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Evaluation of Chemical Stabilizers

State-of-the-Practice Report

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Evaluation of Chemical Stabilizers
State-of-the-Practice Report

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Acknowledgment

Numerous commercially available chemical stabilizers have been developed in recent years for soil improvement and stabilization; the trend is expected to continue through the foreseeable future. Although the manufacturers of the chemical stabilizers often provide information about the expected level of improvement achieved by the use of a certain product, agencies need a method or protocol for performing an unbiased evaluation of the chemical agent as an effective stabilization material for the particular soil in question.

In 1983, Transportation Research Board (TRB) Committee on Chemical Stabilization of Soil and Rock published *Transportation Research Circular 252: Evaluation of Chemical Stabilizers*. With the advent of many new products in the last 20 years, changes in several existing standard test methods (ASTM and AASHTO), and development of new laboratory and nondestructive field tests in response to the forthcoming mechanistic–empirical design procedures, it became essential to update the 1983 TRB Circular. Accordingly, the TRB Committee on Chemical and Mechanical Stabilization (AFS90, formerly A2J02) recently completed this revised version of the 1983 Circular in order to aid highway agencies, engineers, and other end-users in systematically evaluating different chemical stabilizers for geotechnical and pavement applications.

The TRB Committee on Chemical and Mechanical Stabilization would like to sincerely thank Thomas M. Petry for his diligence and efforts in developing the updated E-Circular, and leading the subcommittee. Special thanks to Braja M. Das for spearheading the project as the past Committee Chair and providing the necessary leadership and direction over the years. The committee would also like to acknowledge the efforts of its members who peer-reviewed the document with valuable suggestions. Finally, sincerest thanks to the TRB Staff Representative G. P. Jayaprakash for providing continued support and assistance during this project.

Khaled Sobhan
Chair
TRB Committee on Chemical and Mechanical Stabilization

Contents

A. Introduction

This circular is an update of the *Transportation Research Circular 252: Evaluation of Chemical Stabilizers* published in 1983 by the Transportation Research Board (TRB) and prepared by the Committee on Chemical Stabilization of Soil and Rock. The current Committee on Chemical and Mechanical Stabilization undertook this effort of updating to make available the latest information to the profession with the hope that it will assist professionals in taking a practical approach to frequently occurring problems.

The objective of this circular is to provide information on practices that agencies have found to be successful and provide a reasonable degree of uniformity and standardization in the evaluation of chemical stabilizers used in soil stabilization. The circular is intended to provide the potential user of any chemical stabilizer with important points to consider in evaluating whether or not the stabilizer is suitable for the intended use. Agencies have found that test results from either laboratory tests or field evaluation tests need to be presented in comparison with those performed on untreated soils under the same environmental and loading conditions. For the untreated soils (control specimens), experience has shown that all mixing and mechanical manipulations of the in-place soil should be similar to those performed on the treated soils.

The use of the procedures outlined in this circular can assist in achieving a more uniform approach to the evaluation of chemical stabilizers. However, engineers who are thoroughly familiar with chemical stabilizers or those who are seeking specific performance criteria from the stabilized soil may prefer to use a modified performance testing technique that would be more applicable to the intended use of the product. In such cases, the procedures outlined in this circular may be considered as a norm for judging whether the results obtained using modified techniques are sufficiently different to warrant a departure from the approach described in this circular.

Many chemical stabilizers have been already evaluated in some manner by state transportation departments. A Special Product Evaluation List of some of these chemicals has been published by FHWA (*1*). Another publication that includes similar information was produced by TRB Committee on Chemical Stabilization of Soil and Rock, and was published by TRB (*2*). Additionally, two comprehensive studies on the use of chemical stabilizers were conducted at the University of Arizona (*3*) and Iowa State University (*4*). In addition, two recent papers have been published by TRB summarizing the procedures for evaluating chemical stabilizers and performance-based testing of stabilized soils (*8, 9*). Potential users of any chemical stabilizer are encouraged to review these publications prior to embarking on the evaluation of a product.

B. Information from Manufacturer or Supplier

Potential users should obtain as much of the following information as possible in written or printed form from the manufacturer or supplier of the chemical stabilizer. While some of this information may be supplied directly or indirectly, in an oral presentation or in a brochure describing the benefits of using the product, the prime reason for obtaining such information is to avoid future conflicts arising from initial misunderstandings or misinformation regarding the items outlined below:

1. Legal status of chemical and supplier—whether the chemical stabilizer is proprietary, patented, or franchised; identification of its manufacturer; and the relationship between the chemical supplier and the manufacturer.
2. Purpose for using the stabilizer—strength improvement, compaction aid, water proofer, water repellent, permeability reduction, or shrink-swell reduction.
3. Chemical classification of the stabilizer—silicate, lignin, epoxy, ester, amine, formaldehyde, aliphatic compound, acetate, sulfonate, emulsifier, plasticizer, ether, alcohol, surfactant, chloride (K, Na or Ca), hydroxide (K, Na, or Ca), or biological.
4. Information regarding the manufacturing process and quality control and quality assurance.
5. Mechanism(s) of stabilization—how agent stabilizes; whether verified or hypothesized; and single or multiple-phase stabilization.
6. Physical and chemical properties of stabilizer—solid, powder, liquid, emulsion, unit weights, color, pH, viscosity, range of composition, or chemical constituents.
7. Availability of material when required—capacity to produce and provide the chemical if needed in large enough quantities; potential for production; and seasonal availability.
8. Precautions to be taken during handling and working with the chemical—toxicity, toxic fumes, causticity, flammability, acidity, skin and eye irritations; the need for goggles and gloves.
9. Storage conditions—type of containers, temperature, humidity, sensitivity to sunlight, continuous or intermittent agitation, and aeration.
10. Shelf life under given storage conditions.
11. Environmental impact statement on product—effects on plants and vegetation and groundwater, and leachability.
12. Method(s) of application—mixing, spraying, or injection; and recommended application equipment.
13. Method of dilution, if required—recommended dilution ratio; mixability with water, oils, or other solvents; is mixing required; method of centrifuge, dispersion, or high shear rate.
14. Rate of application to the soil—rate per unit volume, per unit area, parts per million, or percent by dry weight.
15. Cost of chemical—per pound, gallon, or bulk; concentrate or dilution.
16. Compaction method(s), if required—how many passes, type of roller, or lift thickness; maximum rate and thickness of treatment; amount per unit time.
17. Recommended curing conditions—temperature, humidity, time for curing.
18. Durability and permanence of treatment.
19. List of previous users, types of uses, and locations of projects.
20. Previous laboratory and field results.

C. Laboratory Testing Program

1. TESTING THE CHEMICAL

Agencies determine the physical and chemical properties of the stabilizer when not provided by supplier or to verify those given. Some of these properties are

- Chemical constituents and relative composition,
- pH value,
- Specific gravity or weight per unit volume,
- Viscosity,
- Toxicity,
- Color,
- Odor, and
- Zeta potential.

Test methods are specified for each (use ASTM or AASHTO procedures, or other procedures as specified by an appropriate agency). See Table 1 for a partial listing.

2. TESTING THE SOIL

The physical, mechanical, and index properties of the soil to be stabilized are determined (as needed) in its untreated natural state, with particular emphasis on those properties that will be modified by the stabilizer.

- Color,
- Particle size distribution,
- Atterberg limits,
- pH value,
- Classification,
- Mineralogy,
- Organic content,
- Compaction characteristics,
- Swelling potential,
- Compressive strength,
- Durability tests,
- One-dimensional consolidation,
- Tensile strength,
- Flexural strength,
- Shear strength,
- Permeability,
- Resilient modulus,

- Wind erosion,
- Rainwater erosion,
- Traffic erosion,
- Shrinkage potential,
- Cation exchange capacity,
- Exchangeable salts,
- Zeta potential, and
- Compressibility.

Test methods are specified for each (use ASTM or AASHTO procedures, or other procedures as specified by an appropriate agency). See Table 2 for a partial listing.

TABLE 1 Testing the Chemicals

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Chemical Constituents	C 25	C 25-99	None	Chemical Analysis of Limestone, Quicklime, and Hydrated Lime
	None	C 1164-92 (1997)e1	None	Evaluation of Limestone or Lime Uniformity from a Single Source
	None	C 110-00	None	Physical Testing of Quicklime, Hydrated Lime, and Limestone, Test Methods for
	None	C 977-95	M 216-84 (1990)	Specifications for Quicklime and Hydrated Lime for Soil Stabilization
	C 146	C 146-94a (1999)	None	Chemical Analysis of Glass Sand, Test Methods for
	C 471	C 471M-96	None	Chemical Analysis of Gypsum and Gypsum Products [Metric], Test Methods for
	None	C 472-99	None	Physical Testing of Gypsum, Gypsum Plasters, and Gypsum Concrete, Test Methods for
	C 575	None	None	Chemical Analysis of Silica Refractories
	D 1570	D 1570-95	None	Sampling and Chemical Analysis of Fatty Alkyl Sulfates, Test Methods for
Color	D 1535	D 1535-97	None	Specifying Color by the Munsell System, Practice for
	D 1729	D 1729-96	None	Visual Appraisal of Colors and Color Differences of Diffusely Illuminated Opaque Materials, Practice for
Odor	E 679	E 679-91	None	Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits, Practice for

(continued)

TABLE 1 *(continued)* **Testing the Chemicals**

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
pH Value	E 70	E 70-97	T 200-79 (1990)	pH of Aqueous Solution with the Glass Electrode, Test Methods for
	D 2081	D 2081-92 (1998)	None	pH of Fatty Quaternary Ammonium Chlorides, Test Methods for
	E 70	E 70-97	T 200-79 (1990)	pH of Aqueous Solution with the Glass Electrode, Test Methods for
	D 2081	D 2081-92 (1998)	None	pH of Fatty Quaternary Ammonium Chlorides, Test Methods for
	None	D 2076-92 (1998)	None	Acid Value and Amine Value of Fatty Quaternary Ammonium Chlorides, Test Methods for
	D 3643	D 3643-98	None	Acid Number of Certain Alkali-Soluble Resins, Test Methods for
	D 2379	D 2379-99	None	Acidity of Formaldehyde Solutions
	C 110	C 110-00	None	Physical Testing of Quicklime, Hydrated Lime, and Limestone, Test Methods for
Specific Gravity	D 3142	D 3142-97	T 227-89	Density of Liquid Asphalts (Hydrometer Method), Test Methods for
	D 70	D 70-97	T 228-90	Density of Semi-Solid Bituminous Materials (Pycnometer Method), Test Method for
	None	D 3289-97	None	Density of Semi-Solid and Solid Bituminous Materials (Nickel Crucible Method), Test Method for
	D 3505	D 3505-96	None	Density or Relative Density of Pure Liquid Chemicals, Test Method for
	AASHTO T228	D 70-76	T 228-90	Density of Semi-Solid Bituminous Materials (Pycnometer Method), Test Method for
Toxicity	D 1345	None	None	Evaluating Acute Toxicity of Water to Fresh-Water Fishes
	None	E 1440-91	None	Guide for Acute Toxicity Test With the Rotifer Brachionus
	None	E 729-96	None	Guide for Conducting Acute Toxicity Test on Test Materials with Fishes, Macroinvertebrates, and Amphibians
Viscosity	D 88	D 88-94 (1999)	T 72-90	Saybolt Viscosity, Test Method for
	None	D 2161-93 (1999)	None	Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity
	D 445	D 445-97	None	Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity), Test Method for
	D 1725	D 1725-62 (1996)	None	Viscosity of Resin Solutions, Test Method for
	D 2393	None	T 201-90	AASHTO: Kinematic Viscosity of Asphalts

TABLE 2 Testing the Soil

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Atterberg Limits	D 423	None	None	Liquid Limit of Soils
	D 424	None	None	Plastic Limit and Plasticity Index of Soils
	None	D 4318-98	T 89-90, T 90-97	Liquid Limit, Plastic Limit, and Plasticity Index of Soils, Test Method for
Bearing Ratio	D 1883	D 1883-99	T 193-81 (1990)	CBR (California Bearing Ratio) of Laboratory Compacted Soils, Test Method for
	None	D 4429-93	None	CBR (California Bearing Ratio) of Soils in Place, Test Method for
	D 3668	D 3668-78 (1985)	None	Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures, Test Method for
	(*4*)	None	None	Iowa K-Test
Classification	D 2487	D 2487-98	None	Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
	None	D 420-98	T 86-90	Guide to Site Characterization for Engineering, Design and Construction Purposes
	D 3282	D 3282-93 (1997)	None	Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
	None	D 448-98	M 43-88	Classification for Sizes of Aggregate for Road and Bridge Construction
Color	D 2488	D 2488-93	None	Description and Identification of Soils (Visual-Manual Procedure), Practice for
	D 1535	D 1535-97	None	Specifying Color by the Munsell System, Practice for
	D 1729	D 1729-96	None	Visual Appraisal of Color and Color Differences of Diffusely-Illuminated Opaque Materials
Compaction Characteristics	D 698	D 698-91 (1998)	T 99-90	Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft*lbf/ft^3 (600kN*m/m^3)], Test Method for
	D 1557	D 1557-91 (1998)	T 180-90	Laboratory Compaction Characteristics of Soil Using Modified Effort [56,000 ft*lbf/ft^3 (2,700kN*m/m^3)], Test Method for
Compressive Strength	D 2166	D 2166-98a	T 208-90	Unconfined Compressive Strength of Cohesive Soil
	AASHTO T 234	D 2850-95	T 234-85 (1990)	Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression, Test Method for
Durability	None	D 5312-92	None	Evaluation of the Durability of Rock for Erosion Control under Freezing and Thawing
	None	D 5313-92	None	Evaluation of the Durability of Rock for Erosion Control under Wetting and Drying Conditions
	None	D 4644-92	None	Slake Durability of Shales and Similar Weak Rocks
	None	None	T 210-96	Aggregate Durability Index

(continued)

TABLE 2 (*continued*) **Testing the Soil**

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Elastic Properties	C 469	C 469-94	None	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, Test Method for
Flexural Strength	D 1635	D 1635-95	None	Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading, Test Method for
Grain Size Distribution	D 422	D 422-63 (1998)	T 88-90	Particle-Size Analysis of Soils, Test Method for
Mineralogy	D 934	D 934-80 (1999)	None	Identification of Crystalline Compounds in Water-Formed Deposits by X-Ray Diffraction, Practices for
	E 168	E 168-99	None	General Techniques of Infrared Quantitative Analysis, Practices for
	E 14	None	None	Thermal Analysis of Metals and Alloys
Organic Content	D 2974	D 2974-87 (1995)	None	Moisture, Ash, and Organic Matter of Peat and Other Organic Soils, Test Methods for
	AASHTO T194	None	T 194-87	Determination of Organic Matter in Soils by Wet Combustion
	C 40	C 40-99	T 21-87	Organic Impurities in Fine Aggregates for Concrete, Test Method for
Permeability	D 2434	D 2434-68 (1994)	T 215-70 (1990)	Permeability of Granular Soils (Constant Head), Test Method for
	None	None	None	Permeability of Cohesive Soils (Falling Head)
pH Value	D 2976	D 2976-71 (1998)	None	pH of Peat Materials, Test Method for
	G 51	G 51-95 (2000)	None	Measuring pH of Soil for Use in Corrosion Testing, Test Method for
	None	D 4972-95a	None	pH of Soils, Test Method for
Rain Erosion	(*3*)	None	None	
Resilient Modulus	None	None	T 292-91	Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials
Shear Strength	D 3080	D 3080-98	T 236-84 (1990)	Direct Shear Test of Soils Under Consolidated Drained Conditions, Test Method for
	AASHTO T 234	D 2850-95	T 234-85 (1990)	Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression, Test Method for
Shrinkage Potential	D 427	D 427-98	T 92-88	Shrinkage Factors of Soils by the Mercury Method, Test Method for
	None	D 4943-95	None	Shrinkage Factors of Soils by the Wax Method, Test Method for
	D 559	D 559-96	None	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Specific Gravity	D 854	D 854-98	T 100-90	Specific Gravity of Soils, Test Method for
	None	D 5550-94	None	Specific Gravity of Soil Solids by Gas Pycnometer, Test Method for

(*continued*)

TABLE 2 (*continued*) Testing the Soil

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Swell Potential	AASHTO T258	None	T 258-81	Determining Expansive Soils
	D 559	D 559-96	None	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Tensile Strength	C 496-71	C 496-96	T 198-86	Splitting Tensile Strength of Cylindrical Concrete Specimens, Test Method for
	(*5*)	None	None	Static Double Punch Test
Traffic Erosion	(*3*)	None	None	
Wind Erosion	(*3*)	None	None	

3. EFFECTIVENESS OF CHEMICALS IN ACHIEVING DESIRED STABILIZATION OF SOIL

In all laboratory testing of chemically stabilized soils, agencies make serious efforts to test the material (as needed) under simulated in-situ conditions, to replicate to the best of the laboratory's ability the environmental and the loading conditons that will be present in-situ. In addition, stabilization with only the amount and type of water that will be added with the agent is tested to evaluate the stabilization effects of the agent. Simulations include

a. Environmental Conditions

- Temperature extremes, including cyclical;
- Submersion;
- Cyclic freezing and thawing;
- Sunlight exposure;
- Construction sequencing;
- Degree of saturation;
- Type of water (tap or sea);
- Cyclic wetting and drying;
- Leaching or draining effects;
- Preparation of material;
- Curing, either at normal or higher than normal temperature, dry, moist or saturated; and
- Partial or normal duration—to match expected in-situ situations.

b. Loading Conditions

- Rate of loading;
- Strain rates;
- Consolidation;
- Repetitive loading;
- Curing period prior to loading;

- Stress levels;
- Creep effects;
- Conditions of drainage;
- Failure condition (criteria);
- Construction sequencing; and
- Inundation and related hydro-consolidation potential.

Under general circumstances, standardized test techniques (preferably recommended by ASTM or AASHTO) are utilized to verify the properties of the treated soil to compare it with those obtained for untreated soil. However, some laboratory evaluations do not lend themselves to simulation of specialized field conditions. Appropriate performance tests can be applied when they faithfully simulate the field construction, curing, and loading situations, and the lists below indicate both current conventional tests and those which are not commonly used any more in assessing soil improvement by chemical stabilization.

4. CHANGES OF PHYSICAL PROPERTIES

a. List of Conventional Tests

See Table 3.

- Compressive strength test,
- Tensile strength test,
- Flexural strength test,
- Shear strength test,
- Permeability test,
- Particle size distribution,
- Atterberg limits,
- Compaction characteristics,
- Swelling potential, and
- Resilient modulus.

b. List of Tests Previously Developed and Sometimes Used

See Tables 2 and 3 and other references (*3, 4*, *6*, *10*)

- Wind erosion test,
- Rain erosion test,
- Traffic erosion test,
- Water absorption test,
- Cyclic double-punch test,
- Exchangeable cations,
- Soluble salt testing, and
- Iowa K–test.

D. Field Testing

In field evaluation tests, emphasis is on replicating the expected (or recommended) construction methods of subgrade preparation, pulverization, application, mixing, curing, compaction, etc., and then subjecting the final product to the actual field conditions (environmental and loading) for a period of time.

Monitoring of the performance of the stabilized soils is made periodically for a period of time (12-month minimum is preferred). However, field evaluation tests and monitoring of the performance of the stabilized soil may be accelerated in cases where necessary and appropriate to minimize the number of tests and to shorten the duration of the 12-month minimum period provided that there is sufficient information for adequate evaluation. In addition, the potential user should be alert to recognize any incompatibility of the chemical stabilizer with other construction products. For example, the chemical additive may have a detrimental effect on culverts, buried utilities, and vegetation. On the other hand, the chemical may have beneficial effects such as accelerating the growth of shoulder grass, galvanic protection, etc. Monitoring of field performance of untreated soil, agent-treated soil, and soil treated only with the water that would be added with agents being tested for application, is conducted to evaluate the effects due to addition of the agent to the soil.

1. FIELD APPLICATION

At least the items listed below are considered and monitored.

- Site preparation,
- Rate and method of application,
- Densification,
- Degree of pulverization,
- Observations of all aspects of above (e.g., penetration, compactibility, tracking, etc.),
- Chemical preparation,
- Method of compaction and number of passes,
- Mixing efficiency, and
- Curing requirements.

2. FIELD MONITORING

Monitoring is started immediately after curing, prior to subjecting the stabilized soil to loading or extreme environmental conditions, and includes a selected number of different tests chosen from those listed under Methods of Evaluation. But field monitoring also requires detailed observation of the construction operations to note difficulties that need improvement or other ways of making the field application of stabilizer more effective and efficient. These are used as a basis of field performance and evaluation.

3. METHODS OF EVALUATION

The evaluation methods can be divided into direct evaluation in the field (by field testing) or recovering (or coring) of samples from the field for laboratory testing. In both cases, efforts are made to use standardized and accepted methods of evaluation (testing) as recommended by ASTM or AASHTO. Alternatively, methods that have been previously used for evaluation are sometimes utilized to verify performance. Examples of field tests that may be needed are given below:

a. Field Tests

- Penetration resistance,
- Density or unit weight,
- Surface roughness,
- Dust control,
- Soluble salts testing,
- Falling weight deflectometer,
- Subgrade reaction,
- Permeability,
- Skid resistance,
- Wind erosion,
- Exchangeable salts, and
- Road rater.

b. Laboratory Tests on Undisturbed Field Samples

See Table 3.

- Compression test,
- Shear strength,
- Permeability,
- Rain erosion,
- Tensile strength,
- Density, and
- Leaching (chemical residue).

TABLE 3 Laboratory Tests on Treated Soils

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Bearing Ratio	D 1883	D 1883-99	T 193-81 (1990)	CBR (California Bearing Ratio) of Laboratory Compacted Soils, Test Method for
	(*4*)	None	None	Iowa K-Test
	D 3668	D 3668-78(1985)	None	Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures, Test Method for
Chemical Residue After Leaching	(*3*)	None	None	None
Compaction Characteristics	D 698	D 698-91 (1998)	T 99-90	Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft*lbf/ft^3 (600kN*m/m^3)], Test Method for
	D 1557	D 1557-91 (1998)	T 180-90	Laboratory Compaction Characteristics of Soil Using Modified Effort [56,000 ft*lbf/ft^3 (2,700kN*m/m^3)], Test Method for
Compressive Strength	D 1633	D 1633-96	None	Compressive Strength of Molded Soil-Cement Cylinders, Test Method for
	C 39	C 39/C 39M	T 22-90	Compressive Strength of Cylindrical Concrete Specimens, Test Method for
	AASHTO T167	D 1074-96	T 167-84 (1990)	Compressive Strength of Bituminous Mixtures, Test Method for
	D 1075	D 1075-96	T 165-86 (1990)	Effect of Water on Compressive Strength of Compacted Bituminous Mixtures, Test Method for
	None	D 5202-91 (1997)	None	Determining Triaxial Compression Creep Strength of Chemical Grouted Soils, Test Method for
	None	D 4219-93a	None	Unconfined Compressive Strength Index of Chemical-Grouted Soils, Test Method for
	None	D 5102-96	None	Unconfined Compressive Strength of Compacted Soil-Lime Mixtures, Test Method for
Consolidation	D 2435	D 2435-96	T 216-83 (1990)	One-Dimensional Consolidation Properties of Soils, Test Method for
	None	D 4196-89 (1998)e1	None	One-Dimensional Consolidation Properties of Soils Using Controlled-Strain Loading, Test Method for
Cyclic Freezing/ Thawing	C 666	C 666-97	T 161-86 (1990)	Resistance of Concrete to Rapid Freezing and Thawing, Test Method for
	D 560	D 560-96	T 136-76	Freezing and Thawing Compacted Soil-Cement Mixtures, Test Methods for
	None	D 5918-96	None	Frost Heave and Thaw Weakening Susceptibility of Soils, Test Methods for

(continued)

TABLE 3 *(continued)* **Laboratory Tests on Treated Soils**

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Cyclic Wetting/ Drying	D 559	D 559-96	T 135-76	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Deformation/ Cohesion	D 1560	D 1560-92	T 246-82 (1990)	Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of a Vheem Apparatus, Test Methods for
Density	None	D 2922-91	None	Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)
Elastic Properties	C 469	C 469-94	None	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, Test Method for
	(*6*)	None	None	Dynamic Modulus of Elasticity by Cyclic Double-Punch Test
Falling Weight Deflectometer	None	D 4694-87	None	Deflections with a Falling-Weight-Type Impulse Load Device
Flexural Strength	D 1635	D 1635-95	None	Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading, Test Method for
	C 78	C 78-94	T 97-86	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), Test Method for
	None	C 293-94	T 177-81 (1990)	Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
Mixing	D 3551	D 3551-90 (1996)	None	Laboratory Preparation of Soil-Lime Mixtures Using a Mechanical Mixer
Penetration	D 5	D 5-97	T 49-89	Penetration of Bituminous Materials, Test Method for
Permeability	D 3637	None	None	Permeability of Bituminous Mixtures
Plastic Flow	D 1559	None	None	Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus, Test Methods for
	None	D 5581-96	T 245-90	Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus (6-in. Diameter Specimen), Test Method for
Rainwater Erosion	(*3*)	None	None	None
Resistance/ Expansion	D 2844	D 2844-94	T 190-90	Resistance R-Value and Expansion Pressure of Compacted Soils, Test Method for
Road Rater	None	D 4602-93	None	Nondestructive Testing of Pavements Using Cyclic Loading Dynamic Deflection Equipment
Shear Strength	D 3080	D 3080-98	T 236-84 (1990)	Direct Shear Test of Soils Under Consolidated Drained Conditions, Test Methods for
	AASHTO T234	D 2850-95e1	T 234-85 (1990)	Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression, Test Method for

(continued)

TABLE 3 *(continued)* **Laboratory Tests on Treated Soils**

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Shrinkage	D 427	D 427-98	T 92-88	Shrinkage Factors of Soils by the Mercury Method, Test Methods for
	None	D 4943	None	Shrinkage Factors of Soils by the Wax Method, Test Method for
	None	D 3877-96	None	One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures, Test Methods for
	D 559	D 559-96	T 135-76	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Skid Resistance	None	E 274-90	T 242-96	Skid Resistance of Paved Surface Using a Full-Scale Tire
Soluble Salts	None	D 4542-93	None	Pore water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer
	None	None	T 290-95	Determining Water-Soluble Sulfate Ion Content in Soil
	None	None	T 291-94	Determining Water-Soluble Chloride Ion Content in Soil
Specific Gravity	AASHTO T166	None	T 166-88	Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
Surface Roughness	None	E 274-93	None	Measuring Pavement Roughness Using a Profilograph
Swell Potential	AASHTO T258	None	T 258-81	Determining Expansive Soils
	D 559	D 559-96	T 135-76	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Tensile Strength	C 496	C 496-96	T 198-88	Splitting Tensile Strength of Cylindrical Concrete Specimens, Test Method for
	(*5*)	None	None	Static Double-Punch Test
Traffic Erosion	(*3*)	None	None	None
Water Absorption	D 915	None	None	Method of Testing Soil-Bituminous Mixtures
Water Effect	D 1075	D 1075-96	T 165-86 (1990)	Effect of Water on Compressive Strength of Compacted Bituminous Mixtures, Test Method for
Wind Erosion	(*3*)	None	None	None

E. Data Presentation

Test results from either laboratory tests or field evaluation tests are presented in comparison with those performed on untreated soils under the same environmental and loading conditions. For the untreated soils (control sections), all mixing and mechanical manipulations of the in-place soil are similar to those performed on the treated soils.

F. References

1. *Special Product Evaluation List*. FHWA-RD-76. AASHTO, FHWA, U.S. Department of Transportation, Dec. 1975.
2. *Questionnaire Summary—Chemical Stabilization of Soils*. Transportation Research Board Information Series, Group 2, No. 8, April 1977.
3. Sultan, H. A. *Soil Erosion and Dust Control of Arizona Highways. Part II: Laboratory Testing Program; Part IV: Field Monitoring Program*. Report ADOT-RE-10-141-11. Arizona Department of Transportation, FHWA, Feb. 1976.
4. Hoover, J. M., and R. L. Handy. *Chemical Compaction Aids for Fine-Grained Soils. Final Report, Vol. I and II*. R FHWA-RD-79-63 and FHWA-RD-79-64. FHWA, U.S. Department of Transportation, June 1978.
5. Fang, H. Y., and W. F. Chen. New Method for Determination of Tensile Strength of Soils. In *Highway Research Record 345*, HRB, National Research Council, Washington, D.C., 1971, pp. 67–68.
6. Jimenez, R. A. *Structural Design of Asphalt Pavements*. Final Report ADOT-RS-13(142), submitted to the Arizona Department of Transportation, Phoenix, Nov. 1975, p. 10.
7. *Earth Manual* (2nd ed.). U. S. Bureau of Reclamation U. S. Department of the Interior, 1974.
8. Petry, T. M. Performance-Based Testing of Chemical Stabilizers. In *Transportation Research Record, No. 1589*, TRB, National Research Council, Washington, D.C., 1997, pp. 36–41.
9. Petry, T. M. and B. Das. Evaluation of Chemical Modifiers and Stabilizers for Chemically Active Soils—Clays. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1757*, TRB, National Research Council, Washington, D.C., 2001, pp. 43–49.
10. *Cation Exchange Capacity of Soils*, SW-846, Method 9080, Environmental Protection Agency, Washington, D.C., 2005.

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