Concrete Pavement Technology Tuesday Webinar

Soil Stabilization Methods

Greg Halsted, P.E.
Senior Director, Local Paving
National Ready Mixed Concrete Association

Tyler Bodnar, P.E.
Director of Geotechnical Markets
California Nevada Cement Association

Tuesday, July 18, 2023

Your Co-Presenter Today

- Greg Halsted, P.E., Senior Director, Local Paving
- NRMCA West Region
  - Washington
  - Oregon
  - California
  - Nevada
- 38 years in practice (GDOT, CRSI, PCA)
- Pavement, geotechnical, and foundation materials, design, construction, and sustainability
- Bellingham, Washington
- ghalsted@nrmca.org
- 360.920.5119

Your *Other* Co-Presenter Today

- Tyler Bodnar P.E., Director of Geotechnical Markets
- CNCA – Covering all of CA & NV
- 17 years experience (RE, City Engineer, CNCA)
- 3 years as Technical Director of the Recycling & Stabilizing Association (RSA) of California
- Specializes in providing education, design optimization, constructability analysis, costing, and value engineering
- Chico, California
- *tyler.bodnar@cncement.org*
- 530.521.0378

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Learning Objectives

After this presentation, attendees should be able to:

1. List the four types of soil-cement products used to construct pavements
2. Identify the different types of additives used in soil stabilization
3. Outline the thickness/mixture design procedures for soil improvement
4. Explain general mixed-in-place construction and testing procedures

Soil Stabilization Defined

- In civil engineering, soil stabilization is a general term for any physical, chemical, mechanical, biological, or combined method of changing a natural soil to meet an engineering purpose.
- Improved engineering properties of soils include mechanical strength, permeability, compressibility, durability, and plasticity.
- Used on any project (roadway, airfield, dam, or building) where soil acts as the foundation.

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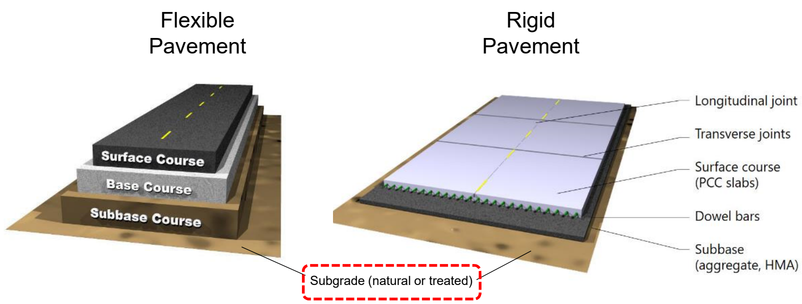
PAVE AHEAD

Structural Layers in Pavements



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Solutions for Poor Subgrade Soils

- Excavate and replace with select fill material such as better soil or aggregate
- Increase the thickness of the pavement base or subbase
- Contain the poor soils using fabrics or other geotextiles
- Alter the physical properties of the soils by incorporating an additive

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Soil Stabilizers

- Portland cement (dry or slurry)
- Lime (hydrated and dry)
- Fly ash (Class C and Class F)
- Bituminous (emulsion and bitumen)
- Chlorides (magnesium and calcium)
- Kiln dust (cement and lime)
- Others
  - Fibers
  - Polymers (synthetic and natural)
  - Enzymes
  - Resins
  - Proprietary products

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Selecting Soil Stabilizers

When selecting the best soil stabilization product and method for your particular project, consider:

- Soils to be treated
- Project type
- Design life
- Budget
- Environmental concerns
- Sustainability

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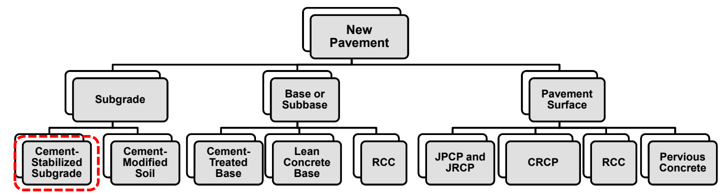
Applications and Benefits

Soil-Cement Products

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

New Pavement Construction



Applications for CSS

- Low volume roadways
- Residential streets
- Medium to high-volume roads
- State routes
- Interstate highways
- Airport runways and taxiways
- Parking lots
- Industrial storage facilities
- Port facilities
- Truck terminals
- Commercial sites

Benefits of CSS

- Eliminates removal/replacement of inferior soils
- Reduces construction time (no mellowing)
- Works for a wide range of soils
- Requires small amounts of portland cement
- Lowers PI and improves volume stability
- Improves compactibility, strength, and bearing capacity of in situ soils
- Forms an all-weather work platform
- Provides permanent (non-leaching) change

Materials and Properties

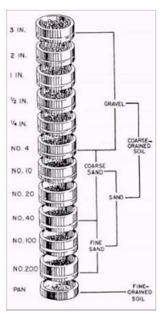
Cement-Stabilized Pavement Materials

- Sand
- Silt
- Clay
- Gravel
- Shell
- Crushed stone
- Slag
- Recycled HMA
- Recycled concrete

Particle Size Distribution

- **Gravel**
  - Smaller than 3.0 inches (75 mm)
- **Sand**
  - Smaller than 0.187 inches (4.75 mm) [#4 sieve]
- **Silt and Clay**
  - Smaller than 0.0029 inches (0.075 mm) [#200 sieve]

Requirement is for 100% to pass the 1.5-inch (38 mm) and a minimum of 60% to pass the No. 4 (4.75 mm) sieves



Challenges with Clay Soils

- High plasticity 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

Challenges with Silty and Sandy Soils

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

Evaluation of Stabilizer Types

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						
Foamed Asphalt PI < 10 and P_{200} 5 to 20%	X		X	X	X		X						
Cement, CKD or Self-Cementing Class C Fly Ash PI < 20 SO_4 < 3000 ppm	X	X	X	X	X	X	X	X	X	X			
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 USACE report "*Chemical Stabilization Technology for Cold Weather*", September 2002

Problem Soils

- Organic soils
  - Greater than 2.0 percent
- Acid soils
  - pH less than 5.3
- Sulfate soils
  - Greater than 0.3 percent of soluble sulfates

Soil Properties

- Sieve analysis
- Atterberg limits
- Moisture-density
- Strength (UCS, CBR, M_r)
- Expansive characteristics
- Sand equivalent
- Organic content
- Soil pH
- Sulfate content

Standard Test Methods for CSS

- **Sieve Analysis (ASTM D6913)**
  – Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
- **Atterberg Limits (ASTM D4318)**
  – Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- **Moisture-Density (ASTM D558)**
  – Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures
- **Compressive Strength (ASTM D1633)**
  – Compressive Strength of Molded Soil-Cement Cylinders
- **Soluble Sulfates (ASTM C1580)**
  – Water-Soluble Sulfate in Soil

Unconfined Compressive Strength (UCS)

- Common 7-day UCS strengths between 100 and 300 psi (0.7 to 2.1 MPa)
- Strengths vary widely according to specific agency and project requirements
- Proven strength and performance in both wet-dry and freeze-thaw environments
- May be used to reduce the overall thickness of a pavement or foundation

Thickness and Mixture Design

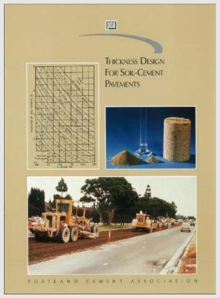
Pavement Thickness Design Procedures

- **Mechanistic**
  - Based on the mechanics of a pavement structure (e.g., PCA procedure)
- **Empirical**
  - Based on observed pavement performance (e.g., 1993 AASHTO Guide)
- **Mechanistic-Empirical**
  - Based on a combination of both mechanics and observed pavement performance (e.g., AASHTOWare Pavement ME Design)

PavementDesigner.org

PCA Thickness Design Procedure

- First published in 1970 as PCA *Thickness Design for Soil-Cement Pavements*
- Based on research, full-scale tests, design theory, and observed pavement performance
- Fatigue consumption ultimately determines the base layer thickness
- Used when base will be covered with bituminous surfacing, although the design covers adequate thickness of the stabilized layer



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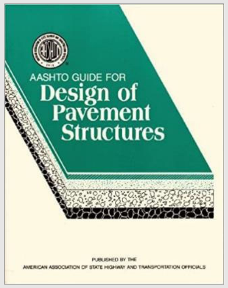
1993 AASHTO Thickness Design Procedure

- *AASHTO Guide For Design of Pavement Structures*
- Based on AASHO Road Test
- Purely empirical method
- Conservative guidance for cement-stabilized base material contribution based on UCS
- Must assume layer coefficients
- Simple and quick determination of pavement design thickness



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AASHTOWare Pavement ME Design

- Design procedure formerly known as MEPDG
- Ultimate pavement thickness design tool
- Use of layered elastic analysis and developed performance models
- Use critical tensile stress at the bottom of the base layer
- Requires a great deal of inputs
- Very expensive to access
- Performance checks of all layers must be made

PvD AASHTOWare Pavement ME Design AASHTO

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PavementDesigner

Created to simplify the cement-based pavement thickness designs for:

- Parking lots
- Roadways
  - JPCP, RCC, CRCP
  - Overlays (bonded / unbonded)
  - Composite pavements
- Industrial / Intermodal yards

PavementDesigner.org

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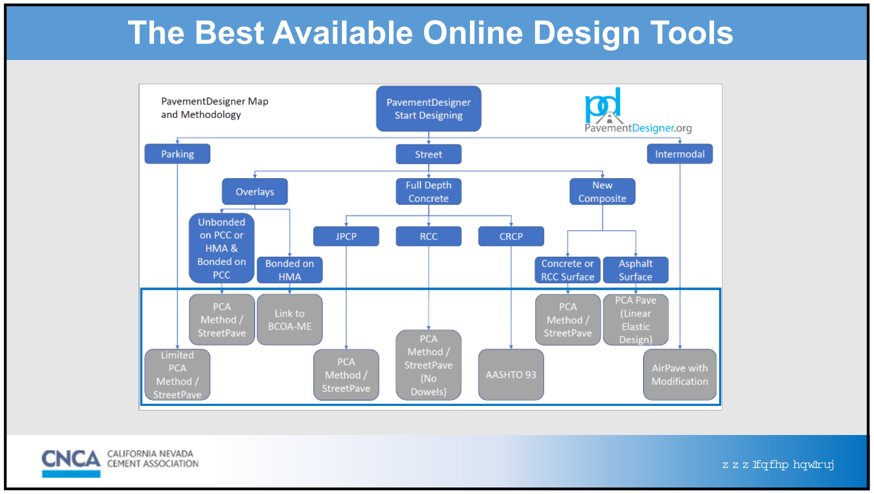
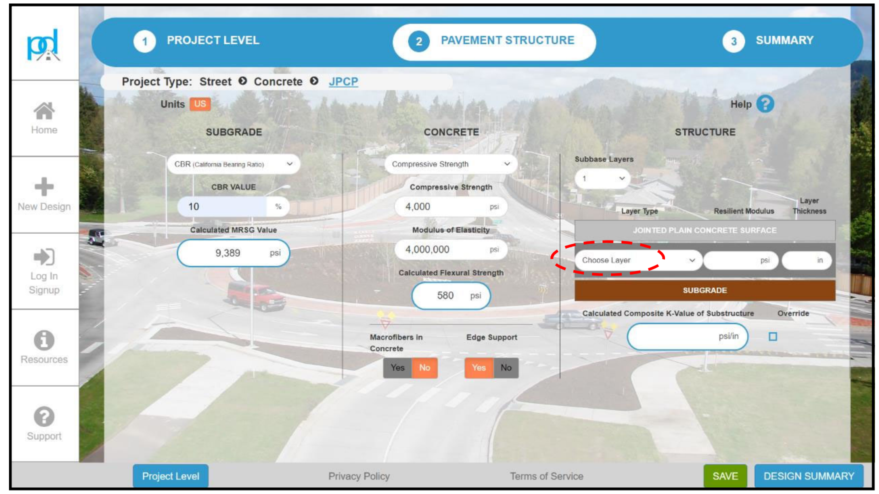
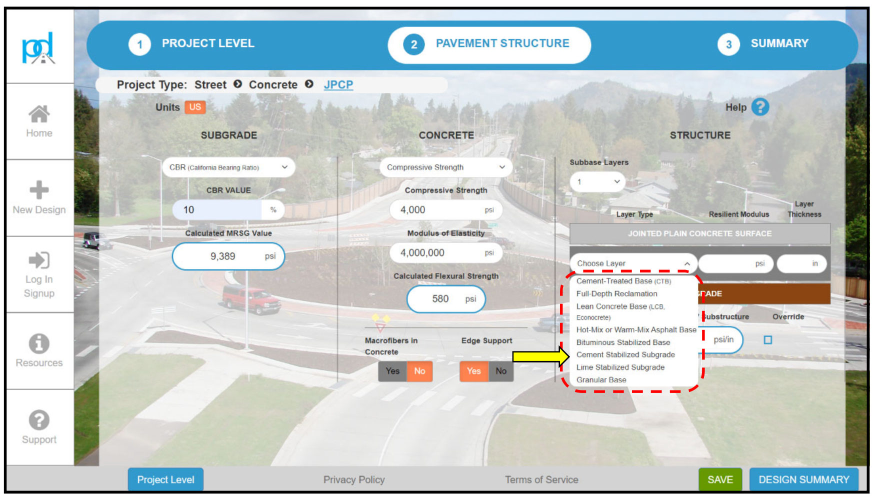


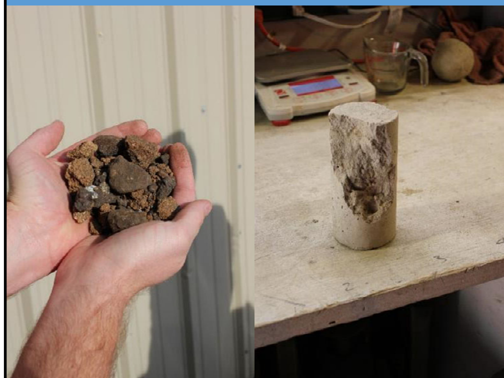


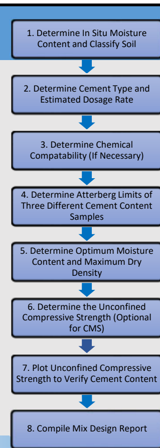


Strength or Thickness?

- The ability of a cement-stabilized pavement layer to carry loads depends on both the strength and thickness of the layer
- A thin, but strong layer can theoretically carry the same load as a thick, but weaker layer; however, the thin, strong layer may have greater shrinkage leading to undesirable cracking
- When selecting thicknesses for CSS layers, a thicker section with less strength but still meeting the durability requirements is preferred

Mix Design Process





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Mixture Design Steps

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

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
GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	MH	CH
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

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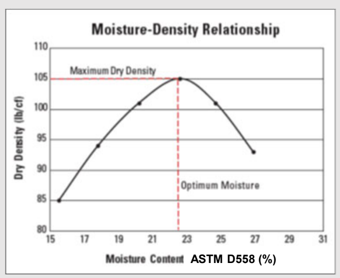
Mixture Design Steps (cont.)

5. Determine Optimum Moisture Content and Maximum Dry Density

- Use cement contents from previous Atterberg limits testing from Step 4
- Match the construction techniques (add cement either dry or slurry)
- Use laboratory- or commercial-grade soil mixer for thorough blending
- Samples should be molded ASAP (within one to two hours)



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Mixture Design Steps (cont.)

6. Determine Unconfined Compressive Strength

- Test at least three different cement contents
  - Test a minimum of two specimens for each cement content
  - Use the OMC from Step 5 to mold the specimens at various cement contents
- Immerse the specimens in water for 4 hours prior to UCS testing

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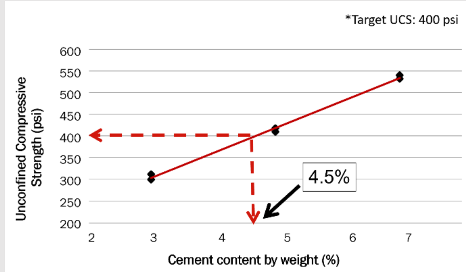
Mixture Design Steps (cont.)

7. Plot Unconfined Compressive Strength to Verify Cement Content

- The UCS results from Step 6 should be plotted on a graph
- The cement content is determined at the intersection of the design UCS
- A common practice is to increase the cement content by 0.5 to 1.0 percent to accommodate for construction uncertainties



Mixture Design Steps (cont.)

8. Compile Mix Design Report

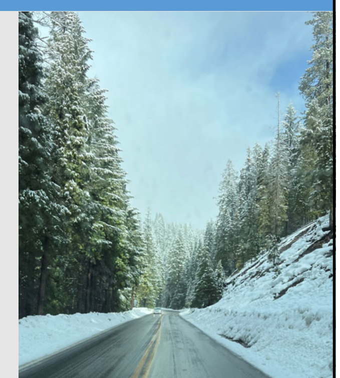
- **Untreated soil properties**
  - In situ moisture content and gradations
  - MDD, OMC, and Atterberg limits
- **Treated soil properties**
  - MDD, OMC, and Atterberg limits
  - UCS for trial cement contents
  - Cement Type and percentage
- **Construction Information**
  - Station limits and/or construction phase
  - Cement spread rate per treatment depth

Percent cement by dry weight of material	Density = 105 lb/ft^3						
	Cement spread requirements in pounds per square yard for compacted thicknesses						
	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
2.0	9.5	11.0	12.6	14.2	15.8	17.3	18.9
2.5	11.8	13.8	15.8	17.7	19.7	21.7	23.6
3.0	14.2	16.5	18.9	21.3	23.6	26.0	28.4
3.5	16.5	19.3	22.1	24.8	27.6	30.3	33.1
4.0	18.9	22.1	25.2	28.4	31.5	34.7	37.8
4.5	21.3	24.8	28.4	31.9	35.4	39.0	42.5
5.0	23.6	27.6	31.5	35.4	39.4	43.3	47.3
5.5	26.0	30.3	34.7	39.0	43.3	47.6	52.0
6.0	28.4	33.1	37.8	42.5	47.3	52.0	56.7
6.5	30.7	35.8	41.0	46.1	51.2	56.3	61.4
7.0	33.1	38.6	44.1	49.6	55.1	60.6	66.2

Construction, Inspection, and Testing

Environmental Considerations

- Do not construct CSS in standing water
- Do not construct CSS on frozen ground
- Do not construct CSS when the air temperature is below 40ºF (4ºC)
- Do not apply dry cement on windy days



CSS Construction Process

- Pulverize the roadbed materials
- Blade to desired roadway template
- Spread cement either dry or as a slurry
- Mix all materials directly on the roadbed
- Bring to optimum moisture content
- Compact to a min. 95 percent density
- Shape the roadway to plan requirements
- Perform curing and finishing

CSS Construction Equipment

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

Inside a Reclaimer/Mixer

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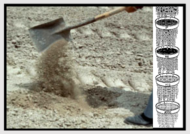
Quality Control

- The engineer and contractor should perform any inspections and tests necessary to ensure a successful project outcome.
- Obtaining samples of soil material and individual components at all stages of processing and after processing is completed.
- Observing the operation of all equipment used and personnel employed to perform the work (test strip sometimes required).
- All testing of processed material or its individual components shall be in accordance with the latest specifications.
- **COMMUNICATION**

Primary Testing Requirements

Gradation/Uniformity



A common gradation requirement is for 100% to pass the 1.5-inch (38 mm) sieve and a minimum of 60% to pass the No. 4 (4.75 mm) sieve (ASTM D6913).

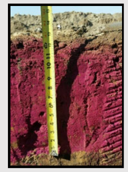
Moisture

A common moisture requirement is to be within 2% of the laboratory established optimum moisture content (ASTM D558).

Density

A common density requirement is to achieve at least 95% of the established laboratory standard Proctor density (ASTM D558).

Thickness



Requirements for subgrade depths can vary from as little as 6 inches (150 mm) up to 2 feet (0.6 m) depending on governing agency.

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Sustainability

Important (often overlapping) Definitions

- **Quality** – "suitable for its intended purpose while satisfying customer expectations"
- **Durability** – "able to withstand wear, pressure, or damage"
- **Resiliency** – "able to recoil or spring back into shape after bending, stretching, or being compressed"
- **Sustainability** – "able to be maintained at a certain rate or level"

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The PCA Roadmap to Carbon Neutrality

- An ambitious journey to carbon neutrality across the entire cement and concrete value chain by 2050
- Industry must act now to further reduce GHGs and create sustainable building solutions (increased pressure to reduce our environmental impact from designers, regulators, even the public)
- The Roadmap demonstrates how the U.S. cement and concrete industry can address climate change, decrease GHGs, and eliminate barriers that are restricting environmental progress

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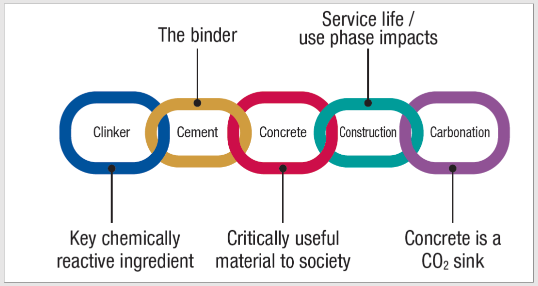
The Cement and Concrete Value Chain

Cement and concrete are so essential to the way we live, that our entire industry must do its part to address climate issues.

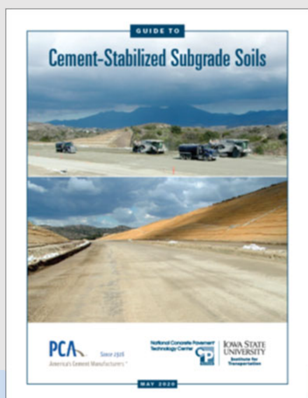


Sustainable Cement-Stabilized Subgrade

- Reduces waste by allowing the use of existing in-place marginal materials, plus minimizes the need to haul in costly select materials resulting in a tremendous reduction in emissions
- Provides for a stronger and more stable subgrade, which often reduces the quantity of virgin base/subbase materials needed
- Can accelerate construction schedules leading to fewer/less severe community interruptions
- Permanent soil changes mean they do not revert back to their original state, even after many cycles or years of weathering and service

CSS Guide

- Describes characteristics, uses, and benefits of CSS and presents methods for evaluation, design, construction, and field testing
  - Chapter 1 – Introduction
  - Chapter 2 – Materials and Properties
  - Chapter 3 – Geotechnical Evaluation and Field Sampling
  - Chapter 4 – Mixture Design
  - Chapter 5 – Construction, Field Inspection, and Testing
  - Chapter 6 – Case Studies
- Guide specifications for the construction of CSS soils



Concluding Comments

Soil-Cement Type	Cement-Modified Soil (CMS)	Cement-Stabilized Subgrade (CSS)	Cement-Treated Base (CTB)	Full-Depth Reclamation (FDR)
Purpose	• Promotes soil drying • Provides a significant improvement to the working platform • Provides a permanent soil modification (does not leach)	• Provides all the benefits of CMS plus the following: - Potentially allows for a reduction in pavement thickness or increased pavement life - Increases the bearing capacity for building slabs, footings, and other structural elements	• Provides a strong, frost-resistant base layer for asphalt or concrete pavements	• Provides a strong, frost-resistant base layer for asphalt or concrete pavements
Materials	• Primarily fine-grained soils • 2%–4% cement	• Primarily fine-grained soils • 3%–6% cement	• Primarily coarse-grained manufactured materials • 3%–6% cement	• Pulverized asphalt blended with existing pavement base, subbase, and/or subgrade • 3%–6% cement
Material Properties	• Reduced moisture susceptibility	• 100–300 psi (0.7–2.1 MPa) seven-day compressive strength	• 300–600 psi (2.1–4.1 MPa) seven-day compressive strength	• 300–600 psi (2.1–4.1 MPa) seven-day compressive strength
Construction Practices	• Minimum 95% of maximum density • Mixed in place	• Minimum 95% of maximum density • Mixed in place	• Minimum 95%–98% of maximum density • Mixed in place or at a plant	• Minimum 95%–98% of maximum density • Typically mixed in place

Concrete Pavement
Technology Tuesday Webinar

Soil Stabilization Methods

Questions / Comments / Discussion

Greg Halsted, P.E.

Tyler Bodnar, P.E.

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