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CONTENTS

CHAPTER - 1
QUALITY PARAMETERS OF WATER

1.1 INTRODUCTION
Water impurities are classified as physical, chemical and biological impurities.

1.2 PHYSICAL WATER QUALITY PARAMETER
1. Suspended solids
2. Turbidity
3. Colour
4. Taste and odour
5. Temperature

1.2.1 Suspended Solids
1. Source

These are called as physical parameters where as dissolved solids are considered as chemical parameters. SS comes from inorganic particles like silt, clay etc. immiscible liquids like oils and greases and organic particles like plant fibre, algae, etc. Inorganic solids are non-degradable solids.

> Problem of SS comes only in surface water not in ground water.

2. Objection

These are objectionable because
(i) Aesthetically displeasing,
(ii) It provides adsorption sites for chemical and biological agents
(iii) They may also be biologically active and may form disease causing organisms as well as organisms such as toxin producing strains of algae.

3. Measurement

(i) Most of the methods are gravimetric i.e. SS are calculated by weighing them.
(ii) Total solids i.e. all solids (suspended or dissolved), are calculated by evaporating the sample and measuring the residue. Heating temperature is 104°C.
(iii) Suspended solid is obtained by filtration and heating the residue on filter at 104°C
Dissolved solids (DS) = Total solids (TS) - Suspended solids (SS)

> Filtration in real terms does not exactly divides the solids into suspended and dissolved fractions because some. colloids may pass through the filter and car, get measured along with dissolved fraction. Hence, classification is done as filterable and non-filterable solids, Hence suspended solids are corresponding to non-filterable solids and dissolved solids are corresponding to filterable solids.

WORKBOOK

Example 1. Water contains 210 gm of CO_3^{2-}, 122 gm of HCO_3^- and 68 gm of OH^- what is the total alkalinity of water expressed as $CaCO_3^-$.

Solution.

210 gm CO_3^{2-} will have

$= \frac{210}{60/2} = \frac{210}{30} = 7$gm equivalent.

$\therefore$ 7 gm equivalent of CO_3^{2-} = 7 gm equivalent of $CaCO_3$

122 mg of HCO_3^- will have $= \frac{122}{61/1} = 2$gm equivalent of HCO_3^-

$\therefore$ 2g equivalent of HCO_3^- = 2 gm equivalent of $CaCO_3$

68 gm of OH^- will have $= \frac{68}{17/1} = 4$gm equivalent of OH^-

$\therefore$ 4gm equivalent of OH^- = 4 gm equivalent of $CaCO_3$

$\therefore$ Total alkalinity of water = 7 + 2 + 4 = 13 gm equivalent of $CaCO_3$

$\therefore$ Weight in gm of $CaCO_3$ = $\frac{100}{2} \times 13$ = 650 gm of $CaCO_3$

$\therefore$ Total alkalinity of water = 650 gm expressed as $CaCO_3$.

Example 2. A 200 ml of sample of water has initial pH of 10.30 ml of 0.02 N H_2SO_4 is required to titrate the sample to pH = 4.5. What is the total alkalinity of water in mg/ℓ s $CaCO_3$?

Solution.

30 ml of 0.02 N H_2SO_4 is required to reduce the pH upto 4.5.

$\therefore$ Total alkalinity of 200 ml of water sample = 30 mg as $CaCO_3$

$\therefore$ Total alkalinity of water in mg/ℓ =

$$30 \times \frac{1000}{200} = 150\text{mg}\ell \text{ as } CaCO_3$$

Example 3.

Size of Sample (mℓ)	Number of +ve	Number of –ve
1	4	1
0.1	3	2
0.01	2	3
0.001	0	5

Determine the MPN using the Thomas equation

Solution.

Number of the tube = 4 + 3 + 2 = 9

mℓ of sample in –ve tube = 1 × 1 + 2 × 0.1 + 3 × 0.01 + 5 × 0.001 = 1.235ml of space in all tube = 5 × 1 + 5 × 0 .1 + 0.01 × 5 + 0.001 × 5 = 5.555

$$\text{MPN}/100\text{m}\ell = \frac{9 \times 100}{\sqrt{1.235 \times 5.555}} = 344$$

Example 4. Determine the most probable number of coliforms. A standard multiple fermentation test is run on a sample of water from a surface stream. The results of the analysis for the confirmed test are shown below.

Size of sample Mℓ	No. of positive	No. of negative
10	4	1
1	2	3
0.1	1	4
0.01	0	5

Determine the MPN of coliform organisms.

Table: MPN index and 95% confidence limits for various combination of positive results when 5 tubes are used per dilution (10 mL, 1 mL, 0.1mℓ)

Combination of positive	MPN index /100 mℓ	95% confidence limit	
		Lower	Upper
2-1-0	7	1	17
4-2-1	26	9	78

CHAPTER - 2
WATER DEMAND, ITS SOURCE & CONVEYANCE

2.1 INTRODUCTION
To design a water supply scheme, we must first estimate the population for which the scheme should be designed. The scheme once installed must cater for the demand of projected population upto some predetermined future date.

2.2 DESIGN PERIODS
1. A water supply scheme includes huge and costly structures (such as dams, reservoirs) which cannot be replaced or increased in their capacities, easily and conveniently. In order to avoid these future complications of expansion, the various components of a water supply scheme are purposely made larger, so as to satisfy the community needs for a reasonable number of years to come.
2. This future period or the number of years for which a provision is made in designing the capacities of various components of the water supply scheme is known as design period.
3. The design period should neither be too long nor should it be too short. It should not exceed the useful life of the component structure.
The design period recommended by the GOI manual on water supply, for designing the various components of a water supply project are as given below.

Units	Design Period
Water treatment units	15 years
Pipe connections to the several treatment units	30 years
Service Reservoirs (overhead or ground level)	15 years
Distribution System	30 years

2.3 POPULATION FORECASTING
Water demand is assessed on the basis of future population. The future population is assessed as discussed below.

2.3.1 Population Growth
There are three main factors responsible for changes in populations
1. Births
2. Deaths
3. Migrations
Population forecasting is done by mathematical formulae and graphical solutions based upon previous population records

2.3.2 Growth Curve
1. The population would probably follow the growth curve characteristics of living things with in limited space or with limited economic opportunity. The curve is S-shaped as shown below and is known as logistic curve

1. Ionic Layer Compression

The quantity of ions in water surrounding a colloid has an effect on reducing the repulsive force.

A high ion concentration compresses the layer composed predominantly of (+ve) charge ions towards the surface of colloid. If this layer is sufficiently compressed then attractive forces (Vanderwaal force) will be predominant. Thus the particles will collese and will grow in size. Thus they will be removed in the sedimentation tank.

2. Adsorption and Charge Neutralisation

Nature rather than quantity of ion is of prime importance in the theory of adsorption and charge neutralisation. If Alum is added in water, it will form Al^{3+} and SO_4^{2-}. The sulphate ion (SO_4^{2-}) may remain in this form or may combined with other cations like Na^+, Mg^{2+}.

However $A1_3^+$ ion will react immediately with water to form various aquametallic cations like. $A1(OH)^{2+}$, $A1(OH_2)^+$, $Al_7(OH)_{17}^{4+}$, $A1(OH)_3 \downarrow H^+$.

These cations surrounds the clouds of (–ve) charge and as they have an affinity for surface, they are adsorbed on to the surface, thereby neutralising the surface charge.

Once the charge is neutralise, free contact can occur. Thus size increases and settling takes place:

Overdosing may lead to net (+ve) charge which will again result in suspension

3. Sweep Coagulation

The aluminium hydroxide ($A1(OH)_3$) formed when alum is added to water is a amorphous (shapeless) and gelatinous (sticky) ppt. These are heavier than water is settles down by gravity. Colloids may become entrapped in the flocs as the flocs settle down. This process by which colloids are swept away from the system in this manner is called sweep coagulation.

4. Inter Particle Bridging

Large molecules may be formed when Al or ferric sulphate dissociate in water (like $Al_7(OH)_{17}^{1+}$).

Several colloids may become attached to one molecule or various molecules may get enmeshed resulting in settleable mass.

Polymers may also be used either alone or in combination with alum or iron salts.

3.4.2 Common Coagulants added in Water

1. Alum
2. Copperas
3. Chlorinated copperas
4. Sodium aluminate
5. Lime

1. Alum

Chemical formula of Alum is $A1_2(SO_4)_3.\ 18H_2O$.

(i) Alum reacts with HCO_3 alkalinity to form gelatinous precipitate of $A1(OH)_3$.

(ii) This attracts other fine particles and suspended matter, thus grow in size and finally settle.

(iii) $$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 \rightarrow \underset{\text{Permanent Hardness}}{3CaSO_4} + \underset{\text{ppt.}}{2Al(OH)_3 \downarrow} + 6CO_2 \uparrow + 18H_2O$$

GATE QUESTIONS

1. A rapid sand filter comprising a number of filter beds is required to produce 99 MLD of potable water. Consider water loss during backwashing as 5%, rate of filtration as 6.0 m/h and length to width ratio of filter bed as 1.35. The width of each filter bed is to be kept equal to 5.2 m. One additional filter bed is to be provided to take care of break-down repair and maintenance. The total number of filter beds required will be

[GATE - 2018]

(a) 19 (b) 20
(c) 21 (d) 22

2. A flocculation contains 1800 m^3 of water, which is mixed using paddles at an average velocity gradient G of 100/s. The water temperature and the corresponding dynamic viscosity are 30°C and 0.798×10^{-3} Ns/m^3, respectively. The theoretical power required to achieve the stated value of G (in kW, up to two decimal places) is ___________

[GATE - 2018]

3. At a small water treatment plant which has 4 Filters, the rates of filtration and backwashing are 200 $m^3/d/m^2$ and 1000 $m^3/d/m^2$, respectively. Backwashing is done for 15 min per day. The maturation, which occurs initially as the filter is put back into service after cleaning takes 30 min. it is proposed to recover the water being wasted during backwashing and maturation. The percentage increase in the filtered water produced (up to two decimal places) would be ________

[GATE - 2018]

4. The spherical grit particles, having a radius of 0.01 mm and specific gravity of 3.0 need to be separated in a settling chamber. It is given that
(i) $g = 9.81$ m/s^2
(ii) The density of the liquid in the settling chamber = 1000 kg/m^3
(iii) The kinematic viscosity of the liquid in the settling chamber = 10^{-6} m^2/s
Assuming laminar conditions, the settlling velocity (in mm/s, up to one decimal place) is _________.

[GATE - 2017]

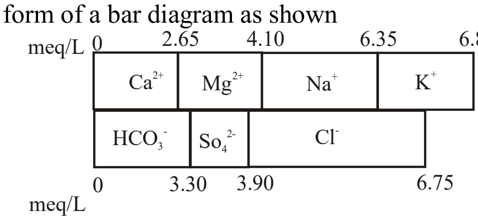
5. A municipal corporation is required to treat 1000 m^3/day of water. If is found that an overflow rate of 20m/day will produce a satisfactory removal of the discrete suspended particles at a depth of 3m. The diameter (in meters, rounded to the nearest integer) of a circular settling tank designed for the removal of these particles would be ________.

[GATE - 2017]

6. Effluent from an industry 'A' has a pH of 4.2. The effluent from another industry 'B' has double the hydroxyl (OH^-) ion concentration than the effluent from industry 'A'. pH of effluent from the industry 'B' will be _____.

[GATE - 2016]

7. A sample of water has been analysed for common ions and results are presented in the form of a bar diagram as shown



The non- carbonate hardness (expressed in mg/L as $CaCO_3$) of the sample is

[GATE - 2016]

(a) 40 (b) 165
(c) 195 (d) 205

8. The hardness of a ground water sample was found to be 420mg/L as $CaCO_3$. A softener containing ion exchange resins was installed t reduce the total hardness to 75mg/L as $CaCO_3$ before supplying to 4 households. Each

CHAPTER - 4
DISTRIBUTION SYSTEM

4.1 METHODS OF DISTRIBUTION

Water is forced in the distribution system by following ways:
1. Gravitational system
2. Direct pumping
3. Combined system

4.1.1 Gravitational System

In this system, water from high level source is distributed at lower levels by simple action of without pumping.
This system works well where lakes are, available at the top of a hill.

4.1.2 Direct Pumping

1. In the direct pumping system, the treated water, instead of pumping to the service or distribution reservoir, is directly pumped to the distribution mains.
2. Since water demand varies, pumps are required to be run at variable speed to meet water requirement at different time periods.
3. Due - to variable speed, the pumps do not work at their maximum efficiency, hence, the system is not so economical.

4.1.3 Combined System

1. In this system of water supply, pumping and gravity system is combined.
2. The treated water is pumped and stored in an elevated distribution reservoir or tank and distribution tank, it is fed to the distribution system by the action of gravity.
3. Pump works at constant and convenient schedule and the pressure can be maintained uniformly during the supply.

4.1.4 System of Supply

There are two system of supply of water:
1. Continuous supply: In continuous supply water is supplied continuously to the consumers.
2. Intermittent supply: In the intermittent supply, water is supplied mostly at peak hours or if the shortage of there then the whole distribution area is divided into different zones and water is supplied to the different zones at different fixed timings.

4.2 LAYOUTS OF DISTRIBUTION SYSTEM

1. The distribution pipe system consists of mains, submains, branches, laterals and finally service connections.
2. Pipes, except the service connections, are usually made of cast iron with some type of coating to avoid rusting where as for service connections galvanised cast iron pipes are used.
3. Distribution pipe are mostly laid along the road below the footpath. Depending upon local conditions and orientation of roads, any of the following pattern of layouts is adopted singly or in combination.
(i) Dead end or tree system.
(ii) Grid system or reticular system.
(iii) Ring or circular system.
(iv) Radial system

CHAPTER - 5
SEWAGE TREATMENT

5.1 INTRODUCTION
Wastewater can be defined as any water or liquid that contains impurities or pollutants in the form of solids, liquid or gases or their combinations in such a concentration that is harmful if disposed into the environment.

5.1.1 Treatment Method
Usually, Physical, Chemical or Biological, means are applied for wastewater to carry out specific function on the principles of either one or a combination of the means employed. Based on the means used, treatment methods have been broadly classified as unit operations and unit processes.

5.1.2 Unit Operations
The means of treatment in which the application of physical forces predominates are known as unit operations. Major treatment methods falling under this category are screening, mixing, sedimentation, etc.

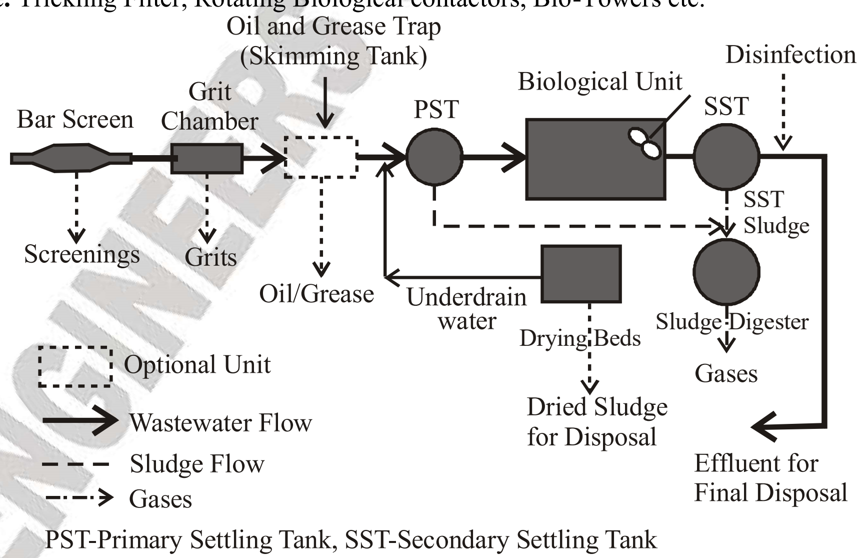
5.1.3 Unit Process
The types of treatment in which the removal of contaminants is brought about by the addition of chemicals or the use of biological mass or microbial activities are known as unit process. Based on the Type of agent used biological unit process are

1. Suspended growth process

Example. Activated Sludge Process, Aerated Lagoon, Oxidation Pond, Aerobic & Anaerobic Digester etc.

2. Attached growth process

Example. Trickling Filter, Rotating Biological contactors, Bio-Towers etc.



Schematic flow diagram of a typical conventional treatment plant

CHAPTER - 6
SOLID WASTE MANAGEMENT

6.1 INTRODUCTION
1. Solid wastes are the total wastes arising from human and animal activities that are normally solid and hence are useless or unwanted.
2. It encompasses the heterogeneous mass of throw away from houses of commercial centres as well as the nearby homogeneous accumulation of a single industrial activity.
3. Refuse represents the dry wastes or solid wastes of the society.
4. The term 'refuse' is often used interchangeably with term solid wastes.
5. The density of Indian refuse is generally higher than that of the developed countries and hence the Indian refuse can be carried efficiently and economically by mechanical transport (carrying more wt. for the same volume).
6. The calorific value of Indian refuse is much smaller, and its moisture content is high.

6.2 TYPES OF SOLID WASTES
Major categories of solid waste generation are :
1. Municipal wastes
2. Industrial wastes
3. Hazardous wastes

6.2.1 Municipal Wastes
1. Solid wastes generated from different zones of the city differ in characteristics. There solid wastes comprise refuse, ordinary refuse (includes garbage & rubbish) and trash.
2. Refuse, refers to nonhazardous solid waste from the community requiring collection and transporting to processing/disposal site.
3. Garbage comprises items that are highly decomposable (putrescible) food, waste vegetables and meat scraps.
4. Rubbish contains mostly dry, nondecomposable (nonputrescible) material - glass, rubber, tin cans, also, or combustible material - paper, textile, wooden articles, etc.
5. Hence, community refuse can be referred to as municipal solid waste (MSW).

6.2.2 Industrial Wastes
1. Industrial wastes are generated from the industrial activities or manufacturing processes.
2. All the three types of wastes, solid, liquid and gaseous are generated
3. Industrial wastes can be categorised as non-hazardous and hazardous. It is well known that hazardous wastes have a potential for very deleterious impact on environment and life in general.
4. Some of the common industries which generate solid waste along with other wastes on a large scale are : (i) Paper and pulp (ii) Metallurgical industries (iii) Pesticides/Insecticides (iv) Fertilizers (v) Plastics (vi) Refineries

6.2.3 Hazardous Wastes
1. Hazardous substance can he defined as anything which because of its quantity, concentration or characteristics may contribute to increased mortality, illness or hazard to human health and environment if not properly stored and transported or disposed off

WORKBOOK

Example 1. Convert 120 mg/m^3 of SO_2 concentration into ppm.

Solution.

We know that all gas at 0^{o}C and atmospheric pressure occupies 22.4 litre/mole. (i.e. at STP (Standard Temp. and Pressure)

$V_1 = 22.4$ litre

Volume at T^{o}C = V_2

Now $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ [From gas law, (temperature is in Kelvin)]

But pressure is always atmospheric

$$\Rightarrow V_2 = \frac{V_1(T_2)}{T_1} = \frac{V_1(273+T)}{273}$$

$$1\text{ppm}\,SO_2 = \frac{1\text{m}^3\text{ of }SO_2}{10^6\text{m}^3\text{ of air}}$$

Molecular wt of SO_2 = 64

$\Rightarrow$ 64 g of SO_2 occupies V_2 litre at T^{o}C

1m^3 of SO_4 will have $\frac{64000\,\text{mg}}{V_2}\times 1000$

$\Rightarrow$ 1 ppm SO_2 at T^{o}C

$$= \frac{64\times 10^6\text{ mg}}{V_2\times 10^6\text{m}^3\text{ of air}} = \frac{64}{V_2}\text{mg}/\text{m}^3\text{ of air}$$

$\Rightarrow$ 1ppm at T^{o}C

$$= \left[\frac{\text{Molecular wt}}{(\text{Volume of T}^o\text{C in litre}/\text{mole})}\right]\frac{\text{mg}}{\text{m}^3\text{ of air}}$$

$$\Rightarrow \frac{1\text{mg}}{\text{m}^3}\text{ of }SO_2$$

$$= \left(\frac{\text{Volume T}^o\text{C in litre}/\text{mole}}{\text{Molecular wt}}\right)\text{ppm}$$

$$\Rightarrow \frac{120\,\text{mg}}{\text{m}^3}\text{ of }SO_2$$

$$= \frac{120\times 22.4\times\frac{293}{273}}{64}\text{ppm} = 45\text{ ppm}$$

Example 2. A factory uses 1.5 ML of fuel oil per month. The exhaust gases from the factory contain the following quantities of pollutants per ML per year;

(i) Particulate matter : 4 t/year

(ii) SO_2 : 20j/year

(iii) NO_x : 5t/year

(iv) HC, CO and other : 3t/year

Determine the safe height of the chimney required for the safe dispersion of the pollutants.

Solution.

The concentrations of NO_x, HC, CO and others are generally very much less than the concentration of SO_2 in various industries. Hence the Board has made only SO_2 as the criterion for design, along with the particulate matter.

(a) Height of chimney on the basis of particulate matter

$h = 74\,(Q_p)^{\mathbf{0.27}}$

Particulate matter emission = 4(1.5 × 12)

= 72 t/year

Assume 300 working days in a year, and 24 hours working a day,

$$Q_p = \frac{72}{300\times 24} = 0.01\,\text{t}/\text{hour}$$

$\therefore$ h = 74 $(0.01)^{0.27}$ = 21.34 m

(b) Height of chimney on the basis of SO_2

$h = 14(Q_s)^{1/3}$

Now, SO_2 emission = 20 (1.5 × 12) = 360t/year

$$\therefore Q_S = \frac{360}{300\times 24} = 0.05\,\text{t}/\text{hour} = 50\text{ kg/hr}$$

$\therefore$ h = $14(50)^{1/3}$ = 51.58 m

$\therefore$ Required height of chimney ≈ 52 m.

Example 3. A factory uses 2,00,000 litres of furnace oil (specific density .097) per month. If for one million litres of oil used per year, the participate matter emitted is 3.0 tonnes per year, SO_2 emitted is 59.7 tonnes per year. NO_x. emitted is 7.5 tonnes per year, hydrocarbons emitted are 0.37 tonnes per year, and carbon

CHAPTER - 7
AIR POLLUTION

7.1 INTRODUCTION
Air is the most essential part of the life and man can hardly survive for few minutes without air although he can survive for few days or few weeks without water or food. But sometimes even the most important life supporting element, if gets polluted, can cause harmful effects both to human beings and plants and animals.

Polluted air is also harmful to non living materials like metals, stones, woods, papers etc. These materials gets spoiled by the contact with polluted air either due to physical corrosive action of polluted air or/and due. to the chemical attack of the pollutants on such material.
1. The earliest pollutants noted in the atmosphere were probably of natural origin.
2. Smoke, fumes, ash, and gases from volcanoes and forest fires: sand and dust from windstorms in arid regions: fog in humid, low-lying areas: were part of our environment long before human-induced or anthropogenic problems came on the scene.
3. Air pollution can be defined as the presence of one or more air contaminants (i.e.. dust, fumes, gas. mist, smoke, or vapor) in the outdoor atmosphere in sufficient quantities, of such characteristics and of such duration, that it becomes injurious to human, plant, or animal life or to property and also interferes with the comfortable enjoyment of life or property.

Smoke is one of the earliest anthropogenic air pollutants.

7.2 SOURCE AND CLASSIFICATION OF AIR POLLUTANTS
Air pollutants can be classified as follows:
1. Natural contaminants: natural fog, pollen grains, bacteria and products of volcanic eruption.
2. Aerosols (particulates): dust, smoke, mists, fog and fumes.
3. Gases and vapours

Air contaminants		
S.No.	**Group**	**Examples**
1.	Sulphur compounds	SO_2^-, SO_3, H_2S mercaptans
2.	Nitrogen compounds	NO, NO_2, NH_3
3.	Oxygen compounds	O_3, CO, CO_2
4.	Halogen compounds	HF, HCl
5.	Organic compounds	Aldehydes, hydrocarbons
6.	Radioactive compounds	Radioactive gases

Some of these contaminants undergo chemical reactions when they enter the atmosphere. As a result, the end products formed are more harmful than the original contaminants. For example, unsaturated hydrocarbons react with nitrogen dioxide in sunlight to form smog.

ESE OBJ QUESTIONS

1. Consider the following statements in respect of the troposphere:
1. The gaseous content constantly churns by turbulence and mixing.
2. Its behaviour makes the weather
3. The ultimate energy source for producing any weather change is the sun
4. The height of the troposphere is nearly 11 km at the equatorial belt and is 5 km at the poles.
Which of these are true of the troposphere?

[ESE - 2018]

(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 1, 3 and 4 only (d) 2, 3 and 4 only

2. Statement (I): The impact of Green House Gas emission on the environment may comprise accelerated increase in global warming as well as a significant rise in mean sea levels.
Statement (II): Green House Gas emission is responsible for decreased land masses, increased population densities and food short ages.

[ESE - 2018]

3. Statement (I): Try quantities of over 30 rare gases would warm the atmosphere over the Earth more rapidly than CO_2.
Statement (II): A single molecule of some CFCs, methane and nitrous oxide absorbs as much heat as 15,000 molecules, 25 molecules and 230 molecules of CO_2, respectively.

[ESE - 2017]

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but statement (II) is true

4. Two parallel rails are running on railway sleepers. The centre-to-centre distance between the rail is 'b' with the sleepers projecting by an amount 'a' at each end beyond the rails. When the train passes over the rails, the reaction exerted by the ground can eb taken as uniformly distributed over the sleeper. The ratio $\frac{b}{a}$ for the condition that the maximum bending moment is as small as possible is

[ESE - 2017]

(a) 2.83 (b) 2.90
(c) 2.50 (d) 3.00

5. Consider the relevance of the following features for causing photochemical smog
1. Air stagnation
2. Abundant sunlight
3. High concentration of NO_x in atmosphere
4. High concentration of SO_2 in atmosphere
Which of the above features are correct ?

[ESE - 2016]

(a) 1, 2 and 4 only (b) 3 and 4 only
(c) 1, 2 and 3 only (d) 1, 2, 3 and 4

6. Assertion **(A):** Gases are normally formless fluids and can be changed to liquid or solid states by change of temperature and pressure.
Reason (R): Smog refers to the occurrence of a heavy, cloudy, hazy floating layer in the atmosphere formed by a mixture of smoke, dust, fog and mist.

[ESE - 2015]

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R-is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

7. Consider the following statements regarding ecology:

CHAPTER - 8
NOISE POLLUTION

8.1 INTRODUCTION
Noise can be defined as that unwanted sound pollutant which produces undesirable physiological and psychological effects in an individual, by interfering with one's social activities like work, rest, recreation, sleep etc.
Noise of sufficient intensity and duration can induce health problems like temporary and some times permanent hearing loss, besides causing several other diseases like general annoyance, irritation, disturbance, headaches, insomnia, fatigue, mental torture, nausea, high blood pressure, high pulse rate, greater perspiration, etc.

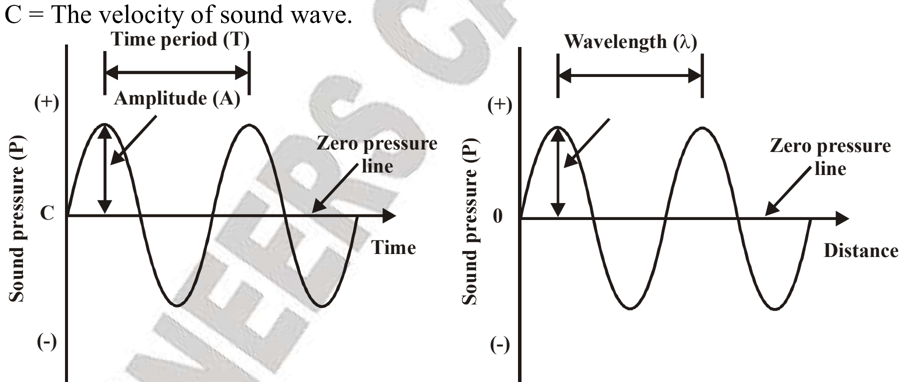
8.2 CHARACTERISTICS OF SOUND AND ITS MEASUREMENT
Alternating compression and rarefaction of the surrounding air produces sound waves which propagate in the form of sinusoidal path.
The time between the successive Peaks or troughs of oscillation is called the Time period (T). and its inverse, which represents the number of times a peak arrives in one second; is called the frequency (f).

Hence, $T = \frac{1}{f}$

The distance between successive peaks or troughs is called the **wave length** (λ), which is related to frequency (f) by the relation

$$\lambda = C.\frac{1}{f}$$

where, C = The velocity of sound wave.



Typical sinusoidal sound waves produced by alternating compression and rarefaction of air molecules.

The amplitude (A) of the wave is the height of the peak sound pressure measured above or below the zero pressure line. The equivalent pressure of such a sine wave is represented" by root mean square pressure (p_{rms}) as

$$p_{rms} = \sqrt{\overline{p_{(t)}^2}} = \sqrt{\frac{1}{T}\int_0^T p_{(t)}^2 dt}$$

where, $p_{(t)}$ is Pressure at any time t

CHAPTER - 9
DESIGN OF SEWER

9.1 INTRODUCTION

9.1.1 Difference in the design of water supply pipes and sewer

The hydraulic design of sewer and drains, which means finding out their sections and gradients, is generally carried out on the same lines as that of the water supply pipes. However, there are two major differences

These differences are :

1. The water supply pipes carry pure water without containing any king of solid particles, either organic or inorganic in nature. The sewage, on the other hand, does contain such particles in suspension ; and the heavier of these particles may settle down at the bottom of the sewers, as a result the flow velocity reduces, thus ultimately resulting in the clogging of the sewers. In order to avoid such clogging or silting of sewere, it is necessary that the sewer pipes be of such a size and laid at such a gradient, as to generate self-cleansing velocities at different possible discharges. The sewer materials must also be capable of resisting the wear and tear caused due to abrasion of the solid particles present in the sewage , with the interior of the pipe.
2. The water supply pipe carry water under pressure, and hence, within certain limits, they may be carried up and down the hills and the valleys, whereas, the sewer pipes carry sewage as gravity conduits (or open channels) and they must, therefore, be laid at a continuous gradient in the downward direction up to the out fall point, from where it will be lifted up, treated and disposed of.

9.1.2 Laying of Sewer

All the sewer pipes are generally laid starting from their out fall ends, towards their starting ends. The advantage gained in starting from the tail end, (i.e. out fall end) is the utilization of the tail length even during the initial period of its construction, thus ensuring that the functioning of the sewage scheme has not to wait till the completion of the entire scheme

The laying of the sewer consists of the following steps

1. Marketing of the Alignment

The alignment (i.e., centre line) of the sewer is marked along the road with a thedolite and inver tape

The centre line may be marked according to the following two methods

(i) By reference line

(ii) By sight Rail

(i) By Reference Line

In this methods, a reference line is marked along any side of the busy roads by theodolite and inver tape. The points F_1F_2… are on the reference line. The starting point (P_1) of the centre line is marked with a peg. Then the distance F_1P_1 is with a peg. Then the distance F_1P_1 is measured by inver tape

CHAPTER - 10
DISPOSAL OF SEWAGE

10.1 INTRODUCTION

10.2 DISPOSAL OF SEWAGE EFFLUENT
There are two general methods of disposing of the sewage effluents
1. Dilution i.e, disposal in water
2. Disposal on land

Disposal by dilution is more common of these two methods

10.2.1 Disposal by dilution
Disposal of dilution is the process where by the treated sewage or the effluent from sewage treatment plant is discharged into a river stream ; or a large body of water , such as a lake or sea

Standards of dilution for discharge of wastewaters into rivers
The ratio of the quantity of the diluting water to that of the sewage is known solution factor ; and depending upon this factor , the Royal commission Report on Sewage Disposal has laid down the following standards and degree of treatment required to be given to a particular sewage

Dilution factor	Standards of purification required
Above 500	No treatment is required , Raw sewage can be directly discharged into the volume of water
Between 300 to 500	Primary treatment such as plain sedimentation should be given to sewage, and the effluents should not contain suspended solids more than 150 ppm
Between 150 to 300	Treatments such as sedimentation, screening and essentially should not contain suspended solids more than 60ppm
Less than 150	Complete through treatment should be given to sewage. The sewage effluent should not contain suspended solids more than 30 ppm, and it 5 days B.O.D should not exceed 20 ppm

10.2.2 BIS standard for Disposal of sewage

Parameter	Domestic sewage if discharged into surface water source	Industrial sewage	
		Surface water	Public sewer
BOD_5	20mgl	30mg/l	500mgl
pH	—	5.5-9.0	5.5-9.0
Suspended solids	30 mg/l	100mg/l	600mg/l
Phenolic compounds	—	1 mg/l	5 mg/l
Cyanides	--	0.2mg/l	2 mg/l

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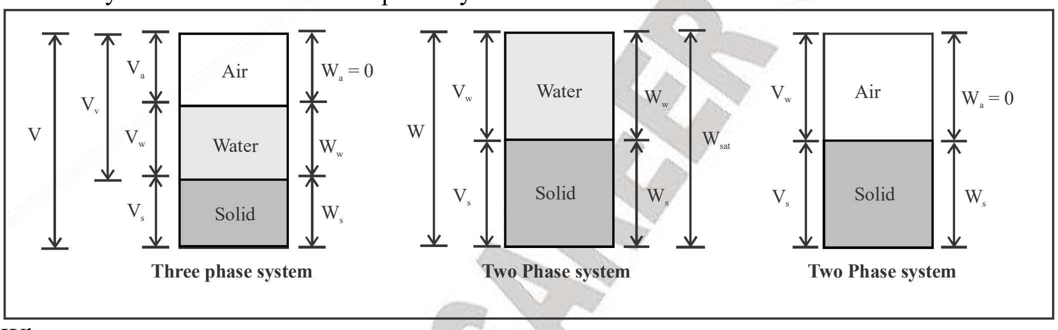
SECTION-B (FOUNDATION ENGINEERING)

SECTION-A
SOIL MECHANICS

CHAPTER - 1
SOIL WATER RELATIONSHIP

1.1 SOIL WATER RELATIONSHIP

1. A soil mass consists of solid particles which form a porous structure. The voids in the soil mass may be filled with air, with water air and partly with water. The three constituents are blended together to form a complex material. However, for convenience, all the solid particles are segregated and placed in the lower layers of the three phase diagram. Likewise, water and air particles are placed separately, as shown. The 3-phase diagram is also known as Block diagram.
2. It may be noted that the three constituents cannot be actually segregated, as shown. A 3-phase diagram is an artifice used for easy understanding and convenience in calculation.
3. Soil can be either two phase or three phase composition.
4. Fully saturated soil and fully dry soil are two phase system.
5. Partially saturated soils are three phase system.



Where,
V_a is Volume of Air
V_w is Volume of water
V_s is Volume of solid
V is Total Volume of Soil mass
V_v is Volume of Voids i.e. sum of volume of air and volume of water.
W_a is Weight of air i.e. equals to zero.
W_w is Weight of water
W_s is Weight of Soil solids
W is Weight of Soil mass
W_{sat} is Saturated weight of soil mass

1.2 IMPORTANT DEFINITIONS
1.2.1 Water Content (w)

$$w = \frac{W_w}{W_s}; w \geq 0$$

1. Water content or moisture content of a soil mass is defined as the ratio of weight of water to the weight of solids (dry weight) of the soil mass $w = \frac{W_w}{W_s} \times 100$

CHAPTER - 2
SOIL COMPACTION

2.1 INTRODUCTION

1. Compaction of soil is the process of increasing the unit wt of soil by forcing the soil solids into a dense state and reducing the air voids.
2. Compaction leads to increase in shear strength and helps improve the stability and bearing capacity of soil. It also reduces the compressibility and permeability of soil.
3. This is achieved by applying static or dynamic loads to the soil.
4. Compaction is measured quantitatively-in terms of dry unit wt (γ_d) of the soil.
5. Difference between compaction and consolidation are as tabulated below.

Compaction	Consolidation
1. Instantaneous phenomenon	1. Time dependent Phenomenon
2. Soil always partially saturated air dry	2. Soil is completely Saturated
3. Densification due to reduction in the volume of air voids at a given water content	3. Volume reduction is due to expulsion of pore water from voids.
4. Specific compaction techniques are used	4. Consolidation occurs on account of a static load placed on the soil.

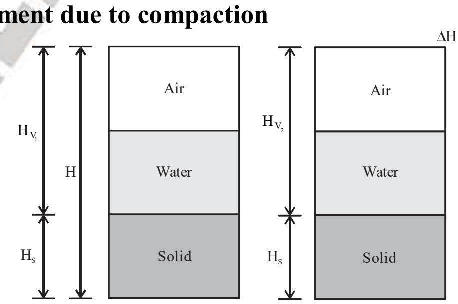
2.1.1 Why do we need to compact soil

1. Max shear strength occurs at min. void ratio.
2. Large air voids if left, may lead to compaction under working loads causing settlement of the structure during service or may get filled with water which reduces the shear strength.
3. Increase in water content is also accompanied by swelling and loss of shear strength with time.

2.1.2 The various advantages of compaction are

1. Settlement can be reduced or prevented.
2. Soil strength increases and stability can be improved.
3. Load carrying capacity of the pavement subgrade can be improved.
4. Undesirable volume changes (by frost action, swelling shrinkage) may be controlled.

2.1.3 General formula for settlement due to compaction



$H_{V1} = e_0 H_s$;

Where e_0 is initial void ratio

$H_{v_2} = e_f H_s$;

CHAPTER - 3
PRINCIPLE OF EFFECTIVE STRESS AND PERMEABILITY

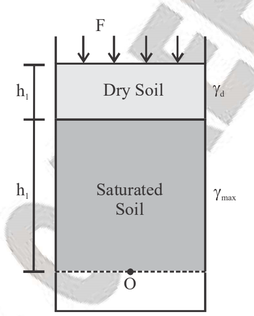
3.1 TOTAL STRESS, PORE WATER PRESSURE AND EFFECTIVE STRESS
3.1.1 Total stress

Total stress (σ) on a plane with in a soil mass is the force per unit area of soil mass transmitted in normal direction across a plane.

$\therefore$ Total stress (σ) = $\dfrac{P}{A}$

Where, P is Force on plane X –X for weight above plane X – X
A is Area of cross section of soil mass
When there is imposed load on soil mass as shown below, the total stress value at point O is given by

Total stress at 'O' = $\dfrac{F+\gamma_d \cdot A \cdot h_1 + \gamma_{sat} \cdot Ah_2}{A_3}$

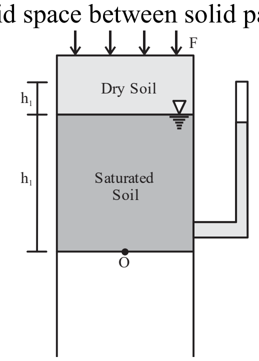


$$\sigma = \frac{F}{A} + \gamma_d h_1 + \gamma_{sat} h_2$$

Total stress is a physical parameter which can be measured by suitable arrangement, such as by **pressure cell**.

3.1.2 Pore Water Pressure (u)

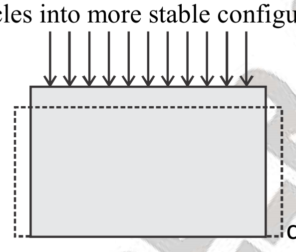
1. It is the Pressures of water filling void space between solid particles.



CHAPTER - 4
CONSOLIDATION

4.1 INTRODUCTION

1. When a soil mass is subjected to a compressive force, like all other materials, its volume decrease.
2. The property of the soil due to which a decrease in volume occurs under compressive forces is known as the compressibility of soil.
3. The decrease in volume of soil, under stress is because of
(i) Compression and Expulsion of Pore-Air.
(ii) Compression and Expulsion of Pore Water.
(iii) Gradual readjustment of clay particles into more stable configuration.



4. Reduction in volume of soil mass results in change of lateral and vertical dimensions of soil mass.
5. As soil being infinitely large in the lateral direction, hence the change in dimension in this direction is considered to be negligible, but there is significant change in vertical direction which is termed as settlement of soil.
6. In other words settlement of soil is the gradual sinking of the structure due to compression of the soil below.
7. Total settlement of soil is expressed as three components.

$$S_t = S_{immidtate} + S_{1^0 \, consolidation} + S_{2^0 \, consolidation}$$

4.1.1 Immediate settlement

1. If the soil is initially partially saturated, expulsion of air as well as compression of pore air may take place with the application of external loads which is called Initial Compression. It is a. immediate phenomenon.

2. After the initial compression, soil reaches into fully saturated state, further reduction in volume occurs due to expulsion of pore water i.e. water present in the soils.

3. Immediate settlement can also occur if significant lateral strain takes place. This is due to deformation of soil under undrained condition. This immediate settlement can be calculated from elastic theory.

4.1.2 Primary Consolidation

1. Primary-consolidation occurs due to expulsion of excess pore water pressure generated due to increase total stress. It is a time dependent phenomenon.

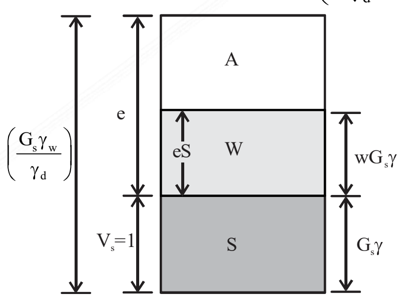
WORKBOOK

Example 1. Prove that $S = \dfrac{w}{\dfrac{\gamma_w}{\gamma_t}\left(1+w\right) - \dfrac{1}{G_s}}$.

Solution.

Proof We have $S = \left(\dfrac{V_w}{V_V}\right)$

$$= \left(\frac{V_w}{V - V_S}\right) \qquad = \frac{\left(\dfrac{wG_s\gamma_w}{\gamma_w}\right)}{\left(\dfrac{G_s\gamma_w}{\gamma_d} - 1\right)}$$



$$\gamma_t = \frac{wG_s}{G_s\left[\dfrac{\gamma_w}{y_d} - \dfrac{1.0}{G_s}\right]} = \frac{w}{\gamma_w\left(1+w\right)-1}G_s$$

$$\left[\because \gamma_d = \frac{\gamma_t}{1+w}\right]$$

$$\therefore S = \frac{w}{\dfrac{\gamma_w}{\gamma_t}\left(1+w\right) - \dfrac{1}{G_s}}$$

Example 2. A sampler with a volume of 45 cm^3 is filled with a soil sample When the soil is poured into a graduated cylinder, it displaces 25 cm^3 water. What is the porosity and void ratio of the soil.

Solution.

Here, Total volume of soil V = 45 cm^3

As we drop the soil in water, the solid particles will displace water.

Hence, volume of soil $V_s = 25cm^3$

$V_v = V - V_s = 45 - 25 = 20$

$e = \dfrac{V_v}{V_a} = \dfrac{20}{25} = 0.80$

$n = \dfrac{V_v}{V} = \dfrac{20}{45} = 0.444$

Example 3. The void-ratio and specific gravity of a sample of clay are 0.73 and 2.7 respectively. If the voids are 92% saturated, find the bulk density, the dry density and the water content.

What would be the water content for complete saturation, the void ratio remaining the same?

Solution.

$e = 0.73$, G = 2.7, S = 92%

S.e = w.G.

$w = \dfrac{0.92 \times 0.73}{2.7}$ w = 0.248

Bulk density γ_t

$= \left(\dfrac{G + Se}{1+e}\right)\gamma_w = \left(\dfrac{2.7 + 0.92 \times 0.73}{1+0.73}\right) \times 9.81$

$= 19.118 kN/m^3$

Dry density

$\gamma_d = \dfrac{\gamma_t}{1+w} = \dfrac{19.118}{1+0.248} = 15.318 kN/m^3$

Water content for full saturation at same at same void ratio.

$\Rightarrow$S.e. = w.G

$\Rightarrow \dfrac{1 \times 0.73}{2.7} = w \Rightarrow w = 0.$

Example 4. In a Proctor compaction test, the soil specimen of one of the observation had a bulk density of 19 kN/m^3 with a moisture content of 15%. Find,

(a) Degree of saturation of the specimen if $G_S = 2.7$

GATE QUESTIONS

1. The percent reduction in the bearing capacity of a strip footing resting on sand under flooding condition (water level at the base of the footing) when compared to the situation where the water level is at a depth much greater than the width of footing, is approximately

[GATE - 2018]

(a) 0 (b) 25
(c) 50 (d) 100

2. In a shrinkage limit test, the volume and mass of a dry soil pat are found to be 50 cm^3 and 88 g respectively. The specific gravity of the soil slides is 2.71 and the density of water is 1 g/cc. The shrinkage limit (in % up to two decimal places) is ___________.

[GATE - 2018]

3. The clay material, whose structural units are held together by potassium bond is

[GATE - 2018]

(a) Halloysite (b) Illite
(c) Kaolinite (d) Smectite

4. The laboratory tests on a soil sample yields the following results; natural moisture content = 18% liquid limit = 60%, plastic limit = 25%, percentage of clay sized fraction = 25%. The liquidity index and activity (as per the expression proposed by Skempton) of the soil, respectively, are

[GATE - 2017]

(a) −0.2 and 1.4 (b) 0.2 and 1.4
(c) −1.2 and 0.714 (d) 1.2 and 0.714

5. The porosity (n) and the degree of saturation (S) of a soil sample are 0.7 and 40%, respectively. In a 100 m^3 volume of the soil, the volume (expressed in m^3) of air is _________

[GATE - 2016]

6. A fine grained soil is found to be plastic in the water content range of 26-48%. As per Indian Standard Classification System, the soil is classified as

[GATE - 2016]

(a) CL (b) CH
(c) CL-ML (d) CI

7. A 588 cm^3 volume of moist sand weighs 1010 gm. Its dry weight is 918 gm and specific gravity of solids, G is 2.67. Assuming density of water as 1 gm/cm^3, the void ratio is _______.

[GATE - 2015]

8. If the water content of a fully saturated soil mass is 100%, the void ratio of the sample is

[GATE - 2015]

(a) Less than specific gravity of soil
(b) Equal to specific gravity of soil
(c) Greater than specific gravity of soil
(d) Independent of specific gravity of soil

9. An earth embankment is to be constructed with compacted cohesion less soil. The volume of the embankment is 5000 m^3 and the target dry unit weight is 16.2 kN/m^3. Three nearby sites (see figure below) have been indentified from where the required soil can be transported to the construction site. The void ratios (e) of different sites are shown in the figure. Assume the specific gravity of soil to be 2.7 for all three sites. If the cost of transportation per km is twice the cost of excavation per m^3 of borrow pits, which site would you choose as the most economic solution? (Use unit weight of water = 10 kN/m^3)

[GATE - 2015]

SOLUTIONS

Sol. 1. (c)
Visual examination should establish the colour, grain size, grain shapes of the coarse grained part of soil.
Dilatancy test is one of the test used in field to identify fine grained soil. In this test, a wet pat of soil is taken and shaken vigorously in the palm. Silt exhibits quick response and water appears on surface, where as clay shows no or slow response.

Sol. 2. (c)
n = 0.3
$G_s = 2.6$
w = 4.94%

$$e = \frac{n}{1-n} = \frac{0.3}{1-0.3} = \frac{3}{7}$$

So, es = wG_s

$$\frac{3}{7} \times s = \frac{4.94}{100} \times 2.6$$

$\Rightarrow$ S = 0.299
S $\approx$ 30%

Sol. 3. (b)
w = 0.38
$G_s = 2.65$
S = 1
es = wG_S
1.e = 0.38 × 2.65 $\Rightarrow$ e = 1.007

$$\gamma_{sat} = \frac{(G_s + Se)\gamma_w}{1+e} = \left(\frac{2.65 + 1 \times 0.007}{1+1.007}\right) \times 9.81$$

= 17.88 kN/m^3

Sol. 4. (d)
$V_1 = (1 + e_1)V_s$
$V_2 = (1 + e_2)V_s$

$$\frac{V_2}{V_1} = \frac{1+e_2}{1+e_1}$$

$$V_2 = \frac{1.7}{2.2} \times 30$$

$$V_2 = 23.18 \simeq 23.2\text{m}^3$$

Sol. 5. (b)
γ_d = 18 kN/m^3
w = 0.16
$G_s = 2.65$

$$\gamma_d = \frac{G_s \gamma_w}{1+e}$$

$$\Rightarrow 18 = \frac{2.65 \times 9.81}{1+e}$$

$\Rightarrow$ e = 0.444
e × s = wG_s
$\Rightarrow$ 0.444 × s = 0.16 × 2.65
$\Rightarrow$ s = 0.9547
s = 95.5%

Sol. 6. (d)
Shear strength of soils at liquid limit is approximately 2.7 kN/m2
The volume of soil do not change, when subjected to drying at water content below shrinkage limit.
Plastic limit is always lower than the liquid limits for any type of soil.

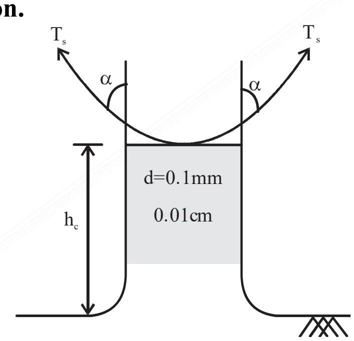
Sol. 7. (b)
Mass of soil + paraffin = 460 g
Mass of paraffin = 9g
Mass of soil = 451 g
Volume of soil + volume of paraffin = 300 cc
Volume of soil +
Volume of soil = 290 cc
Dry density of soil
e = 0.704

Sol. 8. (d)
(i) Illite is the mineral which has plasticity index and activity of intermediate level while montmorillonite is the mineral which is largely responsible for swelling and shrinkage behavior

WORKBOOK

Example 1. A capillary glass tube of 0.1 mm internal diameter is immersed vertically in a beaker full of water. Assume the tube to be perfectly clean and wet, determine the height of the capillary rise of water in the tube when the room t_{temp} is 20°C. Given at 20°C unit weight of water = 0.9980 gm/cc and surface tension = 72.8 dyne/cm.

Solution.



For equilibrium

$$\left(T_s \cos\alpha\right)\times \pi d = \left(\frac{\pi}{4} d^2 h_c \times \rho_w\right) g$$

$$\Rightarrow h_c = \frac{4T_s \cos\alpha}{\left(d\rho_w g\right)}$$

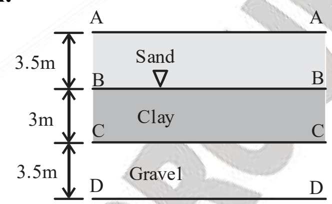
Assuming the tube to be perfectly clean and wet, cos α = 1

$$= \frac{4\times 72.8}{\left(0.998\times 0.01\times 981\right)}$$

[h_c = 29.74 cm]

Example 2. A soil profile consists of a surface layer of sand 3.5 m thick (ρ = 1.65 Mg/m^3), intermediate layer of caly 3 m thick (ρ = 1925 Mg/m^3) and the bottom layer of gravel 3.5 m thick (ρ = 1.925 Mg/m^3). The water table is at the upper surface of the clay layer. Determine the effective pressure at various level after placement of a surcharge load of 58.86kN/m^2 to the ground surface.

Solution.



At section A – A q = 58.86 kN/m^2, u = 0

σ = q = 58.86 kN/m^2

$$\bar{\sigma} = (\sigma - u) = (58.86 - 0) = 58.86\text{kN/m}^2$$

At Section B – B

q = 58.86kN/m^2, ρ = 1.65 Mg/m^3 = 1.65 kg/m^3

σ = (q + γh) = (58.86 + 1.65 × 9.81 × 3.5)

= 115.51 kN/m^2

u = 0

$$\therefore\ \bar{\sigma} = (\sigma - u) = (115.51 - 0) = 115.51\text{kN/m}^2$$

At Section C – C – q = 58.86 kN/m^2

ρ = 1.95 Mg/m^3 = 1.95 kg/m^3

σ = (q + γ_1 h_1 + γ_2 h_2)

= (58.86 + 1.65 × 9.81 × 3.5 + 1.95 × 3 × 9.81)

= 172.90 kN/m^2

u = hγ_w

= (3 × 9.81) = 29.43 kN/m^2

$$\therefore\ \bar{\sigma} = (\sigma - u) = (172.90 - 29.43)$$

= 143.47kN/m^2

At Section D – D q = 58.86 kN/m^2

ρ = 1.925M_g/m^3 = 1.925 kg/m

∴ σ = (q + γ_1 h_1 + γ_2 h_2 + $\gamma_3 h_3$)

= (58.86 + 1.65 × 9.81 × 3.5 +1.95 × 3 × 9.81) + 1.925 × 3.5 × 9.81)

= 238.99 kN/m^2

u = (3 + 3.5)γ_w = (6.5 × 9.81) = 63.765 kN/m^2

∴ $\bar{\sigma}$ (σ - u) = (238.99 – 63.765)

= 175.22 kN/m^2

CHAPTER - 5
SHEAR STRENGTH OF SOIL

5.1 INTRODUCTION

1. Shear strength is the capacity to resist shear stress.
2. If the value of shear stress on any plane or a surface at any point equals or exceeds the shear strength value, failure will occur in the soil mass because of the movement of a portion of soil mass along that particular plane or surface and soil is said to have failed in shear.
3. Thus shear strength is a very important property of soil which keeps it in a stable equilibrium, under type of loading which produces shear stress.
4. Shear strength of soil governs bearing capacity of soil, stability of slopes, Earth pressure retaining structure.

5.2 MECHANISM OF SHEAR RESISTANCE (SHEAR STRENGTH)

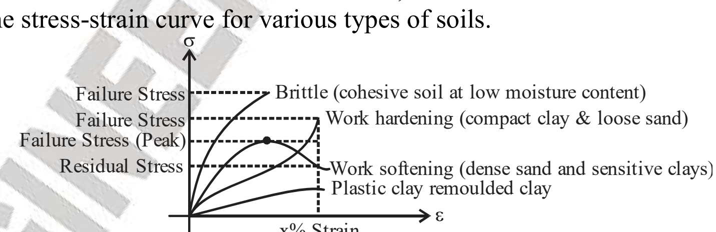
1. Shear strength is the resistance to shear deformation. It is categorized into two broad Categories.
(i) Frictional strength
(ii) Cohesive strength

2. Frictional strength takes into account the particle to particle friction and also the interlocking between particles.

3. Cohesive strength takes into account
(i) True cohesion .between particles.
(ii) Apparent cohesion between particles.

4. To calculate the shear strength of soil and take preventive measures such that soil mass does not fail in shear, we have to define state of failure upon stressing to certain:
(i) At what stress the failure will occur: By knowing the stress at failure, we can design the system such that, the failure stress does not generate
(ii) On what plane failure will occur: By knowing the orientation of potential failure plane we can take suitable strengthening measure to prevent failure on that plane.

5. To define the stress at which failure will occur, we use **stress-strain curve.** The following figure-shows the stress-strain curve for various types of soils.



6. For brittle soil, failure stress is taken corresponding to the Peak Point.

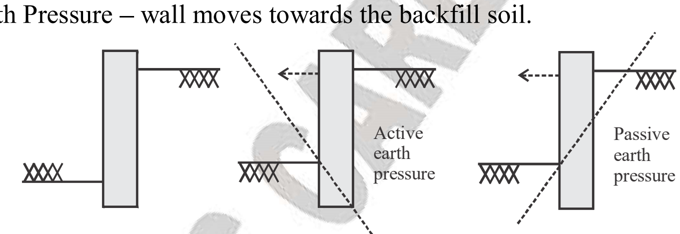
7. For work softening material, failure is taken at peak point.

8. For work hardening material or for plastic clay, failure stress shall be defined at some % of strain.

CHAPTER - 6
EARTH PRESSURE AND RETAINING WALLS

6.1 INTRODUCTION
1. Soil mass is stable when the slope of the surface of the soil mass is flatter than the safe slope. But at some places the space is limited, it is not possible to provide flat slope and the soil is to be retained at a slope steeper than the safe one.
2. Therefore to retain this soil mass in a stable state a retaining structure is provided to provide the lateral support to the soil mass.□
3. In the design of these retaining structure it becomes imperative to know the magnitude and line of action of Earth pressure, where earth pressure is the lateral force exerted by the soil on any structure retaining that soil
4. The magnitude of the lateral earth pressure depends upon a number of factors such as the mode of movement of wall, the flexibility of the wall, the properties of the soil, and drainage conditions

6.2 TYPES OF LATERAL EARTH PRESSURE
Lateral earth pressure can be divided into 3 categories, depending upon the movement of retaining wall with respect to bask fill soil.
1. Earth Pressure **At Rest** – wall does not move at all
2. **Active** Earth Pressure – wall moves away from the backfill soil.
3. **Passive** Earth Pressure – wall moves towards the backfill soil.



At Rest **Active Earth Pressure** **Passive Earth Pressure**

6.2.1 Earth Pressure at Rest
1. A soil element in its natural state at any depth z below the ground surface is not subjected to any strain the element in this condition is known as at rest condition.
2. It is possible to evaluate earth pressure at rest using the theory of elasticity.
3. For analysis of earth pressure at rest, consider a soil mass element at depth z below the ground surface and following assumptions are made.

6.2.1.1 *Assumptions*
1. Soil mass is homogenous, isotropic and semi infinite.
2. Elastic modulus, E and Poission’s ratio, μ is constant throughout the depth.
3. For Plane strain condition we can write ε_x as.

CHAPTER - 7
STABILITY OF SLOPES

7.1 INTRODUCTION

1. A slope in a soil mass is encountered when the elevation of the ground surface gradually charger from a lower level
 to a higher one. Such a slope may be either natural (in hilly region) or man-made (in artificially constructed embankment or excavations).

2. The soil mass bounded by a slope has a tendency to slide down. The principal factor causing such a sliding failure is the self-weight of the soil. However, the failure may be aggravated due to seepage of water or seismic forces. Every man-made slope has to be properly designed to ascertain the safety of the slope against sliding failure.

3. Various methods are available for analyzing the stability of slopes. Generally these methods are based on the following assumptions:
(i) Any slope stability problem is a two-dimensional one.
(ii) The shear parameters of the soil are constant along any possible slip surface.

4. In problems involving seepage of water, the flow net can be constructed and the seepage forces can be determined.

7.2 STABILITY OF INFINITE SLOPES

1. In Fig. (a), X-X represents an infinite slope which is inclined to the horizontal at an angle β. On any plane YY (YY| |XX) at a depth z below the ground level the soil properties and the overburden pressure are constant; Hence, failure may occur along a plane parallel to the slope at some depth. The conditions for such a failure may be analysed by considering the equilibrium of the soil prism ABCD of width b.

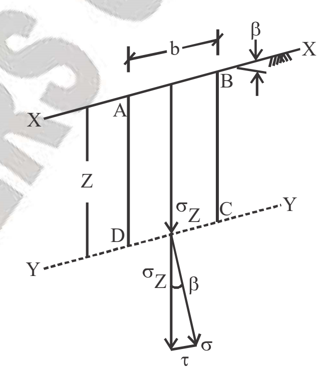


Fig (a)

Considering unit thickness, volume of the prism, V = z b cosβ

And, weight of the prism, W = γz b cosβ

Vertical stress on YY due to self-weight,

$$\sigma_z = \frac{W}{b} = \gamma z \cos\beta \quad \text{…(i)}$$

GATE QUESTIONS

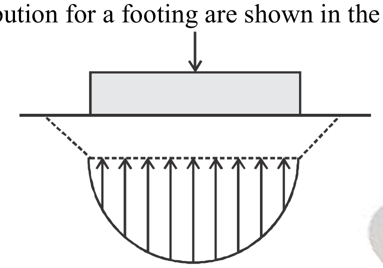
1. The width of a square footing and the diameter of a circular footing are equal. If both the footing are placed on the surface of sandy soil, the ratio of the ultimate bearing capacity of circular footing to that of square footing will be

[GATE - 2018]

(a) $\frac{4}{3}$ (b) 1

(c) $\frac{3}{4}$ (d) $\frac{2}{3}$

2. The contact pressure and settlement distribution for a footing are shown in the figure

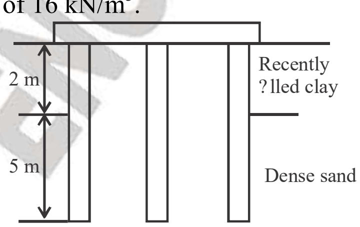


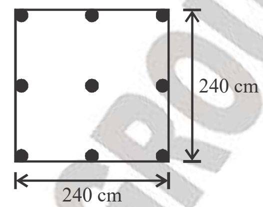
The figure corresponds to a

[GATE - 2018]

(a) Rigid footing on granular soil
(b) Flexible footing on granular soil
(c) Flexible footing on saturated clay
(d) Rigid footing on cohesive soil

3. A group of nine piles in a 3 × 3 square pattern is embedded in a soil strata comprising dense sand underlying recently filled clay layer, as shown in the figure. The perimeter of an individual pile is 126 cm. The size of pile group is 240 cm × 240 cm. The recently filled clay has undrained shear strength of 15 kPa and unit weight of 16 kN/m^3.





The negative frictional load (in kN, up to two decimal places) acting on the pile group is ___________.

[GATE - 2018]

4. The old concert hall was demolished because of fears that the foundation would be affected by the construction of the new metro line in the area. Modern technology for underground metro construction tried to mitigate the impact of pressurized air pockets created by the excavation of large amounts of soil. But even with these safeguards, it was feared that the soil below the concert hall would not be stable.

From this, one can infer that

[GATE - 2017]

(a)The foundation of old buildings create pressurized air pockets underground, which are difficult to handle during metro construction.
(b)Metro construction has to be done carefully considering its impact on the foundations of existing buildings.
(c)Old buildings in an area form an impossible hurdle to metro construction in that area.
(d)Pressurized air can be used to excavate large amounts of soil from underground areas.

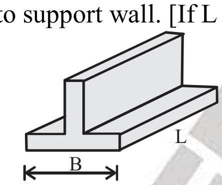
5. A 4m wide strip footing is founded at a depth of 1.5 m below the ground surface in a c-ϕ soil as shown in the figure. The water table is at a depth of 5.5 m below ground surface. The soil properties are: $c' = 35$ kN/m^2, $\phi' = 28.63$o, $\gamma_{sat} = 19$ kN/m^3, $\gamma_{bulk} = 17$ kN/m^3 and $\gamma_w = 9.81$ kN/m^3. The values of bearing capacity factors for different ϕ' are given below:

SECTION-B
FOUNDATION ENGINEERING

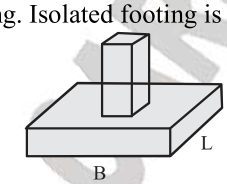
CHAPTER - 1
SHALLOW FOUNDATION

1.1 INTRODUCTION
1. Footings are generally the lowermost supporting part of the structure known as sub-structure and are the last structural elements through which load is transferred to foundation comprising soil/rock.
2. Structural elements transfer the applied loads from one part of the building to the other. These are in turn transmitted to the foundation which transfers it to the underlying soil/rock.

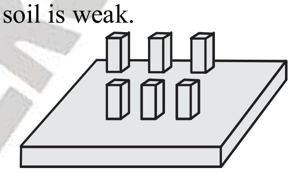
1.2 TYPES OF FOOTING
1. Strip Footing
These are also known as wall footing to support wall. [If L >>B] $\rightarrow$ Strip footing.



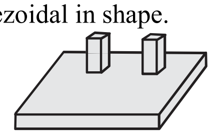
2. Isolated Footing
These are also known as spread footing. Isolated footing is used below the column.



3. Raft/Mat Foundation
These type of foundations are large continuous footing which support all columns and walls of a structure and are constructed when soil is weak.


Raft Foundation

4. Combined Footings
These footings are usually constructed due to space limitations and support two or more columns. They may be either rectangular or trapezoidal in shape.


Combined Footing

WORKBOOK

Example 1. A 2m wide strip footing is formed at a depth of 1.5m below the ground level in a homogeneous bed of Dense Sand, having the following prosperities

ϕ = 36º, γ = 1.85 tm^3, Determine the ultimate, net ultimate

Net safe bearing capacity of the footing. Given for

ϕ = 36º, N_c = 60º N_q = 42, N_γ = 47. Assume a F.O.S of 3

Solution.

As ϕ = 36º, general shear failure likely to occur.

For Dense Sand c = 0, N_c = 60, N_q = 42, N_γ = 47

(i) Ultimate Bearing Capacity

$q_u = (cN_c + \gamma D\, N_q + 0.5\, B\gamma\, N_\gamma)$

$$= \left(0\times 60 + 1.85\times 1.5\times 42 + \frac{1}{2}\times 2\times 1.85\times 47\right)$$

$$= (116.55 + 86.95) = 203.5\,\text{t/m2}$$

(ii) Net ultimate Bearing Capacity

$q_{nu} = (q_u - \gamma D)$

= (203.5–1.85×1.5)

= 200.725 t/m^2

(iii) Net safe Bearing Capacity

$$q_{ns} = \left(\frac{q_{nu}}{\text{F.O.S}}\right) = \left(\frac{200.725}{3}\right) = 66.908\,\text{t/m}^2$$

(iv) Safe Bearing Capacity

$Q_s = (q_{ns} + \gamma D)$

= (66.908+1.85×1.5) = 69.68 t/m^2

Example 2. Determine the safe load that can be carried by a square footing of 2.2m × 2.2m size placed at a depth of 1.6 m below GL. The foundation soil has the following properties

γ = 1.65 t/m^3 c = 1.1 t/m^2, ϕ = 20º

Assume of F.O.S of 2.5. Given For ϕ = 20º

N_c = 17.7, N_q = 7.4 N_γ = 5.0

N_c' = 11.8 N_q' =3.8 N_γ' = 1.3

Solution.

The low value of unit weight suggests that the soil is in the loose state. Moreover Q = 20º < 29º. Hence a local shear failure is likely to occur.

$$q_{nu} = 1.3c'\,N_c' + \gamma D\times(N_q' - 1) + 0.4\,B\gamma\,N_\gamma'$$

$$c' = \frac{2}{3}c = \frac{2}{3}\times 1.1$$

$$= \frac{2}{3}\times 1.1 = 0.73\,\text{t/m}^2$$

$$\therefore q_{nu} = (1.3\times 0.73\times 11.8) + 1.65\times 1.6(3.8-1)$$

$$+(0.4\times 1.65\times 2.2\times 1.3) = 20.52\,\text{t/m}^2$$

The safe bearing capacity of the footing

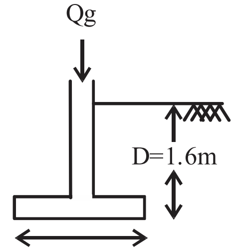
$$q_s = \left(\frac{q_{nu}}{\text{F.O.S}}\right) + \gamma D$$

$$= \left(\frac{20.52}{2.5}\right) + 1.65\times 1.6 = 10.85\,\text{t/m}^2$$

$\therefore$ Gross safe load to be carried by the footing

$= q_s \times (\text{Area of footing})$

$= 10.85\times(2.2)^2 = 52.52$ tonn.



Example 3. A concrete strip footing rectangular in cross section is located at ground level and extends 1.2 m below the ground level. It carries UDL of 15000 kg/m. the soil profile consists of homogeneous clay 6m thick over laying rock. The clay properties are as under.

Saturated unit bulk weight = 1750 kg/m^3

Shear strength (undrained) = 8500 kg/m^2

Compressibility = 1×10^{-4} m^2/100 kg

Determine,

(i) Width of footing for F.O.S. of F = 2

(ii) Ultimate consolidation settlement for F = 2

Assume bulk unit weight of concrete = 2500 kg/m^3

Neglect the spread of load beneath the footing any side cohesion on the foundation

CHAPTER - 2
DEEP FOUNDATION

2.1 INTRODUCTION

In situations where soil at shallow depth is poor, in order to transmit load safely, the depth of foundation has to be increased till the suitable soil strata is met. In view of increased depth, such foundations are called Deep foundation. Well foundation. Pile-Foundation and Pier Foundation are Deep foundations.
Pile is a small dia shaft which can be driven or installed into ground, Where as Piers and well Foundation are large dia shafts, constructed by excavation and sunk to the required depth.

2.2 CLASSIFICATION BASED ON MODE OF TRANSFER OF LOAD

1. End-Bearing Piles
(i) Used to transfer load through the pile tip to a suitable bearing stratum, passing soft soil or water.

2. Friction Piles
(i) Used to transfer loads to a depth in; frictional material by means of skin friction along the surface area of the pile.
(ii) Friction piles are also called as Floating piles, as they do not reach the hard stratum.

3. Combined End Bearing and Friction Pile
(i) Used to transfer, load through the combine action of end bearing and friction along the surface area of pile.

2.3 SINGLE PILE LOAD CAPACITY

1. When a compressive load (P) is applied at-the top of pile, the pile will tend to move vertically downward relative to soil. Due to this shear or friction develops between soil and surface of shaft. As a result applied load is distributed as frictional load along certain length of pile.

2. As load is increased full frictional resistance is mobilised over complete length of pile but by that time point bearing resistance will be very less.

3. When full point bearing resistance is mobilised, the frictional stress will drop from its maximum value.

4. The maximum frictional resistance mobilised is called (Q_f) when the load exceeds (Q_f), the point bearing starts mobilising. This load is known as point load (at base). This point load goes on increasing till failure occurs by punching shear.

5. Load in bearing at this stage is called ultimate point load (Q_{pu}).

6. Hence, for calculation purpose, *we* take Ultimate load Q_u where Q_u = (Q_u = (Q_{pu} + Q_f). although this is not correct because when maximum point bearing is developed, friction reduced from its maximum value.

7. If [Q_{pu} >>> Q_F] Pile is called **Point bearing point**.

WORKBOOK

Example 1. A 12 m long, 300 mm diameter concrete pile is driven in a uniform deposit of dense sand. Water table is at great depth and is not likely to rise. The average dry unit wt. of sand is 18 kN/m^3. Use N_q = 137, Calculate the safe load capacity of a angle pile with a F.O.S. of 2.5, $\phi = 40^o$.

Solution.

1. Driven/Bored Driven pile
2. Sand/clay$\rightarrow$ Dense sand

So, 1. Driven pile
2. Pile is in dense sand.

Here, in case of pile we only work for $P_{ultimate}$ and not for $P_{net\ ultimate}$

$q_{pu} = 0 + \sigma.N_q + 0.5\ B.\gamma.N_\gamma$

Here, 3rd term is negligible. Hence, it is neglected.

$\therefore\ q_{pu} = 0 + \sigma.N_q$

Calculation for σ

We know that, in case of dense sand $\bar{\sigma}$ is calculated at a depth of $20 \times D$.

$20 \times D = 20 \times 0.3 = 6$ m

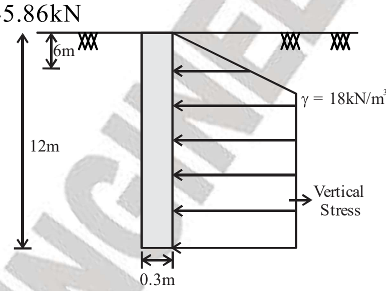
$\bar{\sigma} = \gamma \times 20 \times D$

$= 18 \times 20 \times 0.3 = 108$ kN/m^2

$Q_{pu} = q_{pu}.\ A_b$

$$Q_{pu} = [0 + 108 \times 137] \times \frac{\pi}{4}(0.3)^2$$

$$= 1045.86\text{kN}$$



Also $Q_f = f_s \cdot A_s$

where, f_s is $k\bar{\sigma}_{avg}\tan(\delta)$

Here $Q_f = f_{s1}.A_1 + f_{s2}.A_2$

$$\delta = \left(\frac{3}{4}\phi\right) = \frac{3}{4} \times 40 = 30^o$$

$$Q_f = 2.\tan 30^o\left[\left(\frac{108+0}{2} \times \pi \times 0.3 \times 6\right) + (108 \times \pi \times 0.3 \times 6)\right]$$

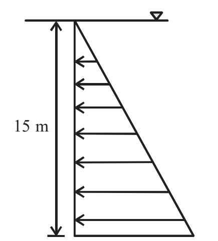
$$= 1057.807\,\text{kN}$$

$$Q_{up} = 1057.807 + 1045.86\text{kN} = 2103.667\text{kN}$$

$$Q_{safe} = \left[\frac{Q_{up}}{\text{F.O.S.}}\right] = 841.452\text{kN}$$

Example 2. For 450 mm side square section concrete pile 15 m long is driven in a deep deposite of uniform clay. The laboratory unconfined compression test on undisturbed sample indicates an avg. value of (Q_u) unconfined compressive Strength = 75 kN/m^2. Calculate the ultimate load capacity of pile. Take α = 0.8. γ_{sat} = 18 kN/m^3, γ_w = 10 kN/m^3.

Solution.



$\bar{\sigma} = (18-10) \times 15 = 120\text{kN}/\text{m}^2$

$$Q_u = C_{ub}.\ N_c.\ A_b + \alpha.\ C_{uavg}.\ A_s$$

$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow \quad \downarrow \quad \downarrow$

37.5kN/m^2 9 0.45x0.45 0.8 q. 0.45x4x15

$$C_{uavg} = \frac{75}{2} = 37.5\text{kN/m}^2$$

Here, (C_{ub}) at the base of pile is not given. Hence, average values will be taken as (C_{ub})

Q_u = 878.34 kN

Example 3. Determine the allowable pile load capacity of 40 cm dia driven concrete pile as shown below. take N_2 = 160

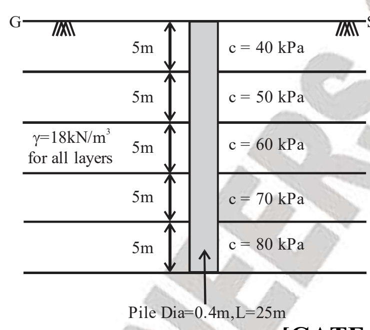
GATE QUESTIONS

1. A 0.5 m × 0.5 m square concrete pile is to be driven in a homogenous clayey soil having undrained shear strength, cu = 50 kPa and unit weight, γ = 18.0 kN/m^3. The design capacity of the pile is 500 kN. The adhesion factor α is given 0.75. The length of the pile required for the above design load with a factor of safety of 2.0 is

[GATE - 2018]

(a) 5.2 m (b) 5.8 m
(c) 11.8 m (d) 12.5 m

2. A pile of diameter 0.4 m is fully embedded in a clay stratum having 5 layers, each 5 m thick as shown in the figure below. Assume a constant unit weight of soil as 18 kN/m^3 for all the layers. Using λ-method (λ = 0.15 for 25 m embedment length) and neglecting the end bearing component, the ultimate pile capacity (in kN/) is ________.



[GATE - 2015]

3. A single vertical friction pile of diameter 500 mm and length 20 m is subjected to a vertical compressive load. the pile is embedded in a homogeneous sandy stratum where: angle of internal friction (φ) = 30º, dry nit weight (γ_d) = 20 kN/m^3. Considering the coefficient of laeral earth pressure (K) = 2.7 and the bearing capacity factor (N_q) = 25, the ultimate bearing capacity of the pile (in kN) is ________.

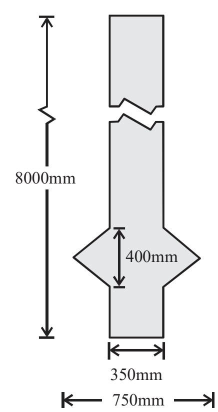
[GATE - 2014]

4. The action of negative skin friction on the pile is to

[GATE - 2014]

(a) Increase the ultimate load on the pile
(b) Reduce the allowable load on the pile
(c) Maintain the working load on the pile
(d) Reduce the settlement of the pile

5. A singly under-reamed, 8-m long, RCC pile (shown in the adjoining figure) weighing 20 kN with 350 mm shaft diameter and 750 mm under-ream diameter is installed within stiff, saturated silty clay (undrained shear strength is 50 kPa, adhesion factor is 0.3, and the applicable bearing capacity factor is 9) to counteract the impact of soil swelling on a structure constructed above. Neglecting suction and the contribution of the under-team to the adhesive shaft capacity, what would be the estimated ultimate tensile capacity (rounded off to the nearest integer value of kN) of the pile



[GATE - 2011]

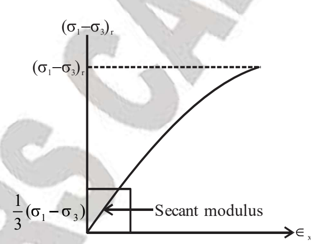
(a) 132 kN (b) 156 kN
(c) 287 kN (d) 301 kN

6. The ultimate load capacity of a 10 m long concrete pile of square cross section 500 mm × 500 mm driven into a homogeneous clay layer having undrained cohesion value of 40 kPa is 700kN. If the cross section of the pile is reduced to 250 mm × 250 mm and the length of the pile

CHAPTER - 3
VERTICAL STRESSES

3.1 INTRODUCTION
1. Stresses are induced in a soil mass due to weight of overlying soil and due. to the applied loads.
2. These stresses are required to design a foundation such that the shear stress on any stratum of soil below it does not exceed, after providing Factor of safety for bearing capacity of soil.
3. Further the vertical stresses transmitted to the soil layers below the foundation will lead to vertical deformation in the soil, causing foundation settlement.
4. This settlement again should not be allowed to exceed the permissible settlement.
5. Hence the know ledge of distribution of stresses with in a soil mass, induced by loads applied on the surface of soil, is a prerequisite for foundation design.
6. The stress induced in soil due to applied loads depend upon its stress strain characteristics. The stress strain behavior of soil is extremely complex and it depends upon a large number of factors, such as drainage conditions, water content, void ratio, rate of loading, the load level, and the stress path.
7. Generally the stress strain relationship is assumed to be linear, and fortunately these results are good enough for the problems usually encountered in practice.
8. Theory of Elasticity is used 10 determine the stresses in soil mass.
9. The main stress-strain parameters required for the application of elastic theories are modulus of Elasticity (E) and Poisson's ratio (μ).

3.1.1 Modulus of Elasticity



1. Modulus of Elasticity (E) can be determined in the laboratory by conducting a triaxial compression test.
2. The stress strain curve is plotted between the deviator stress (σ_1 - σ_3) and the axial strain ($\in_x$).

1. For Saturated, Cohesive Soil
Unconsolidated untrained (U U) test or unconfined compression test is performed.

2. For Cohesionless Soil
Consolidated drained (CD) test is performed.
(i) The value of modulus of elasticity is generally taken as the secant modulus (1/2 to 1/3) of the peak stress. Sometimes, instead of secant modulus, the initial tangent modulus or the tangent modulus at (1/2 to 1/3) of the peak stress is also used.

3.1.2 Poission's Ratio
1. For elastic material generally poission's ratio varies from 0 - 0.5
2. For Undrained conditions, the value of poission's ratio is 0.50.
3. For drained condition value is less than 0.50.

CHAPTER - 4
SOIL EXPLORATION

4.1 WASH BORING
1. In this method a casing pipe is driven through a heavy drop hammer supported by a tripod and pully.

2. Water is forced under pressure through the hollow drill rod and it is rotated up and down inside the casing pipe.

3. The lower end of the drill rod is fitted with a sharp cutting edge or chopping bit which cuts the soil.

4. Soil water mixture floats up through the annular space between the casing pipe and the drill rod.

5. Slurry or soil water mixture flowing out provides an indication of the soil type. Whereas change in soil strata can be determined from the rate of progress and slurry flowing out.

6. As the sample of soil is obtained in the form of soil water mixture, has no value because it is highly disturbed.

7. It cannot be used efficiently in hard soils, rocks and soil containing boulders.

8. This method is not suitable for taking good quality undisturbed samples above ground water table, as the wash water enters the strata below the bottom of the hole and causes an increase in its water content.

4.2 PERCUSSION BORING
1. In this method a heavy drilling bit is alternately dropped and raised in such a manner that it grinds the underlying hard material to the consistency of a sand or silt.

2. The bore hole is kept dry and only a small amount of water is added to form. A slurry with the material cut from the bit.

3. The soil samples are obtained with the means of bailer, and the changes in character of the soil stratum can be determined by the rate of progress.

4. In bouldery and gravelly stratum percussion boring is only suitable method.

4.3 ROTATORY BORING
Rotator Boring is of two types
1. Mud Rotatory Boring
A hole is drilled with the help of a rotating bit. Bentonite soil with some admixture is used as a drilling mud. Drill mud comes upwards through the anular space between the drill rod and the side of the hole.

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CONTENTS

SECTION – A (IRRIGATION)

SECTION - B (HYDROLOGY)

SECTION–A

[IRRIGATION]

CHAPTER - 1

IRRIGATION AND METHODS OF IRRIGATION

1.1 GENERAL UNDERSTANDING

Plants require water and air for their survival. Different types of plants require different quantities of water and at different time, till they grow up completely. Water is normally supplied to these plants by nature through direct rain of through the flood waters of rives. The supply of water by nature does not match the requirement of crops. Thus to control the nature, man discovered various methods by which the eater can be stored during the periods of excess rainfall and to use that strode water during periods of less rainfall or no rainfall. The art of the science by which it is accomplished, is generally termed as irrigation.

The Following are the main concerns of irrigation.

1. How to apply i.e., what should be the method of irrigation Border flooding method, furrow irrigation method, sprinkler irrigation method, drip irrigation method etc.

2. How much to apply i.e., how much moisture the soil can hold in its pores (moisture holding capacity of the soil).

3. When is apply i.e, when has the soil moisture level depleted to 30 to 60% of moisture holding capacity and when is the time to irrigate. In other words what should be frequency of irrigation.

1.1.1 Definition of Irrigation

Irrigation may be defined as the science of artificial application of water to the land in accordance with the crop requirements throughout the crop period for full-fledge nourishment of the crop.

1.1.2 Crop Yield and Productivity

The crop yield from irrigation is expressed as quintal/ha or tones/ha. The productive of the crop is expressed as crop yield per mm of water applied.

1. Increase of Yield Productivity can be Achieved by following Methods

(i) Land shaping or land leveling.
(ii) Suitable crop rotations and crop planning.
(iii) Using high yielding varieties of seeds.
(iv) Using chemicals and fertilizers: inputs like NPK, FYM, green manure (nitrogen-rich crops).
(v) Methods of irrigation such as sprinkler drop, furrow etc.
(vi) Lining of canals, distributaries and water courses by an economical lining material.
(vii) Drainage of irrigated land by surface and subsurface drainage.

1.1.3 Advantage and Disadvantages of Irrigation

1.1.3.1 Advantage of Irrigation

1. Direct Advantage

(i) Increase in Food Production

Increase in crop yield due to irrigation leads to increases in food production, thus developing people as well as society.

(ii) Protection against Drought

The provision of adequate irrigation facilities in any region ensures protection against failure of crops from famine or droughts.

CHAPTER - 2
SOIL-MOISTURE-PLANT RELATIONSHIP

2.1 SOIL MOISTURE

1. Water added to a soil mass during irrigation is held in the pores of the soil and is termed as soil moisture.
2. Soil moisture causes the soil to appear wet or even damp depending upon the amount of moisture present in the soil mass.
3. Soil pores which do not contain liquid water remain filed with air or eater vapor.

2.1.1 Basic Physical Properties of Soil

1. Soil provides the necessary medium for water to be used by plants through their roots that are present in the same medium.
2. Water acts as a medium to carry large amounts of nutrients essential for the growth of a plant.
3. The rate of entry of water into the soil, its retention and then its movement and availability to plant root are physical phenomena that contribute to the growth of vegetation.

Hence there is need to understand the physical aspects of soil in politic to water for efficient management of irrigated agriculture.

2.1.2 Water Holding Capacity of Soil

Water holding capacity of soil is one of the dominant factors influencing irrigation. The water holding capacity of a soil mainly depends on its porosity.

Porosity, $n = \frac{V_V}{V_T}$

Where, V_V is volume of pores, V_T is total volume n is porosity

In general there are two types of soil pores viz.,

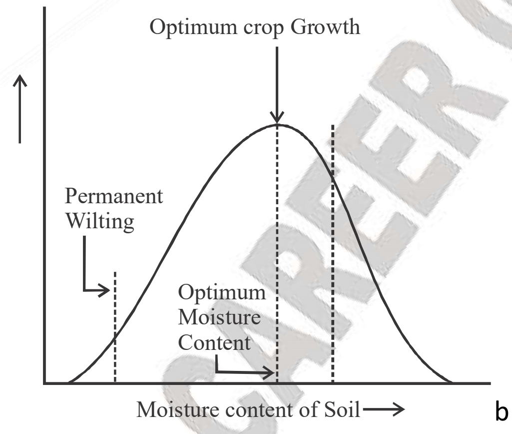
1. Capillary of small pores
2. Non-capillary or large pores
(i) The capillary pores hold a large amount of eater held by the soil at saturation due to capillarity and prevent it from being drained off under gravity.
(ii) On the other hand, the non-capillary pores do not hold water tightly and hence a large amount of water held by the soil at saturation is drained off under gravity.
(iii) Capillary pores induce greater water holding capacity while non capillary pores induce drainage and aeration.
(iv) The relative magnitude of these types of pores in a soil depends on its texture and structure.
(v)A sandy soul has more non-capillary pores which result in better drainage and aeration but low water holding capacity.
(vi) On the other hand clayey soil has more capillary pores which result in better water holding capacity but poor drainage and aeration.

CHAPTER - 3
WATER REQUIREMENTS OF CROPS & CANAL IRRIGATION

3.1. WATER REQUIREMENTS OF CROPS

1.The term water requirements of a crop means the total quantity and the ways in which a crop requires water, from the time it is sown to the time it is harvested.
2. The water requirement varies with the crop as well as with the place.
3. In other words, different crops will have different water requirements, and the same crop may have different water requirements at different places of the same country depending upon the variation in climates, type of soils, methods of cultivation and useful rainfalls etc.

3.1.1 Limiting Soil Moisture Conditions



1.Growth of most crops is retarded by either excessive or deficient amounts of soil moisture content.
2.Excessive moisture content in the soil results in filling the soil pore spaces completely with water thus driving cut air from the soil in the root zone.
3.On the other hand, soils having deficient amounts of moisture hold it is so tightly that plants are required to expend extra energy to obtain it.
4.In between these two extreme soil moisture conditions, there is a moisture content designated as optimum moisture content at which plants grown most rapidly, resulting in the optimum growth of crops.

3.1.2 Crops Seasons and Crops of India

1.There are two main crop seasons of India viz. Rabi and Kharif. The crops grown during these crop seasons are designated as Rabi crops and Kharif crops. Rabi crops are also known as winter crops and Kharif crops are known as monsoon crops (See the details in table).
2.Sometimes in between the Rabi and Kharif crops intermediate crops are grown, in which case the crops may be classified as Hot weather crops, Kharif (or monsoon) crops and Rabi (or winter) crops. Often-the Hot weather crops and the Kharif crops are combined designated as Summer crop (See the details in table below).

CHAPTER - 4
WATER LOGGING AND RECLAMATION OF SALINE SOILS

4.1 WATER LOGGING

1. Water togging is a phenomena in which productivity of land gets affected due to the high water table to flooding of root zone of the plants and making the root zones of the plants ill-aerated.

2. The life of a plant depends upon the nutrients like nitrates, and the form in which the nitrates are consumed by the plants is produced by the bacteria, under a process called nitrification. These bacteria need oxygen for their survival. The supply of oxygen gets cutoff when the land becomes ill aerated, resulting in the death of these bacteria, and fall in the production of plant's food (i.e. nitrates) and consequent reduction in the plant growth.

4.1.1 Other Problems Created by Water Logging are

1.The normal cultivation operation, (such as tilling ploughing, etc) cannot be easily carried out in wet soils. In extreme cases, the free water may rise above the surface of the land making the cultivation operation impossible.

2.Water logging also leads to salinity.

If the water-table has risen up, or if the plant roots cones within the capillary fringe, water is continuously evaporated by capiliarity. Thus, a continuous upward flow of water from the water-table to the land surface, gests established. With this upward flow, the salts which are present in the water also rise towards the surface, resulting in the deposition of salts in the root zone of the crops. The concentration of these alkali salts present in the root zone of the crops has a corroding effect on the roots, which reduces the osmotic activity of the plants and checks the plant growth, and the plant ultimately fades away. Such soil are called saline soils.

> Whenever there is water logging, there is salinity.

4.1.2 Causes of Water Logging

1. Over and Intensive Irrigation

When a policy of intensive irrigation is adopted, then the maximum irrigable area of a small region is irrigated. This leads to heavy irrigation in that region resulting in heavy percolation and subsequent rise of water-table. Hence, policy of extensive irrigation should be preferred.

2. Seepage of Water from the Adjoining High Lands

Water from the adjoining high lands may seep into the sub-soil of the affected land and may raise the water-table.

3. Seepage of Water through the Canals

Water may seep through the beds and sides of the adjoining canals, reservoirs, etc , situated at a higher level then the affected land resulting in high water-table. This seepage is excessive, when soil at the site of canals, reservoirs, etc., is very previous.

CHAPTER - 5
CANAL DESIGN

5.1 SEDIMENT TRANSPORT

Water flowing in a channel has a tendency to scour its surface. Silt, gravel or even large boulders are detached from the bed or sides of the channel and moved d/s by the moving water. This phenomenon is known as Sediment transport.

5.1.1 Importance of Sediment Transport

1.Sediment transport phenomena cause large scale scouring and siltation of irrigation canals.
2.Bed levels may change by direct scouring or deposition of sediment, and thereby leading to change in flood levels.
3.Scouring and silting of the river banks may create sharp and irregular curves, which increases the flow resistance of the channel, thereby, flood levels gets raised for the same discharge.
4.Silting of reservoir and rivers is an important aspect of sediment transport. The storage capacity of the reservoir is reduced by silting, thereby, reducing use and life of the reservoir. Natural rivers used for navigation are frequently silted up. This leads to drastic …. the clear depth for navigation, thus, requiring costly dredging.

5.1.2 Sediment Load

Sediment load is the burden of sediment carried by the flowing water in a canal. The sediment moving in water has been classified as:
1. Bed load
2. Suspended load

(i) Bed load
Sediment load moves along the bed with occasional jumps into the channel.
(ii) Suspended Load
Sediment load is maintained in suspension due to the turbulence of the flowing water.

5.2 MECHANISM OF BED FORMATION

1.The channel bed may get distorted into various shapes by the moving water, depending upon the discharge or the velocity of the water.
2.At low velocities the bed does not move at all, but it goes on assuming different shapes as the velocity increases.
3.When velocity is gradually increased then a stage is reached when the sediment load comes just at the point of motion. This stage in known as threshold stage of motion.
4.On further increase of velocity, bed develops the saw-tooth type ripples.
5.As the velocity is increased further, larger periodic irregularities appear, and are called dunes.
6.When they first appear, ripples are superimposed on them. But at higher velocity, the ripples disappear and only the dunes are left.

CHAPTER - 6
CANAL HEAD WORKS & SEEPAGE THEORY

6.1 INTRODUCTION
An irrigation canal takes its supplies from a river or a stream. In order to divert water from the river into the canal it is necessary to construct certain works or structures across the river and at the head of the off taking canal. These works are termed as canal headworks or headworks.
The canal headworks may be classified into the following types
1. Storage headworks
2. Diversion headworks

1. Storage Head Works
Consists of a dam constructed across the river to create a reservoir in which water is stored during the period of excess flow in the river.
(i) From the reservoir water is supplied to the canal in required quantity as per the demand.
(ii) A storage headworks storage water in addition to its diversion into the canal.

2. Diversion Head Works
Raises the water level in the river and divert the required quantity into the canal.

Our prime focus will be to study in detail about diversion headworks

The various purpose served by a diversion headwork's are as follow:
(i) It raises the water level in the river in order to increase the commanded area.
(ii) It regulates the supply of water into the canal.
(iii) It controls the entry of silt into the canal.
(iv) It provides some storage of water for a short period.
(v) It reduces the fluctuation in the level of supply in the river

6.2 TYPES OF DIVERSION HEADWORKS
The diversion headworks may be classified into the following types.
1. Temporary diversion headworks
2. Permanent diversion headworks
1. Temporary Diversion Headworks
It consists of a super or bund constructed across the river to raise the water level in the river and divert it into the canal.
(i) These bunds are constructed almost every year after the floods, because they may be damaged by the floods.

2. Permanent Diversion Headworks
It consists of a permanent structure such as weir or barrage constructed across the river to raise the water level in the river and divert it into the canal.

CHAPTER - 7
DAMS AND RESERVOIRS

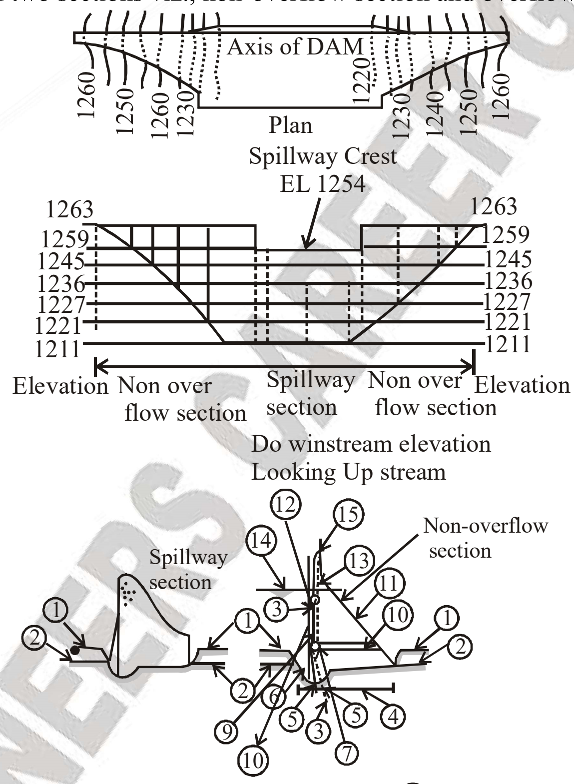
7.1 INTRODUCTION
A dam is barrier constructed across a river in order to create a reservoir for impounding water or to provide the facility of diverting water from the river or to retain debris flowing in the river along with water.

1. A gravity dam is solid masonry or concrete structure with an approximately triangular cross section, so that the external forces exerted on it are resisted by its own weight. It is also called a solid gravity dam.

2. It is mostly straight in plan but in some cases it may be slightly curved as well.

3. A sound rock foundation is an essential requirement for the construction of a gravity dam.

4. The dam consists of two sections viz., non-overflow section and overflow (or-spillway).



① River Del-level ② Foundation Rock level ③ Vertical Dram

④ Base Width ⑤ Grout Hole ⑥ Cutoff Trench ⑦ Drainage Gallery

⑧ Entrance Gallery ⑨ Axis of DAM ⑩ Upstream face

⑪ Downstream face ⑫ Inspection Gallery ⑬ Inspection Shaft

⑭ Maximum water level ⑮ Crest

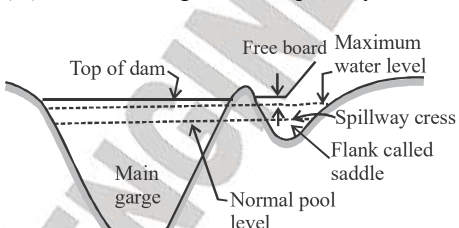
CHAPTER - 8
SPILLWAYS, ENERGY DISSIPATORS & SPILLWAY GATES

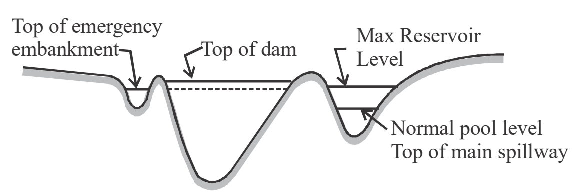
8.1 INTRODUCTION
1.A spillway is a waterway provided to dispose off surplus flood waters from reservoir after it has been filled to its maximum capacity.
2.Spillways are provided for almost all the dams and these acts as safety values for the dams.
3.A spillway may be located either within the body of the dam or at one end of the dam or entirely away from the dam in the saddle as an independent structure.
4.It is essential to provide a spillway of sufficient capacity so that the surplus flood water is discharge keeping the water level in the reservoir below some predetermined maximum level and no damage is done to dam.

8.1.1 Essential Requirements of A Spillway
The essential requirements of a spillway are as follows
1.The spillway must have sufficient capacity
2.It must be hydraulically and structurally adequate
3.It must be so located that it provides safe disposal of water i.e., spillway discharges should not erode or undermine the d/s toe of the dam.
4.The bonding surfaces of the spillway must be erosion resistant to withstand the high scouring velocities created by the drop from the reservoir surface to tail water.
5.Some devices for dissipation of energy on the d/s side of the spillway will be required.

8.1.2 Spillway Capacity
The required capacity of a spillway (i.e. the maximum outflow rate through the spillway) may be determined by flood routing which requires following data.
1.In flow hydrograph (plot of rate of inflow v/s time).
2.Reservoir capacity curve (plot of reservoir storage v/s reservoir water surface elevation).
3.Discharge curve (plot of rate of outflow through spillway v/s reservoir water surface elevation).

The required capacity of a spillway depends on the following factors.
(i) The inflow flood
(ii) The available storage capacity.
(iii) The discharge capacity of other outlet works.
(iv) Provision of gates in a spillway.





WORKBOOK

Example 1. At an energy dissipator structure below a low spillway, the discharge is $19m^2/sec$ and the energy loss is 1m at the hydraulic jump forming therein. Determine the depths of flow at both ends of the jump

Solution.

Given, $q = 19\ m^2/s$; Energy loss, $H_L = 1m$

Energy loss for hydraulic jump,

$$H_L = \frac{(y_2 - y_1)^3}{4y_1y_2}$$

and $\frac{2a^2}{g} = y_1\, y_2(y_1 + y_2)$

$$y_1\, y_2\,(y_1 + y_2) = \frac{2 \times (19)^2}{g}$$

$\Rightarrow y_1\, y_2\,(y_1 + y_2) = 73.6$ …(i)

$$1 = \frac{(y_2 - y_1)^3}{4y_1y_2} \quad \text{…(ii)}$$

Let $\frac{y_2}{y_1} = x \quad \Rightarrow y_2 = xy_1$

Putting the value of y_2 in equation (i)

$y_1^2(y_1 + xy_1) = 73.6 \quad \Rightarrow xy_1^3(1+x) = 73.6$

Similarly putting in (ii), we get

$$\frac{(y_1x - y_1)^3}{4y_1\, y_1\, x} = 1 \qquad \frac{y_1^3(x-1)^3}{4y_1^2\, x} = 1$$

$$\Rightarrow\ 4x = y_1(x-1)^3 \qquad \Rightarrow y_1 = \frac{4x}{(x-1)^3}$$

Substituting the value of y_1 in equation (ii), we get

$$x\left[\frac{4x}{(x-1)^3}\right](1+x) = 73.6$$

$\therefore$ By hit and trial, we get $x = 2.8$,

$$y_1 = \frac{4\times 2.8}{(2.8-1)} = \frac{4\times 2.8}{1.8^3} = 1.92m$$

and $y_2 = y_1x = 1.92 \times 2.8 = 5.377m.$

GATE QUESTIONS

1. Water emerges from an ogee spillway with velocity = 13.72 m/s and depth = 0.3 m at its toe. The tail water depth required to form a hydraulic jump at the toe is

[GATE - 2008]

(a) 6.48m (b) 5.24m
(c) 3.24m (d) 2.24m

2. Which one of the following equations represents the downstream profile of Ogee spillway with vertical upstream face? (x, y) are the coordinates of the point on the downstream profile with origin at the crest of the spillway and H_d is the design head.

[GATE - 2005]

(a) $\frac{y}{H_d} = -0.5\left(\frac{x}{H_d}\right)^{1.85}$

(b) $\frac{y}{H_d} = -0.5\left(\frac{x}{H_d}\right)^{1/1.85}$

(c) $\frac{y}{H_d} = -2.0\left(\frac{x}{H_d}\right)^{1.85}$

(d) $\frac{y}{H_d} = -2.0\left(\frac{x}{H_d}\right)^{1/1.85}$

SOLUTIONS

Sol. 1. (c)

Water depth required to form a hydraulic jump may be given as

$$y_2 = \frac{y_1}{2}\left[-1 + \sqrt{1 + \frac{8V_1^2}{gy_1}}\right]$$

$$= \frac{0.3}{2} \times \left[-1 + \sqrt{\frac{8 \times (13.72)^2}{9.81 \times 0.3}}\right] = 3.24\text{m}$$

Sol. 2. (a)

For a spillway having a vertical u/s face, the d/s crest is given by the equation,

$$X^{1.85} = -2H_d^{0.85} \times y$$

$$\Rightarrow x^{1.85} = -2H_d^{0.85} y \times \frac{H_d}{H_d}$$

$$\Rightarrow x^{1.85} = -2\frac{H_d^{1.85} y}{H_d}$$

$$\Rightarrow \frac{x^{1.85}}{-2H_d 1.85} = \frac{y}{H_d}$$

$$\Rightarrow \frac{x^{1.85}}{-2H_d^{1.85}} = \frac{y}{H_d}$$

$$\Rightarrow \frac{y}{H_d} = -0.5\left(\frac{x}{H_d}\right)^{1.85}$$

ESE OBJ QUESTIONS

1. By considering the channel index as 5/3, the setting of an orifice type irrigation outlet to have proportionality is

[ESE - 2015]

(a) 0.90 (b) 0.67
(c) 0.30 (d) 0.15

2. In a ski-jump bucket provided in an overflow spillway, the lip angle is 30°, and the actual velocity of flow entering the bucket is 30 m/s. The maximum vertical height attained by the trajectory of the jet, measured above the lip of the bucket, is nearly

[ESE - 2015]

(a) 45m (b) 35m
(c) 22 m (d) 11 m

3. Which of the following outlets are of semi-modula^{r} type?
1. Khanna's module
2. Adjustable proportional module
3. Submerged pipe outlet
4. Open flume outlet
5. Kennedy's gauge outlet

[ESE - 2014]

(a) 2, 4 and 5 (b) 1, 2 and 4
(c) 2, 3 and 5 (d) 3, 4 and 5

4. The flip bucket energy dissipator for a spillway is suitable where:
1. The tail water depth is low.
2. The rock on the downstream is fragile and is erodible.
3. The rock on the downstream is good and non-erodible.

[ESE - 2013]

(a) 1,2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

5. A discharge of 72 m^3/s is to be allowed through siphon spillways of 2 m width and 75 cm depth with working head of 8 m. The number of spillways to be provided will be (Take coefficient of discharge for the spillways = 0.64)

[ESE - 2012]

(a) 2 (b) 4
(c) 6 (d) 8

6. A ski-jump bucket is generally used as an energy dissipator when the tail water

[ESE - 2010]

(a)Is greater than 1.1 times the required conjugate depth for the formation of hydraulic jump; and the river bed rock is 'good'
(b)Depth is lesser than the depth required for the jump formation; and the bed of the river channel is composed of 'sound' rock
(c)Depth is equal to the depth required for the jump formation, and the river bed rock is 'good'
(d)Depth is 1.3 times the required for the jump formation and the river bed is composed of 'weak' rock

7. Which one of the following equations represents the downstream curve of the "Ogee" spillway (where *x* and *y* are the co-ordinates of the crest profile measured from the apex of the crest, and *H* is the design head)?

[ESE - 2004]

(a) $x^{185} = 2H^{\circ}\text{-}^{85}y$ (b) $x = 2H^{r85}y^{\circ,85}$
(c) $jc^{a85} = 2H^{1}\text{-}^{85}y$ (d) $x = 2H^{a85}y^{1,85}$

8. The ideal condition for energy dissipation in the design of spillways is the one when the tail water rating curve

[ESE - 2003]

(a)Lies above jump rating curve at all discharges
(b)Coincides with the jump rating curve at all discharges
(c)Lies below jump rating curve at all discharges
(d)Lies either above or below the jump rating curve depending upon discharge

WORKBOOK

Example 1. Determine the time required to irrigate a strip of land of 0.04 hectares in area from a tube well with a discharge of 0.02 cumec. The infiltration capacity of the soil may be taken as 5 cm/hr and the average depth of flow on the field as 10 cm.

Also determine the maximum area that can be irrigated from this tube well.

Solution.

Given, Area of the strip, A = 0.04 hectares = $0.04 \times 10^4\ m^2 = 400\ m^2$.

Discharge, Q = 0.02 cumecs = $0.02\ m^3/sec = 0.02 \times 60 \times 60\ m^3/hr = 72\ m^3/hr$.

Infiltration capacity of soil, f = 5 cm/hr $\frac{5}{100}$ m/hr = 0.05 m/hr

Average depth of flow on the field, y = 10cm = 0.1 m.

Approximate time required to irrigate a strip of land, $t = 2.303\frac{y}{f}\log_{10}\left(\frac{Q}{Q-fA}\right)$

or $t = 2.303\times\frac{0.10}{0.05}\times\log_{10}\left(\frac{72}{72-0.05\times400}\right)$

= $2.303 \times 2 \log_{10}(75/52)$ = 0.651 hr = 39.06 minutes

Maximum area that can be irrigated,

$$A_{max} = \frac{Q}{f} = \frac{72}{0.05}m^2 = 1440m^2 = \frac{1440}{10^4}ha = 0.144ha$$

ASSIGNMENT

1. Assertion (A): Sprinkler method of irrigation has higher water application/use efficiency.
Reason (R): Sprinkler, system causes lees interference in cultivation and other farming operations.
Of these statements
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

2. A sprinkler irrigation system is suitable when
(a) The land gradient is steep and the soil is easily erodible.
(b) The soil is having low permeability
(c) The water table is low
(d) The crops to be grown have deep roots

3. An Indian irrigation project designed to serve a command of more than 2000 hectares and up to 10000 hectares, is known as a :
(a) Major irrigation project
(b) Minor irrigation project
(c) Medium irrigation project
(d) None of them, since irrigation projects are classified on the basis of their costs.

4. The method of growing crops on ridges, running on the sides of water ditches, is known as
(a) Flood irrigation
(b) Furrow irrigation
(c) Check irrigation
(d) None of them

5. In a field under furrow irrigation, 'furrows' are referred to represent
(a) Ridges on which crops are grown
(b) Narrow ditches carrying water
(c) Both (a) and (b)
(d) Neither, (a) nor (b)

6. Pinpoint the correct statement.
(a) Irrigation helps in adopting mixed cropping
(b) Mixed cropping means sowing of a different crop after a particular crop has been grown
(c) Over-irrigation may lead to saving in fertilizers
(d) Irrigation helps in avoiding mixed cropping

7. 'Flood irrigation' method of irrigation fields, works best on
(a) Level or gently rolling terrain
(b) Steeply rolling terrain
(c) Both (a) and (b)
(d) None of the above

8. In a mildly water scarce area, the drip irrigation could be preferred for growing:
(a) Wheat
(b) Fodder
(c) Rice
(d) Fruits & vegetables

9. Border method of irrigation is well suited to
(a) Soil having-infiltration rates that are neither low nor high
(b) Coarse sandy soils having high infiltration rates
(c) Clay soils having very low infiltration rates
(d) Soils having salts which require frequent leaching.

10. In an irrigation system, water was delivered to the field in ditches spaced about 30 m apart, and was allowed to seep into the ground to maintain the water table at such a height that the water is available to the crops through the capillary fringe. This method of irrigation is called
(a) Trickle irrigation
(b) Furrow irrigation
(c) Border irrigation
(d) Sub irrigation

GATE QUESTIONS

1. A sprinkler irrigation system is suitable when **[GATE - 2004]**
(a)The land gradient is steep and the soil is easily erodible
(b)The soil is having low permeability
(c)The water table is low
(d) The crops to be grown have deep roots

SOLUTIONS

Sol.1. (a)
The conditions favouring the use of sprinkler irrigation method are:
(i)When the land topography is irregular.
(ii)When the land gradient is steeper and soil is easily erodible.
(iii)When the land soil is excessively permeable.
(iv)When the water table is high.
(v)When the seasonal water requirement is low.
(vi)When the water availability is difficult and scarce.

ESE OBJ QUESTIONS

1. An identified source of irrigation water has ion concentrations of Na^+, Ca^{++} and Mg^{++} as 20, 10 and 8 mille equivalent per liter, respectively. The SAR of this water is approximately.

[ESE - 2011]

(a) 2.06 (b) 6.67
(c) 2.67 (d) zero

2. Assertion (A): In the border strip method of irrigation, the size of the strip depends on soil characteristics, slope of the land and discharge.
Reason (R): Border strip method is a controlled type of subsurface irrigation method.

[ESE - 2010]

(a)Both A and R are true and R is the correct explanation of A
(b)Both A and R are true but R is not a correct explanation of A
(c)A is true but R is false
(d)A is false but R is true

3. Assertion (A): Sprinkler method of irrigation has a higher water application/use efficiency.
Reason (R): Sprinkler system causes less interference in cultivation and other farming operations.

[ESE - 2002]

(a)Both A and R are true and R is the correct explanation of A
(b)Both A and R are true but R is not a correct explanation of A
(c)A is true but R is false
(d)A is false but R is true

SOLUTIONS

Sol.1. (b)
SAR = Sodium Absorption Ratio

$$= \frac{Na^+}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}} = \frac{20}{\sqrt{\frac{10+8}{2}}} = 6.67$$

Sol.2. (c)

Sol.3. (c)
Sprinkler system consists of network of pipes running across the field. Thus it will cause interference in cultivation and other operation.

WORKBOOK

Example 1. The depth of moisture in root zone at field capacity and permanent wilting point per m depth of soil are 0.5 m/m and 0.2 m/m r respectively. Compute the field capacity and permanent wilting point. Take dry weight of soil as 13.73 kN/m^3.

Solution.

Given,

Depth of moisture in root zone at F.C. per meter depth of soil, $d_a = 0.5$

Depth of moisture in root zone at P.W.P per meter depth of soil, $d_2 = 0.2$ m

Take depth of soil = 1m

$\therefore$ Field capacity

$$= \frac{\text{Wt. of water retained in the root zone corr. to F.C}}{\text{Weight of dry soil}}$$

$$\frac{\gamma_d \times d_w}{\gamma_d . 1} = \frac{9.81 \times 0.5}{13.73} = 0.3572 = 35.72\%$$

Permanent wilting point

$$= \frac{\text{Wt. of water ret. in the root zone corr. to PWP}}{\text{Weight of dry soil}}$$

$$= \frac{9.81 \times 0.2}{13.73} = 0.1429 = 14.29\%$$

Example 2. A loam soil has a field capacity of 25 percent and wilting coefficient of 10%. The dry unit weight of soil is 1.5g/cc. If the root zone depth is 60 cm, determine the storage capacity of the soil irrigation water is applied when moisture content falls to 15 percent. If the water application efficiency is 75%, determine the water depth required to be applied in the field.

Solution.

Given,

Field capacity, FC = 25%, Wilting coefficient WC = 10%

Dry unit wt. of soil, γ_d = 1.5 gm/cc; Root zone depth, d = 60cm

Water application efficiency = 75%

Moisture storage capacity of soil in the root zone depth

$$= \frac{\gamma_d}{\gamma_w} \times d \times (FC - WC)$$

$$= \frac{1.5}{1} \times 60 \times (0.25 - 0.10) = 13.5\text{m}$$

Now, when moisture content falls to 15%, the deficiency of water depth created

$$= \frac{\gamma_d}{\gamma_w} \times d \times (0.25 - 0.15)$$

$$= \frac{1.5}{1} \times 60 \times (0.25 - 0.15) = 9\text{cm}$$

Hence, the net irrigation requirement = 9 cm

$$= \frac{\text{Net irrigation requirment}}{\text{Water applicable efficiency}} = \frac{9}{0.75} = 12\text{cm}$$

Example 3. The following data pertains to healthy growth of a crop.

(i) Field capacity of soil = 30%

(ii)Permanent wilting point = 11%

(iii)Density of soil = 1300 kg/m^3

(iv)Effective depth of root zone = 700 mm

(v)Daily consumptive use of water for the given crop = 12 mm

For healthy growth moisture content must not fall below 25% of the water holding capacity between the field capacity and the permanent wilting point. Determine the watering interval in days.

Solution.

Given

Field capacity of soil (FC) = 30%; Permanent wilting percentage (PWP) = 11%

Density of soil, (γ_d) = 1300 kg/m^3; Effective depth of root zone, (d) = 700 mm

Daily consumptive use of water = 12 mm

Determine water interval (T) in days

Key: Moisture content does not fall below 25%

ESE OBJ QUESTIONS

1. Consider the following statements regarding design of channel by Lacey and Kennedy:
1.The theoretical concept of slit transportation is the same in both the theories.
2.Lacey improved upon Kennedy's formula.
3.There are no defects in either the theories of Lacey or of Kennedy.
Which of the above statements are correct?

[ESE - 2017]

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

2. Statement (I): The shear stress exerted by the stream flow on the bed is responsible for the movement of bed sediment particles.
Statement (II): The trap efficiency is a function of the ratio of reservoir capacity to the total inflow. A small reservoir on a large stream has a low trap efficiency.

[ESE - 2016]

(a)Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b)Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
(c)Statement (I) is true but Statement (II) is false
(d)Statement (I) is false but Statement (II) is true

3. Statement (I): A channel in alluvium running with constant discharge and constant sediment charge will first form its flow section and then its final longitudinal slope.
Statement (II): If a channel in alluvium has a section too small for a given discharge and slope steeper than required, degradation and aggradations happen and then the flow section attains final regime.

[ESE - 2016]

(a)Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b)Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
(c)Statement (I) is true but Statement (II) is false
(d)Statement (I) is false but Statement (II) is true

4. A channel designed by lacey's theory has a mean velocity of 1.1 m/s. The silt factor is 1.1. then hydraulic mean radius will be

[ESE - 2016]

(a) 1.13 m (b) 2.27 m
(c) 3.13 m (d) 4.27 m

5. A barrage on a major river in the Ganetic plains has been designed for a flood discharge 7000 m^3/s. It has been provided with a waterway of 360 m length. The looseness factor of this barrage is

[ESE - 2016]

(a) 1.7 (b) 1.1
(c) 0.7 (d) 0.1

6. The conditions to be satisfied for a channel in 'Regime' as per Lacey are
1.Constant discharge
2.Silt grade and silt concentration are constant.
3.The channel is flowing in unlimited incoherent alluvium of the same alluvial character as that transported.
Which of the above statements are correct?

[ESE - 2016]

(a) 1 and 2 only (b) 1, 2 and 3
(c) 1 and 3 only (d) 2 and 3 only

7. Leaching is a process

[ESE - 2003]

(a)By which alkali salts present in the soil are dissolved and drained away

GATE QUESTIONS

1. The base width of an elementary profile of a gravity dam of height H is b. The specific gravity of the material of the dam is G and uplift pressure coefficient is K. The correct relationship for no tension at the heel is given by

[GATE - 2008]

(a) $\frac{b}{H}=\frac{1}{\sqrt{G-K}}$ (b) $\frac{b}{H}=\sqrt{G-K}$

(c) $\frac{b}{H}=\frac{1}{G-K}$ (d) $\frac{b}{H}=\frac{1}{K\sqrt{G-K}}$

2. While designing a hydraulic structure, the piezometric head at bottom of the floor is computed as 10 m. The datum is 3 m below floor bottom. The assured standing water depth above the floor is 2 m. The specific gravity of the floor material is 2.5. The floor thickness should be

[GATE - 2003]

(a) 2.00m (b) 3.33m

(c) 4.40m (d) 6.00m

3. The live storage requirement for a reservoir is to be determined by

[GATE - 1993]

(a) Topographical survey

(b) Annual demand

(c) Double mass curve analysis

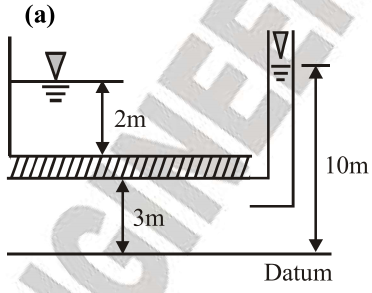
(d) Mass curve analysis

SOLUTIONS

Sol. 1 (a)

Tension will not be developed at the heel with full reservoir, when $b \geq \frac{H}{\sqrt{G-K}}$

Sol. 2 (a)



$G = 2.5$

Pressure head $= 10 - 3 = 7$ m

At critical condition

Uplift = Downward pressure

$7 \times \gamma_w = (\gamma_w \times 2) + (\gamma_{floor} \times t)$

$\frac{5\gamma_w}{\gamma_{floor}} = t = \frac{5}{G} = \frac{5}{2.5}$

$\therefore\ t = 2m$

Sol. 3 (*)

Super passage

SECTION-B

[HYDROLOGY]

ESE OBJ QUESTIONS

1. Which of the following statements are correct as regards aquifer characteristics?
1.The storage coefficient is the volume of water released from storage from the entire aquifer due to unit depression of peizometrix head.
2.The storage coefficient is the same as the specific yield for water table aquifer.
3.Both the aquifer constants, viz, storage coefficient S and Transmissivity T are dimensionless numbers.

[ESE - 2016]

(a) 1 only (b) 2 only
(c) 3 only (d) 1, 2 and 3

2. Which of the following are pertinent to the realization of hydrological cycle?
1.Latitudinal differences in solar heating of the Earth's surface.
2.Inclination of the Earth's axis
3.Uneven distribution of land and water
4.Coriolis effect.

[ESE - 2012]

(a)1, 2 and 3 only (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

3. What is 'Hydrology Cycle'?

[ESE - 2009]

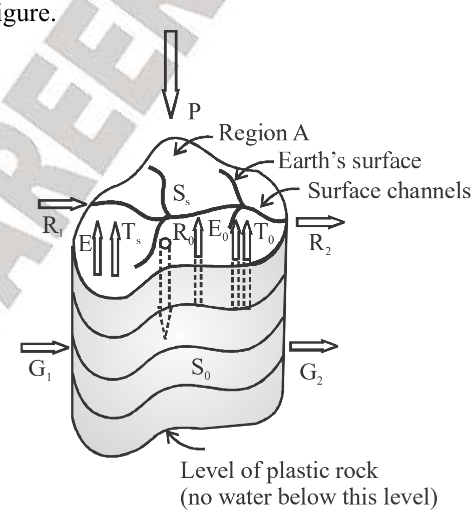
1.Processes involved in the transfer of moisture from sea to land.
2.Processes involved in the transfer of moisture from sea back to sea again
3.Processes involved in the transfer of water from snowmelt in mountains to sea.
4.Processes involved in the transfer of moisture from sea to land and back to sea again.

4. The quantitative of the balance between water gains and losses in a certain basin during a specified period of time is known as which one of the following?
1. Water budget
2. Hydrologic budget
3. Groundwater budget
Select the correct answer using the codes given below:

[ESE - 2007]

(a) 1 only (b) 2 only
(c) 3 only (d) None of these

5. Regional hydrological cycle is shown in the figure.



The correct hydrological budget equations

[ESE - 2002]

(a) $P + R_1 - R_2 - E_S - T_S - I = DS_S$
(b) $I + G_1 - G_2 - R_g - E_g - T_g = DS_g$
(c) $P - (R_2 - R_1) - (E_S + E_g) - (T_S - T_g) - (G_2 - G_2) = D(S_S + S_g)$
(d) $P - R - G - E\ T = DS_S$

WORKBOOK

Example 1. The average normal rainfall of 5 rain gauges in the base stations are 89, 54, 41and 55 cm. If the error in the estimation of rainfall should not exceed 10%, how many additional gauges may be required?

Solution.

The mean rainfall is obtained as:

$$P_x = \frac{91.11+72.23+79.89}{3}$$

$$\text{Now, } \sigma^2 = \frac{\begin{array}{c}(89-56.8)^2+(54-56.8)^2+\\(45-56.8)^2+(41-56.8)^2+\\(55-568)^2\end{array}}{5-1}$$

Or $\sigma^2 = 359.2$

$\therefore \sigma = 18.95$

The coefficient of variation is calculated as :

$$C_V = \frac{19.95}{56.8} = 0.33367$$

$$N = \left(\frac{C_V}{0.10}\right)^2 = \left(\frac{0.33367}{0.1}\right)^2 = 11.13 \equiv 12$$

Thus additional no. required

= (12 – 5) = 7.

Example 2. The normal annual rainfall of stations A,B, C and D in a catchment is 80 mm, 91 mm, 8.5 mm and 87 mm respectively. In the year 2007, the station D was inoperative when stations A, B and C recorded annual rainfall of 91.11, 72.23 and 79.89 mm. Estimate the missing rainfall at station D in the year 2007.

Solution.

Normal precipitation of all the station A, B and C are within 10% of that at station D.

(87 → $87 \times 1.1 = 95.7$

→ $87 \times 0.9 = 78.3$)

Hence simple arithmetic average will he used.

$$\Rightarrow P_x = \frac{91.11+72.23+79.89}{3}$$

= 81.08 mm

Example 3. Find the missing rainfall at station X.

Rain gauge	Normal	Actual
A	1125	875
B	910	1021
C	765	915
X	830	?

Solution.

As the normal ppt of other-stations-A, B and G are not within in 10% of normal ppt at station x.

(830 → 830 x 1.1 = 913

→ 830 x 0.9 = 747) Hence

$$\frac{P_x}{N_x} = \frac{1}{3}\left[\frac{P_A}{N_A}+\frac{P_B}{N_B}+\frac{P_C}{N_C}\right]$$

$$\frac{P_x}{830} = \frac{1}{3}\left[\frac{875}{1125}+\frac{1021}{910}+\frac{915}{765}\right]$$

$\Rightarrow P_x = 856.5$

Example 4. The annual rainfall at station X and the average annual rainfall at 18 surrounding stations during 1952 to 1970 are as follows:

Annual rainfall in cm at X.

30.5, 38.9, 43.7, 32.2, 27.4, 32.0, 49.3, 28.4, 24.6, 21.8, 28.2, 17.3, 22.3, 28.4, 24.1, 26.9, 20.6, 29.5 and 28.4.

18 stations average annual rainfall in cm:

22.8, 35.0, 30.2, 27.4, 25.2, 28.2, 36.1, 18.4, 25.1, 23.6, 33.3, 23.4, 36.0, 31.2, 23.1, 23.4, 23.1, 33.2 and 26.4.

Explain how the consistency of the record at station X can be verified and how to determine the year in which a change in regime has occurred.

Solution.

CHAPTER - 4
SURFACE WATER HYDROLOGY (*RUNOFF*)

4.1 RUNOFF
Runoff may be referred to as stream flow, river discharge or catchment yield. It is normally expressed as volume per unit time.
Based on the time delay between precipitation and runoff is classified into two categories:
1. Direct runoff
2. Base flow

4.1.1 Direct Runoff
It is that part of runoff which enters the stream immediately after the precipitation. It includes surface runoff prompt interflow and precipitation on the channel surface. It is sometimes termed as direct storm runoff or storm runoff.

4.1.1.1 Surface Runoff
It has two components:
1. Overland flow (flow of water over land before joining any open channel)
2. Open channel flow
Over land flows are small and the flow is taken to be in laminar regime. Length of overland flow is generally small. Open channel flow are in turbulent regime.

4.1.1.2 Interflow
1. Water which infiltrates the soil surface and then moves laterally through the upper soil horizons towards the stream channels above the main groundwater table is known as the Interflow. It is also known as subsurface runoff, subsurface storm flow, storm seepage and secondary base flow.
2. If the lateral hydraulic conductivity of the surface layers are substantially greater than the overall hydraulic conductivity, it is a favourable condition for the generation of interflow. Generally interflow more slowly than surface runoff.
3. Depending upon the time delay between infiltration and its **outflow from** the upper crusts of the soil the interflow is sometimes classified into prompt interflow and delayed **interflow.**

4.1.1.3 Direct Precipitation
Direct precipitation onto the water surface and into the stream channels will normally represent only a small percentage of total volume of water flowing in the streams. This component is usually ignored in runoff calculations.

4.1.2 Base Flow or Ground Water Flow
1. The delayed flow that reaches a stream essentially as groundwater flow is called base flow. Many times delayed interflow is also included under this category.
2. The infiltrated water which percolates deeply becomes groundwater and when groundwater table rises and intersects the stream channels of the basin it discharges into streams as the groundwater runoff.
3. Ground water flow is sometimes referred to as base flow, dry weather flow, and effluent seepage.
4. For the practical purpose of analysis total runoff in stream channels is generally classified as direct runoff and base flow.

WORKBOOK

Example 1. Rainfall of 12, 30, 40, 44 and 17 mm were recorder on 3rd, 9th, 10th, 16th, and 17th days of a particular month. Compute the antecedent precipitation index for the first 20 days of the month and sketch its variation with time. Assume that API of the last day in the previous month is 85 mm and the value of the recession factor K is 0.90.

Solution.

The API of any day 't', denoted by I_t . I_t is obtained from equation $I_t = K.I_{t-1} + P_t$, where P_t is the precipitation of t^{th} day. I_0 = 85 and K = 0.9. The tabular calculation is shown below.

Day t	Precipitation in mm P_t	I_{t-1}
1	0	85.00
2	0	76.50
3	12	68.85
4	0	73.97
5	0	66.57
6	0	59.91
7	0	53.92
8	0	48.53
9	30	43.68
10	40	69.31
11	0	102.38
12	0	92.14
13	0	82.93
14	0	74.64
15	0	67.18
16	44	60.46
17	17	98.41
18	0	105.57
19	0	95.01
20	0	85.51

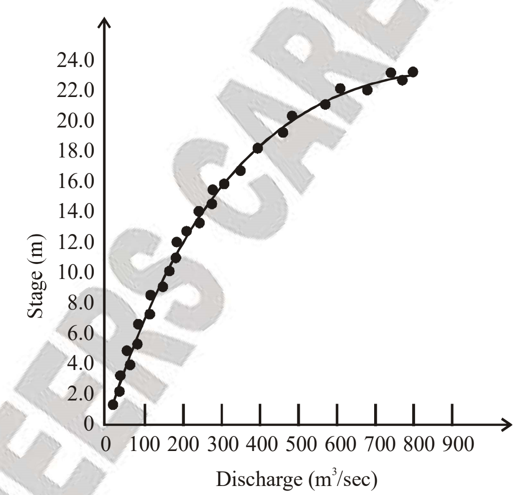
Day t	$K.I_{t-1}$	$I_t = K.I_{t-1} + P_t$
1	76.50	76.50
2	68.85	68.85
3	61.97	73.97
4	66.57	66.57
5	59.91	59.91
6	53.92	53.92
7	48.53	48.53
8	43.68	43.68
9	39.31	69.31
10	62.38	102.38
11	92.14	92.14
12	82.93	82.93
13	74.64	74.64
14	67.18	67.18
15	60.46	60.46
16	54.41	98.41
17	88.57	105.57
18	95.01	95.01
19	85.51	85.51
20	76.96	76.96

Example 2. Given below are the monthly rain-fall P and the corresponding runoff R values covering a period of 18 months for a catchment. Develop a correlation equation between R and P.

Month	P	R
1	5	0.5
2	35	10.5
3	40	13.8
4	30	8.2
5	15	3.1
6	10	3.2
7	5	0.1
8	31	12.0
9	36	16.0
10	30	8.0
11	10	2.3
12	8	1.6
13	2	0.0

CHAPTER - 5
STREAM FLOW MEASUREMENT

5.1 INTRODUCTION
1.Water flowing in a stream is called stream flow.
2.If the stream flow is unaffected by the artificial diversion, storage etc. then it is called runoff (virgin stream flow).'Thus stream flow represents the runoff phase of hydrological cycle.
3.Out of the various processes in hydrological cycle, like evaporation, precipitation, evapo-transpiration etc. stream flow is amenable to fairly accurate measurement.
4.Stream flow is measured in units of discharge (m^3/s)
Flow characteristics of a stream depend upon:
(i) Rainfall characteristics
(ii) Catchment characteristics
(iii) Climatic factors
(iv) It is rather difficult to measure the discharge of flow in the natural streams directly as it is done in the case of flow in pipes or laboratory flumes using the flow meters. But it is very easy to make a direct and continuous measurement of stage in the river which is nothing but the height of the water surface in the river above some arbitrary datum. The higher the stage in the river, the higher is the discharge.



Hence two step procedure is followed for discharge measurement in a stream.
(a) Discharge in a given stream is related to elevation of the water surface (stage) through a series of careful measurements.
(b) Stage of the stream is observed routinely and discharge is estimated by stage-discharge relationship.

5.2 MEASUREMENT OF STAGE
Stage is defined as the water surface elevation measured above a datum (can be MSL or any arbitrary datum,
1. Manual stage measurements are done using
(i) Staff gauge (ii) Wire gauge