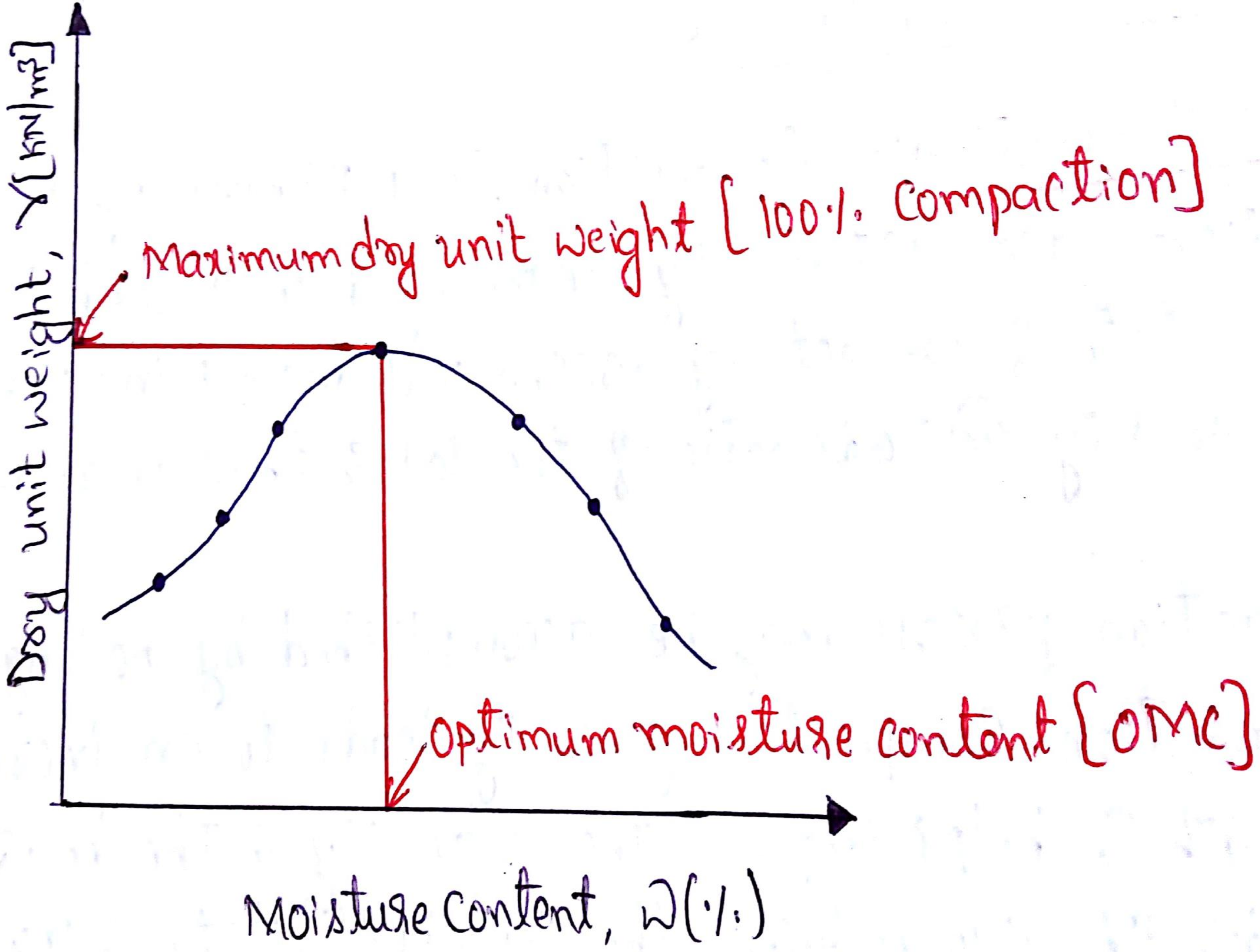
Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Introduction:

- Compaction is a process by which the soil particles are artificially rearranged and packed together into a closer state of contact by mechanical means in order to decrease the porosity of the soil and thus increase its dry density.
- The compaction process may be accomplished by rolling, tamping or vibration.
- Compaction leads to an increase in shear strength, improves stability and bearing capacity of soil.



Dry unit weight, γ [kN/m³]
Maximum dry unit weight [100% compaction]
optimum moisture content [OMC]
Moisture content, ω(%)

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Principle of Compaction:

- Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy.
- The degree of compaction of a soil is measured in terms of its dry unit weight.
- When water is added to the soil during compaction, it acts as a softening agent on the soil particles.
- The dry unit weight after compaction increases as the water content increases.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Principle of Compaction:

- To a certain limit the dry unit weight decreases, any increase in the water content.
- The water content at which the maximum dry unit weight is attained is generally referred as the "optimum moisture content".
- Standard proctor or Modified proctor method are mainly used as compaction process for any type of soil.

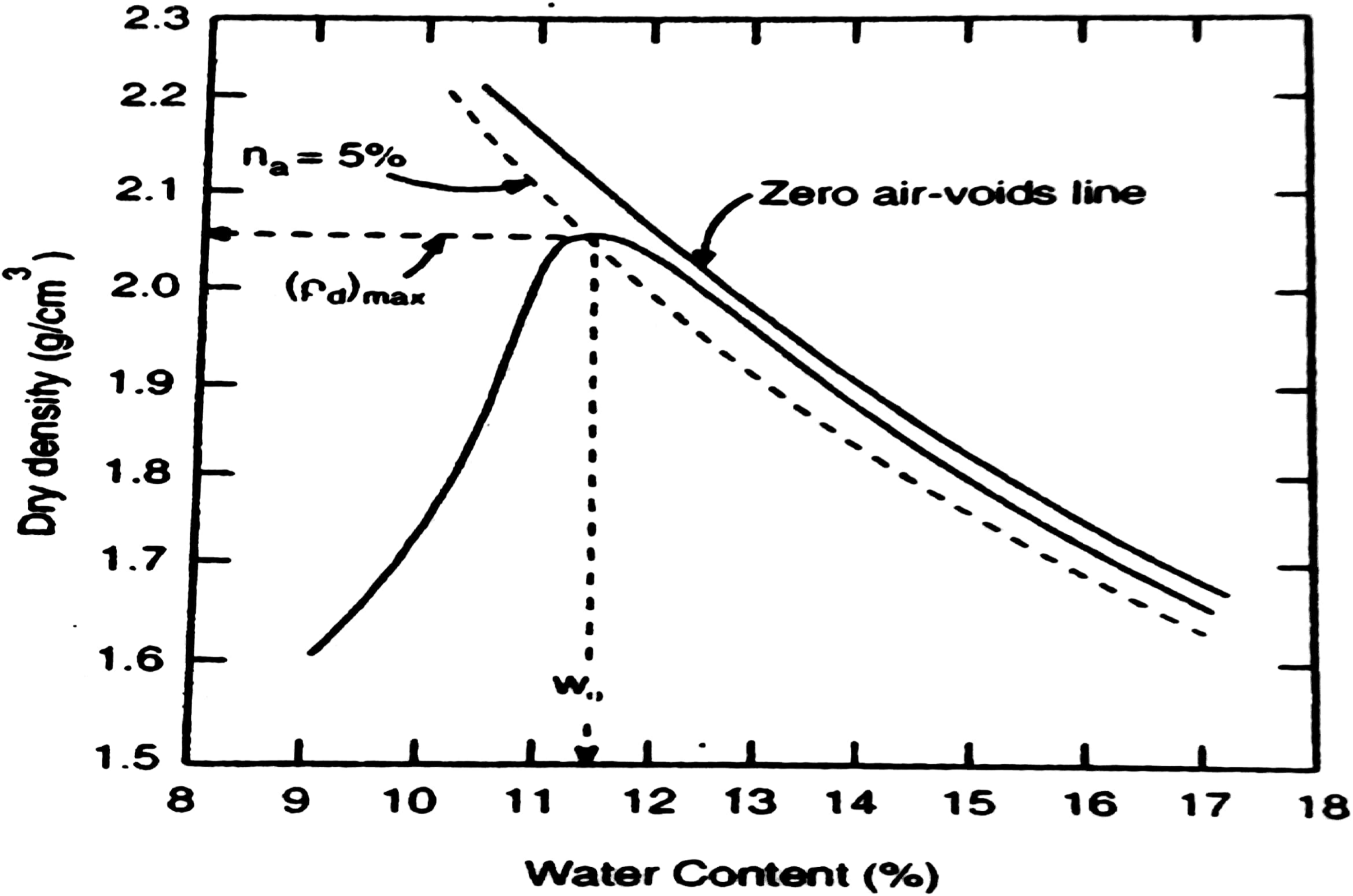


FIG. 17.2. WATER CONTENT DENSITY RELATIONSHIP.

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Module – 2: Compaction of Soils

Compaction:

Air Void and Zero Air Void Line:

- A line which shows the water content dry density relation for the compacted soil containing a constant percentage air voids is known as air-void line.
- The line shows the water content dry density relation for the compacted soil containing no air voids is known as zero air-void line.
- The formula for calculating the Zero air-void line:

$$\gamma_d = G\gamma_w / (1 + (wG / S))$$

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Factors Affecting Compaction:

- Water content
- Amount and type of compaction
- Method of compaction
- Type of soil
- Addition of admixtures

Module – 2: Compaction of Soils

Compaction:

Water Content:

- It has been seen by laboratory experiments that as the water content is increased, the compacted density goes on increasing, till a maximum dry density is achieved after which further addition of water decreases the density.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Amount of Compaction:

- The amount of compaction greatly affects the maximum dry density and optimum water content of a given soil.
- The effect of increasing the compactive energy results in an increase in the maximum dry density and decrease in the optimum water content.
- However, the increase in maximum dry density does not have a linear relationship with increase of compactive effort.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Method of Compaction:

- The density obtained during compaction, for a given soil, greatly depends on the type of compaction in which the compactive effort is applied.
- Weight of the compacting equipment
- The manner of operation such as dynamic, static or rolling, and
- Time and area of contact between the compacting element and the soil.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Type of Soil:

- The maximum dry density achieved corresponding to a given compactive energy largely depends on the type of soil.
- Well graded coarse-grained soil attain a much higher density and lower optimum water content then the fine-grained soils which require more water for lubrication because of the greater specific surface.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Addition of Admixture:

- The compaction properties of a soil can be modified by a number of admixtures other than soil material.
- These admixtures have special application in stabilised soil construction.
- The most commonly used admixtures are lime, flyash etc.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Effect of Compaction on Soil Properties:

- Soil structure
- Permeability
- Shrinkage
- Swelling
- Pore pressure
- Compressibility
- Stress-strain relationship
- Shear strength

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Soil Structure:

- When soil is compacted at low effort with less water content i.e., less than OMC it exhibits a flocculated structure as shown in point A also exhibit the same structure in high compactive effort as shown in figure.
- But when the soil is compacted with higher percentage of water i.e., more then OMC it exhibits a dispersed for both low and heavy compactive effort which is shown in point D and B.

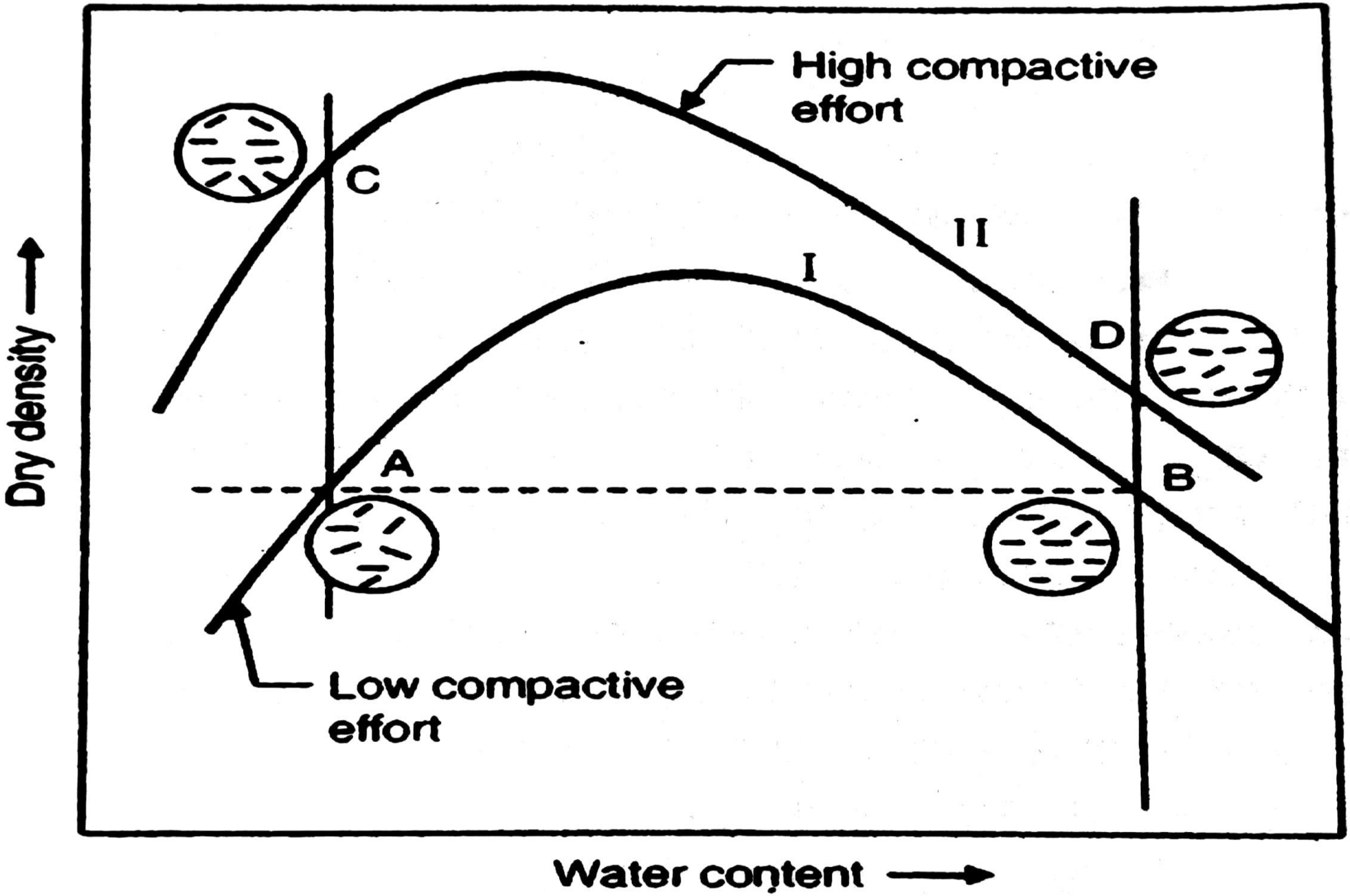

FIG. 17.11. EFFECTS OF COMPACTION ON STRUCTURE OF CLAY (AFTER LAMBE, 1958)

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Module – 2: Compaction of Soils

Compaction:

Permeability:

- As the dry density increases due to compaction, the voids go on reducing and hence the permeability goes on decreasing.
- For the same density, fine grained samples compacted dry of optimum are more permeable then those compacted wet of optimum.
- For a given voids ratio, greater the size of individual pores, greater is the permeability.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Shrinkage:

- For the same density, soil sample compacted dry of optimum shrink less than the sample compacted wet of optimum.
- This is so because the soil particles having dispersed structure have nearly parallel orientation and can pack more efficiently.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Swelling:

- A soil sample compacted dry of optimum water content has high water deficiency and more random orientation and hence exert greater swelling pressure and swell to higher water content than the sample of the same density obtained from wet side compaction.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Pore Pressure:

- A soil sample compacted dry of optimum, tends to develop low pore pressure than that of soil compacted wet of optimum will have higher pore pressure.

Compressibility:

- Soil compacted wet of optimum is more compressible than the soil compacted dry of optimum.
- However, in the high pressure range, a sample compacted dry of optimum is more compressible than the one compacted wet of the optimum.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Stress-Strain Characteristics:

- For a given soil, a sample compacted dry side of optimum has a steeper stress-strain curve and hence has a higher modulus of elasticity, than the one which is compacted wet of optimum at the same density.
- Soil compacted wet of optimum have brittle failure.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Shear Strength:

The shear strength of compacted soil depends on:

- Dry density
- Moulding water content
- Soil structure
- Method of compaction
- Strain used to define strength
- Drainage condition
- Type of soil

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Standard Proctor's Test:

- The standard proctor test was developed by R.R Proctor (1933) for the construction of earth fill dams in the state of California.
- The test equipment consists of (i) cylindrical metal mould, having an internal diameter of 4 inches, an internal effective height of 4.6 inches and a capacity of 0.945 liters, (ii) detachable base plate, (iii) collar and (iv) rammer 2.5 kg in mass and falling height of 30.5cm.

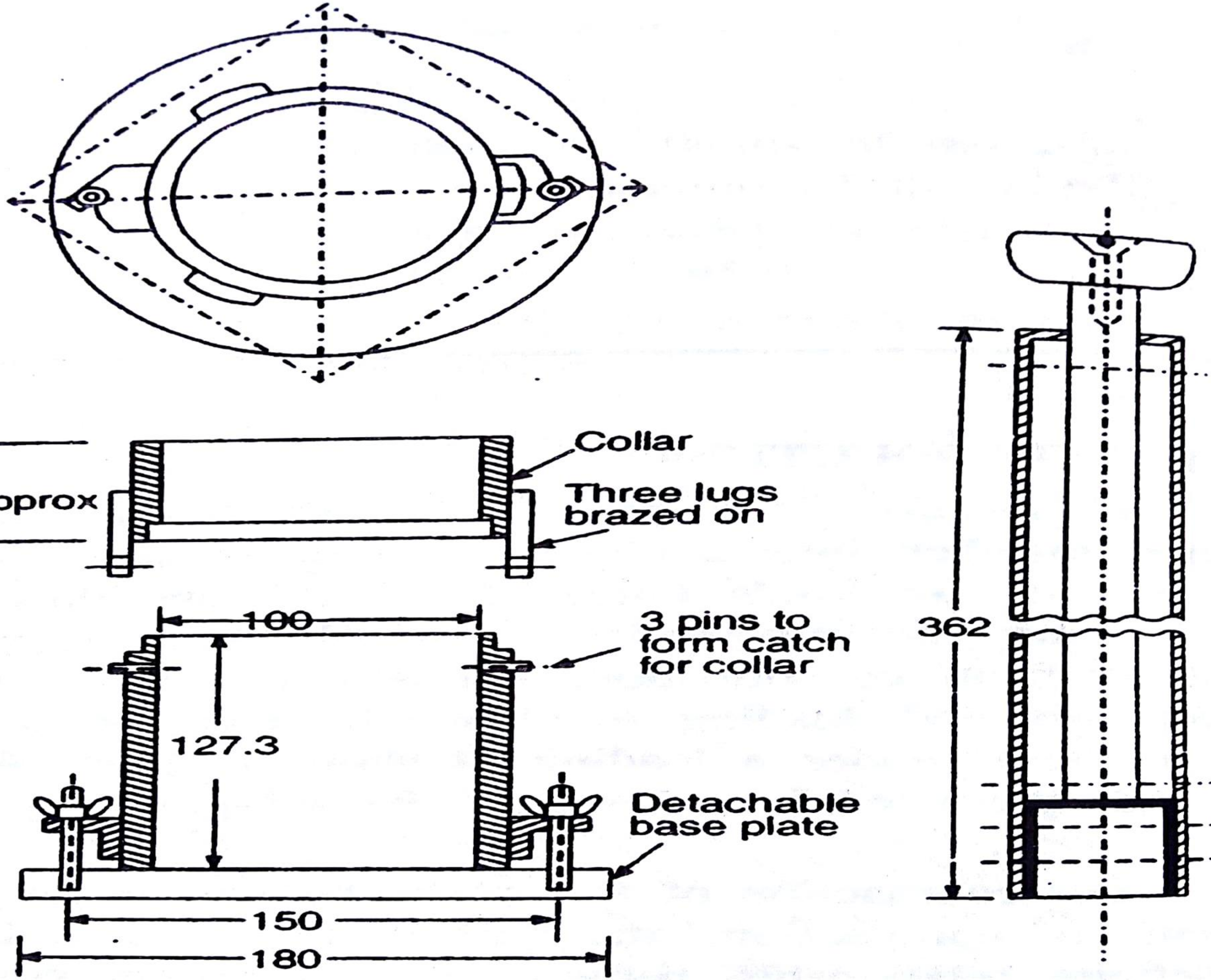


FIG. 17.1. EQUIVALENT FOR STANDARD PROCTOR TEST.
[IS : 2720 *a* (PART VII) : 1965 : LIGHT COMPACTION]

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Standard Proctor's Test:

- About 3kg of air-dried and pulverised soil, passing a 4.75 mm sieve, is mixed thoroughly with a small quantity of water.
- The mixture is covered with wet cloth, and left for a maturing time of about 5 to 30 minutes to permit proper absorption of water.
- The quantity of water to be added for the first test depends upon the probable OMC for the soil.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Standard Proctor's Test:

- The initial water content may be taken 4% for coarse grained soils and 10% for fine grained soils.
- The empty mould attached to the base plate is weighed without collar.
- The collar is then attached to the mould.
- The mixed soil is placed in the mould and compacted by giving 25 blows of the rammer uniformly distributed over the surface, such that the compacted height of soil is about 1/3 the height of mould.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Standard Proctor's Test:

- Before putting the second installment of soil, the top of the first compacted layer is scratched with the help of any sharp edge.
- The second and third layers are compacted, each layer being given 25 blows.
- The last compacted layer should project not more than 6mm into the collar.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Standard Proctor's Test:

- The collar is removed and the excess soil is trimmed off to make it level with the top of mould.
- The weight of the mould, base plate and the compacted soil is taken.
- A representative sample is taken from the centre of the compacted specimen and kept for water content determination.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Standard Proctor's Test:

- The bulk density and the corresponding dry density for the compacted soil are calculated.
- The compacted soil is taken out of the mould, broken with hand and remixed with raised water content (by 2 or 4%).
- After allowing for the maturing time, the soil is compacted in the mould in three equal layers as described above, and corresponding densities are determined.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Standard Proctor's Test:

- The test is repeated on soil samples increasing water contents.
- A compaction curve is plotted between the water content on x-axis and the corresponding dry densities on y-axis.
- The dry density goes on increasing as the water content increased, till maximum density is reached.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Modified Proctor's Test:

- The Modified Proctor test was developed to give a higher standard of compaction.
- In this test, the soil is compacted in the Standard Proctor mould, but in five layers, each layer being given 25 blows of a 4.5 kg rammer dropped through a height of 45cm.
- In the Modified Proctor test, the water content dry density curve lies above the Standard Proctor test curve, and has its peak relatively placed.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Field Compaction Methods:

The equipment that are normally used for compaction consists of:

- Smooth Wheel Rollers
- Pneumatic Type Rollers
- Sheep Foot Rollers
- Vibratory Rollers

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Smooth Wheel Rollers:

- Are suitable for subgrade and for finishing operation of fills with sandy and clayey soils.
- The smooth wheel rollers are of three types: (i) the conventional three-wheel type with two large smooth-faced steel wheels in the rear and one smaller smooth-faced drum in the front weighing from 20 to 150 kN, (ii) tandem rollers weighing from 10 to 140 kN, and (iii) the three axel tandem rollers weighing from 120 to 180 kN.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Smooth Wheel Rollers:

- Smooth wheel rollers are usually self-propelled and are equipped with a clutch type reversing gear so that they can be operated back and forth without turning.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Pneumatic Type Rollers:

- A common form of pneumatic roller consists of a box or platform mounted between two axels, the rear of which has one more wheel than the front, the wheel mounted on the front axel being arranged to track in between those mounted on rear axel.
- The tyre pressure in the small rollers are of the order of 250kN/m2 and in the heavier rollers, the pressure ranges from 400 to 1050kN/m2.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Sheep Foot Rollers:

- Consists of hollow cylindrical steel drum on which projecting feet are mounted.
- The weight of the drum can be varied by filling it partly of fully with water or sand and they are mounted either singly or in pairs on a steel frame which is towed by either track-laying.
- The loaded weight per drum ranges from about 15 to 130 kN, and the foot pressure ranges from 800 to 3500 kN/m2.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Field Compaction Control:

The field compaction control consists of the determination of:

- Water content at which the soil has been compacted
- The dry density and hence the degree of compaction achieved
- For proper compaction control as the work progresses, rapid methods of testing must be used

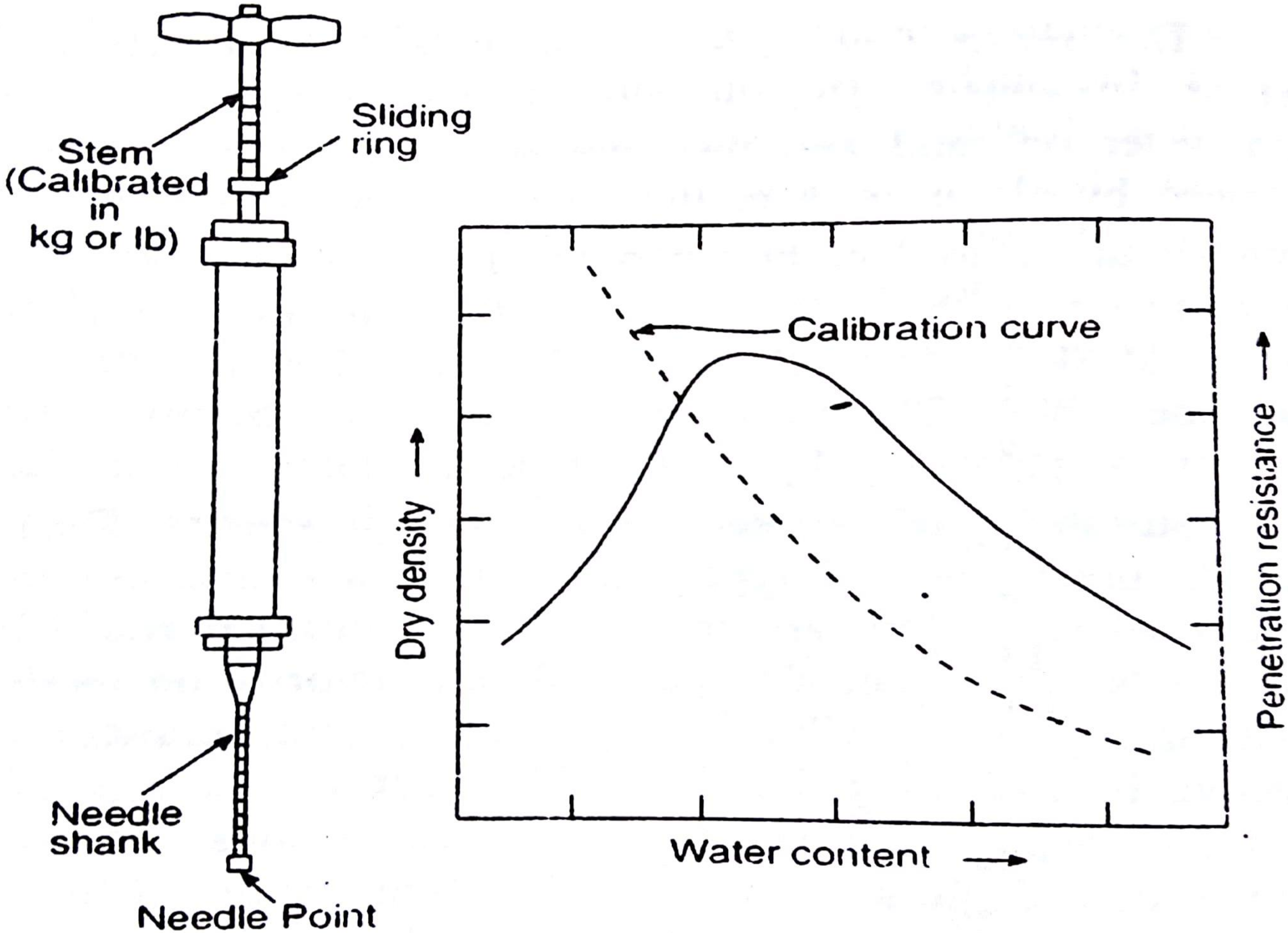


FIG. 17.6. PROCTOR NEEDLE AND CALIBRATION CURVE.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Proctor Needle Method:

- The proctor needle consist of a needle point, attached to graduated needle shank which in turn is attached to a spring loaded plunger.
- The needle point of varying cross-sectional area are available so that a wide range of penetration resistance can be measured.
- The penetration force is read on a loaded gauge fixed over the handle.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Proctor Needle Method:

- To use the needle in the field, a calibration curve is plotted in the laboratory between the penetration resistance as the ordinate and the water content as the abscissa.
- The laboratory penetration resistance is measured by inserting the Proctor needle in the compacted soil in the Proctor mould.

Module – 2: Compaction of Soils

Compaction:

Proctor Needle Method:

- The penetration resistances corresponding to various water contents are thus noted at the end of the each Proctor compaction, and a calibration curve is plotted.
- This curve may be used to determine the placement water content.
- The penetration resistance of the compacted soil in the field is determined with the Proctor's needle, and its water content is read off from the calibration curve.

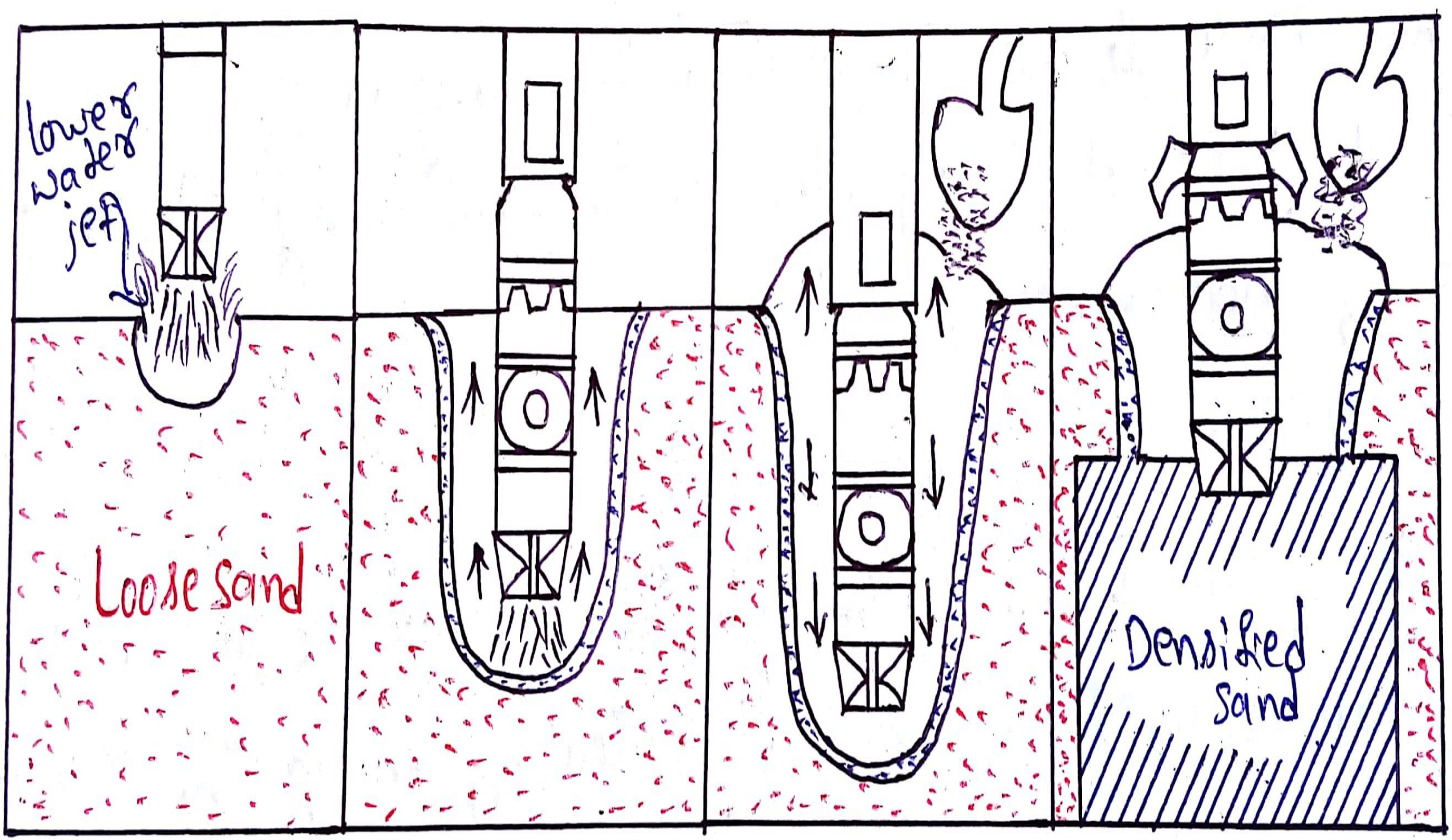
Module – 2: Compaction of Soils

Compaction:

Special Compaction Techniques:

Three types of special compaction techniques are as follows:

- Vibroflotation
- Dropping of a heavy weight or Dynamic compaction
- Blasting



Compaction by Vibroflotation process

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Vibrofloation:

- The vibrofloation technique is used for compacting granular soil only upto a depth of 30m.
- The vibrofloat is a cylindrical tube containing water jets at top and bottom.
- It also consists of a rotating eccentric weight, which develops a horizontal vibratory motion.
- The vibrofloat is sunk into the soil by using lower water jets, during which the surrounding material is compacted by the vibration process.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Vibrofloation:

- Granular material is poured from the top of the hole.
- The water from the lower jet is transferred to the top jet of the vibrating unit through which the granular materials are settled down the hole.
- This method is very effective for increasing the density of a sand deposit for depths upto 30m.
- Hence a higher density is obtained by this process.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Dynamic Compaction:

- This process consists of a crane to lift a steel block weighing upto 500kN and upto a height of 40 to 50cm, and dropped repeatedly on the ground at regular intervals.
- The process is then repeated either at the same location or over other parts of the area to be compacted.

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Dynamic Compaction:

The degree of compaction achieved at a given site depends on the following three factors:

- Weight of hammer
- Height of hammer drop
- Spacing of location at which the hammer is dropped

Geotechnical Engineering (18CV54)

Module – 2: Compaction of Soils

Compaction:

Blasting:

- Blasting is technique that has been used for the densification of granular soils.
- Here the densification of granular soils is done by blasting or by using a dynamite at a certain depth below the ground surface in the saturated soil.
- The lateral spacing of the charges varies from 3 to 10m.

Compaction	Consolidation
Instantaneous phenomenon	Time dependent phenomenon
Dynamic loading is applied	Static loading is commonly applied
Relatively quick process	Relatively slow process
Reduction in the volume of air voids	Reduction in the volume of pore water
Applies to cohesive as well as cohesion less soils	Applies to cohesive soils
Specified compaction techniques	No specified consolidation techniques

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Introduction:

- Permeability is defined as the property of a porous material which permits the passage or seepage of water through its interconnecting voids.
- A material having continuous voids is called permeable.
- Gravels are highly permeable while stiff clay is the least permeable, and hence such a clay may be termed impermeable for all practical purposes.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Introduction:

- The flow of water through soils may either be laminar of turbulent flow.
- In laminar flow, each fluid particle travels along a definite path which never crosses the path of any other particle.
- In turbulent flow, the paths are irregular and twisting, crossing and recrossing at random.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Introduction:

The study of seepage of water through soil is important for the following engineering problems:

- Determination of rate of settlement of a saturated compressible soil layer.
- Calculation of seepage through the body of earth dams, and stability of slopes.
- Calculation of uplift pressure under hydraulic structures and their safety against piping.
- Ground water flow towards wells and drainage of soil.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Darcy's Law:

- The law of flow of water through soil was first studied by Darcy (1856) who demonstrated experimentally that for laminar flow conditions in a saturated soil, the rate of flow or the discharge per unit time is proportional to the hydraulic gradient.

$$q = k\,i\,A \quad (7.1)$$

Or

$$v = (q/A) = k\,i \quad (7.2)$$

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Darcy's Law:

Where

- q = discharge per unit time
- A = total cross-sectional area of soil mass
- i = hydraulic gradient
- k = Darcy's coefficient of permeability
- v = velocity of flow or average discharge velocity

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Darcy's Law:

- If a soil sample of length L and cross-sectional area A, is subjected to differential head of water, $h_1 - h_2$, the hydraulic gradient i will be equal to $(h_1 - h_2 /L)$ and, we have

$$q = k\,(h_1 - h_2 /L)\,A$$

- From Eq 7.2 when hydraulic gradient is unity, k is equal to v. Thus, the coefficient of permeability, or simply permeability, is defined as,

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Darcy's Law:

- The average velocity of flow that will occur through the total cross-sectional area of soil under unit hydraulic gradient.
- The dimensions of the coefficient of permeability k are the same as those of velocity.
- It is usually expressed as cm/sec or m/day or feet/day.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Assumptions of Darcy’s Law:

- The soil mass is homogeneous and fully saturated.
- The flow of water passing through the soil mass is one dimensional.
- The velocity of flow is based on total cross sectional area of the soil mass.
- The soil mass structure is unaltered by the flow of water.
- The void ratio remain constant during the flow.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Validity of Darcy's Law:

- Darcy's law of linear dependency between velocity of flow v and hydraulic gradient i is valid only for laminar flow conditions in the soil.
- Form the experiments on flow through pipes, Reynolds found that the flow is laminar so long as the velocity of flow is less than a lower critical velocity v_c expressed in terms of Reynolds number as follows:

$$(v_c \, d \, \rho_w / \eta \, g) = 2000$$

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Validity of Darcy's Law:

Where

- v_c = lower critical velocity in the pipe (cm/sec)
- d = diameter of pipe (cm)
- ρ_w = density of water (g/ml)
- η = viscosity of water (g sec / cm^2)
- g = acceleration due to gravity (cm/sec^2)

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Validity of Darcy's Law:

- Based on this analogy, the flow through soils may be assumed to depend upon the dimensions of the pore spaces. In coarse grained soils, where the pore dimensions are larger, there will be greater possibility of flow becoming turbulent.
- Francher, Lewis and Branes (1933) demonstrated experimentally that flow through sands remain laminer and the Darcy's law valid so long as the Reynolds number, is equal to or less than unity.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Permeability:

- Permeability is defined as the property of a material containing continuously connected pores which permits fluids to percolate through it.

The study of permeability is important for the following situations:

- Calculation of uplift pressure under hydraulic structures and their safety against piping.
- Determination of shearing resistance of saturated soil.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Permeability:

The study of permeability is important for the following situations:

- Calculation of rate of settlement of a compressible layer under load.
- Determination of quantity of stored water escaping through an earthen dam.
- Forecasting of quantity of water percolating into the foundation pit when a pit has to be excavated below the water table.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

The factors affecting permeability are:

- Grain size
- Properties of the pore fluid
- Voids ratio of the soil
- Structural arrangement of the soil particles
- Entrapped air and foreign matter
- Adsorbed water in clayey soils

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- Permeability varies approximately as the square of the grain size.
- Since soils consists of many different sized grains, some specific grain size has to be used for comparison.
- Allen Hazen (1892), based on his experiments on filter sands of particle size between 0.1 and 3mm, found that the permeability can be expressed as

$$k = CD^2_{10}$$

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

Where

- k = coefficient of permeability
- C = constant, approximately equal to 100 when D_{10} is expressed in centimetre
- D_{10}= effective diameter

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- Permeability is directly proportional to the unit weight of water and inversely proportional to its viscosity.
- Though the unit weight of water does not change much with the change in temperature, there is great variation in viscosity with temperature. Hence, when other factors remain constant.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- The effect of voids ratio on the values of permeability can be expressed as

$$k_1 / k_2 = (C_1 e_1^3 / 1 + e_1) / (C_2 e_2^3 / 1 + e_2)$$

- Laboratory experiments have shown that the factor C changes very little with the change in the voids ratio of un-stratified sand samples.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- The structural arrangement of the particle may vary, at the same voids ratio, depending upon the method of deposition or compacting the soil mass.
- The structure may be entirely different for a disturbed sample as compared to an undisturbed sample which may posses stratification.
- The effect of structural disturbance on permeability is much pronounced in fine grained soil.

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- Stratified soil masses have marked variations in their permeabilities in direction parallel and perpendicular to stratification, the permeability parallel to the stratification being always greater.
- When flow through natural soil deposits is under consideration, permeability should be determined on undisturbed soil as its natural structural arrangement.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- The permeability is greatly reduced if air is entrapped in the voids thus reducing its degree of saturation.
- The dissolved air in the pore fluid may get liberated, thus changing the permeability.
- Ideal condition of test are when air-free distilled water is used and the soil is completely saturated by vacuum saturation, for measuring the permeability.

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- However, since the percolating water in the field may have some gas content, it may appear more realistic to use the actual field water for testing in the laboratory.
- Organic foreign matter also has the tendency to move towards critical flow channels and choke them up, thus decreasing the permeability.

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Factors Affecting Permeability:

- The adsorbed water surrounding the fine soil particles is not free to move, and reduces the effective pore space available for the passage of water.
- According to a crude approximation after Casagrande, 0.1 may be taken as the voids ratio occupied by adsorbed water, and the permeability may be roughly assumed to be proportional to the square of the net voids ratio of (e-0.1).

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Coefficient of Absolute Permeability:

- The coefficient of permeability depends not only on the properties of the soil mass (such as size, shape, specific surface, structural arrangement, stratification, voids ratio etc.) but also on the properties of the permeant (i.e., water) which flows through it.
- Let us now introduce a coefficient which does not depends upon the properties of permeant.
- Such a coefficient, known as coefficient of absolute permeability (K) is defined by the expression.

Module – 2: Flow Through Soils

Coefficient of Absolute Permeability:

$$K = k\,(\eta / \gamma_w)$$

$$K = C\,(e^3 / 1+e)\,D^2$$

- The above equation indicates that the coefficient of absolute permeability is independent of the properties of permeant and it depends solely on the properties of soil mass.
- Dimensions of K

$$[\,K\,] = [\,L / T\,] \times [\,F\,T / L^2\,] \times [\,L^3 / F\,] = [\,L^2\,]$$

Geotechnical Engineering (18CV54)

Module – 2: Flow Through Soils

Coefficient of Absolute Permeability:

- Hence K has the dimensions of area. The units of K are: mm^2 , cm^2 , m^2 or darcy

  $$1 \text{ darcy} = 0.987 \times 10^{-8} \text{ cm}^2$$

- It is interesting to note that for a given voids ratio and structural arrangement of particles, the coefficient of absolute permeability (K) is constant, irrespective of type / properties of fluid.

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Module – 2: Flow Through Soils

Determination of Coefficient of Permeability:

The coefficient of permeability can be determined by the following methods:

- Laboratory methods

  Constant head permeability test

  Falling head permeability test

- Field methods

  Pumping out tests

  Pumping in tests

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Module – 2: Flow Through Soils

Determination of Coefficient of Permeability:

The coefficient of permeability can be determined by the following methods:

- Indirect methods

  Computation from grain size or specific surface

  Horizontal capillary test

  Consolidation test data

7.5 (b).

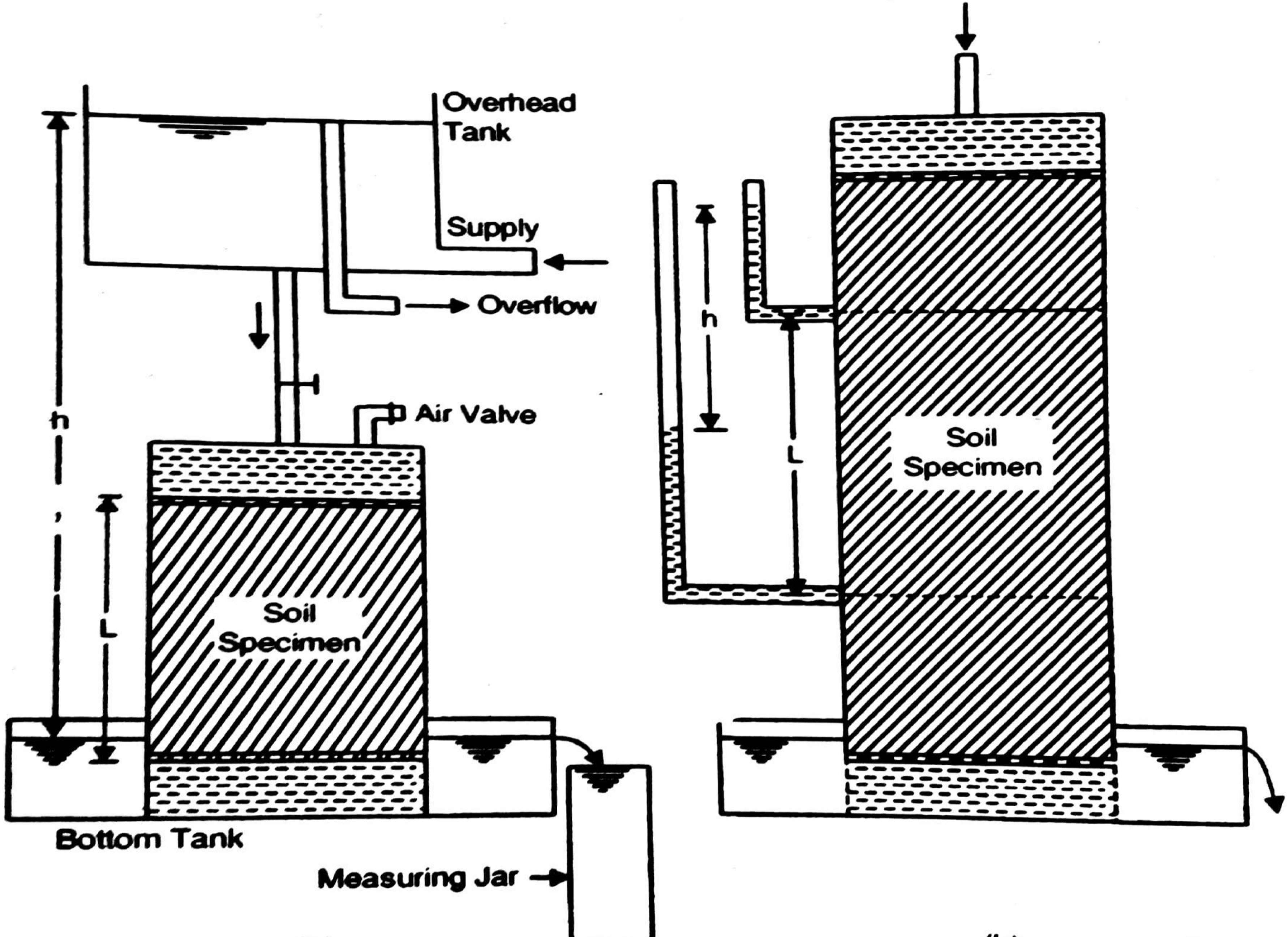

FIG. 7.5. CONSTANT HEAD TEST.

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Constant Head Permeability Test :

- Fig 7.5 shows the diagrammatical representation of constant head test.
- Water flows from the overhead tank consisting of three tubes: the inlet tube, the overflow tube and the outlet tube.
- The constant hydraulic gradient i causing the flow is the head h (i.e., difference in the water levels of the overhead and bottom tanks) divided by the length L of the sample.

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Constant Head Permeability Test :

- If the length of the sample is large, the head lost over a length of specimen is measured by inserting piezometric tubes, as shown in figure 7.5 (b).
- If Q is the total quantity of flow in a time interval t, we have from Darcy's law,

$$q = Q / t = k\,i\,A$$

$$k = (Q / t)\,(1 / i\,A) = (Q / t)\,(L / h)\,(1 / A)$$

- Where A = Cross sectional area of sample

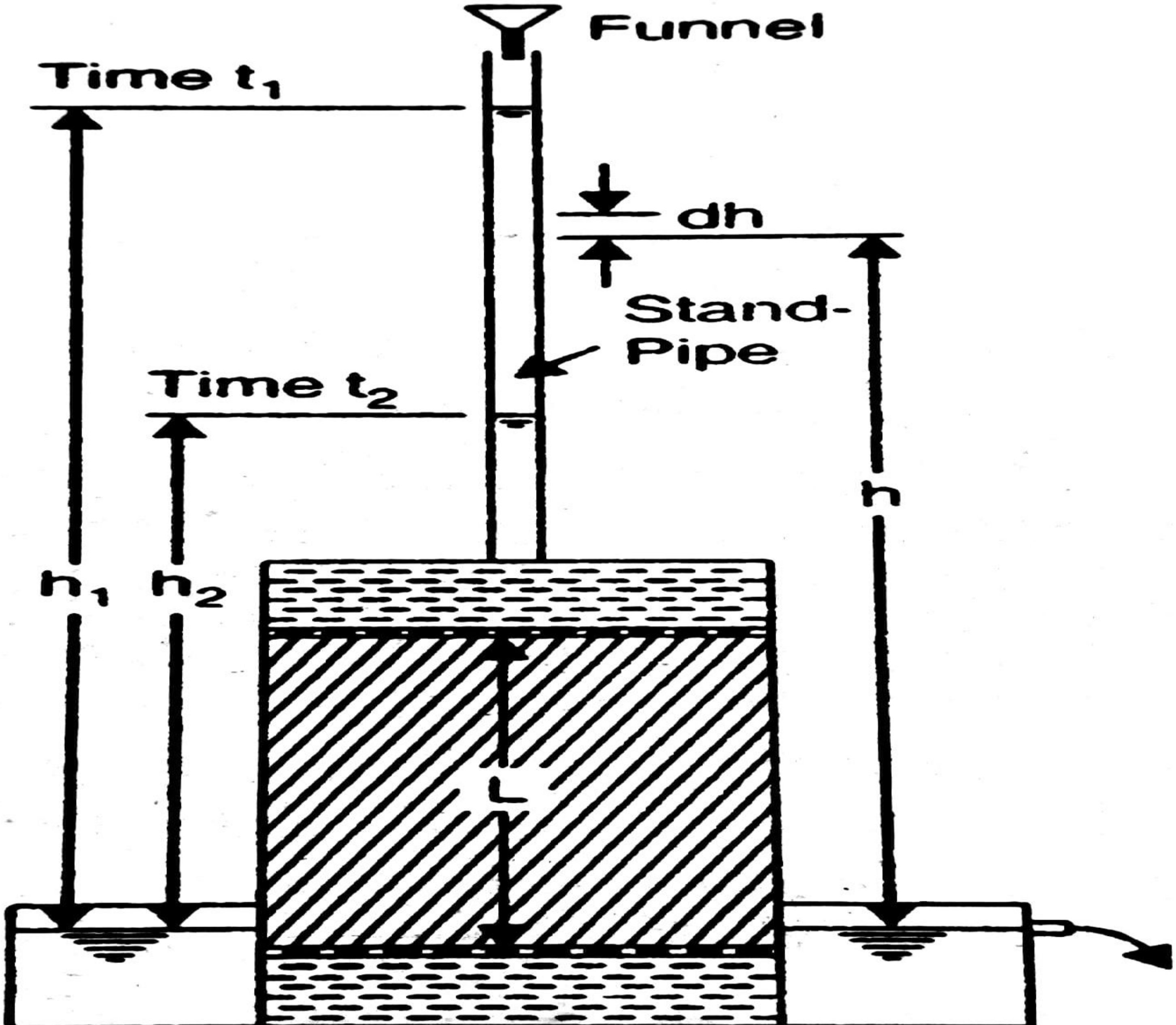

FIG. 7.6. FALLING HEAD TEST.

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Falling Head Permeability Test :

- The constant head permeability test is used for coarse grained soil only where a reasonable discharge can be collected in a given time.
- However, the falling head test is used for relatively less permeable soils where discharge is small.
- Fig 7.6 shows the diagrammatical representation of a falling head test arrangement.

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Falling Head Permeability Test :

- A stand pipe of known cross-sectional area a is fitted over the permeameter, and water is allowed to run down.
- The water level in the stand pipe constantly falls as water flows.
- Observations are started after steady state of flow has reached.
- The head at any time instant t is equal to the difference in water level in the stand pipe and the bottom tank.

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Falling Head Permeability Test :

- Let h_1 and h_2 be heads at time intervals t_1 and t_2 ($t_2 > t_1$) respectively.
- Let h be the head at any intermediate time interval t, and –dh be the change in the head in a smaller time interval dt (minus sign has been used since h decreases as t increases).
- Hence, from Darcy's law, the rate of flow q is given by

$$q = (-dh \cdot a) / dt = kiA$$

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Falling Head Permeability Test :

- Where i = hydraulic gradient at time t = (h / L)
- (k h / L) A = - (dh / dt) a or (Ak / aL) dt = - (dh / h)
- Integrating between two time limits, we get

$$(AK / aL) \int_{t1}^{t2} dt = - \int_{h1}^{h2} (dh / h) = \int_{h2}^{h1} (dh / h)$$

$$(AK / aL) (t_2 – t_1) = \log_e (h_1 / h_2)$$

Denoting $t_2 – t_1 = t$, we get

$$k = (aL /At) \log_e (h_1/h_2) = 2.3 (aL/At) \log_{10} (h_1/h_2)$$

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Module – 2: Flow Through Soils

Permeability of Stratified Soil Deposits:

- In nature, soil mass may consist of several layers deposited one above the other.
- Their bedding planes may be horizontal, inclined or vertical.
- Each layer, assumed to be homogeneous and isotropic, has its own value of coefficient of permeability.
- The average permeability of the whole deposit will depend upon the direction of flow with relation to the direction of the bedding planes.

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Module – 2: Flow Through Soils

Permeability of Stratified Soil Deposits:

- We shall consider both cases of flow:

  Parallel to the bedding planes.

  Perpendicular to the bedding planes.

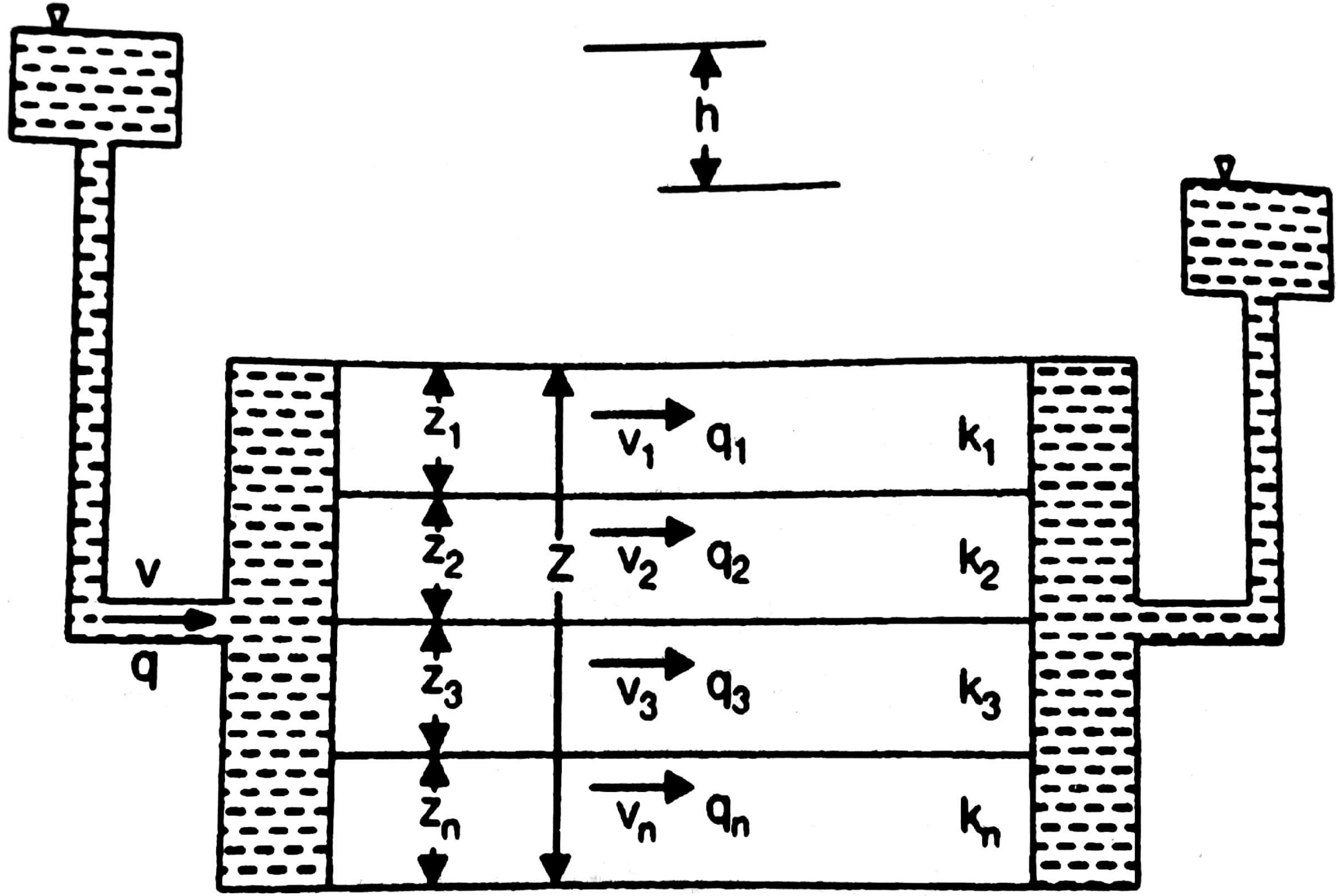

FIG. 7.8. FLOW PARALLEL TO BEDDING PLANE.

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Module – 2: Flow Through Soils

Average Permeability Parallel to the Bedding Planes:

- Let Z_1 , Z_2 …… Z_n = thickness of layers and k_1 , k_2 …… k_n = permeabilities of the layers.
- For flow to be parallel to the bedding planes, the hydraulic gradient i will be same for all the layers.
- However, since v = ki and since k is different, the velocity of flow will be different in different layers.
- Let k_x= average permeability of the soil deposit parallel to the bedding plane.

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Module – 2: Flow Through Soils

Average Permeability Parallel to the Bedding Planes:

- Total discharge through the soil deposit = Sum of discharge through the individual layers

$$q = q_1 + q_2 + \ldots\ldots q_n$$

$$q = k_x\, i\, Z = k_1\, i\, Z_1 + k_2\, i\, Z_2 + \ldots\ldots\ldots K_n\, i\, Z_n$$

$$k_x = (\, k_1 Z_1 + k_2 Z_2 + \ldots\ldots\ldots + k_n Z_n / Z\,)$$

$$(\text{where } Z = Z_1 + Z_2 + \ldots\ldots Z_n)$$

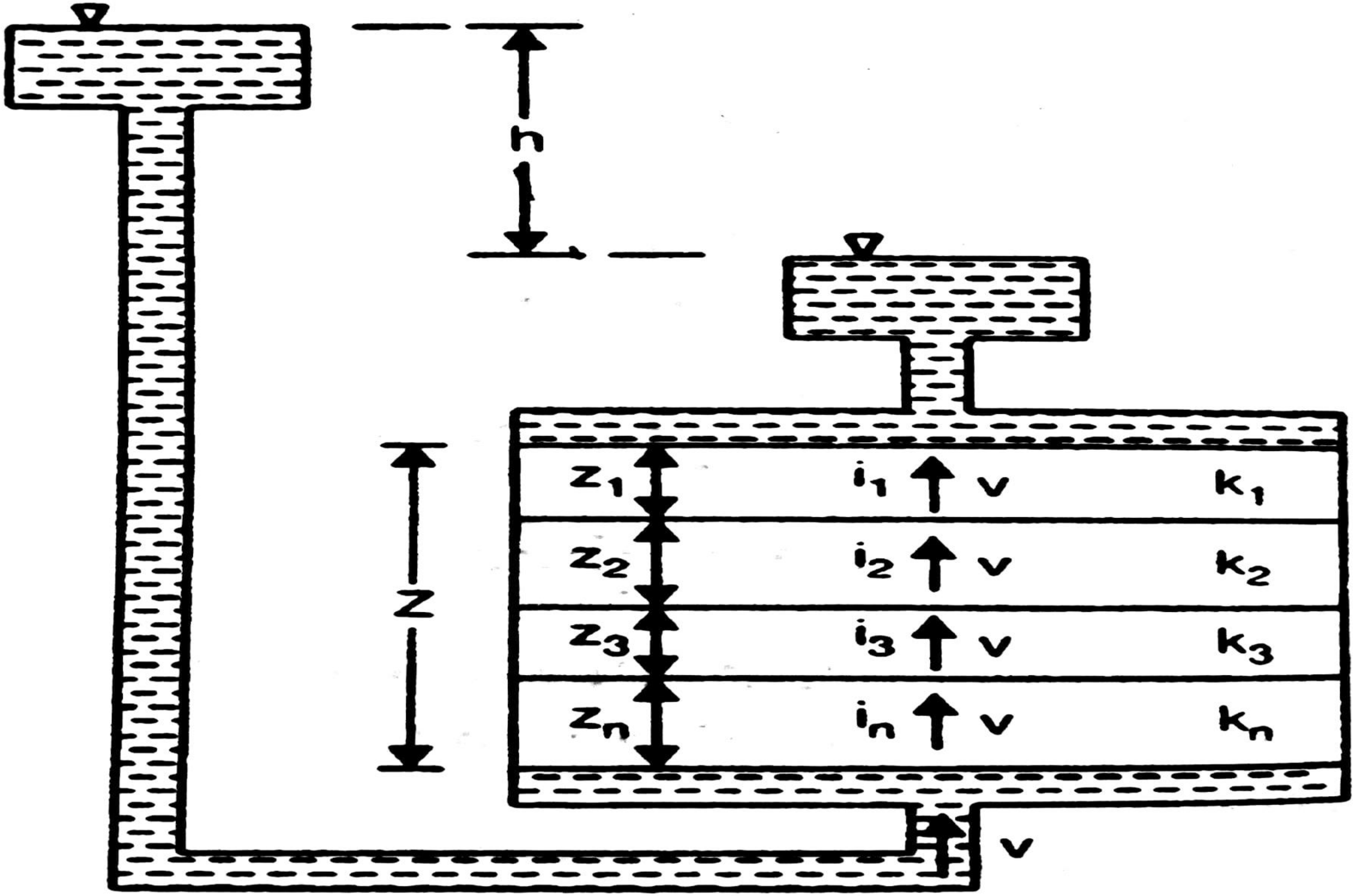

FIG. 7.9. FLOW PERPENDICULAR TO BEDDING PLANE

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Average Permeability Perpendicular to the Bedding Planes:

- In this case, the velocity of flow, and hence the unit discharge, will be the same through each layer.
- However, the hydraulic gradient, and hence the head loss through each layer will be different
- Denoting the head loss through the layers by h_1, h_2 ……. h_n and the total head loss as h, we have

$$h = h_1 + h_2 \ldots\ldots\ldots h_n$$

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Module – 2: Flow Through Soils

Average Permeability Perpendicular to the Bedding Planes:

$$h_1 = i_1 Z_1 , h_2 = i_2 Z_2 \ldots\ldots\ldots\ldots h_n = i_n Z_n$$

$$h = i_1 Z_1 + i_2 Z_2 + \ldots\ldots\ldots i_n Z_n$$

Now, if k_z = average permeability perpendicular to the bedding plane, we have

$$v = k_z i = k_z (h / Z) \text{ or } h = (vZ / k_z)$$

$$\text{Also } i_1 = (v/k_1) , i_2 = (v/k_2) , i_n = (v/k_n)$$

$$k_z = (Z / (Z_1/k_1) + (Z_2/k_2) + \ldots\ldots (Z_n/k_n))$$

Module – 2: Flow Through Soils

Pumping Out Tests:

- In the pumping out test, drawdowns, corresponding to a steady discharge q, are observed at a number of observation wells.
- Pumping must continue at a uniform rate for a sufficient time approach a steady state condition.
- Steady state condition is the one in which the drawn down changes negligibly with time.

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Module – 2: Flow Through Soils

Pumping Out Test in Unconfined Aquifer:

$$k = (q / \pi (H^2 - h^2)) \log_e (R / r) = (q / 1.36 (H^2 - h^2)) \log_{10} (R / r)$$

$$k = (q / \pi (h_2^2 - h_1^2)) \log_e (r_2 / r_1) = (q / 1.36 (h_2^2 - h_1^2)) \log_{10} (r_2 / r_1)$$

Pumping Out Test in Unconfined Aquifer:

$$k = (q / 2\pi b (H - h)) \log_e (R / r) = (q / 2.72b (H - h)) \log_{10} (R / r)$$

$$k = (q / \pi (h_2 - h_1)) \log_e (r_2 / r_1) = (q / 2.72b (h_2 - h_1)) \log_{10} (r_2 / r_1)$$

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Module – 2: Flow Through Soils

Pumping In Tests:

The U S Bureau of Reclamation has devised two types of pumping in tests

- Open end tests
- Packer tests.

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Module – 2: Flow Through Soils

Open End Tests:

- An open-end pipe is sunk in the strata and the soil is taken out of the pipe just to the bottom.
- Clean water, having temperature slightly higher than the ground water, is added through a metering system to maintain gravity flow under constant head.
- Water may also be allowed to enter the hole under some pressure head.
- The permeability is calculated from the following expression determined from the electrical analogy experiments: $k = (q / 5.5\, r\, h)$.

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Module – 2: Flow Through Soils

Open End Tests:

$$k = (q / 5.5\, r\, h)$$

- h = differential head of water (gravity plus pressure, if any)
- r = radius of casing
- q = constant rate of flow

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Module – 2: Flow Through Soils

Packer Tests:

- An uncased portion of the drill hole or a perforated portion of the casing is used for performing the test.
- In case the test is performed during drilling, a top packer is placed just inside or below the casing.
- Water is pumped in the lower portion of the hole.
- To perform the test after completion of the hole, which can stand without casing, two packers are set on a pipe or drill stem keeping the perforated portion of the pipe between the plugs.

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Module – 2: Flow Through Soils

Packer Tests:

- The bottom of the pipe is plugged.
- The length of the packer on expansion should be five times the diameter of the hole.
- Testing is started from the bottom of the hole and continued upwards.
- The coefficient of permeability is determined from the following expression:

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Module – 2: Flow Through Soils

Packer Tests:

$$k = (q / 2\pi L h) \log_{10} (L / r); \; L \geq 10\, r$$

$$k = (q / 2\pi L h) \sinh^{-1} (L / 2\, r); \; 10\, r > L \geq r$$

L = length of portion of the hole tested

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Module – 2: Flow Through Soils

Seepage Velocity:

- It is defined as the rate of discharge of percolating water per unit cross sectional area of voids perpendicular to the direction of flow.

Superficial Velocity:

- It is defined as the velocity of flow or the rate of flow of water through the soil mass after entering in and emerging out of the total voids present in the entire soil mass.

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Module – 2: Flow Through Soils

Coefficient of Percolation:

- The seepage velocity is proportional to hydraulic gradient.

Capillary Rise:

- The height above a free water elevation to which water will rise due to capillary action.

The capillary rise in soils depends on:

- The size of void that is effective. It varies inversely with the size of voids.
- The particle size and density of soil.