Policy and Procedure for the Evaluation of Proposed Soil Stabilization Products

I. Introduction

The guidelines and procedures described herein are for those want Oklahoma DOT (ODOT) to consider the use of a new or proprietary soil stabilization product (i.e., anything other than Portland cement, cement kiln dust (CKD), fly ash, or lime). For the purposes of this procedure, soil stabilization refers to any product added to the soil with the intent to modify its physical properties (i.e. strength, plasticity, etc.), prevent slaking, and/or otherwise create a stabilized base/subbase for pavement. Soil stabilization, as referred to herein, does not refer to physical inclusions which mechanically stabilize the soil such as geosynthetics, for example.

These guidelines and procedures were written with conventional calcium-based stabilizers in mind, but the criteria and general procedures shall also apply to proposed new or proprietary soil stabilization products.

ODOT criteria and procedures for stabilization and modification are detailed in OHD L-50, "Soil Stabilization Mix Design Procedure," and OHD L-51, "Soil Modification Mix Design Procedure," respectively.

It is understood that certain stabilization products may require special handling or testing considerations different than those described herein or within OHD L 50 and OHD L 51; These guidelines serve as a basis for discussion and starting point on how best to evaluate a given soil stabilization product.

II. General Overview of the Process

An overview of the process is as follows:

1. There shall be an initial meeting between the supplier of the candidate product and the Materials Division's Geotechnical Engineer to discuss the proposed applications of the candidate stabilizer; others may be present as well. This initial discussion will determine whether to proceed with the required testing listed herein at all, whether any changes may be necessary (i.e. modifications, additions, and/or omissions to testing, etc.), and provide any clarifications regarding this procedure. The supplier's directions for storage, application, and curing shall be reviewed to verify they reasonably approximate methods used during construction. During the progress of the initially planned testing, questions or findings may indicate further changes are needed. Proposed changes must be discussed and submitted to the Materials Division's Geotechnical Engineer in writing for approval.

2. Meeting minutes which include a summary of all the testing initially agreed upon between the Materials Division's Geotechnical Engineer and the supplier will be submitted by the Geotechnical Engineer to the supplier and other attendees for review. Any appropriate changes and/or revisions will be agreed upon, after which a final copy will be given to the supplier to provide to the consultant testing laboratory to serve as a set of instructions so that the appropriate testing can commence.

3. The supplier shall have an independent, certified testing laboratory perform all required testing. Requirements for independent, certified testing laboratories are detailed in section V.

4. Testing is detailed in section VIII.

5. Many new stabilizers claim to prevent or minimize sulfate-induced heave. These claims shall be verified by expanding the required testing to include soils over a range of soluble sulfate concentrations; details are given in section IX.

6. Submit all required information (i.e., results of laboratory testing, safety data sheets, special handling instructions, and any other pertinent or requested information) for evaluation to the Materials Division's Geotechnical Engineer. The information required is outlined in further detail within this document.

7. All submittals will be reviewed by the Materials Division's Geotechnical Engineer. If the provided laboratory data was sufficient, the Materials Division's Geotechnical Engineer will provide appropriate feedback regarding the next steps to be taken (e.g., creating a test section or the need for further testing) or whether the candidate product has failed.

8. Approval of a product will not be granted for longer than three (3) years and a product may be removed at any time. A letter will be provided stating specifics of the product's approval, such as what soil types it is appropriate to stabilize, limitations, date of approval, etc. At the end of three (3) years, all the laboratory testing listed herein must be re-performed and data must be resubmitted for review. If results are reasonably similar as in the past, a test section may be omitted and the candidate stabilizer will remain on the qualified products list for up to another three (3) years. Regardless of approval, no product will be added to the table in OHD L-50 and all products, although approved, will require project specific mix designs to be performed as per OHD L-50.

Findings of suitability and implementation by ODOT does not constitute an endorsement of the stabilization product by ODOT. Producers or suppliers of stabilization agents shall not use ODOT's name, or the names of ODOT personnel, as part of advertisements implicitly or explicitly implying endorsement. This procedure does not address economic or environmental suitability of the proposed stabilization product.

III. Causes for Determination of Stabilizer Unsuitability

Provided within this section is a list, although not exhaustive, of conditions which would result in rejection of a given candidate stabilizer. This list is for the benefit of all involved so that costly and timely testing can be avoided if any of these conditions are met prior to the completion of all of the laboratory testing. A stabilizer will be determined unsuitable if any of the following are true:

1. The candidate stabilizer cannot stabilize at least three (3) of the AASHTO soil groups listed in the table of OHD L-50.

2. The candidate stabilizer cannot increase the strength of cured specimens, or cured and immersed specimens, by at least one hundred and fifty (150) psi above the untreated soil.

3. Treated specimens slake or otherwise deteriorate during immersion to the extent that they cannot be tested in compression.

4. Treated specimens swell more than untreated specimens or more than 6.25%, whichever is less. *(6.25% corresponds to approximately one-half (0.5) inch of an eight (8) inch layer)*

IV. Requirements of the Independent Laboratory

1. The laboratory shall be independent of the candidate stabilization agent producer or supplier (i.e., internal laboratory testing will not be considered.)

2. The laboratory shall have a professional engineer registered and physically based in the State of Oklahoma on staff. The professional engineer shall be a geotechnical engineer. "Geotechnical engineer," as referred to herein, is a registered professional engineer whose specialty/area of focus is geotechnical engineering.

3. The laboratory shall be, where applicable, AASHTO re:source accredited for all tests they are performing. Being an ODOT certified laboratory alone is not sufficient. ODOT laboratory certification is geared towards basic and routine QC/QA testing for construction projects.

4. All technicians performing tests shall be certified, when applicable, as per AASHTO re:source internal Quality Management System (QMS) requirements.

5. All testing shall be performed by a single laboratory.

6. All laboratory test reports shall be reviewed, signed, and stamped by the professional engineer described in Item 2 above.

Exceptions to and questions about any of the above listed points within this section shall be submitted in writing to the Materials Division's Geotechnical Engineer for approval.

V. Minimum Information and Supplies Required of the Supplier

1. The supplier of the candidate stabilization product shall deliver directly to the testing laboratory a quantity of stabilizer sufficient to conduct the required laboratory testing. This shall include materials safety data, specific directions for storage of the stabilizer, shelf life, and any other pertinent information.

2. The supplier shall provide specific directions, for:

    a. application (e.g., "dilute with water to a 1:10 ratio, mix thoroughly with the soil, cover and allow to stand 30 minutes before compacting");

    b. curing of treated soil. Curing of test specimens shall conform with OHD L-50, unless otherwise requested in writing and approved by the Materials Division's Geotechnical Engineer; and

    c. any other special treatment protocols for certain cases.

    NOTE: Methods for storage, application, and curing in the laboratory must reasonably approximate methods used during construction.

3. The supplier shall provide the list of testing to be performed (Section II, 2.) to the testing laboratory.

VI. General Requirements for Laboratory Testing

1. The source of the tested soils shall be reported. This shall include:

    a. the geographic location of sampling (latitude, longitude, and depth), and any description necessary to provide context (e.g., “reddish brown clay from borrow pit, composite of B and C horizons from Port Series”)

    b. date of sampling

    c. name and affiliation of the person performing the sampling

2. The soils sampled for testing shall meet the current ODOT Standard Specifications for unclassified excavation or unclassified borrow (Section 202) and be free of deleterious materials. Soils that are unsuitable for subgrade construction (except for excessive moisture) shall not be used, unless approved by the Materials Division’s Geotechnical Engineer. Sampled soils shall have a soluble sulfate concentration less than 1000 ppm.

3. A sufficient quantity of soil shall be sampled to allow for split sampling with the Materials Division’s Geotechnical Branch if required for follow-up testing.

4. The soils shall be delivered to the testing laboratory in the condition in which they were sampled (without loss or removal of material or moisture), and shall be clearly identified.

5. All water used in laboratory testing shall be either distilled or deionized water unless the respective standard requires otherwise.

6. All soils evaluated for stabilizer effectiveness shall be tested for moisture-density relationships and unconfined compressive strength over a range of application rates, with at least three (3) rates tested, in addition to the untreated soil. The soil shall initially be tested at application rates of 0.0, 0.5, 1.0, and 1.5 times the suppliers specified or recommended application rate for a given soil. If the supplier believes these application rates are inappropriate, it should be brought to the attention of the Materials Division’s Geotechnical Engineer prior to commencing testing.

7. The range of application rates should yield an increase in unconfined compressive strength of treated soils of approximately 50 psi at the low end, and approximately 250 psi at the high end. If the initial range of application rates is inadequate, additional testing at alternative application rates may be necessary.

8. All laboratory tests shall conform to reporting requirements as per their respective standards, except as noted within this approval process.

9. The name of the technician who performed each test shall be recorded.

10. Results shall be reported in US Customary units.

VII. Laboratory Testing

The laboratory testing specified herein is a suggested minimum and the Materials Division's Geotechnical Engineer may request further testing before the in-house review process begins. Required laboratory testing includes:

1. Index properties and classification of untreated soils
    a. Visual-manual description (ASTM D2488)
    b. Full particle size analysis, including hydrometer (Either ASTM D422, ASTM D7928 and D6913, or AASHTO T-88)
    c. Atterberg limits (ASTM D4318, or AASHTO T-89 and T-90)
    d. Soil classification (ASTM D2487 and AASHTO M-145)
2. In addition to testing of untreated soils, Atterberg limits shall be performed on treated fine-grained soils for the purposes of measuring plasticity index reduction, in accordance with OHD L-51 "Soil Modification Mix Design Procedure", section B, as further detailed in Section X.
3. Soluble sulfate content (OHD L-49), detailed in Section IX
4. Moisture-density relationships (Standard Proctor) (ASTM D698 or AASHTO T-99), detailed in Section XI
5. Unconfined compressive strength (UCS) tests (ASTM D2166 or AASHTO T-208), detailed in Section XII
6. Swell testing (ASTM D4546, Test Method B), detailed in Section XIII

All testing shall conform to the specified standards except as noted herein. For the purposes of this approval process, results of testing according to either the ASTM or AASHTO standards are considered as equivalent. For each test, report all the minimum required elements listed within the standard and elements outlined herein.

Proctor, UCS, and swell testing shall be performed on the fraction passing the #10-sieve. The fraction retained on the #10-sieve shall be reported and included in the soil classification.

These listed tests are a minimum, and as stated earlier, the Materials Division's Geotechnical Engineer may, at their discretion, request tests be performed other than those listed above. Laboratory tests listed above shall be performed for each of the following soil groups: A-2, A-3, A-4, A-5, A-6, and A-7. Exceptions to this shall be requested in writing and submitted to the Materials Division's Geotechnical Engineer. For example, in the case where a stabilization agent supplier may already know their product is suitable only for select soil groups, this process may be abbreviated to include only those groups.

Special Treatment Protocols

If the proposed stabilizer has special use requirements for certain cases, these shall be detailed and provided in writing and approved by the Materials Division's Geotechnical Engineer before use. In order

to determine the net benefit of the proposed stabilizer, testing shall be performed both with and without the special treatment protocol.

1. For example, if when treating a high plasticity clay, it is recommended to use 5% of the candidate stabilizer plus 3% hydrated lime, testing shall be performed with these rates, but testing shall also be performed with only the 3% hydrated lime, to roughly determine the net benefit of the candidate stabilizer.

2. For example, if high-sulfate soils are recommended to be mellowed for 7 days before compaction, testing of high-sulfate soils shall be performed over a range of mellowing periods to determine the net benefit of using the product apart from a lengthy mellowing time.

The above cases are only examples.

VIII. Sulfates

All soils used for the evaluation of the candidate stabilizer shall be tested for soluble sulfates in accordance with OHD L-49. If compatibility of the candidate stabilizer with high sulfate soils is not of interest, ensure all the soils have a soluble sulfate concentration below 1,000 ppm.

Evaluation of Candidate Stabilization Agent with High Sulfate Soils

If one of the goals of the stabilizer evaluation process is to demonstrate compatibility of the stabilizer with high-sulfate soils, this shall be accomplished by testing soils over a range of sulfate contents. These soils should be created by adding organic pulverized agricultural gypsum to the soil. The gypsum is readily available from suppliers and shall be processed to pass the #40 sieve before adding to the soil.

The suggested range of sulfate contents are: at 1000-1500 ppm, 3000 +/-500 ppm, and 8000 +/-500 ppm. The soluble sulfate content shall be measured according to OHD L-49. The target and measured sulfate concentration shall be reported.

For each soil group evaluated as part of this process, the corresponding full battery of tests shall be performed for the high sulfate soils as well. Swell testing is of particular importance in this situation and shall not be omitted. Any exception shall be requested in writing and submitted to the Materials Division's Geotechnical Engineer.

IX. Plasticity Index (PI) Reduction

All testing shall conform to either ASTM D4318 or AASHTO T-89 and T-90 except as noted herein. For the purposes of this approval process, results of testing according to either of these standards are considered as equivalent. Any exception to these test standards shall be requested in writing and submitted to the Materials Division's Geotechnical Engineer.

PI reduction testing shall follow the procedure described in section B of OHD L-51 "Soil Modification Mix Design Procedure." A plot of the PI versus stabilizer application rate will tend to level off as the rate increases. Increasing stabilizer application rate beyond this point will yield negligible reduction in PI. The optimum rate is defined as the rate at which the PI is reduced by 2% per 1% increase in stabilizer application rate. (The slope of the curve is -2.) The candidate stabilizer shall be considered effective for

modification of a particular soil if it can reduce the plasticity index to 10 or less, when applied at less or equal to the optimum rate.

NOTE: PI reduction testing only yields useful results and should only be performed on soils that have an untreated PI of greater than 10.

PI Reduction Reporting

For each specimen, report all the minimum required elements listed within the standard and OHD L-51.

X. Moisture-Density Relationships

All testing shall conform to either ASTM D698 or AASHTO T-99 except as noted herein. For the purposes of this approval process, results of testing according to either of these standards are considered as equivalent. Any exception to these test standards shall be requested in writing and submitted to the Materials Division's Geotechnical Engineer.

Specific to this approval process are the following additional requirements:

1. Testing shall be performed on the soil fraction passing the #10-sieve.

2. Application of the stabilizer to the soil shall follow the supplier's written directions.

3. If the compaction properties of the treated soil change during testing due to the action of the stabilizer, a separate sample shall be mixed and compacted for each moisture content, i.e., material shall not be reused.

Ensure moisture-density relationships are determined for all application rates, and sulfate concentrations if applicable, prior to any unconfined compression test or swell test specimens being molded. For example, it is not acceptable to mold a specimen with 4% Portland cement using the untreated soil's moisture-density curve.

Moisture-Density Relationship Reporting

For each specimen, report all the minimum required elements listed within the standard. In addition, the following shall be reported:

1. Stabilizer application rate

2. Sulfate concentration, if high-sulfate soils are being tested

3. Details of any mellowing before compaction

4. A zero air voids (100% saturation) curve shall be plotted with each moisture-density curve, using an assumed specific gravity of 2.7.

5. Any other relevant notes

XI. Unconfined Compressive Strength (UCS) Testing

All testing shall conform to either ASTM D2166 or AASHTO T-208 except as noted herein. For the purposes of this approval process, results of testing according to either of these standards are considered as equivalent. Any exception to these test standards shall be requested in writing and submitted to the Materials Division's Geotechnical Engineer.

Specific to this approval process are the following additional requirements:

1. Testing shall be performed on the soil fraction passing the #10-sieve.

2. All specimens shall be compacted to 95% maximum dry density +/- 1 pcf and optimum moisture content +/- 1%. Specimens shall be prepared with a minimum of five (5) layers to ensure uniformity, scarifying between layers. The targeted optimum moisture and maximum dry density shall be that obtained from the Standard Proctor test (see above) for the appropriate soil, application rate, and sulfate concentration.

3. Application of the stabilizer to the soil shall follow the supplier's written directions.

4. At least six (6) replicate specimens shall be compacted and cured for each soil and application rate. Kneading or static compaction are acceptable. All specimens shall have a 2:1 length to diameter ratio.

5. Specimens shall be cured according to OHD L-50, unless otherwise approved by the Materials Division's Geotechnical Engineer. After five (5) days of curing, three (3) of the specimens shall be unwrapped, weighed, and immersed in water for two (2) days prior to UCS testing. After the immersion period, any slaking shall be noted, and intact specimens shall be removed from the water, blotted dry, weighed, and tested in unconfined compression.

6. Specimens that slake or otherwise deteriorate during the immersed stage of curing to the extent that they cannot be tested in compression are considered to have zero (0) psi compressive strength.

7. Specimens and testing shall conform to specifications of the standards, including, but not limited to, strain rate and length to diameter ratio, except as noted herein (such as the use of passing #10 material).

8. Ensure, to the extent practical, the same technician completes any given set of UCS tests to avoid potential variability between technicians so that precision and bias may be controlled as much as possible.

UCS Reporting

For each specimen, report all the minimum required elements listed within the standard. In addition, the following shall be reported:

1. Stabilizer application rate

2. Soluble sulfate concentration, if applicable

3. Details of any mellowing before compaction

4. Dry density and moisture content after compaction

5. Percent relative compaction (percent of maximum standard density)

6. Change in mass during curing

7. Whether the specimen was immersed or not

8. Percent moisture absorption and loss in mass of solids during immersion

9. Any other relevant notes

Multiple tests may be reported on a single stress vs. strain graph provided it is clear and the grouping of the specimens is logical. For example, graphing all three (3), 7-day cured specimens at a given application rate is acceptable, but multiple specimens with different application rates and different curing conditions onto one (1) graph is not. Do not place more than three (3) stress vs. strain curves onto one graph. Good practices should be followed, such as using clear legends, labels, units, captions, etc.

For specimens which are immersed in water, provide photos of them before and after UCS testing regardless of if they slake or not. Using a clear container for specimen immersion is recommended.

XII. Swell Testing

All testing shall conform to ASTM D4546 Test Method B except as noted herein. Any exception to these test standards shall be requested in writing and submitted to the Materials Division's Geotechnical Engineer. The specific steps below are intended to follow many of the steps in standard ASTM D3877.

Swell testing shall be performed on each soil group for which the candidate stabilizer is requesting approval for.

If the candidate stabilizer is not being evaluated for its effectiveness in controlling sulfate-induced heave, then each soil group shall be tested for swell at an application rate of 0% and the rate required to achieve sufficient strength gain as per OHD L-50. (i.e. 2 swell tests per soil group). Testing is indicated by the letter "A" in the table below.

If the candidate stabilizer is also being evaluated for its effectiveness in controlling sulfate-induced heave, then swell testing shall be performed as indicated in the preceding paragraph. In addition, swell testing shall be performed on untreated and treated soils with sulfate concentrations of 1,000-1,500 ppm, 3,000 +/-500 ppm, and 8,000 +/-500 ppm for each soil group. (i.e. total of 8 swell tests per soil group). Testing is indicated by the letters "A" and "B" in the table below.

If the candidate stabilizer requires a special treatment protocol, such as mellowing, then swell testing shall be performed as indicated in the preceding two paragraphs. In addition, the special treatment protocol shall be applied to high-sulfate, treated soils (i.e. total of 11 swell tests per soil group). Testing is indicated by the letters "A," "B," and "C" in the table below.

	Required Swell Testing Per Soil Group			
	Sulfate Concentration (ppm)			
	All Soils	Additional testing for high-sulfate soils		
	<1,000 (low-sulfate soils)	1,000 – 1,500	3,000 (+/-500)	8,000 (+/-500)
Untreated	A	B	B	B
Treated	A	B	B	B
Treated + special treatment protocol	-	C	C	C

Specific to this approval process are the following additional requirements:

1. Testing shall be performed on the soil fraction passing the #10-sieve.

2. All specimens shall be compacted to 95% maximum dry density +/- 1 pcf and optimum moisture content +/- 1%. Specimens shall be either:

   a. compacted and trimmed in the specimen ring with a minimum of three (3) layers to ensure uniformity, with scarifying between lifts; or

   b. trimmed from a larger compacted specimen. The specimen shall be trimmed from a single lift of the larger specimen, such as the second lift of a Proctor-sized specimen.

3. The targeted optimum moisture and maximum dry density shall be that obtained from the Standard Proctor test (see above) for the appropriate soil, application rate, and sulfate concentration.

4. Application of the stabilizer to the soil shall follow the supplier's written directions.

5. Specimens shall be trimmed flush with the top and bottom of the specimen rings, then weighed. The ring and specimen shall then be wrapped in plastic wrap and allowed to cure in the same manner as the UCS specimens, unless otherwise approved by the Materials Division's Geotechnical Engineer. Untreated specimens shall be cured in the same manner.

6. After curing, the specimen and ring shall be weighed and height measured to check for moisture change and swelling during curing. Provide three (3) measurements.

7. Using a recess spacer disc, partially extrude the specimen from the bottom of the ring, then trim the bottom surface of the specimen flush with the bottom of the ring. Weigh the newly trimmed specimen and ring before beginning the test.

NOTE: The depth of the specimen recess shall be sufficient to accommodate swelling during the inundated portion of the test. A typical recess depth is 0.10 inch.

8. Swell tests shall be performed at a stress of 100 +/-10 psf.

   NOTE: This stress is intended to simulate the overburden stress due to 8" of asphaltic concrete.

9. Ensure, to the extent practical, the same technician completes any given set of swell tests to avoid potential variability between technicians so that precision and bias may be controlled as much as possible.

Swell Test Reporting

For each specimen, report all the minimum required elements listed within the standard. In addition, the following shall be reported:

1. Stabilizer application rate
2. Soluble sulfate concentration, if applicable
3. Details of any mellowing before compaction
4. Method of specimen compaction
5. Percent of maximum standard density
6. Change in moisture content and percent swell or shrinkage during curing
7. Using percent strain in the graphs is preferred as opposed to void ratio
8. Any other relevant notes

Total swell is the percent swell during curing plus the percent swell during inundated consolidometer testing.

To be considered effective for stabilizing shrink-swell behavior for a particular soil and application rate, the total swell of a treated specimen shall be less than or equal to the total swell of the corresponding untreated specimen (with or without sulfates) or less than 6.25%, whichever is less.