

SECTION 12
HYDRAULIC STRUCTURES

**CITY OF WESTMINSTER
STORM DRAINAGE DESIGN AND TECHNICAL CRITERIA**

SECTION 12 HYDRAULIC STRUCTURES

12.1 INTRODUCTION

The energy associated with flowing water has the potential to damage drainage works especially in the form of erosion. Hydraulic structures are used in storm drainage to control the energy and minimize the damage potential of runoff. Hydraulic structures include rip-rap, energy dissipaters, check dams, and drop structures.

The criteria to be used in the design of hydraulic structures shall be in accordance with the MANUAL except as modified herein.

12.2 RIPRAP

Rip-rap has proven to be an effective means to deter erosion along channel banks, in channel beds, upstream and downstream of hydraulic structures, and at channel bends. The ordinary rip-rap classifications and gradations are shown in Table 1201. The design of the rip-rap protection shall be in accordance with the MANUAL except as modified herein.

12.2.1 Bedding Requirements

The long term stability of ordinary rip-rap erosion protection is strongly influenced by the proper bedding conditions. The two types of bedding are a granular bedding filter and filter fabric.

For the granular bedding filter, the required bedding thickness as shown in Table 1202 is adequate for most ordinary rip-rap. The gradation requirements for the granular bedding filter are shown in Table 1203.

Filter fabric is not a complete substitute for granular bedding. At a minimum, a 4-inch layer of Type II granular bedding material is required with the filter fabric. Filter fabric's use is restricted to slopes no steeper than 2.5 (horizontal) to 1 (vertical). Figure 1201 provides a detail on the typical lap and filter fabric placement.

12.2.2 Channel Bends

The potential for erosion increases along the outside bank of a channel bend due to the acceleration of flow velocities. Rip-rap erosion protection is required on channel bends where the radius of the bend is less than twice the channel top width at the design flow or less than 100-feet. Where erosion protection is required, Type L rip-rap shall be installed as shown in Figure 1202 and shall extend upstream and downstream from the bend a distance equal to the length of the bend.

12.2.3 Conduit Erosion Protection

Erosion resulting from highly turbulent flow at conduit outlets is common. Rip-rap erosion protection is required at outlets. The following design procedure is valid where the conduit slope is equal to the channel gradient and the conduit outlet invert is flush with the rip-rap channel protection. Figure 1203 illustrates rip-rap depth requirements at a conduit outlet.

The required rip-rap classification is selected from Figure 1204 for circular conduits where $Q/D^{2.5}$ is less than 6.0 and from Figure 1205 for rectangular conduits where $Q/WH^{1.5}$ is less than 8.0. The parameters for these two figures are:

$$Q/D^{1.5} \text{ or } Q/WH^{0.5} \quad (12-1)$$

Where: Q = design discharge, cfs
D = diameter of circular conduit, feet
W = width of rectangular conduit, feet
H = height of rectangular conduit, feet - assumes flow is subcritical

$$Y_t/D \text{ or } Y_t/H \quad (12-2)$$

Where: Y_t = tailwater depth, feet
D = diameter of circular conduit, feet
H = height of rectangular conduit, feet – assumes flow is subcritical
In cases where Y_t is unknown or a hydraulic jump is suspected downstream, use Y_t/D or $Y_t/H = 0.40$

If the flow in the conduit is supercritical at the design flow, then D_a is substituted for D and H_a is substituted H in equation 12-1 and 12-2.

$$D_a = 0.5(D + Y_n) \quad (12-3)$$

Where: D = diameter of circular conduit, feet
 Y_n = normal depth of flow in conduit, feet
 D_a shall not exceed D

$$H_a = 0.5(H + Y_n) \quad (12-4)$$

Where: H = height of rectangular conduit, feet
 Y_n = normal depth of flow in conduit, feet
 H_a shall not exceed H

The length of erosion protection shall be determined using the method outlined below. However, in no case shall the length be less than 3D or 3H nor greater than 10D or 10H whenever the Froude parameter of $Q/WH^{1.5}$ or $Q/D^{2.5}$ is less than 8.0 or 6.0 respectively. Whenever the Froude parameter is greater than these maximums, the maximum length of protection shall increase by one-fourth D or H for each whole number the Froude parameter is greater than 8.0 or 6.0 for rectangular or circular conduits respectively.

$$L = (1/(2\tan\theta))(A_t/Y_t - W) \quad (12-3)$$

Where: L = length of protection, feet
W = width of conduit, feet
Y_t = tailwater depth, feet
1/(2tanθ) = expansion factor – see Figures 1206 or 1207

$$A_t = Q/V \quad (12-4)$$

Q = design discharge, cfs
V = allowable non-eroding velocity in the downstream channel, fps
A_t = required area of flow, ft²

For multiple barrel installations, the methods described can be use by replacing the multiple barrels with a single hydraulically equivalent rectangular conduit. The dimensions of the equivalent conduit may be established by distributing the total design flow among the individual barrels and computing the Froude parameter for each individual barrel. Using the barrel with the greatest Froude parameter, the height of the equivalent conduit, H_e, equals the height or diameter of the selected individual barrel. The width of the equivalent conduit, W_e, is determined by equating the Froude parameter from the selected individual barrel with the Froude parameter associated with the equivalent conduit, Q/W_eH_e^{1.5}.

12.3 ENERGY DISSIPATERS

Where rip-rap structures are insufficient or uneconomical to control the erosion potential of storm runoff, concrete energy dissipater structures (stilling basins) shall be provided in accordance with the MANUAL.

For culverts or storm sewers outlets where the Froude number at the outlet is in excess of 2.5, the USBR Type VI impact stilling basin shall be used.

12.4 DROP STRUCTURES

As discussed in the section on open channels, there is a maximum permissible velocity for grass-lined channels. One of the more common methods of controlling the flow velocity is to reduce the channel invert slope. Reducing the channel invert slope requires a drop structure to provide for the elevation difference.

A drop structure spans across the entire waterway area which conveys the entire major storm flow. The purpose of a drop structure is to provide a grade drop in both the trickle channel and the main channels, thus, allowing a milder slope in the channel reach. The geometry of the crest can effectively control the upstream channel stability and to a great extent its ultimate configuration.

The design criteria for the drop structures shall be in accordance with the MANUAL.

12.5 CHECK DAMS

A check structure is similar to a drop structure but is constructed to directly stabilize only the bed and shape of the trickle or low flow channel in natural drainageways. The check dam crosses only a portion of the channel or floodplain. During a major storm, portions of the flow will circumvent the check dam. Overall channel stability is maintained because erosion of the low flow channel is prevented.

The design criteria for check dams shall be in accordance with the MANUAL.

Table 1201
Classification and Gradation of Ordinary Rip-rap

Rip-rap Designation	% Smaller than Given Size by Weight	Intermediate Rock Dimension (in)	d₅₀¹ (in)
Type VL	70-100	12	6 ²
	50-70	9	
	35-50	6	
	2-10	2	
Type L	70-100	15	9 ²
	50-70	12	
	35-50	9	
	2-10	3	
Type M	70-100	21	12
	50-70	18	
	35-50	12	
	2-10	4	
Type H	100	30	18
	50-70	24	
	35-50	18	
	2-10	6	
Type VH	100	42	24
	50-70	33	
	35-50	24	
	2-10	9	

¹ Mean Particle Size

² Bury with native top soil and revegetate to protect the rip-rap from vandalism
Specific Gravity of 2.5 or greater.

Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

Table 1202
Thickness Requirement for Granular Bedding

Rip-rap Designation	Minimum Bedding Thickness (in)		
	Fine Grained Soils ¹		Course Grained Soils ²
	Type I	Type II	Type II
VL, L	4	4	6
M	4	4	6
H	4	6	8
VH	4	6	8

¹ May substitute one 12-inch layer of Type II bedding.

² Fifty percent or more by weight retained on the #40 sieve.

Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

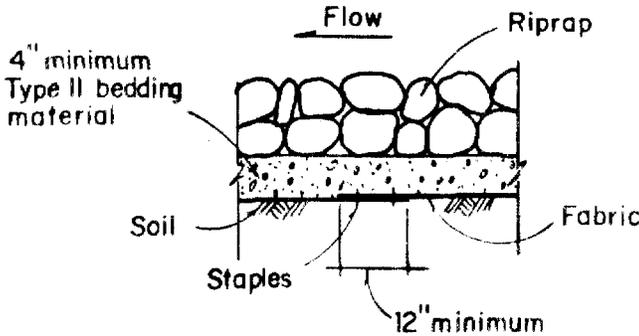
Table 1203
 Gradation for Granular Bedding

U.S. Standard Sieve Size	Percent Weight By Passing Square Mesh Sieves	
	Type I	Type II
3"	-	90-100
1-1/2"	-	-
3/4"	-	20-90
3/8"	100	-
#4	95-100	0-20
#16	45-80	-
#50	10-30	-
#100	2-10	-
#200	0-2	0-3

Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

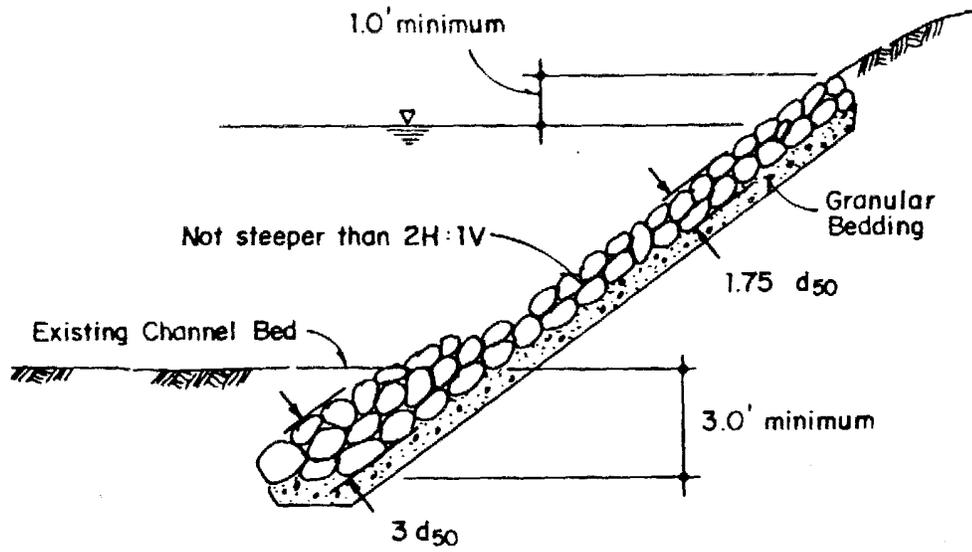
Figure 1201
Typical Lap Detail and Filter Fabric Placement

NOTE: Always place fabric starting downstream and work upstream



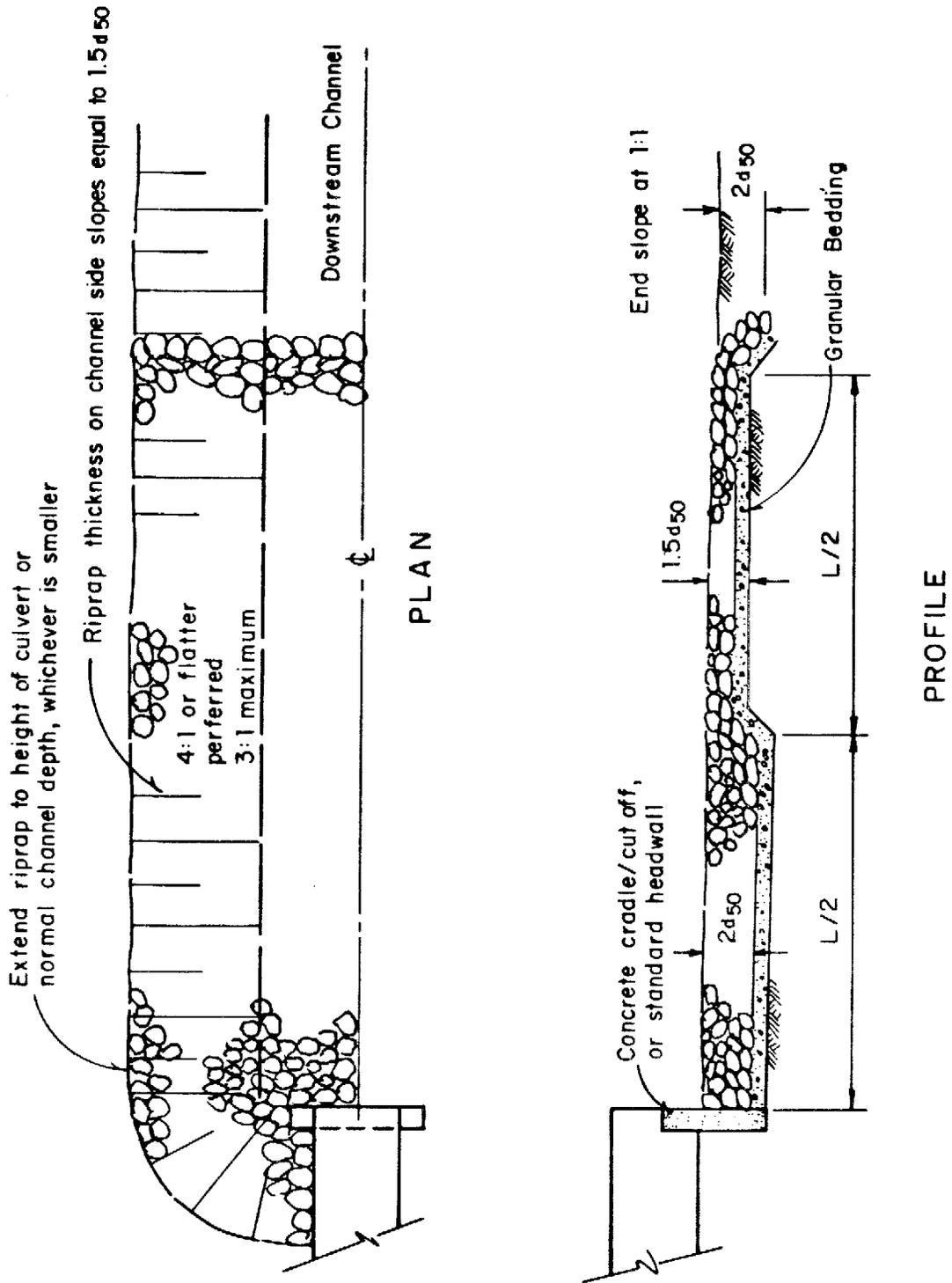
Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

Figure 1202
Erosion Protection for Channel Bends



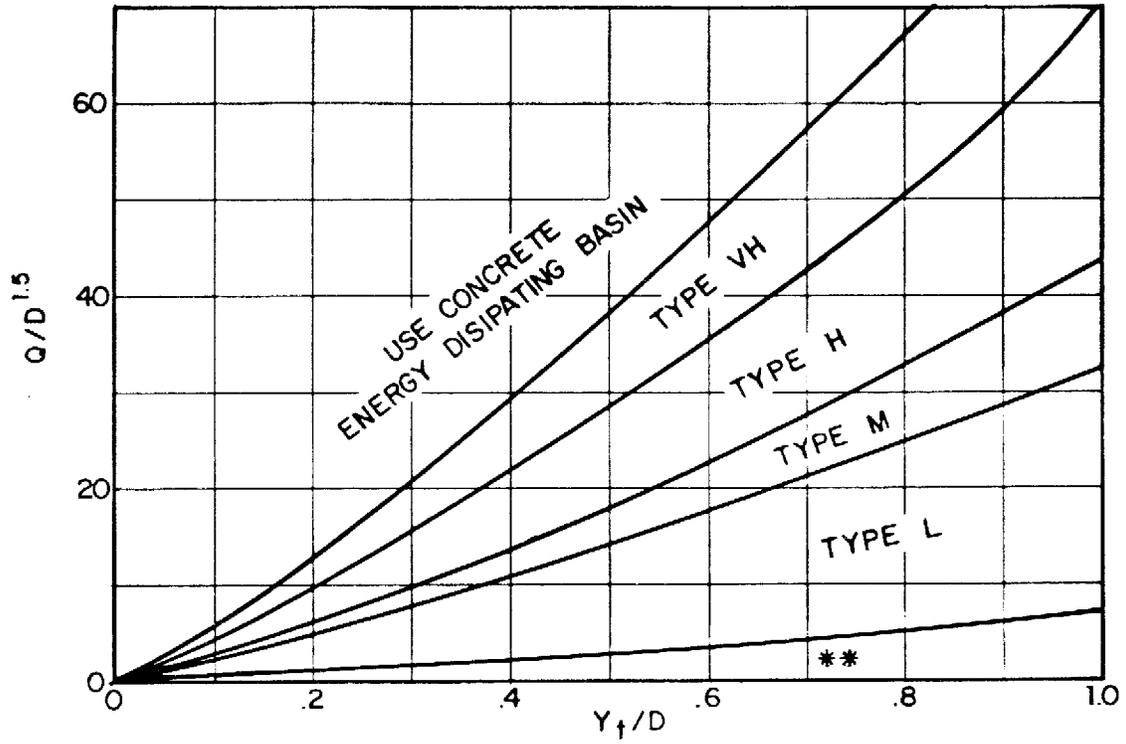
Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

Figure 1203
 Conduit Outlet Erosion Protection



Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

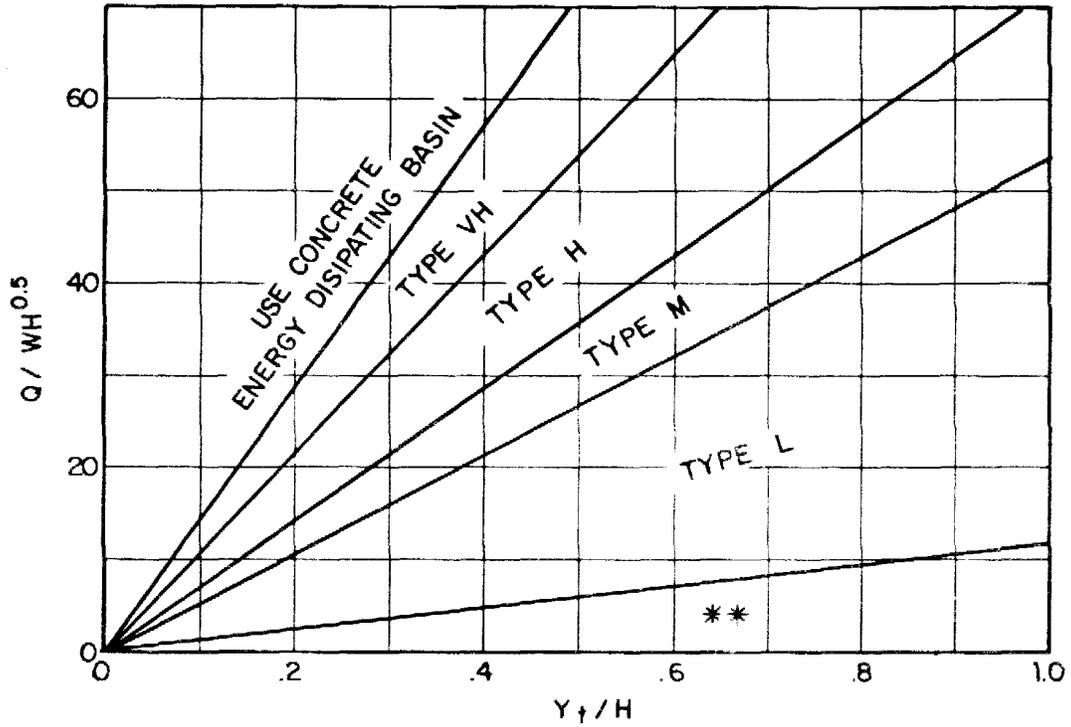
Figure 1204
 Size of Rip-rap Erosion Protection at
 Circular Conduit Outlet



Use D_d instead of D whenever flow is supercritical in the barrel.
 ** Use Type L for a distance of 3D downstream.

Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

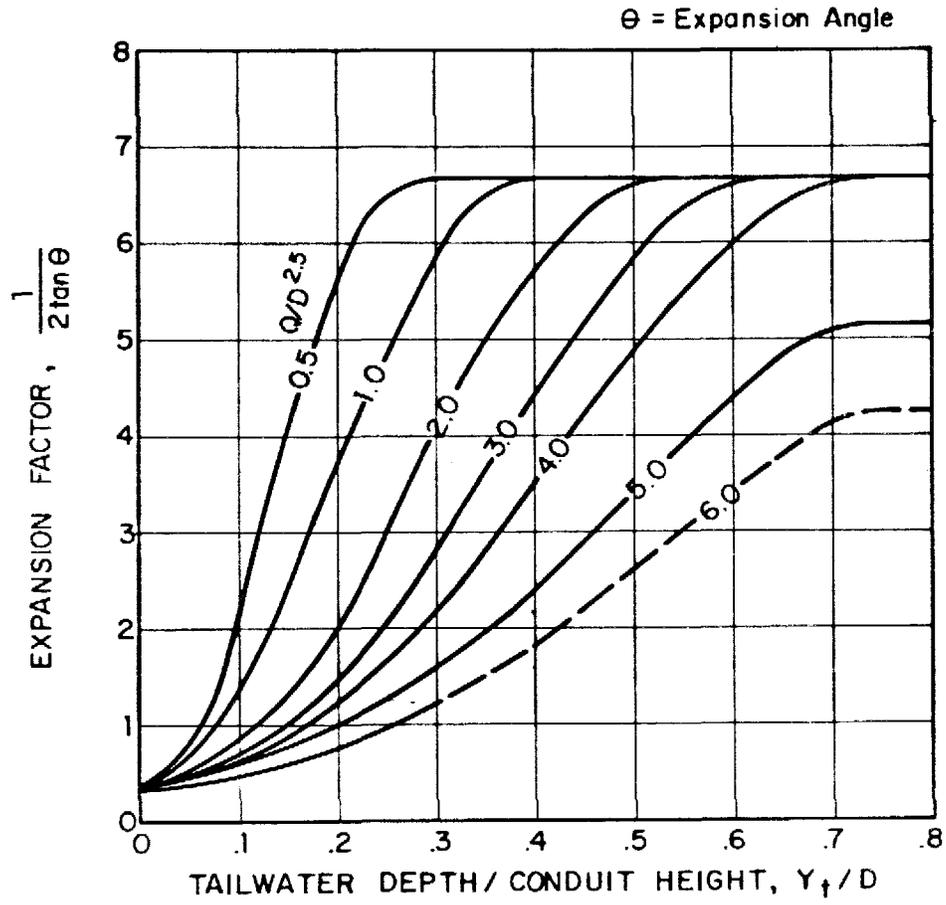
Figure 1205
 Size of Rip-rap Erosion Protection at
 Rectangular Conduit Outlet



Use H_0 instead of H whenever culvert has supercritical flow in the barrel.
 **Use Type L for a distance of $3H$ downstream.

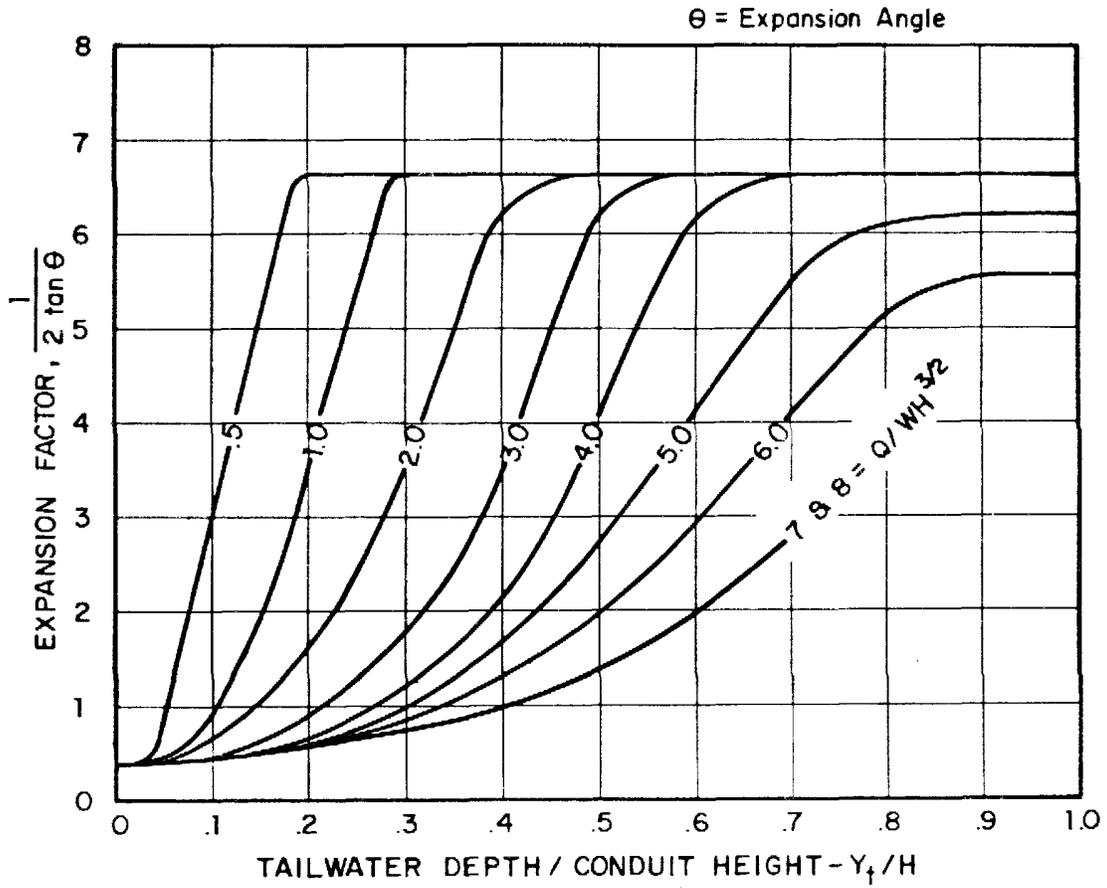
Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

Figure 1206
Expansion Factor for Circular Conduits



Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

Figure 1207
Expansion Factor for Rectangular Conduits



Reference: "Urban Storm Drainage Criteria Manual" DRCOG 1968

