

8.12 Tapered Inlets

8.12.1 General

A tapered inlet is a flared culvert inlet with an enlarged face section and a hydraulically efficient throat section. A tapered inlet may have a depression, or FALL, incorporated into the inlet structure or located upstream of the inlet. The depression is used to exert more head on the throat section for a given headwater elevation. Therefore, tapered inlets improve culvert performance by providing a more efficient control section (the throat). Tapered inlets with FALL also improve performance by increasing the head on the throat. Tapered inlets are discussed in more detail in Hydraulic Engineering Circular No. 13, "Hydraulic Design of Improved Inlets for Culverts."

- Tapered inlets are not recommended for use on culverts flowing in outlet control because the simple beveled edge is of equal benefit.
- Design criteria and methods have been developed for two basic tapered inlet designs: the side-tapered inlet and the slope-tapered inlet.
- Tapered inlet design charts are available for rectangular box culverts and circular pipe culverts.

8.12.2 Side-tapered

The side-tapered inlet has an enlarged face section with the transition to the culvert barrel accomplished by tapering the side walls (Figure 8-11). The face section is about the same height as the barrel height and the inlet floor is an extension of the barrel floor. The inlet roof may slope upward slightly, provided that the face height does not exceed the barrel height by more than 10% (1.1D).

There are two possible control sections, the face and the throat. HW_f , shown in Figure 8-11, is the headwater depth measured from the face section invert and HW_t is the headwater depth measured from the throat section invert. The throat of a side-tapered inlet is a very efficient control section. The flow contraction is nearly eliminated at the throat. In addition, the throat is always slightly lower than the face so that more head is exerted on the throat for a given headwater elevation.

The beneficial effect of depressing the throat section below the streambed can be increased by installing a depression upstream of the side-tapered inlet. Figure 8-12 depicts a side-tapered inlet with the depression contained between wingwalls. For this type of depression, the floor of the barrel should extend upstream from the face a minimum distance of $D/2$ before sloping upward more steeply. The length of the resultant upstream crest where the slope of the depression meets the streambed should be checked to assure that the crest will not control the flow at the design flow and headwater. If the crest length is too short, the crest may act as a weir control section, the barrel is defined as the throat section.

8.12.3 Slope-tapered Inlets

The slope-tapered inlet, like the side tapered inlet, has an enlarged face section with tapered sidewalls meeting the culvert barrel walls at the throat section. (Figure 8-13) In addition, a vertical FALL is incorporated into the inlet between the face and throat sections. This FALL concentrates more head on the throat section. At the location where the steeper slope of the inlet intersects the flatter slope of the barrel, a third section, designated the bend section, is formed.

A slope-tapered inlet has three possible control sections, the face, the bend and the throat. Of these, only the dimensions of the face and the throat section are determined by the design procedures of this manual. The size of the bend section is established by locating it a minimum distance upstream from the throat so that it will not control the flow.

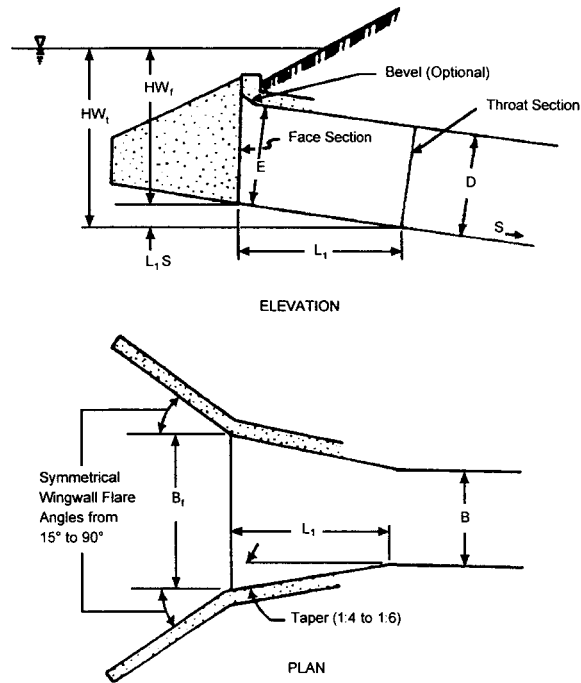


Figure 8-11 Side-Tapered Inlet

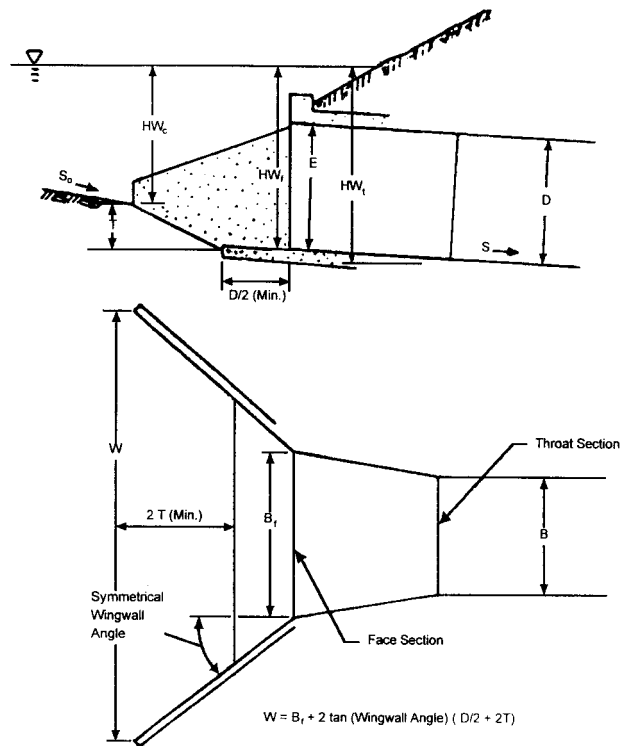


Figure 8-12 Side-tapered Inlet With Upstream Depression Contained Between Wingwalls

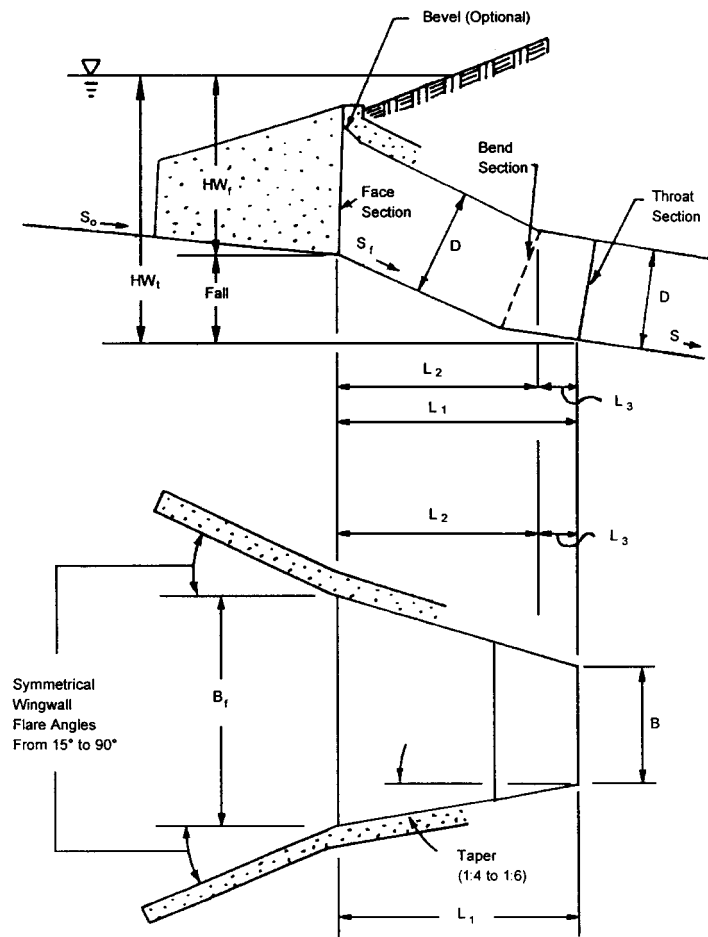


Figure 8-13 Slope-Tapered Inlet With Vertical Face

The slope-tapered inlet combines an efficient throat section with additional head on the throat. The face section does not benefit from the FALL between the face and throat; therefore, the face sections of these inlets are larger than the face sections of equivalent depressed side-tapered inlets. The required face size can be reduced by the use of bevels or other favorable edge configurations. The vertical face slope-tapered inlet design is shown in Figure 8-13.

The slope-tapered inlet is the most complex inlet improvement recommended in this manual. Construction difficulties are inherent, but the benefits in increased performance can be great. With proper design, a slope-tapered inlet passes more flow at a given headwater elevation than any other configuration. Slope-tapered inlets can be applied to both box culverts and circular pipe culverts. For the latter application, a square to round transition is normally used to connect the rectangular slope-tapered inlet to the circular pipe.

8.12.4 Hydraulic Design

(Inlet Control)

Tapered inlets have several possible control sections including the face, the bend (for slope-tapered inlets) and the throat. In addition, a depressed side-tapered inlet has a possible control section at the crest upstream of the depression. Each of these inlet control sections has an individual performance curve. The headwater depth for each control section is referenced to the invert of the section. One method of determining the overall inlet control performance curve is to calculate performance curves for each potential control section, and then select the segment of each curve which defines the minimum overall culvert performance. (Figure 8-14)

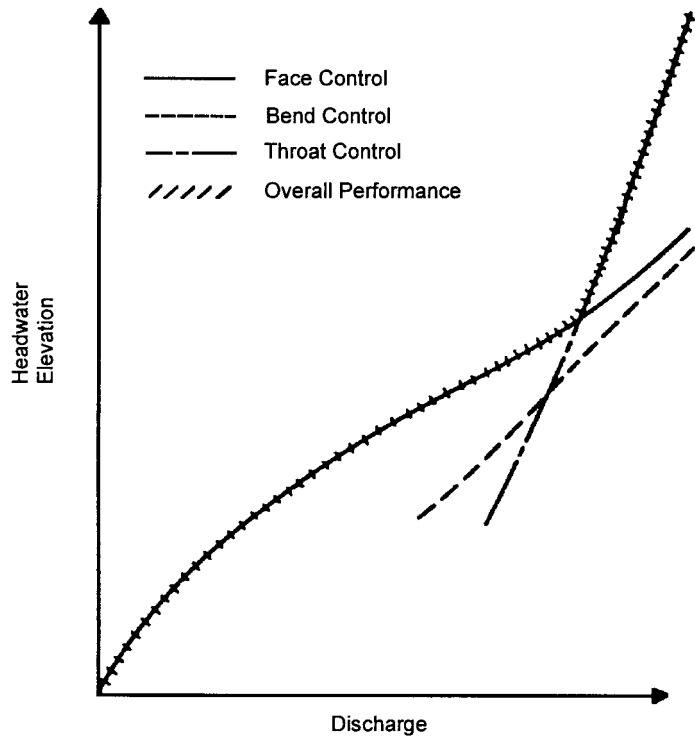


Figure 8-14 Inlet Control Performance Curves (Schematic)

Side-tapered Inlet

The side-tapered inlet throat should be designed to be the primary control section for the design range of flows and headwaters. Since the throat is only slightly lower than the face, it is likely that the face section will function as a weir or an orifice with downstream submergence within the design range. At lower flow rates and headwaters, the face will usually control the flow.

Slope-tapered Inlet

The slope-tapered inlet throat can be the primary control section with the face section submerged or unsubmerged. If the face is submerged, the face acts as an orifice with downstream submergence. If the face is unsubmerged, the face acts as a weir, with the flow plunging into the pool formed between the face and the throat. As previously noted, the bend section will not act as the control section if the dimensional criteria of this publication are followed. However, the bend will contribute to the inlet losses which are included in the inlet loss coefficient, K_E .

When a culvert with a tapered inlet performs in outlet control, the hydraulics are the same as described in Section 8.6 for all culverts. The tapered inlet entrance loss coefficient (K_E) is 0.2 for both side-tapered and slope-tapered inlets. This loss coefficient includes contraction and expansion losses at the face, increased friction losses between the face and the throat and the minor expansion and contraction losses at the throat.

8.12.5 Design Methods

Tapered inlet design begins with the selection of the culvert barrel size, shape and material. These calculations are performed using the Culvert Design Form provided in Appendix D. The design nomographs contained in HDS5 are used to design the tapered inlet. The design procedure is similar to designing a culvert with other control sections (face and throat). The result will be one or more culvert designs, with and without tapered inlets, all of which meet the site design criteria. The designer must select the best design for the site under consideration.

In the design of tapered inlets, the goal is to maintain control at the efficient throat section in the design range of headwater and discharge. This is because the throat section has the same geometry as the barrel, and the barrel is the most costly part of the culvert. The inlet face is then sized large enough to pass the design flow without acting as a control section in the design discharge range. Some slight oversizing of the face is beneficial because the cost of constructing the tapered inlet is usually minor compared with the cost of the barrel.

Performance Curves

Performance curves are of utmost importance in understanding the operation of a culvert with a tapered inlet. Each potential control section (face, throat and outlet) has a performance curve, based on the assumption that particular section controls the flow. Calculating and plotting the various performance curves results in a graph similar to Figure 8-15, containing the face control, throat control and outlet control curves. The overall culvert performance curve is represented by the hatched line. In the range of lower discharges face control governs; in the intermediate range, throat control governs; and in the higher discharge range, outlet control governs. The crest and bend performance curves are not calculated since they do not govern in the design range.

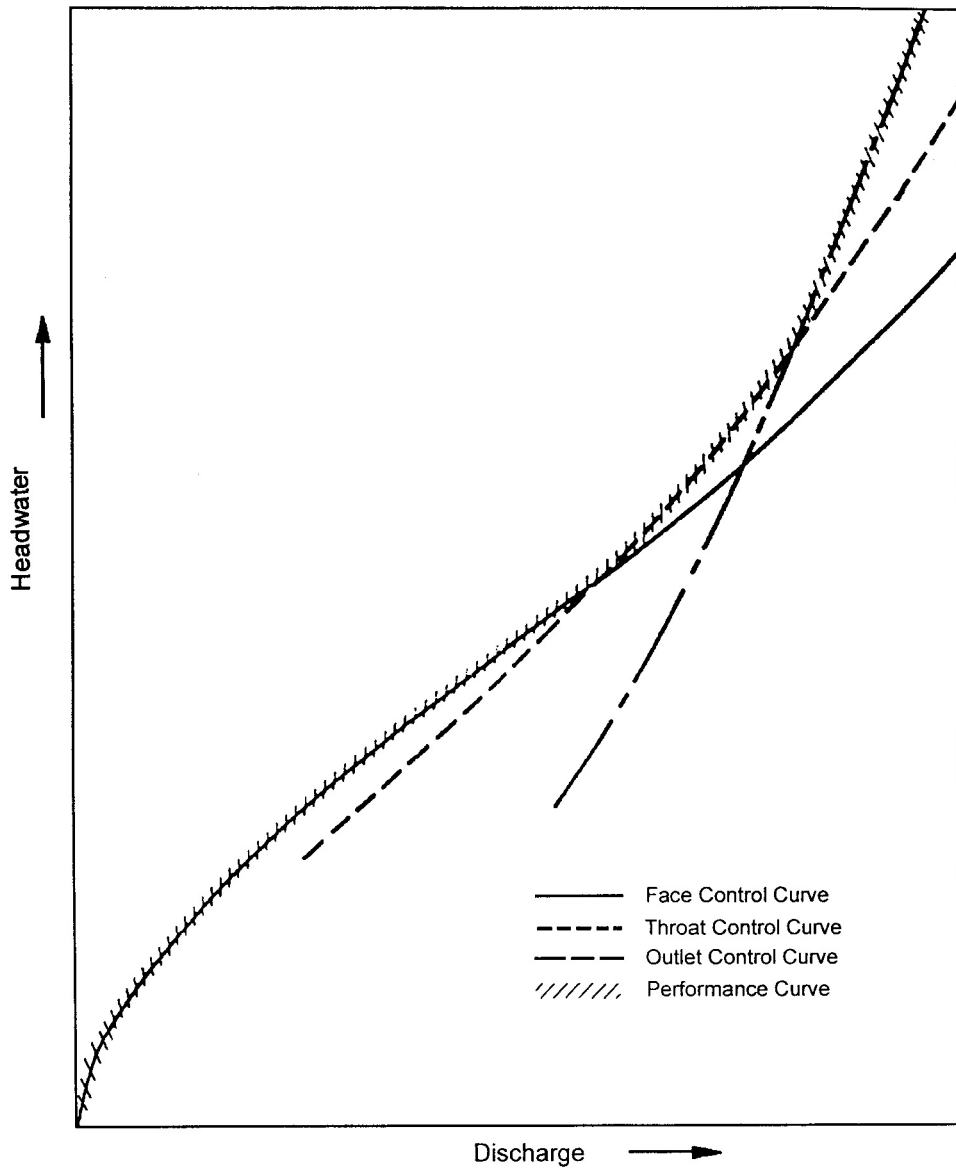


Figure 8-15 Culvert Performance Curve (Schematic)