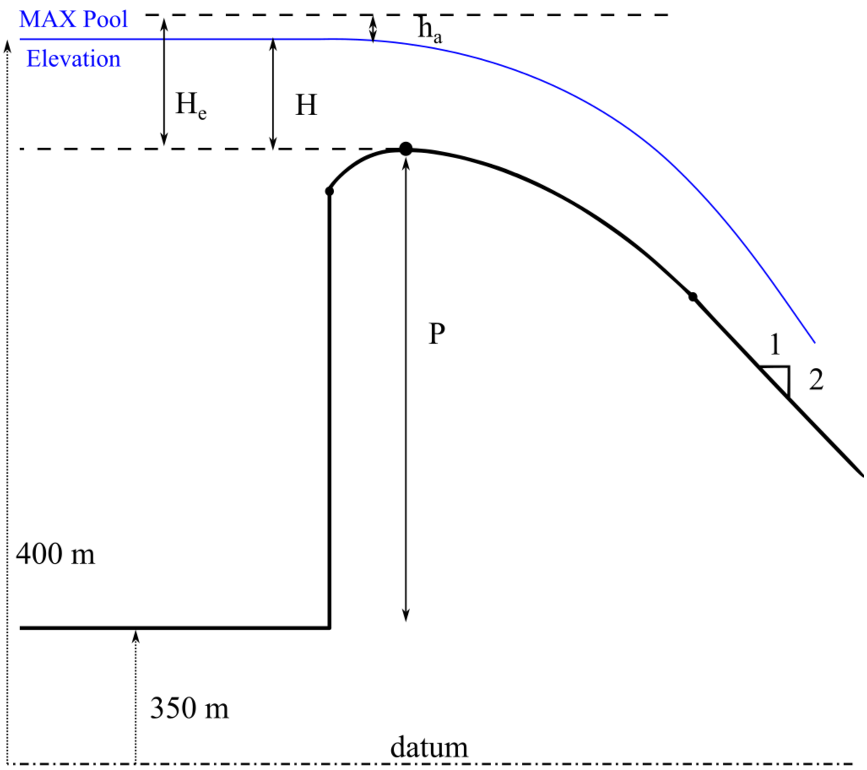
Example — Spillway design

Design an overflow spillway with an effective crest length of 60 m that will discharge at a design flow rate of 1500 m3/s at a maximum-allowable pool elevation of 400 m. The bottom elevation behind the spillway is 350 m, the upstream face of the spillway is vertical, and the spillway chute is to have a slope of 1:2 (H:V).



Assuming that the spillway is sufficiently high that the ratio of the spillway height P to the deisgn head Hd is greater than 3, the plot (a) in slide 65 gives us a basic discharge coefficient of CO = 2.18.

We also assume that the ratio between the effective head He and the design head Hd is equal to 1.33 as recommended by USBR in order to avoid cavitation. Therefore, plot (c) in slide 65 gives us the correcting factor for the discharge coefficient C/Co=1.04 (approximately)

- $C_o = 2.18$
- with $\frac{He}{Hd} = 1.33 \Rightarrow \frac{C}{C_o} = 1.04$

$$\Rightarrow C = \left(\frac{C}{C_o}\right) C_o = (1.04)(2.18) = 2.27$$

From data:

$$Q = 1500\ m^3/s$$
$$L_e = 60\ m$$

$$Q = C L_e (H_e)^{3/2}$$

$$H_e = \left(\frac{Q}{C L_e}\right)^{2/3} = \left(\frac{1500}{(2.27)(60)}\right)^{2/3} = 4.95\ m$$

From the assumption made to underdesign Hd while avoiding cavitation (i.e., He/Hd = 1.33) we can calculate the design head

$$\frac{H_e}{H_d} = 1.33 \rightarrow H_d = \frac{H_e}{1.33} = \frac{4.95}{1.33} = 3.72\ m$$

Now we want to calculate the height of the water above the spillway crest (H) in order to know the required crest elevation of the spillway. To do so we have to remember that the effective height is the sum between the height of the water H and the approaching velocity head h_a, which we calculate estimating the approach velocity.

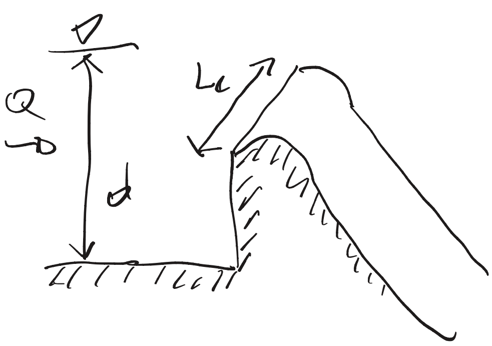
The total water depth upstream of the water is given by the difference in elevation between the max pool elevation and the bottom elevation behind the dam. With that and the discharge we estimate the approach velocity as Q/A:

WATER DEPTH UPSTREAM $\rightarrow d = 400\ m - 350\ m = 50\ m$

$\Downarrow$

the APPROACH VELOCITY is

$$V_a = \frac{Q}{A} = \frac{Q}{L_e \cdot d} = \frac{1500}{(60)(50)} = 0.5\ m/s$$



*Note that in this example there are no piers and not mention of abutments, so the effective length is also the total length. Otherwise, the approaching velocity would have to be calculated using the total geometrical width of the crest (i.e., size of the approaching channel)

So the VELOCITY head is:

$$h_a = \frac{V_a^2}{2g} = \frac{0.5^2}{2(9.81)} = 0.01 \ m$$

Therefore the WATER HEIGHT (H) above the spillway is

$$H_e = H + h_e$$

$$H = H_e - h_a = 4.95 - 0.01 = 4.94 \ m$$

⇓

The ELEVATION of the crest (maximum point) is @

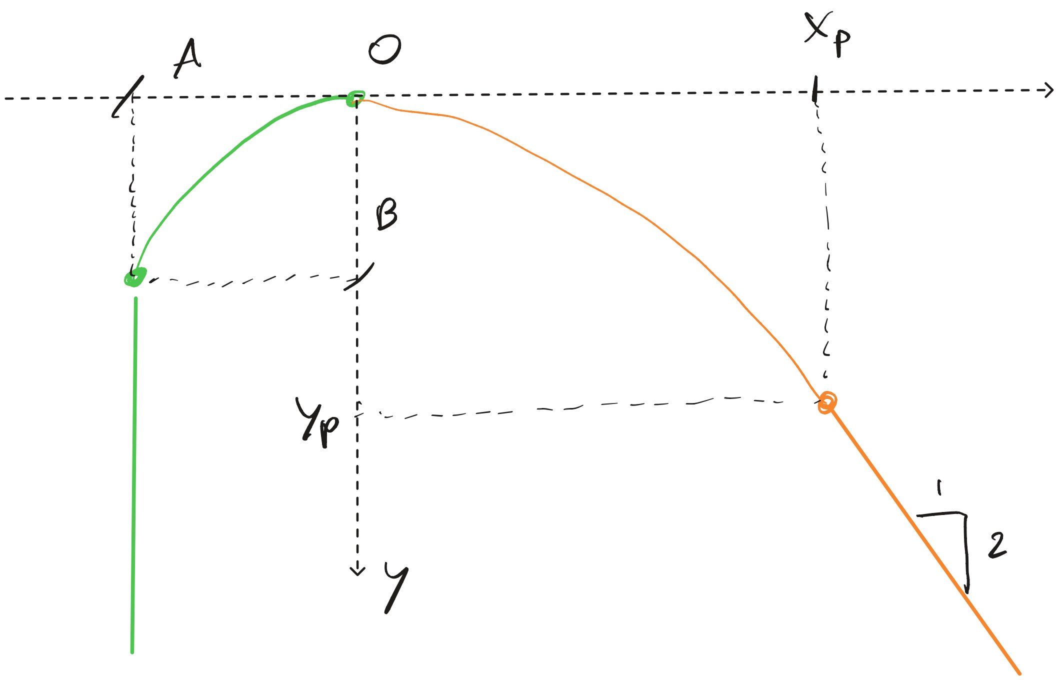
$$400 \ m - 4.94 \ m = 395.06 \ m$$

⇒ The height of the Spillway P:

$$P = 395.06 \ m - 350 \ m = 45.06 \ m$$

and $\frac{P}{H_d} = \frac{45.06}{3.72} \approx 12$ which indicates a "high spillway" with negligible approach velocity

With all these information we can now use the formulas to design the shapes of the downstream and upstream quadrants.



For high spillway (P/Hd=12) and negligible approach velocity, the plot in slide 71 gives K=2 (typical). Taking n=1.85 we have:

$$\frac{Y}{H_d} = \frac{1}{K}\left(\frac{X}{H_d}\right)^n$$

$$\frac{Y}{3.72} = \frac{1}{2}\left(\frac{X}{3.72}\right)^{1.85}$$

$$Y = 0.16\,X^{1.85}$$

Since the slope of the DOWNSTREAM FACE is 1:2 (H:V) then α (α "a") = 2 and the horizontal distance from the apex O to the downstream tangent point X_{DT} is given by:

$$\frac{X_{DT}}{Hd} = 0.485 (K\alpha)^{1.176}$$

$$\frac{X_{DT}}{3.72} = 0.485 (2.2)^{1.176}$$

$X_{DT} = 9.2\ m$ → the corresponding y Value is:

$$Y_{DT} = 0.16\, X_{DT}^{1.85} = 9.7\ m$$

Therefore, at a distance of 9.2 m horizontally and 9.7 m vertically downstream of the crest, the curved spillway profile merges into the liner profile of the spillway chute, which has a slope of 1:2 (H:V).

For the upstream curve: taking P/Hd = 12, we can find the values of A and B from the graphs in slide 73:

- $\frac{A}{Hd} = 0.28$ → $A = 0.28(3.72) = 1.04\ m$
- $\frac{B}{Hd} = 0.165$ → $B = 0.165(3.72) = 0.614\ m$

Therefore the PROFILE IS GIVEN by:

$$\frac{X^2}{A^2} + \frac{(B-y)^2}{B^2} = 1$$

$$\frac{X^2}{(1.04)^2} + \frac{(0.614-y)^2}{(0.614)^2} = 1$$

Which simplifies to:

$$X^2 + 2.87(0.614 - y)^2 = 1.08$$

The upstream crest profile given by this equation interesects the vertical (upstream) spillway wall at x = -A = -1.04 m and y = B = 0.614 m