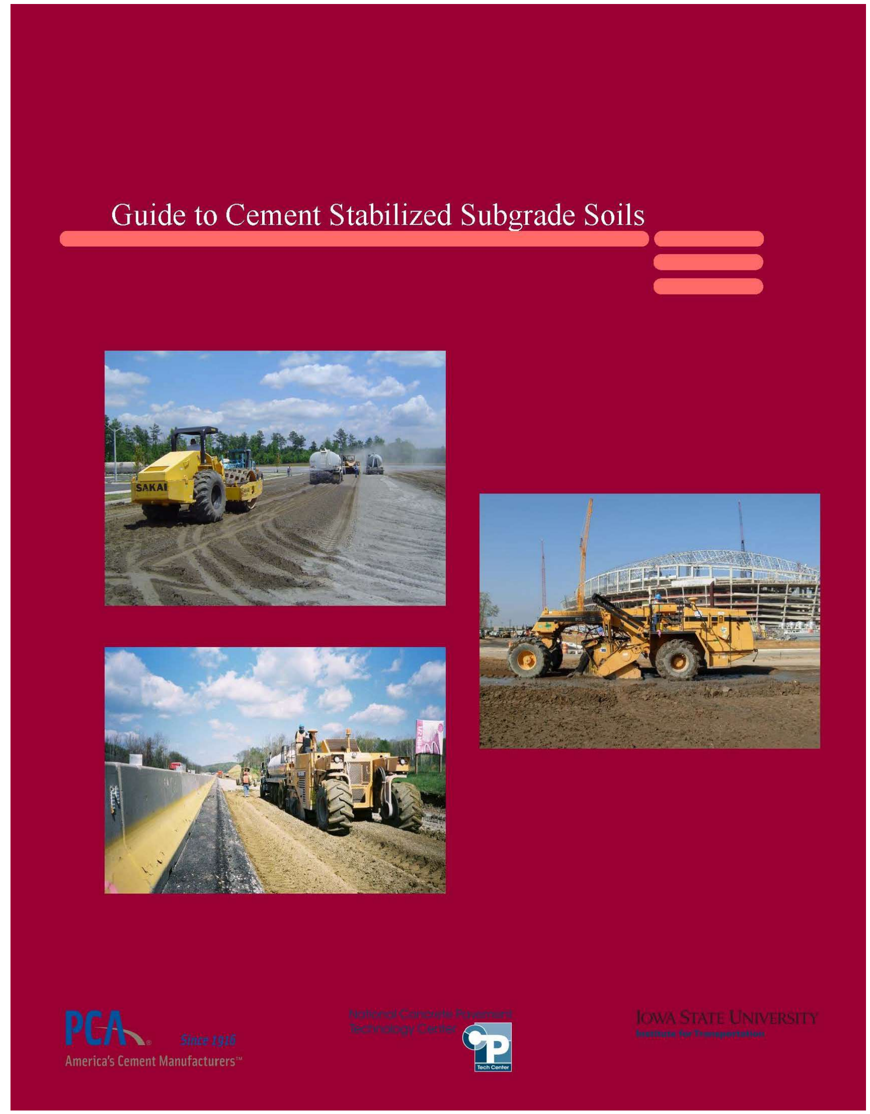
Cement Stabilized Subgrade

Qiang Li, PhD, PE
Infrastructure Solutions Engineer

Qiang.Li@Cemex.com

(339)502-0312



PROBLEMATIC SOILS

1. **Expansive**
2. **Low Strength**
3. **Poor Workability**

What Are the Options / Solutions for Poor Subgrade Soils?

1. **Excavate/replace with select fill**
   - **Aggregate**
   - **Soil**
2. **Increase the base / pavement /foundation slab thickness**
3. **Contain using fabrics or other geotextiles**
4. **Stabilize soils with a calcium-based additive such as portland cement**

Expansive
Low Strength
Poor Workability

Cost
Time
Sustainable

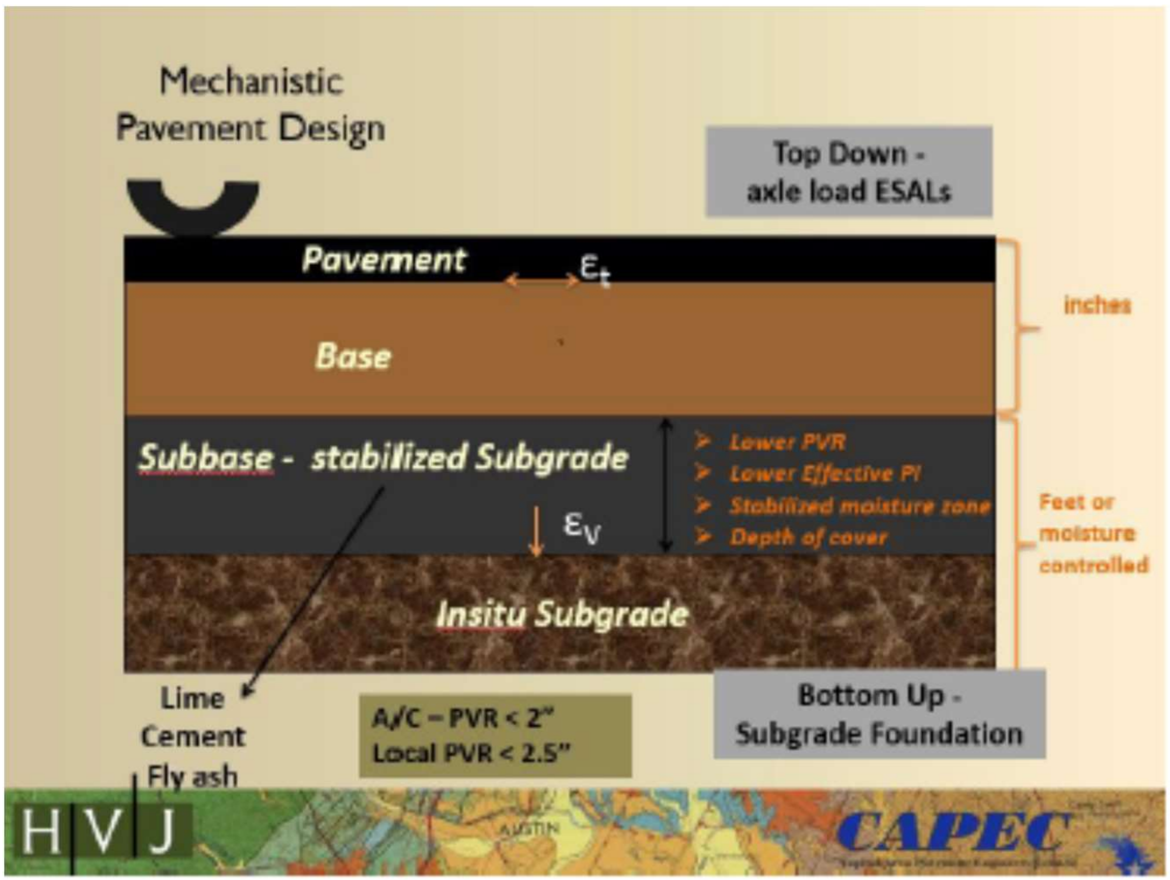
HOW TO MITIGATE SOIL MOVEMENT UNDER A PAVEMENT?

Methods to Mitigate Swell

1. Reduce moisture susceptibility of soil itself
   - Soil Stabilization
2. Reduce moisture infiltration to natural soils
   - Stabilize deep enough
   - Moisture barriers (horizontal or vertical)
   - Moisture treat below stabilization

Methods That Dont Mitigate Swell

1. Aggregate base
2. Concrete or asphalt paving
3. 1 inch of concrete more
4. Steel in concrete
5. Moisture treat only
6. Geotextiles



1. Provide an adequate depth of cover to limit the potential vertical rise
   - Arterial / Collector PVR <2.0
   - Local / Residential PVR <3.0
2. Provide a targeted Effective PI
   - Arterial / Collector PI_{eff} <30
   - Local / Residential PI_{eff} <40

SOIL STABILIZATION IS THE MIXING OF ADDITIVES INTO SOIL TO IMPROVE PROPERTIES FOR CONSTRUCTION & PERFORMANCE

1. What is it?

Mixing calcium based additives into the soil to cause a chemical reaction which results in improved workability of the soil for construction purposes

2. Why Use It?

1. **Meet project deadlines, speed up construction**
2. **Get out of the "Mud" – working platform**
3. **Create select fill from poor soils**
4. **Reduce shrink / swell, plasticity**
5. **Increase soil strength**
6. **Sustainable – reduce soil removal**
7. **Reduce cost**
8. **Dry soils**

HOW SOIL STABILIZATION WORKS (Chemistry)

	Lime	Cement
1. Particle Restructuring	Calcium atoms flocculate the clay structure increasing workability, strength, and compaction	
	100% Calcium	66% Calcium
2. Pozzolanic Reaction	Hydrated Lime + Silica (Clay) = CSH Hydrated Lime + Alumina (Clay) = CAH CSH + CAH = Strength Gain	Hydrated Lime + Silica (Clay) = CSH Hydrated Lime + Alumina (Clay) = CAH CSH + CAH = Strength Gain
3. Cement Hydration	Does Not Occur with Lime	Cement + H_20 = CSH + Hydrated Lime CSH = Strength Gain

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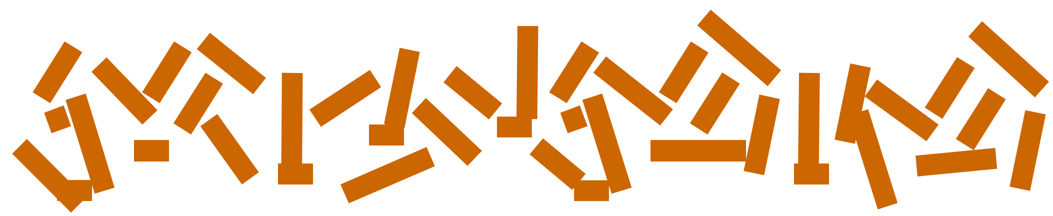
HOW SOIL STABILIZATION WORKS (Physical)

Untreated clays have a layered particle structure. The structure can trap water between layers, causing volume and density changes

Unstabilized Clay Particles

Calcium atoms (from cement or lime) alter clay structure from flat – layered orientation to random edge to face orientation producing a granular type soil (Ion exchange)



Clay Particles after flocculation/agglomeration

The hydrated cement locks the particle together providing a permanent bound structure
(Lime can do this at high percentages)

Clay Particles after Hydration

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TERMINOLOGY OF CEMENT TREATED MATERIALS

	Cement Modified Soil (CMS)	Cement Stabilized Subgrade (CSS)	Cement-Treated Base (CTB)	Full-Depth Reclamation (FDR)
Purpose:	Promotes soil drying Provides a working platform Permanent soil modification (does not leach) Some PI / Swell reduction	Provides all of the benefits of CMS and: Provides a Structural Layer with increased strength Increased bearing capacity for layers above	Provides strong, frost / Moisture resistant base layer for asphalt or concrete pavements Increased Erosion Resistance	Reuse Existing Materials Increase Base structural capacity Frost / moisture resistant layer Increased Erosion Resistance
Materials:	Primarily fine grained soils 2-3% cement	Primarily fine grained soils 3-8% cement	Primarily coarse grained, Virgin, manufactured materials. 3-6% cement	Pulverized asphalt blended with existing pavement base, subbase, and subgrade 2-6% cement added
Material Properties	Reduced plasticity and shrink/swell volume change characteristics Reduced moisture susceptibility No Strength increase	100-300 psi compressive strength (7 days)	200-600 psi compressive strength (7 days)	200-600 psi compressive strength (7 days)
Construction Practices	• Minimum 95% density • Mixed in place	• Minimum 95% density • Mixed in place	• Minimum 95-98% of maximum density • Mixed in place or plant mixed	• Minimum 95-98% of maximum density • Typically mixed in place

Field Sampling & Mix Design

GEOTECHNICAL INVESTIGATION

- Performed early in the design process
- Initial Desktop study (Soil survey publications incl. soil types & properties)
- Review of record drawings, surveys, & previous reports
- Site visit
- Field samples
- Field Testing
- Laboratory Testing
- Geotechnical Report

USE PROPER SAMPLING METHOD DEPENDING ON THE INTENDED PURPOSE OF INVESTIGATION AND TYPE OF SAMPLES NEEDED

Test Pits

Bulk Samples

Core

Small, Intact Sample

Auger

Small, Unbound Sample

DCP

In-situ Strength

LAB TESTING SHOULD BE DONE ON EVERY SOIL TYPE TO DEVELOP ADDITIVE RECOMMENDATIONS

Don't Assume It Will Work

Laboratory Tests on Natural Soil

- Sieve Analysis
- Atterberg Limits
- Moisture-Density
- Soluble Sulfates

Laboratory Tests on Stabilized Soil

- Treated Atterberg Limits
- Treated Moisture - Density
- Compressive Strength (Dry / Wet)
- Swell Potential (Free – Swell)
- Durability (Wet-Dry & Freeze-Thaw)

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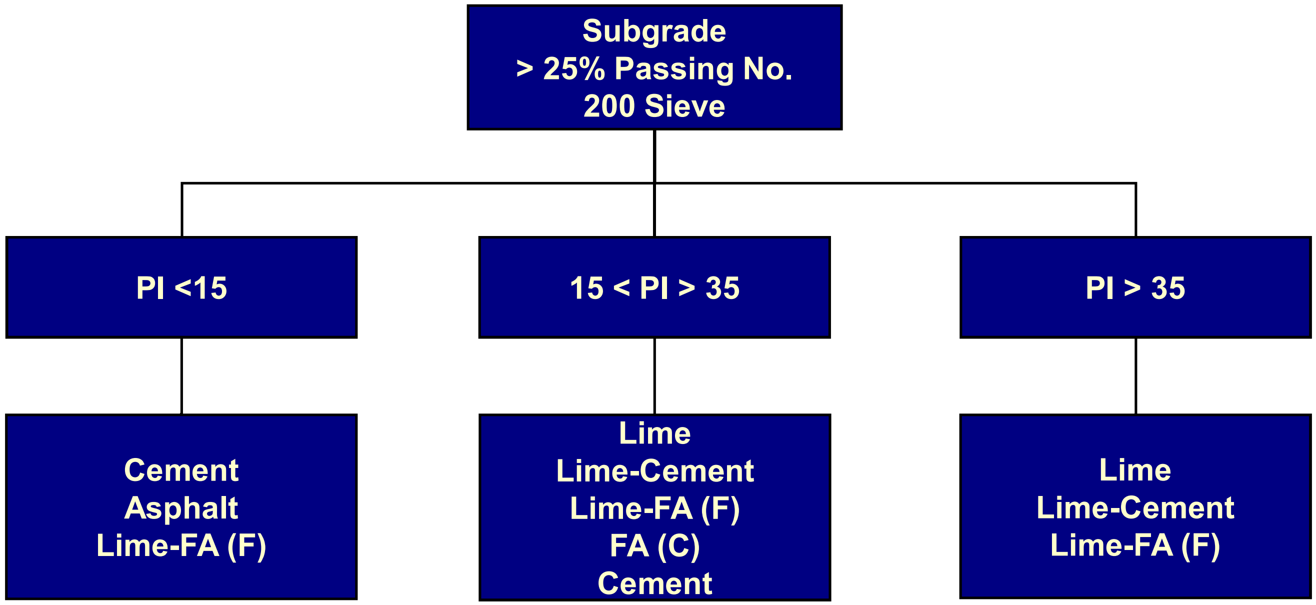
SOME AGENCIES HAVE GUIDELINES FOR ADDITIVE SELECTION FOR SOIL STABILIZATION



1. **Should Plasticity Index be the sole factor for selecting additive type?**

2. **What other factors should be considered when selecting additive type?**

SOIL STABILIZATION IMPROVES THE ENGINEERING PROPERTIES OF THE SOIL

Calcium Based Additive

1. What are your objectives when selecting additives for soil stabilization?
2. What is your design criteria for additive selection for soil stabilization?

Natural Subgrade

PI: 25-60

Mr = 8,000 psi

UCC:35-80 psi

Free Swell: 2-30%

Stabilized Subgrade

PI: <20

Mr > 30 ksi

UCC:>100 psi

Free Swell: <1%

CEMENT BASED ADDITIVES ARE OPTIONS TO STABILIZE ALL SOIL TYPES

	Reasons for Use

Option A: Cement	• Cost savings over lime (Additive quantity & cost)
	• Time Savings over lime (1 day vs 3 days)
	• Comparable performance to lime
	  • Reduces swell, PI
	  • Increase strength
	• Will remain permanent

Option B: Lime/Cement Combination	• High PI Soils > 40
	• Half Lime / Half Cement – same additive total %
	• Significant improvement in performance over lime
	  • Reduced swell, PI
	  • Increased Strength
	• Save time, save money
	• Lime helps to pulverize clay, cement binds particles
	• Will remain permanent

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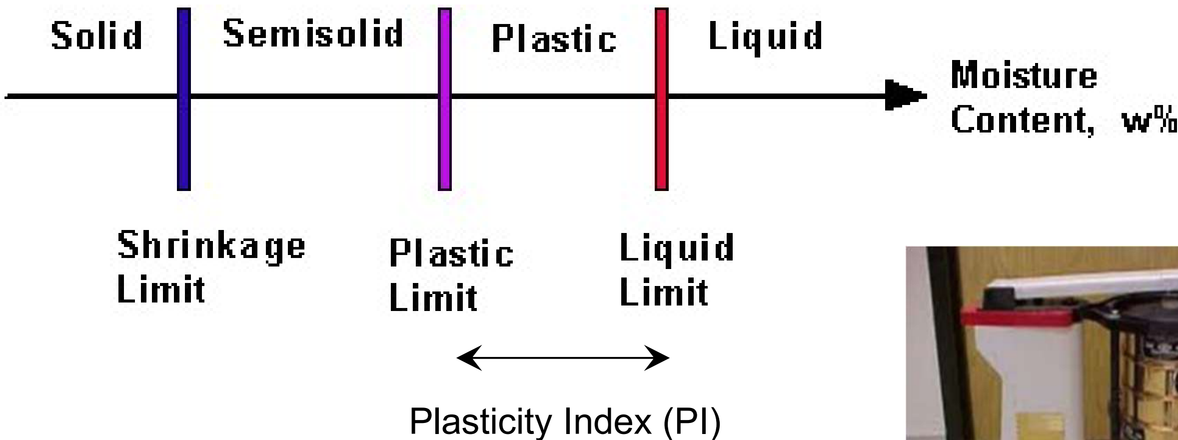
Table 2.4 – Effect of Cement Treatment on Properties of Clay Soils

Soil No.	AASHTO Classification	Cement Content (percent)	Plasticity Index	Shrinkage Limit
1	A-7-6 (20)	None	30	13
		3	13	24
		5	12	30
2	A-6 (8)	None	17	13
		3	2	26
		5	1	28
4	A-6 (9)	None	20	10
		3	9	21
		5	5	25
7	A-7-6 (18)	None	36	13
		3	21	26
		5	17	32
10	A-7-6 (20)	None	43	14
		3	24	24
		5	16	31

*PCA publication *Cement Modification of Clay Soils*, RD002

ATTERBERG LIMITS AND SIEVE ANALYSIS

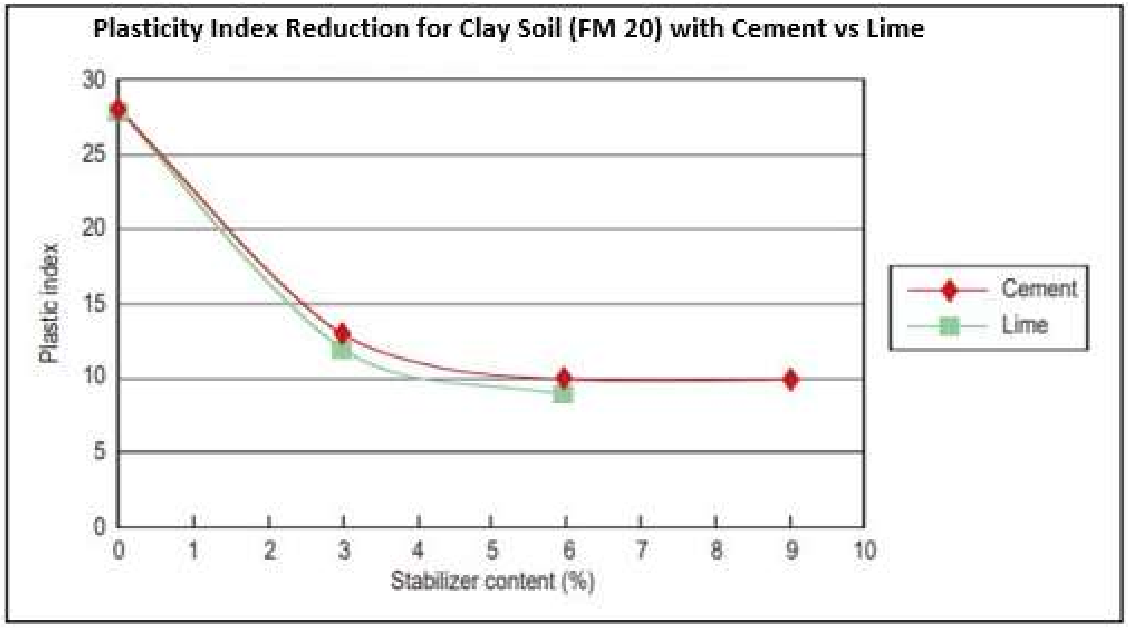


Gravel

Sand

Silt

Clay



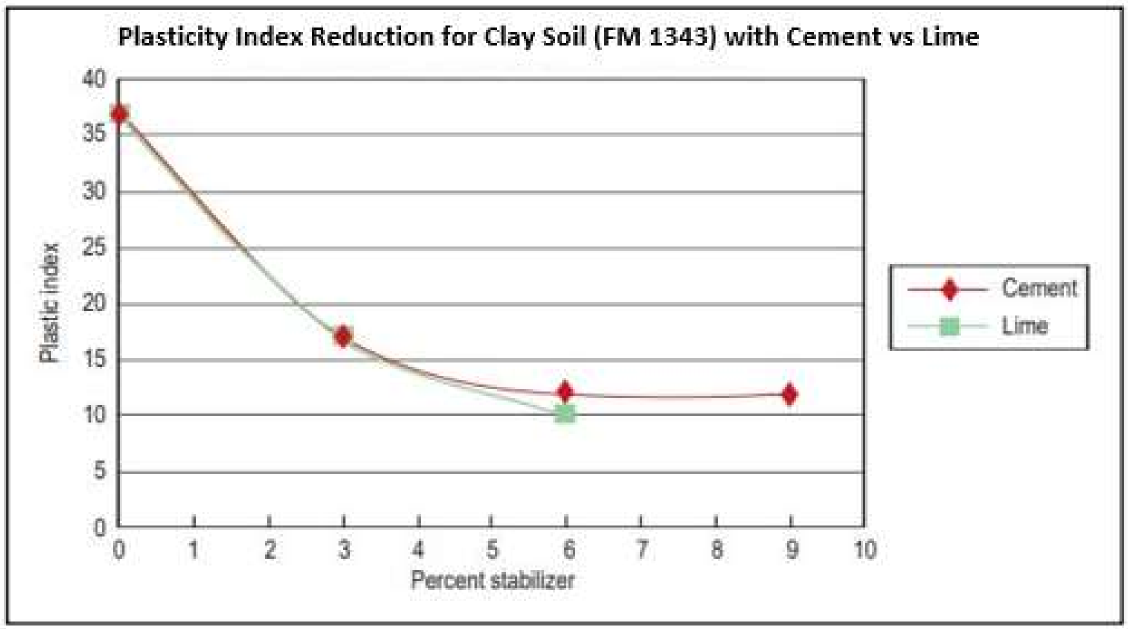
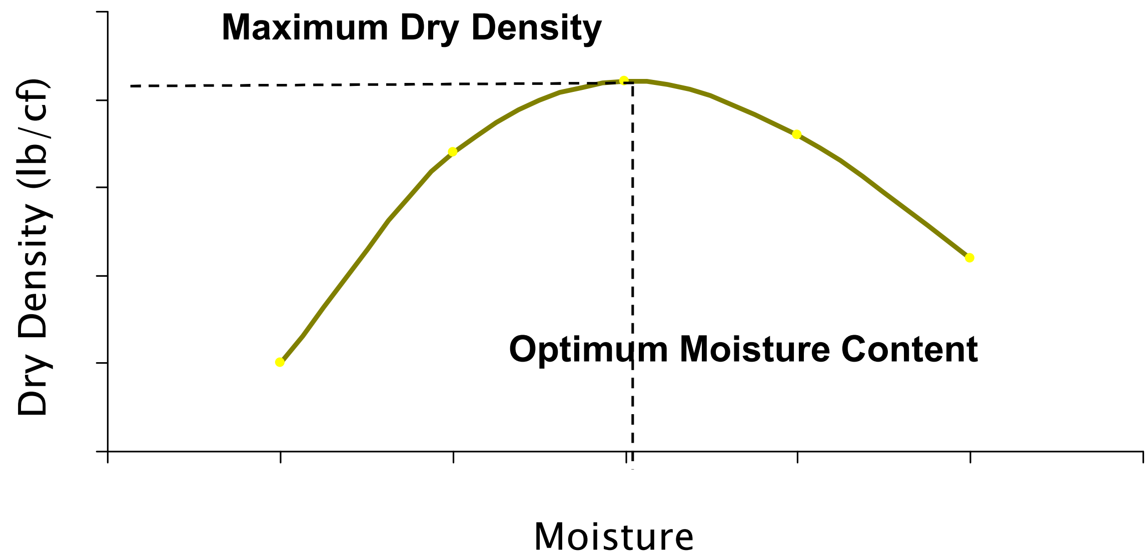


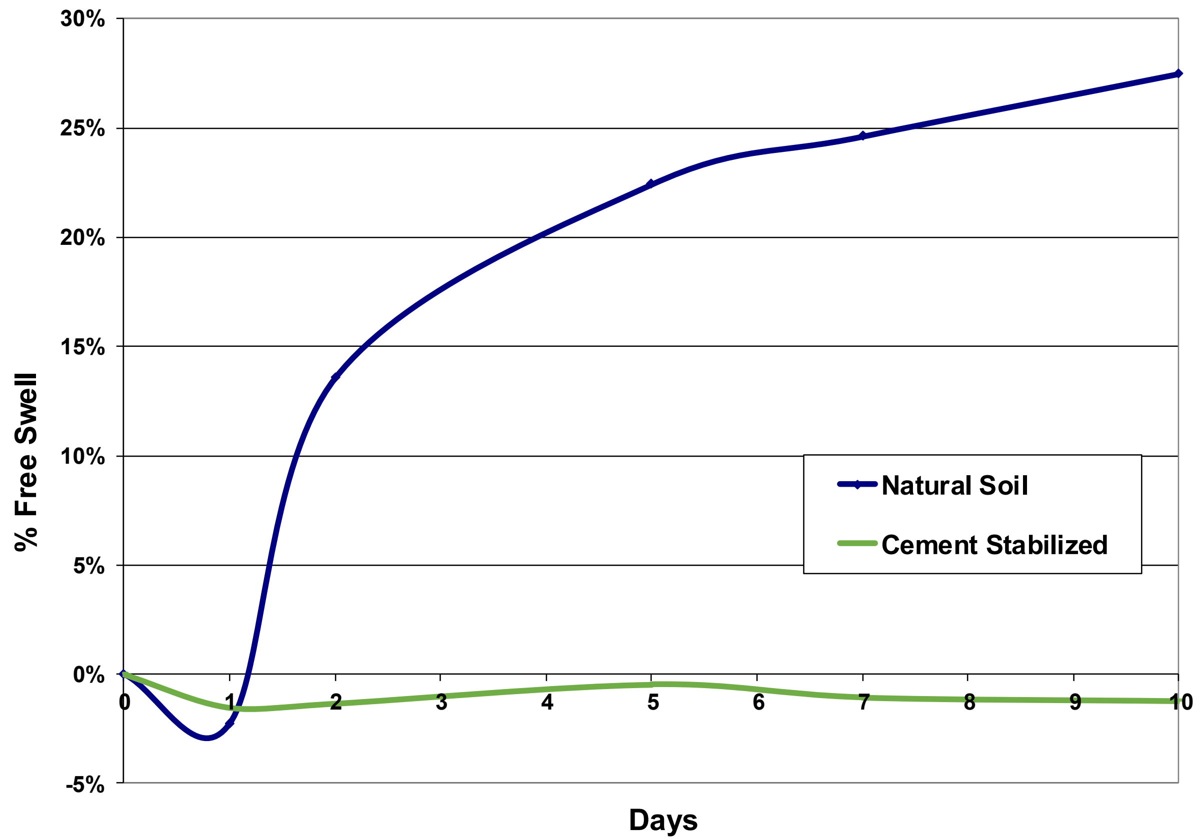
Figure 2.1 – Plastic Index of Soils after Being Stabilized (Scullion, et al, 2005)

Moisture-Density Relationship

ASTM D558



FREE SWELL IS A VERY GOOD TEST TO EVALUATE ADDITIVE PERFORMANCE



- Prepare specimen using Proctor Method
- Cure for 2 days in sealed bag, room temperature
- Place in oven for 4 hours
- Set on Porous stone with water to bottom
- Measure diameter and height every day for 5 days
- Plot % Swell over time

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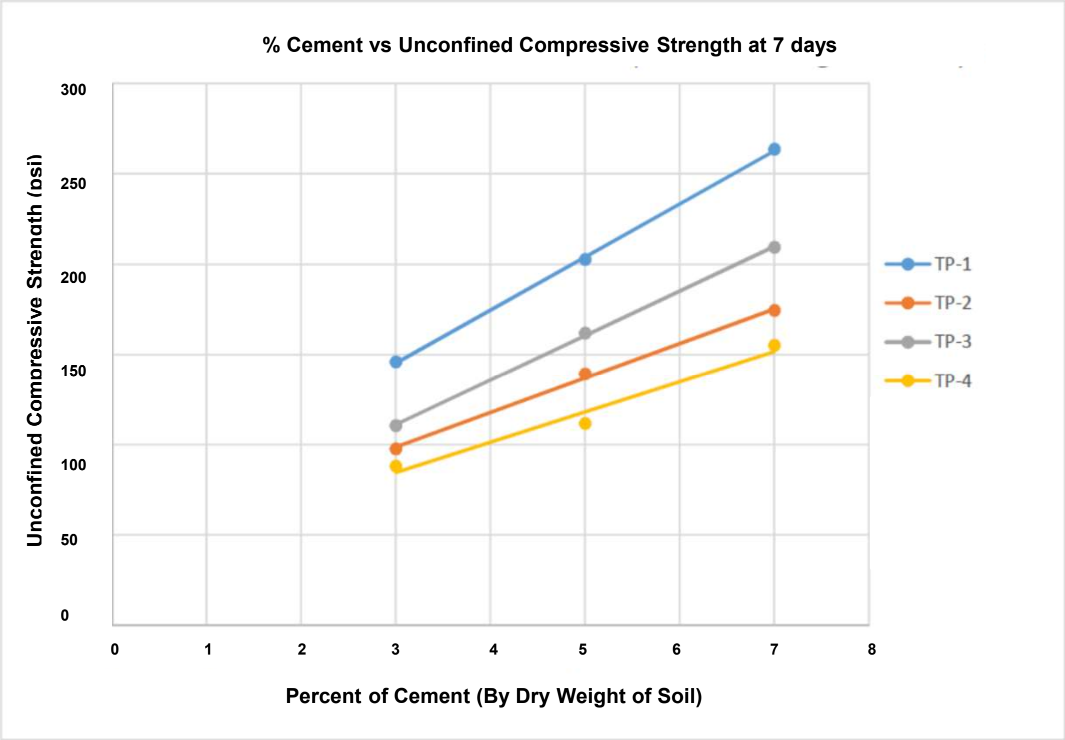
STRENGTH MEASUREMENTS CAN PROVIDE PERFORMANCE MEASUREMENTS TO DETERMINE CEMENT CONTENT

ASTM D1633 Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders

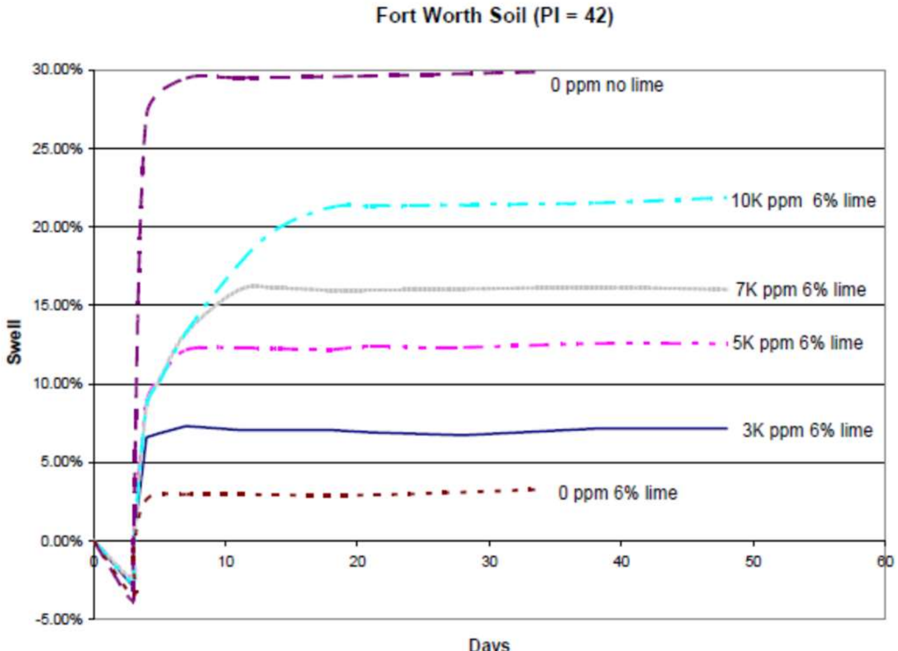


- **Prepare specimen using Proctor Method**
- **Cure for 7 days in sealed bag, room temperature**
- **Test for compressive strength at 7 days**
- **After free swell test, measure compressive strength of "wet specimen"**

SULFATE TESTING SHOULD BE CONDUCTED IF POTENTIAL EXISTS

- **0.00% to 0.30% - Sulfate Levels Too Low to be of Concern**
- **0.31% to 0.50% - Sulfate Levels of Moderate Risk**
- **0.51% to 0.80% - Sulfate Levels of Moderate to High Risk**
- **0.81% and up - Sulfate Levels of High and Unacceptable Risk**

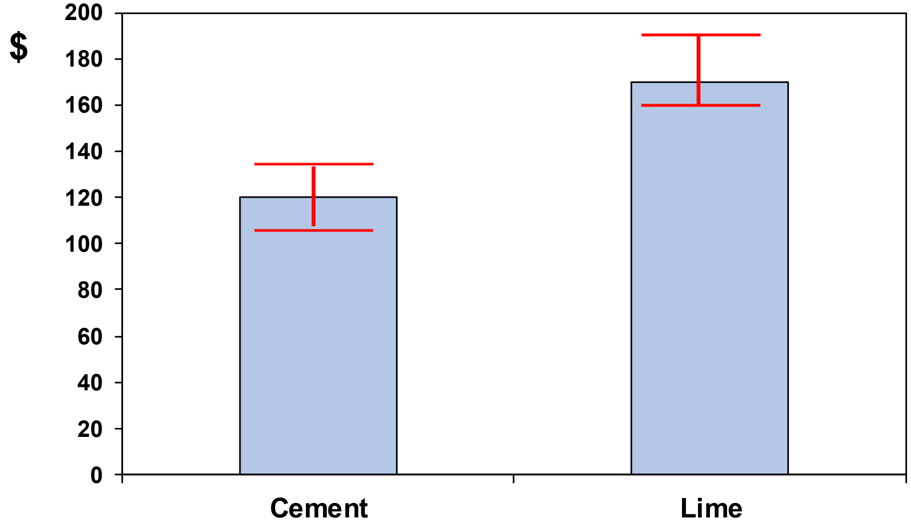
- **Calcium Based Stabilizers will react with Sulfates forming ettringite causing significant swell**
- **Some measures can be taken to use calcium based stabilizers such as double treatments, this will cause the reaction to take place prior to final compaction**



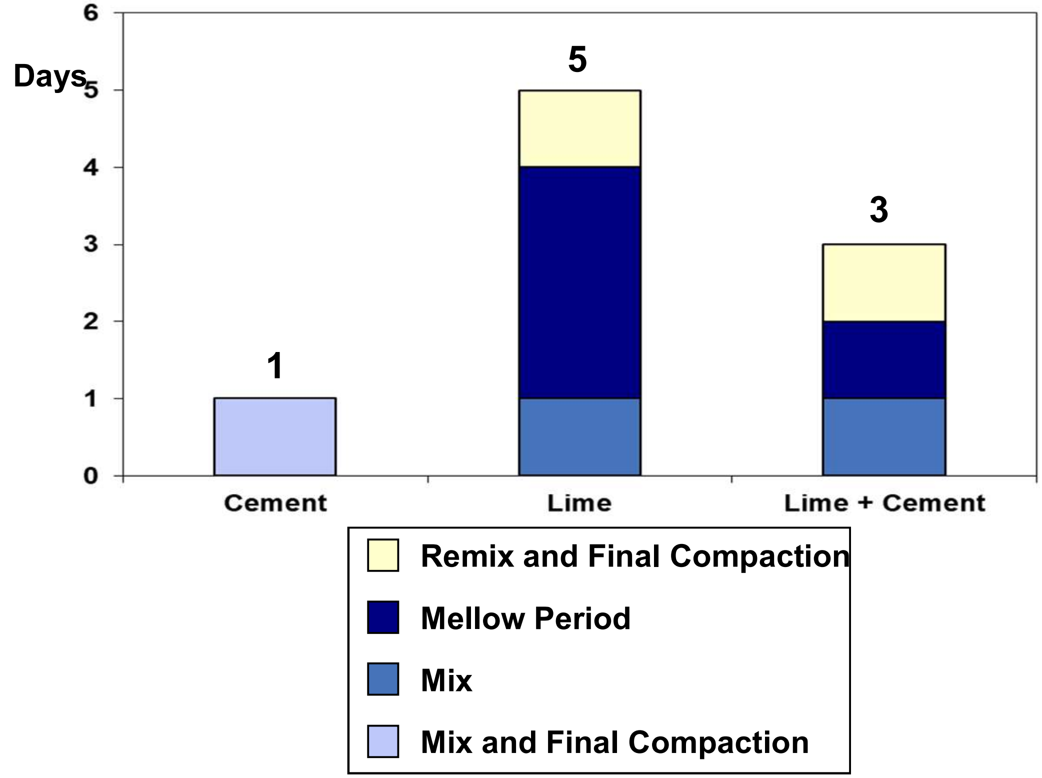
- **From Harris, Scullion, Sebesta, 2004**

CEMENT STABILIZATION CAN SAVE TIME & MONEY

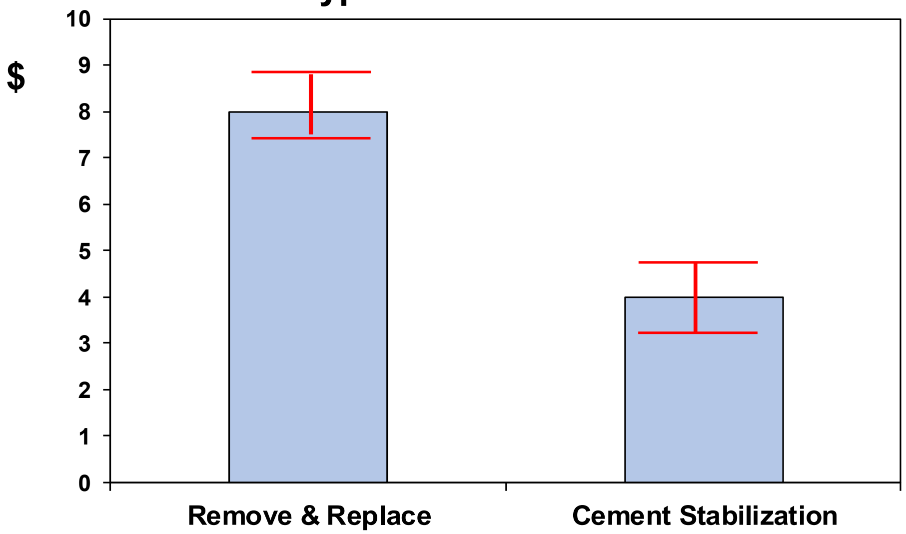
Typical Unit Cost / Ton



Construction Time (1)



Typical Unit Cost / SY



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(1) Assumes 3 days of mellowing for lime, although recommend range is 1 to 7 days by National Lime Association

MIX DESIGN PROCESS REVIEW

1. Determine In-Soil Moisture Content & Classify Soil
2. Determine Cement Type and Estimated Dosage Rate
3. Determine Chemical Compatability, Consider Sulfate Testing of Natural Soil (If Necessary)
4. Prepare Samples With 3 Different Cement Contents (i.e. 2%, 4%, 6%)
5. Determine SL, PL, LL, of Sample (Atterberg Limits) of the 3 Samples 1 Hour After Mixing
6. Determine Optimum Moisture Content and Maximum Dry Density (use cement content from Atterberg Limits testing)
7. Determine the Unconfined Compressive Strength at three different cement contents.
8. Conduct Free Swell & Unconfined Compressive Strength of Wet Samples at 1 Cement Content
9. (Optional) Plot Unconfined Compressive Strength & Swell to Verify Cement Content
10. Create Mix Design Report

TYPICALLY, SOIL STABILIZATION PLANS USE LIME

Why Use Lime?

- Provides working platform (reduce PI, assist pulverization of soil)
- Lime has a good performance history for improving "constructability" of clay soils

Why Not Use Lime?

- Lime may not meet strength & durability requirements
- Lime will "leach out" if rains while mellowing
- Lime may "leach out" over time reducing stabilization effect
- Mellowing process is time consuming
- Lime is more expensive than cement

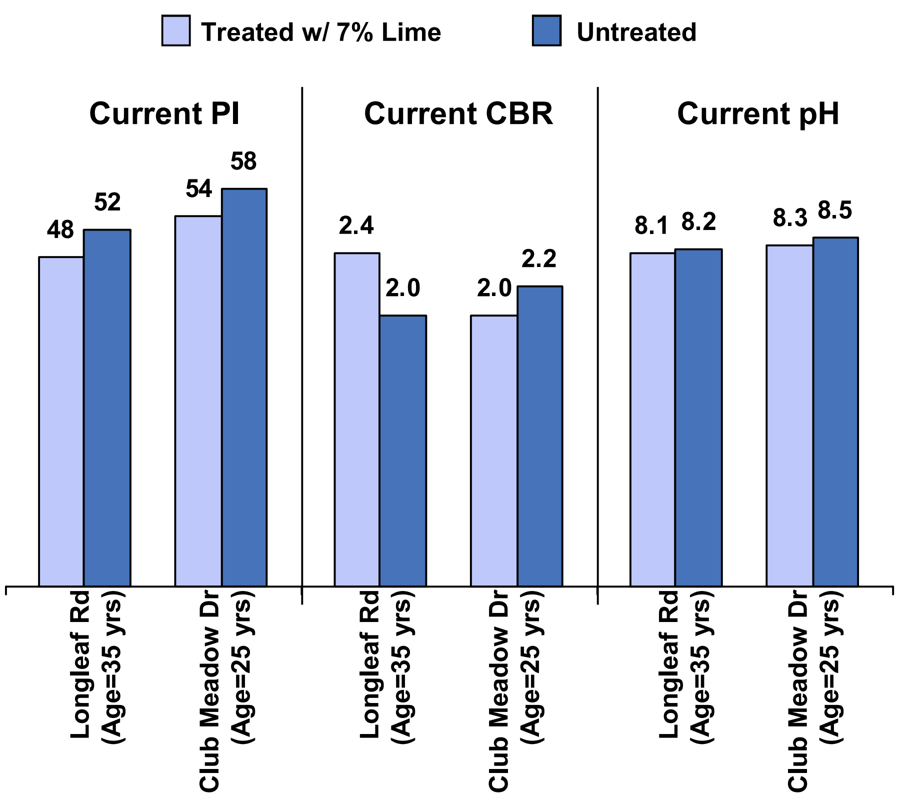
RESEARCH INDICATES LIME TREATMENT MAY BE TEMPORARY

Reducing Long Term Durability

1995 City of Garland, TX Pavement Study [1]

Study of failed pavement sections on Taylor Clay soils (PI = 39)

- **Originally treated with 7% lime**
- **Nearly complete loss of lime modification effects**
- **Average moisture content 10.6% above optimum**



2005 City of Frisco, TX Pavement Study [2]

Study of cracked pavement sections on Eagle Ford Shale (PI = 30 to 71)

- **Originally treated with 8% lime (2-5 yrs old)**
- **Nearly complete loss of lime modification effects**
- **Report Conclusion " Lime treatment is only temporary, results indicate shortly after construction, soils revert to natural state"**

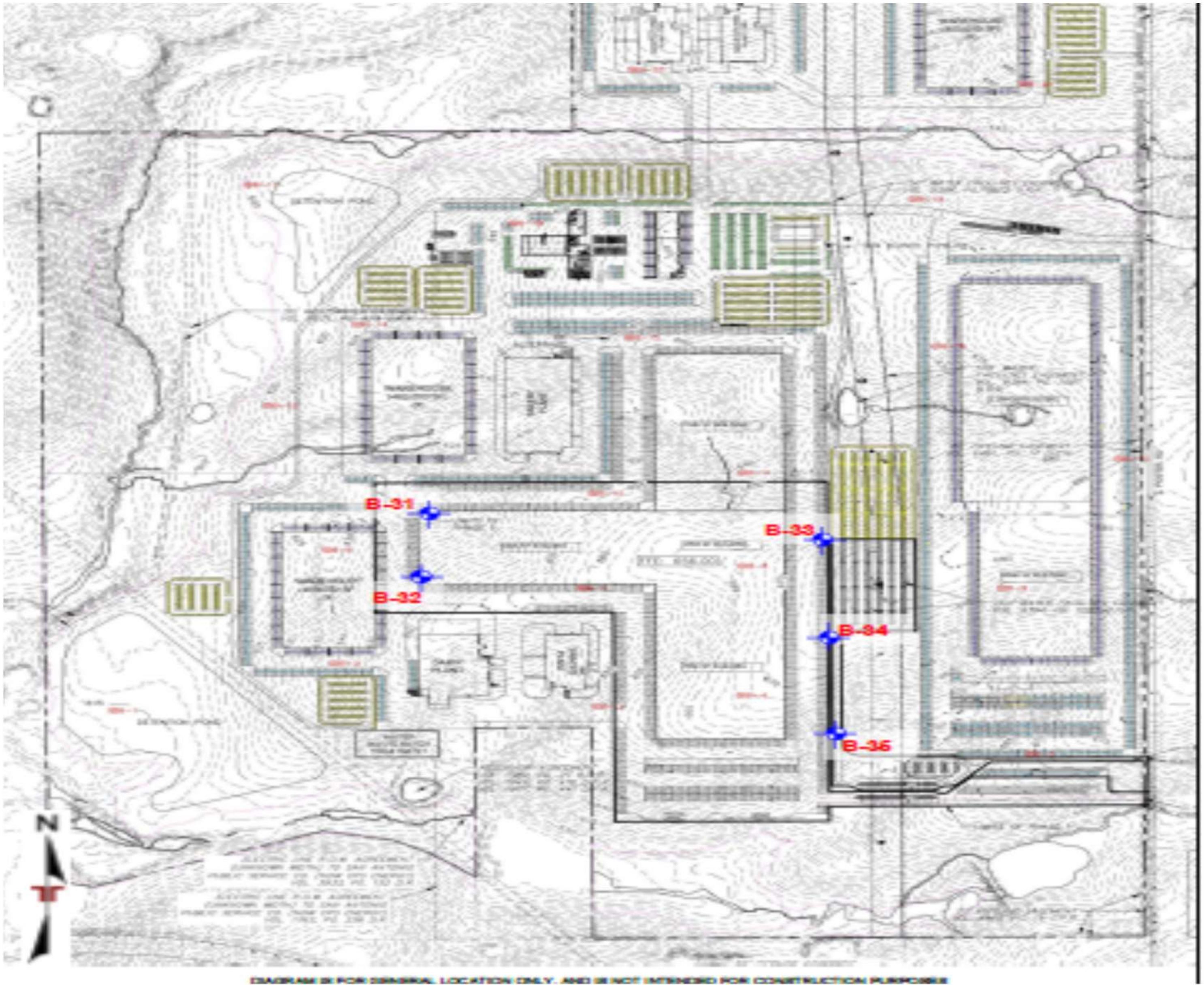
Location	Lime Treated	Current PI	Current pH	% Borings lime Detected
Teel Parkway	8% lime 6" Deep	71	10.4	50%
The Lakeside at Star Ranch	8% lime 6" Deep	43	-	0%
The Trails, Phase 6	8% lime 6" Deep	30	10.4, 8.6	50%

1) Study of Life Extension & Rehabilitation of Residential Streets and Alleys for City of Garland, Texas, J.F. Polma, F.A. Polma, M.B. Addison, D. Zollinger, N. Buch, October 1995

2) Subgrade and Pavement Study: Existing Distressed streets Investigation and Methods for Street Rehabilitation, Frisco Texas, Michael Batuna, CTL Thompson Texas, LLC

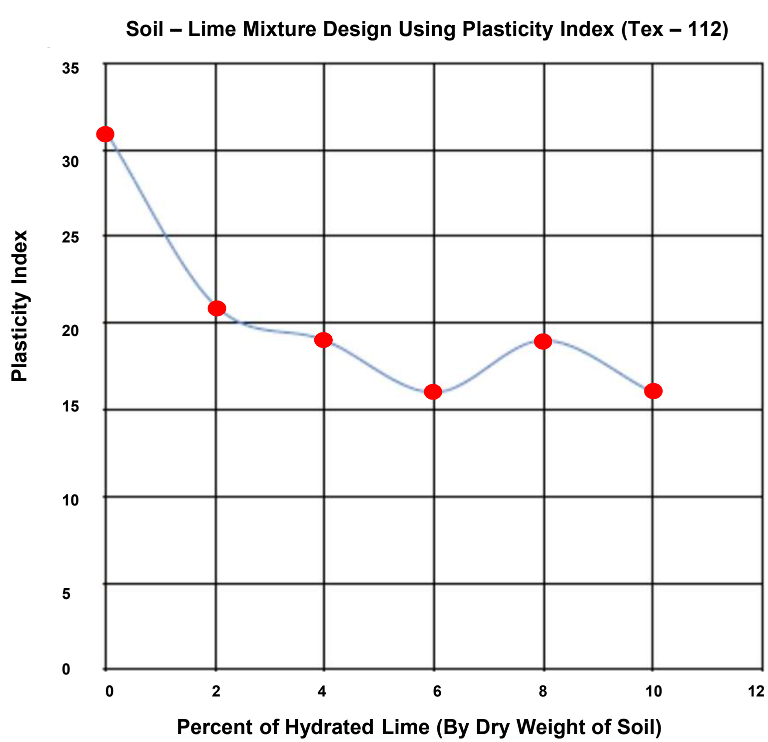
Projects and Test Results

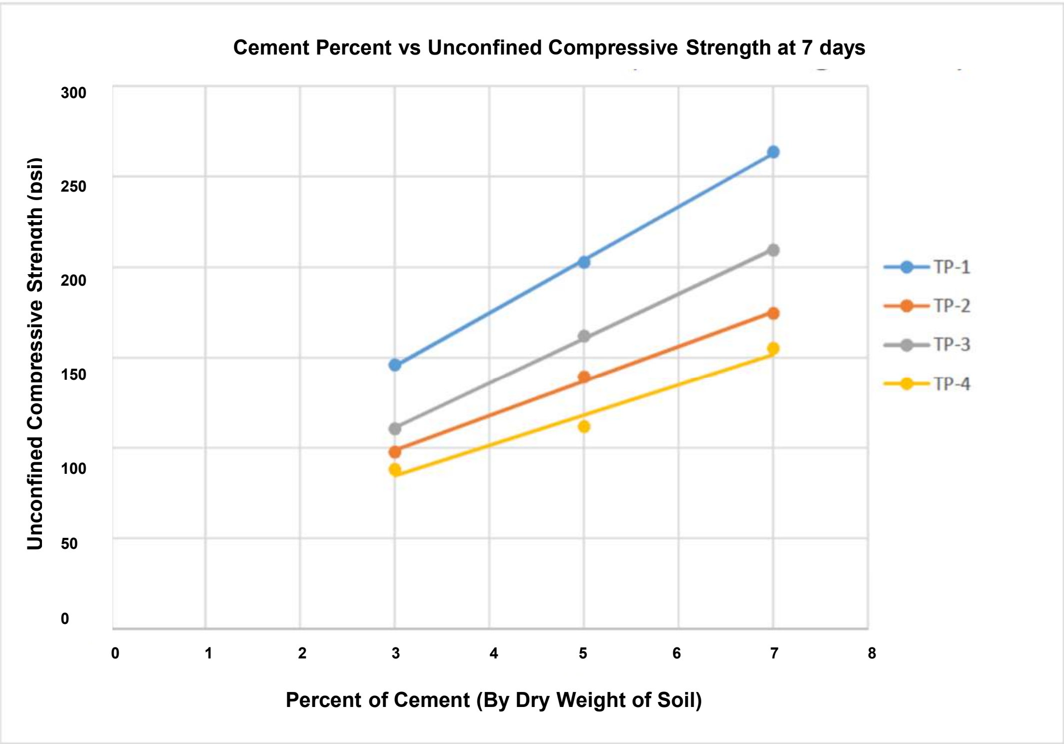
LARGE GROCERY DISTRIBUTION CENTER



TESTING FOR DISTRIBUTION CENTER PROVES CEMENT WORKS AS WELL AS LIME

Sample	Description	Liquid Limit	Plastic Limit	Plasticity Index	Plasticity Index (5% Cement)
TP-1	Tan & Gray Fat Clay	51	20	31	5
TP-2	Brown Fat Clay	57	20	37	12
TP-3	Brown Fat Clay	59	23	36	6
TP-4	Tan Fat Clay	57	21	36	12





Construction

Construction of Cement-Modified Soils

1. Proof Roll to identify deep weak spots
2. Pulverize the roadbed materials
3. Blade to desired roadway template
4. Spread cement
5. Mix all materials directly on the roadbed
6. Bring to optimum moisture content
7. Compact to 95% to 98% standard Proctor
8. Shape the roadway to Plan requirements

PROOF ROLLING WILL IDENTIFY WEAK SPOTS THAT MAY REQUIRE

VARIOUS OPTIONS EXIST FOR CEMENT SPREADING

Dry Powder

- Lowest Cost
- Dusty

Slurry Cement

- Solves dust problem
- Increased Cost

Dustless Dry Powder

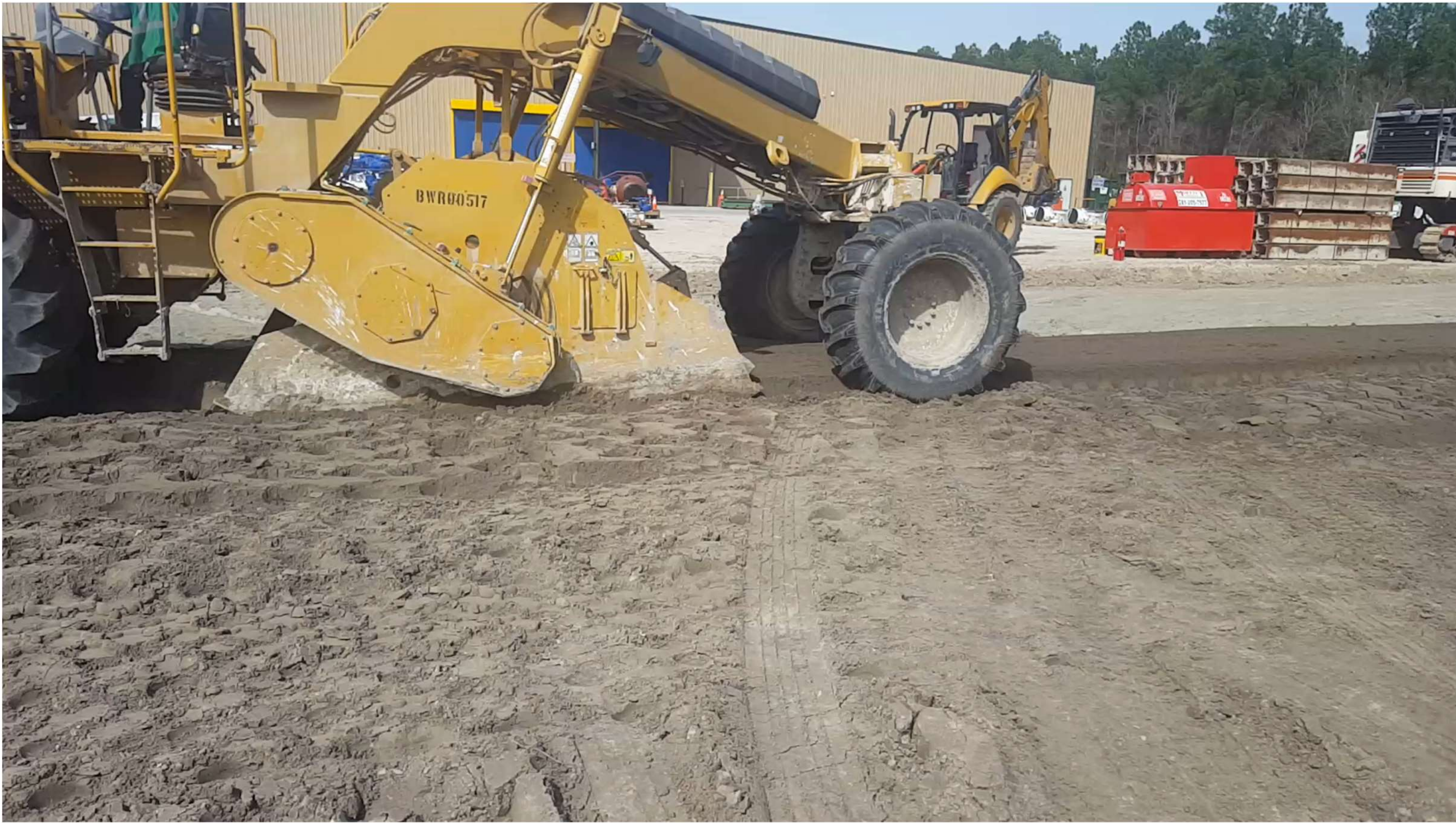
Spreader Trucks

CONSTRUCTION PROCESS – SPREAD RATES

	20 lbs/yd^2 Depth of Stabilization (in.)				30 lbs/yd^2 Depth of Stabilization (in.)				40 lbs/yd^2 Depth of Stabilization (in.)				50 lbs/yd^2 Depth of Stabilization (in.)				60 lbs/yd^2 Depth of Stabilization (in.)				70 lbs/yd^2 Depth of Stabilization (in.)				80 lbs/yd^2 Depth of Stabilization (in.)			
Unit Weight of Soil (pcf)	6	8	10	12	6	8	10	12	6	8	10	12	6	8	10	12	6	8	10	12	6	8	10	12	6	8	10	12
90	5%	4%	3%	3%	7%	6%	4%	4%	10%	7%	6%	5%	12%	9%	7%	6%	15%	11%	9%	7%	17%	13%	10%	9%	20%	15%	12%	10%
100	4%	3%	3%	2%	7%	5%	4%	3%	9%	7%	5%	4%	11%	8%	7%	6%	13%	10%	8%	7%	16%	12%	9%	8%	18%	13%	11%	9%
110	4%	3%	2%	2%	6%	5%	4%	3%	8%	6%	5%	4%	10%	8%	6%	5%	12%	9%	7%	6%	14%	11%	9%	7%	16%	12%	10%	8%
120	4%	3%	2%	2%	6%	4%	3%	3%	7%	6%	4%	4%	9%	7%	6%	5%	11%	8%	7%	6%	13%	10%	8%	7%	15%	11%	9%	7%
130	3%	3%	2%	2%	5%	4%	3%	3%	7%	5%	4%	3%	9%	6%	5%	4%	10%	8%	6%	5%	12%	9%	7%	6%	14%	10%	8%	7%
140	3%	2%	2%	2%	5%	4%	3%	2%	6%	5%	4%	3%	8%	6%	5%	4%	10%	7%	6%	5%	11%	8%	7%	6%	13%	10%	8%	6%

- **% Cement – Based on Dry Weight of Soil to be treated**
- **Calculate the Dry Weight of Soil to be Tested: Length x Width x Depth x Unit Weight of Soil**
- **Spread Rate Calculation: (Dry Weight of Soil to be treated x % Cement) / Area to be treated**

CONSTRUCTION PROCESS – MIX



CONSTRUCTION PROCESS - COMPACTION

After placement and mixing, water is added (if dry mix) and the mixture is compacted with traditional compaction equipment and subsequently proof-rolled. Typically, compaction must be completed within 2-4 hours of cement mixing into soil

CONSTRUCTION PROCESS – SHAPE TO FINAL GRADE

After placement and mixing & compaction, Blades are used to shape the area to the final grade. Curing can be accomplished with water, tack coat / emulsion as appropriate

FIELD TESTING REQUIREMENTS

Primary

- Sieve Analysis
  - 100% passing the 1.5 in. sieve
  - > 60% passing the No. 4 sieve
- Moisture Content: + or - 2% of Optimum
- Density: > 95% of Standard Proctor

Secondary

- Thickness
- Stiffness – Measurement of in-place structural layer
- Stability / Proof Roll – Subgrade must be stable prior to placement of next pavement course
- Cement Spread Rate

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QUESTIONS?

Qiang Li, Ph.D., P.E.

CEMEX, Inc

Paving Solutions Engineer

Qiang.Li@cemex.com

339.502.0312