Chapter 2: Engineering Characteristics of Soils

Introduction

Understanding the engineering characteristics of soils is fundamental in transportation engineering. The design and performance of pavement structures heavily depend on the behavior of the underlying soil, also known as subgrade. Since soils vary greatly in terms of their origin, composition, texture, and strength properties, a detailed understanding is essential for ensuring the stability, durability, and serviceability of transportation infrastructure.

This chapter explores the key engineering properties of soils relevant to the construction and performance of roads, highways, airfields, and railways. It deals with classification, strength behavior, compaction, permeability, moisture sensitivity, and swelling characteristics that influence pavement design and performance.

2.1 Soil Classification Systems

2.1.1 Purpose of Classification

Soil classification is essential to identify and group soils with similar engineering properties, helping engineers make decisions about suitability, treatment, and expected behavior under loading.

2.1.2 Unified Soil Classification System (USCS)

- Divides soils into **coarse-grained**, **fine-grained**, and **highly organic soils**
- Based on grain-size distribution and Atterberg limits
- **Symbols:** GW (Well-graded gravel), CL (Low plasticity clay), etc.

2.1.3 Indian Standard Soil Classification System (ISCS)

- Similar to USCS but slightly adapted to Indian soil conditions
- Soils classified based on **grain size**, **plasticity**, and **compressibility**
- Major groups: **Gravel (G)**, **Sand (S)**, **Silt (M)**, **Clay (C)**, and **Organic (O)** soils

2.1.4 AASHTO Classification

- Used primarily in highway engineering
- Soils classified into groups A-1 to A-7 based on **grain-size** and **Atterberg limits**
- Group Index (GI) used to further evaluate soil performance

2.2 Soil Texture and Gradation

2.2.1 Particle Size Distribution

- Represents the range and proportion of particle sizes
- Important for understanding **drainage**, **compaction**, and **load distribution**

2.2.2 Sieve Analysis

- For particles > 75 μm (mechanical sieving)
- Results plotted on a **gradation curve**

2.2.3 Hydrometer Analysis

- For particles < 75 μm (silt and clay)
- Based on sedimentation principles (Stokes' law)

2.2.4 Types of Gradation

- **Well-graded:** Wide range of sizes
- **Poorly-graded (uniform):** Mostly same-sized particles
- **Gap-graded:** Missing intermediate sizes

2.3 Consistency and Atterberg Limits

2.3.1 Definition of Atterberg Limits

- Describe the behavior of **fine-grained soils** under varying moisture
- **Liquid Limit (LL)**, **Plastic Limit (PL)**, and **Shrinkage Limit (SL)**

2.3.2 Plasticity Index (PI)

- PI = LL - PL
- Indicates soil plasticity and potential volume change

2.3.3 Significance in Pavement Engineering

- High PI → expansive soil → poor subgrade
- Soils with low PI are usually preferred

2.4 Compaction Characteristics

2.4.1 Compaction vs Consolidation

- **Compaction**: Densification by expelling air
- **Consolidation**: Time-dependent volume change due to water expulsion

2.4.2 Standard and Modified Proctor Tests

- Determines **Optimum Moisture Content (OMC)** and **Maximum Dry Density (MDD)**
- Higher compactive effort → higher MDD and lower OMC

2.4.3 Field Compaction Methods

- **Rollers**: Smooth wheel, pneumatic, vibratory, sheep-foot
- Compaction monitored using nuclear density gauge or sand cone method

2.4.4 Compaction Specifications

- Typically 95–100% of laboratory MDD
- Required compaction varies with layer and traffic load

2.5 Permeability and Drainage

2.5.1 Darcy's Law

- Governs flow of water through soil
- $q = k \cdot i \cdot A$, where k = coefficient of permeability

2.5.2 Factors Affecting Permeability

- Grain size, void ratio, fluid viscosity, soil structure

2.5.3 Importance in Pavement Design

- High permeability soils allow water to drain, reducing pore pressure and damage
- Clayey soils (low permeability) retain water → reduced strength

2.6 Shear Strength of Soils

2.6.1 Mohr-Coulomb Failure Criterion

- $\tau = c + \sigma \cdot \tan(\phi)$
- c: Cohesion; φ: Angle of internal friction

2.6.2 Types of Shear Tests

- **Direct Shear Test**
- **Triaxial Shear Test** (UU, CU, CD)
- **Unconfined Compression Test** (for cohesive soils)

2.6.3 Role in Pavement Support

- High shear strength → good load support capacity
- Low shear strength soils may require stabilization

2.7 Compressibility and Consolidation

2.7.1 Compressibility

- The tendency of soil to decrease in volume under pressure

2.7.2 One-Dimensional Consolidation Test

- Determines **Coefficient of Consolidation (Cv)** and **Compression Index (Cc)**

2.7.3 Importance in Pavement Engineering

- Settlements in subgrade → uneven pavement surface
- Peat and clay are highly compressible and problematic

2.8 Swelling and Shrinkage Behavior

2.8.1 Expansive Soils

- Soils that swell when wet and shrink when dry (e.g., black cotton soil)

2.8.2 Swell Potential Testing

- **Free Swell Index**
- **Swelling pressure** determination using oedometer

2.8.3 Effects on Pavements

- Cracking, rutting, and heaving in flexible pavements
- Require special treatments (lime stabilization, sand blankets)

2.9 California Bearing Ratio (CBR) Test

2.9.1 Definition

- CBR = Load carried by soil / Load carried by standard crushed stone × 100%

2.9.2 Test Procedure

- Penetration test conducted on soaked/unsoaked samples

2.9.3 CBR and Pavement Design

- Used for **empirical pavement thickness** design
- CBR value determines strength classification of subgrade

2.10 Resilient Modulus (Mr)

2.10.1 Definition

- Ratio of repeated axial stress to recoverable strain
- $M_r = \frac{\sigma_d}{\epsilon_r}$

2.10.2 Importance

- Used in mechanistic pavement design
- Better indicator of real-life performance than CBR

2.11 Subgrade Reaction Modulus (k-value)

2.11.1 Plate Load Test

- Measures settlement under a rigid circular plate
- k = Load intensity / Settlement

2.11.2 Significance

- Used in rigid pavement design
- Helps assess the stiffness of subgrade under loading

2.12 Soil Stabilization Techniques

2.12.1 Need for Stabilization

- Improve strength, reduce permeability and volume change

2.12.2 Methods

- **Mechanical stabilization** (blending)
- **Chemical stabilization** (lime, cement, fly ash)
- **Bituminous stabilization** (using asphalt emulsion)

2.12.3 Applications

- Subgrade improvement
- Base and sub-base layers

2.13 Frost Action and Soil Behavior in Cold Regions

2.13.1 Frost Heave

- Upward movement of soil due to ice formation

2.13.2 Frost Susceptible Soils

- Silts and fine sands most prone

2.13.3 Mitigation Measures

- Use of non-frost susceptible materials
- Proper drainage and insulation layers

2.14 Summary of Key Soil Parameters in Pavement Design

Property	Relevant Test	Role in Design
Gradation	Sieve & Hydrometer	Drainage, compaction
Atterberg Limits	LL, PL tests	Plasticity, volume change
Compaction	Proctor Test	Density, strength
Permeability	Darcy’s Law	Drainage

Property	Relevant Test	Role in Design
Shear Strength	Triaxial, Direct Shear	Load support
Compressibility	Consolidation Test	Settlement control
Swelling	Free Swell Test	Volume stability
CBR	CBR Test	Pavement thickness
Resilient Modulus	Repeated Load Test	Mechanistic design
Subgrade Reaction	Plate Load Test	Rigid pavement support