BIE 5300/6300 Assignment #11
Siphon Spillway Design

7 Dec 04 (due 10 Dec 04)

Show your calculations in an organized, neat format. Indicate any assumptions and or relevant comments.

Given:

- An overflow spillway needs to be designed for a location along a canal.
- The concrete-lined canal has a maximum flow rate of 4.0 m^3/s.
- The concrete lining depth is 2.3 m, and the depth to the top of the earthen berms is 2.5 m.
- The canal bed elevation at this location is 239 m above mean sea level (msl).
- The maximum water surface elevation in the open drainage channel on the downhill side of the canal at this location is 238.5 m.
- The canal cross section is trapezoidal in shape.
- The canal bed width is 1.65 m, and the inverse side slopes are 1.5.
- The longitudinal bed slope is 0.000284 m/m.

Required:

1. Use metric units for the design.
2. Use the Chezy equation with C = 60.
3. Design a siphon spillway for the given conditions.
4. Assume a C_d value of 0.67 when applying the orifice equation for the siphon spillway capacity.
5. Refer to section 4-14 to 4-16 of the USBR book, and to the lecture notes.
6. Determine the following:

    a. What is the depth of flow in the canal at the maximum discharge? Take this as FSL (full supply level).
    b. What siphon spillway crest elevation (referenced to msl) do you recommend?
    c. What is the estimated available head, H, across the siphon spillway?
    d. Is $H < h_{atm}$, where h_{atm} is mean atmospheric pressure head?
    e. What are the barrel dimensions (b and D), given a rectangular barrel section (according to USBR guidelines, $D \geq 2.0$ ft)?
    f. What are R_{CL}, R_C and R_S?
    g. What is the estimated full-pipe unit discharge, q, in the siphon spillway?
    h. What is the estimated maximum unit discharge through the siphon spillway ("vortex" equation)? Make sure this is more than the discharge calculated from the "orifice equation," otherwise the design is not acceptable.
    i. What is the minimum required vent (siphon breaker) pipe inside diameter?
    j. What is the required height of the outlet deflector sill (1.5D)?

k. What is the required height of the outlet ceiling, h_2?
l. What is the hydraulic seal in the canal, above the top of the opening to the siphon spillway, on the downhill canal back at Q_{max}? Is it greater than the minimum values of $1.5h_v$ +0.5 ft, or 1.0 ft (whichever is greater)?
m. Create a side-view drawing of your design, with Fig. 4-17 as a model.

Solution:

a) *Normal depth in the canal*

By iteration, the normal depth is found to be $\mathbf{h_n = 1.289}$ m at 4.0 m^3/s, with C = 60. This is taken to be the full supply level (FSL).

b) *Elevation of siphon spillway crest*

By USBR design guidelines, the crest elevation is 0.2 ft (0.061 m) above FSL. Then, the crest elevation is: 239.000 + 1.289 + 0.061 = **240.350 m** above msl.

c) *Available head*

The available head, H, is measured from the crest elevation to the downstream water surface elevation (see Fig. 4-17). Taking the maximum downstream water surface elevation: H = 240.350 – 238.500 = **1.850 m**.

d) *Is $H < h_{atm}$?*

The mean atmospheric pressure head at an elevation of 239 m is estimated as:

$$h_{atm} = 10.3 - 0.00105(239.00) = 10.05 \text{ m}$$

Then, $H < h_{atm}$, which is as required for siphonic operation.

e) *Barrel dimensions*

Try the minimum recommended barrel height, **D = 2.0 ft (0.610 m)**. The width, b, will be determined below.

f) *R_{CL}, R_C and R_S*

Use the recommended ratio $R_{CL}/D = 2.0$. Then, $R_{CL} = 2.0(0.610) = 1.22$ m. $R_C = R_{CL} - ½D = 0.915$ m. And, $R_S = R_{CL} + ½D = 1.525$ m.

g) *Full pipe unit discharge*

Use the orifice equation with $C_d = 0.67$:

$$q = C_d D\sqrt{2gH} = 0.67(0.610)\sqrt{2(9.81)(1.850)} = 2.46 \text{ m}^2/\text{s}$$

h) Maximum unit discharge

This is based on the "vortex" equation:

$$\begin{aligned} q_{max} &= R_C\sqrt{2g(0.7h)}\ln\left(\frac{R_S}{R_C}\right) \\ &= 0.915\sqrt{2(9.81)(0.7)(10.05)}\ln\left(\frac{1.525}{0.915}\right) \\ &= 5.49 \text{ m}^2/\text{s} \end{aligned}$$

Thus, $q_{max} > q$, as required. Then, the required barrel width is:

$$b = \frac{Q}{q} = \frac{4.00}{2.46} = 1.63 \text{ m}$$

Finally, the area of the barrel is: A = bD = (1.63)(0.61) = 0.992 m^2.

i) Siphon breaker diameter

This is taken as 1/24th of the barrel area, or 0.992/24 = 0.0413 m^2. For a circular pipe cross section, this give an inside **diameter of 0.229 m**. Round up to the nearest available steel pipe size.

j) Outlet deflector sill height

This height is 1.5D = 1.5(0.61) = **0.915 m**.

k) Outlet ceiling height

This is equal to:

$$h_2 = 1.5D + E_{critical} + 0.3048$$

Critical depth for the design discharge (4.0 m^3/s) is:

$$h_c = \sqrt[3]{\frac{(Q/b)^2}{g}} = \sqrt[3]{\frac{(4.00/1.63)^2}{9.81}} = 0.850 \text{ m}$$

The velocity at critical depth would be:

$$V_c = \frac{Q}{bh_c} = \frac{4.00}{(1.63)(0.850)} = 2.89 \text{ m/s}$$

And, the velocity head at critical flow is:

$$\frac{V_c^2}{2g} = \frac{(2.89)^2}{2(9.81)} = 0.425 \text{ m}$$

Finally,

$$h_2 = 1.5(0.61) + 0.425 + 0.850 + 0.3048 = 2.49 \text{ m}$$

l) Hydraulic seal at inlet

Using the minimum dimensions, the inlet along the side slope of the canal is b x 2D, or 1.63 wide by 1.22 high (in meters). This gives a total inlet area of (1.63)(1.22) = 1.99 m^2. Then, the maximum inlet velocity head is:

$$h_v = \frac{Q^2}{2gA^2} = \frac{(4.00)^2}{2(9.81)(1.99)^2} = 0.206 \text{ m}$$

Minimum hydraulic seal is defined as:

$$1.5h_v + 0.152 = 1.5(0.206) + 0.152 = 0.461 \text{ m}$$

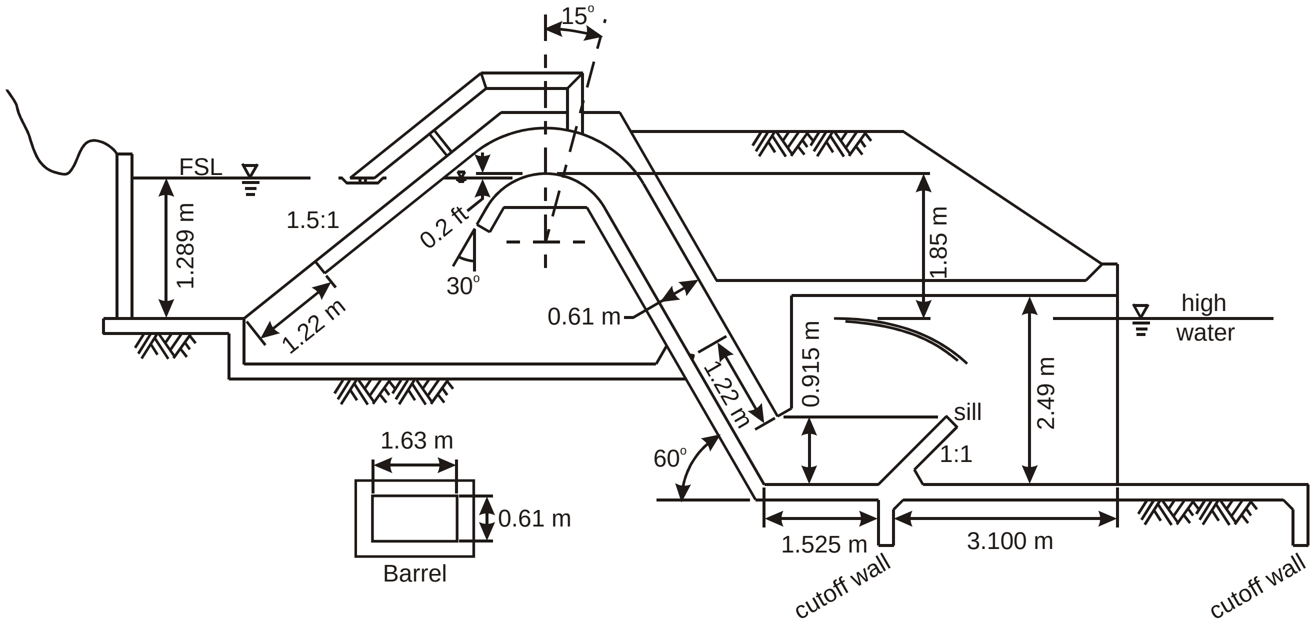
If the inlet begins at the base of the canal side slope (see Fig. 4-17), this hydraulic seal corresponds to a vertical depth of:

$$0.461 \sin\left[\tan^{-1}\left(1/1.5\right)\right] = 0.256 \text{ m}$$

The depth of water above the inlet is, then: 1.289 – 0.256 = 1.033 m, which exceeds the hydraulic seal requirement of 0.461 m. Thus, the hydraulic seal is sufficient.

m) Side-view drawing

See the drawing below.



15°
FSL
1.289 m
1.5:1
0.2 ft
30°
1.22 m
0.61 m
1.85 m
high
water
0.915 m
2.49 m
1.22 m
sill
1:1
60°
1.63 m
0.61 m
Barrel
1.525 m
3.100 m
cutoff wall
cutoff wall