# CTC 261 Hydraulics
# Culvert Design Form

# Objectives

- Know how to use the culvert design form to evaluate and size simple culverts

# Definitions

- $HW_o$=Headwater depth above outlet invert

# Step 1

- Summarize all known data and select a preliminary culvert size, shape and entrance type

# Step 2

- Choose a culvert type and size

# Step 3-Inlet Control Calculations

- Inlet control calculations
  - Determine HW/D from Design Charts
  - Calc HW depth
  - Calc Fall
  - Calc the Elev of the HW for inlet control

# Step 4-Outlet Control Calculations

- Outlet control calculations
  - Determine TW depth
  - Determine critical depth
  - Find the average of critical depth and diameter
  - Determine depth from culvert outlet invert to HGL
  - Determine all head losses
  - Calc the Elev of the HW for outlet control

# Step 5-Evaluate Results

- Higher of the two elevations designates control
- Choose larger culvert if the highest elevation is unacceptable

PROJECT : ____________________

STATION : ____________ SHEET ______ OF ______

**CULVERT DESIGN FORM**

DESIGNER / DATE : ________ / ________

REVIEWER / DATE : ________ / ________

**HYDROLOGICAL DATA**

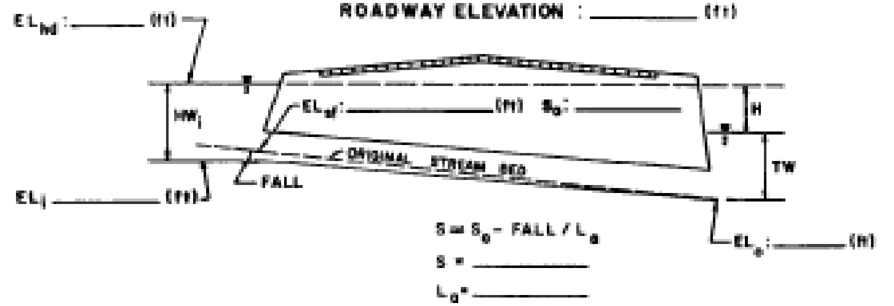
SEE ADD'L SHTS.

- ☐ METHOD: ____________
- ☐ DRAINAGE AREA: ______ ☐ STREAM SLOPE: ______
- ☐ CHANNEL SHAPE: ____________
- ☐ ROUTING: ______ ☐ OTHER: ______

**DESIGN FLOWS/TAILWATER**

| R.I. (YEARS) | FLOW (cfs) | TW (ft) |
|---|---|---|
| | | |
| | | |

ROADWAY ELEVATION : ________ (ft)




| CULVERT DESCRIPTION: MATERIAL - SHAPE - SIZE - ENTRANCE | TOTAL FLOW Q (cfs) | FLOW PER BARREL Q/N (1) | HEADWATER CALCULATIONS — INLET CONTROL: $HW_i/D$ (2) | $HW_i$ | FALL (3) | $EL_{hi}$ (4) | OUTLET CONTROL: TW (5) | $d_c$ | $\frac{d_c+D}{2}$ | $h_o$ (6) | $k_e$ | H (7) | $EL_{ho}$ (8) | CONTROL HEADWATER ELEVATION | OUTLET VELOCITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

**TECHNICAL FOOTNOTES:**

(1) USE Q/NB FOR BOX CULVERTS

(2) $HW_i/D = HW/D$ OR $HW_i/D$ FROM DESIGN CHARTS

(3) $FALL = HW_i - (EL_{hd} - EL_{sf})$ ; FALL IS ZERO FOR CULVERTS ON GRADE

(4) $EL_{hi} = HW_i + EL_i$ (INVERT OF INLET CONTROL SECTION)

(5) TW BASED ON DOWN STREAM CONTROL OR FLOW DEPTH IN CHANNEL.

(6) $h_o = TW$ or $(d_c + D)/2$ (WHICHEVER IS GREATER)

(7) $H = \left[1 + k_e + (K_u n^2 L) / R^{1.33}\right] v^2 / 2g$ WHERE $K_u$ = 19.63 (29 IN ENGLISH UNITS)

(8) $EL_{ho} = EL_o + H + h_o$

**SUBSCRIPT DEFINITIONS :**

- a. APPROXIMATE
- f. CULVERT FACE
- hd. DESIGN HEADWATER
- hi. HEADWATER IN INLET CONTROL
- ho. HEADWATER IN OUTLET CONTROL
- i. INLET CONTROL SECTION
- o. OUTLET
- sf. STREAMBED AT CULVERT FACE
- tw. TAILWATER

**COMMENTS / DISCUSSION :**

**CULVERT BARREL SELECTED :**

SIZE : ____________

SHAPE : ____________

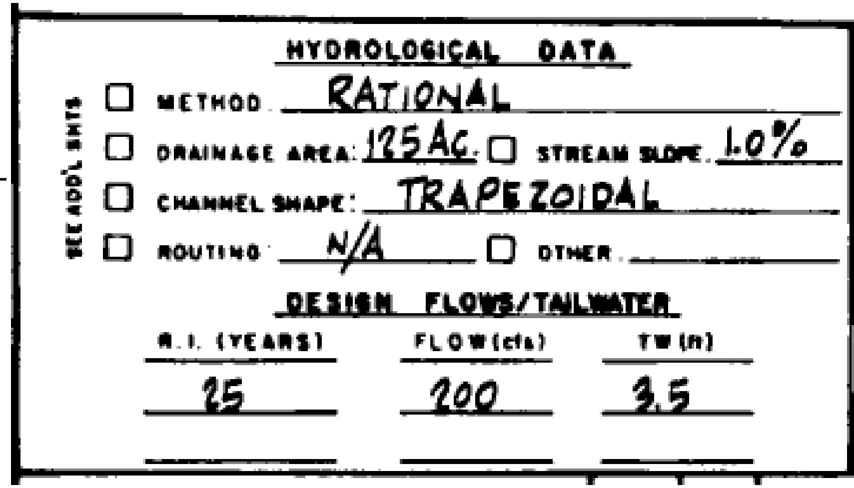
MATERIAL : ________ n ______

ENTRANCE : ____________

Figure III-17--Culvert Design Form

# Example Problem 1

- $Q_{25}$=200 cfs
- Natural channel slope=1%
- TW=3.5 ft
- L=200 ft
- Natl streambed elev. @ entrance = 100 ft
- Shoulder Elev=110 ft (2-ft freeboard)
- Evaluate 72" (6') CMP (45 deg bevel)



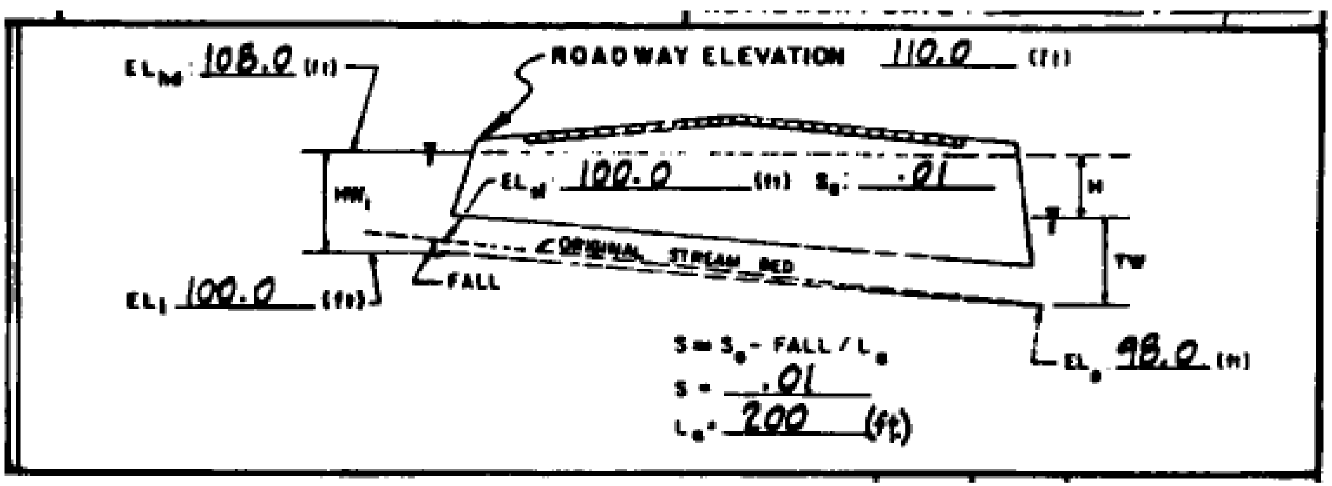
HYDROLOGICAL DATA

SEE ADD'L SHTS

- ☐ METHOD: RATIONAL
- ☐ DRAINAGE AREA: 125 AC. ☐ STREAM SLOPE: 1.0%
- ☐ CHANNEL SHAPE: TRAPEZOIDAL
- ☐ ROUTING: N/A ☐ OTHER:

DESIGN FLOWS/TAILWATER

| R.I. (YEARS) | FLOW (cfs) | TW (ft) |
|---|---|---|
| 25 | 200 | 3.5 |
| | | |

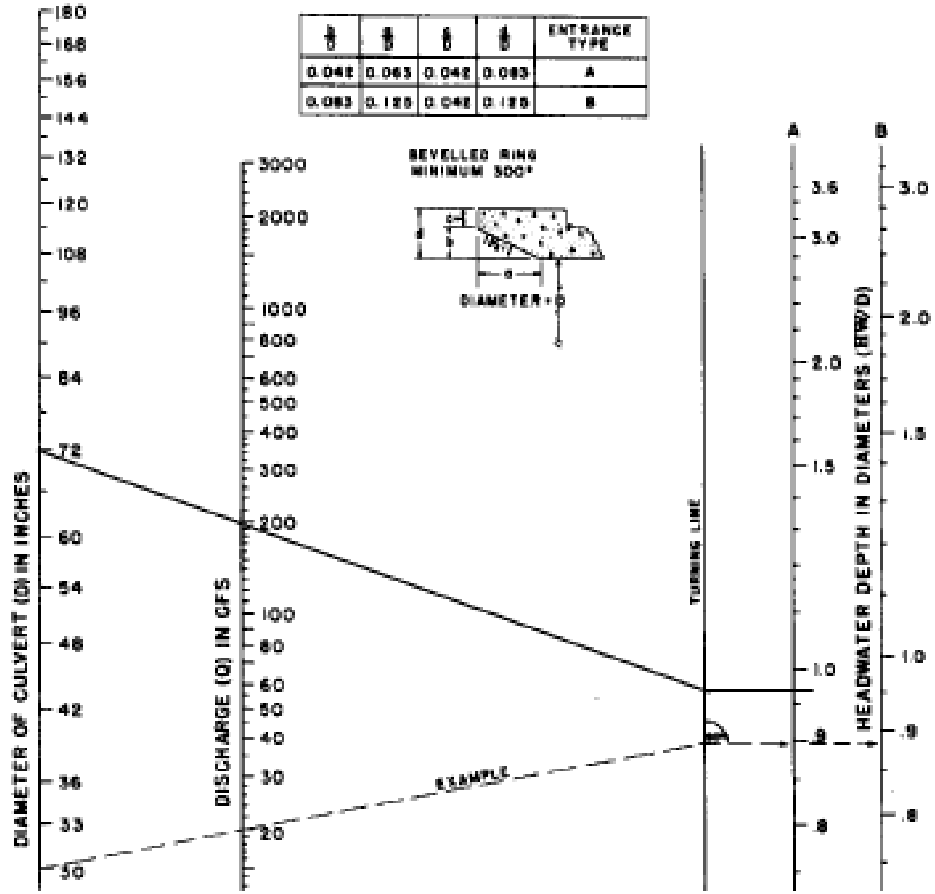


# Step 2

# Inlet Control Calculations

- HW/D from Design Chart 3B = 0.96
- HW=0.96*6’=5.8’
- A =45 deg bevel, pg 27
- B =33.7 deg bevel

CHART 3B



# Step 3-Inlet Control Calculations Calculate Fall

- Max. Available HW depth = 108-100= 8’
- Fall = Calc HW depth – Available HW depth
  - 5.8’-8’= -2.8 ft
  - Fall is negative; therefore set fall = 0
  - Note: If fall is + then the invert must be lowered to allow enough head to “push” desired Q through the culvert

# Step 3-Inlet Control Calculations Calculate HW Elev for inlet control

- $EL_{hi}=HW_i+EL_i$
- 5.8 ft + 100 ft = 105.8 feet

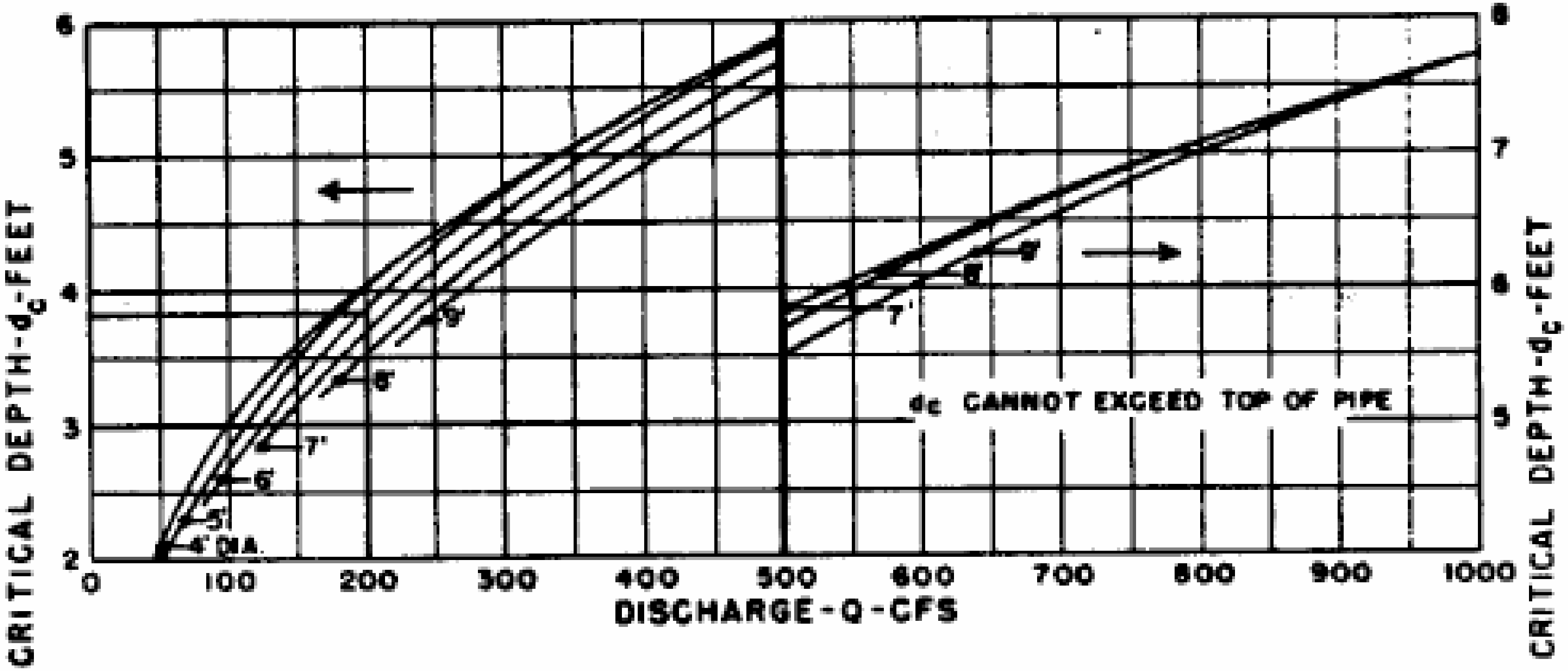
| CULVERT DESCRIPTION: MATERIAL - SHAPE - SIZE - ENTRANCE | TOTAL FLOW Q (cfs) | FLOW PER BARREL Q/N (1) | HEADWATER CALCULATIONS: INLET CONTROL $HW_i/D$ (2) | $HW_i$ | FALL (3) | $EL_{hi}$ (4) | OUTLET CONTROL TW (5) | $d_c$ | $\frac{d_c+D}{2}$ | $h_o$ (6) | $k_e$ | H (7) | $EL_{ho}$ (8) | CONTROL HEADWATER ELEVATION | OUTLET VELOCITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.M.P.- CIRC.-72 IN. - BEVEL 45° IN HEADWALL | 200 | 200 | .96 | 5.8 | – | 105.8 | 3.5 | 3.8 | 6.9 | 6.9 | 0.2 | 2.6 | 105.5 | 105.8 | 9.0 | TRY 60" C.M.P. |

# Step 4-Outlet Control Calculations TW Depth

- Determine TW depth
- backwater or normal depth calculations
- Given as 3.5’

# Step 4-Outlet Control Calculations Critical Depth

- Determine Critical Depth (Chart 4A) 3.8’



# Step 4-Outlet Control Calculations
# Find average of dc + D

(3.8+6)/2 = 4.9’

| CULVERT DESCRIPTION: MATERIAL - SHAPE - SIZE - ENTRANCE | TOTAL FLOW Q (cfs) | FLOW PER BARREL Q/N (1) | HEADWATER CALCULATIONS: INLET CONTROL | | | | OUTLET CONTROL | | | | | | | CONTROL HEADWATER ELEVATION | OUTLET VELOCITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $HW_i/D$ (2) | $HW_i$ | FALL (3) | $EL_{hi}$ (4) | TW (5) | $d_c$ | $\frac{d_c+D}{2}$ | $h_o$ (6) | $k_e$ | H (7) | $EL_{ho}$ (8) | | | |
| CMP - CIRC. - 72 IN. - BEVEL 45° IN HEADWALL | 200 | 200 | 96 | 58 | — | 105.8 | 3.5 | 3.8 | 4.9 | 4.9 | 0.2 | 2.6 | 105.5 | 105.8 | 9.0 | TRY 60" CMP. |

# Step 4-Outlet Control Calculations Determine ho

- $h_o$ is the depth from the culvert outlet invert to the hydraulic grade line
- Larger of:
  - TW (3.5’) or
  - Avg. of ($d_c$ & D-4.9’) ---See Figure III-9 (D)

| CULVERT DESCRIPTION: MATERIAL - SHAPE - SIZE - ENTRANCE | TOTAL FLOW Q (cfs) | FLOW PER BARREL Q/N (1) | HEADWATER CALCULATIONS | | | | | | | | | | | | CONTROL HEADWATER ELEVATION | OUTLET VELOCITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | INLET CONTROL | | | | OUTLET CONTROL | | | | | | | | | | |
| | | | $HW_i/D$ (2) | $HW_i$ | FALL (3) | $EL_{hi}$ (4) | TW (5) | $d_c$ | $\frac{d_c+D}{2}$ | $h_o$ (6) | $k_e$ | H (7) | $EL_{ho}$ (8) | | | | |
| CMP - CIRC. - 72 IN. - BEVEL 45° IN HEADWALL | 200 | 200 | .96 | 5.8 | — | 105.8 | 3.5 | 3.8 | 4.9 | 4.9 | 0.2 | 2.6 | 105.5 | 105.8 | 9.0 | TRY 60" CMP. |

# Step 4-Outlet Control Calculations Find Entrance Loss Coefficient, $K_e$

- $K_e$= 0.2

**Table 12--Entrance Loss Coefficients.**

**Outlet Control, Full or Partly Full Entrance Head Loss**

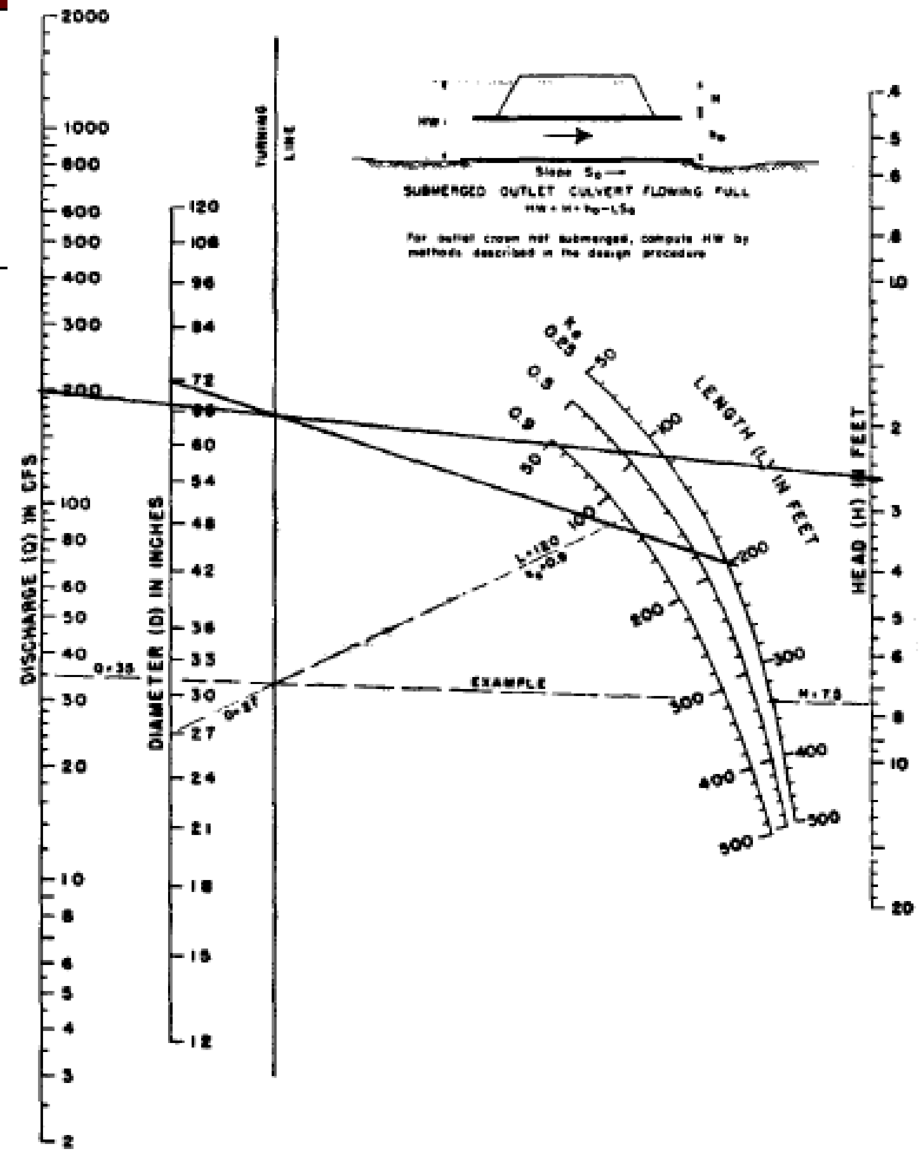
$$H_e = K_e\left[\frac{V^2}{2g}\right]$$

| Type of Structure and Design of Entrance | Coefficient $K_e$ |
|---|---|
| • Pipe, Concrete | |
| Projecting from fill, socket end (groove-end) | 0.2 |
| Projecting from fill, sq. cut end | 0.5 |
| Headwall or headwall and wingwalls | |
| Socket end of pipe (groove-end | 0.2 |
| Square-edge | 0.5 |
| Rounded (radius = D/12 | 0.2 |
| Mitered to conform to fill slope | 0.7 |
| *End-Section conforming to fill slope | 0.5 |
| Beveled edges, 33.7$^0$ or 45$^0$ bevels | 0.2 |
| Side- or slope-tapered inlet | 0.2 |
| • Pipe. or Pipe-Arch. Corrugated Metal | |
| Projecting from fill (no headwall) | 0.9 |
| Headwall or headwall and wingwalls square-edge | 0.5 |
| Mitered to conform to fill slope, paved or unpaved slope | 0.7 |
| *End-Section conforming to fill slope | 0.5 |
| Beveled edges, 33.7$^0$ or 45$^0$ bevels | 0.2 |
| Side- or slope-tapered inlet | 0.2 |

# Outlet Control Head Losses

- Can use Chart 6
- Line D/Ke
- Line Q/Turning Pt
- H=2.6’

CHART 6B




BUREAU OF PUBLIC ROADS JAN 1963

HEAD FOR STANDARD C. M. PIPE CULVERTS FLOWING FULL n = 0.024

# Step 4-Outlet Control Calculations Calculate HW Elevation

- Outlet Invert Elev + Head Losses + $h_o$
- 98+2.6+4.9
- HW elevation based on outlet control = 105.5’

| CULVERT DESCRIPTION: MATERIAL - SHAPE - SIZE - ENTRANCE | TOTAL FLOW | FLOW PER BARREL | HEADWATER CALCULATIONS | | | | | | | | | | | | CONTROL HEADWATER ELEVATION | OUTLET VELOCITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | INLET CONTROL | | | | OUTLET CONTROL | | | | | | | | | | |
| | Q (cfs) | Q/N (1) | $HW_i/D$ (2) | $HW_i$ | FALL (3) | $EL_{hi}$ (4) | TW (5) | $d_c$ | $\frac{d_c+D}{2}$ | $h_o$ (6) | $k_e$ | H (7) | $EL_{ho}$ (8) | | | | |
| CMP - CIRC. - 72 IN. - BEVEL 45° IN HEADWALL | 200 | 200 | 96 | 58 | – | 105.8 | 3.5 | 3.8 | 4.9 | 4.9 | 0.2 | 2.6 | 105.5 | 105.8 | 9.0 | TRY 60" CMP. |

# Step 5 Evaluate Results

- Culvert is operating under inlet control
- There is still 2 ft of head available
- Try a smaller culvert

# Outlet Velocity – Inlet Control

- Velocity at normal depth (in the culvert barrel) is assumed to be the outlet velocity
- Use Manning's equation
  - Calculate d/D which gives a Q of 200 cfs
  - Velocity = 9.2 cfs

# Outlet Velocity- Outlet Control

- Use critical depth if TW>critical depth
- Use TW if TW is between critical depth and top of barrel
- Use full depth of barrel if TW is above top of barrel

# Culvert Design

| CULVERT DESCRIPTION: MATERIAL - SHAPE - SIZE - ENTRANCE | TOTAL FLOW Q (cfs) | FLOW PER BARREL Q/N (1) | HEADWATER CALCULATIONS: INLET CONTROL HW/D (2) | HW | FALL (3) | EL hi (4) | OUTLET CONTROL TW (5) | $d_c$ | $\frac{d_c+D}{2}$ | $h_o$ (6) | $k_e$ | H (7) | EL ho (8) | CONTROL HEADWATER ELEVATION | OUTLET VELOCITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.M.P.- CIRC.-72 IN.- BEVEL 45° IN HEADWALL | 200 | 200 | 96 | 58 | — | 105.8 | 3.5 | 3.8 | 4.9 | 4.9 | 0.2 | 2.6 | 105.5 | 105.8 | 9.0 | TRY 60" C.M.P. |
| " " -60 IN.- " 45° | ↓ | ↓ | 1.63 | 7.15 | — | 107.2 | ↓ | 4.1 | 4.6 | 4.6 | ↓ | 6.3 | 108.9 | 108.9 | 11.9 | TRY 60" CONC. |
| CONC. " -60 IN.- GROOVE END | ↓ | ↓ | 1.36 | 6.8 | — | 106.8 | ↓ | ↓ | 4.6 | 4.6 | ↓ | 2.9 | 105.5 | 106.8 | 15.6 | TRY 54" CONC. |
| " " - 54 IN. - " | ↓ | ↓ | 1.77 | 7.97 | — | 108.0 | ↓ | ↓ | 4.3 | 4.3 | ↓ | 4.7 | 107.0 | 108.0 | 15.3 | OK |

**COMMENTS / DISCUSSION:**

HIGH OUTLET VELOCITY - OUTLET PROTECTION OR LARGER CONDUIT MAY BE NECESSARY

# Culvert Design

- Multiple structures
  - For 2 pipes or boxes of same size, etc. Q/2
- For concrete box culvert
  - 6' x 5' (span x height)—note
    - Ex 9-4 in book violates this "usual"
  - Q/H = Flow per foot of span
  - D = height of culvert box (5')

# Chapter VI – Special Considerations Flow Control & Measurement

- Irrigation Canals
- Stormwater Management Ponds
- Cooling Waterchannels

Figure VI-1--Stormwater Management Pond with Culvert as Outflow Control Device

- Use routing to determine inflow into any pond upstream of culvert

# Chapter VI – Special Considerations Low Head Installations

- Convey water under a roadway w/ min. HW and energy loss
- Usually found in irrigation systems
- Sag culverts sometimes used

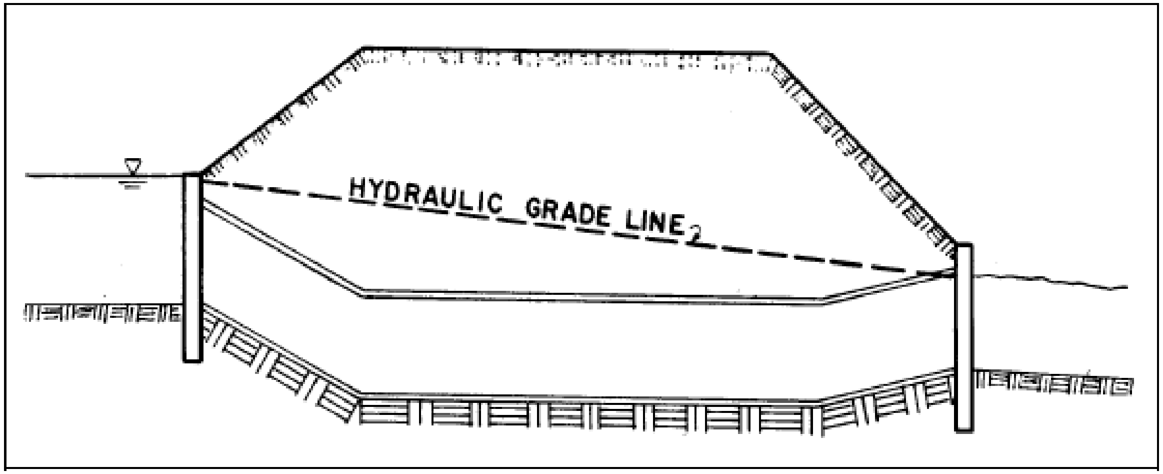



Figure VI-2--Sag Culvert

# Chapter VI – Special Considerations
# Bends – Horizontal or Vertical

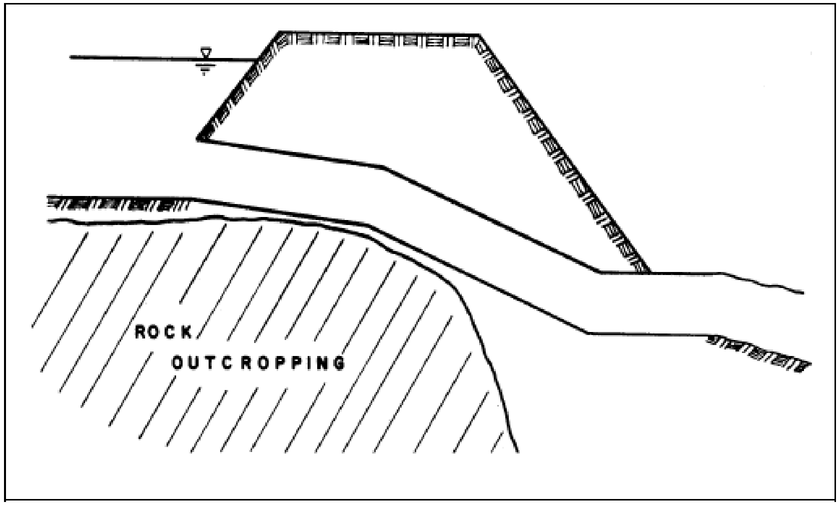



Figure VI-3--"Broken-Back" Culvert

Figure VI-4--Culvert with a Horizontal Bend (Contech)

# Chapter VI – Special Considerations Junctions

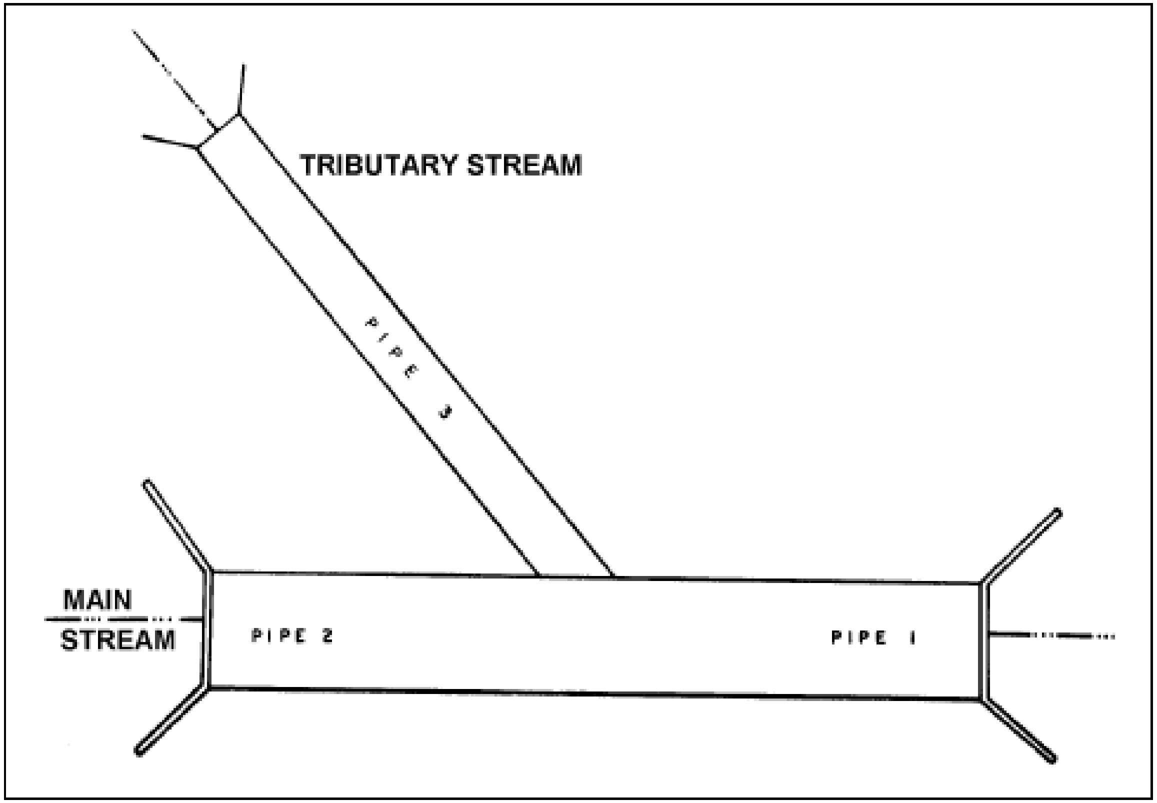



Figure VI-5--Culvert Junction

# Chapter VI – Special Considerations Siphons (vacuum)-rarely designed

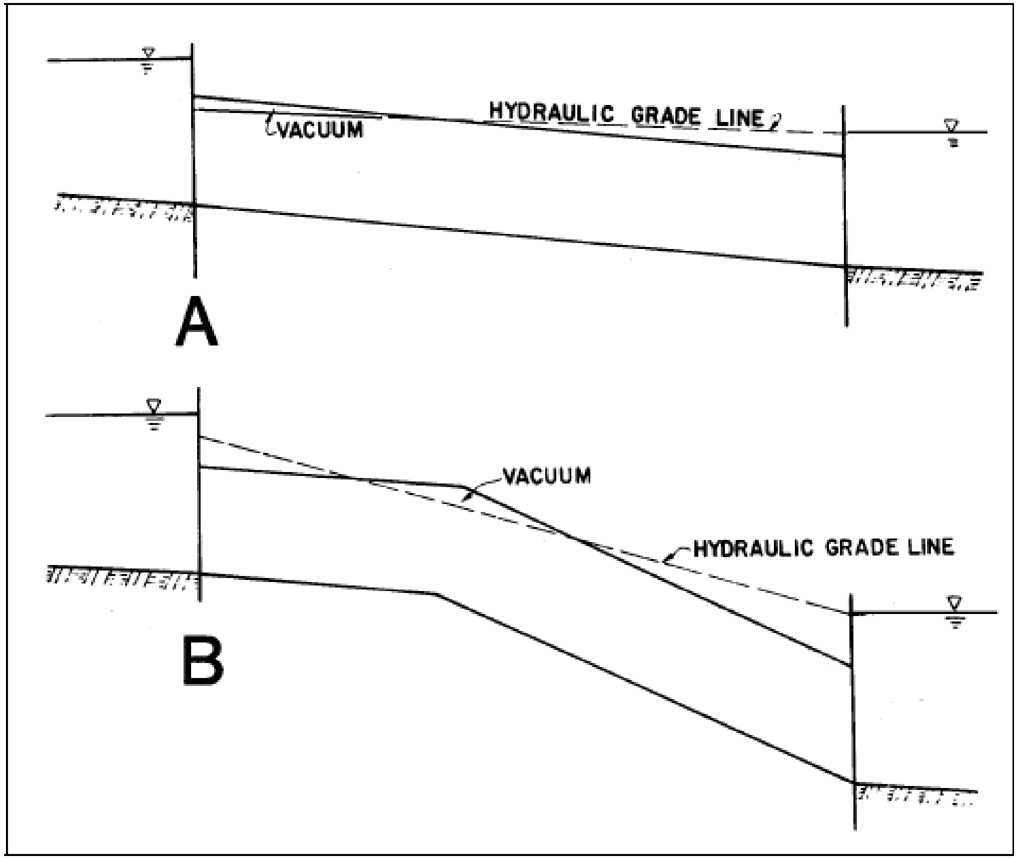



Figure VI-6--Subatmospheric Pressure in Culverts

# Chapter VI – Special Considerations

## Fish Passage

Figure VI-7--Fish Baffles in Culvert

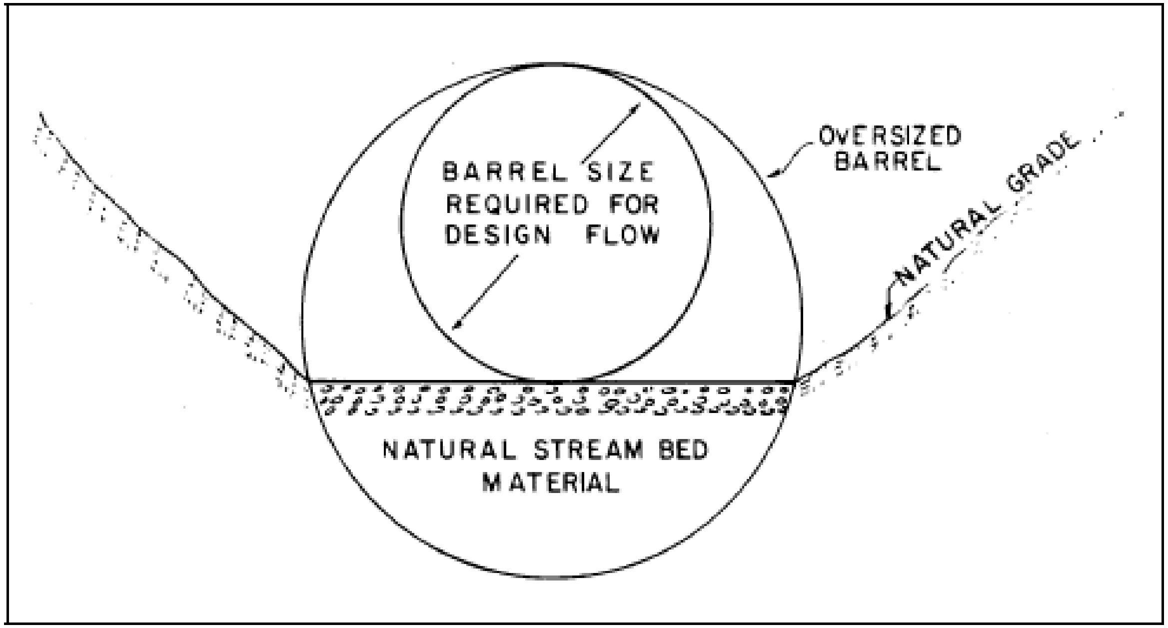



Figure VI-8--Culvert Barrel Partially Buried to Preserve Natural Stream Bed