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Calculator Design Series #4

Texas Instruments TI-59

March 1982

Hydraulic Analysis of Pipe-Arch and Elliptical Shape Culverts Using Programable Calculators

U.S. Department of Transportation
Federal Highway Administration

FEDERAL HIGHWAY ADMINISTRATION

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(Continued on inside of back cover)

PREFACE

This computer program was developed for the TI-59 programable calculator to provide hydraulic design engineers with a tool to make "desk top" culvert review or design for corrugated metal pipe-arch (CMPA), corrugated metal pipe-elliptical (CMPE), concrete pipe-arch and concrete pipe-elliptical (oval) shape pipes. The CM pipe-arch culvert sizes include 18 inch or less, 31 inch and 47 inch corner radius configuration for both riveted and structural plate culverts and 31.8 inch corner radius for the aluminum structural plate culverts. The concrete pipe-arch culverts include variable corner radii up to 26.875 inches.

The long span structures have been accounted for with the 47 inch corner radius CMPA culvert sizes and the CMPE culverts.

This program is not limited to the review and design of culvert sizes tabulated in the manual, other available sizes can be analyzed. However, the necessary geometric data corresponding to that shown in the tables is required (TR, BR, etc).

TABLE OF CONTENTS

List of Tables and Figures

INTRODUCTION

The programable calculator offers many desirable features as a culvert design tool. Compared with the hand method, the calculator is more accurate, less time consuming, and eliminates all the searching through charts and nomographs. In one quarter of the time it takes to design one culvert by hand, the designer could use the calculator to design the culvert and check four or five different sizes to find the most economical size.

The hydraulic analysis procedures presented herein cover conventional inlets for CM pipe-arch and concrete pipe-elliptical (oval) culvert design methods found in "Hydraulic Charts for the Selection of Highway Culverts," Hydraulic Engineering Circular (HEC) No. 5, dated December 1965. The hydraulic design procedures for CM elliptical and concrete pipe-arch culverts were taken from a preliminary draft report prepared by the Federal Highway Administration (FHWA).* As of this date no research data is available for the design of improved inlets for these shapes.

The tables in this manual are organized by type of material and corresponding shape.

Tables 1 and 2 contain the culvert sizes and geometric parameters for the CM welded or riveted, structural plate and aluminum pipe-arch culverts with 2-2/3 x 1/2 inch, 3 x 1 inch, 6 x 2 inch and 9 x 2-1/2 inch corrugations.

Table 3 contains the inlet control equation coefficients for the culverts listed in tables 1 and 2.

Tables 4 and 5 contain the culvert sizes and geometric parameters for the CM structural plate pipe-elliptical culverts with 6 x 2 inch corrugations.

Table 6 contains the inlet control equation coefficients for the culverts listed in tables 4 and 5.

Tables 7 and 8 contain the culvert sizes and geometric parameters for concrete pipe-elliptical culverts and table 9 contains the inlet control equation coefficients for the culverts listed in tables 7 and 8.

Tables 10 and 11 contain the culvert sizes and geometric parameters for concrete pipe-arch culverts and table 12 contains the inlet control coefficients for the culverts listed in tables 10 and 11.

Table 13 contains the hydraulic constants for the culverts listed in the tables.

* See reference no. 1 and 6

The flow chart on page 8 shows the general step-wise hydraulic design or review procedure for the pipe-arch and elliptical shape culverts. Since the hydraulic analysis procedure is subdivided into a series of programs, the results from one program become the input to subsequent programs in the design process. More detailed flow charts of the hydraulic procedures are found in the appendices.

Terminology used in this publication assumes that the designer is familiar with HEC No. 5 and the preliminary report (reference No. 1) and understands the principles and design philosophy expressed therein.

Appendix A describes the algorithm (integral calculus routine) for computing area, wetted perimeter, and top width.

Appendix B shows the micro flow charts for outlet control and the backwater curves (M1 and M2).

Appendix C contains figures 4, 5, and 6 depicting the inlet and outlet control configurations and the annular corrugations used in the program.

This program was developed in the Office of Engineering, Bridge Division, Hydraulics Branch by Mr. Mario Marques and edited by Mr. Phillip Thompson and Stan Davis.

LIST OF SYMBOLS

Symbols	Units	Description
A	sq ft	Area, generally the cross-sectional area of flow
AHW	ft	Allowable Headwater in feet
Alpha		Velocity distribution factor
B	in	Vertical dimension from pipe invert to corner radius center point
BR	in	Bottom radius for culvert
CMPA		Corrugated metal pipe-arch
CMPE		Corrugated metal pipe-elliptical
CR or RC	in	Corner radius for culvert
dep	ft	Variable for water depth in barrel
d_c	ft	Critical depth of flow
d_n	ft	Normal depth of flow
d_y		variable to define integral element (see figure 3)
g	ft/sec^2	Acceleration of gravity: 32.2
H	ft	Head loss required to pass a given quantity of water through a culvert flowing in outlet control
H_e	ft	Head loss for a culvert due to the entrance configuration
HR	ft	Hydraulic radius
H_v	ft	Velocity head
k_e	ft	Entrance energy loss coefficient
n		Manning's roughness coefficient
Q	cfs	Flow rate

LIST OF SYMBOLS (continued)

Symbols	Units	Description
R	ft	Hydraulic radius
RC or CR	in	corner radius of culvert
Rise	in	Depth of pipe-arch culvert
RS or SR	in	side radius for elliptical shape culvert
S	ft/ft	Slope of energy gradiant
Span	in	Width of pipe-arch culvert
SPH	ft	Specific energy
S_o	ft/ft	Slope of natural channel
T	ft	Top width of water surface
TW	ft	Tailwater at culvert outlet
TR or RT	in	Top radius of pipe-arch culvert
V	fps	Velocity of flow
w		variable to define integral element (see figure 3)
WP	ft	Wetted perimeter
Y_1	in	Culvert geometry, tangent point between bottom radius (BR) and corner radius (CR)
Y_1'	ft	Water depth in barrel for backwater
Y_2	in	Culvert geometry, tangent point between top radius (TR) and corner radius.
Y_2'	ft	Water depth in barrel for backwater

PROGRAM LIMITIATIONS

The program is limited to CM and concrete pipe-arch and CM and concrete pipe-elliptical shape culverts with the long axis on the horizontal plane.

The program analyzes culverts based on a single barrel entry. For multiple barrel analysis, the discharge is divided by the estimated number of barrels required for the hydraulic design. This discharge is used in the program.

The hydraulic design of large corrugated metal culverts (31" and 41" CR) are performed with the best estimates established from limited research data for pipe-arch geometry. The concrete pipe-elliptical (oval) sizes and design concepts are taken from HEC No. 5 and the pipe sizes for CM pipe-elliptical shape culverts were taken from existing manufactures publications using the same hydraulic design procedure as for pipe-archs. The concrete pipe-arch culvert sizes were taken from the ASTM publication dated 1980.

The culvert inlet configurations are limited to mitered, headwall, thin edge projecting, and beveled edge.

For the larger structures or for design conditions where tailwater may be critical, a more accurate analysis of tailwater may be warranted by using available methods (HEC-2, HY-4, etc) rather than applying the procedure of program #1.

For the structural plate elliptical shape culverts, the user should add 0.7S (.7 times slope) to the mitered inlet HW/D value (inlet control) to allow for a small slope correction factor.* For the other inlet types the slope correction factor was incorporated in the development of the inlet equations.

For helical corrugated metal pipe, a manning's "n" value equivalent to that for annular (riveted) corrugated pipe is recommended for culvert installations where the culvert barrel flows partially full or when flow conditions are not clearly defined. Where full flow for design conditions is assured, a lower manning's "n" value may be used.**

The grooved-end inlet dimensions for the concrete pipe-arch and elliptical shape culverts are .05 D x .07 D.**

The program can develop two backwater profiles:

1. backwater profile (M1 curve).***
2. drawndown profile (M2 curve).***

* See reference no. 1.
** See reference no. 7.
*** Described in most hydraulic text books.

PROGRAM HYDRAULIC DESIGN OUTLINE

A normal culvert design or review procedure is to compute headwater and develop a performance curve for both the inlet and outlet control conditions. The hydraulic design engineer can make an engineering decision based on the results. This program provides the engineer with the necessary intermediary data (normal and critical depth) and headwater results based on the following step-wise methodology to analyze CMPA, CMPE, concrete pipe-arch and concrete pipe-elliptical shape culverts.

Step # 1

Use program # 1 to compute the tailwater (TW)* in the channel.

Step # 2

Option I of program # 2 is for computing the geometry values Y_1 and Y_2 or these values can be obtained from the respective tables. Option II of program # 2 is for computing the approximate area for a culvert design. Culvert areas and respective dimensions are shown in the tables.

Program # 3 is a utility stand alone program used to compute area, wetted perimeter and top width for any water depth in the culvert.

Step # 3

Use program # 4 to compute normal depth (d_n) and area at d_n in the culvert. The d_n is required to compute the inlet-control velocity at the outlet and checked against critical depth during outlet control analysis to determine if "inlet control governs".

Step # 4

Use program # 5 to compute critical depth (d_c) and area at d_c. The d_c is required for analyzing the outlet control conditions.

Step # 5

Use program # 6 to compute the inlet control headwater for CM and concrete pipe-arch and CM and concrete pipe-elliptical shape culverts. At this point, performance curve data can be obtained by varying the discharge (Q) and TW and computing each respective headwater elevation.

Step # 6

Use program # 7 to compute the outlet control headwater and performance curve data. The program will print a message whether the flow is "Inlet control gov", "Full flow in the barrel" or "Do a backwater analysis".

Step # 7

Programs # 8 and #9 are used to develop backwater profiles in the barrel for an M1 and M2 curve respectively.

* See limitations

PROGRAM INDEX

GENERAL FLOW CHART
PIPE-ARCH and ELLIPTICAL SHAPE CULVERTS

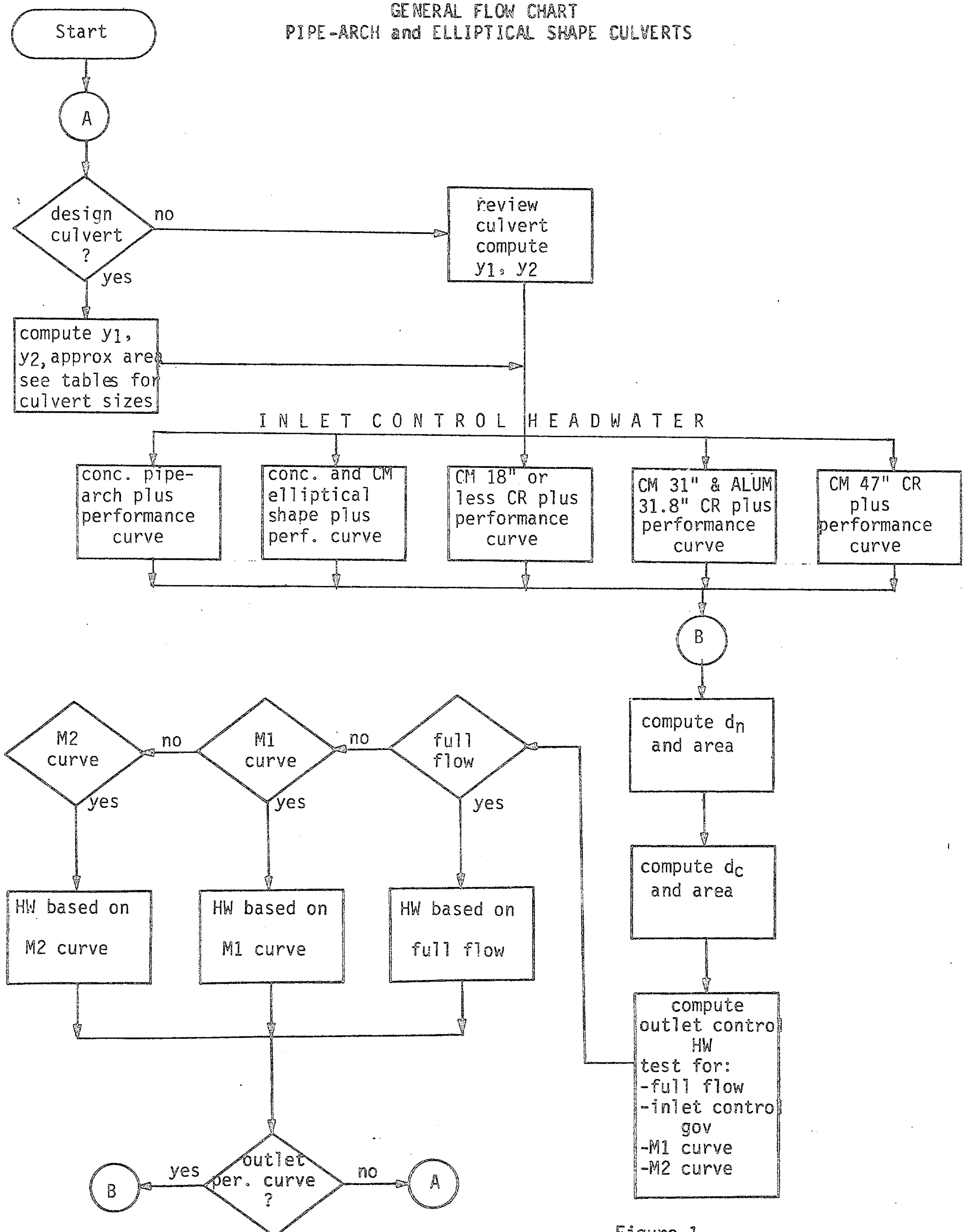


Figure 1

Table No. 1

CM Riveted or Welded Pipe-Arch Culverts (Variable CR)
(2-2/3" X 1/2" Corrugations)

SPAN ft(in)	RISE ft(in)	BR (in)	TR (in)	CR (in)	B (in)	y1* (in)	y2* (in)
1.51(18.1)	0.92(11.0)	19.12	10.06	3.5	4.5	1.247	6.389
1.81(21.7)	1.11(13.3)	37.06	11.87	4.0	4.75	0.804	6.494
2.11(25.3)	1.29(15.5)	33.50	12.75	4.0	5.25	1.472	6.360
2.41(28.9)	1.49(17.8)	55.00	14.75	4.5	5.5	1.078	6.575
3.01(36.1)	1.85(22.2)	73.25	18.25	5.0	6.25	1.351	7.117
3.61(43.3)	2.22(26.6)	91.56	21.56	5.5	7.0	1.626	7.662
4.22(50.6)	2.64(31.7)	97.25	25.12	6.0	8.0	2.200	8.440
4.82(57.8)	2.96(35.5)	115.69	29.12	7.0	9.25	2.372	10.159
5.42(65.0)	3.33(40.0)	129.31	32.75	8.0	10.5	2.664	11.552
6.02(72.2)	3.70(44.4)	142.94	36.31	9.0	11.75	2.956	12.954
6.62(79.4)	4.06(48.7)	145.5	39.75	10.0	13.25	3.538	14.683
7.08(85.0)	4.50(54.0)	154.5	42.63	11.0	14.50	3.768	15.586

CM Structural Plate Pipe-Arch Culverts (18" corner radii)
(6" X 2" Corrugations)

6.08(73.0)	4.58(55.0)	76.30	36.80	18.0	21.0	3.943	23.694
6.33(76.0)	4.76(57.1)	98.60	38.1	18.0	20.5	3.084	21.846
6.77(81.2)	4.91(58.9)	83.50	41.0	18.0	22.0	5.127	25.213
7.02(84.2)	5.09(61.1)	104.2	42.3	18.0	21.4	4.155	23.331
7.25(87.0)	5.27(63.2)	136.2	43.5	18.0	20.8	3.207	21.576
7.70(92.4)	5.42(65.0)	109.8	46.5	18.0	22.4	5.309	24.865
7.93(95.2)	5.60(67.2)	137.9	47.7	18.0	21.7	4.268	23.034
8.15(97.8)	5.78(69.4)	182.9	48.9	18.0	20.9	3.240	21.133
8.62(103.4)	5.93(71.1)	141.0	51.9	18.0	22.7	5.395	24.559
8.83(106.0)	6.11(73.3)	178.7	53.0	18.0	21.9	4.290	22.722
9.32(111.8)	6.26(75.1)	144.6	56.2	18.0	23.8	6.632	26.108
9.52(114.2)	6.44(77.3)	177.5	57.3	18.0	22.9	5.416	24.231
9.72(116.6)	6.63(79.5)	227.7	58.3	18.0	21.9	4.244	22.213
10.22(122.6)	6.77(81.2)	178.3	61.5	18.0	24.0	6.628	25.779
10.70(128.4)	6.91(82.9)	153.2	64.9	18.0	26.1	9.222	29.208
10.92(131.0)	7.09(85.1)	180.4	65.9	18.0	25.1	7.889	27.319
11.40(136.8)	7.24(86.9)	157.9	69.4	18.0	27.4	10.603	30.870
11.62(139.4)	7.43(89.1)	183.2	70.2	18.0	26.3	9.202	28.850
11.82(141.8)	7.61(91.3)	216.4	71.1	18.0	25.2	7.834	26.894
12.32(147.8)	7.75(93.0)	186.5	74.7	18.0	27.5	10.562	30.423
12.52(150.2)	7.93(95.2)	216.8	75.5	18.0	26.4	9.135	28.498
12.70(152.4)	8.12(97.4)	257.4	76.4	18.0	25.2	7.722	26.495
12.87(154.4)	8.31(99.7)	314.7	77.3	18.0	24.0	6.328	24.486
13.40(160.8)	8.44(101.3)	254.8	80.7	18.0	26.4	9.006	28.066
13.93(167.2)	8.58(103.0)	220.7	84.4	18.0	28.9	11.877	31.692
14.12(169.4)	8.77(105.2)	254.1	85.1	18.0	27.6	10.351	29.611

* see figure 3, page 30

Table 1 (Continued)

CM Structural Plate Pipe-Arch Culverts (31" corner radii)
6" X 2" Corrugations)

SPAN ft(in)	RISE ft(in)	BR in	TR in	CR in	B in	y1 in	y2 in
13.28(159.4)	9.56(112.3)	192.6	80.1	31.0	38.6	8.954	42.639
13.52(162.2)	9.53(114.4)	220.8	81.3	31.0	37.8	7.831	40.695
13.97(167.6)	9.68(116.2)	197.9	84.4	31.0	39.6	10.164	44.130
14.22(170.6)	9.87(118.4)	222.6	85.6	31.0	38.9	9.126	42.360
14.40(172.8)	10.04(120.5)	256.6	86.6	31.0	38.0	7.857	40.288
14.88(178.6)	10.19(122.3)	227.7	89.8	31.0	39.9	10.231	43.804
15.35(184.2)	10.34(124.1)	208.5	93.1	31.0	41.9	12.742	47.344
15.58(187.0)	10.53(126.3)	232.1	94.1	31.0	41.0	11.494	45.322
15.80(189.6)	10.71(128.5)	260.6	95.2	31.0	40.1	10.263	43.385
16.28(195.4)	10.85(130.2)	236.0	98.5	31.0	42.2	12.841	47.020
16.50(198.0)	11.03(132.4)	263.2	99.5	31.0	41.2	11.539	44.956
16.97(203.6)	11.18(134.2)	241.0	102.9	31.0	43.4	14.110	48.622
17.18(206.2)	11.36(136.3)	266.8	103.8	31.0	42.4	12.778	46.617
17.40(208.8)	11.54(138.5)	297.9	104.8	31.0	41.4	11.486	44.634
17.88(214.6)	11.69(140.3)	270.6	108.2	31.0	43.6	14.087	48.220
18.10(217.2)	11.87(142.4)	299.7	109.1	31.0	42.5	12.770	46.150
18.58(223.0)	12.02(144.2)	274.5	112.6	31.0	44.8	15.434	49.816
18.78(225.4)	12.20(146.4)	302.3	113.5	31.0	43.7	14.033	47.762
19.28(231.4)	12.34(148.1)	278.6	117.0	31.0	46.0	16.808	51.370
19.50(234.0)	12.53(150.3)	305.1	117.9	31.0	44.9	15.406	49.359
19.70(236.4)	12.71(152.5)	336.5	118.8	31.0	43.8	14.000	47.367
19.88(238.6)	12.89(154.7)	374.3	119.7	31.0	42.6	12.593	45.258
20.40(244.8)	13.03(156.4)	338.1	123.2	31.0	45.0	15.321	48.969
20.58(247.0)	13.22(158.6)	373.5	124.0	31.0	43.8	13.879	46.868

CM Structural Plate Pipe-Arch Culverts (47" Corner Radii)
(Long Spans - 6" X 2" Corrugations)

Span ft(in)	RISE ft(in)	BR in	TR in	CR in	B in	Y1 in	Y2 in
20.00 (240)	13.92 (167)	223.6	122.5	47"	62.8	19.997	74.228
20.50 (246)	14.25 (171)	225.7	124.7	47"	61.4	17.557	70.559
21.42 (257)	14.50 (174)	236.7	131.4	47"	65.3	22.958	77.911
21.92 (263)	14.92 (179)	268.1	133.5	47"	63.7	20.352	73.596
22.42 (269)	15.25 (183)	307.1	135.5	47"	62.1	17.899	69.835
23.33 (280)	15.58 (187)	280.2	142.4	47"	66.2	23.245	76.833
24.17 (290)	15.92 (191)	262.1	149.7	47"	70.7	28.783	84.205
24.67 (296)	16.17 (194)	292.2	151.4	47"	68.8	25.940	80.601
25.17 (302)	16.58 (199)	328.6	153.2	47"	66.9	23.231	76.245
25.58 (307)	16.92 (203)	373.3	155.0	47"	64.8	20.443	72.124
26.58 (319)	17.25 (207)	339.4	162.1	47"	69.4	26.126	79.401
27.50 (330)	17.50 (210)	315.8	169.6	47"	74.2	32.056	87.142
28.00 (336)	17.83 (214)	350.2	171.1	47"	72.1	29.095	83.126
26.50 (341)	18.25 (219)	392.3	172.7	47"	69.9	25.950	78.722
29.33 (352)	18.50 (222)	361.1	180.2	47"	74.8	31.859	86.448
30.33 (364)	18.83 (226)	339.1	188.2	47"	80.0	38.389	94.023

Table No. 1 (Continued)

CM Riveted or Welded Pipe Arch Culverts (18" or less CR)
(3 X 1 in Corrugation)

SPAN (in)	RISE (in)	BR (in)	TB (in)	CR (in)	B (in)	y_1 (in)	y_2 (in)
43	27	54.75	22.50	7.75	9.75	2.395	12.514
50	31	67.00	26.25	9.00	11.25	2.599	14.637
58	36	82.00	30.50	10.50	13.00	2.792	16.944
65	40	91.25	34.50	12.00	14.75	3.106	19.685
72	44	98.50	38.50	13.25	16.25	3.572	21.910
73	55	76.25	36.75	18.00	21.00	3.948	23.646
81	59	92.75	40.75	18.00	21.50	4.301	24.073
87	63	100.50	43.50	18.00	22.00	4.920	23.756
95	67	116.00	47.75	18.00	22.50	5.380	24.471
103	71	132.25	51.75	18.00	23.00	5.813	25.002
112	75	151.75	56.25	18.00	23.50	6.253	25.733
117	79	160.50	58.75	18.00	24.00	6.619	25.659
128	83	185.00	64.50	18.00	24.50	7.156	26.828
137	87	201.00	69.00	18.00	25.00	7.805	27.471
142	91	210.00	71.25	18.00	25.50	8.159	27.441

Table No. 1 (Continued)

Aluminum Structural Plate Pipe Arch Culverts (31.8 corner radii)
(9" X 2-1/2" Corrugations)

SPAN ft(in)	RISE ft(in)	BR in	TB in	CR in	B in	y_1 in	y_2 in
5.92(71)	5.42(65)	104.4	36.5	31.8	31.8	136	52.966
6.17(74)	5.67(68)	68.7	37.1	31.8	32.1	685	39.307
6.50(78)	5.75(69)	121.5	39.0	31.8	32.0	392	40.511
6.83(82)	5.92(71)	91.3	41.5	31.8	32.5	1.098	42.359
7.25(87)	6.00(72)	82.1	44.3	31.8	33.1	2.252	46.426
7.58(91)	6.17(74)	78.0	47.3	31.8	33.9	3.508	48.694
7.92(95)	6.33(76)	96.7	49.1	31.8	33.7	2.872	46.338
8.17(98)	6.42(77)	303.4	49.4	31.8	32.3	.609	40.680
8.58(103)	6.58(79)	177.2	52.3	31.8	33.1	1.634	42.925
8.83(106)	6.75(81)	291.6	53.8	31.8	32.6	.972	40.450
9.25(111)	6.83(82)	189.5	56.9	31.8	33.6	2.156	44.335
9.67(116)	7.00(84)	152.8	60.2	31.8	34.6	3.625	46.719
10.08(121)	7.08(85)	134.3	63.8	31.8	35.9	5.372	50.397
10.42(125)	7.25(87)	164.6	65.1	31.8	35.3	4.458	48.021
10.67(128)	7.42(89)	210.8	66.3	31.8	34.7	3.439	45.805
11.00(132)	7.58(91)	289.0	67.5	31.8	34.0	2.566	43.333
11.50(138)	7.67(92)	155.9	74.0	31.8	37.5	7.169	52.264
11.67(140)	7.83(94)	292.2	72.2	31.8	34.6	3.161	44.703
12.08(145)	7.92(95)	229.5	75.9	31.8	36.0	4.916	48.195
12.42(149)	8.08(97)	296.2	76.9	31.8	35.2	3.888	45.802
12.83(154)	8.25(99)	238.3	80.9	31.8	36.8	5.778	48.957
13.08(157)	8.33(100)	300.8	81.7	31.8	35.9	4.567	47.114
13.58(163)	8.50(102)	246.8	85.8	31.8	37.5	6.684	50.026
14.00(168)	8.58(103)	215.1	90.3	31.8	39.4	8.906	53.881
13.92(167)	9.42(113)	159.3	86.2	31.8	42.8	13.684	52.201
14.25(171)	9.58(115)	176.3	87.2	31.8	42.0	12.626	50.129
14.67(176)	9.67(116)	166.2	90.9	31.8	44.0	15.228	54.136
14.92(179)	9.83(118)	183.0	91.8	31.8	43.2	13.849	52.187
15.33(184)	10.00(120)	173.0	95.5	31.8	45.3	16.511	55.685
15.58(187)	10.17(122)	189.6	96.4	31.8	44.4	15.094	53.668
16.08(193)	10.33(124)	179.7	100.2	31.8	46.6	18.106	57.169
16.33(196)	10.50(126)	196.1	101.0	31.8	45.7	16.622	55.190
16.75(201)	10.67(128)	186.3	105.0	31.8	47.9	19.431	58.736
17.00(204)	10.83(130)	202.5	105.7	31.8	46.9	17.916	56.645
17.25(207)	11.00(132)	221.3	106.5	31.8	45.9	16.452	54.602
17.75(213)	11.17(134)	208.9	110.4	31.8	48.2	19.492	58.147
18.00(216)	11.33(136)	227.3	111.1	31.8	47.2	17.976	56.132
18.42(221)	11.50(138)	215.2	115.2	31.8	49.6	20.820	59.850
18.67(224)	11.67(140)	233.3	115.8	31.8	48.5	19.275	57.721
19.17(230)	11.75(141)	221.5	119.9	31.8	50.9	22.440	61.623
19.42(233)	11.92(143)	239.3	120.5	31.8	49.8	20.844	59.553
19.83(238)	12.08(145)	227.7	124.7	31.8	52.3	23.802	63.255
20.08(241)	12.25(147)	245.3	125.2	31.8	51.1	22.172	61.074
20.08(241)	12.50(150)	310.8	122.5	31.8	46.2	16.125	52.759
20.83(250)	12.58(151)	251.2	130.0	31.8	52.5	23.791	62.682
21.08(253)	12.75(153)	270.9	130.5	31.8	51.2	22.154	60.423
21.50(258)	12.92(155)	257.2	134.8	31.8	53.9	25.144	64.317

Table No. 2

CM Riveted or Welded Pipe-Arch Culverts (variable corner radii)
(2-2/3 X 1/2 Corrugations)

SPAN ft(in)	RISE ft(in)	TOTAL AREA sq ft	TOTAL WP ft	ESTIMATED* "n"
1.51(18.1)	.92(11.0)	1.07	3.859	.025
1.81(21.7)	1.11(13.3)	1.59	4.763	.025
2.11(25.3)	1.29(15.5)	2.10	5.401	.025
2.41(28.9)	1.48(17.8)	2.81	6.305	.025
3.01(36.1)	1.85(22.2)	4.39	7.882	.025
3.61(43.3)	2.22(26.6)	6.28	9.440	.025
4.22(50.6)	2.64(31.7)	8.75	11.105	.024
4.52(57.8)	2.96(35.5)	11.23	12.669	.024
5.42(65.0)	3.33(40.0)	14.23	14.237	.024
6.02(72.2)	3.70(44.4)	17.52	15.782	.024
6.62(79.4)	4.06(48.7)	21.01	17.263	.024
7.08(85.0)	4.50(54.0)	25.17	18.810	.024

CM Structural Plate Pipe-Arch Culverts (18" corner radii)
(6" X 2" Corrugations)

6.08(73.0)	4.58(55.0)	22.09	17.008	.035
6.33(76.0)	4.76(57.1)	24.10	17.791	.035
6.77(81.2)	4.91(58.9)	26.16	18.594	.035
7.02(84.2)	5.09(61.1)	28.40	19.401	.035
7.25(87.0)	5.27(63.2)	30.62	20.215	.034
7.70(92.4)	5.42(65.0)	32.91	20.990	.034
7.93(95.2)	5.60(67.2)	35.39	21.800	.034
8.15(97.8)	5.78(69.4)	37.96	22.606	.034
8.62(103.4)	5.93(71.1)	40.46	23.400	.034
8.83(106.0)	6.11(73.3)	43.10	24.236	.034
9.32(111.8)	6.26(75.1)	45.83	25.018	.034
9.52(114.2)	6.44(77.3)	48.69	25.830	.034
9.72(116.6)	6.63(79.5)	51.67	26.610	.034
10.22(122.6)	6.77(81.2)	54.51	27.420	.034
10.70(128.4)	6.91(82.9)	57.46	28.176	.034
10.92(131.0)	7.09(85.1)	60.72	29.012	.034
11.40(136.8)	7.24(86.9)	63.86	29.817	.034
11.62(139.4)	7.43(89.1)	76.24	30.612	.034
11.82(141.8)	7.61(91.3)	70.70	31.427	.033
12.32(147.8)	7.75(93.0)	74.08	32.204	.033
12.52(150.2)	7.93(95.2)	77.64	33.025	.033
12.70(152.4)	8.12(97.4)	81.37	33.823	.033
12.87(154.4)	8.31(99.7)	85.20	34.645	.033
13.40(160.8)	8.44(101.3)	88.78	35.415	.033
13.93(167.2)	8.58(103.0)	92.58	36.213	.033
14.12(169.4)	8.77(105.2)	96.56	36.998	.033

*For paved culverts, a composite "n" value is calculated by the equation
n = .60n + .40(.012), (AASHTO, M-190)

Table 2 (Continued)

CM Structural Plate Pipe-Arch Culverts (31" corner radii)
(6" X 2" Corrugations)

SPAN ft(in)	RISE ft(in)	TOTAL AREA sq ft	TOTAL WP ft	Estimated "n"
13.28(159.4)	9.56(112.3)	98.13	36.310	.034
13.52(162.2)	9.53(114.4)	102.30	37.109	.034
13.97(167.6)	9.68(116.2)	106.41	37.870	.034
14.22(170.6)	9.87(118.4)	110.88	38.700	.034
14.40(172.8)	10.04(120.5)	115.13	39.496	.034
14.88(178.6)	10.19(122.3)	119.53	40.281	.034
15.35(184.2)	10.34(124.1)	124.05	41.077	.034
15.58(187.0)	10.53(126.3)	128.78	41.893	.034
15.80(189.6)	10.71(128.5)	133.66	42.713	.034
16.28(195.4)	10.85(130.2)	138.29	43.492	.034
16.50(198.0)	11.03(132.4)	143.29	44.291	.034
16.97(203.6)	11.18(134.2)	148.06	45.108	.034
17.18(206.2)	11.36(136.3)	153.04	45.898	.034
17.40(208.8)	11.54(138.5)	158.29	46.727	.034
17.88(214.6)	11.69(140.3)	163.73	47.528	.034
18.10(217.2)	11.87(142.4)	168.73	48.290	.034
18.53(223.0)	12.02(144.2)	173.98	49.114	.034
18.78(225.4)	12.20(146.4)	179.54	49.916	.034
19.28(231.4)	12.34(148.1)	184.79	50.688	.034
19.50(234.0)	12.53(150.3)	190.61	51.502	.034
19.70(236.4)	12.71(152.5)	196.34	52.322	.034
19.88(238.6)	12.89(154.7)	202.23	53.101	.034
20.40(244.8)	13.03(156.4)	207.92	53.912	.034
20.58(247.0)	13.22(158.6)	213.82	54.699	.034

CM Structural Plate Pipe-Arch Culverts (47" corner radii)
(Long Span - 6" X 2" Corrugations)

SPAN ft(in)	RISE ft(in)	TOTAL AREA sq ft.	TOTAL WP sq ft	Estimated "n"
20.00(240)	13.92(167)	216.59	53.84	.033
20.50(246)	14.25(171)	228.61	55.42	.033
21.42(257)	14.50(174)	240.06	56.88	.033
21.92(263)	14.92(179)	254.54	58.61	.033
22.42(269)	15.25(183)	267.48	60.18	.033
23.33(280)	15.58(187)	281.73	61.84	.033
24.17(290)	15.92(191)	295.89	63.51	.033
24.67(296)	16.17(194)	307.80	64.89	.033
25.17(302)	16.58(199)	324.16	66.62	.033
25.58(307)	16.92(203)	338.46	68.12	.033
26.58(319)	17.25(207)	354.57	69.83	.033
27.50(330)	17.50(210)	368.43	71.33	.033
28.00(336)	17.83(214)	383.93	72.89	.033
26.59(341)	18.25(219)	401.84	74.64	.033
29.33(352)	18.50(222)	416.48	76.11	.033
30.33(364)	18.83(226)	434.31	77.80	.033

Table No. 2 (Continued)

CM Riveted or Welded Pipe Arch Culverts (18" or less CR)
(3 X 1 in Corrugations)

SPAN in	RISE in	TOTAL AREA in	TOTAL WP in	ESTIMATED "n"
43	27	6.30	9.32	.028
50	31	8.41	10.82	.028
58	36	11.36	12.62	.028
65	40	14.14	14.07	.028
72	44	17.24	15.48	.028
73	55	22.08	17.00	.028
81	59	26.26	18.66	.028
87	63	30.09	19.98	.028
95	67	34.97	21.64	.028
103	71	40.11	23.20	.028
112	75	45.92	25.06	.028
117	79	50.68	26.39	.028
128	83	57.98	28.39	.027
137	87	64.81	30.07	.027
142	91	70.36	31.38	.027

Table No. 2 (Continued)

Aluminum Structural Plate Pipe-Arch Culverts (31.8" corner radii)
(9" X 2-1/2" Corrugations)

SPAN ft(in)	RISE ft(in)	TOTAL AREA sq ft	TOTAL WP ft	ESTIMATED "n"
5.92(71)	5.42(65)	24.48	17.67	.036
6.17(74)	5.67(68)	27.74	18.64	.036
6.50(78)	5.74(69)	29.75	19.24	.035
6.83(82)	5.92(71)	32.21	20.20	.035
7.25(82)	6.00(72)	34.49	20.90	.035
7.58(91)	6.17(74)	37.05	21.79	.035
7.92(95)	6.33(76)	39.89	22.64	.035
8.17(98)	6.42(77)	42.12	23.23	.035
8.58(103)	6.58(79)	45.19	24.18	.035
8.83(106)	6.75(81)	48.07	24.92	.035
9.25(111)	6.83(82)	50.53	25.75	.035
9.67(116)	7.00(84)	53.83	26.59	.034
10.08(121)	7.08(85)	56.39	27.33	.034
10.42(125)	7.25(87)	59.84	28.16	.034
10.67(128)	7.42(89)	63.07	29.02	.034
11.00(132)	7.58(91)	66.73	29.83	.034
11.50(138)	7.67(92)	69.41	30.61	.034
11.67(140)	7.83(94)	72.98	31.43	.034
12.08(145)	7.92(95)	75.79	32.11	.034
12.42(149)	8.08(97)	79.75	32.97	.034
12.83(154)	8.25(99)	83.70	33.89	.034
13.08(157)	8.33(100)	86.47	34.55	.034
13.58(163)	8.50(102)	90.87	35.41	.034
14.00(168)	8.58(103)	93.91	36.17	.034
13.92(167)	9.42(113)	101.80	37.08	.034
14.25(171)	9.58(115)	106.19	37.86	.034
14.67(176)	9.67(116)	109.42	38.53	.034
14.92(179)	9.83(118)	113.66	39.33	.034
15.33(184)	10.00(120)	118.17	40.17	.034
15.58(187)	10.17(122)	122.61	40.96	.034
16.08(193)	10.33(124)	127.55	41.81	.034
16.33(196)	20.50(126)	132.12	42.61	.034
16.75(201)	10.67(128)	137.02	43.44	.034
17.00(204)	10.83(130)	141.76	44.22	.034
17.25(207)	11.00(132)	146.62	45.02	.034
17.75(213)	11.17(134)	151.97	45.86	.034
18.00(216)	11.33(136)	156.96	46.66	.034
18.42(221)	11.50(138)	162.26	47.52	.034
18.67(224)	11.57(140)	167.41	48.30	.034
19.17(230)	11.75(141)	171.55	48.76	.034
19.42(233)	11.92(143)	176.85	49.76	.034
19.83(238)	12.08(145)	182.43	50.60	.034
20.08(241)	12.25(147)	187.88	51.38	.034
20.08(241)	12.50(150)	194.73	52.26	.034
20.83(250)	12.58(151)	199.54	53.03	.033
21.08(253)	12.75(153)	205.26	53.80	.033
21.50(258)	12.92(155)	211.24	54.67	.033

Table No. 3

CM Pipe-Arch Culverts

Coefficients for Inlet Control Headwater

Inlet type	A*	B	C	D	E	F
Projecting						
18" or less CR**	.08905	.71255	-.27092	.07925	-.00798	.00029
31" CR	.12263	.48250	-.00002	-.04287	.01454	-.00117
47" CR	.14168	.49323	-.03235	-.02098	.00989	-.00086
31.8" CR ALUMINUM	.09219	.65732	-.19423	.04476	-.00176	-.00012
Mitered						
18" or less CR	.08330	.79514	-.43408	.16377	-.02491	.00141
31" CR	.10620	.70370	-.35310	.13740	-.02076	.00117
47" CR	.23645	.37198	-.04010	.03058	-.00576	.00045
31.8" CR ALUMINUM	.10212	.72503	-.34558	.12454	-.01676	.00081
Headwall						
18" or less CR	.11128	.61058	-.19494	.05129	-.00481	.00017
31" CR	.12346	.50432	-.13261	.04020	-.00448	.00021
47" CR	.09728	.57515	-.15977	.04223	-.00374	.00012
31.8 CR ALUMINUM	.09455	.61669	-.22431	.07407	-.01002	.00054

* coefficients for polynomial equations (see equations)

** corner radius

Table No. 4

Corrugated Metal Elliptical Shape Culverts (variable corner radii)
(Long Span - 6" X 2" Corrugations)

SPAN ft(in)	RISE ft(in)	BR & TR in	CR in	B in	Y1 in	Y2 in
19.33(232)	12.75(153)	150	54	76.5	35.48	117.78
20.08(241)	13.00(153)	157	54	78.0	37.11	119.31
20.17(242)	11.92(156)	164	43	71.5	38.62	104.37
20.83(250)	12.17(146)	171	43	73.0	39.70	105.98
21.00(252)	15.17(182)	157	71	91.0	36.30	145.54
21.92(263)	13.08(157)	178	49	78.5	41.16	116.22
22.5 (270)	15.67(188)	171	71	94.0	39.61	148.60
23.00(276)	14.08(169)	185	54	84.5	43.04	125.93
23.25(279)	15.92(191)	178	71	95.5	41.26	150.12
24.33(292)	16.92(203)	185	76	101.5	43.19	159.74
24.50(294)	14.67(176)	198	54	88.0	46.83	129.24
25.17(302)	14.92(179)	205	54	89.5	47.89	130.97
25.42(305)	16.75(201)	198	71	100.5	46.15	154.97
26.08(313)	18.17(218)	198	82	109.0	46.23	171.88
26.25(315)	15.83(190)	212	59	95.0	49.78	140.13
27.00(324)	16.17(194)	219	59	97.0	51.41	142.08
27.17(326)	19.08(229)	205	87	114.5	48.18	181.12
27.92(335)	19.42(233)	212	87	116.5	49.81	183.02
28.08(337)	17.08(205)	226	65	102.5	52.89	152.32
28.83(346)	17.42(209)	233	65	104.5	54.53	154.26
29.42(353)	19.92(239)	226	87	119.5	53.08	186.10
30.08(361)	20.17(242)	233	87	121.0	54.05	187.79
30.25(363)	17.92(215)	247	65	107.5	57.23	157.39
31.17(374)	21.17(254)	240	93	127.0	55.48	198.49
31.33(376)	18.92(227)	253	71	113.5	59.21	167.90
32.08(385)	19.17(230)	260	71	115.0	60.84	169.42
32.25(387)	22.17(266)	247	98	133.0	57.40	208.12
33.00(396)	22.42(269)	253	98	134.5	59.69	209.39
33.17(398)	20.08(241)	267	76	120.5	62.73	178.71
34.08(409)	23.33(280)	260	104	140.0	61.14	219.73
34.58(415)	20.67(248)	281	76	124.0	65.43	182.26
34.92(419)	21.33(256)	281	82	128.0	65.25	190.99
35.05(421)	24.33(292)	267	109	146.0	62.38	229.51
35.75(429)	25.75(309)	267	120	154.5	62.48	246.38
36.0 (432)	22.33(268)	288	87	134.0	67.14	200.69
36.92(443)	25.58(307)	281	115	153.5	65.45	241.76
37.17(446)	22.17(266)	302	82	133.0	70.18	195.96
38.00(456)	26.58(319)	288	120	159.5	67.39	251.36
38.67(464)	27.92(335)	288	131	167.5	67.51	267.90
40.00(480)	28.58(355)	295	142	177.5	68.46	286.55

Table No. 5

Corrugated Metal Elliptical Shape Culverts (variable corner radii)
(Long Span - 6" X 2" Corrugations)

SPAN ft(in)	RISE ft(in)	TOTAL AREA sq ft	TOTAL WP ft	ESTIMATED "n"
19.33(232)	12.75(153)	190.92	50.64	.034
20.08(241)	13.00(153)	201.85	52.19	.034
20.17(242)	11.92(156)	183.84	50.77	.034
20.83(250)	12.17(146)	193.80	52.33	.034
21.00(252)	15.17(182)	248.76	57.13	.033
21.92(263)	13.08(157)	219.92	55.32	.033
22.5 (270)	15.67(188)	274.61	60.24	.033
23.00(276)	14.08(169)	249.11	58.68	.033
23.25(279)	15.92(191)	287.91	61.80	.033
24.33(292)	16.92(203)	320.50	65.16	.033
24.50(294)	14.67(176)	275.26	61.94	.033
25.17(302)	14.92(179)	287.45	63.50	.033
25.42(305)	16.75(201)	329.97	66.62	.033
26.08(313)	18.17(218)	369.00	69.86	.033
26.25(315)	15.83(190)	318.86	66.60	.033
27.00(324)	16.17(194)	334.57	68.42	.033
27.17(326)	19.08(229)	403.89	72.96	.033
27.92(335)	19.42(233)	421.92	74.77	.033
28.08(337)	17.08(205)	368.52	71.41	.033
28.83(346)	17.42(209)	385.42	73.23	.033
29.42(353)	19.92(239)	455.05	77.89	.033
30.08(361)	20.17(242)	471.06	79.45	.033
30.25(363)	17.92(215)	415.21	76.35	.033
31.17(374)	21.17(254)	512.91	82.70	.033
31.33(376)	18.92(227)	454.87	79.49	.033
32.08(385)	19.17(230)	471.28	81.04	.033
32.25(387)	22.17(266)	556.18	86.06	.033
33.00(396)	22.42(269)	574.58	87.51	.033
33.17(398)	20.08(241)	511.23	84.14	.033
34.08(409)	23.33(280)	618.32	90.50	.033
34.58(415)	20.67(248)	547.98	87.52	.033
34.92(419)	21.33(256)	572.78	88.95	.033
35.05(421)	24.33(292)	664.54	93.86	.033
35.75(429)	25.75(309)	718.53	97.09	.033
36.0 (432)	22.33(268)	619.19	92.32	.033
36.92(443)	25.58(307)	735.28	98.67	.033
37.17(446)	22.17(266)	631.58	93.89	.033
38.00(456)	26.58(319)	786.79	102.03	.033
38.67(464)	27.92(335)	842.71	105.01	.033
40.00(480)	29.58(355)	925.52	109.80	.033

Table No. 6

Corrugated Metal Elliptical Shape Culverts

Coefficients for Inlet Control Headwater

Inlet Type	A*	B	C	D	E	F
Headwall	.01267	.79435	-.29440	.07114	-.00612	.00015
Mitered	-.14029	1.4370	-.92636	.32502	-.04865	.00270
Beveled	-.00321	.92178	-.43903	.12551	-.01553	.00073
Thin Edge Projecting	.08510	.70623	-.18025	.01963	.00402	-.00052

* Coefficients for polynomial equations. Equation obtained from curve fitting procedure. Add (.7 X slope) to mitered inlet control value (HW/D) for slope correction factor.

Table No. 7

Concrete Elliptical (Oval) Shape Culverts

SPAN (in)	RISE (in)	BR & TR (in)	CR (in)	B (in)	Y1 (in)	Y2 (in)
23	14	19.94	6.09	7.0	1.58	11.82
30	19	26.24	8.21	9.5	1.93	17.11
38	24	32.80	10.26	12.0	2.57	21.46
42	27	36.20	11.45	13.5	2.80	24.05
45	29	39.36	12.32	14.5	2.89	25.90
49	32	42.66	13.55	16.0	3.13	28.53
53	34	45.90	14.60	17.0	3.45	30.50
60	38	51.60	16.43	19.0	3.99	34.17
68	43	58.40	18.65	21.5	4.53	38.72
76	48	65.09	20.67	24.0	5.16	43.05
83	53	71.52	22.75	26.5	5.49	47.50
91	58	77.95	24.84	29.0	6.14	51.88
98	63	84.38	26.93	31.5	6.47	56.35
106	68	90.81	29.02	34.0	7.12	60.74
113	72	97.24	31.11	36.0	7.45	64.74
121	77	103.66	33.19	38.5	8.10	69.11
136	87	116.27	37.45	43.5	9.09	78.03
151	97	129.13	41.62	48.5	10.07	86.87

Table No. 8

Concrete Elliptical (Oval) Shape Culverts

SPAN (in)	RISE (in)	TOTAL AREA (sq ft)	TOTAL WP (ft)	ESTIMATES "n"
23	14	1.82	4.88	.012
30	19	3.22	6.58	.012
38	24	5.13	8.34	.012
42	27	6.37	9.38	.012
45	29	7.34	10.10	.012
49	32	8.81	11.12	.012
53	34	10.15	11.76	.012
60	38	12.85	13.12	.012
68	43	16.49	14.82	.012
76	48	20.55	16.59	.012
83	53	24.77	18.33	.012
91	58	29.69	20.06	.012
98	63	34.73	21.79	.012
106	68	40.53	23.52	.012
113	72	45.85	24.82	.012
121	77	52.47	26.56	.012
136	87	66.61	29.97	.012
151	97	82.40	33.44	.012

Table No. 9

Concrete Elliptical (Oval) Shape Culverts

Coefficients for Inlet Control Headwater Equations

Type of Inlet	A*	B	C	D	E	F
Sq. edge with Headwall	.13432	.55951	-.15780	.03967	-.00040	.00011
Grooved end with Headwall (05 x .07 D)	.15067	.50311	-.12068	.02566	-.00189	.00005
Grooved end Projecting (.05 x .07 D)	-.03817	.84684	-.32139	.07550	-.00729	.00027

* coefficients for polynomial equations (see equations)

Table No. 10

Concrete Pipe-Arch Culverts (Variable Corner Radii)*

Span in	Rise in	Br in	TR in	CR in	B in	Y1 in	Y2 in
18.00	11.00	22.87	10.62	4.03	4.69	0.810	7.330
22.00	13.50	27.50	13.75	5.25	6.00	0.930	9.860
26.00	15.50	35.50	14.75	5.25	6.25	1.180	9.290
28.50	18.00	40.68	14.56	4.86	5.91	1.420	7.140
36.25	22.50	51.00	18.75	6.03	7.69	1.878	9.550
43.75	26.62	62.00	22.50	6.37	8.56	2.455	10.317
51.12	31.31	73.00	26.25	7.56	10.06	2.816	12.086
58.50	36.00	84.00	30.00	8.75	11.59	3.177	13.897
65.00	40.00	92.50	33.37	9.81	13.00	3.549	15.655
73.00	45.00	105.00	37.50	11.22	14.69	3.887	17.755
88.00	54.00	126.00	45.00	12.56	17.00	4.935	20.098
102.00	62.00	162.50	52.00	13.97	18.66	5.131	21.835
115.00	72.00	183.00	59.00	19.28	23.82	5.050	29.060
122.00	77.25	218.00	62.00	20.06	24.34	4.713	28.690
138.00	87.12	269.00	70.00	22.37	26.84	4.850	31.409
154.00	96.87	301.37	78.00	24.13	29.22	5.531	33.850
168.75	106.50	329.00	85.63	26.87	32.87	6.013	38.456

Table No. 11

Concrete Pipe-Arch Culverts (Variable Corner Radii)

SPAN in	RISE in	TOTAL AREA sq ft	TOTAL WP ft	Estimated "n"
18.00	11.00	1.092	3.886	.012
22.00	13.50	1.650	4.769	.012
26.00	15.50	2.206	5.558	.012
28.50	18.00	2.792	6.147	.012
36.25	22.50	4.424	7.863	.012
43.75	26.62	6.292	9.419	.012
51.12	31.31	8.657	11.033	.012
58.50	36.00	11.397	12.660	.012
65.00	40.00	14.067	14.069	.012
73.00	45.00	17.790	15.806	.012
88.00	54.00	25.686	19.028	.012
102.00	62.00	34.270	22.050	.012
115.00	72.00	45.142	25.109	.012
122.00	77.25	51.629	26.829	.012
138.00	87.12	66.002	30.389	.012
154.00	96.87	81.860	33.873	.012
168.75	106.50	98.560	37.796	.012

* Dimensions obtained from ASTM, Volume 16, 1981

Table No. 12

Concrete Pipe-Arch Culverts

Coefficients for Inlet Control Headwater Equations

Type of Inlet	A*	B	C	D	E	F
Sq. edge with 90^{o} headwall	.16884	.38783	-.03679	.01173	-.00066	.00002
Grooved end with headwall	.13010	.43477	-.07911	.01764	-.00114	.00002
Grooved end projecting	.09618	.52593	-.13504	.03394	-.00325	.00013

* Coefficients for polynomial equations (see equations)

Table No. 13

Hydraulic Constants for CM and Concrete Pipe-Arch, CM and Concrete Elliptical* Culverts

Estimated Manning's n		Entrance Loss Coefficients	
Multiplate-unpaved and paved	see tables	CM Pipe-Arch and elliptical projecting	k_e = 0.90
Helical-unpaved and paved	see limitations	CM Pipe-Arch and elliptical mitered	k_e = 0.70
Riveted or welded unpaved and paved	see tables	CMPA and CMPE with concrete headwall	k_e = 0.50
Concrete elliptical	n = .012	Conc. pipe-arch and elliptical with sq. edge and headwall	k_e = 0.50
Concrete pipe-arch	n = .012	Conc. pipe-arch and elliptical with grooved end with headwall	k_e = 0.20
		Conc. pipe-arch and elliptical with grooved end projecting	k_e = 0.20

Alpha Values	
CM pipe-arch and elliptical culverts	= 1.16
Concrete elliptical and pipe-arch culverts	= 1.05

* Horizontal long axis

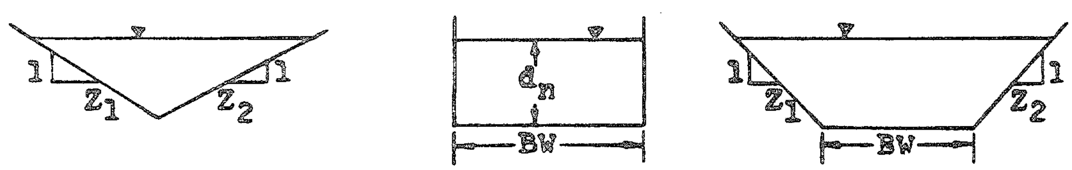
TI-59

PROGRAMS

PROGRAM #1 - NORMAL DEPTH (in channel, Tw) see limitations

The tailwater depth is required in calculating the performance of a culvert. This tailwater depth is used in determining the water surface elevation at the outlet of the culvert. One method of estimating this depth is to set it equal to the normal depth of the flow in the channel.

Program #1 calculates the normal depth of water flowing in a natural channel. For the program to operate, the channel cross section is assumed to be prismatic in shape. Depending upon the inputs, a triangular, rectangular, or trapezoidal section may be evaluated. These various shapes are dimensioned as follows:



triangular rectangular trapezoidal

Figure 2

EQUATIONS

$$Q = \frac{1.486\ AR^{.67}\ S_o^{.5}}{n}$$

$$A = d_n \left(BW + \frac{d_n}{2}(Z_1 + Z_2)\right)$$

$$WP = BW + d_n\left[(Z_1^2 + 1)^{.5} + (Z_2^2 + 1)^{.5}\right]$$

$$R = \frac{A}{WP}$$

$$V = Q/A$$

INSTRUCTIONS

#1 Load program #1

#2 Press Label A

#3 Enter: 1. n - Manning's roughness coefficient for the stream

2. S_o - Slope of natural channel

3. BW - Width of streambed

4. Z_1 - Horizontal distance for side slope

5. Z_2 - Horizontal distance for side slope

6. Q - Flow rate

#4 Read d_n - (TW) - Normal depth

V - Channel velocity

CARD FORMAT

1	TEXAS INSTRUMENTS	4
NORMAL DEPTH		#1
	Partitioning	479.59
START		

LISTING - PROGRAM #1 *

LBL INV RC* 8 OP 28 RTN LBL LNX SBR INV OP 1 SBR INV OP
2 SBR INV OP 3 SBR INV OP 4 ADV OP 5 RTN LBL A 6 X⪌T
1 STO 9 STO 07 1 1 STO 8 SBR LNX ADV 5 1 0 2 STO 0 RCL
0 OP 4 RCL 9 X=T 0 72 R/S OP 6 ST* 9 OP 29 OP 20 GTO 0
51 R/S OP 6 STO 6 FIX 4 CLR X⪌T RCL 7 X (RCL 3 + RCL 7
DIV 2 X (RCL 4 + RCL 5 = STO 0 DIV (RCL 3 + RCL 7 X
((RCL 4 X^2 + 1) SRX + (RCL 5 X^2 + 1) SRX = X^2 y^x 3
1/X X RCL 0 X RCL 2 SRX X 1 . 4 8 6 DIV RCL 1 - RCL 6 = EE
INV EE X=T 1 84 EXC 10 - RCL 10 = X=T 1 84 1/X X RCL 10 X
RCL 9 = STO 9 INV SUM 7 GTO 0 77 SBR LNX 2 1 3 7 FIX 2 OP
4 RCL 7 OP 6 SBR 0 13 2 1 6 3 3 6 OP 4 RCL 6 DIV RCL 0
= OP 6 INV FIX SBR LNX SBR LNX ADV 5 1 0 7 OP 04 1 5
STO 08 6 GTO 0 72 (237 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #1

11.	3132353013	20.	2732152437
12.	2700161733	21.	4500243600
13.	3723002000	22.	2132350032
14.	3322300002	23.	3723173500
15.	1523133131	24.	1624361523
16.	1727001617	25.	1335221736
17.	3337230624	26.	1731371735
18.	3600000000	27.	21273243
19.	1727004217	28.	3513371700
		29.	15213600

SPECIAL SYMBOLS

DIV - DIVIDE

SRX - SQUARE ROOT

*Refer to TI-59 user manual page IV-6 for symbol identification.

PROGRAM #2 - GEOMETRY AND APPROXIMATE CULVERT SIZE (AREA)

This program was developed in two parts:

Part I - used to compute the y1 and y2 values (see figure 3) which delineate the pipe-arch and elliptical shapes into three separate sections.

Part II - used to compute the approximate area for a culvert size based on site conditions (Q and AHW), then choose culvert size from table 2 or 5.

pipe-arch

ellipse

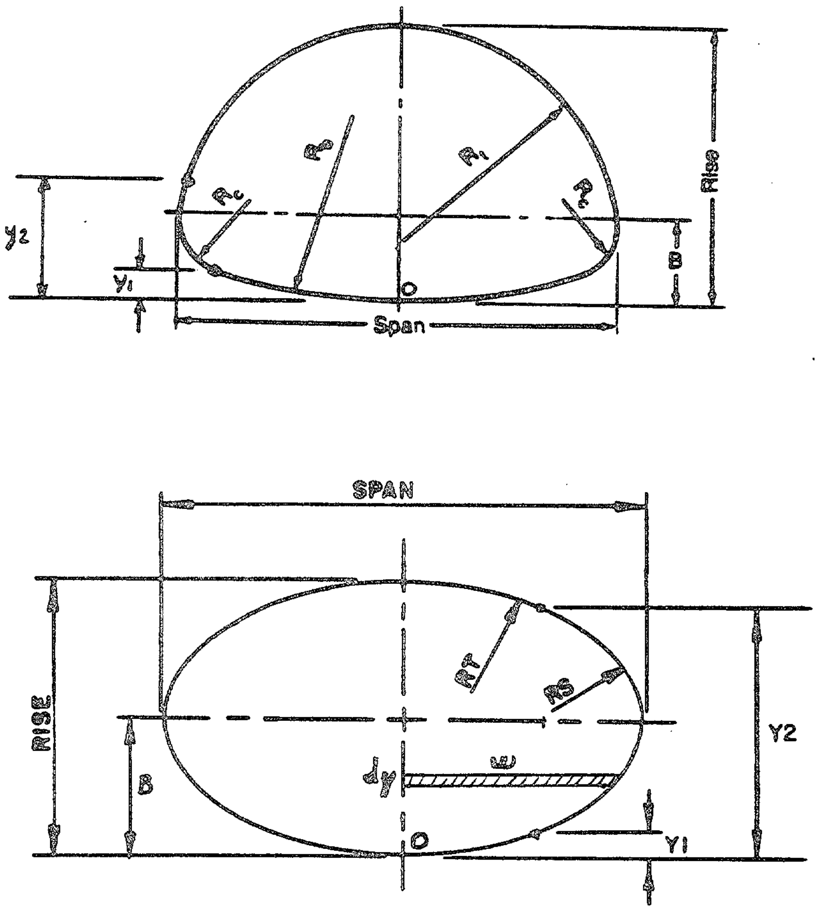


Figure 3

EQUATIONS:

for approximate area,

$$A = .785\ (Q/AHW)$$

Where A = approximate cross-sectional area in sq ft
Q = discharge in cfs
AHW = allowable headwater in ft

INSTRUCTIONS

1. Load program # 2

2. Press RST then R/S
Prints program title

3. Run Part I and/or Part II

To run Part I - which computes y_1 and y_2:

a. Press 2nd label A

b. Enter data, in inches, as listed (see tables)
The program stores the data in the proper register

Span	Press R/S
Rise	"
BR	"
TR	"
CR	"
B	"

To run Part II - which computes approximate culvert area:

a. Press 2nd label B

b. Enter data

Q	Press R/S
AHW	"

PROGRAM OUTPUT

Part I

a. Prints input data
b. Y_1 = ft

y_2 = ft

Part II
a. Prints input data
b. Approx. culvert area = sq ft

CARD FORMAT

1	TEXAS INSTRUMENTS	4
GEOMETRY AND APPROXIMATE CULVERT AREA		# 2
	Partitioning 479.59	
START		

DATA REGISTERS

19	1400000000
20	3324331720
21	1335152300
22	2217323017
23	3735450000
24	6400450200
25	6400450300
26	3633133100
27	3524361700
28	3735000000
29	1435000000
30	1535000000

LISTING

```
OP 00  RCL 20  OP 01  RCL 21  OP 02  0032350017  OP 03  2727243300  OP 04  OP 05
OP 00  RCL 22  OP 01  RCL 23  OP 02  OP 05  ADV  R/S  LBL A  OP 00  RCL 26  OP 04
R/S  STO 03  OP 06  RCL 27  OP 04  R/S  STO 06  OP 06  RCL 29  OP 04  R/S  STO 05
OP 06  RCL 28  OP 04  R/S  STO 07  OP 06  RCL 30  OP 04  R/S  STO 04  OP 06
RCL 19  OP 04  R/S  STO 08  OP 06  ADV  RCL 03  DIV  2  -  RCL 04  =  STO 10  DIV
( RCL 05  -  RCL 04 )  =  STO 02  RCL 10  DIV  ( RCL 08  -  ( RCL 06 - RCL 07 ) =
STO 09  RAD  INV  TAN  STO 12  1  -  ( RCL 02  X^2 )  =  SRX  1/X  X  RCL 02  =
INV  TAN  STO 11  COS  X  RCL 05 +/-  +  RCL 05  =  STO 13  RCL 24  OP 04  RCL 13
OP 06  RCL 12  COS  X  RCL 04  +  RCL 08  =  STO 14  RCL 25  OP 04  RCL 14  OP 06
R/S  LBL B  ADV  34 OP 04  R/S  STO  00  OP 06  132343  OP 04  R/S  STO 01  OP 06
OP 00  1333333532  OP 01  4400133517 OP 02  1300000000  OP 03  OP 05  OP 00
36342137 OP 04  RCL 01  1/X  X  RCL 00  X  0.785  =  OP 06  R/S
```

(300 program steps)

Program # 3 - UTILITY PROGRAM FOR AREA, WETTED PERIMETER , TOP WIDTH

This is a utility program to allow the user to compute the area, wetted perimeter and top width for a given water depth in a corrugated metal pipe-arch or elliptical shape culvert.

This routine has been incorporated in the hydraulic design routines for the convenience of performing the hydraulic analysis of pipe-arch or elliptical shape culverts.

EQUATIONS

The computations in this program are performed by an algorithm based on an integration procedure (see appendix A)

INSTRUCTIONS

1. Load Program # 3

2. Press RST and R/S
Sets up program to receive input data.

3. Enter data, in inches AS LISTED (see Tables)

a.	Span	Press R/S
b.	Rise	"
c.	BR	"
d.	TR	"
e.	CR	"
f.	B	"
g.	enter depth Press R/S	store in 01

To run any other depth:

a. store the depth (inches) in register 01
b. Press GTO GRAD
c. R/S

PROGRAM OUTPUT

1. Prints input data automatically

2.

Depth	ft
Area	sq ft
Wet. per.	ft
Top width	ft

LISTING

RCL 35 OP 04 R/S STO 03 OP 06 X≷T RCL 36 OP 04 R/S STO 06 OP 06 RCL
38 OP 04 R/S STO 05 OP 06 RCL 37 OP 04 R/S STO 07 OP 06 RCL 39 OP 04
R/S STO 04 OP 06 RCL 32 OP 04 R/S STO 08 OP 06 X≷T ADV DIV 2 - RCL 04
= STO 10 DIV (RCL 05 - RCL 04 = STO 02 RCL 10 DIV (RCL 08 - (
RCL 06 - RCL 07 = STO 09 RAD INV TAN STO 12 1 - (RCL 02 X^2 =
SRX 1/X X RCL 02 = INV TAN STO 11 COS X RCL 05 +/- + RCL 05 = STO 13
RCL 12 COS X RCL 04 + RCL 08 = STO 14 <u>LBL GRAD</u> ADV 0 STO 11 RCL 13 STO
12 X≷T RCL 01 X≥T A STO 12 X≷T RCL <u>LBL A'</u> RCL 05 X 2 = STO 18 STO 17
RCL 05 X^2 DIV 2 = STO 16 0 STO 15 SBR COS SRX DIV 6 = STO 19
0 STO 28 STO 10 STO 29 SBR TAN SBR NOP RCL 00 - RCL 02 = X 2 X
RCL 05 = SUM 29 RCL 13 X≷T RCL 01 X≥T D GTO B <u>LBL D</u> RCL 13 STO 11
RCL 14 STO 12 X≷T RCL 01 X≥T A STO 12 X≷T <u>LBL A</u> RCL 08 X 2 = STO 18
RCL 04 X^2 - (RCL 08 X^2 = STO 15 RCL 04 X^2 DIV 2 = STO 16 RCL
18 X^2 + 4 X RCL 15 = SRX STO 17 SBR COS SRX + RCL 03 DIV 2 - RCL
04 = DIV 6 = STO 19 SBR TAN RCL 12 - RCL 11 = X (RCL 03 DIV 2 -
RCL 04 = SUM 10 SBR NOP RCL 00 - RCL 02 = X 2 X RCL 04 = SUM 29
RCL 14 STO 11 X≷T RCL 01 STO 12 X≥T C GTO B <u>LBL C</u> RCL 12 X≷T 2 X (
RCL 06 - RCL 07 = STO 18 2 X RCL 06 X RCL 07 - RCL 06 X^2 = STO 15
RCL 07 X^2 DIV 2 = STO 16 RCL 18 X^2 + 4 X RCL 15 = SRX STO 17 SBR COS
SRX DIV 6 = STO 19 SBR TAN SBR NOP RCL 00 - RCL 02 = X 2 X RCL 07
= SUM 29 <u>LBL B</u> 161733 OP 04 RCL 01 DIV 12 = STO 01 OP 06 13351713 OP 04
RCL 10 DIV 144 X 2 = STO 10 OP 06 4333 OP 04 RCL 29 DIV 12 = STO 29
OP 06 373233 OP 04 RCL 19 OP 06 R/S <u>LBL NOP</u> RCL 11 X≷T X 2 - RCL 18 =
DIV RCL 17 = RAD INV SIN STO 00 X RCL 16 + (4 +/- 1/X X RCL 27 SRX X

LISTING (continued)

(2 +/- X RCL 12 + RCL 18 = SUM 10 X≷T X 2 - RCL 18 = DIV RCL 17 =
INV SIN STO 02 X RCL 16 + (4 +/- 1/X X RCL 28 SRX X (2 +/- RCL 11 +
RCL 18 = INV SUM 10 RTN LBL COS RCL 18 X RCL 12 + RCL 15 - (RCL 12
X^2 = ABSX STO 27 RTN LBL TAN RCL 11 X RCL 18 + RCL 15 - RCL 11 X^2
= STO 28 RTN (618 program steps)

CARD FORMAT

1	TEXAS INSTRUMENTS	4
UTILITY PROGRAM FOR AREA, WETTED PERIMETER, TOP WIDTH		# 3
	Partitioning 639.39	
START		

PROGRAM # 4 - NORMAL DEPTH IN THE CULVERT

This program is used to compute normal depth (d_n) and area at normal depth for a given pipe-arch or elliptical shape culvert. The d_n is required in the hydraulic analysis process for the inlet and outlet control routines.

The program computes d_n using an iteration routine with a starting depth equal to the Rise. Due to the iterative routine, the d_n computation takes about 6-7 minutes.

In the development of this program and because of the calculator storage capacity, the input data is not printed out automatically. The user must keep track of the input data.

EQUATIONS

Normal depth (d_n) is obtained by solving the following equation:

$$\frac{(Q)\ (n)}{1.486\ S^{1/2}} = \frac{A^{5/3}}{WP^{2/3}}$$

where

$A = f(d_n)$ see appendix A-1

$WP = f(d_n)$ see appendix A-1

Q = discharge in cfs

A = area in ft^2

WP = wetted perimeter in ft

S = culvert slope in ft/ft

d_n = normal depth in culvert by balancing above equation in ft

INSTRUCTIONS

1. Load program # 4

2. Press RST

3. Enter data as listed - user must store data in proper register

DATA	Storage REGISTER
Span (in)	03
CR (in)	04
BR (in)	05
Rise (in)	06
TR (in)	07
B (in)	08
y_1 (in)	13
y_2 (in)	14
Q (cfs)	21
n	22
Slope (ft/ft)	23

The program computes the starting depth for the user

4. Press R/S and wait for normal depth print out (5-6 minutes)
For performance curve development compute d_n for various
Q values

OUTPUT

1. Normal depth (d_n) in ft

2. Area based on d_n in sq ft

CARD FORMAT

1	TEXAS INSTRUMENTS	4
NORMAL DEPTH AND AREA IN CULVERT		# 4
		Partitioning 719.29
START		

LISTING

```
OP 00  3132353000 OP 01  1617333723 OP 02  OP 05  RCL 06  DIV 12  X  0.2  =  STO 20
RCL 06  DIV 12  =  STO 01  STF 01  SBR GRAD  LBL FIX  1.486  X  RCL 23  Y^X 0.5  =
1/X  X  RCL 22  X  RCL 21  =  X≷T  RCL 10  Y^X ( 5 DIV 3 )  DIV  RCL 29  Y^X  (  2
DIV 3 )  =  X=T  E  X≥T  CLR  IFF 01  STO  GTO  PI  LBL CLR  RCL 20  INV  SUM 01
INV  STF 01  SBR GRAD  GTO  FIX  LBL STO  GTO E  LBL PI  0.03  X≷T  RCL 20  X≥T
+  GTO E  LBL +  RCL 20  SUM 01  X  0.2  =  STO 20  GTO CLR  LBL E  OP 00  2137 OP 04
RCL 01  OP 06  ADV  OP 00  1335171300  OP 01  OP 05  213770  OP 04  RCL 10  OP 06
R/S  LBL GRAD  RCl 01  X  12  =  STO 01  RCL 03  DIV 2  -  RCL 04  =  STO 09  RCL 13
STO 12  0  STO 11  RCL 13  X≷T  RCL 01  X≥T  A'  STO 12  LBL A'  RCL 05  X  2  =
STO 18  STO 17  RCL 05  X^2  1/X  =  STO 16  RCL 12  X  RCL 18  -  RCL 12  X^2
=  STO 27  SRX  DIV 6  =  STO 19  0  STO 28  STO 10  STO 29  SBR NOP  RCL 00  -
RCL 02  =  X  2  X  RCL 05  =  SUM 29  RCL 13  X≷T  RCL 01  X≥T  D  GTO B  LBL D
RCL 14  STO 12  RCL 13  STO 11  RCL 14  X≷T  RCL 01  X≥T A  STO 12  LBL A  RCL 08
X 2  =  STO 18  RCL 04  X^2  - ( RCL 08 X^2)  =  STO 15  RCL 04  X^2  1/X  =
STO 16  ( RCL 18  X^2  - ( 4 X RCL 15 X ( 1 +/- )))  SRX  =  STO 17  RCL 18  X  RCL
12  +  RCL 15  - ( RCL 12  X^2 ) =  STO 27  SRX  +  RCL 09  =  DIV 6  =  STO 19
RCL 11  X  RCL 18  +  RCL 15  -  RCL 11  X^2  =  STO 28  RCL 09  =  X  RCL 12  -
(( RCL 09 ) X  RCL 11 )  =  SUM 10  SBR NOP  RCL 00  -  RCL 02  =  X  2  X RCL 04  =
SUM 29  RCL 14  X≷T  RCL 01  X≥T  C  GTO B  LBL C  RCL 01  STO 12  RCL 14  STO 11  2
X ( RCL 06  - RCL 07 )  =  STO 18  2 X ( RCL 06 X RCL 07 ) - ( RCL 06 X^2 )  = STO 15
RCL 07 X^2  1/X  STO 16 ( RCL 18 X^2  - ( 4 +/- X RCL 15 ))  SRX  STO 17  RCL 18
X RCL 12  +  RCL 15  - ( RCL 12  X^2 ) = STO 27  SRX  DIV 6 = STO 19  RCL 11  X
RCL 18  +  RCL 15  - ( RCL 11  X^2 ) = STO 28  SBR NOP  RCL 00  -  RCL 02  =  X 2 X
RCL 07 = SUM 29  LBL B  RCL 29  DIV 12 =  STO 29  RCL 10  DIV 144  X 2 = STO 10  RCL
01  DIV 12 = STO 01  RTN  LBL NOP  2 X RCL 12  - RCL 18 =  DIV RCL 17 =  RAD INV SIN
STO 00 ( 2 +/-  X RCL 12  + RCL 18 ) X ( RCL 27  SRX ) X ( .25 +/- ) +  1 DIV ( RCL
16  X 2 ) X RCL 00 =  SUM 10  2 X RCL 11  - RCL 18 = DIV RCL 17 = STO 02  INV SIN STO
02 ( 2 +/-  X RCL 11  + RCL 18 ) X ( RCL 28  SRX ) X ( .25 +/- ) +  1 DIV ( RCL 16 X
2 ) X  RCL 02  = INV SUM 10  RTN                          ( 709 PROGRAM STEPS )
```

PROGRAM # 5 - CRITICAL DEPTH

This program is used to compute critical depth (d_c) and area at critical depth for a given corrugated metal pipe-arch or elliptical shape culvert. The d_c is required in the hydraulic analysis procedure for the computation of outlet control headwater.

The program computes d_c using an iteration routine with a starting depth equal to (.98 x Rise). This program takes about 5-6 minutes to compute critical depth.

EQUATIONS

for critical depth, d_c

$$\frac{\text{alpha } Q^2}{g} = \frac{A^3}{T}$$

where:

$A = f(d_c)$ see appendix A-1

$T = f(d_c)$ see appendix A-1

Q = discharge, in cfs

Alpha = 1.16 for CM culverts

= 1.05 for concrete culverts

A = Area at critical depth, in sq ft

T = Top width, in ft

g = 32.2 ft/sec/sec

d_c = critical depth, when equation is balanced, in ft

INSTRUCTIONS

1. Load Program # 5

2. Press RST

3. Enter data as listed - user must store data in proper storage register

Data		Storage Register
Span	(in)	03
CR	"	04
BR	"	05
Rise	"	06
TR	"	07
B	"	08
y_1	"	13
y_2	"	14
Q	cfs	21
Alpha		22
g (32.2)		23

4. Press R/S and wait for critical depth print out (5-6 minutes) For performance curve development compute d_c for various Q values.

OUTPUT

1. Critical Depth

d_c = ft
Area = ft^2 (at critical depth)

Due to calculator capacity and program size the input data is not printed out automatically.

CARD FORMAT

1	TEXAS INSTRUMENTS	4
CRITICAL DEPTH		# 5
	Partitioning 719.29	
START		

LISTING

OP 00 1535243724 OP 01 1513270016 OP 02 1733372300 OP 03 OP 05 RCL 06 DIV 12
X .2 = STO 20 RCL 06 DIV 12 X .98 = STO 01 STF 01 SBR GRAD LBL FIX RCL 22 X
RCL 21 X^2 DIV RCL 23 = X≷T RCL 10 Y^x 3 DIV RCL 19 = X=T STO X≥T CLR IFF
01 STO STO 25 GTO PI LBL CLR STO 26 RCL 20 INV SUM 01 INV STF 01 SBR GRAD
GTO FIX LBL STO RCL 06 DIV 12 = STO 01 GTO E LBL PI .03 X≷T RCL 20 GE + GTO E
LBL + RCL 20 SUM 01 X .2 = STO 20 GTO CLR LBL E 2137 OP 04 RCL 01 OP 06 OP 00 ADV
13351713 OP 01 OP 05 213770 OP 04 RCL 10 OP 06 R/S LBL GRAD RCL 01 X
12 = STO 01 RCL 03 DIV 2 - RCL 04 = STO 09 RCL 13 STO 12 0 STO 11 RCL 13
X≷T RCL 01 X≥T A' STO 12 LBL A' RCL 05 X 2 = STO 18 STO 17 RCL 05 X^2
1/X = STO 16 RCL 12 X RCL 18 - RCL 12 X^2 = STO 27 SRX DIV 6 = STO 19
0 STO 28 STO 10 STO 29 SBR NOP RCL 00 - RCL 02 = X 2 X RCL 05 = SUM 29 RCL 13
X≷T RCL 01 X≥T D GTO B LBL D RCL 14 STO 12 RCL 13 STO 11 RCL 14 X≷T RCL 01
X≥T A STO 12 LBL A RCL 08 X 2 = STO 18 RCL 04 X^2 - (RCL 08 X^2) = STO 15
RCL 04 X^2 1/X = STO 16 (RCL 18 X^2 - (4 X RCL 15 X (1 +/-))) SRX = STO 17
RCL 18 X RCL 12 + RCL 15 - (RCL 12 X^2) = STO 27 $X^{.5}$ + RCL 09 = DIV 6 = STO
19 RCL 11 X RCL 18 + RCL 15 - RCL 11 X^2 = STO 28 RCL 09 = X RCL 12 - ((RCL 09)
X RCL 11) = SUM 10 SBR NOP RCL 00 - RCL 02 = X 2 X RCL 04 = SUM 29 RCL 14 X≷T
RCL 01 X≥T C GTO B LBL C RCL 01 STO 12 RCL 14 STO 11 2 X (RCL 06 - RCL 07)
= STO 18 2 X (RCL 06 X RCL 07) - (RCL 06 X^2) = STO 15 RCL 07 X^2 1/X STO 16
(RCL 18 X^2 - (4 +/- X RCL 15)) SRX STO 17 RCL 18 X RCL 12 + RCL 15 - (RCL
12 X^2) = STO 27 SRX DIV 6 = STO 19 RCL 11 X RCL 18 + RCL 15 - (RCL 11 X^2)
= STO 28 SBR NOP RCL 00 - RCL 02 = X 2 X RCL 07 = SUM 29 LBL B RCL 29 DIV 12 =
STO 29 RCL 10 DIV 144 X 2 = STO 10 RCL 01 DIV 12 = STO 01 RTN LBL NOP 2 X RCL 12
- RCL 18 = DIV RCL 17 = RAD INV SIN STO 00 (2 +/- X RCL 12 + RCL 18) X (RCL 27
SRX) X (.25 +/-) + 1 DIV (RCL 16 X 2) X RCL 00 = SUM 10 2 X RCL 11 - RCL 18
= DIV RCL 17 = STO 02 INV SIN STO 02 (2 +/- X RCL 11 + RCL 18) X (RCL 28 SRX)
X (.25 +/-) + 1 DIV (RCL 16 X 2) X RCL 02 = INV SUM 10 RTN

(713 PROGRAM STEPS)

PROGRAM # 6 INLET CONTROL HEADWATER

This program is used to analyze the inlet control conditions for a single barrel pipe-arch and elliptical shape culvert. The user enters a culvert size from tables based on a computed approximate area obtained from program #2 or a culvert the user wishes to review.

This program evaluates different inlet configurations (headwall, mitered, beveled, and projecting) as shown in the INSTRUCTIONS section. The HW is computed in terms of elevation.

Because of the calculator's limited capacity, the inlet control computation was divided into seven separate subprograms.

Program 6A is used to evaluate the 18 inch or less CR CM pipe-arch culverts.
Program 6B is used to evaluate the 31 inch CR CM pipe-arch.culverts.
Program 6C is used to evaluate the 47 inch CR CM pipe-arch.culverts.
Program 6D is used to evaluate the CM pipe-elliptical culverts.
Program 6E is used to evaluate the concrete pipe-elliptical (oval) culverts.
Program 6F is used to evaluate the concrete pipe-arch culverts.
Program 6G is used to evaluate the aluminum pipe-arch culverts.

The headwater calculations for each pipe group are based on the polynomial equations developed from the best available research information.

The coefficients for the equations are shown in tables and have been incorporated into each program. Reference no. 6 (HEC no. 5) presents the hydraulic concepts for culverts flowing with inlet control. Figure C-1 shows the inlet control conditions accounted for in this program.

EQUATIONS

$$HW = (Rise)(Y) + \text{inlet invert elevation}$$

where $Y = A + Bx + Cx^2 + Dx^3 + Ex^4 + Fx^5 - (SCORR)(S)$
HW = headwater elevation in feet
Rise = height of pipe in inches
A,B,C,D,E,F = coefficients in Tables 3,6, 9 and 12

$$x = \frac{Q}{(SPAN)\ (RISE^{3/2})}$$

where Q = discharge in cfs
SPAN = horizontal dimension of pipe in inches
S = slope of pipe in ft/ft
SCORR = slope correction factor

PROGRAM # 6A, 6B, 6C, 6D, 6E, 6F and 6G INSTRUCTIONS

1. Read appropriate program: # 6A, 6B, 6C, 6D, 6E, 6F or 6G

2. Press RST, R/S
   Prints the program title and initializes program to receive input data

3. Enter data as listed

			Register
a. Q	(cfs)	Press R/S	(10)
b. Slope	(ft/ft)	" "	(14)
c. Span	(in)	" "	(03)
d. Rise	(in)	" "	(06)
e. d_n	(ft) (program # 3)	" "	(01)
f. Area(d_n)(sq ft)(program # 3)		" "	(00)
g. inlet invert elevation (ft)		" "	(05)

4. For Hydraulic Model No's* 126, 91, or 21 (inlet type and shape)

Program 6A - CM pipe-arch

	Inlet type	Press Key
18 inch or less CR	Projecting	2nd LBL B
18 inch or less CR	Mitered	2nd LBL C
18 inch or less CR	Headwall	2nd LBL D

Program 6B - CM pipe-arch

31 inch CR	Projecting	2nd LBL B
31 inch CR	Mitered	2nd LBL C
31 inch CR	Headwall	2nd LBL D

Program 6C - CM pipe-arch

47 inch CR	Projecting	2nd LBL B
47 inch CR	Mitered	2nd LBL C
47 inch CR	Headwall	2nd LBL D

Program 6D

CM elliptical	Thin edge proj.	2nd LBL B
CM elliptical	Headwall	2nd LBL C
CM elliptical	Mitered	2nd LBL D
CM elliptical	Beveled	2nd LBL E

Program 6E

Conc. elliptical (oval)	Grooved end projecting	2nd LBL B
Conc. elliptical (oval)	Square edge with headwall	2nd LBL C
Conc. elliptical (oval)	Grooved end with headwall	2nd LBL D

(continued)

* see reference no. 2

Program 6F

	Inlet type	Press key
Concrete pipe-arch	Grooved end projecting	2nd LBL B
Concrete pipe-arch	Sq. edge with headwall	2nd LBL C
Concrete pipe-arch	Groved end with headwall	2nd LBL D

Program 6G

31.8 CR ALUM	Projecting	2nd LBL B
31.8 CR ALUM	Mitered	2nd LBL C
31.8 CR ALUM	Headwall	2nd LBL D

PROGRAM # 6A, 6B, 6C, 6D, 6E, 6F, and 6G INLET CONTROL HEADWATER

OUTPUT

HW elevation	ft
Velocity	ft/sec
Span	inch
Rise	inch
Q	cfs

Performance curves

To develop an inlet control performance curve, enter a "Q" into register (10), d_n into register (01) and area (for d_n) into register (00) and press the appropriate B, C, D or E key and repeat for as many. discharges as required.

CARD FORMAT

1	TEXAS INSTRUMENTS	4
INLET CONTROL HEADWATER		# 6
	Partitioning 559.49	
START		

PROGRAM # 6A LISTING - Inlet Control Headwater (CMP 18" or less CR)

ADV OP 00 RCL 17 OP 01 RCL 18 OP 02 RCL 19 OP 03 OP 05 OP 00 R/S STO 10
PRT R/S STO 14 PRT R/S STO 03 PRT R/S STO 06 PRT R/S STO 01 PRT R/S
STO 00 PRT R/S STO 05 PRT R/S LBL A RCL 03 DIV 12 X (RCL 06 DIV 12) Y^X
1.5 = 1/X X RCL 10 = STO 02 234300 OP 04 RCL 20 + (RCL 21 + (RCL 22
+(RCL 23 + (RCL 24 + RCL 25 X RCL 02) X RCL 02) X RCL 02) X RCL 02)
X RCL 02 - RCL 13 X RCL 14 = X (RCL 06 DIV 12) = + RCL 05 = STO 04 OP 06
OP 00 421727 OP 04 RCL 10 DIV RCL 00 = OP 06 36331331 OP 04 RCL 03 OP 06
35243617 OP 04 RCL 06 OP 06 34000000 OP 04 RCL 10 OP 06 R/S LBL B
ADV 0211002431 OP 01 0032350027 OP 02 1736360015 OP 03 3500000000 OP 04
OP 05 OP 00 3335322517 OP 02 1537243122 OP 03 OP 05 ADV RCL 32 STO 20
RCL 33 STO 21 RCL 34 STO 22 RCL 35 STO 23 RCL 36 STO 24 RCL 37 STO 25
0.5 STO 13 GTO A LBL C ADV 0211002431 OP 01 0015350030 OP 02 2437173517
OP 03 1600000000 OP 04 OP 05 ADV RCL 38 STO 20 RCL 39 STO 21 RCL 40
STO 22 RCL 41 STO 23 RCL 42 STO 24 RCL 43 STO 25 0.0 STO 13 GTO A
LBL D ADV 0211002431 OP 01 0015350000 OP 02 2317131643 OP 03 1327270000
OP 04 OP 05 ADV RCL 44 STO 20 RCL 45 STO 21 RCL 46 STO 22 RCL 47
STO 23 RCL 48 STO 24 RCL 49 STO 25 0.5 STO 13 GTO A

(486 PROGRAM STEPS)

note: see data registers. page 53

PROGRAM # 6B LISTING - Inlet Control Headwater (CMP 31" CR)

ADV OP 00 RCL 17 OP 01 RCL 18 OP 02 RCL 19 OP 03 OP 05 OP 00 R/S STO 10 PRT R/S STO 14 PRT R/S STO 03 PRT R/S STO 06 PRT R/S STO 01 PRT R/S STO 00 PRT R/S STO 05 PRT R/S LBL A RCL 03 DIV 12 X (RCL 06 DIV 12) y^x 1.5 = 1/X X RCL 10 = STO 02 234300 OP 04 RCL 20 + (RCL 21 + (RCL 22 + (RCL 23 + (RCL 24 + RCL 25 X RCL 02) X RCL 02) X RCL 02) X RCL 02) X RCL 02 - RCL 13 X RCL 14 = X (RCL 06 DIV 12) = + RCL 05 = STO 04 OP 06 OP 00 421727 OP 04 RCL 10 DIV RCL 00 = OP 06 36331331 OP 04 RCL 03 OP 06 35243617 OP 04 RCL 06 OP 06 34000000 OP 04 RCL 10 OP 06 R/S LBL B ADV 0402002431 OP 01 0015350000 OP 02 3335322517 OP 03 1537243122 OP 04 OP 05 OP 00 ADV RCL 32 STO 20 RCL 33 STO 21 RCL 34 STO 22 RCL 35 STO 23 RCL 36 STO 24 RCL 37 STO 25 0.5 STO 13 GTO A LBL C ADV 0402002431 OP 01 0015350030 OP 02 2437173517 OP 03 1600000000 OP 04 OP 05 ADV RCL 38 STO 20 RCL 39 STO 21 RCL 40 STO 22 RCL 41 STO 23 RCL 42 STO 24 RCL 43 STO 25 0 STO 13 GTO A LBL D ADV 0402002431 OP 01 0015350000 OP 02 2317131643 OP 03 1327270000 OP 04 OP 05 ADV RCL 44 STO 20 RCL 45 STO 21 RCL 46 STO 22 RCL 47 STO 23 RCL 48 STO 24 RCL 49 STO 25 0.5 STO 13 GTO A

(460 PROGRAM STEPS)

note: see data registers, page 53

PROGRAM # 6C LISTING - Inlet Control Headwater (CMP 47" CR)

ADV OP 00 RCL 17 OP 01 RCL 18 OP 02 RCL 19 OP 03 OP 05 OP 00 R/S STO 10 PRT R/S STO 14 PRT R/S STO 03 PRT R/S STO 06 PRT R/S STO 01 PRT R/S STO 00 PRT R/S STO 05 PRT R/S LBL A RCL 03 DIV 12 X (RCL 06 DIV 12) y^x 1.5 = 1/X X RCL 10 = STO 02 234300 OP 04 RCL 20 + (RCL 21 + (RCL 22 + (RCL 23 + (RCL 24 + RCL 25 X RCL 02) X RCL 02) X RCL 02) X RCL 02) X RCL 02 - RCL 13 X RCL 14 = X (RCL 06 DIV 12) = + RCL 05 = STO 04 OP 06 OP 00 421727 OP 04 RCL 10 DIV RCL 00 = OP 06 36331331 OP 04 RCL 03 OP 06 35243617 OP 04 RCL 06 OP 06 34000000 OP 04 RCL 10 OP 06 R/S LBL B ADV 0510002431 OP 01 0015350000 OP 02 3335322517 OP 03 1537243122 OP 04 OP 05 OP 00 ADV RCL 32 STO 20CL 33 STO 21 RCL 34 STO 22 RCL 35 STO 23 RCL 36 STO 24 RCL 37 STO 25 .5 STO 13 GTO A LBL C ADV 0510002431 OP 01 0015350030 OP 02 2437173517 OP 03 1600000000 OP 04 OP 05 ADV RCL 38 STO 20 RCL 39 STO 21 RCL 40 STO 22 RCL 41 STO 23 RCL 42 STO 24 RCL 43 STO 25 0 STO 13 GTO A LBL D ADV 0510002431 OP 01 0015350000 OP 02 2317131643 OP 03 132727000 OP 04 OP 05 ADV RCL 44 STO 20 RCL 45 STO 21 RCL 46 STO 22 RCL 47 STO 23 RCL 48 STO 24 RCL 49 STO 25 0.5 STO 13 GTO A

(460 PROGRAM STEPS)

note: see data registers, page 53

PROGRAM #6D LISTING - CM Elliptical shape culverts

ADV OP 00 RCL 17 OP 01 RCL 18 OP 02 RCL 19 OP 03 OP 05 OP 00 R/S STO 10
PRT R/S STO 14 PRT R/S STO 03 PRT R/S STO 06 PRT R/S STO 01 PRT R/S STO 00 PRT
R/S STO 05 PRT R/S <u>LBL A</u> RCL 03 DIV 12 X (RCL 06 DIV 12) Y^X 1.5 = 1/X X
RCL 10 STO 02 234300 OP 04 RCL 20 + (RCL 21 + (RCL 22 + (RCL 23 + (RCL 24 +
RCL 25 X RCL 02) X RCL 02) X RCL 02) X RCL 02) X RCL 02 = X (RCL 06 DIV 12)
= + RCL 05 STO 04 OP 06 OP 00 421727 OP 04 RCL 10 DIV RCL 00 = OP 06 36331331
OP 04 RCL 03 OP 06 35243617 OP 04 RCL 06 OP 06 34000000 OP 04 RCL 10 OP 06
R/S <u>LBL B</u> ADV 1727272433 OP 01 3724151327 OP 02 0037232431 OP 03 0017162217 OP 04
OP 05 OP 00 3335322517 OP 02 1537243122 OP 03 OP 05 ADV RCL 32 STO 20 RCL 33
STO 21 RCL 34 STO 22 RCL 35 STO 23 RCL 36 STO 24 RCL 37 STO 25 GTO A <u>LBL C</u>
ADV 1727272433 OP 01 3724151327 OP 02 0023171316 OP 03 4313272700 OP 04 OP 05
ADV RCL 38 STO 20 RCL 39 STO 21 RCL 40 STO 22 RCL 41 STO 23 RCL 42 STO 24 RCL
43 STO 25 0 STO 13 GTO A <u>LBL D</u> ADV 1727272433 OP 01 3724151327 OP 02 0030243717
OP 03 3517160000 OP 04 OP 05 ADV RCL 44 STO 20 RCL 45 STO 21 RCL 46 STO 22
RCL 47 STO 23 RCL 48 STO 24 RCL 49 STO 25 GTO A <u>LBL E</u> ADV 1727272433 OP 01
3724151327 OP 02 0014174217 OP 03 2717160000 OP 04 OP 05 ADV RCL 26 STO 20
RCL 27 STO 21 RCL 28 STO 22 RCL 29 STO 23 RCL 30 STO 24 RCL 31 STO 25 GTO A

(552 PROGRAM STEPS)

note: see data registers, page 53

PROGRAM #6E LISTING - Concrete elliptical (oval) shape culverts

ADV OP 00 RCL 17 OP 01 RCL 18 OP 02 RCL 19 OP 03 OP 05 OP 00 R/S STO 10 PRT R/S STO 14 PRT R/S STO 03 PRT R/S STO 06 PRT R/S STO 01 PRT R/S STO 00 PRT R/S STO 05 PRT R/S LBL A RCL 03 DIV 12 X (RCL 06 DIV 12) Y^X 1.5 = 1/X X RCL 10 = STO 02 34300 OP 04 RCL 20 + (RCL 21 + (RCL 22 + (RCL 23 + (RCL 24 + RCL 25 X RCL 02) X RCL 02) X RCL 02) X RCL 02) X RCL 02 = X (RCL 06 DIV 12) = + RCL 05 = STO 04 OP 06 OP 00 421727 OP 04 RCL 10 DIV RCL 00 = OP 06 36331331 OP 04 RCL 03 OP 06 5243617 OP 04 RCL 06 OP 06 34000000 OP 04 RCL 10 OP 06 R/S LBL B ADV 3242132700 OP 01 4324372300 OP 02 2235324217 OP 03 1600173116 OP 04 OP 05 OP 00 3335322517 OP 03 1537243122 OP 04 OP 05 ADV RCL 32 STO 20 RCL 33 STO 21 RCL 34 STO 22 RCL 35 STO 23 RCL 36 STO 24 RCL 37 STO 25 GTO A LBL C ADV 3242132700 OP 01 3634001716 OP 02 2217004324 OP 03 3723000000 OP 04 OP 05 OP 00 231713 OP 03 1643132727 OP 04 OP 05 ADV RCL 38 STO 20 RCL 39 STO 21 RCL 40 STO 22 RCL 41 STO 23 RCL 42 STO 24 RCL 43 STO 25 0 STO 13 GTO A LBL D ADV 3242132700 OP 01 2235324217 OP 02 1600173116 OP 03 0043243723 OP 04 OP 05 OP 00 231713 OP 03 1643132727 OP 04 OP 05 ADV RCL 44 STO 20 RCL 45 STO 21 RCL 46 STO 22 RCL 47 STO 23 RCL 48 STO 24 RCL 49 STO 25 GTO A (521 PROGRAM STEPS)

note: see data registers, page 53

PROGRAM # 6F LISTING - Inlet Control Headwater - Concrete pipe-arch culverts

ADV OP 00 RCL 17 OP 01 RCL 18 OP 02 RCL 19 OP 03 OP 05 OP 00 R/S STO 10 PRT R/S STO 14 PRT R/S STO 03 PRT R/S STO 06 PRT R/S STO 01 PRT R/S STO 00 PRT R/S STO 05 PRT R/S LBL A RCL 03 DIV 12 X (RCL 06 DIV 12) Y^X 1.5 = 1/X X RCL 10 = STO 02 34300 OP 04 RCL 20 + (RCL 21 + (RCL 22 + (RCL 23 + (RCL 24 + RCL 25 X RCL 02) X RCL 02) X RCL 02) X RCL 02) X RCL 02 = X (RCL 06 DIV 12) = + RCL 05 = STO 04 OP 06 OP 00 421727 OP 04 RCL 10 DIV RCL 00 = OP 06 36331331 OP 04 RCL 03 OP 06 35243617 OP 04 RCL 06 OP 06 34000000 OP 04 RCL 10 OP 06 R/S LBL B ADV 0015331300 OP 01 4324372300 OP 02 2235324217 OP 03 1600173116 OP 04 OP 05 OP 00 3335322517 OP 03 1537243122 OP 04 OP 05 ADV RCL 32 STO 20 RCL 33 STO 21 RCL 34 STO 22 RCL 35 STO 23 RCL 36 STO 24 RCL 37 STO 25 GTO A LBL C ADV 0015331300 OP 01 3634001716 OP 02 2217004324 OP 03 3723000000 OP 04 OP 05 OP 00 231713 OP 03 1643132727 OP 04 OP 05 ADV RCL 38 STO 20 RCL 39 STO 21 RCL 40 STO 22 RCL 41 STO 23 RCL 42 STO 24 RCL 43 STO 25 0 STO 13 GTO A LBL D ADV 0015331300 OP 01 2235324217 OP 02 1600173116 OP 03 0043243723 OP 04 OP 05 OP 00 231713 OP 03 1643132727 OP 04 OP 05 ADV RCL 44 STO 20 RCL 45 STO 21 RCL 46 STO 22 RCL 47 STO 23 RCL 48 STO 24 RCL 49 STO 25 GTO A (521 PROGRAM STEPS)

note: see data registers, page 53

PROGRAM # 6G LISTING - Inlet Control Headwater - Aluminum pipe-arch culverts

ADV OP 00 RCL 17 OP 01 RCL 18 OP 02 RCL 19 OP 03 OP 05 OP 00 R/S STO 10 PRT R/S STO 14 PRT R/S STO 03 PRT R/S STO 06 PRT R/S STO 01 PRT R/S STO 00 PRT R/S STO 05 PRT R/S LBL A RCL 03 DIV 12 X (RCL 06 DIV 12) Y^X 1.5 = 1/X X RCL 10 = STO 02 34300 OP 04 RCL 20 + (RCL 21 + (RCL 22 + (RCL 23 + (RCL 24 + RCL 25 X RCL 02) X RCL 02) X RCL 02) X RCL 02) X RCL 02 = X (RCL 06 DIV 12) = + RCL 05 = STO 04 OP 06 OP 00 421727 OP 04 RCL 10 DIV RCL 00 = OP 06 36331331 OP 04 RCL 03 OP 06 35243617 OP 04 RCL 06 OP 06 34000000 OP 04 RCL 10 OP 06 R/S LBL B ADV 0402401100 OP 01 2431001535 OP 02 0013274130 OP 03 2431413000 OP 04 OP 05 OP 00 3335322517 OP 03 1537243122 OP 04 OP 05 ADV RCL 32 STO 20 RCL 33 STO 21 RCL 34 STO 22 RCL 35 STO 23 RCL 36 STO 24 RCL 37 STO 25 GTO A LBL C ADV 0402401100 OP 01 2431001535 OP 02 0013274130 OP 03 2431413000 OP 04 OP 05 OP 00 302437 OP 03 1735171600 OP 04 OP 05 ADV RCL 38 STO 20 RCL 39 STO 21 RCL 40 STO 22 RCL 41 STO 23 RCL 42 STO 24 RCL 43 STO 25 0 STO 13 GTO A LBL D ADV 0402401100 OP 01 2431001535 OP 02 0013274130 OP 03 2431413000 OP 04 OP 05 OP 00 231713 OP 03 1643132727 OP 04 OP 05 ADV RCL 44 STO 20 RCL 45 STO 21 RCL 46 STO 22 RCL 47 STO 23 RCL 48 STO 24 RCL 49 STO 25 GTO A (521 PROGRAM STEPS)

note: see data registers, page 53

DATA REGISTERS - PROGRAM # 6A, 6B, 6C, 6D, 6E, 6F, and 6G

Register no.	Program 6A	Program 6B	Program 6C
17	2431271737 (all seven programs)		
18	8015323137 (all seven programs)		
19	3532270000 (all seven programs)		
32	.08905	.12263	.14168
33	.71255	.48250	.49323
34	-.27092	-.00002	-.03235
35	.07925	-.04287	-.02098
36	-.00798	.01454	.00989
37	.00029	-.00117	-.00086
38	.08330	.10620	.23645
39	.79514	.70370	.37198
40	-.43408	-.35310	-.04010
41	.16377	.13740	.03058
42	-.02491	-.02076	-.00576
43	.00141	.00117	.00045
44	.11128	.12346	.09728
45	.61058	.50432	.57515
46	-.19494	-.13261	-.15977
47	.05129	.04020	.04223
48	-.00481	-.00448	-.00374
49	.00017	.00021	.00012

Register no.	Program 6D	Program 6E	Program 6F	Program 6G
26	-.00321			
27	.92178			
28	-.43903			
29	.12551			
30	-.01553			
31	.00073			
32	.08510	-.03817	.09618	.09[illegible]19
33	.70623	.84684	.52593	.65[illegible]32
34	-.18025	-.32139	-.13504	-.19423
35	.01963	.07550	.03394	.04476
36	.00402	-.00729	-.00325	-.00176
37	-.00052	.00027	.00013	-.00012
38	.01267	.13432	.16884	.10212
39	.79435	.55921	.38783	.72503
40	-.29440	-.15780	-.03679	-.34558
41	.07114	.03967	.01173	.12454
42	-.00612	-.00040	-.00066	-.01676
43	.00015	.00011	.00002	.00081
44	-.14029	.15067	.13010	.09455
45	1.43700	.50311	.43477	.61669
46	-.92636	-.12068	-.07911	-.22431
47	.32502	.02566	.01764	.07407
48	-.04865	-.00189	-.00114	-.01002
49	.00270	.00005	.00002	.00054

PROGRAM # 7 - OUTLET CONTROL HEADWATER

This program is used for the outlet control evaluation of single barrel pipe-arch and elliptical shape culverts for full flow conditions. If a full flow or "Inlet Control Governs" does not exist, the program directs the user to perform a backwater curve (M1 or M2) for the outlet control headwater (HW) computation. Reference no. 6 (HEC no. 5) presents the hydraulic concepts for culverts flowing in outlet control. Figure C-2 shows the outlet control conditions accounted for in this program.

EQUATIONS

Head loss:

$$H = \left[1+k_e+ \frac{(29.132)\ (n^2)\ (L)}{(A/WP)^{4/3}}\right] \left[\frac{Q^2}{64.31\ (A^2)}\right]$$

where
- A = f(y) see appendix A-1
- WP = f(y) see appendix A-1
- H = head for pipe-arch culverts flowing full, in ft
- k_e = coefficient for entrance loss
- n = Manning 's roughness factor
- L = length of pipe in ft
- A = total cross-section area in sq ft
- WP = total wetted perimeter in ft
- Q = discharge in cfs

Critical depth:

see program # 4

Headwater:

$$HW = Temp + H + \text{Elevation outlet invert}$$

$Temp = Rise$ if $d_c = Rise$ and $Rise > TW$

$Temp = (d_c + Rise)/2$ if $d_c < Rise$ and $(d_c + Rise)/2 > Tw$

$Temp = TW$ if $TW > Rise$ or $TW > (d_c + Rise)/2$

where
- Rise = vertical dimension of pipe-arch, in ft
- TW = tailwater depth at outlet, in ft
- HW = headwater, in ft
- H = head for full flow, in ft
- L = length of pipe, in ft
- S = slope of pipe, in ft/ft

EQUATIONS (continued)

Test for full flow:

$$Temp = Whw - (1 + k_e)\, V^2/2g$$

where Temp = temporary value that represents a culvert height
Whw = working headwater, in ft
k_e = coefficient for entrance loss
V = mean velocity for full barrel, in ft/sec

Backwater:

(water surface profiles in barrel see programs 8 and 9)

INSTRUCTIONS

1. Load Program # 7
Press RST , then R/S
Prints program title and pause

2. Enter input data - prints as read in

		(Register)
a. Span (in) tables	Press R/S	(03)
b. Rise (in) "	"	(06)
c. d_n (ft) program no 4	"	(09)
d. d_c (ft) program no 5	"	(11)
e. area at d_c depth program 3	"	(12)
f. Total area (sq ft) tables	"	(10)
g. Total WP (ft) tables	"	(29)
h. Q (cfs)	"	(20)
i. Ke tables	"	(21)
j. n tables	"	(22)
k. Slope (ft/ft)	"	(23)
l. Length (ft)	"	(24)
m. Tw (ft) program no 1	"	(25)
n. area at TW depth program 3	"	(04)
o. elevation outlet invert	"	(05)

3. Press R/S

OUTPUT

1. Head in feet

2. Headwater (HW) elevation will be based on either of the following which will be printed as output:

a. Full flow HW elevation in feet
Span = in
Rise = in
HWEL = ft
Vel = ft/sec

b. "Inlet Control Gov "
c. Do a backwater profile for M1 curve, program no 8

d. Do a backwater profile for M2 curve. program no 9

CARD FORMAT

1	TEXAS INSTRUMENTS	4
OUTLET CONTROL HEADWATER		# 7
	Partitioning 719.29	
START		

LISTING - PROGRAM # 7

OP 00 RCL 18 OP 01 RCL 26 OP 02 RCL 27 OP 03 2343 OP 04 OP 05 ADV OP 00
36331331 OP 04 R/S STO 03 OP 06 35243617 OP 04 R/S STO 06 OP 06 1631 OP 04
R/S STO 09 OP 06 1615 OP 04 R/S STO 11 OP 06 16150013 OP 04 R/S STO 12
OP 06 13351713 OP 04 R/S STO 10 OP 06 4333 OP 04 R/S STO 29 OP 06 34 OP 04
R/S STO 20 OP 06 2617 OP 04 R/S STO 21 OP 06 31 OP 04 R/S STO 22 OP 06
3627 OP 04 R/S STO 23 OP 06 27 OP 04 R/S STO 24 OP 06 3743 OP 04 R/S
STO 25 OP 06 37430013 OP 04 R/S STO 04 OP 06 17271742 OP 04 R/S STO 05
OP 06 R/S RCL 06 STO 01 RCL 20 x^2 DIV RCL 10 X^2 DIV 64.3 = STO 15
RCL 10 DIV RCL 29 = Y^X (4 DIV 3) = 1/X X RCL 24 X RCL 22 X^2 X 29.132
+ RCL 21 +1 = X RCL 15 = STO 16 ADV 23171316 OP 04 RCL 16 OP 06 ADV RCL 25
X≷T RCL 06 DIV 12 + RCL 11 = DIV 2 = X≥T B' X≷T LBL B' + RCL 16 = STO
17 X≷T 0 X≥T D' X≷T - (1 + RCL 21) X RCL 15 = - RCL 06 DIV 12 = X≷T
0 X≥T D' OP 00 2141272700 OP 01 2127324300 OP 02 OP 05 36331331 OP 04 RCL 03
OP 06 35243617 OP 04 RC1 06 OP 06 OP 00 2343001727 OP 04 RCL 17 + RCL 05 =
OP 06 421727 OP 04 RCL 06 DIV 12 = X≷T RCL 25 X≥T A RCL 11 X≥T A X≷T
RCL 25 INV X≥T B RCL 20 DIV RCL 04 = OP 06 R/S LBL A RCL 20 DIV RCL 10
= OP 06 R/S LBL B RCL 12 1/X X RCL 20 = OP 06 R/S LBL D' RCL 11 X≷T
RCL 09 X≥T C' OP 00 RCL 08 OP 01 RCL 07 OP 02 RCL 13 OP 03 OP 05 R/S
LBL C' OP 00 RCL 00 OP 01 RCL 02 OP 02 RCL 19 OP 03 OP 05 RCL 25 X≷T
RCL 11 X≥T E RCL 09 X≥T E' STF 01 GTO E' LBL E OP 00 1617330064 OP 01
0016150000 OP 02 OP 05 OP 00 3003 OP 04 RCL 11 OP 06 R/S LBL E' OP 00
1617330064 OP 01 0037430000 OP 02 OP 05 IFF 01 SUM OP 00 3003 OP 04 RCL 25
OP 06 R/S LBL SUM OP 00 3002 OP 04 RCL 25 OP 06 INV STF 01 R/S

(640 PROGRAM STEPS)

DATA REGISTERS

18 3241372717
26 3700153231
27 3735322700

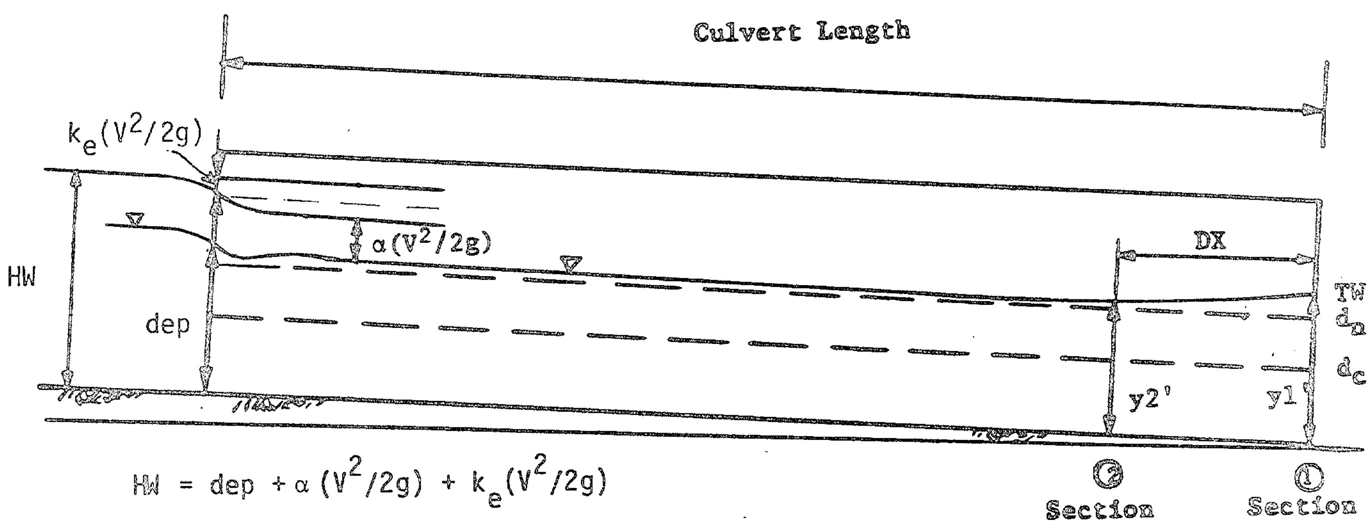
PROGRAM # 8 BACKWATER PROFILES - M1 CURVE

This program is a supplement to program no. 7 which determines outlet control conditions. This program is used to perform a water surface profile in a pipe-arch and elliptical shape culverts for an M1 curve.

The backwater profile starts with a depth equal to the tailwater (TW) at the outlet and decreases in depth as the profile extends into the barrel for an M1 curve and approaches normal depth (d_n) in the barrel, if possible. If normal depth is attained in the barrel then the headwater elevation is computed by the HW equation based on d_n, plus the inlet invert elevation and the outlet velocity is a function of the area at dn. If the profile extends outside the barrel inlet then the HW elevation will be computed based on the last depth used while the profile was still in the barrel and velocity is based on the TW depth. If the water surface touches the top of the culvert, then the HW elevation is computed by using the equations for full flow in program # 7.

Due to TI-59 calculator limitations, the alpha values have to be interchanged in the program depending on the culvert material used. See note at bottom of page 54.

The following diagram shows the M1 curve backwater concept.



Water Surface Profile (M1 Curve) - Starting Depth = TW

EQUATIONS

For $TW > d_n$: use M1 curve

$$X1 = \frac{[\, d_1 + V_1^2 / 2g] - [\, d_2 + V_2^2 / 2g \,]}{S_o - S}$$

where $X1$ = distance (ft) between cross sections 1 and 2 in the barrel

d_1 and d_2 = water depths for cross sections 1 and 2

S_o = slope of pipe in ft/ft

S = average slope of water surface in ft/ft

$= n^2 V^2 / 2.21 R^{4/3}$

$g = 32.2$ ft/sec^2

n = roughness factor

V = average velocity between sections 1 and 2

R = average hydraulic radius for sections 1 and 2

Headwater:

$$Hw = d_1 + V_1^2/2g + K_e V_1^2/2g$$

where Hw = headwater in ft

K_e = entrance loss coefficient

d_1 = depth (ft) previous section

V_1 = velocity (ft/sec) at previous section

INSTRUCTIONS

1. Enter program # 8 and press RST

2. Enter data as LISTED (user inputs data directly into register location)

Variable	Register
Span (in) table no 1	03
CR " "	04
BR " "	05
Rise " "	06
TR " "	07
B " "	08
d_n (ft) program no 4	09
horizontal pipe length	19
Q + Slope (due to storage limits example 2 cfs + .004 ft/ft = 2.004	20
n table 4	21
k_e table 4	22

3. Enter starting depth (ft), tailwater (TW), on key board and Press R/S

OUTPUT - M1 curve

Due to TI-59 capacity limits, the program prints the backwater profile as in the following example. The program performs all the calculations for the backwater and HW.

1. M1 (type of curve)

2.	.7 0.0	Dep X	(example starting TW depth) (distance from outlet to cross section)
	.68 24.2	Dep X	(0.02 decrease in depth by program)
	.66 58.4	Dep X	
	.64 129.79	Dep X	
	.62	Dep	(S_o-S becomes negative, see equation, so d_n is used for HW computations)
	.634	d_n	(normal depth)
	.78	HW	(headwater)

Results indicate profile reaches normal depth in barrel (400'). Velocity can be computed by using area from program no 4 where normal depth was computed.

CARD FORMAT

note: alpha for corrugated metal is 1.16
alpha for concrete is 1.05 so substitute in program for appropriate material

1	TEXAS INSTRUMENTS	4
WATER SURFACE PROFILES - M1 CURVE		#8
	Partitioning 719.29	
START		

LISTING M1 curve

OP 00 3002 OP 02 OP 05 ADV 161733 OP 04 R/S STO 01 OP 06 7744 OP 04 0 OP 06 ADV STO
26 LBL SRX 0 STO 25 SBR GRAD LBL CE RCL 20 INT DIV RCL 10 = STO 12 X≷T RCL 12 X^2
DIV 64.4 X 1.16(see note) + RCL 01 = IFF 00 D' STO 24 X≷T STO 23 IFF 04 DEG GTO C'
LBL D' STO 27 X≷T STO 12 LBL C' RCL 10 DIV RCL 29 = SUM 25 IFF 00 E STF 00 LBL B'
ADV 161733 OP 04 RCL 01 - 0.02 = STO 01 OP 06 +/- + RCL 06 DIV 12 = X≷T 0 X≥T E'
SBR GRAD GTO CE LBL E' OP 00 210021 OP 03 OP 05 R/S LBL E 7744 OP 04 INV STF 00
RCL 23 + RCL 12 = DIV 2 = X≷T RCL 25 DIV 2 = Y^x (4 DIV 3) X 2.21 = 1/X X (X≷T
X^2) X RCL 21 X^2 = +/- + RCL 20 INV INT = X≷T 0 X≥T CP X≷T 1/X X (RCL 24 -
RCL 27 = SUM 26 7744 OP 04 RCL 26 OP 06 - RCL 19 = X≷T 0 X≥T SRX GTO DEG LBL CP
INV STF 00 STF 04 1631 OP 04 RCL 09 STO 01 OP 06 SBR GRAD GTO CE LBL DEG 2343 OP 04
RCL 23 X^2 X RCL 22 DIV 64.4 + RCL 24 = OP 06 R/S LBL GRAD RCL 01 X 12 = STO 01 0
STO 11 RCL 13 STO 12 X≷T RCL 01 X≥T A' STO 12 X≷T LBL A' RCL 05 X 2 = STO 18 STO
17 RCL 05 X^2 DIV 2 = STO 16 0 STO 15 SBR COS 0 STO 28 STO 10 STO 29 SBR TAN SBR
NOP RCL 00 - RCL 02 = X 2 X RCL 05 = SUM 29 RCL 13 X≷T RCL 01 X≥T D GTO B LBL D RCL
13 STO 11 RCL 14 STO 12 X≷T RCL 01 X≥T A STO 12 X≷T LBL A RCL 08 X 2 = STO 18 RCL
04 X^2 - (RCL 08 X^2 = STO 15 RCL 04 X^2 DIV 2 = STO 16 RCL 18 X^2 + 4 X RCL 15 =
SRX STO 17 SBR COS SBR TAN RCL 12 - RCL 11 = X (RCL 03 DIV 2 - RCL 04 = SUM 10 SBR
NOP RCL 00 - RCL 02 = X 2 X RCL 04 = SUM 29 RCL 14 STO 11 X≷T RCL 01 STO 12 X≥T C GTO
B LBL C RCL 12 X≷T 2 X (RCL 06 - RCL 07 = STO 18 2 X RCL 06 X RCL 07 - RCL 06 X^2
= STO 15 RCL 07 X^2 DIV 2 = STO 16 RCL 18 X^2 + 4 X RCL 15 = SRX STO 17 SBR COS
SBR TAN SBR NOP RCL 00 - RCL 02 = X 2 X RCL 07 = SUM 29 LBL B RCL 29 DIV 12 = STO
29 RCL 10 DIV 144 X 2 = STO 10 RCL 01 DIV 12 = STO 01 RTN LBL NOP RCL 11 X≷T X 2 -
RCL 18 = DIV RCL 17 = RAD INV SIN STO 00 X RCL 16 + (4 +/- 1/X X RCL 27 SRX X (2
+/- X RCL 12 + RCL 18 = SUM 10 X≷T X 2 - RCL 18 = DIV RCL 17 = INV SIN STO 02 X RCL
16 + (4 +/- 1/X X RCL 28 SRX (2 +/- X RCL 11 + RCL 18 = INV SUM 10 RTN LBL COS RCL
18 X^2 RCL 12 + RCL 15 - (RCL 12 X^2 = ABSX STO 27 RTN LBL TAN RCL 11 X RCL 18 + RCL
11 X^2 = STO 28 RTN (717 PROGRAM STEPS)

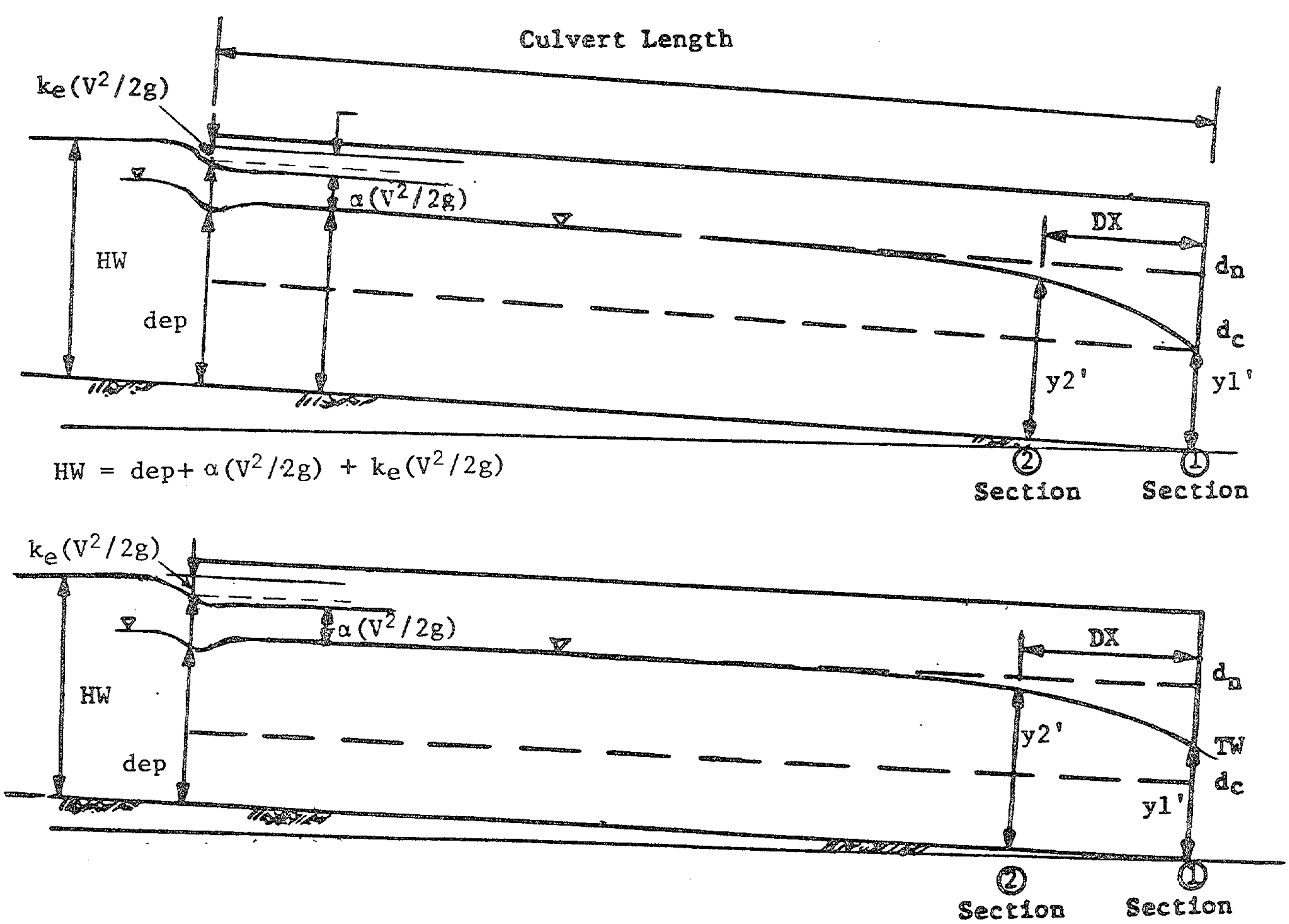
PROGRAM # 9 BACKWATER PROFILES - M2 CURVE

This program is a supplement to program no. 7 which determines outlet control conditions. The program is used to perform a water surface profile in a pipe-arch or elliptical shape culvert for an M2 curve.

The backwater profile starts with a depth equal to critical depth (d_c) or tailwater (TW) at the outlet and increases .02 feet in depth as the profile extends into the barrel and approaches normal depth in the barrel if possible. If normal depth is attained in the barrel then the headwater is computed using normal depth. If normal depth is not reached in the, barrel then the depth for the last cross section in the barrel is used in computing specific energy and headwater .

Due to TI-59 calculator limitations, the alpha values have to be interchanged in the program depending on the culvert material used. See note at bottom of page 59.

The following diagrams show the M2 curve backwater concept.



Water Surface Profile (M2 Curve) - Starting Depth = TW or d_c

EQUATIONS

For $TW \leq d_n$: use M2 curve

$$X2 = \frac{[\,d_2 + V_2^2 / 2g\,] - [\,d_1 + V_1^2 / 2g\,]}{S - S_o}$$

where V = f(Q,A or d) see appendix A
X2 = distance (ft) between cross sections 1 and 2 in the barrel

d_1 and d_2 = water depths for cross sections 1 and 2

S_o = slope of pipe in ft/ft
S = average slope of water surface in ft/ft

$= n^2 V^2 / 2.21 R^{4/3}$

g = 32.2 ft/sec/sec
n = roughness factor
V = average velocity between sections 1 and 2
R = average hydraulic radius for sections 1 and 2

Headwater:

$$Hw = d_1 + V_1^2/2g + K_e V_1^2/2g$$

where Hw = headwater in ft
K_e = entrance loss coefficient
d_1 = depth (ft) section no 1
V_1 = velocity (ft/sec) at section no 1

INSTRUCTIONS - M2 CURVE

1. Read in program # 9
Press RST then R/S

2. Enter data as LISTED - User must store the data into the storage registers

Variable		Register
Span (in)	table no 1	03
CR "	"	04
BR "	"	05
Rise "	"	06
TR "	"	07
B "	"	08
y_1 (ft)	"	13
y_2 (ft)	"	14
d_n (ft)		09
Culvert horizontal length		19
Q + Slope (due to storage limits) example 2 cfs + .004 slope = 2.004		20
n		21
k_e		22

3. Enter starting depth - D_c or Tw, Press R/S — 01

OUTPUT - M2 curve (sample only)

Due to TI-59 capacity limits, the program prints the backwater profile as in the following example. The program performs all calculations for the backwater and HW.

1.	M2		(type of curve)
2.	.7'	Dep	(starting depth = tailwater, TW)
	0.0	Σ X	(distance (DX) from outlet to cross section)
	.72'	Dep	(depth increased .02' by program)
	82.80'	Σ X	
	.74'	Dep	
	431.80'	Σ X	(greater than example culvert length, 400')
	.84'	Hw	Headwater

Results indicate that normal depth was not reached in the barrel so that HW was computed using the .72' depth. Velocity can be computed by using program no. 3 to get area using the starting water depth.

CARD FORMAT

1	TEXAS INSTRUMENTS	4
WATER SURFACE PROFILES M2 - CURVE		# 9
	Partitioning 719.29	
START		

LISTING - M2 CURVE

```
OP 00 3003 OP 02 OP 05 ADV 161733 OP 04 R/S STO 01 OP 06  7744 OP 04  0 OP 06 ADV
STO 26 LBL SRX  0 STO 25 SBR GRAD LBL CE  RCL 20 INT DIV RCL 10 = STO 12 X≷T RCL 12
X^2 DIV 64.4 X 1.16(see note) + RCL 01 = IFF 00 D'  STO 24 X≷T STO 23 IFF 04 DEG GTO C'
LBL D' STO 27 X≷T STO 12 LBL C' RCL 10 DIV RCL 29 = SUM 25 IFF 00 E STF 00 LBL B' ADV
1617330P 04 RCL 01 + .02 = STO 01 OP 06 +/- + RCL 06 DIV 12 = X≷T 0  X≥T E' SBR GRAD
GTO CE LBL E' OP 00  210021 OP 03 OP 05 R/S  LBL E  7744 OP 04  INV STF 00  RCL 23
+ RCL 12 = DIV 2 = X≷T RCL 25 DIV 2 = Y^X (4 DIV 3) X 2.21 = 1/X  X (X≷T X^2) X
RCL 21 X^2 = - RCL 20 INV INT = X≷T  0  X≥T CP  X≷T 1/X  X ( RCL 27 - RCL 24 = SUM 26
RCL 26  OP 06 - RCL 19  =  X≷T  0  X≥T  SRX  GTO DEG  LBL CP INV STF 00 ADV  1631
OP 04 RCL 09 OP 05 R/S STO 01 STF 04 SBR GRAD GTO CE LBL DEG  2343 OP 04 RCL 23 X^2 X
RCL 22 DIV 64.4 + RCL 24 = OP 06 R/S  LBL GRAD  RCL 01 X 12 = STO 01  0 STO 11 RCL 13
STO 12 X≷T RCL 01  X≥T A' STO 12 X≷T  LBL A' RCL 05 X 2 = STO 18  STO 17 RCL 05 X^2
DIV 2 = STO 16  0 STO 15 SBR COS  0 STO 28 STO 10 STO 29 SBR TAN SBR NOP RCL 00 -
RCL 02 = X 2 X RCL 05 = SUM 29 RCL 13 X≷T RCL 01 X≥T D GTO B  LBL D RCL 13 STO 11 RCL
14 STO 12 X≷T RCL 01 X≥T A STO 12 X≷T  LBL A RCL 08 X 2 = STO 18 RCL 04 X^2 - (RCL
08  X^2 =  STO 15  RCL 04 X^2 DIV 2 =  STO 16 RCL 18 X^2 + 4 X RCL 15 = SRX  STO 17
SBR COS SBR TAN RCL 12 - RCL 11 = X (RCL 03 DIV 2 - RCL 04 = SUM 10 SBR NOP RCL 00
- RCL 02 = X 2 X RCL 04 = SUM 29 RCL 14 STO 11 X≷T RCL 01 STO 12 X≥T C GTO B  LBL C
RCL 12 X≷T 2 X (RCL 06 - RCL 07 = STO 18  2 X RCL 06 X RCL 07 - RCL 06 X^2 = STO 15
RCL 07 X^2 DIV 2 = STO 16 RCL 18 X^2 +  4 X RCL 15 = SRX  STO  17 SBR COS  SBR TAN
SBR NOP RCL 00 - RCL 02 = X 2 X RCL 07 = SUM 29  LBL B  RCL 29 DIV 12 = STO 29 RCL 10
DIV 144 X 2 = STO 10 RCL 01 DIV 12 = STO 01 RTN  LBL NOP  RCL 11 X≷T X 2 - RCL 18 =
DIV RCL 17 = RAD INV SIN STO 00 X RCL 16 + (4 +/- 1/X X RCL 27 SRX  X (2 +/- X RCL 12
+ RCL 18 = SUM 10 X≷T X 2 - RCL 18 = DIV RCL 17 = INV SIN STO 02 X RCL 16 + (4 +/-
1/X X RCL 28 SRX  X (2 +/- X RCL 11 + RCL 18 = INV SUM 10 RTN  LBL COS RCL 18 X RCL 12
+ RCL 15 - (RCL 12 X^2 =  ABSX  STO 27  RTN  LBL TAN  RCL 11  X  RCL 18  +  RCL 15 -
RCL 11 X^2  = STO 28 RTN                ( 716 PROGRAM STEPS )
```

note: alpha for corrugated metal is 1.16
alpha for concrete is 1.05 so substitute in program for appropriate material

SAMPLE PROBLEMS

SAMPLE PROBLEM

This problem is to analyze a riveted corrugated metal pipe with the following input data:

Span	=	18.1"	(table 1)
Rise	=	11.0"	"
BR	=	19.12"	"
TR	=	10.06"	"
CR	=	3.5"	"
B	=	4.5"	"
Q	=	2.0 cfs	
k_e	=	0.5	(table 10)
n	=	0.019	"
Slope	=	0.004 ft/ft	
length	=	200.0 ft	
TW	=	0.0	
alpha	=	1.16	(see note at bottom of pages 54 and 59)
inlet invert elevation	=	0.8	
outlet invert elevation	=	0.0	

RESULTS

Program #1 - Tw in channel

Tw assumed as 0.0

Program #2 - compute y1 and y2

y1 = 1.247"

y2 = 6.387"

Program #3 - compute areas, WP, and top width

not used for this problem (if TW > 0 compute area in barrel at TW depth)

Program # 4 - compute normal depth and area

d_n = .63 ft

area = .82 sq ft

Program # 5 - compute critical depth and area

d_c = .46 ft

area = .59 sq ft

SAMPLE PROBLEM (continued)

Program # 6A - Inlet control HW (for riveted pipe-arch culvert)

HW	=	1.5 ft (elevation)
Vel	=	2.4 ft/sec
Span	=	18.1 in
Rise	=	11.0 in
Q	=	2.0 cfs

Program # 7 - Outlet control HW

Do backwater profile, M2 curve, starting depth = d_c = .465

Program # 9 - M2 curve

M2		(curve type)
.465 0.0	Dep X	(starting depth d_c = .465) (distance (DX) from outlet)
.665 45.2	Dep X	(program increments .2' for this example problem)
.865	Dep	(at this cross section $S-S_o^*$ becomes negative so d_n is used for HW)
.634	d_n	(d_n used to compute HW)
.78	HW	(Headwater computed based on d_n)
4.3	Vel	(Velocity at outlet in fps)

The HW was computed using the normal depth value.

Velocity was computed using program #3 to get area with starting depth, d_c

* S is the energy friction slope
S_o is the culvert slope

SAMPLE PROBLEM

This problem is to review an unpaved pipe-arch culvert with a headwall and develop performance curves for the following input data:

span	=	65.0"	
rise	=	40.0"	
BR	=	129.31"	
TR	=	32.75"	
CR	=	8.0"	
B	=	10.5"	
y_1	=	2.664"	
y_2	=	11.552"	
Q	=	150. cfs	
k_e	=	0.5	
n	=	0.024	
slope	=	0.025	
length	=	150.0'	
TW	=	0.0	
alpha	=	1.16	(see note at bottom of pages 54 and 59)
in. in. el.	=	3.75	(inlet invert elevation)
out. in. el.	=	0.0	(outlet invert elevation)

RESULTS

Program # 1 - compute Tw in channel

used 0.0 TW

Program # 2 - compute y1 and y2

y1 = 2.664

y2 = 11.552

Program # 3 - compute area, wetted perimeter and top width

not used in this problem (if TW > zero, user needs to compute area in barrel at TW depth)

Program # 4 - compute normal depth in culvert and area

D_n = 3.3 ft

Area = 14.2 sq ft

Program # 5 - compute critical depth and area

D_c = 2.89 ft

Area = 13. 34 sq ft

SAMPLE PROBLEM (continued)

Program # 6 - compute inlet control headwater

Hw = 6.5 ft
Vel = 10.5 fps
Span = 65.0 in
Rise = 40.0 in
Q = 150.0 cfs

Program # 7 - compute outlet control headwater

Head = 6.9 ft

Full flow conditions

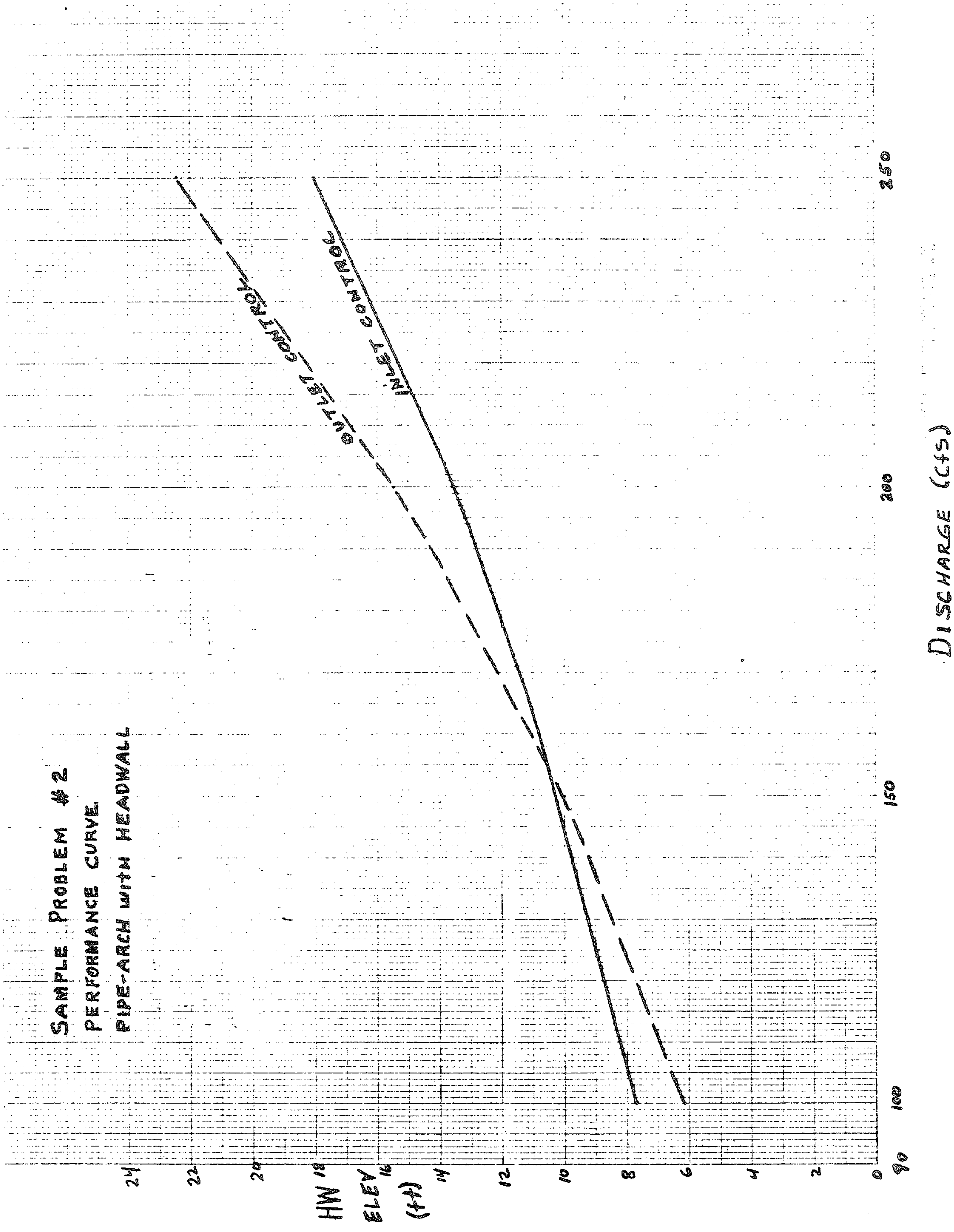
Span = 65.0 in
Rise = 40.0 in
Hw = 6.3 ft
Vel = 11.2 fps

The results show the flow in the barrel to be in inlet control (6.5' vs 6.3'), at design discharge, however the performance curves on page 65 show the culvert goes into outlet control with discharges greater than about 155 cfs.

Performance Curve Data

Q	d_n	Area	d_c	Area	Inlet control HW (elev)	Inlet control Vel	Outlet control HW (elev)	Outlet control Vel
cfs	ft	sq ft	ft	sq ft	ft	ft/sec	ft	ft/sec
100	1.92	9.42	2.36	11.04	7.75	10.62	6.20	7.50
150	3.30*	14.20	2.89	13.34	10.21	10.56	10.05	11.24
200	3.30	14.20	3.16	14.00	13.49	14.08	15.46	14.99
250	3.30	14.20	3.24	14.14	18.01	17.60	22.40	18.74

* d_n equal to barrel depth



SAMPLE PROBLEM #2
PERFORMANCE CURVE
PIPE-ARCH WITH HEADWALL
OUTLET CONTROL
INLET CONTROL
HW ELEV (ft)
DISCHARGE (cfs)
0
2
4
6
8
10
12
14
16
18
20
22
24
90
100
150
200
250

References

1. Normann, Jerome M., "Hydraulic Design of Large Structural Plate Corrugated Metal Culverts", FHWA, Jan. 1974, preliminary draft.

2. Marques, M., "Hydraulics of Pipe-arch Culverts", HY-2, Electronic Computer Program, FHWA, revised May 1969.

3. "Least Squares Polynomial Curve Fitting", U. S. Department of Commerce, Bureau of Public Roads, Library Program M-1, Washington 25, D.C. 1962.

4. French, J. L., "First Progress Report on Hydraulics of Short Pipes, Hydraulic Characteristics of Commonly Used Pipe Entrances", U. S. Department of Commerce, National Bureau of Standards, Report No. 4444, Washington 25, D. C. 1965.

5. Calculator Design Series # 3, Hydraulic Design of Improved Inlets for Culverts using a Programable Calculator (TI-59), FHWA, Oct. 1980.

6. "Hydraulic Charts for the Selection of Highway Culverts", HEC No. 5, U. S. Department of Transportation, Federal Highway Administration, Dec. 1965.

7. "Hydraulic Flow Resistance Factors for Corrugated Metal Conduits," U.S. Department of Transportation, Federal Highway Administration, January 1980.

APPENDICES

APPENDIX A

This presentation deals with a mathematical procedure to compute area, wetted perimeter and top width in a pipe-arch or elliptical shape culvert. Basically, the procedure incorporates integral calculus formulas to compute the required parameters.

To arrive at the formulas requires a brief explanation of how the necessary mathematical functions for the integals are obtained. The geometric configuration of the two mentioned shapes are composed of three sections with differing radii (circles) and with nonconcentric centers. Figure 2 shows the three sections delineated by the y_1 and y_2 values. For each section, we want to sum the finite areas shown in figure 2 as (w dy) for the limits ranging from the bottom of the culvert to y_1, from y_1 to y_2 and from y_2 to the top of the culvert. To obtain the math function 'w' the centers of each circle are translated to the level of point '0' (see figure 2) located at the invert of the culvert by using the following equation.

$$(x + h)^2 + (y + k)^2 = r^2$$

By translating the origin (0,BR) of the circle containing BR, gives

$$(x + 0)^2 + (y - BR)^2 = BR^2$$

so that $$x^2 = 2BRy - y^2$$

then the math function for section I is:

$$w_1 = \sqrt{2BRy - y^2}$$

By translating the origin (SPAN/2-CR,B) of the circle containing CR, gives

$$(x + 0)^2 + (y - B)^2 = CR^2$$

so that $$x^2 = ((CR)^2 - B^2) + 2By - y^2$$

then the math function for section II is:

$$w_2 = \sqrt{((CR)^2 - B^2) + 2By - y^2}$$

By translating the origin (0,RISE-TR) of the circle containing TR, gives

$$(x + 0)^2 + (y - (RISE - TR))^2 = TR^2$$

so that $$x^2 = (2(RISE)(TR) - RISE^2) + 2(RISE - TR)y - y^2$$

then the math function for section III is:

$$w_3 = \sqrt{(2(RISE)(TR) - RISE^2) + 2(RISE - TR) - y^2}$$

The three math functions have the same form for which the following integral formulas* can be used to compute the area, wetted perimeter and top width.

1. $\int f(x)\, dy = \int w\, dy = (2cy + b)\, w + 1/2k \int dy/w$
2. $\int dy/w = 1/ -c \;\; \sin^{-1} ((-2cy - b) / (b^2 - 4ac)$, for $c < 0$
3. Temp = 2(SPAN/2-CR)y

where $w = a + by + cy^2$

$q = 4ac - b^2$

$k = 4c/q$

a,b,c = coefficients

y = any depth in culvert

Temp = portion of area to be added to section II only

For section I, between the bottom of culvert and y_1

$a = 0$

$b = 2BR$

$c = -1$

For section II, between y_1 and y_2,

$a = (CR)^2 - B^2$

$b = 2B$

$c = -1$

* Taken from Calculus text book

For section III, between y_2 and top of culvert,

$$a = 2(RISE)(TR) - RISE^2$$

$$b = 2(RISE - TR)$$

$$c = -1$$

AREA

The area for any depth in a culvert is the summation of each section if the depth extends into the section. For example the total area will include all three sections in the summation where the limits to definite integral range from the bottom of culvert to y_1, from y_1 to y_2, and from y_2 to the top of culvert multiplied by 2. Equations 1 and 2 have to be solved for each individual section based on the water depth. Equation 3 is used to compute the area for that portion of section II delineated by the term (SPAN/2-CR) and the integral limits in section II. In this example y_2 is the upper limit of section II. Remember that when the water depth is located within a section, the water depth becomes the upper limit for the section.

WETTED PERIMETER

The wetted perimeter for each section is obtained from formula number 2 times the respective radius then multiplied by 2.

for section I, $WP = 2BR \int dy/w$

for section II, $WP = 2CR \int dy/w$

for section III, $WP = 2TR \int dy/w$

TOP WIDTH

The top width is obtained from the math function multiplied by 2.

If the water depth falls in section I,

then top width = $2\sqrt{2BRy - y^2}$

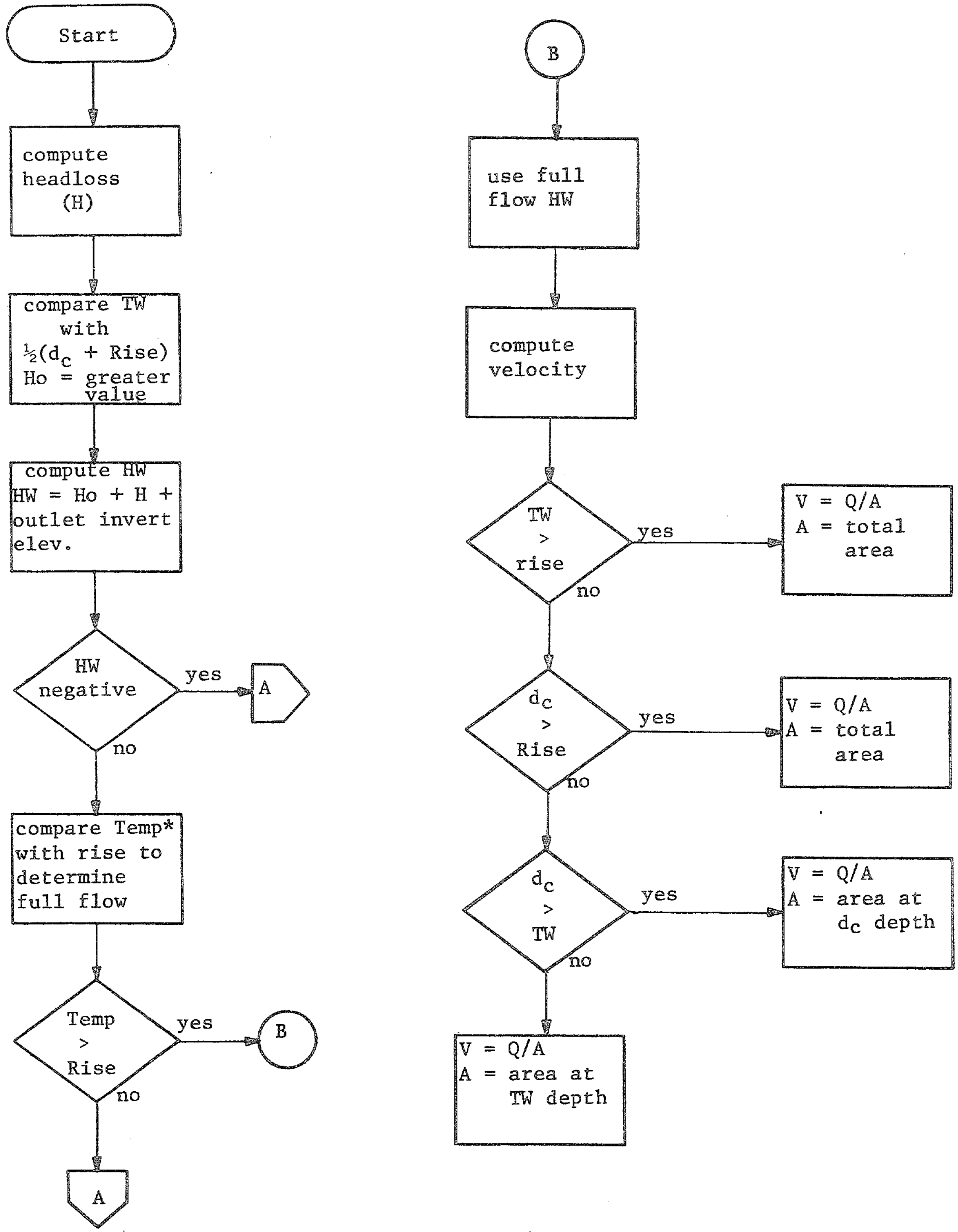
If the water depth falls in section II,

then top width = $2(\sqrt{((CR)^2 - B^2) + 2By - y^2}) + (SPAN/2 - CR))$

If the water depth falls in section III,

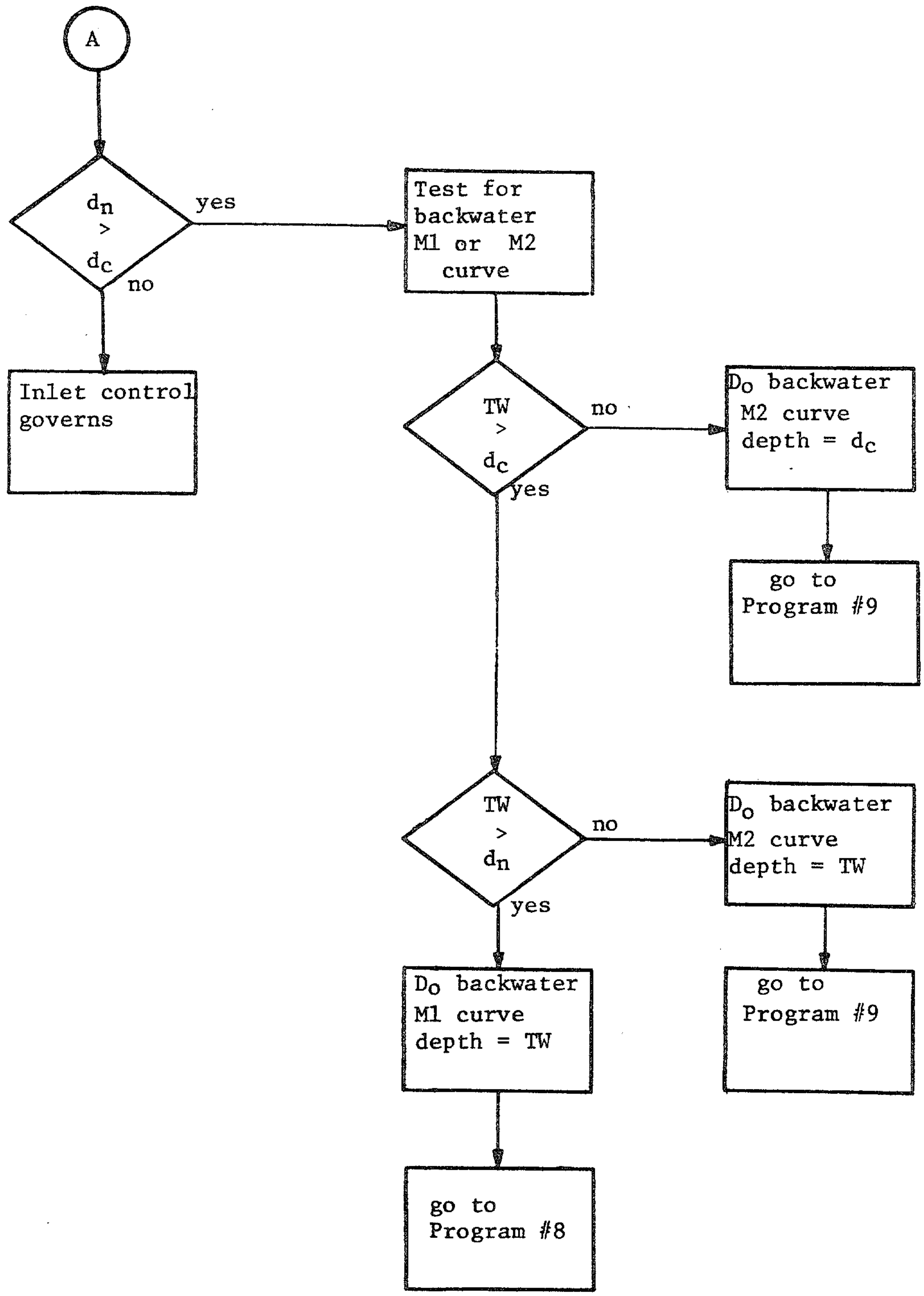
then top width = $2\sqrt{(2(RISE)(TR) - RISE^2) + 2(RISE - TR)y - y^2}$

FLOW CHART - OUTLET CONTROL

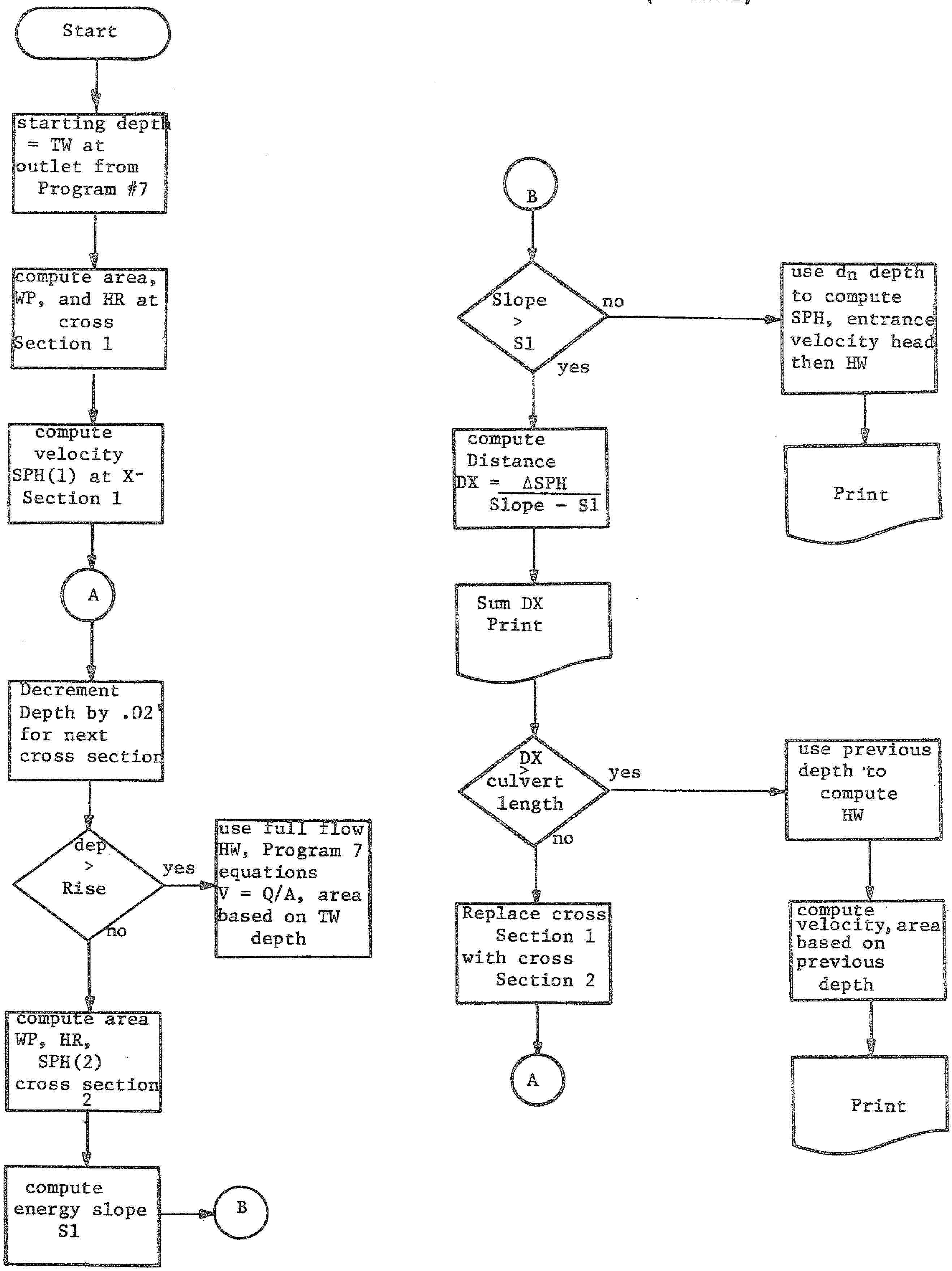


*Temp = HW − $((1 + ke)(Q^2/A^2 2g))$

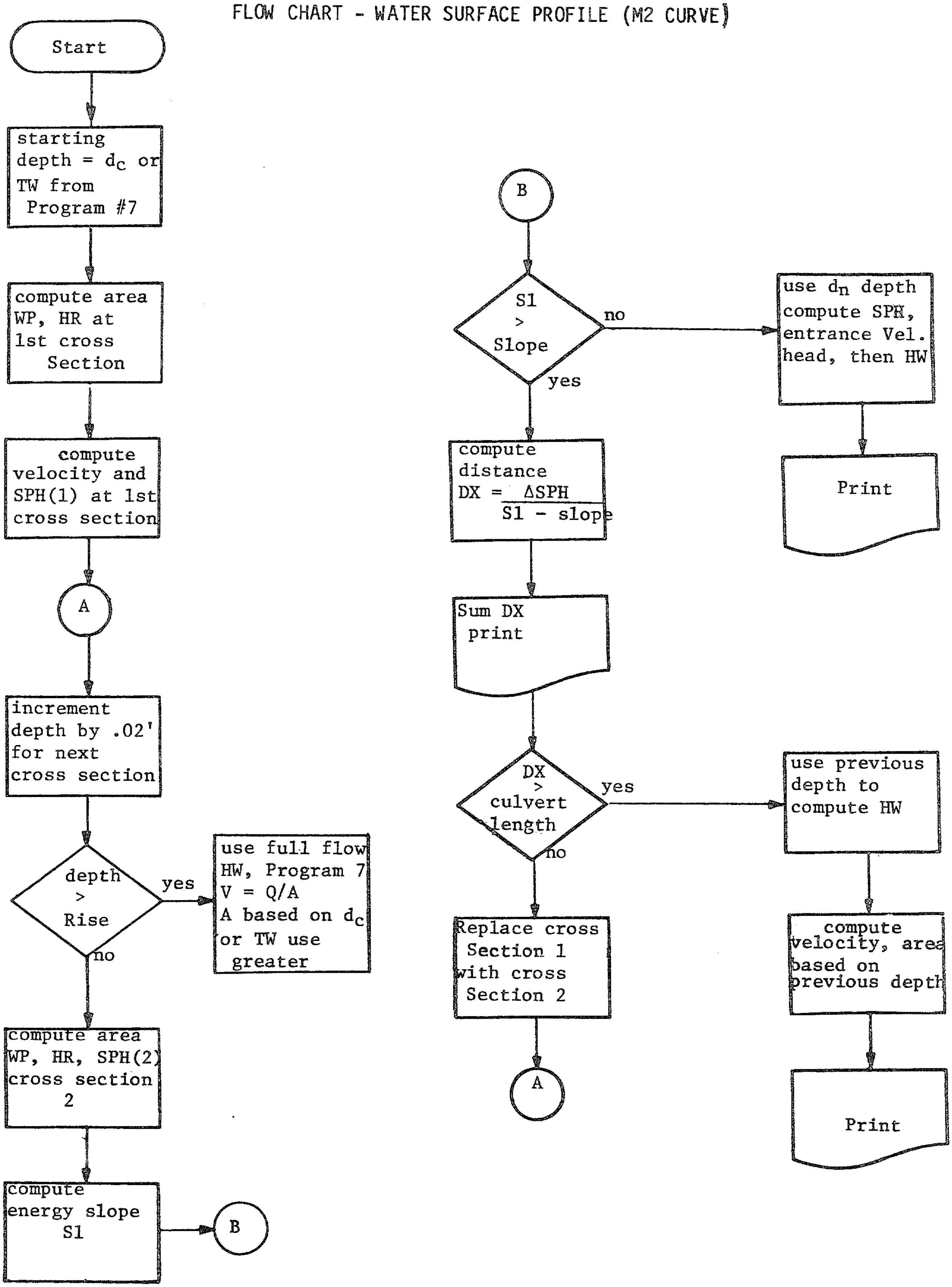
FLOW CHART - OUTLET CONTROL (continued)



FLOW CHART - WATER SURFACE PROFILE (M1 CURVE)

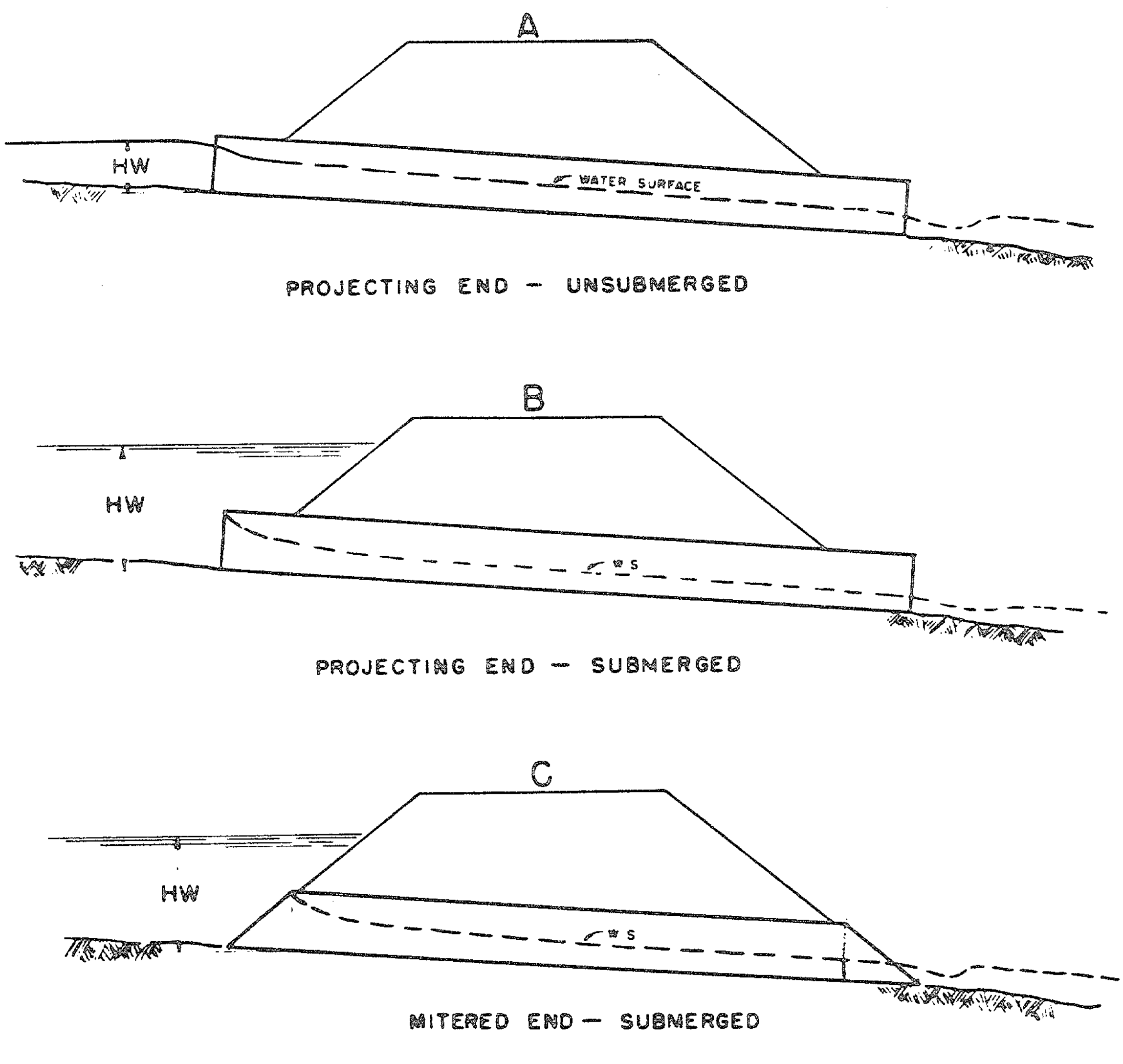


FLOW CHART - WATER SURFACE PROFILE (M2 CURVE)



Inlet Control

Inlet control means that the discharge capacity of a culvert is controlled at the entrance to the culvert. The headwater (HW), barrel shape, cross sectional, area and inlet edge are the parameters affecting the inlet control conditions. Figure 3 shows inlet control for both submerged and unsubmerged projecting entrances and a mitered entrance flowing under submerged conditions.



INLET CONTROL

FIGURE 3

Outlet Control

Culverts flowing with outlet control can flow with the culvert barrel full or partially full. Culverts not flowing full will require a backwater surface profile to determine the headwater elevation. Figure 4 depicts the outlet control conditions analyzed by the program.

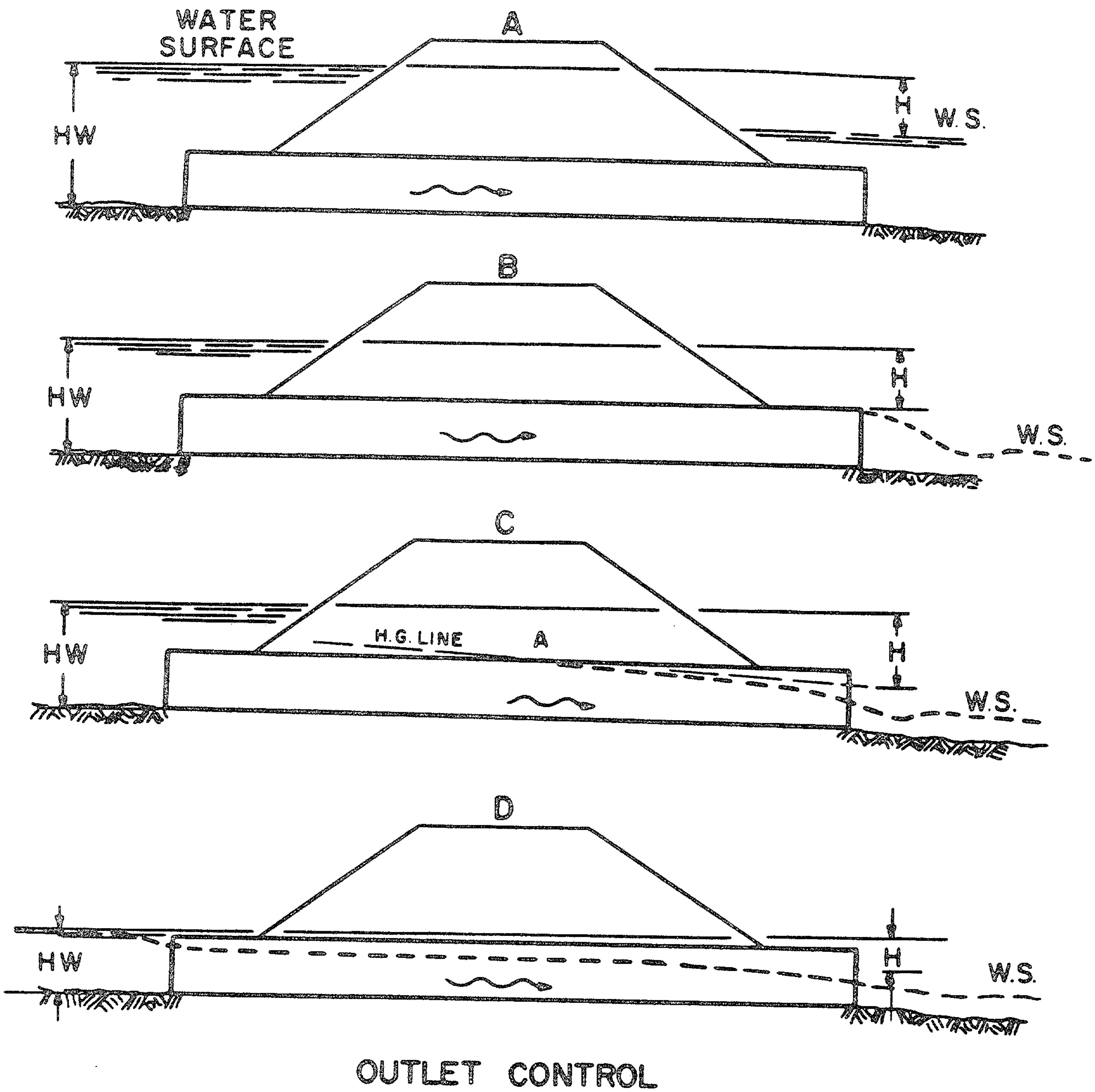
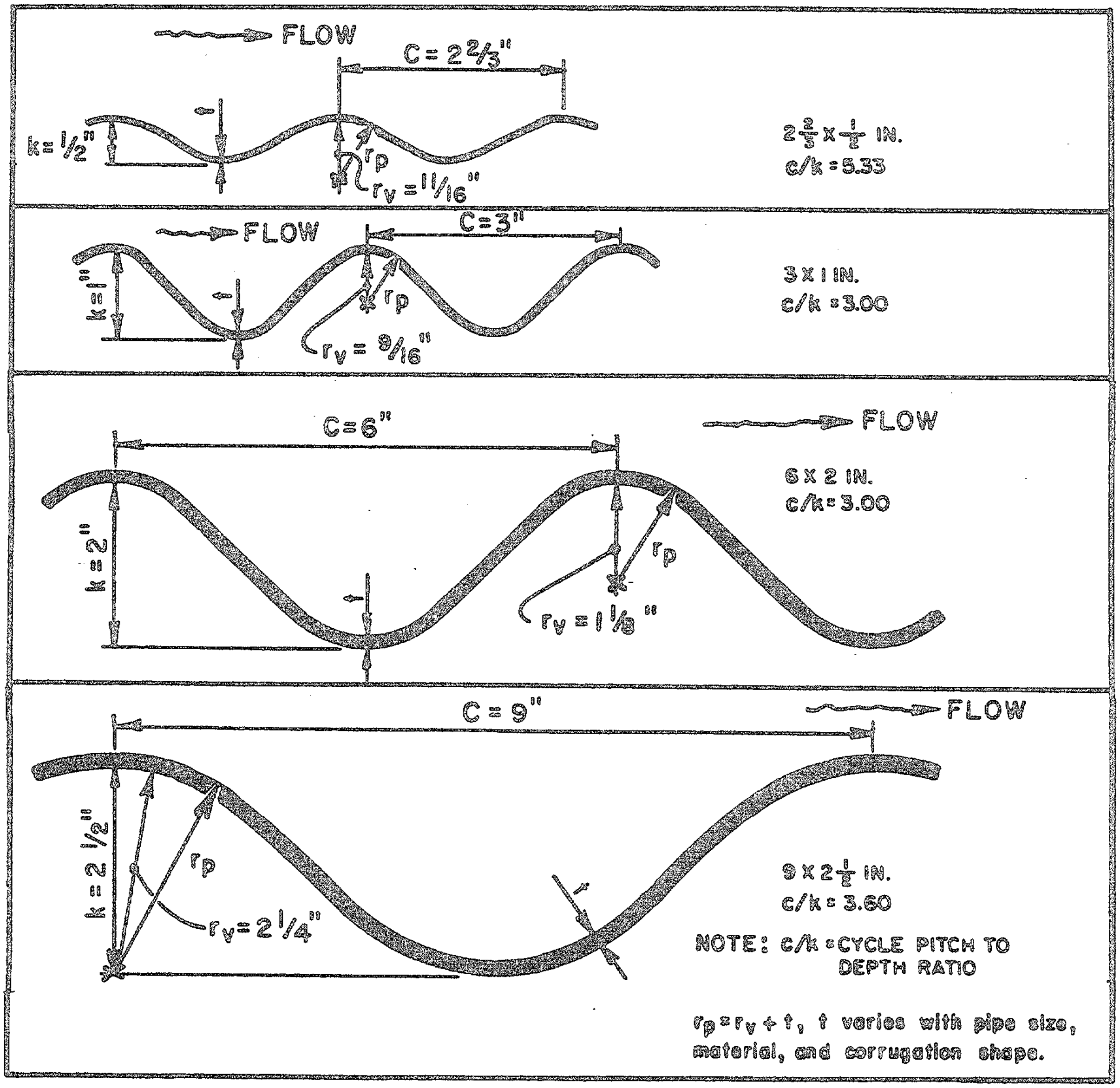


FIGURE 4



Shapes of Annular Corrugations

Figure 5

Publications listed below are not available from the Government Printing Office. These publications are available in limited numbers to State highway agencies and other public agencies from the Federal Highway Administation. Requests for these documents and suggestions on the contents of any publications should be addressed to the Federal Highway Administration, Office of Engineering, Bridge Division, HNG-31, Washington, D.C. 20590

Hydraulic Design Series

HDS No. 2 Discontinued
HDS No. 4 DESIGN OF ROADSIDE DRAINAGE CHANNELS - 1965

Hydraulic Engineering Circulars

HEC No. 1 SELECTED BIBLIOGRAPHY OF HYDRAULIC AND HYDROLOGIC SUBJECTS - December 1979
HEC No. 2, 4, 6, 7 and 8 Discontinued
HEC No. 3 HYDROLOGY OF A HIGHWAY STREAM CROSSING - January 1961
HEC No. 9 DEBRIS-CONTROL STRUCTURES - March 1971
HEC No. 10 CAPACITY CHARTS FOR THE HYDRAULIC DESIGN OF HIGHWAY CULVERTS - November 1972
HEC No. 11 USE OF RIPRAP FOR BANK PROTECTION - June 1967
HEC No. 13 HYDRAULIC DESIGN OF IMPROVED INLETS FOR CULVERTS - August 1972
HEC No. 14 HYDRAULIC DESIGN OF ENERGY DISSIPATORS FOR CULVERTS AND CHANNELS - December 1975
HEC No. 15 DESIGN OF STABLE CHANNELS WITH FLEXIBLE LININGS - October 1975
HEC No. 16 ADDENDUM TO HIGHWAYS IN THE RIVER ENVIRONMENT - HYDRAULIC AND ENVIRONMENTAL DESIGN CONSIDERATIONS - JULY 1980

Electronic Computer Programs

HY-1, 3 and 5 Discontinued
HY-2 HYDRAULIC ANALYSIS OF PIPE-ARCH CULVERTS - May 1969
HY-4 HYDRAULICS OF BRIDGE WATERWAYS - 1969
HY-6 HYDRAULIC ANALYSIS OF CULVERTS (Box and Circular) - 1979

Calculator Design Series

CDS No. 1 HYDRAULIC DESIGN OF IMPROVED INLETS FOR CULVERTS USING PROGRAMABLE CALCULATORS, (COMPUCORP 325) - October 1980
CDS No. 2 HYDRAULIC DESIGN OF IMPROVED INLETS FOR CULVERTS USING PROGRAMABLE CALCULATORS, (HP-65) - October 1980
CDS No. 3 HYDRAULIC DESIGN OF IMPROVED INLETS FOR CULVERTS USING PROGRAMABLE CALCULATORS, (TI-59) - January 1981
CDS No. 4 HYDRAULIC ANALYSIS OF PIPE-ARCH AND ELLIPTICAL SHAPE CULVERTS USING PROGRAMABLE CALCULATORS, (TI-59) - March 1982
CDS No. 5 HYDRAULIC DESIGN OF STORMWATER PUMPING STATIONS USING PROGRAMABLE CALCULATORS, (TI-59), May 1982