Module

3

Irrigation Engineering Principles

Lesson
10
Distribution and Measurement Structures for Canal Flows

Instructional objectives

On completion of this lesson, the student shall learn:

1. What are flow distributing and measurement structures in a canal system
2. What is the function of outlets and what are their classifications
3. What are modules
4. How are notches and weirs used to measure flow in a canal
5. How are flumes used to measure flow in a canal

3.10.0 Introduction

The flow of a main canal bifurcating into a branch canal with the rest flowing downstream is controlled with the help of a cross regulator across the parent canal and a head regulator across the branch canal. At times, the flow of a canal divides into two or three smaller branch canals without any regulating structure by designing the entrance of the canals IN such a way that the flow enters each branch canal proportionate to its size. Again, from a canal, outlet structures may take out water for delivery to the field channel or water courses belonging to cultivators. These outlet works, of course, are generally not provided on the main canal and branches, but are installed in the smaller distributaries. Apart from these, there could be a need to measure the flow in a canal section and different structures have been tried, mostly based on the formation of a hydraulic jump and calibrating the discharge with the depths of flow. Typical structures of these kinds are graphically represented in Figure 1 and this lesson deals with each type in detail.

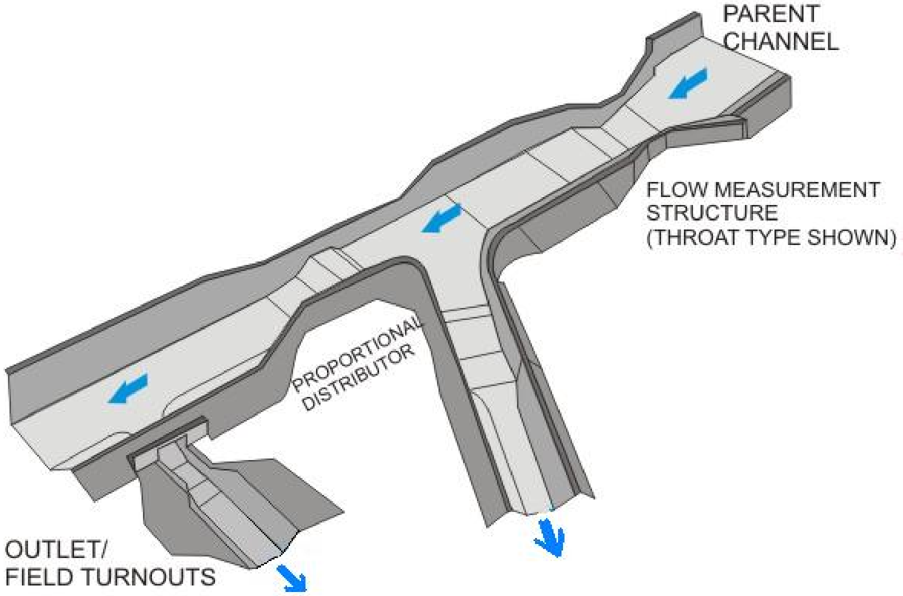


FIGURE 1. Canal structures for flow distribution and measurement

3.10.1 Flow distributing structures

The flow of a canal can be distributed in to smaller branches using a variety of structures which have been developed to suit a wide variety of conditions. The flow being diverted in to each branch is usually defined as a proportion of the total flow. Thus, these flow distributing structures differ from the flow regulating structures discussed in Lesson 3.9 since the latter are designed to draw off any amount of discharge irrespective of the flow in the parent channel. The flow distributing structures require a control section in both the off-take channel and in the parent channel. Flow distributors of fixed proportion type are generally used in India, whereas in some countries a flow splitter with a mechanical arrangement is used to change the flow distribution proportions.

The Punjab type proportional distributor has each opening or ***offtake*** constructed as a flume or ***free overfall weir*** and is dimensioned so as to pass a given fraction of the total flow. The controlling section consisting of the flume, elevated floor or weir crest is located in the individual offtakes, and not in the supply channel. A typical plan of a proportional distributor with two offtakes is shown in Figure 2.

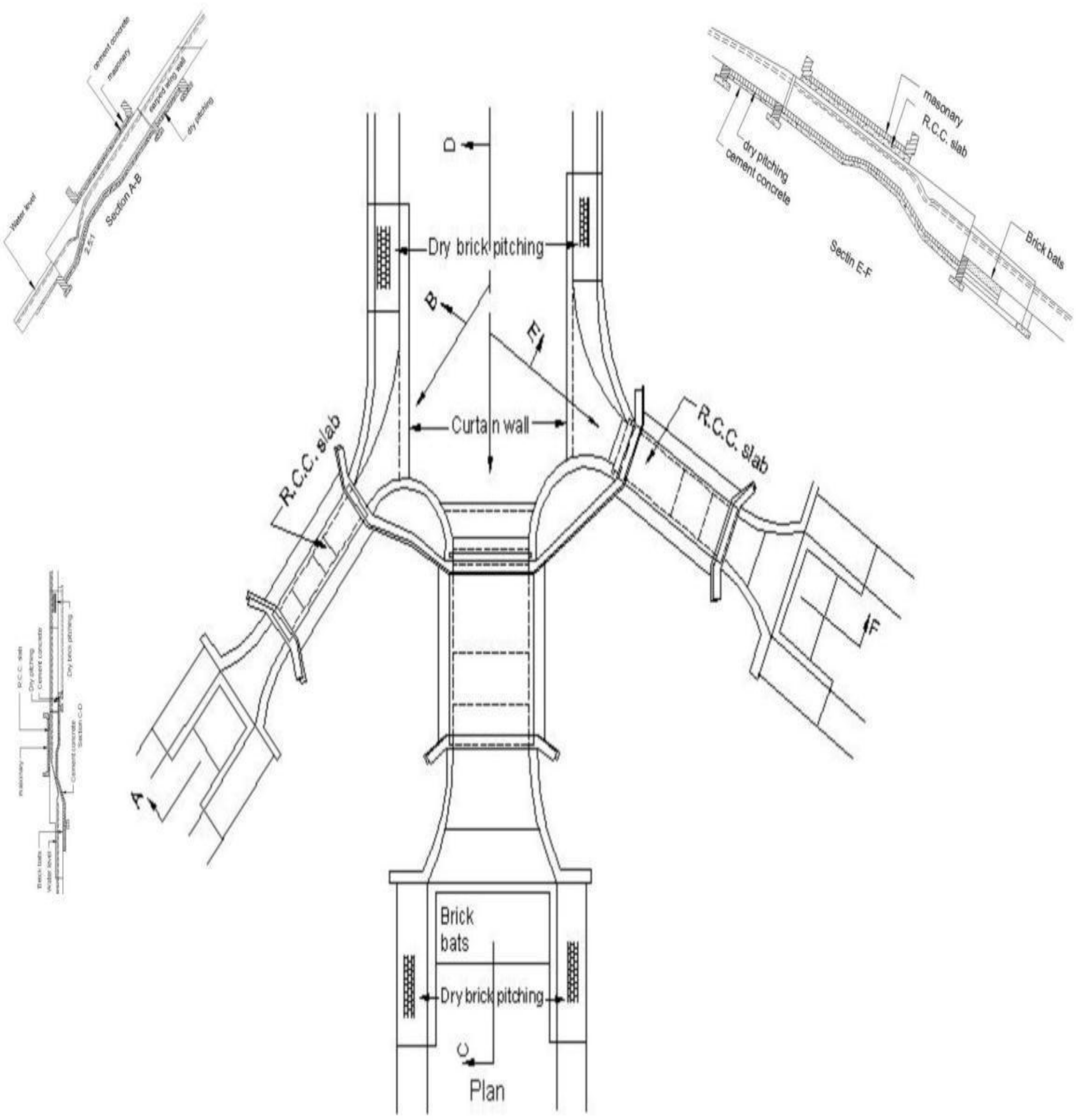


FIGURE 2. Proportional distributor structure with two offtakes

Proportional distributors may have only one offtake as shown in the typical plans shown in Figure 3. Generally, all offtakes should be designed to bifurcate at 60^0 or 45^0. The crest of all the offtakes and the flume in the parent channel should be at the same level and at least 0.15m above the downstream bed level of the highest channel. The parent channel flume may have provisions for a stop log insertion for emergency closures.

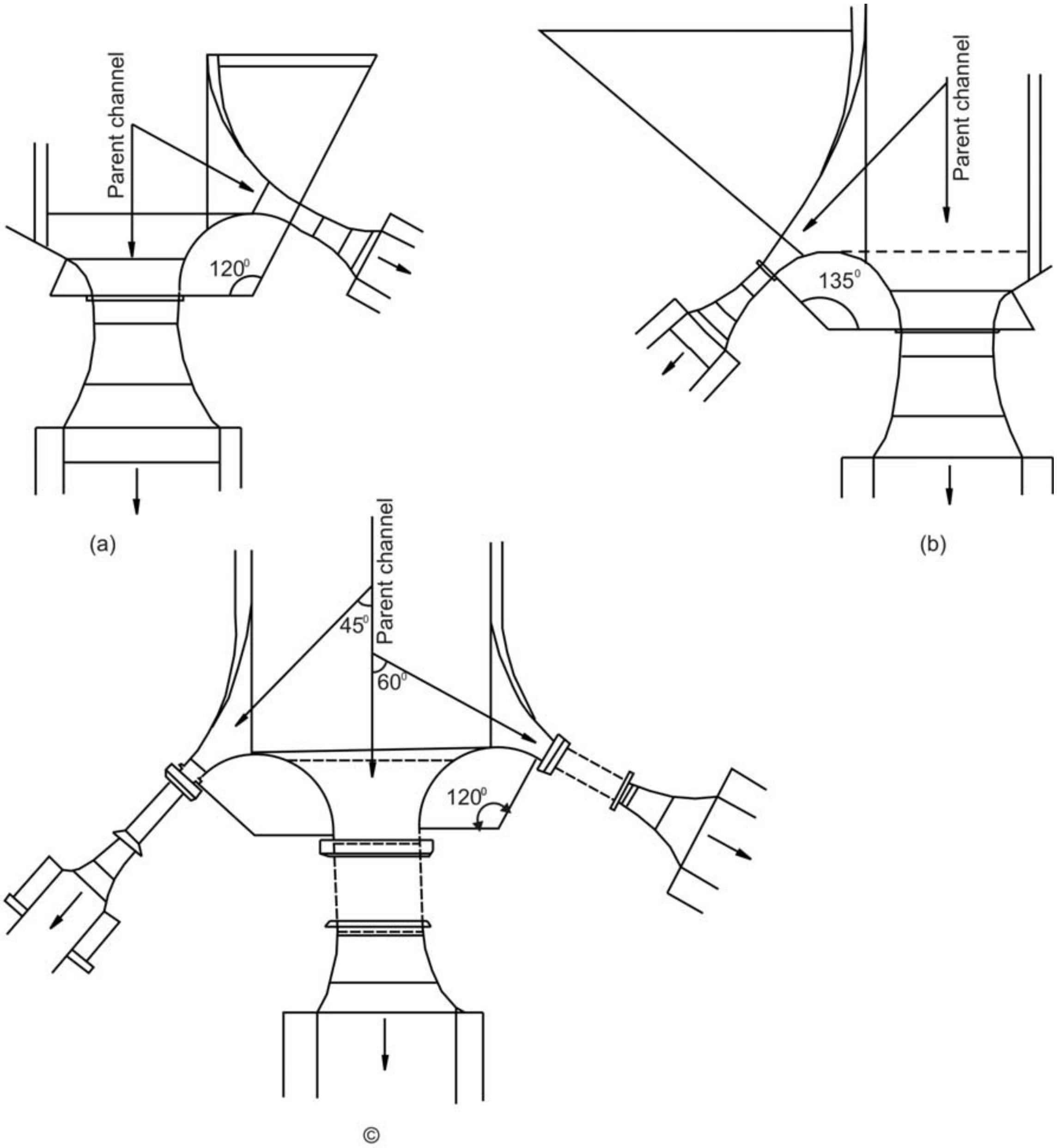


FIGURE 3. PROPORTIONAL OFFTAKES WITH (a) ONE OFFTAKE ON LEFT SIDE (b) ONE OFFTAKE ON RIGHT SIDE (c)ONE OFFTAKE ON EITHER SIDE

3.10.2 Canal outlet

Canal ***outlets***, also called ***farm turnouts*** in some countries, are structures at the head of a ***water course*** or ***field channel***. The supply canal is usually under the control of an irrigation authority under the State government. Since an outlet is a link connecting the government owned supply channel and the cultivator owned field channel, the requirements should satisfy the needs of both the groups.

Since equitable distribution of the canal supplies is dependent on the outlets, it must not only pass a known and constant quantity of water, but must also be able to measure the released water satisfactorily. Also, since the outlets release water to each and every farm watercourse, such structures are more numerous than any other irrigation structure. Hence it is essential to design an outlet in such a way that it is reliable and be also robust enough such that it is not easily tampered with. Further the cost of an outlet structure should be low and should work efficiently with a small working head, since a larger working head would require higher water level in the parent channel resulting in high cost of the distribution system. Discharge through an outlet is usually less than 0.085 cumecs.

Various types of canal outlets have been evolved from time to time but none has been accepted as universally suitable. It is very difficult to achieve a perfect design fulfilling both the properties of ‘flexibility’ as well as ‘sensitivity’ because of various indeterminate conditions both in the supply channel and the watercourse of the following factors:

- Discharge and silt
- Capacity factor
- Rotation of channels
- Regime condition of distribution channels, etc.

These modules are classified in three types, which are as follows:

(a) Non-modular outlets

These outlets operate in such a way that the flow passing through them is a function of the difference in water levels of the distributing channel and the watercourse. Hence, a variation in either affects the discharge. These outlets consist of regulator or circular openings and pavement. The effect of downstream water level is more with short pavement.

(b) Semi-modular outlets

The discharge through these outlets depend on the water level of the distributing channel but is independent of the water level in the watercourse so long as the minimum working head required for their working is available.

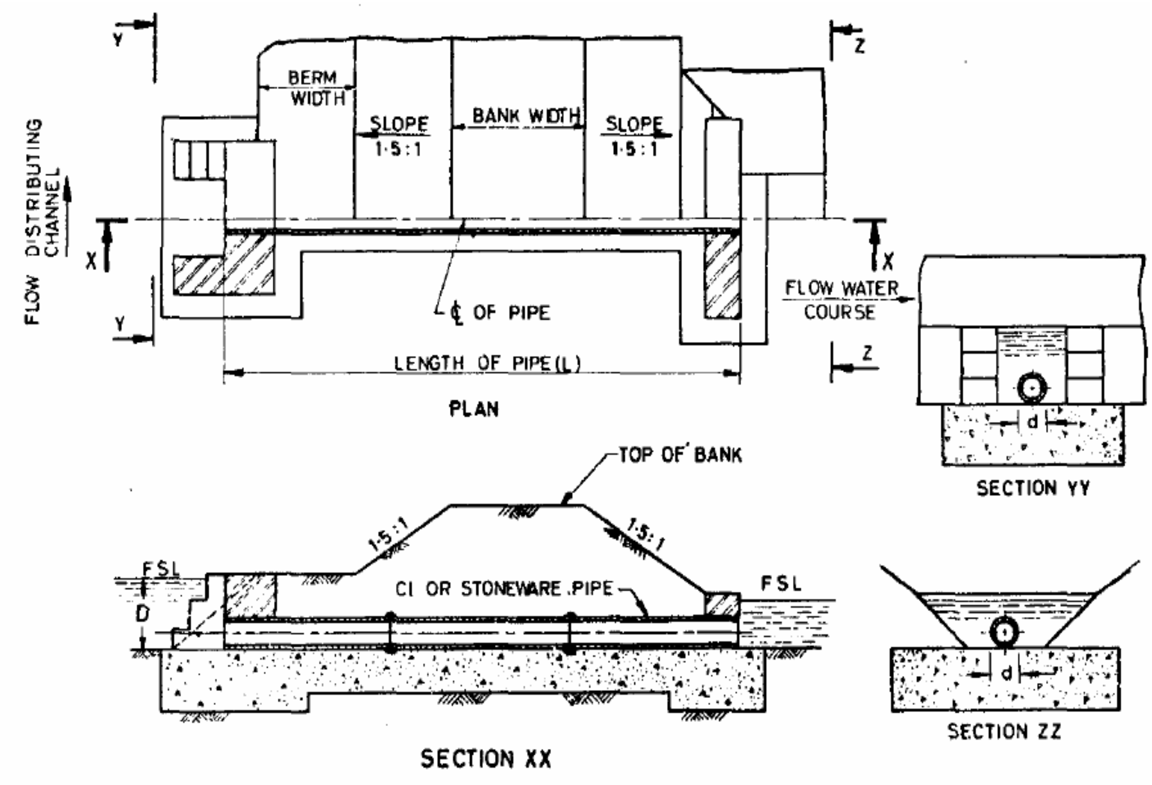
(c) Module outlets

The discharge through modular outlets is independent of the water levels in the distributing channel and the watercourse, within reasonable working limits. This type of outlets may or may not be equipped with moving parts. Though modular outlets, like the Gibb’s module, have been designed and implemented earlier, they are not very common in the present Indian irrigation engineering scenario.

The common types of outlets used in India are discussed in the next sections.

3.10.3 Pipe outlets

This is a pipe with the exit end submerged in the watercourse (Figure 4). The pipes are placed horizontally and at right angles to the centre line of the distributing channel and acts as a non-modular outlet.



Discharge through the pipe outlet is given by the formula:

$$Q = CA\,(2gH)^{1/2} \tag{1}$$

In the above equation, ***Q*** is the discharge; ***A*** is the cross sectional area; ***g*** is the acceleration due to gravity; ***H*** is difference in water levels of supply channel and watercourse and ***C*** is the coefficient of discharge which depends upon friction factor (***f***), length (***L***) and diameter of the outlet pipe (***d***) related by the formula:

$$C = \frac{1}{2 \times 10^5}\sqrt{\frac{d}{f\left(L + \dfrac{1.5d}{400f}\right)}} \tag{2}$$

The coefficient ***f*** is the fluid friction factor and its value may be taken as 0.005 and 0.01 for clear and encrusted iron pipes respectively. For earthenware pipes, ***f*** may be taken as 0.0075. All other variables are in SI units, that is, meters and seconds.

It is a common practice to place the pipe at the bed of the distributing channel to enable the outlets to draw proportional amount of silt from the supply channel. The entry and exit ends of the pipe should preferably be fixed in masonry to prevent tampering. Since the discharge through this type of outlet can be increased by lowering the water surface level of the watercourse (thus increasing the value of H in the discharge equation), it is possible for the irrigator to draw more than fair share of water. A pipe outlet may also be designed as a semi-modular outlet, that is, one which does not depend upon the water level in the watercourse by allowing it to fall freely in to the watercourse (Figure 5).

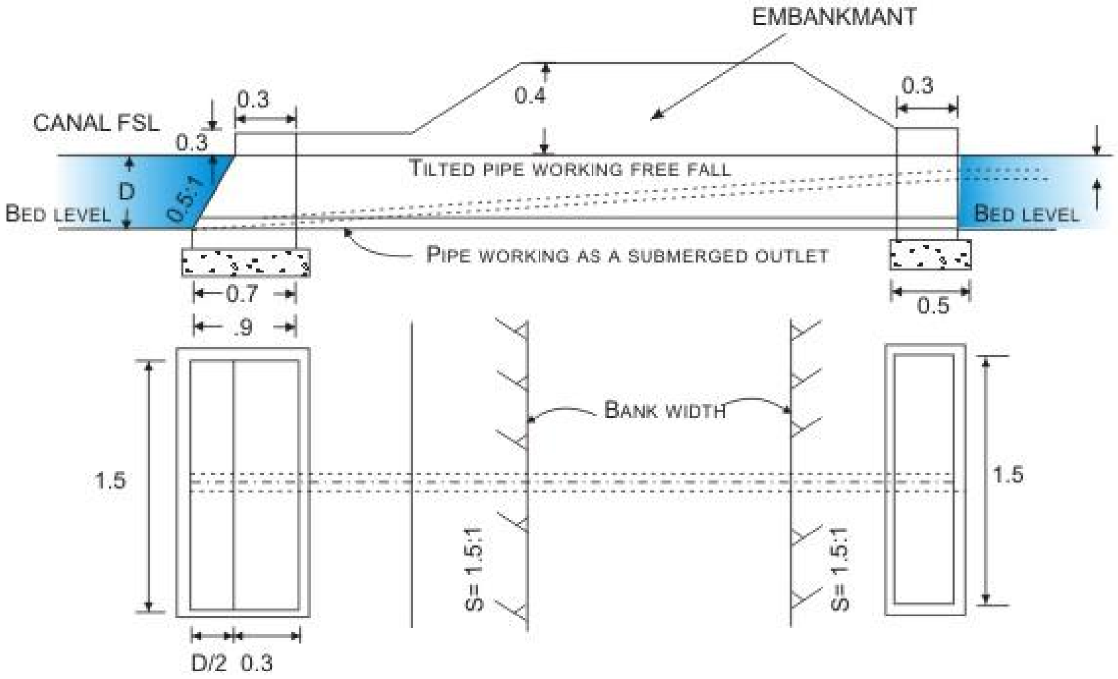


FIGURE 5. Pipe outlet with exit above water- course FSL

Pipe outlets require minimum working head and have higher efficiency. It is also simple and economical to construct and is suitable for small discharges. However, these outlets suffer from disadvantages like the coefficient discharge which varies from outlet to outlet and at the same outlet at different times apart from the possibility of tampering in the non-modular type.

3.10.4 Open flume outlets

This is a smooth weir with a throat constricted sufficiently long to ensure that the controlling section remains with in the parallel throat for all discharges up to the maximum (Figure 6). Since a hydraulic jump forms at the control section, the water level of the watercourse does not affect the discharge through this type of outlet. Hence this is a semi-modular outlet.

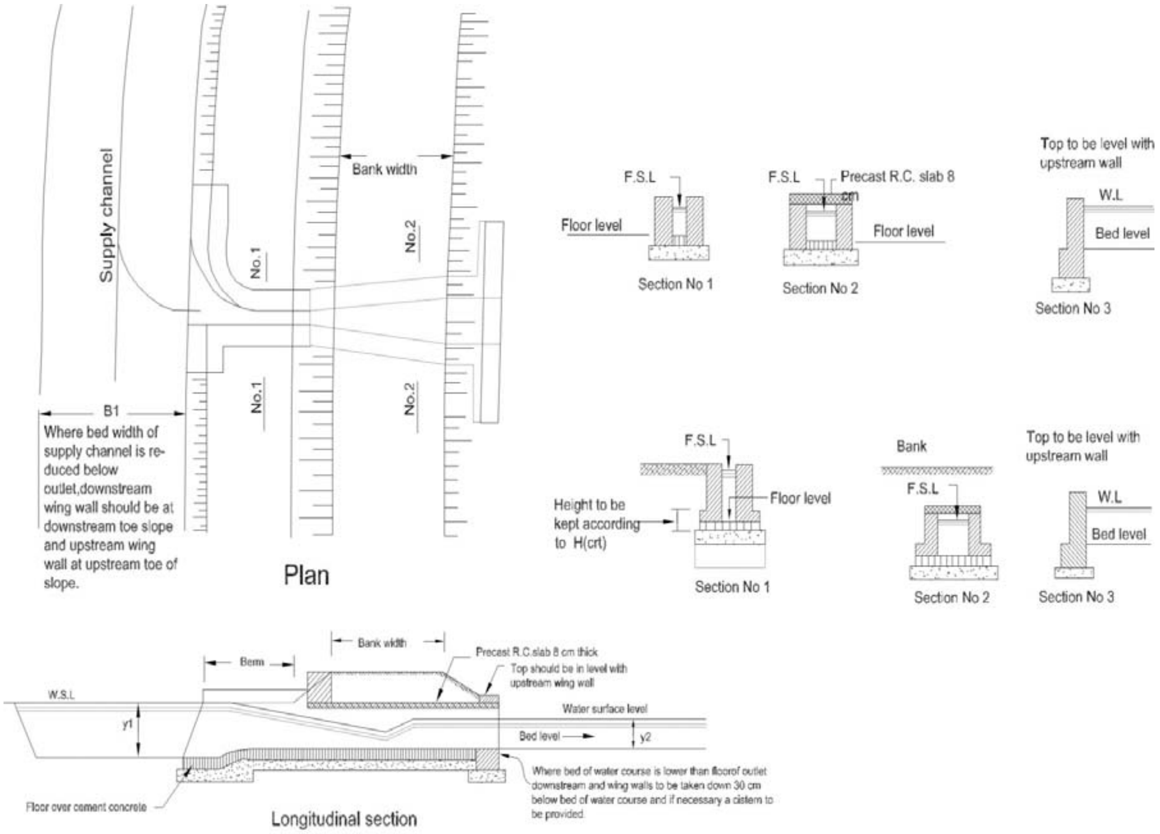


FIGURE 6. OPEN FLUME OUTLET

This type of structure is built in masonry, but the controlling section is generally provided with cast iron or steel bed and check plates. The open flumes can either be deep and narrow or shallow and wide in which case it fails to draw its fair share of silt. Generally, this type of outlet does not cause silting above the work, except when supplies are low for a considerable length of time. The silt which gets accumulated gets washed away during high supplies.

The open flume outlet is also cheaper than the Adjustable Proportional Module (APM), discussed below. The discharge formula for the open flume outlet is given as:

$$Q = C\, B_t\, H^{3/2} \qquad (3)$$

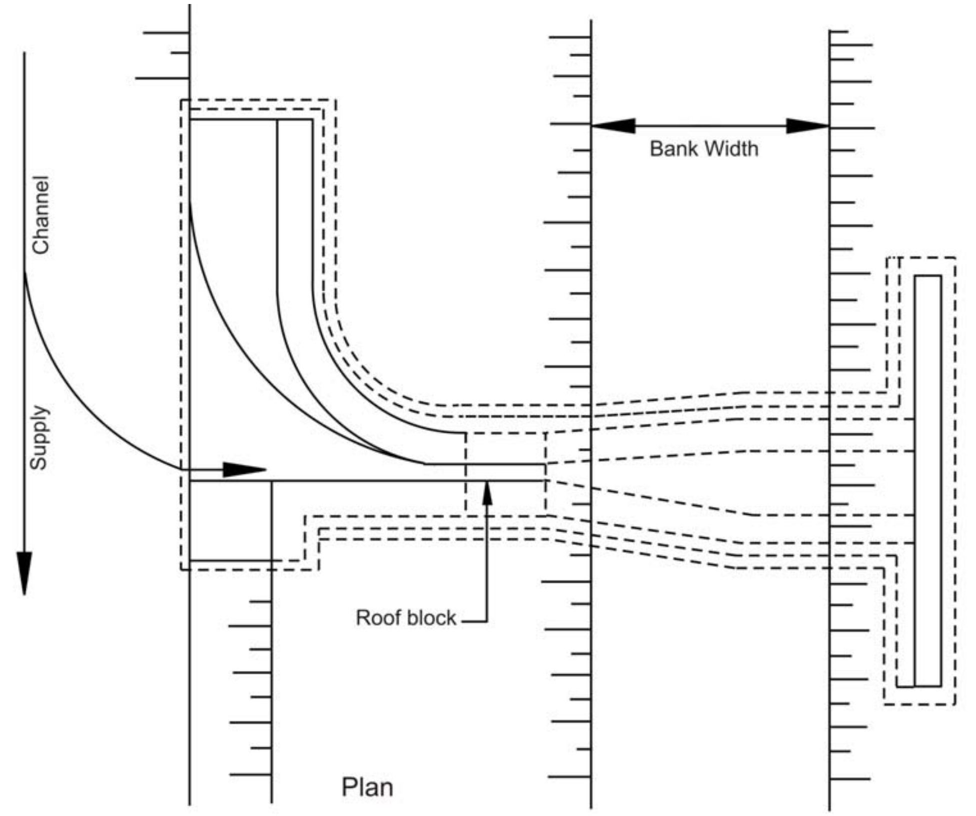
Where ***Q*** (given in l/s) is related to the coefficient of discharge, ***C***, as given in the table below; ***B_t*** is the width of the throat in cm; and ***H*** is the height of the full supply level of the supply channel above the crest level of the outlet in cm.

B_t (cm)	***C***
6 to 9	0.0160
> 9 to12	0.0163
> 12	0.0166

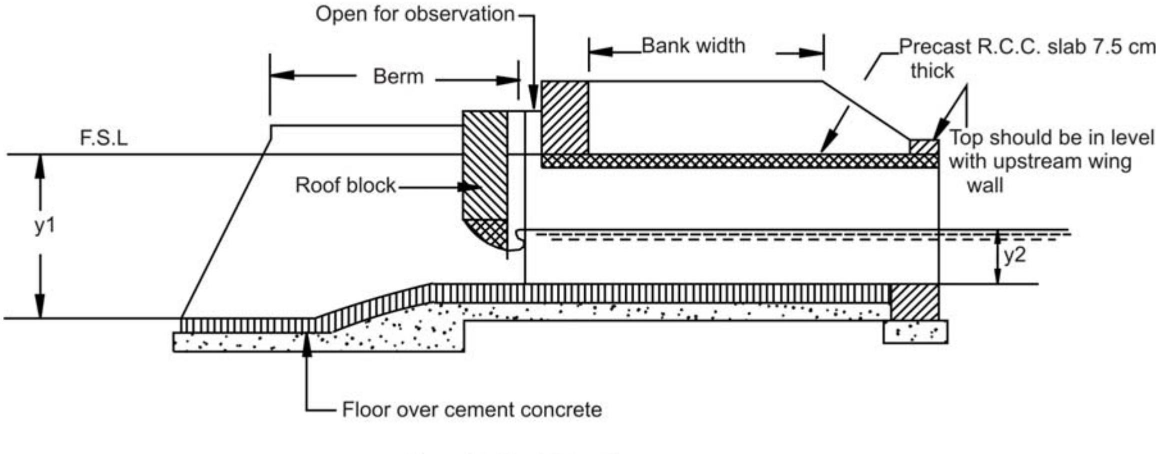
The minimum head required to drive the outlet is about 20 percent of H.

3.10.5 Adjustable Proportional Module (APM)

There are various forms of these outlets but the earliest of them is the one introduced by E.S. Crump in 1992. In this type of outlet, a cast iron base, a cast iron roof block and check plates on either are side are used to adjust the flow and is set in a masonry structure (Figure 7). This outlet works as a semi-module since it does not depend upon the level of water in the watercourse.



Plan



Longitudinal Section

FIGURE 7. PLAN AND SECTION OF ADJUSTABLE PROPORTIONAL MODULE

The roof block is fixed to the check plates by bolts which can be removed and depth of the outlet adjusted after the masonry is dismantled. This type of outlet cannot be easily tampered with and at the same time be conveniently adjusted at a small cast.

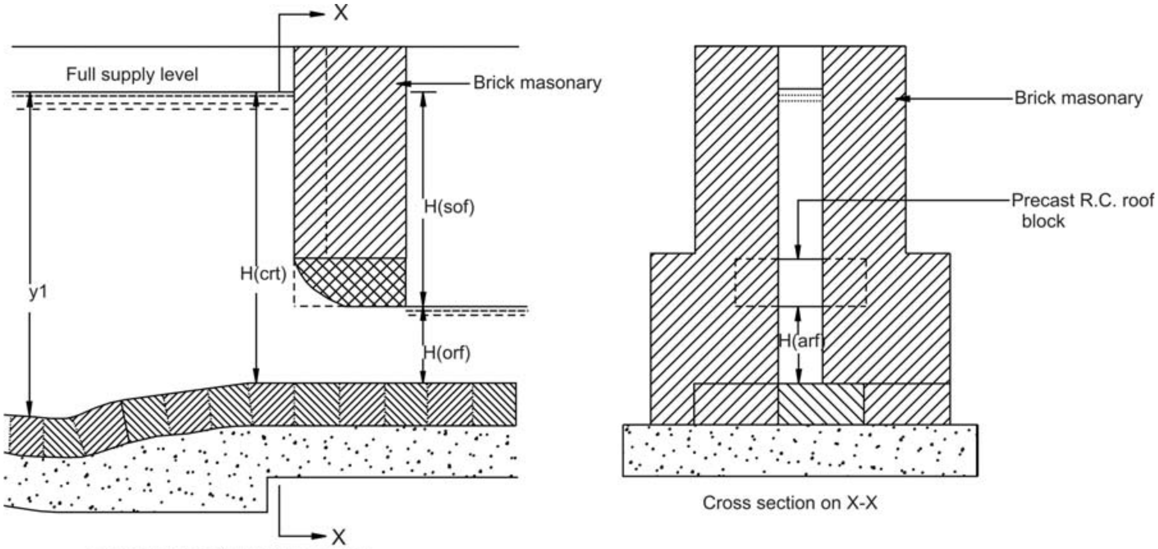
The roof blocks may also be built of reinforced concrete. The face of the roof block is set 5 cm from the starting point of the parallel throat. It has a lamniscate curve at the bottom with a tilt of 1 in 7.5 in order to make the water converge instead of a horizontal base which would cause it to diverge. The cast iron roof block is 30cm thick.

As such, the APM is the best type of outlet if the required working head is available and is the most economical in adjustment either by raising or lowering the roof block or crest. However, it is generally costlier than the other types of outlets and also requires more working head.

The discharge formula for this type of weir is given as:

$$Q = C\, B_t\, H_1 (H_2)^{1/2} \tag{4}$$

Where ***Q*** (given in l/s) is related to the coefficient of discharge, C, which is taken equal to around 0.0403; $\boldsymbol{B_t}$ is the width of the throat in cm; $\boldsymbol{H_1}$ is the depth of head available, that is the difference between the supply channel full supply level and the outlet bed (crest) level; and $\boldsymbol{H_2}$ is the difference between the supply channel full supply level and the bottom level of the roof block (Figure 8) .



Longitudinal section through outlet

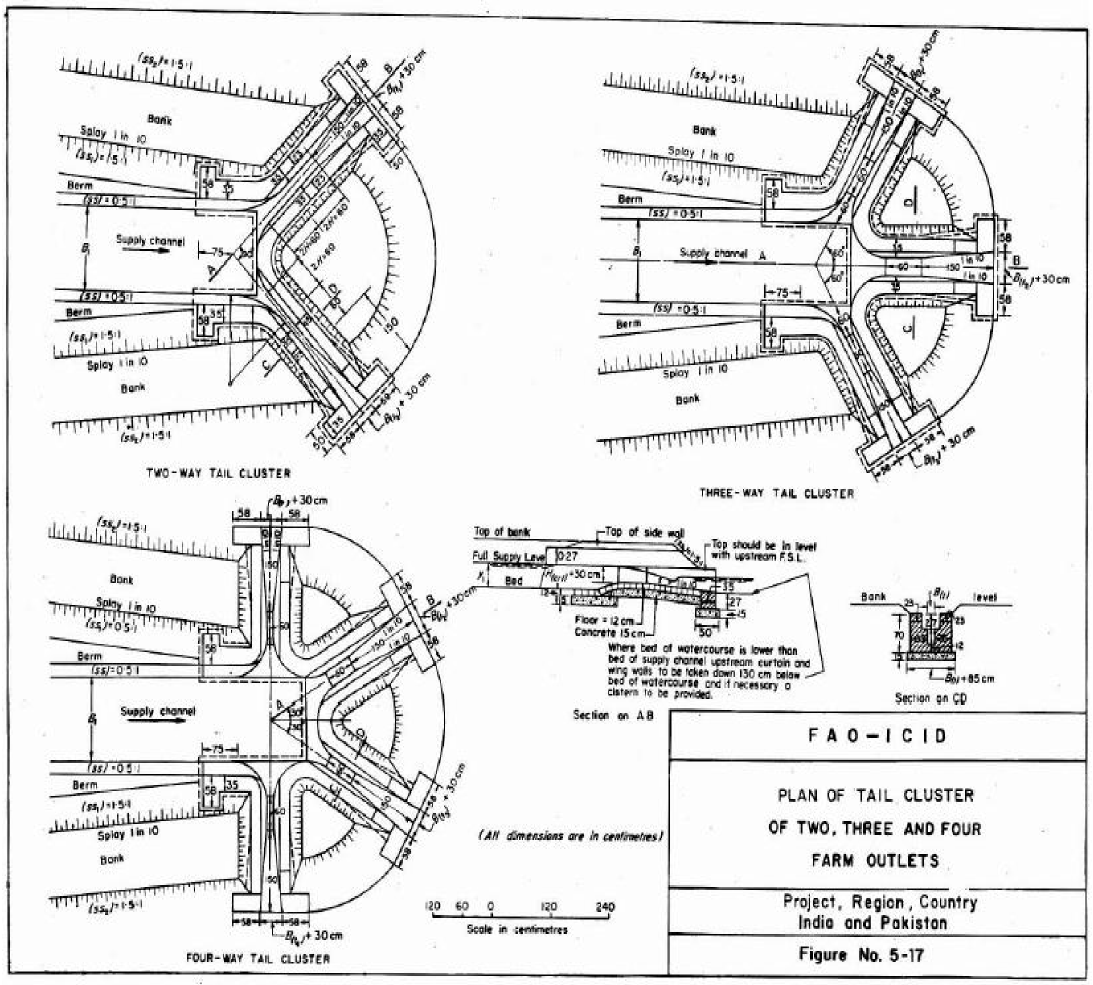
Cross section on X-X

FIGURE 8.DETAILS OF BLOCK FOR ADJUSTABLE PROPORTIONAL MODULE

The base plates and the roof block are manufactured in standard sizes, which with the required opening of the orifice are used to obtain the desired supply through the outlet.

3.10.5 Tail clusters

When the discharge of a secondary, tertiary or quaternary canal diminishes below 150 l/s, it is desirable to construct structures to end the canal and distribute the water through two or more outlets, which is called a tail cluster. Each of these outlets is generally constructed as an open flume outlet (Figure 9).



3.10.6 Flow measurement in canals

The available water resources per person are growing scarcer with every passing day. Although a region may not face a net reduction in water resources, the increasing population of the area would demand increased food production and consequently, agricultural outputs. Such that an equitable distribution of water is ensured as far as possible with a command area, it is required to measure water at important points in the canal network. Measurements may also help in estimating and detecting losses in the canal.

Further, at the form level, advanced knowledge of soil properties and soil moisture / plant relationships permits irrigation systems to be designed so that water can be applied in the right amount and at the right time in relation to the soil moisture status thereby obtaining maximum efficiency of water use and minimum damage to the land. This knowledge can be utilized most effectively only by reasonably accurate measurement of the water applied.

The amount of water being delivered to a field of an irrigator should also be measured in order to make an assessment of water charges that may be levied on him. If the charge to the user of canal water is based on the rate flow, then rate-of-flow measurements and adequate records are necessary. Charges on the basis of volume of water delivered necessitate a volumetric measuring device. Ideally, water flow should be measured at intakes from storage reservoirs, canal head works, at strategic points in canals and laterals and at delivery points to the water users. The most important point for measurement is the form outlet which is the link between the management authority of the canal system and the user.

The degree of need for a measuring device at the outlet varies according to the delivery system employed. Delivery on demand usually relies up on the measurement of water as a basis for equitable distribution as well as for computing possible water charges. Where water is distributed by rotation among farmers along a lateral (or distributary or minor canal) and the where the amount of water supplied to each farmer may be different, a measuring device at the turnout is required. On the other hand, if farmers along a lateral receive water on the basis of area of land or crops irrigated measurement is not entirely necessary, but may still be desirable for other purposes, such as improvement of irrigation efficiency. Similarly in all systems based on constant flow, measurement is not entirely necessary but may be advantageous.

Where several farmers share the water of each outlet and the flow in the canal fluctuates considerably, each such outlet should be equipped with a measuring device, even if equitable distribution among outlets is practiced, so that each group of farmers will know the flow available at any one time from their respective outlet.

Amongst the methods and devices used for measuring water in an irrigation canal network, the weir is the most practical and economical device for water measurement, provided there is sufficient head available. Measuring flumes are also used in irrigation networks and their advantage are smaller head losses, reasonable accuracy over a large flow range, insensitivity to velocity of approach, and not affected much by sediment load. Propeller meters are used in many countries and are particularly suited to systems where no head loss can be permitted for water measurement and where water is sold on volumetric basis. For water measurement in small streams, particularly in field ditches and furrows and where head losses must be small, the deflection or vane meter has proved to be a useful device. Only the weir and the standing wave (hydraulic jump) type flume are discussed in this lesson as these are most commonly used.

3.10.7 Weirs

Weirs have been in use as discharge measuring devices in open channels since almost two centuries and are probably the most extensively used devices for measurement of the rate of flow of water in open channels. Weirs may be divided in to sharp and broad crested types. The broad crested weirs are commonly incorporated in irrigation structures but are not usually used to determine flow. The types of sharp crested weirs commonly used for measuring irrigation water are the following:

3.10.7.1 Sharp crested rectangular weir

A general view of this type of weir is shown in Figure 10.

WEIR SHAPE

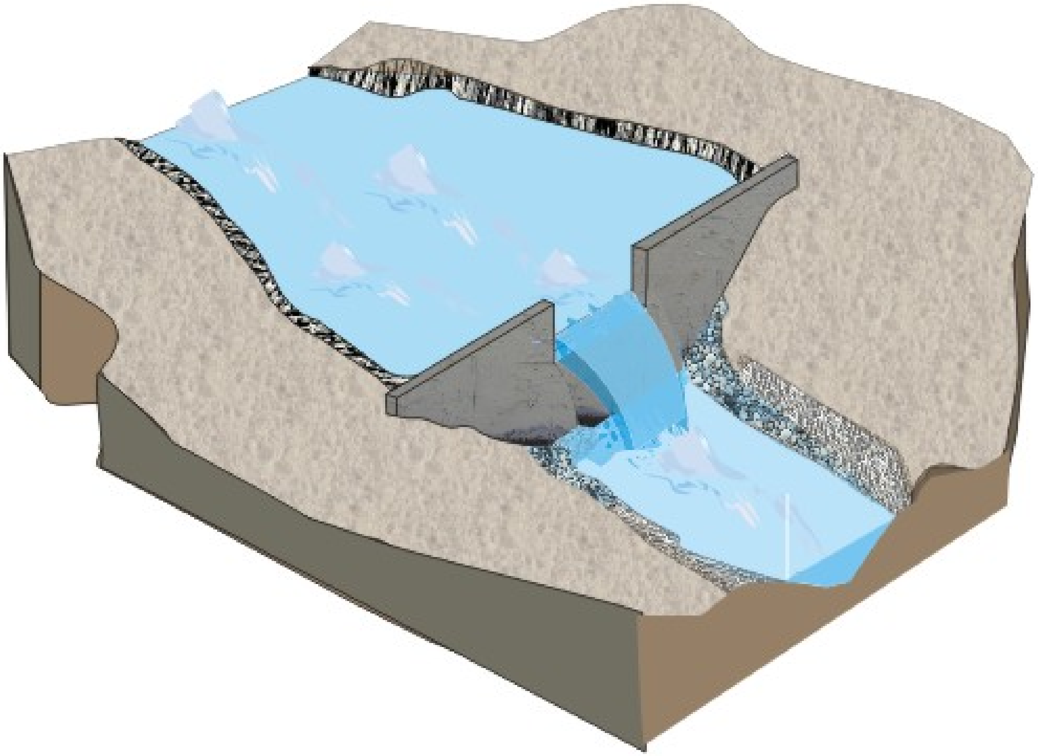


FIGURE 10. General view of a sharp created rectangular weir

Amongst the many formulae developed for computing the discharge of rectangular, sharp crested weirs with complete contraction, the most accepted formula is that by Francis and is given as:

$$Q = 1.84\,(L - 0.2H)\,H^{3/2} \qquad (5)$$

Where Q is the discharge in m^3/s; L is the length of the crest in meters; and H is the head in meters, that is, the vertical difference of the elevation of the weir crest and the elevation of the water surface in the weir pool.

3.10.7.2 Sharp crested trapezoidal (Cipolletti) weir

A general view of this type of weir is shown in Figure 11.

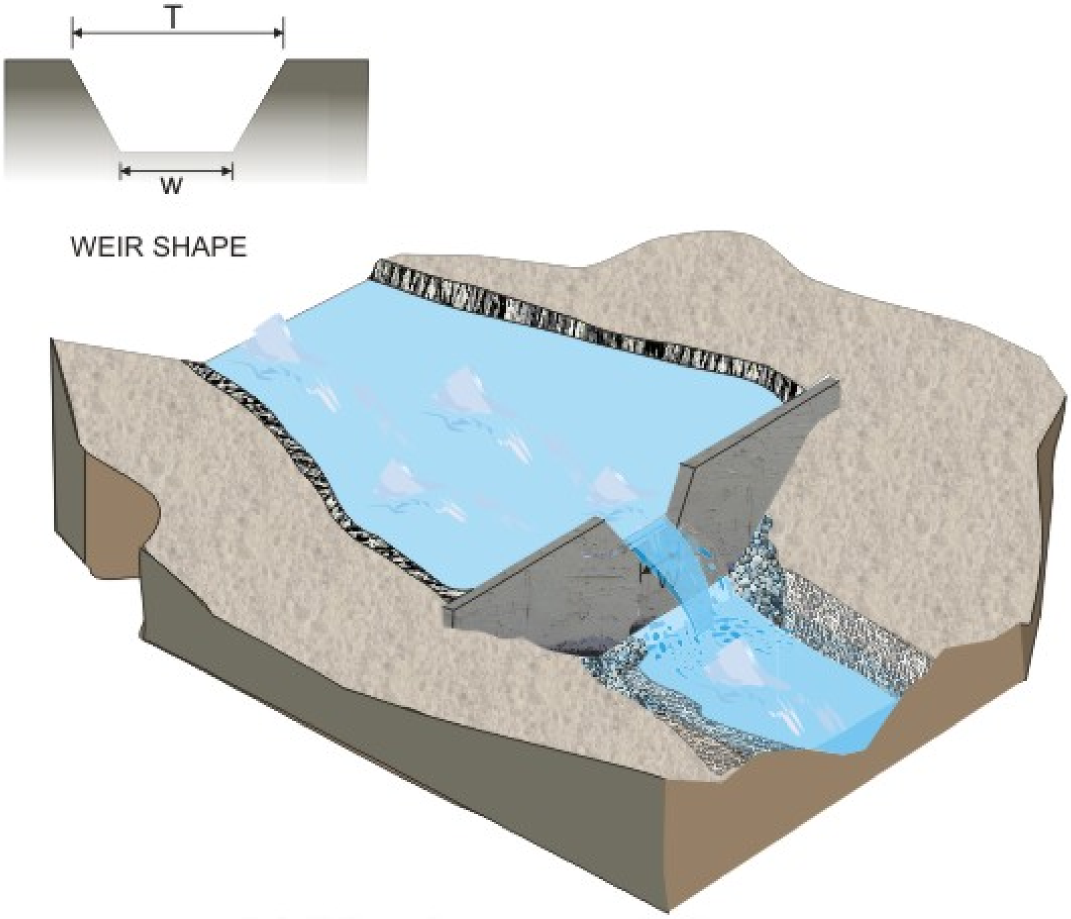


FIGURE 11. General view of a Cipolletti weir

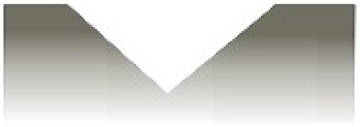
The discharge formula for this type of weir was given by Cipoletti as:

$$Q = 1.86\ L\ H^{3/2} \qquad (6)$$

Where Q is the discharge in m^3/s; L is the length of the crest in meters; and H is the head in meters. The discharge measurements using the above formula for the trapezoidal weir are not as accurate as those obtained from rectangular weirs using the Francis formula.

3.10.7.3 Sharp sided 90^0 V-notch weir

A general view of this type of weir is shown in Figure 12.



WEIR SHAPE

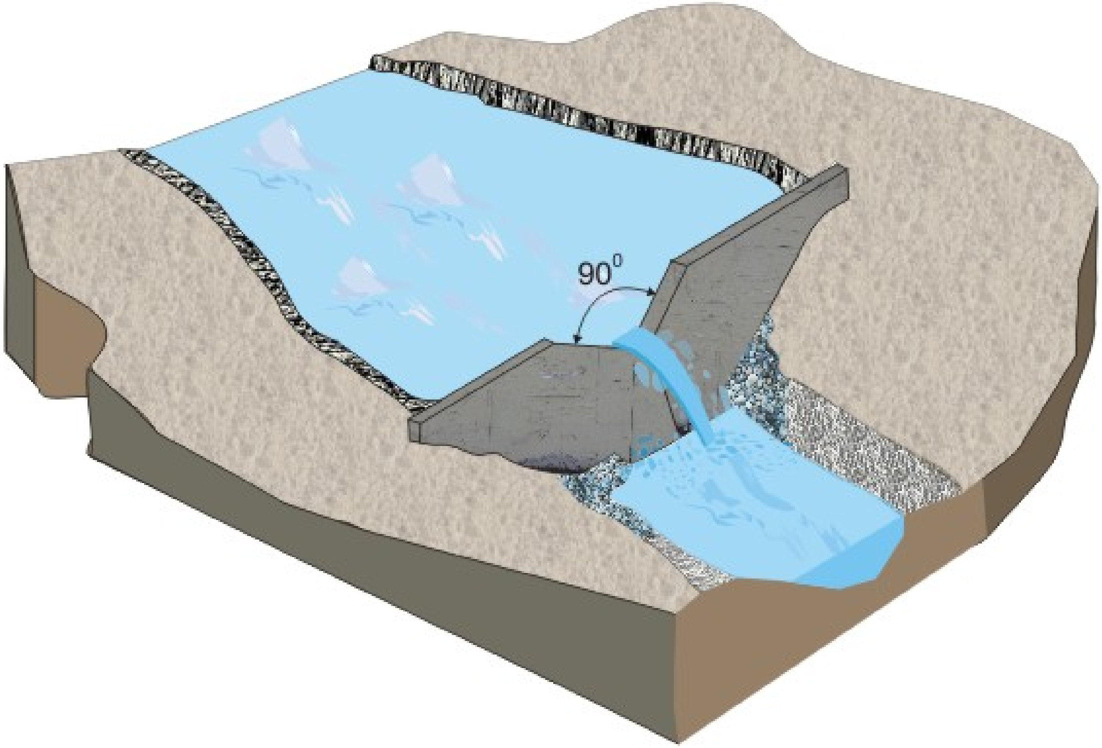


FIGURE 12. General view of 90^0 v-notch weir

Of the several well known formulae used to compute the discharge over 90^0 V-notch weirs the formula recommended generally is the following:

$$Q = 8/15\ (2gC_d)^{1/2}\ H^{5/2} \tag{7}$$

Where Q is the discharge in m^3 /s; g is the acceleration due to gravity ($9.8 m/s^2$); C_d is a coefficient of discharge; and, H is the head in meters. The value of C_d varies according to the variation of H and can be read out from (Figure 13).

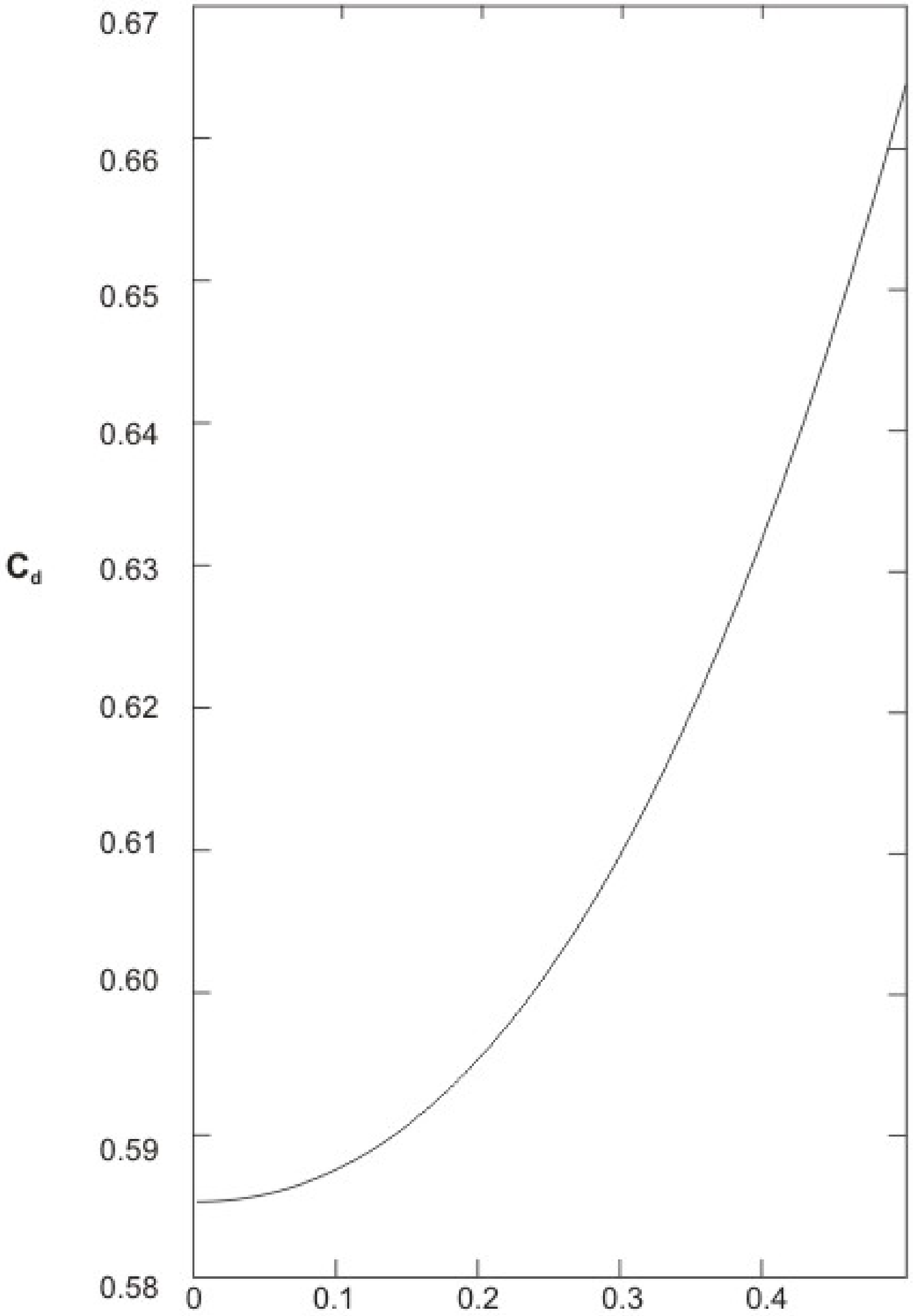


FIGURE 13. Variation of C_d for 90^0V-Notch weir with H^2/A

Each of these weirs has characteristics appropriate to particular operating and site conditions. The 90^0 V-notch weir gives the most accurate results when measuring small discharges and is particularly suitable for measuring fluctuating flows. Weirs require comparatively high heads, considerable maintenance of the weir or stilling pool and protection of the channel downstream of the crest.

3.10.8 Flumes

Flumes are flow measuring devices that works on the principle of forming a critical depth in the channel by either utilizing a drop or by constricting the channel. These two forms of flumes for flow measurement are described below.

3.10.8.1 Flume with a vertical drop

This type of structures has already been discussed in Lesson 3.9 where it was shown to be utilized to negotiate a fall in the canal bed level. One of these, the standing wave flume fall developed at the Central water and Power Research Station (CWPRS), Pune, has been standardized and documented in Bureau of Indian Standard code IS: 6062-1971 “Method of measurement of flow of water in open channels using standing wave flume-fall” and shown in (Figure 14) Because of the inherent free flow conditions the measurement of flow requires only one gauge observation on the upstream side.

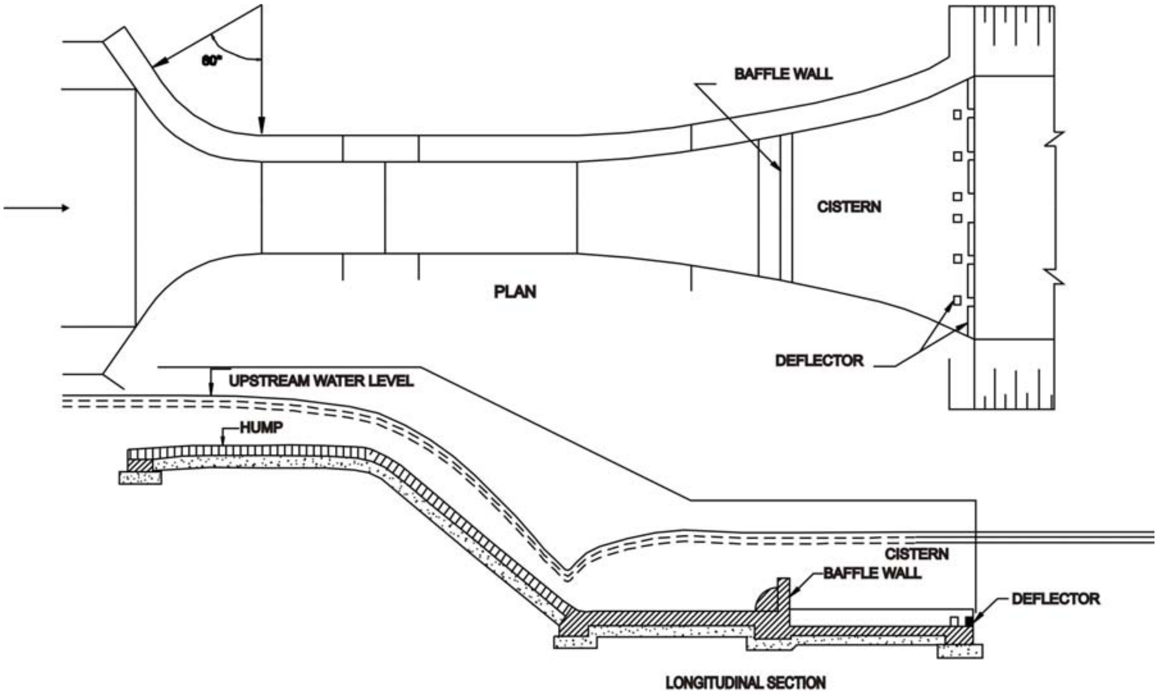


FIG.14. PLAN AND SECTION OH STANDING WAVE FLUME- FALL

The discharge equation for this structure is given by the following equation:

$$Q = 2/3\ (2g)^{1/2}\ CBH^{1.5} \qquad (8)$$

Where Q is the discharge in m^3/s; g is the acceleration due to gravity; C is the coefficient of discharge (=0.97 for $0.05 < Q < 0.3\ m^3/s$ and = 0.98 for $0.31 < Q < 1.5 m^3/s$); B is the width of the flumed section, also called the throat and H is the total head, that is, the depth of water above crest plus the velocity head.

The other type of flume type of fall is the one called the Central Design Office (CDO) Punjab type fall, which is simple and robust in construction. Up to 1m drop, a glacis is used on the downstream side (Figure 15) and if the drop exceeds 1m, the crest ends in a drop wall (Figure 16). The structure is often combined with a bridge, an intake of a third degree canal or both.

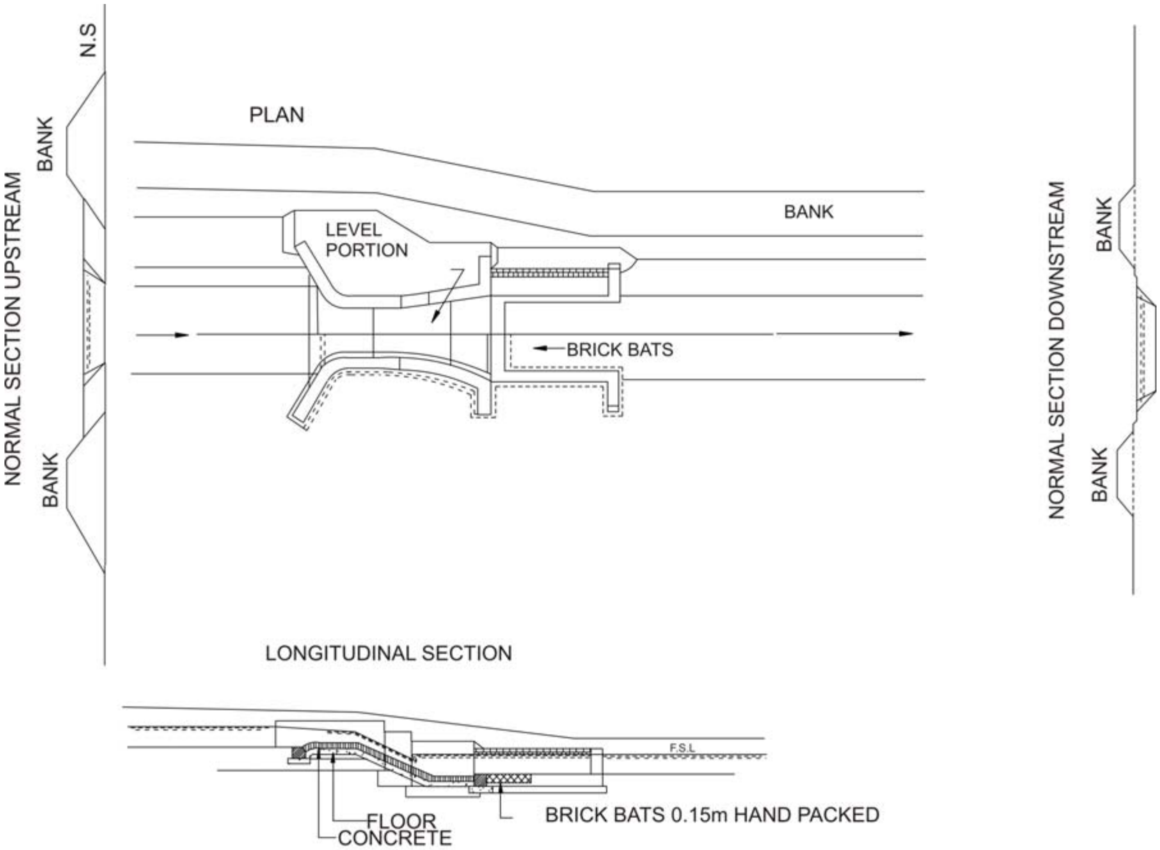


FIGURE.15. CDO PUNJAB TYPE FALL UPTO 1m DROP

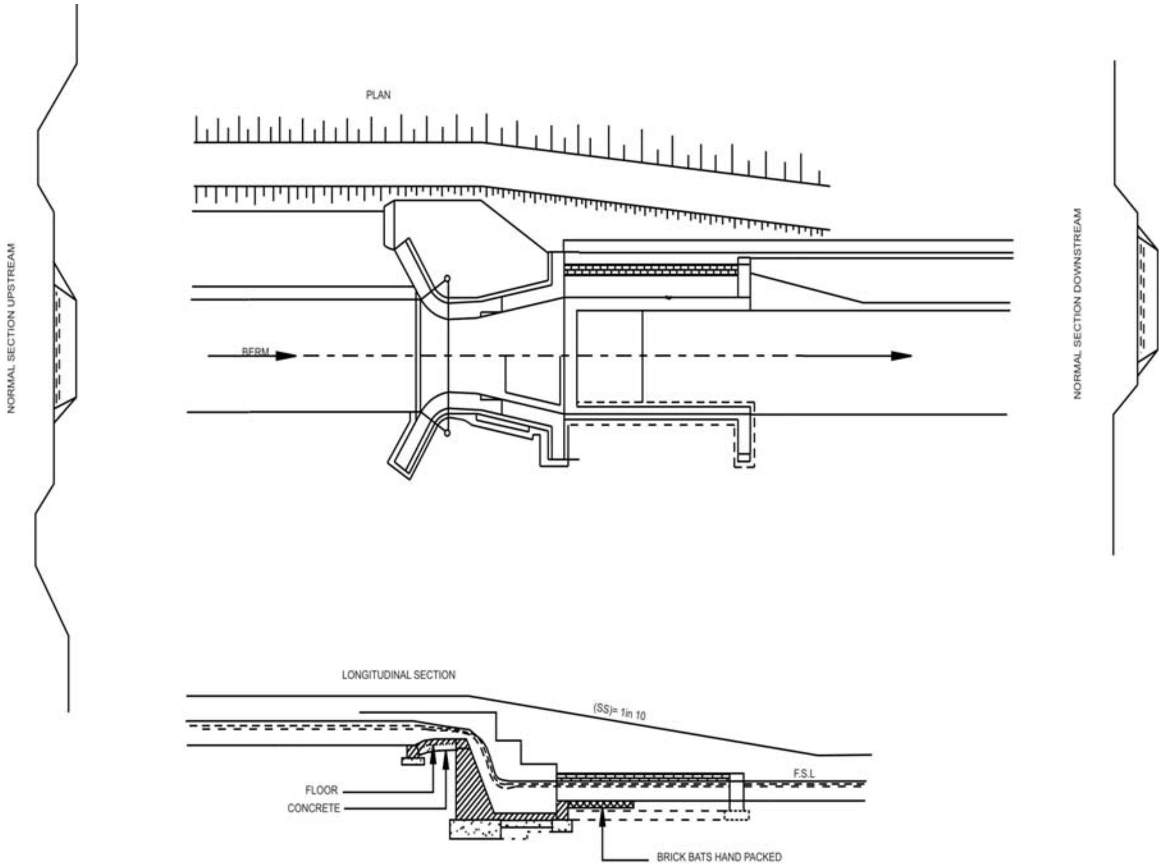


FIGURE.16. CDO PUNJAB TYPE FALL FOR GREATER THAN 1m DROP

3.10.8.2 Flume with a constricted section

This type of structures for measuring water discharge creates a free flow condition followed by a hydraulic jump by providing a very small width at some point with in the flume. These are also further divided in to two types: Long and short-throated flumes. In the former, the constriction is sufficiently long to produce flow lines parallel to the flume crest, for which analytical expression for discharge may be obtained. In the short-throated flumes, the curvature of water surface is large and the flow in the throat is not parallel to the crest of the flume. Hence, due to the non-hydrostatic pressure distribution, there is not analytically derived expression for discharge but has to be calibrated from actual measurements. However, these flumes require small lengths and are economical than long throated flumes. One of the commonly used short-throated flumes is the Parshall flume (Figure 17).

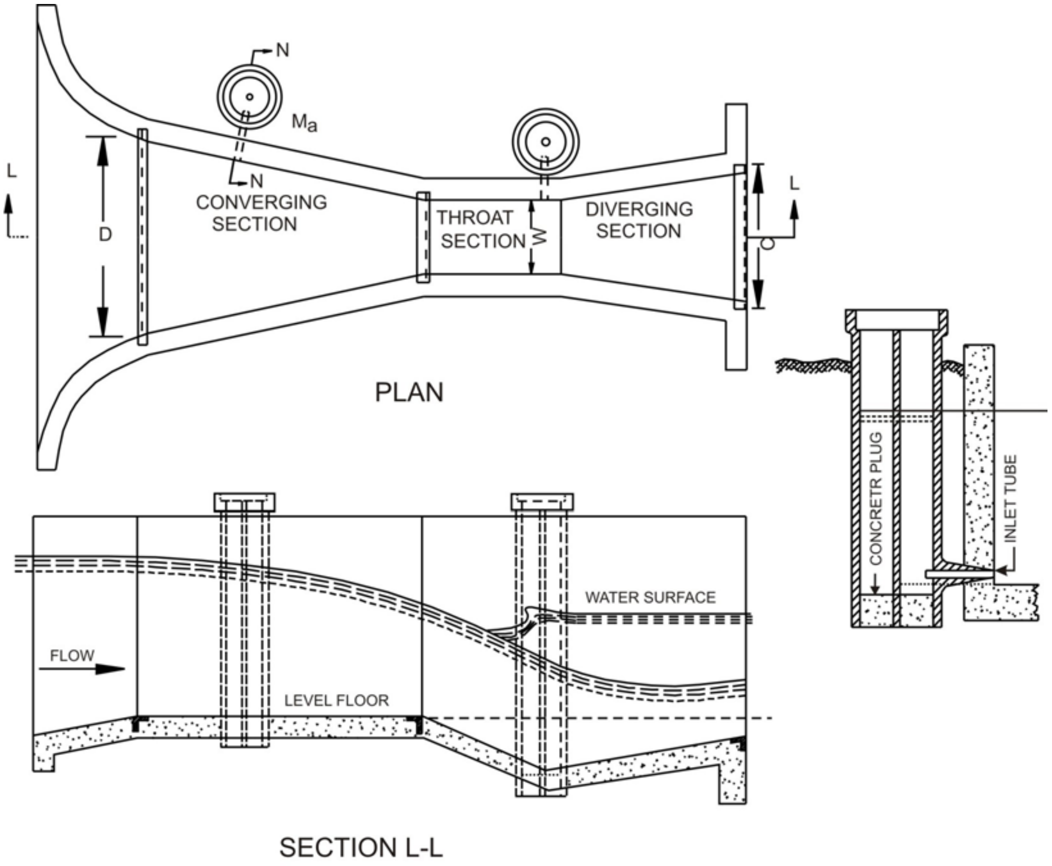


FIGURE 17. PLAN AND SECTION OF PARSHALL MEASURING FLUME

The flume consists of a short parallel throat preceded by a uniformly converging section and followed by a uniformly expanding section. The floor is horizontal in the converging section, slopes downwards in the throat, and is inclined upwards in the expanding section. The control section, at which the depth is critical, occurs near the downstream end of the contraction. There are standard dimensions of Parshall flumes which are available commercially and may be had from the reference “Design of Small Canal Structures” of USBR (1978).

One of the advantages of this type of flume is that it operates with a small head loss, which permits its use in relatively shallow channels with flat grades. For a given discharge, the loss in head through a Parshall flume is only about one fourth that required by a weir under similar free flow conditions. The flume is relatively insensitive to velocity of approach. It also enables good measurements with no submergence (that is free flow with a hydraulic jump downstream) or with submergence (that is the jump is drowned by the downstream water level) as shown in (Figure 17). The velocity of flow within the flume is also sufficient to eliminate any sediment deposition within the structure during operation. A disadvantage of the flume is that standard dimensions must be followed within close tolerance in order to obtain reasonable accuracy of measurement. Further, the flumes cannot be used close to an outlet or regulating devices. Parshall flumes can be constructed in a wide range of sizes to measure discharges from about 0.001m^3/s to 100m^3/s.

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