U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
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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
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REVISION RECORD

REVISION	DESCRIPTION
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.

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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

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

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

QADJ = adjusted discharge in cfs,

AHW = allowable headwater in feet.

Headwater

$$HW = (RISE)\ (Y) \tag{2}$$

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

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

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

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

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

$$\frac{\alpha Q^2}{32.2} = \frac{A^3}{T} \tag{5}$$

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

$$HW = TEMP + H - (L)(S) \tag{6}$$

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

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

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 $TW \leq d_n$

$$X1 = \frac{\left[d_2 + \frac{V_2^2}{2g}\right] - \left[d_1 + \frac{V_1^2}{2g}\right]}{S - S_o} \tag{8a}$$

For $TW > d_n$

$$X1 = \frac{\left[d_1 + \frac{V_1^2}{2g}\right] - \left[d_2 + \frac{V_2^2}{2g}\right]}{S_o - S} \tag{8b}$$

Where $X1$ = 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_o = slope of the pipe in feet per foot,

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

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

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.

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

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,

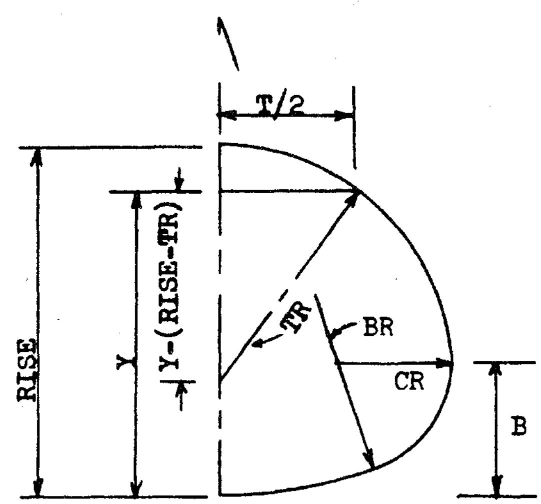
$d_c \geq$ DTW, then Area is for depth equal to d_c,

$d_c <$ 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
2. Slope of pipe
3. Length of pipe
4. Design discharge
5. Allowable headwater
6. Design tailwater
7. Check 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

Table of Pipe-Arch Culverts

Structural Plate Pipe-Arches (18-inch Corner Radii)				
SPAN		RISE		TOTAL AREA
Nominal Ft.-In.	Layout Inches	Nominal Ft.-In.	Layout Inches	Sq. Feet
6-1	73.00	4-7	55.00	22.09
6-4	76.00	4-9	57.10	24.09
6-9	81.20	4-11	58.90	26.14
7-0	84.20	5-1	61.10	28.39
7-3	87.00	5-3	63.20	30.60
7-8	92.40	5-5	65.00	32.92
7-11	95.20	5-7	67.20	35.39
8-2	97.80	5-9	69.40	37.95
8-7	103.40	5-11	71.10	40.40
8-10	106.00	6-1	73.30	43.10
9-4	111.80	6-3	75.10	45.83
9-6	114.20	6-5	77.30	48.70
9-9	116.60	6-7	79.50	51.64
10-3	122.60	6-9	81.20	54.51
10-8	128.40	6-11	82.90	57.46
10-11	131.00	7-1	85.10	60.70
11-5	136.80	7-3	86.90	63.87
11-7	139.40	7-5	89.10	67.23
11-10	141.80	7-7	91.30	70.68
12-4	147.80	7-9	93.00	74.05
12-6	150.20	7-11	95.20	77.64
12-8	152.40	8-1	97.40	81.34
12-10	154.40	8-4	99.70	85.20
13-5	160.80	8-5	101.30	88.74
13-11	167.20	8-7	103.00	92.55
14-1	169-40	8-9	105.20	96.53

Structural Plate Pipe-Arches (31-inch Corner Radii)				
SPAN		RISE		TOTAL AREA
Nominal Ft.-In.	Layout Inches	Nominal Ft.-In	Layout Inches	Sq. Feet
13-3	159.40	9-4	112.30	98.00
13-6	162.20	9-6	114.40	102.00
14-0	167.60	9-8	116.20	106.00
14-2	170.60	10-10	118.40	110.88
14-5	172.80	10-0	120.50	115.28
14-11	178.60	10-2	122.30	119.5[illegible]
15-4	184.20	10-4	124.10	124.00
15-7	187.00	10-6	126.30	129.00
15-10	189.60	10-8	128.50	133.82
16-3	195.40	10-10	130.20	138.00
16-6	198.00	11-9	132.40	143.00
17-0	203.60	11-2	134.20	148.00
17-2	206.20	11-4	136.30	153.06
17-5	208.80	11-6	138.50	158.48
17-11	214.60	11-8	140.30	163.35
18-1	217.20	11-10	142.40	168.00
18-7	223.00	12-0	144.20	174.00
18-9	225.40	12-2	146.40	179.00
19-3	231.40	12-4	148.10	184.68
19-6	234.00	12-6	150.30	190.00
19-8	236.40	12-8	152.50	196.18
19-11	238.60	12-10	154.70	202.40
20-5	244.80	13-0	156.40	207.80
20-7	247.00	13-2	158.60	214.00

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

Designer ____________

Project: ____________________

Date ____________

Hydrologic and Channel Information

Q_1 = ______ c.f.s

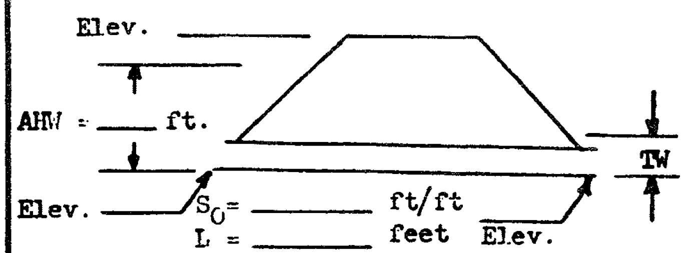
Q_2 = ______ c.f.s

TW_1 = ______ feet

TW_2 = ______ feet

Sketch

Station: ____________



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	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)

* See back of the input data form

CULVERT CODE TABLE

CORRUGATED METAL PIPE						
CIRCULAR					PIPE-ARCH	
Inlet Type	Riveted	Riveted & 25% Paved	Structural Plate	Structural Plate & 25% Paved	Paved 25%	Unpaved
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
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
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
End Section	1 2 3 3 5	1 2 4 3 5				
Bevel (A)	1 2 3 4 6	1 2 4 4 6	1 2 1 4 6	1 2 2 4 6		
Bevel (B)	1 2 3 4 7	1 2 4 4 7	1 2 1 4 7	1 2 2 4 7		
Tapered	1 1 3 4 8	1 1 4 4 8				

CONCRETE PIPE	
CIRCULAR	
Inlet type	
Socket-end Projecting	2 2 5 5 1
Socket-end Headwall	2 2 5 5 2
Square Edge Projecting	2 2 5 3 3
Square Edge Headwall	2 2 5 3 4
End Section	2 2 5 3 5
Bevel (A)	2 2 5 4 6
Bevel (B)	2 2 5 4 7
Tapered	2 1 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
1		P	R	O	J	E	C	T		I	-	4	6	-	2	3			S	T	A	T	I	O

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
N		1	Ø	9	+	2	Ø		L	.	A	.	H	E	R	R		8	/	1	Ø	/	6	2

PROBLEM IDENTIFICATION

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

CARD NO. 2

CULVERT CODE	SLOPE OF PIPE (S_0)	LENGTH OF PIPE (L)	DESIGN DISCHARGE (Q_1)	ALLOWABLE HEADWATER (AHW)	DESIGN TAILWATER (TW_1)	CHECK DISCHARGE (Q_2)	CHECK TAILWATER (TW_2)
Columns 1–5	Columns 8–12	Columns 13–19	Columns 20–26	Columns 29–33	Columns 36–40	Columns 41–47	Columns 50–54
22551	.Ø5	2ØØ.Ø	18Ø.Ø	1Ø.Ø	3.Ø	225.Ø	4.Ø

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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.

DTW -- Design tailwater in feet.

DX1 -- 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.

HWOVD -- 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.
Q2OA	--	A term that is used in the calculation of head for full flow.
Q2OVG	--	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     COMPUTER PROGRAM FOR HYDRAULIC ANALYSIS OF PIPE - ARCH CULVERTS
C
C     BUREAU OF PUBLIC ROADS --  REVISED MAY 1969  -  BY MARIO MARQUES
C
      COMMON ASUB1,ASUB2,ASUB3,XX1,XX2
      COMMON I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW,QADJ,PIPES,IH(
     1     80),SPANK,RISEK,WHW,SPAN1,RISE1,HW1,VEL1,SPAN2,RISE2,HW2,VEL2
     2,NT,K,K1,K2,INVAL,Y,T,Q2OVG,FRISE,TEMP,DEP,DECRM,AREA
      DIMENSION SCORR(3),CN(4),CKE(3),A(3),B(3),C(3),D(3),E(3),F(3),
     3SPAN(61), RISE(61),TOAR(61),TR(61),SPH(2),V(2),HYDR(2),DC(2)
     4 ,BR(61),BDIS(61),CR(61)
      DATA ALPHA/1.16/,SCORR/1.5,0.5,0.0/,CN/.032,.026,.024,.019/,CKE
     1     /.9,.7,.5/,A/.890527E-1,.833006E-1,.111281/,B/.712545,.795145
     2     ,.610579/,C/-.270921,-.434075,-.194937/,D/.792502E-1,.163774,
     3     .512893E-1/,E/-.798048E-2,-.249139E-1,-.480538E-2/,F/.293213
     4     E-3,.141066E-2,.168547E-3/
      DATA SPAN/18.1,21.7,25.3,28.9,36.1,43.3,50.6,57.8,65.0,72.2,79.4,
     173.0,76.0, 81.2,84.2,87.,92.4,95.2,97.8,103.4,106.,111.8,114.2,
     2116.6,122.6,128.4,131.,136.8,139.4,141.8,147.8,150.2,152.4,154.4,
     3160.8,167.2,169.4,159.4,162.2,167.6,170.6,172.8,178.6,184.2,187.0,
     4189.6,195.4, 198.,203.6,206.2,208.8,214.6,217.2,223.,225.4,231.4,
     5234.0,236.4, 238.6,244.8,247./
      DATA RISE/11.0,13.3,15.5,17.8,22.2,26.6,31.7,35.5,40.0,44.4,48.7,
     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,
     281.2, 82.9,85.1,86.9,89.1,91.3,93.,95.2,97.4,99.7,101.3,103.,
     3 105.2, 112.3,114.4,116.2,118.4,120.5,122.3,124.1,126.3,128.5,
     4 130.2,132.4,  134.2,136.3,138.5,140.3,142.4,144.2,146.4,148.1,
     5   148.1,     152.5,154.7,156.4,158.6/
      DATA TOAR/1.07,1.59,2.10,2.81,4.39,6.28,8.55,11.23,14.23,17.52,21.
     101,22.09,24.09,26.14,28.39,30.60,32.92,35.39,37.94,40.4,43.1,45.79
     2,48.67,51.60,54.51,57.46,60.7,63.86,67.18,70.68,74.,77.64,81.34,
     3 85.14,88.68,92.54,96.53,98.,102.,106.,110.,115.,119.,124.,129.,
     4 133.,138.,143.,148.,153.,158.,163.,168.,174.,179.,185.,190.,196.,
     5 202.,208.,214./
      DATA BR/19.12,37.06,33.50,55.00,73.25,91.56,97.25,115.69,129.31,
     1142.94,145.50,76.30,98.60,83.50,104.20,136.20,109.80,137.90,182.90
     2,141.00,178.70,144.60,
     3 177.5,227.7,178.3,153.2,180.4,157.9,183.2,216.4,186.5,216.8,
     4257.4,314.7,254.8,220.7,254.1,192.6,220.6,197.9,222.6,256.6,227.7,
     5 208.5,232.1,260.6,236.,263.2,241.,266.8,297.9,270.6,299.7,274.5,
     6 302.3,278.6,305.1,336.5,374.3,338.1,373.5/
      DATA TR/10.06,11.87,12.75,14.75,18.25,21.56,25.12,29.12,32.75,
     1 36.31,39.75,36.80,
     2 38.1,41.,42.3,43.51,46.5,47.7,48.91,51.9,53.01,56.2,57.3,58.31,61
     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
     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,
     5 104.8,108.2,109.1,112.6,113.5,117.,117.9,118.8,119.7,123.2,124./
      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.
     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.,
```

```
     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,
     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,
     4 43.6,42.5,44.8,43.7,46.,44.9,43.8,42.6,45.,43.8/
      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,
     1 18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,18.,
     2 18.,18.,18.,18.,18.,18.,18.,18.,31.,31.,31.,31.,31.,31.,31.,31.,
     3 31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31.,31./
   20 CALL H18021
C
C     INITIALIZE INLET CONTROL
C
   50 CLTH  = ( DIST*DIST - SLOPE*DIST * SLOPE*DIST )**0.5
      PIPES = 1.0
      DSUBC = 0.0
      CQ    = Q2
      QADJ  = Q1
      II3   = I3
   55 I90   = 0
      I91   = 0
      NSW1  = 0
      NSW2  = 1
      NSW7  = 0
      NSW8  = 1
C
C     CALCULATE APPROXIMATE AREA OF REQUIRED PIPE - ARCH
C
   60 AREA  = 0.785398 * QADJ / AHW
      NSW12 = 4
      GO TO 800
   70 IF ( FRISE - AHW - 1.0 )100,100,80
   80 PIPES = PIPES + 1.0
      IF ( PIPES - 6.0 )95,95,90
   90 CALL WR3
      GO TO 20
   95 QADJ  = Q1 / PIPES
      GO TO 55
C
C           INLET CONTROL CALCULATIONS
C
  100 X      = QADJ / ( FSPAN * FRISE ** 1.5 )
      HWOVD  = A(I5) + ( B(I5) + ( C(I5) + ( D(I5) + ( E(I5) + F(I5)*X )
     1          * X ) * X ) * X ) * X   - SCORR(I2) * SLOPE
      WHW    = HWOVD * FRISE
  120 GO TO (130,650,500,350),NSW2
C
C           SELECTION OF SIZES ROUTINE
C
  130 IF ( WHW - AHW )131,131,195
  131 IF ( I90 )132,132,500
  132 I91   = 1
```

```
      NSW3  = 0
C
C     STORE FIRST SET OF RESULTS
C
  140 SPAN1 = SPAN(K)
      RISE1 = RISE(K)
      HW1   = WHW
      DC(1) = DSUBC
      IF ( NSW3 )170,150,170
  150 IF ( K - 2 )151,160,160
  151 CALL WR4
      GO TO 20
  160 K=K-1
      GO TO 850
  170 K = K+1
      IF( K-61 )850,850,180
  180 K = 11
      IF ( NSW1 )190,80,190
  190 CALL WR5
      Q1    = Q1 * PIPES
      Q2    = Q2 * PIPES
      CALL H18023
      GO TO 80
  195 IF ( I91 )196,196,500
  196 I90   = 1
      NSW3  = 1
      GO TO 140
C
C          INITIALIZE OUTLET CONTROL
C
  200 INVAL = 0
      I90   = 0
      I91   = 0
      K1    = 0
      K2    = 0
      NSW1  = 1
      NSW2  = 1
      NSW12 = 1
      WTW   = DTW
      SW=0.
C
C          OUTLET CONTROL CALCULATIONS
C
  220 Q20A  = QADJ * QADJ / TOAR(K) / TOAR(K) / 64.309
      DEP   = FRISE
      NSW13 = 0
      NSW14 = 2
      GO TO 1100
  221 RFOUR = ( AREA / WP ) ** 1.33333
      HEAD  = ( 1.0 + CKE(I4) + (29.132 * CN(I3) * CN(I3) * DIST /
```

```
     1         RFOUR )) * Q20A
      K1    = K1 + 1
C
C     INITIALIZE CRITICAL DEPTH CALCULATIONS
C
  222 Q20VG = QADJ * QADJ * ALPHA / 32.2
      DEP   = 0.98 * FRISE
      NSW10 = 0
      GO TO 700
  230 DSUBC = DEP
C
C     INITIALIZE NORMAL DEPTH CALCULATIONS
C
      TEMP  = QADJ * CN(I3) / 1.486 / SLOPE**0.5
      DEP   = 0.90 * FRISE
      NSW10 = 1
      GO TO 700
  240 DSUBN = DEP
C
C     DETERMINE OUTLET CONTROL CONDITION
C
      TEMP  = ( FRISE + DSUBC ) * 0.5
      IF ( TEMP - WTW )245,245,250
  245 TEMP  = WTW
  250 WHW   = TEMP + HEAD - SLOPE * CLTH
      IF ( WHW )260,260,255
  255 TEMP  = WHW - ( 1.0 + CKE(I4) ) * Q20A
      IF ( TEMP - FRISE )260,120,120
  260 IF ( DSUBN - DSUBC )300,270,270
  270 NSW6  = 0
      IF ( WTW - DSUBC )290,290,275
  275 IF ( WTW - DSUBN )285,285,280
  280 NSW6  = 1
  285 DEP   = WTW
      GO TO 400
  290 DEP   = DSUBC
      GO TO 400
C
C           INLET CONTROL GOVERNS ROUTINE
C
  300 SPANK=SPAN(K)
      RISEK  = RISE(K)
      CALL WR6
      INVAL = INVAL + 1
      K2    = K2 + 1
      IF ( K1 - 2 )340,360,360
  340 NSW2  = 4
      NSW12 = 2
      IF ( SPAN1 - SPAN2 )170,160,160
  350 NSW4  = 0
```

```
      DC(1) = DSUBC
  351 I      = 1
      NSW7  = -1
      GO TO 540
  355 IF ( NSW4 )380,356,380
  356 SPANK  = SPAN(K)
      RISEK  = RISE(K)
      CALL WR7
      K2     = K2 + 1
      IF(K2-4)357,20,20
  357 GO TO 390
  360 RISE2 = RISE(K)
      SPAN2 = SPAN(K)
      IF(INVAL-2)365,381,381
  365 SW=1.
  370 NSW4  = 1
      IF ( SPAN1 - SPAN2 )371,371,372
  371 K      = K - 1
      GO TO 351
  372 K      = K + 1
      GO TO 351
  380 CALL WR8
      K2     = K2 + 1
  381 IF(K2-3)390,370,20
  390 IF(SW-1.)391,392,391
  391 NSW12 = 6
      NSW7  = 1
      GO TO 590
  392 NSW12 = 6
      NSW7 = 1
      SW = 0.0
      FSPAN= SPAN(K)/12.
      FRISE= RISE(K)/12.
      GO TO 695
C
C           BACKWATER PROFILE ROUTINE
C
  400 SUMX  = 0.0
      I      = 1
      NSW13 = 0
      NSW14 = 3
      IF ( DEP - FRISE )1100,410,420
  410 IF ( NSW6 )1100,490,1100
  420 DEP    = WTW - SLOPE * DIST
      IF ( DEP - DSUBN )425,425,476
  425 SUMX = (WTW-FRISE/(1.+SLOPE*SLOPE)**0.5)*(1.0+1.0/SLOPE/SLOPE)**.5
      DEP     = FRISE
      GO TO 1100
  430 V(I)  = QADJ / AREA
      SPH(I)= DEP + ALPHA * V(I) * V(I) / 64.4
```

```
      HYDR(I) = AREA / WP
      IF ( I - 2 )431,450,450
  431 I     = I + 1
  435 IF ( NSW6 )480,440,445
  440 DEP   = DEP + 0.2
      IF ( DEP - FRISE )1100,490,490
  445 DEP   = DEP - 0.2
      GO TO 1100
  450 AVEV  = ( V(1) + V(2) ) * 0.5
      AVEHR = ( HYDR(1) + HYDR(2) ) * 0.5
C
C     COMPUTE SLOPE OF WATER SURFACE,S1
C
      S1    = CN(I3) * CN(I3) * AVEV * AVEV / 2.21 / AVEHR**1.33333
      IF ( NSW6 )452,451,452
  451 IF ( S1 - SLOPE )475,475,460
  452 IF ( SLOPE - S1 )475,475,461
  460 DX1   = ( SPH(2) - SPH(1) ) / ( S1 - SLOPE )
      GO TO 465
  461 DX1   = ( SPH(1) - SPH(2) ) / ( SLOPE - S1 )
C
C     ACCUMULATE LENGTH OF BACKWATER CURVE
C
  465 SUMX  = SUMX + DX1
      IF ( SUMX - CLTH )470,471,471
  470 V(1)  = V(2)
      SPH(1) = SPH(2)
      HYDR(1) = HYDR(2)
      GO TO 435
  471 IF ( NSW6 )473,472,473
  472 DEP   = DEP - (SUMX - CLTH)/ DX1 * 0.2
      GO TO 476
  473 DEP   = DEP + (SUMX - CLTH) / DX1 * 0.2
      GO TO 476
  475 DEP   = DSUBN
  476 NSW6  = -1
      I     = 1
      GO TO 1100
  480 WHW   = SPH(1) + CKE(I4) * V(1) * V(1) / 64.4
  490 NSW14 = 2
      GO TO 120
C
C     STORE SECOND SET OF RESULTS
C
  500 SPAN2 = SPAN(K)
      RISE2 = RISE(K)
      HW2   = WHW
      DC(2) = DSUBC
C
C     INLET CONTROL VELOCITY CALCULATIONS
```

```
C
      I      = 2
  510 IF ( NSW1 )540,520,540
  520 TEMP   = QADJ * CN(I3) / 1.486 / SLOPE**0.5
      DEP    = 0.9 * FRISE
      NSW10 = -1
      GO TO 700
  530 IF ( DEP - FRISE )580,570,570
C
C     OUTLET CONTROL VELOCITY CALCULATIONS
C
  540 IF ( WTW - FRISE )541,570,570
  541 IF ( DC(I) - FRISE )542,570,570
  542 IF ( DC(I) - WTW )543,550,550
  543 DEP    = WTW
      GO TO 560
  550 DEP    = DC(I)
  560 NSW13 = -1
      NSW14 = 4
      GO TO 1100
  570 AREA   = TOAR(K)
  580 VEL1   = QADJ / AREA
      IF ( I - 1 )610,610,581
  581 VEL2   = VEL1
      I      = I - 1
      NSW12 = 5
  590 IF ( SPAN2 - SPAN1 )170,160,160
C
C        PRINT AND CONTROL ROUTINE
C
  610 IF ( NSW7 )355,620,630
  620 CALL WR9
  630 CALL WR10
      GO TO ( 640,690,695,20  ),NSW8
C
C     SET CONTROLS FOR INLET CONTROL CHECK CALCULATIONS
C
  640 Q1     = QADJ
      QADJ   = Q2 / PIPES
      NSW2   = 2
      NSW9   = 0
      GO TO 100
C
C     STORE RESULTS FOR FIRST SET OF CHECK CALCULATIONS
C
  650 HW1    = WHW
      DC(1) = DSUBC
      NSW12 = 3
      IF ( SPAN2 - SPAN1 )160,170,170
  660 NSW2   = 3
```

```
      IF ( NSW9 )680,670,680
  670 NSW7  = 1
      NSW8  = 2
      GO TO 100
  680 NSW8  = 4
      GO TO 220
C
C     SET CONTROLS FOR OUTLET CONTROL CALCULATIONS
C
  690 CALL WR11
      NSW8  = 3
      Q2    = QADJ
      QADJ  = Q1
      GO TO 200
C
C     SET CONTROLS FOR OUTLET CONTROL CHECK CALCULATIONS
C
  695 QADJ  = CQ / PIPES
      WTW   = CTW
      K1    = 0
      NSW2  = 2
      NSW9  = 1
      GO TO 220
C
C         ITERATIVE ROUTINE USED FOR CALCULATING
C         CRITICAL DEPTH,DSUBC, AND NORMAL DEPTH,DSUBN
C
  700 DECRM = 0.2  * FRISE
      IF ( NSW10 )705,706,705
  705 NSW13 =0
      GO TO 707
  706 NSW13 = 1
  707 NSW14 = 1
      KOUNT = 0
      GO TO 1100
  710 IF ( NSW10 )740,711,740
  711 TEMP  = AREA * AREA * AREA / T
      IF ( TEMP - Q2OVG )720,750,730
  720 IF ( KOUNT )721,750,721
  721 IF (DECRM - 0.03 )760,760,722
  722 DEP   = DEP + DECRM
      DECRM = 0.2 * DECRM
  730 DEP   = DEP - DECRM
      KOUNT = KOUNT + 1
      GO TO 1100
  740 AOVWP = AREA**1.66667 / WP**0.666667
      IF ( AOVWP - TEMP )720,760,730
  750 DEP   = FRISE
  760 IF ( NSW10 )530,230,240
C
```

```
C         PIPE-ARCH SELECTION ROUTINE
C
  800 DO 840 K =1,61
      IF ( TOAR(K) - AREA )840,850,850
  840 CONTINUE
      GO TO 80
  850 FSPAN=SPAN(K)/12.0
      FRISE  = RISE(K) / 12.0
      IF ( FRISE - AHW - 0.5 )854,854,180
  854 IF( K-11 ) 855,855,870
  855 IF ( II3 - 1 )856,856,860
  856 I3      = 3
      GO TO 890
  860 I3      = 4
      GO TO 890
  870 IF ( II3 - 1 )871,871,880
  871 I3      = 1
      GO TO 890
  880 I3      = 2
  890 GO TO ( 895,220,660,70,510,695 ),NSW12
  895 IF ( NSW1 )220,100,220
C
C         ROUTINE FOR CALCULATING AREA,WETTED PERIMETER, AND TOP SURFACE
C         WIDTH OF WATER FOR ANY DEPTH OF FLOW IN PIPE-ARCH CULVERTS
C
 1100 Y3=DEP *12.0
      SPHI1 = (SPAN(K)/2.-CR(K))/(BR(K)-CR(K))
      TPHI2=(SPAN(K)/2.-CR(K))/(BDIS(K)-(RISE(K)-TR(K)))
      PHI1=ATAN(SPHI1/SQRT(1-SPHI1*SPHI1))
      PHI2=ATAN(TPHI2)
      Y1 = BR(K)-BR(K)*COS(PHI1)
      Y2 = BDIS(K) +CR(K)*COS(PHI2)
      AREA3=0.
      AREA2=0.
      AREA1=0.
      WP1=0.
      WP2=0.
      WP3=0.
      TOP=0.0
      B1=2*BR(K)
      A1=0.
      AK1=1./(BR(K)*BR(K))
      RAD1=SQRT(B1*B1)
      B2=2*BDIS(K)
      A2= CR(K)*CR(K)-BDIS(K)*BDIS(K)
      AK2=1./CR(K)**2
      RAD2=SQRT(B2*B2-(4*A2*(-1.)))
      B3=2*(RISE(K)-TR(K))
      A3=2*RISE(K)*TR(K)-RISE(K)*RISE(K)
      AK3=1./TR(K)**2
```

```
      RAD3=SQRT(B3*B3-(4*A3*(-1.)))
      IF(Y3.GT.Y2.OR.Y3.EQ.Y2)GO TO 325
      Y2=Y3
      IF(Y3.GT.Y1.OR.Y3.EQ.Y1)GO TO 345
      Y1=Y3
      IF(Y3.GT.0.0)GO TO 367
  325 X3=ABS(A3+B3*Y3-Y3*Y3)
      X33=A3+B3*Y2-Y2*Y2
  330 CALL MARQUE(3,Y3,Y2,B3,X3,X33,AK3,RAD3)
      AREA3=(ASUB1-ASUB2)/144.0*2.
      WP3 = 2.*TR(K)*(XX1-XX2)
  345 X2=A2+B2*Y2-Y2*Y2
      X22=A2+B2*Y1-Y1*Y1
      CALL MARQUE(2,Y2,Y1,B2,X2,X22,AK2,RAD2)
      ASUB3 = (SPAN(K)/2.-CR(K))* Y2-(SPAN(K)/2.-CR(K))*Y1
      AREA2= (ASUB1-ASUB2+ASUB3)/144.0*2.0
      WP2 = 2.*CR(K)*(XX1-XX2)
  367 X1=B1*Y1-Y1*Y1
      CALL MARQUE(1,Y1,0.,B1,X1,0.,AK1,RAD1)
      AREA1=(ASUB1-ASUB2)/144.0*2.
      WP1 = 2. *BR(K)*(XX1-XX2)
      AREA=AREA1+AREA2+AREA3
      WP  =(WP1+WP2+WP3)/12.0
      IF(Y3.GT.Y2) GO TO 110
      IF(Y3.GT.Y1) GO TO 13
      IF(Y3.GT.0.0) GO TO 15
  110 TOP=2*SQRT(X3)
      GO TO 19
   13 TOP=2*(SQRT (X2)+(SPAN(K)/2.-CR(K)))
      GO TO 19
   15 TOP=2*SQRT(X1)
   19 T=TOP/12.0
 1130 GO TO ( 710,221,430,580 ),NSW14
      END
```

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

```
      SUBROUTINE H18023
      COMMON ASUB1,ASUB2,ASUB3,XX1,XX2
      COMMON I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW,QADJ,PIPES,IH(
     1     80),SPANK,RISEK,WHW,SPAN1,RISE1,HW1,VEL1,SPAN2,RISE2,HW2,VEL2
     2,NT,K,K1,K2,INVAL,Y,T,Q2OVG,FRISE,TEMP,DEP,DECRM,AREA
      INTEGER SYSOT
      DATA SYSOT/3/
      WRITE(SYSOT,902) IH
      WRITE(SYSOT,905) I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW
      RETURN
      ENTRY WR1
      WRITE(SYSOT,906)
      RETURN
      ENTRY WR2
      WRITE(SYSOT,915)
      RETURN
      ENTRY WR3
      WRITE(SYSOT,907)
      RETURN
      ENTRY WR4
      WRITE(SYSOT,908)
      RETURN
      ENTRY WR5
      WRITE(SYSOT,917) QADJ,PIPES
      RETURN
      ENTRY WR6
      WRITE(SYSOT,909) QADJ,PIPES,SPANK,RISEK
      RETURN
      ENTRY WR7
      WRITE(SYSOT,913) QADJ,PIPES,SPANK,RISEK,WHW,VEL1
      RETURN
      ENTRY WR8
      WRITE(SYSOT,913) QADJ,PIPES,SPAN1,RISE1,HW1,VEL1
      RETURN
      ENTRY WR9
      WRITE(SYSOT,910)
      WRITE(SYSOT,912)
      RETURN
      ENTRY WR10
      WRITE(SYSOT,913) QADJ,PIPES,SPAN2,RISE2,HW2,VEL2,QADJ,PIPES,SPAN1,
     1                 RISE1,HW1,VEL1
      RETURN
      ENTRY WR11
      WRITE(SYSOT,911)
      WRITE(SYSOT,912)
      RETURN
C
C           OUTPUT FORMATS
C
  902 FORMAT ( 1H1,80A1)
```

```
905 FORMAT ( 14H0   INPUT DATA / 6X,5HCODE ,8H  SLOPE ,8H  LENGTH,5X,
   1          2HQ1,5X,5HAHW  ,5H  DTW,6X,2HQ2,5X,3HCTW /
   2          5X,5I1,F8.4,2F9.1,2F7.1,F9.1,F7.1 )
906 FORMAT ( 34H0    ALLOWABLE HEADWATER TOO SMALL )
907 FORMAT ( 32H0    NUMBER OF PIPES EXCEEDS SIX )
908 FORMAT ( 33H0    ALLOWABLE HEADWATER TOO HIGH )
909 FORMAT ( F13.1,3F12.1,26H    INLET CONTROL GOVERNS )
910 FORMAT ( 25H0   INLET CONTROL RESULTS )
911 FORMAT ( 26H0   OUTLET CONTROL RESULTS )
912 FORMAT ( 6X,9HDISCHARGE,4X,9HNUMBER OF,5X,4HSPAN, 8X,4HRISE,6X,
   1         9HHEADWATER,3X,8HVELOCITY / 9X,3HCFS, 9X,5HPIPES,6X,
   2         6HINCHES,6X,6HINCHES,7X,4HFEET, 8X,3HFPS )
913 FORMAT ( F13.1,5F12.1 )
914 FORMAT ( 3F10.3,10X,F10.3 )
915 FORMAT ( 25H0    CULVERT CODE INVALID )
917 FORMAT ( 2F13.1,8X,24HAVAILABLE SIZES EXCEEDED /// 12X,9HSEE NEXT
   1        ,14HSET OF ANSWERS )
    END
```

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

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: I-40-25

Designer: RCT

Date: 4-5-63

Hydrologic and Channel Information

CM PIPE-ARCH WITH HEADWALL

Q_1 = 150 c.f.s

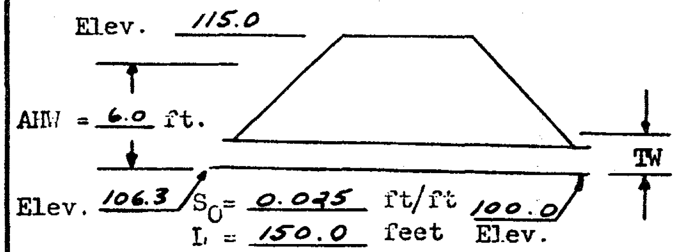
Q_2 = 190 c.f.s

TW_1 = 0 feet

TW_2 = 0 feet

Sketch

Station: 4+35



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
1		P	R	O	J		I	-	4	0	-	2	5		S	T	A		4	+	3	5		C

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
M		P	I	P	E	-	A	R	C	H		R	C	T		4	/	Ø	5	/	6	3		

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
3	2	1	3	3	.	Ø	2	5	Ø			1	5	Ø	.	Ø			1	5	Ø	.	Ø
CULVERT CODE *					SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)						

29	30	31	32	33	36	37	38	39	40	41	42	43	44	45	46	47	50	51	52	53	54
		6	.	Ø			Ø	.				1	9	Ø	.	Ø			Ø	.	
ALLOWABLE HEADWATER (AHW)					DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)				

* See back of the input data form

PROBLEM 1

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	
150.0	1.0	65.0	40.0	6.3	11.2
190.0	1.0	72.2	44.4	INLET CONTROL GOVERNS	
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.

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form	Designer LAH
Project: I-98-888	Date 4-5-63

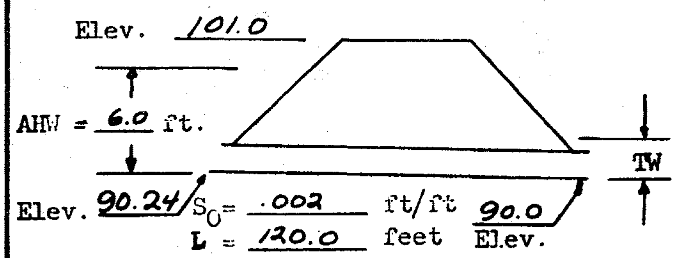
Hydrologic and Channel Information

CM PIPE-ARCH WITH HEADWALL

Q_1 = 400 c.f.s
Q_2 = 500 c.f.s
TW_1 = 4.0 feet
TW_2 = 5.0 feet

Sketch

Station: 86+19.5



PROBLEM 2

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	-	9	8	-	8	8	8		S	T	A		8	6	+	1	9	.	5		C	M		P	I	P	E	-	A	R	C	H		4	/	Ø	5	/	6	3		

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
3	2	1	3	3	.	Ø	Ø	2	Ø			1	2	Ø	.	Ø			4	Ø	Ø	.	Ø			6	.	Ø			4	.	Ø			5	Ø	Ø	.	Ø			5	.	Ø
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)				

* See back of the input data form

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.

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer: LAH

Project: SAMPLE PROBLEM NUMBER 3

Date: 5-1-69

Hydrologic and Channel Information

C M PIPE-ARCH WITH PROJECTING INLET

Q_1 = 2000 c.f.s

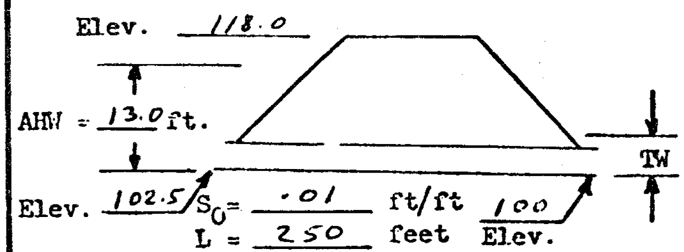
Q_2 = 2300 c.f.s

TW_1 = 8.0 feet

TW_2 = 10.0 feet

Sketch

Station: 00+00.0



PROBLEM 3

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
1			S	A	M	P	L	E		P	R	O	B	L	E	M		N	U	M	B	E	R		3																								

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
3	2	1	1	1	.	ϕ	1	ϕ	ϕ			2	5	ϕ	.	ϕ		2	ϕ	ϕ	ϕ	.	ϕ		1	3	.	ϕ			8	.	ϕ		2	3	ϕ	ϕ	.	ϕ		1	ϕ	.	ϕ
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)				

* 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.

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer: LAH

Project: Sample Problem Using 31" Corner Radius Pipe-Arch

Date: 5/1/69

Hydrologic and Channel Information

CM PIPE-ARCH WITH PROJECTING INLET

Q_1 = 1250 c.f.s

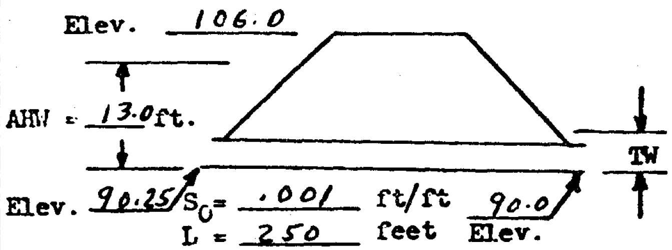
Q_2 = 1350 c.f.s

TW_1 = 8.0 feet

TW_2 = 10.0 feet

Sketch

Station: 00+00.0



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
1		S	A	M	P	L	E		P	R	O	B	L	E	M		U	S	I	N	G		3	1

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
"		C	O	R	N	E	R		R	A	D	I	U	S		P	I	P	E		A	R	C	H

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
3	2	1	1	1	.	Ø	Ø	1	Ø			2	5	Ø	.	Ø		1	2	5	Ø	.	Ø
CULVERT CODE *					SLOPE OF PIPE (S_c)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)						

29	30	31	32	33	36	37	38	39	40	41	42	43	44	45	46	47	50	51	52	53	54
	1	3	.	Ø			8	.	Ø		1	3	5	Ø	.	Ø		1	Ø	.	Ø
ALLOWABLE HEADWATER (AHW)					DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)				

* See back of the input data form

PROBLEM 4

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.

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