TN TDOT Department of Transportation

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Chemical Subgrade Stabilization of Tennessee Soils – Recommended Practices

Final Report

Research Final Report from Tennessee Technological University | Daniel R. VandenBerge, Benjamin J. Mohr, Shushanta Chakraborty, and Henry Asamany | July 15, 2024

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Tennessee TECH

Appendix A Summary of DOT Chemical Treatment Practices

This appendix describes the specifications and design approaches used by USDOT, FHWA, and state DOTs for chemical subgrade treatment. The purpose of this section is to provide an overview of the current practice in the United States and to summarize best practice for the implementation of chemical subgrade treatment into state and federal roadways. Mix design procedures are also summarized in this chapter.

Chemical subgrade treatment practices were reviewed in the publications of 31 state DOTs. The states were selected based on proximity to Tennessee, similarity of geologic conditions, and/or reputation for publication of extensive geotechnical procedures (e.g., California and Texas). In addition, the existence of general-purpose geotechnical design manuals was also noted for each state reviewed. These documents are summarized in Table A-1. Each state DOTs uses its own system to organize its publications, and some of these systems were difficult to obtain information from or were password protected. For this reason, it is possible that some documents exist that were not discovered by this review.

Eighteen (58%) of the states reviewed had a standard specification for some form of chemical subgrade treatment. USDOT (2003) also contains this type of specification. These specifications will be compiled during a later stage of this research project as models for the revision of Tennessee's chemical subgrade treatment specification. A standard practice for subgrade treatment was submitted to AASHTO in 2008 but does not appear to have been adopted (NCHRP 2009).

With respect to design guidance, 11 of 31 DOTs did not have geotechnical guidance available for chemical subgrade treatment, or their geotechnical guidance did not mention chemical subgrade treatment. Nine of the 31 states mentioned chemical subgrade treatment in their geotechnical manuals but didn't provide significant design guidance. The most comprehensive guidance for chemical subgrade treatment was found in the publications of California, Illinois, Indiana, Iowa, Kentucky, Minnesota, Mississippi, North Carolina, Ohio, and Texas.

Detailed description of the mix design approaches of four states is provided in the following sections.

A.1 Illinois DOT Mix Design Approach

Illinois DOT (IDOT 2020) describes procedures for both modification and stabilization. The modification procedure applies to all types of admixtures, while their stabilization procedures differ depending on the type of admixture.

The IDOT procedure for modification compares untreated soil to soil treated with cement (2% to 5%), lime (2% to 6%), or fly ash (5% to 20%). Trial admixture percentages are added to the soil and allowed to mellow, in the case of lime. The standard Proctor test is performed on both untreated and treated soils.

The dynamic cone penetrometer (DCP) test is performed on the compacted specimens, and the effects of treatment on the DCP results are used to select an appropriate admixture percentage for modification. The treated and untreated soil may also be tested to measure the change in CBR caused by chemical subgrade treatment.

Table A-1 State Documentation for Chemical Subgrade Treatment and Geotechnical Design

State	Chemical Treatment Specification?	Geotechnical Manual (GM) or Other Design Guidance for Chemical Subgrade Treatment (CST)
Alabama	Y (2022)	GM (2021) mentions CST but no provides guidance
Arkansas	N	None found
California	Y (2018)	Web-based (GM), separate subgrade stability manual (2010)
Colorado	Y (2019)	GM (2021) mentions CST but no provides guidance
Connecticut	N (2020)	GM (2005) mentions CST but no provides guidance
Delaware	N	None found
Florida	N (2022)	None found
Georgia	N	Web-based, no mention of CST found
Illinois	Y (2022)	GM (2020) provides mix design guidance; additional subgrade stability manual (2005)
Indiana	Y (2022)	Web-based GM; separate CST manual (2022)
Iowa	Y (2021)	Design manual contains some CST guidance
Kansas	Y (2007)	GM has restricted access
Kentucky	Y (2019)	GM (2005) briefly discusses CST with additional guidelines provided in a pavement manual (2018)
Louisiana	Y (2014)	None found
Maryland	N	GM (2021) provides basic guidelines for CST
Michigan	N	GM (2019) states that CST requires a special provision
Minnesota	N	GM (2021) does not discuss CST; separate report on CST (LRRB 2017)
Mississippi	Y (2017)	GM not available; research study of design and construction of CST (FHWA/MS-DOT-RD-13-206 2013)
Nebraska	N	None found
New Jersey	N	None found
New York	Y (2023)	Web-based GM, no mention of CST found
North Carolina	Y (2018)	GM (2021) mentions CST but no provides guidance; separate CST field manual (2019)
Ohio	Y (2023)	GM (2022) focuses on application and construction of CST
Oklahoma	Y (2019)	GM (2021) mentions CST but no provides guidance
Pennsylvania	N	GM (2020) mentions CST but no provides guidance

South Carolina	Y (2015)	GM (2022) does not mention CST
Tennessee	Y (2021)	GM (2020) mentions CST but no provides guidance
Texas	Y (2014)	GM (2020) does not mention CST; web-based pavement manual (2021) provides general guidance; an additional manual (TxDOT 2005) provides CST design guidance
Virginia	Y (2020)	GM (2022) contains limited guidance on CST; VTRC (2019) report on stabilization of unpaved roads
West Virginia	N	Web-based GM, no mention of CST
Wisconsin	N	Web-based GM, no mention of CST

The IDOT mix design procedure for stabilization is illustrated in Figure A-1 for both lime and cement. In addition to a variety of tests on the untreated soil, the lime stabilization mix design measures the standard Proctor for 5% lime. The optimum moisture content and maximum dry unit weight are adjusted up or down empirically for other lime percentages. For multiple lime percentages, unconfined compressive strength testing is completed on specimens compacted to a specified relative compaction at optimum moisture content. The required relative compaction depends on the application. The minimum lime content is the value that generates a 50-psi strength gain and a minimum strength of 100 psi. An additional 1% of lime is added to account for construction loss.

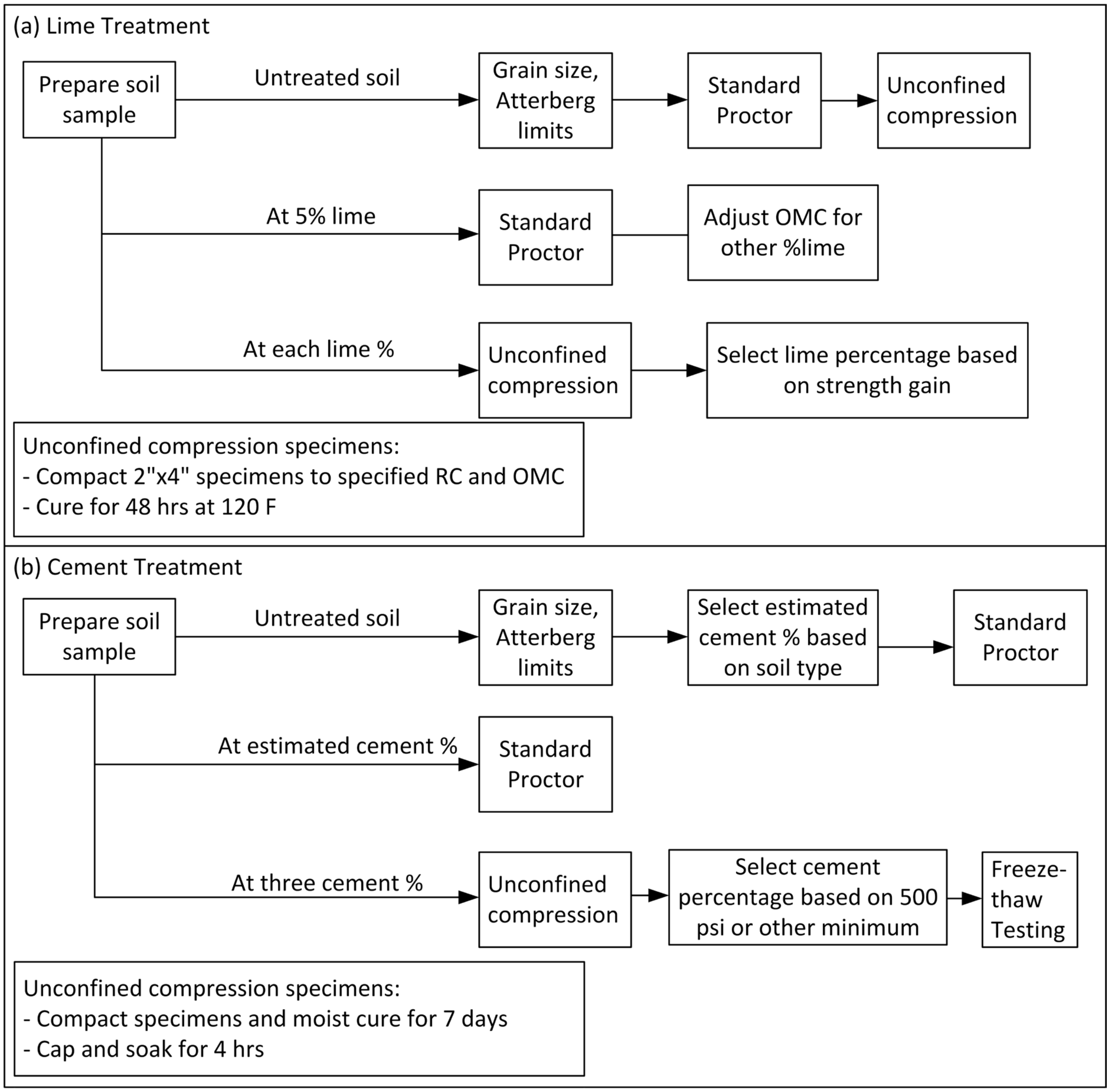

Figure A-1 IDOT mix design procedure for (a) lime and (b) cement (IDOT 2020)

For cement, the initial estimate of the cement percentage is based on AASHTO soil classification. The standard Proctor test is completed at this cement percentage to estimate the compaction conditions for all the soil-cement specimens. Duplicate unconfined compressive strength specimens are compacted using standard Proctor energy at the estimated cement percentage as well as cement contents 2% above and below this estimate. After a seven-day cure period, the lowest cement percentage resulting in an unconfined compressive strength (UCS) of 500 psi is selected for wet/dry (AASHTO T135) and freeze/thaw (AASHTO T136) testing. Specimens are compacted at the selected cement content as well as 2% and 4% higher. Maximum allowable losses from the wet/dry and freeze/thaw testing between 7% and 14% are specified by soil classification.

A.2 Indiana DOT Mix Design Approach

Indiana DOT (INDOT 2022) also distinguishes between modification and stabilization using lower strength gain requirements for modification. Lime and cement are recommended for either objective. Fly ash is used only for modification by INDOT.

As shown in Figure A-2, classification tests are performed on the untreated soil along with screening tests for sulfate and organic content. The standard Proctor is performed to determine compaction conditions for the unconfined compression specimens. Two unconfined compression tests are performed on specimens compacted to 95% of the standard Proctor maximum dry unit weight and the optimum moisture content.

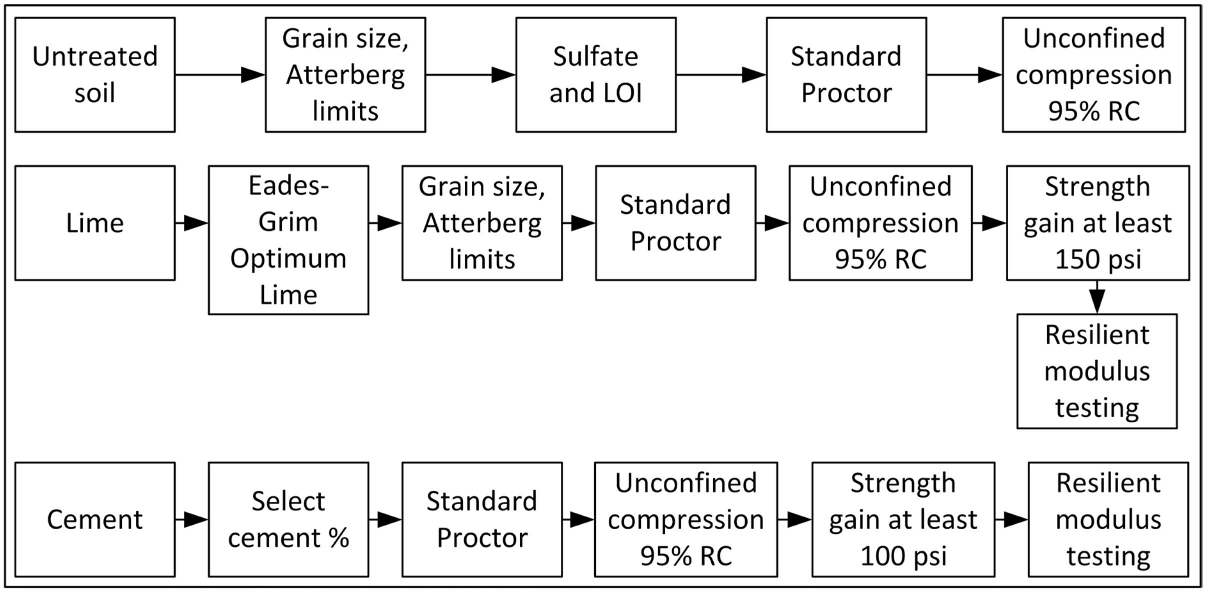

Figure A-2 Indiana DOT mix design procedures for chemical stabilization (INDOT 2022)

Mix designs for lime start with the Eades-Grim pH test to determine the minimum lime percentage[1] (MLP) that produces a pH of 12.4. A treated soil sample is prepared at the MLP, and classification tests and standard Proctor are completed. Unconfined compressive strength specimens (3-inch by 6-inch) are compacted at 95% relative compaction and optimum moisture content and tested after curing for 48 hrs at 70° F. A strength gain of 150 psi over the untreated soil is required, or the lime percentage must be increased, and the testing repeated.

The procedure for cement begins by selecting a trial cement percentage, typically 5%. The standard Proctor test is completed, and two strength specimens are (3-inch by 6-inch) are compacted at 95% relative compaction and optimum moisture content. The specimens are cured for seven days and then tested for unconfined compressive strength. A strength gain of 150 psi over the untreated soil is required, or the cement percentage must be increased, and the testing repeated.

[1] INDOT refers to this as the optimum lime content, which differs from other sources. The term minimum lime percentage is used in this document to indicate the percentage at which the pH reaches 12.4.

In order to incorporate the properties of the stabilized subgrade in pavement design, INDOT (2022) requires resilient modulus testing. This testing is performed on specimens compacted to 95% relative compaction and optimum moisture content, based on the standard Proctor test performed on the treated soil. The resilient modulus tests are performed by the INDOT geotechnical laboratory on specimens prepared by the consultant or contractor.

A.3 Ohio DOT Mix Design Approach

Ohio DOT has a supplemental specification for the mix design of chemically stabilized soils (ODOT 2011). The procedure can be completed for one admixture using a single 75-lb sample. This allows the procedure to consider multiple samples in a given design. The recommended sampling frequency is one sample per 5000 S.Y. of subgrade.

The untreated sample is visually evaluated for gypsum crystals (sulfate) and tested for classification, organic content by loss on ignition (LOI), and sulfate content as indicated in Figure A-3. The one-point standard Proctor method (AASHTO T 272) is used to approximate the optimum moisture content and maximum dry unit weight. Three strength test specimens are compacted at the optimum moisture content using standard Proctor energy. The untreated specimens are tested in unconfined compression within 24 hrs of compaction.

The ODOT (2011) procedure follows a consistent set of steps regardless of the admixture with the exception that the minimum lime percentage must be first determined using the Eades-Grim pH test for lime. The trial percentages for lime are based on the MLP. For cement and lime kiln dust, ODOT (2011) specifies the trial percentages based on regional experience.

Once the admixture and three trial percentages have been selected, three treated mixes are prepared, and a one-point Proctor test is performed on each to approximate the optimum moisture content for each treated mix. Triplicate strength test specimens are compacted using standard Proctor energy. For cement, the optimum moisture content of each treated mix is used. For lime, the moisture contents are adjusted up by 2%. For lime kiln dust, the moisture content is increased by 1%.

The strength test specimens are wrapped in plastic, sealed in bags, and allowed to cure for seven days. The curing temperature is 104° F for lime and 70° F for cement and lime kiln dust.

After curing, the treated strength specimens are removed from the plastic and measured. The specimens are then wrapped in damp fabric and placed on porous stones resting in a pan of water. The fabric and stones contact the water, but the specimens do not. The specimens are soaked in this manner for 24 hrs., after which they are remeasured for expansion. If the volume change exceeds 1.5%, further testing for expansion is recommended. This soaking procedure is also recommended by NCHRP (2009).

The unconfined compressive strength of the test specimens is measured after the moisture conditioning or capillary soak. The unconfined compressive strengths are plotted against the admixture percentage, including the average trend and the untreated value at 0% admixture.

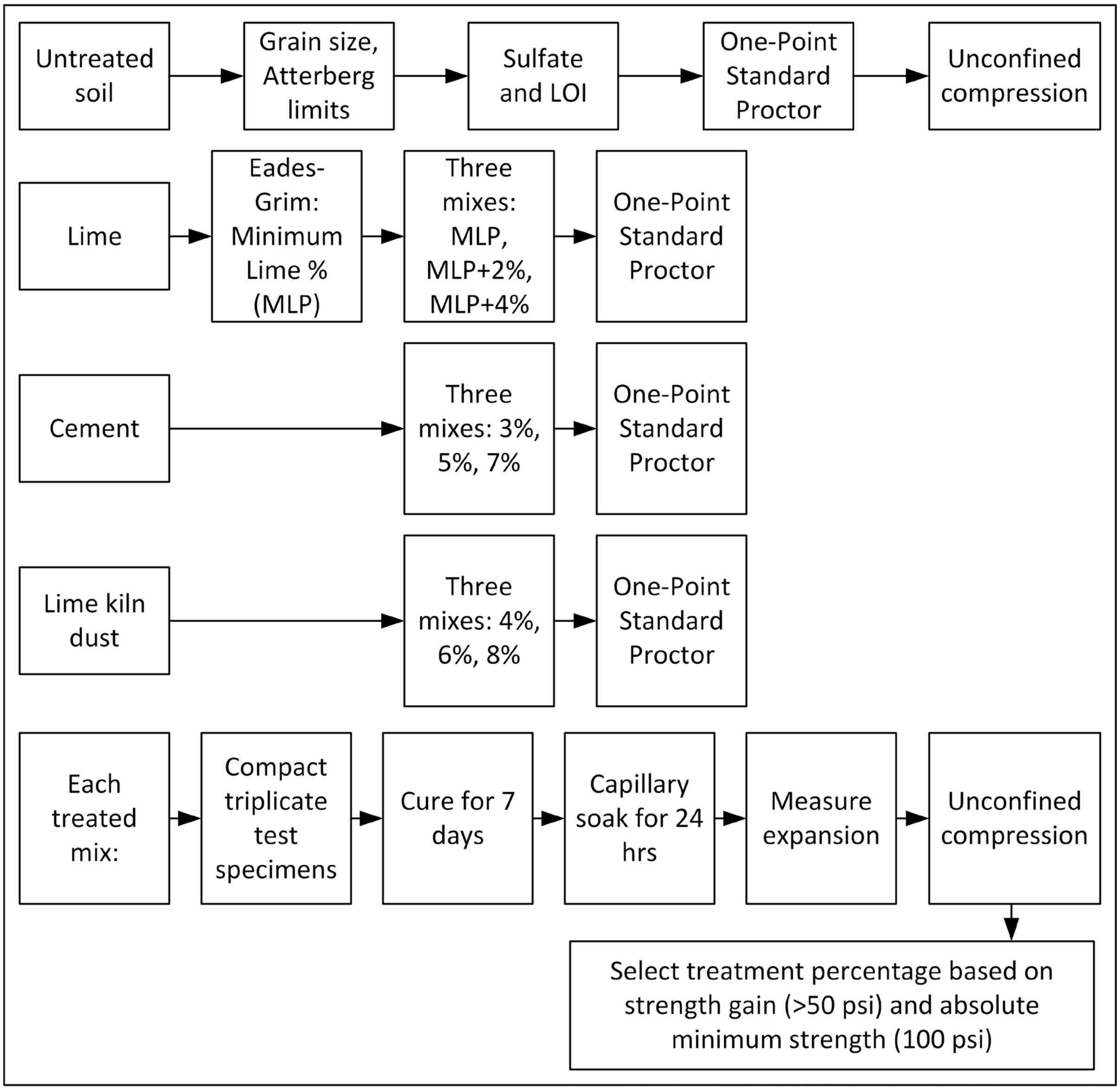

Figure A-3 Ohio DOT mix design procedures for chemical stabilization (ODOT 2011)

The minimum percentage of chemical that produces a UCS of 100 psi and a strength gain of at least 50 psi is selected from the trend. This value is rounded up to the nearest 0.5%, and an extra 0.5% is added for field losses.

For quality assurance, ODOT (2011) recommends obtaining samples of the mixed subgrade soil during construction for every 40,000 S.Y. of subgrade. From the sample, three specimens should be compacted at the in-place moisture content. The specimens are cured, soaked, and tests for expansion and unconfined compressive strength as described above.

A.4 Texas DOT Mix Design Approach

Texas DOT (TXDOT 2019) provides mix design steps in a less prescriptive manner. This approach allows for more flexibility in design but potentially less consistency.

The admixture percentage for stabilization mix designs is selected based on unconfined compressive strength.

TXDOT (2019) provides helpful guidance for dealing with sulfates. Thresholds are designated at sulfate contents of 3000 ppm and 7000 ppm. In Texas, sulfate contents below 3000 ppm have not been found problematic and can be treated with all types of stabilizer. For sulfate contents between 3000 and 7000 ppm, only lime should be used. The soil should be mixed with the minimum lime percentage and allowed to mellow for at least seven days. The mellowing process continues until the sulfate content falls below 3000 ppm, at which point the mix design can proceed and compressive strength is used to verify that the mix meets the project criteria. Soils with sulfate contents greater than 7000 ppm should be removed and replaced according to TXDOT (2019).

TXDOT (2019) recommends using the Eades-Grim pH test to determine if stabilization is possible in soils with organic content greater than 1%. If a pH of 12.4 can be achieved, the mix design can proceed using the minimum lime percentage. Both strength and pH requirements are used to assess the mix design. Where modification is the goal, no special testing is required for organic soils.