Culvert Design

An Online Continuing Education Course for Engineers

Course Number: C-2019

Credit: 2 Hours / 2 PDH / 2 CPD

Culvert Design

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Overview

This course presents terms related to culvert design. Based on certain design conditions, we will design a couple of culverts. We will design a circular concrete pipe culvert and a concrete box culvert. We will use nomographs for the design. We will also design rip rap for erosion control.

Specific Knowledge or Skill Attained

This course teaches the following specific knowledge and skills:

- Terms related to culvert design
- Identify the types of flow in a culvert based on inlet or outlet control
- Design culverts from given design conditions
- Design rip rap

Introduction

Culverts are hydraulic structures intended to convey the flow of water from streams or channels through a road or railroad embankment without overflowing the embankment. The main concern in the design of a culvert is the headwater. *Headwater* is the upstream depth of flow. *Tailwater* is the downstream depth of flow. When the flow of water from a stream or channel encounters a culvert, it usually causes an increase in the headwater depth because of the restriction. The velocity upstream of the culvert is very slow but the velocity through the culvert is fast.

Factors that affect the flow of water through a culvert:

- The size (area)
- Entrance geometry
- Length
- Roughness
- Slope
- Tailwater (downstream depth)

Culverts come in many different sizes, materials and shapes:

- Circular concrete pipe (RCP)
- Corrugated metal pipe (CMP)
- Concrete box
- Corrugated metal box
- Oval concrete pipe
- Corrugated metal pipe-arch
- Corrugated metal arch

We will use circular concrete pipe and concrete box culverts. The minimum diameter may be 18 inches or an area of 2.2 square feet in some jurisdictions.

The entrance to the culvert might be:

- Square edge with headwall
- Groove end with headwall
- Groove end projecting
- Mitered to conform to slope
- Beveled ring
- 30°-75° wingwall
- 90° and 15° wingwall
- Skewed headwalls

The length of the culvert affects the friction loss. The longer the culvert, you have more friction loss. The maximum length may be 200 feet for inlet control in some jurisdictions.

Roughness is associated with the Manning Coefficient (n) and used to calculate the head loss due to friction.

- Concrete; n=0.012
- Corrugated metal pipe; n=0.024

Slope, is the slope of the culvert and is usually expressed in ft/ft but may be in percent. The slope might be subcritical or supercritical. *Subcritical flow* is characterized by low velocities, large depths, mild slopes and a Froude number greater than 1.0. The minimum slope may be 1% for inlet control in some jurisdictions. The maximum slope for concrete pipe may be 10% and 14% for CMP in some jurisdictions. The maximum drop may be 10 feet.

The tailwater depth usually depends on the size, shape, slope and resistance to flow or roughness of the stream. Water is lazy and it will try to maintain a normal depth. *Normal depth* is the depth of flow in a channel or culvert when the slope of the water surface and channel bottom is the same and the water depth remains constant. The depth might be above or below the downstream crown. The *crown* is the top inside point or surface of the culvert. The *invert* is the bottom point or surface of the culvert.

The design storm may be the 100-year flood. The (*100-year flood*) is defined as the flood or storm surge having a 1-percent chance of being exceeded in any given year. The headwater depth may be a depth that will allow at least 18-inch freeboard from the lowest point in the embankment. The maximum velocity may be 15 ft/sec with full flow in the culvert. The minimum velocity may be 3 ft/sec when the culvert is flowing partially full based on the 2-year storm.

Erosion control may be required at inlet, outlet and along the channel.

Culverts can operate under:

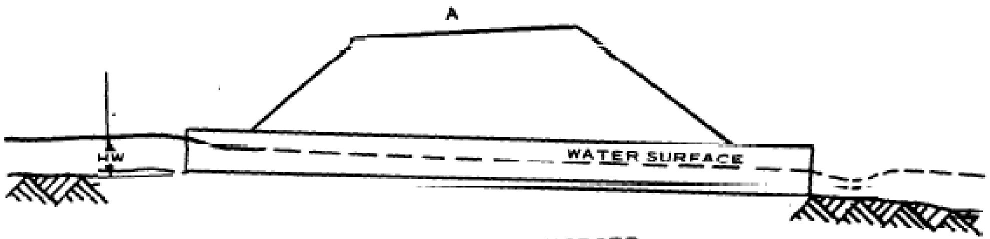
- Inlet control
- Outlet control (may not be allowed in some jurisdictions)

If the culvert is operating on a steep slope it is likely that the entrance geometry will control the headwater and the culvert will be on *inlet control*. Inlet control for culverts may occur as unsubmerged or submerged. For the unsubmerged condition, the culvert invert slope is super-critical and the culvert acts like a weir. For the submerged condition, the culvert doesn't flow full and acts like an orifice.

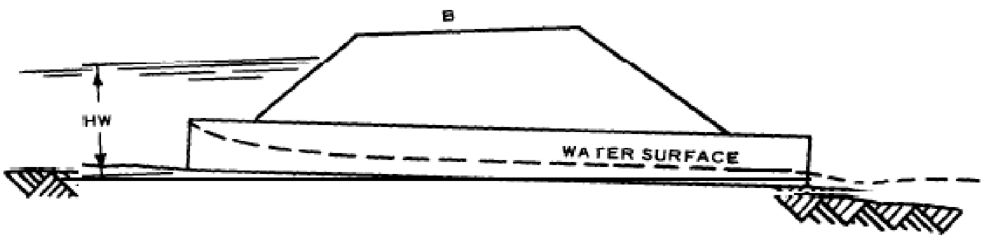
If the culvert is operating on a mild slope, the outlet characteristics will probably control the flow and the culvert will be on *outlet control*. There are three types of outlet control conditions.

- The headwater is submerged and the outlet is submerged with the culvert flowing full.
- The headwater is submerged and the outlet is unsubmerged.
- The headwater is unsubmerged and the outlet is unsubmerged. The culvert slope is sub-critical and the tailwater depth is below the pipe critical depth.

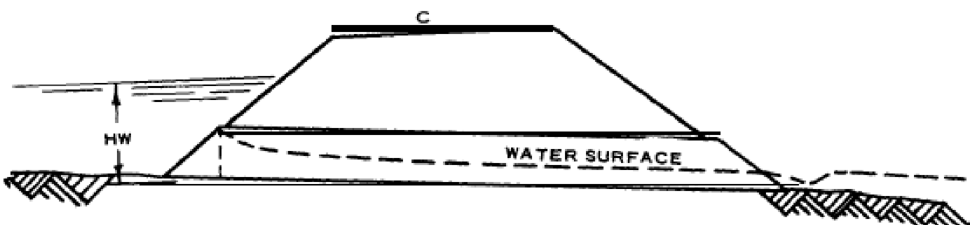
Inlet Control



SQUARE END – UNSUBMERGED

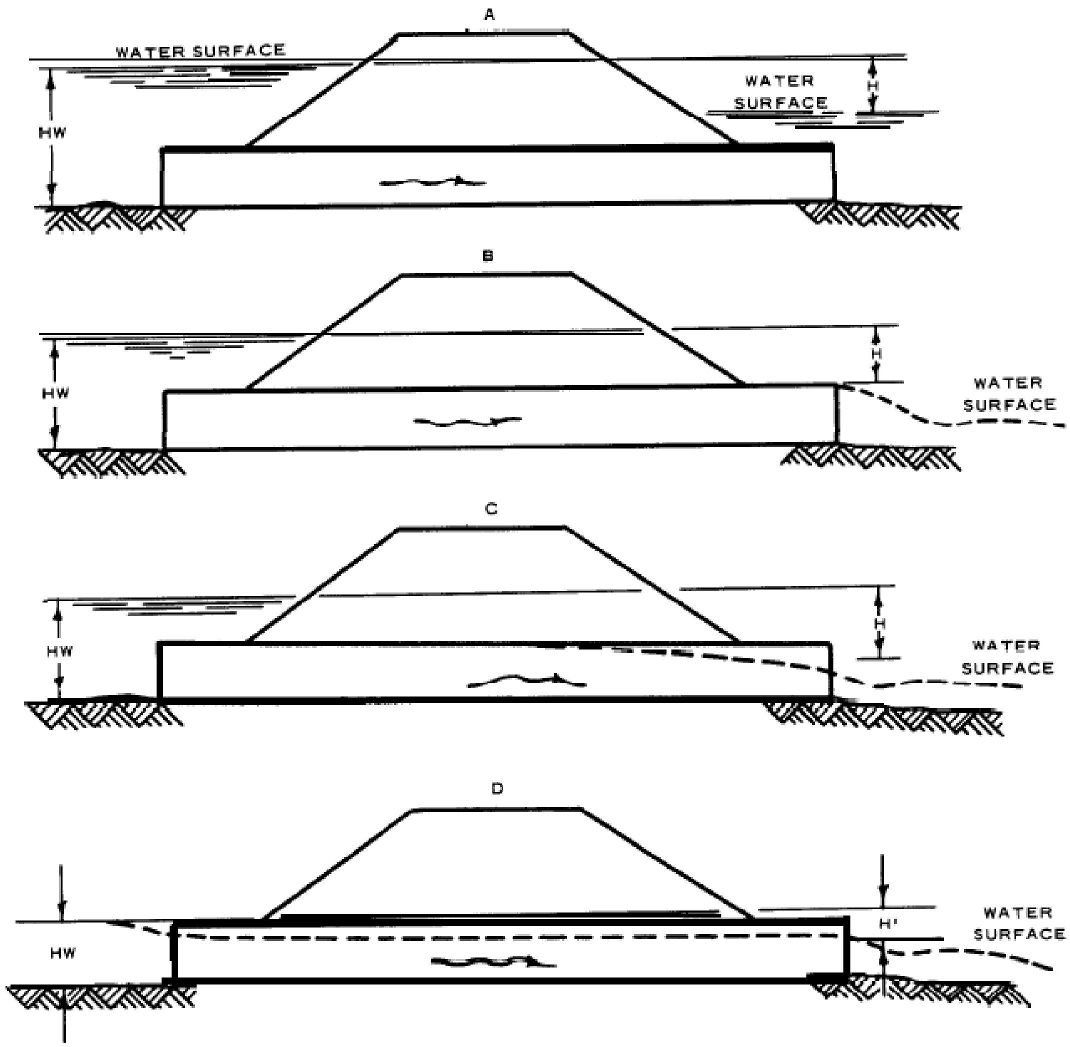


SQUARE END-SUBMERGED



MITERED END – SUBMERGED

Outlet Control



Water Depths

$$TW' = \frac{D_C + D}{2}$$

$$HW = TW + H - Ls$$

$$HW = TW' + H - Ls$$

Use the larger of TW or TW'

HW is headwater
TW is tailwater
D_C is critical depth
D is depth or diameter of culvert
H is head
L is length of culvert
S is slope of culvert

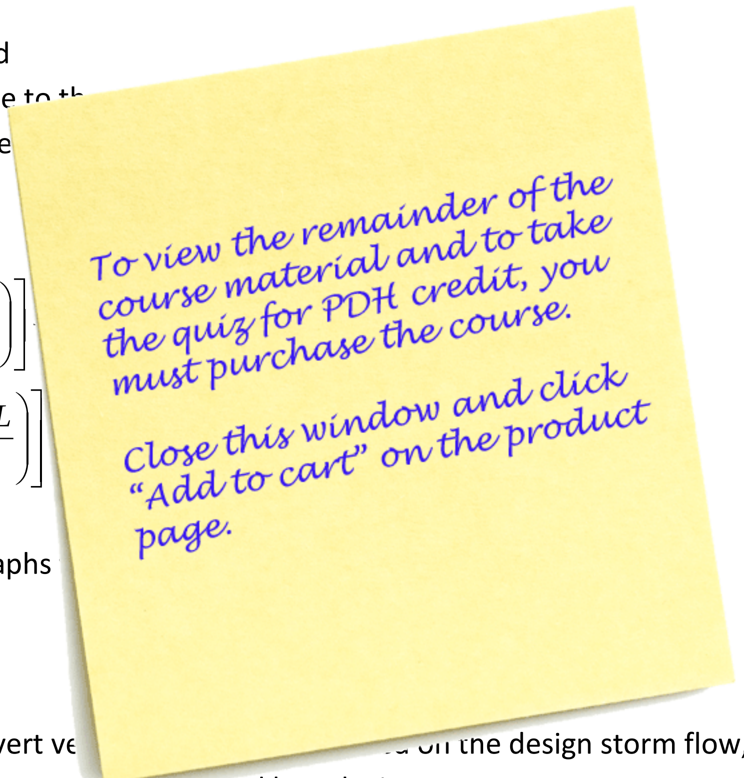
Head; $H = h_v + h_e + h_f$

h_v is the velocity head
h_e is the head loss due to th
h_f is the head loss due

$$H = h_v + h_e + h_f$$

$$H = \left[\frac{v^2}{2g}\right] + \left[K_e\left(\frac{v^2}{2g}\right)\right]$$

$$H = \left[1 + K_e + \left(\frac{29n^2L}{R^{4/3}}\right)\right]$$



You can use nomographs

Design Procedure

1. Assume a culvert ve … on the design storm flow, calculate the required area. Area = … divided by velocity.
2. Determine the shape and size of the culvert from the required area.
3. Based on the entrance condition, use the proper inlet control nomograph to determine HW/D.
4. Calculate the **HW for inlet control** and check to see if it less than the allowable. If it is not, increase the size of the culvert.
5. Based on the entrance loss coefficient (K_e), the culvert length (L), the size and the discharge (Q), determine the head (H) using the proper outlet control nomograph. The **HW for outlet control** is computed by the following equations: