Foundation Subtask Group

WORK PRODUCT
DRAFT REPORT

Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization

Authors

Deepak Maskey, Caltrans Chair
Jordan Roper, Industry Lead
Raghubar Shrestha, Joshua Moore, Samir Ead,
Don Grebs, Narain Hariharan, and Rob Lawrence

February 2022

Table of Contents

List of Tables

Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization

Introduction

Caltrans has successfully utilized lime to stabilize clayey subgrade to enhance load carrying capacity as well as to mitigate volume changes due to the changes in moisture content. The lime stabilized subgrade is stable and has been incorporated in pavement structural section for asphalt concrete pavements and stable construction platform for pavements construction. Currently, standard specifications section 24-2 Lime Stabilized Soils is used to control lime stabilized subgrade construction. Section 24-2 specifies use of CT 373 test method to determine the application rate of lime for the design unconfined compressive strength (UCS) for stabilized clayey subgrade.

Caltrans used to practice asphalt concrete mix design using test specimen fabricated with kneading compactor for the conventional asphalt concrete pavement design. Later, Caltrans adopted Mechanistic Empirical pavement design and consequently replaced the use of kneading compactor with gyratory compactor for the fabrication of test specimen which reduced the use and availability of kneading compactor and skilled laboratory technicians required to operate the equipment. The reduced availability of kneading compactor and skilled laboratory technicians created difficulty to perform CT 373 utilizing kneading compactor for the fabrication of test specimen to determine application rate of lime for lime stabilized soil.

Caltrans has successfully utilized the ASTM test method for the determination of cement application rate for the cement stabilized soils and a similar national test method could be utilized in lieu of CT 373 for the determination of lime application rate for the lime stabilized soils. The procedure for using ASTM test method is relatively simple, and economical with a reduced turnaround time for test results. In addition, the existing CT 373 could be modified replacing kneading compactor with simple compaction method for the fabrication of laboratory test specimen. The modified CT 373 will make testing economical, faster, and allow contractors to change the lime application rate for the varying subgrade types encountered during the construction.

The focus of this report is to determine the application rate of lime for lime stabilized soils using different test methods or modify existing CT 373. The authorized scope of work consists following milestones:

1. Review CT 373, ASTM and AASHTO test methods
2. Review other State DOT Specifications
3. Draft Specification languages
4. Prepare final edited draft Specification

The Pavement and Materials Partnering Committee (PMPC) approved the work product scoping document is presented in Appendix 1.

Methodology

1. Review existing CT 373 test method and available ASTM, and AASHTO test methods pertaining to the fabrication, handling, curing, and strength testing of lime stabilized soil test specimens.
2. Review other State DOT Specifications pertaining to the determination of lime application for lime stabilized soils.
3. Review federal Aviation Administration (FAA), Naval Facility (NAVFAC) and Federal Highway Administration (FHWA) Specifications pertaining to the determination of lime application rate for lime stabilized soils.
4. Develop a document summarizing the analysis of the State DOT specifications review with the objective of finding an alternative national test method to determine lime application rate for lime stabilized soils.
5. Develop specification languages for Caltrans Specifications, Section 24-2, "Lime Stabilized Soil".

Summary and Analysis of DOT Specifications

The Work Product Group (WPG) reviewed specifications for lime and cement stabilized soils from State DOTs, FAA, NAVFAC and FHWA, and pertaining study reports from Caltrans, University of California Pavement Research Center (UCPRC), National Cooperative Highway Research Program (NCHRP), FHWA, and DOTs. In addition, CT, ASTM, and AASHTO test methods were reviewed to find out the most effective test methods to determine lime application rate for the lime stabilized soils.

Out of 50 States, specifications from three States DOTs Louisiana, Minnesota and Texas were selected as they commonly practice lime stabilized soils in pavements. National standards ASTM and AASHTO, and CT test methods were reviewed focusing on the key factors affecting application rate of lime and corresponding unconfined compressive strength. All available test methods were reviewed for laboratory test procedures including materials handling, compaction method to fabricate test sample, curing, and strength testing. The significant soil parameters affecting strength of stabilized soils used in DOTs specifications were identified and summarized in the State DOTs summary sheet in Appendix 2.

The soil characteristics affecting performance of lime and cement stabilized soils from FAA, FHWA, (NAVFAC) and non-State DOTs are identified and summarized in Appendix 3.

In addition to the lime application rate, a minimum unconfined compressive strength (UCS) of lime stabilized soils was also reviewed pertaining to the performance of lime stabilized soils in pavements and agreed to keep a minimum UCS unchanged.

The available test methods for lime stabilized soils (LSS) and cement stabilized soils (CSS) were also reviewed pertaining to the materials handling, test specimen fabrication, and curing, a comparative summary is presented in table -1:

Table-1
A Comparative summary of LSS and CSS

Soil	Test Method	Specimen Size	Compaction method	Curing	Remarks
LSS	CT 373	4" X 4"	Kneading Compactor at 250 psi ± 25 & 300 psi with 100 Strokes	Mellowing 70°F ± 5°F for 16 to 24 hrs and 110±5°F for 7 days (equivalent to 28 days)	Caltrans current method
	ASTM D 5102	**Method A:** H/D = 2.0 to 2.5 (the standard measure of compressive strength) and Mold with inside diameter of 2" min.	D698 (Std Proctor) of 12,400 ft-lbf/ft^3		Currently this test method is withdrawn by ASTM
		Method B: 4.6" x 4" (H/D =1.15)		12 hrs or more in moist room before removal from mold but not specific time mentioned in the method	
CSS	ASTM D 1633-17	**Method A:** 4.6" x 4" (H/D =1.15)	D1557 (Modified Proctor)	12 hrs or more in moist room before removal from mold. Sealed in plastic and cured at 100±5°F for 7 days.	Caltrans current method
		Method B: 5.6" x 2.8" (H/D=2.0)			This method measures 15% less than Method A

Notes:

ASTM D698: This test method covers laboratory compaction methods used to determine the relationship between molding water content and dry unit weight of soils (compaction curve) compacted in a 4 or 6-in diameter mold with a 5.50-lbf rammer dropped from a height of 12.0 in producing a compaction effort of 12,400 ft-lbf/ft3.

ASTM D1557: This test method covers laboratory compaction methods used to determine the relationship between molding water content and dry unit weight of soils (compaction curve) compacted in a 4- or 6-in diameter mold with a 10.00-lbf rammer dropped from a height of 18.00 in producing a compaction effort of 56,000 ft-lbf/ft3.

Discussions and Decisions

The specifications from selected 3 DOTS, FHWA, FAA, and NAVFAC were reviewed in detail pertaining to the laboratory test methods used to determine the application rate of lime for lime stabilized soils and found majority of the specifications uses Atterberg's limits, moisture density relationship, and specified pH value testing under ASTM D6276 or AASHTO M216. These general practices of testing are for index value testing but not the strength of lime stabilized soils. FHWA recommends using ASTM D5102 which utilizes ASTM D 698 for the fabrication of test specimen to determine the unconfined compressive strength. Texas DOT uses their own test method Tex-117 to determine the compressive strength of laboratory test specimen fabricated using 10 pounds hammer dropping 18 inches in 4 layers.

Earlier, Team decided to use FHWA recommended ASTM D 5102 for lime application rate in lieu of CT 373 with compaction modification to use ASTM D1557 replacing ASTM D 698 for fabrication of test specimen. The lime application rate under ASTM D 5102 is based on the unconfined compressive strength of lime stabilized soils, a similar approach Caltrans has been practicing using CT 373. Later Team found ASTM D 5102 is withdrawn by ASTM and Caltrans METS suggested not to use withdrawn test method as there will be no support for certification and independent assurance (IA). Team considered to use ASTM D5102 indirectly by either incorporating test procedure language in specification or change CT test method 373 with language from ASTM D 5102 but later dropped this idea as it is not straight forward and could take substantial amount of time.

Alternatively, Team reviewed existing CT 373 and found easier to use with modification of compaction method for fabrication of test specimen. Two options of compaction methods were reviewed, either use ASTM D 698 where 5 ponds hammer is used for compaction or ASTM D 1557 where 10 pounds hammer is used. Using ASTM D 698 will provide relatively more moisture which will be available for curing of lime. However, ASTM D1557 will provide denser specimen with relatively less moisture but available moisture at optimum+3% moisture content (OMC) will be enough for curing for lime. The ASTM D1557 method is also used for compaction of cement stabilized soils test specimen for the determination of application rate of cement. In addition, similar 10 pound of hammer is used for compaction of test specimen during the onsite relative density testing under CT 126. Industry wide survey was carried out for the application of ASTM D698 and ASTM D

1557, and found ASTM D1557 is commonly used on non-Caltrans projects and testing is widely available and economical.

Keeping mold size of test specimen 4 in diameter will allow to use same equation used in CT 373 for calculating unconfined compressive strength of lime stabilized soil:

5. Determine the height and weight of the compacted test specimen and calculate the dry density using the formula:

$$D_d = \frac{30.3W_w}{(100+M)H}$$

Where:
D_d = Dry density in lb/ft^3
W_w = Wet weight of compacted test specimen (g)
M = Percent total moisture in test specimen
H = Height of test specimen to nearest 0.001 in.

Based on the availability and easy to use, consensus among members reached to use ASTM D1557 for the fabrication of test specimen for UCS testing and use curing procedure as defined for curing of test specimen for cement stabilized soil.

Recommendations

Team members recommended to use existing CT 373 with modification of compaction and curing procedure:

- Use ASTM D1557 compaction method using 4" mold
- Cure test specimen similar to cement stabilized soil specified in Standard Specifications section 24-3:

  Test specimens must be cured by sealing each specimen with 2 layers of plastic at least 4 mil thick. The plastic must be tight around the specimen. Seal all seams with duct tape to prevent moisture loss. Sealed specimens must be placed in an oven for 7 days at 110 ± 5 degree F. At the end of the curing period, specimens must be removed from the oven and air-cooled. Duct tape and plastic wrap must be removed before capping. Specimens must not be soaked before testing.

- Supersede CT 373 section "F. Compacting Test Specimens" with ASTM D1557 compaction method using 4" mold which will allow to use same equation in section "G. 5" for the determination of dry density:

The following specification language is recommended to use for Section 24-2.01D(1)(b):

24-2.01D(1)(b) Applying Lime

The Engineer determines the final application rate for each lime product proposed from the samples submitted based on California Test 373 except:

1. Test specimen must be compacted under ASTM D 1557 using 4 in mold.
2. Test specimens must be cured by sealing each specimen with 2 layers of plastic at least 4 mil thick. The plastic must be tight around the specimen. Seal all seams with duct tape to prevent moisture loss. Sealed specimens must be placed in an oven for 7 days at 110 ± 5 degree F. At the end of the curing period, specimens must be removed from the oven and air-cooled. Duct tape and plastic wrap must be removed before capping. Specimens must not be soaked before testing.

Wherever the basement material to be stabilized changes, the Engineer changes the application rate. The Engineer provides the optimum moisture content determined under ASTM D 1557 for each application rate.

Whenever lime in slurry form is used, report the quantity of slurry placed by measuring the volume of slurry in the holding tank once per 40,000 sq ft stabilized, or twice per day, whichever is greater.

The Engineer verifies the application rate of lime used in dry form with a calibrated tray, or equal, once per 40,000 sq ft of stabilized soil, or twice per day, whichever is greater.

A complete edited specification Section 24-2 Lime Stabilized Soil is presented in Appendix-4.

References

- Caltrans, "Standard Specifications," 2018
- ASTM D1557, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))"
- AASHTO M 216, "Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization," 2017
- CTM 373, "Method of Test for Unconfined Compressive Strength of Lime Treated Soils and Aggregates"
- Louisiana DOT, "Standard Specifications for Roads and Bridges," 2016
- Louisiana DOTD TR 416, "Determination of the Percentage of Lime for Treatment of Soils or Soil-Aggregate Mixtures," 2019
- Minnesota DOT, "Standard Specifications for Construction," 2020
- Texas DOT, "Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges," 2014
- Texas DOT-121-E, "Test Procedure for Soil-Lime Testing," 2002

Appendices

- Appendix 1: PMPC Approved Work Product Scoping Document on 04/30/21
- Appendix 2: Review other State DOTs Summary Sheet
- Appendix 3: Review FAA, FHWA, NAVFAC Summary Sheet
- Appendix 4: Draft specification Section 24-2 Lime Stabilized Soil

Pavement & Materials Partnering Committee
Work Product Scoping Document
New
Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization
April 2, 2021

Task Group

Concrete Task Group

Problem Process

☒ Annual

☐ Expedited

☐ Emerging Initiative

Title

Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization

Statement of Effort/Improvement

Caltrans standard practice to determine the application rate of lime for lime stabilized soils is currently determined using CT 373 test method, which utilizes a kneading compactor for the fabrication of test specimens. The availability of kneading compactors and skilled testers is vanishing as the kneading compactor is not being used in asphalt concrete testing.

The kneading compactor is expensive and takes substantially more time to perform CT 373 testing. The existing economical and less time-consuming ASTM or AASHTO test methods used to determine cement application rate for cement stabilized soils could be beneficial to determine the application rate of lime for the efficient construction of lime stabilized subgrade.

Purpose

The availability of the kneading compactor for the fabrication of test specimens is rapidly vanishing and thus resulting in higher costs for testing under CT 373 test method to determine the lime application rate. The use of available ASTM or AASHTO test methods to determine the lime application rate will reduce time and use of resources for both Industry and Caltrans.

Background

Caltrans has been using CT 373 test method to determine the utilization of lime for the stabilization of clayey subgrade to enhance load carrying capacity and provide a stable construction platform for the pavement construction. In addition, lime stabilized soils improve soil characteristics, mitigate vertical movement of subgrade due to the changes in moisture conditions and ultimately enhance the overall pavement performance.

Asphalt concrete testing has replaced the use of kneading compactor for the fabrication of test specimens with gyratory compactor which has consequently

reduced the use and availability of kneading compactor and skilled laboratory technicians required to operate the equipment.

Caltrans successfully utilizes the ASTM test method for the determination of cement application rate for the cement stabilized soils and a similar national test method could be utilized for the determination of lime application rate for the lime stabilized soils. The procedure for using ASTM test method is relatively simple, and economical with a reduced turnaround time for test results. This will also allow contractors to change the lime application rate for the varying subgrade types encountered during construction.

Approach

1. Street Ready Assurance

   Upon review of existing national ASTM and AASHTO standard test methods and other State DOT specifications, street ready specification language will be prepared.

2. Performance Tracking/Management

   Task will be manageable and simple.

3. Consistently Implemented

   Implementation will take place through the Office of Concrete Pavements. The new specification language will be clearly documented and consistently applied by a lead individual from this office.

4. Pilot Projects (if anticipated)

   Not anticipated

5. Research Needs (if necessary)

   Not necessary

Team Members

CT/Industry	Division/Firm Name	Member Name
CT Chair	HQ Pavements	Deepak Maskey
CT	HQ Pavements	Raghubar Shrestha

CT/Industry	Division/Firm Name	Member Name
CT	HQ Materials Engineering and Testing Services (METS)	Joshua Moore
CT	HQ Construction Standards	Samir Ead
Industry Lead	G3 Quality	Jordan Roper
Industry	Griffin Soil	Don Grebs
Industry	Sierra Geotech	Rob Lawrence
Industry	Graymont	Narain Hariharan

Team should not include any more than 4 Caltrans staffs and 4 members from Industry. See PMPC Standard Operating Procedures for more information.

Objectives/Deliverables/Due Dates

Description:

1. Review existing CT 373 test method and available ASTM, and AASHTO test methods pertaining to the fabrication, handling, curing and strength testing of lime stabilized soil test specimens.
2. Review other State DOT specifications pertaining to the determination of lime application for lime stabilized soils.
3. Review Industry Test Methods pertaining to the determination of lime application for lime stabilized soils.
4. Develop specification languages for determining the application rate of lime for soil stabilization.
5. Provide recommendation for revising the existing Caltrans Standard Specifications, Section 24-2 for Lime Stabilized Soil.
6. Develop field conformance testing of lime stabilized soils for acceptance.

Details:

Milestones	Name - Responsible Party	Due Date (Start/Complete)
1. Review CT 373, ASTM and AASHTO test methods	Deepak Maskey and Don Vivant	May 01/ Aug 31, 2021
2. Review other State DOT	Deepak Maskey and Don	July 01/ Sep 30, 2021

Milestones	Name - Responsible Party	Due Date (Start/Complete)
specifications	Vivant	
3. Draft specification languages	Deepak Maskey and Don Vivant	Oct 01, 2021/ Jan 31, 2022
4. Prepare final edited draft specification	Deepak Maskey and Don Vivant	Feb 01/ April 30, 2022

*Some milestones listed above may not be necessary

Resources To Develop and Implement

	Caltrans Hours in FY 21/22	Industry Hours FY 21/22
Review CT 373, ASTM and AASHTO test methods	80	80
Review other State DOT specifications	100	100
Draft specification languages	40	40
Prepare final edited draft specification	20	20

Benefits

- Reduce laboratory testing time and test result reporting time.
- Reduce cost for testing specimens.
- Efficient application of lime for soil stabilization.
- Requires less skilled personnel to operate equipment.
- Allows the use of more common laboratory testing equipment.

Estimated Impact to Caltrans and Contractor

- Change in Caltrans Standard Specifications for Section 24-2.
- Smooth construction.
- Reduce test results turnaround time.
- Reduce additional expenses for laboratory equipment and trained personnel.

Impediments to Completion of Deliverables

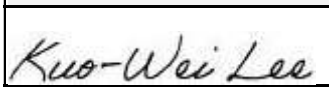
- Stakeholder resistance to change.
- Lack of coordination and contribution of task group members.
- Lack of human and material resources.
- Lack of support by managers, functional units, and staffs.

Recommendation and Approval

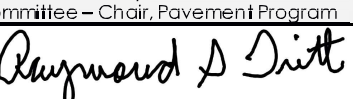
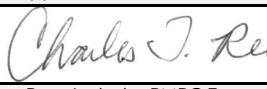
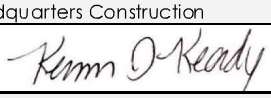
This scoping document for Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization was prepared by Pavement Foundation Sub Task Group to address a priority issue with statewide significance and is within the Pavement & Materials Partnering Committee mission as described in the Pavement & Materials Partnering Committee Charter. The Subtask Group members have determined the scope, resources required and timeline for delivery of this project to attempt and ensure that the deliverables are achievable. A signature here indicates that each Task Group and PMPC Executive Committee is committed to providing the resources to support this effort within the prescribed timeframes. Furthermore, it is everyone's responsibility to ensure that the final effort/improvement will be: is scoping document for *Performance Based ASR Mitigation* was prepared by *Concrete Task Group* to address a priority issue with statewide significance and is within the Pavement & Materials Partnering Committee mission as described in the Pavement & Materials Partnering Committee Charter. The Subtask Group members have determined the scope, resources required and timeline for delivery of this project to attempt to ensure that the deliverables are achievable. A signature here indicates that each Task Group and PMPC Executive Committee is committed to providing the resources to support this effort within the prescribed timeframes. Furthermore, it is everyone's responsibility to ensure that the final effort/improvement will be:

1) Street-Ready,
2) Monitored and reported for performance,
3) Successfully implemented statewide as appropriate.

Scoping Document Recommendation and Industry Concurrence by (name and date):

Caltrans Name (Recommendation)	Date	Industry Name (Concurrence)	Date
	04/14/2021		04/14/2021
Keith Hoffman, Caltrans Task Group Chair		George Butrovich, Industry Task Group Lead	
	04/21/2021		04/20/2021
Kuo-Wei Lee, Caltrans Task Group Member		Mark Hill, Industry Task Group Co-Member	
	04/22/2021		
Ken Solak, Caltrans Task Group Member		Chu Wei, FHWA	

Scoping Document Approval and Industry Concurrence by (name and date):

Caltrans Name (Approval)	Date	Industry Name (Concurrence)	Date
	04/30/2021		04/22/2021
Shaila Chowdhury, Caltrans PMPC Executive Committee – Chair, Pavement Program		Brandon Milar, Industry PMPC Executive Committee	
	04/23/2021		04/22/2021
Raymond Tritt, Caltrans PMPC Executive Committee Headquarters Construction		Charley Rea, Industry PMPC Executive Committee	
	04/23/2021		
Kevin Keady, Caltrans PMPC Executive Committee Structures Policy and Innovation			
	04/30/2021		
Tim Greutert, Caltrans PMPC Executive Committee Materials Engineering and Testing Services			

Approval Date: 04/30/2021

Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization

Date : 06/30/2021

Category of Interest

State DOTs	Louisiana	Minnesota	Texas
Date of Specs	2016	2020	2014
Test Methods	DOTD TR 416- Determination of the % of lime for treatment of soils or soil-aggregate mixtures Standard Specifications Section 304, " Lime Treatment"	Section 3106.2- Provide hydrated lime for use in soil drying or stabilization meeting the requirements of AASHTO M 216, "Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization."	Tex-121-E - Test Procedure for Soil-Lime Testing- Aug 2002
Tests	Atterberg's limits- LL, PL, and PI and TR 418 (Moisture- Density)	ASTM D6276- Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization. AASHTO M 216	Unconfined Compressive Strength - Tex-117-E
Types of Lime Treatment	Hydrated Lime	Hydrated Lime and Quick Lime	Hydrated Lime
Description	Use Type B for base or subbase. Use Type C for conditioning for cement treatment or stabilization. Use Type D for working table treatment under or within an embankment. Use Type E for conditioning and drying of subgrades under a base course.	Quick lime and hydrated lime act on clay soils and may render such soils suitable for highway construction and other load-bearing applications. In most cases, lime causes finely divided clay particles to agglomerate into coarser particles, which improves load-bearing properties, and subsequently the lime-treated soil hardens by chemical reaction.	
Apparatus	DOTD TR 416- Mold of internal dia of 4" X 4.584" Compactive device- Automatic rammer with striking face of 3.1416 sq. in. (rammer of 5.5 lb with a drop height of 12") Manual device- Automatic rammer with		Compression testing machine with a capacity of 60,000 lb and Triaxial screw jack press if anticipated strength ≤ 400 psi

	striking face of 2 in dia. (rammer of 5.5 lb with a drop height of 12")		
Preparing Sample	Obtain approximately 10 lb. of soil or 30 lb. of soil-aggregate mixture sealed in plastic bags, which have been placed in friction top cans and maintained in field condition.	Air dry a sufficient quantity of the soil to be tested and screen through a No. 40 (425-µm) sieve. Store in a closed container to maintain uniform moisture. Determine the mass of a series of 20-g samples of soil and place in separate 150-mL containers with watertight lids. In the case of quicklime, rapidly crush the lime to pass a No. 6 (3.35-mm) sieve.	Approx. 200 lb sample material and prepare in accordance with Tex-101-E, Part II.
Laboratory Mixed	Determine the LL, PL, and PI. Determine the optimum moisture content and maximum dry weight density. The moisture content of the test samples shall be equal to the PL ±2 %, Break up soil clods with fingers until entire sample passes a 1/2 in. sieve. Use minimum pressure when breaking soil clods to prevent sealing the broken faces. Discard any aggregate. Obtain at least 5 test specimens weighing approx. 500 g each at 1, 2, 3, 4, and 5 % lime by dry weight. **For Type A and Type B:** Base (Type A)- Lime treated soils shall have a LL ≤ 40 and PI ≤ 10 Subbase (Type A or B)- Lime treated soils shall have a LL ≤ 40 and PI ≤ 15	Determine the mass of a series of quantities of lime equivalent to 2, 3, 4, 5, Add the 100 mL of 70°F carbon dioxide–free distilled water or, if possible, 70°F actual water to be used on the job to each container of soil and lime. Seal with a screw-cap lid, and mix the three components by shaking the bottles. Shake each bottle for 30 s every 10 min for 1 h. After 1 h, shake vigorously and transfer part of the slurry into a beaker. Measure the pH with a low-sodium error glass electrode (previously standardized to pH 12.45 with an agitated calcium hydroxide slurry). Record the pH reading for each mixture.	**Part I: Compressive Strength Test Methods** Determine the optimum water content and maximum dry density for the soil-lime mixture Determine the amount of lime needed based on the dry mass of the soil. Make three individual samples, add the optimum moisture content and mix thoroughly. Allow the wetted samples to stand for at least 12 hours before compaction with a PI ≥ 12. For PI < 12, standing time for at least 3 hours. Add the desired amount of lime uniformly to a specimen and mix thoroughly. If the material to be improved by lime treatment is a flexible base material, the unconfined compression test is used to evaluate the strength. Compact three identical specimens for each percentage of hydrated

			lime, cure, and test for unconfined compression.
Determination of Lime Application	DOTD TR 433-81- Determine the minimum lime content for soil-lime treatment, Type A and Type B		
Fabrication	Place the test specimen mixed with lime into the mold in one layer. Compact it using 15 blows of the rammer.		Compact three specimens of 6" X 8" or Compact three specimens of 4" X 6" for fine grained less than 20 % retained on the 1/4 in.(6.3 mm) sieve and 100 % passing the 3/8 in. (9.5 mm) sieve. Calculate the number of blows when changing mold size to maintain a compactive effort of 13.26 ft.-lb./in.^{3}.
Curing Testing Specimens	Extrude the sample, place in a plastic bag, seal, and place in moist-curing room for a minimum curing period of 72 hours. At the end of the curing period, remove the compacted test specimens from the plastic bags. Crumble each test specimen into a drying pan. Dry and prepare the test specimens in accordance with DOTD TR 411. Determine the Atterberg Limits for each test specimen.		Store specimens at room temperature for seven days of moist curing at room temperature on the countertop.
Handling	Place each test specimen in a plastic bag, seal, and protect from moisture loss.		Cover specimens with top and bottom porous stones and place in triaxial cells immediately after extrusion from molds. After curing, remove cells and place the specimens in an air dryer oven at a temperature not to exceed 140°F for about six hours or until 1/3 to 1/2 of the molding moisture has been removed.

Strength Testing	Determine the recommended percent's lime by weight for the Liquid Limit and Plasticity Index, by identifying the minimum percent lime for each property which will produce a material which meets specification requirements.		Weigh, measure, and enclose the specimens in triaxial cells, and subject them to capillarity for ten days. Use a constant lateral pressure of 1 psi (6.9 kPa), and a surcharge pressure of 1/2 psi (3.4 kPa) for base to 1 psi for subgrade depending upon the use of the material being tested. Test the specimens for unconfined compression without a cell.
Calculations and Graphs	Determine the percent lime by volume from the Additive Conversion Chart (Fig 2) in accordance with the following steps. When two different percentages of lime have been determined in Step G, use the higher of the two.	If the pH≥ 12.4, the lowest percentage that gives a pH of 12.4 is the percent required to stabilize the soil. If the pH ≤12.3 and 2 percentages give this reading, the lowest percent to give a pH of 12.3 is the percent required to stabilize the soil. If the highest pH reading is a pH of 12.30 and only the highest percentage lime used gives a pH of 12.30, additional testing is required using higher percentages of lime.	Lime stabilized clay soils are not recommended for top course of base, regardless of strength.
Notes	This method of test is designed to determine the minimum percentage of hydrated or quicklime to be added to a soil or soil-aggregate mixture.	This test method usually provides a lime-soil proportion for stabilization. It gives an indication whether the soil in question can be stabilized. For most stabilization work, the results of this test should be verified by performance tests in a soil laboratory.	This test determines the quality of soils treated with lime to be used for subbase or base protected with a wearing surface. Flexible base materials and granular soils can usually be stabilized with about 3% lime. A larger amount of lime may be required to improve the strength of a very plastic clay subgrade. Unconfined compressive strength of 1035 kPa (150 psi) is satisfactory for final course of base construction and it is desirable that materials for such courses contain a minimum of 50 percent plus 425 µm (No. 40) before treatment.

			The amounts of lime from Figure 1 are recommended amounts for stabilization of subgrade soils and base materials. These percentages of lime should be substantiated by these methods to insure adequate strengths. Unconfined compressive strengths of at least 345 kPa (50 psi) are suggested as adequate for subbase soils treated with lime. It is possible for short-term tests of soil-lime mixes, using smaller percentages of lime, to give misleading results due to field variations in materials, mixing, lower densities, and so forth.

Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization

Date : 06/30/2021

Category of Interest

State DOTs	FAA	FHWA	NAVFAC
Date of Specs	2018	2014	2019
Specs	Item P-155	Section 213	Section 32
Test Methods		ASTM D5102, Procedure B	
Types of Lime Treatment	Quicklime, hydrated lime, and either high-calcium dolomitic, or magnesium lime, as defined by ASTM C51, shall conform to the requirements of ASTM C977.		Standard brand of quicklime or hydrated lime
Description	155-1.1 This item shall be used for soil modification that require strength gain to a specific level.	213.01 This work consists of processing and incorporating lime, lime/fly ash, or hydraulic cement into the upper layer of subgrade.	This guide specification covers the requirements for lime stabilization or modification of subgrades airfield pavements and for roads, streets, and parking areas.
Preparing Sample			Develop the mix design using representative samples of each soil to be stabilized(modified) and using the proposed project lime. Conduct three trials for each mix design tested. Prepare samples in accordance with ASTM D3551.
Laboratory Mixed			Allow the prepared samples to mellow for [24 hours for modified materials] [48 hours for stabilized materials] before testing is performed. For soil stabilization, vary the lime content to produce a maximum plasticity index of 10 when tested in accordance with ASTM D4318. Determine the maximum dry density and optimum moisture content for the proposed lime-soil mixture in accordance with ASTM D1557.

Determination of Lime Application	The typical lime content required to bring the soil pH to greater than 12 identifies the minimum lime content needed. Generally, this is between 3-7%. The Engineer will, based on the results of the Geotechnical Report, specify the amount of lime sufficient to lower the Liquid Limit to less than 30 and the Plasticity Index to less than 10 and depth of treatment.		
Fabrication			Prepare three specimens per test evaluation for durability testing for each mix design tested.
Curing Testing Specimens			Cure samples at a constant moisture content and temperature for [7] [28] days.
Strength Testing		Include compressive strength values for at least three application rates with at least one application rate above and one below the strength shown in Table 213-1 with minimum average of 100 psi at 7-day cure at 105 °F.	Refer to Table 2-2 of UFC-3-250-11 for the appropriate values of compressive strength, including applicability of stabilization or modification with lime. Provide a soil stabilization mix design capable of producing an unconfined compressive strength of 150 psi at 28-days (average of three specimens) when compacted to the design percent of laboratory maximum density and tested in accordance with ASTM D5102, Method A. Do not allow samples to exceed loss indicated in Table 2 after 12 cycles of the wet-dry test in accordance with AASHTO T 135. Conduct freeze thaw tests in accordance with AASHTO T 136 (but omitting wire brushing) for projects susceptible to freeze/thaw conditions.]
Field Application		Apply lime and cement by either the dry or slurry method	

24-2 LIME STABILIZED SOIL

24-2.01 GENERAL

24-2.01A Summary

Section 24-2 includes specifications for stabilizing soil by mixing basement material with lime and water.

24-2.01B Definitions

mellowing period: Time between the initial and final mixing to promote initial chemical reactions between lime, water, and basement material.

24-2.01C Submittals

Submit lime samples under ASTM C50. Include the chemical and physical analyses with the submittal.

At least 25 days before applying lime in slurry form, submit the slurry's lime content for authorization.

24-2.01D Quality Assurance

24-2.01D(1) General

Place unique, sequentially numbered lock seals on each load and affix them to trailer blowdown valves that are locked open. The bill of lading for each lime delivery must have that specific lock seal number legibly and visibly imprinted.

24-2.01D(1)(a) Preparing Basement Material

For every 500 cu yd of basement material to be lime stabilized:

1. Test the relative compaction under California Test 231
2. Test the moisture content under California Test 226

24-2.01D(1)(b) Applying Lime

The Engineer determines the final application rate for each lime product proposed from the samples submitted based on California Test 373 except:

1. Test specimen must be compacted under ASTM D 1557 using 4 in mold.

2. Test specimens must be cured by sealing each specimen with 2 layers of plastic at least 4 mil thick. The plastic must be tight around the specimen. Seal all seams with duct tape to prevent moisture loss. Sealed specimens must be placed in an oven for 7 days at 110 ± 5 degree F. At the end of the curing period, specimens must be removed from the oven and air-cooled. Duct tape and plastic wrap must be removed before capping. Specimens must not be soaked before testing.

Wherever the basement material to be stabilized changes, the Engineer changes the application rate. The Engineer provides the optimum moisture content determined under ASTM D 1557 for each application rate.

Whenever lime in slurry form is used, report the quantity of slurry placed by measuring the volume of slurry in the holding tank once per 40,000 sq ft stabilized, or twice per day, whichever is greater.

The Engineer verifies the application rate of lime used in dry form with a calibrated tray, or equal, once per 40,000 sq ft of stabilized soil, or twice per day, whichever is greater.

24-2.01D(2) Quality Control

24-2.01D(2)(a) General

Reserved

24-2.01D(2)(b) Mixing

During mixing operations, measure and record the ground temperature at full mixing depth.

Take a composite sample from 5 random locations after initial mixing. The moisture content of the composite sample tested under California Test 226 must be a minimum of 3 percent greater than

optimum. Determine the moisture versus density relationship of the composite sample material under California Test 216, except part 2, section E, paragraph 6 is modified as follows:

> After adjustment of the moisture content, compact each of the remaining test specimens in the mold, then record the water adjustment, tamper reading, and the corresponding adjusted wet density from the chart on Table 1 using the column corresponding to the actual wet weight of the test specimen compacted. Note each of these wet weights on Line I.

After mixing and before compacting, determine maximum density under California Test 216 from composite samples of mixed material samples from 5 random locations and at each distinct change in material. Test the gradation for compliance with section 24-2.03D. Test the moisture content of the mixed material under California Test 226.

Moisture content during the mellowing period determined under California Test 226 must be at least 3 percent higher than the optimum moisture content.

24-2.01D(2)(c) Compaction

Test relative compaction on a wet weight basis.

After initial compaction determine the in-place density under California Test 231 and moisture content under California Test 226, at the same locations. Perform one test per 500 cu yd of lime stabilized soil. Test in 0.50-foot depth intervals.

24-2.01D(2)(d) Quality Control Testing

Lime stabilized soil quality control must include testing the quality characteristics at the frequencies shown in the following table:

QC Testing Frequencies

Quality characteristic	Test method	Sampling location	Minimum frequency
Ground surface temperature before adding lime and full depth ground temperature during mixing operations	--	Each temperature location	1 test per 20,000 sq ft, minimum 1 per day
Lime application rate	Calibrated tray or equal	Roadway	1 test per 40,000 sq ft, minimum 2 per day
Gradation on mixed material	California Test 202	Roadway	1 per 500 cu yd, minimum 1 per day
Moisture content	California Test 226	Roadway	1 per 500 cu yd on each layer, each day during mixing and mellowing periods, minimum 1 per day
Relative compaction	California Test 231	Roadway	1 per 500 cu yd on each layer, minimum 1 per day

24-2.02 MATERIALS

Lime must comply with ASTM C977 and the requirements shown in the following table:

Lime Quality

Quality characteristic	Test method	Requirement
Available calcium and magnesium oxide (min, %)	ASTM C25 or ASTM C1301 and C1271	High calcium quicklime: CaO > 90 Dolomitic quicklime: CaO > 55 and CaO + MgO > 90
Loss on ignition (max, %)	ASTM C25	7 (total loss) 5 (carbon dioxide) 2 (free moisture)
Slaking rate	ASTM C110	30 °C rise in 8 minutes

A 0.50 lb sample of lime dry-sieved in a mechanical sieve shaker for 10 minutes ± 30 seconds must comply with the percentage passing for the sieve size shown in the following table:

Lime Gradation

Sieve size	Percentage passing
3/8 inch	98–100

Slurry must:

1. Be free of contaminants
2. Contain at least the minimum dry solids
3. Have uniform consistency

Prepare lime slurry at the job site.

24-2.03 CONSTRUCTION

24-2.03A General

Before applying lime, measure the ground surface temperature. Apply lime at ground temperatures above 35 degrees F. Do not apply lime if you expect the ground temperature to drop below 35 degrees F before you complete mixing and compacting.

During mixing, maintain the in-place moisture of the basement material to be stabilized at a minimum of 3 percent above the optimum moisture determined under California Test 216 as modified in section 24-2.01D(2)(b). During compaction and finish grading, add water to the surface to prevent drying until the next layer of mixed material is placed, or until you apply curing treatment.

Scarify the surface of lime stabilized soil at least 2 inches between each layer. Do not scarify the finished surface of the lime stabilized soil.

From the application of lime to 3 days after the application of curing treatment, only equipment and vehicles essential to the lime stabilization work are allowed on the lime stabilized soil.

24-2.03B Preparing Basement Material

Compact the basement material to at least 90 percent relative compaction.

24-2.03C Applying Lime

Apply lime in dry form. You may apply lime in slurry form, if authorized.

Apply lime uniformly over the area to be stabilized using a vane spreader.

Lime slurry must be in suspension during application. Apply lime slurry uniformly making successive passes over a measured section of the roadway until the specified lime content is reached. Apply the residue from lime slurry over the length of the roadway being processed.

24-2.03D Mixing

Mix lime on the same day it is applied. After the initial mixing, allow a mellowing period for at least 36 hours before final mixing. You may add water and mix during the mellowing period.

Complete all the mixing work within 7 days of the initial application of lime.

Before compaction, the mixed material, except rock, must be within the percentage passing limits for the sieve sizes shown in the following table:

Mixed Material Gradation

Sieve size	Percentage passing
1"	98–100
No. 4	60–100

24-2.03E Compaction

Do not use vibratory rollers.

Start compacting immediately after final mixing.

Compact the lime stabilized soil to at least 95 percent relative compaction.

24-2.03F Finish Grading

The finished surface of the stabilized soil must not vary more than 0.08 foot above or below the grade established by the Engineer unless the stabilized soil is to be covered by material paid for by the cubic yard, in which case the finished surface must not vary above the grade established by the Engineer.

Maintain the moisture content of the lime stabilized soil at a minimum of 3 percent above optimum moisture content through the entire finish grading operation.

Wherever lime stabilized soil is below the allowable tolerance, you may use trimmed material to fill low areas only if final grading and final compaction occurs within 48 hours of beginning initial compaction. Before placing trimmed material, scarify the surface of the area to be filled at least 2 inches deep.

24-2.03G Curing

Choose the method of curing and apply the chosen curing method within 48 hours of completing the sheepsfoot or segmented wheel compaction and within the same day of any trimming and finish grading.

24-2.04 PAYMENT

The Department does not adjust the unit price for an increase or decrease in lime quantity.

PMPC Signature Page for Final Reports

Many efforts within the Pavement and Materials Partnering Committee (PMPC) require signature approval from the Executive Committee and Task Group members. This document provides final approval and close out by the Task Group and Executive Committee members for **Replacing the Compaction Method to Determine the Application Rate of Lime for Soil Stabilization** work product and that the working group (WG) has met their commitments for the final report with documentation of decisions/implementation recommendation made. A signature here indicates that each Task group member and Executive Committee has reviewed the final report and agrees the WG has met final report criteria set out in the scoping document and SOP. Furthermore, it is everyone's responsibility to ensure that the final effort/improvement is:

1) Street Ready
2) Monitored and recorded for performance
3) Successfully implemented statewide as appropriate.

Task Group:

Caltrans Name (Recommendation)

Keith Hoffman (Sep 13, 2022 10:50 PDT) — 09/13/2022

Keith Hoffman
Caltrans Task Group Chair
Materials and Engineering Testing Services

Kuo-Wei Lee — 09/13/2022

Kuo-Wei Lee
Caltrans Task Group Member
Pavement Program

09/20/2022

Joseph Dongo
Caltrans Task Group Member
Construction

Industry Name (Concurrence)

George Butorovich (Sep 14, 2022 02:46 PDT) — 09/14/2022

George Butorovich
Industry Task Group Member

Mark Hill (Sep 14, 2022 06:31 PDT) — 09/14/2022

Mark Hill
Industry Task Group Member

Executive Committee:

Caltrans Name (Recommendation)

Tom Pyle — 09/21/2022

Tom Pyle
Caltrans Executive Committee Chair
Pavement Program

Raymond A Tritt — 09/29/2022

Raymond Tritt
Caltrans Executive Committee Member
Construction

Gudmund Setberg — 09/21/2022

Gudmund Setberg
Caltrans Executive Committee Member
Structures Design

12/14/2022

Timothy Greutert
Caltrans Executive Committee Member
Materials Engineering and Testing Services

Industry Name (Concurrence)

Brandon Milar (Sep 28, 2022 13:31 PDT) — 09/28/2022

Brandon Milar
Industry Executive Committee Member

Charles Rea (Sep 21, 2022 15:54 PDT) — 09/21/2022

Charley Rea
Industry Executive Committee Member