THEORY & OBJECTIVE

SOIL MECHANICS

By
Team of
Engineers Academy

- Covers ESE, GATE, IAS, PSUs, DRDO, ISRO & other Technical Exams.
- Covers complete syllabus & all topics of ESE & GATE examination.
- Thoroughly revised, fully solved & error free book.
- Concise, concept oriented and topicwise presentation & authentic solutions.

ENGINEERS ACADEMY™

Your GATEway to Professional Excellence

IES • GATE • PSUs • JTO • IAS • NET

CORPORATE OFFICE

100-102, Ram Nagar, Bambala Puliya, Tonk Road, Pratap Nagar, Jaipur-302033

Ph. : 0141-6540910, +91-8094441777

Website : www.engineersacademy.org | **Email:** info@engineersacademy.org

Ajmer | Jaipur | Kota | Jodhpur | Bhilwara | Delhi | Patna | Lucknow | LPU | Ludhiana | Jalandhar | Kanpur

CONTENTS

❑❑❑

BASIC TYPES OF SOIL

THEORY

1.1 SOIL TYPES AND FORMATIONS

- There are two main groups of soils according to their origin (i) soils formed by physical weathering e.g., Gravel and Sand (ii) Soils formed by chemical weathering e.g., silts and clays.
- If the products of rock weathering are still located at the place of origin, they are called Residual soils.
- Any soil that has been transported from its place of origin by wind, water, ice or any other agency and has been re-deposited is called Transported soil.
- **Alluvial Soils :** deposited from suspension in Running Water.
- **Lacustrine Soils :** deposited from suspension in still, fresh water of lakes.
- **Marine Soils :** deposited from suspension in sea water.
- **Aeolian Soils :** Transported by wind.
- **Glacial Soils :** Transported by Ice.

1.2 SOME SPECIAL/TYPICAL SOILS

- **Loess :** A loose deposit of windblown silt that has been weakly cemented with calcium carbonate and montmorillonite.
- **Bentonite :** A chemically weathered volcanic ash.
- **Peat:** A highly organic soil; fibrous and highly compressible.
- **Muck :** A mixture of fine particles, inorganic soil and black, decomposed organic mater.

  Note : Peat and Muck are also called cumulose soils.
- **Colluvial Soil :** the accumulation of rock debris or **Talus** at the base of a steep cliff or a rock escarpment due to action of gravity.
- **Marl :** A very fine grained calcium carbonated soil of marine origin.

1.3 Some Common Soils and Engineering Problems Encountered with them

- **Marine Deposits :** Marine clays are very soft and may contain organic matter.
- These Possess low shear strength and high compressibility hence, pose problems as foundation material.
- **Laterites And Lateritic Soils :** Formed by decomposition of rock. removal of the bases and silica and formation of oxides of iron and aluminium at the top of the soil profile.
- These are two types – Primary and Secondary. Primary laterite is found at high altitude near hills.
- Secondary laterites are found at coastal belts.
- Generally laterites pose no difficulties as foundation material and retain their slopes well.
- **Black Cotton Soils :** These soils have been formed from basalt or trap and contain clay mineral montmorillonite, which is responsible for the excessive swelling and shrinkage characteristics of the soil.
- Under reamed piles should be used in foundations in these soils.
- **Desert Soils :** These are wind blown deposits of sand.
- Dune sand is non plastic uniformly graded fine sand.
- Problems associated with these soils are of soil stabilization for roads and runways for reducing settlement under static and dynamic loads and reducing its perviousness to make it suitable for storage and transport of water.

❑❑❑

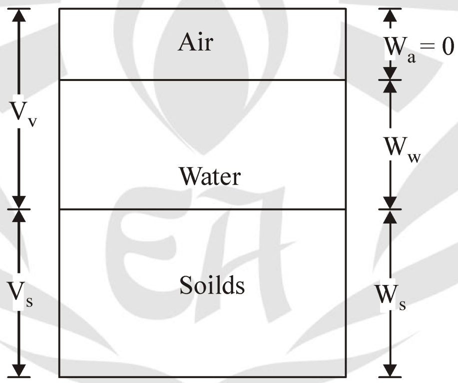
PROPERTIES OF SOILS

THEORY

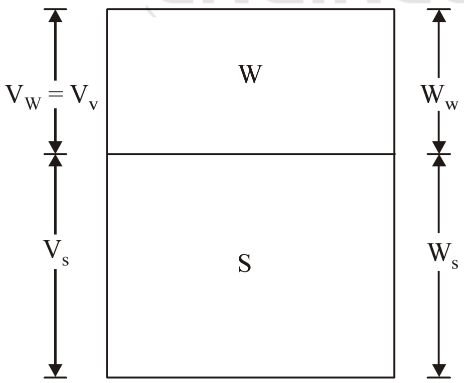
2.1 PROPERTIES OF SOILS

2.1.1 Phase Diagram

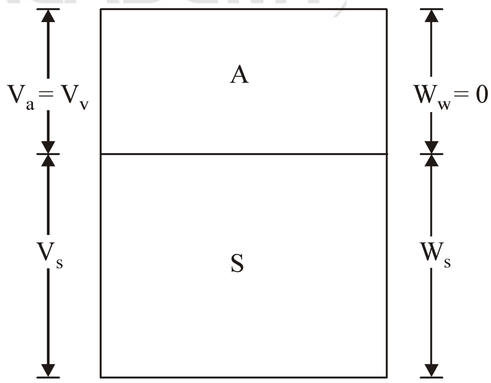
- Soil mass is in general a three phase system composed to solid, liquid and gaseous matter.
- The diagrammatic representation of the different phases in a soil mass is called the "phase diagram."
- A 3-phase system is applicable for partially saturated soil whereas, a 2-phase system is for saturated and dry states of soil.



3-Phase
(Partially Saturated)



2-Phase (Saturated)



2-Phase (Dry)

2.1.2 Water Content

$$w = \frac{W_w}{W_s} \times 100$$

W_w = Weight of water

W_s = Weight of solids

There can be no upper limit to water content. i.e., $w \geq 0$

2.1.3 Void Ratio

$$e = \frac{V_v}{V_s}$$

V_v = Volume of voids

V_s = Volume of solids

Void ratio of fine grained soils are generally higher than those of coarse grained soils.

In general $e > 0$ i.e., no upper limit for void ratio.

2.1.4 Porosity (% voids)

$$n = \frac{V_v}{V} \times 100$$

V_v = Volume of voids

V = Total volume of soil

Porosity cannot equal to 100% i.e.,

$0 < n < 100$

Note : In comparison to porosity, void ratio is more frequently used because volume of solids remains same, whereas total volume changes.

2.1.5 Degree of Saturation

$$S = \frac{V_w}{V_v} \times 100$$

where V_w = Volume of water

V_v = Volume of voids

$0 \leq S \leq 100$

for perfectly dry soil $S = 0$

for Fully saturated soil $S = 100\%$

2.1.6 Air Content

$$a_c = \frac{V_a}{V_v} = 1 - S$$

$$0\% \leq a_c \leq 100\%$$

Percentage air voids (n_a)

$$n_a = \frac{V_a}{V} \times 100$$

$$0\% \le a_c < 100\%$$

Where

V_a = Volume of air

V = Total Volume

2.1.7 Unit Weight

(a) Bulk Unit Weight

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a}$$

Thus Bulk unit weight is total weight per unit volume.

(b) Dry Unit Weight

is the weight of soil solids per unit volume.

$$\gamma_d = \frac{W_s}{V}$$

Dry unit weight is used as a measure of denseness of soil. More dry unit weight means more compacted soil.

(c) Saturated Unit Weight : It is the ratio of total weight of fully saturated soil sample to its total volume.

$$\gamma_{sat} = \frac{W_{sat}}{V}$$

(d) Submerged Unit Weight : $\gamma' = \gamma_{submerged} = \gamma_{sat.} - \gamma_{water}$. Buoyant unit weight ($\gamma'$). It is the submerged weight of soil solids per unit volume.

γ' is roughly $\frac{1}{2}$ of saturated unit weight.

Note : $\gamma_{solid} > \gamma_{sat} > \gamma_{bulk} > \gamma_{dry} > \gamma_{sub}$

(e) Unit Weight of Solids : It is the ratio weight of solids to the volume of solids present in given soil mass.

$$\gamma_{solid} = \frac{W_s}{V_s}$$

2.1.8 Specific Gravity

Absolute/true Specific Gravity : Specific gravity of soil solid (G) is the ratio of the weight of a given volume of solids to the weight of an equivalent volume of water at 4°C.

$$G = \frac{W_s}{V_s \cdot \gamma_w} = \frac{\gamma_s}{\gamma_w}$$

CLASSIFICATION OF SOILS

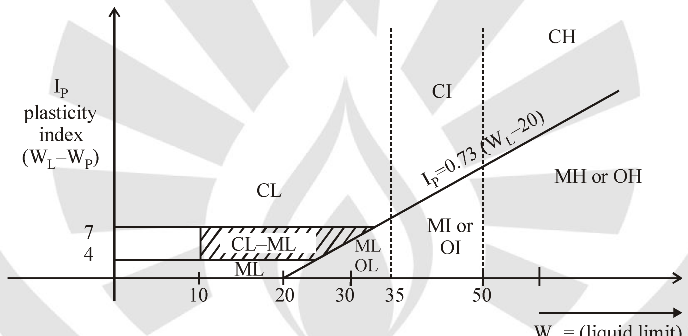
THEORY

3.1 THE UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

- Originally developed by Cassagrande.
- According to USCS, the coarse grained soils are classified on the basis of their grain size distribution and the fine grained soils (whose behaviour is controlled by plasticity) on the basis of their plasticity characteristics.
- All soils are classified into four major groups:
  (a) Coarse grained
  (b) Fine grained
  (c) Organic soils
  (d) Peat
- Coarse grained soils are those having 50% or more retained on the 0.075 mm sieve.
- Further, the coarse grained soils are designated as gravel (G) if 50% or more of the coarse fraction is retained on the 4.75 mm sieve; otherwise, they are designated as sands (S).
- Both Gravel and sand are subdivided into four sub groups
  (a) Well graded (W)
  (b) Poorly graded (P)
  (c) Silty (S)
  (d) Clayey (C)
- Well graded soil (W) has wide distribution of grain sizes present, whereas, a poorly graded (P) soil is either uniform or gap graded.
- Whether a soil is well graded or poorly graded can be determined by plotting the grain size distribution curve and computing the coefficient of uniformity (C_u) and the coefficient of curvature (C_c).
- Prefix and suffix of USCS:

Soil Type	Prefix	Subgroup	Suffix
Gravel	G	Well graded	W
Sand	S	Poorly graded	P
Silt	M	Silty	M
Clay	C	Clayey	C
Organic	O	$W_L < 50\%$	L
Peat	Pt	$W_L > 50\%$	H

- Fine grained soils having more then 50% material passing the 0.075 mm sieve are further subdivided into silt (M) and clay (C), based on their liquid limit and plasticity index.
- The A-line on Cassagrande's plasticity chart generally separates the clay like materials from those that are silty and also the organic from the inorganic.



Plasticity Chart

- Silt, clay and organic fractions are further subdivided into soils possessing low (L) or high (H) plasticity when the LL is less than 50% and more than 50% respectively.
- Some soils possessing the characteristics of more than one group are termed as Boundary soils and hence, are assigned dual group symbols e.g., GW – GC, which means well graded gravel with some clay fines.

3.2 "AASHTO" Soil Classification System

- According to AASHTO system, the soils are classified into eight groups: A – 1 through A – 7 with an additional group A – 8 for peat or muck.
- The system includes several subgroups.
- Soils within each group are evaluated according to the group index calculated from empirical formula:

  GI = 0.2 a + 0.005 ac + 0.01 bd where,

  a = that part of the percent passing the 75 μ sieve greater than 35 and not exceeding 75.

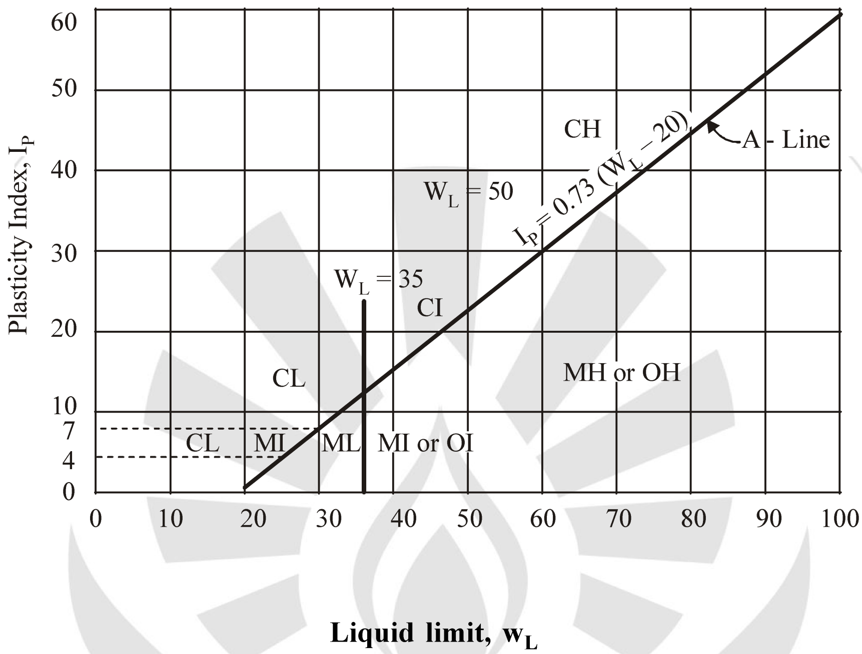
  b = that part of the percent passing the 75 μ sieve greater than 15 and not exceeding 55.

  c = that part of liquid limit greater than 40 and not greater than 60.

  d = that part of plasticity index greater than 10 and not exceeding 30.
- Greater the G.I. value, the less desirable a soil is for highway construction with in that subgroup.

3.3 Indian Standard Soil Classification System : (ISSCS)

- It is based on USCS with the modification that the fine grained soils have been subdivided into three subgroup of low. medium and high compressibility as against only two in the USCS.
- The plasticity chart of ISSCS is:



Prefixes and Suffixes of ISSCS

Soil Type	Prefix	Subgroup	Suffix
Gravel	G	Well graded	W
Sand	S	Poorly graded	P
Silt	M	Silty	M
Clay	C	Clayey	C
Organic	O	$W_L < 35\%$	L
Peat	Pt	$35 < W_L < 50$	I
		$W_L > 50$	H

Division of Soil Fractions on the Basis of Grain Sizes

Boulder	Cobble	Coarse grained Soils					Fine grained Soils	
		Gravel		Sand				
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
> 300	300	80	20	4.75	2	0.425	0.075	< 0.002 mm

$$C_u = \frac{D_{60}}{D_{10}} = \frac{600\mu}{500\mu}$$

$$= 1.20$$

Since $C_u < 4$ it is poorly graded

Since more than 50% of soil is finer than 4.75 mm size, it is sand.

$\therefore$ Group symbol : SP

9. ***Ans. (a)***

$$\% \text{ fines} = \frac{270}{1000} \times 100 = 27\%$$

Since % fines is < 50%,

it is coarse grained soil

As more than 50% of soil passes through 4.75mm sieve, it is sand.

$$I_p = W_L - W_P = 22\%$$

Since I_p is > 7% and Atterberg limits fall above A-line, it is clayey soil

$\therefore$ Group symbol is SC.

10. ***Ans. (c)***

11. ***Ans. (c)***

GW is well graded gravel for which coefficient of uniformity (C_u) > 4.

SW is well graded sand for which coefficient of uniformity (C_u) > 6

ML is silt with low plasticity (<35%)

CL is clay with low plasticity (<35). It also possess low compressibility

12. ***Ans. (c)***

13. ***Ans. (b)***

Since more than 50% retains on 0.075 mm sieve it is a coarse grained soil. As more than 50% is finer than 4.75mm, it is sand.

As the fines are > 12%, the soil may be either SM or SC

The Atterberg limits fall below A-line, hence is "SM".

14. ***Ans. (c)***

$$w_L = 60\%$$
$$w_p = 20\%$$

For Soil, $I_p = w_L - w_P = 40\%$

I_P of A-line ; $I_p = 0.73\ (w_L - 20) = 29.2\%$

I_P of soil is plotted above A-line and hence it is a clayey soil. As the w_L of soil is > 50%, it is highly compressible

Therefore, the soil is "CH".

15. ***Ans. (a)***

16. ***Ans. (b)***

Since liquid limit lies between 35 and 50 it is intermediate compressible (I)

Height of A-Line

$$= 0.73\ (w_L - 20) = 14.6\%$$

Since I_P of soil is more than 14.6%, it falls above A-line, Hence it is clay (C)

$\therefore$ Soil is CI.

❑❑❑

4

SOIL STRUCTURE & CLAY MINERALS

THEORY

4.1 INTRODUCTION

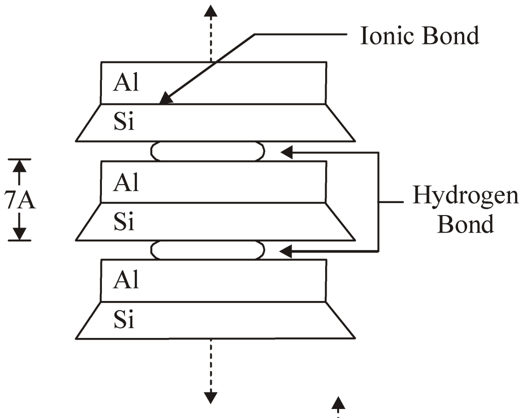
- Soil structure means the mode of arrangement of the soil particles relative to each other and the forces acting between them to hold them in their position.
- The formation of soil structure is governed by several factors. In coarse-grained soils, the force of gravity is the main factor, while in the grained soils, the surface bonding force become predominant.
- **Concept of Specific Surface :** Specific surface is the ratio of the surface area of a material to its mass or volume. It acts as a parameter to decide the importance of surface bonding forces relative to forces of gravity.
- Smaller particles have much larger specific surface than the larger particles. Thus for same void ratio, water contents are more for fine grained soils than for coarse grained soils.
- **Concept of Clay :** Clay is normally understood to mean a clay soil whose grains are predominantly composed of clay minerals and which has plasticity and cohesion.
- The ingredients necessary to give a soil deposit cohesion are clay minerals. They are very active electrochemically and the presence of even a small amount of clay minerals can appreciably alter the engineering properties of a soil mass.
- Generally, when over 50% of the soil deposit consists of particles whose diameter is 0.002 mm or less, deposit is termed CLAY.

4.2 CLAY MINERALS

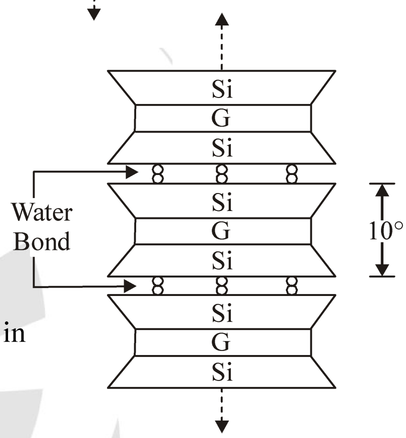
- These are hydrous aluminosilicates with other metallic ions, evolved mainly from the chemical weathering of certain rock forming minerals.
- On the basis of their crystalline arrangement, clay minerals can be divided into three main groups:

Group	Mineral	Structural Formula
Kaolin Group	(a) Kaolinite (b) Halloysite	$(OH)_1Al_1Si_1O_{10}$ $(OH)_1Al_1Si_1O_{10}4H_2O$
Monomorillonite	Montmorilonite	$(OH)_1Al_1Si_1O_{20}nH_2O$
Illite Group	Illite	$(Al_1Mg_1Fe_1Fe_6)O_{20}O$

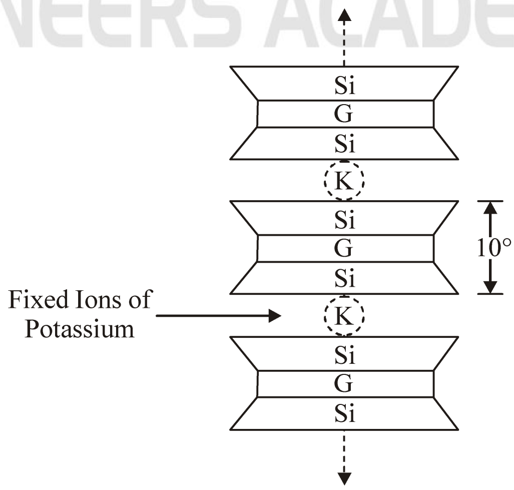
- **Kaolinite :** Consists of alternating layers of silica tetrahedral with the tips embedded in an alumina octahedral unit.
- Some times called 1 : 1 clay mineral.
- The basis layers are 7 Å thick.
- The bonding with hydrogen bond results in considerable strength and stability with little tendency in the inter layers to allow water and swell. Kaolinite is thus, the least active of the clay minerals.



- **Halloysite :** Another 1 : 1 mineral of kaoline group.
- The 7 Å basic layers are separated by water molecules.
- In contrast to other clay minerals, halloysite particles are tubular and rod-like.
- Dehydration by heat will convert it to approximately kaolinite.
- Kaolinite and halloysite clays are used for making chinaware.
- Kaoline clays are also widely used as intestinal absorbent in antidiarrheal medicines.



- **Montmorillonite :** Also called smectite.
- Composed of two silica sheets and one alumina (gibbsite) sheet, so called 2 : 1 mineral.
- Thickness of basic layer is about 9.6 Å.
- The interlayer bonding between the tops of silica sheets is mainly due to Vander wall forces and is, thus, very weak compared to hydrogen or other ion bonding.
- Further, Montmorillonite has the largest specific surface among major clay minerals.
- All these factors lead to extremely high swelling properties in montmorillonite. They swell as the water gains entry into the lattice structure and shrink if the water is removed because of same reason.
- **Illite :** A 2 : 1 mineral similar to montmorillonite.
- Potassium ion occupy positions between the adjacent base planes.



OBJECTIVE SHEET

1. Match List-I (Effect) with List-II (Reason) and select the correct answer using the codes given below the lists:

List-I

A. Excessive settlement

B. High expansivity

C. Reduction of bearing capacity

D. Acceleration of consolidation

List-II

1. Rise of water table

2. High compressibility

3. Montmorillonite

4. Sand drains

Codes:	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	1	3	2
(d)	2	3	1	4

2. Consider the following statements:

1. Increase in volume of a soil sample without external constraints on submergence in water is termed as the 'free swell of soil.'

2. Clay soil rich in montmorillonite exhibits very low swelling characteristic.

3. Generally, free swell of soil sample ceases when its water content reaches the plastic limit.

Which of these statements are correct?

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

3. Black cotton soil exhibits large swelling and shrinkage due to presence of the following clay mineral

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

4. The shape of clay particle is usually

(a) angular (b) flaky
(c) tubular (d) rounded

5. Some of the structural strength of a clayey material that is lost by remoulding is slowly recovered with time. This property of soils to undergo an isothermal gel-to-soil-to-gel transformation upon agitation and subsequent to rest is termed

(a) Isotropy (b) Anisotropy
(c) Thixotropy (d) allotropy

6. ***Assertion (A):*** Black cotton soils are clays and they exhibit characteristic property of swelling.

Reason (R): These clays contain Montmorillonite which attracts external water into its lattice structure.

(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. The correct sequence of plasticity of minerals in soil in an increasing order is

(a) silica, kaolinite, illite, montmorillonite
(b) kaolinite, silica, illite, montmorillonite
(c) silica, kaolinite, montmorillonite, illite
(d) kaolinite, silica, montmorillonite, illite

8. The predominant mineral responsible for shrinkage and swelling in black cotton soils is

(a) illite (b) kaolinite
(c) mica (d) montmorillonite

9. Consider the following clay minerals:

1. Kaolinite

2. Illite

3. Montmorillonite

Which one of the following is the correct sequence of the minerals given below in the increasing order of their grain size?

(a) 3-2-1 (b) 1-3-2
(c) 1-2-3 (d) 3-1-2

ANSWERS AND EXPLANATIONS

1. *Ans.* *(d)*
   - Sand drains reduces the length of drainage path resulting in acceleration of consolidation.
   - High compressibility leads to excessive settlement.
   - rise of water table reduces the bearing capacity of soil.
   - High volume change in clay is due to Montmorillonite.

2. *Ans.* *(b)*

   Clay soil rich in montmorillonite exhibits more swelling characteristics.

   Free swelling of the soil is defined as the increase in volume of soil without any external constraints on submergence in water (IS : 2720, 1997) and in general free swelling ceases at plastic limit.

3. *Ans.* *(c)*
4. *Ans.* *(b)*
5. *Ans.* *(c)*
6. *Ans.* *(a)*

   For black cotton soil:

   (i) Liquid limit – 40 to 100%

   (ii) Plasticity index – 20 to 60%

   (iii) Shrinkage limit – 10 to 15%

   (iv) Optimum Moisture content – 25 to 30%

7. *Ans.* *(a)*

   Silica has least plasticity while Montmorillonite has highest plasticity.

8. *Ans.* *(d)*
9. *Ans.* *(a)*

	Thickness (Å)	Lateral dimension (Å)
Kaolinite	100-1000	1000-20,000
Montmoillonite	10-50	1000-5000
Illite	50-500	1000-5000

The size of kaolinite > illite > montmorillonite

10. *Ans.* *(c)*

    Feldspars are the most common rock minerals which account for the abundance of clays derived from the feldspars on the earth's surface. Quartz comes next in order of frequency. Most sands are composed of quartz.

    Mica constitute small fraction of original igneous rocks and thus it can not be said to be clay minerals.

    Rock flour (rock dust particles) generally consists of more or less uniform size grains of quartz and they are least plastic varieties. Electrical charge on kaolinite are responsible for plastic behaviour of soils and cohesion in clays.

11. *Ans.* *(a)*

    Marine clays, deposited in sea water containing a large amount of dissolved salt, may exhibit flocculated structure

12. *Ans.* *(c)*

    The values of plasticity index of kaolinite, Illite and montmorillonite are 15, 30 and 300 respectively.

    Black cotton soils contain predominantly a clay mineral called montmorillonite, which is responsible for causing appreciable shrinking and swelling. Clay soils containing other clay minerals do not exhibit the volume change characteristics to the same degree as those containing montmorillonite mineral.

13. *Ans.* *(b)*

    Coefficient of uniformity,

    $$C_u = \frac{D_{60}}{D_{10}} = \frac{0.41}{0.23} = 1.75$$

    Coefficient of curvature,

    $$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.3^2}{0.41 \times 0.23} = 0.95$$

    For well graded sand $1 < C_u < 3$ and $C_u > 6$ as per IS classification. So it is a poorly graded sand.

14. *Ans.* *(d)*

❑❑❑