8320 old courthouse road • vienna virginia 22180

design data 19

american concrete pipe association

HYDRAULICS OF CULVERTS: HORIZONTAL ELLIPTICAL CONCRETE PIPE STRUCTURAL PLATE PIPE ARCH

The hydraulic design of culverts establishes the minimum pipe size which has sufficient capacity to discharge a required flow within an allowable headwater depth. In the hydraulic design of culverts where the outlet is not submerged, the two principal types of flow that must be considered are flow under inlet control and flow under outlet control.

For any given headwater depth and pipe size, the capacity of a culvert operating under inlet control is dependent entirely on the inlet geometry. Since the geometric shape of the socket end of a concrete pipe results in less contraction of the flow at the entrance than the sharp edge of a corrugated metal pipe, with or without a headwall, greater and more efficient capacity is realized with concrete pipe.

Under outlet control the primary factor limiting culvert capacity is surface roughness. The relative smoothness of concrete pipe enables concrete pipe to handle substantially greater flow than the same size corrugated metal pipe.

The significance of these hydraulic advantages of concrete pipe is illustrated by the performance curves presented in *Figures 1 through 22.* The curves correlate headwater-discharge and are based on nomographs included in *Hydraulic Engineering Circular Number 5,* Hydraulics Branch, Bridge Division, Office of Engineering and Operations, Bureau of Public Roads.

The headwater depths for inlet controlled flow are read directly from the performance curves. For outlet controlled flow it is necessary to subtract the product of the culvert length and slope (S_oL) from the headwater depth.

A more complete discussion on the hydraulics of culverts is presented in Design Data 18. *The following example illustrates the proper use of the curves:*

EXAMPLE

Given: A highway culvert 400 feet long is to be installed on a 0.5 percent slope. The culvert will be required to carry a design discharge of 400 cubic feet per second within an allowable headwater depth of 9 feet.

Solution: Enter *Figure 1: 58 × 91-Inch Horizontal Elliptical Concrete Pipe* and project a vertical line from Q = 400 on the horizontal scale to the INLET CONTROL curve and the OUTLET CONTROL curve representing L = 400 feet. At the intersecting points read HW = 8.95 feet and HW + S_oL = 11.0 feet on the vertical scale.

The inlet control headwater depth is equal to 8.95 feet. To obtain the outlet control headwater depth, subtract $S_o \times L$ from the outlet control figure.

$$11.0 - (0.005 \times 400) = 9.0 \text{ feet}$$

Since the outlet control headwater depth of 9.0 feet is larger than the inlet control headwater depth of 8.95 feet, outlet control governs.

Repeat the same procedure for corrugated metal pipe arch until a pipe size is found which will handle the design discharge within the allowable headwater depth. From *Figures 2, 4, 6, 8, 10 and 12,* the following headwater depths are obtained:

Pipe Size	Equiv. Circular	HW Inlet Control	HW Outlet Control	Control Condition	Control HW
59 x 81	72	15.50	42.2—2.0=40.20	Outlet	40.2
63 x 87	78	12.60	28.6—2.0=26.60	Outlet	26.6
67 x 95	84	10.10	22.7—2.0=20.70	Outlet	20.7
71 x 103	90	8.90	17.8—2.0=15.80	Outlet	15.8
75 x 112	96	7.80	14.1—2.0=12.10	Outlet	12.1
79 x 117	102	7.40	11.8—2.0= 9.80	Outlet	9.8

Since all of the controlling headwater depths are higher than the allowable, try the next larger size. Enter *Figure 14: 83 × 128-Inch Corrugated Metal Pipe Arch* and project a vertical line from Q = 400 on the horizontal scale to the INLET CONTROL curve and the OUTLET CONTROL curve representing L = 400 feet. At the intersecting points, read HW = 6.75 feet and HW + S_oL = 10.40 feet on the vertical scale.

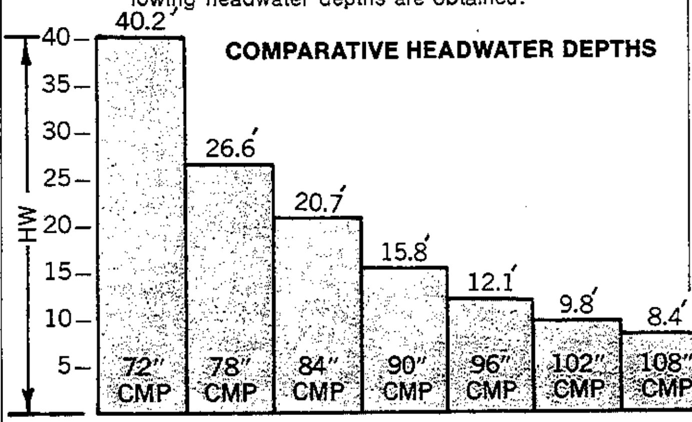
The inlet control headwater depth is equal to 6.75 feet. To obtain the outlet control headwater depth, subtract $S_o \times L$ from the outlet control figure.

$$10.40 - (0.005 \times 400) = 8.40$$

Since the outlet control headwater depth of 8.40 feet is larger than the inlet control headwater depth of 6.75 feet, outlet control governs.

Answer: A 58 × 91-inch horizontal elliptical concrete pipe (equivalent 72-inch circular) or a 83 × 128-inch corrugated metal pipe arch (equivalent 108-inch circular) will carry the design discharge within an allowable headwater depth of 9 feet. Both pipes are operating under outlet control.

The difference in required headwater depths between 58 × 91-inch horizontal elliptical concrete pipe and corrugated metal pipe arch in sizes 59 x 81-inch through 83 x 128-inch is illustrated in the accompanying figure. This example shows that a **corrugated metal pipe six sizes larger than concrete pipe is necessary** to meet the allowable headwater requirements. Comparing the 59 x 81-inch corrugated metal and the 58 x 91-inch concrete pipe sizes indicates that the same size corrugated metal pipe arch must operate at a headwater depth **446%** greater than horizontal elliptical concrete pipe.



72-INCH CIRCULAR

FIGURE 1: 58 x 91-Inch Horizontal Elliptical Concrete Pipe

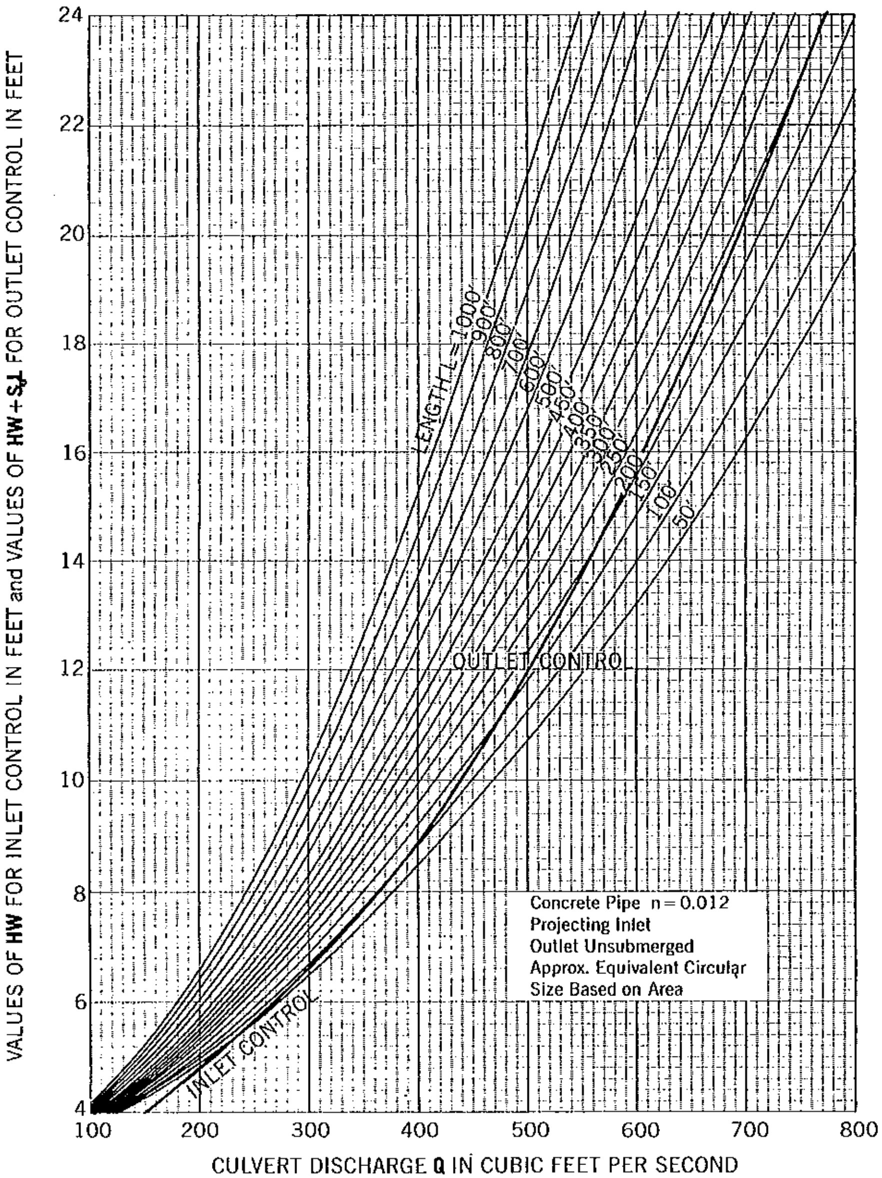
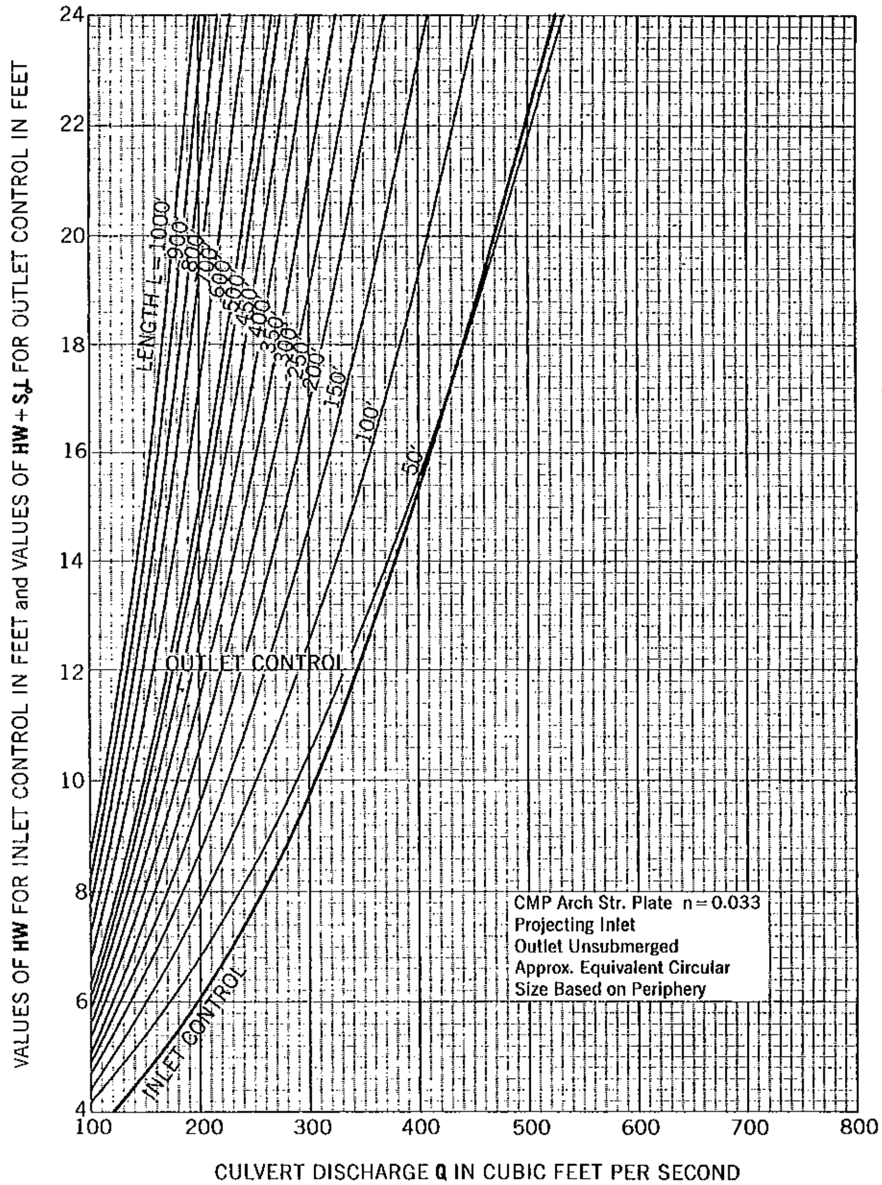


FIGURE 2: 59 x 81 Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

78-INCH CIRCULAR

FIGURE 3: 63 x 98-Inch Horizontal Elliptical Concrete Pipe

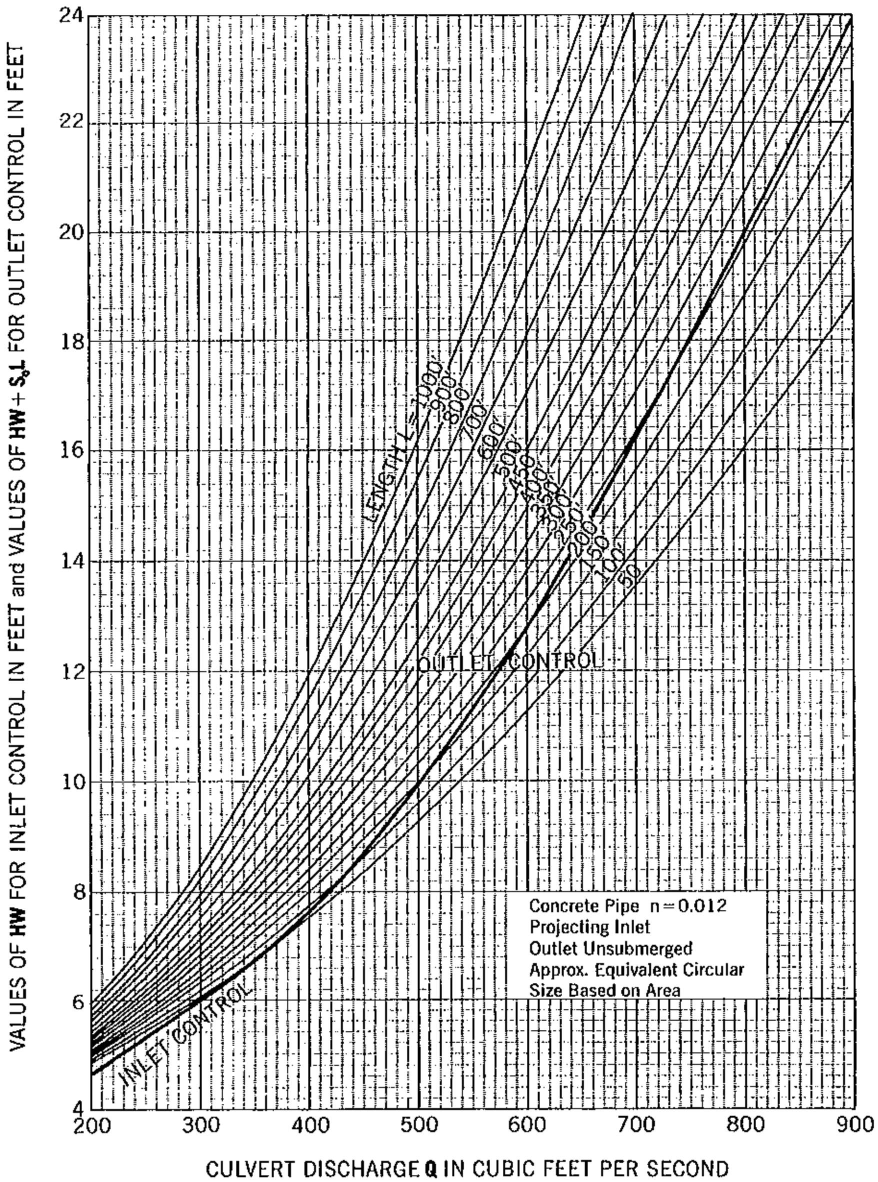
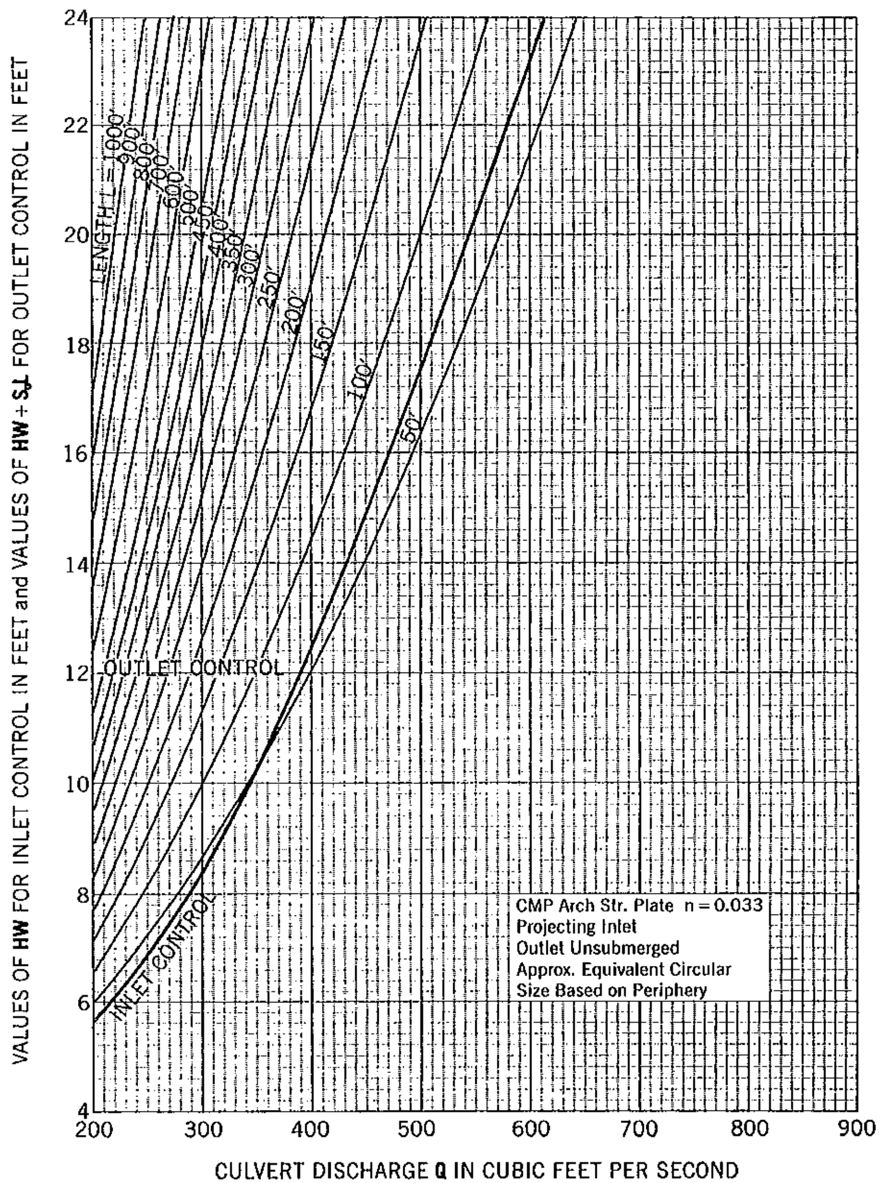


FIGURE 4: 63 x 87 Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

84-INCH CIRCULAR

FIGURE 5: 68 x 106-Inch Horizontal Elliptical Concrete Pipe

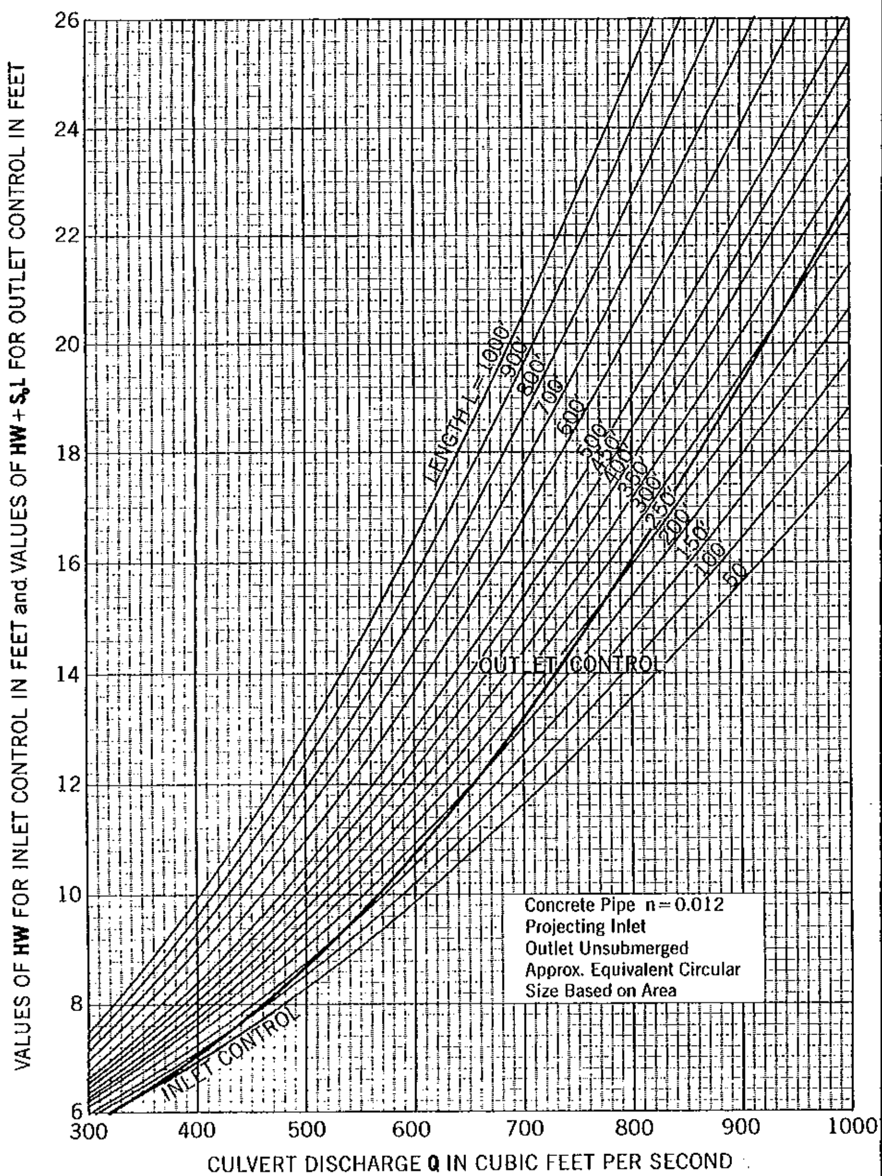
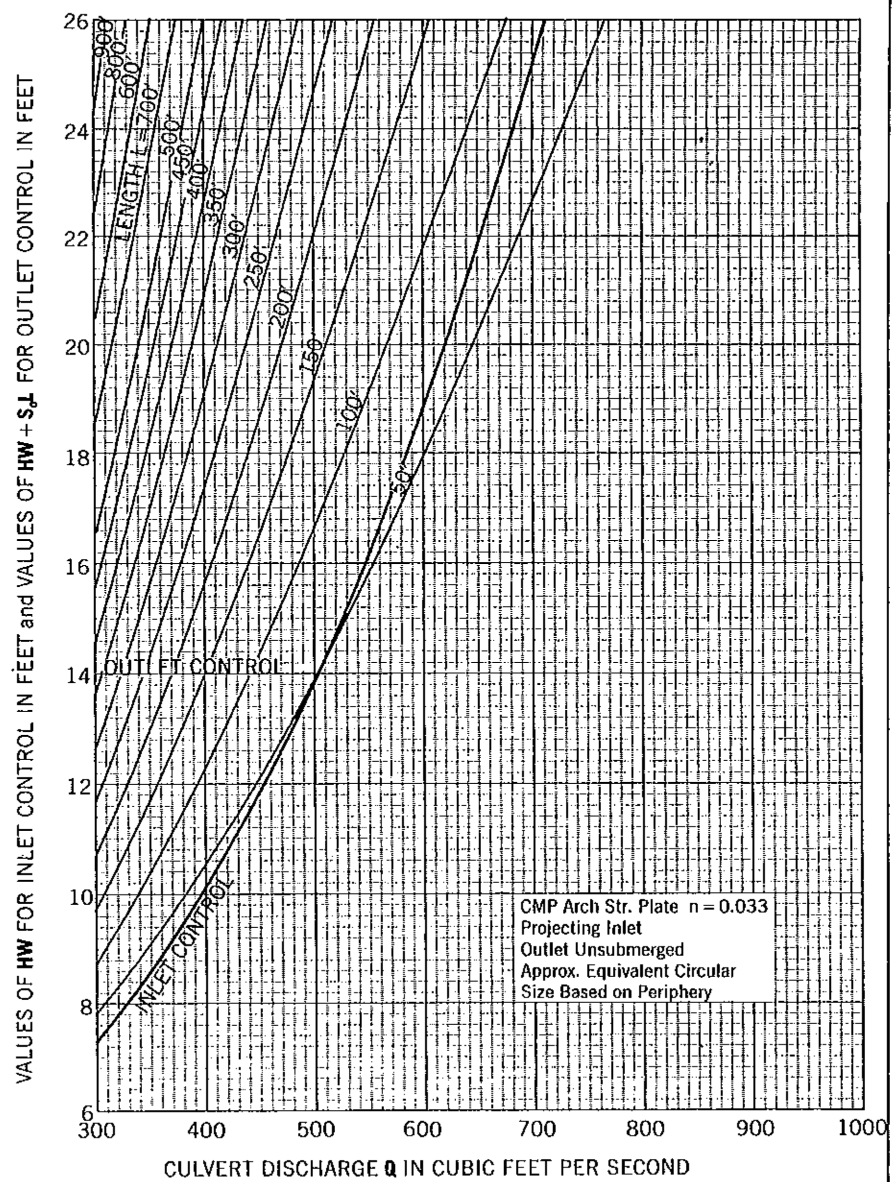


FIGURE 6: 67 x 95-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

90-INCH CIRCULAR

FIGURE 7: 72 x 113-Inch Horizontal Elliptical Concrete Pipe

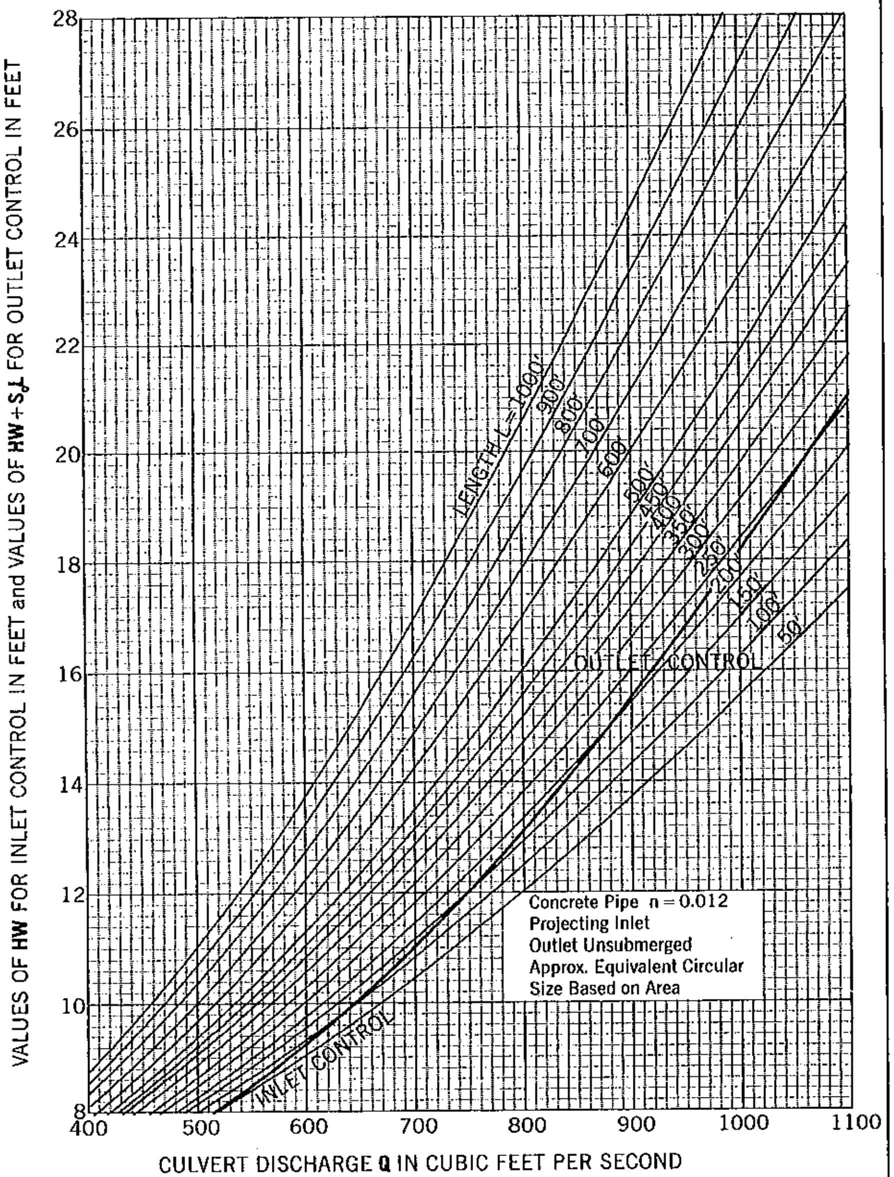
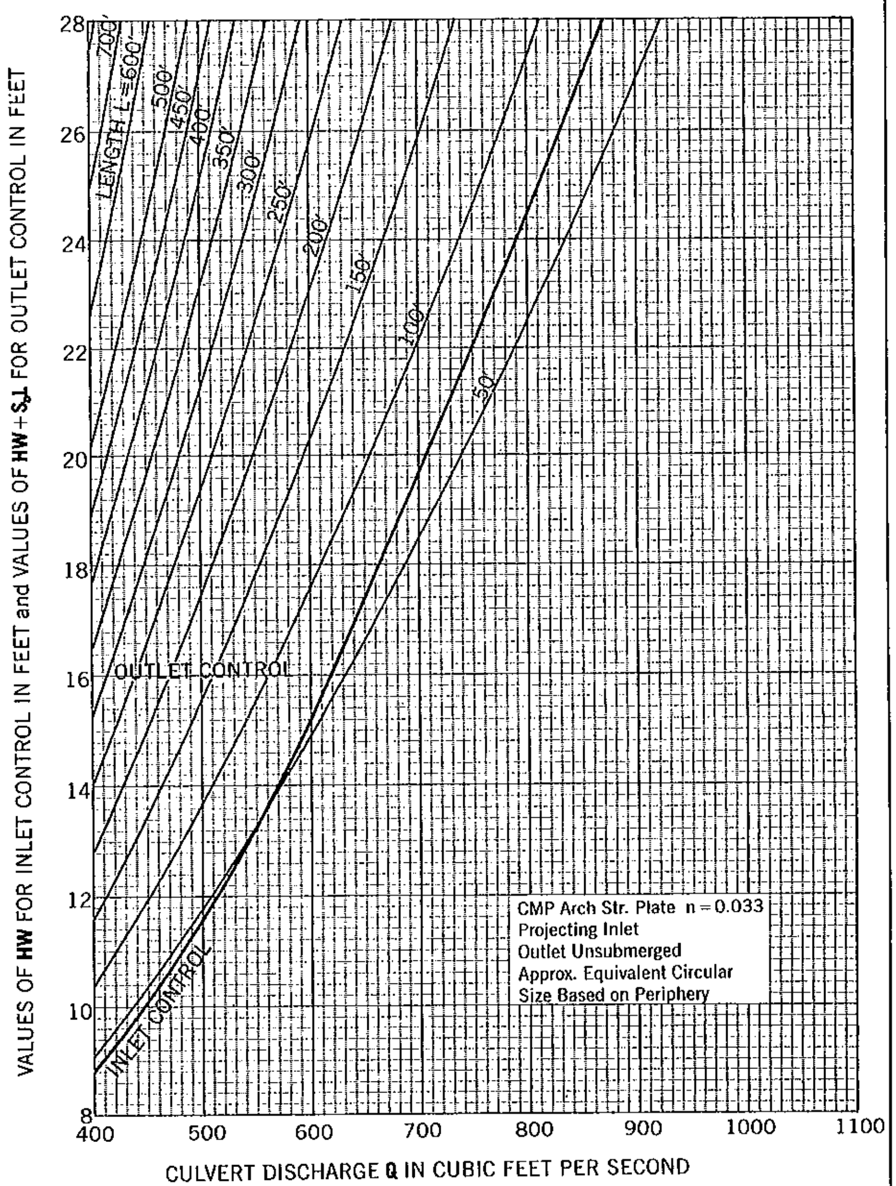


FIGURE 8: 71 x 103-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

FIGURE 9: 77 x 121-Inch Horizontal Elliptical Concrete Pipe

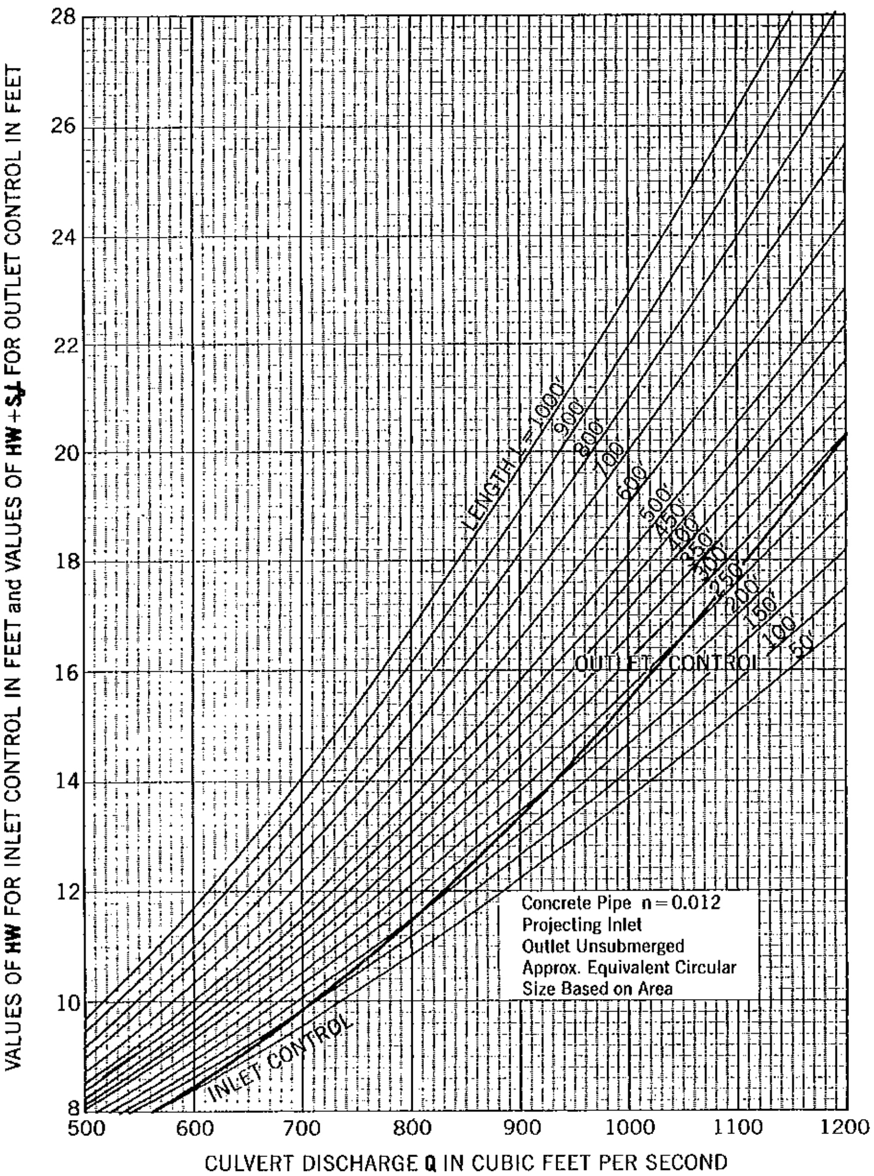
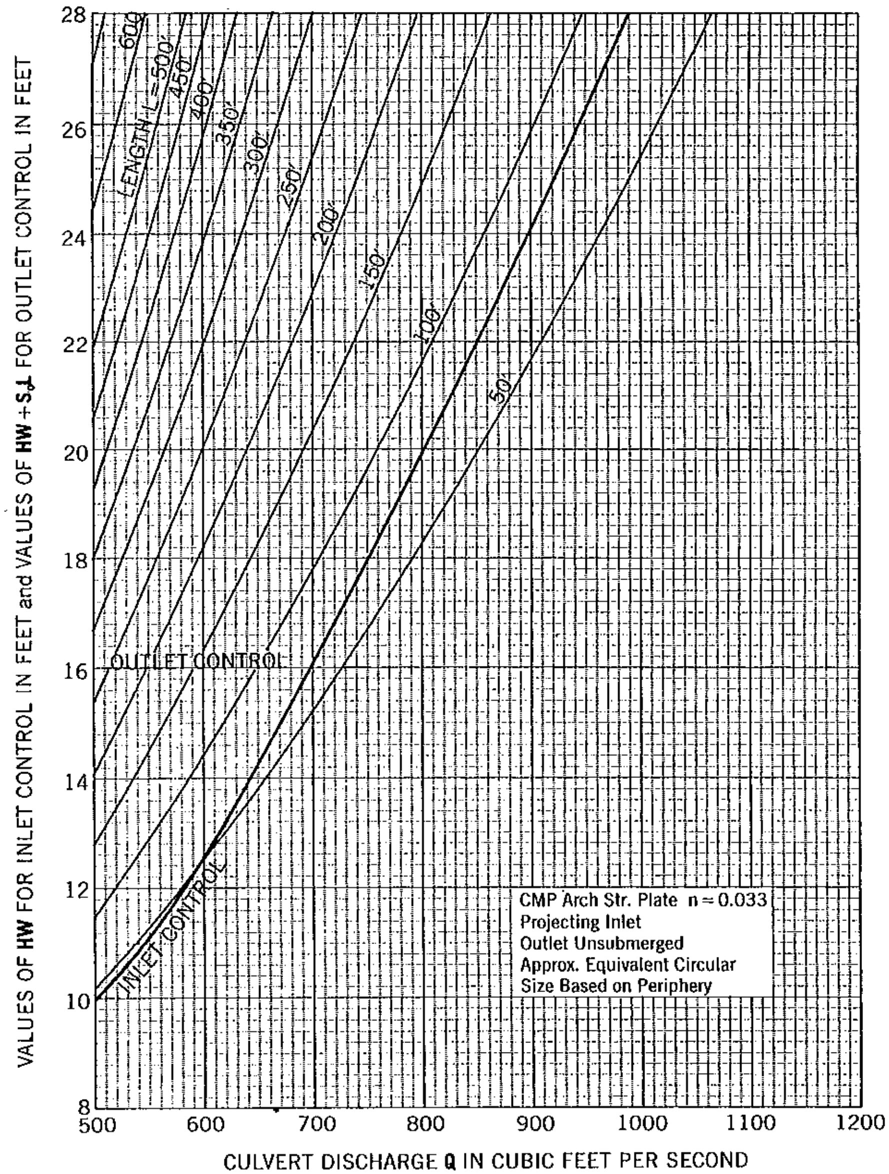


FIGURE 10: 75 x 112-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

102-INCH CIRCULAR

FIGURE 11: 82 x 128-Inch Horizontal Elliptical Concrete Pipe

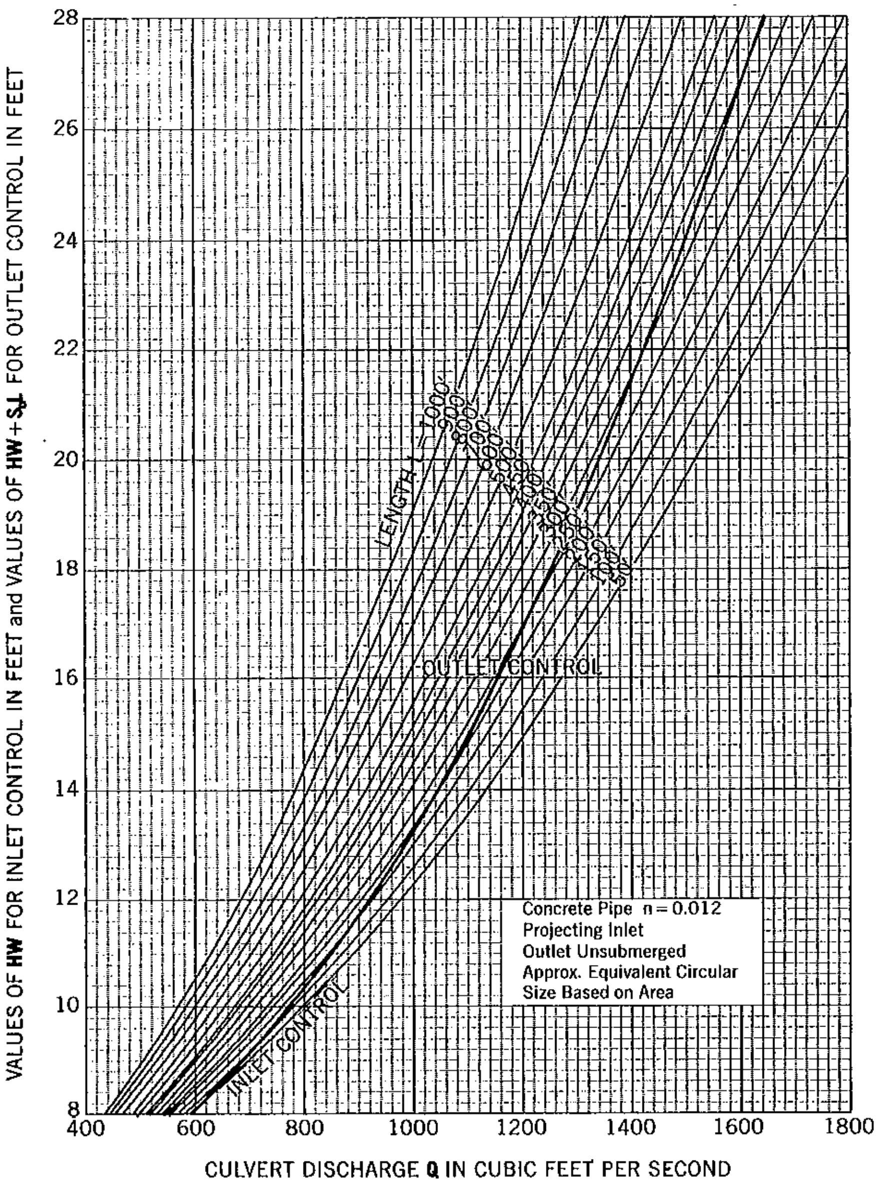
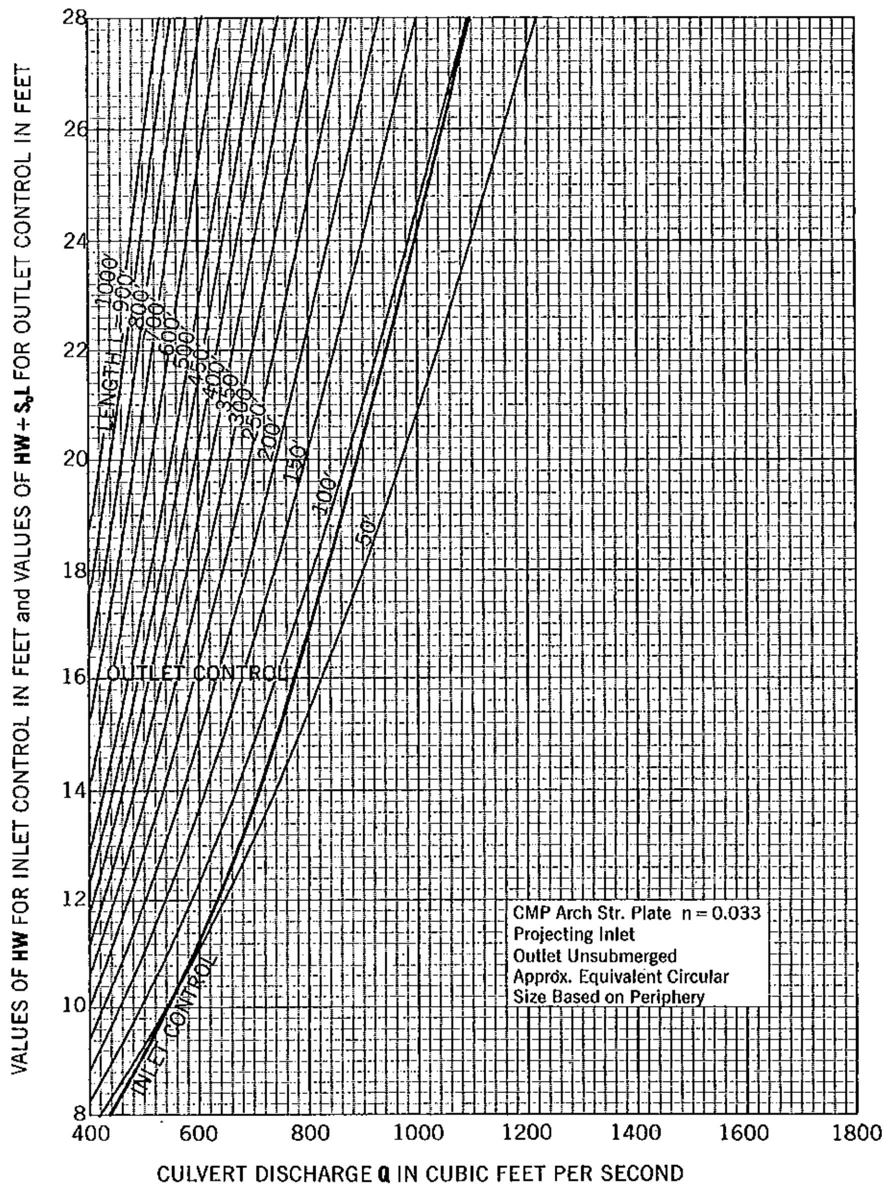


FIGURE 12: 79 x 117-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

FIGURE 13: 87 x 136-Inch Horizontal Elliptical Concrete Pipe

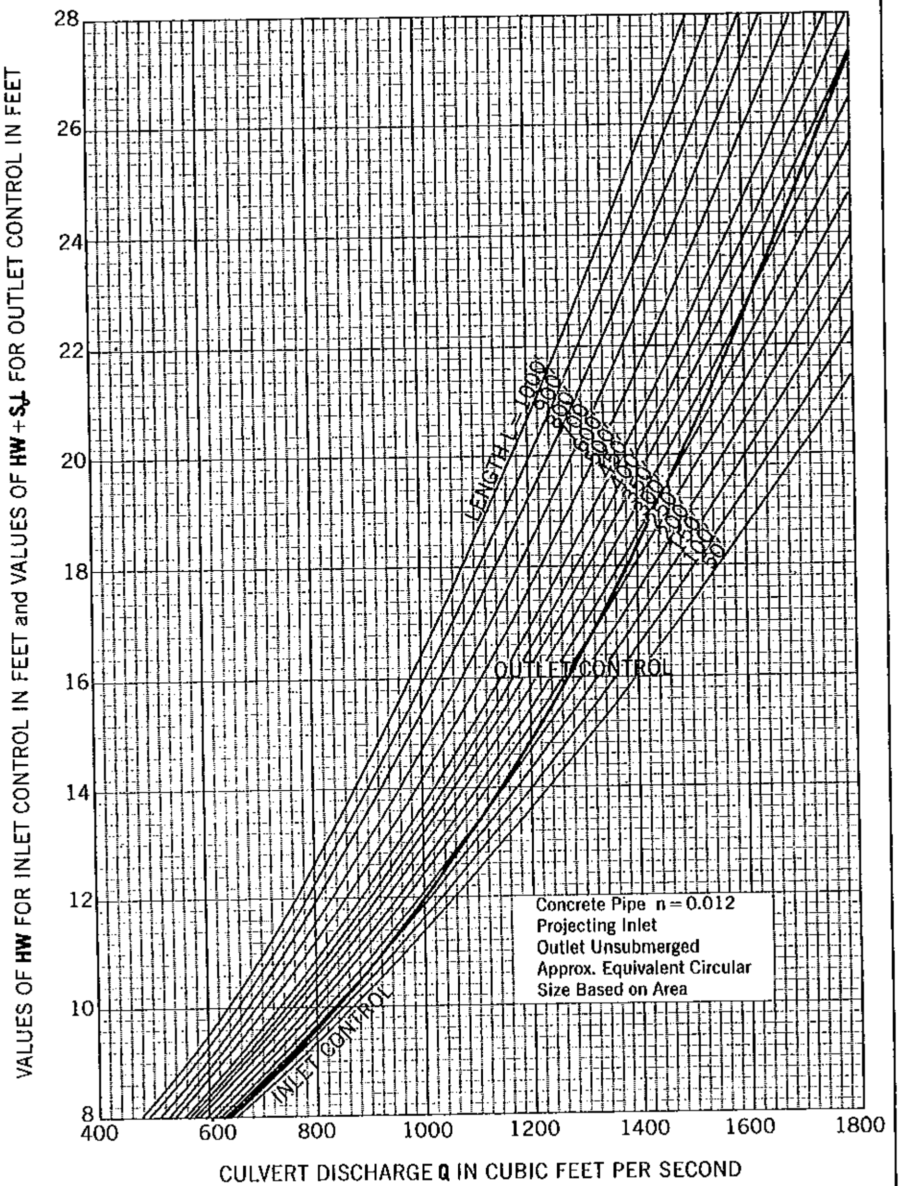
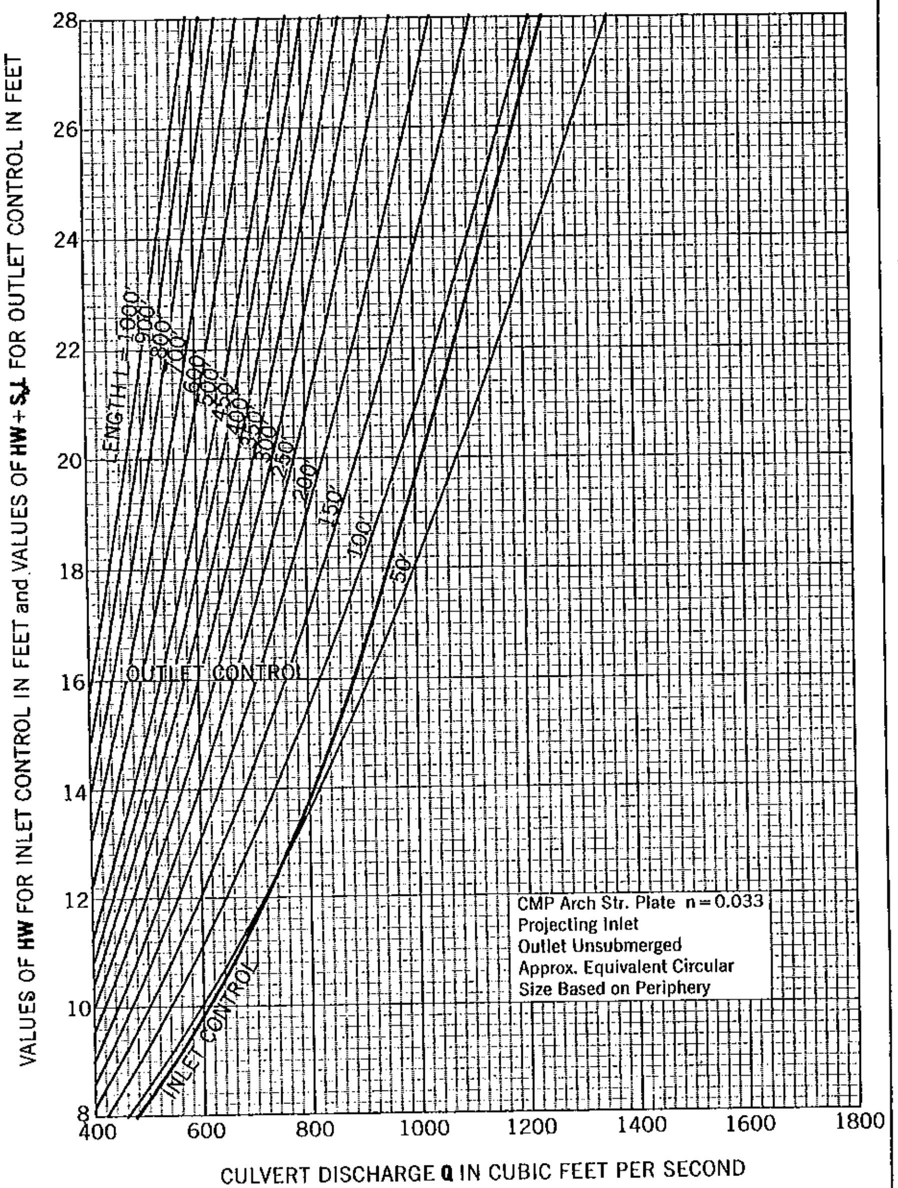


FIGURE 14: 83 x 128-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

114-INCH CIRCULAR

FIGURE 15: 92 x 143-Inch Horizontal Elliptical Concrete Pipe

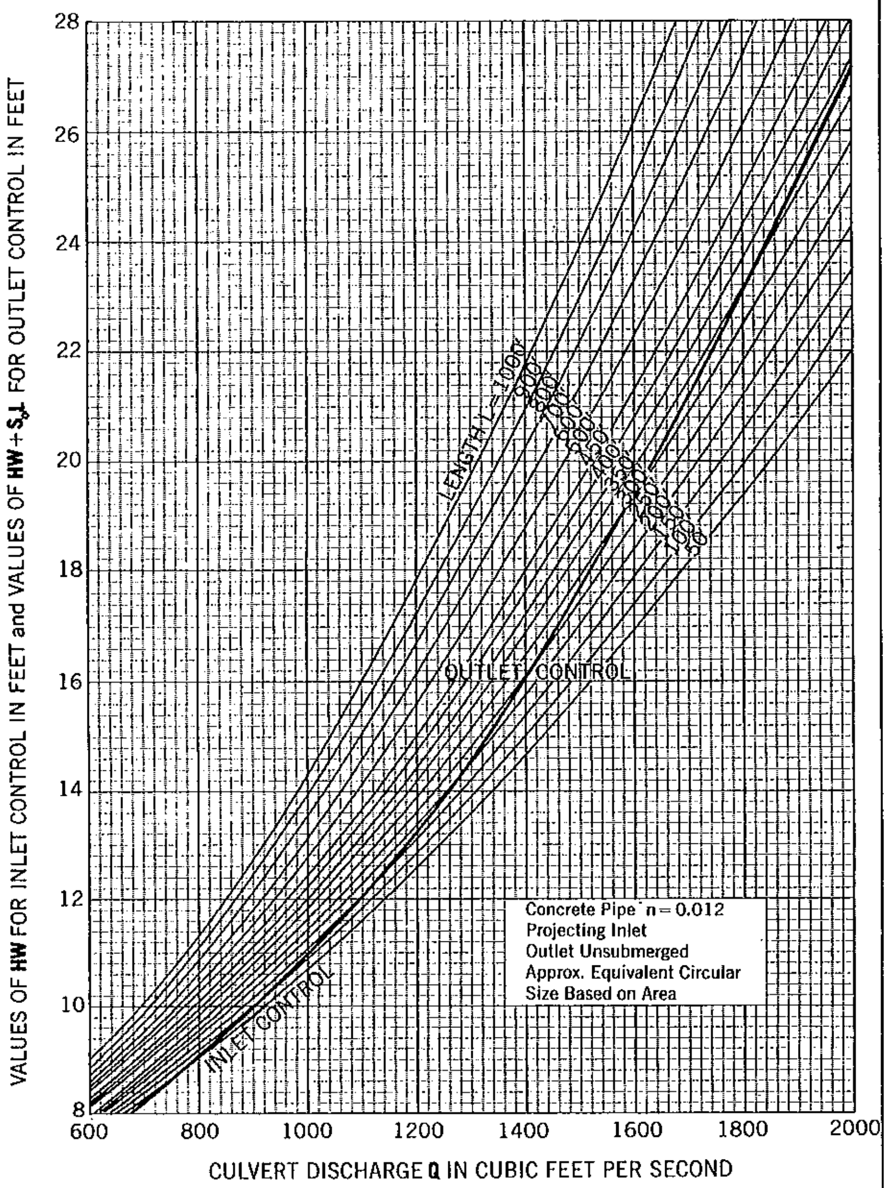
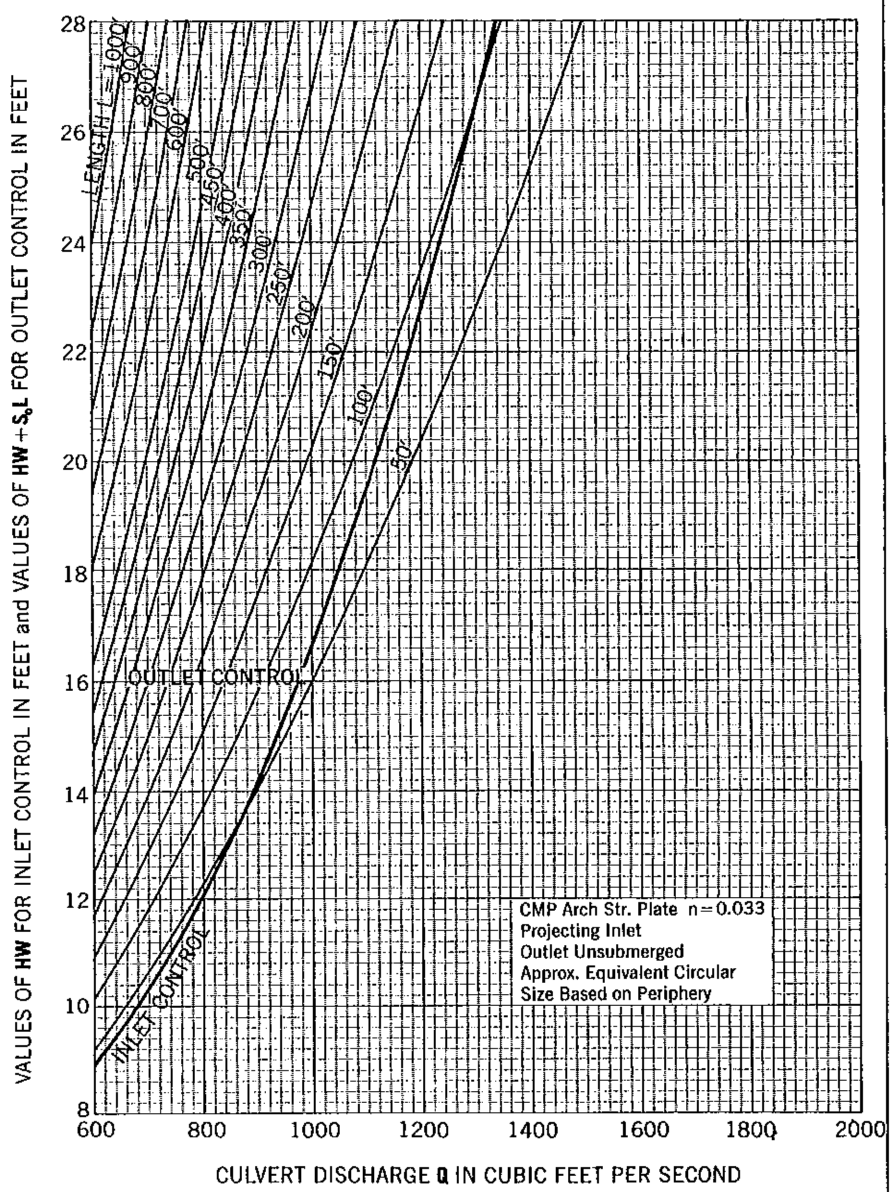


FIGURE 16: 87 x 137 Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

FIGURE 17: 97 x 151-Inch Horizontal Elliptical Concrete Pipe

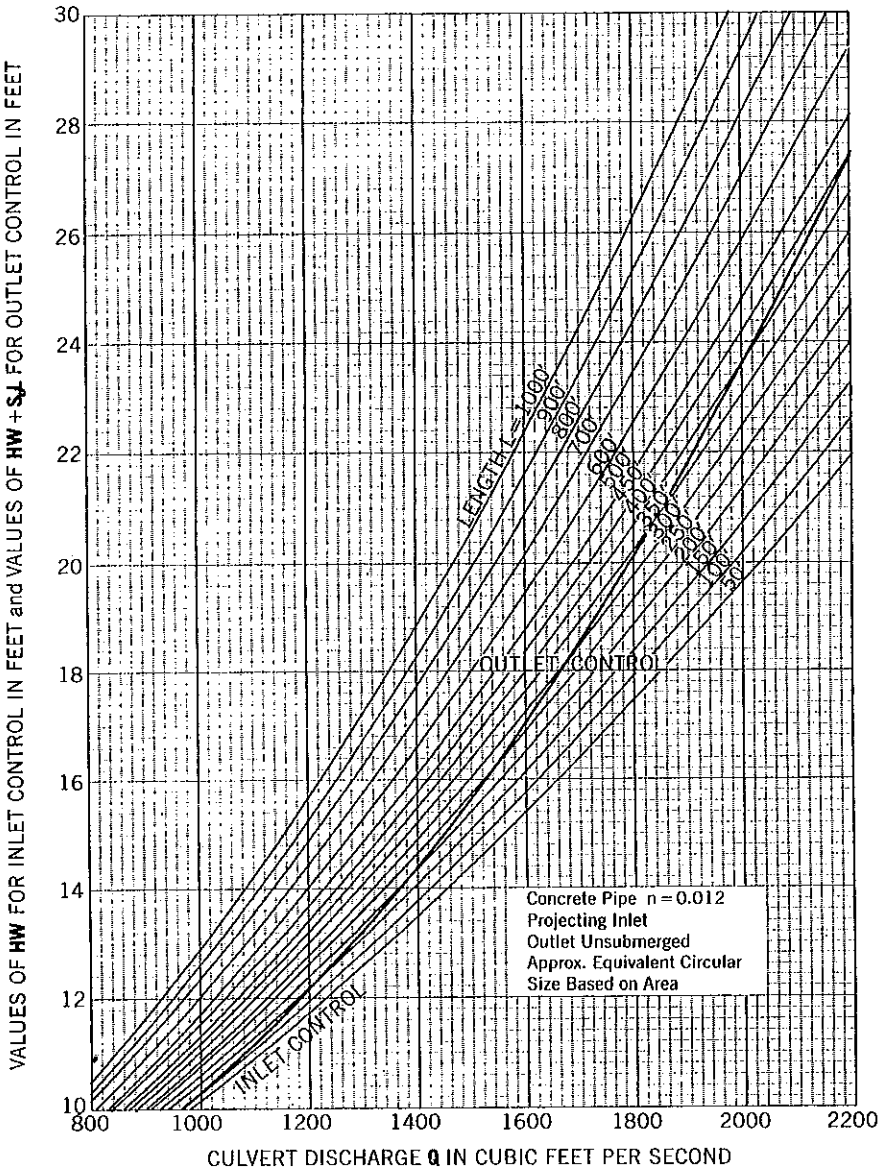
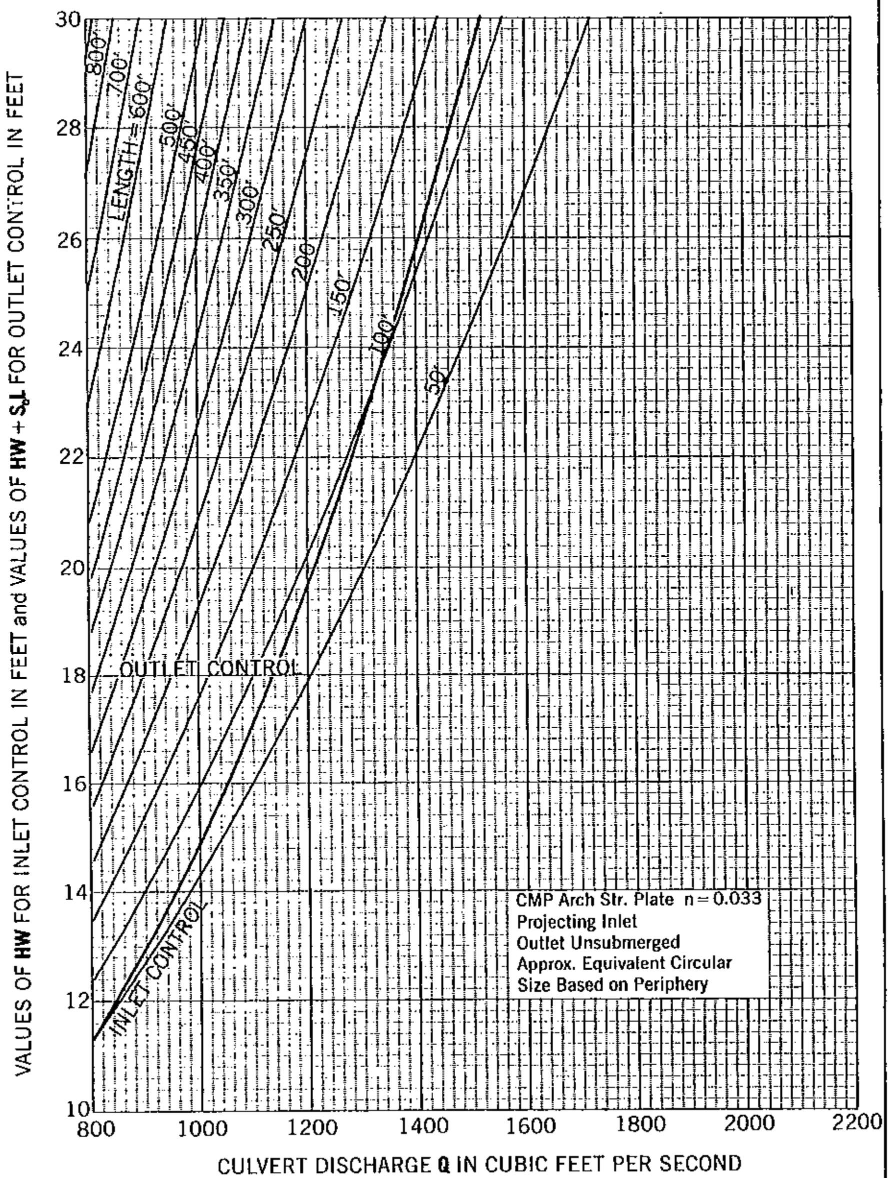


FIGURE 18: 91 x 142-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

132-INCH CIRCULAR

FIGURE 19: 106 x 166-Inch Horizontal Elliptical Concrete Pipe

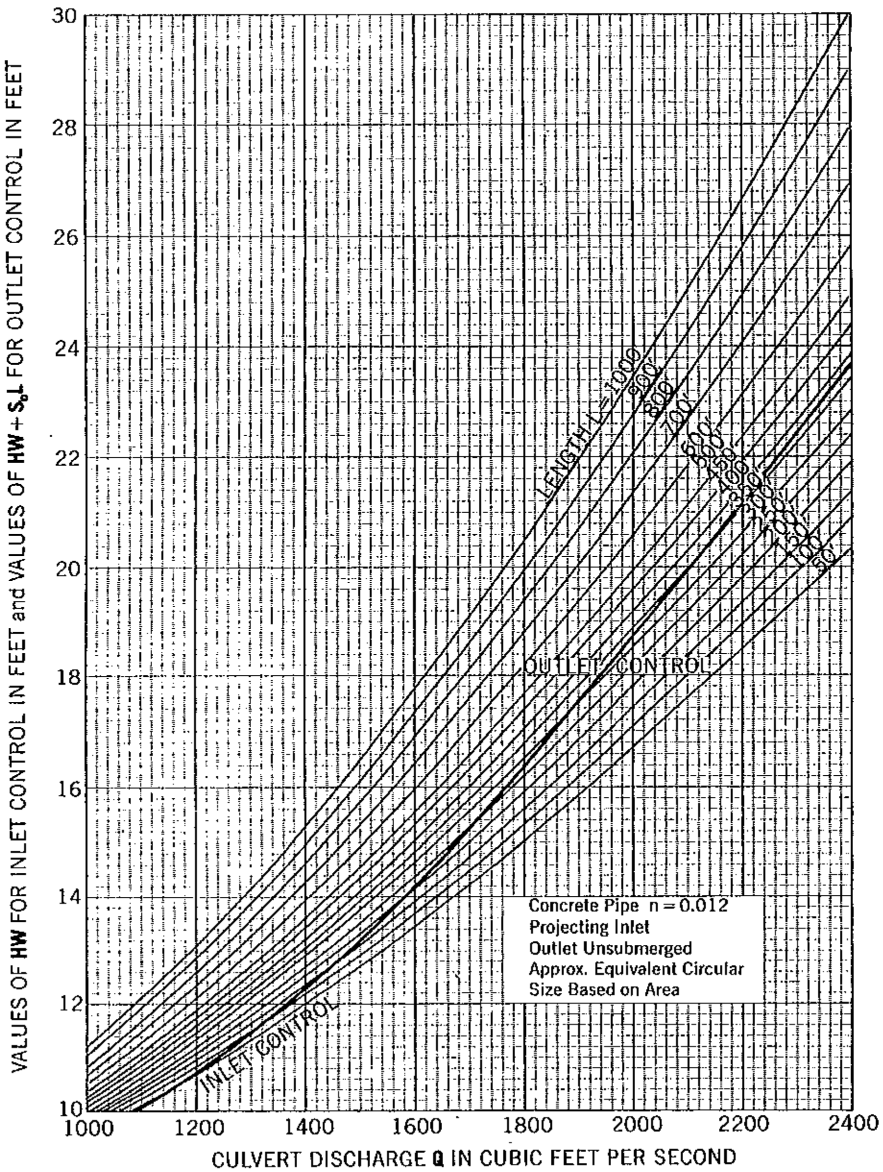
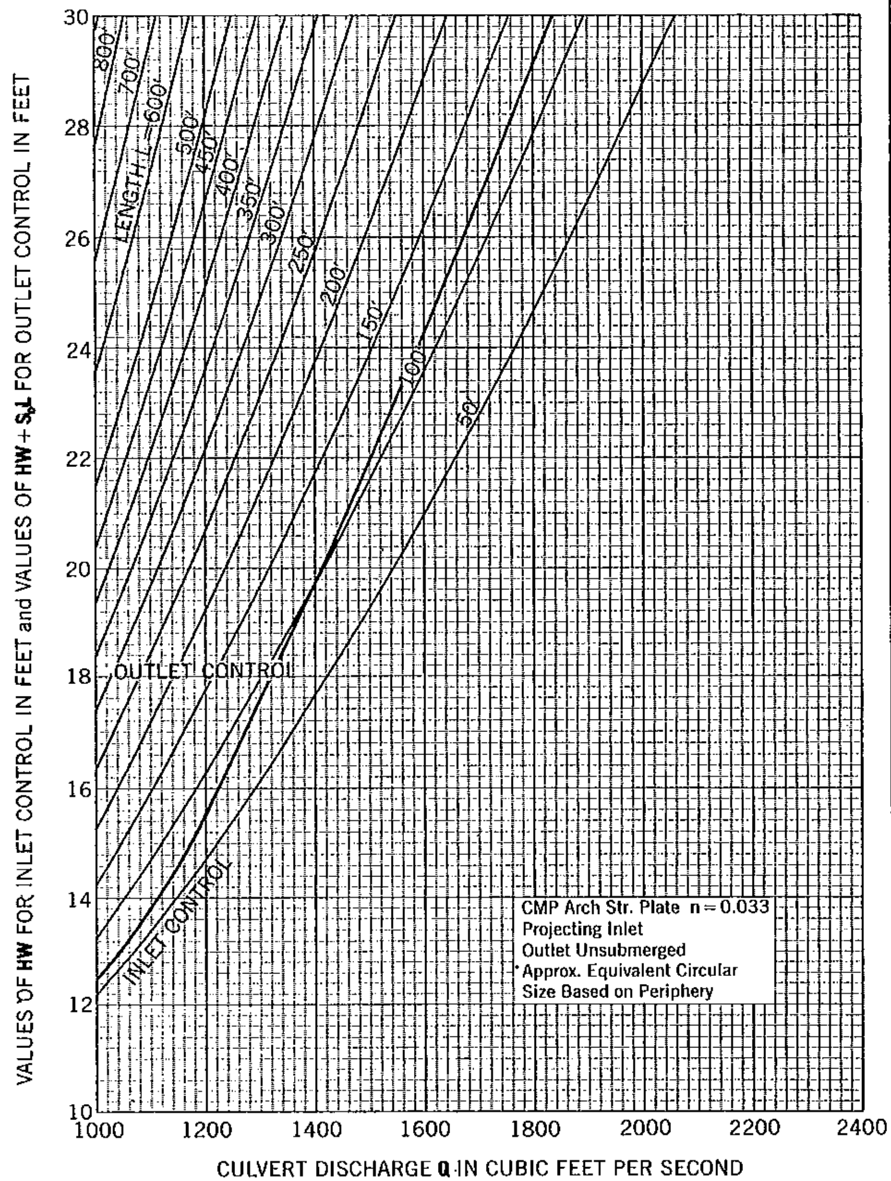


FIGURE 20: 100 x 154-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

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FIGURE 21: 116 x 180-Inch Horizontal Elliptical Concrete Pipe

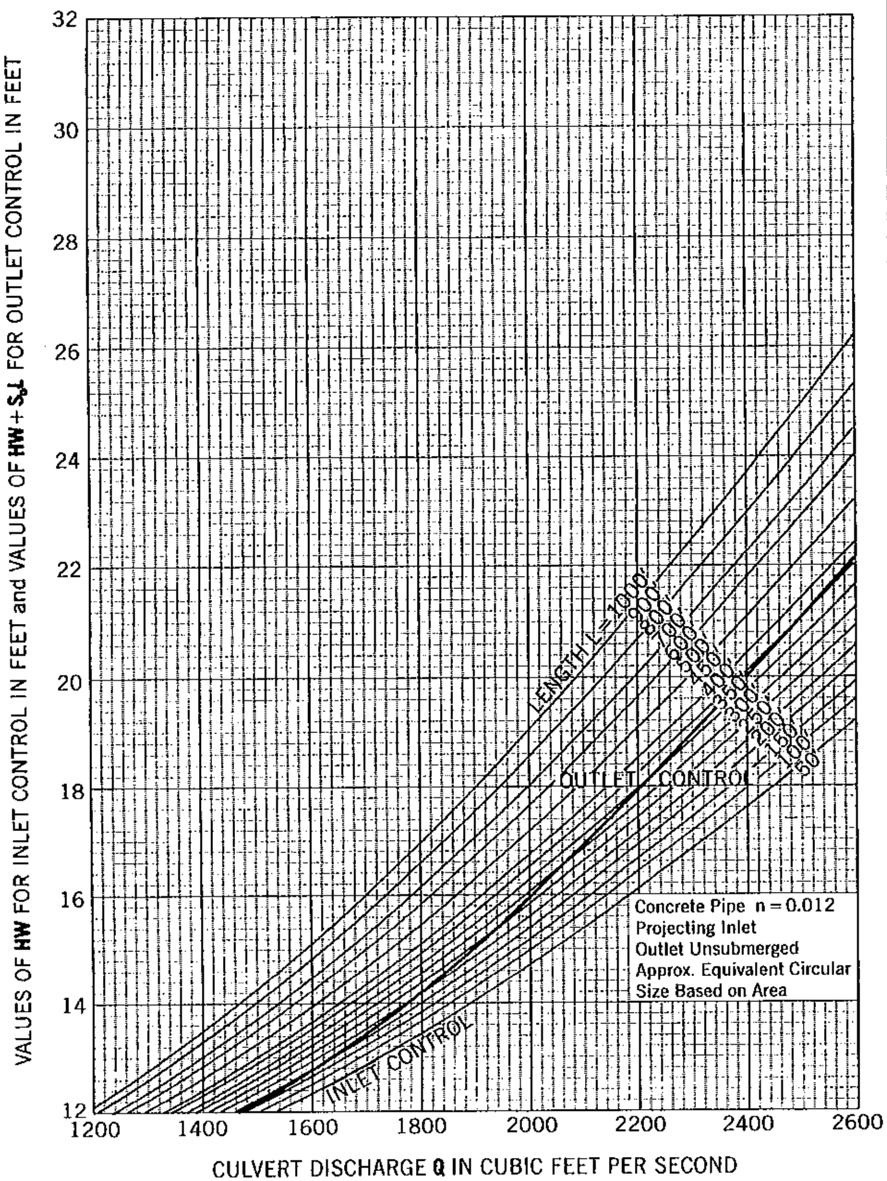
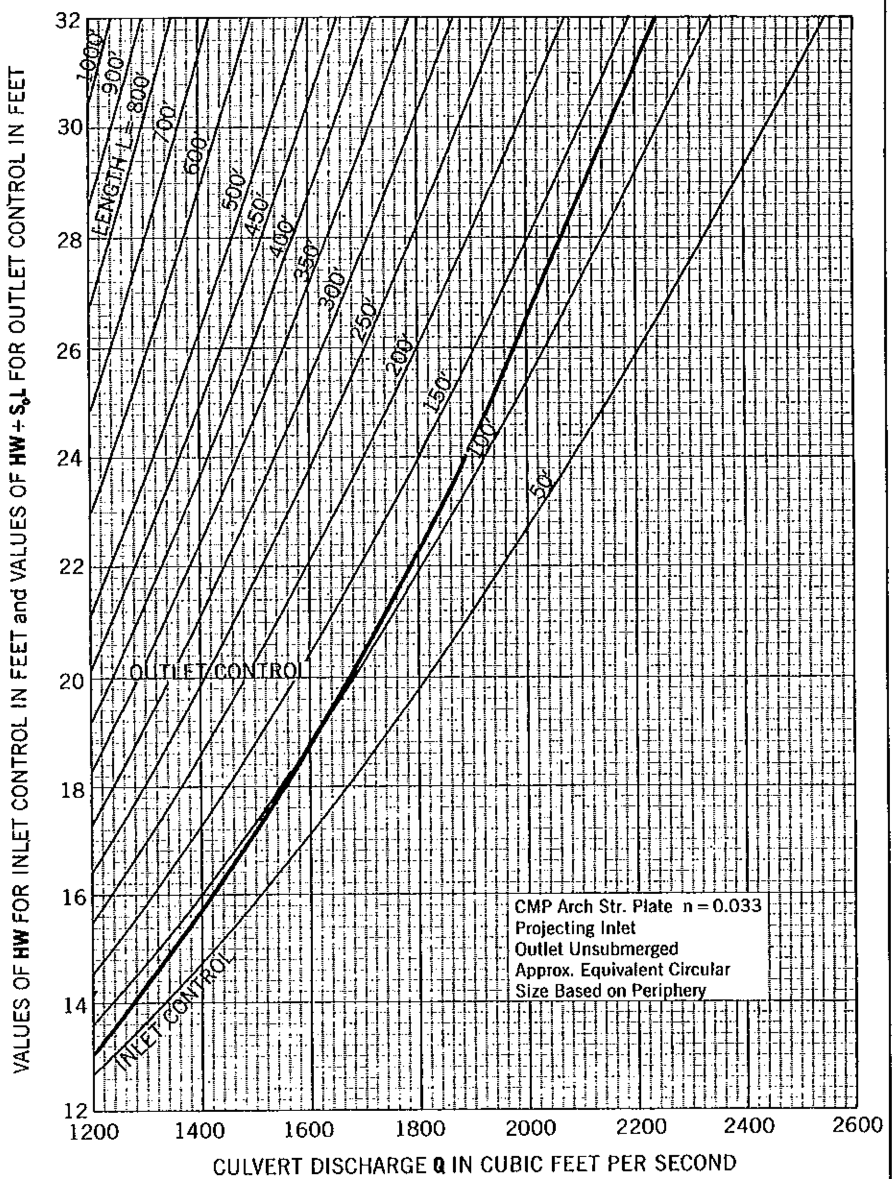


FIGURE 22: 107 x 171-Inch Corrugated Metal Pipe Arch



Interpolate for intermediate culvert lengths

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