8.1 Introduction

8.1.1 Purpose

This chapter provides design procedures for the hydraulic design of highway culverts which are based on FHWA Hydraulic Design Series Number 5 (HDS5), Hydraulic Design of Highway Culverts. A culvert is defined as the following:

- A structure which is usually designed hydraulically to take advantage of submergence to increase hydraulic capacity
- A structure used to convey surface runoff or a watercourse through an embankment
- A structure, as distinguished from bridges, which is usually covered with embankment and is composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert
- Requires a structural design. In addition to its hydraulic function, it must also carry construction and highway traffic and earth loads. (See Chapter 4, Culvert Repair, Materials, and Structural Design.)

8.1.2 Concepts

Following are discussions of concepts which are important in culvert design.

- **Critical Depth:** Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross-section geometry there is only one critical depth.

- **Crown:** The crown (soffit) is the inside top of the culvert.

- **Flow Type:** The USGS has established seven culvert flow types which assist in determining the flow conditions at a particular culvert site. Diagrams of these flow types are provided in the design methods section.

- **Free Outlet:** A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.

- **Improved Inlet:** An improved inlet has an entrance geometry which decreases the flow contraction at the inlet and thus increases the capacity of culverts. These inlets are referred to as either side- (walls tapered) or slope-tapered (increased flow-line slope at the entrance).

- **Invert:** The invert is the flowline of the culvert (inside bottom). However, if the culvert is buried to accommodate fish passage, then the invert should be considered the streambed.

- **Normal Flow:** Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface and channel bottom will be parallel. This type of flow will exist in a culvert operating on a constant slope provided the culvert is sufficiently long.

- **Slope**: Usually a steep slope is present where critical depth is greater than normal depth and a mild slope is present where critical depth is less than normal depth.

- **Submerged:** A submerged **outlet** occurs when the tailwater elevation is higher than the crown of the culvert and a submerged **inlet** occurs when the headwater is greater than 1.2D where D is the culvert diameter or barrel height.

8.1.3 Symbols

To provide consistency within this chapter as well as throughout this manual the symbols given in Table 8-1 will be used. These symbols were selected because of their wide use in culvert publications.

Table 8-1 Symbols And Definitions

Symbol	Definition	Units
A	Area of cross section of flow	m^2 (ft^2)
AHW	Allowable HW	m (ft)
B	Barrel width	mm or m (in or ft)
D	Culvert diameter or barrel height	mm or m (in or ft)
d	Depth of flow	m (ft)
d_c	Critical depth of flow	m (ft)
g	Acceleration due to gravity	m/s^2 (ft/s^2)
H	Sum of $H_E + H_f + H_o$	m (ft)
H_b	Bend headloss	m (ft)
H_E	Entrance headloss	m (ft)
H_f	Friction headloss	m (ft)
H_L	Total energy losses	m (ft)
H_o	Outlet or exit headloss	m (ft)
H_v	Velocity head	m (ft)
h_o	Hydraulic grade line height above outlet invert	m (ft)
HW	Headwater depth	m (ft)
K_E	Entrance loss coefficient	-
L	Length of culvert	m (ft)
n	Manning's roughness coefficient	-
P	Wetted perimeter	m (ft)
Q	Rate of discharge	m^3/s (ft^3/s)
R	Hydraulic radius (A/P)	m (ft)
S	Slope of culvert	m/m (ft/ft)
TW	Tailwater depth above invert of culvert	m (ft)
V	Mean velocity of flow with barrel full	m/s (ft/s)
V_d	Mean velocity in downstream channel	m/s (ft/s)
V_o	Mean velocity of flow at culvert outlet	m/s (ft/s)
V_u	Mean velocity in upstream channel	m/s (ft/s)
γ	Unit weight of water	N/m^3 (lb/ft^3)
τ	Tractive force	Pa (lb/ft^2)