Hydraulic Design of Improved Inlets for
Culverts Using Programmable Calculators
Texas Instruments (TI-59)

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16. Abstract

This manual provides programmable design procedures for both box and pipe culverts with either conventional or improved inlets, for the Texas Instruments, TI-59 calculator.

The same terminology and algorithms used in "The Design of Improved Inlets for Culverts" (HEC No. 13) are used in these programs.

Each program listed in the manual is accompanied by an explanation and an illustration of its use.

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TABLE OF CONTENTS

INTRODUCTION

The programmable calculator as a culvert designing tool offers many desirable features. 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, checking four or five different sizes to find the best one, while also evaluating several inlet configurations including both side- and slope-tapered inlets.

In an office where it is not feasible to use a computer for culvert design, the programmable calculator becomes a desireable alternative. The accuracy remains the same, and the calculator method offers a segment by segment design approach. This method allows the culvert design parameters to be changed as the design is proceeding along.

The procedure herein covers both box and circular pipe culverts and follows the culvert design methods presented in "Hydraulic Design of Improved Inlets for Culverts," Hydraulic Engineering Circular No. 13 (HEC 13), dated August 1972. The programs begin with the computation of tailwater, proceed through the design of the culvert barrel, and conclude with the design of the culvert inlet most applicable to the site. The programs produce detailed inlet dimensions, performance curve data, and the outlet velocity.

Since the procedure is subdivided into a series of programs, the designer may enter the sequence at any point, provided the necessary input data is available, and obtain the desired design results.

These box and pipe culvert programs have been written for use on the Texas Instrument - 59 calculator. It is expected that with the equations, examples, and program listings, a designer will be able to write similar programs for any other calculator he may have available.

Terminology used in this publication assumes that the designer is familiar with HEC 13 and understands the principles and design philosophy expressed therein.

This document was written by Mr. Patrick Wlaschin, edited by Mr. Philip L. Thompson and typed by Ms. Barbara Driver.

PROGRAM LIMITATION

When computing headwater depths, H_f and H_t, the upper and lower limits for these values are 4.5 D and 0.5 D. These limits indicate the range over which research was performed on these culverts. Because polynominal best-fit equations are used to produce the chart values from HEC 13, values outside these limits can be obtained. Since the programs do not check for these conditions, it is left to the designer.

When designing either a side-tapered or slope-tapered inlet, the number of barrels, N, is limited to two for boxes. For multiple barrel pipe installations, each barrel should be designed individually.

In programs for circular pipes where d_n/D is greater than 0.89, the program assumes the pipe to be flowing full in calculating the outlet velocity.

In calculating the "H" value in the outlet control performance programs, it is assumed that the culvert is flowing full.

In the design of slope-tapered inlets, the FALL slope, S_f, must range between a 2:1 and a 3:1 ratio.

In the programs which use FALL, this value is limited to a range of 0.25 D to 1.5 D for slope tapered inlets.

For side-tapered inlets the value of side taper, ST, must be between 4:1 and 6:1.

The value of L_3 must be greater than or equal to 0.5 B. This value has been set so that control will occur at the throat section rather than at the bend section.

In addition to the design limitations given previously for box culverts with slope-tapered inlets, the following criteria apply to slope-tapered and rectangular side-tapered inlets for pipe culverts:

The rectangular throat of the inlet must be a square section with sides equal to the diameter of the pipe-culvert.

The transition from the square throat section to the circular throat section must be no shorter than half the culvert diameter. If excessive lengths are used, the frictional losses within this section of the culvert should be considered in the design.

The design of multiple barrels for circular culverts using slope-tapered improved inlets can be performed the same as that for box culverts except the center wall must be flared in order to provide adequate space between the pipes for proper compaction of the backfill. The amount of flare required will depend on the size of the pipes and the construction techniques used. An alternative would be to design a series of individual circular culverts with slope-tapered inlets. This permits the use of an unlimited number of barrels and the design programs are applicable.

The wingwall flare angles used in side-tapered inlets are limited from 15° to 26° with the top edge beveled, and from 26° to 90° with or without bevels.

The socket entrance used in these programs refers to the bell and spigot type of pipe.

All the dimensions used in these programs are in English units. The programs require all of their inputs to be in this type of format.

The use of slopes equal to a value of zero will produce incorrect results.

These programs do not check for errors in input values.

For the most part, these limitations are repeated in the discussion segment of each program.

In typing the program listings, the following notation was used: DIV = divide, SRT = square root and PI = the Greek symbol for pi.

To execute one of the prerecorded programs, load the program into the calculator and press Label A. The calculator will print the program title and then issue a data prompt. Whichever input data corresponds to this prompt should then be entered into the calculator. To enter the data press the value and then the Run/Stop button. The calculator will either prompt for another entry or will proceed with the calculations.

LIST OF SYMBOLS

Symbols	Units	Description
A	sq. ft.	Area, generally the cross-sectional area of flow
a	ft.	Bevel dimension used for circular pipe culverts
ADJ.L	ft.	Adjusted length of a culvert, after its original length has been altered by the addition of a improved inlet
Alpha		Velocity distribution factor used with pipe culverts, 1.04 for concrete, 1.12 for corrugated metal
B	ft.	Width of the box culvert barrel or the diameter of a pipe culvert
b	ft.	Bevel dimension used for circular pipe culverts
B_f	ft.	Width of the face section of an improved inlet
BW	ft.	Base width of a rectangular or trapezoidal channel section
c	ft.	Bevel dimension used for circular pipe culverts
CW	ft.	Width of the weir crest
D	ft.	Height of a box culvert or the diameter of a pipe culvert
d	ft.	Bevel dimension used for circular pipe culverts
d_c	ft.	Critical depth of flow
DHW EL.	ft.	Design headwater elevation at the culvert entrance
d_n	ft.	Normal depth of flow
d_2, d_3, d_4	ft.	Variable depths of flow

LIST OF SYMBOLS

Symbols	Units	Description
E	ft.	Height of side-tapered pipe culvert face section, excluding bevel dimension
EL.FACE	ft.	Invert elevation of the face section of a culvert
EL.FD	ft.	Catch point elevation of the fill slope at the downstream end of the cross section
EL.FU	ft.	Catch point elevation of the fill slope at the upstream end of the cross section
EL.IN	ft.	Inlet invert elevation of the culvert before any improved inlet adjustments
EL.OUT	ft.	Invert elevation of the culvert outlet
EL.THR	ft.	Invert elevation of the culvert throat section
FALL	ft.	Distance between the culvert inlet and the control section. Measured in a downward direction
g	ft/sec^2	Acceleration of gravity: 32.2
H	ft.	Head or energy required to pass a given quantity of water through a culvert flowing in outlet control
H_c	ft.	The depth of pool, or head, above the weir crest
H_e	ft.	Head loss at a culvert due to the entrance configuration
H_f	ft.	Depth of pool, or head, above the face section invert
H_t	ft.	Depth of pool, or head, above the throat section invert
H_v	ft.	Head due to velocity
HW EL.	ft.	Headwater elevation at the entrance to a culvert
k_e	ft.	Entrance energy loss coefficient
L	ft.	The length of the culvert, measured along the barrel

LIST OF SYMBOLS

Symbols	Units	Description
L_1, L_2 L_3, L_4	ft.	Dimensions relating to the improved inlet as shown in sketches of the different inlet types
N		Number of culvert barrels
n		Manning's roughness coefficient
Q	cfs.	The volume rate of flow
R	ft.	Hydraulic radius
r	ft.	Variable parameter equal to the absolute value of the difference between the flow depth in a pipe culvert and the radius
S	ft./ft.	Slope of the culvert barrel
S_{FD}	ft./ft.	Downstream fill slope
S_{FU}	ft./ft.	Upstream fill slope
S_f	ft./ft.	Slope of FALL for slope-tapered inlets, (ratio of horizontal to vertical) See design sketches
S_o	ft./ft.	Slope of the natural channel
ST	ft./ft.	Sidewall taper
TW	ft.	Tailwater depth at the culvert outlet
V	fps.	Mean velocity of flow
WA	degree	Wingwall taper angle
WP	ft.	Wetted perimeter
WT	ft./ft.	Wingwall taper
X		Variable parameters used to simplify calculations
Y, y		Variable parameters used to simplify calculations
Y_a, Y_b	ft.	Parameters used to indicate the equations of various slope lines
Z		Variable parameter used to simplify calculations
Z_1, Z_2	ft./ft.	Side slopes of a channel section

PROGRAM OUTLINE

PROGRAM OUTLINE

PROGRAM INDEX

Texas Instrument: TI-59

Programs

PROGRAM #1 - NORMAL DEPTH

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:
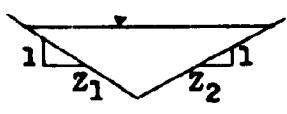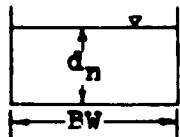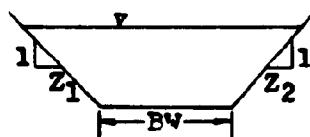
triangular   rectangular   trapezoidal

EQUATIONS

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

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

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

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

$$V = Q/A$$

2

INSTRUCTIONS

#1 Load program #1

#2 Press Label A

#3 Enter:
1. n – Manning's roughness coefficient for the stream
2. S_0 – 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
		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$\gtrless$T

1 STO 9 STO 07 1 1 STO B 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$\gtrless$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.	3337230024	26.	1731371735
18.	3600000000	27.	21273243
19.	1727004217	28.	3513371700
		29.	15213600

4

PROGRAM #2 - CULVERT LENGTH

This program uses the site characteristics to determine the culvert length for a given barrel height. The inlet and outlet elevations for the culvert are also calculated by this program.

Both box and pipe culverts can be evaluated by this program.

The necessary input data are indicated in the diagram below:
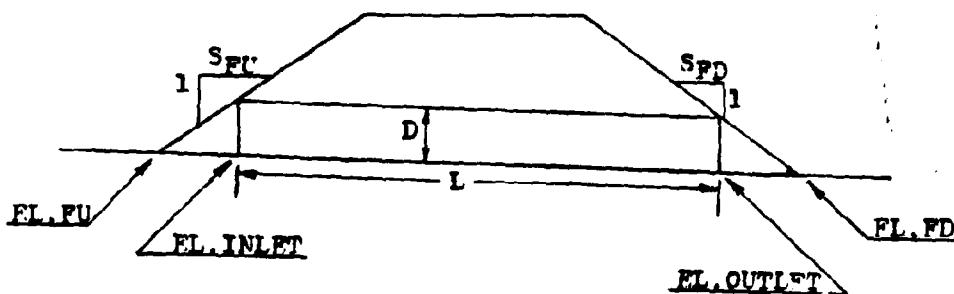
Roadway Cross section

The length of the culvert (L) is measured along the barrel and is not a horizontal dimension.

The ends of the culvert are assumed to be vertical.

EQUATIONS

$$L = (EL.INLET - EL.OUTLET) \frac{(S_o^2 + 1)^{.5}}{S_o}$$

$$EL.INLET = EL.FU - \frac{D\, S_o\, S_{FU}\, (S_o^2 + 1)^{.5}}{1 + S_o\, S_{FU}}$$

$$EL.OUTLET = EL.FD + \frac{D\, S_o\, S_{FD}\, (S_o^2 + 1)^{.5}}{1 - S_o\, S_{FD}}$$

The derivations of these equations are found in the appendix.

5

INSTRUCTIONS

#1 Load program #2

#2 Press Label A

#3 Enter: 1. S_U - Slope of natural channel

        2. S_{FU} - Upstream fill slope

        3. S_{FD} - Downstream fill slope

        4. EL.FU - Upstream fill catch point elevation

        5. EL.FD - Downstream fill catch point elevation

        6. D   - Height of culvert

#4 Read: L   - Culvert length

               El.In   - Inlet elevation

               El.Out - Outlet elevation

CARD FORMAT

[1]	TEXAS INSTRUMENTS	[4]
CULVERT LENGTH		#2
		479.59
START		

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 CE 2 1 3 7 FIX

2 OP 4 RCL 7 OP 6 INV FIX RTN LBL CLR ((RCL 1 x^2 + 1)

SRX X RCL 6 X RCL 1 X RTN LBL A 6 X≷T 1 STO 09 1 1 STO

8 RCL 14 EXC 15 STO 14 SBR LNX EXC 15 STO 14 1 1 STO 8 ADV

5 1 0 2 STO 0 RCL 0 OP 4 RCL 9 X=T 1 20 R/S OP 6 ST* 9 OP

29 OP 20 GTO 0 99 R/S OP 6 STO 6 SBR CLR RCL 2 DIV (1 +

RCL 1 X RCL 2) +/- + RCL 4) STO 9 SBR CLR RCL 3 DIV (1

- RCL 1 X RCL 3) + RCL 5) STO 0 +/- + RCL 9 = DIV RCL 1

X (RCL 1 x^2 + 1) SRX = STO 7 SBR LNX SBR CE OP 28 RCL 9

STO 7 SBR LNX SBR CE RCL 0 STO 7 OP 38 SBR INV OP 4 SBR INV

OP 1 ADV OP 5 SBR CE SBR LNX SBR LNX ADV 5 1 0 7 OP 04 1 1

STO 08 6 GTO 1 20   (237 PROGRAM STEPS)

11.	1541274217	20.	3241372717
12.	3537002717	21.	2132350016
13.	3122372300	22.	2421211735
14.	2436000000	23.	1731370036
15.	3322300003	24.	2446173600
16.	24312717	25.	1731371735
17.	3700172717	26.	15412742
18.	4213372432	27.	1735370023
19.	3100243600	28.	1724222337

PROGRAM #3 - BOX CULVERT: OUTLET CONTROL PERFORMANCE

This program can be used to select an appropriate box culvert size, evaluate the performance of this culvert for various flow rates and determine the velocity of the flow at the outlet.

In determining the best box culvert size, the designer must first select a trial height and width. For these and the other input values, the program computes the water surface elevation of the headwater pool at the culvert inlet. A visual comparision of this value to the design headwater elevation is then made. The designer then adjusts the trial height and width accordingly. If the culvert height is altered, the length and outlet elevation may also have to be adjusted. The program requires all four of these values to be restored during the culvert sizing operations.

Once the box size has been determined, various flow rate values, along with the corresponding tailwater depths, can be placed into the calculator to obtain the performance curve headwater elevations.

The formula used for the outlet control outlet velocity is simply $V = Q/A$. The depth of flow used in the computation of the cross-sectional area is equal to the critical depth or the tailwater depth, whichever is larger. However, if this depth is found to be greater than the height of the box culvert, then the box culvert height is used as the depth of flow.

Since the water at the inlet is considered to be a pool, the velocity at this point is assumed to be zero. This allows the hydraulic grade line to be equated to the energy line.

The number of barrels to be used in the calculations is limited to two.

The following diagram indicates the location of the energy losses associated with the culverts operation.
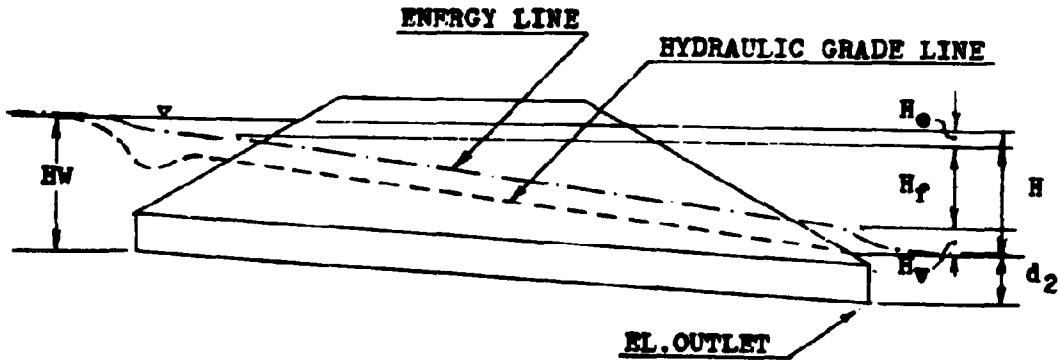
EQUATIONS

$$H_e = k_e V^2/2g$$

$$H_f = 29n^2 L \, V^2/2gR^{4/3}$$

$$H_v = V^2/2g$$

$$H = H_e + H_f + H_v$$

$$= \left[1 + k_e + \frac{29n^2L}{\left(\frac{BD}{2(B+D)}\right)^{4/3}}\right] \frac{\left(\frac{Q}{DBN}\right)^2}{2g}$$

$$d_2 = \frac{(d_c + D)}{2} \text{ or the tailwater depth, whichever is largest}$$

$$\text{HW EL.} = H + d_2 + \text{EL.OUTLET}$$

$$d_c = 0.315\left(\frac{Q}{BN}\right)^{2/3}$$

$$V = \frac{Q}{A} = \frac{Q}{BNd_3}$$

$d_3 = d_c$ or TW, whichever is largest, not to exceed D

INSTRUCTIONS

#1 Load program #3 (2 cards)

#2 Press Label A

#3 Enter: 1. Q - Flow rate

2. N - Number of barrels

3. k_e - Entrance loss coefficient

4. n - Manning's roughness coefficient for the barrel

5. TW - Tailwater depth

6. B - Culvert width

7. D - Culvert height

8. EL.OUTLET - Outlet elevation

9. L - Culvert length

9

Read: HW. EL. - Headwater elevation

#4   Press Label B

   Read: d_c - Critical depth

#5   Press Label C

   Read: H - Total head loss

#6   Press Label D

   Read: V - Outlet velocity

#7   Press Label E

   Enter: Q - Flowrate
            TW - Tailwater depth

   Read: HW EL. - Headwater elevation

CARD FORMAT

1	TEXAS INSTRUMENTS			2
BOX: OUTLET CONTROL PERFORMANCE				#3
				479.59
START	d_c	H	VELOCITY	PERFORMANCE

3	TEXAS INSTRUMENTS			4
DATA - PROGRAM #3				
				479.59

10

<u>LISTING - PROGRAM #3</u>

LBL INV RC* 0 OP 20 RTN LBL LNX INV FIX SBR INV OP 1 SBR INV

OP 2 SBR INV OP 3 SBR INV OP 4 ADV OP 5 RTN LBL CE RCL 1

DIV RCL 2 DIV RCL 6 = Y^X (2 DIV 3) X . 3 1 5 = RTN LBL

CLR 2 1 3 7 Fix 2 OP 4 RTN LBL $X \leq T$ (1 + RCL 3 + 2 9 .

1 6 4 X RCL 4 X^2 X RCL 11 DIV (RCL 6 X RCL 7 DIV (2 X

(RCL 6 + RCL 7))) Y^X (4 DIV 3)) X (RCL 1 DIV RCL

7 DIV RCL 6 DIV RCL 2) X^2 DIV 6 4 . 3 4 8 = RTN LBL X^2

SBR CE $X \leq T$ RCL 7 INV $X \geq T$ 1 50 $X \leq T$ + RCL 7 = DIV 2 =

$X \leq T$ RCL 5 $X \geq T$ 1 64 $X \leq T$ STO 10 SBR LNX SBR CLR SBR $X \leq T$

+ RCL 8 + RCL 10 = OP 6 RTN LBL A 1 2 STO 0 SBR LNX ADV 9

$X \leq T$ 1 STO 09 5 1 0 2 STO 0 RCL 0 OP 4 RCL 9 X=T 2 23

R/S OP 6 ST* 9 OP 29 OP 20 GTO 2 02 R/S $X \leq T$ 5 1 1 2 OP

4 $X \leq T$ OP 6 STO 11 1 6 STO 0 SBR X^2 SBR LNX SBR LNX ADV

9 $X \leq T$ 6 STO 09 5 1 0 7 GTO 2 00 LBL B 2 8 STO 0 SBR

LNX SBR CLR SBR CE OP 6 RTN LBL C 3 2 STO 0 SBR LNX SBR CLR

SBR $X \leq T$ OP 6 RTN LBL D 4 4 STO 0 SBR LNX RCL 48 OP 4 SBR

CE $X \leq T$ RCL 5 INV $X \geq T$ 3 11 $X \leq T$ RCL 7 INV $X \geq T$ 3 18

$X \leq T$ X RCL 6 X RCL 2 DIV RCL 1 = 1/x Fix 2 OP 6 RTN

LBL E 3 6 STO 0 SBR LNX SBR LNX ADV 5 1 0 2 OP 04 1 =

R/S STO 1 OP 06 5 1 0 6 OP 04 5 = R/S STO 5 OP 06 1

6 STO 0 SBR X^2 4 0 STO 0 GTO 3 42   (383 PROGRAM STEPS)

11

DATA REGISTERS - PROGRAM #3

12.	1541274217	31.	2436000000
13.	3537003624	32.	3732371327
14.	4617002000	33.	8023171316
15.	3322300004	34.	8027323636
16.	2317131643	35.	8024360000
17.	1337173500	36.	3317352132
18.	1727174213	37.	3530133115
19.	3724323100	38.	1700154135
20.	2132350030	39.	4217000000
21.	3235170036	40.	1731371735
22.	2446173600	41.	8065346500
23.	1731371735	42.	1331160065
24.	6514570016	43.	3743650000
25.	5700172740	44.	3241372717
26.	3241370013	45.	3700421727
27.	3116002765	46.	3215243745
28.	1535243724	47.	8024360000
29.	1513270016	48.	216336
30.	1733372300		

PROGRAM #4 - BOX CULVERT: INLET CONTROL PERFORMANCE

This program evaluates the hydraulic performance of four different inlet configurations. A detailed explanation of the geometry of these inlets is depicted in the diagrams below:

Square Edged Inlet with Headwalls
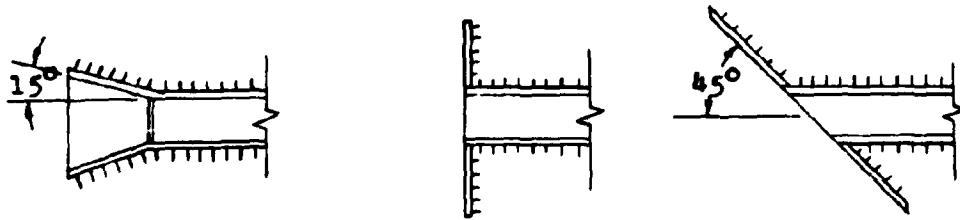
90° and 15° Wingwalls,
Square Edges

Headwalls - Normal or Skewed to 45°,
Square Edges

Square Edged Inlet with 30° - 75° Wingwalls
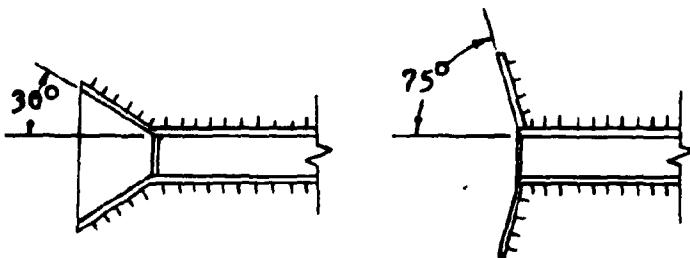
Wingwalls 30° - 75° Flare, Square Edges

1:1 Bevel Edged Inlet with Headwalls
(Note: variable bevel on acute angle of skewed headwall)
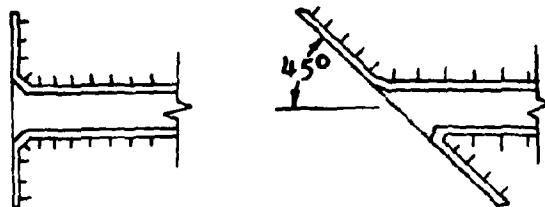
1:1 Bevel Edged Inlet with 45° Wingwalls or
1 1/2:1 Bevel Edged Inlet with 18°-33.7° Wingwalls
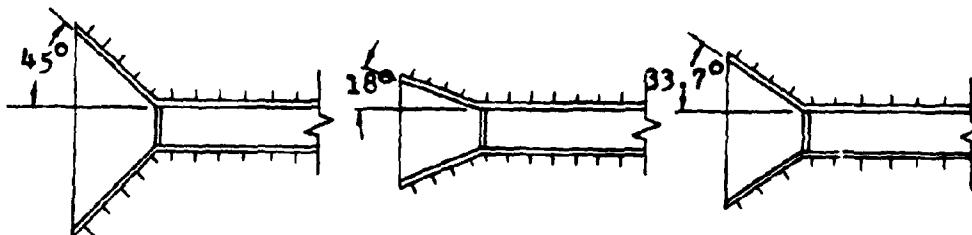
For whichever inlet is chosen, the program calculates the depth of the water at the face of the culvert. This value is then added to the culvert inlet invert elevation. If this sum is less than the design headwater elevation, the inlet elevation becomes the elevation of the face. If, however, this sum exceeds the design headwater elevation, the difference between this sum and the design headwater elevation is subtracted from the inlet invert elevation. This new elevation is now called the elevation of the face. For the culvert to operate properly,

14

the inlet invert must be reset to this face elevation. The drop in elevation
of the inlet invert is called the FALL. The diagrams below graphically show
this occurrence. It should be noted that as the inlet invert drops, the
culvert barrel rotates about the outlet invert.
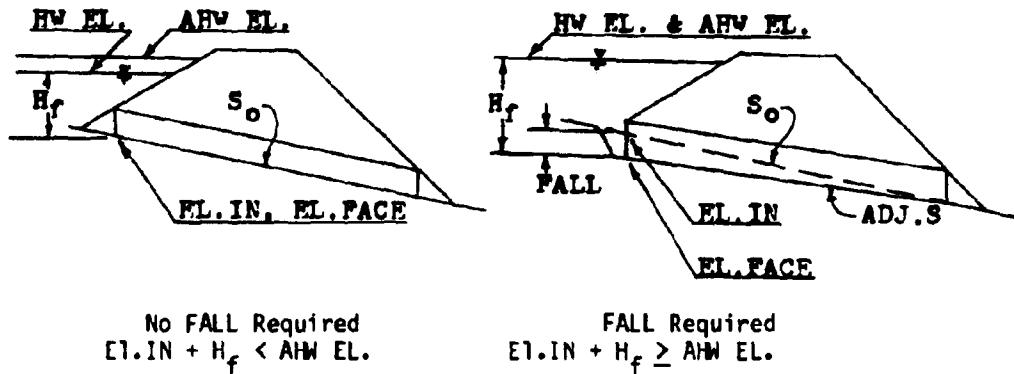
No FALL Required

$El.IN + H_f < AHW\ EL.$

FALL Required

$El.IN + H_f \geq AHW\ EL.$

The diagrams clearly indicate that when the calculated headwater elevation
is above the design headwater elevation, the headwater elevation is set equal
to the design value and the difference is taken up by the FALL.

The inlet invert elevation of the culvert can always be thought of as the
elevation of the face. The original elevation of the culvert inlet invert,
before considering the affects of inlet control and FALL, can be taken as
the "inlet elevation."

The program does not perform checks on the restrictions to the FALL
or the headwater depth. Both of these values must be checked by the
designer.

Once the culvert has been sized for the design flowrate, the performance
of the inlet for other flow rates can be determined. In performing the
performance evaluation the calculator determines the headwater elevation
for any given flow rate.

Whenever applicable, a bevel edged inlet is recommended for use in
lieu of a square edged inlet. The large increase in hydraulic perform-
ance gained by the bevel edged inlet, greatly outweights the small, if any,
additional construction cost.

EQUATIONS

EL.FACE = DHW EL. - H_f (with FALL)

   = EL.INLET   (without FALL)

HW EL. = EL.FACE + H_f

FALL = EL.FACE - EL.INLET

  Note: The FALL is measured in a downward
         direction and therefore is always
         a positive value.

$X = Q/(BND^{1.5})$

Square Edged Inlet with Headwalls

$H_f = D(0.122117 + 0.505435X - 0.108560X^2 + 0.02070809X^3 - 0.00136757X^4$
$+ 0.00003456X^5)$

Square Edged Inlet with Wingwalls

$H_f = D(0.0724927 + 0.507087X - 0.117474X^2 + 0.0221702X^3 - 0.00148958X^4$
$+ 0.0000380X^5)$

A-28

Bevel Edged Inlet with Headwalls

$H_f = D(0.1566086 + 0.3989353X - 0.0640392X^2 + 0.01120135X^3 - 0.0006449X^4$
$+ 0.000014566X^5)$

Bevel Edged Inlet with Wingwalls

$H_f = D(0.0895633 + 0.4412465X - 0.0743498X^2 + 0.01273183X^3 - 0.0007588X^4$
$+ 0.00001774^5)$

INSTRUCTIONS

#1   Load program #4 (2 cards)

#2   Press Label A

#3   Enter: 1. B - Culvert width
            2. D - Culvert height

3. N - Number of barrels

4. EL.INLET - Inlet elevation

5. DHW EL. - Design headwater elevation

6. Q - Flow rate

#4 Select inlet type

Label A' - SQ. Edge w/Headwalls

Label B' - SQ. Edge w/Wingwalls

Label C' - Bevel Edge w/Headwalls

Label D' - Bevel Edge w/Wingwalls

Read: EL.FACE - Elevation of face

      FALL

#5 Press Label D

   Read: H_f - Headwater depth

#6 Run Performance Elevation

Press Label E

   Enter: Q - Flow rate

   Read: HW EL.- Headwater elevation

CARD FORMAT

⬚ 1 ⬚ TEXAS INSTRUMENTS				⬚ 2 ⬚
BOX: INLET CONTROL PERFORMANCE				#4
S W/H	S W/W	B W/H	B W/W	319.79
START	HW EL.	FALL	H_f	PERFORMANCE

⬚ 3 ⬚ TEXAS INSTRUMENTS	⬚ 4 ⬚
DATA - PROGRAM #4	
	319.79

LISTING - PROGRAM #4

```
LBL  INV  =  X  RCL  7  +  LBL  LNX  RC*  8  OP  28  RTN  LBL  CE  INV  FIX
SBR  LNX  OP  1  SBR  LNX  OP  2  SBR  LNX  OP  3  SBR  LNX  OP  4  ADV  OP
5  RTN  LBL  CLR  EXC  8  X≤T  SBR  CE  2  1  3  7  FIX  2  OP  4  X≤T
STO  8  RTN  LBL  X≤T  RCL  6  DIV  RCL  3  DIV  RCL  1  DIV  (  RCL
2  Yˣ  1  .  5  =  S₊0  7  SBR  LNX  SBR  INV  SBR  INV  SBR  INV  SBR  INV
SBR  INV  =  X  RCL  2  ·  X≤T  6  INV  SUM  8  X≥T  STO  9  RTN
LBL  A  1  0  STO  8  SBR  CE  ADV  7  X≤T  1  STO  09  5  1  0  2  STO
0  RCL  0  OP  4  RCL  9  X=T  1  45  R/S  OP  6  ST*  9  OP  20  OP  29
GTO  1  24  OP  0  SBR  0  26  CLR  RTN  LBL  B  6  4  SBR  CLR  SBR  X≤T
+  RCL  0  ·  OP  6  RTN  LBL  A'  1  0  +  LBL  B'  1  0  +  LBL  C'  1  0
+  LBL  D'  1  6  =  STO  8  SBR  CE  6  8  SBR  CLR  SBR  X≤T  X≤T  RCL  5
-  RCL  4  =  X≥T  2  08  X≤T  +/-  +  RCL  5  ·  STO  0  OP  6  LBL  C  7  2
SBR  CLR  RCL  4  -  GTO  1  61  LBL  D  7  6  SBR  CLR  SBR  X≤T  OP  6
RTN  LBL  E  5  6  SBR  CLR  6  0  SBR  CLR  6  INV  FIX  R/S  PRT  STO  6
SBR  B  GTO  2  46    ( 261 PROGRAM STEPS)
```

18

DATA REGISTERS - PROGRAM #4

10.	1432446200	45.	0.0724927
11.	2431271737	46.	3634400017
12.	15323137	47.	1640004363
13.	3532270000	48.	2317131643
14.	2431271737	49.	1327273600
15.	37453317	50.	0.00003456
16.	1442400017	51.	-0.00136757
17.	1640004363	52.	0.0207809
18.	4324312243	53.	-0.10856
19.	1327273600	54.	0.505435
20.	0.00001744	55.	0.122117
21.	-0.0007588	56.	3317352132
22.	0.01273103	57.	3530133115
23.	-0.0743498	58.	1700154135
24.	0.4412465	59.	4217000000
25.	0.0895633	60.	1731371735
26.	1442400017	61.	21273243
27.	1640004363	62.	3513371700
28.	2317131643	63.	15213600
29.	1327273600	64.	2317131643
30.	0.000014566	65.	1337173500
31.	-0.0006449	66.	1727174213
32.	0.01120135	67.	3724323100
33.	-0.0640392	68.	172717
34.	0.3989353	69.	4213372432
35.	0.1566086	70.	3100322100
36.	3634400017	71.	2113151700
37.	1640004363	72.	372317
38.	4324312243	73.	35173441
39.	1327273600	74.	2435171600
40.	0.000038	75.	2113272700
41.	-0.00148958	76.	2317
42.	0.0221702	77.	1316431337
43.	-0.117474	78.	1735001617
44.	0.507087	79.	3337230000

19

PROGRAM # 5 - INLET CONTROL, SLOPE AND LENGTH ADJUSTMENTS

Once a culvert has been designed to operate in inlet control with
FALL, an adjustment must be made to both the slope and the length of
the original culvert. The need for a slope adjustment results from
the lowering of the elevation of the culvert inlet while keeping the
elevation of the outlet a constant. The culvert pivots about the
outlet invert while the slope decreases. The length of the culvert
must be adjusted because when the inlet is lowered the culvert must
be lengthened so the top of the culvert inlet again intersects the
fill slope.

This program can be used to evaluate either box or pipe culverts.
The diagram below indicates the changes in slope and length.
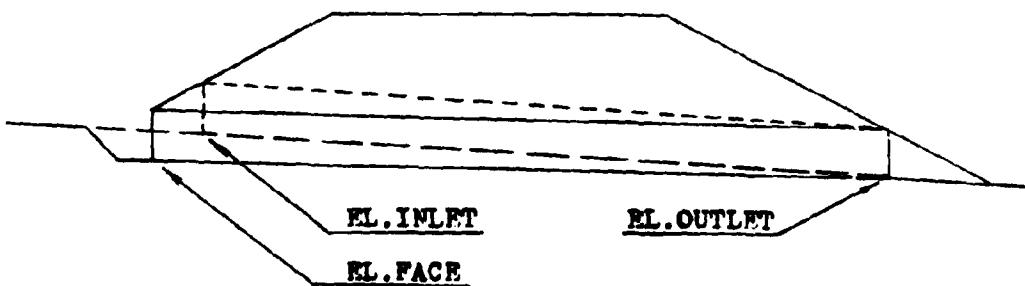
Since this program does not use the width of the culvert in any of the
equations, the program can be applied to multiple barrel applications.

Both, the original culvert length and the adjusted culvert length, are
measured along the barrel. They are not horizontal measurements.

In the design of the streambed entrance to the culvert, the adjusted
slope should be extended a minimum distance of 1/2 D in front of
the culvert. The transition slope which connects the original
streambed slope to the adjusted culvert slope should range between a
3:1 and a 2:1 ratio. This transition slope is referred to as the
FALL slope. The performance of this weir construction is evaluated
in another program.

EQUATIONS

$$\text{ADJ.S} = \frac{LS_0 - FALL\,(S_0^2 + 1)^{.5}}{L + S_{FU}\,(S_0^2 + 1)^{.5}\,(FALL + D[(S_0^2 + 1)^{.5} - (ADJ.S^2 + 1)^{.5}])}$$

$$\text{ADJ.L} = \frac{\left(\dfrac{LS_0}{(S_0^2 + 1)^{.5}}\right) - FALL}{\dfrac{(ADJ.S^2 + 1)^{.5}}{ADJ.S}}$$

The derivations of these equations are found in the appendix.

INSTRUCTION

#1 Load program #5

#2 Press Label A

#3 Enter: 1. D   - Culvert height

2. S_0 - Channel slope

3. FALL

4. S_{FU} - Upstream fill slope

5. L - Culvert length

Read: ADJ.S - Adjusted slope

ADJ.L - Adjusted length

CARD FORMAT

[1]	TEXAS INSTRUMENTS	[4]
INLET CONTROL: SLOPE & LENGTH ADJUSTMENTS		#5
		479.59
Start		

21

LBL INV RC* 8 OP 28 RTN LBL LNX (X^2 + 1) SRX RTN LBL CE

SBP INV OP 1 SBR INV OP 2 SBR INV OP 3 SBR INV OP 4 OP 5

RTN LBL A INV FIX 6 X⟩T 1 STO 09 1 1 STO 8 ADV SBR CE

SBR CE ADV 5 1 0 2 STO 0 RCL 0 OP 4 RCL 9 X=T 0 83 R/S OP 6

ST* 9 OP 29 OP 20 GTO 0 62 1 STO 0 CP FIX 6 RCL 5 X RCL 2

- (RCL 2 SBR LNX X RCL 3 = DIV (RCL 2 SBR LNX X RCL 6

X RCL 4 + RCL 5 = STO 7 SBR LNX X RCL 1 +/- + RCL 3 + (

RCL 2 SBR LNX X RCL 1 = - RCL 6 = EE INV EE X=T 1 76 EXC 10

- RCL 10 = X=T 1 76 1/X X RCL 10 X RCL 0 = STO 0 INV SUM 6

GTO 0 87 RCL 7 X⟩T ADV SBR CE X⟩T PRT SBR LNX DIV RCL 7

X (RCL 5 X RCL 2 DIV RCL 2 SBR LNX - RCL 3 = FIX 2 X⟩T

ADV SBR CE 2 1 3 7 0 0 OP 4 X⟩T OP 6 RTN (222 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #5

11.	2431271737
12.	15323137
13.	3532276200
14.	3627323317
15.	1331160027
16.	1731223723
17.	13162541
18.	3637400000
19.	3723170013
20.	1625413637
21.	1716003627
22.	3233170064
23.	3723170013
24.	1625413637
25.	1716002717
26.	3122372300

PROGRAM #6 - CREST EVALUATION

If not properly designed, the transition section between the streambed and the culvert entrance could adversely affect the operation of the culvert. To insure that the culvert operates in the proper manner, this program computes the required inlet dimensions.

This program is designed to evaluate the crest control dimensions for both box and pipe culverts. These culverts can be operating under either inlet control or side-tapered throat-control.

The diagrams below indicate the dimensions determined by the program.
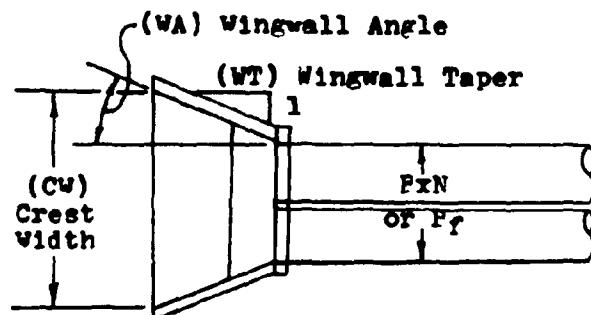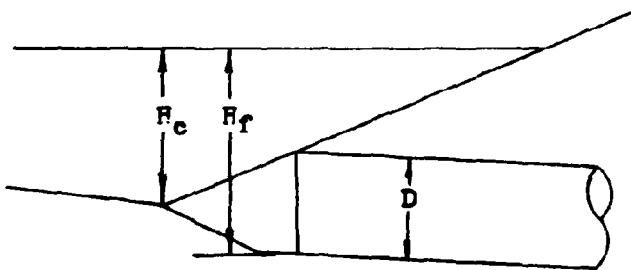
For conventional culverts, the culvert width is input as item #3. When a side tapered inlet is used, the face width value is input for prompt #3.

EQUATIONS

$$H_c = HW\ EL. - EL.OUTLET - \frac{S_0(S_f - ADJ.S)(D/2 + ADJ.L)}{(S_f-S_0)\ (Adj.\ S^2+1)^{.5}}$$

$$CW = \frac{Q}{(2H_c)^{1.5}}$$

$$WT = \frac{L_0 - \frac{L}{(Adj.S^2+1)^{.5}}}{(CW - BN)/2}$$

$$WA = 90° - ARCTANGENT(WT)$$

The derivations of these equations are found in the appendix.

INSTRUCTIONS

#1   Load program #6

#2   Press Label A

#3   Enter: 1.   Q - Flow rate

2.   D - Culvert height

3.   B or Bf - Culvert width or face width

4. S_0 - Channel slope

5.   HW EL. - Headwater elevation

6. S_f - FALL slope

7.   ADJ.L - Adjusted length

8.   ADJ.S - Adjusted slope

9.   N - Number of barrels

10.   EL.OUTLET - Outlet elevation

Read: H_c - Crest height

CW - Crest width

WT - Wingwall taper

WA - Wingwall angle

24

CARD FORMAT

[1]	TEXAS INSTRUMENTS	[4]
	CREST CONTROL EVALUATION	#6
		479.59
Start		.

LISTING - PROGRAM # 6

LBL INV RC* 0 OP 20 RTN LBL LNX INV FIX SBR INV OP 2

SBR INV OP 3 SBR INV OP 4 ADV OP 5 RTN DIV (RCL 8 X^2

+ 1) SRX = RTN = X$\gtrless$T SBR LNX RCL 29 FIX 2 OP 4 X$\gtrless$T

OP 6 RTN LBL A INV FIX 1 0 STO 0 SBR INV OP 1 SBR LNX

OP 0 ADV 5 1 0 2 STO 00 9 X$\gtrless$T 1 STO 9 RCL 0 OP 4 RCL

9 X=T 1 01 R/S OP 6 ST* 9 OP 29 OP 20 GTO 0 80 R/S X$\gtrless$T

5 1 1 2 OP 4 X$\gtrless$T OP 6 PRD 03 1 0 = R/S X$\gtrless$T RCL 26

OP 4 X$\gtrless$T OP 6 INV SUM 05 1 4 STO 0 RCL 7 SBR 0 27 STO

9 + (RCL 2 DIV 2 SBR 0 27 X (RCL 6 - RCL 8 = DIV (

RCL 6 - RCL 4 = INV SUM 9 X RCL 4 +/- + RCL 5 SBR 0 38

X 2 = Y^X 1 . 5 = 1/X X RCL 1 SBR 0 38 - RCL 3 = DIV

2 DIV RCL 9 +/- = 1/X CP X$\geq$T 2 10 0 X$\gtrless$T SBR LNX RCL 27

SBR 0 44 INV TAN - 9 0 = +/- X$\gtrless$T SBR LNX RCL 28 SBR

0 44 CLR RTN (234 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #6

10.	1535173637	21.	1327270037
11.	15323137	22.	1333173500
12.	3532270017	23.	4324312243
13.	4213274000	24.	1327270013
14.	1535173637	25.	3122271700
15.	23172422	26.	510201
16.	2337000000	27.	620002
17.	1535173637	28.	161722
18.	43241637	29.	213700
19.	2300000000		
20.	4324312243		

PROGRAM #7 - BOX CULVERT: THROAT CONTROL PERFORMANCE

Another method which can be used to increase a culverts performance is to redesign the throat. Two different types of throat improvements can be evaluated with this program, side- and slope-tapered inlets.

Like the improved inlet programs, throat control programs often can use FALL to increase the flow capacity of a culvert. The following diagrams describe the throat control inlets.
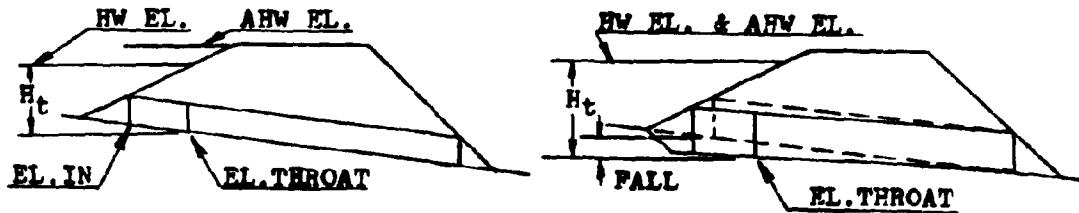
ELEVATION VIEW

PLAN VIEW

SIDE-TAPERED INLET
NO FALL, AHW EL. > HW.EL.

SIDE-TAPERED INLET
WITH FALL, AHW EL. ≤ HW.EL.

26
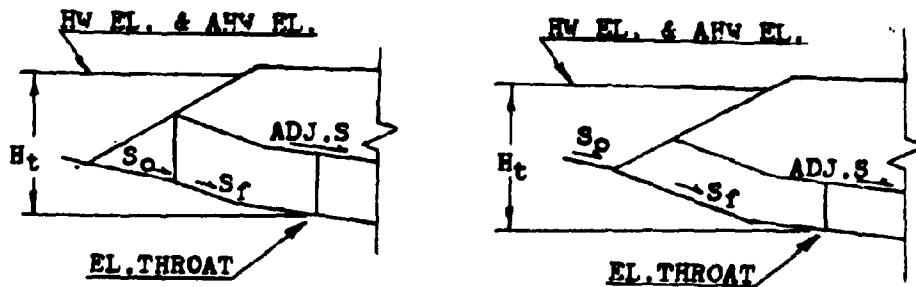
ELEVATION VIEW

PLAN VIEW

| SLOPE-TAPERED INLET | SLOPE-TAPERED INLET |
| VERTICAL FACE | MITERED FACE |

The limits placed on the FALL value for the improved inlet programs also apply to the throat control design. These are a minimum of 1/4 D and a maximum of 1 1/2 D. If the upper limit is exceeded, a larger size should be evaluated. If the minimum value is not achieved, the presence of FALL will not significantly increase the capacity of the culvert.

The designer should be aware that a small error results in the computation of the FALL. The program assumes that the elevation of the inlet and the elevation of the throat are equal before determining the value of the headwater elevation. This assumption is false and a small difference equal to the channel slope times the vertical distance between the inlet and the throat section, is present. This vertical distance is an unknown value and is determined in a later program. By understanding this error, a correction, if necessary, can be made.

27

EQUATIONS

$$\text{EL.THROAT} = \text{DHW EL.} - H_t \quad \text{(with FALL)}$$

$$= \text{EL.INLET} \quad \text{(without FALL)}$$

$$\text{HW EL.} = \text{EL.THROAT} + H_t$$

$$\text{FALL} = \text{EL.INLET} - \text{EL.THROAT}$$

$$H_t = D(0.1295033 + 0.3789445X - 0.0437778X^2 + 0.00426329X^3 - 0.000106358X^4)$$

$$X = Q/(NBD^{1.5})$$

INSTRUCTIONS

#1   Load program #7

#2   Press Label A

#3   Enter: 1. B - Culvert width

               2. D - Culvert height

               3. N - Number of Barrels

               4. EL.INLET - Inlet elevation

               5. DHW EL. - Design headwater elevation

               6. Q - Flow rate

    Read: EL.THROAT - Throat elevation

            FALL

#4   Check FALL limitations for slope-tapered inlet

$$1/4\ D \le \text{FALL} \le 1\ 1/2\ D$$

#5   Press Label D

    Read: H_f - Headwater depth

36   Run Performance evaluation

    Press Label E

    Enter: Q - Flow rate

    Read: HW EL. - Headwater elevation

	TEXAS INSTRUMENTS			4

BOX: THROAT CONTROL PERFORMANCE				#7
.				479.59
Start	HW EL.	FALL	H_t	Performance

LISTING - PROGRAM #7

LBL INV = X RCL 7 + LBL LNX RC* 8 OP 28 RTN LBL CE INV

FIX SBR LNX OP 2 SBR LNX OP 3 SBR LNX OP 4 ADV OP 05 2

1 3 7 FIX 2 OP 4 RTN LBL CLR 1 9 STO 8 RCL 6 DIV RCL

3 DIV RCL 1 DIV (RCL 2 Y^X 1 . 5 = STO 7 SBR LNX SBR

INV SBR INV SBR INV SBR INV = X RCL 2 = STO 9 RTN LBL A 1

0 STO 8 SBR CE SBR CE ADV INV FIX 7 $X \gtrless T$ 1 STO 09 5 1

0 2 STO 0 RCL 0 OP 4 RCL 9 X=T 1 30 R/S OP 6 ST* 9 OP

29 OP 20 GTO 1 09 SBR CE SBR CLR $X \gtrless T$ RCL 5 - RCL 4 =

$X \geq T$ 1 45 $X \gtrless T$ +/- + RCL 5 = STO 0 OP 6 LBL C OP 00 2 1

1 3 2 7 2 7 OP 2 SBR 0 30 RCL 4 - GTO 1 88 LBL B 2 4

STO 8 SBR CE SBR CLR + RCL 0 = OP 6 RTN LBL D RCL 24

OP 2 RCL 25 OP 03 1 6 1 7 3 3 3 7 2 3 SBR 0 28 SBR

CLR OP 6 RTN LBL E 2 7 STO 8 SBR CE 6 = R/S PRT STO 6

SBR B GTO E   (239 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #7

10.	3723353213	20.	0.00426329
11.	3700153231	21.	-0.0437778
12.	3735322700	22.	0.3789445
13.	3713331735	23.	0.1295033
14.	1716002431	24.	2317131643
15.	2717370000	25.	1337173500
16.	1727174240	26.	1727174240
17.	32210037	27.	1731371735
18.	2335321337	28.	21273243
19.	-0.000106358	29.	3513371700

PROGRAM #8 - BOX CULVERT: SIDE-TAPERED INLET DIMENSIONS

This program continues with the design of a culvert operating in throat control. The inlet dimensions for either a square or bevel edged face can be obtained.

Inlets which fall into the square edged catageory include those with wingwall flare angles from 15° to 26° with only a top beveled edge and those with wingwall flare angles from 26° to 90° with all edges squared. These inlets are shown below.
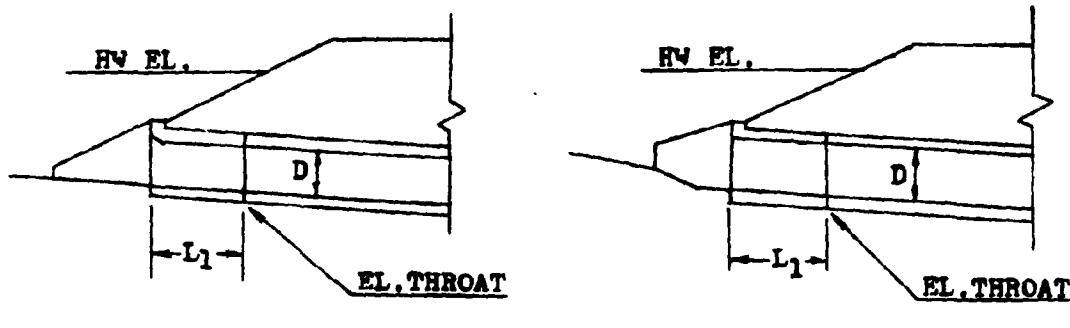
ELEVATION VIEW
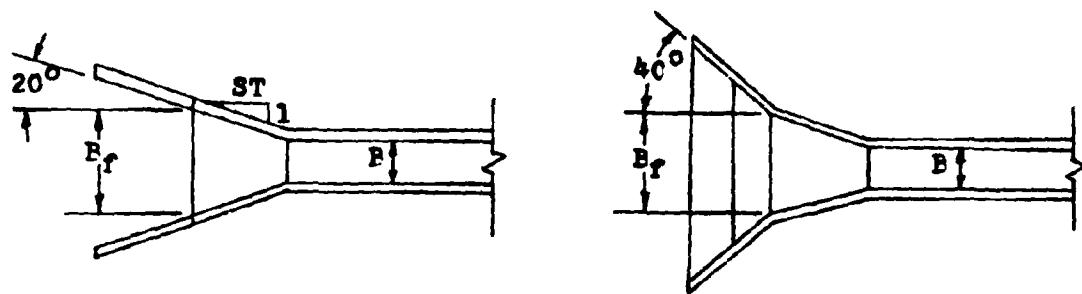
PLAN VIEW

15° to 26° Wingwall Flare
Top Edge Beveled - No FALL

26° to 90 Wingwall Flare
All Edges Square - With FAll

30

The bevel edged inlets have wingwall flare angles of 26° to 45° with top edges beveled or inlets with wingwall flare angles of 45° to 90° with both top and side edges beveled. For further details, refer to the diagrams below.
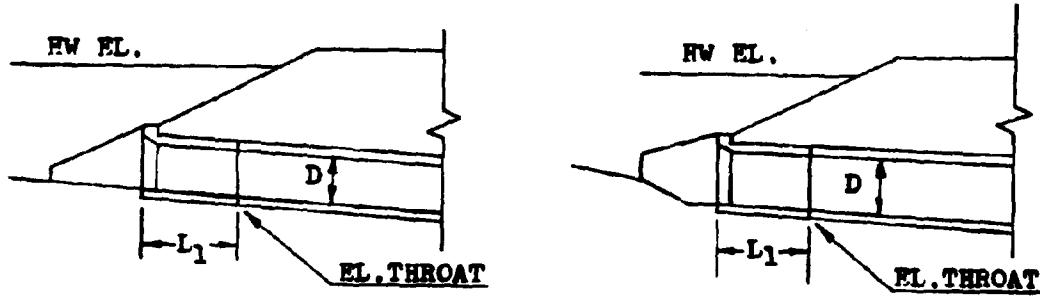
ELEVATION VIEW
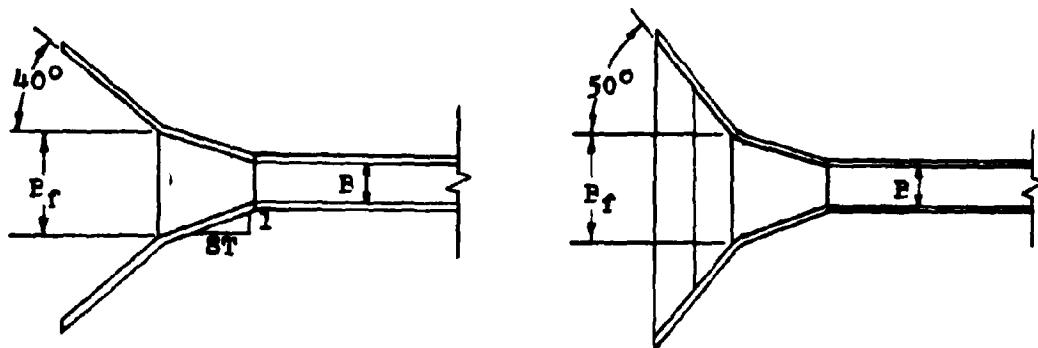
PLAN VIEW

26° to 45° Wingwall Flare
Top Edge Beveled - No FALL

45° to 90 Wingwall Flare
Top and Sides Beveled - FALL

31

This program determines five different inlet dimensions for a side-tapered inlet. These are the adjusted culvert slope, the adjusted length, the culvert face width, the inlet length, and the elevation of the face. The face width and inlet length are a direct result of using the side-tapered inlet. The change in slope, length and face elevation are a result of using FALL in the inlet design.

The adjusted length computed by the calculator does not include the length of the improved inlet.

Where prefabricated inlet sections are available, both the face width and the inlet length have usually been set by the manufacturing company. These values are normally set at 1 1/2 times the culvert diameter.

The sidewall taper chosen for the culvert inlet is limited to a ratio between a 4:1 and a 6:1. Ratios less than 4:1 are unacceptable and will not operate as side-tapered inlets. Values greater than 6:1 will perform better than the design will indicate. With this larger value the design will be conservative.

The value for the inlet length determined by this program is a horizontal measurement. The values of culvert length and the adjusted culvert length are both culvert distances measured along the culvert barrel.

EQUATIONS

$$(ADJ.S)L = L_1 ADJ.S \ (S_0^2+1)^{.5} + S_0 L - FALL \ (S_0^2+1)^{.5} - (FALL + D[(S_0^2+1)^{.5}$$
$$- (ADJ.S^2 + 1)^{.5}]) - L_1 \ ADJ.S \ [S_{fu} \ (S_0^2+1)^{.5} \ ADJ.S]$$

$$L_1 = (B_f - BN)ST/2$$

$$H_f = H_t - L_1 \ (ADJ.S)$$

$$X = H_f/D$$

Square Edges

$$B_f = Q/[D^{1.5}(-1.219 + 4.3X - 0.6153X^2 + 0.0273X^3 + 0.0027^4)]$$

Bevel Edges

$$B_f = Q/[D^{1.5}(-1.13607 + 0.0256923X^4 + 0.12128X^2 - 0.205339X^3 + 0.0256923X^4)]$$

B_f, L_1 and ADJ.S are computed simultaneously by trial and error.

$$ADJ.L = [\frac{S_0 L}{(S_0^2 + 1)^{.5}} - FALL] \ \frac{[(ADJ.S^2 + 1)^{.5}]}{ADJ.S} - L_1 \ (ADJ.S^2 + 1)^{.5}$$

$$EL.FACE = EL.THROAT + L_1 ADJ.S$$

The derivations for these equations can be found in the appendix.

32

INSTRUCTIONS

#1   Load program #8 (2 cards)

#2   Press Label A

#3   Enter: 1. Q - Flow rate

              2. D - Culvert height

              3. N - Number of barrels

              4. H_t - Headwater depth at the throat

              5. ST - Sidewall taper

              6. S_o - Channel slope

              7. FALL

              8. S_{FU} - Upstream fill slope

              9. L - Original culvert length

              10. B - Culvert Width

              11. EL.THROAT - Throat elevation

#4   Choose inlet type

     Label B - Square edges

     Label C - Bevel edges

#5   Read: ADJ.S - Adjusted slope

            ADJ.L - Adjusted length

              B_f - Face width

              L_1 - Inlet length

            EL.FACE - Face elevation

CARD FORMAT

1	TEXAS INSTRUMENTS			2
BOX: SIDE-TAPERED INLET DIMENSIONS				#8
				479.59
Start	SQ.EDGES	BV.EDGES		

3	TEXAS INSTRUMENTS	4
DATA-PROGRAM # 8		
		479.59

LISTING - PROGRAM #8

LBL INV = X RCL 10 + LBL LNX RC* 0 OP 20 RTN LBL CE INV

FIX SBR LNX OP 1 SBR LNX OP 2 SBR LNX OP 3 SBR LNX OP 4

ADV OP 05 2 1 3 7 FIX 2 OP 4 RTN LBL CLR (RCL 6 x^2

+ 1) SRX RTN LBL X$\gtrless$T NOP (RCL 12 SBR 0 51 RTN LBL A 3

5 STO 0 SBR CE OP 0 INV FIX SBR LNX OP 1 SBR LNX OP 2 OP

5 ADV 9 X$\gtrless$T 1 STO 09 5 1 0 2 STO 0 RCL 0 OP 4 RCL

9 X=T 1 22 R/S OP 6 ST* 9 OP 29 OP 20 GTO 1 01 R/S

X$\gtrless$T 5 1 1 2 OP 4 X$\gtrless$T OP 6 STO 09 1 0 = R/S X$\gtrless$T

5 1 0 2 0 1 STO 0 OP 4 X$\gtrless$T OP 6 PRD 3 OP 20 RCL 0

OP 04 1 1 = R/S OP 6 STO 16 OP 00 4 1 STO 0 SBR 0 26

CLR RTN LBL B 9 + LBL C 1 7 = STO 0 RCL 6 STO 12 SBR CE

1 CP +/- + RCL 4 = DIV RCL 2 = STO 10 SBR LNX SBR INV SBR

INV SBR INV SBR INV = 1/x X RCL 1 DIV RCL 2 Y^X 1 . 5 =

FIX 3 EE INV EE X=T 2 69 - X$\gtrless$T RCL 3 = DIV 2 X RCL 5 =

34

STO 11 X RCL 12 = STO 13 5 INV SUM 0 RCL 13 GTO 1 99

X⤸T RCL 3 X≥T 2 81 X⤸T STO 10 GTO 2 88 0 STO 11 RCL

3 STO 10 CP . 1 STO 13 RCL 12 STO 14 RCL 2 X (SBR CLR

- SBR X⤸T = + RCL 7 - RCL 12 X RCL 11 = X SBR CLR

X RCL 8 X RCL 12 - RCL 6 X RCL 9 + SBR CLR X RCL 7 -

SBR CLR X RCL 12 X RCL 11 + RCL 9 X RCL 12 = FIX 6 EE

INV EE INV X=T 3 78 RCL 15 X⤸T RCL 12 X=T 4 02 STO 15

RCL 11 GTO 2 54 EXC 14 - RCL 14 = X=T 3 63 1/x X RCL 14

X RCL 13 = STO 13 SUM 12 GTO 2 97 4 3 STO 0 SBR CE RCL

12 FIX 6 PRT SBR 0 26 RCL 9 X RCL 6 DIV SBR CLR - RCL 7 =

X SBR X⤸T DIV RCL 12 - RCL 11 X SBR X⤸T = OP 6 SBR

CE RCL 10 OP 6 SBR 0 22 RCL 11 OP 6 SBR CE RCL 16 + RCL

12 X RCL 11 = CP 6 RTN (469 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #8

17.	3624161720	39.	1624301731
18.	3713331735	40.	3624323136
19 .	14424000	41.	2431271737
20.	1716221736	42.	37453317
21.	0.0256923	43.	3723170013
22 .	-0.205339	44.	1625413637
23.	0.12128	45.	1716003637
24.	3.69853	46.	3233170064
25.	-1.13607	47.	1716002717
26.	3624161720	48.	3122372300
27.	3713331735	49.	1541274217
28.	36344000	50.	3537002113
29.	1716221736	51.	1517004324
30.	0.0027	52.	1637230000
31.	0.0273	53.	3537002431
32.	-0.6153	54.	2717370027
33.	4.3	55.	1731223723
34.	-1.219	56.	1727174213
35.	1432440015	57.	3724323100
36.	4127421735	58.	3221002113
37.	3700200024	59.	1517000000
38.	3127173700		

PROGRAM #9 - SLOPE-TAPERED INLET DIMENSIONS

The slope-tapered inlet is the second type of improvement which uses throat control. This program evaluates the change in slope and length to the culvert resulting from the use of FALL in the hydraulic design. It also determines the elevation of the face and two inlet dimensions.

The program will calculate these inlet features for either a vertical face inlet or a mitered face inlet. The diagrams below show the differences between these two configurations.
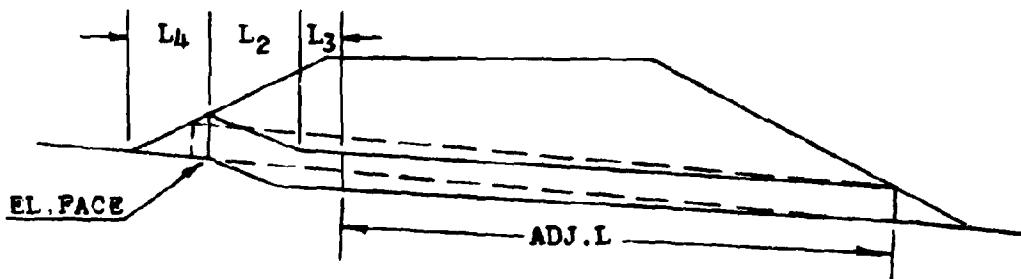
SLOPE-TAPERED, VERTICAL FACE INLET
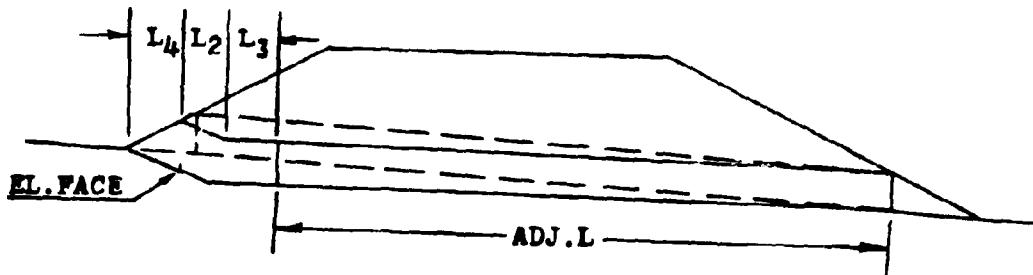
SLOPE-TAPERED, MITERED FACE INLET

The value of L_3, prompt #2, is not calculated by the program but is usually set equal to one-half the culvert width. Values larger may be used but smaller values cannot.

The adjusted length value is measured along the culvert barrel and does not include the length of the improved inlet.

This program can be applied to either box or pipe culverts.

It should be noted that even though the face elevation is calculated for the mitered face inlet, there is no break in the culvert slope to mark this elevation.

EQUATIONS

Vertical Face

$$L_3 ADJ.S = EL.FU + \frac{D(S_f^2 + 1)^{.5}(S_{FU} + S_f)}{(S_{FU}S_o + 1)S_f^2} + \frac{L_3}{S_f} + \frac{EL.OUT - EL.FU}{S_o S_f}$$

$$+ \frac{EL.THROAT - EL.OUT}{S_f ADJ.S} - D(ADJ.S^2 + 1)^{.5} - EL.THROAT$$

$$EL.FACE = EL.FU - L_4 S_o$$

$$L_4 = \frac{S_{FU} D(S_f + 1)^{.5}}{S_f(S_o S_{FU} + 1)^{.5}}$$

Mitered Face

$$L_3 ADJ.S = EL.FU + \frac{D(S_f^2 + 1)^{.5}}{S_f} + \frac{L_3}{S_f} + \frac{EL.OUT - EL.FU}{S_o S_f}$$

$$+ \frac{EL.THR - EL.OUT}{(ADJ.S)S_f} - D(ADJ.S^2 + 1)^{.5} - EL.THROAT$$

$$EL.FACE = EL.FU - L_4/S_f$$

$$L_4 = \frac{S_{FU} D(S_f + 1)^{.5}}{S_{FU} + S_f}$$

Both

$$L_2 = \frac{EL.FU - EL.OUT}{S_o} - L_4 - L_3 - \frac{EL.THR - EL.OUT}{ADJ.S}$$

$$ADJ.L = \frac{(EL.THROAT - EL.OUT)(ADJ.^2 + 1)^{.5}}{ADJ.S}$$

The derivations of these equations can be found in the appendix.

INSTRUCTIONS

#1 Load program #9 (2 cards)

#2 Press Label A

#3 Enter: 1. D - Culvert height

2. L_3 - One-half the culvert width

3. S_o - Channel slope

4. EL.OUTLET - Outlet elevation

5. S_{FU} - Upstream fill slope

6. EL.FU - Upstream fill slope catch point elevation

7. S_f - FALL slope

8. EL.THROAT - Throat elevation

#4 Choose inlet type

Label B - Vertical face

Label C - Mitered face

#5 Read: ADJ.S - Adjusted slope

ADJ.L - Adjusted length

EL.FACE - Face elevation

L_4 - Inlet dimension

L_2 - Inlet dimension

CARD FORMAT

	TEXAS INSTRUMENTS		2
BOX: SLOPE-TAPERED INLET DIMENSIONS			#9
			479.59
Start	VERT.FACE	MIT. FACE	

	TEXAS INSTRUMENTS		4
DATA-PROGRAM #9			
			479.59

LISTING - PROGRAM #9

LBL INV RC* 0 OP 20 RTN LBL LNX INV FIX SBR INV OP 1 SBR

INV OP 2 SBR INV OP 3 SBR INV OP 4 ADV OP 05 2 1 3 7

FIX 2 OP 4 RTN LBL CE (x^2 + 1) SRX RTN LBL A 1 4

STO 0 SBR LNX INV FIX OP 0 SBR INV OP 1 SBR INV OP 2

OP 5 ADV 9 X≷T 1 STO 09 5 1 0 2 STO 0 RCL 0 OP 4

RCL 9 X=T 1 03 R/S OP 6 ST* 9 OP 29 OP 20 GTO 0 82 OP

00 2 0 STO 0 SBR 0 19 CLR RTN LBL B 2 2 STO 0 SBR LNX

RCL 7 SBR CE X RCL 1 X (RCL 5 + RCL 7) DIV RCL 7 x^2

DIV (RCL 5 X RCL 3 + 1 = GTO 1 75 LBL C 2 6 STO 0 SBR

LNX RCL 7 SBR CE X RCL 1 DIV RCL 7 = STF 1 CP + RCL 6 -

RCL 8 + RCL 2 DIV RCL 7 + (RCL 4 - RCL 6) DIV RCL 7 DIV

RCL 3 STO 10 STO 9 STO 11 = STO 12 RCL 8 - RCL 4 = DIV

RCL 7 = STO 13 FIX 6 RCL 1 X RCL 9 SBR CE + RCL 2 X RCL 9 -

RCL 13 DIV RCL 9 - RCL 12 = EE INV EE X=T 2 78 EXC 10 - RCL

10 = X=T 2 78 1/x X RCL 10 X RCL 11 = STO 11 SUM 9 GTO 2 25

3 0 STO 0 SBR LNX RCL 9 FIX 6 PRT SBR 0 19 RCL 9 SBR CE DIV

RCL 9 X (RCL 8 - RCL 4 = OP 6 SBR LNX RCL 1 X RCL 7 SBR CE

IFF 1 3 36 DIV RCL 7 DIV (RCL 3 + RCL 5 1/x GTO 3 46 X RCL

5 DIV (RCL 5 + RCL 7 = STO 11 IFF 1 3 59 X RCL 3 GTO 3 65

INV STF 1 DIV RCL 7 +/- + RCL 6 = OP 6 SBR LNX RCL 11 OF 6

SBR 0 23 RCL 6 - RCL 4 = DIV RCL 3 - RCL 11 - RCL 2 - (

RCL 8 - RCL 4) DIV RCL 9 = OP 6 CLR RTN   (411 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #9

14.	3627323317	30.	3723170013
15.	2037133317	31.	1625413637
16.	3517160024	32.	1716003627
17.	3127173700	33.	3233170064
18.	1624301731	34.	1716002717
19.	3624323136	35.	3122372300
20.	2431271737	36.	172717
21.	37453317	37.	4213372432
22.	4217353724	38.	3100322100
23.	1513270021	39.	2113151700
24.	1315170024	40.	24312717
25.	3127173700	41.	3700271731
26.	30243717	42.	2237236200
27.	3517160021	43.	2705006400
28.	1315170024	44.	2703006400
29.	3127173700		

PROGRAM #10 - SLOPE-TAPERED FACE DIMENSIONS

This program continues with the design of the slope-tapered inlet. The face width and sidewall taper for either a square edged or bevel edged inlet is determined. For a mitered face condition, the designer should evaluate the possibility of crest control. The calculator also performs this operation within program #10 and produces the crest height, the crest width and the minimum sidewall taper which ensures crest control. As long as this last value is exceeded, the culvert will operate properly in throat control.

Inlets with square edges have wingwall flare angles of 15° to 26° with a top beveled edge, or a wingwall flare angle of 26° to 90° with all edges squared. See diagram below .
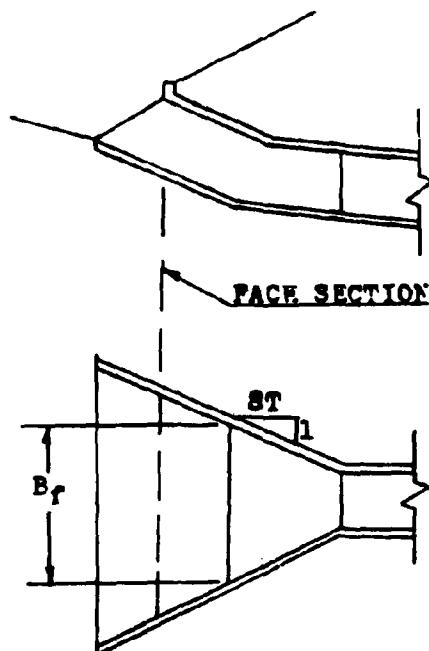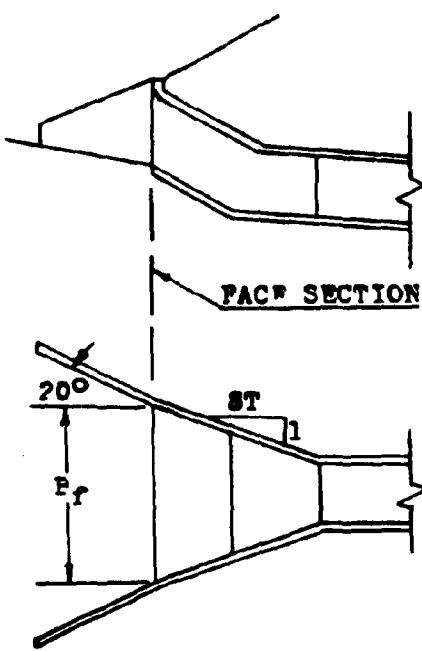
Vertical Face
15° to 26° Wingwall Flare
Top Edge Beveled

Mitered Face
All edges Square

41

The bevel edged segment of this program pertains to inlets with wingwall
flare angles of 26° to 45° with their top edges beveled and to inlets with
wingwall flare angles of 45° to 90° with both top and side beveled edges.
For a more detailed description, see diagram below.
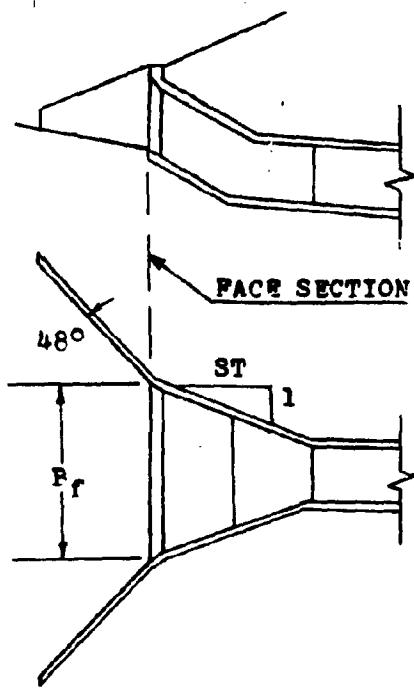
Vertical Face
45° to 90° Wingwall Flare
Both Top & Side Edges Beveled
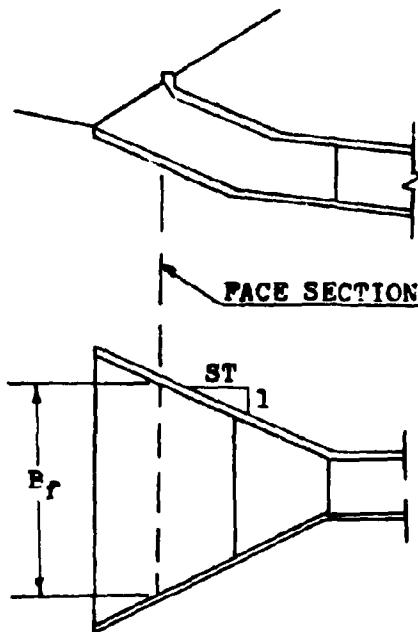
Mitered face
Top Edge Beveled

As mentioned before and as seen in the diagrams, this program can be applied
to either vertical or mitered face inlets. Since the mitered face inlet
generally has no wingwalls, the distinction between the use of these two
selections as they pertain to the mitered inlet is whether the top edge is
to be beveled or squared.

To use the program for the vertical face condition, the face elevation and

the length L_2 should come from the vertical face calculations from the
previous programs. For the mitered face inlet, these two values should
correspondingly come from mitered faced programs.

42

EQUATIONS

$$ST = \frac{L_2 + L_3}{\frac{B_f - BN}{2}}$$

$$X = \frac{HW\ EL. - EL.FACE}{D}$$

Square Edges

$$B_f = Q/[D^{1.5}\,(-1.353 + 5.15X - 1.131X^2 + 0.1578X^3 - 0.0144X^4 + 0.0011X^5)]$$

Bevel Edges

$$B_f = Q/[D^{1.5}(-2.265863 + 7.942441X - 4.0350294X^2 + 1.61981X^3 - 0.3458214X^4$$
$$+ 0.02846767X^5)]$$

Crest Evaluation

$$H_c = HW\ EL. - EL.FACE$$

$$CW = \frac{Q}{(2H_c)^{1.5}}$$

$$\text{Minimum } ST = \frac{2L_4}{CW - B_f}$$

Slope-tapered, Mitered-face Inlet

43
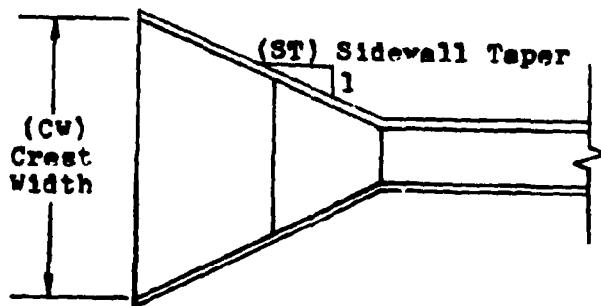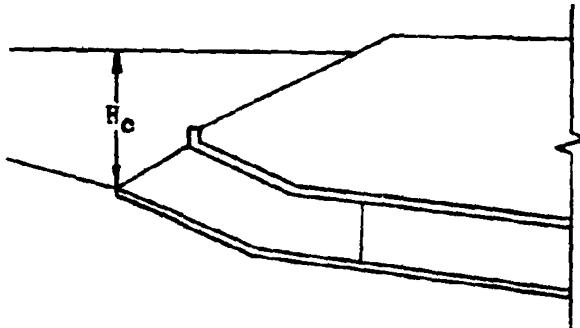
INSTRUCTIONS

#1   Load program #10   (2 cards)

#2   Press Label A

#3   Enter: 1. Q - Flow rate

2. D - Culvert height

3. L_3 - One-half the culvert width

4. N - Number of barrels

5. B - Culvert width

6. HW.EL - Headwater elevations

7. EL.FACE - Face elevation

8. L_2 - An inlet dimension from previous programs

9. L_4 - An inlet dimension from previous programs

#4   Choose inlet type

Label B - Square Edges

Label C - Beveled Edges

#5   Read: B_f - Face width

ST - Sidewall taper

#6   For Crest Evaluation, Mitered Inlet

Press Label D

#7   Read: H_c - Crest height

CW - Crest width

ST - Minimum sidewall taper

.

CARD FORMAT

⬚ 1 ⬚	TEXAS INSTRUMENTS			⬚ 2 ⬚
BOX: SLOPE-TAPERED FACE DIMENSIONS				**#10**
				399.69
Start	SQ.EDGES	BV.EDGES	MIT.CREST	

⬚ 3 ⬚	TEXAS INSTRUMENTS	⬚ 4 ⬚
DATA-PROGRAM # 10		
		399.69

LISTING - PROGRAM #10

```
LBL  INV  =  X  RCL  10  +  LBL  LNX  RC*  0  OP  20  RTN  LBL  CE  INV

FIX  SBR  LNX  OP  1  SBR  LNX  OP  2  SBR  LNX  OP  3  SBR  LNX  OP  4

OP  05  2  1  3  7  FIX  2  OP  4  RTN  LBL  A  1  2  STO  0  SBR  CE  SBR

CE  ADV  INV  FIX  9  X≤T  1  STO  09  5  1  0  2  STO  0  RCL  0  OP

4  RCL  9  X=T  0  90  R/S  OP  6  ST*  9  OP  29  OP  20  GTO  0  69

R/S  X≤T  5  1  1  2  OP  4  X≤T  OP  6  STO  9  ADV  OP  00  2  0

STO  0  SBR  0  26  CLR  RTN  LBL  B  1  0  +  LBL  C  2  2  =  STO  0  ADV

SBR  CE  ADV  RCL  6  -  RCL  7  =  DIV  RCL  2  =  STO  10  SBR  LNX  SBR

INV  SBR  INV  SBR  INV  SBR  INV  SBR  INV  =  1/x  X  RCL  1  DIV  RCL  2

Y^X  1  .  5  =  STO  11  4  2  STO  0  SBR  CE  RCL  11  OP  6  ADV  -

RCL  4  X  RCL  5  =  DIV  2  =  1/X  X  (  RCL  8  +  RCL  3  =  X≤T  OP

0  INV  FIX  SBR  0  22  6  2  0  0  0  2  SBR  0  40  X≤T  OP  6  ADV
```

45

CLR RTN LBL D 4 9 STO 0 SBR CE SBR CE ADV OP 0 CP INV FIX

SBR 0 22 RCL 6 - RCL 7 = OP 6 ADV X 2 = Y^x 1 . 5 =

1/X X RCL 1 = STO 10 INV FIX SBR 0 26 RCL 10 OP 6 ADV -

RCL 11 = DIV 2 DIV RCL 9 = 1/X INV X$\geq$T 2 92 X$\leq$T OP 0 INV

FIX SBR LNX OP 2 SBR LNX OP 3 OP 05 4 6 STO 0 GTO 2 03

(312 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #10

12.	3627323317	38.	0.1578
13.	2037133317	39.	-1.131
14.	3517160024	40.	5.15
15.	3127173700	41.	-1.353
16.	2113151700	42.	2431271737
17.	1624301731	43.	21131517
18.	3624323136	44.	43241637
19.	0	45.	2300000000
20.	2431271737	46.	36241617
21.	37453317	47.	4313272700
22.	3627323317	48.	3713331735
23.	2037133317	49.	3024
24.	3500144240	50.	3717351716
25.	17164000	51.	24312717
26.	0.02846767	52.	3700000000
27.	-0.3458214	53.	153517
28.	1.619481	54.	3637001742
29.	-4.0350294	55.	1327411337
30.	7.942441	56.	2432310000
31.	-2.265863	57.	1535173637
32.	3627323317	58.	23172422
33.	2037133317	59.	2337000000
34.	3500363440	60.	43241637
35.	17164000	61.	2300000000
36.	0.0011	62.	30243124
37.	-0.0144	63.	3041300000

PROGRAM #11 - BOX CULVERT: INLET CONTROL, OUTLET VELOCITY

As is stated in the title, this program computes the velocity of the flow at the outlet of a box culvert which is operating in inlet control. The inlet control mentioned here also includes box culverts operating under throat control.

In performing this velocity computation, this program employs two polynomial equations which approximate the normal depth curve for a rectangular cross-sectional area. The curve referred to was taken from "Open Channel Hydraulics" by Chow. See reference #4.

EQUATIONS

$$X = \frac{Qn}{1.486NS^{.5}B^{8/3}}$$

If $X < 0.22$

$$d_n = B(0.036402 + 3.648374X - 15.152238X^2 + 64.991913X^3 - 110.31635X^4)$$

If $0.22 \leq x \leq 1.1$

$$d_n = B(0.084468 + 2.34061X - 1.53643X^2 + 1.636594X^3 - 0.677621X^4)$$

Note: $\dfrac{d_n}{B}$ is limited to a maximum of 2.

If $X > 1.1$

$$d_n = D$$
$$V = \frac{Q}{BNd_n}$$

INSTRUCTIONS

#1   Load program #11

#2   Press Label A

#3   Enter: 1. Q - Flow rate

                2. D - Culvert height

                3. N - Number of barrels

                4. n - Manning's roughness coefficient

                5. S - Culvert slope

                6. B - Culvert width

    Read: V - Outlet velocity

47

CARD FORMAT

[1] TEXAS INSTRUMENTS	[4]
BOX: INLET CONTROL, OUTLET VELOCITY	#11
	479.59
Start	

LISTING - PROGRAM #11

LBL INV = X RCL 7 + LBL LNX RC* 0 OP 20 RTN LBL CE INV

FIX SBR LNX OP 1 SBR LNX OP 2 SBR LNX OP 3 SBR LNX OP 4 OP

5 RTN LBL A 8 STO 0 SBR CE SBR CE ADV 7 X$T 1 STO 07 5

1 0 2 STO 0 RCL 0 OP 4 RCL 7 X=T 0 79 R/S OP 6 ST* 7 OP

27 OP 20 GTO 0 58 ADV RCL 1 X RCL 4 DIV 1 . 4 8 6 DIV RCL 5

SRX DIV RCL 3 DIV RCL 6 Y^X (8 DIV 3 = STO 7 X$T 1 . 1 X$\geq$T

1 50 RCL 1 DIV RCL 2 DIV RCL 6 DIV RCL 3 = X$T 1 2 STO 0

SBR CE 2 1 6 3 3 6 FIX 2 OP 4 X$T OP 6 ADV RTN . 2 2

X$\geq$T 1 58 5 + 1 6 = STO 0 SBR LNX SBR INV SBR INV SBR INV

SBR INV = X$T 2 INV X$\geq$T 1 81 X$T X RCL 6 = X$T

RCL 2 INV X$\geq$T 1 93 X$T X RCL 3 X RCL 6 = 1/x X RCL 1 =

GTO 1 28 (207 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #11

8.	1432446200	17.	64.991913
9.	2431271737	18.	-15.152238
10.	15323137	19.	3.6483784
11.	3532270000	20.	0.036402
12.	0	21.	-0.677621
13.	3241372717	22.	1.636594
14.	3700421727	23.	-1.53643
15.	3215243745	24.	2.34061
16.	-110.31635	25.	0.084468

PROGRAM #12 - PIPE CULVERT: OUTLET CONTROL PERFORMANCE

This program can be used to select an appropriate pipe culvert size, evaluate the performance of this culvert for various flow rates and determine the velocity of the flow at the outlet.

In determining the best pipe size, the designer must first select a trial diameter. For this value, the program computes the water surface elevation of the headwater pool at the culvert inlet. A visual comparison of this value to the design headwater elevation is made and the designer adjusts the diameter accordingly.

Once the pipe size has been determined, various flow rate values can be used with this program to obtain a performance curve.

The following diagram indicates the location of the energy losses associated with the culvert design.
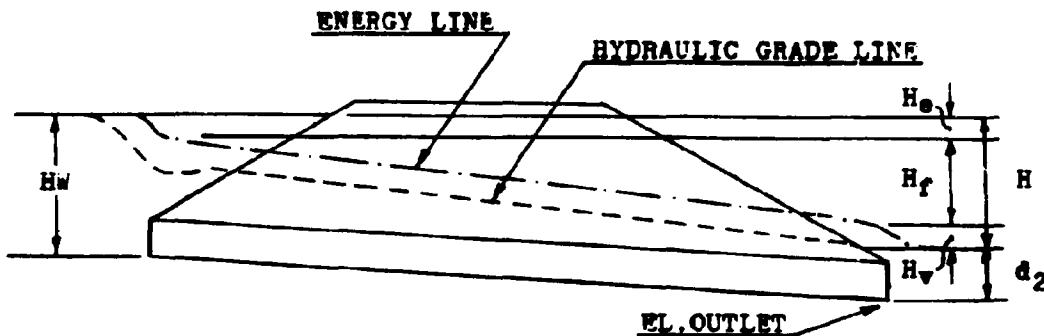
This program also calculates the outlet velocity of a pipe culvert operating in outlet control.

The depth of flow used in the computation of the cross-sectional area of flow through the culvert is equal to the critical depth or the tailwater depth, whichever is greater. However, this value cannot exceed the diameter of the pipe.

Since, the water at the inlet is considered to be a pool, the velocity at this point is assumed to be approximately zero. This allows the hydraulic grade line to be equated to the energy line.

The computations of the outlet velocity require that the calculator be placed in the degree mode. This is normally the mode the calculator is in when it is turned on.

For the sizing and performance curve operations to perform properly, the number of culvert barrels is limited to two.

49

EQUATIONS

$$Z = \frac{Q}{N \, (32.2/alpha)^{.5} D^{25}}$$

$X = \text{Log } Z$

If $X \leq \text{Log } 0.7$

$\quad Y = (- 0.0051657 + 0.407362X - 0.1830236X^2 - 0.0915565X^3)$

If $X > \text{Log } 0.7$

$\quad Y = (- 0.0244603 + 0.2017057X - 0.64009815X^2 + 0.695619X^3)$

$d_c = D \, 10^Y$

Note: d_c has been limited to a maximum valve of D

$$H_e = k_e \frac{V^2}{2g}$$

$$H_f = \frac{29 \, n^2 \, L \, V^2}{2g \, R^{4/3}}$$

$$H_v = \frac{V^2}{2g}$$

$H = H_e + H_f + H_v$

$d_2 = \dfrac{d_c + D}{2}$ or the tailwater depth, whichever is largest

HW EL. $= H + d_2 + $ EL.OUTLET

$d_4 = d_c$ or TW, whichever is larger and does not exceed D

$X = D/2$

$r = (X - d_4)$

Using the Radian Mode

$\theta = \text{Cos}^{-1} \, (r/X)$

$A = X^2 \, (\theta - \text{Sin } \theta \text{ Cos } \theta)$

$V = Q/AN$

50

INSTRUCTIONS

#1   Load program #12

#2   Press Label A

#3   Enter: 1. Q - Flow rate

2. N - Number of barrels

3. k_e - Entrance loss coefficient

4. n - Manning's roughness coefficient

5. TW - Tailwater depth

6. Alpha - Kinetic energy coefficient

= 1.12 for corrugated metal

= 1.04 for concrete

7. D - Culvert diameter

8. EL.OUTLET - Outlet invert elevation

9. L - Culvert length

Read: HW EL. - Headwater elevation

#4   Press Label B

Read: d_c - Critical depth

#5   Press Label C

Read: H - Total head loss

#6   Press Label D

Read: V - Outlet control velocity

#7   Press Label E

Enter: Q - Flow rate

TW - Tailwater depth

Read: HW EL. - Headwater elevation

CARD FORMAT

1	TEXAS INSTRUMENTS			2
PIPE: OUTLET CONTROL PERFORMANCE				#12
				479.59
Start	d_c	H	VELOCITY	PERFORMANCE

CARD FORMAT

3	TEXAS INSTRUMENTS	4
DATA - PROGRAM #12		
		479.59

52

LBL INV = X RCL 11 + LBL LNX RC* 0 OP 20 RTN LBL CE INV

FIX SBR LNX OP 1 SBR LNX OP 2 SBR LNX OP 3 SBR LNX OP 4

ADV OP 05 2 1 3 7 FIX 2 OP 4 RTN LBL CLR STO 0 SBR CE

RTN LBL X$\overset{>}{<}$T RCL 1 DIV RCL 2 DIV (3 2 . 2 DIV RCL 6)

SRX = DIV RCL 7 Y^X 2 . 5 = LOG STO 11 X$\overset{>}{<}$T . 7 LOG

X$\geq$T 0 92 4 + 4 8 = STO 0 SBR LNX SBR INV SBR INV SBR INV

= INV LOG X$\overset{>}{<}$T 1 INV X$\geq$T 1 15 X$\overset{>}{<}$T X RCL 7 = RTN LBL

X^2 2 9 . 1 6 4 X RCL 4 X^2 X RCL 59 DIV (RCL 7 DIV 4

) Y^X (4 DIV 3 = + RCL 3 + 1 = X (4 X RCL 1 DIV RCL

2 DIV RCL 7 X^2 DIV PI) X^2 DIV 6 4 . 4 = RTN LBL SRX

1 6 SBR CLR SBR X$\overset{>}{<}$T X$\overset{>}{<}$T RCL 7 + X$\overset{>}{<}$T INV X$\geq$T 1 97

RCL 7 = DIV 2 = X$\overset{>}{<}$T RCL 5 X$\geq$T 2 08 X$\overset{>}{<}$T STO 10 SBR

X^2 + RCL 8 + RCL 10 = OP 6 CLR RTN LBL A 1 2 SBR CLR INV

FIX ADV 9 X$\overset{>}{<}$T 1 STO 9 RCL 56 STO 0 RCL 0 OP 4 RCL 9 X=T 2

62 R/S OP 6 ST*9 OP 29 OP 20 GTO 2 41 R/S X$\overset{>}{<}$T 5 1 1 2

OP 4 X$\overset{>}{<}$T OP 6 STO 59 SBR SRX 2 0 SBR CLR SBR CE ADV 9

X$\overset{>}{<}$T 7 STO 09 5 1 0 8 GTO 2 39 LBL B 2 8 SBR CLR SBR

X$\overset{>}{<}$T OP 6 RTN LBL C 3 2 SBR CLR SBR X^2 OP 6 RTN LBL D 4

4 SBR CLR RCL 57 FIX 2 OP 4 SBR X$\overset{>}{<}$T X$\overset{>}{<}$T RCL 5 X$\geq$T 3 39

X$\overset{>}{<}$T X$\overset{>}{<}$T RCL 7 X$\geq$T 3 46 X$\overset{>}{<}$T RCL 7 DIV 2 = STO 10 -

X$\overset{>}{<}$T = DIV X$\overset{>}{<}$T = RAD INV COS STO 11 - RCL 11 SIN X RCL

11 COS = DEG X RCL 10 X^2 = 1/x DIV RCL 2 X RCL 1 = OP 6

RTN LBL E 3 6 SBR CLR SBR CE ADV RCL 56 OP 04 1 = R/S STO 1

OP 6 RCL 58 OP 04 5 = R/S STO 5 OP 6 SBR SRX 4 0 STO 0

GTO 3 96   (429 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #12

12.	3324331762	36.	3317352132
13.	15412742	37.	3530133115
14.	1735370036	38.	1700154135
15.	2446170000	39.	4217000000
16.	2317131643	40.	1731371735
17.	1337173500	41.	65346500
18.	1727174213	42.	1331160065
19.	3724323100	43.	3743650000
20.	2132350013	44.	3241372717
21.	3132372317	45.	3700153231
22.	3500362446	46.	3735322700
23.	1700000000	47.	4217274000
24.	1731371735	48.	-0.0915565
25.	65165700	49.	-0.1830236
26.	1727403241	50.	0.407362
27.	3757002765	51.	-0.0051657
28.	1535243724	52.	0.695619
29.	1513270016	53.	-0.64009815
30.	1733372300	54.	0.2017057
31.	2436000000	55.	-0.0244603
32.	3732371327	56.	5102
33.	23171316	57.	216336
34.	27323636	58.	5106
35.	24360000		

PROGRAMS #13 and #14 - PIPE CULVERT: INLET CONTROL PERFORMANCE

These programs evaluate the hydraulic performance of eight different pipe culvert inlet configurations. A detailed explanation of the geometry of these inlets is depicted in the diagrams below:

PROGRAM #13

Corrugated Metal Pipe with a Projecting Edge
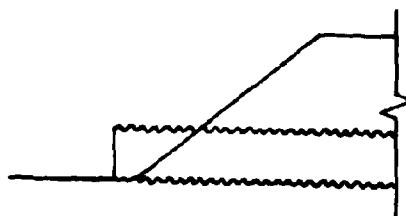
Corrugated Metal Pipe in a Headwall
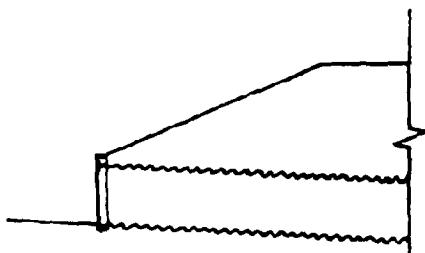
Corrugated Metal or Concrete Pipe with Beveled Edges - Type A and B
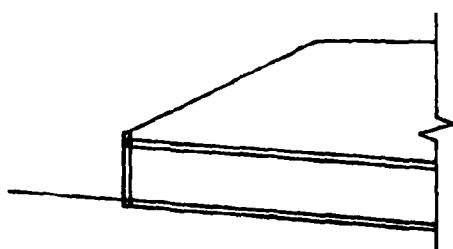
CMP/Concrete - Beveled Edges

Type A and B
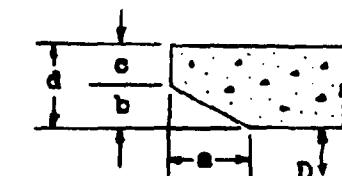
TYPE	$\frac{b}{D}$	$\frac{a}{D}$	$\frac{c}{D}$	$\frac{d}{D}$
A	0.042	0.042	0.042	0.083
B	0.083	0.125	0.042	0.125

55

Corrugated Metal or Concrete Pipe with a Standard End Section
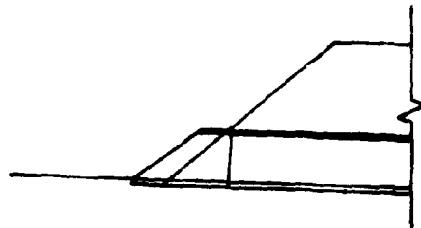
Concrete Pipe with Square Edges in a Headwall
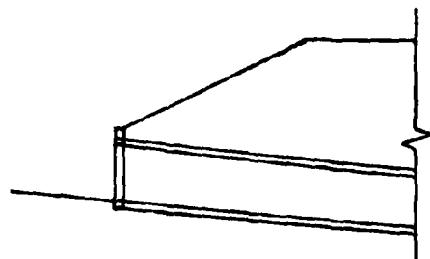
Concrete with a Projecting Socket Edge
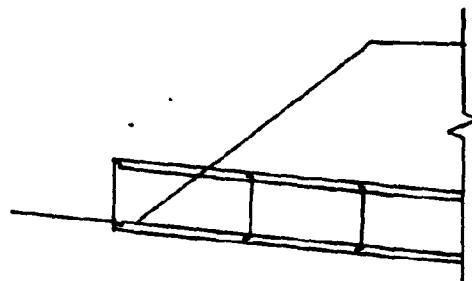
Concrete with a Socket Edge in a Headwall
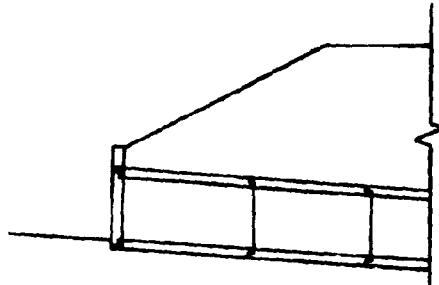
Equations for two other inlets are provided here in the documentation. The two inlets arc as follows:

Corrugated Metal Pipe Mitered to Conform to the Slope
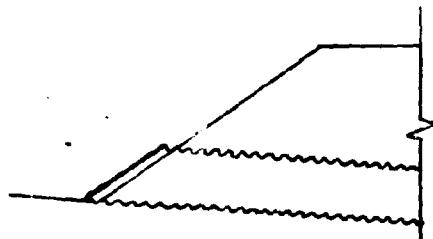
Concrete with Projecting Square Edges
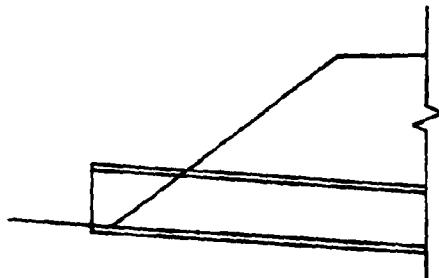
For each particular inlet the program calculates the depth of the water surface at the face of the culvert. This value is then added to the culvert inlet invert elevation. If this sum is less than the design headwater elevation then the inlet elevation becomes the elevation of the face. If this sum exceeds the design headwater elevation, the difference between this sum and the design headwater elevation is subtracted from the inlet invert elevation. This new elevation is now called the elevation of the face. For the culvert to operate properly, the inlet invert must be reset to this elevation. The drop in elevation of t.e inlet invert is called the FALL. The diagrams below graphically show the occurrence. It should be noted that as the inlet invert elevation drops, the culvert barrel rotates about the outlet invert.
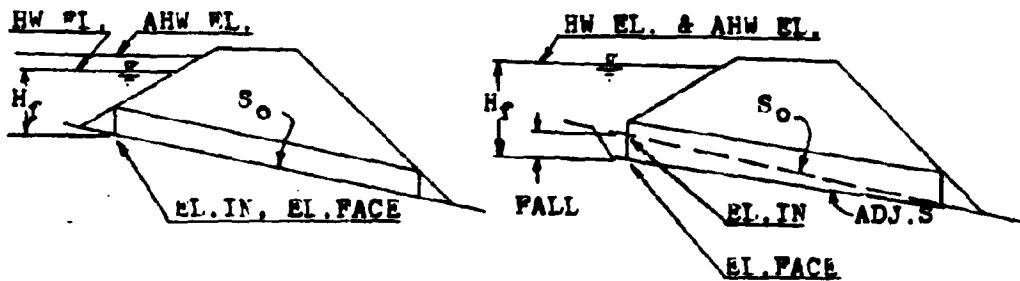
No FALL Required
EL.IN + H_f < AHW EL.

FALL Required
EL.IN + $H_f \geq$ AHW EL.

The diagrams clearly indicate that when the calculated headwater elevation is above the design headwater elevation, the headwater elevation is set equal to the design headwater elevation and the difference is taken up by the FALL.

The inlet invert elevation of the culvert can always be thought of as the elevation of the face. The original inlet invert elevation, before considering the affects of FALL, can be taken as the "inlet elevation." After the design information has been entered and the inlet type selected, the calculator determines the face elevation and the required FALL.

These programs do not perform the checks on restrictions on the FALL and the headwater depth. Both of these values must be checked by the designer.

Once the culvert has been sized for the design flow rate, the performance of the inlet for other flow rates can be determined. In doing the performance evaluation, the calculator determines the headwater elevation for any given flow rate.

Whenever applicable, a bevel edged inlet is recommended for use in lieu of a square edged inlet. The large increase in hydraulic performance gained by the bevel edged inlet, greatly outweights the small, if any, additional cost.

EQUATIONS

$$EL.FACE = DIM\ EL. - H_f \quad (with\ FALL)$$

$$= EL.INLET \quad (without\ FALL)$$

$$IW\ EL. = EL.FACE + H_f$$

$$FALL = EL.FACE - EL.INLET$$

NOTE: The FALL is measured in a downward direction and therefore is always a positive value.

$$X = \frac{Q}{(ND^{2.5})}$$

PROGRAM #13

CMP with a Projecting Edge

$$H_f = D(0.187321 + 0.567710X - 0.156544X^2 + 0.0447052X^3 - 0.00343602X^4 + 0.000089661X^5)$$

CMP in a Headwall

$$H_f = D(0.167433 + 0.538595X - 0.149374X^2 + 0.0391543X^3 - 0.00343974X^4 + 0.000115882X^5)$$

CMP/CONC. with Bevel Type A

$$H_f = D(0.063343 + 0.766512X - 0.316097X^2 + 0.0876701X^3 - 0.00983695X^4 + 0.000416760X^5)$$

CMP/CONC. with Bevel Type B

$$H_f = D(0.081730 + 0.698353X - 0.253683X^2 + 0.0651250X^3 - 0.00719750X^4 + 0.000312451X^5)$$

CMP /CONC with a Standard End Section

$$H_f = D(0.120659 + 0.630768X - 0.218423X^2 + 0.0591815X^3 - 0.00599169X^4$$
$$+ 0.000229287X^5)$$

CONC. with Square Edges in a Headwall

$$H_f = D(0.087483 + 0.706578X - 0.253295X^2 + 0.0667001X^3 - 0.00661651X^4$$
$$+ 0.000250619X^5)$$

CONC. with a Projecting Socket Edge

$$H_f = D(0.108786 + 0.662381X - 0.233801X^2 + 0.0579585X^3 - 0.00557890X^4$$
$$+ 0.000205052X^5)$$

CONC. with Socket Edge in Headwall

$$H_f = D(0.114099 + 0.653562X - 0.233615X^2 + 0.0597723X^3 - 0.00616338X^4$$
$$+ 0.000242832X^5)$$

Optional Inlets

CMP Mitered to Conform to Slope

$$H_f = D(0.107137 + 0.757789X - 0.361462X^2 + 0.1233932X^3 - 0.01606422X^4$$
$$+ 0.000767390X^5)$$

CONC with a Projecting Square Edge

$$H_f = D(0.167287 + 0.558766X - 0.159813X^2 + 0.0420069X^3 - 0.00369252X^4$$
$$+ 0.000125169X^5)$$

With a small amount of programming experience, an operator can insert these last two optional formulas into either program #13 or #14.

<u>INSTRUCTIONS</u>

#1   Load program #13   (2 cards)
        or program #14   (2 cards)

#2.   Press Label A

#3   Enter: 2. D - Culvert diameter
              3. N - Number of Barrels
              4. EL.INLET - Inlet elevation
              5. DHW EL - Design headwater elevation
              6. Q - Flow rate

#4   Select inlet type

Program #13

      Label A' - CMP w/Projecting End
      Label B' - CMP w/Headwalls
      Label C' - CMP/CONC; Bevel A
      Label D' - COM/CONC; Bevel B

Program #14

      Label A' - CMP/CONC Standard End Section
      Label B' - CONC w/SQ ED in Headwall
      Label C' - CMP/CONC W/Projecting Socket
      Label D' - CONC Socket in headwall

      Read EL.FACE - Elevation of face
            FALL

#5   Check FALL

#6   Press Label D

      Read: H_f - Headwater depth

#7   Run Performance Evaluation

      Press Label E

      Enter Q - Flow rate

      Read: HW EL. - Headwater elevation

CARD FORMAT

⌐ 1 ┐ TEXAS INSTRUMENTS				⌐ 2 ┐
PIPE : INLET CONTROL PERFORMANCE				#13 and #14
				319.79

⌐ 3 ┐ TEXAS INSTRUMENTS				⌐ 4 ┐
DATA PROGRAM #13				
CMP PROJ	CMP W/H	C/C Bevel A	C/C Bevel B	319.79
Start	HW EL.	FALL	H_f	PERFORMANCE

⌐ 3 ┐ TEXAS INSTRUMENTS				⌐ 4 ┐
DATA PROGRAM #14				#14
STD. END	SQ. W/HW	PROJ. SOCKET	SOCKET W/HW	319.79
Start	HW EL.	FALL	H_f	PERFORMANCE

LISTING PROGRAM #13 & 14

```
LBL  INV  =  X  RCL  7  +  LBL  LNX  RC*  8  OP  28  RTN  LBL  CE  INV

FIX  SBR  LNX  OP  1  SBR  LNX  OP  2  SBR  LNX  OP  3  SBR  LNX  OP  4

ADV  OP  5  RTN  LBL  CLR  EXC  8  X≷T  SBR  CE  2  1  3  7  FIX

2  OP  4  X≷T  STO  8  RTN  LBL  X≷T  RCL  6  DIV  RCL  3  DIV

( RCL  2  Yˣ  2  .  5  =  STO  7  SBR  LNX  SBR  INV  SBR  INV  SBR

INV  SBR  INV  SBR  INV  =  X  RCL  2  =  X≷T  6  INV  SUM  8  X≷T

STO  9  RTN  LBL  A  1  0  STO  8  SBR  CE  ADV  7  X≷T  2  STO  09

5  1  0  3  STO  0  RCL  0  OP  4  RCL  9  X=T  1  42  R/S  OP  6  ST*  9

OP  29  OP  20  GTO  1  21  OP  0  SBR  0  26  CLR  RTN  LBL  B  6  4  SBR

CLR  SBR  X≷T  +  RCL  0  =  OP  6  RTN  LBL  A'  1  0  +  LBL  B'  1  0  +

LBL  C'  1  0  +  LBL  D'  1  6  =  STO  8  SBR  CE  6  8  SBR  CLR  SBR

X≷T  X≷T  RCL  5  -  RCL  4  =  X≥T  2  05  X≷T  +/-  +  RCL  5  =

STO  0  OP  6  LBL  C  7  2  SBR  CLR  RCL  4  -  GTO  1  58  LBL  D  7

6  SBR  CLR  SBR  X≷T  OP  6  RTN  LBL  E  5  6  SBR  CLR  6  0  SBR

CLR  6  INV  FIX  R/S  PRT  STO  6  SBR  B  GTO  2  43   ( 258 PROGRAM STEPS)
```

DATA REGISTERS - PROGRAM #13

10.	3324331762	42.	0.0391543
11.	24312717	43.	-0.149374
12.	3700153231	44.	0.538595
13.	3735322700	45.	0.167433
14.	2431271737	46.	1530336200
15.	37453317	47.	3335322517
16.	3745331700	48.	1537243122
17.	1400141742	49.	17162217
18.	1727171600	50.	0.000089661
19.	1716221736	51.	-0.00343602
20.	0.000312451	52.	0.0447052
21.	-0.0071975	53.	-0.156544
22.	0.065125	54.	0.56771
23.	-0.253683	55.	0.187321
24.	0.698353	56.	3317352132
25.	0.08173	57.	3530133115
26.	3745331700	58.	1700154135
27.	1300141742	59.	4217000000
28.	1727171600	60.	1731371735
29.	1716221736	61.	21273243
30.	0.00041676	62.	3513371700
31.	-0.00983695	63.	15213600
32.	0.0876701	64.	2317131643
33.	-0.316097	65.	1337173500
34.	0.766512	66.	1727174213
35.	0.063343	67.	3724323100
36.	1530330024	68.	172717
37.	3100130023	69.	4213372432
38.	1713164313	70.	3100322100
39.	2727000000	71.	2113151700
40.	0.000115882	72.	372317
41.	-0.00343974	73.	35173441
		74.	2435171600
		75.	2113272700
		76.	2317
		77.	1316431337
		78.	1735001617
		79.	3337230000

DATA REGISTERS - PROGRAM #14

10.	3324331762	42.	0.0667001
11.	24312717	43.	-0.253295
12.	3700153231	44.	0.706578
13.	3735322700	45.	0.087483
14.	2431271737	46.	3637133116
15.	37453317	47.	1335160017
16.	3632152617	48.	3116003617
17.	3700243100	49.	1537243231
18.	1300231713	50.	0.000229287
19.	1643132727	51.	-0.00599169
20.	0.000242832	52.	0.0591815
21.	-0.00616338	53.	-0.218423
22.	0.0597723	54.	0.630768
23.	-0.233615	55.	0.120659
24.	0.653762	56.	3317352132
25.	0.114099	57.	3530133115
26.	3335322517	58.	1700154135
27.	1537243122	59.	4217000000
28.	36321526	60.	1731371735
29.	1737000000	61.	21273243
30.	0.000205052	62.	3513371700
31.	-0.0055789	63.	15213600
32.	0.0579585	64.	2317131643
33.	-0.233801	65.	1337173500
34.	0.662318	66.	1727174213
35.	0.108786	67.	3724323100
36.	3634400017	68.	172717
37.	1640002431	69.	4213372432
38.	23171316	70.	3100322100
39.	4313272700	71.	2113151700
40.	0.000250619	72.	372317
41.	-0.00661651	73.	35173441
		74.	2435171600
		75.	2113272700
		76.	2317
		77.	1316431337
		78.	1735001617
		79.	3337230000

<u>PROGRAMS #15 and #16 - PIPE CULVERT: THROAT CONTROL PERFORMANCE</u>

These programs evaluate the performance of a pipe culvert operating in throat
control. The formulas incorporated in these programs apply only to side-tapered
inlets for pipe culverts. Program #15 evaluates the performance of corrugated
metal inlets whereas program #16 evaluates concrete inlets. Like the improved
inlet programs, these throat control programs often can use FALL to increase the
flow capacity of a culvert. The following diagrams describe the throat control
inlets.
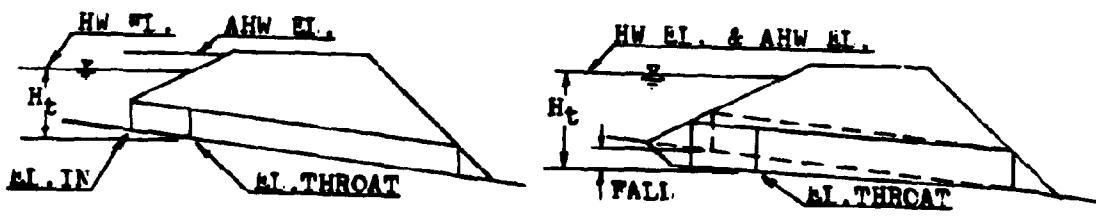
ELEVATION VIEW
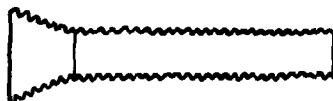
ROUGH THROAT   SMOOTH THROAT
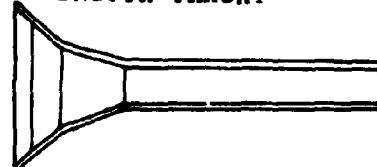
PLAN VIEW

SIDE-TAPERED INLET   SIDE-TAPERED INLET
ROUGH THROAT   SMOOTH THROAT
NO FALL, HWEL. < AHWEL.   WITH FALL AND WINGWALLS

To evaluate the performance of a pipe culvert with a slope-tapered inlet,
program #7 should be used. Program #7 evaluates the performance of box
culverts with either a side- or slope-tapered inlet. The slope-tapered inlet
for a pipe culvert is designed as if it were going to be used with a box
culvert. A transition section is then fabricated to connect the box shaped
inlet to the pipe culvert barrel. The following diagrams will further explain
this situation.

66

SLOPE-TAPERED INLETS

VERTICAL FACE, WITH WINGWALLS

MITERED FACE
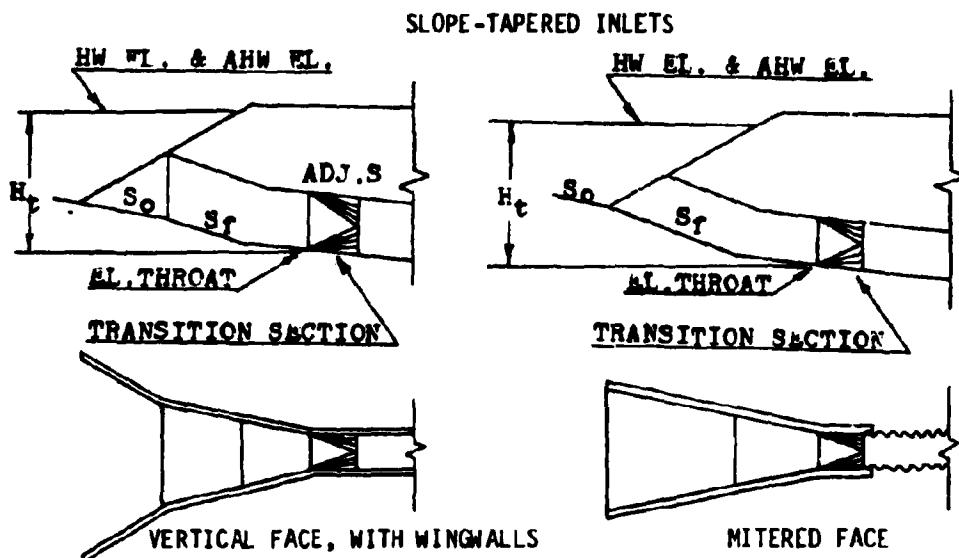
Due to the limitations of this calculator, a small error results in the computation of the FALL. The programs assume that the elevation of the inlet and the elevation of the throat are equal before determining the value of the headwater elevation. This equality is false and a small difference, equal to the channel slope times the vertical distance between the inlet and the throat section, exists. This vertical distance is an unknown value and is determined by the next program. By understanding the error condition; a correction, if necessary, can be made.

EQUATIONS

$$EL.THROAT = DHW \ EL. - H_t \quad (with \ FALL)$$

$$= EL.INLET \quad (without \ FALL)$$

$$HW \ EL. = EL.THROAT + H_t$$

$$FALL = EL.INLET - EL.THROAT$$

$$X = LOG(Q/ND^{2.5})$$

PROGRAM #15

$$H_t = D \ 10^{(- 0.233392 + 0.489125X + 1.068638X^2 - 3.074435X^3 + 3.711165X^4 - 1.32836X^5)}$$

PROGRAM #16

$$H_t = D \ 10^{(- 0.237139 + 0.146792X + 2.189321X^2 - 4.354114X^3 + 4.210539X^4 - 1.347032X^5)}$$

67

<u>INSTRUCTIONS</u>

#1   Load program #15
         or program #16

#2.   Press Label A

#3   Enter: 2. D - Culvert diameter
                   3. N - Number of Barrels
                   4. EL.INLET - Inlet elevation
                   5. DHW EL - Design Headwater elevation
                   6. Q - Flow rate

#4   Read   EL.THROAT - Throat elevation
                  FALL

#5   Check FALL

#6   Press Label D

      Read: H_t - Headwater depth

#7   Run Performance Elevation

      Press Label E

      Enter Q - Flow rate

      Read: HW EL. - Headwater elevation

CARD FORMAT

PROGRAM #15

	TEXAS INSTRUMENTS			4
CMP: THROAT PERFORMANCE				#15
				479.59
Start	HW EL.	FALL	H_f	PERFORMANCE

PROGRAM #16

	TEXAS INSTRUMENTS			4
CONCRETE PIPE: THROAT PERFORMANCE				#16
				479.59
Start	HW EL.	FALL	H_f	PERFORMANCE

LISTING PROGRAM #15 & #16

```
LBL  INV  =  X  RCL  7  +  LBL  LNX  RC*  8  OP  28  RTN  LBL  CE  INV  FIX

SBR  LNX  OP  2  SBR  LNX  OP  3  SBR  LNX  OP  4  ADV  OP  05  2  1  3  7

FIX  2  OP  4  RTN  LBL  CLR  1  8  STO  8  RCL  6  DIV  RCL  3  DIV. RCL

2  Yˣ  2  .  5  =  LOG  STO  7  SBR  LNX  SBR  INV  SBR  INV  SBR  INV  SBR

INV  SBR  INV  =  INV  LOG  X  RCL  2  =  RTN  LBL  A  OP  00  9  STO  8  SBR

CE  SBR  CE  ADV  INV  FIX  7  X²T  2  STO  01  5  1  0  3  STO  0  RCL  0

OP  4  RCL  1  X=T  1  30  R/S  OP  6  ST*  1  OP  21  OP  20  GTO  1  09  SBR

CE  SBR  CLR  X²T  RCL  5  -  RCL  4  =  X≥T  1  45  X²T  +/-  +  RCL  5  =

STO  0  OP  6  LBL  C  OP  00  2  1  1  3  2  7  2  7  OP  2  SBR  0  30  RCL

4  -  GTO  1  88  LBL  B  2  4  STO  8  SBR  CE  SBR  CLR  +  RCL  0  =  OP

6  RTN  LBL  D  RCL  24  OP  2  RCL  25  OP  03  1  6  1  7  3  3  3  7  2  3

SBR  0  28  SBR  CLR  OP  6  RTN  LBL  E  2  7  STO  8  SBR  CE  6  =  R/S

PRT  STO  6  SBR  B  GTO  E       ( 239 PROGRAM STEPS)
```

DATA REGISTERS - PROGRAM #15

9.	3017371327	20.	-3.074435
10.	33243317	21.	1.068638
11.	6200000000	22.	0.489125
12.	3723353213	23.	-0.233392
13.	3700153231	24.	2317131643
14.	3735322700	25.	1337173500
15.	1727174240	26.	1727174240
16.	32210037	27.	1731371735
17.	2335321337	28.	21273243
18.	-1.32836	29.	3513371700
19.	3.711165		

DATA REGISTERS - PROGRAM #16

9.	1532311535	20.	-4.354114
10.	1737170033	21.	2.189321
11.	2433176200	22.	0.146792
12.	3723353213	23.	-0.237139
13.	3700153231	24.	2317131643
14.	3735322700	25.	1337173500
15.	1727174240	26.	1727174240
16.	32210037	27.	1731371735
17.	2335321337	28.	21273243
18.	-1.347032	29.	3513371700
19.	4.210539		

PROGRAM #17 - PIPE CULVERT: SIDE TAPERED INLET DIMENSIONS

This program continues with the design of a culvert operating in throat control. For the side-tapered entrance, this program computes the adjusted slope (if required by the use of FALL in the inlet design) the inlet face width and the inlet length.

The program evaluates either a projecting corrugated metal pipe, a square edged culvert in a headwall or a bevel edged inlet in a headwall. A graphical description of these inlets is as follows.
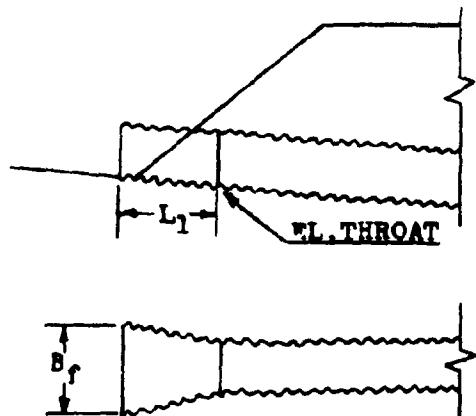
SIDE-TAPERED, PROJECTING EDGE
(NO FALL)
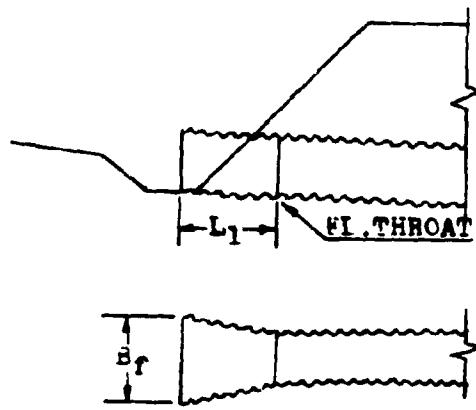
SIDE-TAPERED, PROJECTING EDGE
(WITH FALL)
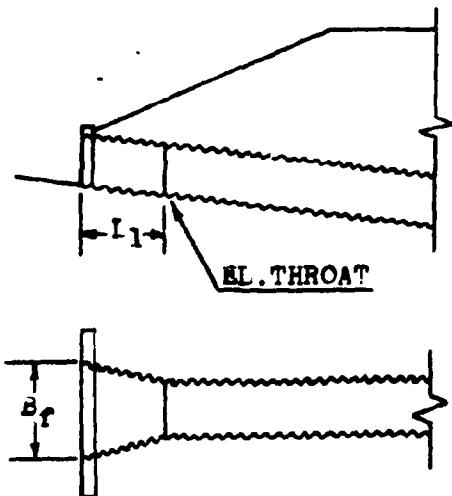
SIDE-TAPERED, SQUARE EDGES
(IN A HEADWALL, CMP OR CONCRETE
WITH OR WITHOUT FALL)
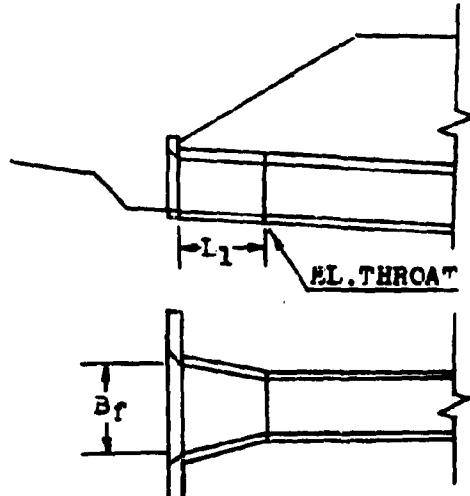
SIDE-TAPERED, BEVELED EDGE
(IN A HEADWALL, CMP OR CONTRETE
WITH OR WITHOUT FALL)

71

One of the values which must be entered into the calculator is the height of the side-tapered inlet face. It is referred to as the value E in the diagram below.
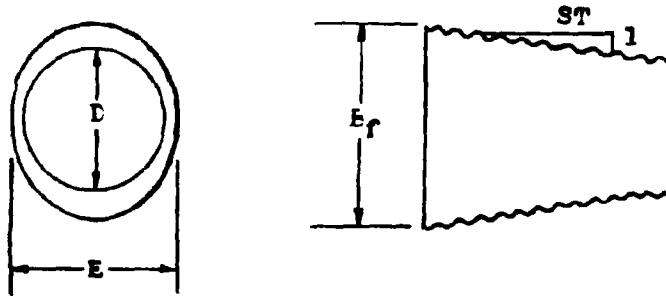
The limitations on the value of E are as a minimum the culvert diameter and 1.1 times the diameter as a maximum.

The sidewall taper should be kept between a value of 4:1 and 6:1 for the program to operate properly.

Where prefabricated inlet sections are available, both the face width and the inlet length have been set by the manufacturing company. These values are normally set at 1 1/2 times the culvert diameter.

The value for the inlet length determined by this program is a horizontal measurement. This is in contrast to the culvert length and the adjusted culvert length values which are measured along the culvert barrel.

$$(ADJ.S)L = L_1 \text{ ADJ.S } (S_0^2+1)^{.5} + S_0 L - \text{FALL } (S_0^2+1)^{.5}$$

$$- [\text{FALL} + D[(S_0^2+1)^{.5} - (ADJ.S^2 + 1)^{.5}] - ADJ.S \ L_1] \ [S_{FU}(/S_0^2+1)^{.5} \ ADJ.S)]$$

$$L_1 = \frac{(B_f - DN) \ ST}{2}$$

$$H_f = H_t - L_1 \ ADJ.S$$

$$X = H_f/E$$

CMP Projecting Edges

$$B_f = 4Q/[(\text{PI } E^{1.5})(0.0144 + 1.1505X + 1.8167X^2 - 0.9642X^3 + 0.1974X^4$$

$$- 0.0148X^5)]$$

Square Edges in a Headwall

$$B_f = 4Q/[\text{PI } E^{1.5})(-0.0048 + 0.9426X + 2.9784X^2 - 1.792X^3 + 0.4228X^4$$

$$- 0.0357X^5)]$$

Bevel Edges in a Headwall

$$B_f = 4Q/[(\text{PI } E^{1.5})(0.73932X + 3.2994X^2 - 1.746X^3 + 0.3744X^4 - 0.0287X^5)]$$

INSTRUCTIONS

#1   Load program #17   (2 Cards)

#2   Press Label A

#3   Enter: 1. Q - Flow rate

2. D - Culvert diameter

3. N - Number of Barrels

4. H_t - Headwater depth @ throat

5. ST - Sidewall taper

6. S_o - Channel slope

<u>INSTRUCTIONS</u>

                7. FALL

                8. S_{FU} - Upstream fill slope

                9. L - Culvert length

                10. E - Face height of inlet

#4   Choose Inlet Type

        Label B - CMP Projecting

        Label C - Square Edges in a Headwall

        Label D - Bevel Edges in a Headwall

#5   Read: ADJ.S - Adjusted slope

             B_f - Inlet face width

             L_1 - Inlet length

<u>CARD FORMAT</u>

☐ 1 ☐ TEXAS INSTRUMENTS				☐ 2 ☐
PIPE: SIDE-TAPERED INLET DIMENSIONS				#17
				479.59
Start	PROJ.EDGE	SQ.EDGE	BV.EDGE	

☐ 3 ☐ TEXAS INSTRUMENTS	☐ 4 ☐
DATA - PROGRAM #17	
	479.59

LISTING PROGRAM #17

LBL INV = X RCL 15 + LBL LNX RC* 0 OP 20 RTN LBL CE INV

FIX SBR LNX OP 1 SBR LNX OP 2 SBR LNX OP 3 SBR LNX OP 4

ADV OP 5 RTN LBL CLR (RCL 6 X^2 + 1) SRX RTN LBL X$<$T

2 1 3 7 FIX 2 OP 4 RTN LBL A 4 7 STO 0 SBR CE OP 00 1 6

2 4 3 0 1 7 3 1 OP 01 3 6 2 4 3 2 3 1 3 6 OP 2 OP 5

ADV 9 X$<$T 1 STO 00 5 1 0 2 STO 11 RCL 11 OP 4 RCL 0 X=T

1 30 R/S OP 6 ST* 00 1 SUM 11 OP 20 GTO 1 08 R/S X$<$T

5 1 1 2 OP 4 X$<$T OP 6 STO 09 1 0 = R/S X$<$T 5 1 0 2

0 1 OP 4 X$<$T OP 6 STO 10 OP 00 2 4 3 1 2 7 1 7 3 7

OP 01 3 7 4 5 3 3 1 7 OP 2 ADV OP 5 CLR RTN LBL B 1 0

+ LBL C 1 0 + LBL D 1 7 = STO 0 RCL 6 STO 11 SBR CE 1

CP +/- + RCL 4 = DIV RCL 10 = STO 15 SBR LNX SBR INV SBR

INV SBR INV SBR INV SBR INV = 1/x X RCL 1 X 4 DIV PI DIV RCL

10 Y^X 1 . 5 = FIX 2 EE INV EE X=T 2 94 - X$<$T RCL 2 X

RCL 3 = DIV 2 X RCL 5 = STO 16 X RCL 11 = STO 15 6 INV SUM

0 RCL 15 GTO 2 15 X$<$T RCL 3 X RCL 2 = X$\geq$T 3 10 X$<$T

STO 15 GTO 3 21 0 STO 16 RCL 3 X RCL 2 = STO 15 CP . 1 STO

12 RCL 2 X (SBR CLR - (RCL 11 SBR 0 43 = + RCL 7 - RCL

11 X RCL 16 = X SBR CLR X RCL 8 X RCL 11 - RCL 6 X RCL

9 + SBR CLR X RCL 7 - SBR CLR X RCL 11 X RCL 16 + RCL 9 X

RCL 11 = FIX 6 EE INV EE INV X=T 4 11 RCL 14 X$<$T RCL 11 X=T

4 35 STO 14 RCL 16 GTO 2 79 EXC 13 - RCL 13 = X=T 3 96 1/X

X RCL 13 X RCL 12 = STO 12 SUM 11 GTO 3 26 5 1 STO 0 SBR

CE RCL 11 FIX 6 PRT OP 0 SBR LNX OP 2 SBR LNX OP 3 ADV OP

5 FIX 2 SBR X$<$T RCL 15 OP 6 INV FIX SBR 0 22 SBR X$<$T

RCL 16 OP 6 RTN   (478 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #17

17.	14424000	39.	1537243122
18.	1716400024	40.	17162217
19.	3100231713	41.	-0.0148
20.	1643132727	42.	0.1974
21.	-0.0287	43.	-0.9642
22.	0.3744	44.	1.8167
23.	-1.746	45.	1.1505
24.	3.2994	46.	0.0144
25.	0.73932	47.	3324331700
26.	0	48.	1541274217
27.	36344000	49.	3537002000
28.	1716400024	50.	2431271737
29.	3100231713	51.	3723170013
30.	1643132727	52.	1625413637
31.	-0.0357	53.	1716003627
32.	0.4228	54.	3233170064
33.	-1.792	55.	2113151700
34.	2.9784	56.	4324163723
35.	0.9426	57.	2431271737
36.	-0.0048	58.	27173122
37.	1530336200	59.	3723000000
38.	3335322517		

PROGRAM #18 - PIPE CULVERT: SIDE - TAPERED LENGTH ADJUSTMENTS

When a culvert is improved with a side-tapered inlet, as in the previous programs, the length of the culvert barrel will be affected. If the new inlet is designed with FALL, the barrel length will increase due to the rotation of the culvert. It will also be shortened by the addition of the inlet section. If no FALL is applied, the original culvert length will be shortened by the length of the improved inlet. This program computes these changes and adjusts the pipe culvert length accordingly.

With the changes in the culvert length, the elevation of the face of the improved inlet may also be affected. This calculation is also handled by the program.

The adjusted length measurement determined by the program is measured along the culvert barrel.

EQUATIONS

$$ADJ.L = [\frac{S_0 L}{(S_0^2 + 1)^{.5}} - FALL] \, [\frac{(ADJ.S^2 + 1)^{.5}}{ADJ.S}] - L_1 \, (ADJ.S^2 + 1)^{.5}$$

$$EL. \, FACE = EL. \, THROAT + L_1 \, ADJ.S$$

INSTRUCTIONS

#1   Load program #18

#2   Press Label A

#3   Enter: 1. EL.THROAT - Throat Elevation

2. ADJ.S - Adjusted Slope

3. S_0 - Channel slope

4. FALL

5. L - Original culvert length

6. L_1 - Improved inlet length

Read: ADJ.L - Adjusted length

EL.FACE - Face elevation

CARD FORMAT

[T] TEXAS INSTRUMENTS		[4]
PIPE: SIDE-TAPERED LENGTH ADJUSTMENT		#18
		479.59
START		

LISTING PROGRAM #18

LBL INV RC* 0 OP 20 RTN LBL LNX INV FIX SBR INV OP 1 SBR

INV OP 2 SBR INV OP 3 SBR INV OP 4 OP 05 2 1 3 7 FIX 2 OP 4

RTN LBL CE x^2 + 1) SRX RTN LBL A 9 STO 0 SBR LNX SBR LNX

ADV INV FIX 7 $x \geq T$ 1 STO 07 5 1 0 2 STO 8 RCL 8 OP 4 RCL 7

X=T 0 90 R/S OP 6 ST* 7 OP 27 OP 28 GTO 0 69 ADV SBR LNX RCL

3 X RCL 5 DIV (RCL 3 SBR CE - RCL 4 = X (RCL 2 SBR CE

DIV RCL 2 = - RCL 6 X (RCL 2 SBR CE = OP 6 ADV SBR LNX RCL

1 + RCL 6 X RCL 2 = OP 6 CLR RTN (145 PROGRAM STEPS)

DATA REGISTERS - PROGRAM #18

9.	3324331700	17.	3723170013
10.	1541274217	18.	1625413637
11.	3537620027	19.	1716002717
12.	1731223723	20.	3122372300
13.	13	21.	1727174213
14.	1625413637	22.	3724323100
15.	3017313736	23.	3221002113
16.	0	24.	1517000000

PROGRAM #19 - PIPE CULVERT: INLET CONTROL, OUTLET VELOCITY

This program determines the outlet velocity for a circular pipe culvert by first calculating the normal depth of the flow in the barrel. Once the depth has been determined, the waterway area is calculated. The outlet velocity is found by dividing the discharge by this area.

Normally as the depth of flow within a pipe culvert increases, the discharge correspondingly increases. However, after the depth of flow reaches a little over 90 percent of the culvert height, the discharge begins to decrease as the depth increases. This decrease in flow is a result in the large increase in wetted perimeter (barrel roughness) with only a small increase in the waterway area. This decrease in discharge continues until the barrel flows full.

A given discharge which requires the barrel to be flowing greater than 82 percent full will have two flow depths. One value will be between 82 percent and 93 percent of the diameter and the other depth will be between 93 percent and 100 percent full. Likewise, there will exist two values for the waterway area and two velocities. This calculator program is written so that it will determine the smaller of the two depths. This value will produce the smaller waterway area and the higher outlet velocity.

The equations used in this program are polynomial expressions for the normal depth curve found in figure 6-1 of reference #4.

EQUATIONS

$$X = [Qn/(1.486NS^{.5})]/D^{8/3}$$

$$Z = LOG (X)$$

If $X < 0.06$

$$d_n = D[10^{(0.13625 + 0.57114Z + 0.02362Z^2)}]$$

If $0.06 \leq X < 0.24$

$$d_n = D[10^{(0.3063639 + 0.907884Z + 0.192615Z^2)}]$$

If $0.24 \leq X < 0.34$

$$d_n = D[10^{(0.6857349 + 2.097532Z + 1.125836Z^2)}]$$

If $X \geq 0.34$

$$d_n = D$$

In the radian mode

$$\theta = \arccos(1 - 2d_n/D)$$

$$A = (D/2)^2 \ (\theta - \sin\theta\cos\theta)$$

$$V = Q/AN$$

INSTRUCTIONS

#1 Load program #19

#2 Press Label A

#3 Enter: 1. Q - Flow rate

2. D - Culvert diameter

3. N - Number of barrels

4. n - Manning's roughness coefficient

5. S - Culvert slope

Read: V - Outlet velocity

CARD FORMAT

[I]	TEXAS INSTRUMENTS	[4]
PIPE: INLET CONTROL - OUTLET VELOCITY		#19
		497.59
START		

LBL INV = X RCL 6 + LBL LNX RC* 0 OP 20 RTN LBL CL INV

FIX SBR LNX OP 1 SBR LNX OP 2 SBR LNX OP 3 SBR LNX OP 4 OP

5 RTN LBL A ADV 9 STO 0 SBR CL SBR CL ADV 6 X<T 1 STO

06 5 1 0 2 STO 8 RCL 8 OP 4 RCL 6 X=T 0 80 R/S OP 6 ST*

6 OP 26 OP 28 GTO 0 59 ADV SBR CE 2 1 6 3 3 6 FIX 2 OP 4

RCL 1 X RCL 4 DIV 1 . 4 8 6 DIV RCL 5 SRX DIV RCL 3 DIV

RCL 2 Y^X (8 DIV 3 = LOG STO 6 INV LOG X<T . 3 4 X≥T

1 36 NOP GTO 1 63 . 2 4 X≥T 1 45 3 SUM 0 . 0 6 X≥T 1 54

3 SUM 0 SBR LNX SBR INV SBR INV = INV LOG X 2 - 1 = +/-

RAD INV COS STO 8 - RCL 8 SIN X RCL 8 COS = DEG X RCL 2

X^2 DIV 4 = 1/x DIV RCL 3 X RCL 1 = OP 6 RTN (201 Steps)

DATA REGISTERS - PROGRAM #19

9.	3324331700	20.	4500243600
10.	1541274217	21.	0.02363
11.	3537002000	22.	0.57114
12.	2431271737	23.	0.13625
13.	1532313735	24.	0.192615
14.	3227002000	25.	0.907884
15.	4217273215	26.	0.3063639
16.	2437450000	27.	1.125836
17.	32413727	28.	2.097532
18.	1737004217	29.	0.685734
19.	2732152437		

STORAGE REGISTERS USED FOR VARIABLES

PROGRAM NUMBER	STORAGE REGISTER NUMBER									OTHER
	1	2	3	4	5	6	7	8	9	
1	n	S_o	BN	Z_1	Z_2	Q				
2	S_o	S_{FU}	S_{FD}	EL.FU	EL.FD	D				
3	Q	N	k_e	n	TW	B	D	EL.OUT		L in 11
4	B	D	N	EL.IN	AHW.EL	Q				
5	D	S_o	FALL	S_{FU}	L					
6	Q	D	BN B_fN	S_o	HW.EL-EL.OUT	S_f	ADJ.L	ADJ.S		
7	B	D	N	EL.IN	AHW.WL	Q				
8	Q	D	BN	H_t	ST	S_o	FALL	S_{FU}	L	EL.THR in 16
9	D	L_3	S_o	EL.OUT	S_{FU}	EL.FU	S_f	EL.THR		
10	Q	D	L_3	N	B	HW.EL	EL.FAC	L_2	L_4	
11	Q	D	N	n	S	B				
12	Q	N	k_e	n	TW	ALPHA	D	EL.OUT		L in 59
13		D	N	EL.IN	AHW.EL	Q				
14		D	N	EL.IN	AHW.EL	Q				
15		D	N	EL.IN	AHW.EL	Q				
16		D	N	EL.IN	AHW.EL	Q				
17	Q	D	N	H_t	ST	S_o	FALL	S_{FU}	L	E in 10
18	EL.THR	ADJ.S	S_o	FALL	L	L_1				
19	Q	D	N	n	S					

WORK SHEETS

STEP #1
CALCULATE TAILWATER

Use Program #1

Enter: 1. n = _____ (channel)

2. S_o = _____

3. BW = _____

4. Z_1 = _____

5. Z_2 = _____
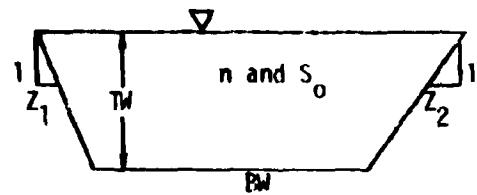
6.	Enter Q	TW, Based on d_n	Channel Velocity	COMMENTS

STEP #2
DETERMINE CULVERT LENGTH

Use Program #2

Enter: 1. S_o = _____

2. S_{FU} = _____

3. S_{FD} = _____

4. EL.FU = _____

5. EL.FD = _____

6.	Enter D	L	EL.INLET	EL.OUTLET	COMMENTS

STEP #3
DETERMINE AN ACCEPTABLE CULVERT SIZE

Use Program #3 for Box Culverts
Use Program #12 for Pipe Culverts

Enter: 1. Q = _____

        2. N = _____

        3. k_e = _____

        4. n = _____

        5. TW = _____

6. Enter B - for Box or alpha for Pipe	7. Enter D	8. Enter EL.OUTLET	9. Enter L	Read. HW.EL.	COMMENTS

Read

d_c = _____

H = _____

V = _____ for Outlet Control

OUTLET CONTROL PERFORMANCE

1. Enter Q	5. Enter TW	Read HW EL.	COMMENTS

STEP #4
INLET CONTROL: DESIGN AND PERFORMANCE

Box Culverts
Program #4 - Square Edged Inlet with Headwalls
         - Square Edged Inlet with Wingwalls
         - Bevel Edged Inlet with Headwalls
         - Bevel Edged Inlet with Wingwalls
Program #7 - Tapered Throat Inlet

Pipe Culverts
Program #13 - CMP with Projecting Edges
         - CMP in a Headwall
         - CMP or Conc. with type A Bevel
         - CMP or Conc. with type B Bevel
Program #14 - CMP or Conc. with Standard End Section
         - Conc. with Square Edges in a Headwall
         - Conc. with a Projecting Socket End
         - Conc. with a Socket End in a Headwall
Program #15 - CMP with a Tapered Throat Inlet
Program #16 - Conc. with a Tapered Throat Inlet

Enter: 1. B = _____ (For Boxes Only)
       2. D = _____
       3. N = _____
       4. EL.INLET = _____
       5. DHW EL. = _____

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS
		Inlet type _____				
		Inlet type _____				

86

STEP #4
INLET CONTROL: DESIGN AND PERFORMANCE
(CONTINUED)

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS
Inlet type _____						
Inlet type _____						
Inlet type _____						
Inlet type _____						

STEP #5
CONVENTIONAL INLETS

Use Program #5

Enter: 1. D = _____   4. S_{FU} = _____

          2. S_o = _____   5. L = _____

          3. FALL = _____

Read: ADJ.S = _____
       ADJ.L = _____

STEP #6
CREST EVALUATION

Use Program #6

Enter: 1. Q = _____   6. S_f = _____

          2. D = _____   7. ADJ.L = _____

          3. B or B_f = _____   8. ADJ.S = _____

          4. S_o = _____   9. N = _____

          5. HW EL = _____   10. EL.OUTLET = _____

Read: H_c = _____   WT = _____

       CW = _____   WA = _____

STEP #7
INLET CONTROL, OUTLET VELOCITY

Box Culverts - program #11
Pipe Culverts - program #19

Enter: 1. Q = _____   4. n = _____

          2. D = _____   5. S = _____

          3. N = _____   6. B = _____   (Boxes Only)

Read: V = _____

SIDE-TAPERED INLETS

Box Culverts - Use Program #8

Pipe Culverts - Use program #17

Enter:
1. Q = _____
2. D = _____
3. N = _____
4. H_t = _____
5. ST = _____

6. S_o = _____
7. FALL = _____
8. S_{FU} = _____
9. L = _____

Boxes

10. B = _____

11. EL.THROAT = _____

Pipes

10. E = _____

Read:
Boxes
INLET TYPE: SQ.ED., BV.ED.
ADJ.S = _____

ADJ.L = _____

B_f = _____

L_1 = _____

EL.FACE = _____

Pipes
SELECT INLET TYPE
PROJ., SQ.ED., BV.ED.

ADJ.S = _____

B_f = _____

L_1 = _____

Pipe Culverts - use program #18

Enter:
1. EL.THROAT = _____
2. ADJ.S = _____
3. S_o = _____

4. FALL = _____
5. L = _____
6. L_1 = _____

Read: ADJ.L = _____   EL.FACE = _____

CREST EVALUATION AND OUTLET VELOCITY

Go to Step 6 previous page

STEP #5
SLOPE-TAPERED INLETS

Program #9

Enter:
1. D = _____
2. L_3 = _____
3. S_0 = _____
4. EL.OUTLET = _____

5. S_{FU} = _____
6. EL.FU = _____
7. S_f = _____
8. EL.THROAT = _____

Select Inlet Type: Vertical Face, Mitered Face

Read:
ADJ.S = _____
ADJ.L = _____
EL.FACE = _____

L_4 = _____
L_2 = _____

Program #10

Enter:
1. Q = _____
2. D = _____
3. L_3 = _____
4. N = _____

5. B = _____ (for pipe use D)
6. HW.EL. = _____
7. EL.FACE = _____
8. L_2 = _____
9. L_4 = _____

Select Inlet Type: Square Edges, Beveled Edges

Read: B_f = _____   ST = _____

STEP #6
Mitered Face Crest Evaluation

Read: H_c = _____   CW = _____
                              ST = _____

STEP #7
INLET CONTROL OUTLET VELOCITY

Box Culverts - Program #11
Pipe Culverts - Program #19

Enter:
1. Q = _____
2. D = _____
3. N = _____
4. n = _____
5. S = _____
6. B = _____ (Boxes only)

Read: V = _____

90

EXAMPLE PROBLEMS

BOX CULVERT EXAMPLE NO. 1

Given: Design Discharge (Q) = 1,000 cfs, for a 50-year recurrence interval

Slope of stream bed (S_o) = 0.05 ft./ft.

Allowable Headwater Elevation = 200

Elevation Outlet Invert = 172.5

Culvert Length = 350 ft.

Downstream channel approximates an 8' wide trapezoidal channel with 2:1 side slopes and a Manning's "n" of 0.03.

Requirements: This box culvert will be located in a rural area where the allowable headwater elevation is not too critical; that is. the damages are low due to exceeding that elevation at infrequent times. Thus, the culvert should have the smallest possible barrel to pass the design Q without exceeding the AHW EL. Use a reinforced concrete box with n - 0.012.

STEP #1
CALCULATE TAILWATER

Use Program #1

Enter: 1.   n = _0.03_ (channel)

      2. S_o = _0.05_

      3.   BW = _8_

      4. Z_1 = _2_

      5. Z_2 = _2_

6.
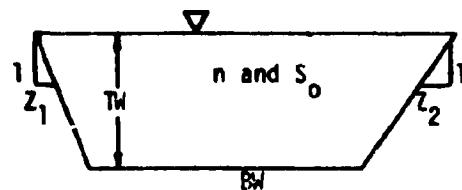
Enter Q	TW, Based on d_n	Channel Velocity	COMMENTS
1000	3.52	18.90	Design Flow
600	2.72	16.45	
800	3.15	17.80	
1200	3.85	19.84	

STEP #2
DETERMINE CULVERT LENGTH

Use Program #2

Enter: 1. S_o = _0.05_

      2. S_{FU} = _3:1_

      3. S_{FD} = _3:1_

      4.   EL.FU = _190.78_

      5.   EL.FD = _171.44_

6.

Enter D	L	EL.INLET	EL.OUTLET	COMMENTS
5	356.5	190.1	172.3	
6	350.4	190.0	172.5	
7	344.2	189.9	172.7	

DETERMINE AN ACCEPTABLE CULVERT SIZE

Use Program #3 for Box Culverts
Use Program #12 for Pipe Culverts

Enter: 1. Q = __1000__

2. N = __1__

3. k_e = __0.2__ (beveled edge)

4. n = __0.012__

5. TW = __3.52__

6. Enter B - for Box or ~~alpha- for Pipe~~	7. Enter D	8. Enter EL.OUTLET	9. Enter L	Read. HW.EL.	COMMENTS
6	5	172.3	356.5	215.1	Exceeds Design
6	6	172.5	350.4	203.2	" "
7	6	172.5	350.4	195.9	OK < 200 ft.
7	7	172.7	344.2	191.9	

Read (Reload 7X6 Data Into Calculator)

d_c = __8.61__

H = __17.41__

V = __23.8__   for Outlet Control

OUTLET CONTROL PERFORMANCE

1. Enter Q	5. Enter TW	Read HW EL.	COMMENTS
600	2.72	184.77	
800	3.15	189.64	
1000	3.52	195.91	
1200	3.85	203.57	

(Plot: Q vs. HW. EL.)

INLET CONTROL: DESIGN AND PERFORMANCE

Box Culverts
Program #4 - ~~Square Edged Inlet with Headwalls~~
- ~~Square Edged Inlet with Wingwalls~~
- ~~Bevel Edged Inlet with Headwalls~~
- Bevel Edged Inlet with Wingwalls

Program #7 - Tapered Throat Inlet

Pipe Culverts
Program #13 - CMP with Projecting Edges
- CMP in a Headwall
- CMP or Conc. with type A Bevel
- CMP or Conc. with type B Bevel

Program #14 - CMP or Conc. with Standard End Section
- Conc. with Square Edges in a Headwall
- Conc. with a Projecting Socket End
- Conc. with a Socket End in a Headwall

Program #15 - CMP with a Tapered Throat Inlet
Program #16 - Conc. with a Tapered Throat Inlet

Enter: 1. B = _____7_____ (For Boxes Only)
        2. D = _____6_____
        3. N = _____1_____
        4. EL.INLET = _190_
        5. DHW EL. = _200_

6.	Enter Q	Read EL.FACE, ~~EL.THROAT~~	Read FALL	Read H_f, ~~H~~	Read HW EL.	COMMENTS
		Inlet type Bevel Edged Inlet with Wingwalls				
	1000	177.3	12.7	22.7	200	
		Fall too large try tapered Inlet				
		Inlet type Tapered Throat Inlet				
		El.Throat		Ht		
	1000	184.1	5.86	15.86	200	From curve,
	600				193.6	H can be seen
	800				196.4	that 2.5' of >
	1200				204.5	FALL can be applie

6.	Enter Q	Read ~~EL.FACE~~ EL.THROAT	Read FALL	Read ~~H~~x. H_t	Read HW EL.	COMMENTS
Inlet type Throat Tapered Inlet (7.4' of FALL)						
1000	181.6	7.4	22.7	197.5	
600		(5.9+2.5)		191.1	
800				193.9	
1200				202.0	

Inlet type _____

Inlet type _____

Inlet type _____

Box Culverts - Use Program #8

~~Pipe Culverts - Use program #17~~

Enter: 1. Q = __1000__   6. S_0 = __0.05__

        2. D = __6__   7. FALL = __74__

        3. N = __1__   8. S_{FU} = __3__

        4. H_t = __22.7__   9. L = __350__

        5. ST = __4.1__

        Boxes   Pipes

        10. B = __7__   10. ~~B~~

        11. EL.THROAT = __181.6__

Read: Boxes   Pipes
        INLET TYPE: ~~SQ.ED.~~, (BV.ED.)   SELECT INLET TYPE
        ADJ.S = __0.0272__   PROJ., SQ.ED., BV.ED.

        ADJ.L = __368.6__   ADJ.S =

        B_f = __7.8__ B_f =

        L_1 = __1.6__ L_1 =

        EL.FACE = __181.64__

Pipe Culverts - use program #18

Enter: 1. EL.THROAT =   4. FALL =

        2. ADJ.S =   5. L =

        3. S_0 =   6. L_1 =

Read: ADJ.L =   EL.FACE =

CREST EVALUATION AND OUTLET VELOCITY

Go to Step 6 previous page

STEP #5
CONVENTIONAL INLETS

Use Program #5

Enter: 1. D = _____

2. S_o = _____

3. FALL = _____

Read: ADJ.S = _____
ADJ.L _____

4. S_{FU} = _____

5. L = _____

STEP #6
CREST EVALUATION

Use Program #6

Enter: 1. Q = __1000__

2. D = __6__

3. ~~B or~~ B_f = __7.8__

4. S_o = __0.05__

5. HW EL = __197.5__

Read: H_c = __6.28__

QW = __22.45__

6. S_f = __3:1__

7. ADJ.L = __368.6__

8. ADJ.S = __0.027__

9. N = __1__

10. EL.OUtLET = __172.5__

WT = __8.1__

WA = __51.2__

STEP #7
INLET CONTROL, OUTLET VELOCITY

Box Culverts - program #11
~~Pipe Culverts - program #19~~

Enter: 1. Q = __1000__

2. D = __6__

3. N = __1__

4. n = __0.012__

5. S = __0.027__

6. B = __7__   (Boxes Only)

Read: V = __31.9 fps__.

98

PERFORMANCE CURVES
7'x6' BOX CULVERT

ADDITIONAL FALL

1.5'

DHW EL.

FALL = 6.1' THROAT TAPERED INLET

FALL = 7.0' THROAT TAPERED INLET

7'x6' THROAT CONTROL — BEVELED INLET

7'x6' OUTLET CONTROL

DESIGN Q

HEADWATER ELEVATION (FT)

DISCHARGE (CFS)

600   800   1000   1200

195   200   195   190   185   180

99
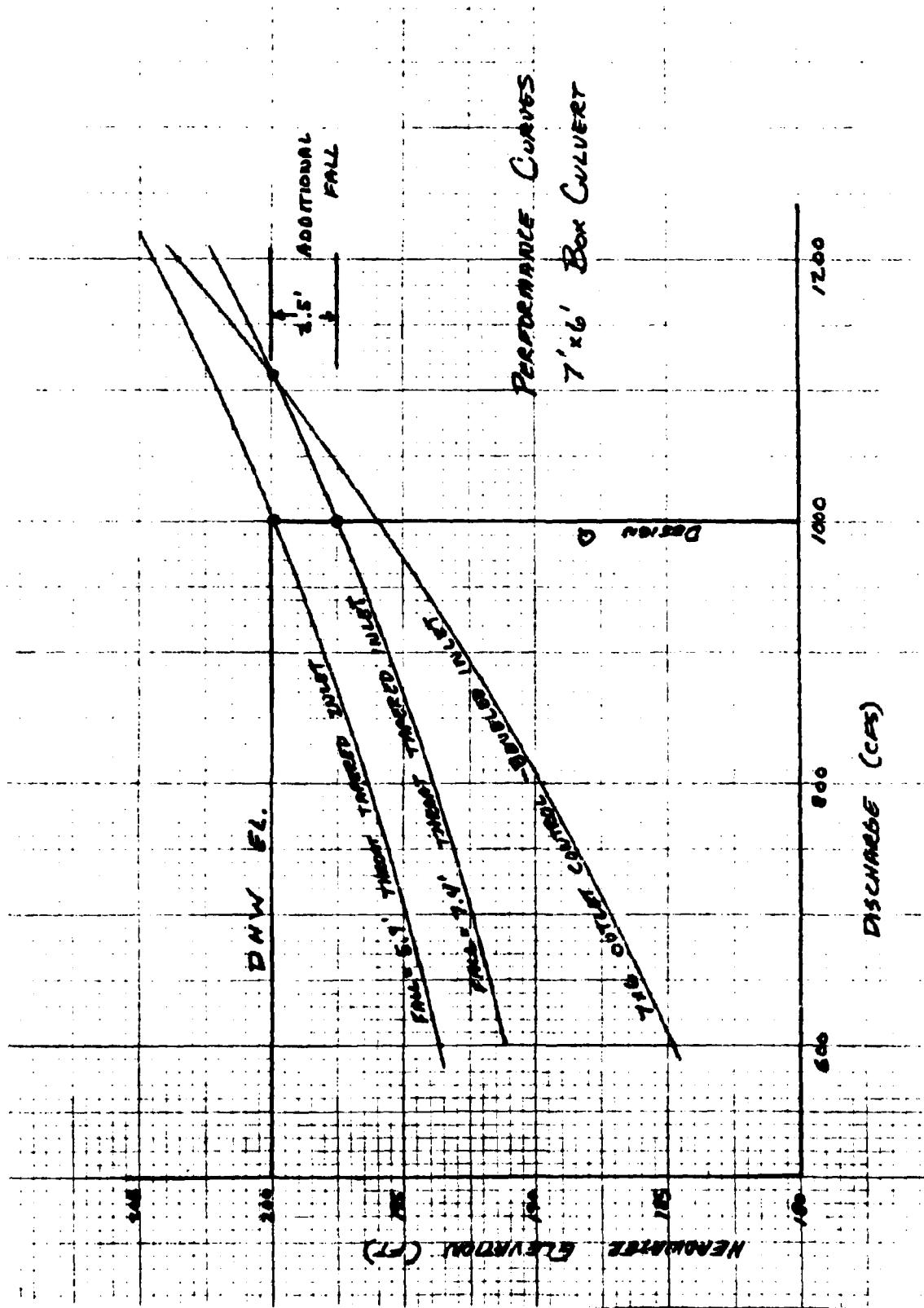
CONCLUSIONS

Since the requirements called for the smallest
possible reinforced concrete box culvert, the
barrel should be a single 7' by 6'.

Selection oif the inlet would be based on cost.
The additional 2.5' of FALL gains 110 cfs at the
AHW EL. of 200 ft. It appears that a side- or
slope-tapered inlet which would meet the design
requirements would be adequate and the least
expensive.

Examination of the outlet shows that it will not
be the governing flow regime above the AHE EL. up
to about EL. 205 unless the additional 2.5' of FALL
is applied.

PIPE CULVERT EXAMPLE NO. 2

Given: Design Discharge (Q) = 150 cfs, for a 50-year
          recurrence interval

          Slope of stream bed (S_0) = 0.05 ft./ft.

          Allowable Headwater Elevation = 100

          Elevation Outlet Invert = 75.0

          Culvert Length = 350 ft.

          Downstream channel approximates a 5' wide
          trapezoidal channel with 2:1 side slopes and
   a Manning's "n" of 0.03.

Requirements: This pipe culvert will be located in a suburban
               area where the allowable headwater elevation
               may be exceeded by 2 to 3 ft. without extreme
               damage. However, headwater elevations greater
               than 103.0 ft. should be avoided for flows
               significantly higher than the design Q of 150 cfs.

STEP #1
CALCULATE TAILWATER

Use Program #1

Enter: 1. n = __0.03__ (channel)

2. S_0 = __0.05__

3. BW = __5__

4. Z_1 = __2__

5. Z_2 = __2__
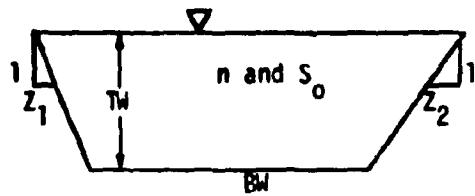
6.	Enter Q	TW, Based on d_n	Channel Velocity	COMMENTS
	90	1.21	10.03	
	120	1.41	10.89	
	150	1.58	11.59	
	180	1.74	12.19	

STEP #2
DETERMINE CULVERT LENGTH

Use Program #2

Enter: 1. S_0 = __0.05__

2. S_{FU} = __3:1__

3. S_{FD} = __3:1__

4. EL.FU = __93.02__

5. EL.FD = __74.29__

6.	Enter D	L	EL.INLET	EL.OUTLET	COMMENTS
	3.5	353.53	92.56	74.91	
	4.0	350.45	92.50	75.00	
	4.5	347.38	92.43	75.09	

STEP #3
DETERMINE AN ACCEPTABLE CULVERT SIZE

~~Use Program #3 for Box Culverts~~
Use Program #12 for Pipe Culverts

Enter: 1. Q = __150__

2. N = __1__

3. k_e = __0.25__ (Beveled Edge) 0.5 (Square Edge)

4. n = __0.024__

5. TW = __1.58__

6. Enter ~~B - for Box or~~ alpha for Pipe	7. Enter D	8. Enter EL.OUTLET	9. Enter L	Read. HW.EL.	COMMENTS Beveled Edge
1.12	3.5	74.91	353.53	109.87	Exceeds AHW.EL.
	4.0	75.0	350.45	94.62	Ok

Read

d_c = __3.66__

H = __15.79__

V = __12.45__ for Outlet Control

OUTLET CONTROL PERFORMANCE

Beveled Edge

1. Enter Q	5. Enter TW	Read HW EL.	COMMENTS
90	1.21	84.16	84.36 HW.EL. for
120	141	88.80	89.15 Square Edge
150	1.58	94.62	95.17
180	1.74	101.65	102.44

103

STEP #4
INLET CONTROL: DESIGN AND PERFORMANCE

Box Culverts
Program #4 - Square Edged Inlet with Headwalls
        - Square Edged Inlet with Wingwalls
        - Bevel Edged Inlet with Headwalls
        - Bevel Edged Inlet with Wingwalls
Program #7 - Tapered Throat Inlet

Pipe Culverts
Program #13 - CMP with Projecting Edges
        - CMP in a Headwall
        - CMP or Conc. with type A Bevel
        - CMP or Conc. with type B Bevel
Program #14 - CMP or Conc. with Standard End Section
        - Conc. with Square Edges in a Headwall
        - Conc. with a Projecting Socket End
        - Conc. with a Socket End in a Headwall
Program #15 - CMP with a Tapered Throat Inlet
Program #16 - Conc. with a Tapered Throat Inlet

Enter: 1. B = _____ (For Boxes Only)
        2. D = ___4___
        3. N = ___1___
        4. EL.INLET = _92.50_
        5. DHW EL. = _100_

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS

Inlet type CMP IN a Headwall

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS
150.	91.82	0.68	8.18	100	FALL Req.	
	FALL is required try beveled Edge					

Inlet type CMP with Type "A" Bevel

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS
150	92.26	0.24	7.74	100	FALL Req.	
	Minor FALL is required try Type "B" Bevel					

104

INLET CONTROL: DESIGN AND PERFORMANCE
(CONTINUED)

6.	Enter Q	Read EL.FACE, ~~EL.THROAT~~	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS
Inlet type CMP Type "B" Bevel						
150	92.50	O	6.88	99.38	OK-Use
90	Run performance curve analysis & proceed to check throat tapered Inlets			96.87	
120				98.00	
180				101.01	
Inlet type CMP with Tapered Throat						
150	92.50	O	6.62	99.12	OK
90	Try a 3.5' Diameter			96.99	
120				98.00	
180				100.42	
Inlet type CMP with Tapered Throat (3.5'= DIA) (EL.IN = 92.56)						
150	91.77	0.79	8.23	100	
90	Note: Culvert is in outlet control with DIA = 3.5'			96.75	
120				98.20	
180				102.21	
Inlet type _____						

105

STEP #5
CONVENTIONAL INLETS

Use Program #5

Enter: 1. D = _____   4. S_{FU} = _____

2. S_0 = _____   5. L = _____

3. FALL = _____

Read: ADJ.S = _____
ADJ.L = _____

STEP #6
CREST EVALUATION

Use Program #6

Enter: 1. Q = _____   6. S_f = _____

2. D = _____   7. ADJ.L = _____

3. B or B_f = _____   8. ADJ.S = _____

4. S_0 = _____   9. N = _____

5. HW EL = _____   10. EL.OUtLET = _____

Read: H_c = _____   WT = _____

CW = _____   WA = _____

STEP #7
INLET CONTROL, OUTLET VELOCITY

~~Box Culverts - program #11~~
Pipe Culverts - program #19

Enter: 1. Q = 150   4. n = 0.024

2. D = 4   5. S = 0.05

3. N = 1   ~~6. B = _____ (Boxes Only)~~

Read: V = 15.56 .

Performance Curves
48" Corrugated Pipe

107

CONCLUSIONS

From the performance curves, beveled edges meet
the AHW EL. of 100 ft. and Q = 150 cfs. While
the use of a side-tapered inlet would increase
Q to 173 cfs at the AHW EL. = 100 ft., in both
cases the FALL = 0, it appears that the beveled
edge inlet would be sufficient and the least
costly in this case, since the culvert performance
curve does not exceed 103.0 ft. until Q is 183 cfs.

PIPE CULVERT EXAMPLE NO. 3

Given: Design Discharge (Q) = 150 cfs, for a 50-year
recurrence interval

Slope of stream bed (S_o) = 0.05 ft./ft.

Allowable Headwater Elevation = 96

Elevation Outlet Invert = 75.0

Culvert Length = 350 ft.

Downstream channel approximates a 5' wide
trapezoidal channel with 2:1 side slopes and
a Manning's "n" of 0.03.

Requirements: Hydrologic estimates are accurate and exceeding
the AHW EL. at higher discharges is not important
at this site. Therefore, use the smallest barrel
possible.

The outlet control curves of problem 2 are
applicable in this situation. The 48" C.M.P. is
the smallest barrel which will meet the AHW EL.
of 96.0 and Q = 150 cfs.

From the inlet control curves, it is clear that
a FALL must be used on the tapered inlet to meet
the AHW EL. Try a side-tapered inlet, with FALL,
and a slope-tapered inlet.

STEP #1
CALCULATE TAILWATER

Use Program #1

Enter: 1. n = __0.03__ (channel)

2. S_o = __0.05__

3. BW = __5__

4. Z_1 = __2__

5. Z_2 = __2__

6.

Enter Q	TW, Based on d_n	Channel Velocity	COMMENTS
90	1.21	10.03	
120	1.41	10.89	
150	1.58	11.59	
180	1.74	12.19	

STEP #2
DETERMINE CULVERT LENGTH

Use Program #2

Enter: 1. S_o = __0.05__

2. S_{FU} = __3:1__

3. S_{FD} = __3:1__

4. EL.FU = __93.02__

5. EL.FD = __74.29__

6.

Enter D	L	EL.INLET	EL.OUTLET	COMMENTS
3.5	353.53	92.56	74.91	
4.0	350.45	92.50	75.00	
4.5	347.38	92.43	75.09	

STEP #3
DETERMINE AN ACCEPTABLE CULVERT SIZE

~~Use Program #3 for Box Culverts~~
Use Program #12 for Pipe Culverts

Enter: 1. Q = __150__

2. N = __1__

3. k_e = __0.25 (Beveled Edge), 0.5 (Square Edge)__

4. n = __0.024__

5. TW = __1.58__

6. Enter ~~B for Box or~~ alpha for Pipe CMP	7. Enter D	8. Enter EL.OUTLET	9. Enter L	Read. HW.EL.	COMMENTS Beveled Edge
1.12	3.5	74.91	353.53	109.87	Exceeds AHW.EL
	4.0	75.0	350.45	94.62	OK

Read

d_c = __3.66__

H = __15.79__

V = __12.45__ for Outlet Control

OUTLET CONTROL PERFORMANCE

1. Enter Q	5. Enter TW	Beveled Edge Read HW EL.	HW.EL. Square Edge COMMENTS
90	1.21	84.16	84.36
120	1.41	88.80	89.15
150	1.58	94.62	95.17
180	1.74	101.65	102.44

111

INLET CONTROL: DESIGN AND PERFORMANCE

Box Culverts
Program #4 - Square Edged Inlet with Headwalls
      - Square Edged Inlet with Wingwalls
      - Bevel Edged Inlet with Headwalls
      - Bevel Edged Inlet with Wingwalls
Program #7 - Tapered Throat Inlet

Pipe Culverts
Program #13 - CMP with Projecting Edges
      - CMP in a Headwall
      - CMP or Conc. with type A Bevel
      - CMP or Conc. with type B Bevel
Program #14 - CMP or Conc. with Standard End Section
      - Conc. with Square Edges in a Headwall
      - Conc. with a Projecting Socket End
      - Conc. with a Socket End in a Headwall
Program #15 - CMP with a Tapered Throat Inlet
Program #16 - Conc. with a Tapered Throat Inlet

Enter: 1. B = _____ (For Boxes Only)
      2. D = __4__
      3. N = __1__
      4. EL. INLET = __92.5__
      5. DHW EL. = __96.0__

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS
			Inlet type CMP Type "B"			
	150.	89.12	3.38	6.88	96.0	
	90	Try tapered throat			93.49	
	120				94.62	
	180				97.63	
			Inlet type Tapered Throat, CMP			
	150	89.38	3.12	6.62	96.0	Use
	90	Plot Performance			93.87	
	120				94.88	
	180				97.30	

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS

Inlet type _Tapered Throat, Concrete_

6.	Enter Q	Read EL.FACE, EL.THROAT	Read FALL	Read H_f, H_t	Read HW EL.	COMMENTS
	150	89.63	2.87	6.37	96.00	
	90	0.25 less FALL, using a concrete side-tapered inlet			93.85	
	120				94.88	
	180				97.26	

Inlet type _____

Inlet type _____

Inlet type _____

SIDE-TAPERED INLETS

~~Box Culverts - Use Program #8~~

Pipe Culverts - Use program #17

Enter: 1. Q = __150__   6. S_0 = __0.05__

2. D = __4__   7. FALL = __3.12__

3. N = __1__   8. S_{FU} = __3:1__

4. H_t = __6.62__   9. L = __350.45__

5. ST = __4:1__

~~Boxes~~   Pipes

10. ~~B~~   10. E = __44__

11. ~~EL.THROAT~~

Read: ~~Boxes~~   Pipes
      ~~INLET TYPE: SQ.ED., BV.ED.~~   SELECT INLET TYPE
      ~~ADJ.S =~~   ~~PROJ., SQ.ED.,~~ BV.ED.
      ~~ADJ.L~~
                              ADJ.S = __0.0402__
      ~~B_f =~~
      ~~L_1 =~~ B_f = __4.59__ } MINIMUM
      ~~EL.FACE =~~ L_1 = __1.18__ } values

Pipe Culverts - use program #18

Enter: 1. EL.THROAT = __89.38__   4. FALL = __3.12__

2. ADJ.S = __0.0402__   5. L = __350.45__

3. S_0 = __0.05__   6. L_1 = __1.18__

Read: ADJ.L = __356.84__   EL.FACE = __89.43__

CREST EVALUATION AND OUTLET VELOCITY

Go to Step 6 previous page

STEP #5
CONVENTIONAL INLETS

Use Program #5

Enter: 1. D = _____   4. S_{FU} = _____

2. S_o = _____   5. L = _____

3. FALL = _____

Read: ADJ.S = _____
ADJ.L = _____

STEP #6
CREST EVALUATION

Use Program #6

Enter: 1. Q = 150   6. S_f = 3:1

2. D = 4   7. ADJ.L = 356.84

3. B or B_f = 4.59   8. ADJ.S = 0.0402

4. S_o = 0.05   9. N = 1

5. HW EL = 96.0   10. EL.OUtLET = 75.00

Read: H_c = 3.01   WT = 1.15:1
CW = 10.14   WA = 41°

STEP #7
INLET CONTROL, OUTLET VELOCITY

~~Box Culverts - program #11~~
Pipe Culverts - program #19

Enter: 1. Q = 150   4. n = 0.024

2. D = 4   5. S = 0.0402

3. N = 1   ~~6. B = _____ (Boxes Only)~~

Read: V = 14.13 .

115

STEP #5
SLOPE-TAPERED INLETS

Program #9
Enter: 1. D = _4_   5. S_{FU} = _3_

2. L_3 = _2_   6. EL.FU = _93.02_

3. S_o = _0.05_   7. S_f = _3:1_

4. EL.OUTLET = _75.0_   8. EL.THROAT = _89.38_

Select Inlet Type: ~~Vertical Face,~~ Mitered Face

Read: ADJ.S = _0.0414_ L_4 = _6.32_

ADJ.L = _347.39_ L_2 = _4.99_

EL.FACE = _90.91_

Program #10
Enter: 1. Q = _150_   5. B = _4_ (for pipe use D)

2. D = _4_   6. HW.EL. = _96.0_

3. L_3 = _2_   7. EL.FACE = _90.91_

4. N = _1_   8. L_2 = _4.99_

                                    9. L_4 = _6.32_

Select Inlet Type: ~~Square Edges,~~ Beveled Edges

Read: B_f = _4.89_   ST = _15.7:1_

STEP #6
Mitered Face Crest Evaluation

Read: H_c = _5.09_   CW = _4.62_
                          ST = _0_

STEP #7
INLET CONTROL OUTLET VELOCITY

Box Culverts - Program #11
Pipe Culverts - Program #19

Enter: 1. Q = _150_   4. n = _0.024_
       2. D = _4_   5. S =
       3. N = _1_   ~~6. B =~~ ~~(Boxes only)~~

Read: V = _14.31 fps_

116

PERFORMANCE CURVES
48" CORRUGATED METAL
PIPE

117
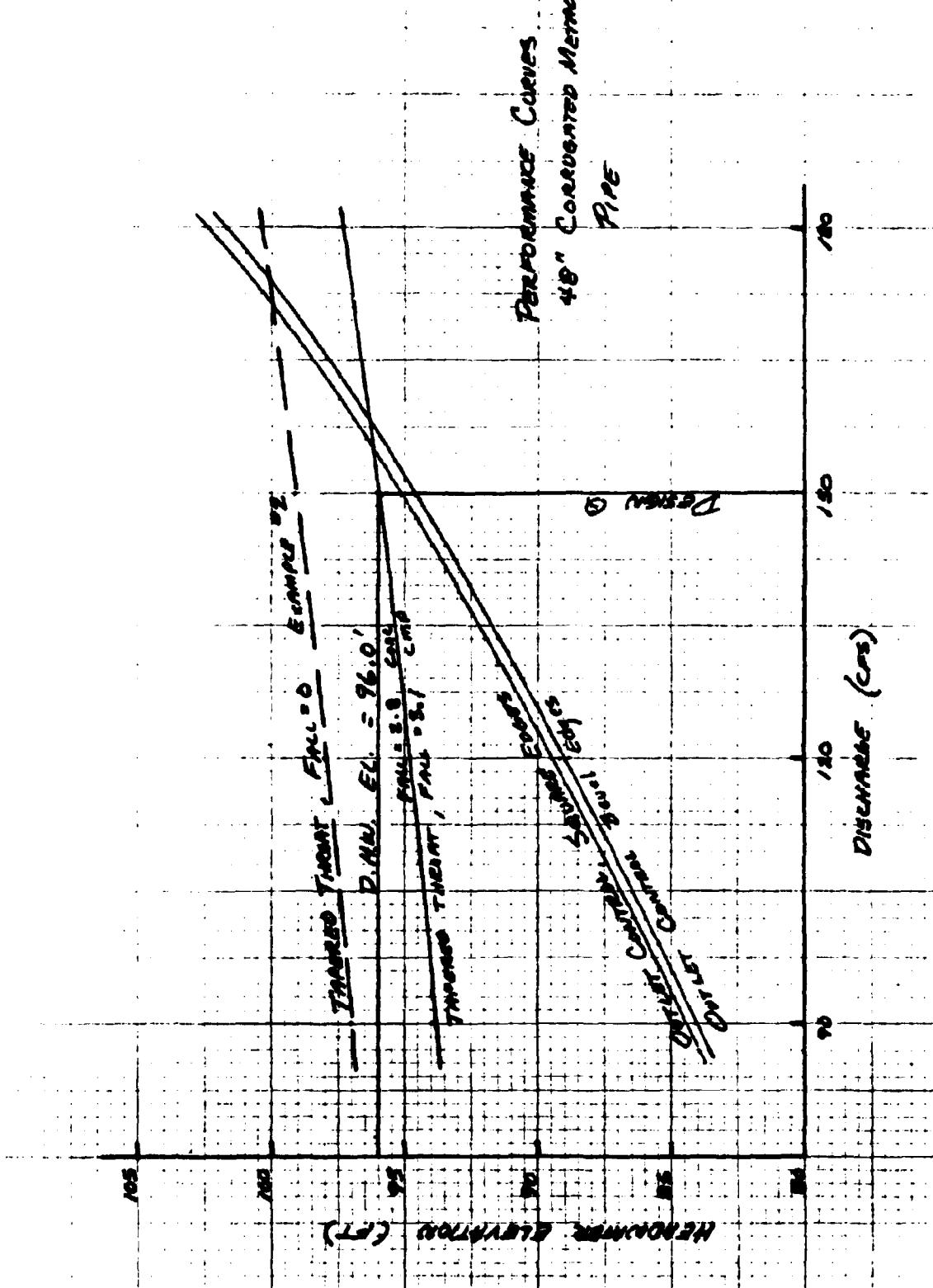
CONCLUSIONS

Selection of a side- or slope-tapered inlet must
be based on economics, as either will perform the
required function. Additional FALl is not warranted
at this site. Face design was selected to pass 150 cfs
at the AHW EL. = 96.0.

The culvert performance curves for the example
illustrate that when a prefabricated side-tapered
inlet (rough) of a cast-in-place slope-tapered inlet
(smooth) may be chosen for the installation, both
the smooth and rough inlet throat control curves
should be plotted. The difference between the throat
control curves represents the difference in friction
losses between the face and throat sections of the inlet.

APPENDIX A

DERIVATIONS OF EQUATIONS

USED IN PROGRAMS

PROGRAM #2
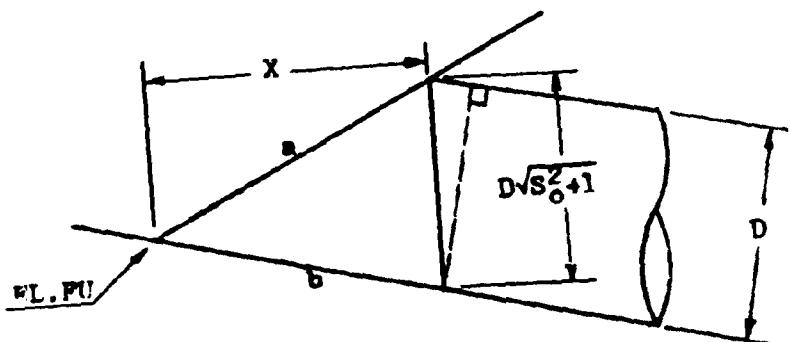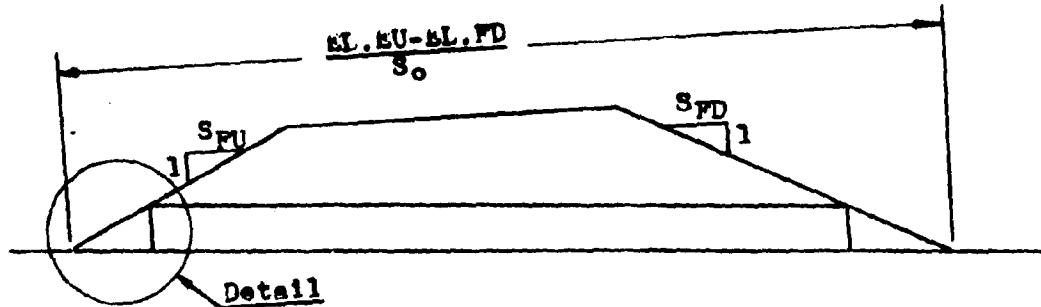
The equation for the fill slope (line a) is:

$$Y_a = \frac{X}{S_{FU}} + EL.FU$$

Similarly, the equation for the channel slope (line b) is:

$$Y_b = -S_o X + EL.FU$$

At the face of the culvert, the difference between these two equations equals the height of the culvert.

120

$$D\sqrt{S_o^2+1} = Y_a - Y_b = \frac{X}{S_{FU}} + EL.FU + S_oX - EL.FU = \frac{X}{S_{FU}} + S_oX$$

Solving for the unknown value X:

$$X = \frac{D\sqrt{S_o^2+1}}{(\frac{1}{S_{FU}} + S_o)} = \frac{S_{FU}D\sqrt{S_o^2+1}}{(1+S_oS_{FU})}$$

For the downstream condition, a similar value for X would be:

$$X = \frac{S_{FD}D\sqrt{S_o^2+1}}{(1-S_oS_{FD})}$$

Multiplying these values by the channel slope will give the change in elevation across the distance X. From this, the inlet and outlet elevations can be determined.

$$EL.INLET = EL.FU - \frac{S_oS_{FU}D\sqrt{S_o^2+1}}{(1+S_oS_{FU})}$$

$$EL.OUTLET = EL.FD + \frac{S_oS_{FD}D\sqrt{S_o^2+1}}{(1-S_oS_{FD})}$$

From these two values, the culvert length can be determined.

$$L = \frac{(EL.INLET-EL.OUTLET)\sqrt{S_o^2+1}}{S_o}$$

PROGRAM #5
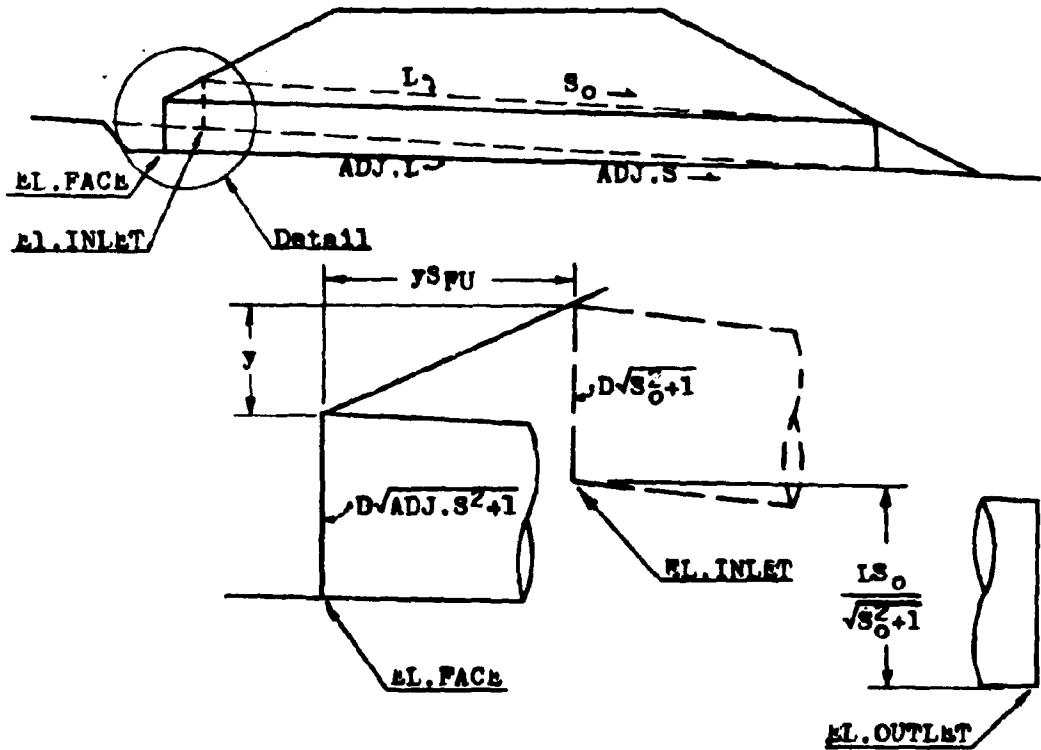
There are three unknowns to be solved for in this program.
ADJ.L, ADJ.S, and the vertical distance y. Knowing that the
FALL is the difference between the inlet and face elevations,
an expression for y can be obtained.

$$y = FALL + D\sqrt{S_0^2+1} - D\sqrt{ADJ.S^2+1}$$

Using a rise/run relationship, the value of ADJ.S becomes:

$$ADJ.S = \frac{(LS_0/\sqrt{S_0^2+1})-FALL}{(L/\sqrt{S_0^2+1})+yS_{PU}} = \frac{LS_0-FALL\sqrt{S_0^2+1}}{L+yS_{PU}\sqrt{S_0^2+1}}$$

122

Due to the complexity of these two equations they are solved by a trial and error method by the calculator.

Once the adjusted slope is found the adjusted length can be obtained by multiplying the difference in elevation between the face invert and the outlet invert by the cosecant of the adjusted slope.

$$ADJ.L = (\frac{LS_o}{\sqrt{S_o^2+1}} - FALL)(\frac{\sqrt{ADJ.S^2+1}}{ADJ.S})$$

PROGRAM #10

123
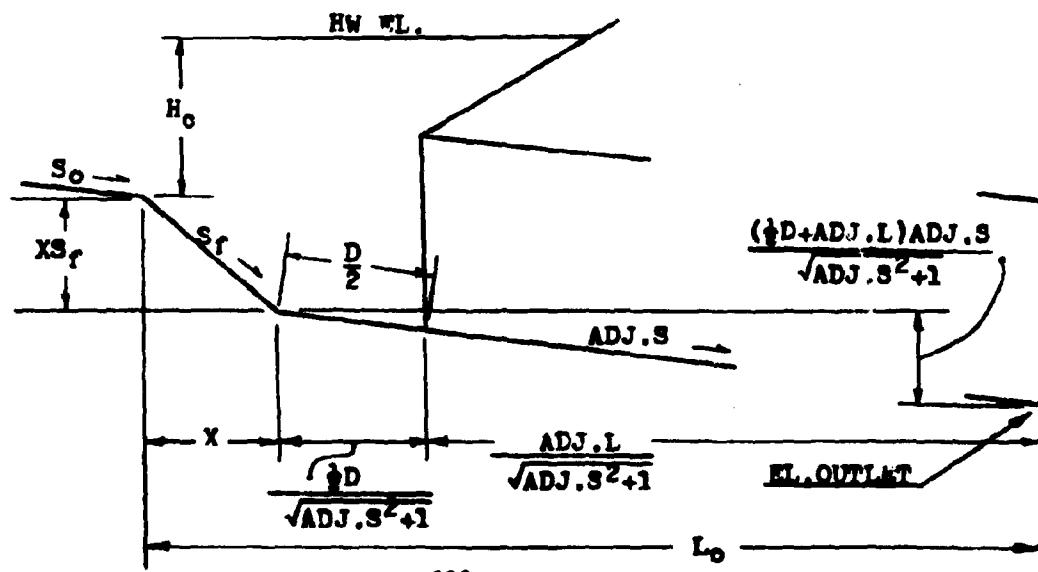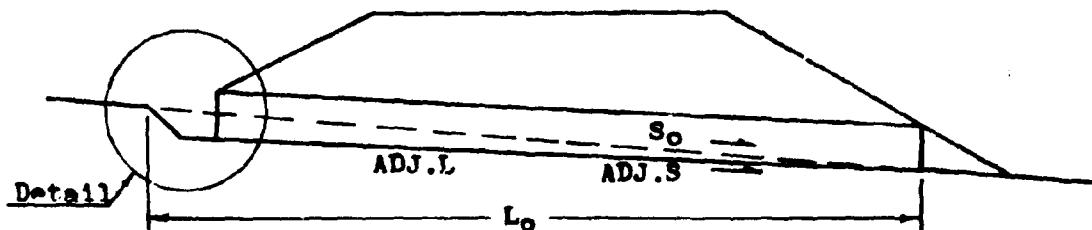
From the diagrams the value of L_o can be determined.

$$L_o = X + \frac{\frac{1}{2}D}{\sqrt{ADJ.S^2+1}} + \frac{ADJ.L}{\sqrt{ADJ.S^2+1}}$$

Since the value of X is also an unknown, an expression for it is also required. Summing vertical distances produces:

$$L_o S_o = XS_f + \frac{(\frac{1}{2}D+ADJ.L)ADJ.S}{\sqrt{ADJ.S^2+1}}$$

Combining these two equations, an expression for L_o without the value of X in it, is obtained.

$$L_o = \frac{(S_f-ADJ.S)(\frac{1}{2}D+ADJ.L)}{(S_f-S_o)\sqrt{ADJ.S^2+L}}$$

Substituting this value in an expression for H_c:

$$H_c = HW\ \text{EL.} - EL.OUTLET - L_o S_o$$

$$H_c = HW\ EL. - EL.OUTLET - \frac{S_o(S_f-ADJ.S)(\frac{1}{2}D+ADJ.L)}{(S_f-S_o)\sqrt{ADJ.S^2+1}}$$

The crest width can be calculated using this value of H_c. The formula relating crest width to the depth of water at the crest is taken from the references and is not derived here.

$$CW = \frac{Q}{(2H_c)^{1.5}}$$

PROGRAM #6   (cont)
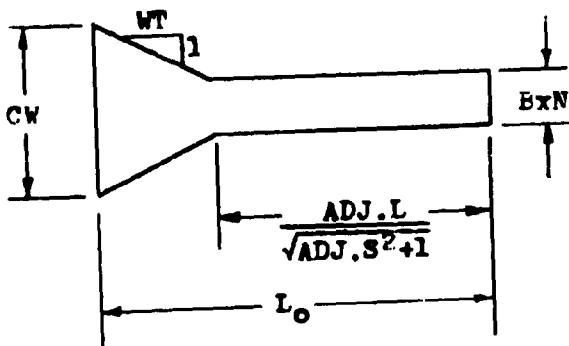

From this diagram, the wingwall taper is determined.

$$WT = \frac{(L_O - L/\sqrt{ADJ.S^2 + 1}}{(CW - BxN)/2}$$

The wingwall angle is just $90°$ - the arctangent of the wingwall taper.

PROGRAM #8#
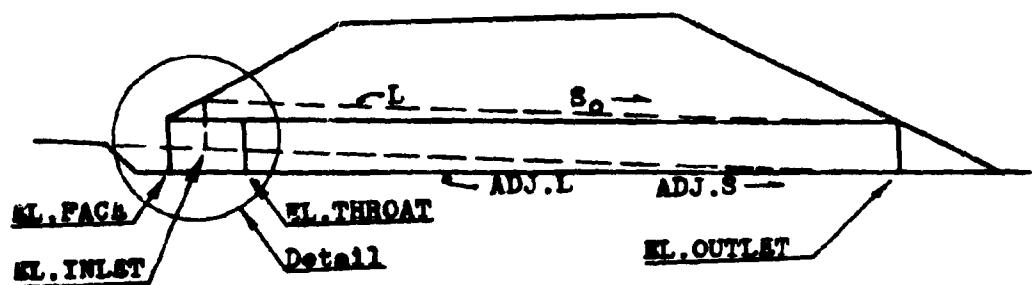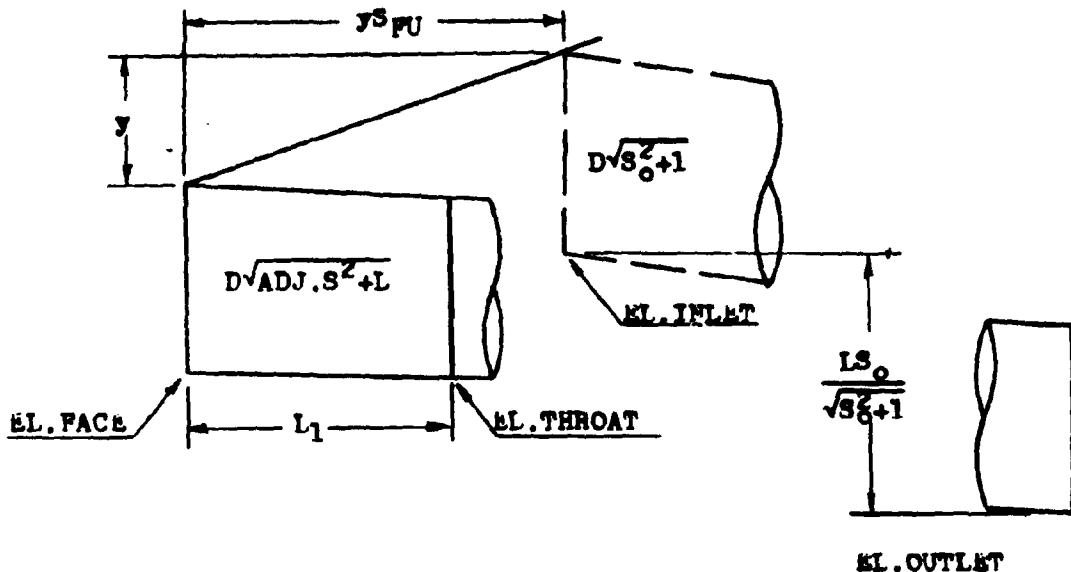
The formulas given here are similar to those given in program
#5, except a new unknown L_1 has been introduced. The meaning
of FALL has changed also. It now equals the difference between
the elevation of the inlet and the elevation of the throat.
The expressions for y and ADJ.S now equal:

$$y = FALL + D\sqrt{S_0^2+1} - D\sqrt{ADJ.S^2+1} - L_1 ADJ.S$$

$$ADJ.S = \frac{LS_0 - FALL\sqrt{S_0^2+1} + L_1 ADJ.S\sqrt{S_0^2+1}}{L + yS_{FU}\sqrt{S_0^2+1}}$$

Substituting:

$$0 = (FALL + D\sqrt{S_0^2+1} - D\sqrt{ADJ.S^2+1})S_{FU}ADJ.S\sqrt{S_0^2+1} - LS_0$$
$$+ FALL\sqrt{S_0^2+1} - L_1 ADJ.S\sqrt{S_0^2+1} + LADJ.S - L_1 ADJ.S^2 S_{FU}\sqrt{S_0^2+1}$$

PROGRAM #8

The adjusted length computations used in program #8 can be
derived using the diagrams of program #8 . Once the adjusted
slope is calculated by program #8 , it is used by this program
to find the new culvert length.

As was the case in program #5 , the adjusted length is the
product of the cosecant of the adjusted slope and a difference
in elevations. In program #5 , the difference was between the
face invert elevation and the outlet invert elevation. For
this program the difference is between the throat invert and
the outlet invert. Although this difference in definition
exists, it has little effect on the formula below. This
difference is resolved by the two different definitions of
the FALL. In program #5 , the FALL is the difference in elevation
between the inlet invert and the face invert. In program #8 ,
it is the difference in elevation between the inlet invert and
and the throat invert. After the culvert length is found,
the length of the improved inlet is subtracted off.

$$ADJ.L = (\frac{LS_o}{\sqrt{S_o^2+1}} - FALL)(\frac{\sqrt{ADJ.S^2+1}}{ADJ.S}) - L_1\sqrt{ADJ.S^2+1}$$

Sliding back up the adjusted slope from the throat section:

$$EL.FACE = EL.THROAT + L_1 ADJ.S$$
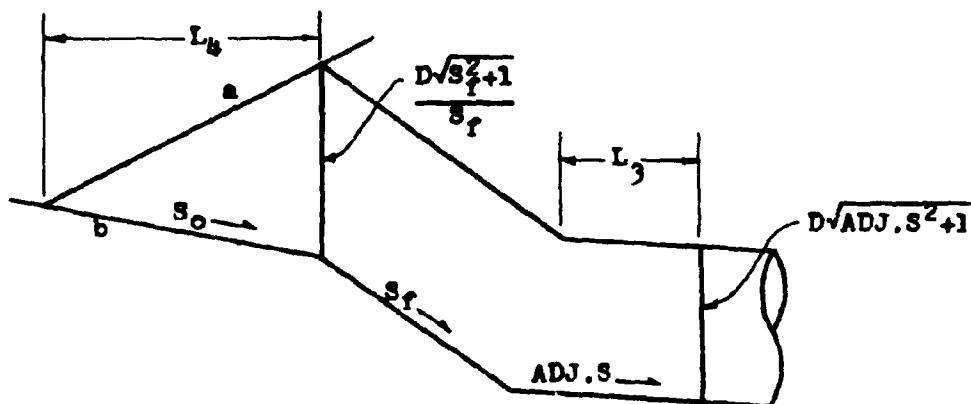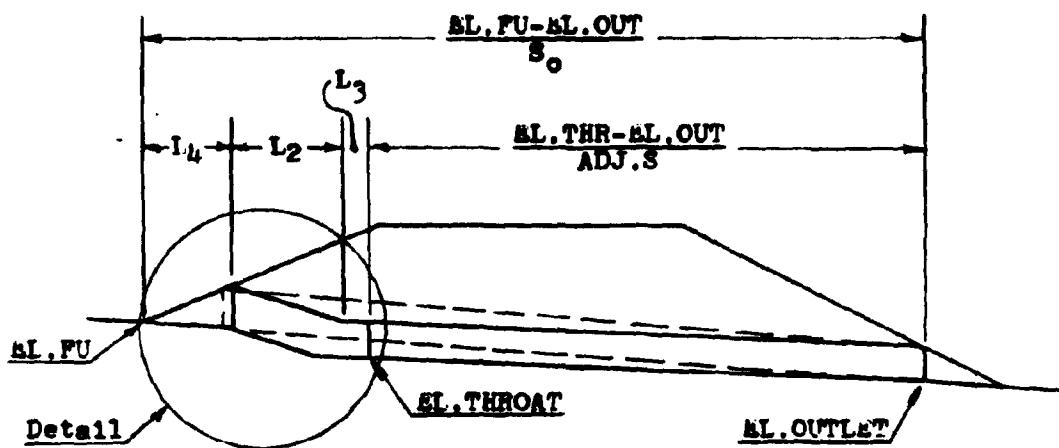
127

The equation for the fill slope (line a) is:

$$Y_a = \frac{L_4}{S_{FU}} + \text{EL.FU}$$

Similarly, the equation for the channel slope (line b) is:

$$Y_b = -S_0 L_4 + \text{EL.FU}$$

At the face of the culvert, the difference between these two equations equals the height of the culvert.

$$\frac{D\sqrt{S_f^2+1}}{S_f} = Y_a - Y_b = \frac{L_4}{S_{FU}} + \text{EL.FU} + S_oL_4 - \text{EL.FU}$$

Solving this expression for L_4:

$$L_4 = \frac{S_{FU}D\sqrt{S_f^2+1}}{S_f(1+S_oS_{FU})}$$

From the first diagram, it can be determined that:

$$L_2 = \frac{\text{EL.FU}-\text{EL.OUT}}{S_o} - L_4 - L_3 - \frac{\text{EL.THR}-\text{EL.OUT}}{\text{ADJ.S}}$$

by summing measurements in the vertical direction, the following expression was obtained.

$$\text{EL.THR} = \text{EL.FU} + \frac{L_4}{S_{FU}} - \frac{L_2}{S_f} - L_3\text{ADJ.S} - D\sqrt{\text{ADJ.S}^2+1}$$

Combining these last three equations, an expression for the adjusted slope can be obtained.

$$0 = \text{EL.FU} + \frac{(S_f+S_{FU})D\sqrt{S_f^2+1}}{S_f(1+S_oS_{FU})} + \frac{L_3}{S_f} + \frac{\text{EL.OUT}-\text{EL.FU}}{S_oS_f} - L_3\text{ADJ.S}$$

$$+ \frac{\text{EL.THR}-\text{EL.OUT}}{S_f\text{ADJ.S}} - D\sqrt{\text{ADJ.S}^2+1} - \text{EL.THROUT}$$

The equation for the fill slope (line a) is:

$$Y_a = \frac{L_4}{S_{FU}} + EL.FU$$
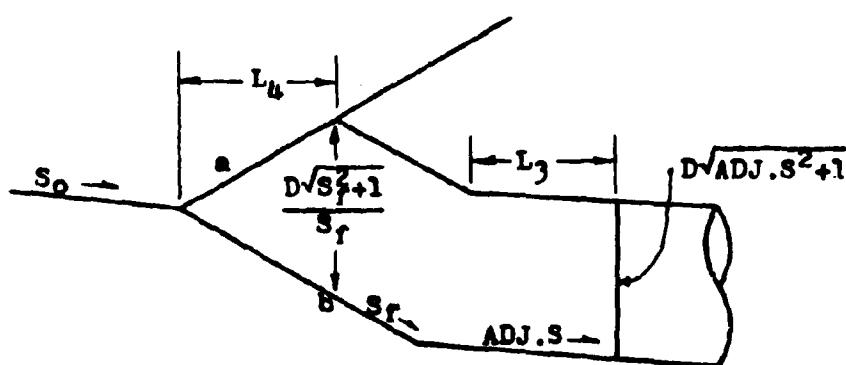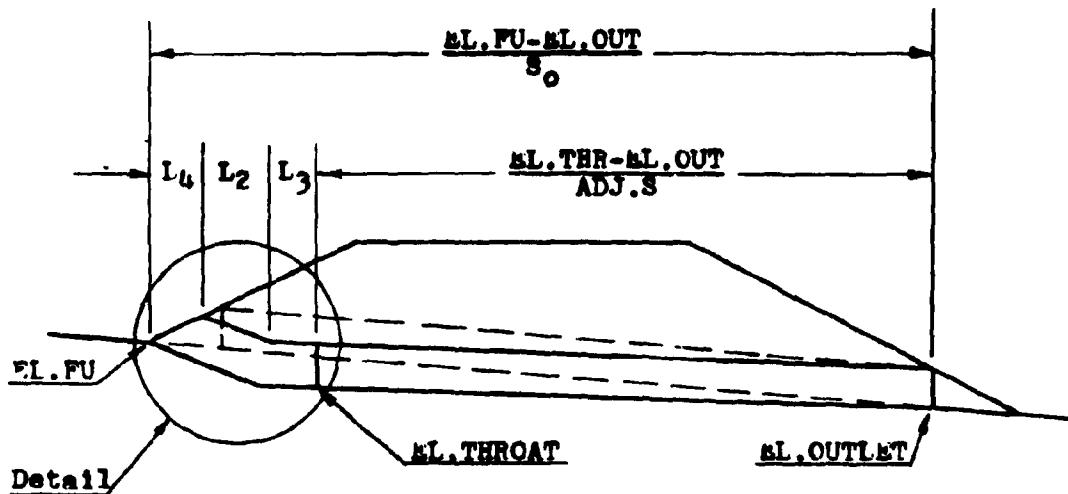
Similarly, the equation for the fall slope (line b) is:

$$Y_b = \frac{-L_4}{S_f} + EL.FU$$

At the face of the culvert, the difference between these two
equations equals the height of the culvert face.

$$\frac{D\sqrt{S_f^2+1}}{S_f} = Y_a - Y_b = \frac{L_4}{S_{FU}} + \text{EL.FU} + \frac{L_4}{S_f} - \text{EL.FU}$$

Solving this expression for L_4:

$$L_4 = \frac{S_{FU}D\sqrt{S_f^2+1}}{S_{FU}+S_f}$$

From the first diagram on the previous page:

$$L_2 = \frac{\text{EL.FU}-\text{EL.OUT}}{S_o} - L_4 - L_3 - \frac{\text{EL.THR}-\text{EL.OUT}}{\text{ADJ.S}}$$

By summing the measurements in the vertical direction, the
following expression was obtained.

$$\text{EL.THR} = \text{EL.FU} + \frac{L_4}{S_{FU}} - \frac{L_2}{S_f} - L_3\text{ADJ.S} - D\sqrt{\text{ADJ.S}^2+1}$$

Combining these last three equations, an expression for the
adjusted slope can be obtained.

$$0 = \text{EL.FU} + \frac{D\sqrt{S_f^2+1}}{S_f} + \frac{L_3}{S_f} + \frac{\text{EL.OUT}-\text{EL.FU}}{S_o S_f} + \frac{\text{EL.THR}-\text{EL.OUT}}{S_f\text{ADJ.S}}$$

$$- L_3\text{ADJ.S} - D\sqrt{\text{ADJ.S}^2+1} - \text{EL.THROAT}$$

131

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