8.10 Design Procedure

The following design procedure provides a convenient and organized method for designing culverts for a constant discharge, considering inlet and outlet control. (The procedure does not address the effect of storage which is discussed in Chapter 10, Storage Facilities.)

- The designer should be familiar with all the equations in Section 8.6 before using these procedures.
- Following the design method without an understanding of culvert hydraulics can result in an inadequate, unsafe, or costly structure.
- Computation forms have been provided in Appendices C through G to use as a guide. They contain blocks for the project description, designer's identification, hydrologic data, culvert dimensions and elevations, trial culvert description, inlet and outlet control HW, culvert barrel selected and comments. The hydraulic control and its elevation should be included.
- Steps 7 through 12 can be accomplished using computer programs.

Step 1 Assemble Site Data And Project File

a. See Data Chapter — The minimum data are:
   - USGS, site and location maps
   - embankment cross section
   - roadway profile
   - photographs
   - field visit (sediment, debris)
   - design data at nearby structures
b. Studies by other agencies including:
   - small dams — NRCS, USCE, ConnDEP
   - floodplain — NRCS, USCE, FEMA, USGS, NOAA, ConnDEP
   - storm drain — local or private
c. Environmental constraints including:
   - commitments contained in review documents
   - fish migration
   - wetland impacts
d. Design criteria
   - review Section 8.3 for applicable criteria
   - prepare risk assessment or analysis

Step 2 Determine Hydrology

a. See Chapter 6, Hydrology.
b. Minimum data are drainage area map and a discharge-frequency plot.

Step 3 Analyze Downstream Channel

a. See Chapter 7, Channels.
b. Minimum data are cross section of channel and the rating curve for channel.

Step 4 Summarize Data On Design Form

a. See Appendices C through G.
b. Data from steps 1-3.

Step 5 Select Design Discharge Q_d

a. See Section 8.3 Design Criteria.
b. Determine flood frequency from criteria.
c. Determine Q from discharge-frequency plot (step 2).
d. Divide Q by the number of barrels.

Step 6 Select Design Alternative

a. See Section 8.4 Design Features.
b. Choose culvert material, shape, size and entrance type.

Step 7 Determine Inlet Control Headwater Depth (HW_i)

Use the inlet control nomograph (HDS 5).

a. Locate the size or height on the scale.
b. Locate the discharge.
   - For a circular shape use discharge.
   - For a box shape use Q per foot of width.
c. Locate HW/D ratio.
   - Use a straight edge.
   - Extend a straight line from the culvert size through the flow rate.
   - Mark the first HW/D scale. Extend a horizontal line to the desired scale and read HW/D.
d. Calculate headwater depth (HW_i).
   - Multiply HW/D by D to obtain HW to energy gradeline.
   - Neglecting the approach velocity HW_i = HW.
   - Including the approach velocity HW_i = HW - approach velocity head.

Step 8 Determine Outlet Control Headwater Depth At Inlet (HW_{oi})

a. Calculate the tailwater depth (TW) using the design flow rate and normal depth (single section) or using a water surface profile. See Section 8.3.5 and 8.3.6.
b. Calculate critical depth (d_c) using appropriate chart in HDS 5.
   - Locate flow rate and read d_c.
   - d_c cannot exceed D.
   - If $d_c > 0.9D$, consult Handbook of Hydraulics (King and Brater) for a more accurate d_c, if needed, since curves are truncated where they converge.
c. Calculate $(d_c + D)/2$.
d. Determine (h_o).
   h_o = the larger of TW or $(d_c + D/2)$.

e. Determine (K_E).
- Entrance loss coefficient from Table 2 in the Appendix B.

f. Determine losses through the culvert barrel (H).
- Use nomograph HDS5 or equation 8.5 or 8.6 if outside range.
- Locate appropriate K_E scale.
- Locate culvert length (L) or (L_1):
  - use (L) if Manning's n matches the n value of the culvert and
  - use (L_1) to adjust for a different culvert n value.

$$\mathbf{L_1 = L(n_1/n)^2} \qquad \textbf{(8.10)}$$

Where:
L_1 = adjusted culvert length, m (ft)
L = actual culvert length, m (ft)
n_1 = desired Manning n value
n = Manning n value on chart

- Mark point on turning line:
  - use a straight edge and
  - connect size with the length.
- Read (H):
  - use a straight edge,
  - connect Q and turning point and
  - read (H) on Head Loss scale.

g. Calculate outlet control headwater (HW_{oi}).
- Use equation 8.18, if V_u and V_d are neglected:

$$\mathbf{HW_{oi} = H + h_o - S_oL} \qquad \textbf{(8.11)}$$

- use equation 8.1, 8.4c and 8.6 to include V_u and V_d.
- If HW_{oi} is less than 1.2D and control is outlet control:
  - the barrel may flow partly full,
  - the approximate method of using the greater of tailwater or $(d_c + D)/2$ may not be applicable,
  - backwater calculations should be used to check the result and
  - if the headwater depth falls below 0.75D, the approximate nomograph method shall not be used.

Step 9 Determine Controlling Headwater (HW_c)

- Compare HW_i and HW_{oi}, use the higher.

Step 10 <u>Compute Discharge Over The Roadway</u> (Q_r) (If applicable)

a. Calculate depth above the roadway (HW_r).
   $HWr = HW_c - HW_{ov}$
   HW_{ov} = height of road above inlet invert
b. If $HW_r \leq 0$, $Q_r = 0$
   If $HW_r > 0$, determine C_d from HDS5
c. Determine length of roadway crest (L).
d. Calculate Q_r using equation 8.9.

Step 11 <u>Compute Total Discharge</u> (Q_t) (If applicable)

$$\mathbf{Q_t = Q_d + Q_r} \qquad \textbf{(8.12)}$$

Step 12 <u>Calculate Outlet Velocity</u> (V_o) <u>And Depth</u> (d_n)

If inlet control is the controlling headwater:
a. Calculate flow depth at culvert exit.
   • use normal depth (d_n) or
   • use water surface profile
b. Calculate flow area (A).
c. Calculate exit velocity (V_o) = Q/A.

If outlet control is the controlling headwater:
a. Calculate flow depth at culvert exit.
   • use (d_c) if $d_c > TW$
   • use (TW) if $d_c < TW < D$
   • use (D) if $D < TW$
b. Calculate flow area (A).
c. Calculate exit velocity (V_o) = Q/A.

Step 13 <u>Review Results</u>

Compare alternative design with constraints and assumptions. If any of the following are exceeded, repeat steps 5 through 12:
• the barrel must have adequate cover,
• the length shall be close to the approximate length,
• the headwalls and wingwalls must fit site,
• the allowable headwater shall not be exceeded and
• the allowable overtopping flood frequency shall not be exceeded.

Step 14 Plot Performance Curve

a. Repeat steps 6 through 12 with a range of discharges.
b. Use the following upper limit for discharge:
- Q_{100} if $Q_o \leq Q_{100}$
- Q_{500} if $Q_o > Q_{100}$
- Q_{max} if no overtopping is possible
- Q_{max} = largest flood that can be estimated

Step 15 Related Designs

Consider the following options.
- Tapered inlets if culvert is in inlet control and has limited available headwater. (See Section 8.11.)
- Flow routing if a large upstream headwater pool exists (See Section 8.10).
- Energy dissipators or other forms of outlet protection if V_o is larger than the normal V in the downstream channel (See Section 8.7).
- Fish passage (See Section 8.5.5).
- Where practicable, some means shall be provided for personnel and equipment access to facilitate maintenance.
- Culverts shall be regularly inspected and maintained.

Step 16 Documentation

- See Section 8.3.12 and Chapter 1, Section 1.6
- Prepare report and file with background information.