Design of Canal Fall

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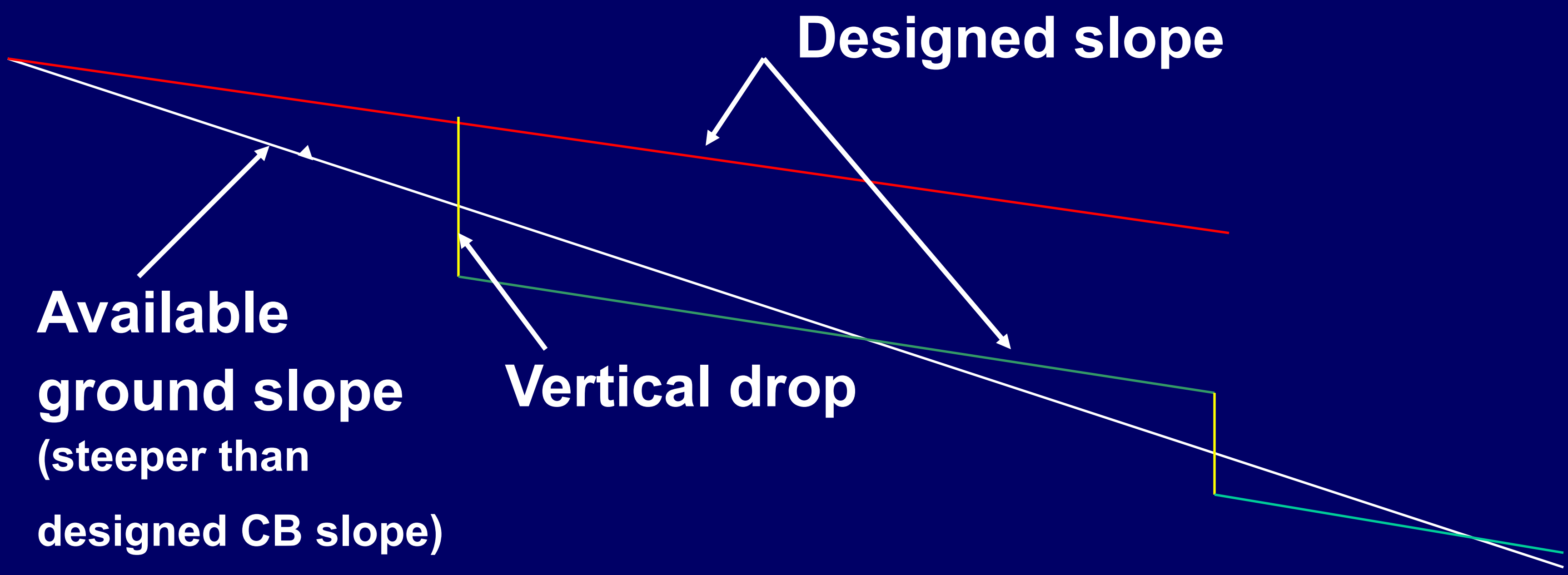
Canal Fall?



A fall is a structure constructed across a channel to permit lowering down of its water level and dissipate the surplus energy possessed by the falling water which may otherwise scour the bed and banks of channel.

Necessity of a Canal Fall

- The necessity of a canal fall arises because the available ground slope usually exceeds the designed bed slope of a canal.

- Disadvantages of a canal in embankment
  - 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

Location of Fall

- Main canal:- Economy in the “cost of excavation and filling” vs cost of Fall.

- Branch Canals and Distributary Channels:- The Falls are located with consideration to command area.

  - Procedure – To fix FSL required at the head of the off taking channels and outlets and mark them on the L-section of the canal.

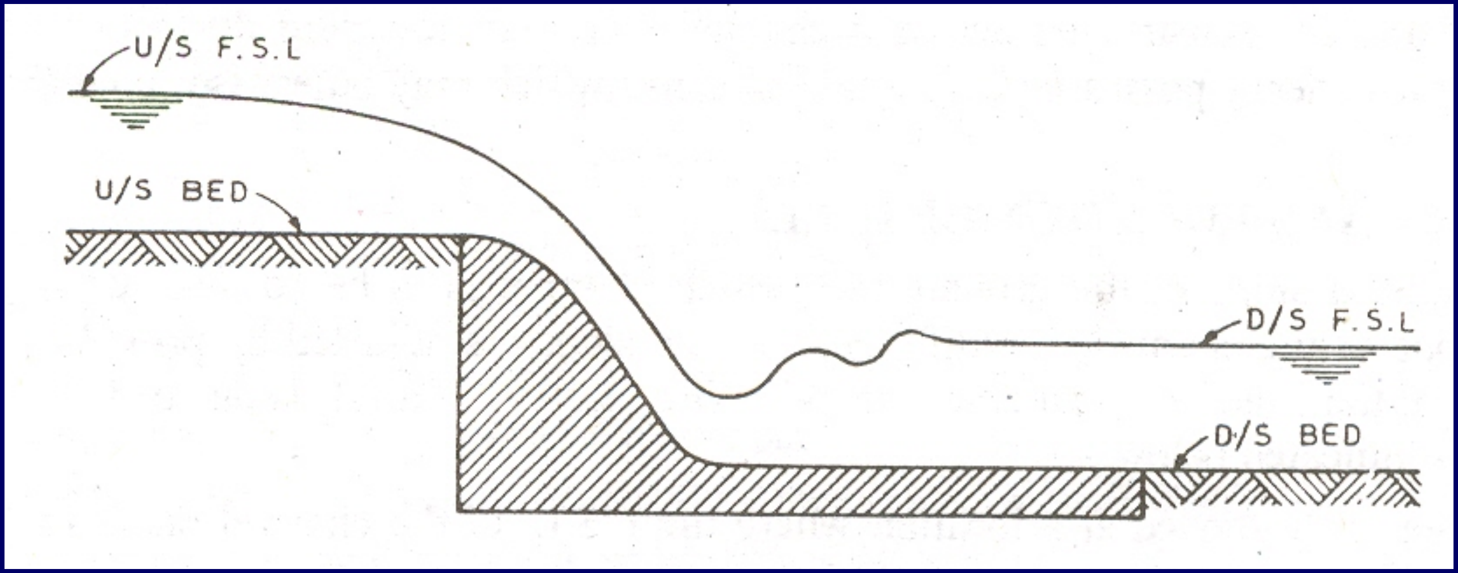
  - The FSL of the canal can then be marked as to cover all the commanded points, thereby deciding suitable locations for falls in canal FSL, and hence in canal beds.

- The location of Falls may also be influenced by the possibility of combining it with a bridge, regulator, or some other masonry work, since such combinations often result in economy and better regulation.

Types of Falls

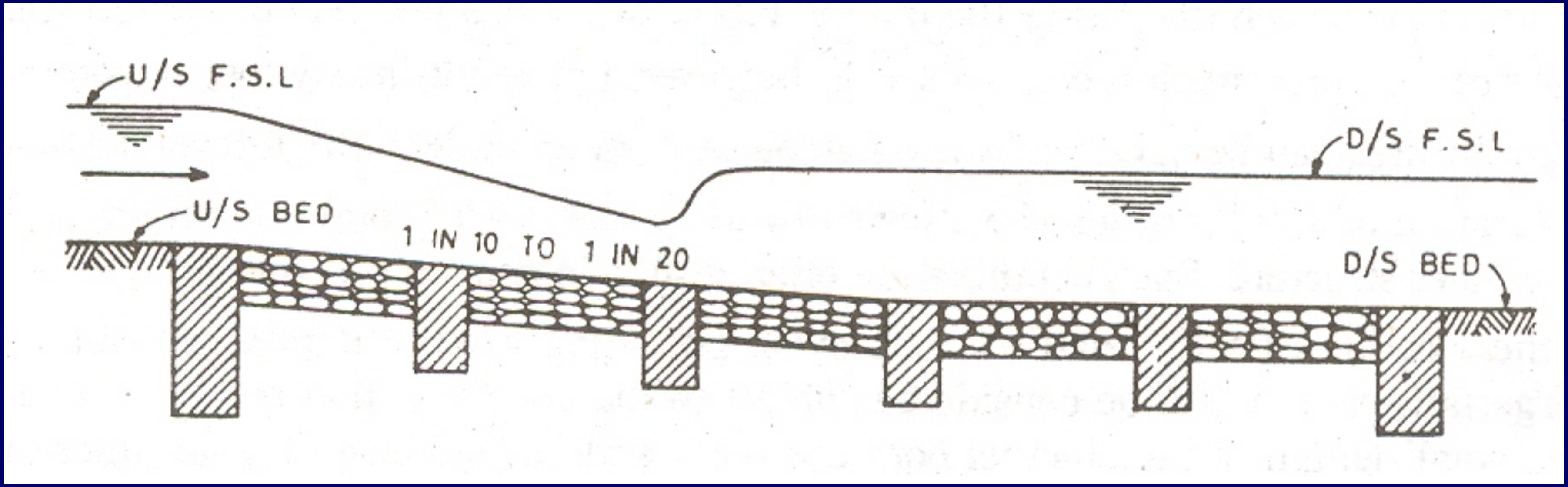
- Ogee Fall
- Rapids
- Stepped Fall
- Trapezoidal Notch Falls
- Well Type falls or cylinder falls or syphon well drops
- Simple vertical drop type and Sarda type falls
- Straight glacis fall
- Montague type fall
- Inglis fall or Baffle fall

Ogee Fall



- **Constructed in olden days (Ganga canal)**
- **water is gradually led down by providing convex and concave curves**
- **Heavy drawdown on the u/s side resulting in lower depth, higher velocities and consequent bed erosion**
- **due to smooth transition, kinetic energy of flow was not at all dissipated, causing erosion of d/s beds and banks.**

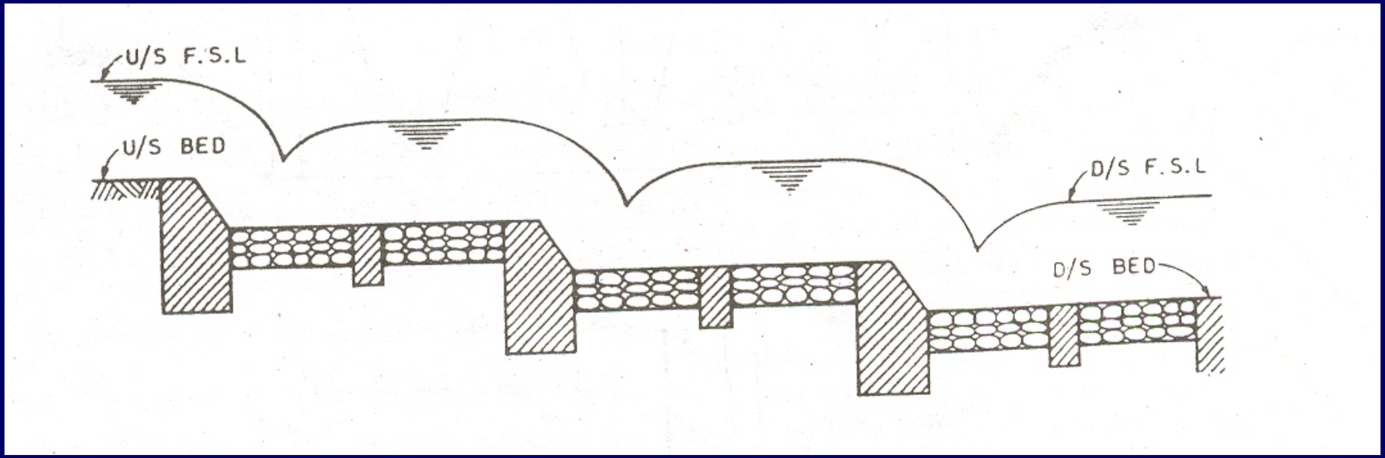
Rapids



- In Western Yamuna canal, long rapids at slopes 1:15 to 1:20 (gently sloping glacis) with boulder facings, were Provided.

- worked quite satisfactorily, but were very expensive.
- Hence, not obsolete.

Stepped Fall

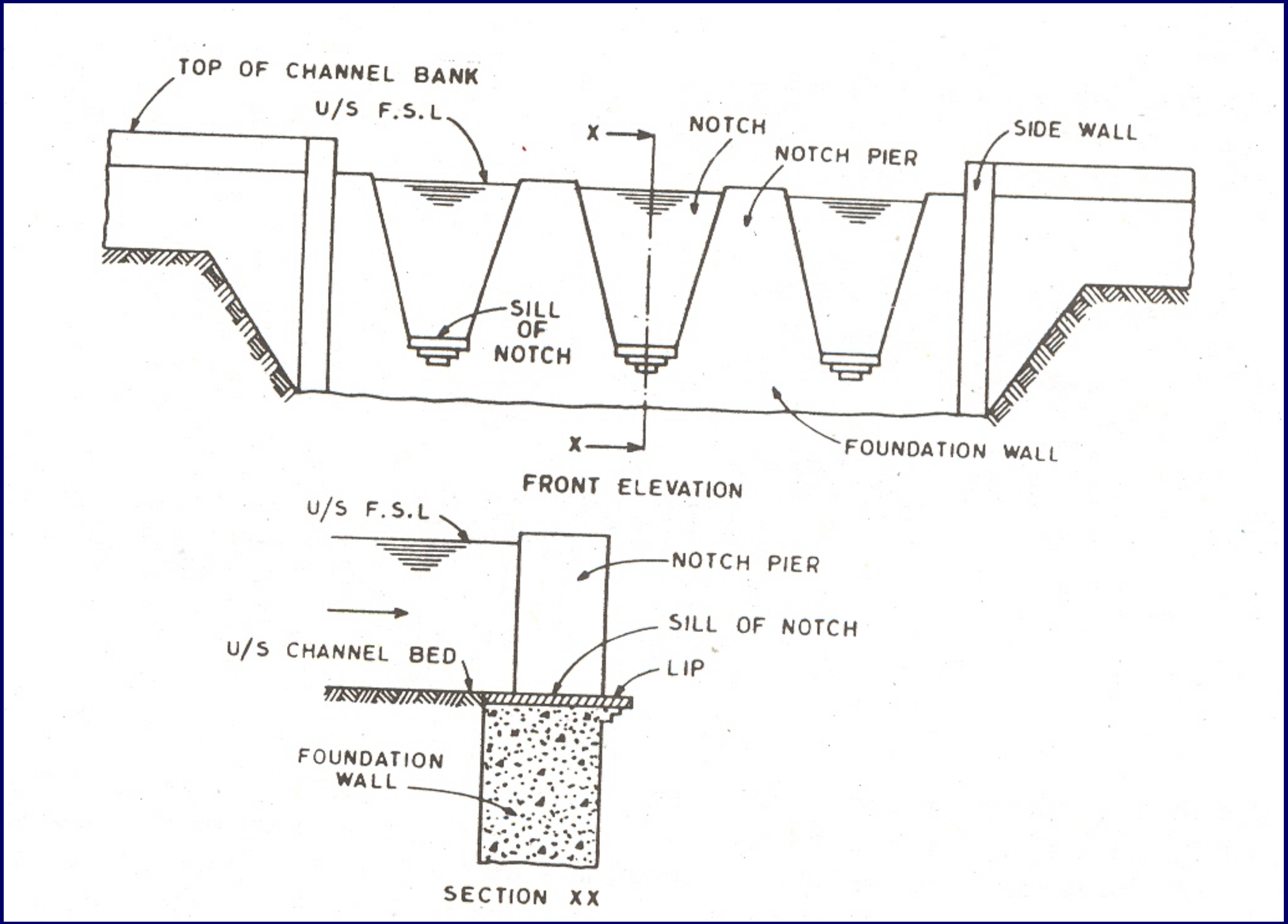


- Stepped falls were the modified form of rapid falls in the respect that the long glacis of the rapid falls were replaced by the floors in steps.
- However, the cost of construction of the stepped falls was also very high.

Stepped Fall

- After Stepped fall, it was recognised that better dissipation of energy could be achieved through vertical impact of falling jet of water on the floor.
- As such, vertical falls with cistern were evolved.
- However, earlier types of vertical falls were not well developed and gave trouble.
- These were superseded by trapezoidal notch, for sometime.
- But it lead the development of vertical drop type fall and glacis type fall.

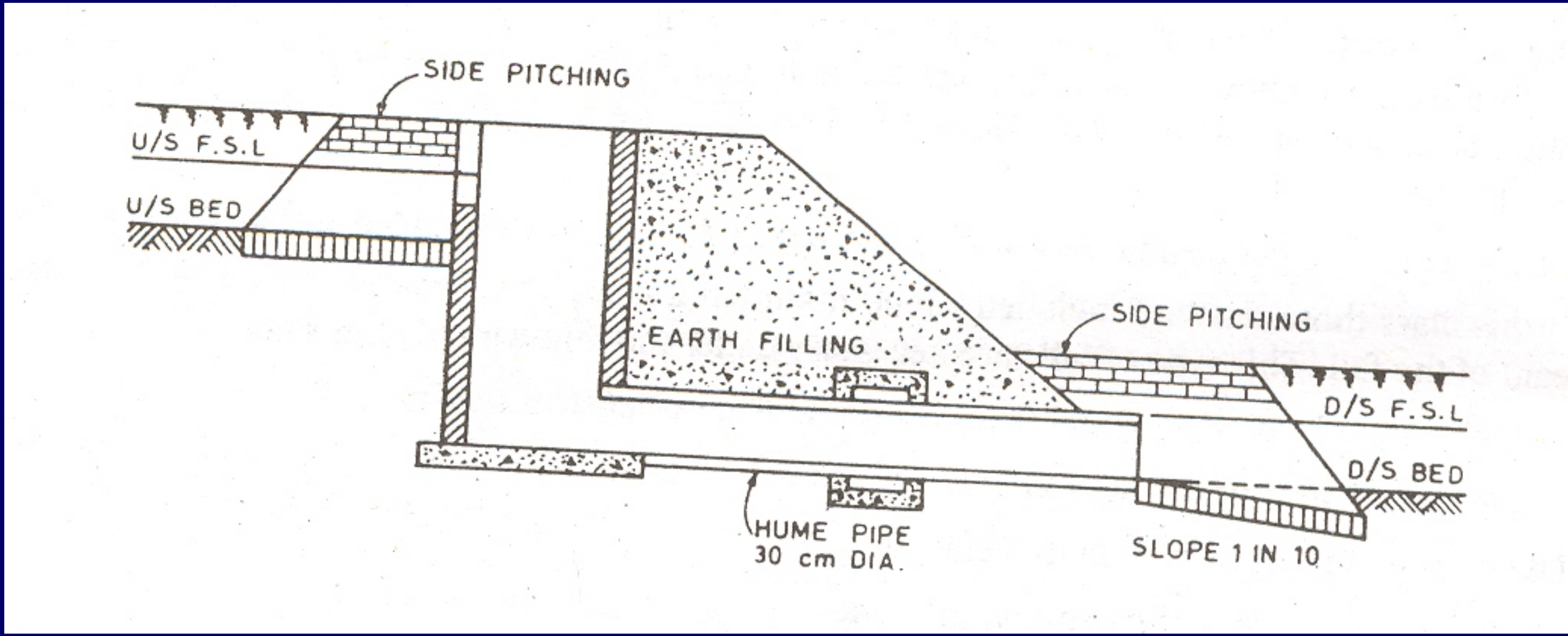
Trapezoidal Notch Fall



Trapezoidal Notch Fall

- Developed by Reid (1894)
- Consists of a number of trapezoidal notches constructed in a high crested wall across the channel with a smooth entrance and a flat circular lip projecting d/s from each notch to spread out the falling jet.
- Notches could be designed to maintain the normal water depth in the u/s channel at any two discharges, as the variation at intermediate value is small.
- These falls remained quite popular, till simpler, economical and better modern falls were developed.

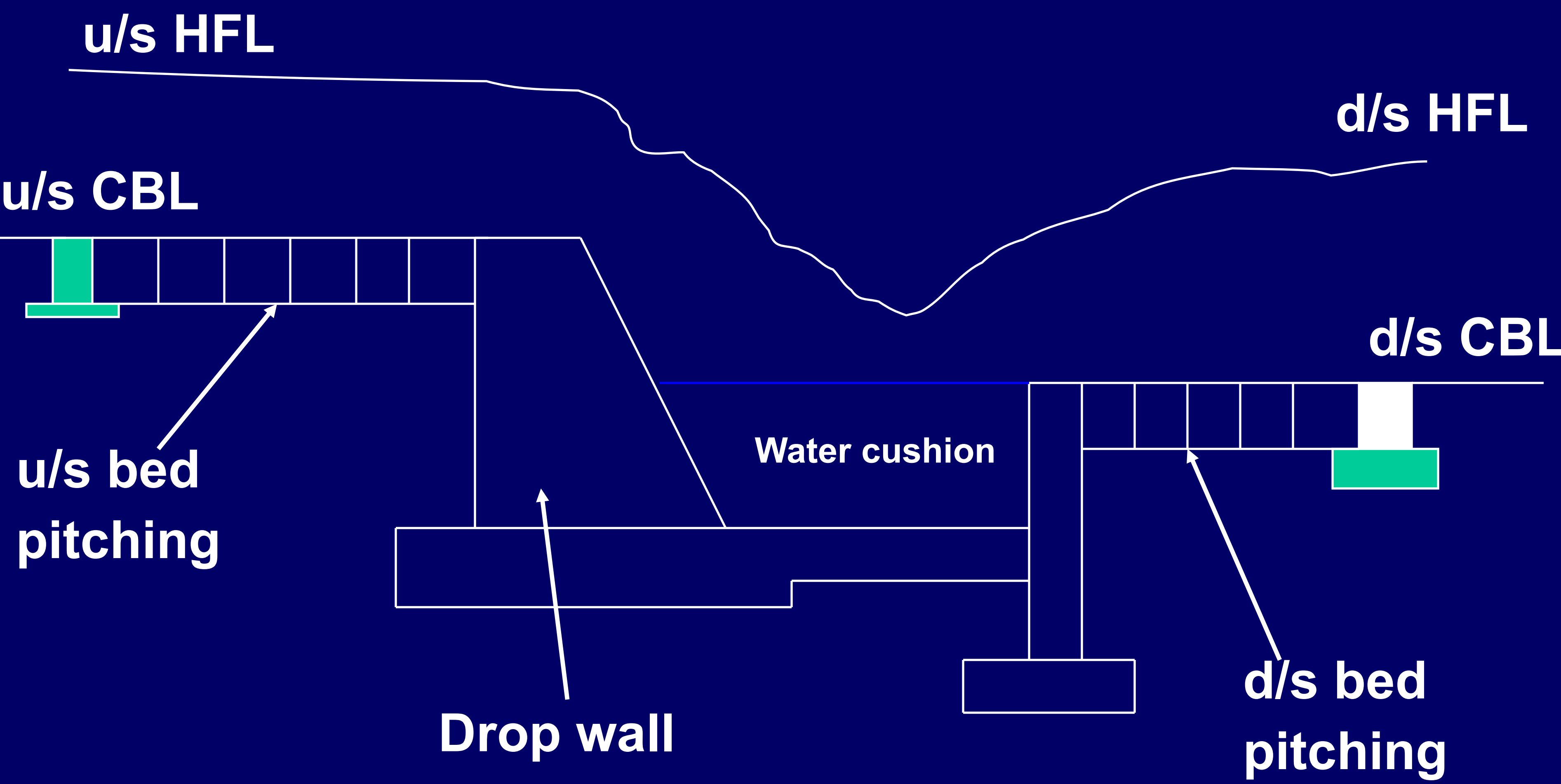
Well Type falls or cylinder falls or syphon well drops



- d/s well is necessary for falls greater than 1.8 m and for discharges greater than 0.29 cumec.
- Very useful for affecting larger drops for smaller discharges.
- Commonly used as tail escapes for small canals, or where high levelled smaller drains do outfall into a low level bigger drain.

Types of Falls

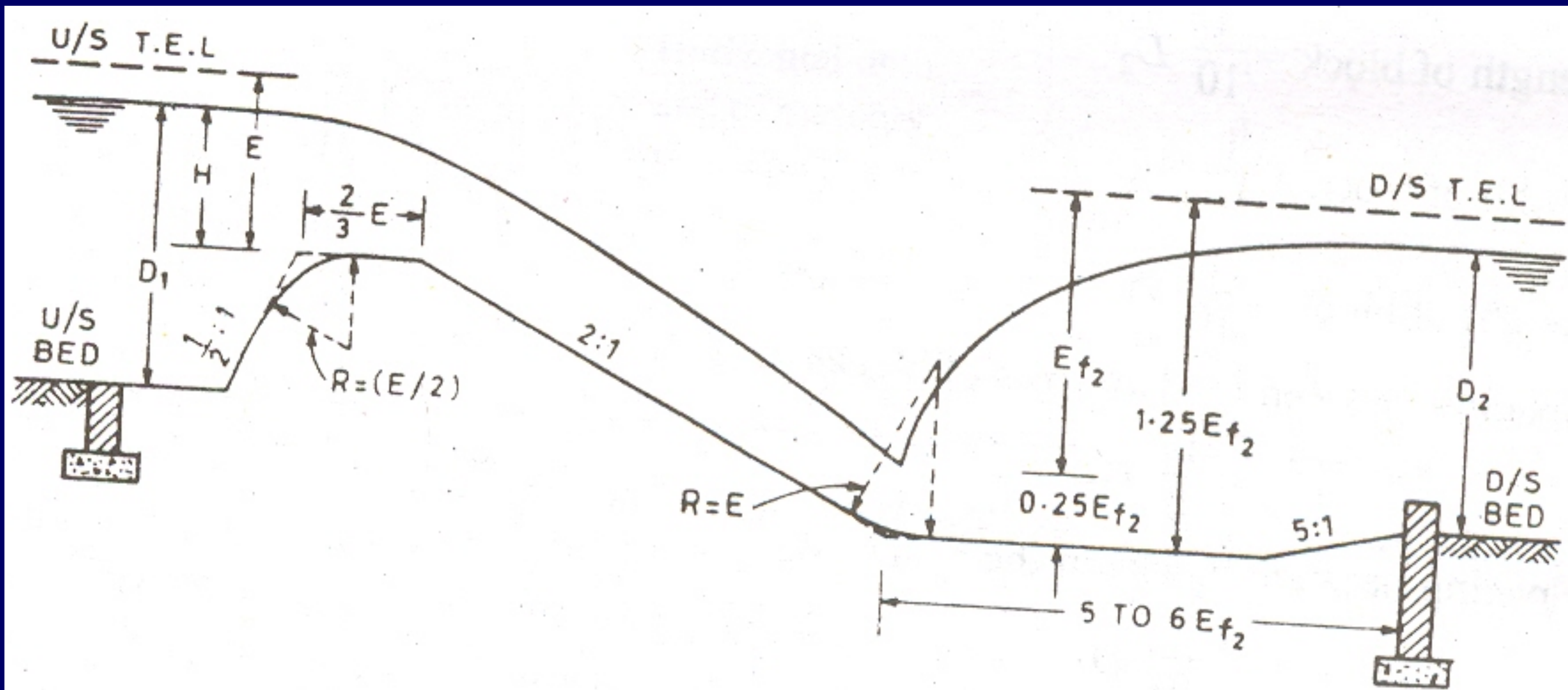
- Simple vertical drop type and Sarda type falls



Simple vertical drop type and Sarda type falls

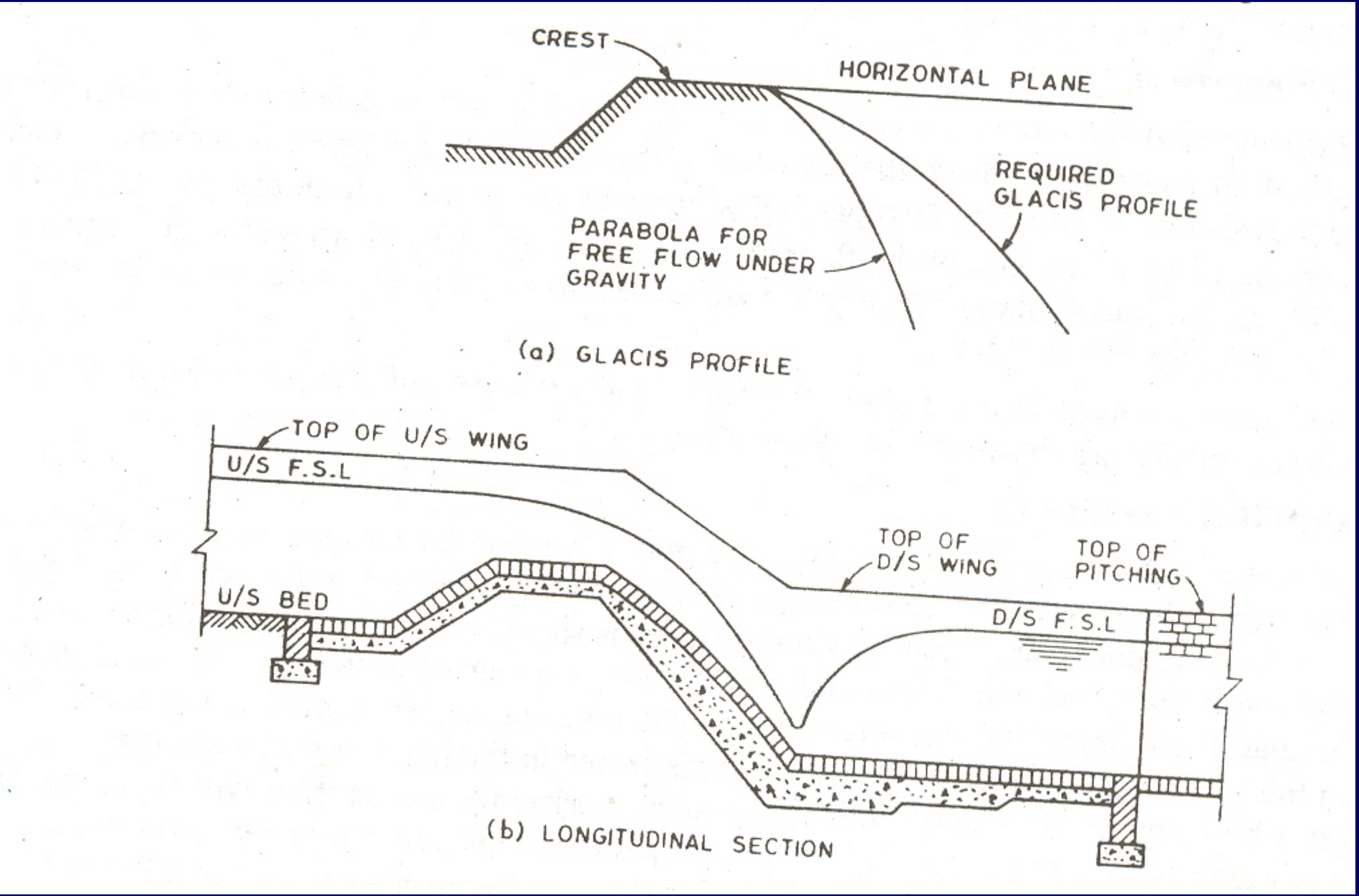
- Introduced in Sarda canal system in UP (required large nos of falls)
- In that area, a thin layer of sandy clay overlaid a stratum of pure sand.
- The clear nappe leaving the crest is made to impinge into a cistern below.
- The cistern provides a water cushion and helps to dissipate the surplus energy of the falling jet.

Straight Glacis Fall



- This is modern type of fall.
- Hydraulic jump is made to occur on the glacis, causing sufficient energy dissipation.
- Suitable upto 60 cumecs discharge and 1.5 m drop.

Montague type of Fall



Montague type of Fall

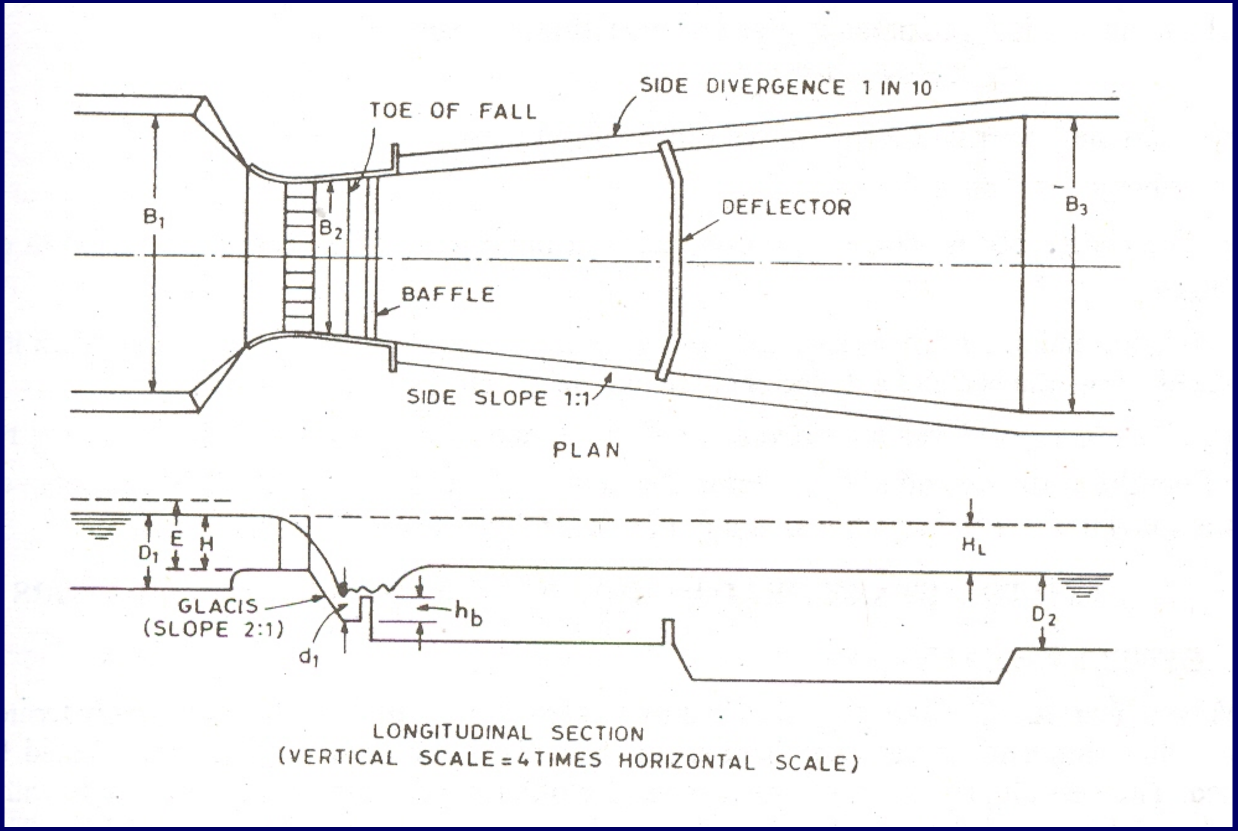
- Energy dissipation on a straight glacis remains incomplete due to vertical component of velocity remaining incomplete.

- An improvement in energy dissipation may be brought about in this type of fall by replacing the straight glacis by a parabolic glacis, commonly known as Montague profile.

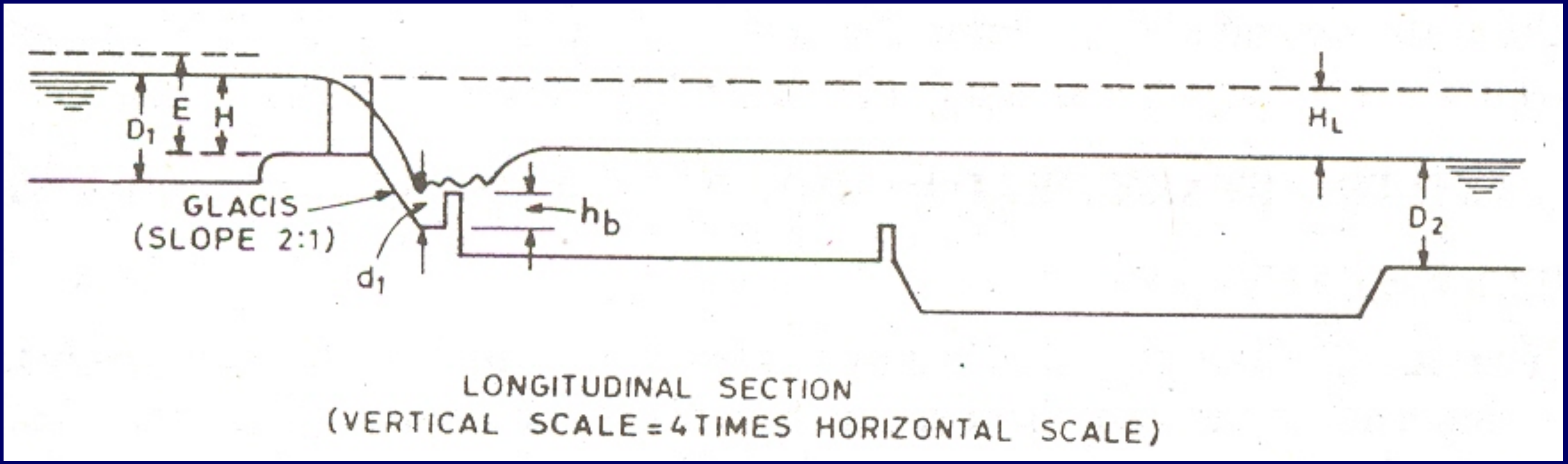
- The curve glacis is difficult to construct.

- Generally not adopted in India.

Inglis fall or Baffle fall



Inglis fall or Baffle fall



- A straight glacis fall added with a baffle platform and a baffle wall, was developed by Inglis and is called “Inglis fall” or “baffle fall”.
- Quite suitable for all discharges and for drops of more than 1.5 m

Design of Sarda type Fall

Complete design of Sarda type fall consists of the following

- Crest wall
- cistern
- Impervious floor
- d/s protection
- u/s approach

Design of Sarda type Fall – Crest wall

(1) Design of crest wall

(i) Length of crest wall

normally length of crest wall = bed width of channel

In case of future development of irrigation & increase in discharge capacity

length of crest wall = bed width of channel + water depth

Design of Sarda type Fall – Crest wall

(ii) Shape of crest wall

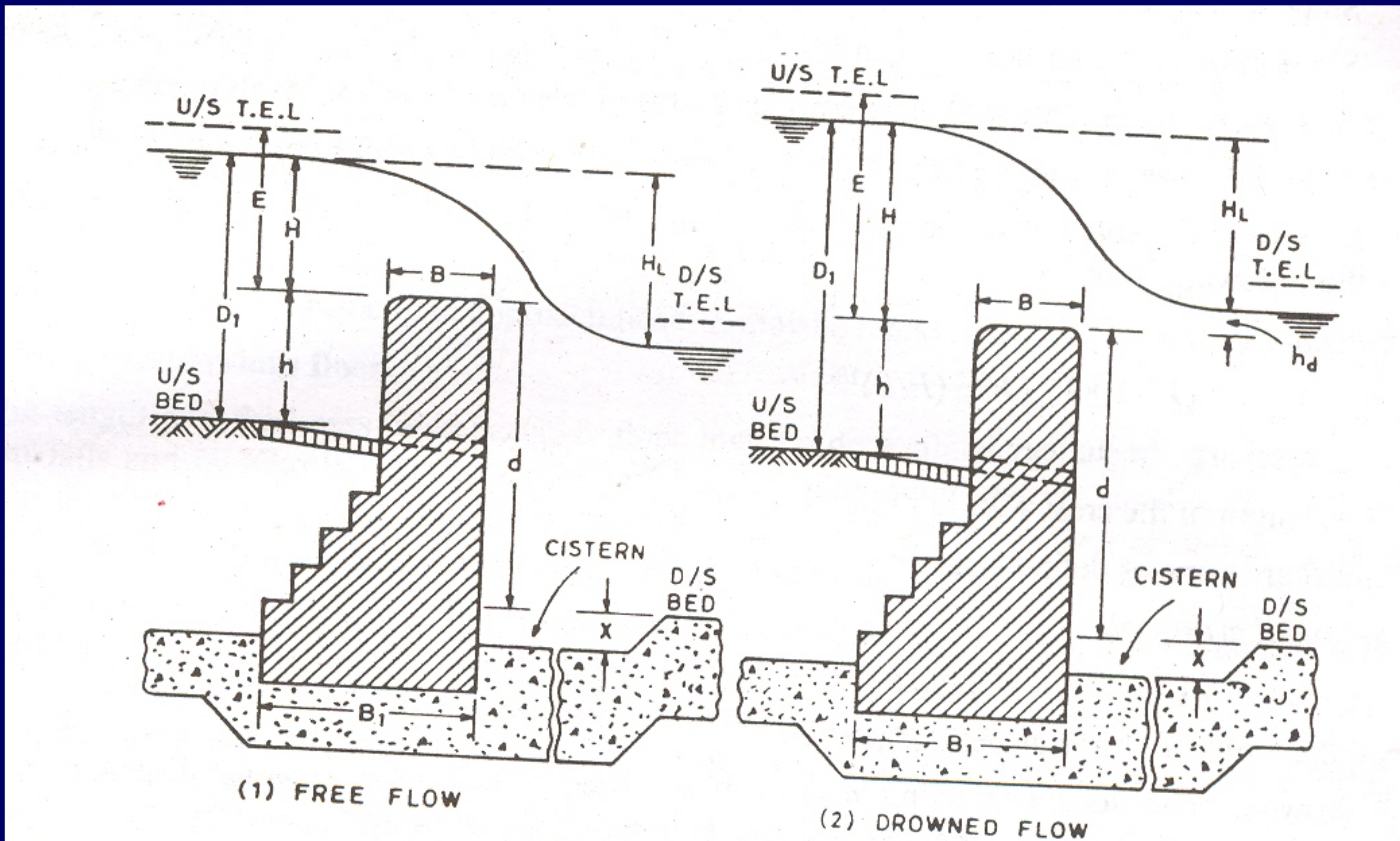
For discharge < 14 cumec →

crest wall rectangular in section with both u/s and d/s faces vertical.

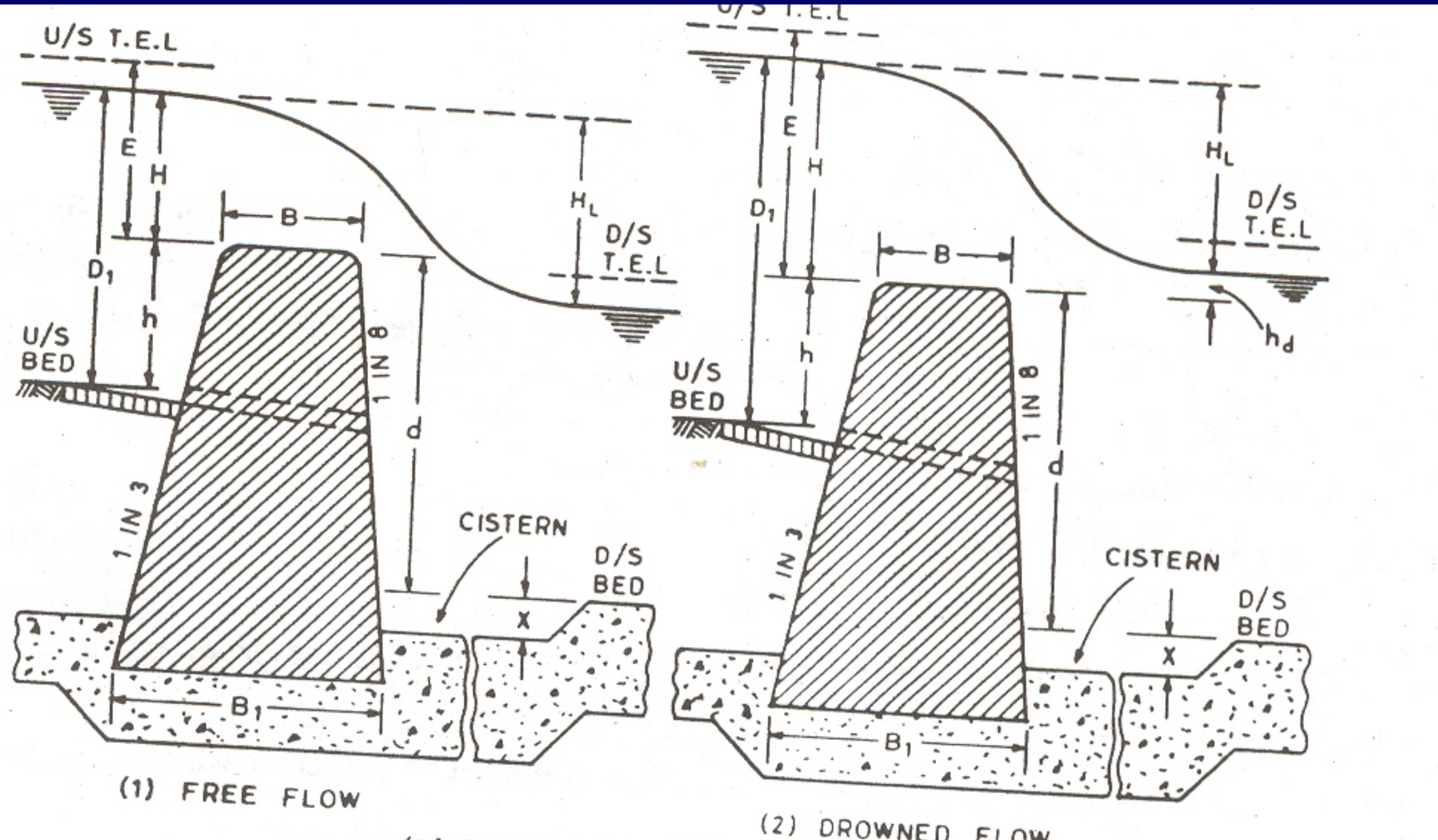
For discharge > 14 cumec →

crest wall TRAPEZOIDAL in section with u/s face having a slope of 1 in 3 and d/s face 1 in 8.

Design of Sarda type Fall – Crest wall



Design of Sarda type Fall – Crest wall



(b) TRAPEZOIDAL CREST

Design of Sarda type Fall – Crest wall

(ii) Shape of crest wall

Rectangular crest wall

$$B = 0.55\sqrt{d}$$

$$B_1 = \frac{H + d}{G}$$

where G = sp gravity of the material of the crest wall (for masonry G =2)

Trapezoidal crest wall

$$B = 0.55\sqrt{H + d}$$

Design of Sarda type Fall – Crest wall

(iii) Discharge formula

Rectangular crest wall

$$Q = 1.835 L H^{3/2} \left(\frac{H}{B} \right)^{1/6}$$

where L = length of crest wall

Trapezoidal crest wall

$$Q = 1.99 L H^{3/2} \left(\frac{H}{B} \right)^{1/6}$$

(iv) Crest level for free overfall condition

Crest level = u/s FSL - H

Design of Sarda type Fall – Crest wall

(v) Bed protection u/s of crest wall

Brick pitching is laid on the channel bed for 2 to 4 m length, sloping downwards towards the crest wall at 1 in 10.

Design of Sarda type Fall – Cistern

(2) Design of cistern

$$L_c = 5\sqrt{EH_L}$$

$$x = \frac{1}{4}(EH_L)^{2/3}$$

(neglecting the small velocity of approach head, E may be replaced by H)

Design of Sarda type Fall – Impervious Floor

(3) Design of Impervious Floor

Bligh's theory – for small & medium falls

Khosla's theory – for large falls

Maximum seepage head :

when there is water on the u/s side upto the top of crest wall and there is no flow on the d/s side.

Thus the Maximum seepage head = d

Out of the total length of the impervious floor a minimum length l_d is to be provided on the d/s of toe of the crest wall, which is

$$l_d = 2(D_1+1.2) + H_L$$

Design of Sarda type Fall – Impervious Floor

- Draw HGL and determine thickness of floor
- Min^m thickness on u/s side = 0.3 m
- Min^m thickness on d/s side = 0.3-0.4 for small falls

  = 0.4-0.6 for large falls

Cutoffs /curtain walls

(a) u/s cutoff Minimum depth = $D_1/3$

D_1 = u/s Full supply depth

(a) d/s cut off Minimum depth = $D_2/2$

D_2 = d/s Full supply depth

Design of Sarda type Fall – Protection Works

(4) Downstream protection works

i. Bed protection
ii. Downstream wings
iii. Side protection
iv. Energy dissipators

Design of Sarda type Fall – d/s protection

(i) Bed protection

- ✓ The bed of the channel needs to be protected for some length on the d/s of the impervious floor.
- ✓ consists of dry brick pitching (i.e. brick laid dry without mortar), about 200 mm thick (one brick on edge laid over one flat brick) resting on 100 mm ballast.
- ✓ Table gives length of pitching and no. of curtain walls (depending upon Head over crest), required to hold the pitching.
- ✓ It is provided horizontal upto end of masonry wings then sloping downwards at 1 in 10.

Design of Sarda type Fall – d/s protection

(ii) Downstream wings (Wing walls)

- After the crest wall the wings are stepped down to the required level of the downstream wings.
- The d/s wings are kept vertical for a length varying from 5 to 8 times $\sqrt{(E.\ H_L)}$ from the crest.
- The wings are then flared or warped, that is their water face is gradually inclined from vertical to a slope of 1.5:1 or 1:1
- In the latter case, warping is continued in the side pitching till a slope of 1.5:1 is attained.

Design of Sarda type Fall – d/s protection works

(iii) Side protection

After the warped wings, pitching protection is provided on the sides.

- The side pitching consists of either one brick on edge or 1.5 brick on edge (i.e. one brick on edge placed over one flat brick) laid in cement mortar.
- In the latter case, warping is continued in the side pitching till a slope of 1.5:1 is attained.
- The side pitching is curtailed at an angle of 45^{o} from the end of the bed pitching in plan.
- A toe wall is provided between the bed pitching and the side pitching to provide a firm support for the side pitching.
- The toe wall is usually 1 ½ brick (i.e. about 0.4 m) thick and of depth equal to $D_2/2$.

Design of Sarda type Fall – d/s protection

(iv) Energy Dissipators

- Energy dissipators are not provided for small discharges. However, for large discharges, additional energy dissipators are provided.
- The energy dissipators consist of two rows of friction blocks in the cistern and two rows of cube blocks on the impervious floor at its d/s end.
- Both the friction blocks and cube blocks are staggered.

Design of Sarda type Fall – d/s protection

(iv) Energy Dissipators

- Size and position of friction blocks

a) Length of block = $2d_c$

b) Width of block = d_c

c) Height of block = d_c

d) Distance of first row of blocks from d/s toe of the crest wall = $1.5d_c$

e) Spacing between two rows of block = d_c

f) Spacing between blocks in same row = $2d_c$

Where d_c is the critical depth.

Design of Sarda type Fall – d/s protection

(iv) Energy Dissipators

- Size and position of cube blocks
- Length of block = $0.1\ D_2$
- Width of block = $0.1\ D_2$
- Height of block = $0.1\ D_2$
- Spacing between the two rows of blocks = $0.1\ D_2$
- Spacing between blocks in the same row = $0.1\ D_2$

Where, D_2 is d/s full supply depth

One of the two rows of cube blocks is provided just at the d/s end of the impervious floor and the other one is provided on the u/s side at above noted spacing.

Design of Sarda type Fall – u/s protection

Design of u/s approach

- The u/s approach consist of wing walls (wings).
- For discharge <14 cumecs, the wing walls may be splayed straight at an angle of 45^o from the u/s edge of crest wall.
- For greater discharges, the wing walls are made segmental (curve) from the u/s edge of crest wall, with radius equal to 5 to 6 times H, subtending an angle of 60^0 at the centre and then carried along straight lines tangential to segment.

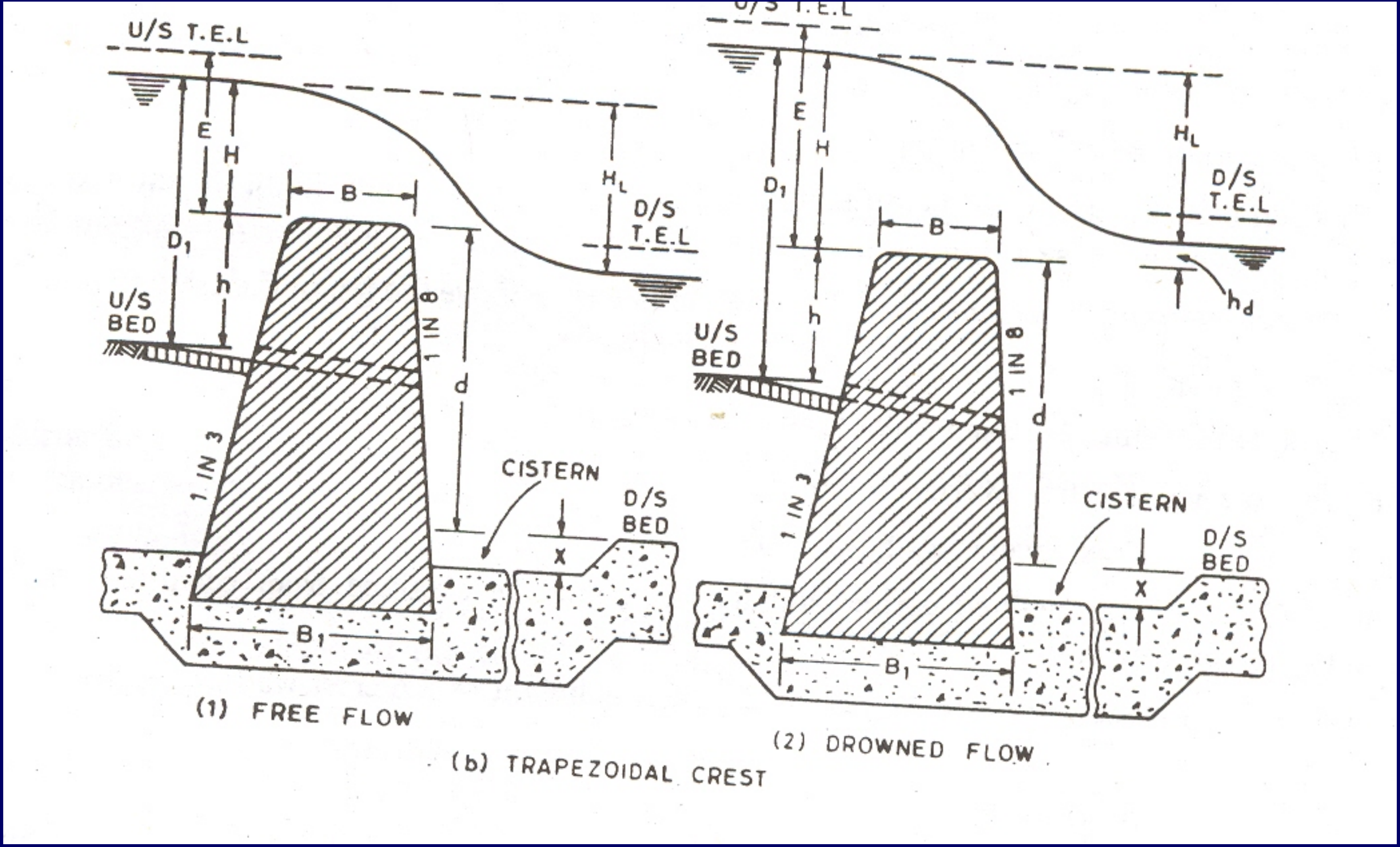
Design Problem - Sarda type Fall

Design a Sarda type Fall for the following data:

	upstream / downstream
Full supply discharge, (cumec)	= 45 / 45
Full Supply level (m)	= 118.30 / 116.80
Full supply depth (m)	= 1.8 / 1.8
Bed width (m)	= 28 / 28
Bed level (m)	= 116.50 / 115
Drop	= 1.5 m

Design the floor on the basis of Bligh's creep theory, taking coefficient of creep = 8

Design of Sarda type Fall – Crest wall



Design problem - Sarda type Fall

Step 1, Calculation of H & d

- Since Q > 14 cumec, trapezoidal crest wall will be provided.

$$Q = 1.99 L H^{3/2} \left(\frac{H}{B} \right)^{1/6}$$

L = Length of crest wall = bed width of channel = 28 m

H + d = D_1 + drop in bed level, or

= u/s FSL – d/s CBL

= 118.30 – 115

= 3.30 m

Design problem - Sarda type Fall

Step 1, Calculation of H & d

- Therefore,

$$B = 0.55\sqrt{H + d}$$

$$\Rightarrow B = 0.55\sqrt{3.3} = 1.0\ \text{m}$$

$$Q = 1.99 L H^{3/2}\left(\frac{H}{B}\right)^{1/6}$$

$$45 = 1.99 \times 28 H^{3/2}\left(\frac{H}{1.0}\right)^{1/6}$$

$$\Rightarrow H = 0.88\ \text{m}$$

Design problem - Sarda type Fall

Step 1, Calculation of H & d

- Since, $H = 0.88$ m

  $H + d = 3.30$ m

- Therefore, $d = 3.30 - 0.88$

  $d = 2.42$ m

- Height of crest wall above u/s bed (h)

  $h = D_1 - H$

  $= 1.8 - 0.88$

  $= 0.92$ m

Design problem - Sarda type Fall

Step 2, Design of Crest wall

Top width B = 1.0 m

Slope of u/s face = 1 in 3

Slope of d/s face = 1 in 8

Assuming channel side slope = 1:1

$$v_a = \frac{45}{1.8(28+1.8)} = 0.84 \text{ m/s}$$

$$\text{velocity head} = \frac{v_a^2}{2g} = \frac{0.84^2}{2\times 9.81} = 0.036$$

u/s TEL = u/s FSL + velocity head

= 118.30 + 0.036

= 118.336 m

Design problem - Sarda type Fall

Step 2, Design of Crest wall

u/s TEL = u/s FSL + velocity head

= 118.30 + 0.036

$$v_a = \frac{45}{1.8(28+1.8)} = 0.84 \text{ m/s}$$

= 118.336 m

$$\text{velocity head} = \frac{v_a^2}{2g} = \frac{0.84^2}{2\times 9.81} = 0.036$$

Crest level = u/s FSL – H

= 118.30 – 0.88

= 117.42 (above d/s FSL 116.80 m, free flow)

E = u/s TEL – crest level

= 118.336 – 117.42 = 0.916 m

Design problem - Sarda type Fall

Step 3, Design of Cistern

- $E = 0.916$ m

  H_L = u/s FSL – d/s FSL

  = 118.30 – 116.80

  = 1.5 m

$$L_c = 5\sqrt{EH_L} = 5\sqrt{0.916 \times 1.5} = 5.86 \text{ m}$$

$$x = \frac{1}{4}(EH_L)^{2/3} = \frac{1}{4}(0.916 \times 1.5)^{2/3} = 0.31 \text{ m}$$

RL of bed of cistern = RL of d/s bed – x = 115 – 0.31 = 114.69 m

Design problem - Sarda type Fall

Step 4, Design of Impervious floor

Seepage head, H_s = d = 2.42 m

Bligh's coefficient, C = 8

Therefore, required length of creep

= 8 × 2.42 = 19.36 m

u/s cutoff d_1 = 1.0 m (Min^m $D_1/3 = 1.8/3 = 0.6$ m)

d/s cutoff d_2 = 1.5 m (Min^m $D_2/2 = 1.8/2 = 0.9$ m)

The vertical length of creep = 2 (1.0 + 1.5) = 5 m

Hence, length of horizontal impervious floor = 19.36 – 5

= 14.36 m say 15 m

Design problem - Sarda type Fall

Step 4, Design of Impervious floor

Provide 15 m length of impervious floor.

Minimum length of impervious floor to be provided on the d/s of the crest wall l_d

$$l_d = 2\,(D_1 + 1.2) + H_L$$

$$= 2\,(1.80 + 1.2) + 1.5$$

$$= 7.5 \text{ m}$$

Provide l_d = 8 m. The balance of the length 15 – 8 = 7 m is provided under and u/s of the crest wall.

Design problem - Sarda type Fall

Step 4, Design of Impervious floor

Calculation of uplift pressure and thickness of floor

Total creep length = 15 + 2 (1.0 + 1.5)

(i) The uplift pressure under the u/s floor will be counter balanced by the weight of water and hence no thickness is required. However, provide a minimum thickness of 0.4 Provide l_d = 8 m.

    The balance of the length 15 – 8 = 7 m is provided under and u/s of the crest wall.

(ii) For other points the minimum vertical ordinate between Bligh's HGL and the floor level gives the uplift pressure.

Design problem - Sarda type Fall

Step 4, Design of Impervious floor

Calculation of uplift pressure and thickness of floor

(ii) For other points the minimum vertical ordinate between Bligh's HGL and the floor level gives the uplift pressure.

The maximum unbalanced head under the d/s toe of the crest wall

$$= 2.42\left(1 - \frac{7 + 2\times 1}{20}\right) + x = 2.42(1 - 0.45) + 0.31 = 1.64\, m$$

$$\therefore \text{Thickness required} = \frac{\text{unbalanced head}}{G - 1} = \frac{1.64}{2.24 - 1} = 1.32\ \text{m}$$

Design problem - Sarda type Fall

Step 4, Design of Impervious floor

Provide 1.4 m thick cement concrete floor overlaid by 0.2 m brick pitching.

Provide a minimum thickness of 0.6 m overlaid by 0.2m thick brick pitching at the d/s end of the floor.

The thickness of the floor at intermediate points may be varied as per requirements of uplift pressures.

Design problem - Sarda type Fall

Step 5, Design of d/s wings

Provide d/s wings vertical for a length of

$$6\sqrt{(E\ H_L)} = 6\ 6\sqrt{(0.916 \times 1.5} = 7.03 \text{ say } 7 \text{ m}$$

Then,

the wings would be warped to 1:1 slope at a splay of 1 in 3.

Height of top of d/s wings above bed

= water depth + freeboard

= 1.8 + 0.5 = 2.3 m

∴ Horizontal projection of this on 1:1 slope = 2.3 m, with a splay of 1 in 3, length of warped wings measured along the centre line of the channel = 2.3 × 3 = 6.9 say 7 m

Design problem - Sarda type Fall

Step 5, Design of d/s bed protection - ***(a) Bed pitching***

Provide about 200 mm thick dry brick pitching consisting of one brick on edge laid over one flat brick resting on 100 mm ballast.

From Table, for H = 0.88 m,

Length of bed pitching = $9.0 + 2\ H_L = 9.0 + 2\times1.5 = 12$ m

This should be provided horizontal upto the end of masonry wings and then sloping downwards at 1 in 10.

Since, the warped wings commence from 1 m u/s of the d/s end of the impervious floor,

the length of the horizontal pitching = 7-1 = 6m

the length of sloping pitching is therefore = 12- 6 = 6 m

Design problem - Sarda type Fall

Step 5, Design of d/s bed protection -

(b) Curtain wall

Thickness of curtain wall = 1 ½ brick (0.4 m)

From Table, for H = 0.88 m,

Depth of curtain wall = 0.75 m, say 1.0 m

Provide 0.4 m thick and 1 m deep curtain wall at the d/s end of bed pitching.

(c) Side pitching

Provide about 200 mm thick side pitching consisting of one brick on edge laid over one flat brick in cement mortar. The side pitching should be warped from a slope of 1:1 to 1.5:1 and it should be curtailed at an angle of 45^{o} from the end of bed pitching in plan.

Step 5, Design of d/s bed protection -

(d) Toe wall

Thickness of toe wall = 1 ½ brick (0.4 m)

Depth of toe wall = d/s water depth / 2 = 0.9 m say 1m

Provide 0.4 m thick and 1 m deep toe wall between the bed pitching and side pitching.

(e) Energy Disipator

Design problem - Sarda type Fall

Step 5, Design of d/s bed protection -

(e) Energy Disipator

Step 5, Design of u/s approach

Radius of segmental (or curved) portion of the u/s wings

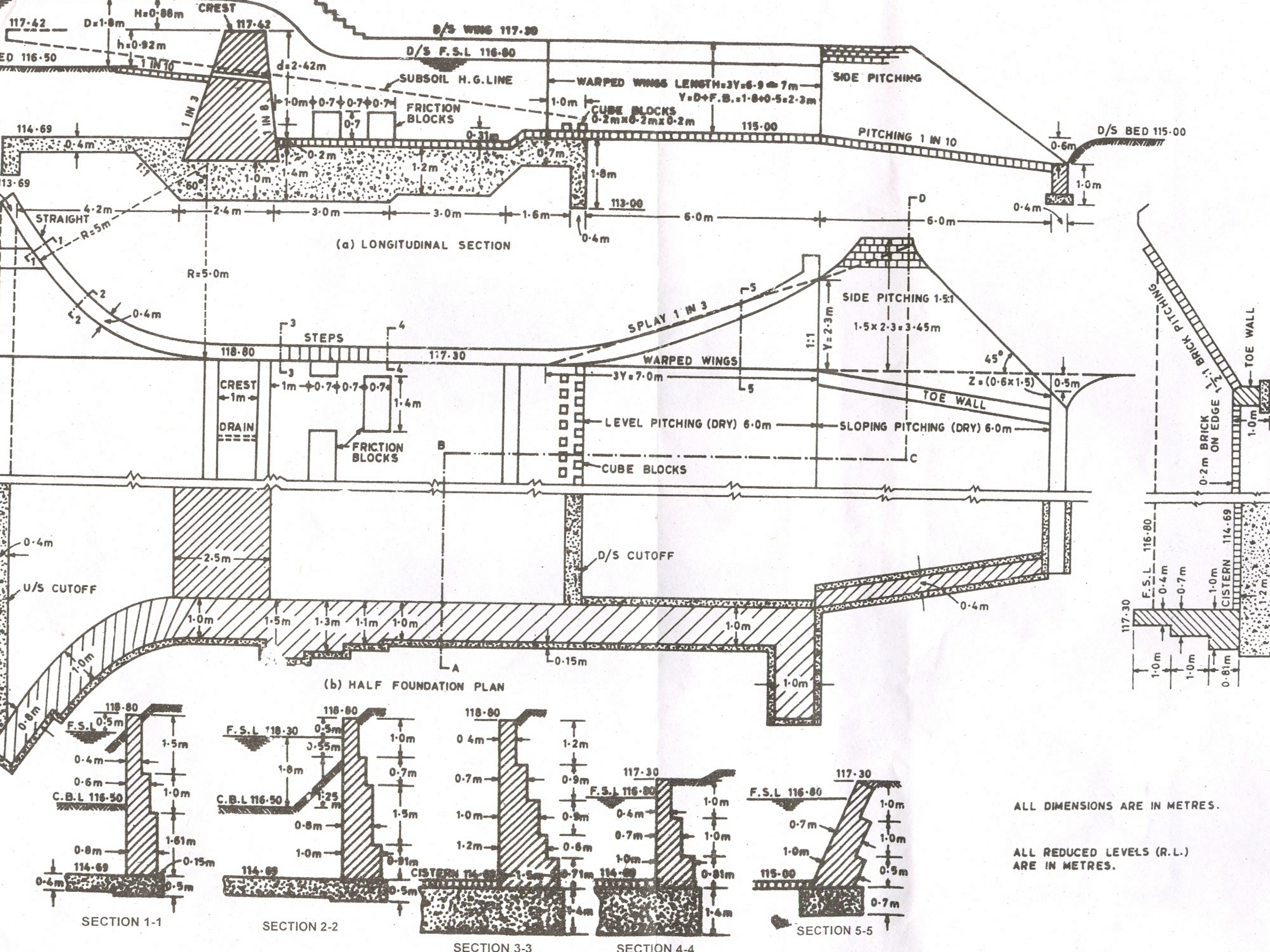
= 5 to 6 times H

= 5 to 6 times 0.88

= 4.4 to 5.28 m

Thus provide u/s wings having segmental (or curved) portion of radius 5 m and subtending an angle of 60^{o} at the centre from u/s edge of the crest wall.

The wings should then be carried along the straight lines tangential to the segment and embedded in the earthen banks of the channel by a minimum of 1 m from the line of FSL.



CREST
H=0·88m
D=1·8m
117·42
h=0·92m
1 IN 10
d=2·42m
D/S WING 117·30
D/S F.S.L 116·80
SUBSOIL H.G.LINE
WARPED WINGS LENGTH=3Y=6·9≈7m
Y=D+F.B.=1·8+0·5=2·3m
SIDE PITCHING
1 IN 3
1 IN 8
1·0m 0·7 0·7 0·7
FRICTION BLOCKS
CUBE BLOCKS 0·2m×0·2m×0·2m
115·00
PITCHING 1 IN 10
D/S BED 115·00
114·69
0·4m
0·2m
1·4m
1·2m
0·7m
1·8m
113·00
113·69
STRAIGHT
R=5m
4·2m
2·4m
3·0m
3·0m
1·6m
6·0m
6·0m
0·4m
1·0m
(a) LONGITUDINAL SECTION
R=5·0m
SPLAY 1 IN 3
SIDE PITCHING 1·5:1
1·5×2·3=3·45m
Y=2·3m
1:1
STEPS
118·80
117·30
WARPED WINGS
45°
3Y=7·0m
Z=(0·6×1·5)
0·5m
TOE WALL
CREST 1m
DRAIN
1·4m
LEVEL PITCHING (DRY) 6·0m
SLOPING PITCHING (DRY) 6·0m
FRICTION BLOCKS
CUBE BLOCKS
1:1 BRICK PITCHING
TOE WALL
0·2m BRICK ON EDGE
D/S CUTOFF
U/S CUTOFF
2·5m
1·0m
1·5m
1·3m
1·1m
1·0m
0·15m
(b) HALF FOUNDATION PLAN
F.S.L 116·80
CISTERN 114·69
117·30
0·81m
SECTION 1-1
F.S.L
C.B.L 116·50
1·61m
SECTION 2-2
F.S.L 118·30
1·8m
SECTION 3-3
SECTION 4-4
SECTION 5-5
ALL DIMENSIONS ARE IN METRES.
ALL REDUCED LEVELS (R.L.) ARE IN METRES.

THANK YOU