0.073 | 20.983 | 0.344 | 12.215 |
| 4251 | 1201.000 | 114.131 | 8.230 | -12.108 | 0.077 | 20.143 | 0.344 | 12.108 |
| 4252 | 1201.000 | 115.218 | 11.266 | -11.986 | 0.081 | 17.479 | 0.401 | 11.986 |
| 4253 | 1201.000 | 116.304 | 13.573 | -11.844 | 0.098 | 14.815 | 0.458 | 11.844 |
| 4254 | 1201.000 | 117.391 | 14.601 | -11.681 | 0.127 | 13.789 | 0.630 | 11.682 |
| 4255 | 1201.000 | 118.478 | 15.630 | -11.502 | 0.162 | 12.763 | 0.802 | 11.503 |
| 4324 | 1212.000 | 111.957 | 6.554 | -12.432 | -0.087 | 21.850 | -0.401 | 12.432 |
| 4325 | 1212.000 | 113.044 | 6.831 | -12.362 | -0.082 | 21.012 | -0.401 | 12.362 |
| 4326 | 1212.000 | 114.131 | 8.225 | -12.284 | -0.080 | 20.175 | -0.401 | 12.284 |
| 4327 | 1212.000 | 115.218 | 11.261 | -12.194 | -0.079 | 17.505 | -0.344 | 12.194 |
| 4328 | 1212.000 | 116.304 | 13.568 | -12.084 | -0.073 | 14.835 | -0.344 | 12.084 |
| 4329 | 1212.000 | 117.391 | 14.596 | -11.956 | -0.061 | 13.809 | -0.286 | 11.956 |
| 4330 | 1212.000 | 118.478 | 15.625 | -11.816 | -0.040 | 12.783 | -0.172 | 11.816 |
| 4399 | 1223.000 | 111.957 | 6.549 | -12.489 | 0.014 | 21.877 | 0.057 | 12.489 |
| 4400 | 1223.000 | 113.044 | 6.826 | -12.432 | 0.016 | 21.042 | 0.057 | 12.432 |
| 4401 | 1223.000 | 114.131 | 8.220 | -12.370 | 0.019 | 20.206 | 0.115 | 12.370 |
| 4402 | 1223.000 | 115.218 | 11.256 | -12.296 | 0.021 | 17.530 | 0.115 | 12.296 |
| 4403 | 1223.000 | 116.304 | 13.563 | -12.203 | 0.015 | 14.855 | 0.057 | 12.203 |
| 4404 | 1223.000 | 117.391 | 14.591 | -12.091 | 0.006 | 13.829 | 0.000 | 12.091 |
| 4405 | 1223.000 | 118.478 | 15.620 | -11.964 | 0.003 | 12.803 | 0.000 | 11.964 |
| 4474 | 1234.000 | 111.957 | 6.544 | -12.394 | 0.048 | 21.907 | 0.229 | 12.394 |
| 4475 | 1234.000 | 113.044 | 6.821 | -12.329 | 0.037 | 21.073 | 0.172 | 12.329 |
| 4476 | 1234.000 | 114.131 | 8.215 | -12.258 | 0.028 | 20.239 | 0.115 | 12.258 |
| 4477 | 1234.000 | 115.218 | 11.251 | -12.178 | 0.022 | 17.571 | 0.115 | 12.178 |
| 4478 | 1234.000 | 116.304 | 13.558 | -12.082 | 0.020 | 14.902 | 0.115 | 12.082 |
| 4479 | 1234.000 | 117.391 | 14.586 | -11.968 | 0.016 | 13.870 | 0.057 | 11.968 |
| 4480 | 1234.000 | 118.478 | 15.615 | -11.839 | 0.001 | 12.837 | 0.000 | 11.839 |
| 4549 | 1245.000 | 111.957 | 6.539 | -12.153 | -0.175 | 21.937 | -0.802 | 12.154 |
| 4550 | 1245.000 | 113.044 | 6.816 | -12.057 | -0.202 | 21.104 | -0.974 | 12.059 |
| 4551 | 1245.000 | 114.131 | 8.210 | -11.950 | -0.225 | 20.271 | -1.089 | 11.952 |
| 4552 | 1245.000 | 115.218 | 11.246 | -11.830 | -0.236 | 17.611 | -1.146 | 11.832 |
| 4553 | 1245.000 | 116.304 | 13.553 | -11.688 | -0.225 | 14.950 | -1.089 | 11.690 |
| 4554 | 1245.000 | 117.391 | 14.581 | -11.526 | -0.210 | 13.911 | -1.031 | 11.528 |
| 4555 | 1245.000 | 118.478 | 15.610 | -11.349 | -0.221 | 12.871 | -1.089 | 11.351 |
| Average | | | | | | 17.456 | -0.146 | 12.064 |

Force Due to Drag

| | | |
|---|---|---|
| $C_D$ | 1.000 | |
| $A_p$ | 69.824 | ft2 |
| p | 4.9201b | s2 / ft4 |
| $V^2$ / 2 | 72.769 | ft2/s2 |
| F (drag) | 24999 | lb |

Force Due to Bed Shear

| | | |
|---|---|---|
| Q | 1373 | ft3 / s |
| n | 0.030 | |
| L | 45.000 | ft |
| $P_w$ | 6.521 | ft |
| A | 113.831 | ft2 |
| F (shear) | 416 | lb |

**Effective F (shear) 25415 lb**
**Effective n 0.149**

6.3.3 Comparing the Results of Examples 2, 3a, and 3b

The depth, velocity, and angle of attack of the approach flow have a large effect on the depth of local scour at bridge piers, as discussed earlier in this paper. For this reason, these variables are examined for each of the three methods presented in this manual.

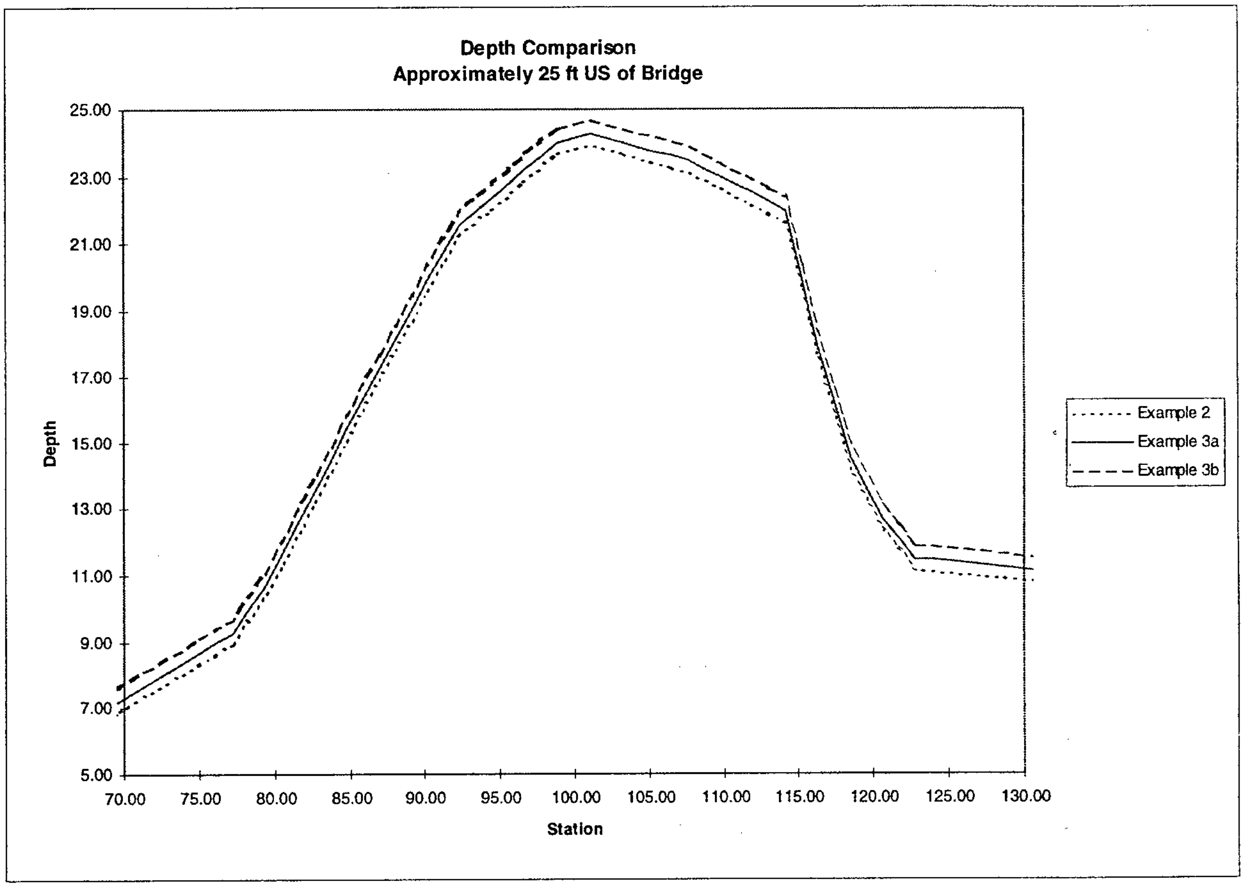



Figure 6.4 -- Comparison of Examples 2, 3a, and 3b
Depth at Approximately 25 foot US of Bridge

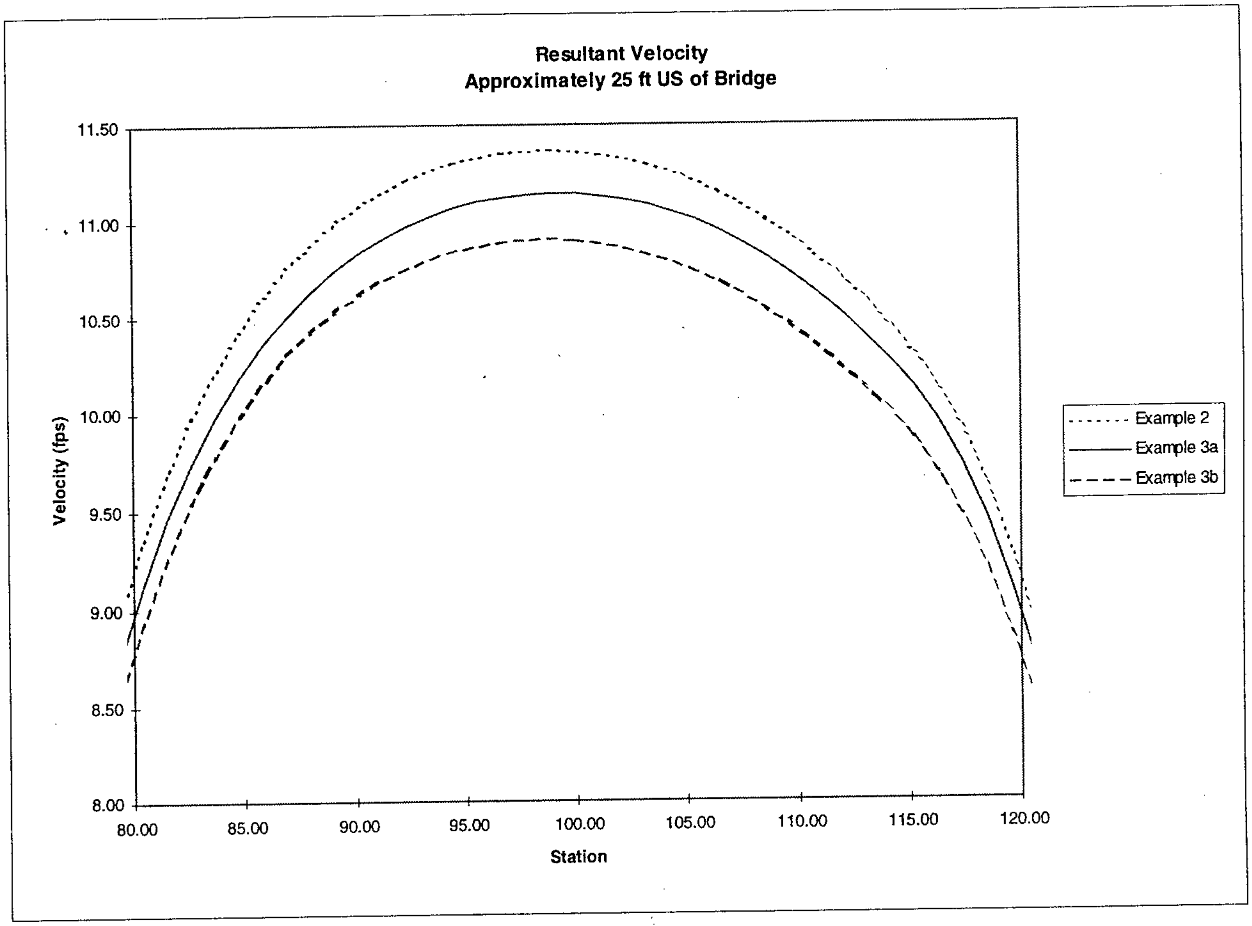



Figure 6.5 -- Comparison of Examples 2, 3a, and 3b
Velocity at Approximately 25 foot US of Bridge

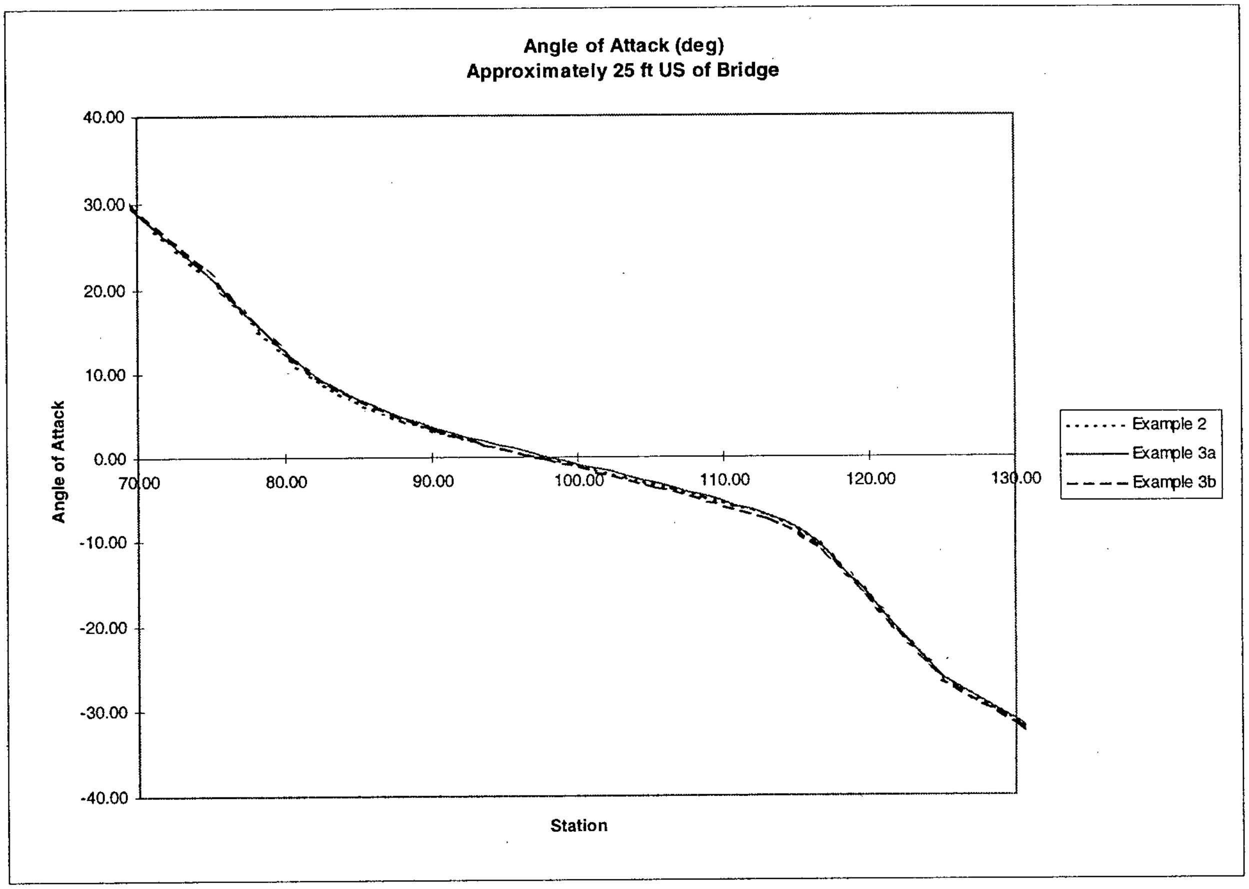



Figure 6.6 -- Comparison of Examples 2, 3a, and 3b
Angle of Attack at Approximately 25 foot US of Bridge

## 7.0 POSTFES and WSPROFES Programs

The execution of FESWMS-2DH results in the generation of several output files. Among them are a primary output file, several files for graphs, a file used for hot start initial conditions, and a file containing information for post-processor computations. The primary output file named FLOMOD.PRT is an enormous output file typically containing more than 10,000 lines with x- and y-coordinates, ground elevations, flow velocity components in x- and y-directions, water depth, and other related information for more than 10,000 nodes. It is very difficult and time-consuming for users to find the pertinent information for bridge scour analysis from these huge files. Consequently, a post-processor program called POSTFES was developed to allow users to easily extract the relevant bridge scour parameters.

The input file required by POSTFES is generated by PREFES and is named NODE.OUT. POSTFES will prompt the user to provide an output file name. This output file is a table of variables used in bridge scour calculations. Specifically, the table has values of flow depth, resultant velocity magnitude and angle of attack for stations across the bridge opening. (Actually, 1 finite element length upstream from the upstream face of the bridge.) Thus, the engineer is provided with transverse distributions of approach velocity, depth and angle of attack for the entire bridge opening. This should greatly aid bridge engineers in the analysis of pier scour for bridges in which large angles of attack pose problems. It should also aid in the design of scour countermeasure structures such as spur dikes by allowing easy numerical testing of various alternative designs.

The current version of POSTFES is essentially a BETA version which was developed to illustrate the potential of a postprocessor. POSTFES could and should be expanded to actually calculate pier, abutment and contraction scour depths from the FESWMS-2DH output files. Such a program would enable the engineer to eliminate much of the guess work now required in determining angle of attack for pier scour and regions of live-bed scour at the approach and bridge sections for contraction scour computation. It would also be quite useful in the design of scour abatement features such as spur dikes.

Another program called WSPROFES was developed to convert a standard WSPRO input file into the input file required by PREFES. Although, this program was tested successfully on several WSPRO input files, it is still deemed a BETA version. This program allows the engineer to easily use FESWMS-2DH without having to prepare the input file for PREFES. Hopefully, this "preprocessor for the preprocessor" will further increase the likelihood that practicing engineers will use FESWMS-2DH to perform scour analysis.

## 8.0 Summary of Installation and Application Procedures

This section summarizes the major steps required to install PREFES, FESWMS-2DH, WSPROFES and POSTFES programs and other files from the enclosed floppy disk and to execute the programs. A minor error has been corrected on this version of PREFES. Consequently, make sure to use the file PREFES.EXE (dated 8-17-97) rather than an older version. Better yet, toss the earlier disks associated with this report and use only the disk submitted with this final report.

1. Program organization

To install and run FESWMS-2DH, the computer should have at minimum 8 M bytes of RAM and 30 M bytes of available hard drive space. First create the directory FESWMS and the subdirectory PROGRAMS on the C-drive. Then copy from the floppy disk FESWMS.ZIP and PKUNZIP.EXE to C:\FESWMS and PROGRAMS.ZIP and PKUNZIP.EXE to C:\FESWMS\PROGRAMS. Unzip both of the ZIP-files. Add C:\FESWMS\PROGRAMS to the PATH statement in your AUTOEXEC.BAT file.

2. Creation of Project Subdirectories

It is recommended that individual project subdirectories be created under C:\FESWMS. For example

C:\FESWMS\EXAMPLE1
C:\FESWMS\EXAMPLE2
C:\FESWMS\EXAMPLE3
C:\FESWMS\EXAMPLE8

The PREFES input file for each project should be placed in the corresponding subdirectory. In this case EX1, EX2 and EX3 are PREFES input files and E8.DAT is a WSPRO input file to which WSPROFES can be applied to produce an input file for PREFES. All of these files can be copied (or cut and pasted) from C:\FESWMS to the appropriate subdirectory.

**NOTE: To execute the programs discussed herein you will usually need to reboot the computer in MS-DOS if you are running WINDOWS 95. Sometimes even this is not sufficient due to memory manager problems. If this situation exists you will need to boot the computer from the floppy drive. You can make a floppy boot disk by putting a blank disk in drive A and entering the command "FORMAT A: /S".**

3. Preparation of input file for PREFES by execution of WSPROFES or an alternative method.

The only input file that needs to be prepared by users is an input file quite similar to a WSPRO input file. The file contains WSPRO cross-sectional data as well as several parameter "cards" containing instructions for the FESWMS-2DH model (see Chapter 3 for details). EX1, EX2 and EX3 are examples of PREFES input files. The BETA-version program WSPROFES does this for you by converting a standard WSPRO input file into a PREFES input file. You can apply WSPROFES to E8.DAT when in the subdirectory C:\FESWMWS\EXAMPLE8 to create the PREFES input file E8.IN (or whatever you want to name it.)

4. Execution of PREFES

Once the input file is prepared by using WSPROFES or some other method, the execution of the PREFES program is initiated by typing "PREFES". The user will then be prompted for the input file name. It takes about 2 minutes for the execution of the program. Six files will be generated: 1) CHECKIN.OUT can be viewed to check the input file and the finite element mesh information; 2) NODE.OUT is used by POSTFES to produce an output file for the nodes near the bridge opening; 3) GRID.DAT, DINMOD.DAT, FLOMOD.DAT, and ANOMOD.DAT are used as input files for FESWMS-2DH programs.

5. Execution of FESWMS-2DH

The menu for running the FESWMS-2DH programs is brought up by typing "FESWMS". The following steps are then carried out.

1) To run the data input module: Modules --> DINMOD --> Run --> Enter;
2) To view the finite element mesh: Modules --> DINMOD --> Graphics—
> Screen --> Enter;
3) To run the flow simulation module: Modules --> FLOMOD --> Run--> Enter;
4) To run the output analysis module: Modules --> ANOMOD--> Run --> Enter;
5) To view the flow velocity field: Modules --> ANOMOD --> Graphics--
> Screen --> Enter (see Chapter 5 for details).

It takes about 10 to 20 minutes to run the FLOMOD module and about 1minute apiece to run DINMOD and ANOMOD. The time depends on the computer capability.

6. Execution of POSTFES

The final step is to run the BETA-version POSTFES program to generate resultant flow velocity, angle of attack, and depth of flow distributions along the upstream bridge opening. This can be accomplished by typing "POSTFES". The program will prompt the user for an output file name. Program execution takes about one minute. The output file contains tabular data that can readily be used with a spreadsheet to make scour computations based on a true two-dimensional flow model.