Irregular Channel Hydraulics for Subcritical Flow

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Abstract

Steady flow in irregular channels is a commonly occurring problem in flood control. In this paper is developed a FORTRAN computer program for the analysis of either supercritical or subcritical steady flow in an irregular channel. The computer output is presented in a form manner, with various hydraulic flow variables included such as pressure-plus-momentum, among others.

1. Introduction

The study of open channel flow hydraulics requires an understanding of the fundamental principles embodied in the conservation of mass, momentum, and energy. Consequently, the basic definitions and equations need to be presented prior to developing the detailed computer software which can be applied to solving engineering problems. In the following, the necessary fundamentals of open channel hydraulics is briefly reviewed. These concepts will then be extended towards the development of comprehensive microcomputer software for the analysis of steady and unsteady flow in open channels.

2. Conservation of Mass, Momentum, and Energy

The study of open channel flow hydraulics is based upon the three conservation laws of mass, momentum, and energy. These laws are applicable to a specified quantity of matter (or system) which preserves its identity while undergoing a change in position, energy level, or other conditions.

The usual application of these laws is to develop integral equations which express the fundamental principles with respect to fluid flow through a control volume. The integral equations can be directly applied to flow problems or rewritten in terms of partial differential equations to analyze the interior of the fluid.

2.1. Conservation of Mass

For a fixed control volume Ω enclosed by the surface Γ, the integral form of the conservation of mass is given in vector notation by

$$\int_\Gamma \rho \mathbf{V} \cdot d\mathbf{A} + \frac{\partial}{\partial t} \int_\Omega \rho \, d\Omega = 0 \tag{1}$$

where $\mathbf{V}$ is the velocity vector with respect to the Cartesian coordinate system, and $d\mathbf{A}$ is the outward normal vector of Γ with magnitude dA. For steady flow the time derivative is zero, giving

$$\int_\Gamma \rho \mathbf{V} \cdot d\mathbf{A} = 0 \tag{2}$$

For incompressible flow

$$\int_\Gamma \mathbf{V} \cdot d\mathbf{A} = 0 \tag{3}$$

The differential equation form of mass conservation is often used in open channel flow hydraulics. This form is obtained by application of Gauss' theorem to (1) giving

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \tag{4}$$

where (u,v,w) are the (x,y,z) directional flow velocities. For steady, incompressible flow (4) reduces to

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{5}$$

2.2. Conservation of Momentum

Newton's second law of motion relates the net force $\mathbf{F}$ acting upon a system to the change in momentum $\mathbf{M}$ by

$$\mathbf{F} = \frac{d\mathbf{M}}{dt} \tag{6}$$

With respect to the fixed control volume Ω, (6) can be in integral form as

$$\int_\Gamma \mathbf{V} \rho \mathbf{V} \cdot d\mathbf{A} + \frac{\partial}{\partial t} \int_\Omega \mathbf{V} \rho \, d\Omega = \mathbf{F} \tag{7}$$

The $\mathbf{F}$ vector is composed of pressure and shear forces acting upon the surface of the system (F_S), and the body force vector ($\mathbf{B}$) which relates body forces (such as gravity) per unit volume of the system. Using $\mathbf{F}_S$ and $\mathbf{B}$, (7) is rewritten as

$$\int_\Gamma \mathbf{V} \rho \mathbf{V} \cdot d\mathbf{A} + \frac{\partial}{\partial t} \int_\Omega \mathbf{V} \rho \, d\Omega = \mathbf{F}_S + \int_\Omega \mathbf{B} \, d\Omega \tag{8}$$

For steady flow, (8) becomes

$$\int_\Gamma \mathbf{V} \rho \mathbf{V} \cdot d\mathbf{A} = \mathbf{F}_S + \int_\Omega \mathbf{B} \, d\Omega \tag{9}$$

An important application of (9) is when the fluid crosses Γ at only one point of entrance (point 1) and exit (point 2). Assuming entrance and exit areas, then (9) becomes

$$\begin{aligned} \Sigma F_x &= \dot{M}(u_2 - u_1) \\ \Sigma F_y &= \dot{M}(v_2 - v_1) \\ \Sigma F_z &= \dot{M}(w_2 - w_1) \end{aligned} \tag{10}$$

where $\dot{M}$ is the mass flowrate through Ω.

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2.3. Conservation of Energy

The first law of thermodynamics is used to develop the integral equation form of the conservation of energy. The conservation law is given by

$$dE = Q - W \tag{11}$$

where dE is the change in the energy of the system, Q is the heat added to the system, and W is the work done by the system. The energy E is written in terms of several contributions by

$$E = U + \frac{1}{2} mV^2 + mgZ \tag{12}$$

where U is the internal energy, m is the system mass, $mV^2/2$ is the kinetic energy, and mgZ is the potential energy. For $e = E/m$, (11) is written in integral equation form with respect to time by

$$\int_\Gamma e\rho \mathbf{V} \cdot d\mathbf{A} + \frac{\partial}{\partial t}\int_\Omega e\rho d\Omega = \frac{dQ}{dt} - \frac{dW}{dt} \tag{13}$$

Flow work done on Γ due to normal stresses (hydrostatic pressure) can be isolated from W term and (13) rewritten as

$$\int_\Gamma (e + p/\rho)\, \rho\mathbf{V} \cdot d\mathbf{A} + \frac{\partial}{\partial t}\int_\Omega e\rho d\Omega = \frac{dQ}{dt} - \frac{dW^*}{dt} \tag{14}$$

where p is the fluid pressure and W^* is the work term W less the flow work contribution.

For steady flow, (14) reduces to

$$\int_\Gamma (e + p/\rho)\, \rho\mathbf{V} \cdot d\mathbf{A} = \frac{dQ}{dt} - \frac{dW^*}{dt} \tag{15}$$

For one entrance (point 1) and exit (point 2) associated to Γ, and constant e,p,ρ over the entrance and exit areas,

$$\dot{M}(e_2 - e_1) + \dot{M}\left(\frac{p_2}{\rho_2} - \frac{p_1}{\rho_1}\right) = \frac{dQ}{dt} - \frac{dW^*}{dt} \tag{16}$$

Noting $e = E/m$, and $\dot{M}$ being the mass flow rate through Ω gives

$$\dot{M}\left[\left(\frac{p_2}{\rho_2} - \frac{p_1}{\rho_1}\right) + \left(i_2 - i_1\right) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g\left(Z_2 - Z_1\right)\right] = \frac{dQ}{dt} - \frac{dW^*}{dt} \tag{17}$$

where $i = U/m$. Letting

$$gH_L = (i_2 - i_1) - \frac{dQ}{dt} / \dot{M} \tag{18}$$

further reduces (17) for zero system work to

$$\frac{(p_2 - p_1)}{\rho} + \frac{(V_2^2 - V_1^2)}{2} + g(Z_2 - Z_1) + g\,H_L = 0 \tag{19}$$

or in terms of length units (or head)

$$\frac{(p_2 - p_1)}{\gamma} + \frac{(V_2^2 - V_1^2)}{2g} + (Z_2 - Z_1) + H_L = 0 \tag{20}$$

where γ is the fluid specific weight, and H_L is the head loss.

3. Fundamentals of Hydrualics

3.1. Hydraulic Grade Line and Energy Grade Line

For any point in the fluid, the summation of the elevation plus the pressure head is known as the piezometric head. The piezometric head represents the level to which liquid will rise in a piezometer tube where a line drawn through the tops of a series of piezometer columns is known as the hydraulic grade line (HGL). The energy grade line (EGL) is determined by the sum of the HGL and the velocity head $(V^2/2g)$ such as shown in Fig. 1.

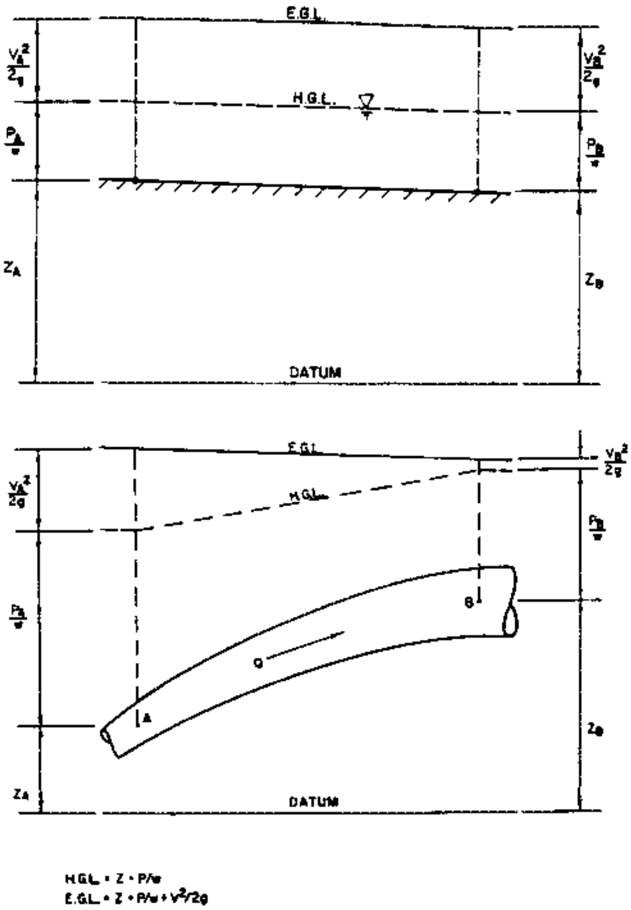


Fig. 1. Open channel flow energy balance.

3.2. Specific Energy

In open channel flow, the specific energy, S_E, is given by

$$S_E = y\cos^2\theta + cV^2/2g \tag{21}$$

where

y = vertical depth of flow
θ = angle of longitudinal bed profile with respect to the horizontal. (In most cases θ is small, therefore $\cos^2\theta = 1$)
c = kinetic energy correction factor. This is equal to one when the velocity distribution is uniform.
V = average flow velocity
g = gravitational acceleration

Given the flow rate (Q), the cross section flow area (A), and for $\cos^2\theta = 1$,

$$S_E = y + Q^2/2gA^2 \tag{22}$$

$$(S_E - y)A^2 = Q^2/2g = \text{constant} \tag{23}$$

From Equation (23), it is clear that the specific energy curve of Fig. 2 has the two asymptotes of $y = S_E$, and $y = 0$.

Alternate depths are defined as the two possible depths of flow for a given Q and S_E, and represent the two possible regimes of flow. For a point on the upper limb of the curve (Fig. 2), flow has a higher depth and thus a

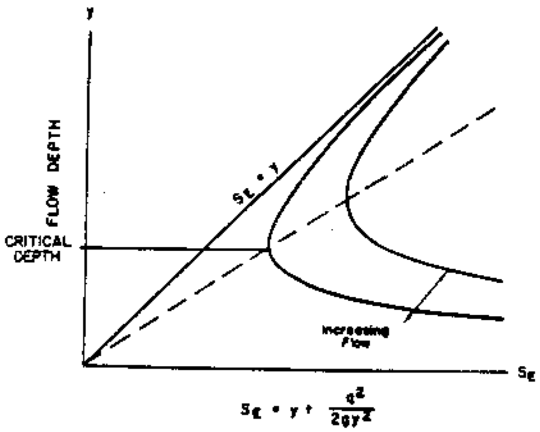


Fig. 2. The specific energy curve.

lower velocity. In this case, the flow is known as subcritical. On the lower limb of the curve the flow has a lower depth and thus a high velocity. This flow is classified as supercritical. When $dS_E/dy = 0$, the flow is critical (the location of this condition is at the crest of the curve). The depth relating to critical flow is known as the critical depth, y_c.

3.3. The Specific Force

Consider a steady, uniform incompressible flow in an open channel between section A to section B, and apply Newton's second law of motion. The second law of motion states that the change of momentum per unit time in the body is equal to the resultant of all the external forces that are acting on the body. Thus for a fixed control volume

$$Q(\beta_B V_B - \beta_A V_A) = P_A - P_B + W\sin\theta - F_f \qquad (24)$$

where

β = momentum correction factor
P_A and P_B = resultant pressures acting on section A and B, respectively
W = equivalent weight of the fluid pressure enclosed between sections A and B
F_f = total external forces (including friction) along the wetted boundary of the channel between section A and section B
θ = angle of channel slope with respect to the horizontal

The pressure forces are calculated by

$$P_A = \gamma A_A \bar{h}_A \text{ , } P_B = \gamma A_B \bar{h}_B \qquad (25)$$

where $\bar{h}$ = the distance to the centroid of the cross section below the water surface

If the difference of $W\sin\theta - F_f$ can be neglected and β_1 and $\beta_2 = 1$, then equation (24) can be simplified as

$$A_A\bar{h}_A + Q^2/gA_A = A_B\bar{h}_B + Q^2/gA_B \qquad (26)$$

Both sums of the terms in (26) involve identical components, and can be grouped together as the specific force, F_S. That is,

$$F_S = A\bar{h} + Q^2/gA \qquad (27)$$

The specific force curve (Fig. 3) is similar in some of its characteristics to the specific energy curve (Fig. 2). Both the specific force and specific energy are asymptotic to the $y = 0$ axis. However, the specific force curve is not asymptotic to the 45° line.

1. The Hydraulic Jump in a Rectangular Channel

Solution of the continuity and momentum equations for the special case of a rectangular channel leads to the following relation for the initial (y_1) and sequential depths (y_2) of a hydraulic jump on a horizontal floor:

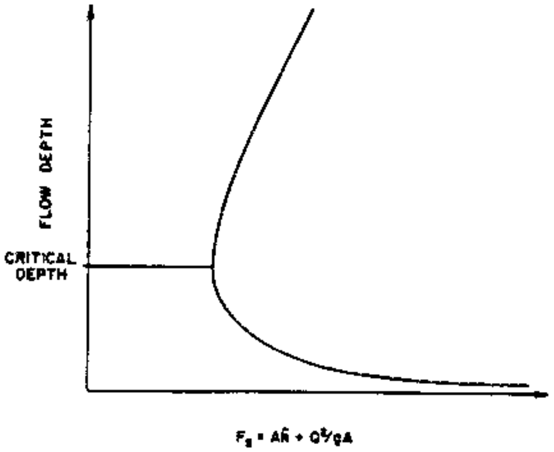


Fig. 3. The specific force curve.

$$y_2/y_1 = 1/2\ ((1 + 8F_1^2)^{.5} - 1) \qquad (28)$$

and

$$y_1/y_2 = 1/2\ ((1 + 8F_2^2)^{.5} - 1) \qquad (29)$$

In the above, F_1 and F_2 are the Froude numbers corresponding to depths y_1 and y_2, respectively. Substituting these values into the energy equation gives the energy loss in the jump

$$dE = (y_2 - y_1)^3/4y_1y_2 \qquad (30)$$

The jump efficiency E_2/E_1 can be expressed as

$$E_2/E_1 = ((8F_1^2 + 1)^{3/2} - 4F_1^2 + 1)/8F_1^2(2 + F_1^2) \qquad (31)$$

The relative height of the jump $(y_2 - y_1)/E_1$ can be expressed as

$$(y_2 - y_1)/E_1 = ((1 + 8F_1^2)^{.5} - 3)/(2 + F_1^2) \qquad (32)$$

The U.S. Bureau of Reclamation has classified various types of hydraulic jumps based on the Froude number, F. Their results are summarized below:

TABLE 1. HYDRAULIC JUMP CLASSIFICATIONS

F	Classification
1 to 1.7	undular jump
1.7 to 2.5	weak jump
2.5 to 4.5	oscillating jump
4.5 to 9.0	steady jump
> 9.0	strong jump

4. Gradually Varied Flow

Gradually varied flow in a prismatic channel can be modeled by the one-dimensional differential equation

$$dy/dx = (S_o - S_f)/(1 - F^2) \qquad (33)$$

where

y = flow depth
S_o = the bed slope
S_f = the friction slope
F = the Froude number
x = coordinate along channel bottom

When S_f approaches S_o, dy/dx approaches zero. Therefore, water surface profiles approach the normal depth of flow asymptotically.

If F approaches unity, dy/dx approaches infinity. Therefore, by (33), the water surface becomes nearly vertical.

4.1. S Profiles

A channel is classified as steep for a discharge when the normal depth is less than the critical depth, and is mild when the normal depth is greater than the critical. When the normal flow is rapid (normal depth less than critical) in a channel, the resulting profiles S_1, and S_2 and S_3 are known as the steep profiles. The S_1 profile approximates gradually varied flow which is above the normal and critical depths, S_2 represents the flow profile occurring between the critical and normal depths, and S_3 occurs below the normal depth, (Fig. 4).

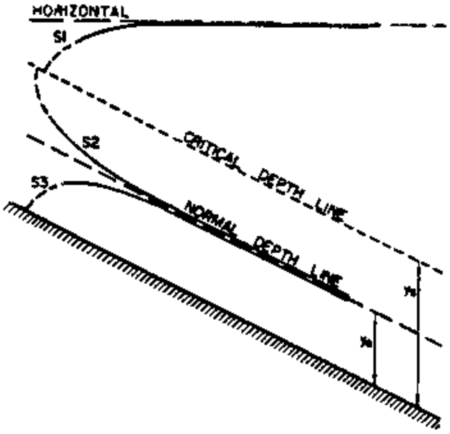


Fig. 4. Gradually varied flow profiles for steep slopes.

For the S_1 curve, both the numerator and denominator of (33) are positive and the depth increases downstream approaching a horizontal asymptote. An example is a steep canal emptying into a pool of high elevation.

For the S_2 curve, the numerator of (33) is negative and the denominator is positive (but approaches zero at $y = y_0$). This curve approaches the normal depth asymptotically. An example is the profile formed on the downstream side of an enlargement of a channel section.

In the S_3 curve, both the numerator and denominator of (33) are negative. An example is the water surface profile as the slope changes from a steep to a milder (but steep) slope.

4.2. M Profiles

A mild slope is one where the normal flow is tranquil (i.e., normal depth, y_0, is greater than the critical depth, y_c). Three profiles may occur, and are classified as M_1, M_2, and M_3, for flow depths above normal depth, below normal and above critical depths, and below critical depth, respectively, (Fig. 5).

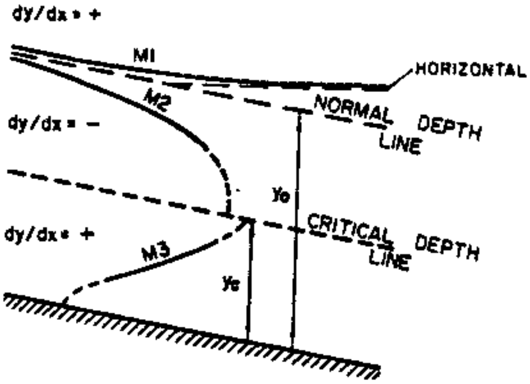


Fig. 5. Gradually varied flow profiles for mild slopes.

For the M_1 profile ($y>y_0>y_c$), the upstream end of the flow profile is tangent to the normal-depth line, since $dy/dx = 0$ as $y = y_0$. The downstream end is tangent to the horizontal because $dy/dx = S_0$ as y approaches infinity. A typical example in this case is the profile behind a dam in a mildly flowing river.

For the M_2 profile ($y_0>y>y_c$), the upstream end of the flow profile is tangent to the normal depth line, since $dy/dx = 0$ as $y = y_0$. The downstream end of the flow profile is less than the normal depth but above (or equal to) the critical depth. A typical example of this profile occurs at the upstream side of a sudden enlargement of a mild channel cross-section.

For the M_3 profile ($y<y_c<y_0$), the upstream flow depth is modeled to begin as an acute angle. The downstream flow terminates with a hydraulic jump. The most upstream flow depth is modeled as $y = 0$, and has an associated infinite flow velocity. The typical example of this profile is when a supercritical flow enters a mild channel.

4.3. C Profiles

When the normal depth and the critical depth are equal, the profiles resulting from this are labeled C_1 and C_3. C_1 occurs when the flow depth is above the critical depth and C_3 occurs when the flow depth is below the critical depth. These profiles represent the transition conditions between M (mild) and S (steep) flow profiles. The C_2 profile is usually associated to the case of uniform critical flow, (Fig. 6).

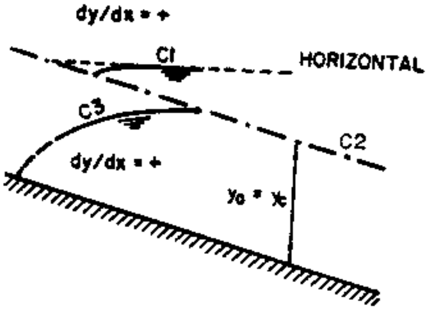


Fig. 6. Gradually varied flow profiles for critical slopes.

4.4. The Standard Step Method

Gradually varied flow profiles are generally computed by using any of three popular methods. Namely, the graphical-integration method, the direct-integration method, and the standard step method. The standard step method continues to be the most commonly used.

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 elevations above the datum at the two end sections can be expressed as (Fig. 7)

$$Z_A = y_A + z_A \tag{34}$$

and

$$Z_B = y_B + z_B \tag{35}$$

The friction losses are estimated between points A and B by

$$h_f = S_f\, dx = (S_A + S_B)dx/2 \tag{36}$$

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

$$S_0 dx + y_A + c_A V_A^2/2g = y_B + c_B V_B^2/2g + S_f dx + h_e \tag{37}$$

By substitution, the following is written

$$Z_A + c_A V_A^2/2g = Z_B + c_B V_B^2/2g + h_f + h_e \tag{38}$$

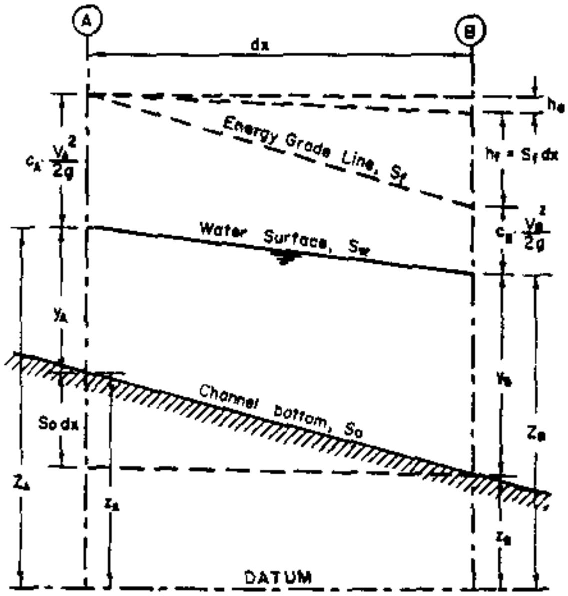


Fig. 7. Channel reach used for derivation of standard step method.

where h_e is the eddy loss defined by

$$h_e = k(cV^2/2g)$$

and k is defined 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

$$H_A = Z_A + c_A V_A^2/2g \tag{39a}$$

and

$$H_B = Z_B + c_B V_B^2/2g \tag{39b}$$

Using (39a,b), equation (38) can be expressed as

$$H_A = H_B + h_f + h_e \tag{40}$$

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

5. PROGRAM 1. Irregular Channel Backwater Curve Analysis

The Standard Step Method provides for the computation of an upstream water surface and EGL given the current values of the water surface elevation, EGL, flow rate, and other flow and channel characteristics. Consequently, the main thrust of the computer program is to develop backwater and drawdown curves for channel flow situations which can be considered mild (i.e., Froude numbers are all less than 1, and the normal depths are greater than the critical depths).

The program data entry requirements fall into two categories:

(1) preparation of channel cross section information
(2) definition of uniform channel flowrate, energy balance locations along the channel, and downstream hydraulic control information

The preparation of channel cross section information entails the definition of up to 20 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 flowline, 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 flowrate to be used through the entire study, the definition of the downstream hydraulic control water surface elevation, and the definition of energy balance locations along the channel. PROGRAM 1 computes the critical depth at each energy balance location. Consequently, should the specified control water surface elevation correspond to a channel flowdepth less than critical depth, the program will redefine the control to equal the critical depth. 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.

As the study 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 flowdepth 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.

PROGRAM 1 is designed to tabulate the hydraulic computations according to the form given in Chow (1959, pg. 269). The computer results also include a report description page which briefly describes the computer program operation and the interpretation of the final results. It should be noted that PROGRAM 1 models the gradually varied flow hydraulics as a one-dimensional channel reach, ignoring all additional losses due to bends, angle points, and so forth. However, the eddy loss factor represents a portion of the velocity head to be used for energy losses, and can be used to include any other additional losses as a function of the flow velocity head, Hv. Should channel flows exceed either channel bank, the model assumes that a vertical line extends upwards from both channel banks, with zero friction assumed along the imaginary boundary. In this flooding situation, the word FLOOD is printed in the computer results.

5.1. Data Entry for PROGRAM 1

In order to determine a water surface profile in a subcritical channel flow, the channel needs to be defined by cross-section coordinate pairs and associated flow parameters. This cross-section information is entered as one travels upstream through the channel. The program input variable names and descriptions are provided below.

PROGRAM CONTROL DATA ENTRY:

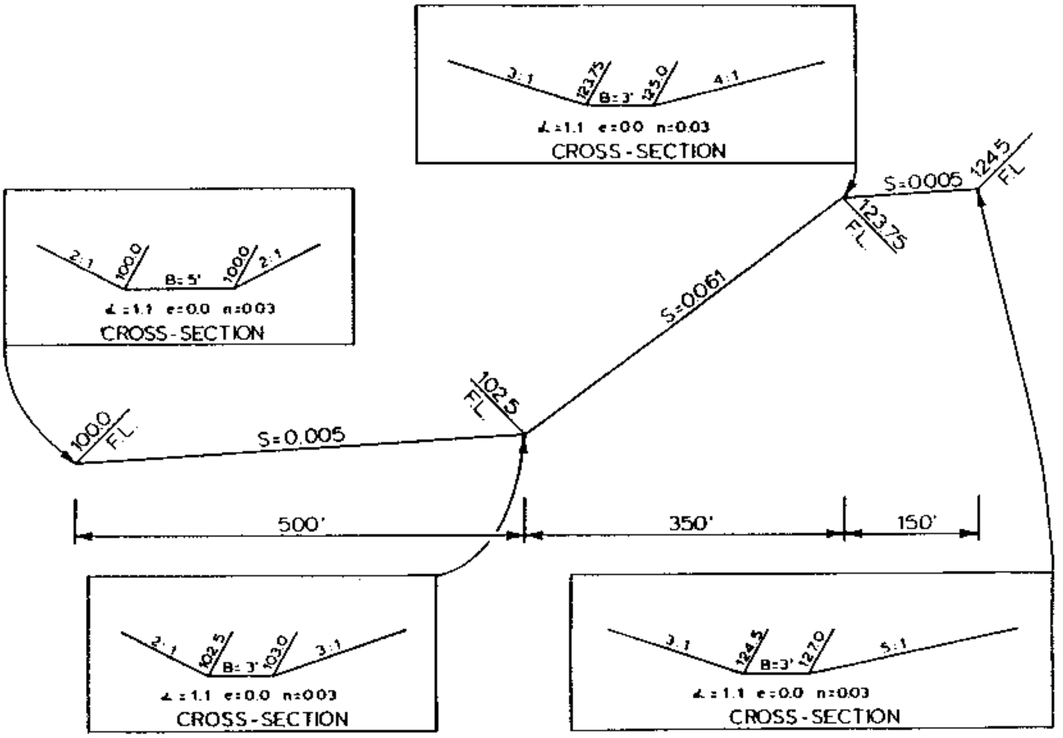
Variable Name	Description
N	Total number of cross-sections
QQ	Channel flow (cfs)
TOL	Tolerance in computation (feet)
YCON	Downstream hydraulic control water surface elevation (feet)

CROSS-SECTION DATA ENTRY (I = 1,N):

Variable Name	Description
M(I)	Number of coordinate pairs
XMAN(I)	Manning's friction factor
ALPHA(I)	Kinetic energy correction factor
EDDY(I)	Eddy loss coefficient
X(I,J),Y(I,J)	(X,Y) coordinates for cross-section number I
DISTS(I)	Distance to hydraulic control (feet)

ENERGY BALANCE LOCATION DATA ENTRY:

Program 1 uses straight line interpolation between cross-sections to define the irregular channel geometry and flow parameter values. To approximately solve the energy



EXAMPLE PROBLEM - IRREGULAR CHANNEL PROFILE AND CROSS-SECTIONS

equation, locations are needed where the energy balance is to be made.

Variable Name	Description
NE	Total number of energy balance locations
DIST(I)	Distance from hydraulic control where energy balance is to be made (I = 1, NE)

References

1. Hromadka II, T.V., Durbin, T.J., and DeVries, J., Computer Methods in Water Resources, Ch. 3, Lighthouse Publications, 1985.

PROGRAM 1

```
$ TYPE P.DOC
C  ----------------------------------------------------------
       SUBROUTINE PROF1E
C  ----------------------------------------------------------
C
C  DATA ENTRY ROUTINE FOR PROFILE BATCH SYSTEM
C
       COMMON /NUT/NUT
       COMMON/MIS/IFORM,IDF
       COMMON/MISC/IFF
       COMMON/INHIB/INH,INH1,INH2,INH3,INH4,INH5
       COMMON/BLK1/X(50,20),Y(50,20),NFL(50),M(50)
       COMMON/BLK2/DISTS(50),ALPHA(50),XMAN(50),EDDY(50)
       COMMON/BLK3/TOL,QQ,N,DIST(200),NE,KMODEL
C
       NUT=6
       IFF=12
C
       DO 1001 I=1,200
       DIST(I)=0.0
1001   CONTINUE
       DO 1002 I=1,50
       NFL(I)=0.0
       M(I)=0
       DISTS(I)=0.0
       ALPHA(I)=0.0
       XMAN(I)=0.0
       EDDY(I)=0.0
1002   CONTINUE
       DO 1003 J=1,20
       DO 1003 I=1,50
       X(I,J)=0.0
       Y(I,J)=0.0
       Y(I,J)=0.
       X(I,J)=0.
1003   CONTINUE
C
C
       OPEN 5,"PROF.DAT"
       OPEN 6,"PROF.ANS"
C
C..READ DATA INPUT
C
       READ FREE(5) N,QQ,TOL,YCON,NE
C
       SVTOL=TOL
       KMODEL=1
       IF(TOL.LT.0)KMODEL=2
       IF(TOL.LT.0)TOL = TOL *(-1)
C
       DO 4016 I=1,NE
       READ FREE(5) DIST(I)
4016   CONTINUE
       DO 4018 I=1,N
       READ FREE(5) DISTS(I)
       READ FREE(5) ALPHA(I)
       READ FREE(5) XMAN(I)
       READ FREE(5) EDDY(I)
       READ FREE(5) NFL(I)
       READ FREE(5) M(I)
       MM=M(I)
       DO 4024 K=1,MM
       READ FREE(5) X(I,K)
       READ FREE(5) Y(I,K)
4024   CONTINUE
4018   CONTINUE
C
C..END OF INPUT
C
       CALL PROF5(NUT,YCON)
       CALL PROF6(NUT)
       CALL PROF2(NUT,YCON)
C
       RETURN
       END
C
C
C  ----------------------------------------------------------
       SUBROUTINE PROF2(NT,YCON)
C  ----------------------------------------------------------
C
C
       BYTE NOTE,IST,BLANK,ITYPE
       CHARACTER*30 MODEL,MODEL1,MODEL2,BUFF*7
       COMMON/TEXTF/NOTE,BLANK,IST(26),IWT(12),IWTS(5)
       COMMON/BLK 1/X(50,20),Y(50,20),NFL(50),M(50)
       COMMON/BLK 2/DISTS(50),ALPHA(50),XMAN(50),EDDY(50)
       COMMON/BLK 3/TOL,Q,N,DIST(200),NE,KMODEL
       COMMON/MISC/IFF
C
C
       DATA MODEL1/' ** SUBCRITICAL FLOW MODEL ** '/,
       MODEL2/'** SUPERCRITICAL FLOW MODEL **'/
C
      DATA (IST(I),I=1,10)/'F','L','O','O','D','S','T','E','E','P',
      DATA(IST(I),I=11,15)/'S','T','A','R','T'/
      DATA(IST(I),I=16,26)/'S','E','C','T','.',' ',' ','M','I',
      'L','D'/
C
      DATA NOTE/'*'/,BLNK/' '/
C
C
C      ERROR = 1 IMPLIES OVERFLOW
C
```

```
        IFIRST=0
        ICOUNT=1
        DCON=YCON
        ITYPE=BLANK
C
        MODEL = MODEL1
        IF(KMODEL.EQ.2) MODEL = MODEL2
C
C  CALCULATE CONTROL SECTION HYDRAULICS
C
        IF(KMODEL.EQ.2)GO TO 201
C
C  SUBCRITICAL FLOW
        CALL PROF4(0,YC,YN,J,K,NT,A,V,R,FR,ERROR)
        IF(YC.GE.YCON)DCON=YC
        IF(YC.GE.YCON)ITYPE=NOTE
        IF(YC.GE.YCON)GOTO 10
        CALL PROF3(1,YCON,A,V,P,DH,TW,R,FR,1.,XPM,NT,ERROR)
        GO TO 10
C
C
C  SUPERCRITICAL FLOW
C
201     CONTINUE
        CALL PROF4(1000,YC,YN,J,K,NT,A,V,R,FR,ERROR)
C
        JY = NFL(N)
        YMINE = Y(N,JY)
        DMIN = YCON-(YMINE + .05)
        IF(DMIN .LT. 0.) YCON = YC
C
        IF(YCON.GE.YC) DCON = YC
        IF(YCON.GE.YC) ITYPE = NOTE
        IF(YCON.GE.YC) YCON = YC
        IF(YCON.GE.YC) FR = 1.
        CALL PROF3(N,YCON,A,V,P,DH,TW,R,FR,1.,XPM,NT,ERROR)
C
C


10      WRITE(NT,1000)IFF
1000    FORMAT(1X,A1,/,50X,'CUT ALONG OUTSIDE BORDER* *',/,
     C  76X,'*',/,76X,'V')
        WRITE(NT,1001)
1001    FORMAT(10X,'+',109('-'),'+')
        WRITE(NT,1002)MODEL
1002    FORMAT(2(10X,'|',109X,'|',/),10X,'|',39X,A30,40X,'|',/,
     .  10X,'|*** IRREGULAR CHANNEL WATER SURFACE PROFILE ANALYSIS ***',
     .  4X,'Copyright 1983,1986 Advanced Engineering Software',
     .  '|',/,
     C  10X,'|Standard Step Method irregular channel',
     C  ' analysis. Based on development in "OPEN CHANNEL'
     C  ' HYDRAULICS",CHOW(1959)|')
        WRITE(NT,1010)Q
1010    FORMAT(10X,'|    STUDY NAME:',46X,'Channel Flow = ',F9.2,' cfs',
     C  4X,'PAGE NUMBER:',4X,'|')
        WRITE(NT,1001)
        WRITE(NT,1003)
1003    FORMAT(10X,'| LENGTH| WATER | FLOW|  FLOW | FLOW|',
     C  '  2   |  TOTAL | HYDR |FRICTION| AVERAGE| REACH|',
     C  ' LOSS|EDDY|  TOTAL |      |',/,10X,'|  from |SURFACE|',
     C  'DEPTH|  AREA |  V  |aV /2g|  HEAD  |RADIUS|  SLOPE |',
     C  '  REACH |LENGTH|  HE |LOSS|  HEAD  |  Fr |',/,
     C  10X,'|CONTROL|(elev.)| (ft)|(ft*ft)|(fps)| (ft) |  (ft)  |',
     C  ' (ft) |   Sf   |   Sf   | (ft) | (ft)|(ft)|  (ft)  |     |')
        WRITE(NT,1004)
1004    FORMAT(10X,'|-------|-------|-----|-------|-----|',
     C  '------|--------|------|--------|--------|------|',
     C  '-----|----|--------|-----|')
C...........USE KINGS HANDBOOK(8-136) FORMULA
C
        ITEMP=1
        IF(KMODEL.EQ.2)ITEMP = N
C
        SF=XMAN(ITEMP)*XMAN(ITEMP)*V*V/2.2082/R**1.3333
        AHV=ALPHA(ITEMP)*V*V/64.4
C
        HVA = AHV
        HVB = 0.
        EDA = EDDY(ITEMP)
        EDB = 0.
C
        H1=DCON+AHV
        H2=H1
        NODE=NFL(ITEMP)
        YY=DCON-Y(ITEMP,NODE)
        WRITE(NT,1005)DISTS(1),DCON,YY,A,V,AHV,H1,R,SF,H2,ITYPE,FR
1005    FORMAT(10X,'|'F7.1,'|',F7.2,'|',F5.2,'|',F7.1,'|',
     C  F5.2,'|',F6.3,'|',F8.3,'|',F6.2,'|',F8.6,'|        |',
     C  '      |      |    |',F8.3,'|',A1,F4.2,'|')
        DO 13 IJ=1,5
13      IWTS(IJ)=BLANK
        DO 131 IJ=1,12
131     IWT(IJ)=BLANK
        IF(ERROR.EQ.0.)GOTO 151
        DO 14 IJ=1,5
14      IWT(IJ)=IST(IJ)
C
151     CONTINUE
C
        DO 141 IJ=6,12
141     IWT(IJ)=IST(10+IJ)
C
C
        DO 78 IJ=1,5
78      IWTS(IJ)=IST(IJ+10)
79      IFIRST=IFIRST+1
C
17      NTEMP=1
        IF(KMODEL.EQ.2)NTEMP = N
C
        WRITE(NT,1011)(IWT(IJ),IJ=6,10),NTEMP,(IWT(IJ),IJ=1,5),
     .  ALPHA(NTEMP),XMAN(1),(IWTS(IJ),IJ=1,5)
1011    FORMAT(10X,'|',5A1,I2,'|',1X,5A1,1X,'|'5X,'|',7X,'|',5X,'|a=',
     C  F4.2,'|',8X,'|',6X,'|n=',F6.4,'|',8X,'|',6X,'|',
     C  5X,'|',4X,'|',8X,'|',5A1,'|')
        WRITE(NT,1004)
C.......INITIALIZE SF1
        SF1=SF
```

```
C
C.......MAIN LOOP
C
        DO 100 LL=1,NE
C
        L=LL
        IF(KMODEL.EQ.2) L = NE-LL+1
C
        CALL PROF4(L,YC,YN,J,K,NT,A,V,R,FR,ERROR)
        YMIN=YC
C
        YMAX=YC+250.
C
        R=(DIST(L)-DISTS(J))/(DISTS(K)-DISTS(J))
        R1=1.-R
        JFL=NFL(J)
        KFL=NFL(K)
        YMINJ=Y(J,JFL)
        YMINK=Y(K,KFL)
        YFL=R*YMINK+R1*YMINJ
C
        IF(KMODEL.EQ.2) YMIN = .01 + YFL
        IF(KMODEL.EQ.2) YMAX = YC
C
C.......ESTIMATE SECTION BANK-ELEVATIONS
        XLBNK=R*Y(K,1)+R1*Y(J,1)
        MMJ=M(J)
        MMK=M(K)
        XRBNK=R*Y(K,MMK)+R1*Y(J,MMJ)
C
C
        DO 50 LLL=1,18
        YTEST=.5*(YMIN+YMAX)
        DY=YTEST-YFL
        YJ=YMINJ+DY
        YK=YMINK+DY
        CALL PROF3(J,YJ,AJ,V,PJ,DHJ,TWJ,XR,FR,1.,XPMJ,NT,ERROR)
        CALL PROF3(K,YK,AK,V,PK,DHK,TWK,XR,FR,1.,XPMK,NT,ERROR)
        A=R*AK+R1*AJ
C
        YBARA = R*XPMK + R1*XPMJ
C
        V=Q/A
        AL=R*ALPHA(K)+R1*ALPHA(J)
        XN=R*XMAN(K)+R1*XMAN(J)
        AHV=AL*V*V/64.36
C
        XPM = (Q/32.18 * Q/A + YBARA) * 62.4
C
        HVB = AHV
C
        TW=R*TWK+R1*TWJ
        P=R*PK+R1*PJ
        RH=A/P
        DH=A/TW
        SF=XN*XN*V*V/2.22/RH**1.3333
        DX=DIST(1)
        IF(L.GT.1)DX=DIST(L)-DIST(L-1)
C
        IF(KMODEL.EQ.2) DX = DISTS(N) - DIST(NE)
        IF(KMODEL.EQ.2 .AND. LL.GT.1)DX = DIST(L+1) - DIST(L)
C
        SFM=.5*(SF1+SF)
        HF=DX*SFM
C
        EDB = R*EDDY(K) + R1*EDDY(J)
        ED = .5*(EDA+EDB)
C
        HE = ED*(ABS(HVB - HVA))
C
        IF(KMODEL .EQ. 2)GO TO 51
C
        H2T=H2+HE+HF
        H1T=YTEST+AHV
        IF(H2T-H1T)30,60,40
30      YMAX=YTEST
        GOTO 50
40      YMIN=YTEST
C
C
        GO TO 50
51      CONTINUE
        H2T = H2-HE--HF
        H1T = YTEST + AHV
        IF(H2T - H1T)511,60,513
C
511     YMIN = YTEST
        GO TO 50
513     YMAX = YTEST
C-------------------------------------------------------------
C
C  REDEFINE ENERGY LEVEL IN CALCULATIONS
C
C-------------------------------------------------------------
50      CONTINUE
60      H1=H1T
        H2=H1
C.......OUTPUT RESULTS
        DO 61 IJ=1,5
61      IWTS(IJ)=BLANK
        DO 611 IJ=1,12
611     IWT(IJ)=BLANK
C--INIT BUFF EACH LOOP INCREMENT
        BUFF = '          '
C
C
        IF(YTEST.LT.XLBNK.AND.YTEST.LT.XRBNK)GOTO 70
        DO 62 IJ=1,5
62      IWT(IJ)=IST(IJ)
70      CONTINUE
        FR=SQRT(AL*V*V/DH/32.18)
C
        HVA = HVB
        EDA = EDB
        SF1 = SF
C
```

```
        ITYPE=BLANK
        TEST=ABS(1.-FR)
        IF(TEST.LT..01)ITYPE=NOTE
C
C
        IF(KMODEL.EQ.1 .AND. YN.GT.YC)GO TO 77
        IF(KMODEL.EQ.2 .AND. YN.LT.YC)GO TO 77
        IF(KMODEL.EQ.2) GO TO 751
C
C
        DO 75 IJ=1,5
75      IWTS(IJ)=IST(IJ+5)
C
C
        GO TO 753
751     CONTINUE
        DO 752 IJ=1,5
        IWTS(IJ) = IST(22+IJ)
752     CONTINUE
C
753     CONTINUE
C
C
77      CONTINUE
C
        XDISTL = DIST(L)
        IF(KMODEL.EQ.2) XDISTL = DISTS(N) - XDISTL
C
        WRITE(NT,1006)XDISTL,YTEST,DY,A,V,AHV,H1,RH,SF,SFM,DX,HF,
     .  HE,H2T,ITYPE,FR
C
1006    FORMAT(10X,'|',F7.1,'|',F7.2,'|',F5.2,'|',F7.1,'|',
     C  F5.2,'|',F6.3,'|',F8.3,'|',F6.2,'|',F8.6,'|',F8.6,'|',
     C  F6.1,'|',F5.2,'|',F4.2,'|',F8.3,'|',A1,F4.2,'|')
C.......SEE IF LOCATION =CROSS-SECTION
        IF(DIST(L).EQ.DISTS(J).OR.DIST(L).EQ.DISTS(K))GOTO 82
        GOTO 85
C
82      DO 83 IJ=6,12
83      IWT(IJ)=IST(10+IJ)
        IF(DIST(L) .EQ. DISTS(J)) ISEC = J
        IF(DIST(L) .EQ. DISTS(K)) ISEC = K
        WRITE(BUFF,95) (IWT(IJ),IJ=6,10),ISEC
95      FORMAT(5A1,I2)
C
85      CONTINUE
C
C
        WRITE(NT,1012)BUFF,(IWT(IJ),IJ=1,5),L,
     C  AL,XN,XPM,ED,(IWTS(IJ),IJ=1,5)
1012  FORMAT(10X,'|',A7,'|',1X,5A1,1X,'|','EB',I3,'|',7X,'|',5X,'|a=',
     C  F4.2,'|',8X,'|',6X,'|n=',F6.4,'|','P+M=',F11.2,'|',5X,
     C  'e=',F5.3,7X,'|',5A1,'|')
C
        WRITE(NT,1004)
C.......PAGE COSMETICS
        ICOUNT=ICOUNT+1
        IF(ICOUNT.LT.13)GOTO 100
        WRITE(NT,1001)
        IF(KMODEL.EQ.1 .AND. L.EQ.NE)GO TO 200
        IF(KMODEL.EQ.2 .AND. L.EQ.1 )GO TO 200
C
        WRITE(NT,1000) IPF
        WRITE(NT,1001)
        WRITE(NT,1002)
        WRITE(NT,1010)Q
        WRITE(NT,1001)
        WRITE(NT,1003)
        WRITE(NT,1004)
        ICOUNT=0
100     CONTINUE
C.......END OF STUDY, BUT IN MIDDLE OF PAGE....FINISH OFF PAGE
        NREM=13-ICOUNT
        DO 150 K=1,NREM
        WRITE(NT,1007)
        WRITE(NT,1007)
1007    FORMAT(10X,'|',7X,'|',7X,'|',5X,'|',7X,'|',5X,'|',6X,
     C  '|',8X,'|',6X,'|',8X,'|',8X,'|',6X,'|',5X,'|',4X,'|',
     C  8X,'|',5X,'|')
        WRITE(NT,1004)
150     CONTINUE
        WRITE(NT,1001)
200     CONTINUE
        WRITE(NT,2000)
2000    FORMAT(/)
C
        RETURN
        END
C
C
C   ----------------------------------------------------------------
        SUBROUTINE PROF3(L,YDEPTH,A,V,P,DH,TW,R,FR,S,XPM,NT,ERROR)
C   ----------------------------------------------------------------
C
C       CALCULATES CROSS-SECTION #L FLOW
C
C       GEOMETRIC DATA GIVEN
C       PARAMETERS, & FLOWDEPTH:YDEPTH
C
        COMMON/BLK 1/X(50,20),Y(50,20),NFL(50),M(50)
        COMMON/BLK 2/DISTS(50),ALPHA(50),XMAN(50),EDDY(50)
        COMMON/BLK 3/TOL,Q,N,DIST(200),NE,KMODEL
C
C
        HYPOT(B,C)=((B*B)+(C*C))**.5
        ERROR=0.
        YBARA = 0.
        XPM= 0.
        I=L
        P=0.
        V=0.
        TW=0.
        A=0.
        KK=M(I)-1
        DO 200 J=1,KK
        IF((YDEPTH.LE.Y(I,J)).AND.(YDEPTH.LE.Y(I,(J+1))))GOTO 200
        XDIF=X(I,(J+1))-X(I,J)
        YDIF=Y(I,(J+1))-Y(I,J)
        IF(YDIF)150,150,160
150     YDIF=-YDIF
        YUP=Y(I,J)
        YLOW=Y(I,(J+1))
        GOTO 170
160     YUP=Y(I,(J+1))
        YLOW=Y(I,J)
170     TEMP=YUP-YDEPTH
        IF(TEMP.LE.0.)GOTO 155
        GOTO 165
C
155     AA=(ABS(YDEPTH-YUP)*XDIF)+(.5*XDIF*ABS(YDIF))
C
        PP=HYPOT(XDIF,YDIF)
        TWTW=XDIF
C---------
        DYBARA = .5*(YDEPTH-YUP) * (YDEPTH-YUP) * XDIF +
                 (ABS(YDEPTH-YUP) + ABS(YDIF)/3.) * .5*XDIF*ABS(YDIF)
C---------
        GOTO 198
C
165     IF(ABS(YDIF).LT. .002)GOTO 155
C
        YDEEP=YDEPTH-YLOW
        TWTW=XDIF*(YDEEP/YDIF)
        AA=.5*YDEEP*TWTW
        PP=(YDEEP/YDIF)*HYPOT(XDIF,YDIF)
C
        DYBARA = (YDEEP/3.)*AA
C
198     A=A+AA
        P=P+PP
        TW=TW+TWTW
C
        YBARA = YBARA + DYBARA
C
200     CONTINUE
C
        IF(P.LE. .01)WRITE(NT,220)
C
C
220      FORMAT(1X,'NOTE: FLOW DEPTH ESTIMATE OF WETTED PERIMETER ',
     .'IS LESS THAN .001',/1X,
     .'SUGGEST: (1) ADDING MORE ENERGY BALANCE LOCATIONS',/1X,
     .'         (2) CHECKING CROSS-SECTION DATA',/1X,
     .'NOTE: WETTED PERIMETER SET TO .01 FEET.')
C
C
        IF(P.LE. .01) P =.01
C
        R=A/P
        V=Q/A
        DH=A/TW
        FR=SQRT(ALPHA(I)*V*V/32.18/DH)
C-----------
        XPM = YBARA
C-----------
180     CONTINUE
C.......CHECK FOR OVERFLOW
        KK=KK+1
C
C  ERROR=1  => FLOW ABOVE CHANNEL CONFINES
C
        IF(YDEPTH.GT.Y(I,1).OR.YDEPTH.GT.Y(I,KK))ERROR=1.
C
C
        RETURN
        END
C
C
C  -----------------------------------------------------------------
        SUBROUTINE PROF4(I,YC,YN,J,K,NT,A,V,RH,FR,ERROR)
C  -----------------------------------------------------------------
C
C.......DETERMINES DC AND DN  ELEVATION AND SURROUNDING
C.......SECTIONS "J" AND "K"
C.......I IS INDEX TO ENERGY-BALANCE LOCATION
C.......I=0 IMPLIES CONTROL SECTION ANALYSIS
C
C
C       I=0    => DOWNSTREAM CONTROL
C       I=1000 => UPSTREAM CONTROL
C
C.......FIND J AND K:
C
        COMMON/BLK 1/X(50,20),Y(50,20),NFL(50),M(50)
        COMMON/BLK 2/DISTS(50),ALPHA(50),XMAN(50),EDDY(50)
        COMMON/BLK 3/TOL,Q,N,DIST(200),NE,KMODEL
C
C
        DD=.01
        L=2
        IF(I.EQ.0)GOTO 15
C
        DD = DISTS(N) - .01
        L = N
        IF(I .EQ. 1000)GO TO 15
C
        IF(I.GT.0)DD=DIST(I)
C
        DO 10 L=1,N
        IF(DD.GT.DISTS(L))GOTO 10
        GOTO 15
10      CONTINUE
15      J=L-1
        K=L
C.......GET LENGTH RATIO R
        R=(DD-DISTS(J))/(DISTS(K)-DISTS(J))
        R1=1.-R
C.......FIND YC
        JFL=NFL(J)
        KFL=NFL(K)
        YMINJ=Y(J,JFL)
        YMINK=Y(K,KFL)
        YMIN=R*YMINK+R1*YMINJ
        YFL=YMIN
C
        YMAX=YMIN+250.
```

```
C
        AL=R*ALPHA(K)+R1*ALPHA(J)
C
        DO 100 L=1,18
C
        YTEST=.5*(YMIN+YMAX)
        DY=YTEST-YFL
        YJ=YMINJ+DY
        YK=YMINK+DY
        CALL PROF3(J,YJ,AJ,V,PJ,DHJ,TWJ,XR,FR,1.,XPM,NT,ERROR)
        CALL PROF3(K,YK,AK,V,PK,DHK,TWK,XR,FR,1.,XPM,NT,ERROR)
        A=R*AK+R1*AJ
        TW=R*TWK+R1*TWJ
        P=R*PK+R1*PJ
        RH=A/P
        DH=A/TW
        V=Q/A
        FR=(AL*V*V/32.18/DH)
        IF(FR-1.)20,120,40
20      YMAX=YTEST
        GOTO 100
40      YMIN=YTEST
100     CONTINUE
120     YC=YTEST
        FR=SQRT(FR)
C.......GET YN
        XN=R*XMAN(K)+R1*XMAN(J)
        SLOPE=(YMINK-YMINJ)/(DISTS(K)-DISTS(J))
        YN=0.
        IF(I.EQ.0)GOTO 300
C
C
        IF(SLOPE.LT. .00001)WRITE(NT,77)
77      FORMAT(5X,'CHANNEL SLOPE ASSUMED AT PROGRAMMED DEFAULT VALUE',
     .  ' OF .00001')
        IF(SLOPE .LT. .00001)SLOPE = .00001
C
C
        FACT=1.486/XN*SQRT(SLOPE)
        YMIN=R*YMINK+R1*YMINJ
C
        YMAX=YMIN+250.
C
        DO 200 L=1,18
        YTEST=.5*(YMIN+YMAX)
        DY=YTEST-YFL
        YJ=YMINJ+DY
        YK=YMINK+DY
        CALL PROF3(J,YJ,AJ,V,PJ,DHJ,TWJ,XR,FR,1.,XPM,NT,ERROR)
        CALL PROF3(K,YK,AK,V,PK,DHK,TWK,XR,FR,1.,XPM,NT,ERROR)
        A=R*AK+R1*AJ
        P=R*PK+R1*PJ
        RH=A/P
        QTEST=FACT*A*RH**.6667
        IF(QTEST-Q)150,220,180
150     YMIN=YTEST
        GOTO 200
180     YMAX=YTEST
200     CONTINUE
220     YN=YTEST
300     CONTINUE
C
        RETURN
        END
C
C
C   ----------------------------------------------------------------
        SUBROUTINE PROF5(NT,YCON)
C   ----------------------------------------------------------------
C
C
        COMMON/BLK 3/TOL,Q,N,DIST(200),NE,KMODEL
C
C
        WRITE(NT,10)
10      FORMAT(16X,'IRREGULAR CHANNEL WATER SURFACE PROFILE ANALYSIS',
     .  ///5X,'Study Name:',49('_'),4X,'Page Number ____')
        WRITE(NT,11)
11      FORMAT(//5X,'The following study is based on the well known ',
     .'STANDARD STEP METHOD to',/5X,
     .'analyse gradually varied flow in an irregular channel. Energy-',
     .'head',/5X,
     .'losses and corresponding notation used in the program are as ',
     .'follows:',/10X,
     .'FRICTION LOSSES:     n = Mannings friction factor',/10X,
     .'EDDY LOSSES:         e = eddy loss coefficient',/10X,
     .'KINETIC ENERGY',/10X,
     .'CORRECTION FACTOR:  a = correction factor')
        WRITE(NT,15)
15      FORMAT(/5X,'The PROGRAM determines gradually varied flow water',
     .' surface elevations',/5X,
     .'by balancing the classical energy equation between user-',
     .'specified',/5X,
     .'"energy balance" locations. All geometric and parameter infor',
     .'mation is',/5X,
     .'averaged between defined channel cross-sections by straight ',
     .'line',/5X,
     .'interpolation.')
        WRITE(NT,20)
20      FORMAT(/5X,'THE ONLY LOSSES INCLUDED ARE FRICTION AND EDDY ',
     .'LOSSES. The analysis',/5X,
     .'formulation and presentation of results follow the develop',
     .'ment given in',/5X,
     .'"OPEN CHANNEL HYDRAULICS", by Chow(1959).')
        WRITE(NT,25)
25      FORMAT(/5X,'The PROGRAM will default to a flow-depth of CRIT',
     .'ICAL DEPTH whenever the',/5X,
     .'flow regime changes between SUBcritical and SUPERcritical flow',
     .' (or vice',/5X,
     .'versa). Therefore, supercritical water surface information is ',
     .'not',/5X,
     .'computed in a subcritical flow model; nor is subcritical water',
     .' surface',/5X,
     .'information developed in a supercritical flow model. In a ',
     .'subcritical',/5X,
     .'flow model where flow may be supercritical, critical depth is',
     .' assumed',/5X,
     .'as a minimum flow depth which exceeds the actual supercritical',
     ./5X,'flowdepth in the channel. Similarly in a supercritical ',
     .'flow model',/5X,
     .'critical depth is assumed as a maximum flow depth. Conse',
     .'quently,',/5X,
     .'rapidly varied flow effects, hydraulic jumps, and transitions',
     .' between',/5X,
     .'flow regimes ARE NOT INCLUDED in the PROGRAM.')
        WRITE(NT,30)Q,N,NE
30      FORMAT(/5X,'For this study, the following information is used:',
     ./10X,'Channel flow(cfs) = ',F8.1,/10X,
     .'Number of channel cross-sections = ',I2,/10X,
     .'Number of Energy-Balance locations = ',I2)
        IF(KMODEL.EQ.1)WRITE(NT,32)YCON
        IF(KMODEL.EQ.2)WRITE(NT,33)YCON,N
32      FORMAT(/5X,'COMPUTER RESULTS are based upon SUBCRITICAL flow ',
     .'model with assumed',/5X,
     .'control water surface elevation(feet) = ',F8.2,' at ',
     .'cross-section 1')
33      FORMAT(/5X,'COMPUTER RESULTS are based upon SUPERCRITICAL flow',
     .' model with assumed',/5X,
     .'control water surface elevation(feet) = ',F8.2,' at ',
     .'cross-section ',I2)
        WRITE(NT,40)
40      FORMAT(/5X,'Special notation given in the computer results are',
     .' as follows:',/10X,
     .'(1) SECT.....the section number appears in the first column',
     ./23X,'whenever the energy-balance channel location occurs',
     ./23X,'at one of the defined channel cross-sections.',/10X,
     .'(2) FLOOD....this word appears in the second column whenever ',
     .'the',/23X,'estimated flowdepth exceeds either bank of the',/23X,
     .'channel section.',/10X,
     .'(3) EB.......the energy balance number is listed in ',
     .'column 3.',/10X,
     .'(4) P+M......the pressure-plus-momentum (in pounds',
     .' force)',/23X,'is provided in columns 10 and 11.',/10X,
     .'(5) STEEP....this word appears in the last column whenever the',
     ./23X,'Channel Critical Depth exceeds the Normal Depth.',/10X,
     .'(6) MILD.....this word appears in the last column whenever the',
     ./23X,'Channel Critical Depth is less then the computed',/23X,
     .'Normal Depth.')
C
C
C
        RETURN
        END
C
C
C   ----------------------------------------------------------------
        SUBROUTINE PROF6(NT,IHEAD,ICOM,IFILE)
C   ----------------------------------------------------------------
C
        CHARACTER BUFF1*9,BUFF2*8
      COMMON/BLK 1/X(50,20),Y(50,20),NFL(50),M(50)
        COMMON/BLK 2/DISTS(50),ALPHA(50),XMAN(50),EDDY(50)
        COMMON/BLK 3/TOL,QQ,N,DIST(200),NE,KMODEL
        COMMON/MISC/IFF
C
C
C.......OUTPUT CROSS-SECTIONS
C
C
        WRITE(NT,10)IFF
10      FORMAT(1X,A1)
        WRITE(NT,4)
4       FORMAT(1X,76('_'))
        WRITE(NT,5)
5       FORMAT(1X,76('*'))
C
        WRITE(NT,161)
C
C
        WRITE(NT,6)
        WRITE(NT,7)
7       FORMAT(5X,'CROSS-SECTION INFORMATION:')
        WRITE(NT,6)
C
C
        DO 50 K=1,N
        WRITE(NT,20)K,XMAN(K),ALPHA(K),EDDY(K),DISTS(K)
20      FORMAT(5X,'INFORMATION FOR CROSS-SECTION NUMBER:',I3,/,
     C  5X,'MANNINGS FRICTION FACTOR = ',F6.5,/,
     C  5X,'KINETIC ENERGY CORRECTION FACTOR = ',F5.3,/,
     C  5X,'EDDY LOSS FACTOR = ',F5.3,/,
     C  5X,'DISTANCE(ft.) TO CROSS-SECTION #1 = ',F8.2,/)
        MM=M(K)
        WRITE(NT,25)
25      FORMAT(5X,'NODAL POINT COORDINATE INFORMATION:',/,
     C  5X,'NODE NO.',5X,'X(ft.)',4X,'Y(elev.)')
        DO 30 KK=1,MM
        WRITE(NT,31)KK,X(K,KK),Y(K,KK)
31      FORMAT(7X,I3,7X,F7.2,5X,F7.2)
30      CONTINUE
        WRITE(NT,6)
6       FORMAT(1X,76('='))
8       FORMAT(1X,76('-'))
50      CONTINUE
        WRITE(NT,163)
163     FORMAT(//)
        WRITE(NT,60)
60      FORMAT(5X,'USER-SPECIFIED ENERGY-BALANCE CHANNEL LOCATIONS:'
     C  ,/,10X,'ENERGY BALANCE          DISTANCE TO',/,
     C  10X,   'LOCATION NUMBER      CROSS-SECTION #1')
        WRITE(NT,61)(I,DIST(I),I=1,NE)
61      FORMAT(18X,I2,13X,F8.2)
        WRITE(NT,6)
        CONTINUE
C
C  FORMATS
C
161     FORMAT(13X,'IRREGULAR CHANNEL WATER SURFACE PROFILE COMPUTATION',
     ./7X,'FOR SUBCRITICAL (SUPERCRITICAL) FLOW BY THE STANDARD STEP ',
     .'METHOD',//6X,
     .'(REF.:"OPEN CHANNEL FLOW HYDRAULICS",V.T.CHOW,MCGRAW-HILL,',
     .'(1959))')
162     FORMAT(1X,76('-'))
C
        RETURN
        END
```

```
                          (AES):
                     Irregular Channel
                     Subcritical Flow
                         Analysis
Study Name________________________________    Page Number______
The following study is based on the well known
STANDARD STEP METHOD to analyse subcritical flow in an
irregular channel. Energy-head losses and corresponding
notation used in the program are as follows:
   FRICTION LOSSES:    n = Mannings friction parameter
   EDDY LOSSES:        e = eddy loss coefficient
   KINETIC ENERGY
   CORRECTION FACTOR: a = correction factor
The PROGRAM determines subcritical flow water
surface elevations by balancing the classical energy
equation between specified channel 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 minimum flow-depth
of CRITICAL DEPTH, where the Froude number (Fr)
equals one (1). Therefore, supercritical water
surface information is not computed in this program.
In reaches of supercritical flow, critical depth is
assumed as a minimum flow depth which exceeds the actual
supercritical flowdepth in the channel.
For this study, the following information is used:
     Channel flow(cfs) =    1000.0
     Number of channel cross-sections =  4
     Number of Energy-Balance locations = 11
Special notation given in the computer results
are as follows:
  (1)FLOOD....this word appears in the first column
          whenever the estimated flowdepth exceeds either
          bank of the channel section.
  (2)STEEP....this word appears in the last column
          whenever the channel Critical Depth exceeds
          the Normal Depth. Because this program
          is intended only for subcritical flow,
          supercritical flow is modeled with flowdepths
          equal to or greater than Critical depth.
          This simplification results in conservative
          channel flowdepth estimations. However, supercritical
          flow effects including hydraulic jumps are
          NOT MODELED ACCURATELY.
  (3)SECTION..this word appears in the second column
          whenever the energy-balance channel location
          occurs at one of the defined channel cross-sections.
**************************************************************
          CROSS-SECTION INFORMATION:
**************************************************************
     INFORMATION FOR CROSS-SECTION NUMBER:  1
     MANNINGS FRICTION FACTOR = .03000
     KINETIC ENERGY CORRECTION FACTOR = 1.100
     EDDY LOSS FACTOR =  .000
     DISTANCE(ft.) TO CROSS-SECTION #1 =       .00
```

```
     NODAL POINT COORDINATE INFORMATION:
     NODE NO.      X(ft.)     Y(elev.)
         1            .00      110.00
         2          20.00      100.00
         3          25.00      100.00
         4          45.00      110.00
*******************************************************************
     INFORMATION FOR CROSS-SECTION NUMBER:  2
     MANNINGS FRICTION FACTOR = .03000
     KINETIC ENERGY CORRECTION FACTOR = 1.100
     EDDY LOSS FACTOR =  .000
     DISTANCE(ft.) TO CROSS-SECTION #1 =   500.00

     NODAL POINT COORDINATE INFORMATION:
     NODE NO.      X(ft.)     Y(elev.)
         1            .00      112.00
         2          19.00      102.50
         3          22.00      103.00
         4          46.00      111.00
*******************************************************************
     INFORMATION FOR CROSS-SECTION NUMBER:  3
     MANNINGS FRICTION FACTOR = .03000
     KINETIC ENERGY CORRECTION FACTOR = 1.100
     EDDY LOSS FACTOR =  .000
     DISTANCE(ft.) TO CROSS-SECTION #1 =   850.00

     NODAL POINT COORDINATE INFORMATION:
     NODE NO.      X(ft.)     Y(elev.)
         1            .00      135.10
         2          34.00      123.75
         3          37.00      125.00
         4          77.00      135.00
-******************************************************************
     INFORMATION FOR CROSS-SECTION NUMBER:  4
     MANNINGS FRICTION FACTOR = .03000
     KINETIC ENERGY CORRECTION FACTOR = 1.100
     EDDY LOSS FACTOR =  .000
     DISTANCE(ft.) TO CROSS-SECTION #1 =  1000.00

     NODAL POINT COORDINATE INFORMATION:
     NODE NO.      X(ft.)     Y(elev.)
         1            .00      136.00
         2          34.50      124.50
         3          37.50      127.00
         4          82.50      136.00
*******************************************************************
*******************************************************************
     USER-SPECIFIED ENERGY-BALANCE CHANNEL LOCATIONS:
          ENERGY BALANCE         DISTANCE TO
          LOCATION NUMBER       CROSS-SECTION #1
                 1                  100.00
                 2                  200.00
                 3                  300.00
                 4                  400.00
                 5                  500.00
                 6                  600.00
                 7                  700.00
                 8                  800.00
                 9                  850.00
                10                  900.00
                11                 1000.00
*******************************************************************
```

```
-------------------------------------------------------------------------------------------------------------------
|                                                                                                                 |
|                                                                                                                 |
                       *** (AES): IRREGULAR CHANNEL SUBCRITICAL FLOW MODEL ***                                    |
Standard Step Method irregular channel analysis. Based on development in "OPEN CHANNEL HYDRAULICS",CHOW(1959)|
  STUDY NAME:                       Channel Flow =   1000.00 cfs                        PAGE NUMBER:              |
-------------------------------------------------------------------------------------------------------------------
| LENGTH| WATER | FLOW| FLOW | FLOW|  2   |  TOTAL | HYDR |FRICTION| AVERAGE| REACH| LOSS|EDDY|  TOTAL |     |
| from |SURFACE|DEPTH| AREA |  V  |aV /2g|  HEAD  |RADIUS| SLOPE  | REACH |LENGTH| Hf |LOSS|  HEAD  | Fr  |
|CONTROL|(elev.)| (ft)|(ft*ft)|(fps)| (ft) |  (ft)  | (ft) |   Sf   |   Sf   | (ft) | (ft)|(ft)|  (ft)  |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|     .0| 105.91| 5.91|   99.4|10.06| 1.729| 107.639|  3.16| .008885|        |      |     |    | 107.639| 1.00|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |     |    |        |GIVEN|
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  100.0| 107.21| 6.71|  123.5| 8.10| 1.121| 108.335|  3.47| .005061| .006973| 100.0| .697| .00| 108.336|  .77|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  200.0| 107.73| 6.73|  123.6| 8.09| 1.119| 108.845|  3.42| .005155| .005108| 100.0| .511| .00| 108.846|  .78|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  300.0| 108.26| 6.76|  124.4| 8.04| 1.105| 109.362|  3.38| .005177| .005166| 100.0| .517| .00| 109.362|  .78|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  400.0| 108.79| 6.79|  125.4| 7.97| 1.087| 109.880|  3.34| .005171| .005174| 100.0| .517| .00| 109.879|  .78|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  500.0| 109.33| 6.83|  126.5| 7.91| 1.068| 110.398|  3.30| .005158| .005164| 100.0| .516| .00| 110.397|  .78|
|       |SECTION|     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  600.0| 114.63| 6.06|  105.4| 9.49| 1.538| 116.170|  2.89| .008861| .007009| 100.0| .701| .00| 111.099|*1.00|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |STEEP|
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  700.0| 120.62| 5.98|  107.4| 9.31| 1.482| 122.106|  2.81| .008875| .008868| 100.0| .887| .00| 117.057|*1.00|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |STEEP|
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  800.0| 126.62| 5.91|  109.3| 9.15| 1.431| 128.054|  2.73| .008892| .008884| 100.0| .888| .00| 122.994|*1.00|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |STEEP|
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  850.0| 129.63| 5.88|  110.3| 9.06| 1.404| 131.032|  2.70| .008866| .008879|  50.0| .444| .00| 128.498|*1.00|
|       |SECTION|     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |STEEP|
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
|  900.0| 130.24| 6.24|  119.3| 8.38| 1.200| 131.438|  2.76| .007355| .008110|  50.0| .406| .00| 131.437|  .91|
|       |       |     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
| 1000.0| 130.98| 6.48|  118.4| 8.45| 1.220| 132.202|  2.65| .007902| .007628| 100.0| .763| .00| 132.201|  .93|
|       |SECTION|     |       |     |a=1.10|        |      |n= .0300|        |      |   e= .00 |        |     |
|-------|-------|-----|-------|-----|------|--------|------|--------|--------|------|-----|----|--------|-----|
```