Chapter 4: Evaluation of Soil Strength for Pavements

Introduction

The strength of subgrade soil is a fundamental parameter in pavement design and performance. Pavement structures, whether flexible or rigid, transfer loads from the surface to the underlying layers, with subgrade soil acting as the ultimate load-bearing stratum. A weak or improperly evaluated subgrade can lead to pavement distress such as rutting, cracking, or complete failure. Hence, accurate evaluation of soil strength is essential for ensuring durability, serviceability, and cost-effectiveness of pavement systems.

This chapter delves into the various methods and principles involved in evaluating the strength of soils used as subgrade in pavements. The process includes both field and laboratory investigations, empirical and mechanistic approaches, and the interpretation of test results in terms of pavement design requirements.

4.1 Importance of Soil Strength Evaluation in Pavement Engineering

- **Foundation Role**: Soil serves as the foundation for all types of pavements. Its strength determines the required thickness and type of the pavement structure.
- **Design Input**: Parameters like California Bearing Ratio (CBR), Resilient Modulus (MR), and unconfined compressive strength (UCS) directly influence the pavement design models.
- **Performance Prediction**: Proper evaluation helps in predicting the long-term behavior of pavement under traffic loading and environmental effects.

4.2 Factors Affecting Soil Strength

1. **Moisture Content**

- Soil strength decreases with an increase in moisture content, particularly in clayey soils.
- Saturated conditions significantly reduce the shear strength due to pore water pressure.

2. **Soil Type and Classification**
    - Cohesive soils (clays) exhibit plastic behavior and strength is dependent on cohesion.
    - Cohesionless soils (sands, gravels) derive strength from inter-particle friction.
3. **Compaction Level**
    - Higher compaction leads to increased dry density and strength.
    - Optimum moisture content (OMC) during compaction ensures maximum strength.
4. **Soil Structure and Fabric**
    - The orientation of particles, stratification, and bonding impact strength.
5. **Stress History and Overconsolidation**
    - Soils with a history of higher loading (overconsolidated soils) tend to exhibit higher strength.

4.3 Methods for Soil Strength Evaluation

4.3.1 Field Tests

(a) ***California Bearing Ratio (CBR) Test***

- **Purpose**: Empirical test to determine the supporting capacity of subgrade soil.
- **Procedure**: Penetration of a standard plunger into a compacted soil specimen at a rate of 1.25 mm/min.
- **Interpretation**: CBR value expressed as a percentage of the resistance compared to standard crushed stone.
- **Usage**: Widely used in empirical pavement design (e.g., IRC:37).

(b) ***Plate Load Test***

- **Purpose**: Determines modulus of subgrade reaction (k-value).
- **Procedure**: Circular plate is loaded in increments; settlements are recorded.

- **Application**: Useful for rigid pavement design.

*(c) **Dynamic Cone Penetration Test (DCPT)***

- **Purpose**: Quick in-situ test to assess subgrade strength.
- **Procedure**: Cone is driven into soil using a standard hammer; penetration per blow is recorded.
- **Advantage**: Correlated with CBR values.

4.3.2 Laboratory Tests

*(a) **Unconfined Compressive Strength (UCS) Test***

- **Applicable to**: Cohesive soils.
- **Procedure**: A cylindrical soil specimen is compressed axially without lateral support until failure.
- **Output**: Peak stress is taken as UCS.

*(b) **Triaxial Compression Test***

- **Types**: Unconsolidated Undrained (UU), Consolidated Undrained (CU), and Consolidated Drained (CD).
- **Procedure**: Soil sample is subjected to confining pressure and axial load.
- **Strength Parameters**: Cohesion (c) and internal friction angle (ϕ).

*(c) **Direct Shear Test***

- **Procedure**: Soil sample is sheared along a predefined plane under a normal load.
- **Strength Parameters**: c and ϕ obtained from failure envelope.

*(d) **CBR Laboratory Test***

- **Same procedure** as field CBR but done under controlled moisture and compaction.

*(e) **Resilient Modulus (MR) Test***

- **Significance**: Represents the elastic response of soil under repeated loading.
- **Test**: Repeated load triaxial test.
- **Application**: Used in mechanistic-empirical pavement design (e.g., AASHTO M-E).

4.4 Interpretation of Soil Strength Parameters for Pavement Design

- **CBR-based Design**:
    - Used in empirical methods like IRC:37 or AASHTO 1993.
    - Higher CBR implies thinner pavement crust.
- **Modulus-based Design**:
    - Mechanistic-empirical methods require resilient modulus.
    - MR can be estimated from CBR or determined via lab test.
- **Shear Strength Parameters (c, ϕ)**:
    - Important for slope stability and layered system analysis.
- **UCS for Stabilized Soils**:
    - Used to verify strength gain in chemically stabilized subgrades (lime, cement).

4.5 Correlation between Soil Properties and Strength Parameters

Empirical relationships are often used to estimate strength properties based on soil index properties:

Property	Estimated Strength Correlation
Plasticity Index (PI)	PI ↑ → CBR ↓ (in clays)
Liquid Limit (LL)	LL ↑ → CBR ↓
Dry Density	Higher density → Higher strength
CBR and MR	MR (MPa) ≈ 10 × CBR (approximate, for fine-grained soils)
DCPT vs. CBR	CBR (%) = a × log(Penetration resistance) (empirical)

4.6 Seasonal and Environmental Considerations

- **Soaked vs. Unsoaked CBR**:

    - Soaked CBR simulates worst-case conditions during monsoon or flooding.
- **Frost and Thaw Cycles**:
    - In cold regions, freeze-thaw can weaken subgrade significantly.
- **Capillarity and Water Table**:
    - Rising water table can reduce soil strength by increasing saturation.

4.7 Improving Subgrade Strength

If the existing subgrade fails to meet strength requirements, improvement techniques are employed:

1. **Compaction** – Most common and cost-effective method.
2. **Chemical Stabilization** – Lime, cement, fly ash.
3. **Mechanical Stabilization** – Blending with stronger materials (gravel, sand).
4. **Geosynthetics** – Use of geogrids, geotextiles for reinforcement and separation.
5. **Drainage Improvements** – Lowering the water table or ensuring surface drainage.

4.8 Quality Control and Assurance

- **Field Density Testing**: Sand cone, nuclear density gauge.
- **Moisture Control**: During compaction and construction.
- **Test Frequency**: Defined as per IRC or MORTH specifications.

4.9 Code Recommendations and Standards

- **IRC:37** – Design guidelines for flexible pavements based on CBR.
- **IRC:58** – Guidelines for rigid pavement design.
- **AASHTO T 307** – For resilient modulus testing.
- **MORTH Specifications** – Field testing and quality control standards.
