HYDRAULIC AND IRRIGATION ENGINEERING

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2.1 Soil–Water Relationships

Any given volume *V* of soil (Fig. 2.1) consists of : (*i*) volume of solids *Vs* , (*ii*) volume of liquids(water) *Vw*, and (*iii*) volume of gas (air) *Va*. Obviously, the volume of voids (or pore spaces) *Vv*=*Vw*+ *Va*. For a fully saturated soil sample, *Va*= 0 and *Vv*= *Vw*. Likewise, for a completely dryspecimen, *Vw*= 0 and *Vv*= *Va*. The weight of air is considered zero compared to the weightsof 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, $w = Sn$

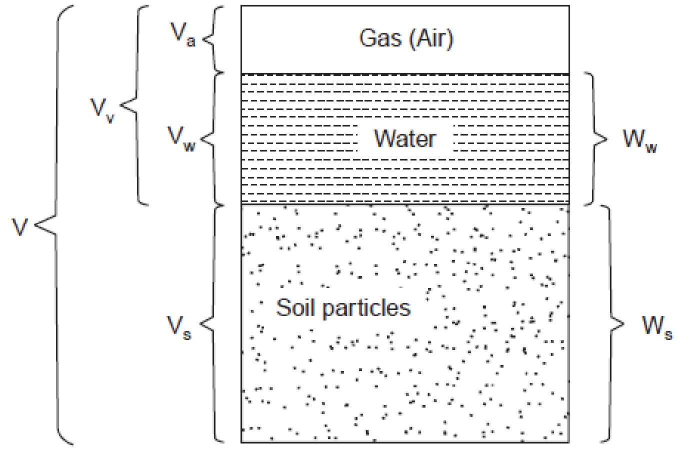

Fig.2.1 Occupation of Space in a Soil Sample

It should be noted that the value of porosity *n* is always less than 1.0. But, the value ofvoid ratio *e* may be less, equal to, or greater than 1.0.Further, if the weight of water in a wet soil sample is *Ww*and the dry weight of thesample is *Ws*, then the dry weight moisture fraction, *W* is expressed as

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

The bulk density (or the bulk specific weight or the bulk unit weight) $\gamma_b$of a soil mass isthe total weight of the soil (including water) per unit bulk volume, *i.e.*,

$$\gamma_b = \frac{W_T}{V}$$

$$W_T = W_s + W_w$$

The specific weight (or the unit weight) of the solid particles is the ratio of dry weight ofthe soil particles *Ws*to the volume of the soil particles *Vs*, *i.e.*, *Ws*/*Vs*. Thus,

$$G_b\,\gamma_w = \frac{W_s}{V} \qquad i.e.,\ V = \frac{W_s}{G_b\gamma_w}$$

and $$G_s\,\gamma_w = \frac{W_s}{V_s} \quad i.e., \quad V_s = \frac{W_s}{G_s\gamma_w}$$

∴ $$\frac{V_s}{V} = \frac{G_b}{G_s}$$

Here, γ_w is the unit weight of water and G_b and G_s are, respectively, the bulk sp gravity of soil and the relative density of soil grains. Further,

$$1 - n = 1 - \frac{V_v}{V} = \frac{V - V_v}{V} = \frac{V_s}{V} = \frac{G_b}{G_s}$$

∴ $$G_b = G_s(1 - n)$$

Also, $$w = \frac{V_w}{V} = \frac{W_w / \gamma_w}{W_s / (G_b\gamma_w)} = G_b\frac{W_w}{W_s}$$

∴ $$w = G_b W$$

and $$w = G_s(1 - n)W$$

Considering a soil of root-zone depth d and surface area A (*i.e.*, bulk volume = Ad

$$W_s = V_s G_s \gamma_w = Ad\,(1 - n)\,G_s\gamma_w$$

Therefore, the dry weight moisture fraction, $W = \dfrac{W_w}{W_s}$

$$= \frac{V_w\gamma_w}{Ad\,(1 - n)\,G_s\gamma_w}$$

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

$$V_w = W\,Ad\,(1 - n)\,G_s$$

2.2 Soil Moisture and its functions

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.

Crop growth (or yield) is directly affected by the soil moisture content in the root zone.

The root zone is defined as the volume of soil or fractured rock occupied by roots of the plants from which plants can extract water. Both excessive water (which results in waterlogging) and deficient water in the root-zone soil retard crop growth and reduce the crop yield. 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 smallfraction of this moisture under drought conditions.

When an oven-dry (heated to 105°C for zero per cent moisture content) soil sample is exposed to atmosphere, it takes up some moisture called *hygroscopic moisture*. If more water is made available, it can be retained as capillary moisture due to surface tension (*i.e.*, intermolecular forces). Any water, in excess of maximum capillary moisture, flows down freely and is the gravitational (or gravity) water.

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. Field capacity is measured in terms of the moisture fraction, $W_{fc}= (W_w/W_s)$ of the soil when, after thorough wetting of the soil, free drainage (at rapid rate) has essentially stopped and further drainage, if any, occurs at a very slow rate. An irrigated soil, *i.e.*, adequately wetted soil, may take approximately one (in case of sandy soil) to three (in case of clayey soil) days for the rapid drainage to stop. This condition corresponds to a surface tension of one-tenth bar (in case of sandy soils) to one-third bar (in case of clayey soils). Obviously, the field capacity depends on porosity and soil moisture tension. The volumetric moisture content at the field capacity w_{fc}becomes equal to G_bW_{fc}.Plants are capable of extracting water from their root-zone soil to meet their transpiration demands. But, absence of further addition to the soil moisture may result in very low availability of soil water and under such a condition the water is held so tightly in the soil pores that the rate of water absorption by plants may not meet their transpiration demands and the plants may either wilt or even die, if not supplied with water immediately and well before the plants wilt. After wilting, however, a plant may not regain its strength and freshness even if the soil is saturated with water.

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. The soil moisture tension at this condition is around 15 bars. The moisture content at the permanent wilting condition will be higher in a hot climate than in a cold climate. Similarly, the percentage of soil moisture at the permanent wilting point of a plant will be larger in clayey soil than in sandy soil. The permanent wilting point is, obviously, at the lower end of the available moisture range and can be approximately estimated by dividing the field capacity by a factor varying from 2.0 (for soils with low silt content) to 2.4 (for soils with high silt content). The permanent wilting point also depends upon the nature of crop. The difference in the moisture content of the soil between its field capacity and the permanent wilting point within the root zone of the plants is termed *available moisture*. It represents the maximum moisture which can be stored in the soil for plant use. It should be noted that the soil moisture content near the wilting point is not easily extractable by the plants. Hence, the term *readily available moisture* is used to represent that fraction of the available moisture which can be easily extracted by the plants. Readily available moisture is approximately 75% of the available moisture.

2.3 Crop water requirement- Delta, Duty and Consumptive use

It is essential to know the water requirement of a crop which is the total quantity of water required from its sowing time up to harvest. Naturally different crops may have different water requirements at different places of the same country, depending upon the climate, type of soil, method of cultivation, effective rain etc.

The total water required for crop growth is not uniformly distributed over its entire life span which is also called **crop period**. Actually, the watering stops some time before harvest and the time duration from the first irrigation during sowing up to the last before harvest is called **base period**. Though crop period is slightly more than the base period, they do not differ from practical purposes. Figure 2.2, indicates the relative usage of water for a typical crop during its entire growth period.

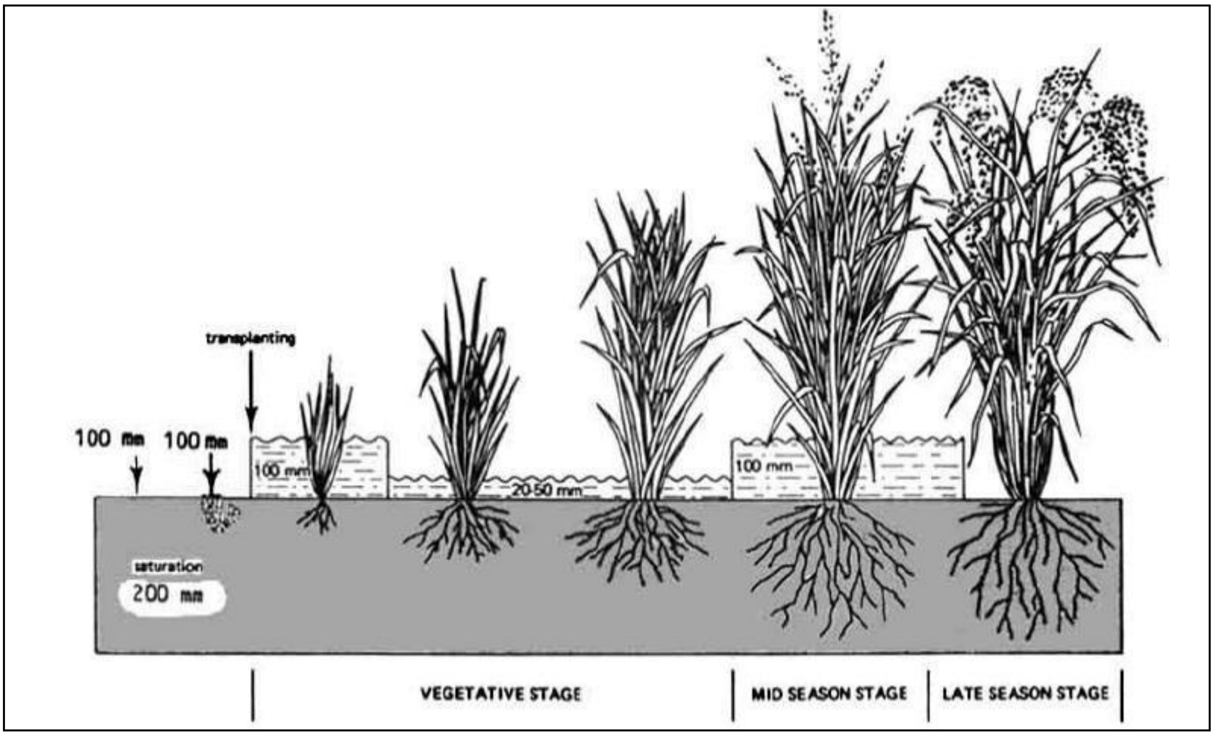

Fig.2.2 Variation in the Requirement of Water for Paddy with Stage of Growth
(Image courtesy: Food and Agricultural Organisation, FAO)

Sometimes, in the initial stages before the crop is sown, the land is very dry. In such cases, the soil is moistened with water as t helps in sowing the crops. This is known as ***paleo*** irrigation. A term ***kor*** watering is used to describe the watering given to a crop when the plants are still young. It is usually the maximum single watering required, and other waterings are done at usual intervals.

2.3.1 Delta

The total depth of water required to raise a crop over a unit area of land is usually called ***delta***. It is denoted by Δ. It should be noted that the entire requirement of water is not fulfilled in a single watering. Watering is done in instalments (Δ1, Δ2….Δn). Therefore the total depth of water supplied over the entire crop period is the summation of these small instalments of waterings. Some typical values of delta for common crops in some regions of India are as follows:

Rice

- 1000mm to 1500mm for heavy soils or high water table
- 1500mm to 2000mm for medium soils
- 2000 to 2500 for light soils or deep water table
- 1600mm for upland conditions

Wheat

- 250mm to 400mm in northern India
- 500mm to 600mm in Central India
- Barley: 450mm

Maize

- 100mm during rainy season
- 500mm during winter season
- 900mm during summer season
- Cotton: 400 – 500mm

Sugarcane

- 1400mm to 1500mm in Bihar
- 1600mm to 1700mm in Andhra Pradesh
- 1700mm to 1800mm in Punjab

- 2200mm to 2400mm in Madhya Pradesh
- 2800mm to 3000mm in Maharashtra

2.3.2 Duty of water

The term ***duty*** means the area of land that can be irrigated with unit volume of irrigation water. Quantitatively, duty is defined as the area of land expressed in hectares that can be irrigated with unit discharge, that is, 1 cumec flowing throughout the base period, expressed in days. 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.If the water supplied is just enough to raise the crop within D hectares of the field, then a **relationship** may be found out amongst all the variables as:

Relationship between Duty(D), Delta(Δ) and Base Period(B)

If 1 cumec of water i.e. $1m^3/s$ is supplied for the entire base period of 'B' days, the quantity of water in m3 of water could be expressed as:

Total Quantity of water supplied(in terms of base period) $= 1m^3/s \times B$ days

$=1x24x60x60xB$

$= 86400B\ m^3$ ------- (i)

Total Quantity of water supplied(in terms of Duty and Delta)= D(hectares)x Δm

$= Dx10^4x\ \Delta\ \ m^3$ ------------------(ii)

(one hectare=10^4 Sq. metre))

Equating i) and ii)

86400B == Dx104x Δ ,

D= 8.64B/ Δ

where D is in hectares,

B is in days and

Δ in metres

Hence, knowing two of the three variables B, D and Δ the third party may be found out.

The duty of irrigation water depends upon a number of factors; some of the important ones are as follows:

- **Type of crop:** As different crops require different amount of water for maturity, duties are also required. The duty would vary inversely as the water requirement of crop.

- **Climate season and type of soil:** Some water applied to the field is expected to be lost through evaporation and deep percolation.

Evaporation loss has a direct bearing on the prevalent climate and percolation may be during drier seasons when the water table is low and soil is also dry. Percolation loss would be more for sandy soils than silty or clayey soils.

- **Efficiency of cultivation methods:** If the tillage and methods of water application are faulty and less efficient, then the amount of water actually reaching the plant roots would be less. Hence, for proper crop growth more water would be required than an equivalent efficient system. Also, if the water is conveyed over long distances through field channels before being finally applied to the field, then also the duty will rise due to the losses taking place in the channels.

2.3.3 Consumptive Use, its variation and estimation

The total water need for various plants, known as delta, has been discussed earlier. However, in planning the supply of irrigation water to a field crop, it is essential to estimate the water requirement of each plot of land growing a crop or crops at any point of time. This may be done by studying the dynamic interaction between a crop and the prevalent climate and the consequent water requirement. The demand would, naturally be also dependant on the type of crop and its stage of growth. Plant roots extract water from the soil. Most of this water doesn't remain in the plant, but escapes to the atmosphere as vapour through the plants leaves and stems, a process which is called ***transpiration*** and occurs mostly during daytime. The water on the soil surface as well as the water attaching to the leaves and stem of a plant during a rainfall also is lost to the atmosphere by evaporation. Hence, the **consumptive water need** of a crop consists of transpiration plus evaporation, together called ***evapotranspiration***.

The effect of the major climatic factors on crop water needs may be summarized as follows:

- Sunshine
- Temperature

• Humidity

• Wind speed

Since the same crop grown in different climatic variations have different water needs, it has been accepted to evaluate the evapotranspiration rate for a standard or reference crop and find out that of all other crops in terms of this reference. Grass has been chosen as standard reference for this purpose. The evapotranspiration rate of this standard grass is, therefore, called the ***reference crop evapotranspiration*** and is denoted as ET_o, which is of course, the function of the climatic variables.

Estimation of reference crop ET_o

Of the many methods available, the commonly used ones are two:

i. Experimental methods, using the experimentation data from evaporation pan and lysimeters.

ii. Theoretical methods using empirical formulae, that take into account, climatic parameters.

Experimental method

Estimation of ET_0 can be made using the formula

$$ET_O = Kpan \times Epan \quad (2)$$

Where ET_O is the ***reference crop evapotranspiration*** in mm/day, Kpan is a coefficient called ***pan coefficient*** and Epan is the ***evaporation*** in mm/day from the pan. The factor Kpan varies with the position of the equipment (say, whether placed in a fallow area or a cropped area), humidity and wind speed. Generally, the details are supplied by the manufacturers of the pan. For the ***US Class A evaporation pan***, which is also used in India, Kpan varies between 0.35 and 0.85, with an average value of 0.7. It may be noticed that finding out ET_C would involve the following expression

$$ET_C = Kcrop \times ET_O = Kc \times Epan \times Kpan \quad (3)$$

K_C has been discussed in the previous section. If instead, Kcrop x Kpan is taken as a single factor, say K, then ET_C may directly be found from Epan as under:

$$ET_C = K \times Epan, \text{ where K may be called the crop factor} \quad (4)$$

The water management division of the Department of Agriculture, Government of India has published a list of factors for common crops and depending upon the stage of growth, which have to be multiplied with the evaporation values of the USWB Class A evaporation pan.

Theoretical methods

The important methods that have been proposed over the years take into account, various climatic parameters. Of these, only the following would be discussed, as they are the most commonly used.

Blanney-Criddle formula:

This formula gives an estimate of the mean monthly values of ET_O, which is stated as

ET_O = p (0.46Tmean + 8.13) (5)

Where p is the mean daily percentage of annual day time hours and has been estimated according to latitude; Tmean is the mean monthly temperature in degrees Centigrade and may be taken as ½ x (Tmax + Tmin) for a particular month. Thus using the Equation (1), one may evaluate ET_C for each month of the growing season, from which the total water need for the full growing season of the crop may be found out.

Penman-Monteith method:

This method suggests that the value of ET_O may be evaluated by the following formula:

$$ET_O = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where the variables have the following meanings:

ET_o reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [MJ m^{-2} day^{-1}], G soil heat flux density [MJ m^{-2} day^{-1}], T mean daily air temperature at 2 m height [°C], u_2 wind speed at 2 m height [m s^{-1}], e_s saturation vapour pressure [kPa], e_a actual vapour pressure [kPa], e_s - e_a saturation vapour pressure deficit [kPa], Δ slope vapour pressure curve [kPa °C^{-1}], g psychrometric constant [kPa °C^{-1}].

2.4 Irrigation Requirements

The water that is required to irrigate a field or plot of land growing the particular crop not only has to satisfy the evapotranspiration needs for growing the crop, but would also include the following:

- Losses in the form of deep percolation while conveying water from the inlet of the field up to its last or tail end as the water gets distributed within the field

- Water requirement for special operations like land preparation, transplanting, leaching of salts, etc.

Further, the evapotranspiration requirement of crops (ET) really doesn't include the water required by crops for building up plant tissues, which is rather negligible compared to the evaporation needs. Hence ET_C is often equivalently taken as the ***consumptive irrigation requirement*** (CIR).

The ***net irrigation requirement*** (NIR) is defined as the amount of irrigation water required to be delivered in the field to meet the consumptive requirement of crop as well as other needs such as leaching, ***pre-sowing*** and ***nursery water requirement*** (if any). Thus,

$$NIR = CIR + LR + PSR + NWR \quad (8)$$

Where

LR = Leaching requirement

PSR = Pre-sowing requirement

NWR = Nursery water requirement

Field Irrigation Requirement (FIR) is defined as the amount of water required to meet the net irrigation requirements plus the amount of water lost as surface runoff and through deep percolation. Considering a factor η_a called the water application efficiency or the field application efficiency which accounts for the loss of irrigation water during its application over the field, we have

$$FIR = \frac{NIR}{\eta_a}$$

Now, consider an irrigated area where there is a single source of water (say, a ground water pump) is supplying water to a number of fields and water is applied to each field by rotation (Figure 8). Naturally, some water is lost through the respective turnouts. Hence, the source must supply a larger amount of water than that required at any point of time by adding up the flows to the fields turnouts that are open at that point of time. Thus, the capacity of the water supply source may be termed as the ***gross irrigation requirement*** (GIR), defined as:

$$GIR = \frac{FIR}{\eta_c}$$

In the above equation, η_c is the ***water conveyance efficiency***.

2.5 Crop Seasons and major Indian crops

Activities relating to crops go on continuously throughout the year in India. In north India, there are two main crop seasons. These are '*Kharif*' (July to October) and '*Rabi*' (October to March). Crops grown between March and June are known as '*Zaid*'. In other parts of the country there are no such distinct seasons but some kind of classification of crop seasons exists everywhere. The Kharif season is characterised by a gradual fall in temperature, larger number of rainy days, low light intensity, a gradual shortening of the photoperiod, high relative humidity, and cyclonic weather. On the other hand, bright sunshine, near absence of cloudy days, and lower relative humidity are the characteristics of the Rabi season. The Kharif season starts earlier in the eastern part of the country because of the earlier arrival of the monsoon and continues until the withdrawal of the monsoon. On the other hand, the Rabi season starts earlier in the western part and continues until the sun attains equatorial position. Thus, Kharif is longer in the eastern part and Rabi is longer in the western part.

There are several cropping patterns which are followed in India depending upon the climatic, edaphic, socio-economic conditions of the region. With a geographic area of about 329 Mha, stretching between 8°N and 36°N latitude and between 68°E and 98°E longitude, and its altitude varying from the mean sea level to the highest mountain ranges of the world, India hosts a variety of flora and fauna in its soil with few parallels in the world. The country has an average annual rainfall of 1,143 mm which varies from 11,489 mm around Cherrapunji in Assam to 217 mm around Jaisalmer in Rajasthan. Just as rainfall and temperature vary over a wide range, there is considerable difference in the socio-economic conditions of peasants of different parts of the country. Due to the variation in soil-climatic conditions there exists considerable variation in crop genotypes. Considering the potential of food grain production in different parts of India, the country has been divided into the following five agricultural regions:

(i) The eastern part including larger part of the north-eastern and south-eastern India, and another strip along the western coast form the rice region of India.

(ii) The wheat region occupies most of northern, western, and central India.

(iii) The millet (*bajra*)–sorghum (*jawar*) region comprising Rajasthan, Madhya Pradesh, and the Deccan plateau.

(iv) The Himalayan region of Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, and some adjoining areas in which potatoes, cereal crops (mainly maize and rice), and fruits are grown.

(v) The plantation crops (*e.g.* tea, coffee, rubber, and spices) are grown in Assam, hills of south India and peninsular region of India which form the plantation region.

2.5.1 Crops of Kharif Season

Kharif (or south-westerly monsoon) crops include rice, maize, *jawar, bajra,* groundnut, cotton and other crops.

Rice

Rice cultivation in India stretches from 8°N latitude to 34°N latitude. Rice is also grown in areas below the sea level (as in the Kuttanad region of Kerala) as well as at altitudes of about 2000 m (as in parts of Jammu and Kashmir). High rainfall or assured irrigation is essential for areas of rice cultivation. Rice crop requires about 30 cm of water per month during the growing period stretching from about 3 to 8 months. Rice is grown on about 40 Mha in the country. This area also includes about 7 Mha which is saline, alkaline or flood-prone. Twenty-five per cent of the rice growing area has assured irrigation and about 55 per cent of the rice growing area is ill-drained or waterlogged. The rest of the rice-growing area is rain fed uplands where the rainfall is marginal to moderate and its distribution is erratic. Rice cultivation in India is either upland cultivation or lowland cultivation. The upland system of cultivation is confined to such areas which do not have assured irrigation facilities. In this system, fields are ploughed in summer, farmyard manure is uniformly distributed 2–3 weeks before sowing, and the rain water is impounded in the field until the crop is about 45–60 days old.

In the lowland system of rice cultivation, the land is ploughed when 5–10 cm of water is standing in the field. Seeds may be sown after sprouting. Alternatively, seedling which are 25–
30 days old are transplanted. The nursery area required to provide seedlings for transplanting on one hectare is roughly one-twentieth of a hectare. The water requirement of lowland rice cultivation is much higher than that of other cereal crops with similar duration.

Maize

Maize is one of the main cereals of the world and ranks first in the average yield. Its world average yield of 27.8 quintals/hectare (q/ha) is followed by the average yields of rice (22.5 q/ha), wheat (16.3 q/ha) and millets (6.6 q/ha). In terms of area of maize cultivation, India ranks fifth (after USA, Brazil, China and Mexico) in the world. However, India stands eleventh in the world in terms of maize production. Within India, maize production ranks only next to rice, wheat, jawar, and bajra in terms of area as well as production. Most of the maize cultivation (around 75 per cent) is in the states of Uttar Pradesh (1.4Mha), Bihar (0.96 Mha), Madhya Pradesh (0.58 Mha), Rajasthan (0.78 Mha) and Punjab (0.52 Mha). Maize requires deep and well-drained fertile soils, but can be grown on any type of soil ranging from heavy clays to light sands provided that the pH does not deviate from the range 7.5 to 8.5. Maize plants, particularly in the seedling stage, are highly susceptible to salinity and waterlogging, and hence, proper drainage of the land is essential for the successful cultivation of maize. Over 85 per cent of the crop area in India is rainfed during the monsoon. Maize is essentially a warm weather crop grown in different regions of the world ranging from tropical to temperate ones. It cannot withstand frost at any stage of its growth. In India, its cultivation extends from the hot arid plains of Rajasthan and Gujarat to the wet regions of Assam and West Bengal. Maize is a short-duration (80–95 days) crop and, hence, can conveniently fit into a wide range of crop rotations. It is usually grown as a pure crop, but sometimes legumes (*e.g*., *moong*,*arhar*or beans), and quick-growing vegetables (*e.g.*, pumkins, gourds) are grown as mixed crops with it.

The sowing of maize starts 7–10 days before the usual date of the onset of monsoon. One irrigation at the initial stage is useful for the establishment of seedlings and the crop yield is increased by about 15–20 per cent. The maize crop is harvested when the grains are nearly dry and do not contain more than 20 per cent moisture. Maize is grown for grains as well as fodder.

Sorghum (Jawar)

Sorghum (popularly known as *jawar*) is the main food and fodder crop of dryland agriculture. It is grown over an area of about 18 Mha with the average yield of about 600 kg/ha. *Jawar* cultivation is concentrated mainly in the peninsular and central India. Andhra Pradesh, Gujarat,

Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, and Uttar Pradesh are the major *jawar*-growing states. *Jawar*is mainly grown where rainfall distribution ranges from 10–20 cm per month for at least 3 to 4 months of the south-westerly monsoon. Sorghum is grown during both Kharif (July–October) and Rabi (October–February) seasons. The Rabi cultivation of *jawar*constitutes about 37 per cent of the total *jawar*-growing area. Sorghum cultivation still remains predominantly traditional in most parts of the country. Mixed cropping of *jawar*and *arhar*(*tur*) is very common. Harvesting and threshing are still carried out manually or with bullock power. The national average yields are still low and around 500 kg/ha. However, the high-yielding hybrid varieties can yield 2000–3000 kg/ha under average growing conditions.

Spiked Millet (Bajra)

*Bajra*is a drought-resistant crop which is generally preferred in low rainfall areas and lighter soils. It is grown in Rajasthan, Maharashtra, Gujarat, and Uttar Pradesh. Over 66 per cent of this crop is grown in areas receiving 10–20 cm per month of rainfall, extending over 1 to 4 months of the south-westerly monsoons. It should be noted that *jawar*and *bajra*are grown mostly under identical environmental conditions and both have a wide range of adaptability to drought, temperature, and soil.

Groundnut

Groundnut is grown over an area of about 7 Mha concentrated in the states of Gujarat (24 percent), Andhra Pradesh (20 per cent), Karnataka (12 per cent), Maharashtra (12 per cent), and Tamil Nadu (13 per cent). Madhya Pradesh, Orissa, Punjab, Rajasthan, and Uttar Pradesh together have about 20 per cent of the total groundnut producing area in the country. Groundnut is generally grown as a rain fed Kharif crop. Groundnut is sown during May and June in the subtropics. In the tropics, however, it is sown during either January and February or June and

July. Under rain fed conditions the average yield is 1200–1400 kg per hectare.

Cotton

Cotton occupies about 7.5 Mha in India. Maharashtra (36 per cent), Gujarat (21 per cent), Karnataka (13 per cent), and Madhya Pradesh (9 per cent) are the leading states which together grow cotton over an area of about 6 Mha. Other cotton growing states are Punjab (5 per cent),

Andhra Pradesh (4 per cent), Tami Nadu (4 per cent), Haryana (3 per cent), and Rajasthan (3 per cent). Most of the cotton-growing areas in the country are in the high to medium rainfall zones. Cotton requires a well-drained soil. It is grown as a rain fed crop in the black cotton and medium black soils and as an irrigated crop in alluvial soils. The sowing season varies from region to region and starts early (April-May) in north India.

2.5.2 Crops of Rabi Season

Main crops of Rabi (Post-monsoon) season are wheat, barley and gram.

Wheat

In terms of production, wheat occupies the first place among the food crops in the world. In India, it is the second most important food crop, next only to rice. The Indo-Gangetic plains form the most important wheat area. The cool winters and hot summers are conducive to a good crop of wheat. Well-drained loams and clayey loams are considered good soils for the cultivation of wheat. However, good crops of wheat can be raised in sandy loams and black soils also. Wheat crop requires a well-pulverized but compact seedbed for good and uniform germination. Under irrigated conditions, the first fortnight of November is considered the optimum time for sowing the medium to long-duration wheats (*e.g.* the 'Kalyanasona' variety).

For short-duration wheats (*e.g.* the 'Sonalika' variety) the second fortnight of November is the optimum time of sowing. In eastern India, wheat is sown in the third week of December due to the late harvesting of paddy. In north-western India also, wheat sowings get delayed due to the late harvesting of paddy, sugarcane or potato.

For wheat sown under irrigated conditions, four to six irrigations are required. The first irrigation should be given at the stage of initiation of the crown root, *i.e.*, about 20–25 days after sowing. Two or three extra irrigations may be required in case of very light or sandy soils.

The crop is harvested when the grains harden and the straw becomes dry and brittle.

The harvesting time varies in different regions. In the peninsular region, harvesting starts in the latter half of February and is over in the first week of March. In the central zone, the peak season for harvesting is in the month of March. In the north-western zone, the peak harvesting period is the latter half of April. In the eastern zone, harvesting is over by mid–April. However, in the hills, the wheat crop is harvested in the months of May and June. Punjab, Haryana, Delhi, Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat, Bihar, and West Bengal together grow wheat over an area exceeding 70 per cent of the total area ofwheat crop for the country. These states also produce 76 percent of the total what production of India and have extensive irrigation systems covering from 85 per cent of the area in Punjab to 51 per cent in Bihar.

Barley

Barley (*Jau*) is an important rabi crop ranking next only to wheat. The total area under this crop is about 3.0 Mha, producing nearly 3 million tonnes of grain. Main barley growing states are Rajasthan, Uttar Pradesh, and Bihar which together grow barley over an area which is about 80 per cent of total barley growing area.

This crop can be grown successfully on all soils which are suitable for wheat cultivation. Barley crop needs less water and is tolerant to salinity. Recent experiments indicate that this crop can be grown on coastal saline soils of Sunderbans in West Bengal and on saline soils in areas of north Karnataka irrigated by canals.

The normal sowing season for barley extends from middle of October to the middle of November, but it can be sown as late as the first week of January. Barley is grown either on conserved moisture or under restricted irrigation. Generally, it needs two to three irrigations. On highly alkaline or saline soils, frequent light irrigations are given. Harvesting period for barley is between mid-March to mid-April. Harvesting starts in the month of February in Maharashtra, Gujarat, and Karnataka. In the foothills of the Himalayas, harvesting time varies from the end of April to the end of May. The average grain yield of the 'dry' crop is about 700–1000 kg/ha whereas that of the irrigated crop is about twice as much.

Gram

Gram (*Chana*) is the most important pulse which accounts for more than a third of the pulse growing area and about 40 per cent of the production of pulses in India. The average annual area and production of gram are about 7–8 Mha and about 4–5 million tonnes of grain respectively. Haryana, Himachal Pradesh, Rajasthan, and Uttar Pradesh together grow gram over an area exceeding 6 Mha. In North India, gram is grown on light alluvial soils which are less suitable for wheat. In south India, gram is cultivated on clay loams and black cotton soils. 'Kabuli gram', however, requires soil better than light alluvial soils. Gram is generally grown as a dry crop in the Rabi season. The preparation of land for gram is similar to that for wheat. The seeds are sown in rows from the middle of October to the beginning of November. The crop matures in about 150 days in Punjab and Uttar Pradesh and in 120 days in south India.

Other Major Crops

Sugarcane

Sugarcane is the main source of sugar and is an important cash crop. It occupies about 1.8 per cent of the total cultivated area in the country. In the past, the area under sugarcane has beenfluctuating between 2 and 2.7 Mha. Uttar Pradesh alone accounts for about 47 per cent of annual production in terms of raw sugar. However, the production per hectare is the highest in Karnataka followed by Maharashtra and Andhra Pradesh. Medium heavy soils are best suited for sugarcane. It can also be grown on lighter and heavy soils provided that there is sufficient irrigation available in the former and drainage is good in the latter type of soils. In north India, it is cultivated largely on the loams and clay loams of the Gangetic and other alluviums. In peninsular India, it is grown on brown or reddish loams, laterites, and black cotton soils. Sugarcane grows over a prolonged period. In north India, planting of sugarcane coincides with the beginning of warm weather and is completed well before the onset of summer. Usually, January and February are the best months for planting of sugarcane in Bihar, February in Uttar Pradesh, and the first fortnight of March in Punjab and Haryana. In the case of sugarcane, the maintenance of optimum soil moisture during all stages of growth is one of the essential requisites for obtaining higher yields. The crop should, therefore, be grown in areas of well-distributed rainfall with assured and adequate irrigation. The total irrigation requirement of the crop for optimum yield varies between 200 and 300 cm. Sugarcane ripens around December and its sugar content continues to rise till about the end of March by which time it is harvested in north India.

Tea

Tea is an important beverage and its consumption in the world is more than that of any other beverage. India and Sri Lanka are the important tea growing countries. In India, tea is grown in Assam, West Bengal, Kerala, Karnataka, and Tamil Nadu. Tea is grown over an area of about 358,000 hectares and about 470 million kilograms of the product is obtained annually. The tea crop is the most important plantation crop of India. The tea plant, in its natural state, grows into a small or medium-sized tree. In commercial plantations, it is pruned and trained to form a multi-branched low bush. Appropriate schedule of fertiliser applications is very useful to produce vigorous vegetative growth of the tea crop. The tea plants are generally raised in nurseries. About one to one-and-a-half year old nursery seedlings are used for field plantation. Timely irrigation is essential for the production of good quality leaves.

Potato

Amongst vegetables, potato is grown over the largest area (for any single vegetable) in the world. In the plains of north India, potato is sown from the middle of September to the beginning of January. Two successive crops can be raised on the same land. Potato needs frequent irrigation depending upon the soil and climatic conditions. Generally, six irrigations are sufficient.

2.6 Multiple Cropping

To meet the food requirements of ever-growing population of India, the available cultivable land (about 143 Mha) should be intensively cropped. This can be achieved by multiple cropping which increases agricultural production per unit area of cultivated land in a year with the available resource in a given environment. 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 time dimension and there is no intercrop competition in sequential cropping. Choice of a suitable cropping pattern for an area is dependent mainly on the soil characteristics and climatic conditions of the area. From the considerations of management of canal supplies, it is important to arrive at a cropping pattern which could be sustainable by the available water and also maximise economic benefits for the people of that area. For this purpose, the systems approach is very useful. Parameters, such as self-sufficiency for the area in staple food and fodder, use of a diversified pattern to reduce risks of failure, problems related to storage and marketing particularly for perishable crops, reasonably uniform demand of water all through the year, and the preferences of the local farmers are always incorporated in the analysis.

LECTURES NOTES ON Hydraulic and Irrigation Engineering

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- ✓ Properties of fluid
- ✓ Fluid Pressure and its measurements
- ✓ Hydrostatics
- ✓ Fluid Flow
- ✓ Flow through pipe
- ✓ Hydraulic pumps

Syllabus: 1.1 Definitions and Units of Density, Specific weight, specific gravity, specific volume 5 1.2 Definitions and Units of Dynamic viscosity, kinematic viscosity, surface tension, Capillary phenomenon

Fluid Definition:

A fluid is a substance which is capable of flowing or a substance which deforms continuously when subjected to external shearing force. Characteristics:

• It has no definite shape of its own but will take the shape of the container in which it is stored.

• A small amount of shear force will cause a deformation.

Classification:

A fluid can be classified as follows:

• Liquid

• Gas Liquid: It is a fluid which possesses a definite volume and assumed as incompressible GAS: It possesses no definite volume and is compressible. Fluids are broadly classified into two types

. • Ideal fluids

• Real fluids

Ideal fluid: An ideal fluid is one which has no viscosity and surface tension and is incompressible actually no ideal fluid exists.

Real fluids: A real fluid is one which has viscosity, surface tension and compressibility in addition to the density

PROPERTIES OF FLUIDS:

1. density or mass density : (rho)
   Density of a fluid is defined as the ratio of the mass of a fluid to its vacuum. It is denoted by y
   The density of liquids are considered as constant while that of gases changes with pressure & temperature variations.
   Mathematically

$$\rho = \frac{mass}{volume}$$

$$\text{Unit} = \frac{kg}{m^3}$$

2. **Specific weight or weight density((W):**

Specific weight of a fluid is defined as the ratio between the weights of a fluid to its valume. It is denoted by W.

$$\text{Mathematically W} = \frac{weight\ of\ fluid}{volume\ of\ fluid}$$

$$= mg/v$$

$$W = \rho g$$

3. **Specific volume:**

Specific volume of a fluid is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid is called specific volume.

Mathematically

$$\text{Specific volume} = \frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\frac{\text{Mass of fluid}}{\text{Volume}}} = \frac{1}{\rho}$$

$$\text{Unit: } \frac{m^3}{kg}$$

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4. **Specific gravity:**

Specific gravity is defined as the ratio of the weight density of a fluid to the density or when density standard fluid.

For liquids the standard fluid is water.

For gases the standard fluid is air.

It is denoted by the symbol S

Simple Problems:

Problem: - 1

Calculate the specific weight, density and specific gravity of one litre of a liquid which weighs 7N.

Solution. Given :

$$\text{Volume} = 1 \text{ litre} = \frac{1}{1000} \text{m}^3 \quad \left(\because \ 1 \text{ litre} = \frac{1}{1000} \text{m}^3 \text{ or } 1 \text{ litre} = 1000 \text{ cm}^3\right)$$

$$\text{Weight} = 7 \text{ N}$$

(*i*) Specific weight (w) $= \dfrac{\text{Weight}}{\text{Volume}} = \dfrac{7\text{N}}{\left(\dfrac{1}{1000}\right)\text{m}^3} = \mathbf{7000 \ N/m^3}$. **Ans.**

(*ii*) Density (ρ) $= \dfrac{w}{g} = \dfrac{7000}{9.81} \text{ kg/m}^3 = \mathbf{713.5 \ kg/m^3}$. **Ans.**

(*iii*) Specific gravity $= \dfrac{\text{Density of liquid}}{\text{Density of water}} = \dfrac{713.5}{1000}$ $\{\because$ Density of water $= 1000 \text{ kg/m}^3\}$

$= \mathbf{0.7135}$. **Ans.**

Problem: - 2

Calculate the density, specific weight and specific gravity of one litre of petrol of specific gravity = 0.7

Solution. Given : Volume = 1 litre = $1 \times 1000\ cm^3 = \frac{1000}{10^6}\ m^3 = 0.001\ m^3$

Sp. gravity $S = 0.7$

(*i*) *Density* (ρ)

Using equation (1.1.A),

Density (ρ) $= S \times 1000\ kg/m^3 = 0.7 \times 1000 =$ **700 kg/m³. Ans.**

(*ii*) *Specific weight* (*w*)

Using equation (1.1), $w = \rho \times g = 700 \times 9.81\ N/m^3 =$ **6867 N/m³. Ans.**

(*iii*) *Weight (W)*

We know that specific weight $= \frac{\text{Weight}}{\text{Volume}}$

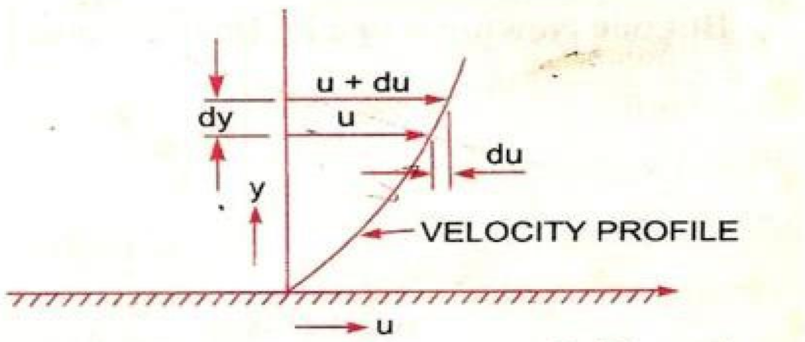
$$w = \frac{W}{0.001} \text{ or } 6867 = \frac{W}{0.001}$$

$$\therefore \quad W = 6867 \times 0.001 = \mathbf{6.867\ N.\ Ans.}$$

Viscosity:

Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.

Let two layers of a fluid at a distance dy apart, move one over the other at different velocities u and u + du.



Velocity variation near a solid boundary.

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Mathematically $\tau \; \alpha \; \frac{du}{dy}$

$$\tau = \mu \frac{du}{dy}$$

Kinematic Viscocity:

It is defined as the ratio between the dynamic viscosity and density of fluid.

It is denoted by ϑ.

Mathematically

$$\nu = \frac{\text{Viscosity}}{\text{Density}} = \frac{\mu}{\rho} \qquad \text{...(1.4)}$$

The units of kinematic viscosity is obtained as

$$\nu = \frac{\text{Units of } \mu}{\text{Units of } \rho} = \frac{\text{Force} \times \text{Time}}{(\text{Length})^2 \times \frac{\text{Mass}}{(\text{Length})^3}} = \frac{\text{Force} \times \text{Time}}{\frac{\text{Mass}}{\text{Length}}}$$

$$= \frac{\text{Mass} \times \frac{\text{Length}}{(\text{Time})^2} \times \text{Time}}{\left(\frac{\text{Mass}}{\text{Length}}\right)} \qquad \left\{\begin{aligned} \because \text{Force} &= \text{Mass} \times \text{Acc.} \\ &= \text{Mass} \times \frac{\text{Length}}{\text{Time}^2} \end{aligned}\right\}$$

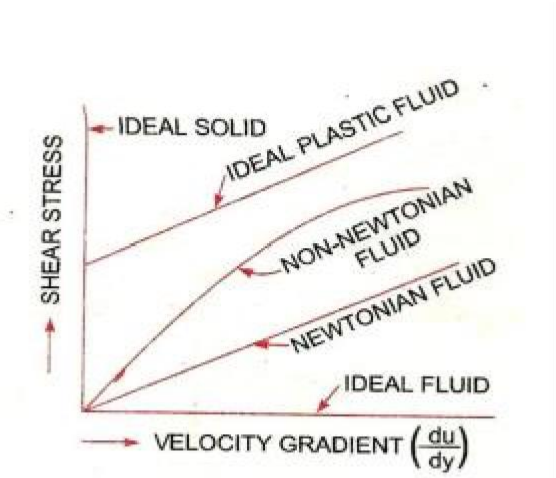
$$= \frac{(\text{Length})^2}{\text{Time}}.$$

Newton's law of viscosity:

It states that the shear stress on a fluid element layer is directly proportional to the rate of shear stear strain. The constant of proportionality is called the co-efficient of viscosity.

Mathematically $$\tau = \mu \frac{du}{dy}$$

Fluids which obey the above equation or law are known as Newtonian fluids & the fluids which do not obey the law are called Non-Newtonian fluids.



Chapter-2

Syllabus: 2.1 Definitions and units of fluid pressure, pressure intensity and pressure head 2.2 Concept of atmospheric pressure, gauge pressure, vacuum pressure and absolute pressure 2.3 Pressure measuring instruments Manometers: Simple and differential Bourdon tube pressure gauge (Simple Numerical)

Pressure of a Fluid:

When a fluid is contained in a vessel, it exerts force at all points on the sides & bottoms of the container. The force exerted per unit area is called pressure.

If P = Pressure at any point

F = Total force uniformly distributed over an area

A = unit area

P = F/A

Pressure head of a liquid:

A liquid is subjected to pressure due to pressure due to its own weight, this pressure increases as the depth of the liquid increases.

Let a bottomless cylinder stand in the liquid

Let w = specific weight of the liquid.

H = height of the liquid in the cylinder.

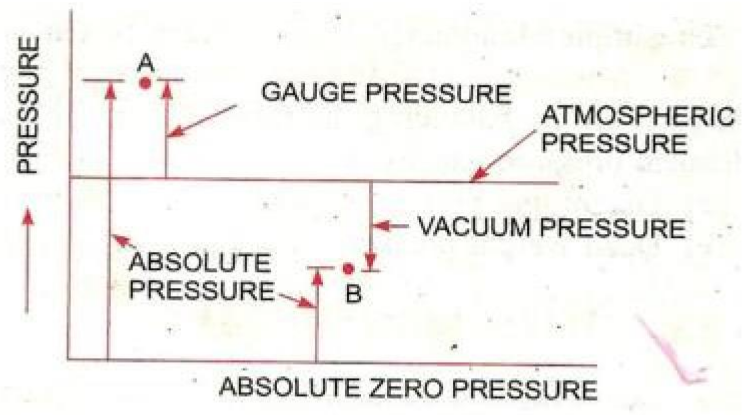
A = Area of the cylinder.

$$P = \frac{F}{A} = \frac{weight\ of\ the\ liquid\ in\ the\ cylinder}{Area\ of\ the\ cylinder}$$

$$= \frac{W \times A\,h}{A}$$

$$= Wh$$

$$= \rho gh$$



Atmospheric Pressure:

The atmospheric air exerts a normal pressure upon all surfaces with which It is in contact & known as atmospheric pressure.

Absolute pressure:

It is defined as the pressure which is measured with reference to absolute vacuum pressure or absolute zero pressure.

Gauge pressure:

It is defined as the pressure which is measured with the help of a pressure measuring instrument in which the atmospheric pressure is taken as datum. The atmospheric pressure on the scale is marked as zero.

Vacuum pressure:

It is defined as the pressure below the atmospheric pressure.

Mathematically:

Absolute pressure = Atmospheric pressure + gauge pressure

Or $P_{abs} = P_{atm} + P_{gauge}$

Pressure Measuring Instruments:

The pressure of a fluid is measured by the following devices :

1. **Manometers**
2. **Mechanical Gauges.**

Manometers:

Manometers are defined as the device used for measuring the pressure at a point in a fluid by balancing the collomn of fluid by the same another column of the fluid. They are classified as:

(a) Simple manometers.
(b) Differential Manometers.

Chapter-3

Syllabus: 3.1 Definition of hydrostatic pressure 3.2 Total pressure and centre of pressure on immersed bodies (Simple Numericals) 3.3 Archimedis' principle, concept of buoyancy, metacentre and metacentric height 3.4Concept of floatation

Hydrostatics:

Hydrostatics means the study of pressure exerted by thye liquid at rest & the direction of such a pressure is always right angle to the surface on which it acts.

Total pressure and center of pressure:

Total pressure

Total pressure is defined as the force exerted by a static fluid on a surface either plane or curved when the fluid comes in contact with surfaces. This force always acts normal to the surface.

Center of pressure:

Center of pressure is defined as the point of application of the total pressure on the surface.

There are four cases of submerged surfaces on which the total pressure force and center of pressure is to be determined. The submerged surfaces may be:

1. **Vertical plane surface**
2. **Horizontal plane surface**
3. **Inclined plane surface**
4. **Curved surface.**

Vertical plane surface submerged in liquid

Consider a plane vertical surface of arbitrary shape immersed in a liquid as shown in figure

Let A = total area of the surface

H = distanced of C.G. of the area from free surface of liquid

G = center of gravity ofplane surface

P = center of pressure

h* = distance of center of pressure from free surface of liquid.

Total pressure(F):

The total pressure on the surface may be determined by dividing the entire surface into a number of small parallel strips. The force on surface is then calculated by integrating the force on small strip.

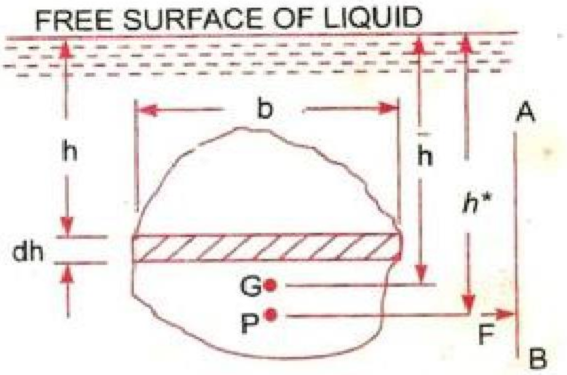
Consider a strip of thickness dh & width b at a depth of h form free surface of liquid.

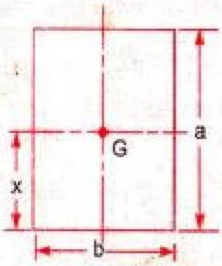
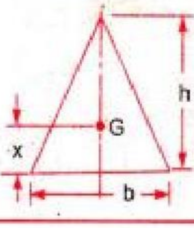
Pressure intensity on the strip

$$p = \rho g h$$

Centre of the pressure:(h*)

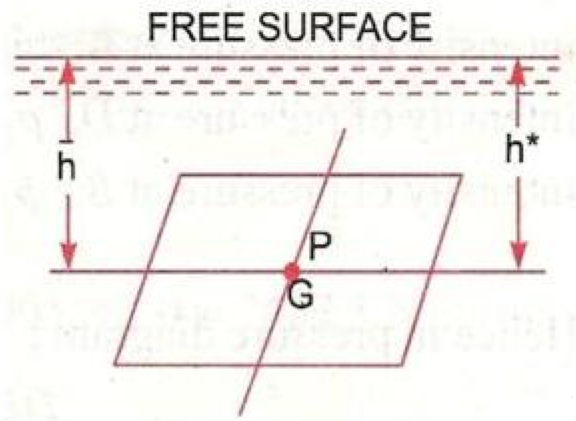
Centre of pressure is calculated by using the principle of moments which states that the moment of resultant force about an axis is equal to the sum of moments of the components about the same axis.



Plane surface	*C.G. from the base*	*Area*	*Moment of inertia about an axis passing through C.G. and parallel to base (I_G)*	*Moment of inertia about base (I_0)*
1. Rectangle 	$x = \frac{d}{2}$	bd	$\frac{bd^3}{12}$	$\frac{bd^3}{3}$
2. Triangle 	$x = \frac{h}{3}$	$\frac{bh}{2}$	$\frac{bh^3}{36}$	$\frac{bh^3}{12}$

Horizontal plane surface submerged in liquid:

Consider a plane horizontal surface immersed in a static fluid as every point of the surface is at the same depth from the free surface of the liquid, the pressure intensity will be equal on the entire surface.



$P = \rho g \bar{h}$

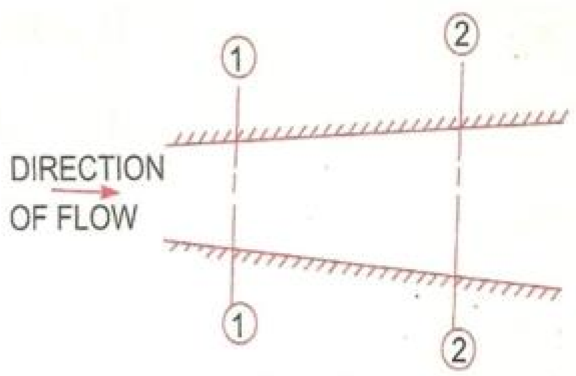
TYPES OF FLOW:-

The fluid flow is classified as follows:

- **STEADY AND UNSTEADY FLOW**
- **UNIFORM AND NON- UNIFORM FLOWS**
- **LAMINAR AND TURBULANT FLOWS**
- **COMPRESSIBLE AND INCOMPRESSIBLE FLOWS**
- **ROTATIONAL AND IRROTATIONAL FLOWS**
- **ONE, TWO, THREE DIMENSIONAL FLOW**

EQUATION OF CONTINUITY:-

It is based on the principle of conservation of mass. For a fluid flowing through the pipe at all the cross-section, the quantity of fluid per second is constant.



Fluid flowing through a pipe.

$$A_1 V_1 = A_2 V_2$$

Application of Bernoulli's equation:

Bernoulli's equation is applied in all problems of incompressible fluid flow where energy consideration are involved.
It is also applied to following measuring devices

1. **Venturimeter**
2. **Orifice meter**
3. **Pitot tube**

Venturimeter:

A venturimeter is a device used for measuring the rate of a flow of a fluid flowing through a pipe it consists of three parts.

I. **Short converging part**
II. **Throat**
III. **Diverging part**

Pitot-tube:

It is a device used for measuring the velocity of flow at any point in a pipe or a channel.

It is based on the principle that if the velocity flow at a point becomes zero, the pressure there is increased due to conversion of the kinetic energy into pressure energy.

The pitot-tube consists of a glass tube, bent an right angles

Consider two points 1 and 2 at te same level. Such a ay that 2 is at he inlet of pitot tube and one is the far away from the tube

Let P_1 = pressure at point 1

V_1 = velocity of fluid at point 1

P_2 = pressure at 2

V_2 = velocity of fluid at point 2

H = Depth of tube in the liquid

h = Rise of the liquid in the tube above the free surface

Different Arrangement of Pitot tubes