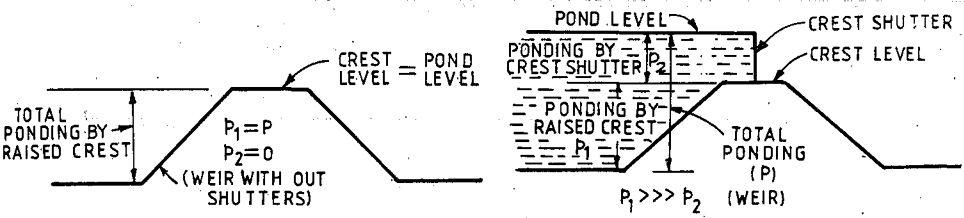
9

# Diversion Head Works

It was stated earlier that the main permanent canal, forming the primary part of a direct irrigation scheme, takes off from a diversion weir or a barrage. In fact, these permanent canals take off from rivers and the arrangements are so well made at their heads, that a constant and a continuous water supply is ensured into the canal, even during the periods of low flow. *The works, which are constructed at the head of the canal, in order to divert the river water towards the canal, so as to ensure a regulated continuous supply of silt-free water with a certain minimum head into the canal, are known as Diversion Head Works.*

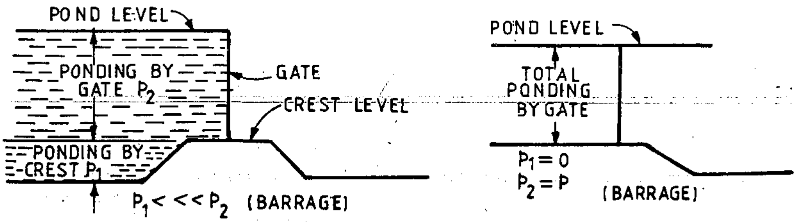
## 9.1. Weir and Barrage

In general, the above purpose can be accomplished by constructing a barrier across the river, so as to raise the water level on the upstream side of the obstruction, and thus, to feed the main canals taking off from its upstream side at one or both of its flanks. The ponding of water can be achieved either only by a permanent pucca raised crest across the river or by a raised crest supplemented by falling counter-balanced gates or shutters, working over the crest. *If the major part or the entire ponding of water is achieved by a raised crest and a smaller part or nil part of it is achieved by the shutters, then this barrier is known as a weir [Fig. 9.1 (a) and (b)]. On the other hand, if most of the ponding is done by gates and a smaller or nil part of it is done by the raised crest, then the barrier is known as a Barrage or a River Regulator [See Fig. 9.2 (a) and (b)].*




(*a*) Weir without shutters (*b*) Weir with shutters

Fig. 9.1




(*a*) Barrage with a small raised crest (*b*) Barrage without any raised crest

Fig. 9.2

If most of the ponding or the entire ponding is done by a permanent raised crest, as in a weir, then the afflux caused during high floods is quite high. On the other hand, if most of the ponding is done by gates, as in a barrage, then the gates can be opened during high floods and the afflux (*i.e.* rise in HFL near the site) will be nil or minimum. Hence, the latter device *i.e.* a barrage, gives less afflux and a better control upon the river flow, because the inflow and outflow can be controlled to a much greater extent by suitable manipulations of its gates.

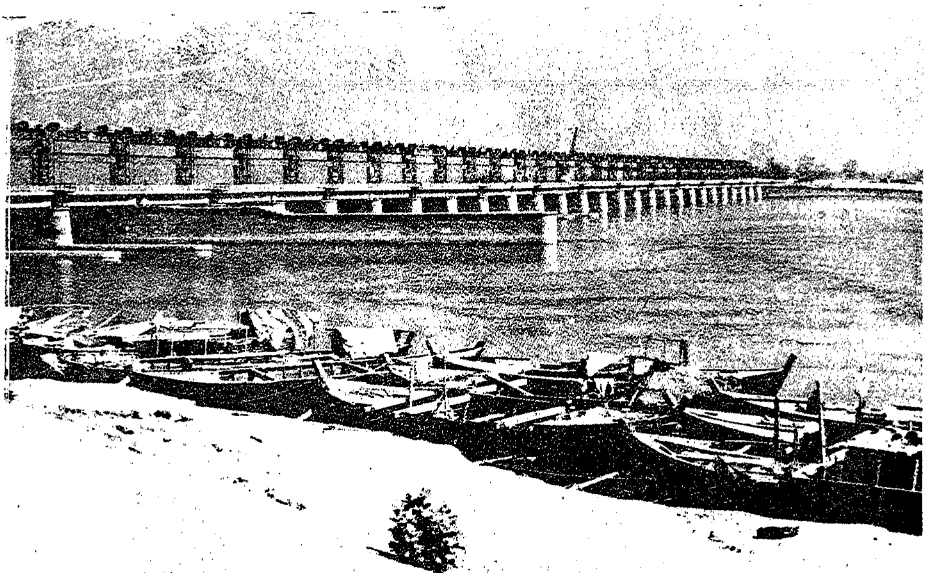


Fig. 9.3. Photoview of a Barrage (Girja Barrage on Ghagra river in U.P.)

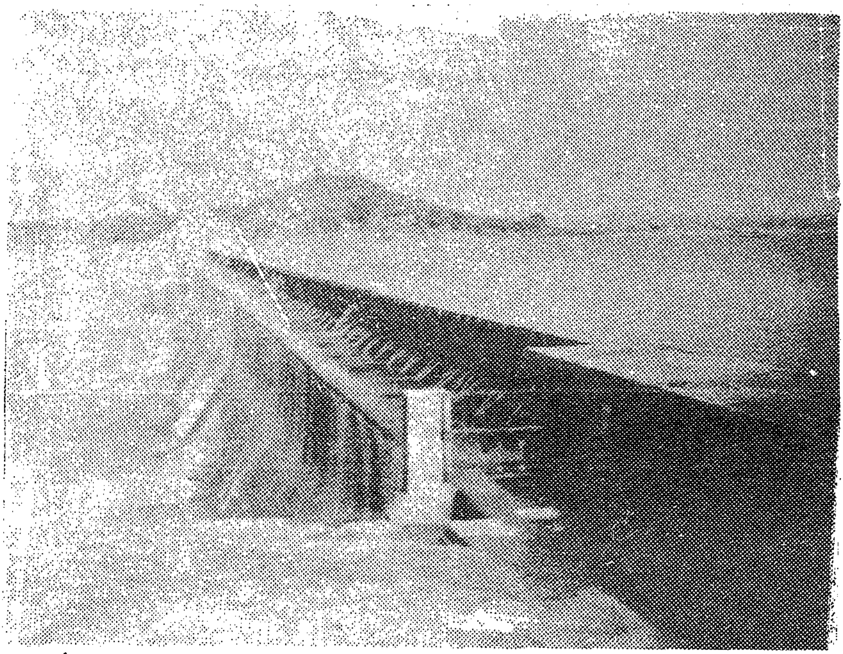


Fig. 9.4. Photoview of a small height. dam like weir, provided with shutters at top of its solid crest (Devri Dam near Jhansi in U.P.)

Moreover, a gate controlled weir (*i.e.* a barrage) can be provided with a roadway across the river at a small additional cost. The choice between a weir with shutters and one with counter-balanced gates (*i.e.* a barrage) is largely a matter of cost and convenience in working. A shuttered weir will be relatively cheaper but will lack the effective control possible in the case of a barrage. Moreover, a barrage type construction can be easily supplemented with a roadway across the river at a small additional cost. *Hence, barrages are almost invariably constructed these days on all important rivers.*

## 9.2. Gravity and Non-Gravity Weirs

When the weight of the weir (*i.e.* its body and floor) balances the uplift pressure caused by the head of the water seeping below the weir, it is called a *Gravity weir.* On the other hand, if the weir floor is designed continuous with the divide piers as reinforced structure, such that the weight of concrete slab together with the weight of divide piers, keep the structure safe against the uplift ; then the structure may be called as a *Non-gravity Weir.* In the latter case, RCC has to be used in place of brick piers, but in particular cases, considerable savings may be obtained, as the weight of the floor can be much less than what is required in a gravity weir.

## 9.3. Layout of a Diversion Head Works and its Components

A typical layout of a canal head-works is shown in Fig. 9.5. Such a head-works consists of :

(1) *Weir proper.*

(2) *Under-sluices.*

(3) *Divide wall,* dividing the river width into two portions ; one is called the weir portion, and the other portion from which the canal takes off, is having openings* and called the 'under-sluice-pocket' or *'under-sluices'* or *'weir scouring sluices'.* If there are two canals, taking off from each flank, then there will be two divide walls and two under-sluices.

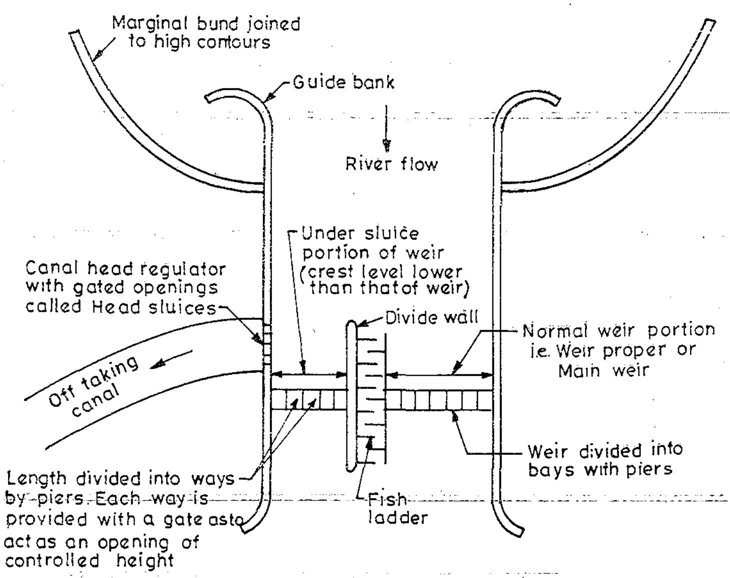



Fig. 9.5. Typical Layout of Diversion Head-Works.

(4) *River training works,* such as marginal bunds, guide banks, groynes, etc.

* These openings are made by partial lifting of gates of the under-sluice ways. During high-floods the gates of the under-sluice ways shall be fully lifted depending on excess discharge in the river.

(5) *Fish Ladder.*
(6) *Canal Head Regulator.*
(7) *Weir's ancillary works,* such as shutters, gates, etc.
(8) *Silt Regulation Works.*

The various parts of a diversion head-works scheme and their design considerations are explained in details in the following pages.

**9.3.1. The Diversion Weir and its Types.** *Alignment.* As stated earlier, *a diversion weir or an anycut or an intake weir* is a raised pucca structure with or without shutters and laid across the river width. It is, essentially, of a height say up to 9 metres or so. The height of shutters over the weir crest seldom exceeds 1.2 metres or so. The entire length of the weir is divided into a number of bays by means of divide piers so as to avoid cross-flows in floods. As far as possible, the weirs should be aligned at right angle to the direction of the main river current. This ensures lesser length of the weir, better discharging capacity and lesser cost. This right-angled alignment is better and, therefore, common, especially when the river bed is silty or sandy. Sometimes, the weir may be aligned at an oblique angle to the direction of the river current, and thereby, obtaining more safe and better foundations. In such a case, the weir will be of greater length, will have less discharging power and will be costlier. Moreover, due to non-axial flow, cross-currents may be developed, which may undermine the weir foundation. An oblique alignment may sometimes become necessary, when the river bed consists of gravel and shingle, which could otherwise enter the head regulator of the main canal and get deposited into the head reach of the main canal.

**Types of Weirs.** The weirs may be divided into the following three classes :

(*i*) *Masonry weirs with vertical drop ;*
(*ii*) *Rock-fill weirs with sloping aprons* ; and
(*iii*) *Concrete weirs with sloping glacis.*

These three important types of weirs are described below :

(*i*) **Masonry weirs with vertical drop**. A typical cross-section of such a weir is shown in Fig. 9.6.

The above type of a weir, consists of a horizontal floor and a masonry crest with vertical or nearly vertical downstream face.

The raised masonry crest does the maximum ponding of water, but a part of it, is usually, done by shutters at the top of the crest. The shutters can be dropped down during floods, so as to reduce the afflux by increasing the waterway opening.

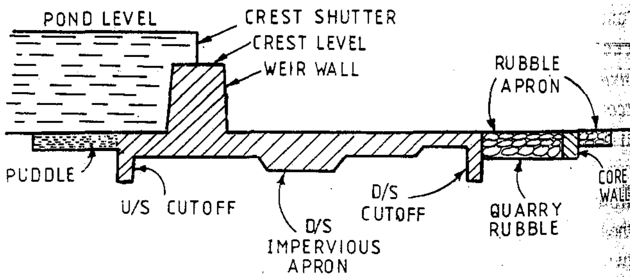



Fig. 9.6. Masonry Weir.

This type of weir was used in all the old head-works, such as Bhimgoda, Rasul, Khanki and Marala works, etc. and is particularly suitable for hard clay and consolidated gravel foundations. However, this type of weir is becoming obsolete and even the old constructions are being replaced by the new modern concrete weirs.

(*ii*) **Rock-fill weirs with sloping aprons.** Such a weir is also called — '*Dry Stone Slope Weir*'. A typical cross-section of such a weir is shown in Fig. 9.7. It is the simplest type of construction, and is suitable for fine sandy foundations like those in alluvial areas in North India.

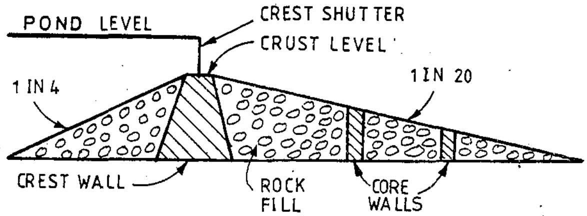


Fig. 9.7. Rock-fill Weir.

The old Okhla weir* across the Yamuna river in Delhi provides an example of such a weir. Such a weir requires huge quantities of stone and is economical only when stone is easily available. The stability of such a weir is not amenable to theoretical treatment.

However, with the development of concrete glacis weirs, the above type is also becoming obsolete.

*(iii)* **Modern concrete weirs with sloping downstream glacis.** Weirs of this type are of recent origin and their design is based on modern concepts of sub-surface flow (*i.e.* Khosla's Theory). A typical cross-section of such a weir is shown in Fig. 9.8. Sheet piles of sufficient depths are driven at the ends of upstream and downstream floor. Sometimes, an intermediate pile line is also provided. *The hydraulic jump is formed on the downstream sloping glacis, so as to dissipate the energy of the flowing water.*

This type of weirs are now exclusively used, especially, on permeable foundations, and are generally provided with a low crest with counter-balanced gates, thus, making it a barrage. A typical cross-section of a barrage is shown in Fig. 9.9.

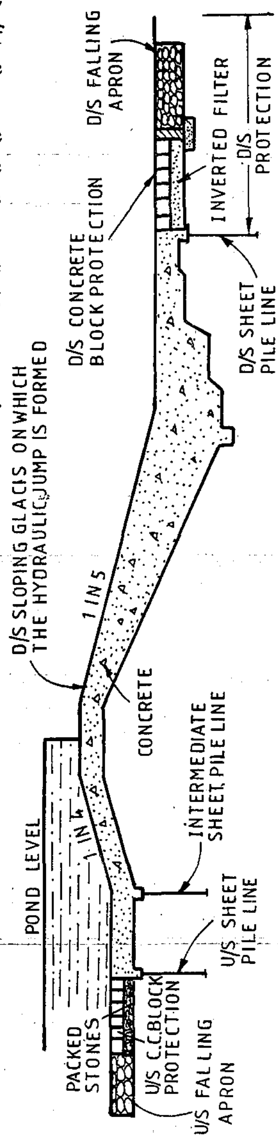


Fig. 9.8. A typical cross-section of a modern concrete weir founded on permeable foundations.

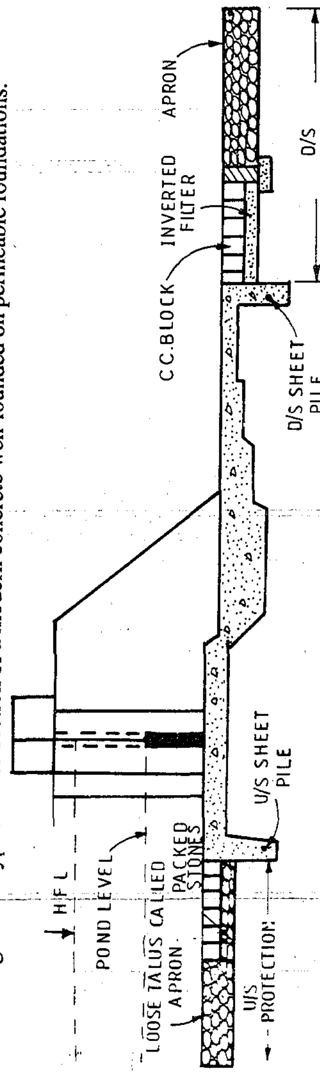


Fig. 9.9. A typical cross-section of a Barrage founded on pervious foundations.

* Now replaced by a new barrage, about 2 km downstream. The old weir has however, not been dismantled.

The barrage shown here is not having a raised crest at all, but barrages can do have slightly raised crests. The detailed design of such a weir or a barrage will be discussed in Chapter 11.

**9.3.2. Afflux and Pond Level.** The rise in the maximum flood level (HFL) upstream of the weir, caused due to the construction of the weir across the river, is called **afflux.**

In the initial stages, the water level is raised on account of afflux up to small distance equal to the length of the back water curve. But with the passage of time, the river bed rises due to silting caused by the reduction in flow-velocity upstream of the weir. (Q remaining same, *y* or *A* increasing and *V* decreasing). The effect, therefore, travels upstream till the river bed slope upstream of the weir is the same as was before its construction. (See Fig. 11.18 in Chapter 11).

**Pond Level.** The water-level required in the under-sluice pocket upstream of the canal head regulator, so as to feed the canal with its full supply, is known as *Pond Level.* The FSL of the canal at the head, depends upon the level of the irrigated areas and the slope of the canal. The pond level is generally obtained by adding 1.0 to 1.2 m to canal full supply level.

Since the weir top is raised upto the pond level, a minimum water level equal to the pond level is always maintained in the under-sluice pocket, so as to ensure a continuous supply of water into the canal with its full supply level.

The available head at the canal head regulator is, therefore, equal to the difference of the pond level and canal FSL. The width of regulator openings (*i.e.* waterway) should, therefore, be governed by this available head. But to make provision for future silting of canal, and for the subsequent rise in FSL, (which correspondingly reduces the available head), the designed available head for its water-way is taken at about $\frac{1}{2}$ of the original available value.

This will be explained in details in the design of Canal Head Regulators (in Chapter 11).

**9.3.3. The Under-Sluices or Scouring Sluices.** A comparatively less turbulent pocket of water is created near the canal head regulator by constructing under-sluice portion of the weir. A divide wall separates the main weir portion from the under-sluice portion of the weir. *The crest of the under-sluice portion of the weir is kept at a lower level than the crest of the normal portion of the weir.*

Normally, the crest level of the under-sluices is kept equal to the deepest bed level of the river during non-monsoon season; whereas, the crest level of the 'weir' is kept higher by about 1 to 1.5 m.

As the crest of the under-sluice pocket is at a low level, a deep channel develops towards this pocket, which helps in bringing low dry weather discharge towards this pocket, thereby, ensuring easy diversion of water into the canal through the canal head regulator.

The under-sluiced length of weir or barrage is divided into a number of ways by piers, and separate gates are installed on these ways. Each way can thus, be opened to any desired height by lifting its gate. Each way can thus, act as a gate controlled opening, and will help in bypassing the excess supplies to the down-stream side of the river. These openings will also help in scouring and removing the deposited silt from the under-sluiced pocket ; and hence are also called the *scouring sluices.*

The crest level of the head regulator is also kept higher than the crest level of the under-sluices, so that only silt free water is admitted into the canal through the *head sluices*. Silt gets deposited over the under-sluice floor, and may be periodically removed over the crest of the under-sluices and towards the downstream side of the river by opening these gate-controlled openings (under-sluices). Since the under-sluices help in removing the silt from near the head regulator, they are also called *scouring sluices.*

The spans of under-sluices (*i.e.* span between two adjoining piers) should be wide enough, to be efficient in scouring action. Stoney gates which can be easily operated from platform at top, are widely used for controlling the flow through the under-sluices. In closed position, the top of these gates should be above the pond level in the pocket, so as to ensure a continuous and a constant supply of water into the off-taking canal through the canal head regulator.

Apart from these two primary objectives served by the under-sluices in all types of weirs and barrages, they may serve a third function in the case of weirs provided with shutters. That is : they help in passing the dry weather flow and low floods without dropping the weir shutters, the raising of which entails a good deal of labour and time. Whenever, water is surplus to canal requirement, it has to be passed across the weir. The surplus water is passed through the under-sluices, so long as it does not exceed their discharging capacity, and the weir shutters are kept raised up. The weir shutters are dropped only to pass down the high floods.

*Design considerations.* Sill of the under-sluice pocket is kept at or slightly above the deepest river bed and about 0.9 to 1.8 metres below the sill of the canal head regulator. The length of the under-sluice pocket between the divide wall and the head regulator may be taken as 1.5 times the upstream length of the divide wall, as shown in Fig. 9.10.

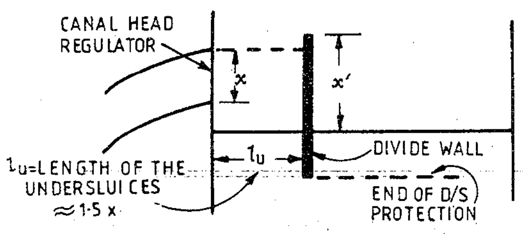



Fig. 9.10

However, this length is governed by the discharging capacity of the under-sluices, which should be sufficient to enable them to serve their main functions, described earlier. The discharging capacity of under-sluices may be selected as follows :

(*i*) They should be able to ensure sufficient scouring capacity, for which the discharging capacity should be atleast twice the full supply discharge of the main canal at its head.

(*ii*) They should be able to pass the dry weather-flow and low floods during the months excluding the rainy season, without the necessity of dropping the weir shutters.

(*iii*) They should be able to dispose of 10 to 15% of the high flood discharge during severe floods.

The spans of the under-sluices should be wide enough (usually 10 to 20 m) in order to be efficient in scouring action. The section of the under-sluices will be similar to that of a weir and will be designed to ensure–proper hydraulic jump formation (from surface flow considerations) and for uplift pressure for pervious foundations (by Khosla's Theory) as per procedure adopted for a normal weir design. Discharge intensity being greater in the under-sluices, its floor and apron will be stronger as compared to those of weir proper. The floor downstream of the crest, should not be kept level with the crest level, because the formation of hydraulic jump as destroyer of energy is very uncertain on a level floor.

**9.3.4. The Divide Wall.** The 'divide wall' is a masonry or a concrete wall constructed at right angle to the axis of the weir, and separates the 'weir proper' from the 'under-sluices'. The divide wall extends on the upstream side beyond the beginning of the canal head regulator; and on the downstream side, it extends up to the end of loose protection of the under-sluices (*see* Fig. 9.10). The top width of divide wall is about 1.5 to 2.5 metres. These walls are founded on wells closely spaced beyond the pucca floor upto the end. The wells are taken well below the deepest possible scour. Typical cross-section of the divide wall on pucca floor and beyond the pucca floor are shown in Fig. 9.11 (*a*) and (*b*).

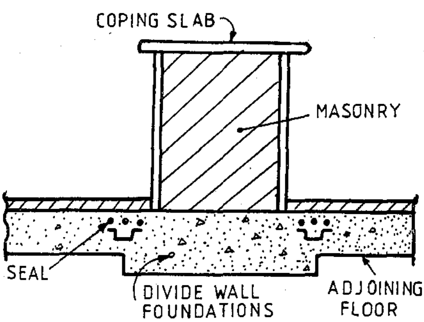



Fig. 9.11. (*a*) Cross-section of Divide Wall on Pucca floor.

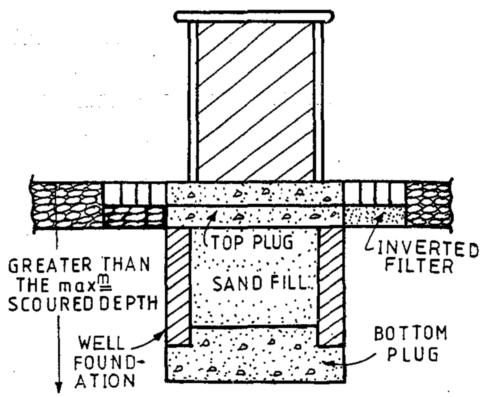



Fig. 9.11. (*b*) Cross-section of Divide Wall beyond Pucca floor.

The main functions served by the divide wall are :

(*a*) It separates the 'under-sluices' from the 'weir proper'. Since the crest level of the under-sluices is lower than that of the weir proper, the two must be separated, and this is being done by the Divide wall.

(*b*) It helps in providing a comparatively less turbulent pocket near the canal head regulator, resulting in deposition of silt in this pocket and, thus, to help in the entry of silt-free water into the canal.

(*c*) Divide wall may keep the cross-currents, if at all they are formed, away from the weir. Cross-currents lead to vortices and deep scours, and therefore, prove hazardous to weirs. For this purpose, additional divide walls projecting at right angle to the weir may sometimes be constructed at equal or desired spacings. They may, then, act as groynes, protecting, in turn, the weir from cross-currents, as shown in Fig. 9.12.

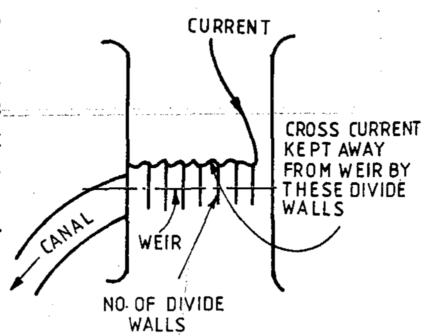



Fig. 9.12

These cross-currents may sometimes develop, when there is a natural tendency for the main river current to attack the bank opposite to the canal head regulator. In such a case, the water will be forced by the weir to flow towards the head regulator, and cross-current will develop. This function of the divide walls, is not fully established, and the most modern practice is only to construct the divide wall for separating the 'under-sluices' from 'weir proper'.

*Design considerations.* The divide walls can be designed as cantilever retaining walls subjected to silt pressure and water pressure from the under-sluice side. For the worst case, the design should be checked for full silt pressure on the pocket side with equal water on two sides during low floods, and also for maximum differential water-head, when full discharge is passing through the under-sluices and no discharge is passing the weir. The value of differential pressure, may be taken, arbitrarily, as 1.0 m for waterhead and about 2.0 m for silt pressure.

**9.3.5. River Training Works.** River training works are required near the weir site in order to ensure a smooth and an axial flow of water, and thus, to prevent the river from outflanking the works due to a change in its course. The river training works required on a canal headworks, are :

(*i*) *Guide banks* ;

(*ii*) *Marginal bunds* ; and

(*iii*) *Spurs or groynes.*

The guide banks force the river into a restricted channel, and thus, ensuring a smooth and an almost axial flow near the weir site. The design and other details of the guide banks have already been discussed in the previous chapter.

Marginal bunds are provided on the upstream side of the works in order to protect the area from submergence due to rise in HFL, caused by the afflux. These bunds are, therefore, continued till they join contours higher than the new HFL. Construction of these bunds would be justified only, when the value of land saved is more than the cost of the marginal bunds. In certain cases, when the ponding is high and the watershed is low, the construction of marginal bunds may almost become obligatory. The layout of the marginal bunds is very important in economising the overall cost of the training works and subsequent cost of maintenance. Apart from their primary purpose of protecting the adjoining area from river spills caused by afflux, these bunds do help in partially controlling and guiding the river flow between the guide banks. For this reason, the length of the guide banks do depend on the layout of the marginal bunds.

Marginal bunds are nothing but earthen embankments, protected by groynes, wherever needed. They are designed on the principles of design of earthen dams or dikes. The design aspects of groynes have already been discussed in the previous chapter.

**9.3.6. Fish Ladder.** Large rivers are generally inhabited by several types of fish, many of which are *migratory*. Such migratory type of fish, called *anadromous fish*, move from one part of the river to another part, according to the season. In India, only one such migratory fish is found, and this specie is known as **Hilsa**. *Salman, Steel head trout,* etc. are the other species of such anadromous fish, found in other countries.

*Generally speaking for India, these anadromous fish have been found to be moving from upstream (hills) to downstream (plains) in the beginning of the winter season in search of warmer waters, and return to their spawning grounds upstream, slightly before monsoons, in the month of May and June.* If no arrangement is made in the weir or the dam, to enable the fish to pass upstream, then such migratory fish have been found to be striking and striking against the water current in their efforts to move up, till death. Non-provision of an arrangement for fish to pass upstream, may thus, lead to large scale destruction of fish life.

It has been established that most kinds of fish can travel upstream, against a flow velocity of about 3 to 3.5 m/sec. Usually, there is a head difference of 5 to 6 metres between the upstream of the weir and the downstream water level in the river. If simply an open gap is left in the weir for this migration, the velocity of flow through such an opening will be very high. Therefore, even the strongest fish will not be able to travel upstream ; resulting in large scale destruction of fish near the downstream end of the fish gap. This had actually happened on the river Ganges at old Bhimgoda weir in Hardwar (U.P.), where a suitable arrangement was later on made for this migration.

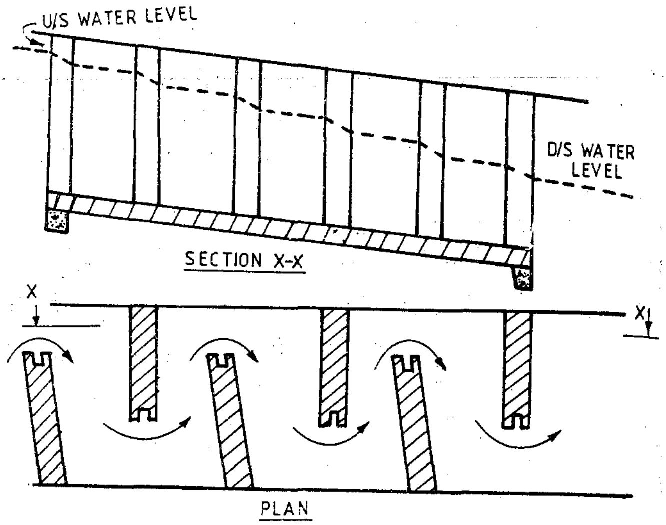



Fig. 9.13. (*a*) Section and plan of a typical fish ladder.

Fig. 9.13. (*b*) Photographic view of a fish ladder.

A structure which enables the fish to pass upstream is called a '*fish ladder*'. It is a device by which the flow energy can be dissipated in such a manner as to provide smooth flow at sufficiently low velocity, not exceeding 3 to 3.5 m/sec. This object is generally accomplished by providing a narrow opening adjacent to the divide wall and provide suitable baffles or staggering devices in it, so as to control the flow velocity.

*Pool type and Steep Channel type* are commonly used types of fish ladders in weirs and barrages. Typical sketches (section, plan and photographic view) of ordinarily used **steep channel type** of a fish ladder, are shown in Fig. 9.13 (*a*) and (*b*).

In this type of ladder, the space between the weir and the divide wall, is provided with oblique walls, and holes are also staggered, so that the fish can take rest after passing one hole before they move on to the other. Sometimes, a fish ladder is provided within the divide wall itself, as shown in Fig. 9.14.

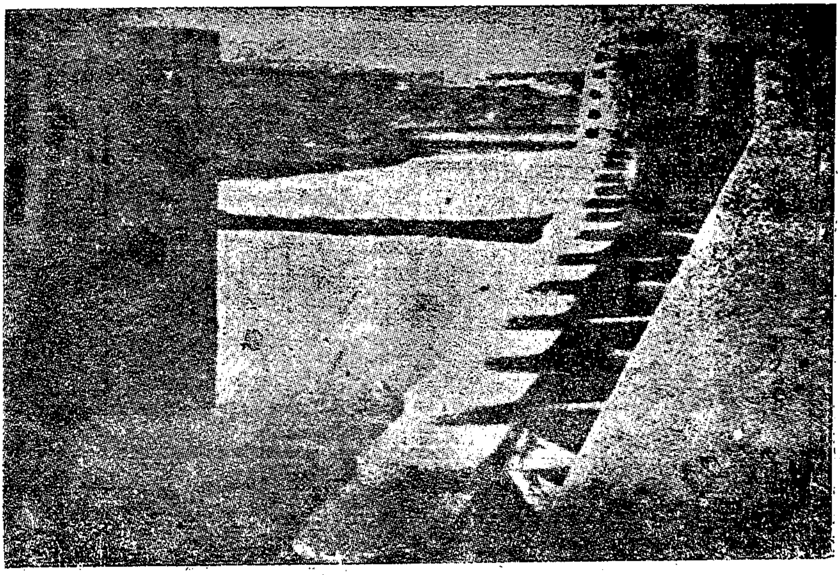


Fig. 9.14. Photographic view of a fish ladder provided in the divide wall.

Fish ladders are generally not found to be economical on dams higher than 100 m or so. For such cases, fish are usually transported upstream by mechanical means, using tramways or tank trucks. In dams, the fish also need to be protected from the turbines and spillways. If the head is less than 5 m or so, the fish can pass through the turbines and spillways with very low mortality.

Various types of screens and louvers are used to divert the fish into a safe by-pass, which may be in the form of a short length of a pressure pipe, through which the fish pass downstream, or the fish may be diverted into a pond, from which they can be extracted for downstream transport by tank trucks.

**9.3.7. The Canal Head Regulator or Head Sluices.** A canal head regulator (C.H.R.) is provided at the head of the off-taking canal, and serves the following functions :

(*i*) *It regulates the supply of water entering the canal.*

(*ii*) *It controls the entry of silt in the canal.*

(*iii*) *It prevents the river floods from entering the canal.*

A typical cross-section of a head regulator is shown in Fig. 9.15. The regulator is generally aligned at right angle to the weir, but slightly larger angles (between 90° to 110°) are now considered preferable for providing smooth entry of water into the regulator, as shown in Fig. 9.16.

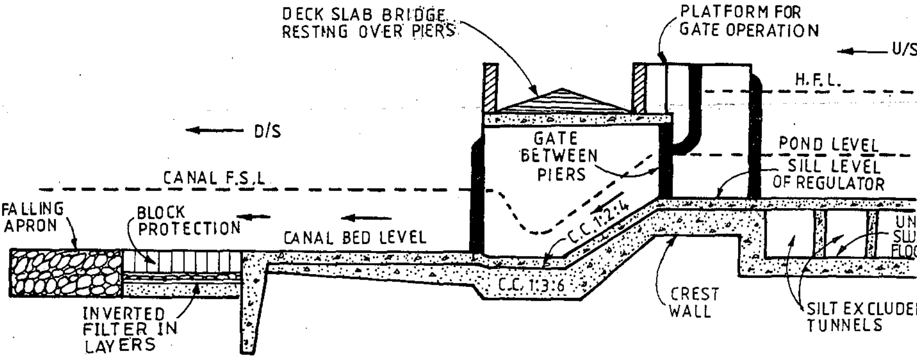



Fig. 9.15. A typical section through a Canal Head Regulator.

The regulator is provided with gates. Smaller spans were used in the past, but with the improvements in gate constructions, larger spans, say between 6 to 10 metres, are generally used these days, if found economical.

The water from the under-sluice pocket is made to enter the regulator bays, so as to pass the full supply discharge into the canal. The maximum height of these gated openings, called **head sluices** will be equal to the difference of Pond Level and Crest Level of the regulator. The entry of silt into the canal is controlled by keeping the crest of the head regulator by about 1.2 to 1.5 metres higher than the crest of the under-sluices. If a Silt-Excluder* is provided, the regulator crest is further raised by about 0.6 to 0.7 metre. Silt gets deposited in the pocket, and only the clear water enters the regulator bays. The deposited silt can be easily scoured out periodically, and removed through the under-sluice openings.

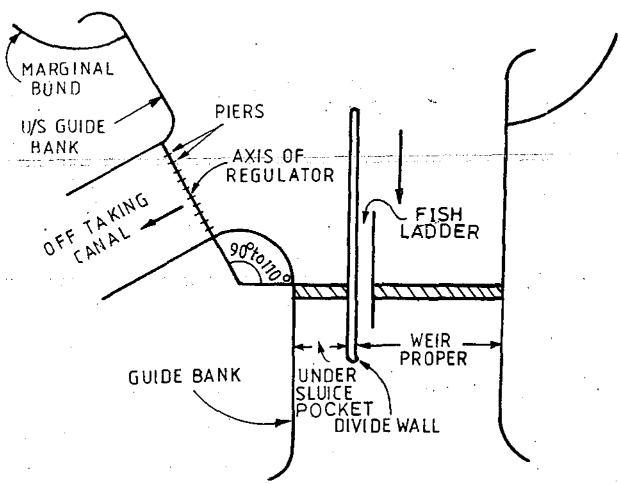



Fig. 9.16. Alignment of a Canal Head Regulator.

The crest level of the regulator, generally called the **sill level,** is not only governed by silt considerations, but is also governed by the discharge considerations. The full supply discharge has to pass through the regulator openings, the height of which will

* Explained in the next article.

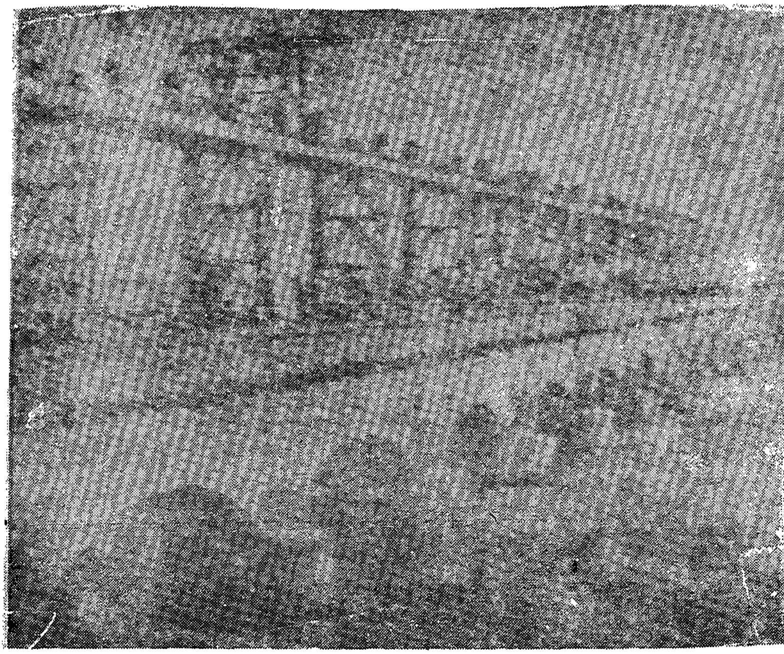


Fig. 9.17. Photographic view of a Canal Head Regulator.

be equal to the difference of pond level and sill level. *The smaller the height of the openings, the larger will be the width of the openings. In other words, if the sill level is raised too much, the clear waterway of the regulator will increase enormously, and, thereby making it more costly.*

The waterway of the regulator is fixed so that the full supply discharge of the canal could easily pass over the crest of the regulator with designed pond level, with ample factor of safety to allow for the future silting up of the canal and the subsequent rise in its FSL. Since a regulator is provided with a very wide and a shallow waterway, the drowned weir formula is used to calculate the discharge, and is given below :

With reference to Fig. 9.18, we have

$$Q_1 = \frac{2}{3} \cdot C_{d_1} \sqrt{2g} \cdot B . \left[ (h + h_v)^{3/2} - h_v^{3/2} \right] \text{(free weir equation)} \qquad ...(9.1)$$

$$Q_2 = C_{d_2} \cdot B \cdot h_1 \sqrt{2g \cdot (h + h_v)} \text{ (drowned weir equation)} \qquad ...(9.2)$$

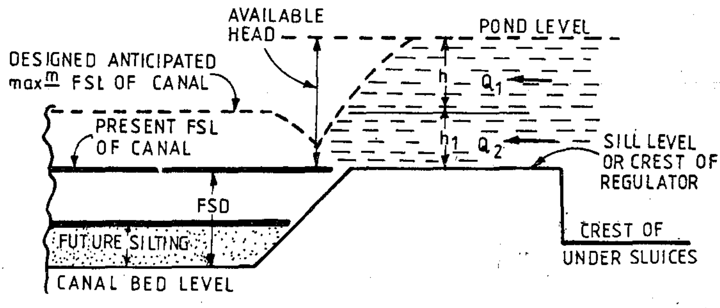



Fig. 9.18

Total discharge $Q = Q_1 + Q_2$

or $$Q = \frac{2}{3} C_{d_1} \cdot \sqrt{2g} \cdot B . \left[ (h + h_v)^{3/2} - h_v^{3/2} \right] + C_{d_2} B \cdot h_1 . \sqrt{2g \cdot (h + h_v)} \quad ...(9.3)$$

The values of $C_{d_1}$ and $C_{d_2}$ may be taken as 0.577 and 0.80, respectively.

where $h$ = Difference of the upstream and downstream water level, *i.e.* (Pond level — Maximum anticipated FSL of canal after making due allowance for future silting up of canal).

*h is called the utilized head or working head or designed head for the regulator, and is generally taken as half of the available head, where available head is equal to the difference of Pond Level and actual FSL of canal.*

$h_v$ = Head due to velocity of approach

$B$ = Clear width of waterway

$h_1$ = Depth of downstream water level above the crest

*i.e.* (maximum anticipated FSL of canal minus sill level)

When all other variables are fixed and known, value of clear waterway width ($B$) can be calculated.

The width of the waterway ($B$) calculated above, generally works out to be more than the normal width of the canal down-stream. In such a case, the sill level may be lowered, so as to increase the head and to decrease waterway to make it equal to the width of the canal. But the sill level is also governed by silt exclusion considerations, and therefore, many a times, it may not be possible to lower the sill level. In such a case, the calculated value of waterway is provided and the normal required width of the canal is obtained by contracting the wings.

As stated earlier, in a canal head regulator, the gate controlled openings are provided from the sill level to the pond level. During high floods, the water level in the river pocket will, however, be much higher than the pond level. To avoid spilling of this water over the canal regulator gates, a R.C.C. wall is provided from the pond level up to river HFL. This wall spans for the entire length of the regulator and will rest over the piers of the regulator bays. This wall is known as **breast wall,** and will be subjected to vertical self-weight and horizontal water pressure acting against it from the upstream side. Its design may be done as cantilever retaining wall for the horizontal water pressure, and as a girder spanning between the supports for its self-weight.

The length and thickness of horizontal floor, glacis, protection aprons, etc. is worked out on the same principles as are applicable to weir design, explained later in chapter 11. Usually, the worst condition for uplift pressure occurs, when high flood is passing down the weir and there is no flow in the canal.

**Example 9.1.** *The head regulator of a canal has 3 openings each 3 m wide. The water is flowing between the upper and lower gates. The vertical opening of the gate is*

*1.0 m. The head on the regulator is 0.45 m (Afflux). If the upstream water level rises by 0.20 m, find how much the upper gates must be lowered to maintain the canal discharge unaltered.* *(Madras University 1976)*

**Solution.**

The width of regulator openings = 3 spans of 3 m each = 9 m.

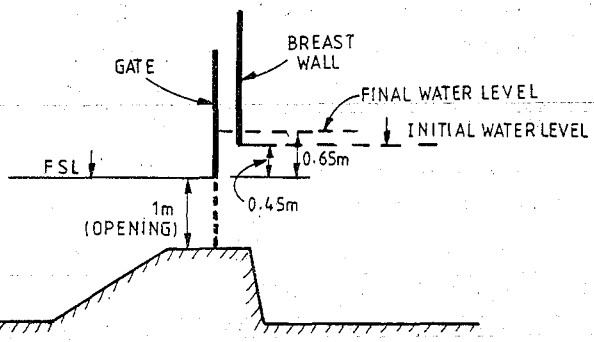



Fig. 9.19

When the gate opening is 1 m. The discharge can be calculated by submerged orifice formula, *i.e.*

$$Q = C_d \cdot A \sqrt{2gh} = 0.62\,(1 \times 9)\sqrt{2 \times 9.81 \times 0.45} \quad ...(i)$$

In the 2nd case, when upstream water level rises by 0.2 m, let the gate opening be $x$ metre to keep the discharge unaltered.

$$\therefore \quad Q = 0.62\,(x \times 9)\sqrt{2 \times 9.81 \times 0.65} \quad ...(ii)$$

Equating (*i*) and (*ii*), we have

$$0.62\,(1 \times 9)\sqrt{2 \times 9.81 \times 0.45} = 0.62\,(x \times 9)\sqrt{2 \times 9.81 \times 0.65}$$

or $\quad 1\sqrt{0.45} = x\sqrt{0.65}$

or $\quad 0.45 = x^2\,(0.65)$

or $\quad x = 0.83$ m

Hence, the gates must be lowered by an amount

$1 - 0.83 = 0.17$ m **Ans.**

## BARRAGE REGULATION AND SILT CONTROL AT HEAD WORKS

The supplies entering a canal which takes off from the upstream side of a weir or a barrage, can be regulated into the following two ways :

(*i*) **Still Pond Regulation Method.** In this method of operation, all the gates of the scouring sluices are kept closed when the canal is running. Only as much discharge is drawn into the under-sluice pocket as much is required for the canal ; the surplus being escaped over some other section of the weir or the barrage. The velocity of water in the under-sluice pocket, therefore, gets reduced, as the smaller discharge enters through the same waterway. The low velocity causes the sediment to settle down and relatively clearer water enters the canal.

The silt is, thus allowed to accumulate in the pocket till it reaches to within 0.5 m below the crest of the regulator. The canal is then closed and the scouring sluices opened, till the entire silt deposit gets washed away on the downstream of river. The scouring operation takes about 24 hours, and for this much of time, the canal supply has to be stopped. After the silt deposit is washed out, the scouring sluices are closed and the canal supply is restored again. This method of barrage regulation is called still pond regulation and is very useful in controlling the amount of silt entering the canal. However, this method of regulation is practicable only where the sill of the canal head regulator is sufficiently higher than the upstream floor of the under-sluices. Moreover, it leads to closure of the off-taking canal atleast once a month, resulting in the wastage of discharge and loss of irrigation to that much extent.

(*ii*) **Semi-Open flow Operation.** In this method, water in excess of the canal requirement, is allowed to enter into the under-sluice pocket. The gates of the scouring sluices are kept partially opened. The total water entering the pocket, thus, gets divided into two parts, in front of the head regulator. The top water (above the sill level of head regulator) enters the canal through the head regulator, and the bottom water escapes downstream through the under-sluices. Due to this, certain velocity is maintained in the pocket and silt remains in suspension. The turbulence created may sometimes cause even the coarser silt to rise up and to enter into the canal. The silt control, is thus reduced in this method. However, the advantage of this method is that the silt is constantly and continuously scoured out, and the canal has not to be closed, as is required to be done in still pond regulation method.

Even in spite of using still pond regulation techniques, certain amount of silt may enter the canal. And also, silt will definitely enter the canal in semi-open flow operation. In order to avoid this silt, special silt control works are constructed, which remove the silt from the canal water either before the water enters the canal or after the water has entered and travelled a certain distance in the canal. These devices are explained below in details :

**9.3.8. Silt Control Devices.** The entry of silt into a canal, which takes off from a Head-Works, can be reduced by constructing certain special works, called silt control works. These works may be classified into the following two types :

(*a*) **Silt Excluders.** Silt excluders are those works which are *constructed on the bed of the river*, upstream of the head regulator. The clearer water enters the head regulator and the silted water enters the silt excluder. In this type of works, the silt is, therefore, removed from the water before it enters the canal.

(*b*) **Silt Ejectors.** Silt ejectors, also called **silt extractors,** are those devices which extract the silt from the canal-water after the silted water has travelled a certain distance in the off-take canal. These works are, therefore, constructed on the bed of the canal, and a little distance downstream from the head regulator.

*Principles of Silt Control*

Before we describe the mechanism and functioning of these silt control devices, we shall explain the basic principle on which the silt is removed from the water.

The fundamental principle behind silt control is : that most of the silt tries to settle down in water, thus, confining itself mostly in the bottom layers of water. We also know that the silt is kept in suspension by the force of the vertical eddies generated by the friction of the flowing water against the bed. In other words, if this bed friction is more, the upward force of eddies shall be more, and hence, lesser chances of silt settlement will exist. Hence, if the friction can be reduced by constructing a smooth approach channel, more settlement of silt and its consequent removal, is possible. Further, the silt from the bottom layers can be removed, by separating the top layers and the bottom layers, without causing any disturbance to the flow. The chances of less disturbance and that of providing a smooth approach channel can be better attained in a canal rather than in the river bed. Hence, the works *which are constructed in the canal* (*i.e.* the silt extractors or silt ejectors) will *definitely be superior and more effective than the works* which are constructed in the river bed (*i.e.* the silt excluders). *Silt extractor is therefore, better than a silt excluder.* However, the silt extractor shall be costlier because surplus water has to be taken into the canal from the head, and an escape channel which will feed the highly silted water back into the river, shall have to be constructed.

**9.3.8.1. Description and Design of a Silt Excluder.** A silt excluder consists of a number of rectangular tunnels running parallel to the axis of the head regulator and terminating near the under-sluiced weir. The tunnel nearest to the crest of the head regulator has to be at least of the same length as the head regulator. Other tunnels may be shorter in length. The roof slab of the excluder tunnels is kept at the same level as that of the regulator crest, as shown in Figs. 9.15 and 9.20. The bottom layer of water which is highly charged with silt and sediment will pass down the tunnels and escape

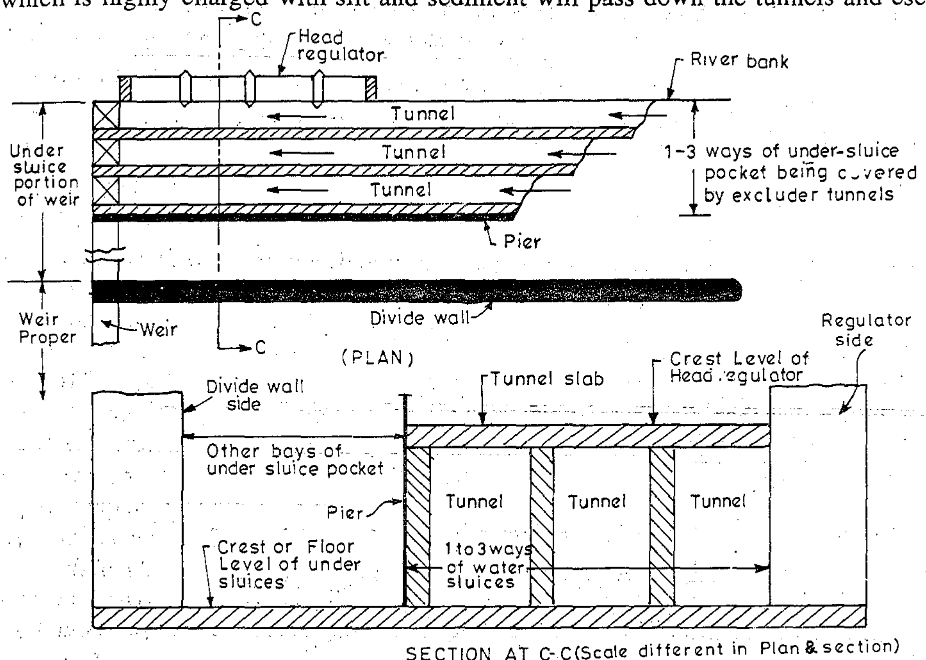



Fig. 9.20. Silt Excluder.

over the floor of the under-sluice way(s), since the gates of the under sluice way(s) shall be kept open upto the top of the tunnels. The clearer water over the top of the roof of the excluder tunnels, will thus enter the canal through the head regulator. Usually, two or three bays of the under-sluices of the weir or the barrage are covered by the excluder. *However, excluder covering only one bay has been designed and is usually adopted for sandy rivers.*

The **major disadvatages of silt excluders** are :

(*i*) Simultaneous use of under sluices-masked by the silt excluder tunnels, for silt exclusion and their assigned purpose of passing high river discharge, cannot be obtained.

(*ii*) The tunnels constructed on the river bed will have to be of robust construction, as to withstand river action.

(*iii*) In the presence of tunnels, on the river bed in the under-sluice pocket, securing of good approach conditions become difficult. If these tunnels were not there, a curved off-take or a curved approach could be provided at a small cost.

The **major advantages of the pocket excluders** are :

(*i*) As the tunnels are large, there are unlikely to be choked by rolling or suspended debris.

(*ii*) Since the same gates of the scouring sluices can be utilised for the excluder tunnels, some economy in cost is secured.

(*iii*) At the weir, sufficient head for operating the excluder is generally available.

**Design of tunnels.** A theoretical design of a silt excluder is confined mainly to find out the area of the tunnel openings required to pass the designed discharge and to determine its structural requirements. On the basis of past experience and model studies, the design of an excluder is finalised. The Punjab Irrigation Research Institute has carried out extensive research in the design of excluders. Based on their research findings, it has been found that if the excluder discharge is restricted to 15 to 20% of the canal discharge, satisfactory silt exclusion can be obtained. A minimum velocity of 2 to 4.5 m/sec must be maintained through the tunnels in order to keep them free from sediment. A value of 3 m/sec is usually adopted for ordinary straight reaches. A higher value of 4 to 4.5 m/sec may be adopted for boulder-stage rivers. A lower value of about 2 m/sec may be adopted for sandy rivers. After fixing the discharge and velocity, the cross-sectional area of the excluder tunnel-openings, can be determined. Knowing the height, the required width can be found and divided into a suitable number of bays.

By model studies, it has been found that the tunnels should be located at selected positions, rather than distributed uniformly over the entire length of the regulator. The position of tunnels being more important than their number. River curvature must be taken into consideration as far as possible. It was found by experience at Khanki that three tunnels were more efficient than six. Also, a smaller number of pocket bays covered by the excluder, give better results as do the openings of the tunnels confined to the mouth. Side openings into the tunnels, have been found to decrease the efficiency. Usually, 4 to 6 tunnels are generally provided.

**Approach and exit.** At the entrance, the tunnels are generally given a bell mouthed shape so as to increase the zone of suction. The radius of bell mouthing varies from 2 to 6 times the tunnel width ; the radii increasing for tunnels away from canal head regulator and for shorter tunnels. At the exit end, the tunnels are throttled for restricting the discharge to the desired value and to increase the velocity to prevent deposition of silt.

**Height of tunnels**. The height of tunnels generally varies from 0.5 to 0.6 m for sandy rivers, and 0.8 to 1.2 m for boulder stage rivers.

**Body and roof of tunnels.** The roof of tunnels must be strong enough to withstand the full water load coming from its top, with no water inside. Such a condition may arise when the tunnels are closed from upstream for repairs or for some other purpose. Moreover, the tunnel walls and roofs must be strong enough, as not to be, damaged by debris, boulders, shingles, etc., during floods. This is all the more important, since damage to excluder is not discovered as they are always under water and difficult to repair. Moreover, even the slight damage to the tunnel roof has found to have made the excluder less efficient.

**Outfall channel.** It should also be ensured that a channel to take the silt laden water into the river is maintained downstream of the excluder. No separate outfall channel is generally required for sandy rivers as a continuous flow through the alluvial bed, itself makes a channel there. However, if gravel and boulders are to be excluded and the main channel is away, a lined channel may be necessary, or a channel may have to be created by suitable training measures. This was done in the case of Tajewala Head Works on Yamuna river, where two short spurs induced the river to flow on the side of the under-sluices, and thus eliminated the construction of a separate outfall channel.

**Losses in tunnels.** The following head losses may be taken into account for calculating the tunnel sections :

(*i*) *Frictional Loss.*

$$h_f = \frac{n^2 \cdot V^2 \cdot L}{R^{4/3}} \text{ (Manning's formula).} \quad \ldots(9.4)$$

where $h_f$ = Head loss in metres.
$L$ = length of tunnel in metres.
$R$ = Hydraulic mean depth in metres.
$n$ = Manning's Rugosity coefficient.

(*ii*) *Loss due to Bend.*

$$h_b = F\left(\frac{V^2}{2g}\right)\left(\frac{\theta}{180°}\right) \quad \ldots(9.5)$$

where $F = 0.124 + 3.134\left(\frac{S}{2r}\right)^{1/2}$ ...(9.6)

$\theta$ = Angle of deviation in degrees
$S$ = Width of tunnel in metres.
$r$ = Radius of bend along centre line of tunnel in metres.
$h_b$ = Head loss in metres.

(*iii*) *Transitional loss due to change of velocity in contraction.*

$$h_c = 0.1\left[\frac{V_2^2}{2g} - \frac{V_1^2}{2g}\right] \quad \ldots(9.7)$$

where $V_1$ = Velocity in canal upstream in m/sec.
$V_2$ = Velocity in tunnel in m/sec
$h_c$ = Head loss in metres.

(*iv*) *Transitional loss due to change of velocity in expansion.*

$$h_e = 0.1\left[\frac{V_2^2}{2g} - \frac{V_3^2}{2g}\right] \quad \ldots(9.8)$$

where $V_2$ = Velocity in tunnel.
$V_3$ = Velocity downstream of tunnel.

**9.3.8.2. Description and Design of a Silt Extractor or a Silt Ejector.** The typical layout of a silt ejector is shown in Fig. 9.21 (*a* and *b*). It essentially consists of a horizontal diaphragm slab, a little distance above the canal bed, which separates out the bottom layers. Under the diaphragm, which is normally spanning the entire width of the

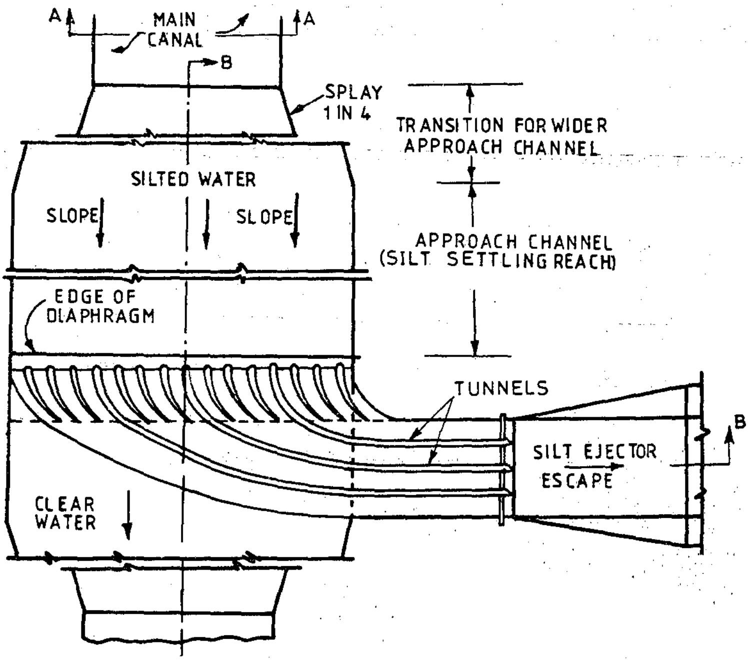



Fig. 9.21. (*a*) Plan of Silt Ejector.

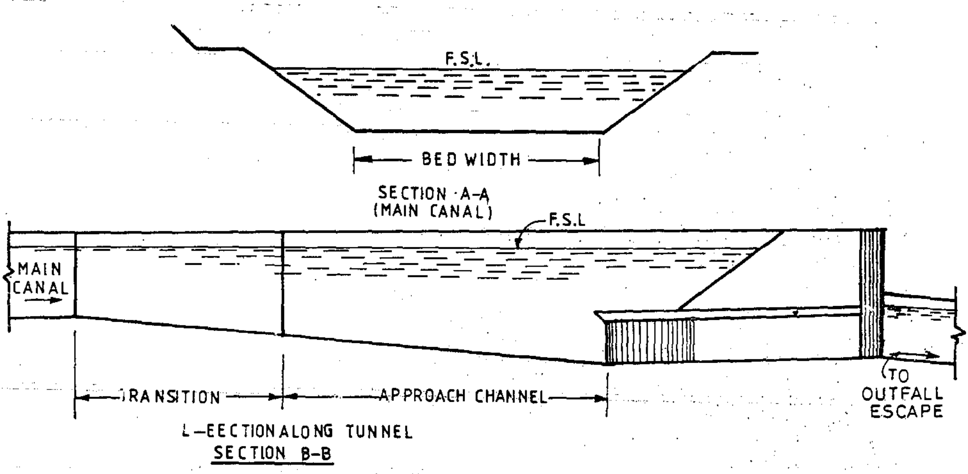



Fig. 9.21. (*b*) Sections of a Silt Ejector.

canal, there are tunnels or compartments which extract the highly silted bottom water into an escape channel. The tunnel entrances should be designed in such a way that there is no disturbance of flow at entry, and the escape flow is quickly accelerated under the diaphragm, so as to prevent the clogging of tunnels. These objectives are achieved by dividing the entire span width into a number of compartments or tunnels by means of *streamlined vanes,* which are gradually converging (thus gradually decreasing the sectional area and correspondingly increasing the flow velocity). These main compartments are sub-divided into smaller compartments or sub-tunnels by vanes of radii varying from 3 to 4 times the width of the sub-tunnels to avoid cross flow in the transition section. The tunnel discharge is regulated by means of gates at the outlet end. The escape channel should have sufficient slope to carry the silt laden water without getting silted up, and should lead the water by the most economical path back to the river. The principles governing the location and design of various components of a silt ejector are briefly described here.

**Location.** The silt ejector should be located in the canal neither too much near the head regulator nor too far away from the head regulator. In the former case, the residual turbulence may keep the silt in suspension, and thus, preventing its extraction up to the desired extent. Similarly, in the latter case, when the ejector is located far away from the head regulator, the silt may settle down earlier and reduce the channel capacity upstream, thus, defeating the very purpose of the ejector.

**Design Principles for Various Components are given below :**

(*i*) **Approach channel.** The normal main canal section is generally widened after the canal takes off from the head regulator, so as to reduce the flow velocity to a desired level. This will help in increasing the silt concentration in the bottom layers. The reduced velocity should be maintained for a sufficient length to achieve the desired sediment concentration in the bottom layers.

(*ii*) **Diaphragm.** The diaphragm should be placed in such a way that it causes least disturbance in front of the ejector tunnels, so as not to disturb silt concentration attained in the bottom layers. The diaphragm is generally placed at the downstream bed level of the canal, *i.e.* the canal bed has to be slightly depressed under the diaphragm. However, if the diaphragm has to be placed higher due to some other considerations, the condition of fall, particularly for low supplies, should be checked, and energy dissipation arrangements made, if found necessary. The diaphragm should be properly tied to the supports, so as to prevent it from being dislodged. The diaphragm shall be extended beyond the pier noses and the underneath of the diaphragm shall be given a streamlined bell mouth shape confirming to the equation of an ellipse, *i.e.*

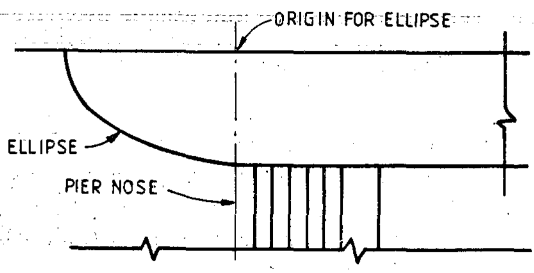



Fig. 9.22

$$\frac{x^2}{4a^2} + \frac{y^2}{a^2} = 1$$

where $a$ is the thickness of the diaphragm. (See Fig. 9.22).

(*iii*) **Tunnels.** The tunnels or compartments shall be constructed by gradually converging vanes, as explained earlier. The upstream noses of the vanes and piers may have cut-water shapes, while the downstream end of vanes may be fish-tailed. The tunnel dimensions at the entry and exit may be so fixed, as to ensure velocities that would carry the size of sediment to be removed. The section of the sub-tunnels at the entry may be so chosen that the velocity of flow at the intake is slightly higher than the velocity of bottom filaments of water upstream of ejector. The section of sub-tunnels up to their exit, where they end into the main tunnels, may be reduced gradually in such a way that there is an overall increase of 10 to 15 per cent in the velocity of emerging flow.

At the exit of sub-tunnels, the section of the main tunnel may be designed such that the flow velocities of the combined discharge are not less than the velocities emerging from the sub-tunnel. The section at the exit of main tunnels may be so designed, as to attain a velocity 2.5 to 6 m/sec depending on the grade of sediment to be ejected ; but in all cases, the exit velocity has to be more than the critical velocity, so as to ensure super-critical flow. The height of the tunnels is generally kept from 0.5 to 0.75 metres.

The width of the tunnels may be so adjusted as to have equal losses in each tunnel.

**Note.** As the lengths of tunnels are different, the head loss in them would be different, if all of them were to take the same discharge. As the difference between the water level in the canal and that in the escape channel is the same, the head available for all the tunnels is the same. Hence, the shorter tunnel would have a higher velocity of flow through it, than in the others, and this would lead to disturbance at entry. To counteract this possibility, either the shorter tunnel may serve a larger width of the canal than a longer one, or the tunnel cross-sections may be altered, each serving an equal width. The adjustment of width is recommended by BIS.

(*iv*) **Gate control regulation.** The discharge from ejector is controlled by gated regulation at the downstream end of the tunnels. The amount of discharge passing down the ejector and the frequency of its operation would vary in different parts of the year depending on the silt load carried by the canal. Proper gate regulation is, therefore, required, as per the intelligence and initiative of the maintenance engineers. The gate must be operated occasionally, so as to ensure it to be in working order.

(*v*) **Escape channel and escape discharge.** The outflow from the ejector is taken to a natural drainage through an escape channel. The escape channel should be designed to have a self-cleansing velocity, so that the ejected material is transported without deposition. Adequate fall between the F.S.L. of the escape channel at its tail end and the normal H.F.L. of the natural drain, is desirable for efficient functioning of the channel.

The escape discharge is generally governed by : (*i*) amount of discharge required to remove the desired sediment size and load ; and (*ii*) minimum discharge required for flushing individual tunnels. Normally, an escape discharge varying from 10 to 20% of the full supply discharge of the canal, downstream of the ejector, is sufficient for this purpose.

**Efficiency of Excluders and Ejectors**

The efficiency of excluders and ejectors, can be expressed by

$$\eta = \frac{I_u - I_d}{I_u} \times 100 \text{ (per cent)} \qquad ...(9.9)$$

where $\eta$ = Per cent efficiency.

$I_u$ = Silt intensity in canal upstream of the ejector.

$I_d$ = Silt intensity in canal downstream of the ejector.

## PROBLEMS

**1.** Draw a neat sketch of a River-regulator and explain its salient components.

Write short notes on :

(*i*) Silt ejector. (*ii*) Scouring sluices.

(*iii*) Dividing groyne. (*Madras University, 1974*)

(**Hint** : Dividing groyne means divide wall.)

**2.** (*a*) Differentiate between a weir and a barrage.

(*b*) Draw a neat layout of Diversion head-works and indicate the various components of the system. Briefly indicate the function of each component. (*Madras University, 1973*)

**3.** (*a*) What is the purpose served by "scouring sluices" at weirs ? What are the important points to be borne in mind in designing these sluices ? (*Madras University, 1975*)

(*b*) How does "scouring-sluices" differ from those of "head-sluices" ?

(*c*) Why is it necessary to provide a "fish ladder" on large rivers, and how does it help in achieving the required objective ?

**4.** Draw a neat layout of a river regulator, and indicate suitable locations for the following :

(*i*) A navigational lock (*ii*) A fish ladder

(*iii*) Scouring sluices (*iv*) Head sluices

Draw a typical cross-section of a head regulator, and indicate the various components of the same. (*Madras University, 1973*)

**5.** What are the functions of a canal head regulator ?

Design a head sluice for a canal, intended to irrigate 24,000 hectares at a duty of 800 hectares per cumec. It is in a main canal taken from a river and has the following data :

Head available to permit full supply in canal = 0.30 m.

Bed width of canal = 20 m.

FSD in canal = 1.5 m

Depth in the river at max. water level = 4.2 m (*Madras University, 1975*)

**6.** Enumerate and explain briefly the different methods for control of entry of silt into canals. Give a neat sketch of any one silt exclusion work to show its structural details and principle of functioning.

Show the component parts of a diversion head-works on a neat sketch. Mention the functions and important design considerations pertinent to the divide wall.

**7.** (*a*) Illustrate with neat sketch the following parts of a barrage :

(*i*) Sheets piles (*ii*) Fish ladder

(*iii*) Silt excluder (*iv*) Divide wall.

(*b*) Briefly describe a system of regulation that is practised to minimise sediment load entering a canal. (*A.M.I.E., 1975*)

**8.** (*a*) Differentiate between the following :

(*i*) A barrage and a dam.

(*ii*) Scouring sluices and head sluices.

(*iii*) Surplus weir and storage weir.

(*iv*) Gravity and non-gravity weirs.

(*v*) Silt excluders and silt ejectors.

(*vi*) River regulator and a canal regulator. (*Madras University, 1976*)

(*b*) What is meant by "afflux", and how does it effect the design of weirs and barrages ?

**9.** (*a*) What is the difference between a weir and a barrage ? Why does a barrage preferred to a weir in modern days ?

(*b*) How does a diversion weir aligned ? Draw a neat sketch showing the different components of a diversion weir scheme.

(*c*) What are the different construction materials which may be used for weirs, and how are the weirs classified on this score ?

**10.** (*a*) What is meant by an "Intake weir" and how does it differ from a "surplus weir" ?

(*b*) What are "under-sluices", and what are their functions in a river regulator ?

(*c*) Draw a neat sketch of a typical fish ladder indicating the purposes served by it.

**11.** (*a*) What are "Divide walls", and how do they help in a diversion weir scheme ? Draw neat sketches showing the cross-section of divide walls on pucca floor as well as beyond the pucca floor. Also discuss the design considerations that are involved in designing divide walls.

(*b*) Discuss the use of 'guide banks' and 'marginal bunds' in a river regulator scheme.

**12.** (*a*) What are the two principal methods of regulating the canal supplies in a diversion head works scheme ? What are their comparative merits and demerits ?

(*b*) Differentiate between a 'Silt extractor' and a 'Silt excluder'. Draw a neat sketch and discuss the principles involved in designing the different components of a silt extractor.

**13.** (*a*) Differentiate between the following, indicating the preference, which you will give to one, in modern days, with proper reasoning :

(*i*) Weir and barrage

(*ii*) Silt excluder and silt-ejector

(*iii*) Rock-fill weirs and sloping glacis concrete weirs.

(*iv*) Still pond regulation and semi open flow operation at a barrage.

(*b*) Draw a neat sketch of a silt excluder and indicate briefly the principles involved in designing its different components. How will you express its efficiency ?

**14.** Describe briefly some of the effects of silting in rivers.

Describe briefly a method of removal of silt accumulation behind a river regulator.

(*Madras University, 1973*)