Why Should You Care About Pavement Designs…

Design Optimization for Designers and Non-Designers Alike…

Concrete Paving Association of Minnesota

65th Annual Concrete Paving Workshop

Breezy Point Resort in Breezy, MN

March 12, 2026

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AMERICAN CONCRETE PAVEMENT ASSOCIATION

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Question

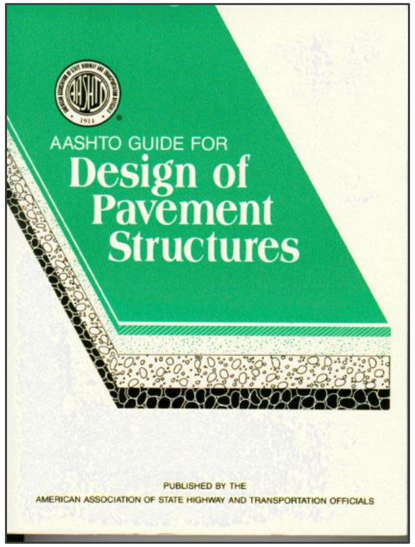
Who has said (or thought) something along the lines of?

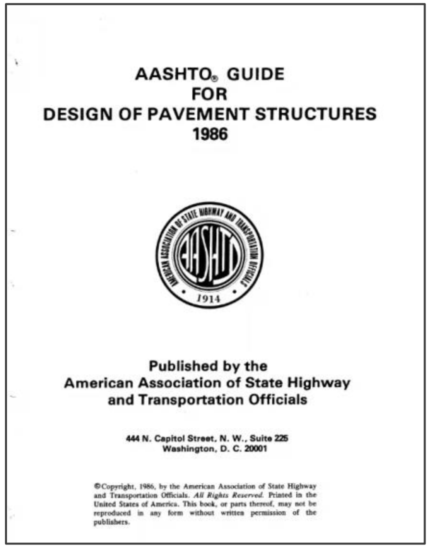
We Don’t do (much) Concrete Pavements because…

No matter what the reason, it all starts with Design

There are Many Pavement Design Methodologies
Which one is correct?

AASHTO 93/86/72





AASHTO GUIDE
FOR
DESIGN OF PAVEMENT STRUCTURES
1986

Published by the
American Association of State Highway
and Transportation Officials

444 N. Capitol Street, N. W., Suite 225
Washington, D. C. 20001

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Pavement ME (PMED)

Industry Methods

PavementDesigner.org

State & University Methods

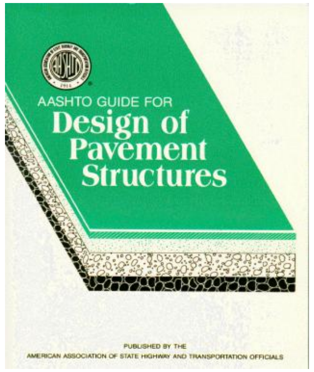
BCOA ME
University of Pittsburgh

They all can work and give Good Designs (as well as bad)

Concrete Pavement Design Methodologies

Understand the limitations of each design tool

Outdated



AASHTO 93
1962-1998
10 inputs
"Performance"
Field Data

THE 40 YEAR DIVIDE

Current Design Tools

StreetPave
2005 - 2017
12 inputs
Crack & Fault
FEA + Field Data

PavementDesigner.org

PavementDesigner
2018 - Present
12 inputs
Crack & Fault
FEA + Field Data

PvD AASHTOWare Pavement ME Design

Pavement ME
2009 - Present
≈ 1,000 inputs
Crack, Fault, IRI
FEA + Field Data

Increasing Complexity = More Accurate Models & More *Optimization* Options

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Source: Adapted from R. Rodden

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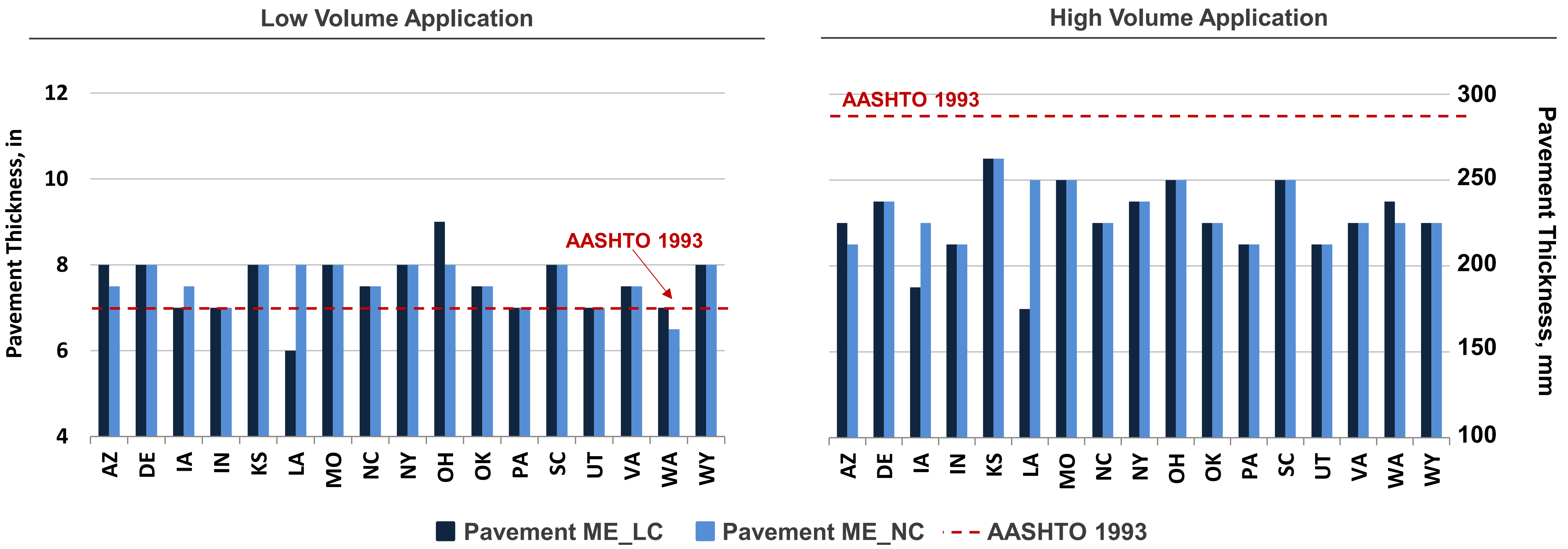
Impact of Design Tools on Pavement Thickness
Local vs National Calibration Impact



However, using Pavement ME result in ~2-3 in thinner JPCPs when compared to the AASHTO 93 guide.

Source: *Review of National and State-Level Calibrations of the AASHTOWare Pavement ME Design for New Jointed Plain Concrete Pavement,* F. Mu; J.W. Mack; and R.A. Rodden, Proceedings of the ASCE 2015 Airfield and Highway Pavement Conference, 2015

Classic Pavement Design Quotes – 1/2

"All models are wrong…

some are useful..."

Classic Pavement Design Quotes – 2/2

"The new pavement will be built in the future, on subgrades often not yet exposed or accessible; using materials not yet manufactured from sources not yet identified; by a contractor who submitted the successful "low dollar" bid, employing unidentified personnel and procedures under climatic conditions that are frequently less than ideal."

NCHRP 1-26 Phase II Final Report

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Pavement-ME is the Most Advanced Design Procedure

Covers a wide range of applications, including nearly all new & rehabilitation options
Can account for new and diverse materials and various failure mechanisms

State-of-the practice design procedure based on advanced models & actual field data collected across the US and Canada

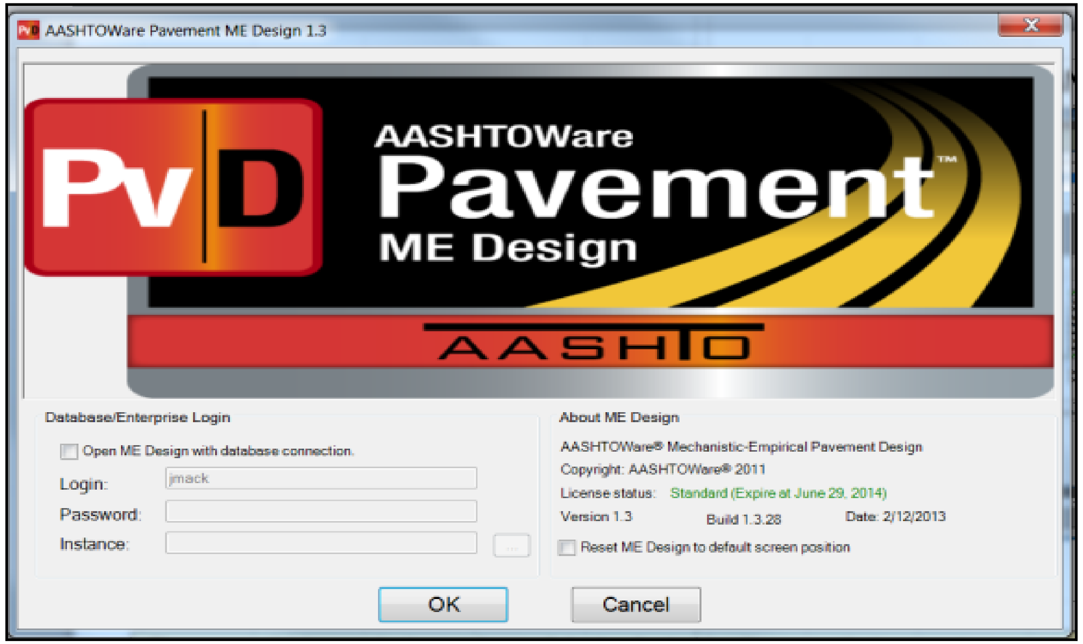
- Adopted by AASHTO in 2011
- Calibrated to more than 2,400 asphalt & concrete pavement test sections, ranging in ages up to ~40+ years

Based on mechanistic-empirical principles that account for site specific:

- Traffic
- Climate
- Materials
- Proposed structure (layer thicknesses and features)

Provides estimates of performance during the analysis period

- Can match rehabilitation activities to performance



Performance modeling allows designers to create specific pavement designs to meet performance objectives

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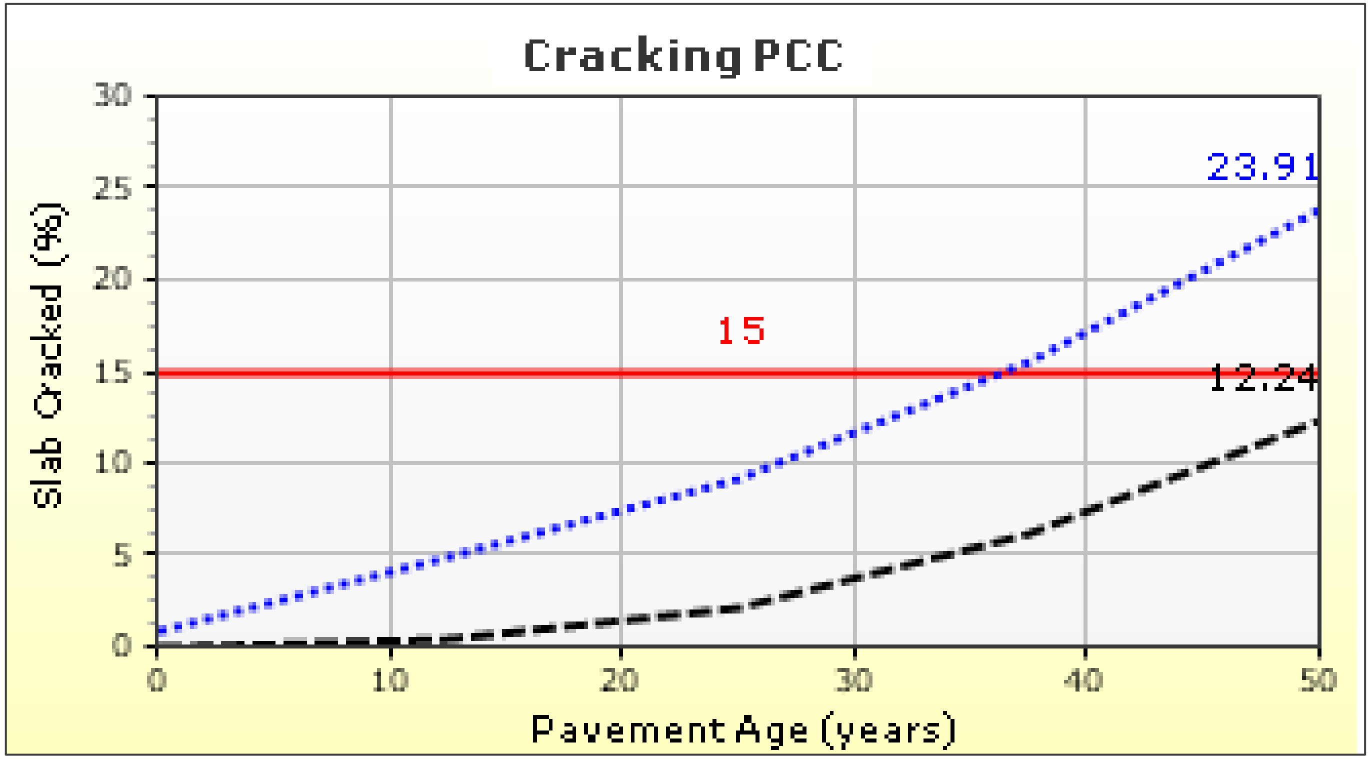
Pavement-ME Defines a Specific Pavement's Performance

Predicting performance of key distresses allows for trade-off analysis with Life Cycle Analysis



Red Line – Predefined Distress Threshold Value. When major rehabilitation is needed (i.e. patching & DG or overlay).

Black Dashed Line - The 50% Reliability (most likely) level of distresses predicted

Blue Dotted Line - The predicted distresses at the Specified Reliability Level (i.e. 90%). Designs are based on when this line hits the defined distress limit

Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~37 years in this case)

Pavement-ME Defines a Specific Pavement's Performance

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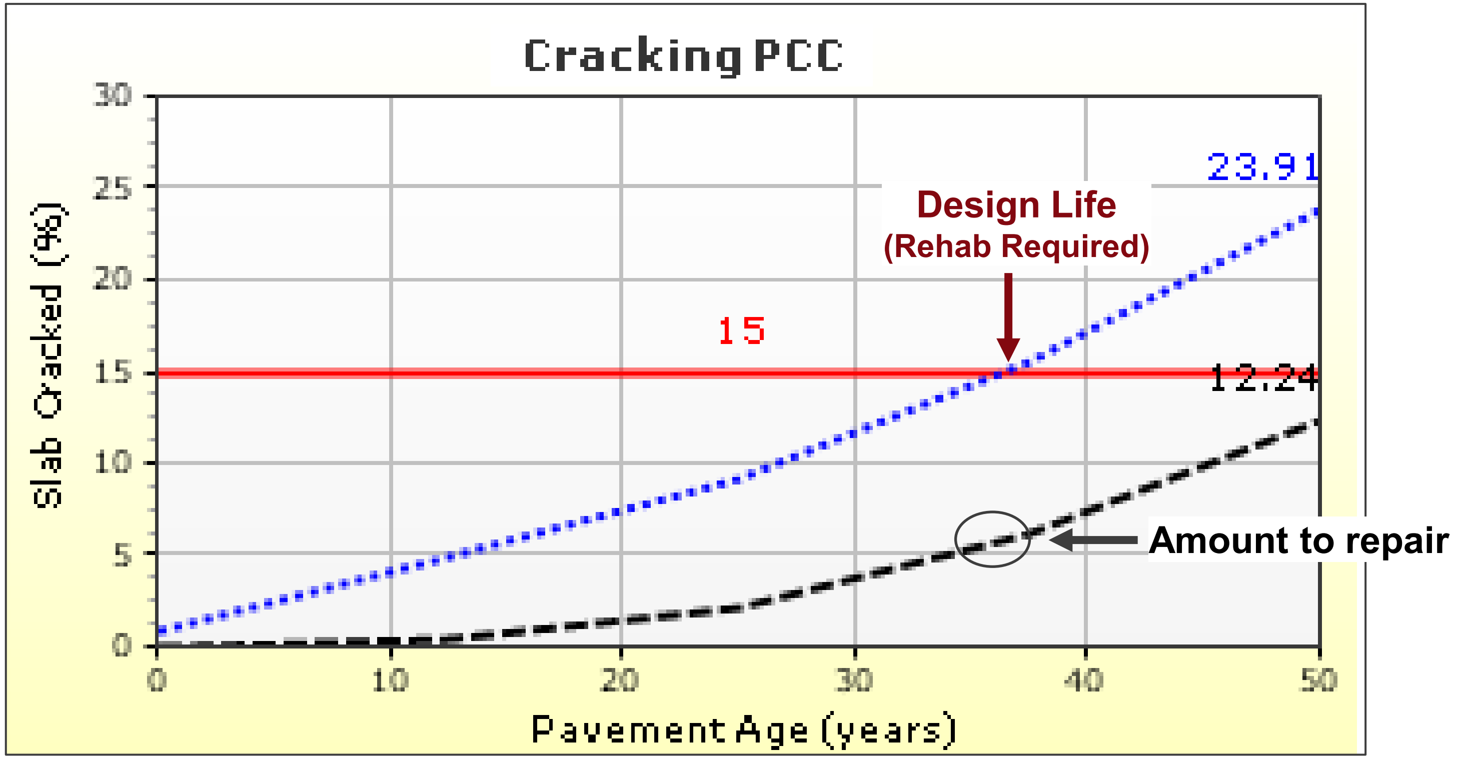

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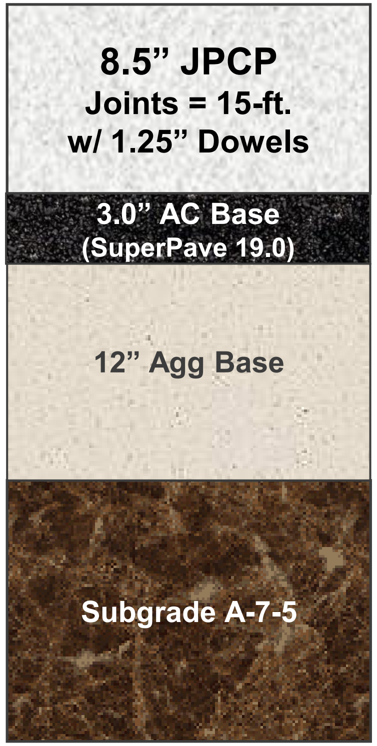
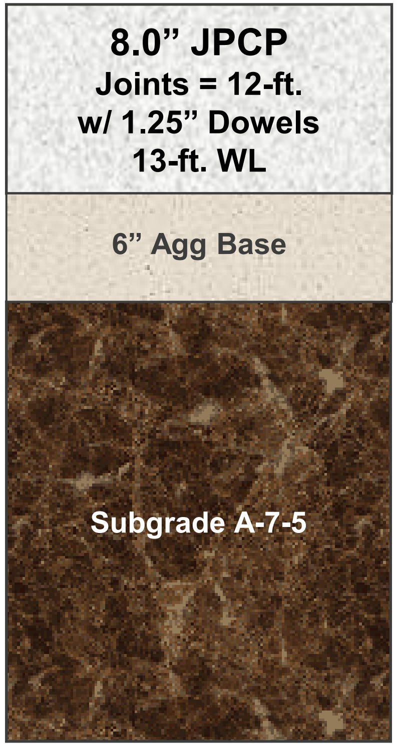
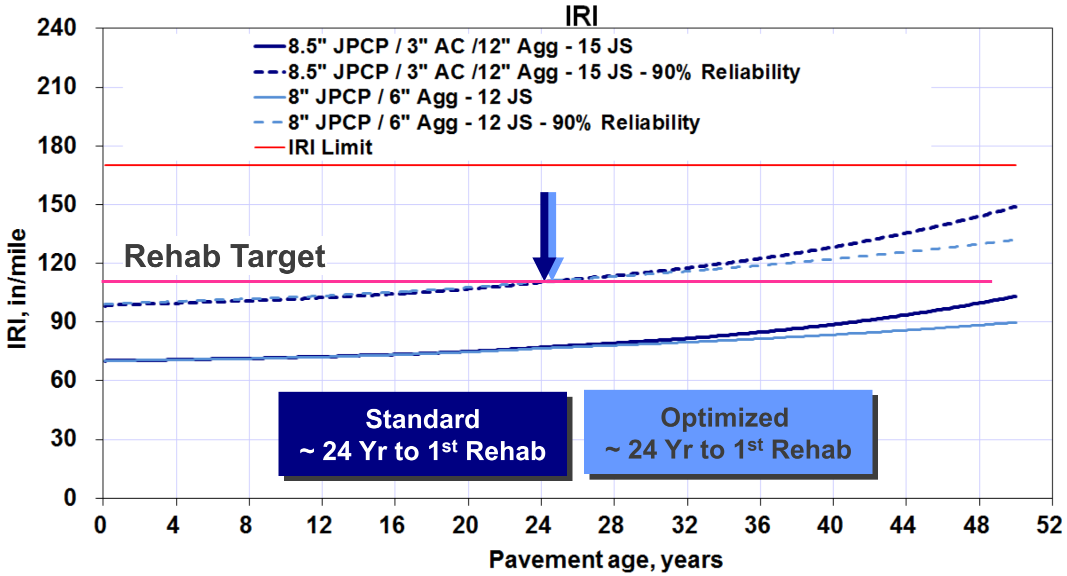
Pavement-ME Allows for Comparisons of Different Designs

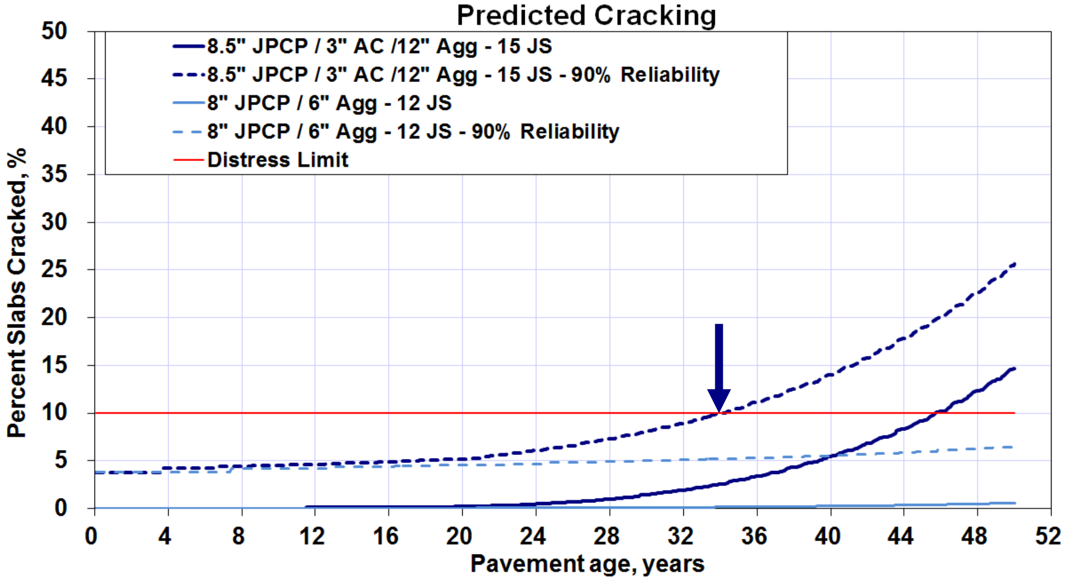
Original Concrete Design



Optimized Concrete Design







Pavement ME gives a repeatable, un-biased process that shows how a specific pavement design will perform

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So, While We Think Pavement ME is Amazing & the Best Thing EVER
It is also fairly complex and the models aren't perfect

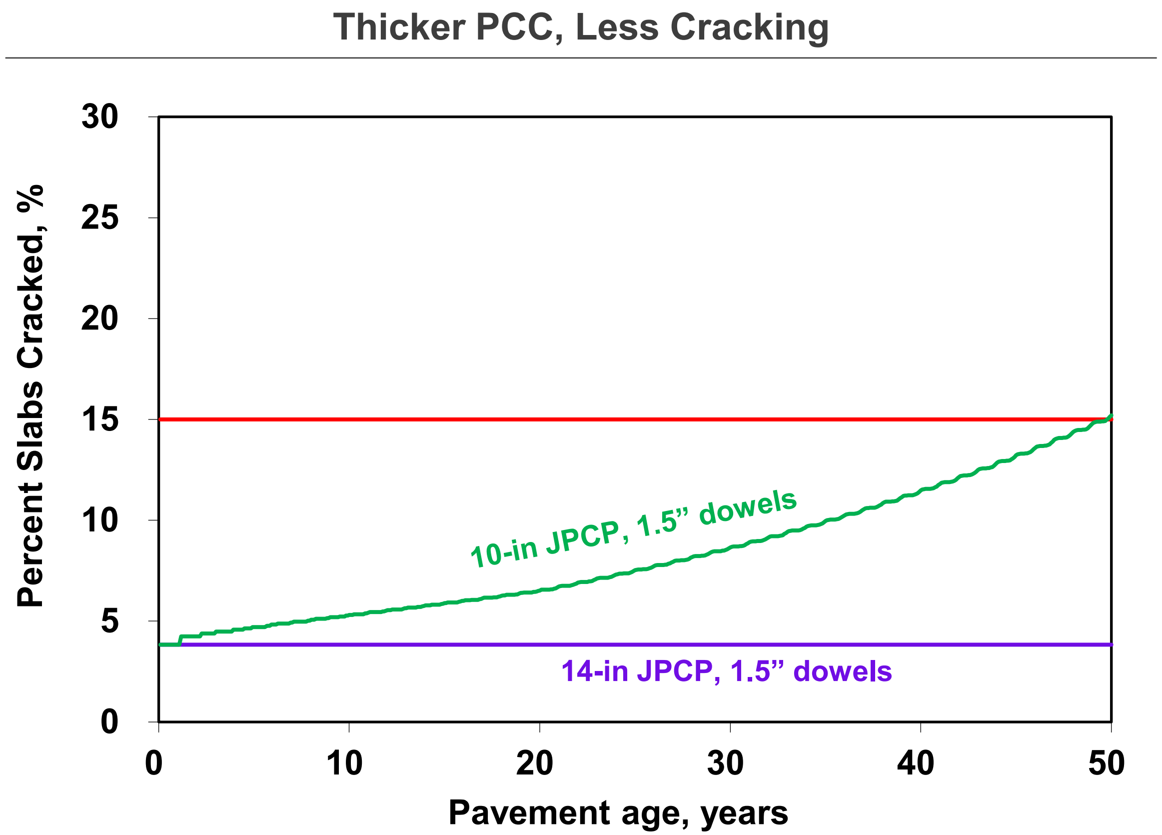
There are a Few Design Conundrums

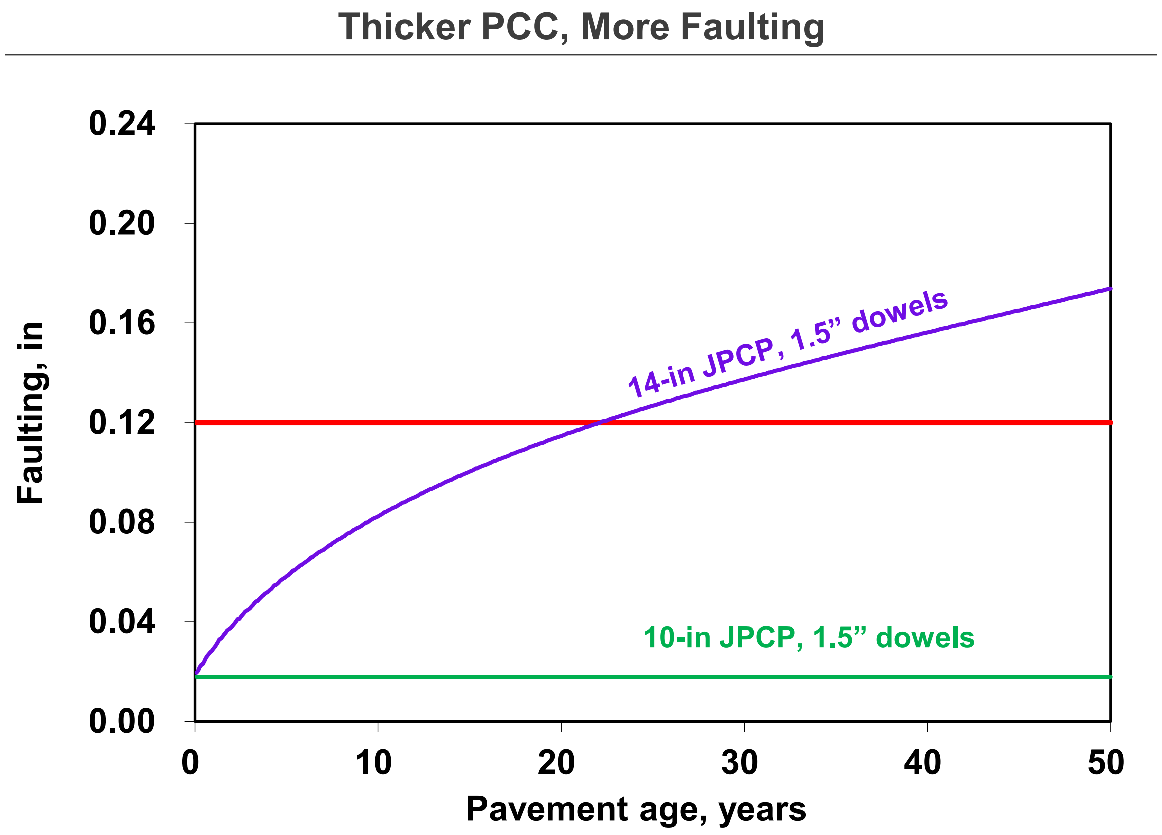
- Joint Faulting Predictions
- IRI Predictions

The designs are only as good as the inputs, and with an understanding of what is driving the final results

Need people with experience of Concrete Pavements to call "BullS---" when something is counter intuitive

Joint Faulting Increases For Thicker Concrete Pavements With Dowels





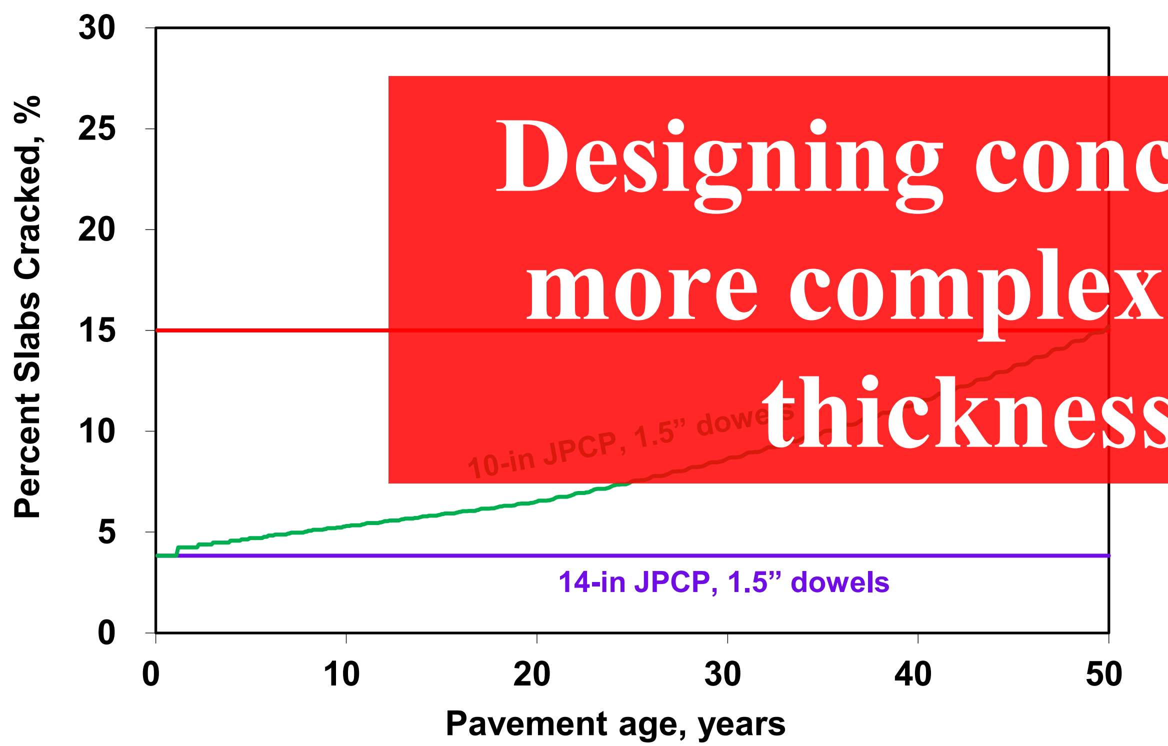
In Pavement ME, LTE is proportional to Dowel Size/PCC Thick Ratio
(e.g. the same dowel setup is more effective for thinner pavements)

In reality, LTE may be more dependent on the absolute amount of dowels.

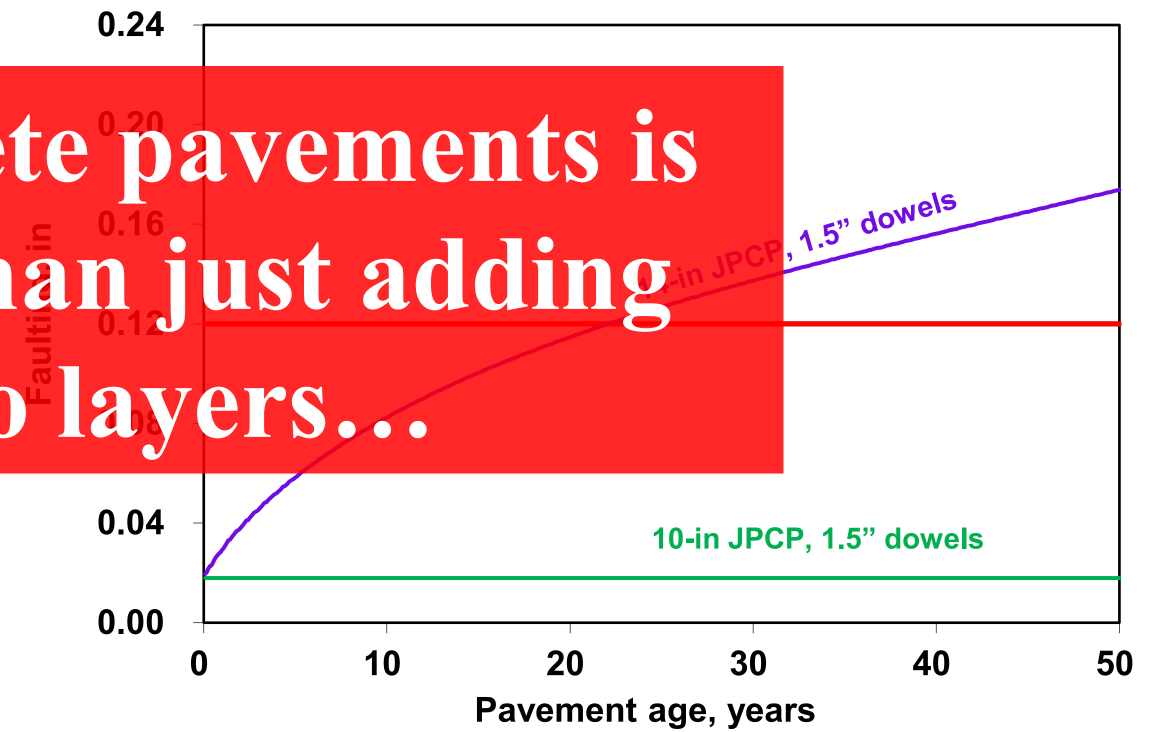
Eric

Joint Faulting Increases For Thicker Concrete Pavements With Dowels

Thicker PCC, Less Cracking



Thicker PCC, More Faulting



Designing concrete pavements is more complex than just adding thickness to layers…

In Pavement ME, LTE is proportional to Dowel Size/PCC Thick Ratio
(e.g. the same dowel setup is more effective for thinner pavements)

In reality, LTE may be more dependent on the absolute amount of dowels.

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For some Soil & Climatic Conditions, IRI Design Criteria Can Not be Met …

IRI = C1*(Crack) + C2*(Spall) + C3*(Fault) + C4*(Site Factor)

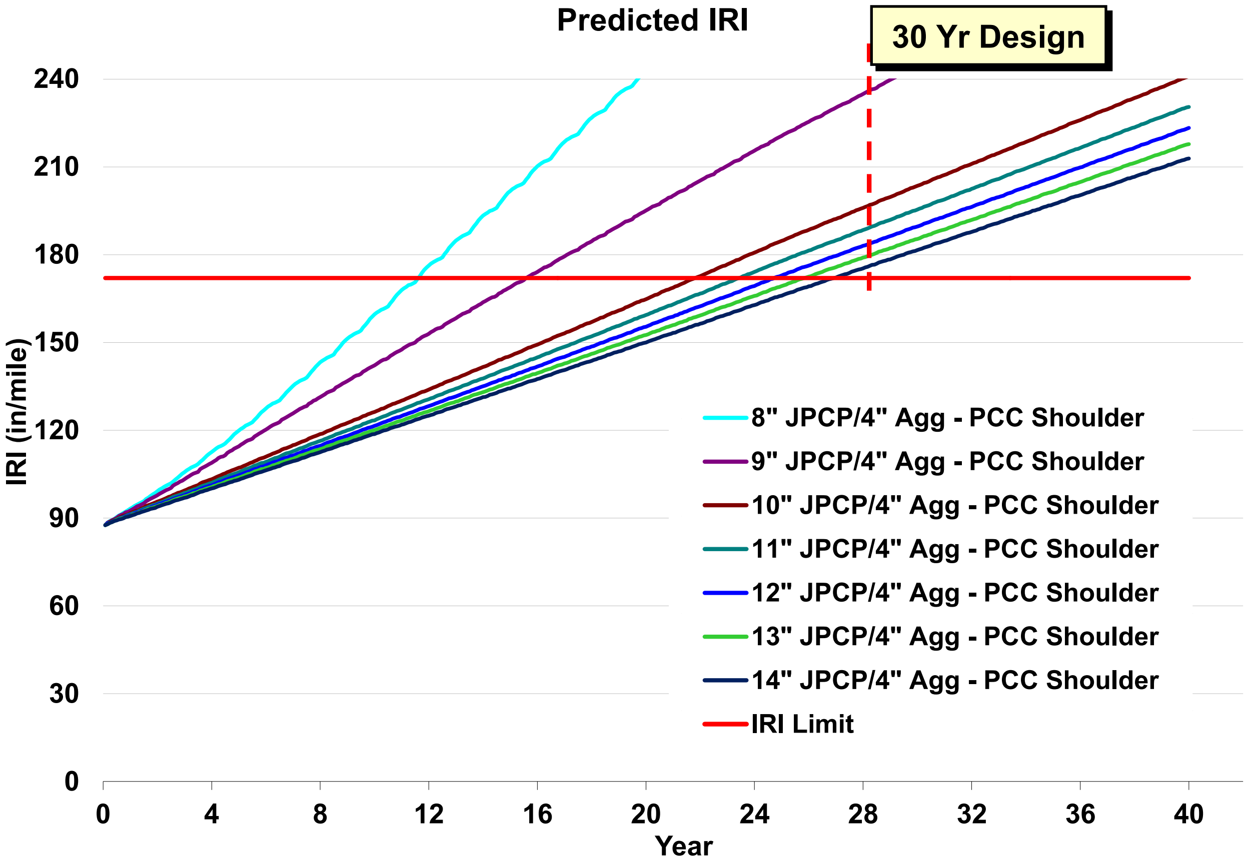
Site Factors

- SF = Age * (1+0.5556*FI) * (1+P200)/1,000,000
- FI=Freezing index
- P200=Percentage of subgrade material passing the 0.075-mm sieve.
- Relates to the potential for soil movements due to frost heaving and settlement

SF is a linear constant increase with age

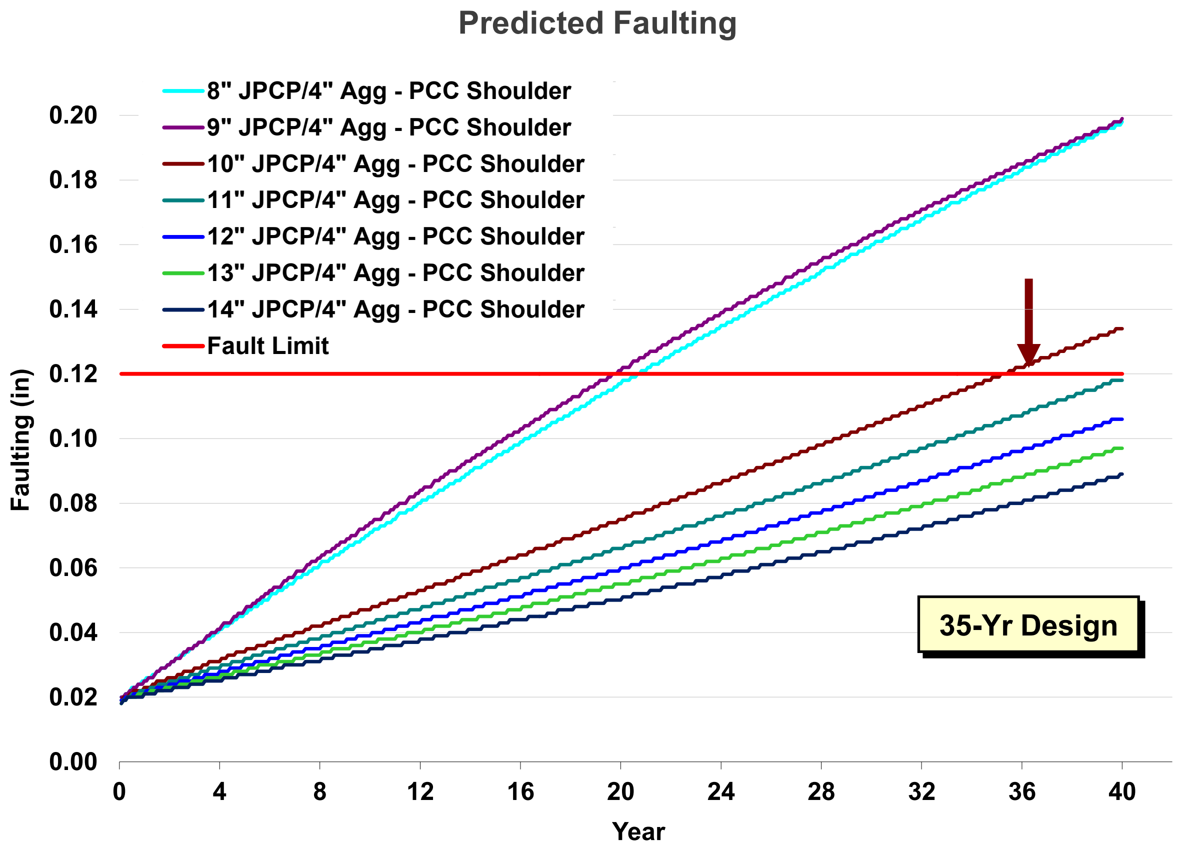
  - For areas with high FI and high P200 soils; the increase is very fast

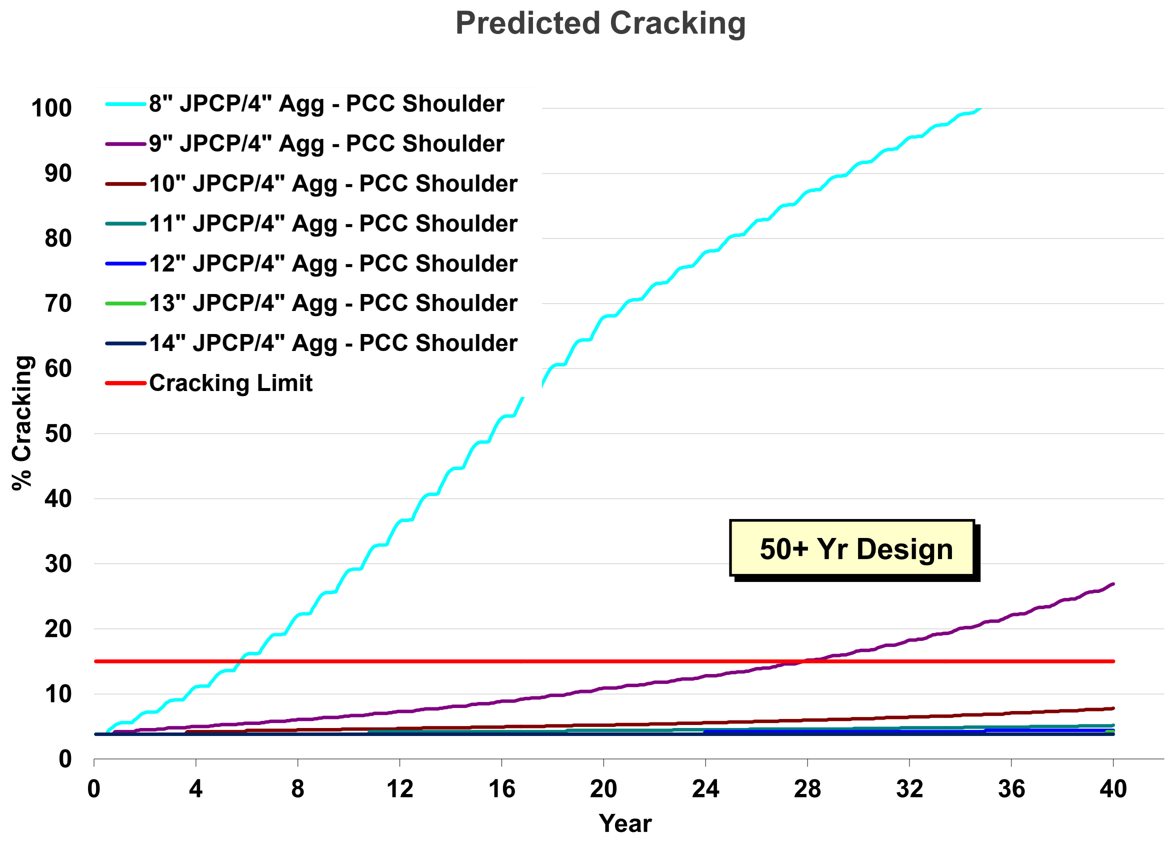
- When fault and cracking are low, IRI distress level is being controlled by “Site Factors”



No matter the concrete thickness, the 30-year IRI default criteria can not be met

… But Pavement ME Shows Cracking & Faulting Limits can be met with a 10-in Pavement

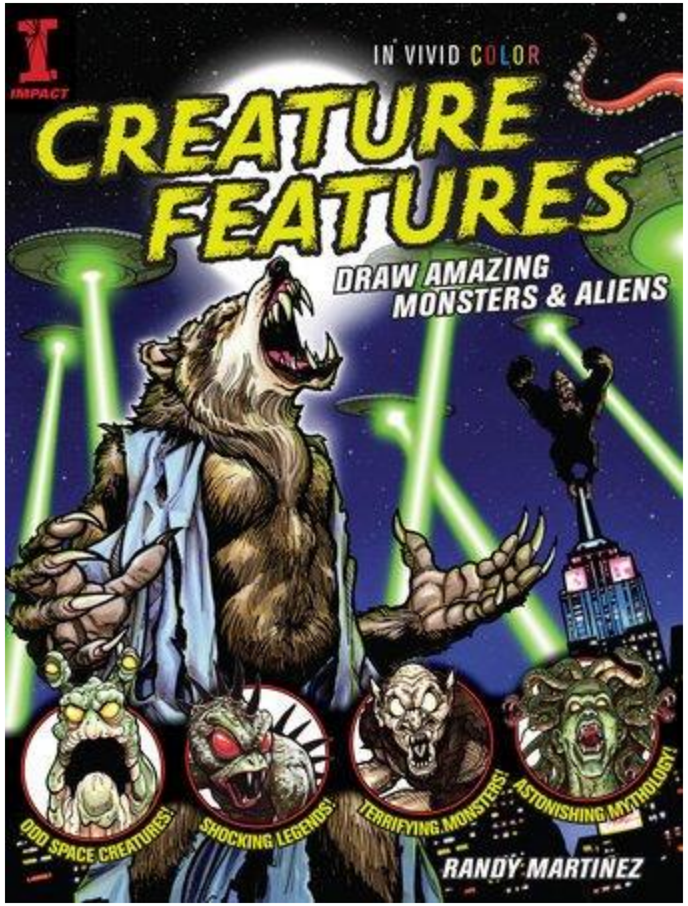


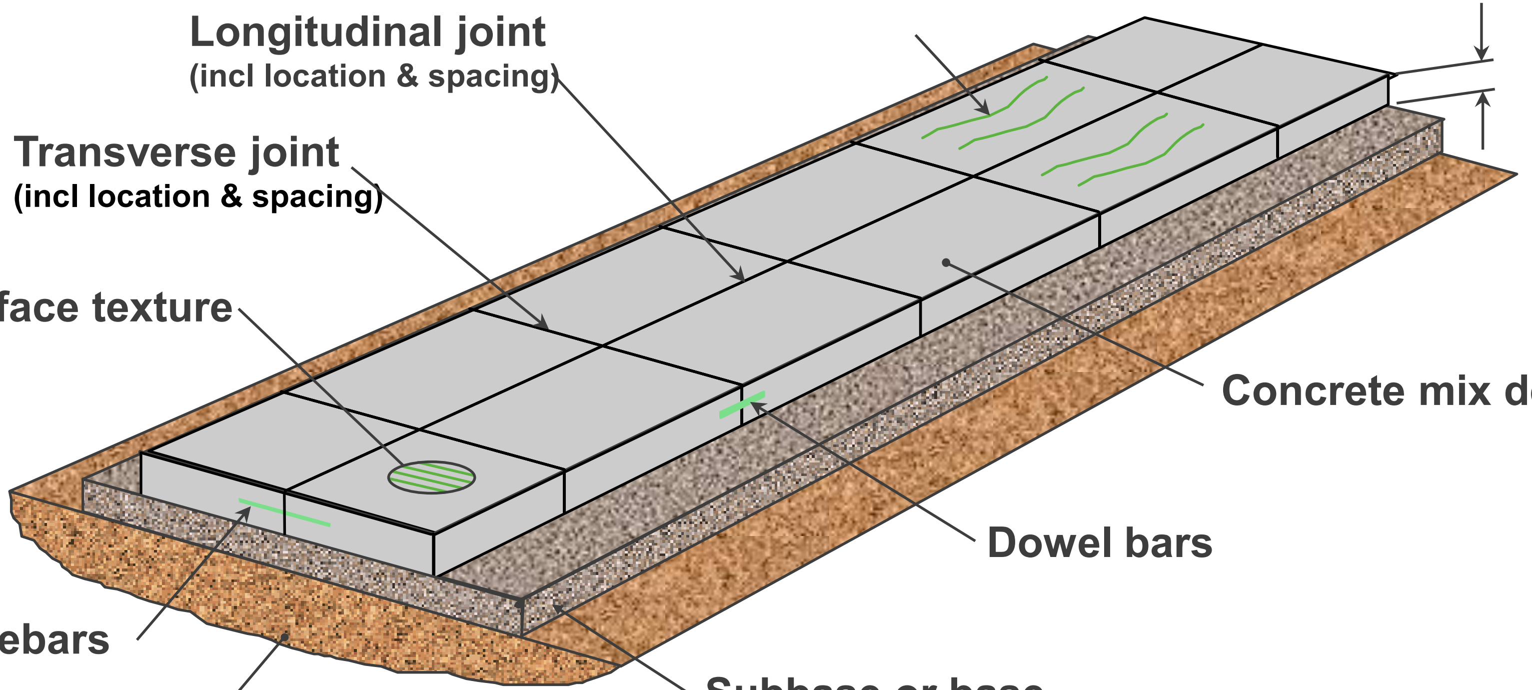


Question: How does a 14" Pavement IRI increase if there is no faulting or cracking?

Selecting Features

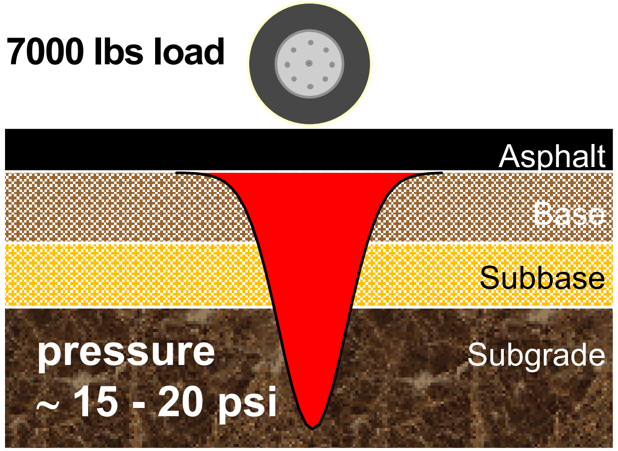
Concrete Pavements are a Creature of Features





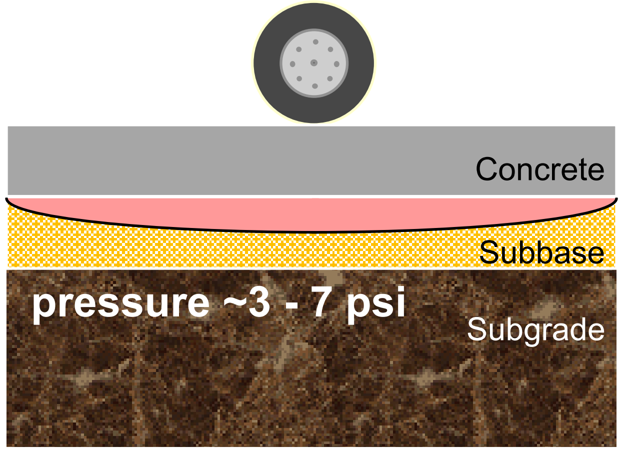
What drives Asphalt & Concrete Pavement Performance is Different

And that difference is reflected in design approaches



Asphalt – Performance is driven by the Materials

- **Asphalt Binder type, Master Curves, Balanced Mix Design**
- **Asphalt Aggregate Gradation**
- **Strength of underlying support**
  - **Much more freedom to make Changes**



Concrete – Performance is driven by the Features

- **Concrete is a Creature of Features**
  - **Features (joints, shoulders, dowels, etc.) have a significant impact on costs and performance**
- **Concrete needs to be durable, but changing concrete material properties has minimal impact on pavement performance**

Most Concrete Features are set by the state with little if any freedom to make changes

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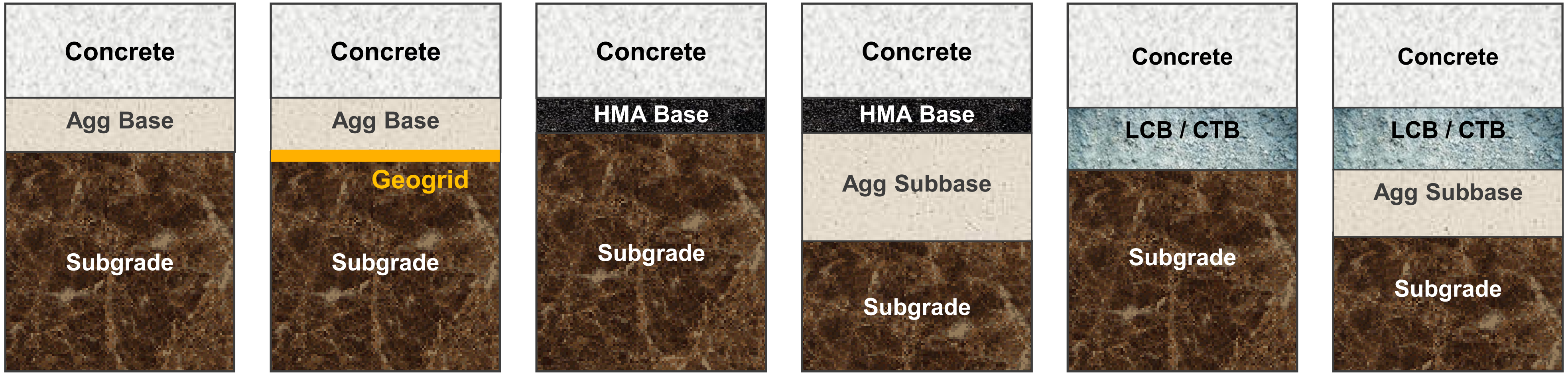
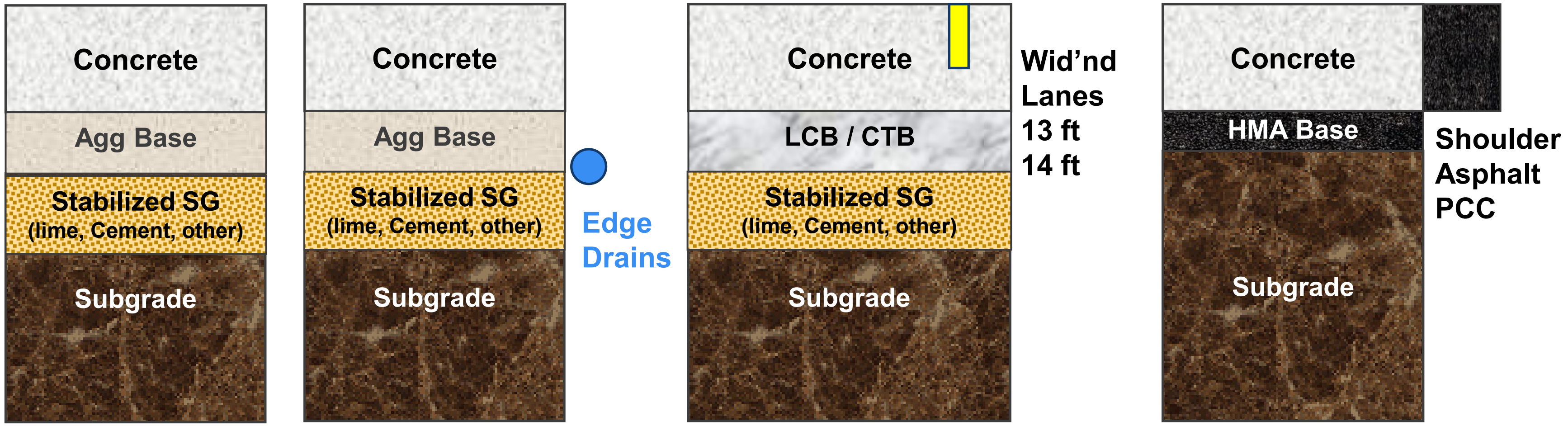
There are Many Pavement Designs that are Being Used
All have been used & can be used successfully in most applications





Others Items

- Joint Spacing
- Dowels – Yes or No
- Dowel Diameter
- CRCP
- Seal / No seal
- Overlays
- Etc.

Most States have ONE standard pavement structural design that they use in ALL applications

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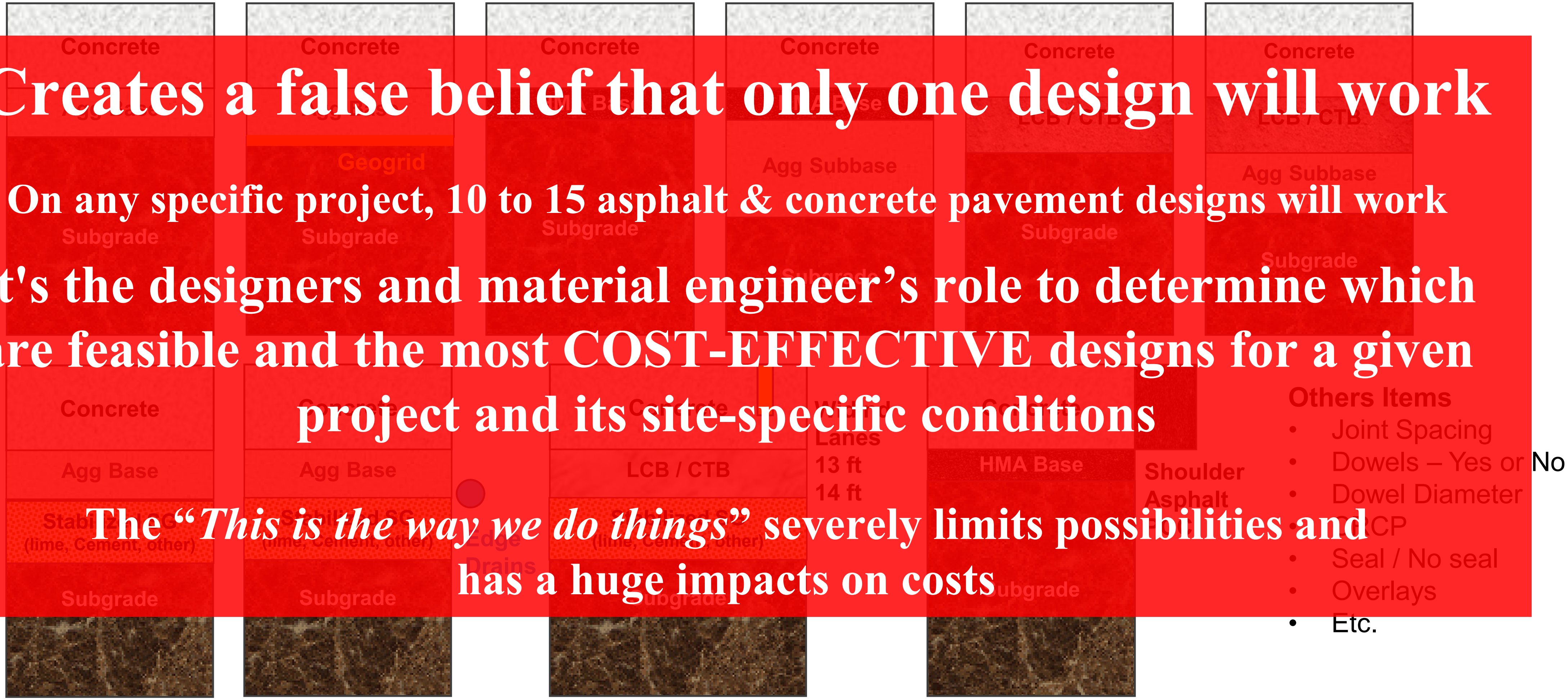
There are Many Pavement Designs that are Being Used

All have been used & can be used successfully in most applications



Creates a false belief that only one design will work

On any specific project, 10 to 15 asphalt & concrete pavement designs will work

It's the designers and material engineer's role to determine which are feasible and the most COST-EFFECTIVE designs for a given project and its site-specific conditions

The "*This is the way we do things*" severely limits possibilities and has a huge impacts on costs

Most States have ONE standard pavement structural design that they use in ALL applications

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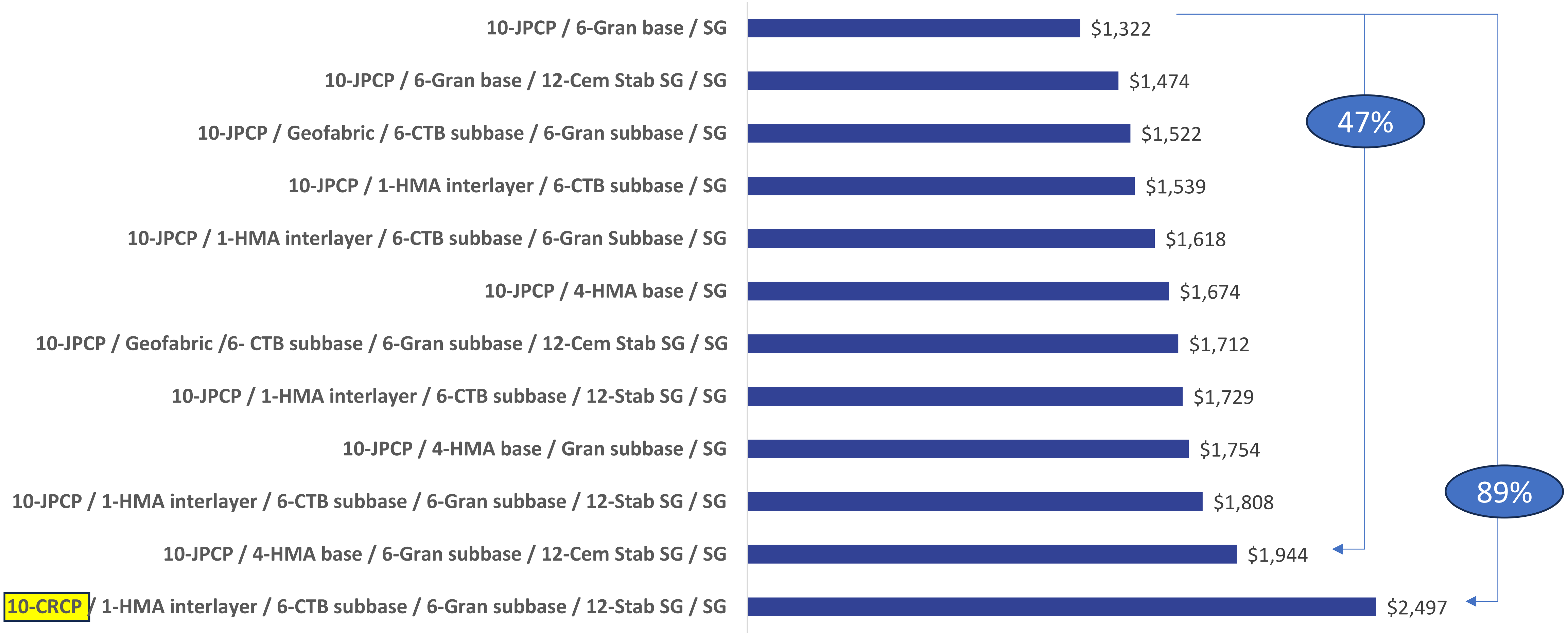
Pavement Structure has a Large Impact on Initial Pavement Cost

Estimated Initial Cost for a 10-inch Concrete Pavement with different base types



Date: June 2024

While standard structures work, additions can lead to overdesigns with no performance credit given

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Pavement = 1 mile, 4 lanes (2 12-ft lanes / direction), no shoulders.

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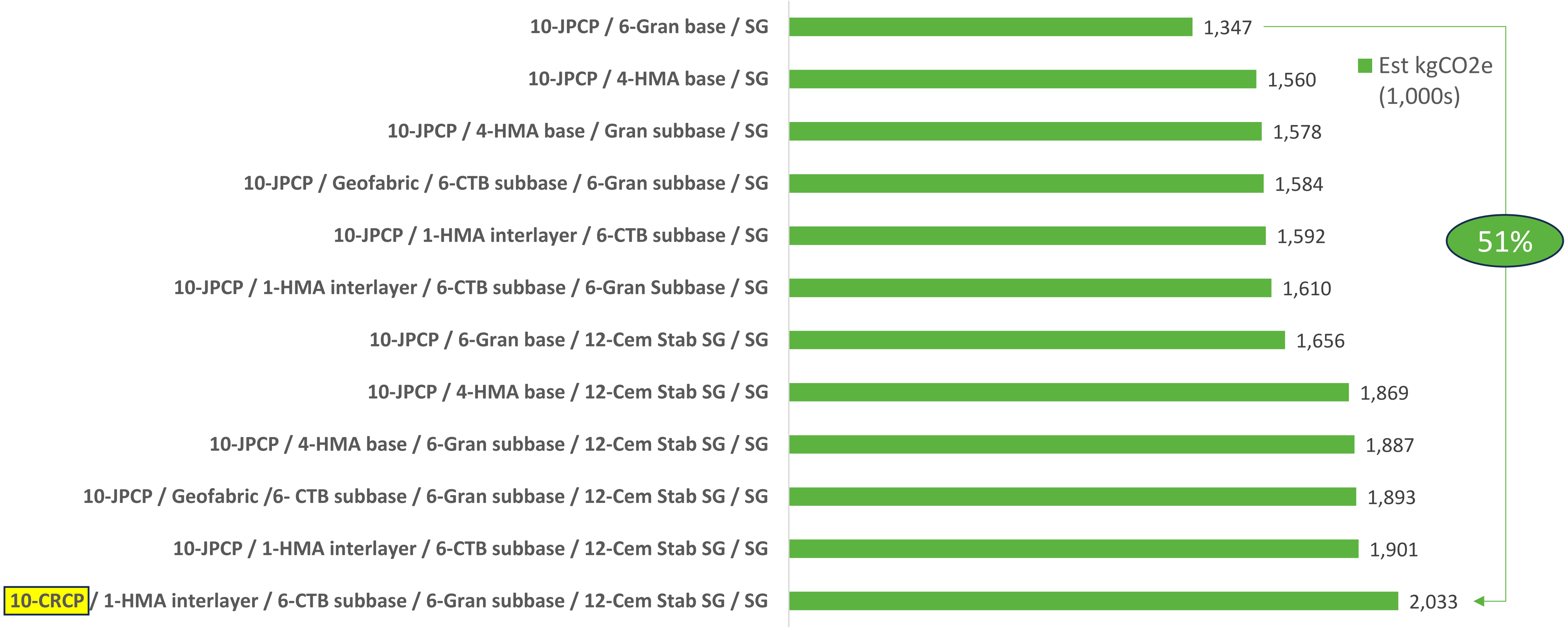
Pavement Structure has a Large Impact on the Initial Pavement CO2

Estimated Material CO2 for a 10-inch Concrete Pavement with different base types



And if worried about sustainability, the same issues exist

Pavement = 1 mile, 4 lanes (2 12-ft lanes / direction), no shoulders. CO2 / GWP values for materials based on IW Average EPDs (cement, concrete, & steel); EC3 median values (asphalt); EU Ecoinvent (aggregate); or representative company EPDs (lime, geogrids and geofabrics)

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So, Which Features should be used?

Each Design Feature must Balance Performance & Cost

Feature	Benefit or Options
Concrete Pavement Type	Jointed, jointed reinforced, continuously reinforced, RCC, overlays
Design Life	20 – 50+ year designs, shift away from short design lives
Thickness	Provides load carrying capacity. Often only design features changed & often too thick
Joint Spacing	Shorter joints reduces curling & warping stresses (& thickness) but does increase joint sawing and dowel costs
Use >13 ft Widened Lanes	Shifts loading to “interior loading” (reduces thickness)
Dowels / Increase Dowel Size	Improves load transfer, reduces bearing stress reduces faulting
Shoulder Design	Tied Concrete vs AC vs RCC; reduced /tapered thickness; no dowels; different mix, etc. (improves edge support)
Optimized aggregate gradation	Reduces cement content, creates denser mix, less shrinkage
Different concrete mixes	Mainline vs shoulder mixes, 2-layer construction
Base type	Granular vs asphalt treated vs cement treated, reduced thickness, dense graded vs permeable; subgrade / chemical stabilization
Single 1/8”-wide single saw cut and filled (not sealed)	Removes second sawing operation and reduces noise
Longitudinal tining or Next Generation Concrete Surface (NGCS)	Reduces noise, NGCS improves initial smoothness

Tools for Optimizing Designs of a Pavement System in an Iterative Process

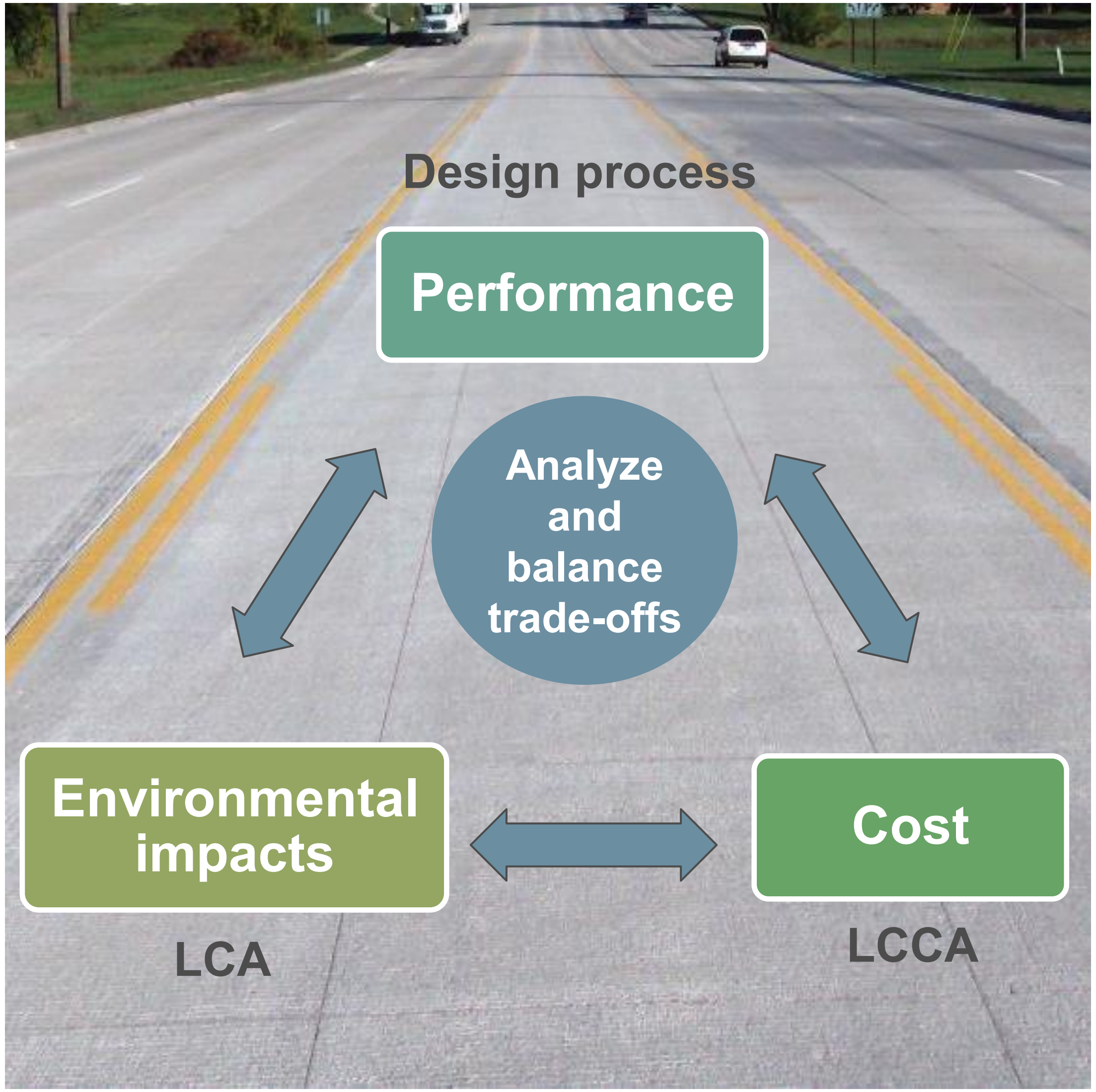
TOOLS

1. **AASHTO Pavement-ME Design Procedure**
   Predicts pavement performance over the analysis period

2. **Life Cycle Cost Analysis (LCCA)**
   Determines which pavement design is most cost effective over the analysis period

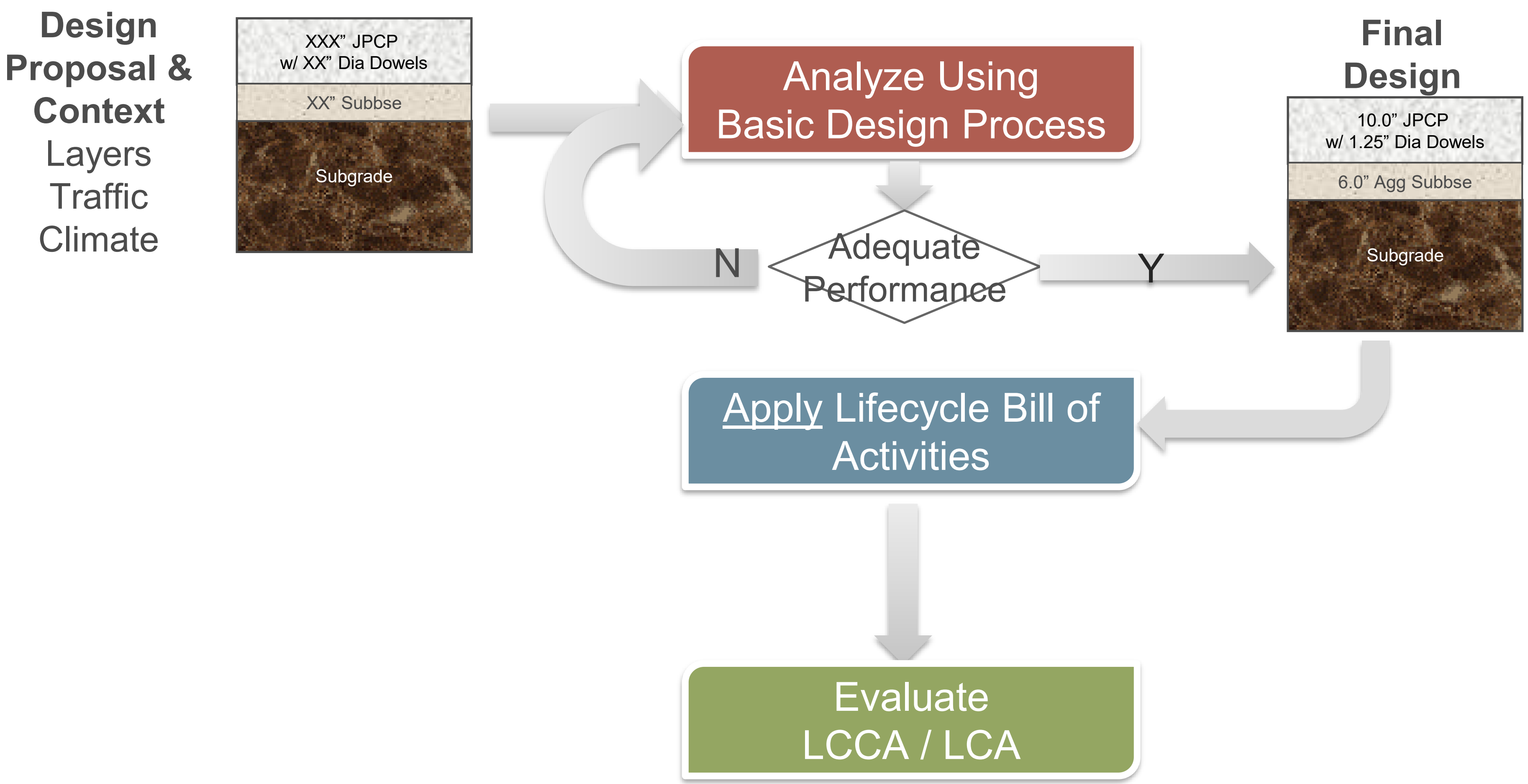
3. **Life Cycle Assessment (LCA)**
   Determines which pavement design is most "sustainable" over the analysis period

Combining performance with the LCCA / LCA allows designers to make trade-offs that balances costs, sustainability, & performance over the full life cycle



To Evaluate Features, we need to Change HOW we Design Pavements

Designs are developed in a "static mode" and then compared to select the final pavement design



Doing a LCCA/LCA at the end misses opportunities to make design changes

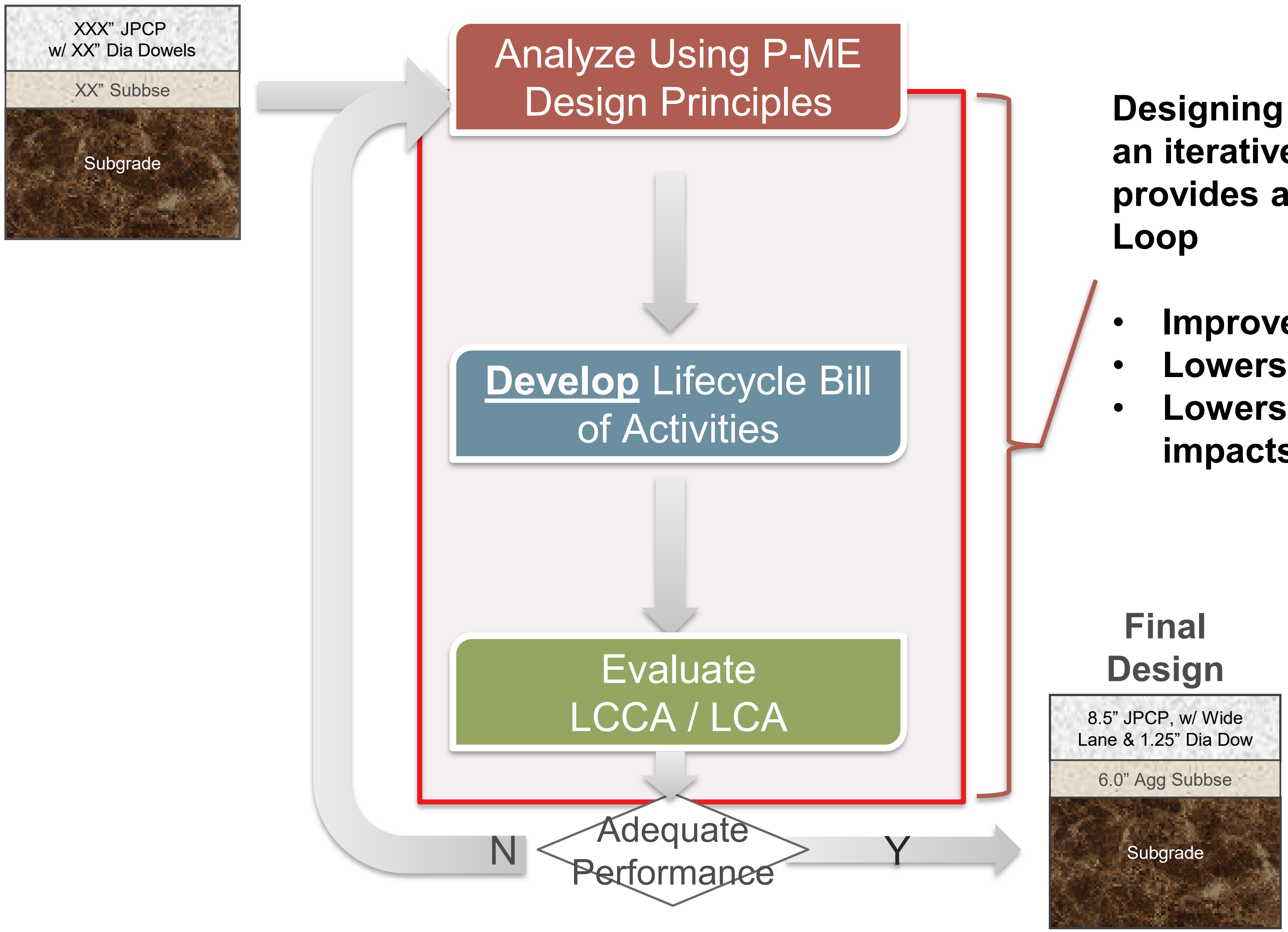
Slide: Courtesy of MIT Concrete Sustainability Hub

Eric

Need to Link Design and Evaluation in an Iterative Process

Assures that performance, costs and CO2 impacts are representative of the actual pavement

Design Proposal & Context
Layers
Traffic
Climate

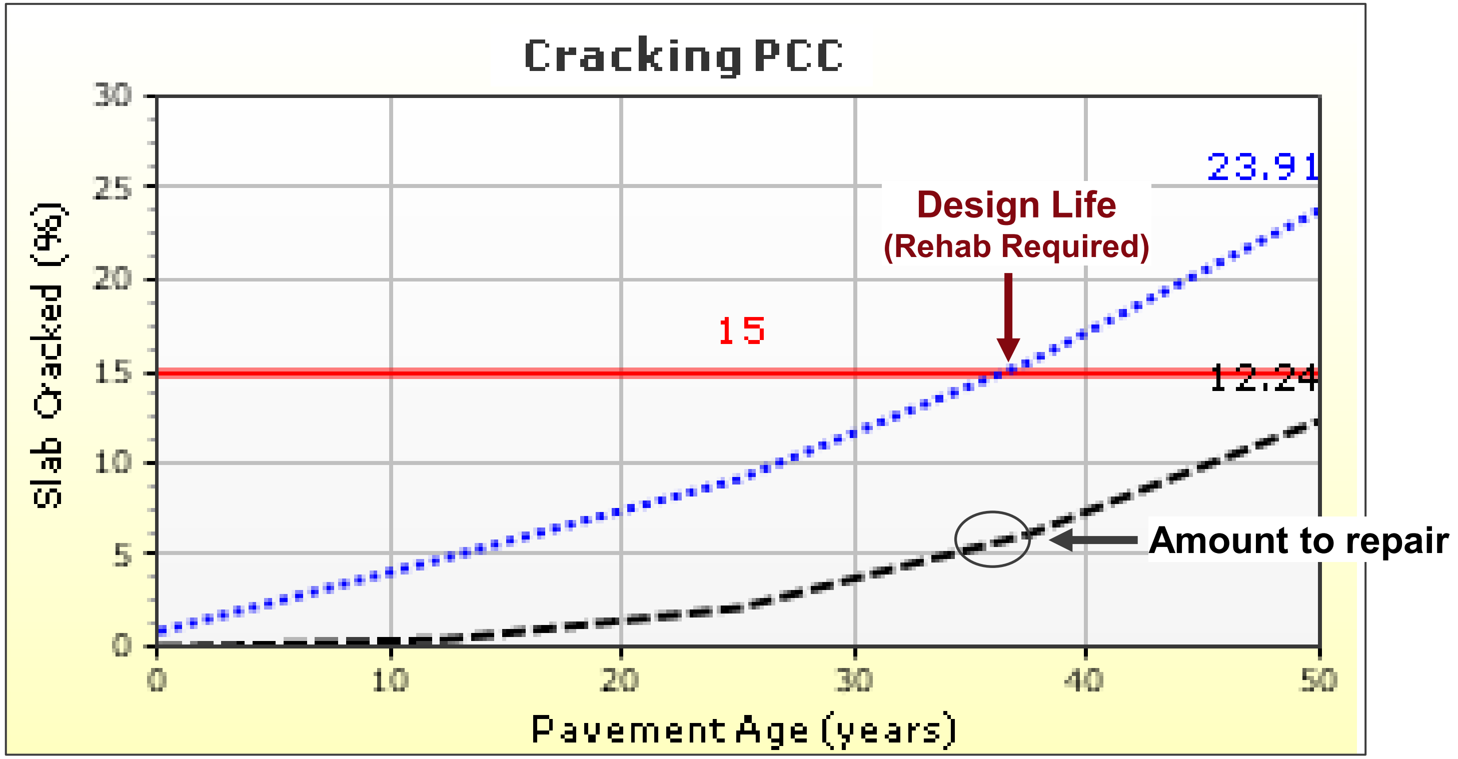


Designing pavements in an iterative procedure provides a Feedback Loop

- **Improves performance**
- **Lowers cost**
- **Lowers environmental impacts**

Pavement-ME Can Help Develop Rehab Cycles

Predicting performance of key distresses allows for trade-off analysis with Life Cycle Analysis



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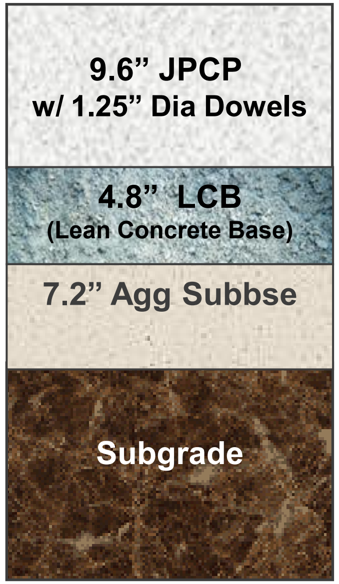
Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~37 years in this case)

Route 67 in Ramona, CA
Falls within the *South Coast* CALTRANS climatic region

Route 67 in Ramona, CA (at Route 78 junction)

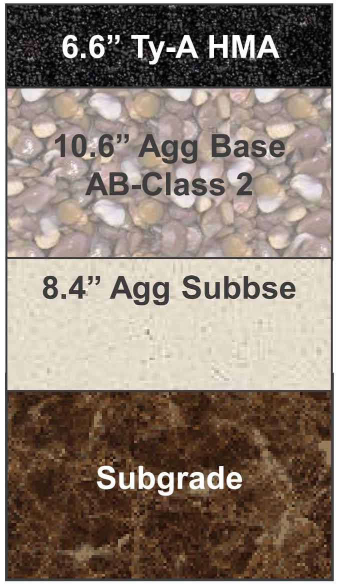
- Moderate volume road:
- 35-mph urban road
- 2 lanes in each direction (+ middle turn lane)
- 2 inner/2 outer shoulders
- Daily traffic: 23,400 (ADTT = 1,357)
- Initial ESAL = 335,000 / year
- 20-year Design Life / 55-year Analysis Period

CALTRANS Concrete Design



JPCP new construction:
Design life = 20-years
Maintenance Level = 1,2,3
- 2% Patch & DG at year 25,
- 4% Patch & DG at year 30
- 6% Patch & DG at year 40
- 3" Asphalt overlay in year 45 (10-year life)

CALTRANS Asphalt Design



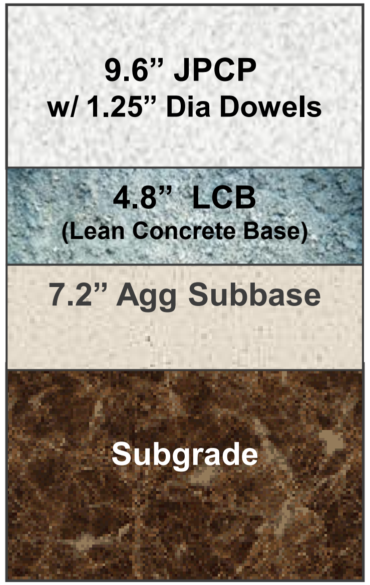
HMA new construction:
Design life = 20-years
Maintenance Level = 1,2
- 3" AC Overlay in years 20,
- Mill / 4" ACOL in year 25
- Mill / 3" ACOL in year 35
- Mill / 4" ACOL in year 45
- Mill / 3" ACOL in year 50 (5-year life)

Highway Design Manual 6th Ed. Sacramento: California Department of Transportation, CALTRANS, 2010.
Life-Cycle Cost Analysis Procedures Manual. Sacramento, CA: California Department of Transportation, CALTRANS, 2010.

Estimated Cost and Environmental Impact for Standard Caltrans Pavement Designs

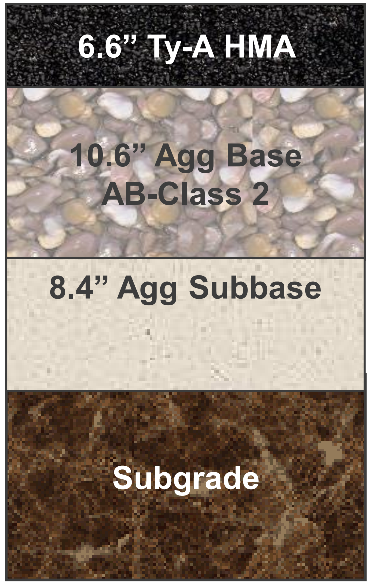
Route 67 - Ramona, CA

CALTRANS
Concrete Design



	LCCA (NPV $/mile)	LCA (tons CO_2e/mile)
Initial Const.	**$3,147,585**	**3,954**
Pavement	*$2,229,803*	*2,860*
LCB	*$644,902*	*781*
Agg Subbase	*$272,880*	*313*
Rehabilitation	**$911,663**	**479**
Carbonation		**(123)**
PVI-Deflection		**604**
PVI-Roughness		**1,912**
Total	**$4,059,248**	**6,826**

CALTRANS
Asphalt Design



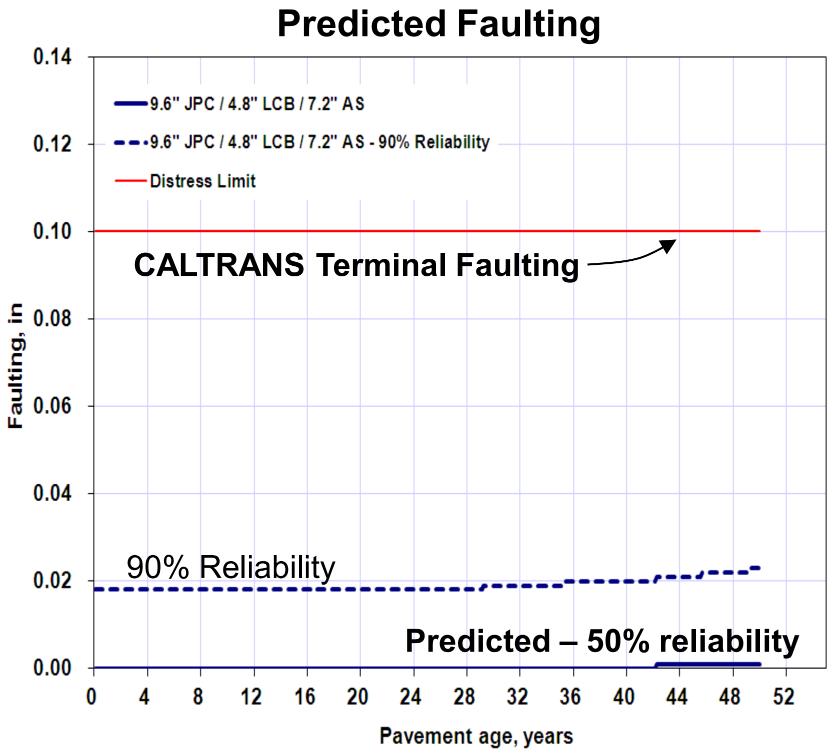
	LCCA (NPV $/mile)
Initial Const.	**$2,278,102**
Pavement	*$1,437,480*
AB-Class 2	*$522,262*
Agg Subbase	*$318,360*
Rehabilitation	**$1,104,504**
Total	**$3,382,606**

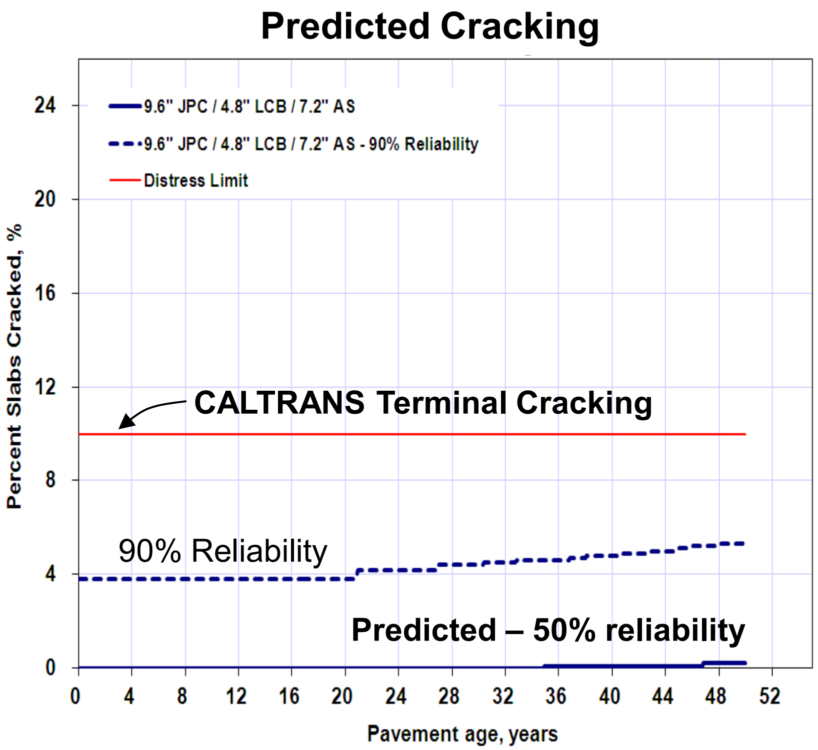
Asphalt is 38% lower in Initial Costs and 20% lower in Life Cycle Costs

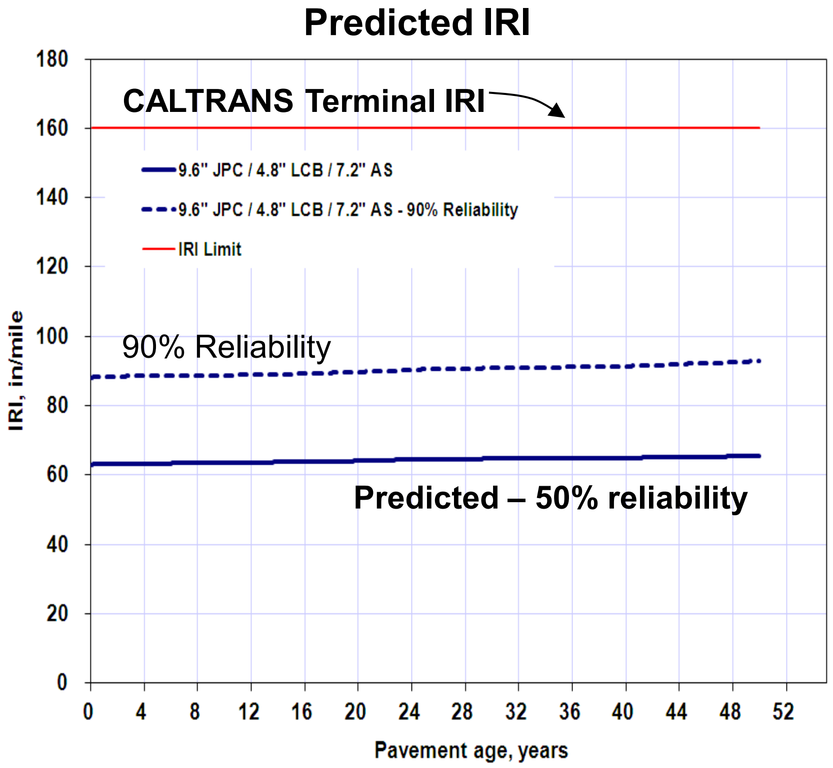
Caltrans Concrete Design: From Table 623.1E (South Coast/Central Coast, Type II SG
Initial AADTT = 1,357 / day, 4% Compound Growth (Initial ESAL = 335,000 / yr)
20 Yr ESALs = 10,650,000; 50 Yr ESALS = 51,151,000

Route 67 Pavement-ME Predicted Performance is High

Faulting, Cracking, & IRI are well below terminal levels for the entire analysis period





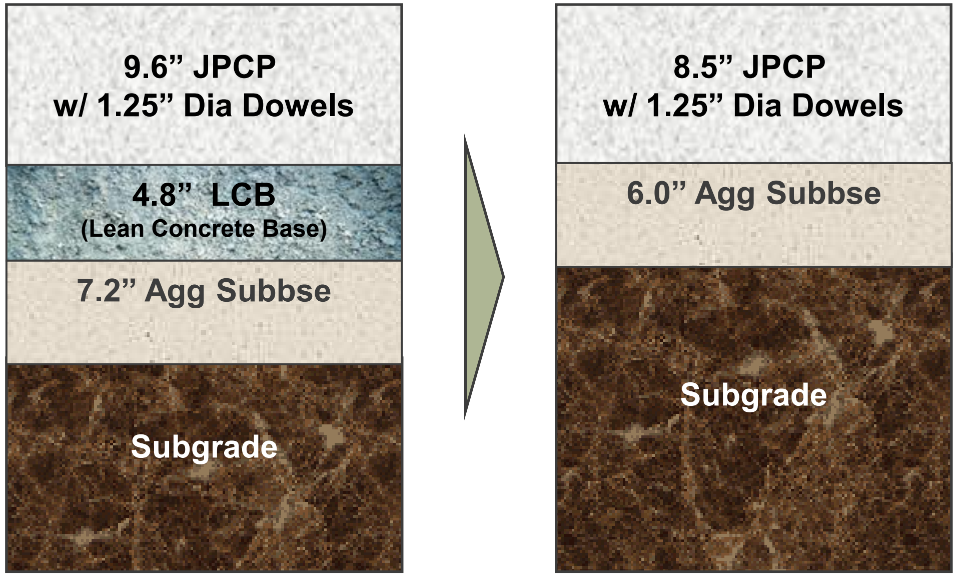


Pavement is over-designed because it does not need rehabilitation for the entire 50-year analysis period
Creates the opportunity for project specific optimization

Over-Design Creates the Opportunity for Optimization
Each design feature needs need to balance performance, cost & environmental impact

CALTRANS Concrete Design

Optimized Concrete Design



Features Evaluated

- Iterated Concrete Thickness
  - 9.0”
  - 8.5”
  - 8.0
- Removed 4.8” Lean Concrete Base
  - Accounts for 20% of the initial construction costs & GWP
  - Performance history shows that aggregate bases have worked in similar applications
- Iterated Aggregate base thickness
- Develop rehabilitation activities based on Pavement-ME distresses

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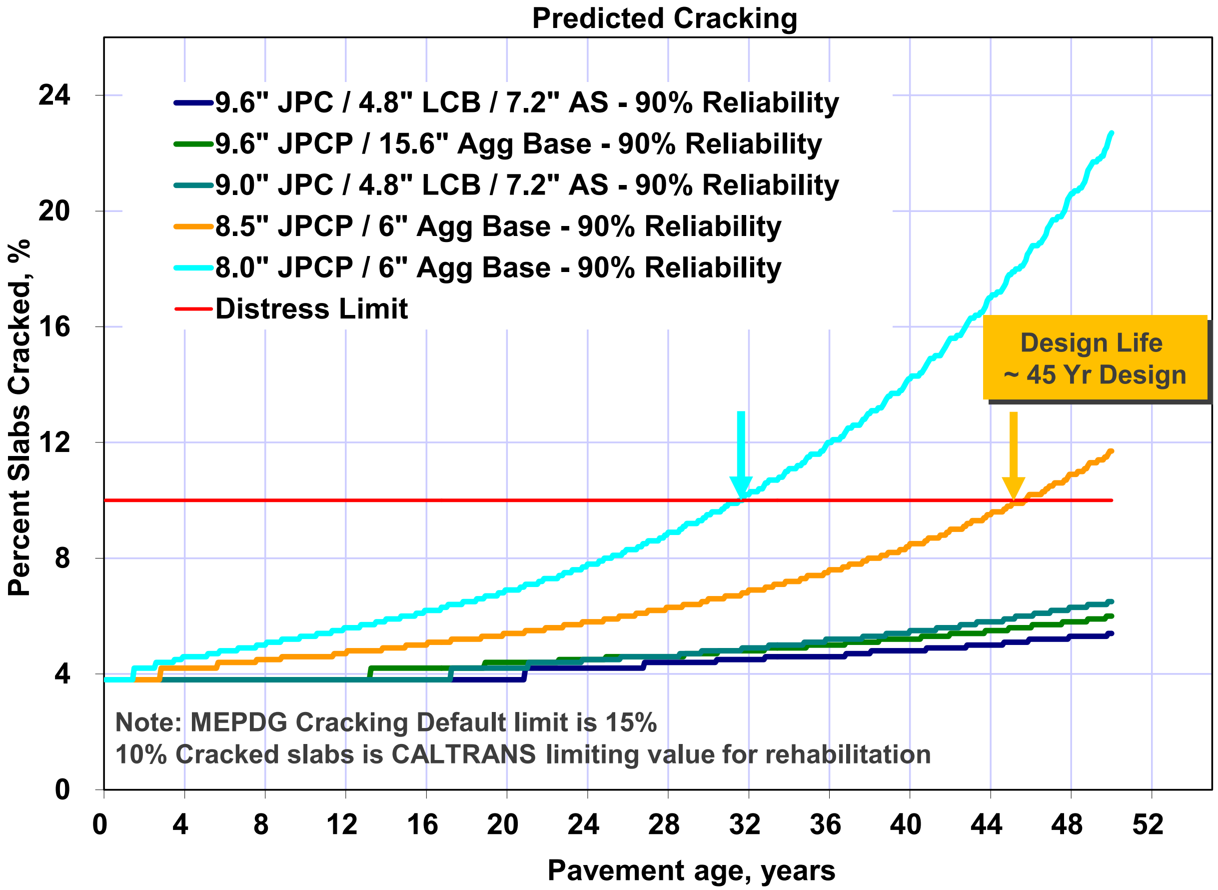
8.5” Jointed Plain Concrete Pvmt w/ Dowels meets the Performance Criteria

Good balance between long term performance and low cost / low GWP

- Performance curves show all the pavement options evaluated exhibited good performance
    - Cracking not an issue until the pavement is at 8.5-inch or less.
    - Faulting and IRI are well below unacceptable levels for all cases
- 8.0-inch pavement met the 20-year design life
- 8.5-inch JPCP design chosen as optimized design
    - Cracking hits terminal level at year 45
    - Good balance between long term performance (and a hedge against increased traffic) and low cost / low GWP

Optimization does not mean choosing the Thinnest (cheapest) Pavement
It's about selecting the Most Effective

Pavement-ME Predicted Performance



Arrows indicate year of predicted 1st rehabilitation for that given pavement

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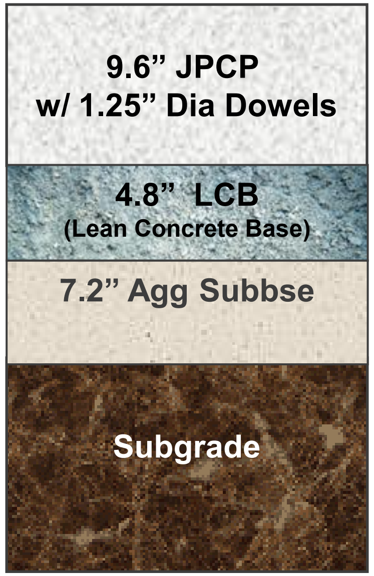
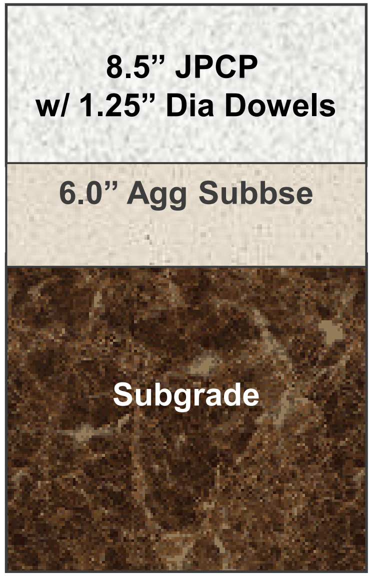
Project Specific Pavement Optimization Lowers Cost & Environmental Impact

CALTRANS Concrete Design



Optimized Concrete Design



	Original CALTRANS Schedule		Optimized Pavement-ME Design	
	LCA (tons CO_2e)	LCCA (NPV $)	LCA (tons CO_2e)	LCCA (NPV $)
Initial Const.	**3,954**	**$3,147,585**	**3,063**	**$2,256,638**
Pavement	*2,860*	*$2,229,803*	*2,803*	*$2,021,307*
LCB	*781*	*$644,902*	*--*	*--*
Agg Subbase	*313*	*$272,880*	*260*	*$235,331*
Rehabilitation	**479**	**$911,663**	**54**	**$315,798**
Carbonation	**(123)**		**(87)**	
PVI-Deflection	**604**		**704**	
PVI-Roughness	**1,912**		**2,110**	
Total	**6,826**	**$4,059,248**	**5,844**	**$2,572,437**

Optimization reduced the initial construction GWP by 890 tons (22.5%) and the life cycle GWP by 980 tons (14.3%)

Optimization reduced the initial construction costs by $890k (28.3%) and the life cycle cost $1.48M (36.6%)

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Caltrans Concrete Design: From Table 623.1E (South Coast/Central Coast, Type II SG
Initial AADTT = 1,357 / day, 4% Compound Growth (Initial ESAL = 335,000 / yr)
20 Yr ESALs = 10,650,000; 50 Yr ESALS = 51,151,000

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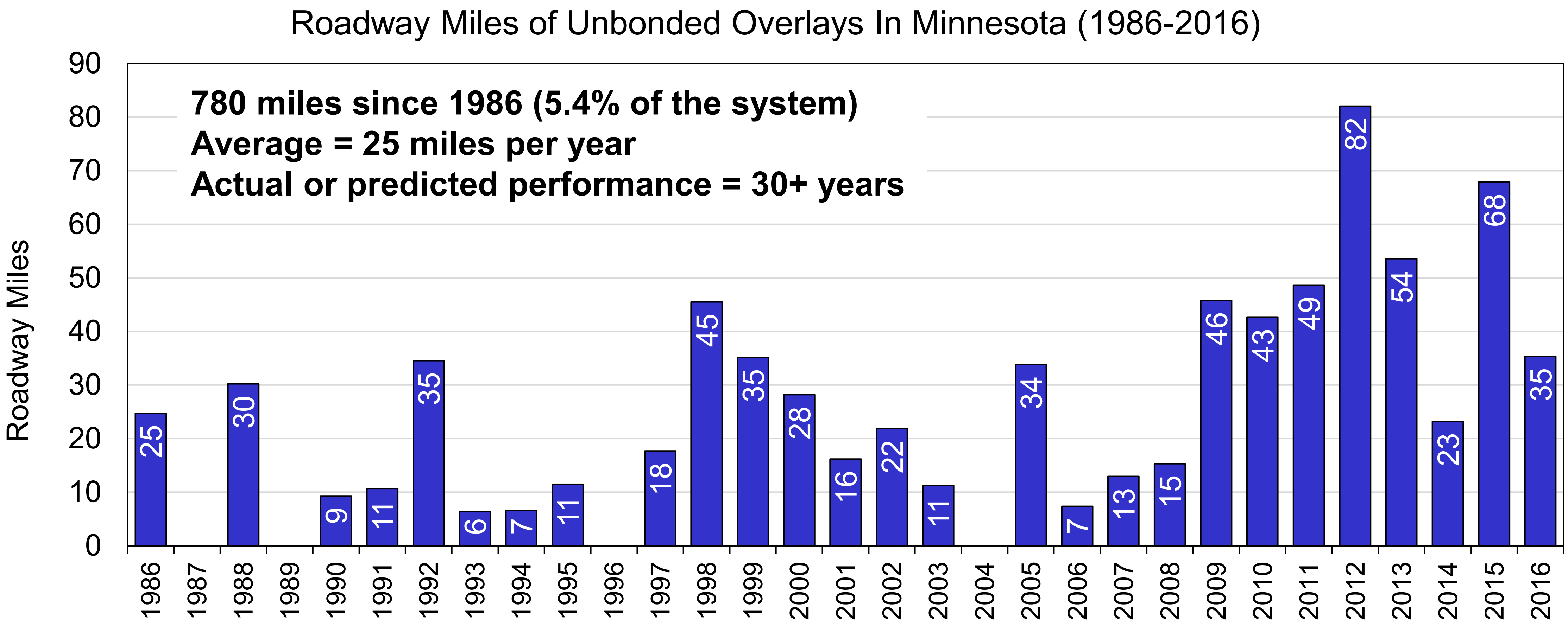
Some of our Favorite Optimization And Design Features

Overlays are a Great Design Optimization Tool Not Used Often Enough

CPTech Overlay Guides have solutions for elevation, bridges, slopes, traffic control, & other constraints

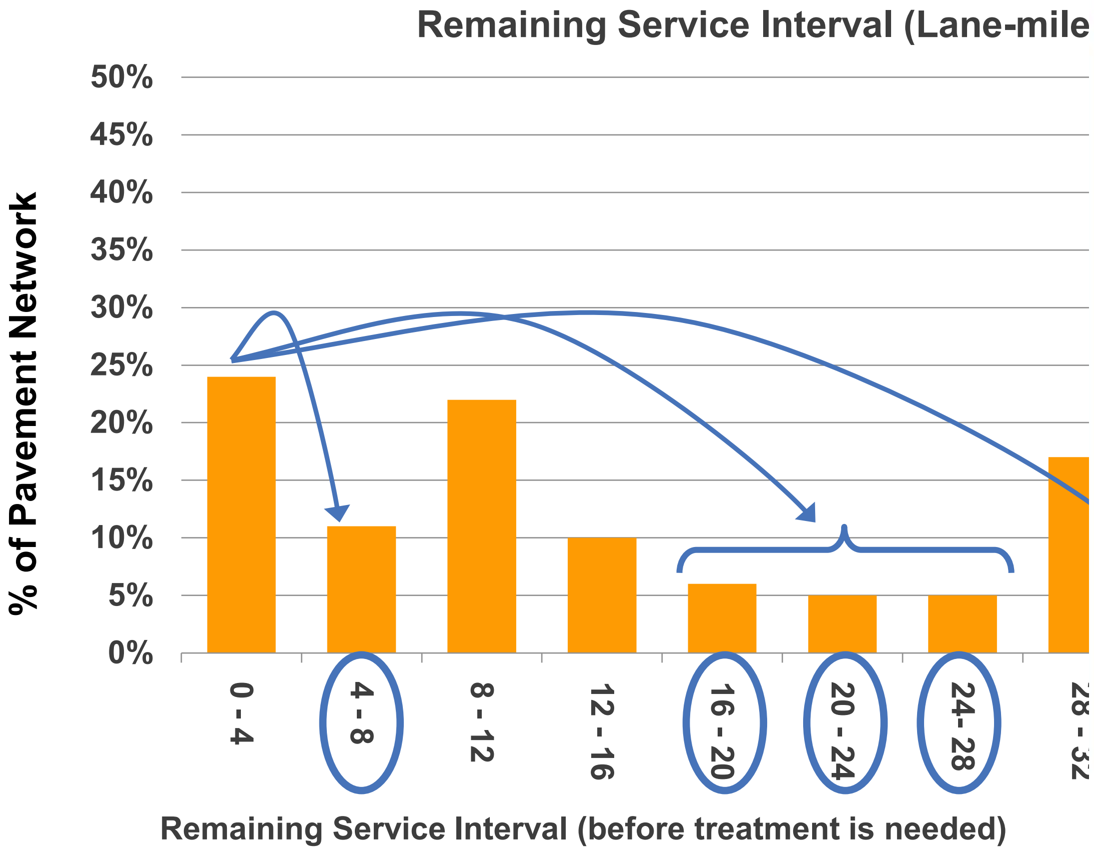


"Unbonded OL's last as long or longer at 1/3 of the price" – Maria Masten, MnDOT

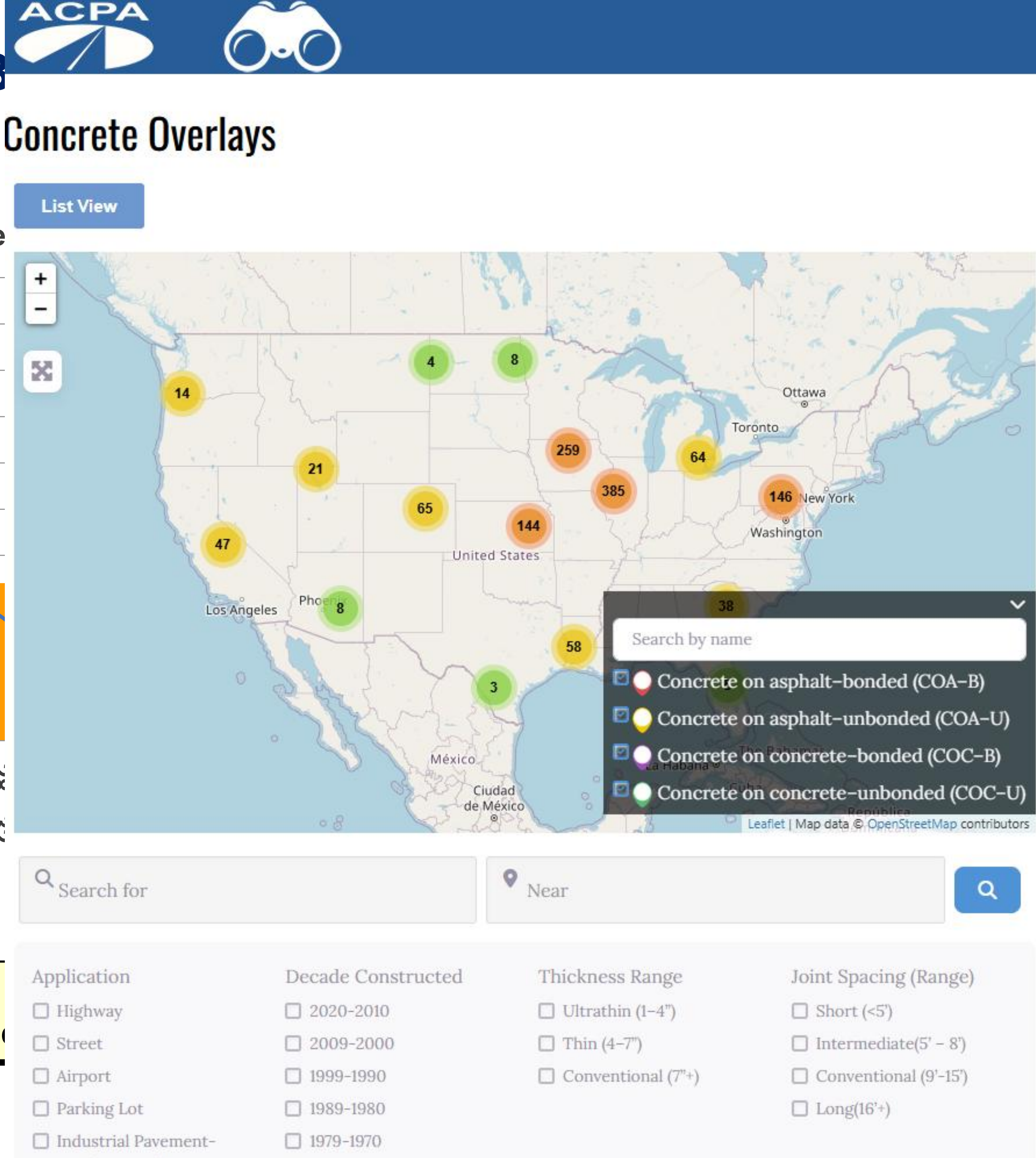
Source: Concrete Paving In Minnesota: Let's Learn from Each Other, Maria Masten, P.E., MnDOT Concrete Engineer
WCPA Annual Concrete Pavement Workshop, February 17, 2017

Eric

Concrete Overlays Help Optimize and B



“Mix of Fixes” reduces the amount to be
Network RSI, lessens likelihood of funding



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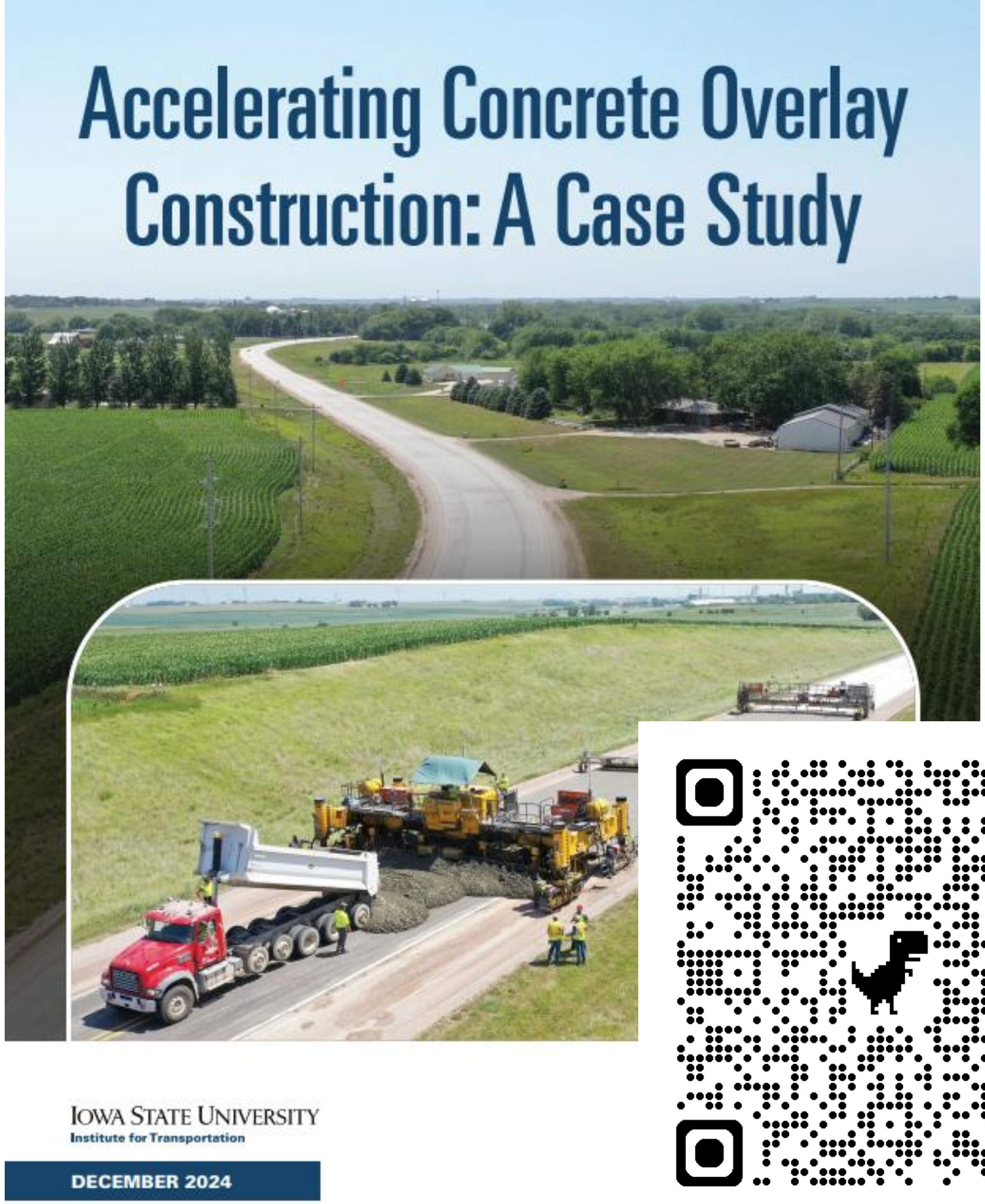
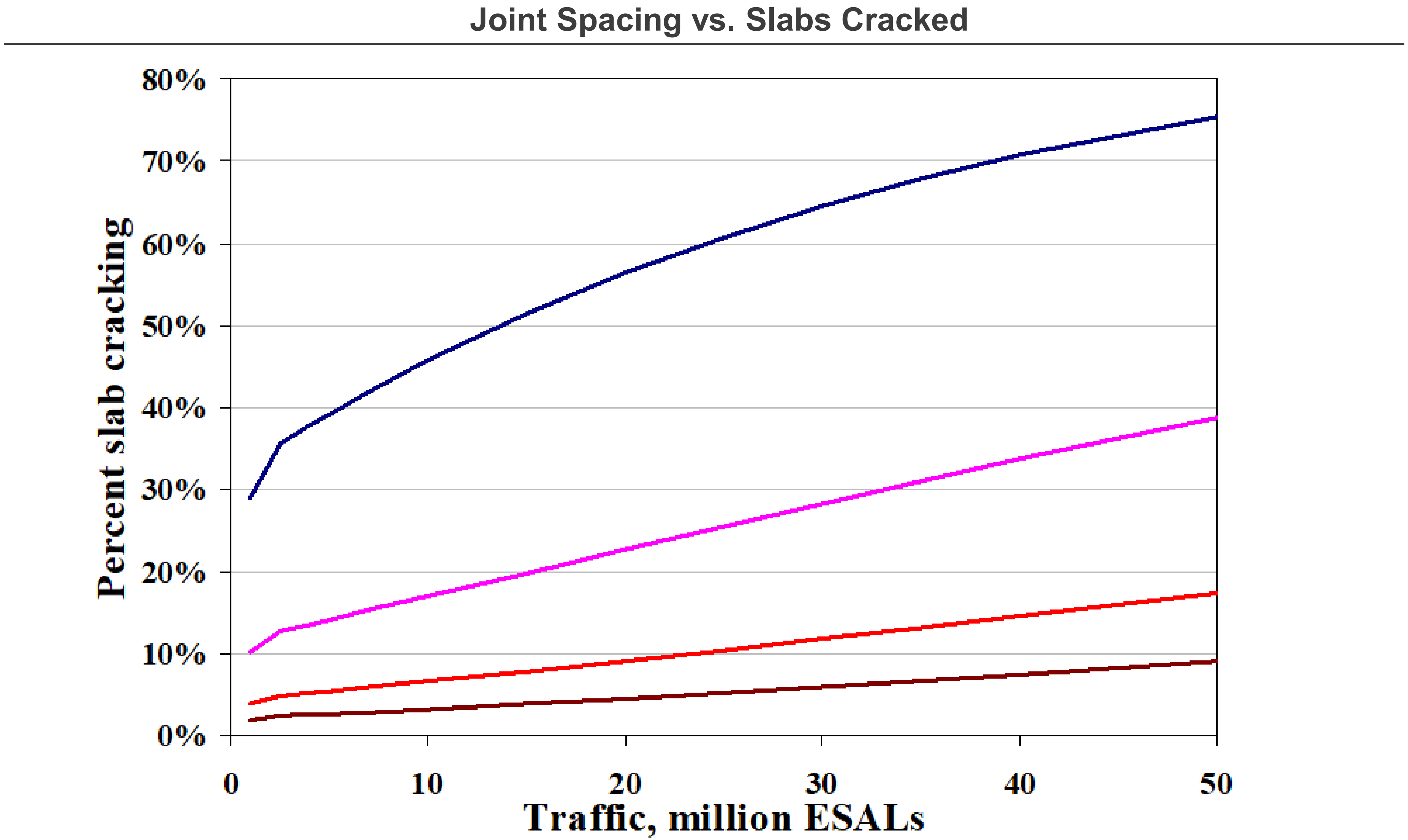
Overlay Optimization – Many Concepts are Similar to Full Depth Concrete



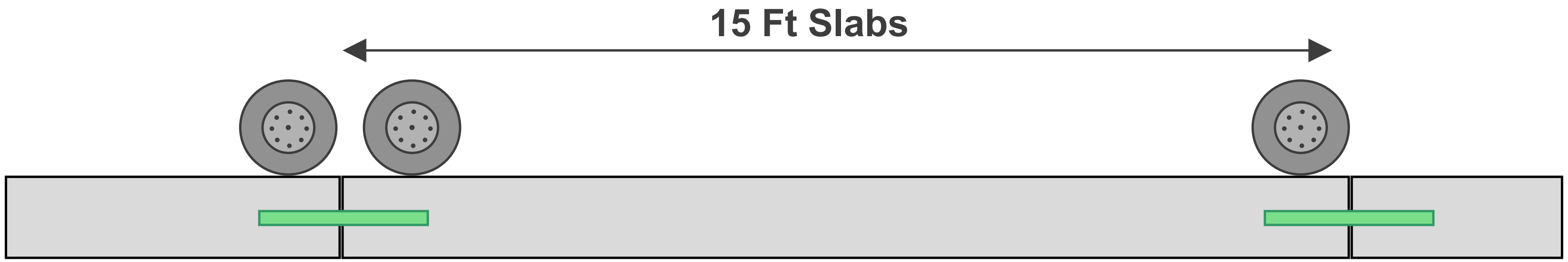
Shorter Joint Spacing Reduces the Required Slab Thickness



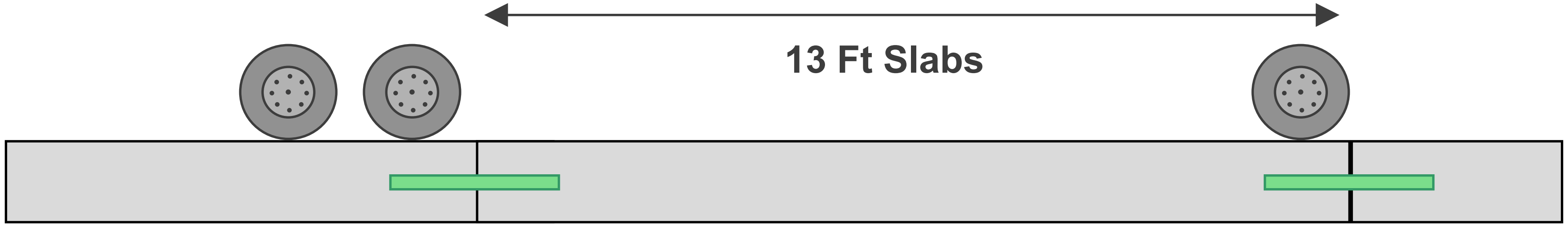
Maximum Joint spacing = 18 to 24 times thickness (15 ft max)

Graph Developed by Tommy E. Nantung, INDOT Office of Research and Development

Shorter Joint Spacing Reduces Wheel Loads Stresses



Loading the slab at each end creates additional top-down stresses and causes earlier top-down cracking



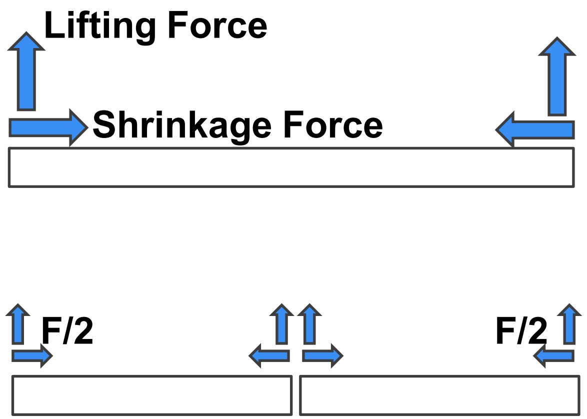
Reducing slab length means only one end is loaded by an axle, which reduces top-down stresses and extends life

Each foot of reduced joint spacing adds ~0.40% or less to pavement costs
Approximately equal to 1/8 to 1/4-inch of Concrete

Short Joint Spacing Improves JPCP Performance

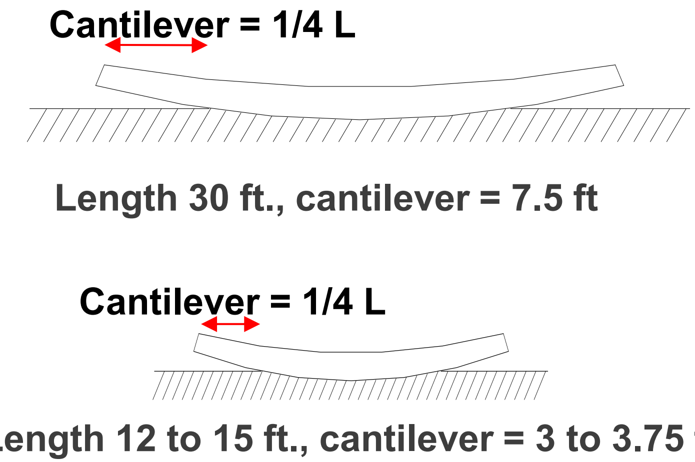
Reduces Shrinkage Force

- Curling & warping is due to the differential drying and thermal shrinkage at the slab surface
- Shorter slabs have less length, which means reduced curling



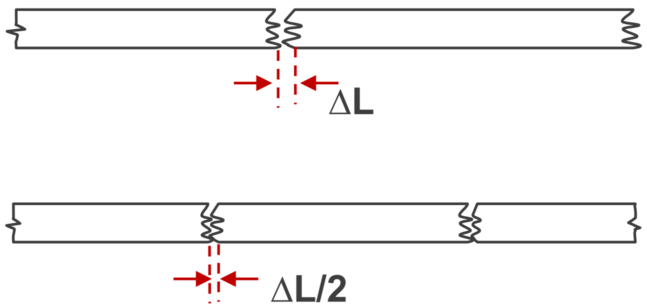
Reduces Environmental Stress

- ~1/4 of slab length is cantilever
- Reducing unsupported length reduces the bending stress
- Reducing length reduces uplift and improves smoothness



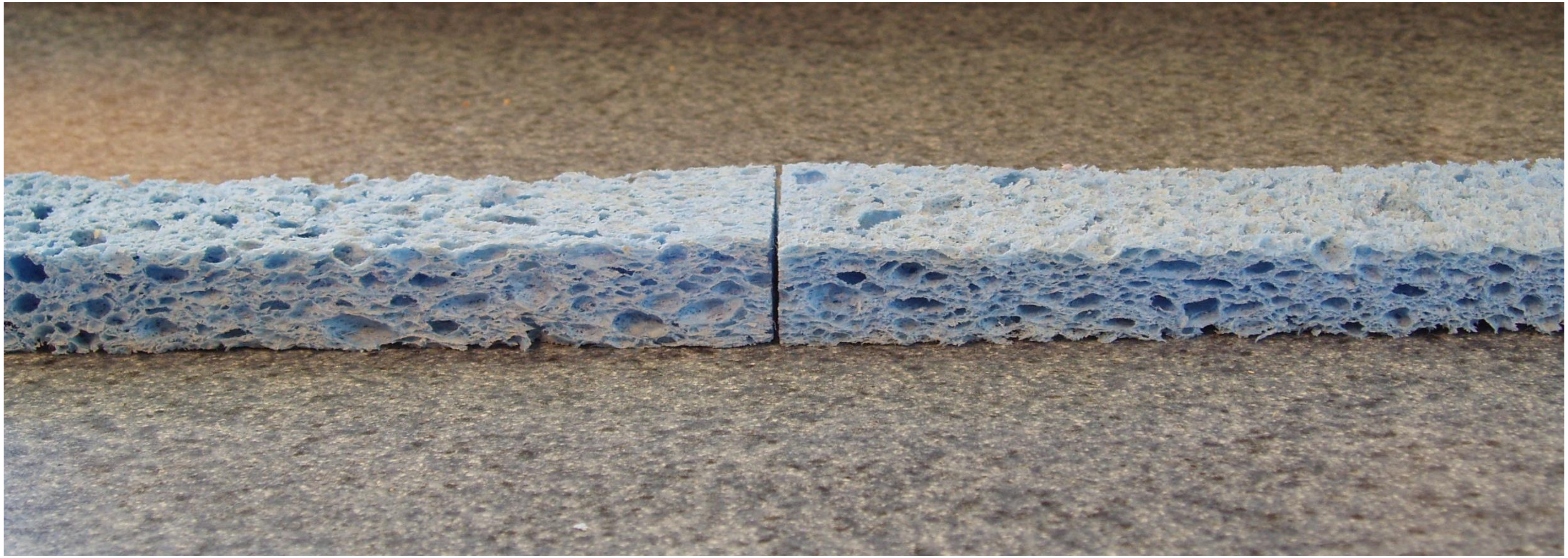
Improves Load Transfer

- Shorter slabs have smaller joint/crack opening
- Agg. Interlock stronger for tighter cracks
- High load transfer results in less stress in concrete



CURLING / WARPING IS PRODUCED BY THE DIFFERENTIAL SHRINKAGE FORCE AT THE SLAB SURFACE

Concrete is a Sponge. The slab starts flat, but warps as the top dries while the bottom remains damp



Sawcut joints start life flat, but drying causes upward warping (shorter joints means smoother ride)

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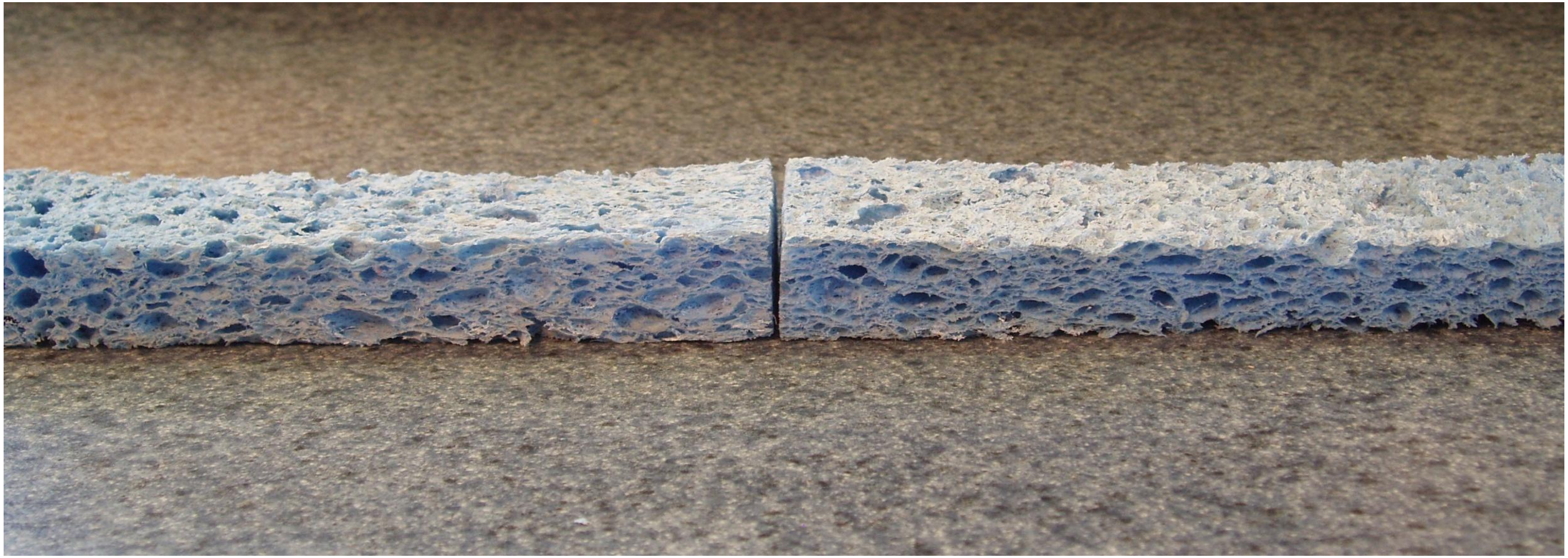

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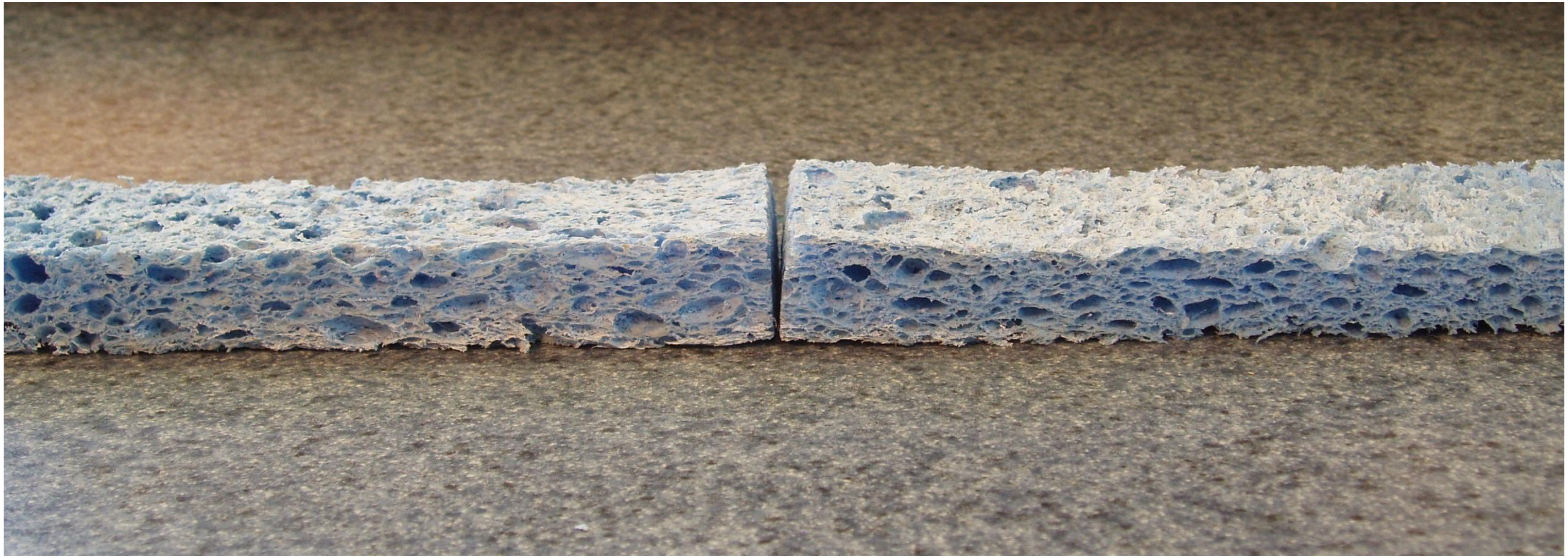

Sawcut joints start life flat, but drying causes upward warping
(shorter joints means smoother ride)

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CURLING / WARPING IS PRODUCED BY THE DIFFERENTIAL SHRINKAGE FORCE AT THE SLAB SURFACE

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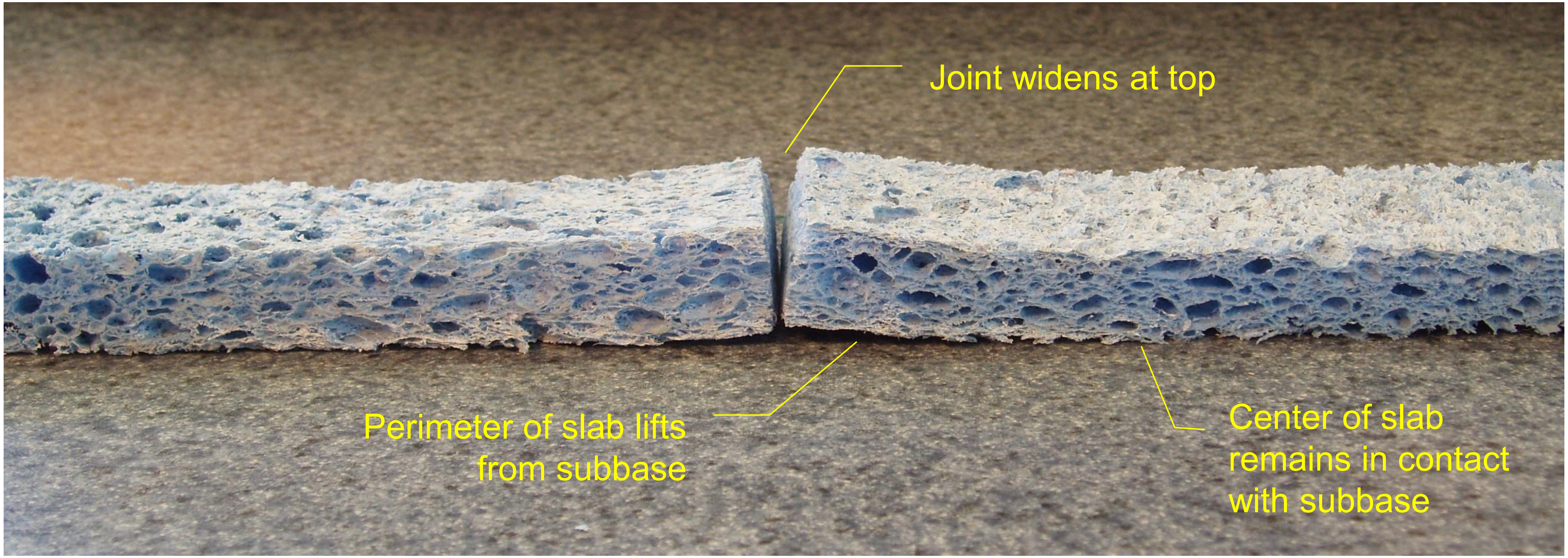
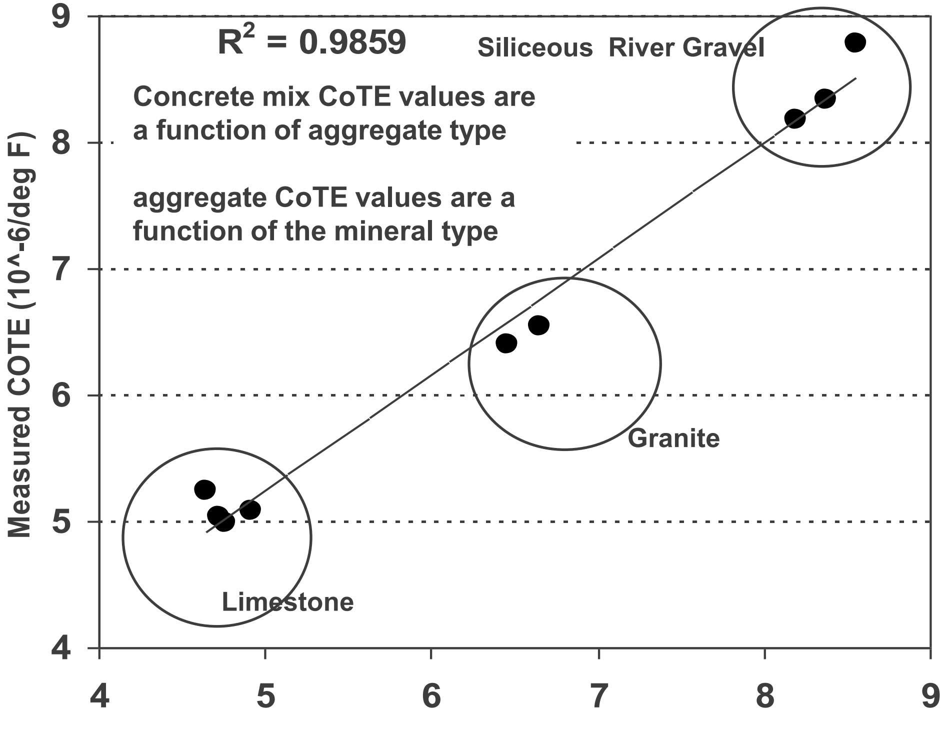


Sawcut joints start life flat, but drying causes upward warping (shorter joints means smoother ride)

COTE IMPACTS JOINTED PAVEMENT CRACKING

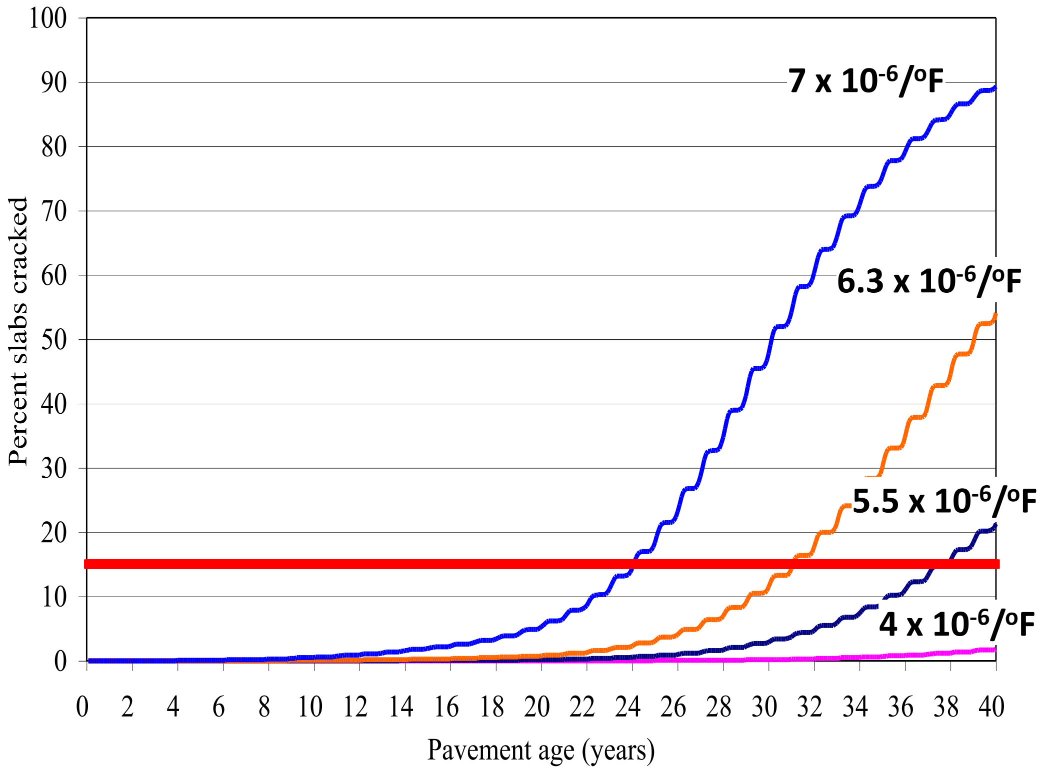
Higher COTE Values increase cracking

CoTE Variations



TP-60 CoTE

CoTE Impacts on JPCP Cracking

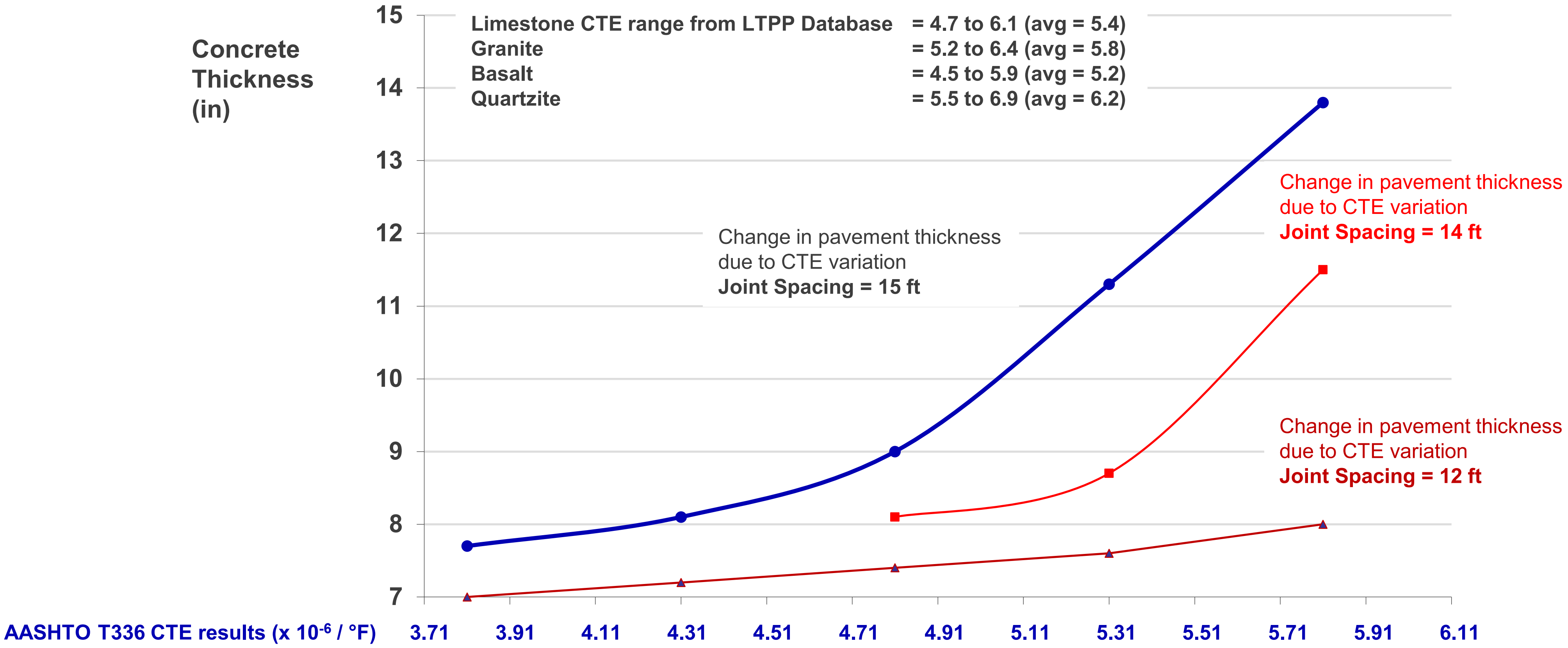


Cracking is due to the curling of the slab so the key design aspect is to be able to deal with the curling

Cote Cracking Graph: Courtesy of ACPA

Mineralogy

Curling Effect Due to CTE can be Mitigated with Thickness or Joint Spacing
Shorter Joints decrease the moment arm for slab uplift



Issue is not how low CTE is, but how to design pavements based on the CTE value for your aggregates

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Pavement = 15 ft jointed concrete pavement on 4” AC base on 12” limerock base. Subgrade =A-3 Soil.
20 Year Design with 2-Way AADTT = 15,000, 2 lanes in each direction (ESAL ~ 127.9 M), Climate = Orlando FL

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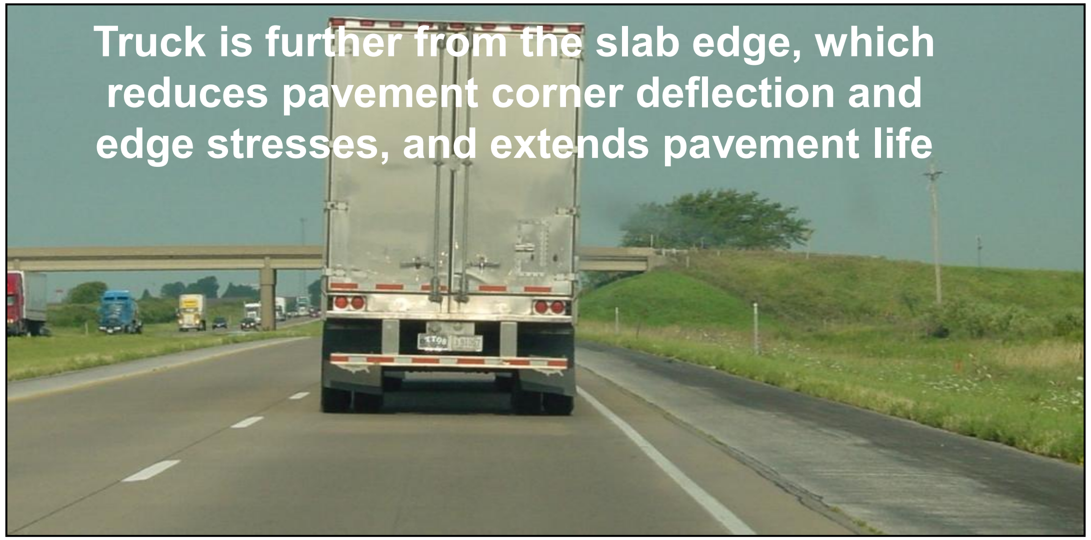
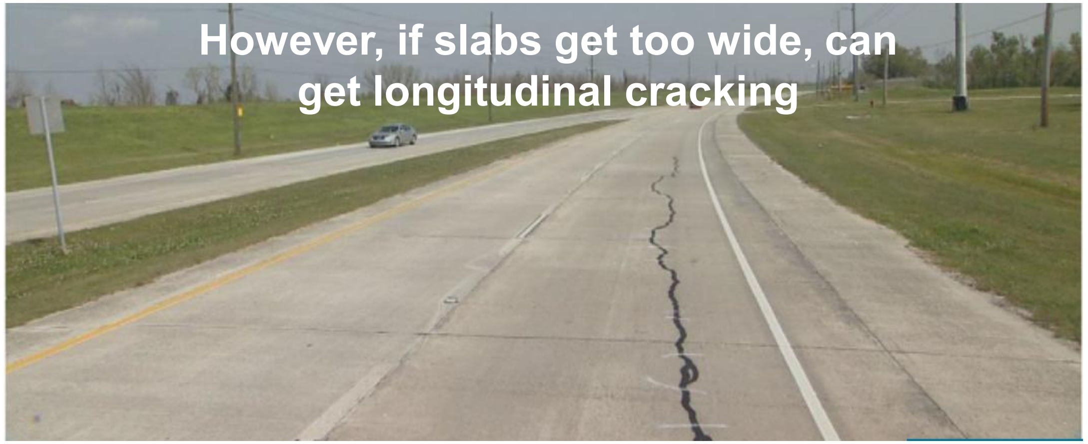
Widened Lanes Shifts Traffic Away From Edge

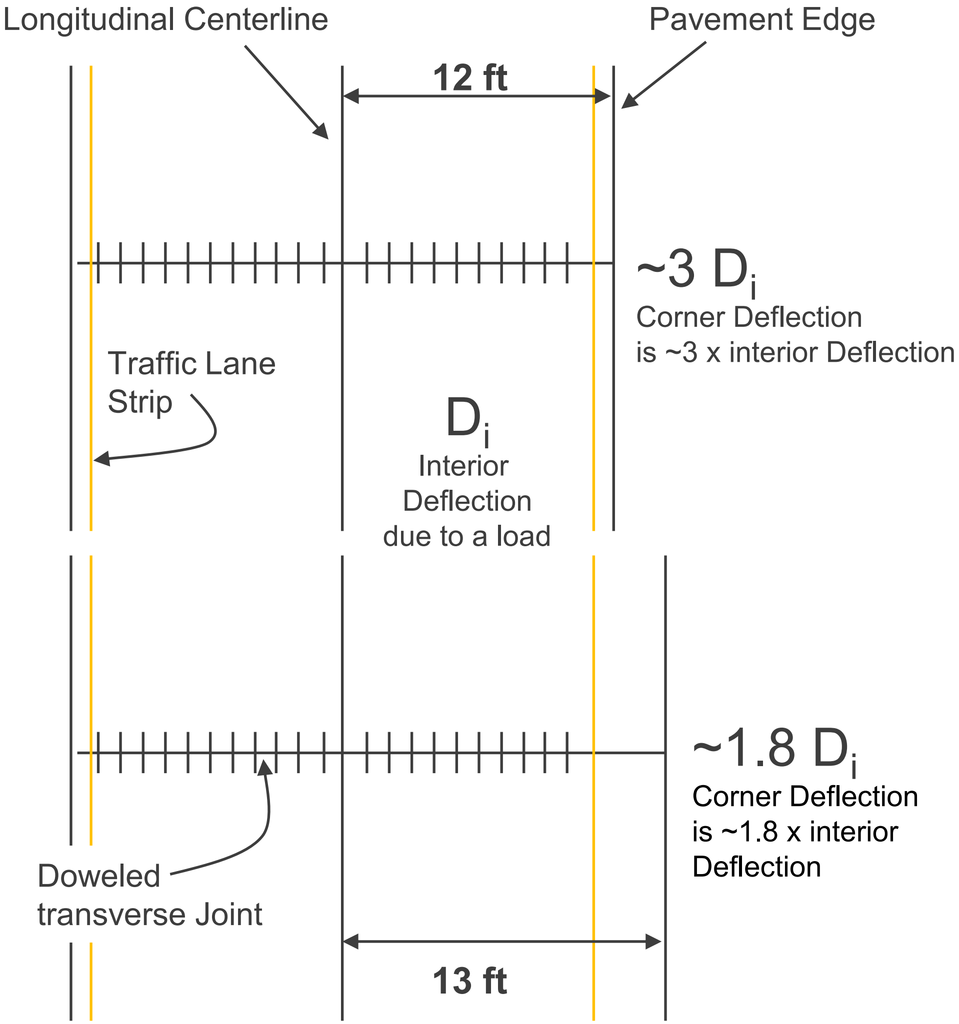
Lowers Deflections & Stresses at the Edge and allows for Thinner Pavements





Standard Width Lanes

Widened Lanes



Each foot of lane widening adds ~6 to 8% to Lane Costs
Approximately equal to 1.25 to 1.50-in of thickness, but cost impact depends on shoulder type

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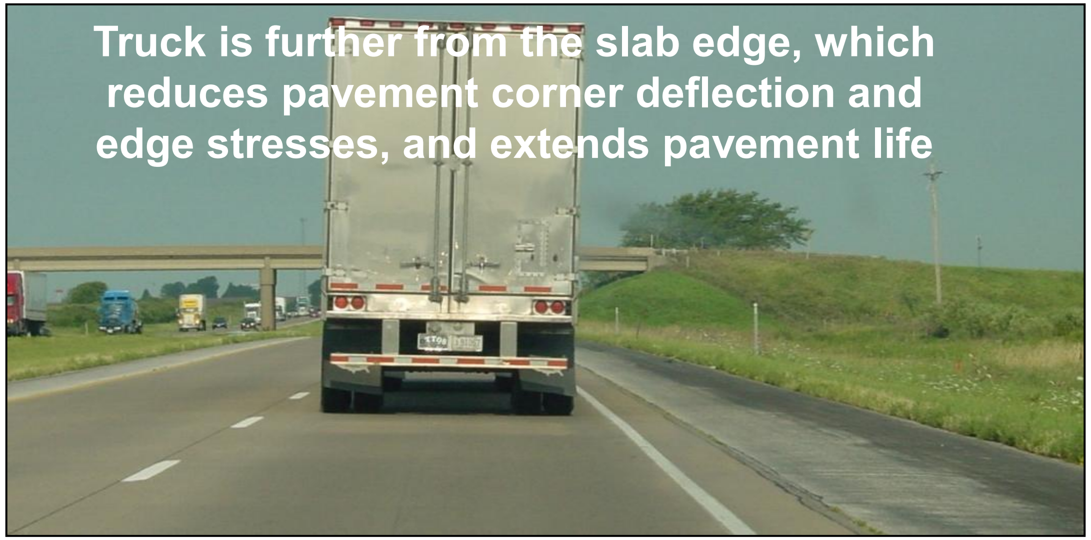

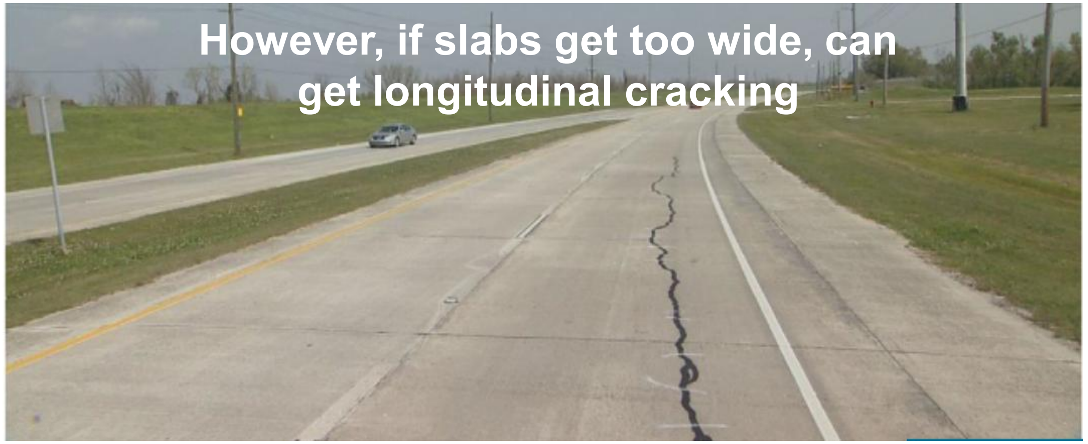

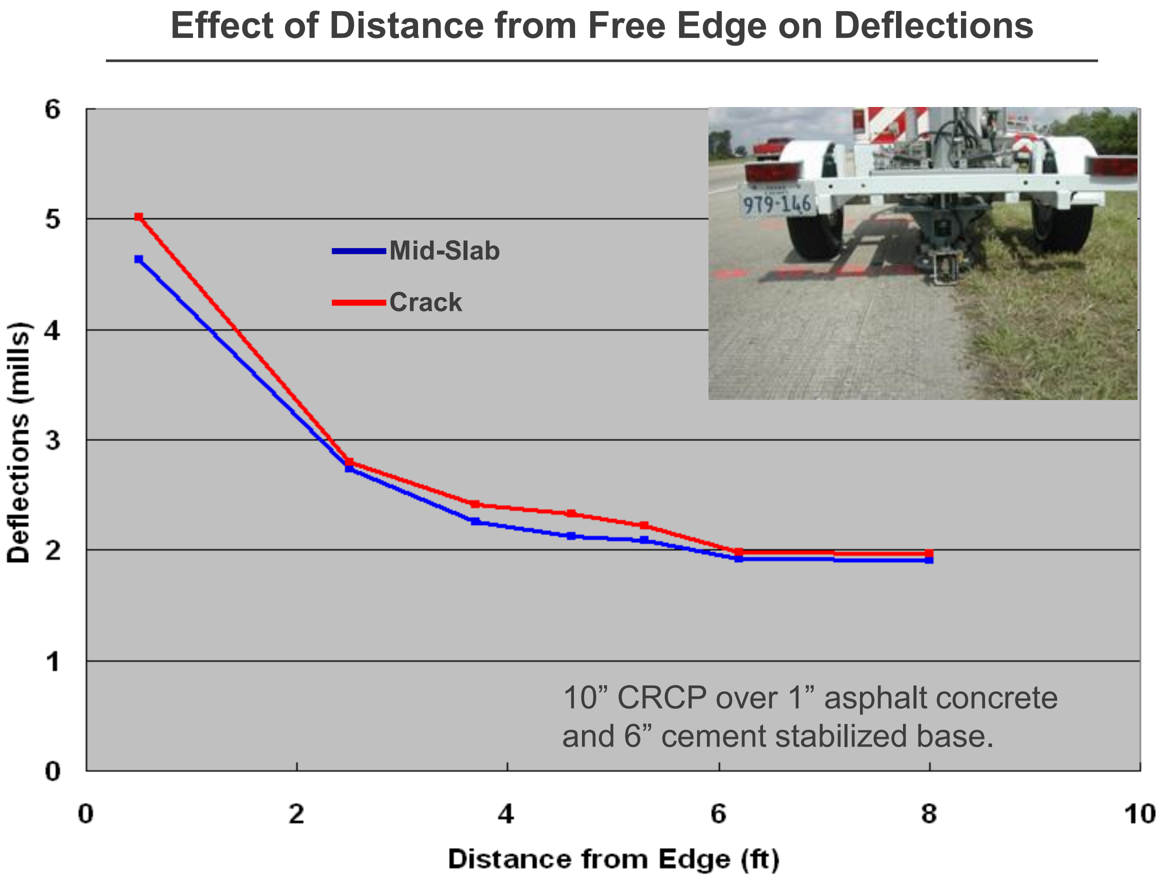

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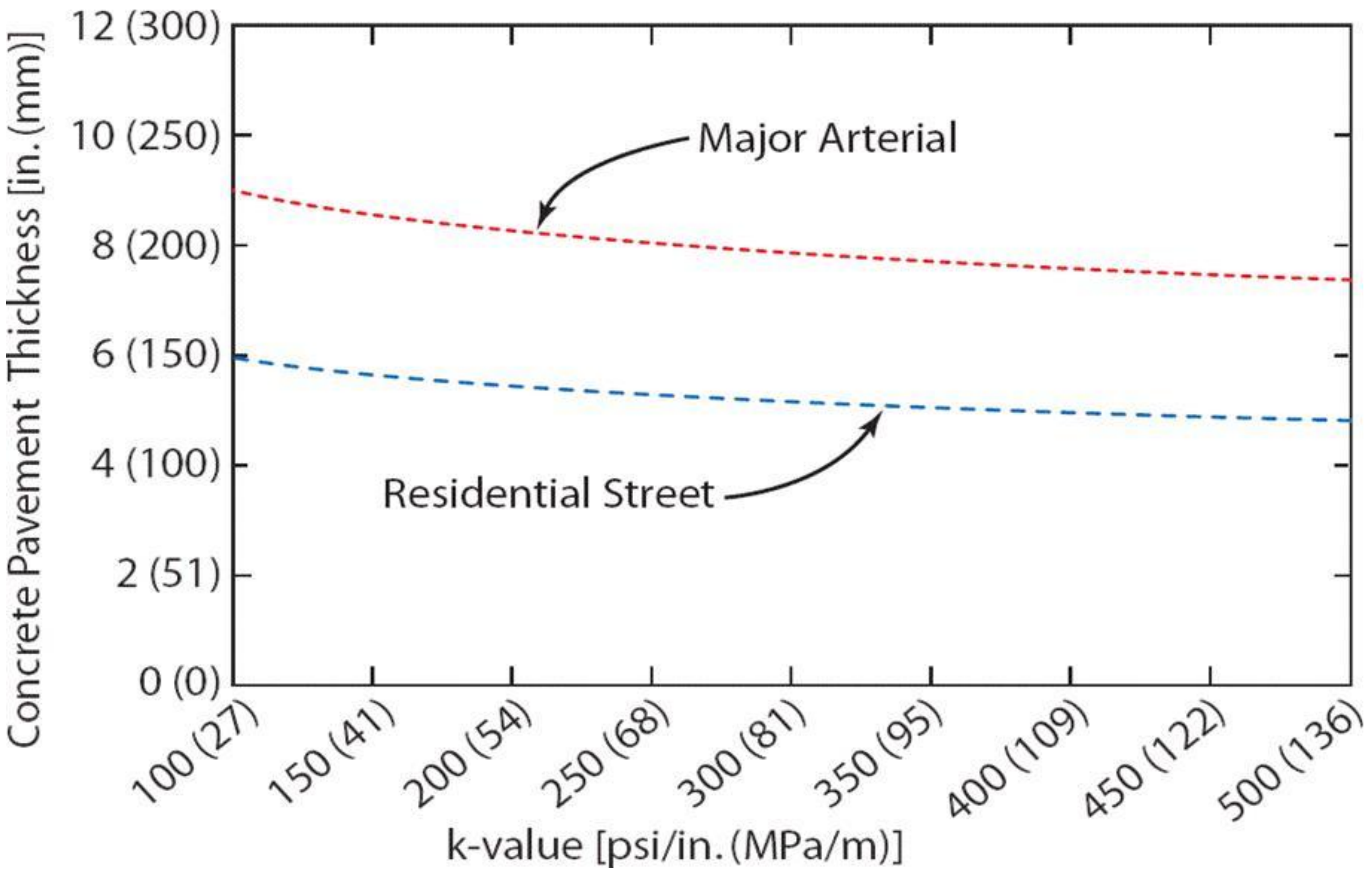
Support Stiffness Is Not A Critical Element In Concrete Thickness Design



Concrete pavement thickness is relatively insensitive to support stiffness (modulus of subgrade reaction (k-value))

- Subgrade
  (k ≈ 50-200 psi/in.)
- Granular
  (k ≈ 100-300 psi/in.)
- Asphalt treated
  (k ≈ 300-400 psi/in.)
- Cement Treated / lean concrete
  (k ≈ 400-500 psi/in.)

Improper engineering to make a subgrade/subbase stronger or thicker to decrease concrete pavement thickness

CALTRANS Pavement Performance with Different Base Types

Basically, all bases can work (and all can have some problems)

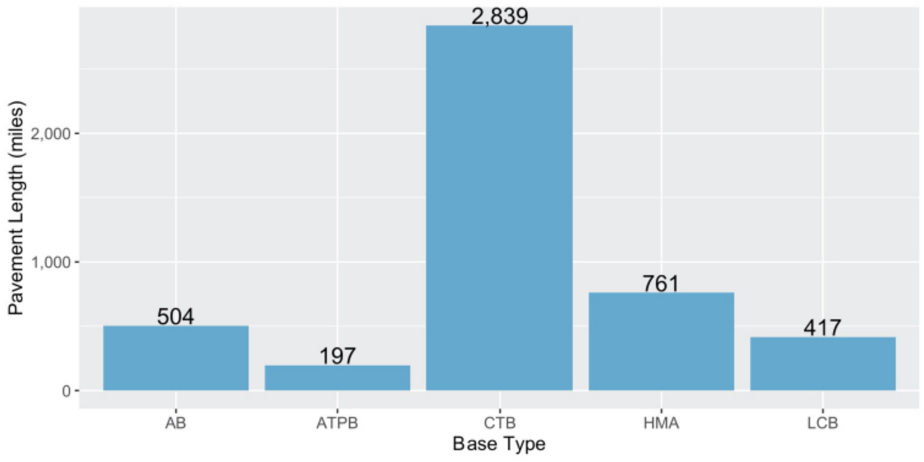


Figure 2.9: Base type distribution.

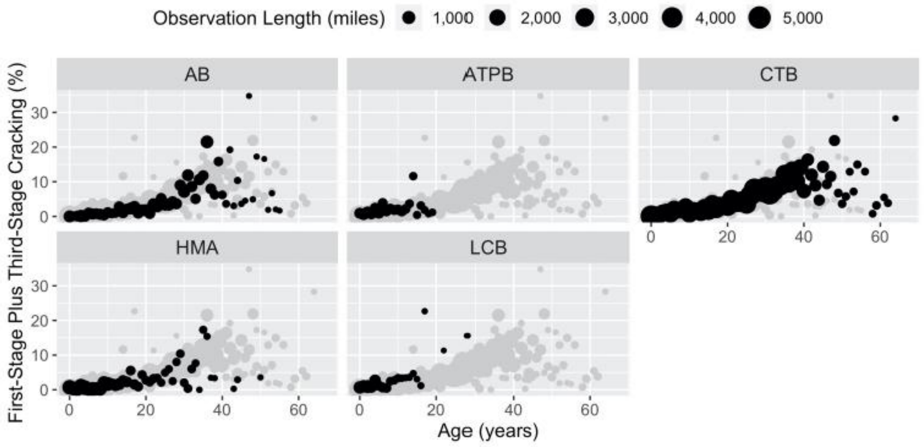


Figure 2.10: JPCP total cracking for different base types.

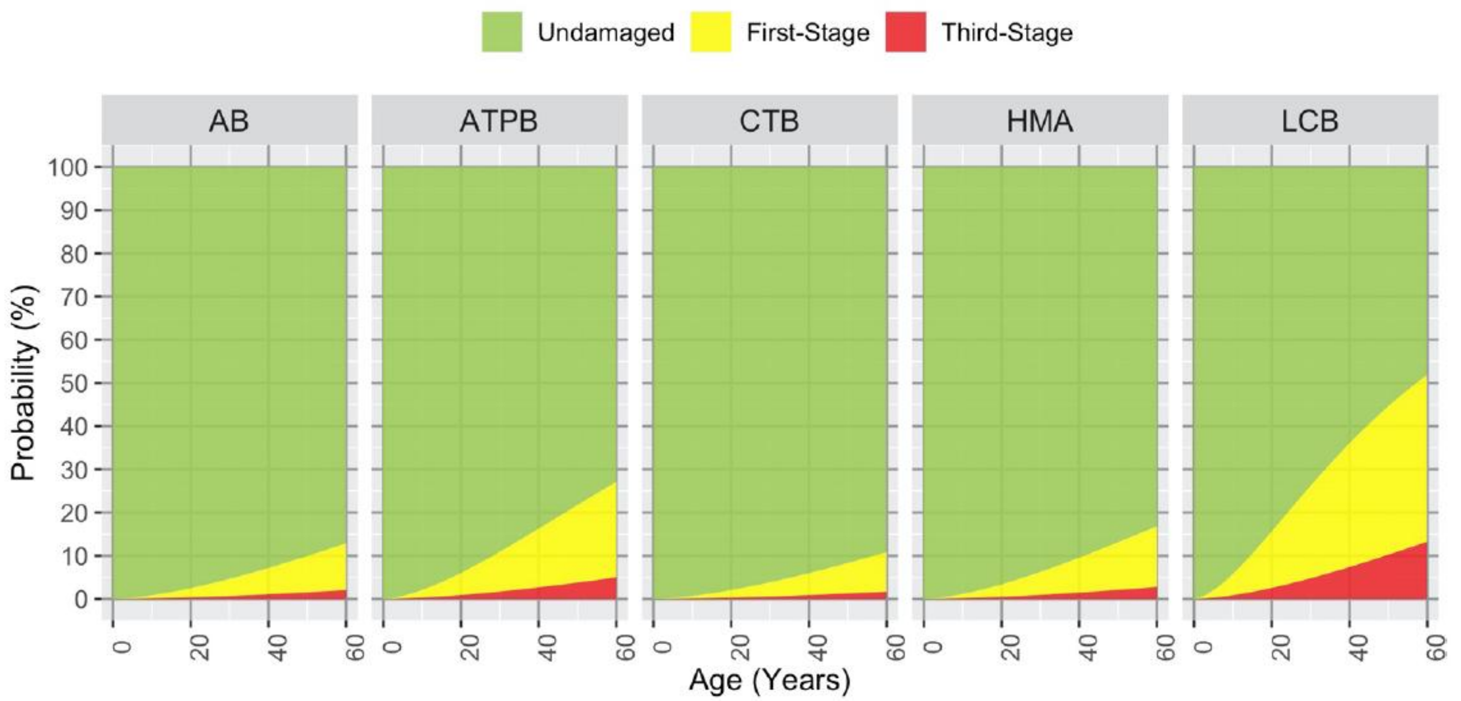


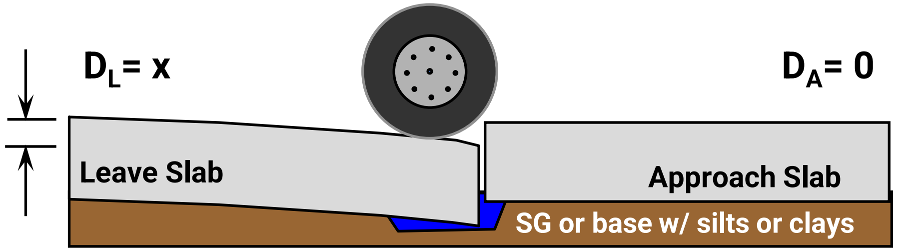
Figure 2.22: Mixed-effects cracking performance model predictions for different base types.

From Draft Report "Pavement ME JPCP Transverse Cracking Model Calibration and Design Catalog Framework (Version 2.5.5)"
UCPRC-RR-2020-02

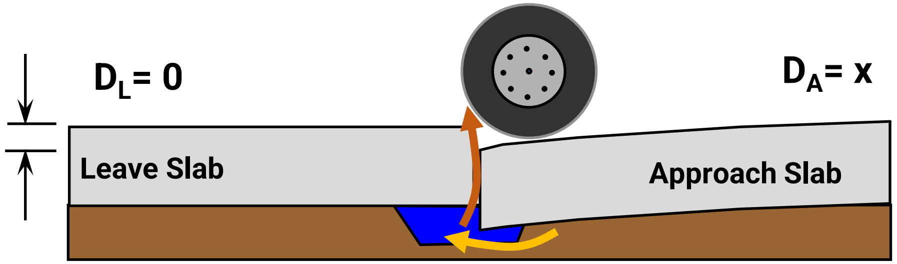
Many Agencies Use Bases & Edge Drains to Minimize Pumping of Subgrade Pumping & Faulting

Three Conditions for Pumping

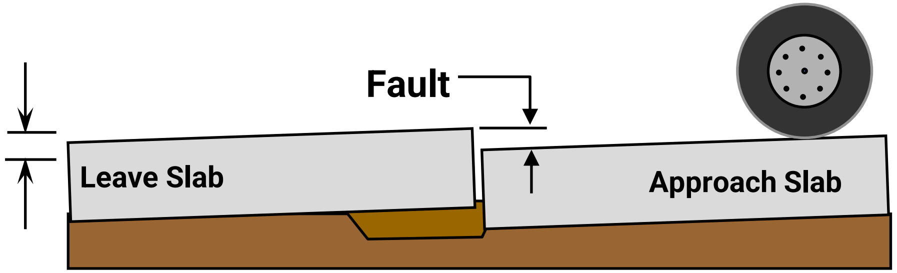
1. A subgrade soil that will go into suspension in water (silts and/or clays)
2. Water to suspend and carry out the silt and/or clay materials
3. Rapid differential deflection at a joint or crack to act as a pump to eject the suspended clays and/or silts



Slabs with no dowels or poor load transfer do not share its load with neighboring slabs



As wheel moves across joint, leave slabs rebound up, and approach slab deflects rapidly down (differential deflection) creating a pumping action that ejects fine subgrade materials



This leads to an accumulation of subgrade under the Leave Slab

The question is are all three necessary?

Many Agencies Use Bases & Edge Drains to Minimize Pumping of Subgrade Pumping & Faulting

Three Conditions for Pumping

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Methods to Control Pumping

Options	How it Works	Cost*
Dowels	Dowels cause the slabs to bend together eliminating the rapid differential deflection	$4.50 / SY
Bases & Subgrades	Stabilized & high quality granular bases eliminate the fine materials that go into suspension in water	$8.77 / SY
Drainage	Edge drains minimize the amount of water flowing under a pavement that can carry out the silt and/or clay materials	$12.09 / SY

*Costs Circa 2011

The question is are all three necessary?

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How to Determine the Cost Effectiveness of a Design Feature

Define the Base Case ("without" scenario)	**Define the baseline design <u>without</u> the feature in question.** • Initial construction cost of the base design • Expected performance, service life, maintenance needs, and risks
Define the Alternative Case ("with" scenario)	**Define the alternative design <u>with</u> the feature included.** • Added construction cost (materials, labor, design, etc.) • Any changes in performance (e.g., durability, reliability, safety, capacity) • Changes in maintenance or rehabilitation needs • Changes in risk of failure or poor performance
Identify and Quantify Benefits (and Risks)	**Define the direct financial and performance benefits and risks** • Longer service life, reduced maintenance / repair costs, fewer replacements or rehabilitations, lower user costs (e.g., Fewer lane closures, delays, or disruptions • Improved durability, lower probability of failure, better resilience (e.g., to climate, loading, or environmental exposure), improved safety, better environmental performance • Opposite of all the above
Compare Costs and Benefits	**Use Life-Cycle Cost Analysis (LCCA) to see if benefits exceed added costs** • Life Cycle Cost base design vs. Live Cycle Cost Alternate Design over its life • Does the Initial costs increase lead to lower Life Cycle costs?

If benefits exceed added costs, the feature is likely cost effective

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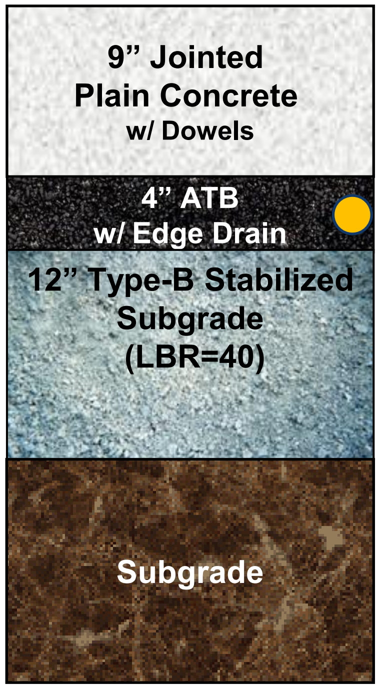
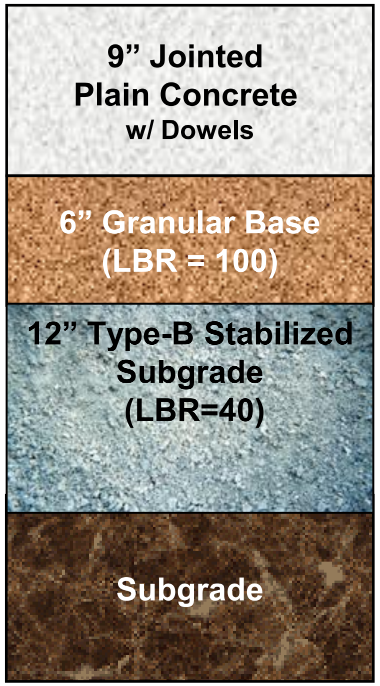
Whether to Add Features should be Based on its Cost / Benefit

If they extend life long enough to cover its NPV, it should be used

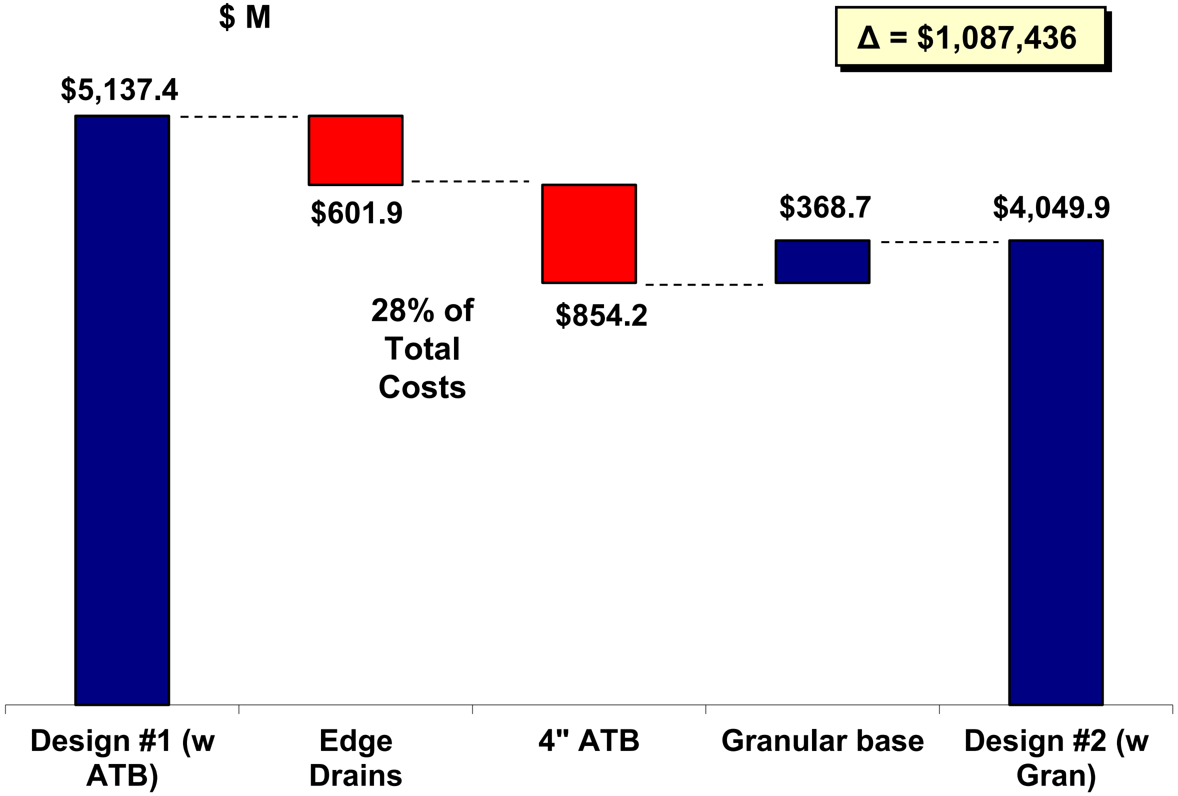
Design #1
(with ATB & Drainage)



Design #2
(6” Granular Base)



Component Cost for 1 mile of pavement

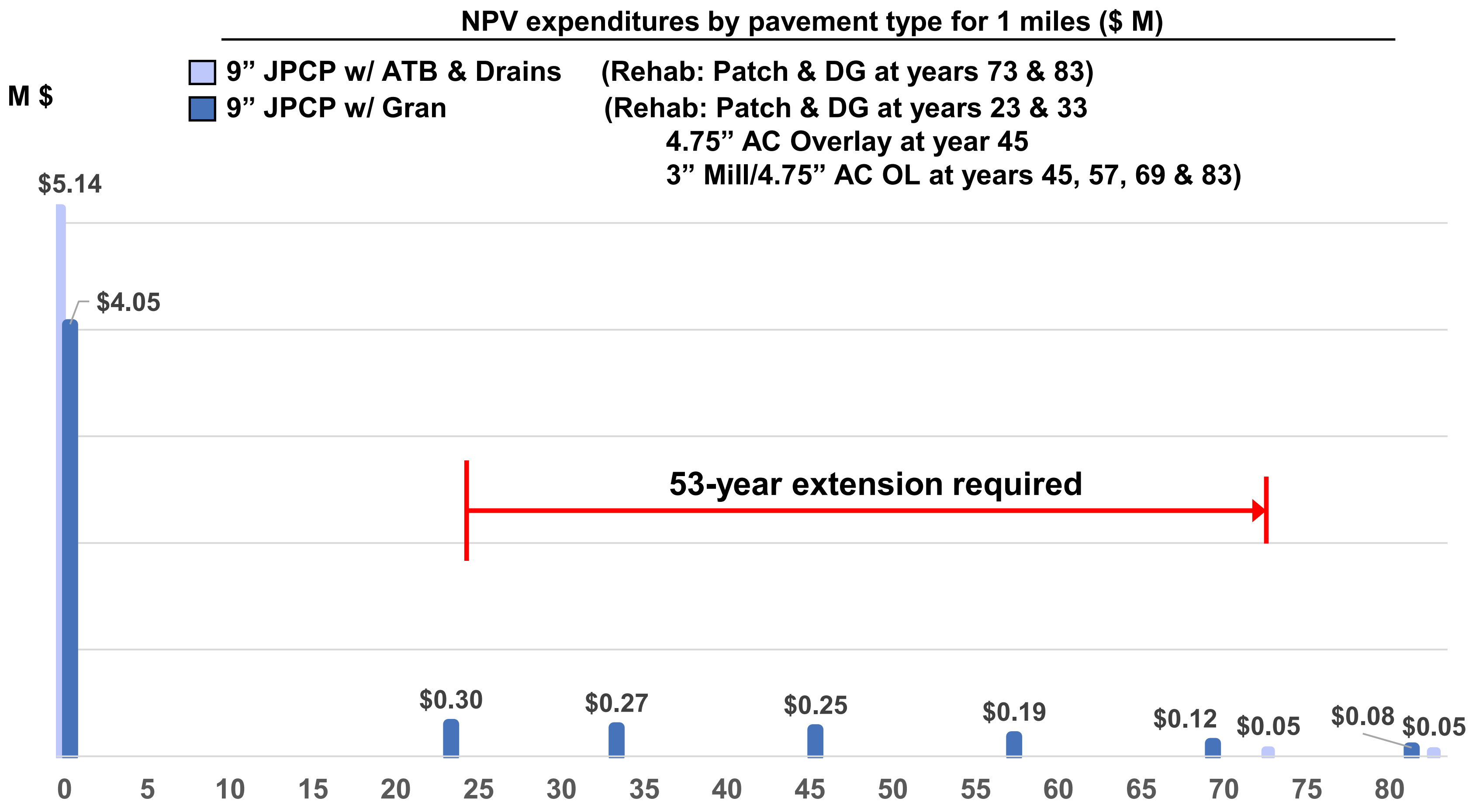


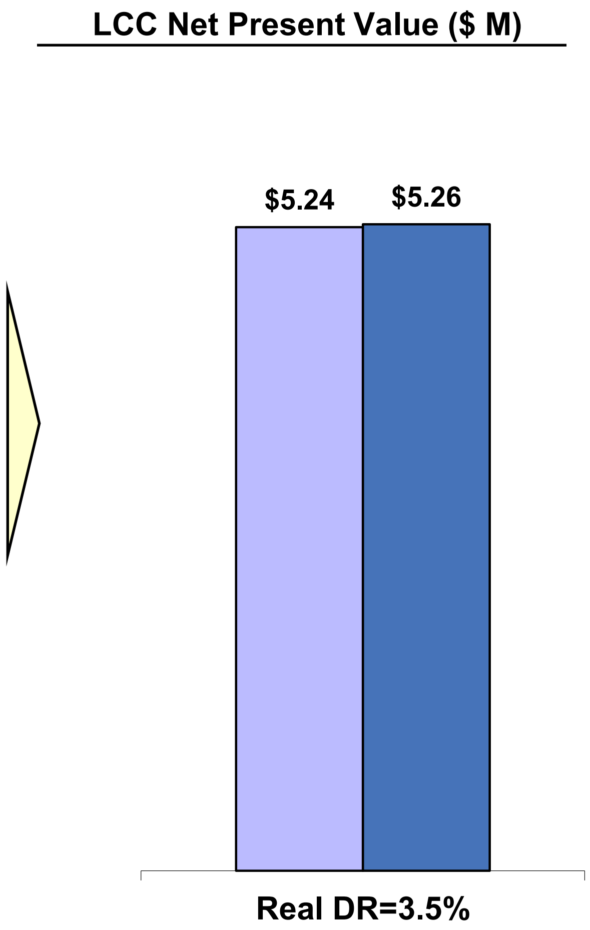
For the drainage and ATB to be effective it must extend the pavements life to overcome <u>$1,087,436</u> initial cost differential

Cost for 1 miles of 4 lane pavement + Shoulders

The Pavement with ATB Must Last 73 Years Before First Rehabilitation

Based on an equivalent Life Cycle Costs comparison

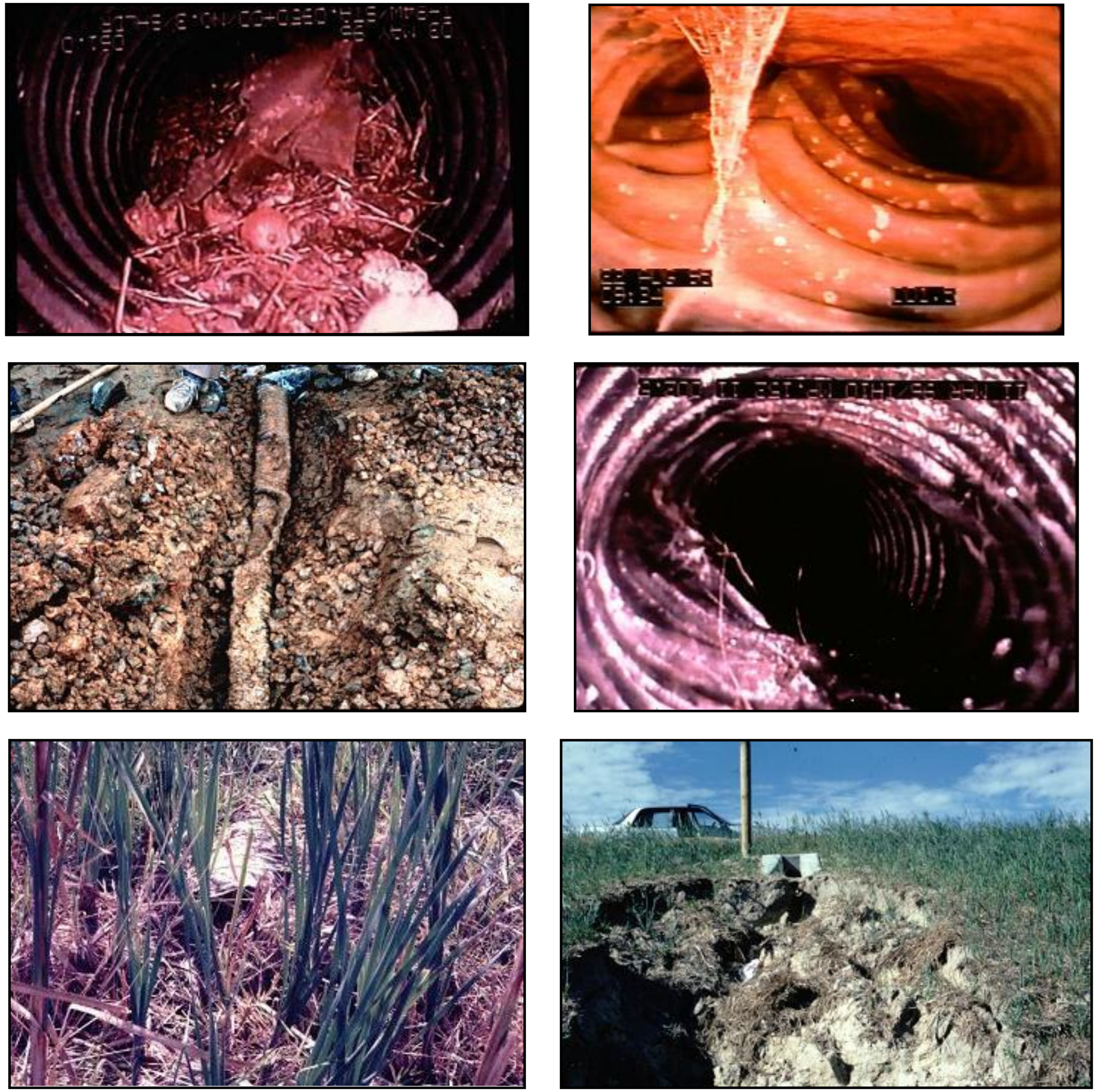




Initial and rehabilitation costs are based on **Suncoast Parkway 2 (SR 589) Segment 3B PTS report**

Issues with Permeable Subbases

- Despite widespread use, problematic history due to:
  - Instability as a construction platform.
  - Loss of support due to breakdown and compaction of the aggregate.
  - Early age cracking due to mortar penetration.
  - Potential for increased curling.
  - Loss of support and decreased permeability due to infiltration of fines from below.
  - Problems associated with an edge drainage system.
  - Poor field performance.
  - Increased cost without a comparable increase in pavement life/performance.



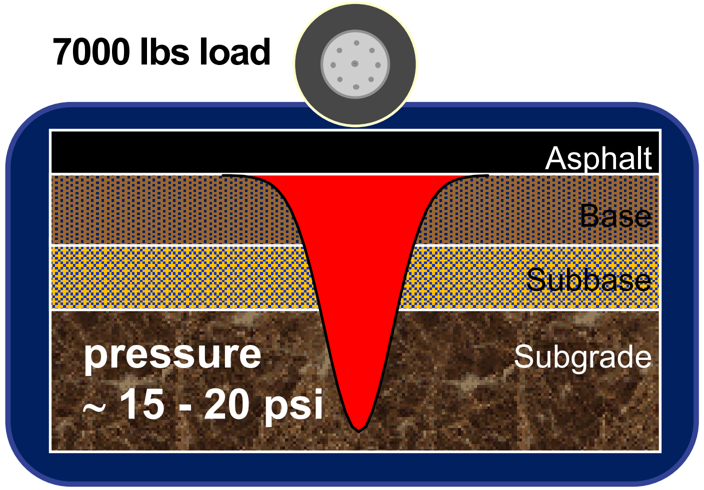
Source: FHWA 2002, “Maintenance of Highway Edge Drains”


2

Eric

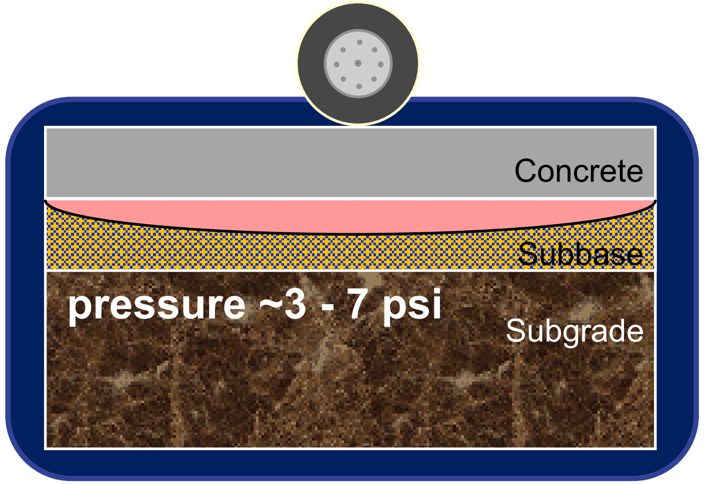
FLOODING CAUSES THE SUBGRADE TO BECOME SUPERSATURATED

Moisture infiltrates base, pushes the subgrade particles apart and weakens the system



Asphalt Pavements are Flexible

- Lowered subgrade strength & reduced modulus
  - Reduced load carrying capacity
  - Takes ~1 year to regain strength
- Loading during this times accelerates pavement damage / deterioration and reduced pavement life



Concrete Pavements are Rigid

- Maintains high level of strength / stiffness
- Subgrade is weak, but still uniform
- Spreading of the load means subgrade is not overstressed
- Little impact on the serviceability / life

A Stiff Pavement System Performs Better in Flooded Conditions

Initial and rehabilitation costs are based on **Suncoast Parkway 2 (SR 589) Segment 3B PTS report**

Pavements in Houston are Concrete and are Very “Stiff”

Also have cement treated bases & stabilized subgrades

Both sections have been flooded at least three times since original construction and were immediately opened to traffic as soon as water receded

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Resilient Pavement Structures in Texas, Andrew Wimsatt, Ph.D., P.E., Texas A&M Transportation Institute and Lisa Lukefahr, P.E., Texas Concrete Pavement Association
ESAL = Equivalent Single Axle Loads. It is how pavement engineering defines traffic

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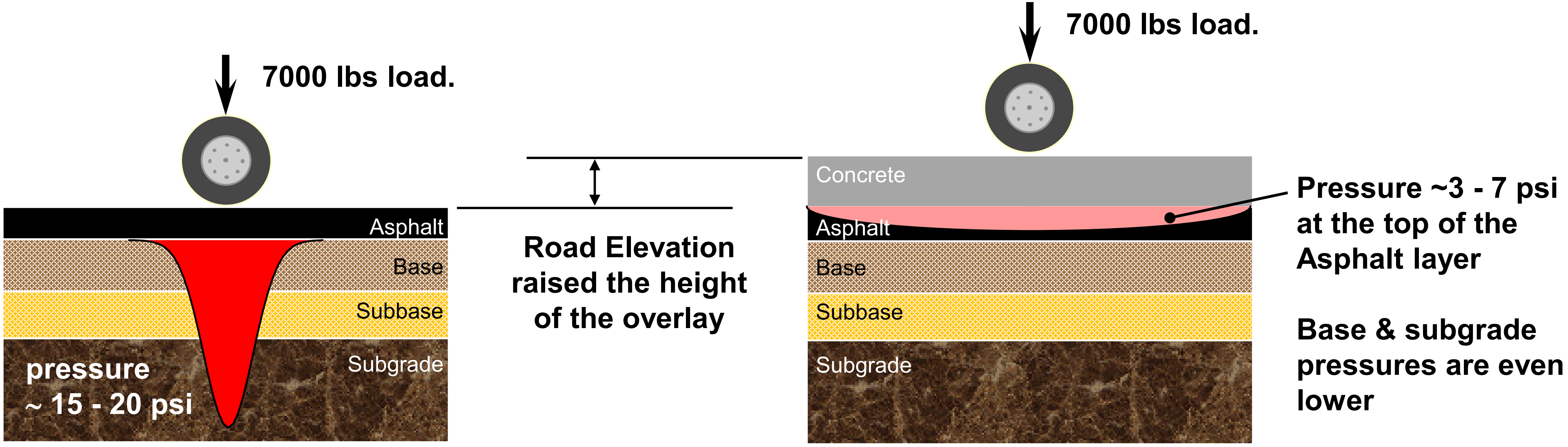
Concrete Overlays Raise Elevation & Change How Loads Are Delivered to the Underlying Layers

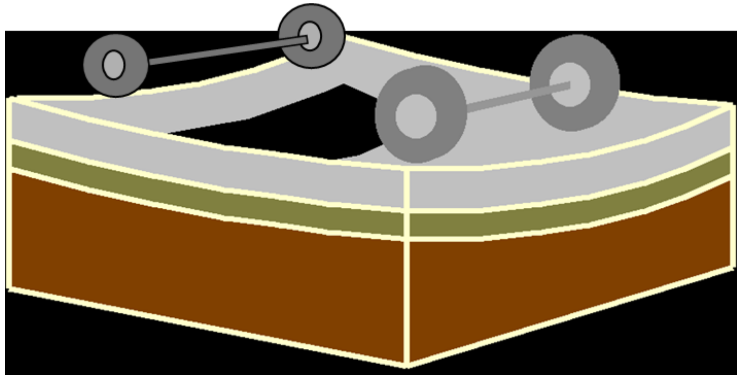


Concrete overlay increases both the height and the structural strength of the roadway

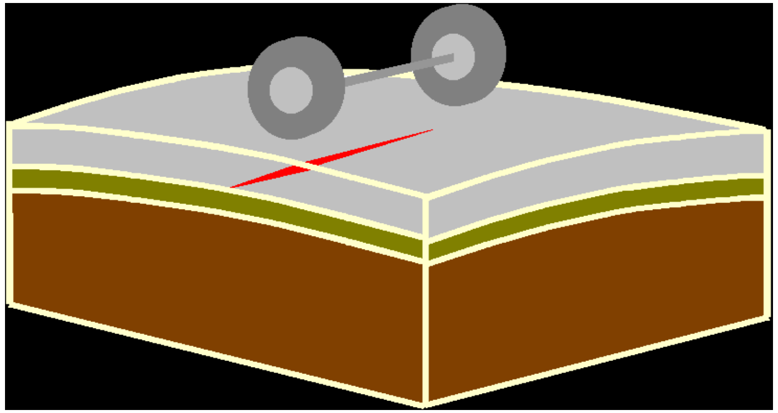
Design Issue Materials Engineers can help with

Be The Concrete Pavement Expert
Know and Share What Impacts the Models

- Top – Down Cracking
  - Increase PCC Thickness
  - Increase PCC Strength
  - Increase Width of Lanes
  - Increase LT w/ Shoulders
  - Increase Support Stiffness
  - Decrease Joint Spacing



- Bottom – Up Cracking
  - Increase PCC Thickness
  - Increase PCC Strength
  - Decrease Joint Spacing
  - Reduce Support Stiffness
  - Change PCC / Base Contact Full-Friction Time



- Improve Mechanical LT
  - Increase Dowel Size
  - Decrease Dowel Spacing
- Decrease Joint Spacing
- Increase Width of Lanes
- Reduce Underlying Layer Erosion
  - Increase Erodibility Index
  - Decrease Joint Spacing
- Reduce Thickness
  - Only if Cracking is Passing

All Current Pavement design Programs Assume Good Concrete Mix

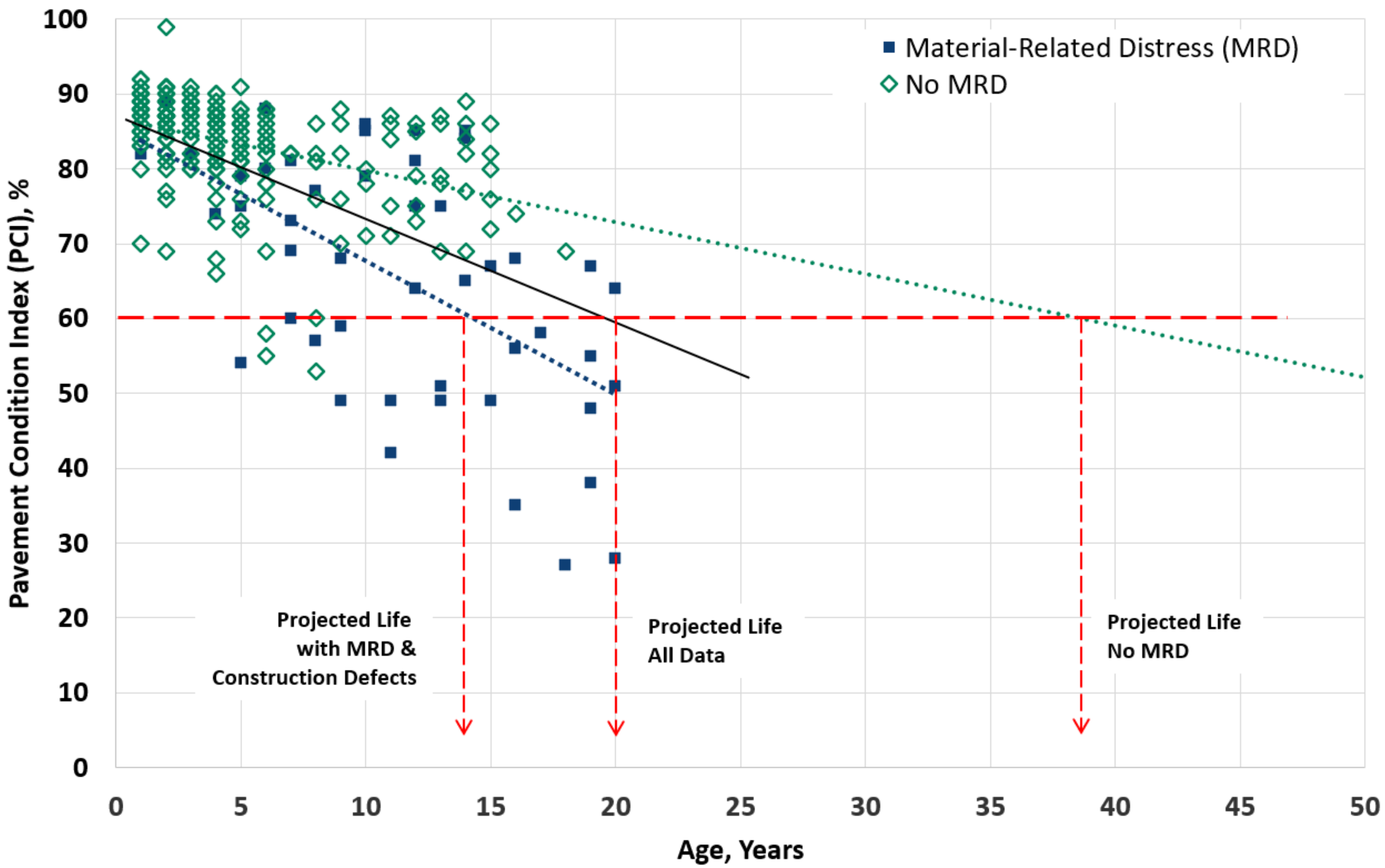
But calibration data" & historical data includes pavements with material durability issues

Causes for poor performance & early failure in Iowa concrete overlays:

- Materials-related distresses (most common)
- Load-related/under-design
- Rough ride

These are many of the same issues found with conventional concrete pavements

Iowa's Thin Bonded & Unbonded Concrete Overlay Performance



With proper materials & construction, it is reasonable to expect much improved performance

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Source: Concrete Overlay Performance on Iowa's Roadways Field, Data Report July 2017, https://www.cptechcenter.org/wp-content/uploads/2017/09/Iowa_concrete_overlay_performance_w_cvr.pdf

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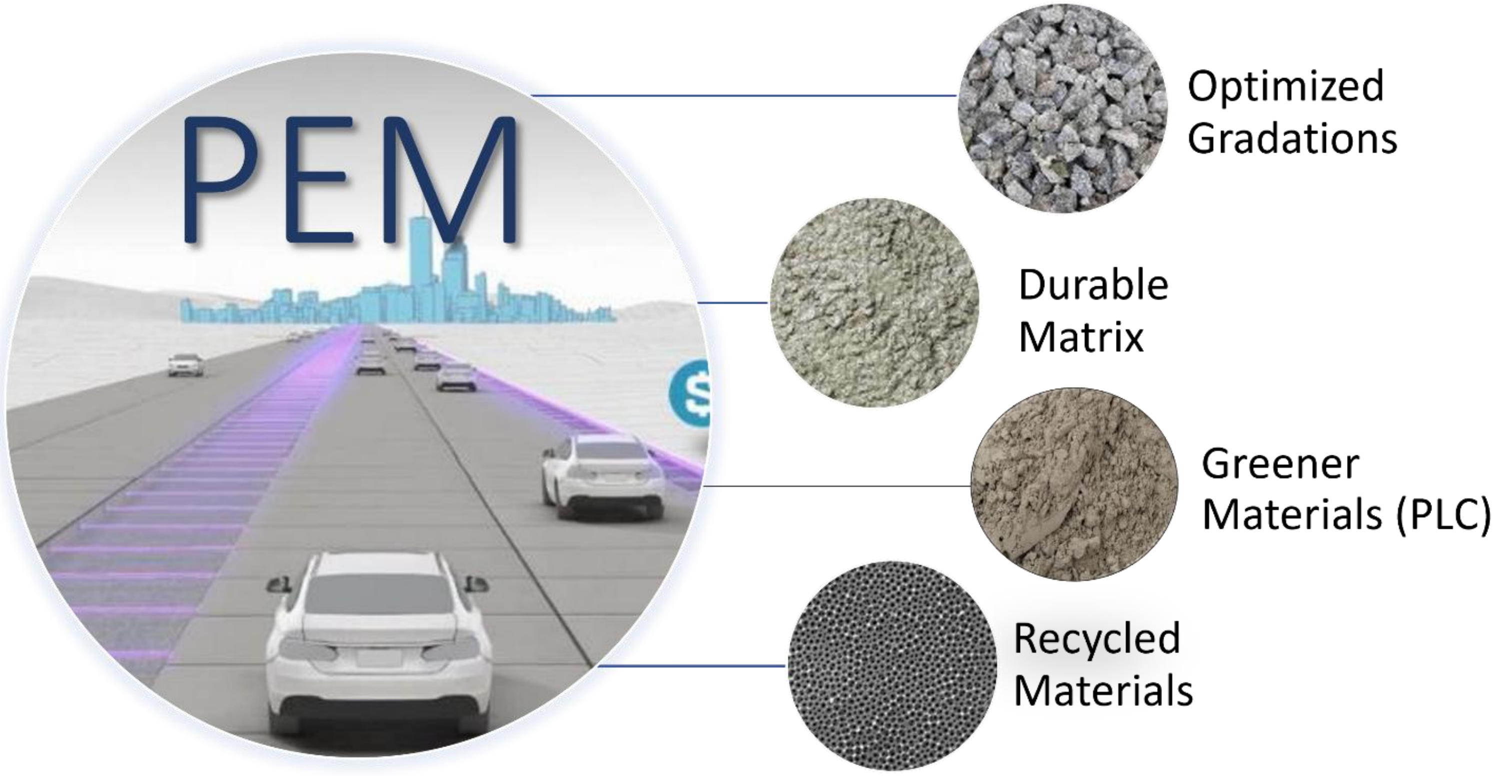
PEM – Performance-Based Approach for Concrete
Shifts from specifying proportions to performance properties

- Strength development
- Shrinkage
- Freeze–thaw (FT) durability
- Aggregate stability
- Transport properties (permeability)
- Workability



Standardized in AASHTO R101, Standard Practice for Developing Performance-Engineered Concrete Pavement Mixtures

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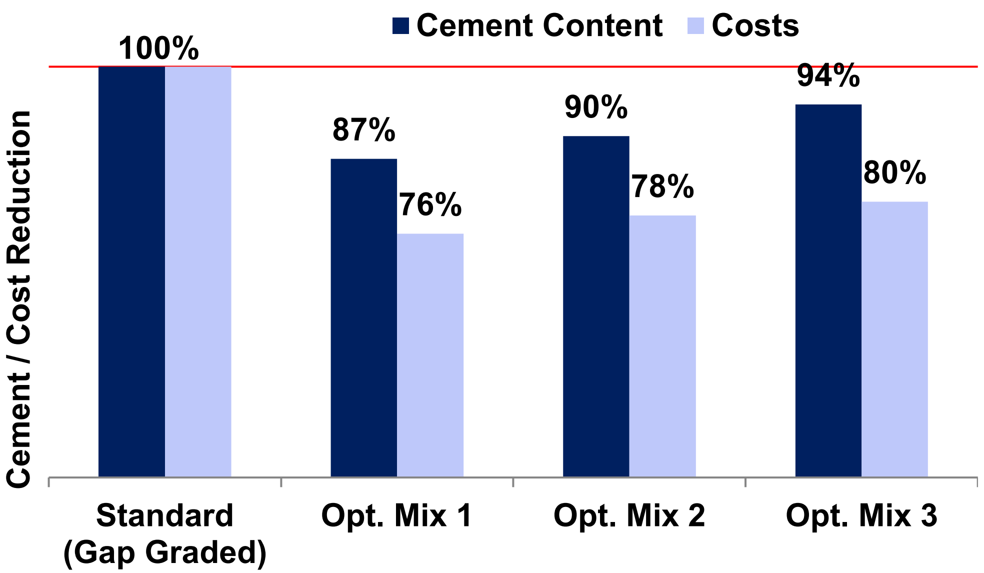
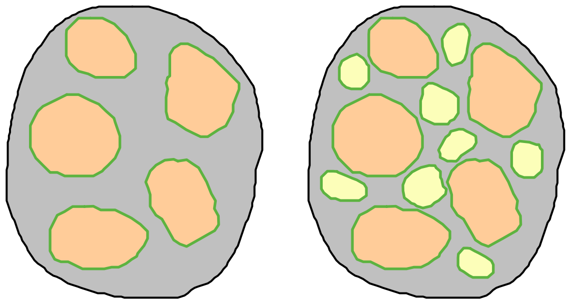
Eric WJE

Well-graded Concrete Aggregate Gradation Improves Performance And Lower Costs

Benefits of Well-graded mixes

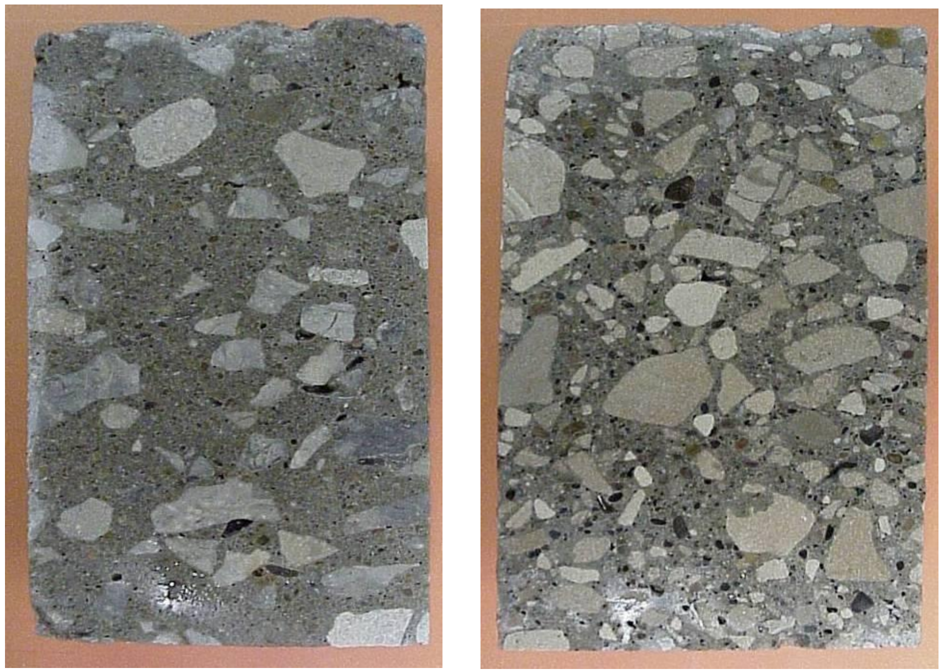
- Increases concrete density (improves durability)
- Reduces water demand (decreases shrinkage)
- Improves workability (easier to construct, reduces edge slump)
- Lower cement contents for the same or higher strength (reduces mix costs)





Gap-graded

Well-graded



Structural / Synthetic Fibers can Improve Performance
Most useful on Pavements less than 6 inches

- **Fibers do not increase the concrete's strength**
  - Increases toughness
  - Increases post-crack integrity / fatigue
  - Improve ductility

- **Helps control plastic/drying cracking**
  - Does not reduce shrinkage
  - Does not change rules for joint spacing
  - Does not control of movement across random cracks

- **Typical Dosage Rates**
  - Synthetic microfiber ~ 1.5 lbs/CY
  - Synthetic macro ~ 3 to 7 lbs/CY
  - Steel ~ 40 to 60 lbs./CY

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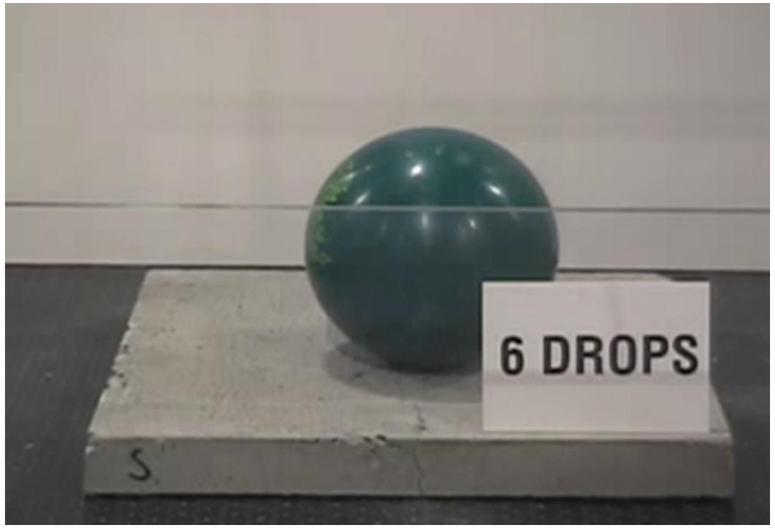
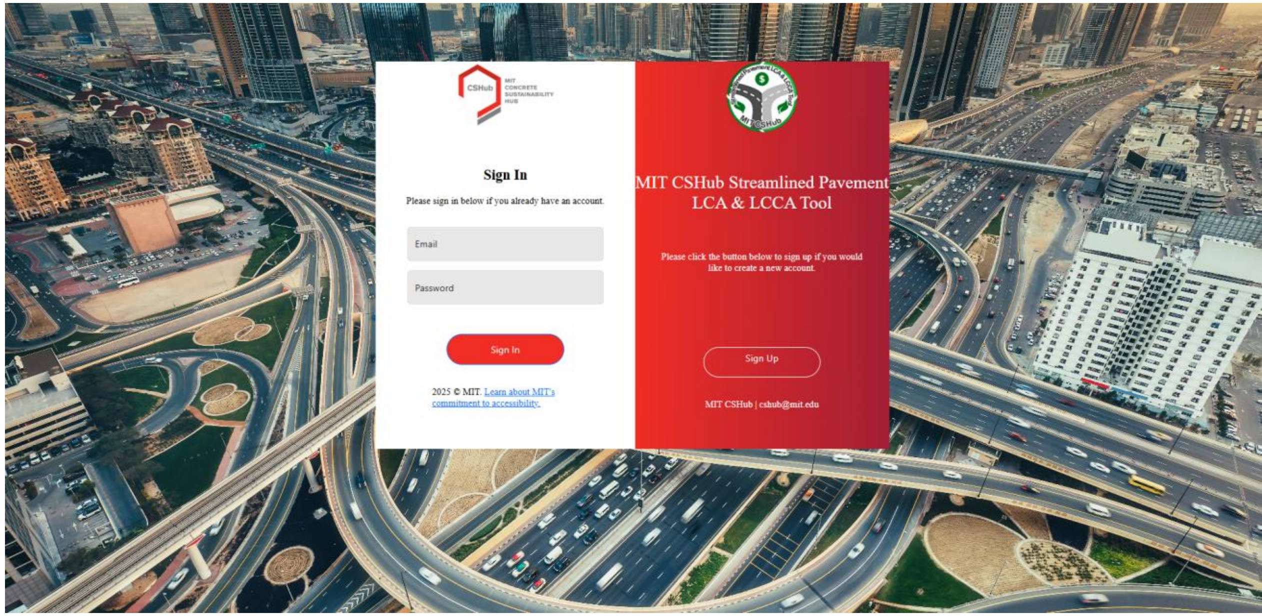


Photos Courtesy of Ron Youngman, ACPA-CO/WY Chapter
Used with Permission

MIT STREAMLINED LCA & LCCA PLATFORM

Recently released

- Generalized tool to enable rapid analysis of the whole-life implications of pavement alternatives
- Estimates the whole-life LCA using whatever level of detail is available to the user (limited or detailed)
- Includes both Embodied Emissions and Use Phase Impacts
  - Initital construction, rehabilitation & maintenance, and End of Life activities
  - PVI, Albedo, carbonation



- Uses Neural Network of based on Pavement-ME to predict pavement performance
- Uses a process called “structured data underspecification” to provide a range of results

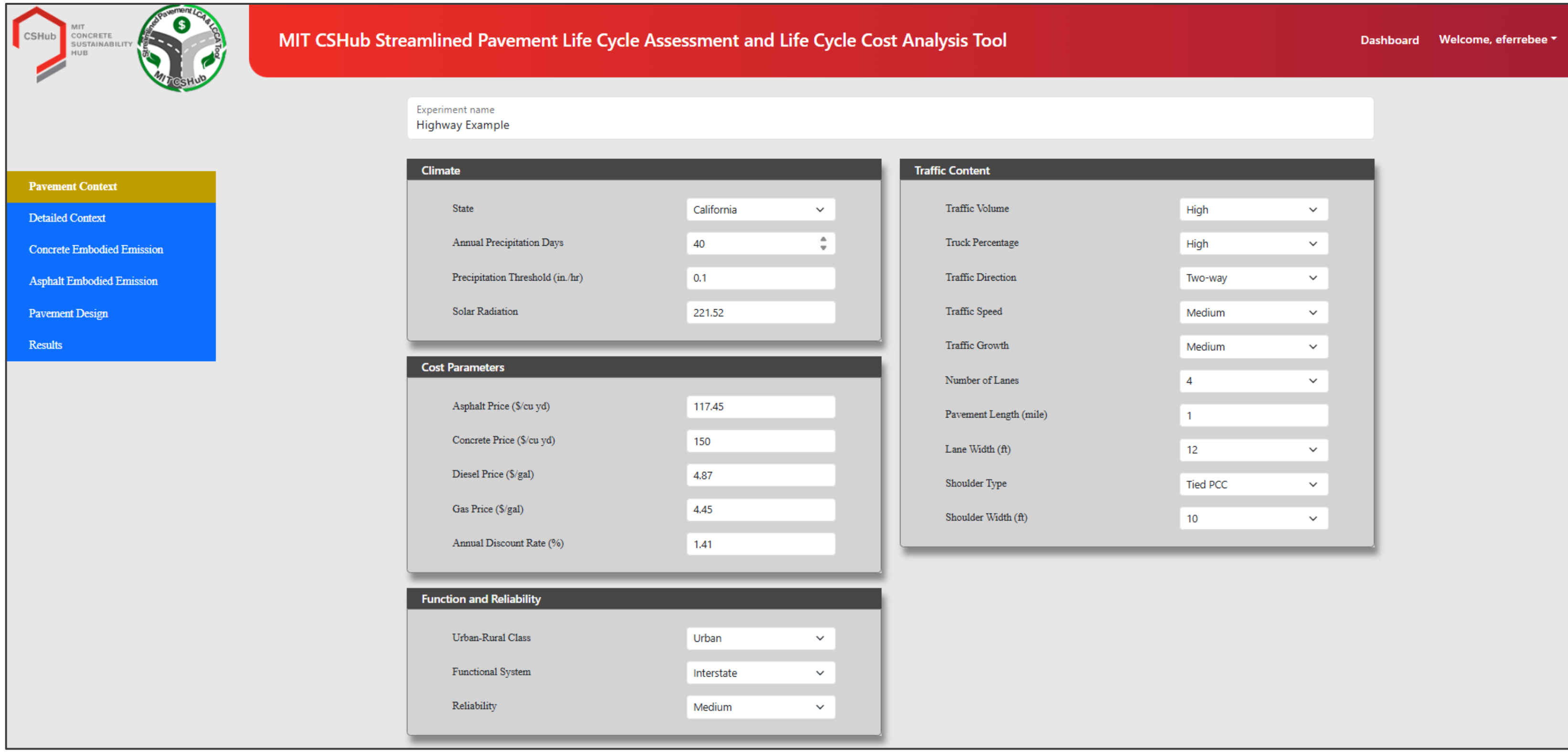
MIT CSHub Streamlined Pavement LCA & LCCA Tool (Online)

http://pavementlca.mit.edu

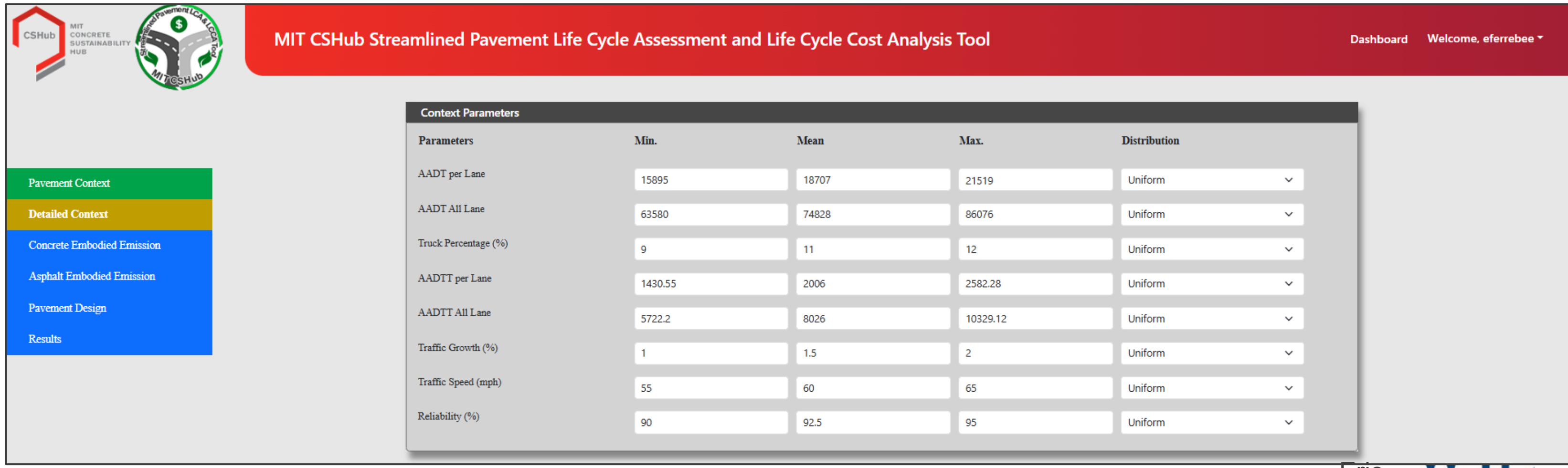
MIT STREAMLINED LCA & LCCA PLATFORM

First 2 sheets define the Pavement Context for the project

- Location
- Climate
- Functionality
- Traffic
- Basic Design Info
  - Length,
  - No. of lanes
  - Shoulders



2nd sheet allows for more detailed Traffic information (optional)



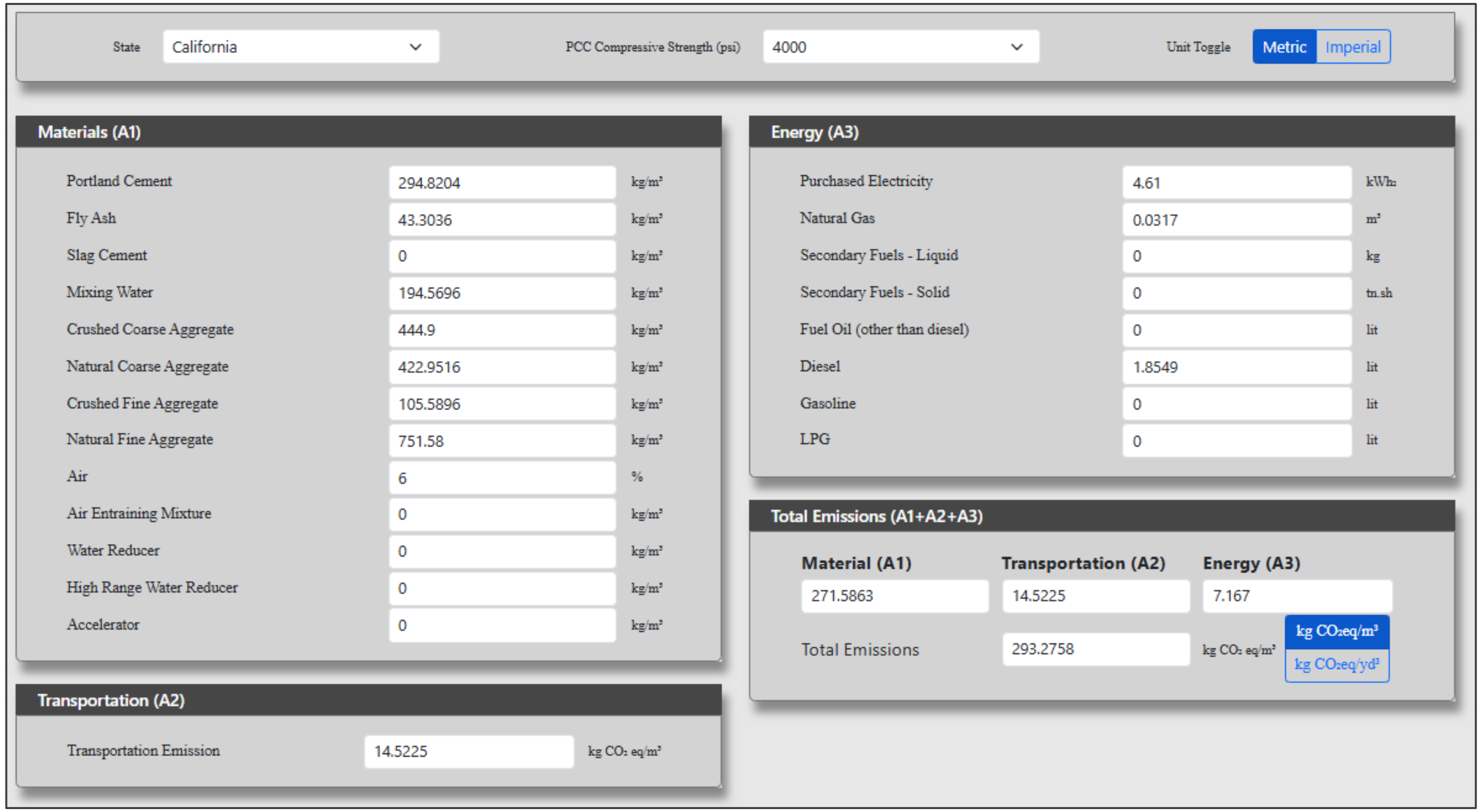
MIT STREAMLINED LCA & LCCA PLATFORM

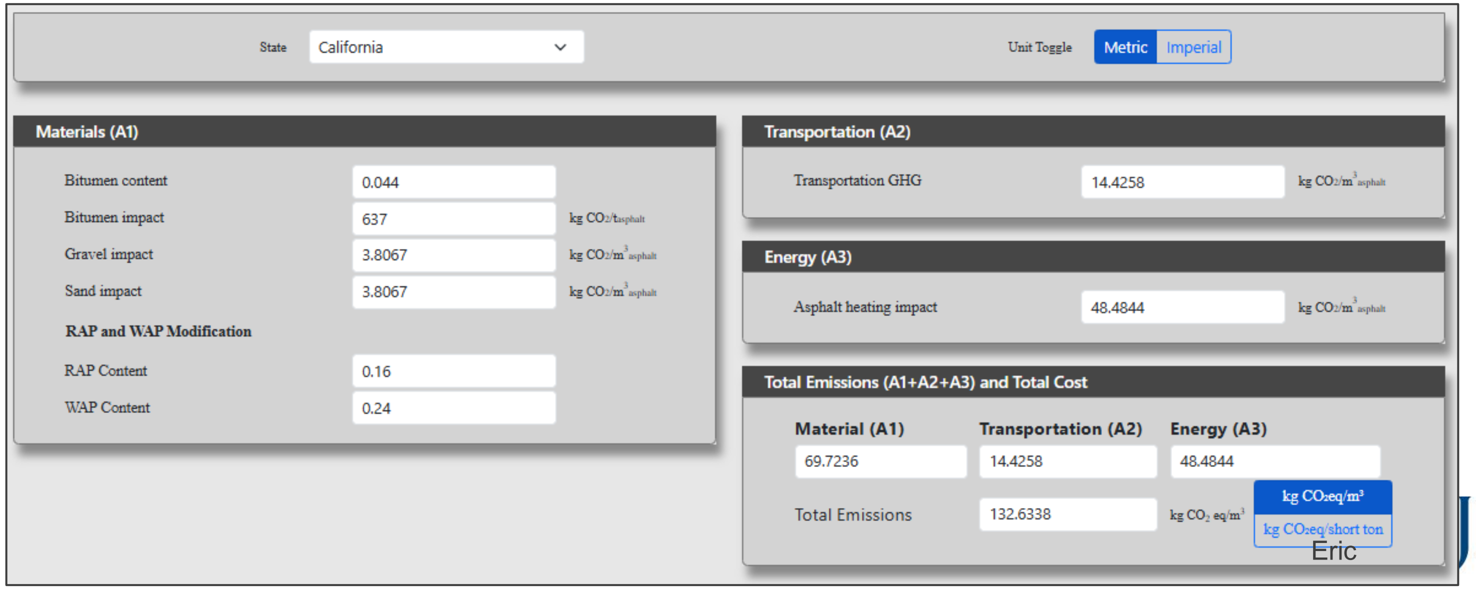
Embodied Emission sheets provide material properties

- 3rd Sheet = Concrete
- 4th sheet = Asphalt

Both start with a “state wide” pre-populated average data, but can be adjusted with EPD data for specific mixes

- Material data covers A1-A3 Stages





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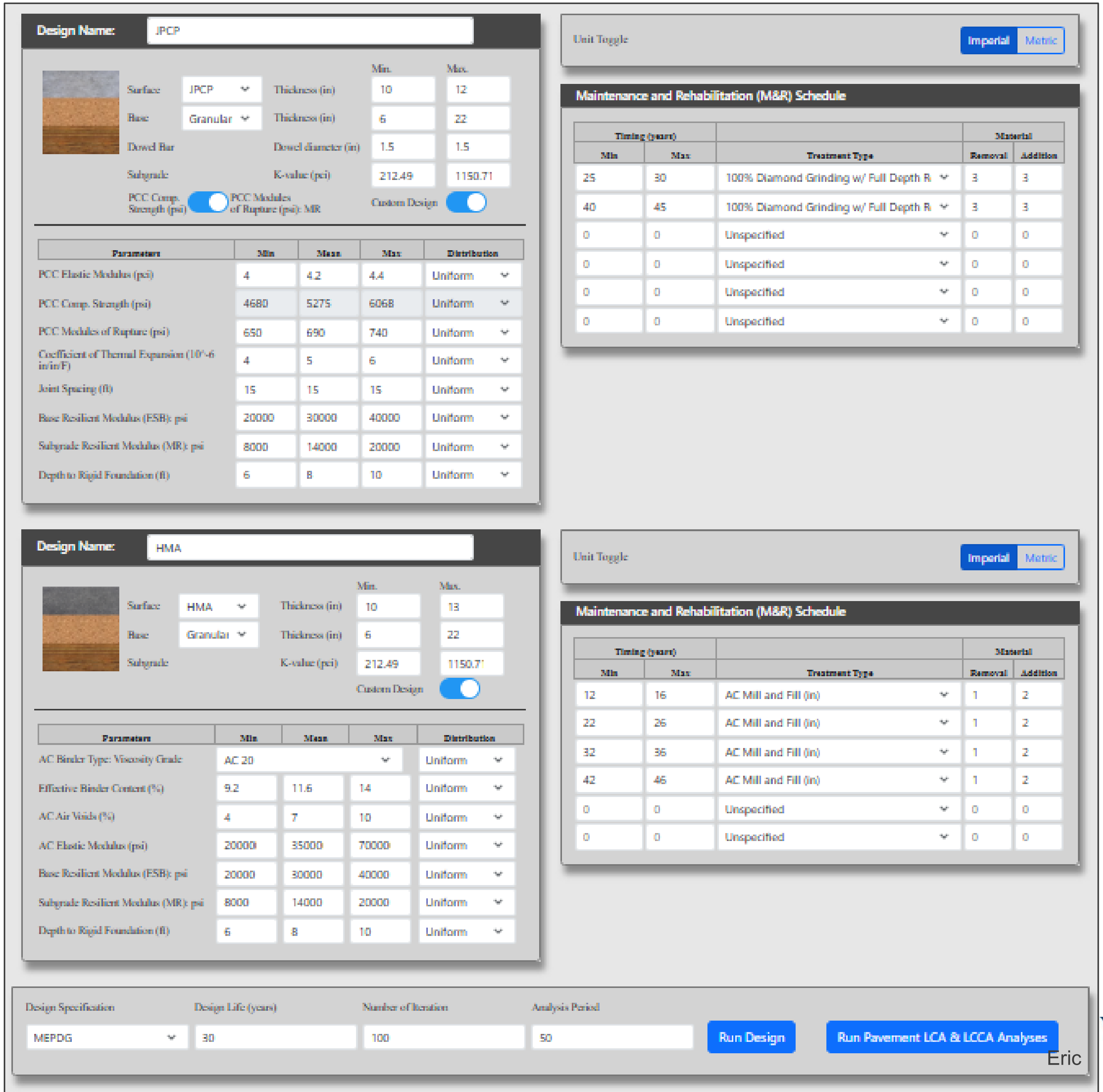
MIT STREAMLINED LCA & LCCA PLATFORM

Pavement Desing sheets provide Initial & Rehab Activities

Initial designs can be input if known

- If unknown, can estimate thicknesses based on AASHTO 93 or Pavement-ME procedures
  - Only allows for 1 base type
- Uses ranges & a probabilistic distribution for material & other inputs

Has pre-populated rehabilitation activities for both pavement types.



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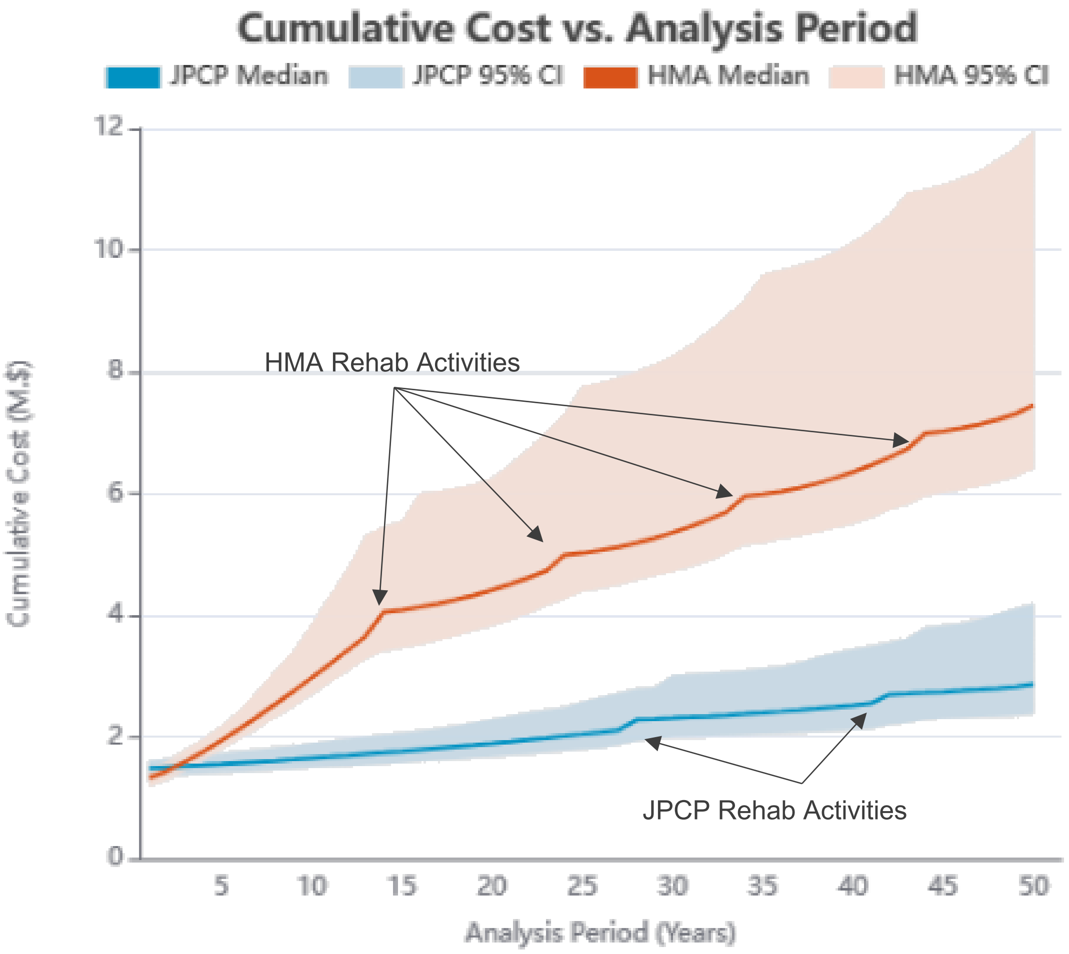
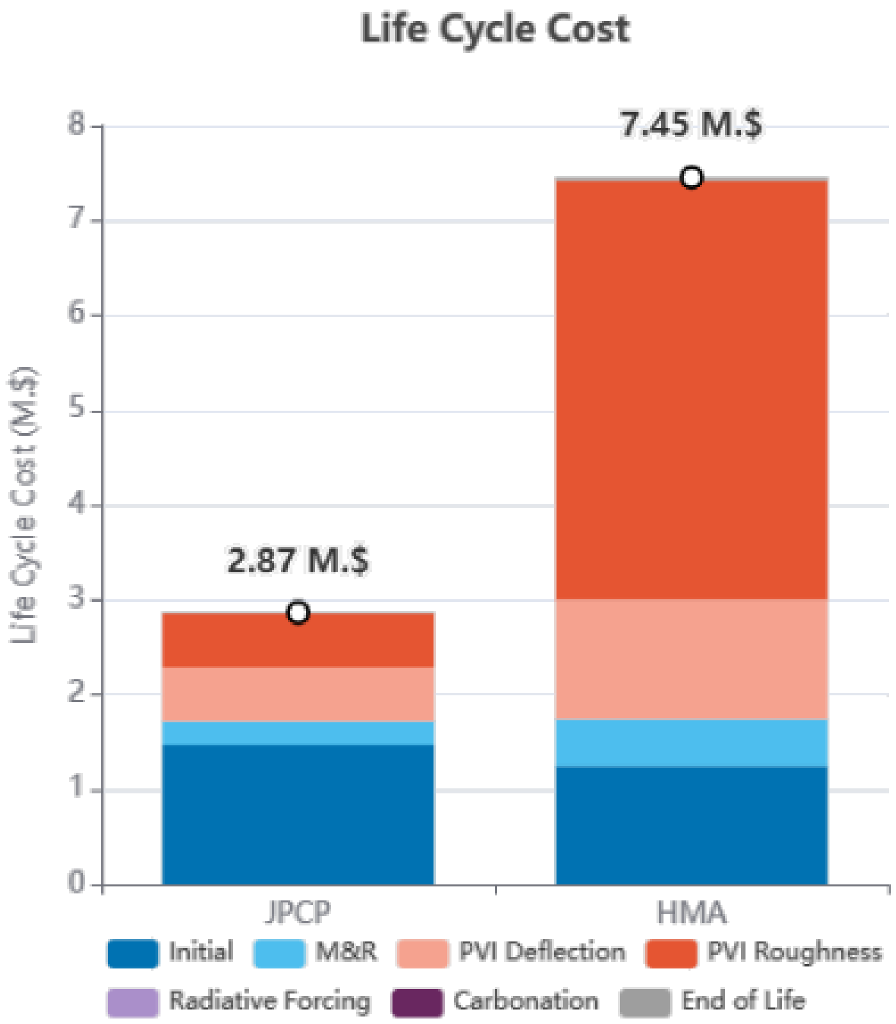
MIT STREAMLINED LCA & LCCA PLATFORM - OUTPUT

http://pavementlca.mit.edu



Shaded – Cost Range

Line – Median Cost



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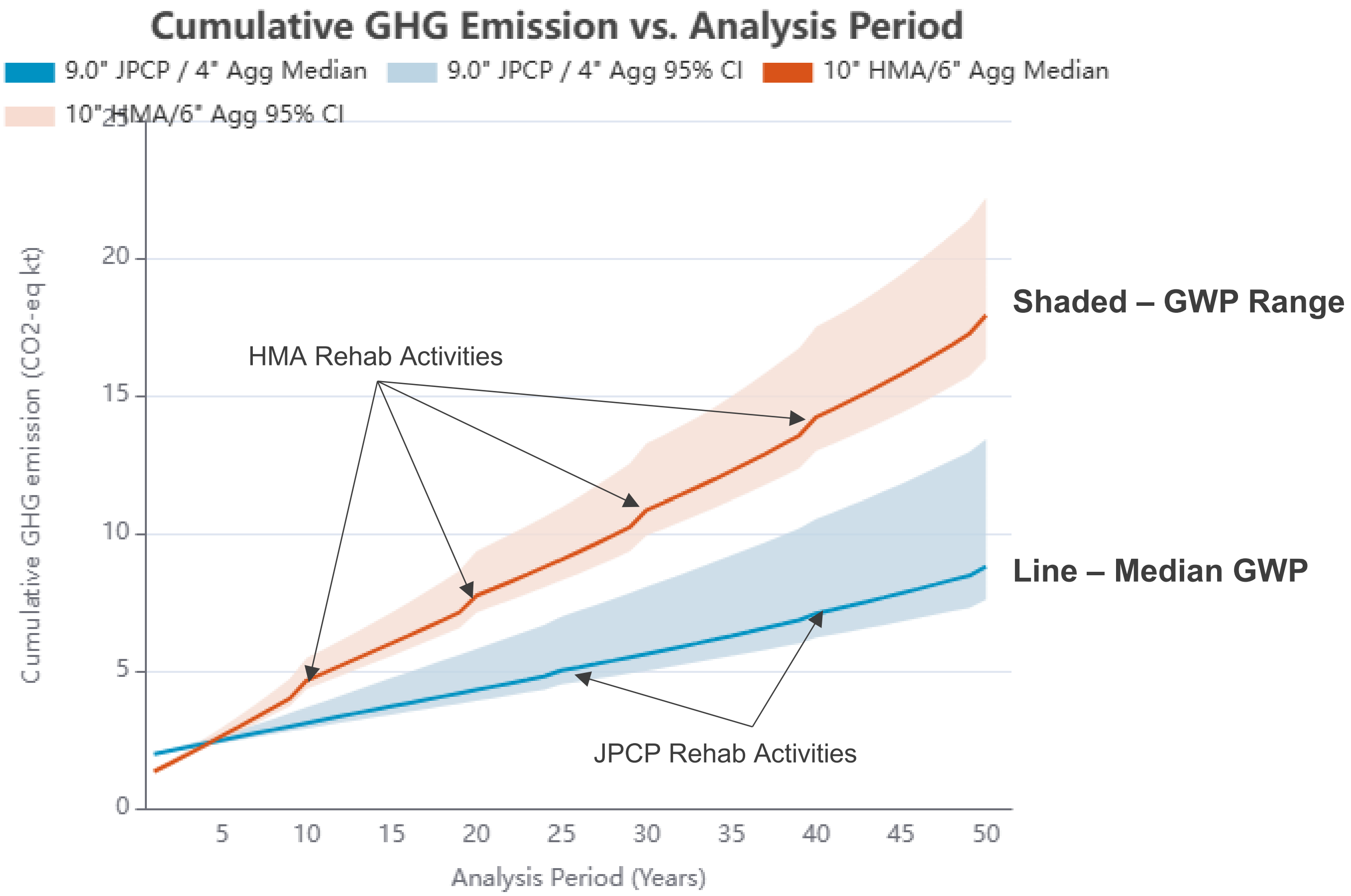

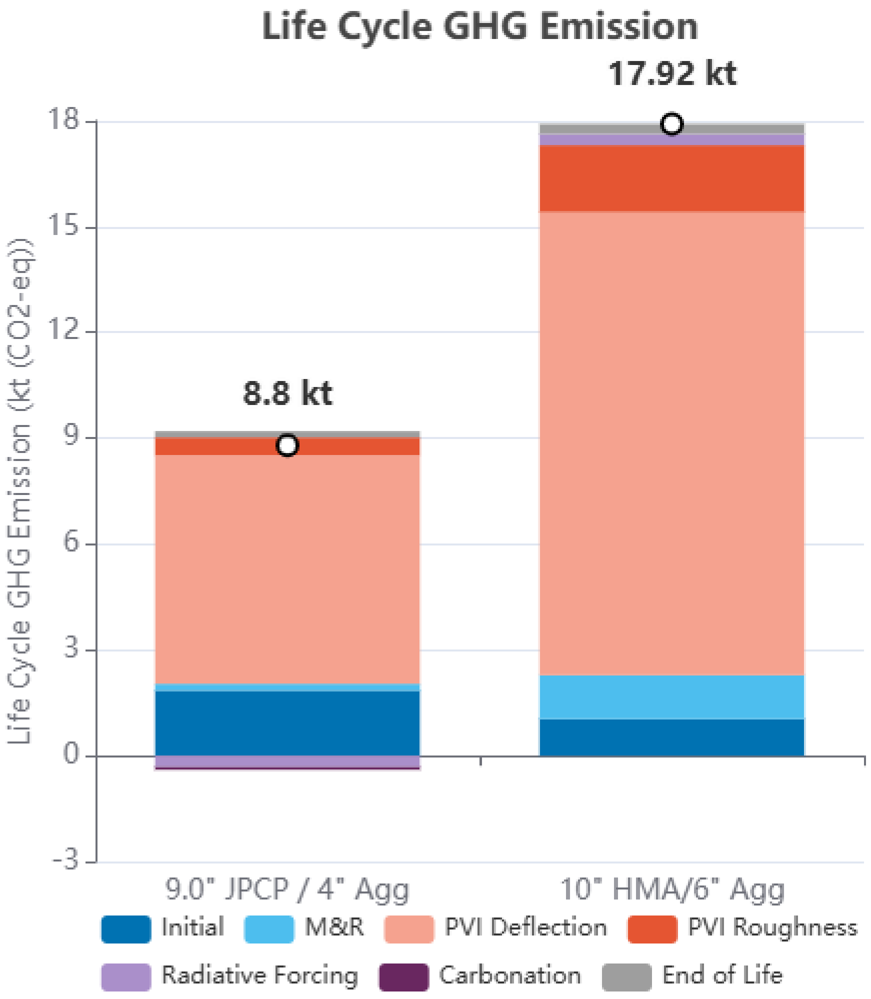

- Albedo
- Carbon Uptake
- End of Life
- Initial Emission
- M&R
- PVI Deflection
- PVI Roughness
- IRI for Asphalt Pavement
- IRI for Concrete Pavement

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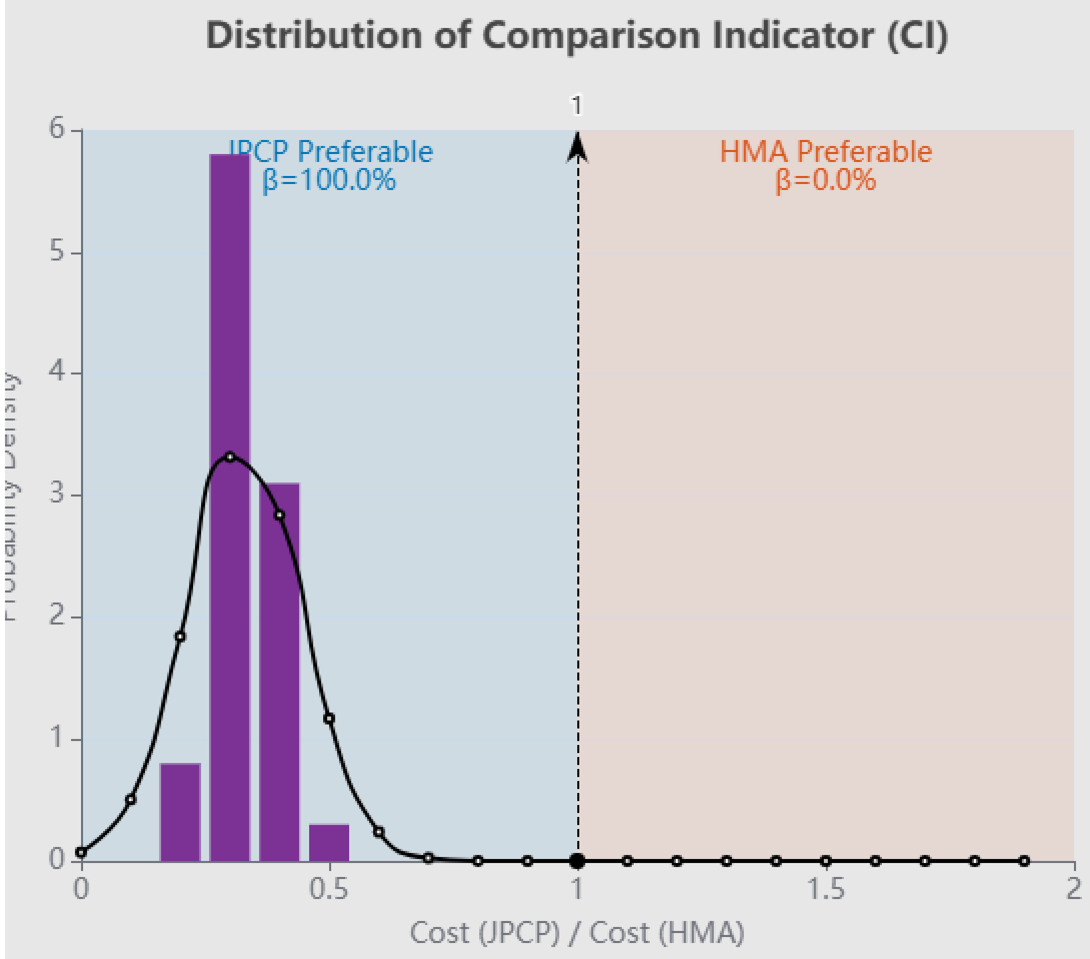

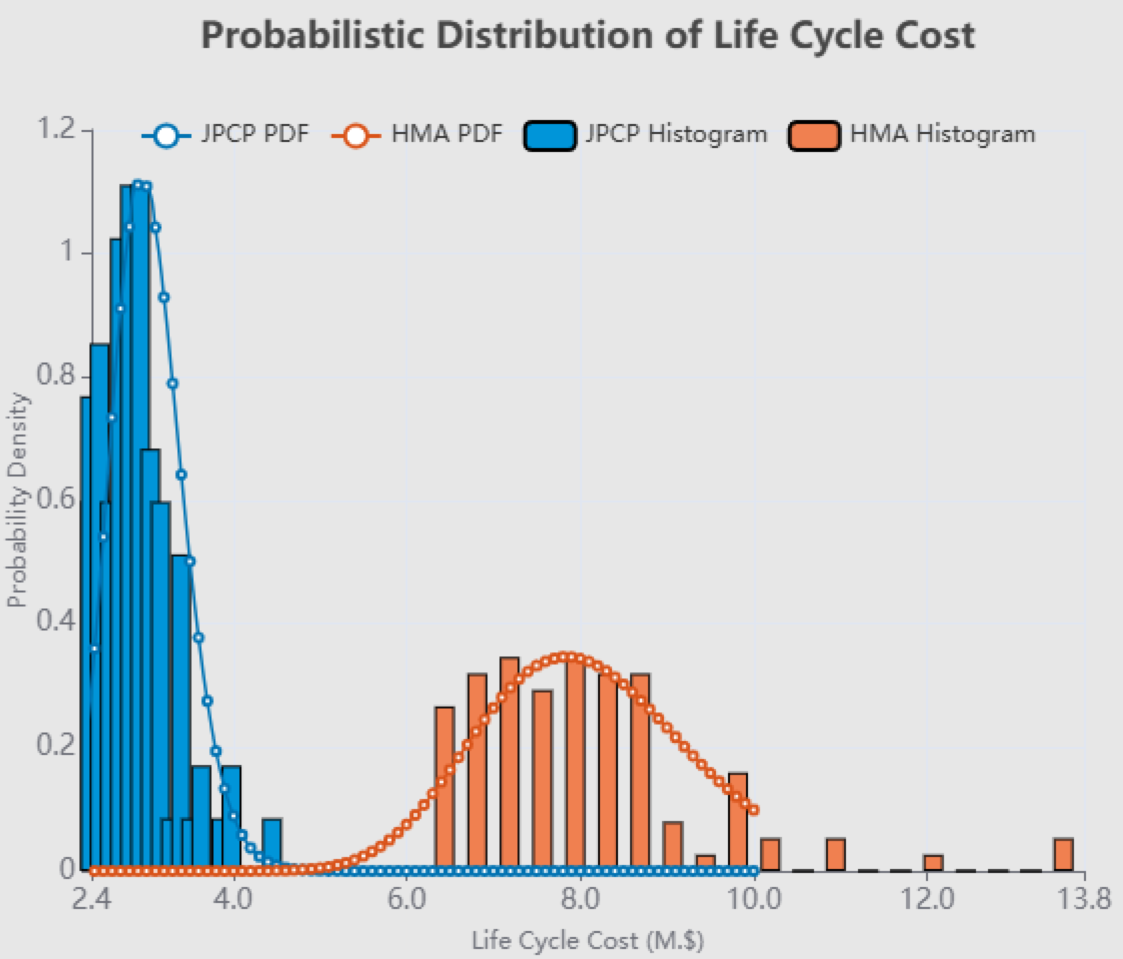

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Thank you. Questions? Feedback?

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