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Electronic Computer Program For

HYDRAULIC ANALYSIS OF CIRCULAR CULVERTS

(BPR PROGRAM NO. HY-1)

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

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ABSTRACT

This program is used for the hydraulic analysis of circular pipe culverts for given hydrological data and site conditions. The program produces number of pipes, pipe sizes, headwater and outlet velocities for inlet conditions and outlet conditions. Outlet control calculations make use of backwater computations, whenever necessary, to compute headwater.

STATEMENT OF THE PROBLEM

Highway organizations find the electronic computer helpful in performing the numerous computations needed for the planning, designing and construction of modern highways. Programs are available for various phases of road and bridge design, but only a few programs deal with hydraulic design. This program then, is an attempt at closing the gap that exists for electronic computation in hydraulic design.

The ideal program for the design of a highway culvert would compute culvert lengths, sizes and select the most economical culvert (circular, pipe-arch or concrete box) from all the various types. The program herein described is for the hydraulic design of circular pipe culverts and is a step towards the ultimate goal of having the electronic computer select the most economical culvert.

The rapidity with which the electronic computer performs calculations makes its use advantageous for selecting culvert sizes on highway projects having a number of installations or for checking culvert sizes in 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." Mathematical equations, listed on pages are used instead of the nomographs in Circular No. 5 for calculating headwater-discharge relationships, head for full flow and backwater computations by the step-method.

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

Inlet Control

Inlet control calculations are begun by calculating the approximate diameter of pipe; this is done by equation (1). The approximate diameter is checked against the allowable headwater, which is input data. If the diameter is greater than the allowable headwater the number of pipes is incremented by one and the discharge is changed by dividing the new number of pipes into the original discharge. Using the adjusted discharge the calculation for a new approximate diameter is made and checked against allowable headwater. When a diameter of pipe has met the test of being less than the allowable headwater, inlet control calculations are continued.

Using the acceptable diameter of pipe, the headwater is calculated by equation (2). The calculated value of headwater is compared to the allowable headwater and on the basis of the comparison the program either increments or decrements the diameter of the pipe by one-half foot to obtain a new diameter. If it is necessary to increment the size of the pipe to obtain a new diameter, a check is made to be sure the diameter does not become greater than the allowable headwater plus one-half foot. If the diameter is incremented above this limit, then the number of pipes is incremented by one, the discharge is adjusted by the method mentioned previously, and the calculations are started over again.

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

Equation (2), which is used for calculating headwater, was calculated by a Least Squares Polynomial Curve Fitting 1/ computer program. The program was used to calculate a 5th degree curve for each set of experimental data for culvert models 1, 4, 7, 51, 81, 101, 102 and 112 as presented in Hydraulic Characteristics of Commonly Used Pipe Entrances 2/.

1/ Least Square Polynomial Curve Fitting, by Electronics Branch, 1962, U. S. Department of Commerce, Bureau of Public Roads Electronic Computer Program Library M-1.

2/ Hydraulic Characteristics of Commonly Used Pipe Entrances, by John L. French, 1955, U. S. Department of Commerce, National Bureau of Standards, pages 48-74.

When the two pipe sizes have been selected, the program proceeds to calculate the 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 interative method using equation (3). The iterative calculations start at full flow and the depth is decremented until equation (3) is satisfied. When equation (3) is satisfied, the area which is calculated by equation (11) is divided into the discharge to calculate the outlet velocity.

After the velocities have been calculated and the results printed, the program branches to a control routine. This routine sets all necessary switches to enable the program to use the check value of discharge in order to calculate new values of headwater and outlet velocity for the pipe sizes originally selected. After printing the results of the check calculations, the program branches to the control routine which resets the original value of the discharge and then sends the program to outlet control calculations.

Outlet Control

Outlet control calculations are begun by using one of the selected pipes from inlet control calculations as the first selection of pipe size to be analyzed. The calculations are started by calculating the head for a circular pipe flowing full by equation (4). After the head is calculated, the value of tailwater, which is input data, is compared to the diameter of the pipe being analyzed. If tailwater is equal to or greater than the diameter, then headwater is calculated by equation (6) using the conditions listed. If the value of tailwater is less than the diameter, it is necessary to calculate critical depth by an interative method using equation (5). The iterative process starts with the depth equal to 0.98 times the diameter and the depth decrements until equation (5) is satisfied. Headwater is then calculated by equation (6) using the listed conditions.

After calculating headwater by one of the above methods a determination is made whether the critical depth is equal to or less than the normal depth. If this condition does not exist the previously calculated value of headwater is correct. If the critical depth is equal to or less than the normal depth, then a water-surface profile or backwater curve must be calculated. The calculations for a backwater curve use equations (7) and (8). The larger of the values of tailwater or critical depth is used as the starting depth of the backwater calculations. When the backwater curve is completed, the headwater is calculated by equation (9).

After a value of headwater is obtained by one of the above methods, it is compared to the allowable headwater. Depending on the comparison, the pipe diameter is either incremented or decremented by one-half foot to obtain a new diameter. This selection and any subsequent selections are then put through the above calculations and comparisons starting with the head calculations. As stated under inlet control, there are only two acceptable selections; one pipe with its headwater equal to or less than the allowable headwater and one pipe with its headwater 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 diameter and when tailwater is equal to or greater than the diameter, the outlet velocity is calculated for full flow. When the tailwater is less than the diameter, tailwater and critical depth are compared and the largest value is used in equation (11) to calculate 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 check values of headwater and outlet velocity for the two pipes selected by outlet control. The check calculations for headwater and outlet velocity are determined in the same manner as the original calculations.

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

MATHEMATICAL EQUATIONS

Inlet Control Equations

Approximate Diameter

$$D = \left[\frac{Q}{AHW}\right]^{1/2} \qquad (1)$$

Where D is the diameter in feet,

Q is the discharge in cfs,

AHW is the allowable headwater in feet.

Inlet Headwater

$$HW = (Y)(DIA) \qquad (2)$$

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

HW is headwater in feet,

DIA is diameter of pipe in feet,

A,B,C,D,E, & F are coefficients as described on page 23,

SCORR is a correction applied to slope,

SLOPE is the slope of the pipe,

$X = \frac{Q}{DIA^{5/2}}$,

Q is discharge in cfs,

Outlet Velocity

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

Where Q is the discharge in cfs,

A is the area of water in square feet at any depth of flow defined by equation (11),

R is the hydraulic radius in feet,

S is the slope of the pipe in feet per foot,

n is Manning's value.

Outlet Control Equations

Head

$$H = \left[1 + k_e + \frac{185.0\, n^2 L}{D^{4/3}}\right] \cdot \left[\frac{Q^2}{(39.725)(D)^4}\right] \qquad (4)$$

Where H is the head for circular culverts flowing full in feet,

k_e is the coefficient of entrance loss,

n is Manning's value for stream channels,

L is length of pipe in feet,

Q is the discharge in cfs,

D is the diameter of pipe in feet.

Critical Depth

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

Where Q is the discharge in cfs,

A is the area of water in square feet at any depth defined by equation (11),

T is the top surface width of water in feet at any depth of flow defined by equation (13).

Outlet Headwater

Where d_n is normal depth and d_c is critical depth.

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

When $d_c = D$ and $D > TW$, then $TEMP = D$;

$d_c < D$ and $\frac{d_c + D}{2} > TW$, then $TEMP = \frac{d_c + D}{2}$;

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

Where D is the diameter of pipe in feet,

TW is tailwater height in feet,

HW is the headwater in feet,

H is the head for full flow in feet,

L is the length of the pipe in feet,

S is the slope of the pipe in feet per foot.

For $d_n \geq d_c$

This is for water-surface profile or sometimes referred to as a backwater curve.

$$X1 = \frac{\left[d_2 + \frac{V_2^2}{2g}\right] - \left[d_1 + \frac{V_1^2}{2g}\right]}{S - S_o} \qquad (7)$$

Where X1 is the distance in feet between two different depths of water,

d_1 and d_2 are the different depths of water in feet,

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

S_o is the slope of the pipe in feet per foot.

$g = 32.2\ ft/sec^2$,

$$S = \frac{n^2 V^2}{2.21 R^{4/3}} \tag{8}$$

S is the slope of the water surface in feet per foot,

n is Manning's value,

V is the average velocity in feet per second of the two cross-sections,

R is the average hydraulic radius in feet of the two cross-sections.

$$HW = d_2 + \frac{V_2^2}{2g} + \frac{k_e V_1^2}{2g} \tag{9}$$

Where HW is the headwater in feet,

k_e is the coefficient of entrance loss,

d_2 is the depth in feet at the last cross-section,

V_1 and V_2 are the velocities in feet per second at the different depths.

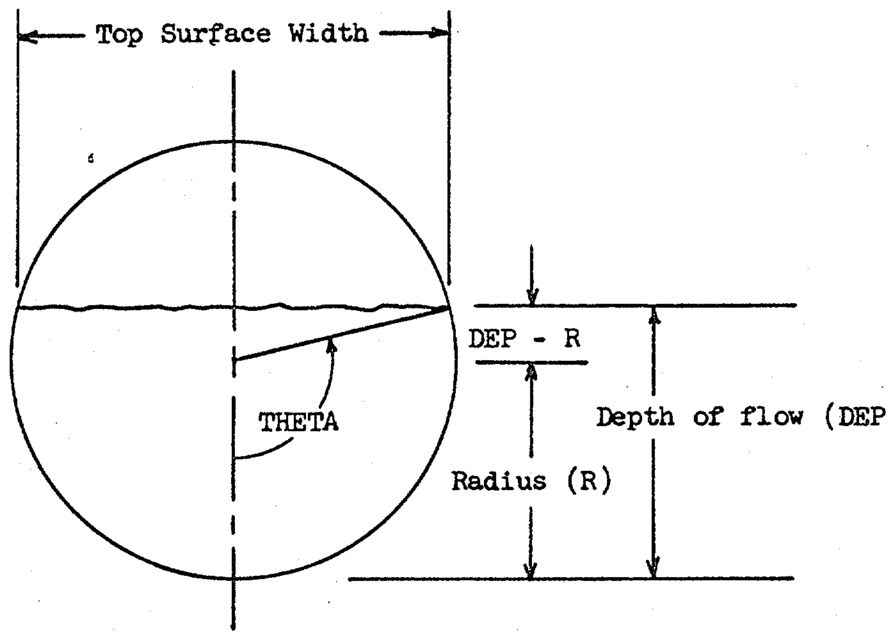
Outlet Velocity

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

Where V is the outlet velocity in feet per second,

Q is the discharge in cfs,

A is the area in square feet for any depth of flow.



$$A = (DEP - R)\sqrt{(2R)(DEP) - DEP^2} + R^2 \left[\pi/2 + \sin^{-1}\left(\frac{DEP - R}{R}\right)\right] \quad (11)$$

Where A is the area in square feet.

$$WP = 2R\left[\pi/2 + \sin^{-1}\left(\frac{DEP - R}{R}\right)\right] \quad (12)$$

Where WP is the wetted perimeter in feet.

$$T = 2\sqrt{R^2 - DEP^2} \quad (13)$$

Where T is the top surface width in feet.

INPUT DATA

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 the table on page 17 of this writeup and incorporates all the necessary constants for the different types of culverts. The first four numbers comprising the culvert code are the subscripts for the constants listed on page 18 and the fifth number is the subscript for the Inlet Control Equation Coefficients.

To find the correct culvert code, select the type of pipe desired; i.e., riveted, riveted with paved invert, structural plate, structural plate with paved invert, or concrete. After selecting the type of pipe, select the type of inlet for the pipe; i.e., projecting, mitered, headwall, etc. Enter the table vertically under the type of pipe selected, read down the table until opposite the type of inlet selected. The five-digit number at the intersection of the appropriate row and column is the culvert code. For example: the culvert code is 12233 for a structural plate pipe, 25% paved with a headwall.

For correct use of the Culvert Code Table the following definitions will be helpful.

1. Type of pipe.

   a. Riveted corrugated metal pipe - commonly used riveted metal pipe with 1/2" by 2" corrugations.

   b. Structural plate pipe - sections of structural steel plates with 2" by 6" corrugations. Plates are usually field bolted.

   c. Concrete pipe - any concrete pipe in common use. No distinction is made for length of sections or method of casting.

2. Paved Invert.

   a. Paved invert relates to a material, asphalt or concrete, plated in the bottom portion of a metal culvert barrel.

3. Types of Inlets.

   a. Projecting - The culvert barrel extends from the embankment. The transverse section at the inlet is perpendicular to the longitudinal axis of the culvert.

   b. Mitered - (sometimes referred to as beveled). The end of the culvert barrel is on a miter or bevel to conform with the fill slope. All degrees of miter are treated alike in this program since research data on this type of inlet are limited. Headwater is measured from the culvert invert midway of the mitered section.

   c. Headwall - A headwall is a concrete or metal structure placed around the entrance of the culvert. Headwalls considered are those giving a flush or square edge with the outside edge of the culvert barrel. No distinction is made for wingwalls or skews.

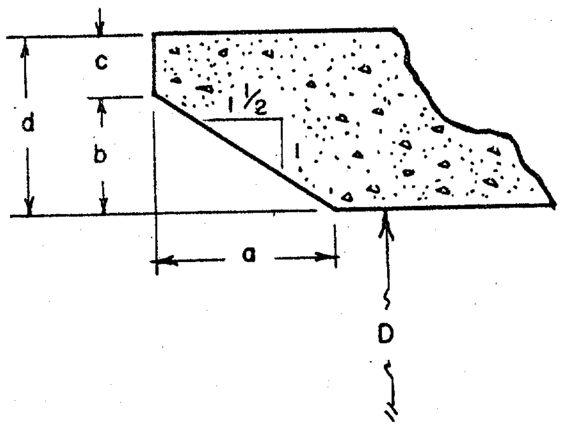
   d. End section - This section is the common prefabricated end made of either concrete or metal and placed on the inlet or outlet ends of a culvert. The closed portions of the section, if present, is not tapered.

   e. Tapered - This inlet is a type of improved entrance which can be made of concrete or metal. Dimensions are given on standard plan No. R8S71, figure 1, page 19.

f. Bevel A and Bevel B - These bevels, a type of improved entrance, can be formed of concrete or metal. The shape and dimension for Types A and B are shown in the following sketch and table.

BEVELED RING

MINIMUM 300°



Bevel can be made of Metal or Concrete

BEVEL	b/D	a/D	c/D	d/D
A	0.042	0.063	0.042	0.083
B	0.083	0.125	0.042	0.125

The bevel should extend a minimum of 300 degrees around the upper portion of the pipe's circumference. See figure 2, page 20 for standard plans of bevel A for structural plate pipe.

g. Grooved edge - The bell or socket end of a standard concrete pipe is an example of this entrance.

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.

Length of Pipe

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

Design Discharge

Design discharge (Q_1), in cfs, 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 with allowance for adequate freeboard, otherwise the culverts selected by this program might not have sufficient cover. If the pipes selected give insufficient cover over the pipes, then the AHW should be decreased and the problem rerun.

Design Tailwater

Design tailwater (DTW), in feet, is the depth of water 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 some greater flood occur; 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 cfs, 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 Q_2 discharge. This value is used in conjunction with Check Discharge as described above.

Input Data Form

The input data form is as shown on page 21 . This form incorporates on one page a sketch of the problem and the two cards used for input data to the computer program. The sketch is filled in with the necessary information about the site. After having the sketch portion of the data form completed, the data cards can be filled in for use by the punch card operator. Card No. 1 is for problem identification and contains 49 columns of alphabetic and/or numeric information. This could be such items as: The project number, the station of the pipe, 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 dunction properly. See examples on pages 71 to 81 .

OUTPUT DATA

The output of this program is either a message or an answer. Messages indicate that something is wrong with the input data.

The messages are:

1. ALLOWABLE HEADWATER TOO SMALL.
2. NUMBER OF PIPES EXCEEDS SIX.
3. CULVERT CODE INVALID.

Message number one is a check to insure enough difference between the elevation of allowable headwater and the elevation of design tailwater to insure flow through the culvert. A difference of one-half foot has been set arbitrarily by the authors but this may be changed merely by changing the constant in the formula for HEIT.

Message number two is a check on the number of pipes being used. Again, 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 three is a check to insure that a valid culvert code is submitted as input data. The individual values that make up the culvert code have a maximum value and the program checks to be sure these values are not exceeded.

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 results consist of two pipes, one pipe having a headwater equal to or less than the allowable headwater and the other a size smaller pipe having a headwater greater than the allowable. For each pipe size selected, the following is printed out.

1. Discharge in cfs.
2. Number of pipes.

3. Diameter of pipe in feet.
4. Headwater in feet.
5. Outlet velocity in fps.

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 previously.

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 when normal depth 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 circular culvert can be selected by comparing the values of headwater listed as the output results. It must be remembered that for any particular pipe the control with the highest headwater is the governing control.

A typical output listing is as shown in the sample problems on pages 71 through 81.

CULVERT CODE TABLE

RIVETED Indicators** I1	I2	I3	I4	I5	Inlet Type	Hydraulic Exper. Model Number [1/]	RIVETED & 25% PAVED Indicators** I1	I2	I3	I4	I5
1	2	3	1	1*	Projecting	112	1	2	4	1	1*
1	3	3	2	2*	Mitered	81	1	3	4	2	2*
1	2	3	3	3*	Headwall	7	1	2	4	3	3*
1	2	3	3	5	End Section	51	1	2	4	3	5
1	2	3	4	6	Bevel (A)		1	2	4	4	6
1	2	3	4	7	Bevel (B)		1	2	4	4	7
1	1	3	4	8	Tapered		1	1	4	4	8

STRUCTURAL PLATE Indicators** I1	I2	I3	I4	I5	Inlet Type	Model Number	STRUCTURAL PLATE & 25% PAVED Indicators** I1	I2	I3	I4	I5
1	2	1	1	1*	Projecting	112	1	2	2	1	1*
1	3	1	2	2*	Mitered	81	1	3	2	2	2*
1	2	1	3	3*	Headwall	7	1	2	2	3	3*
1	2	1	4	6	Bevel (A)		1	2	2	4	6
1	2	1	4	7	Bevel (B)		1	2	2	4	7

CONCRETE Indicators** I1	I2	I3	I4	I5	Inlet Type	Model Number
2	2	5	5	1	Socket-end Projecting	102
2	2	5	5	2	Socket-end Headwall	4
2	2	5	3	3	Square Edge Projecting	101
2	2	5	3	4	Square Edge Headwall	1
2	2	5	3	5	End Section	51
2	2	5	4	6	Bevel (A)	
2	2	5	4	7	Bevel (B)	
2	1	5	4	8	Tapered	

* In the computer, I5 value equals the above value plus 8, giving I5 values of 9, 10 or 11.

**Used in computer program and references the subscripts of the CONSTANTS and Inlet Control Equation Coefficients.

1/ 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.

CONSTANTS

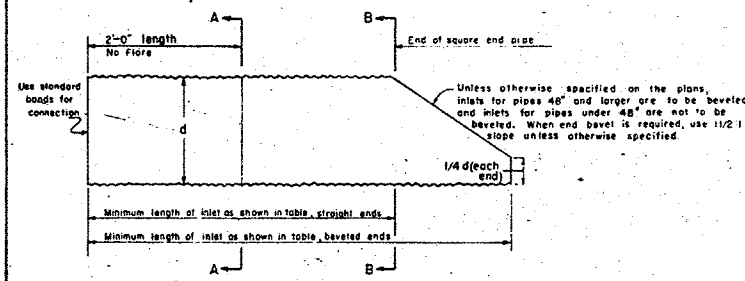
Velocity Distribution Factors	Slope Correction Factors
Associated Indicator: I1 CMP $ALPHA_1 = 1.16$ Concrete $ALPHA_2 = 1.05$	Associated Indicator: I2 $SCORR_1 = 1.50$ $SCORR_2 = 0.50$ $SCORR_3 = 0.00$

Manning's n	Entrance Loss Coefficients
Associated Indicator: I3 Multiplate - plain $CN_1 = 0.032$** Multiplate - 25% paved $CN_2 = 0.026$** CM Riveted - plain $CN_3 = 0.024$ CM Riveted - 25% paved $CN_4 = 0.021$ Concrete $CN_5 = 0.012$	Associated Indicator: I4 CM projecting $CKE_1 = 0.90$ CM mitered $CKE_2 = 0.70$ Sq. edge; Concrete or CM and end section $CKE_3 = 0.50$ Improved inlets $CKE_4 = 0.25$ Socket-end, concrete headwall or projecting $CKE_5 = 0.20$

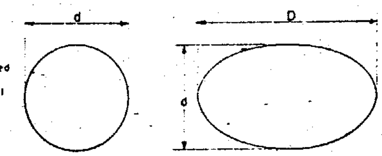
Inlet Control Equation Coefficients

I5	A	B	C	D	E	F	I5
1	0.108786	0.662381	-0.233801	0.0579585	-0.00557890	0.000205052	1
2	0.114099	0.653562	-0.233615	0.0597723	-0.00616338	0.000242832	2
3	0.167287	0.558766	-0.159813	0.0420069	-0.00369252	0.000125169	3
4	0.087483	0.706578	-0.253295	0.0667001	-0.00661651	0.000250619	4
5	0.120659	0.630768	-0.218423	0.0591815	-0.00599169	0.000229287	5
6	0.063343	0.766512	-0.316097	0.0876701	-0.00983695	0.000416760	6
7	0.081730	0.698353	-0.253683	0.0651250	-0.00719750	0.000312451	7
8	0.047266	0.831043	-0.324632	0.0794642	-0.00851125	0.000347801	8
9	0.187321	0.567710	-0.156544	0.0447052	-0.00343602	0.000089661	9
10	0.107137	0.757789	-0.361462	0.1233932	-0.01606422	0.000767390	10
11	0.167433	0.538595	-0.149374	0.0391543	-0.00343974	0.000115882	11

**Values higher than in Sept.'61 edition of HEC No. 5 -- based on recent research on multiplate pipe.

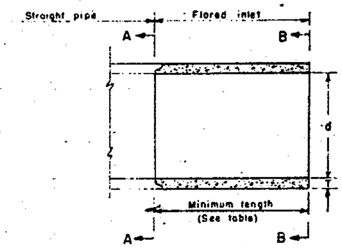


FLARED INLET-METAL PIPE



SECTION A-A
CIRCULAR

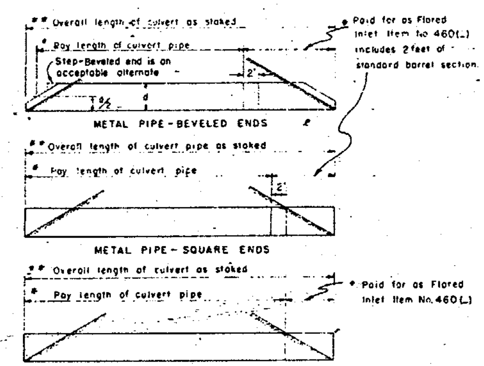
SECTION B-B
ELLIPTICAL



FLARED INLET-CONCRETE PIPE

FLARED INLET DIMENSIONS								
METAL PIPE						CONCRETE PIPE		
d (Inches)	Gage	Minimum length (feet) Straight Ends	Minimum length (feet) Beveled Ends	Entrance Periphery- (Inches)	D (Inches)	Minimum Length (Feet)	Entrance Periphery- (Inches)	D (Inches)
18	16	3.5	5.75	81.0	32.5	1.5	73.5	28.0
24	14	4.0	7.00	108.0	43.5	2.0	98.0	37.5
30	14	4.5	8.25	135.5	54.5	2.5	122.0	46.5
36	12	5.0	9.50	162.0	65.0	3.0	146.5	56.0
42	12	5.5	10.75	189.0	76.0	3.5	171.0	65.0
48	12	6.0	10.50	216.0	86.5	4.0	195.0	74.5
54	12	6.5	11.56	243.0	97.5	4.5	219.5	84.0
60	10	7.0	12.62	270.0	108.0	5.0	243.5	93.0
66	10	7.5	13.69	297.0	119.0	5.5	268.0	102.5
72	10	8.0	14.75	324.0	130.0	6.0	292.5	112.0
78	8	8.5	15.81	351.0	140.5	6.5	316.5	121.0
84	8	9.0	16.88	378.0	151.5	7.0	341.0	130.0
90	8	9.5	17.94	404.0	162.0	7.5	366.0	140.0
96	8	10.0	19.00	431.0	173.0	8.0	389.5	149.0
102	7	10.5	20.06	458.0	184.0	8.5	414.0	158.0
108	7	11.0	21.12	485.0	194.5	9.0	438.0	167.0

Note: Periphery dimension may vary by 0.5% and "D" by 3.0%
"d" and "D" are inside dimensions.

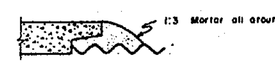


PAY LENGTHS

Flared Inlets for Concrete Pipe may, at the option of the contractor, be made either of concrete as shown hereon or of corrugated, galvanized metal. If metal inlets are used, details shall conform to those shown hereon for metal pipe except that the 2 foot section of straight pipe will not be required. In this case the metal inlet will substitute for the concrete inlet shown in the sketch for Concrete Pipe Pay Lengths and payment made as shown. Dimension "d" may be adjusted, if necessary, so as to provide a fit between the metal inlet and the concrete pipe as indicated in Detail "A" below.

* Bid schedule is based on minimum length of flared inlets shown in the table. If longer flared inlets are furnished, the length of the inlet installed will be deducted from the over-all culvert length to determine the pay length of culvert pipe. The overall length will be measured as provided in the specifications or special provisions.

** The overall length of the culvert as staked will be given to the contactor by the engineer to use in ordering pipe. The length of the straight pipe shall be the staked length less the length of the flared inlet furnished by the fabricator.



DETAIL A

GENERAL NOTES

TYPE - The materials in the flared inlet shall conform to the materials in the connecting main pipe except as shown in note for concrete pipe.
The staggering of longitudinal joints is not required for corrugated metal inlets.

DETAILS - Alternate details conforming substantially to those shown hereon, and providing an inlet area equal to or greater than the inlets shown above, may be used, if approved by the engineer.

SIZE OF CULVERT - Diameter "d" refers to the diameter shown on the Grading Plans and in the Bid Schedule.

THICKNESS OF CONCRETE INLET - The thickness of the concrete inlet (T) and reinforcing are the same as those required for a standard strength pipe of diameter "d". See A.A.S.H.O. Spec. M-41.

TYPE OF CULVERT END - The flared inlet shall have either square ends or beveled ends as called for on the grading plans.

PAY ITEM NO. 460 (_).

PAY ITEM NAME - END SECTION (Flared inlet) for ___ inch pipe.

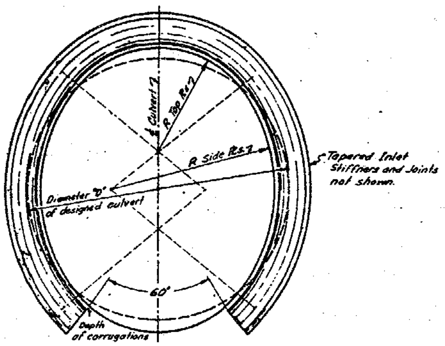
DESIGNED A.H.	REVISIONS	DATE	
DRAWN G.R.F.	REVISED TABLE	OCT-15	
TRACED EARL DAVIS	Rev. Bevel notes	5/1/58	
CHECKED G.R.F.			

U. S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS
REGION EIGHT PORTLAND, OREGON

STANDARD
TAPERED INLETS
FOR
CIRULAR PIPE CULVERT

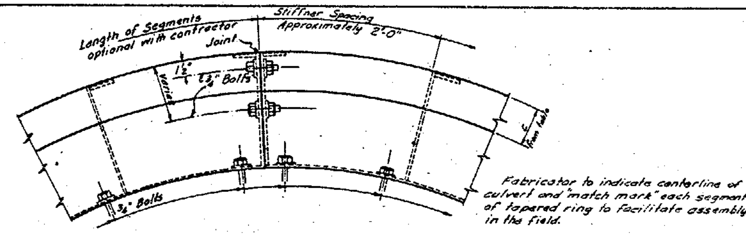
DATE MAY 1959 SCALE NO SCALE
SHEET 1 OF 1 SHEETS DRAWING NO. R8-S-71

FIGURE 1

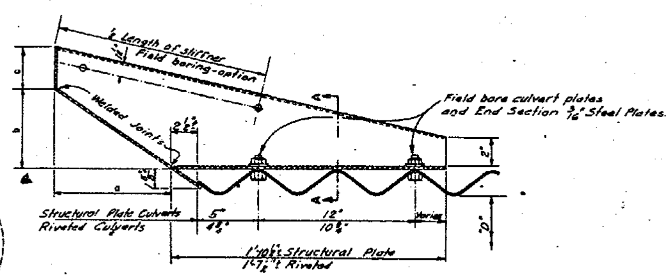


Dimensions are to inside crests of culvert and are subject to manufacturing tolerances. To obtain outside radius add depth of corrugations to applicable radius:
Add ½" for corrugations of riveted culverts.
Add 2" for corrugations of structural plate culverts.

TAPERED INLET ELEVATION

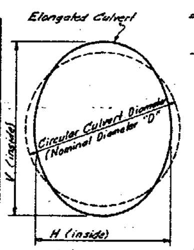


ELEVATION OF PORTION OF TAPER
SHOWING CONSTRUCTION JOINT and STIFFNER SPACING



SECTION THRU TAPER AT STIFFNER

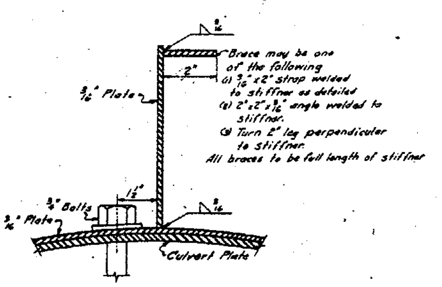
TABLE OF ELONGATION RADII (FACTORY FORMED ELONGATION OF 5%) ALL DIMENSIONS ARE INCHES				
NOMINAL DIAMETER "D"	H	V	RADIUS SIDE PLATES	RADIUS TO PLATES
54	50.3	55.7	29.7	23.3
60	56.0	62.0	33.7	26.3
66	61.7	68.4	37.8	29.3
72	67.4	74.7	41.8	32.3
78	73.3	81.2	44.7	34.7
84	79.2	87.7	47.6	37.2
90	85.4	94.5	49.4	39.8
96	91.1	100.8	53.1	41.1
102	96.8	107.1	56.9	44.4
108	102.8	113.8	59.5	45.6
114	108.5	120.1	63.2	48.9
120	114.6	126.7	65.8	49.9
126	120.3	133.1	69.5	53.4
132	126.1	139.7	72.8	55.4
138	132.2	146.3	75.6	56.0
144	137.9	152.6	79.2	59.7
150	143.8	159.1	82.5	61.7
156	149.6	165.6	85.7	63.8
162	155.5	172.1	88.9	65.8
168	161.4	178.6	92.2	67.8
174	166.1	183.7	100.2	78.4
180	171.5	189.7	106.9	82.3



Circular culvert pipe of nominal diameter "D" is the designed culvert size. However, culverts shall be furnished in an approximate elliptical cross section, with the vertical diameter 5 percent greater and the horizontal diameter 5 percent less than the specified nominal diameter.

TABLE OF DIMENSIONS FOR VARIOUS TAPERED INLETS ALL DIMENSIONS ARE INCHES			
NOMINAL DIAMETER "D"	a (a=0.125D)	b (b=0.083D)	c
54	6.75	4.50	3.0
60	7.50	5.0	3.0
66	8.25	5.50	3.0
72	9.0	6.0	3.0
78	9.75	6.50	3.25
84	10.50	7.0	3.50
90	11.25	7.50	3.75
96	12.0	8.0	4.0
102	12.75	8.50	4.25
108	13.50	9.0	4.50
114	14.25	9.50	4.75
120	15.0	10.0	5.0
126	15.75	10.50	5.25
132	16.50	11.0	5.50
138	17.25	11.50	5.75
144	18.0	12.0	6.0
150	18.75	12.50	6.25
156	19.50	13.0	6.50
162	20.25	13.50	6.75
168	21.0	14.0	7.0
174	21.75	14.50	7.25
180	22.50	15.0	7.50

Riveted Sizes: 54" to 84" inclusive.
Structural Plate Sizes: 60" through 180".



SECTION A—A

GENERAL NOTES

STEEL PLATE:- All steel plate shall be 3/16" and shall conform to AASHO Specification M-94 (ASTM-A7). Fabrication shall be complete prior to galvanizing, except field boring.

ERECTION:- The length of each segment shall be left to the contractor's option, but subject to approval by the engineer. Each segment shall be secured to the culvert by 2-3/4" bolts at each stiffner. Stiffners, back to back, and bolted together by 2-3/4" bolts shall be used to join adjacent segments. Stiffner spacing shall be approximately 2'-0" on centers measured along outer perimeter of Tapered Inlet. Field drill culvert plates as required. Burning of holes in culvert plates will not be permitted.

HARDWARE:- Bolts, nuts, washers, etc. shall be galvanized.

PAY ITEM:- Tapered Inlet shall be paid for under Section 460 of the Standard Specification FP-61 and shall be exclusive of payment for culvert pipe.

The tapered inlet as hereon shown is for square end culverts only. The outlet ends may be beveled if so noted elsewhere on the plans.

DESIGNED	L. A. HERR	REVISIONS	DATE
DRAWN	M.D. REPLOGLE	Title	9/20/61
TRACED		Ann Detail + Match Mar	1/2/62
CHECKED			

APPROVED: R. E. Tarlet
FOR FEDERAL PROJECTS ENGINEER

U. S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS
REGION EIGHT PORTLAND, OREGON

STANDARD
END SECTION
(TAPERED INLET)
FOR CULVERTS 54" to 180"

DATE MARCH 1961 SCALE NONE
SHEET 1 OF 1 SHEETS DRAWING NO 15-10

FIGURE 2

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer ________

Project: ________

Date ________

Hydrologic and Channel Information

Q_1 = ______ c.f.s.

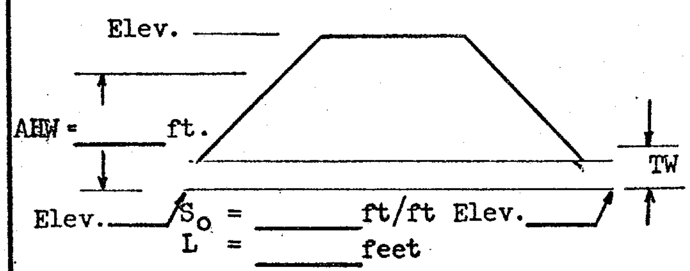
Q_2 = ______ c.f.s.

TW_1 = ______ feet

TW_2 = ______ feet

Sketch

Station: ________



CARD NO. 1

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

PROBLEM IDENTIFICATION

CARD NO. 2

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)
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

* See back of the input data form

CULVERT CODE TABLE

Inlet Type For Steel Pipe	Riveted	Riveted & 25% Paved	Structural Plate	Structural Plate & 25% Paved	Inlet Type For Concrete Pipe	Concrete
Projecting	1 2 3 1 1	1 2 4 1 1	1 2 1 1 1	1 2 2 1 1	Socket-end Projecting	2 2 5 5 1
Mitered	1 3 3 2 2	1 3 4 2 2	1 3 1 2 2	1 3 2 2 2	Socket-end Headwall	2 2 5 5 2
Headwall	1 2 3 3 3	1 2 4 3 3	1 2 1 3 3	1 2 2 3 3	Square Edge Projecting	2 2 5 3 3
End Section	1 2 3 3 5	1 2 4 3 5			Square Edge Headwall	2 2 5 3 4
Bevel (A)	1 2 3 4 6	1 2 4 4 6	1 2 1 4 6	1 2 2 4 6	End Section	2 2 5 3 5
Bevel (B)	1 2 3 4 7	1 2 4 4 7	1 2 1 4 7	1 2 2 4 7	Bevel (A)	2 2 5 4 6
Tapered	1 1 3 4 8	1 1 4 4 8			Bevel (B)	2 2 5 4 7
					Tapered	2 1 5 4 8

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
1		P	R	O	J	E	C	T		I	-	4	6	-	2	3			S	T	A	T	I	O	N		1	Ø	9	+	2	Ø		L	.	A	.	H	E	E	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 *when program is run on the 1401 or 1410.*

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
2	2	5	5	1	.	Ø	5	Ø				2	Ø	Ø	.	Ø			1	8	Ø	.	Ø		1	Ø	.	Ø			3	.	Ø			2	2	5	.	Ø			4	.	Ø
CULVERT CODE					SLOPE OF PIPE (S_o)					LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_1)							ALLOWABLE HEADWATER (AHW)					DESIGN TAILWATER (TW_1)					CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)				

DEFINITION OF TERMS

ALPHA(I1)	--	Velocity Distribution Factor. When I1 equals one, this refers to the first value of the velocity distribution.
SCORR(I2)	--	Slope Correction Factor. When I2 equals one, this refers to the first value of slope correction.
CN(I3)	--	Manning's n for Natural Stream Channels. When I3 equals one, this refers to the first value of n.
CKE(I4)	--	Entrance Loss Coefficients. When I4 equals one, this refers to the first value of entrance loss.
SPH(I)	--	Specific Head in feet. The values of specific head for two cross-sections are stored in SPH(I) during backwater calculations.
A(I5)	--	The first coefficient in the equations used for inlet control headwater. 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.
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.
V(I)	--	Velocity in feet per second. The values of velocity for two cross-sections are stored in V(I) during backwater calculations.

ANGLE	--	The answer from the arcsin subroutine in radians is stored in ANGLE.
AHW	--	Allowable headwater in feet.
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.
CTW	--	Check tailwater in feet.
DAB	--	The difference between depth of flow and radius. This is used in the area equation.
DAC	--	The central angle plus $\pi/2$. This is used in the area equation.
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.
DIA	--	Working diameter in feet. This is used for diameter calculations until pipe size is selected.
DIAM1	--	Diameter one in feet. The first diameter selected is stored in DIAM1.
DIAM2	--	Diameter two in feet. The second diameter selected is stored in DIAM2.
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.

HEAD	--	The Head required for a given flow in outlet control in feet.
HEIT	--	The maximum height in feet that design tailwater can be to insure flow through the culvert.
HWOVD	--	Headwater divided by diameter. This is the answer from the inlet headwater equation.
HW1	--	Headwater one in feet. This is the headwater for the pipe size stored in DIAM1.
HW2	--	Headwater two in feet. This is the headwater for the pipe size stored in DIAM 2.
I	--	A counter used to indicate the particular variable of a group.
I1	--	A counter set by the culvert code for use with the constant ALPHA.
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.
INVAL	--	A counter used to count the number of outlet control invalid calculations.
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.
PHIY	--	A portion of the calculation of the arcsin approximation using Hastings Approximation for Digital Computers.
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.
Q2OVG	--	Discharge squared divided by 32.2. This is used in outlet control in critical depth calculations.
R	--	Radius of the pipe being analyzed in feet.
S1	--	The slope of the water surface between two cross-sections in backwater calculations.
SLOPE	--	Slope of the pipe in feet per foot.
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.
THETA	--	The central angle formed by a verticle line through the center of the pipe and a line from the center of the pipe to the point where the top water surface meets the pipe. This is used in the area equation (see figure 3).
VEL1	--	Outlet velocity one in feet per second. This is the outlet velocity for the pipe size stored in DIAM1.
VEL2	--	Outlet velocity two in feet per second. This is the outlet velocity for the pipe size stored in DIAM2.
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.
Y	--	An entrance storage location where the argument of the arcsin subroutine is stored.
Y1	--	The absolute value of the argument (y) used in the arcsin subroutine.

```
C        COMPUTER PROGRAM FOR HYDRAULIC ANALYSIS OF CIRCULAR CULVERTS
C         BY R.C. TENNENT + L.A. HERR ,BUREAU OF PUBLIC ROADS DEC. 1962
C          REVISED JULY 1964,FEB. 1965
C
      DIMENSION ALPHA(2),SCORR(3),CN(5),CKE(5),SPH(2),V(2),HYDR(2),
     1          A(11),B(11),C(11),D(11),E(11),F(11),DC(2)
C
C     READ AND STORE CONSTANTS
C
      READ 900, (ALPHA(I),I=1,2),(SCORR(I),I=1,3),(CN(I),I=1,5),(CKE(I)
     1          ,I=1,5)
C
C     READ AND STORE MATHEMATICAL EQUATION COEFFICIENTS FOR HYDRAULIC
C     MODELS 1,4,7,51,81,101,102,AND112
C
      READ 901, (A(I),B(I),C(I),D(I),E(I),F(I),I=1,11 )
C
C     READ IDENTIFICATION CARD AND INPUT DATA CARD
C
   10 READ 902
      READ 903, I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW
      IF ( I1 )11,11,12
   11 TYPE 904
      STOP 111
   12 PRINT 902
      PRINT 912, I1,I2,I3,I4,I5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW
      IF ( AHW )21,21,20
   20 HEIT = DIST * SLOPE + AHW - 0.5
      IF ( DTW - HEIT )22,21,21
   21 PRINT 907
      GO TO 10
   22 SLOPE  = SLOPE + 0.000001
      II3    = I3
      II5    = I5
   30 IF ( I1 - 1 )31,31,33
   31 IF ( I5 - 3 )32,32,33
   32 I5   = I5 + 8
C
C     CHECK FOR INVALID CULVERT CODE
C
   33 IF ( I1 - 2 )34,34,38
   34 IF ( I2 - 3 )35,35,38
   35 IF ( I3 - 5 )36,36,38
   36 IF ( I4 - 5 )37,37,38
   37 IF ( I5 - 11 )39,39,38
   38 PRINT 913
      GO TO 10
   39 CLTH    = ( DIST * DIST - SLOPE*DIST * SLOPE*DIST )**0.5
      NSWO   = 0
      NSW11   = 0
```

```
C
C         INITIALIZE INLET CONTROL
C
   40 PIPES = 1.0
      DSUBC = 0.0
      QADJ  = Q1
   50 I90   = 0
      I91   = 0
      NSW1  = 1
      NSW2  = 0
      NSW3  = 0
      NSW5  = 0
      NSW6  = 0
      NSW7  = 1
      NSW10 = -1
C
C     CALCULATE APPOXIMATE DIAMETER OF PIPE ,DIA
C
      DIA   = (QADJ / AHW) **0.5
C
C     ROUND DIAMETER TO NEXT HIGHEST 0.5 FOOT
C
      DIA   = FLOATF( FIXF( DIA*2.0+0.9 ) *5 ) *0.1
      IF ( DIA - AHW - 1.0 )70,70,51
   51 PIPES = PIPES + 1.0
      IF ( PIPES - 6.0 )60,60,52
   52 PRINT 905
      GO TO 10
   60 QADJ  = Q1 / PIPES
      GO TO 50
C
C         INLET CONTROL CALCULATIONS
C
   70 X      = QADJ / (DIA ** 2.5)
      HWOVD  = A(I5) + ( B(I5) + ( C(I5) + ( D(I5) + ( E(I5) + F(I5)*X )
     1         * X ) * X ) * X ) * X    - SCORR(I2) * SLOPE
      WHW    = HWOVD * DIA
   71 GO TO (72,540,400,250),NSW1
C
C         SELECTION OF SIZES ROUTINE
C
   72 IF ( WHW - AHW )80,80,90
   80 IF ( I90 )81,81,400
   81 I91   = 1
      DIAM1 = DIA
      DIA   = DIA - 0.5
C
C     STORE FIRST SET OF RESULTS
C
   82 HW1   = WHW
```

```
      DC(1) = DSUBC
      IF ( NSW2 )101,70,101
   90 IF ( I91 )91,91,400
   91 I90   = 1
      DIAM1 = DIA
      DIA   = DIA + 0.5
      IF ( DIA - (AHW + 0.5) )82,82,92
   92 IF ( NSW3 )93,51,93
C
C     SET SWITCH TO INDICATE NEED FOR ADDITIONAL BARRELS
C
   93 NSW11  = 1
      GO TO 82
C
C        INITIALIZE OUTLET CONTROL
C
  100 INVAL = 0
      K1    = 0
      K2    = 0
      I90   = 0
      I91   = 0
      NSW1  = 1
      NSW2  = 1
      NSW3  = 1
      NSW5  = 1
      WTW   = DTW
C
C        OUTLET CONTROL CALCULATIONS
C
  101 HEAD  = (1. + CKE(I4) + ( 185.0*CN(I3)*CN(I3)*DIST/DIA**1.33333 ))
     1          * ( QADJ*QADJ/39.725/DIA**4 )
      K1    = K1 + 1
C
C     INITIALIZE CRITICAL DEPTH CALCULATIONS
C
      Q2OVG = QADJ * QADJ * ALPHA(I1) / 32.2
      DEP   = 0.98 * DIA
      NSW9  = 0
      GO TO 600
  120 DSUBC = DEP
C
C     INITIALIZE NORMAL DEPTH CALCULATIONS
C
      TEMP  = QADJ * CN(I3) /  1.486 / SLOPE ** 0.5
      DEP   = 0.90 * DIA
      NSW9  = 1
      GO TO 600
  130 DSUBN = DEP
```

```
C
C     DETERMINE OUTLET CONTROL CONDITION
C
      TEMP  = ( DSUBC + DIA ) * 0.5
  160 IF ( TEMP - WTW )161,161,170
  161 TEMP  = WTW
  170 WHW   = TEMP + HEAD - SLOPE * CLTH
      IF ( WHW )200,200,180
  180 IF ( WHW - (DIA+(1.+CKE(I4))*(QADJ*QADJ/39.725/DIA**4)) )200,71,71
  200 IF ( DSUBN - DSUBC )230,205,205
  205 NSW4  = 0
      IF ( WTW - DSUBC )225,225,210
  210 IF ( WTW - DSUBN )220,220,215
  215 NSW4  = 1
  220 DEP   = WTW
      GO TO 320
  225 DEP   = DSUBC
      GO TO 320
C
C        INLET CONTROL GOVERNS ROUTINE
C
  230 PRINT 906, QADJ,PIPES,DIA
      INVAL = INVAL + 1
      K2    = K2 + 1
      IF ( K1 - 2 )240,260,260
  240 DIA   = DIAM2
      NSW1  = 4
      GO TO 101
  250 INV   = 0
      DC(1) = DSUBC
  251 I     = 1
      NSW6  = -1
      GO TO 450
  255 IF ( INV )280,256,280
  256 PRINT 911, QADJ,PIPES,DIA,WHW,VEL1
      K2    = K2 + 1
      GO TO 282
  260 DIAM2 = DIA
      IF ( INVAL - 2 )270,281,281
  270 INV   = 1
      DIA   = DIAM1
      GO TO 251
  280 PRINT 911, QADJ,PIPES,DIAM1,HW1,VEL1
      K2    = K2 + 1
  281 IF ( K2 - 3 )282,270,10
  282 IF ( QADJ - Q2 )290,570,290
  290 DIA   = DIAM1
      NSW6  = 1
      GO TO 560
```

```
C
C         BACKWATER PROFILE ROUTINE
C
  320 SUMX   = 0.0
      I      = 1
      NSW10 = 0
      IF ( DEP - DIA )700,325,330
  325 IF ( NSW4 )700,390,700
  330 DEP     = WTW - SLOPE * DIST
      IF ( DEP - DSUBN )335,335,376
  335 SUMX = (WTW-DIA/(1.0+SLOPE*SLOPE)**0.5)*(1.0+1.0/SLOPE/SLOPE)**0.5
      DEP    = DIA
      GO TO 700
C
C     COMPUTE THE VELOCITY,SPECIFIC HEAD + HYDRAULIC RADIUS
C     FOR TWO CROSS-SECTIONS
C
  340 V(I)   = QADJ / AREA
      SPH(I) = DEP +  ALPHA(I1) *  V(I)*V(I)  / 64.4
      HYDR(I)= AREA / WP
      IF ( I - 2 )350,360,360
  350 I      = I + 1
  351 IF ( NSW4 )380,355,356
  355 DEP    = DEP + 0.2
      IF ( DEP - DIA )700,390,390
  356 DEP    = DEP - 0.2
      GO TO 700
C
C     COMPUTE AVERAGE VELOCITY AND AVERAGE HYDRAULIC RADIUS
C     FOR THE CROSS-SECTIONS
C
  360 AVEV   = (V(1) + V(2)) * 0.5
      AVEHR = (HYDR(1) + HYDR(2)) * 0.5
      S1     = CN(I3) * CN(I3) * AVEV * AVEV / 2.21 / AVEHR**1.33333
      IF ( NSW4 )362,361,362
  361 IF ( S1 - SLOPE )375,375,366
  362 IF ( SLOPE - S1 )375,375,367
C
C     COMPUTE DISTANCE X1
C
  366 DX1    = ( SPH(2) - SPH(1) ) / ( S1 - SLOPE )
      GO TO 368
  367 DX1    = ( SPH(1) - SPH(2) ) / ( SLOPE - S1 )
C
C     COMPUTE ACCUMULATED DISTANCE FROM THE OUTLET
C
  368 SUMX   = SUMX + DX1
      IF ( SUMX - CLTH )370,371,371
  370 V(1)   = V(2)
      SPH(1)= SPH(2)
```

```
      HYDR(1)= HYDR(2)
      GO TO 351
  371 IF ( NSW4 )373,372,373
  372 DEP     = DEP - (SUMX-CLTH)/DX1*0.2
      GO TO 376
  373 DEP     = DEP + (SUMX-CLTH)/DX1*0.2
      GO TO 376
  375 DEP     = DSUBN
  376 NSW4    = -1
      I       = 1
      GO TO 700
  380 WHW     = SPH(1) + CKE(I4) * V(1) * V(1) / 64.4
  390 NSW10 = -1
      GO TO 71
C
C     STORE SECOND SET OF RESULTS
C
  400 DIAM2 = DIA
      HW2   = WHW
      DC(2) = DSUBC
C
C        VELOCITY CALCULATIONS FOR INLET AND OUTLET CONTROL
C
      I       = 2
  401 IF ( NSW5 )450,410,450
C
C     INLET CONTROL CALCULATIONS
C
  410 TEMP   = QADJ * CN(I3) / 1.486 / SLOPE**0.5
      DEP    = 0.90 * DIA
      NSW9   = -1
      GO TO 600
  420 IF ( DEP - DIA )480,470,470
C
C     OUTLET CONTROL CALCULATIONS
C
  450 IF ( WTW - DIA )451,470,470
  451 IF ( DC(I) - DIA )452,470,470
  452 IF ( DC(I) - WTW )453,454,454
  453 DEP    = WTW
      GO TO 460
  454 DEP    = DC(I)
  460 NSW10 = 1
      R      = 0.5 * DIA
      GO TO 700
C
C     AREA CALCULATION FOR PIPE FLOWING FULL
C
  470 AREA   = 0.785398 * DIA * DIA
  480 VEL1   = QADJ / AREA
```

```
      IF ( I - 1 )500,500,490
  490 VEL2  = VEL1
      DIA   = DIAM1
      I     = I - 1
      GO TO 401
  500 IF ( NSW6 )255,510,520
C
C         CONTROL AND PRINT ROUTINE
C
  510 PRINT 908
      PRINT 910
C     WRITE INLET + OUTLET CONTROL RESULTS
  520 PRINT 911, QADJ,PIPES,DIAM2,HW2,VEL2
      PRINT 911, QADJ,PIPES,DIAM1,HW1,VEL1
      GO TO ( 530,550,560,570 ),NSW7
C
C     SET CONTROLS FOR INLET CONTROL CHECK CALCULATIONS
C
  530 Q1    = QADJ
      QADJ  = Q2 / PIPES
      DIA   = DIAM1
      NSW1  = 2
      NSW8  = 0
      GO TO 70
C
C     STORE RESULTS FOR FIRST SET OF CHECK CALCULATIONS
C
  540 HW1   = WHW
      DC(1) = DSUBC
      DIA   = DIAM2
      NSW1  = 3
      IF ( NSW8 )542,541,542
  541 NSW6  = 1
      NSW7  = 2
      GO TO 70
  542 NSW7  = 4
      GO TO 101
C
C     SET CONTROLS FOR OUTLET CONTROL CALCULATIONS
C
  550 PRINT 909
      PRINT 910
      DIA   = DIAM1
      Q2    = QADJ
      QADJ  = Q1
      NSW7  = 3
      GO TO 100
C
C     SET CONTROLS FOR OUTLET CONTROL CHECK CALCULATIONS
C
```

```
  560 QADJ  = Q2
      WTW   = CTW
      K1    = 0
      NSW1  = 2
      NSW8  = 1
      NSW10 = -1
      GO TO 101
  570 Q1    = PIPES * Q1
      Q2    = PIPES * Q2
C
C          CORRUGATED METAL CULVERTS OPTION ROUTINE
C
      IF ( NSW0 )590,571,590
  571 IF ( I1 - 1 )575,575,595
  575 IF ( I5 - 5 )595,595,576
  576 IF ( I5 - 8 )580,595,580
C
C     DETERMINE TYPE OF CULVERT - RIVETED OR PLATE
C
  580 IF ( I3 - 3 )585,581,581
  581 IF ( DIAM1 - 6.0 )582,583,583
  582 IF ( DIAM2 - 6.0 )595,583,583
C
C     WHEN ANY RIVETED CM SIZE IS 6 FEET OR OVER, RETURN TO
C     BEGINNING AND CALCULATE RESULTS FOR STRUCTURAL PLATE
C
  583 I3    = I3 - 2
      PRINT 914
      GO TO 588
  585 IF ( DIAM1 - 8.0 )587,587,586
  586 IF ( DIAM2 - 8.0 )587,587,595
C.
C     WHEN ANY STRUCTURAL PLATE SIZE IS 8 FEET OR LESS RETURN
C     TO BEGINNING AND CALCULATE RESULTS FOR RIVETED CM
C
  587 I3    = I3 + 2
      PRINT 915
  588 NSW0  = 1
      GO TO 40
  590 I3    = II3
C
C     CHECK TO DETERMINE IF THE PROBLEM IS TO BE CALCULATED
C     FOR AN ADDITIONAL BARREL
C
  595 IF ( NSW11 )596,10,596
  596 NSW11  = 0
      PRINT 902
      PRINT 912,I1,I2,I3,I4,II5,SLOPE,DIST,Q1,AHW,DTW,Q2,CTW
      GO TO 51
```

```
C
C         ITERATIVE ROUTINE USED FOR CALCULATING
C         CRITICAL DEPTH,DSUBC, AND NORMAL DEPTH,DSUBN
C
  600 R      = 0.5 * DIA
      DECRM = 0.2 * DIA
      KOUNT = 0
      GO TO 700
  610 IF ( NSW9 )630,611,630
  611 TEMP   = AREA * AREA * AREA / T
      IF ( TEMP - Q2OVG )615,650,620
  615 IF ( KOUNT )616,640,616
  616 IF ( DECRM - 0.03 )650,650,617
  617 DEP    = DEP + DECRM
      DECRM = 0.2 * DECRM
  620 DEP    = DEP - DECRM
      KOUNT = KOUNT + 1
      GO TO 700
  630 AOVWP = AREA ** 1.66667 / WP ** 0.666667
      IF ( AOVWP - TEMP )615,650,620
  640 DEP    = DIA
  650 IF ( NSW9 )420,120,130
C
C          CALCULATIONS FOR PIPE CHARACTERISTICS FOR ANY DEPTH OF FLOW
C          ANSWERS ARE  1. AREA OF PIPE 2. WETTED PERIMETER 3. TOP WIDTH
C
  700 DAB    = DEP - R
      Y      = DAB / R
      Y1     = ABSF( Y )
C
C     ARCSIN APPROXIMATION
C
      PHIY   = 1.570796 + (-0.214512 + ( 0.0878763 + (-0.0449589 + (
     1         0.0193499 - 0.00433777 * Y1) * Y1) * Y1) * Y1) * Y1
      ANGLE  = 1.570796 - ( 1.0 - Y1) ** 0.5 * PHIY
      IF( Y )705,710,710
  705 ANGLE = - ANGLE
  710 DAC    = ANGLE + 1.570796
      AREA   = ( DAB * ( DIA*DEP - DEP*DEP )**0.5 ) + (R*R*DAC)
      T      = 2.0 * ( R*R  -  DAB*DAB ) ** 0.5
      WP     = DIA * DAC
      IF ( NSW10 )610,340,480
C
C                 INPUT AND OUTPUT FORMATS
C
  900 FORMAT (  4F4.2,F5.2,10F5.3  )
  901 FORMAT (  6E12.6  )
  902 FORMAT (  50H
  903 FORMAT (  5I1,F7.4,6F7.1  )
  904 FORMAT (  14H    END OF RUN  )
```

```
905 FORMAT (  31HK   NUMBER OF PIPES EXCEEDS SIX  )
906 FORMAT (  5X,F7.1,10X,F2.0,10X,F5.1,8X,23H INLET CONTROL GOVERNS )
907 FORMAT (  33HK   ALLOWABLE HEADWATER TOO SMALL  )
908 FORMAT (  24HK  INLET CONTROL RESULTS  )
909 FORMAT (  25HK  OUTLET CONTROL RESULTS  )
910 FORMAT (  42H     DISCHARGE     NUMBER OF     DIAMETER ,
   1          28H     HEADWATER     VELOCITY / 7X,4H CFS,9X,6H PIPES,
   2          8X, 5H FEET ,9X,5H FEET,9X,4H FPS  )
911 FORMAT (  5X,F7.1,10X,F2.0,10X,F5.1,8X,F6.1,8X,F6.1  )
912 FORMAT ( 13HK  INPUT DATA / 5X,5HCODE ,8H  SLOPE ,8H  LENGTH,5X,
   1          2HQ1,5X,5HAHW  ,5H  DTW,6X,2HQ2,5X,3HCTW /
   2          4X,5I1,F8.4,2F9.1,2F7.1,F9.1,F7.1 )
913 FORMAT (  24HK   CULVERT CODE INVALID  )
914 FORMAT ( 21HK  MULTI-PLATE OPTION )
915 FORMAT ( 17HK  RIVETED OPTION )
    END
```

PROBLEM I

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer *R.C. TENNENT*

Project: *I-96-666*

Date *8-10-62*

Hydrologic and Channel Information

STRUCTURAL PLATE WITH MITERED INLET

Q_1 = *180* c.f.s.

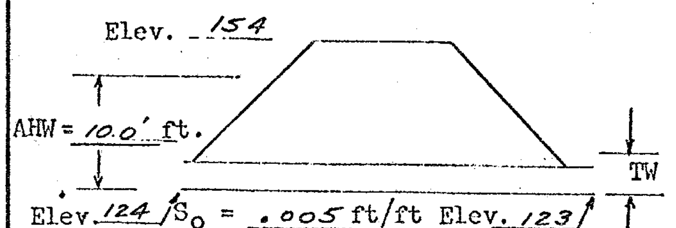
Q_2 = *225* c.f.s.

TW_1 = *15.2* feet

TW_2 = *17.2* feet

Sketch

Station: *44 + 96.8*



S_o = *.005* ft/ft

L = *200* feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		P	R	O	J	.		I	-	9	6	-	6	6	6		S	T	A	.	4	4	+	9

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
6	.	8				R	.	C	.	T	E	N	N	E	N	T		8	/	1	Ø	/	6	2

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
1	3	1	2	2		Ø	.	Ø	Ø	5				2	Ø	Ø	.	Ø			1	8	Ø	.	Ø	
CULVERT CODE					SLOPE OF PIPE (S_o)						LENGTH OF PIPE (L)								DESIGN DISCHARGE (Q_1)							ALLOWABLE HEADWATER (AHW)

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
		1	Ø	.	Ø				1	5	.	2			2	2	5	.	Ø				1	7	.	2
						DESIGN TAILWATER (TW_1)							CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)						

PROBLEM 1

PROJ. I-96-666 STA.44+96.8 R.C.TENNENT 12/17/62

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
13122	0.0050	200.0	180.0	10.0	15.2	225.0	17.2

ALLOWABLE HEADWATER TOO SMALL

Comments: This message was printed out because the DTW is at a higher elevation than the AHW. The AHW must be 0.5 ft. higher in elevation than the DTW. Problem should be recomputed using an AHW equal to or greater than 14.7 ft.

PROBLEM 2

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Designer *L.A. HERR*

Project: *I-97-777*

Date *8-10-62*

Hydrologic and Channel Information

CMP WITH PROJECTING INLET

Q_1 = *500* c.f.s.

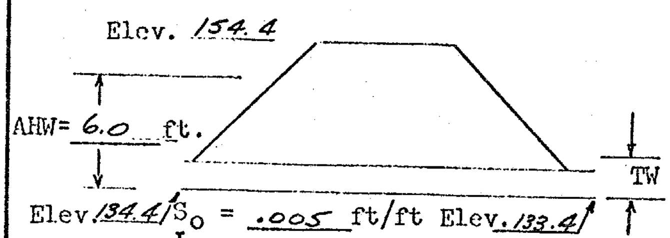
Q_2 = *650* c.f.s.

TW_1 = *3.0* feet

TW_2 = *4.0* feet

Sketch.

Station: *29+49*



S_o = *.005* ft/ft

L = *200* feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
/		P	R	O	J	.		I	-	9	7	-	7	7	7		S	T	A	.		2	9	+

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
4	9					L	.	A	.	H	E	R	R					8	/	1	Ø	/	6	2

PROBLEM IDENTIFICATION

CARD NO. 2

CULVERT CODE						SLOPE OF PIPE (S_o)							LENGTH OF PIPE (L)							DESIGN DISCHARGE (Q_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
/	2	3	/	/		Ø	.	Ø	Ø	5				2	Ø	Ø	.	Ø		5	Ø	Ø	Ø	.	Ø

ALLOWABLE HEADWATER (AHW)							DESIGN TAILWATER (TW_1)							CHECK DISCHARGE (Q_2)							CHECK TAILWATER (TW_2)						
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
				6	.	Ø					3	.	Ø		6	5	Ø	Ø	.	Ø					4	.	Ø

PROBLEM 2

PROJ. I-97-777 STA. 29+49   L.A.HERR   12/17/62

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
12311	0.0050	200.0	5000.0	6.0	3.0	6500.0	4.0

NUMBER OF PIPES EXCEEDS SIX

Comments: This message is printed due to the allowable headwater (AHW) and the design discharge (Q1) imposing conditions that require more than six pipes. In this case however, the input data listed above checks with that given the keypunch operator, but the discharges were copied incorrectly from the hydrologic data given. Hydrologic and other data should be checked carefully before submitting problem for keypunching.

PROBLEM 3

HYDRAULIC ANALYSIS OF CULVERTS - Input Data Form

Project: *I-98-888*

Designer *R. C. TENNENT*

Date *8-10-62*

Hydrologic and Channel Information

CMP WITH HEADWALL INLET

Q_1 = *400* c.f.s.

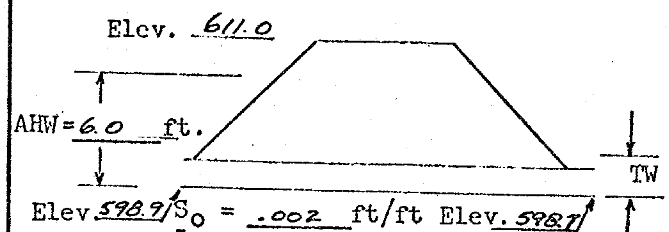
Q_2 = *500* c.f.s.

TW_1 = *4.0* feet

TW_2 = *5.0* feet

Sketch

Station: *86 + 19.5*



S_o = *.002* ft/ft

L = *120* feet

CARD NO. 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		P	R	O	J	.		I	-	9	8	-	8	8	8		S	T	A	.		8	6	+

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	9	.	5		R	.	C	.	T	E	N	N	E	N	T			8	/	1	Ø	/	6	2

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
1	2	8	3	3		Ø	.	Ø	Ø	2				1	2	Ø	.	Ø			4	Ø	Ø	.	Ø	

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
			6	.	Ø					4	.	Ø			5	Ø	Ø	.	Ø					5	.	Ø

Fields (Card No. 2): CULVERT CODE (cols. 1–5); SLOPE OF PIPE (S_o) (cols. 6–12); LENGTH OF PIPE (L) (cols. 13–19); DESIGN DISCHARGE (Q_1) (cols. 20–26); ALLOWABLE HEADWATER (AHW) (cols. 27–33); DESIGN TAILWATER (TW_1) (cols. 34–40); CHECK DISCHARGE (Q_2) (cols. 41–47); CHECK TAILWATER (TW_2) (cols. 48–54)

PROBLEM 3

```
PROJ. I-98-888 STA. 86+19.5 R.C.TENNENT 12/17/62

 INPUT DATA
   CODE    SLOPE    LENGTH      Q1      AHW     DTW       Q2      CTW
  12833  0.0020     120.0    400.0      6.0     4.0    500.0      5.0

  CULVERT CODE INVALID
```

Comments: This is a message that indicates something has been put on the keypunching portion of the data sheet that is not a valid culbert code. In checking the Culvert Code Table for a CMP with headwall, the code should be 12333 instead of 12833. This mistake on the data sheet could be eliminated if the culvert code had been checked.

PROBLEM 4 - PART I

PROJ. I-98-888 STA. 86&19.5 R.C. TENNENT 4/20/65

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
12333	.0020	120.0	400.0	6.0	4.0	500.0	5.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
200.0	2.	5.5	6.4	8.4
200.0	2.	6.0	5.9	7.0
250.0	2.	5.5	8.0	10.5
250.0	2.	6.0	7.1	8.8

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
200.0	2.	7.5	5.9	8.3
200.0	2.	7.0	6.1	8.7
250.0	2.	7.5	6.8	7.9
250.0	2.	7.0	7.1	8.5

MULTI-PLATE OPTION

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
200.0	2.	5.5	6.4	8.4
200.0	2.	6.0	5.9	7.0
250.0	2.	5.5	8.0	10.5
250.0	2.	6.0	7.1	8.8

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
200.0	2.	8.5	5.8	7.6
200.0	2.	8.0	6.0	7.9
250.0	2.	8.5	6.7	7.2
250.0	2.	8.0	6.9	7.5

Comments: The code of 12333 is for a CMP with headwall (riveted). Since at least one riveted CMP size is greater than 6 feet, structural plate pipe results are also presented. Note that inlet control results are identical.

Outlet control governs and two 7.5 ft. CM pipe (riveted) or two 8.0 ft. structural plate pipes are required for headwaters equal to or less than 6.0 ft. As the sizes are being calculated, a check is made to determine if the diameter is greater than the allowable by 1/2 ft. When this occurs, as it does in above results, the problem is calculated using an additional barrel. Part II, following, shows the results.

PROBLEM 4 - PART II

PROJ. I-98-888 STA. 86&19.5 R.C. TENNENT 4/20/65

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
12333	.0020	120.0	400.0	6.0	4.0	500.0	5.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
133.3	3.	4.0	7.0	10.6
133.3	3.	4.5	5.7	8.3
166.6	3.	4.0	9.4	13.2
166.6	3.	4.5	7.2	10.4

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
133.3	3.	5.5	5.6	7.2
133.3	3.	5.0	6.1	7.9
166.6	3.	5.5	6.9	7.3
166.6	3.	5.0	8.1	8.4

Comments: This is the second set of results for Problem 4

This set of answers is calculated using an additional barrel in order to try to design a culvert diameter which is equal to or less than the allowable headwater plus 1/2 foot.

PROBLEM 5

PROJECT I-99-999 STATION 109&20 L.HERR 4/20/65

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
12311	.0500	200.0	180.0	10.0	3.0	225.0	4.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
180.0	1.	4.0	13.6	15.7
180.0	1.	4.5	9.6	16.4
225.0	1.	4.0	20.3	17.9
225.0	1.	4.5	13.6	17.0

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
180.0	1.	4.5	INLET CONTROL GOVERNS	
180.0	1.	4.0	10.6	14.5
225.0	1.	4.5	INLET CONTROL GOVERNS	
225.0	1.	4.0	20.1	17.9

Comments: This problem gives the size of CMP required for a projecting inlet. Problem No. 6 uses the same input data except that concrete pipe is used, Code 22551.

Inlet control governs the single 4.5 ft. CMP selection. In outlet control, the message "Inlet Control Governs" indicates flow condition under which outlet control is not valid.

PROBLEM 6

PROJECT I-99-999 STATION 109&20 L.HERR 4/20/65

INPUT DATA

CODE	SLOPE	LENGTH	Q1	AHW	DTW	Q2	CTW
22551	.0500	200.0	180.0	10.0	3.0	225.0	4.0

INLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
180.0	1.	3.5	13.4	27.3
180.0	1.	4.0	9.1	27.9
225.0	1.	3.5	20.1	28.8
225.0	1.	4.0	12.8	29.4

OUTLET CONTROL RESULTS

DISCHARGE CFS	NUMBER OF PIPES	DIAMETER FEET	HEADWATER FEET	VELOCITY FPS
180.0	1.	4.0	INLET CONTROL GOVERNS	
180.0	1.	3.5	INLET CONTROL GOVERNS	
225.0	1.	4.0	INLET CONTROL GOVERNS	
225.0	1.	3.5	INLET CONTROL GOVERNS	

Comments: Inlet control governs the single 4.0 ft. concrete pipe selection. This is 0.5 ft. in diameter less than that required for CMP shown in Problem No. 5. This is due to the inlet edge geometry of concrete pipe being superior to that of CMP, both projecting. The size required would be identical for concrete pipe and CMP for square-edged headwall condition.

Outlet velocities are considerably higher for the concrete pipe, and the effect of these velocities must be weighed by the designer. Depending upon the location of an installation and material in downstream channel, a form of energy dissipator may be required.

In outlet control, the message "Inlet Control Governs" indicates a flow condition under which outlet control is not valid.