CEMENT -TREATED SOIL

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Introduction

Among the several modes of transportation, the roads have been the most ancient and widely used medium. Since the ancient time for transportation of goods or travelling purpose, we used roads. Heavy loaded trucks running on the roads need special care and attention during construction phase so that they can bear the maximum load. Stabilization is the improvement of a soil or pavement material usually through the addition of a binder or additive. Some of the soil having good and sufficient load bearing capacity but some of having poor. This research work mainly focuses on soil stabilization using cement to improve geotechnical properties such as plasticity, compaction, and Unconfined Compressive Strength of the studied soil. These properties were determined before as well as after the stabilization of soil. In this work it was found that higher the quantity of cement added to the soil, dry density of soil decreased and optimum moisture content increased. With the addition of cement to the soil, unconfined compressive strength increased, and it was also found higher at higher curing period. Cement stabilization of soil is done by mixing pulverized soil and Portland cement with water and compaction the mix to attain a strong material. The material obtained by mixing soil and cement is known as soil-cement. Since 1915 more than 1 lakh miles equivalent 7.5m wide pavement bases has been constructed from cement stabilized soil. Soil Stabilization is a process of treating a soil to improve its stability and bearing capacity for using the soil as Construction material. The most Important Purpose of Soil Stabilization is the increase the strength of pavement layers like sub-base, base course etc. and to increase the stability of earth work in embankment as a whole. The soil to be stabilized is pulverized, water is added and is mixed. The bituminous material is then added and is remixed. The mixture is spread to the required grade and compacted. The compacted surface cured.

Mechanisms of Soil Stabilization with Cement

1. Hydration Reactions
   - Key Components: Cement is primarily composed of calcium silicates. When mixed with water, these calcium silicates undergo a series of hydration reactions.
   - Products: The primary hydration products are:
     - Calcium Silicate Hydrate (C-S-H): A gel-like substance that is the main contributor to strength and bonding.
     - Calcium Hydroxide ($Ca(OH)_2$): Also known as portlandite, it plays a role in early strength development and creates a highly alkaline environment.
2. Cation Exchange
   - Soil Composition: Clay particles have negatively charged surfaces which attract positively charged ions (cations).
   - The Swap: When cement is added, the calcium ions (Ca^{2+}) from the hydrating cement replace the weaker cations on the clay surfaces.
   - Results:
     - Flocculation: Clay particles clump together, improving workability.
     - Reduced Plasticity: The soil becomes less moldable and improves its stability.
3. Pozzolanic Reactions
   - Secondary Reaction: In the presence of moisture, the calcium hydroxide ($Ca(OH)_2$) from the cement hydration reacts with silica and alumina present in the soil.
   - More C-S-H: This reaction forms additional calcium silicate hydrate (C-S-H), further strengthening the soil matrix.
   - Long-Term Benefit: As cement hydration continues, more calcium hydroxide becomes available, boosting long-term strength gain.

4. Cementation and Bonding
    - The Glue: The gel-like C-S-H crystals act as a powerful binding agent. They fill the voids between soil particles and interlock, creating a solidified mass.
    - Stronger Soil Matrix: The C-S-H and its intricate network bind soil particles together, enhancing the overall stiffness of the soil system.
    - Reduced Permeability: The interconnected voids filled by C-S-H significantly reduce the interconnected pore space, leading to less water permeability.

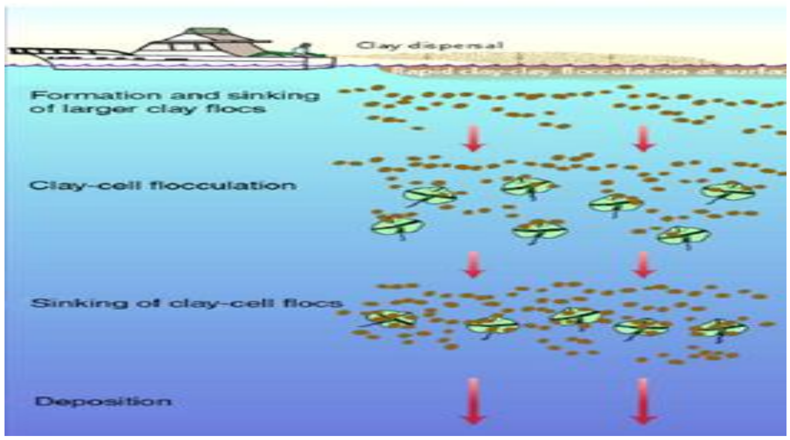
Ideal Soil Characteristics for Cement Stabilization

- Particle Size Distribution: Well-graded soils with a mix of particle sizes (sand, silt, and clay) are optimal. This mix promotes:
    - Dense packing, providing a solid matrix for cementation.
    - Effective distribution of cement and hydration products within the soil matrix.
- Plasticity: Low to moderate plasticity is preferable. Highly plastic soils may require higher cement content or pretreatment with lime.
- Organic Matter: Soils with low organic matter content (< 2%) are preferred. Organic matter interferes with cement hydration reactions.
- Sulphates: Soils with low soluble sulfate content are ideal to minimize the risk of sulfate attack, which can damage the stabilized structure over time.

Studies on Specific Soil Types and Cement Stabilization

1. **Clayey Soils**

- Mechanisms: Cement counteracts high plasticity and compressibility of clay. Cation exchange and pozzolanic reactions create a stronger and less permeable soil structure.
- Challenges: May require higher cement content (more than 10% by weight) and longer curing times.



clay flocculation

2. Sandy Soils

- Mechanisms: Cement acts as a primary binding agent, significantly boosting cohesion, strength, and reducing permeability.
- Challenges: Might need higher cement content compared to well-graded soils to achieve adequate strength.

cement bonding in sand

3. Silty Soils

- Mechanisms: Cement reduces sensitivity to moisture changes, improves strength, and increases load-bearing capacity.
- Challenges: Requires careful moisture control during mixing and curing to prevent instability.

before/after stabilization in silt

❖ Combinations of Soil Types Well-graded soils with varied sand, silt, and clay provide ideal interlocking and facilitate a strong cementing matrix, resulting in superior performance.

Relationship Between Cement Content and Soil Properties

Generally, as cement content (percentage by weight of dry soil) increases, we observe the following trends:

- Strength Improvement: Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and other strength indicators increase significantly.
- Stiffness Increase: The stabilized soil becomes more rigid and resists deformation.
- Reduced Permeability: The interconnected pores within the soil get filled by hydration products, decreasing permeability and water sensitivity.
- Durability Enhancement: Cement stabilization improves the soil's resistance to weathering, wetting-drying cycles, and freeze-thaw conditions.

Optimal Cement Content

Finding the optimal cement content involves striking a balance between achieving desired performance targets and economic feasibility. Here's why there's no single universal optimal percentage:

- **Soil Type**:
  - Clayey Soils: Typically require higher cement content (8-15%) due to fine particles and greater surface area to be coated.
  - Sandy Soils: Can achieve substantial strength gains with lower cement content (5-10%), but may still require higher amounts than well-graded soils.
  - Silty Soils: Fall in between, their optimal cement content varies based on the silt's specific characteristics.
- **Target Properties**:
  - Strength-focused stabilization: Might necessitate higher cement percentages.
  - Modest improvements: Applications aiming for slight enhancement in workability or permeability may require less cement.

Determining Optimal Content

- Laboratory Tests: Soil samples with varying cement contents are tested to determine UCS, CBR values, or other relevant parameters. From these results, an optimum point is identified.
- Economic Considerations: Higher cement content increases project costs. The optimal choice often balances performance requirements with cost constraints.

Important Notes

- Curing Conditions: Adequate curing time and moisture are essential to achieve the full benefits of cement addition.
- Additives: Fly ash, lime, or other materials are sometimes used in conjunction with cement to modify the stabilized soil's properties and reduce costs.

The Role of Curing Time

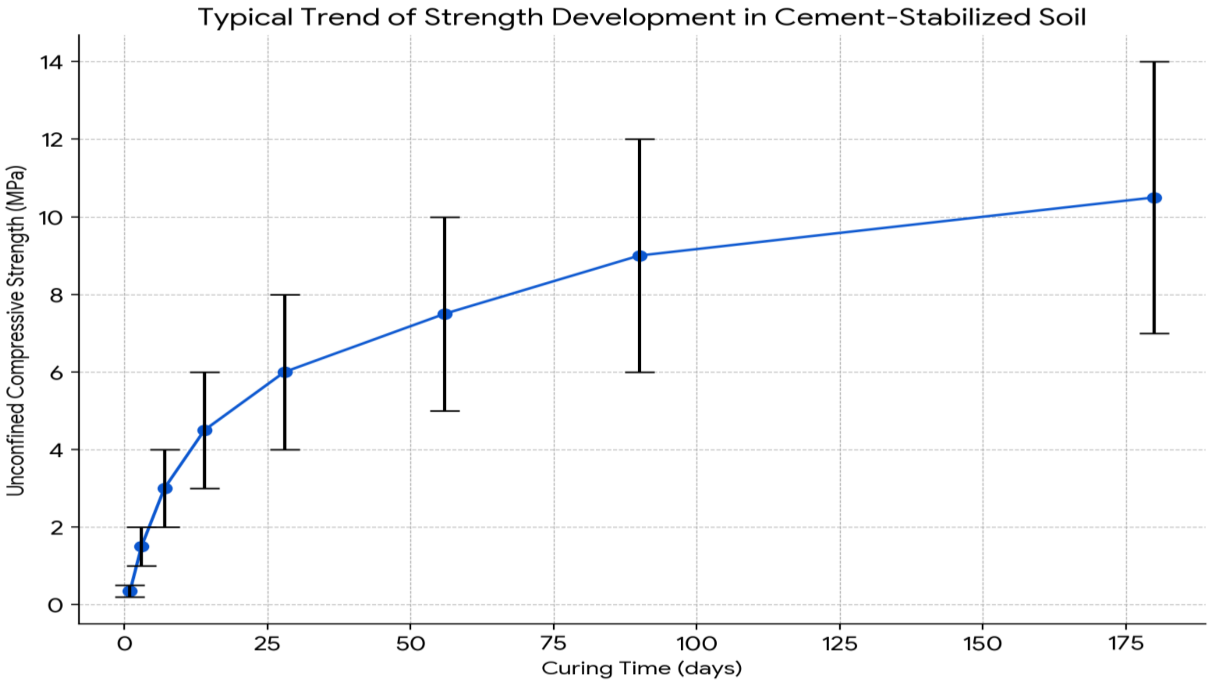
Curing refers to maintaining proper moisture and temperature conditions for a specific period after the stabilized soil mixture has been placed and compacted. Here's why it's crucial:

- Hydration Continuation: Cement hydration, the chemical reaction that leads to cement hardening, requires water and suitable temperatures. Adequate curing ensures that moisture is available for continuous hydration.
- Strength Development: As hydration progresses and bonds form, the stabilized soil gradually gains strength. Longer curing periods generally lead to higher ultimate strength values.
- Durability Enhancement A well-cured cement-stabilized soil forms a denser, less permeable microstructure. This translates to better resistance against:
    - Water damage and erosion
    - Wetting and drying cycles
    - Freeze-thaw cycles

- Reduced Shrinkage Cracking: Proper curing helps control the rate at which moisture is lost from the stabilized soil, reducing the likelihood of early-age shrinkage cracking.

Factors Influencing Curing Time

- Cement Type: Different cement types have varying hydration rates, influencing optimal curing time.
- Ambient Temperature: Higher temperatures accelerate hydration, potentially shortening curing duration. Cooler temperatures necessitate longer curing periods.
- Desired Strength and Durability: Projects requiring higher performance targets often demand longer, more controlled curing.



Effect of curing period on unconfined compressive strength (UCS) of soil

Curing Methods

- Watering: Keeping the surface of the stabilized soil moist by regular misting or sprinkling.
- Covering: Using plastic sheets, wet burlap, or geotextiles to prevent moisture loss and maintain a humid environment.
- Temperature Control: In extreme weather conditions, measures may be necessary to regulate the temperature of the stabilized soil.

Important Notes

- Minimum Curing: Standards like ACI (American Concrete Institute) recommend specific minimum curing times for cement-based materials.
- Field Conditions: Real-world curing may necessitate adjustments based on local climate and specific project requirements.

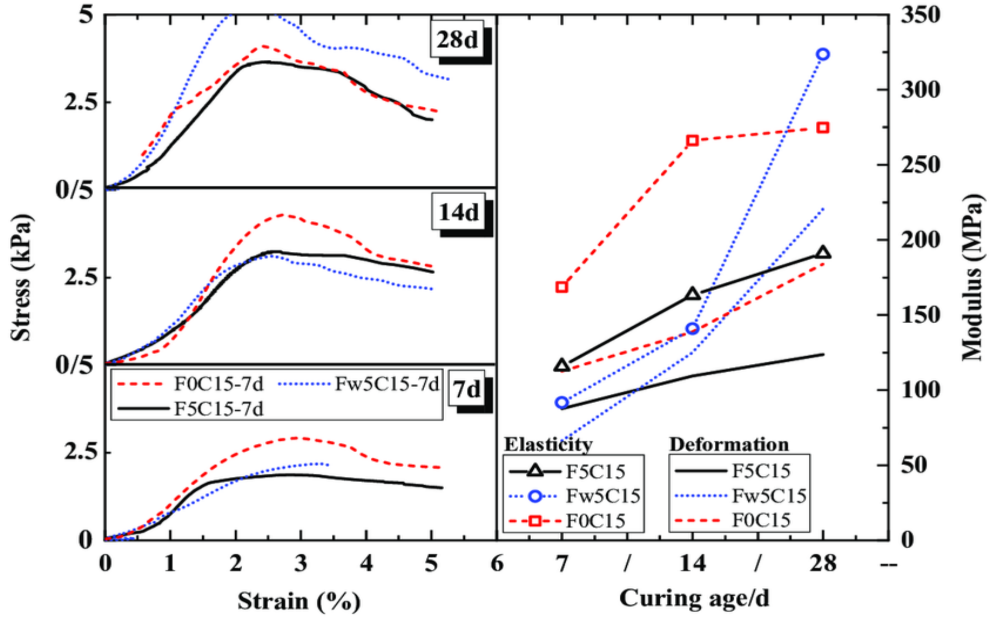
Testing Methods

Familiarize yourself with standard testing methods used to assess the performance of cement-stabilized soils:

1. Unconfined Compressive Strength (UCS)

- Purpose: Determines the maximum compressive stress a soil can withstand before failing. A key indicator of strength and stiffness gain in stabilized soils.
- Procedure:
    - Cylindrical specimens of stabilized soil are prepared and cured to the specified age.
    - Specimens are loaded in a compression machine until failure.
    - Peak load is recorded and UCS is calculated (Force/Area).

- Diagram: Stress-strain curve for a typical cement-stabilized soil showcasing the peak stress point and the change in material behavior.

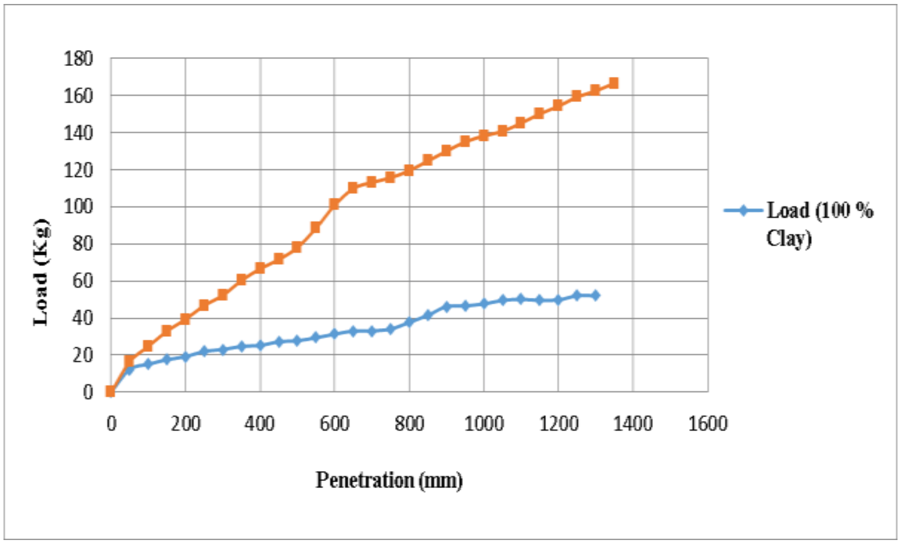


stress strain curve for cement stabilized soil

2. California Bearing Ratio (CBR)

- Purpose: Primarily used to assess the suitability of stabilized soils for subbase and subgrade layers in roads and pavements. CBR value provides a measure of load-bearing capacity and resistance to deformation.
- Procedure:
    - A cylindrical specimen of compacted stabilized soil is prepared and cured.
    - A piston is steadily penetrated into the specimen, and the force required is recorded at specific penetration depths.
    - CBR is calculated as a percentage of the force required on standard crushed rock.

- Diagram: Load vs. penetration curve demonstrating how the CBR value is derived.



load vs. penetration curve for CBR test

3. Durability Tests

- Purpose: To evaluate how well the stabilized soil withstands weathering and environmental stressors over time
- Types:
    - Wetting and Drying Cycles: Simulates the effects of rain and drought by repeatedly soaking and drying stabilized soil specimens and measuring change in strength or mass loss. (e.g., ASTM D559)
    - Freeze-Thaw Cycles: Imitates the effects of freezing and thawing temperatures observed in many climates. Specimens undergo cycles of freezing and thawing, and changes in strength, volume, or surface conditions are monitored. (e.g., ASTM D560)

Important Notes

- Standards: Following specific ASTM or AASHTO testing standards ensures consistent, comparable results.

- Curing: Specimens must be cured following recommended procedures before testing to emulate field conditions.
- Application-Specific: Choice of tests often depends on the intended use of the cement-stabilized soil (e.g., structural base layer, erosion control, etc.).

Strength and Stiffness

- Significant Strength Increase: Cement transforms soil into a stronger, more cohesive material, improving its load-bearing capacity.
- Enhanced Stiffness: Stabilized soil becomes more rigid, resisting deformation under stress. This is crucial for pavement bases, foundations, and slope stability.

1- Significant Strength Increase

- Cementing Action: Hydrated cement products, particularly C-S-H (calcium-silicate-hydrate), act as a powerful binding agent that interlocks soil particles.
- Types of Strength: Cement stabilization improves several strength measures including:
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    - Compressive Strength: The ability to withstand loads that try to crush the soil (measured by UCS tests).
    - Tensile Strength: Resistance to forces acting to pull the soil apart.
    - Shear Strength: Ability to resist sliding failures, crucial in slopes or soil under foundations.

- Application Benefits:
  - Pavements: A stronger base layer can handle heavier traffic loads and reduce wear and tear.
  - Foundations: Supports structures without exceeding allowable settlement limits.
  - Slopes: Improves stability, reducing the risk of landslides.

2- Enhanced Stiffness

- What is Stiffness: The degree to which the soil resists deformation under load. Think of a stiff spring vs. a soft one.
- How Cement Helps: The cementing matrix creates a more rigid and interconnected soil structure. It acts a bit like reinforcing fibers within the soil.
- Benefits:
  - Reduced Settlement: Stiffer soils reduce the amount a structure settles into the ground.
  - Vibration Resistance: Important in areas with earthquake risk or near heavy machinery.
  - Pavement Behavior: Increased stiffness in the base layer helps distribute surface loads more evenly, reducing cracking and pavement fatigue.

Interplay of Strength and Stiffness

- They go hand-in-hand: Stronger materials are often stiffer. Cement stabilization improves both.
- Tailored Outcomes: Depending on the application, the specific ratio of strength to stiffness gain can be influenced by cement content and the type of soil being stabilized.

Let's illustrate with examples:

- Highway Base: Needs significant strength to handle traffic but also enough stiffness to limit deflection and protect the asphalt top layer.
- Embankment: Strength is crucial to prevent sliding failure, stiffness helps minimize settling over time.
- Durability
- Reduced Water Sensitivity: Cement reduces permeability, minimizing the negative impacts of moisture on soil strength and volume stability.
- Weathering Resistance: Increased resistance to erosion, rain damage, and the detrimental effects of wetting-drying cycles.
- Freeze-thaw Resilience: Stabilized soil is less prone to damage caused by expansion and contraction of water under freezing temperatures.

Construction and Workability

- Improved Workability: Especially beneficial in clay soils, reduces plasticity, and making them easier to handle and compact.
- Faster Construction: Stabilized soil can often be used soon after placement, accelerating timelines compared to waiting for natural drying of overly wet soil.
- Reduced Excavation: In-situ stabilization can often eliminate the need to remove unsuitable soil and replace it with costly imported materials.

Cement stabilization can improve the engineering properties of soil, making it suitable for various construction purposes, including:

Pavements

- The Importance of the Base Layer: The base layer lies beneath a pavement's asphalt or concrete surface and is crucial to its longevity. A strong, stiff base:
  - Distributes traffic loads over a larger area, protecting the subgrade underneath from excessive stress.
  - Reduces the risk of rutting (permanent deformations) in the pavement surface.
  - Reduces cracking due to fatigue from repeated bending caused by traffic.
- **Cement-Stabilized Base Advantages:**
  - Can accommodate heavier trucks and greater traffic volume without degradation.
  - Extends pavement lifespan, reduces maintenance costs, and lowers life-cycle costs.
  - Can sometimes enable the use of thinner asphalt surface layers, resulting in potential material savings.

Foundations

- Soil vs. Structure Foundations need to transfer structural loads safely to the soil beneath. Cement stabilization helps by:
  - Increasing the soil's bearing capacity, allowing it to support larger structures or greater point loads.
  - Reducing differential settlement (uneven settling of different parts of a structure). This minimizes the risk of building damage from cracking or distortion.
  - Can be a lifesaver in areas of weak or compressible soil, allowing construction to proceed where it might otherwise be unfeasible.

- Specific Foundation Types:
    - Shallow foundations (footings): Achieve higher allowable pressures.
    - Deep Foundations (piles): Reducing pile lengths needed by improving the surrounding soil
    - Slabs-on-grade: Increased strength and stiffness help the slab bridge over minor soft spots in the subgrade.

<u>Slopes</u>

- Forces at Play: Gravity constantly wants to pull a slope downwards; a failure means a landslide. Cement stabilization:
    - Increases the soil's shear strength, helping it resist this force driving slippage.
    - Improved stiffness means the soil deforms less, which helps it hold its shape better.
    - Reduces water permeability, which is crucial, as saturation can significantly decrease soil strength and trigger landslides.
- Typical Applications:
    - Highway embankments and cuts: Creating stable slopes alongside roads.
    - Earth dams: Enhancing internal stability to prevent failures endangering downstream areas.
    - Erosion control: Stabilizing slopes prone to erosion from rain or water runoff, protecting infrastructure or preserving land.
- Soil Suitability: Cement generally works better in some soils than others. Preliminary testing informs the best mix design for your project.
- Design Approach: The benefits gained depend on proper engineering design incorporating the improved properties of the stabilized soil.

Versatility

- Varied Soil Types: Can be effective on a range of soils, from clays and silts to sandy soils (with appropriate adjustments to cement content).
- Diverse Applications: Suitable for subgrades, pavement bases, slope stabilization, embankment construction, and erosion control.

Economic Factors

- Cost-Effectiveness: Often a more cost-efficient solution compared to extensive soil removal or replacing with aggregates, especially when dealing with onsite soils.
- Resource Conservation: Reduces the reliance on imported aggregates, promoting sustainable construction practices.

Environmental Considerations

- Dust Reduction: Stabilized soil leads to less dust generation compared to untreated surfaces, improving air quality.
- Erosion Control: Enhances slope stability and reduces the risk of soil erosion, protecting the surrounding environment.

Important Notes:

- Soil Specific: The effectiveness and specific benefits of cement stabilization will depend on the properties of the soil being treated and the targeted application.
- Technical Expertise: Proper mix design, placement procedures, and curing are crucial to achieve the desired outcomes.

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