Lecture eight

Hydraulic Design of Culvert

1- Definetion:

Culverts are common hydraulic structures.As such highway design manuals are devoted to the wide range of possible culverts. A culvert is a pipe or box that is located under a roadway,embankment ,or service area to allow the passage of storm runoff While culverts are often circular pipes made of either concrete or corrugated metal, other shapes including elliptical and arch pipes and rectangular box culvert are widely used. A culvert consists of an inlet structure, a pipe or box, and an outlet structure.

2- Culvert classification

2.1-The shape: circular (pipe), rectangular (box), elliptical…

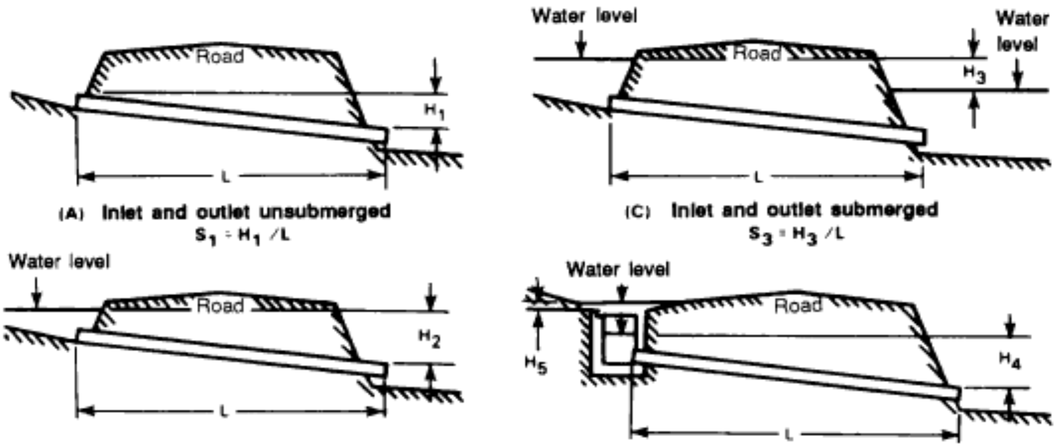
2.2- Inlet and outlet flow condition

2.2.1-Un-submerged inlet & outlet.

Lecture eight

2.2.2-Submerged inlet,um-submerged outlet.

2.2.3-Submerged inlet &outlet.



(A) Inlet and outlet unsubmerged
$S_1 = H_1 / L$

(B) Inlet submerged and outlet unsubmerged
$S_2 = H_2 / L$

(C) Inlet and outlet submerged
$S_3 = H_3 / L$

(D) Drop inlet culvert - inlet submerged and outlet unsubmerged
$S_4 = H_4 / L$ H_5 = head on grate

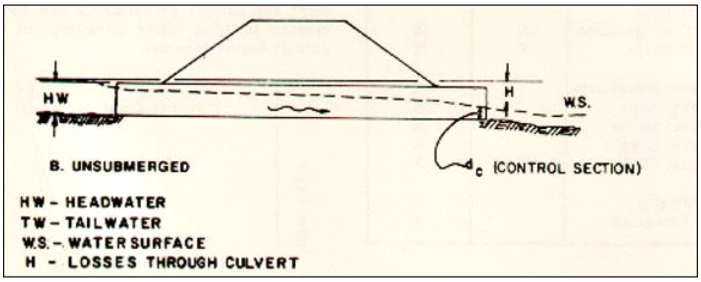
3-Culvert design:

Culverts are designed for the peak flow rate of the design storm. The peak flow is obtained from a U.H.at the culvert site.

Other factors affect the culvert design:

3.1-Head water depth: it is the invert water depth at the culvert inlet.

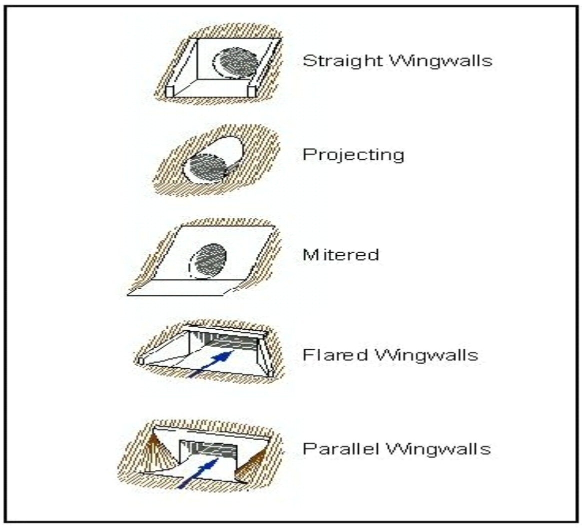
3.2-Tail water :it is the depth of water above the culvert outlet invert as the water flow out of the culvert.



Lecture eight

Headwater depth (Inlet control) process:

Many factors affect the performance of a culvert under inlet control:



a-Inlet shape.

b-Inlet configuration.

c-Inlet area.

d -Headwater depth.

The relation between H.W. and flow is:

-For un-submerged condition:

$$\frac{HWi}{D} = \frac{Hc}{D} + k \frac{Q}{(AD^{0.5})^M} - 0.5*S$$

$$\frac{HWi}{D} = k \frac{Q}{(AD^{0.5})^M}$$

-For submerged condition:

$$\frac{HWi}{D} == c\left(\frac{Q}{(AD^{0.5})^M}\right)^2 + Y - 0.5*S$$

HWi: headwater depth.

D:height of culvert.

Hc: specific head @ critical depth($dc+vc^2/2g$)

Dc: critical depth.

Lecture eight

Q:discharge.

A:barrel cross sec. area.

S: culvert slope.

K, M, C, and Y constants depend on the shape, material, and cross-sec.)

V: velocity.

Vc: critical velocity.

Examples

Ex.1

Determine the required inlet invert elevation for 6*5 ft^2 box culvert under inlet control if the peak discharge is 300 ft^3/s, design HW elevation. ELd=250.00 ft, stream bed invert elevation. ELs=245.00 ft?

.from fig. 3 select points A& B

A: high of box and $B = \frac{Q}{NB} = \frac{250}{5} =$ 50 $ft^3/s/ft$.

. For points, A&B draw a straight line, then extend it to find HW/D

HW/D=1.4

.the required headwater =1.4 *5 =7 ft

When velocity is not neglected HWi= HW –$V^2/2g$

When it is neglected vHWi= 7 ft.

.the required depression HWd = ELh -ELs

250 -245 =5 ft

HWi- HWd =7 - 5 = 2 ft. (+,0,_)when (0 or _ use 0)

Invert ele.=245 – 2 =243 ft.

Lecture eight

Tailwater depth (outlet control) process:

When the barrel is capable of transporting as much flow as the inlet opening, then the design will be under outlet control.

The factors that affect the outlet control will be:

a-Inlet shape.

b-Inlet configuration.

c-Inlet area.

d-Headwater Depth. In addition:

e-Tailwater depth.

Culvert characteristics (roughness, slope & length)

For the outlet, there is a hydraulic analysis of flow based on the energy balance

$H_L + He + H_f + H_E + H_b + H_j + H_g$

L: total loss.

E: energy loss at the entrance.

F: friction loss.

E:energy loss at exit.

B:bend loss.

J:loss at a junction.

G:loss at grates.

I we neglect some losses

$H_L = (1+K_e + \frac{2gn^{2L}}{R^{1.33}})\ v^2/\ 2g$

The ke factor is based on various configurations(from the table).

R: hydraulic radius.

L: length.

V:velocity.

Ex.2

Determine the HW elevation. For a last example, if the culvert is fully under outlet control, the tailwater depth above the invert = 6.5 ft, the length of the culvert =250 ft, and the natural stream slope @ 2%, ?K_e=0.2

From chart B=6 ft find the critical depth

Q/B dc = 4.26 ft or

$$Dc = 0.315\sqrt[3]{\left(\frac{Q}{B}\right)^2}$$

H_{TW} is the depth from the outlet to the hydraulic grade line $= \frac{dc+D}{2}$

Or tail water depth TW whichever is greater.

TW =6.5 ft.

H_{TW}= 4.63 ft

Locate the culvert's size ,length & ke at A and B , then draw a straight line from A to B and locate the intersection C .

Locate D on the discharge scale and draw a straight line from C to D, extend this line to head loss scale at E .

The required outlet headwater ELh is

ELh = EL in+ H +H $_{TW}$

EL inv.: invert elevation. At outlet.

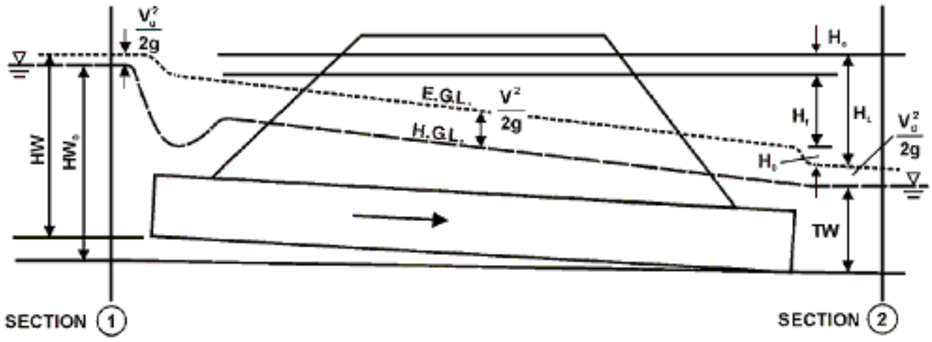
ELhnv. =243 – 0.02 * 250 =238 ft.

EL h =238 + 3.4 +6.5 =247.9 ft .

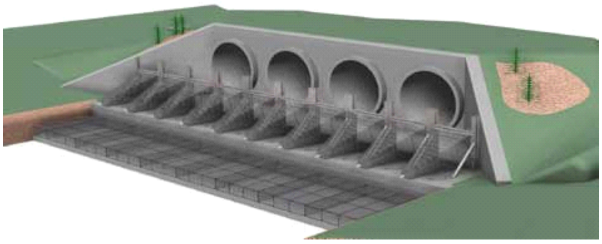
247.9 < 250

∴ Outlet HW < design HW elevation.

Lecture eight



4-Circular Culvert Design:



4.1-For un-submerged inlet and outlet:

Manning's equation is used to estimate the diameter of the circular pipe culvert.

$Q=\frac{1.49}{n} A R^{2/3}/ S^{1/2}$

$D= 1.33(Qn)^{3/8} /S^{3/16}$

Example:

The discharge between the inlet and outlet is 5.7 cfs. Assume the pipe has roughness coef.. 0.014, slope 0.36% and the flow is full, calculate the diameter.

$D= \left(\frac{2.15\, Q\, n}{S^{0.5}}\right)^{0.375} = \left(\frac{2.15 * 5.7 * 0.014}{0.0036^{0.5}}\right)^{0.375}$

=1.48 ft.

$V = Q/A = \frac{5.7}{\pi\, 1.5^2/4}$ =3.2 ft/s.

4.2-Submerged inlet ,un-submerged outlet:

In this case, the system can be treated as an orifice.

$Q = Cd\ A\ \sqrt{2gh}$……………….1

$H+\frac{D}{2} = H$ ………………………2

Substituting 2 in 1 yields

$$Q = Cd \frac{\pi D^2}{4} \sqrt{2g(H - 0.5D)}$$

(……h……), Solving for D

$$D^5 - 2\, hi\, D^4 + \frac{16\, Q^2}{cd^2\, g\, \pi^2} = 0$$

4.3-Submerged inlet and outlet:

This case is treated as a special case where the depth of flow at the outlet equals the pipe diameter ,thus the energy equation between points on the headwater and tail water surface is

$$\frac{p1}{\gamma} + \frac{v1^2}{2g} + z_1 - hL = \frac{p2}{\gamma} + \frac{v2^2}{2g} + z_2$$

For large area v1 &v2 are neglected

Hi = pi/γ

Zi = S L

.h1+0 + SL – hL = h2 + 0 + 0

.hL = h1 – h2 + SL

After using Manning's equation and continuity equation the equation become:.$h_1 - h_2 + SL = (Kin + Kex)\left(\frac{0.0252\, Q^2}{D^4}\right) + \frac{4.637\, n^2\, Q^2 L}{D^{16/3}}$

Kin=0.5 , Kex=1

Example: A new culvert is being discharged , ponding cannot exceed 8 ft above the pipe invert inlet,at the outlet,the maximum pond of 5 ft is permitted. Mannings n = 0.013, length = 110 ft ,S =0.02 ft/ft,Q= 82 cfs, calculate the diameter?

$8 - 5 + 0.02\,(110) = (0.5 + 1)\left(\frac{0.0252(82)^2}{D^4} + \frac{4.637(0.013)^2)(82)^2(110}{D^{16/3}}\right.$, D=.....