THE READY MIX USA COMPANIES
READY MIX USA | BLOCK USA | HARDSCAPES USA

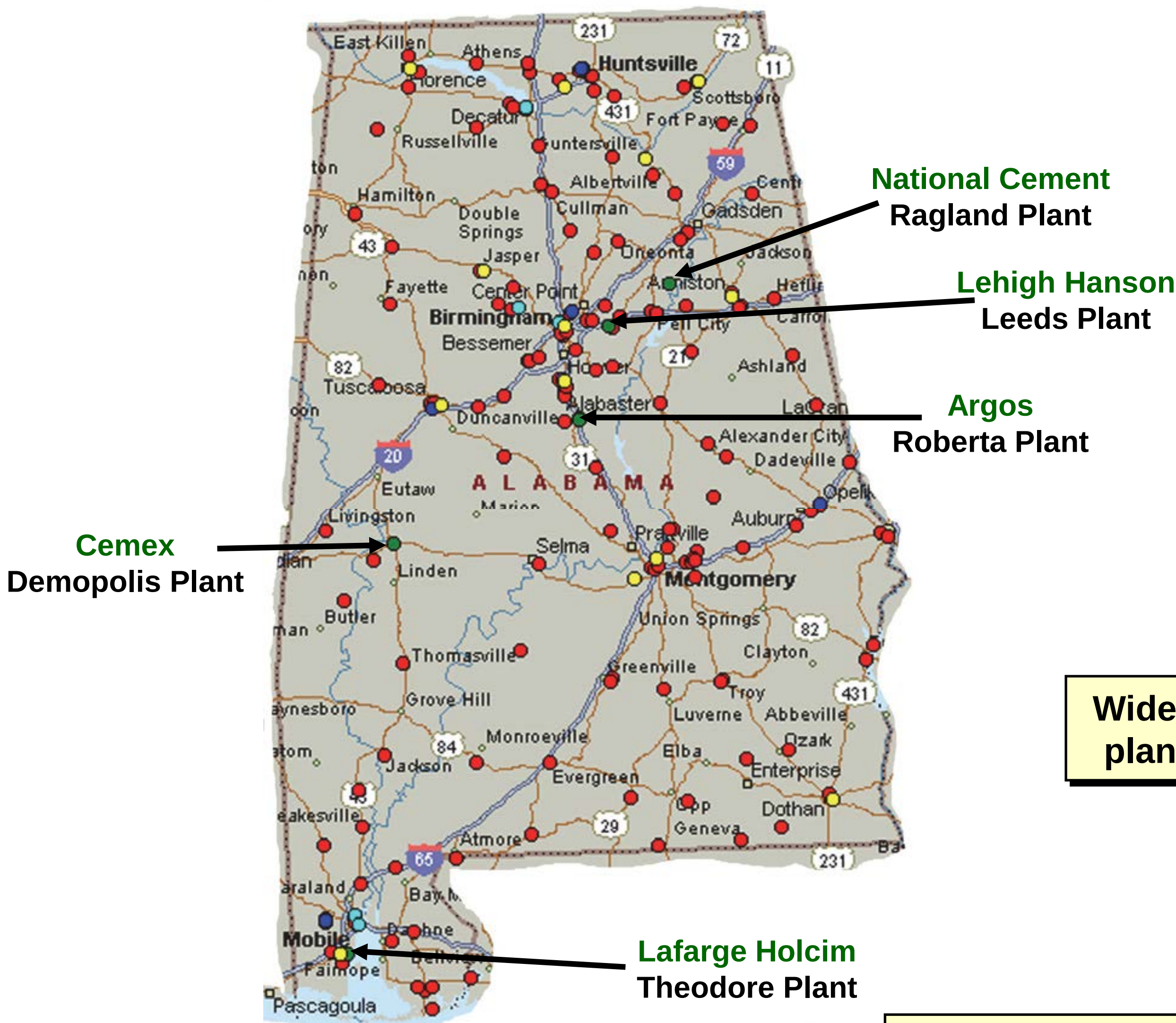
A CEMEX COMPANY

PROVIDING SOLUTIONS THROUGH PAVEMENT DESIGN

Cement Stabilization of Soil

Presented by Shadrack Mboya, P.E.

ALABAMA IS THE FIFTH LARGEST PRODUCER OF CEMENT IN USA[1]



- Cement Plants: 5
- Cement Terminals: 6
- Ready Mix Plants: 156
- Precast/Concrete Pipe Plants: 7
- Block Plants: 13

Cement Economic Data[2]
Cement production: 4.3 million metric tons
Cement consumption: 1 million metric tons

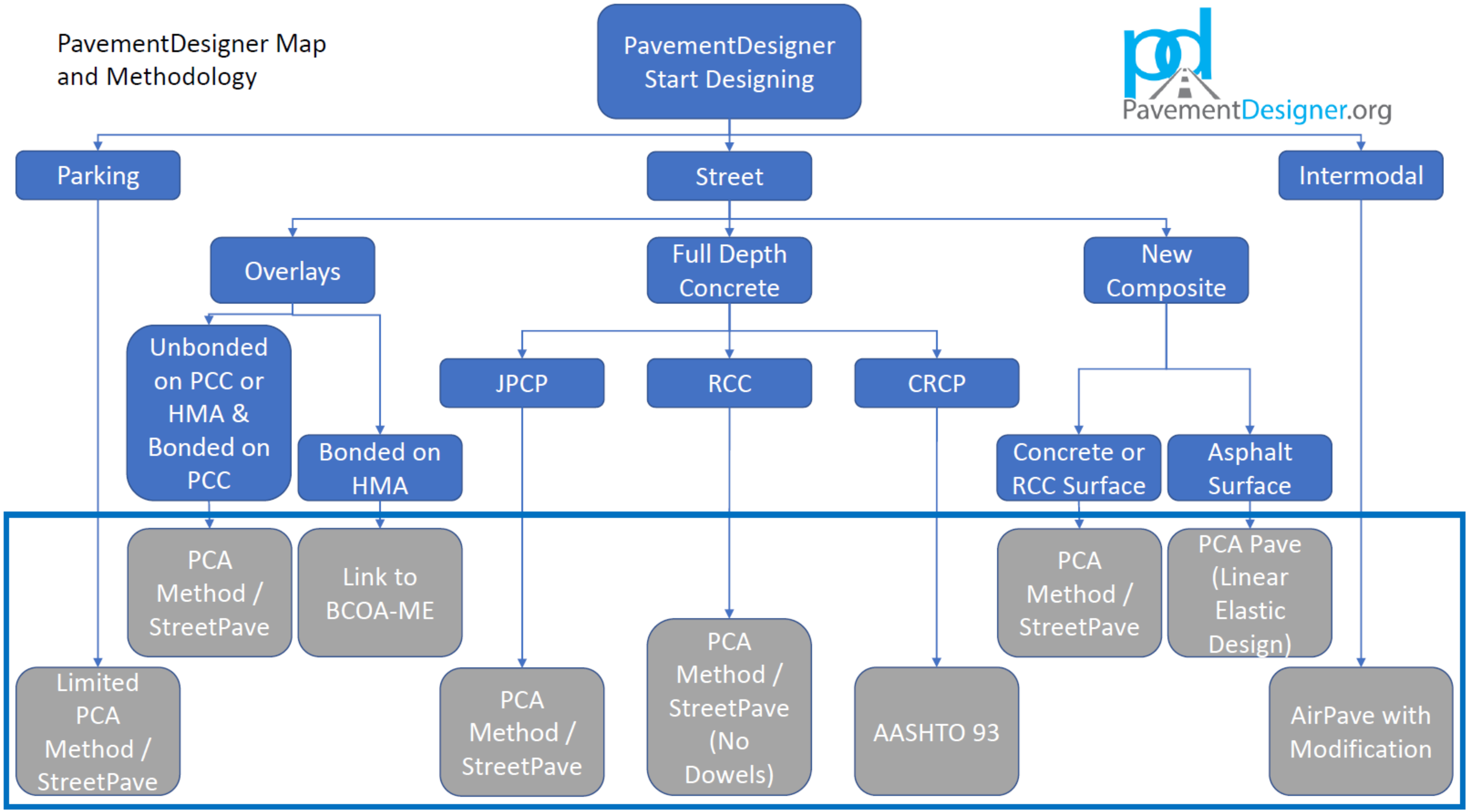
Widespread raw materials reach and portable batch plants allow our industry to supply most locations

Note: Asphalt industry has about 80 Hot Mix Plants in Alabama[3]

Sources:
1. Cement Industry in the United Sates, Wikipedia, 2013
2. Portland Cement Association, Alabama Cement Industry, 2015
3. Alabama Department of Transportation, Hot Mix Asphalt Plants, 2021

PavementDesigner.org

PavementDesigner Map and Methodology



A new, free online resource for the design of roadway, industrial, and parking area pavements

CEMENT-BASED PAVEMENT SOLUTIONS

Application	Conventional Concrete Pavements	Roller Compacted Concrete (RCC)	Concrete Overlays	Full-Depth Reclamation (FDR)	Soil Stabilization	Pervious Concrete
Interstate/ Highways	●	●	●	●	●	
Local Streets	●	●	●	●	●	●
County/Rural Roads	●	●	●	●	●	
Parking Lots	●	●	●	●	●	●
Bus Lanes	●		●	●	●	
Base Course		●		●	●	●
Industrial	●	●	●	●	●	●
Airport Runways and Aprons	●		●	●	●	

AGENDA

Overview of Cement Stabilization of Soils

- What is it?
- How Does it Work?
- Why use it?

Design & Construction Process

- Mix Design
- Durability Testing
- Construction Considerations

Case Studies, Projects Examples, and Troubleshoots

- Publications Case Studies
- Projects Examples
- Cement-Stabilized Subgrade Soils Troubleshoots

WHAT IS SOIL STABILIZATION WITH CEMENT?

- Treatment of soil using Portland cement
- Soils include gravel, sand, silt, clay, and manufactured sand and aggregate
- Typical cement content is between 2 to 6 percent of soil dry weight
- Modify and stabilize the soil

CEMENT MODIFY AND STABILIZE THE SOIL

- **<u>Soil cement modification</u> is typically used for creating a working platform or improve construction conditions and no additional strength is added to the design**
- **Typically soils plasticity and moisture modifications**

- **<u>Soil cement stabilization</u> is typically used to modify and increase the strength of the soils in design**
- **Typically soil plasticity and moisture modification, and bearing capacity increase**

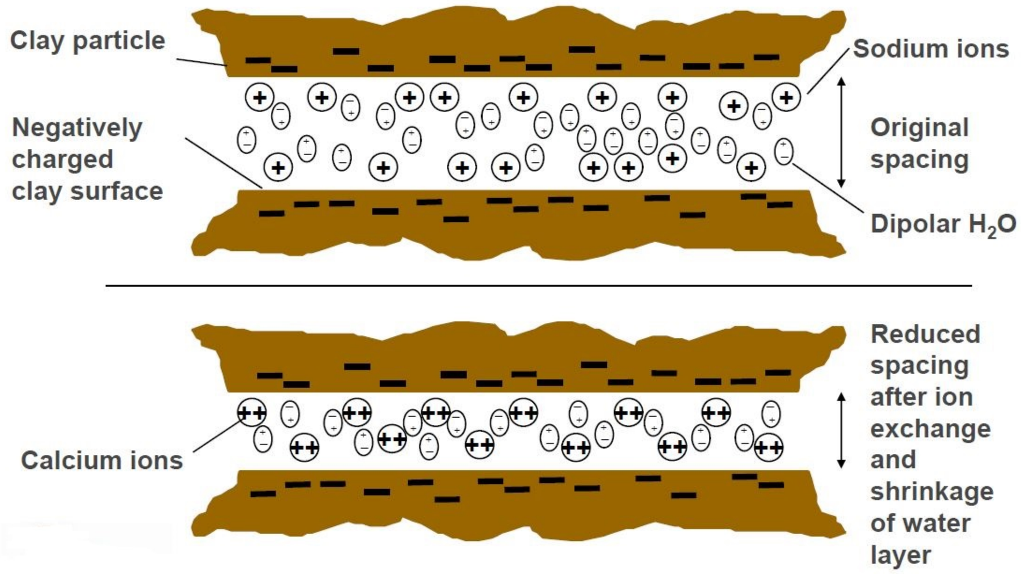
CEMENT HAS SEVERAL EFFECTS ON SOIL PARTICLES

1. Cation Exchange ⇒ Immediately to few hours
2. Particle Restructuring ⇒ Immediate to few hours
3. Cement Hydration ⇒ Large portion of strength gain between 1 day and 1 month
4. Pozolanic Reaction ⇒ Slowly, over months and years

Mechanism	Sand, Gravel, Silt (Non-Cohesive)	Clay (Cohesive)
Cation Exchange		✓
Particle Restructuring		✓
Cement Hydration	✓	✓
Pozzolanic Reaction		✓

1. CATION EXCHANGE
RESULTS IN CLOSER SPACING OF CLAY PARTICLES

- Clay minerals (silica and alumina) naturally forms a bonded crystal structure (negative charge surface) layers
- Cations and water molecules are attracted to negative charge surface in attempt to neutralize the charge deficiency
- Separation of charge surfaces forms a diffuse double layers
- The thicker the double layer, the more plastic the clay soil
- Cement has calcium ions that provides sufficient exchange, shrinking the layer of water between clay particle

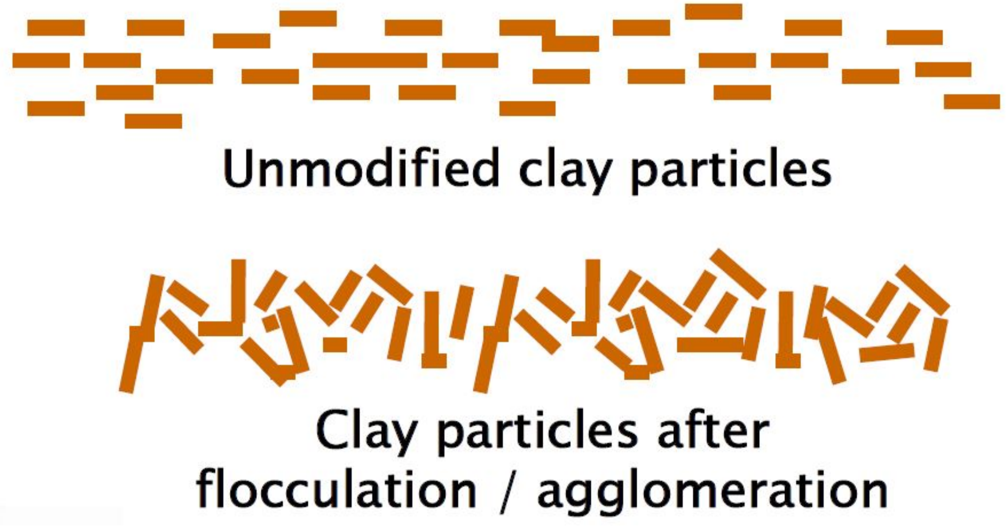


(1) Guide to Cement-Stabilized Subgrade Soils, May 2020

2. PARTICLE RESTRUCTURING
ALLOWS GREATER STABILIZER INTERACTION

Flocculation and agglomerate:

- **Clay particle arrangement from flat to random edge to surface orientation through cation exchange**
- **Weak bonding is formed at the edge to surface interfaces of the clay particles**
- **Changes the texture of the material from plastic (fine-grained materials) to granular/aggregate resembling**
- **Increases shear strength**



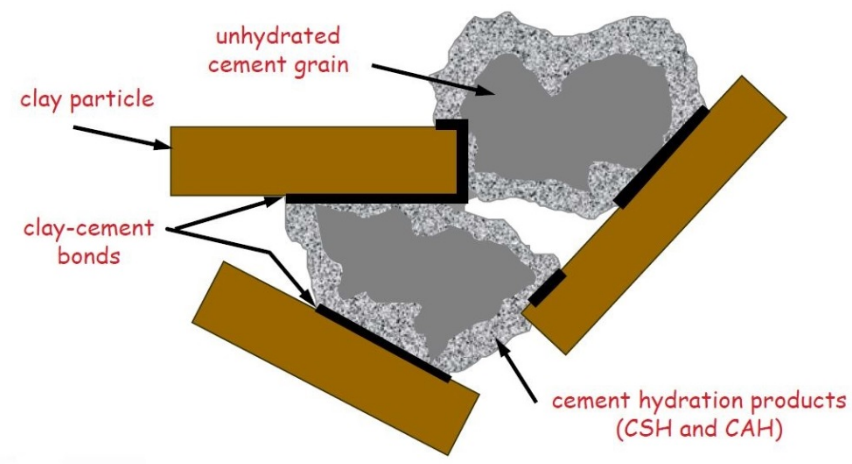
(1) Guide to Cement-Stabilized Subgrade Soils, May 2020

3. CEMENT HYDRATION

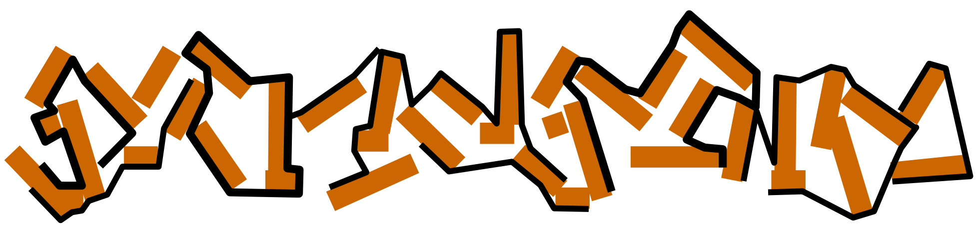
BINDS SOIL PARTICLES AND INCREASES STRENGTH

Cement and water reacts to form:

- **Calcium + Silica = CSH**
- **Calcium + Alumina = CAH**
- **Calcium + Water (H_2O) = Hydrated Lime**
- **CSH + CAH = Strength gain**



In Clay soils:



CSH + CAH = Stabilize flocculated clay particles through a formation of clay-cement bonds

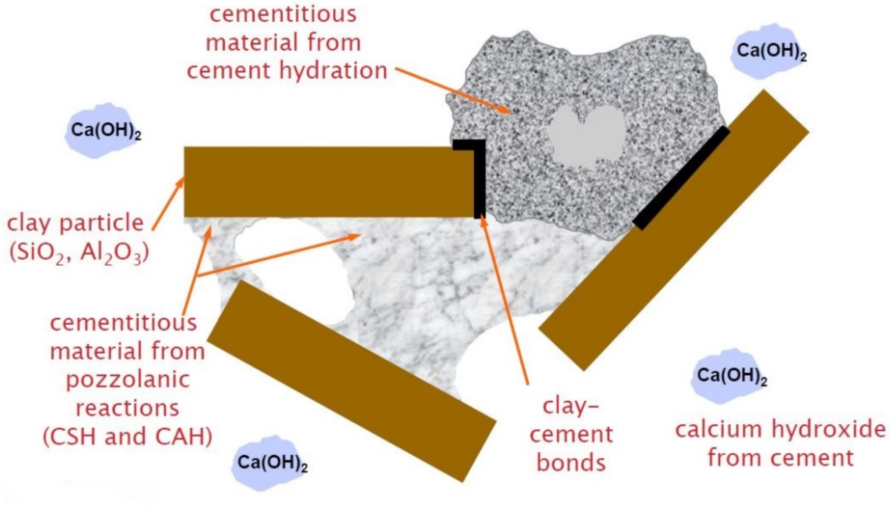
Cement + Water = Calcium-silicate hydrate (CSH) + Calcium-aluminate hydrate (CAH) + Calcium hydroxide (hydrated lime)

(1) Guide to Cement-Stabilized Subgrade Soils, May 2020

4. POZZOLANIC REACTION
PROVIDES STRENGTH GAIN OVER AN EXTENDED TIME PERIOD

Secondary reaction due to hydrated lime:

- **Hydrated Lime [$Ca(OH)_2$] + Silica (Clay) = CSH**
- **Hydrated Lime [$Ca(OH)_2$] + Alumina (Clay) = CAH**
- **CSH + CAH = Additional Strength gain (cement-clay bonds)**



Pozzolanic reaction does not occur unless silica- or alumina-based clay minerals are present

(1) Guide to Cement-Stabilized Subgrade Soils, May 2020

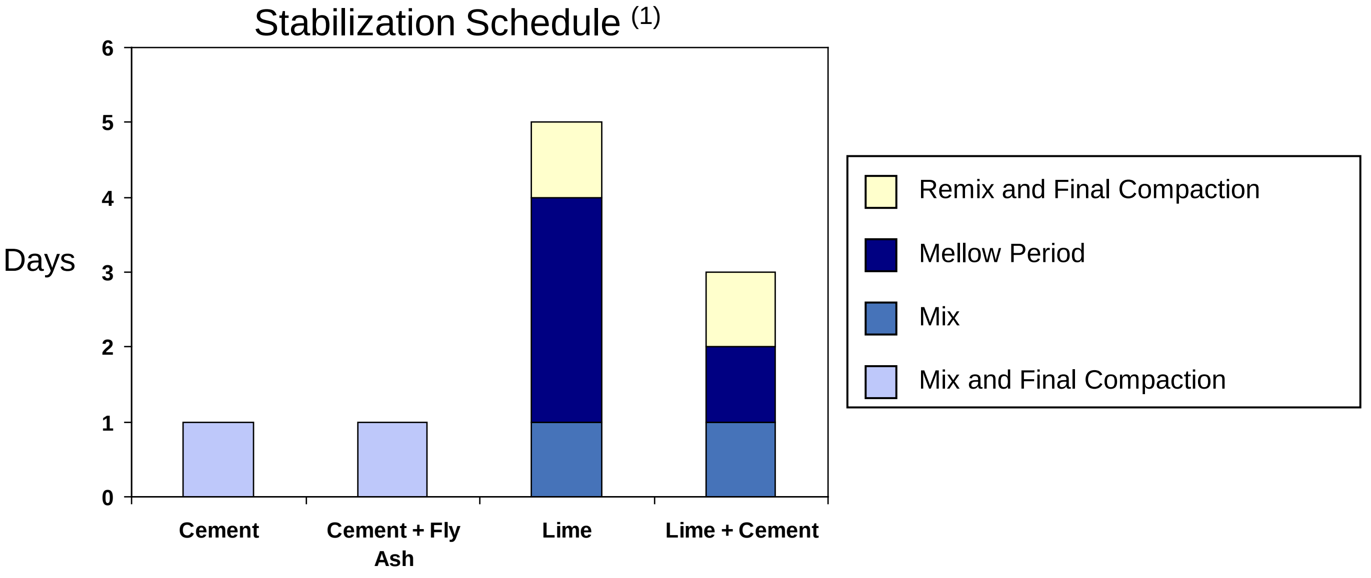
CEMENT STABILIZATION BENEFITS THE CONTRACTOR AND OWNER

Improved subgrade soil properties

- Reduced volume change caused by moisture variation
- Improved strength/bearing capacity (especially when wet)

Expedited construction

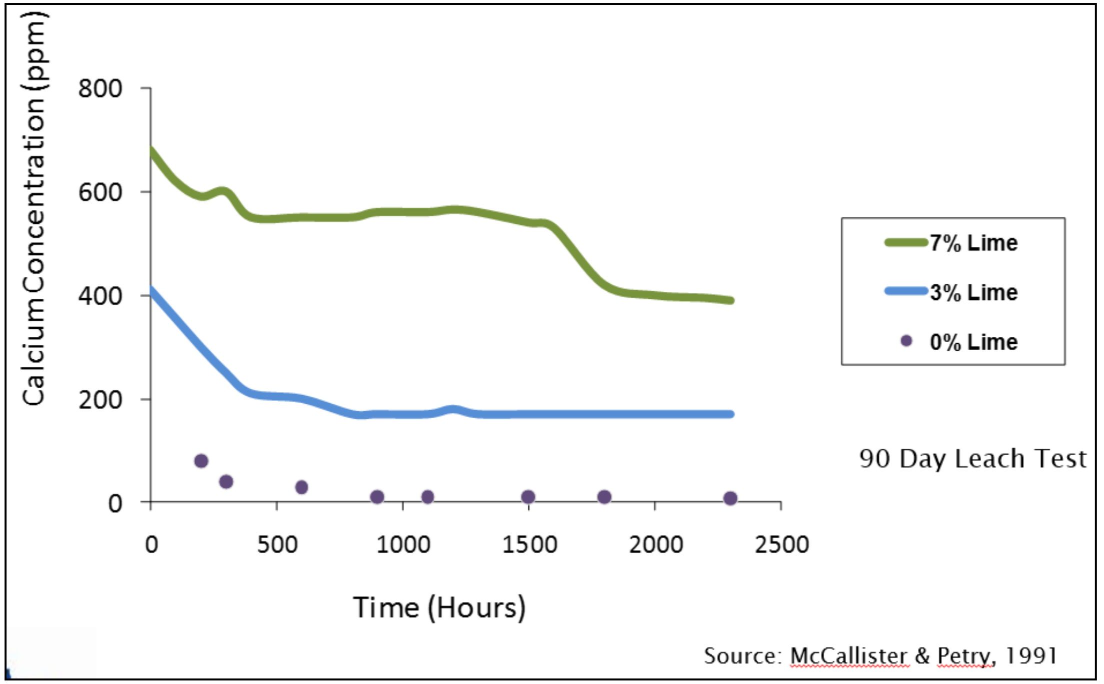
- Improved subgrade support for construction equipment
- Eliminate muddy construction sites
- Mix and compact same day



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

WATER MOVEMENT THROUGH LIME-STABILIZED SOIL MAY LEACH SOLUBLE CALCIUM

- Soil properties may revert to unstabilized levels
- Lime percentage indicated by Eades & Grim pH test might not be adequate
- Additional lime may be required to achieve permanent strength and other desired modifications

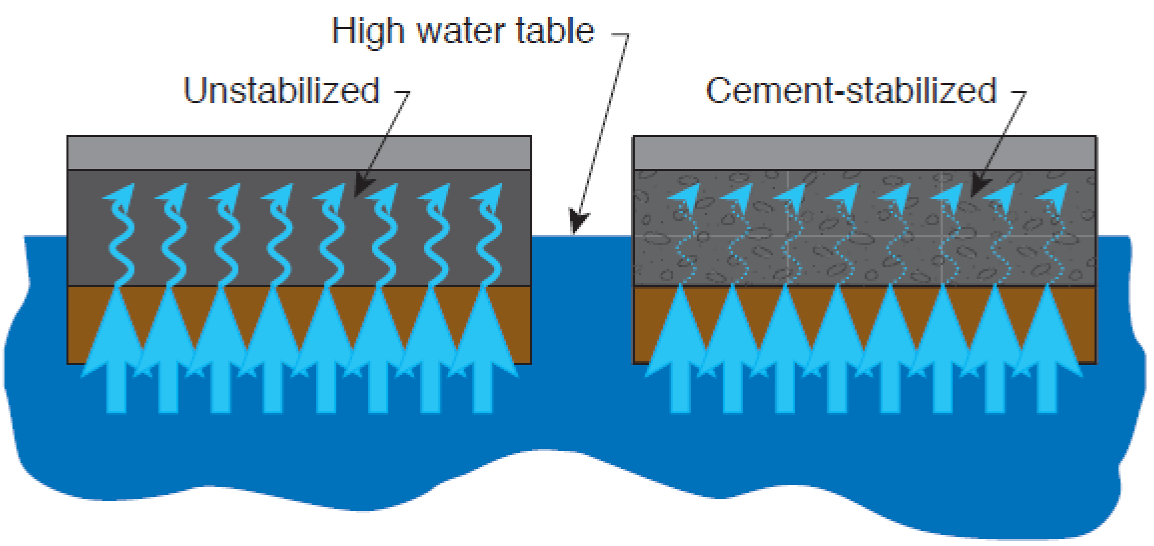


In Lime (hydrated lime) typically does not occur unless silica- or alumina-based clay minerals are present

(1) McCallister, L. and Petry, T., “Leaching Tests on Lime-Treated Clays,” Geotechnical Testing Journal, Vol. 15, No. 2,, 1992,pp. 106-114

CEMENT DECREASES MOISTURE SENSITIVITY OF THE SECTION

- **Tube Suction Test (TST) – Using Adek Percometer™**
- **Measures movement of water in a sample of cement-stabilized material**
- **Used to evaluate permeability and capillarity**



(1) Guide to Cement-Stabilized Subgrade Soils, May 2020

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- Durability Testing
- Construction Considerations

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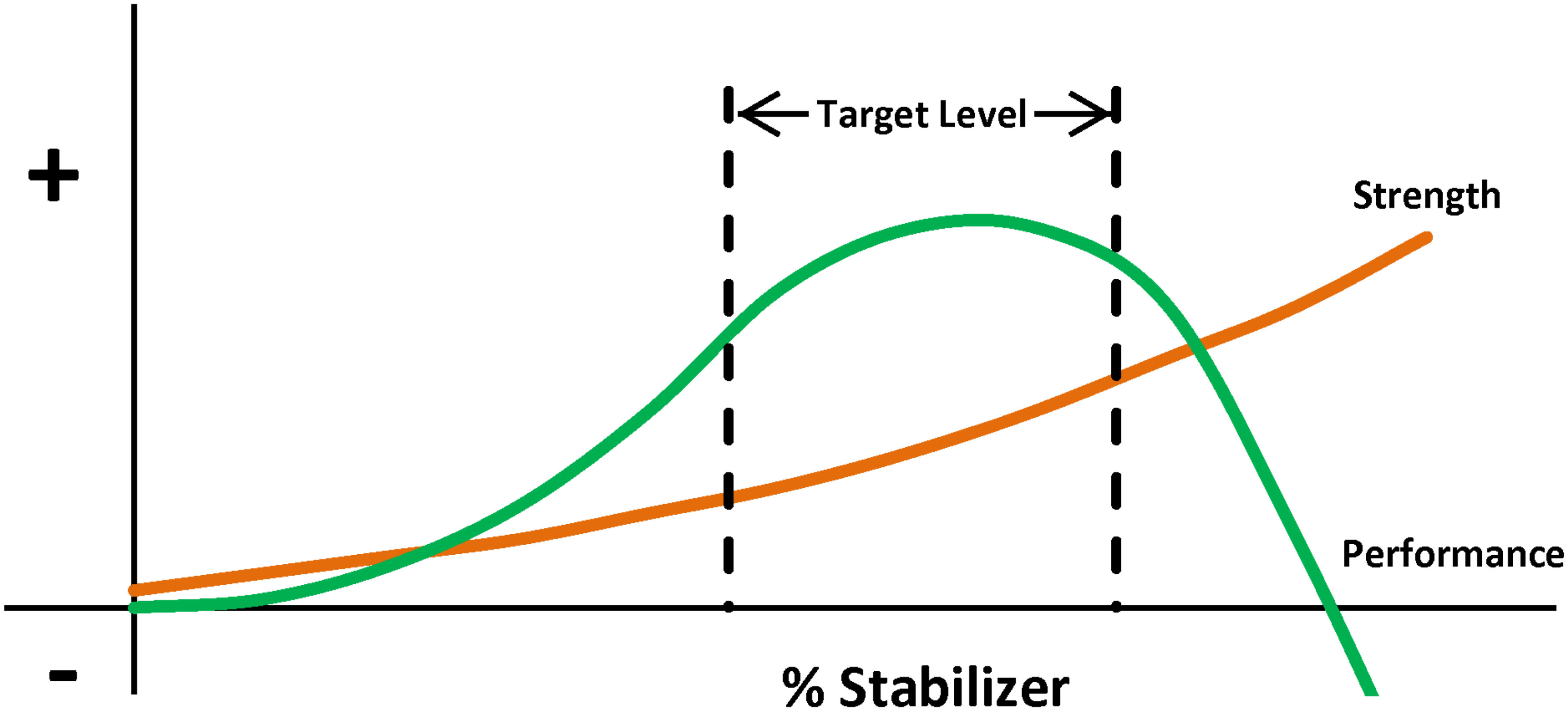
THE GOAL IS TO BALANCE STRENGTH AND PERFORMANCE



- More stabilizer is not necessarily better
- Determine "Target Level" to provide strength without sacrificing durability
- Typically 2-6% cement content or 7 day target Unconfined Compressive Strength (UCS) of 100-300 psi (ALDOT use 250 to 600 psi)

(1) Recommend not to exceed 400 psi in 7 day target Unconfined Compressive Strength

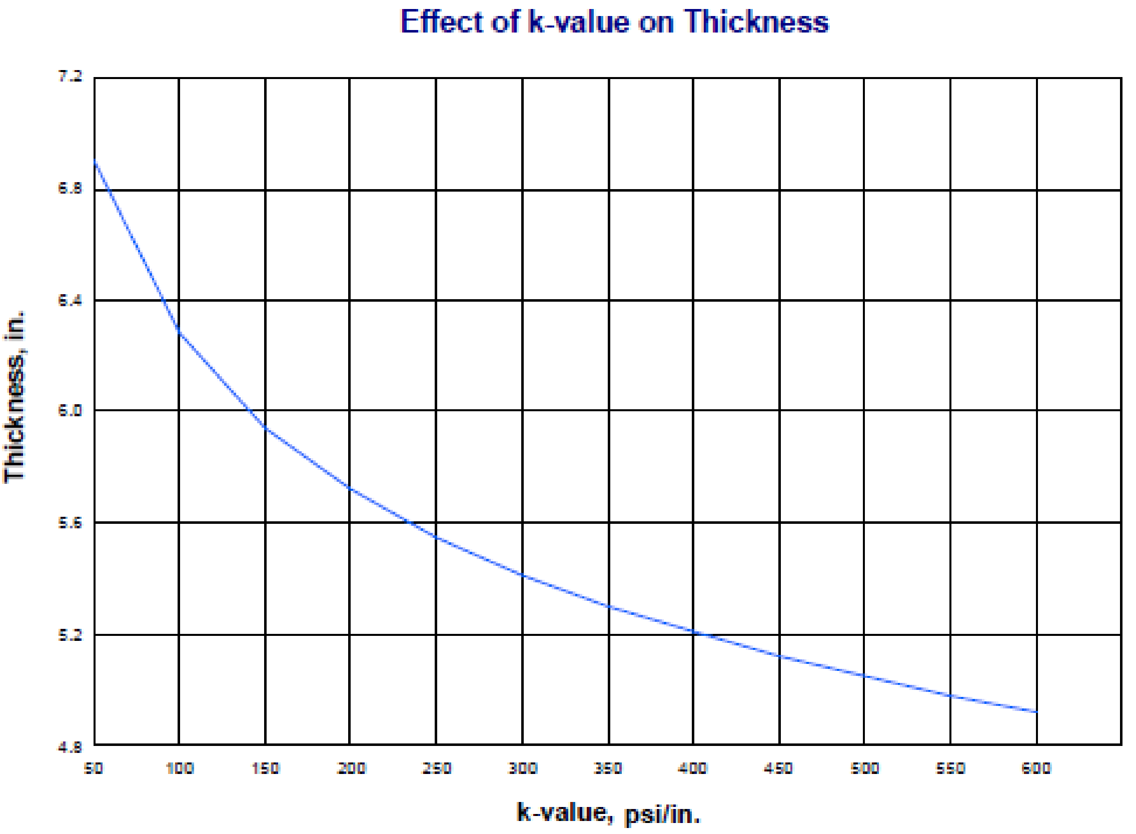
CEMENT INCREASES BEARING CAPACITY

Modulus of Subgrade Reaction (K-Value)*:

Table 3.2—Modulus of subgrade reaction *k**

Subgrade *k* value, psi/in.	Sub-base thickness			
	4 in.	6 in.	9 in.	12 in.
	Granular aggregate subbase			
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430
	Cement-treated subbase			
50	170	230	310	390
100	280	400	520	640
200	470	640	830	—
	Other treated subbase			
50	85	115	170	215
100	175	210	270	325
200	280	315	360	400
300	350	385	420	490

*For subbase applied over different subgrades, psi/in. (Portland Cement Association 1984a,b; Federal Aviation Administration 1978).
Note: 1 in. = 25.4 mm, and 1 psi/in. = 0.27 MPa/m.



(1) ACI 330R-08, Table 3.2

MIX DESIGN IS CONDUCTED WITH STANDARD TESTING

- Cement:
  - Portland Cement (ASTM C150, AASHTO M85)
  - Blended Hydraulic Cement (ASTM C595, AASHTO M240)
- Sieve Analysis (ASTM C6913, AASHTO T27)
- Atterberg Limits (ASTM D4318, AASHTO T89 & 90)
- Compressive Strength (ASTM D1633)
- Moisture-Density Relationship (ASTM D558, AASHTO T134)
- Density of in-place soil cement (ASTM D6938, AASHTO T310)
- Soil Cement Design (ALDOT 416)
- Wet-Dry (ASTM D559)
- Freeze-Thaw (ASTM D560)
- Tube Suction Test (Adek Percometer™)
- Soluble Sulfates (ASTM C1580, AASHTO T290)

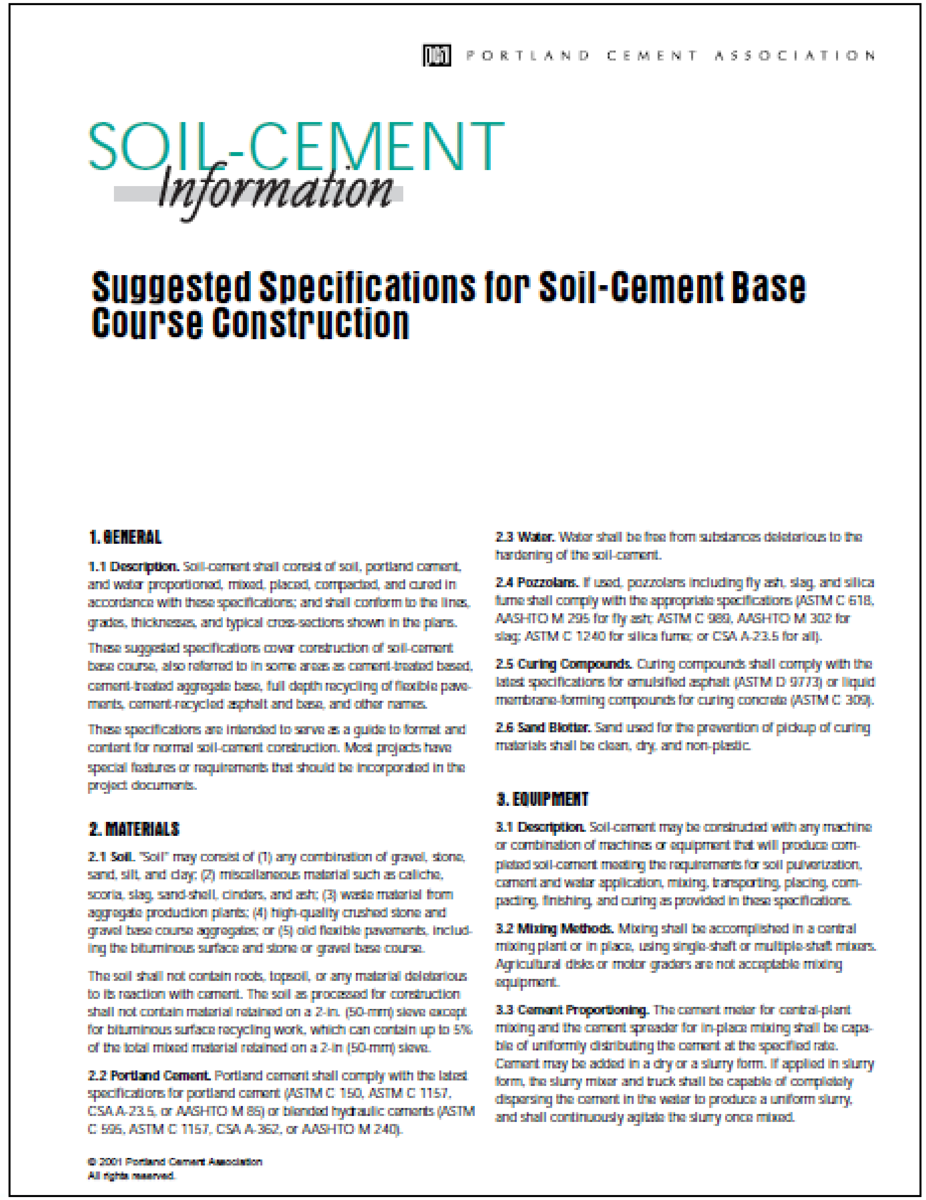
Typical Mix Design Steps[2]:

1. Determine In Situ Moisture Content and Classify Soil
2. Determine Cement Type and Estimated Dosage Rate
3. Determine Chemical Compatability (If Necessary)
4. Determine Atterberg Limits of Three Different Cement Content Samples
5. Determine Optimum Moisture Content and Maximum Dry Density
6. Determine the Unconfined Compressive Strength (Optional for CMS)
7. Plot Unconfined Compressive Strength to Verify Cement Content
8. Compile Mix Design Report

(1) Uncommon
(2) Guide to Cement-Stabilized Subgrade Soils, May 2020

CONSTRUCTION IS PERFORMED IN A SPECIFIC SEQUENCE

1. **Initial pulverize soil materials/ Moisture Conditioning (If Needed)**
2. **Spread Cement in dry or slurry form**
3. **Mixing of cement and soil directly (with water if needed)**
4. **Achieve optimum moisture content of the soil-cement**
5. **Initial Compaction: minimum of 95 to 98% standard Proctor (preferred 98%)**
6. **Finishing: Grading and final compaction**
7. **Curing**
8. **Controlling Reflective Cracking (asphalt Pavements)**


PORTLAND CEMENT ASSOCIATION

SOIL-CEMENT *Information*

Suggested Specifications for Soil-Cement Base Course Construction

1. GENERAL

1.1 Description. Soil-cement shall consist of soil, portland cement, and water proportioned, mixed, placed, compacted, and cured in accordance with these specifications; and shall conform to the lines, grades, thicknesses, and typical cross-sections shown in the plans.

These suggested specifications cover construction of soil-cement base course, also referred to in some areas as cement-treated based, cement-treated aggregate base, full depth recycling of flexible pavements, cement-recycled asphalt and base, and other names.

These specifications are intended to serve as a guide to format and content for normal soil-cement construction. Most projects have special features or requirements that should be incorporated in the project documents.

2. MATERIALS

2.1 Soil. "Soil" may consist of (1) any combination of gravel, stone, sand, silt, and clay; (2) miscellaneous material such as caliche, scoria, slag, sand-shell, cinders, and ash; (3) waste material from aggregate production plants; (4) high-quality crushed stone and gravel base course aggregates; or (5) old flexible pavements, including the bituminous surface and stone or gravel base course.

The soil shall not contain roots, topsoil, or any material deleterious to its reaction with cement. The soil as processed for construction shall not contain material retained on a 2-in. (50-mm) sieve except for bituminous surface recycling work, which can contain up to 5% of the total mixed material retained on a 2-in (50-mm) sieve.

2.2 Portland Cement. Portland cement shall comply with the latest specifications for portland cement (ASTM C 150, ASTM C 1157, CSA A-23.5, or AASHTO M 85) or blended hydraulic cements (ASTM C 595, ASTM C 1157, CSA A-362, or AASHTO M 240).

2.3 Water. Water shall be free from substances deleterious to the hardening of the soil-cement.

2.4 Pozzolans. If used, pozzolans including fly ash, slag, and silica fume shall comply with the appropriate specifications (ASTM C 618, AASHTO M 295 for fly ash; ASTM C 989, AASHTO M 302 for slag; ASTM C 1240 for silica fume; or CSA A-23.5 for all).

2.5 Curing Compounds. Curing compounds shall comply with the latest specifications for emulsified asphalt (ASTM D 9773) or liquid membrane-forming compounds for curing concrete (ASTM C 309).

2.6 Sand Blotter. Sand used for the prevention of pickup of curing materials shall be clean, dry, and non-plastic.

3. EQUIPMENT

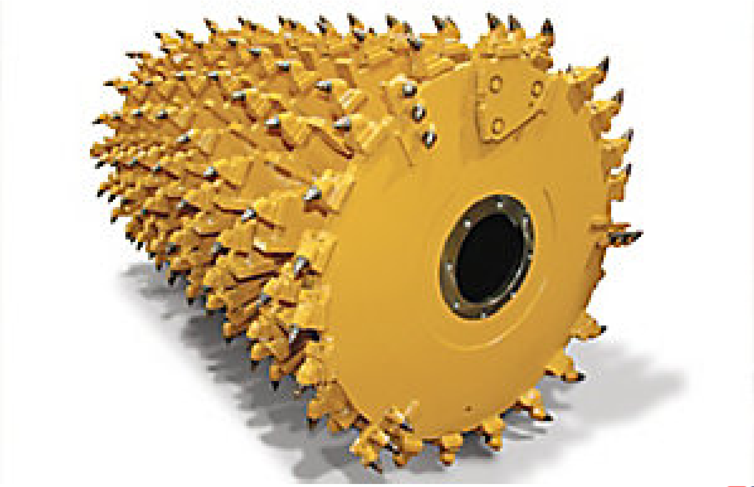
3.1 Description. Soil-cement may be constructed with any machine or combination of machines or equipment that will produce completed soil-cement meeting the requirements for soil pulverization, cement and water application, mixing, transporting, placing, compacting, finishing, and curing as provided in these specifications.

3.2 Mixing Methods. Mixing shall be accomplished in a central mixing plant or in place, using single-shaft or multiple-shaft mixers. Agricultural disks or motor graders are not acceptable mixing equipment.

3.3 Cement Proportioning. The cement meter for central-plant mixing and the cement spreader for in-place mixing shall be capable of uniformly distributing the cement at the specified rate. Cement may be added in a dry or a slurry form. If applied in slurry form, the slurry mixer and truck shall be capable of completely dispersing the cement in the water to produce a uniform slurry, and shall continuously agitate the slurry once mixed.

1. INITIAL PULVERIZE SOIL MATERIALS/ MOISTURE CONDITIONING (IF NEEDED)

- **Initial pulverization and moisture conditioning if needed for unform distribution**
- **Typical single-shaft or multiple-shaft mixers (Reclaimer)**
- **Agricultural disks, motor grader, trackhoe or backhoe bucket are not acceptable mixing equipment**



2. SPREADING OF CEMENT

Dry Placement

Slurry Placement

The time from cement placement on soil to start of mixing should not exceed 30 minutes

CEMEX USA

2. SPREADING OF CEMENT
CEMENT APPLICATION RATE

Cement Application Rates

	20 lbs/yd²				30 lbs/yd²				40 lbs/yd²				50 lbs/yd²				60 lbs/yd²				70 lbs/yd²			
	Depth of Stabilization (in.)				Depth of Stabilization (in.)				Depth of Stabilization (in.)				Depth of Stabilization (in.)				Depth of Stabilization (in.)				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**
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%
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%
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%
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%
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%
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%

*Spread Rate (lb/yd^2) = (Thickness of Stabilization, in) x (Average Dry Density of the Soil, lb/ft^3) x (Percentage of Cement in decimals) x (0.75, conversion factor - $9ft^2/1\ yd^2$ x 1ft/12 in)

Cement application rate depends on laboratory test results of a specific soil mixed with cement to achieve desirable strength and/or plasticity

3. MIXING OF CEMENT AND SOIL DIRECTLY (WITH WATER IF NEEDED) (DRY PLACEMENT)

Mixing should be performed within 30 minutes after spreading of cement

4. ACHIEVE OPTIMUM MOISTURE CONTENT OF THE SOIL-CEMENT

- **Moisture content should be within 2% of the specified optimum moisture**

5. INITIAL COMPACTION OF THE SOIL-CEMENT MIX

- Soil-cement should be uniformly compacted to a minimum of 95 to 98% of maximum density (preferred 98%)
- Based on moving average of five consecutive tests with no individual test below 93%
- Compaction should be completed within 2 hours from start of the mix

6. GRADING AND FINAL COMPACTION

- Grade the soil-cement to a specified final elevations or cross sections
- Final compaction should produce dense and clean finish (no loose materials)
- The finishing of soil-cement process should be completed within 4 hours from start of mixing

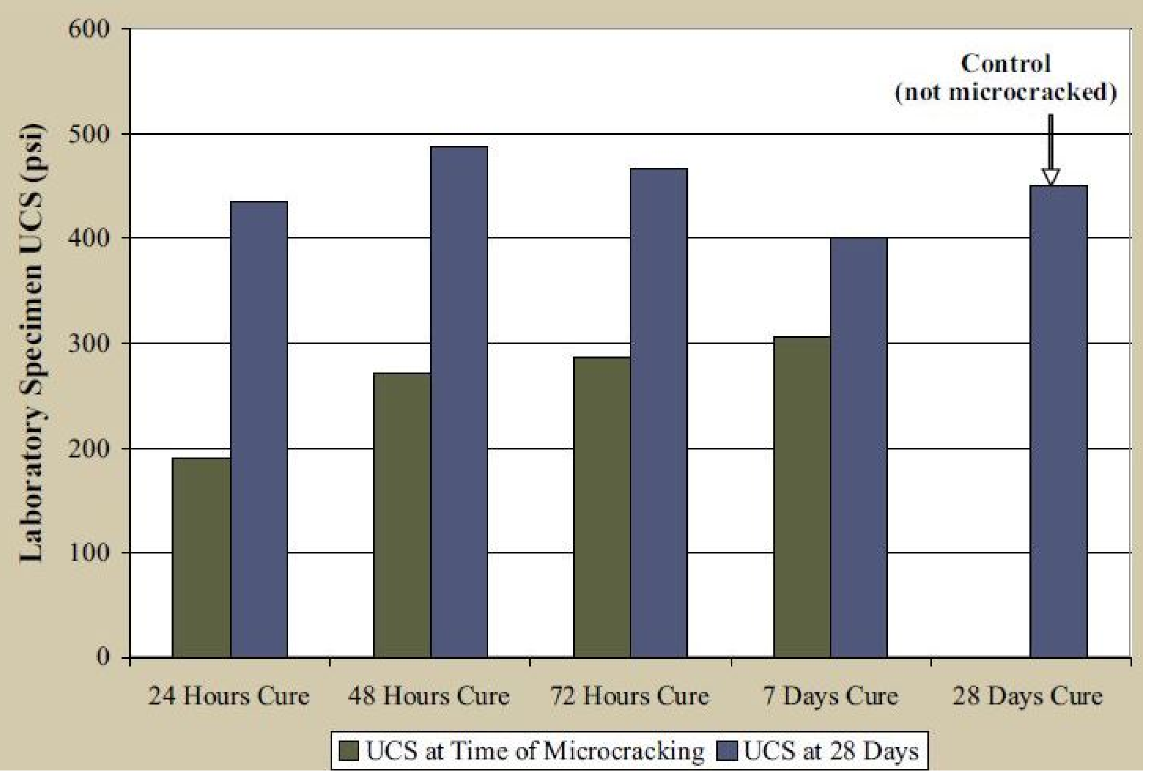
7. CURING

- ➢Curing using continuous moist for a period of 7 days or bituminous or other sealing membrane
- ➢Light traffic may be allowed during curing process

8. CONTROLLING REFLECTIVE CRACKING (ASPHALT PAVEMENTS)

A. MICROCRACKING

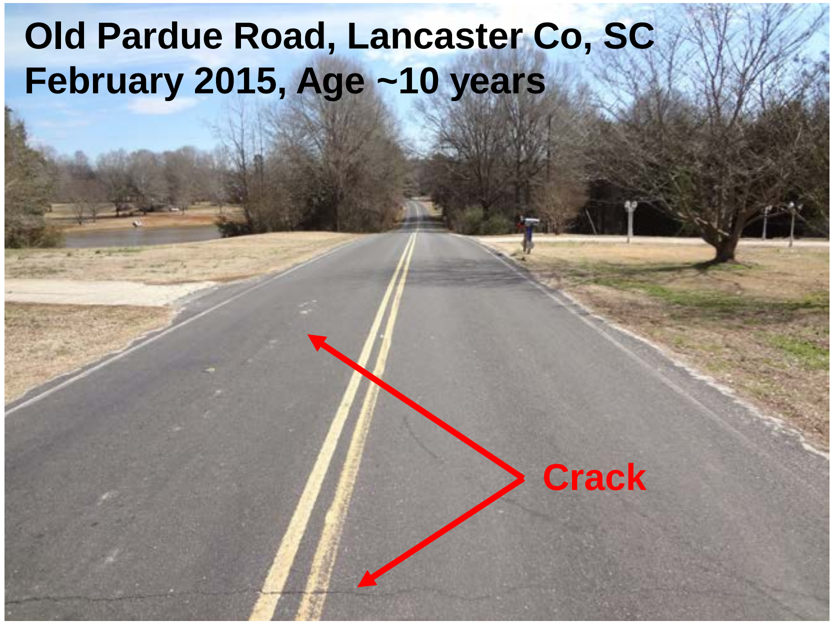
- Application of several vibratory roller passes to create fine network of cracks
- Microcracking should be considered for any properly designed cement-stabilized soil
- Perform after 48 to 72 hours of moist curing after compaction
- Minimum 3 passes of a 10 to 12-ton vibratory steel drum roller at maximum amplitude
- Strength recovers due to continued cement hydration
- Typically no visual changes are detectable, although some hairline cracks may appear
- Measure stiffness with FWD or Geogauge



Source: TxDOT and Texas Transportation Institute data from microcracking project on SH 47 near Bryan, Texas (LT299).

MICROCRACKING PHOTOS

Cracks without Microcracking



Cracks after Microcracking

MICROCRACKING PROJECT EXAMPLE
Blue Ridge Parkway, Virginia

Project:

- Reconstructed in 2013 using FDR process
- Total reconstructed length of 28 miles
- Runs from Virginia to North Carolina (total of 469 miles)
- Microcracking was performed on all 28 miles
- No cracking was noted after the construction on all 28 miles

8. CONTROLLING REFLECTIVE CRACKING (ASPHALT PAVEMENTS)

B. OTHER RECOMMENDED METHODS

I. Stress Relief Layer:

- Bituminous surface treatment (chip seal between cement stabilized base and asphalt
- Geotextile fabric between cement stabilized base and asphalt
- 2 to 4 inches layer of unbonded granular material between cement stabilized base and asphalt

II. Delay Paving:

- Delaying for 14 to 28 days to allow shrinkage cracks to develop after placing prime
- Asphalt tend to bridge over the formed cracks.

III. Proportion of Proper amount of Cement:

- Typically, a 7-day unconfined compressive strength greater than 100 to about 400 psi (depending on soil type) provide a better pavement performance (durability, bearing capacity, and shrinkage properties).

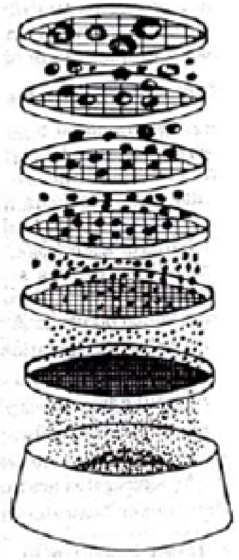
IV. Do Nothing:

- Reflective cracking is a typically aesthetic issue and has high load transfer efficiency

FIELD TESTING

Gradation/Uniformity

➢Typical requirement is 100% passing a 3-in. sieve, minimum 95% passing a 2-in. sieve, and a minimum of 55 percent passing a No. 4 sieve (ASTM C136)



Density

➢Common density requirement is to be between 95 and 98% of the established laboratory standard Proctor density (ASTM D558)

FIELD TESTING

Moisture

➢Common moisture requirement is to be within 2% of the laboratory established optimum moisture content (ASTM D558)

Depth of Stabilization

➢Common depth verification utilizes phenolphthalein indicator

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PUBLICATIONS CASE STUDIES

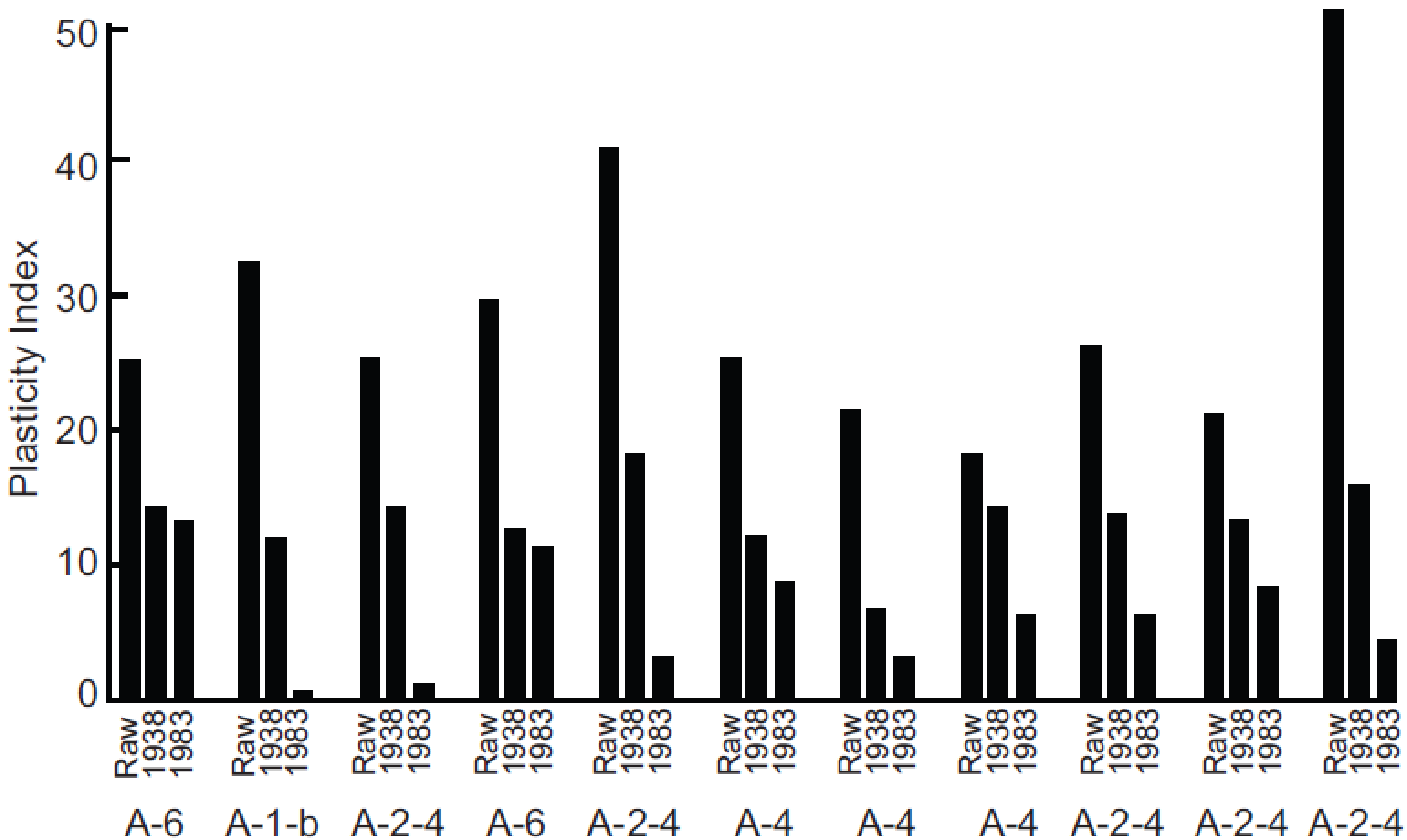
*Table 2. Effect of Cement Treatment on Properties of Clay Soils **

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

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

Shrinkage Limit (SL) determine how much moisture in percent the soil can absorb without swelling

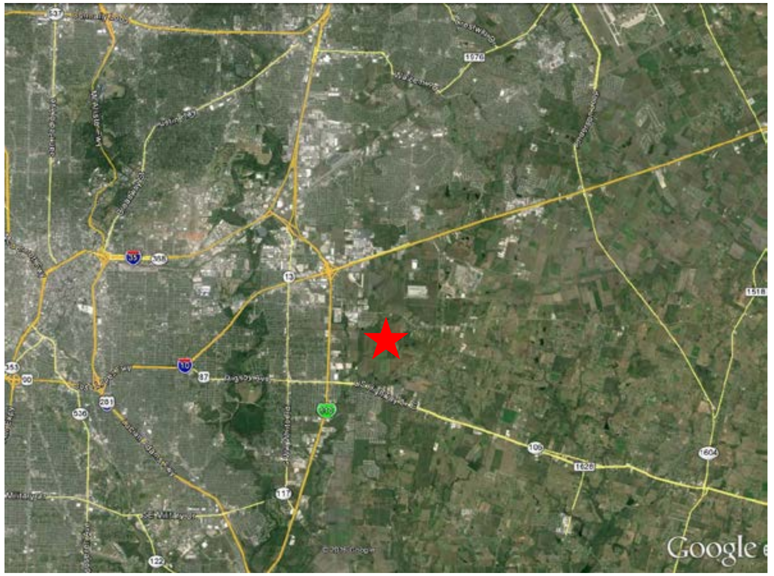
PUBLICATIONS CASE STUDIES



Field Test of 11 samples after 45 years of service between 1938 and 1983 shows improvement in soil properties

PROJECTS EXAMPLES

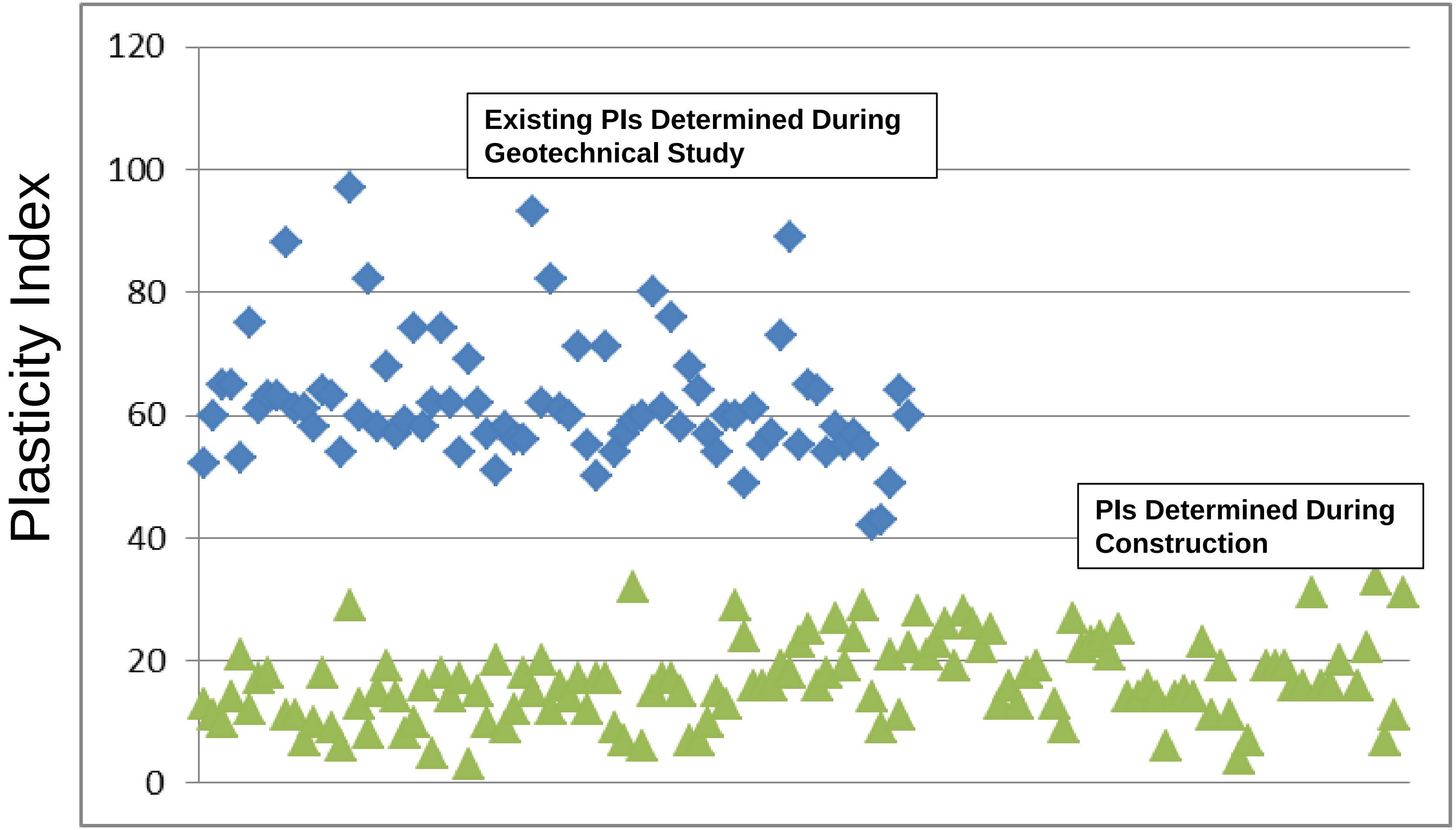
1. DOLLAR GENERAL DISTRIBUTION CENTER - SAN ANTONIO, TEXAS



- Existing PVR = 6 to 8 inches.
- Average PI = 62
- Material stabilized = 7 to 8 feet
- Owner selected cement due to construction schedule

PROJECT EXAMPLES:

1. DOLLAR GENERAL DISTRIBUTION CENTER – SAN ANTONIO, TEXAS



PIs lowered to an average of less than 20

PROJECT EXAMPLES:

2. LIQUEFIED NATURAL GAS (LNG) PLANT - HACKBERRY/SULPHUR, LOUISIANA

- Existing material known as "duck mud" and loses all strength when wet (dredging spoils)
- Utilizing 7% cement placed in three 12 in. lifts to achieve target strength of 25 psi
- Stabilizing solely to support foundation construction equipment
- Contractor not allowed to use lime due to possibility of leaching into surrounding wetlands

PROJECT EXAMPLES:
3. YKTA PLANT – HUNTSVILLE, ALABAMA

Project Information:
- ➢ Contractor: Terra Firma
- ➢ Constructed in 2020
- ➢ Proposed undercut of 100,000 cy of soft soils and replace with suitable soils

Soil Cement:
- ➢ Cement treatment of approximately 12” deep with 3% to 8% cement
- ➢ Estimated cost $1,000,000
- ➢ Saving client nearly $1,500,000

OTHER PROJECTS IN ALABAMA

Projects:

- Briggs & Stratton – Auburn, AL
- 3M Plant - Decatur, AL
- Huntsville Crossroads (TPA Huntsville)
- Google Data Center – Huntsville, AL
- Blue Origin – Huntsville, AL
- Toyota Mazda Project – Huntsville, AL

CEMENT-STABILIZED SUBGRADE SOILS TROUBLESHOOTS

Typical Troubleshoots:

Reflective cracking:

- Reflective cracking is a typically aesthetic issue and has high load transfer efficiency
- Proportion proper amount of cement (typically 3 to 6%). An increased amount of cement leads to more shrinkage and widening of the cracks.

Highly plastic/ expansive soils:

- Perform Atterberg Limits test (ASTM C136, AASHTO T89 & 90) to determine if the soils are highly plastic or expansive
- Cement stabilize the subgrade to a depth required to stabilized the expansive soil (typically 1 to 3 feet in Alabama, seasonal moisture is stable)

Reflective Cracking

Highly Plastic/Expansive Soils

Typically, little to no repair is required in both cases after the project has been completed, unless poses a safety hazard

SUMMARY

1. Cement stabilization can be used in both granular and fine-grained materials
2. Cement provides immediate and long-term increases in soil strength
3. PIs can typically be reduced to specified criteria
4. Construction time is reduced (no mellowing) and project site is open to traffic on the next day
5. Provides a strong foundation for both rigid and flexible pavements

Thank You

& Any Questions?

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