NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Pavement Foundations with Conventional and Unconventional Stabilizers

February 28, 2023

2:30 – 4:00 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING
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Purpose Statement

This webinar will explore examples and case studies using conventional and nonconventional additives. Presenters will discuss non-proprietary additives that are commonly used and alternative proprietary additives that are garnering new interest. Presenters will also share compaction methods to improve pavement foundation layers.

Learning Objectives

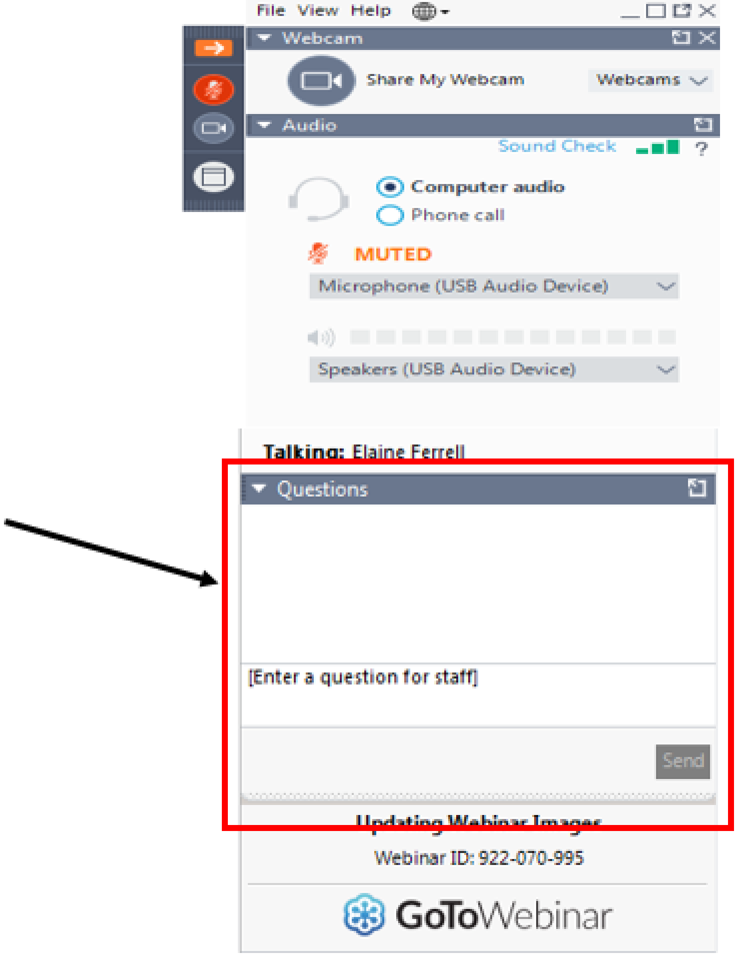
At the end of this webinar, you will be able to:

(1) Determine the impact of different stabilizers on geomechanical properties of pavement foundation geomaterials

(2) Apply different stabilization techniques for pavement foundation improvement

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



● Computer audio
○ Phone call

MUTED

Microphone (USB Audio Device)

Speakers (USB Audio Device)

Talking: Elaine Ferrell

[Enter a question for staff]

Updating Webinar Images

Webinar ID: 922-070-995

Today's presenters

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ILLINOIS

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Minnesota Department of Transportation

DEPARTMENT OF TRANSPORTATION

Transportation Research Board Webinar

Pavement Foundations with Conventional and Unconventional Stabilizers

Prof. Erol Tutumluer Ph.D. - *UIUC*
Prof. Anand Puppala PhD, PE, D-GE, F-ASCE and F-ICE - *TAMU*
John Siekmeier P.E. - *MnDOT*
Bora Cetin Ph.D. – *MSU*

TRB Committee Standing Committees on Stabilization of Geomaterials and Recycled Materials (AKG90) & on Soil and Rock Properties and Site Characterization (AKG20)
Tuesday, February 28, 2023

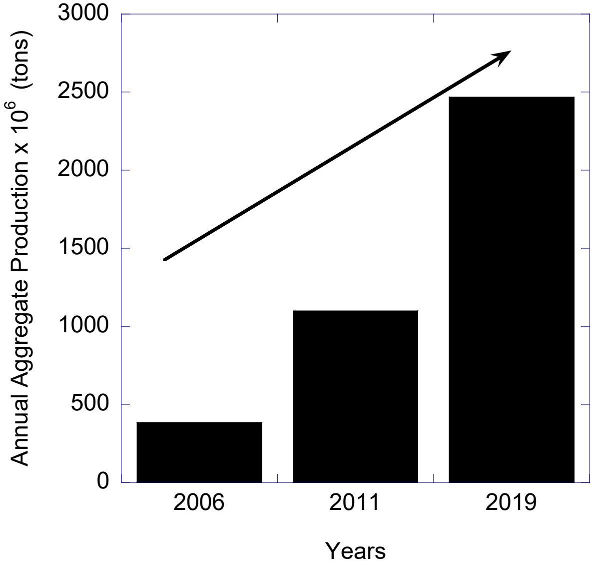
OUTLINE

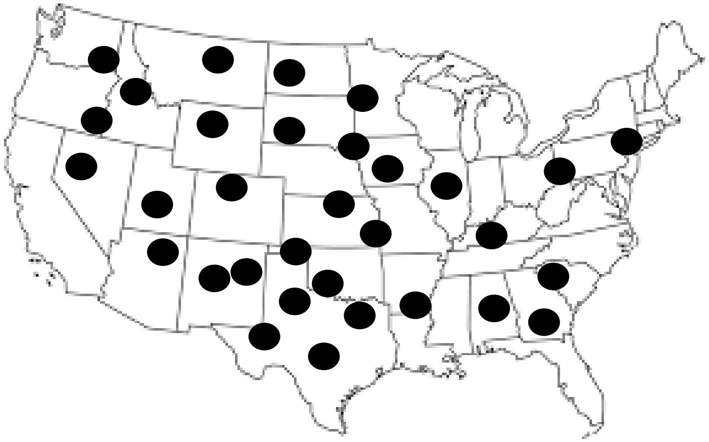
Introduction

Presentations

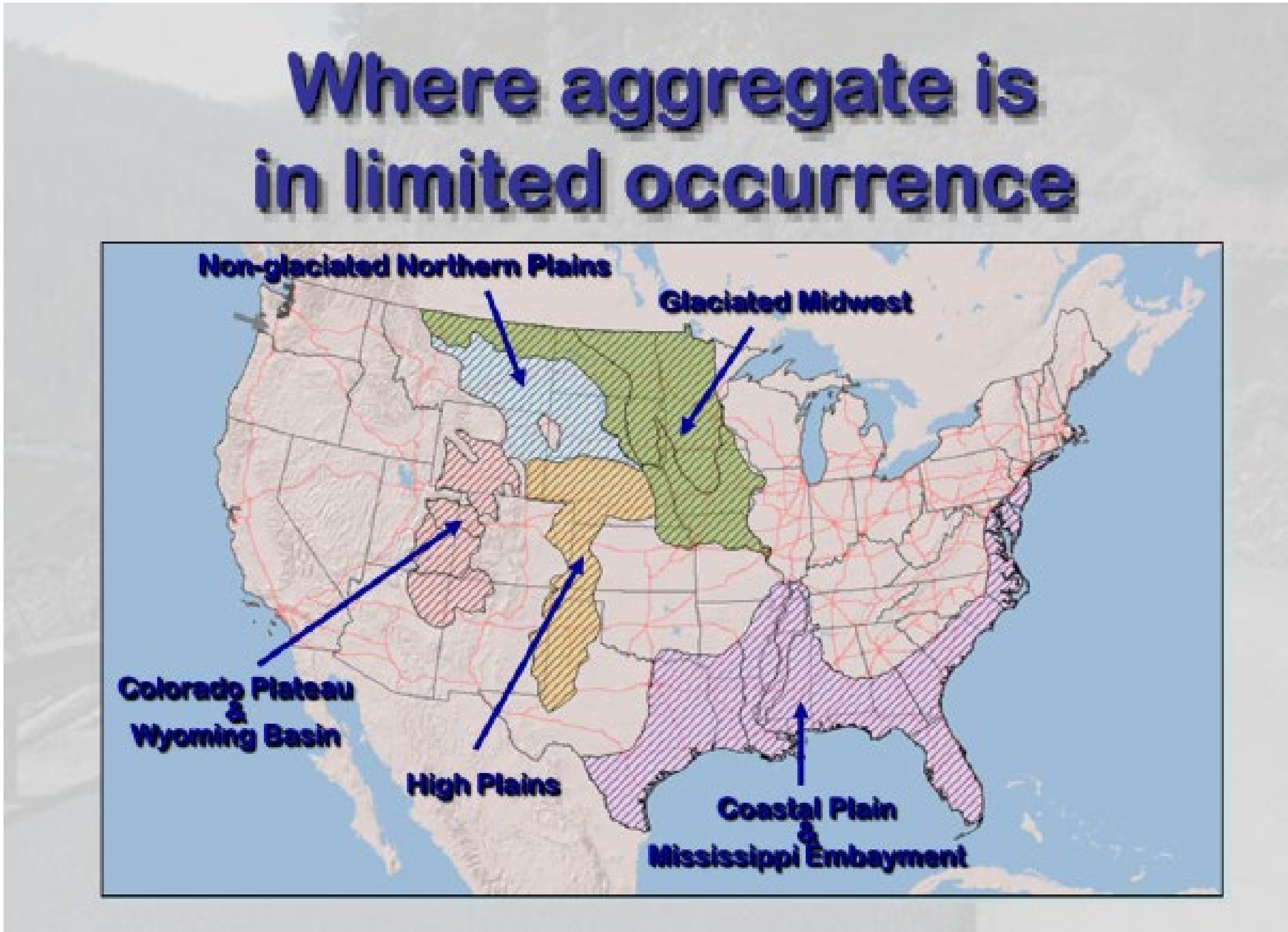
Panel Discussion

PROBLEM STATEMENT





PROBLEM STATEMENT



TYPE OF STABILIZERS

Stabilizers

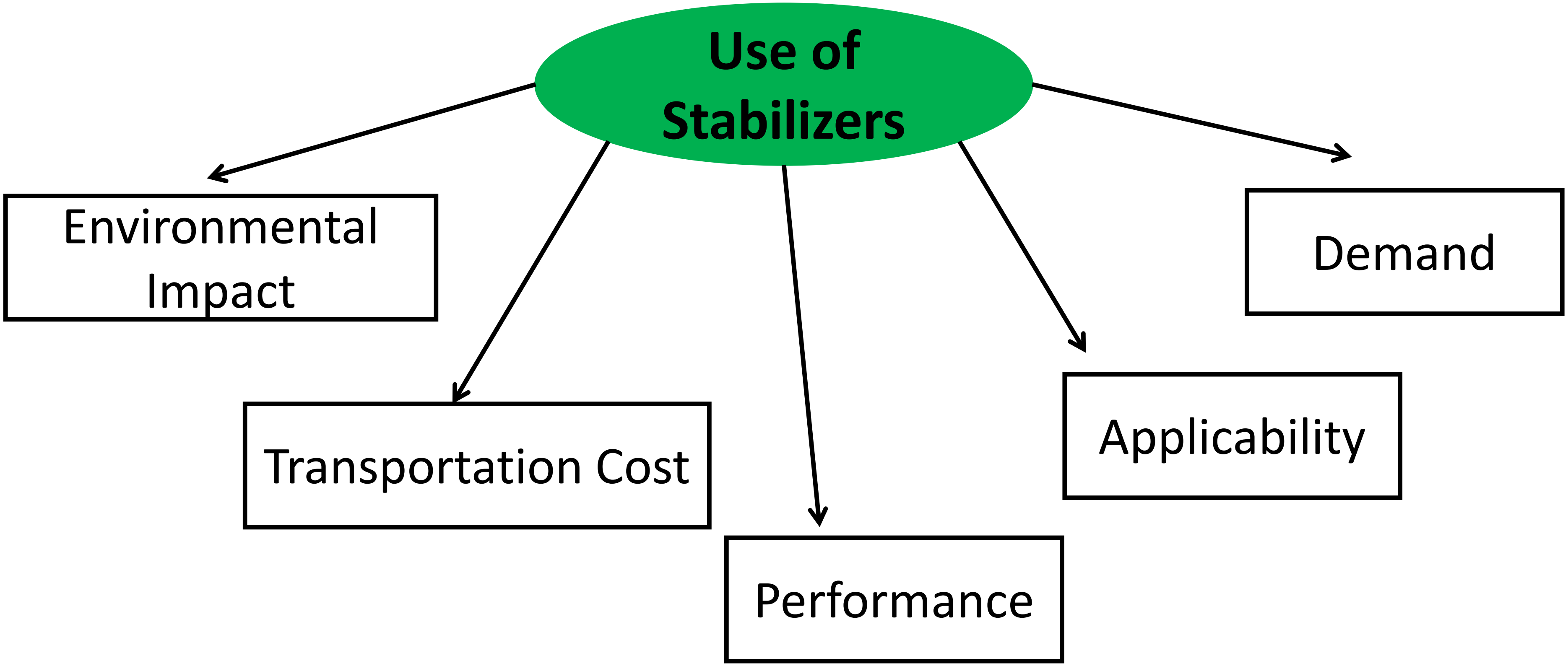
Conventional

- Cement
- Lime
- Fly Ash
- Emulsion
- Basic Chloride

Unconventional

- Geopolymers
- Quarry fines
- Liquid commercial stabilizers
- Biofuel byproducts
- Biocementation
- Intelligent Compaction

CHALLENGES TO USE STABILIZERS



Use of Stabilizers

Environmental Impact

Transportation Cost

Performance

Applicability

Demand

PRESENTATIONS

Speakers	Title of the Presentation
Erol Tutumluer, UIUC	Sustainable Pavement Foundations with Chemically Stabilized Quarry Byproducts
Anand Puppala, TAMU	Novel Stabilization Methods for Sulfate Soils Using Laboratory and Field Studies
John Siekmeier, MnDOT	Improving stabilized full depth reclamation with intelligent compaction
Q & A Session	Discussion

Sustainable Pavement Foundations with Chemically Stabilized Quarry By-products

TRB Webinar: Pavement Foundations with Conventional and Unconventional Stabilizers – February 28, 2023

Erol Tutumluer, PI, Abel Bliss Professor, UIUC

tutumlue@Illinois.edu

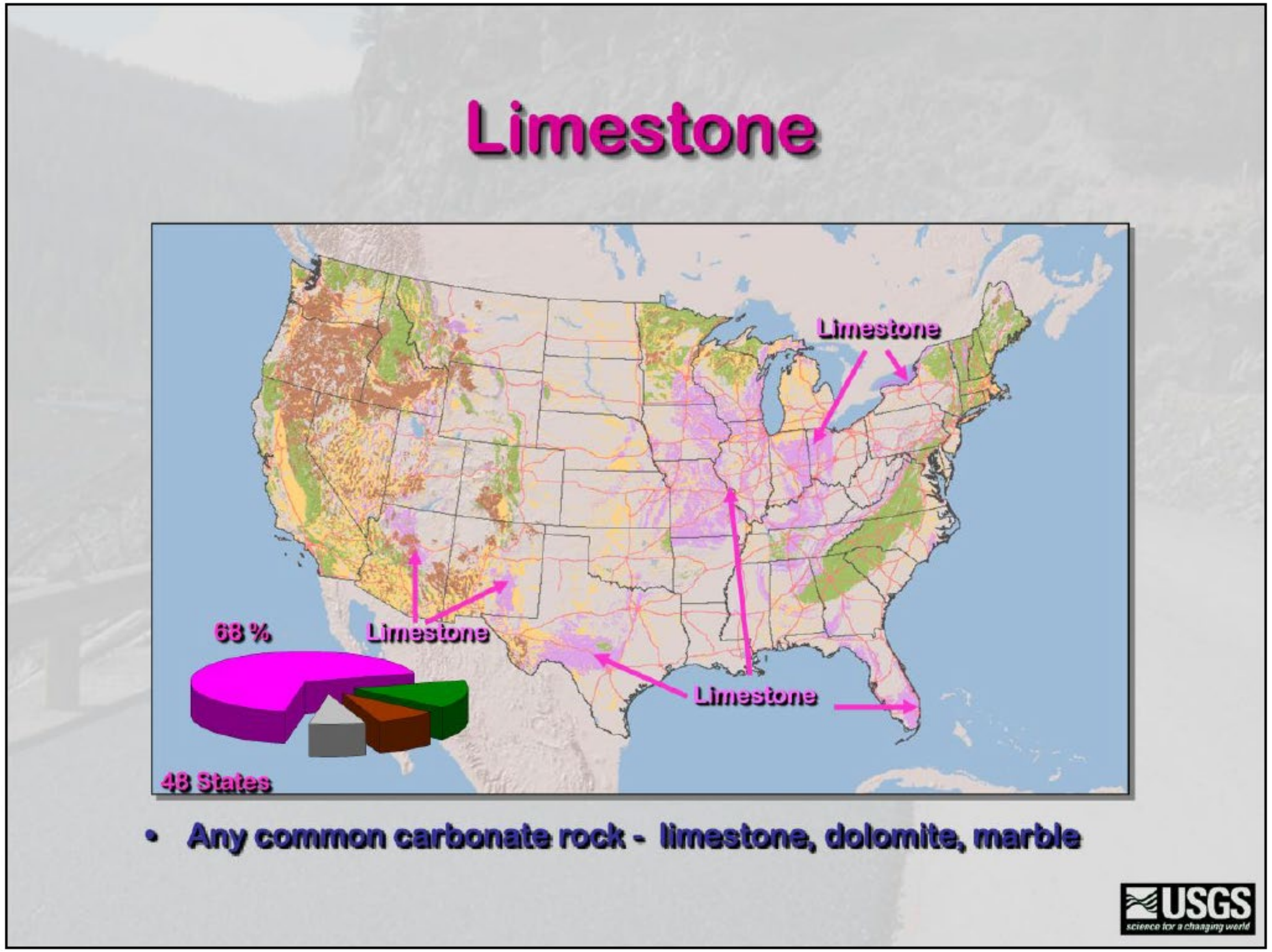
Hasan Ozer, co-PI, now Assistant Professor, ASU

Issam Qamhia, Senior Research Scientist, UIUC

University of Illinois Urbana – Champaign

Courtesy of Brian Rice

Introduction: Carbonates (Limestone / Dolomite)



Limestone

- Any common carbonate rock - limestone, dolomite, marble

Limestone consists of carbonate rocks including limestone, dolomite, and marble

- About 68 percent of crushed stone production (Willett, 2008)
- 39 percent of the total aggregate production
- Widely distributed throughout the US
- Produced in every state except North Dakota and Delaware
- Their suitability for crushed stone varies greatly from location to location

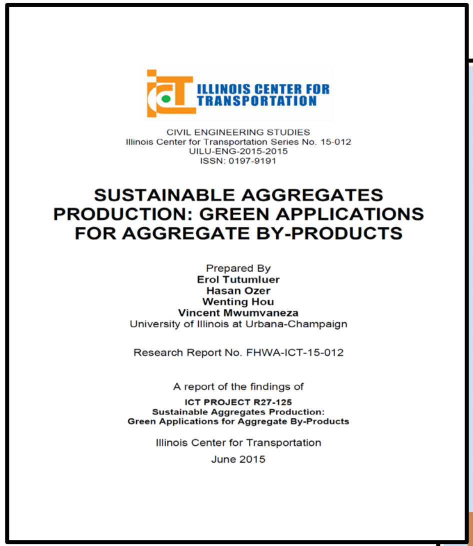
Aggregate Resource Availability in the Conterminous United States, Including Suggestions for Addressing Shortages, Quality, and Environmental Concerns

By William H. Langer

Open-File Report 2011–1119

Background: ICT R27-125, 168 & SP38 Projects

- **Previous field evaluation studies proved sustainable applications of pavement foundation layers constructed with Quarry By-products (QB)**
- **QB are found abundantly all over the limestone and dolomite crushed rock extraction quarry operation in Illinois. Excessive QB produced each year exceeds about 1 million tons (ICT R27-125).**



CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 15-012
UILU-ENG-2015-2015
ISSN: 0197-9191

SUSTAINABLE AGGREGATES PRODUCTION: GREEN APPLICATIONS FOR AGGREGATE BY-PRODUCTS

Prepared By
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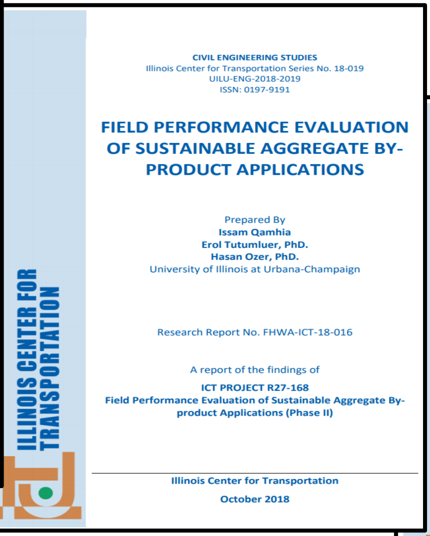
Hasan Ozer
Wenting Hou
Vincent Mwumvaneza
University of Illinois at Urbana-Champaign

Research Report No. FHWA-ICT-15-012

A report of the findings of
ICT PROJECT R27-125
Sustainable Aggregates Production:
Green Applications for Aggregate By-Products

Illinois Center for Transportation
June 2015

ICT R27-125



CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 18-019
UILU-ENG-2018-2019
ISSN: 0197-9191

FIELD PERFORMANCE EVALUATION OF SUSTAINABLE AGGREGATE BY-PRODUCT APPLICATIONS

Prepared By
Issam Qamhia
Erol Tutumluer, PhD.
Hasan Ozer, PhD.
University of Illinois at Urbana-Champaign

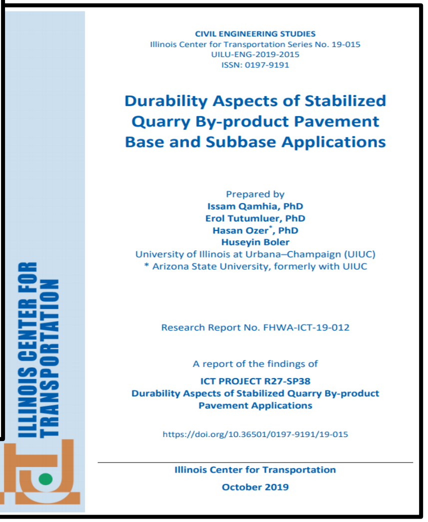
Research Report No. FHWA-ICT-18-016

A report of the findings of
ICT PROJECT R27-168
Field Performance Evaluation of Sustainable Aggregate By-product Applications (Phase II)

Illinois Center for Transportation
October 2018

ICT R27-168

ICT R27-SP38



CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 19-015
UILU-ENG-2019-2015
ISSN: 0197-9191

Durability Aspects of Stabilized Quarry By-product Pavement Base and Subbase Applications

Prepared by
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Huseyin Boler
University of Illinois at Urbana–Champaign (UIUC)
* Arizona State University, formerly with UIUC

Research Report No. FHWA-ICT-19-012

A report of the findings of
ICT PROJECT R27-SP38
Durability Aspects of Stabilized Quarry By-product Pavement Applications

https://doi.org/10.36501/0197-9191/19-015

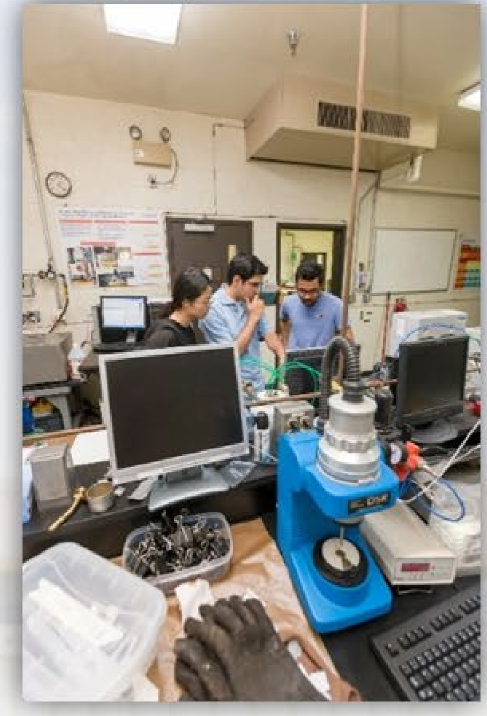
Illinois Center for Transportation
October 2019

ICT Publications:

https://ict.illinois.edu/research/publications

Advanced Transportation Research and Engineering Laboratory (ATREL)

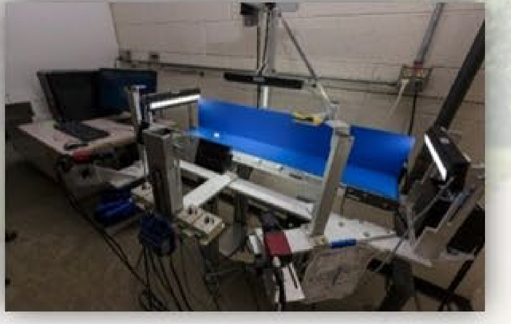
Lab Environment
(testing and modeling)



Servo-hydraulic
Test Equipment

Mobile Accelerated
Loading Facility (ATLAS)

Novel Equipment



ICT R27-125: Sustainable Aggregates Production

Investigate and develop methods to utilize product fractions (*Quarry by-products or QB*) currently being wasted (approximately 8% of mined & less than ¼ in.) to lower overall costs to IDOT and extend the use of natural aggregate resources

Characterize quarry by-products (QB) for sustainable production and green applications in pavements

Modify existing specifications or develop new specifications/mixes to *utilize "higher fines materials"*

PHASE I: STUDY OF ILLINOIS AGGREGATE BY-PRODUCTS

PHASE II: GREEN APPLICATIONS FOR AGGREGATE BY-PRODUCTS

Blasting

Crushing

Screening

ICT R27-125: Quarry By-products (QB)

- In 2020, 1.35 billion metric tons of crushed stone were produced from 3,700 operating quarries in 50 States (USGS, 2019)
- 175 million metric tons of quarry by-products (QB) are generated in over 3000 quarries in the United States each year (NCHRP Synthesis 435, Volume 4)
- Produced in quarry processes

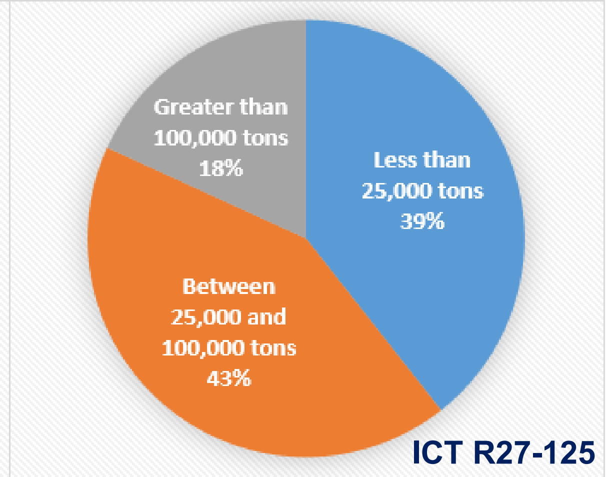
  Blasting, crushing, and screening

- Typically, less than ¼ in. (6 mm) in size
  - Coarse, medium and fine sand particles and a clay/silt fraction
- Stockpiling and disposal of QB is a major problem facing the aggregate industry

Excessive QB produced in Illinois each year exceeds ~1 million tons (ICT R27-125)

Courtesy of Brian Rice

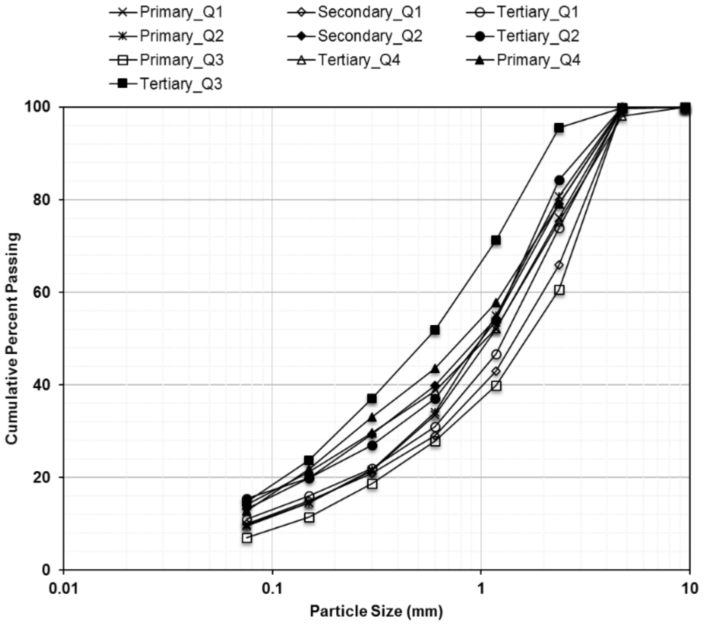
Annual tonnage of QB in ***excess*** category?
(stockpiled or not being sold for any application)



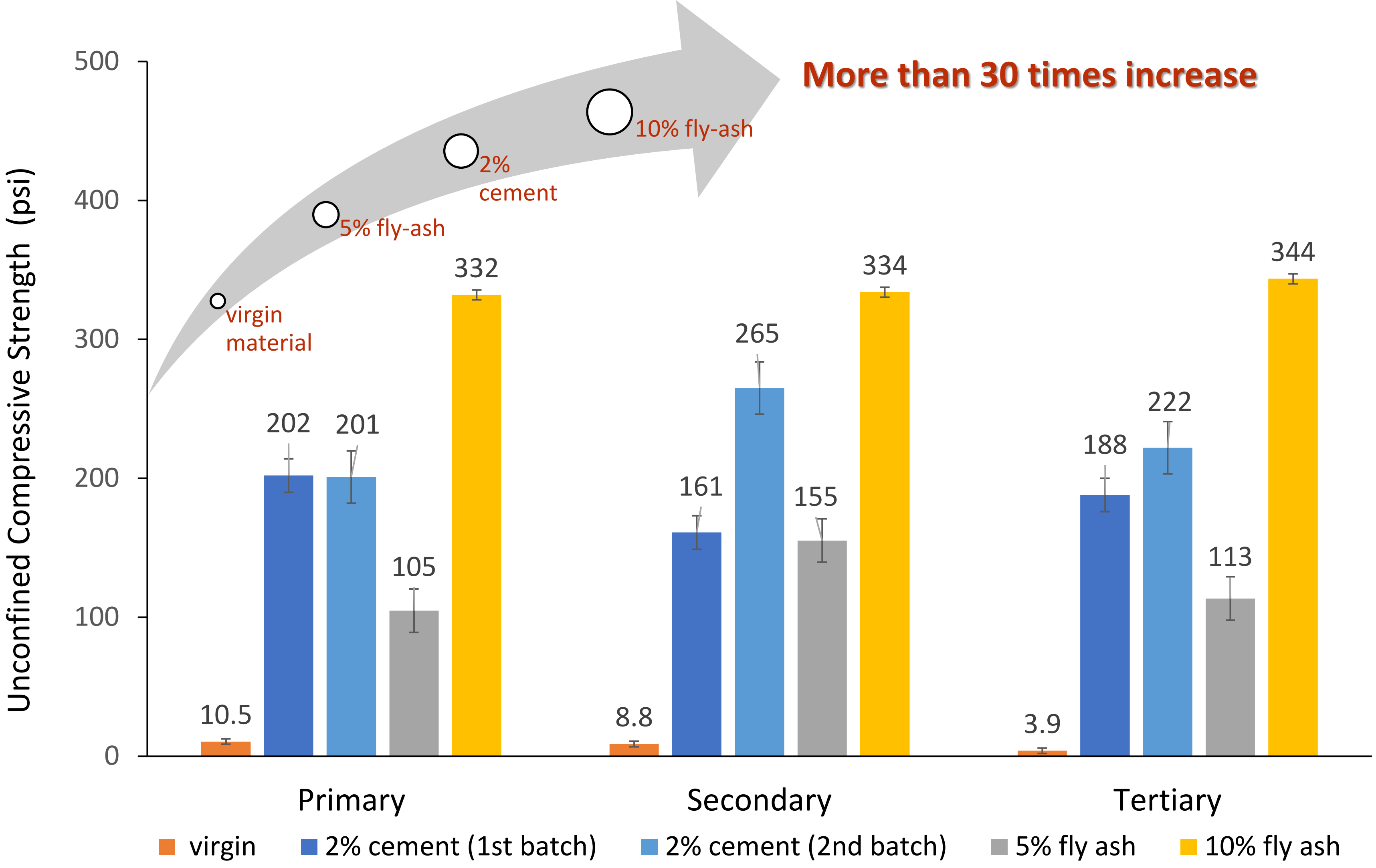
ICT R27-125

ICT R27-125: Quarry By-products (QB)

Typical QB Gradation



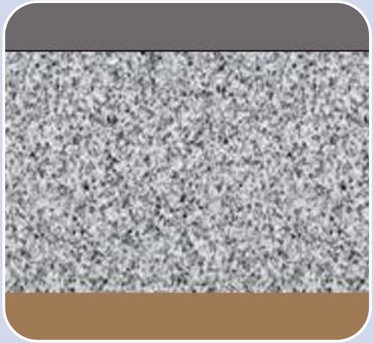
(Well-graded/ poorly-graded) silty sand



ICT R27-125: Sustainable QB Applications

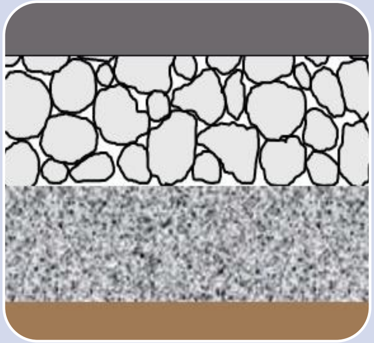
High Fine (QB) Aggregate for Subgrade Remediation

- IDOT CA06 materials with higher fines contents, up to 15%, by utilizing QB (Plastic vs NP fines)



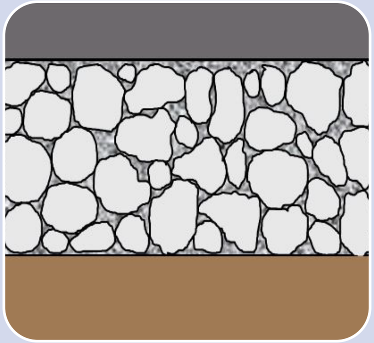
Stabilized Base with QB

- Utilize QB as aggregate base, stabilized with cement or Type C Fly ash, and consider mixing with recycled materials



Stabilized Subbase with QB

- Inverted Pavement
- Better compaction of aggregate placed over stabilized base layer



Aggregate Subgrade + QB

- Aggregate subgrade materials on very weak (CBR = 1) subgrades blended with QB
- Fill gaps/voids between large stones

ICT R27-168

CIVIL ENGINEERING STUDIES
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ISSN: 0197-9191

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Research Report No. FHWA-ICT-18-016

A report of the findings of

ICT PROJECT R27-168
Field Performance Evaluation of Sustainable Aggregate By-product Applications (Phase II)

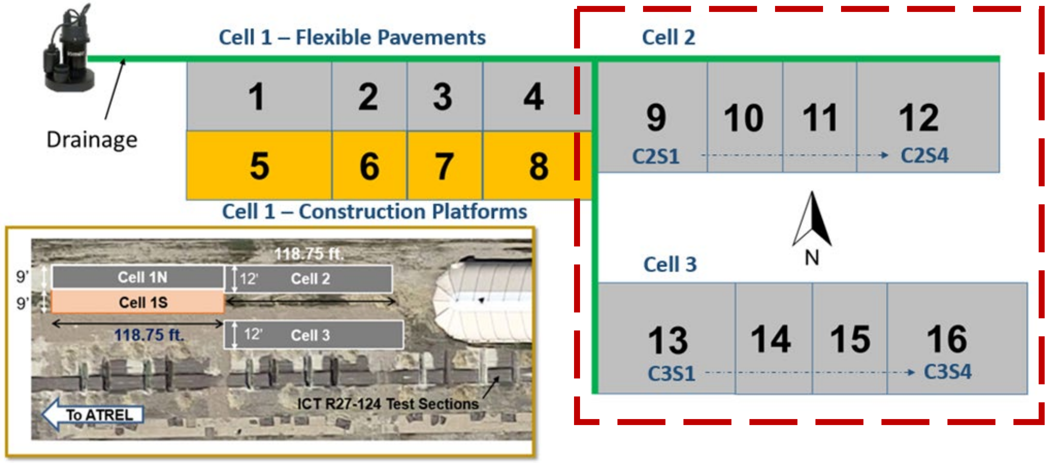
Illinois Center for Transportation

October 2018

ILLINOIS CENTER FOR TRANSPORTATION

ICT R27-168: Field Performance of QB Materials

- Evaluate QB for pavement base, subbase, and aggregate subgrade layers
  - Four Test Cells (1N, 1S, 2 and 3), each with 4 sections
  - Four Construction Platforms
  - Twelve HMA-paved Sections
    - Four with Unbound QB Applications
    - Seven with Stabilized QB (Base or Subbase)
    - One Control (Conventional) Section



Accelerated Pavement Testing (APT)

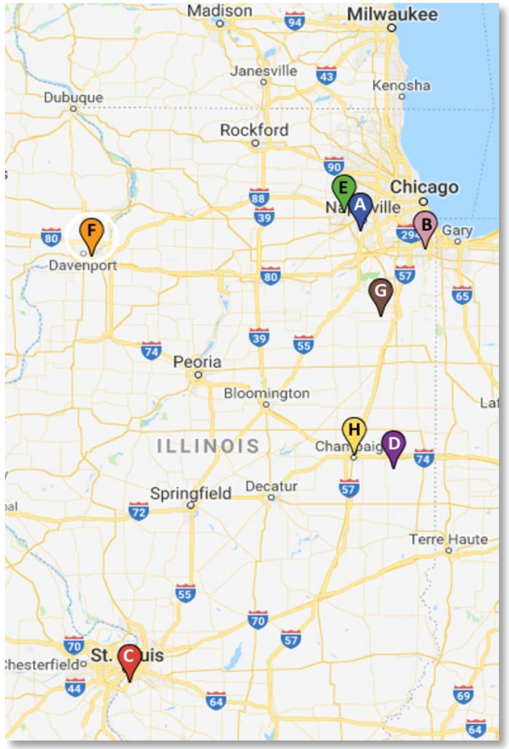
Wide-base tire (455/55R22.5) at constant speed of 5 mph

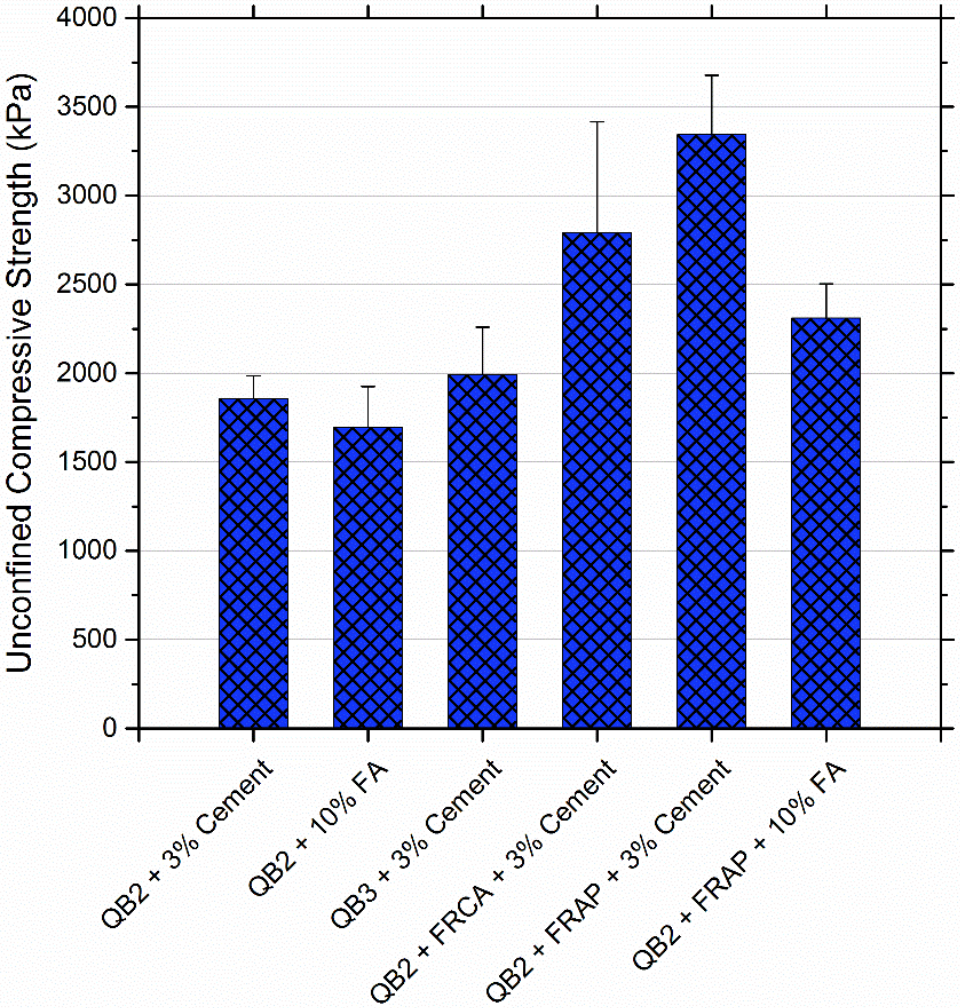
Passes	Unidirectional Load (kips)	Tire Pressure (psi)
1 – 100,000	10	110
100,001 – 135, 000	14	125

ICT R27-168: Field Performance of QB Materials

Material ID	Quarry Location
QB1	(A) Bolingbrook
QB2	(B) Thornton
QB3	(C) Dupo
CA06_R	(D) Fairmont
CA06_15NPF	(E) Aurora
CA06_15PF	(F) Milan
PCR (CS02)	(G) Lisbon
FRAP	(H) Urbana
FRCA	(H) Urbana

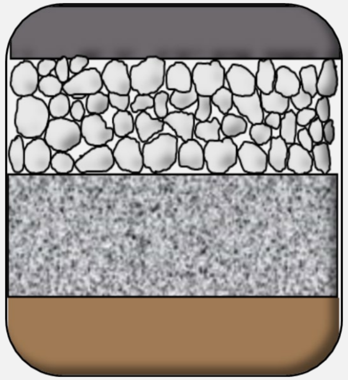
QB1 and QB 3 Limestone
QB2 Dolomite





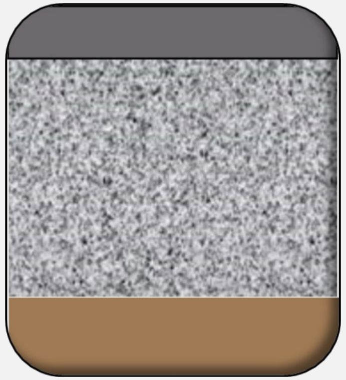
ICT R27-168: Field Performance of QB Materials

Base/Subbase Applications



Stabilized QB Subbase

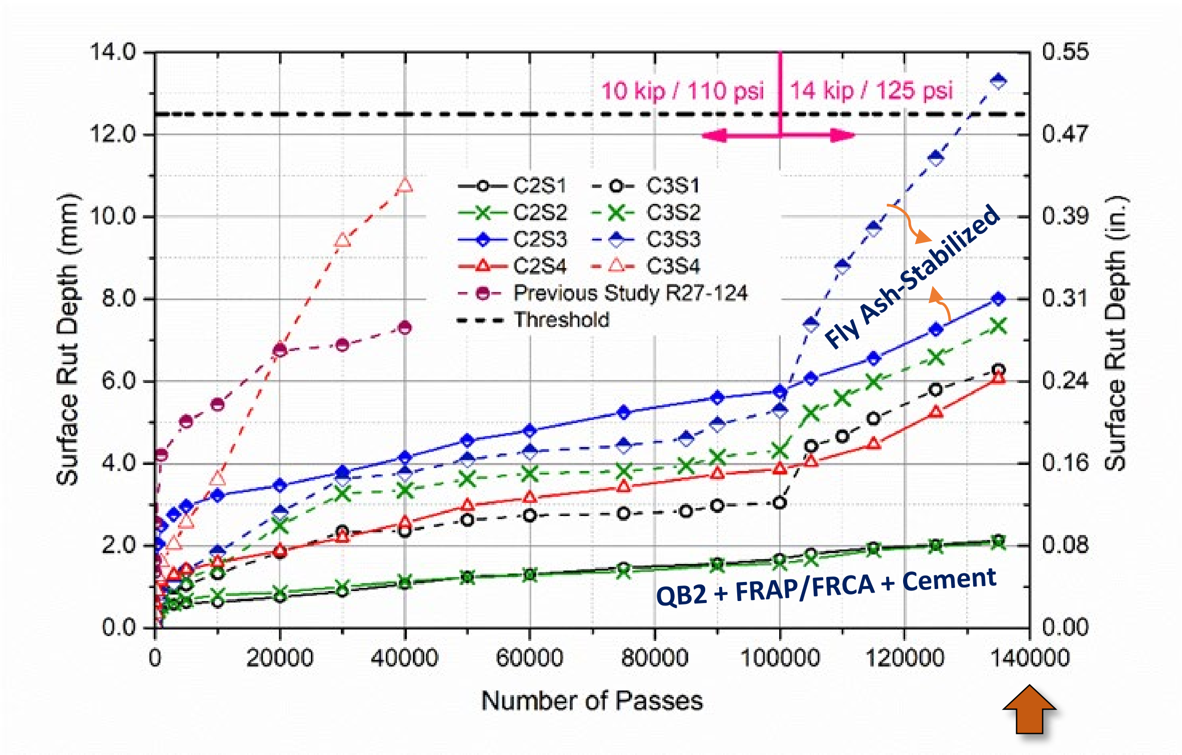
- **Inverted Pavements**
- Stabilized with 3% cement or 10% Type C Fly ash
- Better compaction of aggregate base



Stabilized Base with QB

- Stabilized with 3% cement or 10% Fly ash
- 100% QB Bases
- 70% QB and 30% Recycled asphalt or concrete bases

Section	Description	Section	Description
C2S1	QB2 + FRAP + Cement	C2S2	QB2 + FRCA + Cement
C2S3	QB2 + FRAP + Fly Ash	C2S4	QB2 + Cement
C3S1	QB3+ Cement	C3S2	QB2 + Cement
C3S3	QB2 + Fly Ash	C2S4	Control



ICT R27-SP38: Durability Aspects of QB Materials

ICT R27-SP38

CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 19-015
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Durability Aspects of Stabilized Quarry By-product Pavement Base and Subbase Applications

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Illinois Center for Transportation
October 2019

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February 2019

C2S3
Ice Inside Trench

C2S1
Eroded Subgrade, intact base

C3S2
Eroded Subgrade, intact subbase

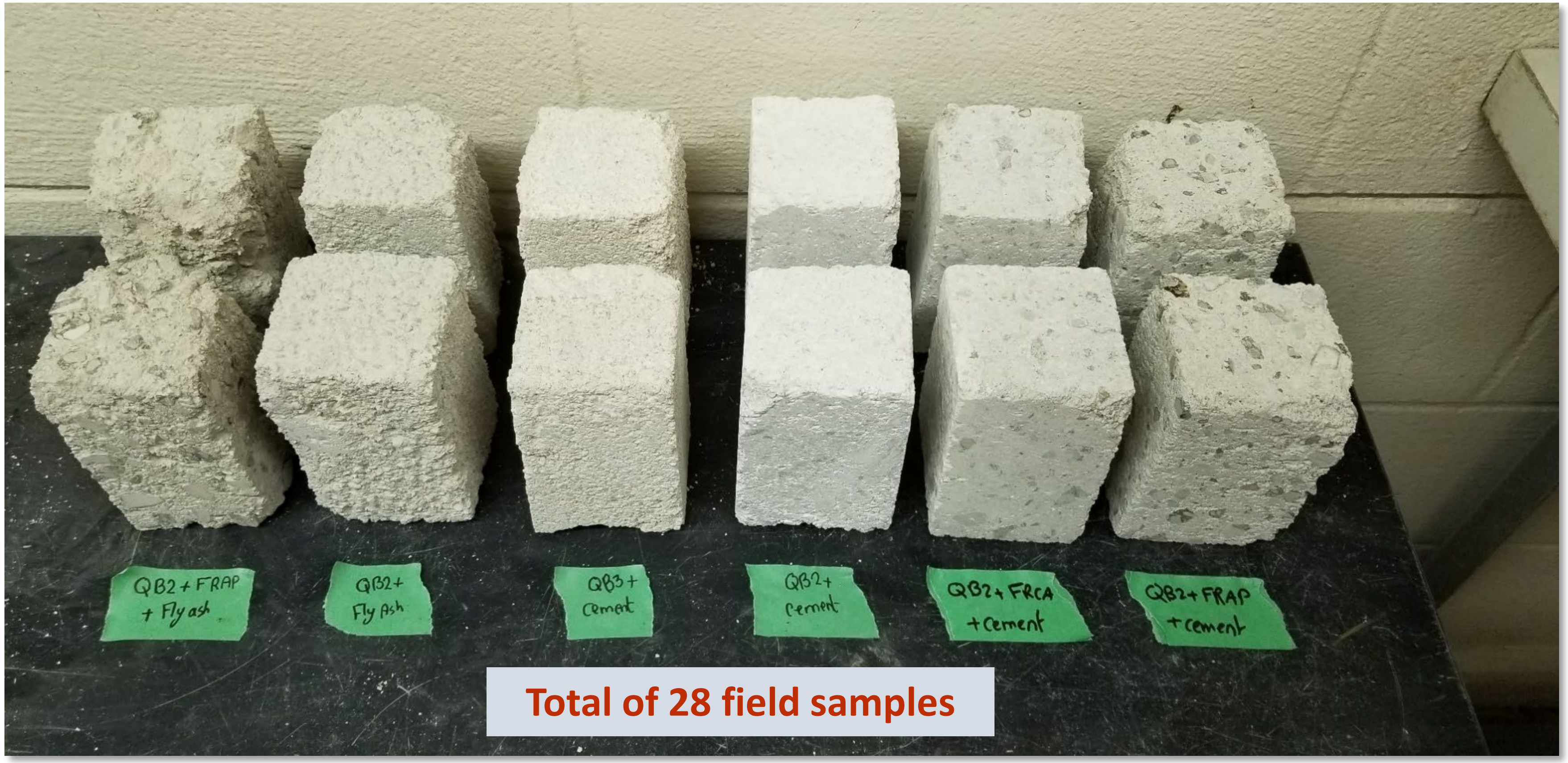
ICT R27-SP38: Durability Aspects of QB Materials

ICT R27-SP38: Durability Aspects of QB Materials

Saw Cutting
Equipment at ATREL

A face cut using the saw cutting equipment at ATREL

ICT R27-SP38: Durability Aspects of QB Materials



Total of 28 field samples

Field samples were cut into prisms (cuboids) with L = W = 2.8” , H = 4.6” (approximately)

The size and shape of the samples was governed by the size of the chunks collected from the field

ICT R27-SP38: Durability Aspects of QB Materials

Sample Preparation Using a Split Mold

Stripping of FRCA Aggregates > ¾ in.

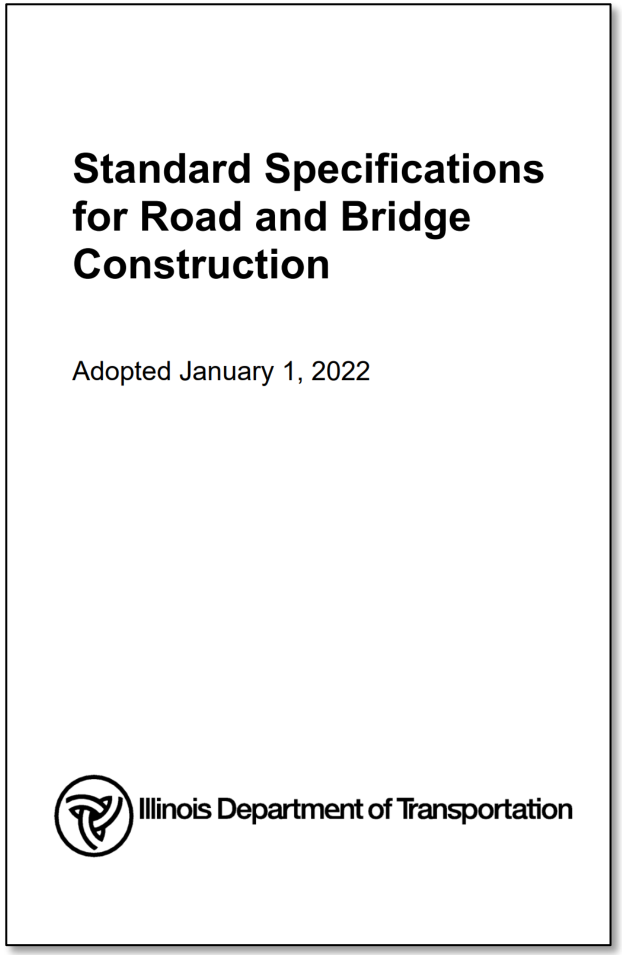
ICT R27-SP38: Durability Aspects of QB Materials

- Laboratory testing for freeze-thaw and wet-dry durability and UCS
- IDOT CBM standard test procedures were closely followed
  - AASHTO T 135 for wet-dry
  - AASHTO T 136 for freeze-thaw
- Durability tests conducted on the **field collected materials** and for **laboratory fabricated specimens**
- 7 mixes x 2 (replicate) specimens x 2 sources (field & lab)

28 specimens for Freeze-Thaw and 28 specimens for Wet-Dry

ICT R27-SP38: Durability Aspects of QB Materials

- IDOT Standard Specifications for Road and Bridge Construction (2016, latest now 2022)
- IDOT mix designs specify a **cement content** such that:
  - Loss in weight (mass) < 10% after 12 cycles of wetting and drying / freezing and thawing
  - Minimum 7-day compressive strength of 500 psi
- Testing for freeze-thaw and wet-dry
  - AASHTO T 135: wet-dry testing
  - AASHTO T 136: freeze-thaw testing

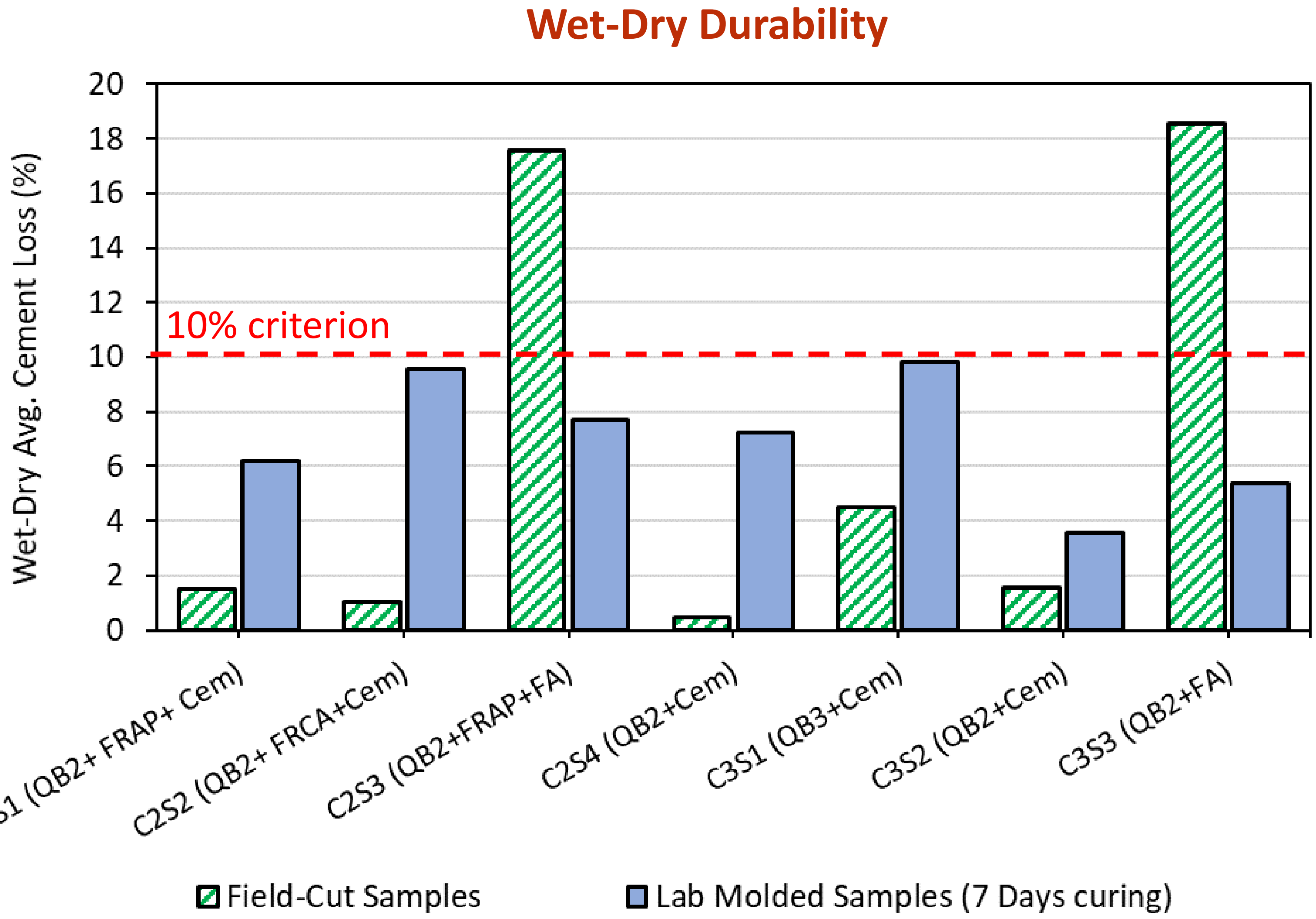


Standard Specifications for Road and Bridge Construction

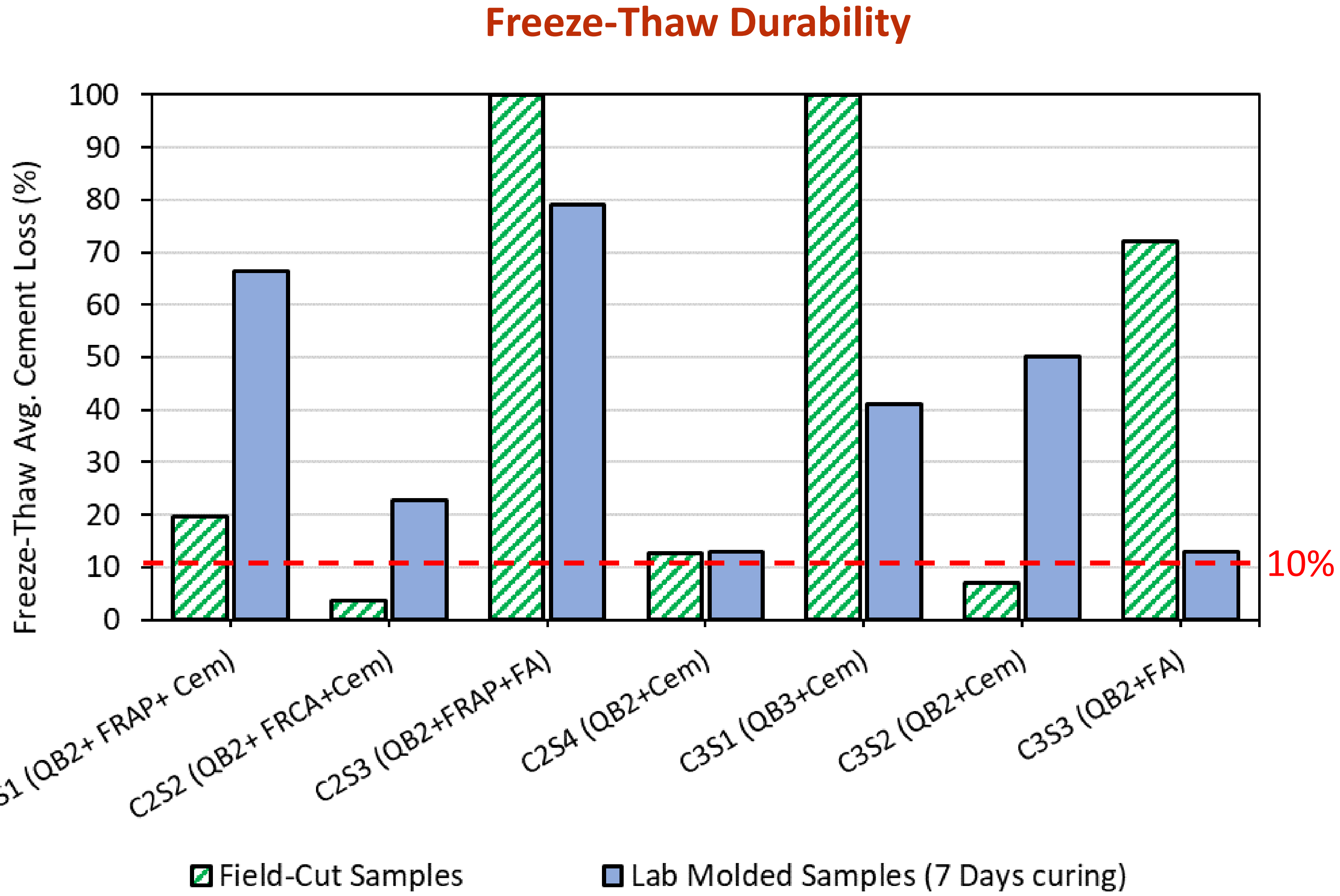
Adopted January 1, 2022

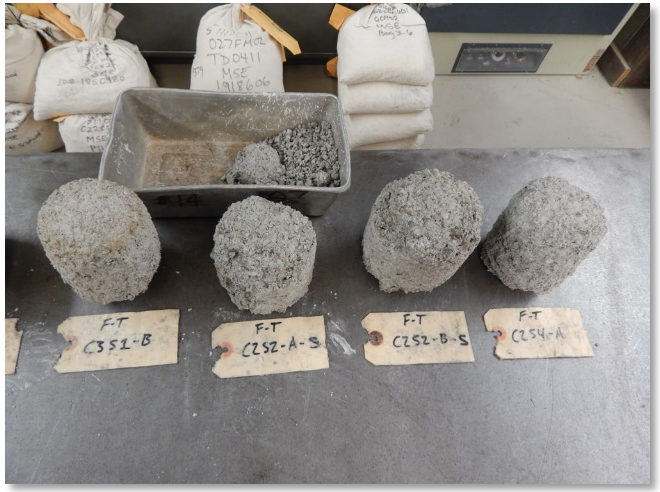
Illinois Department of Transportation

ICT R27-SP38: Comparison of Field & Molded Samples



ICT R27-SP38: Comparison of Field & Molded Samples





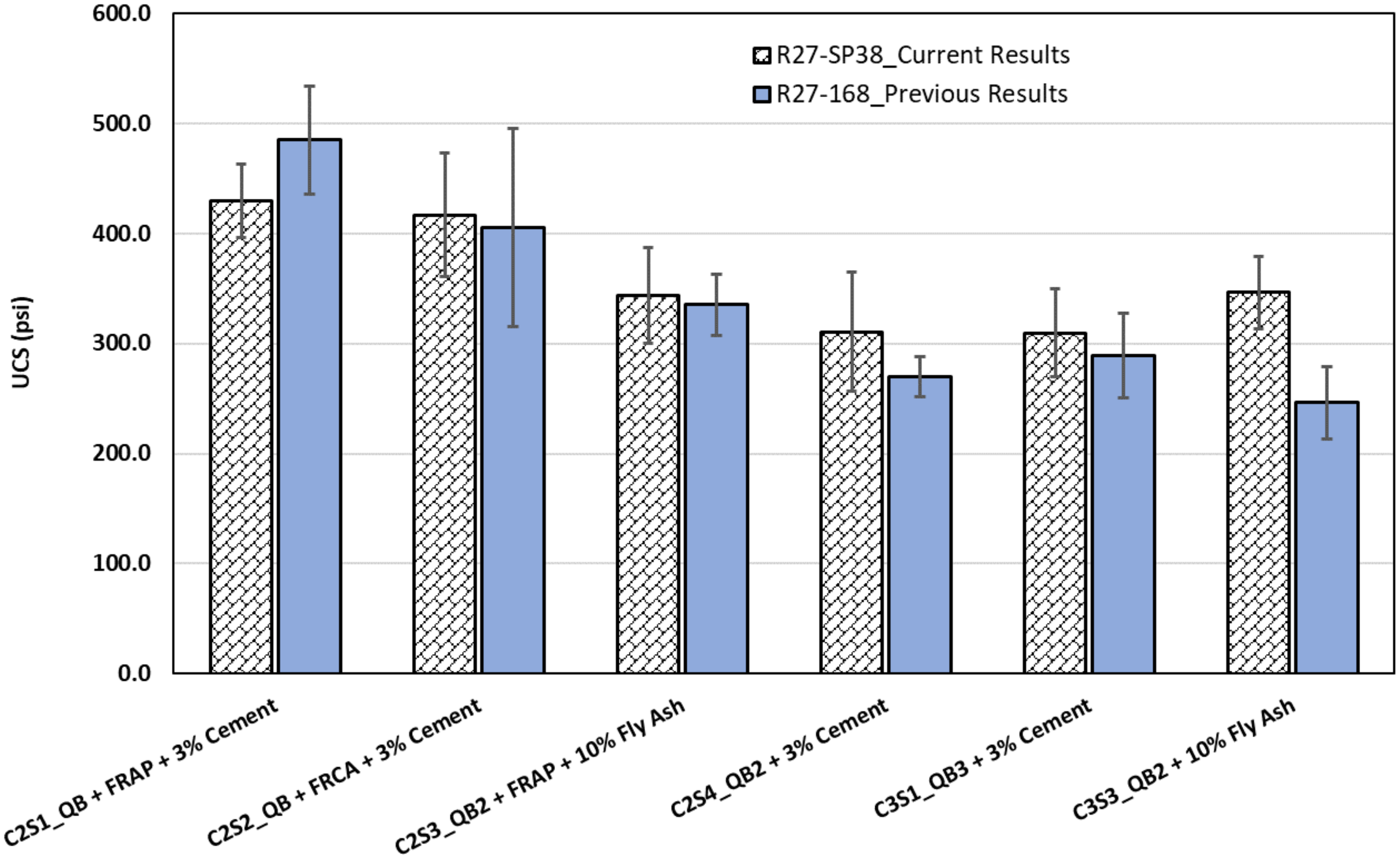
ICT R27-SP38: Unconfined Compressive Strength (UCS)

Molding of Samples (4” x 8” cylinders)

Moist Room Curing (7 days)

Capping and UCS Testing

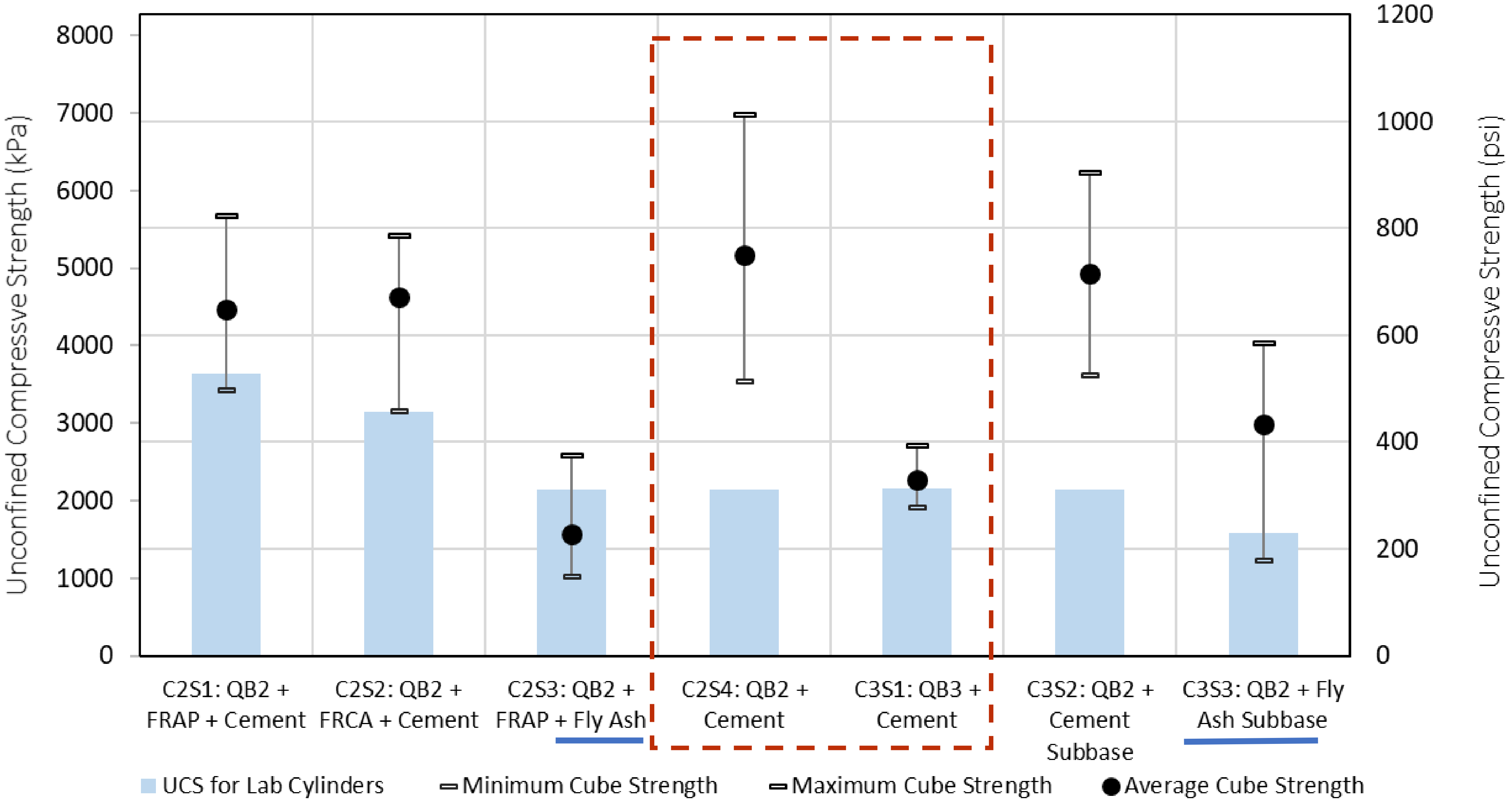
ICT R27-SP38: UCS Testing of Lab Samples



Sources of cement and fly ash might have varied between field specimens and molded samples

No significant difference in UCS except for C3S3

ICT R27-SP38: UCS Testing of Field Cube Samples



ICT R27-SP38: X-Ray Fluorescence Results for QB2 & QB3

- Results are based on samples collected for R27-125 project, from the same sources as QB2 and QB3 for three crushing stages

Material	Crushing Stage	Measurement by Weight (%)						
		CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	K_2O	Others
QB2 Dolomite	Primary	54.7	6.2	36.7	0.8	0.8	0.4	0.4
	Secondary	48.5	14.1	33.4	1.6	0.9	0.8	0.7
	Tertiary	50.4	11.8	34.2	1.1	0.9	0.7	0.9
QB3 Limestone	Primary	58.7	23.2	11.0	4.4	1.1	0.8	0.8
	Secondary	71.4	14.3	10.1	2.0	1.0	0.6	0.6
	Tertiary	71.4	14.8	9.5	2.2	0.8	0.6	0.7

Calcium (Ca) goes to reaction more quickly than Magnesium (Mg)

Carbonation of dolomite contributes to long term strength gain

Investigation of Dolomite Aggregate Long-Term Cementation and Its Potential Advantage for Building Roads (ICT R27-248)

Kickoff Meeting – August 15, 2022

TRP Chair: Tim Peters and Andrew Stolba

Project Investigators: Erol Tutumluer* and Nishant Garg**

Research Scientist: Issam Qamhia

Graduate Research Assistants: Taeyun Kong and Chirayu Kothari

* tutumlue@illinois.edu ** Nishantg@illinois.edu

ICT R27-248 Project: Objectives & Scope

- **Objectives:**
  - Study effects of chemical, mineralogical and physical properties of dolomitic aggregate fines on long-term performance trends of unbound and chemically-stabilized aggregate materials
  - Conduct comprehensive geological survey and review of aggregate quarry maps to characterize dolomite aggregate compositions in Illinois
  - Short- and long-term performance monitoring of samples tested for unconfined compressive strength, and samples tested after a conditioning period to trigger *precipitation-dissolution delayed reaction*

- **Methodology:**
  - Advanced material characterization tests, such as, X-Ray diffraction (XRD), X-Ray fluorescence (XRF), scanning electron microscopy (SEM), and Raman imaging of fine fraction, will be utilized

Anticipated Research Outcomes

- Research findings will help IDOT evaluate relevant mechanisms for the cementation and strength gain in dolomite aggregates based on source and chemical composition
  - Provide IDOT with a sustainable engineering solution for building long-lasting and durable pavement foundations

- Project findings will establish key knowledge on material behavior of different types and compositions of dolomite aggregates
  - Benefit the state by better utilizing large stockpiles of dolomitic QB while achieving low cost, durable and low maintenance foundation layers

Local Road Construction Project (2022 – 2024)

SUSTAINABLE PAVEMENTS PROGRAM

U.S. Department of Transportation
Federal Highway Administration

FHWA CLIMATE CHALLENGE

Illinois Department of Transportation

Field Demonstration of Dolomite Quarry By-products Used in Local Road Construction in Illinois

Project Goals:

(1) Environmental impact assessment along with performance assessment of pavement sections constructed with dolomitic and limestone quarry by-products (QB).
(2) Construct full-scale test sections with dolomitic QB to demonstrate sustainable and effective use of excess dolomitic QB sources in local road construction in Illinois. Both unsurfaced (seal coated) and thin hot-mix asphalt (HMA) surfaced pavements will be constructed as local roads to include (i) lightly cement-treated dolomitic QB; (ii) regular dense-graded dolomite base course layers, and (iii) limestone control section.

Project Scope:

- This demonstration project will provide field data to IDOT related to the long-term pavement performance and pavement life expectancy.
- Conduct a comparative LCA study using FHWA's LCA Pave Tool of the three constructed test sections using field construction and aggregate data from the project and the State of Illinois, utilizing the life cycle inventories from the FHWA LCA Commons Database and dolomite aggregate source from Environmental Product Declarations (EPDs) from quarries.
- A Life Cycle Cost Analysis (LCCA) of the QB applications will also be evaluated.

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(217) 685-0002 (C)

Thank you!

ILLINOIS

ILLINOIS CENTER FOR TRANSPORTATION

Illinois Department of Transportation

Novel Stabilization Methods for Sulfate Soils Using Laboratory Studies

Anand J. Puppala, PhD, PE, D.GE
Professor | A.P. & Florence Wiley Chair
Director – Center for Infrastructure Renewal (CIR)

TRB AKG 90 Webinar: Performance of Stabilized Pavement Foundations with Conventional and Unconventional Stabilizers

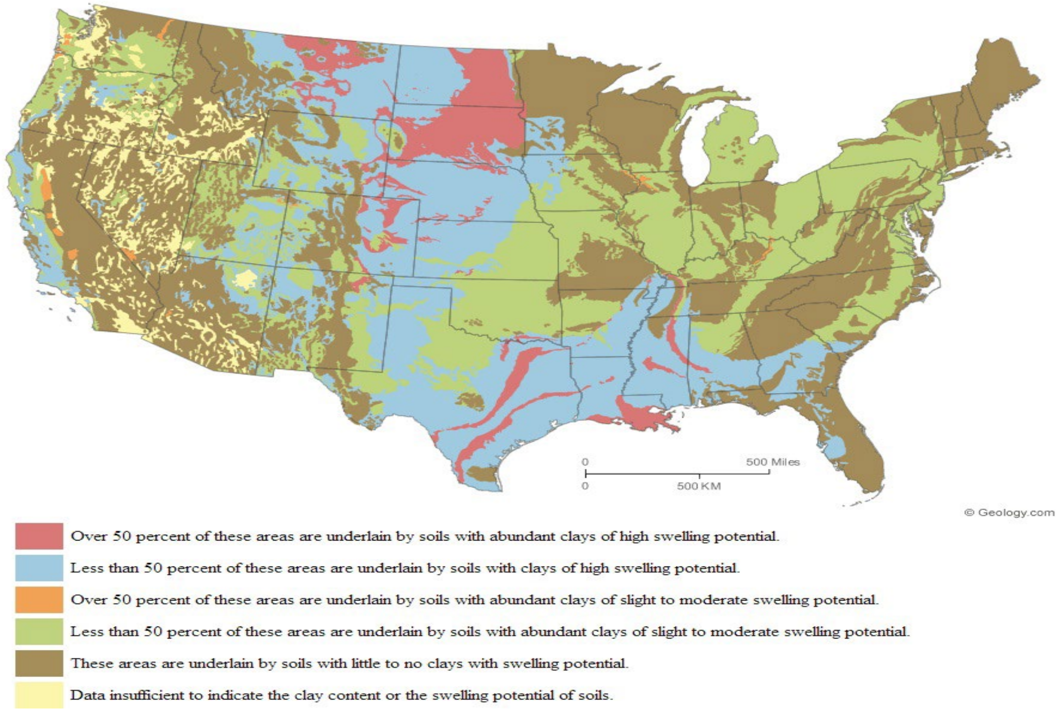
TEXAS A&M UNIVERSITY
Zachry Department of
Civil & Environmental Engineering

February 28, 2023

Presentation Outline

- ☐ **Introduction & Background – Sulfate-rich Soils**
- ☐ **Novel Stabilization Methods for Expansive Sulfate-rich Soils**
  - ➢ **Nano-silica**
  - ➢ **Geopolymer**
- ☐ **Summary**

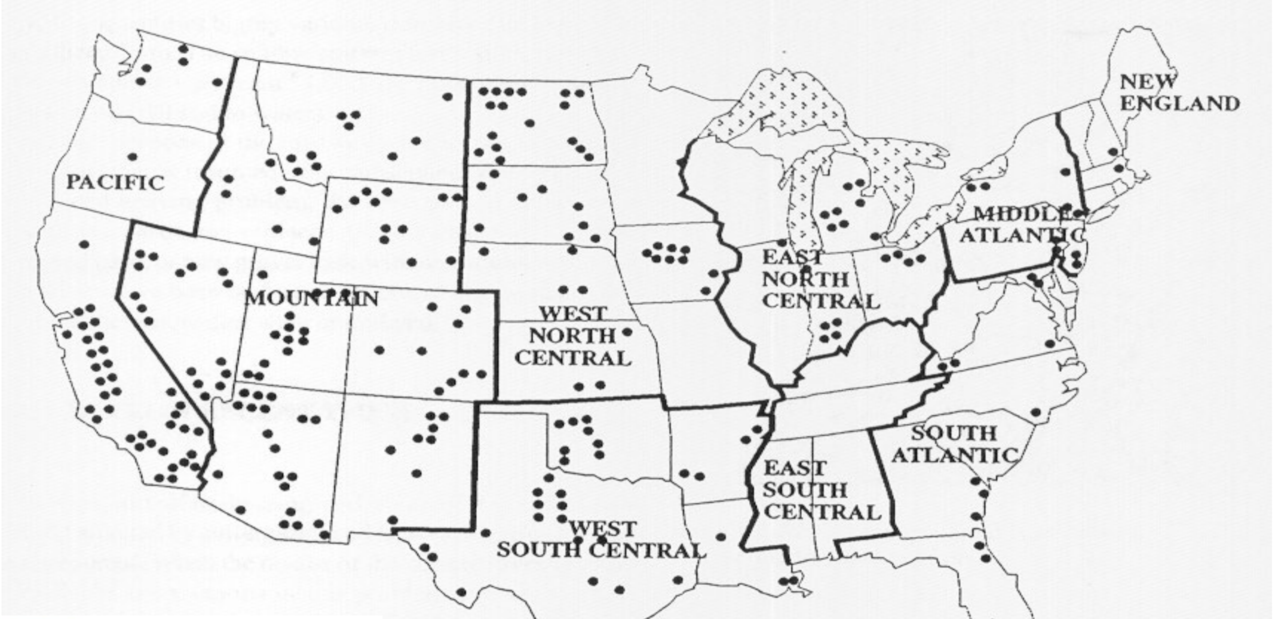
Introduction & Background

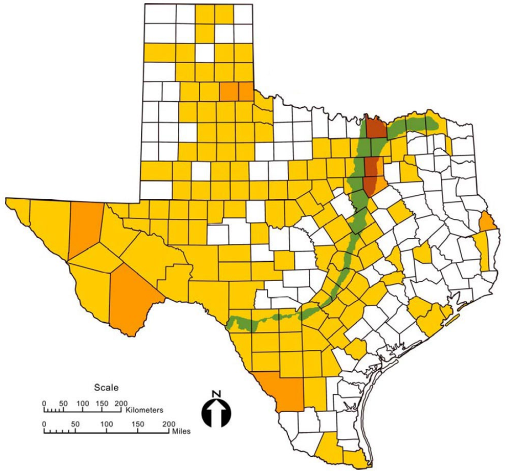


Source: USGS Surveys

Expansive and Sulfate Soils in USA

Sulfate Soils





Focus of my presentation is on sulfate soil; however same is applicable to problematic soils we encounter in the field!

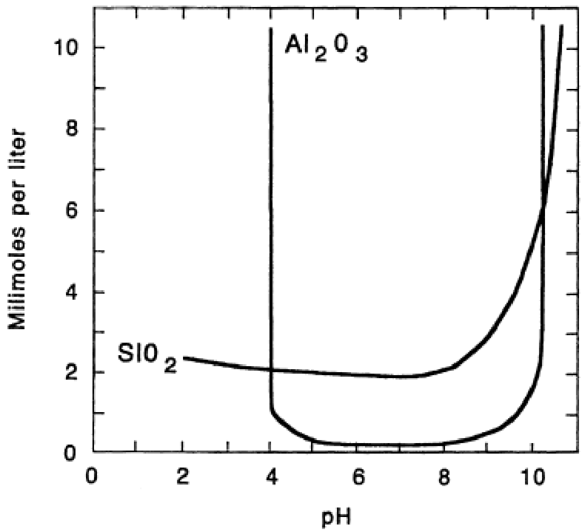
Introduction & Background

Man Made Expansive Soils: Stabilized Sulfate Soils

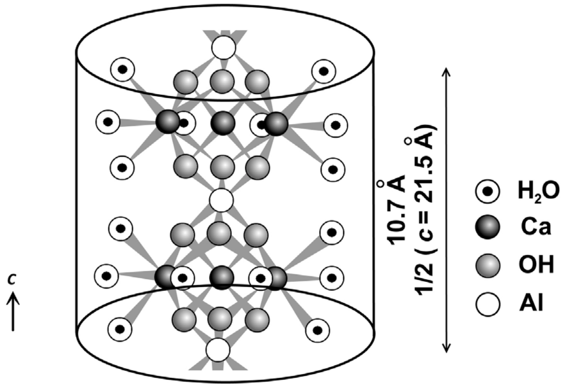
Introduction & Background

Sulfate-induced Heaving

- ❑Sources of sulfates in soil
  - Gypsum ($CaSO_4.2H_2O$)
  - Sodium Sulfate (Na_2SO_4)
  - Magnesium Sulfate ($MgSO_4$)



(Mitchell & Dermatas 1992; Puppala et al. 2018)



Ettringite Mineral Structure

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$$

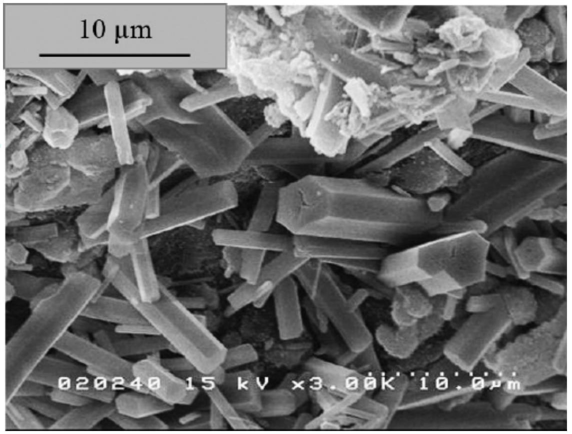
(Dissolution of Lime in Water)

$$Al_2Si_4O_{10}(OH)_2 \bullet nH_2O + 2(OH)^- + 10H_2O \rightarrow 2Al(OH)_4^- + 4H_4SiO_4 + nH_2O$$

(Dissolution of clay mineral at pH>10.5, Free Alumina)

$$6Ca^+ + 2Al(OH)_4^- + 4OH^- + 3(SO_4)^{2-} + 26H_2O \rightarrow Ca_6[Al(OH)_6]_2 \bullet (SO_4)_3 \bullet 26H_2O$$

(Formation of Ettringite, expansive mineral)



Jewell et al. (2014)

Introduction & Background

Joe Pool Lake (Les Perrin, US Army Corps of Engrs)

Sulfate Heave Case Studies

Introduction & Background

Heaving on US 67, Midlothian, Texas

Sulfate Heave Case Studies

Source: Wimsatt, 1999

Introduction & Background

Moderate to High Sulfate Soils – Research and Practice

- **Sulfate Levels < 8000 ppm**
  - ✓ **Low Risk: < 3000**
  - ✓ **Medium Risk: 3000 to 5000ppm**
  - ✓ **Moderate to High Risk: 5000 to 8000ppm**

➢ **Sulfate Levels > 8000ppm**

- ✓ **High Sulfate Soil: Severe Concern**
- ✓ **Lime/Cement Stabilization to be Avoided**
- ✓ **Remove and Replace Sulfate Soils or Blend in Non-Plastic Soils**

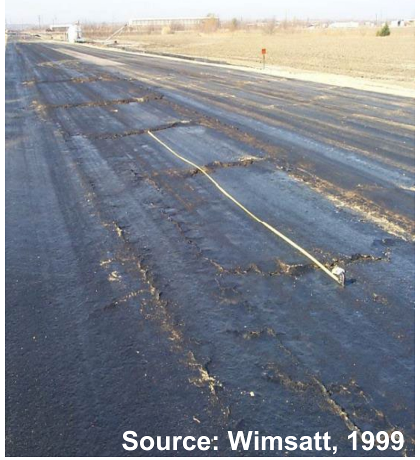
Treatments for Sulfate Soils

- ❖ **Ground Granulated Blast Furnace Slag (GGBFS)**
  - ✓ **Shown to be effective**
- ❖ **Class F Fly Ash**
- ❖ **Sulfate Resistant Cements**
  - ✓ **Results show successful stabilization**
- ❖ **Mellowing / Double Lime Treatment**
  - ✓ **Mixed results**
  - ✓ **Reappearance of heave**

Introduction & Background

- **Problems associated with traditional Ca-based soil treatments**

Sulfate-rich soils??



Source: Wimsatt, 1999

Joe Pool Lake (Les Perrin, USACE)

Durability and Permanency??

https://www.concrete.org.uk/

Novel Stabilization Methods for Sulfate-rich Soils

1) Nanosilica (NS) as ‘Co-additives’

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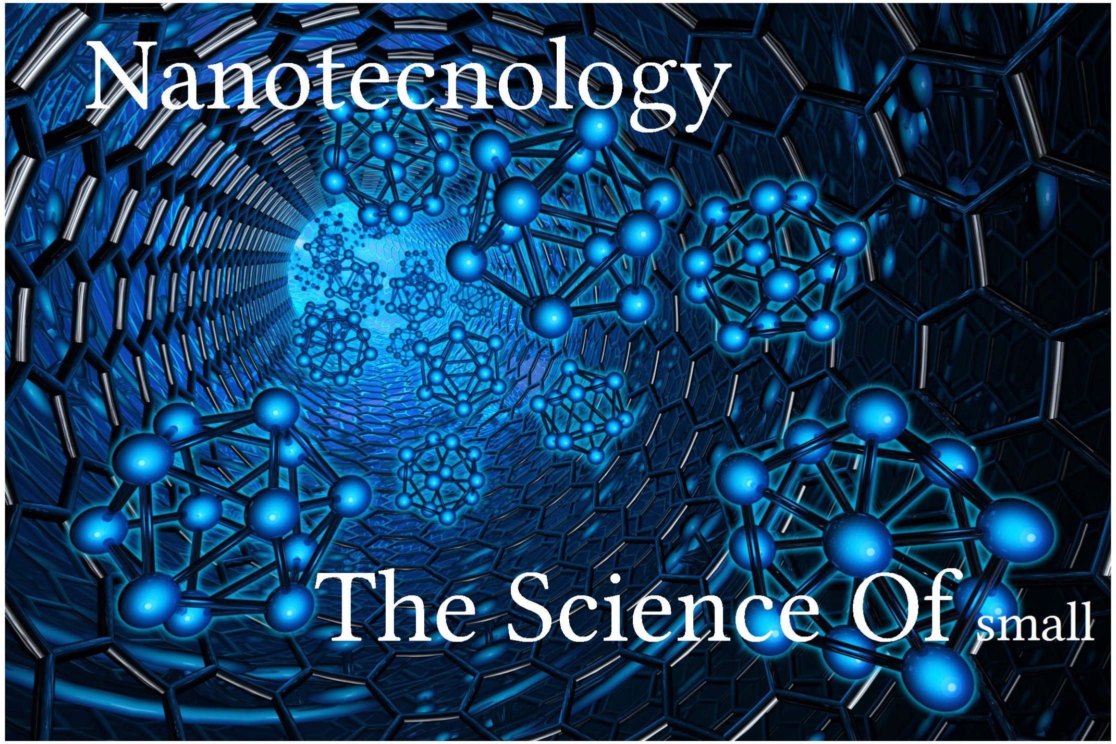
1) GeoPolymer (GP) as ‘Stabilizer’

Novel Stabilization Methods

Nano-Silica as ‘Co-additive’



wordpress.com

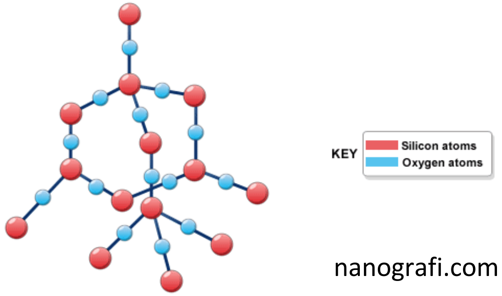
- ➢ **Extensive potential of Nano-technology in the next few decades**

Global
NANOSILICA
Market

Opportunities and Forecast,
2021-2030

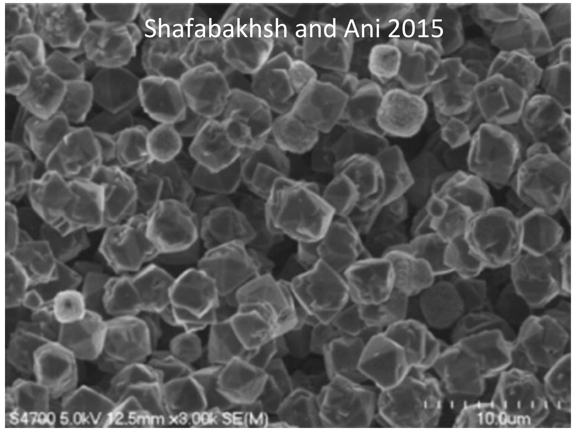
Global Nanosilica Market is expected to reach **$6.4 Billion** by 2030.

Growing at a **CAGR of 6.0%** (2021-2030)



nanografi.com

Ball & stick model of SiO_4



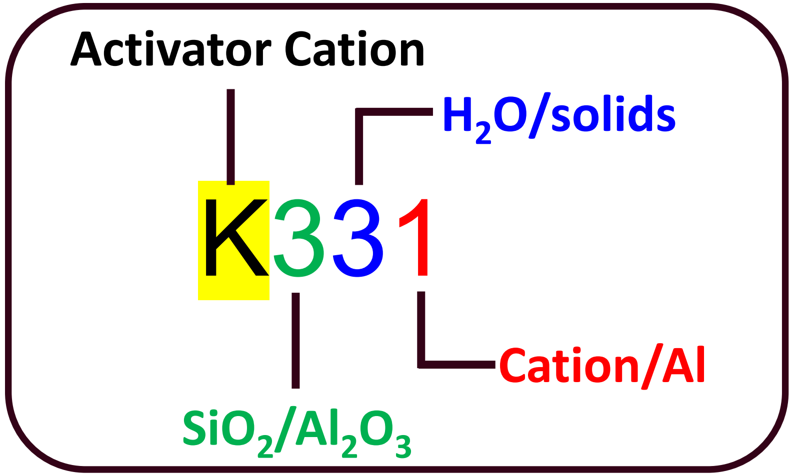
Shafabakhsh and Ani 2015

Can we use Nano Silica (NS) to further improve the efficacy of lime treatment?

Novel Stabilization Methods

Geopolymer as ‘Stabilizer’

- **$M_n(-(SiO_2)_z-AlO_2)\cdot wH_2O$ (Lizcano et al. 2012)**
  - **M is a monovalent cation (K, Na, etc.)**
  - **z is a molar ratio SiO_2/Al_2O_3**
  - **w is a molar amount of water ($H_2O/(SiO_2+Al_2O_3)$)**
  - **n is a molar ratio M/Al = M_2O/Al_2O_3**



- Utilization of ***Metakaolin* as a precursor**: Better control of particles’ homogeneity
  - Pure source of aluminosilicate
  - Alternative to fly ash - Inconsistent and becoming expensive

Can we use Geopolymer (GP) as an alternative to lime treatment in high-sulfate soils?

Laboratory Studies

Nano Silica as Co-additives to Treat Sulfate-rich Soils

Fat Clay (CH Soil)

Sulfate Concentration = 14,000 ppm

Application of NS

Research Work Plan

Optimize lime dosage with Soil-1 (ASTM D6276)

Eades & Grim pH test

Selection of NS dosage

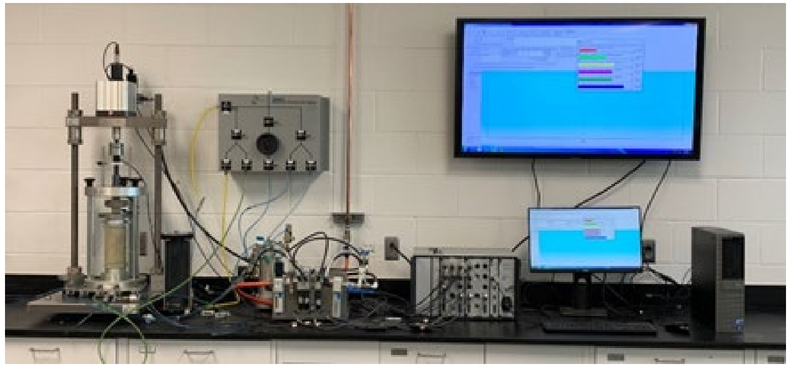
Optimum NS dosage based on UCS

Engineering Tests

UCS

Free Swell

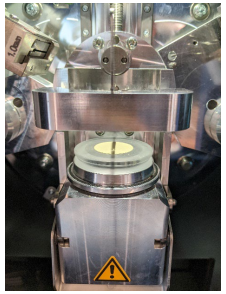
Shrinkage



Resilient Modulus Tests

Micro-studies

XRD



SEM

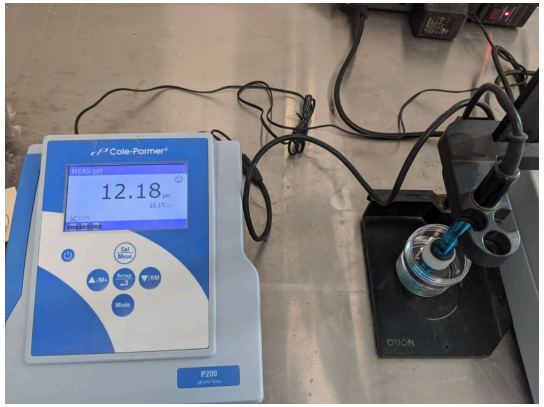
DSC

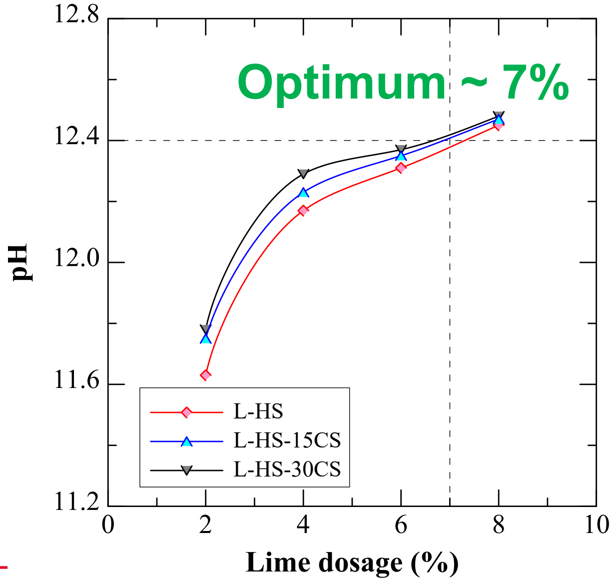
Application of NS

Lime and Co-additive Dosage Selection

- **Optimum Lime dosage (HS Soil) → 7% by dry unit weight of soil (ASTM D6276)**
- **Trial dosage of NS with 7% lime**
    - Selected 0.5, 1, 2 and 4% NS by dry unit weight of soil
    - Molded at same dry density of only lime-treated soils **14.64 kN/m^3** and **20% M/C**
- **Optimum NS dosage → 1% (Based on 7 day cured UCS values)**
- **Performance compared with only lime-treated soils (7% lime by dry unit weight)**

ASTM D6276

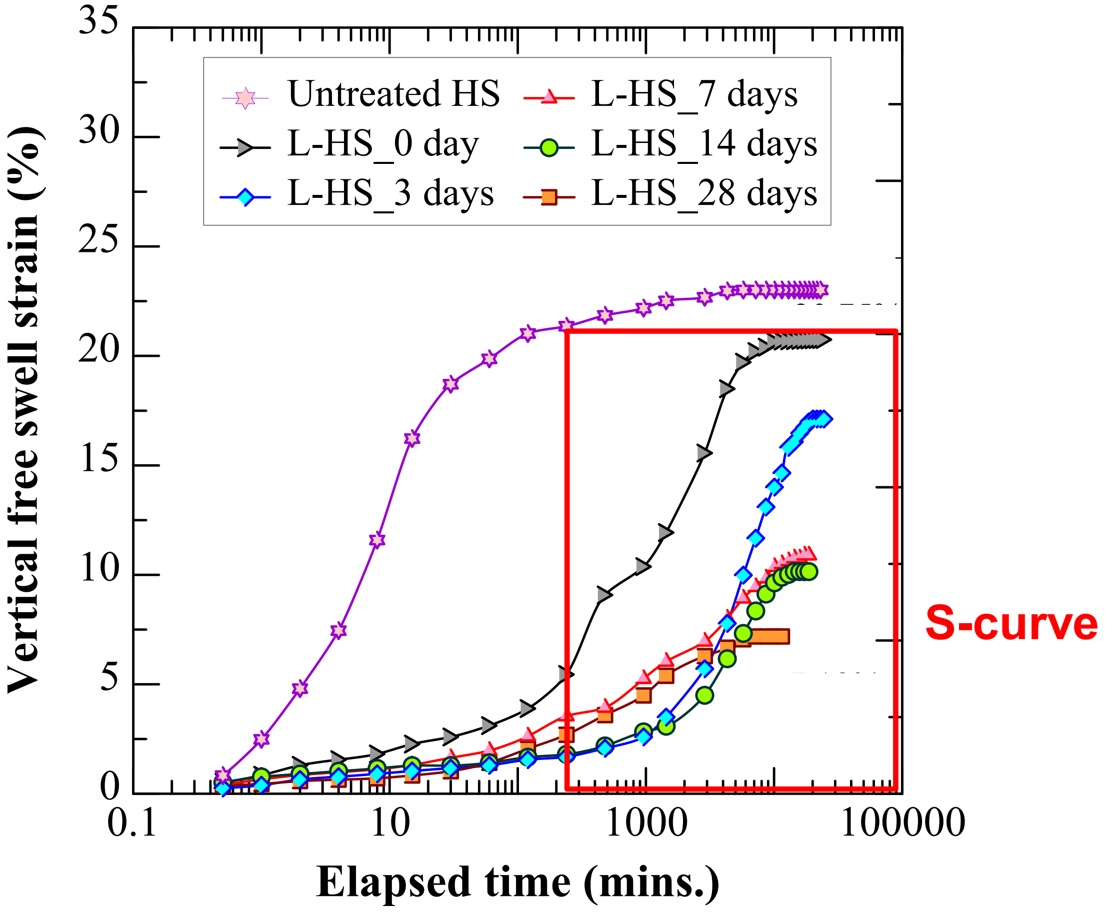




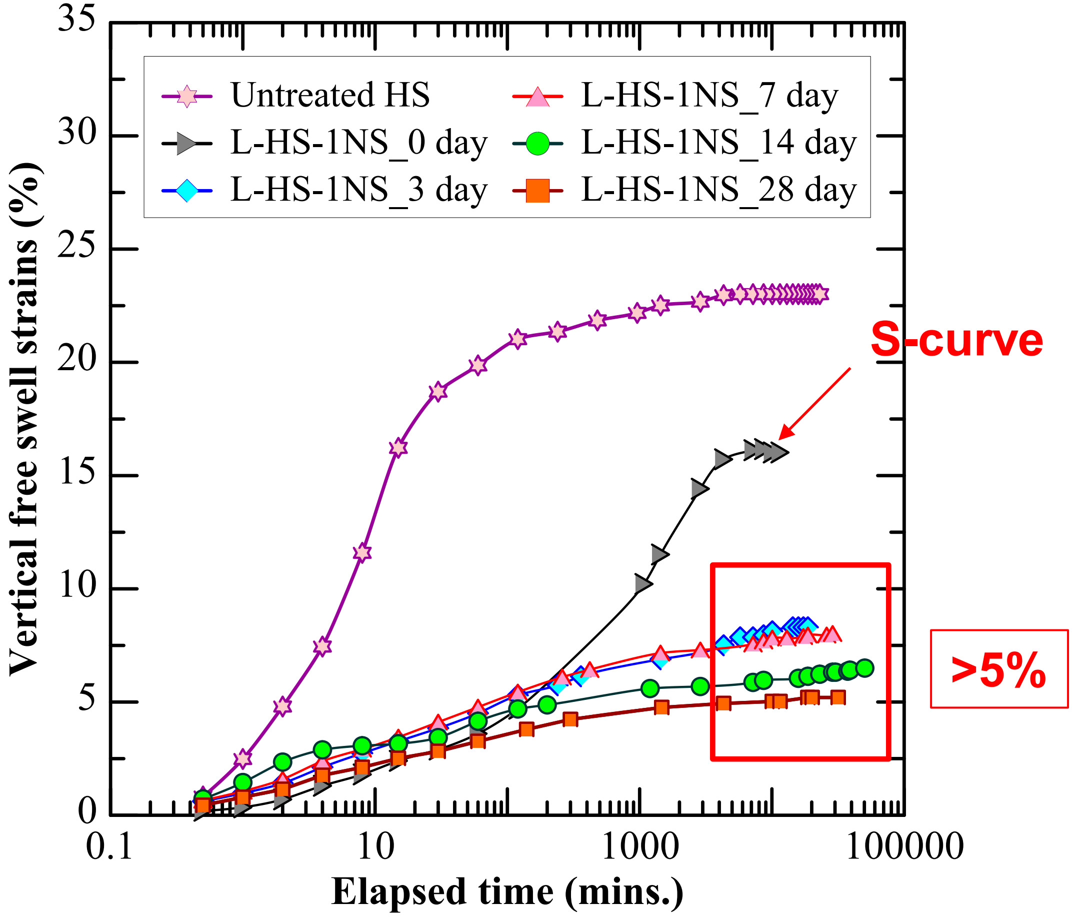
Application of NS

Vertical Free Swell: Sulfate Heave Assessments

Lime-Treated



Lime + NS-Treated

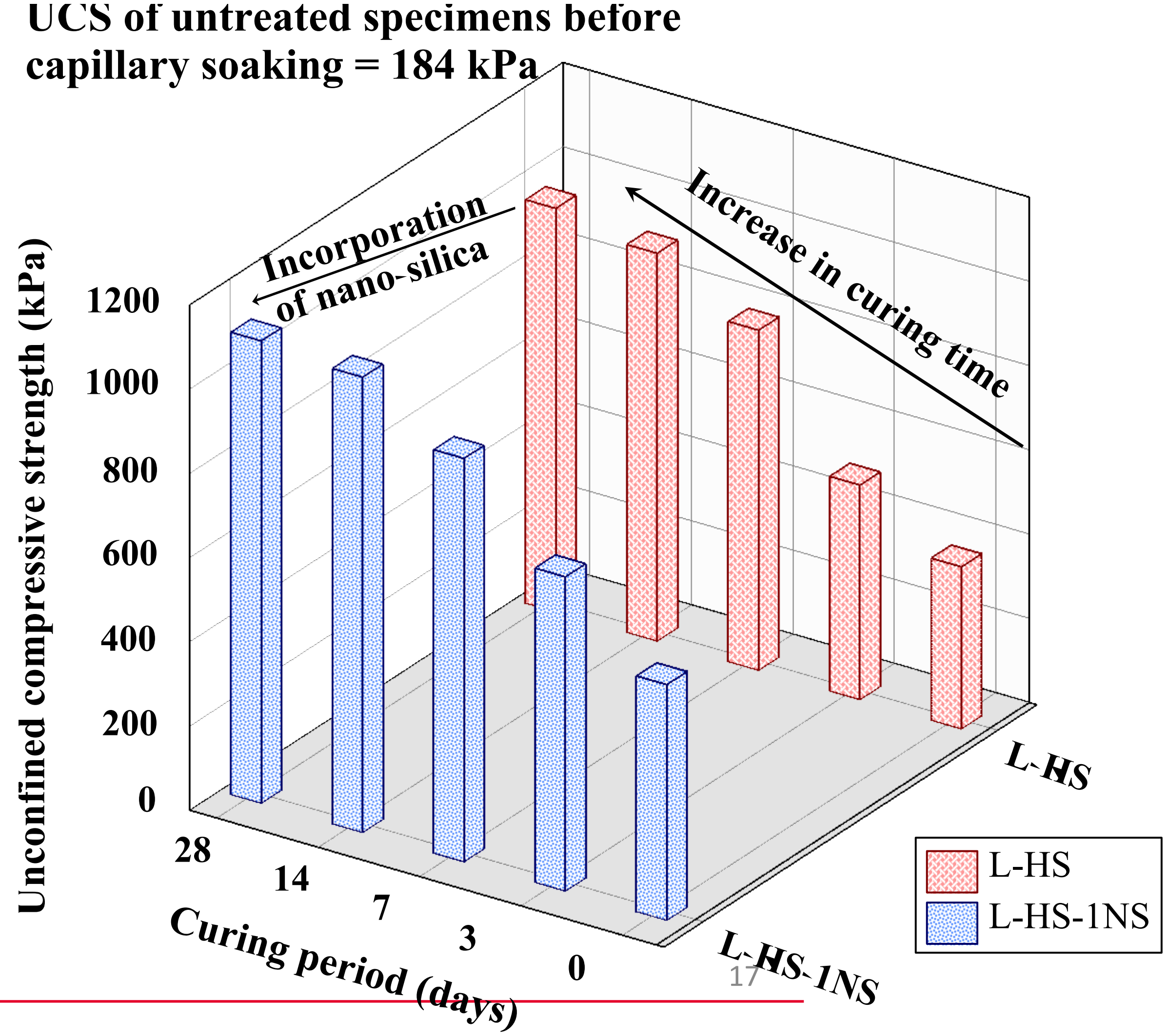


- ➢ **NS with Lime has not effectively reduced the free swell strains!**
- ➢ **No major reduction in %Swell after 3 days of curing → Ettringite or weak C-S-H bond?**

Application of NS

Unconfined Compression Strength (UCS)

- ❑ **NS → Accelerates cementitious reactions**
- ❑ **NS ↑ performance as compared to lime alone (L-HS)**
- ❑ **NS contributed to additional C-S-H phases**



Application of NS

Universal Model Constants for Resilient Modulus (M_r)

Curing Period (days)	k_1		k_2		k_3		R^2	
	L-HS	L-HS-1NS	L-HS	L-HS-1NS	L-HS	L-HS-1NS	L-HS	L-HS-1NS
0	1473	1465	0.128	0.103	0.161	0.071	0.90	0.82
3	1676	1681	0.131	0.257	0.233	0.308	0.97	0.94
7	1877	1822	0.169	0.180	0.310	0.541	0.94	0.90
14	2002	1831	0.127	0.137	0.499	0.693	0.91	0.90
28	2049	2113	0.151	0.204	0.562	0.434	0.90	0.93

Elastic Moduli

Hardening

Hardening

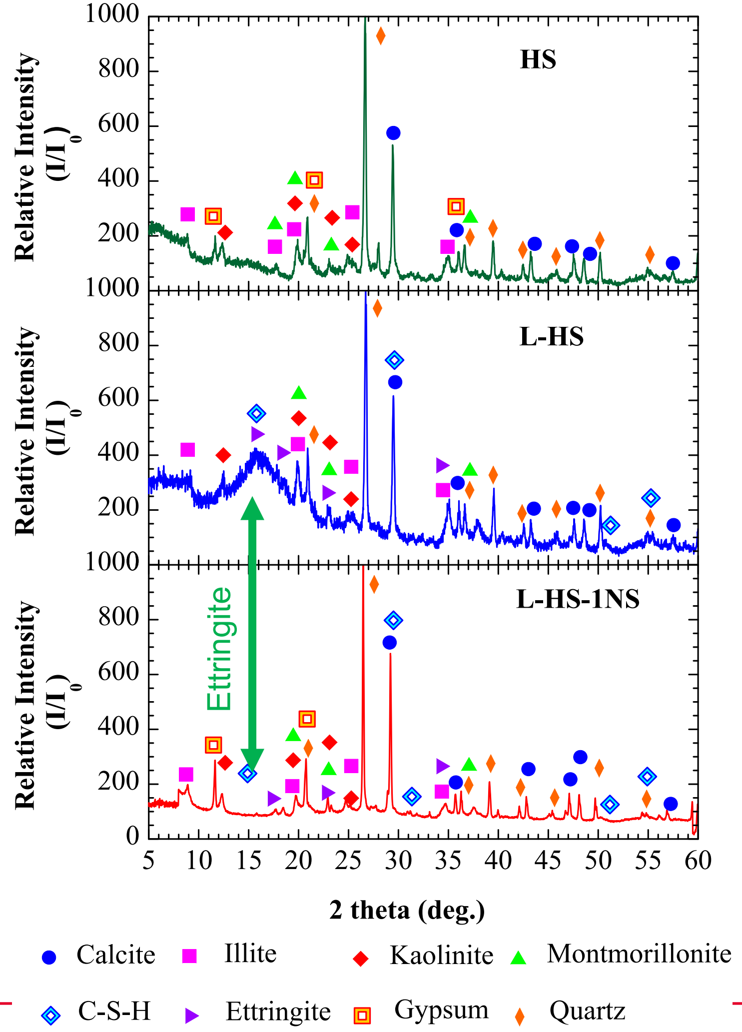
Softening

$$M_r = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left[\left(\frac{\tau_{oct}}{P_a}\right) + 1\right]^{k_3}$$

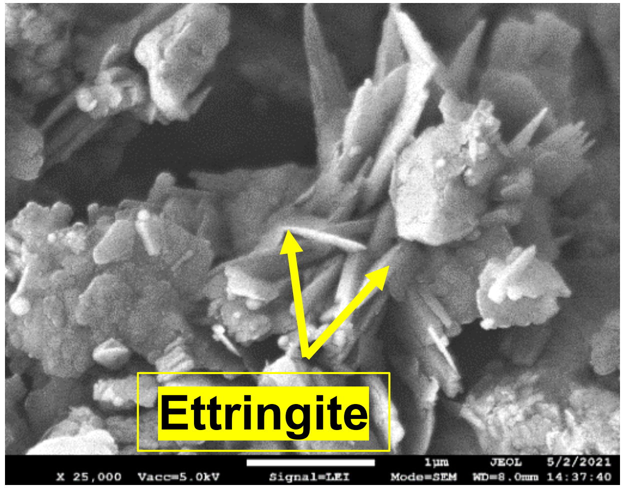
M_r = resilient modulus; k_1, k_2 and k_3 = material specific regression coefficients; θ = bulk stress; P_a = atmospheric pressure; and τ_{oct} = octahedral shear stress

Application of NS

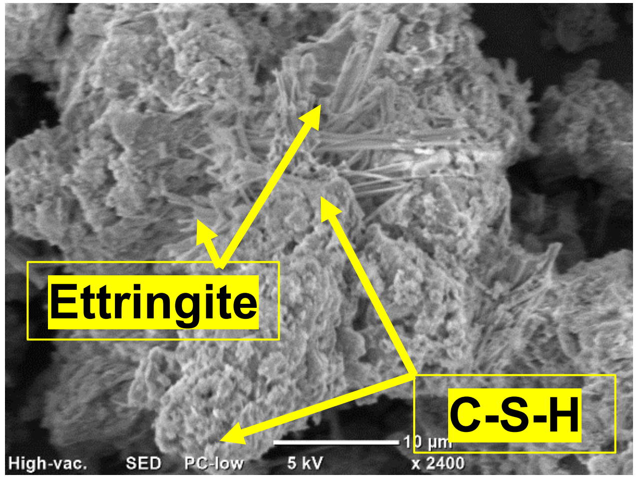
XRD and FESEM Studies: Sulfate Heave Assessments



Lime-HS



Lime-HS-NS



- **XRD → Precipitation of Ettringite ↓**
- **Uniformly coated phases of cementitious compounds**
- **Ettringite crystals and uniformly distributed C-S-H phases detected**

Geopolymer as a Stabilizer to Treat Sulfate-rich Soils

Fat Clay (CH Soil)

Sulfate Concentration = 10,000 ppm

Application of Geopolymer

Geopolymer Synthesis

Geopolymer Gel

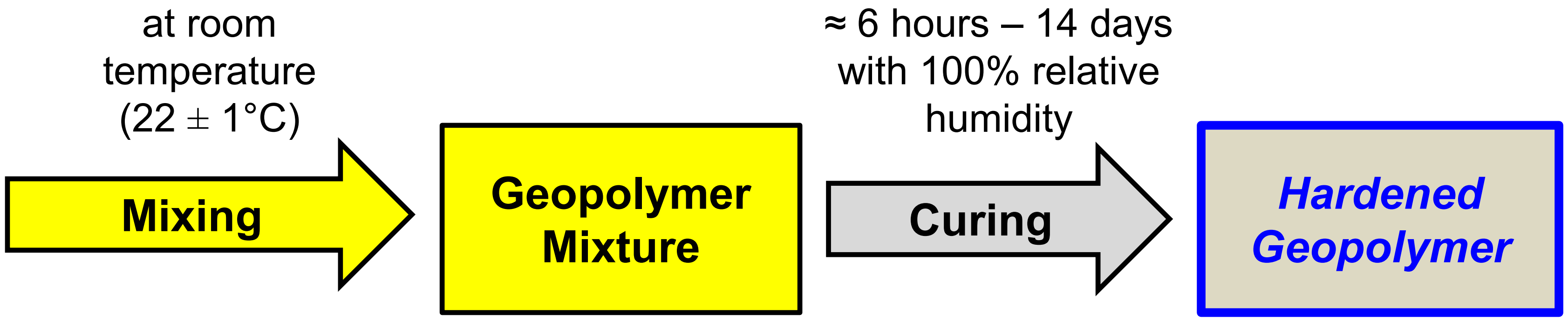
Aluminosilicate Sources

Metakaolin

+

Alkaline Activator Solution

Alkali metal cation
(**KOH**)
+
Additional Silica Source
(**Silica fume**)
+
Water



at room temperature (22 ± 1°C)

Mixing

Geopolymer Mixture

≈ 6 hours – 14 days with 100% relative humidity

Curing

Hardened Geopolymer

Application of Geopolymer

Research Work Plan

Optimize lime dosage with HS-Soil (ASTM D6276)

Eades & Grim pH test

Optimization of GP

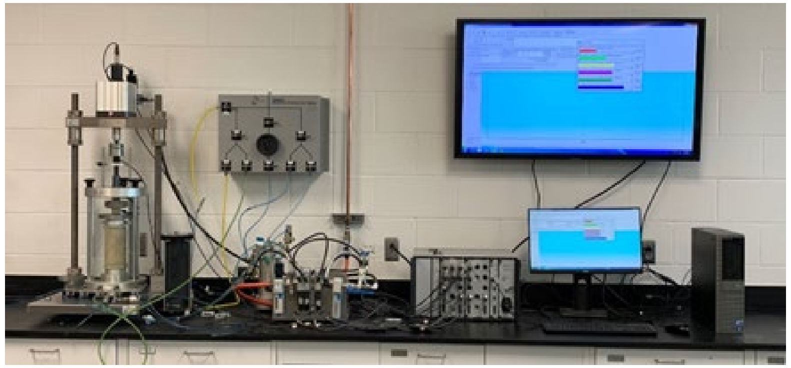
Select 8% and 30% GP

Engineering Tests

UCS

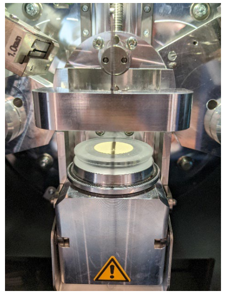
Free Swell

Shrinkage



Resilient Modulus Tests

Micro-studies



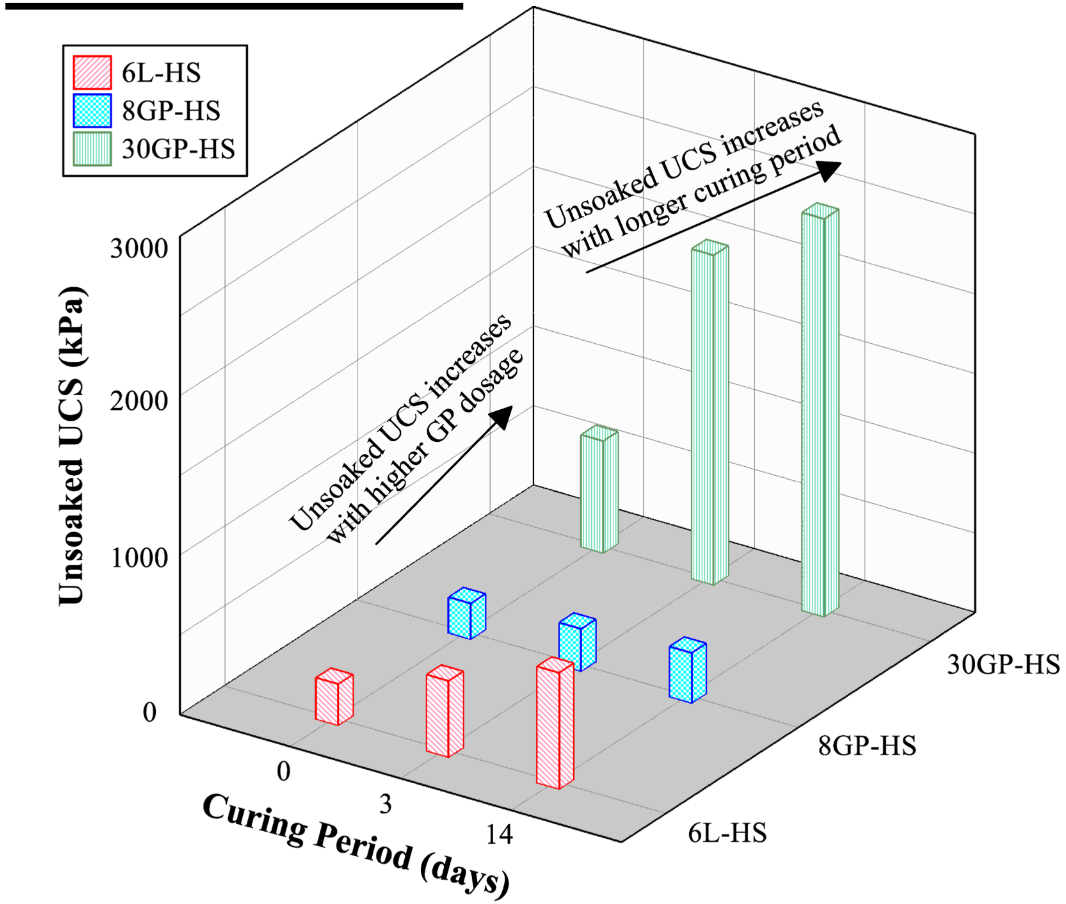
XRD

FESEM-EDS

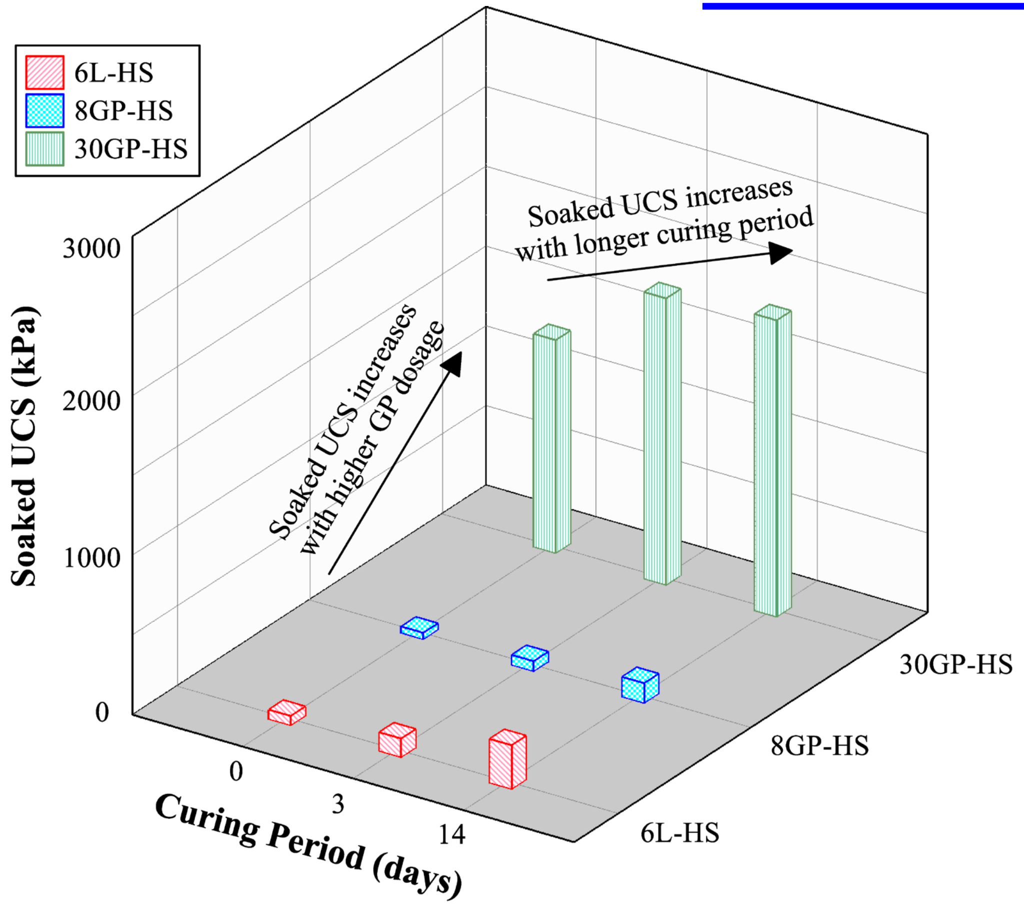
Application of Geopolymer

Unconfined Compression Strength

Unsoaked UCS



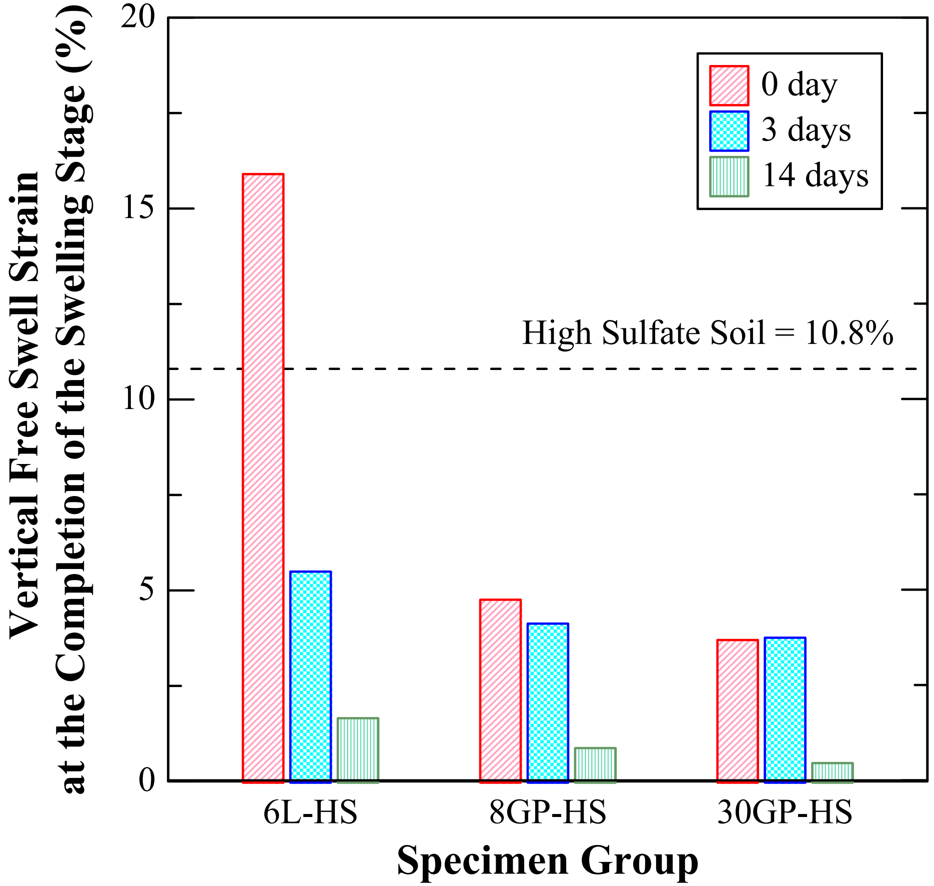
Soaked UCS

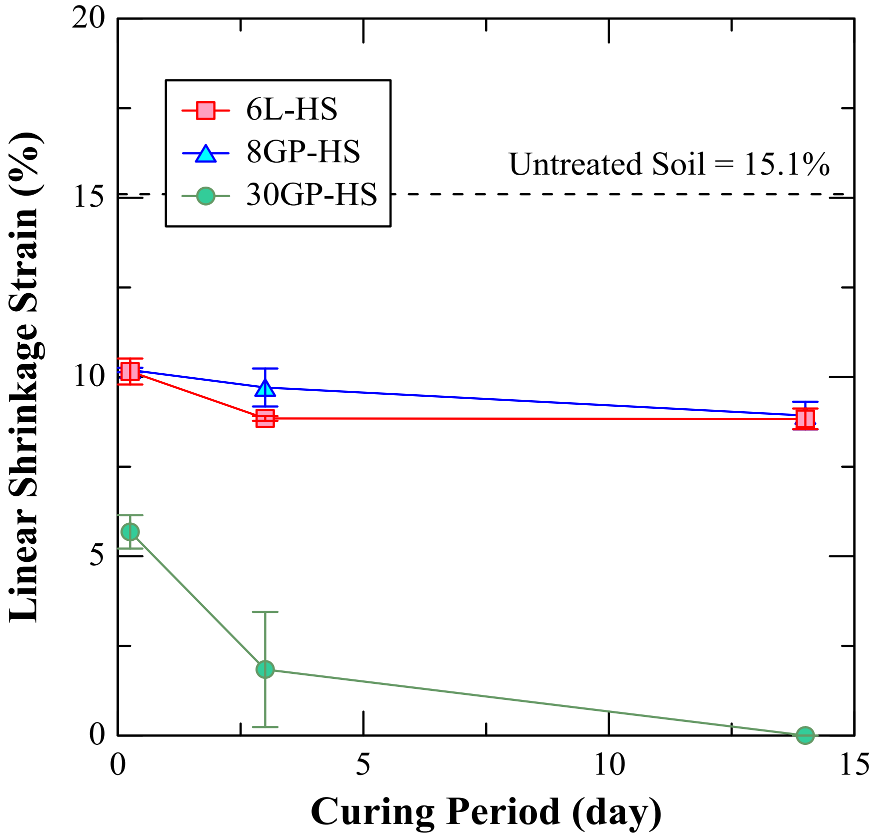


Effect of Strength Enhancement: 30% GP >>> 6% Lime

Application of Geopolymer

Free Swell & Shrinkage Results



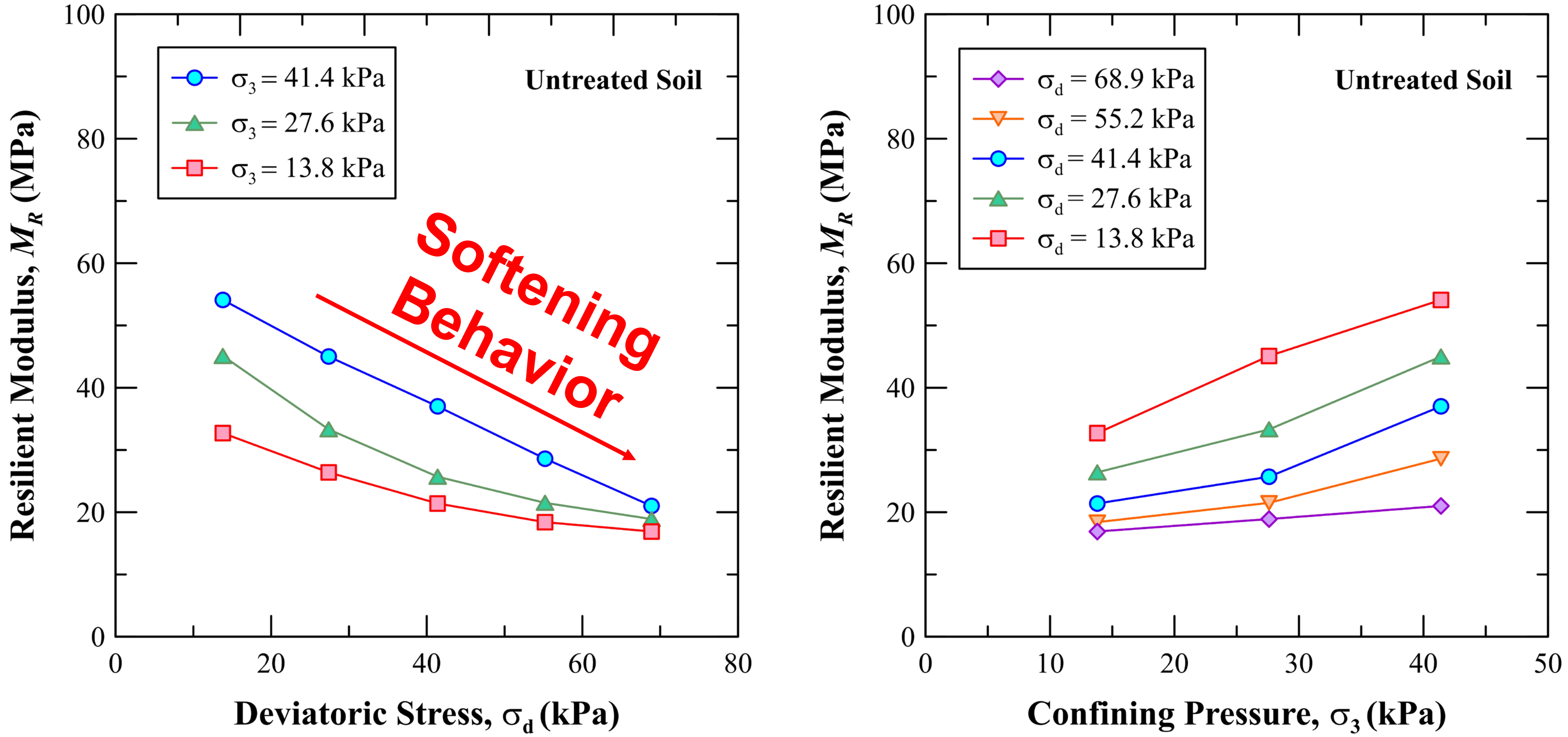


Vertical Free Swell Strain for High Sulfate Soil: 6% Lime > 30% GP

Linear Shrinkage Strain in High Sulfate Soil: 6% Lime > 30% GP

Application of Geopolymer

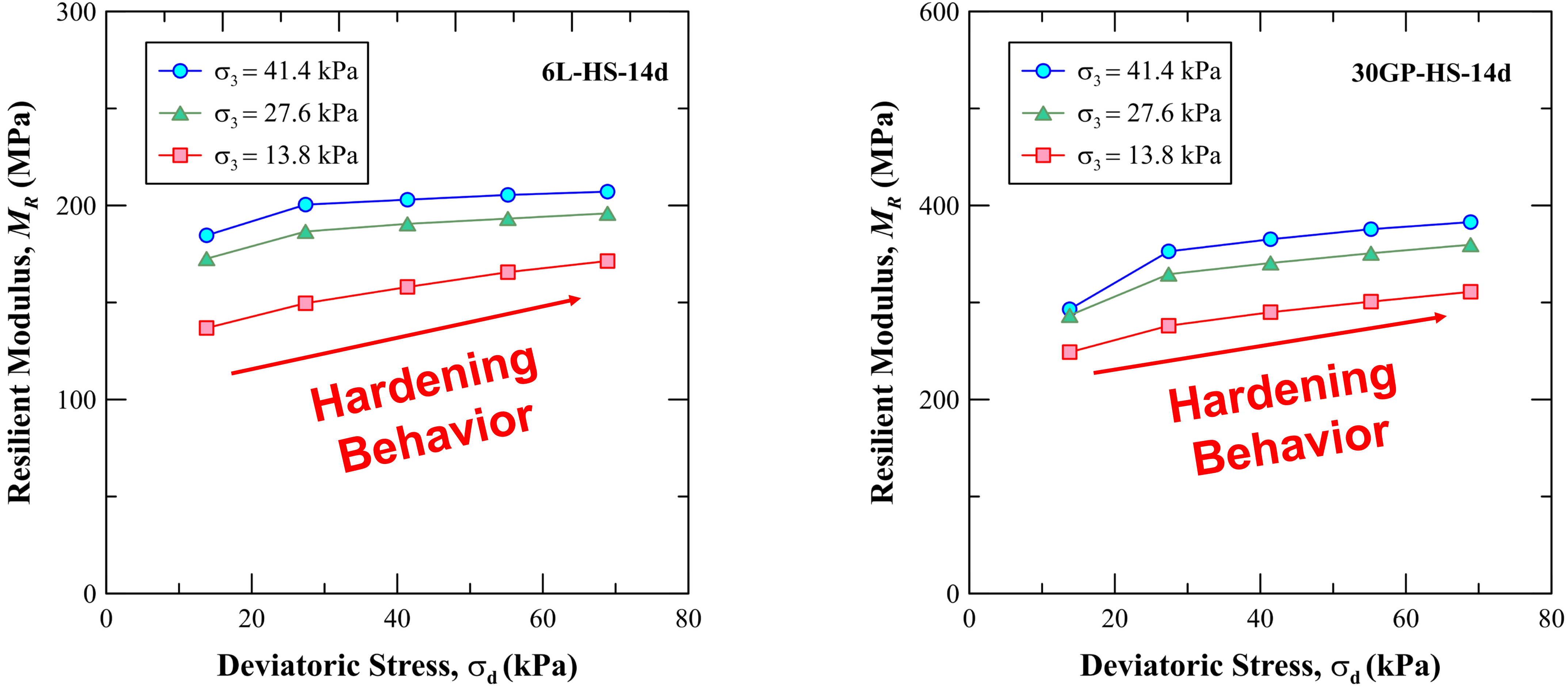
Resilient Moduli Studies



Untreated Soil → Softening Behavior

Application of Geopolymer

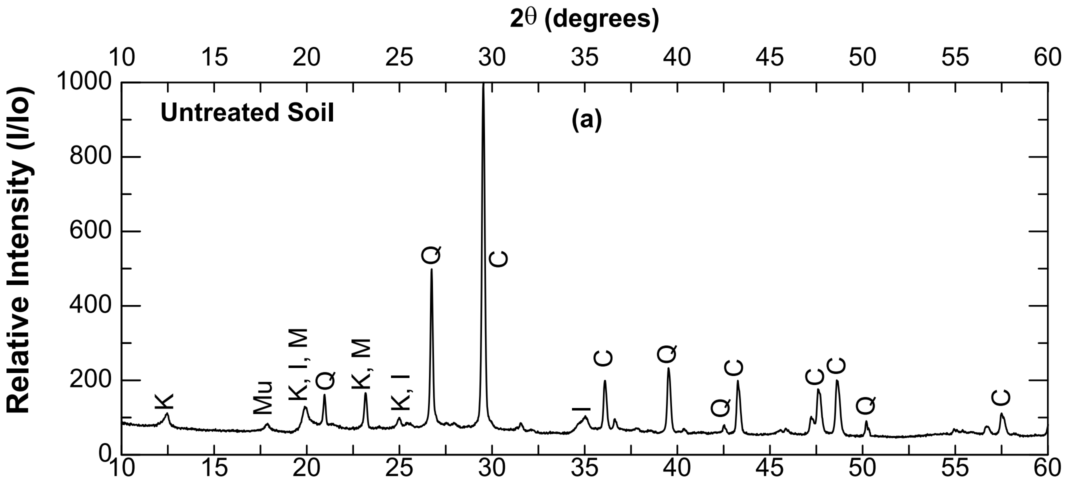
Resilient Moduli Studies

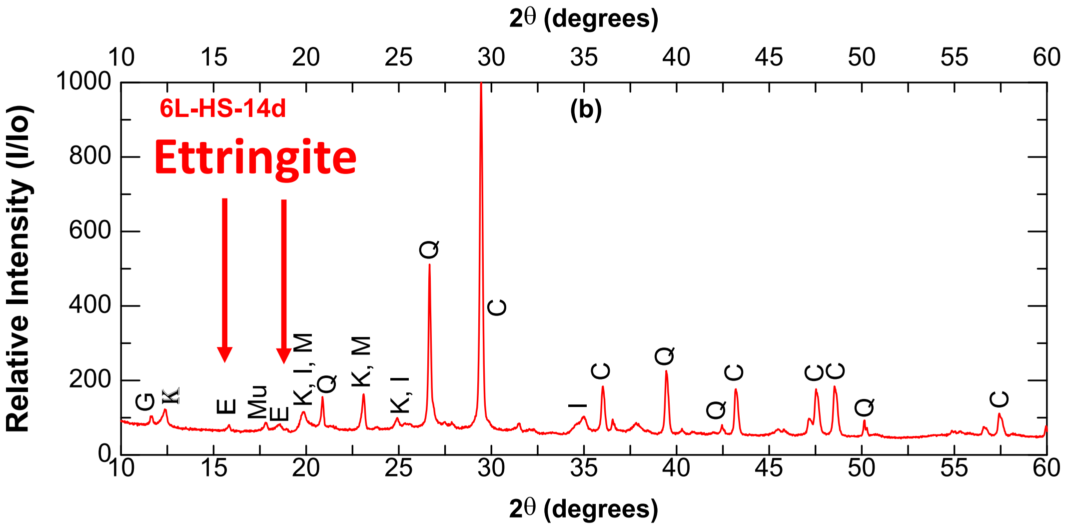


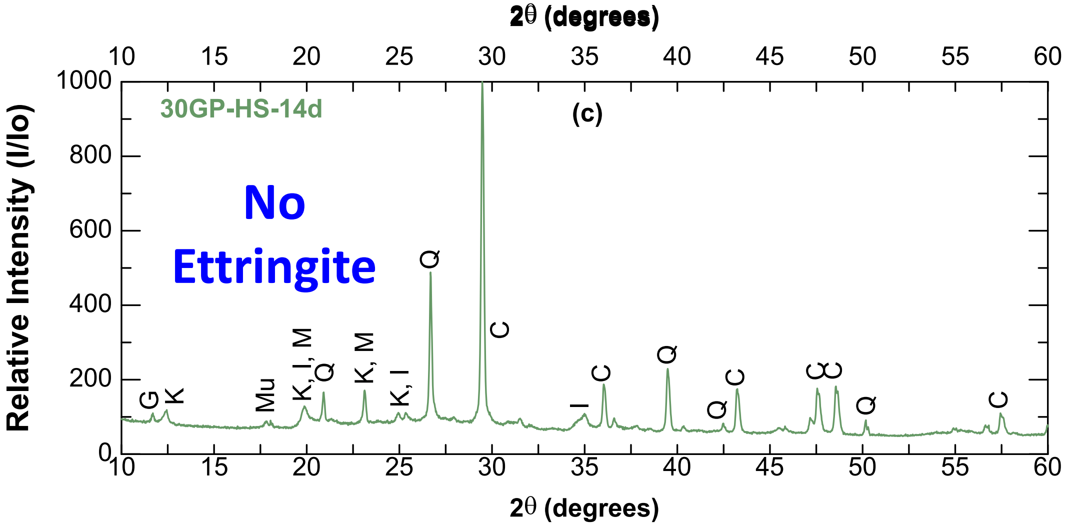
6% lime ↓ Hardening Behavior than 30% GP Treatment

Application of Geopolymer

X-ray Diffraction (XRD) Studies







C: calcite (calcium carbonate); E: ettringite; G: gypsum; I: illite; K: kaolinite; M: montmorilonite; Mu: muscovite; Q:quartz

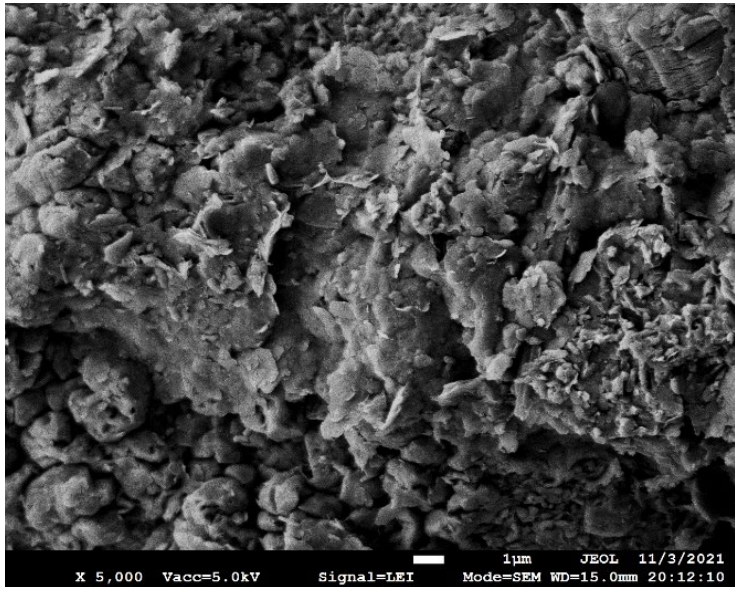
30% GP-treated specimen
→ No Ettringite peaks

VS

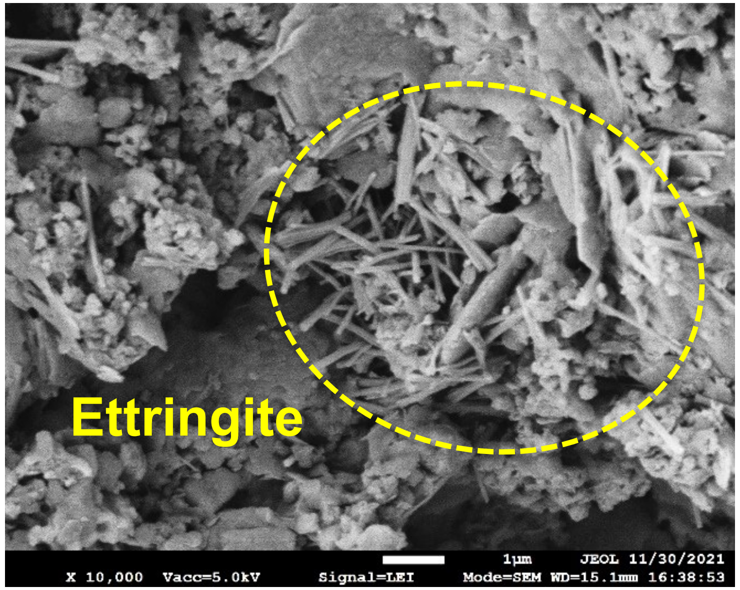
6% Lime-treated specimen
→ Ettringite peaks

Application of Geopolymer

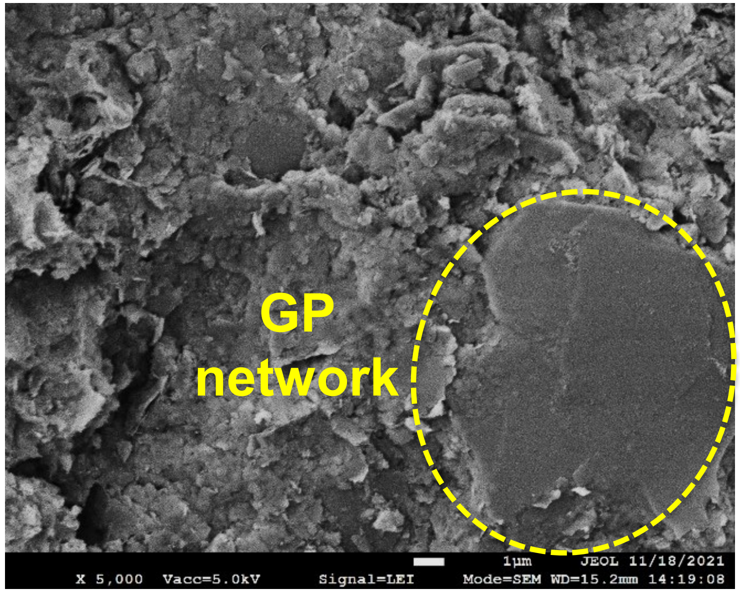
Field Emission Scanning Electron Microscopy (FESEM) Images



Untreated Clayey Soil



Lime-Treated High Sulfate Soil



GP-Treated High Sulfate Soil

Strong GP networks in GP-treated sulfate-rich expansive soil
→ Less chance of occurrence of Ettringite-induced heaving

Mitigation of High Sulfate Soils in Texas

Anand J. Puppala, Ahmed Gaily, Aravind Pedarla, Aritra Banerjee
Department of Civil Engineering, The University of Texas at Arlington, Arlington, Texas, 76019

AASHTO RAC Showcase Poster

Transportation Research Board Annual Meeting, Washington, DC, 2018

Recent Paper in ASCE JGGE 2020: Talluri et al. 2020 – High Sulfate Soils

Concept

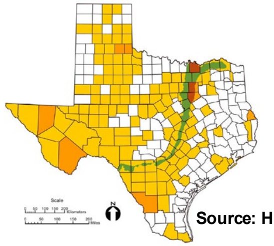
- Pavement distress in chemically stabilized sulfate bearing soils is a growing concern for highway agencies

Source: Les Perrin, USACE

- Researchers have conducted studies on heave mechanisms in chemically treated soils containing sulfate levels below 10,000 ppm
- In most of the heave cases the sulfate contents were reported to be as high as 50,000 ppm
- The main intent of the research is to understand heave mechanisms in soils with sulfate contents above 10,000 ppm

Background & Innovation

- Sulfate Bearing Expansive Soils



Source: Harris et al. (2004)

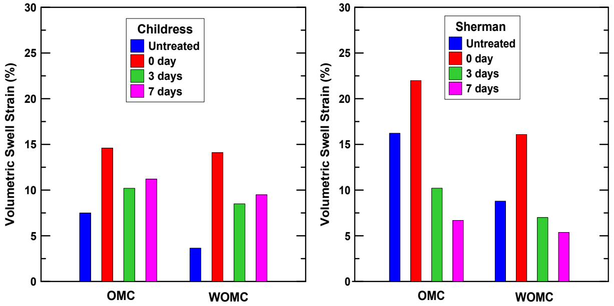
- Lime/Cement treated bases are used to support the pavement infrastructure
- Some of these expansive soils contain sulfate minerals such as Gypsum ($CaSO_4.2H_2O$) in their natural formation
- $6Ca^{+}+2Al(OH)^{4-}+4OH^{-}+3(SO_4)^{2-}+\ 26H_2O \rightarrow Ca_6[Al(OH)_6]_2 \bullet (SO_4)_3 \bullet 26H_2O$

(Formation of Ettringite)

Gypsum Crystals in Natural Soil

Laboratory Testing Program

- Experimental Variables: Soils (Childress, MH & Sherman, CH); Moisture Contents (OMC & WOMC); Sulfate Contents (24,000 & 44,000 ppm); Stabilizer (Lime); Dosage (6%)
- Chemical and Mineralogical Tests Performed: Cation Exchange Capacity (CEC); Specific Surface Area(SSA); Total Potassium(TP) and Reactive Alumina & Silica
- 'Mellowing Technique' is used in stabilizing the soils with lime; Mellowing Periods Considered: 0, 3 and 7 days (swell tests only)
- To compensate moisture loss and early dissolution of Gypsum during mellowing additional 3% moisture is provided
- After the mellowing period, the soils are remixed and compacted
- Engineering tests were performed on the treated mellowed high sulfate soils
- Engineering tests data from treated soils is compared with the untreated data



:ion – US 82 Bells

Performance Evaluation Studies

FWD and Surface Profiler Studies

Conclusior

- Mellowing technique \
volumetric swell increa
- Childress soil showed
compared to Shermar
observed in Childress
- Low initial reactive alu
ineffectiveness of mell

Acknowledgements

- Joe Adams, Wade Odell, Wade Blackmon & Richard Williammee, Texas Department of Transportation
- Pat Harris, Sam Houston State University

Summary

- Sulfate-rich soils – characterization is critical & stabilizer mix design and durability assessments are critical

- Nano Silica (CS) materials, due to particle size and reactions from broken bonds, have significant influence on reducing sulfate-induced heaving

- Geopolymer, as an eco-friendly soil stabilizer for stabilization of high-sulfate soils, showed effective treatment

- Sustainability studies on the novel co-additives needs to be included for understanding the overall benefits of the treatment methods

Acknowledgments – Support

Tran-SET

Texas Department of Transportation

Transportation & Public Facilities State of Alaska

NSF

Center for Integration of Composites into Infrastructure

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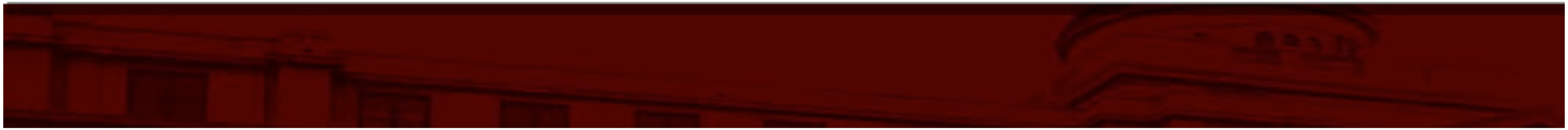


Thank you!

Acknowledgements-
Geomechanics/Geotechnical Research Team

Improving Stabilized Full Depth Reclamation with Intelligent Compaction

TRB Webinar: Pavement Foundations with
Conventional and Unconventional Stabilizers
February 28, 2023

John Siekmeier P.E. M.ASCE
MnDOT Advanced Materials and Technology
Maplewood, Minnesota

Acknowledgements

- Local Governments and DOT Districts
- Contractors, Consultants and Manufacturers
- State DOTs and Federal Highway Administration
- Universities and the National Academies

Introduction

- Stabilized full depth reclamation (SFDR) is an effective pavement foundation construction option.
- The Minnesota DOT quality management roadmap requires intelligent compaction be used during SFDR.
- The benefits of intelligent compaction include:
  - Opportunity to optimize inspection.
  - Opportunity to increase construction uniformity.
  - Opportunity to validate pavement design inputs.
  - Opportunity to comply with state statute.
  - Opportunity to extend service life.

Pavement Foundation Defined

All the different layers and materials constructed to support and distribute traffic loads from the asphalt or concrete surface layer to the non-engineered roadbed material.

Courtesy of the NCHRP 01-62 Project Panel

Quality Management Roadmap Specification

Quality Management – Intelligent Construction Technology

MnDOT 2215 Stabilized Full Depth Reclamation, 2390 Cold-In-Place Recycled Bituminous and Cold Central Plant Recycling Bituminous, 2353 Ultrathin Bonded Wearing Course, 2360 Plant Mixed Asphalt Pavement, and 2365 Stone Matrix Asphalt are supplemented with the following… This work consists of using intelligent construction technology to monitor compaction and placement operations.

Today’s Outline

- Benefits: “Why we are doing this.”
- Construction Examples: “What we are doing.”
- Lessons Learned: “What’s next.”

Benefits of Intelligent Compaction

- Opportunity to optimize inspection.
- Opportunity to increase construction uniformity.
- Opportunity to validate pavement design inputs.
- Opportunity to comply with state statute.
- Opportunity to extend service life.

Opportunity to Optimize Inspection

Remove construction staff from unsafe activities.

Optimize construction staff experience and expertise.

Good Inspection Provides Value

Good inspection may add several [hundred]-thousand dollars to the value of the road without adding materially to its cost.

Minnesota Highway Department, 1925

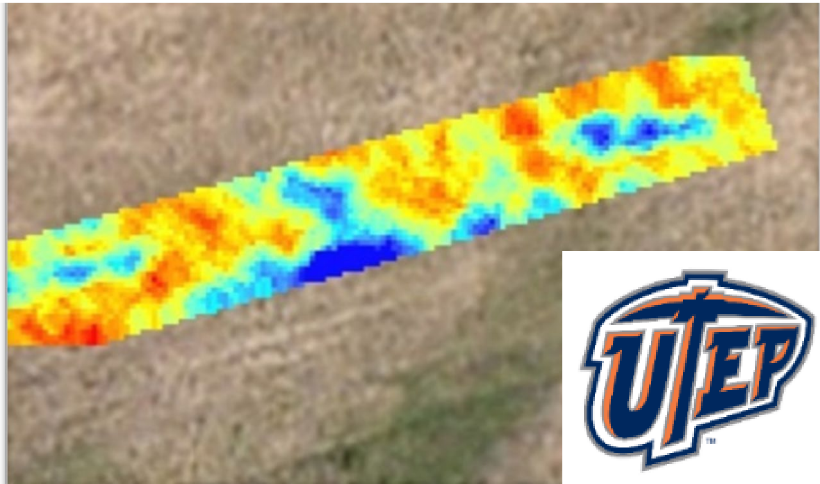
Opportunity to Increase Uniformity

Operator Screen

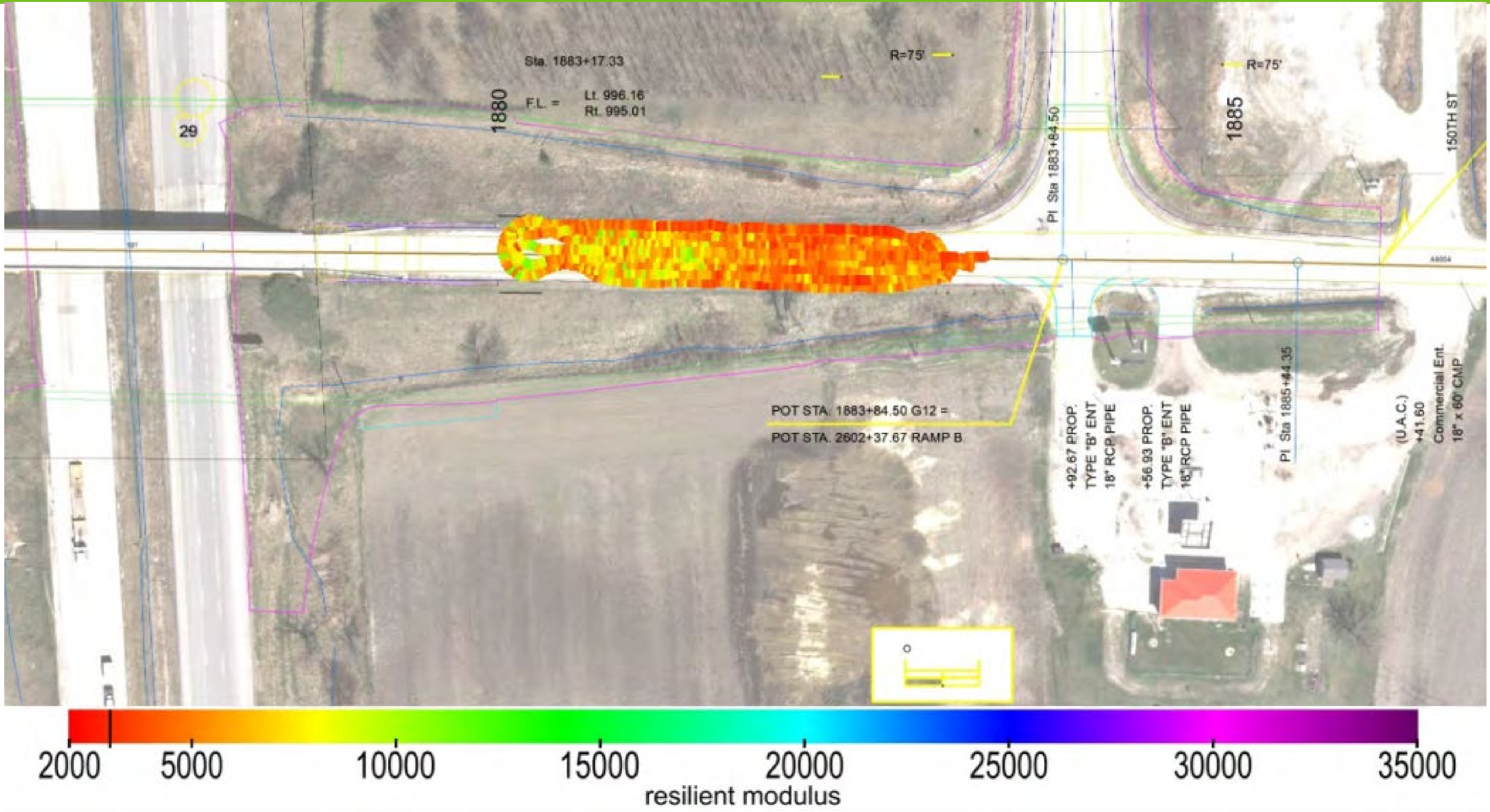
Location

Drum Movement

Compaction Map

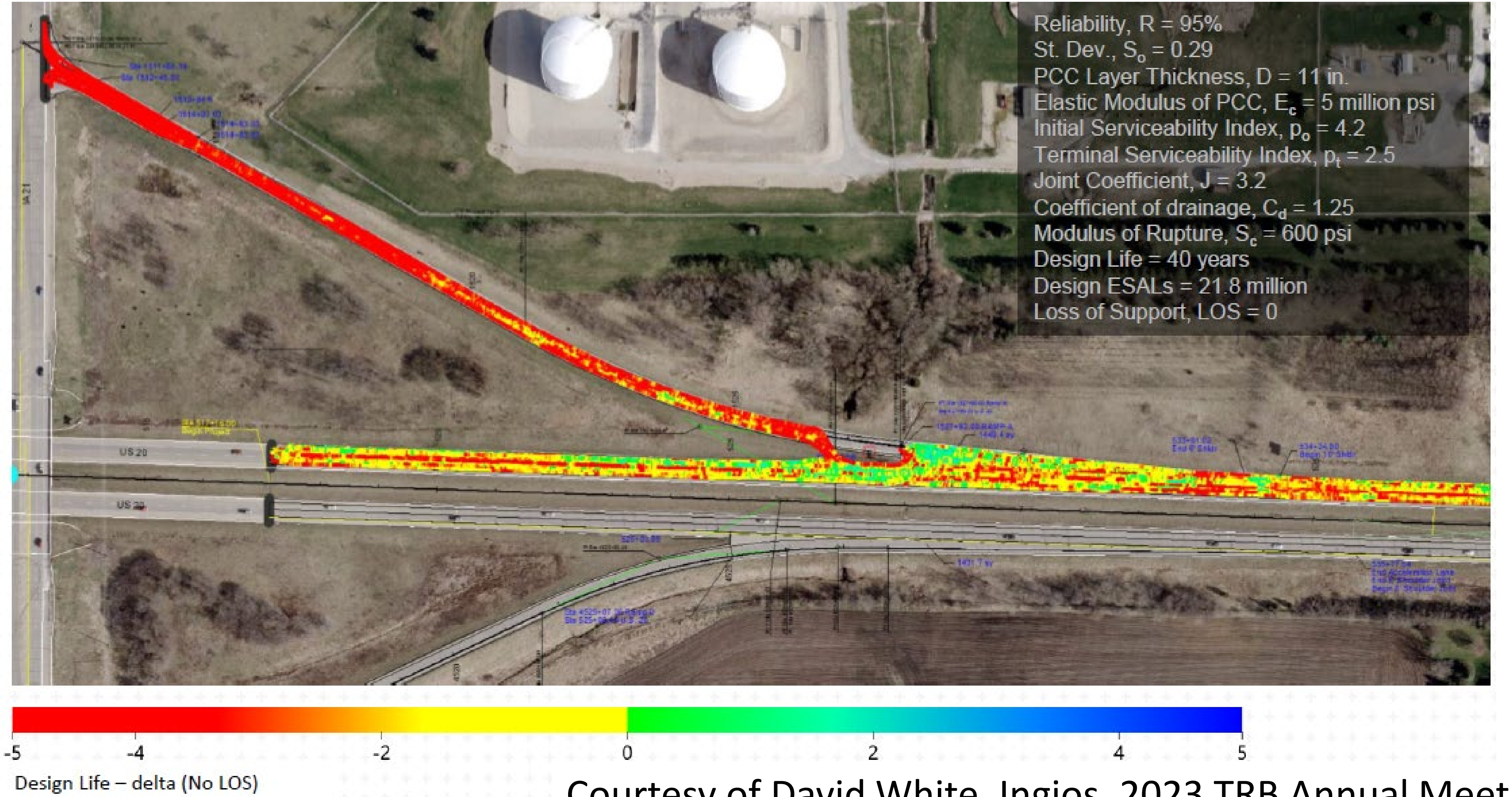


Opportunity to Validate Pavement Design Inputs



Courtesy of Iowa DOT: https://publications.iowa.gov/42872/

Estimating Pavement Life Gained or Lost



Reliability, R = 95%

St. Dev., S_o = 0.29

PCC Layer Thickness, D = 11 in.

Elastic Modulus of PCC, E_c = 5 million psi

Initial Serviceability Index, p_o = 4.2

Terminal Serviceability Index, p_t = 2.5

Joint Coefficient, J = 3.2

Coefficient of drainage, C_d = 1.25

Modulus of Rupture, S_c = 600 psi

Design Life = 40 years

Design ESALs = 21.8 million

Loss of Support, LOS = 0

Courtesy of David White, Ingios, 2023 TRB Annual Meeting

Opportunity to Comply with State Statute

Minnesota Statute 174.03, Subdivision 12

Trunk highway performance, resiliency, and sustainability.

(a) The commissioner must implement performance measures and annual targets for the trunk highway system in order to construct resilient infrastructure, enhance the project selection for all transportation modes, improve economic security, and achieve the state transportation goals established in section 174.01.

(b) At a minimum, the transportation planning process must include:

> (1) an inventory of transportation assets, including but not limited to bridge, pavement, geotechnical, pedestrian, bicycle, and transit asset categories.

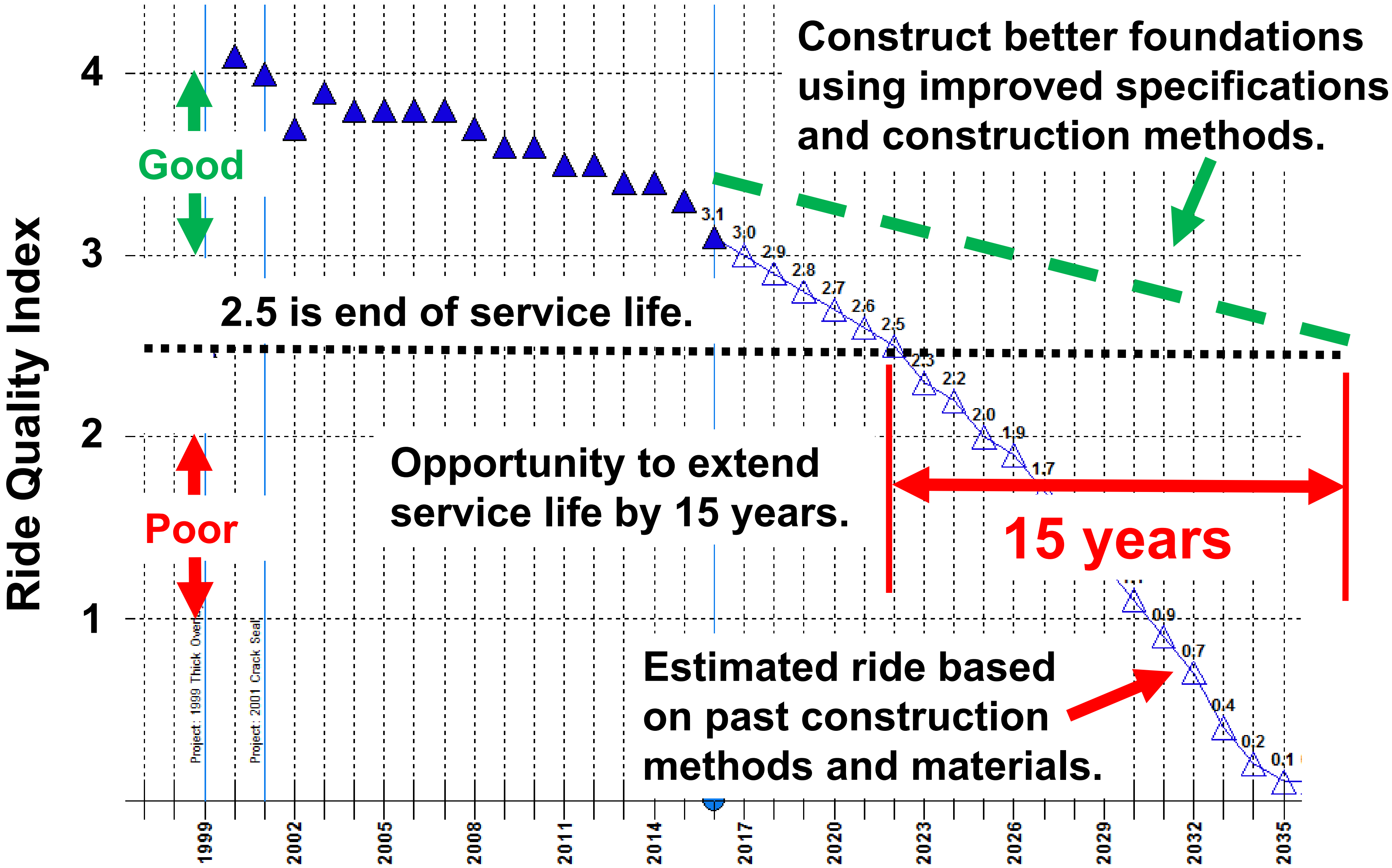
Geotechnical Assets Defined

MnDOT Geotechnical Asset Website:
www.dot.state.mn.us/gisspec/methods/geotechnical.html
Grading and Base Manual, MnDOT, 2021
Other government agencies also include the pavement foundation:

- Embankments and slopes
- Pavement subgrade, subbase, and base
- Stabilized full depth reclamation
- Edge drains and subcut drains
- Aggregate and quarry sites
- Geosynthetics, cement, and lime treated subgrade

Geotechnical Asset Management, NCHRP, 2019

Opportunity to Extend Service Life



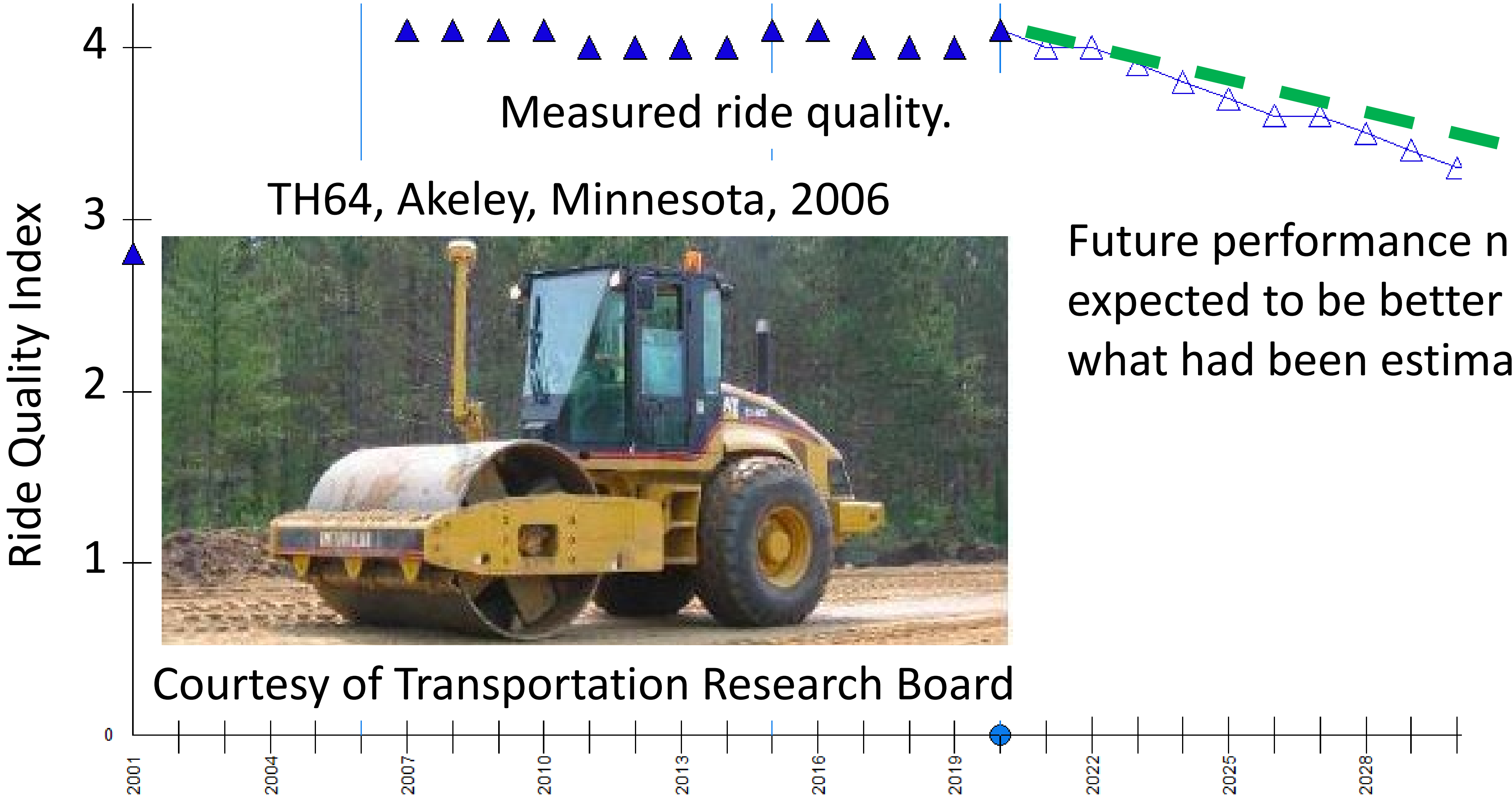
Construct better foundations using improved specifications and construction methods.

2.5 is end of service life.

Opportunity to extend service life by 15 years.

Estimated ride based on past construction methods and materials.

Opportunity to Construct Better Foundations



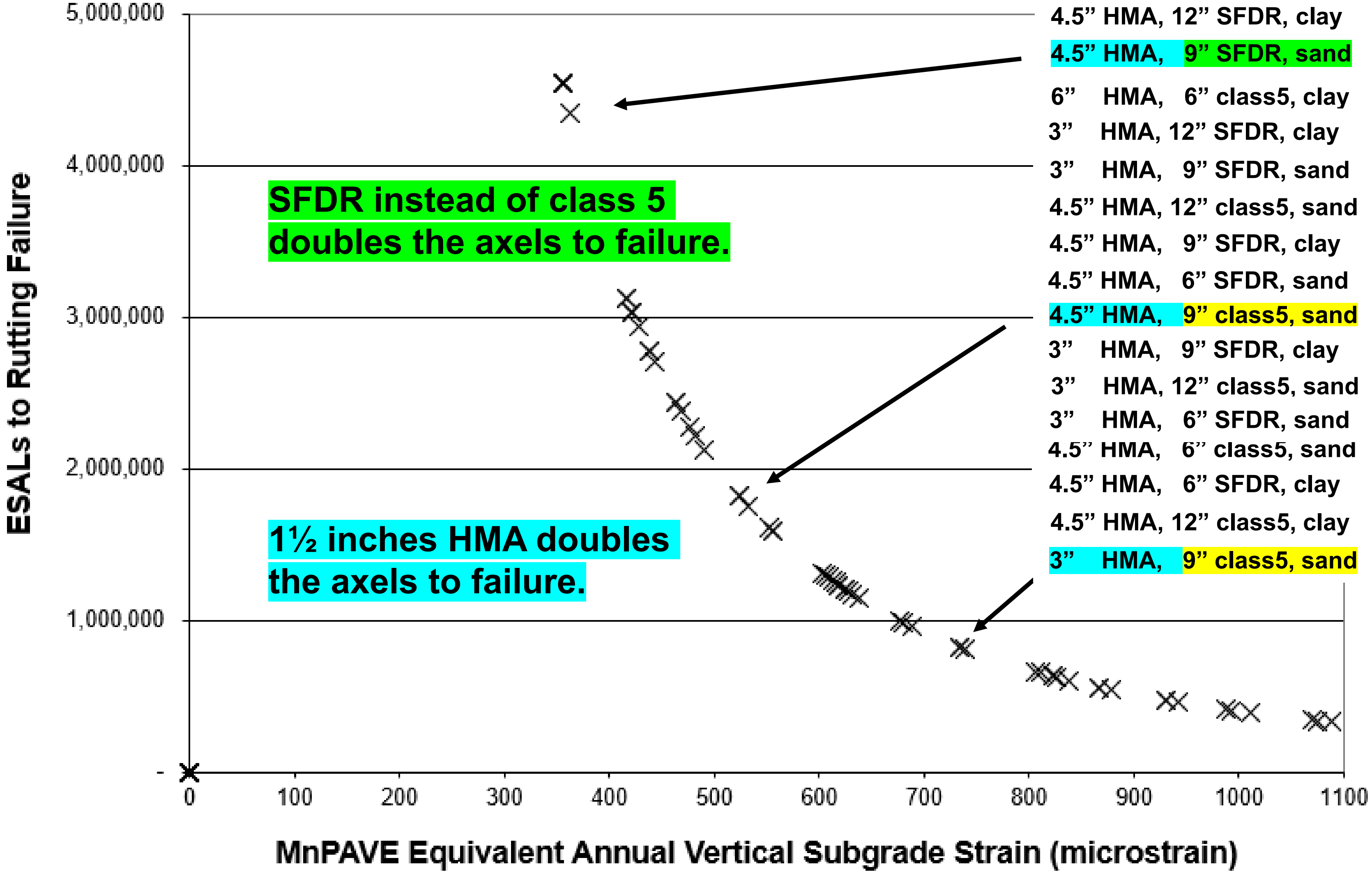
Measured ride quality.

TH64, Akeley, Minnesota, 2006

Courtesy of Transportation Research Board

Future performance now expected to be better than what had been estimated.

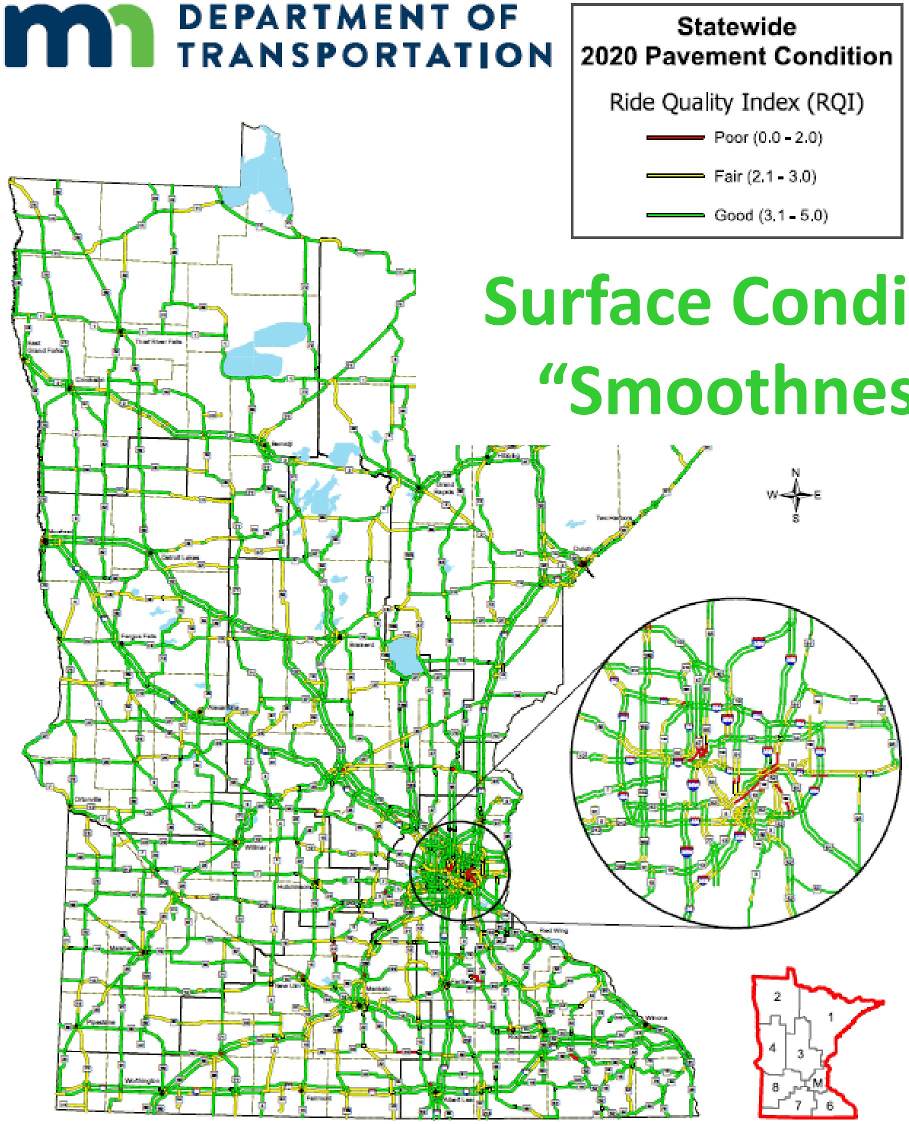
Service Life Expected to be Extended using Stabilized Full Depth Reclamation



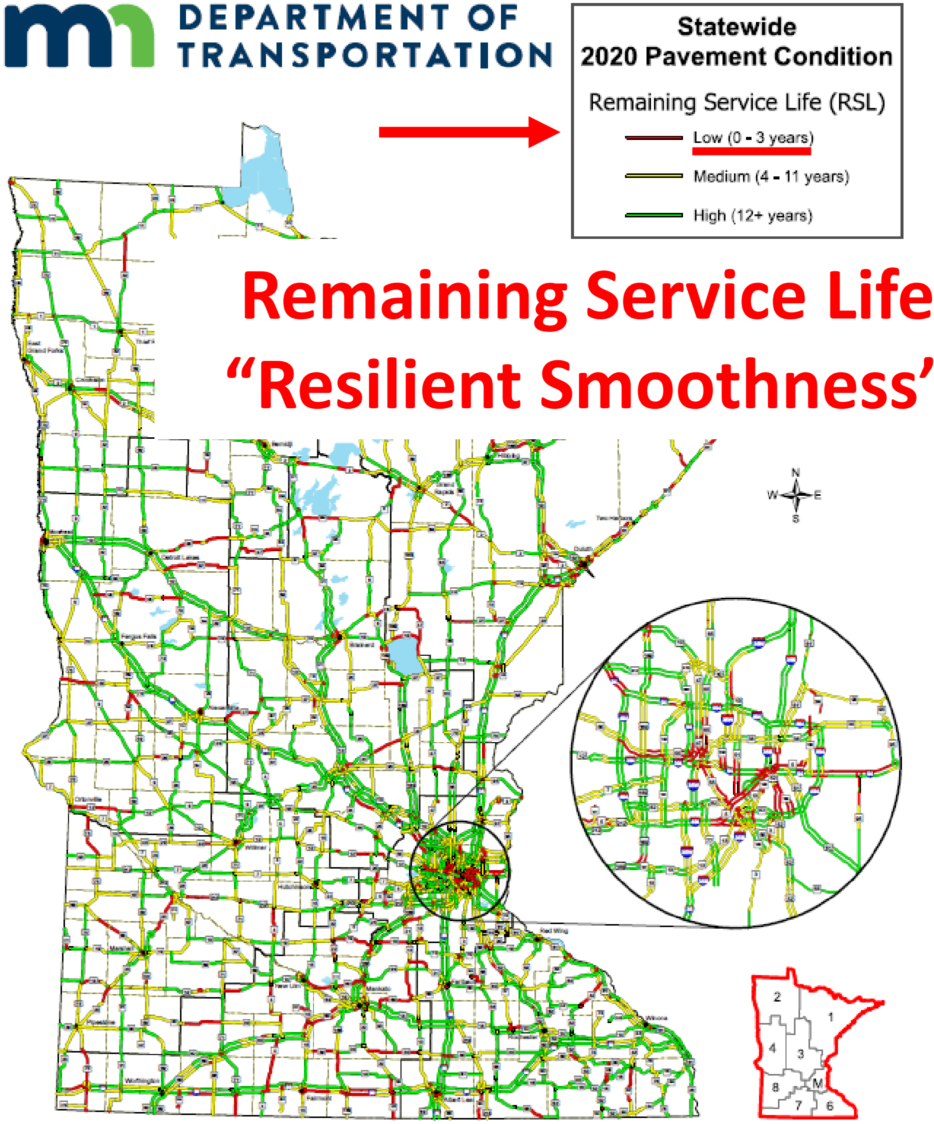
SFDR instead of class 5 doubles the axels to failure.

1½ inches HMA doubles the axels to failure.

Opportunity to Enhance Resilience



Surface Condition
“Smoothness”



Remaining Service Life
“Resilient Smoothness”

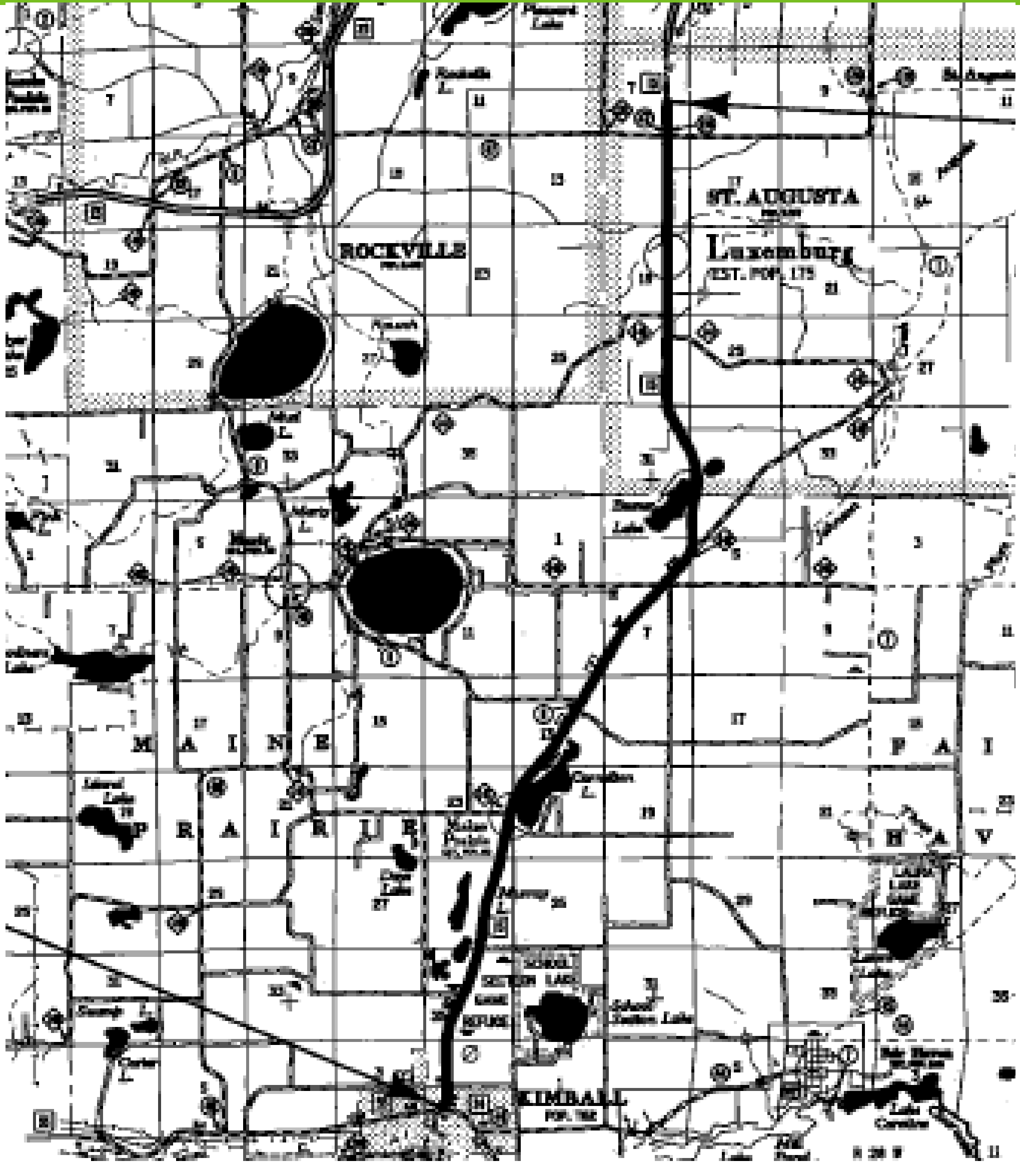
Want to Avoid Mark Twain’s Observation

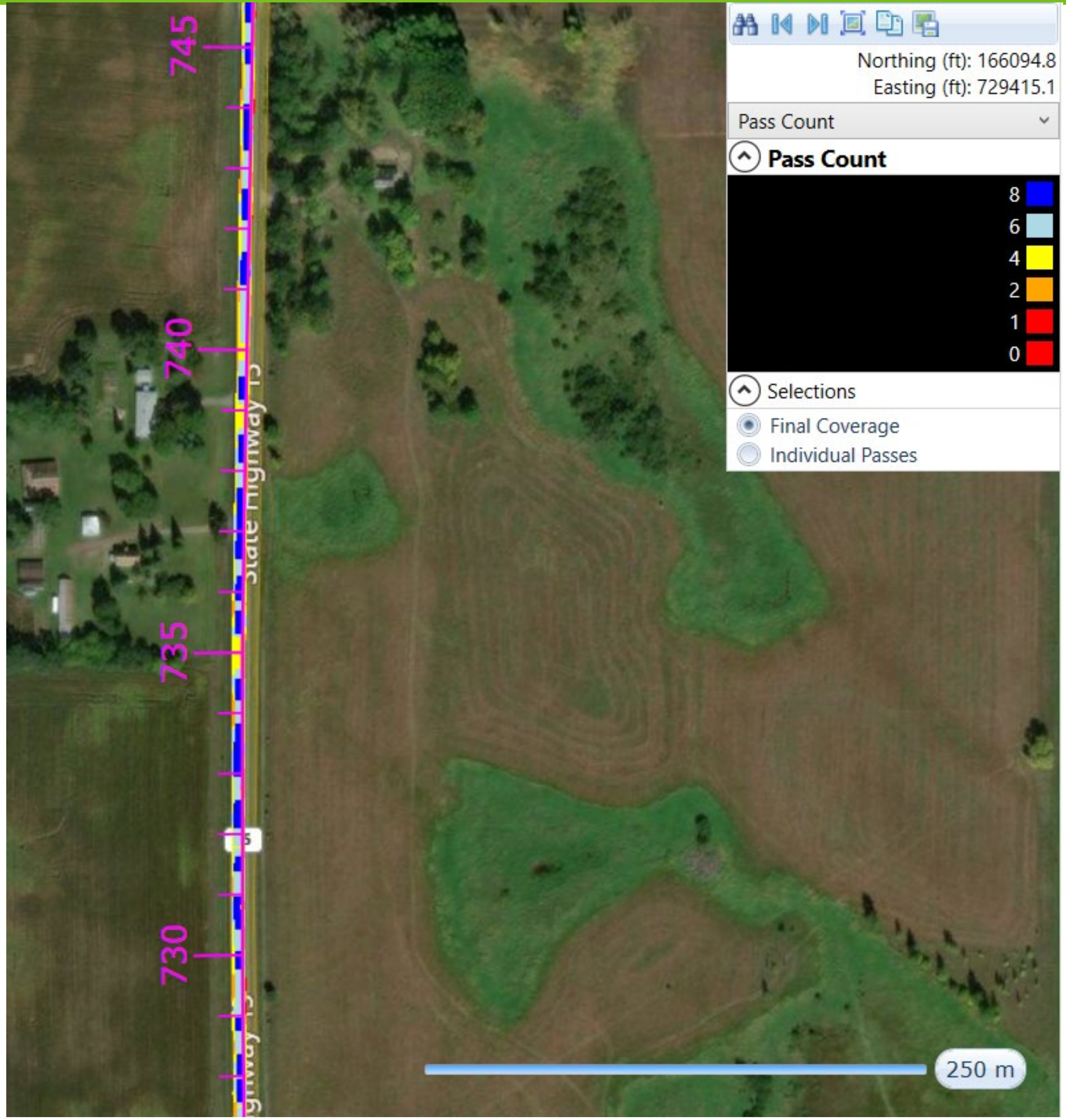
“Where pavements consist exclusively of holes with asphalt around them, these are the most economical because holes never go out of repair.”

2019 Construction Example
Stabilized Full Depth Reclamation

- Construction Schedule: February to July 2019
- Soils: Mixed Sand, Silt and Clay
- Existing Base: 4”, Existing Asphalt 6-15”
- Mill 3”, Reclaim Asphalt/Base Stabilize 6”, HMA 4”
- 2019 Fall Award Winner
- 2020 Winter and Spring differential heave

Stearns County (Kimball to St. Augusta)





Northing (ft): 166094.8
Easting (ft): 729415.1

Pass Count

Pass Count

8	🟦
6	🟦
4	🟨
2	🟧
1	🟥
0	🟥

Selections

● Final Coverage
○ Individual Passes

Roller #1 CP56B

Courtesy of Caterpillar

Roller #2 CP271

Courtesy of Dynapac

Roller #3 CB66B

Courtesy of Caterpillar

Case History Analyses

Northing (ft): 166004.9
Easting (ft): 731193.1

Amplitude

Amplitude (mm)

2.40	🟦
2.20	▨
2.00	🟨
1.80	🟧
1.60	🟥

Selections
- ● Final Coverage
- ○ Individual Passes

Northing (ft): 166116.9
Easting (ft): 730811.9

Pass Count

Pass Count

8	🟦
6	▨
4	🟨
2	🟧
1	🟥
0	🟥

Selections
- ● Final Coverage
- ○ Individual Passes

Northing (ft): 166889.1
Easting (ft): 731196.4

Trimble CMV

Trimble CMV

25.0	🟦
20.0	▨
15.0	🟨
10.0	🟧
5.0	🟥

Selections
- ● Final Coverage
- ○ Individual Passes

Northing (ft): 166379.4
Easting (ft): 730775.9

Speed

Speed (kph)

11.0	🟥
10.0	🟧
9.0	🟨
8.0	▨
7.0	🟦

Selections
- ● Final Coverage
- ○ Individual Passes

Free Software

Veta

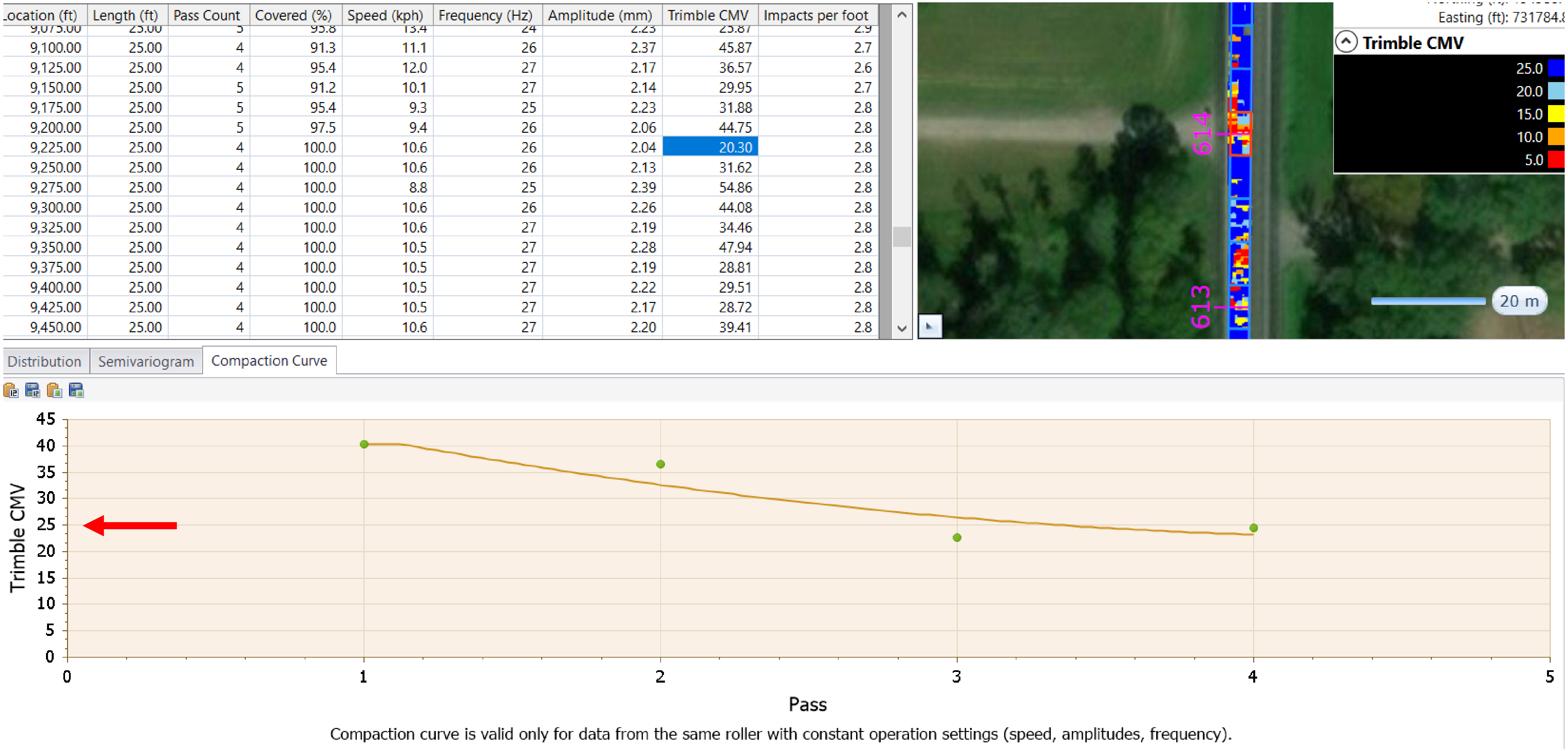
www.fhwa.dot.gov/pavement/ic/

Click on “more information”

Roller #1 CP56B

Courtesy of Caterpillar

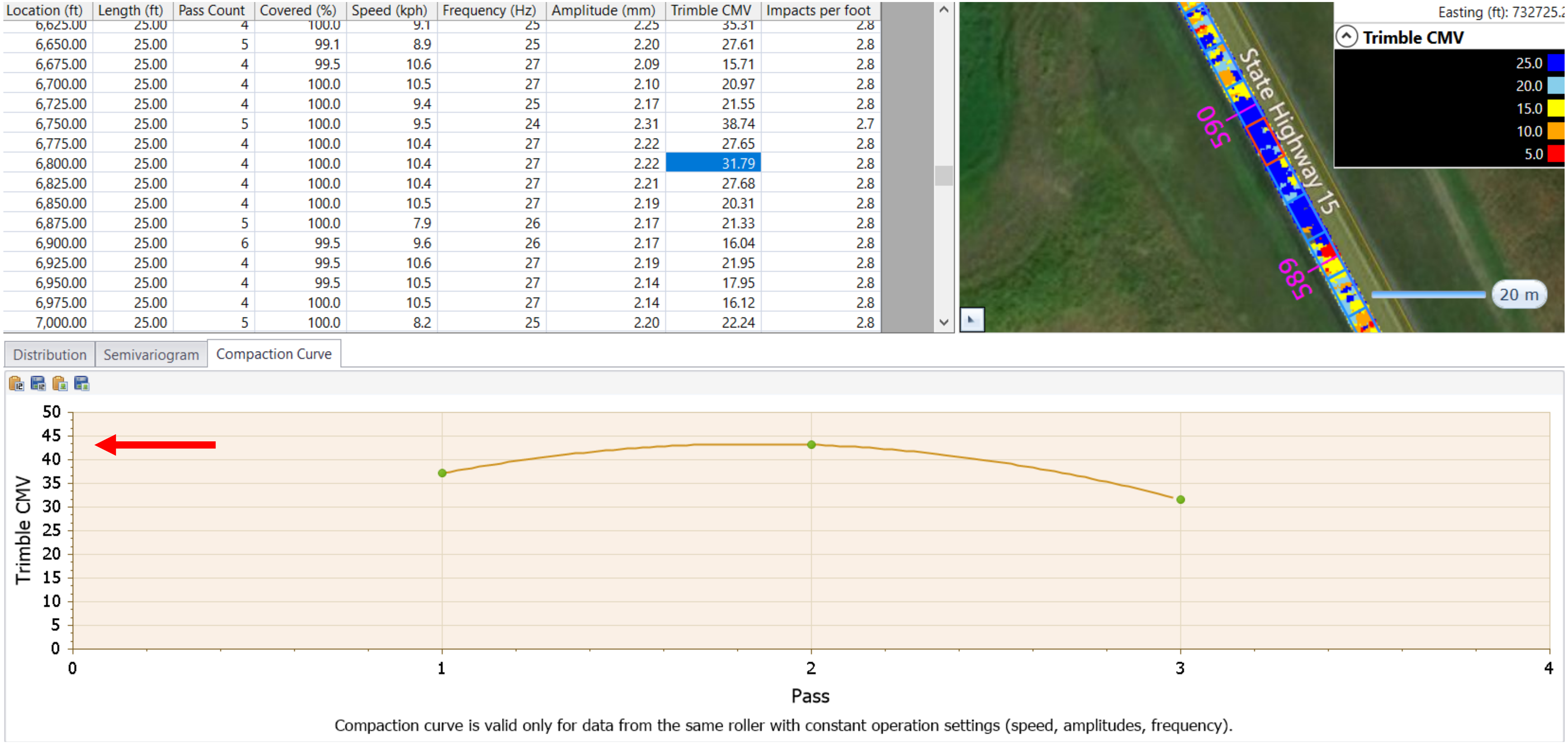
Aggregate Base Compaction Curve (low stiffness)



ocation (ft)	Length (ft)	Pass Count	Covered (%)	Speed (kph)	Frequency (Hz)	Amplitude (mm)	Trimble CMV	Impacts per foot
9,075.00	25.00	5	95.8	13.4	24	2.23	25.87	2.9
9,100.00	25.00	4	91.3	11.1	26	2.37	45.87	2.7
9,125.00	25.00	4	95.4	12.0	27	2.17	36.57	2.6
9,150.00	25.00	5	91.2	10.1	27	2.14	29.95	2.7
9,175.00	25.00	5	95.4	9.3	25	2.23	31.88	2.8
9,200.00	25.00	5	97.5	9.4	26	2.06	44.75	2.8
9,225.00	25.00	4	100.0	10.6	26	2.04	20.30	2.8
9,250.00	25.00	4	100.0	10.6	26	2.13	31.62	2.8
9,275.00	25.00	4	100.0	8.8	25	2.39	54.86	2.8
9,300.00	25.00	4	100.0	10.6	26	2.26	44.08	2.8
9,325.00	25.00	4	100.0	10.6	27	2.19	34.46	2.8
9,350.00	25.00	4	100.0	10.5	27	2.28	47.94	2.8
9,375.00	25.00	4	100.0	10.5	27	2.19	28.81	2.8
9,400.00	25.00	4	100.0	10.5	27	2.22	29.51	2.8
9,425.00	25.00	4	100.0	10.5	27	2.17	28.72	2.8
9,450.00	25.00	4	100.0	10.6	27	2.20	39.41	2.8

Compaction curve is valid only for data from the same roller with constant operation settings (speed, amplitudes, frequency).

Typical Base under Typical Asphalt



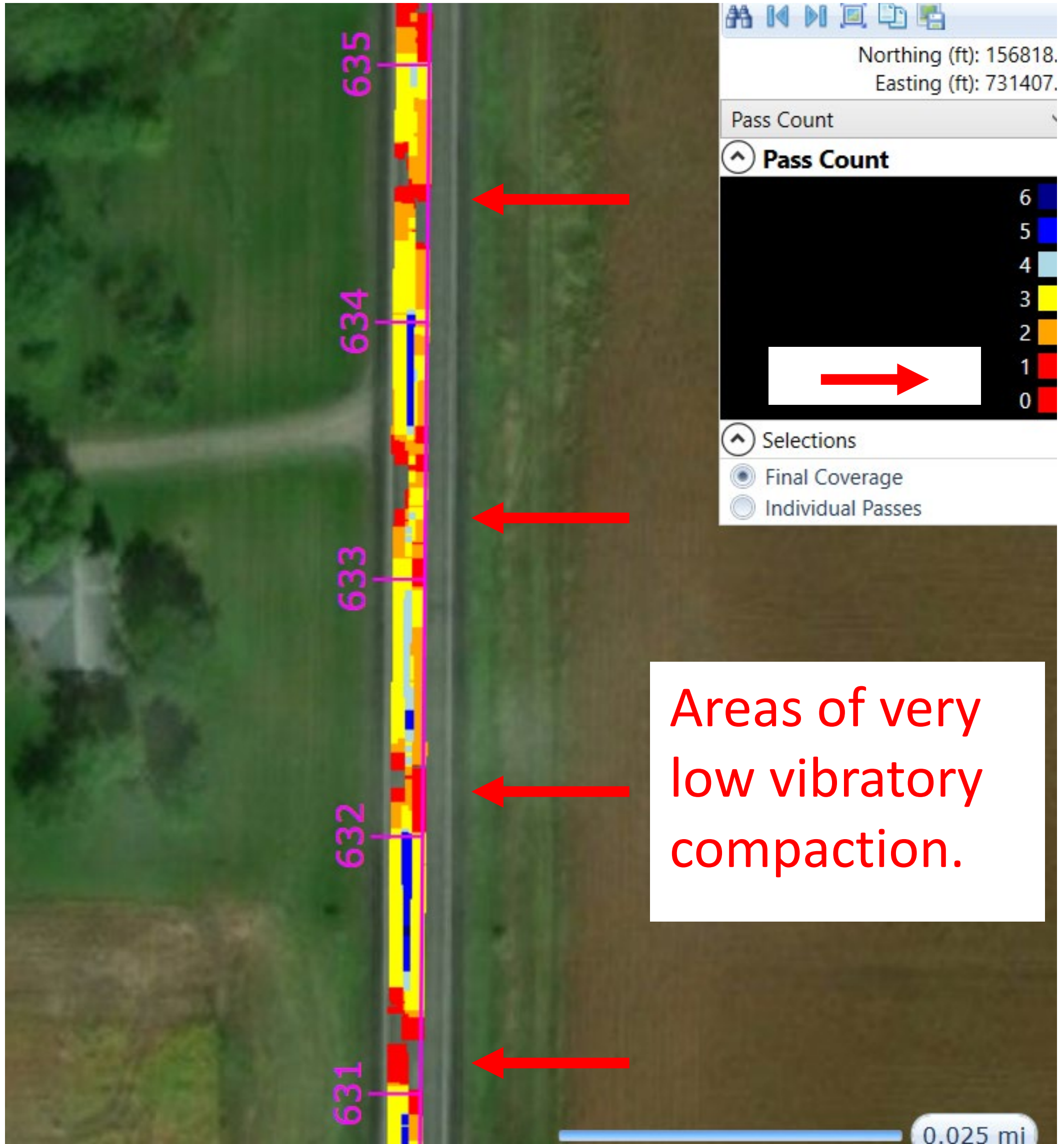
Location (ft)	Length (ft)	Pass Count	Covered (%)	Speed (kph)	Frequency (Hz)	Amplitude (mm)	Trimble CMV	Impacts per foot
6,625.00	25.00	4	100.0	9.1	25	2.25	35.31	2.8
6,650.00	25.00	5	99.1	8.9	25	2.20	27.61	2.8
6,675.00	25.00	4	99.5	10.6	27	2.09	15.71	2.8
6,700.00	25.00	4	100.0	10.5	27	2.10	20.97	2.8
6,725.00	25.00	4	100.0	9.4	25	2.17	21.55	2.8
6,750.00	25.00	5	100.0	9.5	24	2.31	38.74	2.7
6,775.00	25.00	4	100.0	10.4	27	2.22	27.65	2.8
6,800.00	25.00	4	100.0	10.4	27	2.22	31.79	2.8
6,825.00	25.00	4	100.0	10.4	27	2.21	27.68	2.8
6,850.00	25.00	4	100.0	10.5	27	2.19	20.31	2.8
6,875.00	25.00	5	100.0	7.9	26	2.17	21.33	2.8
6,900.00	25.00	6	99.5	9.6	26	2.17	16.04	2.8
6,925.00	25.00	4	99.5	10.6	27	2.19	21.95	2.8
6,950.00	25.00	4	99.5	10.5	27	2.14	17.95	2.8
6,975.00	25.00	4	100.0	10.5	27	2.14	16.12	2.8
7,000.00	25.00	5	100.0	8.2	25	2.20	22.24	2.8

Easting (ft): 732725.

Trimble CMV	
25.0	🟦
20.0	🟦
15.0	🟨
10.0	🟧
5.0	🟥

Compaction curve is valid only for data from the same roller with constant operation settings (speed, amplitudes, frequency).

Vibratory and Static Compaction


Northing (ft): 156818.
Easting (ft): 731407.

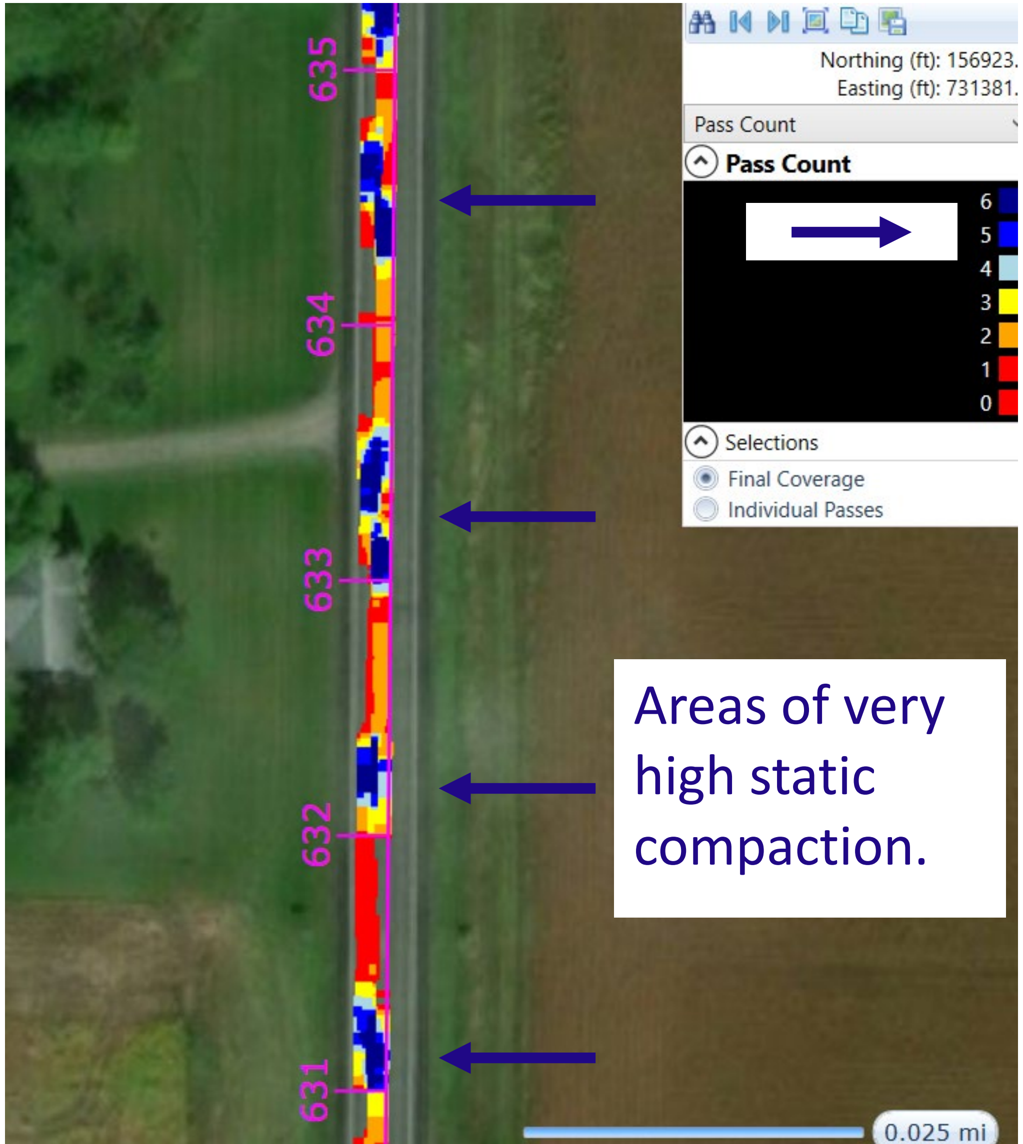
Pass Count

Pass Count

Selections

● Final Coverage
○ Individual Passes

Areas of very low vibratory compaction.


Northing (ft): 156923.
Easting (ft): 731381.

Pass Count

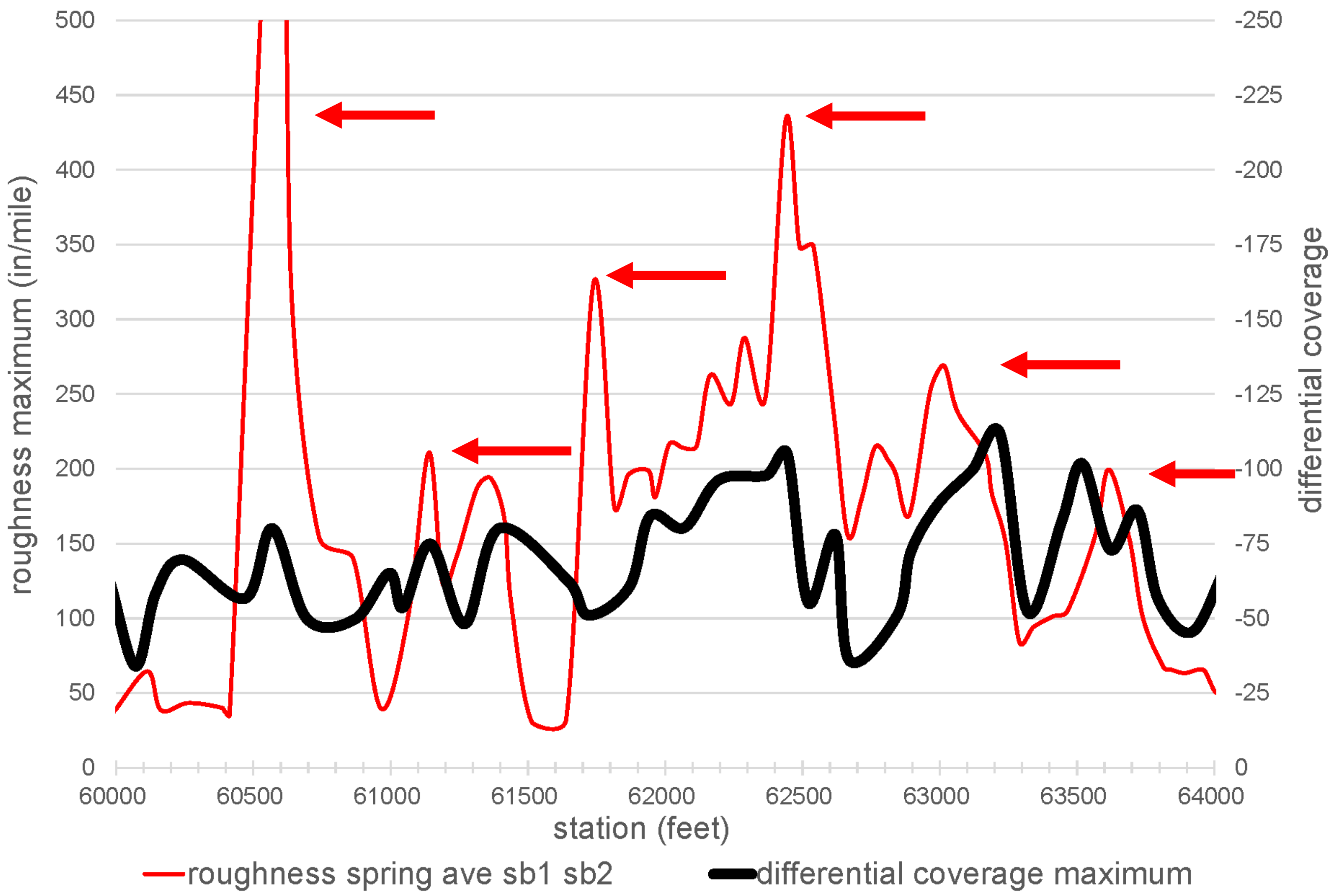
Pass Count

Selections

● Final Coverage
○ Individual Passes

Areas of very high static compaction.

Roughness and Differential Coverage Maximum

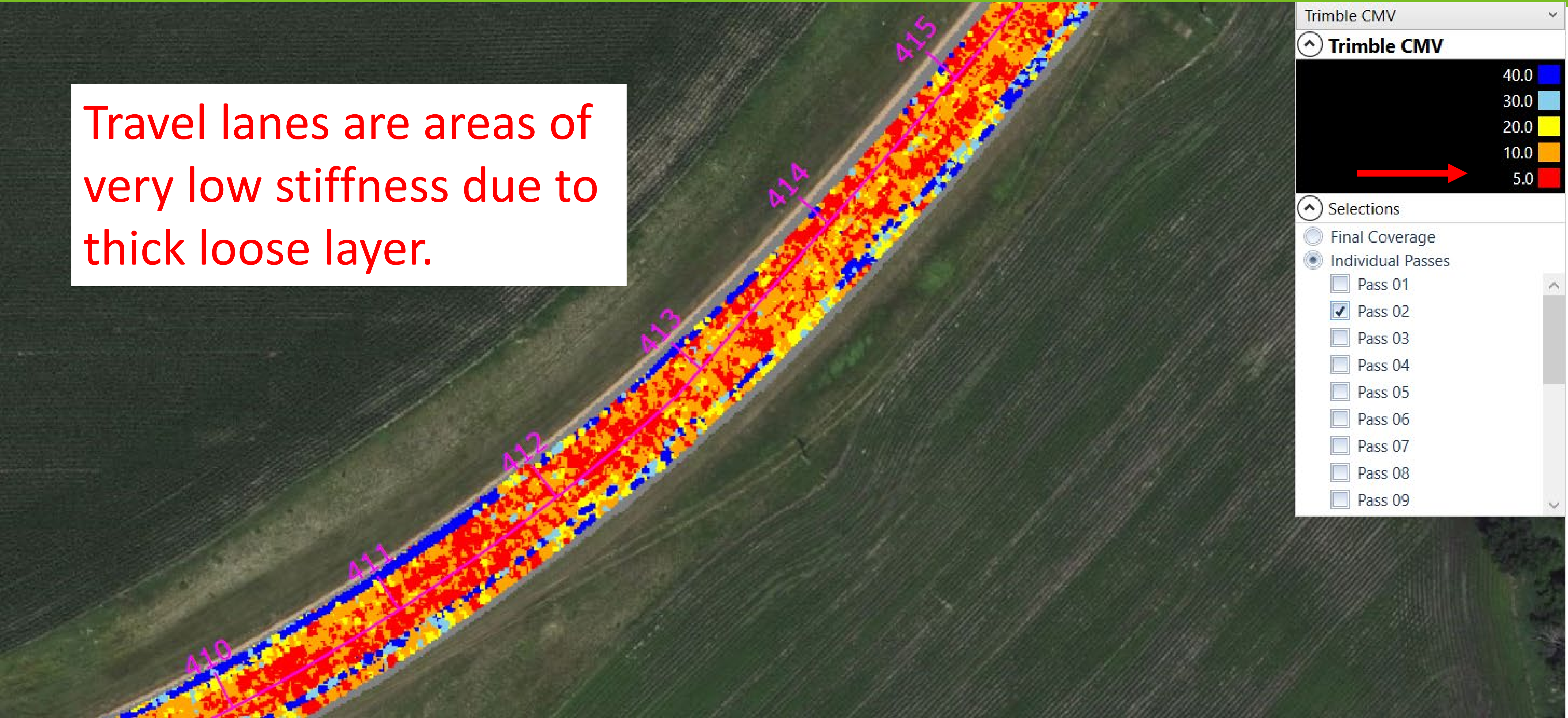


Roughness greater than 10 in/mile and differential coverage greater than 25%.

2021 Construction Example
SFDR and Asphalt Paving

- Construction Schedule: June to October 2021
- Soils: Mixed Silt, Clay, Sand and Gravel
- Existing Base: Variable, Existing Asphalt: 6-15”
- Mill 3”, Reclaim 9”, Stabilize 6”, HMA 3”

Nonuniform Stiffness due to Differential SFDR Thickness



Trimble CMV

Selections

○ Final Coverage

● Individual Passes

☐ Pass 01

☑ Pass 02

☐ Pass 03

☐ Pass 04

☐ Pass 05

☐ Pass 06

☐ Pass 07

☐ Pass 08

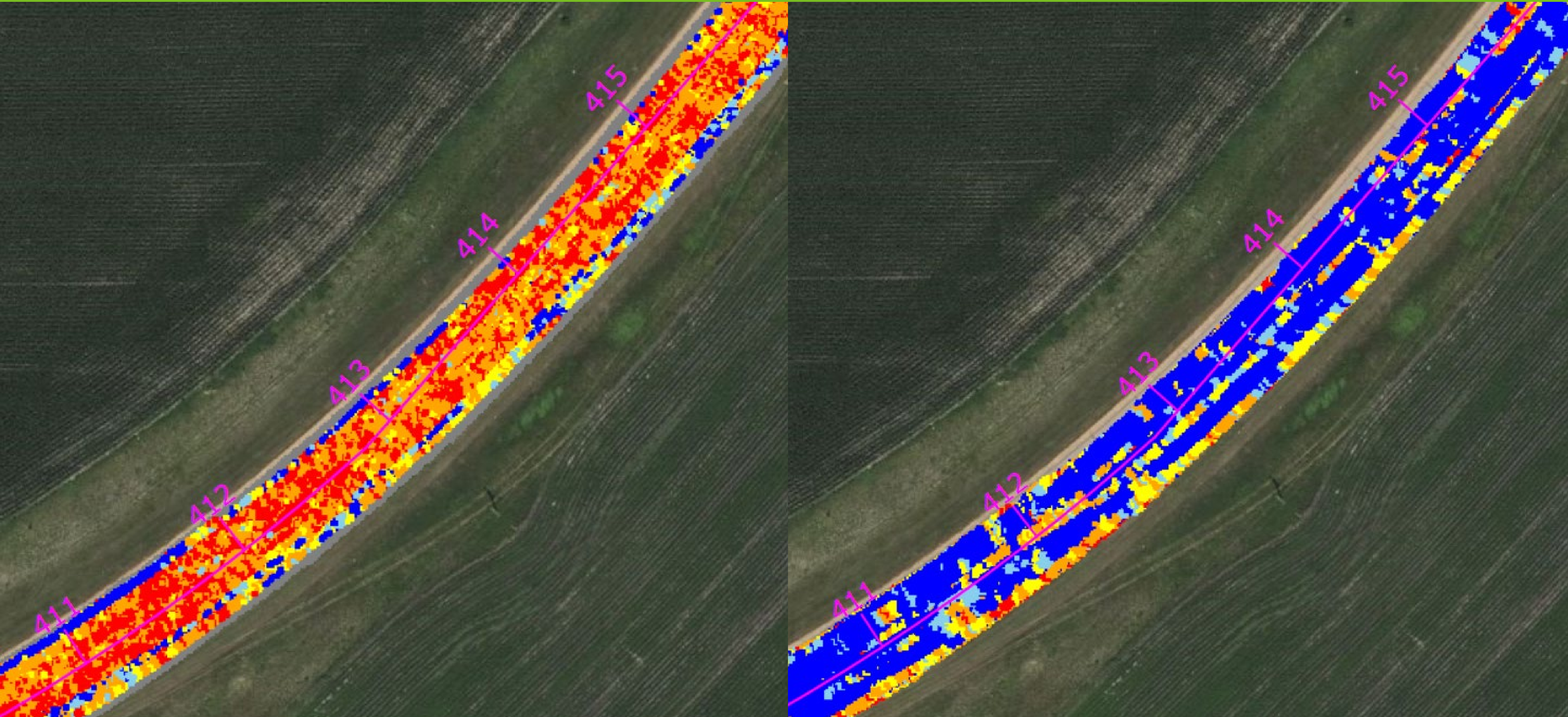
☐ Pass 09

Travel lanes are areas of very low stiffness due to thick loose layer.

Uniform Final Stiffness after Mitigation and Additional Compaction

Travel lanes have been compacted to uniform high stiffness.

Nonuniform Stiffness and Uniform Final Stiffness



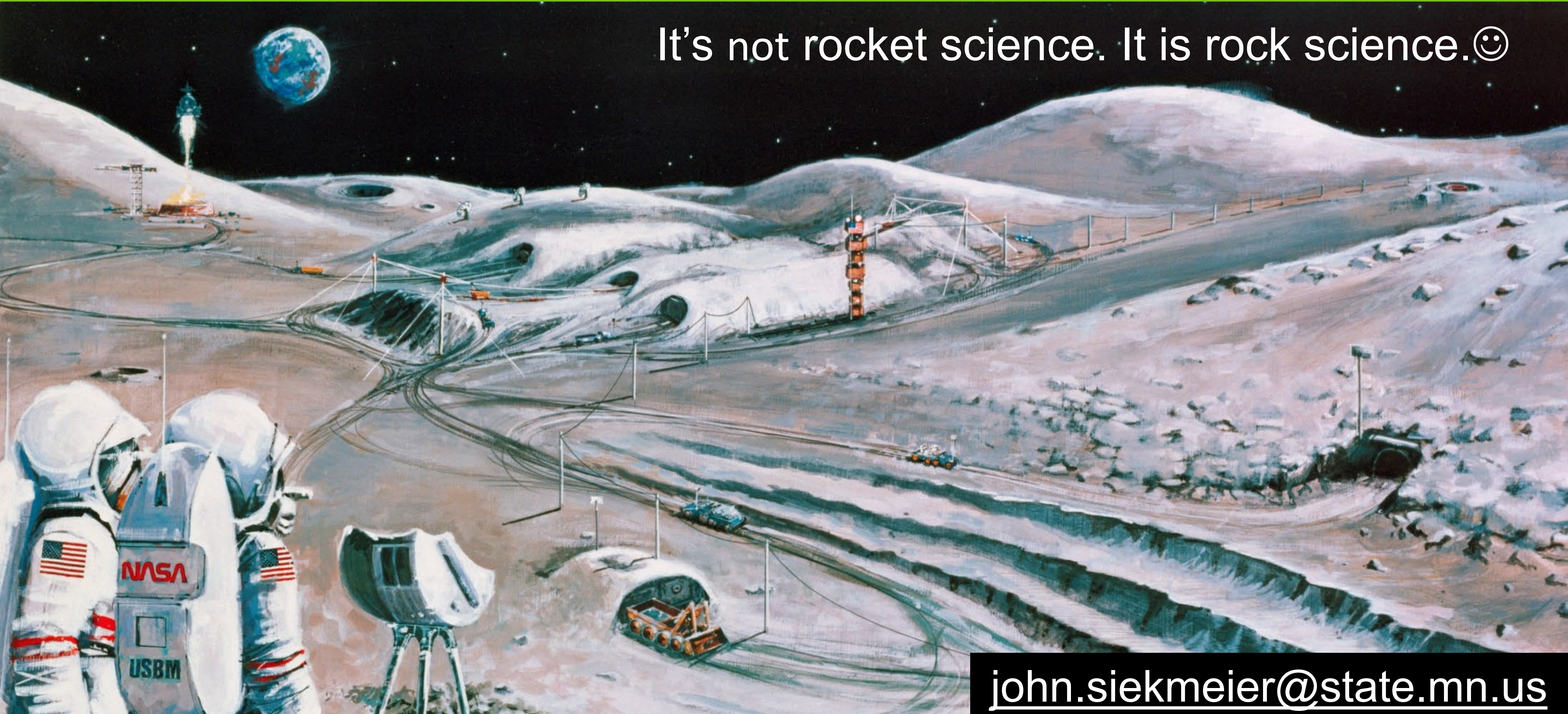
Lessons Learned and Next Steps

- Greater deployment of advanced materials and technology will help our contractors and construction staff build longer lasting roadways.
- Intelligent compaction, light weight deflectometers, and dynamic cone penetrometers provide effective quality assurance.
- Implementation continues so that the people’s investments are well spent.

Important Reminder

> Virtually every structure is supported on soils.
>
> Those which are not, either fly, float or fall over.
>
> Richard Handy

Thank you for Listening. Please ask questions.



It's not rocket science. It is rock science.☺

john.siekmeier@state.mn.us

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tutumlue@illinois.edu
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John Siekmeier
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Minnesota Department of Transportation

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March 13, 2023

TRB Webinar: Use of Recycling Agents in Asphalt Concrete Mixtures

March 16, 2023

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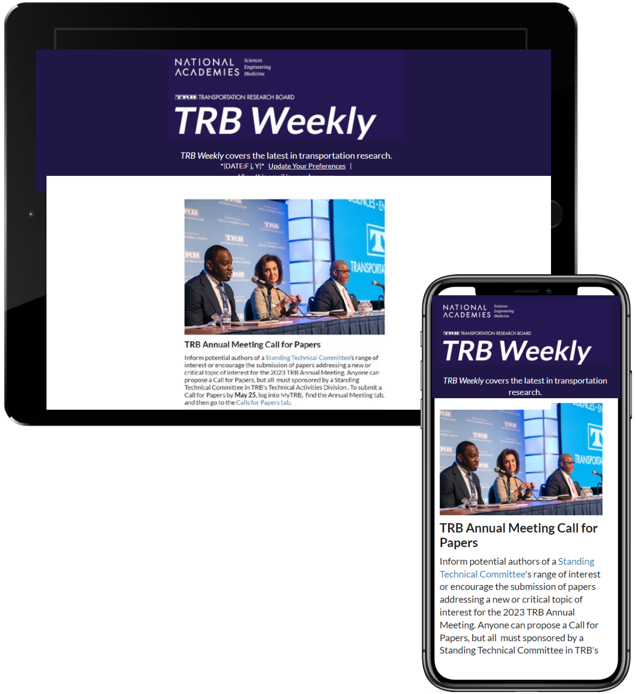

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Thursday, October 6, 2:30 - 4 PM ET
Disruptions to transportation supply chains can cause cascading effects globally and socioeconomically. This webinar will discuss leading-edge technologies and the impacts logistics modeling with artificial intelligence and resilience analytics can have on a larger scale.

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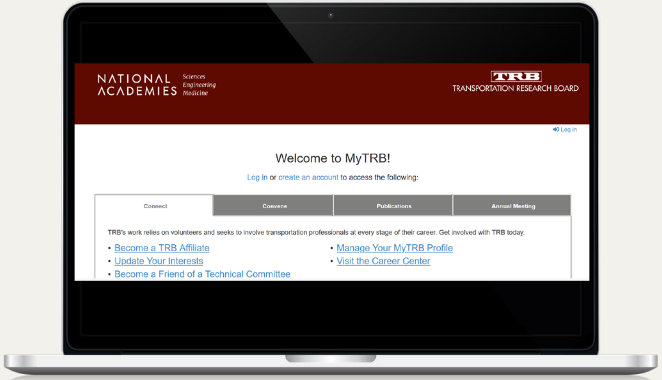

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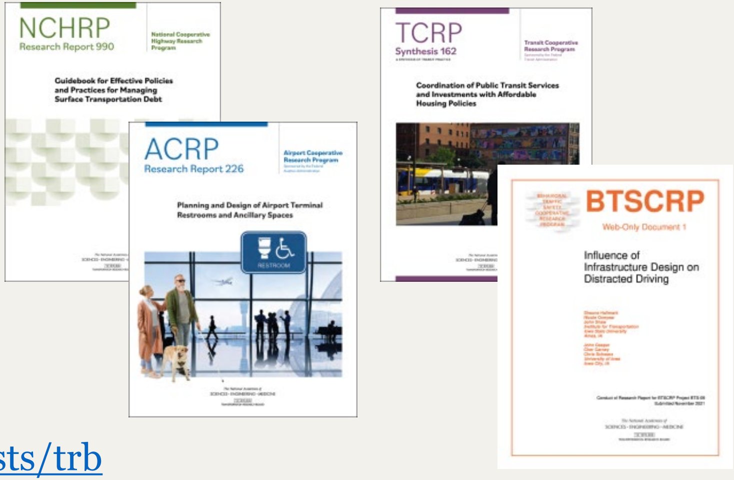
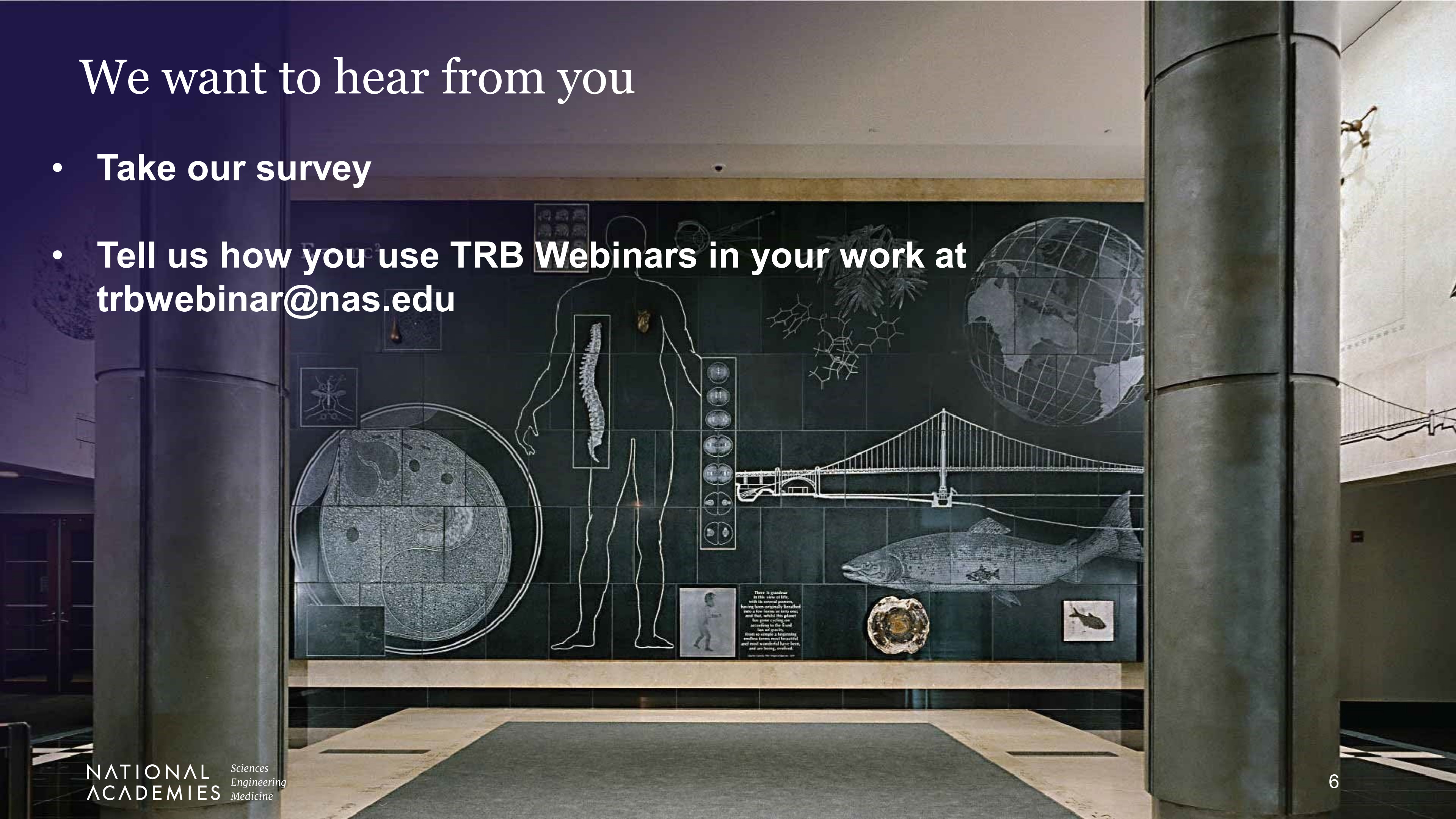


NCHRP Research Report 990
Guidebook for Effective Policies and Practices for Managing Surface Transportation Debt

ACRP Research Report 226
Planning and Design of Airport Terminal Restrooms and Ancillary Spaces

TCRP Synthesis 162
Coordination of Public Transit Services and Investments with Affordable Housing Policies

BTSCRP Web-Only Document 1
Influence of Infrastructure Design on Distracted Driving



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