Culvert Hydraulics

Culverts carry flow across road crossing and detention pond outlets. We typically solve for:

1. Size, shape, and number of these culverts to handle a certain discharge.
2. Flow capacity for a water surface upstream constraints.
3. Water level upstream.

The outlet control and inlet control analysis should be performed. The controlling headwater depth is the larger value of the two analyses.

Outlet control: Head Water = f (H₁, friction + entrance and exit minor losses)
Tailwater condition is important in the culvert system.
Inlet control: HW = f(Entrance losses)
Outlet Control

\[ \text{HW}_o + \frac{V_u^2}{2g} = \text{TW} + \frac{V_d^2}{2g} + H_L \]

\( H_L \) = friction losses + Entrance + Exit minor losses. If velocity heads upstream and downstream are neglected then:

\[ \text{HW}_o = \text{TW} + H_L \]

Where:

\( H_L = H_f + H_E + H_o \)

and \( H_E = \) Entrance, and \( H_O = \) exit losses

\( H_f = \) Manning’s Equation for GVF (short reach):

\[ H_E = k_e \left( \frac{V^2}{2g} \right) \]

\( k_e = \) entrance loss coefficient

\( V = \) flow velocity in barrel

The smoother the transition from channel or point into the culvert, the lower the \( k_e \) value.

\[ H_o = k_o \left[ \frac{V^2}{2g} - \frac{V_d^2}{2g} \right] \]

\( k_o = 1 \)

\( V_d = 0 \) in many cases

Realize that outlet control assumes flow in barrel is full and velocity inside the barrel is constant.
Inlet control hydraulics

\( H_f \) and \( H_o \) are not significant. Critical depth in this type of hydraulics occur at or near entrance. Flows downstream of the inlet are supercritical. The hydraulic profile and outlet velocities are determined using frontwater GVF techniques discussed in the GVF module.

Three types of inlet control hydraulics:

- **Submerged flow (orifice flow)**
  \[ Q = C A \sqrt{2gH}, \quad C = \text{orifice coefficient} \]

- **Unsubmerged flow (weir flow)**
  \[ Q = C L H^{3/2}, \quad C = \text{weir coefficient (m}^{3/2}/\text{s}) \]

- **Transitional flow**

**Unsubmerged flow**:

\[
\frac{H_W}{D} = \frac{H_c}{D} + K \left( \frac{Q}{AD^{0.5}} \right)^M - 0.5 S
\]

\( H_W \) = headwater depth above c.s. invert (ft)
\( D \) = interior depth (height) of the culvert barrel (ft)
\( H_c \) = specific head at critical depth, \( y_c + \frac{V_c^2}{2g} \) (ft)

**Submerged flow**:

\[
\frac{H_w}{D} = C \left( \frac{Q}{AD^{0.5}} \right)^2 + Y - 0.5 S
\]

Where:
\( Q \) = discharge (ft\(^2\)/s)
\( A \) = flow area (ft\(^2\))
\( S \) = slope of culvert
\( C, Y, K, M \) = constants from table