Computer Program E431

USER'S MANUAL

COMPUTER APPLICATIONS FOR STEP-BACKWATER AND FLOODWAY ANALYSES

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COMPUTER APPLICATIONS FOR STEP-BACKWATER AND FLOODWAY ANALYSES

by James O. Shearman

ABSTRACT

A computer program which can be used to compute water-surface profiles for gradually varied, subcritical flow is described. Profiles are computed by the standard step-backwater method. Water-surface profiles may be obtained for both existing stream conditions and for stream conditions as modified by encroachment. The user may specify encroachment patterns in order to establish floodway limits for land-use management alternatives, or for flood-insurance studies. Applicable theories, computer solution methods, data requirements, and input data preparation are discussed in detail. Numerous examples are presented to illustrate the computer output and potential program applications.

INTRODUCTION

Adequate knowledge of water-surface profiles in open channels is essential if the hydrologist, planner, land developer, or design engineer is to successfully accomplish his objectives. Water-surface profile computations may be used to establish or extend stage-discharge relations. When direct measurement of discharges is not possible, such computations enable the hydrologist to improve or expand his streamflow data collection program. Computed water-surface profiles for floods of a given frequency may be used to delineate inundated areas. This information is invaluable in land-use planning, flood-plain zoning, and flood-insurance programs. Planners and land developers must be able to determine water-surface profiles for existing conditions and to determine how these would be affected by proposed developments. A bridge design engineer must have similar capability so that he may eliminate, or at least minimize, any adverse effects of a proposed crossing of an open channel by a transportation route.

The above list of applications, although it could be extended indefinitely, is intended to illustrate the need for a flexible, easy-to-use tool for computing water-surface profiles in open channels. The U.S. Geological Survey (USGS) has long been involved in developing, and subsequently improving, computer programs to satisfy this need. A computer program written by D. G. Anderson and W. L. Anderson (written commun., 1964) served as a primary base for the overall development process. Subsequent refinements, additions, and modifications to that computer program resulted in USGS Computer Program No. E431, the tool currently used by the USGS for computing water-surface profiles in open channels. E431 includes the following major improvements: (1) more complete analysis of flow through bridges, (2) capability for computing flow over roadways, (3) routines for readily determining the effects of encroachments on existing conditions, and (4) extensive data-editing features.

The user must have substantial knowledge of open-channel hydraulics to ensure adequate data input and valid interpretation and evaluation of results. Presentation of a complete discussion of open-channel hydraulics theory in this report is impractical. The user is therefore urged to consult the references cited to obtain an adequate background before attempting to apply E431 to actual field problems.

Water-surface profiles for gradually varied, subcritical flow are computed using the standard step method (Chow, 1959). An adaptation of the Bureau of Public Roads (BPR) method of bridge-backwater computations (Bradley, 1960 and 1970) is used to compute water-surface profiles in the vicinity of bridges. Embankment overflow computations are based on procedures outlined by Hulsing (1967, p. 26) and Matthai (1967, p. 33).

E431 may be used to compute water-surface profiles for existing conditions (backwater-analysis segment) with absolutely no knowledge of the encroachment portion (floodway-analysis segment) of the program.

However, to perform floodway analyses, the user must be completely familiar with the backwater-analysis segment. Therefore, this report will describe the backwater-analysis and floodway-analysis segments separately. Each segment description will discuss: (1) applicable theories, (2) data requirements, (3) computer methods of solution, (4) data preparation, (5) error or warning messages, (6) computer output of results, and (7) examples of applications of the program.

Throughout this report an attempt is made to use symbolic notation identical with the notation used in: (1) the headings on the data input forms, (2) the error messages generated by E431, and (or) (3) the FORTRAN IV statements in the E431 program. Equations are presented in the illustrations and referred to in the text by the figure number and the sequential number of the equation on that figure (for example, equation 3-5 is the fifth equation presented in figure 3).

BACKWATER ANALYSIS

WATER-SURFACE PROFILE COMPUTATION THEORY

This section briefly describes the basic theories of flow applied to the three major phases of water-surface profile computation in E431. More detailed discussion of each of these computational phases is presented in the section entitled Computational Methods.

GRADUALLY VARIED FLOW

Computation of water-surface profiles for gradually varied flow is based upon the principle of the conservation of energy between two cross sections. E431 is programed only for subcritical and (or) critical flow computations. Proper application of the energy equation is thus dependent upon the following assumptions:

1. Steady flow exists in the subreach defined by the two cross sections.
2. The flow regime in the subreach is entirely (a) critical, (b) critical and subcritical, or (c) subcritical.
3. The longitudinal water-surface and channel slopes are small enough that normal depths and vertical depths may be considered equal.
4. The water surface is level across each individual cross section.
5. Effects from sediment and air entrainment are negligible.
6. All losses are correctly evaluated.

Cross-section properties must be available for each end of the subreach to solve the energy equation. Figure 1 illustrates a typical cross section. Subdivision of the section into subareas is usually necessary to adequately evaluate the flow variation across the section due to differences in geometrical shape and (or) roughness of the individual subareas. Definitions of symbols and the basic equations for computing cross-section properties are summarized in figure 1.

Figure 2 illustrates a typical reach for which water-surface profiles are to be computed. Cross sections must be spaced such that they adequately define any variations in the reach. Cross-section selection criteria require a considerably greater detailed discussion than is possible in this report. The most complete discussion of this most important topic is presented by Davidian (1976). Standard hydraulic texts such as Chow (1959) and Woodward and Posey (1941) are also excellent sources of information. Benson and Dalrymple (1967) is an excellent reference for field procedures.

Figure 2 also illustrates a typical subreach (that segment of a reach bounded by successive cross sections) and summarizes the various elements of the energy equation. Balancing the energy equation for subcritical flow in a subreach by the standard step method (Chow, 1959) may be itemized in stepwise fashion as follows:

Step 1: The water-surface elevation, WSD, at the downstream section must be known (that is from a rating curve or from hydraulic computations) or assumed (as discussed later in the applications section).

Step 2: The downstream velocity head, VHD, and the downstream conveyance, KD, are computed, based on WSD.

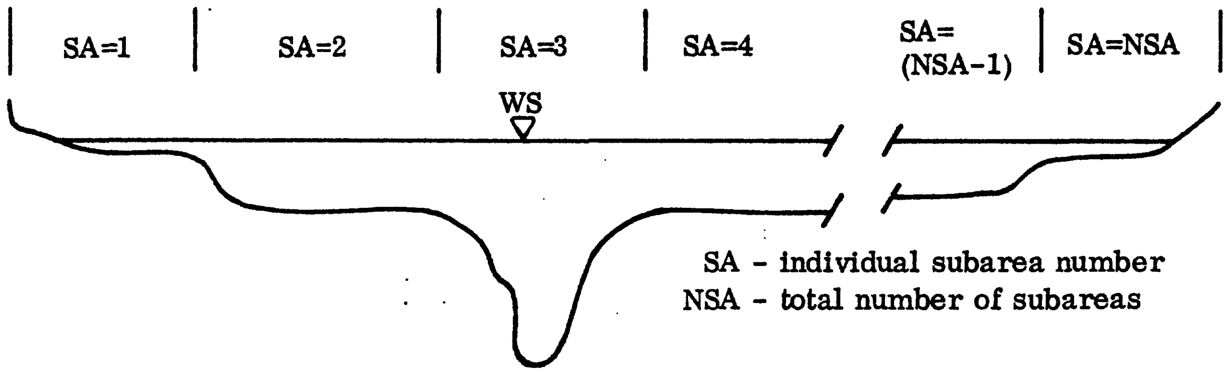
Step 3: An upstream water-surface elevation, WSU, is assumed.

Step 4: The upstream velocity head, VHU, and the upstream conveyance, KU, are computed, based on WSU, and subsequently used to compute subreach energy losses, HF and HE.

Step 5: The energy balance is computed by equation 2-4. If the energy balance is zero (or within an acceptable tolerance), it is necessary to verify that subcritical flow exists at that WSU (step 6). If the energy balance is unacceptable, a new WSU is assumed and the computational sequence re-entered at step 4.

Step 6: If the flow is determined to be subcritical at WSU, computations may proceed with the next subreach upstream (step 7). Otherwise, a higher WSU is assumed and the computational sequence re-entered at step 4.

Step 7: The upstream section becomes the downstream section for the new subreach, in which WSD is the satisfactorily computed WSU for the previous subreach. KD and VHD are assigned the last computed values for KU and VHU respectively. The computational sequence is then re-entered at step 3.



For a given water-surface elevation, WS:

Each subarea with an SA number of i (i = 1, 2, . . . , NSA) has the following properties:

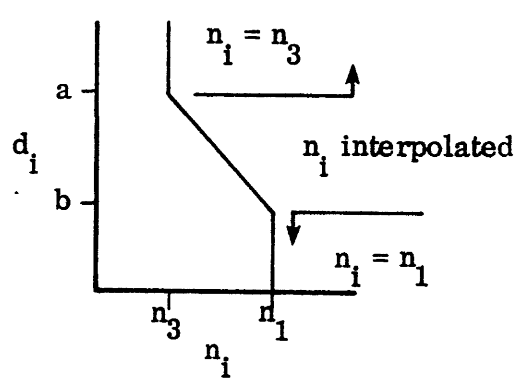
area (ft.^{2}), a_i

wetted perimeter (ft), p_i

top width (ft), b_i

hydraulic depth (ft), $d_i = \frac{a_i}{b_i}$ 1-1

roughness, n_i



hydraulic radius (ft), $r_i = \frac{a_i}{p_i}$ 1-2

conveyance (ft.^{3}/s),

$$k_i = \frac{1.49}{n_i} a_i r_i^{2/3} \quad \text{1-3}$$

The total section has the following properties:

Discharge (ft.^{3}/s), QT

Area (ft.^{2}), $A = \sum_{i=1}^{NSA} a_i$ 1-4

Conveyance (ft.^{3}/s),

$$K = \sum_{i=1}^{NSA} k_i \quad \text{1-5}$$

Mean Velocity (ft./s),

$$V = \frac{QT}{A} \quad \text{1-6}$$

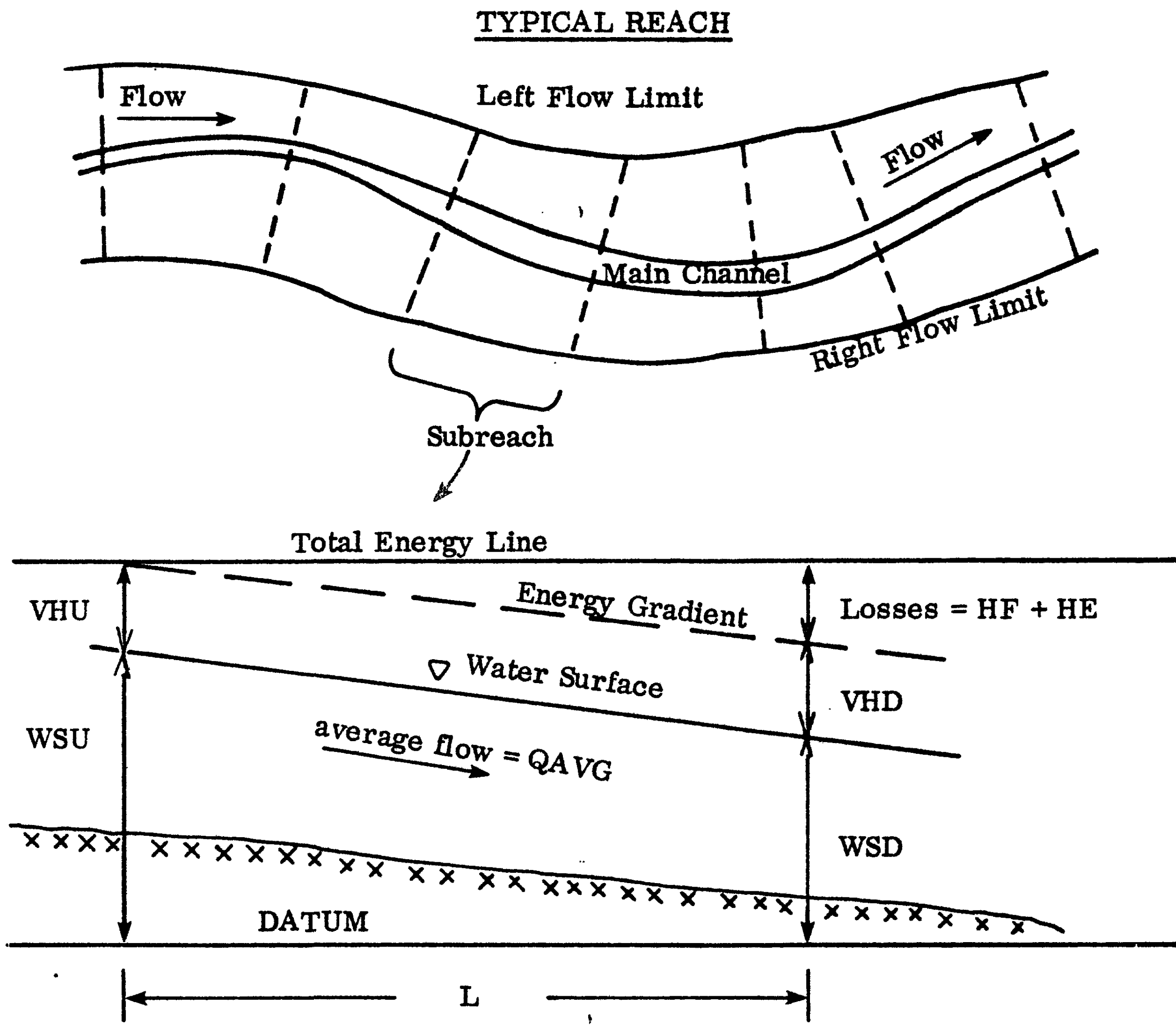
Kinetic Energy Correction Factor,

$$\alpha = \frac{\sum_{i=1}^{NSA} (k_i^3/a_i^2)}{K^3/A^2} \quad \text{1-7}$$

Velocity Head (ft)

$$VH = \frac{\alpha V^2}{64.3} \quad \text{1-8}$$

Figure 1.—Typical cross section with symbols and equations to define properties.



WSU, WSD - upstream and downstream water-surface elevations

QU, QD - upstream and downstream discharges

VHU, VHD - upstream and downstream velocity heads (Eq. 1-8)

KU, KD - upstream and downstream conveyances (Eq. 1-5)

QAVG - average flow in subreach [(QU + QD)/2]

The Energy Equation is:

$$WSU + VHU = WSD + VHD + HF + HE \qquad 2\text{-}1$$

where the friction loss, $HF = L \times QAVG^2/(KD \times KU)$ 2-2

and the eddy loss, $HE = k_e \times (VHU - VHD)$ 2-3

with $k_e = 0.5$ for expanding subreach (i.e. VHU - VHD is +)

or $k_e = 0.0$ for contracting subreach (i.e. VHU - VHD is -)

Eq. 2-1 may be written in terms of ACC, the accuracy of the energy balance

$$ACC = WSU + VHU - WSD - VHD - HE - HF \qquad 2\text{-}4$$

Figure 2.—Typical reach and subreach with symbols and equations used balancing the energy equation.

Of course, this computational sequence is repeated for each successive subreach until WSU for the most upstream cross section has been computed.

FLOW THROUGH BRIDGES

Computation of water-surface profiles in the vicinity of bridges can probably best be described as an "inexact science." Numerous methods, both empirical and scientifically based, may be found in the literature. Probably the two most widely accepted approaches are those currently used by the USGS and the BPR. The contracted-opening method (Matthai, 1967) is used by the USGS to determine flood-peak magnitude from water-surface elevation data which are recovered after a flood occurs. Cragwall (1958) developed a method in which the criteria and coefficients applicable to the contracted-opening method are used to compute the backwater created by a bridge. The BPR has developed a method (Bradley 1960 and 1970) which is used to determine an adequate hydraulic design of bridge openings for new bridges. Both of the above approaches are based on considerable laboratory research and have been subjected to extensive field verification. However, neither approach is directly applicable to computing a water-surface profile for an entire reach of open channel containing existing bridges.

The BPR approach was modified and incorporated in program E431 because the method appeared to offer the following advantages: (1) much more easily and quickly adapted to a water-surface profile computational procedure, (2) computationally faster, and (3) requires less computer storage, primarily due to the lesser number of coefficients involved. Discussion of the BPR method in this report will be limited to the manner in which it is applied in E431. However, users are urged to acquaint themselves with the complete methodology.

FLOW OVER EMBANKMENTS

Economics frequently dictate that a bridge be designed so that approach embankments are overtopped by larger floods. In these cases, the embankment acts as a broad-crested weir. An iterative solution is required to compute the upstream water-surface elevation at which the flow over the embankment plus the flow through the bridge opening equals the total flow.

DATA REQUIREMENTS

The purpose of this section is to provide the user with a general overview of the data requirements for the backwater-analysis segment of E431. More complete explanations of the data and discussion of their use in the computations are presented in the sections entitled Computational Methods and Data Preparation. As mentioned previously, the user is expected to consult additional references for field-survey procedures (Benson and Dalrymple, 1967) and detailed cross-section selection criteria (Woodward and Posey, 1941; Chow, 1959; and Davidian, 1976).

GENERAL

Each reach for which water-surface profiles are to be computed must be defined by a series of cross sections. The term cross section, as used herein, implies a set of data points defining any one of the six different kinds of data that may be required in the analysis. These cross sections, which will be defined as they are introduced, are: (1) regular, (2) exit, (3) bridge-opening, (4) approach, (5) pier, and (6) embankment cross sections.

Certain data are required to describe the entire reach. These data are: (1) reach identification, (2) number of cross sections used to define the reach, (3) number of water-surface profiles to be computed for the reach, (4) acceptable error tolerance for balancing the energy equation, (5) elevation increment to be used in computation of cross-section properties, and (6) Froude number value to be compared with a computed index Froude number to make certain that computed water-surface elevations are in the subcritical flow regime. Also, the discharge and the water-surface elevation for that discharge at the most downstream cross section in the reach must be provided for each water-surface profile to be computed for the reach.

Additional data are required to define each cross section. Regardless of the kind of data, each cross section must be defined in terms of: (1) a section-identification code, (2) a code to identify the type of cross section and (3) the number of data points required to define the cross section. Further definition of a cross section depends on the kind of data being described.

REGULAR CROSS SECTION

In the absence of bridge crossings, a reach is subdivided into subreaches by cross sections located normal to the direction of flow. These cross sections will be referred to as regular cross sections. They must be defined by coordinates of horizontal distance and ground elevation. Sufficient ground points must be obtained so that straight-line connection of the coordinates will adequately describe the cross-section geometry. Horizontal distance is measured from left to right from an arbitrary point in each cross section. All elevations in the entire reach must be measured from a common datum.

Usually, each cross section must be subdivided into subareas for adequate evaluation of flow variation created by the geometric and (or) roughness differences of individual subareas. Therefore, it is necessary to assign a subarea number to each coordinate. Guidelines which should be followed when subdividing a cross section are presented by Davidian (1976). Roughness within each subarea is described in terms of a roughness-depth relationship (see fig.1), which is representative of the average roughness across the entire width of the subarea.

All regular cross sections in the reach must be assigned a section reference distance measured from a common point. The difference between the section reference distances of successive cross sections represents the flow distance in a subreach. Usually the flow distance can be measured along a line representing the locus of the centroids of flow in the reach. In the case of significant meandering it may be necessary to use an average flow distance obtained by weighting the flow distances in the overbank and main channel areas with the appropriate portion of the total discharge for each distance.

BRIDGE SITUATION

Computation of the water-surface profile in the vicinity of a bridge crossing requires: (1) an exit cross section immediately downstream of the bridge, (2) a cross section of the bridge opening, and (3) an approach cross section upstream of the bridge. Cross sections describing piers and the embankment are optional. Four possible combinations result from these required and optional cross sections. The required order of cross sections for each possible combination is shown in table 1.

Table 1.—*Required order of cross sections for a bridge situation*

Optional cross sections used	Required order of cross sections[1]
None	ES - BO - AS
Pier only	ES - BO - PS - AS
Embankment only	ES - BO - RG - AS
Pier and embankment	ES - BO - PS - RG - AS

[1]Symbols ES, BO, PS, RG, and AS indicate exit, bridge-opening, pier, embankment, and approach cross sections, respectively.

Exit Cross Section

An exit cross section is simply a regular cross section which is representative of the flow conditions for the full valley width in the subreach downstream of the bridge embankment. This cross section is required for computing the water-surface elevations that would exist at the downstream face of the bridge opening and at the approach cross section if there were no bridge affecting the profile. The computer is not programed to correct an exit cross section for skew. The user must, therefore, provide input data that describes an exit cross section located normal to the flow. The section reference distance assigned to the exit cross section must be identical with the section reference distance assigned to the bridge-opening cross section.

Bridge-Opening Cross Section

A bridge-opening cross section is always measured parallel to the face of the constriction and should represent the minimum area in the bridge opening. Usually this occurs at the downstream face of the opening. E431 is programed to make the proper correction to the area of a skewed bridge opening. Section reference distance of the bridge opening is the flow distance from the initial downstream reference point to the downstream face of the bridge. Special provisions in the program make possible complete closure of the bridge-opening cross section by using the horizontal stationing and elevations of the low chord. This permits the program to compute the actual wetted perimeter and the correct area of the bridge opening when the water-surface elevation equals or exceeds elevations of the low chord. A bridge-opening cross section is coded as if existing piers did not exist because the gross area of the bridge opening is required to compute free-surface flow through the bridge. Pier data are introduced as a separate cross section if computation of pier area is required. Other required data are: (1) the angle of skew of the bridge opening relative to the direction of flow, (2) the mean elevation of the low chord of the bridge, (3) a code describing the wingwall configuration, and (4) the abutment alinement relative to the plane of the constriction.

Approach Cross Section

An approach cross section should be located such that the distance between the upstream face of the bridge opening and the approach cross section is equal to the width of the bridge opening. The approach cross section is simply a regular cross section for which a special subdivision procedure is required. This procedure enables the computation of conveyances in a manner such that the channel-contraction ratio and the eccentricity of the flow through the bridge opening may be computed. These computations will be fully discussed in the Computational Methods section.

Pier Cross Section

Pier area is required for: (1) determining the effects of piers on free-surface flow, or (2) determining net area for orifice-type flow. A pier cross section consists of a set of data points defining the gross pier width at two or more elevations. Enough points must be provided such that the pier area between specified elevations may be adequately computed by straight-line interpolation. Pier shape and configuration, which affect free-surface flow computations, are defined by a pier code.

Embankment Cross Section

An embankment cross section is defined by coordinates of horizontal stationing and elevation. These coordinates would usually represent the crown of a highway as this would be the "crest" of the weir. The coordinates coded for a city-type street would be the sidewalk or curb elevations if they control weir flow. Segmentation of the embankment is required such that the overflow to the left and right of the bridge opening may be determined. A code indicating the kind of embankment surface, either gravel or paved, must be specified for each segment. Also required are the embankment width and the acceptable error tolerance to be used in balancing the sum of computed embankment overflow and computed flow through the bridge with the specified total discharge.

COMPUTATIONAL METHODS

The major computational phases of E431 will be discussed in rather broad terms in this section. Discussion will be limited to the extent that it should aid the user in data preparation, interpretation of printed messages, and evaluation of computed results. Examples and detailed instructions on the preparation, interpretation, and evaluation phases are reserved for later sections of the report.

GENERAL

The overall computational procedure includes data input, data editing, computation of cross-section properties, and computation of water-surface profiles. Specific examples of computer printout and possible error or warning messages for each of these phases will be presented in later sections.

Input and editing are expedited by card numbers assigned to each data card according to the kind of data, and ascending sequence numbers assigned to each data card for the entire reach. As each data card is input, the card number, the sequence number, and location of data on the card are checked. The card image and any applicable messages are printed. Valid cross-section data are output to a direct-access storage device. This phase continues until all data cards for the entire reach have been input and checked.

Cross-section data are sequentially retrieved from the direct-access storage device for numerical editing. This phase corrects many simple user errors (for example, miscounting the number of data points). Default values are provided for certain invalid or missing data. Some data errors, depending upon their nature and location, will cause total or partial job abortion. Cross sections having such data errors are eliminated from further consideration. Valid cross-section data are again output to the direct-access storage device for input to the subsequent computational phases. Applicable messages and a summary of acceptable input data are printed.

With the exception of pier and embankment cross sections, each valid cross section is retrieved from direct-access storage so that cross-section properties can be computed and printed. A printed summary of cross-section properties, properly controlled by the user, is an invaluable aid to the user in (1) interpreting the computed water-surface profiles and (2) performing any manual computations that may be required. Computations for a minimum of one (1) and a maximum of ninety (90) elevations can be obtained for each cross section. They are made in increments of Δh, specified by the user, over the elevation range including the user-specified, minimum elevation, h_o, through the maximum elevation in the cross section, GMAX. When end-point elevations are less than GMAX, they are extended vertically to GMAX. It is advisable to specify values for h_o and Δh that will provide cross-section properties for the entire elevation range of interest. Also, the value specified for Δh should be small enough so that straight-line interpolation is adequate for computing properties for elevations between those printed in the summary when manual computations are required.

Up to twenty (20) water-surface profiles may be computed for each reach. Each profile is computed and output for the entire reach before computation of the next profile is attempted. Computation errors in one profile will not hinder computation of subsequent profiles. If one or more cross sections have been eliminated because of coding errors, profiles will be computed through the maximum possible number of consecutive, valid cross sections at the downstream end of the reach. Computed results are temporarily stored on a direct-access storage device to permit printing of all applicable profile computation messages for the entire reach before the computed water-surface profile data are printed.

There is no limit to the number of reaches that may be analyzed in a single computer run. Complete sets of data cards for each reach may be input consecutively. Generally, the program can recover from errors in one reach to proceed with the analysis of successive reaches.

BALANCING THE ENERGY EQUATION

Equation 2-4 is used to compute the difference in total energy at two successive cross sections, or the accuracy of the energy balance, ACC. An iterative procedure must be used to determine a value for WSU that results in the absolute value of ACC being less than or equal to a user-specified tolerance, TOL. However, for a value of WSU to be totally acceptable, the computed Froude number for that WSU must be less than or equal to a user-specified Froude number test value, FN. Two additional input data items that influence the iterative procedure are the elevation increment, Δh, and the minimum elevation of interest at each cross section, h_o, as defined above. The program assumes a value of 0.5 feet for Δh is suitable for the balancing process unless the user has specified a lesser value. Primarily, h_o governs the output of cross-section properties, but it does have minor influence on the WSU assumptions.

The initial assumption for WSU is equal to the greater of WSD-0.5Δh and h_o. Successively higher values of WSU are assumed in increments of 0.5Δh. For each of these assumptions, the value of ACC is tested for TOL acceptability. Also, each value of ACC is compared to the previous value of ACC. A change in the algebraic sign of ACC indicates that a mathematically valid root of the energy equation exists between these successive assumptions of WSU. Convergence upon this root is accomplished by the method of false position (Carnahan and others, 1969, p. 178). If the above process does not find a root by the time it reaches GMAX it is assumed that the 0.5Δh stepping increment was too large which resulted in completely missing an ACC sign change. Therefore, the stepping increment is changed to 0.25Δh and the above process is repeated. If the smaller stepping increment also fails to discover a mathematically valid root, between the initially assumed WSU and GMAX, it is assumed that any valid root must be below the initially assumed WSU. The iterative process is then repeated with the 0.25Δh stepping increment, using an initial WSU equal to GMIN + 0.5Δh, where GMIN is the minimum ground elevation in the cross section. Profile computations are aborted if this last step fails to yield a mathematically valid root.

Each mathematically valid root from any of the above procedures must be tested for hydraulic validity. A root for which a computed index Froude number, FRDN, is greater than the test value, FN, is rejected. In this event the iterative procedure is re-entered with an assumed elevation for WSU which is slightly greater than the elevation of the rejected WSU.

The Froude number for a prismatic channel of uniform roughness is computed by equation 3-1. Critical flow occurs at the elevation where specific energy is a minimum, which is the elevation where F = 1.0. In E431, an index Froude number, FRDN, is computed by equation 3-2 which assumes that the flow in the subarea having the largest conveyance is the best index of the flow regime. The assumption that critical flow occurs at FRDN = 1.0 is not necessarily correct. A valid root may exist at FRDN values greater than 1.0. Selection of an appropriate value for FN is discussed later under Data Preparation.

Critical water-surface elevations, as computed by the above procedure, are sometimes unsatisfactory. One of the following procedures, requiring some manual computations, may provide more satisfactory results.

Computation of a Froude number for an entire cross section which has irregular shape and nonuniform roughness must consider the kinetic-energy correction factor, α. Thus, a Froude number, F, for such a case may be computed with equation 3-3. Equation 3-3 may be rewritten for critical flow conditions (F = 1.0) as equation 3-4 which may be used to compute critical discharges. Discharges computed in this manner are printed as part of the E431 cross-section properties output. A plot of these discharges versus water-surface elevation can be used to estimate the critical water-surface elevation for any discharge.

Probably the most accurate estimate of the critical water-surface elevation for a given discharge is that elevation at which that discharge produces minimum energy. Energy, in this context, is defined as the sum of a water-surface elevation and the velocity head (eq. 1-8) for the discharge at that elevation. A plot of water-surface elevation versus energy can be used to determine (1) critical water-surface elevation and (2) alternate water-surface elevations for supercritical flow conditions (see Davidian, 1976).

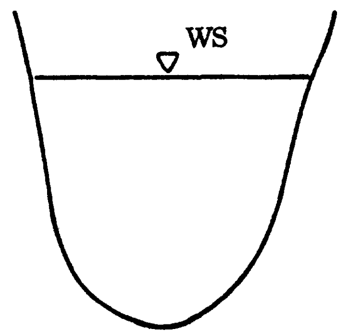
COMPUTATIONS AT BRIDGE SITES

The type of flow at a bridge will vary in accordance with the degree of constriction, the elevation of the low chord of the bridge, and the elevation of the approach embankments. The simplest case is where the entire flow may pass through the bridge opening in the subcritical regime with a free surface. Additional complexity is introduced when the water-surface elevation is high enough to make contact with the bridge girders, creating two possible orifice-type flow situations. Each of these three possible flow situations is arbitrarily assigned a numerical value as follows: (a) free-surface flow is Type 1 flow, (b) orifice-type flow with only upstream girders in contact with the water surface is Type 2 flow, and (c) orifice-type flow with all girders in contact with the water surface is Type 3 flow. This numerical value simplifies identification of the bridge-opening flow condition in pertinent messages and in the profile printout. Of course, if embankment elevations are low enough, a portion of the flow will flow over the embankments with the remainder of the flow passing through the bridge opening under one of the above flow conditions. The following paragraphs discuss the computational procedures used for these flow situations.

Free-Surface Flow Through Bridges

Figures 4a and 4b illustrate a typical bridge situation and summarize the appropriate symbols and equations used for computing the water-surface profile for free-surface, subcritical flow through a bridge opening (Type 1 flow). H1N, the water-surface elevation that would exist at the approach cross section with no bridge, is computed by balancing the energy equation for the subreach defined by the exit cross section and the approach cross section (eq. 2-4 with H1N substituted for WSU). The energy equation with the bridge considered is expressed by equation 4-1. K*, the bridge-loss coefficient (eq. 4-4), depends upon several parameters, among which are the bridge-contraction ratio and flow

For a uniformly rough, prismatic section:



Total Discharge, QT

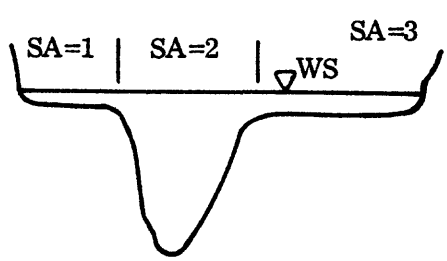
Area, A

Top Width, B

The Froude number is

$$F = \frac{QT}{A\sqrt{gA/B}} \qquad 3\text{-}1$$

For an irregular cross section with non-uniform roughness:



Total Discharge, QT

Total Conveyance, $K_T = k_1 + k_2 + k_3$

The subarea with the largest conveyance has

Conveyance $K_L = k_2$

with associated Area, $A_L = a_2$

and Top Width, $B_L = b_2$

If discharge distribution between subareas is proportional to conveyance, the index Froude number is computed by

$$FRDN = \frac{K_L}{K_T} \times \frac{QT}{A_L\sqrt{gA_L/B_L}} \qquad 3\text{-}2$$

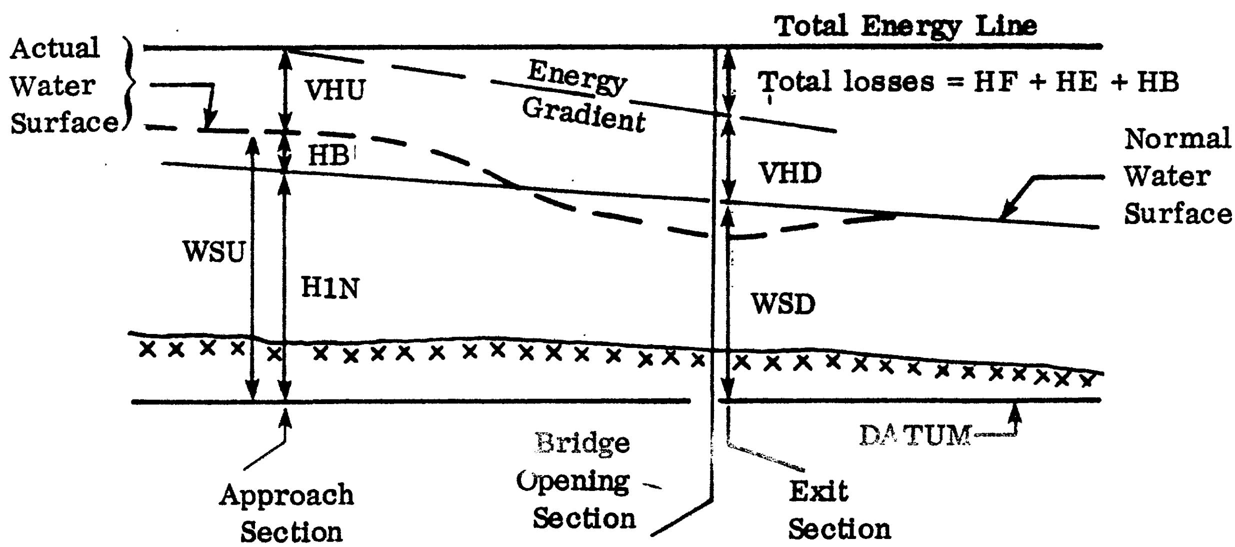
If the kinetic-energy correction factor (α) is considered, the Froude number for the latter case could be computed by

$$F = \frac{QT}{A\sqrt{gA/\alpha B}} \qquad 3\text{-}3$$

For critical flow ($F = 1.0$), the discharge could be computed by

$$QC = A\sqrt{gA/\alpha B} \qquad 3\text{-}4$$

Figure 3.—Froude number and critical discharge equations.



The energy equation for a bridge situation must include the additional losses caused by the bridge opening, HB

$$WSU + VHU = WSD + VHD + HF + HE + HB \qquad 4\text{-}1$$

or, rewriting equation 4-1

$$HB = WSU + VHU - WSD - VHD - HF - HE \qquad 4\text{-}2$$

HB can also be written as $HB = K^* (VHB)$ 4-3

The loss coefficient, $K^* = KB + KE + KS + KP$ (See Figure 4b) 4-4

The velocity head in the bridge opening is

$$VHB = \left(\frac{QBO}{ABO}\right)^2 /2g \qquad 4\text{-}5$$

where QBO is the discharge through the opening and ABO is the gross area of the opening at WSD, corrected for SKEW if necessary.

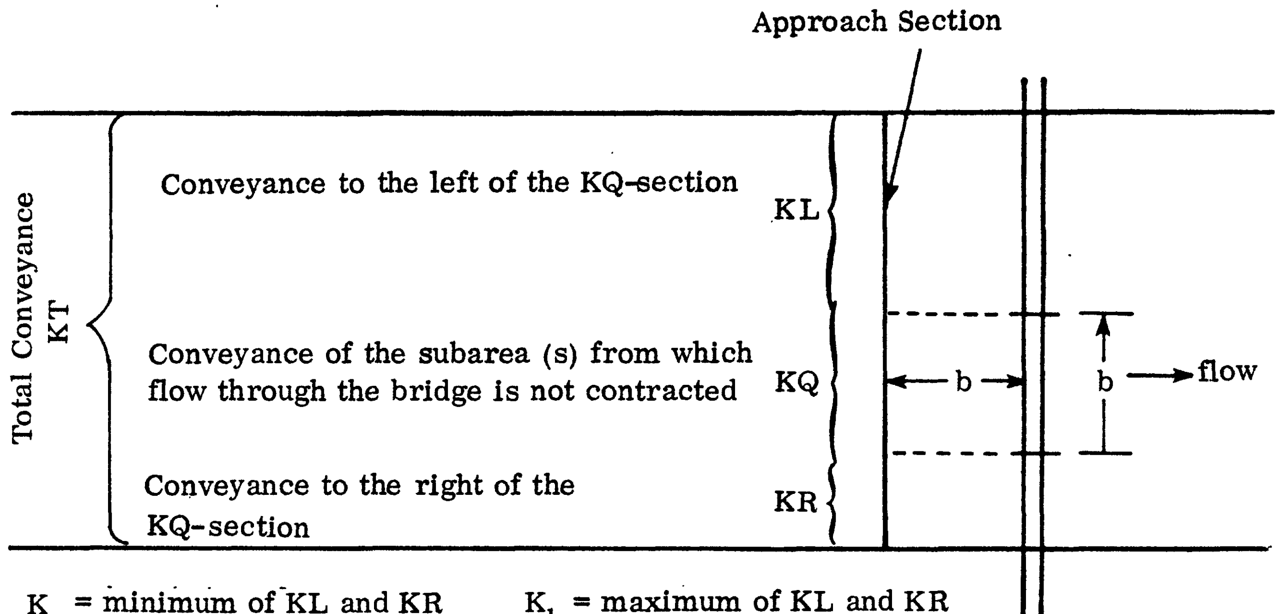
Equations 4-3 and 4-5 may be combined to yield

$$QBO = 8.02\ (ABO) \sqrt{\frac{HB}{K^*}} \qquad 4\text{-}6$$

which can be solved for any WSU with HB computed from Equation 4-2 using the HF and HE values computed for WSD and H1N.

a) energy and flow equations

Figure 4.—Free-surface, subcritical flow



K_a = minimum of KL and KR $\quad$ K_b = maximum of KL and KR

The bridge-contraction ratio is computed by the:

BPR as $\quad M' = \frac{KQ}{KT}$ $\quad$ 4-7a

USGS as $\quad M = 1 - \frac{KQ}{KT}$ $\quad$ 4-7b

Flow eccentricity is computed by the:

BPR as $\quad E' = 1 - \frac{K_a}{K_b}$ $\quad (E' = 0.0 \text{ if } K_a = K_b = 0)$ $\quad$ 4-8a

USGS as $\quad E = \frac{K_a}{K_b}$ $\quad (E = 1.0 \text{ if } K_a = K_b = 0)$ $\quad$ 4-8b

The incremental loss coefficients are:

Base, KB = f (M and wingwall configuration) $\quad$ 4-9

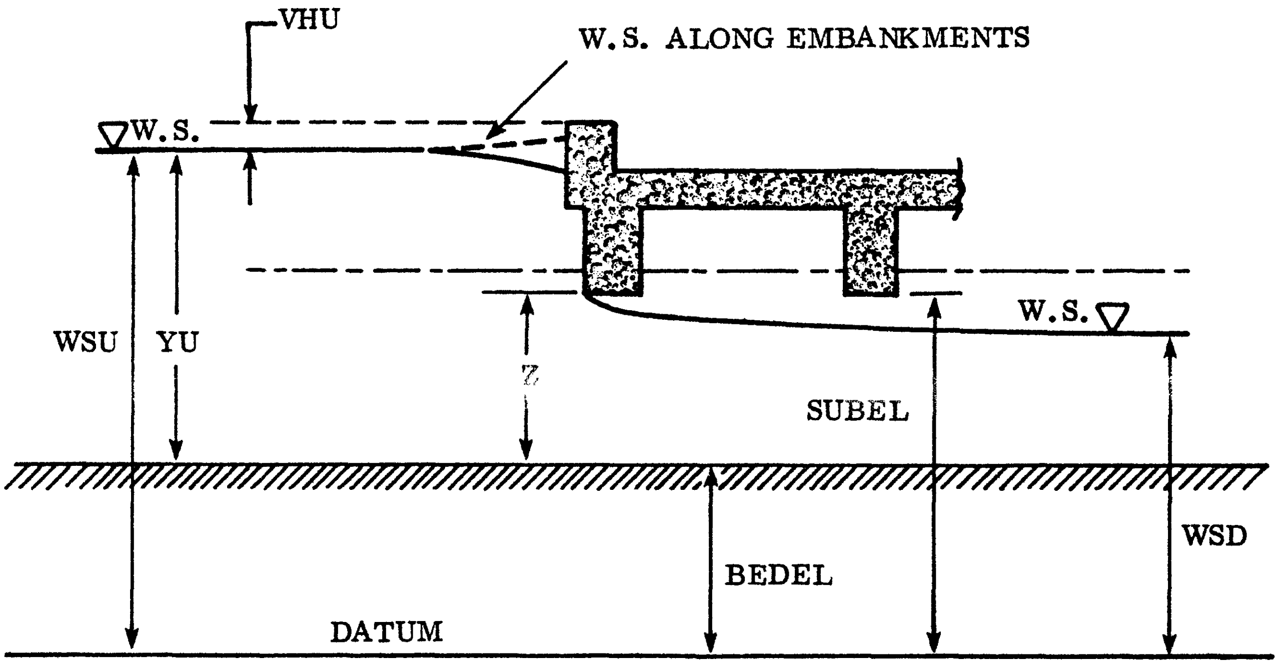
Eccentricity, KE = f (M, E) $\quad$ 4-10

Skew, KS = f (M and bridge skew) $\quad$ 4-11

Pier, KP = f (M and pier area) $\quad$ 4-12

b) flow contraction and eccentricity

through a bridge opening (Type 1 flow).



$$QBO = CD\,(ANET)\sqrt{2g\,(YU - Z/2 + VHU)} \qquad 5\text{-}1$$

Where: QBO is the discharge through the bridge opening.

CD is the discharge coefficient (see Figure 5b)

ANET is the net area of the bridge opening.

Z, the hydraulic depth in the bridge opening is computed as

$$Z = ANET/BRWID \qquad 5\text{-}2$$

where BRWID is the maximum bridge-opening width.

SUBEL is the mean low-chord elevation.

BEDEL (mean bed elevation) = SUBEL - Z 5-3

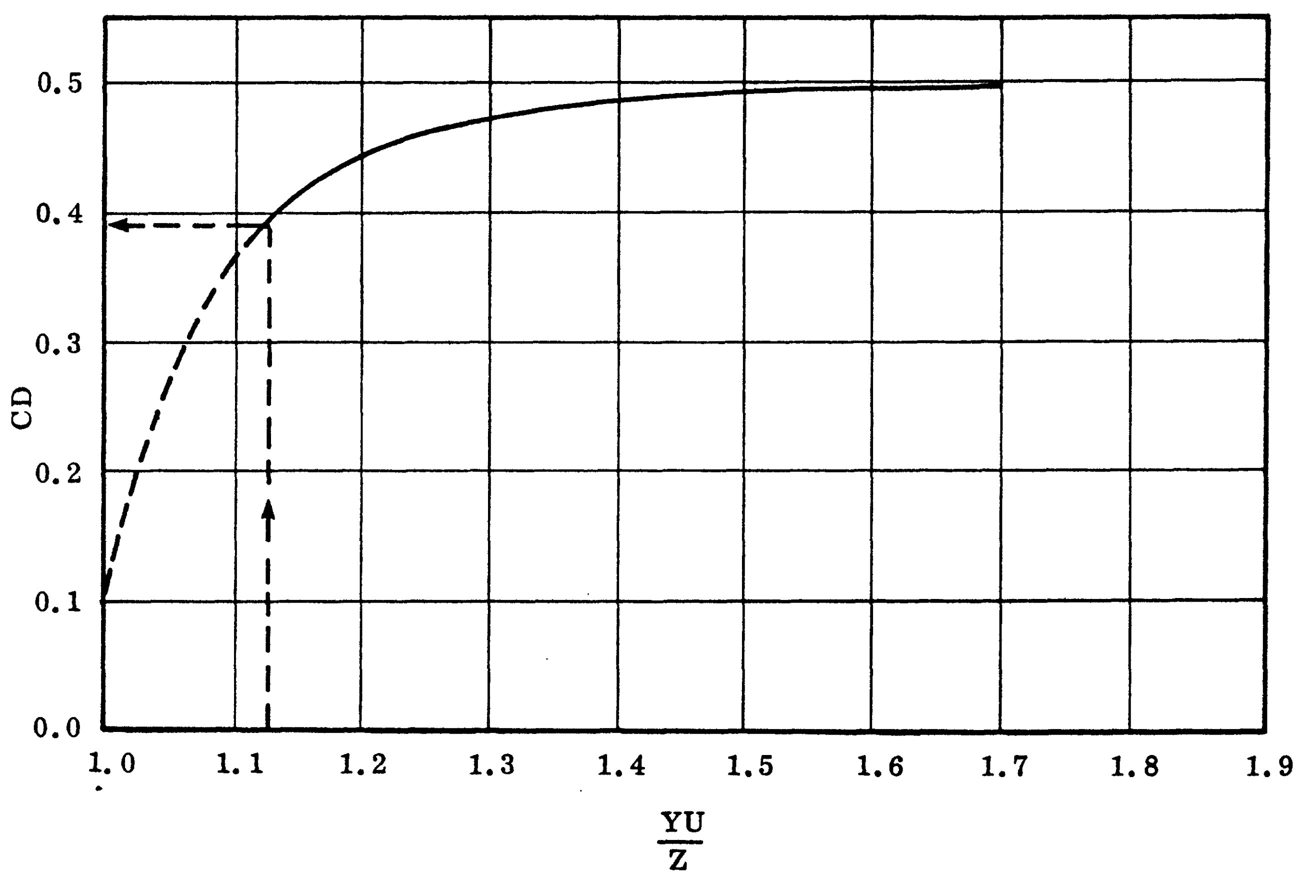
YU = WSU - BEDEL 5-4

a) definition sketch

Figure 5.—Flow through a bridge opening with the

eccentricity. E431 computations are actually based on the M' and E' values as computed by the BPR (eqs. 4-7a and 4-8a). To avoid confusion for the majority of readers, however, this manual and E431 output reflect the values of M and E as computed by the USGS (eqs. 4-7b and 4-8b). Both M and E, which affect HB, may vary with a change in the water-surface elevation at the approach cross section, WSU. Therefore, since both HB and VHU can vary with WSU, solution of equation 4-1 must be a cut-and-try procedure. After an initial assumption that WSU = H1N, subsequent assumptions for WSU are equal to the value of WSU computed on the previous iteration. Iteration continues until the absolute difference between two successive trial values of WSU is less than or equal to TOL.

Computation of M and E are dependent upon the conveyances KL, KR, and KQ (see fig. 4b). KQ is the conveyance of that portion of the approach cross section for which the flow passes through the opening without contraction. KL and KR are the conveyances to the left and right of the KQ section. The KQ section is defined by projecting the bridge opening parallel to the direction of flow to the approach cross section (Matthai, 1967; Bradley, 1960 and 1970). In case of skew and (or) meanders, some judgment may be required to define the KQ section. The approach cross section must be subdivided into a sufficient number of subareas such that the ends of the KQ section coincide with subarea boundaries. SAL and SAR are the subarea numbers of the last subarea in the KL section and the first subarea in the KR section, respectively. Detailed examples of this concept are presented in the section entitled Data Preparation.



b) discharge coefficient

water surface in contact with the upstream grinder.

Flow In Contact With Bridge Girders

Orifice-type flow occurs when the water surface comes in contact with the bridge girders. The two possible situations are (1) Type 2 flow when only the upstream girders are in contact with the water surface, and (2) Type 3 flow when the entire length of the bridge is flowing full (both upstream and downstream girders in contact with the water surface). Flow computations for either case are independent of abutment configuration.

Figure 5 illustrates the first case and shows the sluice-gate type equation used. It is assumed that this type of flow cannot occur unless WSU ⩾ BELMX, where BELMX is the maximum elevation coded in the bridge opening cross section. Since CD, YU, and VHU may vary with WSU, a half-interval iterative method (Carnahan and others, 1969, p. 178) is used to determine whether a valid solution of equation 5-1 exists for values of WSU between BELMX and GMAX.

Figure 6 illustrates the case of all girders in contact with the water surface. It is assumed that this type of flow cannot occur unless WSD ⩾ BELMX and WSU ⩾ WSD. Equation 6-3 is solved by a half-interval iterative method (Carnahan and others, 1969, p. 178) to determine whether there is a valid solution for WSU between WSD and GMAX. For either Type 2 or 3 flow, H1N will be used as the minimum possible elevation if H1N is greater than BELMX.

Embankment Overflow

As mentioned previously, broad-crested weir flow occurs if the water-surface elevation exceeds embankment elevations. A definition sketch and the symbols and equations used for computing embankment overflow are illustrated in figure 7. Figure 8 illustrates the coefficients used in these computations. Overflow for the portions of the embankment to the left and to the right of the KQ-section centerline are computed separately for reasons discussed below. Computations are based on each incremental length of embankment between the user-provided embankment coordinates. An average crest elevation (RDEL) is used for each increment of length. The applicable total head, H, on each increment (eq. 7-4) is based on the energy gradient, EGR, at the upstream side of the embankment. EGR (eq. 7-2) is assumed to be equal to the total energy at the approach cross section less the intervening friction loss (eq. 7-1). The incremental discharges computed by equation 7-5 are summed to obtain the flows over the left (QRL, eq. 7-6) and the right (QRR, eq. 7-7) portions of the embankment. Intersections of the water surface and the embankment for either portion of the embankment are computed on the assumption that the water-surface elevation at the crest, WSRD, equals the minimum crest elevation plus five-sixths of the maximum total head on that side of the KQ-section centerline.

In the event of embankment overflow, a value for WSU must be determined which will yield a sum of the computed discharges for embankment overflow and flow through the bridge opening that is equal to the total specified discharge, plus or minus a reasonable tolerance. Flow through the bridge opening is computed by whichever of equations 4-6, 5-1, or 6-3 is dictated by the computed water-surface profile. Figure 9 illustrates the symbols and equations used for balancing the total computed discharge, QTC (eq. 9-5), against the total specified discharge, QT. A half-interval iterative method is used to compute the value of WSU between H1N and GMAX such that the computational error (QERR in eq. 9-6) satisfies the percent tolerance, QTOL, specified by the user (eq. 9-7).

For free-surface flow in the bridge opening (that is, QBO computed by eq. 4-6), computation of the bridge-contraction ratio and flow eccentricity should be based on conveyance values which are representative of only that portion of the flow passing through the bridge opening. Therefore, it is necessary to segment the embankment so that the embankment overflows to either side of the KQ-section centerline may be computed separately. The ratio of these flows to total flow is used to reduce the conveyances to either side of the KQ section on the basis of the total conveyance as shown by equations 9-2 and 9-3. The adjusted total conveyance, KTB (eq. 9-4) is used to compute M by equation 4-7b. The adjusted overbank conveyances, KLB and KRB, are used in equation 4-8b to compute E. Embankment segmentation is more completely discussed in the section entitled Data Preparation.

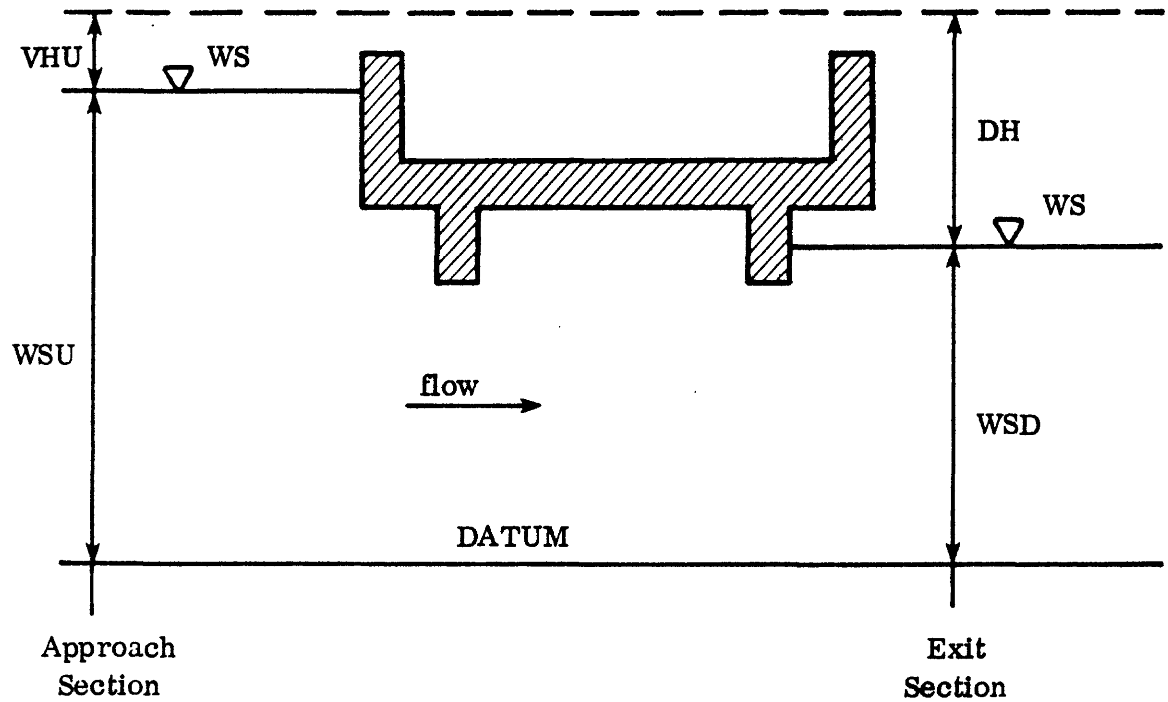
DATA PREPARATION

Input data for the backwater analysis segment of E431 consists of six different categories of data cards. These data cards are numbered 1 through 6 and will be referred to as CARD #1, CARD #2, . . . , CARD #6; or as #1 CARD(S), #2 CARD(S) . . . , #6 CARD(S). Table 2 summarizes the kinds of data that are coded on these cards.

Table 2.—*Summary of data coded on the six categories of data cards for backwater analysis*

Card No.	Data coded
1	Reach description.
2	Initial water-surface elevations.
3	Individual cross-section description.
4	Discharges.
5	Cross-section coordinates.
6	Roughness information.

USGS Form 1891A (see fig. 10) is designed for convenient coding of all required data prior to



$$QBO = CD\,(ANET)\sqrt{2g\,(DH)} \qquad 6\text{–}1$$

The head on the submerged orifice is

$$DH = WSU + VHU - WSD \qquad 6\text{–}2$$

CD is assumed to be 0.8

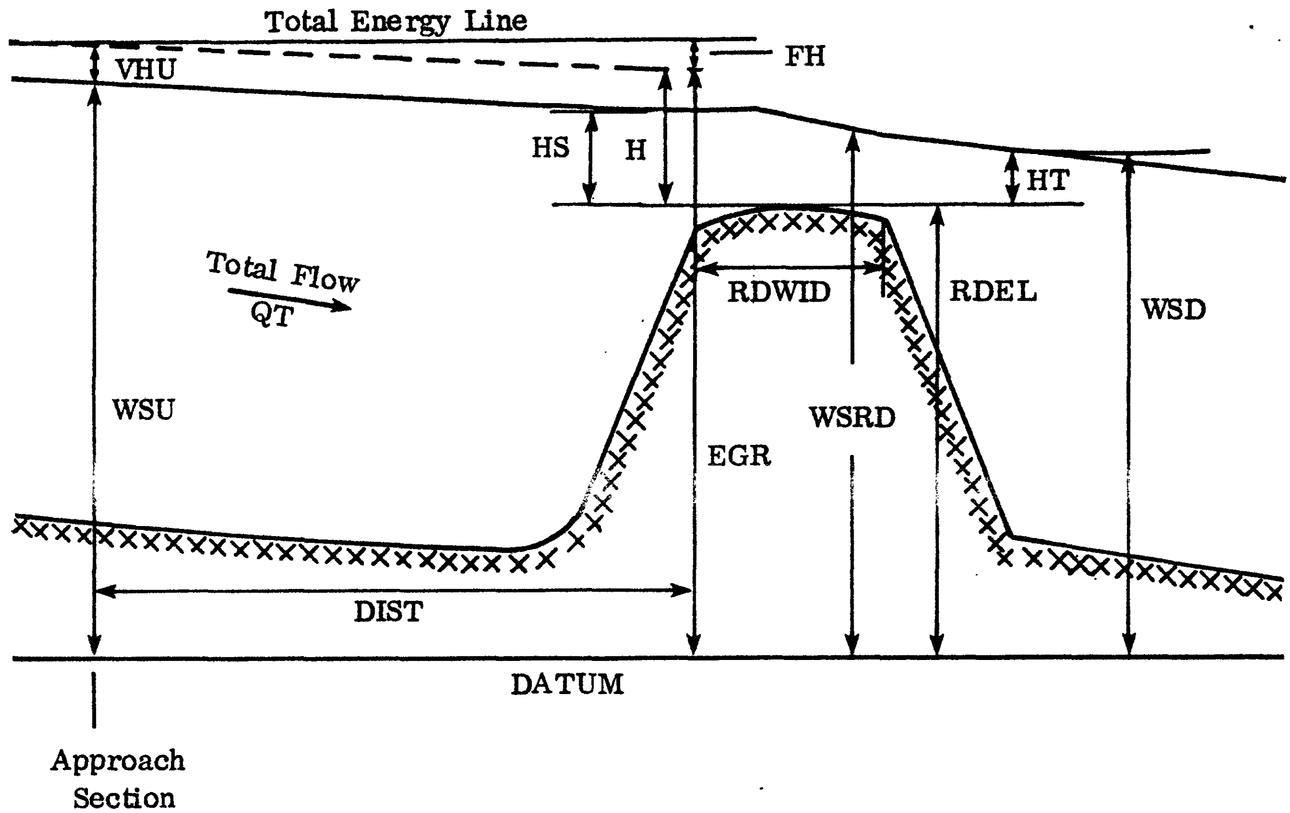
Therefore,

$$QBO = 6.42\,(ANET)\sqrt{WSU + VHU - WSD} \qquad 6\text{–}3$$

Figure 6.—Flow through a bridge opening with all girders in contact with flow.

keypunching. It consists of a blocked-line format on which each blocked, horizontal line represents an individual data card. Certain criteria are common to all data cards. With five exceptions, all data on Form 1891A are strictly numeric. The only valid entries in numeric fields are digits and, in some cases, minus signs. Alphanumeric entries (that is, any combination of alphabetic, numeric, and special characters) are permitted only in columns 9–48, 50–57, and 80 on CARD #1 and columns 9–13 and 80 on CARD #3. Also, the majority of data are expressed in whole units. Data which are required in less than whole units *cannot* be coded (or keypunched) with a decimal. Instead, an implied decimal concept is used. Location of the decimal in these fields is shown by dashed lines. Two exceptions to this concept are the tolerance on CARD #1 and the roughness values on CARD #6 where the implied decimal precedes the data fields. Each numeric entry must be right-justified in its field. If not, the value of X will be input as X x 10^Y where Y is the number of columns between the last digit of X and the right edge of the data field. Leading zeroes are not required in any of the data fields on the form.

Two common entries required on each input data card, regardless of category, are the CARD number and a SEQUENCE number. The CARD number is preprinted in column 1 of the data form. The SEQUENCE number is required in columns 3–7. Valid entries are -9999 to



The only change in energy from the approach section to the embankment is assumed to be a friction loss

$$FH = DIST \left(\frac{QT}{KU}\right)^2 \qquad 7\text{-}1$$

Therefore, the energy gradient immediately upstream of the embankment is

$$EGR = WSU + VHU - FH \qquad 7\text{-}2$$

For each incremental length of embankment, B, between successive, user-provided coordinates, RDEL is the average elevation of the incremental length, the total head is

$$H = EGR - RDEL \qquad 7\text{-}3$$

the static head is

$$HS = H - VHU \qquad 7\text{-}4$$

and the discharge over B is

$$q_i = k_t \, C_f \, BH^{3/2} \qquad 7\text{-}5$$

with k_t from figure 8c

and C_f from { figure 8a for HS/RDWID > 0.15; figure 8b for HS/RDWID ≤ 0.15 }

QRL = sum of all q_i's left of KQ-section ℄ 7-6

QRR = sum of all q_i's right of KQ-section ℄ 7-7

Figure 7.—Embankment overflow.

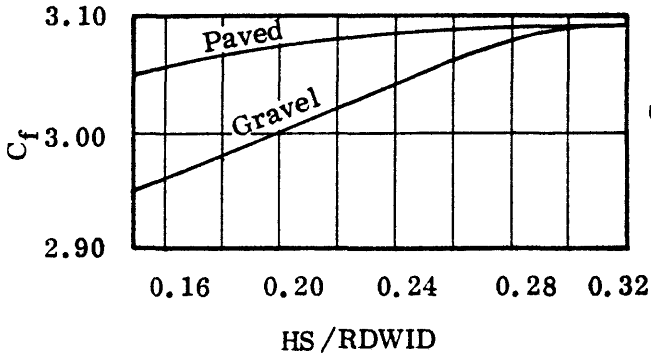


Figure 8a. Discharge Coefficients for HS/RDWID > 0.15

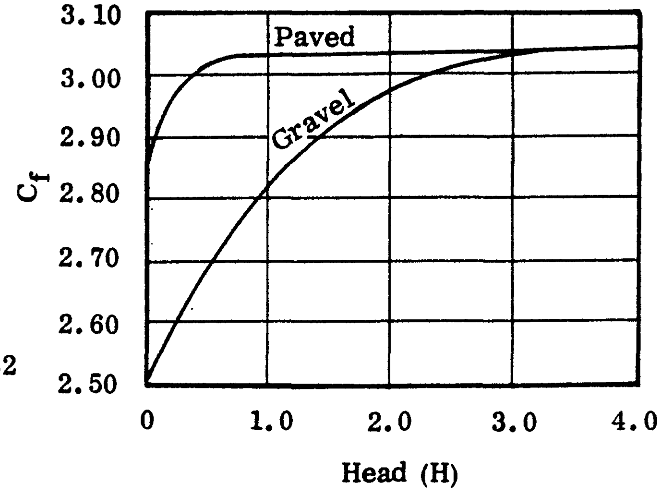


Figure 8b. Discharge Coefficients for HS/RDWID ≤ 0.15

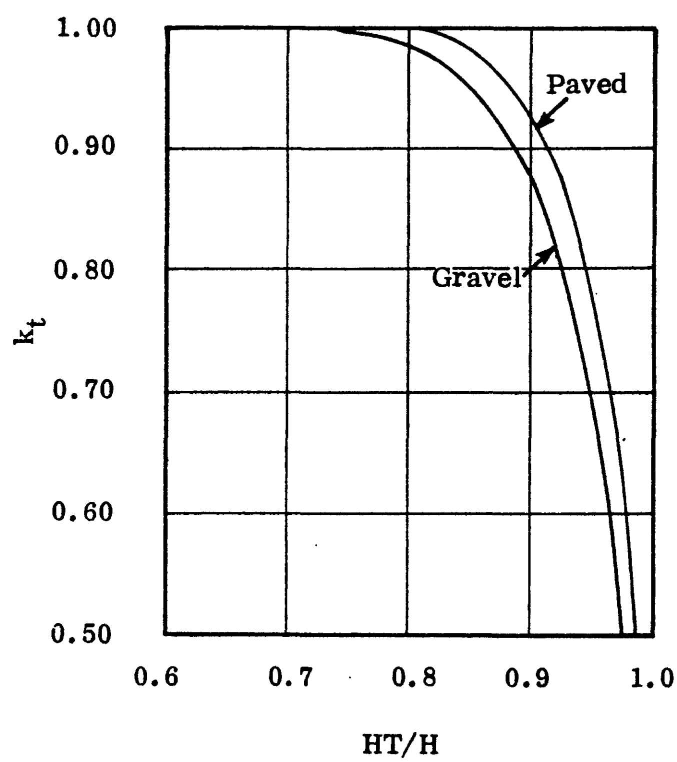
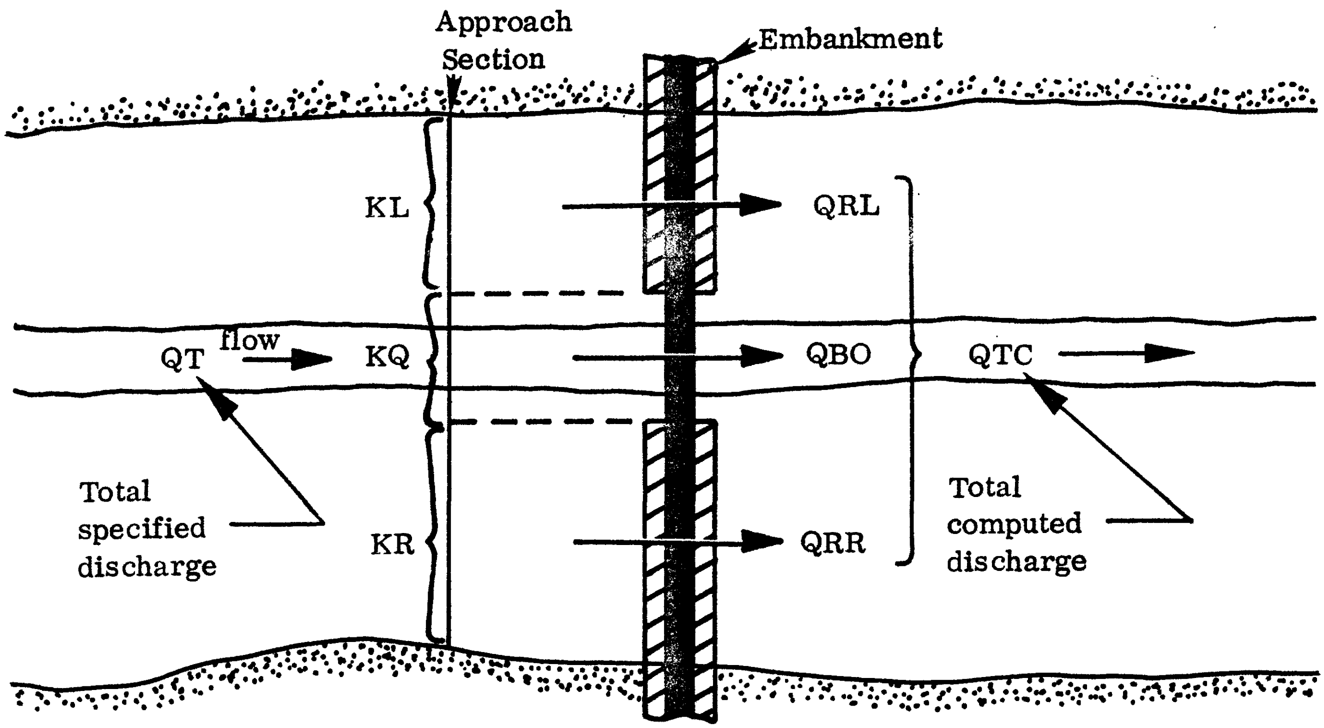


Figure 8c. Submergence Factor

Figure 8.—Coefficients used in E431 for computing embankment overflow.

KT, KL, KQ, KR as defined on figure 4b.
QT is total flow specified
QBO is flow through bridge opening
QRL is embankment overflow to left of KQ-section ℄
QRR is embankment overflow to right of KQ-section ℄
QTC is total flow computed



$$KT = KL + KQ + KR \qquad 9\text{-}1$$

KLB is the portion of KL assumed to pertain to QBO

$$KLB = KL - \frac{QRL}{QT} KT \quad (KLB \geq 0) \qquad 9\text{-}2$$

KRB is the portion of KR assumed to pertain to QBO

$$KRB = KR - \frac{QRR}{QT} KT \quad (KRB \geq 0) \qquad 9\text{-}3$$

KTB is the total conveyance assumed to pertain to QBO

$$KTB = KLB + KQ + KRB \qquad 9\text{-}4$$

$$QTC = QRL + QBO + QRR \qquad 9\text{-}5$$

Computational error

$$QERR = QTC - QT \qquad 9\text{-}6$$

Need to satisfy

$$|QERR| \leq QT \left(\frac{QTOL}{100}\right) \qquad 9\text{-}7$$

Figure 9.—Definition sketch for balancing computation of flows over the embankment and through the bridge opening.

Form 9-1891A
(May 1974)

BACKWATER ANALYSIS

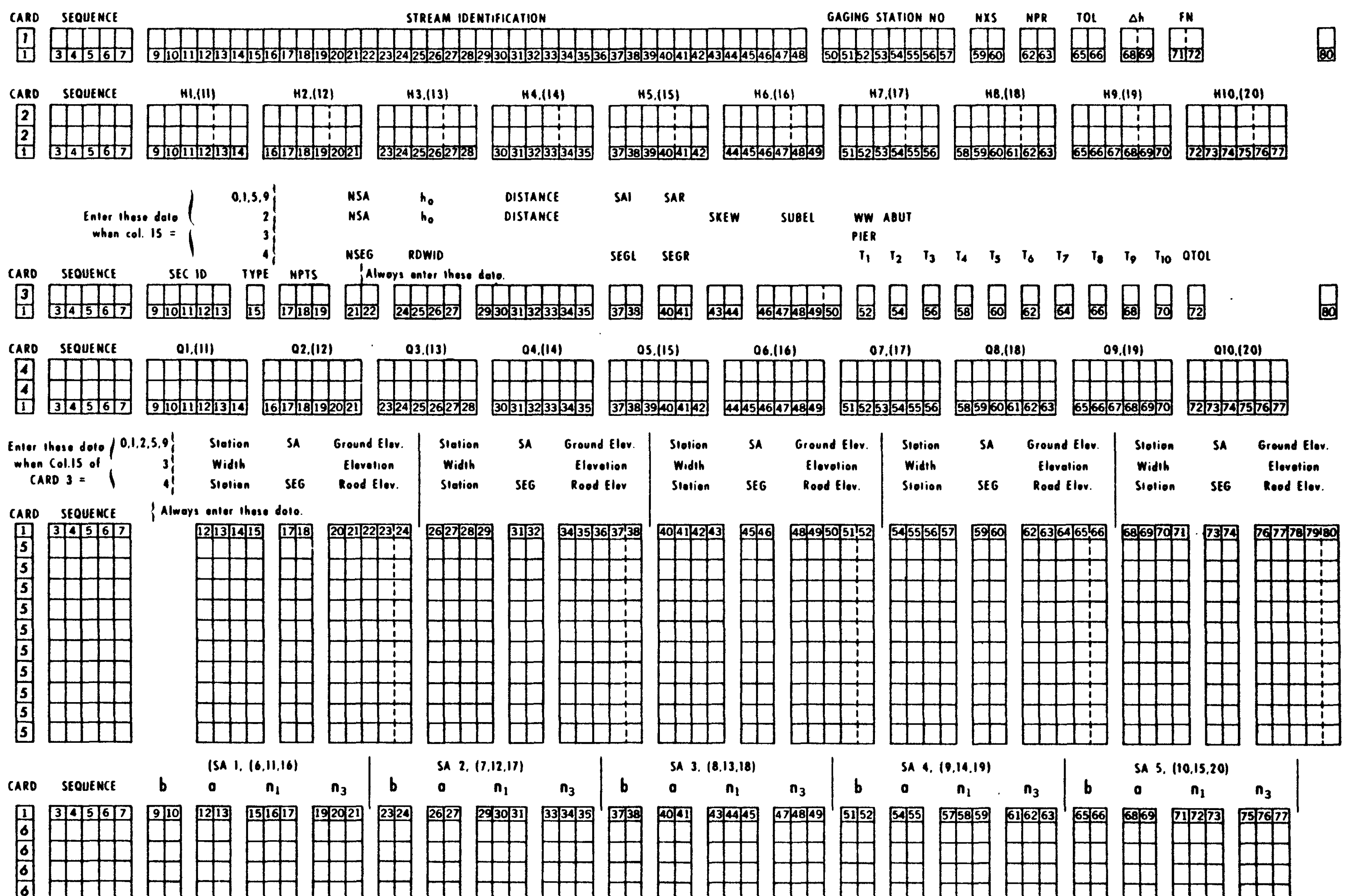


Figure 10.—Form 9-1891A for coding data for backwater analyses using E431.

99999. Sequence numbers need not be consecutive, but each should be algebraically greater than its preceding sequence number. All other required data are unique to their category and the kind of cross section being described. Possible entries for column 80 of the #1 CARD and #3 CARD are discussed under Special Features.

REACH DESCRIPTION

Data required to describe a reach are coded on CARD #1. Only one CARD #1 is required (and allowed) for each reach and it must precede all other data pertaining to that reach. Data on CARD #1 are:

STREAM IDENTIFICATION (cols. 9–48)––identifying the reach in terms of stream name, location, purpose of computations, etc.

GAGING STATION NO. (cols. 50–57)––standard USGS gaging station number, if applicable, or additional alphanumeric data to extend the STREAM IDENTIFICATION field.

NXS (cols. 59–60)––total number of cross sections in the reach. Limited to $1 \leqslant NXS \leqslant 99$.

NPR (cols. 62–63)––total number of water-surface profiles to be computed for the reach. Limited to $1 \leqslant NPR \leqslant 20$.

TOL (cols. 65–66)––tolerance, in hundredths of feet, for balancing the energy equation. Limits of $1 \leqslant TOL \leqslant 99$ represent tolerances of 0.01 through 0.99 feet.

Δ h (cols. 68–69)––elevation increment, in tenths of feet, which dictates the number of elevations for which cross-section properties are printed and, if less than 0.5 feet, influences the energy equation balance. Limits of $1 \leqslant \Delta h \leqslant 99$ represent elevation increments of 0.1 through 9.9 feet.

FN (cols. 71–72)––maximum value of Froude number for which a computed water-surface elevation will be hydraulically acceptable. Limits of $1 \leqslant FN \leqslant 20$ represent test values of 0.1 through 2.0.

The STREAM IDENTIFICATION and GAGING STATION NO. fields are printed on each page of E431 output for job identification. If columns 9 through 48 are blank, a series of question marks is printed.

Total number of cross sections, NXS, is the total number of #3 CARD(S) (discussed later) required to define the reach. An erroneous count is not necessarily abortive, but will generate an error message.

Accuracy of NPR, the number of profiles to be computed, is more critical. If the value specified (or assumed in E431 in the event of missing data) is too high (that is, greater than the number of consecutive positive discharges on the #4 CARD(S)), profile computations will be attempted for all of the discharges provided. However, in no case will the number of profiles computed exceed the number coded by the user in the NPR field.

Care must be exercised in the selection of TOL. A TOL of 0.02 feet is satisfactory for the vast majority of analyses. However, for steep reaches, and (or) high-velocity conditions, it may be necessary to use a larger tolerance to obtain convergence in the energy equation balancing procedure. Rarely should values greater than 0.05 to 0.10 feet be required. Problems can also be created by specifying too high a tolerance. Consider an extreme case of a subreach with a known downstream water-surface elevation of 100.20 feet and an upstream water-surface elevation of 100.22 feet computed by precisely balancing the energy equation (that is, zero tolerance). Balancing the energy equation with a tolerance of 0.10 foot in this subreach with the downstream water-surface elevation of 100.20 feet could result in an upstream elevation as low as 100.12 feet. Thus the printout would show a 0.08-foot rise rather than a 0.02-foot fall for that subreach.

As discussed previously, Δh should be small enough to obtain a summary of cross-section properties that is usable in interpretation of results and in any necessary manual computations. There is no way to totally eliminate cross-section property printout. Once a usable summary for all cross sections in the reach has been obtained, additional analyses can be made with $\Delta h = 9.9$ feet to minimize the lines of printout. In rare instances it is possible that the energy balancing process will break down due to the use of 0.5 foot for Δh in the profile computations. Specifying a Δh less than 0.5 foot on CARD #1 may solve this problem.

Specifying a reasonable value for FN can be very important. A value that is too high can result in final water-surface elevations which are actually in the supercritical flow regime. Conversely, a very low value can result in abortion of the profile computations because no hydraulically acceptable root can be found. A range of 1.1 to 1.3 for FN will generally be satisfactory. FN should never be assigned a value greater than 1.5 except when lesser values yield an insufficient data printout to be useful for manual computations. Any time the computed index Froude number exceeds 1.0, the computed water-surface profile must be closely investigated (Davidian, 1976) before it is accepted it as a valid solution.

INITIAL WATER-SURFACE ELEVATIONS

Computing a water-surface profile for a reach requires the water-surface elevation at the most downstream cross section for the discharge of interest. The initial water-surface elevation for each profile to be computed must be coded on one (for $1 \leqslant NPR \leqslant 10$) or two (for

11 ≤ NPR ≤ 20) #2 CARD(S). Associated discharges are coded on #4 CARD(S) which are discussed below. Elevations, to hundredths of feet, are coded as H1 (cols. 9–14), H2 (cols. 16–21), . . . , H10 (cols. 72–77) on the first #2 CARD and H11 (cols. 9–14), . . . , H20 (cols. 72–77) on the second #2 CARD. Possible entries are -99999 through 999999 representing elevations of -999.99 through 9,999.99 feet. The #2 CARD(S) immediately follow the #1 CARD and precede *all* cross-section data.

INDIVIDUAL CROSS SECTIONS

Data cards for each cross section must be arranged with ascending CARD numbers. All individual cross sections required for profile computations must be coded successively, beginning with the most downstream cross section. A #3 CARD is required as the first data card for each cross section. Required on each #3 CARD, regardless of the kind of cross section, are the following parameters.

- SECID (cols. 9–13)—alphanumeric data for cross-section identification.
- TYPE (col. 15)—numerical code to indicate the type of cross section being defined.
- NPTS (cols. 17–19)—Number of coordinates tabulated on the #5 CARD(S) to define the cross section.

SECID should be unique for each cross section in the reach since it is used to identify error messages and (or) computed results. Responsibility for uniqueness lies entirely with the user as no editing is performed on SECID.

Table 3 summarizes the possible entries for TYPE and the type of cross section that each valid entry indicates.

Table 3.—*Definition of TYPE code on CARD #3*

Type	Type of cross section
0	Regular cross section.
1	Regular cross section with discharge(s).
2	Bridge-opening cross section.
3	Pier elevation-width data.
4	Embankment cross section.
5	Approach cross section.
9	Any cross section (except pier or embankment) for which only cross-section properties are to be computed.

Counting errors for NPTS are not usually fatal but the printout does get cluttered with the error flags and error messages, and the assumptions programmed into E431 may be wrong. Limits for NPTS vary with the type of cross section as follows: 1) pier data (TYPE = 3), 2 ≤ NPTS ≤ 25; 2) embankment data (TYPE = 4), 2 ≤ NPTS ≤ 50: and 3) all other data, 2 ≤ NPTS ≤ 200.

Remaining data preparation is variable in terms of (1) CARD numbers required and (2) number and type of parameters required. This is reflected by the variable headings for the #3 and #5 CARD(S) for different values of TYPE. When there is no heading above a data field, do not make a data entry. Following the discussion of coding discharge data, the remaining instructions are arranged under the same headings used in the Data Requirements section (that is, regular cross section, exit cross section, and so forth).

Discharges

The magnitude of the discharge at the most downstream cross section must be provided for each water-surface profile to be computed. Also, different discharge magnitudes may be specified at any regular cross section to account for changing flow magnitude along the reach. Discharges are coded on one (for 1 ≤ NPR ≤ 10) or two (for 11 ≤ NPR ≤ 20) #4 CARD(S). Valid entries of 1 through 999999 represent discharges of 1 through 999,999 cubic feet per second (ft^3/s). There must be a one-for-one correspondence of discharges on the #4 CARD(S) with the initial water-surface elevations on the #2 CARD(S) (that is, Q1 (cols. 9–14) for H1, Q2 (cols. 16–21) for H2, and so forth). The total number of entries should agree with the NPR specified on CARD #1. If new discharges are introduced anywhere within the reach, the number of entries must also agree with NPR and with the number of entries coded at the most downstream cross section.

Regular Cross Section

Any regular cross section at which discharges need to be entered, such as the most downstream cross section and a cross section immediately upstream from significant tributary inflow, must be coded with TYPE = 1 in column 15 of the #3 CARD. The #3 CARD is followed by the appropriate #4 CARD(S). At any other regular cross section, TYPE = 0 (zero) must be specified, and no #4 CARD(S) are required (or allowed). In addition to the #3 CARD parameters discussed earlier, the following data are required on the #3 CARD describing a regular cross section.

- NSA (cols. 21–22)—total number of subareas used to adequately define the geometric and (or) roughness variation in the cross section (see fig. 1). Limits are 1 ≤ NSA ≤ 20.
- h_o (cols. 24–27)—minimum elevation of interest in the cross section. Coded to nearest foot with limits of -999 feet ≤ h_o ≤ 9,999 feet.
- DISTANCE (cols. 29–35)—cumulative flow distance, in feet, measured from an arbitrary reference point in the reach. Limits are -999,999 ≤ DISTANCE ≤ 9,999,999.

SAL (cols. 37–38) and SAR (cols. 40–41)––not used, advisable to enter dummy value of 99 for each.

NSA and DISTANCE are discussed in the Data Requirements section, and h_o is discussed in the Computational Methods section. SAL and SAR are applicable at regular cross sections only for a particular floodway analysis option to be discussed later. It is not absolutely essential to enter any values for SAL and SAR for backwater analysis. However, entering a dummy value of 99 for each eliminates editing notes generated by missing data for SAL and SAR.

Definition of geometry and roughness for each cross section, as discussed in the Data Requirements section, is accomplished with the #5 and #6 CARD(S). Horizontal stationing-elevation coordinates and subarea numbers are tabulated on the #5 CARD(S) as follows:

Station (cols. 12–15, 26–29, . . . ,68–71)–– horizontal distance, to the nearest foot, from an arbitrary reference point in the cross section. Left to right is positive, and the limits are $-999 \leq$ Station ≤ 9999, or -999 feet through 9,999 feet.

SA (cols. 17–18, 31–32, . . . ,73–74)––subarea number in which the coordinate is located. Limited to $1 \leq SA \leq NSA$, with the leftmost subarea always assigned SA = 1 and rightmost subarea assigned SA = NSA.

Ground Elevation (cols. 20–24, 34–38, . . . ,76–80)––the ground elevation, to tenths of feet, of the coordinate. Possible elevation range is -999.9 feet through 9,999.9 feet.

Up to five sets of coordinate data and subarea numbers may be coded on each #5 CARD. When more than ten cards are required (that is, NPTS > 50), additional sheets must be used. CARD #6 data must be coded only on the *last* sheet. Nothing other than CARD #5 and CARD #6 data are coded on the additional sheets.

The leftmost point in the cross section is coded first and the Station of each point thereafter must be greater than or equal to the Station of the preceding point. Violation of this rule results in elimination of the cross section from the subsequent computational phases of the program.

The proper SA to be assigned to each coordinate is the number of the subarea in which the area between that coordinate and the next coordinate to the right is located. Therefore, at the breakpoint between two subareas, the SA that must be assigned to that coordinate is the larger of the two adjacent subarea numbers. Of course, the last coordinate is located in the last subarea and must have a subarea number equal to NSA. Each successive SA must be equal to or one greater than the preceding SA or the cross section is eliminated from further consideration. Ground elevations receive relatively limited editing, which makes it possible for the program to accept drastically erroneous data (for example, an elevation of 275.0 keypunched on the card as 215.0) which may result in large computational errors. A usable cross-section properties summary, such as discussed in Computational Methods, is instrumental in discovering these gross computational errors.

Roughness data are coded on the #6 CARD(S). Two flow depths and two roughness coefficients must be coded for each subarea to define the roughness-depth relations in the cross section. Up to five sets of these values can be coded on each #6 CARD as follows:

b (cols. 9–10, 23–24, . . . ,65–66)––depth of flow at any point in the subarea below which a constant roughness coefficient may be applied. Coded to the nearest foot with limits of $0 \leq b \leq 98$.

a (cols. 12–13, 26–27), . . . ,68–69)––depth of flow at any point in the subarea above which a constant roughness coefficient may be applied. Coded to the nearest foot with $(b + 1) \leq a \leq 99$.

n_1 (cols. 15–17, 29–31, . . . ,71–73)–– Manning's 'n' to be used for an average depth of b or less. Limits of $1 \leq n_1 \leq 999$ represent a range of 0.001 through 0.999.

n_3 (cols. 19–21, 33–35, . . . ,75–77)––Manning's 'n' to be used for an average depth of a or greater. Limits for n_3 are identical with those for n_1.

The depth of flow used for computing the applicable n-value from the relationship defined by a, b, n_1, and n_3, is the hydraulic depth, d (eq. 1-1). As illustrated in figure 1, the applicable roughness would be equal to: 1) n_1 when $d \leq b$, 2) n_3 when $d \geq a$, and 3) a value computed by straight-line interpolation when $b < d < a$.

Figure 11 illustrates the coding of the #3, #5, and #6, CARD(S) for a regular cross section.

Exit Cross Section

An exit cross section, the first cross section required for a bridge situation (see table 1), is coded exactly like a regular cross section with two minor exceptions. As previously mentioned, the DISTANCE value must be equal to the DISTANCE value of the bridge-opening cross section. Also, there are three possibilities for TYPE. In most cases TYPE will be 0 (zero). However, in cases where bridges are closely spaced along the reach, the approach cross section of one bridge may have to serve as the exit cross section for the next bridge upstream. Therefore, TYPE = 5 is also valid for an exit cross section. Also, for the case where significant tributary inflow enters the reach between the exit cross section and the next cross section downstream, it may be necessary to introduce new discharge(s) at the exit cross section. This is entirely permissible, making TYPE = 1 the third valid possibility.

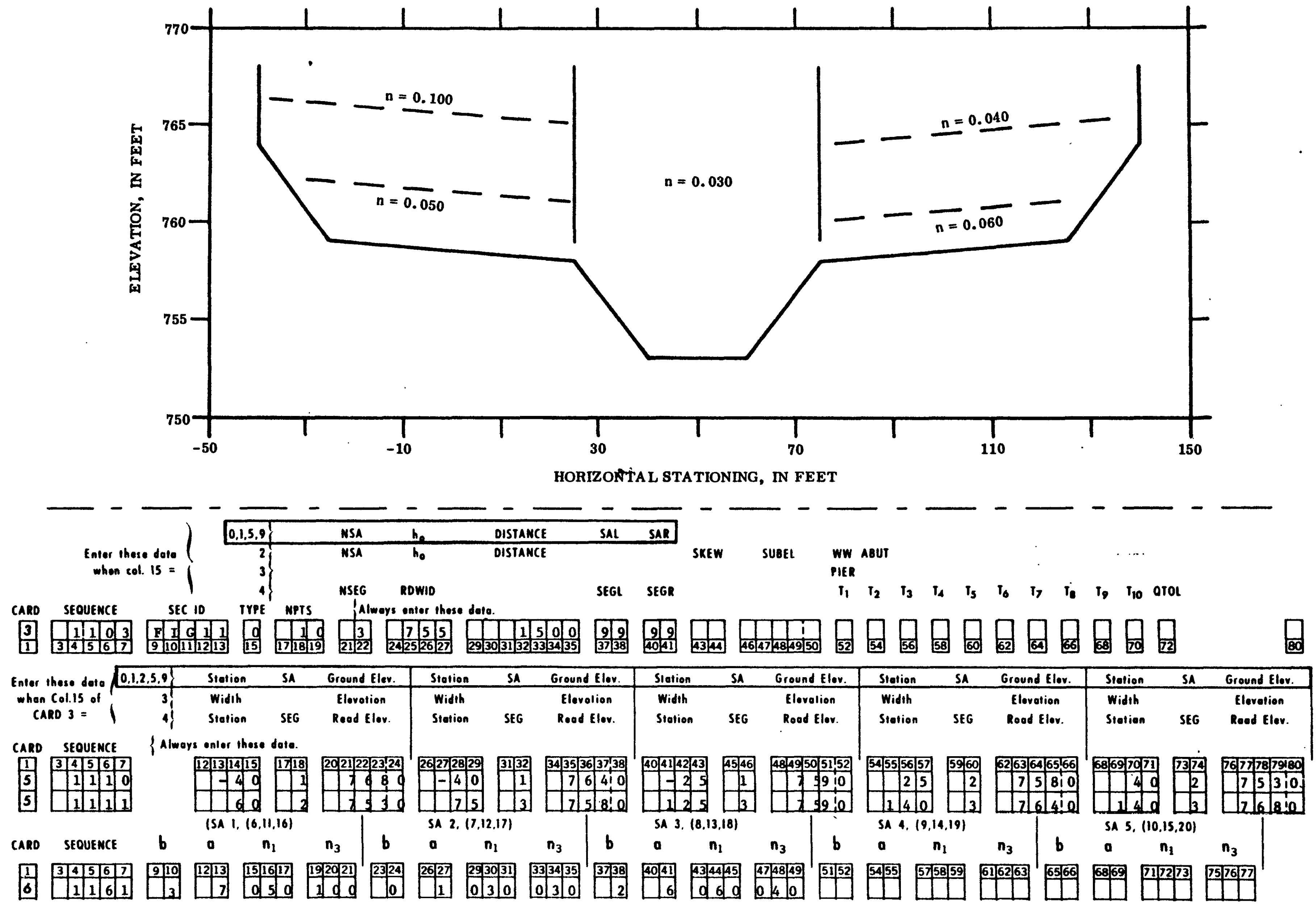


Figure 11.—Data coding example for regular cross sections.

Bridge-Opening Cross Section

A bridge-opening cross section must always be coded with TYPE = 2. It always follows the exit cross section (see table 1). NSA and h_0 are no different from any other cross section. DISTANCE is the flow distance between the downstream face of the opening and initial downstream reference point established for measuring flow distance. Additional parameters required are:

- SKEW (cols. 43–44)—angle of skew of the bridge relative to the general direction of flow (see fig. 12). This angle is equivalent to the acute angle between the plane of the constriction and a line normal to the thread of the stream. SKEW must be expressed to the nearest 15 degrees with the only valid entries being 0, 15, 30, and 45.
- SUBEL (cols. 46–50)—mean elevation of the low chord. Expressed to the nearest tenth of a foot.
- WW (col. 52)—code to define wingwall configuration. The only valid entries are 1 ≤ WW ≤ 4 (see table 4a).
- ABUT (col. 54)—code to define abutment alinement relative to the plane of the constriction. The only valid entries are: 0 for abutments perpendicular to the plane of the constriction (see fig. 12a); and 1 for abutments skewed parallel to the thread of the stream (see fig. 12b).

Tables 4a–4c.—*WW Codes and the KB and KE components of the bridge-loss coefficient*

[4a.—Definition of valid WW codes]

WW code	Wingwall configuration	Data source
1*	45° and 60° wingwalls and spill-through abutments.	Bradley (1960)
2	30° wingwalls	Bradley (1960)
3	90° wingwalls	Bradley (1960)
4	45° and 60° wingwalls and spill-through abutments.	Bradley (1970)

*Average value of all applicable curves.

[4b.—KB values used in E431 (adapted from Bradley, 1960, figures 5 and 6, and Bradley, 1970, figure 6)]

M	WW = 1	2	3	4
0.0	0.00	0.00	0.00	0.00
.1	.10	.13	.17	.07
.2	.25	.33	.40	.25
.3	.46	.56	.65	.50
.4	.70	.80	.90	.79
.5	.94	1.04	1.15	1.12
.6	1.18	1.28	1.40	1.50
.7	1.42	1.52	1.65	1.95
.8	1.66	1.76	1.90	2.46
.9	1.90	2.00	2.15	3.11
1.0	2.14	2.24	2.40	3.58

[4c.—KE values used in E431 (adapted from Bradley, 1970, figure 8)]

M	E ≥0.20	0.15	0.10	0.05	0.00
0.80	0.000	0.020	0.052	0.100	0.173
.45	.000	.020	.049	.095	.163
.30	.000	.017	.043	.084	.144
.15	.000	.011	.027	.056	.097
.00	.000	.000	.000	.000	.000

Two of the components of the loss coefficient, K* (eq. 4-4) are determined using these data. The KS component (eq. 4-11) is computed from the curves of figure 12 using the values of SKEW and ABUT provided by the user. Also, since the bridge-opening cross section is measured parallel to the plane of the constriction, the cosine of SKEW is used to compute the cross-sectional area normal to the flow. This corrected area is used in the profile computations. The summary of cross-section properties for a bridge-opening cross section, however, reflects the uncorrected, gross properties which are more generally applicable in manual computations such as those described by Matthai (1967).

The KB component (eq. 4-9) is a function of wingwall configuration and the bridge-contraction ratio. Table 4a summarizes the wingwall configuration indicated by valid WW codes. WW = 4 should be used only for reaches with very flat slopes and a high ratio of flood-plain width to bridge-opening width. KB values for each WW code are tabulated in table 4b. Values of the KE component (eq. 4-10), which is a function of M and E, are tabulated in table 4c. The KP component is discussed later in the section entitled Pier Cross Section.

SUBEL is used only in the computation of Type 2 flow as illustrated in figure 5. The flexibility permitted in coding the bridge opening eliminates a totally accurate method of computing the hydraulic depth or mean bed elevation. Instead the maximum bridge width (BRWID) is used to compute the hydraulic depth, Z (eq. 5-2), which is subsequently substracted from SUBEL to obtain the mean bed elevation (eq. 5-3). Obviously, if a meaningful value of Z is computed by equation 5-2 and the low-chord is virtually horizontal, assigning an average low-chord elevation to SUBEL will yield a representative value for BEDEL from equation 5-3. However, irregular low chords (for example, arches, variable-depth box girders, and so forth) and (or) bridge openings for which maximum bridge width is not appropriate for use in equation 5-2, require special attention. SUBEL must be assigned an elevation that results in meaningful BEDEL. In extreme cases of irregularity, it may be necessary to code an "equivalent" bridge opening to obtain a valid computer solution, or it may be necessary to resort to manual computations. If SUBEL is not coded, or is equal to zero, no attempt is made to compute Type 2 or

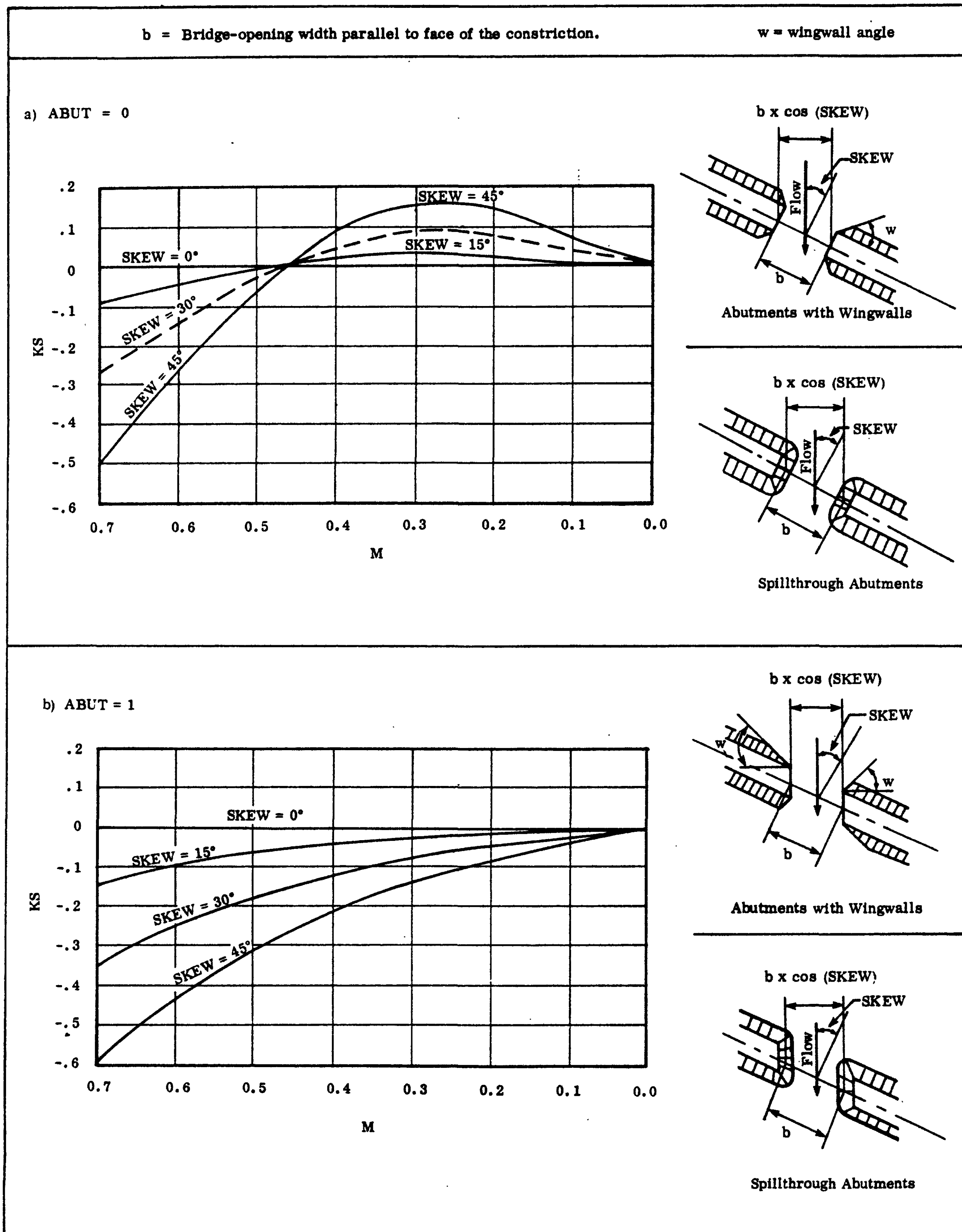


Figure 12.—Skew component of bridge-loss coefficient.

Type 3 flow. The user may thus force a Type 1 flow analysis if the need arises. Therefore, if an elevation of 0.0 happens to be the correct value for SUBEL, and a Type 2 or Type 3 flow computation is desired, SUBEL should be coded as either -0.1 or +0.1 in order to achieve a solution.

It is advisable to provide a completely closed loop when coding a bridge-opening cross section. This enables the computer to determine the correct area and the extra wetted perimeter of the bridge opening when the water surface makes contact with or exceeds the elevation of all or part of the low chord of the bridge. Internally, extra data checks and special computing techniques are required. Therefore, the user must do some special coding on the #5 CARD(S) as illustrated by figures 13, 14, and 15.

Coding the #3, #5, and #6 CARD(S) for a very simple bridge opening with no piers and a uniform roughness is illustrated by figure 13. The location, within the cross section, of the first coordinate to be coded on the #5 CARD(S) is not critical to the program. However, consistency is recommended to avoid confusion. The upper, lefthand coordinate of the opening is a good, logical choice. Coordinates are coded in counter-clockwise fashion with the last coordinate being identical with the first coordinate, but identified with a -9 subarea number. Note that this repeated first coordinate makes 13 points to define the bridge opening (NPTS on CARD #3 is 13). Note, also, that the -9 value of subarea for the last point does not count as an addition to the total number of subareas (NSA on CARD #3 is 1).

Figure 14 illustrates coding #3, #5, and #6 CARD(S) for a bridge opening with piers. The roughness is the same in all three spans. However, since gross area is used to compute the velocity head in the bridge opening the ground line and low chord are assumed to pass through the piers. Coding is done in the same manner as for figure 13.

Figure 15 illustrates coding the #3, #5, and #6 CARD(S) for the same bridge opening as figure 14 except that the roughness is different in each span. Therefore, three subareas are required, and the wetted perimeter for the appropriate segment of the low chord is allocated to each subarea by coding two extra coordinates along the low chord. Out-or-order SA numbers are permitted in a bridge-opening cross section.

Net area of a bridge opening may be obtained if needed for a special case. This feature is described in the Special Features section (p. 39).

Approach Cross Section

An approach cross section must always be coded with TYPE = 5. It is always the last cross section in a bridge situation, as shown in table 1. Except for two parameters, CARD #3 is coded exactly as for a regular cross section. The two parameters are:

- SAL (cols. 37–38)——highest subarea number to the left of the KQ section. Valid entries are $1 \leqslant SAL \leqslant (NSA\text{-}1)$ or a dummy value of 99.
- SAR (cols. 40–41)——lowest subarea number to the right of the KQ section. Valid entries are $2 \leqslant SAR \leqslant NSA$ or a dummy value of 99.

SAL and SAR enable the computer to sum the appropriate subarea conveyances to obtain the KL, KR, and KQ values (see fig. 4b). Subdivision of an approach section may differ from subdivision of a similar regular section because the KQ-section limits must coincide with subarea breakpoints. Figure 16 illustrates this difference for a typical cross section. Equations 16-1, 2 and 3 are used to computed KL, KQ, and KR, respectively. A dummy value of 99 must be used for SAL and (or) SAR when there are no subareas to the left and (or) right of the KQ section (see fig. 17).

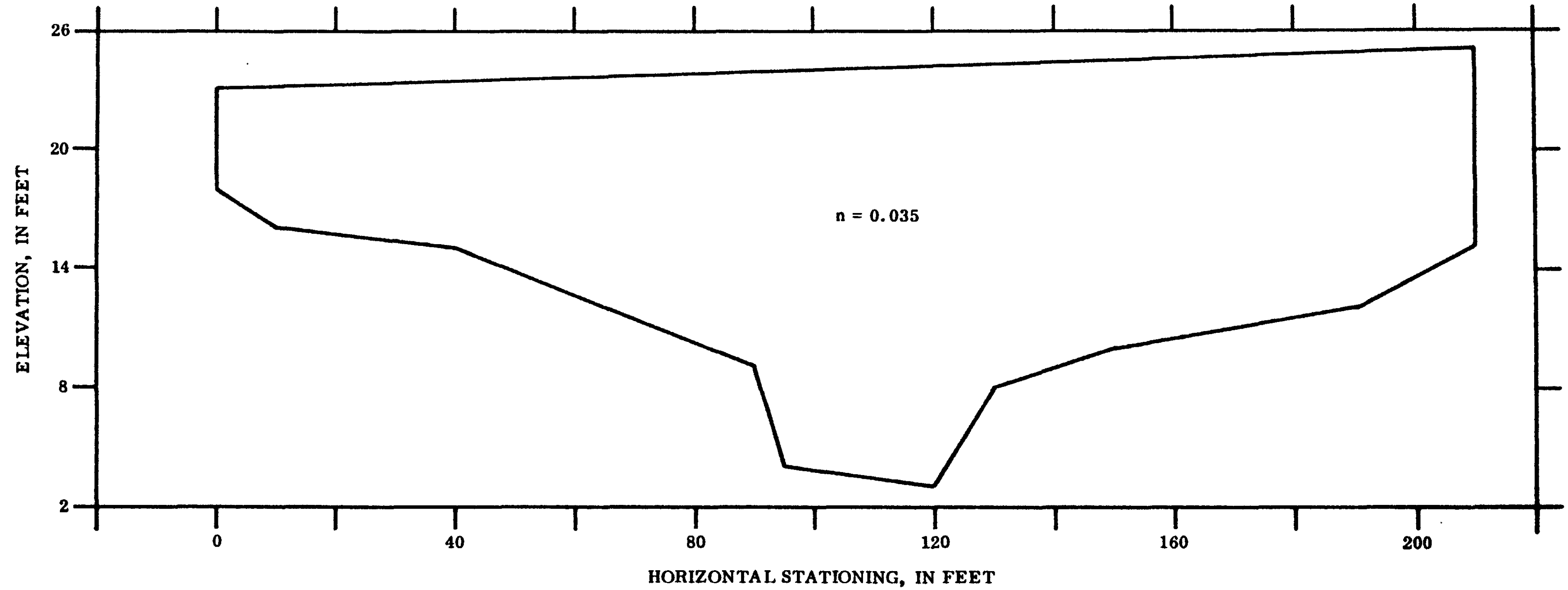
Pier Cross Section

A pier cross section must always be coded with TYPE = 3. A pier cross section is optional and need not be coded if there are no piers (or if pier effects are considered insignificant). If coded, the pier cross section immediately follows the bridge-opening cross section (see table 1). Except for those parameters required on every #3 CARD, there is only one parameter required for description of the pier cross section. This parameter is:

- PIER (col. 52)——code describing the shape and configuration of piers in the bridge opening. Valid entries are $1 \leqslant PIER \leqslant 8$ which correspond to the curve numbers in figure 18.

Figure 18 illustrates the relationships and equations used to compute the KP component (eq. 4-12) of K*. The PIER code dictates the applicable curve numbers for determining ΔK and σ. Determination of J (eq. 18-1) requires data from which pier areas may be computed. Therefore, the gross pier width, projected normal to the flow, at two or more elevations is required. These data are coded on the #5 CARD(S) as follows:

- Width (cols. 12–15, 26–29, . . . ,68–71) for the Elevation coded in cols. 20–24, 34–38, . . . , 76–80——gross width, projected normal to the flow, of all piers. Expressed to the nearest foot with limits of $0 \leqslant Width \leqslant 9999$, or a range of 0 through 9,999 feet.
- Elevation (cols. 20–24, 34–38, . . . ,76–80)——elevation, in tenths of a foot, associated with the



Enter these data when col. 15 =
- 0,1,5,9: NSA, h_o, DISTANCE, SAL, SAR
- 2: NSA, h_o, DISTANCE, SKEW, SUBEL, WW ABUT
- 3: PIER
- 4: NSEG, RDWID, SEGL, SEGR, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, QTOL

Always enter these data: CARD, SEQUENCE, SEC ID, TYPE, NPTS.

CARD	SEQUENCE	SEC ID	TYPE	NPTS	21-22	24-27	29-35	37-38	40-41	43-44	46-50	52	54	56	58	60	62	64	66	68	70	72	80
3 1	1303	B013	2	13	1	8	8880			0	240	1	0										

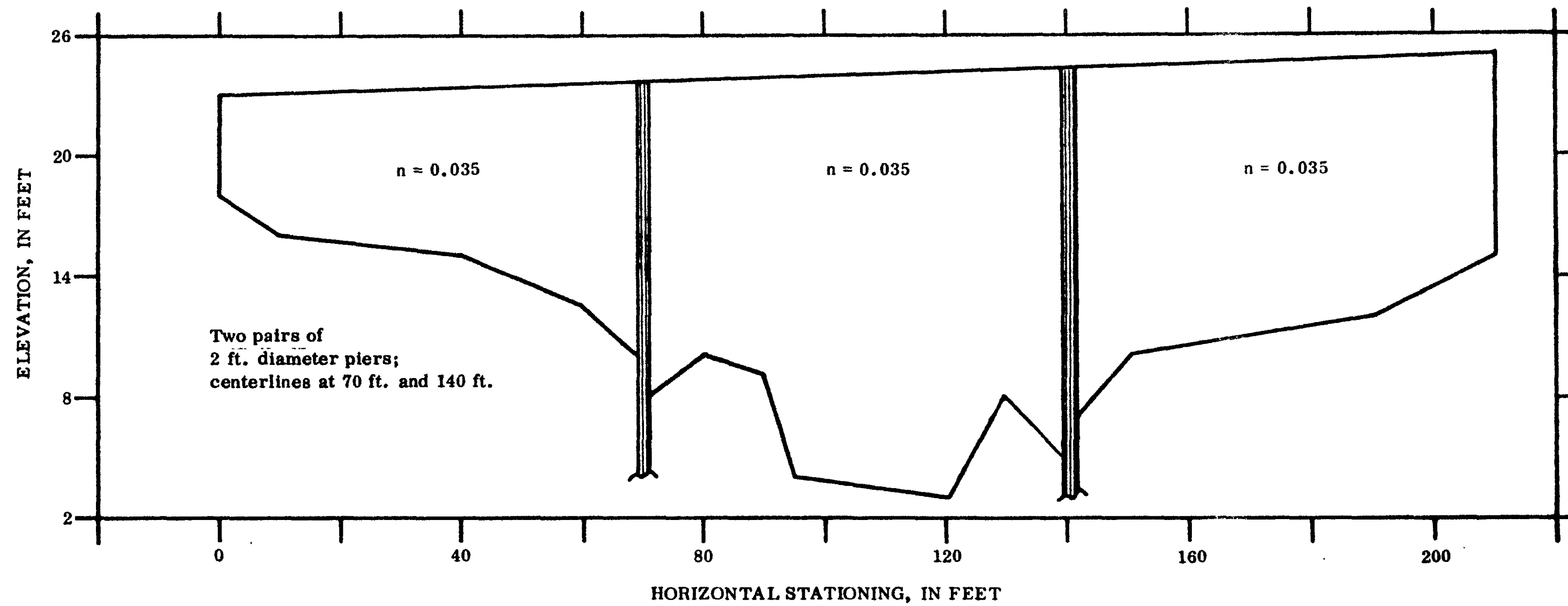
Enter these data when Col. 15 of CARD 3 =
- 0,1,2,5,9: Station, SA, Ground Elev.
- 3: Width, Elevation
- 4: Station, SEG, Road Elev.

Always enter these data: CARD, SEQUENCE.

CARD	SEQUENCE	Station (12-15)	SA (17-18)	Ground Elev. (20-24)	Station (26-29)	SA (31-32)	Ground Elev. (34-38)	Station (40-43)	SA (45-46)	Ground Elev. (48-52)	Station (54-57)	SA (59-60)	Ground Elev. (62-66)	Station (68-71)	SA (73-74)	Ground Elev. (76-80)
1 5	1350	0	1	230	0	1	180	10	1	160	40	1	150	90	1	90
5	1351	95	1	40	120	1	30	130	1	80	150	1	100	190	1	120
5	1352	210	1	150	210	1	250	0	-9	230						

CARD	SEQUENCE	b (9-10)	SA 1, (6,11,16) a (12-13)	n_1 (15-17)	n_3 (19-21)	SA 2, (7,12,17) b (23-24)	a (26-27)	n_1 (29-31)	n_3 (33-35)	SA 3, (8,13,18) b (37-38)	a (40-41)	n_1 (43-45)	n_3 (47-49)	SA 4, (9,14,19) b (51-52)	a (54-55)	n_1 (57-59)	n_3 (61-63)	SA 5, (10,15,20) b (65-66)	a (68-69)	n_1 (71-73)	n_3 (75-77)
1 6	1361	0	1	035	035																

Figure 13.—Data coding example for simple bridge-opening cross section.



Enter these data when col. 15 =

Col. 15																			
0,1,5,9	NSA	h_o	DISTANCE	SAL	SAR														
2	NSA	h_o	DISTANCE			SKEW	SUBEL	WW ABUT											
3								PIER											
4	NSEG	RDWID		SEGL	SEGR			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	QTOL	

Always enter these data (CARD, SEQUENCE, SEC ID, TYPE, NPTS).

CARD (1)	SEQUENCE (3-7)	SEC ID (9-13)	TYPE (15)	NPTS (17-19)	21-22	24-27	29-35	37-38	40-41	43-44	46-50	52	54	56	58	60	62	64	66	68	70	72	80
3	1403	BC14	2	19	1	8	8880			0	246	1	0										

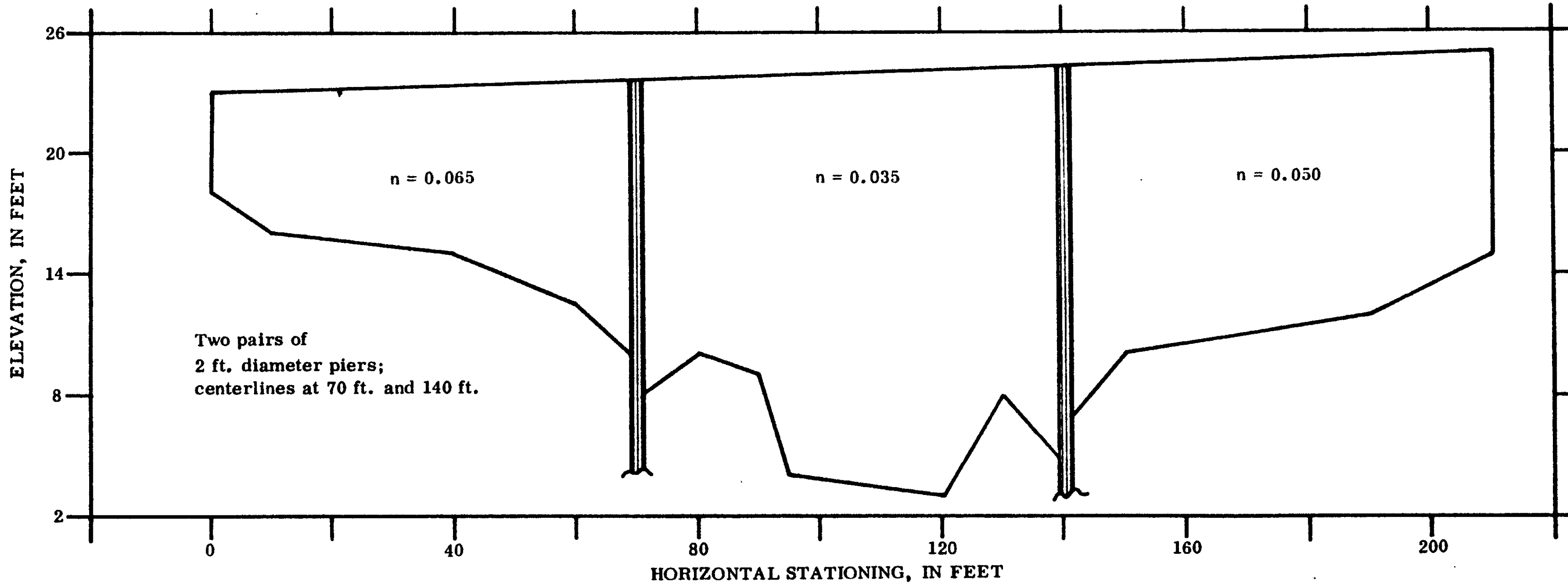
Enter these data when Col 15 of CARD 3 =
0,1,2,5,9: Station, SA, Ground Elev.
3: Width, Elevation
4: Station, SEG, Road Elev.

Always enter these data (CARD, SEQUENCE).

CARD (1)	SEQUENCE (3-7)	Station (12-15)	SA (17-18)	Ground Elev. (20-24)	Station (26-29)	SA (31-32)	Ground Elev (34-38)	Station (40-43)	SA (45-46)	Ground Elev (48-52)	Station (54-57)	SA (59-60)	Ground Elev (62-66)	Station (68-71)	SA (73-74)	Ground Elev. (76-80)
5	1420	0	1	230	0	1	180	10	1	160	40	1	150	60	1	125
5	1421	69	1	100	71	1	80	80	1	100	90	1	90	95	1	40
5	1422	120	1	30	130	1	80	139	1	50	141	1	70	150	1	100
5	1423	190	1	120	210	1	150	210	1	250	0	-9	230			

CARD (1)	SEQUENCE (3-7)	SA 1 (6,11,16) b (9-10)	a (12-13)	n_1 (15-17)	n_3 (19-21)	SA 2 (7,12,17) b (23-24)	a (26-27)	n_1 (29-31)	n_3 (33-35)	SA 3 (8,13,18) b (37-38)	a (40-41)	n_1 (43-45)	n_3 (47-49)	SA 4 (9,14,19) b (51-52)	a (54-55)	n_1 (57-59)	n_3 (61-63)	SA 5 (10 15 20) b (65-66)	a (68-69)	n_1 (71-73)	n_3 (75-77)
6	1430	0	1	035	035																

Figure 14.—Data coding example for bridge-opening cross section, no changes in roughness.



Enter these data when col. 15 = 0,1,5,9: NSA, h_o, DISTANCE, SAL, SAR
2: NSA, h_o, DISTANCE, SKEW, SUBEL, WW, ABUT
3: PIER
4: NSEG, RDWID, SEGL, SEGR, T_1 T_2 T_3 T_4 T_5 T_6 T_7 T_8 T_9 T_{10} QTOL

Always enter these data: CARD, SEQUENCE, SEC ID, TYPE, NPTS.

CARD (1)	SEQUENCE (3-7)	SEC ID (9-13)	TYPE (15)	NPTS (17-19)	NSA / NSEG (21-22)	h_o / RDWID (24-27)	DISTANCE (29-35)	SAL / SEGL (37-38)	SAR / SEGR (40-41)	SKEW (43-44)	SUBEL (46-50)	WW / PIER / T_1 (52)	ABUT / T_2 (54)	T_3 (56)	T_4 (58)	T_5 (60)	T_6 (62)	T_7 (64)	T_8 (66)	T_9 (68)	T_{10} (70)	QTOL (72)	(80)
3	1553	BØ15	2	21	3	8	880			0	240	1	0										

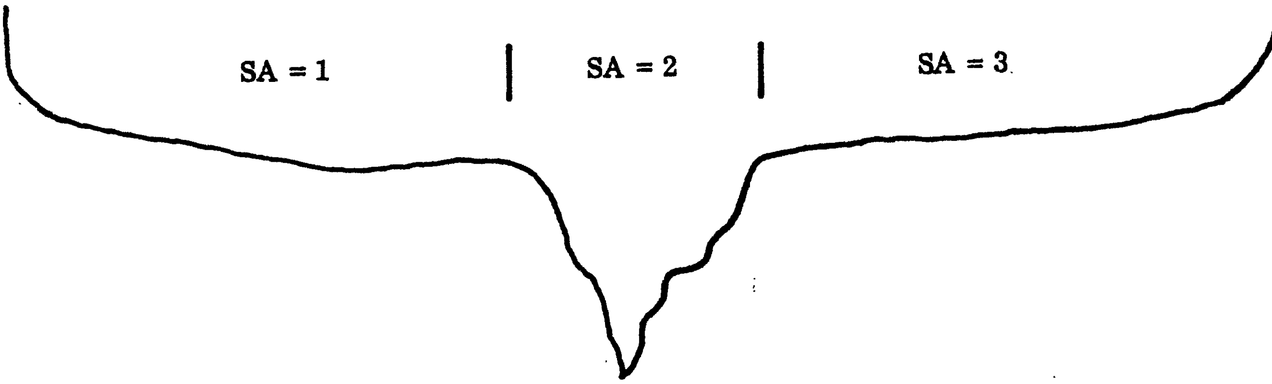
Enter these data when Col. 15 of CARD 3 = 0,1,2,5,9: Station, SA, Ground Elev; 3: Width, Elevation; 4: Station, SEG, Road Elev.

Always enter these data: CARD, SEQUENCE.

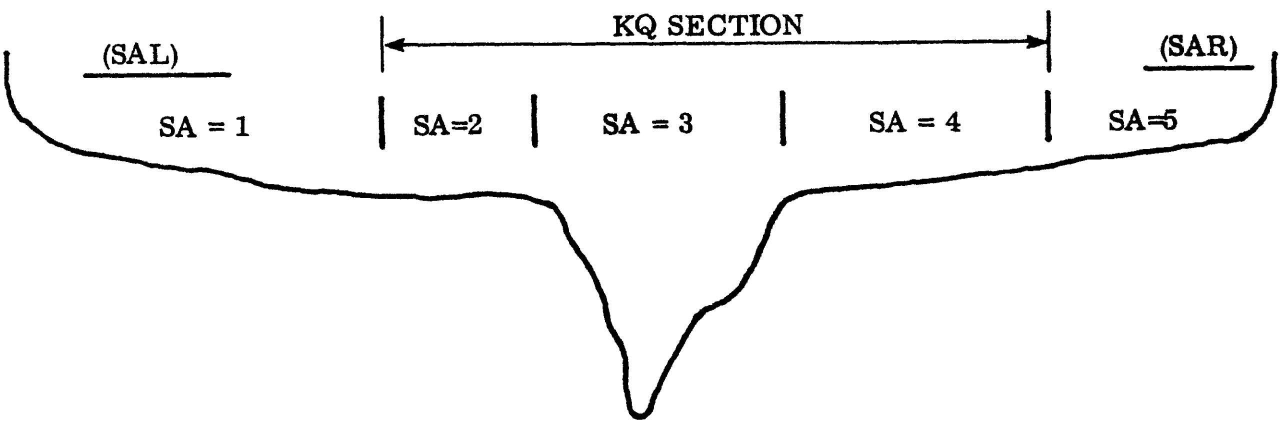
CARD (1)	SEQUENCE (3-7)	Station (12-15)	SA (17-18)	Ground Elev (20-24)	Station (26-29)	SA (31-32)	Ground Elev (34-38)	Station (40-43)	SA (45-46)	Ground Elev (48-52)	Station (54-57)	SA (59-60)	Ground Elev (62-66)	Station (68-71)	SA (73-74)	Ground Elev (76-80)
5	1560	0	1	230	0	1	180	10	1	160	40	1	150	60	1	125
5	1561	69	2	100	71	2	80	80	2	100	90	2	90	95	2	40
5	1562	120	2	30	130	2	80	139	2	50	141	3	70	150	3	100
5	1563	190	3	120	210	3	150	210	3	250	141	2	243	69	1	237
5	1564	0	-9	230												

CARD (1)	SEQUENCE (3-7)	SA 1 (6,11,16) b (9-10)	a (12-13)	n_1 (15-17)	n_3 (19-21)	SA 2 (7,12,17) b (23-24)	a (26-27)	n_1 (29-31)	n_3 (33-35)	SA 3 (8,13,18) b (37-38)	a (40-41)	n_1 (43-45)	n_3 (47-49)	SA 4 (9,14,19) b (51-52)	a (54-55)	n_1 (57-59)	n_3 (61-63)	SA 5 (10,15,20) b (65-66)	a (68-69)	n_1 (71-73)	n_3 (75-77)
6	1570	0	1	0,65	065	0	1	035	035	0	1	050	050								

Figure 15.—Data coding example for bridge-opening cross section, different subarea roughness.



a) Subdivided as a regular cross section.



b) Subdivided as an approach cross section.

For each SA number i (i = 1, 2, ···, NSA) there is a subarea conveyance k_i (Eq. 1-3). Total conveyance KT (Eq. 1-5) is also

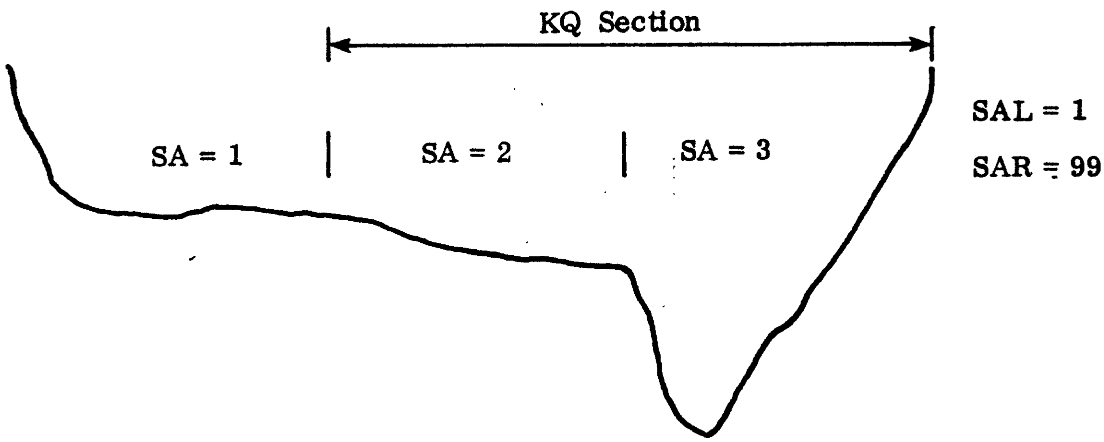
$$KT = KL + KQ + KR \quad \text{(Eq. 9-1)}$$

$$KL = \sum_{i=1}^{SAL} k_i \qquad 16\text{-}1$$

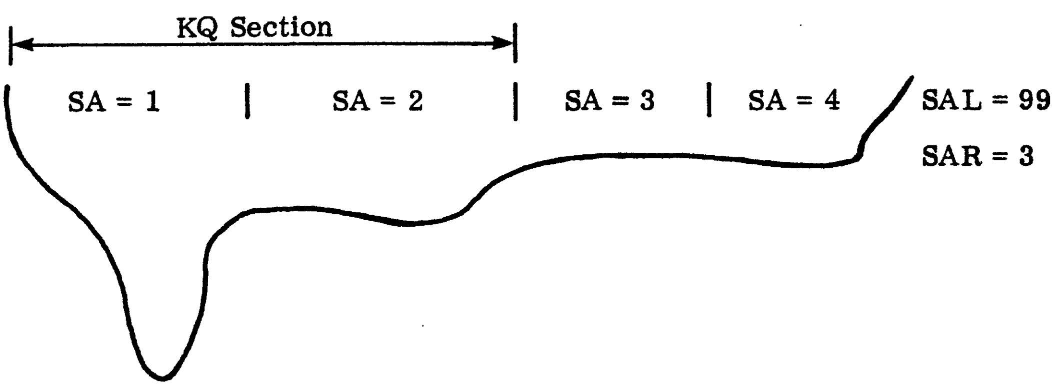
$$KQ = \sum_{i=SAL+1}^{SAR-1} k_i \qquad 16\text{-}2$$

$$KR = \sum_{i=SAR}^{NSA} k_i \qquad 16\text{-}3$$

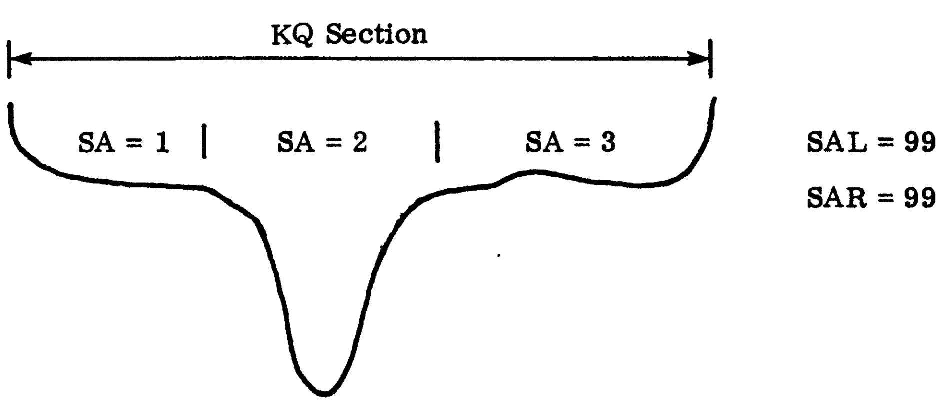
Figure 16.—Subdivision of approach cross section.



a) KQ Section at far right of approach



b) KQ Section at far left of approach



c) KQ Section occupies entire approach

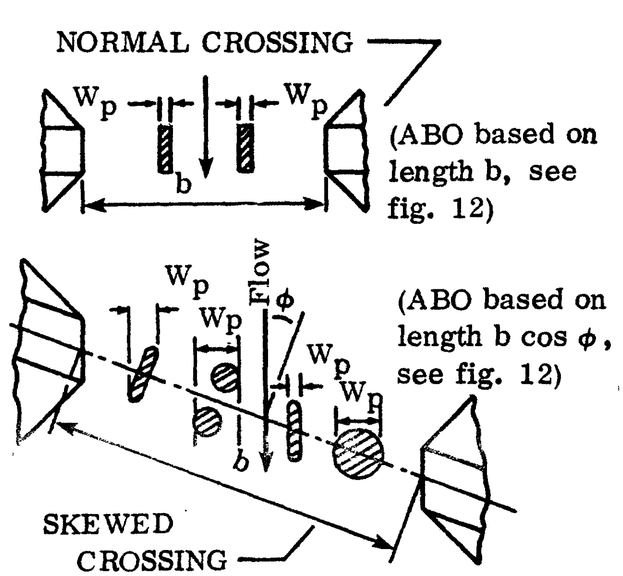
Figure 17.—Special cases of KQ-section location.

$J = APIER/ABO$ 18-1

where: $AB\phi$ = Gross area of bridge opening.
APIER = Total area of piers normal to flow.

$KP = (\Delta K)\sigma$ 18-2

(Circled numbers on figure below indicate proper PIER code.)



Flow direction is parallel to the pier curves in the figures below.

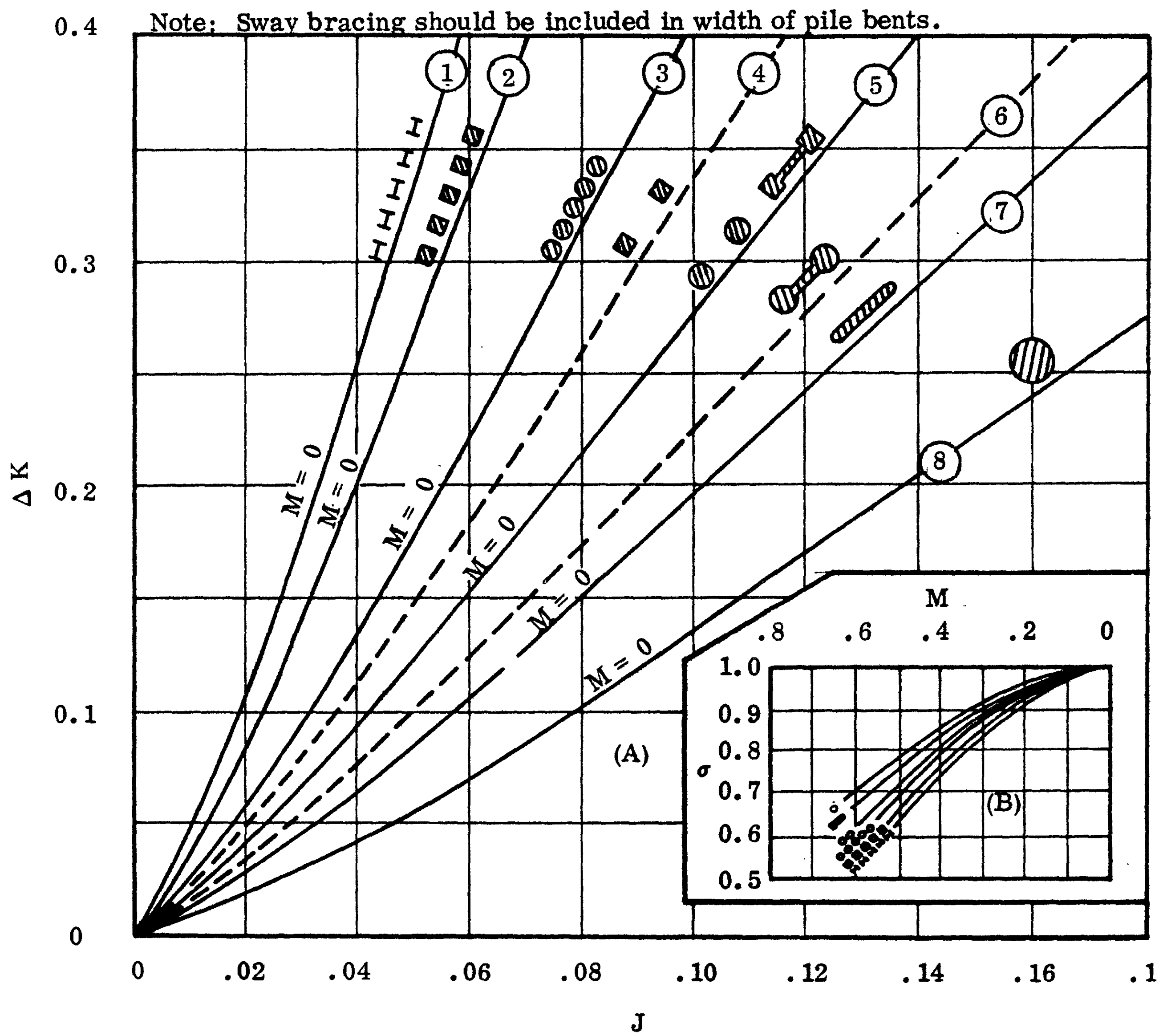


Figure 18.—Pier component of bridge-loss coefficient.

Width value coded in cols. 12–15, 26–29, . . . , 68–71. Limits are -9999 ⩽ Elevation ⩽ 99999, or a range of -999.9 through 9,999.9 feet.

A pier area-elevation relationship is computed from the Width and Elevation data. A sufficient number of points must be tabulated so that pier area at any elevation between tabulated Elevation points can be adequately determined by straight-line interpolation. Each successive Elevation must equal or exceed the preceding Elevation or the cross section will be eliminated. If all piers in the bridge opening have equal elevations at ground intersection, equal elevations at low chord intersection, and a gross width that is either constant or uniformly varying throughout the elevation range, two points of Width-Elevation data are sufficient. Usually, however, extra points must be coded because any nonuniform increase in gross pier width requires that both gross widths at that Elevation be tabulated. It should be recalled that 2 ⩽ NPTS ⩽ 25 for a pier cross section.

Roughness data are not applicable, so #6 CARD(S) must not be coded for a pier cross section. A properly coded pier cross section consists of a #3 CARD and one or more #5 CARD(S) as shown in figure 19 for a typical pier configuration in a bridge opening. Points a, b, c, and d in figure 19 indicate the elevations at which gross pier width is required.

Embankment Cross Section

An embankment cross section must always be coded with TYPE = 4. An embankment cross section is optional and is only required when there is a possibility of road overflow. If coded, the embankment cross section immediately precedes the approach cross section (see table 1). Parameters required to describe the embankment cross section, other than those required on every #3 CARD, are:

NSEG (cols. 21–22)—–number of segments into which the embankment has been divided. Limited to 1 ⩽ NSEG ⩽ 10.

RDWID (cols. 24–27)—–distance, to the nearest foot, between the top points of the upstream and downstream embankment faces (see fig. 7). Limited to 1 ⩽ RDWID ⩽ 9999, or a range of 1 through 9,999 feet.

SEGL (cols. 37–38)—–highest segment number for which embankment overflow can be assumed to have flowed to the left of the KQ-section centerline at the approach cross section. Valid entries are 1 ⩽ SEGL ⩽ NSEG or a dummy value of 99.

SEGR (cols. 40–41)—–lowest segment number for which embankment overflow can be assumed to have flowed to the right of the KQ-section centerline at the approach cross section. Valid entries are 1 ⩽ SEGR ⩽ NSEG or a dummy value of 99.

$T_1, T_2, \ldots T_{10}$ (cols. 52, 54, . . . ,70)—–code to indicate type of road surface for each segment. Valid entries are 1 for a paved surface and 2 for a gravel surface.

QTOL (col. 72)—–percent error allowable between the specified total discharge and the sum of the computed embankment overflow and the computed flow through the bridge opening. Valid entries are 1 ⩽ QTOL ⩽ 9.

NSEG, SEGL, and SEGR are highly interrelated. Selection of these parameters is affected by: 1) the portion of the lateral length of the embankment which can act as a broad-crested weir, 2) variation of surface type along the lateral length of the embankment, and 3) the location of the KQ-section relative to the end points of the embankment.

Figure 20 illustrates the following general cases: 1) the entire lateral length of the embankment can act as a broad-crested weir; and 2) the bridge superstructure or railings prohibit the portion of the embankment directly over the bridge opening from performing as a broad-crested weir. In each case, QRL and QRR are computed by equations 20-1 and 20-2. E431 contains no provisions for computing the magnitude of flow through or over such superstructure or railing configuration. If such flow is significant a partially manual solution is required.

Figure 21 illustrates four specific examples for specifying NSEG, SEGL, SEGR, and $T_1, T_2, \ldots, T_{NSEG}$. Figure 22 illustrates use of the dummy value of 99 for SEGL (or SEGR) when the alinement of embankment and approach cross sections is such that there can be no embankment overflow to the left (or right) of the KQ-section centerline.

QTOL is the tolerance to which the user wishes equation 9-7 to be satisfied. A value of one or two percent is generally satisfactory. It is a rare situation for which a discharge balance within 2 percent cannot be achieved.

The horizontal distance-elevation coordinates for the embankment cross section and their applicable segment numbers are coded on the #5 CARD(S) as follows:

Station—–see Station instructions for Regular Cross Sections.

SEG—–see SA instructions for Regular Cross Sections but substitute SEG for SA and NSEG for NSA.

Road Elev.—–see Ground Elev. instructions for Regular Cross Sections.

Up to five sets of coordinate-segment number data may be coded on each #5 CARD with a maximum of ten cards since 2 ⩽ NPTS ⩽ 50 for an embankment cross section. All rules and precautions pertaining to the

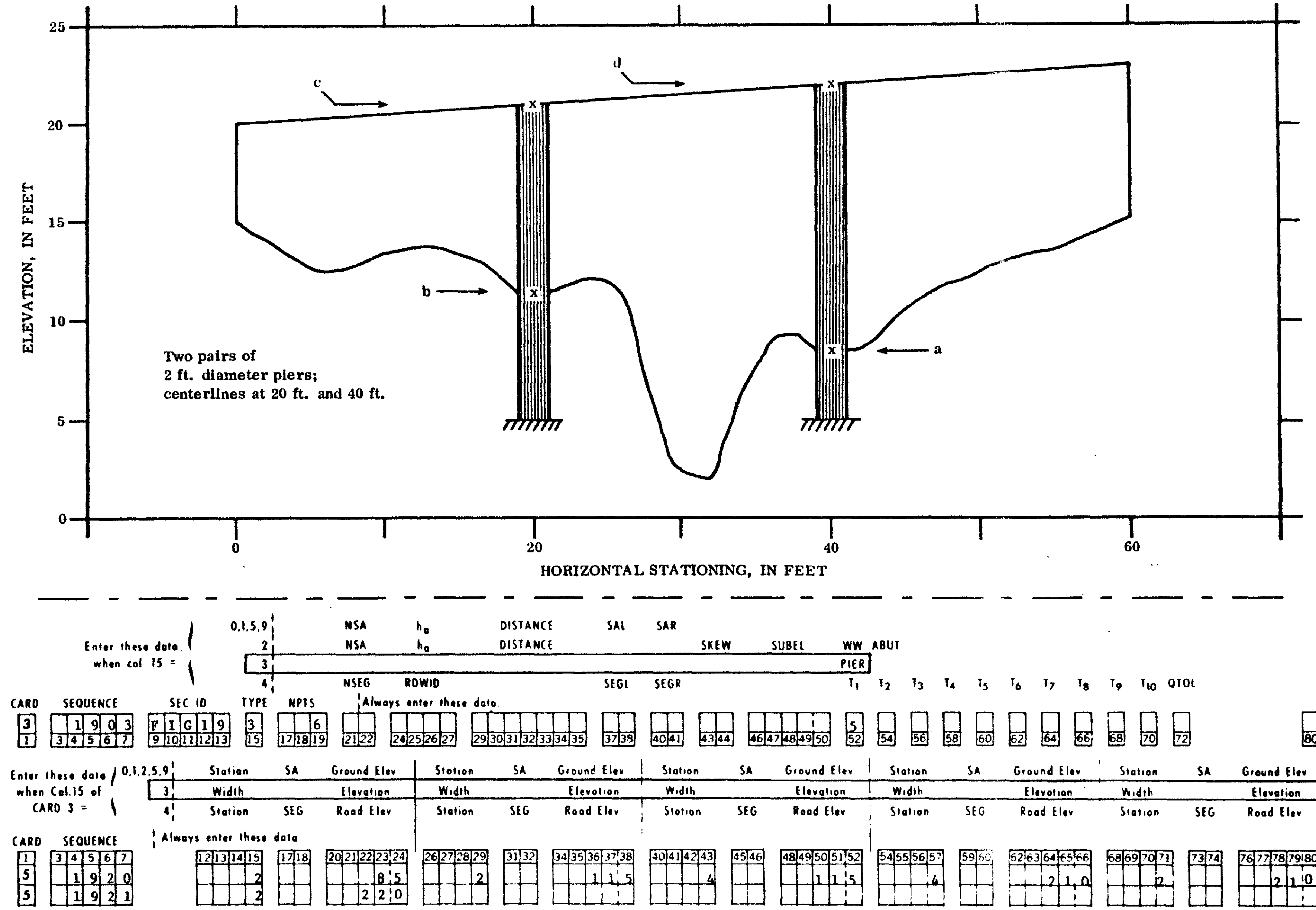
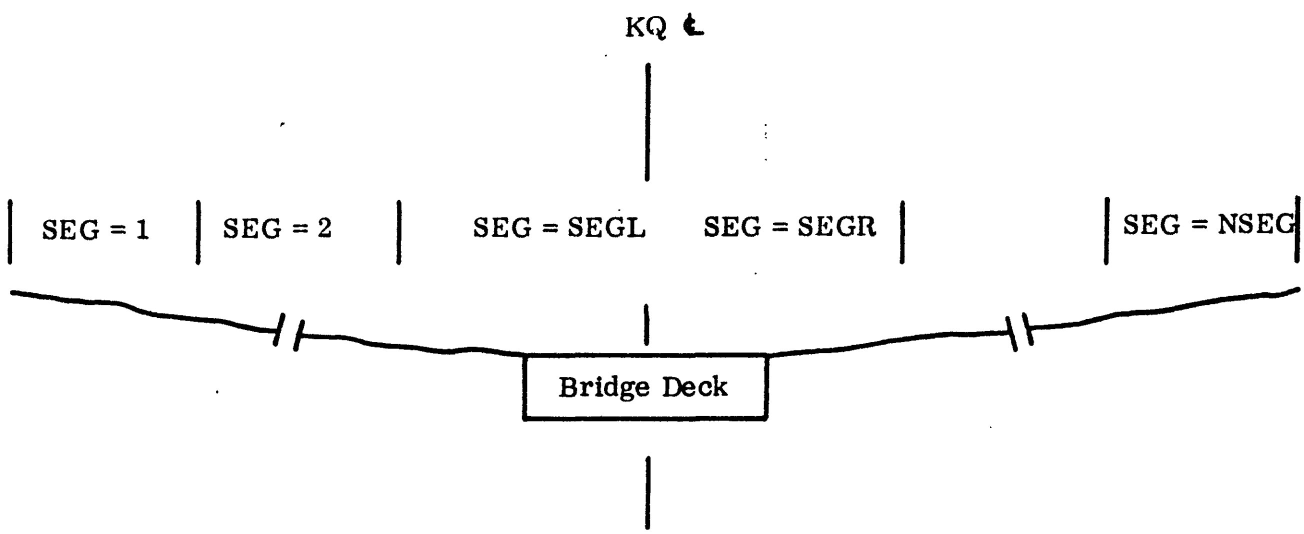
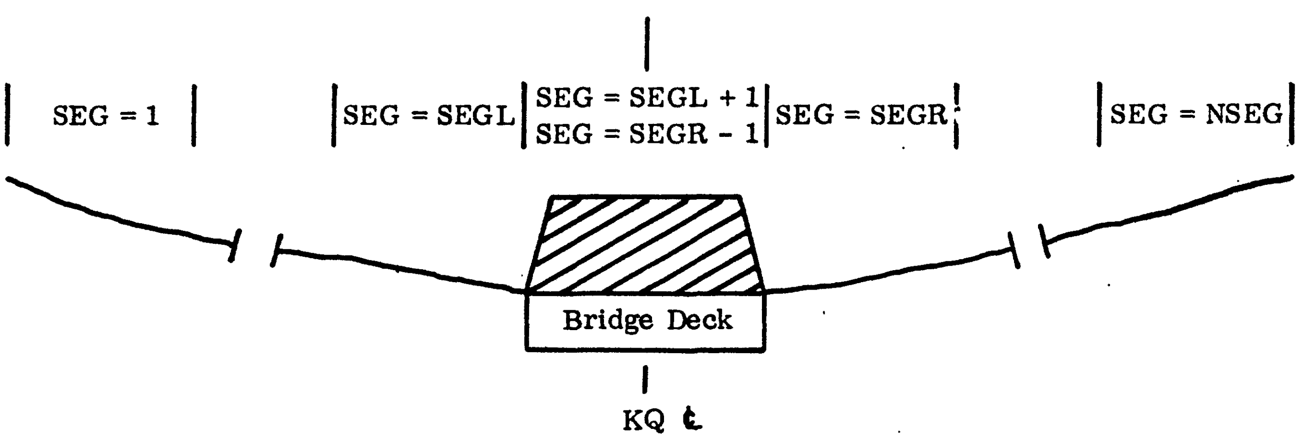


Figure 19.—Data coding example for pier cross section.



a) Entire embankment acts as broad-crested weir.



b) Flow over bridge deck is non-weir flow.

For each SEG numbered i (i = 1, 2, ···, NSEG) there is flow q_i (Eq. 7-5).

$$QRL = \sum_{i=1}^{SEGL} q_i \qquad (QRL = 0 \text{ when } SEGL = 99) \qquad 20\text{-}1$$

$$QRR = \sum_{i=SEGR}^{NSEG} q_i \qquad (QRR = 0 \text{ when } SEGR = 99) \qquad 20\text{-}2$$

Figure 20.—Segmentation of embankment.

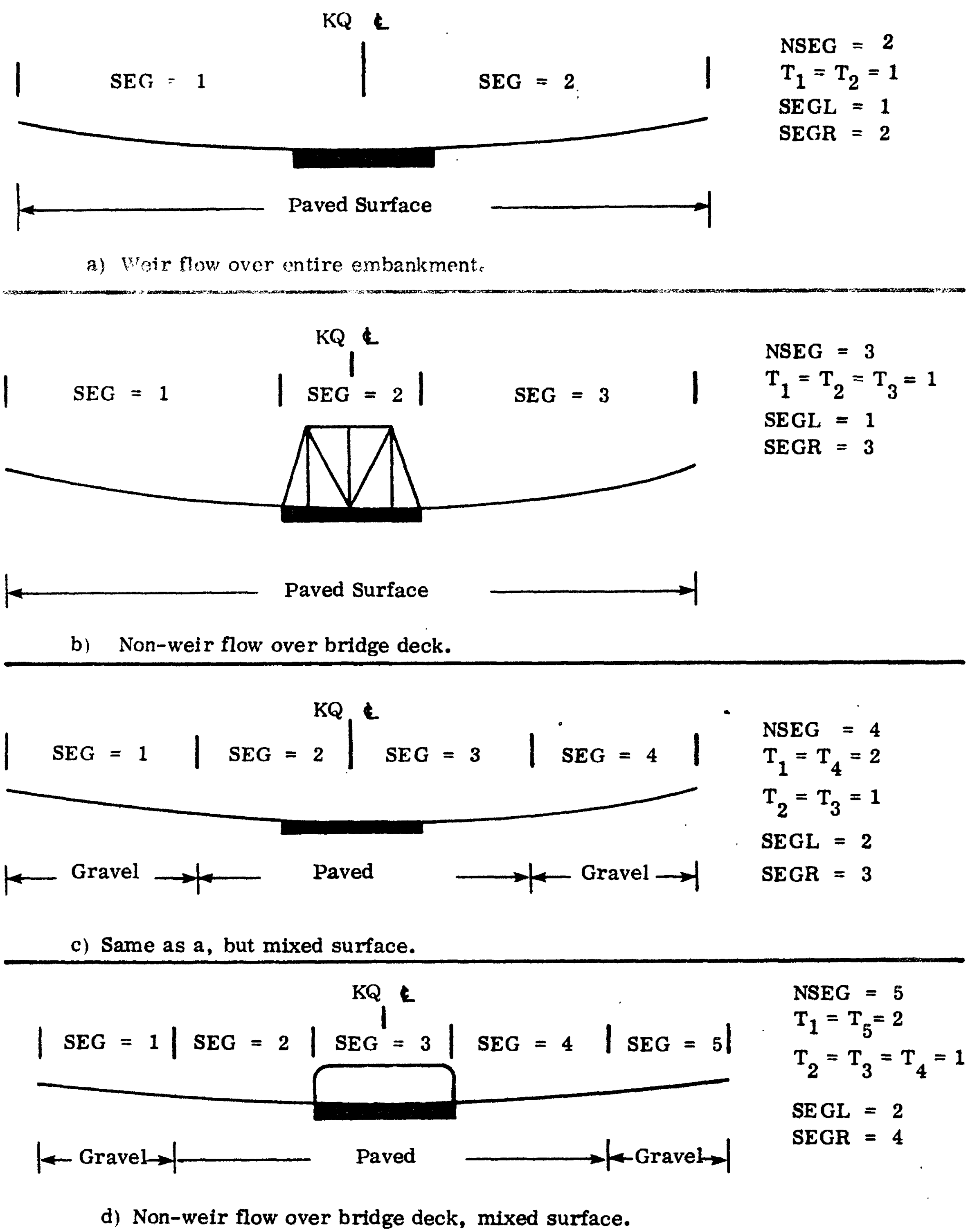


Figure 21.—Illustration of NSEG, SEGL, SEGR, and T_i.

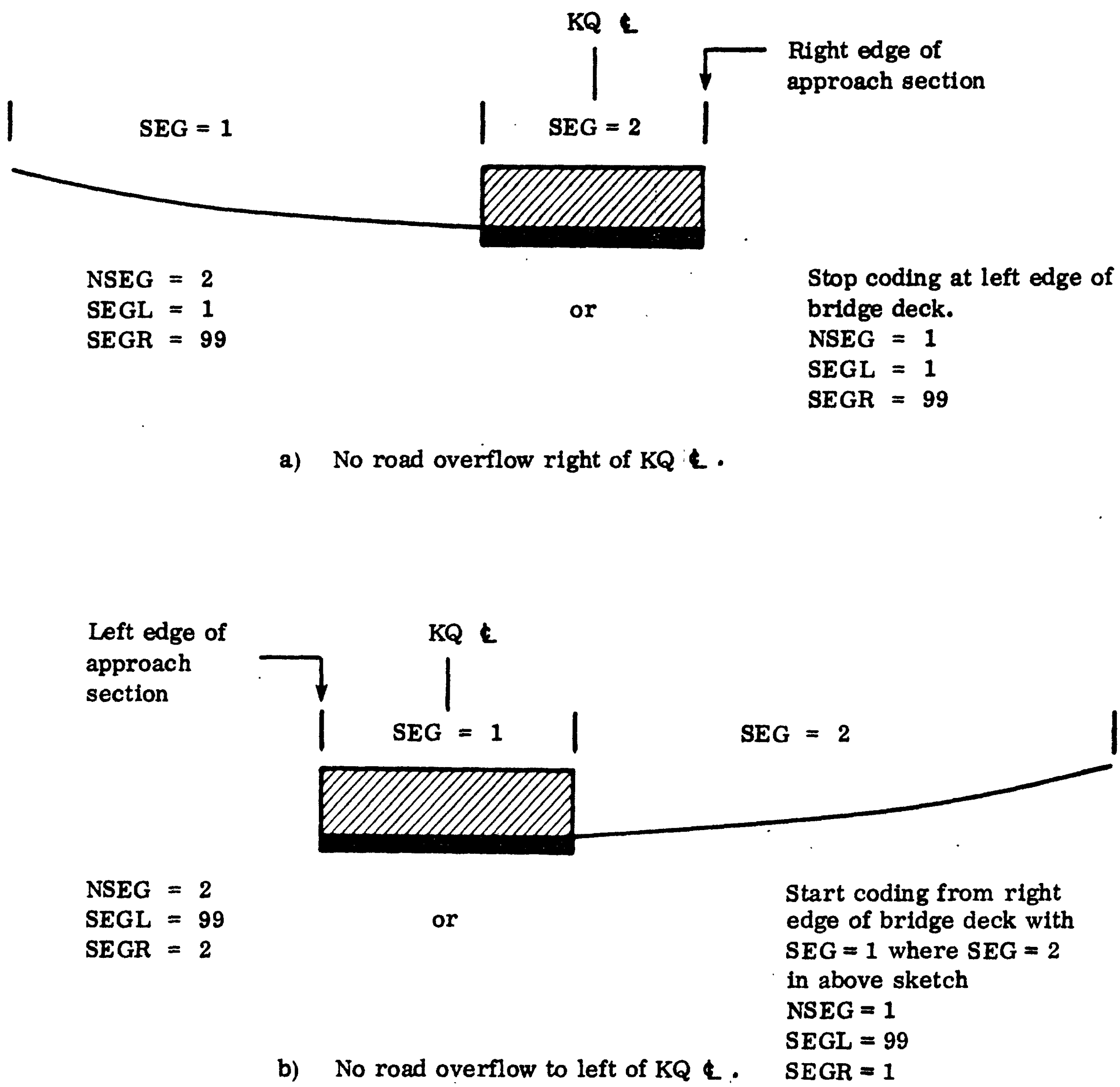
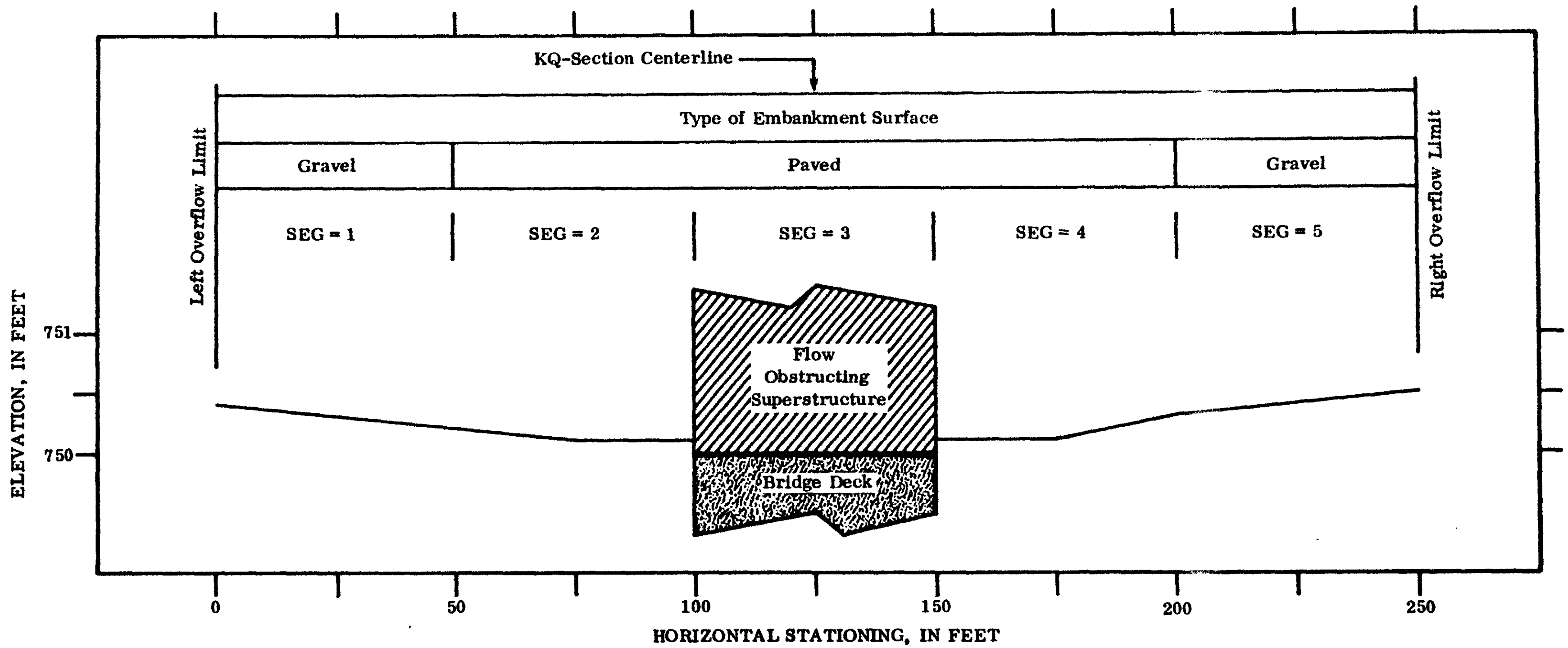


Figure 22.—Use of dummy value for SEGL and SEGR.

coordinates for a regular cross section apply to the coordinates of an embankment cross section. SA rules and precautions pertain directly to SEG with the exception that NSEG has an upper limit of 10.

Roughness data are not required since the type of surface is specified by the T-values on the #3 CARD. Therefore, #6 CARD(S) must not be coded for an embankment cross section. A properly coded embankment cross section consists of a #3 CARD and one or more #5 CARD(S) as illustrated in figure 23.

E431 is not programed to recognize inconsistencies in the alinement of the exit, embankment, and approach cross sections. The user must prepare the input data such that they correctly reflect the physical possibility for water to flow from the approach cross section, over the embankment, and into the exit cross section. The following absurd example should illustrate a potential problem created by erroneous data. Assume that a user provides E431 with input data describing an exit and an approach cross section which are each 100 feet wide. However, the embankment cross section input data describe an embankment that is 1,000 feet wide and at a uniform elevation. For any water-surface elevation at the approach cross section which is high enough to provide road overflow (see fig. 7), E431 will compute that road overflow for a total weir length of 1,000 feet, which obviously is physically impossible.



Enter these data when col. 15 =
- 0,1,5,9: NSA, h_o, DISTANCE, SAL, SAR
- 2: NSA, h_o, DISTANCE, SKEW, SUBEL, WW ABUT
- 3: PIER
- 4: NSEG, RDWID, SEGL, SEGR, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, OTOL

Always enter these data: CARD, SEQUENCE, SEC ID, TYPE, NPTS.

Field	CARD	SEQUENCE	SEC ID	TYPE	NPTS	NSEG	RDWID	(29–35)	SEGL	SEGR	(43–44)	(46–50)	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	OTOL	(80)
Columns	1	3–7	9–13	15	17–19	21–22	24–27	29–35	37–38	40–41	43–44	46–50	52	54	56	58	60	62	64	66	68	70	72	80
Value	3	2303	RD 23	4	10	5	30		2	4			2	1	1	1	2						2	

Enter these data when Col. 15 of CARD 3 =
- 0,1,2,5,9: Station, SA, Ground Elev.
- 3: Width, Elevation
- 4: Station, SEG, Road Elev.

Always enter these data: CARD, SEQUENCE.

CARD (1)	SEQUENCE (3–7)	Station (12–15)	SEG (17–18)	Road Elev. (20–24)	Station (26–29)	SEG (31–32)	Road Elev. (34–38)	Station (40–43)	SEG (45–46)	Road Elev. (48–52)	Station (54–57)	SEG (59–60)	Road Elev. (62–66)	Station (68–71)	SEG (73–74)	Road Elev. (76–80)
5	2320	0	1	750.4	25	1	750.3	50	2	750.2	75	2	750.1	100	3	750.1
5	2321	150	4	750.1	175	4	750.1	200	5	750.3	225	5	750.4	250	5	750.5

Figure 23.—Data coding example for an embankment cross section.

SPECIAL FEATURES

E431 is also programed to perform analyses which might be helpful in solving special problems. These special problems need not be directly related to backwater analyses. Special features available make it possible to: (1) edit the data without performing the cross-section property and water-surface profile computations, (2) expand data fields for data which do not conform to the format of Form 9-1891A, (3) obtain cross-section properties for individual cross sections which are not to be included in the water-surface profile computations, (4) obtain a tabulation of the cross-section properties for an individual cross section by subareas, and (5) obtain the net area of a bridge-opening cross section. The last three of the above features are not applicable to pier or embankment cross sections.

Data Edit Without Computations

The letter X may be coded and keypunched in column 80 of CARD #1. This will cause E431 to abort the analysis of that reach after the data have been edited. The usefulness of this option is strictly dependent upon the individual situation. If the user(s) tend to be error-prone, significant savings can be realized by postponing the computations until the data have been satisfactorily edited. The entry in column 80 will cause the edit phase to generate a "blank-column" flag. This flag (discussed later) may be ignored.

Expanded Data Fields

There are situations for which the discharge field(s) on the #4 CARD(S) and (or) the Station field(s) on the #5 CARD(S) are not sufficiently large to accommodate the data required to solve the problem. Therefore, when (1) discharge exceeds 999,999 cfs or (2) excessively wide cross sections require coding 9999 < Station < -999, the appropriate field(s) may be expanded by incorporating the column preceding the field(s) as an integral part of the field(s). For example, a discharge of 2,500,000 ft^3/s could be coded on #4 CARD(S) as 2500000 in columns 8–14, or 15–21, . . . ,or 71–77. Likewise, a horizontal distance of 10,750 feet could be coded on #5 CARD(S) as 10750 in columns 11–15, or 25–29, . . . ,or 67–71. Since these situations are infrequent the data editing phase is not designed to accommodate this feature. Therefore, the "blank-column" flag will appear on the computer printout under columns 8, 15, . . . 71 for the #4 CARD(S) and under columns 11, 25, . . . ,67 for the #5 CARD(S) when those columns are used to expand the data field(s). However, the data will be accepted as intended.

Cross-Section Properties Only

By coding TYPE = 9 on the #3 CARD, the cross-section properties may be computed for one or more individual cross sections which are not to be included in water-surface profile computations. This feature can be very useful for problems that are not directly related to or cannot be directly solved by backwater analysis (for example, manual culvert or bridge computations). If water-surface profiles are being computed, the cross section(s) with TYPE = 9 may appear almost anywhere in the reach with the exception that they cannot be interspersed within a series of exit through approach cross sections required to define a bridge situation. To utilize this feature independent of water-surface profile computations, the #2 and #4 CARD(S) need not be coded and CARD #1 is optional. Several error messages are generated, but cross-section properties would be obtained for each cross section coded with TYPE = 9 that is correctly coded in all other respects. The #3 CARD is coded as for a regular cross section with the exceptions that TYPE = 9 and there are no criteria for DISTANCE. The #5 and #6 CARD(S) must satisfy the same criteria governing a bridge-opening cross section. Of course, if it is not a cross section of a bridge opening or culvert opening, the cross section would not be closed.

Subarea Properties

Sometimes it is desirable to obtain cross-section properties tabulated by individual subareas. By coding and keypunching the letter K in column 80 of CARD #3 this tabulation is obtained in addition to the regular printout for that cross section. To eliminate "mixed-up" output (that is, subarea properties interspersed with cross-section properties) the subarea properties are temporarily stored on a direct-access storage device. Therefore, there are limitations as to the number of elevations for which subarea properties may be obtained, as shown in table 5. Selection of h_o and Δh should be made accordingly. The extent to which this feature should be utilized should take into account the additional printout that is generated, which is also indicated in table 5. The entry in column 80 will cause the edit phase to generate the "blank-column" flag. This flag, of course, may be ignored.

Table 5.—*Limitations of subarea properties printout*

Number of subareas	Maximum number of elevations for which subarea properties can be printed	Maximum additional printout (approx.)	
		Pages	Lines
1 ⩽ NSA ⩽ 6	90	12	625
7 ⩽ NSA ⩽ 12	75	20	1,050
13 ⩽ NSA ⩽ 18	50	20	1,050
19 ⩽ NSA ⩽ 20	37	16	850

Computing Net Area

Net area of a bridge opening may be required for manual computations. Net area can be obtained by coding the data in a manner which reflects individual openings. An example of this coding is shown in figure 24. Each opening is coded in succession in counterclockwise fashion with the first point repeated and assigned a -9 subarea. Net areas may be obtained for cross sections coded with TYPE = 2 or TYPE = 9.

E431 MESSAGES

DATA EDITING MESSAGES

As briefly discussed earlier, E431 is programed to perform extensive data editing before any computations are made. Editing is separated into two phases. The first phase edits each data card for: 1) proper order by CARD number, 2) ascending SEQUENCE number, and 3) proper location of valid characters (or no characters) in each column. Messages and warning flags indicating errors (or potential errors) are discussed below in the section entitled Sequence-Location Editing Messages.

Each cross section for which the sequence-location edit reveals one or more serious coding errors is eliminated from subsequent analyses. Each cross section which is free of coding errors, or contains only minor coding errors, is output to a direct-access storage device to be saved for subsequent analyses.These cross sections, along with reach description data, water-surface elevation data, and discharge data are then subjected to numerical checks. Numerical editing does not reveal all possible data errors. However, a considerable variety of numerical errors (or potential numerical errors) may be brought to the user's attention by various messages. These messages are discussed below in the section entitled Numerical Editing Messages.

Sequence-Location Editing Messages

The first output for a reach is the 80-character card image of all input data cards for that reach. Any sequence-location errors are brought to the user's attention by printing warning flags and error or warning messages along with the card images. Warning flags and their meanings are summarized in table 6. Table 7 tabulates the error and warning messages associated with sequence-location editing.

For each data card on which mislocated (B-flag), missing (M-flag), unexpected (U-flag), or invalid (I-flag) characters are detected, one (or more) warning flag(s) and message SL-5 are printed on a line below the printed card image. The applicable character is printed directly beneath each questionable column of the card image. Mislocated, missing, or unexpected characters do not always produce fatal errors as will be illustrated later. However, any invalid character(s) in a data field will cause the analysis of the reach to be partially or totally aborted. The existence of invalid characters is made more obvious to the user by the SL-6 message printed on the second line following the printed card image.

When an error in the order of the CARD numbers is detected, either SL-1 or SL-2 is printed to the right of the printed card image. Obviously, SL-1 is printed in a situation where there is only one valid possibility and SL-2 is printed when there are two possibilities. An error in CARD number order may not be fatal if: 1) it results from a user counting error which can be corrected, or 2) it creates a situation for which sufficient default values can be assigned to missing data. However, out-of-order or missing CARD(S) will frequently create a situation in which subsequent data cards cannot be subjected to sequence-location editing and the cross section(s) involved cannot be subjected to numerical editing. Invalid characters also create this situation. Message SL-4 is printed to the right of the printed card image of each unedited data card and analysis of the reach is partially or totally aborted.

Message SL-3 is printed below any printed card image for which the SEQUENCE number is not algebraically larger than the preceding SEQUENCE number. This error is assumed to be the result of a careless keypunch or coding error in SEQUENCE and the data are used in

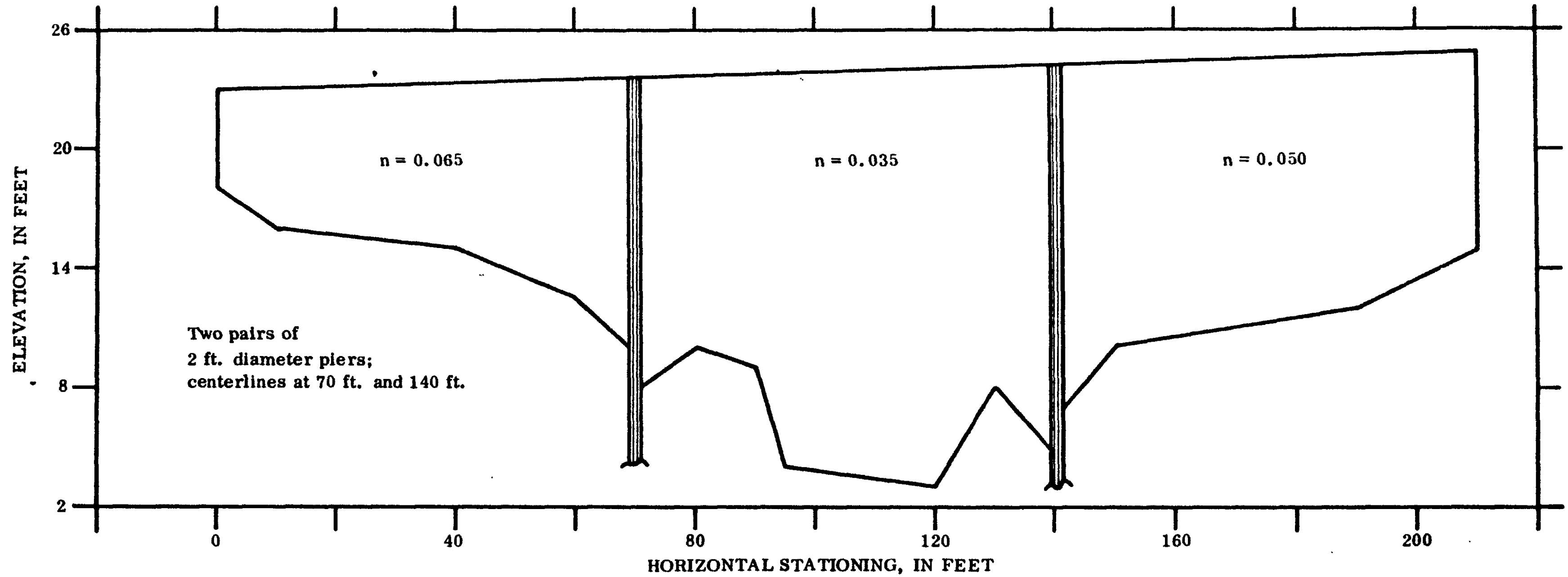
Table 6.—*Summary of warning flags printed by the sequence-location editing phase of E431*

Referred to in text as	Character printed	Meaning
"blank-column" flag or B-flag	B	A character is located in a column which should be blank.
"missing-data" flag or M-flag	M	No character is located in the last column of a data field.
"unexpected-data" flag or U-flag	U	A character is located in a column in which a character is permitted but, because of previous data (for example, a point-count parameter), the program expected a blank.
"invalid-data" flag or I-flag	I	An alphabetic or special character is located in a column in which only a numeric character (or a minus sign) is valid.

Table 7.—*Summary of messages that may result from sequence-location editing*

Message Number[1]	Message printed[2] on *** INPUT CARD PRINTOUT ***
SL – 1	EXPECTED #__ CARD
SL – 2	EXPECTED #__OR #__CARD
SL – 3	**SEQUENCE**
SL – 4	**NO EDIT**
SL – 5	**ERROR(S)**
SL – 6	**INVALID CHARACTER(S) ON PRECEDING CARD**
SL – 7	**PREMATURE END OF DATA**
SL – 8	**REPEAT PRINT**
SL – 9[3]	**INVALID FW OPTION**

[1]Used only for reference to message in manual; not printed on computer output.
[2]Underscores indicate where E431 will print variable information.
[3]Discussed in Floodway Analysis section.



Enter these data when col. 15 = 0,1,5,9: NSA, h_o, ~~DISTANCE~~, ~~SAL~~, ~~SAR~~
2: NSA, h_o, DISTANCE, SKEW, SUBEL, WW ABUT
3: PIER
4: NSEG, RDWID, SEGL, SEGR, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, QTOL

Always enter these data.

CARD	SEQUENCE	SEC ID	TYPE	NPTS	NSA	h_o	DISTANCE	SEGL	SEGR	SKEW	SUBEL	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	QTOL	
1	3 4 5 6 7	9 10 11 12 13	15	17 18 19	21 22	24 25 26 27	29 30 31 32 33 34 35	37 38	40 41	43 44	46 47 48 49 50	52	54	56	58	60	62	64	66	68	70	72	80
3	2403	NA24	9	25	3	8																	

Enter these data when Col.15 of CARD 3 = 0,1,2,5,9: Station, SA, Ground Elev.; 3: Width, Elevation; 4: Station, SEG, Road Elev.

Always enter these data.

CARD	SEQUENCE	Station	SA	Ground Elev.	Station	SA	Ground Elev.	Station	SA	Ground Elev	Station	SA	Ground Elev.	Station	SA	Ground Elev
1	3 4 5 6 7	12 13 14 15	17 18	20 21 22 23 24	26 27 28 29	31 32	34 35 36 37 38	40 41 42 43	45 46	48 49 50 51 52	54 55 56 57	59 60	62 63 64 65 66	68 69 70 71	73 74	76 77 78 79 80
5	2425	0	1	23.0	0	1	18.0	10	1	16.0	40	1	15.0	60	1	12.5
5	2426	69	1	10.0	69	1	23.7	0	-9	23.0	71	2	23.7	71	2	8.0
5	2427	80	2	10.0	90	2	9.0	95	2	4.0	120	2	3.0	130	2	8.0
5	2428	139	2	5.0	139	2	24.3	71	-9	23.7	141	3	24.3	141	3	7.0
5	2429	150	3	10.0	190	3	12.0	210	3	15.0	210	3	25.0	141	-9	24.3

		(SA 1, (6,11,16)				SA 2, (7,12,17)				SA 3, (8,13,18)				SA 4 (9,14,19)				SA 5 (10,15,20)			
CARD	SEQUENCE	b	a	n_1	n_3	b	a	n_1	n_3	b	a	n_1	n_3	b	a	n_1	n_3	b	a	n_1	n_3
1	3 4 5 6 7	9 10	12 13	15 16 17	19 20 21	23 24	26 27	29 30 31	33 34 35	37 38	40 41	43 44 45	47 48 49	51 52	54 55	57 58 59	61 62 63	65 66	68 69	71 72 73	75 76 77
6	2460	0	1	0.65	065	0	1	035	035	0	1	050	050								

Figure 24.—Data coding example for net area of a bridge opening.

Table 8.—*Summary of messages that may result from numerical editing*

Message Number[1]	Numerical editing messages as printed[2] under the following headings:							
	SECID	ERROR SEVERITY	FIRST VARIABLE	NO.[3]	ERROR MESSAGE	SECOND VARIABLE	NO.[3]	VALUE ASSUMED
EN–1		WARNING	NXS		INVALID			99
EN–2		WARNING	NPR		INVALID			20
EN–3		WARNING	TOL		INVALID			0.02′
EN–4		WARNING	TOL		HIGH			
EN–5		WARNING	DELTA H		INVALID			0.5′
EN–6		WARNING	FN		INVALID			1.2
EN–7		WARNING	FN		HIGH			
EN–8		WARNING	FN		LOW			
EN–9	______	WARNING	TYPE		WRONG			1
EN–10	______	ABORTIVE	TYPE		WRONG			
EN–11	______	WARNING	TYPE		INVALID			0
EN–12	______	WARNING	NPR		WRONG			__
EN–13	______	WARNING	NPTS		WRONG			__
EN–14	______	WARNING	HSUBO		IS LESS THAN	GMIN		> GMIN
EN–15	______	ABORTIVE	DISTANCE		WRONG			
EN–16	______	WARNING	NSA		INVALID			20
EN–17	______	ABORTIVE	SA	1	MUST = 1			
EN–18	______	ABORTIVE	SA	__	INVALID			
EN–19	______	ABORTIVE	STATION	___	IS LESS THAN	STATION	___	
EN–20	______	ABORTIVE	SA	__	OUT OF ORDER			
EN–21	______	WARNING	NSA		WRONG			__
EN–22	______	ABORTIVE	SA	__	GREATER THAN	NSA		
EN–23	______	ABORTIVE	NSA		< MAX.VALUE OF	SA		
EN–24	______	WARNING	NSA		> MAX.VALUE OF	SA		__
EN–25	______	ABORTIVE	N1 & N3	__	NOT SPECIFIED			
EN–26	______	WARNING	N1	__	NOT SPECIFIED			N1=N3
EN–27	______	WARNING	N3	__	NOT SPECIFIED			N3=N1
EN–28	______	WARNING	B	__	< ZERO			0
EN–29	______	WARNING	A	__	IS LESS THAN	B	__	A=B
EN–30	______	WARNING	A	__	IS EQUAL TO	B	__	N3=N1
EN–31	______	WARNING	N1	__	HIGH			
EN–32	______	WARNING	N3	__	HIGH			
EN–33	______	WARNING	N1	__	LOW			
EN–34	______	WARNING	N3	__	LOW			
EN–35	______	WARNING	SAL		INVALID			99
EN–36	______	WARNING	SAR		INVALID			99
EN–37	______	ABORTIVE	SAL		IMPROPER FOR	SAR		
EN–38	______	WARNING	ABUT		INVALID			1
EN–39	______	WARNING	WW		INVALID			1
EN–40	______	WARNING	SKEW		INVALID			__
EN–41	______	WARNING	DISTANCE		WRONG			EXIT SRD
EN–42	______	WARNING	STATION	___	IS LESS THAN	STATION	___	
EN–43	______	WARNING	SA	__	OUT OF ORDER			
EN–44	______	WARNING	PIER		WRONG			1
EN–45	______	ABORTIVE	WIDTH	__	< OR = ZERO			
EN–46	______	ABORTIVE	PIER EL.	__	IS LESS THAN	PIER EL.	__	
EN–47	______	ABORTIVE	RDWID		< OR = ZERO			
EN–48	______	WARNING	T	__	INVALID			1
EN–49	______	WARNING	QTOL		INVALID			1%
EN–50	______	WARNING	NSEG		INVALID			10
EN–51	______	ABORTIVE	SEG	1	MUST = 1			
EN–52	______	ABORTIVE	SEG	__	INVALID			
EN–53	______	ABORTIVE	SEG	__	OUT OF ORDER			
EN–54	______	WARNING	NSEG		<MAX. VALUE OF	SEG		__
EN–55	______	WARNING	NSEG		>MAX. VALUE OF	SEG		__
EN–56	______	WARNING	SEGL		INVALID			99
EN–57	______	WARNING	SEGR		INVALID			99
EN–58	______	ABORTIVE	SEGL		IMPROPER FOR	SEGR		

[1] Used only for reference to message in manual; not printed on computer output.
[2] Underscores indicate where E431 will print variable information.
[3] Indicates the number of the data point in question (for example, for EN-17 the 1 refers to the SA value for the first coordinate point; for EN-48 a 3 would refer to the T value for the third segment, and so forth).

the order that they were input. Therefore, the user must carefully check the input data when SL-3 is printed.

Message SL-7 is printed beneath the last printed card image for a reach if more input data were expected for the reach. This situation may arise due to: 1) user counting errors, 2) missing reach-description parameters, or 3) missing cross-section data. A complete analysis of all data that were input is always attempted.

Certain user errors may cause the first card image of the next reach to be printed with the card images of the reach being analyzed when two or more reaches are included in a single computer job. This card image is internally stored to be reprinted in its appropriate place on the analysis of the next reach. Message SL-8 is printed to the right of any reprinted card image.

The number of potential user errors, along with combinations and permutations of these errors, must approach infinity. If not impossible, it is at least highly impractical to illustrate all of the possibilities. Also, sequence-location errors interact with numerical errors discussed below. Therefore, a selected group of sequence-location and numerical errors are illustrated in the Computer Output section.

Numerical Editing Messages

Table 8 summarizes all of the error and warning messages that may be generated by the numerical editing phase of E431. Table 9 cross references these messages with the value(s) of TYPE and the number(s) of the CARD(S) on which the errors may be located.

Table 9.—*Cross-reference table of numerical editing messages with TYPE value(s) and CARD number(s)*

Message Number(s)[1]	Error(s) possibly associated with:	
	TYPE(S)	CARD(S)
1–8	N.A.	1
9	1	3
10–11	All	3
12	1	1,4
13	All	3,5
14	0,1,2,5,9	3,5
15	0,1,5	3
16	0,1,2,5,9	3
17–18	0,1,2,5,9	5
19	0,1,4,5	5
20	0,1,5	5
21	0,1,2,5,9	3,6
22–23	0,1,2,5,9	5,6
24	0,1,2,5,9	3,5,6
25–34	0,1,2,5,9	6
35–37	0,1,5	3
38–40	2	3
41	0,1,2,5	3
42–43	2,9	5
44	3	3
45–46	3	5
47–50	4	3
51–53	4	5
54–58	4	3,5

[1]See footnote 1 on table 8.

Applicable names, numbers, and messages are printed under each column heading as follows:

SECID—the user-assigned SECID is printed to identify the cross section in question.

ERROR SEVERITY—WARNING indicates that: (1) a potential problem exists but the data will be used as input, or (2) default or computed values have been assigned to erroneous or missing data. ABORTIVE indicates that a serious error necessitates either partial or total abortion of analyses for the reach.

FIRST VARIABLE—the name of a variable printed which represents either: (1) the first variable used in a comparison or; (2) the only variable in question.

SECOND VARIABLE—when a comparison is made the name of the second variable is printed.

NO. (4th and 7th cols.)—for arrays of data the number of the element in the array that is of questionable validity.

ERROR MESSAGE—a word or phrase that describes the problem.

VALUE ASSUMED—value that has been assigned to questionable, missing, or erroneous data so that a complete analysis may be attempted.

Table 10 provides the user with more complete description and definition of: (1) the problem, (2) the programed action(s) of E431, and (3) the appropriate user response(s) for each of these messages. As mentioned previously, a selected group of typical problems are illustrated in the Computer Output section.

PROFILE COMPUTATION MESSAGES

Table 11 summarizes all of the error and warning messages that may be generated by the profile computation phase of E431. Messages PN–1 through PN–7 are associated with balancing the energy equation. Figure 25 is a flowchart of the portion of the computer program that performs that phase of the profile computations. Messages PN–13 through PN–32 are related to bridge situations and figure 26 is a flowchart of that portion of the computations. The digits (1, 2, or 3) appearing in parentheses in messages PN–13 through PN–32 indicate the flow Type through the bridge opening. An underscore within parentheses in table 11 and figure 26 indicates that more than one flow Type is possible, and the appropriate digit will replace the underscore on E431 output. The flowcharts are designed to provide the user with a means for tracing computational problems and do not exactly describe every actual detail programed into E431. Table 12 provides the user with more complete description and definition of: (1) the problem, (2) the programed action(s) of E431, and (3) the appropriate user response(s) for messages PN–1 through PN–33.

Table 10.—*Definition of problem, E431 action, and user response for messages resulting from numerical editing*

Message No.[1]	Problem *** E431 Action *** User Response
EN– 1	NXS $\leqslant$ 0. *** Assumes NXS = 99 and determines the actual number of cross sections by counting the #3 CARD(S) found. *** If additional runs are required using these data, code the appropriate value for NXS on CARD #1.
EN– 2	NPR $\leqslant$ 0 or NPR > 20. *** Assumes NPR = 20, but may change this assumption later (see EN–12). *** If additional runs are required using these data, code the appropriate value for NPR on CARD #1.
EN– 3	TOL $\leqslant$ 0.0 or TOL > 0.99 *** Assumes TOL = 0.02. *** None if 0.02 is satisfactory, otherwise code suitable value on CARD #1.
EN– 4	TOL > 0.10 *** None. *** None if the excessively high tolerance is permitting valid profile computations, otherwise code more suitable value for TOL on CARD #1.
EN– 5	$\Delta h \leqslant 0.0$. *** Assumes $\Delta h = 0.5$. *** None if one-half foot is suitable, otherwise code suitable value on CARD #1.
EN– 6	FN $\leqslant$ 0.0 or FN > 2.0 *** Assumes FN = 1.2 *** None if 1.2 is suitable, otherwise code suitable value on CARD #1.
EN– 7	FN > 1.5. *** None. *** None if the excessively high FN value is permitting valid profile computations, otherwise code more suitable FN value on CARD #1.
EN– 8	FN < 1.0. *** None. *** None if excessively low FN value is permitting valid profile computations, otherwise code more suitable FN value on CARD #1.
EN– 9	First cross section in a reach must be either TYPE = 1 or TYPE = 9 (not to be used in profile). This message is printed when the first cross section which is not TYPE = 9 is not TYPE = 1. *** Assumes TYPE = 1 and looks for #2 CARD(S) and #4 CARD(S).*** Verify assumption and (or) correct the TYPE value or data arrangement.
EN–10	Error in the order of cross sections, or an erroneously assigned TYPE. *** This cross section and all subsequent cross sections are eliminated from profile computations. If the abortive cross section has 2 $\leqslant$ TYPE < 5, the preceding exit cross section will be the last cross section included in the profile computations. This and subsequent cross sections are completely edited and cross section properties computed for each valid cross section (except pier and embankment cross sections). *** Place cross section data in correct order or correct erroneous TYPE value. Remember that in a bridge situation TYPE codes of 2 through 5 must be in ascending order (with TYPE codes 3 and 4 optional), and TYPE = 9 may not be placed within the 2 $\leqslant$ TYPE $\leqslant$ 5 series.
EN–11	TYPE < 0, or 6 $\leqslant$ TYPE $\leqslant$ 8. *** Assumes TYPE = 0 and attempts to include the cross section in the analysis which may create additional problems *** Code appropriate TYPE value on CARD #3.
EN–12	NPR (from CARD #1 or previous E431 assumption) is greater than NQ (the number of consecutive, greater-than-zero values coded on the #4 CARD(S)) *** Assumes NPR = NQ and continues analyses. *** Verify assumption and (or) correct NPR on the #1 CARD or the discharge values coded on the #4 CARD(S).
EN–13	NPTS ≠ NCNT (NCNT is the number of non-blank triads of Station, SA, and Ground Elev. counted on the #5 CARD(S) during input). *** Assumes NPTS = NCNT and continues the editing. *** Verify the assumption and (or) correct NPTS on CARD #3 or the data codes on the #5 CARD(S).
EN–14	h_0 < GMIN (the minimum ground elevation in the cross section) *** Assigns a value to h_0 that is a multiple of Δh above the whole foot portion of GMIN such that $h_0 \geqslant$ (GMIN + 0.05). *** None necessary but it may be desirable to code a more suitable h_0 value on CARD #3. Also, since h_0 is restricted to the nearest foot on the coding form, it may be necessary to code h_0 < GMIN if properties very near channel bottom are absolutely essential.
EN–15	DISTANCE $\leqslant$ the section reference distance of the preceding cross section. *** Same as EN–10. *** Correct coding of DISTANCE on appropriate cross section.
EN–16	NSA $\leqslant$ 0 or NSA > 20. *** Initially assumes NSA = 20, but may change this assumption after further editing. *** Code the correct value for NSA.

Table 10.—*Definition of problem, E431 action, and user response for messages resulting from numerical editing* —Continued

Message No.[1]	Problem *** E431 Action *** User Response
EN–17	SA value of first coordinate $\neq 1$. ***Same as EN–10 except properties are not computed for this cross section. *** Recode the #5 CARD(S) with proper SA values.
EN–18	For the i^{th} coordinate, SA ≤ 0 or SA > 20. *** Same as EN–17. *** Same as EN–17.
EN–19	For the i^{th} coordinate, Station is less than Station for the preceding coordinate. *** Same as EN–17. *** Correct Station value(s) on the #5 CARD(S).
EN–20	For the i^{th} coordinate, violation of the criteria that $SA_i = SA_{i-1}$ or $SA_i = SA_{i-1} + 1$. *** Same as EN–17. *** Same as EN–17.
EN–21	NSA $\neq$ NCNT (NCNT is the number of non-blank tetrads of a, b, N1, and N3 counted on the #6 CARD(S) during input). *** Assumes NSA = NCNT and continues editing. *** Verify the assumption and (or) correct NSA on CARD #3 or the data coded on the #6 CARD(S).
EN–22	For the i^{th} coordinate no roughness-depth relationship is coded on the #6 CARD(S) for that SA number. *** Same as EN–17. *** Check the coding of: a) the roughness-depth relationships on the #6 CARD(S), or b) the SA value(s) on the #5 CARD(S).
EN–23	Incorrect SA value(s) on the #5 CARD(S) or too few roughness-depth relationships on the #6 CARD(S). *** Same as EN–17. *** Same as EN–22.
EN–24	The number of roughness-depth relationships on the #6 CARD(S) exceed that required by the SA values on the #5 CARD(S). *** Assumes NSA = maximum SA value.*** Verify assumption and (or) correct: a) NSA, b) SA values, or c) the #6 CARD(S).
EN–25	$n_1 \leq 0$ and $n_3 \leq 0$ for the i^{th} subarea. *** Same as EN–17. *** Correct #6 CARDS(S).
EN–26	$n_1 \leq 0$ for the i^{th} subarea. *** Assumes $N1_i = N3_i$. *** Same as EN–25 if assumption is invalid.
EN–27	$n_3 \leq 0$ for the i^{th} subarea. *** Assumes $N3_i = N1_i$. *** Same as EN–26.
EN–28	$b < 0$ for the i^{th} subarea. *** Assumes $B_i = 0$. *** Same as EN–26.
EN–29	$a < b$ for the i^{th} subarea. *** Assumes $A_i = B_i$. *** Same as EN–26.
EN–30	$a = b$ for the i^{th} subarea. *** Assumes $N3_i = N1_i$. *** Same as EN–26.
EN–31	$n_1 \geq 0.200$ for the i^{th} subarea. *** None. *** None if n-value is correct, otherwise correct n-value.
EN–32	$n_3 \geq 0.200$ for the i^{th} subarea. *** None. *** Same as EN–31.
EN–33	$n_1 \leq 0.015$ for the i^{th} subarea. *** None. *** Same as EN–31.
EN–34	$n_3 \leq 0.015$ for the i^{th} subarea. *** None. *** Same as EN–31.
EN–35	SAL ≤ 0 or SAL $>$ NSA. *** Assumes SAL = 99. *** Verify assumption and (or) correct SAL.
EN–36	SAR ≤ 0 or SAR $>$ NSA. *** Assumes SAR = 99. *** Verify assumption and (or) correct SAR.
EN–37	SAL $\geq$ (SAR - 1) *** Same as EN–10. *** Correct SAL and (or) SAR.
EN–38	ABUT < 0 or ABUT > 1. *** Assumes ABUT = 1. *** Verify assumption and (or) correct ABUT.
EN–39	WW ≤ 0 or WW > 4. *** Assumes WW = 1. *** Verify assumption and (or) correct WW.
EN–40	a) SKEW < 0, b) SKEW > 45, or c) SKEW not a multiple of 15. *** Assumes a) SKEW = 0, b) SKEW = 45, or c) rounds SKEW to nearest multiple of 15.*** Verify assumption and (or) correct SKEW.
EN–41	The section reference distance for the bridge-opening cross section is not equal to that assigned to the exit cross section. *** Assumes the appropriate value is the section reference distance assigned to the exit cross section. *** Verify assumption and (or) correct whichever DISTANCE is incorrect.
EN–42	Same as EN–19, except this case applies only to TYPE = 2 or TYPE = 9. *** None. *** Verify Station coding and correct if necessary.
EN–43	Same as EN–20, except this case applies only to TYPE = 2 or TYPE = 9. *** None. *** Verify SA coding and correct if necessary.
EN–44	PIER ≤ 0 or PIER > 8. *** Assumes PIER = 1. *** Verify assumption and (or) correct PIER code.

Table 10.—*Definition of problem, E431 action, and user response for messages resulting from numerical editing* —Continued

Message No.[1]	Problem *** E431 Action *** User Response
EN–45	The i^{th} pier WIDTH ≤ 0. *** Same as EN–10. *** Correct WIDTH value(s) on the #5 CARD(S).
EN–46	For the i^{th} coordinate, the PIER EL. is less than the PIER EL. for the preceding coordinate. *** Same as EN–10. *** Correct PIER EL. value(s) on the #5 CARD(S).
EN–47	RDWID ≤ 0. *** Same as EN–10. *** Correct RDWID.
EN–48	The i^{th} road surface indicator is not 1 or 2. *** Assumes $T_i = 1$. *** Verify assumption and (or) correct T_i.
EN–49	QTOL ≤ 0 or QTOL > 9. *** Assumes QTOL = 1. *** None if assumption yields acceptable solution, otherwise code acceptable value for QTOL.
EN–50	NSEG ≤ 0 or NSEG > 10. *** Initially assumes NSEG = 10, but may change this assumption after further editing. *** Code the correct value for NSEG.
EN–51	SEG value for first coordinate ≠1. *** Same as EN–10. *** Correct SEG value(s) on the #5 CARD(S).
EN–52	For the i^{th} coordinate, SEG ≤ 0 or SEG > 10. *** Same as EN–10. *** Same as EN–51.
EN–53	For the i^{th} coordinate, violation of the criteria that $SEG_i = SEG_{i-1}$ or $SEG_i = SEG_{i-1} + 1$. *** Same as EN–10. *** Same as EN–51.
EN–54	NSEG less than maximum SEG number found on #5 CARD(S). *** Assumes NSEG = maximum SEG value. *** Verify assumption and (or) correct NSEG on CARD #3 or the values of SEG on #5 CARD(S).
EN–55	NSEG greater than maximum SEG number found on #5 CARD(S). *** Same as EN–54. *** Same as EN–54.
EN–56	SEGL ≤ 0 or SEGL > NSEG. *** Assumes SEGL = 99. *** Verify assumption and (or) correct SEGL.
EN–57	SEGR ≤ 0 or SEGR > NSEG. *** Assumes SEGR = 99. *** Verify assumption and (or) correct SEGR.
EN–58	SEGL ≥ SEGR. *** Same as EN–10. *** Correct SEGL and (or) SEGR.

[1]See footnote 1 on table 8.

Table 12 and figure 26 may not be totally adequate for problem tracing for bridge situations because of the great number of paths that the computations may follow. More than 670 possible computational paths exist between connector circles numbered 3 and 43 on figure 26. Initial, intermediate, and final results combined with the amount of input data provided, dictate the computational path and the resultant message (or sequence of messages). Table 13 provides an overview of the criteria that determine which flow Type(s) will be considered. Table 13 refers to figure 27 which is designed to supplement table 12 for determining appropriate user response(s) to computational problems associated with messages PN–14 through PN–32. Table 14 presents several examples of computational paths from figure 27 and the resultant messages. A few of the profile computation messages are illustrated in the Computer Program Applications sections.

COMPUTER OUTPUT

Output from the backwater analysis portion of E431 is printed for each reach in the following order: (1) input data card images along with any applicable sequence-location editing messages, (2) numerical editing messages (if any), (3) input data summary, (4) cross-section properties, (5) profile computation messages (if any), and (6) computed profile results. As implied above, the second and fifth items are omitted from the output when no such messages are applicable for the reach being analyzed. Explanation of E431 output (and E431 applications) are best accomplished using simple examples. The following example (and those examples in the next section) are thus designed for illustrative purposes and are not totally realistic.

Figure 28 shows the most downstream cross section of the 6,000-foot reach to be analyzed. The cross section (identified with a SECID of ONE) is arbitrarily assigned a section reference distance (DISTANCE) of 1,000 feet. All subsequent upstream cross sections are identical with section ONE except that ground elevations rise at a rate of five feet per 1,000 feet. Seven regular cross sections at 1,000-foot intervals are assumed adequate for computing water-surface profiles for discharges of 4,000 and 6,600 ft^3/s. The known water-surface elevations at section

Table 11.—*Summary of messages that may result from profile computations*

Message Number[1]	Profile computation messages as printed[2] under the following heading: SECID,ERROR OR WARNING MESSAGE,INTERMEDIATE RESULTS(IF ANY),ACTION TAKEN		
PN- 1	_____,INITIAL WS TOO LOW		,ABORTED PROFILE
PN- 2	_____,TOL FAILURE BETWEEN	,LO = ____.__ HI = ____.__	,USED HIGHER WS
PN- 3	_____,WS NOT FOUND BETWEEN	,LO = ____.__ HI = ____.__	,USED DEL = 0.25
PN- 4	_____,WS NOT FOUND BETWEEN	,LO = ____.__ HI = ____.__	,USED LOWER WS
PN- 5	_____,WS NOT FOUND		,ABORTED PROFILE
PN- 6	_____,FRDN FAILURE	,WS = ____.__ FN = ____.__	,USED HIGHER WS
PN- 7	_____,TEN FRDN FAILURES		,ABORTED PROFILE
PN- 8	_____,LEFT BANK EXTENDED		,USED COMPUTED WSU
PN- 9	_____,RIGHT BANK EXTENDED		,USED COMPUTED WSU
PN-10	_____,KU/KD < 0.7 OR > 1.4		,USED COMPUTED WSU
PN-11	_____,MIN TOO LOW		,ASSUMED MIN=WSO+0.01
PN-12	_____,J EXCEEDS RANGE		,USED J LIMIT
PN-13	_____,QRD > QT		,ASSUMED WSU = MIN
PN-14	_____,MIN QBO > QT (2)		,ASSUMED QBO (1)
PN-15	_____,MIN QBO > QT (2)		,ASSUMED WSU = BELMX
PN-16	_____,MIN QBO > QT (_)		,ASSUMED WSU = MIN
PN-17	_____,MAX QBO < QT (_)		,CHECKED QRD
PN-18	_____,ROAD NOT CODED		,ASSUMED QBO (1)
PN-19	_____,ROAD NOT CODED		,ASSUMED WSU = GMAX
PN-20	_____,QTOL FAILURE (2)		,CHECKED QRD
PN-21	_____,TOL FAILURE (_)		,CHECKED QRD
PN-22	_____,ROAD NOT CODED		,CHECKED QBO (2)
PN-23	_____,ROAD NOT CODED		,USED COMPUTED WSU
PN-24	_____,MAX QTC < QT (1)		,CHECKED QBO (2)
PN-25	_____,MAX QTC < QT (2)		,ASSUMED QBO (1)
PN-26	_____,MAX QTC < QT (_)		,ASSUMED WSU = GMAX
PN-27	_____,MIN QTC > QT (2)		,ASSUMED QBO (1)
PN-28	_____,MIN QTC > QT (2)		,ASSUMED WSU = BELMX
PN-29	_____,MIN QTC > QT (_)		,ASSUMED WSU = MIN
PN-30	_____,QTOL FAILURE		,USED COMPUTED WSU
PN-31	_____,WSU > BELMX (1)		,CHECKED QBO (2)
PN-32	_____,YU/Z < 1.1 (1)		,ASSUMED QBO (1)
PN-33[3]	_____,FLOODWAY DATA FLUSHED		,ABORTED PROFILE

[1] Used only for reference to message in manual; not printed on computer output.
[2] Underscores indicate where E431 will print variable information.
[3] Discussed in Floodway Analysis section.

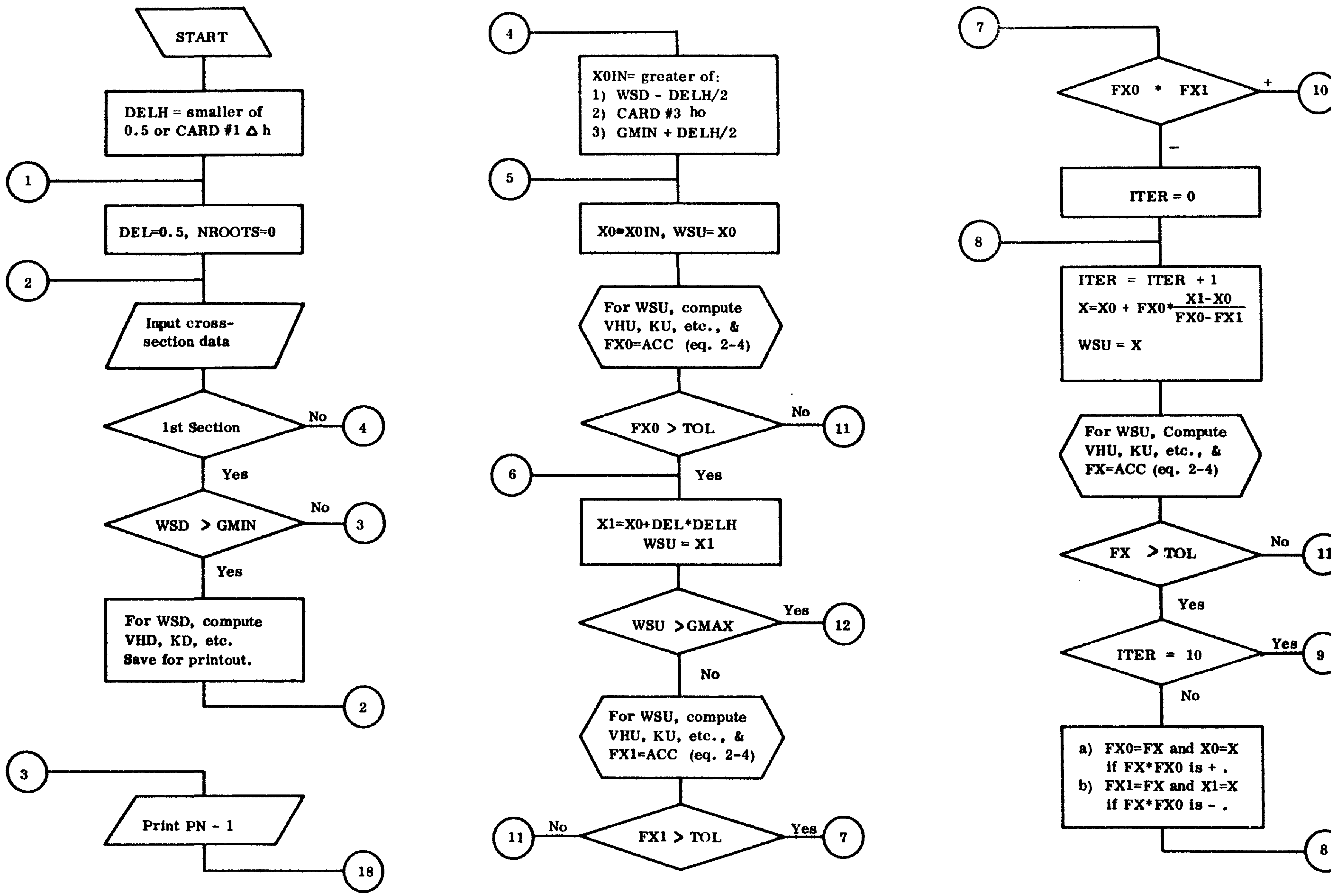


Figure 25.—Flowchart of computations for balancing the energy equation.

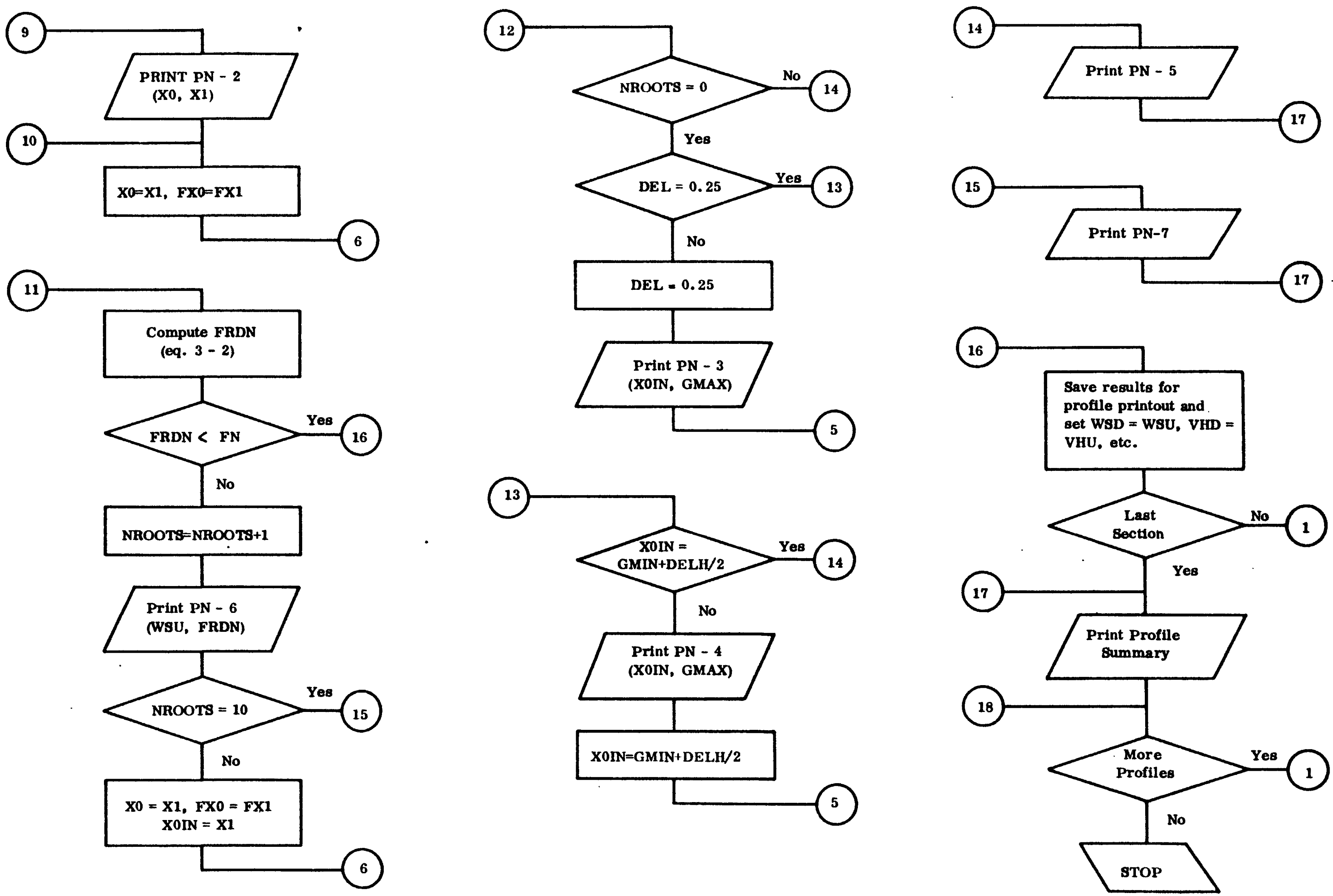


Figure 25.—Flowchart of computations for balancing the energy equation.—Continued

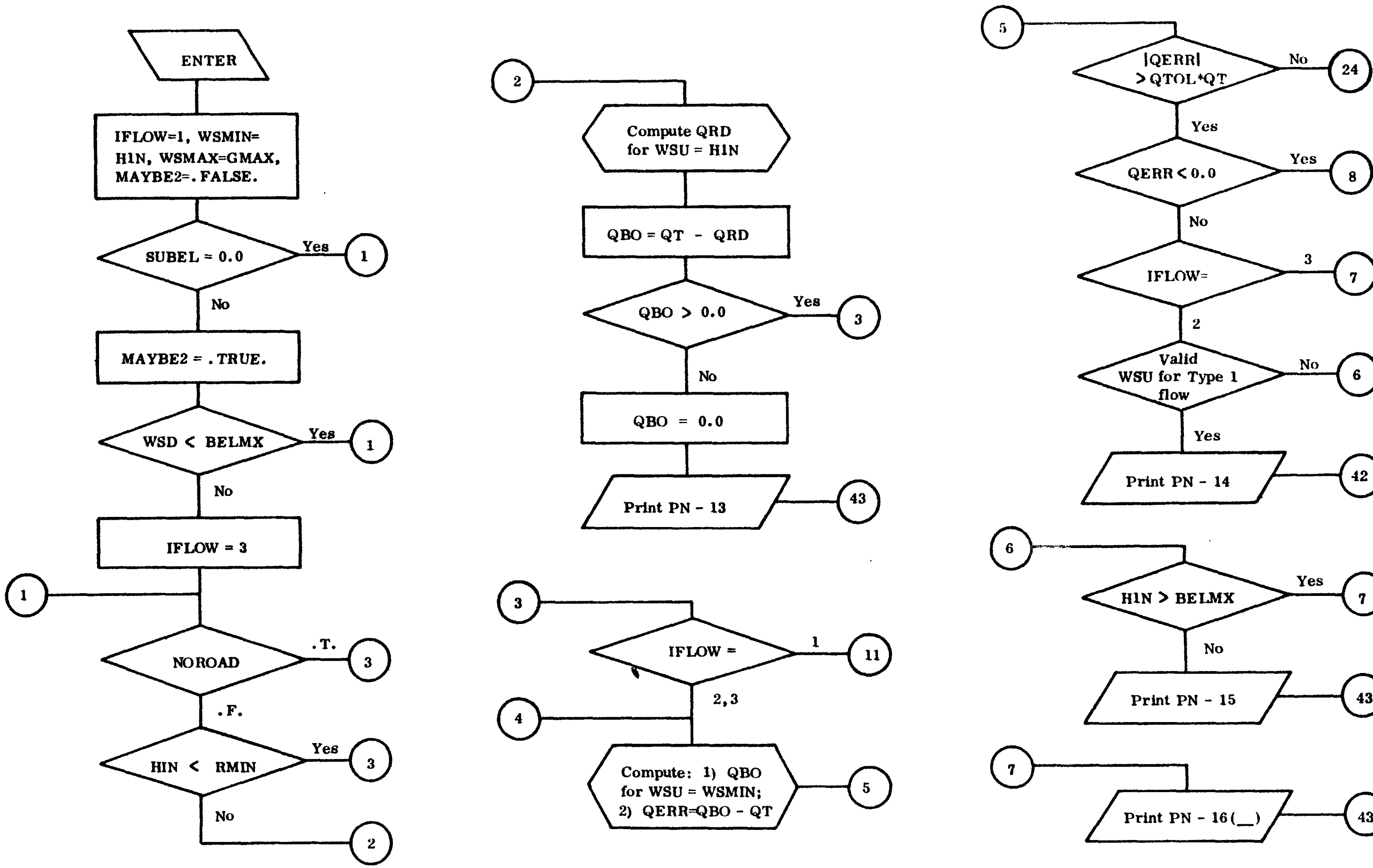


Figure 26.—Flowchart of water-surface profile computations for bridge situations.

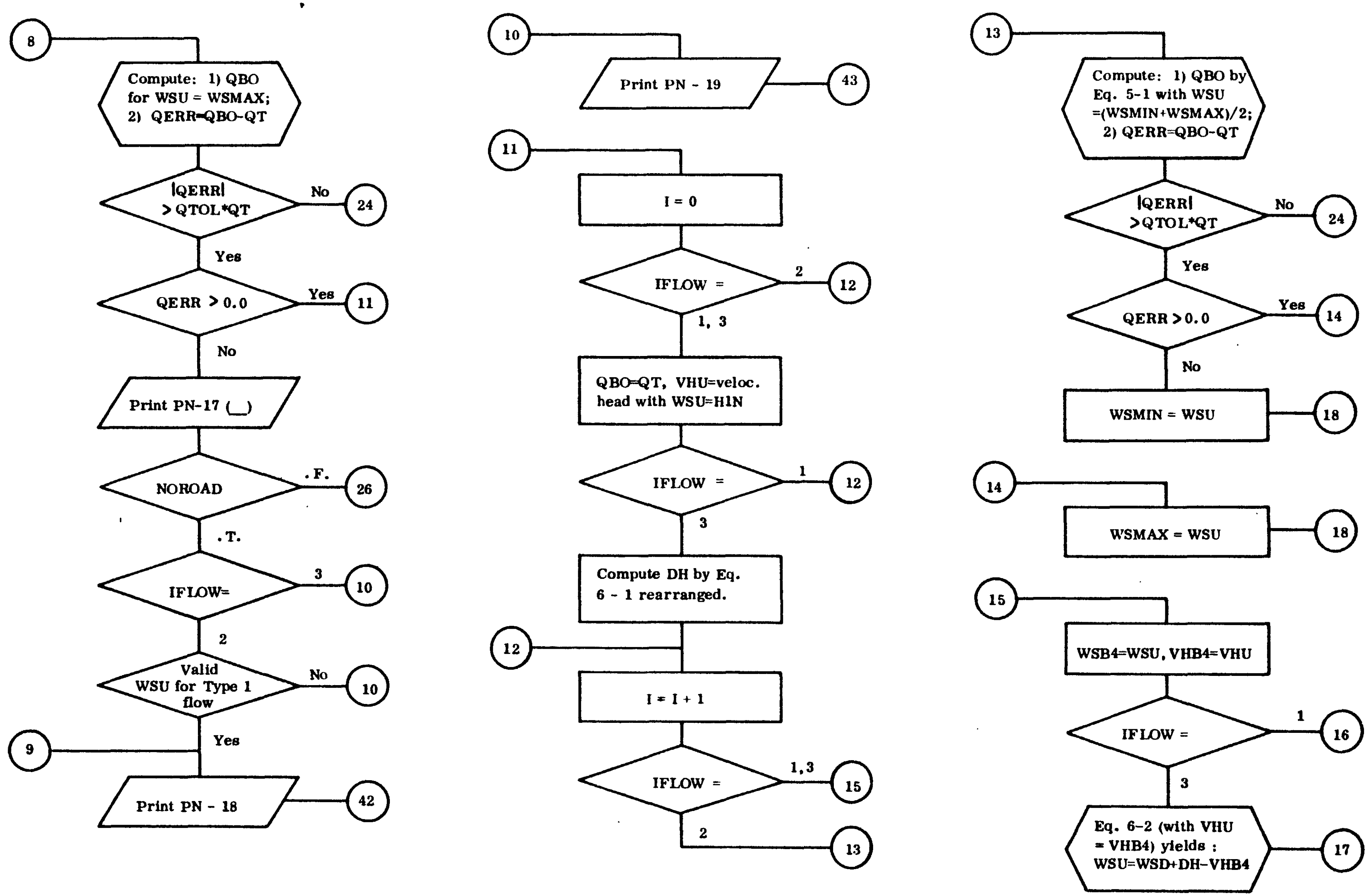


Figure 26.—Flowchart of water-surface profile computations for bridge situations.—Continued

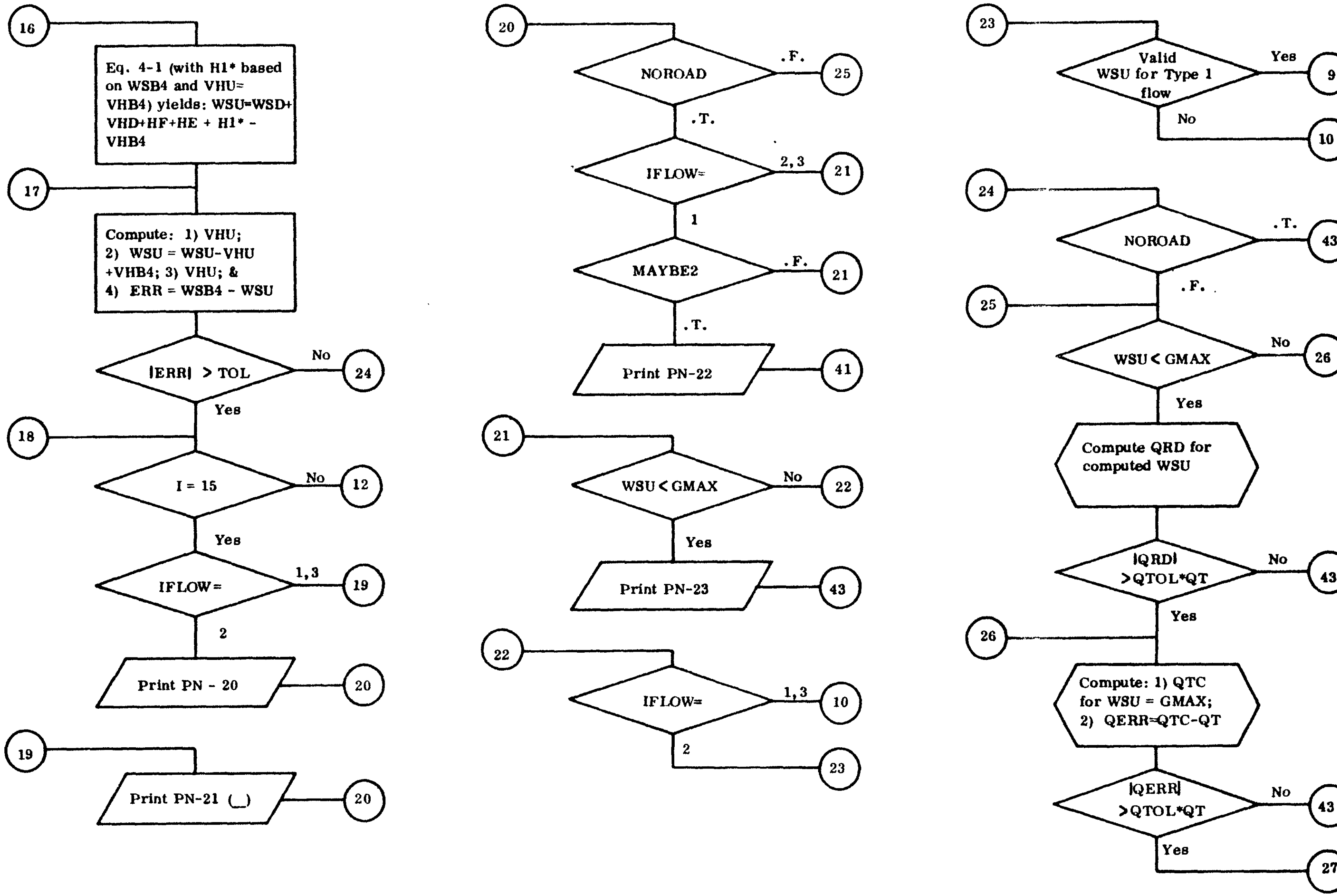


Figure 26.—Flowchart of water-surface profile computations for bridge situations.—Continued

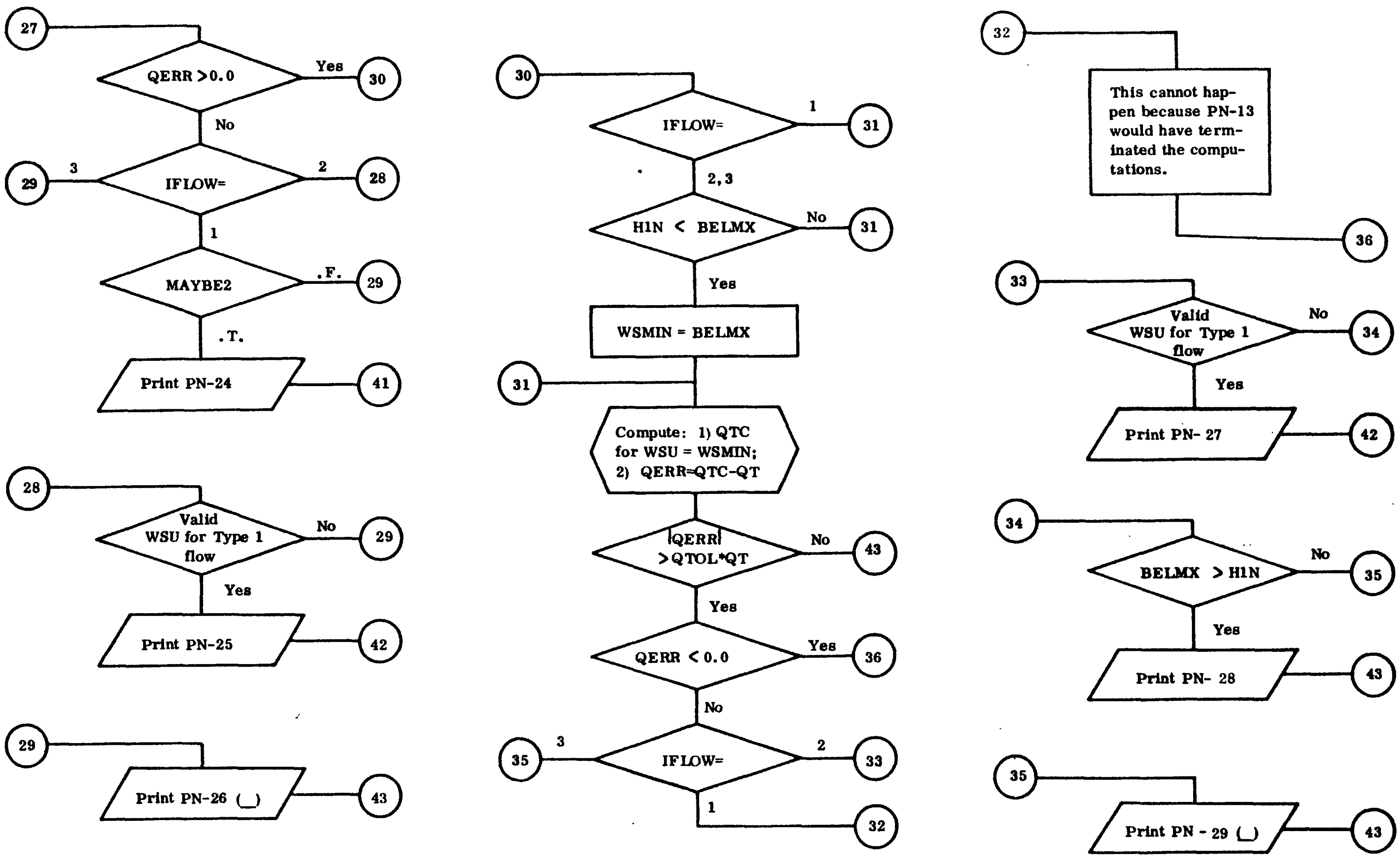


Figure 26.—Flowchart of water-surface profile computations for bridge situations.—Continued

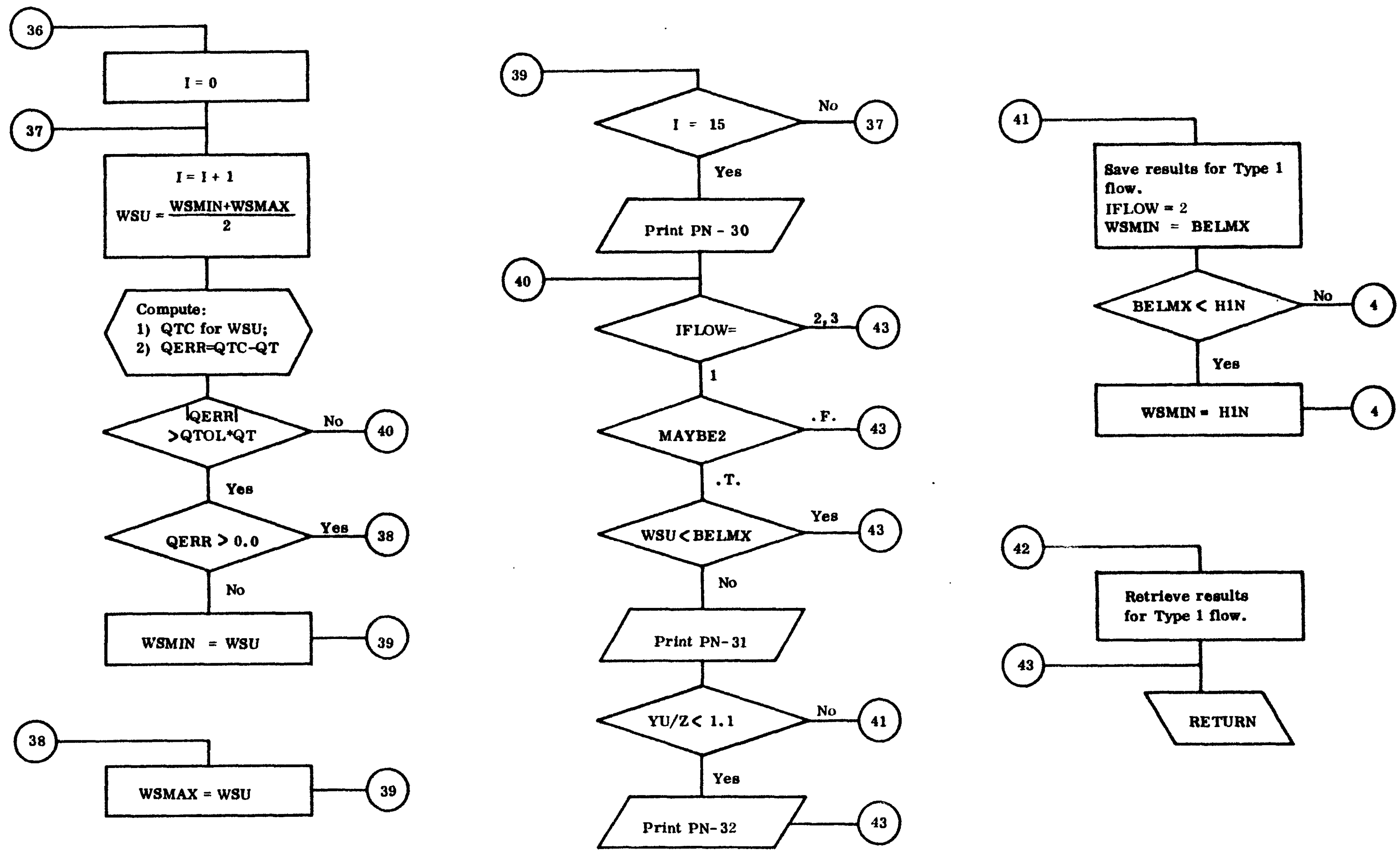


Figure 26.—Flowchart of water-surface profile computations for bridge situations.—Continued

Table 12.—*Definition of problem, E431 action, and user response for messages resulting from profile computations*

Message No.[1]	Problem *** E431 Action *** User Response
PN– 1	Water-surface elevation specified on CARD #2 is less than the minimum ground elevation in the starting cross section. *** No computations are performed for that profile. Attempts computations for the next profile (if any). *** Correct #2 CARD (or #5 CARD(S) if cross section is improperly coded).
PN– 2	Successive trials values of WSU (printed after LO= and HI=, where HI is equal to LO+DEL*DELH) resulted in a sign change for ACC. However, the method of false position failed to converge upon an answer within the specified TOL. *** Attempts to find a satisfactory answer at a higher elevation. *** If no satisfactory answer results from this action (or from subsequent actions discussed for the next two messages), increasing the TOL parameter on Card #1 may be necessary.
PN– 3	No satisfactory answer was found between the initially assumed WSU (printed after LO=) and GMAX (printed after HI=). *** Investigates the same elevation range using DEL = 0.25 (rather than DEL = 0.5 as used initially). *** See PN–5.
PN– 4	The action of PN–3 failed to yield an acceptable answer. *** Investigates the elevation range from GMIN + DELH/2 to GMAX using DEL = 0.25. *** See PN–5.
PN– 5	All attempts failed to find a mathematically valid water-surface elevation. *** Computations for that profile are terminated. Prints all profile results preceding the problem cross section. Attempts computations for the next profile (if any). *** Proper response varies considerably since the problem(s) may be: a) too few cross sections; b) flow is not subcritical (or bordering on critical); c)GMAX is not high enough; d) Δh is too large; e) TOL is too small; and (or) f) some data are coded wrong.
PN– 6	A mathematically valid answer (printed after WS=) has been rejected because the computed Froude number index, FRDN (printed after FN=), exceeds the FN test value specified on CARD #1. *** Same as PN–2. *** None if this or subsequent actions yield an acceptable answer. Otherwise, see PN–5 and (or) PN–7.
PN– 7	The problem of PN–6 has occurred ten times. *** Same as PN–5. *** a) Manual computations are required to determine at which cross section critical depth may be assumed. An adequate cross-section properties summary is essential for these manual computations. E431 can be used to compute the subcritical profile upstream by introducing the cross section at which critical depth occurs as the initial cross section. b) Some of the problems of PN–5 may exist (especially a and f). c) In extremely rare cases a valid answer may exist between the elevation of the highest Froude number failure and GMAX. Increasing h_o would eliminate investigation in the lower range of the cross section (thereby eliminating Froude number failures).
PN– 8	*Left* bank elevation < final WSU $\leqslant$ GMAX. *** *Left* bank is extended vertically. *** None if vertical extension is adequate, otherwise recode *Left* bank to extend to an adequate elevation.
PN– 9	Same as PN–8 with *Right* substituted for *Left*.
PN–10	Friction loss computations are probably incorrect due to extreme conveyance change between successive cross sections. *** None. *** Provide additional cross sections. At abrupt contractions or expansions minimize error with closely spaced cross sections.
PN–11	The energy equation balance between the exit and approach cross sections yielded H1N (approach elevation) < WSD (exit elevation). *** This can cause failure in computing free-surface flow through the bridge opening. HE is therefore increased so that H1N = WSD + 0.01. *** a) None if results are judged acceptable. b) Check cross-section coding and correct if necessary. c) Check for alternative solutions by manual computations. d) If judgement dictates the use of a water-surface elevation at the approach cross section different from that obtainable by computer solution, restart profile computations by recoding the approach cross section as an initial cross section. (TYPE = 1) and coding desired initial water-surface elevation and discharge on the #2 and #4 CARD(S).
PN–12	Ratio of pier area to gross bridge-opening area exceeds highest value of J in figure 18 for curve numbered PIER. *** J is assigned that highest value for free-surface flow computations. *** a) See PN–11b. b) Check alternate solutions by manual and (or) computer computations using net bridge-opening area. c) See PN–11d.
PN–13	With WSU = H1N (any type flow), QRD exceeds QT. *** Assumes WSU = H1N, QBO = 0, and continues computations upstream. *** a) Same as PN–11 (a - c). b)Weir flow may be greatly overestimated in E431 for high submergence. It may be advisable to compute an alternative solution assuming non-weir, non-bridge flow. This may be accomplished by coding a set of *regular* cross sections

Table 12.—*Definition of problem, E431 action, and user response for messages resulting from profile computations* —Continued

Message No.[1]	Problem *** E431 Action *** User Response
PN–13 (Cont.)	representing: 1) the exit cross section stationed at the downstream face of the opening; 2) a composite cross section of the embankment and bridge opening stationed at the center line of the road (TYPE = 0); 3) the approach cross section stationed at the upstream face of the opening (TYPE = 0); and 4) the approach cross section stationed at one bridge width upstream (TYPE = 0). c) See PN–11d.
PN–14	An attempt to compute Type 2 flow with WSU = WSMIN (the greater of H1N or BELMX) resulted in the minimum possible QBO exceeding QT. H1N ⩽ WSU < GMAX for the preceding Type 1 flow solution. *** Uses Type 1 flow results and continues computations upstream. *** Same as PN–11 (all).
PN–15	Same as PN–14 except that WSU ⩾ GMAX for the preceding Type 1 flow solution and BELMX > H1N. *** Assumes WSU = BELMX and continues computations upstream. *** a) Same as PN–11 (all). b) Extending approach cross section to a higher GMAX and (or) coding the embankment cross section (if not already coded) may yield valid Type 1 flow results. c) Type 1 flow may be obtained as the final solution by assigning a zero value to SUBEL.
PN–16	An attempt to compute either Type 2 or Type 3 flow with WSU = H1N resulted in the minimum possible QBO exceeding QT. If Type 2 flow is being analyzed, the preceding Type 1 flow yielded WSU > GMAX. No Type 1 flow solution precedes Type 3 flow analysis (when WSD ⩾ BELMX). *** Assumes WSU = H1N and continues computations upstream. *** a) Same as PN–15 (all).
PN–17	An attempt to compute either Type 2 or Type 3 flow with WSU = GMAX resulted in the maximum possible QBO being less than QT. *** Checks for the possibility of QRD. *** a) None if subsequent actions yield satisfactory results. b) Extend approach cross section to higher GMAX and (or) code the embankment cross section (if not already coded). c) See PN–18 and (or) PN–19.
PN–18	During Type 2 flow solution, PN–17 or PN–20 has occurred. The embankment cross section has not been coded and H1N ⩽ WSU < GMAX for the preceding Type 1 flow solution. *** Same as PN–14. *** a) Same as PN–11 (all). b) See PN–17b or PN–20b.
PN–19	Either: 1) PN–21 has occurred for Type 1 flow; 2) PN–17 or PN–20 has occurred for Type 2 flow; or 3) PN–17 or PN–21 has occurred for Type 3 flow. In all cases, the embankment cross section has not been coded and the computed WSU ⩾ GMAX. *** Assumes WSU = GMAX and continues computations upstream. *** a) Same as PN–11 (all). b) See PN–17b, PN–20b, or PN–21b.
PN–20	After 15 attempts to compute QBO = QT with values of WSU between WSMIN and GMAX the criterion of $\lvert QBO - QT \rvert \leqslant QTOL * QT$ has not been satisfied. *** Depends upon: 1) if embankment cross section has been coded; 2) if computed WSU < GMAX; and 3) if WSU < GMAX for preceding Type 1 flow solution. *** a) Same as PN–17a. b) May be necessary to code higher value for QTOL. c) Same as PN–11 (all).
PN–21	After 15 attempts to compute WSU between H1N and GMAX with QBO = QT (Type 1 or Type 3 flow), no two successive values of WSU satisfied the TOL criterion. *** Depends upon: 1) if embankment cross section has been coded; 2) if SUBEL = 0.0 (Type 1 flow only); and 3) if the computed WSU < GMAX. *** a) Same as PN–20 (all).
PN–22	PN–21 has occurred for Type 1 flow, the embankment has not been coded, and SUBEL ≠ 0.0. *** Attempts Type 2 flow analysis. *** Same as PN–20 (all).
PN–23	PN–21 has occurred for Type 1 or Type 3 flow, or PN–20 has occurred for Type 2 flow. In all cases the embankment cross section has not been coded and the computed WSU < GMAX. For Type 1 flow only, SUBEL = 0.0. *** Uses computed WSU and continues computations upstream. *** Same as PN–20 (all).
PN–24	An attempt to compute Type 1 flow with WSU = GMAX resulted in the maximum possible QTC being less than QT. The embankment cross section has been coded and SUBEL ≠ 0.0. *** Same as PN–22. *** a) Same as PN–17a. b) Same as PN–11 (b–d). c) Extending the approach section to a higher GMAX may yield valid Type 1 flow results.
PN–25	An attempt to compute Type 2 flow with WSU = GMAX resulted in the maximum possible QTC being less than QT. The embankment cross section has been coded and H1N ⩽ WSU < GMAX for the preceding Type 1 flow solution. *** Same as PN–14. *** a) Same as PN–11 (all). b) Response of PN–24c may yield valid Type 2 flow results.

Table 12.—*Definition of problem, E431 action, and user response for messages resulting from profile computations* —Continued

Message No.[1]	Problem *** E431 Action *** User Response
PN–26	Same as PN–24 for Type 1 flow (except SUBEL = 0.0). Same as PN–25 for Type 2 flow (except WSU ≥ GMAX for preceding Type 1 flow solution). Type 3 flow situation comparable to Type 2 flow situation (except Type 1 flow solution not attempted). *** Same as PN–19. *** a) Same as PN–11 (all). b) Response of PN–24c may yield valid results for Type 1, Type 2, or Type 3 flow.
PN–27	An attempt to compute Type 2 flow with WSU = WSMIN (the greater of HIN or BELMX) resulted in the minimum possible QTC exceeding QT. The embankment cross section has been coded and HIN ≤ WSU < GMAX for the preceding Type 1 flow solution. *** Same as PN–14. *** a) Same as PN–11 (all). b) Depends upon the messages preceding this message.
PN–28	Same as PN–27 except that the WSU ≥ GMAX for the preceding Type 1 flow solution and BELMX > H1N. *** Same as PN–15. *** Same as PN–27 (all).
PN–29	With WSU = H1N (Type 2 or Type 3 flow) the minimum possible QTC exceeded QT. For Type 2 flow, WSU ≥ GMAX for the preceding Type 1 flow solution. In all cases the embankment cross section is coded. *** Same as PN–16. *** Same as PN–27 (all).
PN–30	After 15 attempts to compute QTC = QT with values of WSU between H1N and GMAX (for Type 1 or Type 3 flow) or WSMIN and GMAX (for Type 2 flow), the criterion of |QTC - QT| ≤ QTOL * QT has not been satisfied. *** For Type 1 flow it depends upon subsequent checks of SUBEL, WSU, and YU/Z. For Type 2 or Type 3 flow, same as PN–23. *** a) Same as PN–27 (all). b) For Type 1 flow, depends upon subsequent messages (if any). c) See PN–20b.
PN–31	SUBEL ≠ 0.0 and WSU ≥ BELMX for the final Type 1 flow solution. *** If YU/Z ≥ 1.1 see PN–33. Otherwise same as PN–14. *** a) Same as PN–27 (all). b) Same as PN–30b.
PN–32	SUBEL ≠ 0.0, WSU ≥ BELMX, and YU/Z ≥ 1.1 for final Type 1 flow solution. *** Same as PN–22. *** Same as PN–31 (all).

[1] See footnote 1 on table 11.

Table 13.—*Criteria that determine flow Type computed for bridge situations*

Initial action and conditions	Subsequent: Results and conditions	Subsequent: Action	See fig. 27:
Type 1 flow is computed if: 1) WSD < BELMX *OR* 2) WSD ≥ BELMX *AND* SUBEL = 0.0	SUBEL = 0.0	Type 1 WSU is used.	A, B, and C.
	SUBEL ≠ 0.0 *AND* 1) No computation problems, *OR* 2) the Type 1 WSU does not indicate that Type 2 flow may occur.		
	SUBEL ≠ 0.0 *AND* 1) Computation problems, *OR* 2) the Type 1 WSU indicates that Type 2 flow may occur.	Type 2 flow is checked.	A, B, C, and D.
Type 2 flow is computed if: SUBEL ≠ 0.0 *AND* Type 1 WSU 1) is assumed equal to GMAX *OR* 2) indicates Type 2 flow possibility.	No computation problems.	Type 2 WSU is used.	E and F.
	Computation problems *AND* Type 1 WSU = GMAX.		
	Computation problems *AND* Type 1 WSU < GMAX.	Type 1 WSU is used.	E, F, and G.
Type 3 flow is computed if WSD ≥ BELMX *AND* SUBEL ≠ 0.0	None checked since neither Type 1 nor Type 2 flow possibility will be considered.	Type 3 WSU is used.	H and I.

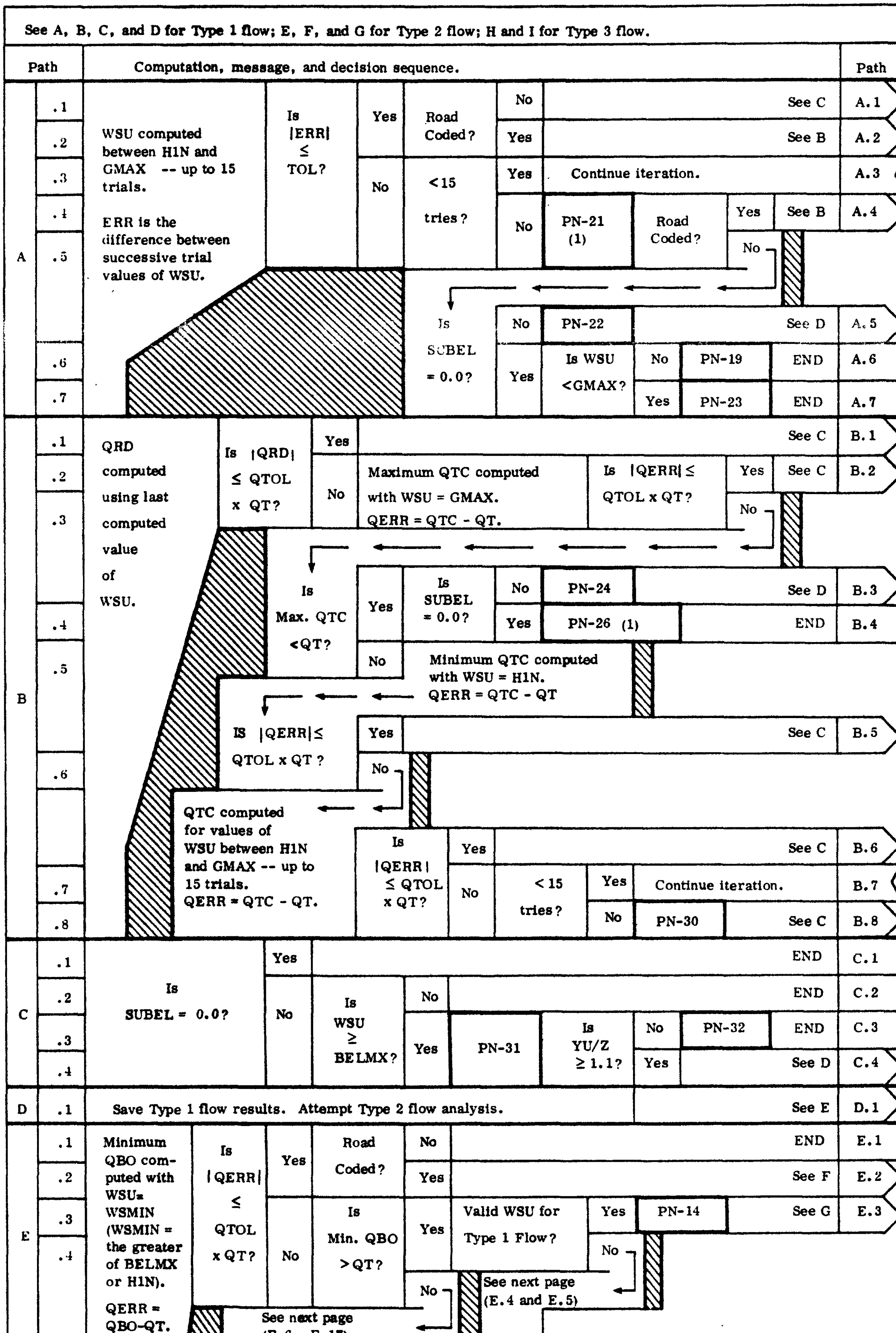


Figure 27.—Partial summary of computation, message, and decision sequence for flow at bridges.

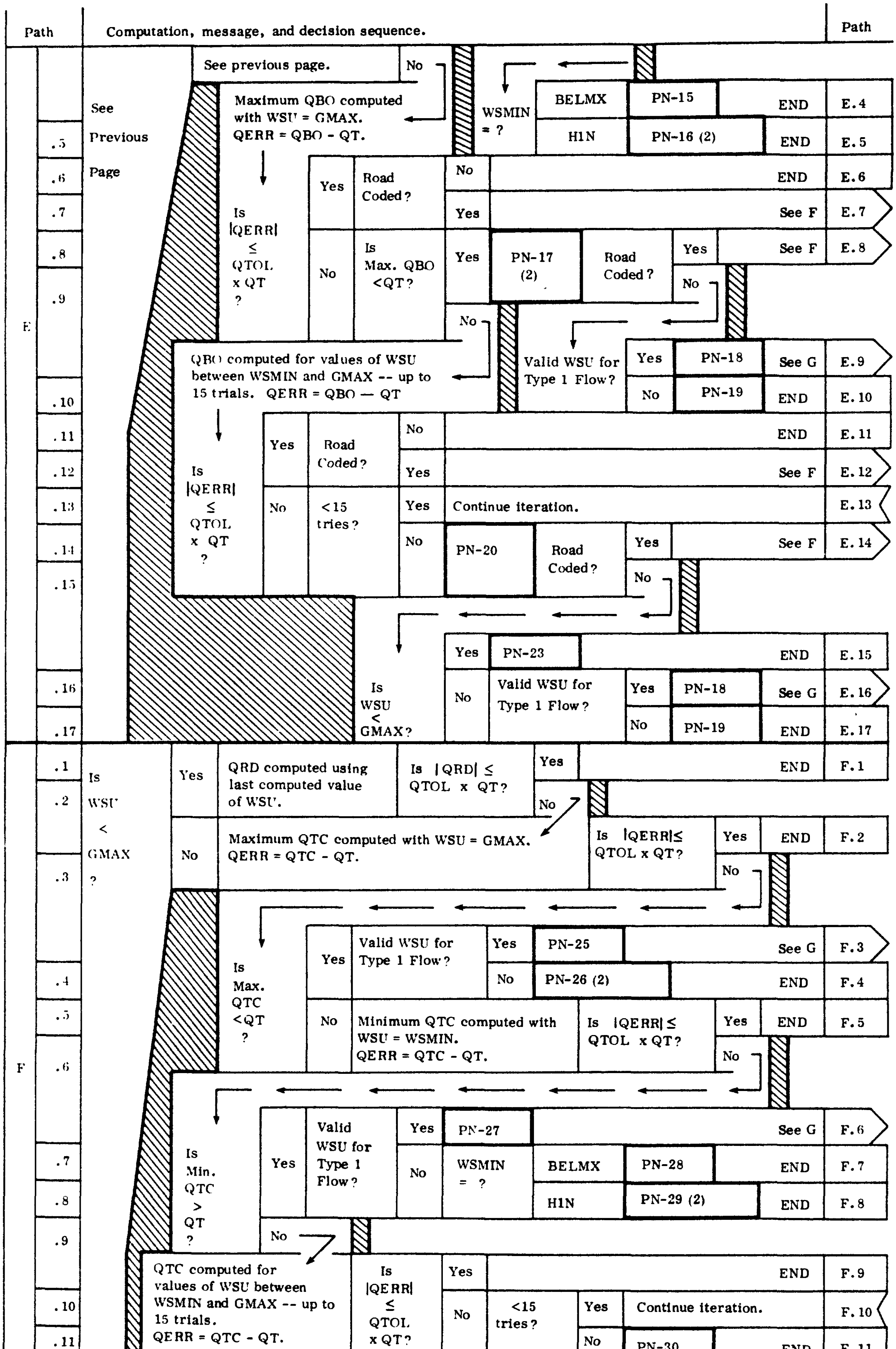


Figure 27.—Partial summary of computation, message, and decision sequence for flow at bridges.—Continued

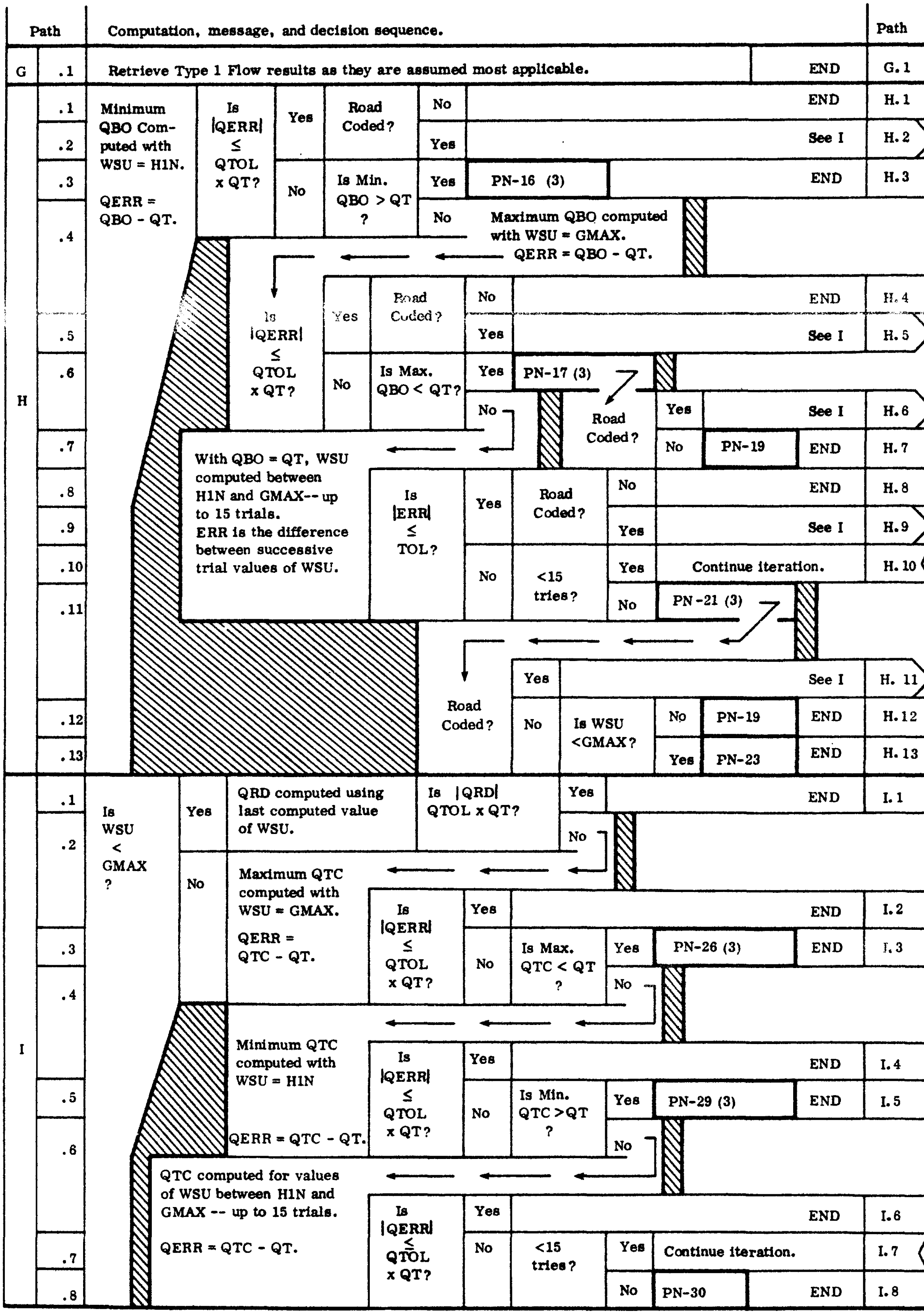


Figure 27.—Partial summary of computation, message, and decision sequence for flow at bridges.—Continued

Table 14.—*Selected messages(s) and related computational paths*

Message (s) printed	SUBEL = 0.0?		Road coded?		Computational path (s) related to printed message (s). (See fig. 27.)
	Yes	No	Yes	No	
	X		X		A.2/B.8/C.1
PN–30					
		X	X		A.2/B.8/C.2
PN–30					
PN–31		X	X		A.2/B.8/C.3
PN–32					
PN–21 (1)					
PN–22		X		X	A.5/D.1/E.3/G.1
PN–14					
PN–21 (1) PN–19	X			X	A.6
PN–21 (1) PN–23	X			X	A.7
PN–31 PN–28		X	X		A.2/B.1[1]/C.4/D.1/E.2[2]/F.7
PN–16 (3)		X X	X	 X	H.3
PN–17 (3) PN–26 (3)		X	X		H.6/I.3

[1]Could also be either B.2 or B.6
[2]Could also be either E.7 or E.12

ONE for these discharges are 211.79 and 213.54 feet, respectively. Figure 29 shows the first page of output resulting from an error-plagued data deck for this example reach. Encircled lower-case letters are used in figure 29 to tag items to be discussed in the following paragraphs.

A line containing a program version number, a page number, and a date is printed on every page of E431 output. All of these data are internally determined by E431 and are totally independent of user efforts. The version number (item a) represents the latest program revision date with the first two digits denoting the year and the last three digits indicating the Julian day. All output pages of an E431 job, regardless of the number of reaches being analyzed, are numbered consecutively (item b). Item c is the date on which the E431 job was executed. Item d denotes two lines of digits and dots which are printed to aid the user in determining column numbers on the input card printout.

The remainder of the tagged items in figure 29 represent some of the errors that may be found by the sequence-location edit. Many of these errors also result in associated errors in the subsequent numerical edit. All numerical editing messages for this example reach are shown in figure 30. Only the second and fifth messages in figure 30 are not related to errors discovered in the sequence-loccation edit. Thus, all but these two messages will be discussed along with the sequence-location editing messages.

Message SL-3 (item e) is printed because the intended SEQUENCE of 1003 is shifted one column to the right. This same error also causes the printing of messages SL-5 and the B-flag in column 8 (item f) on the next line. No user action is required since it is simply a sequence number error.

Disagreement between NPR (CARD #1) and the number of entries on CARD #4 is brought to the user's

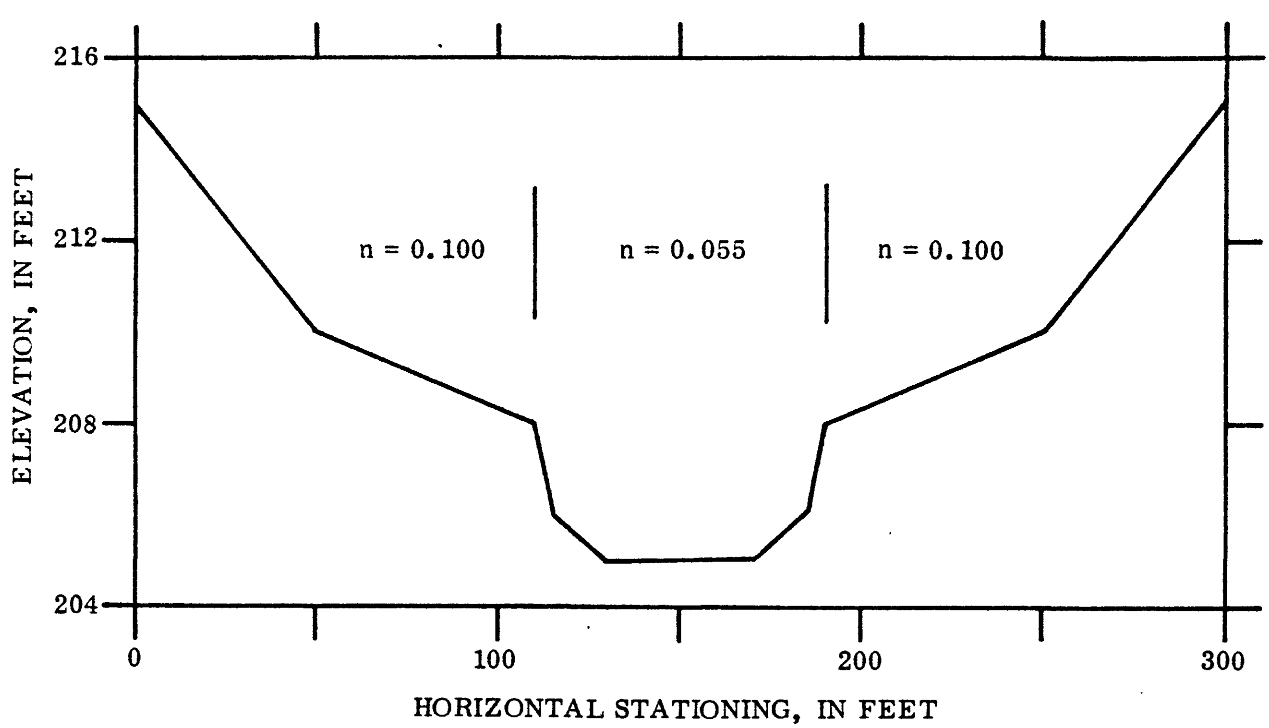


Figure 28.—Regular cross section used to illustrate computer output.

```
           USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    1.DATE= 4/  /76
                                                 (a)                       (b)          (c)
                   *** INPUT CARD PRINTOUT ***

        1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0 <-(d)     (  )->See Text

1  1001 EXPLANATION OF OUTPUT ------ E431 USER'S MANUAL   10  2 01 50 12
2  1002  21179  21354
3   1003 ONE  1  13  3  207     1000 99 99
**SEQUENCE**                          <-(e)                                         <-(f)->   **ERROR(S)**
      B
4  1004    4000
                 M                                                                  <-(g)->   **ERROR(S)**
5  1010        0  1  2150   50  1  2100  110  2  2080  115  2  2060  130  2  2050
5  1011      170  2  2050  185  2  2060  190  3  2080  250  3  2100  300  3  2150
6  1020  0  1 100 100  0  1 055 055  0  1 100
                                                M                                   <-(h)->   **ERROR(S)**
3  2003 TWO    0   8  3  202     2000 99 99
5  2010        0  1  2200   50  1  2150  110  2  2130  115  2  2110  130  2  2100
5  2011      170  2  2100  185  2  2110  190  3  2130  250  3  2150  300  3  2200
                                                      UUU  U  UUUU  UUU  U  UUUU    <-(i)->   **ERROR(S)**
6  2020  0  1 100 100  0  1 055 055  0  1 100 100
3  3003 THREE 0  10  3  217      3000
                                    B M  M                                          <-(j)->   **ERROR(S)**
5  3010        0   1 2250   50  1  2200 110  2  2180  115  2  2160  130  2  2150
                MB                          M                                       <-(k)->   **ERROR(S)**
5  3011      170  2  2150  185  2  2160  190  3  2180  250  3  2200  300  3  2250
6  3020  0  1 100 100  0  1 055 055  0  1 100 100
3  4003 FOUR  0  10  1  222      4000 99 99
5  4010        0  1  2300   50  1  2250  110  2  2230  115  2  2210  130  2  2200
5  4011      170  2  2200  185  2  2210  190  3  2230  250 3   2250  300  3  2300
                                                           M                        <-(l)->   **ERROR(S)**
6  4020  0  1 100 100  0  1 055 055  0  1 100 100
                       U  U UUU UUU  U  U UUU UUU                                   <-(m)->   **ERROR(S)**
3  5003 FIVE  0  10  6  227      5000 99 99
5  5010        0  1  2350   50  1  2300  110  2  2280  115  2  2260  130  2  2250
5  5011      170  2  2250  185  2  2260  190  3  2280  250  3  2300  300  3  2350
6  5020  0  1 100 100  0  1 055 055  0  1 100 100
                                                  M   M   M   M  M   M   M   M      <-(n)->   **ERROR(S)**
5  6010        0  1  2400   50  1  2350  110  2  2330  115  2  2310  130  2  2300  EXPECTED #6 OR #3 CARD**NO EDIT**
5  6011      170  2  2300  185  2  2310  190  3  2330  250  3  2350  300  3  2400      (o)->    **NO EDIT**
6  6020  0  1 100 100  0  1 055 055  0  1 100 100                                               **NO EDIT**
3  7003 SEVEN 0  10  3  237      7000 99 99
5  7010        0  1  2450   50  1  2400  110  2  2380  115  2  2360  130  2  2350
5  7011      170  2  2350  185  2  2360  190  3  2380  250  3  24//  300  3  2450
                                                              II                                **ERROR(S)**
**INVALID CHARACTER(S) ON PRECEDING CARD**        <-(p)->                                       **NO EDIT**
6  7020  0  1 100 100  0  1 055 055                                                             **NO EDIT**
```

Figure 29.— E431 output of card images and messages from sequence-location edit.

attention by item g, M-flag in column 21 and message SL-5, being printed beneath the card image of CARD #4. The first message in figure 30 indicates that E431 will assume NPR = 1. Thus, a rerun with corrected data will be necessary to obtain the water-surface profile for 6,600 ft^3/s even if all other data are correct.

A missing roughness value on SEQUENCE 1020 is indicated by item h. The third message in figure 30 indicates that the missing N3 value for the third subarea will be assigned the same value as N1 for that subarea. In this case, this assumption is valid and no user action would be required.

Item i indicates that the last two sets of coordinate data were unexpected (NPTS = 8 on CARD #3 for section TWO). However, as shown by the fourth message in figure 30, the correct number of points was determined, thus no user action is required.

The B-flag and M-flags of item j indicate a shifted DISTANCE value and missing SAL and SAR values. The DISTANCE problem also causes the sixth message of figure 30 to be printed. Of course corrective action by the user is required to overcome this abortive problem. As indicated by the ninth and tenth messages of figure 30, SAL and SAR are both assigned a value of 99.

The first #5 CARD for section THREE has the first SA value shifted one column to the right and the third station value shifted one column to the left (item k). Thus, these two values are input as 0 (zero) and 1100, respectively. Therefore, the abortive seventh and eighth messages of figure 30, which require corrective action, are printed.

A single error frequently causes many messages as illustrated by item ℓ. The ninth SA value, being shifted one column to the left, is input as 30. Thus, it is (1) invalid, (2) out of order, (3) greater than NSA, and (4) makes it appear as though the tenth SA value is out of order. These abortive problems are brought to the user's attention by the twelfth through fifteenth messages in figure 30.

The U-flags of item m are due to NSA = 1 on the #3 CARD for section FOUR. As indicated by the eleventh message of figure 30, a value of three was assumed for NSA (since three sets of roughness data were punched on CARD #6). Similarly, NSA = 6 on CARD #3 for section FIVE produces the M-flags of item n and the last message of figure 30.

Item o indicates that E431 expected a #6 CARD or a #3 CARD following SEQUENCE 5020. Of course the problem is a missing #3 CARD for section SIX. Therefore, data cards for section SIX are not subjected to sequence-location editing as indicated by message SL-4. Also, section SIX is not edited for numerical errors since that operation relies heavily upon parameters specified on the #3 CARD.

Item p shows the results of slashes appearing in places of zeros. This problem results in messages SL-6 and SL-4 for that data card and message SL-4 for remaining data cards for section SEVEN. Since invalid characters can cause serious problems for which recovery is difficult to program, section SEVEN is not subjected to numerical editing.

NPTS specifies 13 coordinates for section ONE when there are only 10 coordinates provided. The sequence-location edit cannot indicate this problem with M-flags since a third #5 CARD was not in the deck. However, the numerical edit does reveal this problem by printing

USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT= 2,DATE= 4/ /76

PAGE 1 OF EDITING NOTES FOR: EXPLANATION OF OUTPUT ------ E431 USER'S MANUAL

SECID	ERROR SEVERITY	FIRST VARIABLE	NO.	ERROR MESSAGE	SECOND VARIABLE	NO.	VALUE ASSUMED
ONE	WARNING	NPR		WRONG			1
ONE	WARNING	NPTS		WRONG			10
ONE	WARNING	N3	3	NOT SPECIFIED			N3=N1
TWO	WARNING	NPTS		WRONG			10
TWO	WARNING	HSUBO		IS LESS THAN	GMIN		> GMIN
THREE	ABORTIVE	DISTANCE		WRONG			
THREE	ABORTIVE	SA	1	MUST = 1			
THREE	ABORTIVE	STATION	4	IS LESS THAN	STATION	3	
THREE	WARNING	SAL		INVALID			99
THREE	WARNING	SAR		INVALID			99
FOUR	WARNING	NSA		WRONG			3
FOUR	ABORTIVE	SA	9	INVALID			
FOUR	ABORTIVE	SA	9	OUT OF ORDER			
FOUR	ABORTIVE	SA	9	GREATER THAN	NSA		
FOUR	ABORTIVE	SA	10	OUT OF ORDER			
FIVE	WARNING	NSA		WRONG			3

Figure 30.—E431 output of messages from numerical edit.

the second message in figure 30. Since NPTS was correctly determined to be 10, no user action is required.

An input data summary is printed immediately following the output from the data editing phases. Figure 31 presents this summary for the example reach. NXS (CARD #1) was specified as 10. However, only six #3 CARDS were found (that for section SIX was missing). Only five of those six cross sections were subjected to numerical editing (section SEVEN being rejected because of invalid characters). Numerical editing eliminated sections THREE and FOUR due to abortive errors. Thus, only three sections remain for computation of cross-section properties (sections ONE, TWO, and FIVE). Profile computations are limited to the one subreach defined by sections ONE and TWO.

Figure 32 is the output of cross-section properties for the three valid cross sections. Δh of 5.0 feet was purposely used to reduce space requirements in the report. For each water-surface elevation printed (WS, first column) the data represent (from left to right): A, total area (eq. 1-4); K, total conveyance (eq. 1-5); α, kinetic-energy correction factor (eq. 1-7); B, net top width of water surface; P, total wetted perimeter (sum of p_i for all subareas, fig. 1); LEW and REW, horizontal station of intersection of water surface with left bank

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=      3,DATE= 4/  /76

INPUT SUMMARY FOR: EXPLANATION OF OUTPUT ------ E431 USER'S MANUAL

                  10 CROSS SECTIONS SPECIFIED (OR ASSUMED)

           FOUND  6 TYPE 3 CARDS

           KEPT   5 CROSS SECTIONS FOR EDITING

                  3   "      "      VALID FOR PROPERTY COMPUTATIONS

                  2   "      "       "    "  PROFILE         "
```

Figure 31.—E431 input summary.

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=      4,DATE= 4/  /76

CROSS-SECTION PROPERTIES FOR: EXPLANATION OF OUTPUT ------ E431 USER'S MANUAL
    SECID= ONE   AT DISTANCE=   1000                                 PART  1 OF  1

   WS        A          K      ALPHA      B       P      LEW     REW       QC

 207.0      128       4900     1.00      75      75     113     188       943
 212.0      925      60475     1.74     240     241      30     270      7819
 215.0     1735     131518     1.88     300     301       0     300     17239

CROSS-SECTION PROPERTIES FOR: EXPLANATION OF OUTPUT ------ E431 USER'S MANUAL
    SECID=TWO    AT DISTANCE=   2000                                 PART  1 OF  1

   WS        A          K      ALPHA      B       P      LEW     REW       QC

 215.0      485      28801     1.46     200     201      50     250      3544
 220.0     1735     131518     1.88     300     301       0     300     17239

CROSS-SECTION PROPERTIES FOR: EXPLANATION OF OUTPUT ------ E431 USER'S MANUAL
    SECID=FIVE   AT DISTANCE=   5000                                 PART  1 OF  1

   WS        A          K      ALPHA      B       P      LEW     REW       QC

 227.0      128       4900     1.00      75      75     113     188       943
 232.0      925      60475     1.74     240     241      30     270      7819
 235.0     1735     131518     1.88     300     301       0     300     17239
```

Figure 32.—E431 output of cross-section properties.

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=     5,DATE= 4/  /76

================================================================================
WATER-SURFACE PROFILE FOR: EXPLANATION OF OUTPUT ------ E431 USER'S MANUAL
PAGE  1 OF  1
================================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /    HV  /    HF  /    HE  /      EG  /     V  /    FN  /   ACC   *ID*
================================================================================
ONE  AT    1000 /      0 /   4000. /   875. /   56560. / 1.72 /   32. /  268.
  211.79 /   0.56 /                       /  212.35 /   4.57 /   0.46/        *IS*
--------------------------------------------------------------------------------
TWO  AT    2000 /   1000 /   4000. /   876. /   56628. / 1.72 /   32. /  268.
  216.79 /   0.56 /   5.00 /   0.0  /  217.35 /   4.57 /   0.46 /  0.007  *XS*
--------------------------------------------------------------------------------

                            END OF THIS PROFILE
```

Figure 33.—E431 output of profile computations.

```
           USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=     1,D

                         *** INPUT CARD PRINTOUT ***

         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1  1001 SIMPLE REACH EXAMPLE ------- E431 USER'S MANUAL     6  2 01 05 12
2  1002  21179  21354
3  1003 ONE   1  10  3  207     1000 99 99
4  1004   4000    6600
5  1010         0  1  2150   50  1  2100  110  2  2080  115  2  2060  130  2  2050
5  1011       170  2  2050  185  2  2060  190  3  2080  250  3  2100  300  3  2150
6  1020  0  1 100 100  0  1 055 055  0  1 100 100
3  2003 TWO   0  10  3  212     2000 99 99
5  2010         0  1  2200   50  1  2150  110  2  2130  115  2  2110  130  2  2100
5  2011       170  2  2100  185  2  2110  190  3  2130  250  3  2150  300  3  2200
6  2020  0  1 100 100  0  1 055 055  0  1 100 100
3  3003 THREE 0  10  3  217     3000 99 99
5  3010         0  1  2250   50  1  2200  110  2  2180  115  2  2160  130  2  2150
5  3011       170  2  2150  185  2  2160  190  3  2180  250  3  2200  300  3  2250
6  3020  0  1 100 100  0  1 055 055  0  1 100 100
3  4003 FOUR  0  10  3  222     4000 99 99
5  4010         0  1  2300   50  1  2250  110  2  2230  115  2  2210  130  2  2200
5  4011       170  2  2200  185  2  2210  190  3  2230  250  3  2250  300  3  2300
6  4020  0  1 100 100  0  1 055 055  0  1 100 100
3  5003 FIVE  0  10  3  227     5000 99 99
5  5010         0  1  2350   50  1  2300  110  2  2280  115  2  2260  130  2  2250
5  5011       170  2  2250  185  2  2260  190  3  2280  250  3  2300  300  3  2350
6  5020  0  1 100 100  0  1 055 055  0  1 100 100
3  6003 SIX   0  10  3  232     6000 99 99
5  6010         0  1  2400   50  1  2350  110  2  2330  115  2  2310  130  2  2300
5  6011       170  2  2300  185  2  2310  190  3  2330  250  3  2350  300  3  2400
6  6020  0  1 100 100  0  1 055 055  0  1 100 100
```

Figure 34.—Input data for a simple reach.

and right bank, respectively; and QC, the critical discharge as computed by eq. 3-4. B is equal to the difference between LEW and REW (with possible round-off error) except when islands (which are accounted for in the computations) exist.

Note the minimum elevation for which properties are printed for section TWO. It is relatively high due to a mistake in h_o (as indicated by the fifth message on figure 30) which forced E431 to compute a higher h_o value (see EN-14, table 10).

There are no profile computation messages for this reach. Therefore, the output of the profile computations (fig. 33) immediately follows the properties output. Two lines are printed for each cross section with the applicable headings indicated by arrows. The data printed on the first line for each cross section (from left

USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT= 3,DATE= 4/ /76

CROSS-SECTION PROPERTIES FOR: SIMPLE REACH EXAMPLE ------- E431 USER'S MANUAL
SECID=ONE AT DISTANCE= 1000 PART 1 OF 1

WS	A	K	ALPHA	B	P	LEW	REW	QC
207.0	128	4900	1.00	75	75	113	188	943
207.5	166	7403	1.00	78	78	111	189	1373
208.0	205	10328	1.00	80	81	110	190	1861
208.5	253	13945	1.05	110	111	95	205	2115
209.0	315	18167	1.17	140	141	80	220	2482
209.5	393	23091	1.31	170	171	65	235	2957
210.0	485	28800	1.46	200	201	50	250	3544
210.5	588	35532	1.56	210	211	45	255	4456
211.0	695	43064	1.64	220	221	40	260	5475
211.5	808	51380	1.69	230	231	35	265	6597
212.0	925	60475	1.74	240	241	30	270	7819
212.5	1048	70348	1.77	250	251	25	275	9141
213.0	1175	81001	1.80	260	261	20	280	10562
213.5	1308	92437	1.82	270	271	15	285	12082
214.0	1445	104665	1.85	280	281	10	290	13701
214.5	1588	117689	1.87	290	291	5	295	15419
215.0	1735	131518	1.88	300	301	0	300	17239

CROSS-SECTION PROPERTIES FOR: SIMPLE REACH EXAMPLE ------- E431 USER'S MANUAL
SECID=TWO AT DISTANCE= 2000 PART 1 OF 1

WS	A	K	ALPHA	B	P	LEW	REW	QC
212.0	128	4900	1.00	75	75	113	188	943
212.5	166	7403	1.00	78	78	111	189	1373
213.0	205	10328	1.00	80	81	110	190	1861
213.5	253	13945	1.05	110	111	95	205	2115
214.0	315	18167	1.17	140	141	80	220	2482
214.5	393	23091	1.31	170	171	65	235	2957
215.0	485	28800	1.46	200	201	50	250	3544
215.5	588	35532	1.56	210	211	45	255	4456
216.0	695	43064	1.64	220	221	40	260	5475
216.5	808	51380	1.69	230	231	35	265	6597
217.0	925	60475	1.74	240	241	30	270	7819
217.5	1048	70348	1.77	250	251	25	275	9141
218.0	1175	81001	1.80	260	261	20	280	10562
218.5	1308	92437	1.82	270	271	15	285	12082
219.0	1445	104665	1.85	280	281	10	290	13701
219.5	1588	117689	1.87	290	291	5	295	15419
220.0	1735	131518	1.88	300	301	0	300	17239

Figure 35.—Partial cross-section properties output for data figure 34.

to right) are: SECID; DISTANCE; subreach length (L in fig. 2); QT, discharge specified on the #4 CARD(S); and A, K, α, LEW, and REW as discussed above. The second line shows: computed water-surface elevation (for section ONE this is simply the initial water-surface elevation specified on CARD #2); HV, velocity head (eq. 1-8); HF, friction loss (eq. 2-2); HE, eddy loss (eq. 2-3); EG, energy gradient (see fig. 2); V, mean velocity (eq. 1-6); FN, which is actually the index Froude number, FRDN, as computed by eq. 3-2; ACC, final accuracy of energy balance (eq. 2-4); and *ID* which indicates cross-section type. The possible codes for ID and the related cross-section types are: (1) IS-initial, (2) XS-regular, (3) BO-bridge opening, (4) RG-embankment, and (5) AS-approach. HF, HE and ACC are blank for section ONE since they apply to the subreach and are printed for section TWO. Bridge situations require some additional output which will be described in the next section.

COMPUTER PROGRAM APPLICATIONS

A limited variety of additional examples are presented below to: (1) further illustrate data preparation and (2) illustrate some potential E431 applications for backwater analyses. Output features not illustrated in the previous section are also discussed. As stated previously,

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=     6,DATE= 4/  /76

================================================================================
WATER-SURFACE PROFILE FOR: SIMPLE REACH EXAMPLE ------- E431 USER'S MANUAL
PAGE  1 OF  1
================================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /     HV  /    HF  /    HE  /      EG  /     V  /     FN  /   ACC   *ID*
================================================================================
ONE    AT     1000 /       0 /   4000. /    875. /    56560. / 1.72 /    32. /  268.
   211.79 /   0.56 /                   /  212.35 /    4.57 /   0.46/           *IS*
--------------------------------------------------------------------------------
TWO    AT     2000 /  1000 /   4000. /    876. /    56628. / 1.72 /    32. /  268.
   216.79 /   0.56 /   5.00 /    0.0  /  217.35 /    4.57 /   0.46 /  0.007   *XS*
--------------------------------------------------------------------------------
THREE AT      3000 /  1000 /   4000. /    876. /    56605. / 1.72 /    32. /  268.
   221.79 /   0.56 /   4.99 /   0.00 /  222.35 /    4.57 /   0.46 /  0.007   *XS*
--------------------------------------------------------------------------------
FOUR   AT     4000 /  1000 /   4000. /    876. /    56613. / 1.72 /    32. /  268.
   226.79 /   0.56 /   4.99 /    0.0  /  227.35 /    4.57 /   0.46 /  0.007   *XS*
--------------------------------------------------------------------------------
FIVE   AT     5000 /  1000 /   4000. /    876. /    56610. / 1.72 /    32. /  268.
   231.79 /   0.56 /   4.99 /   0.00 /  232.35 /    4.57 /   0.46 /  0.007   *XS*
--------------------------------------------------------------------------------
SIX    AT     6000 /  1000 /   4000. /    876. /    56611. / 1.72 /    32. /  268.
   236.79 /   0.56 /   4.99 /    0.0  /  237.35 /    4.57 /   0.46 /  0.007   *XS*
--------------------------------------------------------------------------------

                                END OF THIS PROFILE

USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=     7,DATE= 4/  /76

================================================================================
WATER-SURFACE PROFILE FOR: SIMPLE REACH EXAMPLE ------- E431 USER'S MANUAL
PAGE  1 OF  1
================================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /     HV  /    HF  /    HE  /      EG  /     V  /     FN  /   ACC   *ID*
================================================================================
ONE    AT     1000 /       0 /   6600. /   1318. /    93386. / 1.83 /    15. /  285.
   213.54 /   0.71 /                   /  214.25 /    5.01 /   0.47/           *IS*
--------------------------------------------------------------------------------
TWO    AT     2000 /  1000 /   6600. /   1318. /    93386. / 1.83 /    15. /  285.
   218.54 /   0.71 /   4.99 /    0.0  /  219.25 /    5.01 /   0.47 /  0.005   *XS*
--------------------------------------------------------------------------------
THREE AT      3000 /  1000 /   6600. /   1318. /    93386. / 1.83 /    15. /  285.
   223.54 /   0.71 /   4.99 /    0.0  /  224.25 /    5.01 /   0.47 /  0.005   *XS*
--------------------------------------------------------------------------------
FOUR   AT     4000 /  1000 /   6600. /   1318. /    93386. / 1.83 /    15. /  285.
   228.54 /   0.71 /   4.99 /    0.0  /  229.25 /    5.01 /   0.47 /  0.005   *XS*
--------------------------------------------------------------------------------
FIVE   AT     5000 /  1000 /   6600. /   1318. /    93386. / 1.83 /    15. /  285.
   233.54 /   0.71 /   4.99 /    0.0  /  234.25 /    5.01 /   0.47 /  0.005   *XS*
--------------------------------------------------------------------------------
SIX    AT     6000 /  1000 /   6600. /   1318. /    93386. / 1.83 /    15. /  285.
   238.54 /   0.71 /   4.99 /    0.0  /  239.25 /    5.01 /   0.47 /  0.005   *XS*
--------------------------------------------------------------------------------

                                END OF THIS PROFILE
```

Figure 36.—Profile output for data of figure 34.

```
                 USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=

                               *** INPUT CARD PRINTOUT ***

          1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1  1001 TRIBUTARY INFLOW EXAMPLE --- E431 USER'S MANUAL     6  2 01 05 12
2  1002  21179  21354
3  1003 ONE   1  10  3  207     1000 99 99
4  1004    4000    6600
5  1010         0  1  2150   50  1  2100  110  2  2080  115  2  2060  130  2  2050
5  1011       170  2  2050  185  2  2060  190  3  2080  250  3  2100  300  3  2150
6  1020  0  1 100 100  0  1 055 055  0  1 100 100
3  2003 TWO   0  10  3  212     2000 99 99
5  2010         0  1  2200   50  1  2150  110  2  2130  115  2  2110  130  2  2100
5  2011       170  2  2100  185  2  2110  190  3  2130  250  3  2150  300  3  2200
6  2020  0  1 100 100  0  1 055 055  0  1 100 100
3  3003 THREE 0  10  3  217     3000 99 99
5  3010         0  1  2250   50  1  2200  110  2  2180  115  2  2160  130  2  2150
5  3011       170  2  2150  185  2  2160  190  3  2180  250  3  2200  300  3  2250
6  3020  0  1 100 100  0  1 055 055  0  1 100 100
3  4003 FOUR  1  10  3  222     4000 99 99
4  4004    3000    4950
5  4010         0  1  2300   50  1  2250  110  2  2230  115  2  2210  130  2  2200
5  4011       170  2  2200  185  2  2210  190  3  2230  250  3  2250  300  3  2300
6  4020  0  1 100 100  0  1 055 055  0  1 100 100
3  5003 FIVE  0  10  3  227     5000 99 99
5  5010         0  1  2350   50  1  2300  110  2  2280  115  2  2260  130  2  2250
5  5011       170  2  2250  185  2  2260  190  3  2280  250  3  2300  300  3  2350
6  5020  0  1 100 100  0  1 055 055  0  1 100 100
3  6003 SIX   0  10  3  232     6000 99 99
5  6010         0  1  2400   50  1  2350  110  2  2330  115  2  2310  130  2  2300
5  6011       170  2  2300  185  2  2310  190  3  2330  250  3  2350  300  3  2400
6  6020  0  1 100 100  0  1 055 055  0  1 100 100
________________________________________________________________________________

USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    7,DATE= 4/  /76


===============================================================================
WATER-SURFACE PROFILE FOR: TRIBUTARY INFLOW EXAMPLE --- E431 USER'S MANUAL
PAGE  1 OF  1
===============================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /    HV  /    HF  /    HE  /      EG  /      V  /    FN  /    ACC   *ID*
===============================================================================
ONE   AT    1000 /      0 /   6600. /  1318. /    93386. / 1.83 /    15. /  285.
  213.54 /   0.71 /                        /  214.25 /    5.01 /   0.47/         *IS*
-------------------------------------------------------------------------------
TWO   AT    2000 /  1000 /   6600. /  1318. /    93386. / 1.83 /    15. /  285.
  218.54 /   0.71 /    4.99 /    0.0  /  219.25 /    5.01 /   0.47 /  0.005  *XS*
-------------------------------------------------------------------------------
THREE AT    3000 /  1000 /   6600. /  1318. /    93386. / 1.83 /    15. /  285.
  223.54 /   0.71 /    4.99 /    0.0  /  224.25 /    5.01 /   0.47 /  0.005  *XS*
-------------------------------------------------------------------------------
FOUR  AT    4000 /  1000 /   4950. /  1197. /    82859. / 1.80 /    19. /  281.
  228.08 /   0.48 /    4.31 /    0.0  /  228.56 /    4.14 /   0.40 /  0.002  *XS*
-------------------------------------------------------------------------------
FIVE  AT    5000 /  1000 /   4950. /  1015. /    67681. / 1.76 /    26. /  274.
  232.37 /   0.65 /    4.37 /    0.09 /  233.02 /    4.88 /   0.48 /  0.002  *XS*
-------------------------------------------------------------------------------
SIX   AT    6000 /  1000 /   4950. /  1054. /    70862. / 1.77 /    25. /  275.
  237.53 /   0.61 /    5.11 /    0.0  /  238.13 /    4.70 /   0.46 /  0.004  *XS*
-------------------------------------------------------------------------------

                               END OF THIS PROFILE
```

Figure 37.—Illustration of discharge reduction within a reach.

the examples are designed for illustration and not realism. In some of the examples presented below, a relatively high value was coded for Δh to minimize computer output.

The first of these examples is identical with the preceding example except that (1) all errors are corrected, and (2) only six cross sections (defining a 5,000-foot reach) are used. A portion of the input data printout is shown in figure 34. The input data summary is not shown. The first page of the cross-section properties output is shown in figure 35. All of the profile printouts are shown in figure 36. This analysis generates no messages during data editing and profile computations. This example illustrates the simplest application of E431 and provides a basis for illustrating subsequent variations of the data for additional applications.

The next example is based on the assumption that a tributary stream enters the midpoint of this reach. It is further assumed that this tributary accounts for twenty-five percent of the downstream discharges of 4,000 and 6,600 ft^3/s. Figure 37 shows the input data printout for this problem and the resultant profile for the highest discharge. Note that the only changes to the data of the previous example are: (1) TYPE = 1 on SEQUENCE 4003 (col. 15) and (2) an additional #4 CARD (SEQUENCE 4004) is required to introduce the reduced discharges at section FOUR.

Frequently the water-surface elevation for a given discharge has not been determined through data collection and cannot be accurately determined by direct computation. As discussed by Davidian (1976), backwater analysis can be applied for subcritical-flow conditions to indirectly determine the desired elevation, since a profile computed with an incorrect starting elevation at a downstream point will converge upon the actual profile as computations proceed upstream. Figure 38 illustrates input data for determining actual water-surface elevations at section SIX using estimated water-surface elevations at section ONE. Table 15 summarizes the water-surface elevation estimates for discharges of 4,000 and 6,600 ft^3/s. Altered data (relative to figure 34) are NPR on CARD #1 and the data coded on CARD #2 and CARD #4. The final water-surface elevation at section SIX for each starting elevation of the three starting elevations shown in table 15 are identical. The final result for each discharge is the same as that shown in figure 36.

```
                    USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=    1.0

                              *** INPUT CARD PRINTOUT ***

         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1  1001 DISCHARGE RATING EXAMPLE --- E431 USER'S MANUAL     6  6 01 05 12

2  1002  21130  21160  21200  21310  21333  21375
3  1003 ONE    1  10  3  207     1000 99 99
4  1004   4000   4000   4000   6600   6600   6600
5  1010         0  1  2150   50  1  2100  110  2  2080  115  2  2060  130  2  2050
5  1011      170  2  2050  185  2  2060  190  3  2080  250  3  2100  300  3  2150
6  1020  0  1 100 100  0  1 055 055  0  1 100 100
3  2003 TWO    0  10  3  212     2000 99 99
5  2010         0  1  2200   50  1  2150  110  2  2130  115  2  2110  130  2  2100
5  2011      170  2  2100  185  2  2110  190  3  2130  250  3  2150  300  3  2200
6  2020  0  1 100 100  0  1 055 055  0  1 100 100
3  3003 THREE 0  10  3  217     3000 99 99
5  3010         0  1  2250   50  1  2200  110  2  2180  115  2  2160  130  2  2150
5  3011      170  2  2150  185  2  2160  190  3  2180  250  3  2200  300  3  2250
6  3020  0  1 100 100  0  1 055 055  0  1 100 100
3  4003 FOUR  0  10  3  222     4000 99 99
5  4010         0  1  2300   50  1  2250  110  2  2230  115  2  2210  130  2  2200
5  4011      170  2  2200  185  2  2210  190  3  2230  250  3  2250  300  3  2300
6  4020  0  1 100 100  0  1 055 055  0  1 100 100
3  5003 FIVE  0  10  3  227     5000 99 99
5  5010         0  1  2350   50  1  2300  110  2  2280  115  2  2260  130  2  2250
5  5011      170  2  2250  185  2  2260  190  3  2280  250  3  2300  300  3  2350
6  5020  0  1 100 100  0  1 055 055  0  1 100 100
3  6003 SIX   0  10  3  232     6000 99 99
5  6010         0  1  2400   50  1  2350  110  2  2330  115  2  2310  130  2  2300
5  6011      170  2  2300  185  2  2310  190  3  2330  250  3  2350  300  3  2400
6  6020  0  1 100 100  0  1 055 055  0  1 100 100
```

Figure 38.—Input data for indirectly determining water surface elevations.

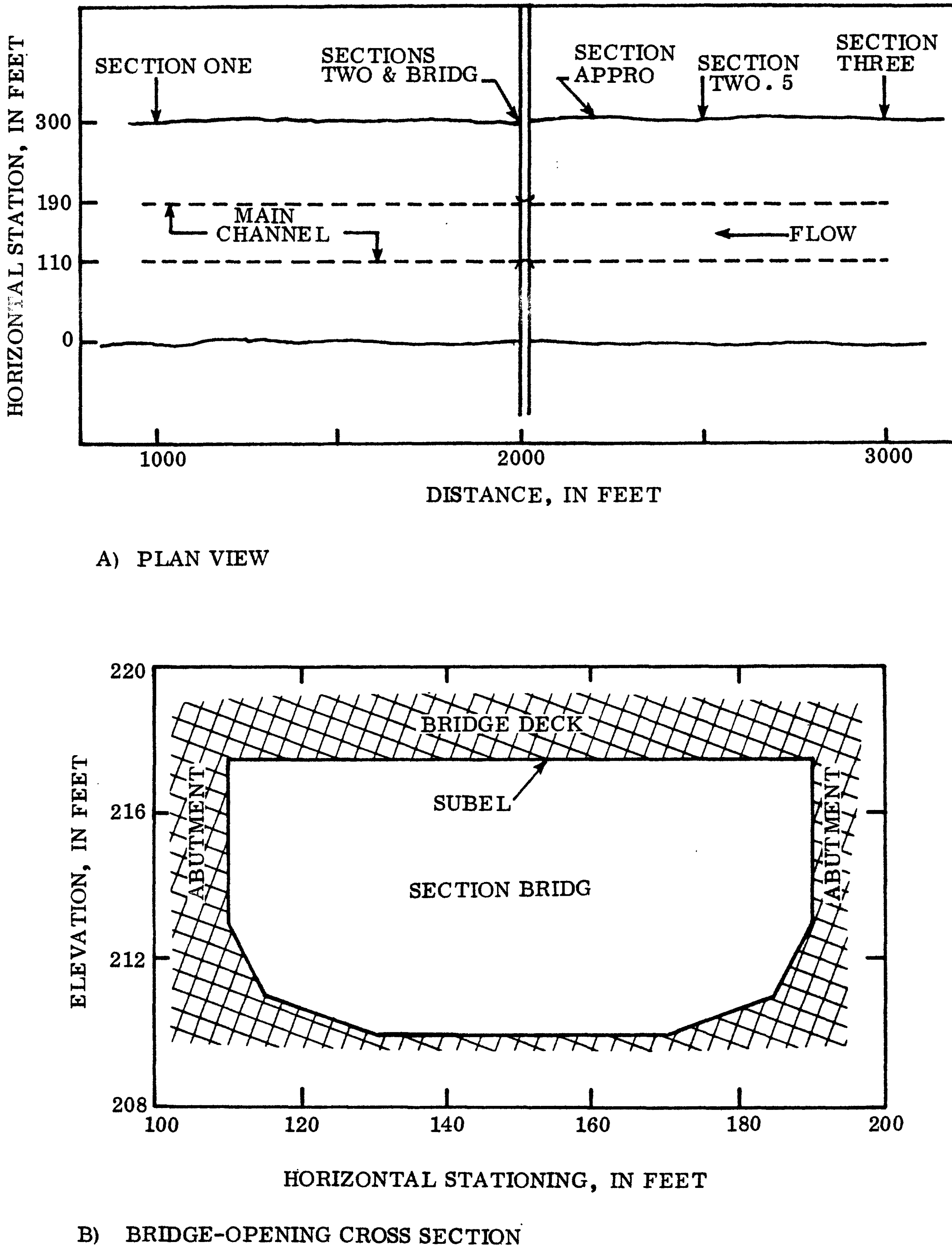


Figure 39.—Plan view and bridge-opening cross section for bridge situation example.

Table 15.—*Estimated water-surface elevations at section ONE for 4,000 and 6,600 ft^3/s*

Discharge ft^3/s	Water-surface elevations at section ONE, feet	
	Best possible estimate	Bracketing estimates
4,000	211.60	211.30 212.00
6,600	213.33	213.10 213.75

Additional data requirements and special output features for a bridge situation are illustrated in the following example. Only the first three cross sections of the previous reach are used, and a 20-foot wide embankment crosses the reach immediately upstream from section TWO. Both the plan view of the reach and the bridge-opening cross section are shown in figure 39. Figure 40 shows the input data and figures 41 and 42 show the resultant profile computation messages and profile printouts. Not shown are the input data summary, editing notes (EN-42 for section BRIDG, because of the decreasing Station when the first coordinate is repeated), and cross-section properties output.

The profile output for a bridge analysis always consists of: (1) two lines for the bridge-opening cross section; (2) one line for the embankment cross section; and (3) four lines for the approach cross section. Two of the output items (encircled a and b in figure 41) are unique to the bridge-opening cross section. Item a indicates the Type of flow through the bridge opening. Item b is the ratio of pier area to gross area. When negative, as in this example, it indicates that no pier data were coded. The embankment output indicates either: (1) no embankment data coded (as in this example); (2) no road overflow; or (3) the amount(s) of road overflow (see fig. 46). The first two lines of output for the approach cross section present the results for H1N. The second two lines present results for the final WSU and include the values for M, E, and K* for Type 1 flow. M, E, and K* are not computed for Type 2 or for Type 3 flow; thus asterisks are printed (see fig. 42).

The 4,000 ft^3/s discharge resulted in a WSU for Type 1 flow that was greater than BELMX. However, since $YU/Z < 1.1$, Type 1 flow was assumed to be valid.

The 6,600 ft^3/s discharge resulted in a WSD greater than BELMX thereby forcing a Type 3 flow analysis. The profile computation messages (see PAGE COUNT 8, top of fig. 42) indicate that a smaller DEL was required in the energy balance (see PN-3, table 12) for the last two cross sections.

If the bridge-situation example above is analyzed without section TWO.5, a conveyance-ratio problem occurs.

```
                    USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    1.0

                              *** INPUT CARD PRINTOUT ***

            1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1  1001 BRIDGE SITUATION EXAMPLE --- E431 USER'S MANUAL    6  2 01 20 12
2  1002  21179  21354
3  1003 ONE   1  10  3  208     1000 99 99
4  1004   4000    6600
5  1010      10  1  2140   50  1  2100  110  2  2080  115  2  2060  130  2  2050
5  1011     170  2  2050  185  2  2060  190  3  2080  250  3  2100  290  3  2140
6  1020  0   1 100 100  0   1 055 055  0   1 100 100
3  2003 TWO    0  10  3  213     2000 99 99
5  2010      10  1  2190   50  1  2150  110  2  2130  115  2  2110  130  2  2100
5  2011     170  2  2100  185  2  2110  190  3  2130  250  3  2150  290  3  2190
6  2020  0   1 100 100  0   1 055 055  0   1 100 100
3  2043 BRIDG 2   9  1  213     2000         0  2175 1  0
5  2050     110  1  2175  110  1  2130  115  1  2110  130  1  2100  170  1  2100
5  2051     185  1  2110  190  1  2130  190  1  2175  110 -9  2175
6  2060  0   1 055 055
3  2103 APPRO 5  10  3  214     2100  1  3
5  2110     -15  1  2220   50  1  2155  110  2  2135  115  2  2115  130  2  2105
5  2111     170  2  2105  185  2  2115  190  3  2135  250  3  2155  315  3  2220
6  2120  0   1 100 100  0   1 055 055  0   1 100 100
3  2503 TWO.5 0  10  3  217     2500 99 99
5  2510       0  1  2225   50  1  2175  110  2  2155  115  2  2135  130  2  2125
5  2511     170  2  2125  185  2  2135  190  3  2155  250  3  2175  300  3  2225
6  2520  0   1 100 100  0   1 055 055  0   1 100 100
3  3003 THREE 0  10  3  218     3000 99 99
5  3010      10  1  2240   50  1  2200  110  2  2180  115  2  2160  130  2  2150
5  3011     170  2  2150  185  2  2160  190  3  2180  250  3  2200  290  3  2240
6  3020  0   1 100 100  0   1 055 055  0   1 100 100
```

Figure 40.—Input data for bridge situation example.

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=     6,DATE= 3/22/76

PAGE  1 OF PROFILE NOTES FOR: BRIDGE SITUATION EXAMPLE --- E431 USER'S MANUAL
     INITIAL VALUES ARE:  Q =    4000.  H =  211.79

SECID,ERROR OR WARNING MESSAGE,INTERMEDIATE RESULTS(IF ANY),ACTION TAKEN

APPRO,WSU > BELMX (1)                                       ,CHECKED QBO (2)
APPRO,YU/Z < 1.1 (1)                                        ,ASSUMED QBO (1)

__________  __________  __________  __________  __________  __________


USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=     7,DATE= 3/22/76

==================================================================================
WATER-SURFACE PROFILE FOR: BRIDGE SITUATION EXAMPLE --- E431 USER'S MANUAL
PAGE  1 OF  1
==================================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /    HV  /    HF  /    HE  /     EG  /     V  /    FN  /   ACC   *ID*
==================================================================================
ONE    AT     1000 /      0 /  4000. /    875. /   56560. / 1.72 /   32. /  268.
   211.79 /   0.56 /                   / 212.35 /   4.57 /   0.46/          *IS*
----------------------------------------------------------------------------------
TWO    AT     2000 /  1000 /  4000. /    876. /   56628. / 1.72 /   32. /  268.
   216.79 /   0.56 /   5.00 /    0.0  /  217.35 /   4.57 /   0.46 /  0.007  *XS*
=========================== BEGIN BRIDGE ANALYSIS ===========================
BRIDG AT     2000 /        /  4000. /    508. /   44217. / 1.00 /  110. /  190.
   216.79 /   0.96 /       ....1...  (-.001)    /   7.87 /   0.55 /          *BO*
----------------------------------------------------------------------------------
 NO ROAD-GRADE DATA          (a)          (b)                                *RG*
----------------------------------------------------------------------------------
APPRO AT     2100 /    100 /  4000. /    876. /   56628. / 1.72 /   32. /  268.
   217.29 /   0.56 /   0.50 /    0.0  /  217.85 /   4.57 /   0.46 /  0.001  *AS*
----------------------------------------------------------------------------------
   M = 0.19 / E = 1.00 / K* = 0.23 /    945. /   62078. / 1.74 /   29. /  271.
   217.58 /   0.49 /                   / 218.07 /   4.23 /   0.42 /          *AS*
============================ END BRIDGE ANALYSIS ============================
TWO.5 AT     2500 /    400 /  4000. /    888. /   57580. / 1.72 /   32. /  268.
   219.35 /   0.54 /   1.79 /   0.03 /  219.89 /   4.50 /   0.45 /  0.000  *XS*
----------------------------------------------------------------------------------
THREE AT     3000 /    500 /  4000. /    876. /   56626. / 1.72 /   32. /  268.
   221.79 /   0.56 /   2.45 /   0.01 /  222.35 /   4.57 /   0.46 /  0.002  *XS*
----------------------------------------------------------------------------------

                              END OF THIS PROFILE
```

Figure 41.—Profile computation results for bridge situation example (4,000 ft^3/s).

Figure 43 presents the profile computation message and profile printout that result when the preceding example is analyzed with section TWO.5 omitted. The conveyance-ratio problem is indicated by message PN-10 as shown on top of fig. 43. Although the difference in water-surface elevation at section THREE (223.92 ft in fig. 42 compared with 223.80 ft in fig. 43) may not be terribly significant and the problem is not totally realistic, the potential problem of too few cross sections is illustrated.

A road overflow situation is illustrated in the next example. Figure 44 shows the most downstream cross section of a reach which has a slope of 1 foot per 100 feet. All subsequent upstream cross sections are identical except, of course, the bridge-opening and embankment cross sections which are also shown in figure 44. Figure 45 is the input data for the problem and figure 46 is the resultant profile computation message and profile printout. Since the total road overflow is greater than QT (PN-13), H1N is assumed applicable at section APPRO in

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=     8,DATE= 4/  /76

PAGE  1 OF PROFILE NOTES FOR: BRIDGE SITUATION EXAMPLE --- E431 USER'S MANUAL
     INITIAL VALUES ARE:  Q =    6600.  H =  213.54

SECID,ERROR OR WARNING MESSAGE,INTERMEDIATE RESULTS(IF ANY),ACTION TAKEN

TWO.5,WS NOT FOUND BETWEEN     ,LO =  221.30     HI =  222.50,USED DEL = 0.25
THREE,WS NOT FOUND BETWEEN     ,LO =  222.07     HI =  224.00,USED DEL = 0.25
```

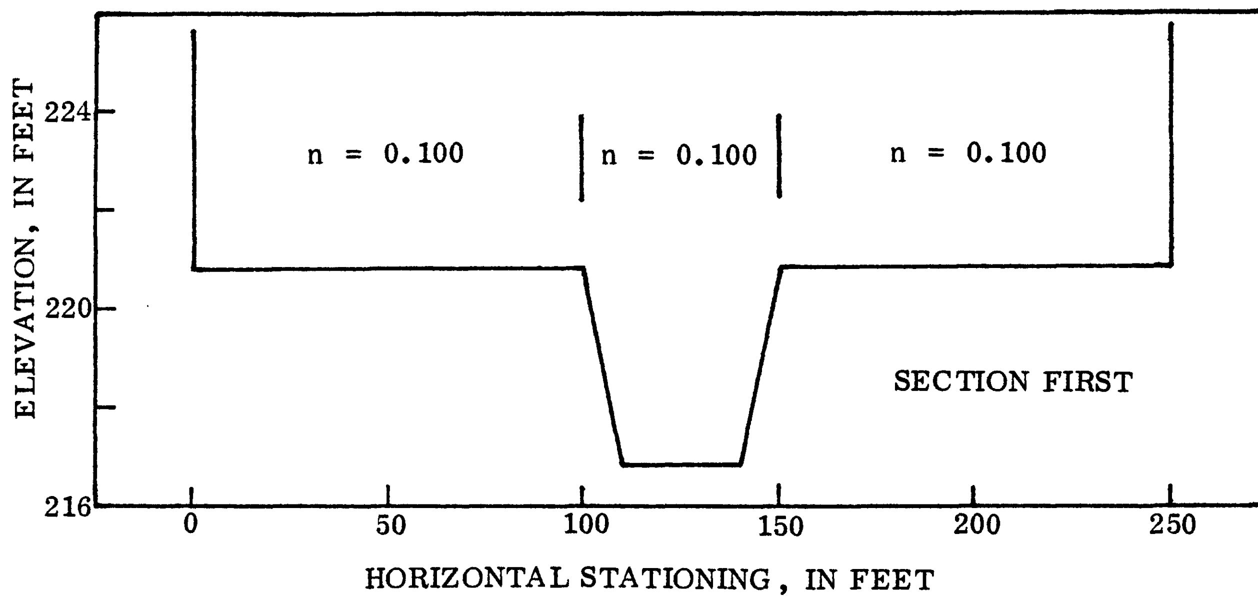
```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=     9,DATE= 4/  /76

==============================================================================
WATER-SURFACE PROFILE FOR: BRIDGE SITUATION EXAMPLE --- E431 USER'S MANUAL
PAGE  1 OF  1
==============================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /    HV  /    HF  /    HE  /      EG  /      V  /     FN  /   ACC   *ID*
==============================================================================
ONE   AT    1000 /      0 /   6600. /  1318. /   93386. / 1.83 /    15. /  285.
   213.54 /   0.71 /                         /  214.25 /   5.01 /   0.47/         *IS*
------------------------------------------------------------------------------
TWO   AT    2000 /   1000 /   6600. /  1318. /   93386. / 1.83 /    15. /  285.
   218.54 /   0.71 /   4.99 /    0.0  /  219.25 /   5.01 /   0.47 /  0.005   *XS*
========================== BEGIN BRIDGE ANALYSIS ===========================
BRIDG AT    2000 /        /   6600. /   565. /   34110. / 1.00 /   110. /  190.
   217.50 /   2.12 /        ...3...  (-.001)     /  11.68 /   0.77 /           *BO*
------------------------------------------------------------------------------
 NO ROAD-GRADE DATA                                                         *RG*
------------------------------------------------------------------------------
APPRO AT    2100 /    100 /   6600. /  1318. /   93386. / 1.83 /    15. /  285.
   219.04 /   0.71 /   0.50 /    0.0  /  219.75 /   5.01 /   0.47 /  0.000   *AS*
------------------------------------------------------------------------------
   M = **** / E = **** / K* = **** /  2060. /  163083. / 1.92 /   -10. /  310.
   221.55 /   0.31 /                         /  221.85 /   3.20 /   0.28 /           *AS*
=========================== END BRIDGE ANALYSIS ============================
TWO.5 AT    2500 /    400 /   6600. /  1681. /  126416. / 1.88 /     2. /  298.
   222.32 /   0.45 /   0.85 /   0.07 /  222.77 /   3.93 /   0.36 /  0.000   *XS*
------------------------------------------------------------------------------
THREE AT    3000 /    500 /   6600. /  1421. /  102540. / 1.84 /    11. /  289.
   223.92 /   0.62 /   1.68 /   0.08 /  224.53 /   4.64 /   0.44 /  0.000   *XS*
------------------------------------------------------------------------------

                              END OF THIS PROFILE
```

Figure 42.—Profile computation results for bridge situation example (6,600 ft^3/s).

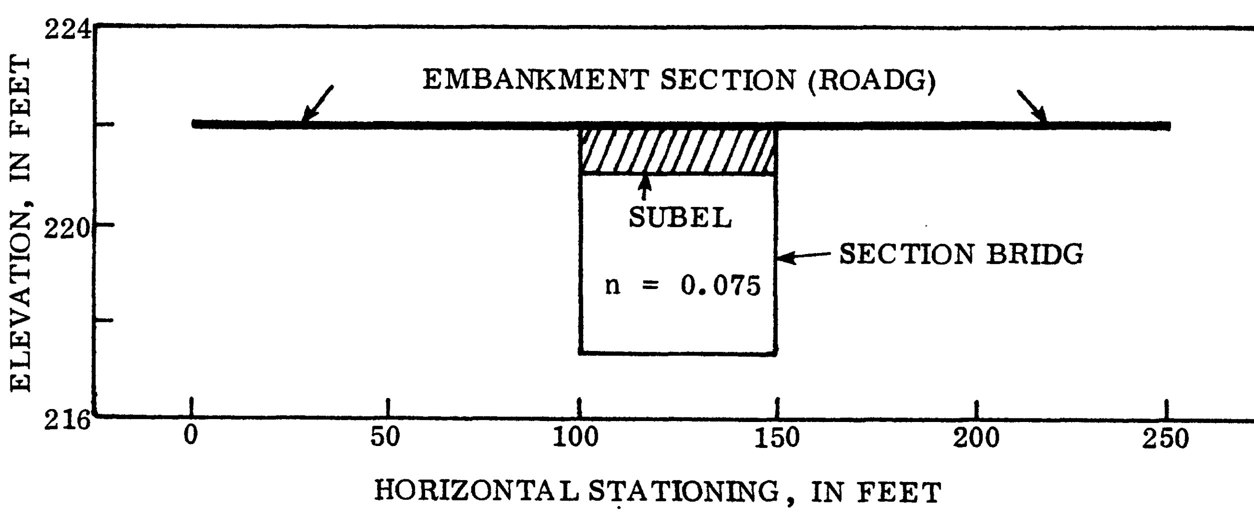
```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    8,DATE= 4/  /76

PAGE  1 OF PROFILE NOTES FOR: TOO FEW CROSS SECTIONS ----- E431 USER'S MANUAL
     INITIAL VALUES ARE:  Q =    6600.  H =  213.54

SECID,ERROR OR WARNING MESSAGE,INTERMEDIATE RESULTS(IF ANY),ACTION TAKEN

THREE,KU/KD < 0.7 OR > 1.4                                     ,USED COMPUTED WSU
```

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    9,DATE= 4/  /76

==================================================================================
WATER-SURFACE PROFILE FOR: TOO FEW CROSS SECTIONS ----- E431 USER'S MANUAL
PAGE  1 OF  1
==================================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /    HV   /    HF  /    HE  /      EG  /      V  /     FN  /   ACC   *ID*
==================================================================================
ONE   AT    1000 /      0 /   6600. / 1318. /    93386. / 1.83 /    15. /  285.
  213.54 /   0.71 /                      / 214.25 /    5.01 /   0.47/          *IS*
----------------------------------------------------------------------------------
TWO   AT    2000 /  1000 /   6600. / 1318. /    93386. / 1.83 /    15. /  285.
  218.54 /   0.71 /   4.99 /    0.0  /  219.25 /    5.01 /   0.47 /  0.005   *XS*
============================ BEGIN BRIDGE ANALYSIS ===============================
BRIDG AT    2000 /         /   6600. /  565. /    34110. / 1.00 /  110. /  190.
  217.50 /   2.12 /        ...3...   (-.001)    /  11.68 /    0.77 /           *BO*
----------------------------------------------------------------------------------
 NO ROAD-GRADE DATA                                                          *RG*
----------------------------------------------------------------------------------
APPRO AT    2100 /    100 /   6600. / 1318. /    93386. / 1.83 /    15. /  285.
  219.04 /   0.71 /   0.50 /    0.0  /  219.75 /    5.01 /   0.47 /  0.000   *AS*
----------------------------------------------------------------------------------
   M = **** / E = **** / K* = **** /  2060. /  163083. / 1.92 /  -10. /  318.
  221.55 /   0.31 /                      / 221.85 /    3.20 /   0.28 /           *AS*
============================= END BRIDGE ANALYSIS ================================
THREE AT    3000 /    900 /   6600. / 1388. /    99575. / 1.84 /    12. /  288.
  223.80 /   0.65 /   2.41 /    0.17 / 224.44 /    4.75 /   0.45 /  0.006   *XS*
----------------------------------------------------------------------------------

                            END OF THIS PROFILE
```

Figure 43.—Profile results with too few cross sections (6,600 ft^3/s).



A) REGULAR CROSS SECTION



B) EMBANKMENT AND BRIDGE-OPENING CROSS SECTIONS

Figure 44.—Cross sections used to illustrate road overflow.

```
                    USGS STEP-BACKWATER PROGRAM - VEHSION 76.0/6 *** PAGE COUNT=     1.0

                                 *** INPUT CAHD PRINTOUT ***

            1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1    101 HOAD OVERFLOW PROBLEM ------ E431 USER'S MANUAL    6  3 01 20 12
2    102  22390
3    103 FIRST 1   8  3  220        0 99 99
4    104   3500
5    110        0  1  2258    0  1  2208  100  2  2208  110  2  2168  140  2  2168
5    111      150  3  2208  250  3  2208  250  3  2258
6    120  0  1 100 100  0  1 100 100  0  1 100 100
3    203 EXIT  0   8  3  221        50 99 99
5    210        0  1  2263    0  1  2213  100  2  2213  110  2  2173  140  2  2173
5    211      150  3  2213  250  3  2213  250  3  2263
6    220  0  1 100 100  0  1 100 100  0  1 100 100
3    303 BRIDG 2   5  1  218        50         0  2210 1 0
5    310      100  1  2210  100  1  2173  150  1  2173  150  1  2210  100 -9  2210
6    320  0  1 075 075
3    403 ROADG 4   3  2   20         1  2         1 1            1
5    410        0  1  2220  125  2  2220  250  2  2220
3    503 APPRO 5   8  3  221       120  1  3
5    510        0  1  2270    0  1  2220  100  2  2220  110  2  2180  140  2  2180
5    511      150  3  2220  250  3  2220  250  3  2270
6    520  0  1 100 100  0  1 100 100  0  1 100 100
3    603 LAST  0   8  3  222       170 99 99
5    610        0  1  2275    0  1  2225  100  2  2225  110  2  2185  140  2  2185
5    611      150  3  2225  250  3  2225  250  3  2275
6    620  0  1 100 100  0  1 100 100  0  1 100 100
```

Figure 45.—Input data for road overflow problem.

order that profile computations can proceed upstream. Since QT minus road overflow results in a negative discharge, flow through the bridge is simply assumed to be zero.

The error in computed versus specified discharge for the preceding problem is only about 4 percent. However, the total head is quite high and flow submergence is fairly significant. FH (eq. 7-1, with DIST = 50 feet) is 0.50 feet. EGR (eq. 7-2) is 224.86 feet (225.11 + 0.26 - 0.50) and H (eq. 7-3) is 2.86 feet (224.86 - 222.00). HT, the difference between WSD and RDEL is 2.4 feet (224.40 - 222.00). The degree of submergence, HT/H is 0.84. Therefore, it may be desirable to analyze this problem as a non-weir flow situation (see PN-13, table 12).

Figure 47 shows the input data and profile printout for such an analysis. The composite section (section RG-BO) consists of the embankment cross section connected to the bridge-opening cross section. In this example, it was assumed that the bridge deck would stay in place. Therefore, the bottom of the bridge-opening cross section was raised 1 foot to provide an equivalent area. This composite section is placed at the centerline of the embankment. An additional regular cross section (section EXTRA) is placed at the upstream face of the bridge (elevations should be adjusted for channel slope when required). All sections are coded with TYPE = 0.

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    6,DATE= 4/  /76

PAGE  1 OF PROFILE NOTES FOR: ROAD OVERFLOW PROBLEM ------ E431 USER'S MANUAL
     INITIAL VALUES ARE:  Q =    3500.  H =  223.90

SECID,ERROR OR WARNING MESSAGE,INTERMEDIATE RESULTS(IF ANY),ACTION TAKEN

APPRO,QRD > QT                                               ,ASSUMED WSU = HIN
```

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    7,DATE= 4/  /76

================================================================================
WATER-SURFACE PROFILE FOR: ROAD OVERFLOW PROBLEM ------ E431 USER'S MANUAL
PAGE  1 OF  1
================================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /    HV  /    HF  /    HE  /     EG  /     V  /    FN  /   ACC   *ID*
================================================================================
FIRST AT       0 /     0 /  3500. /    935. /   34935. / 1.18 /     0. /  250.
  223.90 /   0.26 /                     / 224.16 /   3.74 /   0.35/        *IS*
--------------------------------------------------------------------------------
EXIT  AT      50 /    50 /  3500. /    935. /   34935. / 1.18 /     0. /  250.
  224.40 /   0.26 /   0.50 /   0.0  / 224.66 /   3.74 /   0.35 / -0.002  *XS*
========================== BEGIN BRIDGE ANALYSIS ===============================
BRIDG AT      50 /       /     0. /    185. /    5281. / 1.00 /   100. /  150.
  221.00 /   0.0  /          ...3...  (-.001)    /   0.0  /   0.0  /       *BO*
--------------------------------------------------------------------------------
 ROAD OVERFLOW (CFS) / LEFT    1821. / RIGHT    1821. /                    *RG*
--------------------------------------------------------------------------------
APPRO AT     120 /    70 /  3500. /    936. /   35009. / 1.18 /     0. /  250.
  225.11 /   0.26 /   0.70 /   0.0  / 225.36 /   3.74 /   0.35 /  0.003  *AS*
--------------------------------------------------------------------------------
   M = **** / E = **** / K* = **** /    936. /   35009. / 1.18 /     0. /  250.
  225.11 /   0.26 /                     / 225.36 /   3.74 /   0.35 /       *AS*
=========================== END BRIDGE ANALYSIS ================================
LAST  AT     170 /    50 /  3500. /    936. /   35009. / 1.18 /     0. /  250.
  225.61 /   0.26 /   0.50 /   0.0  / 225.86 /   3.74 /   0.35 /  0.000  *XS*
--------------------------------------------------------------------------------

                          END OF THIS PROFILE
```

Figure 46.—Profile computation results for road overflow problem.

```
                    USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=    1.

                              *** INPUT CARD PRINTOUT ***

          1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1   101 ROAD-BRIDGE COMPOSITE ------ E431 USER'S MANUAL    6  1 01 20 12
2   102  22390
3   103 FIRST 1   8  3  220        0 99 99
4   104   3500
5   110        0  1  2258    0  1  2208  100  2  2208  110  2  2168  140  2  2168
5   111      150  3  2208  250  3  2208  250  3  2258
6   120  0  1 100 100  0  1 100 100  0  1 100 100
3   203 EXIT  0   8  3  221       50 99 99
5   210        0  1  2263    0  1  2213  100  2  2213  110  2  2173  140  2  2173
5   211      150  3  2213  250  3  2213  250  3  2263
6   220  0  1 100 100  0  1 100 100  0  1 100 100
3   303 RG-BO 0   8  3  222       60 99 99
5   310        0  1  2264    0  1  2220  100  2  2220  100  2  2183  150  2  2183
5   311      150  3  2220  250  3  2220  250  3  2264
6   320  0  1 100 100  0  1 075 075  0  1 100 100
3   403 EXTRA 0   8  3  221       70 99 99
5   410        0  1  2265    0  1  2215  100  2  2215  110  2  2175  140  2  2175
5   411      150  3  2215  250  3  2215  250  3  2265
6   420  0  1 100 100  0  1 100 100  0  1 100 100
3   503 APPRO 0   8  3  221      120 99 99
5   510        0  1  2270    0  1  2220  100  2  2220  110  2  2180  140  2  2180
5   511      150  3  2220  250  3  2220  250  3  2270
6   520  0  1 100 100  0  1 100 100  0  1 100 100
3   603 LAST  0   8  3  222      170 99 99
5   610        0  1  2275    0  1  2225  100  2  2225  110  2  2185  140  2  2185
5   611      150  3  2225  250  3  2225  250  3  2275
6   620  0  1 100 100  0  1 100 100  0  1 100 100
```

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.0/6 *** PAGE COUNT=    5.DATE= 4/  /76

===========================================================================
WATER-SURFACE PROFILE FOR: ROAD-BRIDGE COMPOSITE ------ E431 USER'S MANUAL
PAGE  1 OF  1
===========================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/  AREA  /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /    HV  /    HF  /    HE  /     EG  /      V  /     FN  /   ACC   *ID*
===========================================================================
FIRST AT       0 /      0 /   3500. /   935. /   34935. / 1.18 /     0. /  250.
  223.90 /   0.26 /                     /  224.16 /    3.74 /   0.35/          *IS*
---------------------------------------------------------------------------
EXIT  AT      50 /     50 /   3500. /   935. /   34935. / 1.18 /     0. /  250.
  224.40 /   0.26 /   0.50 /   0.0   /  224.66 /    3.74 /   0.35 / -0.002  *XS*
---------------------------------------------------------------------------
RG-BO AT      60 /     10 /   3500. /   785. /   31070. / 1.57 /     0. /  250.
  224.40 /   0.48 /   0.11 /   0.11 /  224.88 /    4.46 /   0.49 /  0.001  *XS*
---------------------------------------------------------------------------
EXTRA AT      70 /     10 /   3500. /   974. /   37197. / 1.17 /     0. /  250.
  224.76 /   0.23 /   0.11 /   0.0   /  224.99 /    3.59 /   0.33 / -0.001  *XS*
---------------------------------------------------------------------------
APPRO AT     120 /     50 /   3500. /   961. /   36441. / 1.17 /     0. /  250.
  225.20 /   0.24 /   0.45 /   0.00 /  225.45 /    3.64 /   0.34 /  0.000  *XS*
---------------------------------------------------------------------------
LAST  AT     170 /     50 /   3500. /   952. /   35937. / 1.17 /     0. /  250.
  225.67 /   0.25 /   0.47 /   0.00 /  225.92 /    3.68 /   0.34 /  0.000  *XS*
---------------------------------------------------------------------------

                           END OF THIS PROFILE
```

Figure 47.—Input data and profile printout using composite road and bridge section.

FLOODWAY ANALYSIS

THEORY

This section briefly describes the theory of floodway analyses as applied in E431. Floodway, as used in this manual, refers to a land-use control measure widely used in the field of flood-plain management. In this context, a floodway may be defined as that portion of a watercourse required to convey a discharge of specified magnitude without exceeding a specified surcharge (see fig. 48). The discharge magnitude and surcharge limit depend upon criteria established by the appropriate regulatory agency (which may be federal, state, regional, or local).

Ideally, floodway limits should be located such that the encroachments on both sides of the watercourse contribute equally to the surcharge. Encroachments could be based on equal area or equal horizontal distance. However, elimination of an area of open pasture on one overbank would contribute far more to the surcharge than would elimination of an equal area of dense forest on the other overbank. Likewise, encroachments of equal length on overbanks with unequal flow depths and (or) unequal roughness would also contribute unequally to the surcharge. Encroachments having equal conveyance (eqs. 1-3 and 1-5), which includes area (thereby length and depth) and roughness, would be more likely to contribute equally to surcharge. Therefore, conveyance is used in E431 as the basis for establishing floodway limits.

Figure 48 illustrates the simplest case of establishing floodway limits at a cross section. The encroached cross section, with its increased water-surface elevation, will have the same total conveyance that existed for the original cross section with the normal water-surface elevation. Furthermore, equal conveyances are removed from each overbank to provide the desired surcharge. When floodway limits are established at a cross section such that equations 48-1, 48-2, and 48-3 are satisfied, it will be categorized as a Case I analysis.

When a cross section is subjected to a Case I analysis, either the left or right floodway limit would be established within the main channel if conveyance is severely limited on one overbank. This may not be a satisfactory solution. Therefore, options are available whereby the user can prohibit encroachment upon any given area within a cross section by specifying horizontal constraints. Figure 49 illustrates this situation. When horizontal constraints are specified, and floodway limits are established to satisfy equations 48-1 and 48-2 but not equation 48-3, it will be referred to as a Case II analysis.

A third possibility is shown in figure 50. If analyzed as a CASE I cross section, both floodway limits are established within the main channel. If horizontal constraints are specified the floodway limits will be established at the specified constraining points. When horizontal constraints are specified, and both floodway limits are established at the constraining points without satisfying any of the conveyance criteria, it will be referred to as a Case III analysis.

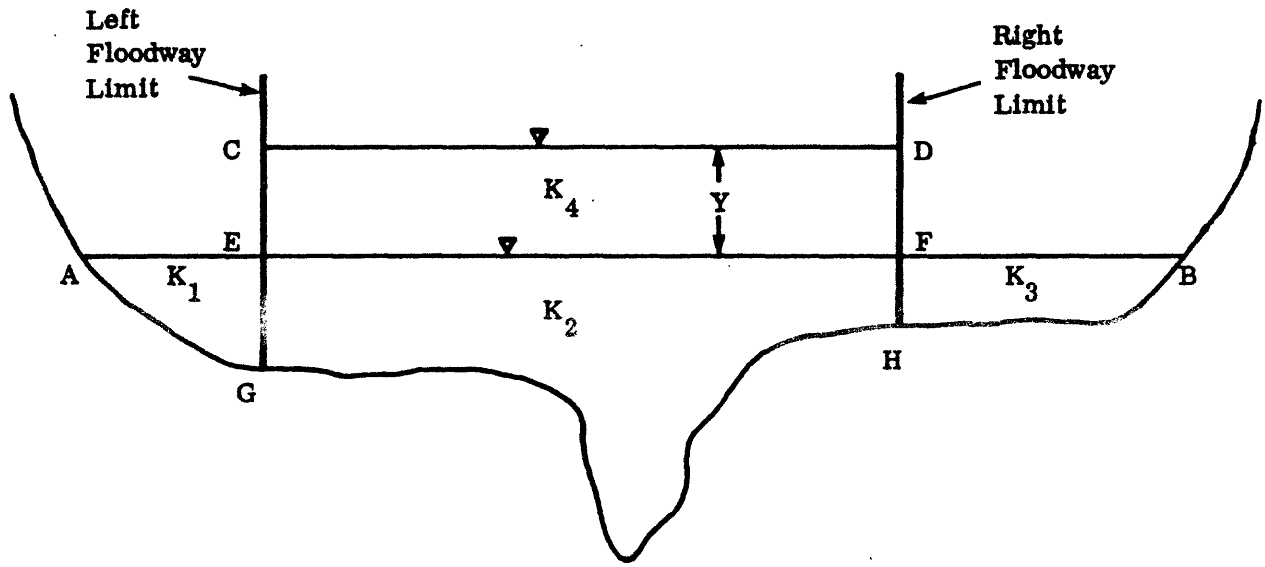
The desired water-surface elevation at an encroached cross section is equal to the normal water-surface elevation at that cross section plus the specified surcharge. This may not be the water-surface elevation that would actually exist at that cross section for the encroached conditions. Obviously, for a Case III analysis the actual encroached water-surface elevation must be computed by equation 2-4. Even for Case I and Case II analyses the actual water-surface elevation may differ from that desired. This is due to the fact that equal conveyance for natural and encroached conditions does not necessarily assure equal areas or kinetic energy correction factors for those conditions. Therefore, the velocity head (eq. 1-8) may vary for the two conditions. Furthermore, the difference in velocity heads for two successive cross sections may be different for the two conditions, thereby affecting the eddy loss (eq. 2-3). Therefore, the actual floodway profile must be computed for the encroached reach using backwater analysis. The actual surcharge attributable to the floodway can then be determined by computing the difference between the floodway profile and the normal profile.

E431 can also be used to readily determine the effects of a specific encroachment pattern on the water-surface profile. This may be accomplished by specifying the points at which the encroachments (or floodway limits) are desired and not specifying a surcharge. Vertical walls are established at the specified points. This method of analysis will be referred to as a Case IV analysis. A floodway profile is then computed for the encroached conditions. The difference between this floodway profile and the normal profile shows the effects of that specific encroachment pattern on the water-surface profile.

DATA REQUIREMENTS

The major data requirement for a floodway analysis is a valid deck of input data for the backwater analysis segment of E431. Slight modifications to this deck are usually required. Possible modifications are: (1) NPR on CARD #1, (2) initial water-surface elevation(s) and discharge(s) on #2 and #4 CARD(S), and (3) SAL and SAR on #3 CARD(S).

Additional data requirements are quite minimal. As few as four additional data cards are required to compute a single floodway profile. However, certain options require a data card for each cross section to be encroached. Also, several floodway profiles may be computed consecutively during a single computer run. The total number of additional cards required depends upon the number and complexity of the floodway analyses. Regardless of the requirements, the additional



AB - Water-surface elevation for natural or existing conditions (normal water-surface elevation).

CD - Water-surface elevation desired for encroached condition.

Y - Specified surcharge (in feet).

Partial conveyances are:

K_1 - segment AEGA K_3 - segment FBHF

K_2 - segment EFHGE K_4 - segment CDFEC

Total conveyances are:

Original conveyance, KØRIG - section AEFBHGA

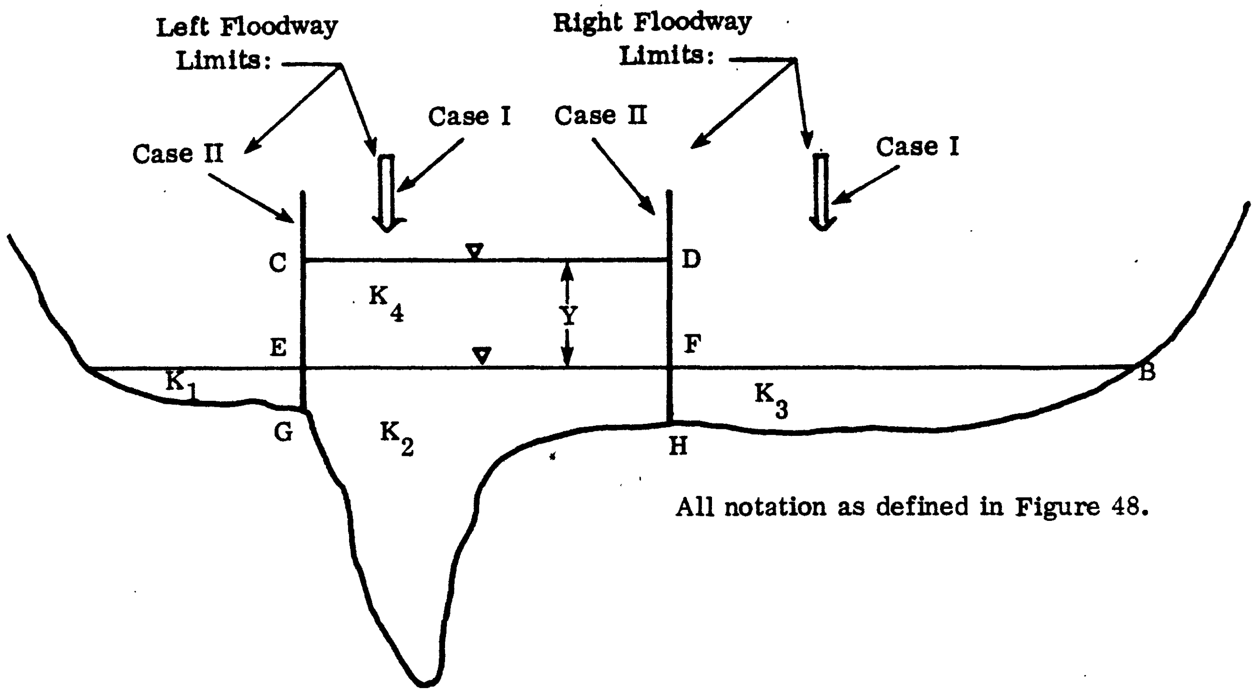
Encroached conveyance, KENC - section CDFHGEC

$$KENC = KØRIG = K_1 + K_2 + K_3 = K_2 + K_4 \quad 48\text{-}1$$

$$K_4 = K_1 + K_3 \quad 48\text{-}2$$

$$K_1 = K_3 \quad 48\text{-}3$$

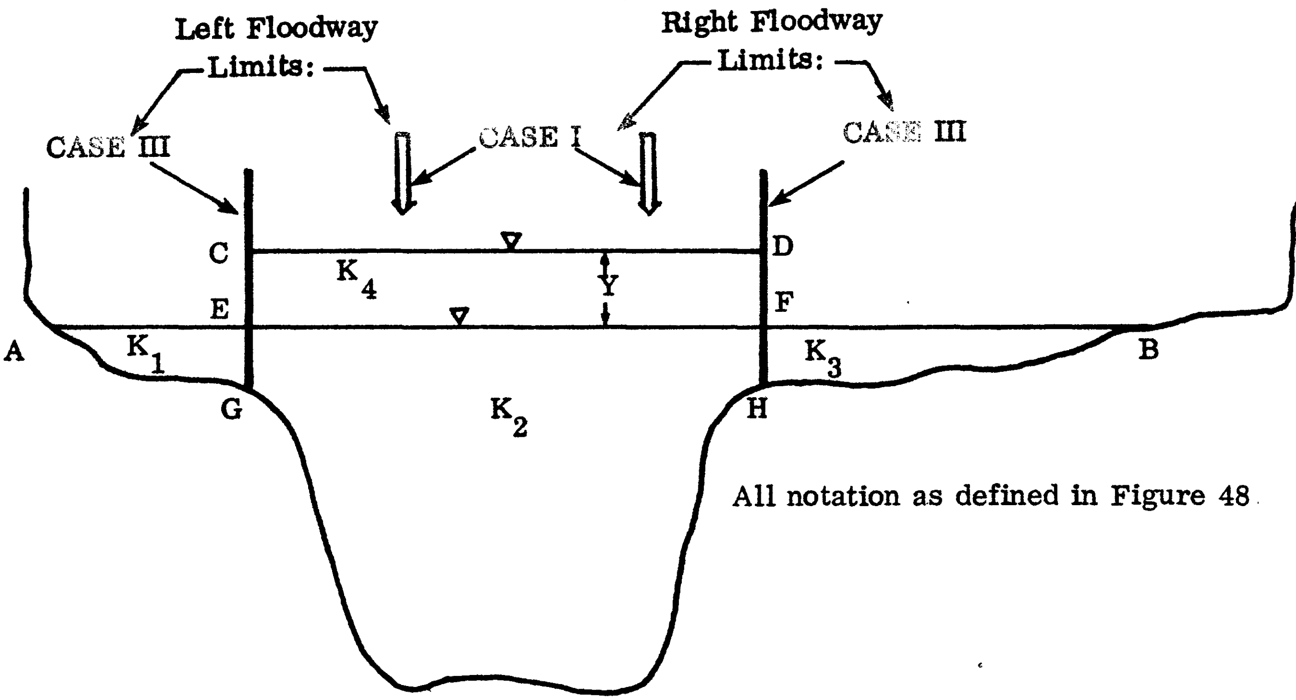
Figure 48.—Floodway analysis, Case I.



Case I analysis would satisfy equations 48-1, 48-2, and 48-3, but encroach upon the main channel.

Specification of horizontal constraints permits establishing encroachment limits as shown to satisfy equations 48-1 and 48-2, but $K_3 > K_1$ (or $K_1 > K_3$ for the mirror image of the situation shown).

Figure 49.—Floodway analysis, Case II.



To satisfy equations 48-1, 48-2 and 48-3, the main channel would be encroached upon from the left and right.

Encroachment limits are placed at the constraining points specified. None of the conveyance criteria equations are satisfied (except by pure chance K_1 and K_3 could be equal).

Figure 50.—Floodway analysis, Case III.

data cards are simply added to the backwater analysis deck immediately following the last #6 CARD. The following paragraphs provide a general description of the data required on the additional data cards.

E431 may be used to compute almost any combination of normal profiles and floodway profiles in a single computer run. Therefore the user must specify, for each profile to be computed, whether it is a normal profile computation or a floodway profile computation. This is accomplished by coding a #7 CARD.

Establishment of floodway limits based on a specific surcharge requires knowledge of the normal water-surface elevation at each cross section that is to be encroached. There are two methods of acquiring the normal water-surface elevations. If the normal profile is computed immediately prior to computation of the floodway profile(s) during a single computer run the normal water-surface elevations may be acquired directly from storage (memory). When the normal profile and floodway profile(s) are computed in separate computer runs the normal water-surface elevations must be input on data cards. For each floodway profile to be computed the user must specify the source of the normal water-surface elevations. A #8 CARD is required to provide this information.

Only regular, exit, and approach cross sections (TYPE equal to 0, 1, or 5) may be modified in a floodway analysis. Certain data are required for each cross section for which encroachment is desired. They are: (1) a cross-section number, (2) an option code to specify the encroachment method, (3) the desired surcharge (if any), and (4) horizontal constraints (if any). These data are coded on the #9 CARD(S). For certain situations it is possible to specify these data for an entire reach or for a series of regular, exit, and approach cross sections within the reach on a single #9 CARD. These cross-section data are discussed in greater detail below in the section entitled Data Preparation.

COMPUTATIONAL METHODS

Data input, data edit, and cross-section property computation steps for the CARD #1 through CARD #6 data are performed as described in the backwater analysis segment of this manual. The presence of a #7 CARD indicates the user's desire for floodway profile computations, either in addition to or completely independent of normal profile computations. For each normal profile specified on CARD #7, backwater analysis is accomplished as previously described. For each floodway profile specified on CARD #7, E431 is programed to operate as follows:

1. input those floodway data required for each cross section;
2. perform the analysis required to place the encroachment limits for each cross section as specified by the user, obtaining the normal water-surface elevations from the source specified on CARD #8.
3. upon completing the encroachment of each cross section as specified, compute and print the cross-section properties for the modified cross section and store the modified coordinates on a separate direct-access storage device;
4. upon completing encroachment of all specified cross sections in the reach, compute the floodway profile for the reach using an initial water-surface elevation which is equal to the elevation specified on CARD #2 plus the specified surcharge;
5. print appropriate profile computation messages and the floodway profile in the same manner as a normal profile.

DATA PREPARATION

Additional data cards required for floodway profile computations consist of three different categories numbered 7 through 9. Table 16 tabulates the data that are coded on these cards.

Table 16.—*Summary of data coded on the three additional categories of data cards required for floodway analysis*

CARD NO.	Data coded
7	Specification of profile types.
8	Specification of source of normal water-surface elevations.
9	Encroachment data for individual cross-sections and profile identification.

USGS Form 1891B (see fig. 51) is designed for convenient coding of the required floodway data prior to keypunching. Of course, it is to be used in conjunction with Form 1891A (fig. 10). Like 1891A, 1891B is a blocked-line format with each blocked, horizontal line representing a single data card. All data entries, except those in columns 15–17 and 40–59 on CARD #9, must be numeric and right-justified in their respective field. The CARD number in column 1 and the SEQUENCE number in columns 3–7 follow the same criteria as those for backwater analysis. The following paragraphs describe in detail the remaining data that must be coded on the #7, #8, and #9 CARD(S).

Only one #7 CARD is to be coded for a given reach. The number of entries on CARD #7 must correspond with the total number of profiles (which includes both floodway and normal profiles) to be computed (NPR on CARD #1) which in turn must correspond with the number of entries on the #2 and #4 CARD(S). Entries are made in columns 42, 44, 46, . . . ,80. Valid entries are either 0 (zero) or 1 (one). A zero indicates that a normal profile is to be computed. A one indicates that a floodway profile is to be computed. The entry in

Form 9-1891B
(May 1974)

FLOODWAY ANALYSIS

GPO : 1974 O - 547-557

(THIS FORM IS USED IN CONJUNCTION WITH BACKWATER ANALYSIS FORM 9—1891A)

CARD	SEQUENCE
7	
1	3 4 5 6 7
8	

PROFILE TYPE: 0 = NORMAL, 1 = FLOODWAY
NORMAL WS ELEV FROM: 0 = MEMORY, 1 = CARDS

PROFILE FOR H(I) AND Q(I) SPECIFIED ON CARD TYPES 2 AND 4

I = 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80

CARD	SEQUENCE	CARD 3 SEQUENCE	FW OPTION	Y	LEFT STA.	RIGHT STA.	NORMAL WS ELEV	FLOODWAY ID (Enter only on END option card)
1	3 4 5 6 7	9 10 11 12 13	15 16 17	19 20 21	23 24 25 26	28 29 30 31	33 34 35 36 37 38	40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
9								
9								
9								
9								
9								
9								
9								
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9								
9								
9								
9								
1	3 4 5 6 7	9 10 11 12 13	15 16 17	19 20 21	23 24 25 26	28 29 30 31	33 34 35 36 37 38	40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59

FW OPTIONS

VER — specify Y
— no constraints

VSA — specify Y
— sub-area constraint

VHD — specify Y
— horizontal stationing constraints

HØR — Y not specified
— horizontal stationing of encroachment specified.

NØE — no encroachment

ADD — add Y to Y of previous FW analysis

END — must be last card of the set for each FW analysis.

Figure 51.—Form 9-1891B for coding data for floodway analyses using E431.

column 42 indicates the profile type for the first profile to be computed. The first profile to be computed uses the first pair of initial water-surface elevation and discharge entries on the #2 and #4 CARD(S). The type of profile to be computed for the second, third, . . . , twentieth profile is indicated by the appropriate digit in columns 44, 46, . . . , 80. The second, third, . . . , twentieth profile to be computed uses the second, third, . . . , twentieth pair of initial water-surface elevation and discharge entries on the #2 and #4 CARD(S). Again it is stressed that the number of entries on CARD #7 must be equal to the total number of profiles (floodway and normal) to be computed (NPR, CARD #1) which in turn must correspond to the number of initial water-surface elevation and discharge entries on the #2 and #4 CARD(S).

A single #8 CARD must follow the #7 CARD. Each entry of 1 (one) in columns 42, 44, . . . , 80 on CARD #7 requires an associated entry in the same column of CARD #8. The entry on CARD #8 indicates to the computer where it is to obtain the normal water-surface elevation for each cross section that is to be encroached. An entry of 0 (zero) indicates that the normal profile is available in the computer's memory. For this to be possible, the desired normal profile must be computed during the same computer run immediately prior to the first floodway profile to be computed. An entry of 1 (one) indicates that, for each cross section to be encroached, the user will provide the normal water-surface elevation on a #9 CARD for that cross section. Logical and necessary choices between these two alternatives will be clarified below.

Data required for each cross section to be encroached are coded on a #9 CARD. In addition to the CARD number and the SEQUENCE number (which are required on every #9 CARD), the data required are:

CARD 3 SEQUENCE (cols. 9–13)—the floodway analysis segment of E431 finds a cross section by using the SEQUENCE number of that cross section's #3 CARD.

FW OPTION (cols. 15–17)—one of the three-letter codes briefly defined in the box on Form 1891B. More detailed explanation of each of these options is presented below.

Y (cols. 19–21)—specified surcharge (if any). Entries of 1 through 999 represent desired surcharges of 0.01 through 9.99 feet.

LEFT STA. (cols. 23–26)—horizontal station in whole feet at which: (1) the left encroachment will be placed using the HOR option, or (2) encroachment on the right bank will stop using the VHD option.

RIGHT STA. (cols. 28–31)—horizontal station in whole feet at which: (1) the right encroachment will be placed using the HOR option, or (2) encroachment on the right bank will stop using the VHD option.

NORMAL WS ELEV (cols. 33–38)—the normal water-surface elevation upon which the encroachment of a cross section will be based (CASE I, II, or III analysis). Only applicable for entries of 1 on CARD #8.

FLOODWAY ID (cols. 40–59)—on the END option card only, alphanumeric data coded in this field will be printed on the appropriate output to identify each floodway analysis.

The above data requirements vary depending upon the FW OPTION. Table 17 summarizes the combinations of data required for each of the seven possible options. Five of the options (VER, VSA, VHD, HOR, and NOE) are used to dictate the placement (or prohibition) of encroachment limits at each cross section (or for a series of cross sections). Each of these options may be used singly, or two or more may be used in combination, thus providing extreme flexibility for investigation of encroachment patterns. The following paragraphs provide more detail of the data requirements indicated in table 17. Examples of coding floodway data are presented in subsequent sections entitled Computer Output and Computer Program Applications.

Table 17.—*CARD #9 data requirements*

CARD 3 SEQUENCE	FW OPTION[1]	Y	LEFT STA.	RIGHT STA.	NORMAL WS ELEV[2]	FLOODWAY ID[3]
Yes	VER	Yes	No	No	Yes	No
Yes	VSA	Yes	No	No	Yes	No
Yes	VHD	Yes	Yes	Yes	Yes	No
Yes	HOR	No	Yes	Yes	No	No
Yes	NOE	No	No	No	No	No
No	ADD	Yes	No	No	No	No
No	END	No	No	No	No	Yes

[1]CARD and SEQUENCE numbers required on every #9 CARD.
[2]Only applicable when 1 (one) is entered on CARD #8.
[3]Only the entry in columns 40–59 of the END option card will appear on the floodway cross-section property and profile printout. However, any entry made in columns 40–80 of a #9 CARD will be printed on the card-image printout. A user may wish to utilize this feature as a convenient bookkeeping aid.

Each cross section is recognized and retrieved by its CARD #3 SEQUENCE number. Therefore, the CARD #3 SEQUENCE number of a cross section must be coded in columns 9–13 on any #9 CARD specifying one of the first five options of table 17. A single #9 CARD can apply to a series of regular, exit, and approach cross sections if each of these cross sections is to be analyzed identically. Data from a single #9 CARD will be applied to successive cross sections (except when TYPE is equal to 2, 3, or 4) as long as the CARD #3 SEQUENCE of each successive cross section is less than the CARD #3 SEQUENCE specified on the next #9 CARD coded with a VER, VSA, VHD, HOR, or NOE option.

The VER option will establish floodway limits by applying the Case I analysis. CARD #9 data requirements are: (1) the CARD 3 SEQUENCE of the cross section (or first of a series of cross sections) to be encroached; (2) VER; and (3) the desired surcharge, Y.

The VSA and VHD options permit establishing floodway limits with both surcharge and horizontal constraints specified. This is intended to provide a CASE II analysis. Of course, if the conveyance criteria cannot be met within the specified constraints a CASE III analysis will be obtained. Horizontal constraints may be specified in terms of subarea numbers (VSA) or horizontal stationing (VHD).

Use of the VSA option requires: (1) foresight when coding the #3 CARD(S) and (2) that the area from which encroachment is to be excluded coincides with subarea breakpoints. The SAL and SAR fields on CARD #3 for TYPE values of 0, 1, or 5 may be coded such that the encroachment limits will not be placed within SAL < SA < SAR. Figure 52 illustrates appropriate values of SAL and SAR for various situations. CARD #9 data requirements (other than FW OPTION) are identical for the VSA and VER options.

Of course, any cross section could be further subdivided so that the constraining points coincide with subarea breakpoints. This is usually not advisable since the values computed for conveyance (eq. 1-5) and alpha (eq. 1-7) can be significantly different with extra subareas as compared to those obtained with normally accepted subdivision procedures (Davidian, 1976). Therefore, the VHD option was designed to permit the use of LEFT STA. and RIGHT STA. to specify the horizontal stationing of the left and right constraining points. Figure 53 illustrates appropriate values for LEFT STA. and RIGHT STA. for various situations. Data required on each #9 CARD are: (1) CARD 3 SEQUENCE; (2) VHD; (3) the desired surcharge, Y; (4) LEFT STA.; and (5) RIGHT STA. Rarely are the constraining points exactly the same for a series of regular, exit, and approach cross sections. Thus, a #9 CARD will generally be required for each cross section to be encroached when the VHD option is used.

CASE IV analysis of a cross section can be obtained using the HOR option. Surcharge is not specified and encroachment limits are placed at the horizontal stationing specified by LEFT STA. and RIGHT STA. Figure 54 illustrates LEFT STA. and RIGHT STA. coding for the HOR option. Like the VHD option, a #9 CARD (with Y not coded) will generally be required for each regular and approach cross section when the HOR option is used.

The NOE option may be used to prevent a cross section (or a series of regular, exit, and approach cross sections) from being encroached upon. The only data requirement on the #9 CARD (in addition to NOE) is the CARD 3 SEQUENCE of the cross section (or the first of a series of cross sections) that is not to be encroached.

E431 is programed to automatically apply the NOE option to all bridge-opening, pier, and embankment cross sections. Any modification to these cross sections (TYPE equal to 2, 3, or 4) must be accomplished by recoding the appropriate input data cards in the backwater analysis deck. Any attempt to input #9 CARD data (even for the NOE option) for one (or more) of these cross sections in a reach may cause severe (and expensive) computational problems. These unwanted #9 CARD data will be applied to subsequent upstream cross sections for which encroachment is permissible (TYPE equal to 0, 1, or 5). Therefore, even in the unlikely absence of computational problems, any results obtained are most probably incorrect since some #9 CARD data have been applied to the wrong cross sections.

It is sometimes desirable to compute floodway profiles for more than one desired surcharge for the same encroachment pattern. The ADD option provides this capability while minimizing #9 CARD coding. The #9 CARD(S) for the first floodway profile to be computed are prepared for any one of the desired surcharges. Each successive floodway analysis may be accomplished using the ADD option. The only data required on the #9 CARD are (1) ADD and, (2) a Y value. The coded Y value is equal to the elevation difference (positive or negative) between the desired surcharge for that floodway analysis and the surcharge of the preceeding floodway analysis. Successive execution of the ADD option is limited only by the number of profiles that can be computed (i.e., NPR $\leqslant$ 20).

The END option card is required to terminate CARD #9 input for each floodway analysis. Any alphanumeric entry in columns 40–59 of the END card is printed on the output to identify each floodway profile (see footnote 3, table 17).

E431 MESSAGES

DATA EDITING MESSAGES

Very limited data editing is performed on the #7, #8, and #9 CARD(S). Each of these cards is edited for

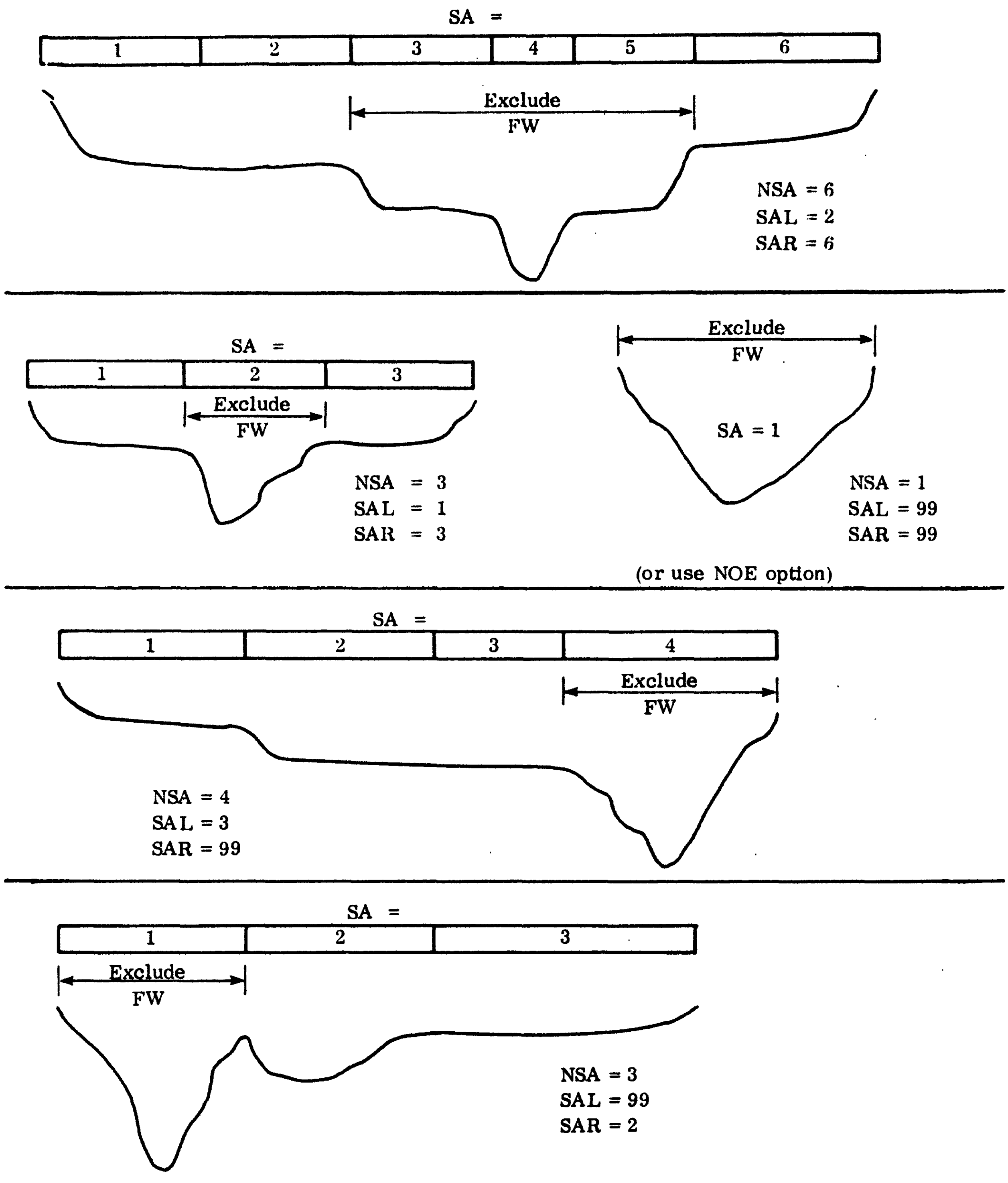
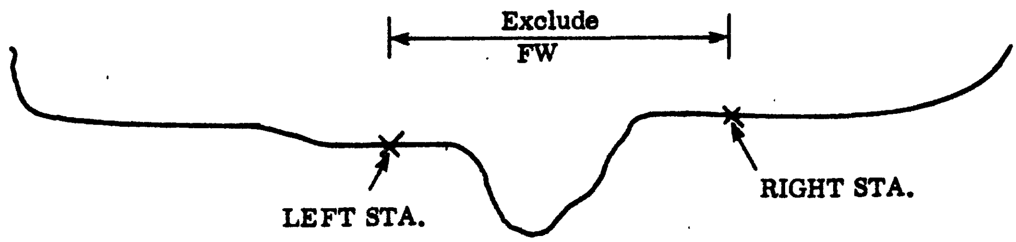
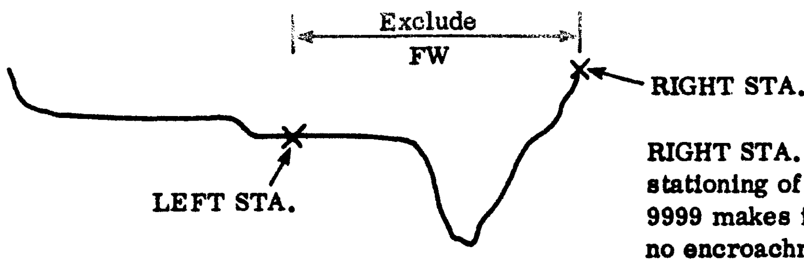


Figure 52.—SAL and SAR coding examples for floodway analysis using VSA option.



a) Usual situation.

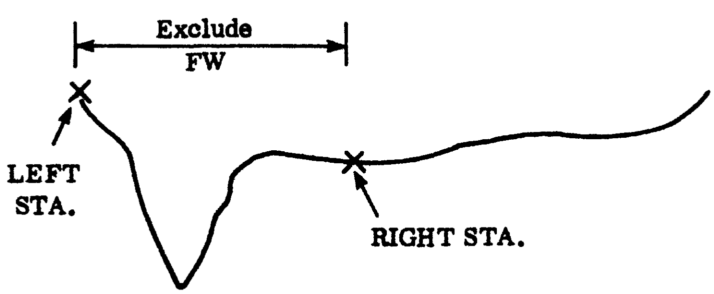


RIGHT STA. may be greater than stationing of right bank. Coding 9999 makes it abundantly clear that no encroachment on the right bank is allowed.

b) No encroachment allowed on right bank.

If no constraint desired on left bank for above situation, code LEFT STA. as 9999 also.

c) No encroachment on right bank, left bank unconstrained.



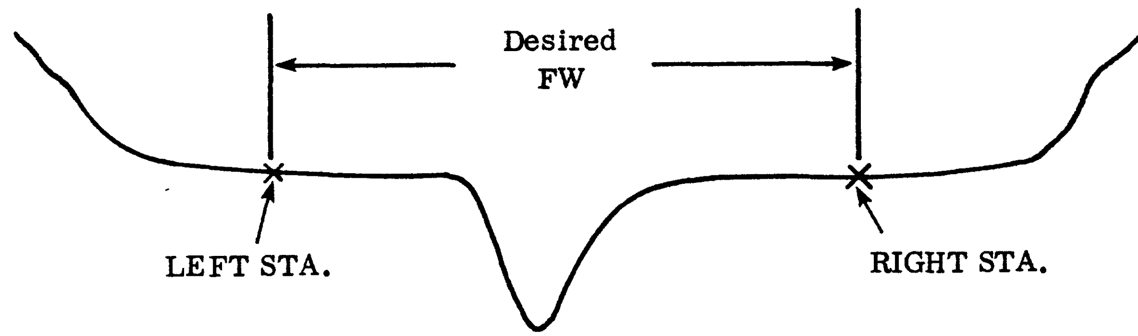
Suggest LEFT STA. coded as -999 to make obvious that no encroachment allowed on left bank.

d) No encroachment allowed on left bank.

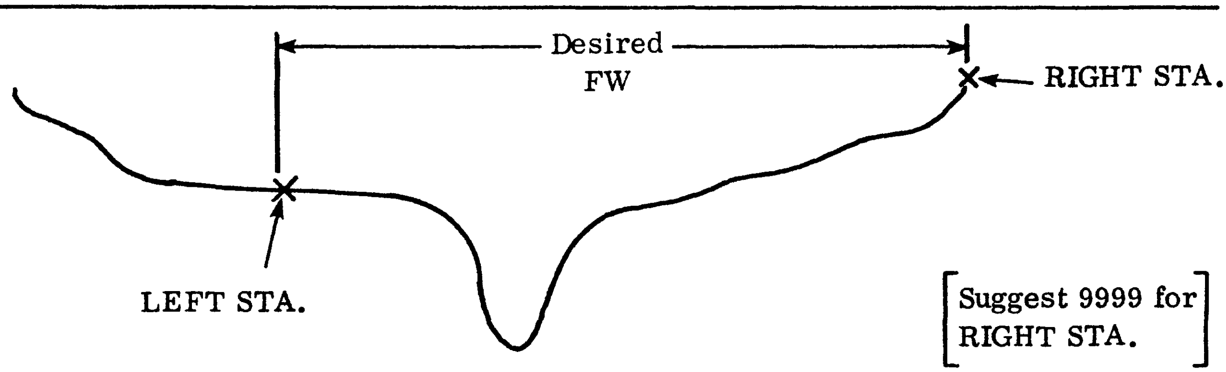
If no constraint desired on right bank for above situation, code RIGHT STA. as -999 also.

e) No encroachment on left bank, right bank unconstrained.

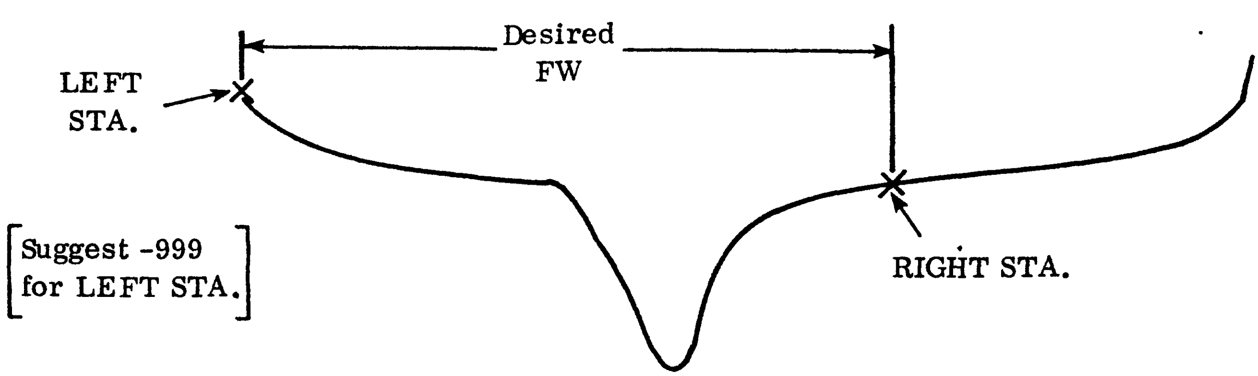
Figure 53.—LEFT STA. and RIGHT STA. Coding examples for floodway analysis using VHD option.



a) Specified limits on both banks.



b) Specified left limit only.



c) Specified right limit only.

Figure 54.—LEFT STA. and RIGHT STA. Coding examples for floodway analysis using the HOR option.

proper order by CARD number and ascending SEQUENCE number as previously described. CARD #9 data are edited only for a valid FW OPTION code. An invalid code will cause message SL-9 (table 7) to be printed and abortion of floodway computations for the remainder of the CARD #9 data. No numerical editing is performed on floodway analysis input data.

PROFILE COMPUTATION MESSAGES

All of the profile computation messages discussed for backwater analyses are equally applicable to floodway analyses. An additional message (PN-33, table 11) is printed when a floodway profile computation must be aborted. The possible problems, the action taken by program E431, and the necessary user responses are discussed in the following paragraphs.

Floodway profile computations using normal water-surface elevations from memory are bypassed when the normal profile computations have been aborted. Of course, an incomplete normal profile can be caused by either abortive backwater-analysis input data or abortive profile computation errors. The bypass of floodway computations is accomplished by ignoring ("flushing") all floodway analysis input data for the reach. Message PN-33 is printed for each floodway profile that was requested. The user must make the necessary data corrections and (or) alterations that will result in a complete normal profile (this should be accomplished before attempting a floodway analysis).

An abortive profile computation error also can occur during a floodway profile computation. Of course, the abortive problem is indicated by the appropriate profile computation message. Any remaining floodway analysis input data are ignored and PN-33 is printed for each subsequent floodway profile that was requested. The user must make necessary adjustments in the floodway analysis scheme to eliminate the abortive problem.

A FW OPTION coding error (see discussion of SL-9 above) causes abortion of the floodway profile for which the error occurred and all subsequent floodway profiles. PN-33 is printed for each aborted floodway profile. The user must correct the FW OPTION coding.

COMPUTER OUTPUT

Output from the floodway analysis phase of E431 is identical with that from the backwater analysis phase up to the point where the cross-section properties have been printed for all valid cross sections. Card images of the #7 CARD and the #8 CARD are then printed. All subsequent output depends upon the sequence of normal profiles and floodway profiles that are to be computed. Output identical with that for backwater analyses is obtained for each normal profile. Each floodway profile results in output consisting of: (1) card images for all #9 CARDS for that floodway profile; (2) cross-section properties for each modified cross section; (3) profile computation messages (if any); and (4) the floodway profile.

Figure 55 shows portions of the output from a floodway analysis of the simple reach used previously (see fig. 34). Assumptions upon which the analysis is based are: (1) 4,000 ft^3/s is the regulatory flood; (2) the desired surcharge is one-half foot; (3) both normal and floodway profiles are desired; and (4) there is no need to constrain the encroachment. Appropriate coding of the initial water-surface elevations and discharges is illustrated on the portion of the input card printout shown. The input data summary (1 page) and cross-section properties output (4 pages) are not shown. Card image printout of the #7 CARD and #8 CARD is shown. Since the first entry on CARD #7 (col. 42) is a zero the normal profile is computed and the results printed (not shown, see fig. 36). The second entry on CARD #7 (one in col. 44) causes the program to input all #9 CARDS for the floodway profile and print them as shown. As each cross section is modified in accordance with the #9 CARD instructions, the new cross-section properties are printed. Portions of the modified properties and the resultant floodway profile are shown. The encircled line in the headings simply indicates how floodway analysis output can be distinguished from backwater analysis output.

The following section presents several additional examples of floodway analysis applications. Because the output is voluminous, only the card images of the #1 through #4 and #7 through #9 CARD data are illustrated. The user should be able to ascertain the resultant output from the above example and brief discussions that accompany the following examples.

COMPUTER PROGRAM APPLICATIONS

Figure 56 illustrates the altered and additional data that would be required for the example in the previous section if the normal profile computation were eliminated. A #9 CARD is required for each cross section to input the normal water-surface elevations. The only output that is eliminated is the normal profile printout. Individual situations will dictate which method provides the easiest, most convenient, and most economically feasible way to accomplish the desired analyses.

In either of the above methods, additional floodway profiles for different surcharges are easily obtained using the ADD option. To illustrate, assume that floodway profiles are also required for 1.0 and 1.5 foot surcharges. Figure 57 illustrates the revisions and additions to acquire these profiles when the normal profile is computed. If the normal profile is not computed the data requirements are: (1) NPR = 3 (with like number of entries on the #2 and #4 CARD; (2) entries of 1 in cols. 42, 44, and 46 of the #7 and #8 CARDS; (3) the VER

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    1

                    *** INPUT CARD PRINTOUT ***

        1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

1  1001 SIMPLE FLOODWAY EXAMPLE ---- E431 USER'S MANUAL     6  2 01 05 12
2  1002  21179  21179
3  1003 ONE    1  10  3  207     1000 99 99
4  1004    4000     4000
5  1  0        0  1   50    50  1    00  110  2  2  0   115  2  2  0  130  2  2
```

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    6,D

                    *** INPUT CARD PRINTOUT ***

        1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

7  7001                                            0 1
8  8001                                              0
```

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    8,D

                    *** INPUT CARD PRINTOUT ***

        1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0

9  9001   1003 VER 050
9  9002        END                       0.50' SURCHARGE
```

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=    9,DATE= 4/  /76

CROSS-SECTION PROPERTIES FOR: SIMPLE FLOODWAY EXAMPLE ---- E431 USER'S MANUAL
     SECID=ONE     AT DISTANCE=     1000                             PART  1 OF  1
*** FLOODWAY ANALYSIS *** 0.50' SURCHARGE

    WS         A          K     ALPHA       B        P      LEW      REW       QC

  207.0       128       4900     1.00       75       75     113      188       943
  207.5       166       7403     1.00       78       78     111      189      1373
  208.0       205      10328     1.00       80       81     110      190      1861
  208.5       252      13948     1.05      106      107      97      203      2157
  209.0       305      18134     1.10      106      108      97      203      2803
  20  5       358      22815     1         106       9      97        3      351
```

```
USGS STEP-BACKWATER PROGRAM - VERSION 76.076 *** PAGE COUNT=   12,DATE= 4/  /76

================================================================================
WATER-SURFACE PROFILE FOR: SIMPLE FLOODWAY EXAMPLE ---- E431 USER'S MANUAL
PAGE   1 OF   1
*** FLOODWAY ANALYSIS *** 0.50' SURCHARGE
================================================================================
SECID AT DISTANCE/ LENGTH/DISCHARGE/    AREA   /CONVEYANCE/ ALPHA/  LEW  /  REW
  WS ELEV /      HV  /      HF  /      HE  /      EG  /      V  /    FN  /  ACC   *ID*
================================================================================
ONE    AT    1000 /       0 /   4000. /    653. /   56561. / 1.19 /    97. /  203.
   212.29 /    0.69 /                       /  212.98 /    6.12 /    0.46/          *IS*
--------------------------------------------------------------------------------
TWO    AT    2000 /   1000 /   4000. /    653. /   56561. / 1.19 /    97. /  203.
   217.29 /    0.69 /    5.00 /    0.00 /  217.98 /    6.12 /    0.46 / -0.001   *XS*
--------------------------------------------------------------------------------
THREE AT     3000 /   1000 /   4000. /    654. /   56594. / 1.19 /    97. /  203.
      .29 /    0.69 /     .00 /    0.0   /  22   98 /    6.11 /    0    /  0.000   *XS*
```

Figure 55.—Partial output from floodway analysis.

```
          1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
1  1001 FLOODWAY ANALYSIS EXAMPLE -- E431 USER'S MANUAL      6  1 01 05 12
2  1002  21179
3  1003 ONE   1  10   3  207     1000 99 99
4  1004   4000
                                 ***********************************
                                 * REST OF BACKWATER ANALYSIS DATA *
                                 ***********************************
7  7001                                             1
8  8001                                             1
9  9001    1003 VER 050             21179       SECTION ONE
9  9002    2003 VER 050             21679       SECTION TWO
9  9003    3003 VER 050             22179       SECTION THREE
9  9004    4003 VER 050             22679       SECTION FOUR
9  9005    5003 VER 050             23179       SECTION FIVE
9  9006    6003 VER 050             23679       SECTION SIX
9  9007          END                     0.50' SURCHARGE
```

Figure 56.—Floodway analysis input with normal profile input on cards.

```
          1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
1  1001 FLOODWAY ANALYSIS EXAMPLE -- E431 USER'S MANUAL      6  4 01 05 12
2  1002  21179  21179  21179  21179
3  1003 ONE   1  10   3  207     1000 99 99
4  1004   4000   4000   4000   4000
                                 ***********************************
                                 * REST OF BACKWATER ANALYSIS DATA *
                                 ***********************************
7  7001                                         0 1 1 1
8  8001                                           0 0 0
9  9001    1003 VER 050
9  9002          END                     0.50' SURCHARGE
9 10001          ADD 050
9 10002          END                     1.00' SURCHARGE
9 10003          ADD 050
9 10004          END                     1.50' SURCHARGE
```

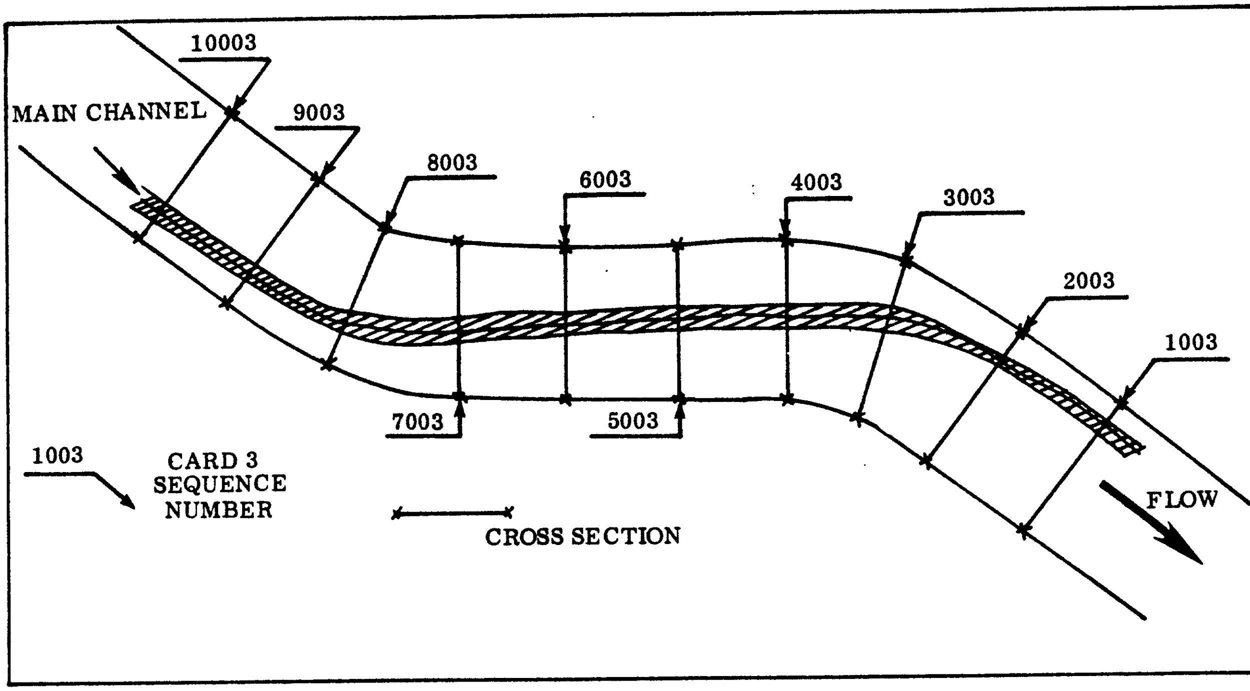
Figure 57.—Illustration of the ADD option.

option cards of figure 56 (SEQUENCE 9001 through 9006); and (4) the same four additional #9 CARDS for ADD and END instructions (SEQUENCE 10001 through 10004).

If the main channel (SA = 2) might possibly be encroached upon in any of the preceding examples the VSA option can be exercised. This would necessitate coding SAL = 1 and SAR = 3 on the #3 CARD for each cross section and coding VSA instead of VER for the FW OPTION on the applicable #9 CARD(S).

A combination of options is illustrated using the reach shown in figure 58. Encroachment into the main channel is likely from the left bank at the downstream end (CARD 3 SEQUENCE 1003 through 3003) and from the right bank at the upstream end (CARD 3 SEQUENCE 8003 through 10003). Cross sections in the middle of the reach (CARD 3 SEQUENCE 4003 through 7003) need no encroachment constraints. Assume that the floodway profiles for 0.5 and 1.0 foot surcharges as well as a normal profile are desired. If NPR is coded as 3 (along with three values of initial water-surface elevation and regulatory discharge, respectively, on the #2 and #4 CARD) the #7 through #9 CARDS shown in figure 58 will provide the desired profiles.

One potential application of the VHD option is illustrated in the next example. A floodway analysis for one-half foot surcharge is required. Furthermore, there is a minimum width restriction for the floodway. This minimum width is represented on figure 59 by the distances A–B, C–D, . . . , I–J. Coding of the floodway data is shown on figure 59 with LEFT STA. and RIGHT STA. represented by the appropriate letters (A through J). The figures in cols. 33–38 on the #9 CARD(S) represent the NORMAL WS ELEV, which are those elevations resulting from a previously computed normal profile. On CARD #1, NPR = 1 is coded, 100.23 is coded on CARD #2, and the appropriate discharge is coded on CARD #4.



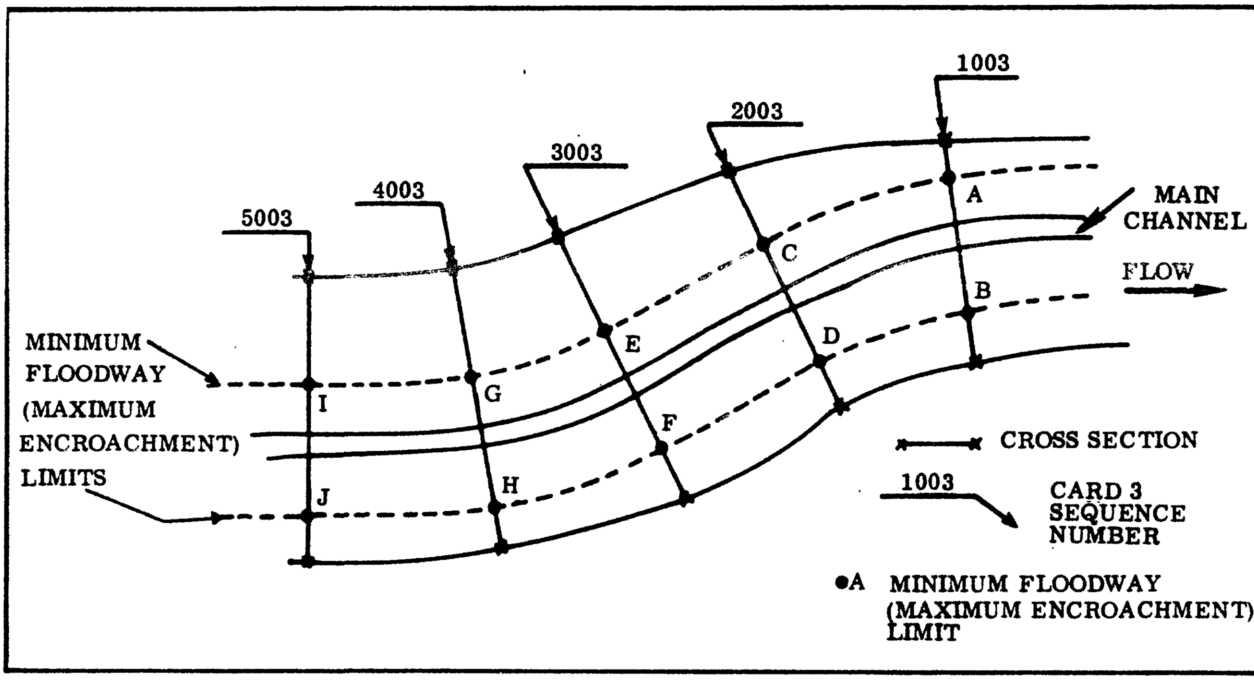

```
          1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
7 17001                                      0 1 1
8 18001                                        0 0
9 19001   1003 VSA 050                      X-SEC'S 1 - 3
9 19004   4003 VER 050                      X-SEC'S 4 - 7
9 19008   8003 VSA 050                      X-SEC'S 8 - 10
9 19100        END                          0.50' SURCHARGE
9 19199        ADD 050
9 19200        END                          1.00' SURCHARGE
```

Figure 58.—Illustration of combining floodway options.

The HOR option could be used to determine the water-surface profile for the minimum floodway (maximum encroachment) condition. Floodway data input cards are illustrated on figure 60. No entry is needed in column 42 of CARD #8 for the HOR option, but the #8 CARD cannot be omitted. Also, Y and NORMAL WS ELEV are not coded for the #9 CARDS since a fixed encroachment pattern is being analyzed. The #1 and #4 CARDS would be identical with those of the preceding example. Assume (for the sake of illustration) that the maximum encroachment condition would result in an increased water-surface elevation of 101.83 at the initial cross section. Therefore, 101.83 (rather than 100.23) must be coded on the #2 CARD. Both of these analyses can be accomplished in one computer run if the data are coded as shown in figure 61.

Another application of the HOR option is illustrated in figure 62. Line V–Z represents some physical barrier to be constructed in the left overbank (such as highway, land-fill, levee, and so forth). If the barrier can be represented as a vertical wall the data cards shown in figure 62 would provide a normal profile and a profile reflecting the effects of overbank removal. Stations W, X, and Y indicate the LEFT STA. of encroachment, and the 9999 values coded for RIGHT STA. represent no encroachment on the right bank. More cross sections than are shown upstream from the end of the encroachment might be required to determine how far upstream the normal profile would be affected. However, this would require no changes in the floodway data input.

Extreme caution must be exercised in floodway analyses involving bridge situations. Unconstrained encroachment can result in encroached approach and (or) exit cross sections which are narrower than the bridge-opening cross section. This situation (which is most likely undesirable and (or) illogical) can easily be avoided upstream from the bridge by exercising the VSA option for the approach cross section since SAL and SAR are always coded for that section. It is strongly recommended that the VSA option always be exercised




```
         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
7  7001                                1
8  8001                                1
9  9001  1003 VHD 050 ***A ***B  10023
9  9002  2003 VHD 050 ***C ***D  10087
9  9003  3003 VHD 050 ***E ***F  10140
9  9004  4003 VHD 050 ***G ***H  10183
9  9005  5003 VHD 050 ***I ***J  10218
9  9006       END                      0.50' SURCHARGE
```

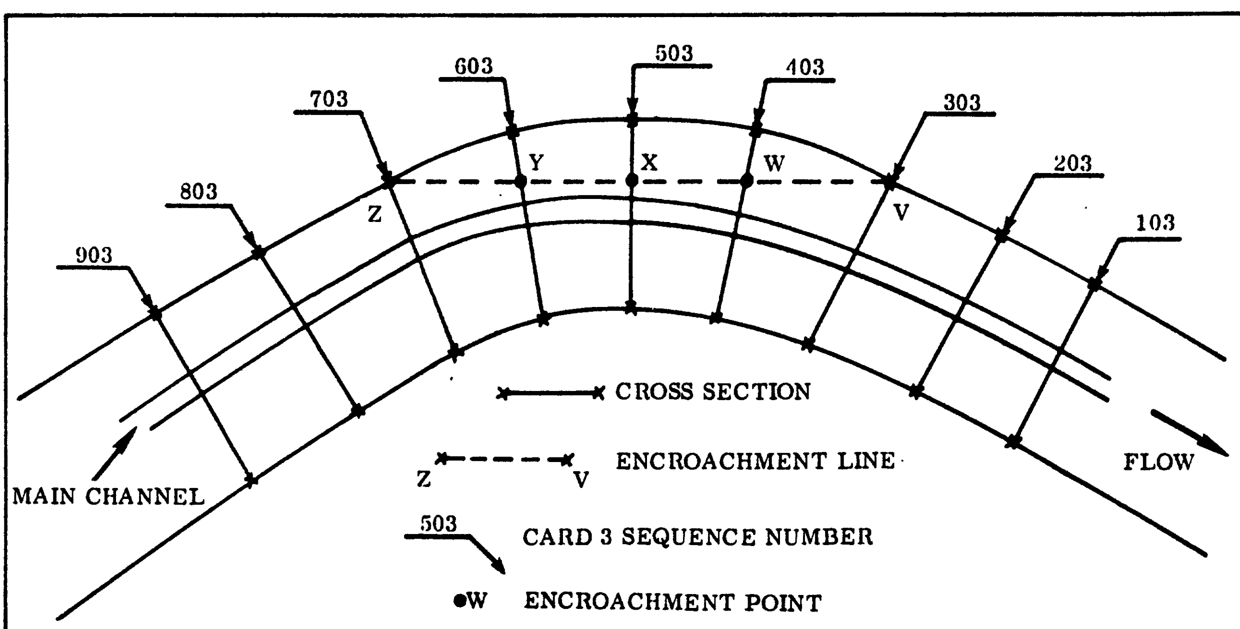
Figure 59.—Illustration of the VHD option.

```
         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
7  7001                                1
8  8001
9  9011  1003 HOR     ***A ***B
9  9012  2003 HOR     ***C ***D
9  9013  3003 HOR     ***E ***F
9  9014  4003 HOR     ***G ***H
9  9015  5003 HOR     ***I ***J
9  9016       END                      MINIMUM FLOODWAY
```

Figure 60.—Illustration of the HOR option.

```
         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
1  1001 FLOODWAY ANALYSIS EXAMPLE -- E431 USER'S MANUAL      5  2 01 05 12
2  1002  10023   10183
3  1003     1 1  10   3    97     1000 99 99
4  1004 **QT** **QT**
                         ***********************************
                         * REST OF BACKWATER ANALYSIS DATA *
                         ***********************************
7  7001                                         1 1
8  8001                                         1
9  9001  1003 VHD 050 ***A ***B  10023
9  9002  2003 VHD 050 ***C ***D  10087
9  9003  3003 VHD 050 ***E ***F  10140
9  9004  4003 VHD 050 ***G ***H  10183
9  9005  5003 VHD 050 ***I ***J  10218
9  9006       END                      0.50' SURCHARGE
9  9011  1003 HOR     ***A ***B
9  9012  2003 HOR     ***C ***D
9  9013  3003 HOR     ***E ***F
9  9014  4003 HOR     ***G ***H
9  9015  5003 HOR     ***I ***J
9  9016       END                      MINIMUM FLOODWAY
```

Figure 61.—Illustration of multiple floodway analyses.




```
         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
7  7001                                         0 1
8  8001
9  9001   103 NOE                      FIRST 3 X-SEC'S NOT ENCROACHED
9  9002   403 HOR     ***W 9999        X-SEC 4
9  9003   503 HOR     ***X 9999        X-SEC 5
9  9004   603 HOR     ***Y 9999        X-SEC 6
9  9005   703 NOE                       REMAINING X-SEC'S NOT ENCROACHED
9  9006       END                      LEFT OVERBANK ENC.
```

Figure 62.—Illustration of HOR and NOE options.

for an approach cross section when encroachment of the approach cross section is permitted. Either the VSA or VHD option can be exercised for the exit cross section depending upon the location of subarea break-points in the exit cross section relative to the bridge opening. Table 18 tabulates a series of cross sections with their CARD 3 SEQUENCE numbers for a reach involving a bridge situation.

Table 18.—*Cross sections and CARD 3 SEQUENCE numbers for a reach involving a bridge situation*

Cross section	CARD 3 SEQUENCE
Five regular	103 through 503
Exit	603
Bridge opening	703
Embankment	803
Approach	903
Five regular	1003 through 1403

Figure 63a illustrates the CARD #9 data for the case where the bridge opening width coincides with subarea break-points in the exit cross section. Of course, SAL and SAR must be coded properly on CARD #3 for the exit cross section. CARD #9 data for the case where the VHD option is required are shown in figure 63b. Abbreviations of LT and RT on SEQUENCE 9002 are used to indicate that the horizontal stationing in the exit cross section relative to the left and right ends of the bridge opening are to be coded in the LEFT STA. and RIGHT STA. fields. Both of the above examples are based on the assumption that the VER option is entirely adequate for all regular cross sections in the reach.

Embankment overflow also warrants special consideration in floodway analyses. Encroachment of the exit and (or) approach cross sections can create inconsistency in the widths and (or) alinement of these cross sections and the embankment cross section. Thus, an invalid hydraulic analysis can result because E431 is not programed to recognize such problems.

Consider a case where the entire embankment is overflowed for the normal profile. Any encroachment upstream and (or) downstream should be accompanied by an adjustment of the embankment cross section to assure that the program uses a valid weir length for computing the embankment overflow. If no adjustment is made to the embankment cross section, the NOE option should be used for the exit and approach cross sections to assure hydraulic validity. The #9 CARD data of figure 63a with VSA on SEQUENCE 9002 changed to NOE (and Y omitted) would suffice if the entire embankment of the preceding example were overflowed.

When only a portion of the embankment is overflowed the VHD option may be useful. Encroachment of the exit and approach cross sections can be constrained with the VHD option to assure consistency with the overflowed section(s). However, a trial and error solution might be necessary since the higher water-surface elevations for encroached conditions may significantly affect the embankment overflow limits. In any event, when embankment overflow occurs, the user must closely scrutinize floodway analysis output to confirm the hydraulic validity of the results.

REFERENCES

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Bradley, J.N., 1960, Hydraulics of bridge waterways: Bureau of Public Roads Hydraulic Design Series No. 1, 53 p.

———, 1970, Hydraulics of bridge waterways: Bureau of Public Roads Hydraulic Design Series No. 1, 111 p.

Carnahan, Brice, Luther, H.A., and Wilkes, J.O., 1969, Applied numerical methods: New York, John Wiley and Sons, Inc., 604 p.


```
         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
9  9001    103 VER *Y*                  X-SEC'S 1 - 5
9  9002    603 VSA *Y*                  EXIT & APPROACH X-SEC'S
9  9003   1003 VER *Y*                  X-SEC'S 10 - 14
9  9004        END                      *Y*' SURCHARGE
```

a) Using VSA Option Only

```
         1         2         3         4         5         6         7         8
....5....0....5....0....5....0....5....0....5....0....5....0....5....0....5....0
9  9001    103 VER *Y*                  X-SEC'S 1 - 5
9  9002    603 VHD *Y* *LT* *RT*        EXIT X-SEC
9  9003    903 VSA *Y*                  APPROACH X-SEC
9  9004   1003 VER *Y*                  X-SEC'S 10 - 14
9  9005        END                      *Y*' SURCHARGE
```

b) Using VHD and VSA Options

Figure 63.—Illustration of floodway analysis input for bridge situation.

Chow, V.T., 1959, Open-channel hydraulics: New York, McGraw-Hill Book Co., 680 p.

Cragwall, J.S., Jr., 1958, Computation of backwater at open-channel constrictions: U.S. Geol. Survey open-file report, 25 p.

Davidian, Jacob, 1976, Computation of water-surface profiles in open channels: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A9, (in press).

Hulsing, Harry, 1967, Measurement of peak discharge at dams by indirect methods: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A5, 29 p.

Matthai, H.F., 1967, Measurement of peak discharge at width contractions by indirect methods: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A4, 44 p.

Woodward, S.M., and Posey, C.J., 1941, Hydraulics of steady flow in open channels: New York, John Wiley and Sons, Inc., 151 p.

SYMBOLS

Symbol	*Definition*	*Units*
A	Total area of a cross section (see fig. 1)	ft^2
ABO	Gross area of a bridge opening projected normal to the flow (see figs. 4–6).	ft^2
ABUT	Code to indicate alinement of abutments relative to direction of flow (see fig. 10: #3 CARD; TYPE = 2 and fig. 12).	
ACC	Accuracy of the energy equation balance (see fig. 2).	ft
ADD	Code for an option used in floodway analyses (see fig. 51).	
ANET	Net area of a bridge opening projected normal to the flow (see figs. 5 and 6).	ft^2
APIER	Pier area projected normal to the flow (see fig. 18).	ft^2
a	The hydraulic depth in a subarea above which roughness is assumed constant (see fig. 1 and fig. 10: #6 CARD).	ft
a_i	Area of the i^{th} subarea of a cross section (see fig. 1).	ft^2
B	Total top width of a cross section (see fig. 3).	ft
B	Incremental length between specified points on an embankment (see fig. 7).	ft
BEDEL	Mean bed elevation for a bridge situation (see fig. 5).	ft
BELMX	Maximum Ground Elev. in a bridge-opening cross section.	ft
BRWID	Maximum width in a bridge-opening cross section (see fig. 5).	ft
b	The hydraulic depth in a subarea below which roughness is assumed constant (see fig 1 and fig. 10: #6 CARD).	ft
b	Width of a bridge opening parallel to the plane of the contraction (see figs. 4 and 12).	ft
b_i	Top width of the i^{th} subarea of a cross section (see fig. 1).	ft
CARD	Number indicating the category of a data card (see figs. 10 and 51).	
CD	Discharge coefficient for computing pressure flow through a bridge (see figs. 5 and 6).	
C_f	Free-discharge coefficient for computing embankment overflow (see figs. 7 and 8).	
DEL	Fraction of DELH used in balancing the energy equation (see fig. 25).	
DELH	Elevation increment used in balancing the energy equation (see fig. 25).	ft
DH	Total head for computing pressure flow through totally submerged bridge opening (see fig. 6).	ft
DIST	Flow distance between approach cross section and upstream side of embankment (see fig. 7).	ft
DISTANCE	Section reference distance for a crosssection (see fig. 10: #3 CARD, TYPE ≠ 3 or 4).	ft
d_i	Hydraulic depth of the i^{th} subarea of a cross section (see fig. 1).	ft
E	Eccentricity ratio for flow through a bridge (see fig. 4).	
EG	Elevation of the energy gradient at a cross section (see fig. 33).	ft
EGR	Elevation of the energy gradient at the upstream side of an embankment (see fig. 7).	ft
Elevation	Elevation specified at each change in Width (see fig. 10: #5 CARD, TYPE = 3 and fig. 19).	ft
END	A code used to end each floodway analysis (see fig. 51).	
F	Froude number (see fig. 3).	
FH	Energy loss due to friction between approach cross section and upstream side of embankment (see fig. 7).	ft
FN	Value of Froude number specified for testing for supercritical flow conditions (see fig. 10: #1 CARD).	

Symbol	*Definition*	*Units*
FRDN	Index Froude number computed for the subarea having the largest conveyance (see fig. 3).	
FW	Abbreviation for floodway.	
f	Function of.	
GMAX	Maximum specified Ground Elev. in a cross section.	ft
GMIN	Minimum specified Ground Elev. in a cross section.	ft
Ground Elev.	Specified elevation for each point of a cross section (see fig. 10: #5 CARD, TYPE $\neq$ 3 or 4 and fig. 11).	ft
g	Gravitational constant (acceleration)	ft/s^2
H	Total head for computing weir flow over an embankment (see fig. 7).	ft
HB	Energy losses due to contraction of flow by a bridge (see fig. 4).	ft
HE	Energy loss due to expansion of flow in a subreach (see fig. 2).	ft
HF	Energy loss in a subreach due to friction (see fig. 2).	ft
HOR	Code for an option used in floodway analyses (see fig. 51).	
HS	Static head at the upstream side of an embankment (see fig. 7).	ft
HT	Vertical distance of water-surface elevation at the downstream side of an embankment above the embankment elevation (see fig. 7).	ft
HV	Velocity head at a cross section (see fig. 33).	ft
H1N	Water-surface elevation that would exist at the approach cross section if there were not a bridge (see fig. 4).	ft
H1,H2, . . . , H20	Water-surface elevations specified for the initial cross section for profile numbers 1, 2, . . . , 20 (see fig. 10: #2 CARD).	ft
h_o	Minimum elevation for which cross-section properties are computed (see fig. 10: #3 CARD, TYPE $\neq$ 3 or 4).	ft
i	Subscript.	
J	Ratio of pier area to gross area of bridge opening (see fig. 18).	
K	Total conveyance of a cross section (see figs. 1 and 33).	ft^3/s
KB	Base component of bridge-loss coefficient (see fig. 4).	
KD	Conveyance computed for an elevation of WSD (see fig. 2).	ft^3/s
KE	Incremental component of bridge-loss coefficient due to eccentricity (see fig. 4).	
KL	Conveyance to the left of the KQ-section (see fig. 4).	ft^3/s
KLB	KL adjusted for embankment overflow (see fig. 9).	ft^3/s
KP	Incremental component of bridge-loss coefficient due to piers (see figs. 4 and 18).	
KQ	Conveyance of that portion of the approach cross section from which the flow is not contracted to flow through the bridge opening (see fig. 4).	ft^3/s
KQ-section	That portion of the approach cross section associated with KQ.	
KR	Conveyance to the right of the KQ-section (see fig. 4).	ft^3/s
KRB	KR adjusted for embankment overflow (see fig. 9).	ft^3/s
KS	Incremental component of the bridge-loss coefficient due to skew of the bridge (see figs. 4 and 12).	
KT	Total conveyance of the approach cross section (see figs. 4 and 9).	ft^3/s
KTB	KT adjusted for embankment overflow (see fig. 9).	ft^3/s
KU	Conveyance computed for an elevation of WSU (see fig. 2).	ft^3/s
K_a	The minimum of KL and KR (see fig. 4).	ft^3/s
K_b	The maximum of KL and KR (see fig. 4).	ft^3/s
K^*	Bridge-loss coefficient (see fig. 4).	
k_e	Coefficient for computing losses due to expansion of flow in a subreach (see fig. 2).	
k_i	Conveyance of the i^{th} subarea of a cross section (see fig. 1).	ft^3/s
k_t	Submergence factor to adjust free-discharge coefficient for submerged embankment overflow (see figs. 7 and 8).	
L	Length of flow distance in a subreach (see fig. 2).	ft
L	Subscript indicating subarea having largest conveyance (see fig. 3).	

Symbol	*Definition*	*Units*
LEW	Horizontal station at left edge of water in a cross section (see figs. 32 and 33).	ft
M	Contraction ratio for flow through a bridge opening (see fig. 4).	
NOE	Code for an option used in floodway analyses (see fig. 51).	
NPR	Number of profiles to be computed for a reach (fig. 10: #1 CARD).	
NPTS	Number of sets of coordinates coded to describe a cross section (see fig. 10: #3 CARD).	
NSA	Number of subareas in a cross section (see fig. 1 and fig. 10: #3 CARD, TYPE≠3 or 4).	
NSEG	Number of segments in an embankment cross section (see fig. 10: #3 CARD, TYPE = 4 and figs. 20–22).	
NXS	Total number of cross sections coded to describe the entire reach (see fig. 10: #1 CARD).	
n_i	Manning's roughness coefficient for the i^{th} subarea of a cross section (see fig. 1).	$ft^{1/6}$
n_1	Manning's roughness coefficient applicable at or below the hydraulic depth, b (see fig. 1 and fig. 10: #6 CARD).	$ft^{1/6}$
n_3	Manning's roughness coefficient applicable at or above the hydraulic depth, a (see fig. 1 and fig. 10: #6 CARD).	$ft^{1/6}$
P	Total wetted perimeter of a cross section (see fig. 32).	ft
PIER	Code to indicate the shape and configuration of piers in a bridge opening (see fig. 10: #3 CARD, TYPE = 3 and fig. 18).	
p_i	Wetted perimeter of the i^{th} subarea of a cross section (see fig. 1).	ft
QAVG	Average discharge through a subreach (see fig. 2).	ft^3/s
QBO	Discharge through a bridge opening (see figs. 4–6 and 9).	ft^3/s
QC	Critical-flow discharge (see fig. 3).	ft^3/s
QD	Discharge at the downstream cross section of a subreach (see fig. 2).	ft^3/s
QERR	Difference between QTC and QT (see fig. 9).	ft^3/s
QRL	Embankment oveflow to the left of the KQ-section centerline (see figs. 7 and 9).	ft^3/s
QRR	Embankment overflow to the right of the KQ-section centerline (see figs. 7 and 9).	ft^3/s
QT	Total specified discharge (see figs. 1 and 9).	ft^3/s
QTC	Total computed discharge for a bridge situation (see fig. 9).	ft^3/s
QTOL	Allowable tolerance (in percent) between QTC and QT (see fig. 9 and fig. 10: #3 CARD, TYPE = 4).	
QU	Discharge at the upstream cross section of a subreach (see fig. 2).	ft^3/s
Q1,Q2, . . . , Q20	Specified discharges for profile numbers 1, 2, . . . , 20 (see fig. 10: #4 CARD).	ft^3/s
q_i	Discharge over incremental length of an embankment (see fig. 7).	ft^3/s
RDEL	Average elevation of an incremental length of an embankment (see fig. 7).	ft
RDWID	Width of an embankment transverse to the direction of flow (see fig. 7 and fig. 10: #3 CARD, TYPE = 4).	ft
REW	Horizontal station at right edge of water in a cross section (see figs. 32 and 33).	ft
Road Elev.	Elevation of specified point in an embankment cross section (see fig. 10: #5 CARD, TYPE = 4 and fig. 23).	ft
r_i	Hydraulic radius of the i^{th} subarea in a cross section (see fig. 1).	ft
SA	Individual subarea number (see fig. 1 and fig. 10: #5 CARD, TYPE ≠ 3 or 4).	
SAL	For approach cross section (see figs. 16 and 17), the highest subarea number to the left of the KQ-section. For floodway analyses (see fig. 52), the highest subarea number to the left of the area to be excluded from encroachment (see fig. 10: #3 CARD, TYPE ≠ 2, 3 or 4).	
SAR	For approach cross section (see figs. 16 and 17), the lowest subarea number to the right of the KQ-section. For floodway analyses (see fig. 52), the lowest subarea number to the right of the area to be excluded from encroachment (see fig. 10: #3 CARD, TYPE ≠ 2, 3, or 4).	

Symbol	*Definition*	*Units*
SECID	Alphanumeric code to identify a cross section (fig. 10: #3 CARD).	
SEG	Individual segment number in an embankment cross section (see fig. 10: #5 CARD, TYPE = 4 and figs. 20–22).	
SEGL	The highest segment number to the left of the KQ-section centerline for which embankment overflows will be computed (see fig. 10: #3 CARD, TYPE = 4 and figs. 20–22).	
SEGR	The lowest segment number to the right of the KQ-section centerline for which embankment overflow will be computed (see fig. 10: #3 CARD, TYPE = 4 and figs. 20–22).	
SEQUENCE	Sequence number of data cards (see figs. 10 and 51).	
SKEW	Angle of skew of bridge opening relative to direction of flow (see fig. 10: #3 CARD, TYPE = 2 and fig. 12).	degrees
Station	Horizontal station specified for each ground point in a cross section (see fig. 10: #5 CARD, TYPE ≠ 3 and fig. 11).	ft
SUBEL	Mean low-chord elevation of a bridge opening (see fig. 5 and fig. 10: #3 CARD, TYPE = 2).	ft
T	Subscript indicating total cross-section properties (see fig. 3).	
TOL	Allowable error in ACC (see fig. 10: #1 CARD).	ft
TYPE	Code indicating the kind of cross-section data (see fig. 10: #3 CARD).	
T1,T2, . . . , T10	Code to indicate type of embankment surface for segment numbers 1, 2, . . . , 10 see fig. 10: #3 CARD, TYPE = 4).	
V	Mean velocity in a cross section (see fig. 1).	ft/s
VER	Code for an option used in floodway analyses (see fig. 51).	
VH	Velocity head (see fig. 1).	ft
VHB	Velocity head in a bridge opening (see fig. 4).	ft
VHD	Velocity head computed for an elevation of WSD (see fig. 2).	ft
VHD	Code for an option used in floodway analyses (see fig. 51).	
VHU	Velocity head computed for an elevation of WSU (see fig. 2).	ft
VSA	Code for an option used in floodway analyses (see fig. 51).	
Width	Gross width of piers projected normal to flow direction (see fig. 10: #5 CARD, TYPE = 3 and figs. 18–19).	ft
WS	Water-surface elevation.	ft
WSD	Water-surface elevation at the downstream cross section in a subreach (see fig. 2) or at the exit cross section in a bridge situation (see figs. 4–6).	ft
WSRD	Water-surface elevation at the centerline of an embankment (see fig. 7).	ft
WSU	Water-surface elevation at the upstream cross section in a subreach (see fig. 2) or at the approach cross section in a bridge situation (see figs. 4–6).	ft
WW	Code to indicate wingwall configuration (see fig. 10: #3 CARD, TYPE = 2).	
w	Wingwall angle (see fig. 12).	degrees
Y	Specified surcharge for a floodway analysis (see fig. 51: #9 CARD).	ft
YU	Estimated hydraulic depth of an approach cross section (see fig. 5).	ft
Z	Hydraulic depth of a bridge-opening cross section (see fig. 5).	ft
Δh	Elevation increment for computing cross-section properties (see fig. 10: #1 CARD).	ft
ΔK	Pier component of bridge-loss coefficient for contraction ratio equal to zero (see fig. 18).	
α	Kinetic energy (velocity head) correction coefficient (see fig. 1).	
ϕ	Acute angle between plane of bridge opening and line of flow direction (see fig. 18).	degrees
σ	Factor to adjust ΔK for contraction ratio not equal to zero (see fig. 18).	
Σ	Summation of values.	
$<$	Less than.	
$\leqslant$	Less than or equal to.	
$>$	Greater than.	
$\geqslant$	Greater than or equal to.	
$\neq$	Not equal to.	

APPENDIX

APPENDIX

USER INFORMATION FOR COMPUTER PROGRAM E431

FUNCTION

This program is used to compute water-surface profiles for gradually varied subcritical flow by means of the standard step method. It includes provision for computing water-surface profiles in the vicinity of bridges, including bridges at which there is embankment overflow. The program also is used in floodway analyses, for definition of that part of a watercourse required to convey a specified discharge without exceeding a specified surcharge. Various types of flood-plain encroachment are explained.

INPUT

All input data are on cards prepared in the formats of USGS Forms 9-1891A and 9-1891B. Input data are extensively edited before computations, and messages and warning flags resulting from numerical editing are tabulated to indicate errors, possible errors, and abortive errors. Messages define the problem, describe the E431 program action, and outline the user response to the messages.

Messages resulting from profile computations describe the problem; any intermediate results and the action taken by the computer; and suggested user response.

JCL INFORMATION FOR USGS USERS

The cataloged procedure for computing and printing water-surface profile information has been stored in the WRD system library as procedure SWBWFA. The procedure only contains JCL for E431 and may be executed using the following cards:

```
/*RELAYbbPUNCHbRE2
//xxxxxxxxbJOBb(xxxxxxxxx,E431,--,--),
      'xxxxxxxxxx',CLASS=x
/*PROCLIBbbWRD.PROCLIB
//bEXECbSWBWFA
//STEP1.FT05F001bDDb*
      INPUT DATA CARDS FOR PGM. E431
                  .
                  .
                  .
/*
//
$$$
```

The execution time coded within the procedure is 2 minutes, which is sufficient for most runs. To increase the execution time, code the EXEC card as follows:

```
//bEXECbSWBWFA,TIME1=time
```

where "time" is the execution time (minutes) required.

A special option is available whereby cross-section properties can be obtained for each subsection of each cross section (see p. 39, "Subarea Properties", and table 5). This option, when exercised, will multiply the printed output lines many fold (it might also increase execution time). To increase the number of lines of printout, the appropriate change should be made on the JOB card.

PROGRAM INFORMATION FOR NON-USGS USERS

Program E431 is written in FORTRAN IV for the IBM 360 and 370 computer series. The following cards are required to run program E431:

```
  ***JOB CARD***
//EXEC PGM=E431,REGION=150K,TIME=2
//FT06F001 DD SYSOUT=A
//FT11F001 DD SPACE=(2844,(99),,CONTIG),
//      DCB=(RECFM=VS,BLKSIZE=2844),
//      UNIT=SYSDK
//FT12F001 DD SPACE=(2844,(99),,CONTIG),
//      DCB=(RECFM=VS,BLKSIZE=2844),
//      UNIT=SYSDK
//FT13F001 DD SPACE=(100,(150),,CONTIG),
//      DCB=(RECFM=VS,BLKSIZE=100),
//      UNIT=SYSDK
//FT05F001 DD *

  ***DATA CARDS***

/*
//
```

where

FT05F001 is a card reader,
FT06F001 is a printer,
FT11F001 is a temporary work file on the disk,
FT12F001 is a temporary work file on the disk, and
FT13F001 is a temporary work file on the disk.

Program execution time will vary, of course, with different computer systems. Different computer systems should not significantly change the output requirements. Additional consideration must be given to JCL requirements if E431 is to be used on a non-USGS computer system. E431 utilizes three direct-access files on magnetic disk for intermediate input/output and temporary storage. These files are assigned logical unit numbers 11, 12, and 13. Space allocation for these logical units within the JCL must be compatible with the DEFINE FILE specification statement in the source program. Thus the user must allocate space for direct-access files on magnetic disk as follows:

1) 99 contiguous records with a length of 2,844 storage locations (bytes) for each of file 11 and file 12, and
2) 150 contiguous records with a length of 100 storage locations (bytes) for file 13.

Program E431 uses logical unit numbers 5 and 6 for card input and printed output, respectively. It requires a corė REGION=150K.

E431 may not be totally compatible with non-IBM computer systems. The primary factors affecting compatibility are:

1) the direct-access input/output,
2) data editing relies heavily upon an IBM machine-language subroutine, REREAD, which allows repeated access to a card image,
3) another IBM maching-language subroutine, JULDAT, provides the current date which is printed on each page of output, and
4) the E431 source deck does not fully adhere to ANS FORTRAN programing conventions.

The user must accept total responsibility for conversion of E431 to non-USGS and(or) non-IBM computers.

COMPUTATION CONSIDERATIONS

Program execution time and lines of printed output for a single E431 job are dependent upon several factors, the most influential of which are:

1) number of reaches in the job,
2) number of cross sections within each reach,
3) number of bridge situations within each reach,
4) number of elevations within each cross section for which cross-section properties are computed and printed,
5) number of profiles computed for each reach,
6) type of profiles computed (normal or floodway), and
7) whether or not there are any data-editing and(or) computational problems.

There is no practical means of combining all pertinent factors into some easy formula to predict time and output requirements. Therefore, the following paragraphs present the execution time and lines of output for two relatively typical examples. These rough benchmark results, along with experience gained through using E431, should provide users with means for making reasonable estimates.

An E431 backwater analysis performed on the IBM 370-155 computer consisted of a single reach defined by 27 cross sections. There were three bridge situations in the reach, all requiring the optional cross sections to define both piers and embankments. The number of elevations for which cross-section properties were computed and printed averaged 30 per cross section for 21 cross sections (27 total cross sections minus 3 pier and 3 embankment cross sections). Normal profiles were computed for four different discharges. There were no data-editing or computational problems. This job used about 30 seconds of computer time and resulted in about 1700 lines of output.

An E431 floodway analysis was performed on the same reach. Four profiles were computed using the same discharge for each profile. The first profile was for existing conditions (normal profile) followed by three floodway profiles, each with a different specified surcharge. Each floodway profile permitted unconstrained modification (VER option) of all 18 encroachable cross sections (27 total cross sections minus the 9 bridge-opening, pier, and embankment cross sections). There were no data-editing or computational problems. This job used slightly more than 1 minute of computer time and resulted in about 4100 lines of printed output. The additional time and output are due to the cross-section modifications and the computation and printout of cross-section properties for each modified cross section for each of the floodway profiles.