# National Concrete Pavement Technology Center

CP Tech Center

Iowa State University

Institute for Transportation

# Optimizing Bases, Subbases and Subgrades for Concrete Pavement

March 2, 2021
Michigan Concrete Association Webinar

Iowa State University
Institute for Transportation

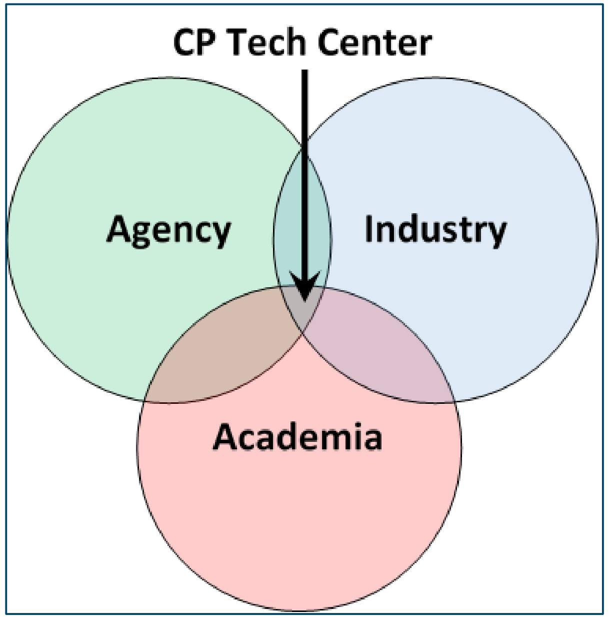
National Concrete Pavement Technology Center

# National Concrete Pavement Technology Center

## *Making a difference*

through focused collaboration:

- Problem solving
- Implementing the latest and greatest
- Saving money by doing good things
- Building better concrete pavements




www.cptechcenter.org

Taylor, Peter | Smith, Gordon | Tritsch, Steven | Adam, John

# Presenter – Jerod Gross, P.E., LEED AP

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# Webinar Objectives

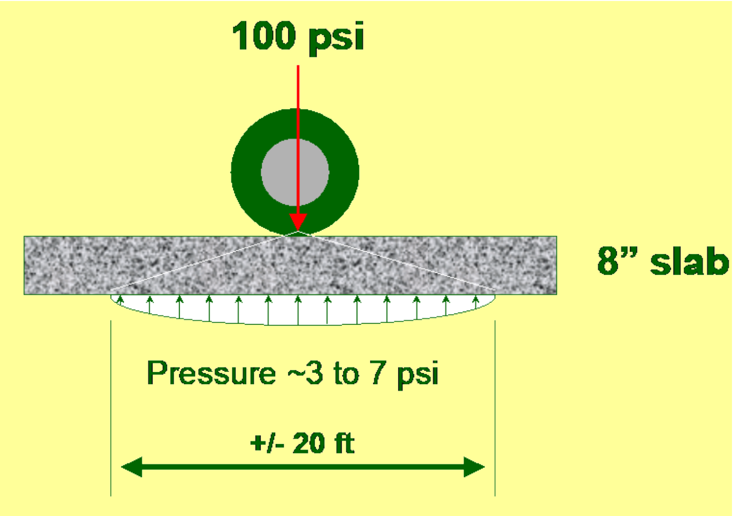
- Concrete pavement support
- Soils / Subgrades
- Subbases
- Geotextiles
- Chemical Stabilization
- Current Research

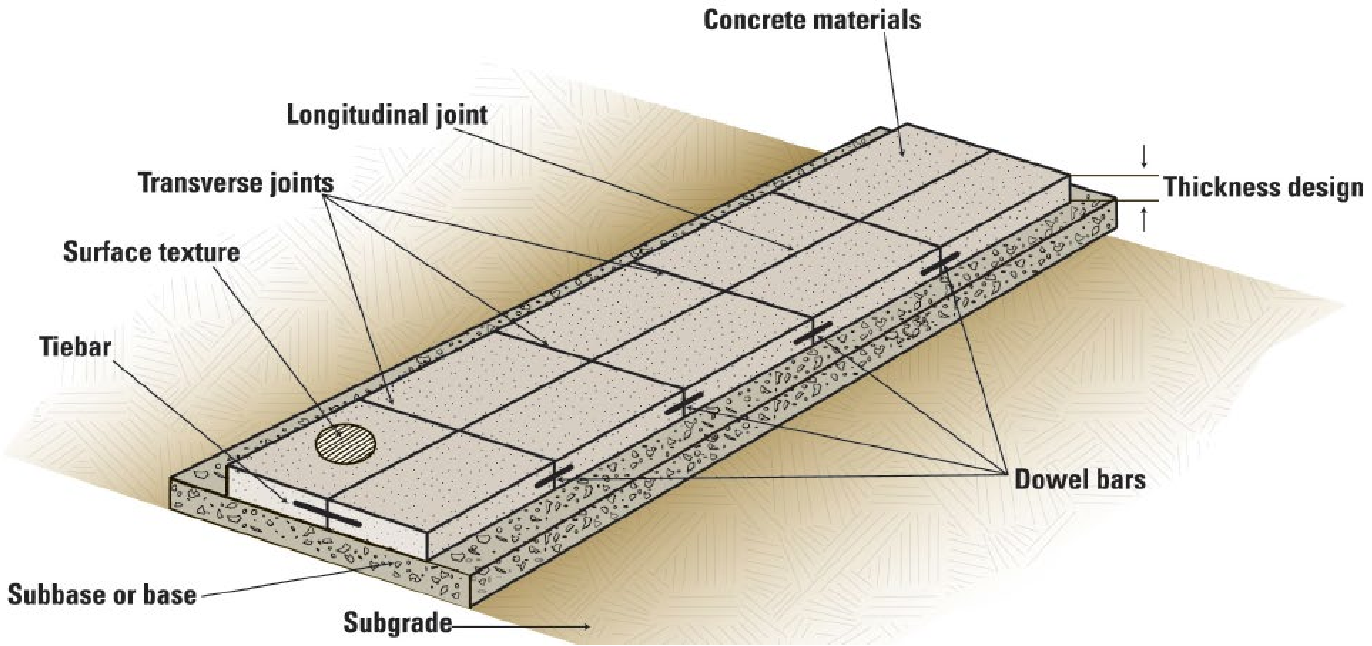
# Pavement Support Basics

Firm, uniform, and non-erodible support is essential for concrete pavements

A stable working platform will typically expedite construction operations

Subgrade uniformity is more important than strength



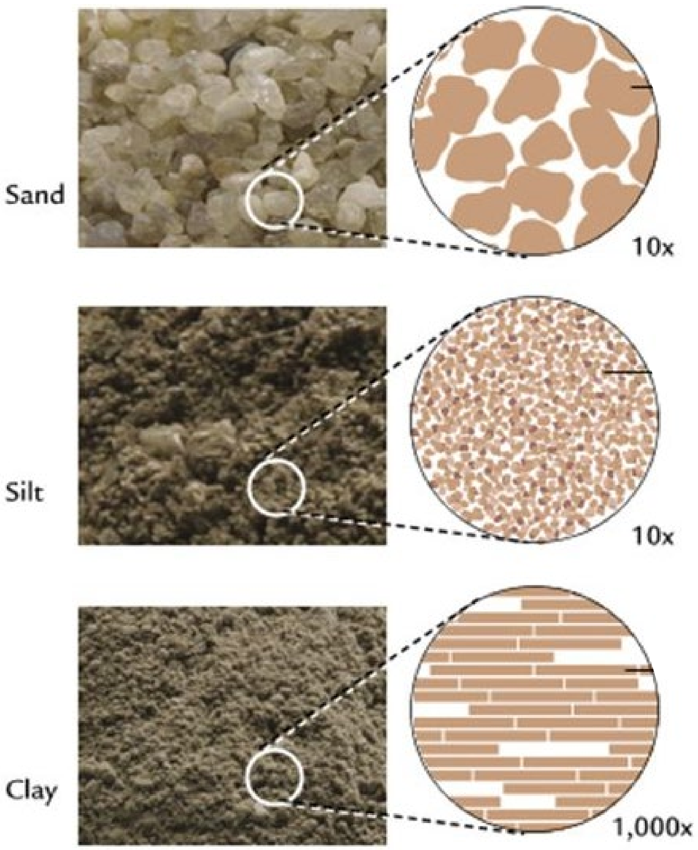



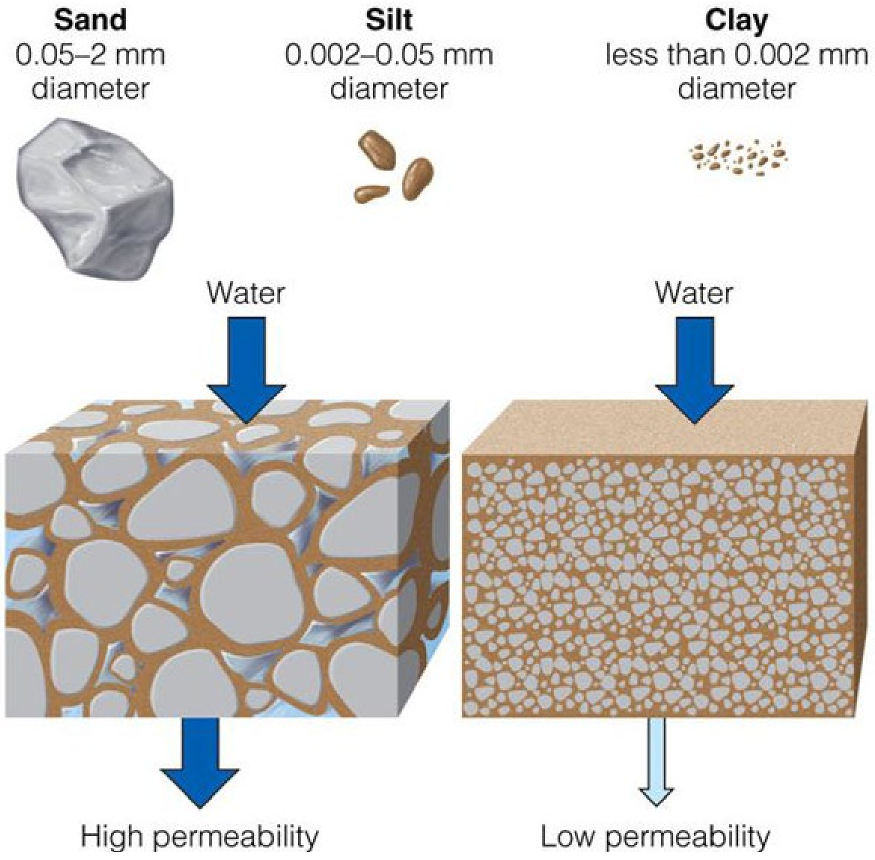
# Pavement Support Basics

- Uniformity of the subgrade and subbase layers is more important than the strength or stiffness of those layers (ACPA 2008)
- Uniformity of the subgrade and subbase layers:
  - avoids stress concentrations
  - reduces pavement defections from vehicle loadings

Placing a subbase layer over a nonuniform subgrade does little to improve uniformity (White et al., 2021)

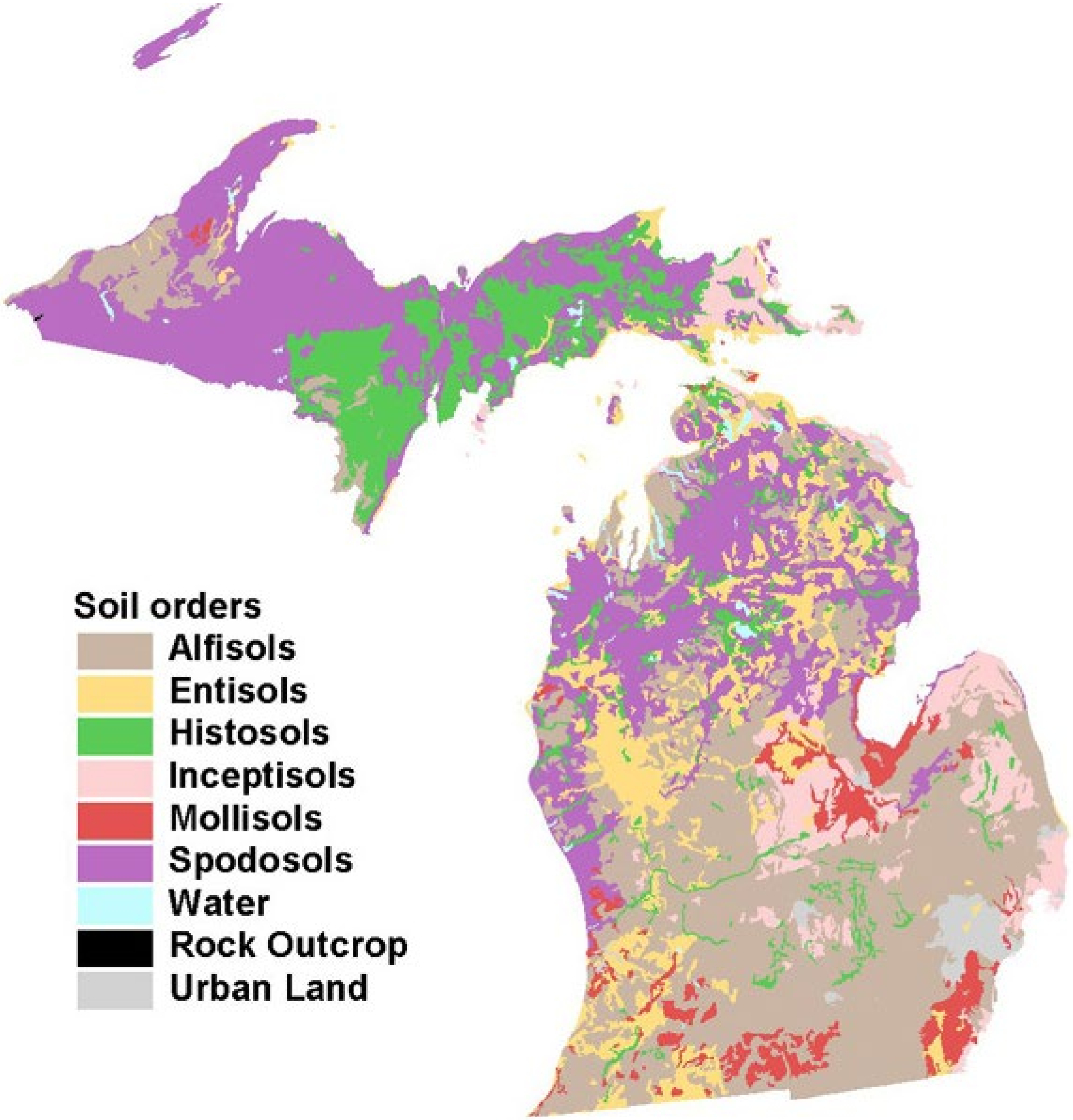
# Soil Particle Size (by themselves)




Source: Thomson Higher Education

# Michigan Soils

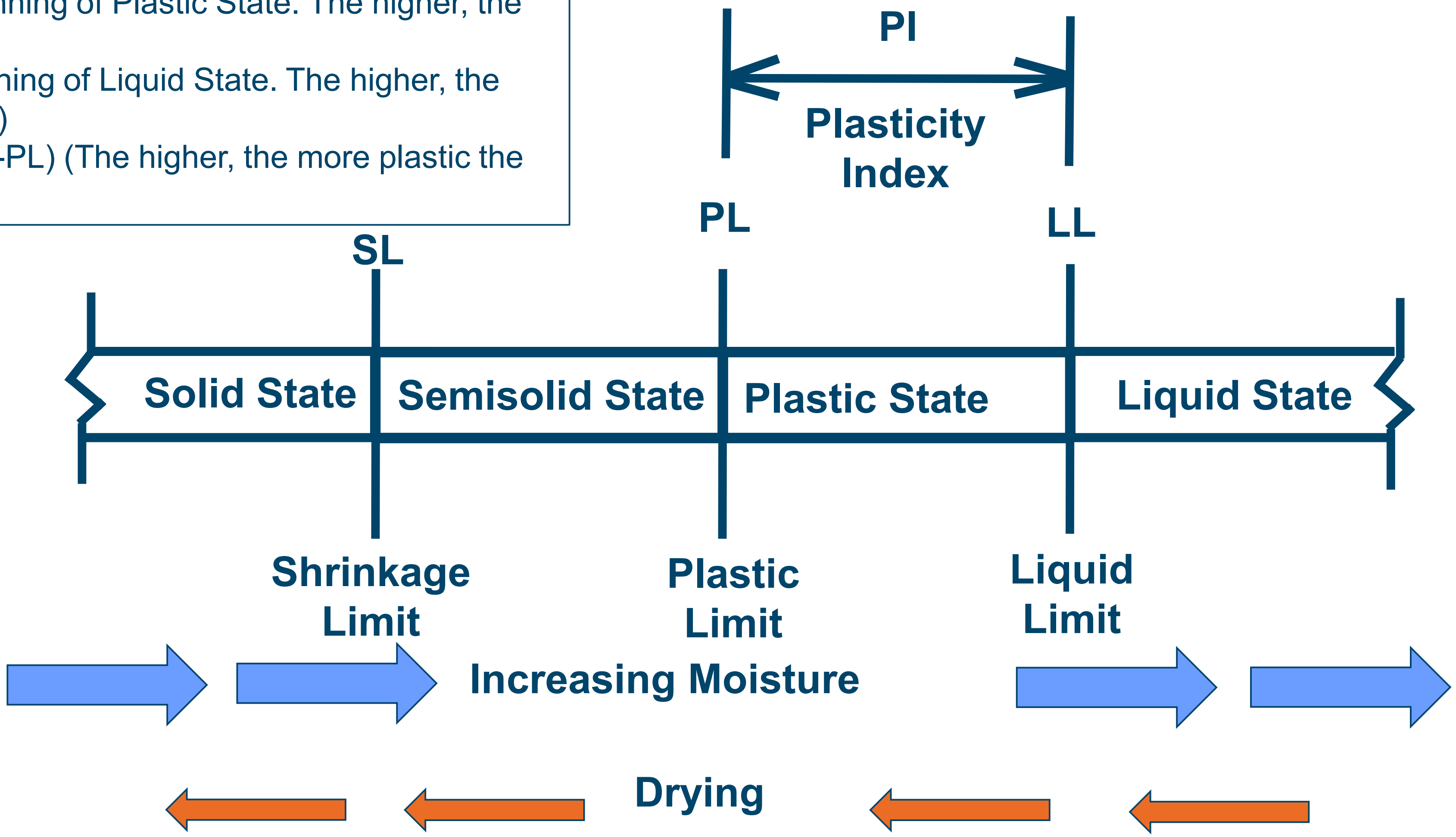


# Cohesive Soils (Plastic)

- The consistency of these soils can range from a dry, solid state to a wet, liquid state with the addition of water.
- Eventually, all of the empty pores will be occupied by water and the addition of any more water will cause the system to expand.

# Atterburg Limits

SL=Shrinkage Limit (While drying, no more shrinkage)
PL=Plastic Limit (Beginning of Plastic State. The higher, the more swelling)
LL=Liquid Limit (Beginning of Liquid State. The higher, the greater compressibility)
PI=Plasticity Index (LL-PL) (The higher, the more plastic the soil and higher swell)

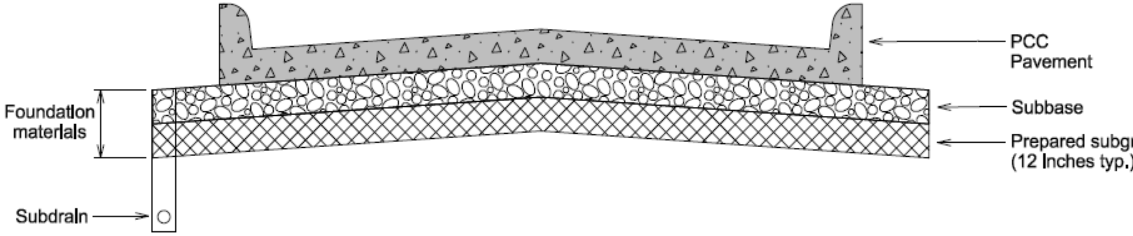


# Working Platform Problems

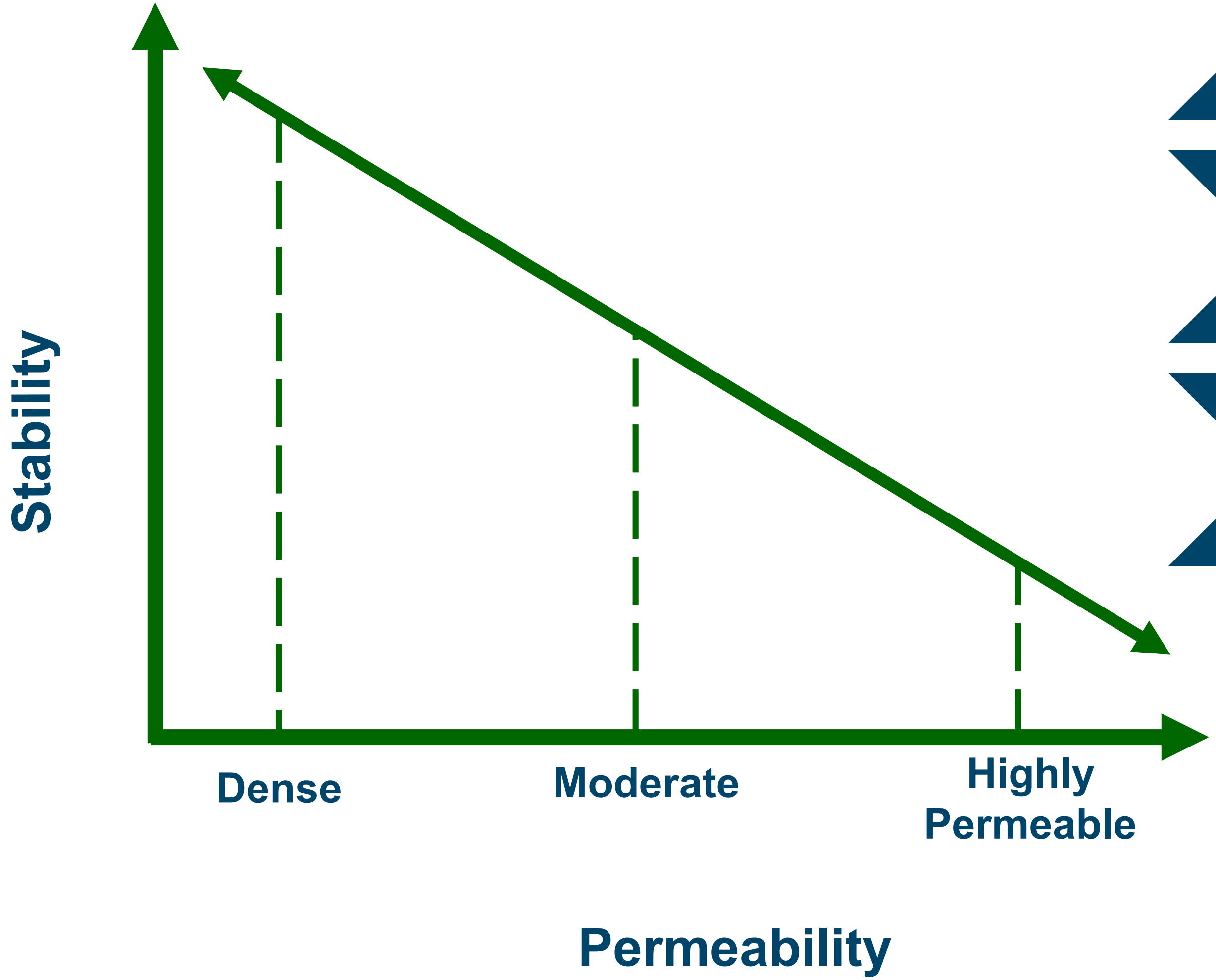
- High Plasticity = High Plasticity Index = Instability
- Expansive clays = Volume change
- Weak soils = Poor bearing capacity
- Wet/soft subgrade = Poor support

# Subbases

- Used when soil is reasonably stable & not excessively wet
- Provides a working platform during construction
- Provides uniformity as a support layer – subgrade must be uniform
- Serves as a drainage system to help drain surface water away from the pavement
- Provides a cutoff layer from subsurface moisture (and risk for pumping)
- Reduces shrink and swell of high volume change soils
- A subdrain and outlet system needs to be provided



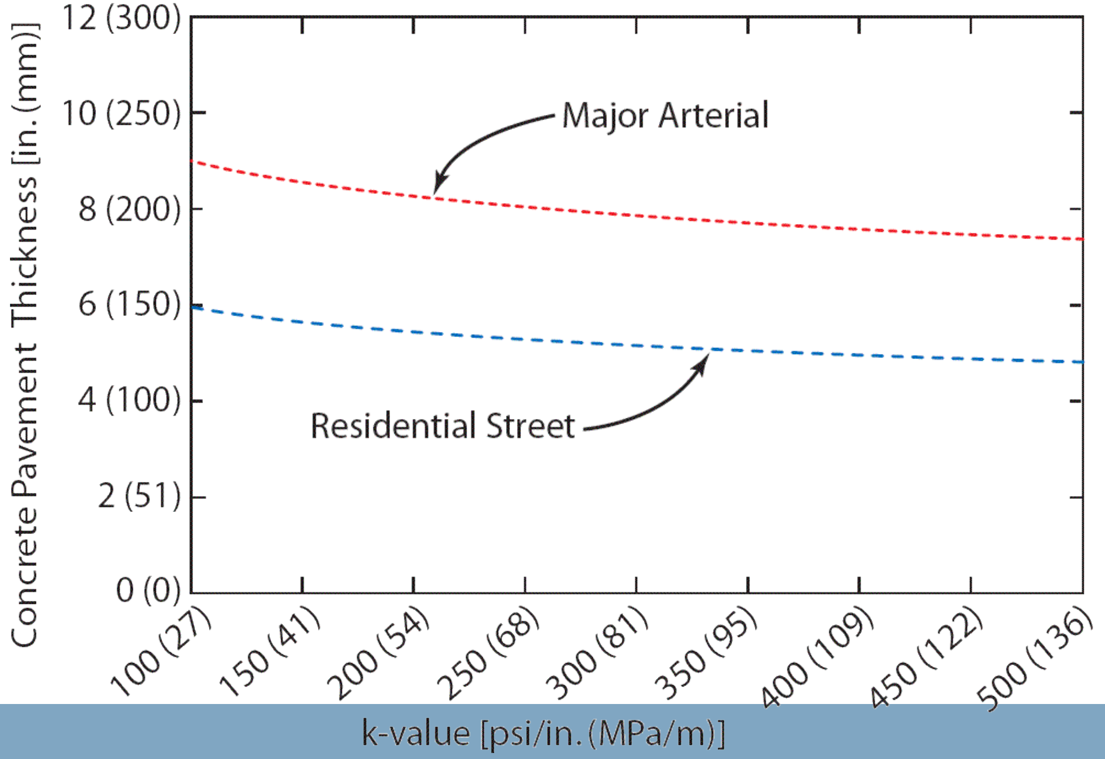
# Granular Subbases Stability versus Permeability

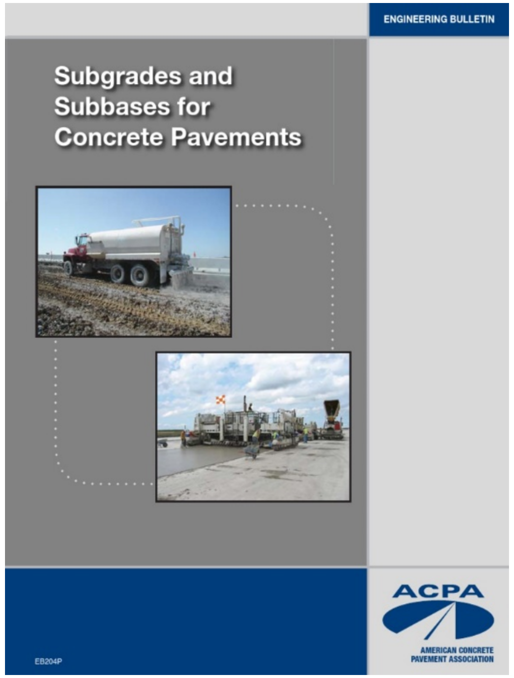



| | | |
|---|---|---|
| Dense stable (Class "A") | High fines/High Stability | Low Permeability |
| Moderately Permeable (Modified Subbase) | Medium Fines/Medium Stability | |
| Highly Permeable (Granular Subbase) | Few if any Fines/Low stability | |

# Subbases

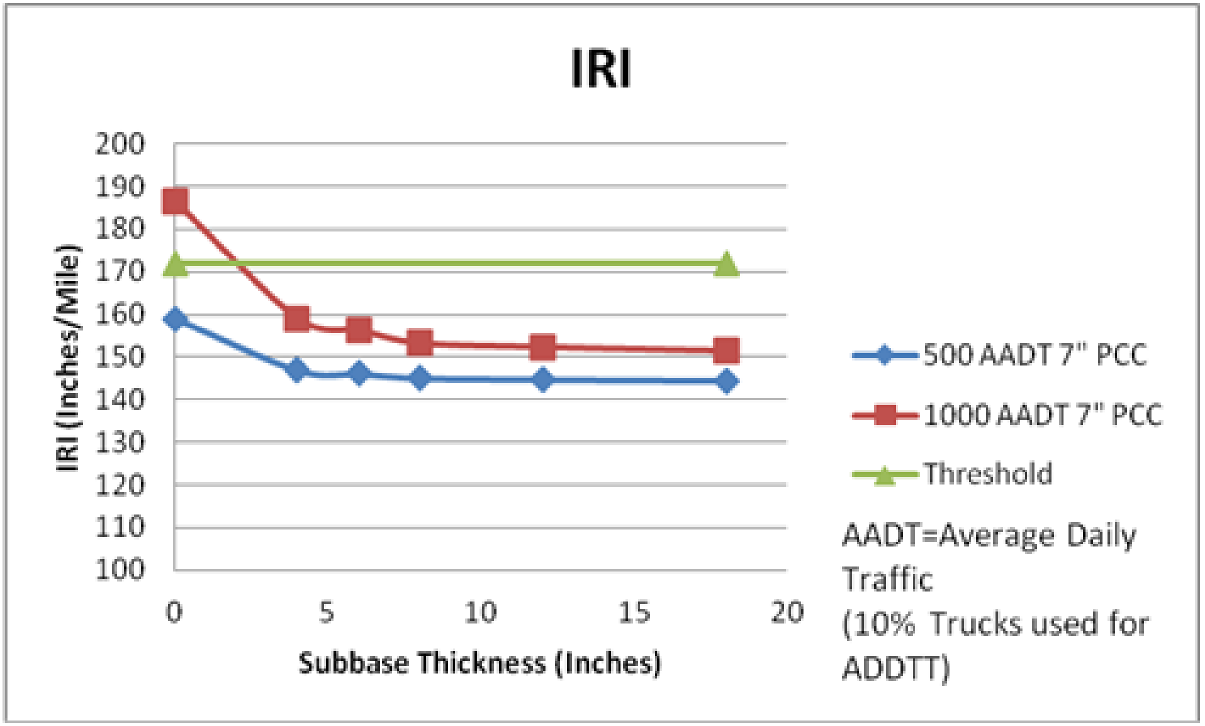
Concrete pavement design thickness is not real sensitive to support stiffness (modulus of subgrade reaction), so to make a subgrade/subbase stronger or thicker in an attempt to decrease concrete pavement thickness is not always cost-effective. – ACPA 2008



# Aggregate Subbase Thickness Limitations (IRI)

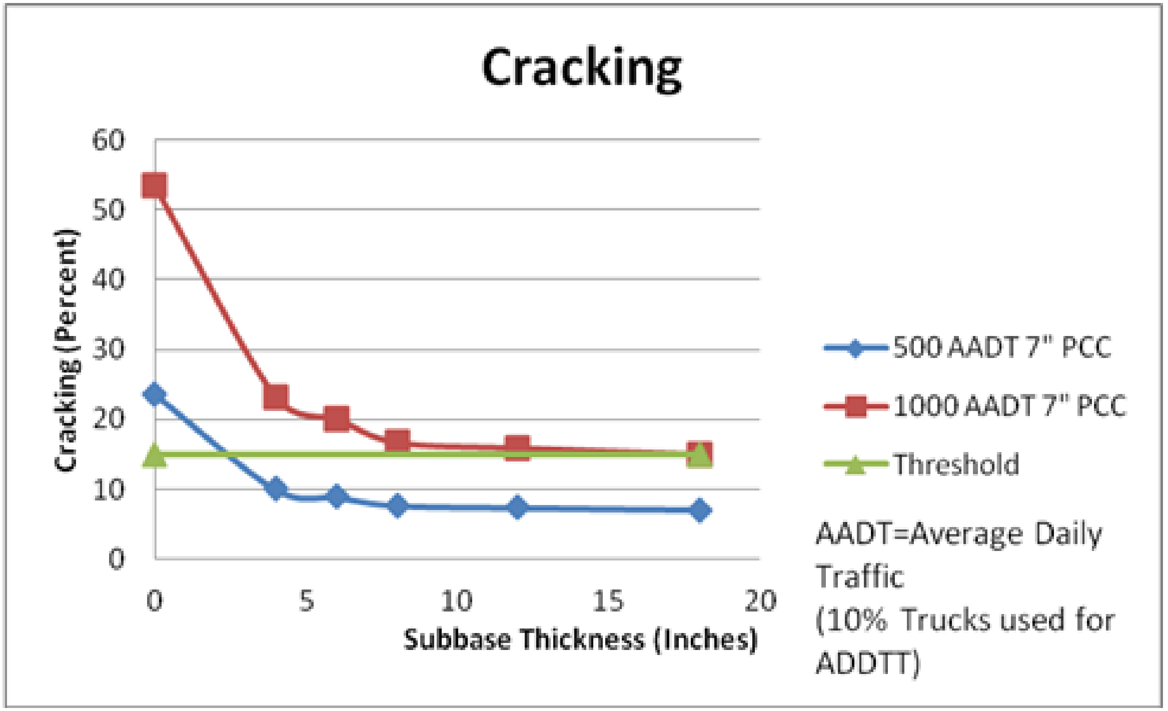
MEPDG Failure mode: IRI (in./mi)




Subbase thickness over 5” does not benefit PCC

# Aggregate Subbase Thickness Limitations

MEPDG Failure mode: % Cracked Slabs




Subbase thickness over 5” does not benefit PCC

# Soil Improvement Options

## Subbase is an insurance layer

- Scarify and drying
- Blending soil
- Add geogrid and subbase
- Add chemical stabilization
- Remove unsuitable and replace with select material in at least upper 2’

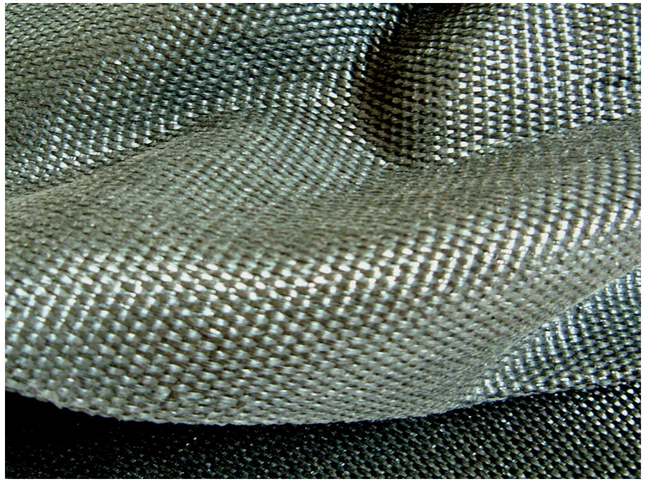
# Geotextiles

## Woven

- High strength support
- Less permeable
- Used to increase support & stabilization (and filtration and separation)

## Nonwoven

- Felt-like
- More permeable
- Used for filtration and separation



Made of Polypropylene fibers

# Geogrids

**Geogrid + aggregate subbase:**

- Creates stronger composite structure
- Minimizes subbase fill
- Serves as construction platform
- Extends service life

Source: Geofabrics

## Iowa DOT 4196.01B

- Rectangular or Triangular
- Max. Aperture size 2”
- Min. Aperture size 0.5”
- Min. Tensile strength @2% strain 250 lbs/ft
- Min. Ultimate junction strength 800 lbs/ft

# Chemical Soil Stabilization Options

## Soil Stabilization:

- To amend the undesirable properties of poor native soils to make suitable for construction

## Fly Ash

- Class C 15-18%

## Quick lime

- High quality 3-4%
- Dolomite quicklime 6-8%

## Cement Modified Soils (CMS)

- Cement 2-3%

# Fly Ash & Lime

## Fly Ash

- Some concern for weakening in spring thaw
- May tend to group clay particles together and make more frost susceptible
- Recommend compaction within 2 hours

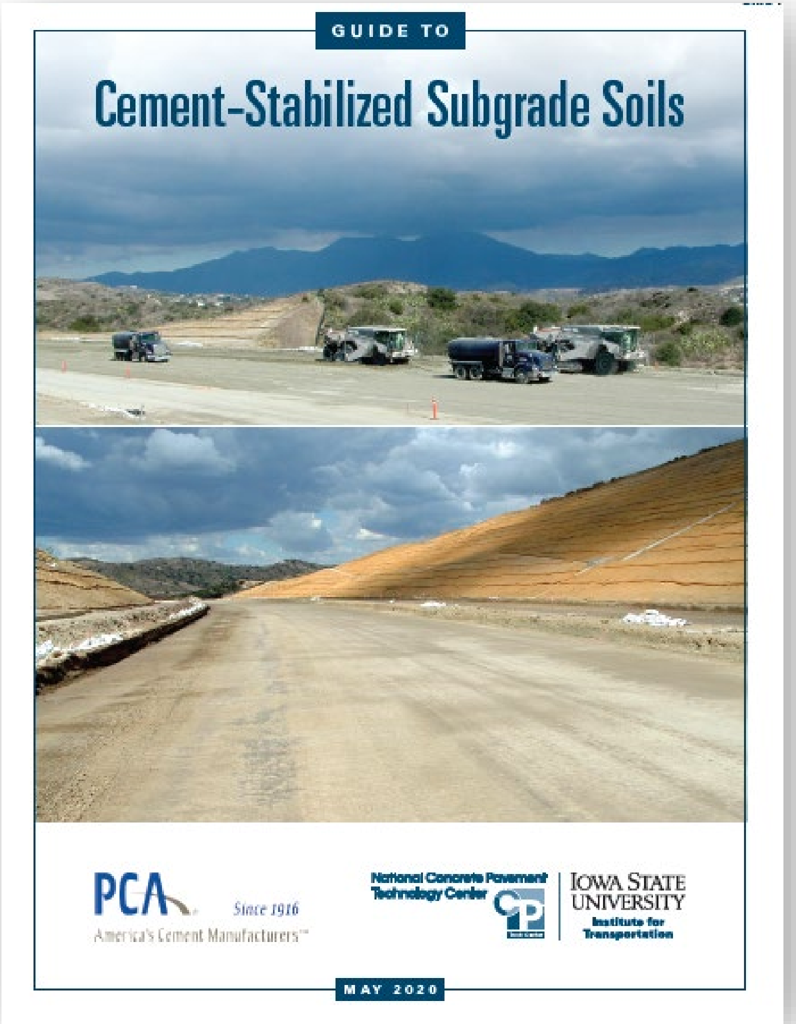
## Quicklime

- Has slower reaction than Fly Ash
- If applied to dry soil, it can expand later

## Both create a working platform

Source: Boone County Expo Research Study

# Cement-Stabilized Subgrade Soils Guide



# Terminology

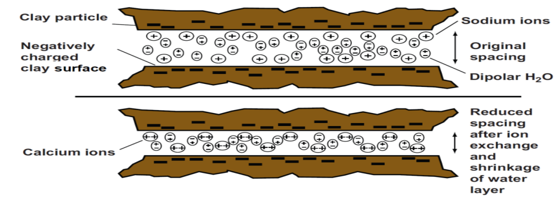
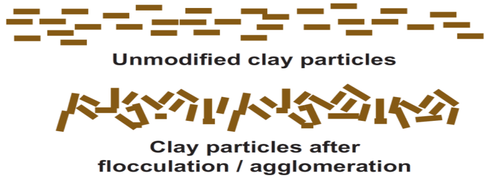
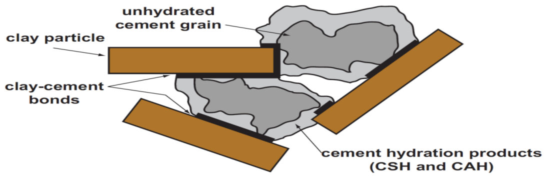
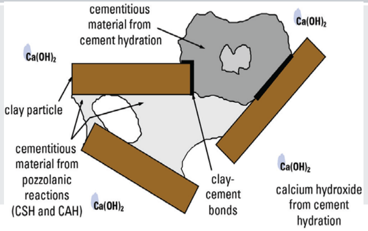
**Cement Modified Soil (CMS):** A compacted mixture of pulverized in situ soil, water and small portion of cement that results in an unbounded or slightly bounded material, similar to a soil, but with improved engineering properties.

**Cement Stabilized Subgrade (CSS) Soil:** A compacted, engineered mixture of pulverized in situ soil, water and moderate proportions of cement (more than CMS) that results in a semi-bound or bound material with structural engineering properties similar to those of granular material.

# Cement Modified/Stabilized Soil (CMS/CSS)

- Eliminates removal/replace of inferior soils
- Reduces construction time (no mellowing)
- Works for wide range of soils-granular to clay
- Small quantity of cement (2-4%) added to soils to change properties. CSS slightly more than CMS
- Lowers plasticity index (PI) and improves volume stability
- Improves compactibility & bearing capacity of soil
- Forms all-weather work platform

# Modification Mechanisms

| Mechanism | Time of Modification Processes | Sand, Gravel, Silt (non-cohesive) | Clay (cohesive) | |
|---|---|---|---|---|
| Cation exchange | Immediate to a few hours | | X |  |
| Particle restructuring | Immediate to a few hours | | X |  |
| Cementitious Hydration | Major strength gains from 1 to 28 days | X | X |  |
| Pozzolanic Reaction | Strength gains slowly, over months & years | | X |  |

# 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 |
| <u>Emulsified Asphalt</u> SE > 30 or PI < 6 and $P_{200}$ < 20% | X | X | X | X | X | X | X | | | | | | |
| <u>Foamed Asphalt</u> PI < 10 and $P_{200}$ 5 to 20% | X | | X | X | X | | X | | | | | | |
| <u>Cement, CKD or Self-Cementing Class C Fly Ash</u> PI < 20 $SO_4$ < 3000 ppm | X | X | X | X | X | X | X | X | X | X | | | |
| <u>Lime/LKD</u> PI > 20 and $P_{200}$ > 25% $SO_4$ < 3000 ppm | | | | | | | | X | | X | | X | X |

From ARRA *Basic Asphalt Recycling Manual*, 2015

# Clay Soils (A-6, A-7)

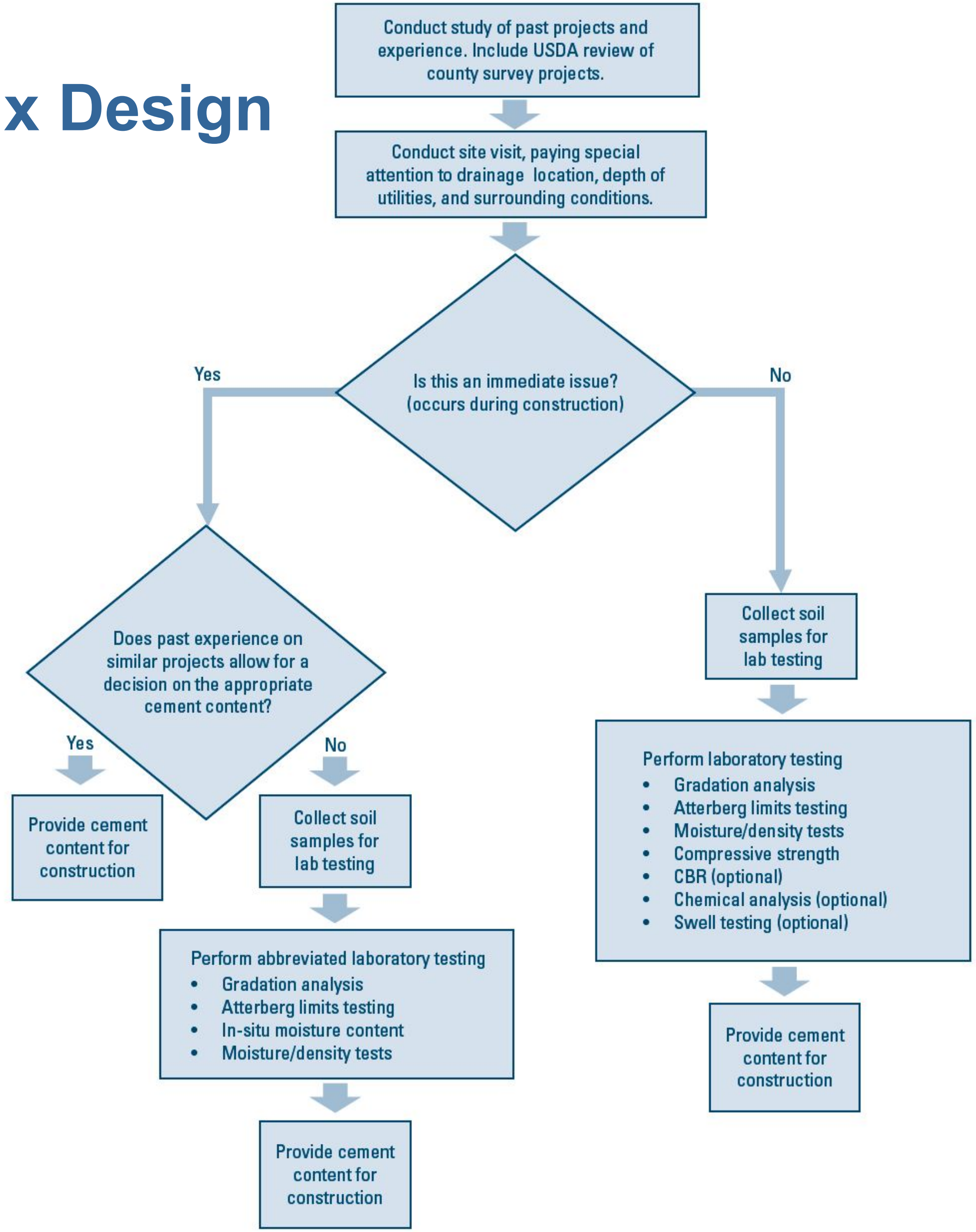
- High plasticity and cohesiveness
- Fine-grained with high porosity
- Low permeability
- High shrink and swell potential
- Expansive when wet
- Low bearing strength when moist and easily deforms under load
- Difficult to dry out
- Difficult to compact

# Silty and Sandy Soils (A-4, A-3)

- 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

# Decision Tree – CSS (or CMS) Mix Design

- Design Path (right leg)
- Construction Path (left leg)



# CSS Mixture Design

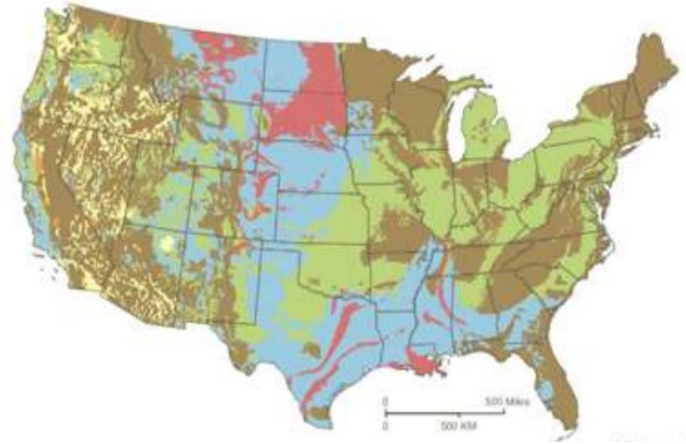
1. Determine In Situ Moisture Content and Classify Soil
2. Determine Cement Type and Estimated Dosage Rate
3. Determine Chemical Compatibility (If Necessary)
4. Determine Atterberg Limits of Three Different Cement Content Samples

**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

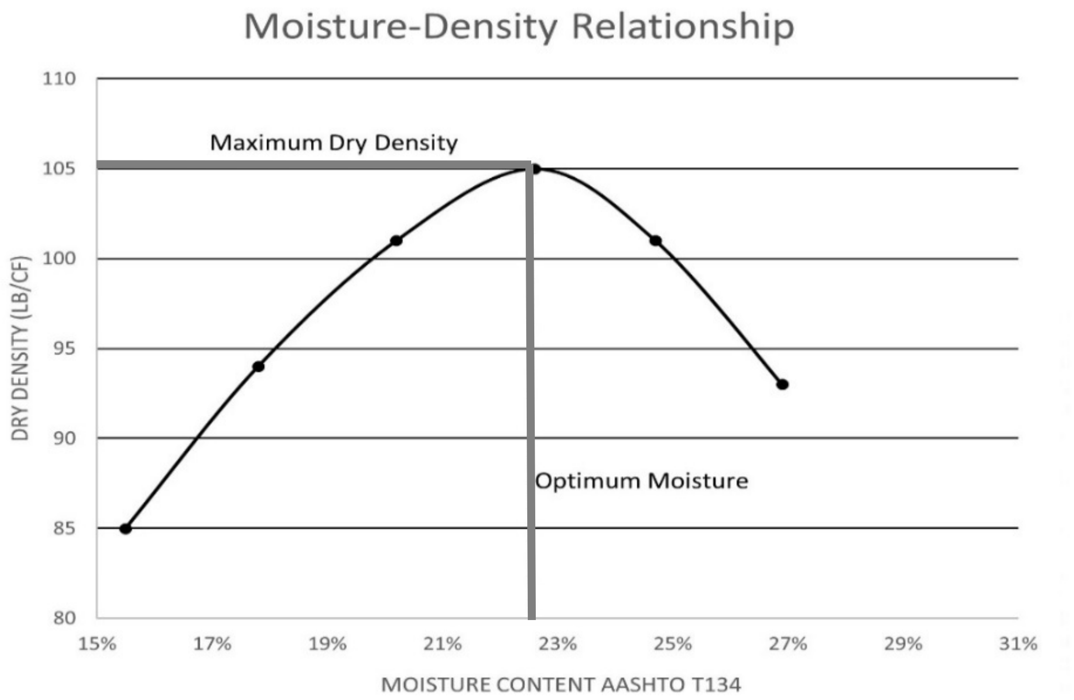
Swelling Clays Map of the Conterminous United States" (Olive et al., 1989)



# CSS Mixture Design

## 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




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

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

# CSS Mixture Design

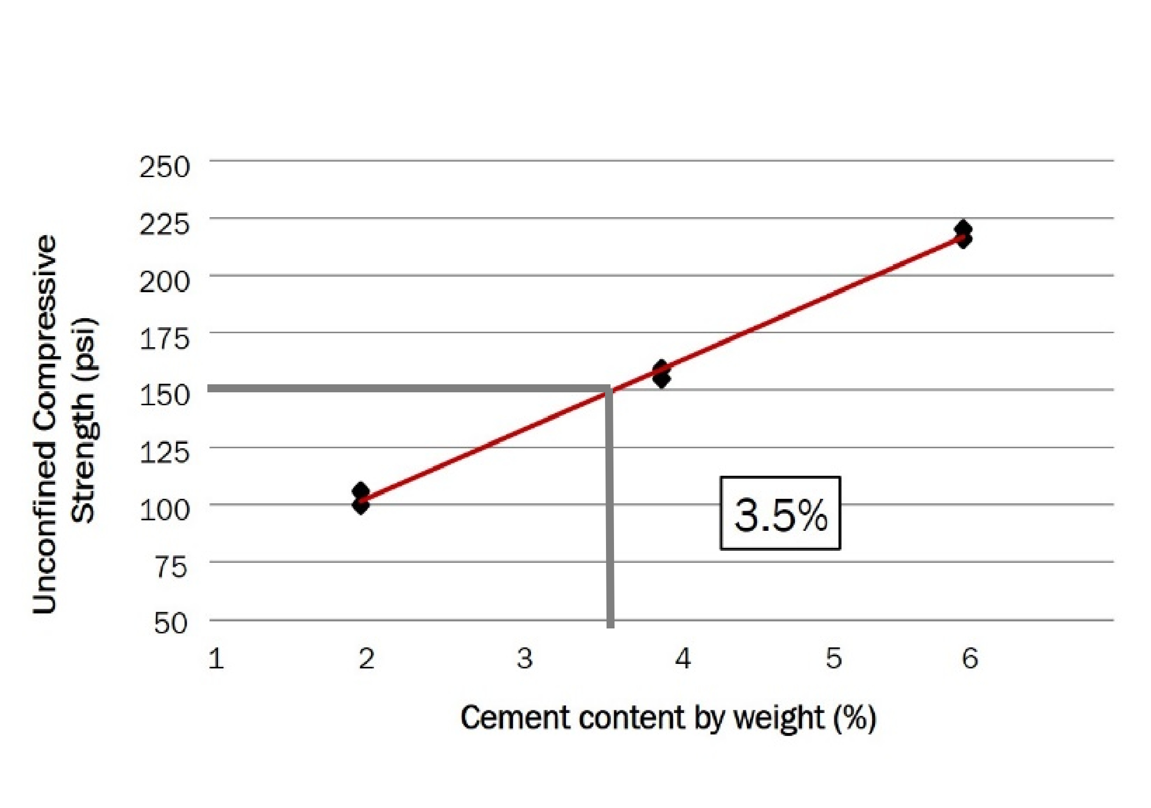
## 6. Determine Unconfined Compressive Strength

- Immerse specimens in water for 4 hours prior to UCS testing
- 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

# CSS Mixture Design

## 7. Plot Unconfined Compressive Strength to Verify Cement Content



# CSS Mixture Design

## 8. Compile Mix Design Report

Untreated soil properties

- in situ moisture content
- gradation
- Atterberg limits
- moisture and density testing (when applicable)

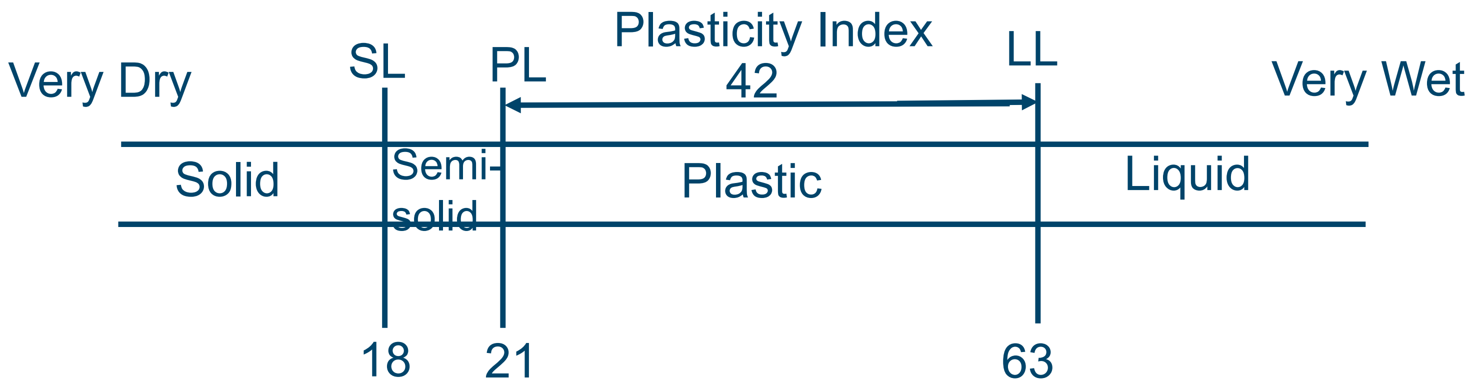
Treated soil properties

- MDD and OMC (AASHTO T 134)
- Atterberg limits
- Wet density of UCS test specimens (before and immediately after the moist curing period)
- Cement type (Type I, Type II, Type I/II, or Type II/V (for high sulfate)
- Recommended cement content as a percentage of dry materials
- UCS at each trial cement content (if applicable)

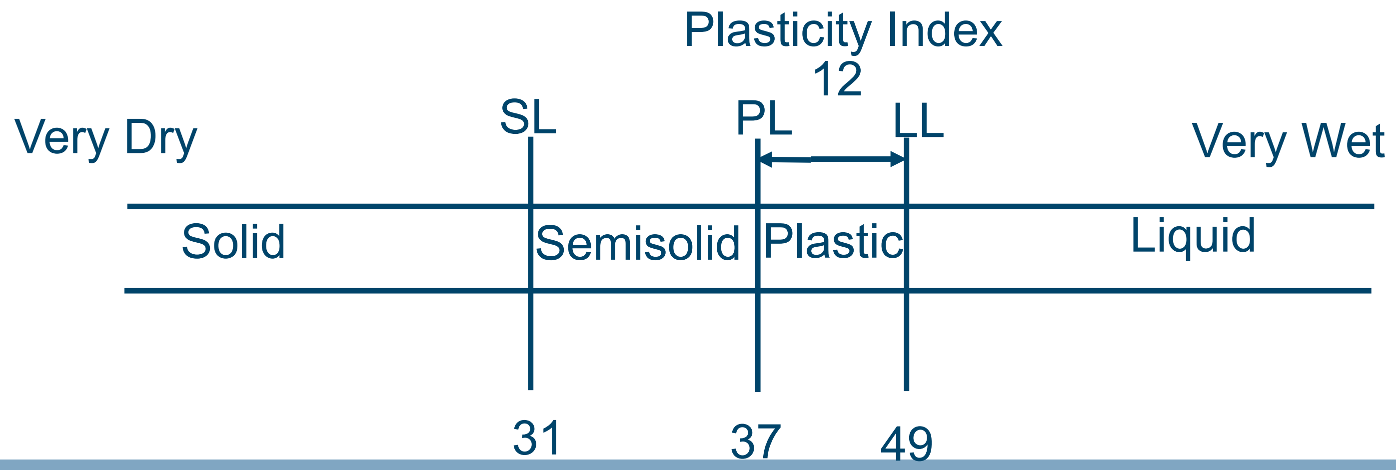
# Effect of 3%Cement on Cohesive Soils

SL=Shrinkage Limit (While drying, no more shrinkage)
PL=Plastic Limit (Beginning of Plastic State. The higher, the more swelling)
LL=Liquid Limit (Beginning of Liquid State. The higher, the greater compressibility)
PI=Plasticity Index (LL-PL) (The higher, the more plastic the soil and higher swell)

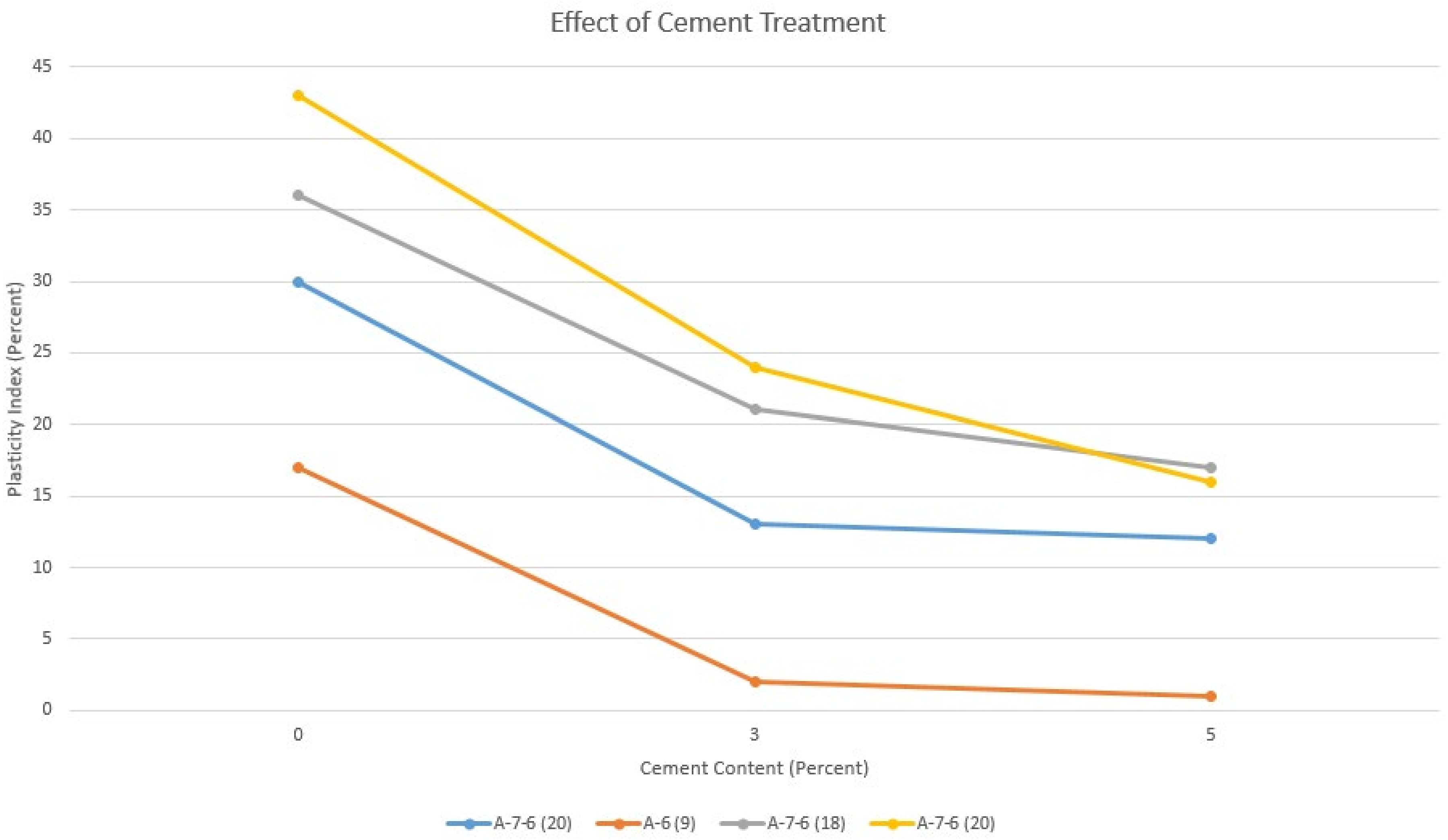
Before CMS




7 days after adding 3% cement



# Effect of Cement Treatment



# Construction

## Construction Process

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

photo credit:
Corey Zollinger

# Construction

- Proof rolling to identify application area
- Moisture conditioning (as necessary)
- Initial pulverization (as necessary)
- Preliminary Grading



Top image credit:
Corey Zollinger

# Construction – Adding Cement

**Bulk Cement**

- Lowest Cost
- Dusty

**Slurry Cement**

- Solves  dust problem
- Increased Cost

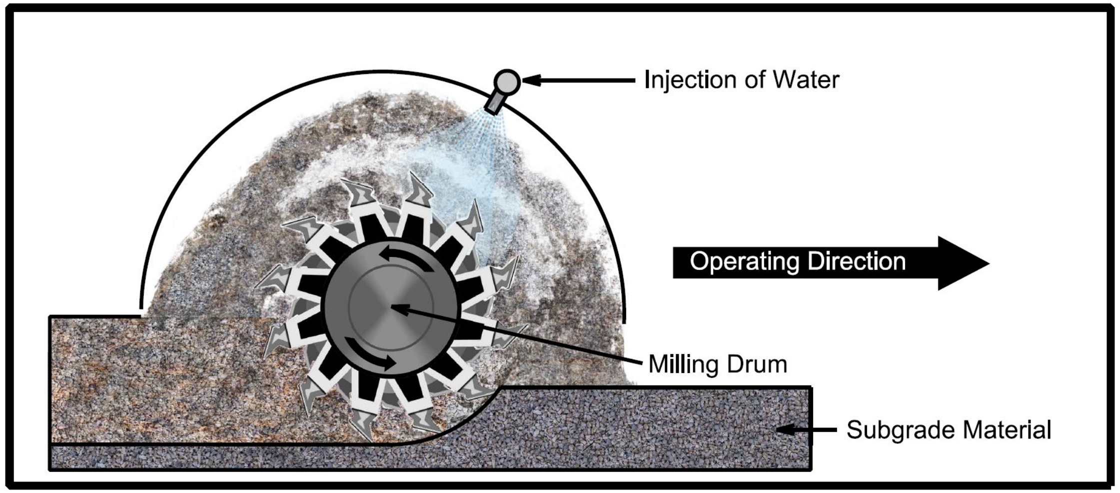
**Slurry Train – Slurry injected into mixing chamber**

**Spreader Trucks**

slide credit:
Corey Zollinger

# Construction - Mixing

## Achievement of Optimum Moisture Content




Roadway reclaimer

Image: Jeff Wykoff

# Construction - Mixing

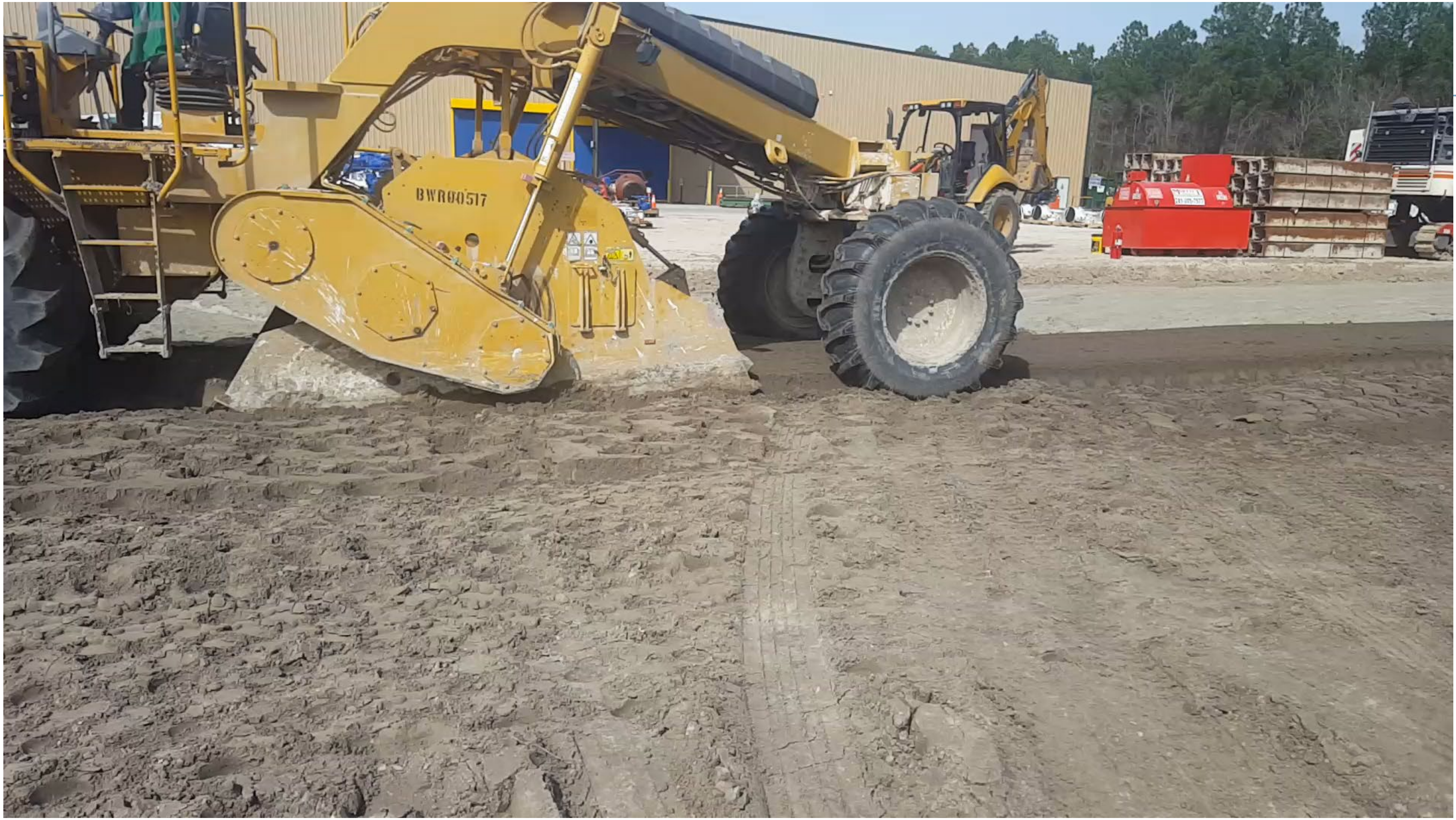
## Mixing with a reclaimer

Table 5.3. Comparison of typical gradation requirements for CSS, CTB, and FDR

| Type of Soil-Cement | Minimum Percent Passing | | | |
|---|---|---|---|---|
| | 3 in. (75 mm) Sieve | 2 in. (50 mm) Sieve | 1½ in. (38 mm) Sieve | No. 4 (4.75 mm) Sieve |
| Cement-stabilized subgrade | — | — | 100 | 60 |
| Cement-treated base | 100 | 95 | — | 55 |
| Full-depth reclamation | 100 | 95 | — | 55 |

image credit:
Corey Zollinger

# Construction Process - Mixing



# Construction - Compaction

## Compaction

- If adequate compaction cannot be achieved in a single lift of CSS due to unstable conditions, multiple-lift construction may be necessary
- For silty & clayey soils, initial compaction should be done with a vibratory tamping roller
- For compaction of sandy or gravelly material and for final compaction of silty and clayey soils, a vibratory smooth drum or pneumatic tire roller is used.
- Minimum of 95 percent of maximum dry density
- Final proof roll (optional)


Vibratory padfoot/tamping/sheepsfoot roller

Vibratory smooth drum roller

# 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 – Final Steps

## Final Grading

- motor grader or similar
- final grade slightly overbuilt for trimming

## Curing

- fog water spray
- bituminous emulsion

Image: Virginia DOT

# Construction - Weather

## Weather Conditions

- Do not construct CSS in standing water
- Do not construct CSS on frozen ground
- Do not apply on windy days
- Air temperatures should be 40º F or higher

# More information

You can watch a 60 minute webinar on Cement Stabilized Subgrade Soils as well as other webinars at this link:

https://www.cement.org/cement-concrete/cement-concrete-applications/pca-infrastructure-webinar-series

# Subgrade Testing – Compaction with M & D

Compact to 95% of maximum Standard Proctor Density

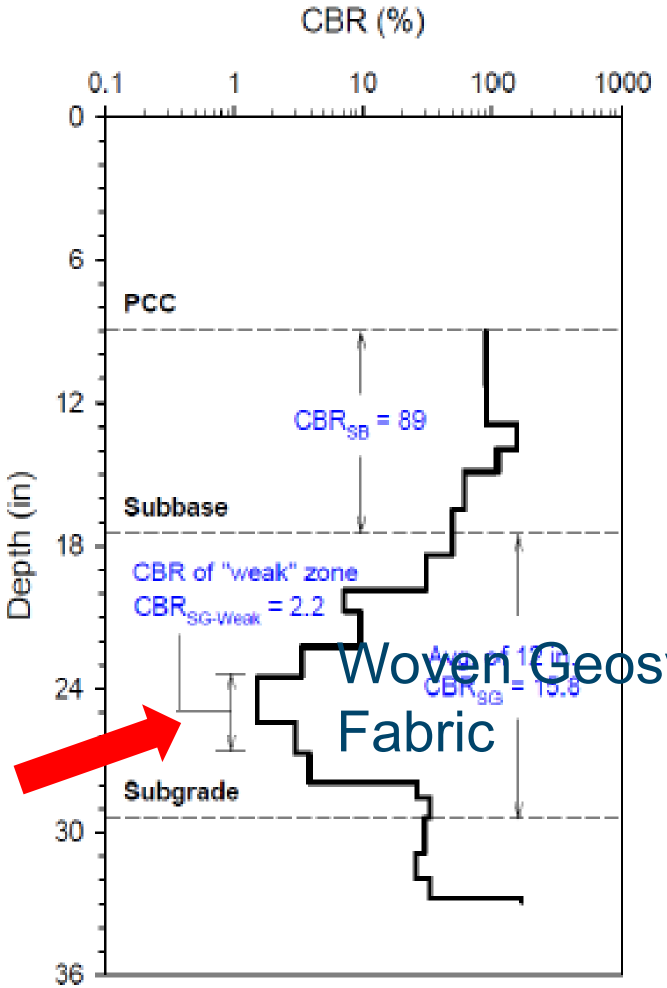
Ensure moisture content is within range of optimum moisture to 4% above optimum (SUDAS)

Test soil strength with CBR Test

- Compares soil bearing capacity vs. well graded crushed stone
- High quality crushed stone CBR = 100%
- Typically 3-4 in Iowa

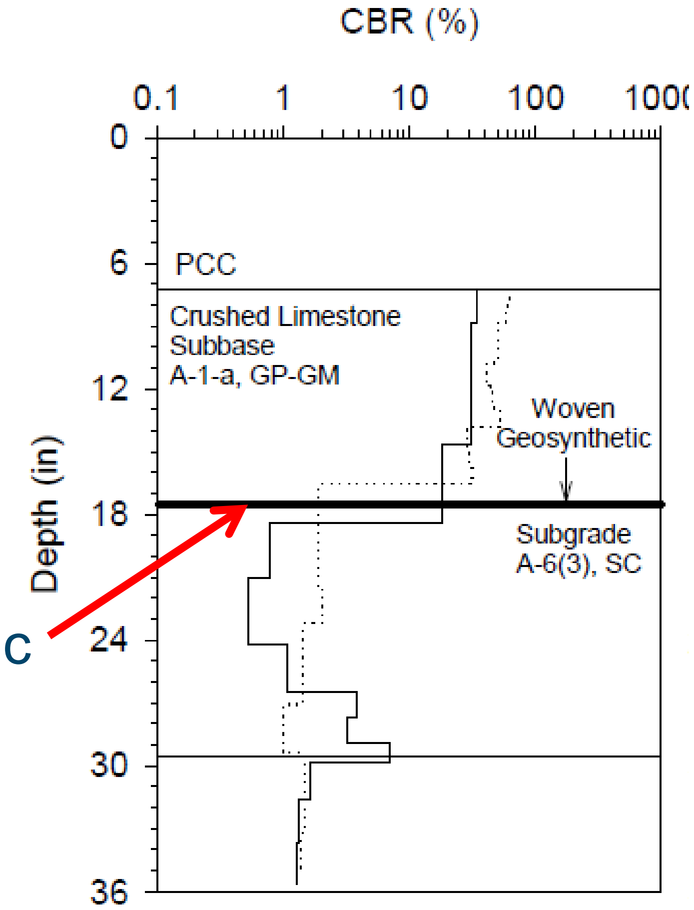
Source: ELE International

# Subgrade Testing - Dynamic Cone Penetrometer (DCP)




Weak Zone

Woven Geosynthetic Fabric



# Subgrade Testing – Proof Roll

## Proof Roll

- loaded single axel (20,000 pounds)
- loaded tandem axle (34,000 pounds)
- 10 mph

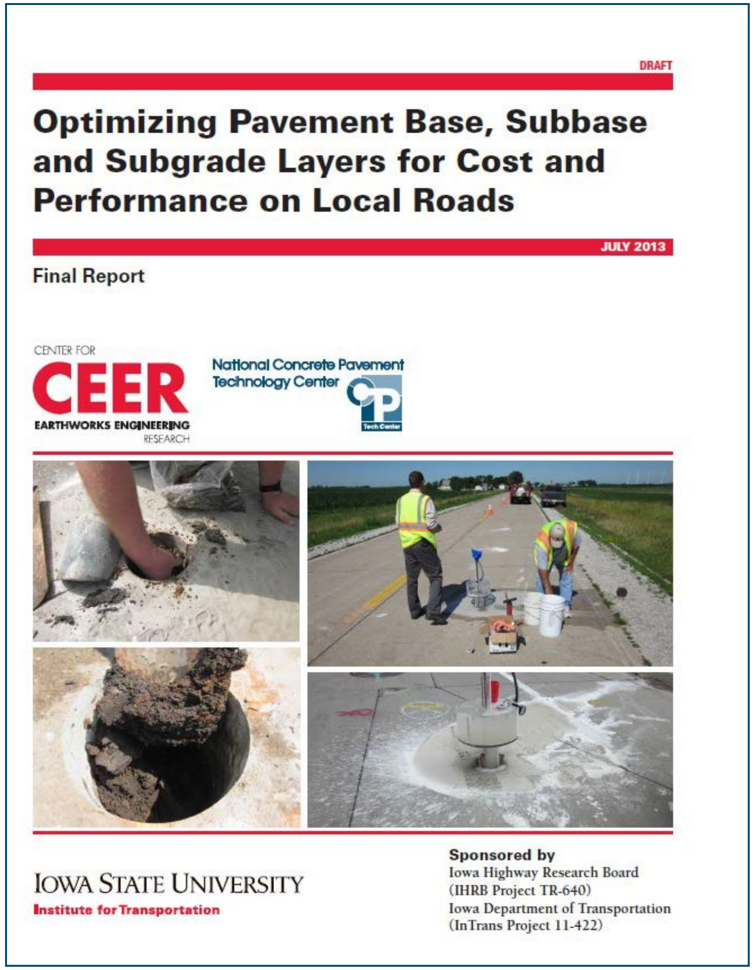
## Unstable if:

- soil wave in front of load
- rutting >2 inches

Source; Geomax Soil Stabilization

# Research Findings on Pavement Support Layers

# IHRB TR–640 - Optimizing Pavement Base, Subbase and Subgrade Layers for Cost and Performance on Local Roads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Optimizing Pavement Base, Subbase and Subgrade Layers for Cost and Performance on Local Roads

JULY 2013

Final Report

CENTER FOR CEER EARTHWORKS ENGINEERING RESEARCH

National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
(IHRB Project TR-640)
Iowa Department of Transportation
(InTrans Project 11-422)

## Field Investigation


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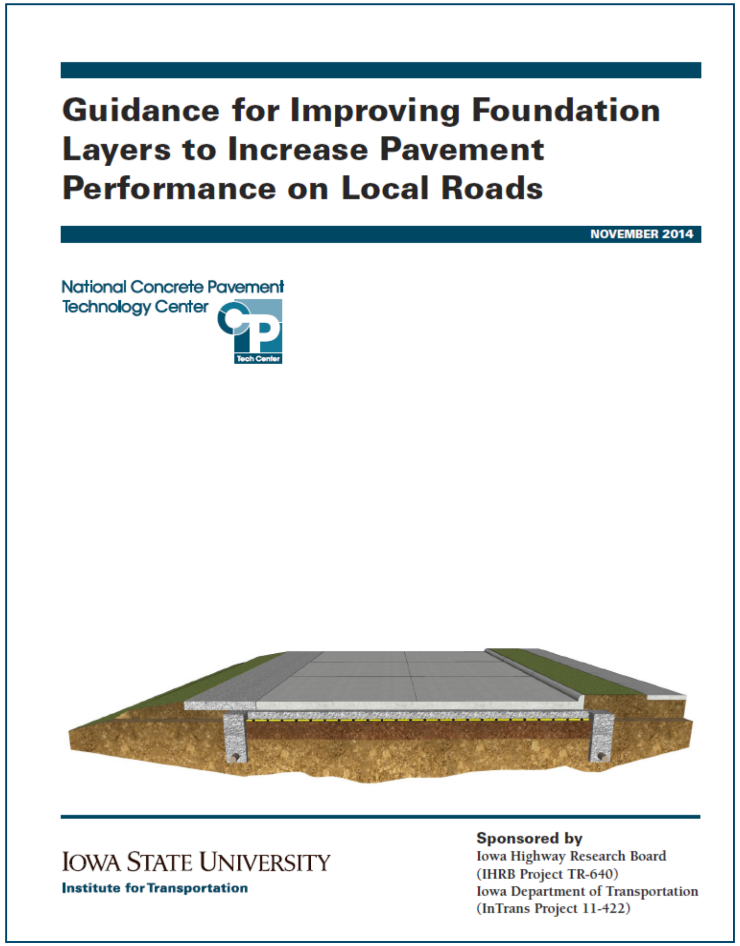

Guidance for Improving Foundation Layers to Increase Pavement Performance on Local Roads

NOVEMBER 2014

National Concrete Pavement Technology Center

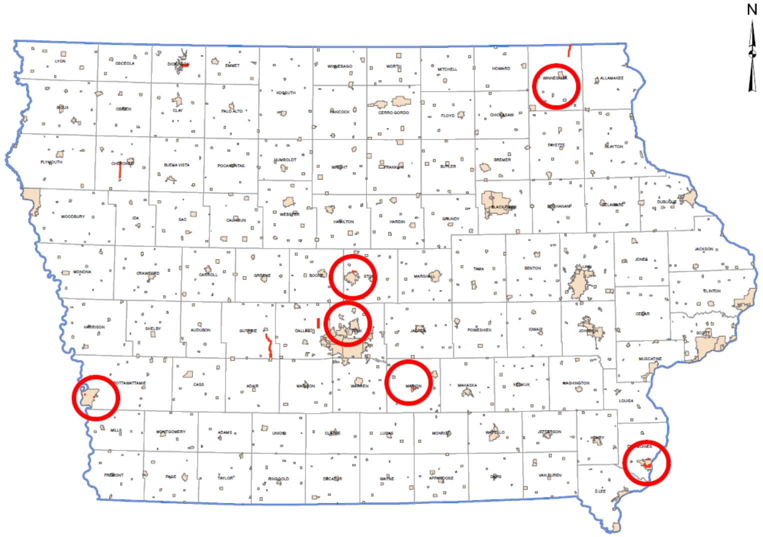
IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
(IHRB Project TR-640)
Iowa Department of Transportation
(InTrans Project 11-422)

# IHRB TR-640

## Quantitative research relating subgrade to pavement performance

- Age: 30 days to 42 years
- Poor to Excellent PCI: (35 to 92)
- Support Conditions:
  - Natural Subgrade
  - Fly Ash Stabilized Subgrade
  - 6 - 12 in. Granular Subbase (open graded)
- Pavement: 6 to 11 in. thick
- Traffic (AADT): 110 to 8900



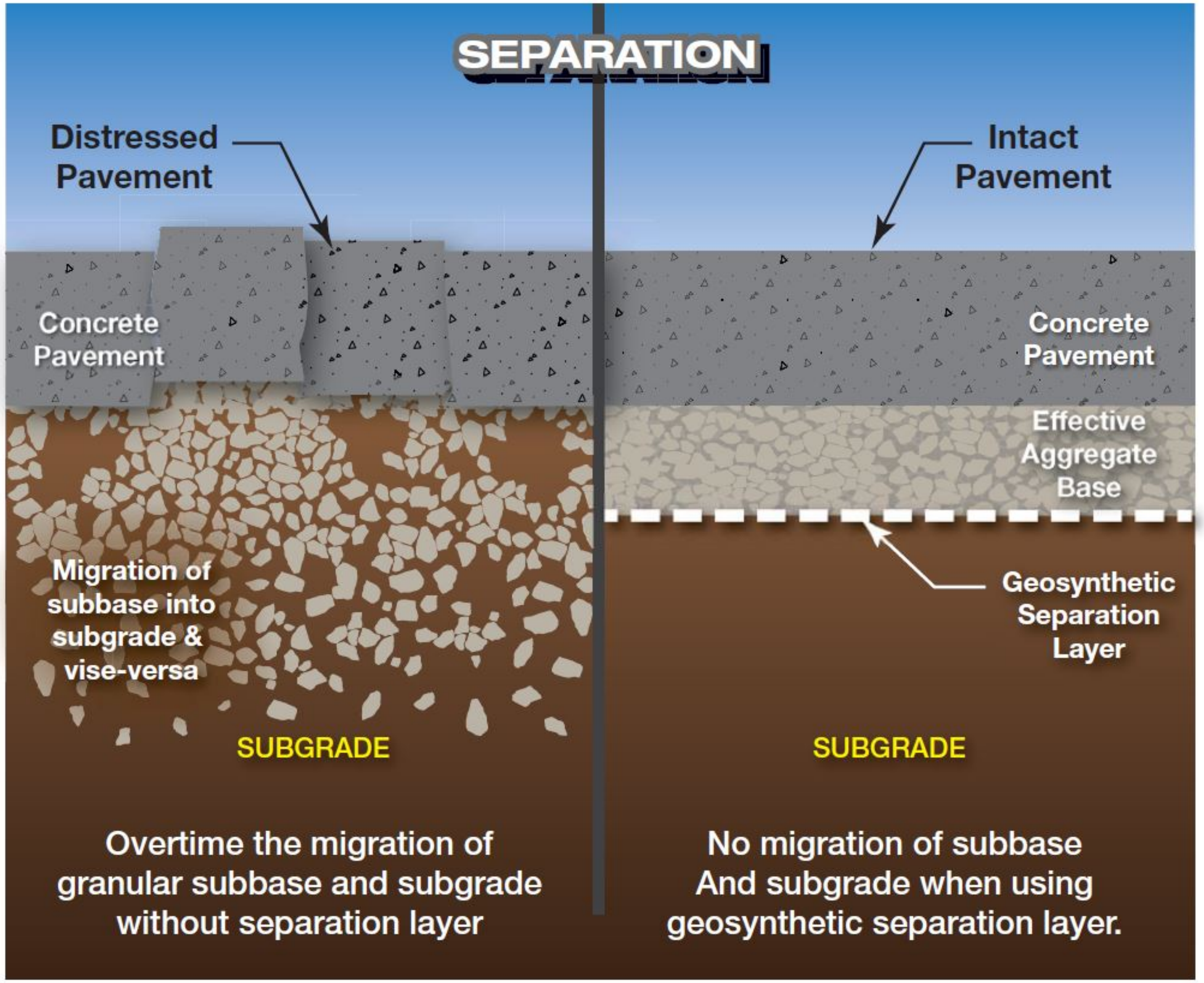
# TR-640 Findings

- Low & variable support values (due to low CBR)
- Poor drainage (Cd)
- Loss of support
- More uniform subgrade and higher coefficient of drainage (Cd) performed better
- Increase in drainage (Cd) has the largest effect on the PCI

# What Impacted Subbase Drainage?

Aggregate subbase loss

Pavement thickness designs do not reflect actual pavement foundation conditions except immediately after construction



# Improving the Foundation Layers for Concrete Pavements

Authors: David J. White, Pavana K. R. Vennapusa, Bora Cetin

TPF-5(183) – California, Iowa, Michigan, Pennsylvania, Wisconsin

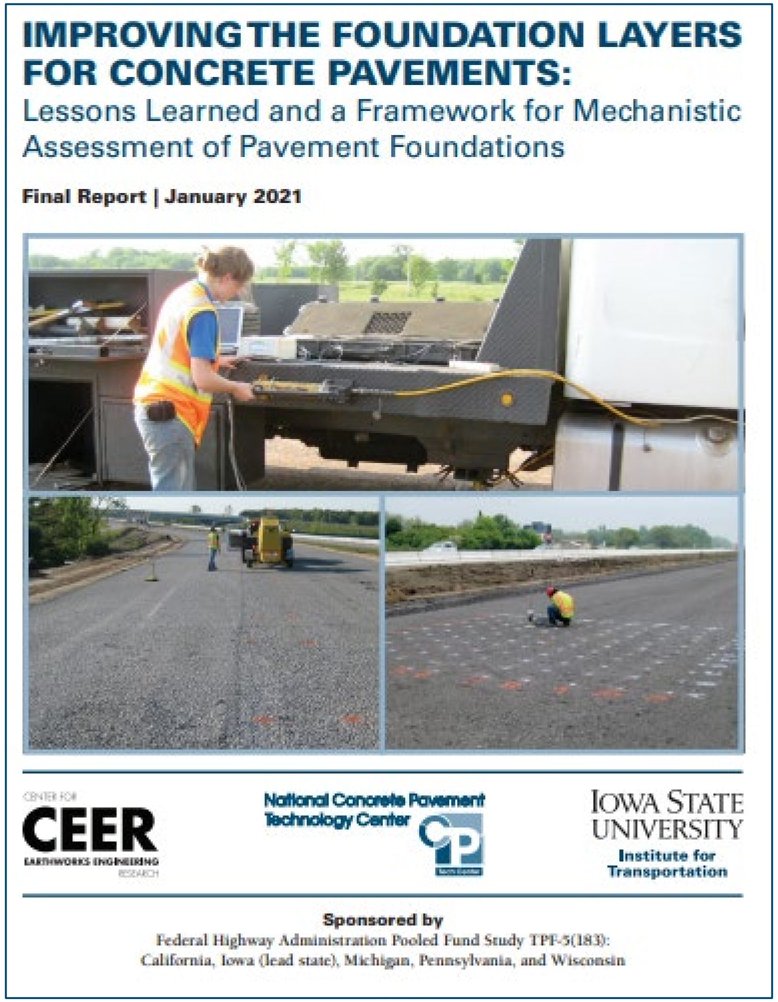
Chapter 1 – Objectives, Summary of lessons learned, Addressing non-uniformity, New framework for assessment

Chapter 2 – Lessons learned from field

Chapter 3 – Mechanistic characteristics of pavement foundation layers

Chapter 4 – Mechanistic pavement foundation specification

Chapter 5 – Conclusion and recommendations



IMPROVING THE FOUNDATION LAYERS FOR CONCRETE PAVEMENTS:
Lessons Learned and a Framework for Mechanistic Assessment of Pavement Foundations

Final Report | January 2021

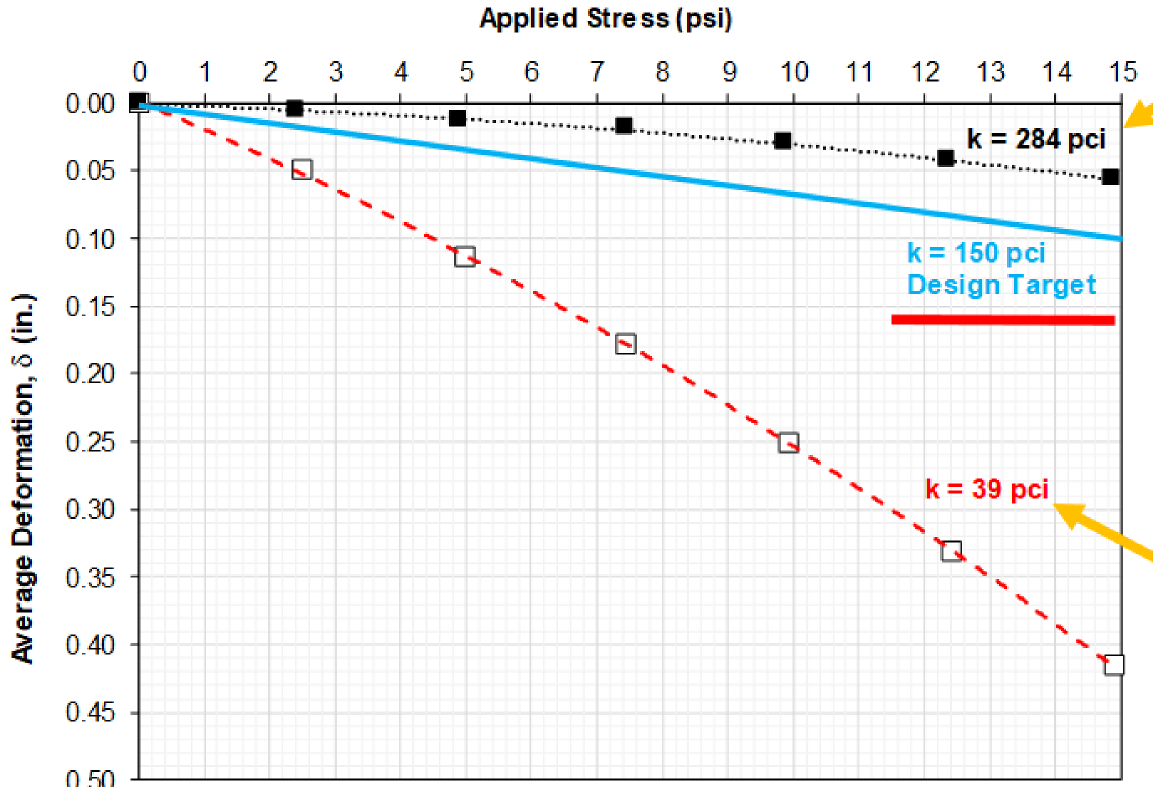
Iowa State University Institute for Transportation

Sponsored by
Federal Highway Administration Pooled Fund Study TPF-5(183):
California, Iowa (lead state), Michigan, Pennsylvania, and Wisconsin

# Improving the Foundation Layers for Concrete Pavements

<u>Current Practice Challenges:</u>

- No field verification of engineering parameters (used in foundation layer mechanistic design) is being used for quality acceptance
- While pavement design (AASHTOWare Pavement ME) has shown that pavement performance has a low sensitivity to the support provided by the foundation materials, poor support conditions (non-uniformity, permanent deformation) are well documented as affecting the long-term performance of pavements
- Non-uniformity exists in newly constructed pavement foundations
- Limited geotechnical testing (1%) used for acceptance
- Modern lab testing to determine resilient modulus does not accurately replicate field conditions




Stress vs. Deformation I-80 Polk County Iowa (12" subbase over subgrade)

# Improving the Foundation Layers for Concrete Pavements

Current Practice Challenges:

- Loss of support (foundation layer irreversible plastic deformation) can significantly decrease pavement fatigue life
- More frost heave and thaw testing needed to characterize complex foundation geomaterials, especially stabilized materials.
- Impact of wetting and drying cycles on geomaterials should be evaluated and characterized in terms of volume, stiffness and strength
- Soil water characteristics curves (SWCCs) important if using AASHTOWare Pavement ME (SWCCs have direct impact on post-construction variations in resilient moduli)
- Current practice for selecting design input parameters for pavement foundation materials is largely emperical

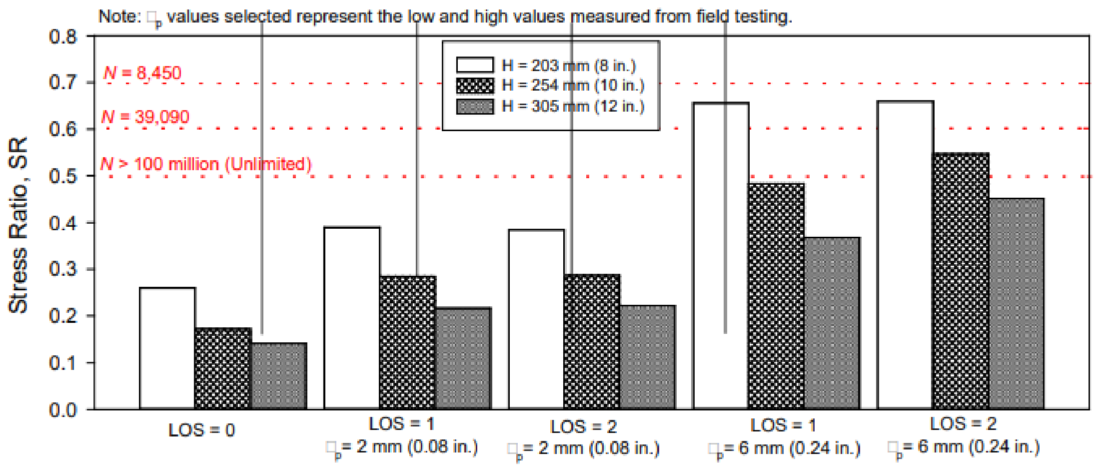



**Figure 21. Influence of LOS and magnitude of gap on SR values for LOS for different pavement thickness cases**

# Improving the Foundation Layers for Concrete Pavements

Ideal Foundation Layer for long-life concrete pavements:

- Uniform support
- Balance between excessive softness and stiffness
- Adequate drainage
- No plastic (permanent) deformation
- Use of sustainable methods and materials

- From state surveys, current specs for foundation layers are a combination of construction method requirements and end-result requirements – these serve a practical function but limit advancement in terms of pavement foundation improvement

I-94 St. Clair and Macomb Counties, Michigan, woven geotextile separator on subgrade

# Improving the Foundation Layers for Concrete Pavements

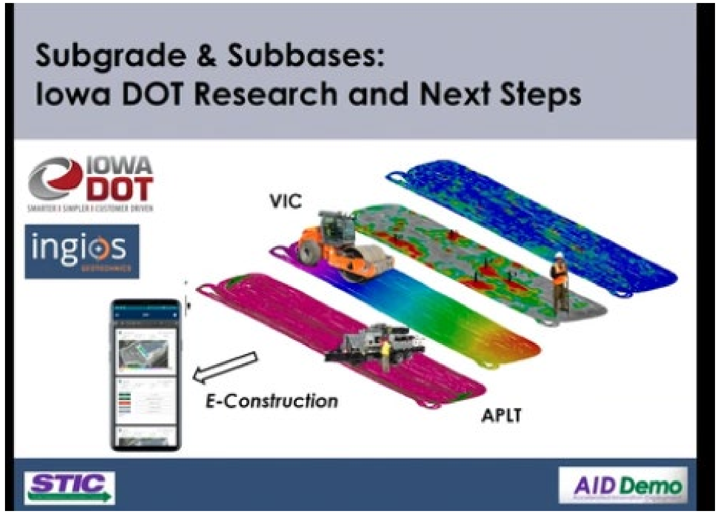
This report proposes a performance-based specification approach that specifies the support conditions provided by the pavement foundation layer in terms of pavement designer's requirements and includes a new requirement for uniformity (coefficient of variation of resilient modulus)

Performance-based construction specification key features:

- Measurement technologies that provide near 100% coverage
- Acceptance and verification testing procedures that measure performance-related parameters that are relevant to the mechanistic design inputs
- Protocols for establishing target values for acceptance based on design
- Quality statements that require achievement of special uniformity
- Protocols for data analysis and reporting that ensures the construction process is field-controlled in an efficient manner

# Iowa DOT Research

Iowa concrete Lunch and Learn Series:
https://cptechcenter.org/concrete-lunch-and-learn/
Subgrade and Subbases: Iowa DOT Research and Next Steps
Melissa Serio, Earthwork Field Engineer, Iowa DOT



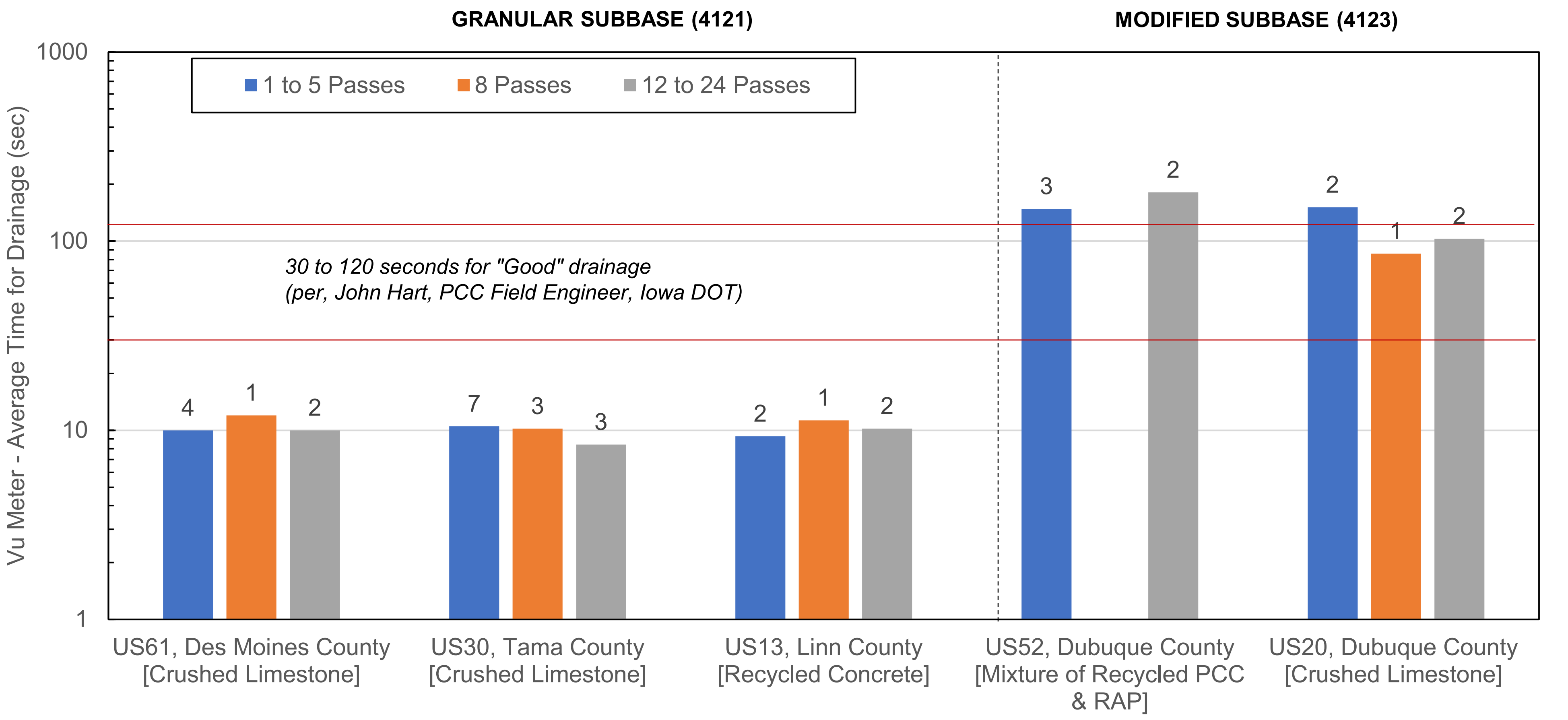
# Roller Mapping of Modulus

# How does current compaction specification on Granular Subbase affect Drainage Vs. Stiffness

US61, Des Moines County (06/16/2020) Granular Subbase – Crushed Limestone

# Drainage Summary from Multiple Project Sites

*Number on each bar represents the number of tests*



# Thank You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Please contact us with any questions

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