UNIT 11 CROSS DRAINAGE WORKS

Structure

11.1 INTRODUCTION

When a canal takes off from a river, it has to cross some streams or rivers before it can reach the top of the intended watershed for the purpose of irrigating an area. Such crossings constitute various types of cross drainage works that are required to be provided on the canal alignment. Cross drainage works are required to carry the canal by negotiating it above, below or at the same level as the stream across which the canal is meant to be aligned.

Objectives

By studying this unit you should be able to conceptualize the basics of the following cross drainage works :

- an aqueduct,
- a syphon aqueduct,
- a syphon,
- a superpassage,
- an inlet and outlet, and
- a level crossing.

Further you should be able to :

- select a suitable type of cross drainage work that is appropriate to given site conditions, and
- get an understanding of the various design parameters regarding cross drainage works.

11.2 NECESSITY OF CROSS DRAINAGE WORKS

Figure 11.1 shows a canal aligned between the headworks and the main watershed. The canal taking off from point *A* on the river has to cross some streams or drainages, *a*, *b*, *c* and *d*, before it can be taken on the watershed at *B*. At the intersections of the canal and the tributaries or streams, major cross drainage works will be required. These cross drainage works are provided on the alignment of the canal such that the water in the canal is taken across the stream, above, below or at the same level as the stream it is intended to cross, as per practical conditions. Usually no cross drainage works are needed once the canal mounts the watershed except in places where the canal is required to leave the watershed as at DEFG for a short distance and the cross streams at *E* and *F*.

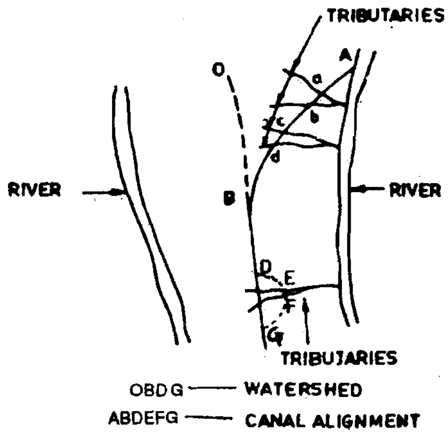

Figure 11.1 : Canal Alignment – Offtake to Main Watershed

SAQ 1

Why are cross drainage works needed? Why do they cross the natural drainage at different levels?

11.3 AQUEDUCT

An aqueduct is a hydraulic structure which carries a canal (through a trough or a duct) across and above the drainage, just as a bridge carries the road or rail traffic over a river. In this case the highest flood level of the drainage should remain lower than the level of the underside of the canal trough.

Types of an Aqueduct

There are three types of aqueducts as described below :

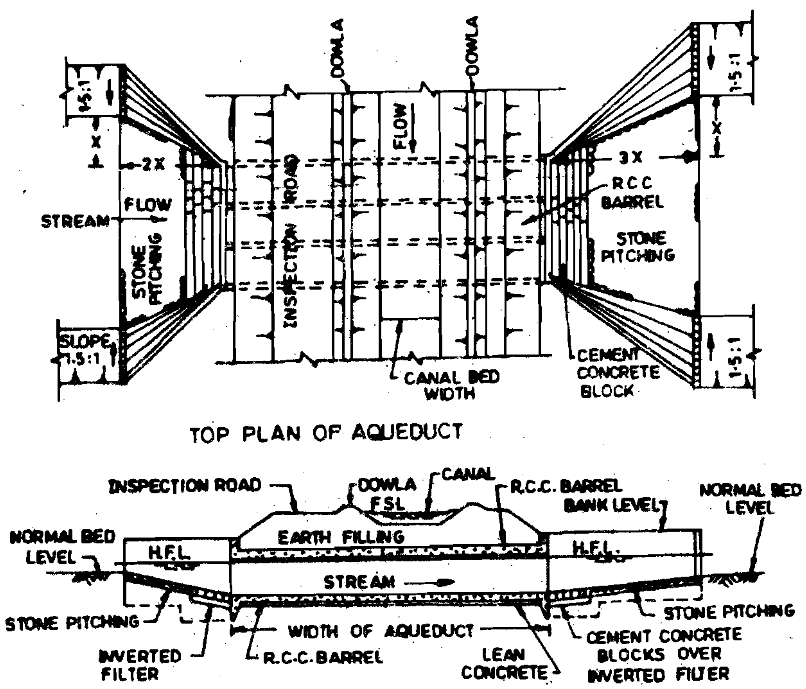

Figure 11.2 : Typical Plan and Section of an Aqueduct (*Type I*)

Type I : In this type of structure the entire section of the canal (without any change in it) along with its earthen banks is carried across the drainage. Hence the length of the barrels through which the drainage water is passed under the canal has to be long so as to support the section of flow of water and the canal banks (Figure 11.2). In this type of work there is no fluming of the canal section (i.e., there is no reduction in the width of the section), and so the width of the structure across the canal is maximum possible. The advantage of this type of aqueduct is that this structure saves on the canal wings and bank connections and is recommended only for small streams where, obviously, the length of the structure along the canal is small. An extreme example of this type would be where a small stream is passed through a large pipe or a series of pipes laid under the bed of the canal with the pipes flowing freely.

Type II : In this type of structure, which is similar to Type I, the outer slopes of the earthen canal banks are replaced by retaining walls which reduces the length of the culvert while the inner slopes of the canal are retained as earthen sections. Streams of intermediate size are negotiated by this type of structure (Figure 11.3).

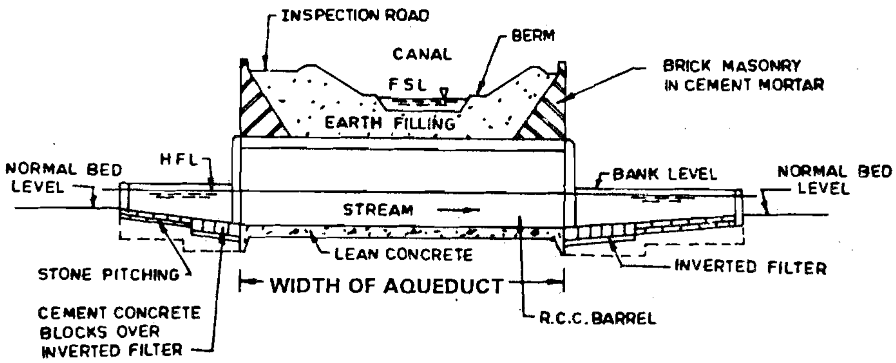

Figure 11.3 : A Typical Section of an Aqueduct (*Type II*)

Type III : Here the normal earthen banks of the canal are replaced by a flumed trough of concrete or masonry (Figure 11.4) over and across the drain for carrying the canal discharge. The side walls of the trough are extended on the upstream and downstream of the canal and connected to the earthen canal banks by means of suitable wing walls designed to provide a smooth transition for the flow. This provides the shortest length of the barrels for the drainage and is thus suited to large streams requiring considerable length of aqueduct between the abutments. Thus, the cost of the barrels for the drain would be least while the cost of the flumed canal trough would be the highest.
Figure 11.5 shows a typical section of an aqueduct of Type III.

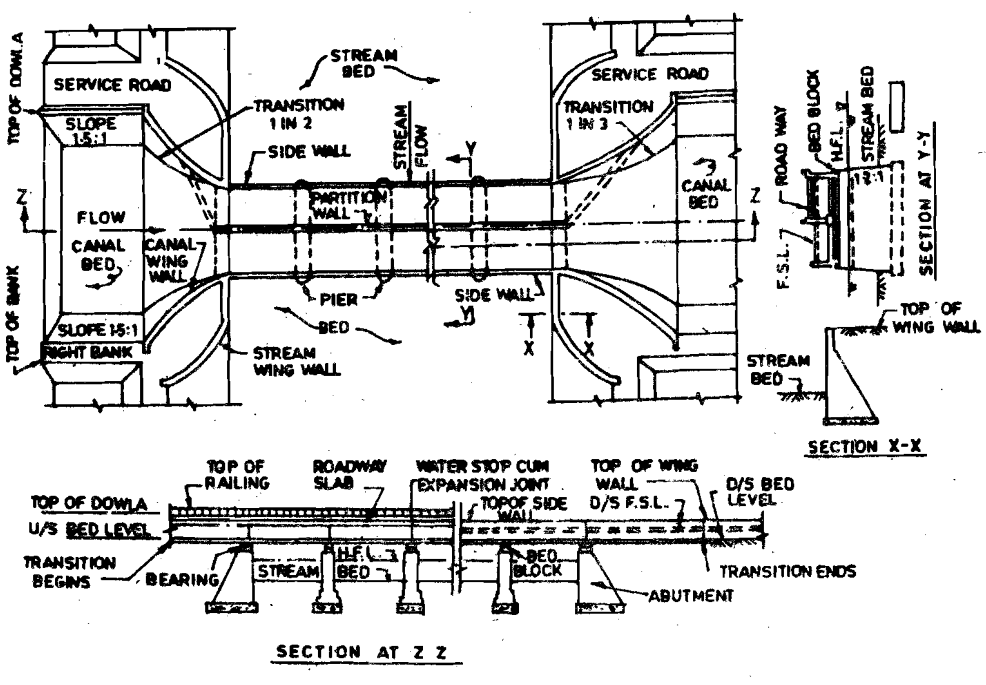

Figure 11.4 : Typical Plan and Section of an Aqueduct (*Type III*)

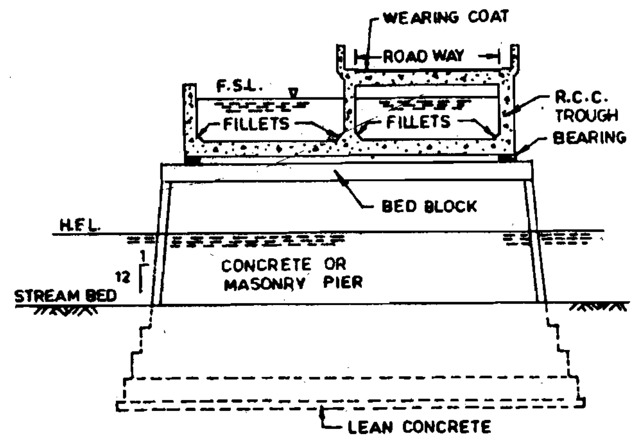

Figure 11.5 : Enlarged Typical Section of an Aqueduct (*Type III*)

SAQ 2

Discuss the factors that influence the choice of an open aqueduct out of the three types discussed above. What is the importance of cost factor while choosing an alternative out of these types?

11.4 SYPHON AQUEDUCT

A syphon aqueduct is a cross drainage structure similar to an ordinary aqueduct except that the bed of the stream is depressed locally where it passes under the trough of the canal, and the barrels discharge the stream flow under pressure. In order to control the shape of the barrel, the stream bed is usually provided with a concrete or masonry floor.

Types of Syphon Aqueduct

Syphon aqueducts are of three types almost exactly like the ordinary aqueducts except that the HFL of the stream is higher than the underside of the canal trough. Figures 11.6, 11.7 and 11.8 show the three types of syphon aqueducts – Type I, Type II and Type III, respectively.

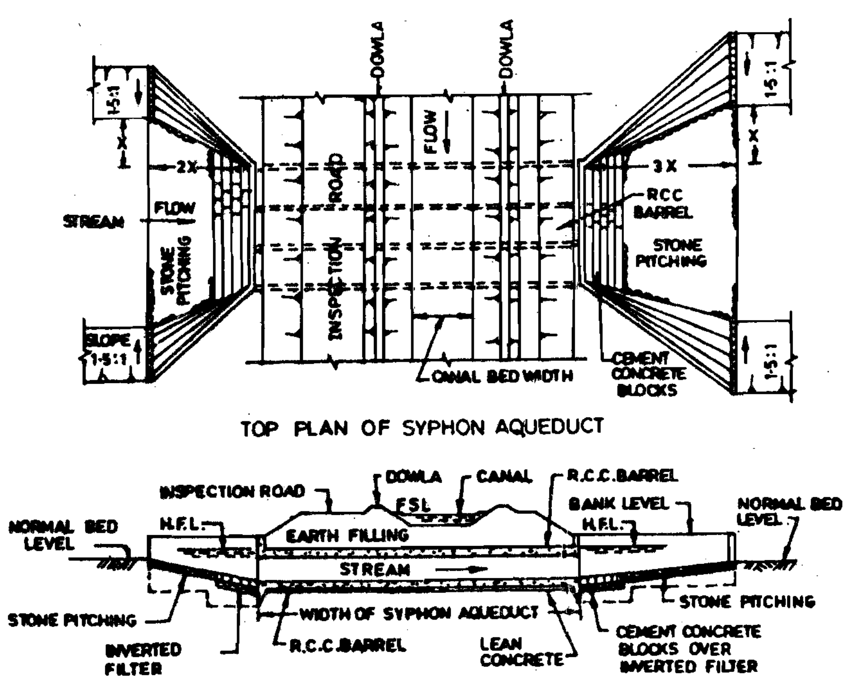

Figure 11.6 : Typical Plan and Section of Syphon Aqueduct (*Type I*)

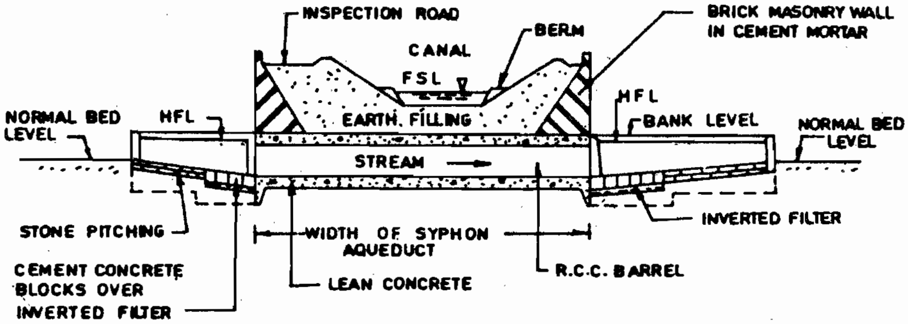

Figure 11.7 : Typical Section of Syphon Aqueduct (*Type II*)

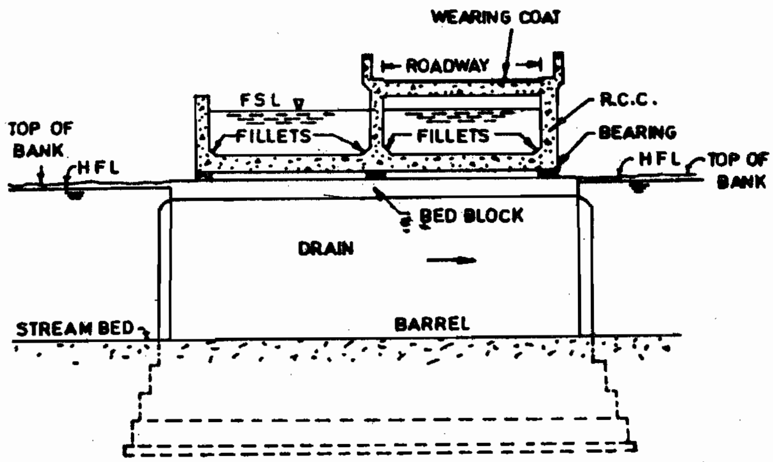

Figure 11.8 : Typical Section of Syphon Aqueduct (*Type III*)

SAQ 3

How do syphon aqueducts differ from ordinary aqueducts; and what are their respective mechanics of flow?

11.5 SYPHON

A syphon carries the natural drainage over the canal, while the canal is discharged

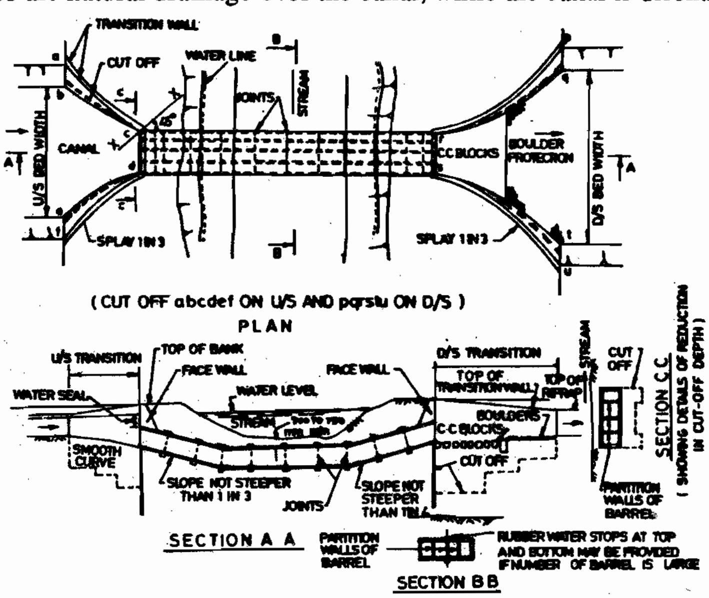

Figure 11.9 : Profile of a Typical Canal Syphon

through the barrels under the trough meant for the drain. Thus, the flow through the barrels is a pressure flow. If the canal carries small discharges the barrels in the form of precast RCC pipes will be economical. Where higher discharges are required to be carried by the canal, the barrels may be horse shoe shaped, rectangular or circular; either single or multiple (Figure 11.9) or even box type structures. For the sake of economy, the roofs of rectangular barrels are shaped as arches. In case the discharges are under high pressure, the more suitable shape would be circular or horse shoe.

SAQ 4

Is there an alternative to a situation that demands putting up a syphon, discuss?

11.6 SUPERPASSAGE

In this type of cross drainage work the canal maintains its flow at atmospheric pressure while negotiating the crossing below the drainage with the full supply level in the canal maintained lower than the underside of the slab of the supporting structure (Figure 11.10). The stream flows through a trough.

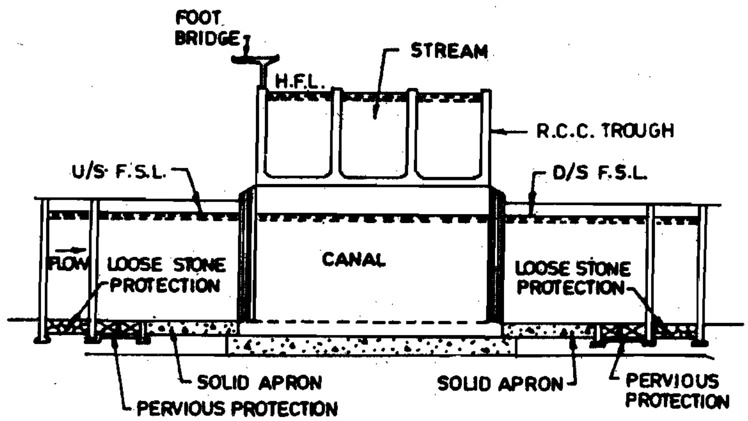

Figure 11.10 : A Typical Cross-Section of a Superpassage

SAQ 5

What is the difference between a superpassage and an aqueduct as well as between a syphon and a superpassage?

11.7 INLET AND OUTLET

This is a type of cross drainage work in which there is an intermixing of the waters of the small drainage and the canal that crosses the formar; and the excess water brought in by the drainage is released at some convenient location further downstream of the canal. This arrangement is provided only where the silt load of the drainage is small. Even so it would lead to some silt deposition in the canal which is a drawback of this arrangement. The inlet is provided where the bed level of the drainage is higher than the FSL of the canal. This permits the drainage water to flow into the canal. The inlet is a non-regulating structure. It includes a fall or a pitched rapid confined by the side wing walls to introduce the drainage water into the canal. The drainage carries a small discharge as compared to the canal; however, the capacity of the canal between the inlet and the outlet will have to be sufficient to accommodate this extra water (Figure 11.11).

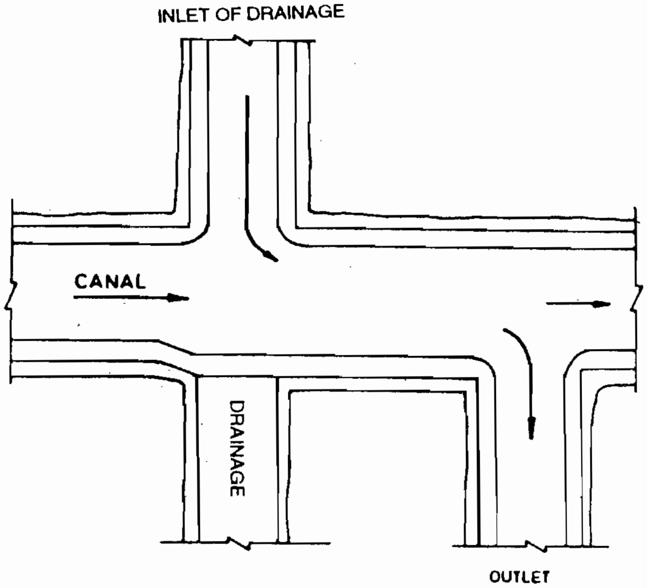

Figure 11.11 : Inlet-Outlet Arrangement as a Cross Drainage Work

The outlet is generally combined with an outlet or some other arrangement that would be needed for escaping un-necessary water; or the outlet as such may be included separately at a small additional expenditure.

11.8 LEVEL CROSSING

A level crossing is a cross drainage work in which the drainage and the canal meet each other at about the same level (Figure 11.12). Such an arrangement is adopted when both the canal and the drainage carry considerable discharges, the latter during the high flood season when syphoning either the canal or the stream proves to be extremely costly or else the head loss through the syphon barrels is very high. At the upstream end of the junction a barrier with its top at the same level as the canal FSL is provided across the stream. On the downstream end of the junction regulators are provided across the canal as well as the stream. The regulators are meant to control the discharges into the canal and the stream downstream of the crossing. This type of arrangement is advantageous in that the canal supplies can be augmented by the discharge in the stream provided the stream does not bring in considerable amounts of sediments.

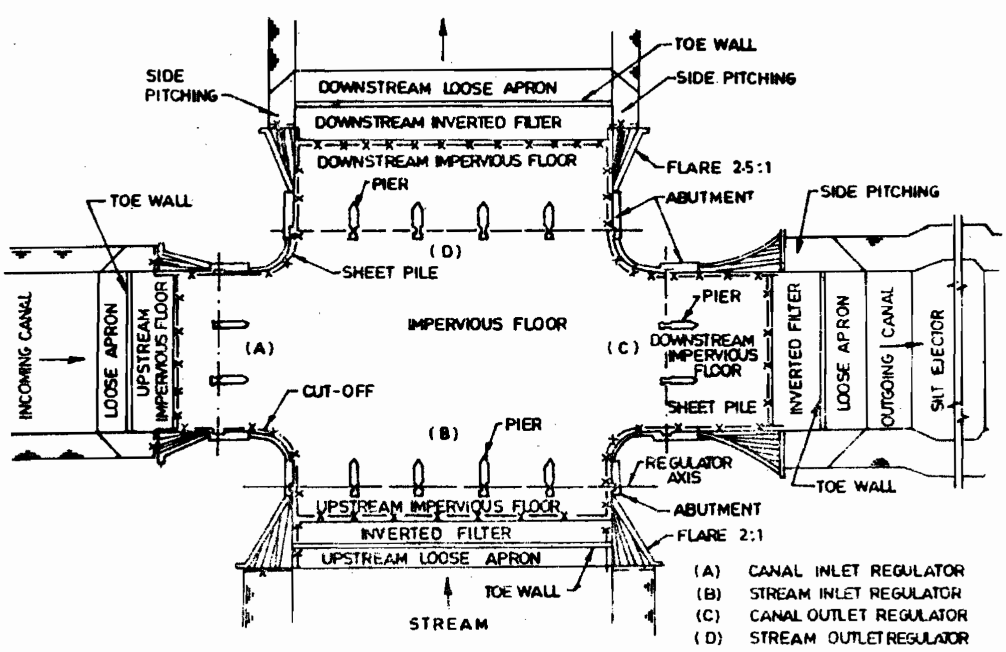

Figure 11.12 : Layout Plan of a Level Crossing

11.9 SELECTION OF A SUITABLE TYPE OF CROSS DRAINAGE WORK TO CONFORM TO SITE CONDITIONS

The most suitable type of a cross drainage work at any location is determined by the relative bed levels and the high water levels of the canal and the drainage corresponding to their respective high discharges.

Where the bed level of the canal happens to be much higher than the high flood level of the drain the most suited structure would be an aqueduct.

On the other hand, where the bed level of the drain happens to be much higher than the full supply level of the canal the most appropriate structure would be a superpassage.

A syphon would be the best choice where the discharge in the canal is small while the discharge in the drain is large.

The syphon aqueduct would be suitable where the drain carries a much smaller discharge than the canal.

A level crossing would be suited where the bed level of the canal as well as the drain are nearly the same and the drain does not carry excessive sediment load but carries considerable discharge.

An inlet-outlet is suited where the drain carries less discharge and both the canal and the drain have nearly the same bed level.

Before making a final selection of a particular cross drainage work, relative economics of the various possible alternatives are to be considered. Factors to be accounted for in the economic analysis include the following :

(a) Topography of the terrain and canal alignment,

(b) Foundation strata spectrum,

(c) Position of ground water table and requirements of dewatering,

(d) Permissible loss of head in the canal, and

(e) Sediment characteristics of the drain and its regime conditions.

It is possible to alter the alignment of the canal thereby adjusting the relative bed levels of the canal and the drainage. Therefore, the canal alignment should be finally selected with regard to the location of the cross drainage works. Aqueducts are superior to superpassages as cross drainage works both from the consideration of economy as well as safety. A syphon aqueduct is superior to a canal syphon provided the bed of the drain need not be lowered too much. Excessive lowering of the canal bed will involve considerable loss of head in the syphon. Moreover, syphoning a canal under a drain having erodible bed is expensive as heavy protection works would often be necessary.

Where a canal carrying considerable flow crosses a river carrying a high flood discharge and the beds of the two are almost at the same level, a level crossing is the only choice. In such situations, the perennial discharge in the river may be utilised to provide additional irrigation.

An inlet may be provided when the small drainage has its bed level at the full supply level of the canal or is slightly higher than it. In case the drain carries heavy sediment load it is bound to affect the performance of the canal. Inlets and outlets are generally avoided since their performance is not satisfactory.

SAQ 6

What are the considerations for selecting a suitable type of cross drainage works at a given site? Give some examples from the field.

11.10 DESIGN PARAMETERS

The design of a cross drainage includes the following twin aspects :

(a) Hydraulic design, and

(b) Structural design.

(a) **Hydraulic Design**

The hydraulic design covers aspects that are related to :

(i) Surface flow, and

(ii) Subsurface flow.

The surface flows determine the configuration of the most economical structure from functional considerations. The design parameters with respect to surface flow include :

(1) Design discharge,

(2) Determination of the waterway of the drain,

(3) Affluxed HFL of the drain,

(4) Head loss through the cross drainage works, and

(5) Contraction or fluming of the canal waterway,

The design consideration regarding sub-surface flow mainly involves provisions against uplift pressures.

All these aspects are discussed briefly in the following sections.

(i) ***Design Discharge***

The maximum flood discharge for the drain may be determined by any of the standard methods that are available.

The foundations and the free board are designed for a higher discharge to safeguard against unprecedented damages. Table 11.1 gives the recommended increase in the design discharge for the design of foundations and the free board.

Table 11.1 : Recommended Discharge for Design of Foundations

No.	Area of Catchment, (km^2)	Increase in Design Discharge (%)
1.	< 500	30 - 25 % decreasing with increase in area
2.	500 - 5000	25 - 20 % decreasing with increase in area
3.	5000 - 25000	20 - 10 % decreasing with increase in area
4.	> 25000	upto 10 %

(ii) ***Waterway of the Drain***

The required waterway is determined as in the case of barrages. However, the velocity of the dominant flood (once in 5 years) through the vents of the drain should be such as to scour and remove the material deposited during the recession of the previous flows. But care should be taken not to allow such high velocities as may damage the works. Thus, the limiting velocities are : (a) 1 m /s during dominant floods, and between 2 and 3 m /s during design flood for drains with soil-silt material in the bed, and (b) 3 m /s during dominant floods, but 6 m /s during design flood for drains in bouldery strata. These considerations may mean reducing the Lacey's waterway from 60 to 80% of the normal one. In mountainous and sub-mountainous regions the waterway is defined only by the banks of the existing stream. The bed slope of the barrel should normally be the same as that of the drain itself. However, if the natural slope induces very high velocities then it is preferable to provide a milder slope in the barrel and a fall at the end of the barrel with a suitable energy dissipating device there.

(iii) ***Affluxed HFL***

The HFL in the stream increases when the waterway is reduced. Molesworth formula gives the affluxed HFL for rigid beds as :

$$h = \left[\frac{V^2}{17.85} + 0.0152\right] \times \left[\frac{A^2}{a^2} - 1\right] \qquad \ldots (11.1)$$

where, h = afflux, m

V = velocity in the unobstructed stream, m /s

A = unobstructed area of the stream, m^2

a = constricted area of the stream, m^2.

Afflux obtained by Equation (11.1) will be much more than what would occur in erodible materials.

(iv) ***Head Loss through the Cross Drainage Works***

The head loss through the barrel of syphons and syphon aqueducts is given by Unwin's formula (neglecting velocity of approach) as :

$$h_f = \left[1 + f_1 + f_2 \times L/R\right] \times V^2/2g \qquad \ldots (11.2)$$

where, L = length of barrel, m

R = hydraulic mean depth of barrel, m

V = velocity of flow through barrel, m / s

f_1 = head loss coefficient at the entry

= 0.505 for an unshaped entry, and

= 0.08 for a bell mouth entry

f_2 = head loss coefficient due to friction given by $a\,(1 + b/R)$

Table 11.2 gives the values of a and b for different barrel materials.

Table 11.2 : Values of *a* and *b*

No.	Material Used in Barrel	*a*	*b*
1.	Brickwork or ashlar masonry	0.00401	0.070
2.	Incrusted iron pipe	0.00996	0.025
3.	Smooth cement plaster	0.00316	0.030
4.	Smooth iron pipe	0.00497	0.025
5.	Stone pitching or rubble masonry	0.00507	0.250

To minimise entry losses a bell mouthed entry should be provided. For manual clearance of debris inside the barrel, the height of the barrel should not be less than 2 m.

A freeboard of 0.6 m of above the HFL of the drain in case of superpassages is adequate. In case of barrels, a freeboard of 0.25 m in case of canals and 0.5 m in case of a nallah is sufficient.

(v) ***Contraction or Fluming of the Canal Waterway***

It is customary to reduce the canal bed width to 75 % in the trough portion of the canal. The normal section and the trough portion are negotiated by providing suitable transitions. On the upstream side a ratio of 2 : 1 and on the downstream side a ratio of 3 : 1 is usually adopted for transition side slopes. A splay of 3 : 1 on the upstream side and a splay of 5 : 1 on the downstream side are also provided.

(vi) *Uplift Pressure on the Bottom of Trough*

On the underside of the trough (that experiences the uplift, as per practical situation) the uplift pressure at the downstream end is equal to the difference in water level on the downstream side of the drain and the level of the underside of the trough. At all other points along the barrel, the uplift is equal to the difference between the hydraulic gradient line and the underside of the trough at that point. The hydraulic gradient is the line joining the water levels on the upstream and downstream sides of the barrel. The water surface elevation on the upstream side of the barrel is got by adding the afflux obtained by Unwin's formula to the downstream water level (Figure 11.13).

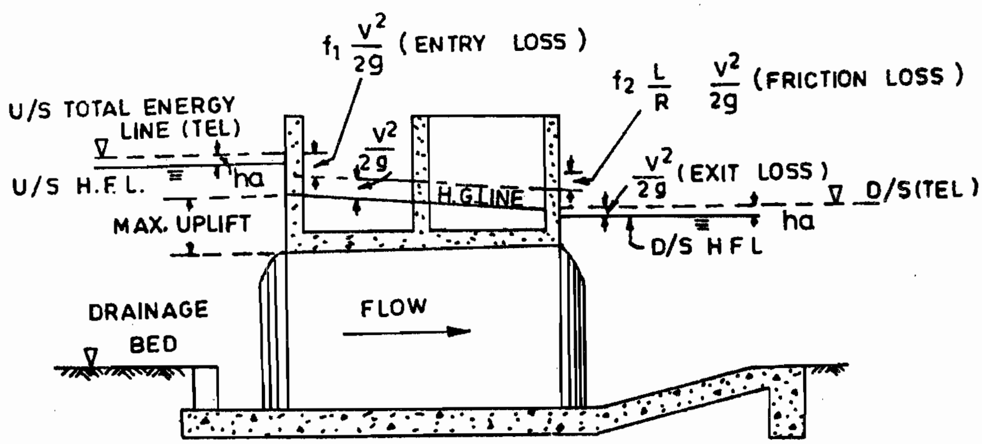

Figure 11.13 : Uplift Pressure on the Roof of a Barrel Running Full

The dead weight of the trough and the water contained in it counterbalance the uplift pressure. The most critical situation obviously, is when the trough is empty and the highest flood is passing through the drain.

The trough is designed for two conditions : (1) maximum uplift without water in the trough, and (2) full canal discharge in the trough without water in the drain. The thickness of the bottom slab of the trough is designed for water contained in the trough and sufficient to counterbalance the uplift pressure. If, however, the water is not able to counterbalance the uplift, it is more economical to anchor the slab to the piers rather than increasing the thickness of the slab. A further economical solution is to provide RCC box culverts for the drain.

(vii) *Uplift Pressure under the Floor of a Syphon Aqueduct*

There are two reasons for uplift pressure existing under the syphon floor :

(a) **Seepage from the canal to the drain :** It is maximum when the drain is empty and the canal is running full.

(b) **Sub-soil water table under the floor :** It is maximum when the drain is empty and is represented by the level difference of the sub-soil water level and the bottom of the floor slab.

The subsurface flow being three dimensional in nature, the uplift due to the seepage of water from the canal cannot be ascertained so very easily. Bligh's theory may be adopted to determine the uplift pressure under the floor in small works.

The seepage flow emerges on both sides of the canal trough and on either side of the impervious floor in the drainage bed. The total creep length can be computed from the total length of the seepage path. The residual pressure at any place along the creep length is proportional to its distance as per Bligh's theory.

(viii) *Uplift in Syphon Barrels*

The barrel section should be checked against uplift pressure under the following conditions :

(a) The canal is running full, the drain is dry and the barrel has been drained for maintenance. Here, the total uplift is the difference between the canal FSL and the bottom of the barrels.

(b) The canal is dry while the drain is carrying the maximum design flood.

(c) The canal is suddenly closed while the barrel is empty.

(ix) ***Exit Gradient***

In cross drainage works having a pucca floor, a suitable cut off is provided at either end of the pucca floor. The depth of the cut off is determined by considering the exit gradient or expected depth of scour.

SAQ 7

What are the various design parameters for cross drainage works ? Discuss the individual influence of each parameter, and measures necessary to ensure structural safety of the works.

Example 11.1

Design a syphon aqueduct, given the following data :

	Drain	Canal
Discharge, (cumec)	400	40
Bed level, (m)	148.00	150.00
Canal FSL, (m)	—	152.00
Bed width, (m)	—	25.00
Canal side slopes (H :V)	—	1.5 : 1
Drain HFL, (m)	150.05	—

The general terrain level is 150.00 m.

Solution

(A) *Drainage Waterway*

Lacey's perimeter, (P) is given by :

$$P = 4.75 \sqrt{Q}$$

$$= 4.75 \times (400)^{0.5}$$

$$= 95 \text{ m}$$

Provide 11 spans each of 7.5 m and 10 piers each of 1.2 m thickness. Thus, the waterway provided = 11 × 7.5 + 10 × 1.2 = 94.5 m (satisfactory). In fact the free warerway provided is given by the original width of the drain minus 10 × 1.2 (= 12 m). If this 12 m deficit is supposed to be compensated by the wetted perimeter along the banks, then Lacey's perimeter (without looseness factor) is taken as provided for.

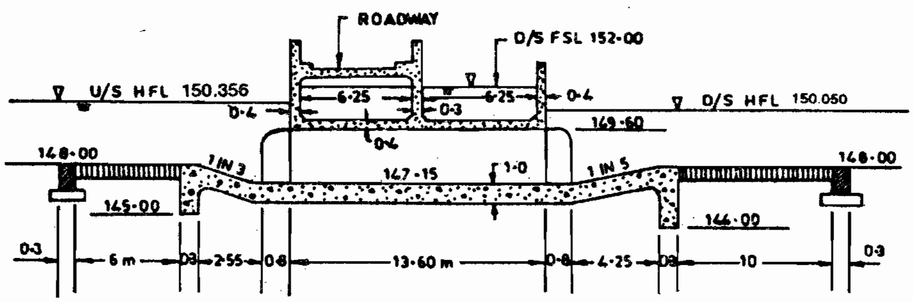

Figure 11.14 : Longitudinal Section on the Syphon Aqueduct
(All dimensions in m)

Assuming a maximum velocity through the syphon barrels as 2 m / s, the height of barrels = 400/ (11× 7.5 × 2) = 2.424 m (which is more than 2 m, so adequate). Provide rectangular barrels, 7.5 m wide and 2.45 m high (Figure 11.14).

(B) *Canal Waterway*

Since the drainage width is large (94.5 m at the crossing) it is economical to take the canal across the drain as a concrete flume (with $n = 0.014$). Adopt a flume ratio of 0.5. Thus, the flumed width of the canal trough = 0.5 × 25 = 12.5 m. Providing a splay of 2 : 1 in the contraction transition and a splay of 3 : 1 in the expansion transition, we have :

Length of transition in contraction = (25 – 12.5) × 2/2 = 12.5 m

Length of transition in expansion = (25 – 12.5) × 3/2 = 18.75 m

The length of the trough from abutment to abutment = 94.5 m.

(C) *Design of Flumed Section and Transitions*

(a) Referring to Figure 11.15, the following results can be obtained to maintain a constant depth of flow of 2.0 m (assumed above). The

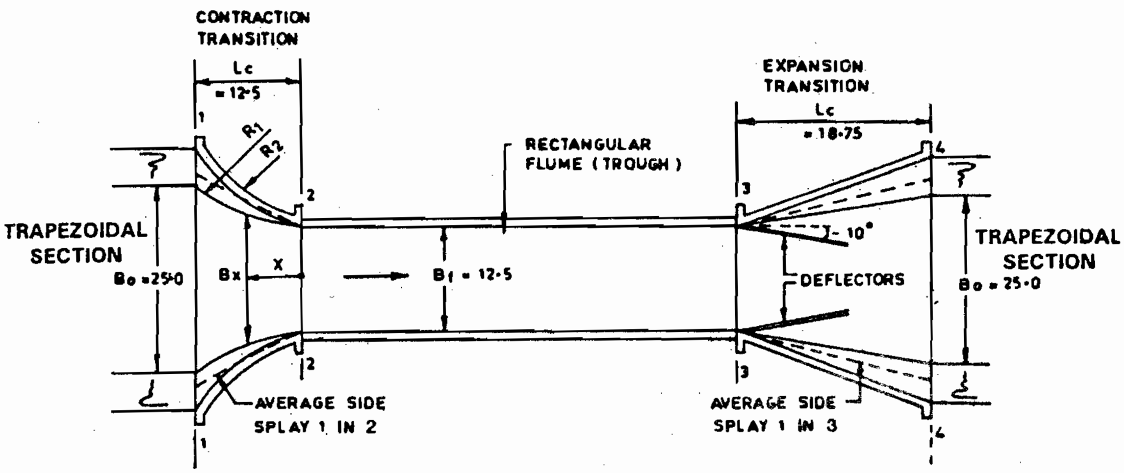

Figure 11.15 : Transition with Cylindrical Inlet and Linear Outlet

computations begin from section 4-4, and we proceed section by section to 1- 1 to get the following values :

	Parameters	**Section**			
		4 - 4 (D/S)	3 - 3	2 - 2	1 - 1 (U/S)
a.	Width, (m)	25.00	12.50	12.50	25.00
b.	Area of flow, (m^2)	56.00*	25.00	25.00	56.00
c.	Velocity, (m/s)	$\left(\frac{40}{56}\right)$ = 0.714	1.600	1.600	0.714
d.	Losses, (m) (see note below)	0.031 (expansion)	0.027 (friction)	0.021 (contraction)	
e.	Velocity head, (m)	0.026	0.130	0.130	0.026
f.	TEL, (m)	152.026 (= 152 + 0.026)	152.057 (= 152.026 + 0.031)	152.084 (= 152.057 + 0.027)	152.105 (= 152.084 + 0.021)
g.	Flow depth, (m)	2.000	2.000	2.000	2.000
h.	Water surface level, (m)	152.00 (given)	151.927 (= TEL – vel head)	151.954 (= TEL – vel head)	152.079 (= TEL – vel head)
i.	Bed level, (m)	150.000 (given)	149.927 (= W. S – 2.0)	149.954 (= W. S – 2.0)	150.079 (= W. S – 2.0)

* (Canal of trapezoidal section having base width as 25 m, side slope 1.5 : 1 and depth of flow 2 m)

Note : The contraction losses = $\dfrac{0.2\left(V_2^2 - V_1^2\right)}{2}$ g;

the expansion losses = $\dfrac{0.3\left(V_3^2 - V_4^2\right)}{2}$ g;

and friction losses = $V_f^2\, n^2\, L_f / R_f^{4/3}$, where suffix f denotes the flume.

Here, $R_f = \dfrac{25}{(12.5+4)} = 1.515$ m; $V_f = 1.6$ m / s ; $L_f = 94.5$ m;
$n = 0.014$. Therefore, friction loss = 0.027 m as given above.

(b) For a constant depth of flow the transition may be designed such that the rate of change of velocity per unit length of transition remains constant. This approach yields the bed width of the transition at a distance x from the flumed section that is given by

$$x = \frac{L\, B_0^{\,3/2}\left[1 - \left(B_f / B_x\right)^{3/2}\right]}{\left(B_0^{3/2} - B_f^{\,3/2}\right)} \qquad \ldots (11.3)$$

where L = length of transition,
B_0 = bed width in the original channel,
B_f = bed width in flumed section,
B_x = bed width in the transition at distance x.

Based on the above equation, the geometrics of the transition work out as follows :

Bed width, B_x (m)	Distance, x (m)	
	Contraction	Expansion
12.5	0.00	0.00
15.0	4.63	6.94
17.5	7.66	11.5
20.5	10.13	15.19
22.5	11.33	16.99
25.0	12.50	18.75

Note : (1) For Equation 11.3, in the case of contraction, $L = 12.5$, $B_0 = 25$ and $B_f = 12.5$

(2) In the case of expansion, $L = 18.75$, and other things remaining unchanged.

The transitions are streamlined and warped to avoid any abrupt changes in the width.

It is reported that a cylindrical inlet with an average splay of 2 : 1 and a linear outlet with a splay of 3 : 1 provided with flow deflectors perform better than long curved expansions.

(D) *Water Surface Profile in Transition*

The water surface in the transition may be assumed as two smooth parabolic curves (one convex and the other concave) meeting tangentially. Figure 11.16 gives a typical water surface profile in transitions, whose equations are given below :

Inlet transition :

$$y = C x^2 \qquad \ldots (11.4)$$

where, C (in the present case)

$= (152.079 - 151.954)/(2\times 6.25)^2 = 8\times 10^{-4}$ or $y = 8\times 10^{-4}x^2$

Outlet transition :

$$y = Ex^2 \qquad \ldots(11.5)$$

where,

$E = (152.000 - 151.927)/(2\times 9.375)^2 = 2.076\times 10^{-4}$, or $y = 2.076\times 10^{-4}x^2$

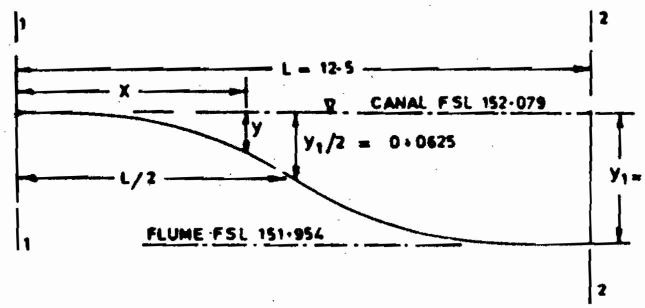

Figure 11.16 : Water Surface Profile in Inlet Transition (*Example 11.1*)

A highway 6 m wide is provided over the canal trough by dividing the flume into two compartments by a 0.3 m thick partition wall as shown in Figure 11.14. The entire trough (flumed section) can be designed as a monolithic concrete structure. Provide sidewalls and a bottom slab of 0.4 m thickness.

(E) *Syphon Barrels*

Eleven barrels, each of 7.5 m width and 2.45 m height are provided. The length of the barrel, $L = 12.50 + 0.3 + 2\times 0.4 = 13.60$ m (Figure 11.14). The head loss through the barrel, calculated from Unwin's formula and assuming a smooth cement plastered surface is given as under :

$$h_f = \left[1 + f_1 + f_2 \times L/R\right] \times V^2/2g \qquad \ldots(11.2)$$

$$= [1 + 0.505 + 0.00316\,(1 + 0.030/R) \times (L/R)] \times (V^2/2g)$$

(for unshaped entry, and smooth cement plaster)

$$R = (7.5\times 2.45)/(7.5 + 2\times 2.45) = 1.481 \text{ m, and}$$

$$V = 400/(11\times 7.5\times 2.45) = 1.979 \text{ m/s}$$

Thus, $$h_f = \left[1.505 + 0.00316\,(1 + 0.030/1.481)\times\frac{13.6}{1.481}\right]\times\left(1.979^2/19.62\right)$$

$$= 0.306 \text{ m}$$

Therefore, the

U/S $HFL = 150.050 + 0.306 = 150.356$ m

The uplift pressures on the roof of the barrel are determined as follows. The entry loss at the barrel $= 0.5\,V^2/2g = 0.5\times 1.979^2/19.62 \approx 0.100$ m. The RL of the bottom of the trough = 150.00 – 0.40 = 149.6 m. Therefore, the pressure head inside the barrel just d/s of its entry

= 150.356 – 0.100 – 149.600 = 0.656 m and pressure = 0.656 t / m^2.

The most critical situation arises when the canal is empty and the syphon barrels are full. The weight of the roof slab = $0.4\times 2.4 = 0.96$ t / m^2. Hence the roof needs no additional reinforcement at its top since the self weight of the slab can resist the uplift pressures. The trough floor slab has to be checked when canal is carrying water at FSL and the level in the drain is low, that is when the barrels are part full, or empty.

The uplift on the floor of the barrel (assuming the barrel floor thickness to be 1 m initially) is as follows :

RL of the bottom of the barrel = 149.6 – 2.45 – 1.00 = 146.15 m.

RL of the drain bed = 148.00 m.

Therefore, the static uplift on the floor = 148.00 – 146.15 = 1.85 m (the worst condition with the water table as the drain bed level). The seepage head (a maximum when the canal is at FSL and the drainage is empty) = 152.00 – 148.00 = 4.00 m.

Inspite of the three dimensional seepage flow pattern, Bligh's creep length may be determined as a first approximation. Creep flow commences from the beginning of the upstream transition (downstream of this the canal floor is impervious) and enters the bottom of the first barrel floor; and, then from its centre the flow follows the bottom towards the downstream of the drain, and emerges at the end of the impervious concrete floor of the barrel. Therefore, the total creep length can be visualised as being equal to inlet transition length + 0.5 × barrel span + 0.5 length of barrel impervious floor.

Let the total length of the impervious floor of the barrel be 22.6 m (assumed from inspection), consisting of the following :

$$\text{Length of barrel} = 2 \times 0.4 + 12.5 + 0.3 = 13.60 \text{ m}$$

$$\text{Pier projections,} \quad 2 \times 0.8 = 1.60 \text{ m}$$

$$\text{D/s ramp } (1:5), \quad 0.85 \times 5 = 4.25 \text{ m}$$

$$(149.60 - 2.45 = 147.15; \ \therefore \ 148 - 147.15 = 0.85)$$

$$\text{U/s and D/s cutoffs,} \quad 2 \times 0.3 = 0.60 \text{ m}$$

$$\therefore \text{ Total floor length (without u/s floor length)} = 20.05 \text{ m}$$

Therefore, provide the U/s floor (1 : 3) length = 22.60 – 20.05 = 2.55 m. The total creep length as above mentioned = 12.5 + 7.5/2 + 22.6/2 = 27.55 m. The creep length upto the centre of the barrel = 12.5 + 7.5/2 = 16.25 m. Therefore, the seepage head at the centre of the barrel = 4[1 – (16.25/27.55)] = 1.64 m. The total uplift on the floor can then 1.85 + 1.64 = 3.49 m, and pressure = 3.49 t/m^2; but, the weight of the floor = 1.00 × 2.4 = 2.4 t/m^2. Hence additional reinforcement has to be provided to resist the unbalanced uplift forces.

(F) *Features of Upstream and Downstream Protection Works*

$$\text{Scour depth, } R = 0.47\,(400/1)\sqrt{3} = 3.46 \text{ m}$$

[$R = 0.47\,(Q/f)^{1/3}$, according to Lacey's theory, where f is the silt factor; assuming $f = 1$]

$$\text{Take u/s cutoff below HFL} = 1.5\,R = 1.5 \times 3.46 = 5.19 \text{ m}$$

$$\text{Therefore, RL of u/s cutoff} = 150.356 - 5.19 = 145.166 \text{ say } 145.00 \text{ m}$$

$$\text{Take d/s cutoff below HFL} = 1.75\,R = 1.75 \times 3.46 = 6.055 \text{ m}$$

$$\text{Therefore, RL of d/s cutoff} = 150.0500 - 6.055 = 143.995 \text{ say } 144.00 \text{ m}$$

$$\text{Length of u/s apron, say} = 2.0\,(148.00 - 145.00) = 6 \text{ m}$$

$$\text{Length of d/s apron, say} = 2.5\,(148.00 - 144.00) = 10 \text{ m}$$

The longitudinal section through the barrel is shown in Figure 11.14.

11.11 SUMMARY

While a canal follows its designed course, it has necessarily to cross various streams (i.e., natural drainage) as per the topographical features. These crossings are negotiated through various cross drainage works, such as, an aqueduct, syphon aqueduct, simple syphon, superpassage, etc. Each crossing has its own factors what make particular type of crossing most suited to the given situation. When the H. F. L. of a drainage is much lower than the underside of the canal bed, the crossing is done through an aqueduct, which can be of several types. A syphon aqueduct is similar to a simple aqueduct, and is provided when the stream bed is not sufficiently lower, and needs to be depressed to some extent, and the drain carries a much smaller discharge than the canal. Similarly as per the practical situation, sometimes a syphon is provided to pass off canal waters under the drainage bed under pressure, the canal discharge is much smaller than that of the drainage. In the case of a superpassage the drainage waters are made to flow over the canal, the bed level of the formar being much higher than the HFL of canal. However, when the difference between canal and drainage levels is not much, we go in for cheaper alternatives like inlet-and-outlet on level crossing works.

While selecting the most suited type of cross drainage work, vis-a-vis, a given field situation, it is the relative economics of various alternatives that is the governing consideration.

The design of any hydraulic structure consists of two parts – hydraulic design, and structural design. Fixing of important dimenisons and relative levels fall in the domain of hydraulic design, while later on structural design takes care of stability and safety of the structure. The basics of hydraulic designing have been presented through a solved example.

11.12 KEY WORDS

Affluxed HFL : The raising of the high flood level on account of an obstruction such as a pier or narrowing of the cross section.

Aqueduct : A structure for carrying a canal across a stream or drainage with the canal trough high above the high flood level (HFL) of the drain.

Bligh's Theory : A theory suggested by Bligh for determining the uplift pressure under the floor in small hydraulic structures.

Cross Drainage Works : Structures constructed across a drainage to carry water on to the other bank of the stream.

Expansion Transition : The increase in the cross-sectional area of a water trough in the direction of flow.

Contraction Transition : The reduction in thr cross-sectional area of a water trough in the direction of flow, while negotiating a crossing.

Design Discharge : The quantity of water (expressed as flowing per unit time) assumed to flow for the purpose of designing a structure.

Exit Gradient : It is the rate of loss of head (or the gradient) at the exit end from where the water emerges at the ground surface under the action of a hydraulic structure.

Fluming : Contracting a canal section for purposes of reducing the width and thus the overall cost of the total structure.

Head Loss : It is well understood that when water flows some energy is lost. This loss of energy is termed head loss.

Inlet and Outlet : A type of cross drainage work in which the stream is allowed to enter the canal at some place and after mixing and flowing along with the canal water for some distance is released at some convenient downstream point.

Level Crossing : A type of cross drainage work where the drain and the canal cross each other at about the same level.

Syphon : A hydraulic structure in which the canal crosses through a barrel under a stream of drainage under inverted syphonic action.

Superpassage : A hydraulic structure in which the drainage is carried across and above the canal in a trough. The canal flows at atmospheric pressure.

Transitions : Changes in cross-sectional area of flow of a canal (done gradually or reduce losses) as it approaches or leaves a flumed section, are called transitions.

Uplift Pressure : The seepage water flowing under a hydraulic structure exerts a pressure in the upward direction causing the floor to be lifted upward unless prevented by suitbale means.

Waterway : The cross-sectional area through which water flows past any hydraulic structure.

11.13 ANSWERS TO SAQs

Refer the relevant preceding text in the unit or other useful books on the topic listed in the section "Further Reading" to get the answers of the SAQs.