7th Semester B.TECH.

[CIVIL ENGINEERING]

HYDRAULIC STRUCTURES

A hydraulic structure is a structure submerged or partially submerged in any body of water, which disrupts the natural flow of water. They can be used to divert, disrupt or completely stop the flow. An example of a hydraulic structure would be a dam, which slows the normal flow rate of river in order to power turbines. A hydraulic structure can be built in rivers, a sea, or any body of water where there is a need for a change in the natural flow of water.

The basin knowledge about Hydraulic structures with their usefulness and design etc will be dealt with in this course.

Module – II

Systems of irrigation:-

Various types of irrigation techniques differ in how the water obtained from the source is distributed within the field. In general, the goal is to supply the entire field uniformly with water, so that each plant has the amount of water it needs, neither too much nor too little. The various irrigation techniques are as under:

i) Surface irrigation
ii) Sub-surface irrigation

1) **<u>Surface irrigation:-</u>**
   a) Flow irrigation
   b) Lift irrigation

When the water is available at a higher level and it is supplied to lower level by the mere action gravity, then it is called flow irrigation. But if the water is lifted up by some mechanical (or) manual means such as by pumps etc. and then supplied for irrigation then it is called Lift irrigation. Use of wells and tube wells for supplying water for irrigation falls under the category of Lift irrigation.

Flow irrigation:-

- Perennial irrigation

- Flood irrigation

Perennial Irrigation:

In perennial system of irrigation constant and continuous water supply is assure to the crops in accordance with the requirements of the crop throughout the crop period. In this system of irrigation water is supplied through canal distribution system taking off above a weir or a reservoir. When irrigation is done by diverting the river runoff into the main canal by constructing a diversion weir or a barrage across the river then it is called direct irrigation but if a dam is constructed across a river to store water during monsoons so as to water in the off taking channel during periods of low flow.

Flood Irrigation:

Flood irrigation is also known as inundation irrigation. In this method of irrigation soil is kept submerged and thoroughly flooded with water so as to cause thorough saturation of the land. The moisture soaked by the soil when occasionally supplemented by natural rainfall (or) minor watering.

2) **Sub surface irrigation:**

It is termed as sub surface irrigation because in this type of irrigation water does not wet the soil surface. The underground water nourishes the plant roots by capillary. It may be divided into the following two types.

- Natural sub irrigation
- Artificial sub irrigation

Natural sub irrigation:

Leakage water from channels etc. goes underground and during passing through the sub soil it may irrigate crops sown on lower lands by capillary.

Artificial sub irrigation:

When a system of open joined drains is artificially laid below the soil so as to apply water to the crops by capillary then it is known as artificial sub irrigation

Various techniques of distribution of water in the farms:-

a. Flooding irrigation
b. Drip irrigation
c. Furrow irrigation
d. Sprinkler irrigation

Flooding irrigation methods:

- Free flooding method
- Basin flooding method
- Border flooding method
- Check flooding method

Free flooding method:

In this method ditches are excavated in the field, and they may be either on the contour or up and down of the slope . Water from these ditches, flow across the field. After water leaves the ditches no attempt is made to control the flow. Since the movement of water is not controlled, it is sometimes called wild flooding. Although the initial cost is low, labour requirement are usually high and water application efficiency is also low. This type is suitable for close growing crops etc., particularly where the land is steep. Contour ditches, are generally spaced at about 20 to 50 m apart.

Border flooding method:

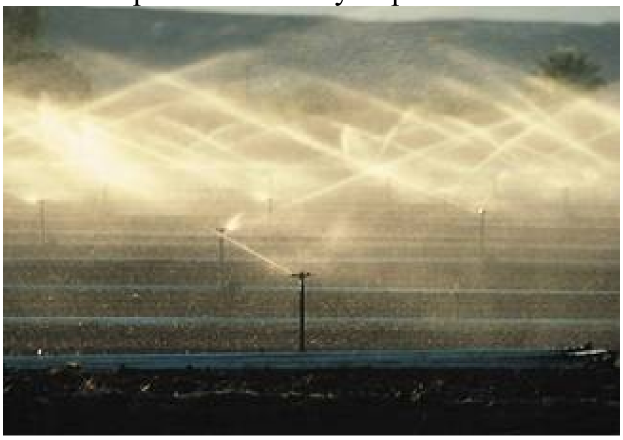
In this method, the land is divided into number of strips, separated by low levees called borders. The land areas confined in each strips is of the order of 10 to 20 m in width and 100 and 400 min length. Ridges between borders should be sufficiently high to prevent overtopping during irrigation. To prevent water from concentrating on either side of the border, the land should be levelled perpendicular to the flow. Water is made to flow from the supply ditch into each strip. The water slowly towards the lower end and infililtrates into the soil ass it advances. When the advancing water reaches the lower end of the strip, the supply of water to the strip is turned off.

Check flooding method:

Check flooding is similar to ordinary flooding that the water is controlled by surrounding the check area low and flat levees. Levees are generally constructed along the contour, having vertical interval of about 5 to 10 cm. these levees are connected with cross levees at the convenient places. In this method, water at fairly high rate and allowed to stand until the water infilitrates. This method is suitable for permeable and non permeable soil.

Sprinkler irrigation method:

In this form water application method water applied to the soil in the form of spray through a network of pipes and pumps. Is kind of an artificial rain and therefore gives very good results. It is costly process and widely used in U.S.A. It can be used for all type of soils and for widely used in all topography and slopes. It can advantageously be used for many crops, because it fulfils the normal requirement of uniform distribution of water. In this method is very suitable for irrigation area in Rajasthan in India, where other type of irrigation are very difficult. In spite of the numerous advantages which this method over other methods. It has not become popular in India for the simple reason that occurs in a poor and developing nation. This method is only costly but requires lot technicalities. The correct design and efficient operation are very important for the success of this method.



Sprinkler irrigation

Types of Sprinkler system are classified under three heads as

a. Permanent system
b. Semi-Permanent system
c. Portable system

Permanent system:

The main pipes and lateral pipes are buried in the soil and they not interfere the farming operation.

Semi-Permanent system:

The main pipes are buried in the soil and lateral pipe are portable.

Portable system:

The main pipe and lateral pipes both are portable and the network can move from farm to farm.

Advantages of sprinkler irrigation are enumerated below

a) Seepage losses are completely eliminated.
b) Land leveling is not required.
c) No cultivation area is lost for making ditches.
d) Avoid surface run off.
e) Fertilizer can be uniformly applied.
f) Leaches down salt and prevent water logging or salinity.
g) It is labor oriented and 80% efficiency is achieved.

The limitation of sprinkler irrigation is

a. High wind may distort sprinkler pattern and non – uniform spreading of water on the crops.
b. In areas of high temperature and considerable evaporation losses of water may take place.
c. They are not suitable to crop requiring frequent and larger depths of irrigation irrigation such as paddy.
d. It require large electrical power
e. A constant supply water is needed for commercial use of equipment.

Drip/Trickle Irrigation Method:-

This system involves laying of a system of head, mains, sub mains, laterals and drop nozzles. Water oozes out of these small drip nozzles uniformly and at a very small rate directly into the plants root area. The head consists of a pump to lift power so as to produce the desired pressure of about 2.5 atmospheres for ensuring proper flow of water through the system. The lifted material like black PVC. These are generally buried or laid on the ground. There sizes should be sufficient to carry the design discharge of the systems. The laterals are very small sized (usually 1 to 1.25 cm) specially designed black PVC pipes taking off from the mains (or) sub mains. Laterals can usually be up to 59 m long and one lateral line is laid for each row of crops. Hardie Biwall is a patented name of dual chambered micro tubing manufactured from a linear low density polyethylene and is being used these days for laterals. The drip nozzles also called emitters (or) valves are fixed on laterals of about 0.5 to 1 m (or) discharging water at very small rates of the order 2 to 10 Liters per hour. Like the sprinkler system this method also involves specialized knowledge and is not being adopted by our ordinary formers. This method is however being used for small nurseries, orchards or gardens. The widely known commercial Indian company which specializes in this field irrigation method is known as Jain irrigation systems Ltd. This firm can be contacted in special needs for layout of such an irrigation system.

Drip/trickle irrigation

Quality of Irrigation Water:-

The quality of irrigation water is very much influenced by the constituents of the soil which is to be irrigated. The various types of impurities which make the water unfit for irrigation, are classified as:

i) Sediment concentration in water
ii) Total concentration of soluble salts in water
iii) Proportion of sodium ions to other cat ions
iv) Concentration of potentially toxic elements present in water
v) Bicarbonate concentration as related to the concentration of calcium plus magnesium
vi) Bacterial contamination

<u>Proportion of sodium ions to other cat ions</u>

Most of soils contain Ca and Mg ions and small quantities of Na ions. The %of the Na ions is generally less than 5% of the total exchangeable cat-ions. If this % increases to about 10% or more, the aggregation of soil grains breaks down. The soil becomes less permeable and poorer tilth. It starts crusting when dry and its pH increases towards that of an alkaline soil. High Na soils are, therefore, plastic, sticky when wet, and are prone to form clods, and they crust on drying.

The proportion of Na ions present in the soils is generally measured by a factor called ***Sodium-Absorption Ratio (SAR)*** and represents the Sodium hazards of water. SAR is defined as:

Where, the concentration of the ions is expressed in equivalent per million (epm); epm is obtained by dividing the concentration of salt in mg/l or ppm by its combining weight (i.e. Atomic wt. / valence.)

SITE SELECTION FOR A DAM

A dam is a huge structure requiring a lot of funds. Extreme care shall be taken while selecting the site of a dam. A wrong decision may lead to excessive cost and difficulties in construction and maintenance. Various factors should be considered when selecting the site of a dam. Those are listed below:

i) Topography
ii) Suitable Foundation
iii) Good Site for reservoir
    - Large storage capacity
    - Shape of reservoir basin
    - Water tightness of the reservoir
    - Good hydrological conditions
    - Deep reservoir
    - Small submerged

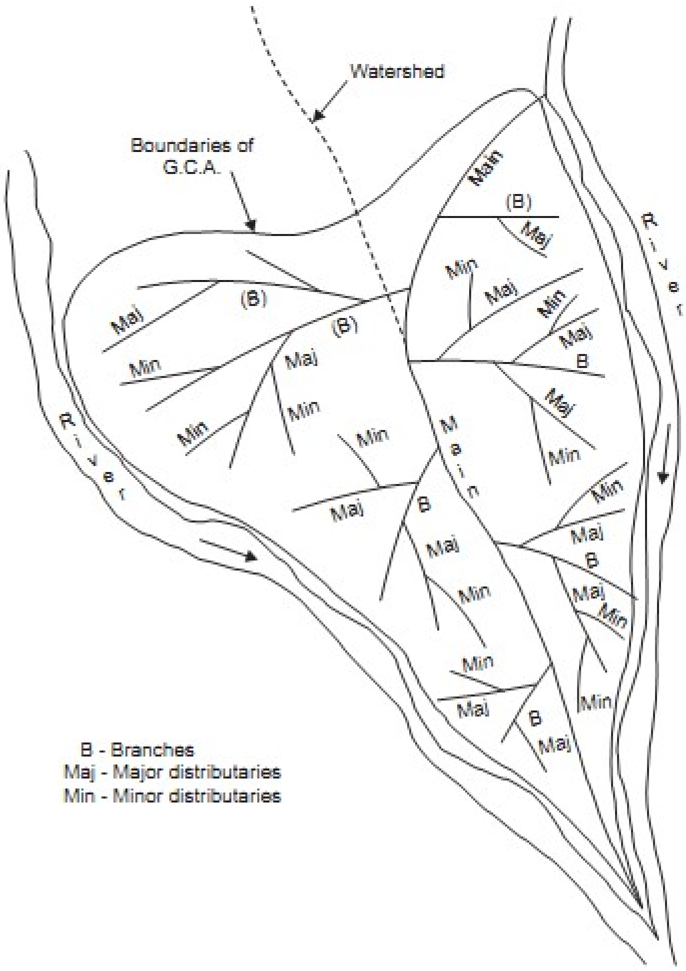
iv) Area
    - Low silt inflow
    - No objectionable minerals
v) Spillway site
vi) Availability of materials
vii) Accessibility
viii) Healthy surroundings
ix) Minimum overall cost
x) Other considerations

CANAL IRRIGATION (IRRIGATION AND WATER RESOURCES ENGINEERING by G.L. ASAWA)

CANALS:-

A conveyance subsystem for irrigation includes open channels through earth or rock formation, flumes constructed in partially excavated sections or above ground, pipe lines installed either below or above the ground surface, and tunnels drilled through high topographic obstructions. 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 cross-section. 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 head-works 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. A canal can serve more than one function. The slope of an irrigation canal is generally less than the ground slope in the head reaches of the canal and, hence, vertical falls have often to be constructed. Power houses may be constructed at these falls to generate power and, thus, irrigation canals can be used for power generation also. Similarly, irrigation canals can also be utilised for the transportation of goods and serve as navigation canals. Inland navigation forms a cheap means of transportation of goods and, hence, must be developed. However, in India, inland navigation has developed only to a limited extent. This is mainly due to the fact that irrigation canals generally take their supplies from alluvial rivers and, as such, must flow with sufficient velocity to prevent siltation of the canal. Such velocities make upstream navigation very difficult. Besides, the canals are generally aligned on the watershed1 so that water may reach the fields on both sides by flow. This alignment may not be suitable for navigation which requires the canal to pass through the areas in the vicinity of industries.

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



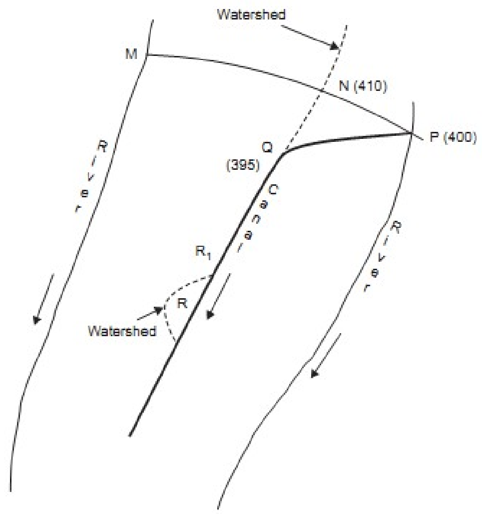
(Layout of an irrigation canal network)

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 water courses 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.

ALIGNMENT OF IRRIGATION CANALS:-

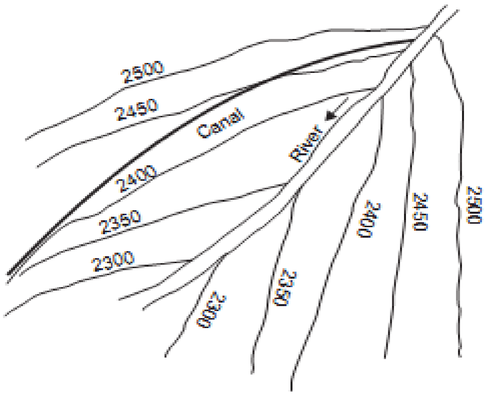
Desirable locations for irrigation canals on any gravity project, their cross-sectional designs and construction costs are governed mainly by topographic and geologic conditions along different routes of the cultivable lands. Main canals must convey water to the higher elevations of the cultivable area. 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 distributaries) 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. 5.2 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 15km. 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.



(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. 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 R1and 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 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.



(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.

ESTIMATION OF DESIGN DISCHARGE OF A CANAL

The amount of water needed for the growth of a crop during its entire crop-growing period is known as the water requirement of the crop, and is measured in terms of depth of water spread over the irrigated area. This requirement varies at different stages of the growth of the plant. The peak requirement must be obtained for the period of the keenest demand. One of the methods to decide the water requirement is on the basis of kor watering. When the plant is only a few centimetres high, it must be given its first watering, called the kor watering, in a limited period of time which is known as the kor period. If the plants do not receive water during the kor period, their growth is retarded and the crop yield reduces considerably. The kor watering depth and the kor period vary depending upon the crop and the climatic factors of the region. In UP, the kor watering depth for wheat is 13.5 cm and the kor period varies from 8 weeks in north-east UP (a relatively dry region) to 3 weeks in the hilly region (which is relatively humid). For rice, the kor watering depth is 19 cm and the kor period varies from 2 to 3 weeks.

If D represents the duty (measured in hectares/m3/s) then, by definition,
1 m3/s of water flowing for b (i.e., base period in days) days irrigates D hectares.

∴ 1 m3/s of water flowing for 1 day (i.e., 86400 m3 of water) irrigates D/b hectares

This volume (i.e., 86400 m3) of water spread over D/b hectares gives the water depth, Δ.

$$\Delta = \frac{86400}{(D/b) \times 10^4} = 8.64\ b/D \text{ (metres)}$$

For the purpose of designing on the basis of the keenest demand (i.e., the kor period requirement) the base period b and the water depth Δ are replaced by the kor period and kor water depth, respectively.

Example: - The culturable command area for a distributary channel is 10,000 hectares. The intensity of irrigation is 30 per cent for wheat and 15 per cent for rice. The kor period for wheat is 4 weeks, and for rice 3 weeks. Kor watering depths for wheat and rice are 135 mm and 190 mm, respectively. Estimate the outlet discharge.

Solution:-

Quantity	*Wheat*	*Rice*
Area to be irrigated (hectares)	$0.30 \times 10,000 = 3000$	$0.15 \times 10,000 = 1500$
Outer factor $D = 8.64\ b/\Delta$ (in hectares/m^3/s)	$\frac{8.64(4 \times 7)}{0.135} = 1792$	$\frac{8.64(3 \times 7)}{0.19} = 954.95$
Outlet discharge (m^3/s)	$3000/1792 = 1.674 \approx 1.7$	$1500/954.95 = 1.571 \approx 1.6$

Since the water demands for wheat and rice are at different times, these are not cumulative. Therefore, the distributary channel should be designed for the larger of the two discharges, viz., and 1.7 m3/s. The above calculations exclude channel losses and the water requirement of other major crops during their kor period. The kor period for a given crop in a region depends on the duration during which there is likelihood of the rainfall being smaller than the corresponding water requirement. Accordingly, the kor period is least in humid regions and more in dryer regions. The kor depth requirement must be met within the kor period. As such, the channel capacity designed on the basis of kor period would be large in humid regions and small in dry regions. Obviously, this method of determining the channel capacity is, therefore, not rational, and is not used in practice. A more rational method to determine the channel capacity would be to compare evapo-transpiration and corresponding effective rainfall for, say, 10-day (or 15-day) periods of the entire year and determine the water requirement for each of these periods. The channel capacity can then be determined on the basis of the peak water requirement of the 10-day (or15-day) periods.

CANAL REGULATION

The amount of water which can be directed from a river into the main canal depends on: (i) the water available in the river, (ii) the canal capacity, and (iii) the share of other canals taking off from the river. The flow in the main canal is diverted to various branches and distributaries.

The distribution of flow, obviously, depends on the water demand of various channels. The method of distribution of available supplies is termed canal regulation. When there exists a significant demand for water anywhere in the command area of a canal, the canal has to be kept flowing. The canal can, however, be closed if the water demand falls below a specified quantity. It is reopened when the water demand exceeds the specified minimum quantity. Normally, there always exists a demand in some part of the command area of any major canal. Such major canals can, therefore, be closed only for a very small period (say, three to four weeks in a year). These canals run almost continuously and carry discharges much less than their full capacity, either when there is less demand or when the available supplies are insufficient. If the demand is less, only the distributaries which need water are kept running and the others (including those which have very little demand) are closed. In case of keen demand, but insufficient supplies, either all smaller channels run simultaneously and continuously with reduced supplies, or some channels are closed turn by turn and the remaining ones run with their full or near-full capacities. The first alternative causes channel silting, weed growth, increased seepage, water-logging, and low heads on outlets. The second alternative does not have these disadvantages and allows sufficient time for inspection and repair of the channels. A roster is usually prepared for indicating the allotted supplies to different channels and schedule of closure and running of these channels. It is advantageous to have flexible regulation so that the supplies can be allocated in accordance with the anticipated demand. The allocation of supplies is decided on the basis of the information provided by the canal revenue staffs who keeps a close watch on the crop condition and irrigation water demand. The discharge in canal is usually regulated at the head regulator which is usually designed as a meter. When the head regulator cannot be used as discharge meter, a depth gauge is provided at about 200 m downstream of the head regulator. The gauge reading is suitably related to the discharge. By manipulating the head regulator gates, the desired gauge reading (and, hence, the discharge) can be obtained.

Lining of Irrigation Channels

Most of the irrigation channels in India are earthen channels. The major advantage of an earth channel is its low initial cost. The disadvantages of an earth channel are:

(i) the low velocity of flow maintained to prevent erosion necessitates larger cross-section of channels, (ii) excessive seepage loss which may result in water-logging and related problems such as salinity of soils, expensive road maintenance, drainage activities, safety of foundation structures, etc., (iii) favourable conditions for weed growth which further retards the velocity, and (iv) the breaching of banks due to erosion and burrowing of animals. These problems of earth channels can be got rid of by lining the channel.

A lined channel decreases the seepage loss and, thus, reduces the chances of water-logging. It also saves water which can be utilised for additional irrigation. A lined channel provides safety against breaches and prevents weed growth thereby reducing the annual maintenance cost of the channel. Because of relatively smooth surface of lining, a lined channel requires a flatter slope. This results in an increase in the command area. The increase in the useful head is advantageous in case of power channels also. The lining of watercourses in areas irrigated by tube wells assumes special significance as the pumped water supply is more costly. As far as practicable, lining should, however, be avoided on expansive clays. But, if the canal has to traverse a reach of expansive clay, the layer of expansive clay should be removed and replaced with a suitable non-expansive soil and compacted suitably. If the layer of expansive clay is too thick to be completely excavated then the expansive clay bed is removed to a depth of about 60 cm and filled to the grade of the underside of lining with good draining material. The excavated surface of expansive clay is given a coat of asphalt to prevent the entry of water into the clay.

The cost of lining a channel is, however, the only factor against lining. While canal lining provides a cost-effective means of minimising seepage losses, the lining itself may rapidly deteriorate and require recurring maintenance inputs if they are to be effective in controlling seepage loss. A detailed cost analysis is essential for determining the economic feasibility of lining a channel. The true cost of lining is its annual cost rather than the initial cost. The cost of lining is compared with the direct and indirect benefits of lining to determine the economic feasibility of lining a channel. Besides economic factors, there might be intangible factors such as high population density, aesthetics, and so on which may influence the final decision regarding the lining of a channel.

Types of Lining

Types of lining are generally classified according to the materials used for their construction. Concrete, rock masonry, brick masonry, bentonite-earth mixtures, natural clays of low permeability, and different mixtures of rubble, plastic, and asphaltic materials are the commonly used materials for canal lining. The suitability of the lining material is decided by: (i) economy, (ii) structural stability, (iii) durability, (iv) reparability, (v) impermeability, (vi) hydraulic efficiency, and (vii) resistance to erosion (15). The principal types of lining are as follows:

(i) Concrete lining,
(ii) Shotcrete lining,
(iii) Precast concrete lining,
(iv) Lime concrete lining,
(v) Stone masonry lining,

(vi) Brick lining,
(vii) Boulder lining,
(viii) Asphaltic lining, and
(ix) Earth lining.

Concrete Lining

Concrete lining is probably the best type of lining. It fulfils practically all the requirements of lining. It is durable, impervious, and requires least maintenance. The smooth surface of the concrete lining increases the conveyance of the channel. Properly constructed concrete lining can easily last about 40 years. Concrete linings are suitable for all sizes of channels and for both high and low velocities. The lining cost is, however, high and can be reduced by using mechanised methods. The thickness of concrete depends on canal size, bank stability, amount of reinforcement, and climatic conditions. Small channels in warm climates require relatively thin linings.

Channel banks are kept at self-supporting slope (1.5H: 1V to 1.25H: 1V) so that the lining is not required to bear earth pressures and its thickness does not increase. Concrete linings are laid without form work and, hence, the workability of concrete should be good. Also, experienced workmen are required for laying concrete linings.

Reinforcement in concrete linings usually varies from 0.1 to 0.4% of the area in the longitudinal direction and 0.1 to 0.2% of the area in the transverse direction. The reinforcement in concrete linings prevents serious cracking of concrete to reduce leakage, and ties adjacent sections of the lining together to provide increased strength against settlement damage due to unstable sub-grade soils or other factors. The reinforcement in concrete linings does not prevent the development of small shrinkage which tend to close when canals are operated and linings are water soaked. The damage due to shrinkage and temperature changes is avoided or reduced by the use of special construction joints. Reinforced concrete linings may result in increased water tightness of the lining. However, well-constructed unreinforced concrete linings may be almost equally watertight.

The earlier practice of using reinforced concrete linings is now being replaced by the employment of well-constructed unreinforced concrete linings. However, reinforcement must be provided in: (a) large canals which are to be operated throughout the year, (b) sections where the unreinforced lining may not be safe, and (c) canals in which flow velocities are likely to be very high. Proper preparation of sub-grade is essential for the success of the concrete lining which may, otherwise, develop cracks due to settlement. Natural earth is generally satisfactory for this purpose and, hence, sub-grade preparation is the least for channels in excavation. Thorough compaction of sub-grade for channels in filling is essential for avoiding cracks in lining due to settlement. Some cracks usually develop in concrete linings. These can be sealed with asphaltic compounds. The lining may be damaged when flow in the canal is suddenly stopped and the surrounding water table is higher than the canal bed. This damage occurs in excavated channels and can be prevented by providing weep holes in the lining or installing drains with outlets in the canal section.

Shotcrete Lining

Shotcrete lining is constructed by applying cement mortar pneumatically to the canal surface. Cement mortar does not contain coarse aggregates and, therefore, the proportion of cement is higher in shotcrete mix than in concrete lining. The shotcrete mix is forced under pressure through a nozzle of small diameter and, hence, the size of sand particles in the mix should not exceed 0.5 cm. Equipment needed for laying shotcrete lining is light, portable, and of smaller size compared to the equipment for concrete lining. The thickness of the shotcrete lining may vary from 2.5 to 7.5 cm. The preferred thickness is from 4 to 5 cm. Shotcrete lining is suitable for: (a) lining small sections, (b) placing linings on irregular surfaces without any need to prepare the subgrade, (c) placing linings around curves or structures, and (d) repairing badly cracked and leaky old concrete linings. Shotcrete linings are subject to cracking and may be reinforced or unreinforced. Earlier, shotcrete linings were usually reinforced. A larger thickness of shotcrete lining was preferred for the convenient placement of reinforcement. The reinforcement was in the form of wire mesh. In order to reduce costs, shotcrete linings are not reinforced these days, particularly on relatively small jobs.

Precast Concrete Lining

Precast concrete slabs, laid properly on carefully prepared sub-grades and with the joints effectively sealed, constitute a serviceable type of lining. The precast slabs are about 5 to 8cm thick with suitable width and length to suit channel dimensions and to result in weights which can be conveniently handled. Such slabs may or may not be reinforced. This type of lining is best suited for repair work as it can be placed rapidly without long interruptions in canal operation. The side slopes of the Tungabhadra project canals have been lined with precast concrete slabs.

Lime Concrete Lining

The use of this type of lining is limited to small and medium size irrigation channels with capacities of up to 200 m3/s and in which the velocity of water does not exceed 2 m/s (16). The materials required for this type of lining are lime, sand, coarse aggregate, and water. The lime concrete mix should be such that it has a minimum compressive strength of about 5.00 kN/m2 after 28 days of moist curing. Usually lime concrete is prepared with 1 : 1.5 : 3 of kankar lime : kankar grit or sand : kankar (or stone or brick ballast) aggregate. The thickness of the lining may vary from 10 to 15 cm for discharge ranges of up to 200 m3/s. Lime concrete lining has been used in the Bikaner canal taking off from the left bank of the Sutlej.

Stone Masonry Lining

Stone masonry linings are laid on the canal surface with cement mortar or lime mortar. The thickness of the stone masonry is about 30 cm. The surface of the stone masonry may be smooth plastered to increase the hydraulic efficiency of the canal. Stone masonry linings are stable, durable, erosion-resistant, and very effective in reducing seepage losses. Such lining is very suitable where only unskilled labour is available and suitable quarried rock is available at low price. This lining has been used in the Tungabhadra project.

Brick Lining

Bricks are laid in layers of two with about 1.25 cm of 1:3 cement mortar sandwiched in between. Good quality bricks should be used and these should be soaked well in water before being laid on the moistened canal surface. Brick lining is suitable when concrete is expensive and skilled labour is not available. Brick lining is favoured where conditions of low wages, absence of mechanisations, shortage of cement and inadequate means of transportation exist. Brick linings have been extensively used in north India. The Sarda power channel has been lined with bricks. The thickness of the brick lining remains fixed even if the sub-grade is uneven. Brick lining can be easily laid in rounded sections without form work. Rigid control in brick masonry is not necessary. Sometimes reinforced brick linings are also used.

Boulder Lining

Boulder lining of canals, if economically feasible, is useful for preventing erosion and where the ground water level is above the bed of the canal and there is a possibility of occurrence of damaging back pressures. The stones used for boulder linings should be sound, hard, durable, and capable of sustaining weathering and water action. Rounded or sub-angular river cobbles or blasted rock pieces with sufficient base area are recommended types of stones for boulder lining.

Asphaltic Lining

The material used for asphaltic lining is asphalt-based combination of cement and sand mixed in hot condition. The most commonly used asphaltic linings are: (a) asphaltic concrete, and (b) buried asphaltic membrane. Asphaltic linings are relatively cheaper, flexible, and can be rapidly laid in any time of year. Because of their flexibility, minor movements of the sub-grade are not of serious concern. However, asphaltic linings have short life and are unable to permit high velocity of flow. They have low resistance to weed growth and, hence, it is advisable to sterilise the sub-grade to prevent weed growth. Asphaltic concrete is a mixture of asphalt cement, sand, and gravel mixed at a temperature of about 110°C and is placed either manually or with laying equipment. Experienced and trained workmen are required for the purpose. The lining is compacted with heavy iron plates while it is hot. A properly constructed asphaltic concrete lining is the best of all asphaltic linings. Asphaltic concrete lining is smooth, flexible, and erosion-resistant. Since asphaltic concrete lining becomes distorted at higher temperatures, it is unsuitable for warmer climatic regions. An asphaltic concrete lining is preferred to a concrete lining in situations where the aggregate is likely to react with the alkali constituents of Portland cement.

Buried asphaltic membrane can be of two types:

(a) Hot-sprayed asphaltic membrane, and

(b) Pre-fabricated asphaltic membrane.

A hot-sprayed asphaltic membrane is constructed by spraying hot asphalt on the Sub-grade to result in a layer about 6 mm thick. This layer, after cooling, is covered with a layer of earth material about 30 cm thick. The asphalt temperature is around 200°C and the spraying pressure about 3 × 105 N/m2. For this type of lining, the channel has to be over-excavated. The lining is flexible and easily adopts to the sub-grade surface. Skilled workmen are required for the construction of this type of lining. Pre-fabricated asphaltic membrane is prepared by coating rolls of heavy paper with a 5mm layer of asphalt or 3 mm of glass fibre-reinforced asphalt. These rolls of pre-fabricated asphaltic membrane are laid on the sub-grade and then covered with earth material. These linings can be constructed by commonly available labour. Materials used for covering the asphaltic membrane determine the permissible velocities which are generally lower than the velocities in unlined canals. Maintenance cost of such linings is high. Cleaning operations should be carried out carefully so as not to damage the membrane.

Earth Linings

Different types of earth linings have been used in irrigation canals. They are inexpensive but require high maintenance expenditure. The main types of earth linings are: (a) stabilised earth linings, (b) loose earth blankets, (c) compacted earth linings, (d) buried bentonite membranes, and (e) soil-cement linings.

Stabilised earth linings: Stabilised earth linings are constructed by stabilizing the Sub-grade. This can be done either physically or chemically. Physically stabilised linings are constructed by adding corrective materials (such as clay for granular subgrade) to the subgrade, mixing, and then compacting. If corrective materials are not required, the subgrade can be stabilised by scarifying, adding moisture, and then compacting. Chemically stabilised linings use chemicals which may tighten the soil. Such use of chemicals, however, has not developed much.

Loose earth blankets: This type of lining is constructed by dumping fine-grained soils, such as clay, on the subgrade and spreading it so as to form a layer 15 to 30 cm thick. Such linings reduce seepage only temporarily and are soon removed by erosion unless covered with gravel. Better results can be obtained by saturating the clay and then pugging it before dumping on the subgrade. The layer of pugged clay is protected by a cover of about 30 cm silt. This type of lining requires flatter side slopes.

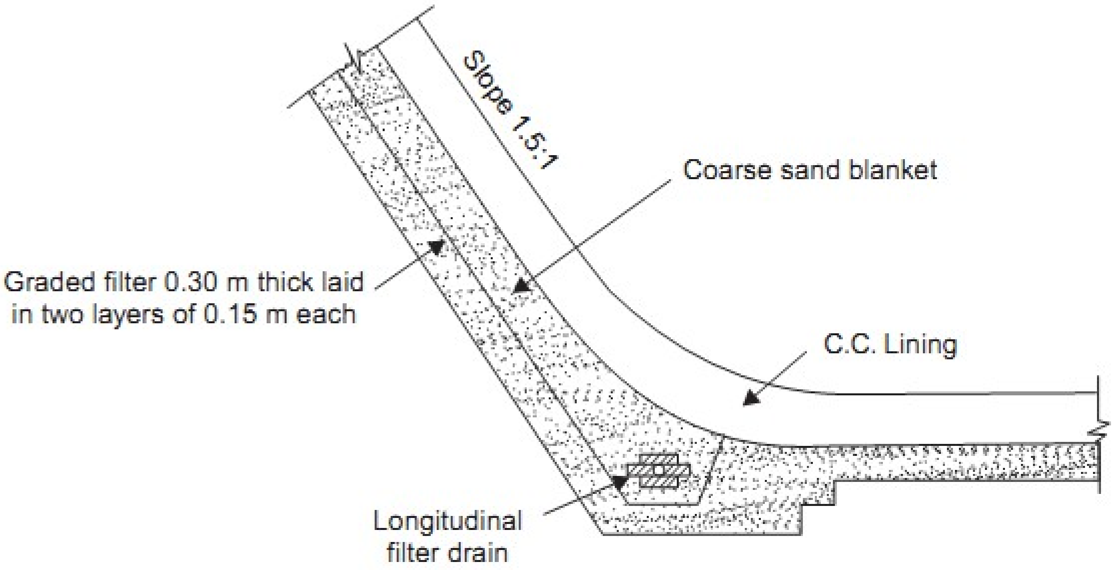
Compacted earth linings: These linings are constructed by placing graded soils on the subgrade and then compacting it. The graded soil should contain about 15% of clay. The compacted earth linings may be either thin-compacted or thick-compacted. In thin-compacted linings, the layer thickness of about 15 to 30 cm along the entire perimeter is used. Thick compacted linings have a layer about 60 cm thick on the channel bed and 90 cm thick on the sides. If properly constructed, both types are reasonably satisfactory. However, the thick linings are generally preferred. Compacted-earth linings are feasible when excavated materials are suitable, or when suitable materials are available nearby. Compaction operations along the side slopes are more difficult (particularly in thin-compacted linings) than along the channel bed. The lining material should be tested in the laboratory for density, permeability, and optimum moisture contents.

The material must be compacted in the field so as to obtain the desired characteristics. Buried Bentonite Membranes: Pure bentonite is a hydrous silicate of alumina. Natural deposits of bentonite are special types of clay soil which swell considerably when wetted. The impurities of these soils affect the swelling and, hence, the suitability of these as canal lining material. Buried bentonite linings are constructed by spreading soil-bentonite mixtures over the subgrade and covering it with about 15 to 30 cm of gravel or compacted earth. Sandy soil mixed with about 5 to 25 per cent of fine-grained bentonite and compacted to a thickness of 5 to 7.5 cm results in a membrane which is reasonably tough and suitable for lining.

Soil-cement Linings: These linings are constructed using cement (15 to 20 per cent by volume) and sandy soil (not containing more than about 35 per cent of silt and clay particles). Cement and sandy soil can be mixed in place and compacted at the optimum moisture content. This method of construction is termed the dry-mixed soil-cement method. Alternatively, soil-cement lining can be constructed by machine mixing the cement and soil with water and placing it on the subgrade in a suitable manner. This method is called the plastic soil-cement method and is preferable. In both these methods, the lining should be kept moist for about seven days to permit adequate curing. The construction cost of soil-cement linings is relatively high. But these resist weed growth and erosion and also permit velocities slightly higher than those permitted by unlined earth channels. The use of soil-cement linings for irrigation canals is restricted to small irrigation canals with capacities of up to 10 m3/s and in which the velocity of water does not exceed 1 m/s (18).

Failure of Lining

The main causes of failure of lining are the water pressure that builds up behind the lining material due to high water table, saturation of the embankment by canal water, sudden lowering of water levels in the channel, and saturation of the embankment sustained by continuous rainfall. The embankment of a relatively pervious soil does not need drainage measures behind the lining. In all situations requiring drainage measures to relieve pore pressure behind the lining, a series of longitudinal and transverse drains satisfying filter criteria are provided. A typical arrangement of longitudinal filter drain is as shown in Fig below:



(Longitudinal filter drain)

The growth of weeds on canal banks and other aquatic plant in channels may not result in failure of the lining but would affect the conveyance of channels which may be lined or unlined. Weeds and aquatic plants consume water for their growth and thus the consumptive use of irrigation water increases. Weed growth increases channel roughness and, hence, reduces the flow velocity thereby increasing evaporation losses. The cleaning of channels having excessive weed growth is, therefore, a vital maintenance problem. Cleaning operations can be carried out manually or by mechanical devices, such as used in dragline excavation and tractor-drawn cranes. Commonly used methods are pasturing, mowing, burning, and applying chemical weed killers.

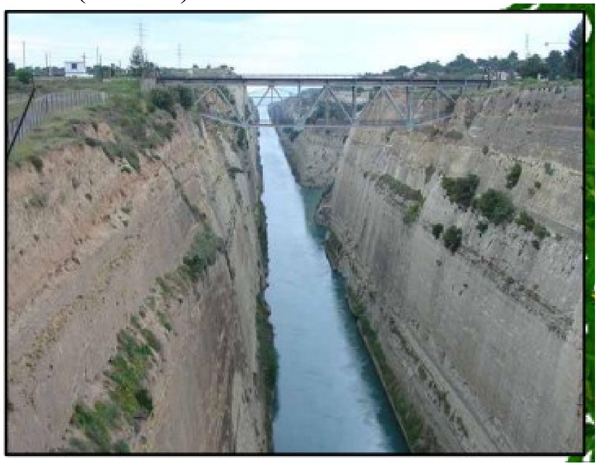
CANAL DESIGN TYPES

Canal Design

i) Drainage channel design
ii) Irrigation canal design

Design Parameters:-

- The design considerations naturally vary according to the type of soil.
- Velocity of flow in the canal should be critical.
- Design of canals which are known as 'Kennedy's theory' and 'Lacey's theory' are based on the characteristics of sediment load (i.e. silt) in canal water.



Terms Associated with Canal Design:-

- Alluvial soil
- Non-alluvial soil
- Silt factor
- Co-efficient of rugosity
- Mean velocity
- Critical velocity
- Critical velocity ratio (c.v.r), m
- Regime channel
- Hydraulic mean depth
- Full supply discharge
- Economical section

Alluvial Soil:

The soil which is formed by the continuous deposition of silt is known as alluvial soil. The river carries heavy charge of silt in rainy season. When the river overflows its banks during the flood, the silt particles get deposited on the adjoining areas. This deposition of silt continues year after year. This type of soil is found in deltaic region of a river. This soil is permeable and soft and very fertile. The river passing through this type of soil has a tendency to change its course.

Non-alluvial Soil:

The soil which is formed by the disintegration of rock formations is known as non-alluvial soil. It is found in the mountainous region of a river. The soil is hard and impermeable in nature. This is not fertile. The river passing through this type of soil has no tendency to change its course.

Silt Factor:

During the investigations works in various canals in alluvial soil, Gerald Lacey established the effect of silt on the determination of discharge and the canal section. So, Lacey introduced a factor which is known as 'silt factor'. It depends on the mean particle size of silt. It is denoted by 'f'. The silt factor is determined by the expression,

Where mean particle size of silt in mm

Silt Type	Particle Size (mm)	Silt Factor
Very Fine	0.05	0.40
Fine	0.12	0.60
Medium	0.23	0.85
Coarse	0.32	1.00

Coefficient of Rugosity (n)

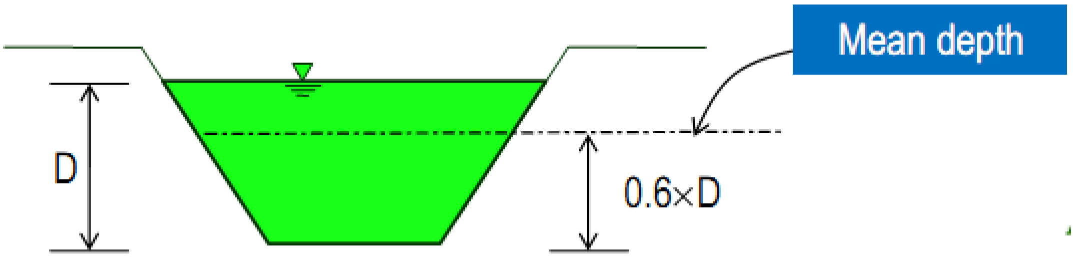
The roughness of the canal bed affects the velocity of flow. The roughness is caused due to the ripples formed on the bed of the canal. So, a coefficient was introduced by R.G Kennedy for calculating the mean velocity of flow. This coefficient is known as *coefficient of rugosity* and it is denoted by 'n'. The value of 'n' depends on the type of bed materials of the canal.

Material	Value of n
Earth	0.0225
Masonry	0.02

Concrete	0.013-0.018

Mean Velocity

It is found by observations that the velocity at a depth 0.6D represents the mean velocity (V), where 'D' is the depth of water in the canal or river.



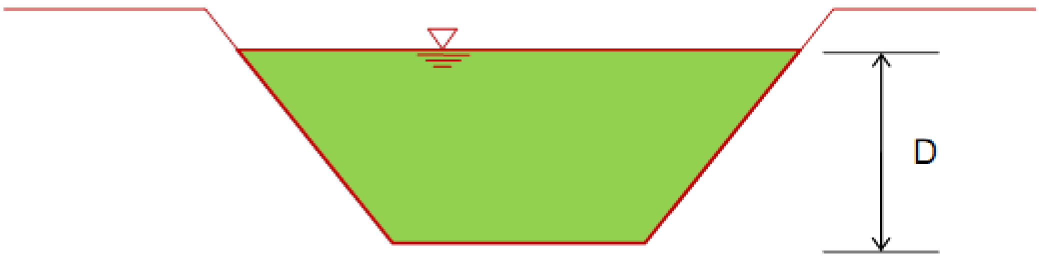
(a) Mean Velocity by Chezy's expression:

(b) Mean Velocity by Manning's expression:

Critical velocity:

When the velocity of flow is such that there is no silting or scouring action in the canal bed, then that velocity is known as critical velocity. It is denoted by 'Vo'. The value of V_0 as given by Kennedy according to the following expression,

Where D = Depth of water



Critical velocity ratio (C.V.R):

The ratio of mean velocity 'V' to the critical velocity 'Vo' is known as critical velocity ratio (CVR). It is denoted by m i.e.

When m = 1, there will be no silting or scouring.
When m > 1, scouring will occur
When m < 1, silting will occur
So, by finding the value of m, the condition of the canal can be predicted whether it will have silting or scouring.

Regime Channel:

When the character of the bed and bank materials of the channel are same as that of the transported materials and when the silt charge and silt grade are constant, then the channel is said to be in its regime and the channel is called regime channel. This ideal condition is not practically possible.

Hydraulic Mean Depth/Ratio:

The ratio of the cross-sectional area of flow to the wetted perimeter of the channel is known as hydraulic mean depth or radius. It is generally denoted by R.

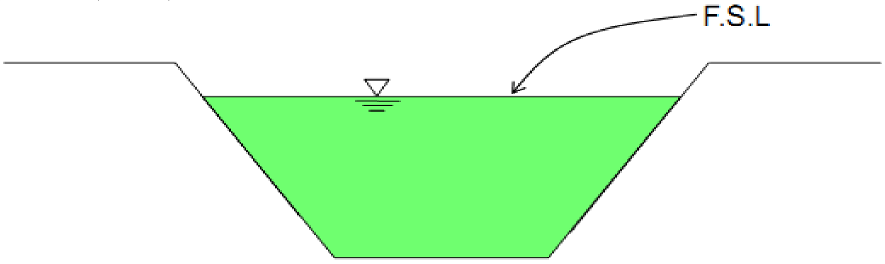
Where,

A = Cross-sectional area

P = Wetted perimeter

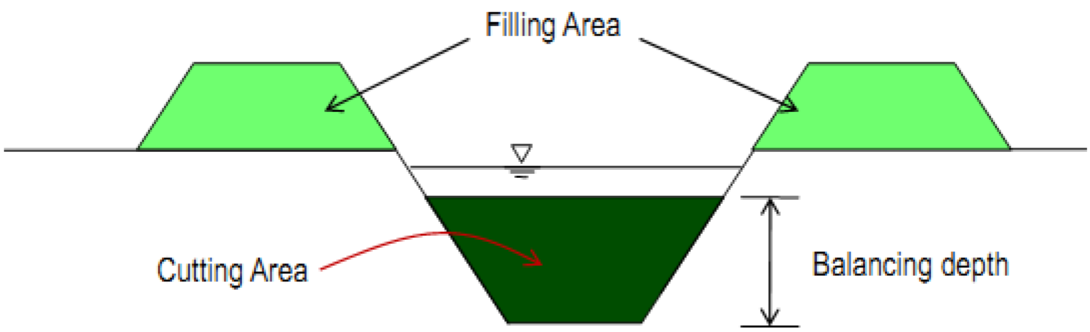
Full Supply Discharge:

The maximum capacity of the canal for which it is designed, is known as full supply discharge. The water level of the canal corresponding to the full supply discharge is known as full supply level (F.S.L).



Economical Section:

If a canal section is such that the earth obtained from cutting (i.e. excavation) can be fully utilized in forming the banks, then that section is known as economical section. Again, the discharge will be maximum with minimum cross-section area. Here, no extra earth is required from borrow pit and no earth is in excess to form the spoil bank. This condition can only arise in case of partial cutting and partial banking. Sometimes, this condition is designated as balancing of cutting and banking. Here, the depth of cutting is called balancing depth.



Unlined Canal Design on Non-alluvial soil:

The non-alluvial soils are stable and nearly impervious. For the design of canal in this type of soil, the coefficient of rugosity plays an important role, but the other factor like silt factor has no role. Here, the velocity of flow is considered very close to critical velocity. So, the mean velocity given by Chezy's expression or Manning's expression is considered for the design of canal in this soil. The following formulae are adopted for the design.

(1) Mean velocity by Chezy's formula

Where,

V = mean velocity in m/sec,

C = Chezy's constant,

R = hydraulic mean depth in m

S = bed slope of canal as 1 in n.

Again, the Chezy's constant C can be calculated by:

(a) Bazin's Formula:

Where,

K = Bazin's constant,
R = hydraulic mean depth

(b) Kutter's Formula:

Where,
n = Co-efficient of rugosity,
S = bed slope,
R = hydraulic mean depth

(2) Mean velocity by Manning's formula

(3) Discharge by the following equations:

Where,
Q = discharge in cumec
A = cross-sectional area of water section in m2
V = mean velocity in m/sec

Example-1

Design an irrigation channel with the following data:
Discharge of the canal = 24 cumec
Permissible mean velocity = 0.80 m/sec.
Bed slope = 1 in 5000
Side slope = 1:1
Chezy's constant, C = 44

Solution:-

We know, A = 24/0.80 = 30 m2
30 = (B + D) D
And P = B + 2.828 D
But, R = 30/ (B + 2.828 D)
From Chezy's formula,

Putting the value of R and solving, D = 2.09 m and B = 12.27 m

Problem – 1

Design a most economical trapezoidal section of a canal having the following data:
Discharge of the canal = 20 cumec
Permissible mean velocity = 0.85 m/sec.
Bazin's constant, K = 1.30
Side slope = 1.5:1
Find also the allowable bed slope of the canal

Problem – 2

Find the bed width and bed slope of a canal having the following data:
Discharge of the canal = 40 cumec
Permissible mean velocity = 0.95 m/sec.
Coefficient of rugosity, n = 0.0225
Side slope = 1:1
B/D ratio = 6.5

Problem – 3

Find the efficient cross-section of a canal having the discharge 10 cumec. Assume, bed slope 1 in 5000, value of n = 0.0025, C.V.R (m) = 1, full supply depth not to exceed 1.60 m and side slope = 1:1

Unlined Canal Design on Alluvial soil by Kennedy's Theory

After long investigations, R.G Kennedy arrived at a theory which states that, the silt carried by flowing water in a channel is kept in suspension by the vertical component of eddy current which is formed over the entire bed width of the channel and the suspended silt rises up gently towards the surface.

The following assumptions are made in support of his theory:

- The eddy current is developed due to the roughness of the bed.
- The quality of the suspended silt is proportional to bed width.
- It is applicable to those channels which are flowing through the bed consisting of sandy silt or same grade of silt.
- It is applicable to those channels which are flowing through the bed consisting of sandy silt or same grade of silt.

He established the idea of critical velocity 'Vo' which will make a channel free from silting or scouring. From, long observations, he established a relation between the critical velocity and the full supply depth as follows,

The values of C and n where found out as 0.546 and 0.64 respectively, thus

Again, the realized that the critical velocity was affected by the grade of silt. So, he introduced another factor (m) which is known as critical velocity ratio (C.V.R).

Drawbacks of Kennedy's Theory

- The theory is limited to average regime channel only.
- The design of channel is based on the trial and error method.
- The value of m was fixed arbitrarily.
- Silt charge and silt grade are not considered.
- There is no equation for determining the bed slope and it depends on Kutter's equation only.
- The ratio of 'B' to 'D' has no significance in his theory.

Design Procedure:-

1) Critical velocity,
2) Mean velocity,

Where, m = critical velocity ratio,
D = full supply depth in m,
R = hydraulic mean depth of radius in m,
S = bed slope as 1 in ‘n’.

3) The value of ‘C’ is calculated by Kutter’s formula,

Where, n = rugosity coefficient which is taken as unlined earthen channel.

4) B/D ratio is assumed between 3.5 to 12.
5) Discharge

Where, A = Cross-section area in m2,
V = mean velocity in m/sec

6) The full supply depth is fixed by trial to satisfy the value of ‘m’. Generally, the trial depth is assumed between 1 m to 2 m. If the condition is not satisfied within this limit, then it may be assumed accordingly.