Design Procedures for Soil Modification or Stabilization

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1.0 General

It is the policy of the Indiana Department of Transportation to minimize the disruption of traffic patterns and the delay caused today's motorists whenever possible during the construction or reconstruction of the State's roads and bridges. INDOT Engineers are often faced with the problem of constructing roadbeds on or with soils, which do not possess sufficient strength to support wheel loads imposed upon them either in construction or during the service life of the pavement. It is, at times, necessary to treat these soils to provide a stable subgrade or a working platform for the construction of the pavement. The result of these treatments are that less time and energy is required in the production, handling, and placement of road and bridge fills and subgrades and therefore, less time to complete the construction process thus reducing the disruption and delays to traffic.

These treatments are generally classified into two processes, soil modification or soil stabilization. The purpose of subgrade modification is to create a working platform for construction equipment. No credit is accounted for in this modification in the pavement design process. The purpose of subgrade stabilization is to enhance the strength of the subgrade. This increased strength is then taken into account in the pavement design process. Stabilization requires more thorough design methodology during construction than modification. The methods of subgrade modification or stabilization include physical processes such as soil densification, blends with granular material, use of reinforcements (Geogrids), undercutting and replacement, and chemical processes such as mixing with cement, fly ash, lime, lime by-products, and blends of any one of these materials. Soil properties such as strength, compressibility, hydraulic conductivity, workability, swelling potential, and volume change tendencies may be altered by various soil modification or stabilization methods.

Subgrade modification shall be considered for all the reconstruction and new alignment projects. When used, modification or stabilization shall be required for the full roadbed width including shoulders or curbs. Subgrade stabilization shall be considered for all subgrade soils with CBR of less than 2.

INDOT standard specifications provide the contractor options on construction practices to achieve subgrade modification that includes chemical modification, replacement with aggregates, geosynthetic reinforcement in conjunction with the aggregates, and density and moisture controls. Geotechnical designers have to evaluate the needs of the subgrade and include where necessary, specific treatment above and beyond the standard specifications.

Various soil modification or stabilization guidelines are discussed below. It is necessary for designers to take into consideration the local economic factors as well as environmental conditions and project location in order to make prudent decisions for design.

It is important to note that modification and stabilization terms are not interchangeable.

2.0 Modification or Stabilization of Soils

2.01 Mechanical Modification or Stabilization

This is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material.

A common remedial procedure for wet and soft subgrade is to cover it with granular material or to partially remove and replace the wet subgrade with a granular material to a pre-determined depth below the grade lines. The compacted granular layer distributes the wheel loads over a wider area and serves as a working platform. (1)

To provide a firm-working platform with granular material, the following conditions shall be met.

1. The thickness of the granular material must be sufficient to develop acceptable pressure distribution over the wet soils.

2. The backfill material must be able to withstand the wheel load without rutting.

3. The compaction of the backfill material should be in accordance with the Standard Specifications.

Based on the experience, usually 12 to 24 in. (300 to 600mm) of granular material should be adequate for subgrade modification or stabilization. However, deeper undercut and replacement may be required in certain areas

The undercut and backfill option is widely used for construction traffic mobility and a working platform. This option could be used either on the entire project or as a spot treatment. The equipment needed for construction is normally available on highway construction projects.

2.02 Geosynthetic Stabilization

Geogrid has been used to reinforce road sections. The inclusion of geogrid in subgrades changes the performance of the roadway in many ways (6). Tensile reinforcement, confinement, lateral spreading reduction, separation, construction uniformity and reduction in strain have been identified as primary reinforcement mechanisms. Empirical design and post-construction evaluation have lumped the above described benefits into better pavement performance during the design life. Geogrid with reduced aggregate thickness option is designed for urban area and recommendations are follows;

Excavate subgrade 9 in. (230 mm) and construct the subgrade with compacted aggregate No. 53 over a layer of geogrid, Type I. This geogrid reinforced coarse aggregate should provide stable working platform corresponding to 97 percent of CBR. Deeper subgrade problem due to high moisture or organic soils requires additional recommendations.

Geogrid shall be in accordance with 918.05(a) and be placed directly over exposed soils to be modified or stabilized and overlapped according with the following table.

SPT blow Counts per foot (N)	Overlap
> 5	12 in. (300 mm)
3 to 5	18 in. (450 mm)
less than 3	24 in. (600 mm)

2.03 Chemical Modification or Stabilization

The transformation of soil index properties by adding chemicals such as cement, fly ash, lime, or a combination of these, often alters the physical and chemical properties of the soil including the cementation of the soil particles. There are the two primary mechanisms by which chemicals alter the soil into a stable subgrade:

1. Increase in particle size by cementation, internal friction among the agglomerates, greater shear strength, reduction in the plasticity index, and reduced shrink/swell potential.

2. Absorption and chemical binding of moisture that will facilitate compaction.

3.0 Design Procedures

3.01 Criteria for Chemical Selection

When the chemical stabilization or modification of subgrade soils is considered as the most economical or feasible alternate, the following criteria should be considered for chemical selection based on index properties of the soils. (2)

1. Chemical Selection for Stabilization.

    a. Lime: If PI > 10 and clay content (2μ) > 10%.

    b. Cement: If PI ≤ 10 and < 20% passing No. 200.

    Note: Lime shall be quicklime only.

2. Chemical Selection for Modification

    a. Lime: PI ≥ 5 and > 35 % Passing No. 200

    b. Fly ash and lime fly ash blends: 5 < PI < 20 and > 35 % passing No. 200

    c. Cement and/ or Fly ash: PI < 5 and ≤ 35 % Passing No. 200

    Fly ash shall be class C only.
    Lime Kiln Dust (LKD) shall not be used in blends.
    Appropriate tests showing the improvements are essential for the exceptions listed above.

3.02 Suggested Chemical Quantities For Modification Or Stabilization

a. Lime or Lime By-Products: 4% to7 %

b. Cement: 4% to 6%

c. Fly ash Class C: 10% to 16%

% for each combination of lime-fly ash or cement-fly ash shall be established based on laboratory results.

3.03 Strength requirements for stabilization and modification

The reaction of a soil with quick lime, or cement is important for stabilization or modification and design methodology. The methodology shall be based on an increase in the unconfined compression strength test data. To determine the reactivity of the soils for lime stabilization, a pair of specimens measuring 2 in. (50 mm) diameter by 4 in. (100 mm) height (prepared by mixing at least 5% quick lime by dry weight of the natural soil) are prepared at the optimum moisture content and maximum dry density (AASHTO T 99). Cure the specimens for 48 hours at 120^o F (50^o C) in the laboratory and test as per AASHTO T 208. The strength gain of lime-soil mixture must be at least **50 psi** (350 kPa) greater than the natural soils. A strength gain of **100 psi** (700 kPa) for a soil-cement mixture over the natural soil shall be considered adequate for cement stabilization with 4% cement by dry weight of the soils and tested as described above

In the case of soil modification, enhanced subgrade support is not accounted for in pavement design. However, an approved chemical (LKD, cement, and fly ash class C) or a combination of the chemicals shall attain an increase in strength of **30 psi** over the natural soils when specimens are prepared and tested in the same manner as stabilization.

4.0 Laboratory Test Requirements

Soil Sampling and Suitability: An approved Geotechnical Engineer should visit the project during the construction and collect a bag sample of each type of soil in sufficient quantity for performing the specified tests. The geotechnical engineer should review the project geotechnical report and other pertinent documents such as soil maps, etc., prior to the field visit. The geotechnical consultant shall submit the test results and recommendations, along with the current material safety data sheet or mineralogy to the engineer for approval.

When the geotechnical engineer determines the necessity of chemical-soil stabilization during the design phase, they should design a subgrade treatment utilizing the chemical for the stabilization in the geotechnical report in accordance with INDOT guidelines. Following tests should be performed and the soils properties should be checked prior to any modification or stabilization.

a. Grain size and Hydrometer test results in accordance with AASHTO T 89, 90, and M145,

b. Atterberg limits,

c. Max. Dry unit weight of 92 pcf (Min.) in accordance with AASHTO T 99,

d. Loss of ignition (LOI) not more than 3% by dry weight of soil in accordance with AASHTO T 267,

e. Carbonates not more than 3 % by dry weight of the soils, if required,

f. As received moisture content in accordance with AASHTO T 265.

4.01 <u>Lime or Lime By-Products Required for Modification or Stabilization</u>.

Lime reacts with medium, moderately fine and fine-grained soils to produce decreased plasticity, increased workability, reduced swelling, and increased strength. The major soil properties and characteristics that influence the soils ability to react with lime to produce cementitious materials are pH, organic content, natural drainage, and clay mineralogy. As a general guide, treated soils should increase in particle size with cementation, reduction in plasticity, increased in internal friction among the agglomerates, increased shear strength, and increased workability due to the textural change from plastic clay to friable, sand like material.

The following procedures shall be utilized to determine the amount of lime required to stabilize the subgrade. Hydrated or quick lime and lime by-products should be used in the range of 4 ± 0.5% and 5 ± 1% by weight of soil for modification respectively. The following procedures shall be used to determine the optimum lime content.

Perform mechanical and physical tests on the soils.

Determine the separate pH of soil and lime samples.

Determine optimum lime content using Eades and Grim pH test.

- A sufficient amount of lime shall be added to soils to produce a pH of 12.4 or equal to the pH of lime itself. An attached graph is plotted showing the pH as lime content increases. The Optimum lime content shall be determined corresponding to the maximum pH of lime-soil mixture. (See Figure 4.0 A).

- Representative samples of air-dried, minus No. 40 soil is equal to 20 g of oven-dried soil are weighed to the nearest 0.1 g and poured into 150-ml (or larger) plastic bottles with screw on tops.

- It is advisable to set up five bottles with lime percentages of 3, 4, 5, 6, and 7. This will insure, in most cases, that the percentage of lime required can be determined in one hour. Weigh the lime to the nearest 0.01 g and add it to the soil. Shake the bottle to mix the soil and dry lime.

- Add 100 ml of CO_2-free distilled water to the bottles.

- Shake the soil-lime mixture and water until there is no evidence of dry material on the bottom. Shake for a minimum of 30 seconds.

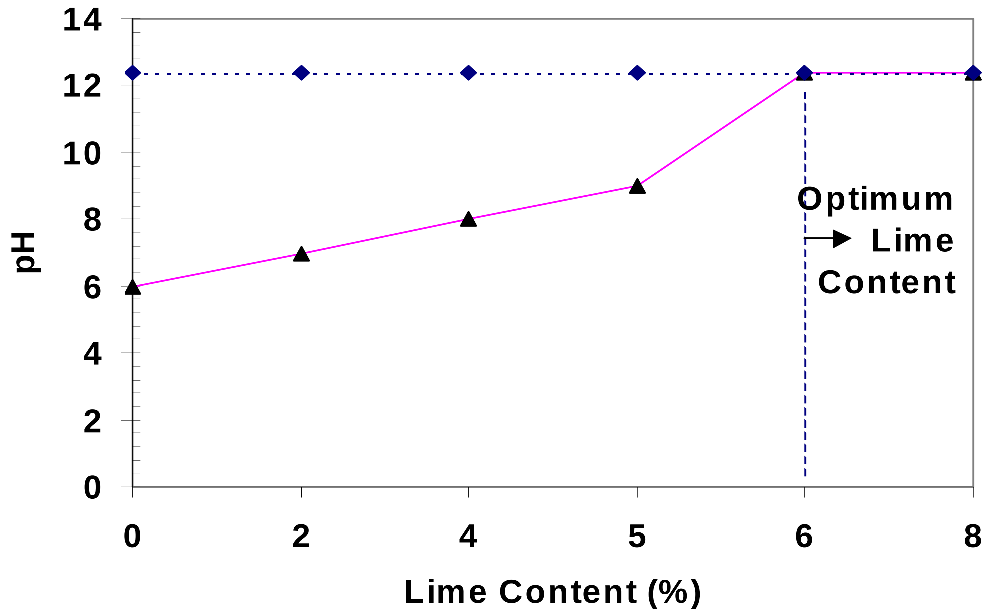
- Shake the bottles for 30 seconds every 10 minutes.

- After one hour, transfer part of the slurry to a plastic beaker and measure the pH. The pH meter must be equipped with a Hyalk electrode and standardized with a buffer solution having a pH of 12.00.

- Record the pH for each of the lime-soil mixtures. If the pH readings go to 12.40, then the lowest percent lime that gives a pH of 12.40 is the percentage required to stabilize the soil. If the pH does not go beyond 12.30 and 2 percentages of lime give the same readings, the lowest percent which gives a pH of 12.30 is the amount required to stabilize the soil. If the highest pH is 12.30 and only 1 percent lime gives a pH of 12.30, additional test bottles should be started with larger percentages of lime.

d. Atterberg limits should be performed on the soil-lime mixtures corresponding to optimum lime content as determined above.

e. Compaction shall be performed in accordance with AASHTO T 99 on the optimum lime and soil mixture to evaluate the drop in maximum dry density in relation to time (depending on the delay between the lime-soil mixing and compaction.)



pH vs. Lime Content

Figure 4.0 A

In the case of stabilization, the Unconfined Compression Test (AASHTO T 208) and California Bearing Ratio (AASHTO T 193, soaked) or resilient modulus (AASSHTO T 307) tests at 95% compaction shall be performed in addition to the above tests corresponding to optimum lime-soil mixture of various predominant soils types.

4.02 Cement Required for Stabilization or Modification

The criteria for cement percentage required for stabilization shall be as follows. The following methodology shall be used for quality control and soil-cement stabilization.

1. Perform the mechanical and physical property tests of the soils.

2. Select the Cement Content based on the following:

AASHTO Classification	Usual Cement Ranges for Stabilization (% by dry weight of soil)
A-1-a	3 – 5
A-1-b	5 – 8
A-2	5 – 9
A-3	7 – 10

Suggested Cement Contents
Figure 4.0B

3. Perform the Standard Proctor on soil-cement mixtures for the change in maximum dry unit weight in accordance with AASTO T 134.

4. Perform the unconfined compression and CBR tests on the pair of specimens molded at 95% of the standard Proctor in case of stabilization. A gain of 100 psi of cement stabilization is adequate enough for stabilization and % cement shall be adjusted.

Although, there is no test requirement for the optimum cement content when using cement to modify the subgrade. An amount of cement 4% ± 0.50% by dry weight of the soil should be used for the modification of the subgrade.

4.03 Fly Ash Required for Modification

1. The in-situ soils should meet the criteria for modification.

2. Standard Proctor testing should be performed in accordance with AASHTO T 99 to determine the maximum dry density and optimum moisture content of the soil.

3. A sufficient amount of fly ash (beginning from 10% by dry weight of soil) should be mixed with the soil in increments of at least 5%. The moisture content of the mix shall be in the range of optimum moisture content + 2%. Each blend of the fly ash soil mixture should be compacted as per the standard Proctor to determine the maximum dry density.

4. The compaction of the mixes shall be completed within 2 hours.

5. The percentage of fly ash, which provides the maximum dry density, should be considered the **optimum amount of fly ash** for that soil.

6. The compressive strength of the **optimum fly ash mix** should be determined 2, 4, and 8 hours after compaction.

7. A pair of specimens of the **optimum fly ash** mix should be molded of standard Proctor and soaked for 4 days. The swelling should be observed daily. A percentage swell of more than 3 not be allowed in soils modification.

4.04 Combination of Cement Fly Ash and Lime Mixture

To enhance the effectiveness of lime, cement or fly ash modification or stabilization combinations, the subsequent guidelines shall be used. An increase of **50 to 100 psi** over the natural soil is required for the stabilization and an increase of **30 psi** over the natural soils is required for modification.

1. Lime and Fly ash: The ratio between lime and fly ash mixture should be in the range of 1:1 to 1:9 respectively.

2. Cement and Fly ash: The ratio of cement and fly ash should be in the range of 1:3 to 1:4 respectively.

3. Lime, cement, and fly ash ratio should be 1:2:4 respectively.

5.0 Construction Considerations

Modification of soils to speed construction by drying out wet subgrades with lime, cement and fly ash is not as critical as completely stabilizing the soil to be used as a part of the pavement structure. With the growth of chemical modification throughout Indiana, a variety of applications are being suggested due to such factors as soil types, percentage of modification/stabilization required, environmental restraints, and availability of chemicals. Furthermore, when chemically stabilized subgrades are used to reduce the overall thickness of the roadway then the stabilized layer must be built under tight construction specifications; whereas the requirements for the construction of a working platform are more lenient. Following are a few recommendations for modification or stabilization of subgrade soils.

1. Perform recommended tests on each soil to see if the soil will react with chemicals then determine the amount of chemical necessary to produce the desired results.

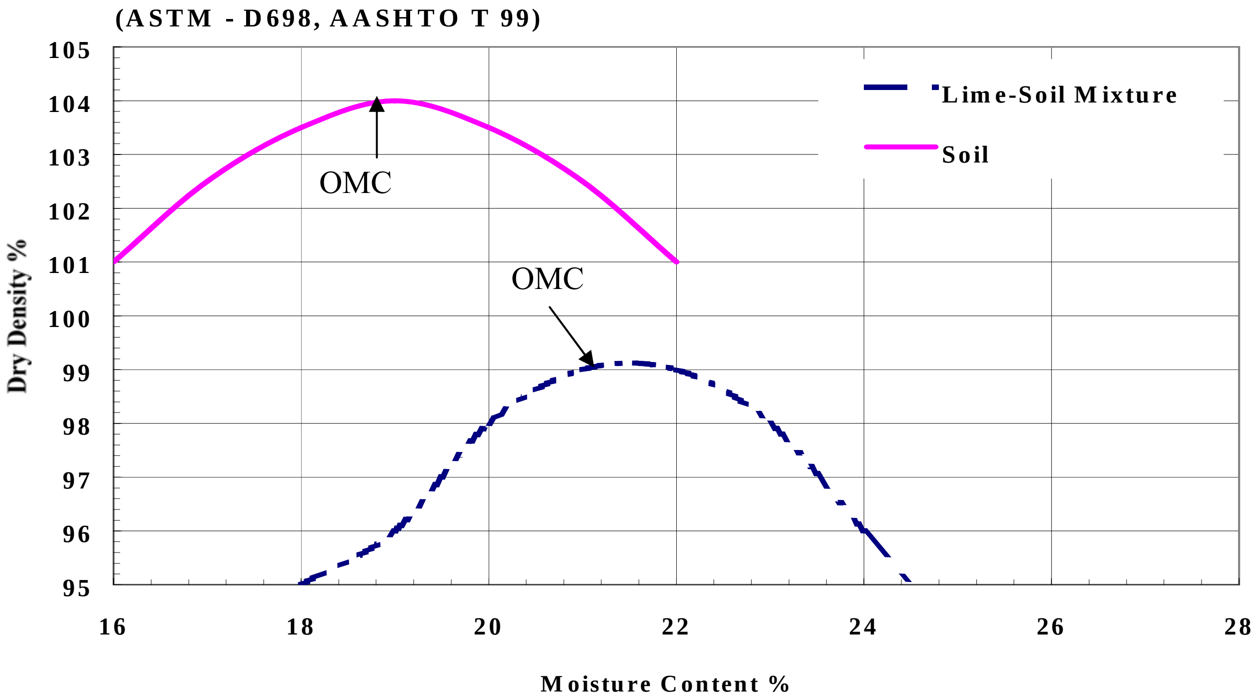
2. More chemicals may not always give the best results.

3. Sulfate, when mixed with calcium will expand. Soils having over 10% sulfate content shall not be mixed with chemicals.

4. Chemicals used shall meet the INDOT Standard Specifications.

5. One increment of chemical is recommended to produce a working platform. Proofrolling is required before placing the base or subbase. Pavement shall not be installed before curing is completed.

6. The density of cement treated soils may likely be different than that of untreated soils. Standard Proctor tests should be performed in the laboratory to estimate the appropriate target density.



Moisture Density Relationship
Figure 5.0 A

7. The grade should be set low to account for the swell in the lime. A swell factor of 10% is an approximate estimate.

8. Uniform distribution of chemical, throughout the soil is very important.

9. Curing takes 7 days of 50^{o} F or above weather for stabilization. No heavy construction equipment should be allowed on the stabilized grade during the curing period.

10. The maximum dry density of the soil-lime mixture is lower than in untreated soils. Maximum dry density reduction of 3-5 Pcf approximately, is common for a given compactive effort. It is, therefore, important that the laboratory for field control purposes provide appropriate density. (See Figure 5.0A).

11. The modified or stabilized roadbed must be covered with pavement before suspending work for the winter and construction traffic shall be limited

12. Cement or fly ash treated soils exhibit shrinkage cracks due to soil type, curing, chemical contents, etc. Therefore, it is recommended to provide surface sealing on stabilized subgrade after the curing period.

13. Moisture content of modified or stabilized subgrade should be maintained above the optimum moisture content of modified subgrade during the curing.

14. Lime raises the pH of the soil. Phenolphthalein, a color sensitive indicator solution can be sprayed on the soil to determine the presence of lime. If lime is present, a reddish-pink color develops. (See Figure 5.0B).

Lime Modified Subgrade Uniformity Determination by Phenolphthalein
Figure 5.0B

15. Because lime can cause chemical burns, safety gear, such as gloves, eye protection, and dust masks shall be used during construction and inspection.

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