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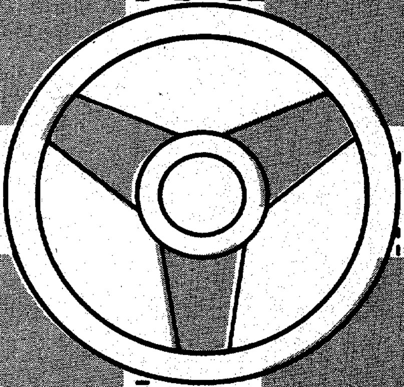
Electronic Computer Program For

HYDRAULIC ANALYSIS OF BOX CULVERTS

(BPR PROGRAM HY-3)

Developed by:
U. S. DEPARTMENT OF COMMERCE
Bureau of Public Roads



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HYDRAULIC ANALYSIS OF BOX CULVERTS

Program Developed by

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ABSTRACT

This program is used for the hydraulic analysis of box culverts for given hydrological data and site conditions. The program determines the size of culvert which satisfies the hydrological data and site conditions for inlet control and outlet control. The output includes: number of barrels, culvert width, culvert height, headwater and outlet velocities. Outlet control calculations make use of backwater calculations, whenever necessary, to compute headwater.

STATEMENT OF THE PROBLEM

This program, Hydraulic Analysis of Box Culverts, is an addition to the family of computer programs written to assist engineers in making hydraulic analyses of culverts for highway drainage. The other programs in this family are: BPR HY-1, Hydraulic Analysis of Circular Culverts 1/; and BPR HY-2, Hydraulic Analysis of Pipe-Arch Culverts 2/.

The advantages of using this electronic computer program can be fully appreciated on highway projects requiring the construction of many box-type culverts or for checking culvert dimensions in review of drainage plans. Here the time spent on engineering is reduced considerably. Also the output of efficient culvert designs enable effective and economic use of materials. Another advantage is that headwater is computed for a quantity of water flowing through the culvert other than that amount used as design flood. This gives the engineer an added check on the culvert dimensions determined by the program. Headwater is the depth to which water ponds at a culvert entrance. It should be remembered, however, that benefits from this program are not limited to the use of the program on projects involving many culverts. Benefits can be realized, as well, on single and isolated cases.

Since there are no given or manufactured sizes of box culverts, the width and height dimensions must be determined by the engineer. In order to arrive at a shape or size that is hydraulically efficient, the engineer generally selects a height for a culvert that is less than or equal to the width dimension of the structure and yet larger than one-half of the width dimension. This program will determine culvert cross-sectional details to the nearest foot for an engineer by using the same technique.

This program is based on the principles discussed in Hydraulic Engineering Circular No. 5 by L. A. Herr 3/. In that circular, nomographs are used for determining the headwater. Because of the inability of the computer to handle nomographs or curves directly, the nomographs have been replaced by mathematical equations. These equations appear under the section titled MATHEMATICAL EQUATIONS. A backwater routine has been included in the program for part-full conditions in outlet control. Backwater computations define points along a free-water surface within the culvert.

1/ "Hydraulic Analysis of Circular Culverts", BPR Program No. HY-1, by R. C. Tennent and L. A. Herr, U. S. Department of Commerce, Bureau of Public Roads, 1962.

2/ "Hydraulic Analysis of Pipe-Arch Culverts", BPR Program No. HY-2, by R. C. Tennent, L. A. Herr, and W. H. Collins, U. S. Department of Commerce, Bureau of Public Roads, 1963.

3/ "Hydraulic Charts for the Selection of Highway Culverts", Hydraulic Engineering Circular No. 5, by L. A. Herr, U. S. Department of Commerce, Bureau of Public Roads, 1961.

DESCRIPTION OF PROGRAM

The first action of the program is to read and store the input data for a particular culvert problem. Once a problem is read and the data stored within the computer, certain tests are made on the data to determine if the data are valid. If the data are invalid, an invalid data message is printed and the problem is bypassed by the program.

The remaining functions of the program can best be described in the following four phases: 1) Inlet Control, 2) Outlet Control for Inlet Dimensions, 3) Outlet Control, and 4) Inlet Control for Outlet Dimensions.

It is beyond the scope of this report to define inlet control and outlet control. The hydraulic circular by L. A. Herr that was mentioned earlier, is an excellent reference for the discussion of inlet control, outlet control and other factors related to culvert flow.

Inlet Control

This phase of the program begins by determining approximate culvert dimensions using equations (1) and (2). After the dimensions are computed, the trial height of culvert is tested. If the height is greater than the allowable headwater, the number of barrels is incremented by one. Then the approximate culvert dimensions are computed again using a discharge equal to the design discharge divided by the number of barrels. If the number of barrels exceeds a given amount, such as five barrels, an excessive number of barrels message is printed by the computer. Next, headwaters are computed, using equation (3), that will bracket the allowable headwater. This is accomplished by comparing the last computed headwater, WHW, against the allowable headwater, AHW. If WHW is less than or equal to AHW, the culvert dimensions are decremented. If WHW is greater than AHW, the culvert dimensions are incremented. Until the AHW is bracketed the culvert size is changed and a new headwater is computed. Thus two box culverts are stored for output, one with a headwater above the allowable headwater and one with a headwater equal or below the allowable headwater. This assures a selection of box culverts that have headwaters closest to the allowable headwater.

During the Inlet Control phase there are times when two box culverts, bracketing the allowable headwater, differ in the number of required barrels. When this occurs a complete set of answers is computed for each of the two number of barrels selected. This is done by using the number of barrels and discharge selected in each case as input

for the approximate culvert dimension equations (1) and (2) and by lifting the restriction that the culvert height must not exceed the allowable headwater. See example problem 6.

The velocities in each box are computed for output from equation (4). Equation (5) is solved by an iteration process to obtain the normal depth in the culvert for computing the area used in the velocity equation. At this point in the program, inlet control results are printed for design discharge. The design discharge and tailwater are replaced by a check discharge and tailwater. New headwaters and velocities are then computed for the two sizes previously selected and inlet control results are printed for the check discharge. This check-value routine is repeated at the end of each of the four phases.

Outlet Control for Inlet Dimensions

Outlet control results are computed for the culvert dimensions as determined by inlet control conditions. The results are computed much like those in the Outlet Control phase which follows. However, since the dimensions are given, the culvert selection part of the routine is bypassed. These answers are necessary because the culvert dimensions determined in the Outlet Control phase may be different from those of the Inlet Control phase. Thus, the headwater values for each condition can not be compared by the engineer. The results from this phase are printed and Outlet Control is initiated.

Outlet Control

Culvert dimensions are selected in Outlet Control using a method much like that used in Inlet Control. The initial culvert dimensions used are the base and height of one of the culvert sizes selected during Inlet Control. Normal depth is computed by means of equation (5) and an iteration process. Then the hydraulic head based on full flow is computed by using equation (6). Headwater is computed using equation (8) with the conditions shown below the equation.

Next, critical depth is computed using equation (7). Critical depth is set equal to the culvert height when the result of equation (7) is greater than the culvert height. If the headwater is positive, a test is made to determine whether the culvert is flowing full or with a free water surface by the use of equation (9). If the computed headwater, WHW, is equal to or greater than the result of equation (9), the culvert is considered to be flowing full. For a negative or zero headwater, or for WHW less than the result of equation (9), the normal depth is compared to critical depth. Inlet control governs when normal

depth is less than critical depth. A message is printed when this occurs as shown in example problem 5. If normal depth is equal or greater than critical depth, however, a water surface profile known as a backwater curve must be computed.

Inasmuch as the occurrence of either one of two different backwater curves is possible, it is necessary that the tailwater be compared with critical depth and normal depth to ascertain the appropriate curve. When tailwater is equal to or less than critical depth or normal depth, equations (10) and (11) are to be used in computing the water surface profile. When tailwater is greater than normal depth and critical depth, equations (11) and (12) are used in computing the water surface profile.

After backwater computations are completed, the headwater is computer using equation (9) with D and V taken at the previous cross section. Outlet Velocity is computed from equation (13). The results are printed, check values are also computed and printed, and the fourth phase is begun.

Inlet Control for Outlet Dimensions

As in Outlet Control for Inlet Dimensions, the selection of a new culvert size is bypassed in the program. Inlet control results are computed for the culvert sizes that were selected during outlet control.

These four sets of results should give the engineer sufficient information to enable him to select the culvert best suited for a given condition.

MATHEMATICAL EQUATIONS

Inlet Control

Approximate Box Dimensions

$$B = (Q/AHW)^{1/2} \qquad (1)$$

$$D = B/2 \qquad (2)$$

Where: B = width in feet

Q = discharge in cubic feet per second

AHW = allowable headwater in feet

D = height of culvert in feet

Headwater

$$HW = (D)(Y) - (S)(SCORR) \qquad (3)$$

Where: HW = headwater in feet

D = height of culvert in feet

$Y = a+bX+cX^2+dX^3+eX^4+fX^5$

a, b, c, d, e, f = coefficients determined by polynomial curve fitting

S = slope of culvert in feet per foot

$SCORR$ = slope correction factor

$X = Q/[(B)(D)]^{3/2}$

Q = discharge in cubic feet per second

B = width in feet

The coefficients in the equation were determined by a computer program[4] which fitted a polynomial curve by the method of least squares to data taken from the nomographs (Chart 12) for inlet control in Hydraulic Engineering Circular No. 5. They can be found in Table 3, page 16.

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[4] "Least Squares Polynomial Curve Fitting", by R. C. Tennent, U. S. Department of Commerce, Bureau of Public Roads, Library Program M-1, Washington 25, D. C., 1962.

Outlet Velocity

$$V = Q/A \qquad (4)$$

$$A = Q/[(1.468/n)(R^{2/3} S^{1/2})] \qquad (5)$$

Where: V = outlet velocity in feet per second

Q = discharge in cubic feet per second

A = cross-sectional area of water in square feet at any depth of flow

R = hydraulic radius in feet

S = slope of culvert in feet per foot

n = Manning's roughness factor

Outlet Control

Head

$$H = (Q/10)^2 [(1.555 (K_e + 1.0)/A^2) + (45.095n^2L/(A^2R^{4/3}))] \qquad (6)$$

Where: H = head in feet for culvert flowing full

Q = discharge in cubic feet per second

K_e = coefficient for entrance loss

A = total cross-sectional area of box

n = Manning's roughness factor

L = length of culvert in feet

R = hydraulic radius in feet

Critical Depth

$$D_c = 0.315(Q/B)^{2/3} \qquad (7)$$

Where: D_c = critical depth in feet

Q = discharge in cubic feet per second

B = width of box in feet

Headwater

$$HW = HO + H - (S)(L) \tag{8}$$

Where: HW = headwater in feet

H = head for full flow in feet

S = slope of culvert in feet per foot

L = length of culvert in feet

HO = design tailwater or $(D_c + D)/2$ whichever is greater

D_c = critical depth in feet

D = height of culvert in feet

The critical depth cannot exceed the height of the box.

$$HW = D + (1 + K_e)\ V^2/2g \tag{9}$$

Where: HW = headwater in feet

K_e = coefficient for entrance loss

D = height of culvert in feet

V = mean velocity for full cross section of barrel in feet per second

Backwater (water surface profile for normal depth greater than or equal to critical depth)

$$Xl = [(d_2 + V_2^2/2g) - (d_1 + V_1^2/2g)]/(S - S_o) \tag{10}$$

Where: Xl = distance in feet between two different cross sections

d_1, d_2 = depths of water in feet at cross sections 1 and 2

V_1, V_2 = velocities in feet per second at sections 1 and 2

S_o = slope of the culvert in feet per foot

g = 32.2 ft./sec.^{2}

$S = n^2V^2/(2.21R^{4/3})$, average slope of the water surface between cross sections 1 and 2 in feet per foot (11)

n = Manning's roughness factor

V = average velocity in feet per second of the two cross sections

R = average hydraulic radius in feet of the two cross sections

$$X1 = [(d_1 + V_1^2/2g) - (d_2 + V_2^2/2g)]/(S_o - S) \quad (12)$$

Outlet Velocity

$$V = Q/A \quad (13)$$

Where: V = outlet velocity in feet per second

Q = discharge in cubic feet per second

A = cross-sectional area of water in square feet

When: $DTW \geq D$, $A = (B)(D)$

$DSUBC > D$, $DSUBC = D$

$DSUBC \geq DTW$, $A = (B)(DSUBC)$

$DSUBC < DTW$, $A = (B)(DTW)$

Where: DTW = design tailwater in feet

D = height of culvert in feet

DSUBC = critical depth in feet

INPUT DATA

The input data items for the program are:

1.	Culvert code	XXXXX
2.	Slope of culvert	XX.XXX
3.	Length of culvert	XXXXX.X
4.	Design discharge	XXXXX.X
5.	Allowable headwater	XXXXX.X
6.	Design tailwater	XXXXX.X
7.	Check discharge	XXXXX.X
8.	Check tailwater	XXXXX.X

The field size and number of decimals to the right of the units position are shown to the right of each item. A more detailed discussion of the input data follows.

Culvert Code

The culvert code is a five digit number. Actually the code is a composite of five separate integers that are used by the program to define different culvert types. These five separate code integers are referred to as I1, I2, I3, I4, and I5. The symbol I1 indicates a type of culvert that the program is to analyze. Thus, for all box culverts I1 is the integer 4. Different integers are assigned to I1 for circular and pipe-arch culverts which can be analyzed by using BPR Program Nos. HY-1 1/ and HY-2 2/. Symbols I2 and I3, at the present time, are dummy values in order to keep the input consistent with culvert programs HY-1 and HY-2. The only value that can be assigned to code I2 and I3 is 1. The last two digits in the culvert code, I4 and I5, each have three values that can be assigned to them; 1, 2, or 3. I4 defines the type of wingwall and enables the program to select an appropriate value for the entrance loss coefficient. I5 also refers to a particular entrance condition and enables the program to select values from Table 3. This table consists of coefficients that are used in mathematical equations which replace the previously mentioned nomographs for inlet control. An example culvert code that might be

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1/ ibid.

2/ ibid.

used is 41133. This five digit number indicates to the program that coefficients must be used for a box culvert with parallel wingwalls. It should be mentioned here that the same input data can be used on each of the programs HY-1, HY-2, and HY-3 by simply using the appropriate culvert code in the first five card columns of the data card.

Slope of Barrel

Slope of the barrel, SLOPE, is the elevation of the invert at the inlet of the culvert minus the elevation of the invert at the outlet divided by the horizontal distance between those points. It is measured in feet per foot.

Length of Barrel

Length of barrel, DIST, is the length of the barrel measured along the invert from the inlet to the outlet in feet.

Design Discharge

Design discharge, Q1, is the quantity of water in cubic feet per second to be used in the selection of the barrel dimensions.

Allowable Headwater

Allowable headwater, AHW, is a depth of water and is measured in feet. It is the difference between the water surface elevation and the invert elevation at the entrance end of the culvert.

Design Tailwater

Design tailwater, DTW, is a depth of water in feet. The depth of water is measured between the water surface elevation and the invert elevation at the outlet end of the culvert.

Check Discharge

Check discharge, Q2, is a second quantity of water that is given in cubic feet per second. It can be used for two purposes: (1) To find a headwater for a discharge greater than the design discharge, Q1, whenever a greater flood condition needs to be investigated. (2) To obtain various headwater-discharge values that are used for plotting performance curves for the culvert sizes selected by the program for any given problem. In order to obtain several values for plotting the curve, it is necessary that the program be run for a series of problems using separate input data cards for each problem. All input data should be identical excepting check discharge, Q2, and check tailwater, CTW. The quantity Q2 can be greater than or less than the original Q1.

Check Tailwater

Check tailwater, CTW, is similar to design tailwater. The difference between check tailwater and design tailwater is that the CTW is used with the check discharge Q2.

Input Data Form

An example data form is shown on page 12. This form includes a problem sketch, space for recording basic hydrologic and channel information, along with spaces for recording information for subsequent card punching. The data form in most cases should be self-explanatory. In those cases where the form is not clear, the confusion is probably related to the problem identification card and the following comments may prove helpful. Problem identification consists of 50 characters of information, the first character of which must be the digit 1. The remaining 49 characters may be used to include such items as the project number, the centerline station number of the culvert, the date of the problem solution, and the designers name. All of this information is reproduced later on the output tabulation in order that the results may be identified whenever several problems are submitted at one time. When recording the data for the second data card it is not necessary to fill in leading or trailing zeros on the data form. See example problems for samples of completed input data forms.

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer ____________

Project: ____________________

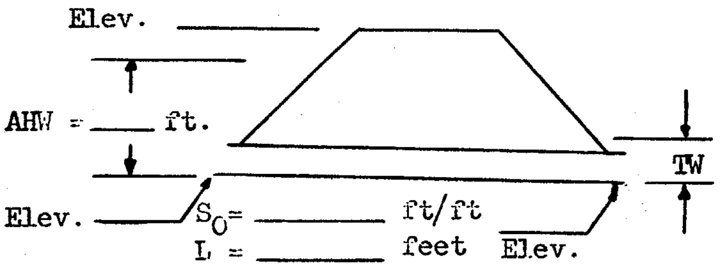
Date ____________

Hydrologic and Channel Information

Q_1 = ______ c.f.s
Q_2 = ______ c.f.s
TW_1 = ______ feet
TW_2 = ______ feet

Sketch

Station: ____________



CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
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PROBLEM IDENTIFICATION

CARD NO. 2

1	2	3	4	5		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		29	30	31	32	33		36	37	38	39	40	41	42	43	44	45	46	47		50	51	52	53	54
						•										•					•		•						•						•							•						•	
CULVERT CODE *					SLOPE OF PIPE (S_c)						LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)							ALLOWABLE HEADWATER (AHW)						DESIGN TAILWATER (TW_1)						CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)					

OUTPUT DATA

The problem identification, which was read in as input data, is printed at the top of each output sheet. See page 36. This is always followed by a listing of the input data for the problem that the designer can check.

Answers for each problem are printed under four headings: (1) Inlet Control Results, (2) Outlet Control for Inlet Dimensions, (3) Outlet Control Results, and (4) Inlet Control for Outlet Dimensions. Under each heading there are four rows of answers. The top two rows are computed from design discharge. Here the computed headwater brackets the allowable headwater. The bottom two rows are computed from the check discharge. The computed headwater for these answers need not bracket the allowable headwater.

There are six items under each heading.

Column one is the discharge in cfs.
Column two is the number of barrels.
Column three is the barrel width in feet.
Column four is the barrel height in feet.
Column five is the computed headwater in feet.
Column six is the outlet velocity in fps.

The results under each of the four headings are printed in the form discussed above. The only difference occurs when "INLET CONTROL GOVERNS" is printed instead of the values for headwater and outlet velocity for outlet control. This is printed whenever the normal depth is less than the critical depth and thus the culvert is functioning under inlet control.

The following messages indicate that something is wrong with the input data or that the answer computed is not an applicable solution:

1. ALLOWABLE HEADWATER TOO SMALL.
2. NUMBER OF BARRELS EXCEEDS FIVE.
3. CULVERT CODE INVALID.

Message number one is printed when the elevation of the headwater is not above the elevation of the tailwater by at least one-half foot. This difference of one-half foot has been set arbitrarily by the authors but may be changed merely by changing the constant in the formula for HEIT. See example problem 1.

Message number two is a check on the number of barrels being used. The number of barrels that can be used in this program has been set at five. See example problem 2. This number too can be changed to suit the needs of the user by the insertion of the desired number in the test for maximum number of barrels.

Message number three is a check to insure that a valid culvert code is submitted as input data. A table of valid culvert codes is stored in the computer. The message is printed if the code submitted as input does not match a value in the table. See example problem 3.

Table 1.

Square Edge R.C. Box Code Table

Code					Inlet Type
I1	I2	I3	I4	I5	
4	1	1	1	1	30° to 75° wingwall flair
4	1	1	2	2	90° and 15° wingwall flair
4	1	1	3	3	Parallel wingwalls

Table 2.

Associated Indicator		Table of Constants	
NONE		Velocity Distribution Factors	ALPHA = 1.00
NONE		Slope Correction Factor	SCORR = 0.50
NONE		Manning's n	CN = 0.012
		Entrance Loss Coefficients	
	= 1	30° to 75° WW	$CKE_1 = 0.40$
I4	= 2	90° and 15° WW	$CKE_2 = 0.50$
	= 3	Parallel WW	$CKE_3 = 0.70$

Table 3.

Inlet Headwater Coefficients						
I5	A	B	C	D	E	F
1	0.0724927	0.507087	-0.117474	0.0221720	-0.00148958	0.0000358431
2	0.122117	0.505435	-0.108560	0.0207809	-0.00136757	0.0000345642
3	0.144138	0.461363	-0.0921507	0.0200028	-0.00136449	0.0000380126

DEFINITION OF TERMS

AK(I5) -- The first coefficient of the fifth degree polynomial used to compute headwater over depth for inlet control. The subscript I5 refers to the particular set of coefficients to be used by the program for the type of culvert being analyzed.

BK(I5) -- The second coefficient of the polynomial used for inlet control calculations.

CK(I5) -- The third coefficient of the polynomial used for inlet control calculations.

DK(I5) -- The fourth coefficient of the polynomial used for inlet control calculations.

EK(I5) -- The fifth coefficient of the polynomial used for inlet control calculations.

FK(I5) -- The sixth coefficient of the polynomial used for inlet control calculations.

BASE(J) -- Culvert width in feet. The subscript J identifies the particular variable where there are more than one with the same name.

BBLS(J) -- Number of barrels.

CKE(I4) -- Entrance loss coefficient. The subscript I4 refers to the particular coefficient to be used by the program for the type of entrance on the culvert being analyzed.

DC(J) -- Critical depth in feet.

DPTH(J) -- Culvert height in feet.

HW(J) -- Headwater in feet.

KT(I) -- A table of valid culvert codes. The subscript I identifies the particular variable where there are more than one with the same name.

R(I) -- Hydraulic radius in feet for backwater calculations.

SPH(I) -- Specific head in feet for backwater calculations.

V(I) -- Velocity in feet per second for backwater calculations.

AHW -- Allowable headwater in feet.

ALPHA -- Velocity distribution factor.

AOVWP -- Area of the barrel to the 4/3 power over the wetted perimeter to the 2/3 power.

AREA -- Cross-sectional area of water in square feet for any depth of flow.

AVER -- Average of the hydraulic radii for backwater computations.

AVEV -- Average of the velocities for backwater computations.

B -- Culvert width in feet for intermediate computations.

BARL -- Number of barrels.

BOV2 -- The width of culvert over two.

BRLS -- Number of barrels for intermediate computations.

CLTH -- Corrected length of barrel.

CN -- Manning's (n) for natural stream channels.

CTW -- Check tailwater in feet.

D -- Height of culvert in feet for intermediate computations.

DCRM -- Amount of decrement in depth when iterating for normal depth.

DEP -- Depth of flow in feet.

DIST -- Length of the barrel in feet.

DSUBC -- Critical depth in feet for intermediate computations.

DSUBN -- Normal depth in feet.

DTW -- Design tailwater in feet.

DX1 -- The distance in feet between two cross sections for backwater computations.

HEAD -- The hydraulic head required for a given flow in outlet control measured in feet.

HEIT -- A variable used to test the validity of the AHW. HEIT equals SLOPE times DIST plus AHW minus one-half foot.

HO -- This variable is equal to the tailwater, or to one-half the sum of critical depth and the height of culvert, whichever is larger.

HR -- Hydraulic radius in feet.

HWOVD -- Headwater over depth. This is the result of the fifth degree polynomial for inlet control.

I -- An integer variable used to indicate a particular variable of a group.

I1 -- An integer variable in the culvert code used to tell the computer the type of culvert for which a size is being selected.

I2, I3 -- Integer variables used in the culvert code.

I4 -- An integer variable in the culvert code. This indicates which CKE constant is used.

I5 -- An integer variable in the culvert code. This indicates which set of constants AK, BK...FK are to be used in the fifth degree polynomial.

J -- An integer variable used to indicate a particular variable of a group.

K1, K2, ...K22 -- Integer variables used to control movement of data in the program.

KODE -- A variable computed from the culvert code to check the validity of the input data.

LTEMP -- A variable used in rounding the width and height of the culvert to even feet.

NSW1, NSW2 -- Integers used to control movement of data in the program.

Q1 -- Design discharge in cubic feet per second.

Q2 -- Check discharge in cubic feet per second.

QADJ -- Discharge in cubic feet per second for intermediate computations.

S1 -- The slope of the water surface between two cross sections for backwater computations.

SCORR -- Coefficient for slope correction.

SLOPE -- Slope of the barrel in feet per foot.

SUMX -- The accumulated distance in feet from the outlet end of the barrel for backwater computations.

TEMP -- A variable for intermediate computations.

VEL1, VEL2 -- Outlet velocities in feet per second for inlet control.

VEL3, VEL4 -- Outlet velocities in feet per second for outlet control.

WHW -- Headwater in feet for intermediate computations.

WP -- Wetted perimeter in feet for any depth of flow.

X -- The independent variable in the fifth degree polynomial for inlet control headwater calculations.

PROGRAMMING PROCEDURES

What must be done to put this program into operation? Frequently a programmer must recode an application for a computer model that is different from the computer model used for the original program. In the past it was felt that the block diagram was the most useful bit of material to be used by a programmer in this sort of task. It is now felt that a listing of a program written in a problem oriented language is just as meaningful as the flow chart. This feeling was brought about because the problem oriented coded program embraces all of the logical information shown in the typical block diagram for an engineering application.

It is hoped that the following steps will indicate how easily a production program can be developed.

1. Determine the availability of a FORTRAN compiler for the data processing system used. Study the storage capacity of the system being considered to determine whether it is adequate to handle a program of this size. The original program was developed and compiled to run on the IBM 1410 - 40K data processing system. It used 75% of the available storage for the program and the data. If a FORTRAN compiler is not available on the user's data processing system, then he must develop his own coded computer program. This can be done using the program coding system he knows the best by following the computing operations shown in the FORTRAN listing on page 24. This new program coding work will have to be done by an experienced programming technician.

2. Review the FORTRAN program listing and note necessary changes. In many cases changes in the program operations will have to be made so that the program can be compiled and run on the user's equipment. Generally, the changes that are needed will be limited to the input and output statements. Changes may be required for those operations that bring information into the system, or transfer results out of the system for the user. As an example, it may be necessary to change all PRINT statements in the attached listing to PUNCH statements because the system to be used produces results in punched card form instead of tabulating them on a printing device. The format statements included in the program that control the arrangement of information for input and output must be checked carefully. Special attention should be given to the printer carriage control codes.

3. Keypunch or type the source FORTRAN program. For punched card systems the FORTRAN statements should be keypunched into cards from the corrected program listing. The source program is then compiled on the user's system by means of the compiler program to obtain the object computer program.

4. Operate the program. For a punched card system, the addition of control cards needed by the user's system, constant cards, and data cards to the object program make the system ready for doing the hydraulic computations. The constant cards that are needed in the production runs should be keypunched according to the specification or card arrangement that is given in the FORMAT statement in the listing. The values for the various constants that are to be keypunched are to be taken from Tables 1, 2, and 3. The cards should be assembled and presented to the computer system in the order shown in figure 1.

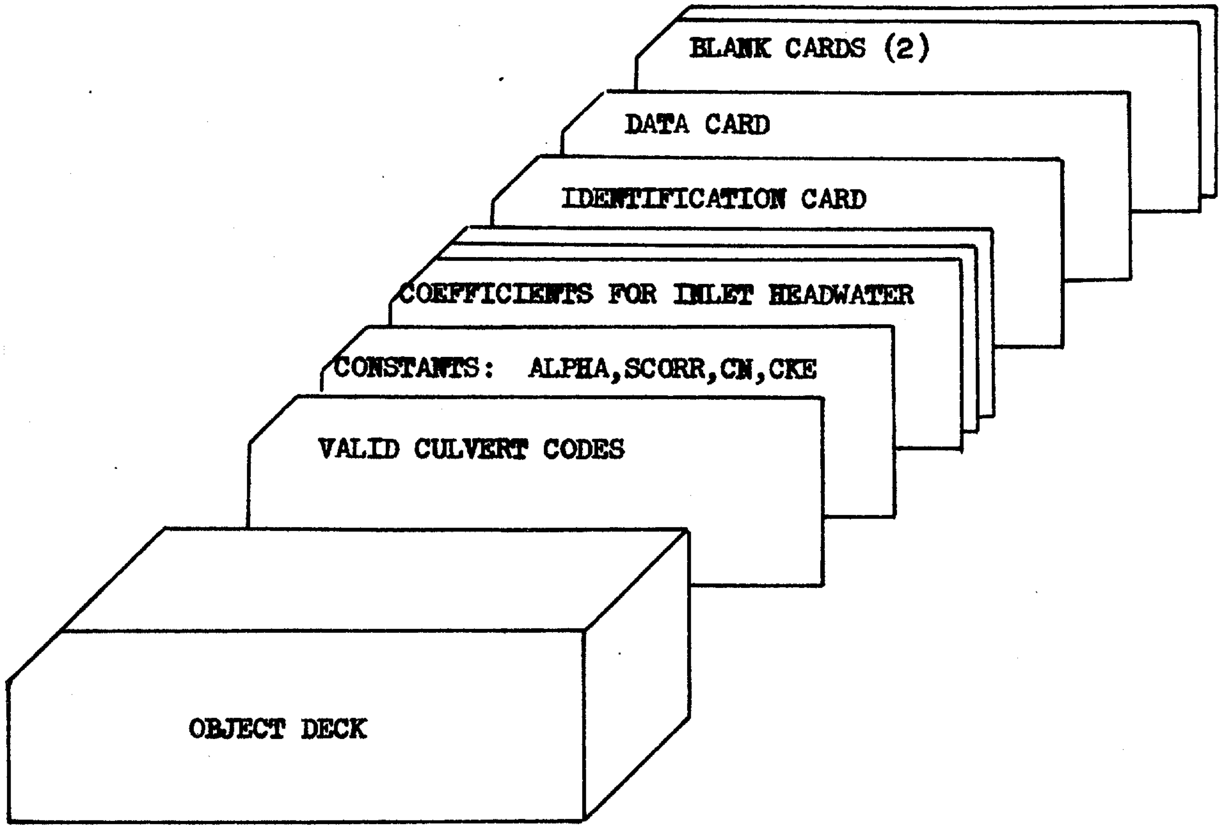


Figure 1

As shown in the figure, the card containing the valid culvert codes, obtained from Table 1, is placed at the front of the group of input cards. This is followed by the constant card containing information from Table 2. Next are the cards containing information from TABLE 3. The problem data cards are then placed behind the COEFFICENT CARDS. Each set of problem data cards consists of an identification card followed by a data card. Any number of problem sets can be used. The last two cards in the group of input cards must be blank cards. The two blank cards are needed to indicate the end of run for the program.

FORTRAN LIST

```
C          COMPUTER PROGRAM FOR HYDRAULIC ANALYSIS OF BOX CULVERTS
C          L.J. HARRISON AND J.R. LINK - BUREAU OF PUBLIC ROADS
C
      DIMENSION CKE(3),AK(3),BK(3),CK(3),DK(3),EK(3),FK(3),V(2),
     1R(2),SPH(2),HW(4),BASE(4),DPTH(4),DC(4),BBLS(4),KT(9)
C
C          READ AND STORE VALID CULVERT CODES
C
      READ 2160, (KT(I),I=1,9)
C
C          READ AND STORE HYDRAULIC COEFFICIENTS
C
      READ 2000, ALPHA, SCORR, CN, (CKE(I),I=1,3)
C
C          READ AND STORE INLET EQUATION COEFFICIENTS
C          FOR HYDRAULIC MODELS
C
      READ 2010, (AK(I),BK(I),CK(I),DK(I),EK(I),FK(I),I=1,3)
C
C          READ AND STORE PROBLEM IDENTIFICATION
C
   10 READ 2040
C
C          READ INPUT DATA.  CONSTANT INDICATORS = I1,I2,I3,I4,I5,
C          SLOPE = SLOPE, LENGTH = DIST, DESIGN DISCHARGE = Q1,
C          ALLOWABLE HEADWATER = AHW, DESIGN TAILWATER = DTW,
C          CHECK DISCHARGE = Q2, CHECK TAILWATER = CTW
C
      READ 2020, I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW
C
C          TEST FOR END OF RUN
C
      IF (I1) 20,20,30
C
C          PRINT END OF RUN
C
   20 TYPE 2030
      STOP 111
C
C          PRINT PROBLEM IDENTIFICATION
C
   30 PRINT 2040
C
C          PRINT INPUT DATA
C
      PRINT 2050, I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW
C
C          TEST FOR INVALID ALLOWABLE HEADWATER
C
      IF (AHW) 110,110,40
C
C          TEST FOR VALID CULVERT CODE
C
   40 IF (I1-4) 70,50,70
```

```
   50 KODE = I2*1000+I3*100+I4*10+I5
      DO 60 I = 1,9
      IF (KODE-KT(I)) 60,90,60
   60 CONTINUE
C
C          PRINT CULVERT CODE INVALID
C
   70 PRINT 2130
      GO TO 10
   90 SLOPE = SLOPE+0.000001
      HEIT = SLOPE*DIST+AHW-0.5
C
C          TEST FOR INVALID ALLOWABLE HEADWATER
C
      IF (HEIT-DTW) 110,110,120
C
C          PRINT ALLOWABLE HEADWATER TOO SMALL
C
  110 PRINT 2060
      GO TO 10
C
C          COMPUTE CORRECTED BARREL LENGTH
C
  120 CLTH = ((DIST*DIST)-(SLOPE*SLOPE*DIST*DIST))**.5
C
C          PRINT INLET CONTROL HEADINGS
C
  125 PRINT 2100
      PRINT 2110
C
C          INITIALIZE INLET CONTROL
C
      K1 = 0
      K2 = -1
      QADJ = Q1
      BRLS = 1.
  130 K3 = -1
      K9 = -1
      K10 = 0
      K19 = 0
  140 K4 = 0
      K5 = 0
      K6 = 0
      J = 1
      HW(1) = 999.
      HW(2) = 0.
      IF (K1) 150,150,230
C
C          COMPUTE APPROXIMATE BOX DIMENSIONS, BASE(B) AND HEIGHT(D)
C
  150 B = (QADJ/AHW)**.5
      LTEMP = B
      B = LTEMP
  160 D = .5*B
```

```
      LTEMP = D
      BOV2 = LTEMP
      IF (BOV2-D) 170,180,180
  170 D = D+.5
  180 IF (K2) 190,230,580
C
C          TEST FOR DEPTH OF BARREL GREATER THAN ALLOWABLE HEADWATER
C
  190 IF (D-AHW) 230,230,200
  200 BRLS = BRLS+1.
C
C          TEST FOR NUMBER OF BARRELS GREATER THAN FIVE
C
      IF (BRLS-5.) 220,220,210
C
C          PRINT NUMBER OF BARRELS EXCEEDS FIVE
C
  210 PRINT 2070
      GO TO 10
  220 QADJ = Q1/BRLS
      GO TO 150
C
C          INLET CONTROL COMPUTATIONS
C
  230 X = QADJ/(B*D**1.5)
      HWOVD = AK(I5)+(BK(I5)+(CK(I5)+(DK(I5)+(EK(I5)+FK(I5)*X)*X)
     1*X)*X)*X-SCORR*SLOPE
      WHW = HWOVD*D
  240 IF (K3) 250,300,310
C
C          SELECTION ROUTINE.  CULVERTS HAVING HEADWATERS
C          BRACKETING THE ALLOWABLE HEADWATER
C
  250 IF (WHW-AHW) 270,270,260
  260 IF (K4) 280,280,265
  265 IF (K6) 266,266,267
  266 NSW1 = 3
      GO TO 300
  267 NSW1 = 7
      GO TO 300
  270 IF (K5) 290,290,275
  275 IF (K6) 276,276,277
  276 NSW1 = 3
      GO TO 310
  277 NSW1 = 7
      GO TO 310
  280 K5 = 1
      NSW1 = 1
C
C          COMPARE HEADWATER WITH PREVIOUSLY STORED HEADWATER
C
      IF (WHW-HW(J)) 300,320,320
  290 K4 = 1
      NSW1 = 2
```

```
      IF (WHW-HW(J+1)) 340,340,310
  300 IF (K6) 301,301,302
  301 J = 1
      GO TO 303
  302 J = 3
C
C          STORE CULVERT SELECTED
C
  303 BASE(J) = B
      DPTH(J) = D
      HW(J) = WHW
      BBLS(J) = BRLS
      DC(J) = DSUBC
      GO TO 360
  310 J = J+1
      GO TO 303
C
C          INCREMENT BOX DIMENSIONS
C
  320 D = D+1.
      IF (D-B) 180,180,330
  330 B = B+1.
      GO TO 160
C
C          DECREMENT BOX DIMENSIONS
C
  340 D = D-1.
      BOV2 = .5*B
      IF (D-BOV2) 350,180,180
  350 B = B-1.
      D = B
      GO TO 180
  360 GO TO (320,340,370,400,510,550,990,1140,1180), NSW1
C
C          TEST SELECTED CULVERTS FOR SAME NUMBER OF BARRELS
C
  370 IF (BBLS(1)-BBLS(2)) 380,400,380
C
C          NUMBER OF BARRELS DIFFER.  SOLVE FOR BBLS(1)
C
  380 K1 = 0
      K2 = 0
      K19 = 1
      BRLS = BBLS(1)
      BARL = BBLS(2)
      QADJ = Q1/BRLS
      GO TO 140
C
C          PRINT INLET CONTROL HEADINGS
C
  390 PRINT 2100
      PRINT 2110
C
C          SOLVE FOR BBLS(2)
```

```
C
      K1 = 0
      K2 = 0
      BRLS = BARL
      QADJ = Q1/BRLS
      GO TO 130
C
C          INITIALIZE INLET CONTROL VELOCITY COMPUTATIONS
C
  400 K8 = 1
6     K21 = -1
      B = BASE(2)
      D = DPTH(2)
C
C          COMPUTE NORMAL DEPTH
C
  410 K7 = 1
      DEP = D
      DCRM = .1*DEP
  420 AREA = B*DEP
      WP = 2.*DEP+B
      TEMP = QADJ*CN/(1.486*SLOPE**.5)
      AOVWP = AREA**1.66667/(WP**.666667)
      IF (AOVWP-TEMP) 440,440,430
  430 DEP = DEP-DCRM
      K7 = 2
      GO TO 420
  440 IF (K7-2) 470,450,450
  450 IF (DCRM-.03) 470,470,460
  460 DEP = DEP+DCRM
      DCRM = .1*DCRM
      DEP = DEP-DCRM
      GO TO 420
  470 IF (K21) 475,585,585
C
C          COMPUTE INLET CONTROL VELOCITY
C
  475 VEL1 = QADJ/AREA
      IF (K8-2) 480,490,490
  480 VEL2 = VEL1
      B = BASE(1)
      D = DPTH(1)
      K8 = 2
      GO TO 410
C
C          PRINT INLET CONTROL RESULTS
C
  490 PRINT 2080, QADJ, BBLS(1), BASE(1), DPTH(1), HW(1), VEL1
      PRINT 2080, QADJ, BBLS(2), BASE(2), DPTH(2), HW(2), VEL2
      IF (K9) 500,540,1190
C
C          INITIALIZE INLET CHECK DISCHARGE COMPUTATIONS
C
  500 QADJ = Q2/BRLS
```

```
      K3 = 0
      NSW1 = 5
      GO TO 230
  510 B = BASE(2)
      D = DPTH(2)
      K3 = 1
      NSW1 = 4
      IF (K10) 520,520,530
  520 K9 = 0
      GO TO 230
  530 K9 = 1
      GO TO 230
C
C           PRINT HEADINGS FOR OUTLET CONTROL FOR INLET DIMENSIONS
C
  540 PRINT 2150
      PRINT 2110
C
C           INITIALIZE OUTLET CONTROL FOR INLET DIMENSIONS
C
      K3 = 0
      NSW1 = 6
      NSW2 = 1
      GO TO 561
  550 B = BASE(2)
      D = DPTH(2)
      K3 = 1
      K18 = 1
      K20 = 0
      NSW1 = 7
      GO TO 580
C
C           PRINT OUTLET CONTROL HEADINGS
C
  560 PRINT 2120
      PRINT 2110
C
C           INITIALIZE OUTLET CONTROL
C
      K2 = 1
      K3 = -1
      K4 = 0
      K5 = 0
      K20 = 1
      NSW2 = 2
      HW(3) = 999.
      HW(4) = 0.
      B = BASE(1)
      D = DPTH(1)
  561 QADJ = Q1/BRLS
      J = 3
      K6 = 1
      K11 = 0
      K13 = 0
```

```
      K14 = 0
      K16 = 0
      K17 = -1
      K18 = 0
      GO TO 580
  570 B = BASE(2)
      D = DPTH(2)
C
C           OUTLET CONTROL COMPUTATIONS
C
  580 K21 = 0
      GO TO 410
  585 DSUBN = DEP
      AREA = B*D
      HR = AREA/(2.*(D+B))
      HEAD = (QADJ/10.)*(QADJ/10.)*((1.555*(1.+CKE(I4)))/(AREA*
     1AREA)+(45.095*CN*CN*DIST/(AREA*AREA*HR**1.333333)))
      DSUBC = .315*(QADJ/B)**.666667
      IF (DSUBC-D) 630,630,620
  620 DSUBC = D
  630 TEMP = (DSUBC+D)/2.
      IF (DTW-TEMP) 640,640,650
  640 HO = TEMP
      GO TO 655
  650 HO = DTW
  655 WHW = HO+HEAD-SLOPE*CLTH
  660 IF (WHW) 710,710,690
  690 TEMP = D+(1.+CKE(I4))*((QADJ*QADJ)/(64.4*AREA*AREA))
      IF (WHW-TEMP) 710,700,700
  700 IF (K11) 705,705,960
  705 K13 = K13+1
      GO TO 240
  710 K22 = 0
C
C           TEST FOR INLET CONTROL GOVERNS
C
      IF (DSUBN-DSUBC) 830,720,720
  720 IF (DTW-DSUBC) 730,730,725
  725 IF (DTW-DSUBN) 740,740,735
  730 DEP = DSUBC
      GO TO 750
  735 K22 = 1
  740 DEP = DTW
  750 I = 1
      SUMX = 0.
C
C           BACKWATER COMPUTATIONS
C
  760 AREA = DEP*B
      V(I) = QADJ/AREA
      SPH(I) = DEP+ALPHA*V(I)*V(I)/64.4
      R(I) = AREA/(2.*DEP+B)
      IF (DEP-D) 770,700,700
  770 IF (I-2) 780,790,790
```

```
 780 I = 2
     IF (K22) 781,781,782
 781 DEP = DEP+.2
     GO TO 760
 782 DEP = DEP-.2
     GO TO 760
 790 AVEV = (V(1)+V(2))/2.
     AVER = (R(1)+R(2))/2.
     S1 = CN*CN*AVEV*AVEV/(2.21*AVER**1.33333)
     IF (K22) 795,795,796
 795 IF (S1-SLOPE) 800,800,810
 796 IF (SLOPE-S1) 800,800,811
 800 SPH(2) = SPH(1)
     WHW = SPH(2)+CKE(I4)*V(1)*V(1)/64.4
     GO TO 700
 810 DX1 = (SPH(2)-SPH(1))/(S1-SLOPE)
     GO TO 812
 811 DX1 = (SPH(1)-SPH(2))/(SLOPE - S1)
 812 SUMX = SUMX+DX1
     IF (SUMX-CLTH) 820,800,800
 820 V(1) = V(2)
     SPH(1) = SPH(2)
     R(1) = R(2)
     GO TO 780
 830 IF (K13) 890,890,840
 840 IF (K14) 850,850,880
 850 IF (K5)  860,860,870
 860 BASE(3) = BASE(4)
     DPTH(3) = DPTH(4)
     HW(3) = HW(4)
     BBLS(3) = BBLS(4)
 870 BASE(4) = B
     DPTH(4) = D
     K16 = 1
     NSW2 = 3
     GO TO 990
 880 K16 = 1
     IF (K20) 881,881,882
 881 NSW2 = 6
     GO TO 990
 882 NSW2 = 5
     GO TO 990
 890 IF (K14-1) 900,920,930
C
C          PRINT INLET CONTROL GOVERNS
C
 900 PRINT 2090, QADJ, BRLS, B, D
     K11 = K11+1
     K14 = K14+1
 910 GO TO (550,570,1100,1140,1170,560), NSW2
 920 NSW2 = 3
     BASE(3) = BASE(1)
     DPTH(3) = DPTH(1)
     BASE(4) = BASE(2)
```

```
      DPTH(4) = DPTH(2)
      GO TO 900
  930 IF (K14-3) 940,950,950
  940 NSW2 = 4
      GO TO 900
  950 IF (K20) 951,951,952
  951 NSW2 = 6
      GO TO 900
  952 NSW2 = 5
      GO TO 900
  960 BASE(4) = B
      DPTH(4) = D
      DC(4) = DSUBC
      HW(4) = WHW
      K15 = 3
      IF (K14-1) 970,970,980
  970 BASE(3) = BASE(1)
      DPTH(3) = DPTH(1)
      NSW2 = 3
      GO TO 1000
  980 IF (K20) 981,981,982
  981 NSW2 = 6
      GO TO 1000
  982 NSW2 = 5
      GO TO 1000
C
C           INITIALIZE OUTLET CONTROL VELOCITY COMPUTATIONS
C
  990 DSUBC = DC(3)
      B = BASE(3)
      D = DPTH(3)
      K15 = 1
C
C           COMPUTE OUTLET CONTROL VELOCITY
C
 1000 IF (DSUBC-D) 1010,1020,1020
 1010 IF (DTW-D) 1030,1020,1020
 1020 AREA = B*D
      GO TO 1060
 1030 IF (DSUBC-DTW) 1050,1050,1040
 1040 AREA = B*DSUBC
      GO TO 1060
 1050 AREA = B*DTW
 1060 VEL4 = QADJ/AREA
      IF (K15-2) 1070,1090,1160
 1070 VEL3 = VEL4
      IF (K16) 1080,1080,1150
 1080 DSUBC = DC(4)
      B = BASE(4)
      D = DPTH(4)
      K15 = 2
      GO TO 1000
C
C           PRINT OUTLET CONTROL RESULTS
```

```
C
 1090 PRINT 2080, QADJ, BRLS, BASE(3), DPTH(3), HW(3), VEL3
      PRINT 2080, QADJ, BRLS, BASE(4), DPTH(4), HW(4), VEL4
      K14 = K14+2
      IF (K17) 1100,1170,1105
C
C          INITIALIZE OUTLET CHECK DISCHARGE COMPUTATIONS
C
 1100 QADJ = Q2/BRLS
      B = BASE(3)
      D = DPTH(3)
 1105 TEMP = DTW
      DTW = CTW
      CTW = TEMP
      IF (K17) 1106,1106,560
 1106 K3 = 0
      NSW1 = 8
      IF (K18) 1110,1110,1120
 1110 K17 = 0
      GO TO 1130
 1120 K17 = 1
 1130 K11 = 0
      K13 = 0
      GO TO 580
 1140 B = BASE(4)
      D = DPTH(4)
      K3 = 1
      NSW1 = 7
      GO TO 580
 1150 B = BASE(4)
      D = DPTH(4)
C
C          PRINT OUTLET CONTROL RESULTS WHEN DIMENSIONS(4) INVALID
C
      PRINT 2080, QADJ, BRLS, BASE(3), DPTH(3), HW(3), VEL3
      K14 = K14+1
      K16 = 0
      GO TO 900
C
C          PRINT OUTLET CONTROL RESULTS WHEN DIMENSIONS(3) INVALID
C
 1160 PRINT 2080, QADJ, BRLS, BASE(4), DPTH(4), HW(4), VEL4
      K14 = K14+1
      GO TO 910
C
C          PRINT HEADINGS FOR INLET CONTROL FOR OUTLET DIMENSIONS
C
 1170 PRINT 2140
      PRINT 2110
C
C          INITIALIZE INLET CONTROL FOR OUTLET DIMENSIONS
C
      J = 1
      K3 = 0
```

```
      K6 = 0
      K9 = -1
      K10 = 1
      NSW1 = 9
      QADJ = Q1/BRLS
      B = BASE(3)
      D = DPTH(3)
      GO TO 230
 1180 B = BASE(4)
      D = DPTH(4)
      K3 = 1
      NSW1 = 4
      GO TO 230
 1190 IF (K19) 10,10,1200
C
C          PRINT PROBLEM IDENTIFICATION AND INPUT DATA
C
 1200 PRINT 2040
      PRINT 2050, I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW
      GO TO 390
 2000 FORMAT ( 2F4.2,4F5.3 )
 2010 FORMAT ( 6E12.6 )
 2020 FORMAT ( 5I1,F7.4,6F7.1 )
 2030 FORMAT ( 13H1  END OF RUN )
 2040 FORMAT ( 50H                                                 )
 2050 FORMAT ( 13HK  INPUT DATA / 24H     CODE      SLOPE    ,
     1          7H LENGTH,8X,3H Q1,7X,4H AHW,6X,4H DTW,8X,3H Q2,7X,
     2          4H CTW/5X,5I1,F10.4,F11.1,F12.1,2F10.1,F12.1,F10.1)
 2060 FORMAT ( 32HK  ALLOWABLE HEADWATER TOO SMALL )
 2070 FORMAT ( 33HK  NUMBER OF BARRELS EXCEEDS FIVE )
 2080 FORMAT ( 2F12.1,3F13.1,F14.1 )
 2090 FORMAT ( 2F12.1,2F13.1,29H       INLET CONTROL GOVERNS   )
 2100 FORMAT ( 24HK  INLET CONTROL RESULTS )
 2110 FORMAT ( 44H    DISCHARGE    NUMBER OF      WIDTH      ,
     1          7H HEIGHT,28H      HEADWATER     VELOCITY/7X,4H CFS,
     2          7X,8H BARRELS,6X,3(13H FEET        ),5H  FPS)
 2120 FORMAT ( 25HK  OUTLET CONTROL RESULTS )
 2130 FORMAT ( 23HK  CULVERT CODE INVALID )
 2140 FORMAT ( 38HK  INLET CONTROL FOR OUTLET DIMENSIONS )
 2150 FORMAT ( 38HK  OUTLET CONTROL FOR INLET DIMENSIONS)
 2160 FORMAT ( 9I6)
      END
```

EXAMPLE PROBLEMS

PROBLEM 1

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer J.R. LINK

Project: I-00-000

Date 1-6-64

Hydrologic and Channel Information

Q_1 = 500.0 c.f.s

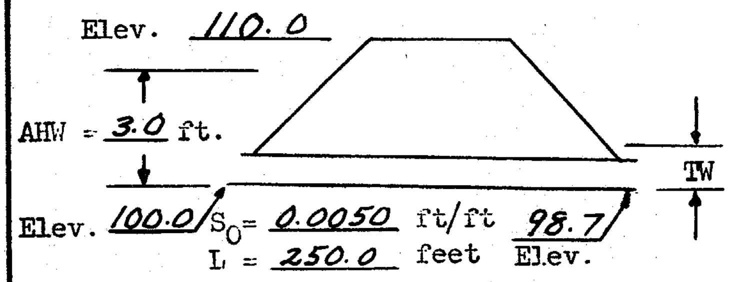
Q_2 = 750.0 c.f.s

TW_1 = 4.0 feet

TW_2 = 4.0 feet

Sketch

Station: 00+00



Elev. 110.0

AHW = 3.0 ft.

Elev. 100.0 / S_0 = 0.0050 ft/ft 98.7 Elev.

L = 250.0 feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1		P	R	O	J		I	-	0	0	-	0	0	0		S	T	A		0	0	+	0	0			L	I	N	K			1	-	6	-	6	4											

PROBLEM IDENTIFICATION

CARD NO. 2

1	2	3	4	5	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	29	30	31	32	33	36	37	38	39	40	41	42	43	44	45	46	47	50	51	52	53	54
4	1	1	1	1	.	0	0	5	0			2	5	0	.	0			5	0	0	.	0			3	.	0			4	.	0			7	5	0	.	0			4	.	0
CULVERT CODE *					SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)							ALLOWABLE HEADWATER (AHW)					DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)				

PROBLEM 1

```
PROJ I-00-000 STA 00600  LINK  1-6-64

 INPUT DATA
   CODE       SLOPE      LENGTH         Q1         AHW       DTW        Q2        CTW
   41111      .0050       250.0       500.0        3.0       4.0       750.0      4.0

 ALLOWABLE HEADWATER TOO SMALL
```

Remarks: This message was printed because the tailwater was at a higher elevation than the headwater. The headwater must be 0.5 feet higher in elevation than the tailwater.

PROBLEM 2

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer U.R. LINK

Project: I-00-000

Date 1-6-64

Hydrologic and Channel Information

Q_1 = 1500.0 c.f.s

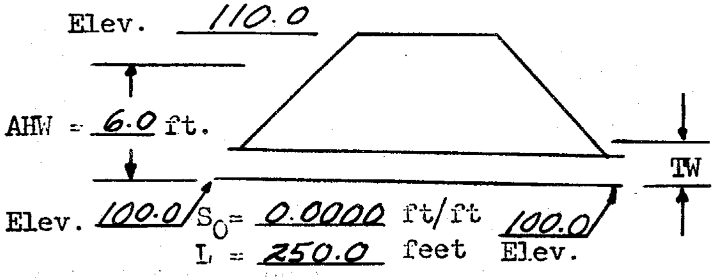
Q_2 = 1750.0 c.f.s

TW_1 = 4.0 feet

TW_2 = 4.0 feet

Sketch

Station: 00+00



Elev. 110.0

AHW = 6.0 ft.

Elev. 100.0 S_0 = 0.0000 ft/ft 100.0 Elev.

L = 250.0 feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1		P	R	O	J		I	-	0	0	-	0	0	0		S	T	A		0	0	+	0	0			L	I	N	K			1	-	6	-	6	4											

PROBLEM IDENTIFICATION

CARD NO. 2

1	2	3	4	5		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		29	30	31	32	33		36	37	38	39	40	41	42	43	44	45	46	47		50	51	52	53	54
4	1	1	1	1		.	0	0	0	0			2	5	0	.	0		1	5	0	0	.	0				6	.	0				4	.	0		1	7	5	0	.	0				4	.	0
CULVERT CODE *						SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)							ALLOWABLE HEADWATER (AHW)						DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)					

PROBLEM 2

```
PROJ I-00-000 STA 00&00  LINK  1-6-64

 INPUT DATA
   CODE       SLOPE      LENGTH        Q1         AHW        DTW         Q2         CTW
   41111      .0000       250.0      1500.0       6.0        4.0       1750.0       4.0

 INLET CONTROL RESULTS
   DISCHARGE    NUMBER OF     WIDTH       HEIGHT      HEADWATER     VELOCITY
      CFS        BARRELS      FEET         FEET         FEET          FPS

 NUMBER OF BARRELS EXCEEDS FIVE
```

Remarks: This message was printed because the limit of five barrels set in the program was exceeded. The number of barrels increases each time the culvert height becomes greater than the allowable headwater, AHW.

PROBLEM 3

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: I-00-000

Designer J.R. LINK

Date 1-6-64

Hydrologic and Channel Information

Q_1 = 500.0 c.f.s

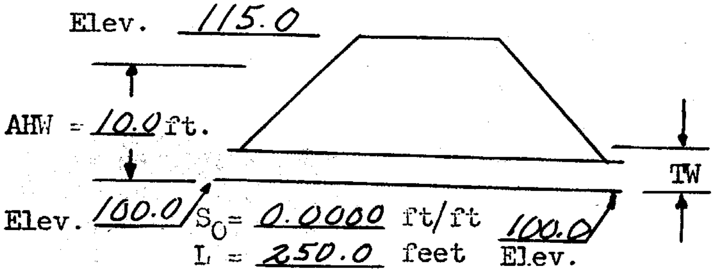
Q_2 = 750.0 c.f.s

TW_1 = 0.0 feet

TW_2 = 0.0 feet

Sketch

Station: 00+00



Elev. 115.0

AHW = 10.0 ft.

Elev. 100.0 S_0 = 0.0000 ft/ft 100.0 Elev.

L = 250.0 feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1		P	R	O	J		I	-	0	0	-	0	0	0		S	T	A		0	0	+	0	0			L	I	N	K			1	-	6	-	6	4											

PROBLEM IDENTIFICATION

CARD NO. 2

1	2	3	4	5	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	29	30	31	32	33	36	37	38	39	40	41	42	43	44	45	46	47	50	51	52	53	54
4	1	2	2	0	.	0	0	0	0			2	5	0	.	0			5	0	0	.	0		1	0	.	0			0	.	0			7	5	0	.	0			0	.	0
CULVERT CODE *					SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)							ALLOWABLE HEADWATER (AHW)					DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)				

PROBLEM 3

```
PROJ I-00-000 STA 00&00  LINK  1-6-64

 INPUT DATA
   CODE        SLOPE       LENGTH          Q1          AHW          DTW           Q2          CTW
   41220       .0000        250.0         500.0        10.0          .0          750.0         .0

 CULVERT CODE INVALID
```

Remarks: This message indicates that the input data contained a five integer number that is not a valid culvert code for box-type culverts.

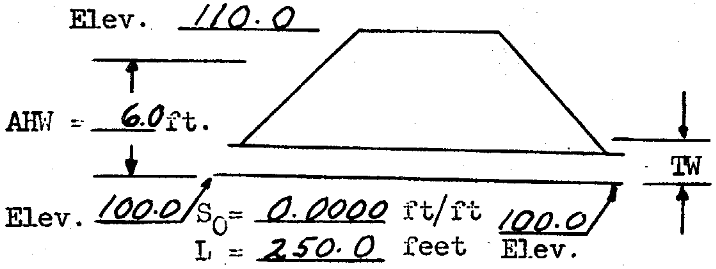
PROBLEM 4

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form
Project: I-00-000
Designer J.R. LINK
Date 1-6-64

Hydrologic and Channel Information

Q_1 = 500 c.f.s
Q_2 = 750 c.f.s
TW_1 = 0.0 feet
TW_2 = 0.0 feet

Sketch
Station: 00+00



Elev. 110.0
AHW = 6.0 ft.
Elev. 100.0 S_0 = 0.0000 ft/ft 100.0 Elev.
L = 250.0 feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1		P	R	O	J		I	-	0	0	-	0	0	0		S	T	A		0	0	+	0	0			L	I	N	K			1	-	6	-	6	4											

PROBLEM IDENTIFICATION

CARD NO. 2

1	2	3	4	5			8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26			29	30	31	32	33			36	37	38	39	40	41	42	43	44	45	46	47			50	51	52	53	54
4	1	1	1	1			.	0	0	0	0			2	5	0	.	0			5	0	0	.	0					6	.	0					0	.	0			7	5	0	.	0					0	.	0
CULVERT CODE *							SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)									ALLOWABLE HEADWATER (AHW)							DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)									CHECK TAILWATER (TW_2)				

PROBLEM 4

```
PROJ I-00-000 STA 00&00  LINK  1-6-64

 INPUT DATA
   CODE       SLOPE      LENGTH        Q1         AHW        DTW          Q2          CTW
   41111      .0000       250.0       500.0       6.0         .0         750.0         .0

 INLET CONTROL RESULTS
   DISCHARGE    NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS        BARRELS        FEET         FEET          FEET           FPS
     250.0         2.0           6.0          5.0           6.0            8.3
     250.0         2.0           6.0          6.0           5.8            6.9
     375.0         2.0           6.0          5.0           9.3           12.5
     375.0         2.0           6.0          6.0           8.2           10.4

 OUTLET CONTROL FOR INLET DIMENSIONS
   DISCHARGE    NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS        BARRELS        FEET         FEET          FEET           FPS
     250.0         2.0           6.0          5.0           6.6           11.0
     250.0         2.0           6.0          6.0           6.5           11.0
     375.0         2.0           6.0          5.0          10.0           12.5
     375.0         2.0           6.0          6.0           8.8           12.5

 OUTLET CONTROL RESULTS
   DISCHARGE    NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS        BARRELS        FEET         FEET          FEET           FPS
     250.0         2.0           7.0          4.0           6.3           10.4
     250.0         2.0           7.0          5.0           5.9           10.4
     375.0         2.0           7.0          4.0          10.0           13.3
     375.0         2.0           7.0          5.0           8.3           11.9

 INLET CONTROL FOR OUTLET DIMENSIONS
   DISCHARGE    NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS        BARRELS        FEET         FEET          FEET           FPS
     250.0         2.0           7.0          4.0           5.7            8.9
     250.0         2.0           7.0          5.0           5.3            7.1
     375.0         2.0           7.0          4.0           9.4           13.3
     375.0         2.0           7.0          5.0           7.7           10.7
```

Remarks: The results of this problem give an example where outlet control governs the selection of a culvert. Here a culvert with two 7 ft. by 5 ft. barrels, under Outlet Control Results, is the only culvert that has a headwater not greater than the allowable headwater, AHW. It should be noted, also, that the sizes determined for Inlet Control Results differ from those computed for Outlet Control Results. This illustrates the need for the results called Outlet Control for Inlet Dimensions and Inlet Control for Outlet Dimensions.

PROBLEM 5

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: I-00-000

Designer J.R. LINK

Date 1-6-64

Hydrologic and Channel Information

Q_1 = 500 c.f.s

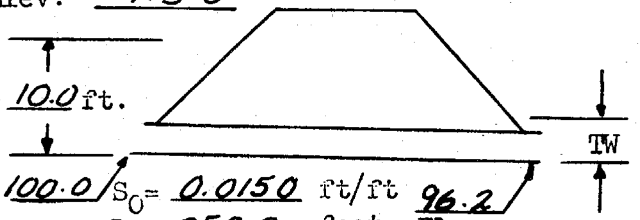
Q_2 = 750 c.f.s

TW_1 = 5.0 feet

TW_2 = 5.0 feet

Sketch

Station: 00+00



Elev. 115.0

AHW = 10.0 ft.

Elev. 100.0 / S_0 = 0.0150 ft/ft 96.2 Elev.

L = 250.0 feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
/		P	R	O	J		I	-	0	0	-	0	0	0		S	T	A		0	0	+	0	0			L	I	N	K			/	-	6	-	6	4											

PROBLEM IDENTIFICATION

CARD NO. 2

1	2	3	4	5	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	29	30	31	32	33	36	37	38	39	40	41	42	43	44	45	46	47	50	51	52	53	54
4	/	/	/	/	.	0	/	5	0			2	5	0	.	0			5	0	0	.	0		/	0	.	0			5	.	0			7	5	0	.	0			5	.	0
CULVERT CODE *					SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)							ALLOWABLE HEADWATER (AHW)					DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)				

PROBLEM 5

```
PROJ I-00-000 STA 00&00  LINK  1-6-64

 INPUT DATA
   CODE       SLOPE      LENGTH         Q1        AHW       DTW         Q2         CTW
   41111      .0150      250.0        500.0      10.0       5.0       750.0        5.0

 INLET CONTROL RESULTS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET          FEET           FPS
     500.0          1.0          7.0           5.0          11.0           21.6
     500.0          1.0          7.0           6.0           9.4           21.6
     750.0          1.0          7.0           5.0          20.7           23.8
     750.0          1.0          7.0           6.0          16.1           23.8

 OUTLET CONTROL FOR INLET DIMENSIONS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET          FEET           FPS
     500.0          1.0          7.0           5.0       INLET CONTROL  GOVERNS
     500.0          1.0          7.0           6.0       INLET CONTROL  GOVERNS
     750.0          1.0          7.0           5.0        15.7           21.4
     750.0          1.0          7.0           6.0       INLET CONTROL  GOVERNS

 OUTLET CONTROL RESULTS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET          FEET           FPS
     500.0          1.0          7.0           5.0       INLET CONTROL  GOVERNS
     500.0          1.0          7.0           6.0       INLET CONTROL  GOVERNS
     750.0          1.0          7.0           5.0        15.7           21.4
     750.0          1.0          7.0           6.0       INLET CONTROL  GOVERNS

 INLET CONTROL FOR OUTLET DIMENSIONS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT       HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET          FEET           FPS
     500.0          1.0          7.0           5.0          11.0           21.6
     500.0          1.0          7.0           6.0           9.4           21.6
     750.0          1.0          7.0           5.0          20.7           23.8
     750.0          1.0          7.0           6.0          16.1           23.8
```

Remarks: This problem illustrates the use of the message "Inlet Control Governs". It indicates that the headwater is negative or that the normal depth is less than the critical depth. Steep slopes and relatively low tailwaters contribute to this condition. The culvert to be selected from these results would be the single-barrel, 7 ft. by 6 ft. culvert under Inlet Control Results.

PROBLEM 6

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: I-00-000

Designer J.R.LINK

Date 1-6-64

Hydrologic and Channel Information

Q_1 = 500.0 c.f.s

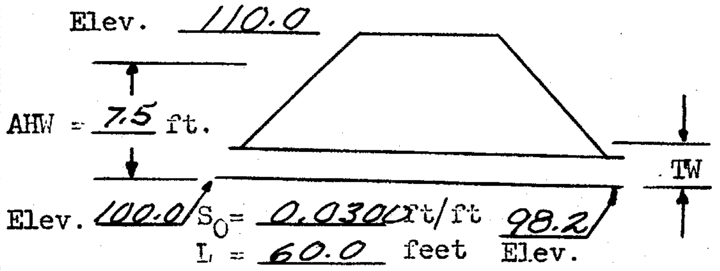
Q_2 = 750.0 c.f.s

TW_1 = 0.0 feet

TW_2 = 0.0 feet

Sketch

Station: 00+00



Elev. 110.0

AHW = 7.5 ft.

Elev. 100.0/S_0= 0.0300ft/ft 98.2 Elev.

L = 60.0 feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1		P	R	O	J		I	-	0	0	-	0	0	0		S	T	A		0	0	+	0	0			L	I	N	K			1	-	6	-	6	4											

PROBLEM IDENTIFICATION

CARD NO. 2

1	2	3	4	5		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		29	30	31	32	33		36	37	38	39	40	41	42	43	44	45	46	47		50	51	52	53	54
4	1	1	1	1		.	0	3	0	0				6	0	.	0			5	0	0	.	0				7	.	5				0	.	0			7	5	0	.	0				0	.	0
CULVERT CODE *						SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)								ALLOWABLE HEADWATER (AHW)						DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)								CHECK TAILWATER (TW_2)				

PROBLEM 6 - Part I

```
PROJ I-00-000 STA 00&00  LINK  1-6-64

 INPUT DATA
   CODE        SLOPE     LENGTH          Q1        AHW        DTW        Q2        CTW
   41111       .0300      60.0        500.0        7.5         .0      750.0        .0

 INLET CONTROL RESULTS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT      HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET         FEET           FPS
     500.0          1.0          8.0           8.0          7.5           27.5
     500.0          1.0          9.0           6.0          7.3           27.0
     750.0          1.0          8.0           8.0         10.6           30.9
     750.0          1.0          9.0           6.0         11.2           30.5

 OUTLET CONTROL FOR INLET DIMENSIONS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT      HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET         FEET           FPS
     500.0          1.0          8.0           8.0       INLET CONTROL GOVERNS
     500.0          1.0          9.0           6.0       INLET CONTROL GOVERNS
     750.0          1.0          8.0           8.0       INLET CONTROL GOVERNS
     750.0          1.0          9.0           6.0       INLET CONTROL GOVERNS

 OUTLET CONTROL RESULTS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT      HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET         FEET           FPS
     500.0          1.0          8.0           8.0       INLET CONTROL GOVERNS
     500.0          1.0          9.0           6.0       INLET CONTROL GOVERNS
     750.0          1.0          8.0           8.0       INLET CONTROL GOVERNS
     750.0          1.0          9.0           6.0       INLET CONTROL GOVERNS

 INLET CONTROL FOR OUTLET DIMENSIONS
   DISCHARGE     NUMBER OF      WIDTH        HEIGHT      HEADWATER      VELOCITY
      CFS         BARRELS       FEET          FEET         FEET           FPS
     500.0          1.0          8.0           8.0          7.5           27.5
     500.0          1.0          9.0           6.0          7.3           27.0
     750.0          1.0          8.0           8.0         10.6           30.9
     750.0          1.0          9.0           6.0         11.2           30.5
```

Remarks: The number of barrels associated with the two culverts that bracket the allowable headwater are compared in the program. This example illustrates the results when the culvert size above the allowable headwater has a different number of barrels than the culvert size below the allowable headwater. Both of the sizes selected are retained internally and used to initialize the problem again. This time the height of culvert is not compared with the allowable headwater. A complete set of results are computed and printed for each of the number of barrels determined when the allowable headwater was bracketed initially. Part I, above, shows one set of results. The number of barrels is one. Part II, following, shows the other set of results. The number of barrels is two. Both sets of results have the same problem identification and input data printed at the top of the page.

PROBLEM 6 - Part II

```
PROJ I-00-000 STA 00&00  LINK  1-6-64

 INPUT DATA
   CODE       SLOPE      LENGTH          Q1          AHW        DTW          Q2          CTW
   41111      .0300        60.0       500.0          7.5         .0        750.0          .0

 INPUT CONTROL RESULTS
   DISCHARGE      NUMBER OF       WIDTH          HEIGHT        HEADWATER      VELOCITY
      CFS          BARRELS        FEET            FEET           FEET           FPS
     250.0           2.0           5.0             4.0            8.5           23.5
     250.0           2.0           5.0             5.0            7.1           23.5
     375.0           2.0           5.0             4.0           16.0           26.0
     375.0           2.0           5.0             5.0           11.8           26.0

 OUTLET CONTROL FOR INLET DIMENSIONS
   DISCHARGE      NUMBER OF       WIDTH          HEIGHT        HEADWATER      VELOCITY
      CFS          BARRELS        FEET            FEET           FEET           FPS
     250.0           2.0           5.0             4.0         INLET CONTROL GOVERNS
     250.0           2.0           5.0             5.0         INLET CONTROL GOVERNS
     375.0           2.0           5.0             4.0         INLET CONTROL GOVERNS
     375.0           2.0           5.0             5.0         INLET CONTROL GOVERNS

 OUTLET CONTROL RESULTS
   DISCHARGE      NUMBER OF       WIDTH          HEIGHT        HEADWATER      VELOCITY
      CFS          BARRELS        FEET            FEET           FEET           FPS
     250.0           2.0           5.0             4.0         INLET CONTROL GOVERNS
     250.0           2.0           5.0             5.0         INLET CONTROL GOVERNS
     375.0           2.0           5.0             4.0         INLET CONTROL GOVERNS
     375.0           2.0           5.0             5.0         INLET CONTROL GOVERNS

 INLET CONTROL FOR OUTLET DIMENSIONS
   DISCHARGE      NUMBER OF       WIDTH          HEIGHT        HEADWATER      VELOCITY
      CFS          BARRELS        FEET            FEET           FEET           FPS
     250.0           2.0           5.0             4.0            8.5           23.5
     250.0           2.0           5.0             5.0            7.1           23.5
     375.0           2.0           5.0             4.0           16.0           26.0
     375.0           2.0           5.0             5.0           11.8           26.0
```

Remarks: This is the second set of results from Problem 6. The results under the column for number of barrels need not be 1.0 and 2.0 as shown in these two sets of answers. Any number of barrels that do not exceed the limit set in the program could be produced.