

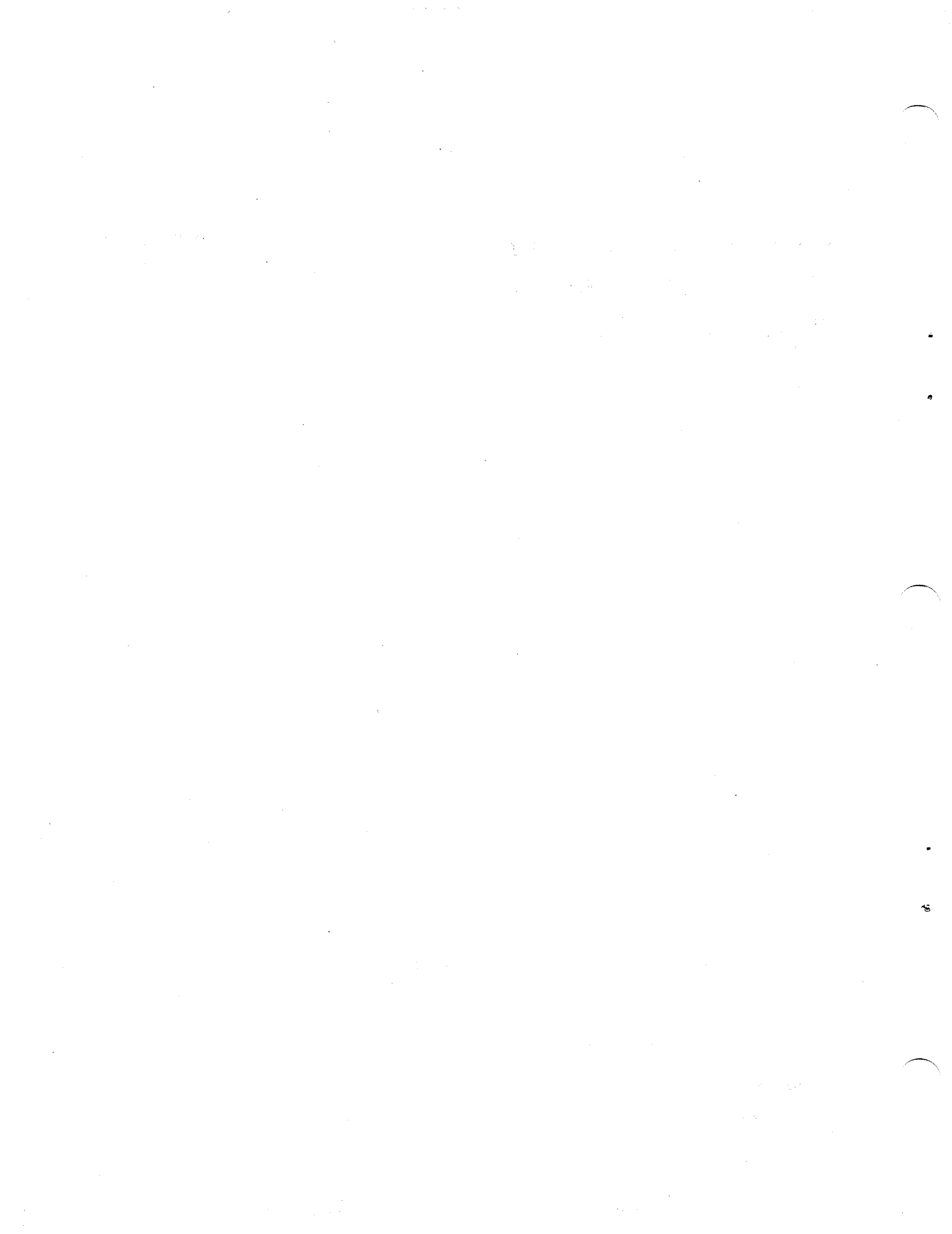
FHWA-EPD-86-113

Computer Program Hydraulic Analysis of Pipe-Arch Culverts

PROGRAM HY-2
MAY 1969



US Department
of Transportation
Federal Highway
Administration



U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS
Washington, D. C.

HYDRAULIC ANALYSIS OF PIPE-ARCH CULVERTS

(BPR PROGRAM HY-2)

Program developed by
Engineering Systems Division
Office of Research and Development
In cooperation with
Hydraulic Branch - Bridge Division
Office of Engineering and Operations

Revised
May 1969

REVISION RECORD

<u>REVISION</u>	<u>DESCRIPTION</u>
February 1964	First printing
November 1965	Second printing
January 1968	Third printing - (revised)
March 1969	Fourth printing
May 1969	Fifth printing - (revised) Substituted a mathematical routine to compute areas and wetted perimeters in place of a polynomial equation with constants. Increased number of available pipes from 16 to 61, to include 31", 18" and variable corner radii.

ABSTRACT

This program is used for the hydraulic analysis of pipe-arch culverts. The program selects, from a table of pipe-arch culverts, the culverts which satisfy the hydrologic data and site conditions for inlet control and outlet control. The output includes: number of pipes, span, rise, headwater, and outlet velocities. Outlet control calculations make use of backwater calculations, whenever necessary, to compute headwater.

SPECIAL NOTICE

The initial version of the computer program "Hydraulic Analysis of Pipe-Arch Culverts" HY-2, was limited to the analysis of eight riveted and eight structural plate pipe-arch culverts. These sizes used 18" and smaller corner radii. The program necessitated the internal storing of precalculated constants utilized in equations for computing the area and wetted perimeter for the available pipe-arch culverts.

Subsequent to May 1969, the HY-2 program was revised to include sixty-one pipe-arch culverts, both riveted and structural plate having 31", 18" and smaller corner radii. A mathematical routine to compute the area and perimeter has been incorporated in the program, thus eliminating the need for constants for each pipe size.

TABLE OF CONTENTS

	<u>PAGE</u>
REVISION RECORD	ii
ABSTRACT	iii
SPECIAL NOTICE	iii
STATEMENT OF THE PROBLEM	1
METHOD OF FUNCTIONING OF PROGRAM	2
MATHEMATICAL EQUATIONS	5
INPUT DATA	11
OUTPUT DATA	13
TABLE OF PIPE-ARCH CULVERTS	15
CULVERT CODE TABLE	16
CONSTANTS AND COEFFICIENTS	17
INPUT DATA FORM	18
DEFINITION OF TERMS	20
PROGRAM LISTING	26
EXAMPLE PROBLEMS	40

STATEMENT OF THE PROBLEM

Hydraulic analysis of pipe-arch culverts is an extension of the method presented in BPR HY-1, "Hydraulic Analysis of Circular Culverts."

The rapidity with which the electronic computer performs calculations makes its use advantageous for selecting culvert sizes on highway projects having a number of drainage installations or for checking culvert sizes in the review of drainage plans. An added advantage of the program is the computation of headwater required, for the culverts selected, to pass floods other than the design flood.

This program is based on the principles discussed in Hydraulic Engineering Circular No. 5 ^{1/}, "Hydraulic Charts for the Selection of Highway Culverts." The nomographs used in Hydraulic Engineering Circular No. 5 are replaced by mathematical equations in the computer program. In addition, a backwater computation is incorporated for the solution of part-full outlet control problems.

^{1/} "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

METHOD OF FUNCTIONING OF PROGRAM

The functioning of the program can be separated into two parts; (1) inlet control calculations and (2) outlet control calculations. Each part will be discussed separately, but in the program these parts are interconnected in order to avoid duplication of computer instructions.

Inlet-Control

The computer begins inlet-control calculations by calculating the approximate cross-sectional area required. This is done by equation (1), page 5. This area is compared with the total cross-sectional areas of the various pipe-arches listed in Table 1, pages 15 and 16. The area table is searched until a minimum-sized pipe-arch is found that has a total area equal to or greater than the approximated area. This size of pipe-arch then becomes the first trial size for use in making inlet-control computations. If the rise (vertical dimension) of the trial-size pipe is greater than the allowable headwater, the number of pipes is incremented by one and the discharge is changed to an adjusted discharge (QADJ) by dividing the number of pipes into the design discharge. Using the adjusted discharge, a new size of pipe-arch is selected from the table in the same manner as described above. Again, the rise of the newly selected pipe-arch is compared to the allowable headwater. The above procedure continues until a pipe-arch with a rise less than the allowable headwater is found, then inlet control calculations are performed.

Using the selected pipe-arch as the first trial size, the headwater is calculated by equation (2) and is compared to the allowable headwater. When the calculated headwater is equal to or less than the allowable headwater, the next smaller size in the table of pipe-arches is selected as the next trial size. However, if the headwater for the first trial size is greater than the allowable headwater, the next larger size in the table of pipe-arches is selected as the next trial size. When it is necessary to select a larger size, a check is made to be sure that the rise of the pipe-arch does not become greater than the allowable headwater. If the rise is greater than the allowable headwater, then the number of pipe-arches is incremented by one, the discharge is adjusted by the method previously described and the calculations for inlet control are started again. When this is the case, the first size selected is discarded and all inlet-control answers will be for multiple culverts.

By testing counters, the program makes a decision whether two acceptable sizes have been selected. The two acceptable selections are: (1) a pipe-arch with headwater equal to or less than the allowable headwater and (2) the next size of pipe-arch with headwater

greater than the allowable headwater. The rise of all pipe-arches selected is always equal to or less than the allowable headwater.

After two pipe-arch sizes have been selected for inlet control, the program calculates outlet velocities for each selection. In order to calculate the outlet velocity it is necessary to calculate the normal depth of flow. The normal depth is calculated by an iterative method using equation (3). The iterative calculations start by using the full pipe cross-section and the depth is decremented until equation (3) is satisfied. A mathematical routine for computation of area has been incorporated into the program in place of a polynomial equation with constants. When equation (3) is satisfied, the depth used is normal depth. The area that was calculated for normal depth is divided into the discharge to find the outlet velocity.

When the velocities have been calculated and the inlet-control results printed, the program branches to a control routine. The control routine sets all necessary switches to enable the program to compute headwaters and outlet velocities for the two pipes selected using the check discharge. After printing the results of the inlet calculations using the check discharge, the program branches to the control routine which restores the adjusted discharge that was used in inlet calculations prior to the calculating of headwaters and outlet velocities for the check discharge. The program then branches to the outlet-control calculations.

Outlet-Control

Outlet-control calculations are begun by analyzing one of the selected pipe-arches along with the number of pipes and the adjusted discharge from inlet-control calculations. The calculations are started by calculating the head required for a pipe-arch flowing full by equation (4). After the head is calculated, the value of tailwater, which is input data, is compared to the rise of the pipe-arch being analyzed. If tailwater is equal to or greater than the rise, then headwater is calculated by equation (6) using the conditions listed. If the value of tailwater is less than the rise, it is necessary to calculate critical depth by an iterative method using equation (5). The iterative method starts with the depth equal to 0.98 times the rise and the depth decrements until equation (5) is satisfied. Headwater is then calculated by equation (6) using the listed conditions.

If the headwater is positive, a test is made to determine whether the culvert is flowing full or with a free-water surface by comparing the results of equation (7) with the rise of the pipe-arch being analyzed. If the results of equation (7) are equal to or greater than the rise being considered, the culvert is considered to

be flowing full. For a negative or zero headwater, or a result from equation (7) less than the rise being considered, critical depth is compared with normal depth. Inlet control governs when normal depth is less than critical depth. The message "Inlet Control Governs" is printed when this occurs as shown in example problem 1. If normal depth is equal to or greater than critical depth, a water surface profile known as a backwater curve must be computed.

Since the occurrence of 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 normal depth, equations (8a) and (8c) are used in computing the water surface profile with either tailwater or critical depth, whichever is the greater, used as the starting depth for backwater calculations. When tailwater is greater than normal depth, equations (8b) and (8c) are used to compute the water surface profile. When either backwater analysis is completed, the headwater is calculated by equation (9).

After headwater is computed by one of the above methods, it is compared to the allowable headwater. Depending on the results of the comparison, either the next smaller or next larger size in the table of pipe-arches is selected to obtain a new trial size. The calculations, and comparisons described are repeated for this selection and any subsequent selections. As in inlet control, there are only two acceptable selections; one pipe-arch with headwater equal to or less than the allowable headwater and the next smaller size pipe-arch with headwater greater than the allowable headwater. The rise of the pipe-arches selected for outlet control can be greater than the allowable headwater.

When the program, by testing counters, has selected two pipe sizes, then outlet velocity calculations are begun. The tailwater is compared with the rise of the pipe-arch and when tailwater is equal to or greater than the rise, the outlet velocity is calculated using the total cross-sectional area of the pipe. When the tailwater is less than the rise, tailwater and critical depth are compared and the larger value is used to calculate the flow area. This area is then used in equation (10) to calculate outlet velocity.

After printing the results of the pipes selected for outlet control, the program branches to the control routine. The control routine sets the switches in the program that are necessary to calculate headwaters and outlet velocities for the two pipes selected for the check discharge when the culvert is flowing in outlet control. These calculations for headwater and outlet velocity are determined in the same manner as the original calculations for outlet control.

After printing the check discharge calculations the control routine returns the program to the beginning to read-in another problem.

MATHEMATICAL EQUATIONS

Inlet Control

Approximate Area

$$A = .785 \left(\frac{QADJ}{AHW} \right) \quad (1)$$

Where A = approximate cross-sectional area in square feet,

QADJ = adjusted discharge in cfs,

AHW = allowable headwater in feet.

Headwater

$$HW = (RISE) (Y) \quad (2)$$

Where $Y = A + BX + CX^2 + DX^3 + EX^4 + FX^5 - (S) (SCORR)$

HW = headwater in feet,

RISE = vertical dimension of the pipe-arch in feet,

A, B, C, D, E, & F = coefficients determined by polynomial curve fitting

$$X = \frac{QADJ}{(SPAN)(RISE^{3/2})}$$

QADJ = adjusted discharge in cfs,

SPAN = horizontal dimension of the pipe-arch in feet,

S = slope of the pipe in ft./ft.,

SCORR = correction applied to the slope.

The coefficients in the equation were determined by a computer program^{1/} which fitted a polynomial curve, by the method of least squares to the experimental data obtained by the National Bureau of Standards^{2/}. Data for models 126, 91 and 21 were used. This is essentially the same data as used to develop the nomographs (chart 5) for inlet control given in Hydraulic Engineering Circular No. 5.

Outlet Velocity

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2} \text{ (Mannings Equation)} \quad (3)$$

Where Q = discharge in cfs,
 A = Cross-sectional area of water in square
 feet at any depth of flow,

 R = hydraulic radius in feet,

 S = slope of the pipe in feet per foot,

 n = roughness factor.

^{1/} "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.

^{2/} "First Progress Report on Hydraulics of Short Pipes, Hydraulic
Characteristics of Commonly Used Pipe Entrances" by J. L. French,
U. S. Department of Commerce, National Bureau of Standards,
Report No. 4444, Washington 25, D. C., 1955, p. 48-74.

Outlet Control

Head

$$H = \left[1 + K_e + \frac{(29.132)(n^2)(L)}{\left(\frac{A}{WP}\right)^{4/3}} \right] \cdot \left[\frac{Q^2}{(64.309)(A^2)} \right] \quad (4)$$

Where H = head for pipe-arch culverts flowing full, in feet,
K_e = coefficient of entrance loss,
n = roughness factor,
L = length of pipe in feet,
A = total cross-sectional area of the pipe-arch
WP = wetted perimeter of full pipe in feet,
Q = discharge in cfs.

Critical Depth

$$\frac{\alpha Q^2}{32.2} = \frac{A^3}{T} \quad (5)$$

Where Q = discharge in cfs,
A = cross-sectional area of water in square feet at any depth of flow as defined by equation (11),
T = top surface width of water in feet at any depth of flow,
 α = velocity distribution factor.

Headwater

$$HW = TEMP + H - (L) (S) \quad (6)$$

When a) $d_c = RISE$ and $RISE > TW$, then $TEMP = RISE$

b) $d_c < RISE$ and $\frac{d_c + RISE}{2} > TW$, then $TEMP = \frac{d_c + RISE}{2}$

c) $TW > RISE$ or $TW > \frac{d_c + RISE}{2}$, then $TEMP = TW$;

Where $RISE =$ vertical dimension of the pipe-arch invert at outlet,

$TW =$ tailwater height in feet from culvert invert at outlet,

$HW =$ headwater in feet from culvert invert at inlet,

$H =$ head for full flow in feet,

$L =$ length of pipe in feet,

$S =$ slope of pipe in feet per foot

$$TEMP = WHW - (1 + K_e) \frac{V^2}{2g} \quad (7)$$

Where $TEMP =$ temporary value that represents a culvert height

$WHW =$ working headwater in feet

$K_e =$ coefficient for entrance loss

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

Backwater (computation for water surface profile)

For $TW \leq d_n$

$$x_1 = \frac{\left[d_2 + \frac{V_2^2}{2g} \right] - \left[d_1 + \frac{V_1^2}{2g} \right]}{S - S_0} \quad (8a)$$

For $TW > d_n$

$$x_1 = \frac{\left[d_1 + \frac{V_1^2}{2g} \right] - \left[d_2 + \frac{V_2^2}{2g} \right]}{S_0 - S} \quad (8b)$$

Where X_1 = distance in feet between two different depths of water,

d_1 and d_2 = different depths of water in feet,

V_1 and V_2 = velocities in feet per second at the different depths of water,

S_0 = slope of the pipe in feet per foot,

g = 32.2 ft./sec.²

$$S = \frac{n^2 V^2}{2.21 R^{4/3}} \quad (8c)$$

S = average slope of the water surface in feet per foot,

n = 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.

$$HW = d_1 + \frac{V_1^2}{2g} + \frac{K_e V_1^2}{2g} \quad (9)$$

Where HW = headwater in feet,

K_e = coefficient of entrance loss,

d_1 = depth in feet at the previous cross-section,

V_1 = velocity in feet per second at the previous cross-section.

Outlet Velocity

$$V = \frac{Q}{A} \tag{10}$$

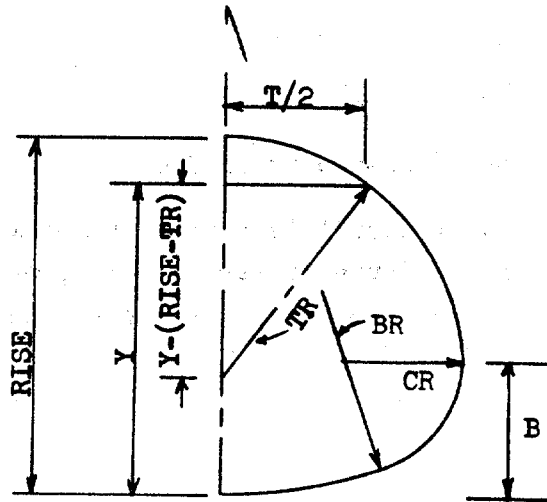
Where V = outlet velocity in feet per second,
 Q = discharge in cfs,
 A = cross-sectional area of water in square feet,

When $DTW \geq RISE$ or $d_c = RISE$, then Area is the total cross-sectional area,

$d_c \geq DTW$, then Area is for depth equal to d_c ,

$d_c < DTW$, then Area is for depth equal to DTW ,

Where DTW = design tailwater in feet,
 $RISE$ = vertical dimension of the pipe-arch in feet,
 d_c = critical depth in feet.



Half Section of Pipe-Arch Culvert

INPUT DATA

The input data for this program are the same as described for the Hydraulic Analysis of Circular Culverts, HY-1. The input data for the program are:

- | | |
|---------------------|------------------------|
| 1. Culvert code | 5. Allowable headwater |
| 2. Slope of pipe | 6. Design tailwater |
| 3. Length of pipe | 7. Check discharge |
| 4. Design discharge | 8. Check tailwater |

These input data are discussed in detail in the following paragraphs.

Culvert Code

The culvert code is taken from Table 2, page 16, and incorporates all the necessary constants for the different inlets and the types of paving listed. The first four numbers comprising the culvert code are the subscripts for the constants in Table 3, page 17, and the fifth number is the subscript for the Inlet Control Coefficients in Table 4, page 17.

To find the correct culvert code, from Table 2, only the type of pipe-arch invert treatment and the type of inlet need be known. Types of inlets are described in BPR HY-1. Enter Table 2 under the type of pipe-arch invert treatment and read down the table until opposite the type of inlet to be used. The five digit number at the intersection of the appropriate row and column is the Culvert Code. For example: A riveted or structural plate pipe-arch with mitered inlet and an unpaved invert has a culvert code of 33122. (The pipe roughness n is changed automatically when the size selected indicates riveted or structural plate.)

Slope of Pipe

Slope of pipe (SLOPE), in feet per foot, is the elevation of the invert at the inlet minus the elevation of the invert at the outlet divided by the length of pipe.

Length of Pipe

Length of pipe (DIST), in feet, is the total length of pipe measured along the invert from the inlet to the outlet.

Design Discharge

Design discharge (Q_1), in c.f.s., is the quantity of water that is used in the selection of pipe size.

Allowable Headwater

Allowable headwater (AHW), in feet, is the height of water above the invert at the inlet end of the pipe selected by the designer. The allowable headwater should be below the shoulder line, otherwise the culverts selected by this program might not have sufficient cover. If the sizes selected give insufficient cover over the arch, the AHW should be decreased and the problem rerun.

Design Tailwater

Design tailwater (DTW), in feet, is the depth of water in the outlet channel above the invert at the outlet end of the pipe. This depth is determined by downstream flow conditions in the natural channel.

Check Discharge

Check discharge (Q_2), can be used for two purposes: (1) to find headwater for a discharge greater than the Design Discharge (Q_1) should a greater flood need to be investigated; and (2) to obtain various headwater-discharge values for plotting performance curves for the culvert sizes selected by the program for the input problem. Values of Q_2 in c.f.s., can be less than or greater than Q_1 to obtain the values under (2) above. The solution for finding these values requires a series of problems using different input cards, keeping all the input data the same except Q_2 and check tailwater (CTW).

Check Tailwater

Check tailwater (CTW), in feet, is the depth of water above the invert of the outlet end of the pipe for the check discharge (Q_2).

Input Data Form

The input data form is as shown on page 18. This form incorporates on one page a sketch and data of the problem and the two cards used for input data to the computer program. After having the sketch portion of the data form completed, the input data portion of the form is filled in for use by the punch card operator. Card No. 1 is for problem identification and contains 80 columns of alphabetic and/or numeric information. (Position 1 must contain the number one.) This could be such items as: The project number, the station of the culvert, and the date submitted to the computer. Card No. 2 is for the data listed under the card columns and all data are necessary for the program to function properly. See examples on pages 40 to 48. All items of input data should have a value recorded on the input data form. If any of the items have a zero value, a zero should be shown to the left of the decimal point on the form. Leading zeros are not necessary.

OUTPUT DATA

The output of this program is either a message or an answer. Messages indicate that something is wrong with the input data or the answer computed is not an applicable solution.

The messages are:

1. ALLOWABLE HEADWATER TOO SMALL.
2. ALLOWABLE HEADWATER TOO HIGH.
3. NUMBER OF PIPES EXCEEDS SIX
4. CULVERT CODE INVALID.
5. AVAILABLE SIZES EXCEEDED.

Message number one is printed when the elevation of the allowable headwater is not above the elevation of design 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. This message is used to check against tailwater elevation being higher than headwater elevations.

Message number two is a check to insure that the selection of pipe-arch sizes does not require a size smaller than the minimum size in the table of pipe-arches. This condition occurs when the program is selecting a smaller size from the table in order to increase the calculated headwater to meet a given allowable headwater.

Message number three is a check on the number of pipes being used. The maximum number of pipes that can be used in this program has been set at six. If this number is too high or too low, the constant can be changed in the test for maximum number of pipes.

Message number four 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. If the code submitted does not match a value in the table, then a message "Culvert Code Invalid" is printed.

Message number five is printed when the number of barrels selected for inlet control are inadequate for outlet control. In such a problem the number of barrels selected for inlet control are increased by one. Then inlet and outlet control results are printed out. This procedure makes the comparison of inlet and outlet control results possible which would not be the case for differing numbers of barrels.

The answers are:

1. Problem identification.
2. List of input data.
3. Inlet-control results.
4. Outlet-control results.

Problem identification is the same as was read-in as input data. This is used for identification of the analysis as well as for a record.

The input data is listed to assist the designer in selecting an acceptable culvert. Also, this information is helpful in correcting the input data if one of the messages is printed out.

Inlet-control consists of two pipe-arch sizes, one arch having a headwater equal to or less than the allowable headwater, and the other, a size smaller, having a headwater greater than the allowable. For each size selected, the following is printed out:

1. Discharge in c.f.s.
2. Number of pipes.
3. Span of arch in inches.
4. Rise of arch in inches.
5. Headwater in feet.
6. Outlet velocity in f.p.s.

The span and rise are printed in inches and are the layout dimensions as given by the pipe-arch manufacturers. The nominal dimensions for the corresponding layout dimensions can be obtained from Table 1, pages

Using the check discharge of the input data, new values of headwater and outlet velocity are computed for the two culverts selected for both inlet control and outlet control. These results are printed out in the same form as given for the design discharge.

Outlet-control results are the same general form as inlet-control results. The only difference occurs when "INLET CONTROL GOVERNS" is printed instead of the values for headwater and outlet velocity. This is printed whenever the normal depth (DEP) of flow is less than critical depth. Inlet control governs when this message appears.

The value under discharge will only correspond to the Q_1 or Q_2 used as input when the number of pipes shown is equal to one. For multiple pipes the input discharge, Q_1 and Q_2 , is divided by the number of pipes used, changing the discharge to equal that carried by one pipe.

Selection of Culvert

Knowing the Allowable Headwater (AHW), the size of a pipe-arch culvert can be selected by comparing the values of headwater listed as the output results. It must be remembered that for any particular pipe-arch the control with the highest headwater is the governing control.

A typical output listing is as shown in the sample problems on pages 40 to 48.

TABLE 1 - Continued *

Riveted Metal Pipe-Arches				
SPAN		RISE		TOTAL AREA
Nominal Inches	Layout Inches	Nominal Inches	Layout Inches	Sq. Feet
18	18.10	11	11.00	1.07
22	21.70	13	13.30	1.59
25	25.30	16	15.50	2.10
29	28.90	18	17.80	2.81
36	36.10	22	22.20	4.39
43	43.30	27	26.60	6.28
51	50.60	31	31.10	8.55
58	57.80	36	35.50	11.23
65	65.00	40	40.00	14.23
72	72.20	44	44.40	17.52
79	79.40	49	48.70	21.01

* For some of the arch sizes common to this and previous editions, the layout dimensions differ slightly. The above noted values reflect current usage.

TABLE 2

Culvert Code Table

Riveted or Structural Plate Unpaved	Inlet Type	Hydraulic** Exper. Model No.	Riveted or Structural Plate Paved
3 2 1 1 1	Projecting	126	3 2 2 1 1
3 3 1 2 2	Mitered	91	3 3 2 2 2
3 2 1 3 3	Headwall	21	3 2 2 3 3

** First Progress Report on Hydraulics of Short Pipes, Hydraulic Characteristics of Commonly Used Pipe Entrances, by John L. French, 1955, U. S. Department of Commerce, National Bureau of Standards, pages 48-74.

TABLE 3

Table of Constants

Velocity Distribution Factor	Slope Correction Factors
Metal Pipe ALPHA = 1.16	$SCORR_1 = 1.50$ $SCORR_2 = 0.50$ $SCORR_3 = 0.00$
Manning's n	Entrance Loss Coefficients
Multiplate-unpaved $CN_1 = 0.032$ Multiplate-paved $CN_2 = 0.026$ Riveted-unpaved $CN_3 = 0.024$ Riveted-paved $CN_4 = 0.019$	CM projecting $CKE_1 = 0.09$ CM mitered $CKE_2 = 0.70$ Concrete headwall $CKE_3 = 0.50$

TABLE 4

Table of Coefficients for Inlet Headwater

Inlet Headwater Coefficients						
Hydraulic Model No.	A	B	C	D	E	F
126	0.0890527	0.712545	-0.270921	0.0792502	-0.00798048	0.000293213
91	0.0833006	0.795145	-0.434075	0.163774	-0.0249139	0.00141066
21	0.111281	0.610579	-0.194937	0.0512893	-0.00480538	0.000168547

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: _____ Designer: _____
 Date: _____ Station: _____

Hydrologic and Channel Information

$Q_1 =$ _____ c.f.s.
 $Q_2 =$ _____ c.f.s.
 $TW_1 =$ _____ feet
 $TW_2 =$ _____ feet

Sketch

Front of input data form

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	

PROBLEM IDENTIFICATION

CARD NO. 2	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	
39	
40	
41	
42	
43	
44	
45	
46	
47	
48	
49	
50	

* See back of the input data form

CULVERT CODE TABLE

CORRUGATED METAL PIPE						CONCRETE PIPE	
CIRCULAR			PIPE-ARCH			CIRCULAR	
Inlet Type	Riveted	Riveted & 25% Paved	Structural Plate	Structural Plate & 25% Paved	Paved 25%	Unpaved	Inlet type
Projecting	1 2 3 1 1	1 2 4 1 1	1 2 1 1 1	1 2 2 1 1	3 2 2 1 1	3 2 1 1 1	Socket-end Projecting
Mitered	1 3 3 2 2	1 3 4 2 2	1 3 1 2 2	1 3 2 2 2	3 3 2 2 2	3 3 1 2 2	Socket-end Headwall
Headwall	1 2 3 3 3	1 2 4 3 3	1 2 1 3 3	1 2 2 3 3	3 2 2 3 3	3 2 1 3 3	Square Edge Projecting
End Section	1 2 3 3 5	1 2 4 3 5	1 2 1 4 6	1 2 2 4 6			Square Edge Headwall
Bevel (A)	1 2 3 4 7	1 2 4 4 7	1 2 1 4 7	1 2 2 4 7			End Section
Bevel (B)	1 2 3 4 8	1 2 4 4 8	1 2 1 4 7	1 2 2 4 7			Bevel (A)
Tapered	1 1 3 4 8	1 1 4 4 8					Bevel (B)
							Tapered
							2 2 5 5 1
							2 2 5 5 2
							2 2 5 3 3
							2 2 5 3 4
							2 2 5 3 5
							2 2 5 4 6
							2 2 5 4 7
							2 2 5 4 8

Back of input data form

SAMPLE INPUT CARDS

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
PROJECT I-46-23 STATION 109+20 L.A. HERRING / 10/62																																																	

PROBLEM IDENTIFICATION

NOTE: For Key Punching Purposes, the number zero is shown as ϕ and "eye" as I. Number one (1) must appear under position 1 on Card No. 1.

CARD NO. 2																																																					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
2255 / .05 200.0 100.0 3.0 225.0 5051525354																																																					
CULVERT CODE SLOPE OF PIPE (S ₀) LENGTH OF PIPE (L) DESIGN DISCHARGE (Q ₁) ALLOWABLE HEADWATER (AW) DESIGN TAILWATER (TW ₁) CHECK DISCHARGE (Q ₂) CHECK TAILWATER (TW ₂)																																																					

DEFINITION OF TERMS

- A(I5) -- The first coefficient in the equations used for inlet control. When I5 is equal to 4, this refers to the fourth value of A.
- B(I5) -- The second coefficient in the equations used for inlet control headwater calculations.
- C(I5) -- The third coefficient in the equations used for inlet control headwater calculations.
- D(I5) -- The fourth coefficient in the equations used for inlet control headwater calculations.
- E(I5) -- The fifth coefficient in the equations used for inlet control headwater calculations.
- F(I5) -- The sixth coefficient in the equations used for inlet control headwater calculations.
- CR(K) -- A table of corner radii for the pipe-arches.
- BDIS(K) -- A table of "B" dimensions for the pipe-arches.
- BR(K) -- A table of bottom radii for the pipe-arches.
- CKE(I4) -- Entrance Loss Coefficients. When I4 equals one, this refers to the first value of entrance loss.

- CN(I3) -- Manning's n for various types of pipe. When I3 equals one, this refers to the first value of n.
- DC(I) -- Critical Depth in feet. Two values of critical depth are stored, one for each diameter of pipe chosen by outlet control. Critical depth is recalled later for outlet control velocity calculations.
- HYDR(I) -- Hydraulic Radius in feet. The values of hydraulic radius for two cross-sections are stored in HYDR(I) during backwater calculations.
- KT(I) -- A table of valid culvert codes.
- RISE(K) -- A table of the vertical dimensions of the pipe-arches.
- SCORR(I2) -- Slope Correction Factor. When I2 equals one, this refers to the first value of slope correction.
- SPAN(K) -- A table of the horizontal dimensions of the pipe-arches.
- SPH(I) -- Specific Head in feet. The values of specific head for two cross-sections are stored in SPH(I) during backwater calculations.
- TOAR(K) -- A table of the total cross-sectional area of the pipe-arches.
- TR(K) -- A table of the top radii of the pipe-arches.
- V(I) -- Velocity in feet per second. The values of velocity for two cross-sections are stored in V(I) during backwater calculations.

AHW -- Allowable headwater in feet.

ALPHA -- Velocity Distribution factor.

AOVWP -- Area of pipe to the $4/3$ power divided by wetted perimeter to the $2/3$ power.

AREA -- The area of water in square feet in any pipe for any depth of flow.

AVEHR -- Average of the hydraulic radii calculated in backwater calculations.

AVEV -- Average of the velocities calculated for two cross-sections in backwater calculations.

CQ -- A working storage location for check discharge.

CTW -- Check tailwater in feet.

DECRM -- The amount of decrement of the depth of flow in the pipe during critical depth calculations in feet.

DEP -- Working depth of flow in the pipe in feet.

DIST -- Length of the pipe in feet.

DSUBC -- A temporary storage location for storing the critical depth while doing backwater calculations.

DIW -- Design tailwater in feet.

DXL -- The distance between the two cross-sections in backwater calculations.

FRISE -- The working location for the rise of the pipe-arch being analyzed and it is in feet.

FSPAN -- The working location for the span of the pipe-arch being analyzed and it is in feet.

HEAD -- The Head required for given flow in outlet control in feet.

HEIT -- The maximum value that design tailwater may obtain.

- HWQVD -- Headwater divided by rise. This is the answer from the inlet headwater equation.
- HW1 -- Headwater one in feet. This is the headwater for the pipe size stored in SPAN1.
- HW2 -- Headwater two in feet. This is the headwater for the pipe size stored in SPAN2.
- I -- A counter used to indicate the particular variable of a group.
- I1 -- A counter set by the culvert code.
- I2 -- A counter set by the culvert code for use with the constant SCORR.
- I3 -- A counter set by the culvert code for use with the constant CN.
- I4 -- A counter set by the culvert code for use with the constant CKE.
- I5 -- This is a counter set by the culvert code that designates which hydraulic model is to be used; therefore, it is used to refer to the coefficients A, B, C, D, E and F.
- I90 -- A counter used to determine when the working diameter has been incremented.
- I91 -- A counter used to determine when the working diameter has been decremented.
- II3 -- A working location for the counter I3.
- INVAL -- A counter used to count the number of outlet control invalid calculations.
- K -- A counter that keeps count of which one of the pipe-arches from the table of pipe-arches that is being analyzed.
- K1 -- A counter which counts the number of times outlet control is calculated.
- K2 -- A counter which counts the number of times an answer has been printed by the outlet control invalid routine.
- KOUNT -- A counter which counts the number of times critical depth is calculated.

PIPES -- The number of pipes calculated by inlet control.

Q1 -- Design discharge in cfs.

Q2 -- Check discharge in cfs.

QADJ -- Adjusted discharge in cfs. This is used for storing working discharge and it is Q1 or Q2 divided by the number of pipes.

Q20A -- A term that is used in the calculation of head for full flow.

Q20VG -- Discharge squared divided by 32.2. This is used in outlet control in critical depth calculations.

RISE1 -- Rise one in inches. The rise of the first pipe-arch selected is stored in RISE1.

RISE2 -- Rise two in inches. The rise of the second pipe-arch selected is stored in RISE2.

RFOUR -- A term that is used in the calculation of head for full flow.

S1 -- The slope of the water surface between two cross-sections in backwater calculations.

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

SPAN1 -- Span one in inches. The span of the first pipe-arch selected is stored in SPAN1.

SPAN2 -- Span two in inches. The span of the second pipe-arch selected is stored in SPAN2.

SUMX -- The accumulated distance in feet from the outlet end of the pipe in backwater calculations.

T -- The top surface width of water in feet in any size pipe for any depth of flow.

TEMP -- A temporary location used for storing temporary calculations.

VEL1 -- Outlet velocity one in feet per second. This is the outlet velocity for the pipe size stored in SPAN1.

VEL2 -- Outlet velocity two in feet per second. This is the outlet velocity for the pipe size stored in SPAN2.

- WHW -- Working headwater in feet. The calculations for headwater are stored in WHW until the pipe sizes are selected.
- WP -- Wetted perimeter in feet of the water in any pipe for any depth of flow.
- X -- The independent variable in the equation for inlet control headwater calculations.

C
C
C
C
C

COMPUTER PROGRAM FOR HYDRAULIC ANALYSIS OF PIPE - ARCH CULVERTS	00000
BUREAU OF PUBLIC ROADS -- REVISED MAY 1969 - BY MARIO MARQUES	00050
COMMON ASUB1,ASUB2,ASUB3,XX1,XX2	00100
COMMON I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW,QADJ,PIPES,IH(00150
1 60),SPANK,RISEK,WHW,SPAN1,RISE1,HW1,VEL1,SPAN2,RISE2,HW2,VEL2	00200
2,NT,K,K1,K2,INVAL,Y,T,Q2OVG,FRISE,TEMP,DEP,DECRM,AREA	00250
DIMENSION SCORR(3),CN(4),CKE(3),A(3),B(3),C(3),D(3),E(3),F(3),	00300
3SPAN(61),RISE(61),TOAR(61),TR(61),SPH(2),V(2),HYDR(2),DC(2)	00350
4,BR(61),BDIS(61),CR(61)	00400
DATA ALPHA/1.16/,SCORR/1.5,0.5,0.0/,CN/.032,.026,.024,.019/,CKE	00450
1 /.9,.7,.5/,A/.890527E-1,.833006E-1,.111281/,B/.712545,.795145	00500
2 .610579/,C/-.270921,-.434075,-.194937/,D/.792502E-1,.163774,	00550
3 .512893E-1/,E/-.798048E-2,-.249139E-1,-.480538E-2/,F/.293213	00600
4 E-3,.141066E-2,.168547E-3/	00650
DATA SPAN/18.1,21.7,25.3,28.9,36.1,43.3,50.6,57.8,65.0,72.2,79.4,	00700
173.0,76.0,81.2,84.2,87.,92.4,95.2,97.8,103.4,106.,111.8,114.2,	00750
2116.6,122.6,128.4,131.,136.8,139.4,141.8,147.8,150.2,152.4,154.4,	00800
3160.8,167.2,169.4,159.4,162.2,167.6,170.6,172.8,178.6,184.2,187.0,	00850
4189.6,195.4,198.,203.6,206.2,208.8,214.6,217.2,223.,225.4,231.4,	00900
5234.0,236.4,238.6,244.8,247./	00950
DATA RISE/11.0,13.3,15.5,17.8,22.2,26.6,31.7,35.5,40.0,44.4,48.7,	01000
155.0,57.1,58.9,61.1,63.2,65.,67.2,69.4,71.1,73.3,75.1,77.3,79.5,	01050
281.2,82.9,85.1,86.9,89.1,91.3,93.,95.2,97.4,99.7,101.3,103.,	01100
3105.2,112.3,114.4,116.2,118.4,120.5,122.3,124.1,126.3,128.5,	01150
4130.2,132.4,134.2,136.3,138.5,140.3,142.4,144.2,146.4,148.1,	01200
5148.1,152.5,154.7,156.4,158.6/	01250
DATA TOAR/1.07,1.59,2.10,2.81,4.39,6.28,8.55,11.23,14.23,17.52,21.	01300
101,22.09,24.09,26.14,28.39,30.60,32.92,35.39,37.94,40.4,43.1,45.79	01350
2,48.67,51.60,54.51,57.46,60.7,63.86,67.18,70.68,74.,77.64,81.34,	01400
385.14,88.68,92.54,96.53,98.,102.,106.,110.,115.,119.,124.,129.,	01450
4133.,138.,143.,148.,153.,158.,163.,168.,174.,179.,185.,190.,196.,	01500
5202.,208.,214./	01550
DATA BR/19.12,37.06,33.50,55.00,73.25,91.56,97.25,115.69,129.31,	01600
1142.94,145.50,76.30,98.60,83.50,104.20,136.20,109.80,137.90,182.90	01650
2,141.00,178.70,144.60,	01700
3177.5,227.7,178.3,153.2,180.4,157.9,183.2,216.4,186.5,216.8,	01750
4257.4,314.7,254.8,220.7,254.1,192.6,220.8,197.9,222.6,256.6,227.7,	01800
5208.5,232.1,260.6,236.,263.2,241.,266.8,297.9,270.6,299.7,274.5,	01850
6302.3,278.6,305.1,336.5,374.3,338.1,373.5/	01900
DATA TR/10.06,11.87,12.75,14.75,18.25,21.56,25.12,29.12,32.75,	01950
136.31,39.75,36.80,	02000
238.1,41.,42.3,43.51,46.5,47.7,48.91,51.9,53.01,56.2,57.3,58.31,61	02050
3.5,64.9,65.9,69.4,70.2,71.1,74.7,75.5,76.4,77.3,80.7,84.4,85.1,80	02100
4.1,81.3,84.4,85.6,86.6,89.8,93.1,94.1,95.2,98.5,99.5,102.9,103.8,	02150
5104.8,108.2,109.1,112.6,113.5,117.,117.9,118.8,119.7,123.2,124./	02200
DATA BDIS/4.5,4.75,5.25,5.5,6.25,7.0,8.0,9.25,10.5,11.75,13.25,21.	02250
1,20.5,22.,21.4,20.8,22.4,21.7,20.9,22.7,21.9,23.8,22.9,21.9,24.,	02300
	02350
	02400
	02450


```
2 26.1,25.1,27.4,26.3,25.2,27.5,26.4,25.2,24.,26.4,28.9,27.6,38.6, 02500
3 37.8,39.6,38.9,38.,39.9,41.9,41.,40.1,42.2,41.2,43.4,42.4,41.4, 02550
4 43.6,42.5,44.8,43.7,46.,44.9,43.8,42.6,45.,43.8/ 02600
DATA CR/3.5,4.0,4.0,4.5,5.0,5.5,6.0,7.0,8.0,9.0,10.0,18.0,18.0, 02650
1 18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18., 02700
2 18.,18.,18.,18.,18.,18.,18.,18.,18.,31.,31.,31.,31.,31.,31., 02750
3 31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31./ 02800
20 CALL H18021 02850
C INITIALIZE INLET CONTROL 02900
C 02950
C 03000
50 CLTH = ( DIST*DIST - SLOPE*DIST * SLOPE*DIST )**0.5 03050
PIPES = 1.0 03100
DSUBC = 0.0 03150
CQ = Q2 03200
QADJ = Q1 03250
II3 = I3 03300
55 I90 = 0 03350
I91 = 0 03400
NSW1 = 0 03450
NSW2 = 1 03500
NSW7 = 0 03550
NSW8 = 1 03600
C 03650
C CALCULATE APPROXIMATE AREA OF REQUIRED PIPE - ARCH 03700
C 03750
60 AREA = 0.785398 * QADJ / AHW 03800
NSW12 = 4 03850
GO TO 800 03900
70 IF ( FRISE - AHW - 1.0 )100,100,80 03950
80 PIPES = PIPES + 1.0 04000
IF ( PIPES - 6.0 )95,95,90 04050
90 CALL WR3 04100
GO TO 20 04150
95 QADJ = Q1 / PIPES 04200
GO TO 55 04250
C 04300
C INLET CONTROL CALCULATIONS 04350
C 04400
100 X = QADJ / ( FSPAN * FRISE ** 1.5 ) 04450
HWOVD = A(I5) + ( B(I5) + ( C(I5) + ( D(I5) + ( E(I5) + F(I5)*X ) 04500
1 * X ) * X ) * X ) * X - SCORR(I2) * SLOPE 04550
WHW = HWOVD * FRISE 04600
120 GO TO (130,650,500,350),NSW2 04650
C 04700
C SELECTION OF SIZES ROUTINE 04750
C 04800
130 IF ( WHW - AHW )131,131,195 04850
131 IF ( I90 )132,132,500 04900
132 I91 = 1 04950
```

	NSW3 = 0	05000
C		05050
C	STORE FIRST SET OF RESULTS	05100
C		05150
140	SPAN1 = SPAN(K)	05200
	RISE1 = RISE(K)	05250
	HW1 = WHW	05300
	DC(1) = DSUBC	05350
	IF (NSW3)170,150,170	05400
150	IF (K - 2)151,160,160	05450
151	CALL WR4	05500
	GO TO 20	05550
160	K=K-1	05600
	GO TO 850	05650
170	K = K+1	05700
	IF(K-61)850,850,180	05750
180	K = 11	05800
	IF (NSW1)190,80,190	05850
190	CALL WR5	05900
	Q1 = Q1 * PIPES	05950
	Q2 = Q2 * PIPES	06000
	CALL H18023	06050
	GO TO 80	06100
195	IF (I91)196,196,500	06150
196	I90 = 1	06200
	NSW3 = 1	06250
	GO TO 140	06300
C		06350
C	INITIALIZE OUTLET CONTROL	06400
C		06450
200	INVAL = 0	06500
	I90 = 0	06550
	I91 = 0	06600
	K1 = 0	06650
	K2 = 0	06700
	NSW1 = 1	06750
	NSW2 = 1	06800
	NSW12 = 1	06850
	WTW = DTW	06900
	SW=0.	06950
C		07000
C	OUTLET CONTROL CALCULATIONS	07050
C		07100
220	Q20A = QADJ * QADJ / TOAR(K) / TOAR(K) / 64.309	07150
	DEP = FRISE	07200
	NSW13 = 0	07250
	NSW14 = 2	07300
	GO TO 1100	07350
221	RFOUR = (AREA / WP) ** 1.33333	07400
	HEAD = (1.0 + CKE(I4) + (29.132 * CN(I3) * CN(I3) * DIST /	07450

DC(I) = DSUBC	10000
351 I = 1	10050
NSW7 = -1	10100
GO TO 540	10150
355 IF (NSW4)380,356,380	10200
356 SPANK = SPAN(K)	10250
RISEK = RISE(K)	10300
CALL WR7	10350
K2 = K2 + 1	10400
IF(K2-4)357,20,20	10450
357 GO TO 390	10500
380 RISE2 = RISE(K)	10550
SPAN2 = SPAN(K)	10600
IF(INVAL-2)365,381,381	10650
365 SW=1.	10700
370 NSW4 = 1	10750
IF (SPAN1 - SPAN2)371,371,372	10800
371 K = K - 1	10850
GO TO 351	10900
372 K = K + 1	10950
GO TO 351	11000
380 CALL WR8	11050
K2 = K2 + 1	11100
381 IF(K2-3)390,370,20	11150
390 IF(SW-1.)391,392,391	11200
391 NSW12 = 6	11250
NSW7 = 1	11300
GO TO 590	11350
392 NSW12 = 6	11400
NSW7 = 1	11450
SW = 0.0	11500
FSPAN= SPAN(K)/12.	11550
FRISE= RISE(K)/12.	11600
GO TO 695	11650
C	11700
C	11750
C	11800
BACKWATER PROFILE ROUTINE	11850
400 SUMX = 0.0	11900
I = 1	11950
NSW13 = 0	12000
NSW14 = 3	12050
IF (DEP - FRISE)1100,410,420	12100
410 IF (NSW6)1100,490,1100	12150
420 DEP = WTW - SLOPE * DIST	12200
IF (DEP - DSUBN)425,425,476	12250
425 SUMX = (WTW-FRISE/(1.+SLOPE*SLOPE)**0.5)*(1.0+1.0/SLOPE/SLOPE)**.5	12300
DEP = FRISE	12350
GO TO 1100	12400
430 V(I) = QADJ / AREA	12450
SPH(I)= DEP + ALPHA * V(I) * V(I) / 64.4	

	HYDR(I) = AREA / WP	12500
	IF (I - 2)431,450,450	12550
431	I = I + 1	12600
435	IF (NSW6)480,440,445	12650
440	DEP = DEP + 0.2	12700
	IF (DEP - FRISE)1100,490,490	12750
445	DBP = DEP - 0.2	12800
	GO TO 1100	12850
450	AVEV = (V(1) + V(2)) * 0.5	12900
	AVEHR = (HYDR(1) + HYDR(2)) * 0.5	12950
C		13000
C	COMPUTE SLOPE OF WATER SURFACE, S1	13050
C		13100
	S1 = CN(I3) * CN(I3) * AVEV * AVEV / 2.21 / AVEHR**1.33333	13150
	IF (NSW6)452,451,452	13200
451	IF (S1 - SLOPE)475,475,460	13250
452	IF (SLOPE - S1)475,475,461	13300
460	DX1 = (SPH(2) - SPH(1)) / (S1 - SLOPE)	13350
	GO TO 465	13400
461	DX1 = (SPH(1) - SPH(2)) / (SLOPE - S1)	13450
C		13500
C	ACCUMULATE LENGTH OF BACKWATER CURVE	13550
C		13600
465	SUMX = SUMX + DX1	13650
	IF (SUMX - CLTH)470,471,471	13700
470	V(1) = V(2)	13750
	SPH(1) = SPH(2)	13800
	HYDR(1) = HYDR(2)	13850
	GO TO 435	13900
471	IF (NSW6)473,472,473	13950
472	DEP = DEP - (SUMX - CLTH) / DX1 * 0.2	14000
	GO TO 476	14050
473	DEP = DEP + (SUMX - CLTH) / DX1 * 0.2	14100
	GO TO 476	14150
475	DEP = DSUBN	14200
476	NSW6 = -1	14250
	I = 1	14300
	GO TO 1100	14350
480	WHW = SPH(1) + CKE(I4) * V(1) * V(1) / 64.4	14400
490	NSW14 = 2	14450
	GO TO 120	14500
C		14550
C	STORE SECOND SET OF RESULTS	14600
C		14650
500	SPAN2 = SPAN(K)	14700
	RISE2 = RISE(K)	14750
	HW2 = WHW	14800
	DC(2) = DSUBC	14850
C		14900
C	INLET CONTROL VELOCITY CALCULATIONS	14950

C	I = 2	15000
	510 IF (NSW1)540,520,540	15050
	520 TEMP = QADJ * CN(I3) / 1.486 / SLOPE**0.5	15100
	DEP = 0.9 * FRISE	15150
	NSW10 = -1	15200
	GO TO 700	15250
	530 IF (DEP - FRISE)580,570,570	15300
C		15350
C	OUTLET CONTROL VELOCITY CALCULATIONS	15400
C		15450
	540 IF (WTW - FRISE)541,570,570	15500
	541 IF (DC(I) - FRISE)542,570,570	15550
	542 IF (DC(I) - WTW)543,550,550	15600
	543 DEP = WTW	15650
	GO TO 560	15700
	550 DEP = DC(I)	15750
	560 NSW13 = -1	15800
	NSW14 = 4	15850
	GO TO 1100	15900
	570 AREA = TOAR(K)	15950
	580 VEL1 = QADJ / AREA	16000
	IF (I - 1)610,610,581	16050
	581 VEL2 = VEL1	16100
	I = I - 1	16150
	NSW12 = 5	16200
	590 IF (SPAN2 - SPAN1)170,160,160	16250
C		16300
C	PRINT AND CONTROL ROUTINE	16350
C		16400
	610 IF (NSW7)355,620,630	16450
	620 CALL WR9	16500
	630 CALL WR10	16550
	GO TO (640,690,695,20),NSW8	16600
C		16650
C	SET CONTROLS FOR INLET CONTROL CHECK CALCULATIONS	16700
C		16750
	640 Q1 = QADJ	16800
	QADJ = Q2 / PIPES	16850
	NSW2 = 2	16900
	NSW9 = 0	16950
	GO TO 100	17000
C		17050
C	STORE RESULTS FOR FIRST SET OF CHECK CALCULATIONS	17100
C		17150
	650 HW1 = WHW	17200
	DC(1) = DSUBC	17250
	NSW12 = 3	17300
	IF (SPAN2 - SPAN1)160,170,170	17350
	660 NSW2 = 3	17400
		17450

	IF (NSW9)680,670,680	17500
670	NSW7 = 1	17550
	NSW8 = 2	17600
	GO TO 100	17650
680	NSW8 = 4	17700
	GO TO 220	17750
C		17800
C	SET CONTROLS FOR OUTLET CONTROL CALCULATIONS	17850
C		17900
690	CALL WR11	17950
	NSW8 = 3	18000
	Q2 = QADJ	18050
	QADJ = Q1	18100
	GO TO 200	18150
C		18200
C	SET CONTROLS FOR OUTLET CONTROL CHECK CALCULATIONS	18250
C		18300
695	QADJ = CQ / PIPES	18350
	WTW = CTW	18400
	K1 = 0	18450
	NSW2 = 2	18500
	NSW9 = 1	18550
	GO TO 220	18600
C		18650
C	ITERATIVE ROUTINE USED FOR CALCULATING	18700
C	CRITICAL DEPTH,DSUBC, AND NORMAL DEPTH,OSUBN	18750
C		18800
700	DECRM = 0.2 * FRISE	18850
	IF (NSW10)705,706,705	18900
705	NSW13 = 0	18950
	GO TO 707	19000
706	NSW13 = 1	19050
707	NSW14 = 1	19100
	KOUNT = 0	19150
	GO TO 1100	19200
710	IF (NSW10)740,711,740	19250
711	TEMP = AREA * AREA * AREA / T	19300
	IF (TEMP - Q20VG)720,750,730	19350
720	IF (KOUNT)721,750,721	19400
721	IF (DECRM - 0.03)760,760,722	19450
722	DEP = DEP + DECRM	19500
	DECRM = 0.2 * DECRM	19550
730	DEP = DEP - DECRM	19600
	KOUNT = KOUNT + 1	19650
	GO TO 1100	19700
740	AOVWP = AREA**1.66667 / WP**0.666667	19750
	IF (AOVWP - TEMP)720,760,730	19800
750	DEP = FRISE	19850
760	IF (NSW10)530,230,240	19900
C		19950

	RAD3=SQRT(B3*B3-(4*A3*(-1.)))	22500
	IF(Y3.GT.Y2.OR.Y3.EQ.Y2)GO TO 325	22550
	Y2=Y3	22600
	IF(Y3.GT.Y1.OR.Y3.EQ.Y1)GO TO 345	22650
	Y1=Y3	22700
	IF(Y3.GT.0.0)GO TO 367	22750
325	X3=ABS(A3+B3*Y3-Y3*Y3)	22800
	X33=A3+B3*Y2-Y2*Y2	22850
330	CALL MARQUE(3,Y3,Y2,B3,X3,X33,AK3,RAD3)	22900
	AREA3=(ASUB1-ASUB2)/144.0*2.	22950
	WP3 = 2.*TR(K)*(XX1-XX2)	23000
345	X2=A2+B2*Y2-Y2*Y2	23050
	X22=A2+B2*Y1-Y1*Y1	23100
	CALL MARQUE(2,Y2,Y1,B2,X2,X22,AK2,RAD2)	23150
	ASUB3 = (SPAN(K)/2.-CR(K))* Y2-(SPAN(K)/2.-CR(K))*Y1	23200
	AREA2= (ASUB1-ASUB2+ASUB3)/144.0*2.0	23250
	WP2 = 2.*CR(K)*(XX1-XX2)	23300
367	X1=B1*Y1-Y1*Y1	23350
	CALL MARQUE(1,Y1,0.,B1,X1,0.,AK1,RAD1)	23400
	AREA1=(ASUB1-ASUB2)/144.0*2.	23450
	WP1 = 2.*BR(K)*(XX1-XX2)	23500
	AREA=AREA1+AREA2+AREA3	23550
	WP =(WP1+WP2+WP3)/12.0	23600
	IF(Y3.GT.Y2) GO TO 110	23650
	IF(Y3.GT.Y1) GO TO 13	23700
	IF(Y3.GT.0.0) GO TO 15	23750
110	TOP=2*SQRT(X3)	23800
	GO TO 19	23850
13	TOP=2*(SQRT (X2)+(SPAN(K)/2.-CR(K)))	23900
	GO TO 19	23950
15	TOP=2*SQRT(X1)	24000
19	T=TOP/12.0	24050
1130	GO TO (710,221,430,580),NSW14	24100
	END	24150

```

SUBROUTINE H18021                                00000
COMMON ASUB1,ASUB2,ASUB3,XX1,XX2                00050
COMMON I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW,QADJ,PIPES,IH( 00100
1      80),SPANK,RISEK,WHW,SPAN1,RISE1,HW1,VEL1,SPAN2,RISE2,HW2,VEL2 00150
2,NT,K,K1,K2,INVAL,Y,T,Q2OVG,FRISE,TEMP,DEP,DECRM,AREA 00200
INTEGER SYSIN                                    00250
DIMENSION KT(6)                                  00300
DATA SYSIN/1/,KT/2211,3222,2233,2111,3122,2133/ 00350
C
C READ IDENTIFICATION CARD AND INPUT DATA CARD 00400
C
20 READ(SYSIN,902) IH,I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW 00500
   IF ( I1 .EQ. 0 ) STOP                          00600
   CALL H18023                                     00650
   IF ( AHW )34,34,33                              00700
33 HEIT = DIST * SLOPE + AHW - 0.5                00750
   IF ( DTW - HEIT )40,34,34                       00800
34 CALL WR1                                        00850
   GO TO 20                                         00900
40 SLOPE = SLOPE + 0.000001                        00950
   IF ( I1 - 3 )47,43,47                           01000
43 KODE = I2*1000 + I3*100 + I4*10 + I5           01050
   DO 46 I =1,6                                    01100
   IF ( KODE - KT(I) )46,50,46                     01150
46 CONTINUE                                        01200
47 CALL WR2                                        01250
   GO TO 20                                         01300
50 RETURN                                          01350
902 FORMAT (80A1 / 5I1,F7.4,6F7.1 )              01400
END                                                01450
```

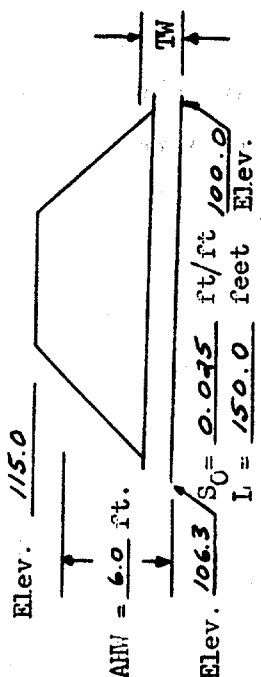
```
SUBROUTINE H18023                                00000
COMMON ASUB1,ASUB2,ASUB3,XX1,XX2                00050
COMMON I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW,QADJ,PIPES,IH1 00100
1      80),SPANK,RISEK,WHW,SPAN1,RISE1,HW1,VEL1,SPAN2,RISE2,HW2,VEL2 00150
2,NT,K,K1,K2,INVAL,Y,T,Q20VG,FRISE,TEMP,DEP,DECRM,AREA          00200
INTEGER SYSOT                                     00250
DATA SYSOT/3/                                     00300
WRITE(SYSOT,902) IH                                  00350
WRITE(SYSOT,905) I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW    00400
RETURN                                              00450
ENTRY WR1                                          00500
WRITE(SYSOT,906)                                    00550
RETURN                                              00600
ENTRY WR2                                          00650
WRITE(SYSOT,915)                                    00700
RETURN                                              00750
ENTRY WR3                                          00800
WRITE(SYSOT,907)                                    00850
RETURN                                              00900
ENTRY WR4                                          00950
WRITE(SYSOT,908)                                    01000
RETURN                                              01050
ENTRY WR5                                          01100
WRITE(SYSOT,917) QADJ,PIPES                        01150
RETURN                                              01200
ENTRY WR6                                          01250
WRITE(SYSOT,909) QADJ,PIPES,SPANK,RISEK           01300
RETURN                                              01350
ENTRY WR7                                          01400
WRITE(SYSOT,913) QADJ,PIPES,SPANK,RISEK,WHW,VEL1 01450
RETURN                                              01500
ENTRY WR8                                          01550
WRITE(SYSOT,913) QADJ,PIPES,SPAN1,RISE1,HW1,VEL1 01600
RETURN                                              01650
ENTRY WR9                                          01700
WRITE(SYSOT,910)                                    01750
WRITE(SYSOT,912)                                    01800
RETURN                                              01850
ENTRY WR10                                         01900
WRITE(SYSOT,913) QADJ,PIPES,SPAN2,RISE2,HW2,VEL2,QADJ,PIPES,SPAN1, 01950
1      RISE1,HW1,VEL1                                02000
RETURN                                              02050
ENTRY WR11                                         02100
WRITE(SYSOT,911)                                    02150
WRITE(SYSOT,912)                                    02200
RETURN                                              02250
C                                                    02300
C      OUTPUT FORMATS                               02350
C                                                    02400
902 FORMAT ( I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW, 02450
```

905	FORMAT (14HO	INPUT DATA / 6X,5HCODE ,8H SLOPE ,8H LENGTH,5X,	02500
1		2HQ1,5X,5HAHW ,5H DTW,6X,2HQ2,5X,3HCTW /	02550
2		5X,5I1,F8.4,2F9.1,2F7.1,F9.1,F7.1)	02600
906	FORMAT (34HO	ALLOWABLE HEADWATER TOO SMALL)	02650
907	FORMAT (32HO	NUMBER OF PIPES EXCEEDS SIX)	02700
908	FORMAT (33HO	ALLOWABLE HEADWATER TOO HIGH)	02750
909	FORMAT (F13.1,3F12.1,26H	INLET CONTROL GOVERNS)	02800
910	FORMAT (25HO	INLET CONTROL RESULTS)	02850
911	FORMAT (26HO	OUTLET CONTROL RESULTS)	02900
912	FORMAT (6X,9HDISCHARGE,4X,9HNUMBER OF,5X,4HSPAN, 8X,4HRISE,6X,	02950	
1		9HHEADWATER,3X,8HVELOCITY / 9X,3HCFS, 9X,5HPIPES,6X,	03000
2		6HINCHES,6X,6HINCHES,7X,4HFEET, 8X,3HFPS)	03050
913	FORMAT (F13.1,5F12.1)		03100
914	FORMAT (3F10.3,10X,F10.3)		03150
915	FORMAT (25HO	CULVERT CODE INVALID)	03200
917	FORMAT (2F13.1,8X,24HAVAILABLE SIZES EXCEEDED /// 12X,9HSEE NEXT	03250	
1		,14HSET OF ANSWERS)	03300
	END		03350

```
SUBROUTINE MARQUE(ICODE,UL,LL,BB,UX,LX, AK,RAD) 00000
COMMON ASUB1,ASUB2,ASUB3,XX1,XX2 00050
COMMON I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW,QADJ,PIPES,IHI 00100
1 80),SPANK,RISEK,WHW,SPAN1,RISE1,HW1,VEL1,SPAN2,RISE2,HW2,VEL2 00150
2,NT,K,K1,K2,INVAL,Y,T,Q2OVG,FRISE,TEMP,DEP,DECRM,AREA 00200
REAL LL,LX 00250
XX1 = (2.*UL-BB)/RAD 00300
IF(XX1.GT.1.0) XX1=1.0 00350
XX1= ASIN(XX1) 00400
ASUB1=(((-2*UL+BB)*SQRT(UX))*(-.25))+1./(2*AK)*XX1 00450
XX2= ASIN((2.*LL-BB)/RAD) 00500
ASUB2=((((-2)*LL+BB)*SQRT(LX))*(-.25))+1./(2*AK)*XX2 00550
100 RETURN 00600
END 00650
```

PROBLEM 1

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form	
Project: <u>I-40-25</u>	Designer: <u>RCT</u>
Date: _____	Date: <u>4-5-63</u>
Hydrologic and Channel Information	
CM PIPE-ARCH WITH HEADWALL	
$Q_1 = \underline{150}$ c.f.s $Q_2 = \underline{190}$ c.f.s $TW_1 = \underline{0}$ feet $TW_2 = \underline{0}$ feet	Elev. <u>115.0</u> AHW = <u>6.0</u> ft. Elev. <u>106.3</u> / $S_0 = \underline{0.045}$ ft/ft <u>100.0</u> L = <u>150.0</u> feet Elev.



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	PROJ		I-40-25		57A		4+35		CM		PIPE-ARCH		RCT		4		φ5		63																														

PROBLEM IDENTIFICATION

CARD NO. 2																																																					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
3	2	1	3	3	φ25φ		15φ		φ		15φ		φ		φ		φ		φ		19φ		φ		φ		φ		φ		φ		φ		φ		φ		φ		φ		φ		φ		φ		φ				
CULVERT CODE *		SLOPE OF PIPE (Sc)		LENGTH OF PIPE (L)		DESIGN DISCHARGE (Q1)		ALLOWABLE HEADWATER (AHW)		DESIGN TAILWATER (TW1)		CHECK DISCHARGE (Q2)		CHECK TAILWATER (TW2)																																							

* See back of the input data form

PROBLEM 1

PROJ I-40-25 STA 4&35 CM PIPE-ARCH RCT 4/05/63

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
32133	.0250	150.0	150.0	6.0	.0	190.0	.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
150.0	1.0	65.0	40.0	6.5	10.5
150.0	1.0	72.2	44.4	5.2	11.8
190.0	1.0	65.0	40.0	9.1	13.4
190.0	1.0	72.2	44.4	6.9	12.0

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
150.0	1.0	72.2	44.4	INLET CONTROL GOVERNS	11.2
150.0	1.0	65.0	40.0	6.3	11.2
190.0	1.0	72.2	44.4	INLET CONTROL GOVERNS	13.7
190.0	1.0	65.0	40.0	10.6	13.7

Comments: Results for both inlet control and outlet control show the same pipe sizes and number of pipes required. This is not always the case because both the sizes and number of pipes can be different for the two types of control (see Problem 3).

For inlet control a 72.2" x 44.4" (72" x 44" nominal) is required to keep the headwater below the AHW of 6.0 ft. The message for outlet control reads "Inlet Control Governs" indicating normal depth is less than critical depth and inlet control governs. Note that tailwater equals zero, indicating a drop off at the end of the culvert.

All sizes selected are of the riveted arch type.

PROBLEM 2

PROJ I-98-888 STA 86&19.5 CM PIPE-ARCH 4/05/63

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
32133	.0020	120.0	400.0	6.0	4.0	500.0	5.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
200.0	2.0	73.0	55.0	6.2	9.1
200.0	2.0	76.0	57.1	5.9	8.3
250.0	2.0	73.0	55.0	8.0	11.3
250.0	2.0	76.0	57.1	7.4	10.4

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
200.0	2.0	95.2	67.2	5.9	7.1
200.0	2.0	92.4	65.0	6.1	7.4
250.0	2.0	95.2	67.2	7.4	7.4
250.0	2.0	92.4	65.0	7.9	7.8

Comments: In this problem two pipes are needed, each assumed to carry one-half the discharge. No size selected is common to both the inlet and outlet control results.

Comparing headwater values with the AHW of 6.0 ft. the 95.2"x67.2" (7'-11"x5'-7" nominal) arch under outlet control must be selected since smaller pipes are adequate if flowing with inlet control. This is, therefore, an outlet control design.

This problem uses the same input data as Problem No. 4 appearing in BPR HY-1.

All sizes selected are structural plate arches with 18" corner radii.

PROBLEM 6

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: SAMPLE PROBLEM NUMBER 3 Designer: L A H
 Date: 5-1-69

Hydrologic and Channel Information

C M PIPE-ARCH WITH PROJECTING INLET

Station: 00+00.0

$Q_1 = \frac{2000}{c.f.s}$
 $Q_2 = \frac{2300}{c.f.s}$
 $TW_1 = \frac{8.0}{feet}$
 $TW_2 = \frac{10.0}{feet}$

Elev. 118.0
 AHW = 13.0 ft.
 Elev. 102.5 / $S_0 = \frac{.01}{ft/ft}$ / 100 feet Elev.
 L = 250 feet Elev.

Front of input data form

CARD NO. 1		PROBLEM IDENTIFICATION																																															
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
SAMPLE		PROBLEM NUMBER 3																																															
1																																																	

CARD NO. 2		PROBLEM IDENTIFICATION																																															
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
CULVERT CODE #		SLOPE OF PIPE (S _c)		LENGTH OF PIPE (L)		DESIGN DISCHARGE (Q ₁)		ALLOWABLE HEADWATER (AHW)		DESIGN TAILWATER (TW ₁)		DISCHARGE (Q ₂)		CHECK TAILWATER (TW ₂)																																			
32111		.61		25		20		13		8		23		10																																			

* See back of the input data form

PROBLEM 3

1 SAMPLE PROBLEM NUMBER 3

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
32111	.0100	250.0	2000.0	13.0	8.0	2300.0	10.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
2000.0	1.0	238.6	154.7	12.9	12.8
2000.0	1.0	236.4	152.5	13.1	12.7
2300.0	1.0	238.6	154.7	14.5	12.9
2300.0	1.0	236.4	152.5	14.7	12.8

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
2000.0	1.0	AVAILABLE SIZES EXCEEDED			

SEE NEXT SET OF ANSWERS

Comments: Outlet control governs in this problem due to the large design discharge and relatively flat slope. Rather than present results that reflect fewer culvert barrels for inlet control than for outlet control, an outlet control message "Available Sizes Exceeded" indicates that a greater number of barrels would be required for outlet control. The number of barrels selected for inlet control, one in this problem, is increased by one. Then inlet and outlet control results are computed as illustrated by this problem on the following page.

Problem 3 (continued)

1 SAMPLE PROBLEM NUMBER 3

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
32111	.0100	250.0	2000.0	13.0	8.0	2300.0	10.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
1000.0	2.0	152.4	97.4	12.7	12.3
1000.0	2.0	150.2	95.2	13.2	12.9
1150.0	2.0	152.4	97.4	15.2	14.1
1150.0	2.0	150.2	95.2	15.9	14.8

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
1000.0	2.0	167.2	103.0	12.8	11.1
1000.0	2.0	160.8	101.3	13.6	11.5
1150.0	2.0	167.2	103.0	17.2	12.4
1150.0	2.0	160.8	101.3	18.2	13.0

Comments: It was noted on the previous page that a single barrel culvert was inadequate for outlet control; hence, the message "Available Sizes Exceeded." The above data illustrates inlet and outlet control results for two barrels.

All sizes selected are structural plate arches with 18" corner radii.

PROBLEM 4

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: SAMPLE PROBLEM USING 31" CORNER RADIUS PIPE-ARCH Designer: LAH Date: 5/1/69

Hydrologic and Channel Information

Station: 00+00.0

CM PIPE-ARCH WITH PROJECTING INLET

$Q_1 = \frac{1250}{c.f.s}$
 $Q_2 = \frac{1350}{c.f.s}$
 $TW_1 = \frac{8.0}{\text{feet}}$
 $TW_2 = \frac{10.0}{\text{feet}}$

Elev. 106.0
 AHW = 13.0ft.
 Elev. 90.25 $S_0 = .001$ ft/ft 90.0
 $L = 250$ feet Elev.

Front of input data form

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
SAMPLE PROBLEM USING 31" CORNER RADIUS PIPE ARCH	

PROBLEM IDENTIFICATION

CARD NO. 2	
1	2
3	4
5	6
7	8
9	10
11	12
13	14
15	16
17	18
19	20
21	22
23	24
25	26
27	28
29	30
31	32
33	34
35	36
37	38
39	40
41	42
43	44
45	46
47	48
49	50
51	52
53	54
55	56
57	58
59	60
61	62
63	64
65	66
67	68
69	70
71	72
73	74
75	76
77	78
79	80
81	82
83	84
85	86
87	88
89	90
91	92
93	94
95	96
97	98
99	100
CULVERT CODE * SLOPE OF PIPE (Sc) OF PIPE (L) DESIGN DISCHARGE (Q1) ALLOWABLE HEADWATER (AHW) DESIGN TAILWATER (TW1) CHECK DISCHARGE (Q2) CHECK TAILWATER (TW2)	

* See back of the input data form

SAMPLE PROBLEM USING 31" CORNER RADIUS PIPE-ARCH

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
32111	.0010	250.0	1250.0	13.0	8.0	1350.0	10.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
1250.0	1.0	167.6	116.2	13.0	11.8
1250.0	1.0	162.2	114.4	13.6	12.3
1350.0	1.0	167.6	116.2	14.1	12.7
1350.0	1.0	162.2	114.4	14.8	13.2

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	SPAN INCHES	RISE INCHES	HEADWATER FEET	VELOCITY FPS
1250.0	1.0	195.4	130.2	13.0	11.0
1250.0	1.0	189.6	128.5	13.3	11.2
1350.0	1.0	195.4	130.2	15.0	10.1
1350.0	1.0	189.6	128.5	15.4	10.3

Comments: Outlet control governs since a 195.4" x 130.2" is required as shown, while only a 167.6" x 116.2" for inlet control.

All sizes selected are structural plate arches with 31" corner radii.

- - -

