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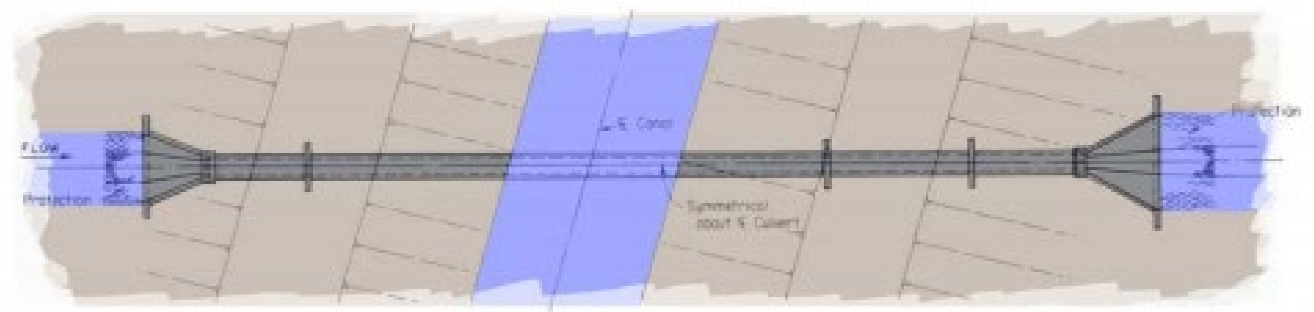
Design of Pipe Culverts



2

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Water Resources Engineering Department

Hydrauilc Structures CE404 and WR401

Design of Pipe Culverts

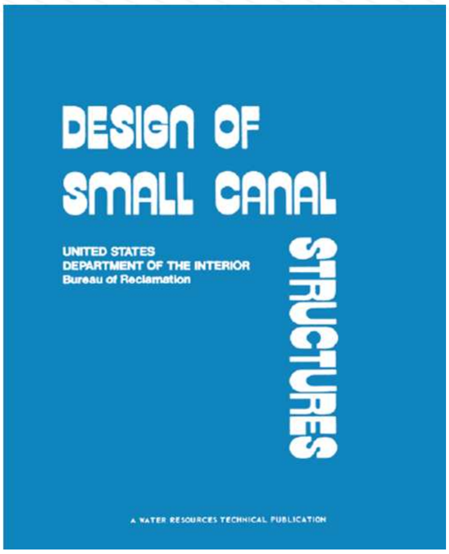
http://hyd.uod.ac/

References

The main reference for this chapter is:

United States Dept. of the Interior Bureau of Reclamation, "*Design of Small Canal Structures*", United States Government Printing Office, Denver, 1978.

The book is available in the **Books** page on the course website and is downloadable free on usbr.gov.



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Overview

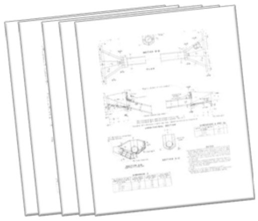
- Objectives
- Introduction
- Design Criteria
- Design Example

Objectives

The objective is to design pipe culverts according to USBR guidelines including all the necessary parts and appurtenances.

You Will Need

- **Lecture notes** can be taken in class, copied from notes given to students representatives, or printed from the course website.
- **Recommended reading**: Pages 202-215 "*Small Canal Structures*" Book.
- The following **charts and tables** the following are necessary for the design procedure.



Transitions details
(5 pages)

Erosion Protection works
(2 pages)

Table 21 and 22
(2 pages)

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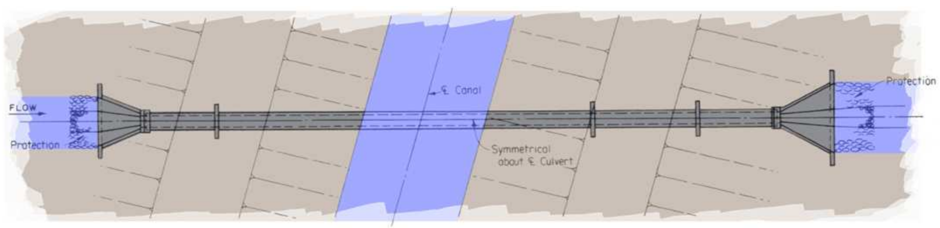
Introduction

Culvert in cross-drainage works



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Design Criteria
1. Alinement

Location of culvert is to use the natural channel. If a canal crosses a natural channel with a skew, it is better to locate the culvert on a skew with the canal.

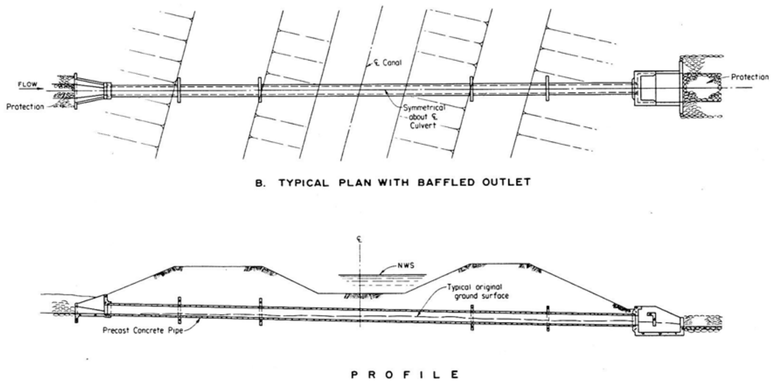

Figure 4-26. **Plan and profile of typical culverts. 103-D-1303**

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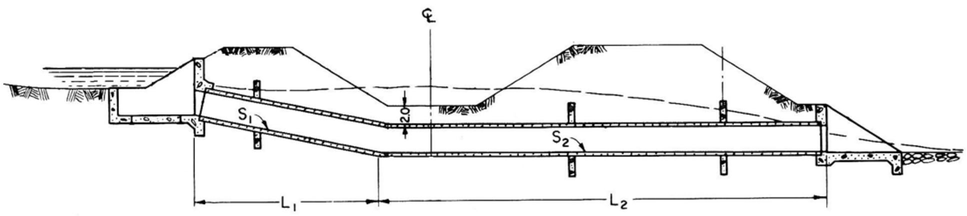
Design Criteria
2. Profile

- S_1 should be much steeper than critical slope.
- S_2 is usually 0.005 to facilitate dissipation of energy by hydraulic jump in the pipe without being flat enough to permit sedimentation in the pipe. The pipe should be under canal prism with at least 2 *feet* below the invert of an earth section canal, and at least 0.5 *foot* below the lining of concrete lined canal.



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Design Criteria
3. Conduit

Culverts may be single or multi barreled and may consist of the following types:

- Precast reinforced concrete pressure pipe (PCP),
- Precast reinforced concrete culvert pipe (RCCP),
- Asbestos-cement pressure pipe (AC),
- Reinforced plastic mortar pressure pipe (RPM), or
- Rectangular concrete box section.

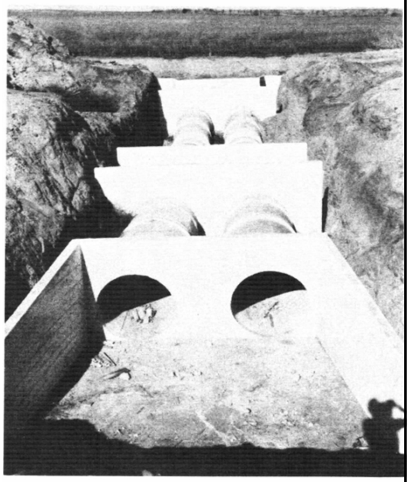

Figure 4-20. Double-barreled pipe culvert with concrete percolation collars. P-328-701-2021

Design Criteria
3. Conduit (continued)

Selection of the type of culvert conduit depends on:

- The project life.
- Life expectancy of the pipe.
- Loading conditions to be imposed on the pipe.
- The cost of each type.
- Its availability at the site.

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Design Criteria
4. Inlet

Several types of transitions are used as culvert inlets namely type 1 through type 4. The best choice for any particular situation is dependent upon the hydraulics, the topographic character of the site, and the relative elevations of the canal and drainage channel.

See details P337-341 "*Small Canal structures*"

Figure 7-7. **Type 4 inlet concrete transition. P-328-701-9300**

Figure 4-23. Precast concrete pipe culvert with precast concrete inlet transition. P-328-701-6507

Design Criteria
4. Inlet (Continued)

Benefits of concrete transitions:

- A greater capacity is provided by good transitioning.
- The required length of pipe may be shortened by the length of the concrete transitions.

continued on next slide

Figure 4-19. Culvert, constructed prior to construction of canal. P514-417-366

Design Criteria
4. Inlet (Continued)

Figure 4-22. Precast concrete pipe culvert with type 3 inlet transition. P482-417-824

Benefits of concrete transitions (Continued):

- Reduction in erosion. Reduces the threat to the canal bank.
- The cutoff walls of concrete transitions reduce the danger of piping by percolation.

Note: Freeboard from inlet water surface to the top of bank should be at least 2 *feet*.

Design Criteria
5.Outlet

Its function is to release water to the outlet channel without excessive erosion.

a. Concrete transitions

In case of concrete transitions, the culvert conduit is sized on the basis of maximum full pipe velocity of 10 *ft/sec*. there are two types of concrete transitions:

- *Type* 1 *concrete transition* is used for well-defined outlet channel.
- *Type* 2 *concrete transition* is used for poorly defined outlet channel.

Figure 7-1. Type 1 concrete transition. P33-D-25693

Design Criteria
5.Outlet (Continued)

b. Outlet energy dissipators

- *Baffled outlet* performs well in dissipating excess energy, provided clogging by weeds or other debris can be avoided. The culvert pipe should be sized on full pipe velocity of 12 *ft/sec*. the theoretical velocity should not exceed 50 *ft/sec*.

Figure 4-24. Baffled outlet at end of a culvert. P328-701-8219

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Design Criteria
5.Outlet (Continued)

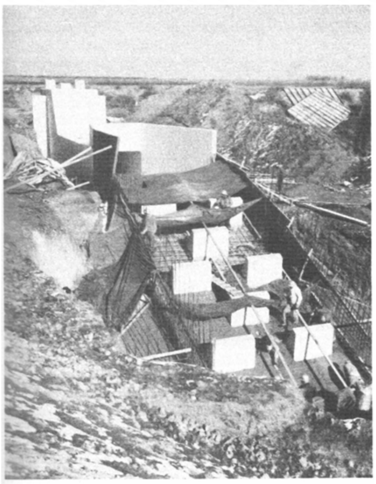

Figure 4-25. Concrete box culvert with baffled apron drop at outlet. P-707-729-1947

- *Other types of energy dissipators.*

  Example *baffled apron drop.*

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Design Criteria
6. Hydraulics

a. Design capacity

Generally, for small irrigation structures, cross drainage are sized on the basis of storm runoff for a 25-years flood frequency.

b. Pipe velocity

The culvert should be designed for a maximum pipe velocity of 10 *ft/sec* if a concrete transition is used at outlet, and for a maximum full pipe velocity of 12 *ft/sec* if an energy dissipator is used.

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Design Criteria
6. Hydraulics

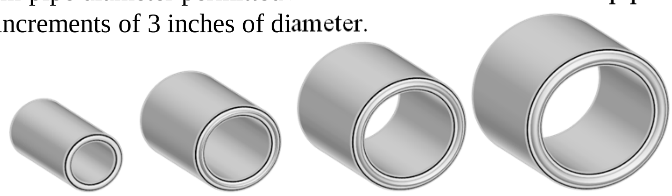
c. Pipe diameter

$$Q = AV$$

$$= \frac{\pi D^2}{4} V$$

$$D = 1.13\sqrt{\frac{Q}{V}}$$

The minimum pipe diameter permitted is 24 inches. Precast concrete pipe is widely supplied in increments of 3 inches of diameter.



Page ▪ 18 24” 27” 30” 33”

Design Criteria
6. Hydraulics (Continued)

d. Hydraulic control

- *Inlet control*: if the upstream water surface is not influenced by flow conditions d.s. from inlet, it is said to have inlet control.
- *Outlet control*: if the water surface is influenced by downstream flow conditions, it is said to have outlet control.

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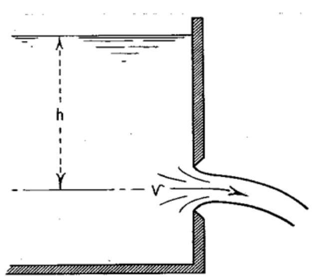
Design Criteria
6. Hydraulics (Continued)

e. Determination of inlet or outlet control

1. Inlet control hydraulics

Where inlet control exits, the head required at culvert inlet is computed from the orifice equation:

$$Q = CAV$$
$$= CA\sqrt{2gh}$$
$$h = \frac{Q^2}{2gC^2A^2}$$
$$C = 0.6, V = \frac{Q}{A}, g = 32.2 ft/sec^2$$
$$h = 0.0433V^2$$



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Design Criteria
6. Hydraulics (Continued)

2. Outlet control hydraulics
   i. *Inlet losses*

   $$h_i = k_i \Delta h_v$$

   ii. *Pipe losses*

   The pipe losses consist of friction losses and bend losses.

   iii. *Outlet losses*

   $$h_o = k_o \Delta h_v$$

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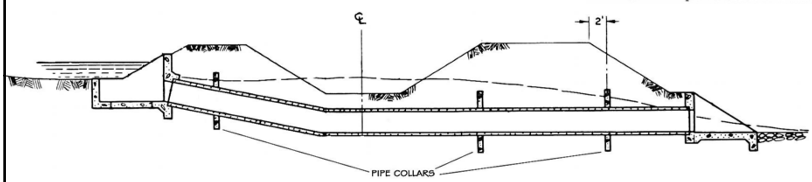
Design Criteria
7. Pipe Collars

It is customary to locate collars on the pipe as follows: one collar below the centerline of the uphill bank, two collars under downhill bank, with one under the inside edge and one located 2 *ft* downstream the outside edge.

Figure 4-21. Concrete box culvert with concrete percolation collars. P328-701-3743



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Design Criteria
7. Pipe Collars (Continued)

A "short path" between collars will occur if the resistance to percolation through the soil is less than the resistance to percolation along concrete surface of the pipe and collars.

$$K_3X = K_2X + 2K_1Y$$

$$2X = 0.33X + 2(1\times Y)$$

Solving for X in terms of Y

$$2X - 0.33x = 2Y$$

$$1.67X = 2Y$$

$$X_{(\text{min.})} = 1.2Y$$

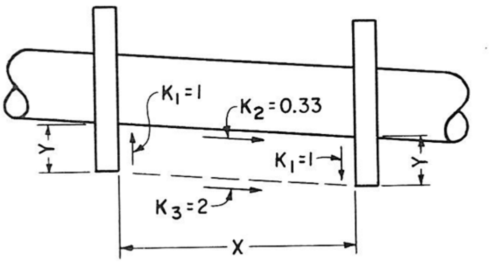
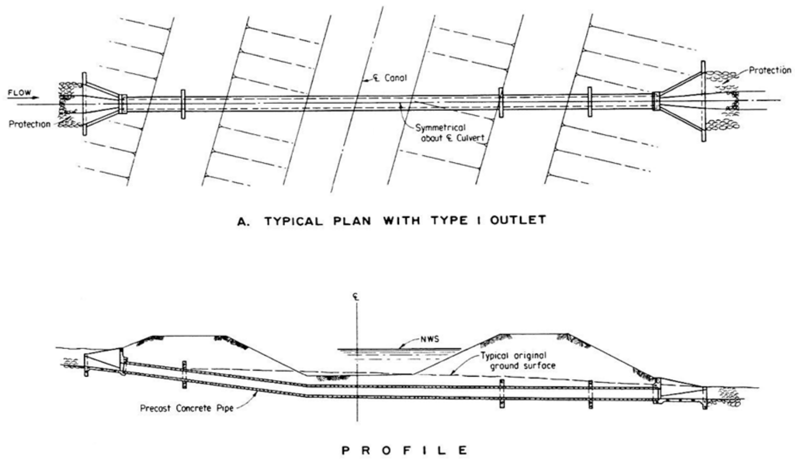


Figure 4-27. Weighted-creep method. 103-D-1304

Design Example

Assume that a precast concrete pipe culvert is needed to convey storm runoff water under a canal at its intersection with the natural channel.



Design Example

A. Assumptions

1. Properties of the canal section are:

   $b = 8ft$, $h_b = 6ft$, $ss = 1\frac{1}{2}H : 1V$, $d_n = 4ft$, $W_1 = 6ft$ and $W_2 = 12ft$ to accommodate an operating road.
2. The cross drainage channel is wide, shallow and poorly defined both at inlet and outlet. It is estimated that the outlet channel will support a depth of 1 *ft* and a velocity of 1*ft*/*sec* for the design flow.
3. The outside bank heights $h_{b_1} = 4ft$, $h_{b_2} = 9ft$.
4. It has been determined that the 25-year flood could yield a discharge of 45 *cfs*.

   Use n = 0.013 for concrete.

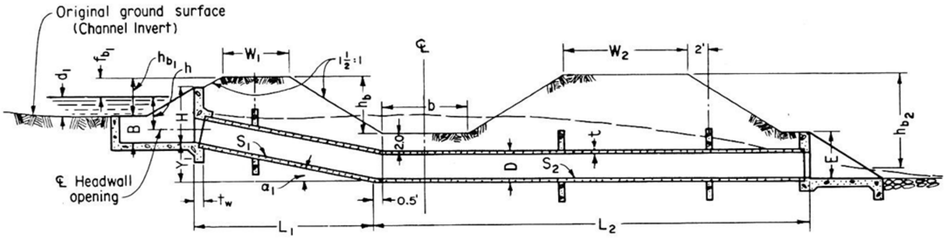


Figure 4-28, **Culvert—typical profile. 103-D-1305**

Design Example

B. Design

1. Pipe velocity

$$V = 10 ft/sec$$

2. Pipe diameter

$$D = 1.13\sqrt{\frac{Q}{V}} = 1.13\sqrt{\frac{45}{10}} = 2.38 ft$$

$$D = 2\times 12 + 0.38\times 12 = 28.56 in$$

Provide 30 *inches* diameter = 2.5 *ft*

$$A = \frac{\pi}{4}(2.5)^2 = 4.91 ft^2$$

$$V = \frac{Q}{A} = \frac{45}{4.91} = 9.17 ft/sec$$

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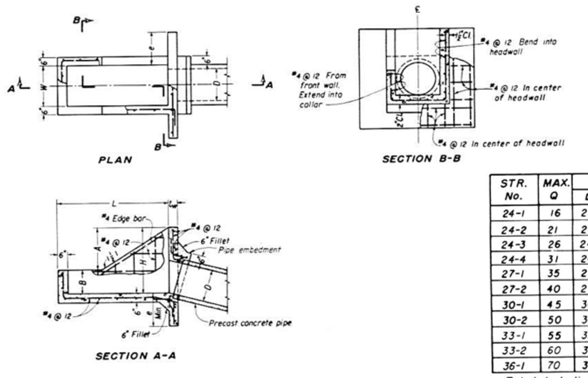
Design Example
Inlet Type

3. Inlet type

As the drainage channel is poorly defined and the upper canal bank is only 4 *ft* higher than channel invert, a type 3 or 4 inlet transition will be good.

Use type 3 transition (Fig. 7.5).



$$B = 3ft, L = 7ft\ 6inches,$$
$$t_w = 6inches, H = 6ft$$

STR. No.	MAX. Q	DIMENSIONS D	L	W	H	A	B	t_w	e	EST. QUANTITIES CONCRETE CUBIC YDS.	REINF. STEEL LBS.
24-1	16	24"	6'-0"	2'-6"	4'-0"	2'-6"	18"	6"	24"	1.8	140
24-2	21	24"	6'-0"	2'-6"	4'-6"	2'-6"	24"	6"	24"	2.0	160
24-3	26	24"	6'-0"	2'-6"	5'-0"	2'-6"	2'-6"	6"	24"	2.2	180
24-4	31	24"	6'-0"	2'-6"	5'-8"	2'-6"	3'-2"	6"	24"	2.4	200
27-1	35	27"	6'-9"	2'-9"	5'-6"	2'-6"	3'-0"	6"	24"	2.6	210
27-2	40	27"	6'-9"	2'-9"	6'-0"	2'-6"	3'-6"	6"	24"	2.8	220
30-1	45	30"	7'-6"	3'-3"	6'-0"	3'-0"	3'-0"	6"	24"	3.0	240
30-2	50	30"	7-6"	3'-3"	6'-6"	3'-0"	3'-6"	6"	24"	3.2	260
33-1	55	33"	9-0"	3'-9"	6'-0"	3'-0"	3'-0"	8"	2'-6"	4.3	290
33-2	60	33"	9'-0"	3'-9"	6'-6"	3'-0"	3'-6"	8"	2'-6"	4.6	320
36-1	70	36"	9'-0"	3'-9"	7'-0"	3'-0"	4'-0"	8"	2'-6"	5.0	340

Tabulated dimensions and maximum Q's, provide freeboard at the headwall, with full-pipe velocities ranging up to 10 fps.

Design Example
Pipe Friction Slope

4. Pipe friction slope

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

using $n = 0.013$

$$R = \frac{A}{P} = \frac{D}{4} = \frac{2.5}{4} = 0.625ft$$

$$S_f = \left[\frac{V\ n}{1.486R^{2/3}}\right]^2 = \left[\frac{9.17 \times 0.013}{1.486(0.625)^{2/3}}\right]$$

$$S_f = 0.012$$

Design Example
Critical Slope

5. Critical Slope

$$D^{5/2} = (2.5)^{5/2} = 9.882$$

$$D^{8/3} = (2.5)^{8/3} = 11.51$$

$$\frac{Q}{D^{5/2}} = \frac{45}{9.882} = 4.55$$

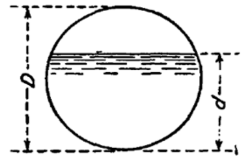
Using Table 22

$$\frac{d_c}{D} = 0.89$$

$$d_c = 0.89 \times D = 0.89 \times 2.5 = 2.22\,ft$$

Table 22.—*Velocity head and discharge at critical depths and static pressures in circular conduits partly full*

D=Diameter of circle.
d=Depth of water.
h_v=Velocity head for a critical depth of d.
Q=Discharge when the critical depth is d.
P=Pressure on cross section of water prism in cubic units of water. To get P in pounds, when d and D are in feet, multiply by 62.5.



$\frac{d}{D}$	$\frac{h_v}{D}$	$\frac{Q}{D^{5/2}}$	$\frac{P}{D^3}$	$\frac{d}{D}$	$\frac{h_v}{D}$	$\frac{Q}{D^{5/2}}$	$\frac{P}{D^3}$	$\frac{d}{D}$	$\frac{h_v}{D}$	$\frac{Q}{D^{5/2}}$	$\frac{P}{D^3}$
1	2	3	4	1	2	3	4	1	2	3	4
.21	.0736	.2609	.0103	.54	.2170	1.6164	.0998	.87	.5392	4.2721	.2938
.22	.0773	.2857	.0115	.55	.2224	1.6735	.1042	.88	.5632	4.4056	.3011
.23	.0811	.3116	.0128	.56	.2279	1.7327	.1087	.89	.5900	4.5486	.3084
.24	.0848	.3386	.0143	.57	.2335	1.7923	.1133	.90	.6204	4.7033	.3158
.25	.0887	.3667	.0157	.58	.2393	1.8530	.1179	.91	.6555	4.8725	.3233

Design Example
Critical Slope (Continued)

From Table 21 get $\frac{Q_n}{D^{8/3} S_c^{1/2}} = 0.491$

Table 21.—*Uniform flow in circular sections flowing partly full*

d=Depth of flow
D=Diameter of pipe
A=Area of flow
R=Hydraulic radius
Q=Discharge in second-feet by Manning's formula
n=Manning's coefficient
S=Slope of the channel bottom and of the water surface

$\frac{d}{D}$	$\frac{A}{D^2}$	$\frac{R}{D}$	$\frac{Qn}{D^{8/3}S^{1/2}}$	$\frac{Qn}{d^{8/3}S^{1/2}}$	$\frac{d}{D}$	$\frac{A}{D^2}$	$\frac{R}{D}$	$\frac{Qn}{D^{8/3}S^{1/2}}$	$\frac{Qn}{d^{8/3}S^{1/2}}$
0.35	0.2450	0.1935	0.1218	2.00	0.85	0.7115	0.3033	0.477	0.736
0.36	0.2546	0.1978	0.1284	1.958	0.86	0.7186	0.3026	0.481	0.720
0.37	0.2642	0.2020	0.1351	1.915	0.87	0.7254	0.3018	0.485	0.703
0.38	0.2739	0.2062	0.1420	1.875	0.88	0.7320	0.3007	0.488	0.687
0.39	0.2836	0.2102	0.1490	1.835	0.89	0.7384	0.2995	0.491	0.670

$$\frac{Q_n}{D^{8/3} S_c^{1/2}} = 0.491$$

$$S_c = \left[\frac{45 \times 0.013}{11.51 \times 0.491}\right]^2 = 0.0107$$

Design Example
Invert Slope

6. Invert slope

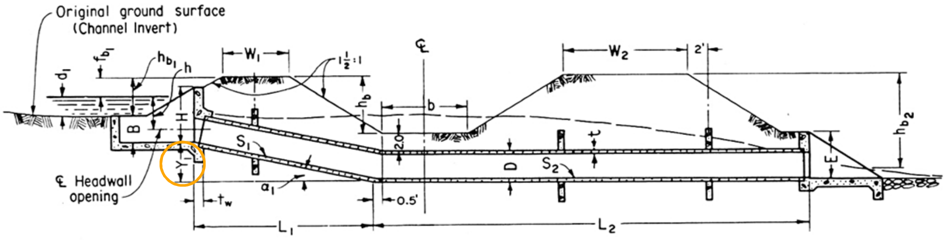


Figure 4-28, Culvert–typical profile. 103-D-1305

Assume class B-25 pipe with thickness $t = 3.5\,inches$.

Provide a minimum cover of 2 *ft* over concrete pipe.

$$y_1 = D + t + 2 + h_b - h_{b_1} - B$$

$$= 2.5 + \frac{3.5}{12} + 2 + 6 - 4 - 3 = 3.8\,ft$$

"These pressure pipes are classed as to their capacity to withstand external loads of cover and wheel (equivalent earth cover) and internal hydrostatic head measured to the centerline of the pipe. Designations of A, B, C, and D represent 5, 10, 15, and 20 feet of cover respectively, while the associated number such as 25, 50, 75, 100, 125, and 150 represents feet of hydrostatic head. As an example, C 50 would be pressure pipe for 15-foot maximum cover and 50-foot maximum head."

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Design Example
Invert Slope (Continued)

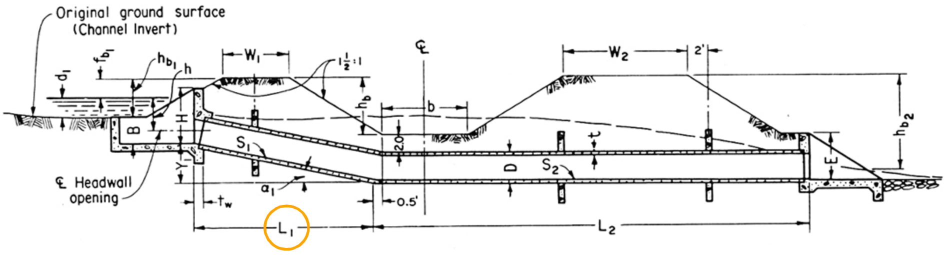

Figure 4-28, Culvert–typical profile. 103-D-1305

$$L_1 = 1.5h_b + W_1 + 1.5\left(h_{b_1} + B - H\right) + t_w - 0.5$$

$$= 1.5 \times 6 + 6 + 1.5\left(4 + 3 - 6\right) + 0.5 - 0.5 = 16.5\,ft$$

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Design Example

Invert Slope (Continued)

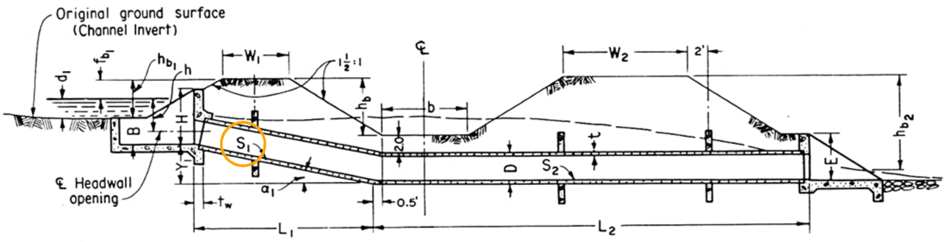


Figure 4-28, Culvert–typical profile. 103-D-1305

$$S_1 = \frac{y_1}{L_1} = \frac{3.8}{16.5} = 0.23$$

$$\alpha_1 = \tan^{-1}(S_1) = 12.95° \text{ say } 13°$$

$$S_1 \gg S_c$$

$$0.23 \gg 0.0107$$

This permits free flow at pipe inlet with inlet control.

Design Example

Invert Slope (Continued)

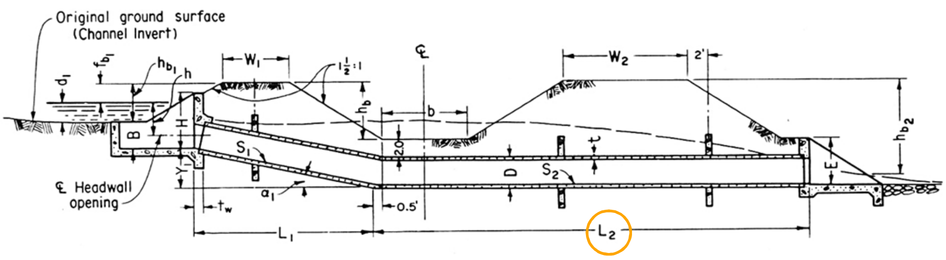
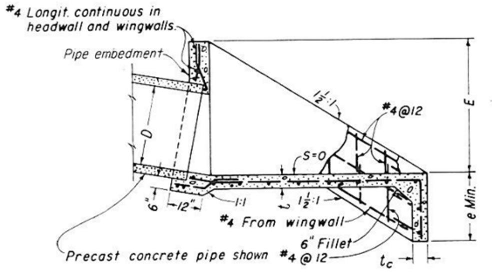


Figure 4-28, Culvert–typical profile. 103-D-1305

$$L_2 = 41ft$$

Design Example
Outlet type

7. Outlet type
   As outlet channel is poorly defined, use type 2 transition.
   From Fig. 7.4, with D = 30 *inches*
   $L = 6\,ft\ 9\,inches, E = 4\,ft\ 6\,inches, e = 24\,inches, B = 6\,ft\ 6\,inches,$
   $C = 4\,ft\ 2\,inches, t = 6\,inches$,
   Concrete (*Cubic yds.*) = 2.2, Reinforcement steel (*lbs*) = 180



LONGITUDINAL SECTION

TABLE OF DIMENSIONS AND EST. QUANTITIES

D	E	e	L	B	C	t	t_c	CONC. (CU. YDS.)	REINF. (LBS.)
24"	4'-0"	24"	6'-0"	5'-6"	3'-6"	5"	6"	1.7	140
27"	4'-6"	24"	6'-9"	5'-6"	3'-9"	5"	6"	2.0	160
30"	4'-6"	24"	6'-9"	6'-6"	4'-2"	5"	6"	2.2	180
33"	5'-0"	2'-6"	7'-6"	7'-6"	4'-4"	5"	8"	2.4	200
36"	5'-0"	2'-6"	7'-6"	7'-6"	4'-8"	5"	8"	2.7	220
39"	5'-6"	2'-6"	8'-3"	9'-0"	5'-0"	6"	8"	3.5	280
42"	5'-6"	2'-6"	8'-3"	9'-0"	5'-3"	6"	8"	3.6	290
45"	6'-0"	2'-6"	9'-0"	10'-6"	5'-6"	7"	8"	4.7	370
48"	6'-0"	2'-6"	9'-0"	10'-6"	6'-0"	7"	8"	4.8	380

Design Example
Inlet Hydraulics

8. Inlet Hydraulics

$$h = 0.0433V^2$$
$$= 0.0433(9.17)^2 = 3.64\,ft$$

   Where h is the head to discharge the design flow.

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Design Example
Inlet Freeboard

9. Inlet freeboard

For type 3 transition,

$$d_1 = h + \frac{D'}{2} - B$$

$$\cos(\alpha_1) = \frac{D/2}{D'/2}$$

$$D' = \frac{D}{\cos(\alpha_1)}$$

$$D' = \frac{2.5}{\cos(13^o)} = 2.56 ft$$

$$d_1 = 3.64 + \frac{2.56}{2} - 3 = 1.9 ft$$

$$f_{b_1} = h_{b_1} - d_1 = 4 - 1.9 = 2.1 ft > 2 ft \text{ (Minimum freeboard) O.K.}$$

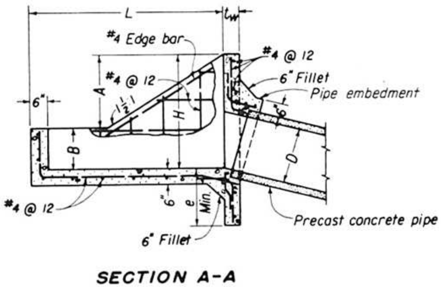

Figure 7-5: Concrete inlet transition

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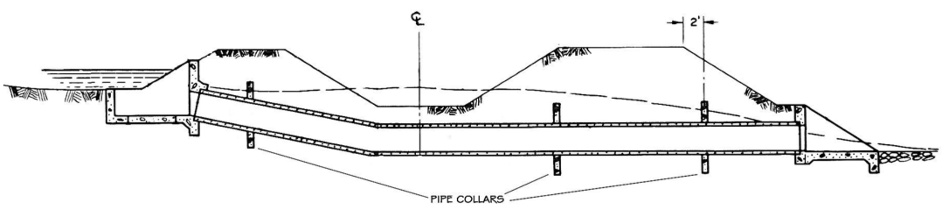
Design Example
Collars

10. Collars

Provide 1 collar under upper bank of canal and 2 collars under lower bank.



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Design Example
Erosion Protection

11. Erosion Protection

Erosion protection is not required at culvert inlet.

For $Q = 45$ *cfs* use type 2 protection at outlet (12 *inches* of coarse gravel for outlet length = 12 *ft*)

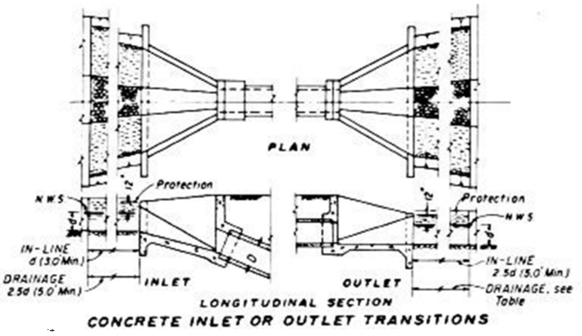

Figure 7-8

"

7-14. *Cross-drainage Structures.* —The following protection is considered minimum for cross-drainage structures with concrete transitions.

Q, cfs	Type of protection		Outlet length, feet
	Inlet	Outlet	
0 to 30	None	Type 2	8
31 to 90	None	Type 2	12
91 to 240	Type 1	Type 3	16

Where the velocity in the conduit is greater than 15 feet per second at the outlet, use the protection type for the next higher discharge (type 3 minimum). Where baffled outlets are provided at the outlet of a structure the protection should be a thickness of $\frac{W}{6}$ with the minimum diameter of rock equal to $\frac{W}{20}$ and extending a distance W (5 feet minimum) beyond the baffled outlet. W is the inside width of the baffled outlet box.

"

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Design Example
Verification of Hydraulics

C. Verification of hydraulics by Bernoulli's method

1. Energy balance at outlet

$$E_{s_4} = d_4 + \frac{V_4^2}{2g}$$

$$= 1 + \frac{(1)^2}{2 \times 32.2} = 1.02\,ft$$

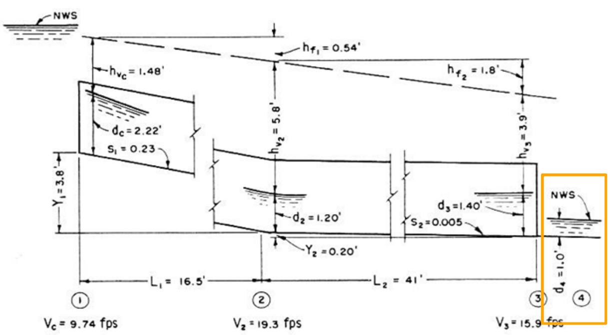

Figure 4-29. Culvert hydraulics. 103-D-1306

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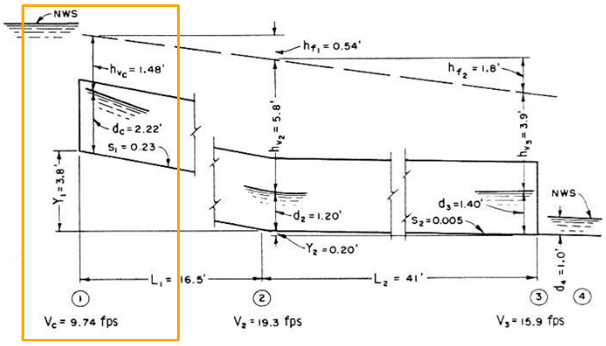
Design Example
Verification of Hydraulics

At section (1)

$$\frac{d_c}{D} = 0.89,\ d_c = 2.22\,ft$$

$$\frac{A_c}{D^2} = 7.384 \text{ (Table 21)}$$

$$\frac{A_c}{(2.5)^2} = 0.738,\ A_c = 4.62\,ft^2$$



$$V_c = \frac{Q}{A_c} = \frac{45}{4.62} = 9.74\,ft$$

$$h_{v_c} = \frac{V_c^2}{2g} = \frac{9.74^2}{2 \times 32.2} = 1.48\,ft$$

$$E_{s_c} = d_c + h_{v_c} = 2.22 + 1.48 = 3.7\,ft > 1.02\,ft$$

If $E_{s_c} > E_{s_4}$ the structure is inlet controlled.

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Design Example
Verification of Hydraulics

2. Specific energy at section (2)

Try $d_2 = 1.2\,ft$

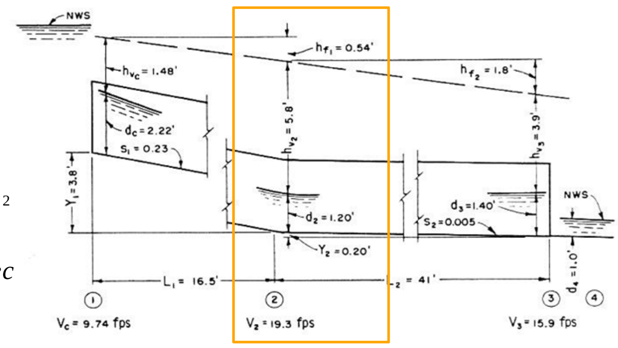
$$\frac{d_2}{D} = \frac{1.2}{2.5} = 0.48$$

$$\frac{A_2}{D^2} = 0.3727 \text{ (Table 21)}$$

$$A_2 = 0.3727(2.5)^2 = 2.33\,ft^2$$

$$V_2 = \frac{Q}{A_2} = \frac{45}{2.33} = 19.3\,ft/sec$$

$$h_{v_2} = \frac{V_2^2}{2g} = \frac{(19.3)^2}{2 \times 32.2} = 5.8\,ft$$



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Design Example
Verification of Hydraulics

$$\frac{Q\,n}{D^{8/3}\left(S_{f_2}\right)^{1/2}} = 0.216 \text{ (Table 22)}$$

$$\frac{45\times 0.013}{11.51\left(S_{f_2}\right)^{1/2}} = 0.216$$

$$S_{f_2} = 0.0554$$

$$h_{f_1} = \left[\frac{S_c + S_{f_1}}{2}\right] L_1$$

$$= \left[\frac{0.0107 + 0.0554}{2}\right]\times 16.5$$

$$= 0.54\,ft$$

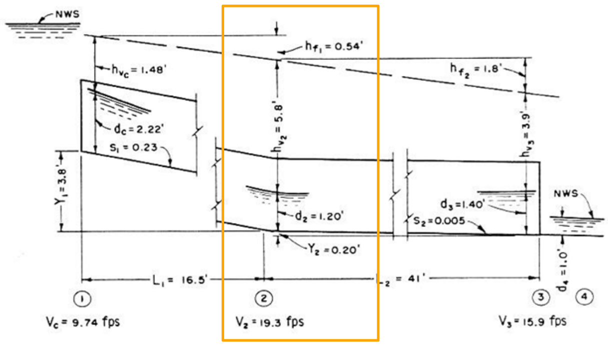

Figure 4-29. Culvert hydraulics. 103-D-1306

$$1.48 + 2.22 + 3.8 \overset{?}{=} 0.54 + 5.8 + 1.2$$

$$7.50 \overset{?}{=} 7.54 \text{ O.K.}$$

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Design Example
Verification of Hydraulics

3. Specific energy and velocity at section (3)

$$y_2 = 0.005\times 41 = 0.2\,ft$$

$$\text{Try } d_3 = 1.4\,ft$$

$$\frac{d_3}{D} = \frac{1.4}{2.5} = 0.56$$

$$\frac{A_3}{D^2} = 0.4526$$

$$A_3 = 0.4526\left(2.5\right)^2 = 2.83\,ft^2$$

$$V_3 = \frac{Q}{A_3} = \frac{45}{2.83} = 15.9\,ft\,/\,sec$$

$$h_{v_3} = \frac{V_3^{\,2}}{2g} = \frac{15.9^2}{2\times 32.2} = 3.9\,ft$$

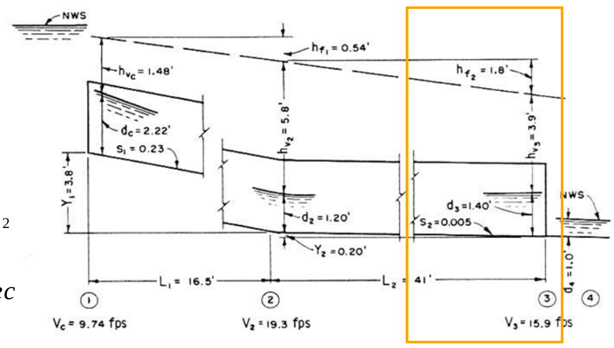

Figure 4-29. Culvert hydraulics. 103-D-1306

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Design Example
Verification of Hydraulics

$$\frac{Q\,n}{D^{8/3}\left(S_{f_3}\right)^{1/2}} = 0.279 \text{ (Table 21)}$$

$$\frac{45\times 0.013}{11.51\left(S_{f_3}\right)^{1/2}} = 0.279$$

$$S_{f_3} = 0.033$$

$$h_{f_2} = \left[\frac{S_{f_2}+S_{f_3}}{2}\right]L_2$$

$$= \left[\frac{0.055+0.033}{2}\right]\times 41 = 1.8\,ft$$

$$5.8+1.2+0.2 \overset{?}{=} 1.8+3.94+1.4$$

$$7.20 \overset{?}{=} 7.14$$

Therefore, $V_3 = 15.9\,ft\,/\,sec$

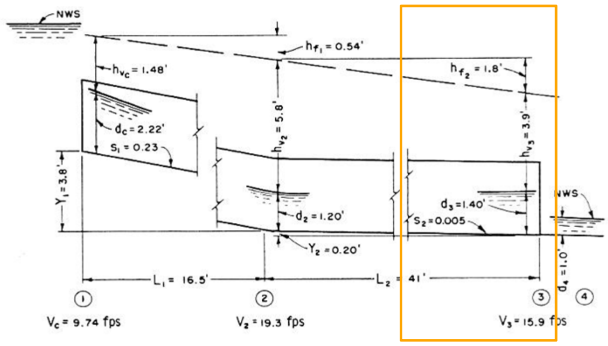

Figure 4-29. **Culvert hydraulics. 103-D-1306**

Design Example
Erosion Protection (Revisited)

4. Outlet protection
Since the velocity is 15.9 *ft/sec* exceeding 15 *ft/sec*,
type 3 protection (12 *inches* of riprap on 6 *inches* sand and gravel bedding for protection outlet length = 16 *ft*)

"**7-14.** ***Cross-drainage Structures.***—The following protection is considered minimum for cross-drainage structures with concrete transitions.

Q, cfs	Type of protection Inlet	Type of protection Outlet	Outlet length, feet
0 to 30	None	Type 2	8
31 to 90	None	Type 2	12
91 to 240	Type 1	Type 3	16

Where the velocity in the conduit is greater than 15 feet per second at the outlet, use the protection type for the next higher discharge (type 3 minimum). Where baffled outlets are provided at the outlet of a structure the protection should be a thickness of $\frac{W}{6}$ with the minimum diameter of rock equal to $\frac{W}{20}$ and extending a distance W (5 feet minimum) beyond the baffled outlet. W is the inside width of the baffled outlet box."

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Finished ☺