13TH INTERNATIONAL CONFERENCE ON CONCRETE PAVEMENTS (ICCP)

ENGINEERING THE PAVEMENT FOUNDATION LAYERS WORKSHOP

August 27, 2024

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WORKSHOP SUMMARY

The National Concrete Pavement Technology Center (CP Tech Center), with support from the Federal Highway Administration (FHWA), sponsored a workshop at the 13th International Conference on Concrete Pavements (ICCP), held in Minneapolis, Minnesota from August 25 – 29, 2024. The Pavement Foundation Workshop was presented on August 27, 2024, from 1 to 5 PM. The workshop showed how to engineer and field-control the construction of pavement foundations using currently available advanced technologies to meet design requirements reliably. Ingios was responsible for planning the workshop, identifying appropriate subject matter experts, and developing technical content.

The workshop focused on the FHWA's 2019-2020 report to Congress on the Accelerated Implementation and Deployment of Pavement Technologies, AID-PT program. The report identifies that "Foundation design is a key aspect of pavement structural design that needs to be considered in design processes."

Current practice for owner agencies typically consists of a detailed pavement structural design without a similar process for the foundation system that the pavement structure is built. In addition, the construction process commonly does not include any meaningful verification that the pavement design assumption for the foundation system is achieved in the field, leading to foundations being a significant cause of early pavement distress.

The intended outcome of the workshop was to help owner agencies understand that pavement foundation layers can be engineered and field-controlled to meet the design intent. The presentations were coordinated to address the following objectives:

- Understand the critical design inputs or lack thereof for pavement performance relative to the foundation,
- Understand that typically, what is built is not accepted on engineering criteria assumed during the design of the pavement,
- Understand there are intelligent technologies available to measure design inputs during construction,
- Mechanistic modeling needs to be confirmed with performance over time,
- A technical pooled fund (TPF) is proposed to assist SHA's with building pilot projects.

Leif Wathne, CP Tech Center moderated the workshop which was organized into five presentations.

1. Why is this important?

Tom Cackler, General Manager for Ingios and former Chief Engineer for the Iowa DOT, discussed why building quality foundations is a strategic decision for being able to manage an agency's pavement network fiscally.

2. The Ideal Pavement

Tom Yu, FHWA, discussed the elements of an ideal pavement that will have a long life and low maintenance requirements.

3. Pavement Foundation Design 101

Prof. Jeff Roesler, University of Illinois Urban-Champaign, overviewed key foundation inputs for a successful pavement design and why they are important. Prof. Roesler also addressed shortcomings in the current design methodologies related to foundations.

4. How to Achieve Engineered Foundations

Dr. David White, Chief Engineer for Ingios, discussed how currently available technologies enable the engineer to design and control the construction process to ensure pavement foundations meet the design requirements.

5. Advancing National Practice.

Tom Yu also reviewed the objectives of a proposed TPF project by the Iowa DOT to further advance pavement foundation design and construction practices.

On Thursday, August 29, the ICCP offered an optional MnROAD pavement test track tour. As a follow-up to the workshop, Ingios demonstrated advanced technologies for Automated Plate Load Testing (APLT) and e-Compaction Mapping, allowing workshop attendees to experience the technologies discussed in the workshop firsthand. Approximately 80 meeting attendees, including participants from multiple state/federal agencies and research institutions, participated in the field demonstration.

This summary report's appendices include the workshop handouts, presentation slides, attendee list, and photos from the workshop and MnROAD tour.

APPENDIX A: WORKSHOP HANDOUTS

- AID Survey – Pavement Performance
- Iowa DOT innovations Solutions
- Roadmap for Long-life Pavements

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National DOT Survey Findings & Results

Accelerated Innovation Deployment (AID) Demonstration Project

Increasing Pavement Performance through Pavement Foundation Design Modulus Verification and Construction Quality Monitoring

Of all responding agencies:

97% Want more effective quality acceptance (QA) for pavement foundation construction.

94% Want data reports to support field process controls during foundation layer construction.

94% Want to field verify the engineering properties used in pavement design for the foundation layers.

100% Are interested in learning more about Iowa DOT's AID implementation efforts to bring improved solutions to pavement foundation layers.

97% Want real-time QA data to determine if design and specification requirements are achieved.

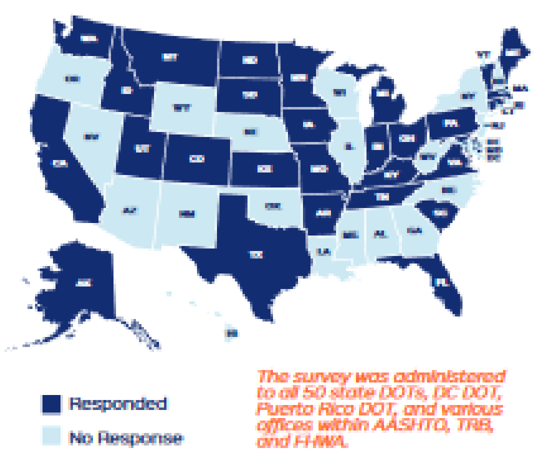
3% **Only 3% of agencies have a quality acceptance parameter that directly measures design requirements.**

e-Compaction Keeps Traffic Moving by Exending Pavement Life (a TSMO Strategy)

When every minute counts to keep traffic moving, DOTs can count on e-Compaction to:

- Accelerate quality inspection documentation x 1,000x's in real-time
- Increase pavement life by 20-50%
- Avoid costly delays by as much as $10,000+/- per day

Build Better From the Ground Up.™



The survey was administered to all 50 state DOTs, DC DOT, Puerto Rico DOT, and various offices within AASHTO, TRB, and FHWA.

A smooth drum roller equipped with modulus mapping technology can detect less compacted areas of a road's foundation during construction. An in-cab touch screen (inset) displays results in near real time.

INNOVATION SOLUTIONS

Advanced technologies ensure Iowa's pavement foundations are built as designed

Beneath every pavement are foundational layers of aggregate, soil, and other materials designed to suit the road's location, traffic demands, and other factors. When roadway foundations are properly constructed, the finished pavement should perform well for decades. Until recently, however, inspection methods and tools have not been able to detect certain problems within the foundation until after the road is complete, making cracks and other premature distresses difficult to prevent. Through a demonstration project, Iowa DOT piloted innovative new technologies at several project sites that make it possible to assess and remediate issues during construction, leading to stronger foundations and better-performing pavements.

THE NEED

Road maintenance and repair activities are not just a financial expense for transportation agencies; they can also be hazardous for crews working near traffic and frustrating for travelers who experience road closures and delays. To help pavements last longer and require less maintenance, Iowa DOT—like other transportation agencies across the United States—has reevaluated nearly every aspect of road building, implementing a variety of innovations related to design, construction, and materials. Despite real progress in this area, some pavements continue to deteriorate faster than they should.

In 2017 Iowa DOT initiated a research project evaluating the foundational layers of 10 highways in the state and found that most were not constructed exactly as designed. While studies have consistently shown a direct correlation between the compaction uniformity of a road's foundation and its long-term perfor-

(continued)

"We're constantly looking for ways to make pavements perform better and last longer. We've already improved the materials, specifications, and construction practices we use, and evaluating foundations is another way we can extend the life of the state's pavements."

– CHRIS BRAKKE,
Iowa DOT Pavement Design & Pavement Management Engineer

mance, traditional testing equipment and inspection methods have not been capable of detecting under-compacted areas during the construction process.

Now, recent strides in technology are making it possible for inspectors and construction teams to assess the quality and uniformity of pavement foundations on-site and in real time, allowing contractors to fix any problems before the road is complete and assuring transportation agencies that foundations are being built as intended. With a grant from the federal Accelerated Innovation Deployment (AID) Demonstration program, which aims to help states put innovations into practice, Iowa DOT and a team of engineers piloted two new state-of-the-art technologies at five road construction projects across the state to gain hands-on experience and to develop specifications for using these tools in the future.

PROJECT APPROACH

The project team tested two new commercially available technologies: roller mapping, which measures a foundation's uniformity, and Automated Plate Load Testing, a proprietary innovation used to gauge the foundation's ability to support heavy traffic loads. Project participants learned how to use and calibrate the equipment, as well as how data should be interpreted and applied.

In addition, a customized reporting tool was developed for Iowa DOT that analyzes the collected data and generates digital compaction reports within minutes to help contractors, engineers, and inspectors make informed decisions in real time.

WHAT IOWA LEARNED

The new mapping and data analysis technologies successfully measured and reported foundation compaction values in real time as expected, revealing areas of nonuniformity at the five test sites that otherwise might have gone undetected. The reporting tool, which continues to evolve to meet Iowa DOT's needs, helped participants share compaction results effectively.

The demonstration project also served to provide the project team with a better understanding of the interrelationships between specific procedures and measurement outcomes. This will help in the development of specifications that guide the various processes involved for maximum effectiveness.

PUTTING IT TO WORK

Iowa DOT has developed a detailed implementation plan with a target to incorporate the new technologies into standard practice statewide by 2025. Steps include bringing key stakeholders together for process review and oversight, training agency staff and contractors, and selecting additional pilot projects to help regional engineers gain hands-on experience.

As these and other new technologies help build roads that last longer and require less maintenance and repair, Iowa DOT—and agencies across the country—stand to realize significant financial, safety, and mobility benefits.

ABOUT THIS PROJECT

PROJECT NAME: Accelerated Innovation Deployment (AID) Demonstration Project: Increasing Pavement Performance Through Pavement Foundation Design Modulus Verification and Construction Quality Monitoring
Final Report | Technical Brief

PROJECT NUMBER: ST-008

REPORT DATE: October 2021

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iowadot.gov/research
ideas.iowadot.gov

IHRB IOWA HIGHWAY RESEARCH BOARD

STIC State Transportation Innovation Councils

Roadmap for Long-Life Pavements

Sustainable Pavements are only possible by starting with quality foundations.

Our nation needs pavements that will last longer. The key to improving pavement performance is building quality foundations and ensuring that they meet the design requirements at the time of initial construction. Integrating direct measurement of critical pavement design inputs into the pavement construction workflow reduces the owner's risk and eliminates unnecessary repairs in the future.

5 Steps to Build Better Foundations

Start Here

1 Assess

Study and describe your pavement design-construction-inspection-maintenance workflow.

Determine if how your current mechanistic design practices translate to quality requirements of the pavement foundation during construction.

2 Measure

Directly measure the in-situ modulus and deformation parameters of pavement foundation materials used in your state.

Establish a design database and improve knowledge for selecting achievable design parameter values.

3 Test

Build pilot projects using 100% design modulus verification mapping for quality assurance.

Report real-time results to promote on-time construction and improve areas that do not meet the minimum design requirements.

4 Define

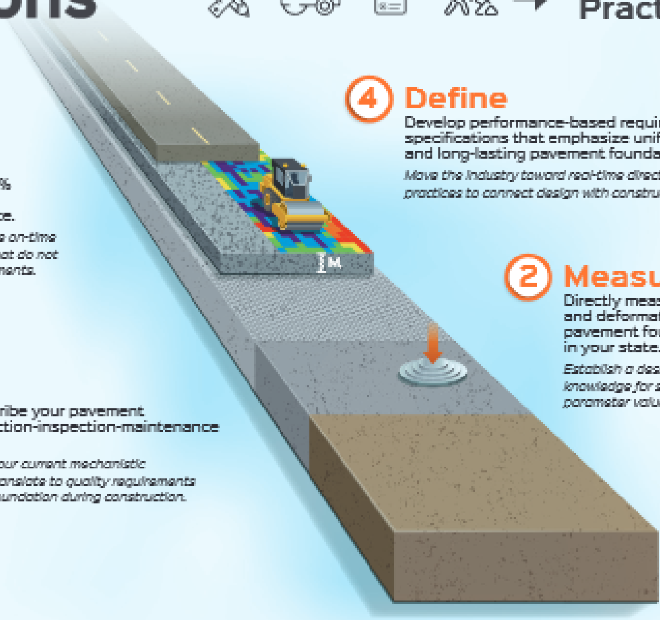
Develop performance-based requirements and specifications that emphasize uniform, stable, and long-lasting pavement foundations.

Move the industry toward real-time direct measurement practices to connect design with construction.

5 Implement

Share knowledge and collaborate to improve pavement foundation design-construction-inspection-maintenance practices in your state.

Integrate the findings in support of our national performance measurement goals.



Critical Needs

A disconnect exists between the inputs used in modern pavement design and the quality acceptance requirements during construction.[i] It is critically important to link these requirements. **97% of state DOTs want more effective quality acceptance (QA) technologies** for pavement foundations,[ii] and there is broad national interest in modernizing pavement foundation specifications and construction practices.[iii]

[i] White, D.J., P. Vennapusa, and B. Cetin. Improving the Foundation Layers for Concrete Pavements: Lessons Learned and a Framework for Mechanistic Assessment of Pavement Foundations. National Concrete Pavement Technology Center and Center for Earthworks Engineering Research, Institute for Transportation, Ames, IA.

[ii] National DOT Survey Findings and Results: Accelerated Innovation Deployment (AID) Demonstration Project: Increasing Pavement Performance through Pavement Foundation Design Modulus Verification and Construction Quality Monitoring Interim Report February 26, 2021.

[iii] FHWA. Accelerated Implementation and Deployment of Pavement Technologies 2019–2020 Annual Report. Federal Highway Administration, Washington, D.C.

About Ingios

Ingios partners with state agencies and academic collaborators to improve engineering and construction solutions by bringing state- of-the-art into practice. Learn more about our capabilities and projects at **www.ingios.com**

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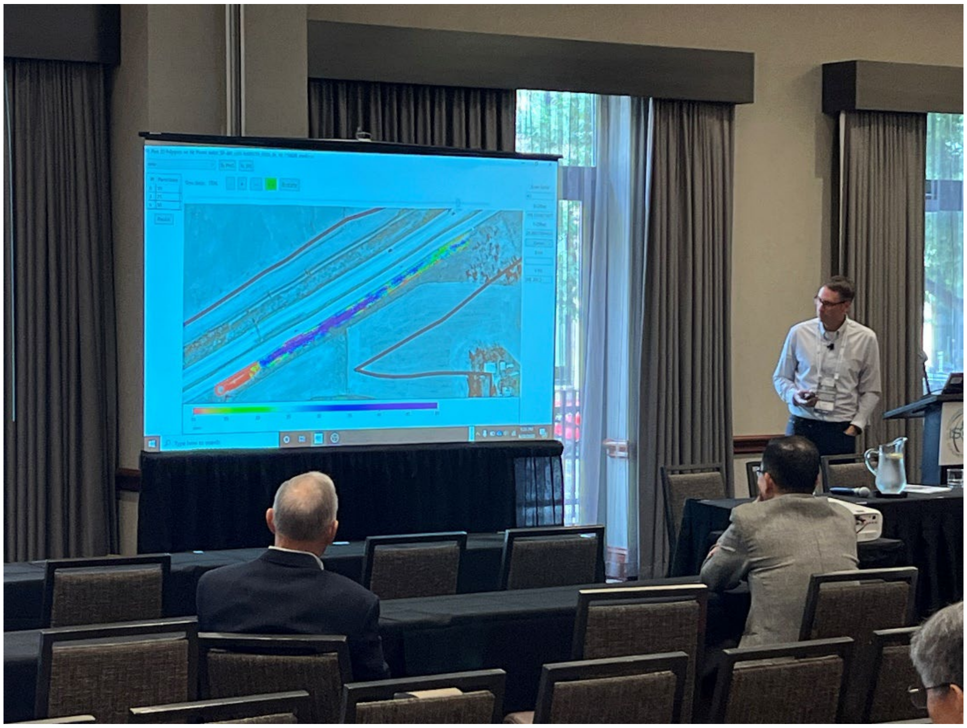
APPENDIX B: WORKSHOP AND DEMONSTRATION PHOTOS



5

Photos of workshop speakers, audience, and equipment used in demonstration.

APPENDIX C: PRESENTATION SLIDES

Pavement Foundation Workshop

13th ICCP | Minneapolis, MN | Aug 13, 2024

U.S. Department of Transportation
Federal Highway Administration
CPM Concrete Pavement Materials Program

1

Welcome and Introductions

CPM

2

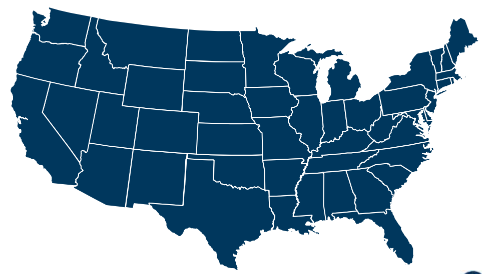
slido

What type of organization do you represent?

ⓘ Start presenting to display the poll results on this slide.

3

Attendees

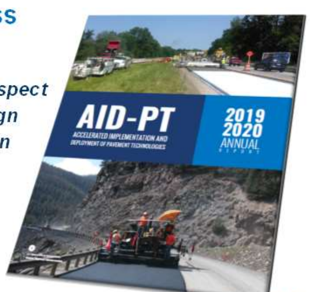


4 CPM

4

FHWA Report to Congress

- *Foundation design is a key aspect of pavements structural design that needs to be considered in design processes.*



Source: FHWA-HIF-21-024, AID-PT Annual Report, 2019-20

5 CPM

5

Objectives and Outcomes

Understand that pavement foundations layers can be engineered and field controlled to meet the design intent.

- Understand the critical design inputs or lack thereof for pavement performance relative to the foundation,
- Understand that typically what is built is not accepted on engineering criteria assumed during the design of the pavement,
- Understand there are intelligent technologies available to measure design inputs during construction,
- Mechanistic modeling needs to be confirmed with performance over time,
- TPF is proposed to assist SHA's with building a pilot project.

6 CPM

6

Agenda

- ▶ Why is this important?
- ▶ The ideal pavement
- ▶ Pavement foundation design 101
- ▶ *Break*
- ▶ How to achieve engineered foundations
- ▶ Advancing national practice
- ▶ Recap and adjournment

7 CPM

7

Why is this important?

Tom Cackler, Ingios

U.S. Department of Transportation
Federal Highway Administration
CPM Concrete Pavement Materials

8

Quality Foundations Are Strategic For DOTs

- What is the problem?
- How did we get here?
- Quality pavement foundations as a key strategy for achieving a sustainable network.

9 CPM

9

What is the problem?

- Condition of the national system is not good and there is not enough funding to address the needs.
- ASCE Report Card – 2021
  - Roads rated D
  - 42% Good; 15% Fair; 23% Mediocre: 20% Poor
  - $786 billion backlog
- The cost of restoring pavements accelerates in relation to condition

10 CPM

10

What The Gap Means To An Agency

- Iowa Analysis
  - Pavements need to last 100 years to match revenue
- Rehabilitation cycle
  - 16 years for HMA
  - 32 years for PCC
- ~3 time current performance

11 CPM

11

What does this problem look like to agency managers?

- Disinvestment in lower end of system to allow funding to go higher traffic portions.
- Less than acceptable pavement condition, ie: rough pavements
- Higher maintenance costs
- More traffic disruptions
- Public perception/opinion of the agency

12 CPM

12

How did we get here?

- Overly focused on the pavement
- Geotechnical design has not kept pace with pavement design
- Lack of recognition/urgency
  - Problems don't show up for 10-20 years
- Pavement maintenance costs become institutionalized

13

13

What are our options?

- Unlikely to fund our way out of this gap.
  - Highway funding is a public policy decision, not an engineering decision
  - Last federal fuel tax increase was 1994
  - NHCCI 2003-2023 = 317.8%

14

14

Improve Professional Practice

- Pavement ~40-50% total roadway costs
  - Can't afford poor foundations
- Address misconceptions
  - Just make the pavement thicker
  - Soft and uniform is ok
  - Better foundations cost too much

15

15

Improve Professional Practice

- Move from specified to engineered foundations
- Measure and control what is important
  - Design assumptions
- Become familiar with currently available intelligent technologies
  - Direct measurement

16

16

Build Better through Good Engineering

- National sustainable system requires well engineered pavements <u>and foundation layers</u>.
- The normalization of long-life pavement is possible.
- Let's get started.

17

17

slido

In your experience, what is the #1 reason for premature pavement failure?

ⓘ Start presenting to display the poll results on this slide.

18

The ideal pavement…

Tom Yu, FHWA

U.S. Department of Transportation
Federal Highway Administration

CPM Concrete Pavement Materials PROGRAM

19

The Ideal Pavement

Image Source: FHWA

H. Thomas Yu, P.E.
Program Manager, Pavement Design
Federal Highway Administration
Office of Infrastructure

13th International Conference on Concrete Pavements *August 27, 2024*

20

Disclaimer

Except for any statutes or regulations cited, the contents of this presentation do not have the force and effect of law and are not meant to bind the public in any way. This presentation is intended only to provide information to the public regarding existing requirements under the law or agency policies.

21

FHWA Mission Statement

FY2022-26 Strategic Plan

"To deliver a world-class system that advances safe, efficient, equitable, and sustainable mobility choices for all while strengthening the Nation's economy"

(emphasis added)

https://highways.dot.gov/about/fhwa-strategic-plan

22

Pavement-Design Program

Vision

FHWA should lead the way to providing durable, long-life pavements that remain in excellent condition throughout their service lives

Approach

- Demonstrate performance and sustainability advantages of long-life, distress-free pavements
- Provide technical resources needed to improve long-term, pavement performance

23

State-of-Good-Repair vs. Good Pavement

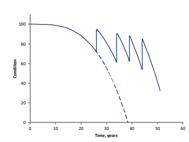


Image Source: FHWA

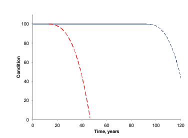


Image Source: FHWA

State of Good Repair
- Condition: Fair
- M&R: high
- Cost: $$$$

Good Pavement
- Condition: Excellent
- M&R: very low
- Cost: $$

24

What is needed

- Design pavements to last as long as the materials
  - Pavements should remain distress-free within the design period
  - Utilize design features that ensure good long-term performance
- Build it right
- Apply preventive treatments to preserve the pavement structure

25

Keys to achieving well-performing pavement

- Effective structural design
  - Good foundation
  - Adequate structural section
  - Appropriate design features
- Durable material
  - Durable surface
  - No material-related problems
- Quality construction

26

slido

Does your agency have a pavement foundation design procedure?

ⓘ Start presenting to display the poll results on this slide.

27

Structural Model

Image Source: FHWA

28

Pavement Design

- Structural design
  - Focus on strength and stiffness
  - Surface thickness dominates the design; foundation layers have minimal impact
- Foundation
  - Not designed systematically in current practice
  - Different design requirements than the surface
    - ✓ Uniformity, adequate stiffness, and drainage
    - ✓ Must retain integrity throughout the life of the roadway
  - A separate design procedure is needed for pavement foundation design

29

Pavement Foundation Design

- Practices vary from agency to agency
- No standard exists
- Best-practice needs to be established
  - Ensure uniformity at the time of construction
  - Prevent deterioration over time that leads to non-uniformity and localized failures
    - ✓ *Pumping and loss of fines*
    - ✓ *Contamination*
    - ✓ *Decompaction*
  - Include consideration of resilience

30

Ideal Pavement Design Process

- Foundation Design
  - Engineer the layering of materials from natural subgrade up to the surface layer
  - Design to remain in good condition (i.e., no degradation) throughout the life of the roadway
    - ✓ *Use of chemical or mechanical stabilization as appropriate*
    - ✓ *Consideration of compatibility of adjacent layers to prevent decompaction*
    - ✓ *Incorporation of drainage features as appropriate*
- Structural Design
  - Based on the layers defined in the foundation design
  - The layers can be abstracted in any manner appropriate for structural analysis

31

Pavement Foundation Design Procedure

- Can be established based on existing knowledge
  - Priority is in formalizing the process
  - A comprehensive research program is not needed
  - Research needs can be identified for improvement over time
- Refine over time through research

32

Summary

- An ideal pavement is a long-life, distress-free pavement
  - Pavement should be designed to last as long as the material and remain distress free over the life of the pavement
  - Good foundation design is essential to achieve ideal pavement
- An ideal pavement is one that can be preserved
  - Preservation treatments address functional and material issues
  - No structural degradation is prerequisite for preservation
- Pavement foundations have different design requirements
  - The key requirement is to remain in good condition throughout the life of the roadway
  - A separate design procedure is needed for pavement foundation

33

Roman Road

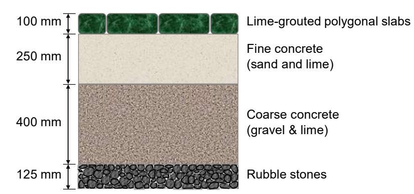


Image Source: FHWA

34

Thank you!

Tom Yu
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202-366-1198

35

Pavement foundation design 101

Jeff Roesler, University of Illinois

36

Concrete Pavement Foundation Basics

Jeffery Roesler, Ph.D., P.E.
University of Illinois
Department of Civil and Environmental Engineering

13th ICCP Workshop: Engineering the Pavement Foundation Layers
August 27, 2024

37

Acknowledgments

- *Improving the Foundation Layers for Concrete Pavement*
  - Federal Highway Administration and Iowa State University, DTFH61-06-H-00011, Work Order No. 18
  - Dr. David White (PI)
- Prof. Alex Brand (Virginia Tech)
- Mr. Hemant Chavan
- *Dr. A.M. Ioannides*

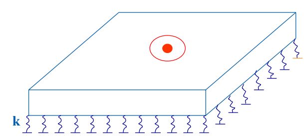
38

How are concrete pavement foundations generally characterized?

39

Concrete Pavement Foundations

- Idealized dense liquid (spring) foundation
- Modulus of Subgrade Reaction or k-value (psi/in or MPa/m)
  - Uniform, *stable*, *non-erodible*, and full contact w/ slab



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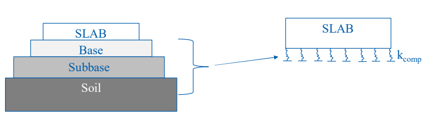
Concrete Pavement Foundations (2)

- Base/subbase layers
  - Layer thickness (h_i) and stiffness (E_i)
- Interface (bond, no bond, friction)
- k_{comp} = composite stiffness of support layers
- Other - CBR (DCP), E_{soil}, M_R



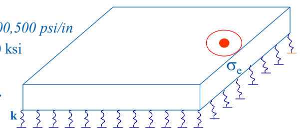
41

Should foundation inputs affect the structural design of concrete pavement?

42

Effect of Foundation on Westergaard Solution
Slab Edge Stress

Single Wheel Load = 10,000 lbs.
Tire Pressure = 100 psi
Subgrade k-values = 50,100,500 psi/in
Concrete Modulus = 4,000 ksi
Poisson's Ratio = 0.15
Slab Thickness (h) = 8 in.



Edge Load	Stress	Deflection
k = 50 psi/in	**450 psi** (h=8.0")	0.0412 in.
k = 100 psi/in	**415 psi** (h=7.6")	0.0285 in.
k = 500 psi/in	**333 psi** (h=6.6")	0.0118 in.

Stress - ↓*8%* (k=50 to 100 psi/in); ↓*26%* (k=50 to 500 psi/in)

43

What are foundation inputs for concrete pavement design?

44

Foundation Inputs for Design

- Soil k-value (k_s) or K_{comp}
- Base/subbase layers
  - Layer thickness (h_i) and stiffness (E_i)
- Interface conditions (bond, no bond, friction)
- Erosion factor
  - AASHTO 1993 – Loss of Support
  - PCA/ACPA – Erosion damage
  - AASHTO Pavement ME – erodibility for CRCP, slab-base friction-JPCP

45

How do we determine k-value of foundation?

46

Determination of K-value

- Direct – Plate Load Test
  - See NCHRP 1-30

Alliance Geotechnical

Table 1. Effect of Untreated Subbase on *k* Values.

Subgrade *k* value, pci	Subbase *k* value, pci			
	4 in.	6 in.	9 in.	12 in.
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

PCA (1984)

Table 2. Design *k* Values for Cement-Treated Subbases

Subgrade *k* value, pci	Subbase *k* value, pci			
	4 in.	6 in.	8 in.	10 in.
50	170	230	310	390
100	280	400	520	640
200	470	640	830	—

PCA (1984)

47

Determination of K-value

- Indirect – correlations
  - CBR (DCP), Soil type, or E-value

PCA (1984)

48

How sensitive to k-value are design methods like AASHTO (1993) or Pavement ME?

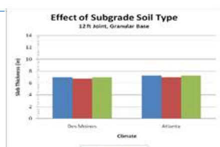
49

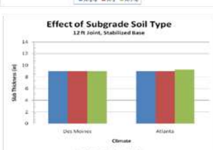
Design Sensitivity to K-value

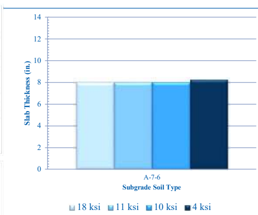
- **AASHTO 1993** vs. AASHTO Pavement (PCC thickness) sensitive to k-value
  - 10M ESALs, MOR=650 psi, R=90%,…
- k =50 psi/in → D=11.0 in.
- k=100 psi/in → D=10.5 in.
- k =500 psi/in → D=10.0 in.

50

AASHTO Pavement ME







AASHTO Pavement ME suggests foundation layer is generally not that important?

51

Recall k-value Assumptions

- k-value – modulus of subgrade reaction
- Uniform spatial distribution
- Stable
  - no plastic deformation or fails
- Non-erodibility
  - Doesn't change or deteriorate w/ load+climate
- Do these guarantee long-term performance?

52

How do we know if a foundation layer is non-erodible?

53

Erodibility Measurements

- Minimum foundation CBR or k-values
  - Stabilize soil or undercut + aggregate
  - Density requirements
- Base/Subbase layers -
  - Hamburg Wheel Tracking Device (HWTD)
- Other



54

How do we know if a foundation layer is uniform?

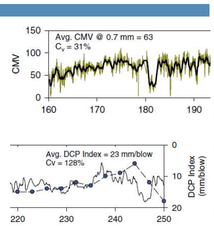
55

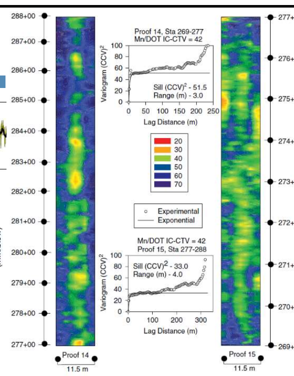
Foundation Layer Spatial Measurements

- White et al. (2007-2021) FHWA study: *Improving the Foundation Layers for Concrete Pavements*
- Li, J., D. J. White, and P. Vennapusa. 2018. Improving the Foundation Layers for Pavements: Field Assessment of Variability in Pavement Foundation Properties. *National Concrete Pavement Technology Center and Center for Earthworks Engineering Research*, Iowa State University, Ames, IA.
- **Does non-uniformity affect stresses and performance?**
  - Analysis of non-uniform support on concrete slabs

56

IC Output





White et al. 2008

57

Non-Uniform Analysis Assumptions

- IC Roller makes longitudinal passes over subgrade
- 12 ft by 15 ft single slab
- Modulus of subgrade reaction (*k*)
  - 50 and 500 psi/in
- Subgrade is a Winkler foundation
- Test various axle types and locations
- Vary temperature differentials

1. Brand, A. and Roesler, J. (2014), "Finite Element Analysis of a Concrete Slab under Various Nonuniform Support Conditions," *International Journal of Pavement Engineering*, V. 15, pp. 460-470.
2. Roesler, Chavan, King, Brand (2016), Concrete Slab Analyses with Field-Assigned Non-Uniform Support Conditions, *International Journal of Pavement Engineering*, Vol. 17, pp. 578-589.

58

Full Factorial 2-D Analysis

- Axle Type (3)
  - Single, tandem, steer-drive combo
- Longitudinal positions (10, 11, 4)
  - 10-single, 11-tandem, 4-steer-drive
- Lateral offset (2)
  - Edge(0 in) and wheel path (19 in.)
- Temperature Differential (3)
  - -20°F, 0, +20°F
- Subgrade conditions (12)

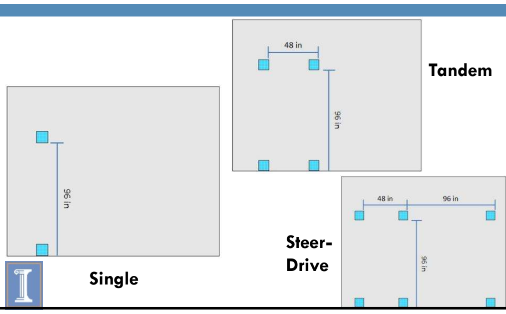
59

Fixed Slab Properties

- Slab Thickness: 8 in.
- Elastic Modulus: 4.0x10^6 psi
- Poisson Ratio: 0.15
- Coefficient of Thermal Expansion: 5.5x10^{-6}/°F
- Unit Weight: 0.087 lb/in^3

60

Slab Loading – Axle Types



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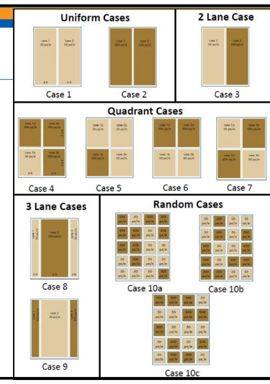
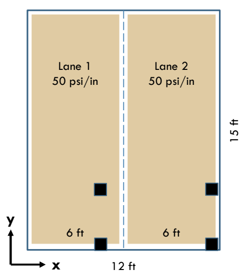


62

Case 1: Uniform Soft (50 psi/in)

- The 7 ft roller makes two passes
- Both passes are of uniform modulus at 50 psi/in



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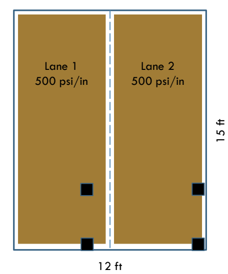
Case 2: Uniform Stiff (500 psi/in)

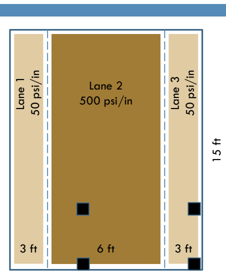
- The 7 ft roller makes two passes
- Both passes are of uniform modulus at 500 psi/in



64

Case 3: Nonuniform Soft Edges

- The 7 ft roller makes three passes
- Passes are nonuniform
- Lane 1 is 50 psi/in
- Lane 2 is 500 psi/in
- Lane 3 is 50 psi/in



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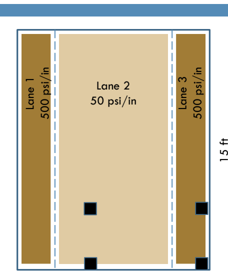
Case 4: Nonuniform Stiff Edges

- The 7 ft roller makes three passes
- Passes are nonuniform
- Lane 1 is 500 psi/in
- Lane 2 is 50 psi/in
- Lane 3 is 500 psi/in



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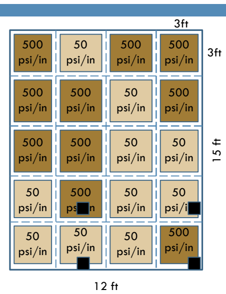
Case 5a: Nonuniform Random

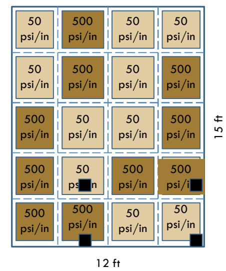
- 3 ft by 3 ft sections are randomly assigned a modulus of 50 or 500 psi/in
- Half of the sections are 50 psi/in and the other half are 500 psi/in



67

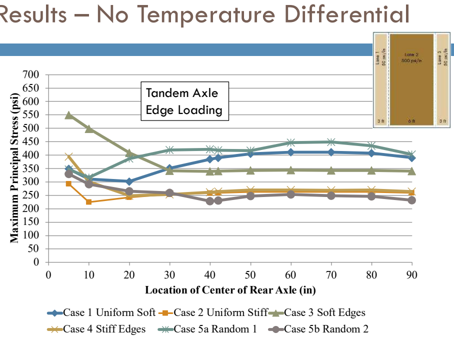
Case 5b: Nonuniform Random

- Same principle as in Case 5a, but with a different random assignment



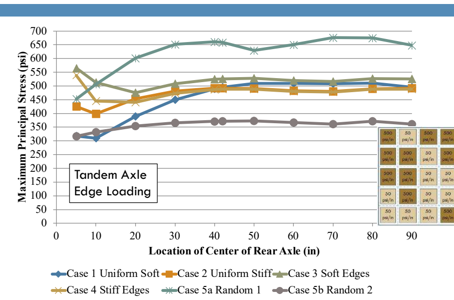
68

Results – No Temperature Differential



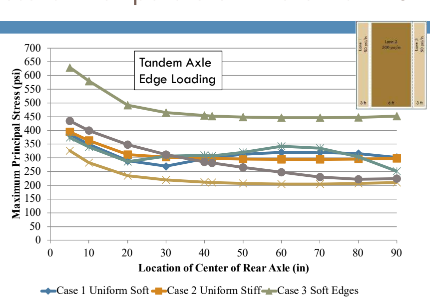
69

Results – Temperature Differential +20F



70

Results – Temperature Differential -20F



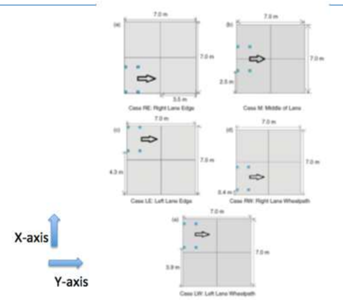
71

Spatial Data Test Bed: MI I-94

White et al. 2011

72

Slab Configuration (7mx7m)



73

MI I-94: 121 k-values (Field Correlated)

55	51	47	84	80	40	60	92	75	95	60
47	43	69	91	84	80	55	65	62	62	96
97	34	45	37	42	48	92	71	60	68	71
87	47	57	60	97	55	109	99	57	68	67
36	52	60	113	43	43	47	36	31	51	32
65	48	40	42	58	48	52	65	77	47	40
58	31	54	95	85	71	60	60	77	80	69
54	80	39	95	89	72	91	99	112	36	57
114	67	65	37	54	55	60	50	57	50	52
48	76	71	43	81	36	48	55	61	36	31
55	57	148	202	39	114	87	43	51	43	106

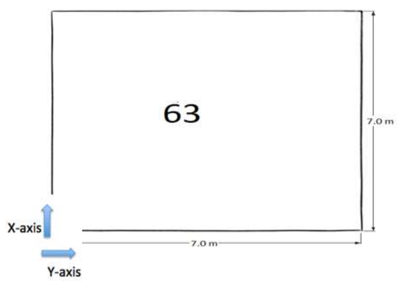
7.0 m × 7.0 m

X-axis
Y-axis

- k-value range: (32 to 202 psi/in)
- Mean = 63 psi/in
- Std Dev = 25.58 psi/in

74

Case 2: 1 k-value (Uniform)



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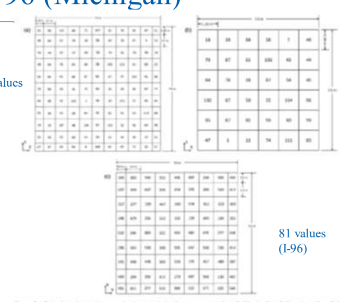
I-94 & I-96 (Michigan)

121 values (I-94)

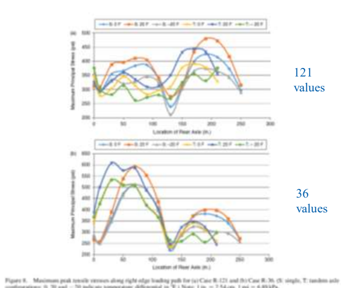
36 values (I-94)

81 values (I-96)



76

Tensile Stress for I-94



121 values

36 values

77

Summary of Field Non-Uniformity

Table 3. Maximum peak tensile stress results for random assignment of k-values.

Support case	Loading path	Axle type	Temperature differential[a] (°F)	Maximum peak tensile stress (psi)[b]	Change from uniform condition (%)
R-121 (I-94)	RE	Single	+20	479	+3.5
	LE	Single	+20	486	+5.0
	M	Steer-drive	+20	461	+2.9
	RW	Tandem	+20	325	+10.5
	LW	Tandem	+20	328	+11.6
R-36 (I-94)	RE	Tandem	+20	608	+31.3
	LE	Single	+20	558	+20.5
	M	Steer-drive	+20	432	−3.6
	RW	Tandem	+20	409	+39.1
	LW	Tandem	−20	391	+33.0
R-81 (I-96)	RE	Single	+20	507	+4.8
	LE	Single	+20	537	+11.0
	M	Steer-drive	+20	494	+7.9

[a] Analysis conducted for three different temperature differentials (i.e. 0, +20 and −20°F) but only the maximum peak tensile stress is reported here.
[b] Conversion: 1 psi = 6.894 kPa.

Roesler, Chavan, King, Brand (2016), Concrete Slab Analyses with Field-Assigned Non-Uniform Support Conditions, *International Journal of Pavement Engineering*, Vol. 17, pp. 578-589.

78

What does this all mean?

- Is k-value input important? YES, but..
- Is performance of foundation important to concrete? YES
- Are foundation strengths are important? YES
- Is knowing non-uniformity? It seems YES
- Is erosion resistance important? YES

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79

What does this all mean?

- Looking forward:
  - K-value measurement for Design Input
  - "Uniformity" verification
    - Uniform weak or strong; Strong and variable; or Min k-value with some variability
  - Stability (minimum strength)
  - Non-erodible test (all foundation layers)
- We do need accelerated pavement testing (APT) of non-uniform support!!!

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80

Foundation Layers - Design Framework

- K-value measurement (stiffness)
  - Stability (minimum strength)
- K-value "Uniformity" verification
  - Uniform weak or strong; Strong and variable; or Min. k-value with some variability??
- Non-erodible test (all foundation layers)
- We do need APT of stiffness, stability, and non-uniform support performance!!!

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81

Relevant Publications

- NCHRP 1-30 by Darter, Hall, Kuo (1995)
- Iowa State Reports (Dr. White et al. 2007-2021)
- Brand, A. and Roesler, J. (2014), "Finite Element Analysis of a Concrete Slab under Various Nonuniform Support Conditions," *International Journal of Pavement Engineering*, V. 15, pp. 460-470.
- Roesler, Chavan, King, Brand (2016), Concrete Slab Analyses with Field-Assigned Non-Uniform Support Conditions, *International Journal of Pavement Engineering*, Vol. 17, pp. 578-589.
- DeSantis, J. and Roesler, J. (2024) Erosion Potential of Stabilized Support Layers for Concrete Pavements and Overlays," accepted to *Transportation Research Record*.
- Brand, A. and Roesler, J. (2012), "Effect of Nonuniform Foundation Support on Concrete Slab Responses," *International Conference on Concrete Pavement*, Quebec City, Canada.

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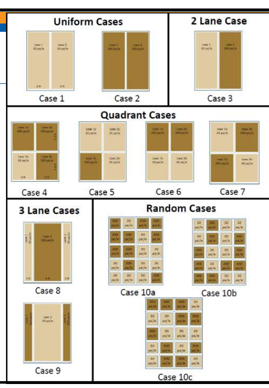
82



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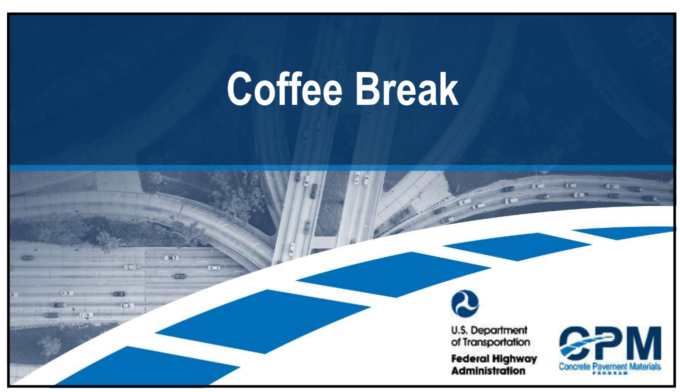
83



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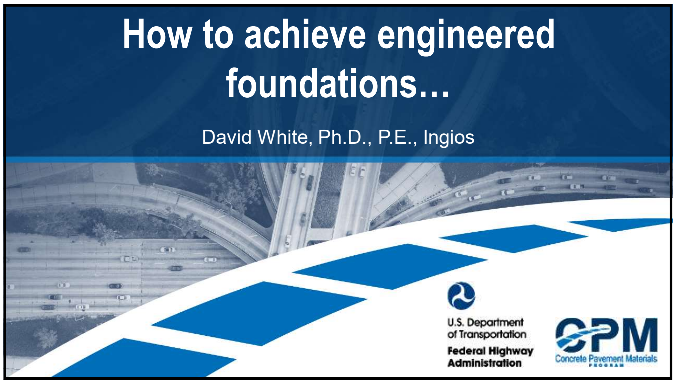

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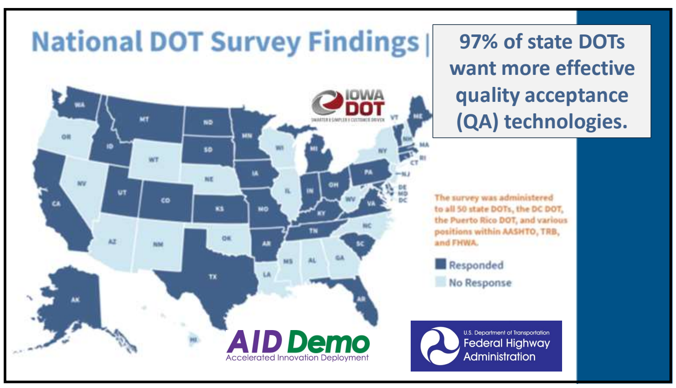

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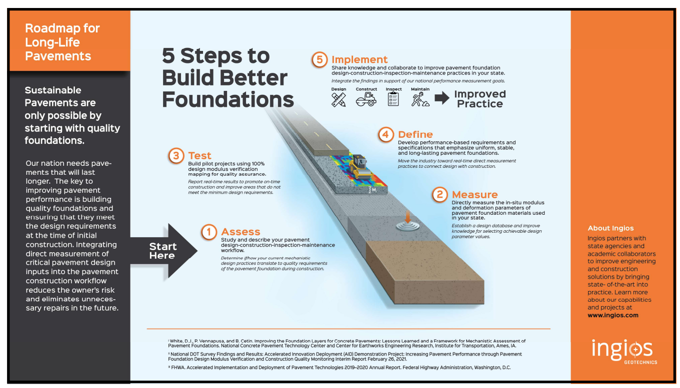

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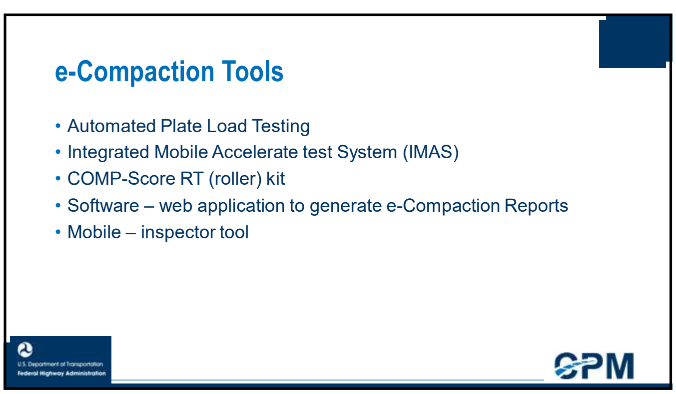

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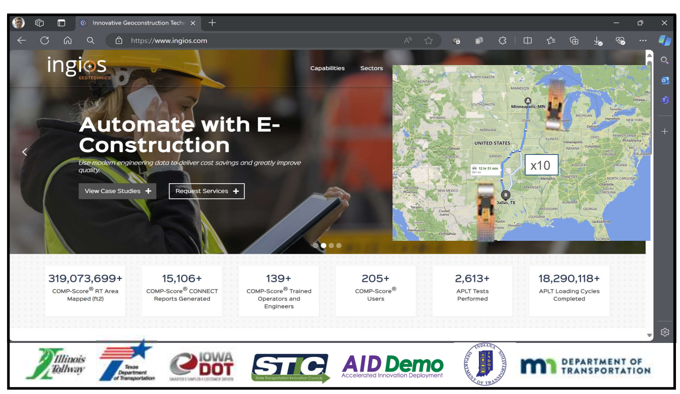

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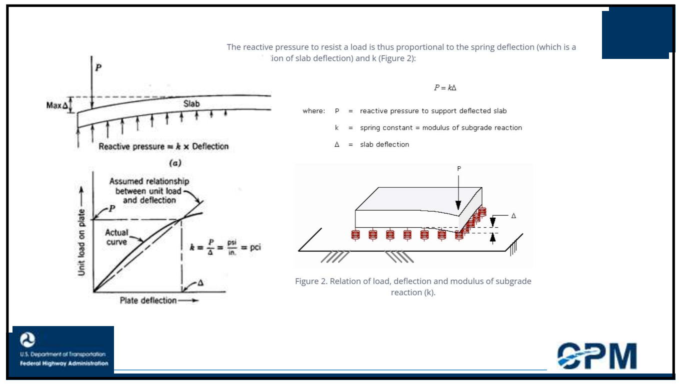

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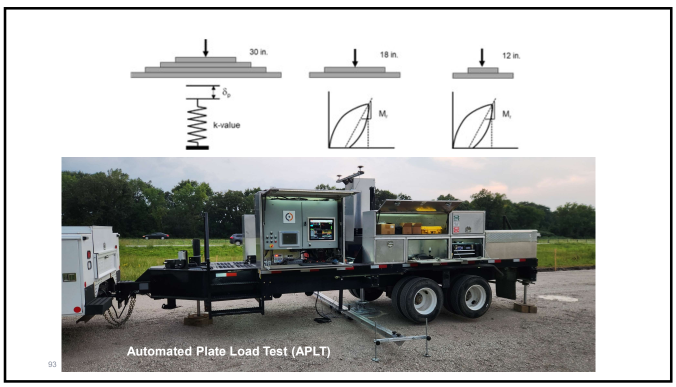

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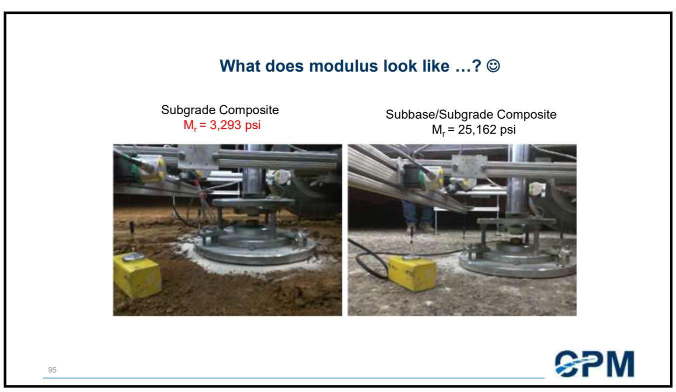

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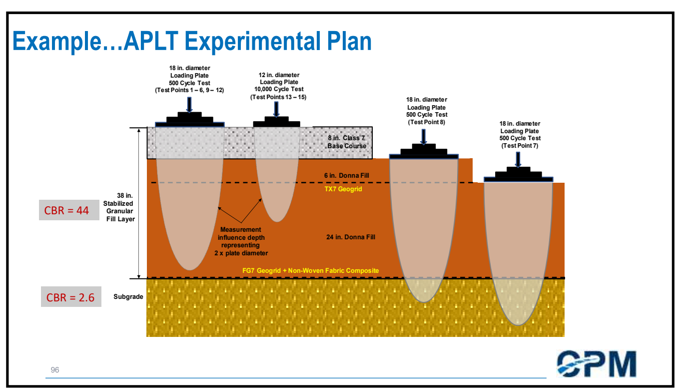

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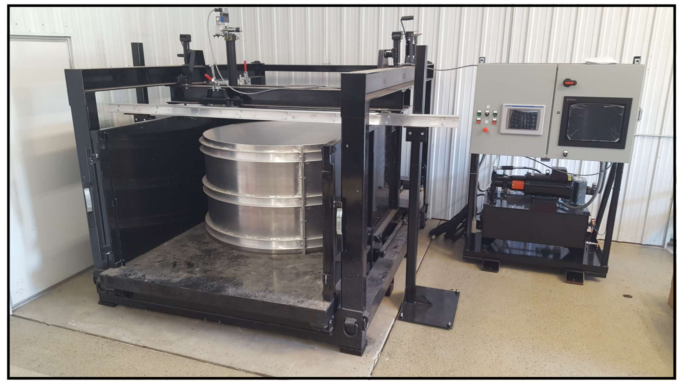

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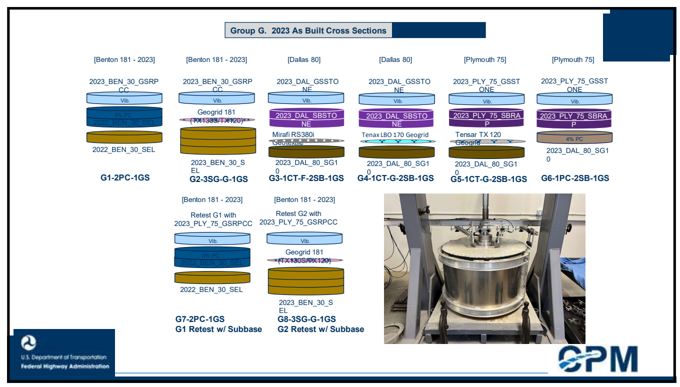

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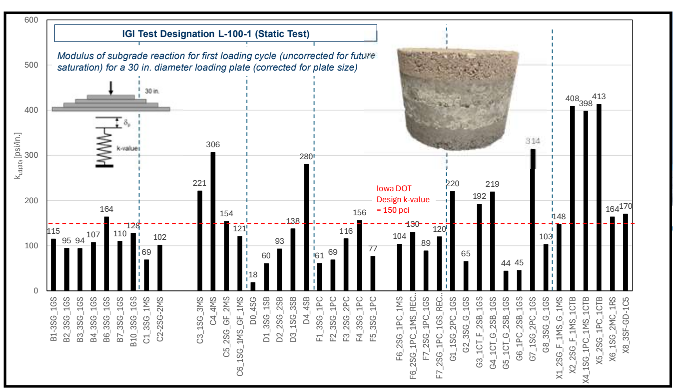

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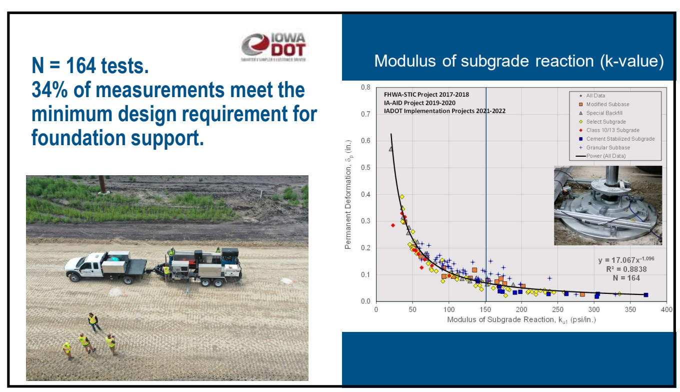

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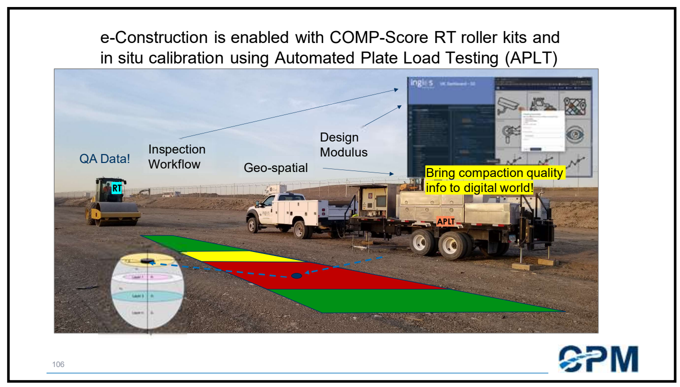

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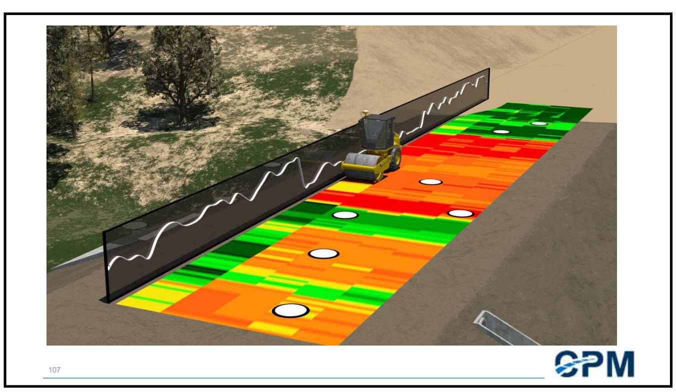

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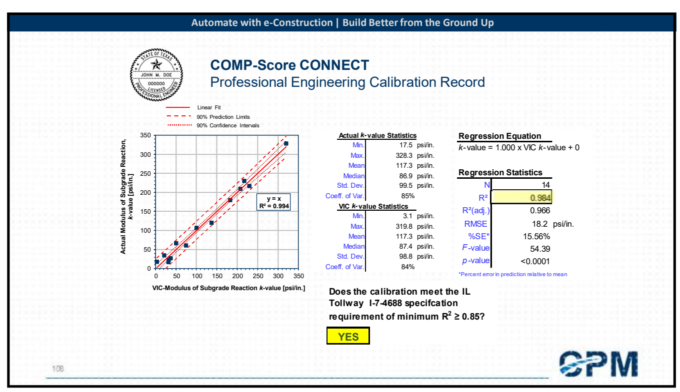

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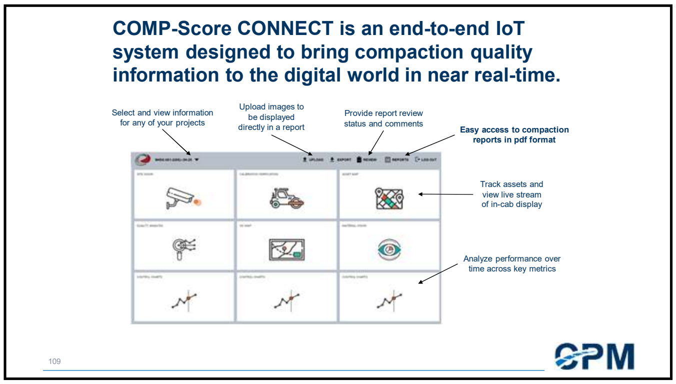

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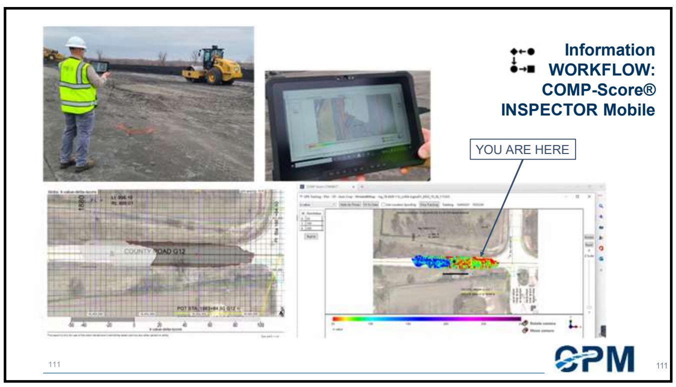

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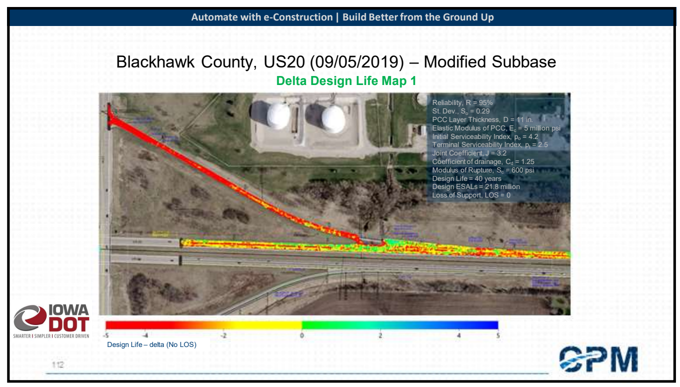

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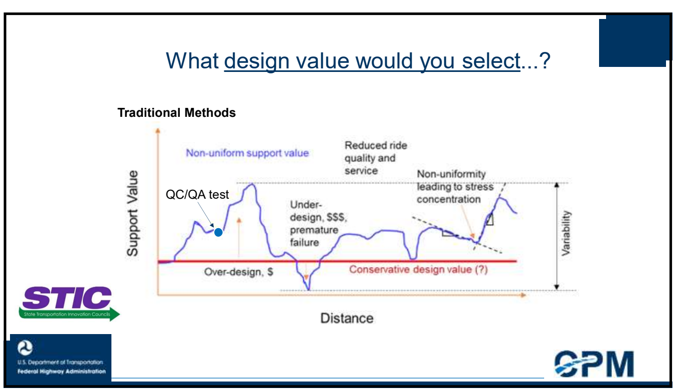

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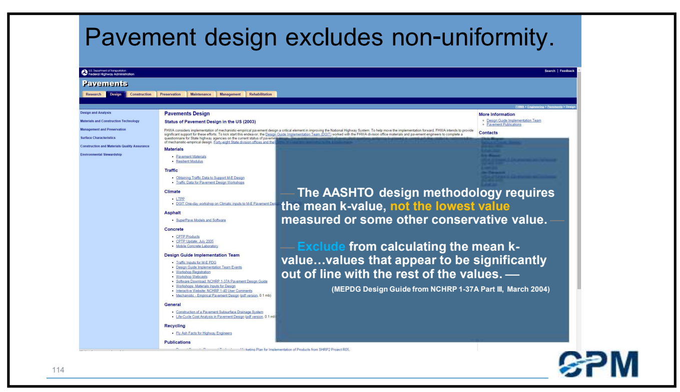

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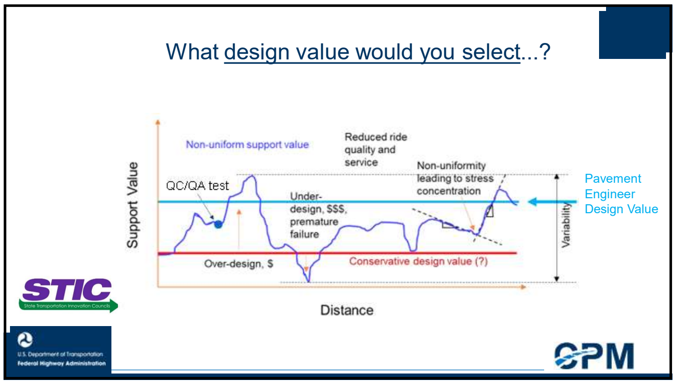

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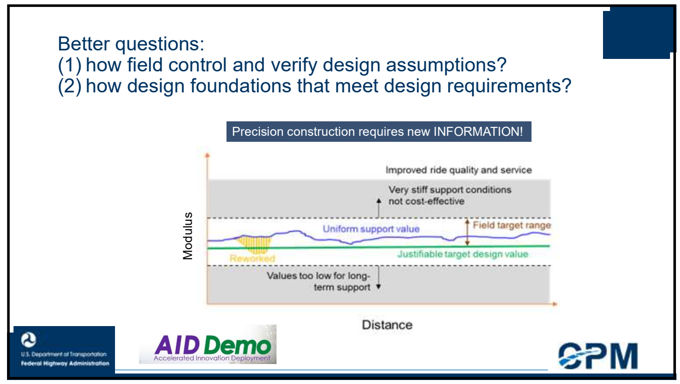

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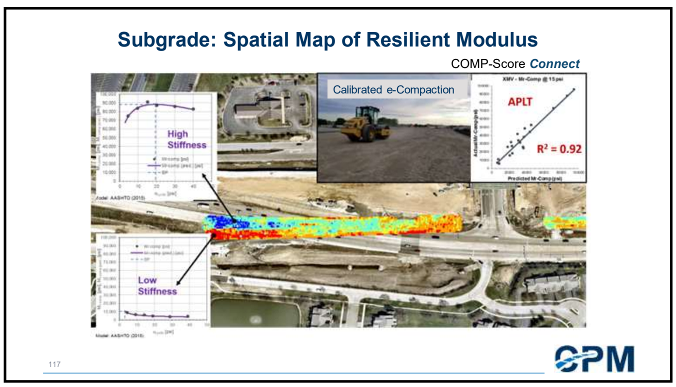

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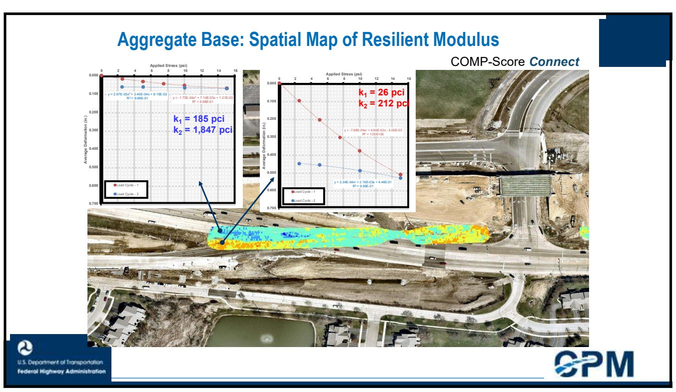

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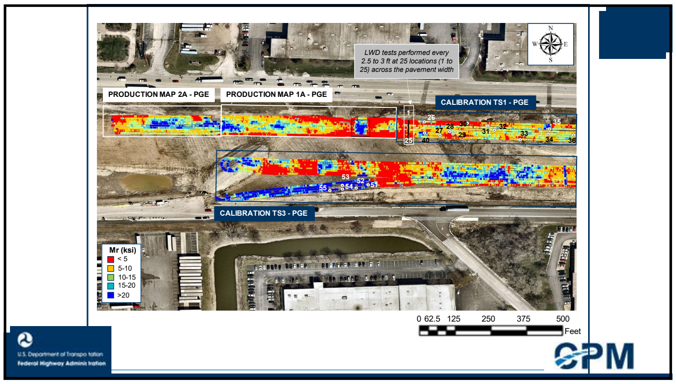

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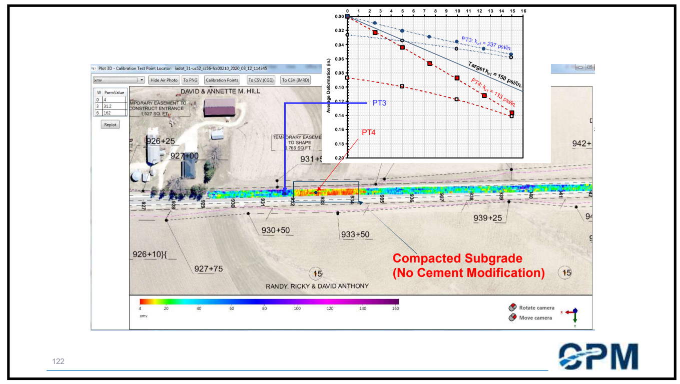

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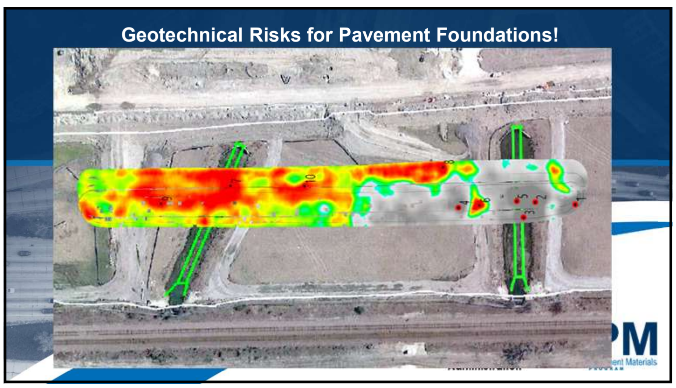

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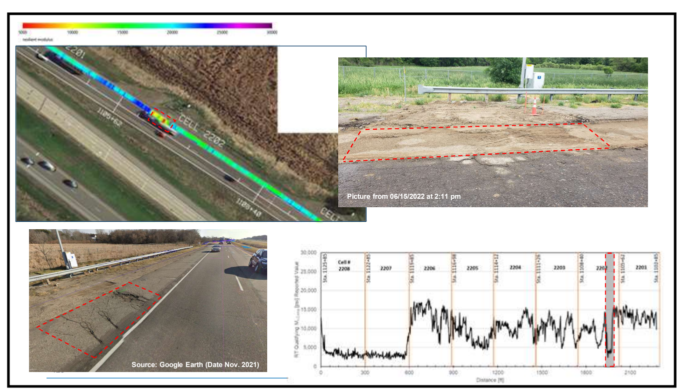

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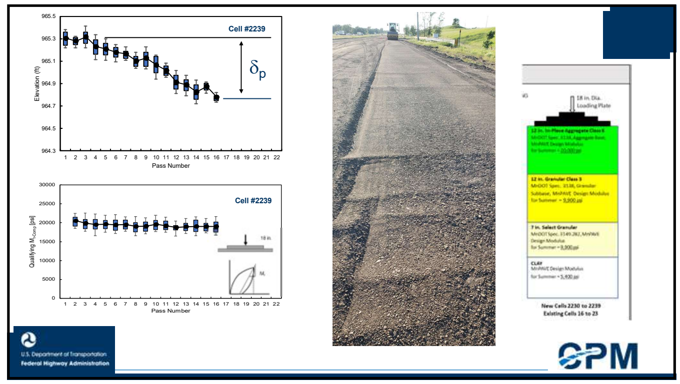

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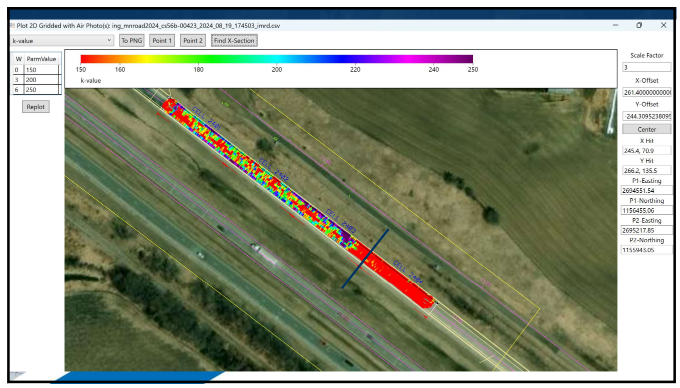

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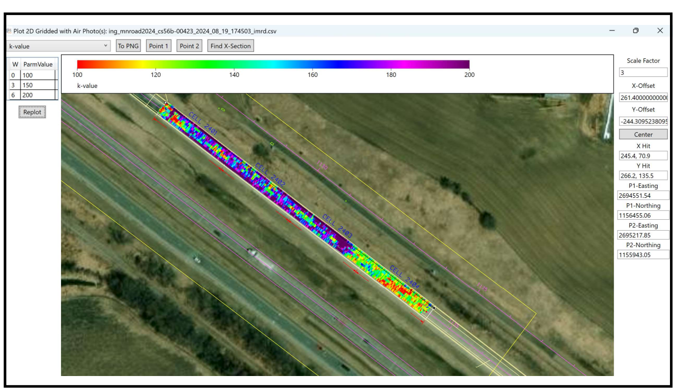

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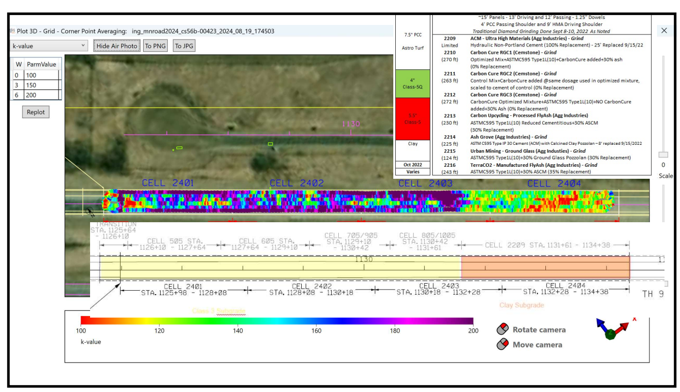

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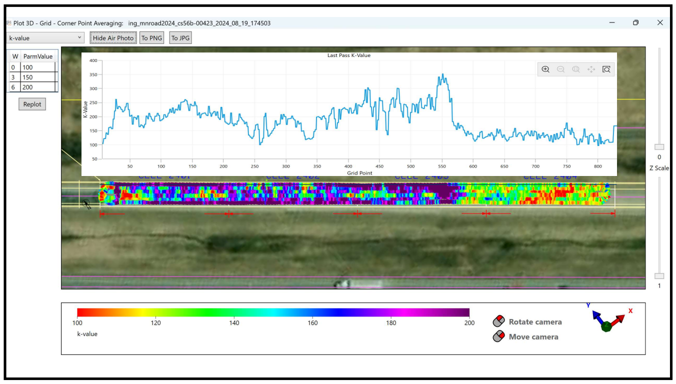

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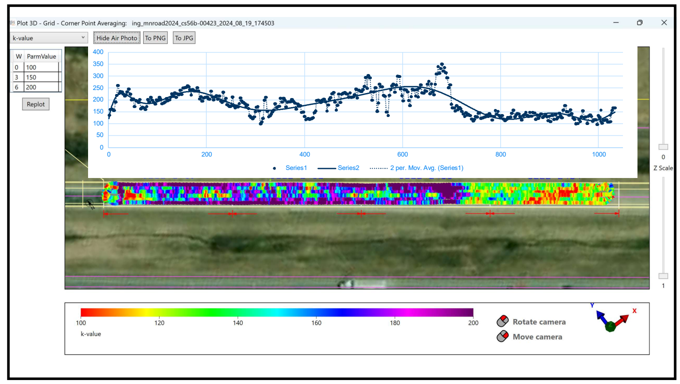

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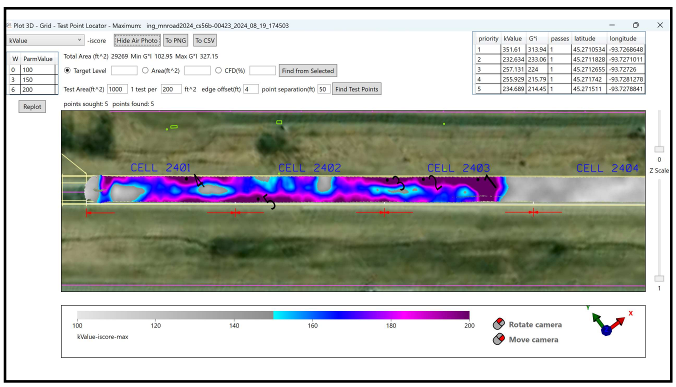
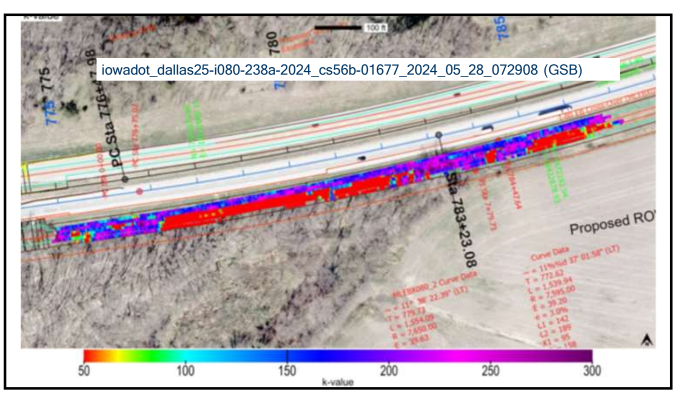


priority	kValue	G*i	passes	latitude	longitude
1	351.61	313.94	1	45.2710534	-93.7268648
2	232.634	233.06	1	45.2711828	-93.7271011
3	257.131	224	1	45.2712655	-93.72726
4	255.929	215.79	1	45.271742	-93.7281278
5	234.689	214.45	1	45.271511	-93.7278841

135

priority	kValue	G*i	passes	latitude	longitude
1	96.938	104.3	2	45.2706927	-93.72628
2	108.839	106.78	1	45.2707453	-93.7264701
3	86.084	110.64	1	45.2718689	-93.728469
4	119.076	115.73	1	45.2705772	-93.726133
5	121.122	119.44	1	45.270905	-93.7267606

136



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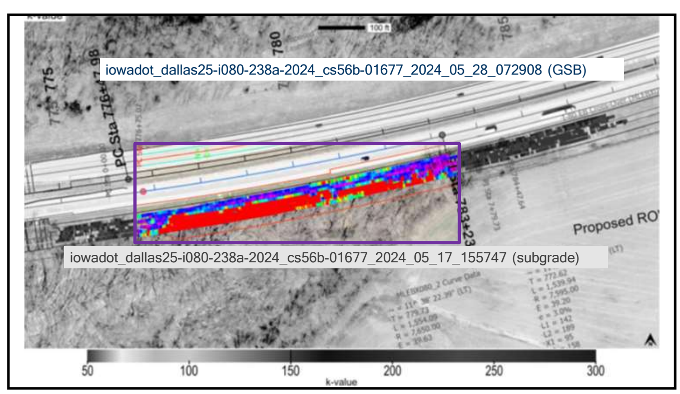

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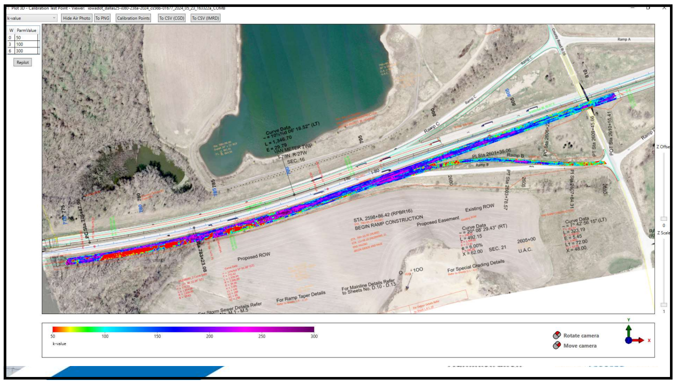

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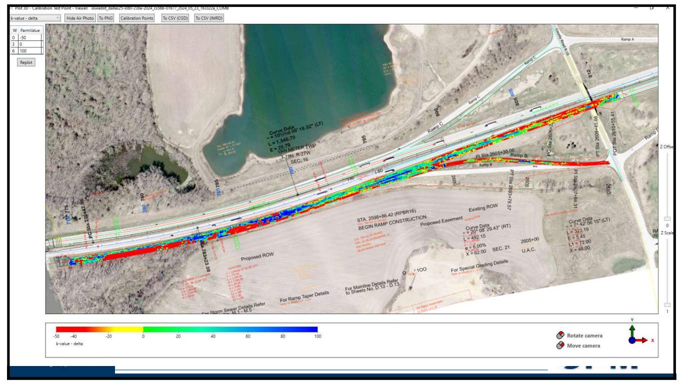

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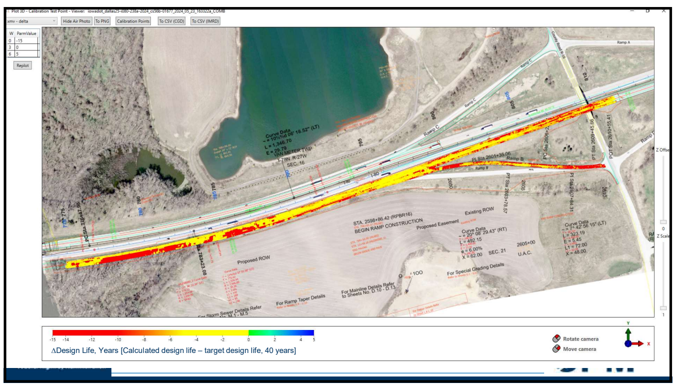


141

<u>The effective modulus of subgrade reaction is a direct input in the AASHTO design procedures for rigid pavements.</u>

The subgrade, base, and subbase <u>resilient moduli</u> values are the direct inputs in the NCHRP 1-37A design methodology. These values are adjusted internally within the NCHRP 1-37A Design Guide software for environmental effects and then converted into an average monthly effective k-value for structural response calculation and damage analysis.

Correct the effective modulus of subgrade reaction k_{eff} for loss of support due to subbase erosion. **This corrected k_{eff} is the value to be used for design.**

"Typically, large changes in k_{eff} have only a modest impact on PCC slab thickness."

142

142

Typical ranges of loss of support LS factors for various types of materials (AASHTO, 1993).		Conversion from Modulus to k-value (/56)
Type of Material	Loss of Support (LS)	K-values
Cement treated granular base (E = 1,000,000 to 2,000,000 psi)	0.0 to 1.0	17,852 to 35,714
Cement aggregate mixtures (E = 500,000 to 1,000,000 psi)	0.0 to 1.0	8929 to 17,852
Asphalt treated base (E = 350,000 to 1,000,000 psi)	0.0 to 1.0	6250 to 17,857
Bituminous stabilized mixtures (E = 40,000 to 300,000 psi)	0.0 to 1.0	714 to 5357
Lime stabilized (E = 20,000 to 70,000)	1.0 to 3.0	357 to 1250
Unbound granular materials (E = 15,000 to 45,000 psi)	1.0 to 3.0	268 to 804
Fine grained or natural subgrade materials (E = 3,000 to 40,000 psi)	2.0 to 3.0	54 to 714

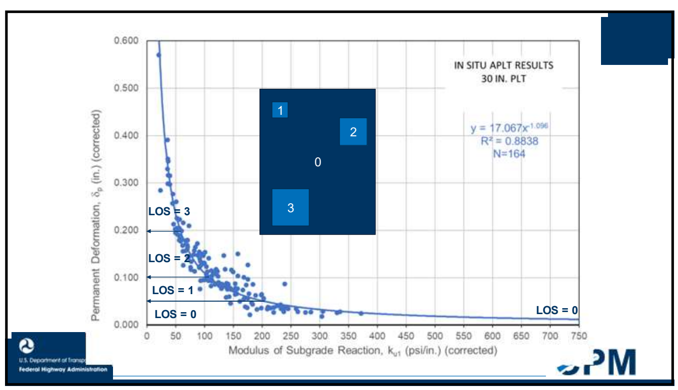
Chapter 5 (continued) - NHI-05-037 - Geotech - Bridges & Structures - Federal Highway Administration (dot.gov)

Suggested ranges for modulus of subgrade reaction for design (AASHTO, 1993).

Roadbed Soil Quality	Range for k_{eff} (pci)
Very Good	> 550
Good	400 - 500
Fair	250 - 350
Poor	150 - 250
Very Poor	< 150

143

143



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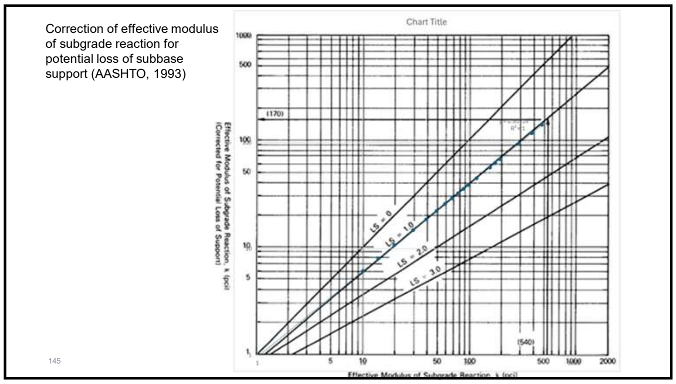

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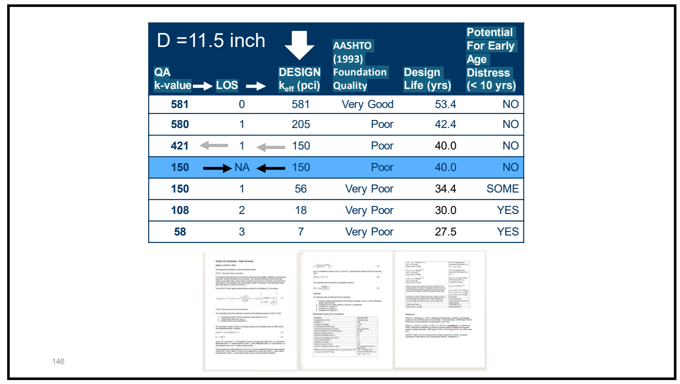
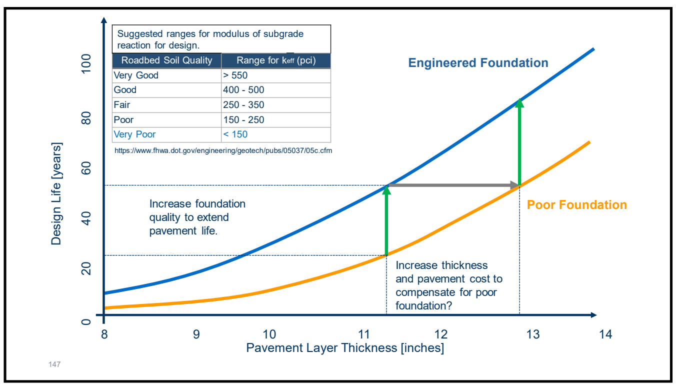


QA k-value	LOS	DESIGN k_{eff} (pci)	AASHTO (1993) Foundation Quality	Design Life (yrs)	Potential For Early Age Distress (< 10 yrs)
581	0	581	Very Good	53.4	NO
580	1	205	Poor	42.4	NO
421	1	150	Poor	40.0	NO
150	NA	150	Poor	40.0	NO
150	1	56	Very Poor	34.4	SOME
108	2	18	Very Poor	30.0	YES
58	3	7	Very Poor	27.5	YES

146



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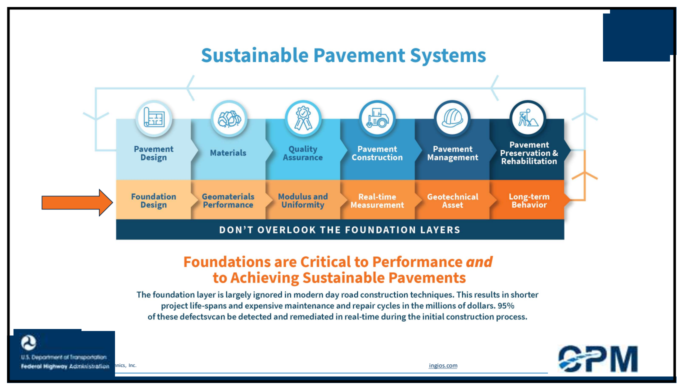

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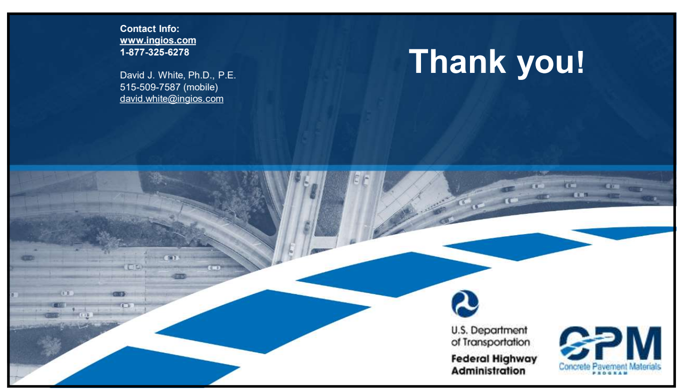

150

Advancing national practice

Tom Yu, FHWA

151

152

Objective

- Demonstrate intelligent construction technologies (ICT) for ensuring quality of pavement-foundation construction
  - 100% modulus verification with roller mapping
  - Automated plate-load testing
- Develop guidelines for pavement foundation design to ensure good, long-term performance
  - Design guidelines for long-life pavement foundation
  - Consideration of resilience

153

Proposed Project Activities

- Technology demonstrations and implementation support
  - Demo projects for 100% mapping using ICT and validation testing using automated plate-load testing
  - Technical support for pilot projects
  - Establish process for QA, including draft specification
- Guidelines for pavement-foundation design
  - Establish best-practice to ensure good, long-term performance
    - ✓ *No deterioration over time – prevent pumping, loss of support, contamination, de-compaction*
    - ✓ *Use of geotextiles and soil stabilization*
  - Address resilience

154

Proposed TPF

- 5-year program
  - Up to 3, SHA pilot projects per year
  - Seeking 10 SHA commitments
- Funding
  - $30,000/yr for SHA
  - FHWA

155

Contact

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Pavement Team Lead
Construction & Materials Bureau
Iowa Department of Transportation
Chris.brakke@iowadot.us

156

Thank you!

157

Wrap-Up and Recap

U.S. Department of Transportation
Federal Highway Administration

CPM Concrete Pavement Materials PROGRAM

158

Pooled Fund Planning Meeting…

- Pooled fund is still in process
- Web-meeting planned
- Interested….?

159

159

Don't Forget….

MnROAD

Thursday, August 29, 2024 | 8AM-12 PM

MnROAD, located near Albertville, Minnesota (33 miles northwest of the Depot), is a cold region testing facility and laboratory operated by the Minnesota Department of Transportation (MnDOT) that includes both low-volume and freeway instrumented pavement sections.

As part of the 13 th ICCP meeting, ISCP would like to invite participants to tour the MnROAD to see the history, current projects, and capabilities of this unique full-scale testing facility.

Attendees of the field trip will be provided a reflective vest for use during tour.

Buses will leave the Depot hotel around 8am on Thursday, August 29 and return by 12:00pm to the Depot.

- Demo of equipment at MnROAD during filed visit on Thursday
- Please visit Ingios in the exhibit hall (booth #112) for more details.

160

160

CPM Concrete Pavement Materials PROGRAM

161