



Geotechnical Engineering

Detailed notes + compact revision summary

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The notes are prepared for exam revision. Always check design values against the current IS codes before using them in real work.

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CHAPTER 01

Soil Formation, Clay Minerals & Phase Relations

How soils form, the main Indian soil deposits, clay mineralogy and soil structure, and the weight–volume relationships used in every soil calculation.

1.1 Origin and formation of soils

Soil is an uncemented or weakly cemented accumulation of mineral particles formed by weathering of rocks, with void spaces filled by water and/or air. **Weathering** is of two kinds: *physical (mechanical)* weathering by temperature changes, frost, wedging and abrasion, which breaks rock into smaller pieces of the same minerals (gravel, sand, silt); and *chemical* weathering by oxidation, hydration, carbonation and leaching, which changes the minerals themselves and produces clay minerals.

If the weathered material stays at its place of origin it is a **residual soil**; if it is carried away by an agent and deposited elsewhere it is a **transported soil**. Residual soils usually grade gradually into the parent rock, while transported soils are sorted according to the transporting agent.

Transported soils — agent and characteristics

Soil type	Agent	Typical features / examples
Alluvial (fluvial)	Running water (rivers)	Stratified sands, silts and clays; Indo-Gangetic plain
Lacustrine	Still water (lakes)	Fine, soft, often varved clays (alternate silt & clay layers)
Marine	Sea water	Soft, compressible, often organic clays along coasts
Aeolian	Wind	Uniform fine sand (dunes) and loess — silt-sized, collapsible on wetting
Glacial (drift, till)	Glaciers (ice)	Unsorted mixture of boulders to clay (boulder clay); moraines
Colluvial	Gravity	Talus / scree — angular fragments at the foot of slopes

- **Loess** is a wind-blown, lightly cemented silt with a loose open structure; it loses strength and collapses on saturation.
- **Marl** is a calcareous clay; **peat** is highly organic, fibrous and very compressible; **muck** is organic silt/clay.
- **Varved clay** shows thin alternating layers of silt (summer) and clay (winter) deposited in glacial lakes.

Exam trap: Gravel, sand and silt are products mainly of *physical* weathering and keep the mineral of the parent rock (mostly quartz). Clay minerals are products of *chemical* weathering.

1.2 Major soil deposits of India

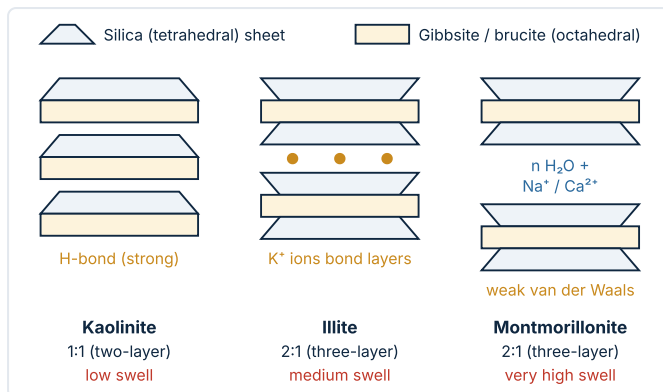
Indian soils and their engineering behaviour

Soil	Origin / region	Engineering behaviour
Alluvial	River-borne; Indo-Gangetic plains, deltas	Layered sand–silt–clay; shallow WT; fair bearing
Black cotton (BC)	Residual from Deccan basalt; MP, Maharashtra	Montmorillonite; severe swell–shrink; cracks when dry
Laterite	Residual; hot humid regions (Kerala, Odisha)	Silica leached, Fe/Al oxides left; red; hardens in air
Desert	Aeolian; Rajasthan	Uniform fine sand; poorly graded; no cohesion
Marine clay	Coastal (Mumbai, Kolkata, Kochi)	Soft, very compressible; large settlement

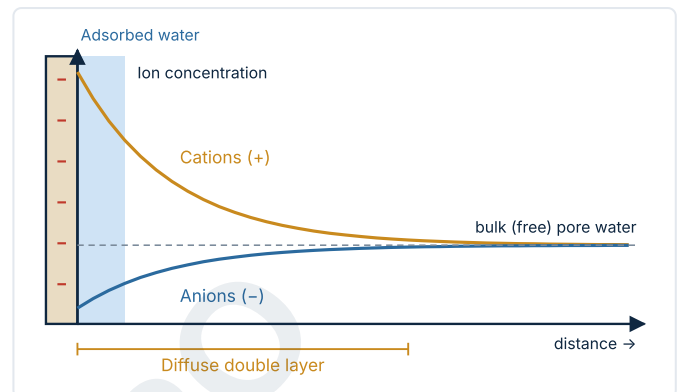
Exam tip: BC soil → montmorillonite → expansive. Laterite → leaching of silica (silica removed, sesquioxides $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$ remain).

1.3 Clay minerals, adsorbed water and soil structure

Clay minerals are built from two basic sheets: the **silica sheet** of SiO_4 tetrahedra and the **octahedral sheet** — gibbsite (aluminium) or brucite (magnesium). The way these sheets stack and bond controls the swelling, plasticity and permeability of the clay. **Isomorphous substitution** (e.g. Al^{3+} replacing Si^{4+}) leaves the clay particle with a net negative surface charge.



Schematic structure of the three common clay minerals

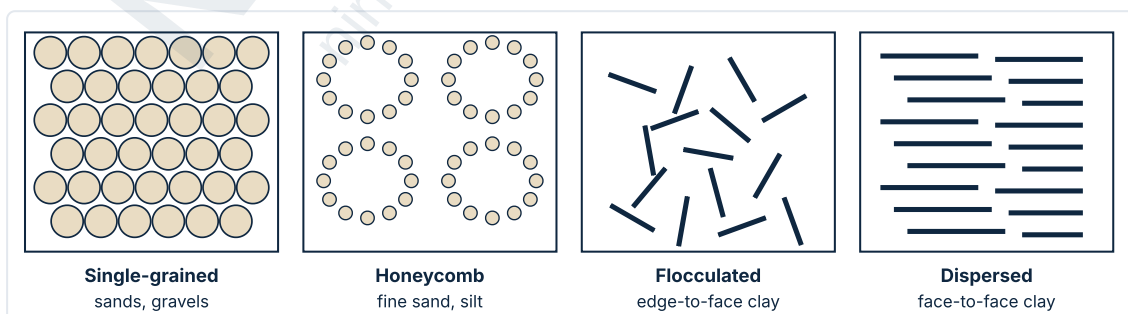


Diffuse double layer next to a negatively charged clay surface

Comparison of clay minerals

Property	Kaolinite	Illite	Montmorillonite
Structure	1:1 (silica-gibbsite)	2:1 with K^+ between units	2:1 with water + exchangeable cations
Bond between units	Hydrogen bond — strong	Potassium ions — fairly strong	van der Waals — weak
Specific surface (m^2/g)	$\approx 10\text{--}20$	$\approx 80\text{--}100$	≈ 800
Activity (typical)	≈ 0.4	≈ 0.9	1.5 (Ca) to 7 (Na)
Swelling / shrinkage	Low	Medium	Very high
Permeability	Highest of the three	Medium	Lowest
Occurrence	China clay, laterite	Marine & alluvial clays	BC soil, bentonite (volcanic ash)

Adsorbed water is the thin film of water held strongly to the negatively charged clay surface by electrical attraction. It behaves more like a semi-solid than free water and gives clay its plasticity and cohesion. Beyond it, cations from the pore water are attracted to the surface and their concentration decreases with distance — this charged surface plus the cloud of cations is the **diffuse double layer** (Gouy-Chapman). A thick double layer keeps particles apart (dispersion); higher cation valence or higher salt concentration makes it thinner and lets particles flocculate.



Common soil structures

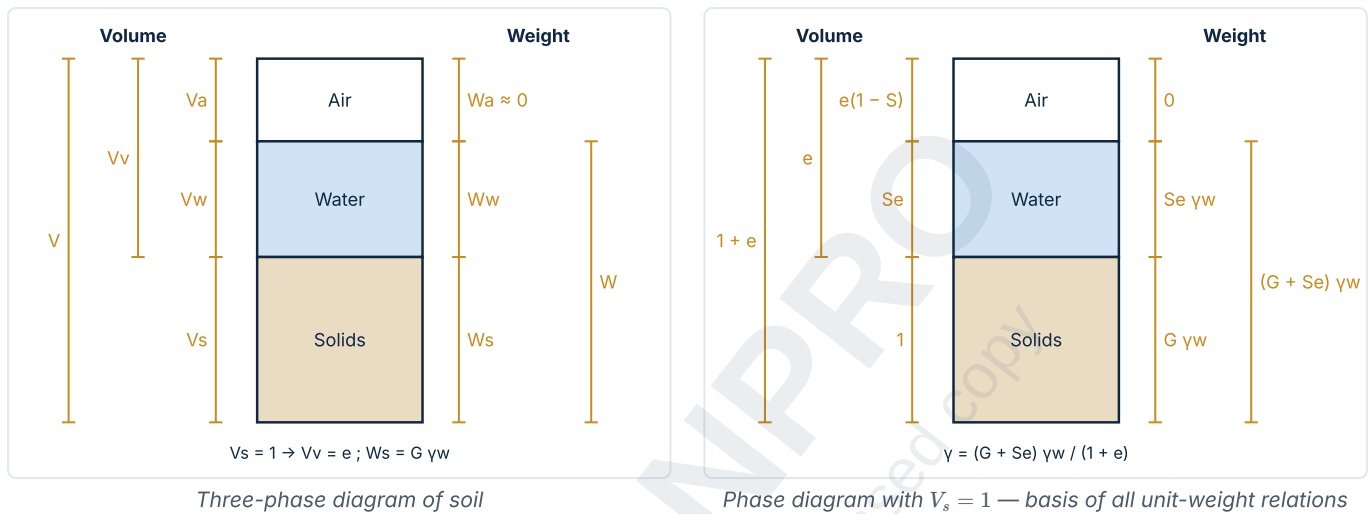
- Single-grained:** coarse particles in grain-to-grain contact; may be loose or dense.
- Honeycomb:** fine sand/silt grains forming arches that enclose large voids; collapses on vibration or loading.
- Flocculated:** edge-to-face contact (attraction dominant) — marine clays; higher strength, permeability and void ratio.
- Dispersed:** face-to-face parallel arrangement (repulsion dominant) — remoulded clays, clay compacted wet of optimum.

- **Composite / coarse-grained skeleton:** coarse grains with clay binder filling the voids (e.g. glacial till).

Remember: Adsorbed water is not removed completely by oven drying at 105–110 °C. Clays with gypsum or organic matter are dried at a lower temperature to avoid driving off water of crystallisation.

1.4 Phase diagram and basic definitions

A soil mass is a **three-phase system** of solids, water and air. For calculation the phases are drawn separately in a **phase diagram** with volumes on one side and weights on the other. A fully saturated or fully dry soil becomes a two-phase system.



Basic volume and weight ratios

Term	Definition	Range / remark
Void ratio e	V_v/V_s	> 0 , can exceed 1 (soft clays 1–3)
Porosity n	V_v/V	$0 < n < 1$ (usually as %)
Degree of saturation S	V_w/V_v	0 (dry) to 1 (saturated)
Air content a_c	$V_a/V_v = 1 - S$	0 to 1
Percentage air voids n_a	$V_a/V = n a_c$	Used in compaction (≈ 5 –10 % at OMC)
Water content w	W_w/W_s	Can exceed 100 % (peats, marine clays)
Specific gravity G	γ_s/γ_w	2.65–2.80 for most soils

Porosity–void ratio

$$n = \frac{e}{1 + e}, \quad e = \frac{n}{1 - n}$$

e = void ratio, n = porosity (fractions)

Fundamental relation

$$S e = w G$$

For saturated soil ($S = 1$): $e = w G$

Most used relation in phase problems

Exam trap: Water content is defined on the weight of **solids**, not the total weight — so w may exceed 100 %. Porosity cannot exceed 100 %, but void ratio can exceed 1.

1.5 Unit weights and key relationships

Unit weight is weight per unit total volume. Five unit weights are used: bulk, dry, saturated, submerged and unit weight of solids. All can be written in terms of G , e , S and w by taking $V_s = 1$ in the phase diagram.

CHAPTER 06

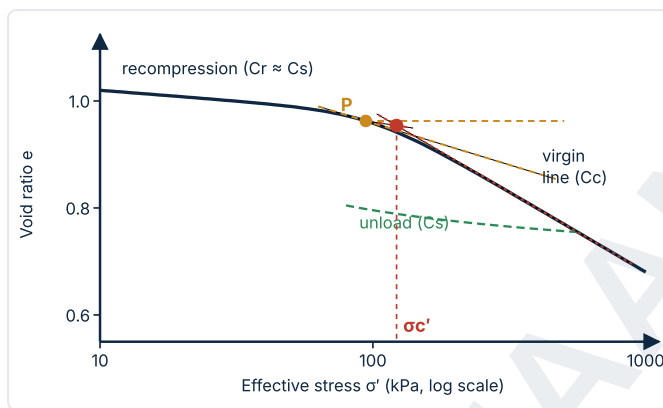
Consolidation & Settlement

Compressibility, stress history, consolidation settlement, Terzaghi's theory and time rate, the oedometer test, secondary compression and permissible settlements.

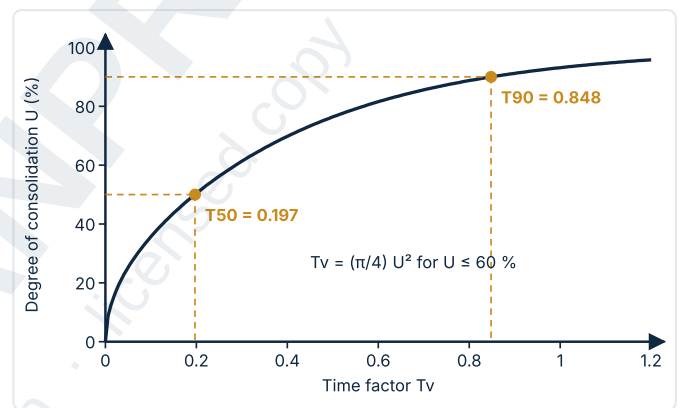
6.1 Compressibility and stress history

Consolidation is the gradual reduction in volume of a saturated fine-grained soil under sustained load, caused by the slow expulsion of pore water. When load is applied the excess pore pressure first carries it; as water drains, the load is transferred to the soil skeleton and effective stress rises. Total settlement = immediate (elastic) + primary consolidation + secondary compression.

The **preconsolidation pressure** σ'_c is the maximum effective stress the soil has ever carried. A **normally consolidated (NC)** clay has never carried more than its present overburden ($OCR = 1$); an **over-consolidated (OC)** clay has ($OCR > 1$) — due to erosion of overburden, a former glacier, a lowered and restored water table, or desiccation. An **under-consolidated** clay is still consolidating under its own weight.



e -log σ' curve and Casagrande's construction for σ'_c



Theoretical U - T_v relation (Terzaghi, uniform initial excess pore pressure)

1. Mark the point of maximum curvature P on the e -log σ' curve.
2. Draw a horizontal line and a tangent at P ; bisect the angle between them.
3. Extend the straight virgin portion backwards; its intersection with the bisector gives σ'_c (**Casagrande method**).

Over-consolidation ratio

$$OCR = \frac{\sigma'_c}{\sigma'_0}$$

σ'_0 = present effective overburden

Coefficient of compressibility

$$a_v = -\frac{\Delta e}{\Delta \sigma'}$$

m^2/kN

Coefficient of volume compressibility

$$m_v = \frac{a_v}{1 + e_0} = \frac{\Delta V/V_0}{\Delta \sigma'}$$

m^2/kN ; reciprocal of constrained modulus

Compression index

$$C_c = \frac{e_1 - e_2}{\log_{10}(\sigma'_2/\sigma'_1)}$$

Slope of virgin line; dimensionless

Skempton / Terzaghi-Peck correlations

$$C_c = 0.009 (w_L - 10) \text{ undisturbed; } 0.007 (w_L - 10) \text{ remoulded}$$

w_L in %

Swelling / recompression index

$$C_s \approx \left(\frac{1}{5} \text{ to } \frac{1}{10}\right) C_c$$

Slope of unloading-reloading line

Exam tip: Sample disturbance makes the e - $\log \sigma'$ curve flatter and more rounded, so the measured C_c and σ_c' are lower than the true field values.

6.2 Consolidation settlement

Final primary consolidation settlement of a clay layer of thickness H is computed at the middle of the layer (or in sub-layers for thick deposits) from the change in void ratio between the initial and final effective stresses.

General

$$S_c = \frac{\Delta e}{1 + e_0} H = m_v \Delta \sigma' H$$

NC clay

$$S_c = \frac{C_c H}{1 + e_0} \log_{10} \frac{\sigma_0' + \Delta \sigma}{\sigma_0'}$$

OC clay, $\sigma_0' + \Delta \sigma \leq \sigma_c'$

$$S_c = \frac{C_s H}{1 + e_0} \log_{10} \frac{\sigma_0' + \Delta \sigma}{\sigma_0'}$$

OC clay, $\sigma_0' + \Delta \sigma > \sigma_c'$

$$S_c = \frac{H}{1 + e_0} \left[C_s \log \frac{\sigma_c'}{\sigma_0'} + C_c \log \frac{\sigma_0' + \Delta \sigma}{\sigma_c'} \right]$$

Worked example — NC and OC clay settlement

A 4 m clay layer ($w_L = 45\%$, $e_0 = 1.0$) has $\sigma_0' = 60$ kPa at mid-depth. A building adds $\Delta \sigma = 40$ kPa. Find S_c (a) if the clay is NC (undisturbed correlation), (b) if $\sigma_c' = 80$ kPa and $C_s = 0.05$.

1. $C_c = 0.009(45 - 10) = 0.315$

2. (a) $S_c = 0.315 \times 4/2 \times \log(100/60) = 0.63 \times 0.2218 = 0.140$ m

3. (b) $S_c = (4/2)[0.05 \log(80/60) + 0.315 \log(100/80)] = 2[0.00625 + 0.03053] = 0.074$ m

Answer: (a) 140 mm; (b) 74 mm — over-consolidation halves the settlement

Immediate (elastic) settlement occurs as the load is applied, without volume change in saturated clays (undrained distortion) and quickly in sands. It is estimated from elastic theory.

Immediate settlement

$$S_i = \frac{q B (1 - \mu^2)}{E_s} I_f$$

$\mu = 0.5$ for saturated clay (undrained); I_f = influence factor

Influence factor I_f for immediate settlement

Footing	Flexible — centre	Flexible — corner/edge	Flexible — average	Rigid
Circle	1.00	0.64	0.85	0.79
Square	1.12	0.56	0.95	0.82

6.3 Terzaghi's one-dimensional consolidation theory

Terzaghi's theory gives the rate at which excess pore pressure dissipates. **Assumptions:** soil is homogeneous and fully saturated; solids and water are incompressible; flow and compression are one-dimensional (vertical); Darcy's law is valid; k and m_v remain constant during consolidation; strains are small; the time lag is due only to low permeability (no secondary compression); load is applied instantly and stays constant.

PART B

Compact Summary Notes

Geotechnical Engineering

Illustrated one-page-per-topic revision sheets — read these in the last days before the exam, after studying the detailed notes in Part A.

Summary notes

page 59

11 pages of summary notes

CIVIL ENGINEERING

SOIL MECHANICS

Handwritten-Style Chapterwise Notes

- 1. Soil mechanics: introduction & phase relationships
- 2. Index properties, saturation & density relationships
- 3. Atterberg limits & soil classification
- 4. Field identification, clay minerals & soil structure
- 5. Soil compaction
- 6. Effective stress, pore-water pressure & capillarity
- 7. Permeability, seepage & stress distribution
- 8. Consolidation & settlement
- 9. Shear strength of soil & slope stability
- 10. Earth pressure, bearing capacity & piles

Quick revision | Key formulas | Improved sketches

CHAPTER 1 – SOIL MECHANICS: INTRODUCTION & PHASE RELATIONSHIPS

1.1 Introduction

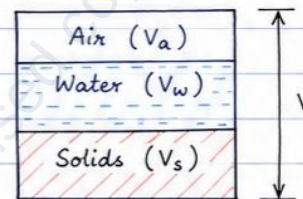
- Soil mechanics is the study of the behaviour of soil under various conditions of loading.
- Geotechnical Engineering is a branch of engineering that deals with the behaviour of soil, rock and their interaction with structures.

1.2 Origin and Formation of Soil

- Soil is formed by the disintegration of rocks.
 - Physical weathering : disintegration of rocks into smaller pieces (e.g., due to temperature changes, frost action, abrasion, etc.)
 - Chemical weathering : decomposition of rocks by chemical action (e.g., solution, hydration, oxidation, carbonation, etc.)
 - Organic origin : Soil may also be formed from the accumulation and decomposition of organic remains of plants and animals.

1.3 Soil as a Three-Phase System

- Soil consists of three constituents (phases):
 - (i) Solid particles (ii) Water (iii) Air
- Thus, soil is a three-phase system.



1.4 Basic Relationships

Volume relationships:

$$V = V_s + V_w + V_a$$

where, V = Total volume of soil

V_s = Volume of solid particles

V_w = Volume of water

V_a = Volume of air

V_v = Volume of voids = $V_w + V_a$

W = Total weight of soil

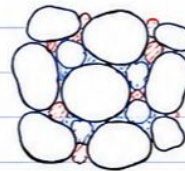
W_s = Weight of solids

W_w = Weight of water

Weight relationships:

$$W = W_s + W_w$$

(Weight of air is usually neglected)



 Air
 Water
 Solid particles

1.5 Index Properties and Phase Relationships

① Natural water content (w)

$$w = \frac{W_w}{W_s} \times 100 \quad (\%)$$

* Important property of soil.

② Void ratio (e)

$$e = \frac{V_v}{V_s} \quad (\text{dimensionless})$$

③ Porosity (n)

$$n = \frac{V_v}{V} \times 100 \quad (\%)$$

④ Degree of saturation (S)

$$S = \frac{V_w}{V_v} \times 100 \quad (\%)$$

Note:

n = porosity

e = void ratio

S = degree of saturation

Other useful relations:

$$V_v = V_w + V_a$$

$$n = \frac{e}{1 + e} \times 100 \quad (\%)$$

$$e = \frac{n}{100 - n}$$

$$S = \frac{w \times G_s}{e} \quad (\text{using } w \text{ as decimal})$$

where, G_s = Specific gravity of solids

Remember: Soil is a three-phase system → Solids + Water + Air. 😊



End of the free preview

Geotechnical Engineering

The full PDF has 69 pages:

Part A — detailed typed notes: 11 chapters, 54 pages

Part B — handwritten compact summary: 11 pages

Chapters in the full notes

- 01 Soil Formation, Clay Minerals & Phase Relations
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- 11 Site Investigation, Expansive Soils & Machine Foundations

Formula boxes with every symbol explained · IS / IRC code values in tables · labelled sketches
Worked examples step by step · exam tips & traps · quick revision points after every chapter

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