A unified computer model for irregular channel hydraulics

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A unified computer model wherein a specific force (pressure-plus-momentum) analysis is incorporated into the standard step method to analyze the irregular channel hydraulics has been developed. This model provides hydraulic engineers a realistic water surface profile which includes both the subcritical flow and supercritical flow regimes for an irregular channel in the model output. FORTRAN source code is included that provides the unified water surface determination capability.

INTRODUCTION

The standard step method[1,3] has been widely used in determining the water surface profile in irregular channels (e.g., natural rivers). Due to the variable topography of the water course, both the subcritical flow and supercritical flow regimes can be observed throughout the entire water course. The standard step method provides for the computation of an upstream (downstream) water surface and energy grade line (EGL) given the current values of the downstream (upstream) water surface elevation, EGL, flow rate, and other flow and channel characteristics. *The main thrust of this paper is to develop* a unified water surface profile analysis procedure which analyzes both the subcritical flow and supercritical flow regimes according to the specific force (pressure-plus-momentum) analysis. In addition to the water surface profile determination, the model also locates a *specific force balancing point in lieu of a hydraulic jump* where the supercritical flow regime changes into the subcritical flow regime.

In the standard step method, the computation of the flow depth is carried out on a station to station basis where the hydraulic characteristics are known. The computation procedure is a trial and error method to balance the energy equation.

For convenience, the position of the water surface is measured with respect to a horizontal datum. The water surface elements above the datum at the two end sections can be expressed as (see Fig. 1)

$$Z_A = y_A + z_A \tag{1a}$$

and

$$Z_B = y_B + z_B \tag{1b}$$

The friction losses are estimated between points A and B by

$$h_f = S_f\,dx = (S_A + S_B)\,dx/2 \tag{2}$$

where S_f can be taken as the average of the friction slopes at the two end sections. The total head at sections A and B can be equated by the energy equation

$$S_0\,dx + y_A + c_A V_A^2/2g = y_B + c_B V_B^2/2g + S_f\,dx + h_e \tag{3}$$

By substitution, the following is written

$$Z_A + c_A V_A^2/2g = Z_B + c_B V_B^2/2g + h_f + h_e \tag{4}$$

where c_A and c_B are the kinetic (velocity head) correction factors and h_e is the eddy loss defined by

$$h_e = k(dV^2/2g) \tag{5}$$

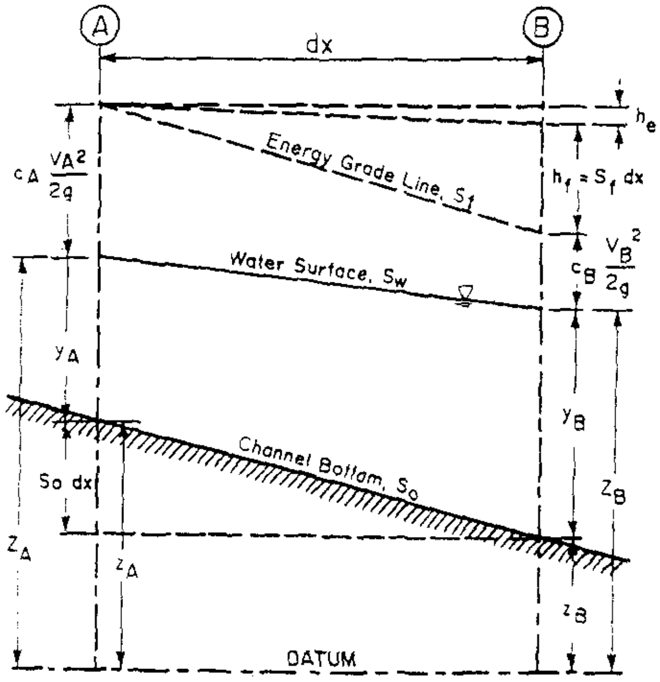


Fig. 1. Channel reach used for derivation of standard step method

Received June 1989. Discussion closes April 1990.

where $dV^2/2g$ is the change in velocity head, and k is given by

$k=0$ to 0.1 for gradually converging reaches
$k=0$ to 0.2 for gradually diverging reaches
$k=0.5$ for abrupt expansion and contraction
$k=0$ for prismatic and regular channel

The total heads at the two end sections A and B are

$$H_A = Z_A + c_A V_A^2/2g \quad (6a)$$

and

$$H_B = Z_B + c_B V_B^2/2g \quad (6b)$$

Using equation (6), equation (4) can be expressed as

$$H_A = H_B + h_f + h_e \quad (7)$$

Given the values of H_A (or H_B), the energy head for H_B (or H_A) is computed by estimating possible flow depths until the governing energy equation is satisfied.

UNIFIED COMPUTER MODEL

The unified computer model for irregular channel hydraulics is based upon the irregular channel water surface profile computer program by Hromadka *et al.*[4]. This program employed the user-friendly, form fill-out data technique[2] to increase the user efficiency, and decrease the total cost of engineering design process.

The program data entry (see Appendix A) fall into two categories:

(1) preparation of channel cross-section information,
(2) definition of uniform channel flow rate, energy balance locations along the channel, and downstream (or upstream) hydraulic control information.

The preparation of channel cross-section information entails the definition of up to 50 cross-sections along the channel. Each cross-section is defined to have up to 20 (x, y) coordinate pairs, a Manning's friction factor, a kinetic energy correction factor, and an eddy loss factor. Each cross-section is assumed to have a single flowline such that the section begins on one bank decreases in elevation constantly to the flowlines, and then increases in elevation until the other bank elevation is reached. The section coordinate data is entered with the first x-coordinate being defined as $x=0.0$. Thus the coordinate data must be entered consistently in order to scan the cross-sections properly. That is, all sections should have the coordinate data prepared from left-to-right (or right-to-left). The cross-section data entry begins with the most downstream section, with subsequent section data entered in the upstream direction.

The second set of data entry requirements includes the constant flow rate to be used through the entire study, the definition of the downstream (or upstream) hydraulic water surface elevation, and the definition of energy balance locations along the channel. The standard step method computes the water surface profile by balancing the energy losses (between energy balance locations) to the change in the EGL. Thus the engineer locates those points where the energy balance computations are to occur within the study. Energy balance locations are always defined with respect to the most downstream section. The use of energy balance locations simplifes the data entry efforts in that unnecessary cross-section data need not be entered. Rather, this program linearly interpolates all hydraulic parameters, with respect to distance between surrounding cross-sections.

For a subcritical flow study, the analysis proceeds in the upstream direction. The upstream water surface and EGL are computed at energy balance locations by linearly interpolating all cross-section geometric and hydraulic information. Should the water surface fall below the corresponding critical depth, the channel flow depth is redefined to equal the critical depth (Froude number equals 1, modified by the kinetic energy correction factor). In reaches where normal depth flows could be supercritical the word STEEP is noted in the right hand column of the computer solution tabulation. Other program output features are listed in the program description page which is included in the program output (see Appendix C).

Similarly for a supercritical flow study, the analysis proceeds in a downstream direction. And should the water surface exceed the critical depth, the flow depth is redefined to be critical.

WATER SURFACE PROFILE DETERMINATION

First, the water depths at each energy balance location are estimated by the standard step method for both the previously discussed subcritical flow and supercritical flow regimes, independently. The specific forces (pressure-plus-momentum) are also calculated at each energy balance location. Water depths corresponding to the higher specific force will be used to determine the water surface profile. Table 1 illustrates the water surface profile determination logic for the unified computer model.

A hydraulic jump in a reach can occur only when upstream flow is in a supercritical flow regime and the downstream flow is in a subcritical flow regime. However, the determination of the location and length of hydraulic jump is not included in the programming. Rather, a specific force 'balance point', where specific forces are equal for both the subcritical flow and supercritical flows, is determined for the user's convenience.

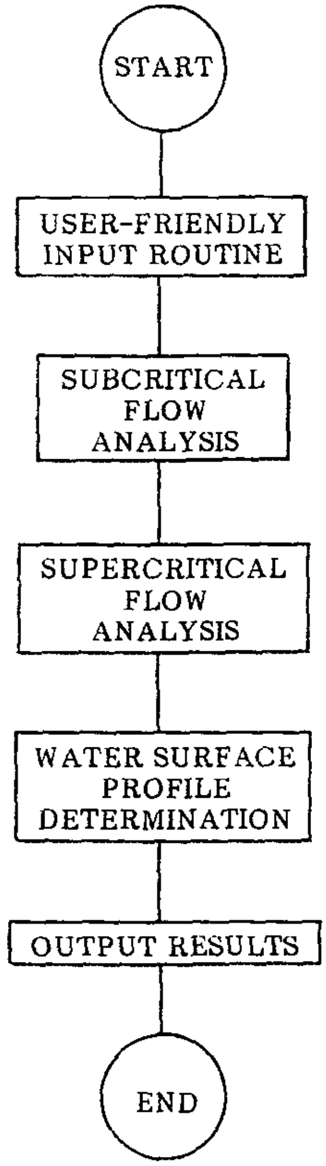
IMPLEMENTATION OF THE WATER SURFACE PROFILE DETERMINATION ROUTINE

The water surface profile determination routine (see Appendix B) was incorporated into the irregular channel water surface profile computer program[4]. Figure 2 shows the flow chart of the above mentioned computer program.

Table 1. Logic for water surface profile determination

(at each energy-balance location) Subcritical flow analysis	Supercritical flow analysis	Assumed flow regime
$P+M$ at upstream EBL	$\geq P+M$ at upstream EBL	subcritical flow
and $P+M$ at EBL	$>P+M$ at EBL	
$P+M$ at EBL	$<P+M$ at EBL	supercritical flow
$P+M$ at upstream EBL	$<P+M$ at upstream EBL	hydraulic jump
and $P+M$ at EBL	$\geq P+M$ at EBL	
$P+M$ at EBL	$=P+M$ at EBL	control point

Note: $P+M$ indicates pressure-plus-momentum.
EBL indicates energy-balance location.



Note: Using any word processor can create the same input data file as the user-friendly input routine does.

Fig. 2. Flow chart for unified computer model

The FORTRAN source codes for the flow analysis routine and the output routine are listed in Hromadka *et al.*[5].

EXAMPLE PROBLEM: HYDRAULIC JUMP ANALYSIS IN A PRISMATIC CHANNEL

Determine the profile and approximate hydraulic jump location for the trapezoidal channel shown on Fig. 2.

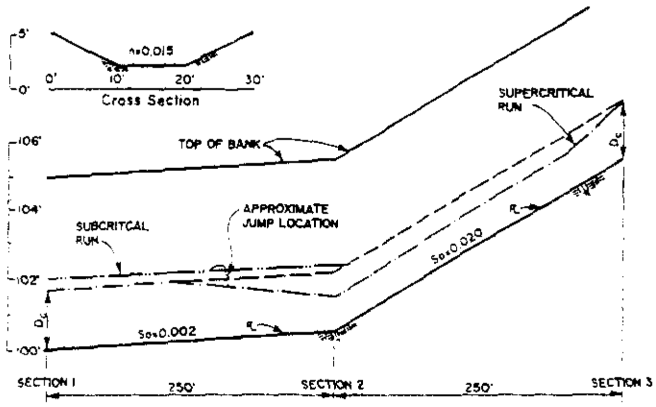


Fig. 3. Water surface profile for example problem

Analyze the profile for a discharge rate of 150 cfs and a friction factor of 0.015. Use a kinetic energy correction factor of 1.0 and a eddy loss factor of 0.0 for all cross-sections. Note that the specific force balancing point where the subcritical pressure-plus-momentum equals the supercritical pressure-plus-momentum is at a location 144.8 feet (see Appendix C) upstream of cross-section # 1. The hydraulic jump may occur somewhere near this location.

CONCLUSIONS

The unified computer model has the capability of analyzing subcritical flow and/or supercritical flow regimes in irregular channels. The various gradually varied flow water surface profiles are approximated by the standard step method. This analysis provides the hydraulic engineers a convenient tool to analyze irregular channel hydraulics when the subcritical flow and supercritical flow regimes co-exist in the channel system.

Because the unified computer program is interactive and user-friendly, the irregular channel hydraulics can be quickly analyzed without the use of a data batch-file approach.

REFERENCES

1 Chow, V. T. *Open Channel Hydraulics*. McGraw-Hill Book Company, New York, 1959
2 Clements, J. M. and Hromadka II, T. V. User-friendly, form fill-out data for engineering software, *Microsoftware for Engineers*, 1986, **2**(1)
3 Henderson, F. M. *Open Channel Flow*, Macmillan Publishing Company, Inc., New York, 1966
4 Hromadka II, T. V., Seits, M. H. and Clements, J. M. *Computational Hydraulics in Irregular Channels*, Lighthouse Publications, Mission Viejo, California, 1988
5 Hromadka II, T. V., Clements, J. M. and Saluja, H. *Computer Method in Urban Watershed Hydraulics*, Lighthouse Publications, Mission Viejo, California, 1984

```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE--- PAGE 1

In order to determine a water surface profile in an
irregular channel, the channel needs to be defined by
cross-sections. These sections are entered sequentially
(from £1) as one travels upstream.
Enter TOTAL NUMBER of cross-sections................ ===>    "N"
:ALLOWABLE VALUES ARE [2] TO [50    ]

Enter the CONSTANT irregular channel FLOW(CFS)...... ===>    "QQ"
:ALLOWABLE VALUES ARE [1      ] TO [999999]

Enter allowable ERROR(FEET) in water surface
determination....................................... ===>    "TOL"
:ALLOWABLE VALUES ARE [.01    ] TO [.50    ]

---------------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of page
```

```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE--- PAGE 2


FLOW REGIME MODELS:

    1= SUBcritical flow   (Flow regime is limited to
       flow depths greater than critical)

    2= SUPERcritical flow (Flow regime is limited to
       flow depths less than critical)

Select flow regime MODEL desired.................... ===>    "KMODEL"


Enter hydraulic control water surface(ELEVATION)
at cross-section __ ................................ ===>    "YCON"
:ALLOWABLE VALUES ARE [-9999 ] TO [9999  ]

---------------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of page
                            ; BACK to go back one page
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```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE--- PAGE 3

CHANNEL CROSS-SECTION DATA ENTRY GROUP  1 OF  2:

Enter TOTAL number of nodal points to describe
cross-section.................................... ===>     "M(I)"
:ALLOWABLE VALUES ARE [3] TO [20     ]
(NOTE: INCLUDE BOTH END POINTS IN TOTAL NUMBER)

Enter Mannings friction factor...................... ===>     "XMAN(I)"
:ALLOWABLE VALUES ARE [.008  ] TO [.99    ]

Enter kinetic energy correction factor.............. ===>     "ALPHA(I)"
:ALLOWABLE VALUES ARE [1.0    ] TO [2.0    ]
(NOTE: THIS CROSS-SECTION FACTOR INCREASES THE
VELOCITY HEAD TERM IN ORDER TO ACCOUNT FOR VARIATIONS
IN VELOCITY FROM THE AVERAGE FLOW VELOCITY.  GENERALLY,
[1.0] IS AN ADEQUATE VALUE FOR TYPICAL CHANNEL FLOWS.)

--------------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of page
                            ; BACK to go back one page
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```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE---PAGE 3A

CHANNEL CROSS-SECTION DATA ENTRY GROUP  1 OF  2:

Enter eddy loss coefficient......................... ===>     "EDDY(I)"
:ALLOWABLE VALUES ARE [0.0    ] TO [3.0    ]
(NOTE: THIS VALUE IS USED TO APPROXIMATE ENERGY LOSSES
DUE TO CHANGES IN THE CHANNEL SHAPE AND OTHER RELATED
LOSSES.  GENERALLY, THE MORE IRREGULAR THE CHANNEL,
THE HIGHER THE EDDY LOSS TERM.  THE PROGRAM USER MAY
ALSO INCLUDE OTHER ENERGY LOSSES IN THE ANALYSIS BY
SELECTING AN EQUIVALENT EDDY LOSS.)

 EACH CHANNEL CROSS-SECTION IS LOCATED WITHIN THE CHANNEL BY ITS
 DISTANCE(FEET) FROM CROSS-SECTION £1(THE MOST DOWNSTREAM SECTION).
 ALL CHANNEL LOCATIONS WILL BE REFERENCED WITH RESPECT TO
 CROSS-SECTION NUMBER ONE.

--------------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of page
                            ; BACK to go back one page
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```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE---PAGE 3A

CHANNEL CROSS-SECTION DATA ENTRY GROUP  2 OF  2:

Enter eddy loss coefficient......................... ===>    "EDDY(I)"
:ALLOWABLE VALUES ARE [0.0    ] TO [3.0    ]




Enter distance(FEET) from the most downstream
section defined..................................... ===>    "DISTS(I)"
:ALLOWABLE VALUES ARE [        1.00] TO [  10000.00]



-----------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of page
                            ; BACK to go back one page
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```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE---PAGE 3B
             CROSS-SECTION £ 1 NODAL POINT  1 OF  3:

Enter (X) coordinate................................ ===>    "X(I,J)"
:ALLOWABLE VALUES ARE [0          ] TO [9999      ]

Enter (Y) elevation................................. ===>    "Y(I,J)"
:ALLOWABLE VALUES ARE [-9999      ] TO [9999      ]

NODE  (X) COORDINATE      (Y) ELEVATION
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
         [       ]           [       ]
-----------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of entry
                            ; BACK to go back one page
```

```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE--- PAGE 4
This computer program uses straight line interpolation between
cross-sections to define the total irregular channel.  Consequently,
channel shape,slope,friction, and other factors are all averaged
with respect to distance between cross-sections. For water-
surface profile determination, the locations where the hydraulic
energy balances are to be made is important to the correct solution.

On the next page, the user is requested to enter the locations
where the hydraulic energy balances are to be made.  These locations
may be specified at or between the various channel cross-sections
previously entered.  Again, only subcritical (or supercritical) flow
is analysed by this program, and critical-depth will be assumed
at all sections where supercritical (subcritical) flow occurs.
Hydraulic jumps,transitions between supercritical and subcritical flow
(and vice versa), and rapidly varying flow effects are ignored.

Enter total number of locations where hydraulic energy
balances are to be made(STANDARD STEP METHOD)....... ===>    "NE"
:ALLOWABLE VALUES ARE [5] TO [200   ]
-----------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of page
```

```
---DATA ENTRY FOR IRREGULAR CHANNEL WATER SURFACE PROFILE--- PAGE 5

HYDRAULIC ENERGY BALANCE LOCATION  1 OF  5:

Enter (FEET) from cross-section £1 to where
energy balance is to be made........................ ===>    "DIST(1)"
:ALLOWABLE VALUES ARE [       1.00] TO [    495.00]

               HYDRAULIC ENERGY
 LOCATION      BALANCE DISTANCES
                 [          ]
                 [          ]
                 [          ]
                 [          ]
                 [          ]
                 [          ]
                 [          ]
                 [          ]
                 [          ]
                 [          ]
-----------------------------------------------------------------------
TYPE: EXIT to leave program ; TOP  to go to top of page
                            ; BACK to go back one page
```

APPENDIX B. WATER SURFACE PROFILE DETERMINATION ROUTINE

```
C
      SUBROUTINE PROFILE
C..PROFILE DETERMINATION
      WRITE(*,*)' ** DETERMINE WATER SURFACE PROFILE **'
      CALL REVSUP(LINE)
C
      OPEN(UNIT=1,FILE='SUP.TMP',FORM='UNFORMATTED')
      OPEN(UNIT=2,FILE='SUB.TMP',FORM='UNFORMATTED')
      WRITE(3,21)
 21   FORMAT(/,78('*'),/,13X,'IRREGULAR CHANNEL WATER SURFACE PROFILE',
     C ' COMPUTATION',/,24X,'BY THE STANDARD STEP METHOD',/,78('*'),//,
     C 27X,'NODAL POINT STATUS TABLE',/,
     C 17X,'(Note: "*" indicates nodal point data used.)',/,78('-'),/,
     C 22X,'UPSTREAM RUN',20X,'DOWNSTREAM RUN',/,3X,'LENGTH from',3X,
     C 'WATER    FLOW    PRESSURE+      WATER    FLOW     PRESSURE+',/,
     C 3X,'DOWNSTREAM   SURFACE   DEPTH   MOMENTUM      SURFACE   DEPTH'
     C ,'   MOMENTUM',/,4X,'CONTROL       (elev.)    (FT)     (POUNDS)',
     C '       (elev.)    (FT)     (POUNDS)',/,78('-'))
C
      KSET=1
      DISTX=0.
      DO 400 I=1,LINE
      LL=LINE-I+1
      DO 410 K=1,LL
      READ(1)DX,YTEST,DY,A,V,AHV,H1,HR,SF,SFM,HF,HE,H2,FR,
     C        AL,XXN,XPM,ED,XCOD,XCOD1
 410  CONTINUE
      REWIND 1
      READ(2)DX,YTEST1,DY1,A,V,AHV,H1,HR,SF,SFM,HF,HE,H2,FR1,
     C        AL,XXN,XPM1,ED,XCOD,XCOD1
      DISTX=DISTX+DX
      IF(ABS(FR-FR1).LE..01)KJUMP=0
      TP=ANINT(XPM*100.)/100.
      TP1=ANINT(XPM1*100.)/100.
      IF(TP.GE.TP1)THEN
      UDC='  '
      UDC1='  '
      CONT='*'
      CONT1=' '
      IF(ABS(FR1-1.).LE..01)UDC1='Dc'
      IF(ABS(FR-1.).LE..01)UDC='Dc'
       IF(KJUMP.EQ.2)THEN
       CALL HJUMP(DX,XPM1,XPM,XPM11,XPM01,XJUMP)
       XJUMP=DX-XJUMP
       WRITE(3,14)XJUMP,I-2
 14    FORMAT(10X,') HYDRAULIC JUMP : P+M BALANCE OCCURS AT ',F4.1,
     C  ' FT. FROM EB ',I3)
       ENDIF
      WRITE(3,13)DISTX,YTEST1,DY1,CONT1,UDC1,XPM1,YTEST,DY,CONT,UDC,XPM
 13   FORMAT(3X,F7.1,6X,F7.2,2X,F5.2,A1,A2,F10.2,5X,F7.2,2X,F5.2,A1,A2,
     C F10.2)
       IF(ABS(DIST(KSET)-DISTX).LE..1)THEN
        IF(I.EQ.1 .OR. I.EQ.LINE)THEN
        WRITE(3,18)KSET
 18     FORMAT('   SECT.',I3)
        ELSE
        WRITE(3,16)KSET,I-1
 16     FORMAT('   SECT.',I3,'    EB ',I3)
        ENDIF
       KSET=KSET+1
       ELSE
       WRITE(3,17)I-1
 17    FORMAT(13X,'EB ',I3)
       ENDIF
      KJUMP=1
      ELSE
      UDC='  '
      UDC1='  '
```

```
      CONT=' '
      CONT1='*'
      IF(ABS(FR1-1.).LE..01)UDC1='Dc'
      IF(ABS(FR-1.).LE..01)UDC='Dc'
      WRITE(3,13)DISTX,YTEST1,DY1,CONT1,UDC1,XPM1,YTEST,DY,CONT,UDC,XPM
       IF(ABS(DIST(KSET)-DISTX).LE..1)THEN
        IF(I.EQ.1 .OR. I.EQ.LINE)THEN
        WRITE(3,18)KSET
        ELSE
        WRITE(3,16)KSET,I-1
        ENDIF
       KSET=KSET+1
       ELSE
       WRITE(3,17)I-1
       ENDIF
      KJUMP=2
      ENDIF
      XPM11=XPM1
      XPM01=XPM
 400  CONTINUE
C
      WRITE(3,22)
 22   FORMAT(78('='))
      CLOSE(UNIT=1,STATUS='KEEP')
      CLOSE(UNIT=2,STATUS='KEEP')
C
      REUTRN
      END
C
C  DETERMINE TEMPERORY FILE LENGTH
C
      SUBROUTINE REVSUP(LINE)
C
      OPEN(UNIT=1,FILE='SUP.TMP',FORM='UNFORMATTED',STATUS='OLD')
      LINE=0
 10   READ(1,END=11)DX,YTEST,DY,A,V,AHV,H1,HR,SF,SFM,HF,HE,H2,FR,
     C          AL,XXN,XPM,ED,XCOD,XCOD1
      LINE=LINE+1
      GO TO 10
 11   CLOSE(UNIT=1,STATUS='KEEP')
C
      RETURN
      END
C
C  SUBROUTINE DETERMINES P+M BALANCE FOR HYDRAULIC JUMP
C
      SUBROUTINE HJUMP(DX,XPM1,XPM,XPM11,XPM01,XL)
C
      A1=XPM-XPM01
      A2=XPM11-XPM1
      XL=DX*(XPM-XPM1)/(A1+A2)
C

      RETURN
      END
C
```

APPENDIX C. EXAMPLE PROBLEM OUTPUT

```
              IRREGULAR CHANNEL WATER SURFACE PROFILE ANALYSIS

Study Name:________________________________________   Page Number ____

The following study is based on the well known STANDARD STEP METHOD to
analyse gradually varied flow in an irregular channel. Energy-head
losses and corresponding notation used in the program are as follows:
     FRICTION LOSSES:     n = Manning's friction factor
     EDDY LOSSES:         e = eddy loss coefficient
     KINETIC ENERGY
     CORRECTION FACTOR:   a = correction factor
```

```
The PROGRAM determines gradually varied flow water surface profile by
balancing the classical energy equation between user specified
"energy balance" locations. All geometric and parameter information is
averaged between defined channel cross-sections by straight line
interpolation.

THE ONLY LOSSES INCLUDED ARE FRICTION AND EDDY LOSSES. The analysis
formulation and presentation of results follow the development given in
"OPEN CHANNEL HYDRAULICS", by Chow(1959).

The PROGRAM will default to a flow-depth of CRITICAL DEPTH whenever the
flow regime changes between SUBcritical and SUPERcritical flow (or vice
versa). Therefore, supercritical water surface information is not
computed in a subcritical flow model; nor is subcritical water surface
information developed in a supercritical flow model. In a subcritical
flow model where flow may be supercritical, critical depth is assumed
as a minimum flow depth which exceeds the actual supercritical
flowdepth in the channel. Similarly in a supercritical flow model
critical depth is assumed as a maximum flow depth. Consequently,
rapidly varied flow effects, hydraulic jumps, and transitions between
flow regimes ARE NOT INCLUDED in the PROGRAM.

For this study, the following information is used:
     Channel flow(cfs) =     150.0
     Number of channel cross-sections =  3

COMPUTER RESULTS are based upon the assumed DOWNSTREAM
water surface elevation(feet) =   102.00 at cross-section 1

Special notation given in the computer results are as follows:
     (1) SECT.....the section number appears in the first column
                  whenever the energy-balance channel location occurs
                  at one of the defined channel cross-sections.
     (2) FLOOD....this word appears in the second column whenever the
                  estimated flowdepth exceeds either bank of the
                  channel section.
     (3) EB.......the energy balance number is listed in column 4.
     (4) P+M......the pressure-plus-momentum (in pounds force)
                  is provided in columns 10 and 11.
     (5) STEEP....this word appears in the last column whenever the
                  Channel Critical Depth exceeds the Normal Depth.
     (6) MILD.....this word appears in the last column whenever the
                  Channel Critical Depth is less than the computed
                  Normal Depth.


------------------------------------------------------------------------
************************************************************************
            IRREGULAR CHANNEL WATER SURFACE PROFILE COMPUTATION
                     BY THE STANDARD STEP METHOD

  (REF.:"OPEN CHANNEL HYDRAULICS",V.T.CHOW,McGraw-Hill Book Co.,(1959))
------------------------------------------------------------------------
   FILE NAME : 111.DAT
   TIME/DATE OF STUDY: 13: 4  12/28/1988
========================================================================
   CROSS-SECTION INFORMATION:
========================================================================
   INFORMATION FOR CROSS-SECTION NUMBER:  1
   MANNING'S FRICTION FACTOR = .01500
   KINETIC ENERGY CORRECTION FACTOR = 1.000
   EDDY LOSS FACTOR =  .000
   DISTANCE(ft.) TO CROSS-SECTION #1 =        .00

   NODAL POINT COORDINATE INFORMATION:
   NODE NO.      X(ft.)      Y(elev.)
      1             .00        105.00
      2           10.00        100.00
      3           20.00        100.00
      4           30.00        105.00
========================================================================
```

INFORMATION FOR CROSS-SECTION NUMBER: 2
MANNING'S FRICTION FACTOR = .01500
KINETIC ENERGY CORRECTION FACTOR = 1.000
EDDY LOSS FACTOR = .000
DISTANCE(ft.) TO CROSS-SECTION #1 = 250.00

NODAL POINT COORDINATE INFORMATION:

NODE NO.	X(ft.)	Y(elev.)
1	.00	105.50
2	10.00	100.50
3	20.00	100.50
4	30.00	105.50

===

INFORMATION FOR CROSS-SECTION NUMBER: 3
MANNING'S FRICTION FACTOR = .01500
KINETIC ENERGY CORRECTION FACTOR = 1.000
EDDY LOSS FACTOR = .000
DISTANCE(ft.) TO CROSS-SECTION #1 = 500.00

NODAL POINT COORDINATE INFORMATION:

NODE NO.	X(ft.)	Y(elev.)
1	.00	110.50
2	10.00	105.50
3	20.00	105.50
4	30.00	110.50

===

ENERGY BALANCE LOCATIONS:

ENERGY BALANCE LOCATION NUMBER	DISTANCE TO CROSS-SECTION #1
1	50.00
2	100.00
3	150.00
4	200.00
5	250.00
6	300.00
7	350.00
8	400.00
9	450.00

===

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IRREGULAR CHANNEL WATER SURFACE PROFILE COMPUTATION
BY THE STANDARD STEP METHOD

****

NODAL POINT STATUS TABLE
(Note: "*" indicates nodal point data used.)

LENGTH from DOWNSTREAM CONTROL	UPSTREAM RUN WATER SURFACE (elev.)	UPSTREAM RUN FLOW DEPTH (FT)	UPSTREAM RUN PRESSURE+ MOMENTUM (POUNDS)	DOWNSTREAM RUN WATER SURFACE (elev.)	DOWNSTREAM RUN FLOW DEPTH (FT)	DOWNSTREAM RUN PRESSURE+ MOMENTUM (POUNDS)
.0	102.00	2.00*	3139.00	101.70	1.70 Dc	3021.30
SECT. 1						
50.0	102.07	1.97*	3119.65	101.80	1.70 Dc	3021.30
EB 1						
100.0	102.15	1.95*	3107.47	101.90	1.70 Dc	3021.30
EB 2						
) HYDRAULIC JUMP : P+M BALANCE OCCURS AT 44.8 FT. FROM EB 2						
150.0	102.24	1.94	3099.76	101.76	1.46*	3109.69
EB 3						
200.0	102.33	1.93	3095.11	101.62	1.22*	3411.04
EB 4						
250.0	102.43	1.93	3092.40	101.51	1.01*	3953.74
SECT. 2 EB 5						
300.0	103.20	1.70 Dc	3021.31	102.52	1.02*	3936.56
EB 6						
350.0	104.20	1.70 Dc	3021.31	103.53	1.03*	3898.19
EB 7						
400.0	105.20	1.70 Dc	3021.31	104.55	1.05*	3811.89
EB 8						

450.0		106.20	1.70 Dc	3021.31	105.63	1.13*	3613.64
	EB	9					
500.0		107.20	1.70*Dc	3021.31	107.20	1.70 Dc	3021.30
SECT. 3							

** SUBCRITICAL FLOW MODEL **

*** IRREGULAR CHANNEL WATER SURFACE PROFILE ANALYSIS *** (c) Copyright 1983-88 Advanced Engineering Software

Standard Step Method irregular channel analysis. Based on development in 'OPEN CHANNEL HYDRAULICS',CHOW(1959)

STUDY NAME: Channel Flow = 150.00 cfs PAGE NUMBER:

LENGTH from CONTROL	WATER SURFACE (elev.)	FLOW DEPTH (ft)	FLOW AREA (ft*ft)	FLOW V (fps)	2 aV /2g (ft)	TOTAL HEAD (ft)	HYDR RADIUS (ft)	FRICTION SLOPE Sf	AVERAGE REACH Sf	REACH LENGTH (ft)	LOSS Hf (ft)	EDDY LOSS (ft)	TOTAL HEAD (ft)	Fr
.0	102.00	2.00	28.0	5.36	.446	102.446	1.48	.001737					102.446	.76
SECT. 1					a=1.00			n= .0150	P+M=	3139.00	e= .000			START
50.0	102.07	1.97	27.5	5.45	.462	102.535	1.46	.001825	.001781	50.0	.09	.00	102.535	.77
			EB 1		a=1.00			n= .0150	P+M=	3119.65	e= .000			
100.0	102.15	1.95	27.2	5.52	.473	102.628	1.45	.001889	.001857	50.0	.09	.00	102.628	.79
			EB 2		a=1.00			n= .0150	P+M=	3107.47	e= .000			
150.0	102.24	1.94	27.0	5.56	.481	102.723	1.44	.001932	.001910	50.0	.10	.00	102.723	.80
			EB 3		a=1.00			n= .0150	P+M=	3099.76	e= .000			
200.0	102.33	1.93	26.8	5.59	.485	102.820	1.44	.001960	.001946	50.0	.10	.00	102.820	.80
			EB 4		a=1.00			n= .0150	P+M=	3095.11	e= .000			
250.0	102.43	1.93	26.8	5.61	.488	102.919	1.44	.001977	.001969	50.0	.10	.00	102.919	.80
SECT. 2			EB 5		a=1.00			n= .0150	P+M=	3092.40	e= .000			
300.0	103.20	1.70	22.7	6.60	.676	103.874	1.29	.003149	.002563	50.0	.13	.00	103.047	*1.00
			EB 6		a=1.00			n= .0150	P+M=	3021.31	e= .000			STEEP
350.0	104.20	1.70	22.7	6.60	.676	104.874	1.29	.003149	.003149	50.0	.16	.00	104.031	*1.00
			EB 7		a=1.00			n= .0150	P+M=	3021.31	e= .000			STEEP
400.0	105.20	1.70	22.7	6.60	.676	105.874	1.29	.003149	.003149	50.0	.16	.00	105.031	*1.00
			EB 8		a=1.00			n= .0150	P+M=	3021.31	e= .000			STEEP
450.0	106.20	1.70	22.7	6.60	.676	106.874	1.29	.003149	.003149	50.0	.16	.00	106.031	*1.00
			EB 9		a=1.00			n= .0150	P+M=	3021.31	e= .000			STEEP
500.0	107.20	1.70	22.7	6.60	.676	107.874	1.29	.003149	.003149	50.0	.16	.00	107.031	*1.00
SECT. 3					a=1.00			n= .0150	P+M=	3021.31	e= .000			STEEP

** SUPERCRITICAL FLOW MODEL **

*** IRREGULAR CHANNEL WATER SURFACE PROFILE ANALYSIS *** (c) Copyright 1983-88 Advanced Engineering Software

Standard Step Method irregular channel analysis. Based on development in 'OPEN CHANNEL HYDRAULICS', CHOW(1959)

STUDY NAME: Channel Flow = 150.00 cfs PAGE NUMBER:

LENGTH from CONTROL	WATER SURFACE (elev.)	FLOW DEPTH (ft)	FLOW AREA (ft*ft)	FLOW V (fps)	$aV^2/2g$ (ft)	TOTAL HEAD (ft)	HYDR RADIUS (ft)	FRICTION SLOPE Sf	AVERAGE REACH Sf	REACH LENGTH (ft)	LOSS Hf (ft)	EDDY LOSS (ft)	TOTAL HEAD (ft)	Fr
.0	107.20	1.70	22.7	6.60	.676	107.873	1.29	.003152					107.873	*1.00
SECT. 3					a=1.00			n= .0150	P+M=	3021.30	e= .000			START
50.0	105.63	1.13	13.8	10.85	1.831	107.458	.92	.013445	.008298	50.0	.41	.00	107.458	1.96
			EB 9		a=1.00			n= .0150	P+M=	3613.64	e= .000			
100.0	104.55	1.05	12.8	11.74	2.143	106.698	.87	.016977	.015211	50.0	.76	.00	106.698	2.18
			EB 8		a=1.00			n= .0150	P+M=	3811.89	e= .000			
150.0	103.53	1.03	12.4	12.12	2.281	105.808	.85	.018623	.017800	50.0	.89	.00	105.808	2.28
			EB 7		a=1.00			n= .0150	P+M=	3898.19	e= .000			
200.0	102.52	1.02	12.2	12.28	2.342	104.858	.84	.019376	.018999	50.0	.95	.00	104.858	2.32
			EB 6		a=1.00			n= .0150	P+M=	3936.56	e= .000			
250.0	101.51	1.01	12.1	12.35	2.370	103.880	.84	.019718	.019547	50.0	.98	.00	103.880	2.34
SECT. 2			EB 5		a=1.00			n= .0150	P+M=	3953.74	e= .000			
300.0	101.62	1.22	15.2	9.86	1.512	103.134	.98	.010141	.014930	50.0	.75	.00	103.134	1.72
			EB 4		a=1.00			n= .0150	P+M=	3411.06	e= .000			MILD
350.0	101.76	1.46	18.8	7.97	.987	102.744	1.14	.005441	.007791	50.0	.39	.00	102.744	1.29
			EB 3		a=1.00			n= .0150	P+M=	3109.69	e= .000			MILD
400.0	101.90	1.70	22.7	6.60	.677	102.574	1.29	.003152	.004296	50.0	.21	.00	102.530	*1.00
			EB 2		a=1.00			n= .0150	P+M=	3021.30	e= .000			MILD
450.0	101.80	1.70	22.7	6.60	.677	102.474	1.29	.003152	.003152	50.0	.16	.00	102.416	*1.00
			EB 1		a=1.00			n= .0150	P+M=	3021.30	e= .000			MILD
500.0	101.70	1.70	22.7	6.60	.677	102.374	1.29	.003152	.003152	50.0	.16	.00	102.316	*1.00
SECT. 1					a=1.00			n= .0150	P+M=	3021.30	e= .000			MILD