Chemical Treatment of Subgrades
For Constructability and Performance
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Mt. Carmel Stabilization Group, Inc.
What Took so Long???
What are We Talking About Here Today...
Chemical Stabilization is Not New
The Stabilization Family

- Soil Drying
- Chemical Stabilization
- Soil Modification
- Soil Stabilization
- Depth Reduction
Presentation Outline

• Soils and Subgrade Basics Overview
  • What makes soil “good”? What makes “poor soil”?
  • What Impact does that have on your project?
  • What options do you have?

• How Stabilization Chemicals work with soils
  • Drying, Modification and Stabilization
  • Different Chemicals based on various factors

• Designing with Soil Stabilization (Planning Ahead)

• The Construction Process for Chemical Stabilization
Goals Today

• Understand how different soils behave.
• Know options for dealing with poor subgrade soils.
• Understand the different chemicals used to treat subgrade soils.
• To be confident in evaluating your subgrade pre-construction and during construction.
• To be educated enough to speak intelligently about chemical stabilization of soils.
Soils Basics
Soils 101

• Every soil has a classification, proctor and Atterberg limits.
• Proctor is moisture and density information for compaction purposes.
• Atterberg Limits
  • Liquid Limit
  • Plastic Limit
  • Plasticity Index
    • PI tells us a lot when it comes to stabilization and chemical selection.
# Soils Classification

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Unified Group Symbol</th>
<th>AASHTO Group Classification</th>
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### Soils Type
- **Peat, muck, and other highly organic soils**
- **AASHTO Group Classification**

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The Proctor Curve

1. Typical specification is 95% maximum density.
2. If moisture is too high density is impossible to achieve.
3. High moisture = poor compaction.
4. Undercutting or Stabilization is common solution.

OMC = 17%
Atterberg Limits

• Liquid Limit – Moisture content at which the soil behaves like a liquid.
• Plastic Limit – Moisture Content at which the soil exhibits plastic behavior.
• Plasticity Index is: $LL - PL = PI$

Basic PI Chart

<table>
<thead>
<tr>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>Low – Medium 5-20</td>
<td>High 20-50+</td>
</tr>
</tbody>
</table>
PI and Clay Content is Critical

• Clay is primarily Silica and Alumina, sand and silt have little or none of either.

• This makes the soil clay content and the PI absolutely critical to understand what chemical will, or will not work for stabilization applications.

• My first questions are always 1) What are you trying to do? 2) soil type, 3) moisture and 4) schedule.
Subgrade Basics
The Role of The Subgrade

• The subgrade is anything underneath the pavement or foundation and base.

• Typically built up with on-site excavated soils for elevation.
The Role of The Subgrade

- The subgrade layer is vital to constructability and performance of pavement or foundation.
- Subgrade soil conditions are a major problem in construction.

The subgrade layer is vital to constructability and performance of pavement or foundation.

Subgrade soil conditions are a major problem in construction.
1) Soil Stabilization is primarily a subgrade treatment application.

2) Subgrade Problems are the #1 cause of major change orders in earthwork construction.

3) This leads to unanticipated (unbudgeted) cost and significant changes in the scope of work and SCHEDULE.

4) Surface performance, durability and quality are greatly influenced by subgrade conditions.
Stability vs. Soil Type & Moisture

• All soils are different but have 1 thing in common:
  • Higher Moisture Content = Reduced Stiffness.
• Some are more stable than others near OMC, i.e. sands, clays.
• Others are unstable even at or near OMC, i.e. silts, silty clays.
• If constructed conventionally, subgrade soils follow seasonal cycles for moisture and thus stiffness, strength varies with the season.
Most Common Subgrade Treatment Types
Common Subgrade Recommendations

• “In areas of the proposed field, the existing soil is high in moisture and subsequently weak. Those soils should be undercut to a depth of 3’-4’ and replaced with granular fill.”

• “The subgrade should be proof rolled prior to placing base course. All weak areas should be marked and undercut to a depth of 3’ and replaced with granular fill.”

• Reminder: 1,000 CY of excavation = 100 truck loads of export and 100 truck loads of import. Total of 200 loads for 1,000 CY.
Stabilization vs. Undercut

- Lime, Cement, Other chemicals can be used based on soil type and condition.
- Early strength gives stability needed quickly.
- Provides uniform load distribution for base, pavement.
- Fraction of the time and cost of undercutting.
Soil Stabilization at a Glance

• SS is essentially chemically engineering existing poor soil into a high performance material.
• We treat the unsuitable soils in place.
• We use the appropriate chemical for the soil types...
• At the appropriate application rate...
• Mix thoroughly to a depth up to 16”...
• Then compact, shape and seal.
Materials and Applications
Materials and Construction Procedures

• In soil stabilization applications, the largest contributing factors to performance and success are:

  1. Materials Used (chemicals)
  2. Construction Procedures
  3. Equipment
  4. Contractor Experience
Stabilization Chemicals

• There are many different chemicals used to accomplish drying, modification and stabilization.

• With few exceptions, materials can be divided into 2 categories:
  • Lime based products
    • Quicklime
    • Lime Kiln Dust
  • Portland Cement and Cement Blends
Material Performance

• We base performance on 3 criteria:
  1. **Drying** – Moisture Reduction
  2. **Modification** – The ability of the chemical to react with the soils to create a solid working platform quickly. Modification is soil and condition dependent.
  3. **Stabilization** – Long term strength gains that gives a pavement subgrade higher design strength and service life durability.

• Most common chemicals are **Quicklime**, **Portland Cement** and **Lime Kiln Dust (LKD)**. Fly Ash in some markets.
Lime Products Superior Drying

• Lime based products are by far and away the most effective in soil drying applications.
• This is because of their tremendous thirst for moisture and because of available lime (available CaO).
• A lot of chemicals look similar chemically but available CaO is the major difference.
Chemistry is The Key to Performance

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>90% - 95%</td>
</tr>
<tr>
<td>Available CaO</td>
<td>85% - 90%</td>
</tr>
<tr>
<td>Gradation</td>
<td>¼” x 0</td>
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</tbody>
</table>

Quicklime

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>60% - 67%</td>
</tr>
<tr>
<td>SiO₂</td>
<td>19% - 23%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>2% - 6%</td>
</tr>
<tr>
<td>Gradation</td>
<td>85% &lt; 325 Mesh</td>
</tr>
</tbody>
</table>

Portland Cement

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>50 – 65%</td>
</tr>
<tr>
<td>Available CaO</td>
<td>35-45%</td>
</tr>
<tr>
<td>SiO₂</td>
<td>5 – 8%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>3 – 8%</td>
</tr>
<tr>
<td>Gradation</td>
<td>75% &lt; 200 Mesh</td>
</tr>
</tbody>
</table>

Lime Kiln Dust
Why are Lime Products so Effective in Drying?

CaO + MgO + H₂O → Ca(OH)₂ + Mg(OH)₂

Lime + Water → Hydrated Lime

- Lime Products absorb 30-40% of their weight in water during hydration.
- That hydration lets off heat, driving off additional moisture through increased evaporation.
- The key to the reaction is the “Available CaO”.
Soil Drying - Construction

- Used primarily for treating fill soils.

- Typically a spread & mix operation only and we add just enough lime to dry the soil to facilitate grading operations.

- No strength or stability requirement for treated soil, only treating for moisture reduction.

- Widely used on mass grading projects, building pads, etc.
Lime Drying/Modification in Cold Weather
Drying Project Example

• Bexley, OH Running Track
  • Subgrade had passed proof roll and then had multiple heavy rains prior to surface.
  • Surface would not dry.
  • 5% LKD applied to 12” depth to dry the subgrade so surface could be applied.
Performance - Soil Modification

• Soil Modification encompasses a number of benefits including:
  • Moisture reduction (drying)
  • Plasticity reduction
  • OMC Increase
  • Reduction or elimination of swell potential
  • Improved stability
  • Solid working platform
Chemical Modification

• Chemical Modification is the most common stabilization application and is the most widely used.

• Chemical Modification is the immediate results that you see in the field during and after our operation.

• Typically use more lime for Modification than drying and the end product is a physically modified soil and stable subgrade that is weather resistant.

• Cement is commonly used for modification in sandy or very silty soils.
Lime Modification
Lime Reacts Chemically with Clay to Alter Molecular Interactions

Untreated clays have a molecular structure similar to some polymers, and give plastic properties. The structure can trap water between its molecular layers, causing volume and density changes.

In treated clays Calcium and Magnesium atoms (from Lime) have replaced Sodium and Hydrogen atoms producing a soil with very friable characteristics.
Soil Before And After Treatment
Lime Changes Proctor Through Modification

Compaction should target the modified OMC moisture and density, not the OMC/density of the untreated material.

OMC = 17%
OMC = 21%
Effective Change in Moisture Content

### In – Situ Soil Conditions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Current Moisture Content</td>
<td>27%</td>
</tr>
<tr>
<td>Optimum Moisture Content</td>
<td>17%</td>
</tr>
<tr>
<td>Tolerance</td>
<td>OMC + 3%</td>
</tr>
<tr>
<td>Targeted Moisture Content</td>
<td>17% - 20%</td>
</tr>
</tbody>
</table>

### 3% LKD Addition

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<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Moisture Content</td>
<td>24%</td>
</tr>
<tr>
<td>Optimum Moisture Content</td>
<td>21%</td>
</tr>
<tr>
<td>Tolerance</td>
<td>OMC + 3%</td>
</tr>
<tr>
<td>Targeted Moisture Content</td>
<td>21% - 24%</td>
</tr>
</tbody>
</table>

- Adding 3% LKD gives you the net drying effect of 7% in the field:
  - Decrease moisture content by 3%
  - Increase OMC by 4%
- This effect is unique to lime products.
Modification Includes Strength/ Stability

• Strength increase resulting from moisture reduction and textural change in the soil in the first 4-48 hours is **modification**.

• Cement is used for modification in sandy or very silty soils.

• This strength is adequate to provide stability, pass proof roll, create working platform, etc.

• Not true stabilization.
Cement Modification – Project Example

• MLS Practice Facility Milford, OH
• Soft, pumping silty clays.
• High in Moisture.
• Schedule was in jeopardy
  • Chose stabilization in lieu of undercutting.
• 5% Cement, 12” Treatment Depth.
Stabilization is All About Chemistry
Soil Stabilization: Taking Full Advantage of a Construction Practice

1) Designing High Quality Subgrade:
   • Improves stability during construction and long term pavement performance.
   1) Stabilized layer is taken into account structurally for savings.
      1) Increased CBR, Mr or;
      2) Stabilized layer is used as a structural layer of pavement.
      0.11 – 0.25/in.
   2) Very significant cost savings and the most effective use of our services.
Definition: Pozzolanic Reaction

• **Pozzolan** – A siliceous or aluminous material that when combined with calcium hydroxide forms cementious compounds.
  • Silica & Alumina are primary elements in clay soil and small amounts in LKD.
  • Calcium Hydroxide is “hydrated lime” (CaOH$_2$).
• The Pozzolanic Reaction is the fundamental reaction that takes place for lime stabilization.
• Portland Cement is purely self cementing, doesn’t react with soil.
Soil Stabilization
Pozzolanic Reactions Using Lime Products

On-going reaction with 
CaOH$_2$ and available silica and alumina in the soil forms complex cementitious materials (the POZZOLANIC effect)
The Importance of pH in Stabilization

- The high pH keeps alumina and silica soluble for the reaction to continue over time.
- INDOT results from soil 5-9 years since treatment.
Portland Cement Stabilization

- Cement hydration process is very complex but its effect on soil is simple.
- Cement coats and bonds soil particles together like glue.
- Coarser soil = less surface area = more effective.
- Most effective in granular soils.
Stabilization With LKD

- Lime Kiln Dust is a by-product of lime production and is essentially a “hybrid” material.
- Available Lime makes it effective in high PI soils and combination of CaO, Silica and Alumina make it self-cementing for low PI soils.

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Value in LKD</th>
</tr>
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<tbody>
<tr>
<td>CaO</td>
<td>50 – 65%</td>
</tr>
<tr>
<td>Available CaO (available lime)</td>
<td>35-45%</td>
</tr>
<tr>
<td>SiO₂</td>
<td>5 – 8%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>3 – 8%</td>
</tr>
<tr>
<td>S</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Passing #200 Sieve</td>
<td>75 – 90%</td>
</tr>
</tbody>
</table>
## Typical Application Rates

<table>
<thead>
<tr>
<th>Material</th>
<th>Drying</th>
<th>Modification</th>
<th>Stabilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>----</td>
<td>4-6%</td>
<td>5-10%</td>
</tr>
<tr>
<td>Quicklime</td>
<td>2-4%</td>
<td>4-5%</td>
<td>4-6%</td>
</tr>
<tr>
<td>Lime Kiln Dust</td>
<td>3-5%</td>
<td>4-6%</td>
<td>5-8%</td>
</tr>
</tbody>
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Common Stabilization Strength Gains
## Soils Classification

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<tr>
<td>SANDY</td>
<td>SP, SM, SC</td>
<td>A-1-b or A-3, A-2-4 or A-2-5, A-2-6 or A-2-7</td>
</tr>
<tr>
<td>CLAY</td>
<td>OL, MH, CH, OH, PT</td>
<td>A-7-6, A-7-5, A-8</td>
</tr>
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*Note: The table above categorizes soils based on their physical properties and classification systems.*

**AASHTO Group Classification**
- **A-1-a** for well-graded gravels and gravel-sand mixtures.
- **A-1-b** for poorly graded gravels and gravel-sand mixtures.
- **A-2-4** or **A-2-5** for silts, silt-clay mixtures, and clays with moderate plasticity.
- **A-7-5** for clays with high plasticity.

**Recommended Additives**
- Lime Kiln Dust
- Portland Cement

**Typical Uses**
- **GRAVEL**: For subgrades and foundations.
- **SANDY**: For drainage and paving bases.
- **Silty**: For roads and embankments.
- **CLAY**: For foundations and embankments.
Designing with Modification & Stabilization

• Depth – 8”, 12”, 14”, 16”
• For stability – Deeper is better.
• Modification of Fat Clays – 12” minimum.
• For stabilization – depends on soil conditions and project situation.
• Most projects perform 12-16” in construction.
• Old vs. New
Overview of The Construction Process for Soil Stabilization
Stabilization Construction Procedures Have Improved Dramatically

1) We know more today than we ever have about various chemicals, application rates, various soil mineralogy reactivity, mixing, hydration, time to compaction, etc.

2) What this means is that done right, by qualified contractor with proper equipment, soil stabilization is a controlled process with high quality, predictable results.
We Live in The Worst Conditions
This is Not Soil Stabilization...
Material is delivered by Pneumatic Tanker and transferred into Spreaders
Spreading – Quality Control

- Application rate (lbs/sy) is controlled by vein feeder.
- Vein feeder controls are in the operator’s cab.
- Application rate is within 1-2 lbs/sy.
- I.e. – 4% = 40 lbs/sy
Water Addition
Slurry Applications

Slakers Used to Make Slurry on Site or Off Site
Self Powered Rotary Mixers – Key to Quality in Stabilization
Mixing Chambers
Shaping and Compaction
Steel Wheel Roller
Finished Product
Curing

• In modification and stabilization applications, we recommend 3-5 day minimum curing for the layer to gain strength enough to hold up to construction traffic.

• There are many different factors that serve to reduce and extend this recommendation.

• You should always plan on a minimum of 3 days before any heavy loads.
Chemical Stabilization In Summary

- 3 Applications Within The Stabilization Family:
  - Drying
  - Modification
  - Stabilization

- All applications are significant cost savings, schedule savings, conserve materials and reduce truck traffic vs. their alternative.
- Many chemicals available to solve a variety of soils and conditions.
- Our industry strongly encourages planning for stabilization in design.
Thank You

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