

ERRATA

Pages 78 and 79 changes —Values in some of the equations have been adjusted. Also a note has been added in the first column on page 79 stating that there is more than one solution to the above equation and only professionals experienced in hydraulic analysis should determine which answer should be used for design purposes.

Unit Flow Discharge (cfs/ft)	Skimming Flow Limiting Depth (ft)		
	Spillway Slope 2:1	Spillway Slope 2.5:1	Spillway Slope 3:1
5	1.02	0.98	0.95
10	1.62	1.55	1.51
20	2.57	2.46	2.40
30	3.37	3.23	3.14
40	4.08	3.91	3.80
50	4.74	4.54	4.41
60	5.35	5.12	4.98
80	6.48	6.21	6.04

$$\frac{\Delta h}{H_{\max}} = 1 - \left[\frac{\frac{d_o}{d_c} \cos \alpha + \frac{1}{2} E_c \left(\frac{d_c}{d_o} \right)^2}{\frac{3}{2} + \frac{h_{\text{dam}}}{d_c}} \right] \quad (\text{Chanson 1995})$$

Where:

- H_{\max} = maximum available head from downstream toe to waterlevel at top of the stepped spillway (ft)
- h_{dam} = head from downstream toe to crest of stepped spillway (ft)
- d_o = uniform flow depth (ft)
- d_c = critical flow depth (ft)
- E_c = kinetic energy correction/coefficient
- α = spillway slope

A detailed description of these terms, and the relationships described herein are presented in Chanson (1995).

$$d_c = \left(\frac{q^2}{g} \right)^{1/3}$$

$$E_c = \frac{(N + 1)^3}{N^2 (N + 3)}$$

Typically, N varies from 6 to 10: Assume N=8.

With the given flow discharge, dam geometry, and geometry of spillway steps for "Typical Dam," the different components required to calculate the energy dissipation are calculated:

$$d_c = \left[\frac{(52.9)^2}{32.2} \right]^{1/3} = 4.43 \text{ ft}$$

$$H_{\max} = h_{\text{dam}} + 1.5 d_c = 38 + 1.5 (4.43) = 44.65 \text{ ft}$$

$$\frac{d_o}{d_c} = \sqrt[3]{\frac{f_c}{8 \sin \alpha}} \quad (\text{From Chanson 1995})$$

$$= 0.407$$

Where:

f_c = Darcy friction factor (for aerated flow assume 0.2)

$$\alpha = \tan^{-1} \left(\frac{1}{2.5} \right) = 21.8^\circ$$

$$\Delta h = (44.65) \left[1 - \frac{(0.407 \cos 21.8^\circ) + \frac{1}{2} (1.0355) \left(\frac{1}{0.407} \right)^2}{\frac{3}{2} + \frac{38}{4.43}} \right]$$

$$\Delta h = 29.13 \text{ ft}$$

Step 4:

Determine the flow depth and flow velocity at the toe of the spillway.

After the calculation of energy dissipation over the stepped spillway, an energy equation (such as the Bernoulli equation, USBR 1987a) can be used to calculate the depth of flow at the base of a spillway:

$$\frac{V_0^2}{2g} + Z_0 + d_c = \frac{V_1^2}{2g} + Z_1 + \Delta h + d_1$$

where V_0 is the velocity of water at the top of the stepped spillway, and Z_0 is the elevation of the upstream apron (see Figure A.4); and V_1 is the flow velocity at the base of the spillway, Z_1 is the elevation of the stilling basin (see Figure A.4), and d_1 is the flow depth before the jump, at the toe of the spillway (see Figure A.6). It was assumed that the upstream apron is sufficiently long so that flow over the sharp-crested weir does not affect the development of critical flow at the top of the spillway. With the flow characteristics given in this example, the flow depth at the base of the spillway was determined as follows:

Since,

$$V_0 = \frac{q}{d_c} = \frac{52.9 \text{ cfs / ft}}{4.43 \text{ ft}} = 11.94 \text{ fps}$$

Then,

$$\frac{(11.94)^2}{2(32.2)} + 605.0 + 4.43 =$$

$$\frac{V_1^2}{2(32.2)} + 567 + 29.13 + \frac{52.9}{V_1}$$

$$\frac{V_1^2}{64.4} + \frac{52.9}{V_1} = 15.51$$

$$V_1 = 29.7 \text{ fps}$$

Note: There may be more than one solution to the above equation. Only professionals experienced in hydraulic analysis should determine which answer should be used for design purposes.

The flow depth at the toe of the spillway is:

$$d_1 = \frac{q}{V_1} = \frac{52.9}{29.7} = 1.78 \text{ ft}$$

Step 5:

Compute the conjugate (sequent) depth, d_2 , and flow velocity:

$$d_2 = \frac{-1.78}{2} + \sqrt{\frac{(1.78)^2}{4} + \frac{2(29.7)^2 \times 1.78}{32.2}}$$

$$= \frac{-1.78}{2} + \sqrt{0.79 + 97.5}$$

$$d_2 = 9.0 \text{ ft}$$

$$V_2 = \frac{q}{d_2} = \frac{52.9}{9.0} = 5.88 \text{ fps}$$

The conjugate flow depth after the hydraulic jump is calculated to be 9.0 ft. Therefore the bottom of the stilling basin should be set at an elevation 9.0 ft below the tailwater elevation in order to have a fully developed hydraulic jump in the basin. If the tailwater depth is greater than 9.0 ft, the hydraulic jump will become submerged. If the tailwater is less than 9.0 ft an undulating hydraulic jump will develop in the basin. Assume that the tailwater elevation for the maximum spillway discharge of 68,200 cfs is elevation 576. Therefore, the elevation of the stilling basin will be set at elevation 567.

Step 6:

Calculate required length of stilling basin:

The length of a basin is usually based on a multiple of depth d_2 . The length of the basin will vary depending on the type of basin selected. A Type II basin, as defined in USBR 1987a, was assumed in determining the length of the basin for this example.

Determine Froude number parameter:

$$= \frac{V_1}{\sqrt{gd_1}} = \frac{29.7}{\sqrt{32.2 \times 1.78}} = 3.9$$

Based on design charts in Design of Small Dams (USBR 1987a) Figure 9-39, the length of stilling basin is equal to 5.75 d_2 . For a depth (d_2) of 9.0 ft, the length of the stilling basin would be approximately 52 ft.

Note: The basin floor elevation with respect to tailwater must be within the proper range for the hydraulic jump basin to operate for the entire range of spillway discharges. If the tailwater is too low, a sweep out condition could occur. The undesirable result of a sweep out condition is that high velocity flow can cause significant erosion downstream of the basin. If the tailwater is too high, a drowned condition could occur and reduce the effectiveness of the basin. Site conditions or other restraints may exist which require placing a stilling basin floor at an elevation outside of the recommended range for the hydraulic jump. In such cases, the designer must accept that the basin will not operate properly. Refer to various publications (such as USBR 1987a) for further discussion.

Task 3 – Training Wall Height

The training wall height is calculated by computing the water surface profile along the training wall. The height of the wall will depend upon the computed depth of flow plus additional factors for: bulking due to air entrainment, wave action, and freeboard from the water surface to the top of the wall.

An empirical expression for estimating freeboard for straight spillway walls and has been developed by the USBR (1987a). Because of the greater surface roughness in RCC stepped spillways, the design should consider increasing freeboard height estimated for smooth spillway chutes. In a smooth channel conducting flow at supercritical stage the surface roughness, wave action, air bulking, and splash and spray can be approximated using the following empirical expression from USBR (1987a).

$$H_F = 2.0 + 0.025V^3\sqrt{d}$$

Where:

- H_F = freeboard height
- V = velocity of unbulked flow
- d = depth of flow

The required wall height should be computed at several locations along the spillway wall. For this example assume that the water surface depth and velocity at several locations along the chute have been estimated and the wall height is being computed where the maximum flow depth is 3 ft.

Where:

$$V = \frac{q}{A}$$

- q = unit discharge from Task 2, Step 1
- A = unbulked area of flow per foot width (flow depth)

$$V = \frac{q}{A} = \frac{52.9}{3(1)}$$

$$V = 17.63$$

$$H_F = 2.0 + 0.025(17.63)^3\sqrt{3}$$

$$H_F = 2.0 + 0.64 = 2.64$$

$$\text{Wall Height (unbulked depth of flow + freeboard)} = 3 + 2.64 = 5.64 \text{ ft}$$

$$\text{Use Wall Height} = 6 \text{ ft}$$

CLARIFICATION

Page 34, Figure 6.13 changes —The thickness derived from the figure in the publication is for unformed sloping RCC steps. The figure below is an addendum to the current figure and includes the graphic representation and equation for determining the thickness (d) of the RCC step normal to the embankment slope for both formed and unformed RCC steps.

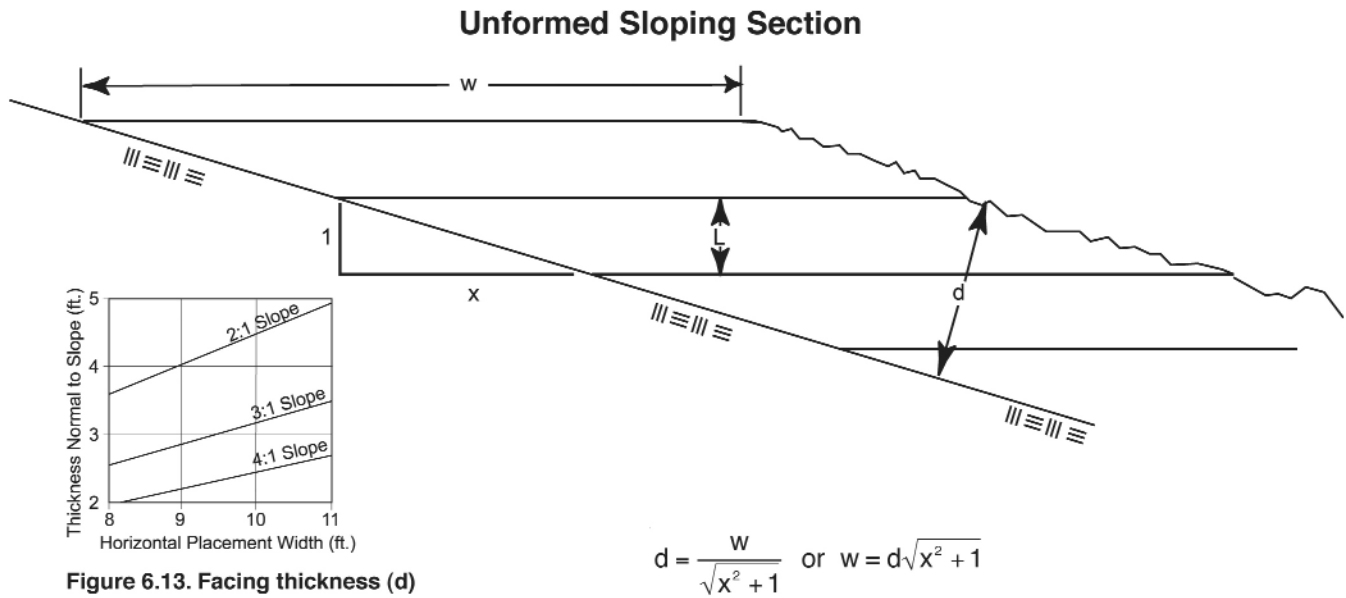


Figure 6.13. Facing thickness (d) of RCC versus width (w) for a 1-ft thick (L) unformed sloping RCC step.

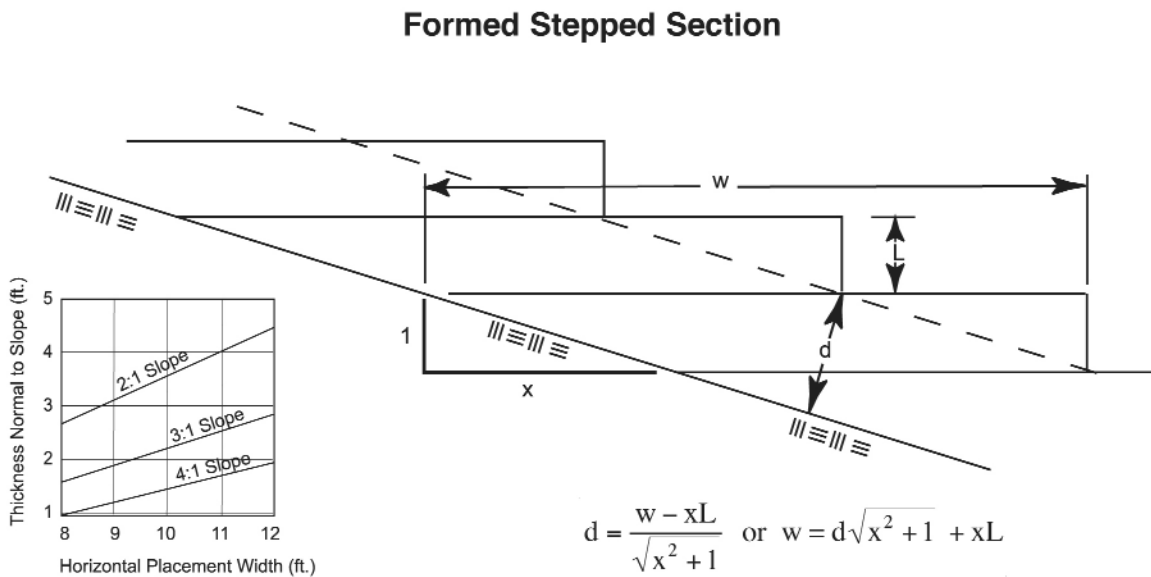


Figure 6.13a. Facing thickness (d) of RCC versus width (w) for a 1-ft thick (L) unformed RCC step.