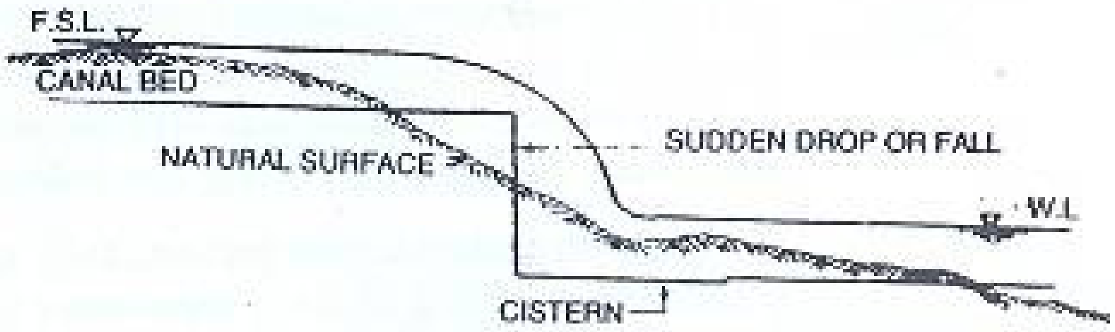
Canal Falls

Introduction

Introduction

- A canal fall is a hydraulic structure constructed across a canal to lower its water level.
- This is achieved by negotiating the change in bed elevation of the canal necessitated by the difference in ground slope and canal slope.



- The necessity of a fall arises because the available ground slope usually exceeds the designed bed slope of a canal.
- Thus, an irrigation channel which is in cutting in its head reach soon meets a condition when it has to be entirely in filling.

Introduction

- An irrigation channel in embankment has the disadvantages of:
  - Higher construction and maintenance cost
  - Higher seepage and percolation losses
  - Adjacent area being flooded due to any possible breach in the embankment
  - Difficulties in irrigation operations.

- Hence, irrigation channel should not be located on high embankments due to above mentioned problems.
- Falls are, therefore, introduced at appropriate places to lower the supply level of an irrigation channel.

Location of a Canal Fall

- The location of a fall is primarily influenced by the topography of the area and the desirability of combining a fall with other masonry structures such as bridges, regulators, and so on

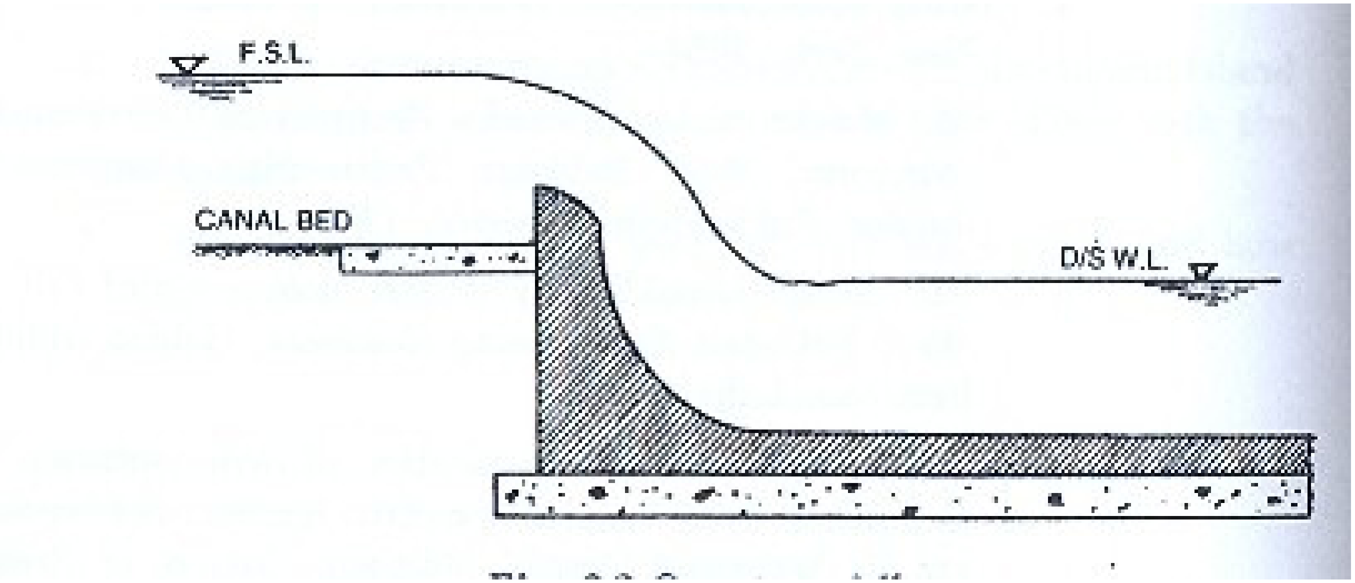
- In case of main canals, economy in the cost of excavation is to be considered (Cutting and filling is balanced)

- Besides, the relative economy of providing a large number of smaller falls (achieving balanced earth work and ease in construction) compared to that of a smaller number of larger falls (resulting in reduced construction cost and increased power production) is also worked out

- In case of channels which irrigate the command area directly, a fall should be provided before the bed of the channel comes into filling

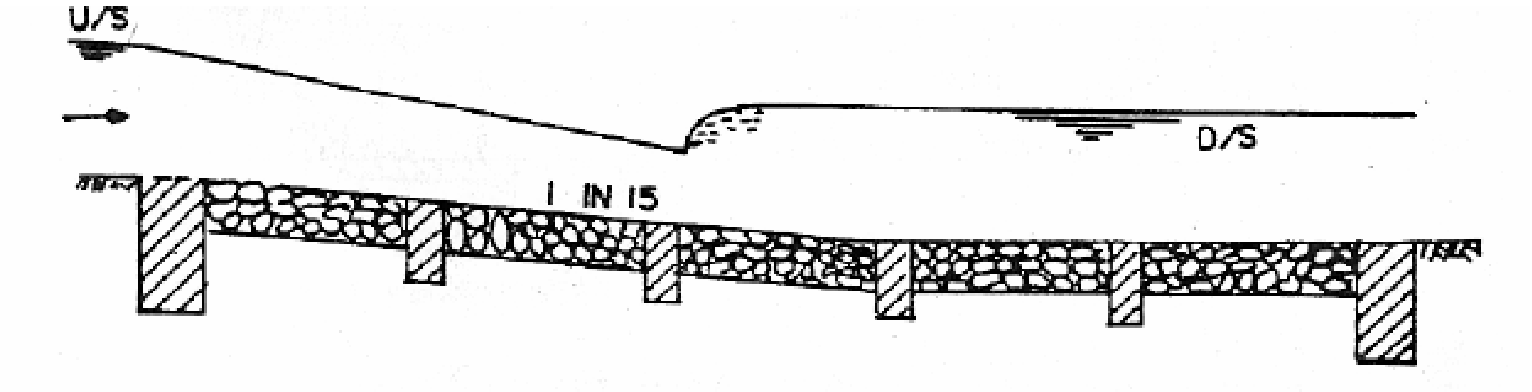
Historical Development

- **i. Ogee Type**
- The first of this type was constructed in the Indo-Pakistan subcontinent by the British in 1842.
- It smoothly deflects the vertical stream into a horizontal direction thereby avoiding the damage resulting from vertical impact on the cistern floor.
- But this result in an extensively high velocity causing erosion of the d/s bed.
- Require heavy cost in stone pitching and maintenance.



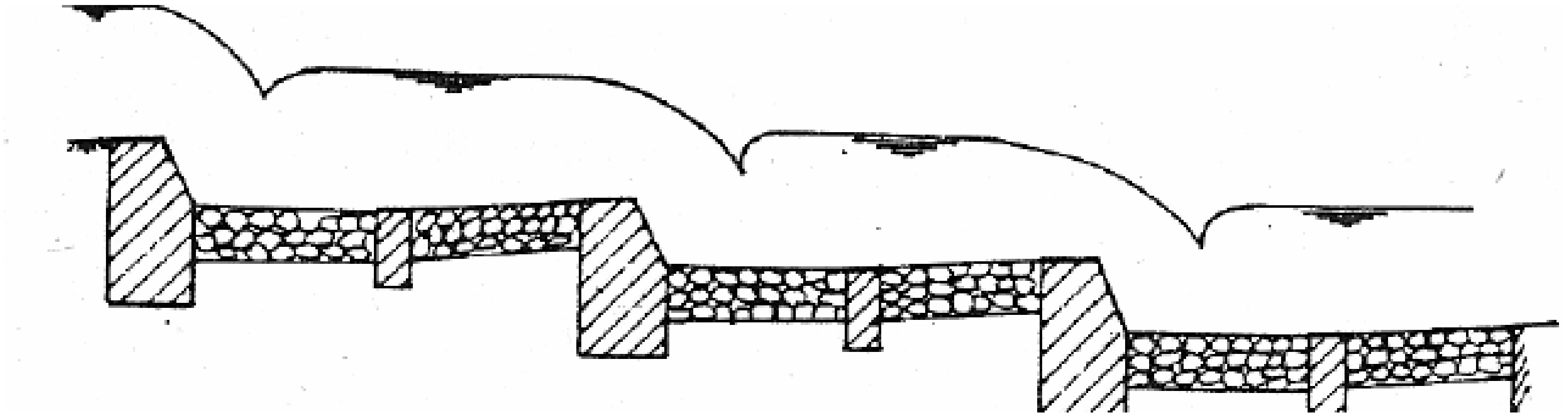
Historical Development

- **ii. Rapids**
- Ogee type was followed by Rapids and these were designed by Crofton.
- The drop in bed of channel is negotiated by the a gradually sloping glacis of 1:10 to 1:20.
- It successfully reduced the d/s velocities due to formation of hydraulic jump, a fact which was unknown to designer.
- The phenomenon of hydraulic jump as an energy dissipator was discovered and established in 1918.
- Rapids were quite successful but they were expensive.



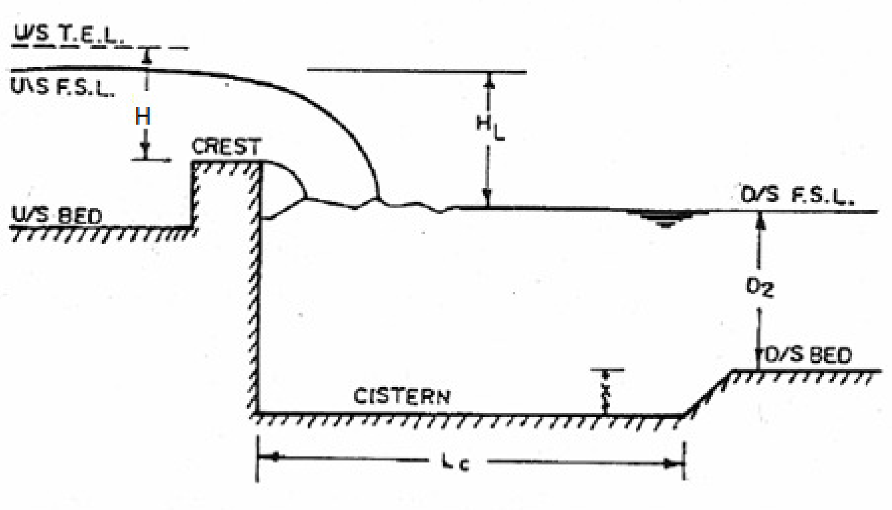
Historical Development

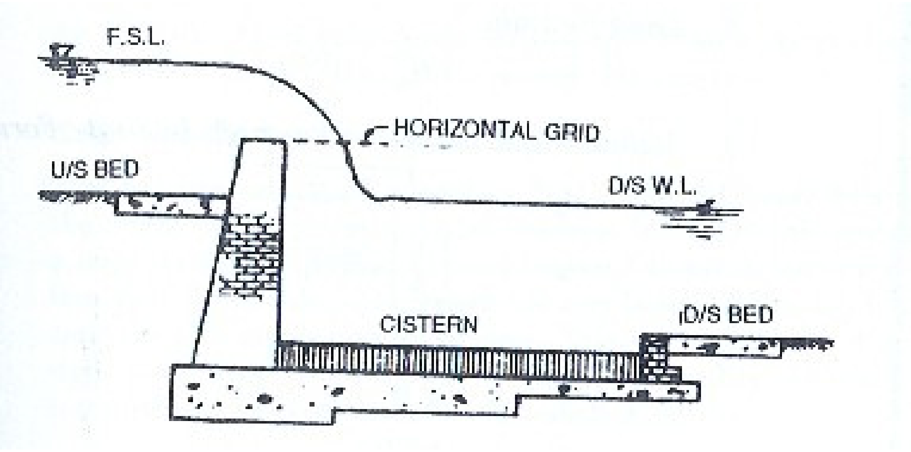
- **ii (a). Stepped Fall**
- This fall is practically a modification of the rapid fall.
- Stepped fall consists of a series of vertical drops in the form of steps.
- This fall is suitable in places where the sloping ground is very long and requires long glacis to connect the higher bed level with lower bed level.



Historical Development

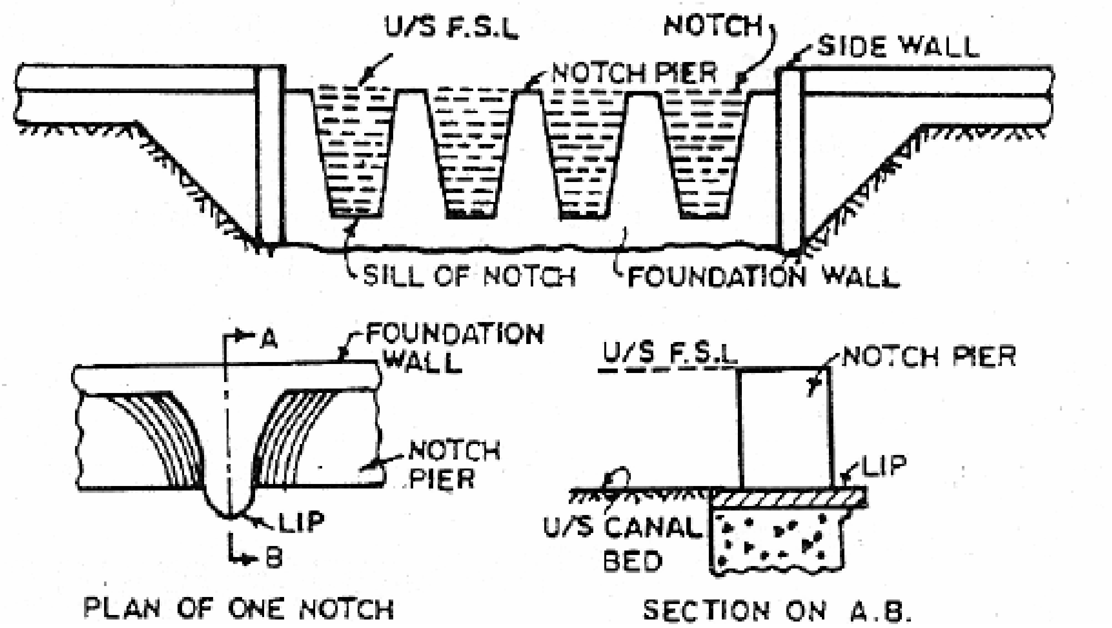
- **iii. Vertical Drop Falls**
- Rapids were followed by the vertical drop falls with cistern having a cushion of water to take the impact of the falling jet.
- The cistern dimensions were fixed arbitrary or by empirical formulae.





Historical Development

- iv. Trapeziodal notch fall
- Designed by Reid in 1894.
- It consists of trapezoidal notches across channel with smooth entrance.
- The main advantage is a constant depth discharge relationship maintained u/s in the channel by notches.
- In disadvantages, it gave a lot of trouble d/s even with provision of a cistern when submerged.

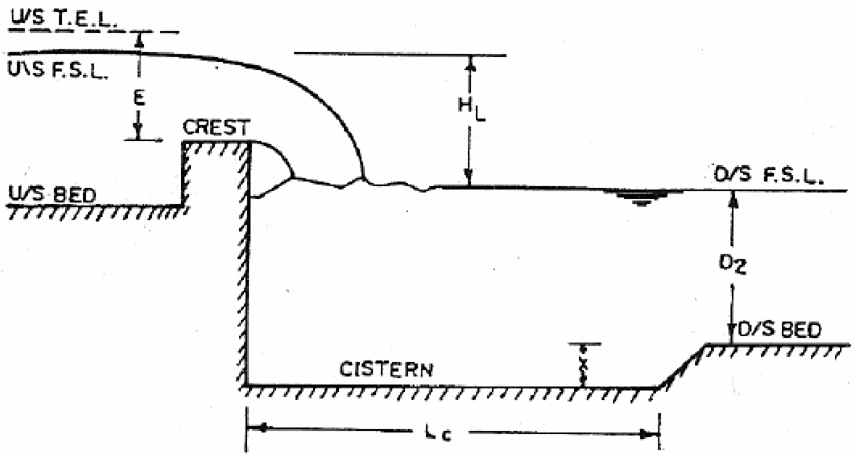


Historical Development

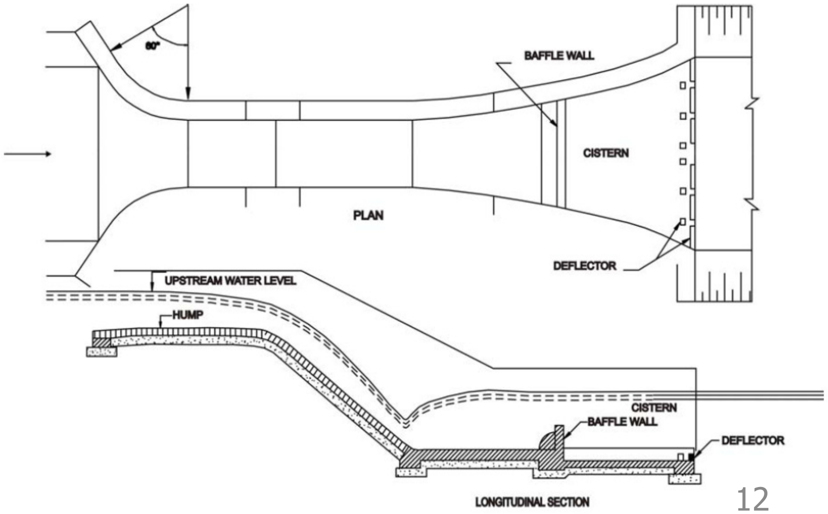
- iv. Modern Falls
- After the world war II, quite a few falls of the vertical drop type without fluming and sloping glacis fall with fluming were developed and are still in use.
- Examples are Sarda type fall, Mushtaq’s design, Punjab CDO (Central Design Office) type flumed falls with sloping glacis, Montague’s fall and Inglis type fall.

Types of Canal Falls

- Modern falls can be divided into
- Vertical Drop Falls
- Consists of a vertical wall and cistern to take impact of falling jet and friction blocks to destroy remaining energy



- Sloping Glacis type
- Similar to modern weirs
- Use hydraulic jump as energy dissipater



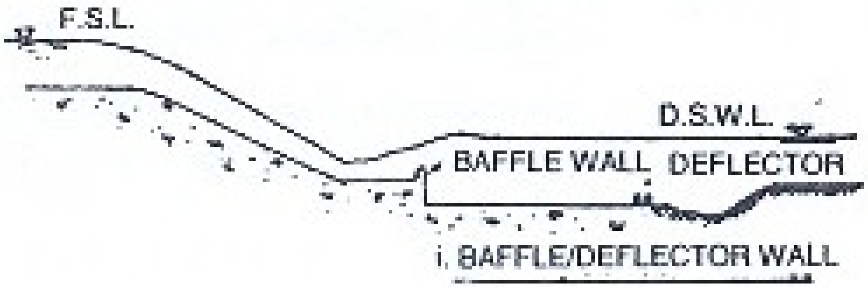
Classification of Canal Falls

- **Meter and non-meter falls:**
- Meter falls measure the discharge of the canal while the non-meter falls do not measure the discharge.
- For a meter fall, have broad weir type crest so that the discharge co-efficient is constant under variable head.
- Generally, glacis type fall is suitable as a meter.
- The vertical drop fall is not suitable as a meter due to the formation of partial vacuum under the nappe.

- **Flumed and Un-flumed falls:**
- A fall may either be constructed of the full channel width or it may be contracted.
- The contracted falls are known as the flumed falls while full channel width falls as the un-flumed falls.

Roughness devices for stilling basin appurtenances

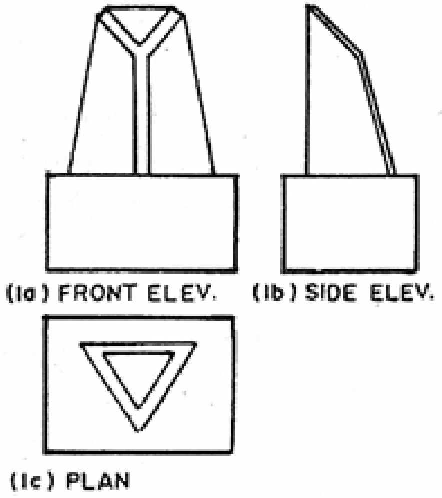
- **Baffle wall**
- A baffle wall is a sort of low weir constructed at the toe of the cistern to serve two purposes:
- (a) to head up water to its upstream to such a height that hydraulic jump is formed, and
- (b) to withstand the actual impact of the high velocity jet to dissipate the energy.



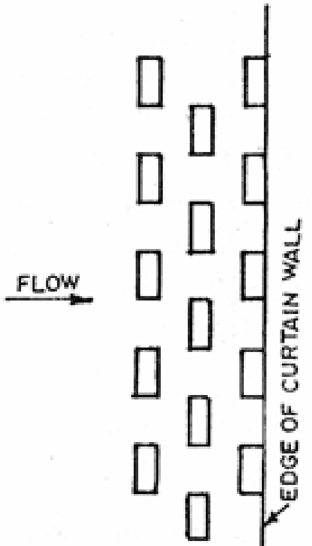
Roughness devices for stilling basin appurtenances

- **Friction blocks or arrows**
- Staggered friction blocks are one of the most useful and simple devices to dissipate the energy. They consist of rectangular blocks of concrete.

- Their height may be up to ¼ water depth and widths are 1.5 to 2.0 times the height of the block.
- The distance between successive lines is equal to twice the height.



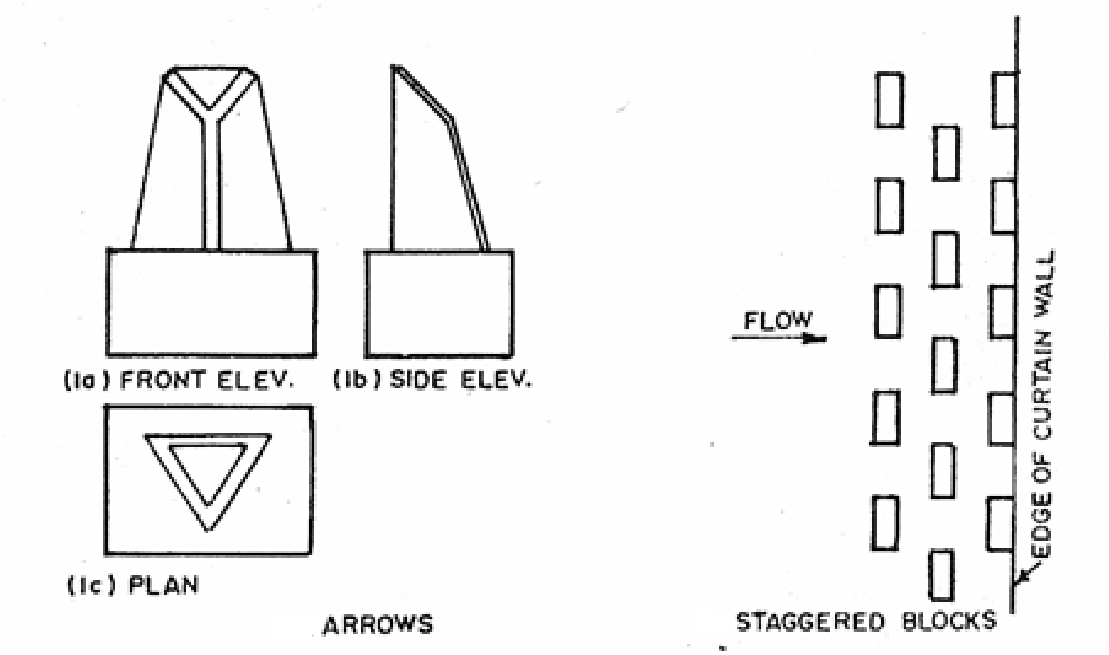
ARROWS



STAGGERED BLOCKS

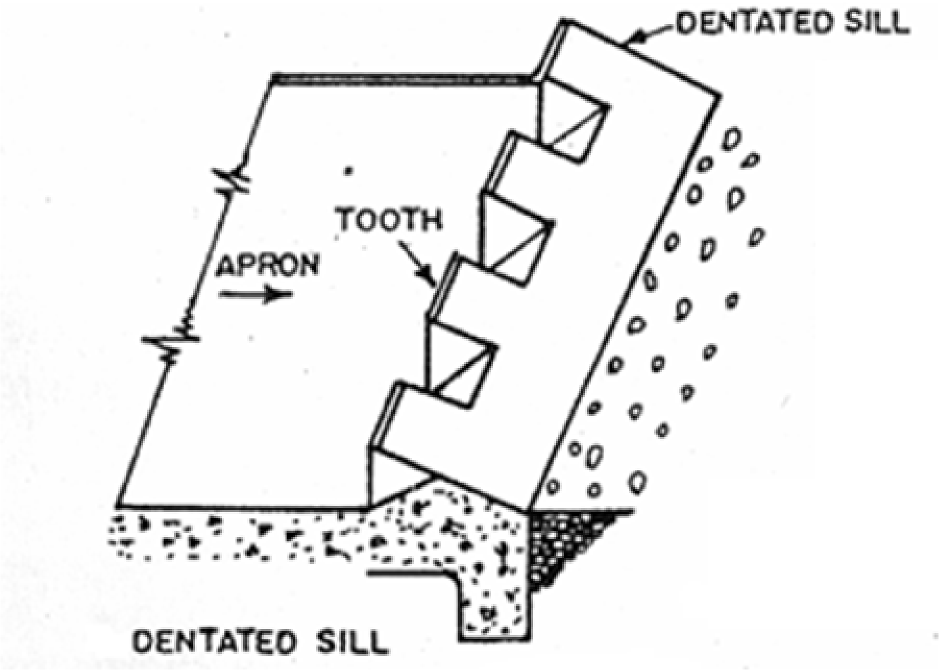
Roughness devices for stilling basin appurtenances

- **Friction blocks or arrows**
- Arrows are specially shaped friction blocks.
- Both of these are built on d/s floor of the falls below the glacis or cistern with the objective to divide the bottom high velocity water laterally.
- They just serve to reduce the bottom velocity of water leaving the pucca floor of the fall.



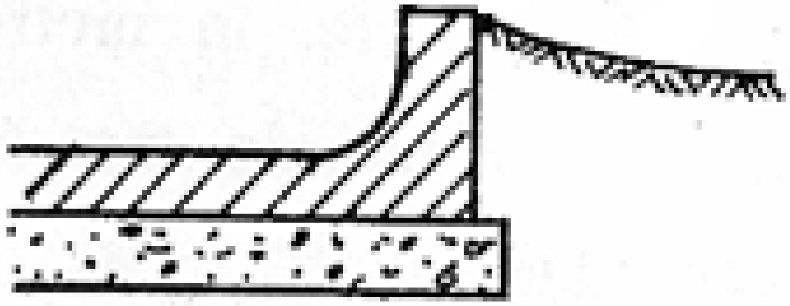
Roughness devices for stilling basin appurtenances

- **Dentated sill**
- A dentated sill is provided at the end of cistern if high velocity jet persists to the end of the cistern.
- The objective of the sill is to deflect up the high velocity jet from near the bed and to break it.

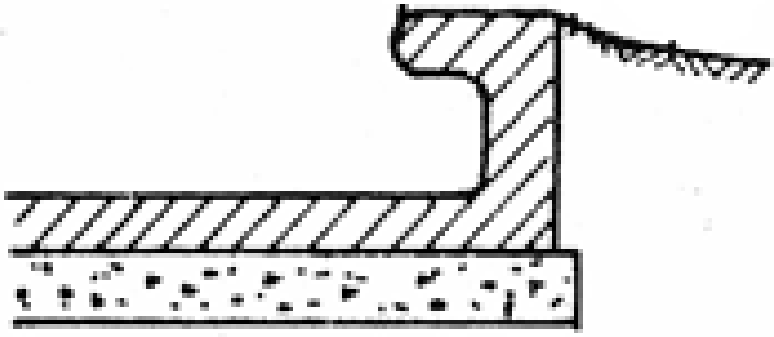


Roughness devices for stilling basin appurtenances

- **Deflectors**
- Structurally deflector is a baffle provided at the end of cistern or pukka floor.
- It is of uniform height, unlike the dentated sill.
- Its object is to deflect up the high velocity current upward away from the bed causing a reverse roller thereby bringing the flow back to normal.



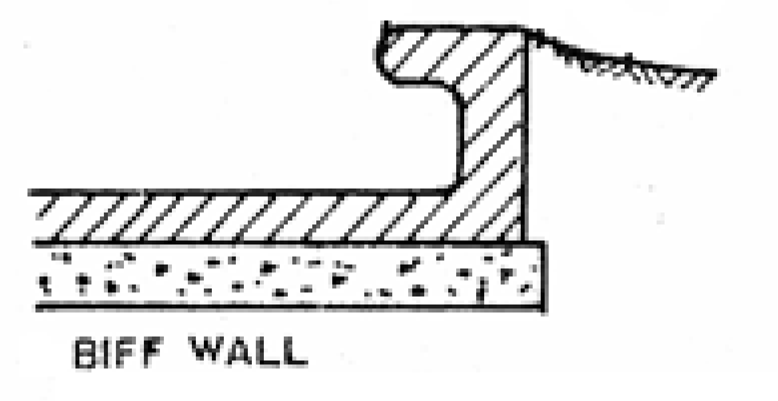
DEFLECTOR



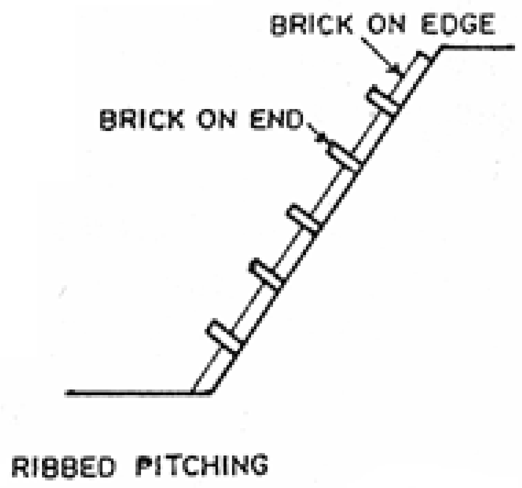
BIFF WALL

Roughness devices for stilling basin appurtenances

- **Biff wall**
- Similar to deflector it is provided at the end of cistern, causing a deep pool of water behind it in the cistern.
- Its objective is to deflect back the water from the cistern to create super turbulence in it.



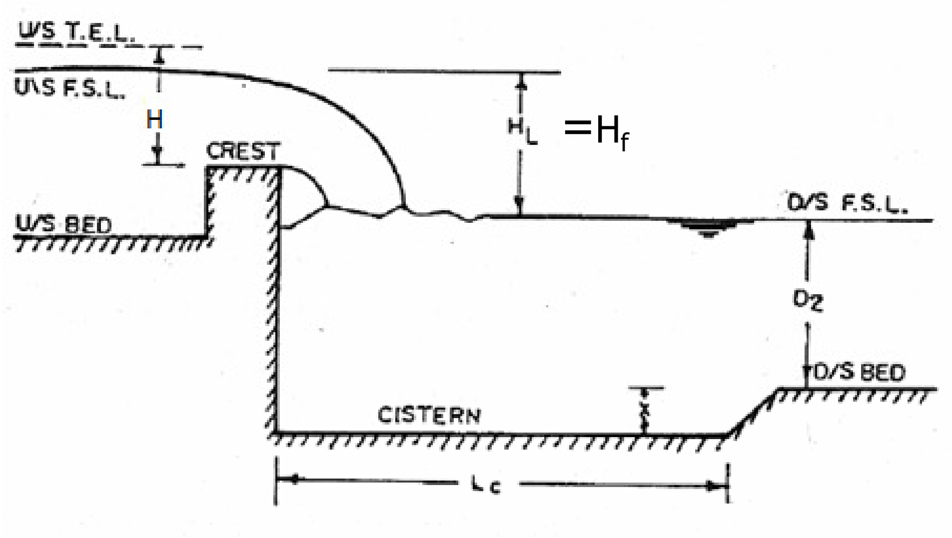
- **Cellular or ribbed pitching**
- Ribbed pitching is provided on the sides by putting bricks flat and on edge alternatively, as shown in Fig.
- Its function is to increase the roughness of the perimeter to destroy surplus energy downstream of the fall.



Design of Vertical Drop Falls: Sarda Type Fall

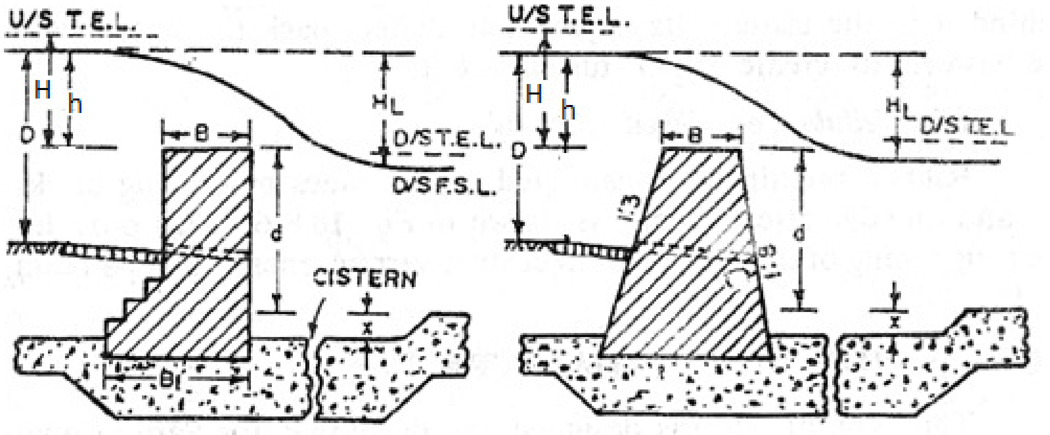
- Design consists of the following component:

- (1) Crest,
- (2) Cistern,
- (3) Impervious floor,
- (4) D/s protection, and
- (5) U/s protection



Design of Vertical Drop Falls: Sarda Type Fall

- **(1) Crest,**
- **1.1 Length of crest**
- Since the fluming is not permissible in such type of falls, the length of the crest is kept equal to width of canal.
- **1.2 Shape of crest**
- It depends upon discharge
- If $Q < 14$ cumecs >> Rectangular
- If $Q > 14$ cumecs >> Trapezoidal



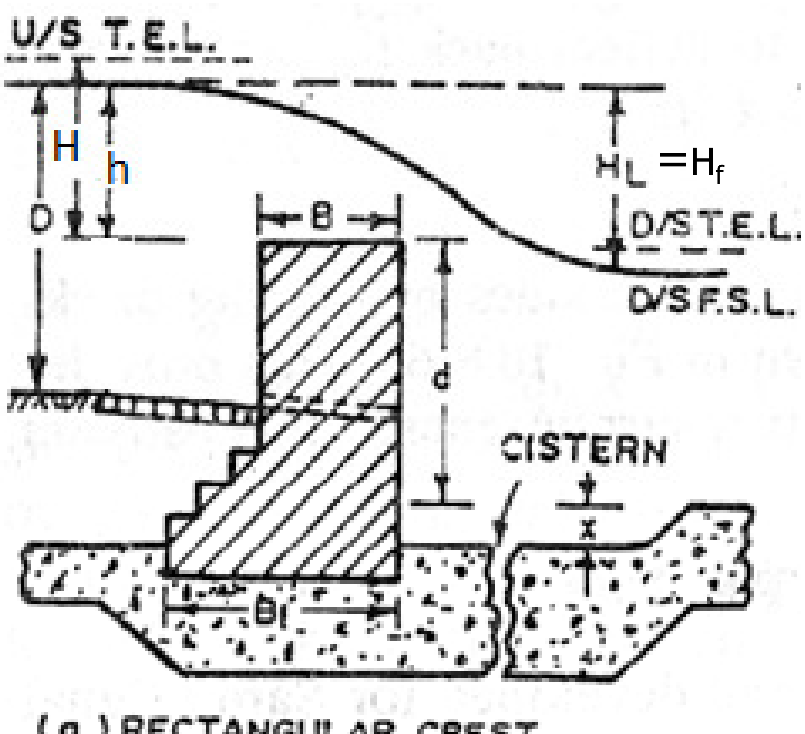
(a) RECTANGULAR CREST
(Q < 14 CUMECS)

(b) TRAPEZOIDAL CREST
(Q > 14 CUMECS)

Design of Vertical Drop Falls: Sarda Type Fall

- For the rectangular crest the Top width (B) and Base width (B_1) of crest are given by
- $B = 0.55(d)^{0.5}$;
- $B_1 = (h + d)/Sc$
- where *Sc = specific gravity of masonry or concrete=2.*
- d= height of crest above d/s bed

- Corresponding discharge (*Q in* m^3/s) *is* given by
- $Q = 1.835LH^{3/2}(H/B)^{1/6}$
- where *L = length of the crest in m.*



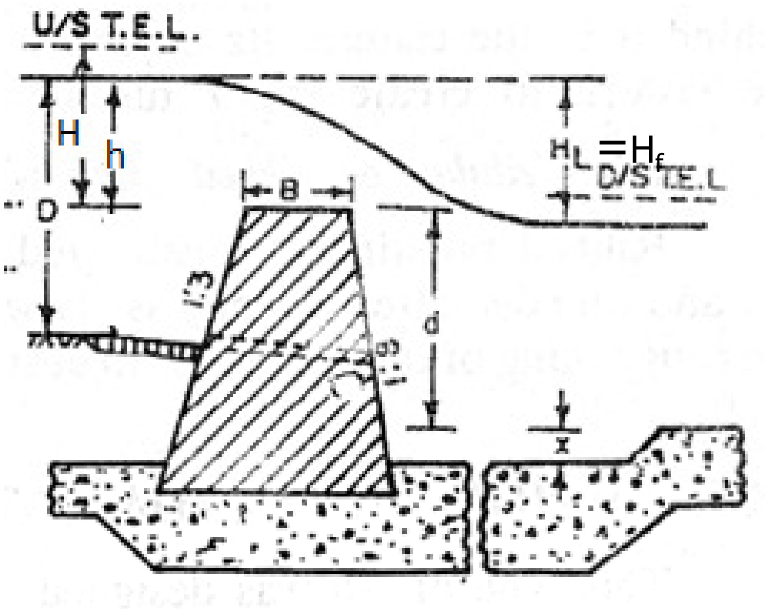
(a) RECTANGULAR CREST
(Q < 14 CUMECS)

Design of Vertical Drop Falls: Sarda Type Fall

- For a trapezoidal crest the Top width of crest is given by:
- $B = 0.55\,(H + d)^{0.5}$

- Slope of U/s face = 1 : 3 and slope of D/s face= 1 : 8.
- Thus the base width is determined by the slopes

- Discharge is given by
- $Q = 1.99LH^{3/2}\,(H/B)^{1/6}$



(b) TRAPEZOIDAL CREST
(Q >14 CUMECS)

Design of Vertical Drop Falls: Sarda Type Fall

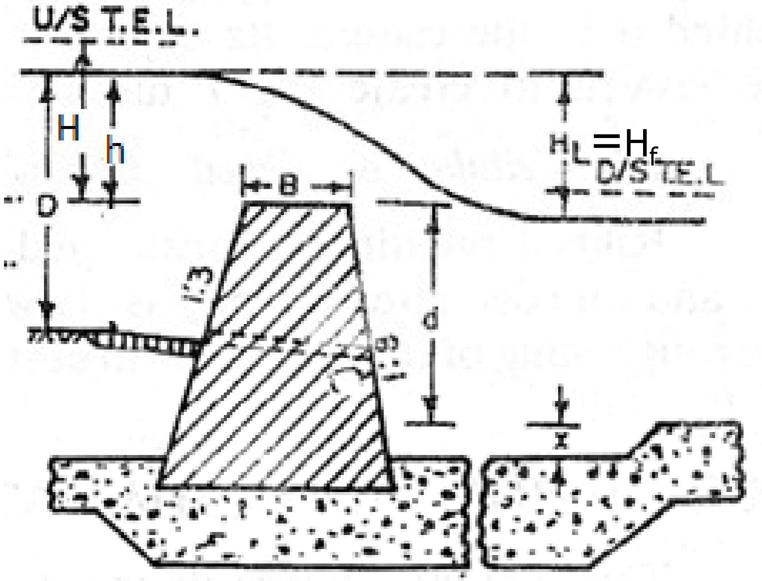
- **Therefore,**

$$Q = C_d \sqrt{2g}\, L H^{3/2} \left(\frac{H}{B} \right)$$

- Cd= 0.415 for rectangular
- Cd=0.45 for trapezoidal crest

- **1.3 Crest level:**
- Find H from discharge formula and then
- Crest level = u/s F. S. L+ velocity head – H
- Crest height = u/s crest level-u/s bed level

- Velocity head=Q/Area of flow at upstream



(b) TRAPEZOIDAL CREST
(Q >14 CUMECS)

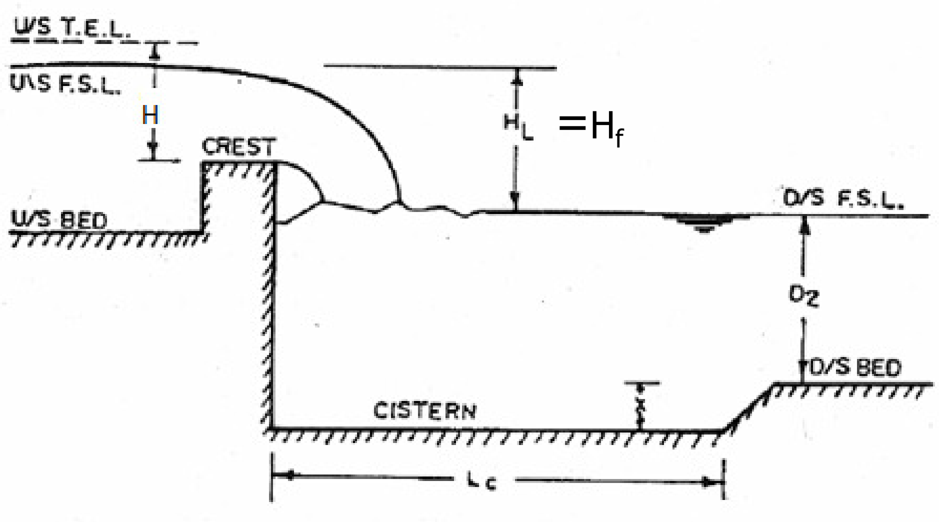
Design of Vertical Drop Falls: Sarda Type Fall

- **(2) Design of Cistern**

- $Lc=5(H.\ H_f)^{0.5}$
- $X=0.25(H.\ H_f)^{2/3}$

- Where;
- Lc= length of cistern in meter
- X=Cistern depression (depth) below the downstream bed in meter.

- H = Head of water over crest, including velocity head, in meter, i.e., (U/S EL – Crest Level)
- H_f= height of fall/drop

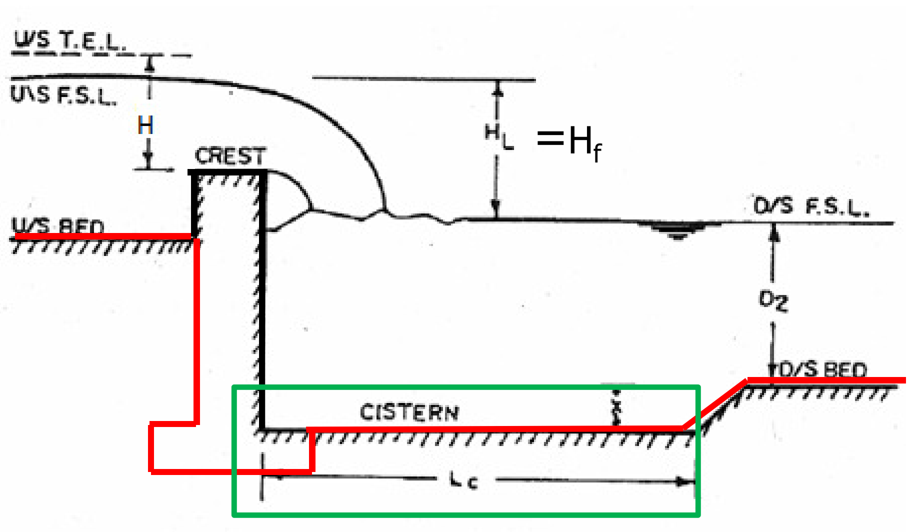


Design of Vertical Drop Falls: Sarda Type Fall

- **(3) Design of impervious floor**
- The total length of impervious floor is determined either by Bligh's theory (for small works) or by Khosla's theory. i.e.,

$$h / L \le 1 / c$$

- Where *h* is head causing seepage

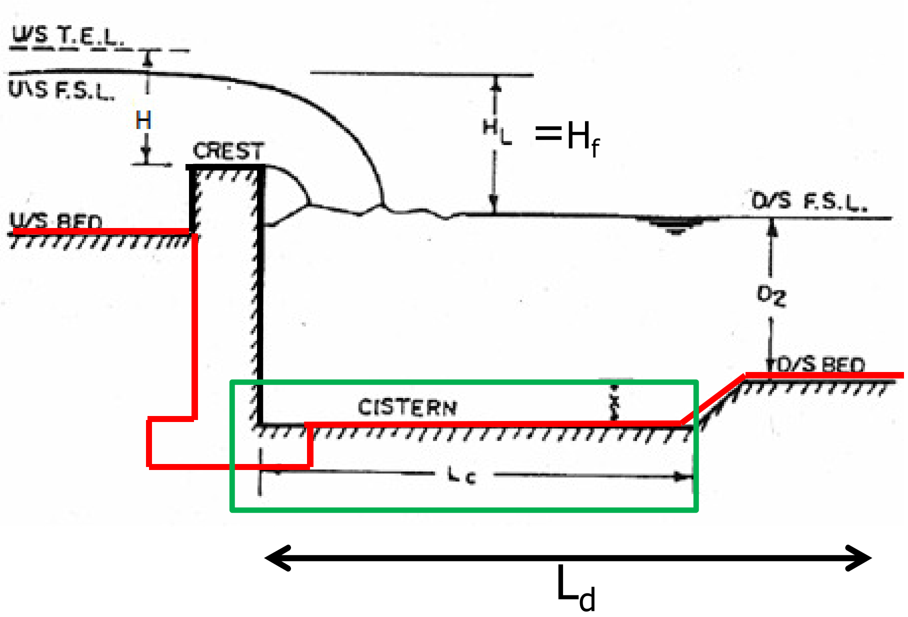


Already decided by the empirical formulae

- **Seepage head is estimated under different operating condition such as**
- i. canal is flowing at maximum level
  - h= U/S FSL-D/S FSL
- ii. Canal is at zero D/S discharge
  - h=CL-D/S BL
- iii. Canal is flowing at partial discharge

Design of Vertical Drop Falls: Sarda Type Fall

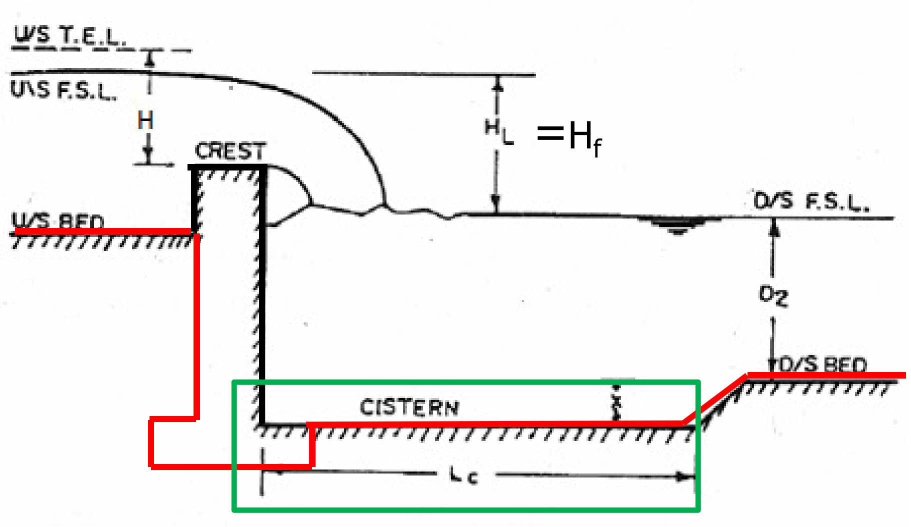
- **(3) Design of impervious floor**
- Out of the total impervious floor length, a minimum length (L_d), to be provided to the d/s of the crest, is given by the following expression:
  - $L_d = 2(D_2+1.2) + H_f$
- The balance of the impervious floor length may be provided under and u/s of the crest.



Already decided by the empirical formulae

Design of Vertical Drop Falls: Sarda Type Fall

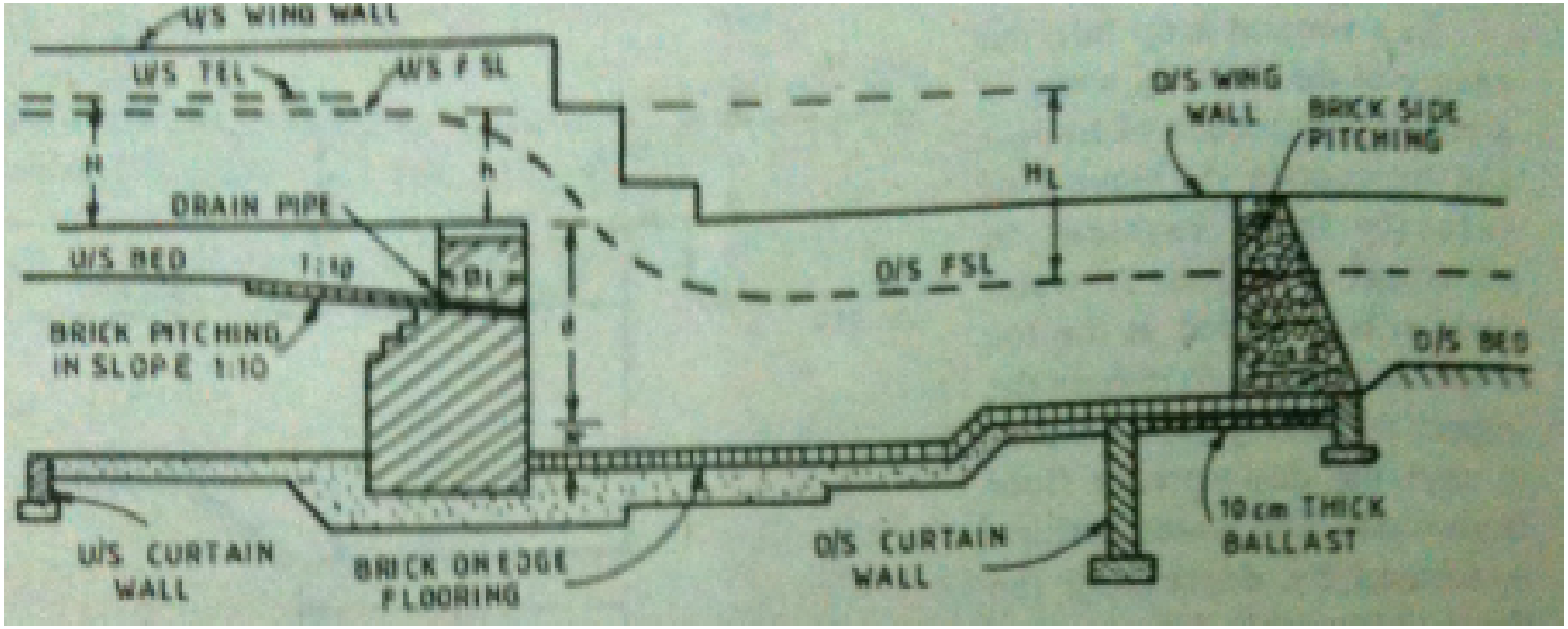
- **3.1 Thickness of impervious floor**
- The thickness of the impervious floor is determined based on the uplift pressure.
- However, a minimum thickness of 0.3 m to 0.4 m is provided for the floor to the u/s of the crest.
- For the floor to the d/s of the crest, the actual thickness depends upon the uplift pressures subject to a minimum of 0.3 to 0.4 m for small falls and 0.4 to 0.6 for large falls.



Already decided by the empirical formulae

Design of Vertical Drop Falls: Sarda Type Fall

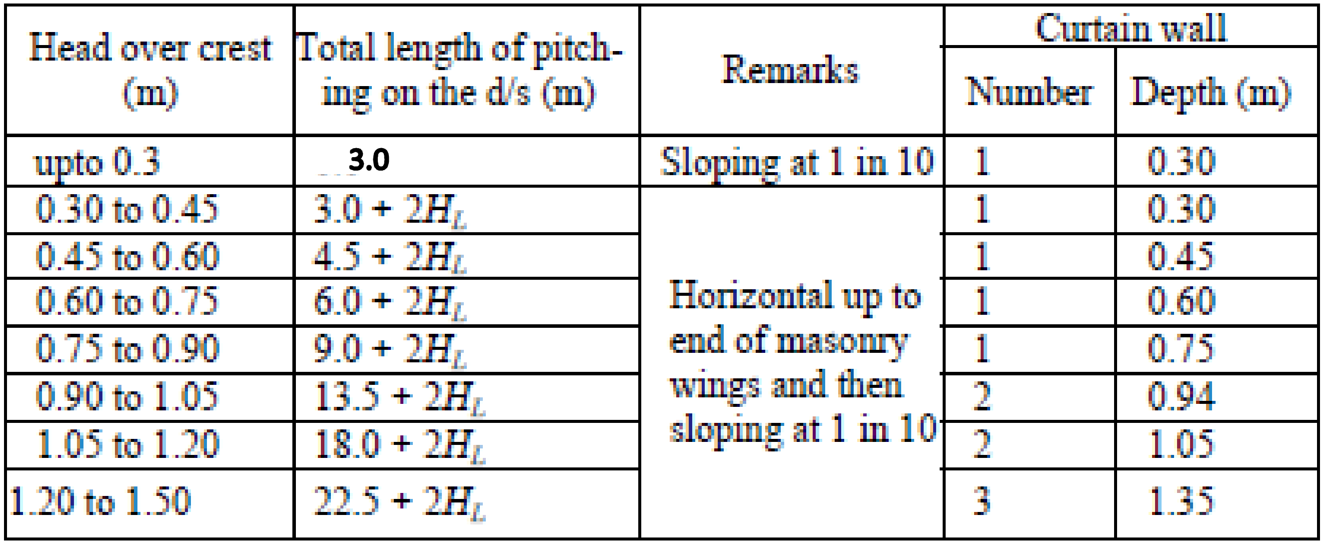
- **(4) D/S protection**
- The d/s protection consists of (i) bed protection, (ii) side protection, and (iii) d/s wings.



Rectangular crest for Sarda type of fall

Design of Vertical Drop Falls: Sarda Type Fall

- **4.1 Bed protection**
- The bed protection consists of dry brick pitching about 20 cm thick resting on 10 cm ballast. The length of d/s pitching is given by the values of Table or **<u>3 times the depth of water</u>**, whichever is greater.
- The pitching may be provided between two or three curtain walls. The curtain wall may be 1.5 inch thick and depth equal to 0.5 d/s water depth



Head over crest (m)	Total length of pitching on the d/s (m)	Remarks	Curtain wall	
			Number	Depth (m)
upto 0.3	3.0	Sloping at 1 in 10	1	0.30
0.30 to 0.45	$3.0 + 2H_L$	Horizontal up to end of masonry wings and then sloping at 1 in 10	1	0.30
0.45 to 0.60	$4.5 + 2H_L$		1	0.45
0.60 to 0.75	$6.0 + 2H_L$		1	0.60
0.75 to 0.90	$9.0 + 2H_L$		1	0.75
0.90 to 1.05	$13.5 + 2H_L$		2	0.94
1.05 to 1.20	$18.0 + 2H_L$		2	1.05
1.20 to 1.50	$22.5 + 2H_L$		3	1.35

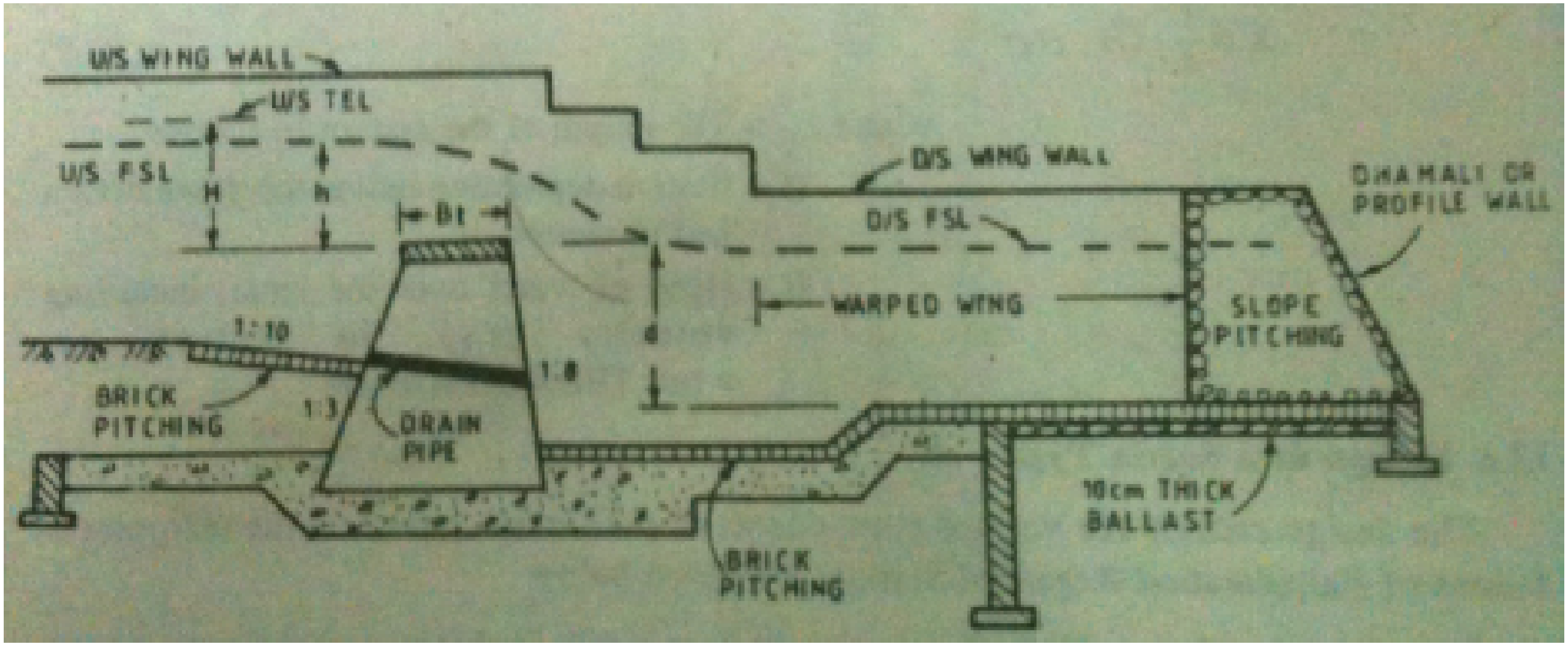
Design of Vertical Drop Falls: Sarda Type Fall

- **4.2. Side Protection,**
- Side pitching, consisting of one brick on edge, is provided after the warped wings. The side pitching is curtailed at any angle of 45° from the end pitching in plan.

- **4.3 D/S Wings**
- The d/s wings are kept vertical for a length of 5 ~ 8 times $(H. H_f)^{0.5}$ *from the* Crest and may then be gradually warped. They should be taken up to end of pakka floor.
- Wing walls must be designed as retaining walls, subjected to full pressure of submerged backfill soil when the channel is closed. For such walls base width is kept equal to 1/3 of its height

Design of Vertical Drop Falls: Sarda Type Fall

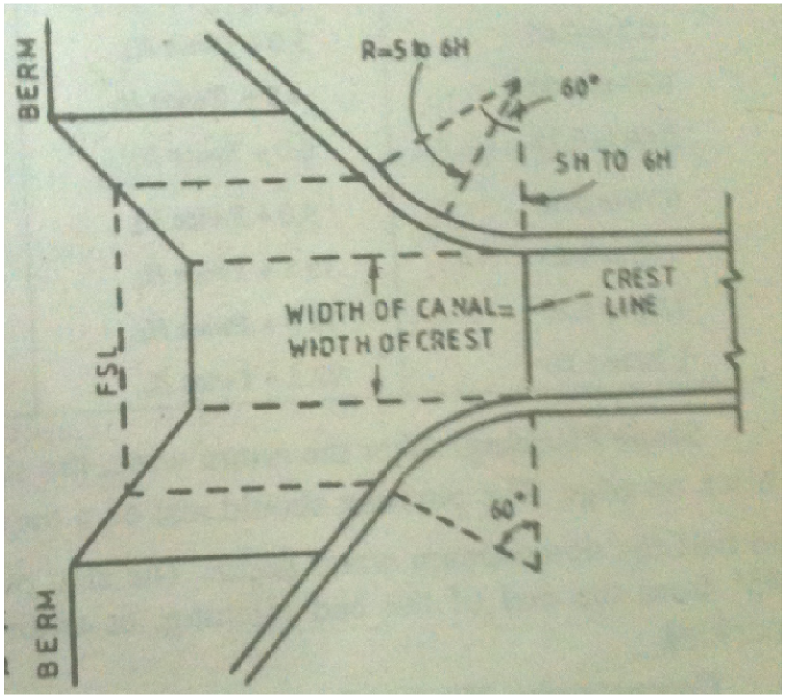
- **(5) U/S Protection**
- It consists of (i) U/S wing wall, (ii) U/S bed protection, and (iii) u/s curtain wall.



Trapezoidal crest for Sarda type of fall

Design of Vertical Drop Falls: Sarda Type Fall

- **5.1 U/S Wing Walls**
- For **rectangular falls** (discharge up to 14 m^3/s), the u/s wings may be splayed, straight at an angle of 45°.
- For **trapezoidal fall** (discharge greater than 14 m^3/s), the wings are kept segmental with radius equal to 5 to 6 times *H,* subtending an angle of 60° at the centre, and then are carried straight into the berm.
- The embedment in the berms or earth banks should be a minimum of 1 m.
- The foundations of the u/s wings are kept on the u/s impervious floor itself



u/s wing wall for trapeziodal crest of Sarda fall

Design of Vertical Drop Falls: Sarda Type Fall

- **5. 2 U/S Bed Protection**
- Brick pitching in a length equal to upstream water depth may be laid on the u/s bed, sloping towards the crest at a slope of 1:10.

- Drain pipes should also be provided at the u/s bed level in the crest so as to drain out the u/s bed during the closer of canal

- **5.3 U/S Curtain Wall**
- 1.5 brick thick upstream curtain wall is provided, having a depth equal to 1/3 rd water depth

Design Problem

- Design a 1.5m Sarda type fall for a canal having a discharge of 12 cumecs with the following data

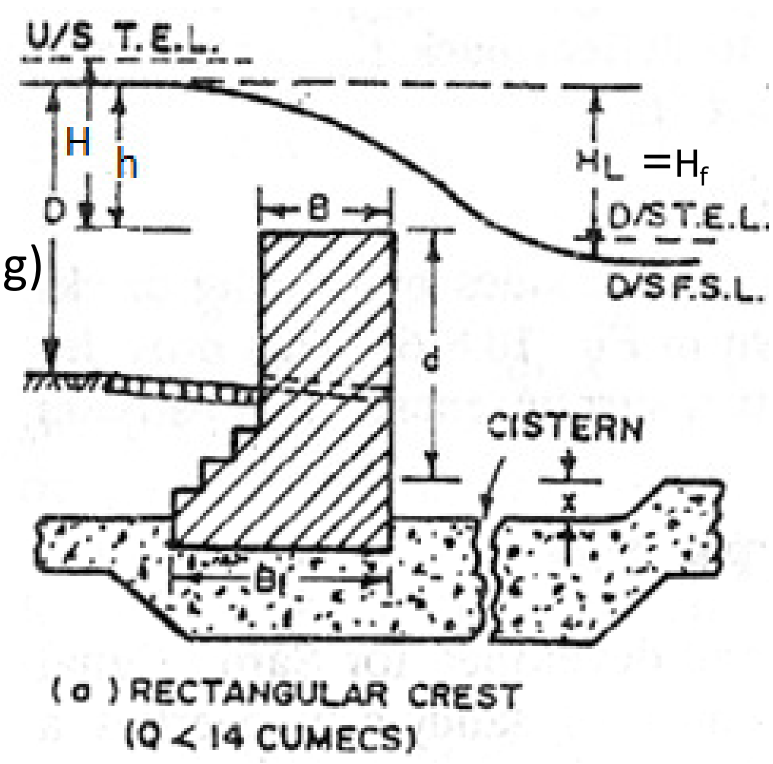
- U/S bed level= U/S BL= 103.0m
- Side slopes of Channel=1:1
- D/S bed level=D/S BL=101.5m
- U/S full supply level=U/S FSL=104.5m
- Bed width at U/S and D/S=10m
- Bligh's coefficient=c=7.5

Design Problem

- **Solution**

- **Length of Crest:**
- Same as d/s bed width = 10m (No fluming)

- **Crest level**
- First of all assume top width, B=0.8m



(a) RECTANGULAR CREST
(Q < 14 CUMECS)

$$Q = 1.84 L H^{3/2} \left(\frac{H}{B} \right)^{1/6}$$

$$12 = (1.84)(10) H^{3/2} \frac{H^{1/6}}{(0.8)^{1/6}}$$

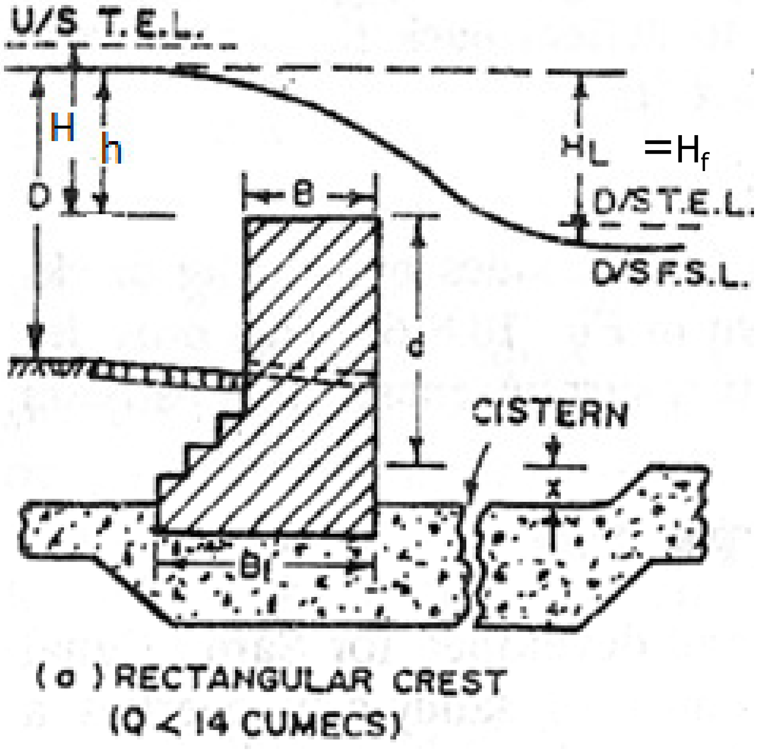
$$H = 0.755 = 0.76m$$

$$\text{Velocity of approach, Va} = Q/A = 12/[(10+1.5)1.5]$$

$$Va = 0.696 m/s$$

Design Problem

$$\text{Velocity head} = Va^2/2g = 0.025m$$
$$U/S\ EL = U/S\ FSL + Velocity\ head$$
$$U/S\ EL = 104.5 + 0.025 = 104.525m$$
$$R.L\ of\ Crest = U/S\ EL - H$$
$$R.L\ of\ Crest = 104.525 - 0.755 = 103.77m$$



(a) RECTANGULAR CREST
(Q < 14 CUMECS)

- **Shape of crest**

$$B = 0.55\sqrt{d}$$
$$d = \text{height of crest above d/s bed}$$
$$d = 103.77 - 101.5 = 2.27m$$
$$B = 0.55\sqrt{2.27} = 0.825m > 0.8m\ !!$$

Therefore, keep width of crest as 0.85m

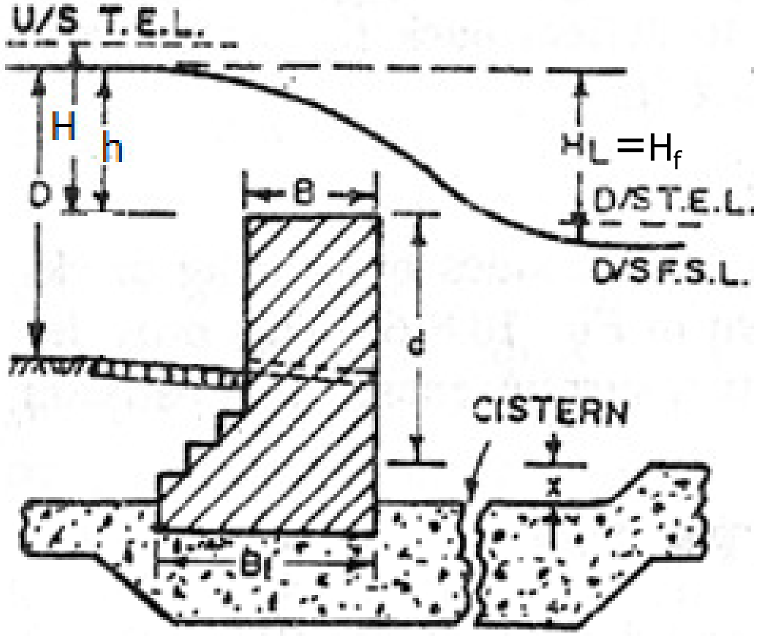
Design Problem

- **Shape of crest**

$$\text{Thickness at base} = \frac{\mathrm{h} + \mathrm{d}}{S_c}$$

$$\text{Thickness at base} = \frac{(0.755 - 0.025) + 2.27}{2} = 1.5m$$

Where, h in above formula is head over crest of water excluding velocity head



(a) RECTANGULAR CREST
(Q < 14 CUMECS)

Design Problem

- **Design of Cistern**

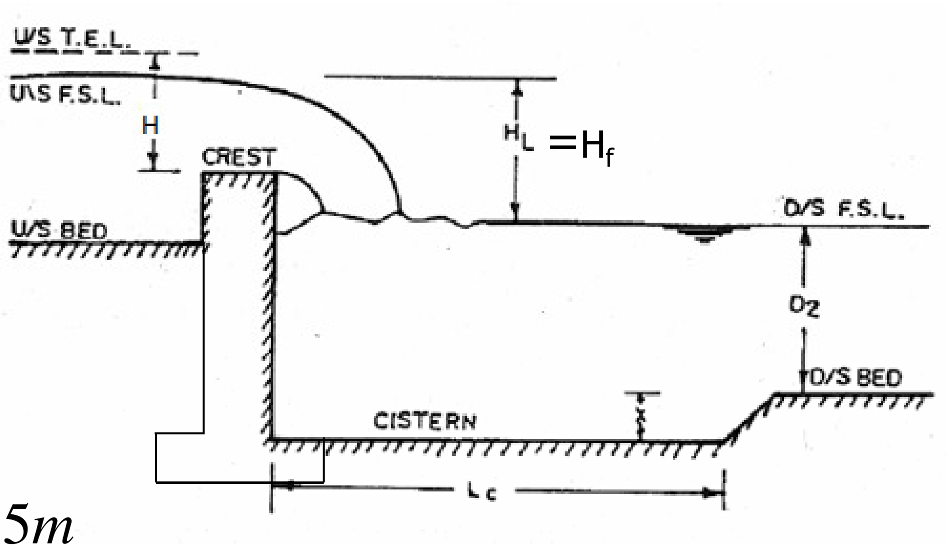
$$Depth = X = 0.25(H.H_f)^{2/3}$$

$$X = 0.25(0.76 \times 1.5)^{2/3}$$

$$\mathrm{X} = 0.273m = say\ 0.3m$$

$$Length = Lc = 5\sqrt{H.H_f}$$

$$Lc = 5\sqrt{0.76 \times 1.5} = 5.34m = say\ 5.5m$$



Now lets compute length of impervious floor. For this , first of all, lets assume a footing geometry as shown in figure

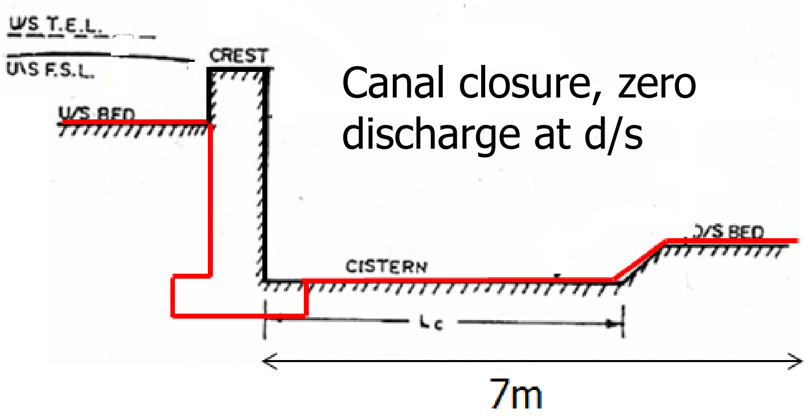
Design Problem

- **Length of Impervious floor**
- According to Bligh's theory

$$h/L \leq 1/c$$

- h=Head causing seepage
- **h=CL-D/S Bed Level**
- **h=103.77-101.5=2.27m**
- Minimum creep length=say minimum length of impervious floor

$$L = h \times c$$
$$L = 2.27 \times 7.5$$
$$= 17.025m$$
$$= say\ 17.1m$$

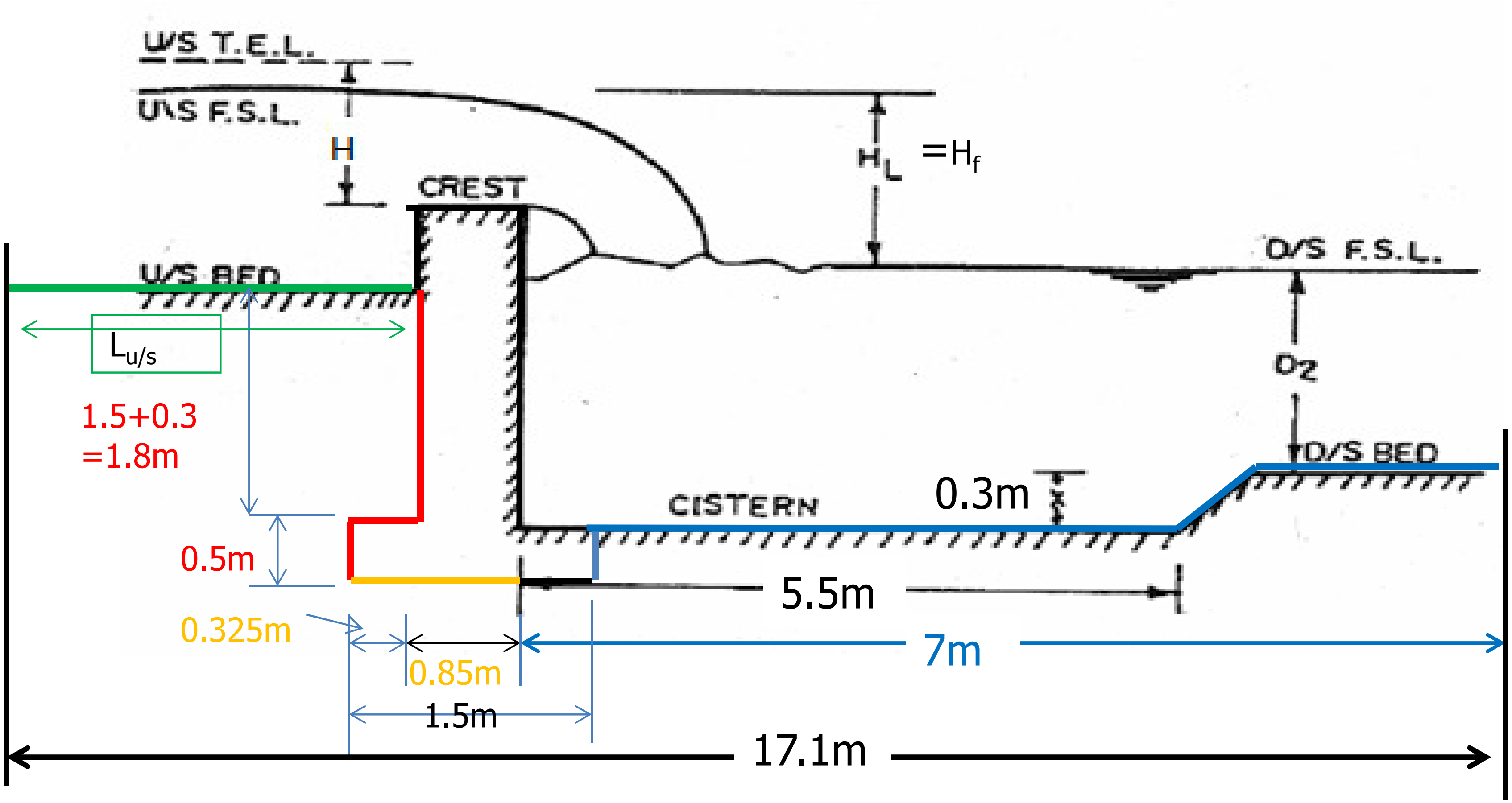


Canal closure, zero discharge at d/s

Minimum Length of D/S floor

$$= 2(water\ depth + 1.2) + H_f$$
$$= 2(1.5 + 1.2) + 1.5 = 6.9m = say\ 7m$$

Design Problem



U/S Floor Length=Lu/s=17.1-7-0.85-0.325*2-2*0.5-1.8=5.8m

U/S Floor Length=Lu/s=say **5.8m**

Design Problem

- Design other u/s and d/s protections with the help of guidelines already discussed in lecture.

Design Problem

- Design a suitable fall structure over an irrigation canal (Hydraulic Design only) for the following set of data:

Full Supply Discharge	25 m^3/s
Canal Bed width	20 m
U/S full supply level	414.4 m
D/S full supply level	412.9 m
U/S bed level	412.8 m
D/S bed level	411.3 m
Natural surface level	412.5 m
Bligh’s coefficient	7.5

Draw the neat sketch of the designed values.

Design Problem

- The following set of data relates to a fall structure:
- Full Supply Discharge = 60 m^3/s Bed width = 25 m
  U/S full supply level = 245.5 m   D/S full supply level = 244 m
  U/S bed level = 243.5 m   D/S bed level = 242 m
  Natural surface level = 241 m C_d = 0.65
- Estimate the crest level of the fall if water level has to be maintained u/s of fall structure.