The National Academies of
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TRANSPORTATION RESEARCH BOARD

TRB Webinar: Designing and Constructing Concrete with Advancing Technologies

February 22, 2022
2:00 pm – 4:00 pm

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 2 Professional Development Hour (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact TRBWebinar@nas.edu

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

RCEP
REGISTERED CONTINUING EDUCATION PROGRAM

#TRBwebinar

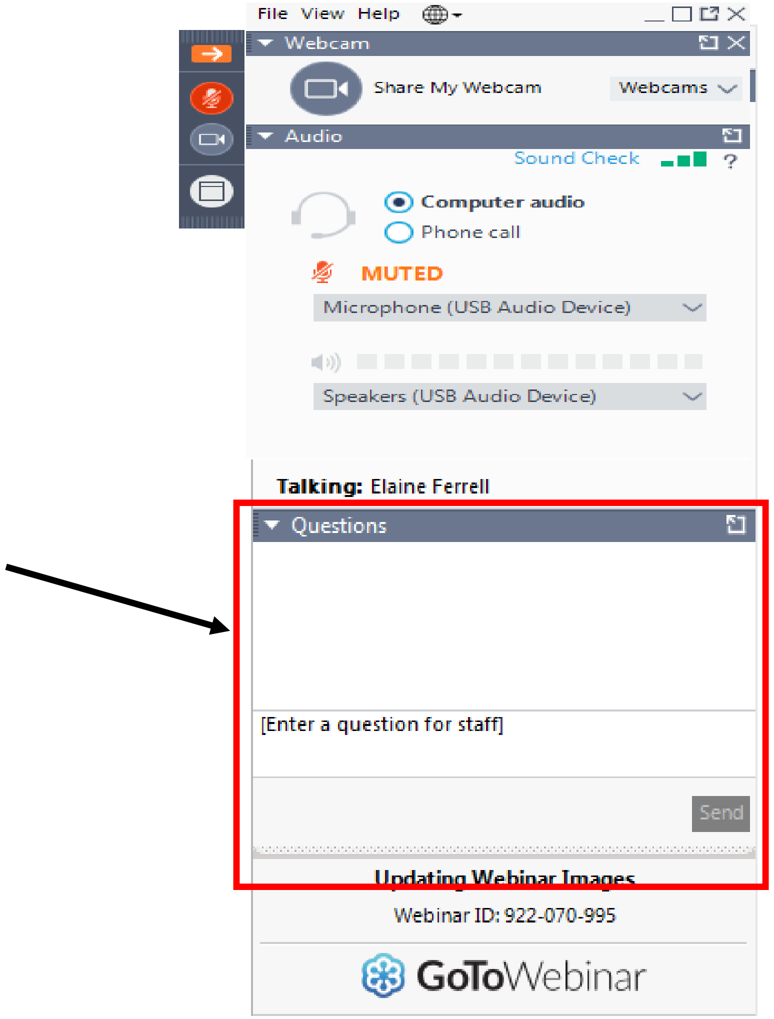
Learning Objectives

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

1. Discuss design considerations for connected and autonomous vehicles
2. Discuss how to improve concrete pavement design through instrumented data
3. Identify effective rehabilitation methods for concrete pavements

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



#TRBwebinar

Today’s Moderator and Panelists

Kurt Smith
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Eric Ferrebee
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American Concrete Pavement Association

Jamie Greene
james.greene@dot.state.fl.us
Florida Dept. of Transportation

Julie Vandenbossche
jmv7@pitt.edu
University of Pittsburgh

Mark Snyder
mbsnyder2@yahoo.com
Pavement Engineering and Research Consultants, LLC.

Welcome

- Designing and Constructing Concrete Pavements with Advancing Technologies
- Host: Kurt Smith
- Today's webinar sponsored by TRB Committees:
  - » AKP20, Concrete Pavement Design and Rehabilitation
  - » AKC50, Concrete Pavement Construction
- Webinar Objectives:

1. *Discuss design considerations for connected and autonomous vehicles*
2. *Describe how to improve concrete pavement design through the use of instrumented data*
3. *Identify effective rehabilitation methods for concrete pavements*

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Today's Program

- Concrete pavement design considerations for connected and autonomous vehicles: Eric Ferrebee, ACPA
- Advancing concrete pavement design through instrumented test road: Jamie Greene, Florida DOT
- Thin concrete overlay design refinements and applications: Julie Vandenbossche, University of Pittsburgh
- Rapid rehabilitation of pavements using long-life precast concrete panels: Mark Snyder, PERC

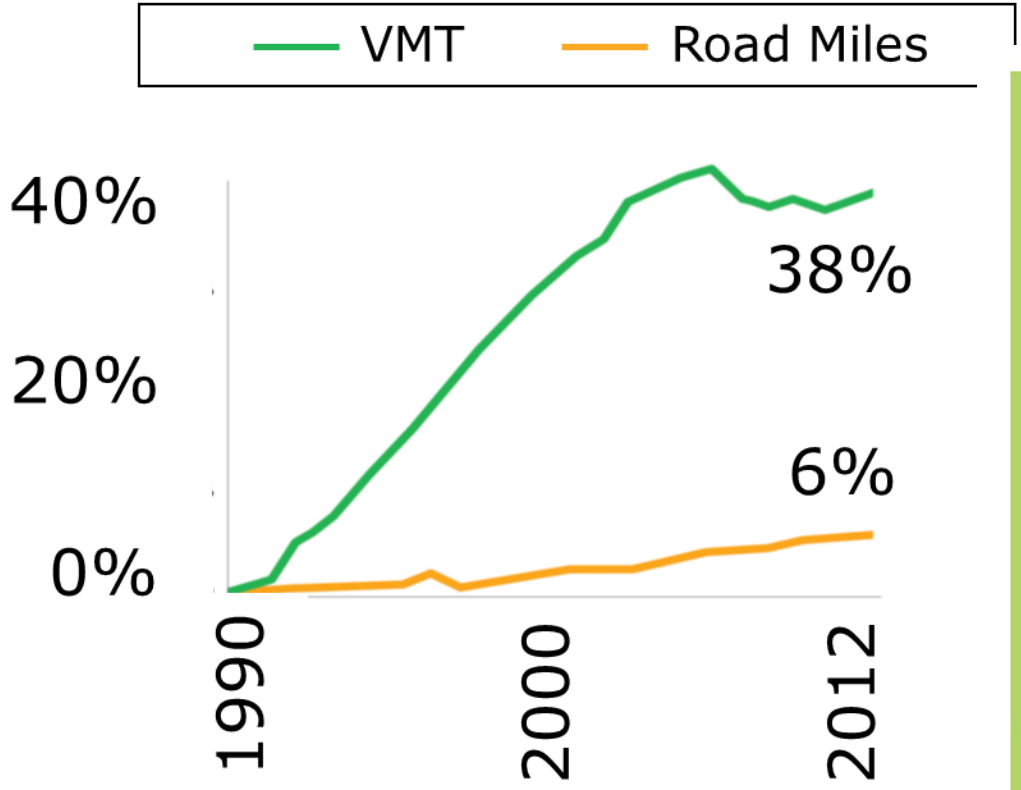
February 22, 2022

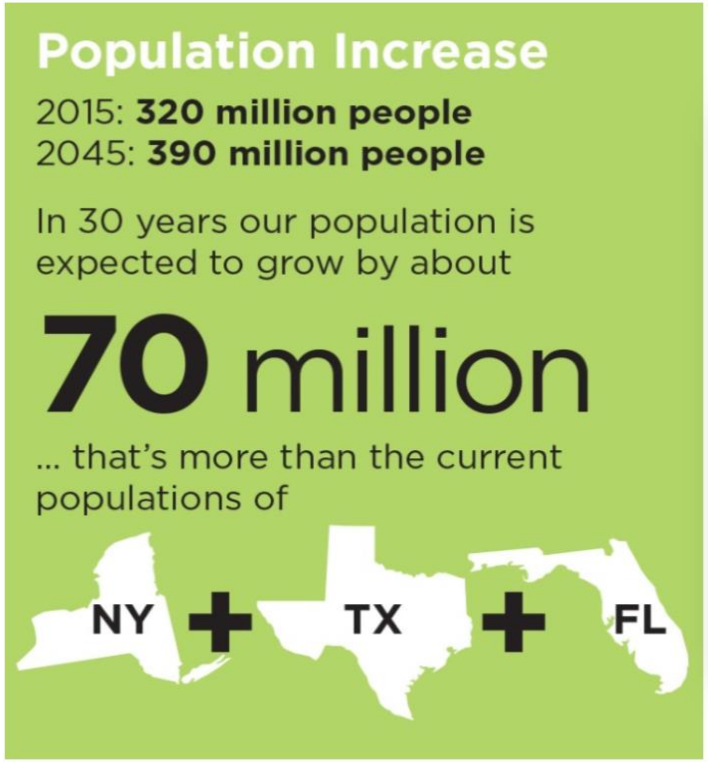
Designing and Constructing Concrete with Advancing Technologies

Design Considerations for Connected and Autonomous Vehicles

Eric Ferrebee, P.E.
Director of Technical Services
American Concrete Pavement Association

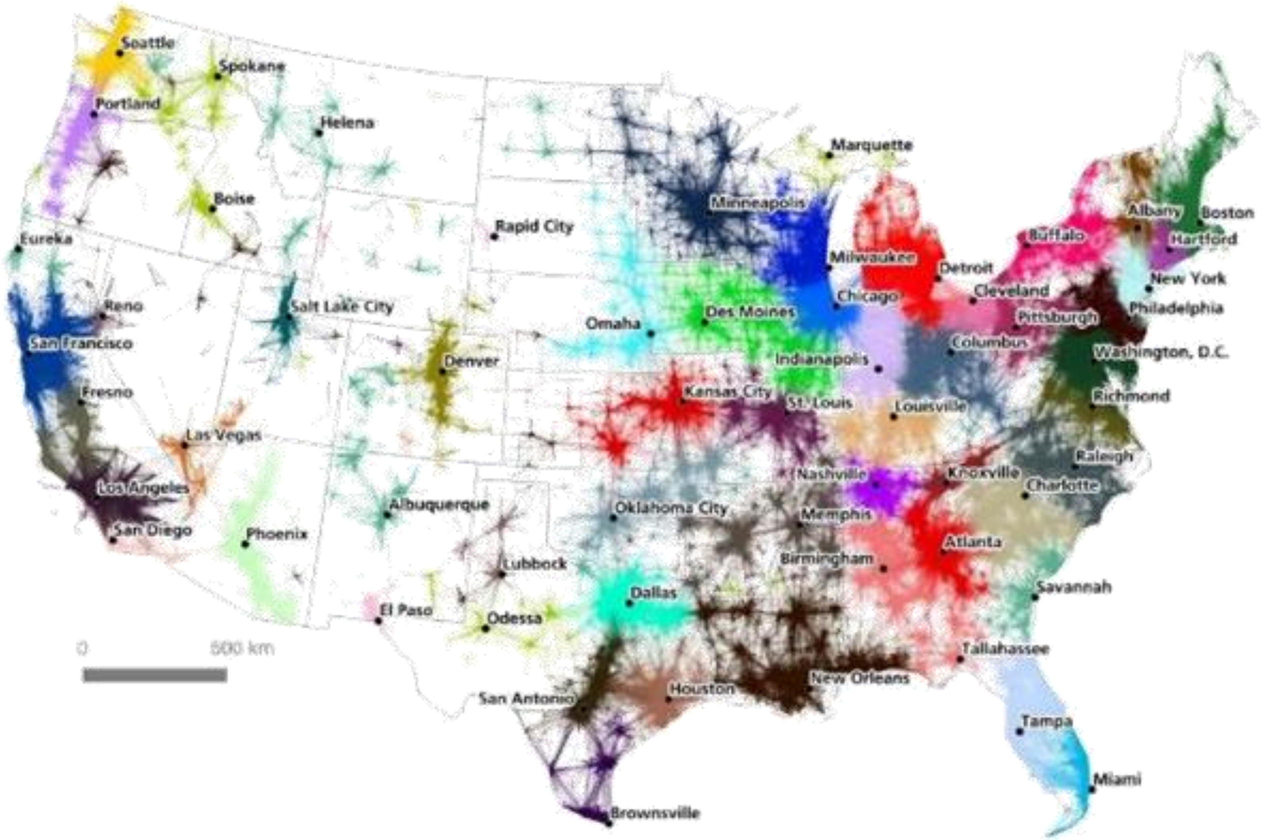
CHANGE IS HERE





...and more change is coming...

POPULATION CENTERS…



- The majority of US population lives in **mega regions**, comprised of urban areas surrounded by growing suburban and exurban areas.

- Urban areas are reimagined as livable communities with open spaces, plazas, and greater and more flexible mobility options

Implication… Density Impacts Congestion

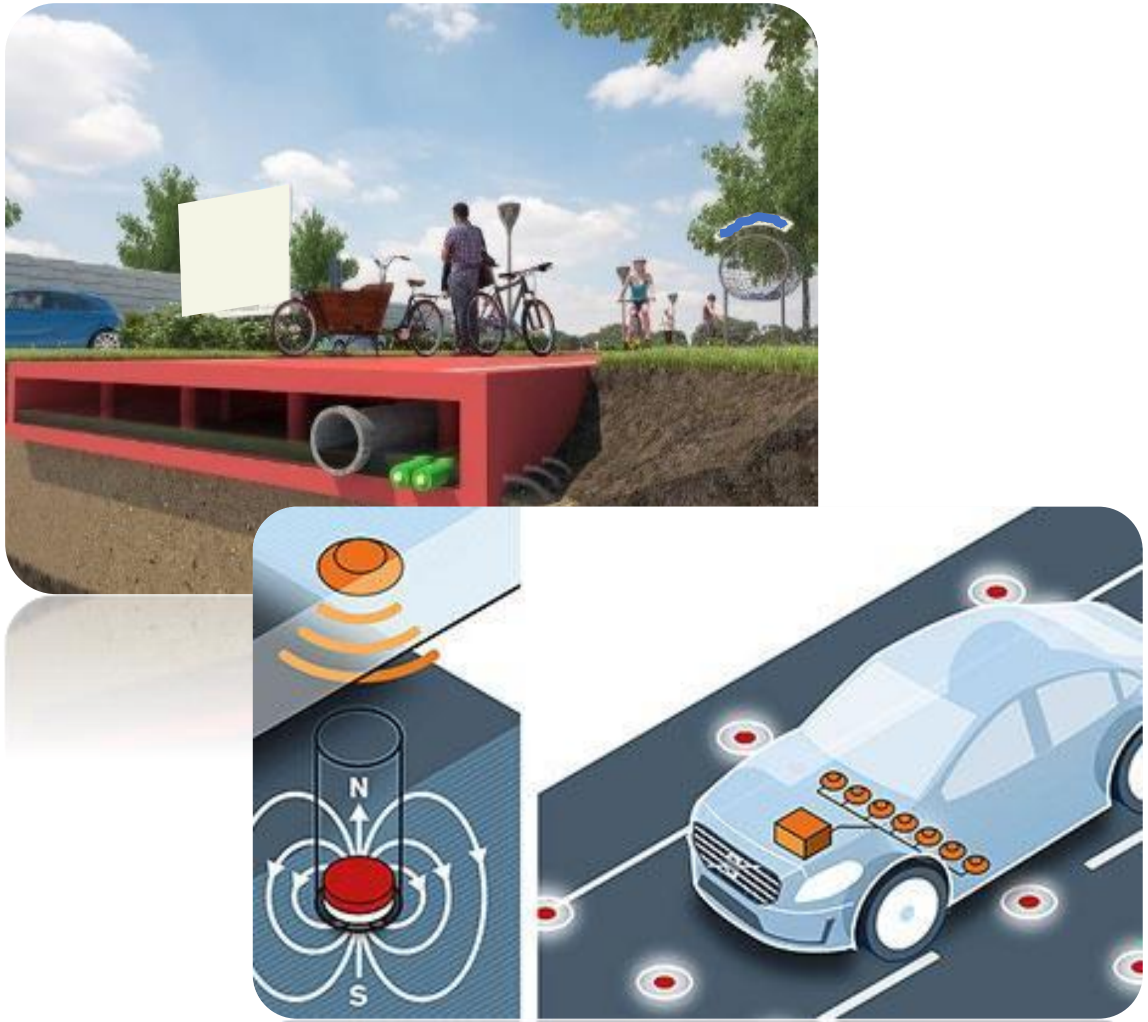
POPULATION CENTERS…

Implication… Density Impacts Congestion

IN URBAN AREAS…

- Open and adaptable pavement design options for multi-functionality and ease of utility access

- Incorporate new and emerging technologies related to energy generation, energy storage, charging, LED arrays etc…

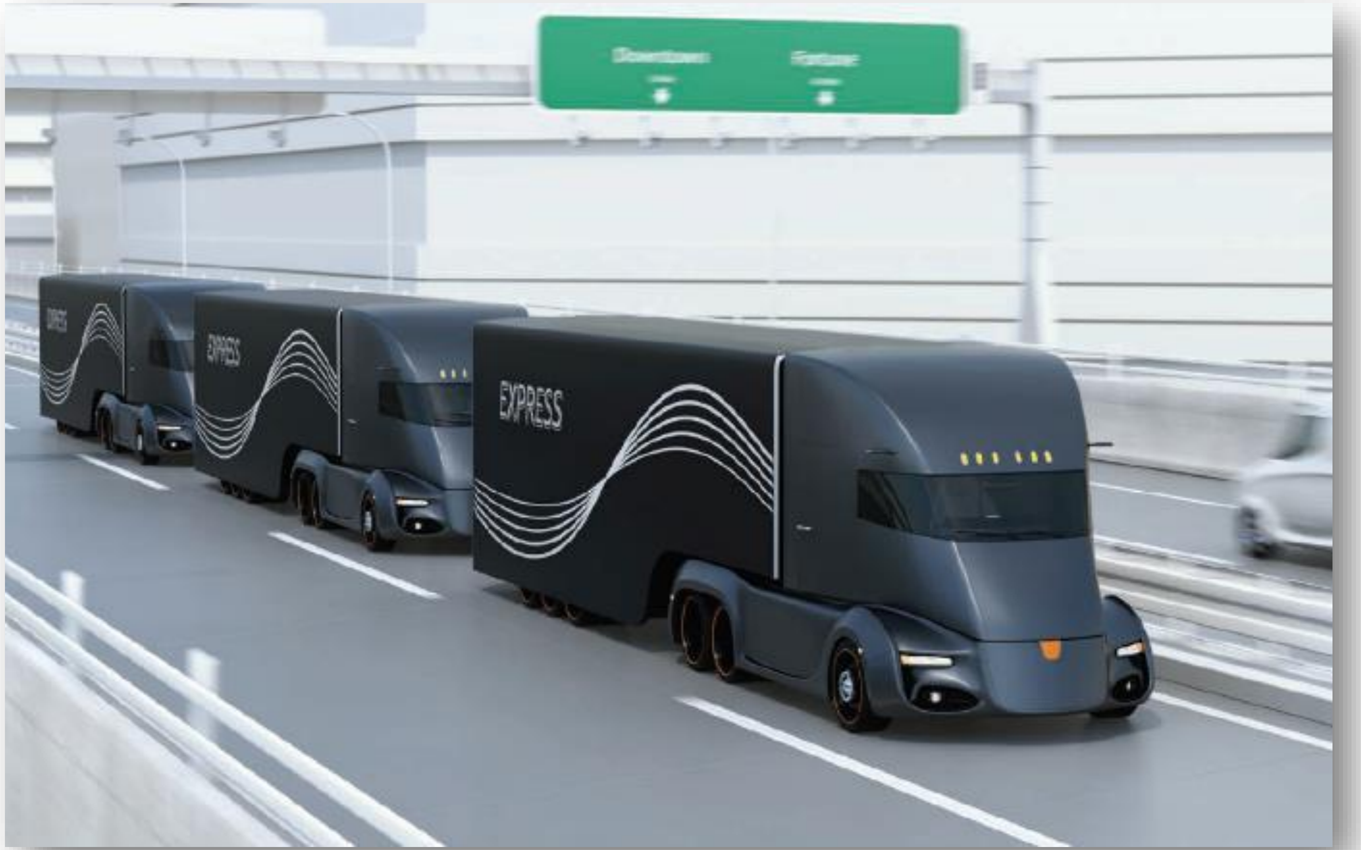


[Image: Google Images]

Connected Vehicles…

Implication…Technology Invades Surface Transportation!
(Safety, Congestion, Pavement Condition)

FREIGHT MOVEMENT



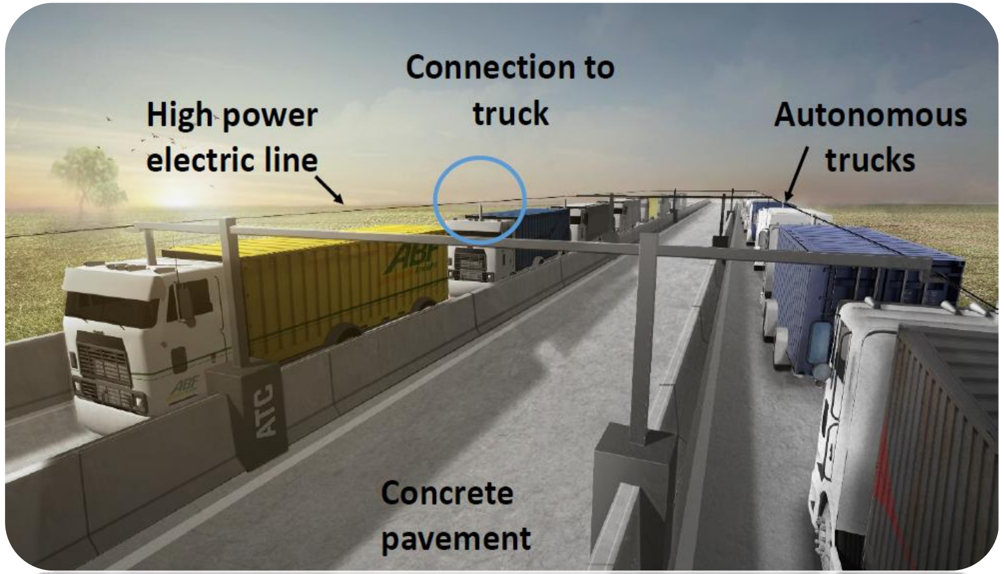
[Source: USDOT]

Imagine...

- Freight moves on autonomous connected trucks.
- Designed for maximum longevity and minimum service disruption
- Increased axle loads, tire pressures, platooning?

HELP IMPROVE CAPACITY / EFFICIENCY

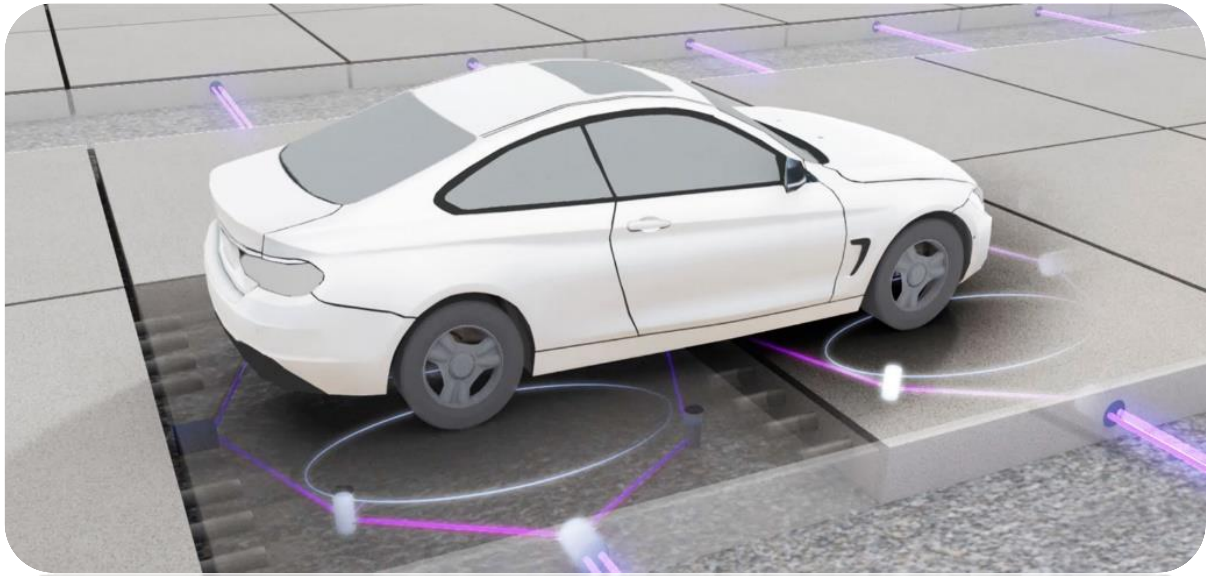
- Dedicated truck corridors to facilitate lane use and freight efficiency:
- Heavy-duty channelized traffic designs (for road trains)
- Heavy-duty designs to accommodate:
    - Higher Axle loads
    - Tire pressures



[Image: Courtesy Tyler Ley]

INNOVATE TO MEET USERS NEEDS…

*Agencies will need **better**, **adaptable**, **resource efficient** pavements that have **reliable long-term performance**… accommodating variety of sensing and measurement technologies needed for connected vehicles of the future.*

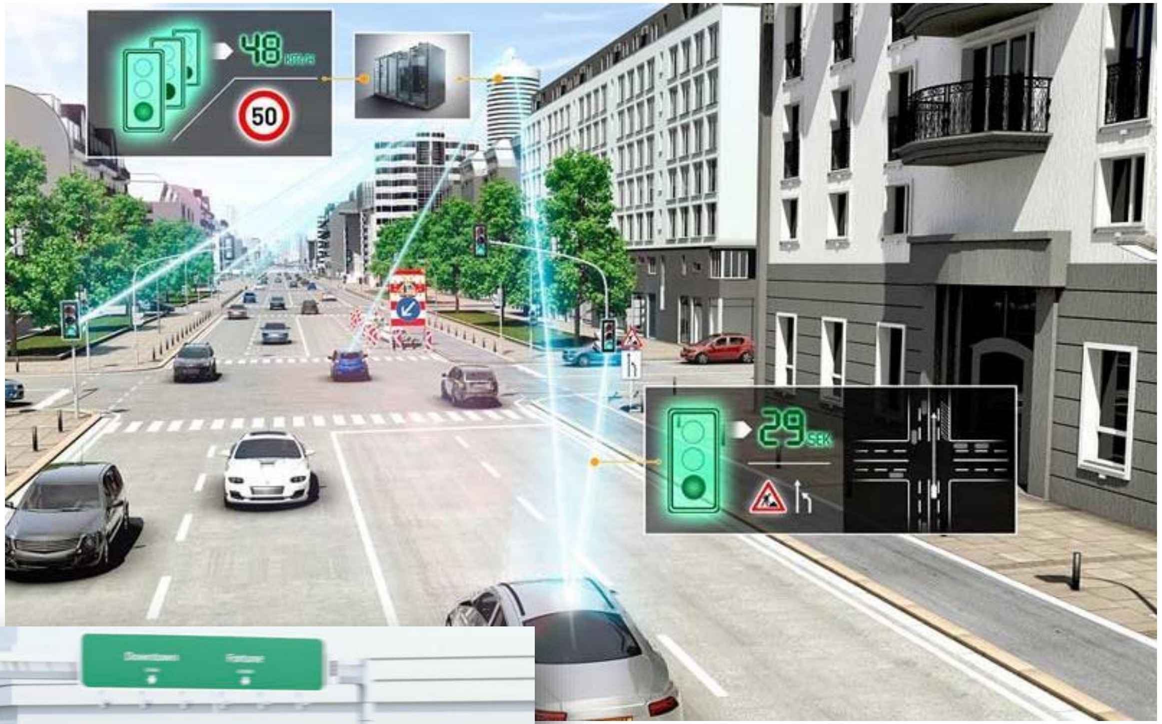


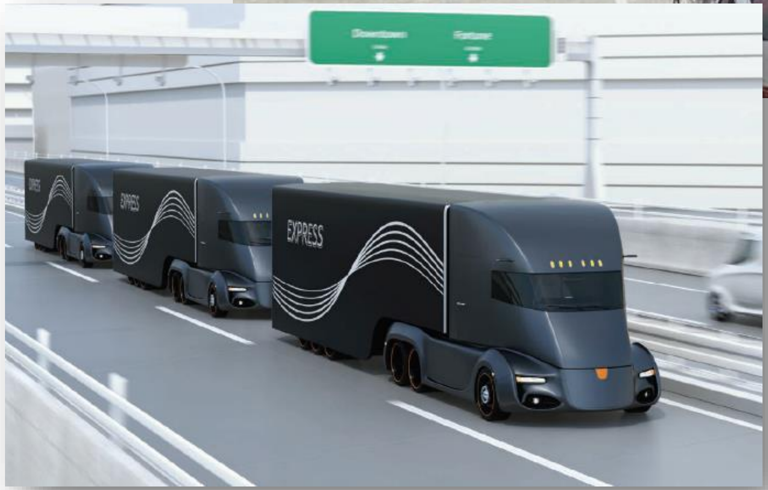
[Image: Integrated Roadways]

AUTONOMOUS AND CONNECTED VEHICLES

Design Considerations

- Higher Density and Congestion
- Integrated and Multi-Use Pavements
- Incorporate New Technologies
- Increased Freight
- Higher Axle Loads
- Greater Tire Pressures
- Reduced Wheel Wander
- Longevity
- Minimal Disruption





AUTONOMOUS AND CONNECTED VEHICLES

Design Considerations

- Integrated and Multi-Use Pavements
- Incorporate New Technologies
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Solutions…

Concrete Pavement & Overlays

AUTONOMOUS AND CONNECTED VEHICLES

Design Considerations

- Integrated and Multi-Use Pavements
- Incorporate New Technologies
- Increased Freight
- Higher Axle Loads
- Greater Tire Pressures
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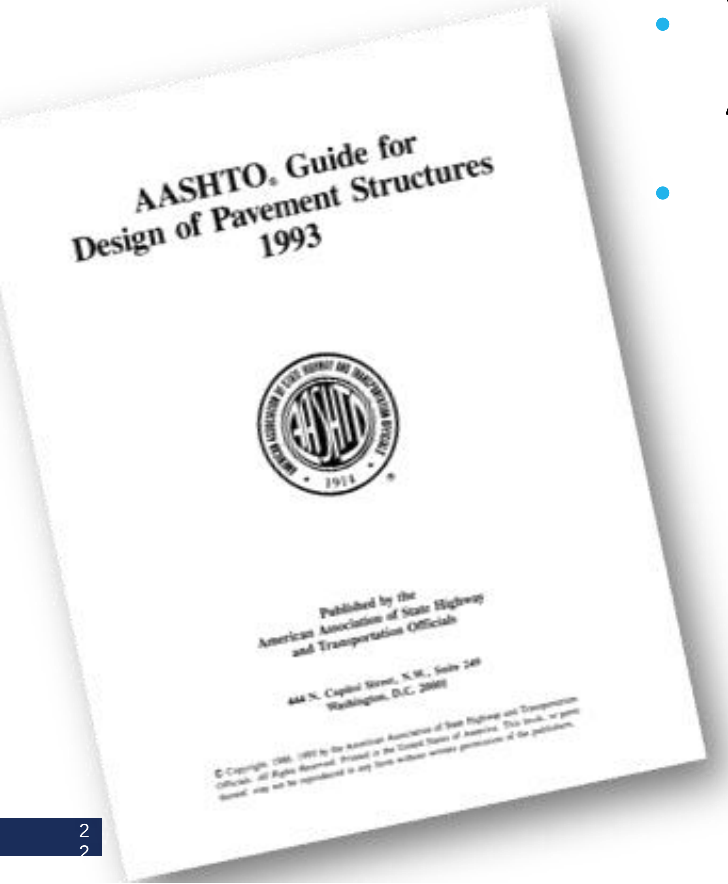
- Longevity
- Minimal Disruption

How can we account for some of these in design?

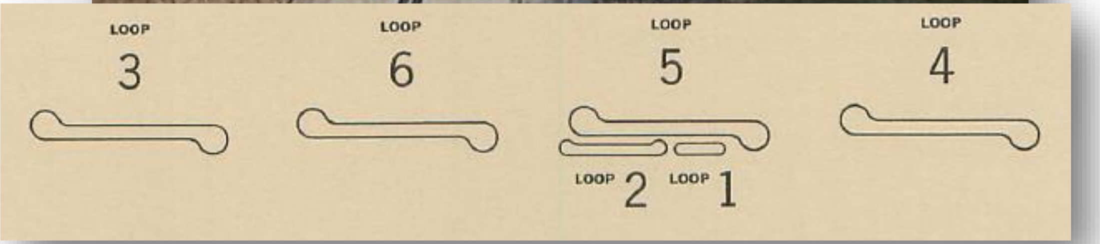
Solutions…

Concrete Pavement & Overlays

Can we keep designing as we have in the past?



- Wholly empirical – AASHO Road Test
- Limited inference space:
  - Materials
  - Structural sections
  - Soils
  - Traffic



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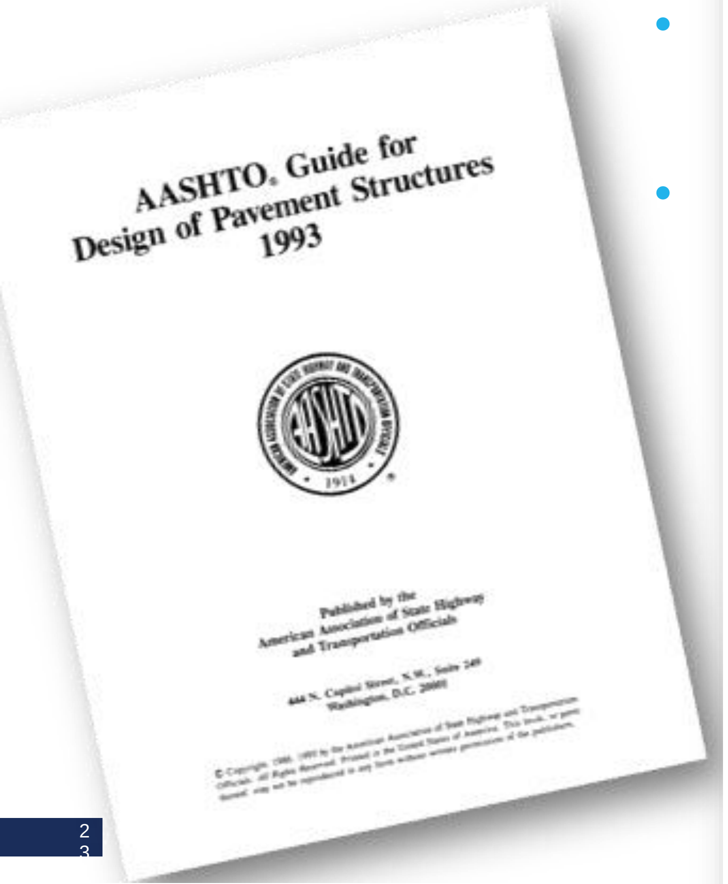
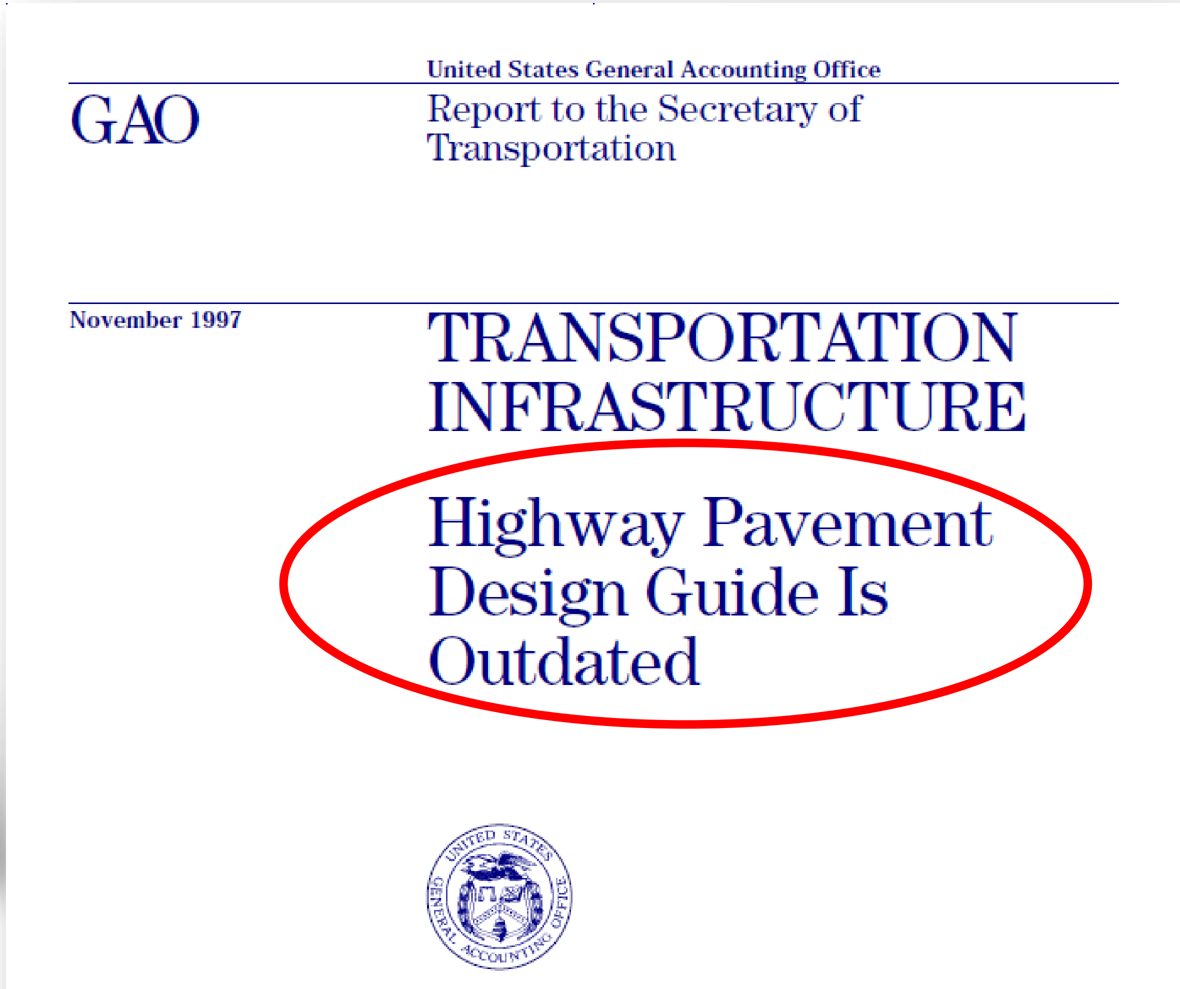


AASHTO. Guide for
Design of Pavement Structures
1993

Published by the
American Association of State Highway
and Transportation Officials

444 N. Capitol Street, N.W., Suite 249
Washington, D.C. 20001



United States General Accounting Office

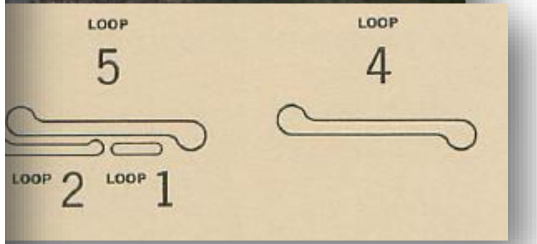
GAO

Report to the Secretary of Transportation

November 1997

TRANSPORTATION INFRASTRUCTURE

Highway Pavement Design Guide Is Outdated

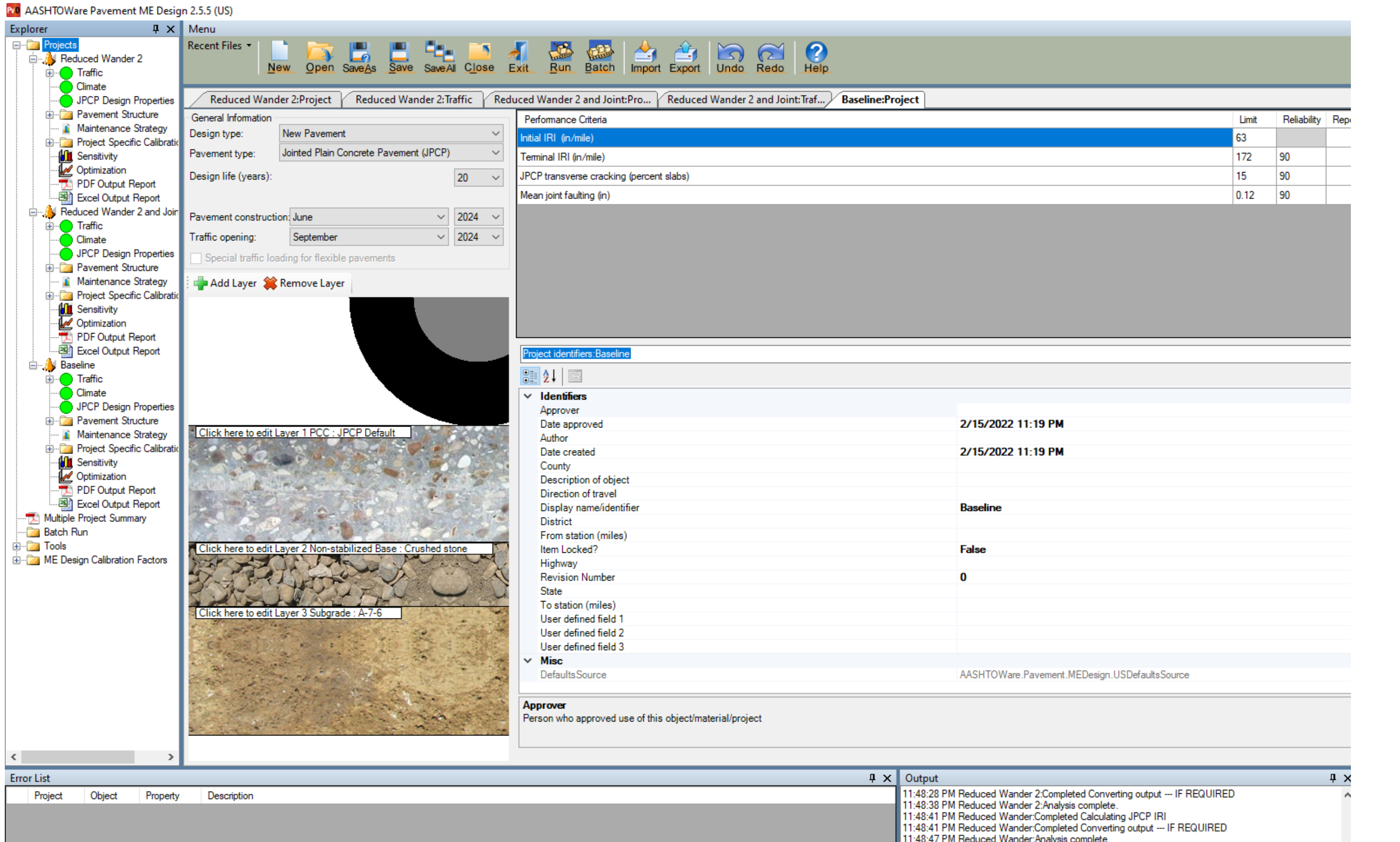


Must keep improving designs…

- **Mechanistic – Empirical tools are a requirement**
  - **Pavement ME**
  - **BCOA – ME**
  - **UBOL Design**
  - **PavementDesigner.org**

Must keep improving designs…

- Mechanistic – Empirical tools are a requirement
  - **Pavement ME**
    - Concrete Pavements
    - Concrete Overlays

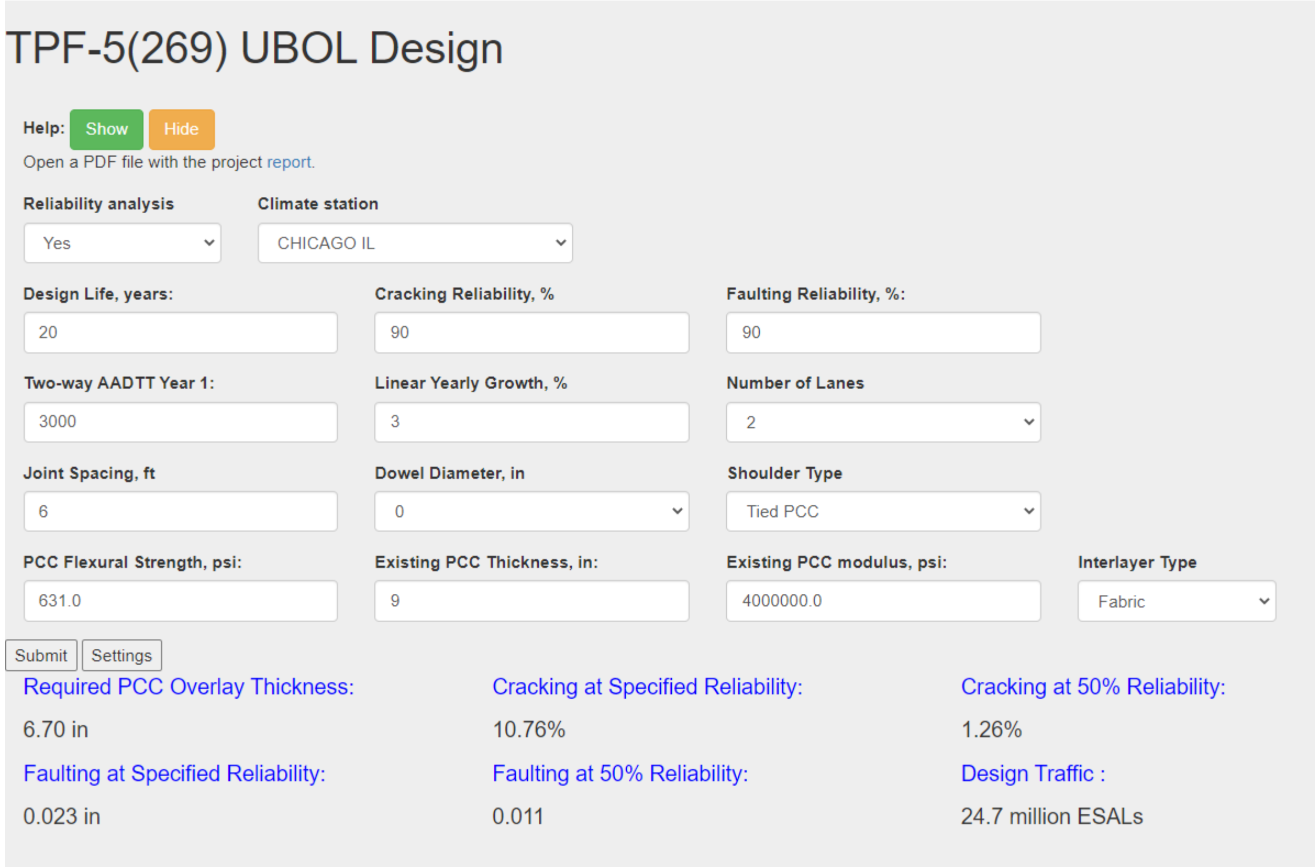


Must keep improving designs…

- Mechanistic – Empirical tools are a requirement
  - **BCOA – ME**
    - FHWA TPF 5 – 165
    - Concrete Overlays of Asphalt

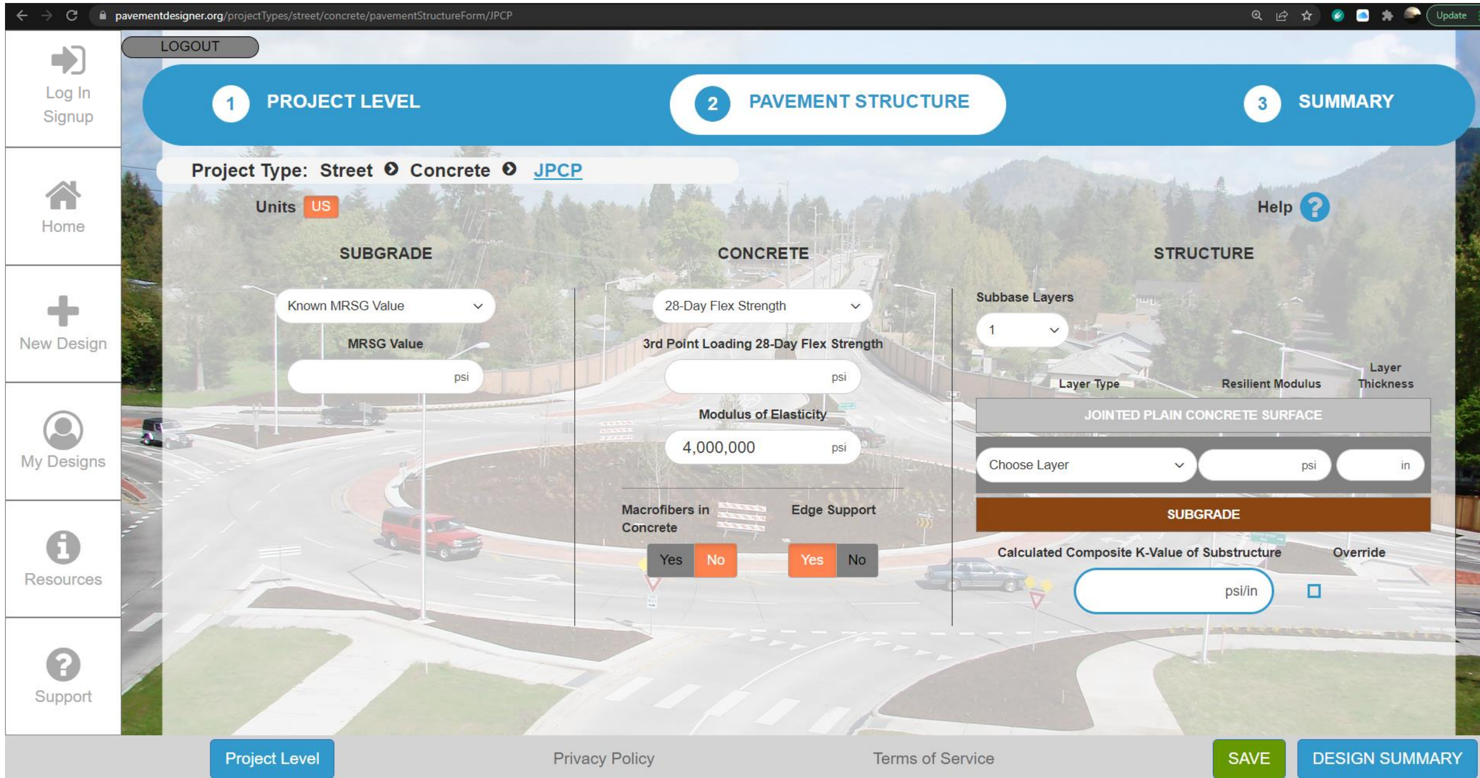
Must keep improving designs…

- Mechanistic – Empirical tools are a requirement
  - **UBOL Design**
    - FHWA TPF – 5(269)
    - Concrete Overlays of Concrete



Must keep improving designs…

- Mechanistic – Empirical tools are a requirement
  - **PavementDesigner.org**
    - City Roads & Streets
    - Concrete Pavements
    - Concrete Overlays



Design Considerations

- Integrated and Multi-Use Pavements
- Incorporate New Technologies
- Increased Freight
- Higher Axle Loads
- Greater Tire Pressures
- Reduced Wheel Wander
- Longevity
- Minimal Disruption

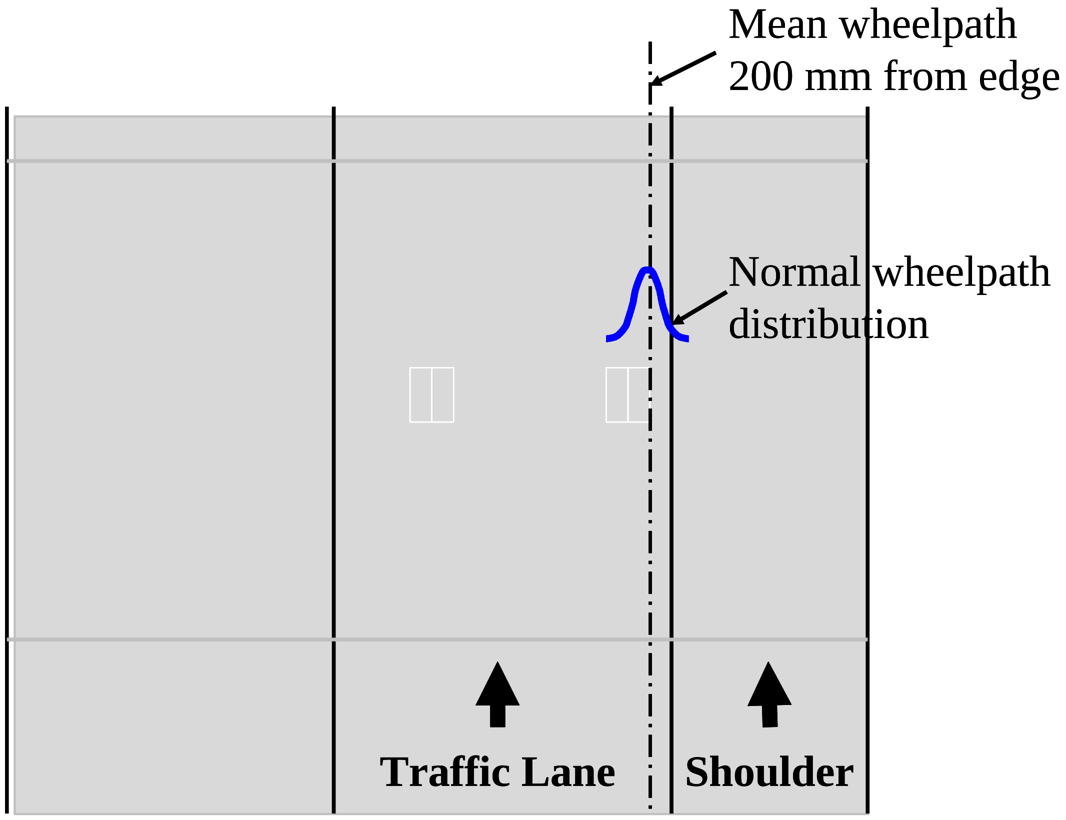
M-E Tools Can Easily Assist Designing Concrete Solutions for These Considerations

Solutions…

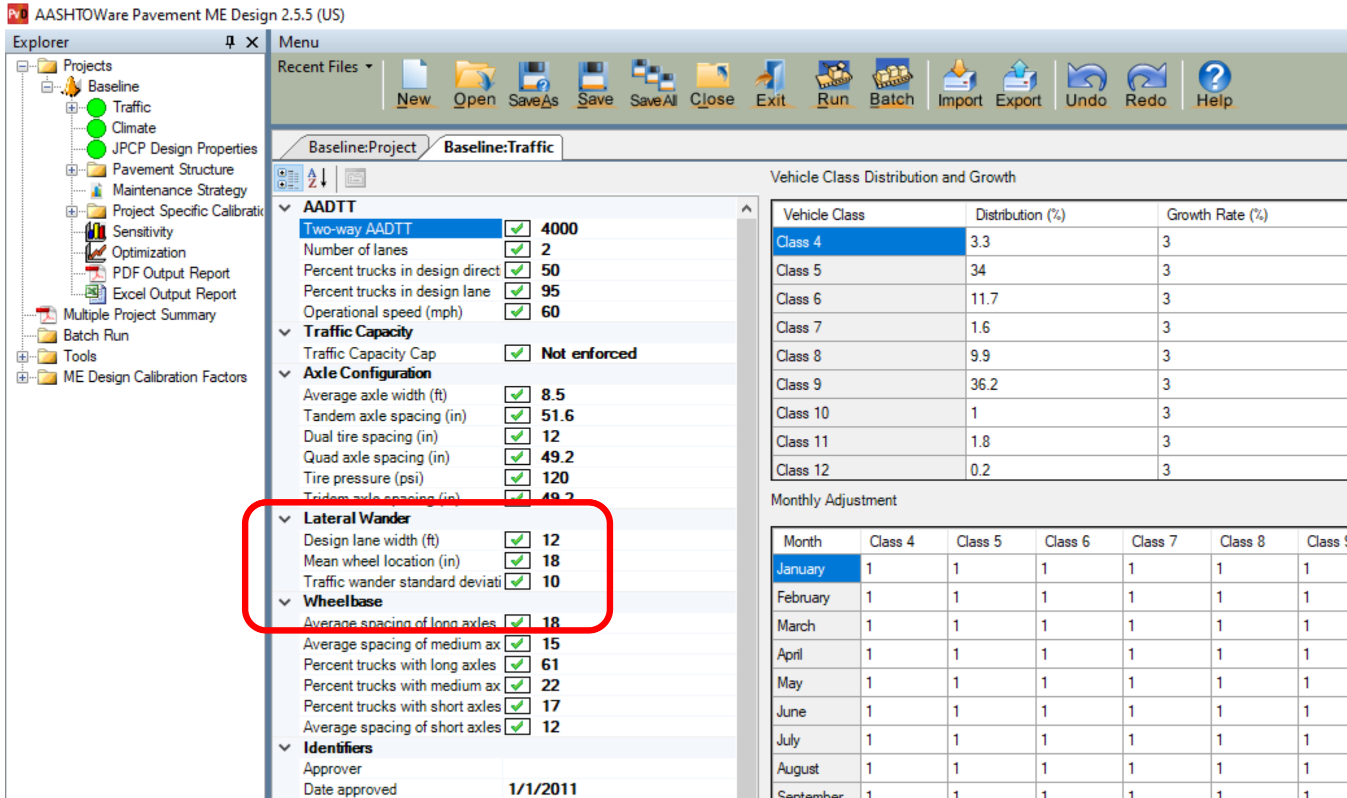
Concrete Pavement & Overlays

DESIGNING FOR THE FUTURE… TODAY

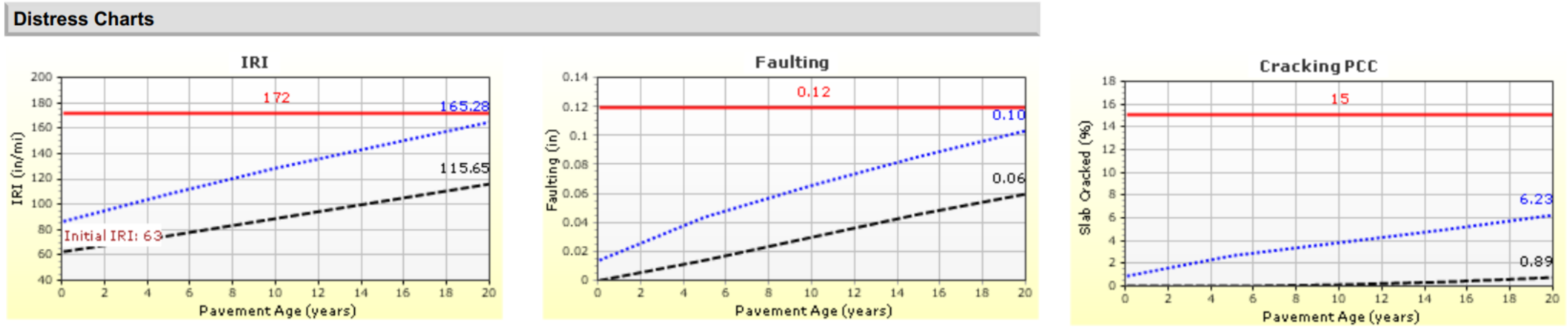
Example – Lateral Wheel Wander



- **Truck platooning could have a big impact on wheel wander…**

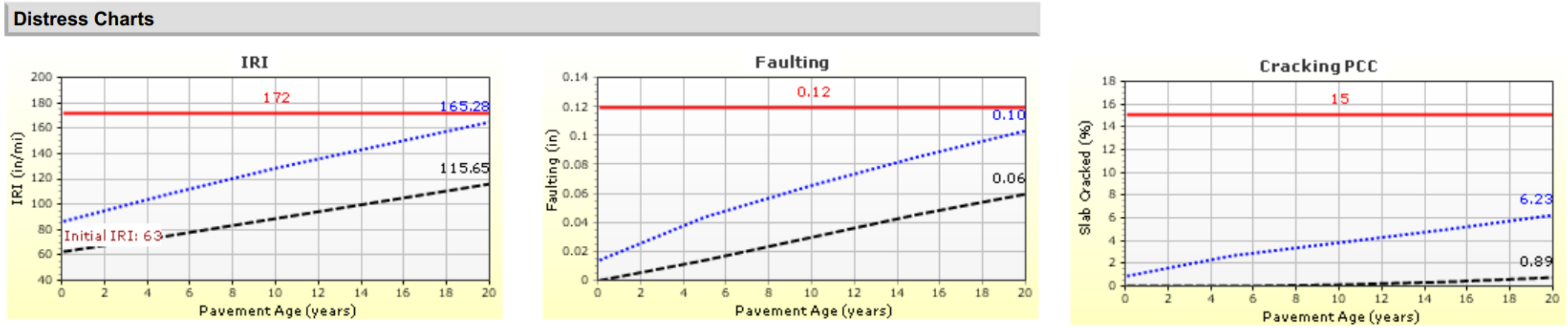


Example – Lateral Wheel Wander



- Baseline – Default Wander = 10 in

Example – Lateral Wheel Wander



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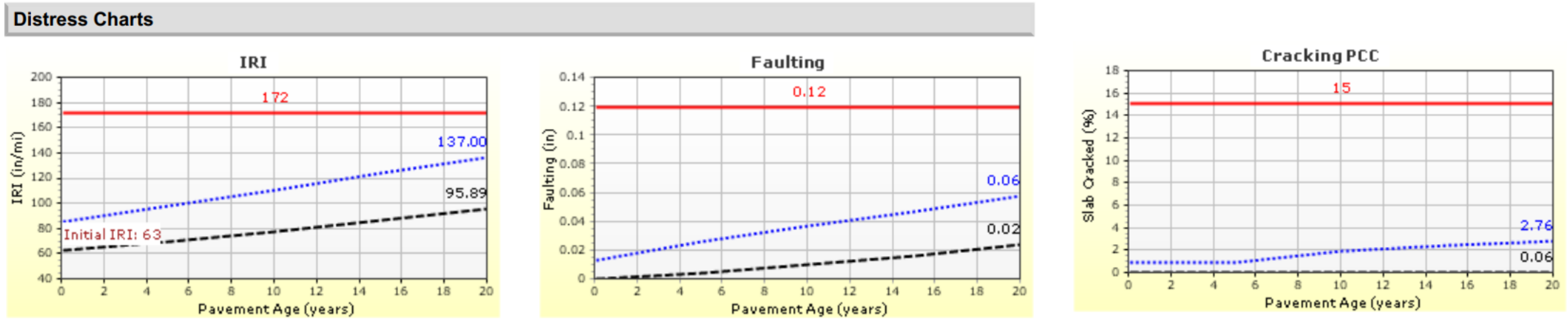
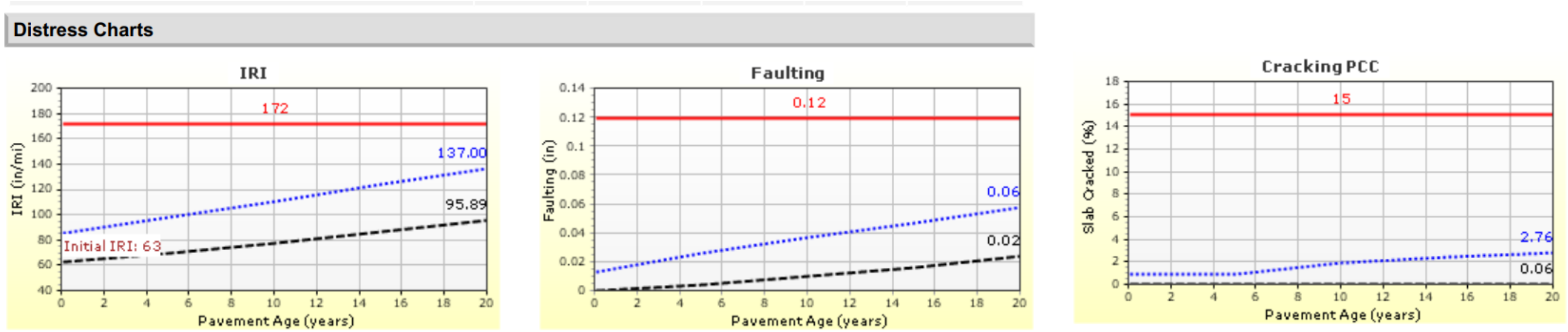


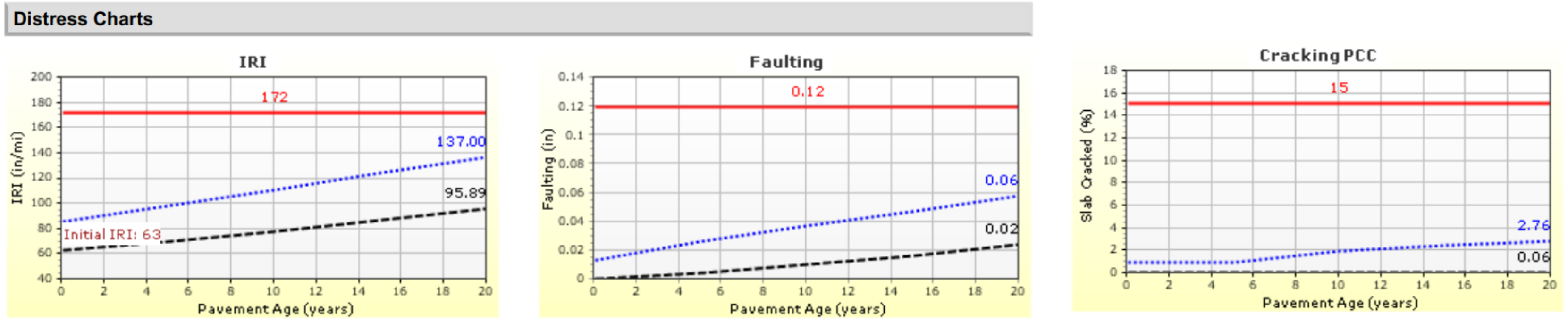
- Alternate – Reduced Wander = 2 in

Example – Lateral Wheel Wander

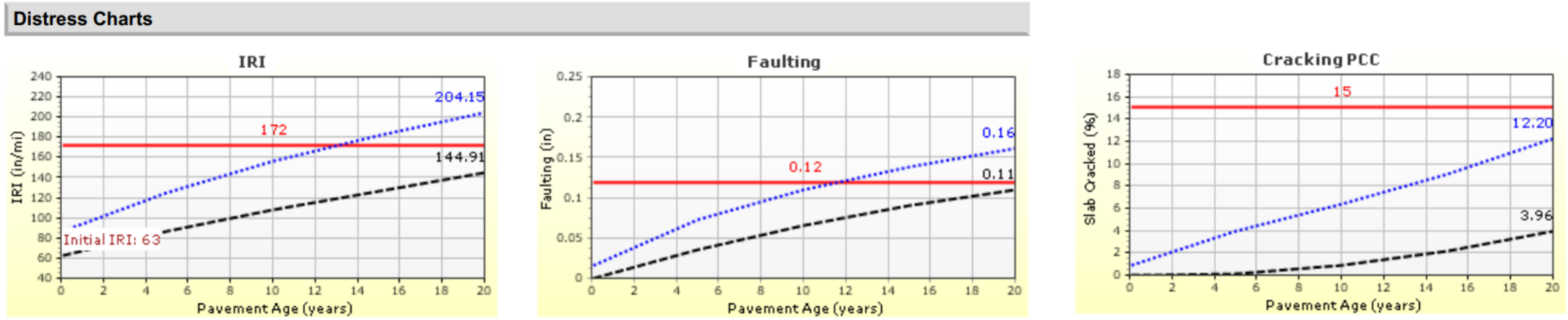


- Alternate – Reduced Wander = 2 in

Example – Lateral Wheel Wander



- Alternate – Reduced Wander = 2 in



- Alternate 2 – Reduced Wander = 2 in
  Location = 6 in off joint

ALLEVIATING CONGESTION

Better utilization of the available space…

IS THAT ALL?

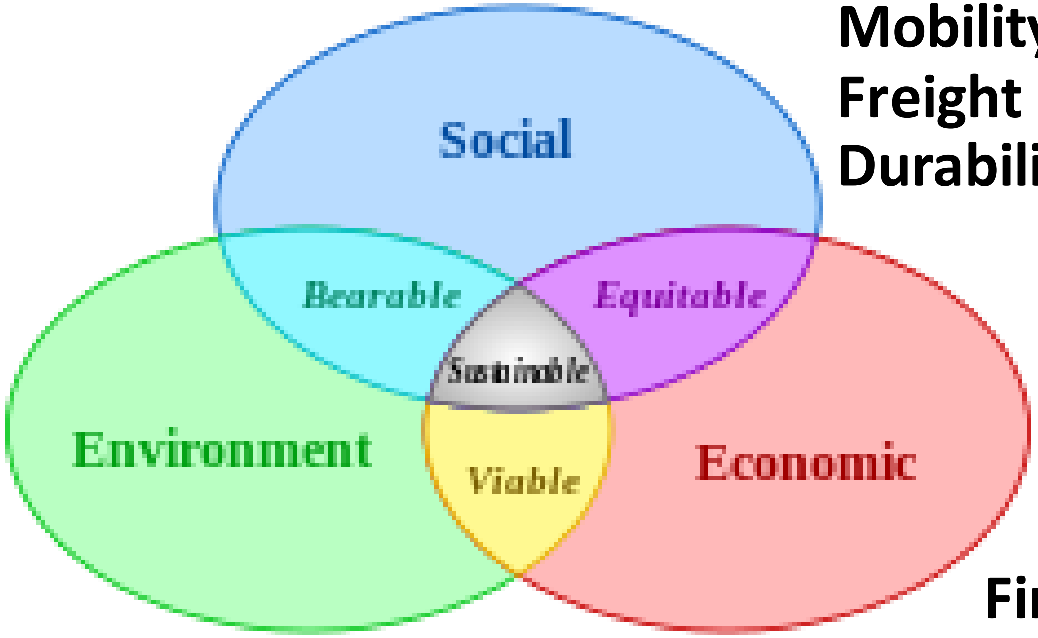
Can we just consider autonomous and connected vehicles?

What else needs to be considered?

MORE CHALLENGES…

Sustainability…

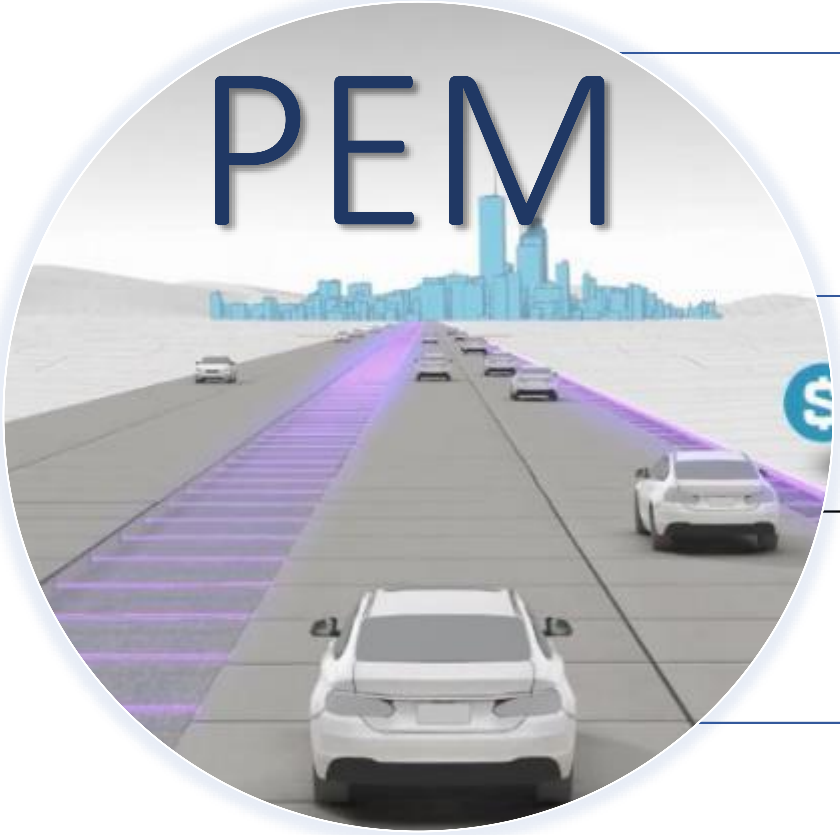
Noise
Traffic Disruption
Mobility
Freight
Durability



EPDs…
Life-Cycle Assessment (LCA)

First cost…
Life-Cycle Cost Analysis (LCCA)

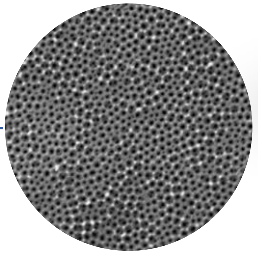
MORE CHALLENGES… IMPROVED SOLUTIONS



Optimized
Gradations

Durable
Matrix

Greener
Materials (PLC)



Recycled
Materials

Deliver Durability and Sustainability Every Time!

***

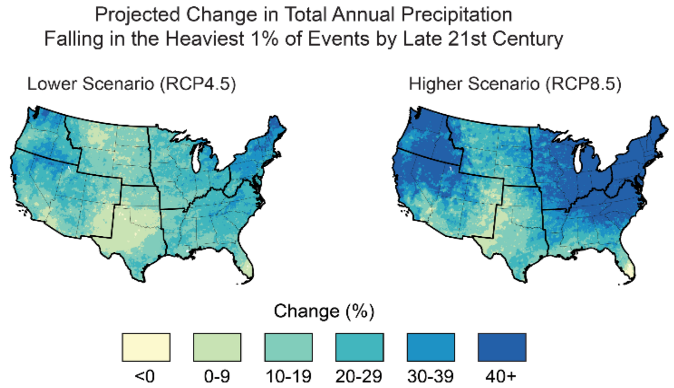
Performance Engineered Mixtures

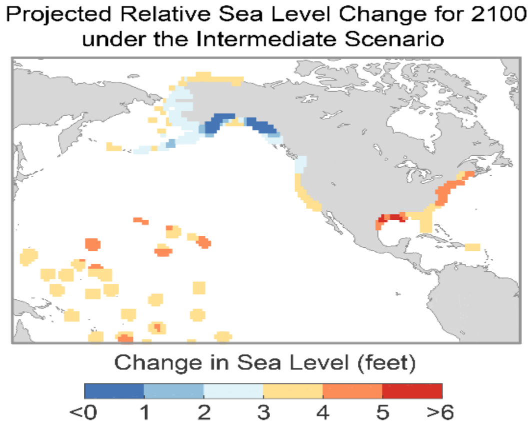
[Image: Integrated Roadways]

MORE CHALLENGES…

We live in a changing environment…

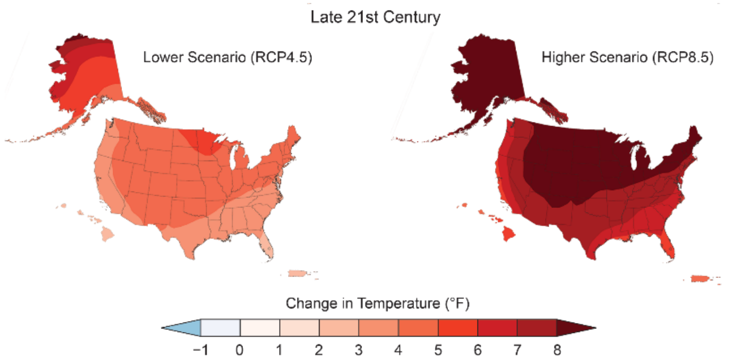
U.S. severe storms, heavy precipitation events:
Greater intensity *and* frequency
Continued increases expected





Global mean sea level:
7–8 inches higher since 1900 - about half since 1993
Expected to rise by 1–4 feet by 2100

Increased Extreme heat events and drought:
Increased incidence of large forest fires



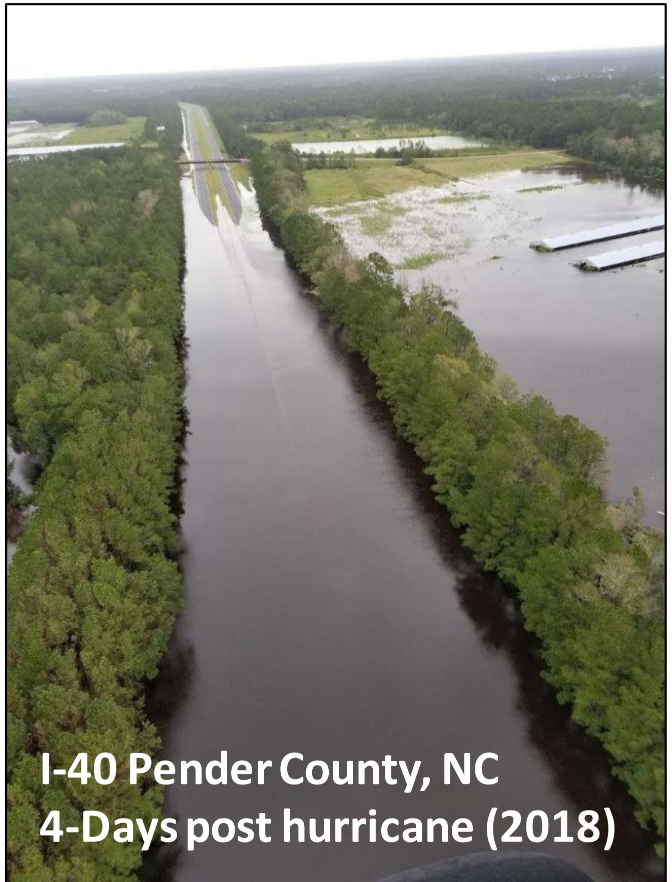
USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Report-in-Brief [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 186 pp.

Slide Credit: Jim Mack - Cemex

MORE CHALLENGES…

Change is already here…

- **Resilience**



Slide Credit: Jim Mack – Cemex

Putting it all together…

- Increased population and freight require sustainable and resilient infrastructure
- Autonomous and connected vehicles are a technological solution… that disrupt how we currently think about infrastructure
- Must be ready with long-lasting, sustainable solutions… such as concrete pavement and overlays
- Need Mechanistic – Empirical design solutions that can help model changes we haven't faced before

CONCLUSION

Thank You!

We have a bright but challenging future ahead!

Eric Ferrebee, P.E.
Director of Technical Services
American Concrete Pavement Association
eferrebee@acpa.org | 847.423.8709

Advancing Concrete Pavement Design Through Instrumented Data

JAMIE GREENE

FLORIDA DEPARTMENT OF TRANSPORTATION

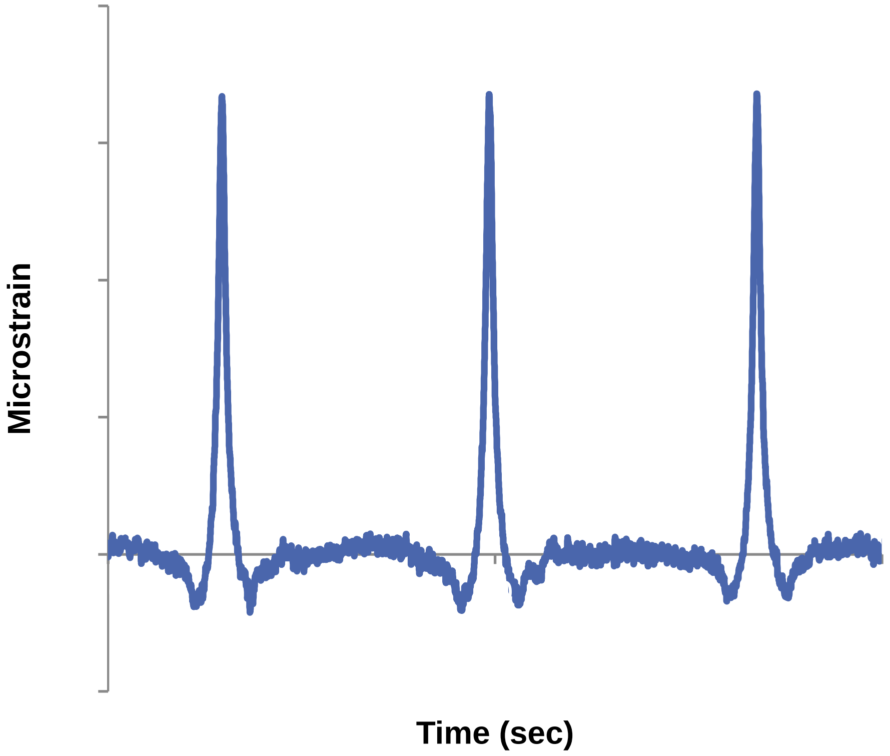
Presentation Topics

- Pavement instrumentation philosophy
- Things to consider during planning
- Example of a real-world pavement instrumentation project

Vibrating wire strain gauges & thermocouple tree

Philosophy

- Pavement design has shifted to mechanistic & mechanistic-empirical methods
- Pavement instrumentation is a tool to monitor the behavior of pavement systems
- There are significant benefits from a well-designed pavement instrumentation program



Dynamic Strain data from Heavy Vehicle Simulator loading

Items to Consider

- Every project is different…
  - What are the objectives?
  - What are the critical responses?
  - How much data is needed?
  - How do I relate sensor data to mechanistic principles?
  - What predictive models should be used?

Instrumentation Design

- Identification of critical locations
- Selection of sensors
- Calibration of sensors
- Identification of possible errors
- Installation
- Data collection & storage
- Data analysis

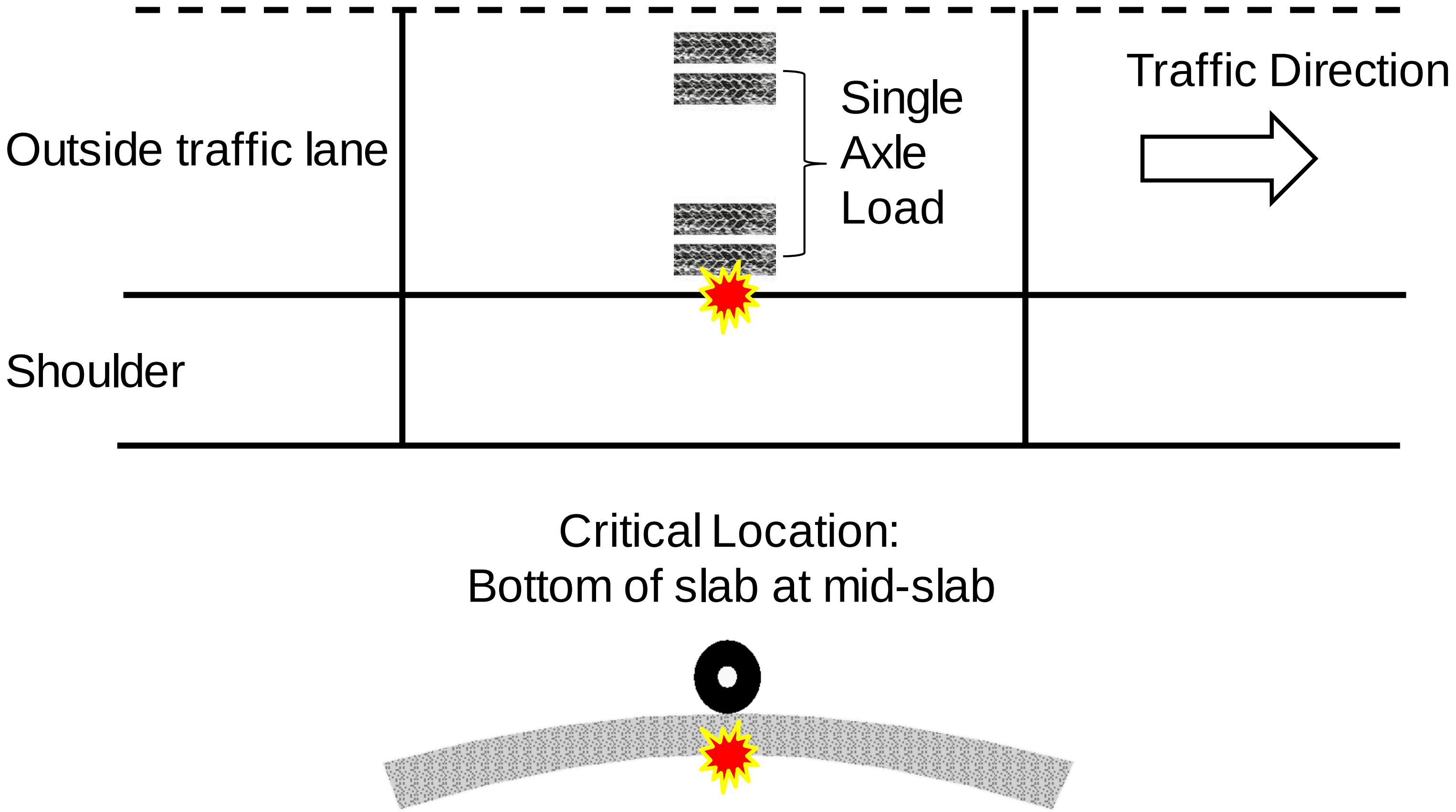
Installing strain gauges & thermocouple trees on US-301

Common Concrete Pavement Response Measurements

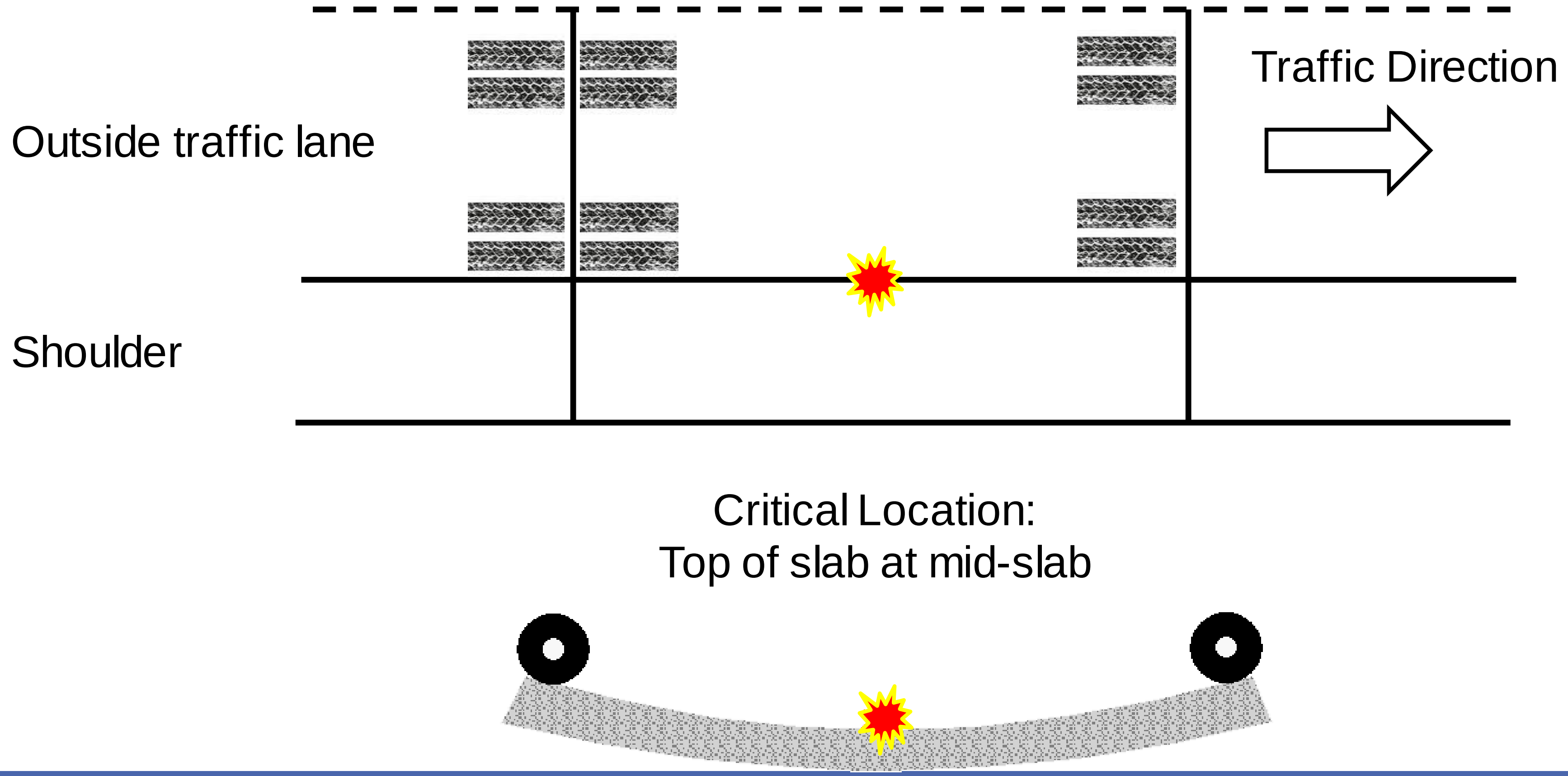
- Dynamic strain due to wheel loads
- Environmental strain due to slab curl/warp
- Deflection due to slab curl/warp or wheel loads
- Temperature gradient throughout slab depth
- Soil moisture change & movement through supporting soil layers

Linear Variable Differential Transformer (LVDT) measurement of slab corner lift-off

Bottom-Up Transverse Cracking



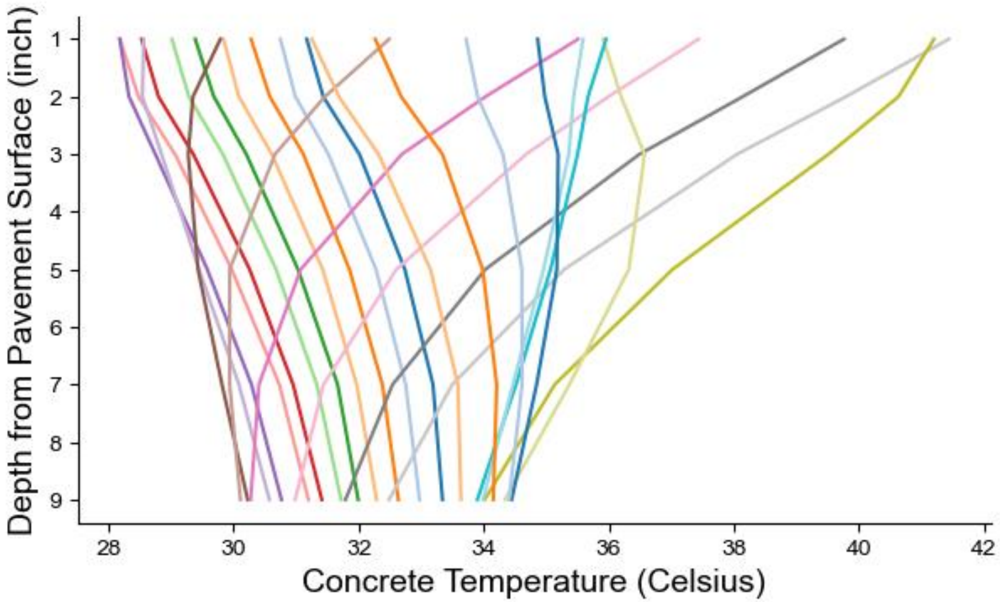
Top-Down Transverse Cracking



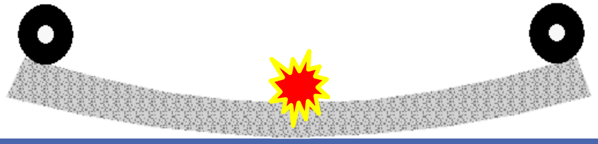
Curling & Warping

Early Morning

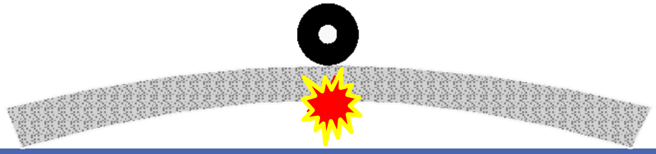
Late Afternoon



Slab Surface Cooler & Drier than Base

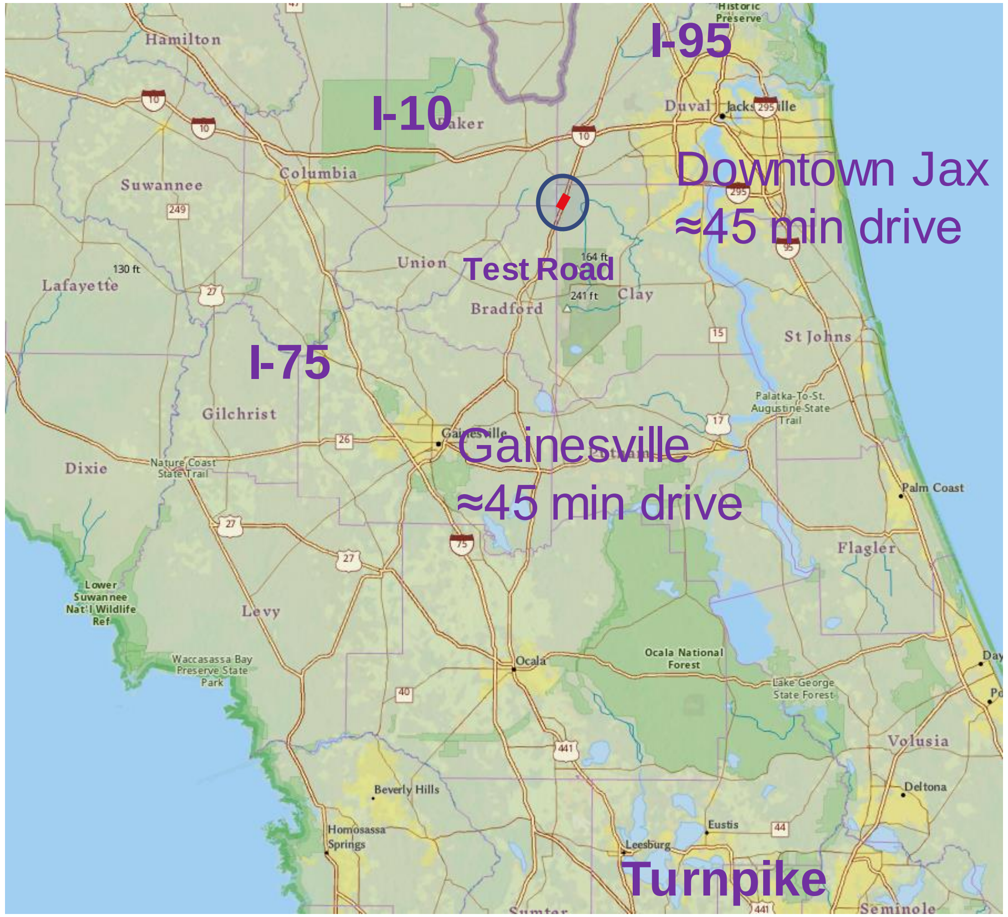


Slab Surface Warmer & Drier than Base



Florida Test Road Location

- Clay County, SR 200/US 301
- Adjacent to existing NB Lanes
- Significant truck corridor connecting SW & NE Florida
  - I-75 & Turnpike to I-10 & I-95
  - Interconnects multiple seaports & rail yards



US-301 Concrete Test Road Objectives

- Structural experiment
  - Are Florida concrete pavements under/over designed?
  - How do alternative base types perform?
- Drainage experiment
  - How effective are edge drains?
  - Should they be required for all Florida concrete pavements?
- Calibration experiment
  - Calibrate Pavement ME cracking models

Structural Experiment

- 20 test sections (includes replicates)
- Four thicknesses (6 to 10 inches)
- Multiple base types (asphalt, limerock, A-3)
- RAP & fiber mix designs

Section	Layer 1	Layer 2	Layer 3	Layer 4	Length (ft)	Joint Spacing(ft)	Edge Drain
1	10" PCC (RAP)	4" Type B	12" Stabilized Subgrade (LBR 40)		225	15	Y
2	10" PCC	4" Type B	12" Stabilized Subgrade (LBR 40)		225	15	Y
3	8" PCC	4" Type B	12" Stabilized Subgrade (LBR 40)		225	15	Y
4	10" PCC (RAP)	4" Type B	12" Stabilized Subgrade (LBR 40)		225	15	Y
5	7" PCC (RAP)	4" Type B	12" Stabilized Subgrade (LBR 40)		225	13	Y
6	6" PCC	4" Type B	12" Stabilized Subgrade (LBR 40)		225	12	Y
7	7" PCC	2" Type B	12" Stabilized Subgrade (LBR 40)		225	13	Y
8	7" PCC	4" Type B	12" Stabilized Subgrade (LBR 40)		225	13	Y
9	6" PCC	4" Type B	12" Stabilized Subgrade (LBR 40)		225	12	Y
10	7" PCC (RAP)	4" Type B	12" Stabilized Subgrade (LBR 40)		225	13	Y
11	7" PCC	2" Type B	12" Stabilized Subgrade (LBR 40)		225	13	Y
12	7" PCC	12" Special Select (A-3)			225	13	Y
13	7" PCC	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)		225	13	Y
14	10" PCC	2" Type SP	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)	225	15	Y
15	8" PCC	2" Type SP	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)	225	15	Y
16	6" PCC	2" Type SP	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)	225	12	Y
17	7" PCC	2" Type SP	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)	225	13	Y
18	6" PCC 6' X 6' Slabs with Fiber	2" Type SP	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)	225	6	Y
19	7" PCC	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)		225	13	N
20	6" PCC 6' X 6' Slabs with Fiber	2" Type SP	4" LR Base (LBR 100)	12" Stabilized Subgrade (LBR 40)	125	6	Y

Drainage Experiment

- Two thicknesses (7 & 10 inches)
- Three base types
- With & w/o edge drains & joint sealant

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	10" PCC (RAP)	10" PCC	8" PCC	10" PCC (RAP)	7" PCC (RAP)	6" PCC	7" PCC	7" PCC	6" PCC	7" PCC (RAP)	7" PCC	7" PCC	7" PCC	10" PCC	8" PCC	6" PCC	7" PCC	6" PCC 6' X 6' Slabs with Fiber	7" PCC	6" PCC 6' X 6' Slabs with Fiber
	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	2" Type B	4" Type B	4" Type B	4" Type B	2" Type B	12" Special Select (A-3)	4" LR Base (LBR 100)	2" Type SP	2" Type SP	2" Type SP	2" Type SP	2" Type SP	4" LR Base (LBR 100)	2" Type SP
														4" LR Base (LBR 100)	4" LR Base (LBR 100)	4" LR Base (LBR 100)	4" LR Base (LBR 100)	4" LR Base (LBR 100)		4" LR Base (LBR 100)
	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)		12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)
Length (ft)	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	125
Joint Spacing(ft)	15	15	15	15	13	12	13	13	12	13	13	13	13	15	15	12	13	6	13	6
Edge Drain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y

Cracking Calibration Experiment

- Two thicknesses (7 & 10 inches)
- Two joint spacings (13 & 17 feet)
- Curing quality

	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
	10" PCC	10" PCC	10" PCC	10" PCC	10" PCC	10" PCC	10" PCC	10" PCC	7" PCC	7" PCC	7" PCC	7" PCC	7" PCC	7" PCC	7" PCC	7" PCC
	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B	4" Type B
	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)	12" Stabilized Subgrade (LBR 40)
Length(ft)	234	234	238	238	234	238	234	238	234	238	238	234	234	238	234	238
Joint Spacing (ft)	13	13	17	17	13	17	13	17	13	17	17	13	13	17	13	17
Set Gradient	Low	High	Low	High	High	High	Low	Low	High	Low	High	Low	High	Low	Low	High

Typical Test Section Layout

- Cores taken from either end of test sections
- Instrumentation will be limited to north end
- Ten interior slabs will be monitored for performance

Weather Stations & Monitoring Wells

- Two weather stations installed at south & north end of test road
- Four monitoring wells installed near test sections 1, 21, 27, & 52
  - North & south end of test road
  - Drainage experiment
- Monitoring wells & weather stations connected to DAQ in roadside cabinet

Pavement Instrumentation

- Primary instrumentation
  - Concrete strain (traffic & environmental)
  - Concrete temperature
- Drainage sections
  - Granular support layer moisture
  - Edge drain outflow

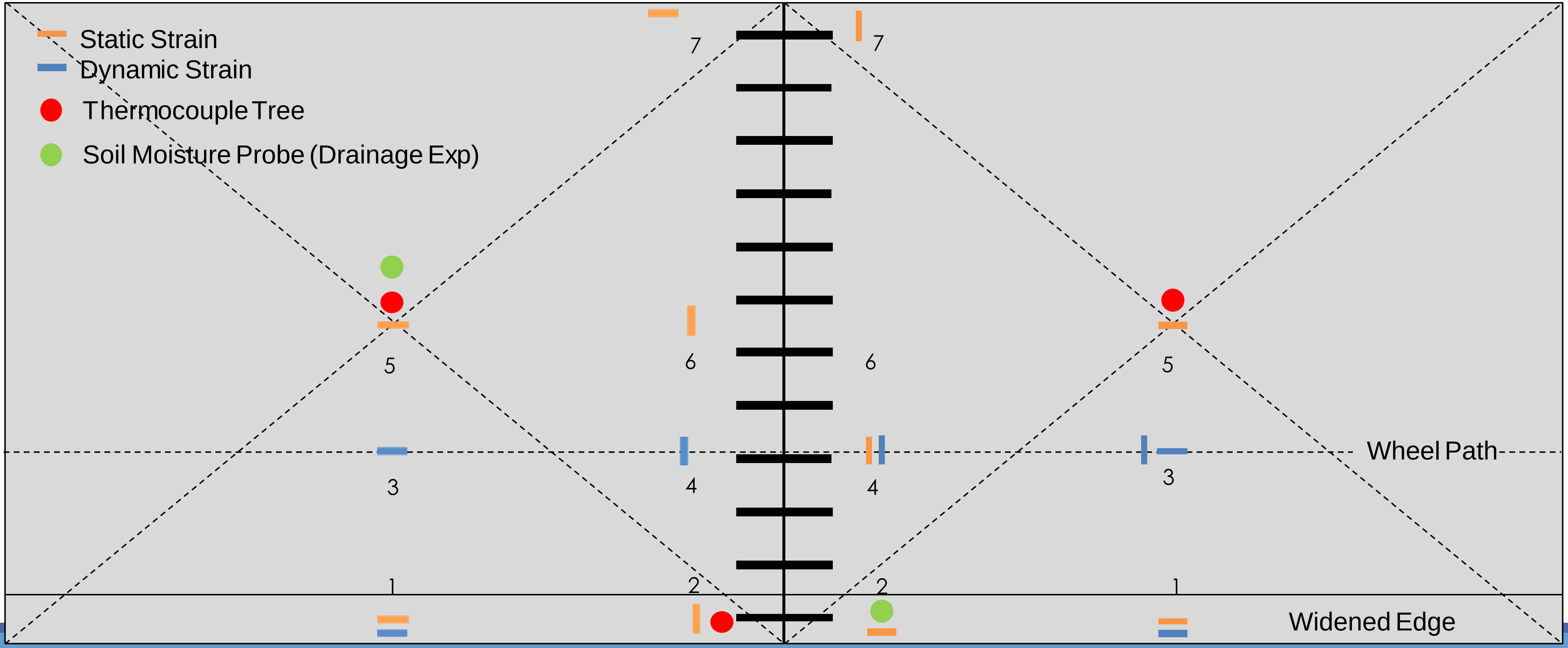
Vibrating Wire Strain Gauge (Environmental)

Thermocouple Tree

Fiber Optic Strain Gauge (Dynamic & Environmental)

Resistive Strain Gauge (Dynamic)

Outside Travel Lane Sensor Locations



Sensor Numbers

- 760 environmental strain gauges
- 770 thermocouples
- 470 dynamic strain gauges
- 250 fiber optic strain gauges
- 40 moisture probes
- 4 monitoring wells
- 2 weather stations
- 15,000 zip ties

Vibrating wire strain gauge & thermistor (Environmental)

Strain gauge & 3-axis accelerometers (Dynamic)

Fiber optic strain gauge (Dynamic & Environmental)

Instrumentation Conduits

Strain Gauge Installation

Concrete Paving Around Sensors

Concrete Paving Around Sensors

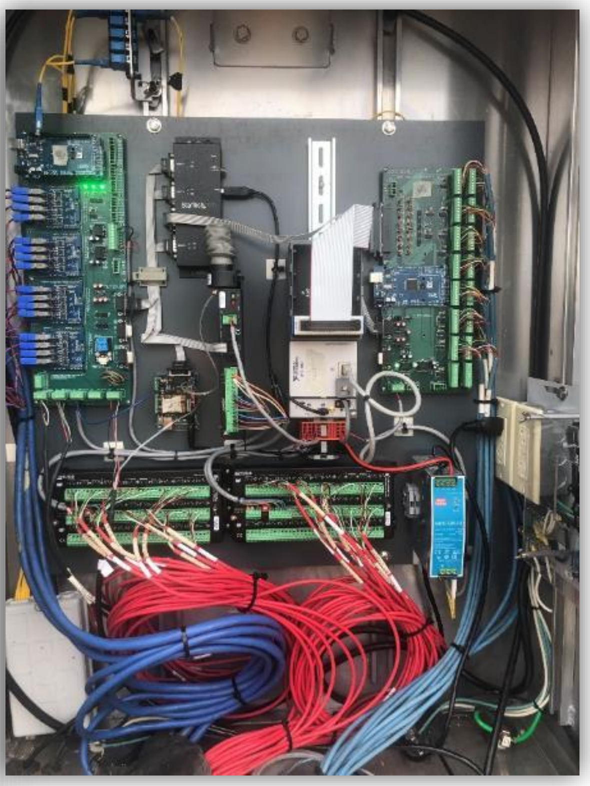
Raise arm to avoid sensors

Raise travel lane set of vibrators when near sensors but keep them on

Edge Drains & Inspection Box

Roadside Data Cabinets

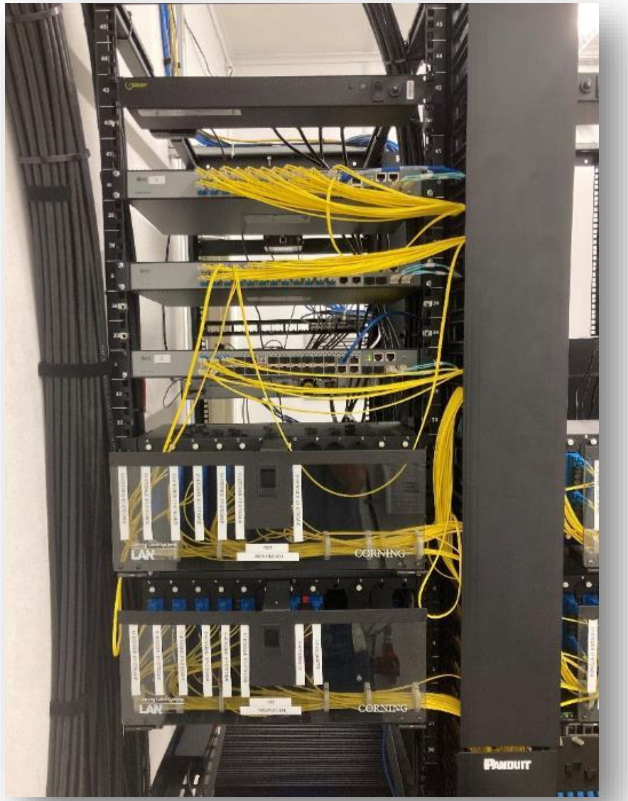
- 52 roadside cabinets to house sensor acquisition equipment
- Cabinets connected to data building on south end of test road via fiber connection



Remote Data Collection

- No staff at test road site
- Internet connection established for remote access to data
- SQL database created based on LTPP InfoPave
- Internal database but developing a website with public access

Fiber Optic Cables from Roadside Cabinets



Field Performance Surveys

- Field performance surveys at least twice annually
- Structural & functional measurements
- Traffic diverted to existing roadway during field testing

Automated Pavement Condition (Ride, Crack, & Fault)

Pavement Support (FWD)

Test Road Status

- Ten-years planning & design nearly complete
- Extensive material sampling/testing & instrumentation
- Early/preliminary sensor data already being gathered & analyzed
- Not too early to begin thinking about next round of experiments…

Longitudinal diamond grinding at the US-301 Concrete Test Road

Closing

- Instrumentation must be accompanied by well thought out experimental design
- Instrumentation projects can be large & small
- Inexpensive sensors & data acquisition systems are becoming more common
- Advanced sensors are becoming more practical (e.g., fiber optic, wireless)

Thank You

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Rapid Rehabilitation of Pavements Using Long-Life Precast Concrete Panels

Presented by
Mark B. Snyder, Ph.D., P.E.
President, Pavement Engineering and Research Consultants (PERC), LLC

TRB Webinar on Advanced Concrete Pavement Technologies

February 22, 2022

Photo: R.M. Towill

The Primary Motivation for PCP Technology

145,000 ADT
I-287, Tarrytown, NY

200,000 ADT
I-15, Ontario, CA

180,000 ADT
I-66, Fairfax, VA

Precast Concrete Pavement is one such rapid repair alternative

The need is to explore repair alternatives that :

- ✓ ***Offer rapid construction in short work windows***
- ✓ ***Cause minimum disruption***
- ✓ ***Are durable – long service life***

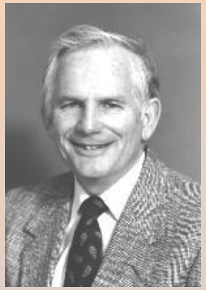
Photos: The Fort Miller Co., Inc.

Advantages of Precast Concrete Pavement

- **For Agencies:**
  - Rapid opening to traffic = reduced congestion and user delay
  - Little potential for early-age construction-related failures
  - Potential 40-year-plus service life with reduced maintenance
  - More …

- **For Contractors:**
  - Eliminates lengthy design, submittal, and approval process for fast-track concrete mixes
  - Fewer placement risks
    - No finishing
    - No cure time
    - Immediate opening to traffic
    - Less weather sensitive = extended construction season
  - More …

Brief History of Modern U.S. Precast Concrete Pavement

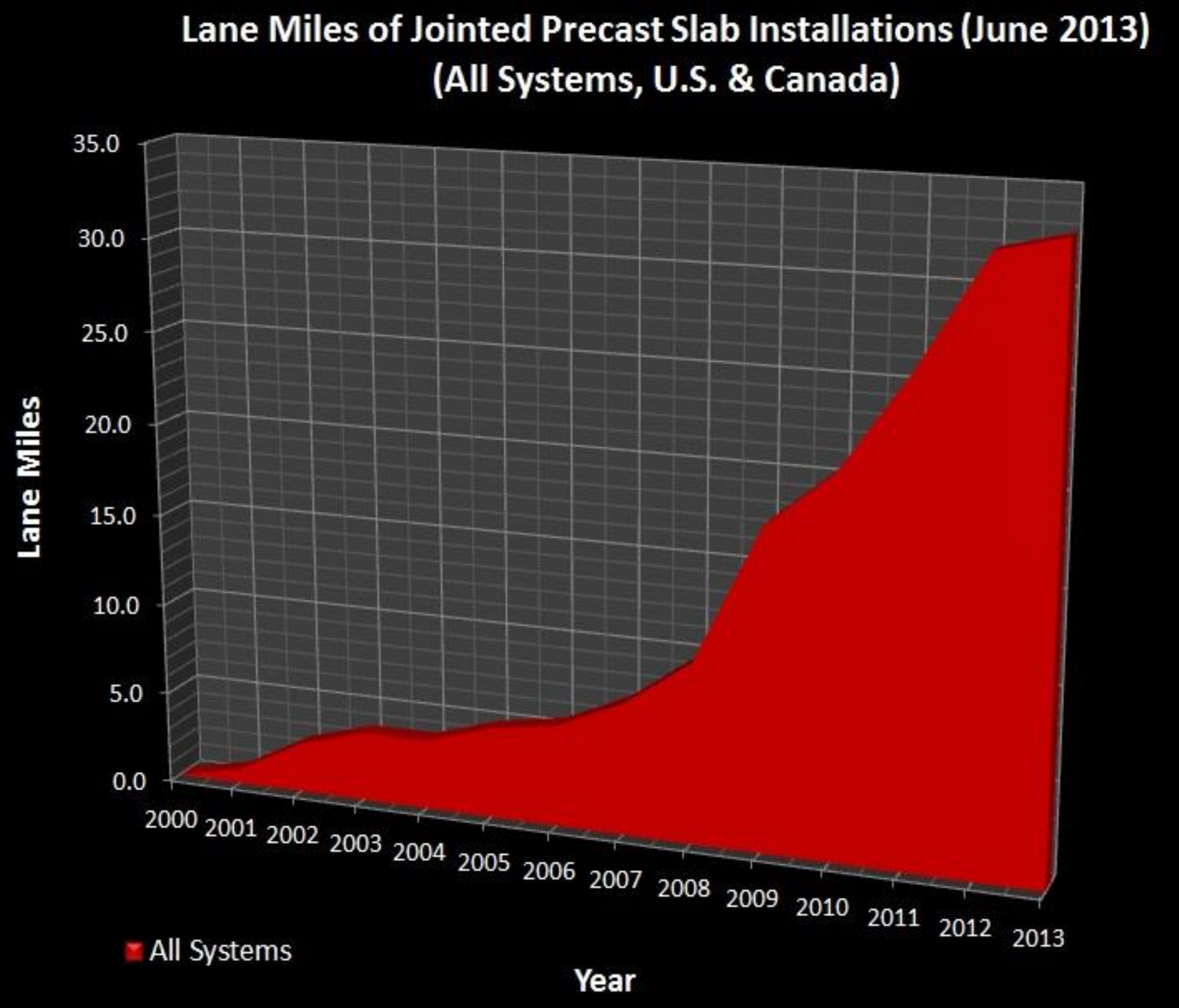


B. Frank McCullough

- Georgetown, TX Demonstration
  - 2001 – 2002 PPCP Demo reconstruction on I-35 Frontage Road
  - ~2300 centerline-ft of 8-inch, two-lane roadway and shoulders (36 ft wide, post-tensioned 2 directions)
  - Demonstrated advantages of precast pavement for rapid reconstruction and several specific construction techniques for PPCP.
- Tappan Zee Bridge Toll Plaza, NYC Metro
  - Oct 2001 – July 2002 reconstruction under traffic (off-peak)
  - 1st major U.S. PCP construction project
  - 1088 doweled and tied 10-inch thick JCP panels; 162,876 s.f.
  - Production = 3,000 s.f. installed/8-hour shift, ±1/8 inch elevation – no grinding
  - Proved viability of precast pavement (re)construction in high-volume urban areas

Peter J. Smith

Ernest Barenberg



More than 113.5 lane-miles of JPrCP as of Sept 2018, including:

- CA – 51.7 ln-mi
- NY – 28.0 ln-mi
- **IL – 7.4 ln-mi**
- NJ – 7.1 ln-mi
- HI – 3.6 ln-mi
- ONT – 3.2 ln-mi

Source: NPCA

General Categories of Precast Pavement Systems

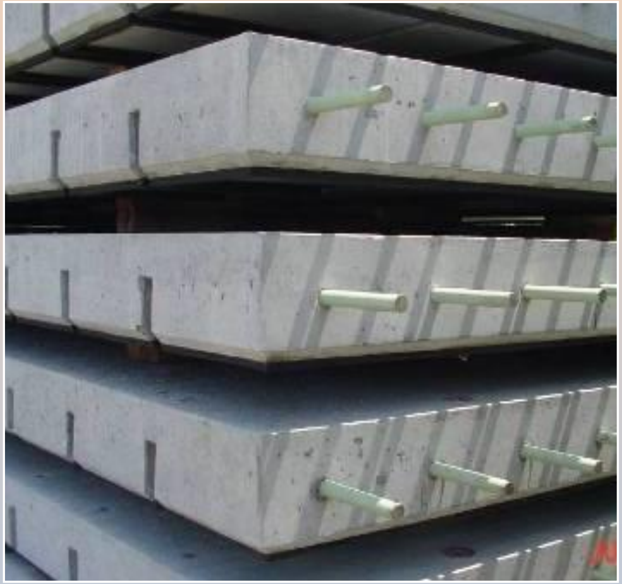
~~Precast Post-Tensioned Concrete Pavement (PPCP)~~

Jointed Precast Concrete Pavement (JPrCP)

JPrCP - Typical Characteristics

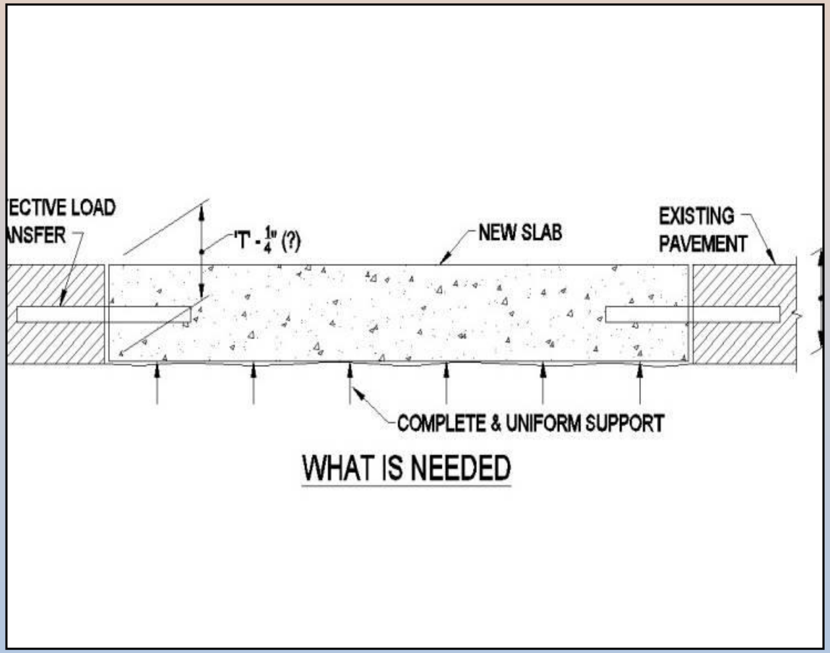
- Useful in any application, including complex geometry
- Customized slab sizes for specific applications (e.g., joint repair vs lane reconstruction)
  - Full lane-width, similar thickness to adjacent panels
  - Lengths up to 16 ft unless prestressed
- Generally reinforced for transportation and handling
  - 0.2 – 0.4% steel each direction and/or fiber reinforcing
- *Options: Prestressing and/or structural fiber reinforcing*
- Joints like cast-in-place pavement joints (i.e., doweled, tied or butt, expansion)
- Standard dowel load transfer systems (only steel so far … some tubular steel)

Jointed Precast Concrete Pavement (JPrCP) Systems



Precast Concrete Pavements Should Emulate Cast-in-Place Concrete Pavements

- Load Transfer Dowels
- Uniform Slab Support
- Slab Surface Geometry



Source: The Fort Miller Co., Inc.

Differences in JPrCP Systems

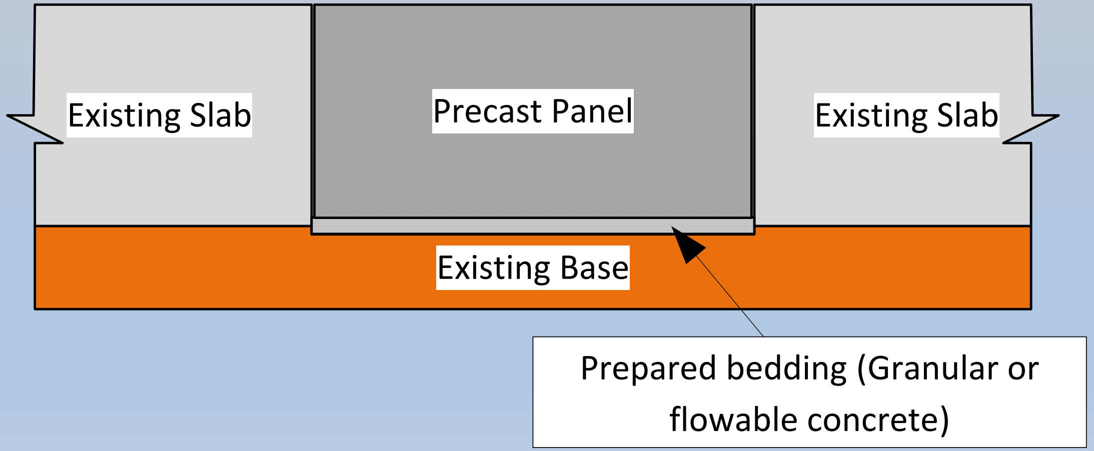
- Methods of achieving support
  - Grade-supported, grout-supported, urethane-supported
- Leveling
  - Precision grading, shims, lift systems, grout or urethane injection
- Load transfer systems
  - Top slots (various), bottom slots
  - Various dowels and connectors
- Achieving surface geometry
  - Nonplanar slabs, plane slabs + diamond grinding

Methods of Achieving Slab Support and Leveling

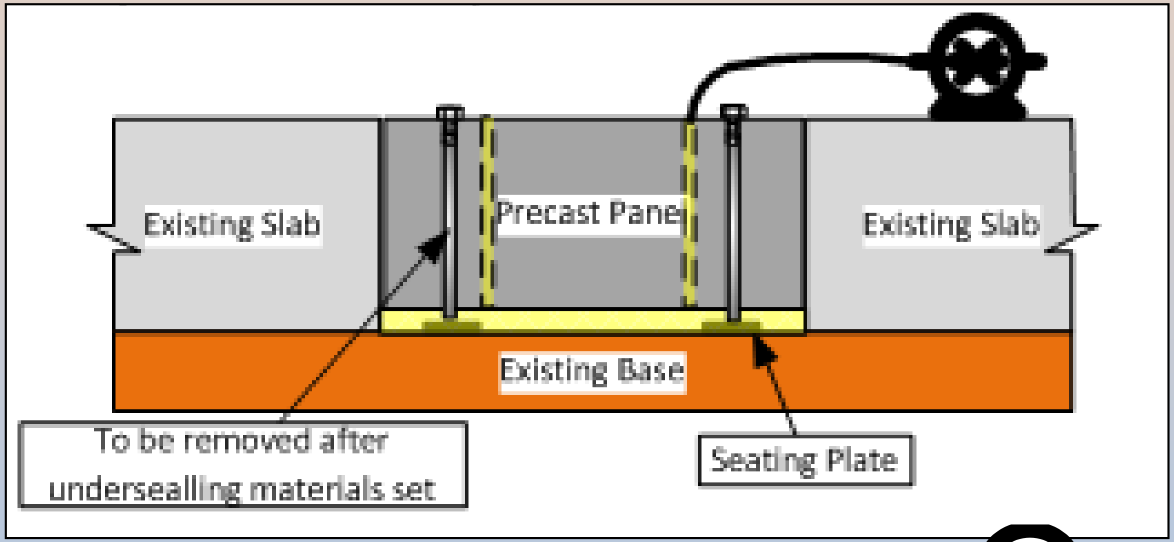
Uniform support is key to precast concrete pavement performance.

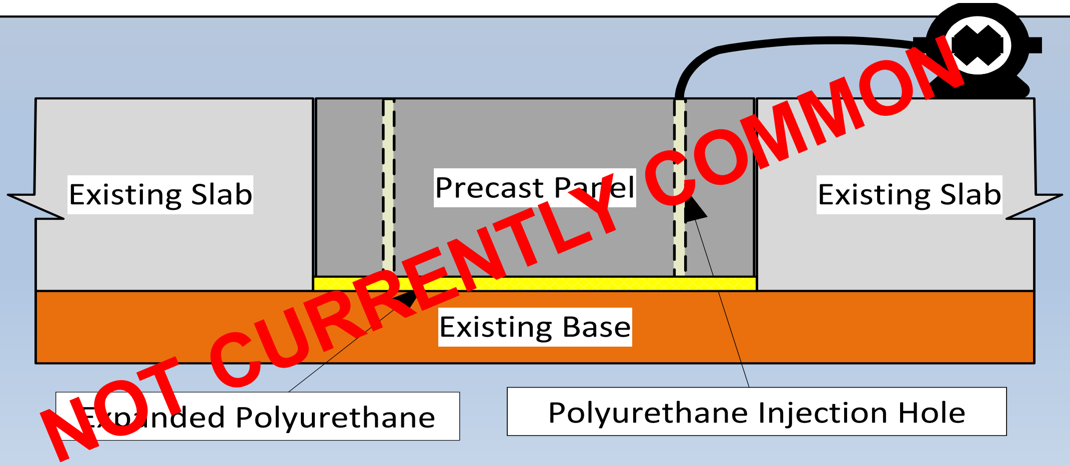
(The same is true for conventional concrete pavements!)

Grade-supported



Grout-supported



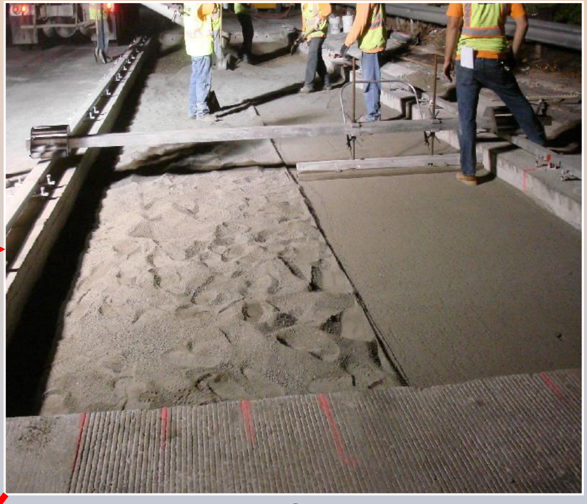


Images: Dr. Shiraz Tayabji, Advanced Concrete Pavement Consultancy, LLC

Grade-Supported Systems:

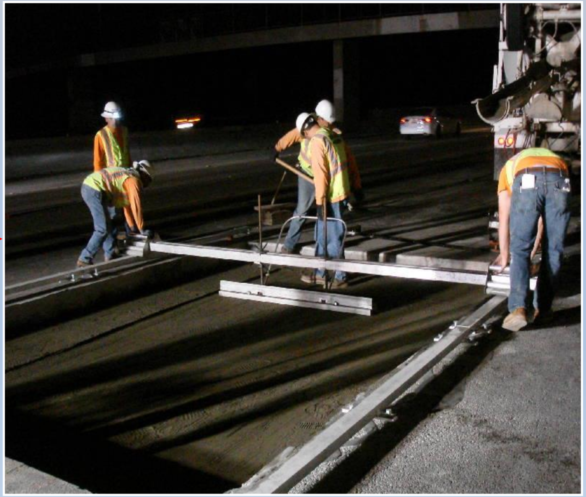
Placing, Compacting & Grading Bedding Material

Placement of Bedding Material



First Grading Pass

Wetting & Compacting



Final Grading Pass

Hand-Operated Grader (H.O.G.)

Laser-Controlled Grader

Images: The Fort Miller Company, Inc.

Gracie-Lift Leveling System
(Grout-Supported Top Slot System)

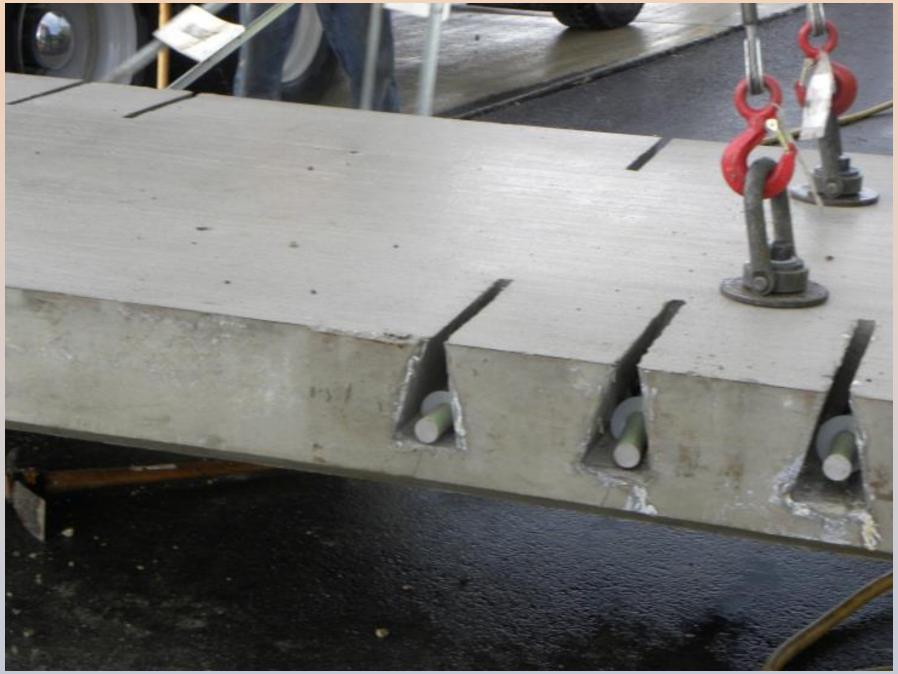
Gracie-Lift In Form

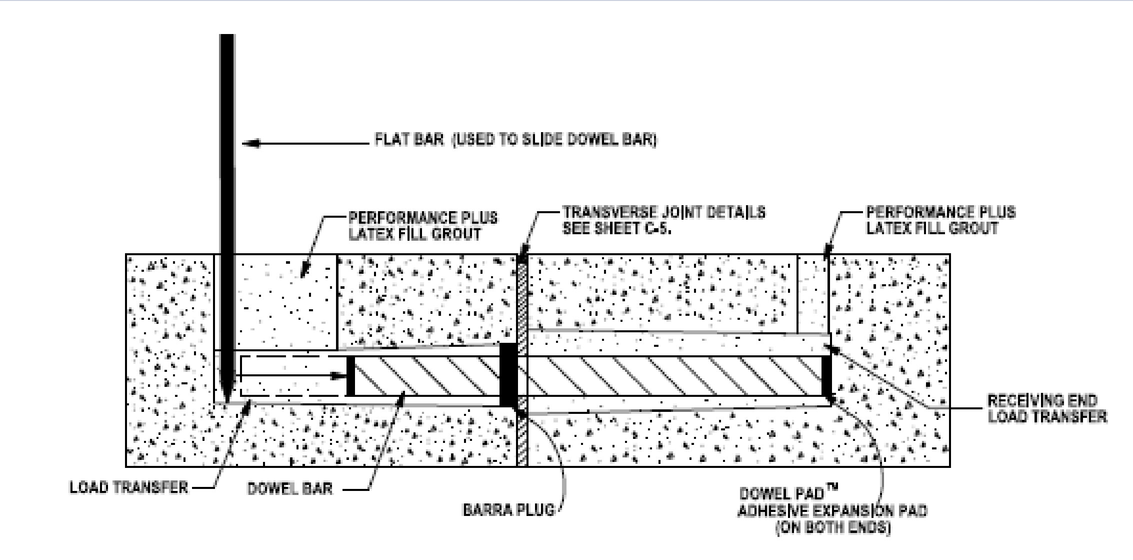
Leveling Screw Grade Control

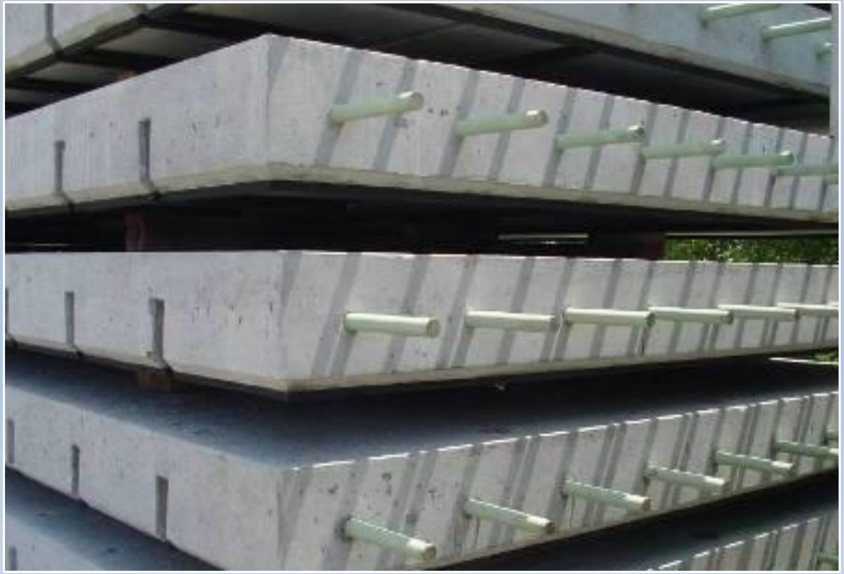
Joint Load Transfer Considerations

- Dowel bar-based load transfer system
  - 4 dowel bars per wheel path is generally adequate for highways
  - Dowels distributed uniformly for airfield applications
    - Rel. defl. < 2-3 mils, more important than LTE
    - LTE and relative deflection requirements may be changing
- Requires use of dowel bar slots (top, bottom or center)

Load Transfer System Options







Super-Slab® Bottom Slot System

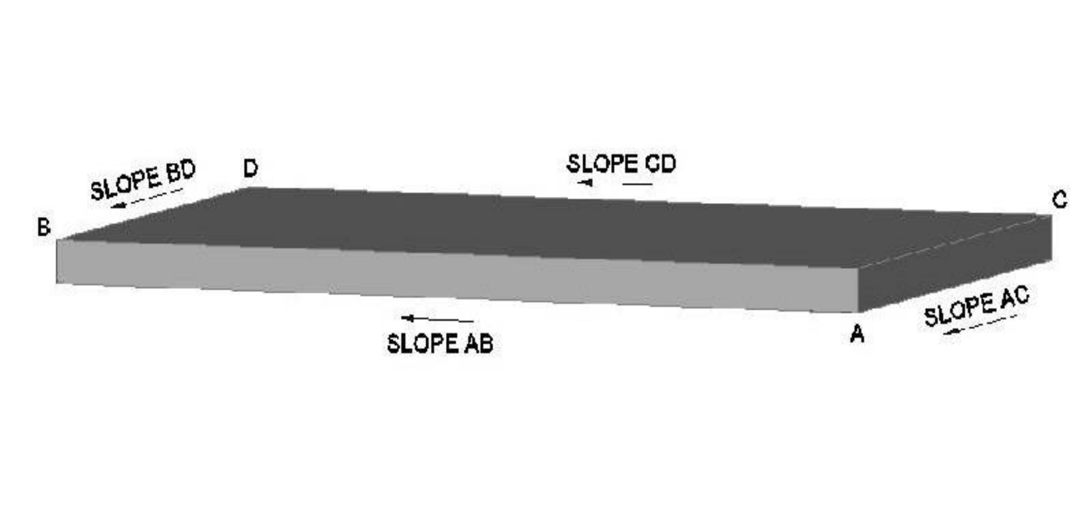
- Dowels engage slots in adjacent slab
- Pump dowel group into ports
  - Grout reaches 2500 psi in about 2 hours
- Fill slots and joint between slabs
- Dove-tail slot resists bar pop out
- “Clean” pavement surface

Dove tail-shaped slot

Source: The Fort Miller Co., Inc.

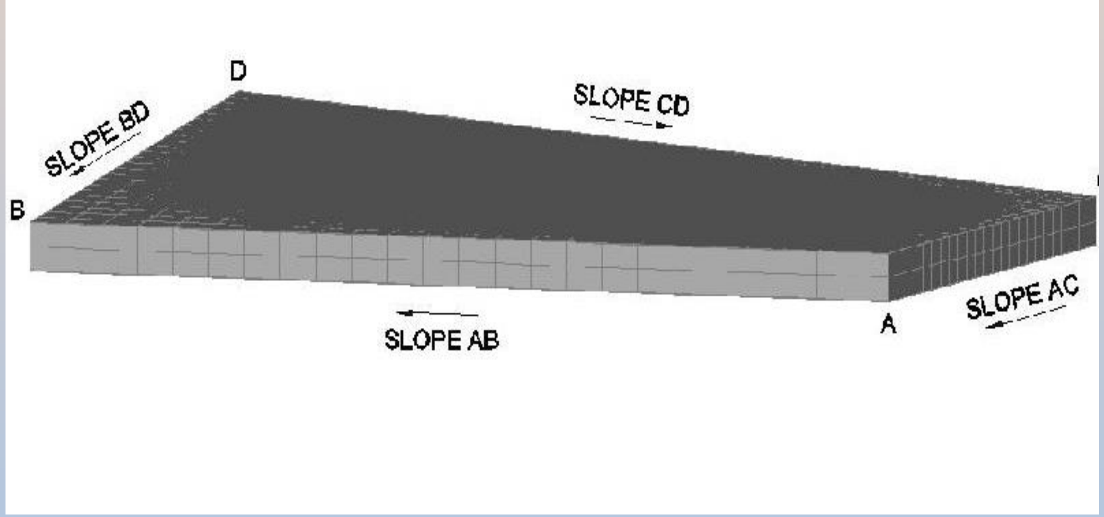
Matching Pavement Surface Geometry

Slab shape must match geometry of surrounding pavement surface



Single Plane

Slopes of opposite sides are equal



Warped Plane

Slopes of opposite sides are un-equal

Source: The Fort Miller Co., Inc.

Creating Nonplanar Pavement Surfaces

Grind Flat Slabs to Profile

- Pros:
  - Flat slabs are easily fabricated and less costly
- Cons:
  - Added cost of grinding
  - May require added slab thickness
  - Voids between single-plane panel and nonplanar foundation
    - Extra bedding grout required
    - May prevent opening to traffic without grouting.

Fabricate Nonplanar Panels

- Pros:
  - Minimize need for diamond grinding (less cost)
  - No significant thickness reduction or need for added thickness
  - Less bedding grout
  - Allows opening to traffic without grout
- Cons:
  - Need 3D data for design, fabrication
  - Needs more engineering, special forming equipment, more fabrication labor
  - Can complicate prestressing

Jointed PCP Design Considerations

(from SHRP2 Guidelines for PCP Design)

- Design criteria similar to Cast-in-Place JCPs
  - Service life: “long-life” (30 to 40+ years)
  - Cracking: Up to 25% panel cracking
    - All panels are reinforced or prestressed; cracking will not deteriorate
  - Faulting - Same as for conventional JCP (0.15 to 0.25 in.)
- Can assume (or specify) higher concrete strength
  - 750 psi 28-day flexural and 6000 psi compressive are common
- Jointed PCP thickness
  - Conventionally reinforced panels are typically designed using typical design procedures – similar thickness for similar strength
  - Prestressed panels ~ 2 to 4 in. less than conventional JCP

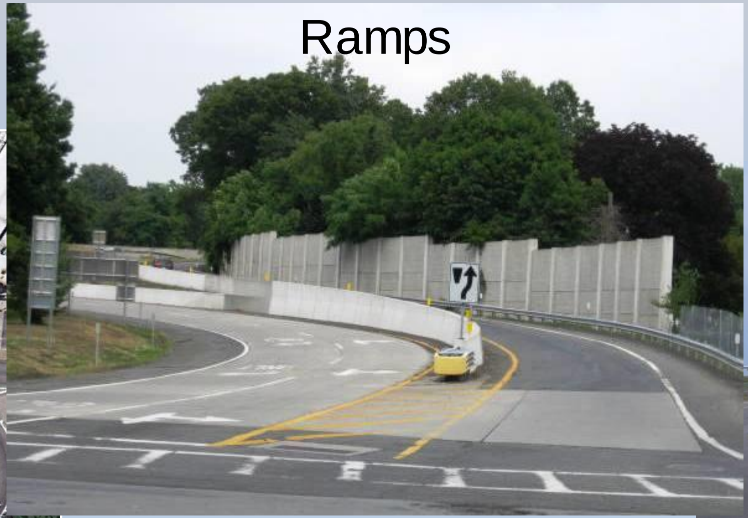
Uses for Precast Concrete Pavement Systems

Continuous Pavement


Panel Replacements and Joint Repairs

Bus Pads


Bridge Approach Panels


Ramps

Taxiways and Aprons


Industrial Driveways

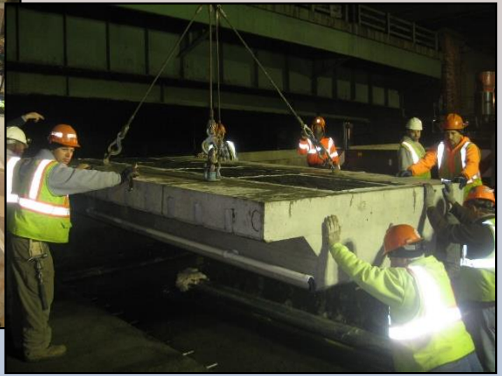

Complex Intersections

Innovations in Precast Concrete Pavement

- **High-Speed Axle-Sensing Panels (for toll roads)**

"Plug-and-Play" installation: data collection cables attached to embedded treadles

Photos: Peter Smith – Fort Miller Company, Inc.



- **Weigh-In-Motion (WIM) Panels**

Photo: Laboratoire Central des Ponts et Chaussées

- **Solar Power Generating Panels**

Not shown: Inlays of asphalt-surfaced pavements

- **Electrified Roadways – Inductive Power Transfer**

Photos: Dr. Anne Beeldens, AB-Roads

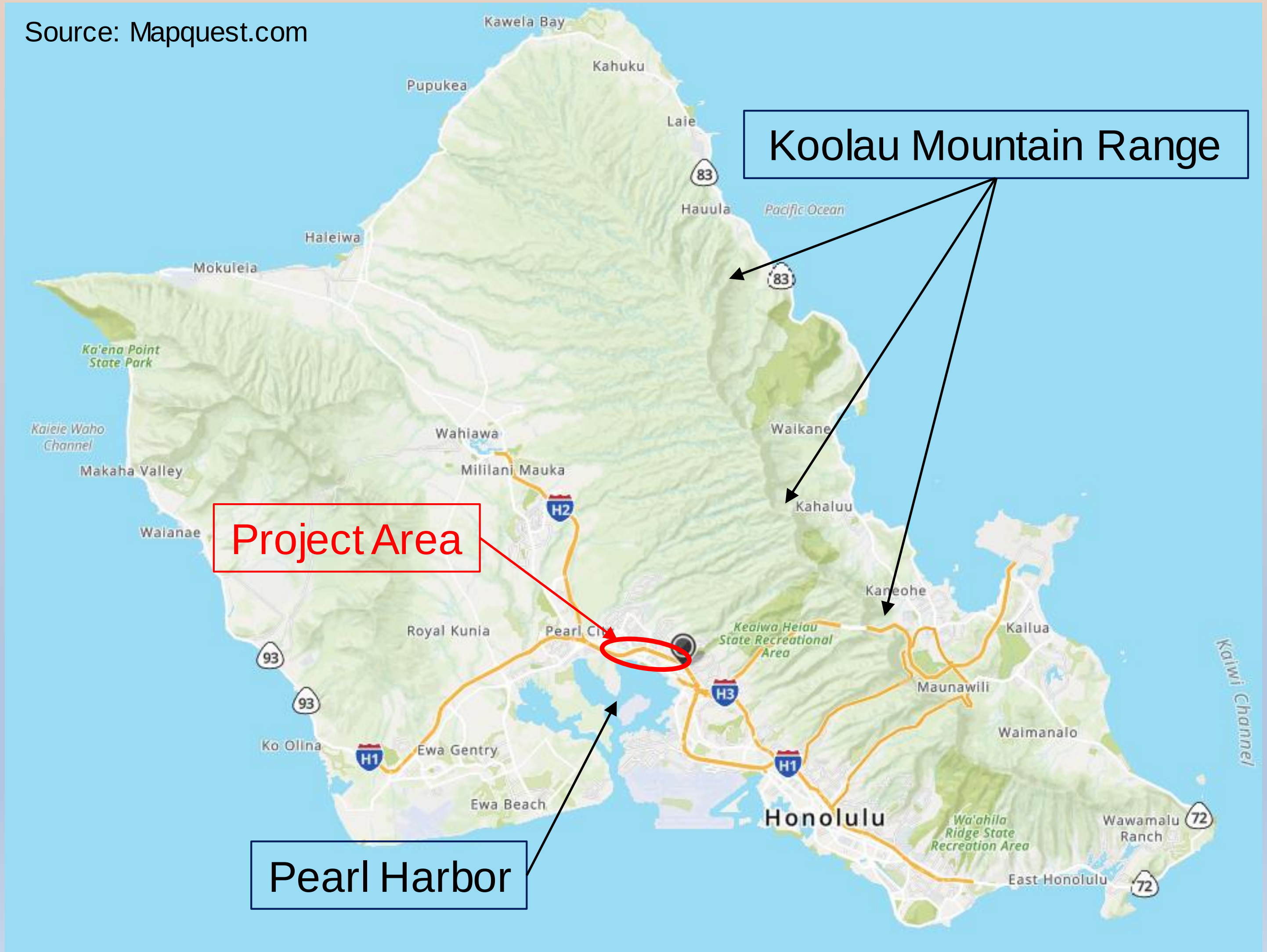
Key JPrCP Design/Construction Resources

- NPCA Manual for Jointed Precast Concrete Pavement (4th Ed, 2021)
- FHWA Report: Precast Concrete Pavement Technology Implementation (2019)
- FHWA/SHRP2 IAP Case Study Reports (2014-2019)
- FHWA Tech Briefs (2011 – 2019)
- SHRP2 Project R05 Documents (2012)
  - Guidelines for PCP project selection, design, fabrication and installation, and system acceptance
  - Model specifications

Interstate H-1 on Oahu (Aiea to Waimalu Viaduct)

(For more info, see Transportation Research News, Jan-Feb 2021)

- First built 1959, Hawai'i's busiest freeway (>230,000 vpd, 5+ lanes each way)
- Lies between Koolau mountain range and Pearl Harbor



Interstate H-1 on Oahu (Aiea to Waimalu Viaduct)

(For more info, see Transportation Research News, Jan-Feb 2021)

- Deep fill between lava flows, settlements up to 46 cm [18 in]

- Portions in poor condition – roughness, irregular profile

- **50-year solution desired without prolonged lane closures**
  - **5.84 lane-km [3.63 lane-miles]**
  - **>1200 precast panels**

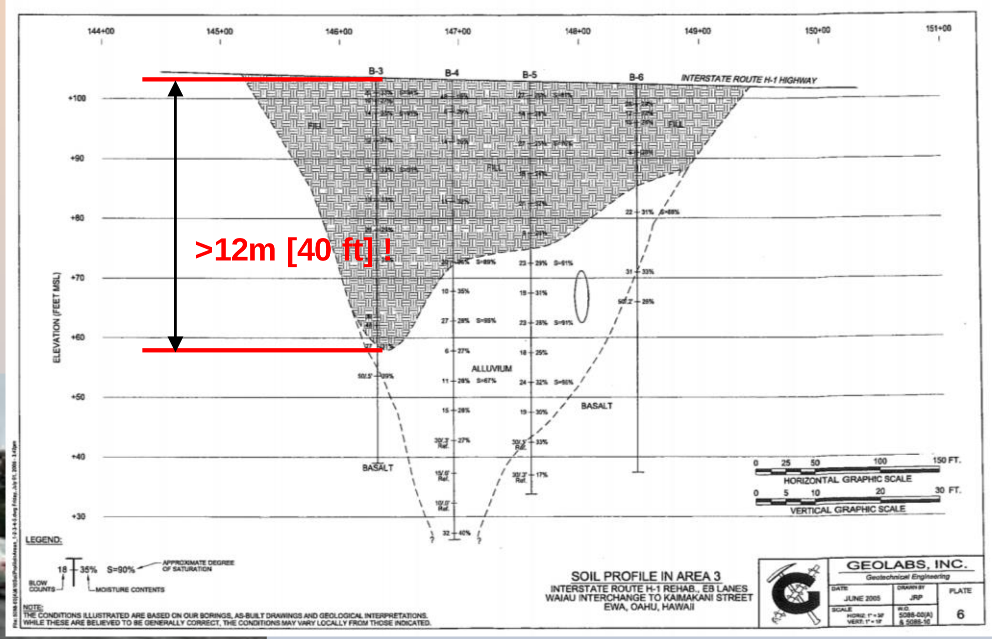



Photo: HDOT


Photo: HDOT

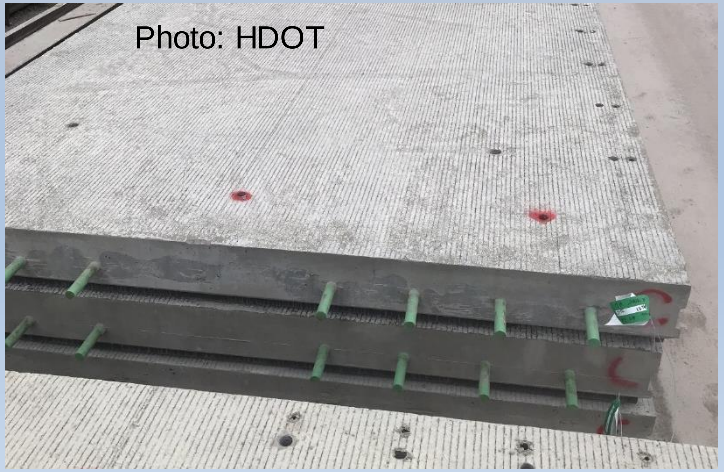
Logistics – A Highly Compressed, Accelerated Schedule

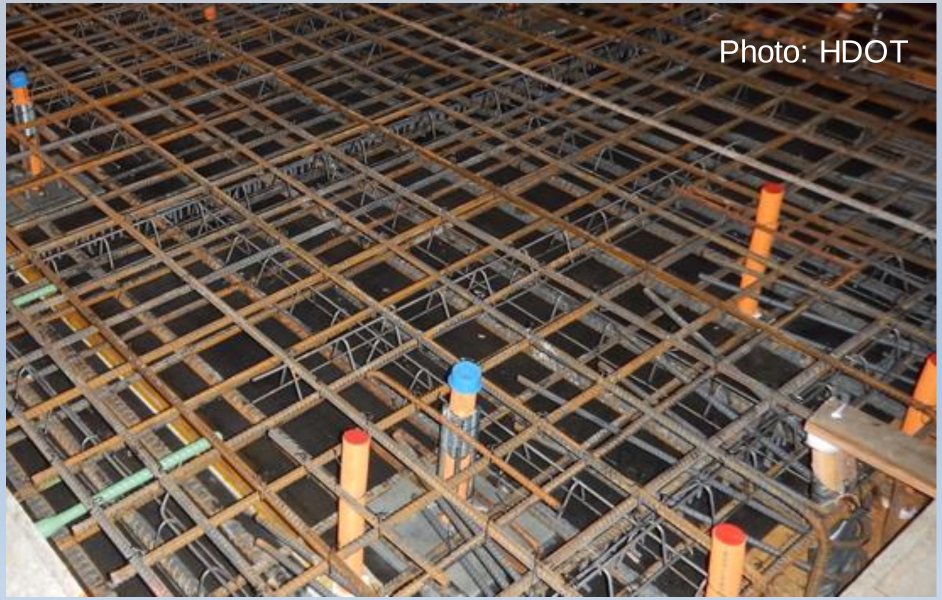
- Design-build contract awarded January 2018
- Custom-design, fabricate and install >1200 panels in <7 months (Aug 2018)
- Mainly night work windows (8 hours or less)
- Fabrication must start by April 1 (~10 weeks after contract signed)
- Casting form order (and shipping to Hawai’i!) impossible until structural design finalized

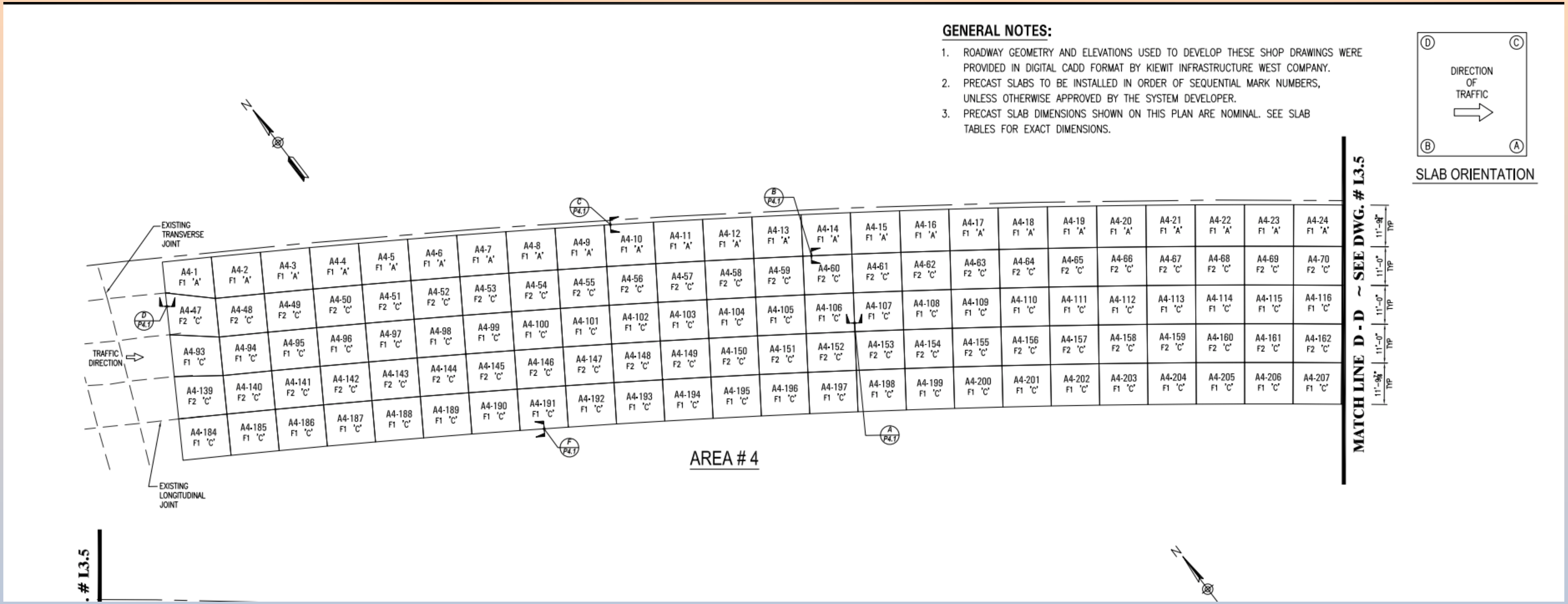
- Complex design:
  - Longitudinal and transverse profile modifications
  - Localized foundation improvements
  - Pavement joint layout considering remaining lanes (variable length panels, skewed joints) and HDOT panel aspect ratio restrictions

Panel Design Considerations

- Wide range of variable support conditions due to added lanes, frequent overlays
  - Conditions mapped using GPR (all lanes and sections) – key to success on this project!
- Structural design based on 1984 PCA
  - 9.75 inches PCC (includes ¼ sacrificial for grinding) over 4 inches (min) CTB
  - 0.2% reinforcing each way, top and bottom (not considered in thickness design)
- Four 1.5” dowels/wheel path







AREA 1

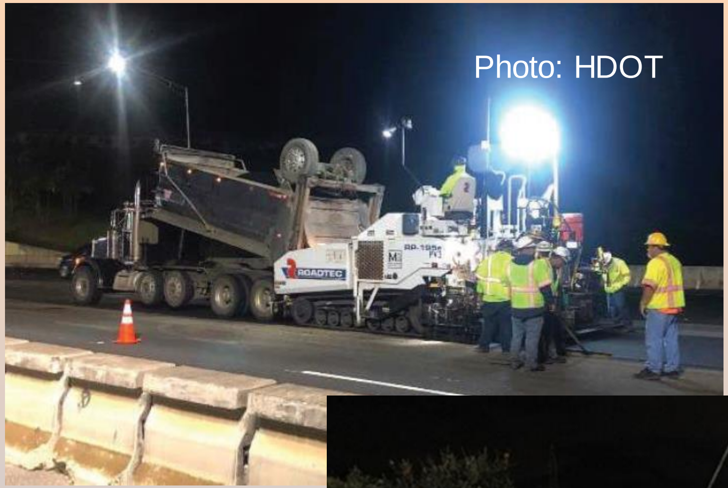
MK #	SLAB TYPE	FORM TYPE	VOLUME (CY)	WEIGHT (TON)	DELTA * @ D	SLAB WARP TYPE	AB	CD	AC	BD	Hc	Wc	Hd	Wd	AD	BC
							GEOMETRIC VARIABLES: LENGTH OF LINE SEGMENT				ADDITIONAL VARIABLES				DIAGONALS (3D)	
A1-1	A	F1	3.07	6.21	(+) 0 13/16"	WARPED	11'-7 13/16"	11'-8 5/16"	8'-8 3/8"	8'-9"	8'-8 3/8"	0 5/16"	8'-9"	0 3/16"	14'-7"	14'-6 3/4"
A1-2	B	F1	3.16	6.41	(-) 0 3/8"	WARPED	12'-1 5/16"	12'-1 13/16"	8'-7 5/8"	8'-8 3/8"	8'-7 5/8"	0 5/8"	8'-8 3/8"	-0 1/16"	14'-10 7/8"	14'-11"
A1-3	C	F2	5.39	10.92	(+) 1 9/16"	WARPED	14'-11"	15'-0 1/16"	12'-0 7/8"	11'-10 11/16"	12'-0 7/8"	0"	11'-10 11/16"	1"	19'-1 11/16"	19'-2 5/16"
A1-4	C	F2	4.23	8.57	(-) 1 7/8"	WARPED	11'-7 3/16"	11'-7 13/16"	12'-1 9/16"	12'-0 7/8"	12'-1 9/16"	-0 3/16"	12'-0 7/8"	0 7/8"	16'-9 1/2"	16'-9 1/4"
A1-5	H	F2	4.42	8.94	(+) 0 3/4"	WARPED	12'-0 1/2"	12'-1 5/16"	12'-2 1/16"	12'-1 9/16"	12'-2 1/16"	0 5/16"	12'-1 9/16"	0 7/16"	17'-1 7/16"	17'-1 11/16"
A1-6	C	F1	3.87	7.84	(+) 0 3/8"	WARPED	10'-9 3/8"	10'-10 1/16"	11'-11 1/16"	11'-10 11/16"	11'-11 1/16"	0 7/8"	11'-10 11/16"	-0 1/4"	16'-0 7/16"	16'-1 1/2"
A1-7	C	F1	5.33	10.8	(-) 0 3/8"	WARPED	14'-10 1/16"	14'-11"	11'-10 13/16"	11'-11 1/16"	11'-10 13/16"	0 3/16"	11'-11 1/16"	0 13/16"	19'-1 1/16"	19'-0 3/8"
A1-8	D	F1	4.18	8.47	(+) 0 5/8"	WARPED	11'-6 1/2"	11'-7 3/16"	12'-1 9/16"	11'-10 13/16"	12'-1 1/2"	-3 1/16"	11'-10 3/4"	3 11/16"	16'-9 1/2"	16'-6 3/4"
A1-9	C	F2	3.88	7.85	(+) 0 1/16"	PLANAR	10'-8 11/16"	10'-9 3/8"	11'-11 13/16"	11'-11 13/16"	11'-11 13/16"	0 15/16"	11'-11 13/16"	-0 1/4"	16'-0 13/16"	16'-1 5/8"
A1-10	C	F2	5.33	10.79	(+) 0 1/4"	WARPED	14'-9 1/16"	14'-10 1/16"	11'-11 5/16"	11'-11 13/16"	11'-11 5/16"	0 9/16"	11'-11 13/16"	0 7/16"	19'-0 7/16"	19'-0 1/4"
A1-11	D	F2	4.09	8.28	(+) 0 5/16"	WARPED	11'-5 13/16"	11'-6 1/2"	11'-8 1/16"	11'-11 5/16"	11'-8 1/16"	0 5/16"	11'-11 5/16"	0 5/16"	16'-7 1/16"	16'-4 11/16"
A1-12	E	F1	3.88	7.86	(-) 0 1/2"	WARPED	10'-8 1/16"	10'-8 11/16"	12'-1 3/16"	12'-0 5/16"	12'-1 3/16"	0"	12'-0 5/16"	0 11/16"	16'-1 3/8"	16'-1 5/8"
A1-13	E	F1	5.35	10.82	(+) 0 9/16"	WARPED	14'-8 1/16"	14'-9 1/16"	12'-0 9/16"	12'-1 3/16"	12'-0 9/16"	1"	12'-1 3/16"	-0"	19'-0 3/16"	19'-0 9/16"
A1-14	F	F1	4.13	8.37	(+) 0 1/2"	WARPED	11'-5 1/8"	11'-5 13/16"	11'-11 1/4"	12'-0 9/16"	11'-11 1/4"	1 11/16"	12'-0 9/16"	-1"	16'-6 9/16"	16'-7 1/2"

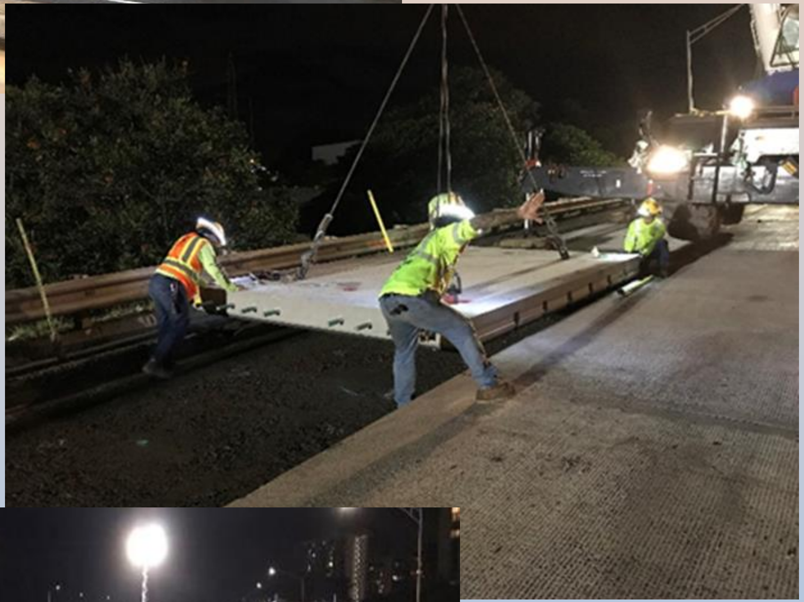
MK #	'AB' COMPONENTS No. COMP	'AB' COMPONENTS 'T1'	'CD' COMPONENTS No. COMP	'CD' COMPONENTS 'T2'	'AC' COMPONENTS No. COMP	'AC' COMPONENTS 'D1'	'BD' COMPONENTS No. COMP	'BD' COMPONENTS 'D2'	TRANSVERSE REINFORCEMENT BAR MK# 401 TOP QTY.	BAR MK# 401 TOP 'L'	BAR MK# 401 BOT QTY.	BAR MK# 401 BOT 'L'	LONGITUDINAL REINFORCEMENT BAR MK# 402 TOP QTY.	BAR MK# 402 TOP 'L'	BAR MK# 402 BOT QTY.	BAR MK# 402 BOT 'L'
A1-1	4	3'-7 13/16"	---	---	7	1'-8 3/8"	7	1'-9"	13	8'-3"	12	8'-3"	10	11'-2 1/4"	10	11'-2 1/4"
A1-2	5	2'-1 5/16"	---	---	7	1'-7 5/8"	7	1'-8 3/8"	13	8'-2 1/2"	12	8'-2 1/2"	10	11'-7 3/4"	10	11'-7 3/4"
A1-3	6	2'-11"	6	3'-0 1/16"	9	3'-0 7/8"	8	3'-10 11/16"	16	11'-7"	15	11'-7"	13	14'-6"	12	14'-6"
A1-4	4	3'-7 3/16"	4	3'-7 13/16"	9	3'-1 9/16"	9	3'-0 7/8"	13	11'-7 1/2"	12	11'-7 1/2"	13	11'-1 3/4"	12	11'-1 3/4"
A1-5	5	2'-0 1/2"	5	2'-1 5/16"	9	3'-2 1/16"	9	3'-1 9/16"	13	11'-8"	12	11'-8"	13	11'-7 1/4"	12	11'-7 1/4"
A1-6	4	2'-9 3/8"	4	2'-10 1/16"	8	3'-11 1/16"	8	3'-10 11/16"	12	11'-5"	11	11'-5"	13	10'-4"	12	10'-4"
A1-7	6	2'-10 1/16"	6	2'-11"	8	3'-10 13/16"	8	3'-11 1/16"	16	11'-5"	15	11'-5"	13	14'-5"	12	14'-5"
A1-8	4	3'-6 1/2"	4	3'-7 3/16"	9	3'-1 9/16"	8	3'-10 13/16"	13	11'-7 1/2"	11	11'-7 1/2"	13	11'-1 1/4"	12	11'-1 1/4"
A1-9	4	2'-8 11/16"	4	2'-9 3/8"	8	3'-11 13/16"	8	3'-11 13/16"	12	11'-5 3/4"	11	11'-5 3/4"	13	10'-3 1/2"	12	10'-3 1/2"
A1-10	6	2'-9 1/16"	6	2'-10 1/16"	8	3'-11 5/16"	8	3'-11 13/16"	16	11'-5 3/4"	15	11'-5 3/4"	13	14'-4"	12	14'-4"
A1-11	4	3'-5 13/16"	4	3'-6 1/2"	8	3'-8 1/16"	8	3'-11 5/16"	13	11'-5 1/4"	11	11'-5 1/4"	13	11'-0 1/2"	12	11'-0 1/2"
A1-12	---	---	4	2'-8 11/16"	9	3'-1 3/16"	9	3'-0 5/16"	12	11'-7 1/4"	11	11'-7 1/4"	13	10'-2 3/4"	12	10'-2 3/4"
A1-13	---	---	6	2'-9 1/16"	9	3'-0 9/16"	9	3'-1 3/16"	16	11'-7 1/4"	15	11'-7 1/4"	13	14'-3"	12	14'-3"
A1-14	---	---	4	3'-5 13/16"	8	3'-11 1/4"	9	3'-0 9/16"	12	11'-6 1/2"	11	11'-6 1/2"	13	10'-11 3/4"	12	10'-11 3/4"

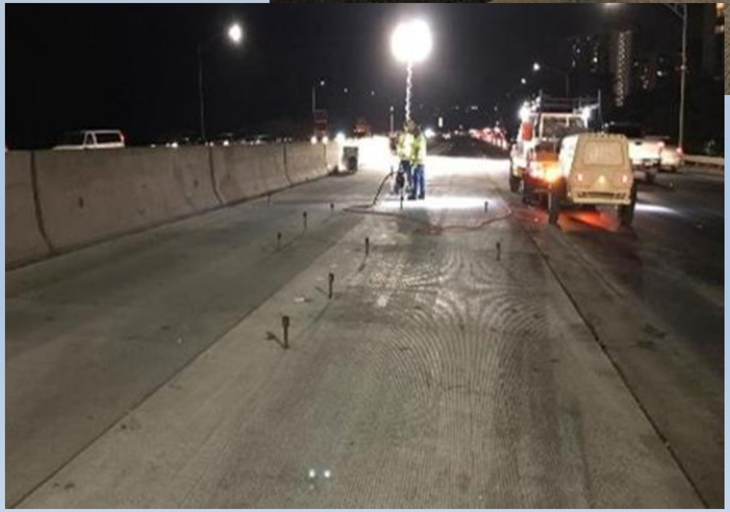
ALL REINFORCING BAR LENGTHS ARE TAKEN FROM LONGEST BULKHEAD, TRIM ALL BARS AS REQUIRED TO MAINTAIN CLEAR COVER PER DRAWING P6, NOTE 5. SPACE REINFORCING BARS TO MAINTAIN 12" MAXIMUM SPACING VIA SPLAYING BARS (IF REQUIRED).

Images: Fort Miller Company

Construction Considerations





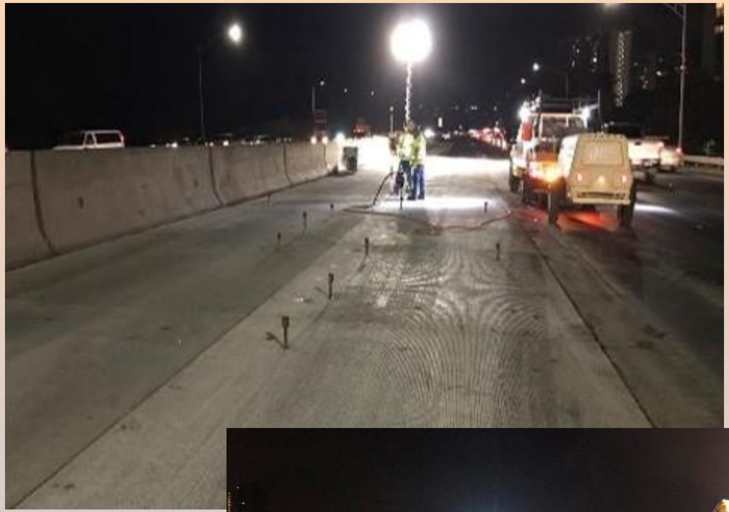


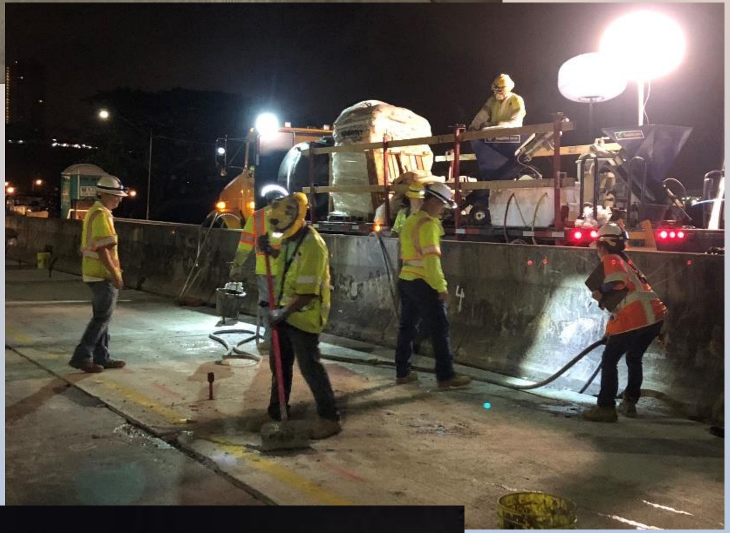
- Temporary Asphalt Surface
  - Up to 8-in elevation difference between lanes during construction. 6-in temporary asphalt layer used to approximate final surface profile before excavation and install
- Installed 20 – 50 panels per 7.5-hour shift
- Grade-supported system (for opening to traffic without bedding grout)
  - Laser-controlled skid steer to place bedding material
  - Leveling jacks activated before grouting (next night) – less than 1/8” elevation diff!

Panel Leveling and Grouting

- Bedding and dowel/tie grouts typically installed during next work shift
  - Grade-supported under traffic for short durations
  - Leveling jacks activated prior to grouting
  - Elevation differences limited to 3 mm [1/8 in]
- Intermittent diamond grinding except in one area with large horizontal curve.

- Pavement installation substantially complete by 2nd week of August, about 3 months after starting.

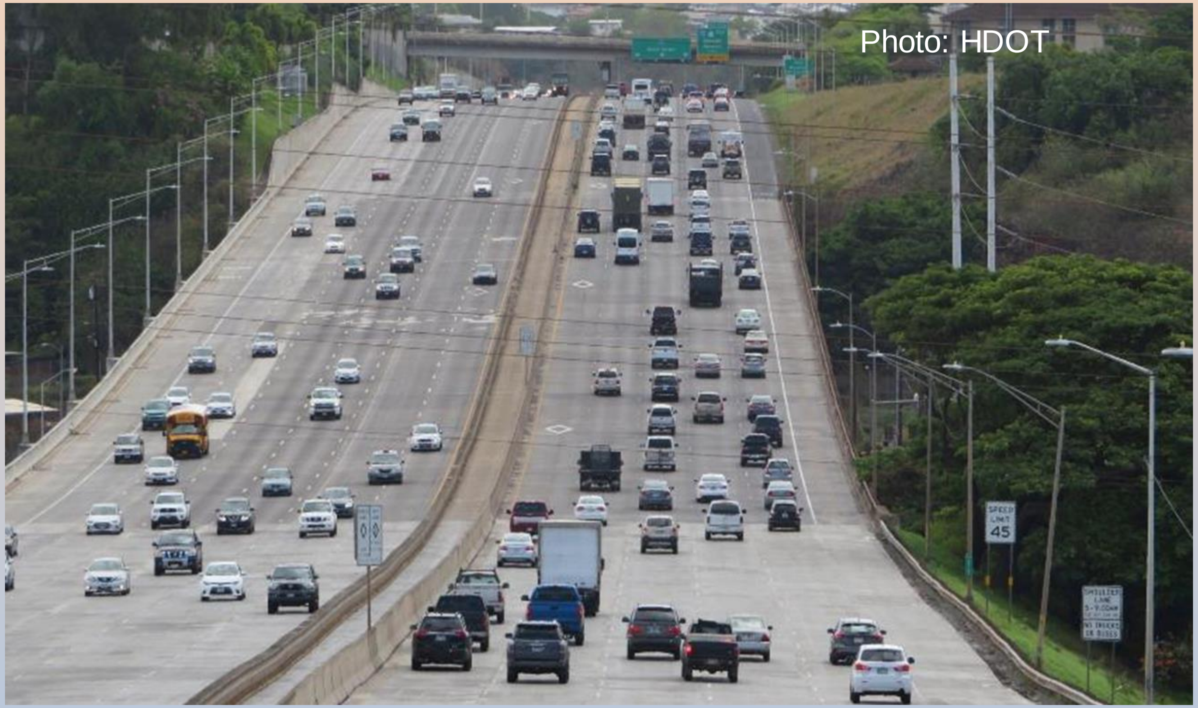




Photos: HDOT

Project Completion and Accolades

- Completed early
- Completed within budget



- Notable Quotes:

"The technology worked out really well … If we could not have used the precast concrete panels, we never would have touched this project." HDOT's Deputy Directory of the Highways Division, Edwin Sniffen

"I am proud that this project finished ahead of schedule… and hopefully this becomes the new normal." Governor David Ige

- ACEC Hawai'i Chapter Engineering Excellence Award (2020)

Thank You For Your Attention!

Questions??

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