1- Canal drops:

1-1 Definition and Location of Canal drops:

Definition: Whenever the available natural ground slope is steeper than the designed bed slope of the channel, the difference is adjusted by constructing vertical 'falls' or 'drops' in the canal bed at suitable intervals, as shown in Fig..1. Such a drop in a natural canal bed will not be stable and, therefore, in order to retain this drop, a masonry structure is constructed. Such a pucca structure is called a canal fall or a canal drop.

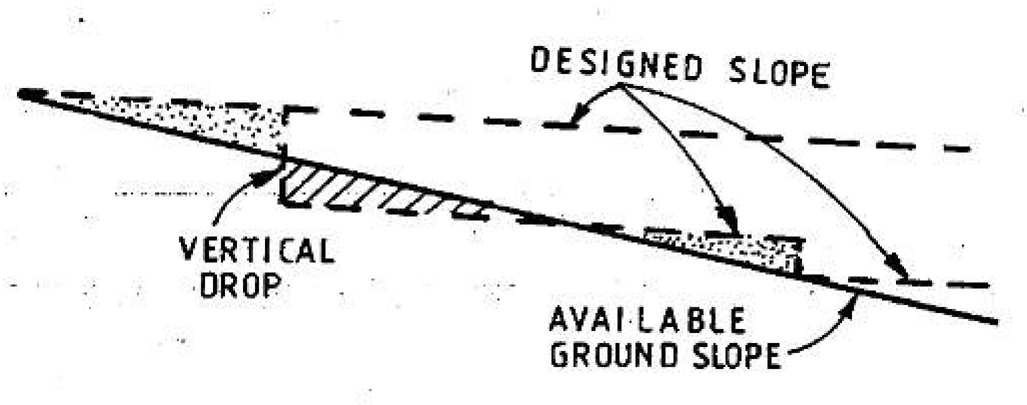


Fig.1

Proper location: The location of a fall in a canal depends upon the topography of the country through which the canal is passing. In case of the main canal, which does not directly irrigate any area, the site of a fall is determined by considerations of economy in 'cost of excavation and filling' versus 'cost of fall'. The excavation and filling on two sides of a fall should be tried to be balanced, because the unbalanced earthwork is quite costly. An economy between these two factors has to be worked out before deciding the locations and extent of falls.

2- Types of drops:

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

1- **Ogee Falls**: The 'Ogee type fall' was constructed in olden days on projects like Ganga canal. The water was gradually led down. by providing convex and cincave curves , as shown in fig.2

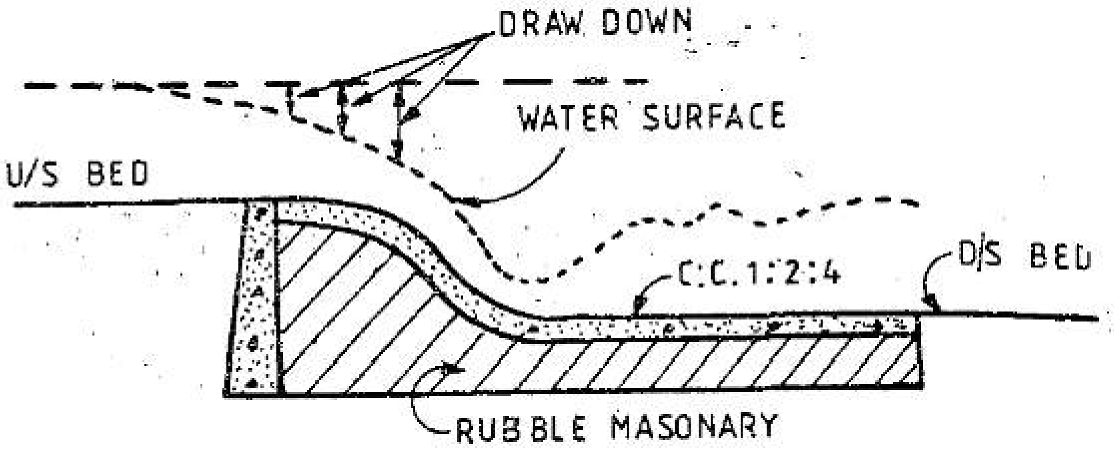


fig.2 Ogee Falls

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

3- **Trapezoidal Notch Falls**. The trapezoidal notch fall was designed by Ried in 1894. It consists of a number of trapezoidal notches constructed in a high crested wall across the channel with a smooth entrance and a flat.circular lip projecting downstream from each notch to spread out the falling jet. Fig.3

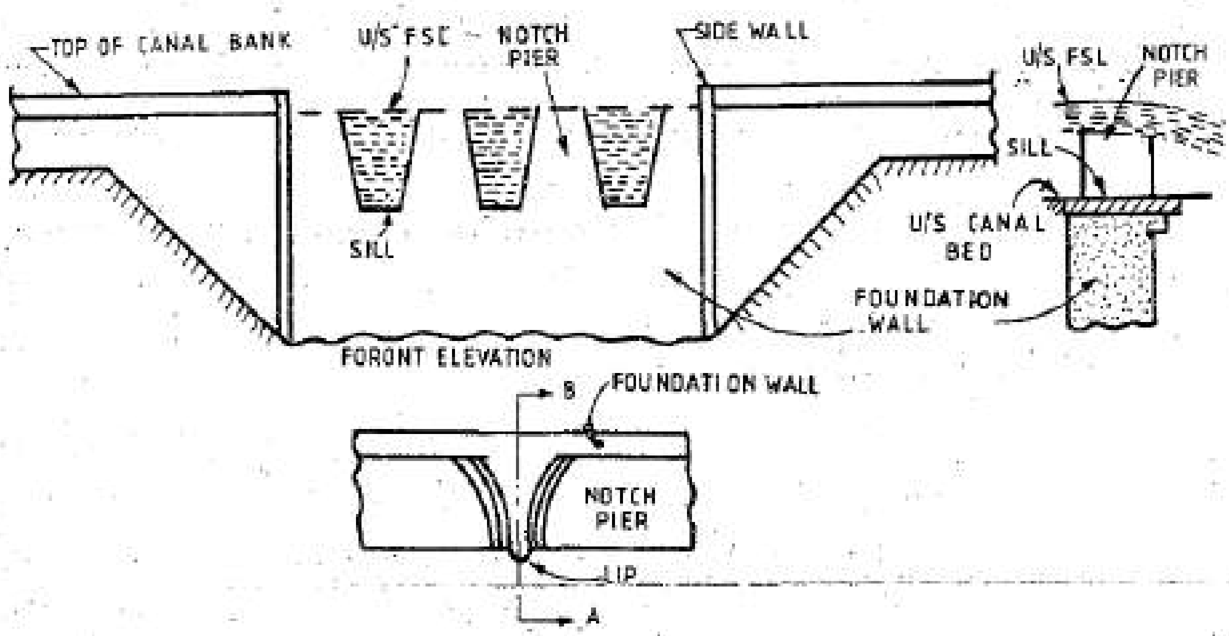


Fig.3 **Trapezoidal Notch Falls**

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

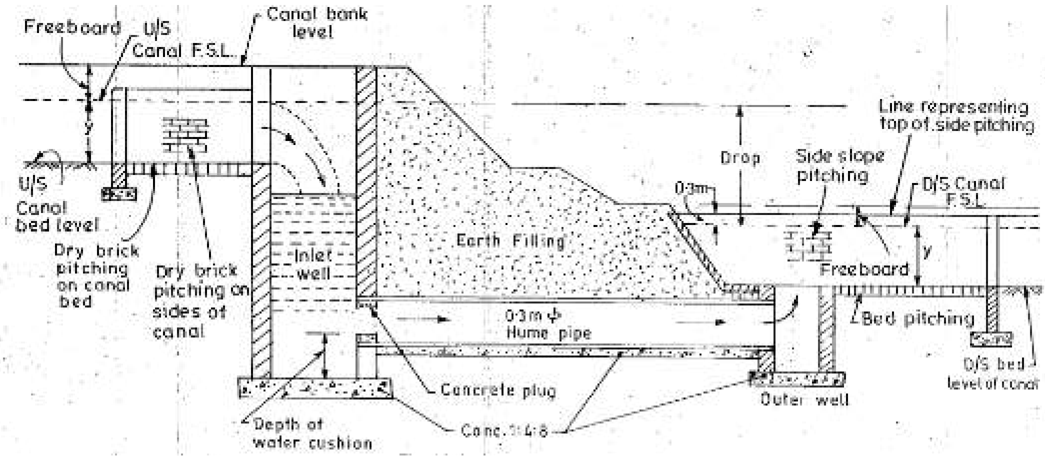


Fig.4 Syphon Well

5- **Simple Vertical Drop Type and Sarda Type Falls**. A raised crest fall with a vertical impact (Fig. 5) was first of all introduced on Sarda. Canal System in U.P, owing to its economy and simplicity. The necessity for economic falls.· arose because of the need for construction of a large number of smaller falls on the Sarda.

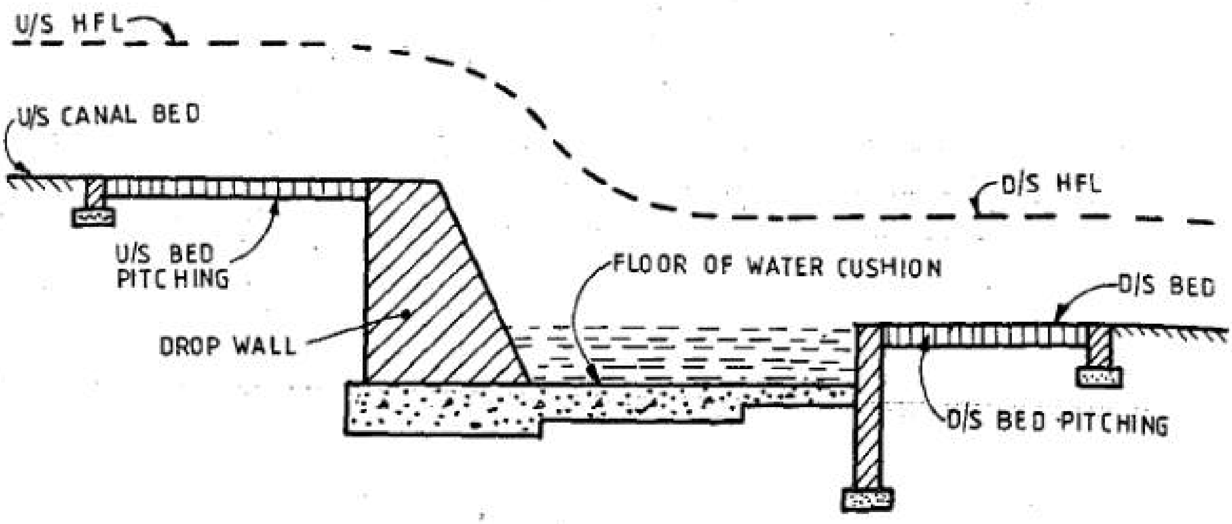


Fig.5 Simple Vertical Drop

6- **Straight Glacis Falls in this type of a modern fall**: a 'straight glacis' (generally sloping 2 : 1) .is provided after a 'raised crest' (see Fig .6). The hydraulic jump is made to occur on the glacis, causing sufficient energy dissipation. This type of falls gives very good performance if not fumed, although they may be flumed for economy. They are suitable for up to 60 cumecs discharge and 1.5 m drop.

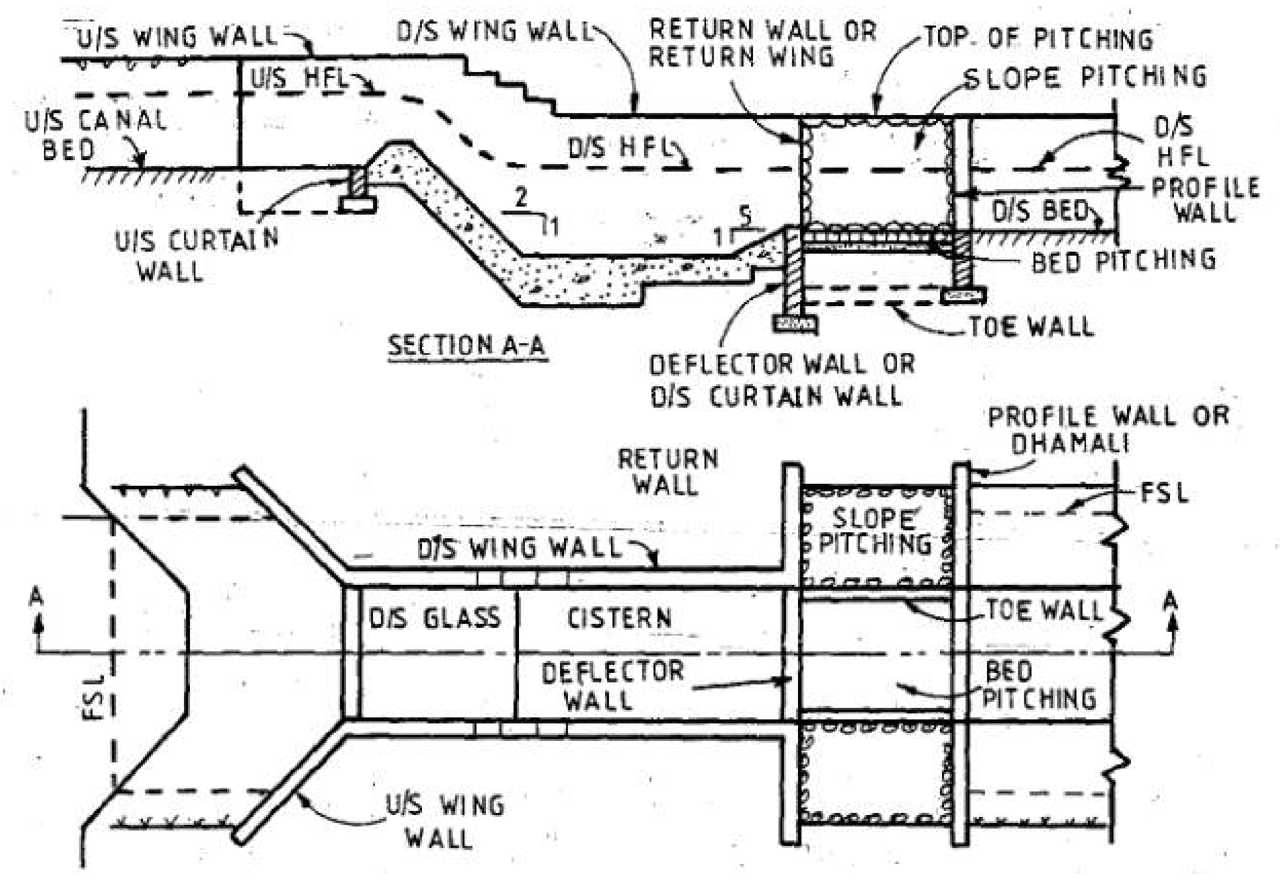


Fig .6 'Straight Glacis fall (without fuming), without Regulator and Bridge Details.

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

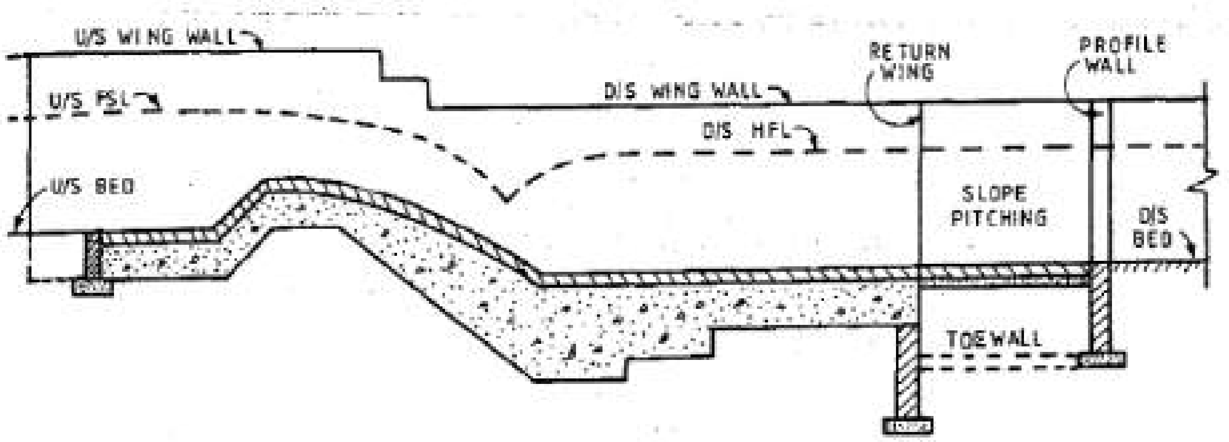


Fig.7 a. Montague Type fall.

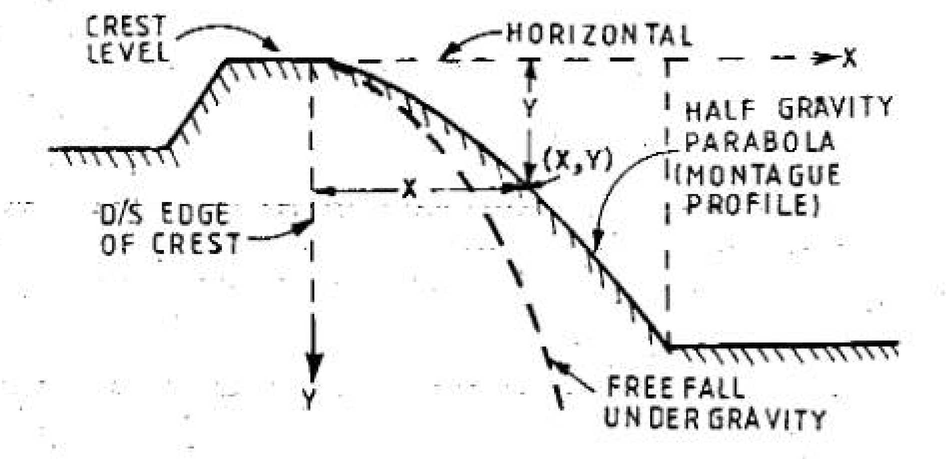


Fig.7 b. Montague Profile.

The Montague profile is given by the equation.

$$X = U\sqrt{\frac{4Y}{g}} + Y$$

Where

X = The horizontal ordinate of any point of the proflie measuredfrom the dis edge of crest.

Y = Vertical ordinate measured from the crest level.

U = Initial velocity of water leaving the cres.

8- **Inglis Falls or Baffle Falls:** A straight glacis type fall when added with a baffle platform and a baffle wall as shown in Fig. 12.8, was developed by Englis, and is called 'Englis Fall' or 'Baffle Fall'. They are quite suitable for all discharges and for drops of more than 1.5 m. They can be flumed easily as to affect economy. The baffle wall is provided at a calculated height and a calculated distance from the toe of the glacis, so as to ensure the formation of the . jump on the baffle platform, as shown in Fig.8

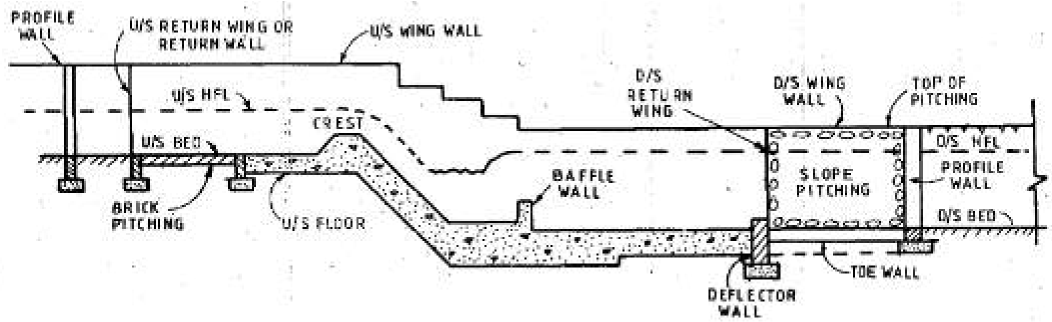


Fig.8 Inglis Falls or Baffle Falls

3- Design principles of various types of falls

1- Design of a Trapezoidal Notch Fall.

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

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

The discharge passing .through a trapezoidal notch such as shown in Fig..9 is given by

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

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

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

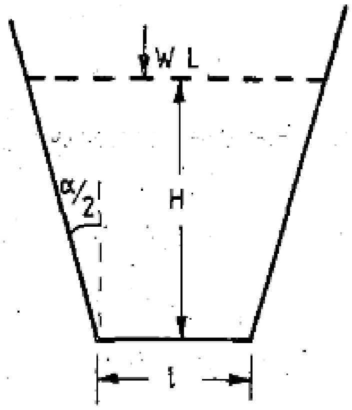


fig 9

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

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

where, C_d = Coefficient of discharge ≈ 0.75

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

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

The above discharge equation contains two unknowns l and n. For solving this equation,two values of Q and corresponding values of H must be assumed. It is a common practice to design notches for full supply discharge (Q100) and half supply discharge (Q50) with values of H equal to the normal water depths in the channel in the 'respective cases. Let the normal water depths in the channel at full discharge and half discharge be represented by Y100 andy50 respectively. Then H100 =Y100, and H50 = Y50·

The depth of water in the channel at 50% discharge (i.e. y50 can be approximately evaluated in terms of full supply depth (y100) as follows :

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

Now $Q = A.V.$

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

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

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

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

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

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

$\therefore$ $$y_{50} = 0.66 \cdot y_{100}$$

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

Notch Piers. The thickness of notch piers should not be less than half the water depth and maybe kept more if they have to carry a heavy super structure. The top length of piers should not be less than their thickness. In plan, the notch profile is set back by 0.5 m from the downstream face of the notch . fall for larger canals, and by 0.25 m for distributaries. All curves are circular arcs, and all centers lie in the plane of the profile. The splay upstream from the notch section is 45°, and the downstream splay is kept at 22.5°. The lip is circular and is corbelled 'out by 0.8 m on larger canals, and by 0.6 m on distributaries.

Example 1. Design the size and number of notches required for a canal drop with the following particulars.

Full supply discharge =4cumecs

Bed width =6.0m

F.S. depth. =I.5m

Half supply depth =I.0m

Assume any other data if required.

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

Full supply discharge through e.ach notch=4/3= 1.33 cµmecs

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

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

where $Q_{100} = 1.33$ cumecs

$y_{100} = 1.5$ m

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

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

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

Now, using

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

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

$y_{50} = 1.0$ m

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

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

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

$0.2n = 0.026$

or $n = 0.13.$

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

$l + 0.4 \times 0.13 = 0.3$

or $l = 0.248$; say, **0.25 m.**

By this trial, we find the top width

$= 0.25 + 2\tan\alpha \cdot H = 0.25 + n.\,H$

$= 0.25 + 0.13 \times 1.5 = 0.25 + 0.195$

$= 0.445$; say 0.45 m, which is much less than the full depth of 1.5 m.

To increase the top width, and to make it near 1 to 3/4th FSD, it is necessary to increase l and n which can be done by reducing the number of notches. The values of l and n obtained for 3 notches will increase in direct proportion, when number of notches are reduced. In other words, the values l of and n will become 3 times, when number of notches are reduced 3 times. Thus, when we provide only one notch instead of 3 notches, the values of n and l will triple. Similarly, when we use 2 notches against 3, i.e., 1/5 times the values n and l will become 1.5 times of those obtained for 3 notches.

Hence when we use 2 notches, values will be:

$$n = 1.5 \times 0.13 = 0.20$$
$$l = 1.5 \times 0.25 = 0.3 \text{ m}$$
and $$\text{Top width} = 1.5 \times 0.45 = \mathbf{0.68\ m.}$$

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

When we use only one notch, the values will be:

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

Since this condition gives us top width = 1.35 m, which is O.K., we may pro-vide one notch, centrally placed in the given channel of 6 m width. The section of the. notch to be adopted is also shown in Fig.10

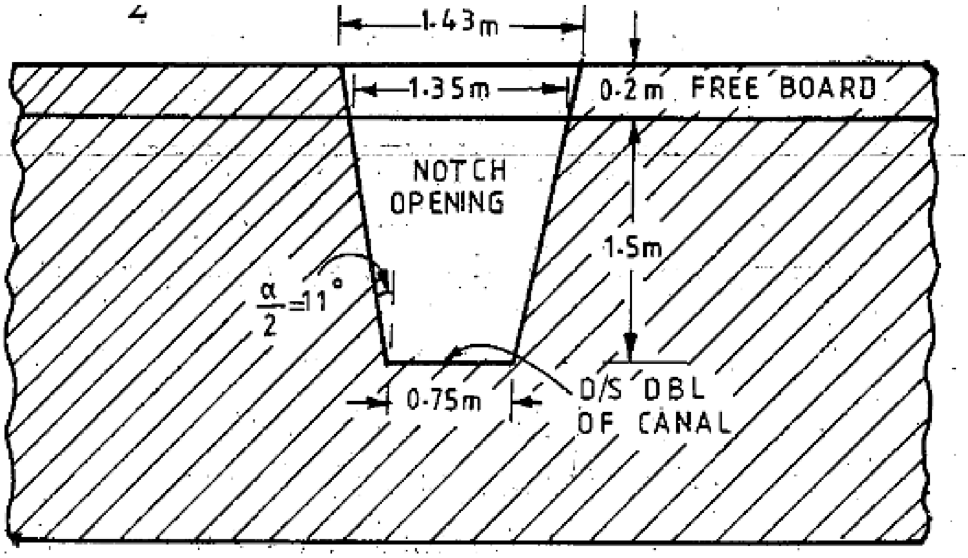


Fig 10

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

These calculations for the above question will be as follows :

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

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

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

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

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

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

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

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

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

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

This gives a negative value of n, which is not feasible, and hence such a raised crest may not be feasible in this particular case. Hence, the design made earlier, and shown in Fig. 10, holds good.

1- CANAL IRRIGATION:

Irrigation conduits of a typical gravity project are usually open channels through earth or rock formations. These are called **canals**.

A ***canal* is defined as an artificial channel constructed on the ground to carry water from a river or another canal or a reservoir to the fields. Usually, canals have a trapezoidal crosssection.**

2- Classification of canals

Canals can be classified in many ways:

Based on the **nature of source of supply**, a canal can be either a **permanent** or **an inundation canal**. *A permanent canal* has a continuous source of water supply. Such canals are also called perennial canals. *An inundation canal* draws its supplies from a river only during the high stages of the river. Such canals do not have any headworks for diversion of river water to the canal, but are provided with a canal head regulator.

Depending **on their function**, canals can also be classified as: (i**) irrigation**, (ii**) navigation**, (iii) **power**, and (iv) **feeder canals**. An irrigation canal carries water from its source to agricultural fields. Canals used for transport of goods are known as navigation canals. Power canals are used to carry water for generation of hydroelectricity. A feeder canal feeds two or more canals.

An irrigation canal system consists of canals of different sizes and capacities (Fig.1). Accordingly, the canals are also classified as: (i) **main canal**, (ii) **branch canal**, (iii) **major distributary**, (iv) **minor distributary**, and (v) **watercourse**.

The main canal takes its supplies directly from the river through the head regulator and acts as a feeder canal supplying water to branch canals and major distributaries. Usually, direct irrigation is not carried out from the main canal.

Branch canals (also called 'branches') take their supplies from the main canal. Branch canals generally carry a discharge higher than 5 m3/s and act as feeder canals for major and minor distributaries. Large branches are rarely used for direct irrigation. However, outlets are provided on smaller branches for direct irrigation.

Major distributaries (also called 'distributaries' or rajbaha) carry 0.25 to 5 m3/s of discharge. These distributaries take their supplies generally from the branch canal and sometimes from the main canal. The distributaries feed either watercourses through outlets or minor distributaries.

Minor distributaries (also called 'minors') are small canals which carry a discharge less than 0.25 m3/s and feed the watercourses for irrigation. They generally take their supplies from major distributaries or branch canals and rarely from the main canals.

A watercourse is a small channel which takes its supplies from an irrigation channel (generally distributaries) through an outlet and carries water to the various parts of the area to be irrigated through the outlet.

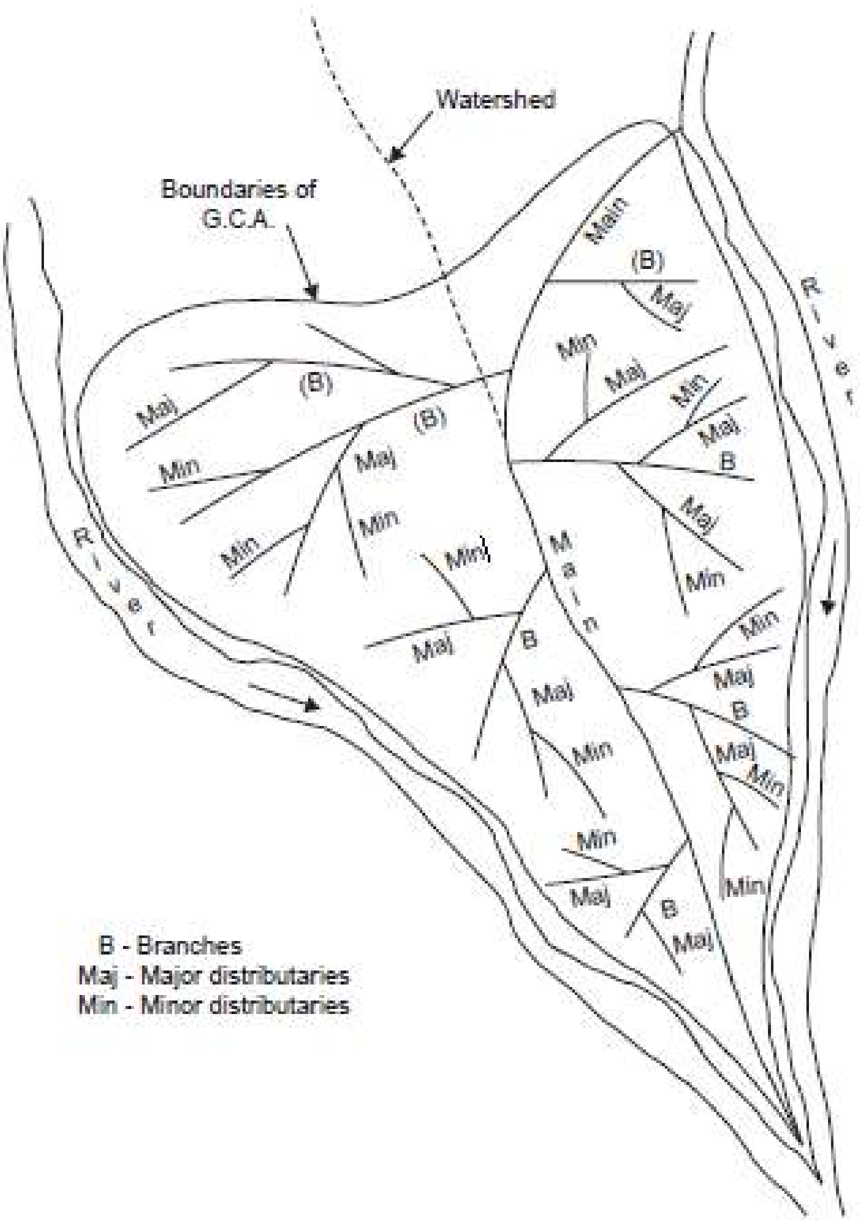


Fig (.1) Layout of an irrigation canal network

3- ALIGNMENT OF IRRIGATION CANALS

Desirable locations for irrigation canals on any gravity project, their cross-sectional designs and construction costs are governed mainly by topographic and geologic conditions along different routes of the cultivable lands. Main canals must convey water to the higher elevations of the cultivable area. Branch canals and distributaries convey water to different parts of the irrigable areas.

On projects where land slopes are relatively flat and uniform, **it is advantageous to align channels on the watershed of the areas to be irrigated**. The natural limits of command of such irrigation channels would be the drainages on either side of the channel. Aligning a canal)main, branch as well as distributary) on the watershed ensures gravity irrigation on both sides of the canal. Besides, the drainage flows away from the watershed and, hence, no drainage can cross a canal aligned on the watershed. Thus, **a canal aligned on the watershed saves the cost of construction of cross-drainage structures.** However, the main canal has to be taken off from a river which is the lowest point in the cross-section, and this canal must mount the watershed in as short a distance as possible. Ground slope in the head reaches of a canal is much higher than the required canal bed slope and, hence, the canal needs only a short distance to mount the watershed. This can be illustrated by Fig.2 in which the main canal takes off from a river at P and mounts the watershed at Q. Let the canal bed level at P be 400 m and the elevation of the highest point N along the section MNP be 410 m. Assuming that the ground slope is 1 m per km, the distance of the point Q (395 m) on the watershed from N would be 15 km. If the required canal bed slope is 25 cm per km, the length PQ of the canal would be 20 km. Between P and Q, the canal would cross small streams and, hence, construction of cross-drainage structures would be necessary for this length. In fact, the alignment PQ is influenced considerably by the need of providing suitable locations for the cross-drainage structures. The exact location of Q would be determined by trial so that the alignment PQ results in an economic as well as efficient system. Further, on the watershed side of the canal PQ, the ground is higher than the ground on the valley side (i.e., the river side). Therefore, this part of the canal can irrigate only on one side (i.e., the river side) of the canal.

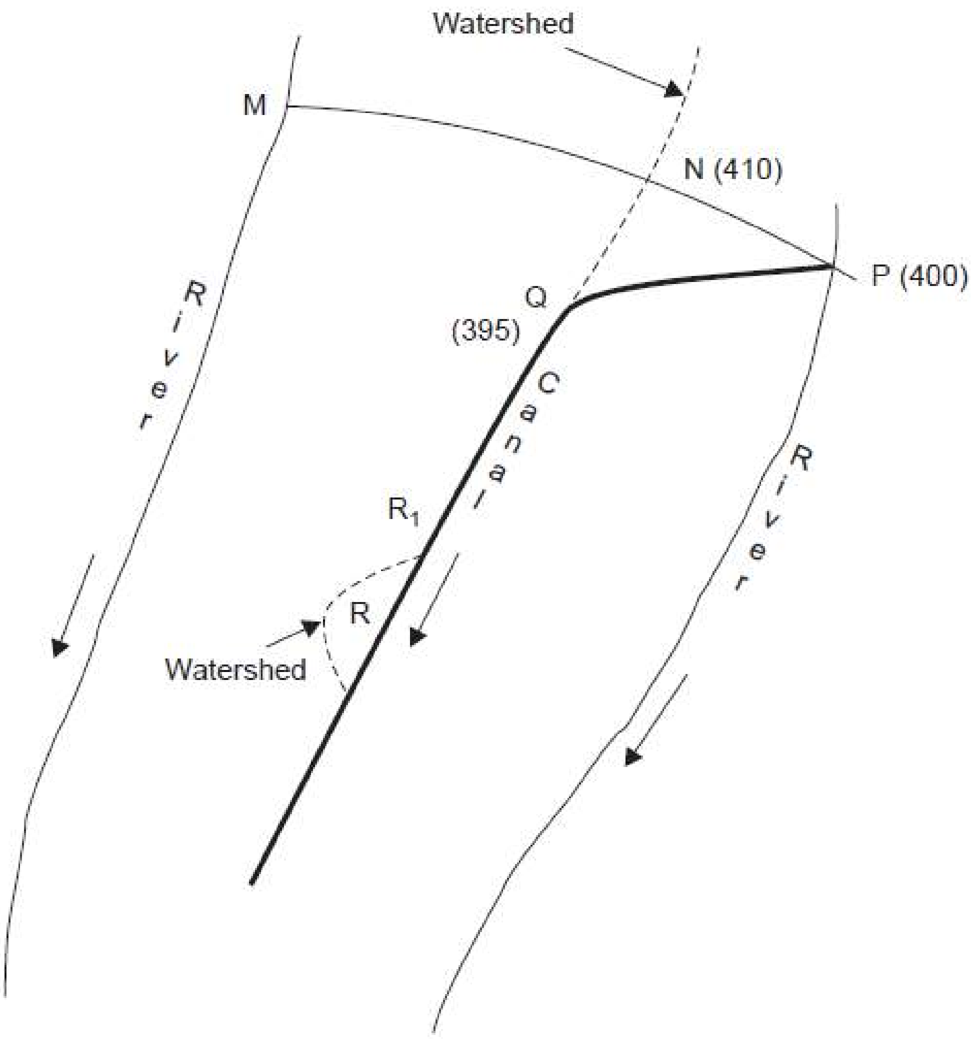


Fig. (.2) Head reach of a main canal in plains

Once a canal has reached the watershed, it is generally kept on the watershed, except in certain situations, such as the looping watershed at R in Fig.2. In an effort to keep the canal alignment straight, the canal may have to leave the watershed near R. The area between the canal and the watershed in the region R can be irrigated by a distributary which takes off at R1 and follows the watershed. Also, in the region R, the canal may cross some small streams and, hence, some cross-drainage structures may have to be constructed. If watershed is passing through villages or towns, the canal may have to leave the watershed for some distance.

In hilly areas, the conditions are vastly different compared to those of plains. Rivers flow in valleys well below the watershed or ridge, and it may not be economically feasible to take the channel on the watershed. In such situations, contour channels (Fig.3) are constructed. Contour channels follow a contour while maintaining the required longitudinal slope. It continues like this and as river slopes are much steeper than the required canal bed slope the canal encompasses more and more area between itself and the river. It should be noted that the more fertile areas in the hills are located at lower levels only.

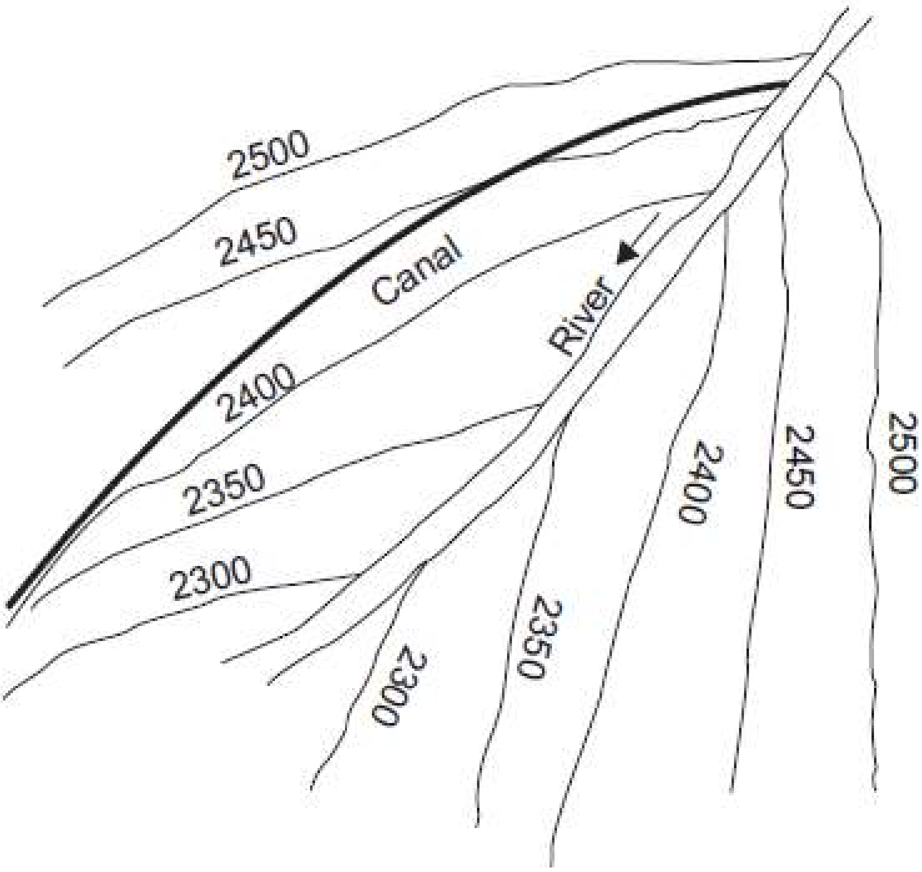


Fig.(.3) Alignment of main canal in hills

In order to finalise the channel network for a canal irrigation project, trial alignments of channels are marked on the map prepared during the detailed survey. A large-scale map is required to work out the details of individual channels. However, a small-scale map depicting the entire command of the irrigation project is also desirable. The alignments marked on the map are transferred on the field and adjusted wherever necessary. These adjustments are transferred on the map as well. The alignment on the field is marked by small masonry pillars at every 200 metres. The centre line on top of these pillars coincides with the exact alignment. In between the adjacent pillars, a small trench, excavated in the ground, marks the alignment.

4- CURVES IN CANALS

Because of economic and other considerations, the canal alignment does not remain straight all through the length of the canal, and curves or bends have to be provided. The curves cause disturbed flow conditions resulting in eddies or cross currents which increase the losses. In a curved channel portion, the water surface is not level in the transverse direction. There is a slight drop in the water surface at the inner edge of the curve and a slight rise at the outer edge of the curve. This results in slight increase in the velocity at the inner edge and slight decrease in the velocity at the outer edge. As a result of this, the low-velocity fluid particles near the bed move to the inner bank and the high-velocity fluid particles near the surface gradually cross to the outer bank. The cross currents tend to cause erosion along the outer bank. The changes in the velocity on account of cross currents depend on the approach flow condition and the characteristics of the curve. When separate curves follow in close succession, either in the same direction or in the reversed direction, the velocity changes become still more complicated.

Therefore, wherever possible, **curves in channels excavated through loose soil should be avoided. If it is unavoidable, the curves should have a long radius of curvature**. The permissible minimum radius of curvature for a channel curve depends on the type of channel, dimensions of cross-section, velocities during full-capacity operations, earth formation along channel alignment and dangers of erosion along the paths of curved channel. In general, the permissible

minimum radius of curvature is shorter for flumes or lined canals than earth canals, shorter for small cross-sections than for large cross-sections, shorter for low velocities than for high velocities, and shorter for tight soils than for loose soils. Table 1 indicates the values of minimum radii of channel curves for different channel capacities.

Table 1 Radius of curvature for channel curves

Channel capacity (m^3/s)	*Minimum radius of curvature (metres)*
Less than 0.3	100
0.3 to 3.0	150
0.3 to 15.0	300
15.0 to 30.0	600
30.0 to 85.0	900
More than 85	1500

5- CANAL LOSSES

When water comes in contact with an earthen surface, whether artificial or natural, the surface absorbs water. This absorbed water percolates deep into the ground and is the main cause of the loss of water carried by a canal. In addition, some canal water is also lost due to evaporation.

The loss due to evaporation is about 10 percent of the quantity lost due to seepage. The seepage loss varies with the type of the material through which the canal runs. Obviously, the loss is greater in coarse sand and gravel, less in loam, and still less in clay soil. If the canal carries silt-laden water, the pores of the soil are sealed in course of time and the canal seepage reduces with time. In almost all cases, the seepage loss constitutes an important factor which must be accounted for in determining the water requirements of a canal.

Between the headworks of a canal and the watercourses, the loss of water on account of seepage and evaporation is considerable. **This loss may be of the order of 20 to 50 percent of water diverted** at the headworks depending upon the type of soil through which canal runs and the climatic conditions of the region.

For the purpose of estimating the water requirements of a canal, the total loss due to evaporation and seepage, also known as conveyance loss, is expressed as m3/s per million square metres of either wetted perimeter or the exposed water surface area. Conveyance loss can be calculated using the values given in Table.2., the total loss (due to seepage and evaporation) per million square metres of water surface varies from 2.5 m3/s for ordinary clay loam to 5.0 m3/s for sandy loam. The following empirical relation has also been found to give comparable results .

$$q_l = (1/200)\,(B + h)^{2/3}$$

Table.2 Conveyance losses in canals

Material	*Loss in m^3/s per million square metres of wetted perimeter (or water surface)*
Impervious clay loam	0.88 to 1.24
Medium clay loam underlaid with hard pan at depth of not over 0.60 to 0.90 m below bed	1.24 to 1.76
Ordinary clay loam, silty soil or lava ash loam	1.76 to 2.65
Gravelly or sandy clay loam, cemented gravel, sand and clay	2.65 to 3.53
Sandy loam	3.53 to 5.29
Loose sand	5.29 to 6.17
Gravel sand	7.06 to 8.82
Porous gravel soil	8.82 to 10.58
Gravels	10.58 to 21.17

In this relation, *ql* is the loss expressed in m3/s per kilometre length of canal and *B* and *h* are, respectively, canal bed width and depth of flow in metres.

1- Crop and Crop seasons.

One of the primary drivers in irrigation system selection is crop type. For example, vegetable crops cannot be flooded. the crops were divided into four general categories.

Category 1. Row or bedded crops: sugar beets, sugarcane, potatoes, pineapple, cotton, soybeans, corn, sorghum, milo, vegetables, vegetable and flower seed, melons, tomatoes, and strawberries.

Category 2. Close-growing crops (sown, drilled, or sodded): small grain, alfalfa, pasture, and turf.

Category 3. Water flooded crops: rice and taro.

Category 4. Permanent crops: orchards of fruit and nuts, citrus groves, grapes, cane berries, blueberries, cranberries, bananas and papaya plantations, hops, and trees and shrubs for windbreaks, wildlife, landscape, and ornamentals.

1-1 Multiple Cropping

There are two forms of multiple cropping:

(i) intercropping, and (ii) sequential cropping. When two or more crops are grown simultaneously on the same field, it is termed **intercropping**. Crop intensification is in both time and space dimensions. There is, obviously, strong intercrop competition in this form of multiple cropping. On the other hand, when two or more crops are grown in sequence on the same field in a year, it is termed **sequential cropping**. The succeeding crop is planted after the preceding crop has been harvested. Crop intensification is only in the time dimension and there is no intercrop competition in sequential cropping.

2- consumptive use (OR EVAPOTRANSPIRATION)

The combined loss of water from soil and crop by vaporisation is identified as evapotranspiration. Crops need water for transpiration and evaporation. During the growing period of a crop, there is a continuous movement of water from soil into the roots, up the stems and leaves, and out of the leaves to the atmosphere. This movement of water is essential for carrying plant food from the soil to various parts of the plant. Only a very small portion (less than 2 percent)of water absorbed by the roots is retained in the plant and the rest of the absorbed water, after performing its tasks, gets evaporated to the atmosphere mainly through the leaves and stem. This process is called transpiration. In addition, some water gets evaporated to the atmosphere directly from the adjacent soil and water surfaces and from the surfaces of the plant leaves(i.e., the intercepted precipitation on the plant foliage). The water needs of a crop thus consists of transpiration and evaporation and is called evapotranspiration or consumptive use.

Consumptive use refers to the water needs of a crop in a specified time and is the sum of the volume of transpirated and evaporated water. **Consumptive use is defined as the amount of water needed to meet the water loss through evapotranspiration.** It generally applies to a crop but can be extended to a field, farm, project or even a valley. **Consumptive use is generally measured as volume per unit area or simply as the depth of water on the irrigated area.**

Knowledge of consumptive use helps determine irrigation requirement at the farm which should, obviously, be the difference between the consumptive use and the effective precipitation.

Evapotranspiration is dependent on climatic conditions like temperature, daylight hours,humidity, wind movement, type of crop, stage of growth of crop, soil moisture depletion, and other physical and chemical properties of soil. For example, in a sunny and hot climate, crops need more water per day than in a cloudy and cool climate. Similarly, crops like rice or sugarcane need more water than crops like beans and wheat. Also, fully grown crops need more water than crops which have been just planted.

While measuring or calculating **potential evapotranspiration**, it is implicitly assumed that water is freely available for evaporation at the surface. Actual evapotranspiration, in the absence of free availability of water for evaporation will, obviously, be less and is **determined by: (i) the extent to which crop covers the soil surface, (ii) the stage of crop growth which affects the transpiration and soil surface coverage, and (iii) soil water supply.**

Potential evapotranspiration from a cropped surface can be estimated either by correlating potential evapotranspiration with water loss from evaporation devices or by estimations based on various climatic parameters. Correlation of potential evapotranspiration assumes that the climatic conditions affecting crop water loss (Det) and vaporation from a free surface of water (Ep) are the same. Potential evapotranspiration Det can be correlated to the pan evaporation Ep as ,

$$D_{et} = KE_p \quad \ldots 1$$

in which, K is the crop factor for that period. The crop factor K depends on the crop as well as its stage of growth (Table 1). The main limitations of this method are the differences in physical features of evaporation surfaces compared with those of a crop surface.

Table 1 Values of crop factor *K* from some major crops

Percentage of crop growing season since sowing	*Maize, cotton, potatoes, peas and sugarbeets*	*Wheat, barley and other small grains*	*Sugarcane*	*Rice*
0	0.20	0.08	0.50	0.80
10	0.36	0.15	0.60	0.95
25	0.75	0.33	0.75	1.10
50	1.00	0.65	1.00	1.30
75	0.85	0.90	0.85	1.15
100	0.20	0.20	0.50	0.20

In the absence of pan evaporation data, the consumptive use is generally computed as follows:

(i) Compute the seasonal (or monthly) distribution of potential evapotranspiration, which is defined as the evapotranspiration rate of a well-watered reference crop which completely **shades** the soil surface . It is thus an indication of the climatic evaporation demand of a vigorously growing crop. Usually, grass and alfalfa (a plant with leaves like that of clover and purple flowers used as food for horses and cattle) are taken as reference crops.

(ii) Adjust the potential evapotranspiration for the type of crop and the stage of crop growth. Factors such as soil moisture depletion are ignored so that the estimated values of the consumptive use are conservative values to be used for design purposes.
Thus, evapotranspiration of a crop can be estimated by multiplying potential evapotranspiration by a factor known as crop coefficient.

Potential evapotranspiration can be computed by one of the several methods available for the purpose. These methods range in sophistication from simple temperature correlation (such as the Blaney-Criddle formula) to equations (such as Penman's equation) which account for radiation energy as well. Blaney-Criddle formula for the consumptive use has been used extensively and is expressed as

$$u = kf \quad \ldots 2$$

in which, u = consumptive use of crop in mm,
k = empirical crop consumptive use coefficient (Table 2), and
f = consumptive use factor.

The quantities u, k, and f are determined for the same period (annual, irrigation season,growing season or monthly). The consumptive use factor f is expressed as

$$f = \frac{p}{100}(1.8t + 32) \quad \ldots..3$$

in which, t = mean temperature in °C for the chosen period, and
p = percentage of daylight hours of the year occurring during the period.
Table 3 lists the values of p for different months of a year for 0° north latitude. The value of the consumptive use is generally determined on a monthly basis and the irrigation system must be designed for the maximum monthly water needs. It should be noted that Eq.(2) was originally in FPS system with appropriate values of k. Similarly, Eq. (3) too had a different form with t in Fahrenheit.

Table 2 Consumptive use coefficient for some major crops (1)

Crop	*Lenght of normal growing season or period*	*Consumptive use coefficient, k*	
		*For the growing period**	*Monthly (maximum value)***
Corn (maize)	4 months	19.05 to 21.59	20.32 to 30.48
Cotton	7 months	15.24 to 17.78	19.05 to 27.94
Potatoes	3-5 months	16.51 to 19.05	21.59 to 25.40
Rice	3-5 months	25.40 to 27.94	27.94 to 33.02
Small grains	3 months	19.05 to 21.59	21.59 to 25.40
Sugarbeet	6 months	16.51 to 19.05	21.59 to 25.40
Sorghums	4-5 months	17.78 to 20.32	21.59 to 25.40
Orange and lemon	1 year	11.43 to 13.97	16.21 to 19.05

*The lower values are for more humid areas and the higher values are for more arid climates.
** Dependent upon mean monthly temperature and stage of growth of crop.

Table 3 Per cent daylight hours for northern hemispere (0-50° latitude)

Latitude North (in degrees)	*Jan.*	*Fab.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*
0	8.50	7.66	8.49	8.21	8.50	8.22	8.50	8.49	8.21	8.50	8.22	8.50
5	8.32	7.57	8.47	8.29	8.65	8.41	8.67	8.60	8.23	8.42	8.07	8.30
10	8.13	7.47	8.45	8.37	8.81	8.60	8.86	8.71	8.25	8.34	7.91	8.10
15	7.94	7.36	8.43	8.44	8.98	8.80	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9.00	9.25	8.96	8.30	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.40	7.42
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15
32	7.20	6.97	8.37	8.76	9.62	9.59	9.77	9.27	8.34	7.95	7.11	7.05
34	7.10	6.91	8.36	8.80	9.72	9.70	9.88	9.33	8.36	7.90	7.02	6.92
36	6.99	6.85	8.35	8.85	9.82	9.82	9.99	9.40	8.37	7.85	6.92	6.79
38	6.87	6.79	8.34	8.90	9.92	9.95	10.10	9.47	8.38	7.80	6.82	6.66
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	6.52
42	6.63	6.65	8.31	9.00	10.14	10.22	10.35	9.62	8.40	7.69	6.62	6.37
44	6.49	6.58	8.30	9.06	10.26	10.38	10.49	9.70	8.41	7.63	6.49	6.21
46	6.34	6.50	8.29	9.12	10.39	10.54	10.64	9.79	8.42	7.57	6.36	6.04
48	6.17	6.41	8.27	9.18	10.53	10.71	10.80	9.89	8.44	7.51	6.23	5.86
50	5.98	6.30	8.24	9.24	10.68	10.91	10.99	10.00	8.46	7.45	6.10	5.65

Table 4 gives typical values of the water needs of some major crops for the total growing period of some of the crops . This table also indicates the sensitivity of the crop to water shortages or drought. High sensitivity to drought means that the crop cannot withstand water shortages, and that such shortages should be avoided.

Table 4 Indicative values of crop water needs and sensitivity to drought

Crop	Crop water need (mm / total growing period)	Sensitivity of drought
Alfalfa	800 - 1600	low - medium
Banana	1200 - 2200	high
Barley/oats/wheat	450 - 650	low - medium
Bean	300 - 500	medium - high
Cabbage	350 - 500	medium - high
Citrus	900 - 1200	low - medium
Cotton	700 - 1300	low
Maize	500 - 800	medium - high
Melon	400 - 600	medium - high
Onion	350 - 550	medium - high
Peanut	500 - 700	low - medium
Pea	350 - 500	medium - high
Pepper	600 - 900	medium - high
Potato	500 - 700	high
Rice (paddy)	450 - 700	high
Sorghum/millet	450 - 650	low
Soybean	450 - 700	low - medium
Sugarbeet	550 - 750	low - medium
Sugarcane	1500 - 2500	high
Sunflower	600 - 1000	low - medium
Tomato	400 - 800	medium - high

Example 1: Using the Blaney-Criddle formula, **estimate the yearly consumptive use** of water for sugarcane for the data given in the first four columns of Table 5.

Solution:

According to Eqs 2 & 3

$$u = k \frac{p}{100}(1.8\,t + 32)$$

Values of monthly consumptive use calculated from the above formula have been tabulated in the last column of Table 5. Thus, yearly consumptive use = Σu = 1.75 m.

Table 5 Data and solution for Example 1

Month	*Mean monthly temperature, t°C*	*Monthly crop coefficient, k*	*Per cent sunshine hours, p*	*Monthly consumptive use, u (mm)*
January	13.10	19.05	7.38	78.14
February	15.70	20.32	7.02	85.96
March	20.70	21.59	8.39	125.46
April	27.00	21.59	8.69	151.22
May	31.10	22.86	9.48	190.66
June	33.50	24.13	9.41	209.58
July	30.60	25.40	9.60	212.34
August	29.00	25.40	9.60	205.31
September	28.20	24.13	8.33	166.35
October	24.70	22.86	8.01	140.01
November	18.80	21.59	7.25	103.06
December	13.70	19.05	7.24	78.15

2- Design of a Syphon Well Drop

A syphon well drop, such as shown in Fig.4, is generally adopted for smaller discharges and larger drops. The main features of the design involve determining the size of the inlet well and that of the pipe. Suitable size for the outer well, a proper provision of water cushion at the bottom of the inlet well, the bed and side slope pitchings in the canal upstream as well as downstream for suitable lengths, are also provided. The size of the inlet well and that of the syphon pipe are determined on the following considerations w .r. to Fig. 11.

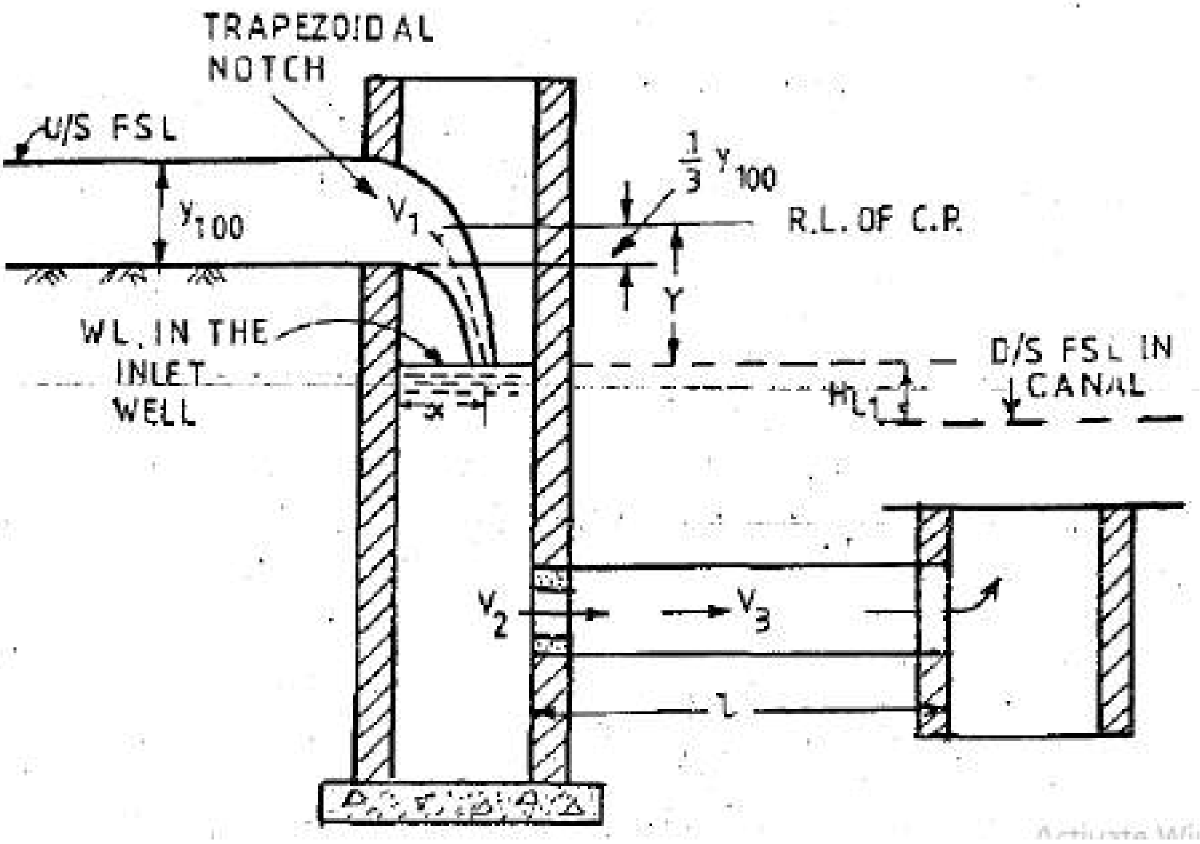


Fig.11

First of all, the size of the trapezoidal notch is determined to pass the designed discharge·by using eq. (12.4) in the same way, as is done for a trapezoidal notch. Then let V1 be the velocity over the notch, V2 be the velocity of entry in the pipe, and V3 be the velocity through the pipe. All these values of velocities can be determined easily as below :

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

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

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

The head loss between the inlet well and the d/s FSL is then given by HL_1 as

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

$$+\frac{V_3^2}{2g} \text{ (loss due to exit).}$$

Knowing all the above values, HL_1 can be determined, and thus the R.L. of water surface inlet well *(i.e. d/s* FSL + *HL)* can be determined.

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

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

$$= \text{(which can be calculated)}$$

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

$$= \text{R.L. of C.P.} - \text{R.L. of water level in inlet well}$$

$$= \text{(Known)}$$

Now using the eq.

$$V_1 = \sqrt{\frac{gX^2}{2.Y}}$$

where X and Y are the coordinates of the jet (issuing from centre of pressure) w.r. t. the water surface level in the inlet well *as fig.12*

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

$Y = \frac{1}{2} g t^2$

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

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

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

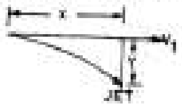


Fig .12

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

Example .2. Design the salient dimensions of a syphon well drop for the following particulars :
Fall =3.8m , General ground level = + 163.36 m , Full supply depth = 75 cm , Bed level upstream = + 162.83 , Discharge = 1 cumec , Bed width upstream and downstream = 2.4 m

Solution. For a trapezoidal notch, we have the discharge eq. as

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

At full supply discharge, we have

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

where y_{100} = F.S.D. = 0.75 m , Q_{100}= F.S.Q= 1 cumec

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

0.71=l+0.3n ……(i)

At 50% full discharge, we have

$Q_{50} = 2.22\ y_{50}\ [l + 0.4n\ y_{50}]$

where y_{50}= 0.66 y_{100}

=0.66x0.75

=0.5 m

Q_{50} = 0.5 cumec

0.5 = 2.22 (0.5)312 [l + 0.4n (0.5)]

0.64= l + 0.2 n ….(ii)

Subtracting (ii) from (i) we get

0.07=0.l n

n=0.7

$$2\tan\frac{\alpha}{2} = 0.7, \text{ or } \frac{\alpha}{2} = 19.3^\circ$$

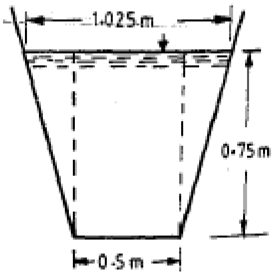
Substituting this value of n in (ii), we get

l=0.64-0.14=0.50

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

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

= 0.5 + 0.7 x (0.75) = 0.5 + 0.525 = 1.025 m.



Velocity (V_1) over the notch

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

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

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

fig .13

Velocity V_3 through the pipe

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

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

The velocity of entry into the pipe (V2)

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

Loss of head between the inlet well and the dis FSL is given by Eq.

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

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

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

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

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

$$= \text{d/s FSL} + 1.52 \qquad \begin{bmatrix} \text{d/s FSL} = \text{u/s FSL} - \text{fall} \\ \quad = (162.83 + 0.75) - 3.8 = 159.78) \end{bmatrix}$$

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

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

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

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

Height Y of C.P .. above the water level in the inlet well
= 163.08-161.30= 1.78 m.

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

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

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

Now, the dia. of the inlet well may be kept at about 1.5 X, i.e. l.5 x 1.05 = 1.575 m, say 1.6 m. Keep the dia. of the d/s outlet well, as say 1.2 m. Also, provide a water cushion at the bottom of the inlet well. Bed and sides of the channel for suitable lengths on the u/s as well as d/s side are protected by dry brick pitching. The complete details are shown in Fig.14.

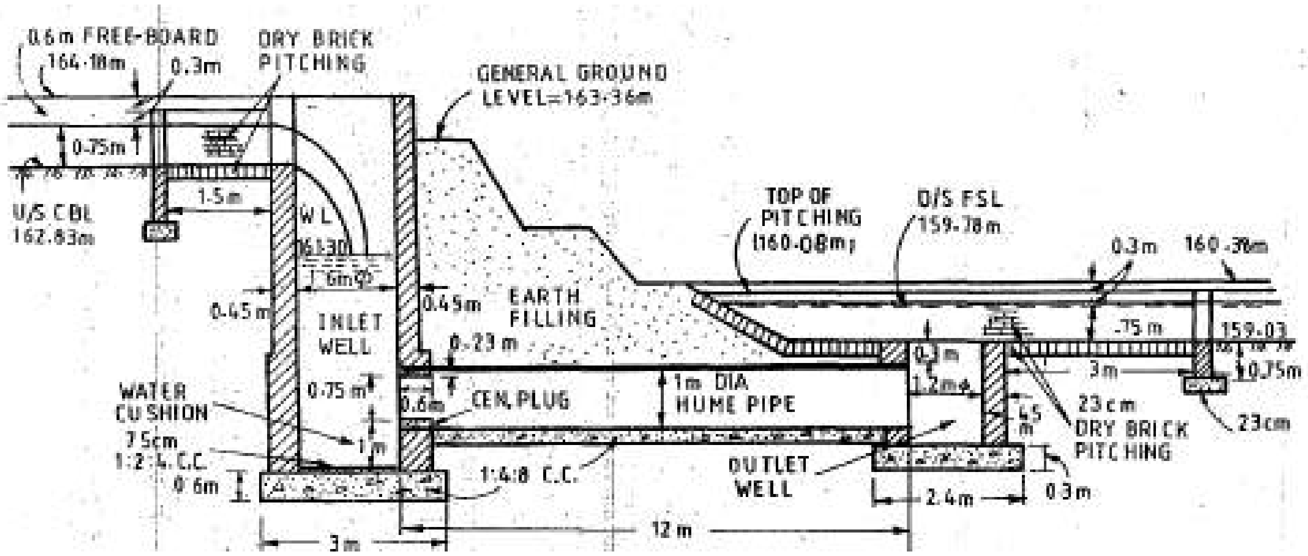


Fig.14

1- DUTY OF WATER:

For proper planning of a canal system, the designer has to first decide the 'duty of water' in the locality under consideration. **Duty is defined as the area irrigated by a unit discharge of water flowing continuously for the duration of the base period of a crop**. The ***base period*** of **a crop is the time duration between the first watering at the time of sowing and the last watering before harvesting the crop**. Obviously, the base period of a crop is smaller than the crop period. **Duty is measured in hectares/m3/s**. **The duty of a canal depends on the crop, type of soil, irrigation and cultivation methods, climatic factors, and the channel conditions**.

By comparing the duty of a system with that of another system or by comparing it with the corresponding figures of the past on the same system, one can have an idea about the performance of the system. Larger areas can be irrigated if the duty of the irrigation system is improved. Duty can be improved by the following measures:

(i) The channel should not be in sandy soil and be as near the area to be irrigated as possible so that the seepage losses are minimum. Wherever justified, the channel may be lined.

(ii) The channel should run with full supply discharge as per the scheduled program so that farmers can draw the required amount of water in shorter duration and avoid the tendency of unnecessary over irrigation.

(iii) Proper maintenance of watercourses and outlet pipes will also help reduce losses, and thereby improve the duty.

(iv) Volumetric assessment of water makes the farmer to use water economically. This is, however, more feasible in well irrigation

Well irrigation has higher duty than canal irrigation due to the fact that water is used economically according to the needs. Open wells do not supply a fixed discharge and, hence, the average area irrigated from an open well is termed its duty. Between the head of the main canal and the outlet in the distributary, there are losses due to evaporation and percolation. As such, duty is different at different points of the canal system. The duty at the head of a canal system is less than that at an outlet or in the tail end region of the canal. Duty is usually calculated for the head discharge of the canal. Duty calculated on the basis of outlet discharge is called 'outlet discharge factor' or simply 'outlet factor' which excludes all losses in the canal system.

Imagine a field growing a single crop having a base period B days and a Delta Δ mm which is being supplied by a source located at the head (uppermost point) of the field. The water being supplied may be through the diversion of river water through a canal, or it could be using ground water by pumping. If the water supplied is just enough to raise the crop within D hectares of the field, then a relationship may it found out amongst all the variables as:

$D =$ duty in hectares/cumec
$\Delta =$ total depth of water supplied (in metres)
$B =$ base period in days.

(*i*) If we take a field of area D hectares, water supplied to the field corresponding to the water depth Δ metres will be $= \Delta \times D$ hectare-metres

$$= D \times \Delta \times 10^4 \text{ cubic-metres.} \qquad ...(1)$$

(*ii*) Again for the same field of D hectares, one cumec of water is required to flow during the entire base period. Hence, water supplied to this field

$$= (1) \times (B \times 24 \times 60 \times 60) \text{ m}^3 \qquad ...(2)$$

Equating Equations (1) and (2), we get

$$D \times \Delta \times 10^4 = B \times 24 \times 60 \times 60$$

or
$$\Delta = \frac{B \times 24 \times 60 \times 60}{D \times 10^4} = 8.64 \frac{B}{D} \text{ metres}$$

Note : 1 hectare $= 10^4$ sq. metres
1 cumec-day $=$ 8.64 hectare-metres.

Example *Find the delta for a crop if the duty for a base period of 110 days is 1400 hectares/cumec.*

Solution : Given : $B = 110$ days and $D = 1400$ hectares/cumec

$$\therefore \quad \Delta = 8.64 \frac{B}{D} = \frac{8.64 \times 110}{1400} \text{ m} = 0.68 \text{ m} = \mathbf{68\ cm}$$

Example *A crop requires a total depth of 92 cm of water for a base period of 120 days. Find the duty of water.*

Solution : Given : $B = 120$ days and $\Delta = 92$ cm $= 0.92$ m

$$D = \frac{8.64\,B}{\Delta} \text{ hectares/cumec} = \frac{8.64 \times 120}{0.92} = \mathbf{1127\ hectares/cumec.}$$

FACTORS AFFECTING DUTY

The duty of water of canal system depends upon a variety of the factors. The principal factors are :

1. Methods and system of irrigation ;
2. Mode of applying water to the crops ;
3. Method of cultivation ;
4. Time and frequency of tilling ;
5. Type of the crop ;
6. Base period of the crop ;
7. Climatic conditions of the area;
8. Quality of water ;
9. Method of assessment of irrigation method ;
10. Canal conditions ;
11. Character of soil and sub-soil of the canal ;
12. Character of soil and sub-soil of the irrigation fields.

IRRIGATION EFFICIENCIES

Efficient use of irrigation water is an obligation of each user as well as of the planners. Even under the best method of irrigation, not all the water applied during an irrigation is stored in the root zone. In general, efficiency is the ratio of water output to the water input and is expressed as percentage. The objective of efficiency concepts is to show when improvements can be made which will result in more efficient irrigation. The following are the various types of irrigation efficiencies : (*i*) water conveyance efficiency, (*ii*) water application efficiency, (*iii*) water use efficiency, (*iv*) water storage efficiency, (*v*) water distribution efficiency and (*vi*) consumptive use efficiency.

1. *Water Conveyance Efficiency* (η_c)

This takes into account the conveyance or transit losses and is determined from the following expression :

$$\eta_c = \frac{W_f}{W_r} \times 100$$

where η_c = water conveyance efficiency
W_f = water delivered to the farm or irrigation plot
W_r = water supplied or diverted from the river or reservoir.

2. *Water Application Efficiency* (η_a)

The water application efficiency is the ratio of the quantity of water stored into the root zone of the crops to the quantity of water delivered to the field. This focuses the attention of the suitability of the method of application of water to the crops. It is determined from the following expression :

$$\eta_a = \frac{W_s}{W_f} \times 100$$

where η_a = water application efficiency
W_s = Water *stored* in the root zone during the irrigation
W_f = water delivered to the farm.

The common sources of loss of irrigation water during water application are (*i*) surface run off R_f from the farm and (*ii*) deep percolation D_f below the farm root-zone soil. Hence

$$W_f = W_s + R_f + D_f$$

and

$$\eta_a = \frac{W_f - (R_f + D_f)}{W_f} \times 100$$

In a well designed surface irrigation system, the water application efficiency should be atleast 60% ; in the sprinkler irrigation system this efficiency is about 75%.

3. *Water Storage Efficiency* (η_s)

The concept of water storge efficiency gives an insight to how completely the required water has been stored in the root zone during irrigation. It is determined from the following expression:

$$\eta_s = \frac{W_s}{W_n} \times 100$$

where η_s = water storage efficiency

W_s = water *stored* in the root zone during irrigation

W_n = water *needed* in the root zone prior to irrigation

= (Field capacity – Available moisture).

4. *Water Distribution Efficiency* (η_d)

Water distribution efficiency evaluates the degree to which water is uniformly distributed throughout the root zone. Uneven distribution has many undesirable results. The more uniformly the water is distributed, the better will be the crop response. It is determined from the following expression :

$$\eta_d = 100\left[1 - \frac{y}{d}\right]$$

where η_d = water distribution efficiency

y = average numerical deviation in depth of water stored from average depth stored during irrigation.

d = average depth of water stored during irrigation.

The efficiency provides a measure for comparing various systems or methods of water application, *i.e.* sprinkler compared to surface, one sprinkler system compared to the other system or one surface method compared to other surface method.

Example *If the depths of water stored at 5 points in a field are 1.0, 0.9, 0.8, 0.7 and 0.60 m, determine the water distribution efficiency.*

Solution. Average depth $= \frac{1.0 + 0.9 + 0.8 + 0.7 + 0.6}{5} = 0.80$ m

Deviations from the mean $= +0.20 + 0.10, 0.0 - 0.10 - 0.2$

Absolute values of these deviations from the mean $= 0.2, 0.1, 0.0, 0.10, 0.2$

Average of these absolute values of deviations $= \frac{0.2 + 0.10 + 0.0 + 0.10 + 0.20}{5} = 0.12$

Therefore, water distribution efficiency $= \left(1 - \frac{0.12}{0.80}\right) \times 100 = 85\%$

Example *Five cumecs of water is supplied to a field having an area of 30 ha for 6 hours. It is found that 25 cm of water depth has been stored in the root zone of the crop. Determine the water application efficiency.*

Solution. Quantity of water applied $= 5 \times 6 \times 3600 = 10.8 \times 10^4$ m^3 $= 10.8$ ha–m

Quantity of water stored in the root zone $= 30 \times 0.25 = 7.5$ ha–m

Water application efficiency $= \frac{7.5}{10.8} \times 100 = 69.44\%$

Alternative Method

Depth of water applied $= 10{\cdot}8/30{\cdot}0 = 0{\cdot}36$ m

Depth of water stored $= 0{\cdot}25$

Water application efficiency $= \frac{0 \cdot 25}{0 \cdot 36} \times 100 = 69{\cdot}44\%$

PLANNING OF IRRIGATION PROJECTS

These projects mainly consist of engineering (or hydraulic) structures which collect, convey, and deliver water to areas on which crops are grown. Irrigation projects may range from a small farm unit to those serving extensive areas of millions of hectares. A small irrigation project may consist of a low diversion weir or an inexpensive pumping plant along with small ditches (channels) and some minor control structures. A large irrigation project includes a large storage reservoir, a huge dam, hundreds of kilometers of canals, branches and distributaries, control structures, and other works. Assuming all other factors (such as enlightened and experienced farmers, availability of good seeds, etc.) reasonably favorable, the following can be listed as conditions essential for the success of any irrigation project.

(i) Suitability of land (with respect to its soil, topography and drainage features) for continued agricultural production,

(ii) Favorable climatic conditions for proper growth and yield of the crops,

(iii) Adequate and economic supply of suitable quality of water, and

(iv) Good site conditions for the safe construction and uninterrupted operations of the engineering works.

Most of the irrigation projects divert stream flow into a canal system which carries water to the cropland by gravity and, hence, are called gravity projects. In pumping projects, water is obtained by pumping but delivered through a gravity system

A gravity type irrigation project mainly includes the following works:

(i) Storage (or intake) and diversion works,

(ii) Conveyance and distribution channels.

(iii) Conveyance, control, and other hydraulic structures,

(iv) Farm distribution, and

(v) Drainage works.

Development of an Irrigation Project

A small irrigation project can be developed in a relatively short time. Farmers having land suitable for agriculture and a source of adequate water supply can plan their own irrigation system, secure necessary finance from banks or other agencies, and get the engineering works constructed without any delay. On the other hand, development of a large irrigation project is more complicated and time-consuming. Complexity and the time required for completion of a large project increase with the size of the project. This is due to the organizational, legal, financial administrative, environmental, and engineering problems all of which must be given detailed consideration prior to the construction of the irrigation works. The principal stages of a large irrigation project are: (i) the promotional stage, (ii) the planning stage, (iii) the construction stage, and (iv) the settlement stage. The planning stage itself consists of three substages: (i) preliminary planning including feasibility studies, (ii) detailed planning of water and land use, and (iii) the design of irrigation structures and canals. Engineering activities are needed during all stages (including operation and maintenance) of development of an irrigation project. However, the planning and construction stages require most intensive engineering activities. A large irrigation project may take 10–30 years for completion depending upon the size of the project.

1. Introduction

Irrigation engineering is the analysis and design of systems that optimally supply the right amount of water to the soil at the right time to meet the needs of the plant system.

2. Necessity

1- Less Rainfall
2- Non-uniform Rainfall
3- Growing a number of crops during a year.
4- Growing Perennial crops.
5- Commercial crops with additional water.
6- Controlled water supply.

3. Advantage of application of water by modern methods

1- It adds water to the soil to supply the moisture essential for the plant growth.
2- It saves the crops from drying during short duration droughts.
3- It cools the soil and the atmosphere, and thus makes more favorable environment for healthy plant growth.
4- It washes out or dilutes salts in the soil.
5- It reduces the hazard of soil piping.
6- It softens the tillage pans.

4. Scope of irrigation science

The scope of irrigation is not limited to the application of water to the soil. It deals with all aspects and problems extending from the watershed to the agricultural farms. It deals with the design and construction of all works, such as dams, weirs, head regulators etc. in connection with the storage or diversion of water, as well as he problems of subsoil drainage, soil reclamation and water-soil-crop relationships, An irrigation engineer is also required to have the knowledge of cultivation of various crops, their maturing and protection from pests. Briefly speaking, the scope of irrigation can be divided into two heads:

a-Engineering aspect

1- Storage, Diversion, or lifting of water
2- Conveyance of water to the Agricultural fields.
3- Application of water to Agricultural fields.
4- Drainage and relieving water-Logging.
5- Development of water power.

b-Agricultural Aspect

the agricultural aspect deals with the thorough study of the following points.
1- Proper depth of water necessary in single application of water for various crops.
2- Distribution of water uniformly and periodically.
3- Capacities of water uniformly and periodically.
4- Reclamation of waste and alkaline lands, where this can be carried out through the agency of water.

5. Benefits of irrigation

1- Increase in food production.

2- Protection from famine .

3- Cultivation of cash crops.

4- Elimination of mixed cropping.

5- Addition to the wealth of the country.

6- Increase in prosperity of people.

7- Generation of Hydro-Electric power.

8- Domestic and industrial water supply.

9- Inland navigation .

10- Improvements of communication.

11- Canal plantations.

12- Improvement in the Ground water storage.

13- Aid in Civilization.

14- General Development of the country .

6. Basic Design Factors

1- Consumptive Use (or Evapotranspiration)

Consumptive use refers to the water needs of a crop in a specified time and is the sum of the volume of transported and evaporated water.

2- Root-zone soil water

Water serves the following useful functions in the process of plant growth:

(i) Germination of seeds
(ii) All chemical reactions,
(iii) All biological processes,
(iv) Absorption of plant nutrients through their aqueous solution,
(v) Temperature control,
(vi) Tillage operations ,and
(vii) Washing out or dilution of salts.

Soil water can be divided into three categories:

(i) Gravity (or gravitational or free) water,
(ii) Capillary water, and
(iii) Hygroscopic water.

Gravity water is that water which drains away under the influence of gravity. Soon after irrigation (or rainfall) this water remains in the soil and saturates the soil, thus preventing circulation of air in void spaces.

The *capillary water* is held within soil pores due to the surface tension forces (against gravity) which act at the liquid-vapour (or water-air) interface.

Water attached to soil particles through loose chemical bonds is termed *hygroscopic water.* This water can be removed by heat only. But, the plant roots can use a very small fraction of this moisture under drought conditions.

The water remaining in the soil after the removal of gravitational water is called the field capacity. Field capacity of a soil is defined as the moisture content of a deep, permeable, and well-drained soil several days after a thorough wetting.

Permanent wilting point is defined as the soil moisture fraction, Wwp at which the plant leaves wilt (or droop) permanently and applying additional water after this stage will not relieve the wilted condition.

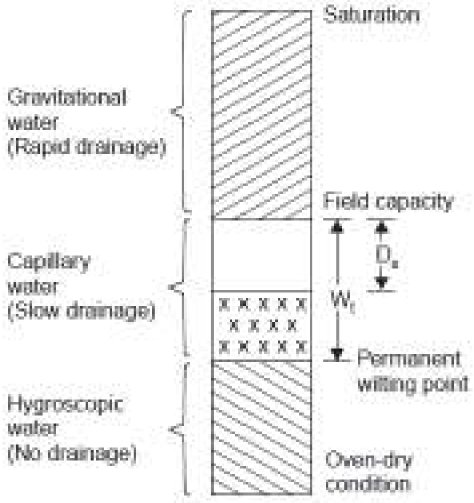


Fig 1. Different stages of soil moisture content in a soil

SOIL–WATER RELATIONS

1. SOILS

Soil mainly consists of finely divided **organic matter** and **minerals** (formed due to disintegration of rocks). It **holds the plants** upright, **stores water** for plant use, **supplies nutrients to the plants** and **helps in aeration**. Soils can be classified in many ways, such as **basis on size** (**gravel, sand, silt, clay,** etc.), geological process of formation, and so on. Based on their process of formation (or origin)ulgdm, they can be classified into the following categories:

(i) Residual soils : Disintegration of natural rocks due to the action of air, moisture, frost, and vegetation results in residual soils.

(ii) Alluvial soils: Sediment material deposited in bodies of water, deltas, and along the banks of the overflowing streams forms alluvial soils.

(iii) Aeolian soils: These soils are deposited by wind action.

(iv) Glacial soils: These soils are the products of glacial erosion.

(v) Colluvial soils: These are formed by deposition at foothills due to rain wash.

(vi) Volcanic soil: These are formed due to volcanic eruptions and are commonly called as volcanic wash.

2. PHYSICAL PROPERTIES OF SOIL

The permeability of soils with respect to air, water, and roots are as important to the growth of crop as an adequate supply of nutrients and water. The permeability of a soil depends on the porosity and the distribution of pore spaces which, in turn, are decided by the texture and structure of the soil.

2.1 Soil Texture

Soil texture is determined by the size of soil particles. Most soils contain a mixture of sand (particle size ranging from 0.05 to 1.00 mm in diameter), silt (0.002 to 0.05 mm) and clay (smaller than 0.002 mm). If the sand particles dominate in a soil, it is called sand and is a coarse-textured soil. When clay particles dominate, the soil is called clay and is a fine-textured soil. Loam soils (or simply loams) contain about equal amount of sand, silt, and clay and are medium-textured soils.

The texture of a soil affects the flow of water, aeration of soil, and the rate of chemical transformation all of which are important for plant life. The texture also determines the water holding capacity of the soil

2.2. Soil Structure

Volume of space (i.e., the pores space) between the soil particles depends on the shape and size distribution of the particles. The pore space in irrigated soils may vary from 35 to 55 per cent.The term porosity is used to measure the pore space and is defined as the ratio of the volume of voids (i.e., air and water-filled space) to the total volume of soil (including water and air).

The pore space directly affects the soil fertility (i.e., the productive value of soil) due to its influence upon the water-holding capacity and also on the movement of air, water, and roots through the soil.

2.3. Depth of Soil عمق التربة

Shallow soils require more frequent irrigations and cause excessive deep percolation losses when shallow soils overlie coarse-textured and highly permeable sands and gravels. On the other hand, deep soils would generally require less frequent irrigations, permit the plant roots to penetrate deeper, and provide for large storage of irrigation water.

As a result, actual water requirement for a given crop (or plant) is more in case of shallow soils than in deep soils even though the amount of water actually absorbed by the crop (or plant) may be the same in both types of soils. This is due to the unavoidable water losses at each irrigation.

3. CHEMICAL PROPERTIES OF SOIL

For satisfactory crop yield, soils must have sufficient plant nutrients, such as nitrogen, carbon,hydrogen, iron, oxygen, potassium, phosphorus, sulphur, magnesium, and so on. Nitrogen is the most important of all the nutrients. Nitrogenous matter is supplied to the soil from fertilisers. Plants absorb nitrogen in the form of soluble nitrates.

4. SOIL–WATER RELATIONSHIPS

Any given volume V of soil (Fig. 1) consists of : (i) volume of solids V_s , (ii) volume of liquids (water) V_w, and (iii) volume of gas (air) V_a. Obviously, the volume of voids (or pore spaces) $V_v = V_w + V_a$. For a fully saturated soil sample, $V_a = 0$ and $V_v = V_w$. Likewise, for a completely dry specimen, $V_w = 0$ and $V_v = V_a$. The weight of air is considered zero compared to the weights of water and soil grains. The void ratio e, the porosity n, the volumetric moisture content w, and the saturation S are defined as

$$e = \frac{V_v}{V_s}, n = \frac{V_v}{V}, w = \frac{V_w}{V}, S = \frac{V_w}{V_v}$$

Therefore, $$w = Sn \quad ...(1)$$

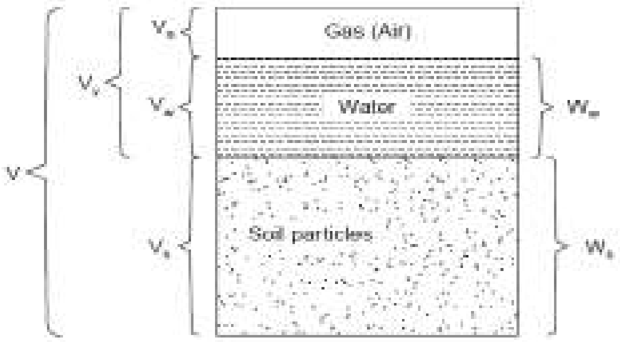


Fig. 1 Occupation of space in a soil sample

It should be noted that the value of porosity n is always less than 1.0. But, the value of void ratio e may be less, equal to, or greater than 1.0.

Therefore, the volume of water in the root-zone soil,

$$V_w = W A d\,(1-n)\,G_s \qquad (6)$$

This volume of water can also be expressed in terms of depth of water which would be obtained when this volume of water is spread over the soil surface area A.

$$\therefore \text{ Depth of water, } \quad d_w = \frac{V_w}{A}$$

$$d_w = G_s\,(1-n)\,Wd \qquad (7)$$

or

$$d_w = w\,d \qquad (8)$$

Example 1 If the water content of a certain saturated soil sample is 22 per cent and the specific gravity is 2.65, determine the saturated unit weight γ_{sat}, dry unit weight γ_d, porosity n and void ratio e.

Solution:

$$W = \frac{W_w}{W_s} = 0.22$$

and

$$G_s = \frac{W_s}{V_s \gamma_w} = 2.65$$

$$W_s = 2.65\,\gamma_w\,V_s$$

and

$$W W_s = W_w$$

$$= 0.22 \times 2.65\,\gamma_w V_s$$

$$V_w = \frac{W_w}{\gamma_w} = 0.22 \times 2.65 \times V_s = 0.583\,V_s$$

Total volume $V = V_s + V_w$ (as $V_a = 0$ since the sample is saturated)

$$= V_s\,(1 + 0.583)$$

$$= 1.583\,V_s$$

$$n = \frac{V_v}{V} = \frac{0.583\,V_s}{1.583\,V_s} = 36.8\%$$

(since $V_v = V_w$ as the soil sample is saturated)

and

$$e = \frac{V_v}{V_s} = 0.583 = 58.3\%$$

and total weight

$$W = W_w + W_s$$

$$= 0.22 \times 2.65 \times \gamma_w V_s + 2.65\,\gamma_w V_s$$

$$= 3.233\,\gamma_w V_s$$

$$\gamma_{sat} = \frac{W}{V} = \frac{3.233\,\gamma_w V_s}{1.583\,V_s}$$

$$= 20.032 \text{ kN/m}^3 \qquad (\text{since } \gamma_w = 9810 \text{ N/m}^3)$$

$$\gamma_d = \frac{W_s}{V} = \frac{2.65\,\gamma_w V_s}{1.583\,V_s}$$

$$= 16.422 \text{ kN/m}^3.$$

Example 2 A moist clay sample weighs 0.55 N. Its volume is 35 cm^3. After drying in an oven for 24 hours, it weights 0.50 N. Assuming specific gravity of clay as 2.65, compute the porosity n, degree of saturation S, original moist unit weight, and dry unit weight.

Solution:

$$W_T = 0.55 \text{ N}$$
$$W_s = 0.50 \text{ N}$$
$$W_w = 0.05 \text{ N}$$
$$V_s = \frac{W_s}{\gamma_s} = \frac{0.5}{2.65 \times 9810}$$
$$= 1.923 \times 10^{-5} \text{ m}^3 = 19.23 \text{ cm}^3$$
$$V_w = \frac{W_w}{\gamma_w} = \frac{0.05}{9810}$$
$$= 5.1 \times 10^{-6} \text{ m}^3 = 5.10 \text{ cm}^3$$
$$V_v = V - V_s = 35 - 19.23$$
$$= 15.77 \text{ cm}^3$$

Porosity, $$n = \frac{V_v}{V} = \frac{15.77}{35} = 45.06\%$$

Degree of saturation, $$S = \frac{V_w}{V_v} = \frac{5.10}{15.77} = 32.34\%$$

Moist unit weight, $$\gamma = \frac{0.55}{35} = 0.016 \text{ N/m}^3$$

Dry unit weight, $$\gamma_d = \frac{0.50}{35} = 0.014 \text{ N/m}^3.$$

Example 3 A moist soil sample has a volume of 484 cm^3 in the natural state and a weight of 7.94N. The dry weight of the soil is 7.36 N and the relative density of the soil particles is 2.65. Determine the porosity, soil moisture content, volumetric moisture content, and degree of saturation.

Solution:

$$G_b = \frac{7.36}{484 \times 10^{-6} \times 9810} = 1.55$$

The porosity, $$n = 1 - \frac{G_b}{G_s}$$
$$= 1 - \frac{1.55}{2.65} = 0.415 = 41.5\%$$

The soil moisture fraction,

$$W = \frac{7.94 - 7.36}{7.36} = 0.0788 = 7.88\%$$

The volumetric moisture content,

$$G_b\, W = 1.55\,(0.0788)$$
$$= 12.214\%$$

Degree of saturation, $$S = \frac{w}{n} = \frac{12.214}{41.5} = 0.2943 = 29.43\%$$