Chapter Three

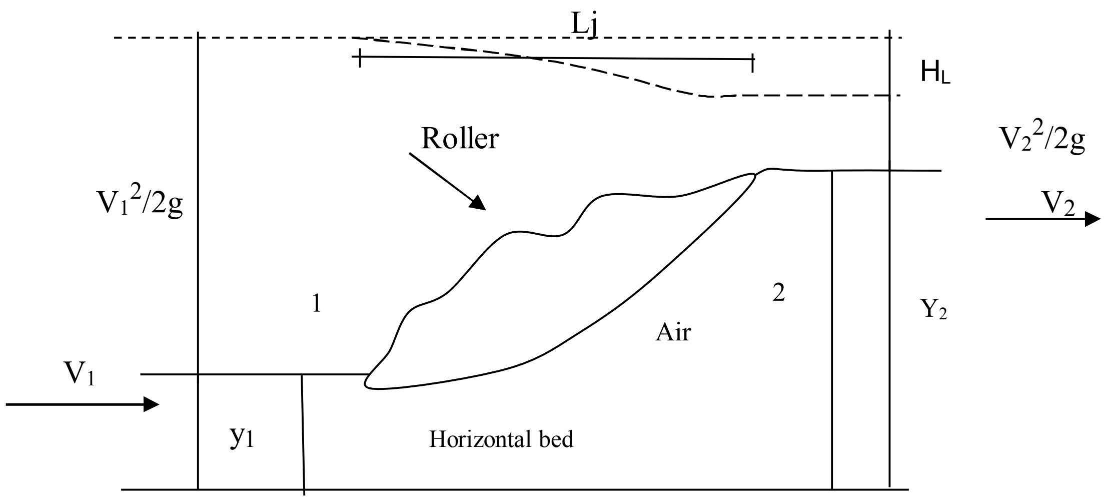
Hydraulic Jump and Energy Dissipation Devices.

The failure due to surface flow may occur by suction pressure due to hydraulic jump or by scouring of the bed.

(a) Failure by suction pressure

In the glacis type of weirs, a hydraulic jump is formed on the d/s glacis. In this case, the water surface profile in the hydraulic jump trough is much lower than the subsoil H.G.L. Therefore uplift pressure occurs on the glacis. This uplift pressure is known as the suction pressure. If the thickness of floor is not adequate, the rupture of floor may occur.

Hydraulic Jump is distinct rise or jump of water accompanied by a great deal of turbulence. This may occur when shallow stream water moving with a high velocity strikes a stream of water moving with low velocity. Hydraulic jump can be used to destroy kinetic energy. Its application in the design of barrages, falls…etc.



At section 1 incoming super critical stream undergoes an abrupt rise in the depth forming the commencement of the jump, is called the toe of the jump.

L_j= length of jump.

y_1 and y_2 called sequent depth.

H_L= loss of energy.

It's difficult to use energy equation, so momentum equation is used with following assumption.

1- Friction is negligible

2- The jump is assumed to take place instantaneously.

3- Parallel side constraints

4- Horizontal bed or θ is very small.

1- Sequent depths:

$y_2/y_1 = ½ \{(\sqrt{1+8Fr_1^2})- 1\}$ (1) This equation is known as Belanger momentum equation

Also can be expressed as: $y_1/y_2 = ½ \{(\sqrt{1+8Fr_2^2}) - 1\}$

Where $Fr = q/ \sqrt{gy^3}$ (2)

2- Energy loss:

$H_L= E_{f1}- E_{f2} = (y_1 +V_1^2/2g) + (y_2 +V_1^2/2g)$, solving for H_L

$H_L = (y_2 – y_1)^3/ 4y_1y_2$ (3)

Procedure for finding y1 and y2 (given q and H_L):
1- Assume y_1
2- Calculate Fr using equation 2
3- Calculate y using equation 1
4- Calculate H_L using equation 3
5- If HL given= H_L calculated then OK, otherwise assume new values of y1

In actual design problems, q and H_L are known, then y_1 and y_2 are to be found.

For simplifying the problems, three curves are prepared

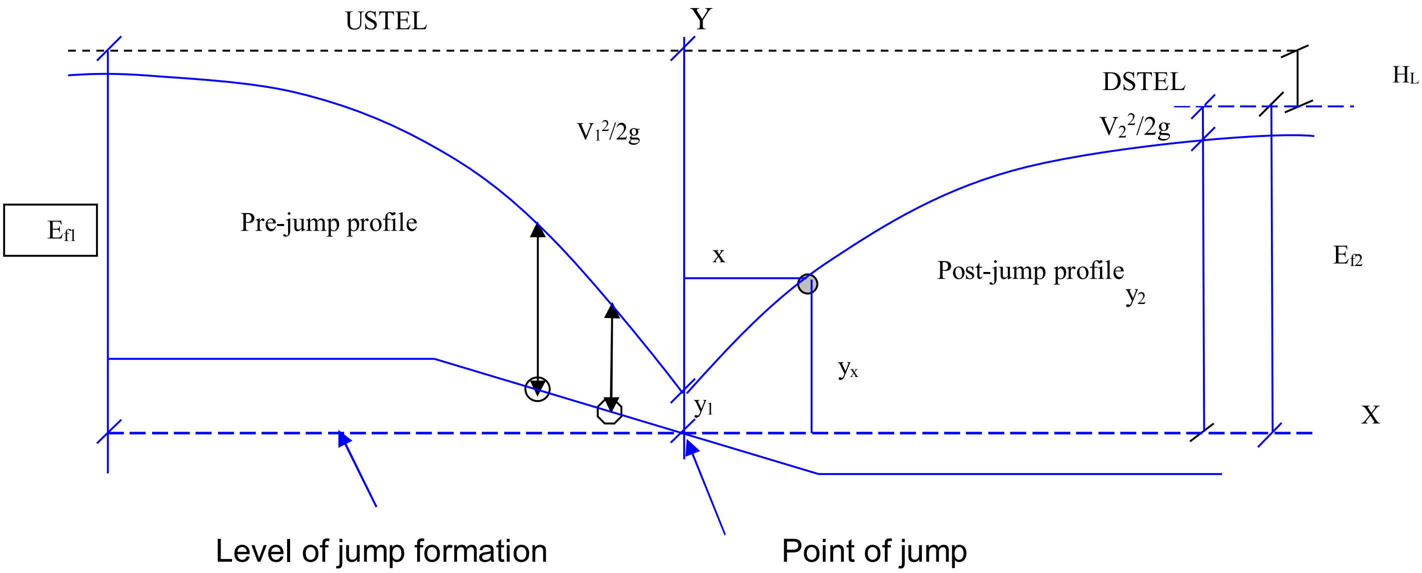
-Energy-Flow curves. E versus y.

-Modified Blench curves H_L versus q and E_{f2}.

- Curve for plotting profile of the jump

3-Location and profile of hydraulic jump.

q and H_L are known:



Plotting profile of hydraulic jump.

1-From known values of q and H_L, find value of E_{f2} from Blench curve

2-Find $E_{f1}= E_{f2}+H_L$ H_L= USTEL-DSTEL

($H_{dynamic}$= USTWL-DSWL) , (H_{static}= U/S pond level-D/S floor level)

3-Read y_1 and y_2 for values of Ef_1 and Ef_2 from energy flow curve, y_1 on supercritical side and y_2 on sub-critical side

Both y_1 and y_2 measured from the level where the jump forms.

Level of which jump forms = DSTEL - Ef_2 = USTEL - Ef_1

D/S floor level is commonly lower by 0.2 m at least from level of the jump

4-For pre-jump profile (where depth of water is super critical).

a- Find E_f at different points on the glacis

Ef_i= USTEL - Elevation of glacis at point i

b- Read y for Ef_i and q (y is depth of water from the glacis) {from table or figure on super critical side}

5-For post jump profile:

a- Find Fr_1 for y_1 (E_{f1})

$Fr_1 = v_1 / \sqrt{gy_1} = q / (\sqrt{gy_1^3})$

b- For different values of x and for each value of x/y_1 and Fr_1^2 read values of y_x/y_1 from figures then plot x versus y.

6-Unbalanced dynamic head is calculated by subtracting elevation of water profile from subsoil hydraulic gradient.

7- 2/3 dynamic head is compared with unbalanced static head of uplift for max static head. The larger of the two is used for finding thickness of the required floor.

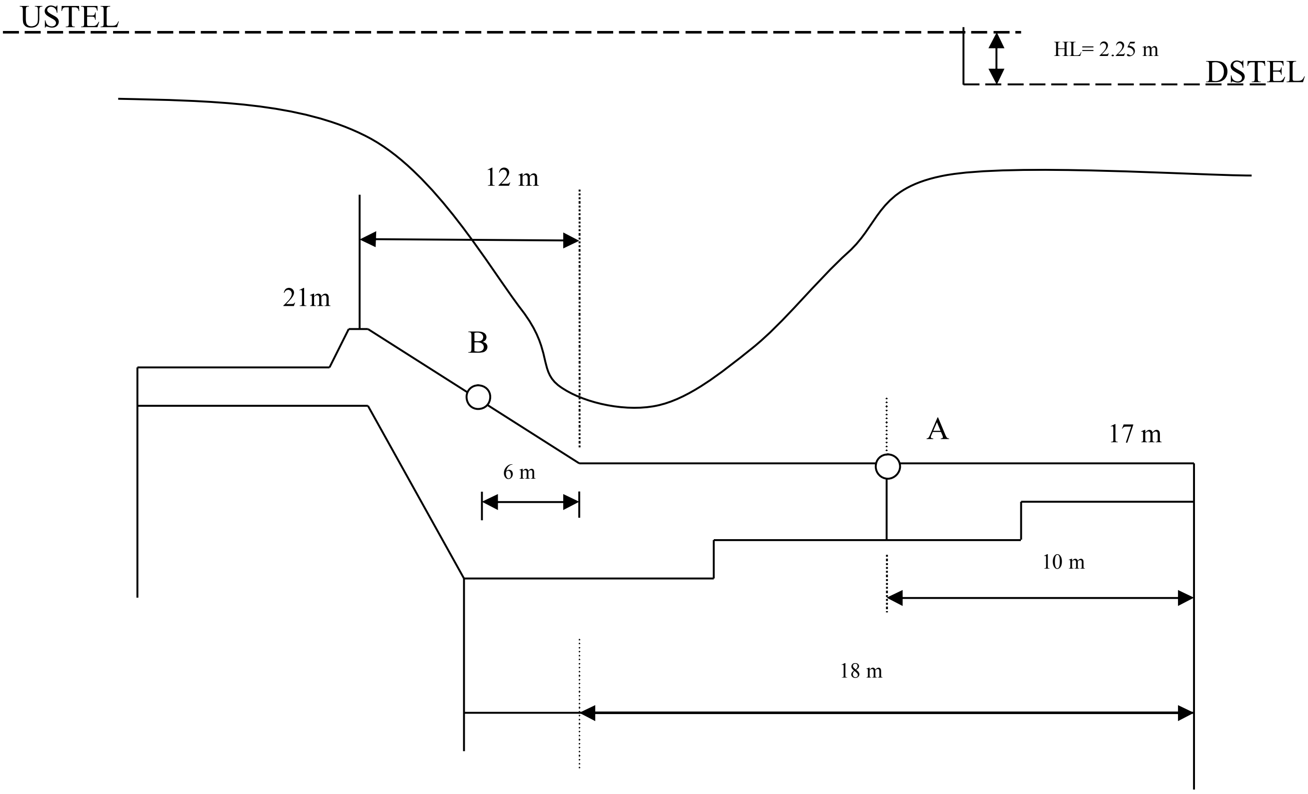
Example: Calculate unbalanced dynamic head at A and B.

Take q = 24 m^3/sec/m

USWL= 26 m DSWL= 24.5 m

USTEL= 26.95 m DSTEL= 24.7 m

Φ_A= 0.388 Φ_B= 0.484



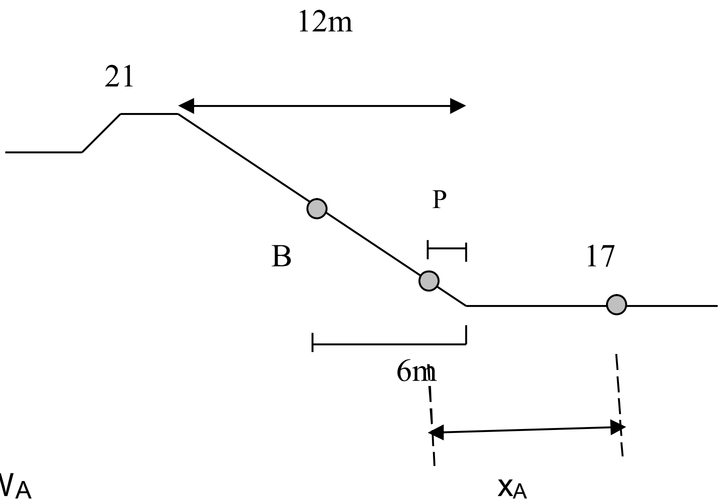
Solution:

H_L= USTEL-DSTEL

= 26.95-24.7=2.25 m

From Blench curve or from tables for H_L= 2.25 m and q = 24 m^3/sec/m, then Ef_2 =7.49 m

$E_{f1}=E_{f2}+H_L$ = 7.49+2.25= 9.74 m



Elevation of glacis where jump forms

= DSTEL-Ef_2 = 24.7-7.49 = 17.21 m

Or = USTEL- Ef_1 = 26.95-9.74 = 17.21 m

d/s floor level is 17.21-0.21= 17 m

x/12 = (17.21- 17) / (21-17)

x = 0.63 m

Point A is at post jump side, water level at A =W_A

For Ef_1 = 9.74 m, q= 24 m^3/sec/m, using energy curve y_1 = 1.9 (on supercritical side), this is first trail, check:

$Ef_1 = y_1 + q^2/2gy_1^2$

$= 1.9 + (24)^2/ 2g\,(1.9)^2$

$= 10.03 > 9.74$

Take y_1 =1.92 Ef_1 = 9.88 not O.K.

Take y_1 =1.94 Ef_1 = 9.74 O.K.

Distance of A from point of jump (x)

x_A= (18-10) +0.63 = 8.63 m

x_A/y_1= 8.63/1.94 = 4.448

$(Fr_1)^2 = q^2/gy_1^3 = (24)^2/ 9.81(1.94)^3 = 8$

Using special figure or from tables, y_A/y_1 = 2.362

y_A= 2.362*1.94 = 4.582 m

Elevation of water at point A (W_A)

W_A= y_A + elevation of glacis where jump forms.

= 4.582 + 17.21= 21.792 m

Elevation of sub-soil pressure HGL of A (E_A)

Max. Dynamic head = USWL – DSWL

= 26 – 24.5 = 1.5 m.

$H_A = \Phi_A * \max H_{dynamic}$ = 0.338 * 1.5 = 0.582 m (max $H_{dynamic}$= USTWL-DSWL)

HGL A (E_A)= H_A+DSWL

=0.582+24.5 = 25.082 m

Unbalanced dynamic head at A = $E_A - W_A$

= 25.082 – 21.792 = 3.29 m

<u>Point B:</u> is at pre-jump side.

Level of glacis at B = 2+17 = 19 m

Ef_B = USTEL – elevation at B

= 26.95 – 19 = 7.95 m

From energy curve, for supercritical side

q= 24 E_{fB} = 7.95 y_B= 2.2 m this first trial.

$E_{fB} = y_B + q^2/2gy_B^2 = 8.265 > 7.949$ not O.K.

Finally y_B = 2.276 E_{fB} = 7.949 O.K.

$W_B = Y_B$ + elevation at B = 2.276 + 19 = 21.276 m

Sub-soil elevation of water pressure (HGL) of B = E_B

$H_B = \Phi_B * \max H_{dynamic} = 0.484 * 1.5 = 0.726$ m

$E_B = H_B + DSWL = 0.726 + 24.5 = 25.226$ m

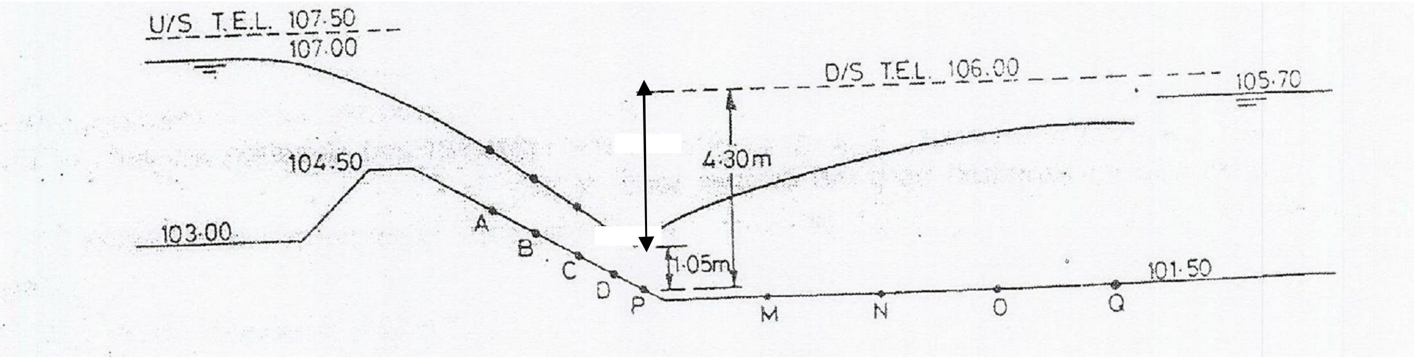
Unbalanced Dynamic head at B = $E_B - W_B$

= 25.226 – 21.276 = 3.95 m

H.W#1

For the hydraulic structure shown below. Determine the location of the point P where the hydraulic jump will be formed. Also draw the pre-jump and post-jump profiles. Take at least 4 points on each side

Assume *q=10 cumecs/m*, *H_L =1.5 m. U/S TEL=107.50*

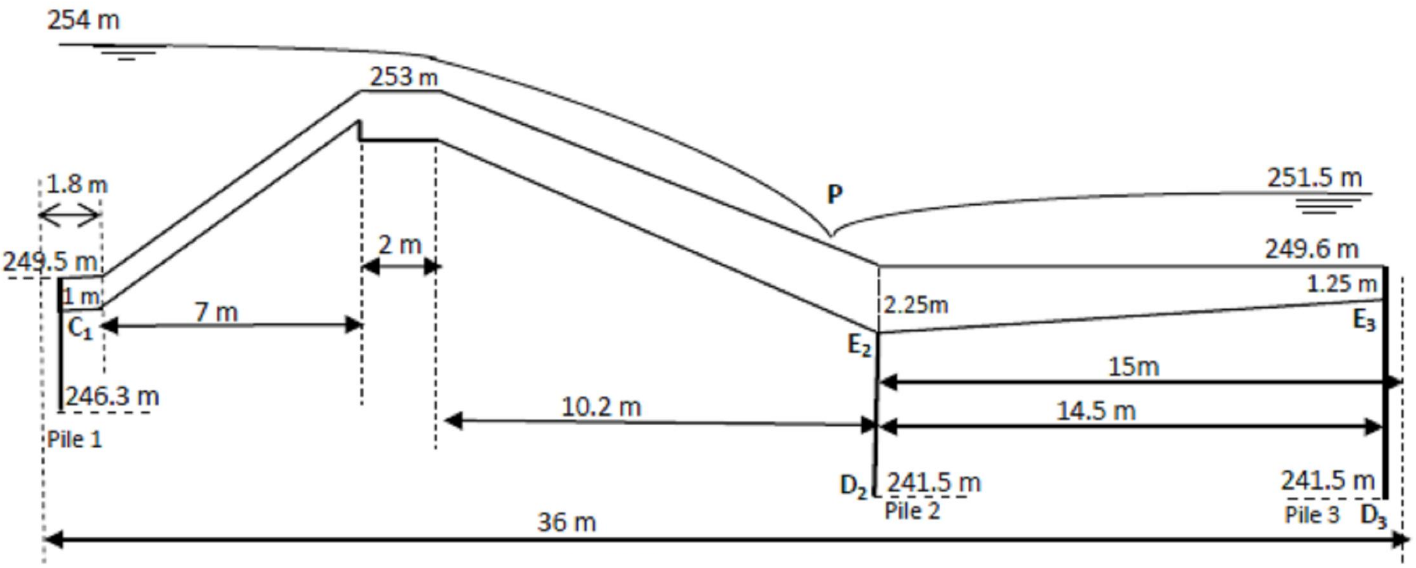


H.W 2

Figure below demonstrates a weir constructed on permeable floor. G_s=2.24, q= 2.9 $m^3/s/m$ Assume T.E.L = W.S.L for u/s and d/s. No adjusting of values of depths required. Uplift pressure coefficient should be corrected for all possible corrections. Consider outer face slope of the floor for slope corrections wherever required.

$Ef_2 = 0.7 \ Ln\ (H_L) + 0.362 * q)$

1) Check safety of the structure against piping for safe Lane's weighted coefficient of 7
2) Determine thickness of the floor at point **Q**
3) Estimate elevation of water surface at point **P** where the jump will be formed
4) Check exit gradient for the structure. Permissible exit gradient= 1/7
5) Check thickness of the floor at pile3 using Khoslas theory
6) Estimate the unbalanced dynamic head at pile 2 (d/s end of the glacis) and check its floor thickness using Khoslas theory


254 m
253 m
1.8 m
P
251.5 m
2 m
249.5 m
249.6 m
1 m
1.25 m
2.25m
7 m
C_1
E_2
E_3
15m
246.3 m
10.2 m
14.5 m
Pile 1
D_2
241.5 m
241.5 m
Pile 2
Pile 3
D_3
36 m