Lesson 10: Culvert and Ditch Design (HM Chpt 3 & 4)

Objectives

- Understand the different types of culverts
- Know the culvert design process for conveyance
- Complete a roadway culvert design using nomographs and determine headwater to diameter ratio (HW/d)
- Discuss the roadway ditch design and review the design criteria

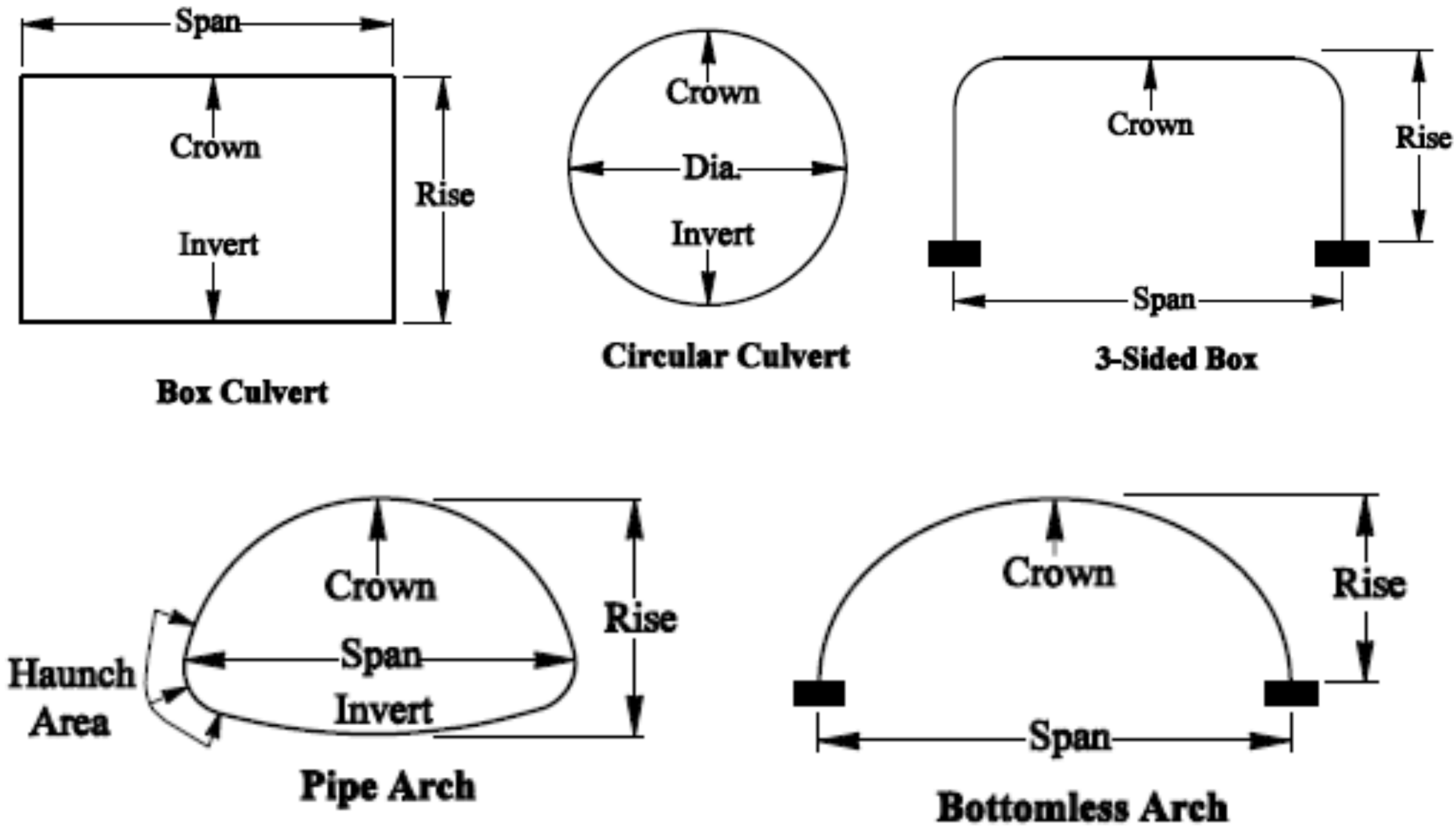
Culvert Design

A culvert is a closed conduit under a roadway or embankment used to maintain flow from a natural channel or drainage ditch. A culvert should convey flow without causing damaging backwater, excessive flow constriction, or excessive outlet velocities.

There are culverts for:
conveyance
fish passage (HM Chapter 3-3.1 and HM Chapter 7)
Temporary conditions (HM Chapter 3-3.1.1)

We will focus on a **conveyance culvert** in this lesson

Culvert Design



Culvert Design

Information and Field Data	Type A&B New Sites	Type B Extending or Replacing
1. Topographic survey	R	O
2. Ground cover description	R	O
3. Stream descriptions & investigation	R	O
4. Ground soil investigation	R	O
5. Streambed profile & alignment	R	O
6. Streambed cross section	R	O
7. Proposed roadway profile & alignment	R	O
8. Proposed roadway cross section	R	O
9[1]. Corrosion Zone, pH, resistivity	R[1]	O[1]
10. Historical information	R	R
11. Fish passage	R	O
12. Unique features	R	O

1. Only required if replacing with dissimilar material.

R=REQUIRED, O=OPTION UNLESS NEW CULVERT

Field Data Requirements for Type A or B Hydraulic Reports

Figure 3-2.3

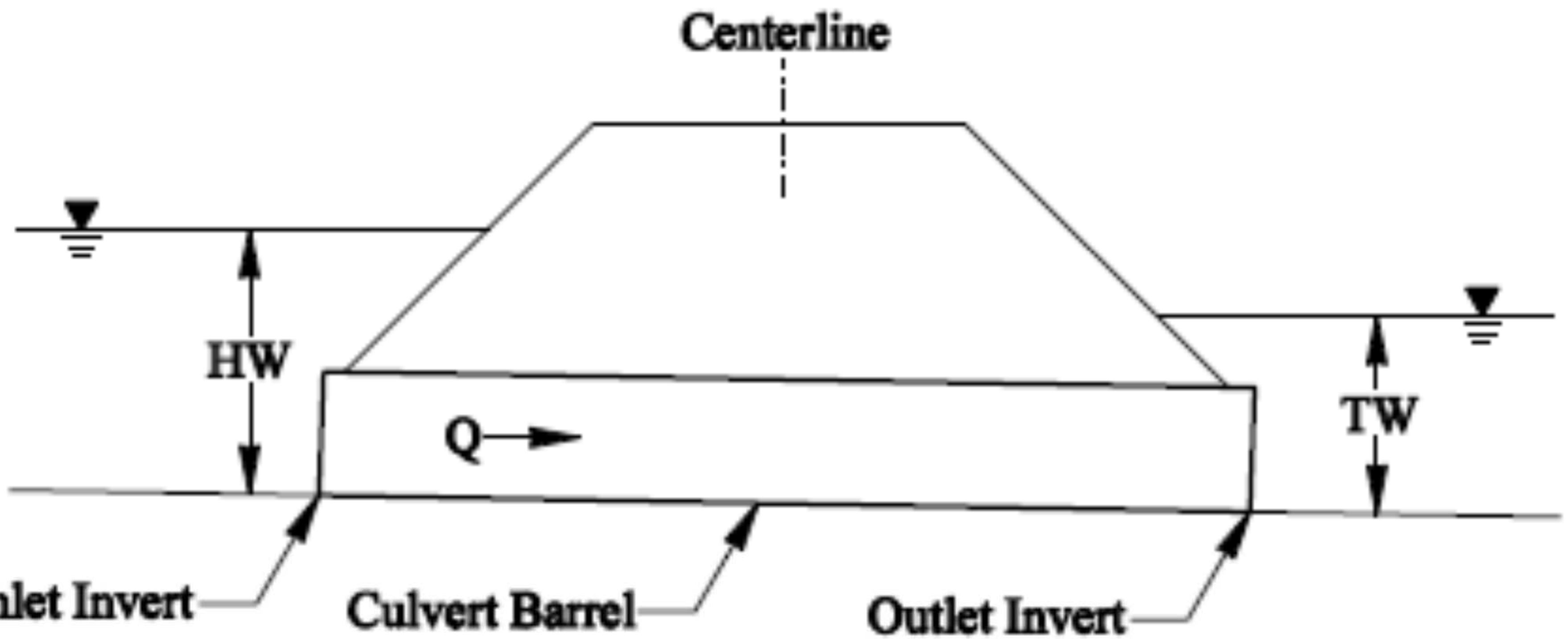
Culvert Design Cheat Sheet

1. Minimum diameter = 18 inches; culverts under roadway approaches have a minimum diameter of 12 inches
2. No minimum velocity
3. No minimum pipe slope; 10% max for concrete, 20% max for corrugated metal and thermoplastic pipe
4. The headwater and tailwater conditions determine which equations (nomographs) are used for design
5. Culverts over 20 feet wide are designed as a bridge (see HM 3-3.1.2) and need a backwater and scour analysis
6. Generally design for the 25-year event and check the 100-year for overtopping of the highway

Culvert Design Cheat Sheet

1. Interstate or major highway - Culvert must pass the 100-year flow with no overtopping of highway
2. Minor state highway - overtopping of highway may be allowed if it's more cost effective than installing more culverts to pass the 100-year flow
3. Bottomless culverts with footings should be designed to pass the 100-year flow with the headwater less than the top of the culvert. The 25-year should allow 1 foot of freeboard for debris flow.
4. Headwater to culvert diameter (HW/D) should be less than or equal to 1.25 though it can be up to 3 to 5 if approved by the Region Hydraulics Engineer or HQ Hydraulics Section under certain conditions.

General Culvert Design Method



Headwater and Tailwater Diagram

Figure 3-3.2.1

General Culvert Design Method

1. Calculate the culvert design flows (Section 3-3.1)
2. Determine the allowable headwater elevation (Section 3-3.2)
3. Determine the tailwater elevation at the design flow (Section 3-3.3)
4. Determine the type of control that exists at the design flow(s), either inlet control or outlet control (Section 3-3.4)
5. Calculate outlet velocities (Section 3-3.5)
6. Provide outlet protection if high velocities

General Culvert Design Method

Project: Example

Designer:

SR:

Date

Hydrologic and Channel Information

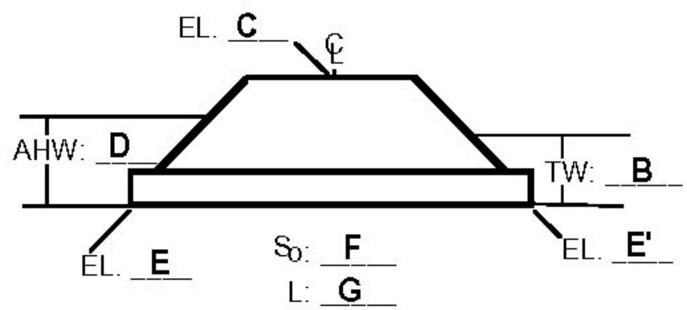
Q_1: A TW_1: B

Q_2: A' TW_2: B'

Q_3: A" TW_3: B"

Sketch

Station:



			Headwater Computations											
			Inlet Control		Outlet Control									
Column 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Culvert Type	Q	Size	$\frac{HW}{D}$	HW	k_e	d_c	$\frac{d_c+D}{2}$	h_o	H	LS_o	HW	Cont. HW	Outlet Vel.	Comments

Summary and Recommendations:

Calculating Headwater

- It is an iterative process depending on if the culvert is flowing with inlet or outlet control (different equations for each condition)
- The headwater elevation will let you know how much ponding is on the upstream side of the culvert and if water might overtop or flow over the highway
- The headwater elevation will also give you an idea if any upstream flooding might occur so you can compare against potential property damage

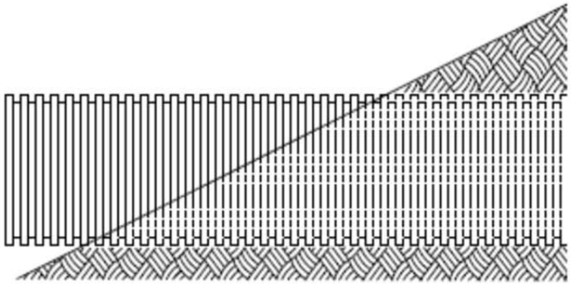
Calculating Headwater

- Assuming the culvert is flowing with inlet control
  - act as an orifice if the inlet is submerged
  - act as a weir if inlet is unsubmerged
- Inlet and outlet control nomographs
  - HM Figures 3-3.4.2A to 3-3.4.2E are nomographs
  - Different pipe types (round, corrugated metal, pipe-arch, structural plate, and box culvert)
  - Use a square or straight edge to draw lines on the nomograph to figure out things

Culvert Design

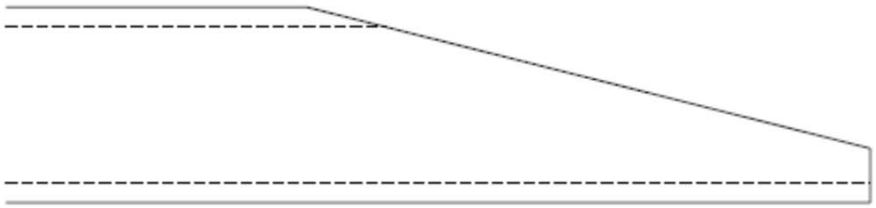
You can improve culvert efficiency by adding culvert end treatments (HM 3-4)

Some end treatments make the culvert safer such as beveled end sections



Projecting End

Figure 3-4.1

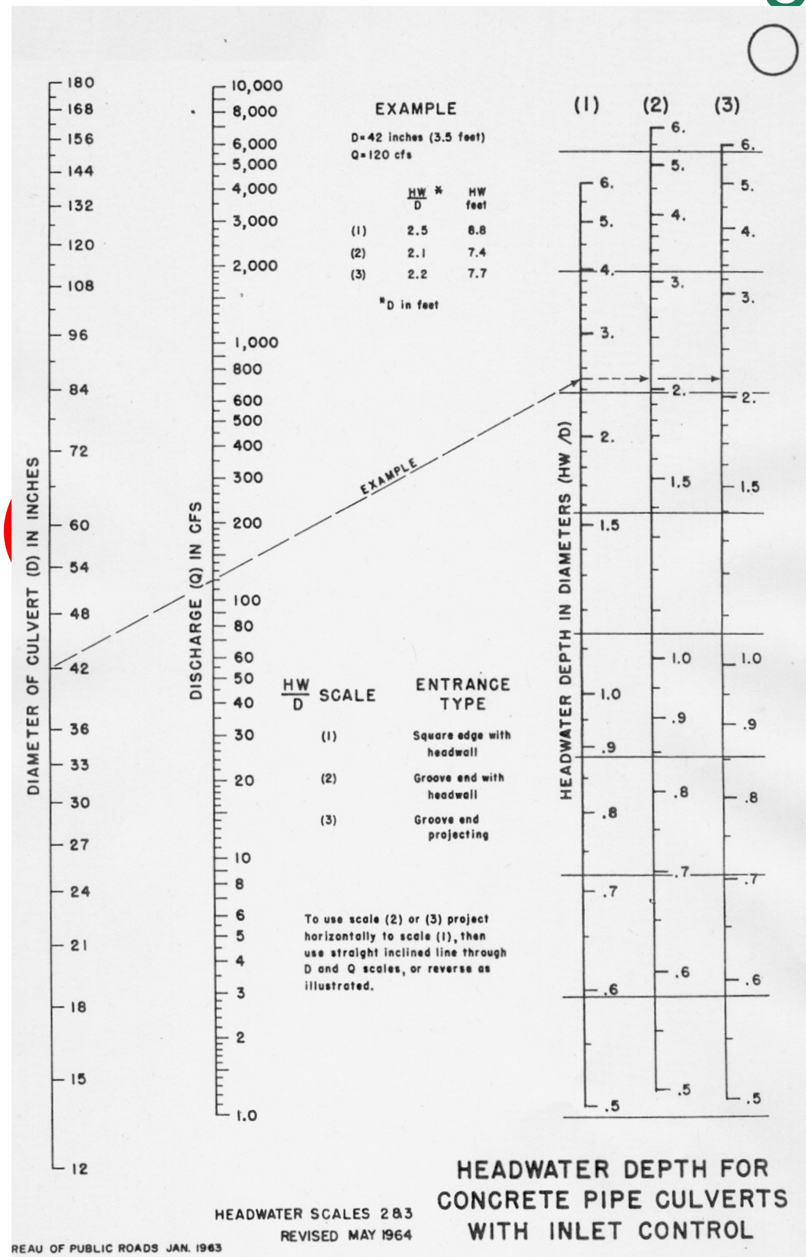


Beveled End Section

Figure 3-4.2

Inlet Control Nomographs

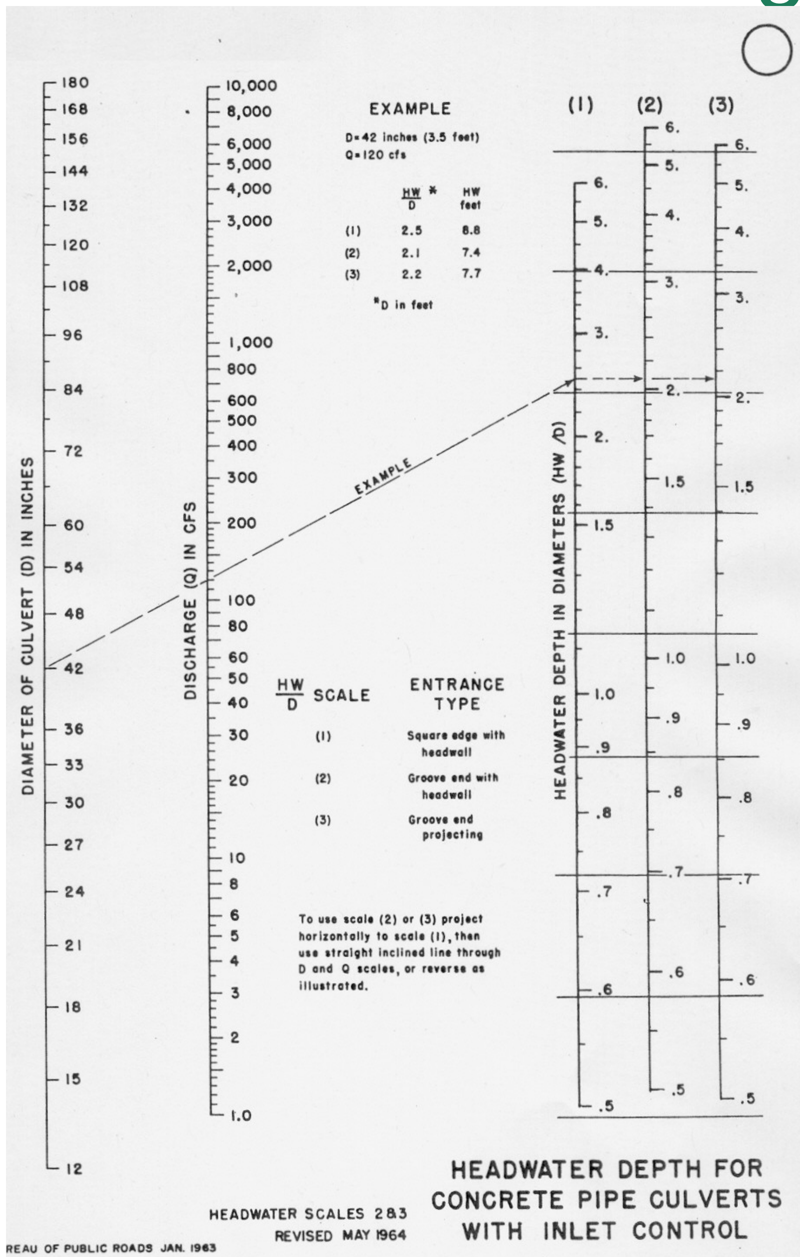
If we have an HW/D of 0.9 with a (3) entrance type and a flow rate of 100 cfs, what size culvert do we need?



(1) Is also the turning line

A 60 inch diameter round concrete culvert is needed since you round up to the next nominal size.

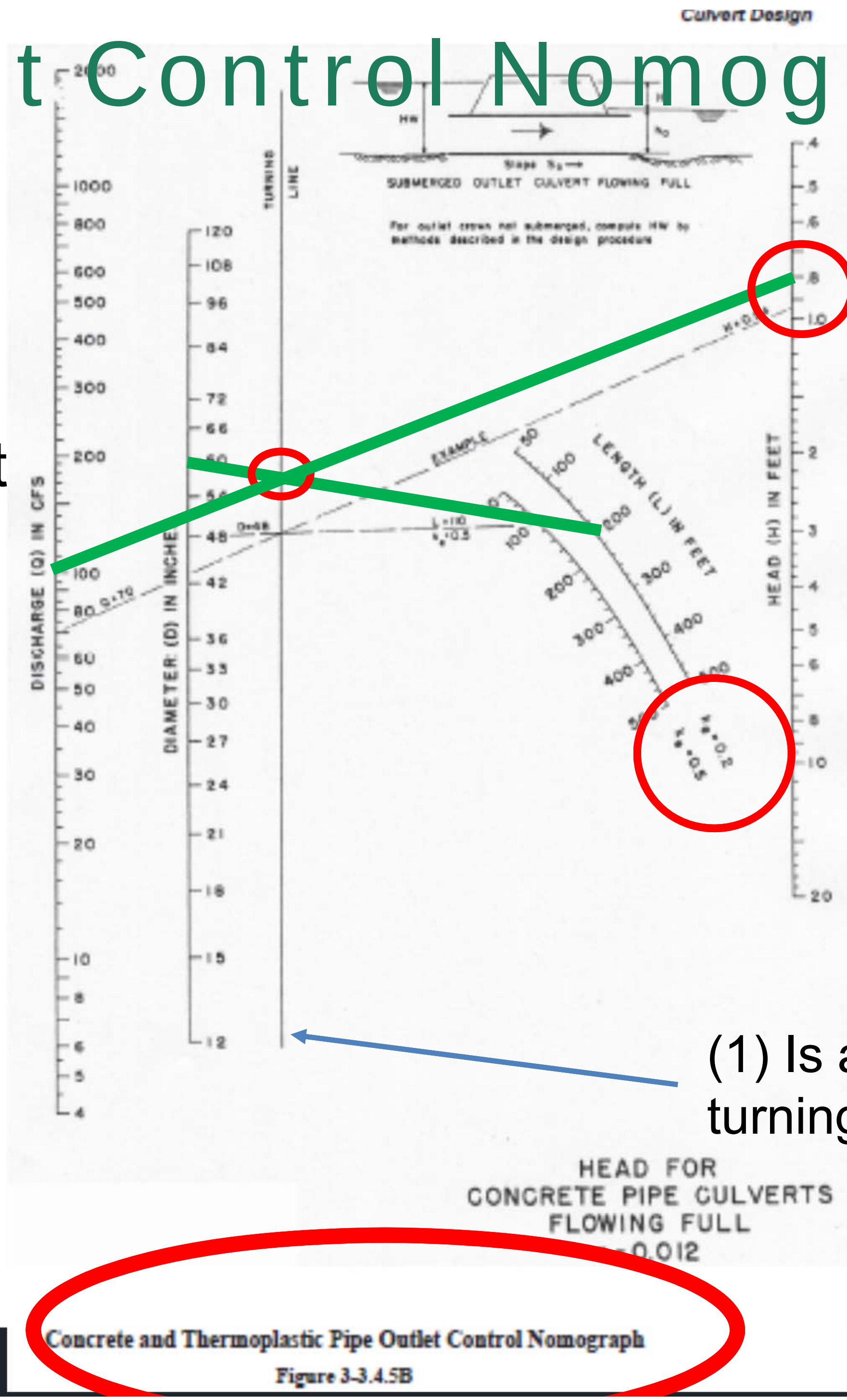
Inlet Control Nomographs



Using a 60 inch diameter culvert, the HW/d is now 0.85.

Outlet Control Nomographs

Given a 200 foot long 60 inch diameter pipe with a flow of 100 cfs, what is the headloss H in feet? Assume a Ke of 0.2.



Concrete and Thermoplastic Pipe Outlet Control Nomograph

Figure 3-3.4.5B

The outlet control nomograph shows a headloss H of 0.8 feet

(1) Is also the turning line

Group Designs

Exercises:

4) Culver Design Example 4 – we will do this now

Open up Culvert Design Example 4 packet and PowerPoint file!

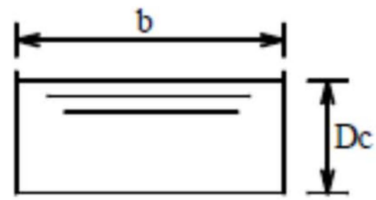
Roadside Drainage Ditch

A roadside drainage ditch primarily conveys roadway runoff. It may also convey offsite flows so the designer should be aware of where water is coming from that shows up in the roadside ditch.

Roadside Drainage Ditch Sections

1. Rectangular Channel

$$D_C = \left[\frac{C_1 Q}{b}\right]^{2/3}$$

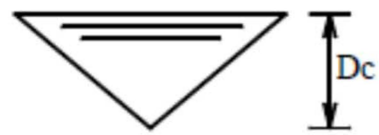


(4-6a)

Where C_1 = is 0.176 (English units) or 0.319 (metric units)

2. Triangular Channel

$$D_C = C_2\left[\frac{Q}{Z_1 + Z_2}\right]^{2/5}$$



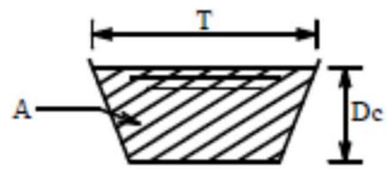
(4-6b)

Where C_2 = is 0.757 (English units) or 0.96 (metric units)

3. Trapezoidal Channel

A trial and error or successive approximations approach is required with equation 4-7a when Dc is unknown:

$$Q = \left[\frac{gA^3}{T}\right]^{1/2}$$



(4-7a)

Where g = is the gravitational constant, 32.2 ft/s^2 (English units) or 9.81 m/s^2 (metric units)

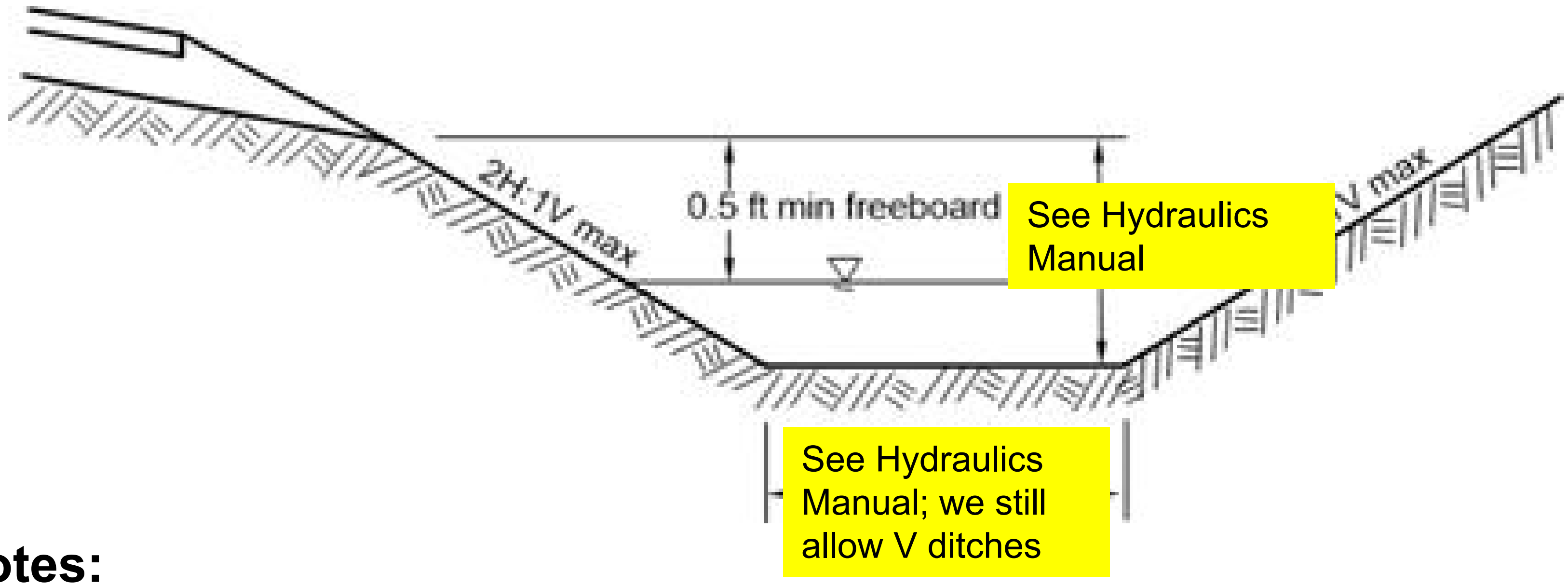
A = can be found using equation 4-5 in Figure 4-2.2.1

Drainage Ditch Cheat Sheet

- Minimum ditch depth = water depth to convey the 10-year design event with a 0.5 foot minimum freeboard between the bottom of roadway subgrade to the 10-year design water surface elevation
- Maximum flow velocity of 5 feet per second and longitudinal ditch slope for grass lined ditches
- Trapezoidal section is preferred by “V” ditch is OK too
- Maximum ditch side slopes of 2:1
- Ditches are not biofiltration swales
- Make sure the 10 year water surface elevation is not equal to the critical depth
  - If the depth of flow is less than the critical depth, a hydraulic jump may occur

Roadside Drainage Ditch Sections

WSDOT Design Manual 2017
Exhibit 1239-4 Drainage Ditch Details



Notes:

•Freeboard is the vertical distance from the bottom of base course to the 10-year storm water surface (see the Hydraulics Manual for more information.)

•Coordinate ditch design with region Hydraulics

•See Design Manual Errata sheet for ditch depth and width changes, may not be in the Design Manual until next year

Drainage Ditch Design Method

1. Calculate the ditch design flows
2. Select the type of ditch section ("V" or trapezoid)
3. Determine the depth of flow in the ditch using Manning's equation
4. Determine the critical depth and make sure the 10-year flow depth is not equal to the critical depth
5. Determine the roadway subgrade elevation to ensure minimum freeboard of 0.5 feet.
6. Determine ditch velocity for to determine if grass is ok or if another channel lining is needed