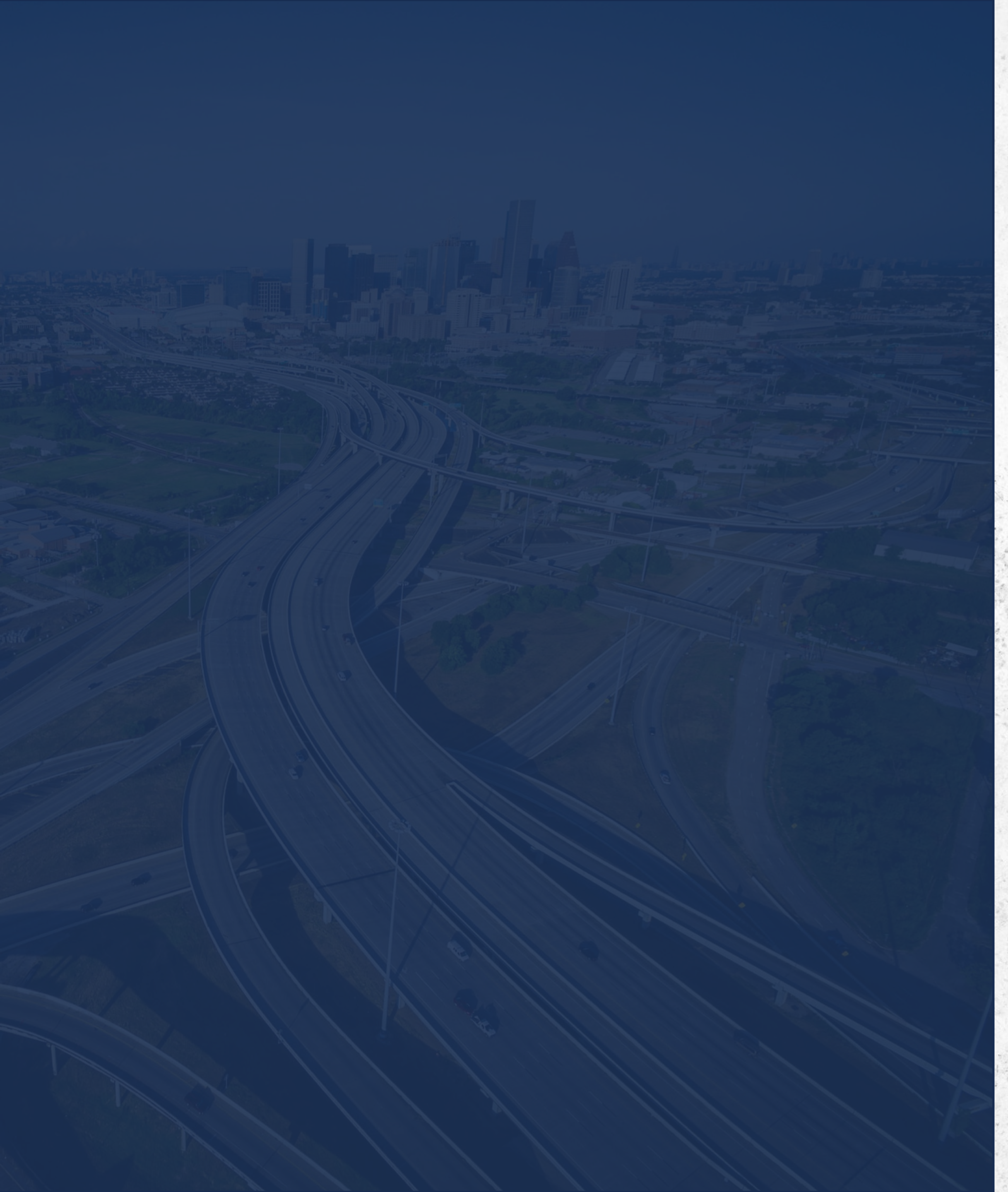

The Role of Stabilized Soils in Concrete Pavement Performance

Randy Bowers, P.E.

SOIL CEMENT

(by any other name)

- **Cement Modified Soil (CMS)**
- **Cement Stabilized Subgrade (CSS) Soil**
- Cement Treated Base (CTB)
- Full-Depth Reclamation (FDR) with Cement

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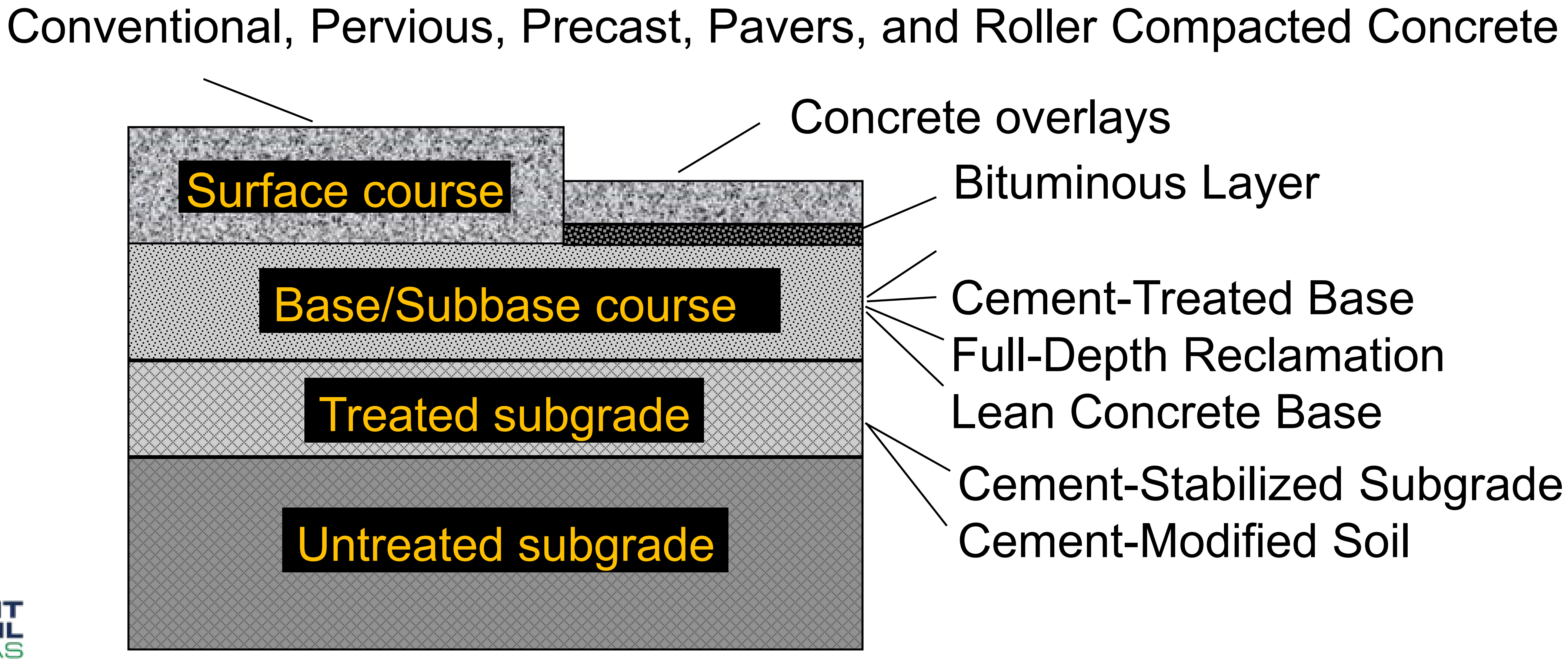
Cement-Based Materials in Pavements



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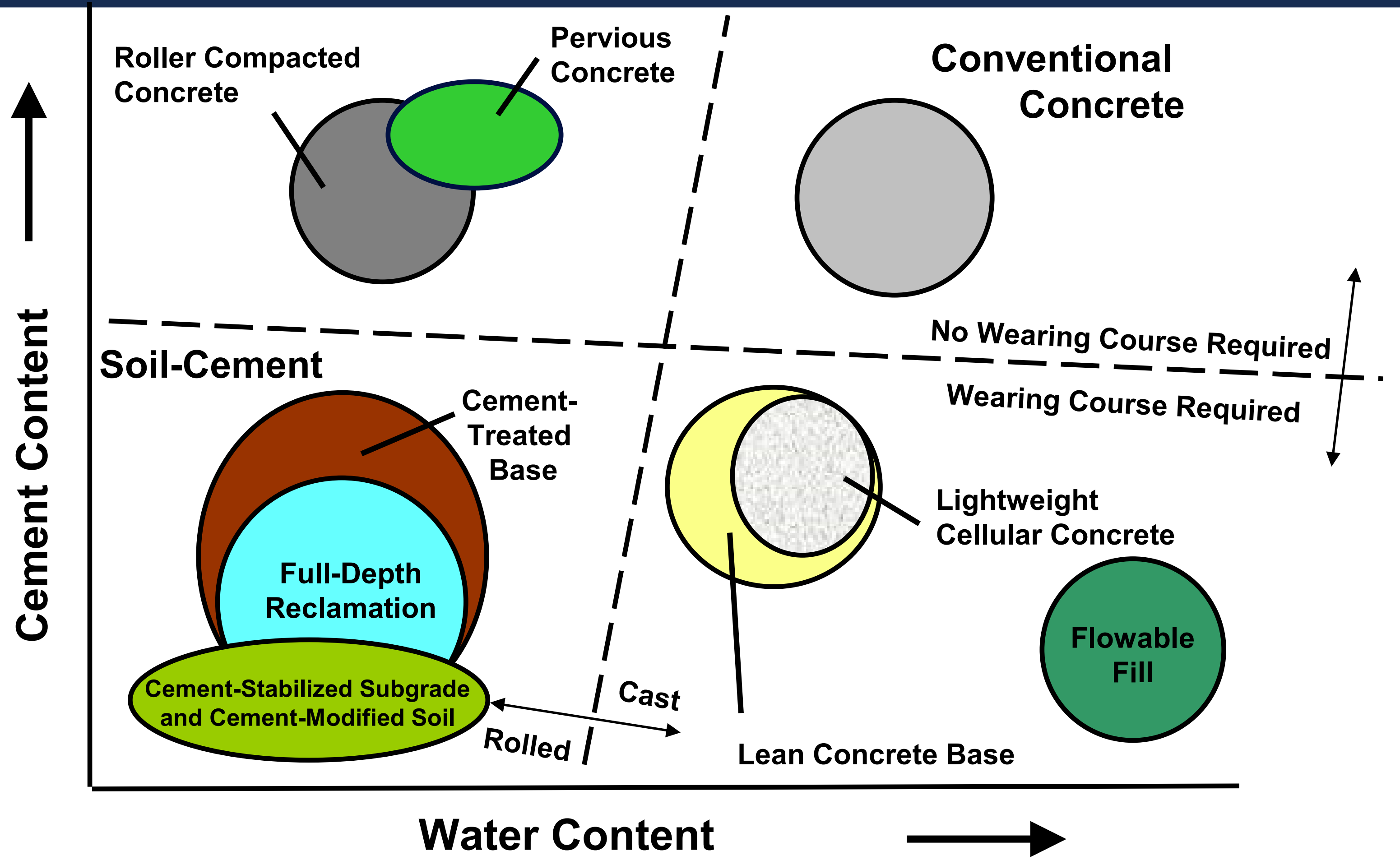
Cement-Based Pavement Materials



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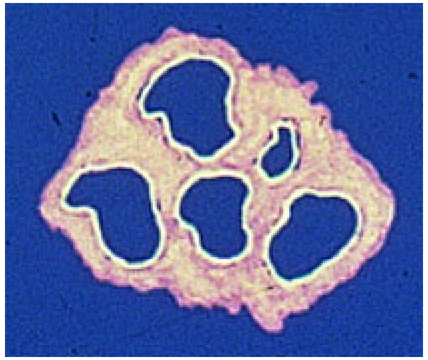
Concrete vs. Soil-Cement

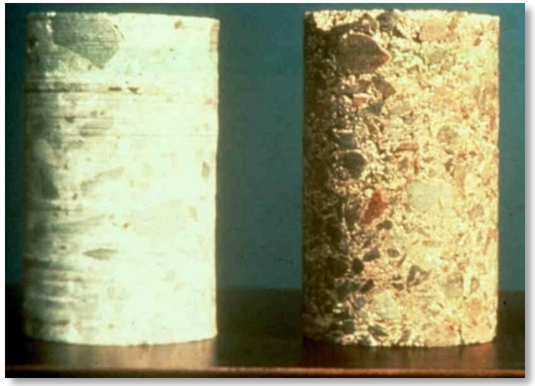
CEMENTITIOUS GEL OR PASTE

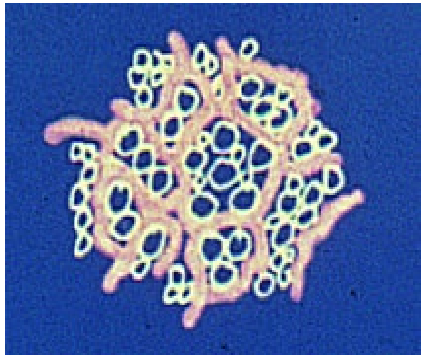
- All particles coated
- All voids filled
- Aggregates glued together

HYDRATION PRODUCTS

- Not all particles coated
- All voids not filled
- Agglomerations linked together







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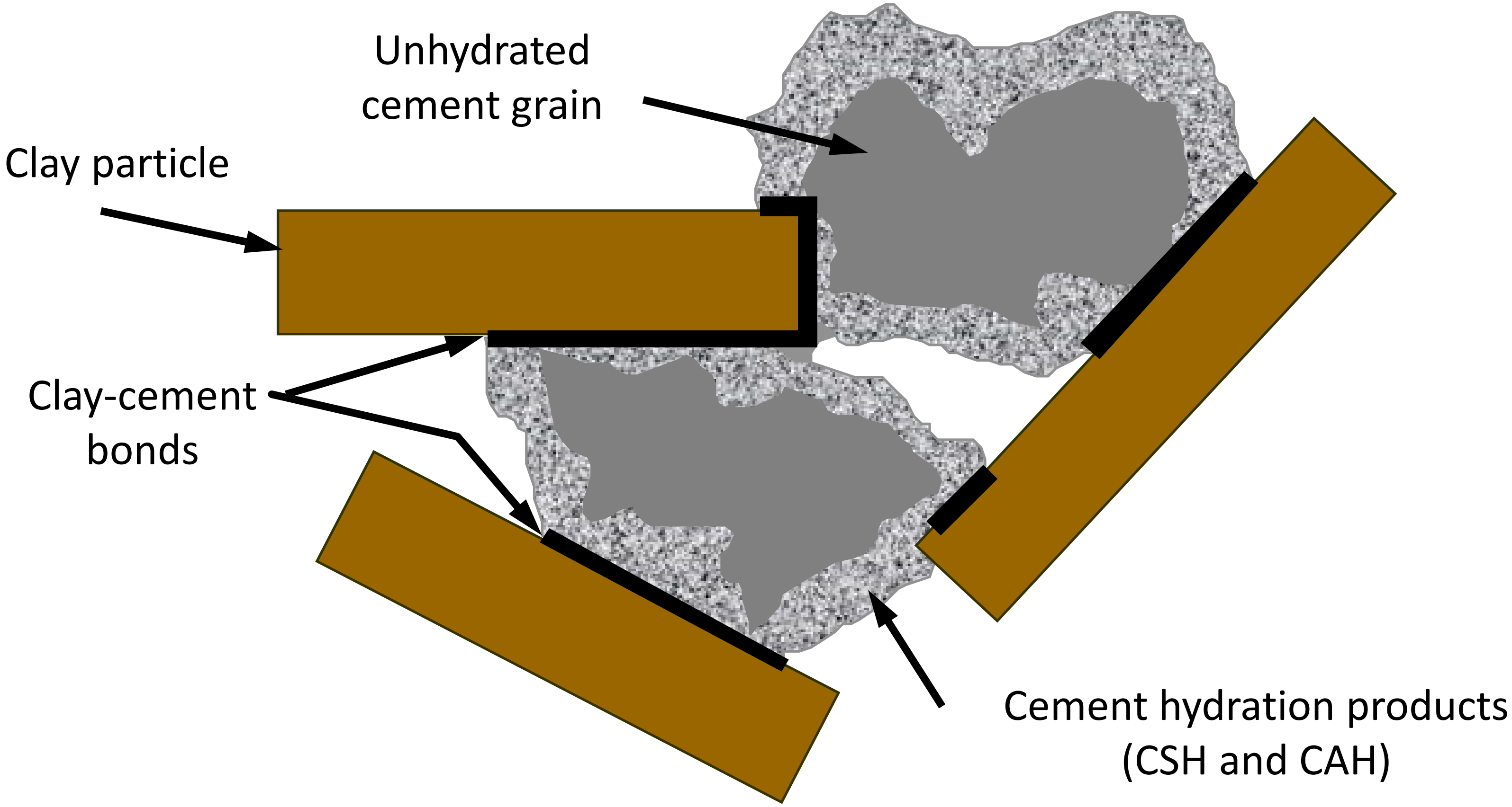
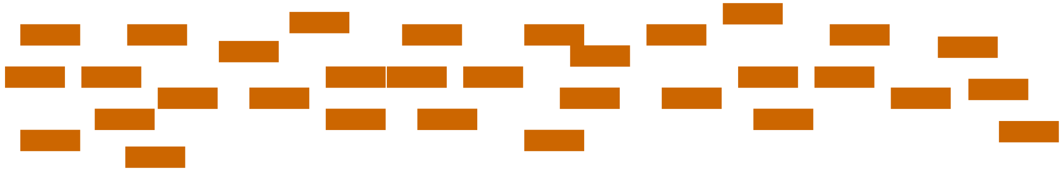
Cement Hydration



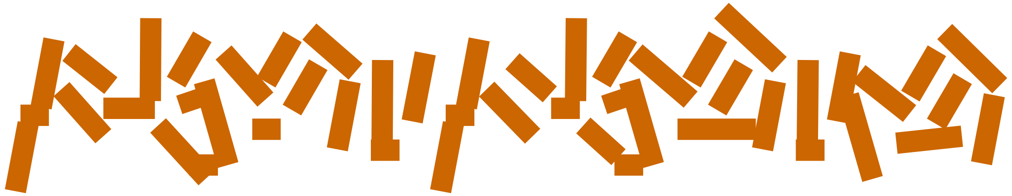
Particle Restructuring

Floculation / Agglomeration

UNMODIFIED CLAY PARTICLES



CLAY PARTICLES AFTER FLOCCULATION / AGGLOMERATION



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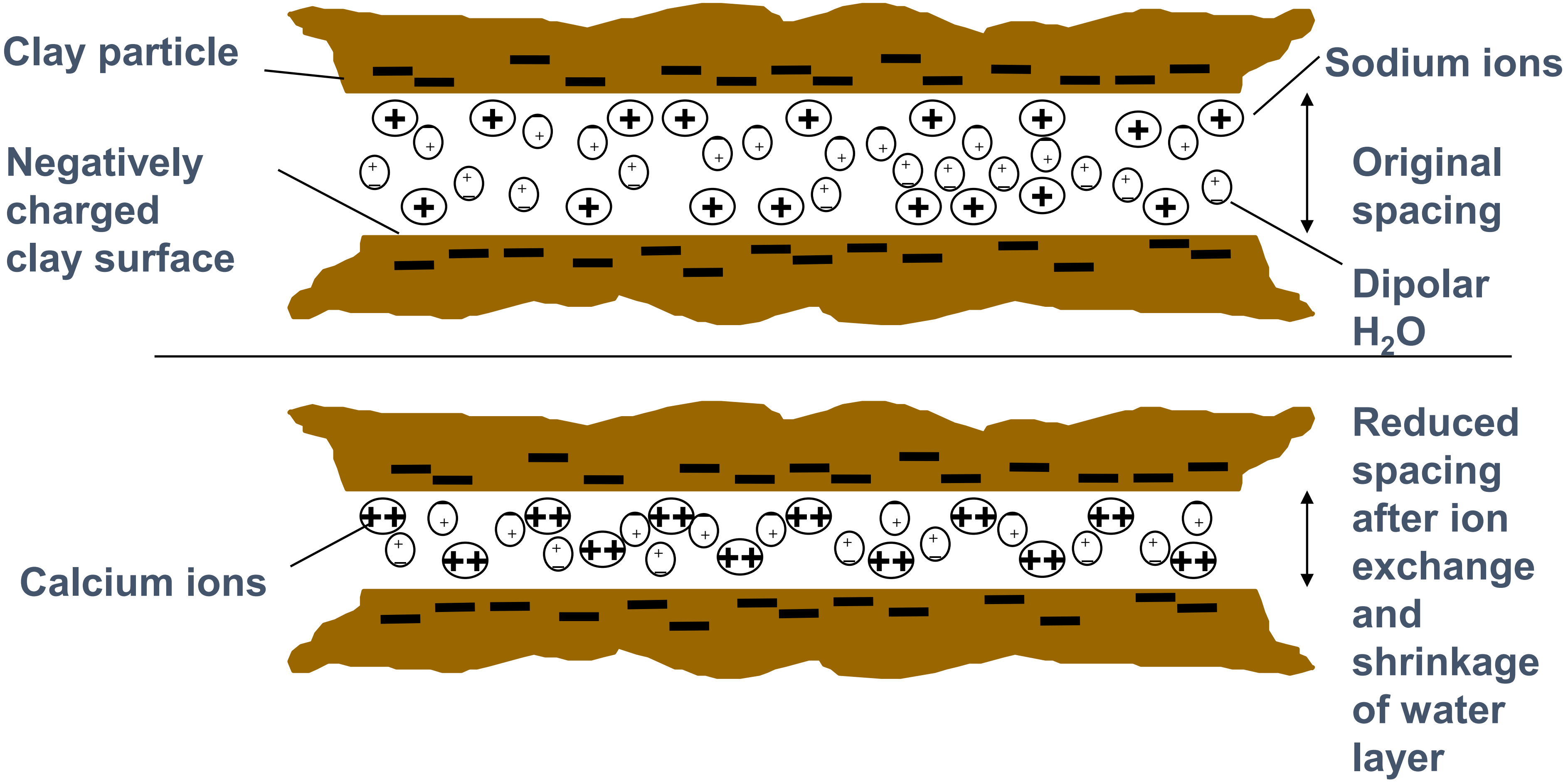
Cation Exchange



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Pozzolanic Reaction

Hydrated Lime + Silica = Calcium-Silicate-Hydrate
Hydrated Lime + Alumina = Calcium-Aluminate-Hydrate

From Cement Hydration

From Clay Minerals

Additional Cementitious Material

Note: Without silica or alumina-based clay minerals, this process does not occur (e.g. sandy or silty soils)

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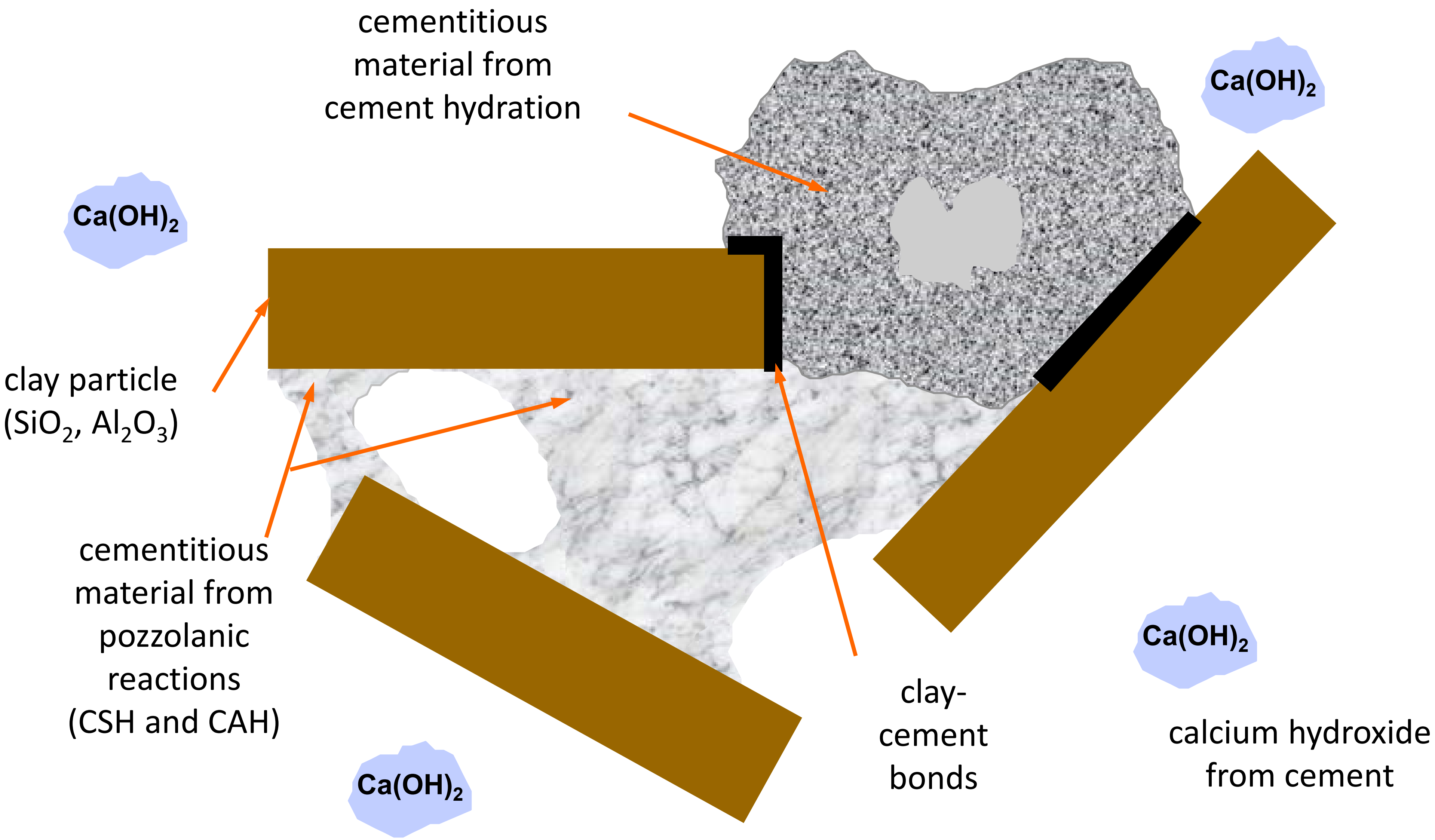

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Time of Modification Processes

1. Particle restructuring → Immediate to a few hours

2. Cement hydration → Largest strength gain between 1 day and 1 month

3. Pozzolanic reaction → Slowly, over months and years

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Silty and Sandy Soils

- Silts (A-4) are fine-grained and difficult to compact
- Uniform sands (A-3) have poor gradation and difficult to compact
- Low bearing capacity
- Low cohesiveness and shear strength
- Unstable under construction equipment

Clay Soils

- High plasticity (A-7-6) and cohesiveness
- Fine-grained with high porosity
- Low permeability
- High shrink and swell potential
- Expansive when wet
- Low bearing strength when moist
  and easily deforms under load
- Difficult to dry out
- Difficult to compact

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Solutions Clay Soil Subgrades

- Excavate/replace with select fill
  - Aggregate
  - Soil
- Increase the base/ pavement thickness
- Contain using fabrics or other geotextiles
- Modify soils with a calcium-based stabilizer

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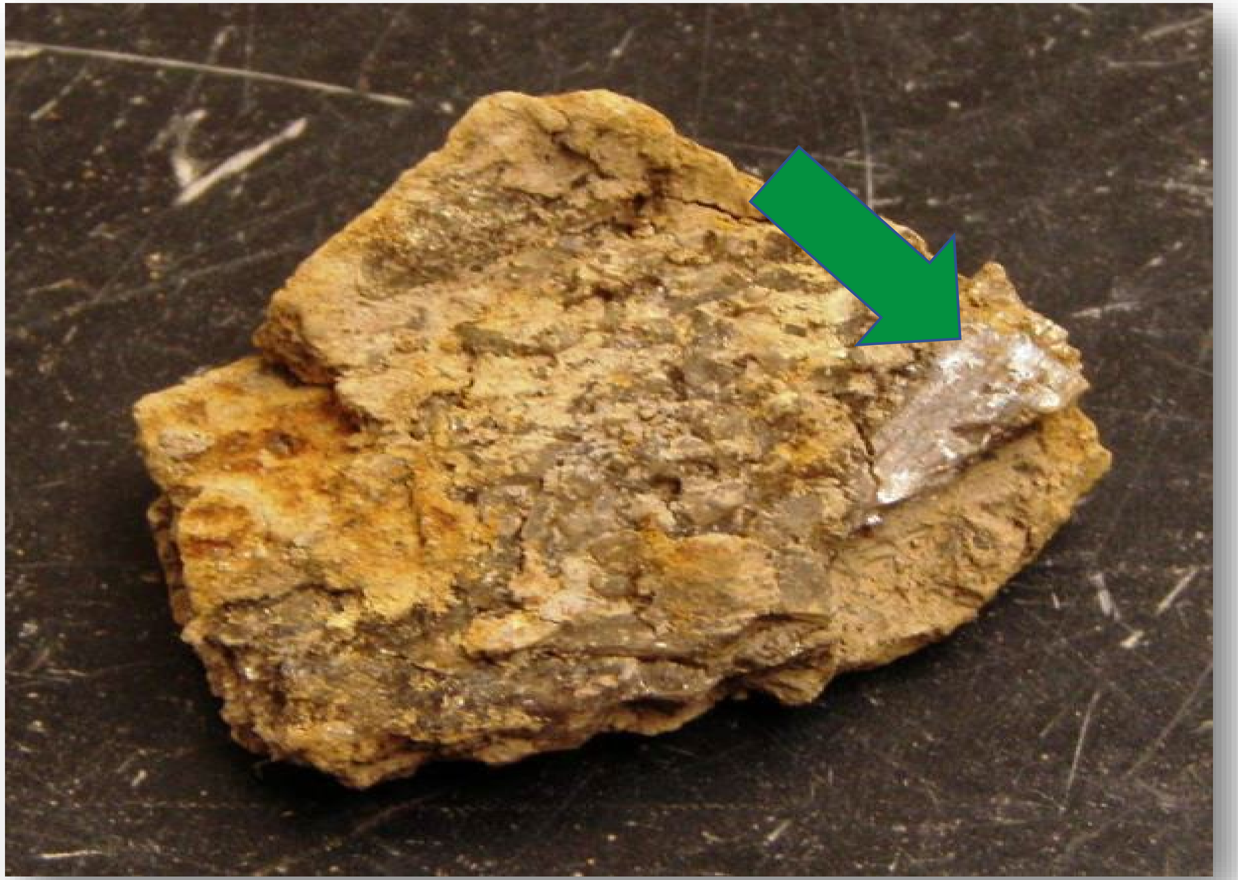
Problem Soils

- Organic soils
  - Greater than two percent
- Acid soils
  - pH less than 5.3
- Sulfate soils
  - Greater 0.3% of soluble sulfates
- Expansive soils
  - Volume change more than 20%
- Uniform sands
  - Less than 5% minus # 200 sieve



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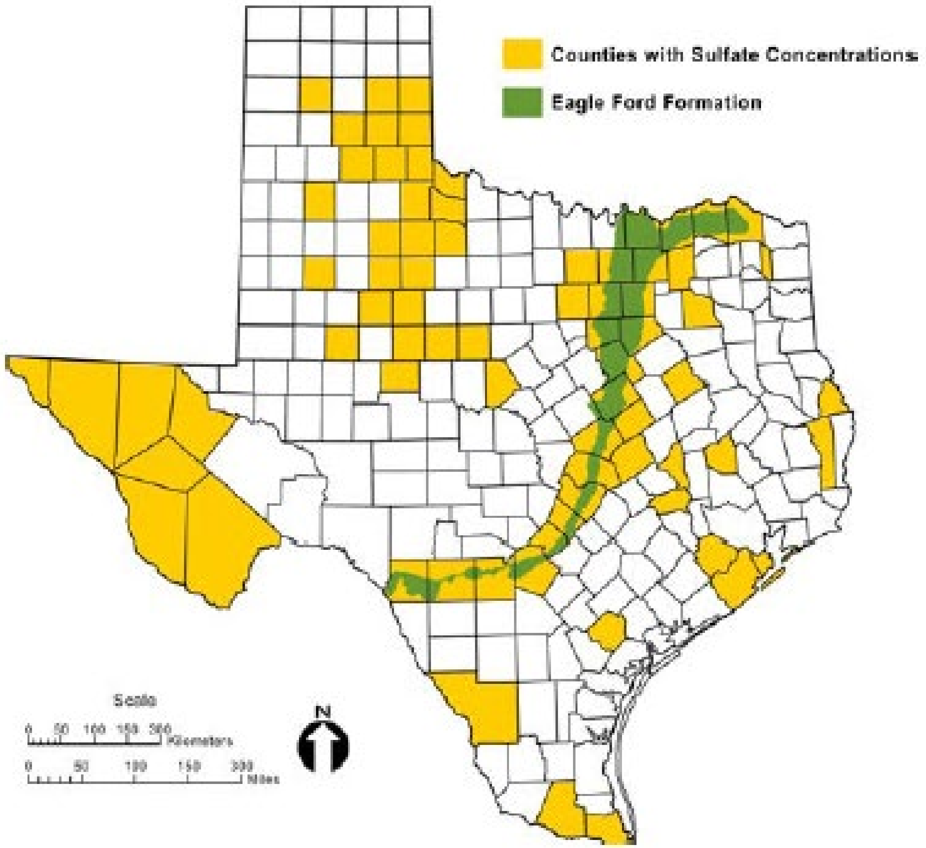
Soluble Sulfates

- Modifications to stabilization:
  - No stabilization
  - Remove/replace
  - Modify with granular materials*
  - Double lime treatment*
  - Use Type II (I/II) or Type V cement *
  - Use cement – *Class F* fly ash*



* Lab testing w/ in-situ soils recommended

Soil Stabilizers

- Cement
- Lime
- Fly ash (lime/cement)
- Bituminous (asphalt emulsion/foamed asphalt)
- Calcium chloride
- Others
  - Cement kiln dust
  - Fibers
  - Polymers
  - Proprietary products

Evaluation of Stabilizer Type

Material Type - Including RAP	Well Graded Gravel	Poorly Graded Gravel	Silty Gravel	Clayey Gravel	Well Graded Sand	Poorly Graded Sand	Silty Sand	Clayey Sand	Silt, Silt with Sand	Lean Clay	Organic Silt/Organic Lean Clay	Elastic Silt	Fat Clay, Fat Clay with Sand
USCS[2]	GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	MH	CH
AASHTO[3]	A-1-a	A-1-a	A-1-b	A-1-b A-2-6	A-1-b	A-3 or A-1-b	A-2-4 or A-2-5	A-2-6 or A-2-7	A-4 or A-5	A-6	A-4	A-5 or A-7-5	A-7-6
Emulsified Asphalt SE > 30 or PI < 6 and P_{200} < 20%	X	X	X	X	X	X	X						
Foame… PI < 10 … P_{200} 5 to…													
Cemen… Self-Ce… Class (… PI < 20 … SO_4 < 3…													
Lime/LKD PI > 20 and P_{200} > 25% SO_4 < 3000 ppm								X		X		X	X

"Portland Cement is probably the closest thing we have to a universal stabilizer."

From U.S. Army Corps of Engineers report "*Chemical Stabilization Technology for Cold Weather*", Sept. 2002

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Types of Portland Cement

ASTM C150/AASHTO M 85

- Type I – Normal Use
- Type II – Moderate Sulfate Resistance
- Type III – High Early Strength
- Type IV – Low Heat of Hydration
- Type V – High Sulfate Resistance

TESTING & MIX DESIGN

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CSS Mixture Design

1. Determine In Situ Moisture Content & 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 at three different cement contents (Optional for CMS)
7. Plot Unconfined Compressive Strength to Verify Cement Content
8. Compile Mix Design Report

**Using cement content from Atterberg Limits Testing*

Images: Raba Kistner Inc

Unconfined compressive strength test

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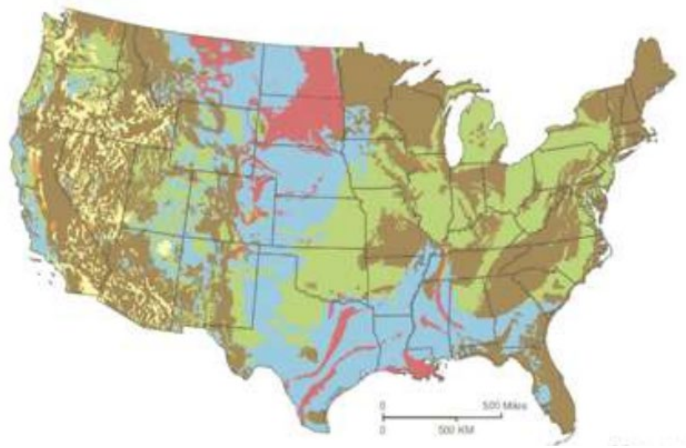
CSS Mixture Design – cont.

1. Determine In Situ Moisture Content and Classify Soil
2. Determine Cement Type and Estimated Dosage Rate
3. Determine Chemical Compatibility
   (If Necessary)
4. Determine Atterberg Limits of Three Different Cement Content Samples

Swelling Clays Map of the Conterminous United States" (Olive et al., 1989)



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CSS Mixture Design – cont.

Table 6A-2.02: AASHTO Soil Classification Chart

General Classification	Granular Materials (35% or Less Passing No. 200)							Silt-Clay Materials (More Than 35% Passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, percent passing:											
No. 10	50 max	--	--	--	--	--	--	--	--	--	--
No. 40	30 max	50 max	51 max	--	--	--	--	--	--	--	--
No. 200	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40											
Liquid limit	--		--	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity limit	6 max		NP	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

Source: AASHTO M 145-2

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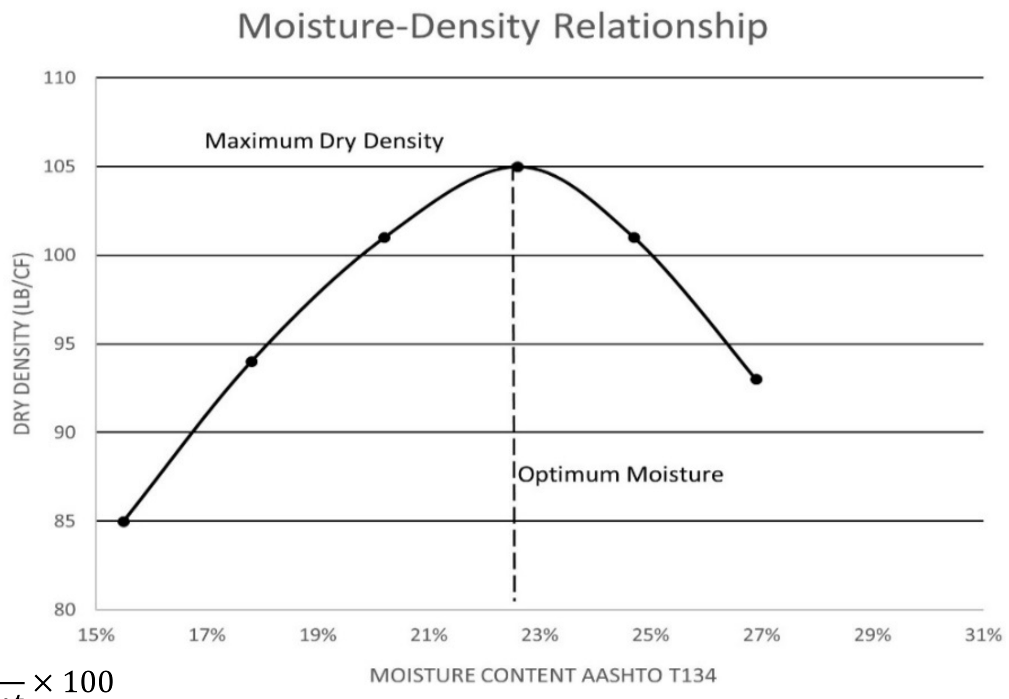
CSS Mixture Design – cont.

5. Determine Optimum Moisture Content and Maximum Dry Density

- Use cement contents from Atterberg Limits Testing
- AASHTO T 134, Standard Method of Test for Moisture-Density Relations of Soil-Cement Mixtures
- Sample should be molded within one to two hours
- Use laboratory- or commercial-grade soil mixer



$$water\ content, w(\%) = \frac{weight\ of\ water\ in\ mixture}{oven - dry\ weight\ of\ soil/aggregate/cement} \times 100$$

$$cement\ content, c(\%) = \frac{weight\ of\ cement}{oven - dry\ weight\ of\ soil/aggregate\ (excluding\ cement)} \times 100$$

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CSS Mixture Design – cont.

6. Determine Unconfined Compressive Strength
   - At least three different cement contents
     - Minimum two specimens for each cement content
     - OMC from Step 5 used to mold the specimens at various cement contents

Image: Raba Kistner Inc

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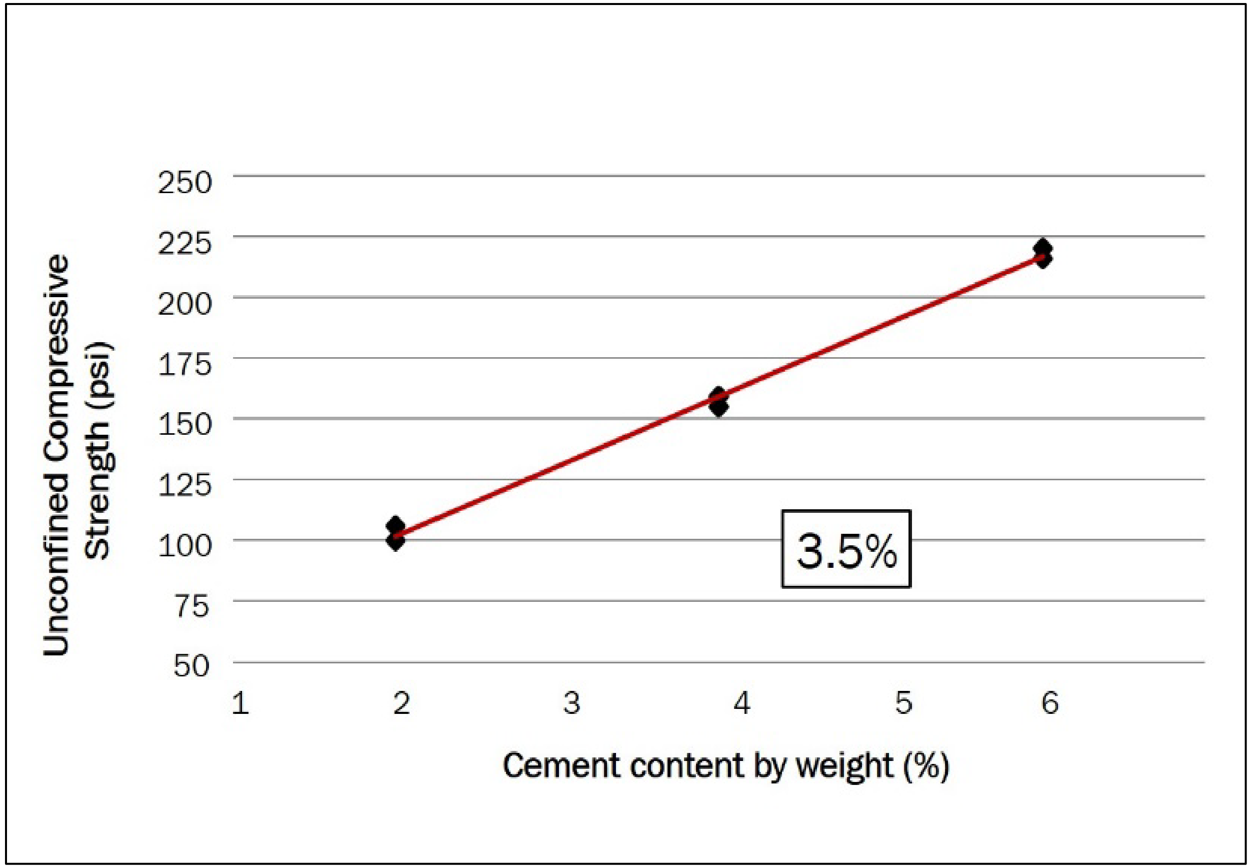
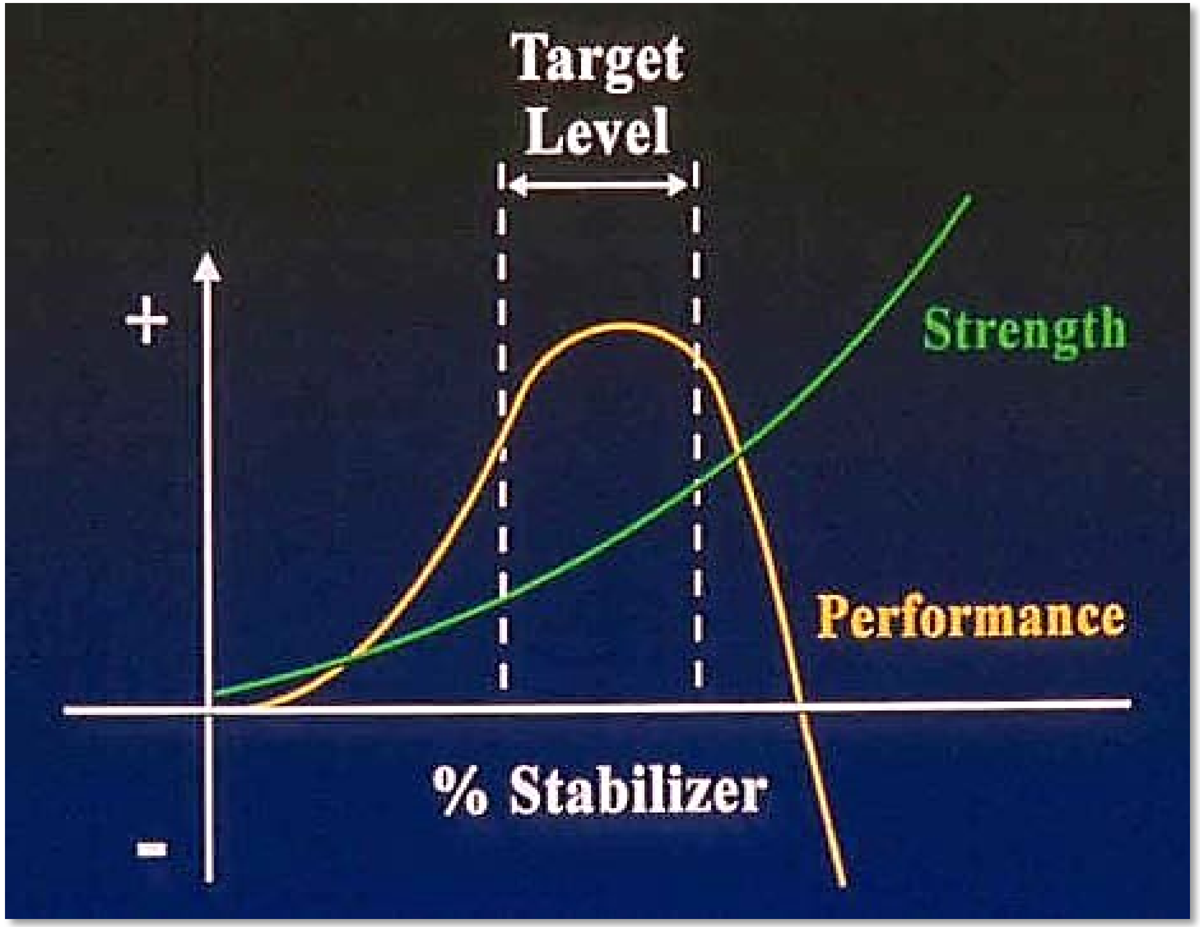
CSS Mixture Design – cont.

7. Plot Unconfined Compressive Strength to Verify Cement Content



Strength and Performance

- The purpose of the mix design procedure is to select the correct amount of cement that most closely balances both strength AND performance for the roadway materials.



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LIME PLUS CEMENT

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City of Garland, TX Study
Addison, 2007

- Poor street performance
- Near complete loss of lime modification effects
  - PI's within 1 to 2 points of original untreated soils (PI = 39)
  - pH of lime treated subgrade actually slightly lower than untreated soils
  - Subgrade strength ~same as untreated soils
- Attributed to leaching of lime (LMO vs LSO)

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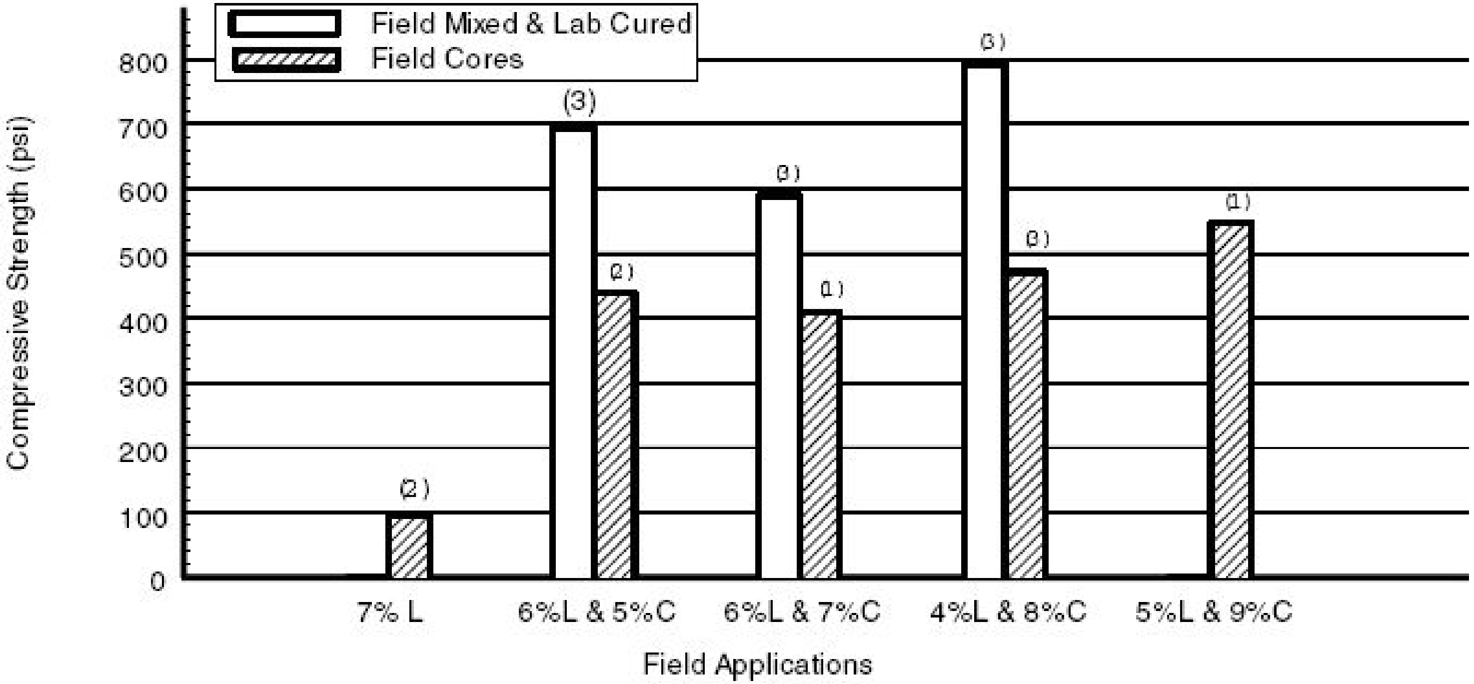
City of Garland, TX Study

Field Mixed Samples, Lab Cure vs. Field Cores



Source: Addison, 2007

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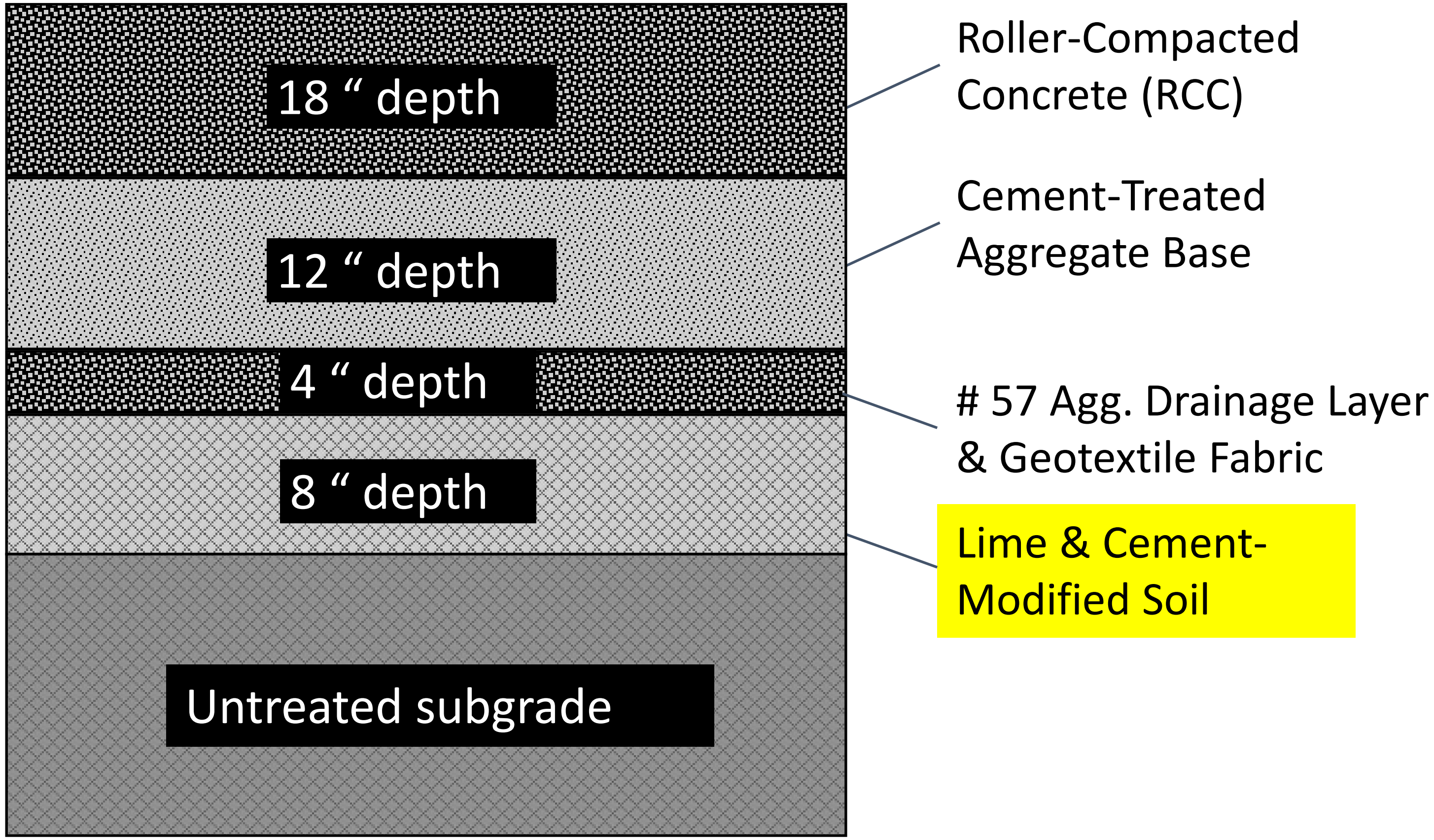
Port of Houston, Bayport Terminal

46 acres in 2007-2008

Port of Houston, Bayport Terminal



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TxDOT Pharr District

UP281 in Rio Grande Valley

- Used 6% Lime + 2% Cement
- Added Cement because 6% lime alone did not stabilize or add significant strength to the to the subgrade
- For this reason, UCS test should not be waived when using lime alone

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TxDOT Waco District
IH 35 in Hill County

- Using Lime + Cement
- Using the combination because of the varying soil types encountered on the project
- Recently, other parts of IH 35 had significant heave using soil replacement with select fill
- It is suspected that insufficient depth of replacement and existing subgrade pressure may have contributed to the problems in southern Hill County.

City of Arlington, TX

- In 2008 and 2009 Dr. Puppala from UTA studied 3 roads using the combination of Lime + Cement for road base-soil mixture
- Lab analysis was performed using 4% Lime and 4% Cement
- Road work and field samples were performed using 6% lime and 6% cement
- City is happy with the process and is using this stabilization method under concrete pavement without a bond breaker

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Hoyer Yard
Pasadena, TX

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High PI soil that is treated with 4% lime and 4% cement for strength and expedited construction

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Cement-Stabilized Clay Soil

- Clay soils present numerous construction challenges
- Stabilizing with cement or lime can alleviate some of the problems with clay
- Cement and lime stabilize in a similar manner; but only cement provides the additional benefit of hydration
- Cement and lime both can achieve similar levels of PI reduction
- Cement only can be successfully blended into soils with PI's up to 50 with increased mechanical effort.

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Why Combine Lime Plus Cement in High PI Soil

- In the fat PI clays Cement alone has difficulty blending in, especially in saturated soils
- Lime plus Cement has a higher UCS strength than lime alone
- Lime alone does not always provide a stabilized strong bound soil layer
- Cement adds higher early strength and speeds up road construction
- Lime plus cement can provide more certainty when there are variations in the soil.

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Conclusions - Cement-Stabilized Clay Soil

- Cement provides higher strength and bearing capacity than lime at similar dosages
- Cement provides better long-term durability
  - Proven long-term track record
  - Problems with lime leaching out when “lime stabilization optimum” is not achieved
- Cement can be compacted immediately, whereas lime needs several days for “mellowing”
- Numerous successful projects in Texas, both dry and slurry application

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Recommendations for Lime plus Cement Application – Portland Cement Association (PCA)

- The steps for determining how much lime and cement in combination are simple and are as follows:
  - Take samples of soil to be tested and use Tex-112-E to determine how much lime is needed to reduce the PI to around 20.
  - Use Tex-120-E to do a cement series using 2, 4, 6 percent cement and determine which sample obtains a target 7-day unconfined compressive strength of 150 to 250 psi.

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Construction

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Construction Process

- Moisture Conditioning (If Necessary)
- Initial Pulverization (If Necessary)
- Preliminary Grading
- Cement Application
- Mixing
- Optimum Moisture Content
- Compaction
- Final Grading
- Curing

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Construction Equipment

- Cement or slurry spreader/distributor truck
- Reclaimer/mixer
- Water truck
- Grader
- Tamping/sheepsfoot/padfoot roller
  - for clayey and silty material
- Smooth drum roller (for granular soils)
- Pneumatic tire roller (optional)

Images: Virginia DOT

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Construction

BULK CEMENT

- **Lowest Cost**
- **Dusty**

SLURRY CEMENT

- **Solves dust problem**
- **Increased cost**

slide credit:
Corey Zollinger

Construction – cont.

Slurry Train – Slurry injected into mixing chamber

Spreader Trucks

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slide credit:
Corey Zollinger

Cement Spread Requirements

Percent cement by weight		Percent cement by volume	Cement spread requirements in pounds per square yard (kg/m²) for compacted thicknesses				
100 pcf (1602 kg/m³)	110 pcf (1762 kg/m³)		5 inches (125 mm)	6 inches (150 mm)	7 inches (175 mm)	8 inches (200 mm)	9 inches (225 mm)
1.9	1.7	2.0	7.1 (3.8)	8.5 (4.6)	9.9 (5.4)	11.3 (6.1)	12.7 (6.9)
2.4	2.1	2.5	8.8 (4.8)	10.6 (5.7)	12.3 (6.7)	14.1 (7.6)	15.9 (8.6)
2.8	2.6	3.0	10.6 (5.7)	12.7 (6.9)	14.8 (8.0)	16.9 (9.2)	19.0 (10.3)
3.3	3.0	3.5	12.3 (6.7)	14.8 (8.0)	17.3 (9.4)	19.7 (10.7)	22.2 (12.0)
3.8	3.4	4.0	14.1 (7.6)	16.9 (9.2)	19.7 (10.7)	22.6 (12.2)	25.4 (13.8)
4.2	3.8	4.5	15.9 (8.6)	19.0 (10.3)	22.2 (12.0)	25.4 (13.8)	28.6 (15.5)
4.7	4.3	5.0	17.6 (9.6)	21.2 (11.5)	24.7 (13.4)	28.2 (15.3)	31.7 (17.2)
5.2	4.7	5.5	19.4 (10.5)	23.3 (12.6)	27.1 (14.7)	31.0 (16.8)	34.9 (18.9)
5.6	5.1	6.0	21.1 (11.5)	25.4 (13.8)	29.6 (16.1)	33.8 (18.4)	38.1 (20.7)
6.1	5.6	6.5	22.9 (12.4)	27.5 (14.9)	32.1 (17.4)	36.7 (19.9)	41.2 (22.4)
6.6	6.0	7.0	24.7 (13.4)	29.6 (16.1)	34.5 (18.7)	39.5 (21.4)	44.4 (24.1)

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Source: Guide to Cement-Modified Soil (PCA, EB242)

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Compaction and Grading

Material is compacted to 96 to 98 percent minimum <u>standard proctor density</u> and then graded to appropriate lines, grades, and cross-sections.

Curing

Bituminous Compounds (cutbacks or emulsions)

Water (kept continuously moist)

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Projects

Who Is Using It In Texas? (Partial List)

- Goliad County
- Bell County
- Bexar County
- Grand Prairie
- City of Fort Worth
- Tarrant County
- Port of Houston

- Town of Navasota
- Corpus Christi District
- Lubbock District
- Bryan District
- San Antonio District
- Fort Worth District
- Houston District
- Beaumont District

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Euless, TX City Streets

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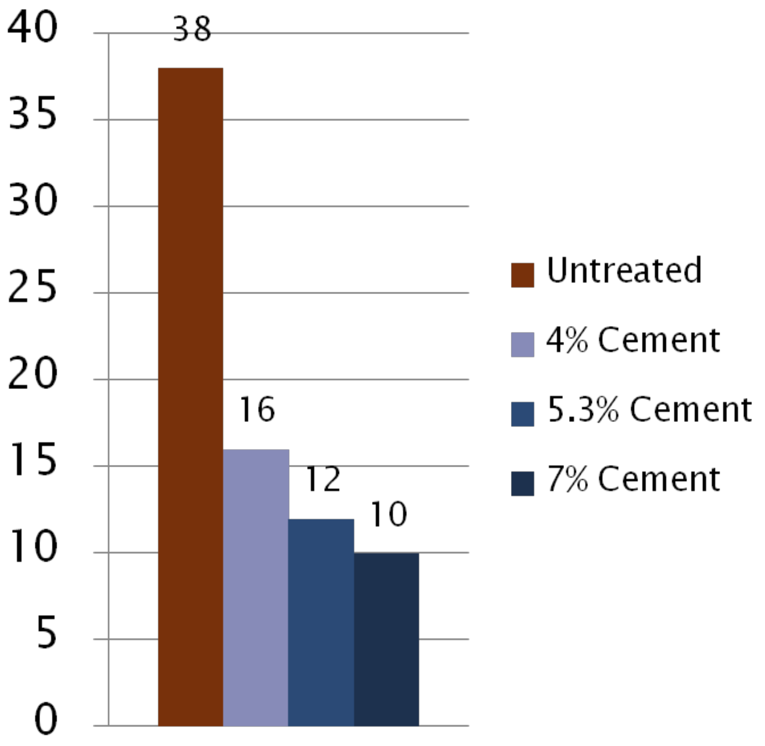
TxDOT, San Antonio - Spur 66 Watson Road Widening

- 2006 fast track project, Zachry Construction
- Time
  - Cement – 2 day
  - Lime - 5 to 7 days
- Production
  - Cement – 4,500 sy/day
  - Lime – 2,500 sy/day



Summary

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Summary: Why Cement Stabilized Soil?

- Cement factors of 2 to 8% (3 to 5% common)
- Effective in granular and clay soils
- Significant and immediate reductions in PI
- Immediate increases in soil strength
  - Next-day or same day traffic and construction (no “mellowing”)
  - All-weather work platform
- Produces workable foundation for both rigid and flexible pavements
- Permanent modification:
  - Strength improves immediately and increases over years
  - No long-term effects from leaching
- Save cost

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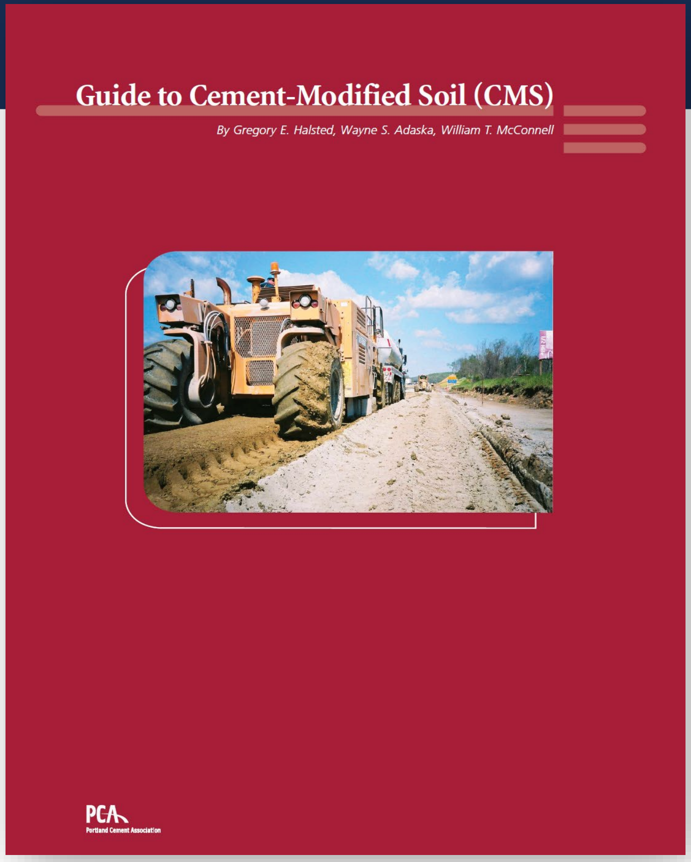
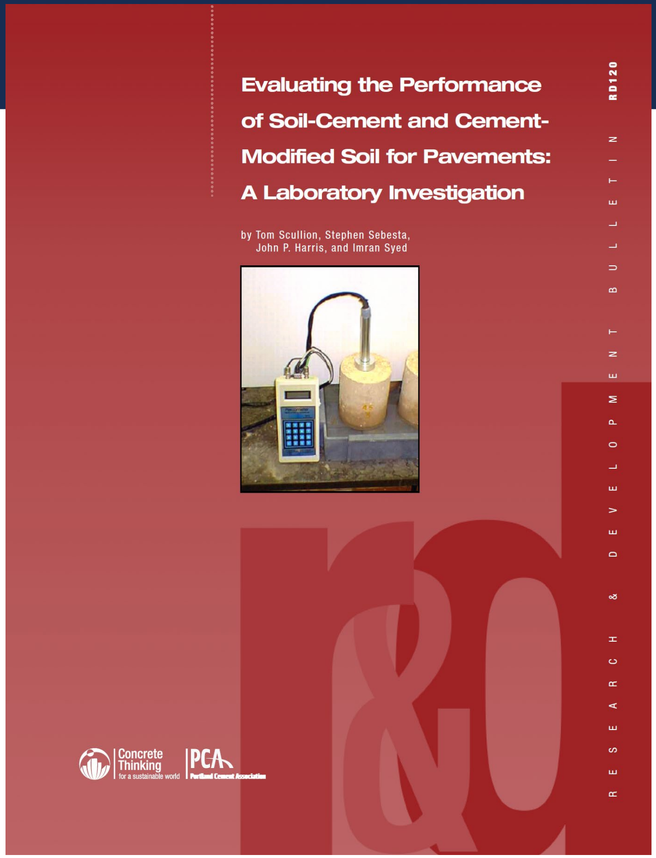
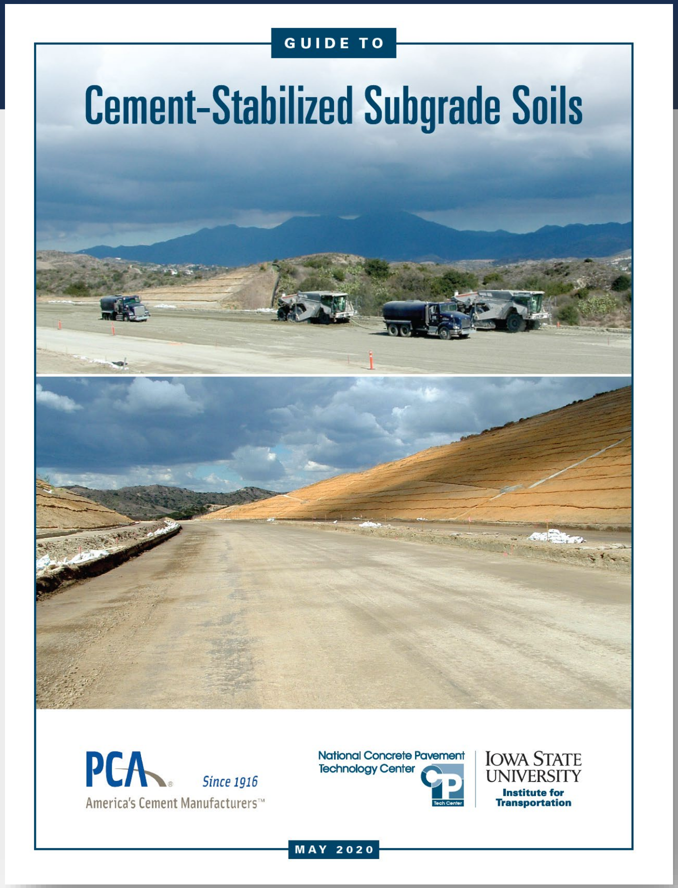
Primary Resource Materials







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