12

Canal Falls

12.1. Definition and Location of Canal Falls

12.1.1. Definition. Whenever the available natural ground slope is steeper than the designed bed slope of the channel, the difference is adjusted by constructing vertical 'falls' or 'drops' in the canal bed at suitable intervals, as shown in Fig. 12.1.

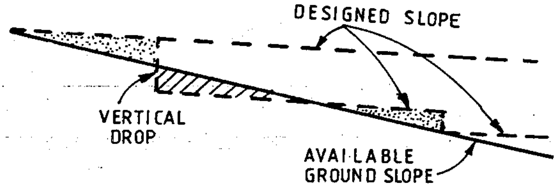

Fig. 12.1

Such a drop in a natural canal bed will not be stable and, therefore, in order to retain this drop, a masonry structure is constructed. Such a pucca structure is called a *canal fall* or a *canal drop.*

12.1.2. Proper location. The location of a fall in a canal depends upon the topography of the country through which the canal is passing. In case of the main canal, which does not directly irrigate any area, the site of a fall is determined by considerations of economy in 'cost of excavation and filling' *versus* 'cost of fall'. The excavation and filling on two sides of a fall should be tried to be balanced, because the unbalanced earthwork is quite costly. By providing a larger drop in one step, the quantity of unbalanced earth work increases, but at the same time, the number of fall reduces. An economy between these two factors has to be worked out before deciding the locations and extent of falls.

In case of branch canals and distributary channels, the falls are located with consideration to commanded area. The procedure is to fix the 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 the 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. When a fall is combined with a regulator and a bridge, it is called a fall-regulator with road bridge.

12.2. Types of Falls

Various types of falls have been designed and tried since the inception of the idea of 'falls construction' came into being. The important types of such falls, which were used in olden days and those which are being used in modern days, are described below:

(1) Ogee Falls. The 'Ogee type fall' was constructed in olden days on projects like Ganga canal. The water was gradually led down by providing convex and concave curves, as shown in Fig. 12.2.

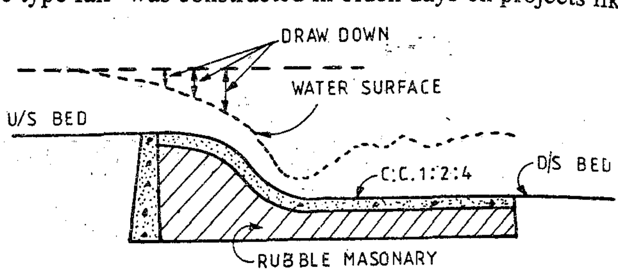

Fig. 12.2. Ogee fall.

The performance of such a fall was found to have the following major defects :

(*i*) There was heavy draw-down on the upstream side, resulting in lower depths, higher velocities and consequent bed erosion. Draw-down would also affect the supply in a distributary, situated just upstream of fall.

(*ii*) Due to smooth transition, the kinetic energy of the flow was not at all dissipated, causing erosion of downstream bed and banks.

A 'raised crest' was soon added to restrict the draw-down and a long protection was provided on the downstream side. Later, it was converted into a much better type of fall, called a 'Vertical Impact type'.

(2) Rapids. In Western Yamuna canal, long rapids at slopes of 1 : 15 to 1 : 20 (*i.e.*, gently sloping glacis) with boulder facings, were provided. They worked quite satisfactorily, but were very expensive, and hence became obsolete.

(3) Trapezoidal Notch Falls. The trapezoidal notch fall was designed by Ried in 1894. It 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 downstream from each notch to spread out the falling jet (See Fig. 12.3).

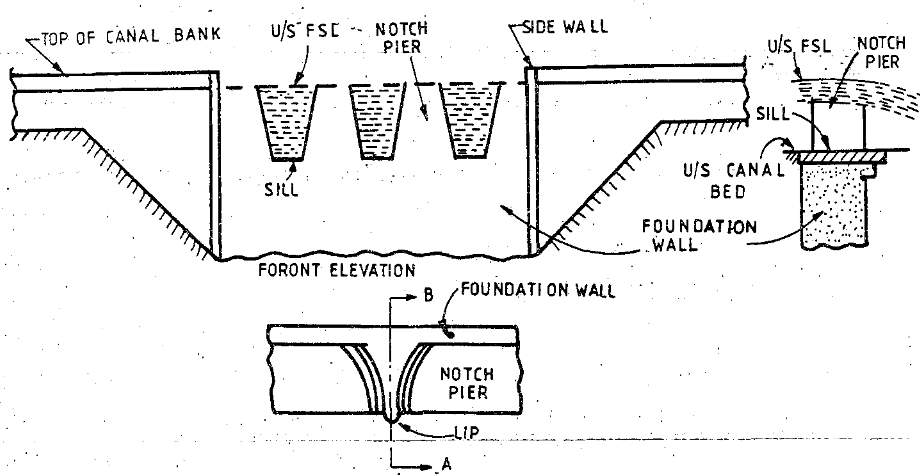

Fig. 12.3. Trapezoidal Notch fall.

The notches could be designed to maintain the normal water depth in the upstream channel at any two discharges, as the variation at intermediate values is small. Hence, the depth discharge relationship of the channel remains practically unaffected by the introduction of the fall. In other words, there would neither be drawdown nor heading up of water, as the channel approaches the fall. These falls remained quite popular, till simpler, economical, and better modern falls were developed.

(4) **Well Type Falls or Cylinder Falls or Syphon Well Drops**. This type of a fall consists of an inlet well with a pipe at its bottom, carrying water from the inlet well to a downstream well or a cistern. The downstream well (as shown in Fig. 12.4) is necessary in the case of falls greater than 1.8 m and for discharges greater than 0.29 cumecs. The water falls into the inlet well, through a trapezoidal notch constructed in the steining of the well, from where it emerges near the bottom, dissipating its energy in turbulence inside the well.

This type of falls are very useful for affecting larger drops for smaller discharges. They are commonly used as tail escapes for small canals, or where high levelled smaller drains do outfall into a low levelled bigger drain.

(5) **Simple Vertical Drop Type and Sarda Type Falls.** A raised crest fall with a vertical impact (Fig. 12.5) was first of all introduced on Sarda Canal System in U.P., owing to its economy and simplicity. The necessity for economic falls arose because of the need of construction of a large number of smaller falls on the Sarda Canal System. In that area, a thin layer of sandy clay overlied a stratum of pure sand. If the canal bed was to be cut deep and up to the sand stratum, the seepage losses would have been tremendous. Hence, the depth of cutting had to be kept low, necessitating the construction of a large number of smaller falls.

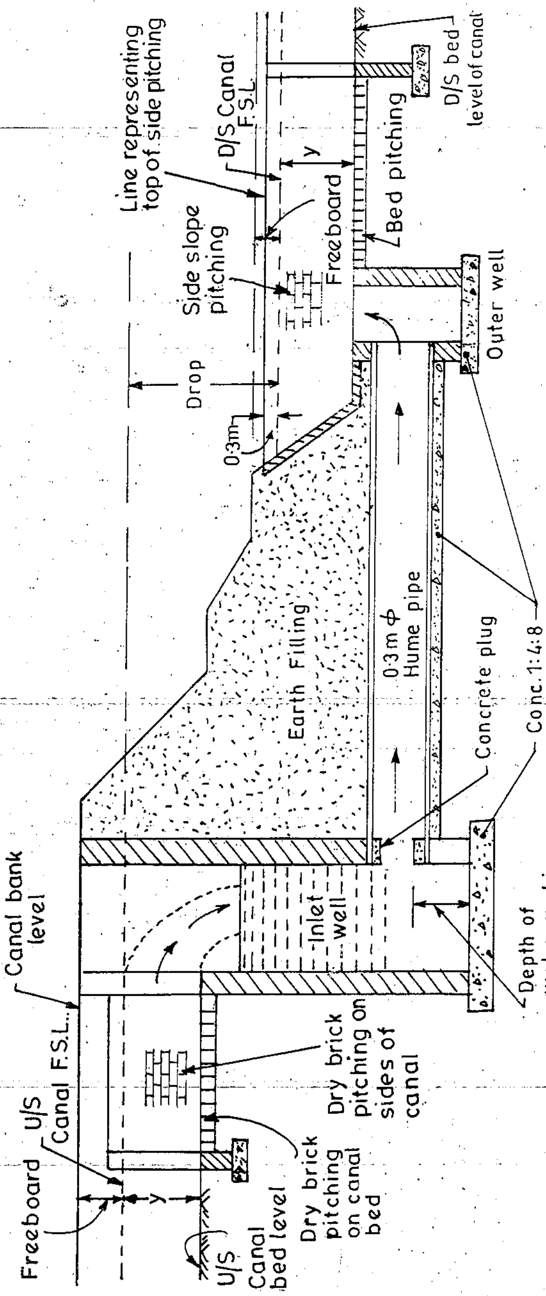

Fig. 12.4. Siphon Well drop.

In this type of a high crested fall, the nappe impinges into the water cushion below. *There is*

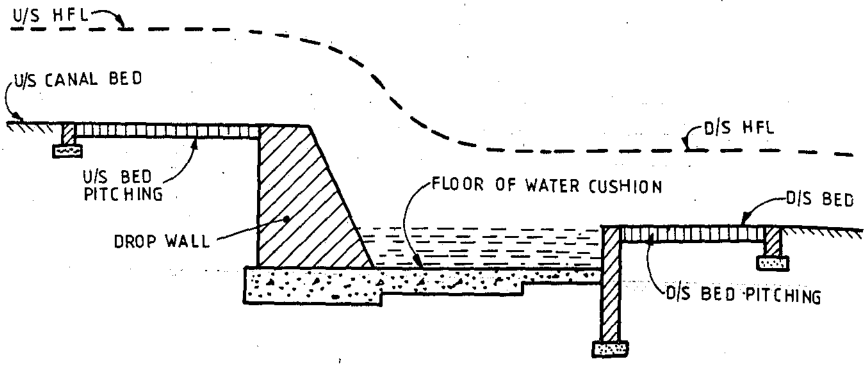

Fig. 12.5. Simple Vertical Drop fall.

no clear hydraulic jump and the energy dissipation is brought about by the turbulent diffusion, as the high velocity jet enters the deep pool of water downstream.

Two types of crests which are used in Sarda type falls are shown a little later in Figs. 12.10 (*a*) and (*b*).

Sarda type fall is a high crested fall, and if the discharge in the canal varies (say between 50 to 100%), the water will head up on the upstream side at low discharges. The reach upstream of the crest will silt up as the clearer water will pass downstream of the crest. Due to reduction in silt in the d/s discharge, there may be a tendency of scouring on d/s, so as to make up the silt loss. Hence, this type of fall is not quite suitable for canals in which discharge varies within a wide range. A trapezoidal notch fall, although costlier than Sarda type or glacis type fall, is free from such troubles and, therefore, preferred for canals where the discharge is very small and also varies over a wide range.

(6) Straight Glacis Falls. In this type of a modern fall, a 'straight glacis' (generally sloping 2 : 1) is provided after a 'raised crest' (see Fig. 12.6). The hydraulic jump is

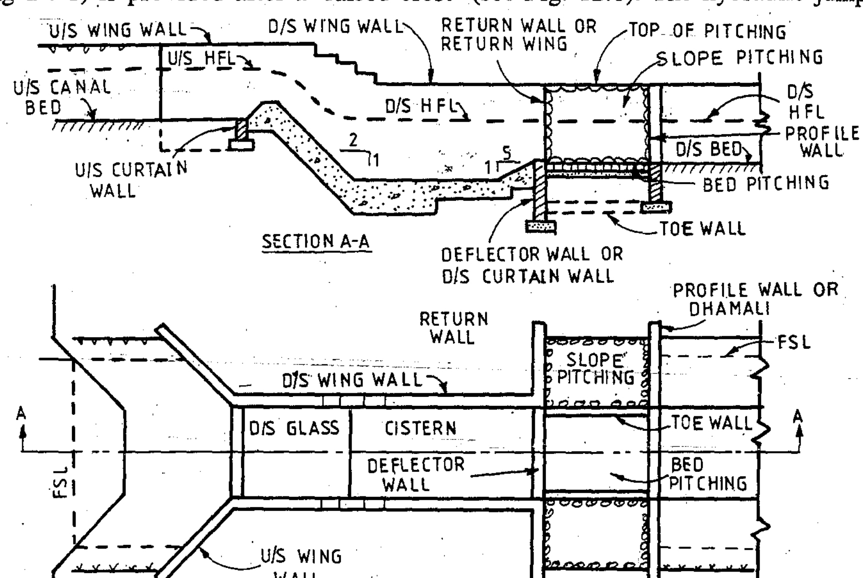

Fig. 12.6. '*Straight Glacis fall*' (without fluming), without Regulator and Bridge Details.

made to occur on the glacis, causing sufficient energy dissipation. This type of falls give very good performance if not flumed, although they may be flumed for economy. They are suitable up to 60 cumecs discharge and 1.5 m drop.

(7) **Montague Type Falls.** The energy dissipation on a straight glacis remain incomplete due to vertical component of velocity remaining unaffected. An improvement in energy dissipation may be brought about in this type of fall [see Fig. 12.7 (*a*)], by replacing the straight glacis by a parabolic glacis, commonly known as 'Montague Profile'.

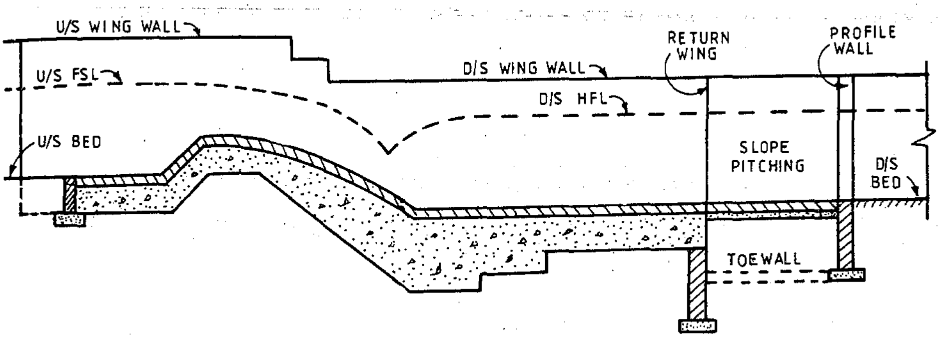

Fig. 12.7. (*a*) Montague Type fall.

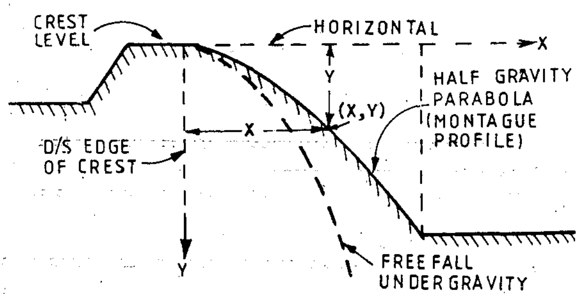

Fig. 12.7. (*b*) Montague Profile.

The Montague profile is given by the equation.

$$X = U\sqrt{\frac{4Y}{g}} + Y \qquad \text{...(12.1)}$$

where X = The horizontal ordinate of any point of the profile measured from the d/s edge of crest.

Y = Vertical ordinate measured from the crest level.

U = Initial velocity of water leaving the crest.

The curved glacis is difficult to construct and thereby rendering it costlier. This type of fall is, therefore, generally not adopted in India.

(8) Inglis Falls or Baffle Falls. A straight glacis type fall when added with a baffle platform and a baffle wall as shown in Fig. 12.8, was developed by Englis, and is called 'Englis Fall' or 'Baffle Fall'. They are quite suitable for all discharges and for drops of more than 1.5 m. They can be flumed easily as to affect economy.

The baffle wall is provided at a calculated height and a calculated distance from the toe of the glacis, so as to ensure the formation of the jump on the baffle platform, as shown in Fig. 12.8.

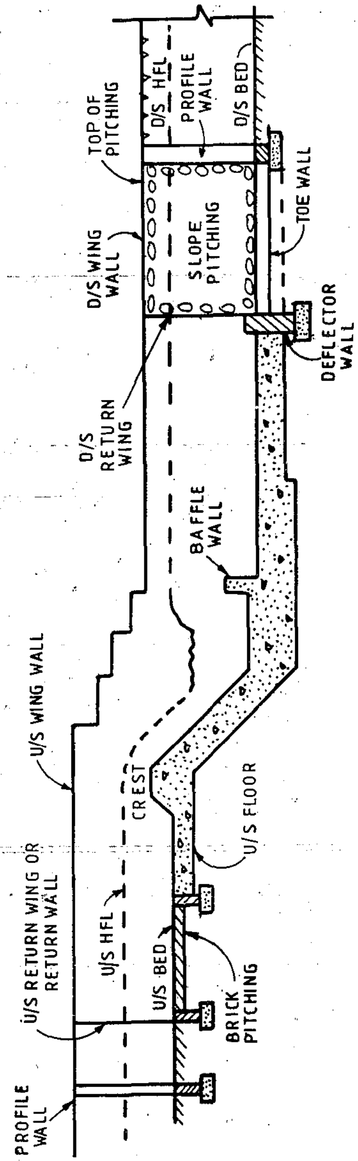

Fig. 12.8. 'Baffle fall' or 'English-fall'.

Comparison of Different Types of Falls. Extensive testing of various modern types of falls was carried out in 1952 at Research Station Poona, and the following recommendations were made :

(*i*) 'Vertical drop' falls are quite suitable *for discharges upto 15 cumecs and drops upto. 1.5 metres.* But this type of fall should not be flumed.

(*ii*) For 'Straight glacis' type falls, the conclusion was, that they work satisfactorily for all conditions, if unflumed ; but in that case they become costly. *Even then, they can be adopted suitably for discharges upto 60 cumecs and drops upto 1.5 metres, and can even be flumed.*

(*iii*) 'Baffle fall' or 'English fall' may be used for all discharges when drop is more than 1.5 metres. *This type of fall functions very satisfactorily, either flumed or unflumed, so long as it is undrowned.*

(*iv*) Well type falls are suitable and economical for high drops and very low discharges. They can hence be easily used, as tail escapes of small channels.

Meter and Non-Meter Falls. Meter falls are those which can be used to measure the discharge of the canal. If the discharge cannot be measured accurately at the site of the fall, then it is called a non-meter fall. Vertical drop fall is not suitable as a meter due to the formation of partial vacuum under the nappe. Glacis type fall is quite suitable as a metering device. *Since a sharp crest does not give a constant coefficient of discharge with varying heads, while a broad crest does so reasonably ; a fall to be used as meter must be provided with a broad crest.* Generally, a flumed glacis fall or a flumed baffle fall, is used as meter, while an unflumed glacis fall is used as a non-meter fall.

DESIGN PRINCIPLES OF VARIOUS TYPES OF FALLS

12.3. Design of a Trapezoidal Notch Fall

As pointed out earlier, a notch fall provides a proportionate fall, in the sense that there is no heading up or drawdown of water level in the canal near the fall. The whole width of the channel is divided into a number of notches. The crest (*i.e.* the sill level or the level of the bottom of notch) may be kept higher than the bed level of the canal, which will tend to increase the length of the weir, but in no case, the total length of the weir openings should exceed the bed width of the canal upstream, and may well be reduced to about $\frac{7}{8}$th of the bed width.

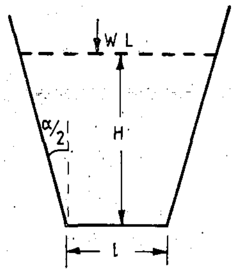

Fig. 12.9
Trapezoidal notch

Discharge Formula. The discharge passing through one notch of a notch fall can be obtained by adding the discharge of a rectangular notch and a V-notch.

∴ The discharge passing through a trapezoidal notch such as shown in Fig. 12.9 is given by

$$Q = \frac{2}{3} C_d \cdot \sqrt{2g}\ l \,.\, H^{3/2} + \frac{8}{15} \cdot C_d \cdot \sqrt{2g} \tan\frac{\alpha}{2} H^{5/2}$$

$$= \frac{2}{3} C_d \cdot \sqrt{2g}\left[lH^{3/2} + \frac{4}{5}\tan\frac{\alpha}{2} H^{5/2}\right]$$

$$= \frac{2}{3} C_d \cdot \sqrt{2g}\left[lH^{3/2} + \frac{2}{5}\left(2\tan\frac{\alpha}{2}\right)H^{5/2}\right] \quad ...(12.2)$$

If $2\tan\frac{\alpha}{2}$ is represented by n, then

$$Q = \frac{2}{3} C_d \cdot \sqrt{2g}\left[lH^{3/2} + 0.4 \,.\, nH^{5/2}\right] \quad ...(12.3)$$

where, C_d = Coefficient of discharge ≈ 0.75

$$\therefore \quad Q = \frac{2}{3} \times 0.75 \sqrt{2 \times 9.81}\left[lH^{3/2} + 0.4\, nH^{5/2}\right]$$

or

$$Q = 2.22 H^{3/2}\left[l + 0.4nH\right] \quad ...(12.4)$$

The above discharge equation contains two unknowns l and n. For solving this equation, two values of Q and corresponding values of H must be assumed. It is a common practice to design notches for full supply discharge (Q_{100}) and half supply discharge (Q_{50}) with values of H equal to the normal water depths in the channel in the respective cases. Let the normal water depths in the channel at full discharge and half discharge be represented by y_{100} and y_{50} respectively. Then $H_{100} = y_{100}$, and $H_{50} = y_{50}$.

The depth of water in the channel at 50% discharge (*i.e.* y_{50}) can be approximately evaluated in terms of full supply depth (y_{100}) as follows :

Let $\quad V = C \cdot y^{0.64}$ ...(Kennedy's Eq. for Vel. in channels)

Now $\quad Q = A.V.$

$\therefore \quad Q = B \,.\, y \,.\, C \,.\, y^{0.64}$ Using $A \approx B.y$ (neglecting sy^2)

or $\quad Q = C \,.\, B \,.\, y^{1.64}$

$\therefore \quad Q_{100} = C \,.\, B \,.\, y_{100}^{1.64}$

and $$Q_{50} = C \cdot B \cdot y_{50}^{1.64}$$

or $$\frac{Q_{50}}{Q_{100}} = \left(\frac{y_{50}}{y_{100}}\right)^{1.64}$$

or $$\frac{y_{50}}{y_{100}} = \left(\frac{Q_{50}}{Q_{100}}\right)^{\frac{1}{1.64}} = (0.5)^{\frac{1}{1.64}} = 0.66$$

$\therefore$ $$y_{50} = 0.66 \cdot y_{100} \quad ...(12.5)$$

Number of Notches. The number of notches should be so adjusted by hit and trial method that the top width of the notch lies between $\frac{3}{4}$ to full water depth above the cill of the notch. This hit and trial procedure would become clear when we solve a numerical example.

Notch Piers. The thickness of notch piers should not be less than half the water depth and may be kept more if they have to carry a heavy super structure. The top length of piers should not be less than their thickness.

In plan, the notch profile is set back by 0.5 m from the downstream face of the notch fall for larger canals, and by 0.25 m for distributaries. All curves are circular arcs, and all centres lie in the plane of the profile. The splay upstream from the notch section is 45°, and the downstream splay is kept 22.5°. The lip is circular and is corbelled out by 0.8 m on larger canals, and by 0.6 m on distributaries.

Example 12.1. *Design the size and number of notches required for a canal drop with the following particulars :*

Full supply discharge = *4 cumecs*
Bed width = *6.0 m*
F.S. depth = *1.5 m*
Half supply depth = *1.0 m*
Assume any other data if required. (*Madras University 1975*)

Solution. The bed width of the canal is 6 m. Each notch at top should be roughly equal to F.S. depth *i.e.* 1.5 m. So let us, in the first trial, provide 3 notches.

$\therefore$ Full supply discharge through each notch $= \frac{4}{3} = 1.33$ cumecs

From Eq. (12.4) we have

$$Q = 2.22 H^{3/2} [l + 0.4\, nH]$$

Using $$Q_{100} = 2.22\, (y_{100})^{3/2} [l + 0.4n\, y_{100}]$$

where $Q_{100} = 1.33$ cumecs

$y_{100} = 1.5$ m

$\therefore$ We have $$1.33 = 2.22 \,.\, (1.5)^{3/2} [l + 0.4n \times 1.5]$$

or $$1.33 = 2.22 \times 1.84 [l + 0.6n]$$

or $$l + 0.6n = 0.326 \quad ...(i)$$

Now, using

$$Q_{50} = 2.22 \,.\, (y_{50})^{3/2} [l + 0.4n \,.\, y_{50}]$$

where $Q_{50} = \frac{1.33}{2} = 0.67$ cumecs

$y_{50} = 1.0$ m

$$\therefore \quad 0.67 = 2.22 \,.\, (1.0)^{3/2} \, [l + 0.4n \times 1]$$

or $$l + 0.4n = 0.3 \qquad ...(ii)$$

Subtracting (*ii*) from (*i*) we get

$$0.2n = 0.026$$

or $$n = 0.13.$$

Putting the value of n in (*ii*) we get

$$l + 0.4 \times 0.13 = 0.3$$

or $$l = 0.248; \text{ say } \mathbf{0.25\ m.}$$

By this trial, we find the top width

$$= 0.25 + 2 \tan \alpha \cdot H = 0.25 + n.\, H$$
$$= 0.25 + 0.13 \times 1.5 = 0.25 + 0.195$$
$$= 0.445; \text{ say } 0.45 \text{ m, which is much less than the full depth of } 1.5 \text{ m.}$$

In order to increase the top width, and to make it near 1 to $\frac{3}{4}$th *FSD*, it is necessary to increase l and n : which can be done by reducing the number of notches.

The values of l and n obtained for 3 notches will increase in direct proportion, when number of notches are reduced.

In other words, the values l of and n will become 3 times, when number of notches are reduced 3 times. Thus, when we provide only one notch instead of 3 notches, the values of n and l will triple. Similarly, when we use 2 notches against 3, *i.e.*, $\frac{1}{1.5}$ times the values n and l will become 1.5 times of those obtained for 3 notches.

Hence when we use 2 notches, values will be

$$n = 1.5 \times 0.13 = 0.20$$
$$l = 1.5 \times 0.25 = 0.3 \text{ m}$$

and $$\text{Top width} = 1.5 \times 0.45 = \mathbf{0.68\ m.}$$

Since the width is still quite low, we may use only one notch.

When we use only one notch, the values will be

$$n = 3 \times 0.13 = 0.39$$
$$l = 3 \times 0.25 = 0.75 \text{ m}$$
$$\text{Top width} = 3 \times 0.45 = 1.35 \approx \text{FSD (O.K.)}$$
$$\frac{\alpha}{2} = \tan^{-1} \frac{n}{2} = \tan^{-1} \frac{0.39}{2} = 11°$$

Since this condition gives us top width = 1.35 m, which is O.K., we may provide one notch, centrally placed in the given channel of 6 m width. The section of the notch to be adopted is also shown in Fig. 12.10.

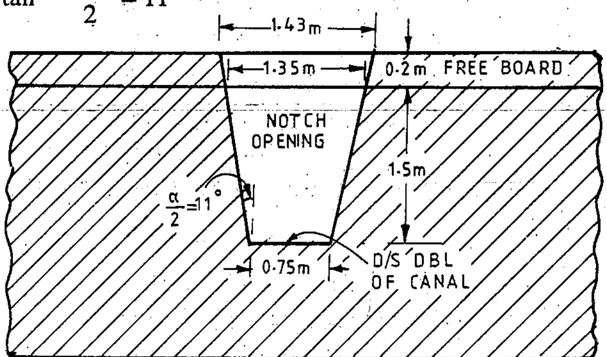

Fig. 12.10

Check for raised crest if possible. It has also been noticed that when lesser number of notches are provided, with their bottoms kept at U/S DBL of canal, the concentration of flow gets increased considerably. To avoid such an eventuality, it is preferable to increase the number of notches, and this may sometimes be achieved by providing the notches in the raised crest. In other words, the bottom of notch opening will be kept higher than U/S DBL of canal. This raising may be between 10% to 30% of full depth. The design calculations are hence to be repeated to compute n and l with a raised crest, whenever a detailed designing is being done, and number of notches determined are low.

These calculations for the above question 12.1 will be as follows :

Let us assume a raised crest equal to 20% of FSD

$$= 20\% \times 1.5 \text{ m} = 0.3 \text{ m}.$$

Using Eqn. (12.4) as

$$Q = 2.22\, H^{3/2}\, [l + 0.4nH], \text{ we have}$$

$$Q_{100} = 2.22\,(1.5 - 0.3)^{3/2}\,[l + 0.4n\,(1.5 - 0.3)]$$

or $$Q_{100} = 2.92\,(l + 0.48n) \quad ...(iii)$$

Also $$Q_{50} = 2.22\,(1.0 - 0.3)^{3/2}\,[l + 0.4n\,(1.0 - 0.3)]$$

$$[\because \text{FSD at } \tfrac{1}{2} \text{ discharge} = 1.0 \text{ m (given)}]$$

or $$Q_{50} = 1.3\,(l + 0.28\,n) \quad ...(iv)$$

But $$Q_{100} = 2Q_{50}$$

$\therefore$ $$2.92\,(l + 0.48\,n) = 2 \times 1.3\,(l + 0.28\,n)$$

This gives a negative value of n, which is not feasible, and hence such a raised crest may not be feasible in this particular case. Hence, the design made earlier, and shown in Fig. 12.10, holds good.

12.4. Design of a Syphon Well Drop

A syphon well drop, such as shown in Fig. 12.4, is generally adopted for smaller discharges and larger drops. The main features of the design involves determining the size of the inlet well and that of the hume pipe. A suitable size for the outer well, a proper provision of water cushion at the bottom of the inlet well, the bed and side slope pitchings in the canal upstream as well as downstream for suitable lengths, are also provided. The size of the inlet well and that of the syphon pipe are determined on the following considerations w.r. to Fig. 12.11.

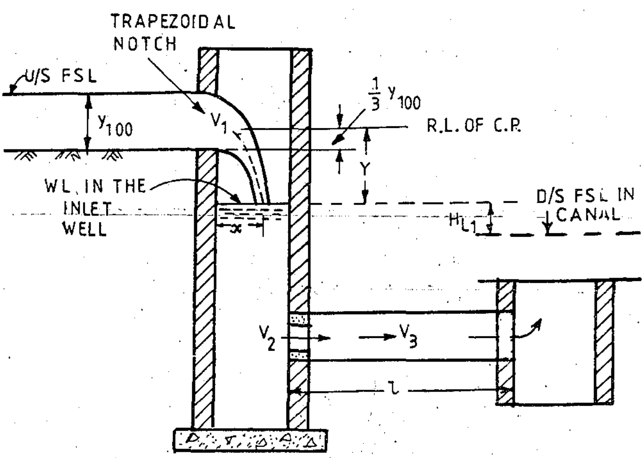

Fig. 12.11

First of all, the size of the trapezoidal notch is determined so as to pass the designed discharge by using eqn. (12.4) in the same way as is done for a trapezoidal notch. Then let V_1 be the velocity over the notch, V_2 be the velocity of entry in the pipe, and V_3 be the velocity through the pipe. All these values of velocities can be determined easily as below :

$$V_1 = \frac{\text{Full supply discharge}}{\text{Area of flow over the notch}}$$

$$V_2 = \frac{\text{Full supply discharge}}{\text{Area of opening at entry (for assumed dia of opening)}}$$

$$V_3 = \frac{\text{Full supply discharge}}{\text{Area of pipe (for assumed dia)}}$$

The head loss between the inlet well and the d/s FSL is then given by H_{L_1} as

$$H_{L_1} = 0.5\frac{V_2^2}{2g} \text{ (i.e. loss due to entry)} + \frac{(V_2 - V_3)^2}{2g} \text{ (i.e. the loss due to sudden enlargement)} + \frac{f' L V_3^2}{2gd} \text{ (i.e. the loss in the assumed pipe length } L\text{)} + \frac{V_3^2}{2g} \text{ (loss due to exit).} \quad ...(12.6)$$

Knowing all the above values, H_{L_1} can be determined, and thus the R.L. of water surface inlet well (*i.e.* d/s FSL + H_{L_1}) can be determined.

Now, approximate *R.L.* of centre of pressure (C.P.) of the trapezoidal waterway through the notch

$= \text{u/s canal bed level} + \frac{1}{3}\text{FSD.}$

= (which can be calculated)

Then, the height (Y) of the centre of pressure above the water level in the inlet well

= R.L. of C.P. – R.L. of water level in inlet well

= (Known)

Now using the eqn.

$$V_1 = \sqrt{\frac{gX^2}{2.Y}}\ * \quad ...(12.7)$$

where X and Y are the coordinates of the jet (issuing from centre of pressure) w.r.t. the water surface level in the inlet well.

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*The eqn. (12.7) can be derived as below w.r.t. to Fig. 12.12 :

$X = V_1\, t$ (after a time t)

$Y = \frac{1}{2}gt^2$ $\left[\because \text{using } S = ut + \frac{1}{2}gt^2 \text{ and } u = 0, \text{ we have } S = \frac{1}{2}gt^2\right]$

or $Y = \frac{1}{2}g \cdot \left(\frac{X}{V_1}\right)^2$

or $V_1 = \sqrt{\frac{gX^2}{2y}}$

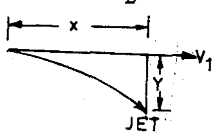


Fig. 12.12

The value of X can be determined. Finally the dia of the inlet well may be kept at about 1.5 times the value of X. The entire procedure will become more clear when we solve the following numerical example.

Example 12.2. *Design the salient dimensions of a syphon well drop for the following particulars :*

Fall	$= 3.8$ *m*	
General ground level	$= +163.36$ *m*	
Full supply depth	$= 75$ *cm*	
Bed level upstream	$= +162.83$	
Discharge	$= 1$ *cumec*	
Bed width upstream and downstream	$= 2.4$ *m*	*(Madras University 1972)*

Solution. For a trapezoidal notch, we have the discharge eqn. (12.4) as

$$Q = 2.22 \cdot H^{3/2}\,[l + 0.4\,n\,H]$$

At full supply discharge, we have

$$Q_{100} = 2.22\,(y_{100})^{3/2}\,[l + 0.4\,n\,y_{100}]$$

where $y_{100} = F.S.D. = 0.75$ m

$Q_{100} = F.S.Q = 1$ cumec

$$\therefore \quad 1 = 2.22\,(0.75)^{3/2}\,[l + 0.4n\,(0.75)]$$

or $\quad 0.71 = l + 0.3\,n \quad$ ...(*i*)

At 50% full discharge, we have

$$Q_{50} = 2.22\,y_{50}^{3/2}\,[l + 0.4n\,y_{50}]$$

where $y_{50} \approx 0.66\,y_{100}$ (eqn. 12.5)

$= 0.66 \times 0.75$

$= 0.5$ m.

$Q_{50} = 0.5$ cumec

$$\therefore \quad 0.5 = 2.22\,(0.5)^{3/2}\,[l + 0.4n\,(0.5)]$$

or $\quad 0.64 = l + 0.2\,n \quad$ ...(*ii*)

Subtracting (*ii*) from (*i*) we get

$$0.07 = 0.1\,n$$

or $\quad n = 0.7$

$$\therefore \quad 2\tan\frac{\alpha}{2} = 0.7, \text{ or } \frac{\alpha}{2} = 19.3°$$

Substituting this value of n in (*ii*), we get

$$l = 0.64 - 0.14 = 0.50$$

Hence, provide a trapezoidal notch in the steining of the inlet well, with 0.5 m bottom width and each side inclined to an angle of 19.3° with the vertical.

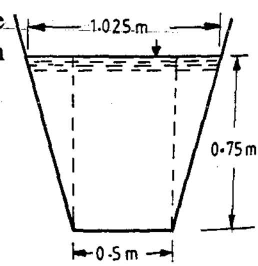


Fig. 12.13

Now, the width of water (at FSL) flowing over notch

$$= 0.5 + 0.7 \times (0.75) = 0.5 + 0.525 = 1.025 \text{ m}.$$

Velocity (V_1) over the notch

$$= \frac{\text{F.S.Q.}}{\text{Area of flow over the notch}}$$

$$= \frac{1}{\frac{0.5+1.025}{2} \times 0.75} \text{ m/sec} = \frac{1}{0.76 \times 0.75} \text{ m/sec} = 1.75 \text{ m/sec}$$

Let us now assume that the diameter of the pipe used be 1 m

∴ Velocity V_3 through the pipe

$$= \frac{1}{\frac{\pi}{4}(1)^2} \text{ m/sec.} = 1.27 \text{ m/sec.}$$

Let us assume that the diameter of the opening at the inlet of pipe be 0.5 m

∴ The velocity of entry into the pipe (V_2)

$$= \frac{1}{\frac{\pi}{4}(0.5)^2} \text{ m/s} = 5.1 \text{ m/sec.}$$

Now

Loss of head between the inlet well and the d/s FSL is given by Eqn. (12.6).

$$= 0.5 \cdot \frac{V_2^2}{2g} + \frac{(V_2 - V_3)^2}{2g} + \frac{f' L V_3^2}{2gd} + \frac{V_3^2}{2g}$$

Let us assume that the length of the pipe is kept as 12 m and f' = Darcey's coefficient of friction be taken as equal to 0.012, we then have

$$H_{L_1} = 0.5 \times \frac{(5.1)^2}{2 \times 9.81} + \frac{(5.10 - 1.27)^2}{2 \times 9.81} + \frac{0.012 \times 12 \times (1.27)^2}{2 \times 9.81 \times 1.0} + \frac{(1.27)^2}{2 \times 9.81}$$

$$= 0.66 + 0.77 + 0.01 + 0.08 = \mathbf{1.52\ m.}$$

∴ R.L. of water surface in the inlet well

$$= \text{d/s FSL} + 1.52$$

$$\left[\begin{array}{l} \text{d/s FSL} = \text{u/s FSL} - \text{fall} \\ \qquad = (162.83 + 0.75) - 3.8 = 159.78) \end{array}\right]$$

$$= 159.78 + 1.52 = \mathbf{161.30}.$$

Approximate R.L. of the centre of pressure (C.P.) of the trapezoidal waterway through notch

$$= \text{u/s canal bed level} + \frac{1}{3} \text{FSD}$$

$$= 162.83 + \frac{0.75}{3} = 162.83 + 0.25 = \mathbf{163.08}$$

∴ Height Y of C.P. above water level in the inlet well

$$= 163.08 - 161.30 = 1.78 \text{ m.}$$

Now using Eqn. (12.7), we have

$$V_1 = \sqrt{\frac{g \cdot X^2}{2Y}}$$

or

$$X = \sqrt{\frac{V_1^2\, 2Y}{g}}$$

$$= \sqrt{\frac{(1.75)^2 \times 2 \times 1.78}{9.81}} = 1.75 \times 0.6 = 1.05 \text{ m.}$$

Now, the dia. of the inlet well may be kept at about 1.5 *X*, *i.e.* 1.5 × 1.05 = 1.575 m, say 1.6 m. Keep the dia of the d/s outlet well, as say 1.2 m. Also provide a water cushion at the bottom of the inlet well. Bed and sides of channel for suitable lengths on the u/s as well as d/s side are protected by dry brick pitching. The complete details are shown in Fig. 12.14.

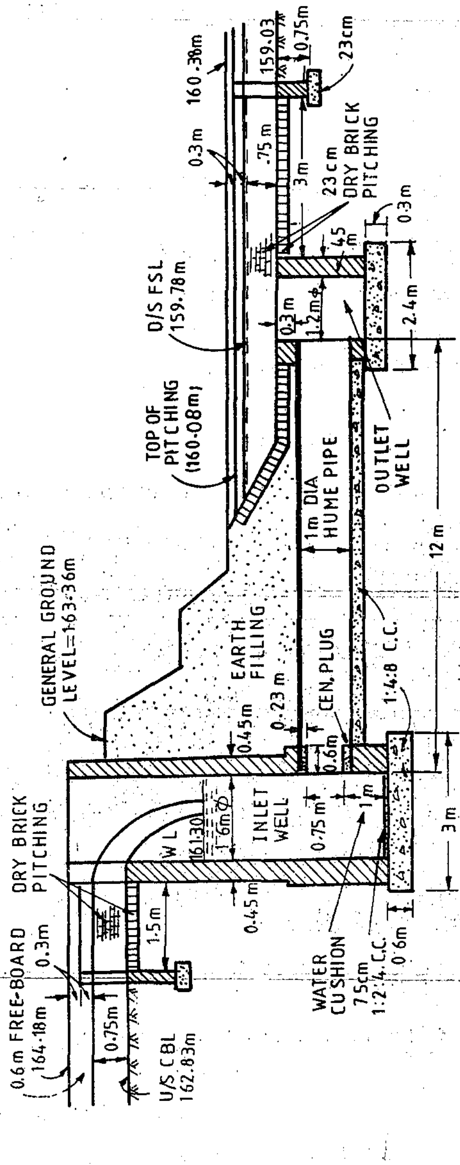


Fig. 12.14

12.5. Design of Simple Vertical drop Fall

In a vertical drop fall, the energy of the flowing water is dissipated by means of impact and by sudden deflection of velocity from vertical to horizontal direction. A water cushion is provided at the toe of the drop, so as to reduce the impact of falling jet and thus to save the downstream floor from scour. The water cushion is formed by depressing the floor below the downstream bed of the canal, as shown in Fig. 12.15.

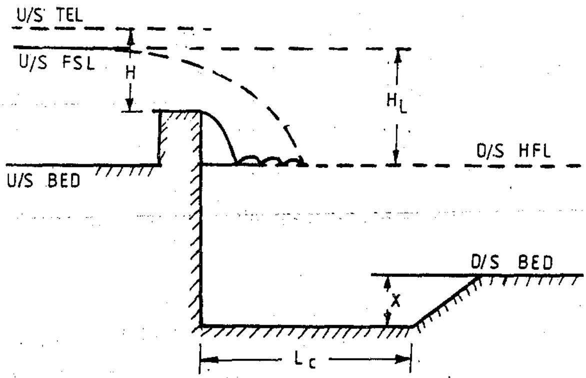


Fig. 12.15

The following dimensions for the cistern have been suggested by U.P. Irrigation Research Institute :

$$L_C = 5 \cdot \sqrt{H \,.\, H_L} \qquad ...(12.8)$$

$$X = \frac{1}{4} \cdot (H \,.\, H_L)^{2/3} \qquad ...(12.9)$$

where L_C = The length of the cistern in metres.

X = Cistern depression below the downstream bed in metres.

H = Head of water over the crest, including velocity head, in metres, *i.e.* = (u/s TEL – Crest level).

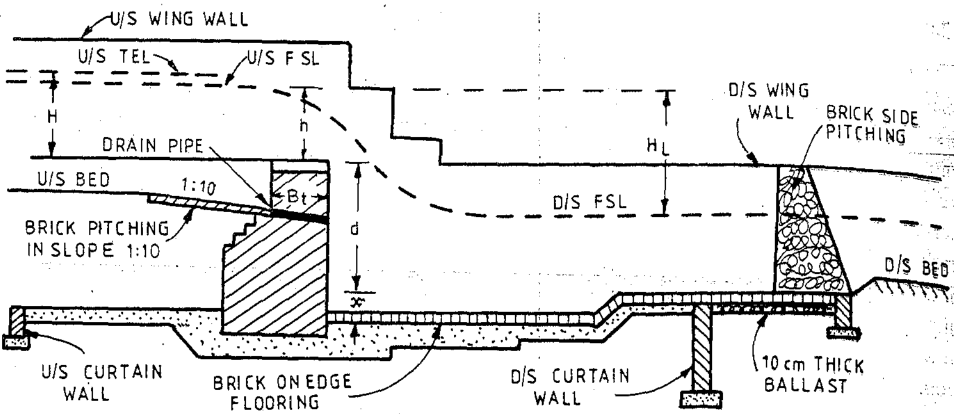
12.6. Design of a Sarda Type Fall

The design criteria for various components of such a fall, based on the recommendations of Bahadarabad Research Station, are given below :

Length of the Crest. Since fluming is not permissible in this type of falls, *the length of the crest is kept equal to the bed width of the canal.* Sometimes, for future expansion, the crest length may be kept equal to (bed width + depth).

Shape of the Crest. A rectangular crest with both faces vertical has been suggested for discharges under 14 cumecs. The top width is kept equal to $0.55\sqrt{d}$ and the minimum base width is kept equal to $\frac{h+d}{G}$ (Take $G = 2$ for masonry) where, d is the height of the crest above the downstream bed level and h is the head over the crest [See Fig. 12.16 (*a*)].

For discharges over 14 cumecs, a trapezoidal crest with top width equal to $0.55 \cdot \sqrt{H+d}$ with upstream side slope of 1 : 3 and downstream side slope of 1 : 8 is adopted [See Fig. 12.16 (*b*)].



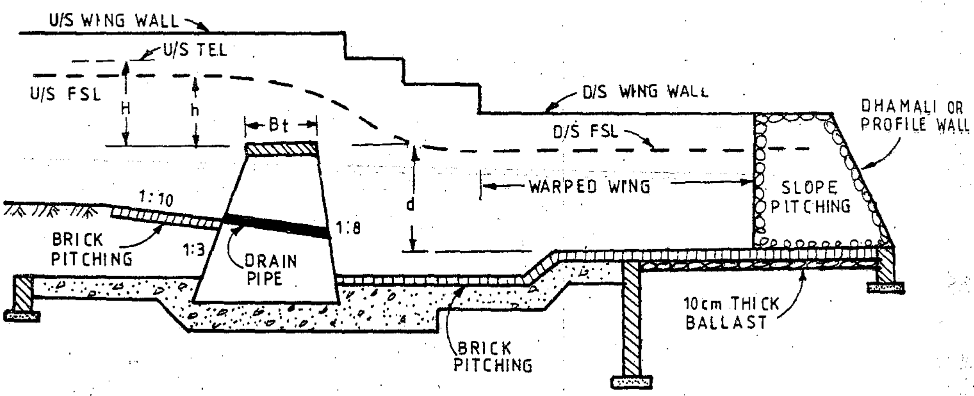
Q = upto a maximum of 14 cumecs

B_t = Top width of crest = $0.55\sqrt{d}$

Base width = $\dfrac{h+d}{2}$

$$Q = 1.84 \cdot LH^{3/2}\left(\frac{H}{B_t}\right)^{1/6}$$

Fig. 12.16. (*a*) Rectangular Crest for Sarda Type fall.



Q = for 14 cumecs and over

B_t = Top width of crest = $0.55\sqrt{H+d}$

Base width = as determined by the batters

$$Q = 1.99 \cdot LH^{3/2}\left(\frac{H}{B_t}\right)^{1/6}$$

Fig. 12.16. (*b*) Trapezoidal crest for a Sarda Type fall.

Crest level. The following discharge formula is used to determine the height of the crest.

$$Q = C_d \, . \, \sqrt{2g} \, . \, L \, . \, H^{3/2}\left(\frac{H}{B_t}\right)^{1/6} \qquad \text{...(12.10)}$$

where C_d = 0.415 for rectangular crest

= 0.45 for trapezoidal crest

L = Length of the crest

B_t = Top width of crest.

Height of the crest above bed $= y - h$

$\approx y - H$ (assuming $h \approx H$ *i.e.* neglecting velocity of approach)

where y is the normal depth of channel (upstream).

Upstream Wing Wall. For trapezoidal crest, the upstream wing walls are kept segmental with radius equal to 5 to 6 times H and subtending an angle of 60° at centre, and then carried tangential into the berm as shown in Fig. 12.17. The foundations of the wing walls are laid on the impervious concrete floor itself.

For rectangular crest (*i.e.* discharge less than 14 cumecs), the approach wings may be splayed straight at an angle of 45°.

Upstream Protection. Brick pitching in a length equal to upstream water depth may be laid on the upstream 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 the channel.

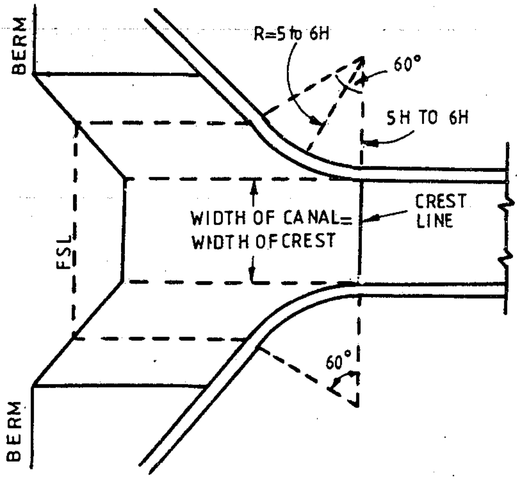


Fig. 12.17. Upstream wing walls for Trapezoidal crest of Sarda Type fall.

Upstream Curtain Wall. $1\frac{1}{2}$ brick thick upstream curtain wall is provided, having a depth equal to $\frac{1}{3}$rd of water depth.

Impervious Concrete Floor. The total length of impervious floor can be determined by Bligh's theory for small works and by Khosla's theory for large works. The minimum length of floor on d/s of the toe of the crest wall should be = [2(water depth + 1.2 m) + drop]. The balance can be provided under the crest and on upstream.

The floor thickness required on the downstream side can be worked out for uplift pressures (using minimum thickness of 0.4 m to 0.6 metre) and only a nominal thickness of 0.3 metre is provided on the upstream side. The maximum seepage head will occur when water is stored upto top of crest on u/s side and there is no flow on the downstream side.

Cistern. The length and depth of cistern can be worked out from equations (12.8) and (12.9).

Downstream Protection. The d/s bed may be protected with dry brick pitching, about 20 cm thick resting on 10 cm thick ballast. The length of the d/s pitching is given by the values of Table 12.1; or 3 times the depth of downstream water, whichever is more. The pitching may be provided between two or three curtain walls. The curtain walls may be $1\frac{1}{2}$ brick thick and of depth equal to $\frac{1}{2}$ the downstream depth; or as given in Table 12.1 (minimum = 0.5 m).

Table 12.1

Head over the crest H (metres)	*Total length of d/s pitching (metres)*	*Remarks*	*Curtain walls*	
			No.	*Depth in metres*
Upto 0.3 m	3.0	All sloping down at 1 in 10	1	0.30
0.3 to 0.45	3.0 + Twice H_L	Horizontal up to end of masonry wings and then sloping down at 1 : 10	1	0.30
0.45 to 0.60	4.5 + Twice H_L		1	0.45
0.60 to 0.75	6.0 + Twice H_L		1	0.60
0.75 to 0.90	9.0 + Twice H_L	"	1	0.75
0.90 to 1.05	13.5 + Twice H_L	"	2	0.90
1.05 to 1.20	18.0 + Twice H_L	"	2	1.05
1.20 to 1.50	22.5 + Twice H_L	"	3	1.35

Slope Pitching. After the return wing, the sides of the channel are pitched with one brick on edge. The pitching should rest on a toe wall $1\frac{1}{2}$ brick thick and of depth equal to half the downstream water depth. The side pitching may be curtailed at an angle of 45° from the end of the bed pitching, or extended straight from the end of the bed pitching.

Downstream Wings. Downstream wings are kept straight for a length of 5 to 8 time $\sqrt{H \cdot H_L}$ and may then be gradually wrapped. They should be taken upto the end of the pucca floor.

All wing walls must be designed as retaining walls, subjected to full pressure of submerged soil at their back when the channel is closed. Such a wall generally has a base width equal to $\frac{1}{3}$rd its height.

Example 12.3. *Design a 1.5 metres Sarda type fall for a canal having a discharge of 12 cumecs, with the following data :*

Bed level upstream	*= 103.0 m*
Side slopes of channel	*= 1 : 1 m*
Bed level downstream	*= 101.5 m*
Full supply level upstream	*= 104.5 m*
Bed width u/s and d/s	*= 1.0 m*
Soil	*= Good loam*
Assume Bligh's Coefficient	*= 6*

Solution.

Length of crest. Same as d/s bed width = 10 m

Crest level. A rectangular crest is provided, since the discharge is less than 14 cumecs. The discharge formula is given by

$$Q = 1.84 \,.\, L \,.\, H^{3/2}\left[\frac{H}{B_t}\right]^{1/6}$$

Assume top width of the crest as 0.8 m.

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

or $$H^{5/3} = \frac{12 \times 0.964}{1.84 \times 10} = 0.628$$

or $$H = (0.628)^{3/5} = 0.755 \text{ m} ; \text{ Say } \mathbf{H = 0.76\ m.}$$

Velocity of approach

$$= V_a = \frac{\text{Discharge}}{\text{Area}} = \frac{12}{(10 + 1.5)\ 1.5} \quad (\because \text{ Depth of water } = 1.5 \text{ m})$$

$$= \frac{12}{11.5 \times 1.5} = 0.696 \text{ m/sec.}$$

Velocity head $= \dfrac{V_a^2}{2g} = 0.025$ m.

u/s TEL = u/s FSL + Velocity Head

= 104.5 + 0.025 = 104.525 m

R.L. of the crest

= (u/s TEL – H)

= 104.525 – 0.755 = **103.77 m.**

Use crest level of 103.77 metres

Height of the crest above d/s floor

= 103.77 – 103.0 = **0.77 m.**

Shape of the crest.

Width of the crest (B_t)

$= 0.55 \cdot \sqrt{d}$

where d = Height of the crest above d/s bed

= 103.77 – 101.5 = 2.27 m

$$\therefore \quad B_t = 0.55 \cdot \sqrt{d} = 0.55 \cdot \sqrt{2.27} = \mathbf{0.825\ m.}$$

Keep 0.85 m width of the crest

Thickness at base $= \dfrac{h + d}{2}$

$$= \frac{(0.755 - 0.025) + 2.27}{2} = \frac{0.73 + 2.27}{2} = 1.5 \text{ m.}$$

The top shall be capped with 20 cm thick C.C. 1 : 2 : 4

Upstream wing wall. It shall be splayed straight at an angle of 45° from the u/s edge of the crest and shall be embedded by 1.0 m into the berm. On the d/s side, wing walls are kept straight and parallel up to the end of the floor and joined to return walls, as shown in Fig. 12.19.

Upstream protection. 1.5 m long brick pitching (equal to u/s water depth) is laid on the u/s bed, sloping down towards the crest at 1 : 10, and *three drain pipes of 15 cm diameter at the u/s bed level should be provided in the crest so as to drain out the u/s bed during the closure of the canal.*

Upstream curtain wall. Maximum depth of u/s curtain wall

$$= \frac{y_u}{3} = \frac{1.5}{3} = 0.5 \text{ m.}$$

Provide 0.4 m × 0.8 m deep curtain wall on the u/s.

Cistern. Depth of cistern, is given by Eq. 12.9 as

$$X = \frac{1}{4}[H \cdot H_L)^{2/3} = \frac{1}{4}[0.76 \times 1.5]^{2/3} = \frac{1}{4} \times (1.14)^{0.667} \quad ...(12.9)$$

$$= \frac{1}{4} \times 1.091 = 0.273 \text{ m} \text{ ; } \textbf{Say 0.3 m deep.}$$

∴ R.L. of cistern = 101.5 − 0.3 = **101.2 m.**

Length of cistern $= 5\sqrt{H \cdot H_L}$

$$= 5 \times \sqrt{0.76 \times 1.5} = 5 \times \sqrt{1.14} = 5.34 \text{ m ; say } \textbf{5.5 m.}$$

Provide 5.5 m long cistern at R.L. 101.2 m.

Impervious floor.

Maximum Static Head

= (Crest level − d/s bed level)

= 103.77 − 101.5 = 2.27 m.

Total floor length required

= *C.H.*; where *C* is Bligh's coefficient

= 6 × 2.27 = 13.62 m. ; say **13.7 m.**

Minimum d/s floor length required

$= [2 \text{ (Water depth } + 1.2) + H_L)$

= 2 (1.5 + 1.2) + 1.5 = 2 (2.7) + 1.5 = 5.4 + 1.5 = 6.9 m ; say **7 m.**

Provide 7 m d/s floor and the balance 6.7 m under and upstream of the crest, as shown in Fig. 12.18.

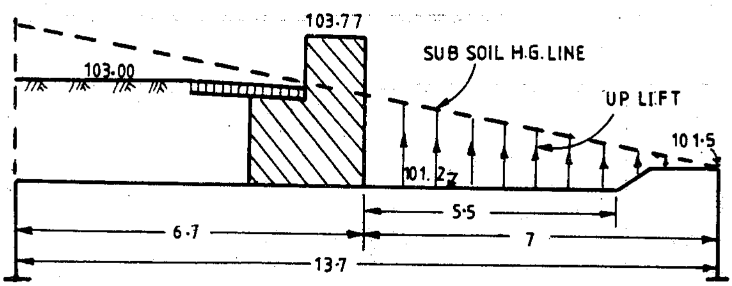


Fig. 12.18

Floor Thicknesses. H.G. line for the maximum static head is shown in Fig. 12.18.

Maximum unbalanced uplift at the d/s toe of the crest

$$= 0.3 + \frac{(103.77 - 101.3)}{13.7} \times 7 = 0.3 + 1.16 = 1.46 \text{ m}$$

Thickness required $\frac{1.46}{1.24} = 1.29$ m ; say 1.3 m.

Provide 1.1 m thick concrete overlain with 0.2 m thick brick pitching.

Unbalanced head at 3 m from the toe of the crest

$$= 0.3 + \frac{2.27}{13.7} \times 4 = 0.3 + 0.67 = 0.97$$

Thickness required $= \frac{0.97}{1.24} = 0.78$ m ; say 0.8 m.

Use 0.6 m thick concrete with 0.2 m brick layer.

Unbalanced head at 5 m from the toe

$$= 0.3 + \frac{2.27}{13.7} \times 2 = 0.3 + 0.33 = 0.63 \text{ m.}$$

Thickness required

$$= \frac{0.63}{1.24} = 0.51 \text{ m ; Say } 0.55 \text{ m.}$$

Use 0.35 m thick concrete with 20 cm thick brick layer, as shown in Fig. 12.19.

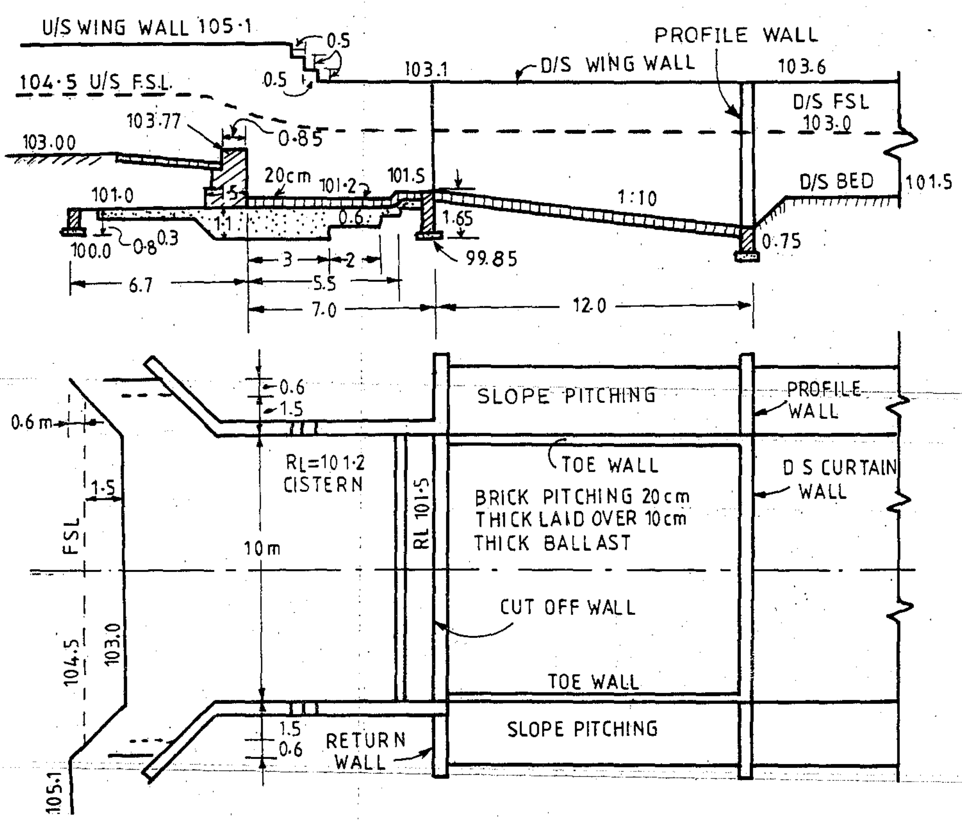


Fig. 12.19. Details of the Sarda Type fall (rectangular crest) of example 12.3.

D/s Curtain Wall. The curtain wall at the d/s end of the floor should be 0.75 m deep (for $H = 0.76$ m in Table 12.1)

Provide $0.4 \text{ m} \times 1.65$ m deep curtain wall at d/s end of floor, *i.e.* upto a level of $101.5 - 1.65 = 99.85$ metres, *i.e.* the deepest foundation level.

Downstream pitching. From Table 12.1,

Total length of d/s pitching

$$= 9 + 2 \times 1.5 = 12 \text{ metres.}$$

Pitching is kept sloped at 1 : 10. A curtain wall of 0.4 m × 0.75 m shall be provided at the end of the pitching, as shown in Fig. 12.19.

Example 12.4. *Design a 1.5 metres Sarda Type fall for a canal carrying a discharge of 40 cumecs with the following data :*

Bed level upstream	*= 105.0 m.*
Bed level downstream	*= 103.5 m.*
Side slopes of channel	*= 1 : 1*
Full supply level upstream	*= 106.8 m.*
Full supply level downstream	*= 105.3 m.*
Berm level u/s	*= 107.4 m*
Bed width u/s and d/s	*= 30 m.*
Safe exit gradient for Khosla's Theory	*= 1/5.*

Solution.

Length of the crest. Is kept equal to bed width = 30 metres.

Crest level. A trapezoidal crest is provided, since the discharge is more than 14 cumecs.

The discharge formula is given by

$$Q = 1.99\, LH^{3/2} \left(\frac{H}{B_t}\right)^{\frac{1}{6}}$$

Assume $B_t = 1.0$ m.

$$\therefore \quad 40 = 1.99 \times 30 \frac{H^{3/2} \cdot H^{1/6}}{(1)^{1/6}}$$

or $$H^{5/3} = \frac{40}{1.99 \times 30} = 0.796$$

or $$H = (0.796)^{3/5} = 0.862 \text{ m; say } \mathbf{0.865 \text{ m.}}$$

Velocity of approach

$$\therefore \quad = V_a = \frac{40}{(30 + 1.8)\, 1.8} = 0.7 \text{ m/sec} \qquad (\because \text{Full supply depth} = 1.8 \text{ m})$$

Velocity head $= \dfrac{(0.7)^2}{2g} = 0.025$ m.

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

$$= 106.8 + 0.025 = \mathbf{106.825 \text{ m.}}$$

∴ R.L. of the crest

$$= \text{u/s TEL} - H$$

$$= 106.825 - 0.862 = \mathbf{105.963 \text{ m.}}$$

Adopt a crest level of 105.97 m.

Shape of the crest. Adopt crest width at top

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

where $H = 0.865$ m

d = Height of the crest above d/s bed

$= 105.97 - 103.5 = 2.47$ m.

$$\therefore \quad B_t = 0.55\sqrt{0.865 + 2.47} = 0.55\sqrt{3.335} = \mathbf{1.0\ m.}$$

Adopt a trapezoidal crest **with top width of 1.0 m** and u/s slope 1 : 3 and d/s slope 1 : 8.

Upstream Wing Walls. Radius of the wings should be 5 to 6 times the head over the crest $= 5 \times 0.865 = 4.325$, to $6 \times 0.865 = 5.19$ m. Use 5.0 m radius for the wings. U/s wing walls shall be kept segmental with 5 m radius subtending an angle of 60° at centre and then carried tangentially into the berm.

Downstream Wing Walls. The downstream wings shall be kept straight up to a distance of say $6 \cdot \sqrt{H \cdot H_L}$, *i.e.* $6 \cdot \sqrt{0.865 \times 1.5} = 6.8$ m; say 7 m, and then warped in a slope of 1 : 1 and shall be taken upto the end of pucca floor.

Upstream Protection. Brick pitching equal to u/s water depth *i.e.* 1.8 m is laid on the u/s towards the crest at 1 : 10 slope. Provide 20 cm drain holes in the entire length at 3 m c/c to drain out the u/s bed during the closure of the canal.

Upstream Curtain Wall. The minimum depth of curtain wall $= \frac{1}{3}$rd water depth, *i.e.* $\frac{1}{3} \times 1.8 = 0.6$ m. Provide 0.7 m deep masonry wall over 0.3 m thick concrete.

Thus, provide a curtain wall 0.4 m × 1.0 m deep on the u/s.

Downstream Curtain Wall. Minimum thickness

$$= \frac{\text{Depth}}{2} = \frac{1.8}{2} = 0.9 \text{ m.}$$

or from Table 12.1, it is equal to 0.75 m.

Provide a d/s curtain wall 0.4 m × 1.4 m over 0.3 m cement concrete. Thus, total depth of d/s curtain wall shall be 1.7 m with its bottom level at 101.8 m.

Cistern. Depth of cistern

$$= X = \frac{1}{4}(\text{H} \cdot H_L)^{2/3} \qquad \text{...(12.9)}$$

$$\therefore \quad X = \frac{1}{4}\left[(0.865 \times 1.5)^{2/3}\right] = \frac{1}{4} \times 1.19 = 0.3 \text{ m (say)}$$

R.L. of Cistern $= 103.5 - 0.3 = 103.2$ *m.*

Length of cistern $= 5\sqrt{H \cdot H_L} = 5 \cdot \sqrt{0.865 \times 1.5} = 5 \times 1.14 = 5.7$ m.

Provide 5.7 m long Cistern

Total Floor Length and Exit Gradient

$$G_E = \frac{H}{d} \cdot \frac{1}{\pi\sqrt{\lambda}}$$

Maximum static head (H) is caused when water is stored upto the crest level and there is no water d/s.

$H = 105.97 - 103.5 = 2.47$ m.

$d = 1.7$ m (*i.e.* Depth of d/s curtain wall)

$G_E = 1/5$ (given)

$$\therefore \quad \frac{1}{5} = \frac{2.47}{1.7} \cdot \frac{1}{\pi\sqrt{\lambda}}$$

or $$\frac{1}{\pi\sqrt{\lambda}} = \frac{1.7}{2.47} \times \frac{1}{5} = 0.137$$

From plate 11.2

$$\alpha = 10$$

or $$\frac{b}{d} = 10$$

or $b = 10 \times 1.7 = 17$ m. ; **Use 18 m.**

Minimum floor length required on the d/s

$$= 2\,(\text{Water depth } + 1.2) + H_L$$

$$= 2\,(1.8 + 1.2) + 0.865 = 6.865 \text{ m} ; \textbf{say 7 m.}$$

Provide the balance length of 11 m under and upstream of the crest, as shown in Fig. 12.20.

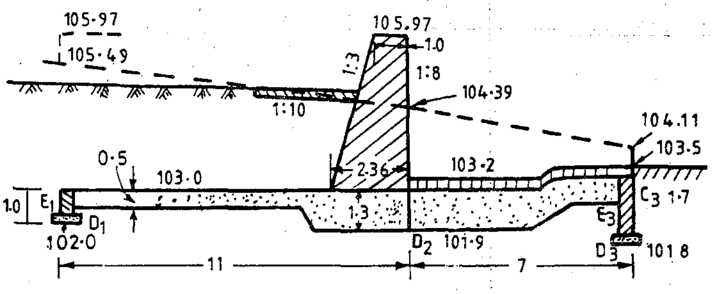


Fig. 12.20

Uplift Pressure Calculations

Assume u/s floor thickness as 0.5 m, and d/s floor thickness as 0.8 m, and floor thickness at toe of the crest as 1.3 m.

(1) *Upstream Wall.*

$$b = 18 \text{ m.}$$

$$d = 1.0 \text{ m.}$$

$$\frac{1}{\alpha} = \frac{d}{b} = \frac{1.0}{18.0} = 0.056$$

From Plate 11.1 (*a*)

$$\phi_{E_1} = 0\%$$

$$\phi_{D_1} = 100 - \phi_D = 100 - 16 = 84\%$$

$$\phi_{C_1} = 100 - \phi_E = 100 - 23 = 77\%.$$

Correction to ϕ_{C_1} *for depth of floor*

$$= \frac{84\% - 77\%}{103.0 - 102.0} \times 0.5 = \frac{7}{1} \times 0.5 = 3.5\% \text{ (+ ve)}$$

Correction due to influence of other wall is very small and neglected.

$\therefore \quad \phi_{C_1}$ **(corrected)** $= 77\% + 3.5\% = \mathbf{80.5\%}$

(2) *Toe of Crest.*

$$b_1 = 11 \text{ m}$$
$$b = 18 \text{ m}$$
$$\frac{b_1}{b} = \frac{11}{18} = 0.61$$
$$d = 103.2 - 101.9 = 1.3 \text{ m}$$
$$\alpha = \frac{b}{d} = \frac{18}{1.3} = 13.9$$

From Plate 11.1(*b*)

$$\phi_{D_2} = 36\%$$

(3) *Downstream Curtain Wall.*

$$d = 1.7 \text{ m}$$
$$b = 18 \text{ m}$$
$$\frac{d}{b} = \frac{1.7}{18} = 0.094$$

From Plate 11.1(*a*)

$$\phi_{E_3} = \phi_E = 29\%$$
$$\phi_{D_3} = \phi_D = 20\%$$
$$\phi_{C_3} = 0\%$$

Correction for depth to ϕ_{E_2}

$$= \frac{29\% - 20\%}{1.7} \times 0.8 = \frac{9}{1.7} \times 0.8 = \mathbf{4.2\%} \ (-\text{ve})$$

ϕ_{E_3} **(corrected)** = 29 – 4.2 = **24.8%**

The levels of H.G. line for **maximum static head** are worked out in Table 12.2 and plotted in Fig. 12.20.

Table 12.2

Condition of flow	*u/s W.L. in metres*	*d/s W.L. in metres*	*Head H in metres*	*Height/Elevation of H.G. line above datum*						
				ϕ_{E_1} *100%*	ϕ_{D_1} *84%*	ϕ_{C_1} *80.5%*	ϕ_{D_2} *36%*	ϕ_{E_3} *24.8%*	ϕ_{D_3} *20%*	ϕ_{C_3} *0%*
Maximum static head, *i.e.* Water up to crest level on u/s and no water downstream	105.97	103.50	2.47	2.47 105.97	2.08 105.58	1.99 105.49	0.89 104.39	0.61 104.11	0.50 104.00	0.90 103.5

Floor Thicknesses

Provide a nominal thickness of 0.4 m under u/s floor.

Unbalanced head at d/s toe of glacis = 104.39 – 103.2 = 1.19 m

$$\text{Thickness required} = \frac{1.19}{1.24} = 0.97 \text{ m ; Use 1.2 m.}$$

Provide 1.0 m thick C.C. overlain by 0.2 m thick brick pitching.

Unbalanced head at d/s end of floor = 104.11 – 103.5 = 0.61 m.

If the height of the crest works out to be more they 0.4 times the upstream water depth, the fall may be flumed or fluming ratio increased, so as to increase H and to lower the crest.

Hump. For an unflumed non-meter ordinary fall, the bed approach may have a slope of $\frac{1}{2}:1$ ($\frac{1}{2}H:1V$), joined tangentially to the u/s edge of the crest with a radius of $H/2$, as shown in Fig. 12.23.

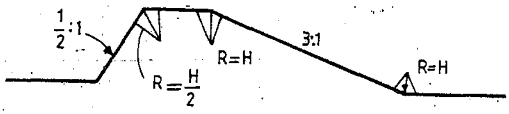


Fig. 12.23

For a flumed meter fall, the curve should start at the same cross-section as the side curves. The radius of hump or bed curve is equal to $\frac{L_a^2+h^2}{2h}$ (see Fig. 12.24).

Upstream Protection. No upstream protection is required for an ordinary unflumed fall. However, for a flumed fall, dry brick pitching on edge may be laid both in bed and sides for a length equal to u/s water depth (in a slope of 1 : 10 in the bed).

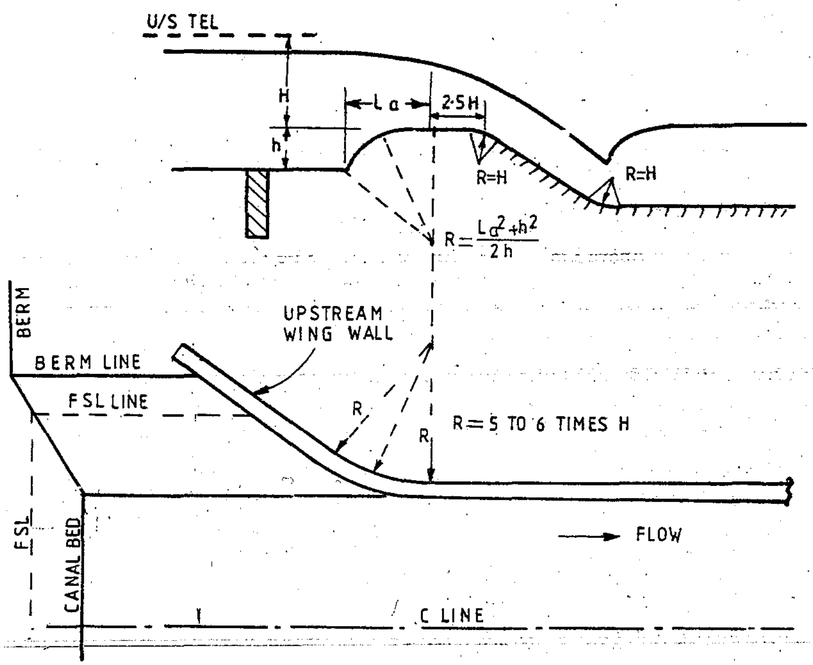


Fig. 12.24

Downstream Glacis. A straight glacis with 2 : 1 slope has been found to be quite suitable for this type of falls. The glacis may be joined to the crest at the u/s end, and to the floor at the d/s end, with a radius = H, as shown in Fig. 12.23.

Length and Thickness of Floor. The floor is designed as per Khosla's theory and the total length of the floor is determined from exit gradient considerations, as was done for Trapezoidal Sarda type fall.

Downstream Protection. With the provision of a deflector wall, no d/s bed pitching is provided, and only side slope pitching is provided for a length equal to 3 times the d/s water depth and should rest on a toe wall.

Upstream Wing Walls. For an unflumed non-meter fall, the side walls may be splayed at 45° from u/s edge of crest and carried into the berm for about one metre [as was done in rectangular crest—Sarda type fall (see Fig. 12.19)].

For a flumed meter fall, curved wings with a radius of 5 to 6 times H subtending an angle of 60° at centre, and therefore, carried tangentially into the berm [as was done in Trapezoidal crest – Sarda type fall (see Fig. 12.17)] may be provided.

Downstream Wing Walls. For an unflumed fall, the walls are taken straight up to the d/s end of the floor and then joined with return walls (as was done in a rectangular crest — Sarda type fall—Fig. 12.19.

For a flumed fall, the d/s wings shall have to be expanded up to the normal width of the river. The expansion can be achieved straight with 1 in 3 slope for smaller works, and a hyperbolic expansion (Fig. 12.25), given by equation (12.11), may be used for large works. The hyperbolic expansion is given by equation :

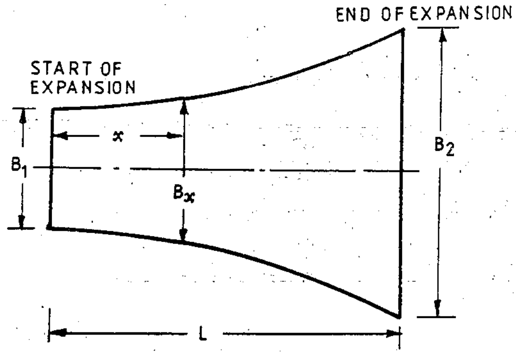


Fig. 12.25. Hyperbolic Expansion.

$$B_x = \frac{B_1 \cdot B_2 \cdot L}{L \cdot B_2 - (B_2 - B_1) \cdot x} \quad ...(12.11)$$

where B_x is the width of expanding flume at any distance x from the beginning of expansion.

The wings shall be embedded into the berms by at least 1 metre.

Roughening Devices or Energy Dissipators

In Sarda type fall, where energy is dissipated by impact, roughening devices can serve as an additional source of energy dissipation. Similarly, in Glacis fall, roughening devices may be employed to arrest the energy left after jump formation. They may help in jump formation also. Various types of roughening devices used in falls are given below :

(1) Friction Blocks. These are the most simple and useful of all such devices. They consist of rectangular concrete blocks securely anchored into the floor. Their height is approximately $\frac{1}{4}$th water depth. The spacing between the blocks is about twice the height of the blocks. The specific recommendations for their use in the modern falls are as given below :

(*a*) *For Vertical Drop Fall or Sarda Type Fall with Trapezoidal crest.* Two rows of friction blocks staggered in plan may be provided, as shown in Fig. 12.26.

The first row may start from a distance 1.5 y_c (where y_c = critical depth) from the d/s toe of the crest. Spacing between the rows is kept equal to y_c.

Spacing between the blocks $= 2 \cdot y_c$.

The dimensions of the blocks

$$= 2y_c \times y_c \times y_c$$

In addition, cube blocks of size $\frac{1}{8}$th to $\frac{1}{16}$th of water depth may be provided at the end of the impervious floor.

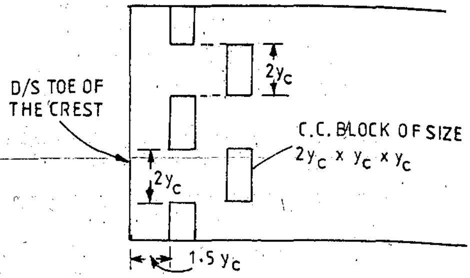


Fig. 12.26. Provision of friction blocks in Sarda type fall.

(*b*) *For Glacis Fall.* Four rows of staggered blocks are generally provided *in case of flumed falls only. Nothing is provided for unflumed falls.* The first row may be provided at a distance equal to 5 × height of block from the toe of the glacis, as shown in Fig. 12.27. The height of the block is generally kept 1/8th of the water depth. The distance between two rows is equal to h (where h is the height of block).

The dimensions of the blocks are $3h \times h \times h$.

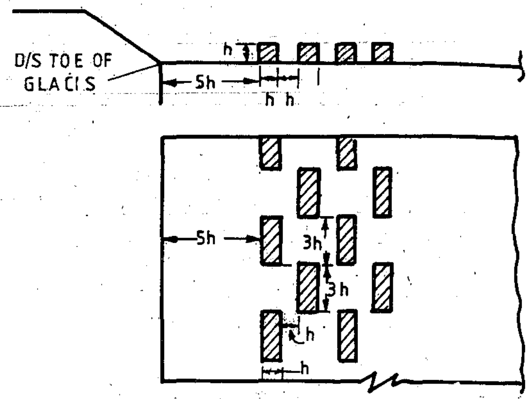


Fig. 12.27. Provision of friction blocks in flumed glacis fall.

(*c*) *For Baffle Fall.* Two rows of friction blocks staggered in plan may be provided only when the drop is more than 2 metres. The suitable dimensions are

Height $(h) = 0.26\, y_2$

where y_2 is the sub-critical depth in the canal d/s, required for formation of jump for parallel downstream sides, in metres.

Length $= h$.

Top width $= \frac{2}{3}h$.

Distance between rows $= h$.

The first row may be placed at a distance $\frac{2}{3}$rd of the cistern length from the upstream end of the cistern.

(2) **Glacis Blocks.** A single row of blocks called Glacis blocks and of the same dimensions as friction blocks may be provided just at the d/s toe of the glacis, in case of flumed falls with drops more than 2 metres, as shown in Fig. 12.28. It helps in reducing turbulence in flow, which in turn, reduces wave wash, thus ensuring uniform flow.

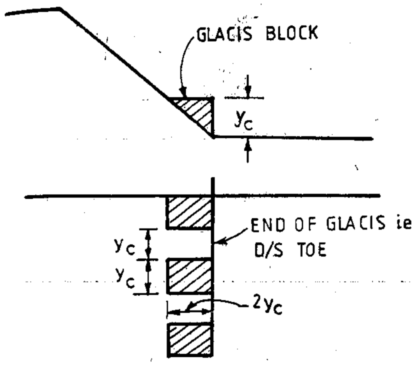


Fig. 12.28. Provision of glacis blocks in flumed falls with drops more than 2 metres.

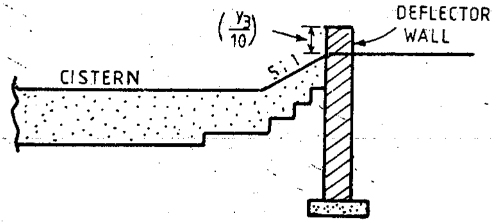


Fig. 12.29. Provision of a deflector wall.

(3) **Biff Wall or Deflector Wall.** A deflector wall of height approximately $\frac{1}{10}$th of water depth may be provided at the downstream end of concrete floor (in cast with d/s cutoff) as shown in Fig. 12.29.

Example 12.3. *Design a straight flumed meter glacis fall with the following data :*

Full supply discharge of the canal = *120 cumecs.*
Bed level of the canal upstream = *107.5 m*
Bed level of the canal downstream = *106.0 m*
Drop (H_L) = *1.5 m.*
FSL of the canal upstream = *109.7 m*
FSL of the canal downstream = *108.2 m*
Bed width of the canal u/s and d/s = *60 m*
Safe Exit Gradient for canal material $= \frac{1}{5.5}$.

Solution

Length of Crest. From Table 12.3, for $H_L = 1.5$,

flumingratio = 75%

∴ Length of the crest

= 75% of Bed width of canal

= 75% × 60 m = **45 m.**

Adopt crest length = 45 m.

Crest Level. Since the fall is to be used as a meter, a broad crest shall be provided.

∴ Discharge Q is given by

$$Q = 1.70\, LH^{3/2}.$$

$$\therefore \quad 120 = 1.70 \times 45\, H^{3/2}.$$

or $$H^{3/2} = \frac{120}{1.7 \times 45} = 1.57$$

or $$H = (1.57)^{2/3} = \mathbf{1.35\ m}$$

Velocity of approach

$$= V_a = \frac{120}{(60+2.2)\,2.2} = 0.876$$

[assuming 1 : 1 side slopes of canal and taking depth = 2.2 as given]

Velocity head $= \dfrac{(0.876)^2}{2 \times 9.81} = 0.039$ m; say **0.04 m.**

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

$= 109.7 + 0.04 = 109.74$ m.

Crest Level = u/s TEL − H

$= 109.74 - 1.35 = 108.39$ m.

Adopt crest level = 108.39 m.

Height of the crest above u/s bed

$= 108.39 - 107.5 = 0.89$ m.

which is approximately equal to 0.4 times the upstream water depth ($2.2 \times 0.4 = 0.88$ m) and hence, we can go ahead with this fluming ratio and the present crest level.

Crest Width. Adopt crest width for broad crest

$= 2.5H = 2.5 \times 1.35 = 3.375$ m.

Provide crest width = **3.38 m.**

Hump. The crest shall be joined with upstream bed with a curve of radius

$$R = \frac{L_a^2 + h^2}{2h}$$

where $L_a = 2$ m (assume).

$h = 0.89$ (ht. of crest above u/s bed).

∴ Radius of the curve

$$R = \frac{2^2 + (0.89)^2}{2 \times 0.89} = \frac{4.79}{1.78} = \mathbf{2.69\ m}$$

Cistern. The d/s glacis is provided in a slope of 2 : 1. The cistern level is worked out as below :

$Q = 120$ cumecs.

Width provided = 45 m.

q = Discharge intensity $= \dfrac{120}{45} = 2.27$ cumecs/metre

$H_L = 1.5$ m.

From plate 10.1, $E_{f_2} = 1.85$ m.

Level at which jump will form

$=$ d/s TEL $- E_{f_2} = 108.24 - 1.85 =$ **106.39 m.**

$1.25\, E_{f_2} = 2.31$ m

R.L. of Cistern = d/s TEL $- 1.25\, E_{f_2}$

$= (108.2 + 0.04) - 2.31.$

$= 108.24 - 2.31 =$ **105.93 m.**

which is lower than the d/s bed level, and hence, **adopt cistern level = 105.93 m.**

Length of Cistern. 5 to 6 times E_{f_2} *i.e.* $5 \times 1.85 = 9.25$ m; or $6 \times 1.85 = 11.10$ m. Hence, **use 10 m length of cistern** joined to d/s bed in a slope of 5 : 1 in a length of $5\,(106 - 105.93) = 0.35$ m.

Downstream Curtain Walls. Depth of d/s curtain wall below bed $= \frac{\text{water depth}}{2}$

$= \frac{2.2}{2} = 1.1$ m; or from Table 10.2, it is equal to 1.35 m, therefore, adopt a curtain wall of total depth equal to 1.4 m, *i.e.* 1.1 m masonry laid over 0.3 m concrete.

Total Floor Length and Exit Gradient. Maximum static head (H) is caused when water is stored up to crest level on the u/s and there is no water d/s.

Maximum static head (H) = 108.39 – 106.0 = 2.39 m

Depth of d/s curtain wall (d) = 1.4 m.

Safe Exit gradient $G_E = \frac{1}{5.5}$

But $$G_E = \frac{H}{d} \cdot \frac{1}{\pi\sqrt{\lambda}}$$

∴ $$\frac{1}{5.5} = \frac{2.39}{1.4} \cdot \frac{1}{\pi\sqrt{\lambda}}$$

or $$\frac{1}{\pi\sqrt{\lambda}} = \frac{1}{5.5} \times \frac{1.4}{2.39} = \mathbf{0.107}$$

From Plate 11.2,

$$\alpha = 17$$

Total floor length required

$$= \alpha \cdot d = 17 \times 1.4 = 23.8 \text{ m. ; } \textbf{say 24 m.}$$

The distribution of floor length is shown in Fig. 12.29. 20.65 m is already provided and the balance of 3.35 m is provided as u/s floor length.

Upstream Curtain Wall. A curtain wall of minimum depth $\frac{y_u}{3} = \frac{2.2}{3} = 0.73$ m must be provided at the end of pucca floor. Let us provide an u/s curtain wall (cutoff) of 0.4 m × 0.8 m deep masonry wall laid over 0.3 m thick cement concrete, thus giving a total depth of cutoff as 1.1 m.

Uplift Pressures. Refer Fig. 12.30. Assume floor thickness on the u/s = 0.3 m and thickness on d/s = 0.8 m

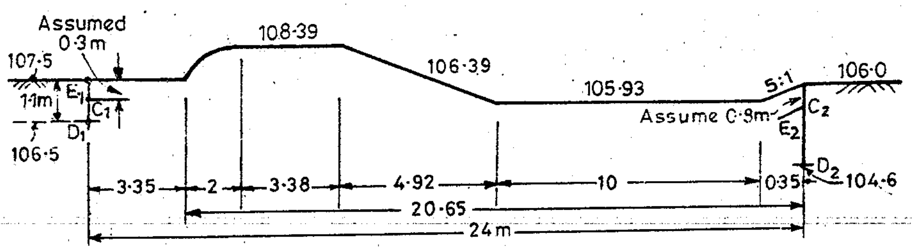


Fig. 12.30

U/s Curtain Wall

$$b = 24 \text{ m}$$
$$d = 1.1 \text{ m}$$
$$\frac{1}{\alpha} = \frac{d}{b} = \frac{1.1}{24} = 0.046$$

From Plate 11.1 (*a*)

$$\phi_{E_1} = \mathbf{100\%}$$

$$\phi_{C_1} = 100 - \phi_C = 100 - 20 = 80\%$$

$$\phi_{D_1} = 100 - \phi_D = 100 - 13 = \mathbf{87\%}$$

Correction for depth to ϕ_{C_1}

$$= \frac{87\% - 80\%}{1.1} \times 0.3 = 1.91\% \text{ (+ ve)}$$

ϕ_{C_1} **(corrected)** $= 80 + 1.91 = \mathbf{81.91\%}$

D/s Curtain Wall

$$b = 24 \text{ m}$$

$$d = 1.4 \text{ m}$$

$$\frac{1}{\alpha} = \frac{d}{b} = \frac{1.4}{24} = 0.0583$$

From Plate 11.1 (*a*)

$$\phi_{E_2} = \phi_E = 23\%$$

$$\phi_{D_2} = \phi_D = \mathbf{15\%}$$

$$\phi_{C_2} = \mathbf{0\%}$$

Correction for depth to ϕ_{E2}

$$= \frac{23\% - 15\%}{1.4} \times 0.8 = 4.6\% \text{ (– ve)}$$

ϕ_{E_2} **(corrected)** $= 23\% + 4.6\% = \mathbf{27.6\%}$

The levels of H.G. lines for maximum static head and flow at FSL are worked out in Table 12.4 and plotted in Figs. 12.31 (*a*) and (*b*), respectively.

Table 12.4

Condition of flow	*u/s W.L. in metres*	*d/s W.L. in metres*	*Head in metres*	*Height/elevation of H.G. line above datum*					
				ϕ_{E_1} *100%*	ϕ_{D_1} *87%*	ϕ_{C_1} *81.91%*	ϕ_{E_2} *27.6%*	ϕ_{D_2} *15%*	ϕ_{C_2} *0%*
Maximum Static Head, *i.e.* Water upto Crest level on u/s and no water on d/s	108.39	106.0	2.39	2.39 108.39	2.08 108.08	1.96 107.96	0.61 106.61	0.36 106.36	0 106.0
Flow at FSL	109.7	108.2	1.5	1.5 109.7	1.30 109.50	1.23 109.43	0.41 108.61	0.22 108.42	0 108.2

Floor Thicknesses. Provide 0.3 m thickness under upstream floor.

At Toe of Glacis. Level of H.G. line (*for static head*) at toe of glacis.

$$= 106.61 + \frac{107.96 - 106.61}{24} \times 10.35$$

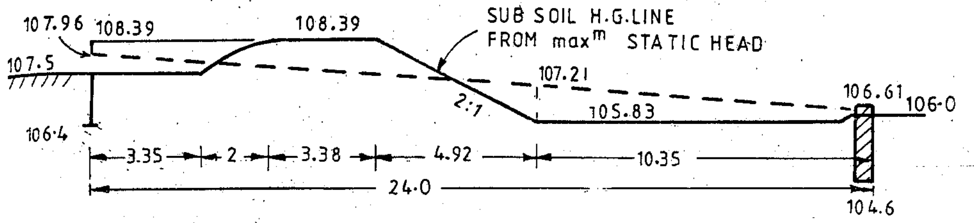


Fig. 12.31. (*a*) Maximum static head condition.

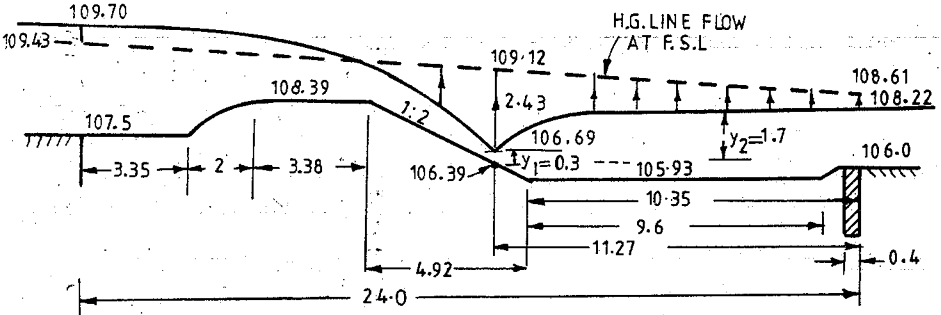


Fig. 12.31. (*b*) Flow at FSL condition.

$$= 106.61 + \frac{1.35}{24} \times 10.35$$

$$= 106.61 + 0.59 = 107.20 \text{ m.}$$

Unbalanced head at the toe due to static head

$$= 107.20 - 105.93 = 1.27 \text{ m}$$

Jump formation

$q = 2.27$ cumecs/metre.

$H_L = 1.5$ m.

$E_{f_2} = 1.85$ m.

$E_{f_1} = E_{f_2} + H_L = 1.85 + 1.50 = 3.35$ m.

From Plate 10.2

y_1 (for E_{f_1}) = 0.3 m.

y_2 (for E_{f_2}) = 1.7 m.

The maximum ordinate at point of jump; from Fig. 12.31 (*b*) = 2.43 m.

$\frac{2}{3}$rd of this ordinate $= \frac{2}{3} \times 2.43 = 1.62$ m, which is more than that for static head.

Hence, the floor thickness at point of jump must not be less than

$$= \frac{1.62}{1.24} = 1.31 \text{ m.}$$

Provide 1.5 m at this point and extend upto 2 m beyond toe

Level of H.G. line at 2 m beyond toe (due to static head)

$$= 106.61 + \frac{1.35}{24} \times 8.35 = 106.61 + 0.47 = \mathbf{107.08\ m.}$$

Unbalanced head = 107.08 − 105.93 = **1.15 m.**

Thickness required $= \frac{1.15}{1.24} = 0.925$ m., **Provide 1.0 m.**

Level of H.G. line at 5 m beyond toe (due to static head)

$$= 106.61 + \frac{1.35}{24} \times 5.35 = 106.61 + 0.30 = 106.91$$

Unbalanced head due to static head at this point

$$= 106.91 - 105.93 = 0.98 \text{ m.}$$

Thickness required $= \frac{0.98}{1.24} = 0.79$ m., **Use 0.8 m.**

Upstream Wing Walls. Curved wing walls with radius equal to $6H = 6 \times 1.35 = 8.10$ m subtending an angle of 60° at centre and then carried tangentially into the berm for a suitable length shall be provided as shown in the attached chart Fig. 12.32.

Downstream Expansion. The width of 45 m shall be expanded to 60 m in a splay of 3 : 1.

Minimum length of expansion required $= \frac{3\,(60-45)}{2} =$ **22.5 m.**

The wings can be splayed straight from the d/s toe of the glacis in a length equal to 22.5 m. The bed shall have to be pitched upto the end point of wings. Slope pitching shall be provided in a length $3 \times 2.2 = 6.6$ m beyond this point.

Upstream pitching in a minimum length of 2.2 m (equal to u/s water depth) is required. It shall, however, be provided as shown in Fig. 12.32.

Energy Dissipators. Four rows of staggered friction blocks shall be provided. The height of the block is $\frac{1}{8}$th of water depth, *i.e.* $\frac{1}{8} \times 2.2 = 0.275$ m. The first row shall be at a distance $5 \times 0.275 = 1.375$ m from the d/s toe of glacis. The size of the blocks shall be $0.825 \text{ m} \times 0.275 \text{ m} \times 0.275$ m. Distance between rows = 0.275 m.

A deflector wall at end point of floor is provided and is to have a height equal to $\frac{y_d}{10}$, *i.e.* $\frac{2.2}{10} =$ **0.22 m.**

The detailed arrangement is shown in attached chart Fig. 12.32.

12.8. Design of a Baffle Fall or Inglis Fall

Certain flumed type ordinary straight Glacis falls constructed in Punjab were later found to give some serious troubles, which gave rise to the conclusion that considerable surplus energy might remain in water even after the jump formation. One major cause of these troubles was found to be, too rapid expansion after fluming, which may generate cork screw eddies causing deep scours. Research was carried out to eliminate these defects and Baffle fall was evolved.

A baffle fall makes use of the principle of horizontal impact for energy dissipation. The jump is held stable on a horizontal platform by means of a baffle wall (called baffle).

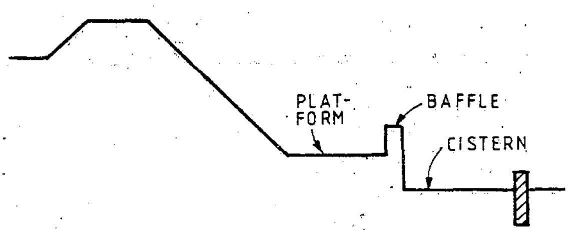


Fig. 12.33. Baffle fall.

Baffle Platform. The horizontal platform is provided at the level at which the jump would normally form. This can be determined by Blench curves in case there is no expansion of the wings in the region of supercritical jet. If the supercritical jet is splayed, the optimum level at which the baffle platform should be provided, can be determined by designer's curves (given in C.B.I. publication No. 10). In the absence of curves, the values can be determined by using the formulas given below.

Subcritical depth (y_2) required for jump formation in ordinary cases without fluming is very nearly given by

$$y_2 = 0.98\, q^{0.52}\, H_L^{0.21} \qquad ...(12.10)$$

where q = the discharge intensity in cumecs/metre

H_L = Drop in metres.

y_2 = the subcritical depth in metres.

The subcritical depth [y_2 (flumed)] required for jump formation, in case there is a fluming, is given by

$$y_2\,(\text{flumed}) = y_2 + (H_X - H_L) \qquad ...(12.11)$$

where H_X is the calculated drop in metres given by

$$H_X = \frac{H_L}{K^{0.152}} \qquad ...(12.12)$$

where K is the fluming ratio (more than 1), *i.e.*

$$= \frac{\text{Actual width of canal before fluming}}{\text{Flumed width of canal}}$$

The R.L. of the baffle platform will then be given by

(*i*) For unflumed fall = d/s FSL $- y_2$.

(*ii*) For flumed fall = d/s FSL $- y_2$ (flumed)

Baffle Wall. Height of the baffle wall = $h_b = y_c - y_1$ ...(12.13)

where y_c is the critical depth, given by

$$y_c = \left[\frac{q^2}{g}\right]^{1/3} \qquad ...(12.14)$$

and y_1 is prejump super critical depth, given by

$$y_1 = 0.183\, q^{0.89} \cdot H_X^{-0.35} \qquad ...(12.15)$$

$H_X = H_L$, when there is no fluming

Thickness of the baffle wall $= \frac{2}{3} h_b$ ...(12.16)

Length of baffle platform $= 5.25\, h_b$. ...(12.17)

Cistern. A cistern of length equal to 5 y_2 (flumed) (equal to $5 \cdot y_2$, for without fluming) may be provided after the baffle wall. The depth of the cistern below the downstream bed should be 10% of the downstream water depth (y_d), subject to a minimum of 15 cm for distributaries and minors and 30 cm for main canals and branches.

Upstream Wings. The upstream wings can be curved with a radius equal to $3.6\, H^{3/2}$ (where H is the total head over the crest) when H is more than 0.3 m, and equal to $2H$ when H is less than 0.3 m. The circular wings are continued till they subtend an angle of 60° at the centre, and afterwards they can be extended tangentially for the required length into the berm or bank.

Downstream Wings. The downstream divergence for flumed meter falls can be provided at a slope of 1 in 3 to 1 in 4.

A milder divergence is preferable for straight Glacis fall as well as for Baffle fall (1 in 4 to 1 in 10 depending upon the bed width depth ratio of the downstream channel); but that will make the structure costlier. Hence, a divergence of 1 in 3 is generally used for meter falls of both types. The d/s wings of the unflumed baffle fall are kept as are kept for unflumed straight Glacis fall.

Downstream Glacis. The d/s glacis for unflumed baffle falls is kept at 2/3 : 1; but for flumed meter falls, it is kept as 2 : 1. The glacis is joined to crest at the u/s end and to the floor at the d/s end with a radius equal to H, as was done in the case of a glacis fall.

All other details of pitching, etc. remain the same as for straight glacis fall.

The friction blocks are either not provided (upto 2 m fall); or provided as explained earlier (for drops of more than 2 m.)

Example 12.6. *Design an unflumed non-meter baffle fall for the canal having the following data :*

Full supply discharge	= *30 cumecs*
Bed level u/s	= *203.0 m*
Bed level d/s	= *201.2 m*
FSL u/s	= *204.3 m*
FSL d/s	= *202.5 m*
Bed width	= *28 m*
Drop (H_L)	= *1.8 m*
Side slopes of channel	= *1 : 1.*

Solution.

Crest Length. Equal to bed width : Provide 28 m. crest length

Crest level. A sharp narrow crest is provided, for which

$$Q = 1.84\, LH^{3/2}$$

$$\therefore \quad 30 = 1.84 \times 28\, H^{3/2}$$

or $$H^{3/2} = \frac{30}{1.84 \times 28} = 0.582$$

or $$H = (0.582)^{2/3} = 0.697 \text{ m; say } \mathbf{0.7\ m.}$$

Velocity of approach

$$= V_a = \frac{30}{(28 + 1.3)\ 1.3} = 0.787 \text{ m/sec.}$$

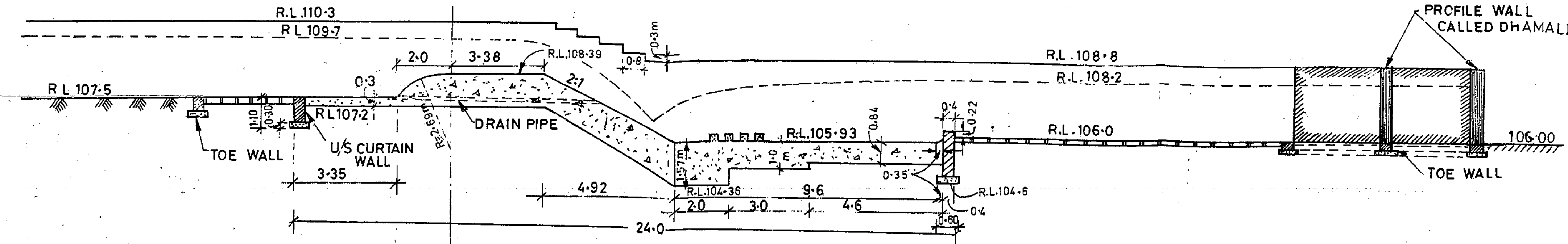
$$\text{Velocity Head} = \frac{V_a^2}{2g} = \frac{(0.787)^2}{2 \times 9.81} = 0.0315 \text{ m; say } \mathbf{0.03\ m.}$$

Now, u/s TEL = u/s FSL + Velocity head

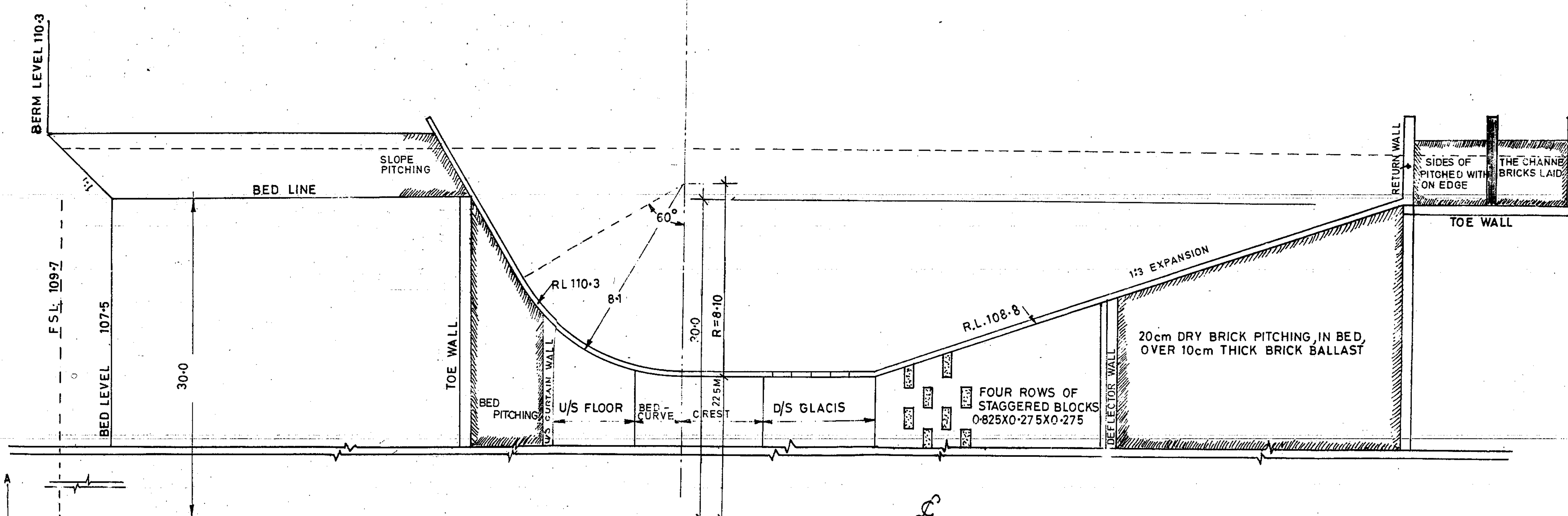
= 204.3 + 0.03 = 204.33 m.

Crest Level = u/s TEL − H

= 204.33 − 0.7 = 203.63 m.



SECTION A-A



TOP PLAN

Fig.12·32

FLUMED GLACIS FALL (FIG. 12.23)

Adopt crest level = 203.6 m.

Width of the crest is kept equal to $\frac{2}{3}H = \frac{2}{3} \times 0.7 = 0.47$ m

Provide **crest width = 0.47 m.**

U/s Glacis. Glacis of $\frac{1}{2}:1$ joined tangentially to the crest with a radius equal to $\frac{H}{2} = 0.35$ m shall be provided.

D/s Glacis. Glacis of $\frac{2}{3}:1$ joined tangentially to the baffle platform with a radius equal to $H = 0.70$ m shall be provided.

Upstream Wings. The u/s wing walls shall be splayed at an angle of 45° from the u/s end of the floor and shall be embedded into the bank by 1.0 m beyond FSL line.

Downstream Wings. Parallel vertical sides up to the end of pucca floor shall be provided, which shall be connected with the return walls at 90°.

Upstream Protection. No pitching is required in bed and on sides. Depth of u/s curtain wall required is

$$= \frac{y_u}{3} = \frac{1.3}{3} = 0.43 \text{ m.}$$

Provide $0.4 \text{ m} \times 0.6$ m deep curtain wall over 0.3 m foundation concrete, thus making its overall depth as 0.9 m.

Baffle Platform and Baffle Wall

Baffle Platform. Since there is no fluming,

$$H_L = H_x = 1.8 \text{ m}$$

Now $\quad y_2 = 0.98 \cdot q^{0.52} \cdot H_L^{0.21} \qquad$ (*i.e.* Eq. 12.10)

where $q = \frac{30}{28} = 1.07$ cumecs/metre

$$\therefore \quad y_2 = 0.98 \cdot (1.07)^{0.52} \cdot (1.8)^{0.21}$$
$$= 0.98 \times 1.0358 \times 1.133 = 1.15 \text{ m.}$$

R.L. of baffle platform

$$= \text{d/s FSL} - y_2 = 202.5 - 1.15 = 201.35 \text{ m.}$$

Provide Baffle platform at R.L. = 201.35 m

Baffle Wall. Height of the baffle wall

$$= h_b = y_c - y_1$$

where $\quad y_c = \left[\frac{q^2}{g}\right]^{1/3} = \left[\frac{(1.07)^2}{9.81}\right]^{1/3} = (0.117)^{0.33} = 0.49 \text{ m}$

$y_1 = 0.183 \cdot q^{0.89} \cdot (H_x)^{-0.35} \qquad$ (*i.e.* Eq. 12.15)

$$= 0.183\,(1.07)^{0.89}\,(1.8)^{-0.35} = \mathbf{0.16\ m}$$

∴ **Height of the baffle wall**

$$h_b = y_c - y_1$$
$$= 0.49 - 0.16 = \mathbf{0.33\ m.}$$

Thickness of baffle wall $= \frac{2}{3} h_b = \mathbf{0.22\ m.}$

Length of baffle platform

$$= 5.25\ h_b = 5.25 \times 0.33 = 1.73\ \text{m.}\ ;\ \text{say}\ \mathbf{1.8\ m.}$$

Cistern. Depth of cistern below d/s bed

$$= 0.1\ y_d = 0.1 \times 1.3 = 0.13\ \text{m.}$$

R.L. of cistern = 201.2 – 0.13 = **201.07 m.**

Length of cistern $= 5 \cdot y_2$

$$= 5 \times 1.15 = 5.75\ \text{m; say}\ \mathbf{5.8\ m.}$$

D/s Curtain Wall. Depth of the downstream curtain wall required

$$= \frac{y_d}{2} = \frac{1.3}{2} = 0.65\ \text{m;}$$

or from Table 12.1, the depth for the curtain wall is equal to 0.6 m.

Provide 0.4 m × 1.0 m deep curtain wall, over 0.3 m thick foundation concrete, thus making a total depth of curtain wall = 1.3 m

Height of deflector above d/s bed

$$= \frac{y_d}{10} = \frac{1.3}{10} = 0.13\ \text{m.}$$

Hence, the d/s curtain wall shall be raised by 0.13 m above d/s bed.

D/s Bed Pitching. No pitching is required.

D/s Side Slope Pitching. Is required in a length equal to

$$3 \cdot y_d = 3 \times 1.3 = 3.9\ \text{m.}$$

Provide 0.2 m thick dry brick pitching over 0.1 m thick brick ballast in a length equal to 3.9 m. The slope pitching shall rest on a toe wall 0.4 m thick and 0.8 m deep (overall) constructed in the bed at the junction of bed and sides. A solid profile wall called 'Dhamali' shall be constructed at the end of pitching. It shall be 0.4 m thick and plastered in cement mortar.

Friction Blocks. Not required.

Total Floor Length from Exit Gradient Considerations

Safe exit gradient = 1/5

Maximum static head (*H*) is exerted when water is stored upto crest level on u/s and there is no water on d/s.

∴ $H = 203.6 - 201.2 = 2.4$ m.

Depth of d/s curtain wall $= d = 1.3$ m

Now, $$G_E = \frac{H}{d} \cdot \frac{1}{\pi\sqrt{\lambda}}$$

$$\frac{1}{5} = \frac{2.4}{1.3} \cdot \frac{1}{\pi\sqrt{\lambda}}$$

or $$\frac{1}{\pi\sqrt{\lambda}} = \frac{1}{5} \times \frac{1.3}{2.4} = 0.108$$

From Plate 11.2,

$$\alpha = 16.5$$

$\therefore$ Total floor length required $= \alpha d = 16.5 \times 1.3 = 21.45$ m;

Provide **22 m** overall length.

The floor length already provided (12.365 m) is shown in Fig. 12.34 ; the balance, *i.e.* 9.635 m is now provided on the u/s, as shown in Fig. 12.34.

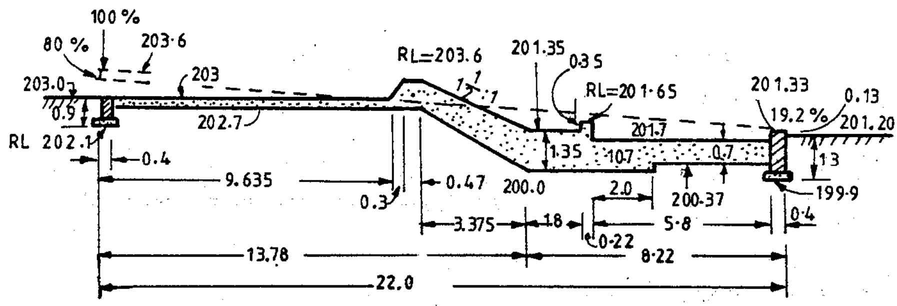


Fig. 12.34. Dimensions of the baffle fall of example 12.6.

Calculations for Uplift Pressures

(*i*) *Upstream curtain wall*

$$b = 22 \text{ m}$$
$$d = 0.9 \text{ m}$$
$$\frac{1}{\alpha} = \frac{d}{b} = \frac{0.9}{22} = 0.041$$

From Plate 11.1 (*a*),

$$\phi_{E_1} = \mathbf{100\%}$$
$$\phi_{D_1} = 100 - \phi_D = 100\% - 14\% = \mathbf{86\%}$$
$$\phi_{C_1} = 100 - \phi_E = 100\% - 20\% = \mathbf{80\%}$$

Assume upstream floor thickness = 0.3 m.

Correction to ϕ_{C_1} for depth

$$= \frac{86\% - 80\%}{0.9} \times 0.3 = 2.0\% \text{ (+ ve)}$$

ϕ_{C_1} **(Corrected)** $= 80\% + 2\% = \mathbf{82\%}$

(*ii*) *Downstream curtain wall*

$$b = 22 \text{ m}$$
$$d = 1.3 \text{ m}$$
$$\frac{1}{\alpha} = \frac{d}{b} = \frac{1.3}{22} = 0.059$$

From Plate 11.1 (*a*)

$$\phi_{E_2} = \phi_E = 23\%$$

$\phi_{D_2} = \phi_D = \mathbf{16\%}$

$\phi_{C_2} = \mathbf{0\%}$

Assume d/s floor thickness near d/s curtain wall = 0.7 m

Correction to ϕ_{E_2} for floor thickness

$$= \frac{23\% - 16\%}{1.3} \times 0.7 = 3.8\% \text{ (– ve)}$$

ϕ_{E_2} **(Corrected)** = 23% – 3.8% = **19.2%.**

Uplift pressure at the toe of the glacis

$$= 19.2\% + \frac{80\% - 19.2\%}{22} \times 8.22$$

$$= 19.2\% + 22.7\% = 41.9\%$$

Floor Thicknesses

U/s Floor. Provide a nominal thickness of 0.3 m on the upstream side and extend it up to d/s end of crest. Its bottom level shall be at R.L. 202.7 m.

Toe of Glacis

Level of H.G. line at toe of glacis

$$= 201.2 + 41.9\% \times 2.4$$
$$= 201.2 + 1.0 = 202.2 \text{ m}$$

∴ Unbalanced head due to this maximum static head of 2.4 m

$$= 202.2 - 201.35 = \mathbf{0.85\ m}$$

Unbalanced head due to dynamic condition may be taken as

$= 50\% \ (y_2 - y_1) + \%\ \text{pressure} \times H_L$ (Refer page 558 Chapter 11)

$$= 50\% \ (1.15 - 0.16) + 41.9\% \times 1.8$$
$$= 0.495 + 0.754 = 1.249 \text{ m}; \textbf{ say 1.25 m.}$$

Thus, at toe of glacis, the head due to dynamic condition is more than that due to static condition. Hence, minimum thickness required at toe $= \frac{1.25}{1.24} = 1.01$ m. Provide 1.35 m thickness in the entire length of baffle platform, thus keeping its bottom at R.L. 201.0 m.

Thickness at the start of cistern

Percentage pressure at 2.02 m from toe of glacis (*i.e.* start point of cistern)

$$= 19.2\% + \frac{80\% - 19.2\%}{22} \times 6.2$$

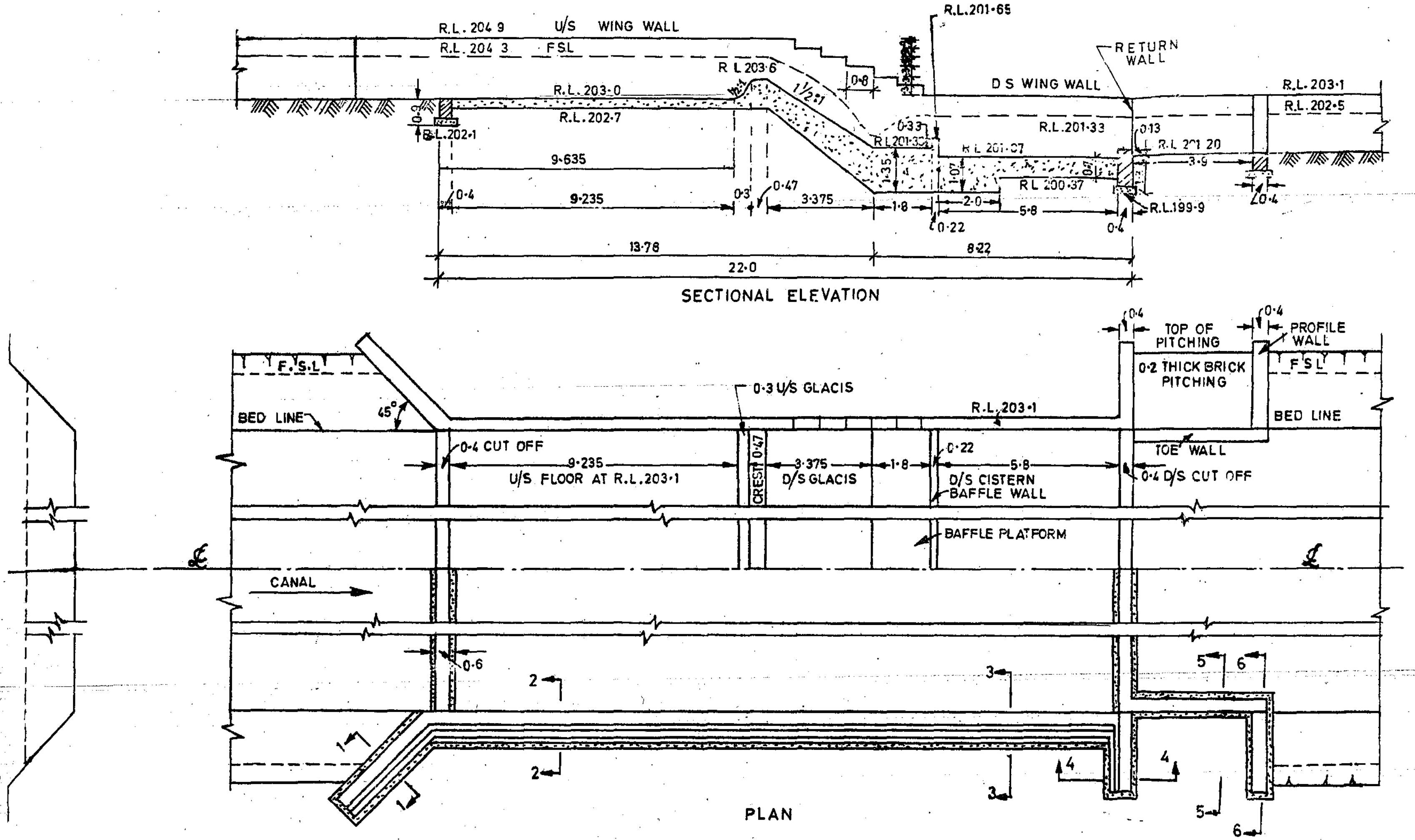
$$= 19.2\% + 17.2 = 36.4\%$$

Level of H.G. line at this point

$$= 201.2 + 36.4\% \ (2.4)$$
$$= 201.2 + 0.87 = 202.07 \text{ m.}$$

Maximum unbalanced head at this point

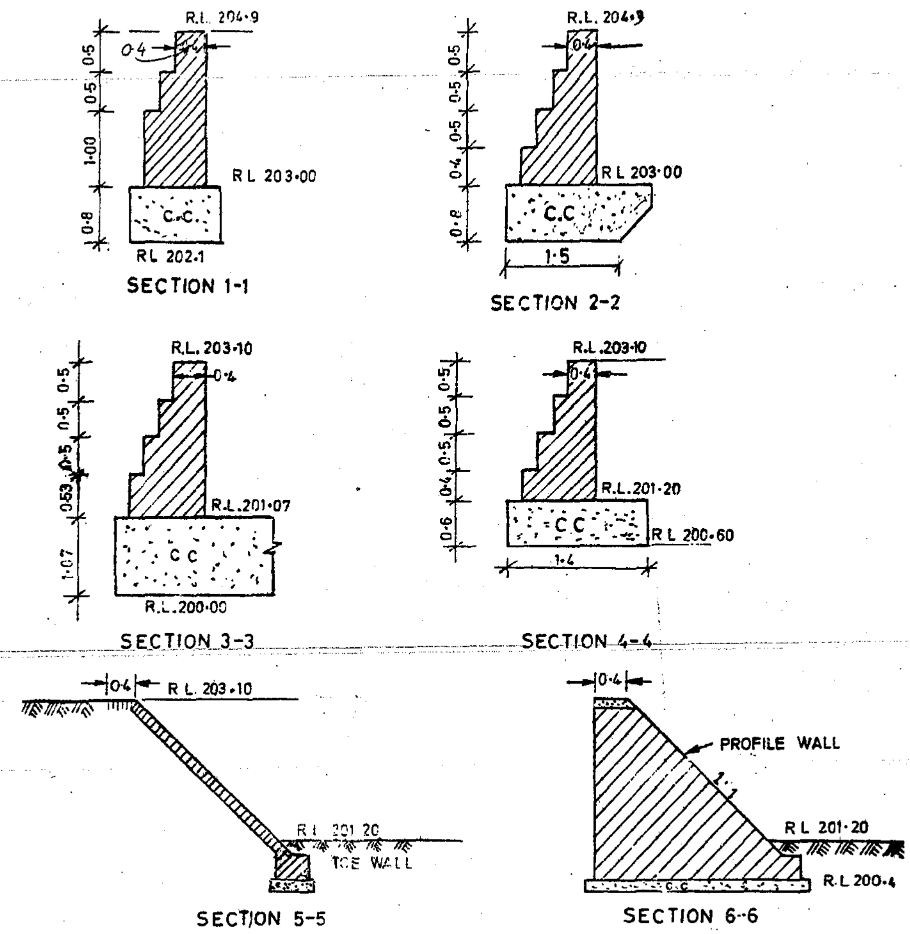
$$= 202.07 - 201.07 = 1.0 \text{ m}$$



UNFLUMED BAFFLE FALL

Scale 1cm = 1m

Fig.12·35.



SCALE 1cm=0·5M

Floor thickness required at this point

$$= \frac{1.0}{1.24} = 0.81 \text{ m}$$

Provided thickness = 201.07 − 200.0 = 1.07 m.

Thickness required at 3 m beyond the baffle wall

$$= 19.2\% + \frac{80\% - 19.2\%}{22} \times 3.2$$

$$= 19.2\% + 8.85\% = 28.05\%$$

Level of H.G. line at this point

$$= 201.2 + 28.05\% \ (2.4)$$
$$= 201.2 + 0.67 = 201.87 \text{ m}$$

Maximum unbalanced head at this point

$$= 201.87 - 201.07 = 0.80 \text{ m}$$

Floor thickness required at this point

$$= \frac{0.80}{1.24} = 0.645 \text{ m}$$

Hence, provide 0.7 m thickness in the remaining portion, as shown in Fig. 12.34. Full details of the fall are shown in the attached chart Fig. 12.35.

PROBLEMS

1. (*a*) What is meant by 'Canal drops' ? Why are canal drops constructed in a canal system ?

(*b*) Enumerate the various types of canal drops which have been used since olden days. Explain in details the design principles governing any one of the modern types.

2. Why are "drops" constructed in an irrigation canal ?

Draw a neat sketch of a syphon well drop and explain briefly its components.

(*Madras University, 1973*)

3. (*a*) What is meant by "falls" and where are they located ?

(*b*) Discuss briefly the components of various types of falls with neat sketches. Also discuss the suitability of each type.

4. Sketch a syphon well drop to carry 0.3 cumec of water from the following data :

Ground level	= 30.00 m.
B.L. of channel above drop	= 28.00 m.
F.S.L. of channel above drop	= 30.00 m.
F.S.L. of channel below drop	= 28.50 m.
B.L. Of channel below drop	= 26.50 m.

Provide a 4 m cart track over the well drop. The earthwork connections should be clearly shown. Assume any other data that you may require. (*Madras University, 1976*)

5. (*a*) Explain why trapezoidal notches are preferred to rectangular notches in the design of canal drops. (*Madras University, 1974*)

(*b*) Design the size and number of notches required for a canal drop with the following particulars:

Full supply discharge	= 20 cumecs
Bed width	= 14 m.
F.S. depth	= 1.9 m.

Assume any other data if required.

Ans. [6 Notches as with $l = 0.83$ m and $n = 0.37$, provided in a crest raised above the bed level by 0.6 m.]

6. (*a*) Discuss the comparative merits and demerits of Notch falls and Sarda type falls.

(*b*) Design 1 m Sarda type fall on a channel carrying 20 cumecs discharge whose bed width and water depth are 14 m and 1.9 m respectively.

7. (*a*) What are canal falls and why are they constructed ?

(*b*) Design an unflumed non-meter hydraulic jump type fall (*i.e.* glacis fall) on a distributary carrying 10 cumecs discharge. The drop to be affected is 2 m, and the depth of flow and the bed width of channel are 1.4 m and 8.0 m respectively.

8. (*a*) Discuss the principle advantage offered by a baffle fall in comparison to a straight glacis fall.

(*b*) Design a flumed baffle fall for a canal having the following data :

Full supply discharge of the canal	= 120 cumecs.
Bed level of canal upstream	= 107.5 m.
Bed level of canal downstream	= 105.5 m.
Drop (H_L)	= 2 m.
F.S.L. of canal upstream	= 109.7 m
F.S.L. of canal downstream	= 107.7 m.
Bed width of canal u/s and d/s	= 60 m.
Bligh's safe hydraulic gradient for the soil	= C = 12.

9. (*a*) What are "canal falls" and where are they located ?

(*b*) What is meant by "flumed falls" and what are their advantages ?

(*c*) Discuss how fluming is done for flumed falls. Write down the equations etc. that you will adopt for designing the upstream as well as downstream wing walls of flumed falls.

(*d*) What are "roughening devices" ? Discuss their use in 'falls construction' ? What roughening device would you recommend for a straight glacis fall ? (*a*) when flumed (*b*) when not flumed.

10. (*a*) State briefly how you will decide the location of a canal drop. Explain how a trapezoidal notch type fall helps to maintain depth discharge relation in the canal.

(*b*) Following data were observed in a canal fall :

Full supply level	= 115 m.
Bed level of canal	= 112 m.
Bed width of canal	= 15 m.
Full supply discharge	= 30 cumecs
Side slope of canal	= 2 (H) : 1 (V)
Length of crest of the fall	= 10 m (crest section is rectangular)
Coefficient of discharge over crest	= 1.70 $m^{1/2}$/sec.

Calculate the crest level.

[**Solution.** $Q = 30$ cumecs

$y = 3$ m.

$B = 15$ m.

$A = (B + 2y)\, y$ (with $2H : 1\ V$ slopes) = 63 sq. m.

V_a = velocity in channel

$$= \text{velocity of approach} = \frac{Q}{A} = \frac{30}{63} = 0.48$$

$$\frac{V_a^2}{2g} = 0.0117; \textbf{ say } \mathbf{0.012\ m}$$

$$\therefore \text{ U/s T.E.L.} = \text{u/s F.S.L.} + \frac{V_a^2}{2g} = 115 + 0.012 = 115.012 \text{ m.}$$

Now, $Q = 1.7\, L \cdot H^{3/2}$

$$30 = 1.7 \times 10\, H^{3/2}$$

$$H = 1.462 \text{ m.}$$

$\therefore$ Crest level $= \text{u/s T.E.L.} - H$

$= 115.012 - 1.462 = 113.65$ m. **Ans.]**

11. Write short notes on any three of the following :

(*i*) Syphon well drop.

(*ii*) Roughening Devices.

(*iii*) Wing wall for flumed falls.

(*iv*) Trapezoidal notch fall.

(*v*) Simple vertical drop type fall.

(*vi*) Sarda type fall.

(*vii*) Straight glacis fall

(*viii*) Baffle or Inglis fall.

(*ix*) Different types of falls and their suitability for a particular project.