GUIDELINES FOR CHEMICALLY STABILIZING PROBLEMATIC SOILS

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Technical Manual

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

April 2020

prepared by
Bhaskar Chittoori, Ph.D., P.E. | Boise State University |
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RESEARCH PROGRAMS

MDT

Guidelines for Chemically Stabilizing Problematic Soils

Technical Manual

Prepared by:
Bhaskar Chittoori, Ph.D., P.E.,
Associate Professor
Civil Engineering Department
Boise State University
1910 University Dr.
Boise ID 8372

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Boise State University
1910 University Dr.
Boise ID 8372

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16. Abstract
The main goal of this project was to establish protocols for conducting efficient chemical stabilization design for problematic soils with and without soluble sulfates within the state of Montana. A major portion of chemical stabilization protocols involves the selection of type and amount of the additives. The proper selection of type and concentration of additive for a given soil should consider, the complex interactions between the mineralogy of the materials and additives, the presence or absence of moisture, and the method of construction and curing. Keeping this in mind several tasks were undertaken to meet the project goal. The study focused on lime and cement as additives and six different soils with varying geology were selected from different parts of Montana. This report contains the step-by-step procedures to be followed for additive selection criteria (lime or cement) and determination of the additive content depending on the type of additive (lime or cement).

17. Key Words
Problematic soils, soil stabilization, soil tests, sandy soils, clay soils, soil types, limestone soils, soil remediation, additives, calcium oxide, fly ash, soil samplers, mix design, cement, accelerating agent, curing and setting agents, freeze thaw durability, durability tests, wetting and drying tests, life cycle analysis

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GENERAL

MDT Engineers often face problems with constructing pavements on soils with poor strength to support wheel loads from either construction activities or during the service life. As a result, it is necessary to strengthen these soils to offer a stable subgrade or a working platform for construction activities. This strengthening can be in the form of chemical processes such as mixing with cement and lime. Soil properties such as strength, compressibility, hydraulic conductivity, workability, swelling potential, and volume change tendencies may be altered by these processes. The alteration of soil properties by mixing with chemicals such as lime and cement or a combination of these often modifies the physio-chemical behavior of the soil via various chemical reactions that lead to the cementation of the soil particles. The following sections discuss the design procedures for altering soil behavior using lime and cement as additives.

ADDITIVE SELECTION CRITERIA

The following chart is recommended to determine the type of chemical additive for preliminary design of chemical stabilization for Montana soils. The information from the chart applies to most, but not all cases, and validation testing must be performed to verify whether the selected additive accomplishes the goals and requirements for the treated soil. To determine the optimal additive content the following set of steps are recommended in case of lime and cement stabilization.

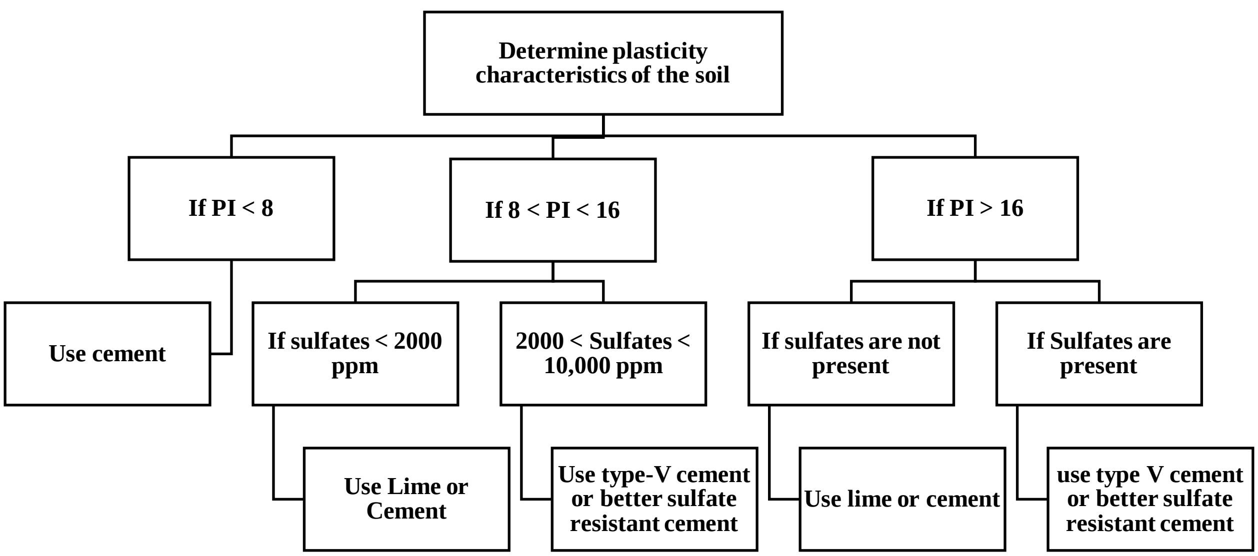

Figure 1 Flowchart to select optimal additive type for chemical stabilization in Montana

STRENGTH REQUIREMENTS

It is recommended that a target unconfined compressive strength of 50 psi should be achieved after treatments regardless of the application of stabilization (stable ground for pavement or working platform for construction activities). To determine the soil strength, 2.8 in. (71.1 mm) diameter by 5.6 in. (142.2 mm) height soil sample should be prepared by mixing the appropriate additive content and compacted at the optimum moisture content and maximum dry density (AASHTO T 99).

SELECTION OF LIME CONTENT

The following steps must be followed to determine the optimum amount of lime content for a given soil.

- **Step 1: Verify that the sulfate and organic contents are within acceptable limits.** Measure the sulfate and organics content prior to addition of additive. Sulfates should be less than 2000 ppm (if the PI of the soil is less than 16) and organics should be less than 1%. If the sulfates are more than 2000 ppm, do not use lime as additive. If organics are more than 1%, be cognizant that the soil may require higher dosages to counter the effect of cation exchange capacity.
    1) *Soil sampling for this testing should be as per MT 201*
    2) *Determine plasticity characteristics as per AASHTO T 89 and T 90*
    3) *Soluble sulfates can be determined using MT 532 or AASHTO T 290*
    4) *Organic content of the soil can be determine using AASHTO T267*
- **Step 2: pH test.** The initial optimum lime content is established using a procedure developed by Eades and Grim (1966) which targets a pH of 12.4 or higher. The following steps should be followed:
    1) *10 g of air-dried representative soil sample passing No. 40 sieve is weighed to the nearest 0.1 g and poured into 100-ml (or larger) plastic bottles with caps.*
    2) *Weigh the lime required (as a percentage of dry soil) to the nearest 0.01 g and add it to the soil. Typically starts at 1%. Mix the soil and dry lime thoroughly by shaking the bottle.*
    3) *Add 50 ml of deionized water to the bottle.*
    4) *Shake the soil-lime-water mixture for about 30 seconds to ensure that no dry material is sticking at the bottom of the bottle. Shake the bottles for 30 seconds every 10 minutes.*
    5) *After one hour, measure the pH of the mix by transferring a portion of the slurry to a smaller container. Use a pH meter that is calibrated to a pH of 12.00 using the corresponding buffer.*
    6) *Record the pH for the lime-soil mixture.*
    7) *Repeat this for different lime-soil mixtures with varying lime percentage (1%, 2%, 3%, etc.…). If the pH readings go to 12.40, then the lowest percent lime that gives a pH of 12.40 is the initial optimum lime content.*
- **Step 3: Moisture Density curve.** Establish the moisture density curve using the lime content established in Step 2. This will be used to prepare soil samples for unconfined compressive strength (UCS) testing.
    1) *Moisture-density curve will be developed using AASHTO T99 procedure.*
- **Step 4: Plasticity Index.** Conduct Atterberg limits tests to evaluate shrink/swell characteristics of treated soil. Most soils turn non-plastic at optimum lime content.

1) *Determine plasticity characteristics as per AASHTO T 89 and T 90*

- **Step 5: Strength Testing.** Conduct UCS test at optimum moisture content and maximum dry unit weight established in Step 3. Verify if the strength meets the governing specification (Target strength requirement).
    1) *UCS test will be conducted as per AASTHO T 208*
    2) ***Curing Protocol**: The prepared samples for UCS test should be cured for two days using the following procedure*:
        1) *Wrap the prepared samples inside a household shrink wrap to ensure no loss in moisture during the curing process. Use duct tape to seal the edges of the sample.*
        2) *Place this sample inside a glass jar that has an arrangement to hold water at the bottom of the jar. This water should not come in direct contact of the shrink-wrapped sample.*

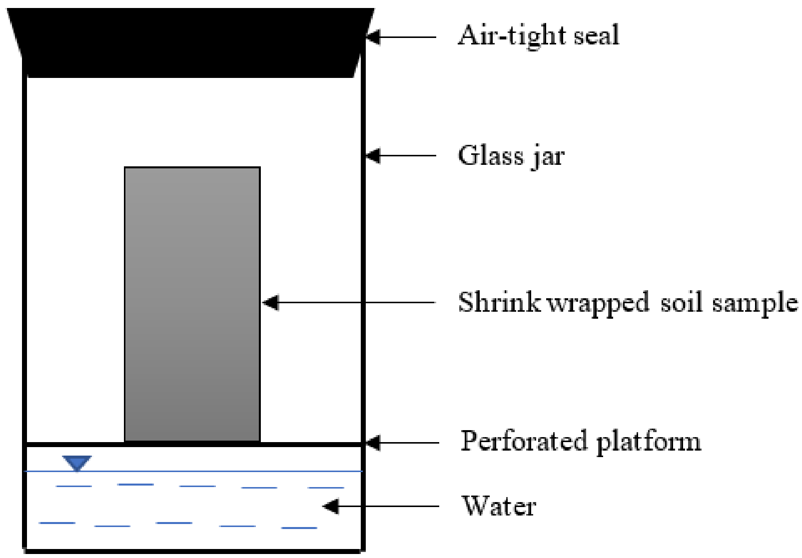

Figure 2 Schematic of sample setup for HCAC

        3) *Place the glass jar with the soil sample inside an oven maintained at 150°F (65.5°C).*
        4) *Let the sample cure for two days.*
        5) *At the end of two days, remove the sample from the jar and the undo the shrink-wrap.*
        6) *Test the sample for UCS as per AASHTO T 208*

- **Step 6: Durability Testing.** Perform durability tests if stabilization is targeting long-term performance. This step can be ignored if the stabilization is used mainly to create a working platform for construction equipment. To address the durability of chemical treated soils, a series of specimens should be subjected to various cycles of Freezing and Thawing processes as per ASTM D560.

- **Step 7: Life Cycle Cost Analysis (LCCA).** The procedures suggested in the Interim Technical Bulletin published by FHWA (1998) titled "Life-Cycle Cost Analysis in Pavement Design" can be followed for this step. The general procedural steps involved in conducting a life cycle cost analysis include the following:
    1) ***Establish alternative pavement design strategies for the analysis period.*** *A Pavement Design Strategy is the combination of initial pavement design and necessary supporting maintenance and rehabilitation activities. Analysis Period is the time horizon over which future cost are evaluated (generally 40 years).*
    2) ***Determine performance periods and activity timing.*** *Use experience and historical data on pavement performance to determine the frequency and timing of future maintenance and repair activities on the pavement.*
    3) ***Estimate agency costs.*** *Determine the quantities and unit prices of items to calculate construction, maintenance and rehabilitation costs that are mutually exclusive to the alternatives being evaluated. Agency costs can also include maintenance of traffic cost or operating cost such as pump station energy costs, tunnel lighting, and ventilation. At times, the salvage value, the remaining value of the investment at the end of the analysis period, can also be included as a negative cost.*
    4) ***Estimate user costs.*** *Determine the cost per unit time and the total costs accrued by vehicle users during the construction, maintenance and/or rehabilitation and everyday use of a roadway section.*
    5) ***Develop expenditure stream diagrams****. Develop graphical representations of expenditures over time for each pavement design strategy to help visualize the extent and timing of expenditures.*
    6) ***Compute net present value****. Select an appropriate discount rate to discount the cost of future activities to a base year and compute the net present value of an alternative.*
    7) ***Analyze results****. Compute net present value of each alternative strategy at various possible discount rates to analyze the sensitivity of change in results. Analyze the best case/ worst case scenario and analyze outcomes for all alternatives.*
    8) ***Reevaluate design strategies****. Once the analysis is complete and net present values computed for all strategies, use the results to reevaluate the design strategies. Modify the proposed alternatives to develop more cost-effective strategies and select the best possible alternative.*
- **Step 8: Select the optimal content.** Select the lowest modifier content necessary to satisfy the project requirements.

SELECTION OF CEMENT CONTENT

The following steps must be followed to determine the optimum amount of cement content for a given soil.

- **Step 1: Verify that the sulfate and organic contents are within acceptable limits.** Measure the sulfate and organics content prior to addition of additive. Sulfates should be less than 2000 ppm (if the PI of the soil is less than 16) and organics should be less than 1%. If the sulfates are more than 2000 ppm, do not use lime as additive. If organics are more than 1%, be cognizant that the soil may require higher dosages to counter the effect of cation exchange capacity.
    1) *Soil sampling for this testing should be as per MT 201*
    2) *Determine plasticity characteristics as per AASHTO T 89 and T 90*
    3) *Soluble sulfates can be determined using MT 532 or AASHTO T 290*
    4) *Organic content of the soil can be determine using AASHTO T267*
- **Step 2: Moisture Density curve.** Establish the moisture density curve using an initial cement content of 5%. This will be used to prepare soil samples for UCS testing.
    1) *Moisture-density curve will be developed using AASHTO T99 procedure.*
- **Step 3: Strength Testing.** Conduct UCS test at optimum moisture content and maximum dry unit weight established in Step 2. Verify if the strength meets the governing specification (Target strength requirement).
    1) *UCS test will be conducted as per AASTHO T 208*
    2) ***Curing Protocol**: Follow the same curing protocol as explained in the determination of lime content.*
- **Step 4: Durability Testing.** Perform durability tests if stabilization is targeting long-term performance. This step can be ignored if the stabilization is used mainly to create a working platform for construction equipment. To address the durability of chemical treated soils, a series of specimens should be subjected to various cycles of Freezing and Thawing processes as per ASTM D560.
- **Step 5: Life Cycle Cost Analysis (LCCA).** The general procedural steps involved in conducting a life cycle cost analysis are similar to the ones shown for lime content determination, please follow the same procedure.
- **Step 6: Select the optimal content.** Select the lowest modifier content necessary to satisfy the project requirements.

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