HYDRAULICS OF CULVERTS: PRECAST CONCRETE BOX SECTIONS 7-FOOT THROUGH 10-FOOT SPANS

Reinforced concrete box culverts have been designed and used for many years because of special waterway requirements, unusual load conditions at certain locations, or designer preference. As labor costs continue to rise, so do the costs associated with cast-in-place reinforced concrete. As the volume of highway traffic increases, so does the cost of inconvenience and delay associated with cast-in-place construction methods. American Society for Testing and Materials Standard C799, Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewer Pipe, and Standard C650, Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 Feet of Cover Subjected to Highway Loadings, were developed to provide a standard product for these applications and an opportunity for specifiers to utilize the inherent advantages of a precast product. For any project, the use of precast concrete pipe, which has recognized superior hydraulic, structural and construction advantages, should be thoroughly evaluated. The availability and construction details of box sections should be discussed with local concrete pipe producers.

The hydraulic design of culverts establishes the minimum size which has sufficient capacity to discharge a required flow within an allowable headwater depth. When the culvert 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 box culvert size, the capacity of a box culvert operating under inlet control is dependent entirely on the inlet geometry. Therefore, if a box culvert is to function as an efficient hydraulic structure under inlet control conditions, an inlet geometry which results in minimum contraction of the flow at the entrance is of utmost importance.

In outlet control, all of the hydraulic factors affect culvert capacity with the primary limiting factor being surface roughness. A precast concrete box culvert has an interior surface which results in a minimum of frictional resistance to flow and provides superior hydraulic efficiency.

### TABLE I: Standard Box Sizes

<table>
<thead>
<tr>
<th>SPAN, FEET</th>
<th>(T_T)</th>
<th>(T_S)</th>
<th>(T_B)</th>
<th>RISE, FEET</th>
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NOTE: The haunch dimension \(H\) is equal to the wall thickness \(T_s\).
The standard precast concrete box section produced under Standards C789 and C850 is shown in Figure 1, and the standard sizes and wall thicknesses in Tables I and II. Generally, box culverts are designed with wingwalls and a wingwall flare of 30-75 degrees as shown in Figure 2 encompass a majority of installations. The precast concrete box sections commonly have a tongue and groove joint configuration similar to precast concrete pipe. The entrance loss coefficient, \( K_e \), is 0.2 for concrete pipe with the groove end projecting. The box section groove also provides basically a rounded crown edge and therefore, an entrance loss coefficient of 0.2 should apply.

Performance curves for the hydraulic design of the standard precast concrete box culvert are presented in Figures 3 through 22. These curves correlate discharge-headwater depth and are based on nomographs included in Hydraulic Engineering Circular Number 5, Federal Highway Administration, with a recommended roughness coefficient of 0.012. 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 from the headwater depth.

A complete discussion of the hydraulics of culverts is presented in Design Data B, Hydraulics of Culverts; 12-inch through 21-inch Diameter Pipe and specifics on the hydraulic properties of precast concrete box sections in Design Data 26, Hydraulic Capacity of Precast Concrete Boxes.

![TABLE II: Standard Thicknesses](image)

<table>
<thead>
<tr>
<th>Span, Feet</th>
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<th>( T_B ), inches</th>
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<td>C789</td>
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**FIGURE 2: Wingwall Flare**

An 800-foot long box culvert is to be installed on a 0.5 percent slope. Due to minimum cover requirements, the maximum rise is limited to 8 feet. It is required to carry a maximum flow of 1,000 cubic feet per second with an allowable headwater depth of 15 feet.

**Given:**
Size of precast concrete box section required and type of control.

**Solution:**
Investigate three concrete box culvert sections, 8 \( \times \) 8-foot, 9 \( \times \) 7-foot and 10 \( \times \) 6-foot, which meet the maximum rise limit of 8 feet.

Enter Figure 11: 8 \( \times \) 8-foot concrete box section, and project a vertical line from \( Q = 1,000 \) to the inlet control curve and the outlet control curve for \( L = 800 \) feet. Project horizontally to the vertical scale and read a headwater depth of 14.8 feet for inlet control and a value of 17.5 feet for outlet control. To obtain outlet control headwater depth, subtract the value \((S_o \times L)\) from the outlet control value: \(17.5 - (0.005 \times 800) = 13.5 \) feet for the outlet control headwater depth. Therefore, inlet control governs.

Entering Figure 14: 9 \( \times \) 7-foot concrete box section and proceeding in a similar manner, read a headwater depth of 14.7 feet for inlet control and obtain 13.1 feet for the outlet control headwater depth with inlet control governing.

Entering Figure 18: 10 \( \times \) 6-foot concrete box section and again proceeding in a similar manner, read a headwater depth of 14.4 feet for inlet control and obtain 13.5 feet for the outlet control headwater depth with inlet control governing.

**Answer:**
Therefore, each of the concrete box culvert sections, 8 \( \times \) 8-foot, 9 \( \times \) 7-foot and 10 \( \times \) 6-foot, will carry the design discharge within the allowable headwater depth of 15 feet and is under inlet control.
FIGURE 5: Culvert Capacity—7 x 6-foot Precast Box Section Equivalent 87-Inch Circular

VALUES OF HW FOR INLET CONTROL IN FEET AND VALUES OF HW + SL FOR OUTLET CONTROL IN FEET

Manning's n = 0.012
3x7.5 Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular Size Based on Area

CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Interpolate for intermediate culvert lengths

FIGURE 6: Culvert Capacity—7 x 7-foot Precast Box Section Equivalent 94-Inch Circular

VALUES OF HW FOR INLET CONTROL IN FEET AND VALUES OF HW + SL FOR OUTLET CONTROL IN FEET

Manning's n = 0.012
3x7.5 Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular Size Based on Area

CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND
FIGURE 7: Culvert Capacity—8 x 4-foot Precast Box Section
Equivalent 76-inch Circular

Manning's n = 0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area

FIGURE 8: Culvert Capacity—8 x 5-foot Precast Box Section
Equivalent 85-inch Circular

Manning's n = 0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area

VALUES OF HW FOR INLET CONTROL IN FEET AND VALUES OF HW + SL FOR OUTLET CONTROL IN FEET

CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Interpolate for intermediate culvert lengths.
FIGURE 9: Culvert Capacity—8 x 6-foot Precast Box Section Equivalent 93-inch Circular

FIGURE 10: Culvert Capacity—8 x 7-foot Precast Box Section Equivalent 101-inch Circular

Interpolate for intermediate culvert lengths
FIGURE 13: Culvert Capacity—9 x 6-foot Precast Box Section
Equivalent 99-inch Circular

Manning's n = 0.012
30°-75° Wing Wall flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area

VALUES OF HW FOR INLET CONTROL IN FEET AND VALUES OF HW + S.L. FOR OUTLET CONTROL IN FEET

CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600

28 26 24 22 20 18 16 14 12 10 8 6 4 2

FIGURE 14: Culvert Capacity—9 x 7-foot Precast Box Section
Equivalent 107-inch Circular

Manning's n = 0.012
30°-75° Wing Wall flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area

VALUES OF HW FOR INLET CONTROL IN FEET AND VALUES OF HW + S.L. FOR OUTLET CONTROL IN FEET

CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600

25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2

Interpolate for intermediate culvert lengths
FIGURE 15: Culvert Capacity—9 x 8-foot Precast Box Section Equivalent 114-inch Circular

FIGURE 16: Culvert Capacity—9 x 9-foot Precast Box Section Equivalent 121-inch Circular

Interpolate for intermediate culvert lengths
FIGURE 19: Culvert Capacity—10 x 7-foot Precast Box Section Equivalent 112-inch Circular

Manning’s n = 0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area

VALUES OF HW FOR INLET CONTROL IN FEET AND VALUES OF HW + SL FOR OUTLET CONTROL IN FEET

CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

FIGURE 20: Culvert Capacity—10 x 8-foot Precast Box Section Equivalent 120-inch Circular

Manning’s n = 0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area

VALUES OF HW FOR INLET CONTROL IN FEET AND VALUES OF HW + SL FOR OUTLET CONTROL IN FEET

CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Interpolate for intermediate culvert lengths