PAVEMENT DESIGN FOR DESIGNERS & NON-DESIGNERS…
And Why You Should Care…

Technology Tuesday

November 18, 2025

AMERICAN CONCRETE PAVEMENT ASSOCIATION

Eric Ferrebee, P.E.

Senior Director of Technical Services

eferrebee@acpa.org

WJE ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

Wiss, Janney, Elstner Associates, Inc.

Jim Mack, P.E.

Associate Principal

jmack@wje.com

Question

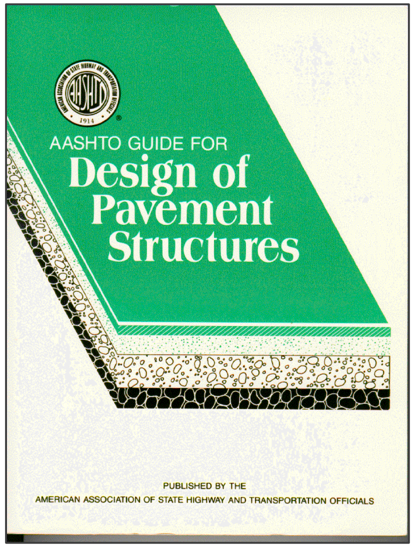
Who has said (or thought) something along the lines of?

We Don’t do 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

Pavement ME (PMED)

AASHTOWare Pavement ME Design

Industry Methods

PavementDesigner.org

State & University Methods

BCOA ME
University of Pittsburgh

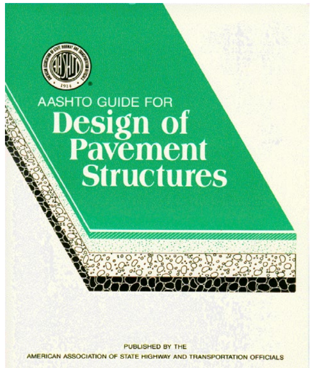
They all can work and give Good Designs (as well as bad)

Concrete Pavement Design Methodologies

Understand the limitations of each design tool

Outdated

Current Design Tools



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

THE 40 YEAR DIVIDE

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

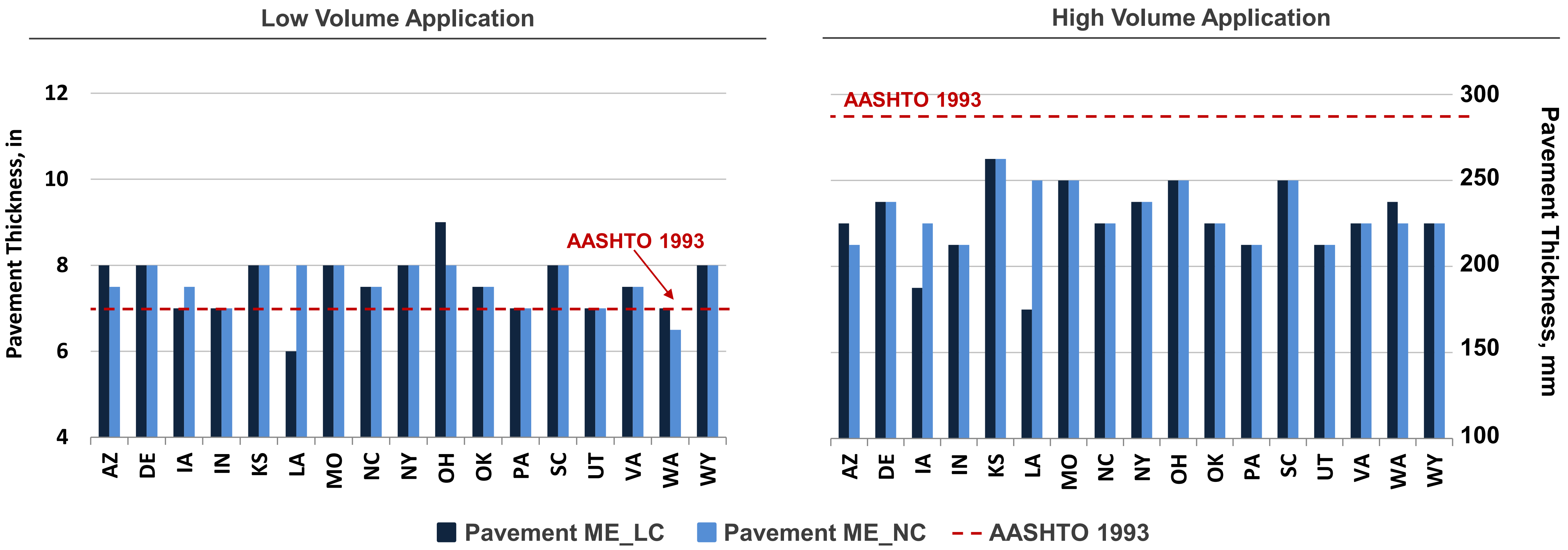
PavementDesigner
2018 - Present
12 inputs
Crack & Fault
FEA + Field Data

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

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

Source: Adapted from R. Rodden

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.

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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

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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

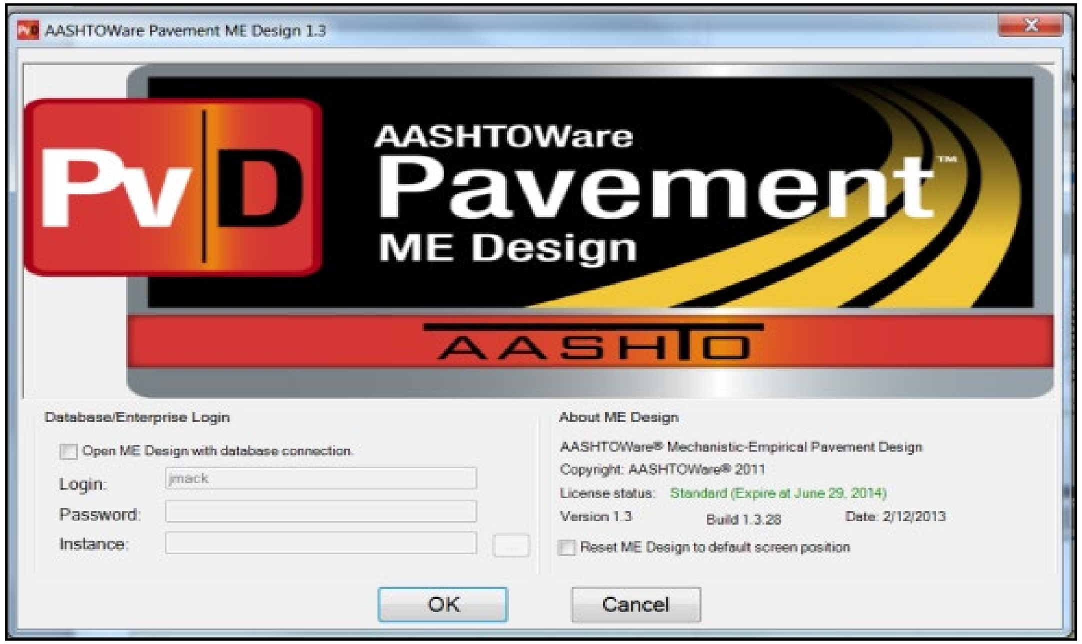
- Adopted by AASHTO in 2011
- Calibrated to more than 2,400 asphalt & concrete pavement test sections, ranging in ages up to ~40+ years

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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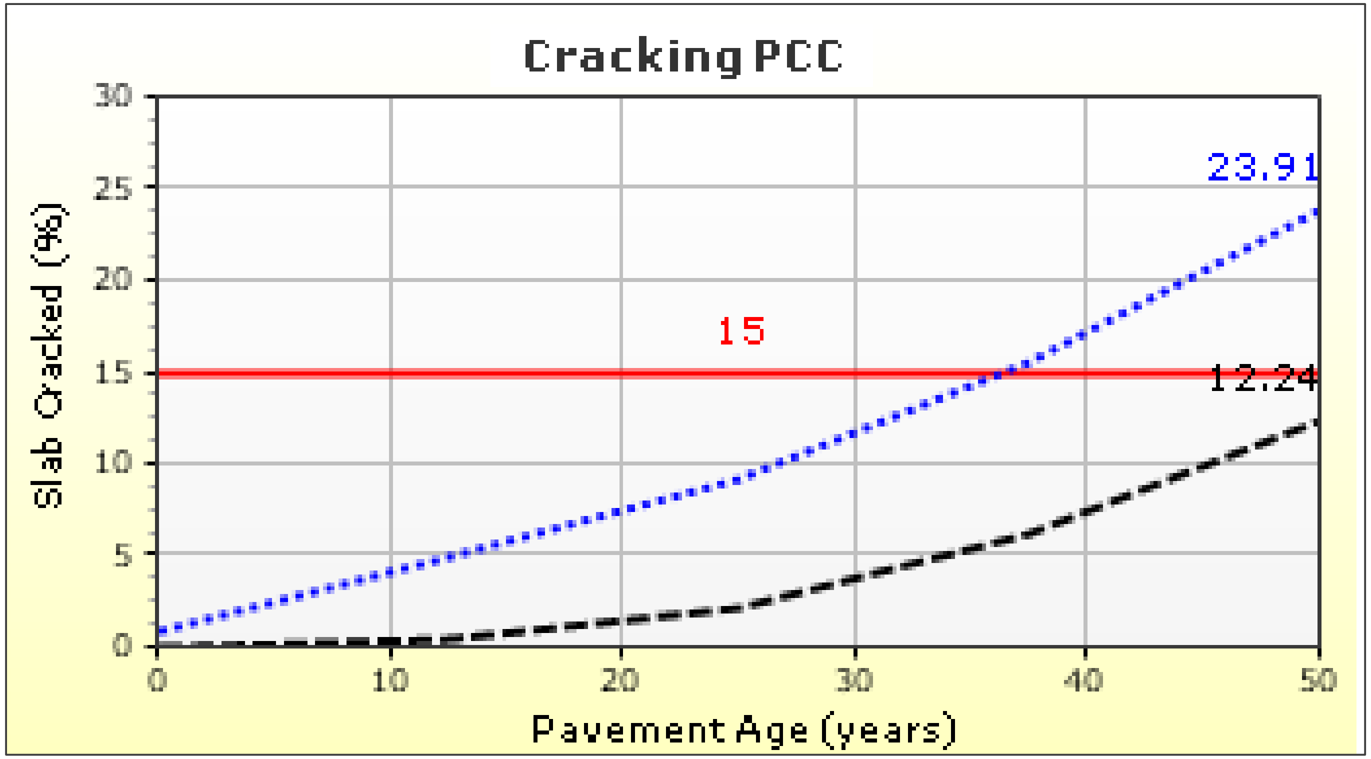
Pavement-ME Defines a Specific Pavement's Performance

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)

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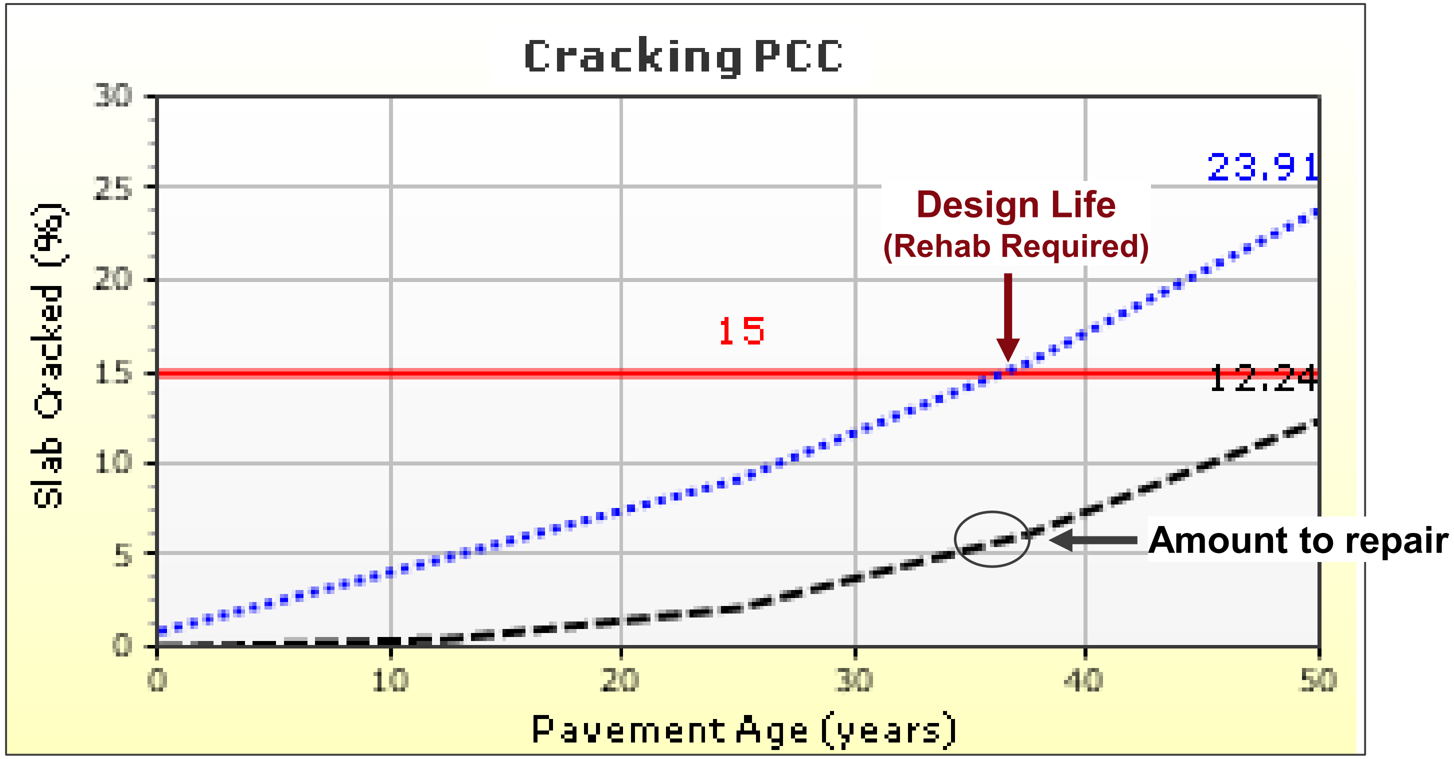

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Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~37 years in this case)

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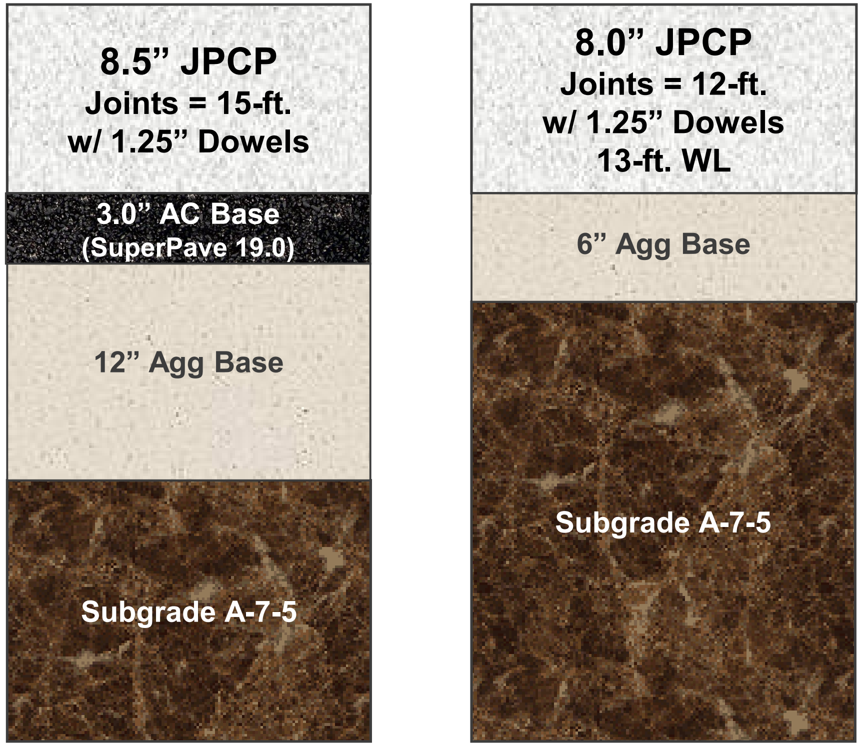
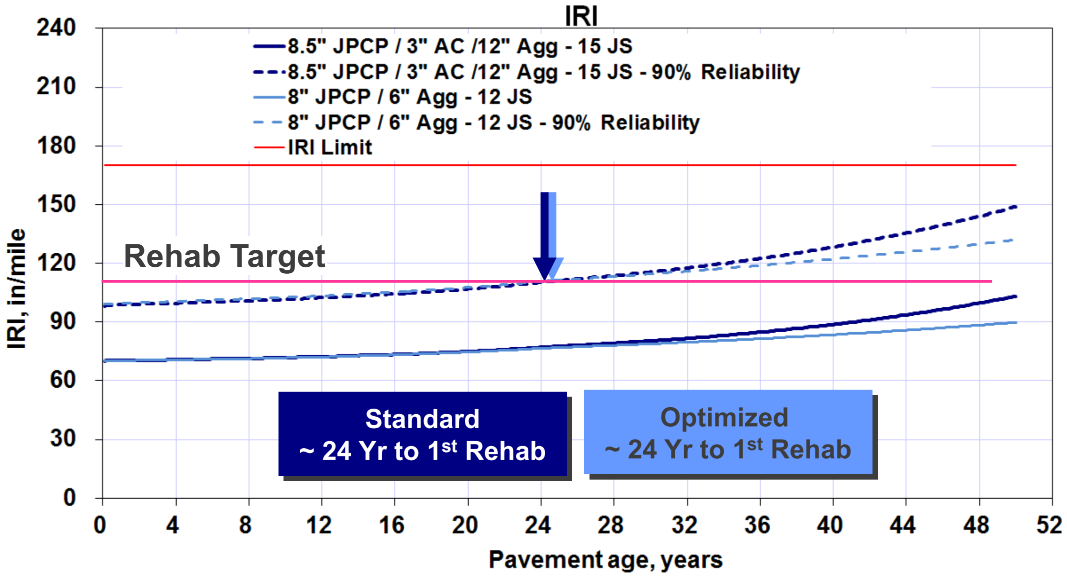
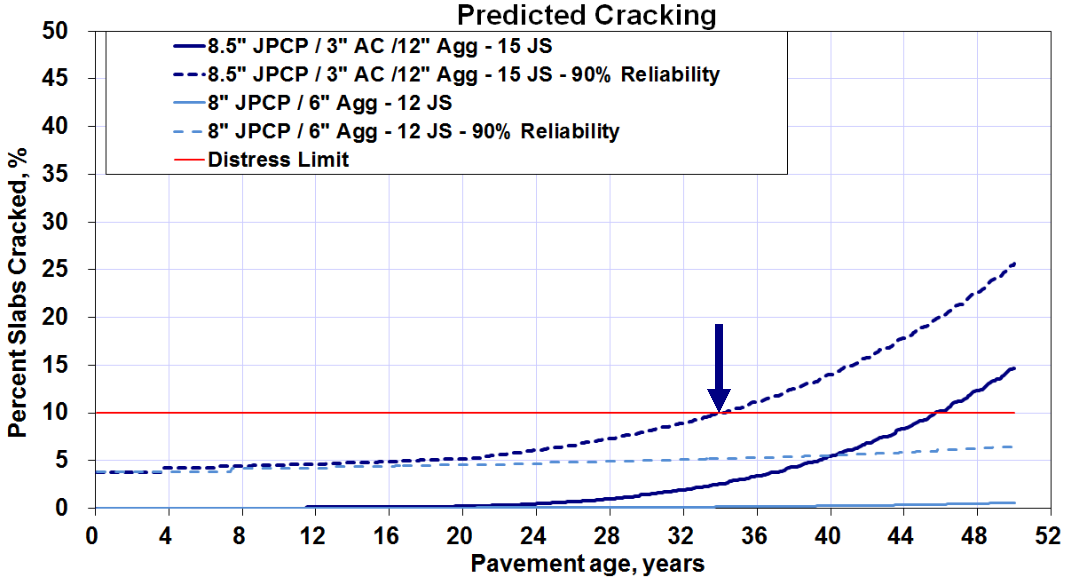
Pavement-ME Allows for Comparisons of Different Designs

Original Concrete Design | **Optimized Concrete Design**







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

So, While We Think Pavement ME is Amazing & the Best Thing EVER

It is also fairly complex and the models aren't perfect

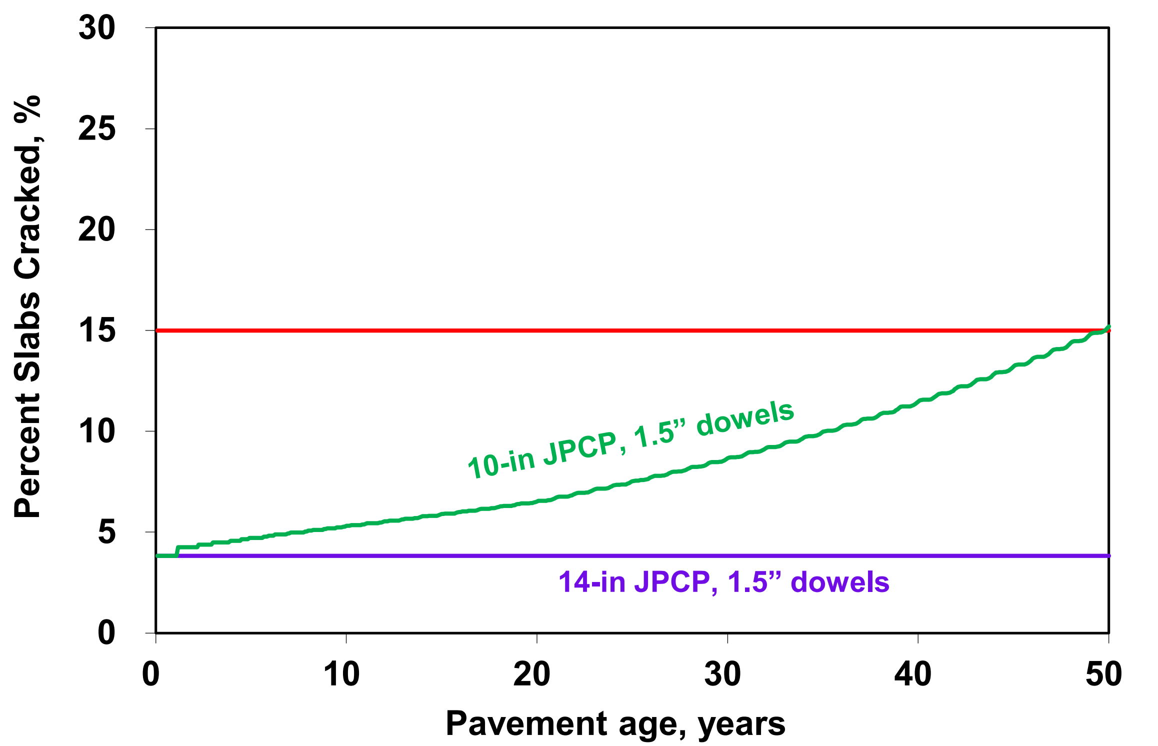
There are a Few Design Conundrums

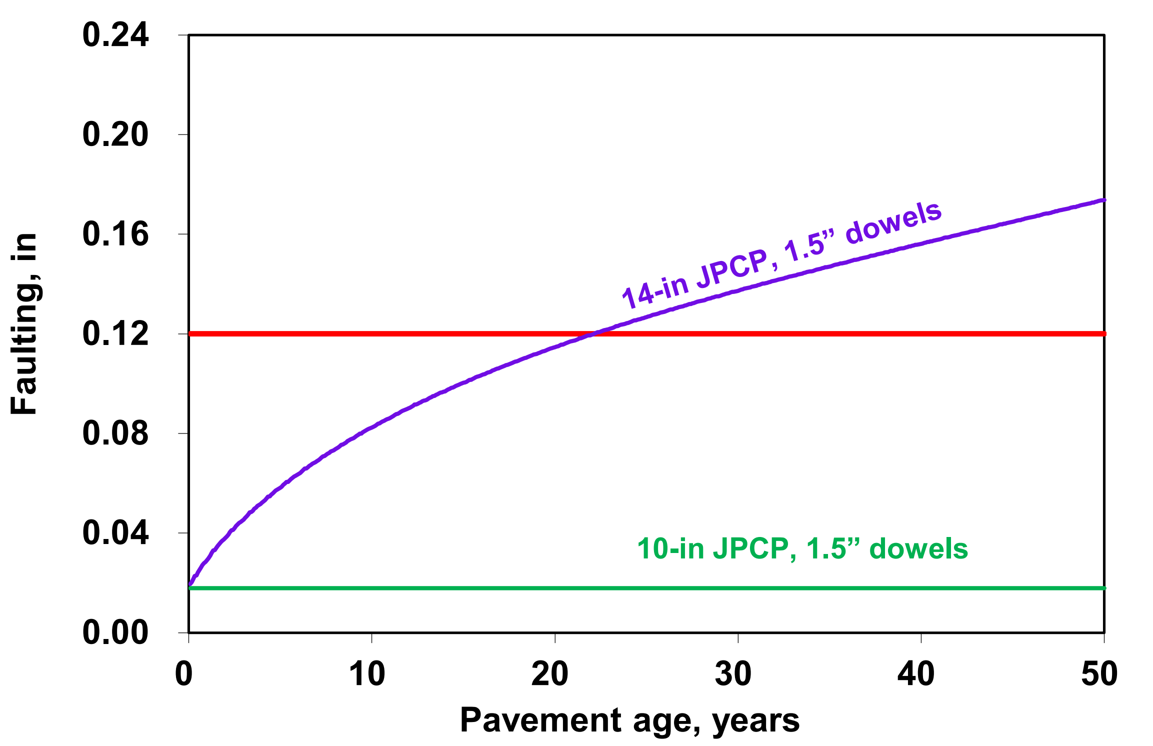
- Joint Faulting Predictions
- IRI Predictions

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



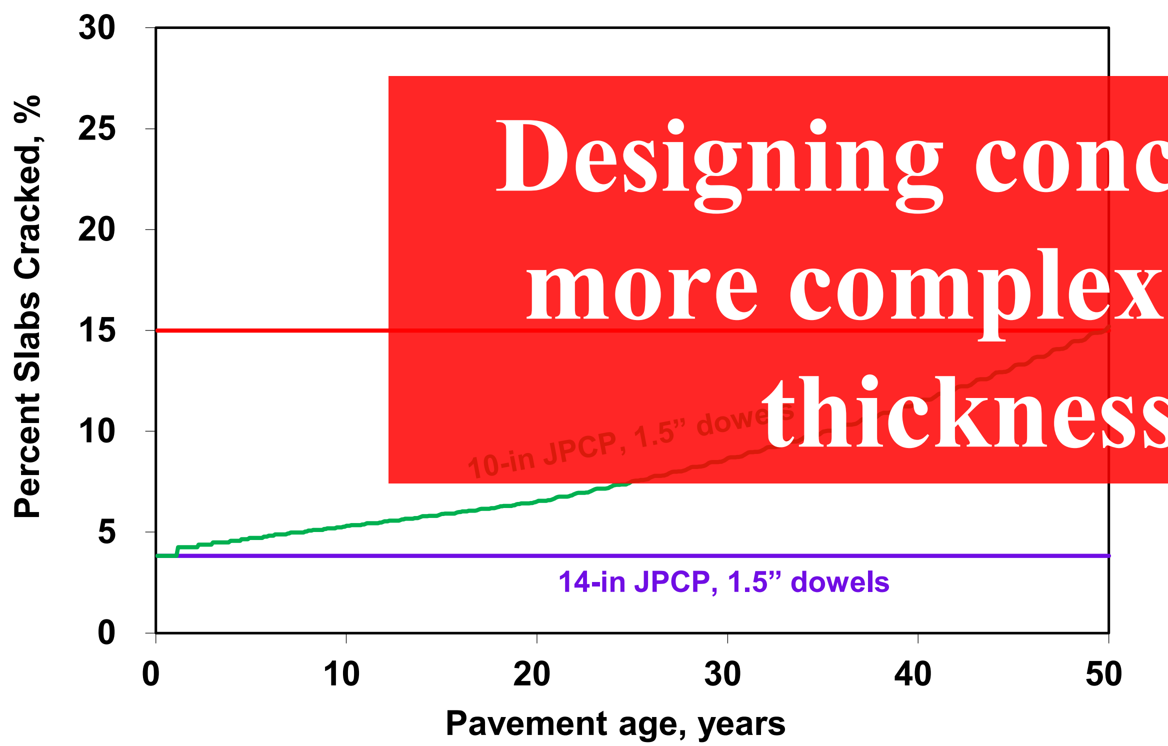


In Pavement ME, LTE is proportional to Dowel Size/PCC Thick Ratio
(e.g. the same dowel setup is more effective for thinner pavements)

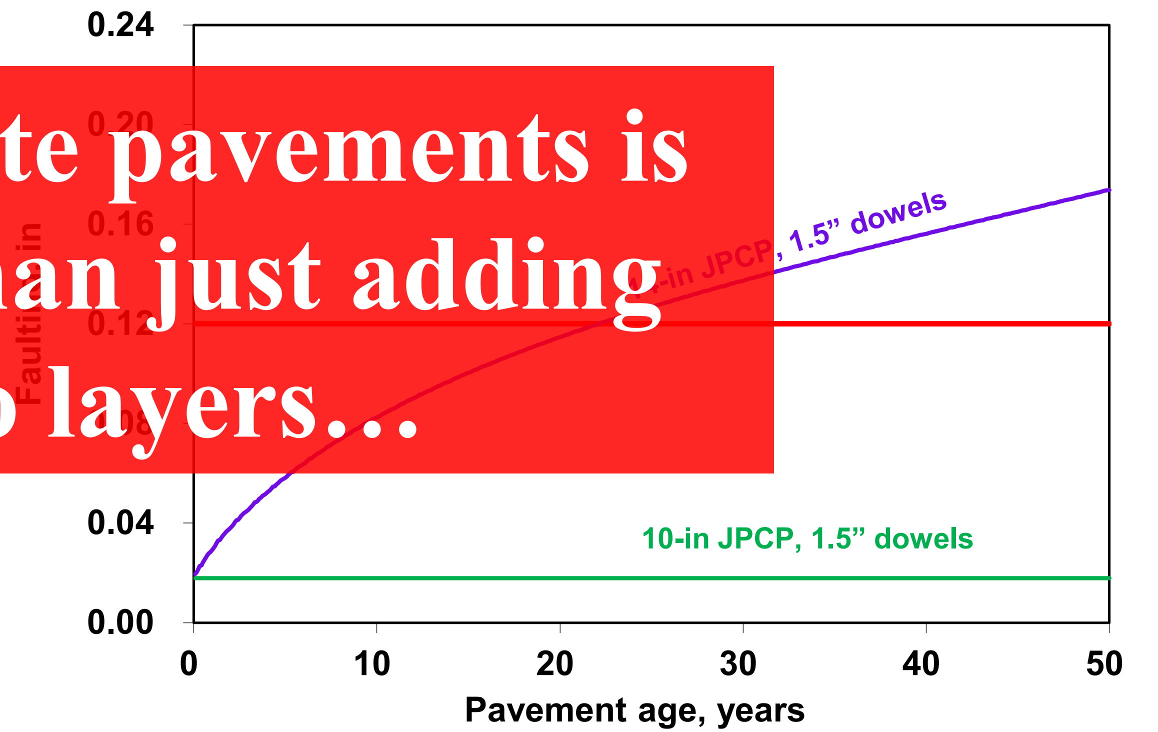
In reality, LTE may be more dependent on the absolute amount of dowels.

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.

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

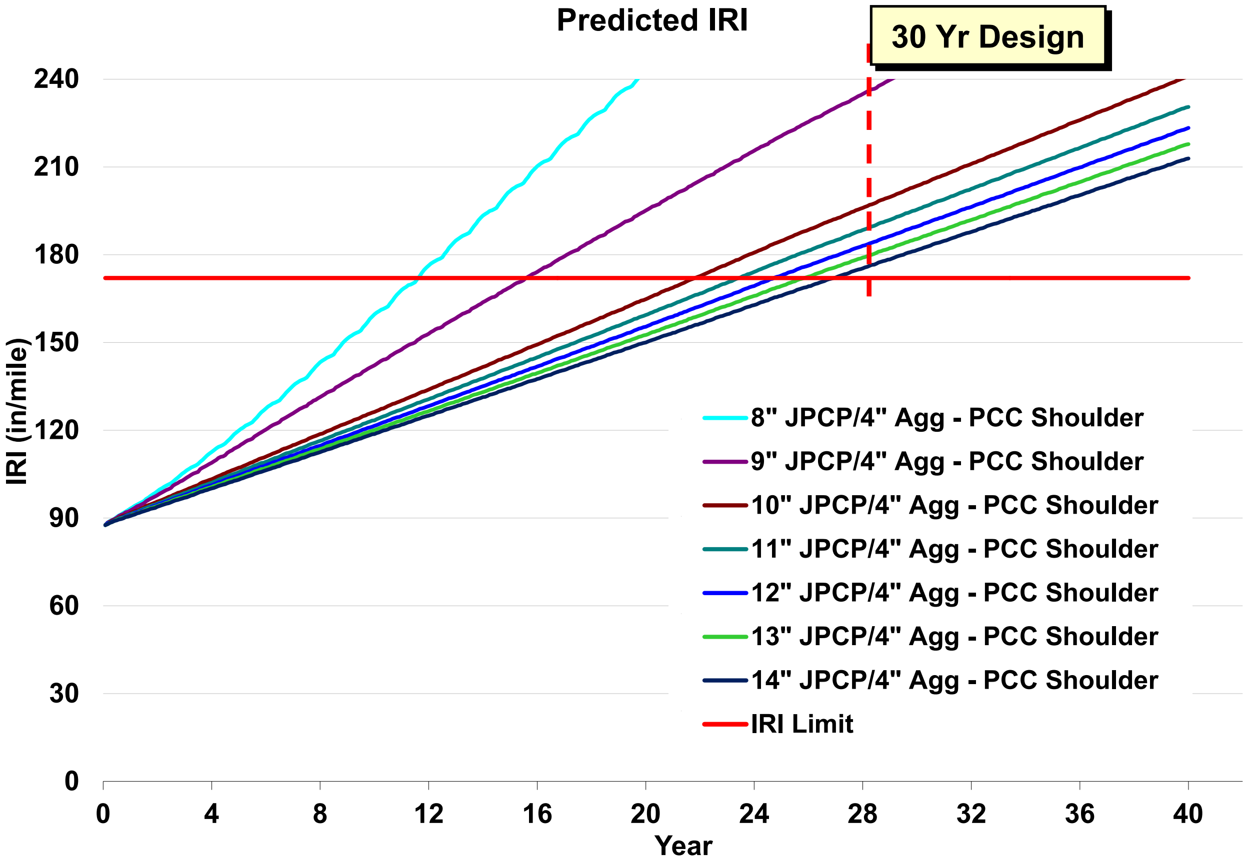
IRI = C1*(Crack) + C2*(Spall) + C3*(Fault) + C4*(Site Factor)

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

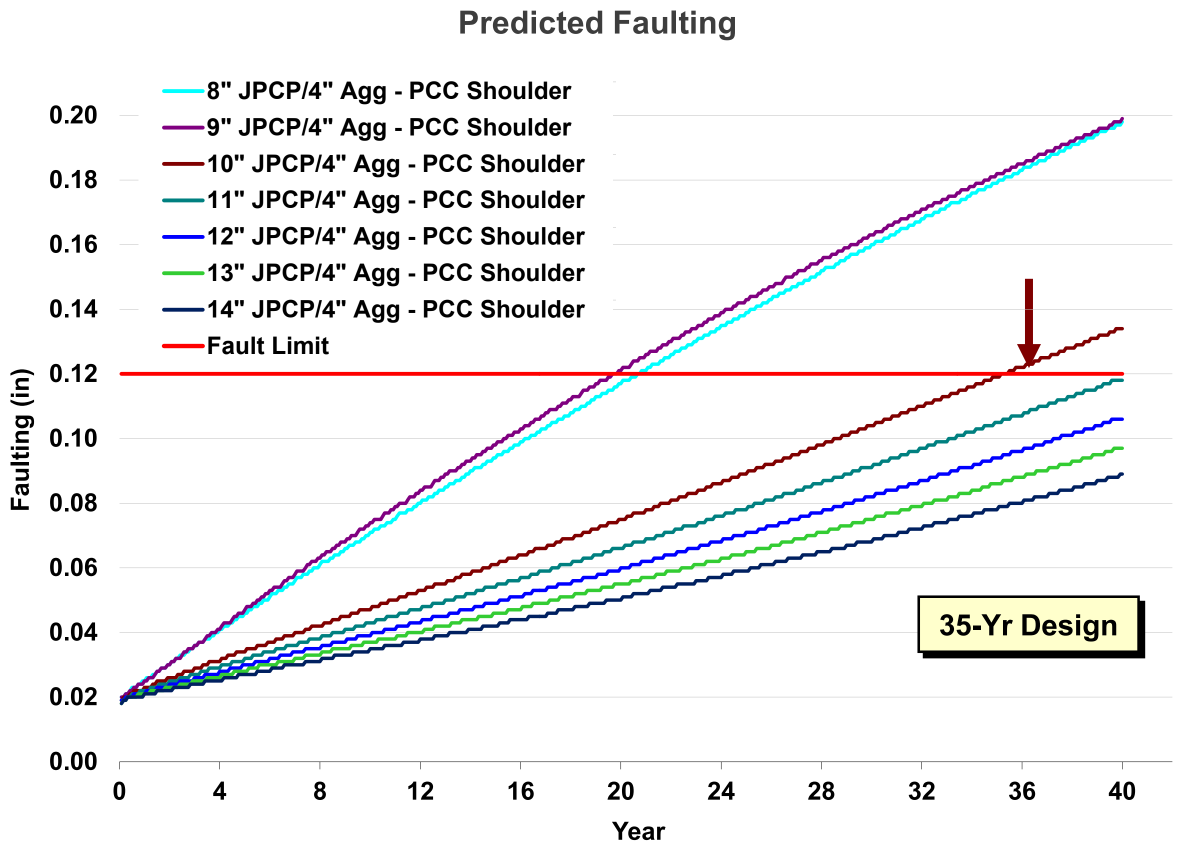
SF is a linear constant increase with age

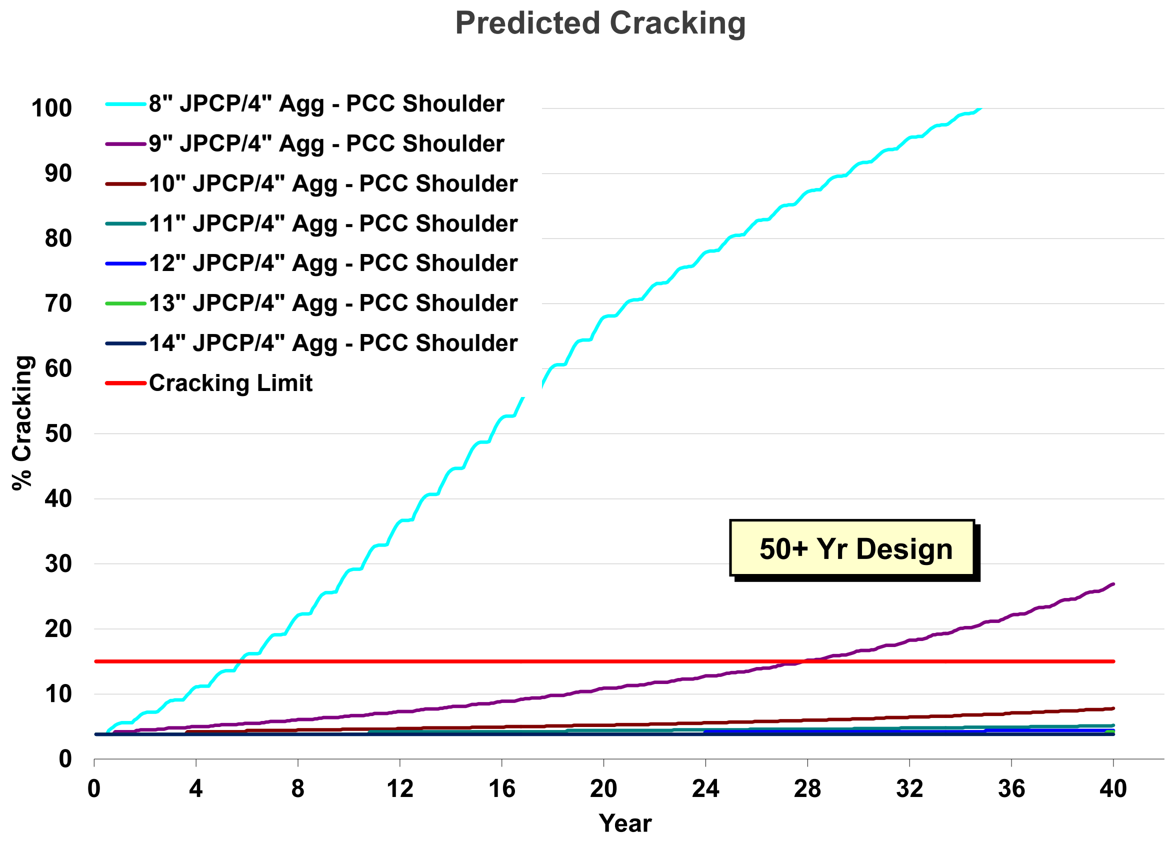
- For areas with high FI and high P200 soils; the increase is very fast
- When fault and cracking are low, IRI distress level is being controlled by "Site Factors"



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?

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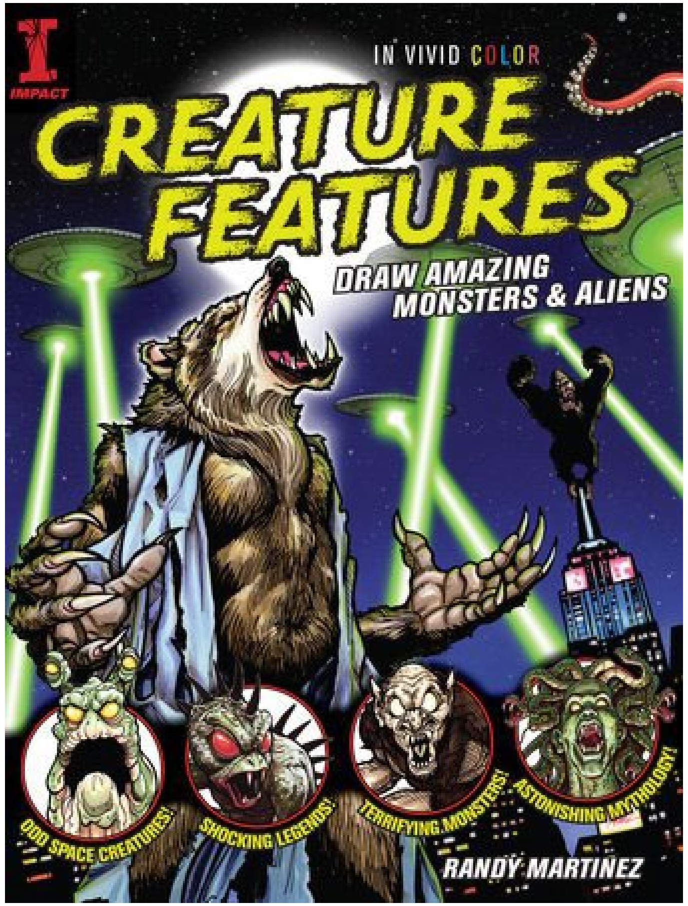
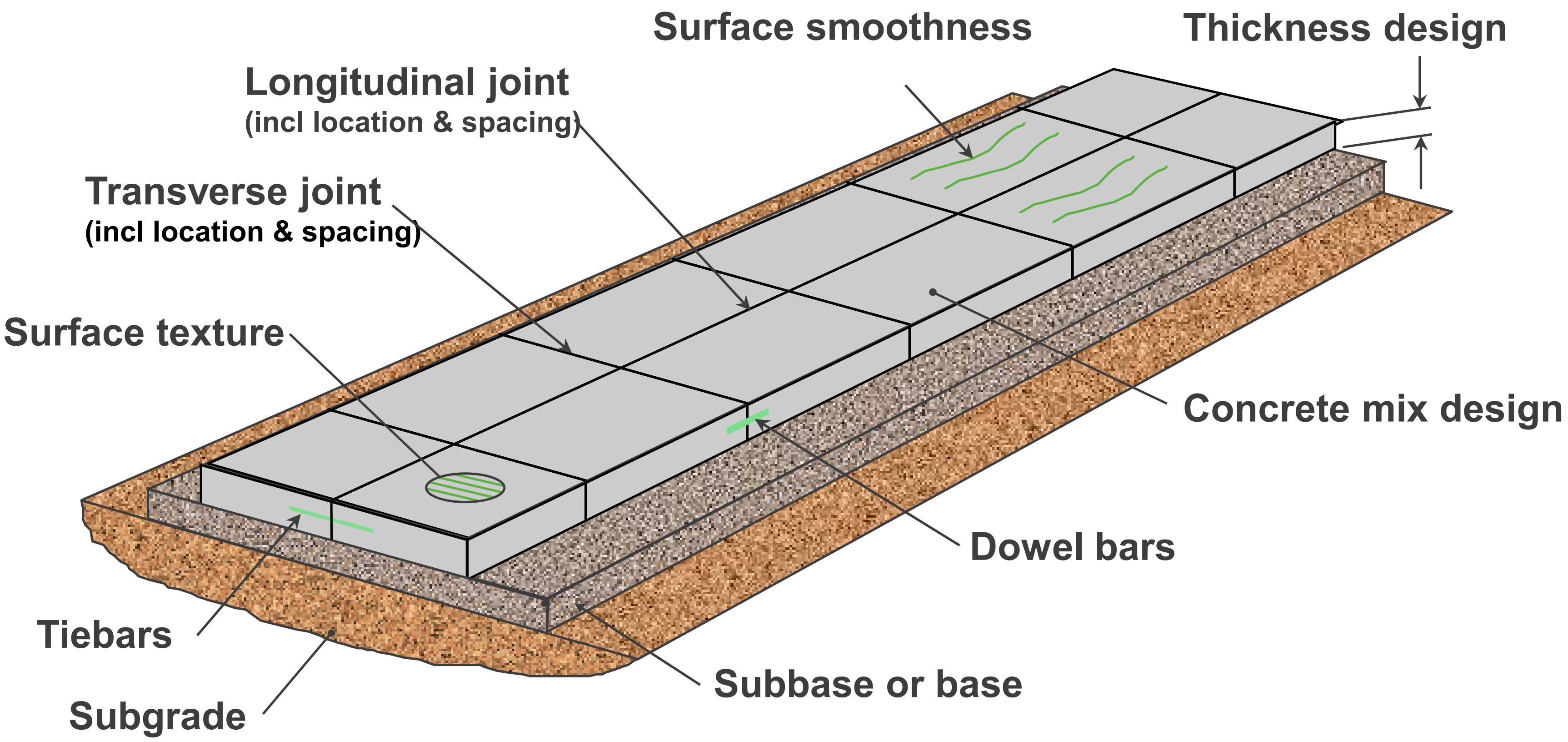
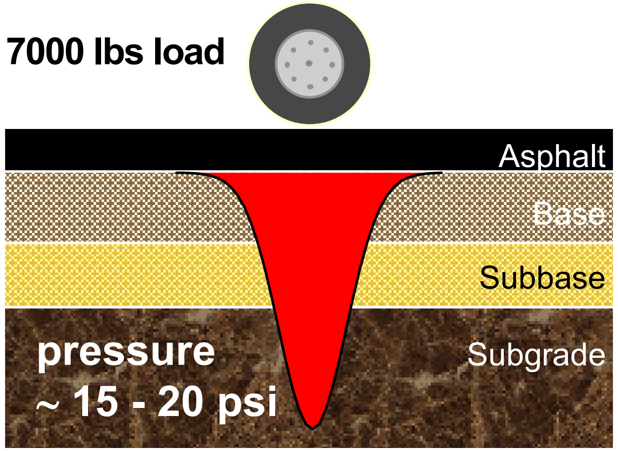
Selecting Features

Concrete Pavements are a Creature of Features



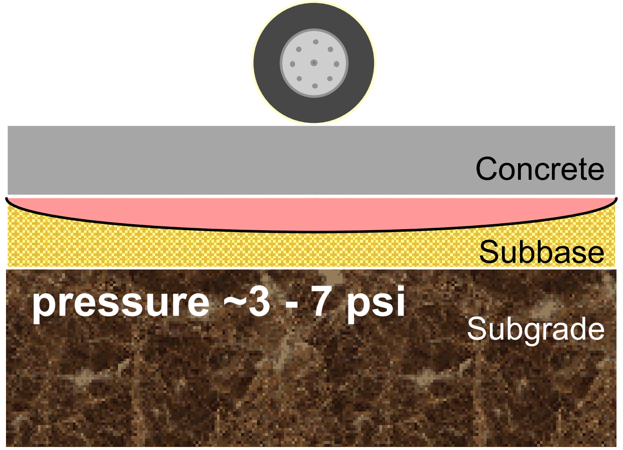


What drives Asphalt & Concrete Pavement Performance is Different
And that difference is reflected in design approaches



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**



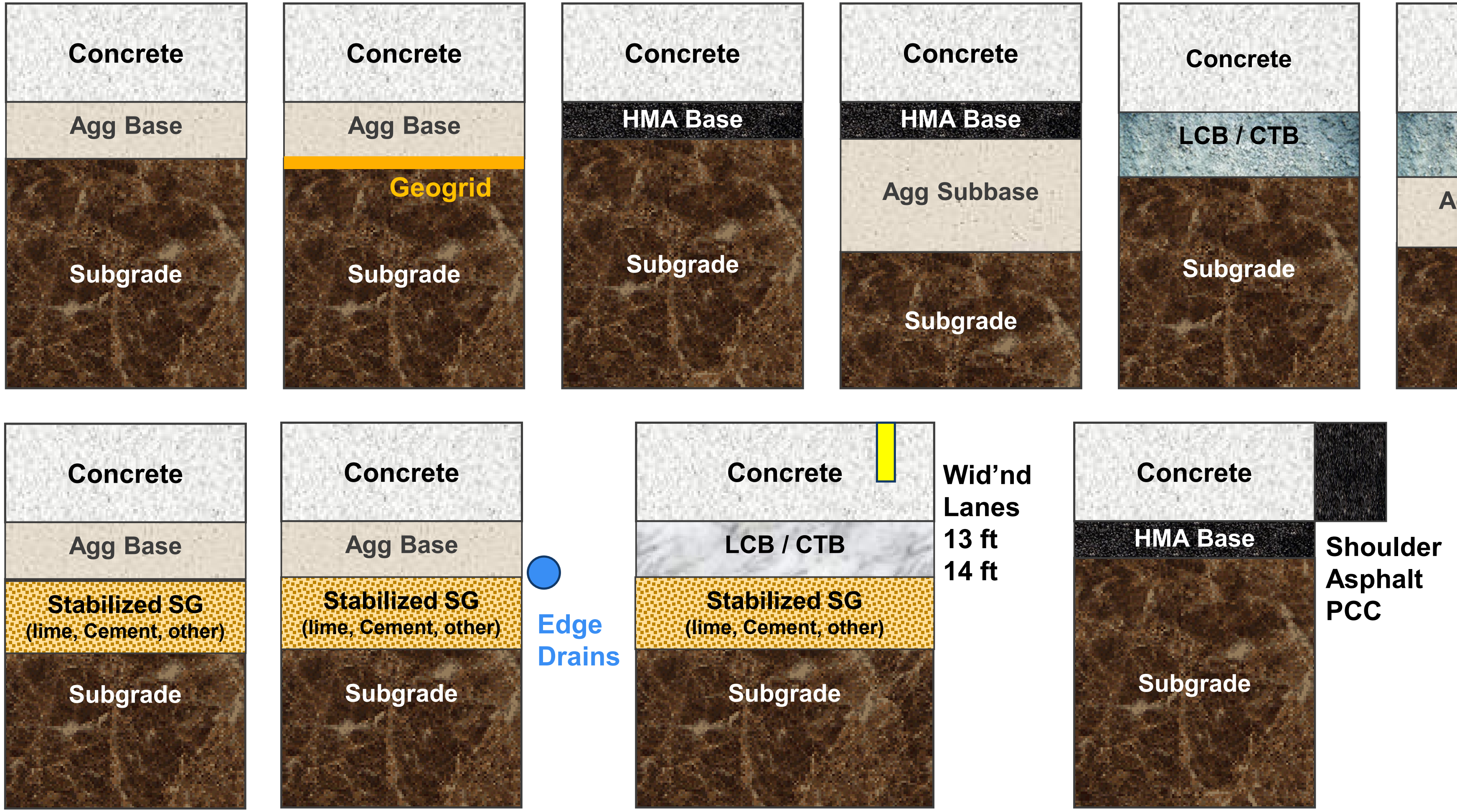
Concrete – Performance is driven by the Features

- **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

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 can have huge impacts on costs

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

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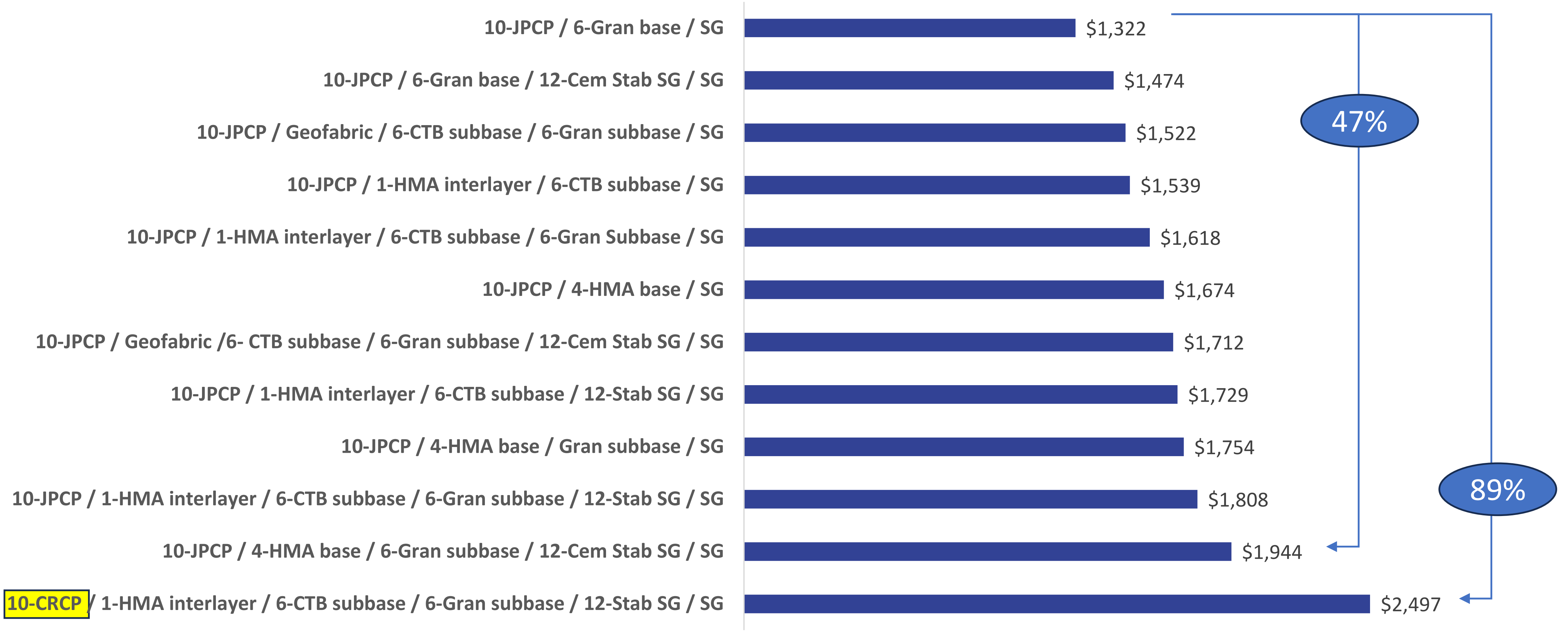
Pavement Structure has a Large Impact on Initial Pavement Cost

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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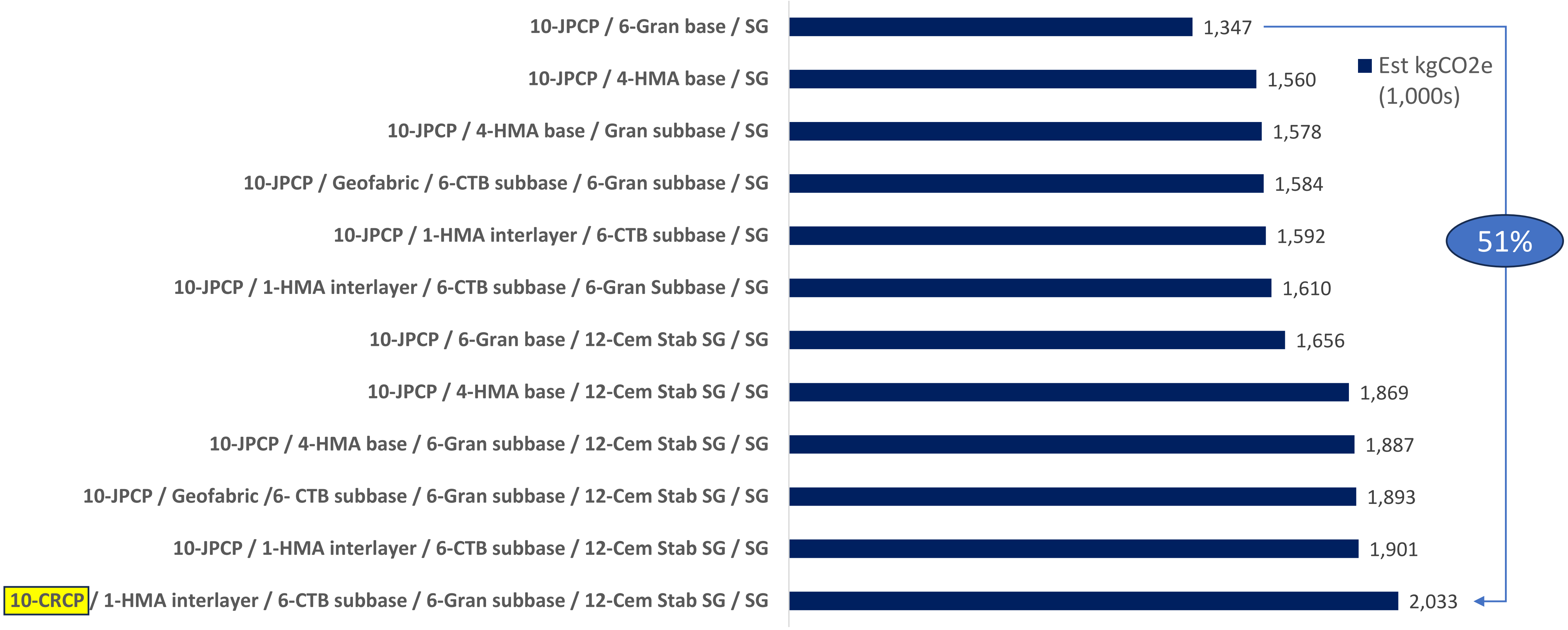
Pavement Structure has a Large Impact on the Initial Pavement CO2

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



And if worried about sustainability, the same issues exist

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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
Optimize Thickness	Reduces overdesign, lowers costs and environmental impact
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 / No Dowels	Increases load transfer, reduces bearing stress reduces faulting
Change 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
Use different concrete mixes	Mainline vs shoulder mixes, 2-layer construction
Change base type	Granular vs asphalt treated vs cement treated, reduce thickness, dense graded vs permeable; subgrade / chemical stabilization
Use single 1/8”-wide single saw cut and filled (not sealed)	Removes second sawing operation and reduces noise
Use Longitudinal tining or Next Generation Concrete Surface (NGCS)	Reduces noise

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

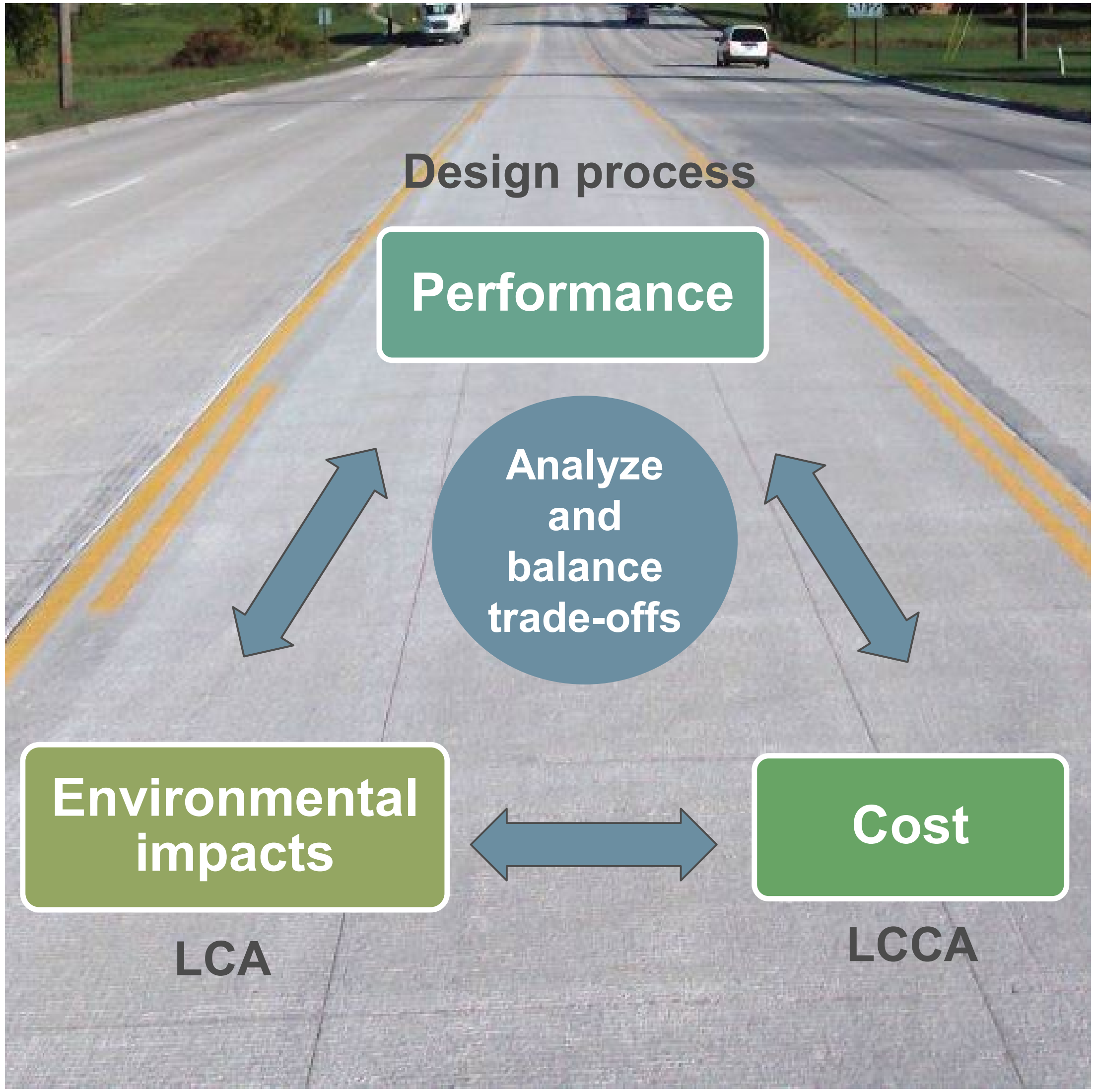
TOOLS

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



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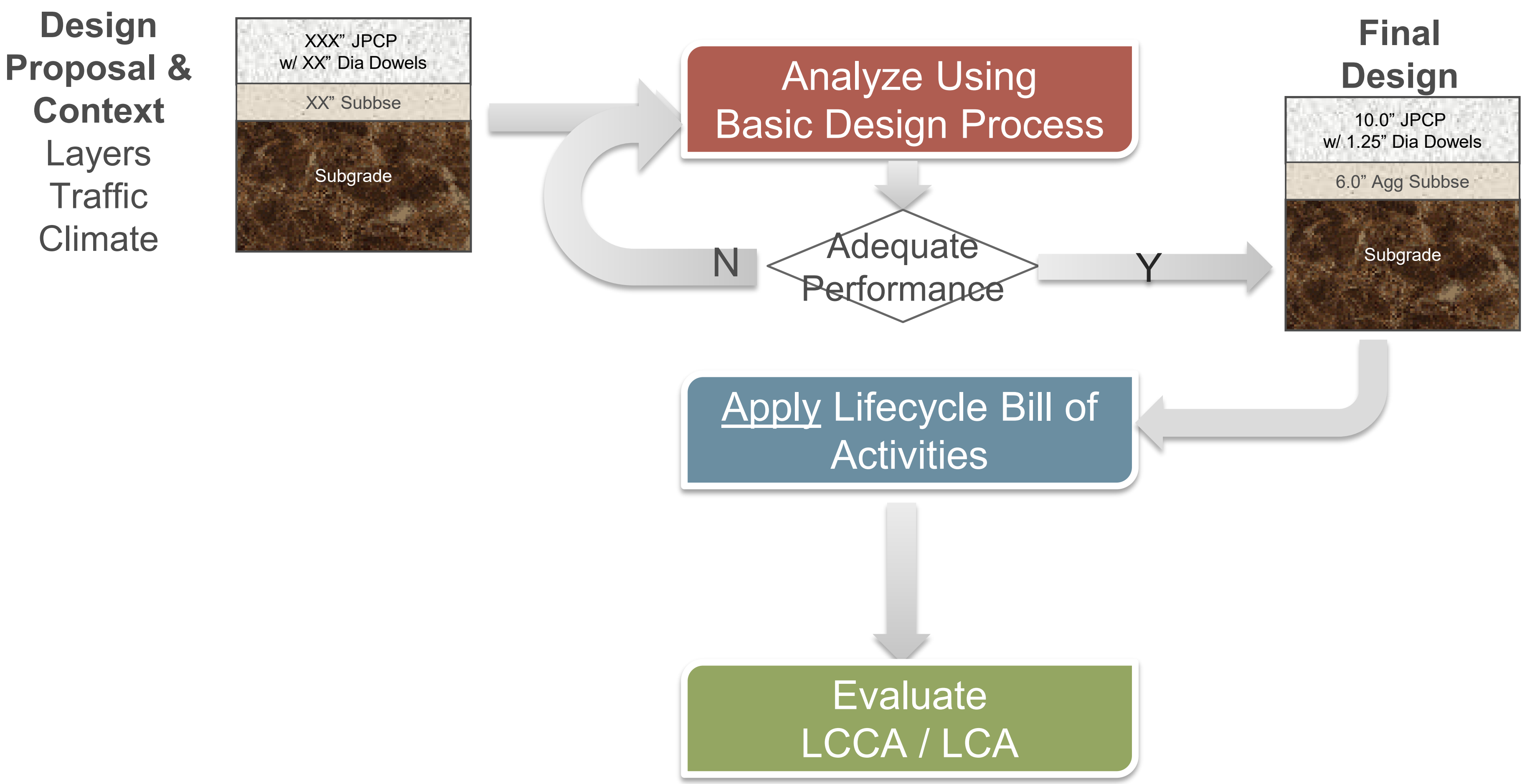
To Evaluate Features, we need to Change HOW we Design Pavements

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

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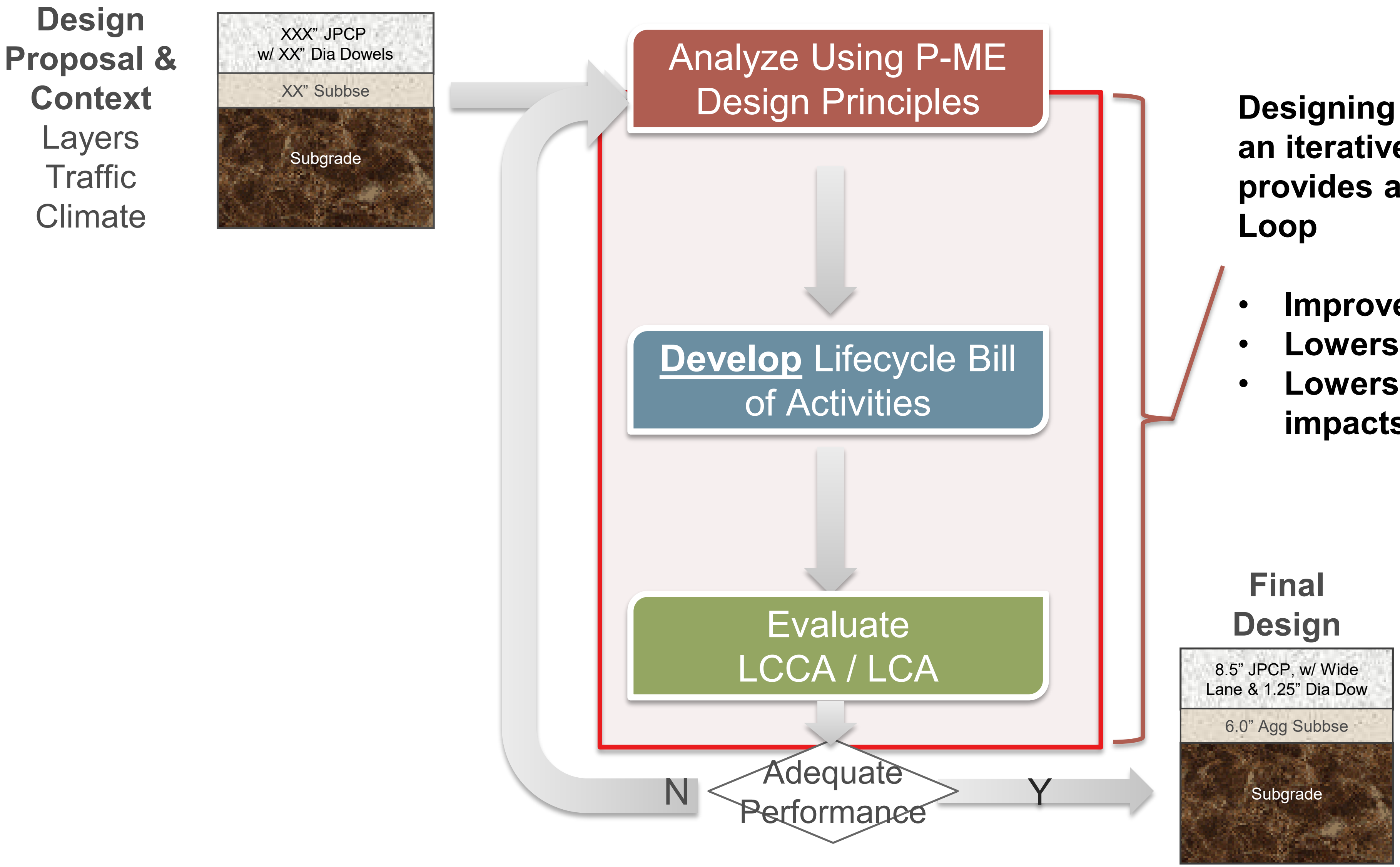
Need to Link Design and Evaluation in an Iterative Process

Assures that performance, costs and CO_2 impacts are representative of the actual pavement



Designing pavements in an iterative procedure provides a Feedback Loop

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

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Slide: Courtesy of MIT Concrete Sustainability Hub

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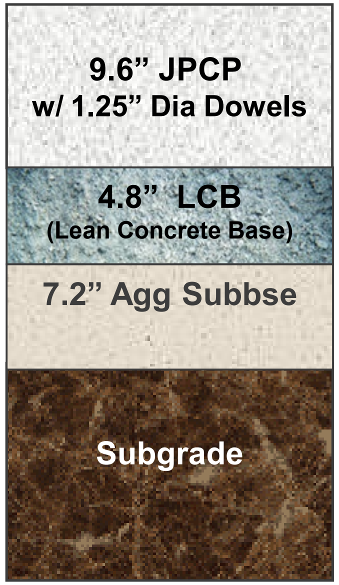
Route 67 in Ramona, CA

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

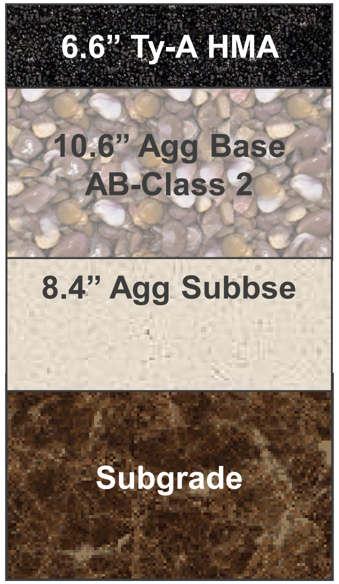
CALTRANS Concrete Design



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

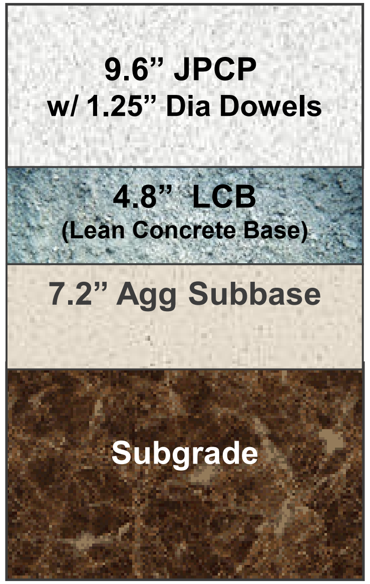
- 3” AC Overlay in years 20,
- Mill / 4" ACOL in year 25
- Mill / 3" ACOL in year 35
- Mill / 4" ACOL in year 45
- Mill / 3" ACOL in year 50 (5-year life)

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

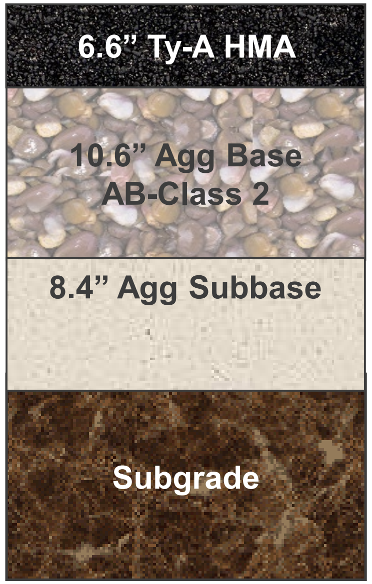
Route 67 - Ramona, CA

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



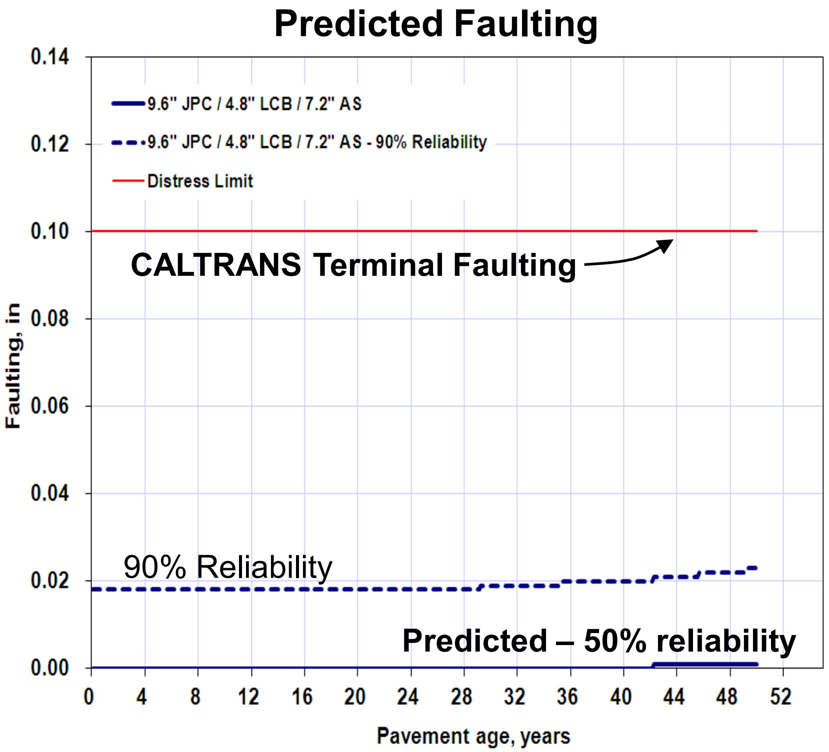
	LCCA (NPV $/mile)
Initial Const.	**$2,278,102**
Pavement	*$1,437,480*
AB-Class 2	*$522,262*
Agg Subbase	*$318,360*
Rehabilitation	**$1,104,504**
Total	**$3,382,606**

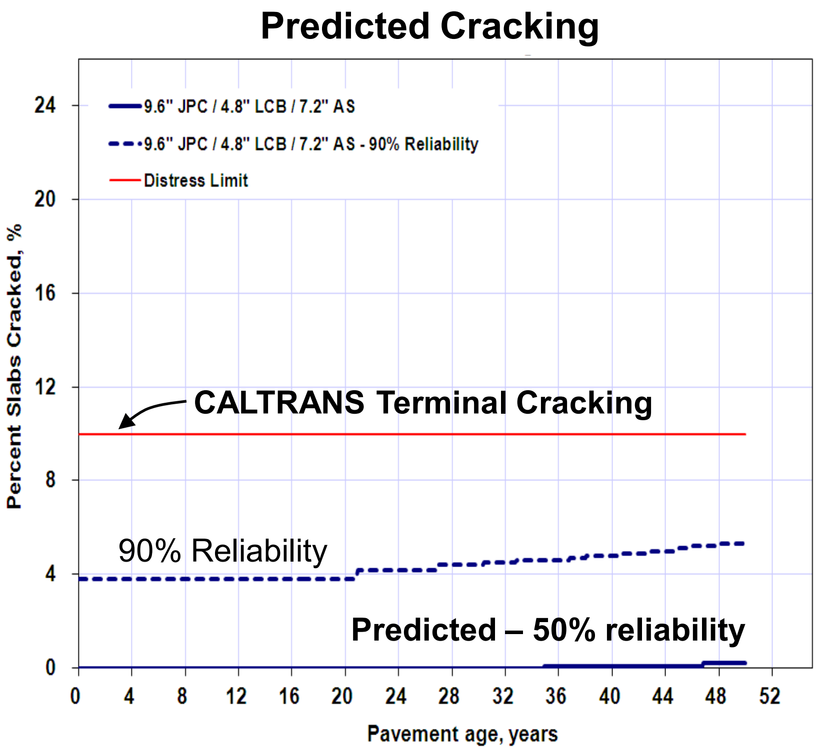
Asphalt is 38% lower in Initial Costs and 20% lower in Life Cycle Costs

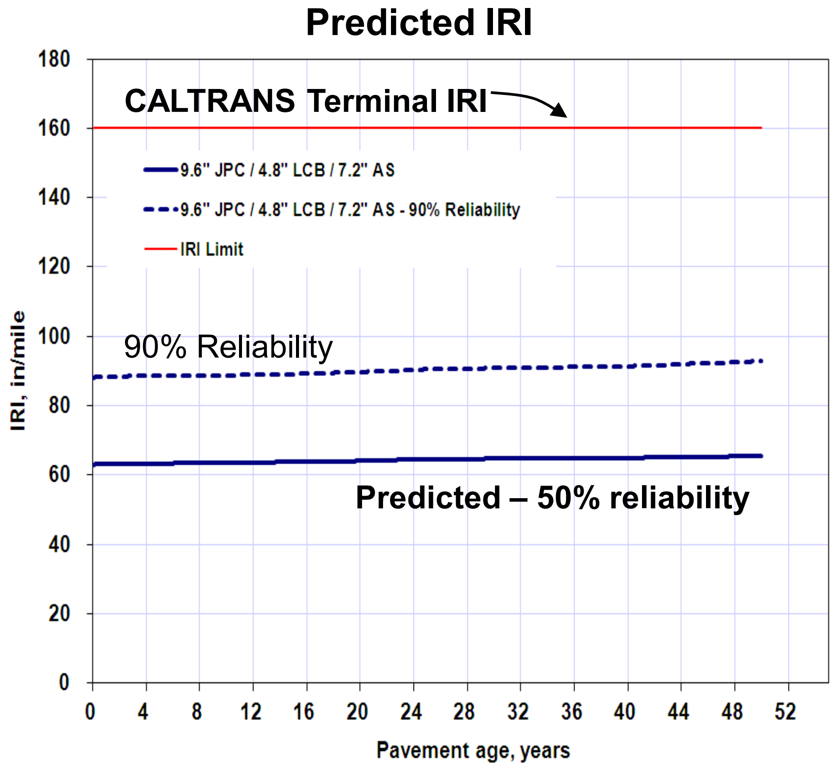
Caltrans Concrete Design: From Table 623.1E (South Coast/Central Coast, Type II SG
Initial AADTT = 1,357 / day, 4% Compound Growth (Initial ESAL = 335,000 / yr)
20 Yr ESALs = 10,650,000; 50 Yr ESALS = 51,151,000

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

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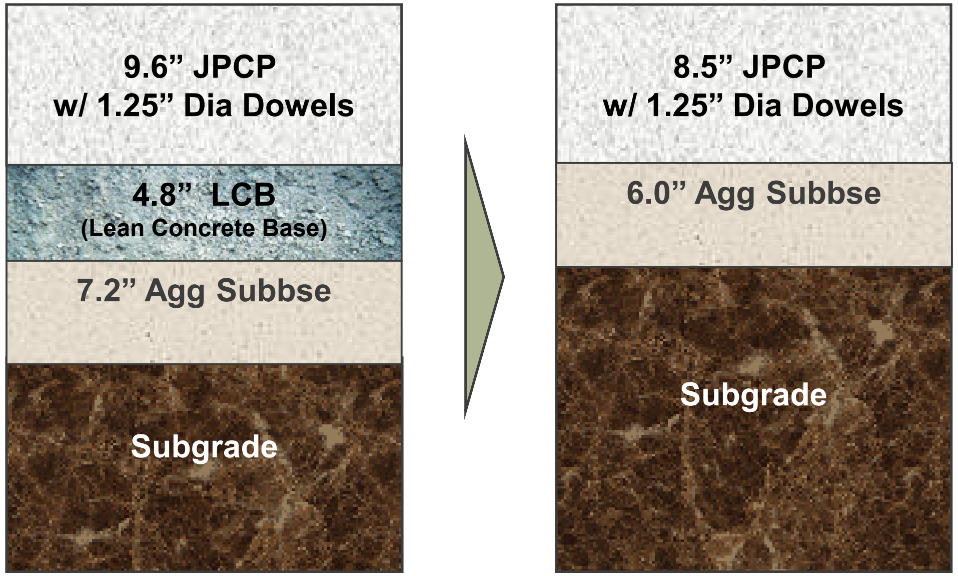
Over-Design Creates the Opportunity for Optimization

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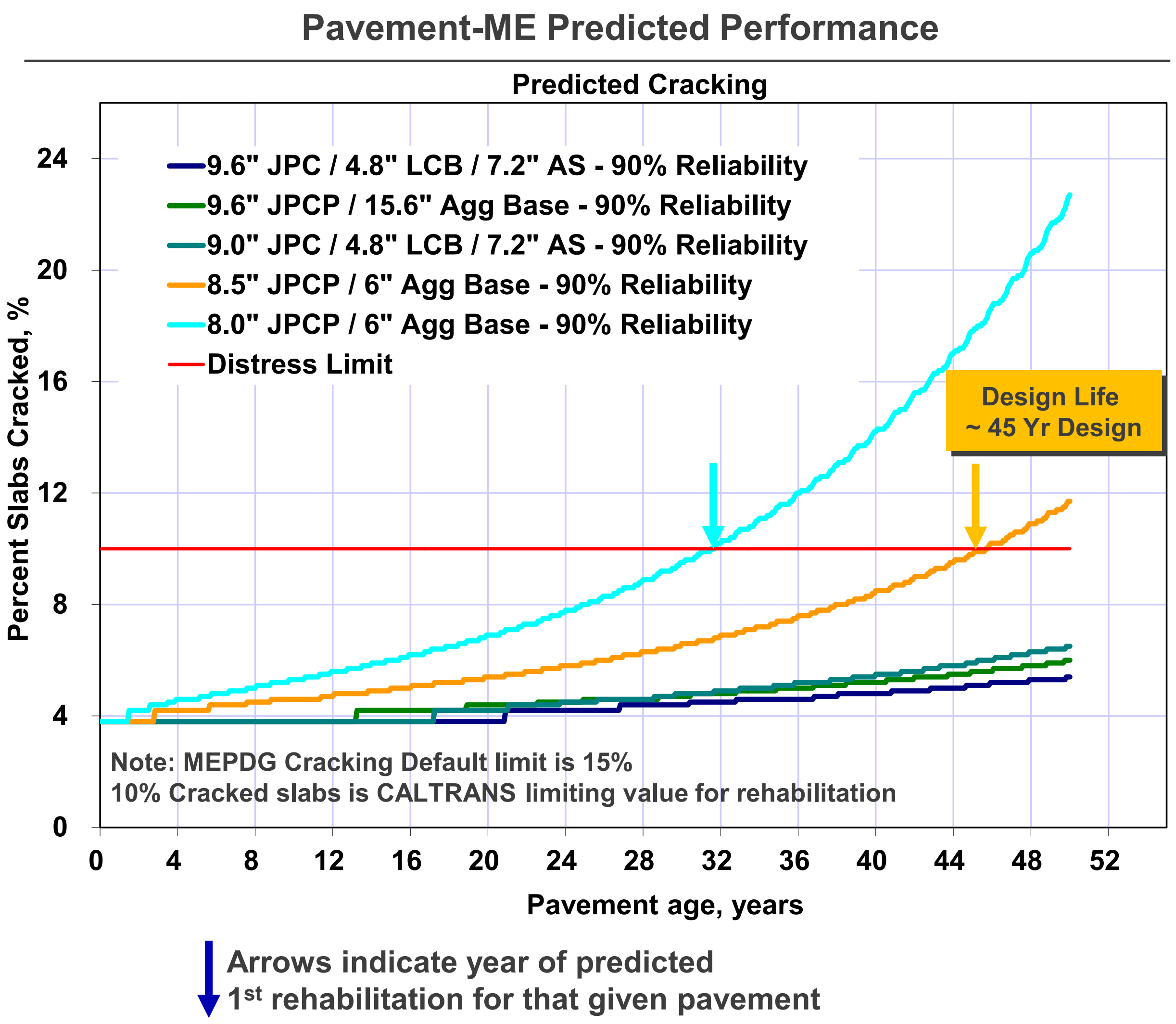
8.5” Jointed Plain Concrete Pvmt w/ Dowels meets the Performance Criteria

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



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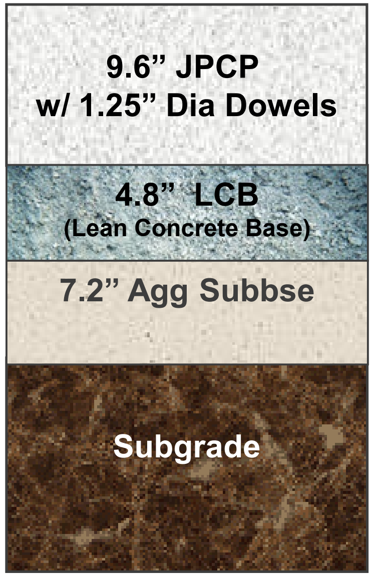
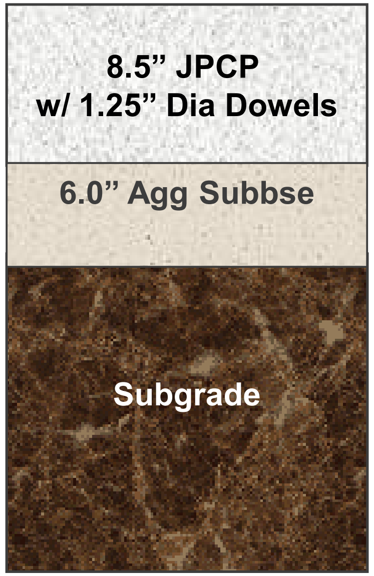
Project Specific Pavement Optimization Lowers Cost & Environmental Impact

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%)

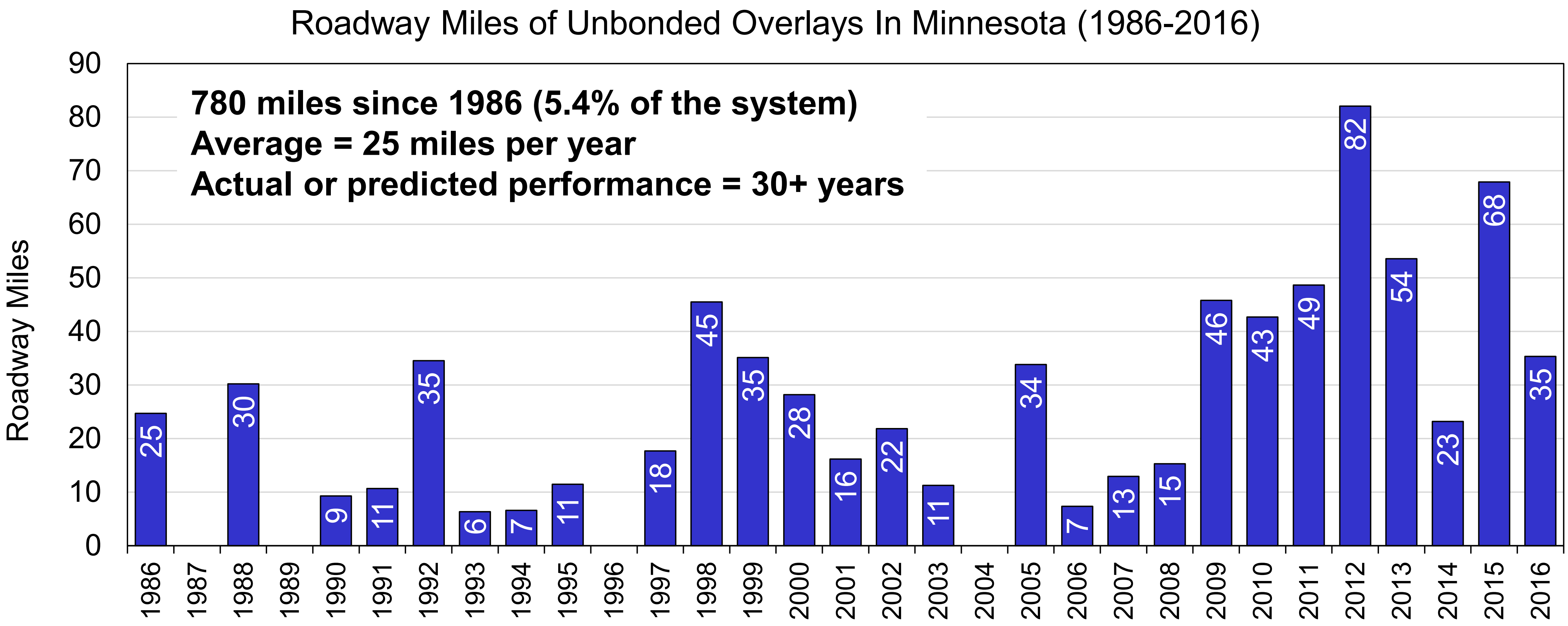
Optimization reduced the initial construction costs by $890k (28.3%) and the life cycle cost $1.48M (36.6%)

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

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

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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

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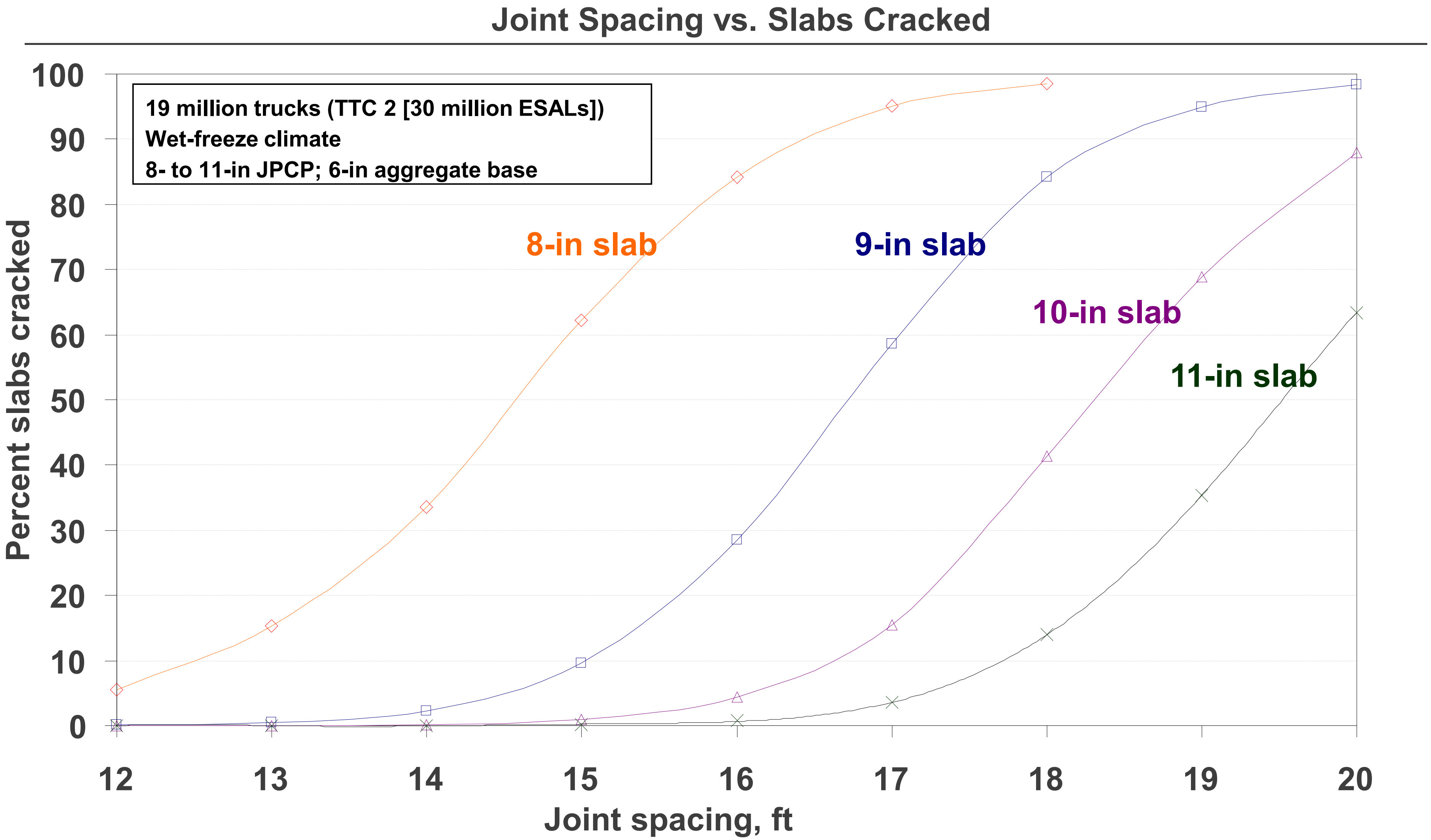
Shorter Joint Spacing Reduces the Required Slab Thickness



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

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

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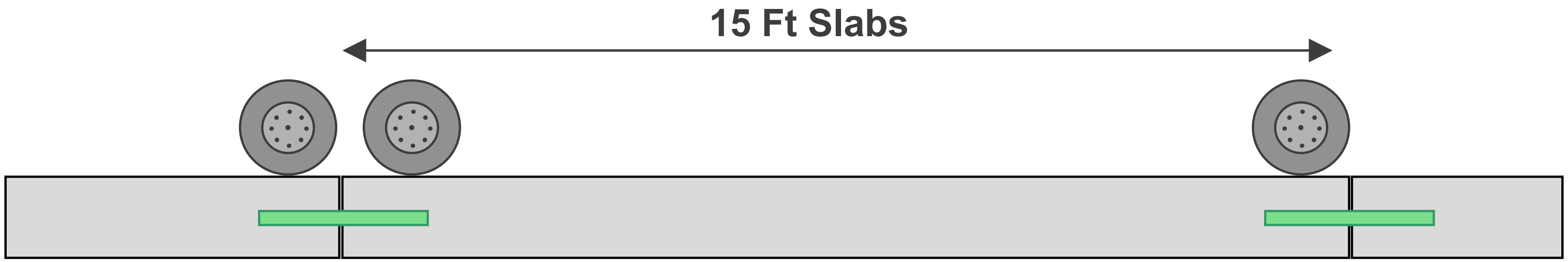
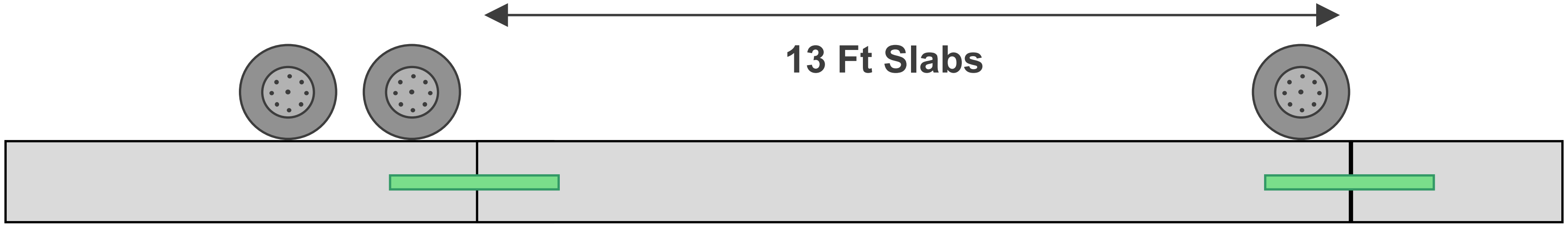
Shorter Joint Spacing Reduces Wheel Loads Stresses



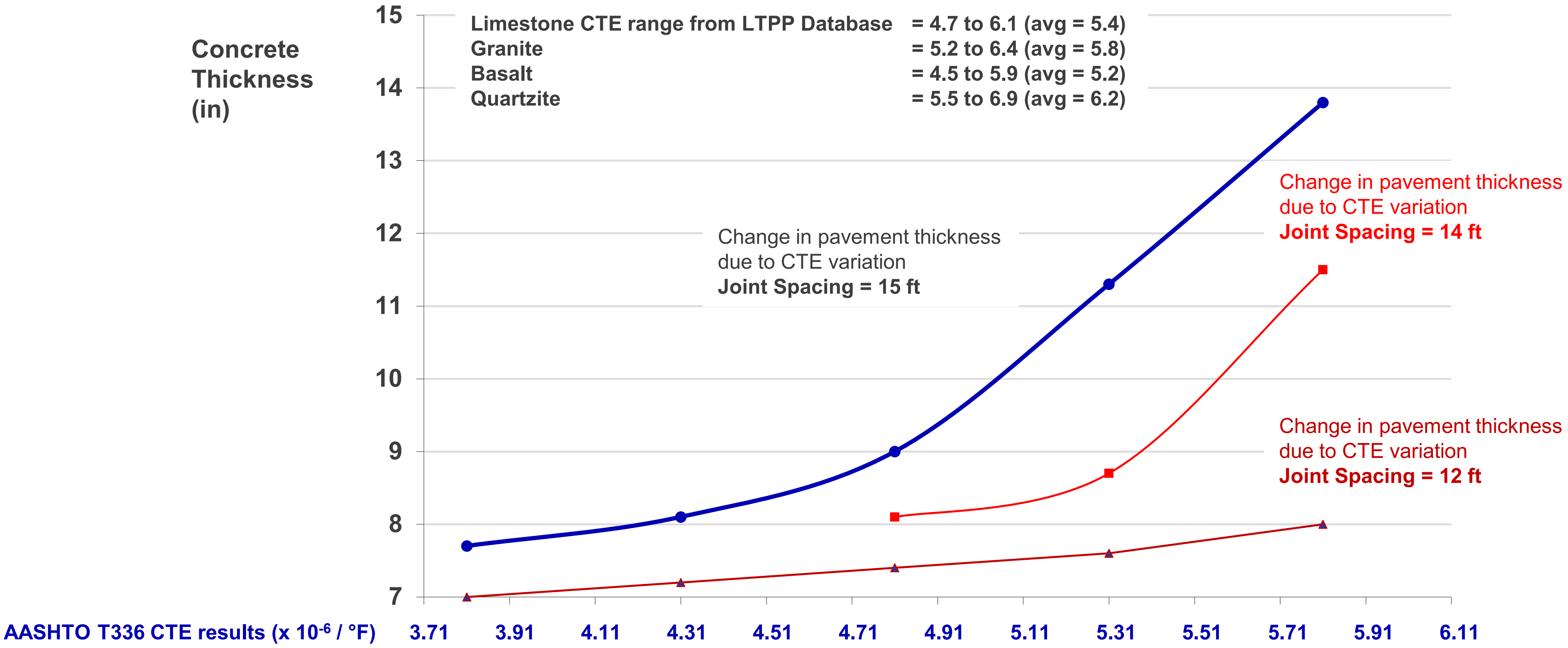
Loading the slab at each end creates additional top-down stresses and causes earlier top-down cracking



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

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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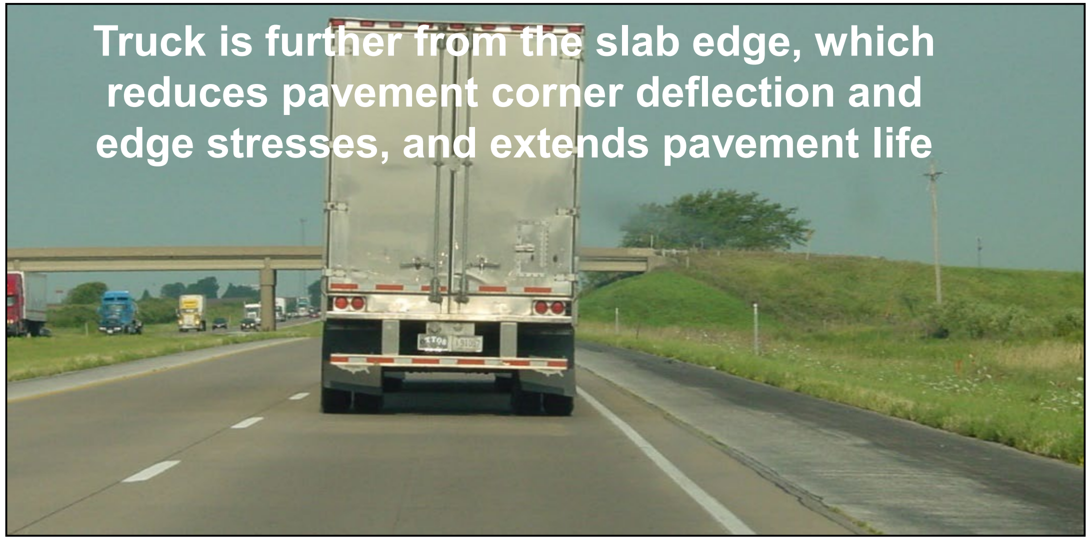
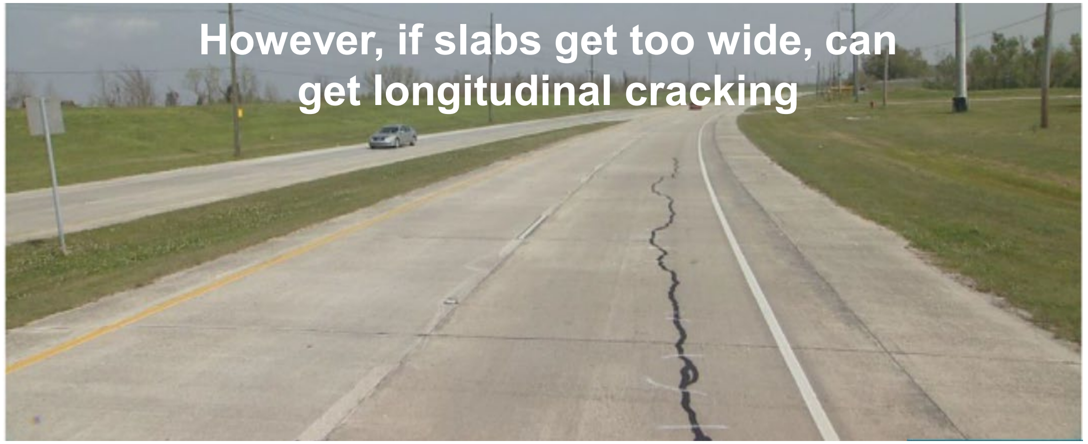
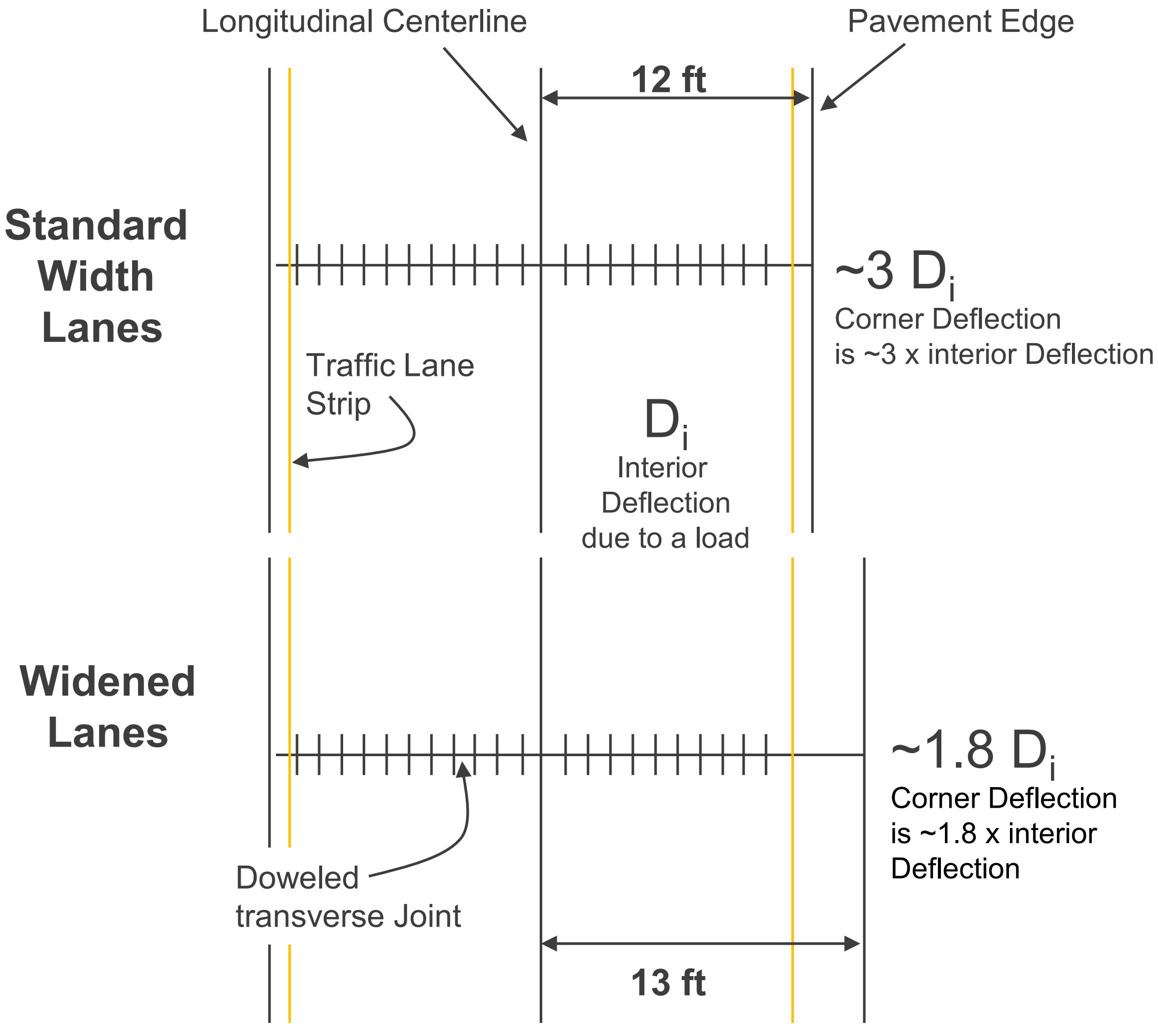
Widened Lanes Shifts Traffic Away From Edge

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







Each foot of lane widening adds ~6 to 8% to Lane Costs

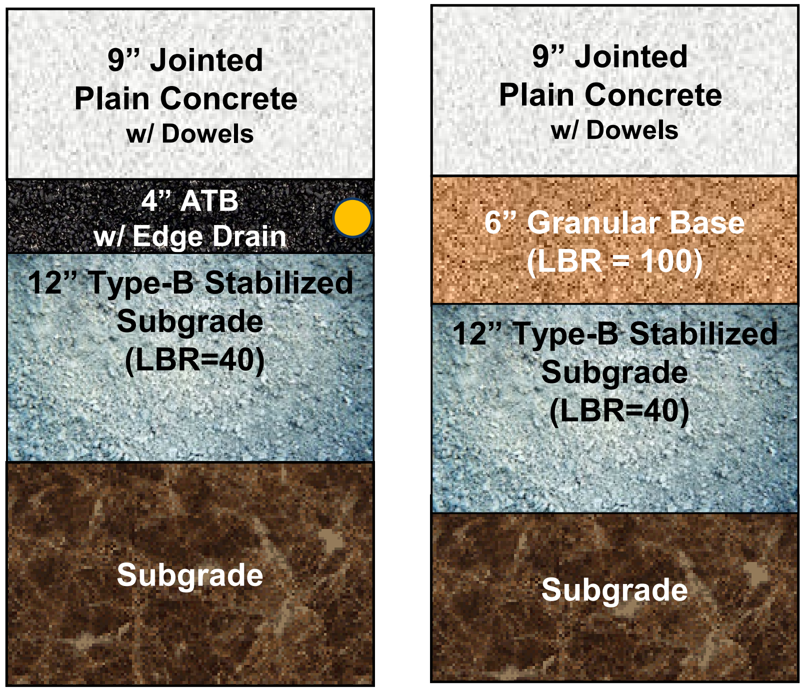
Approximately equal to 1.25 to 1.50-in of thickness, but cost impact depends on shoulder type

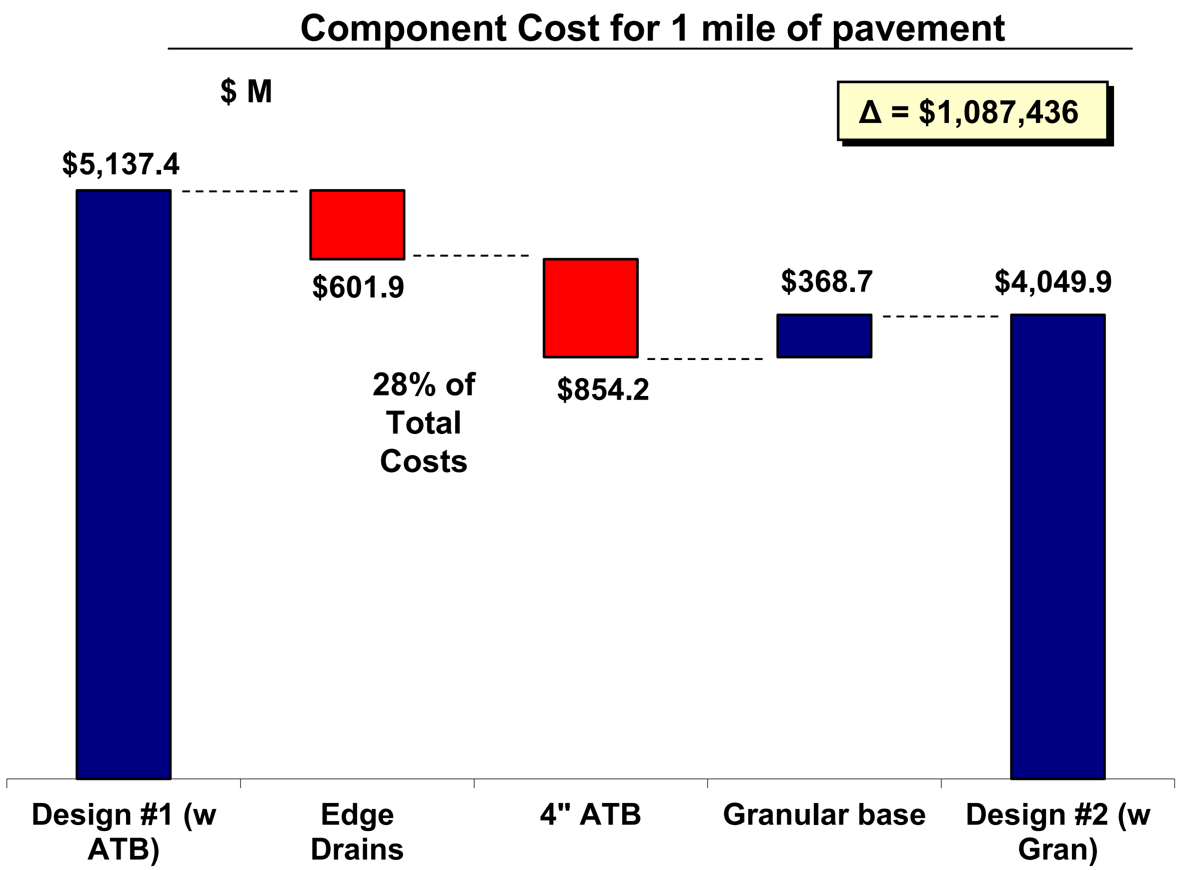
Whether to Add Features should be Based on its Cost / Benefit

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

Design #1
(with ATB & Drainage)

Design #2
(6” Granular Base)



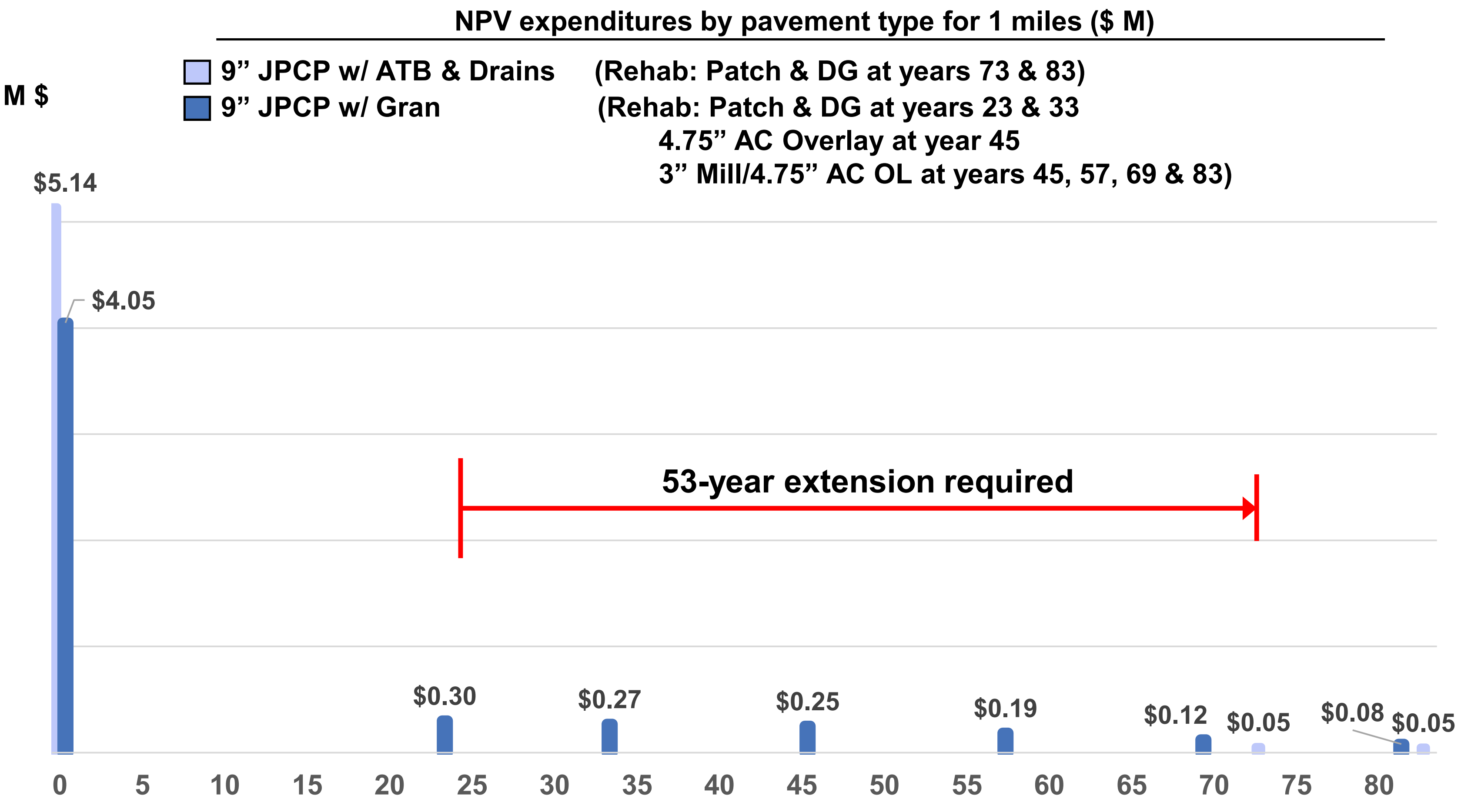


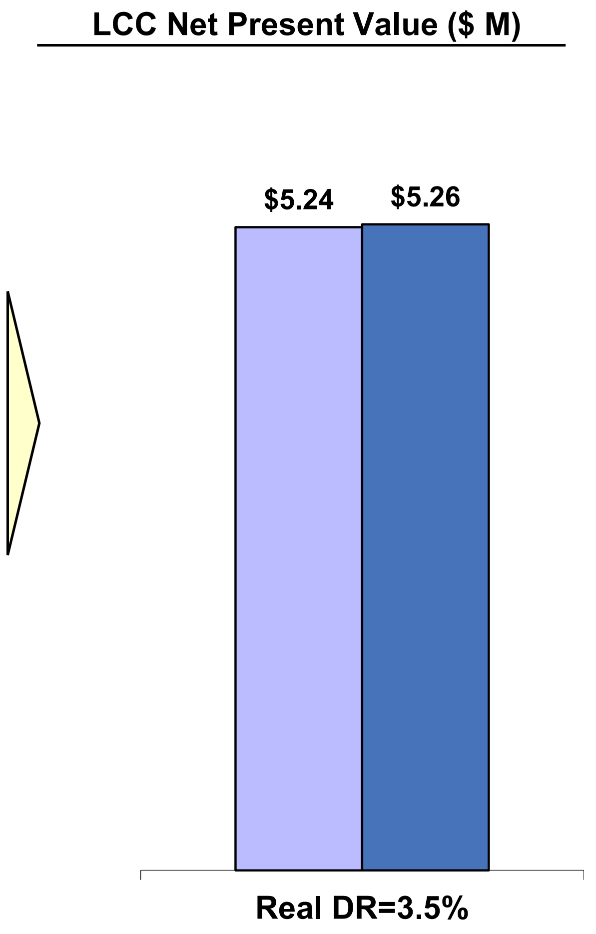
For the drainage and ATB to be effective it must extend the pavements life to overcome $1,087,436 initial cost differential

Cost for 1 miles of 4 lane pavement + Shoulders

The Pavement with ATB Must Last 73 Years Before First Rehabiltation

Based on an equivalent Life Cycle Costs comparison

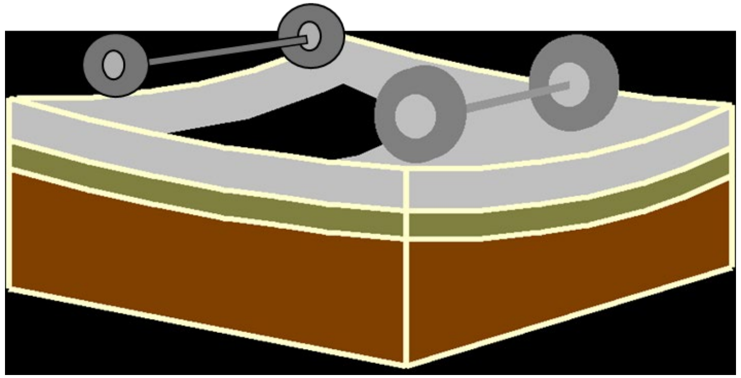




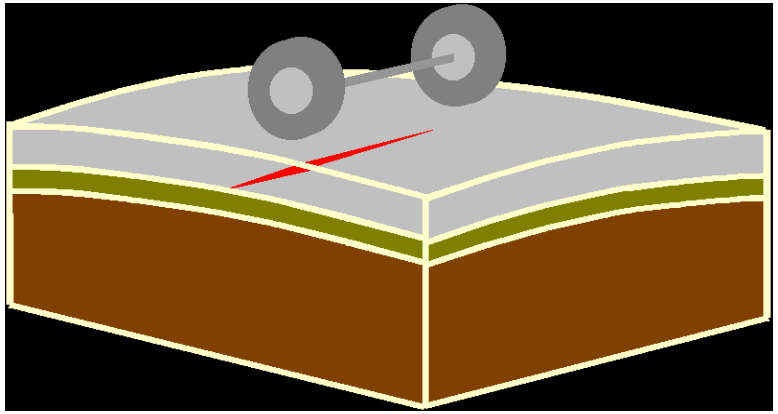
Design Issue Materials Engineers can help with

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

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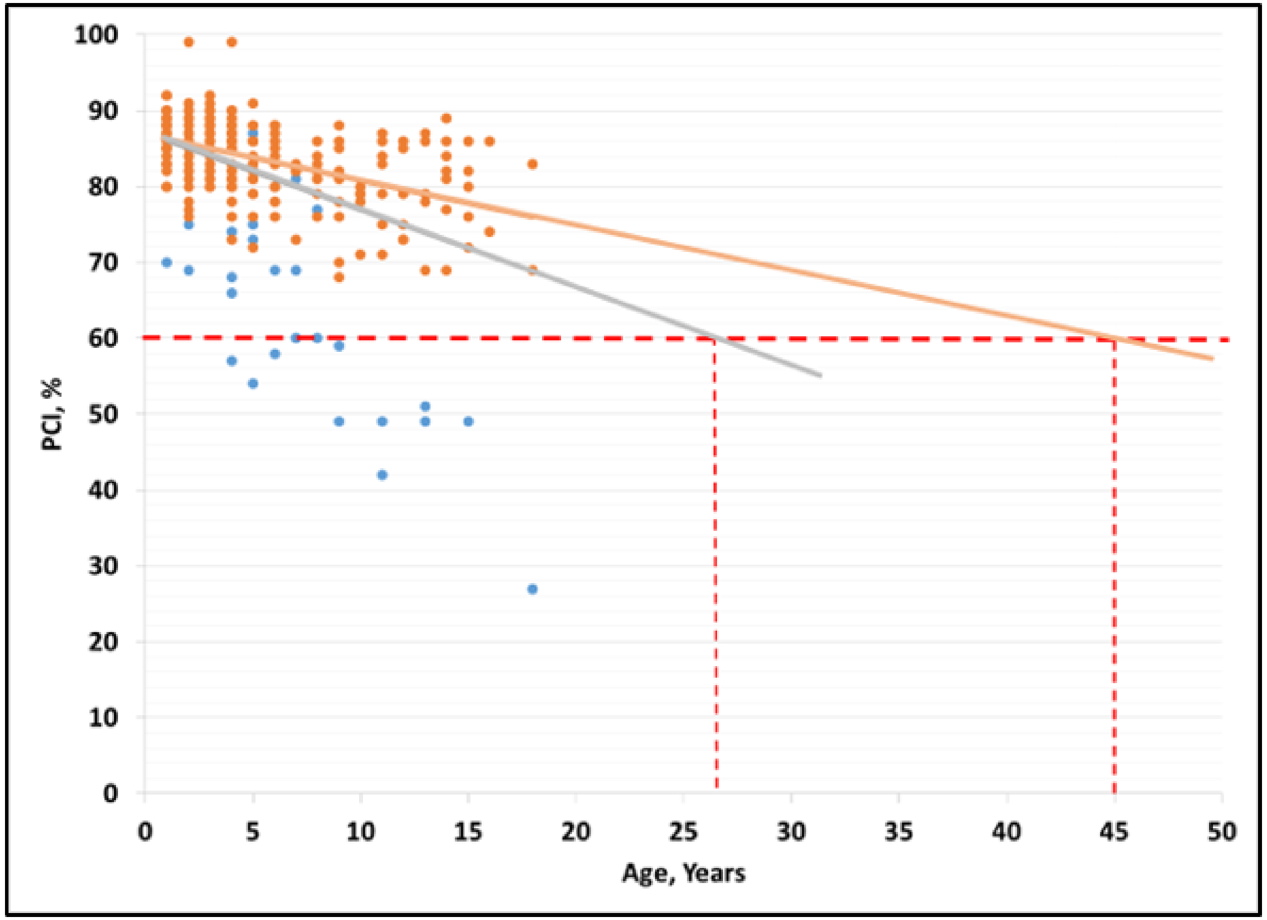
All Current Pavement design Programs Assume Good Concrete Mix

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

Iowa's Thin Bonded & Unbonded Concrete Overlay Performance



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

With proper materials & construction, it is reasonable to expect much improved performance (that is not accounted for in design)

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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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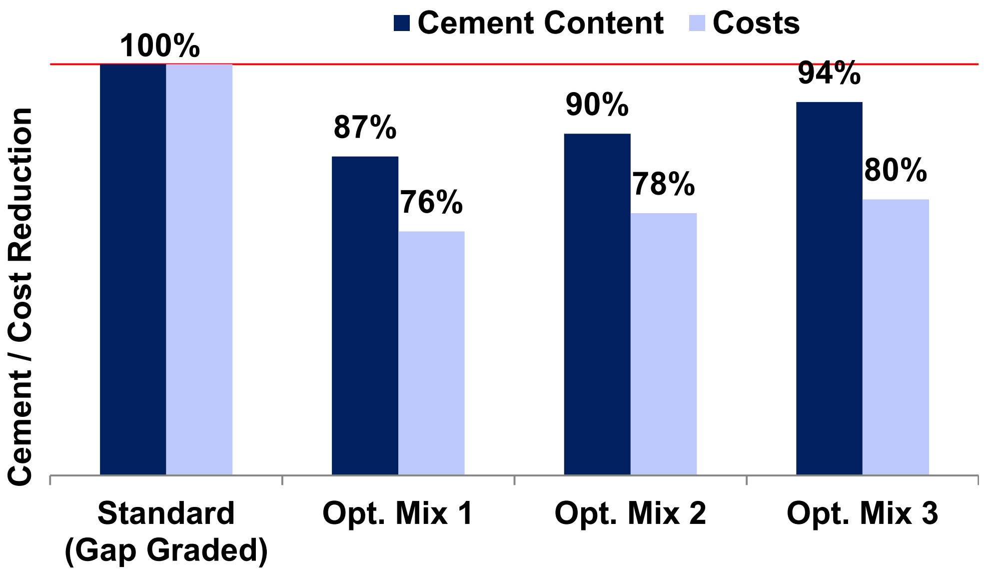
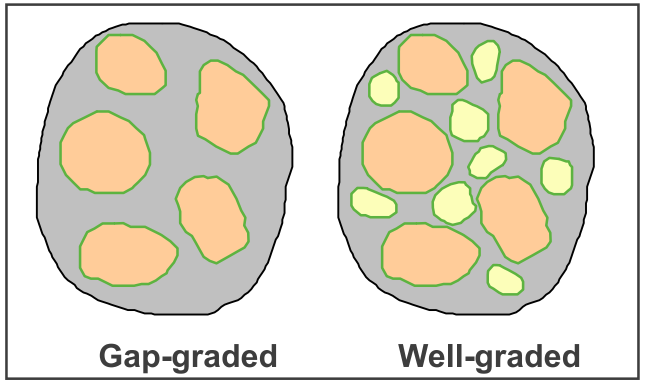
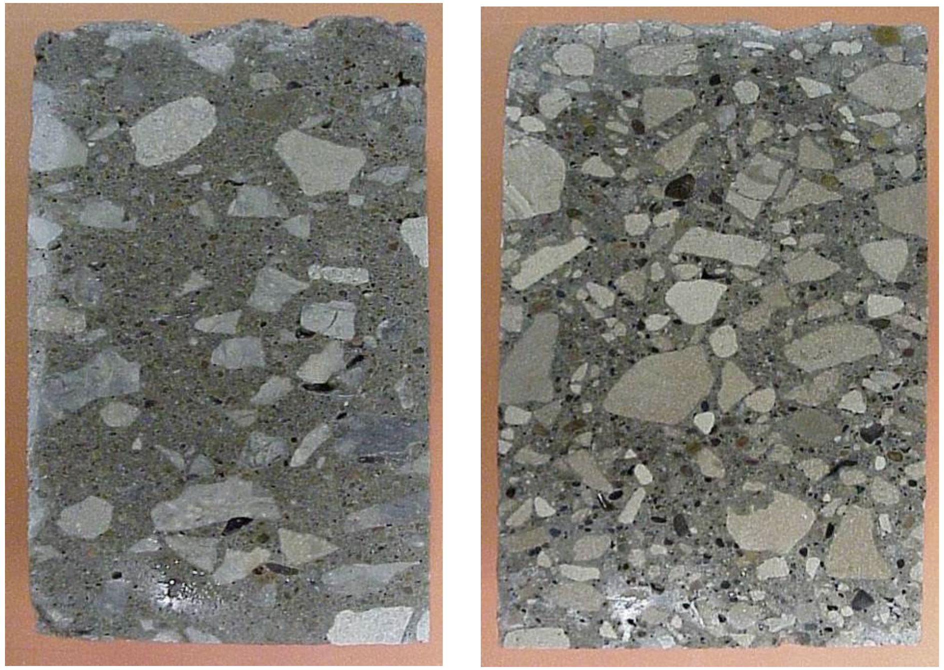
Using Well-graded Concrete Aggregate Gradation Improves Performance And Lower Costs

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)







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

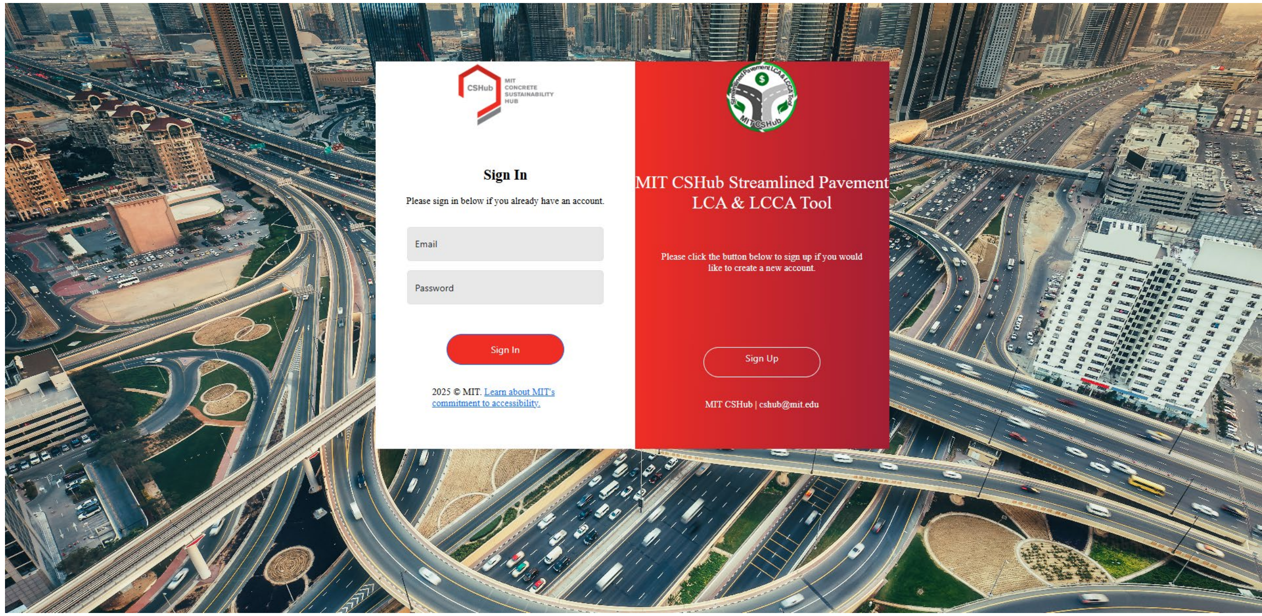
- **Fibers do not increase the concrete's strength**
  - Increases toughness
  - Increases post-crack integrity / fatigue
  - Improve ductility

- **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**
  - Polypropylene ~ 3 lbs./CY
  - Steel ~ 40 to 60 lbs./CY
  - Synthetic ~ 3 to 5 lbs./CY

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

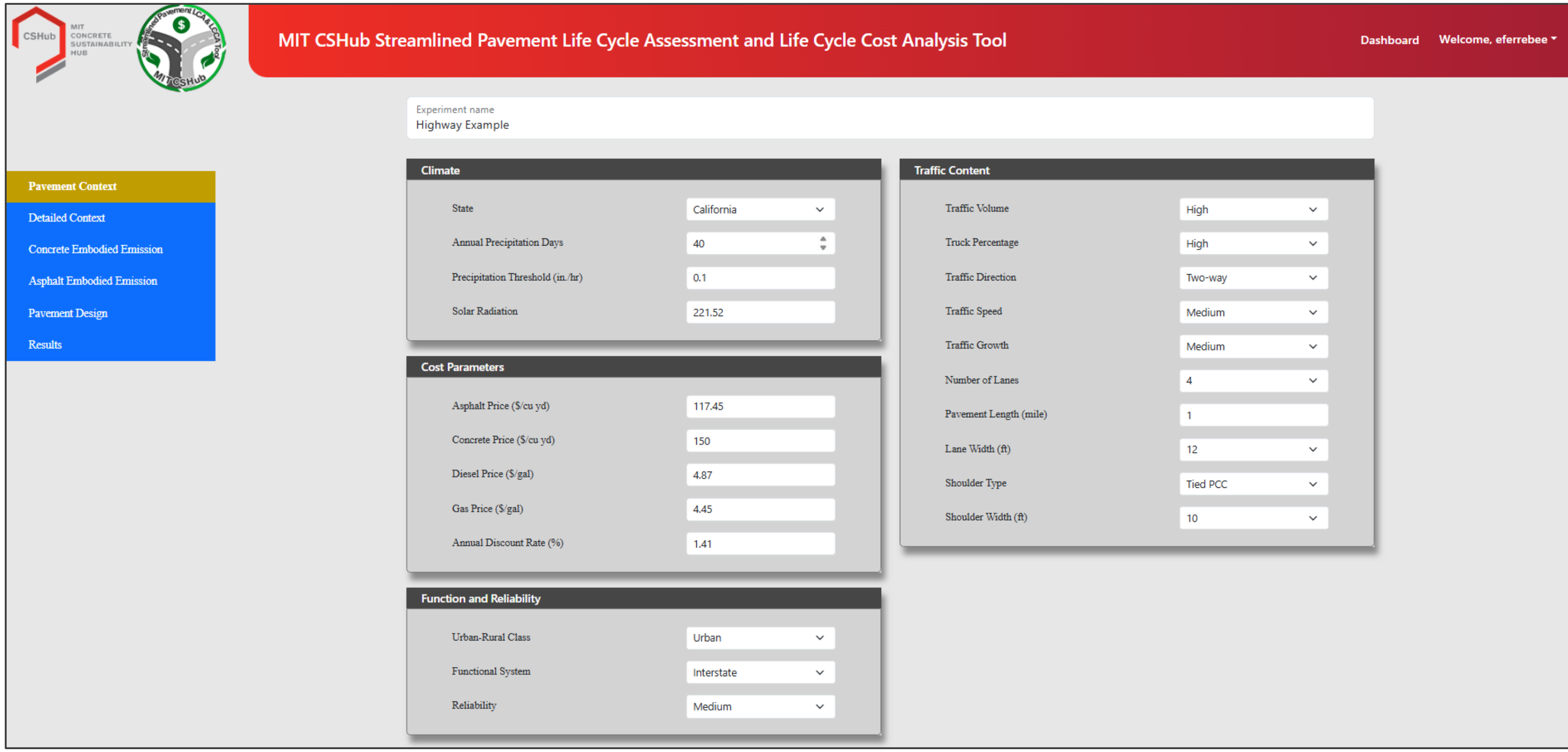
MIT CSHub Streamlined Pavement LCA & LCCA Tool (Online)

http://pavementlca.mit.edu

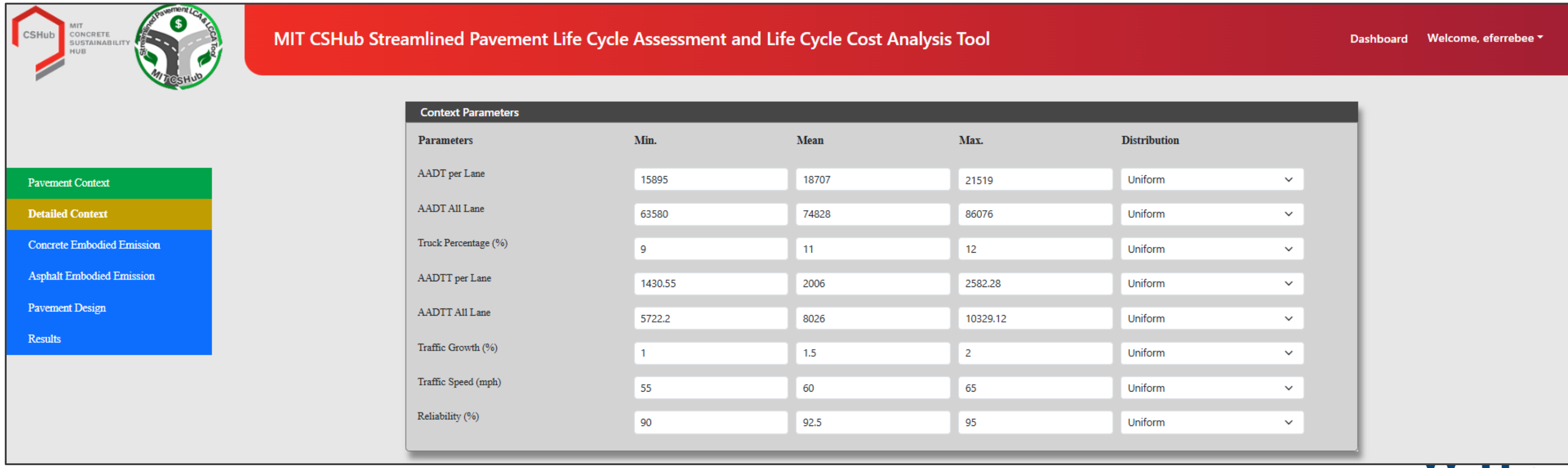
MIT STREAMLINED LCA & LCCA PLATFORM

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)



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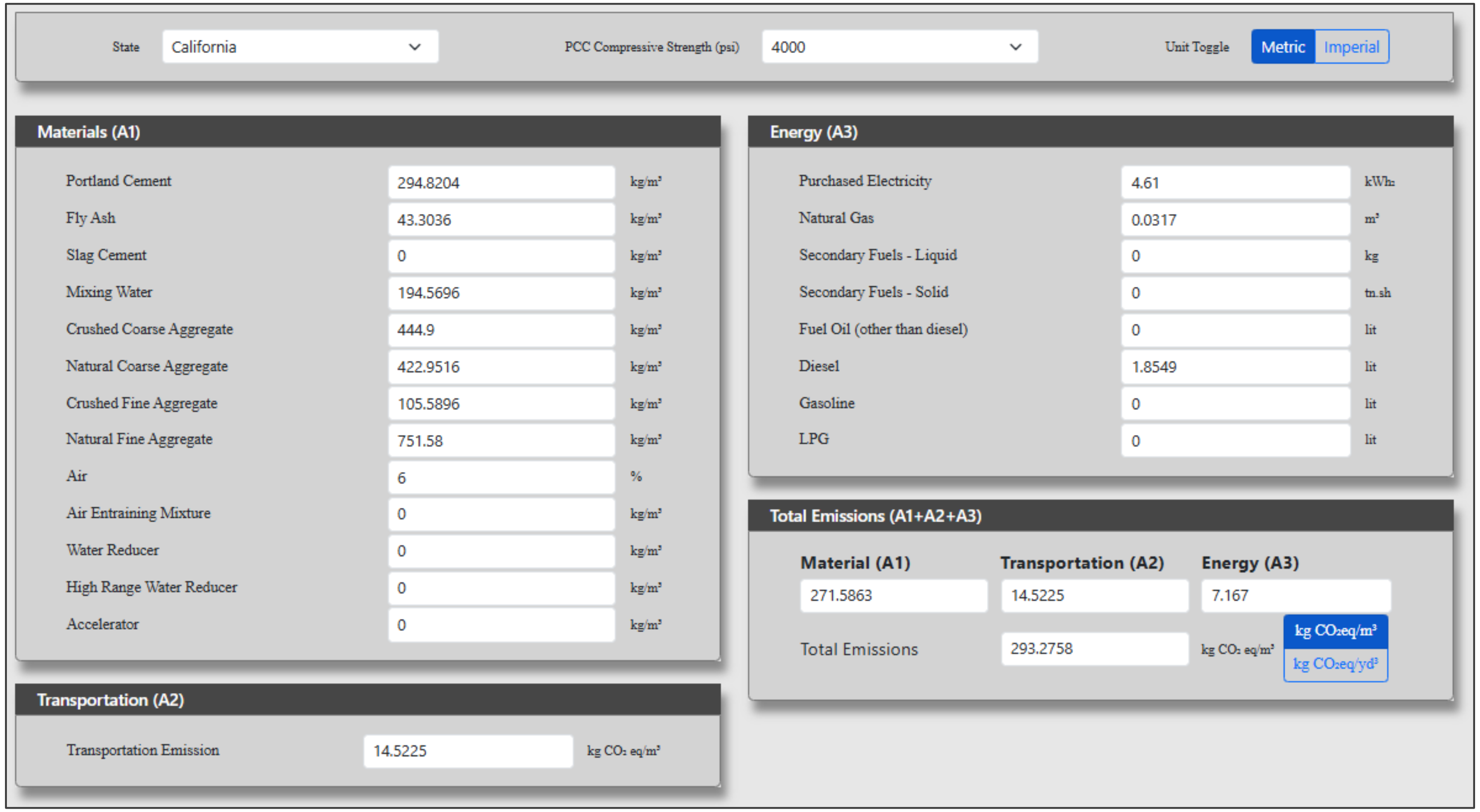
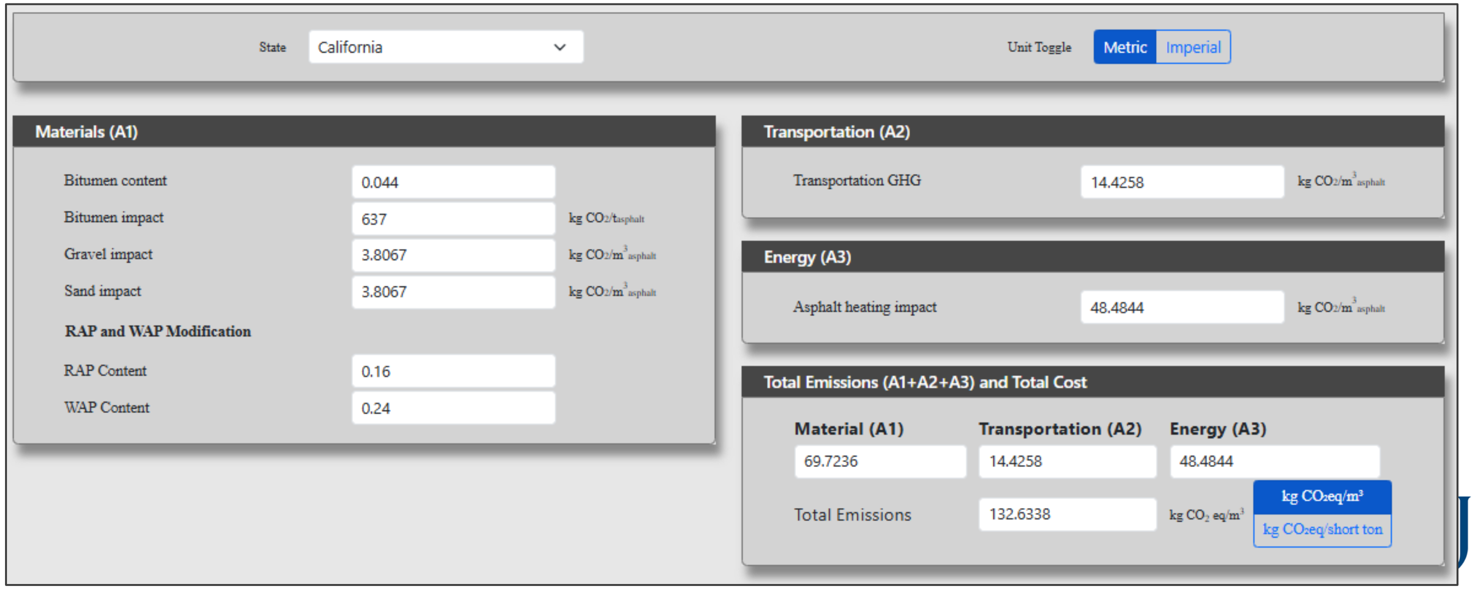
Embodied Emission sheets provide material properties

- 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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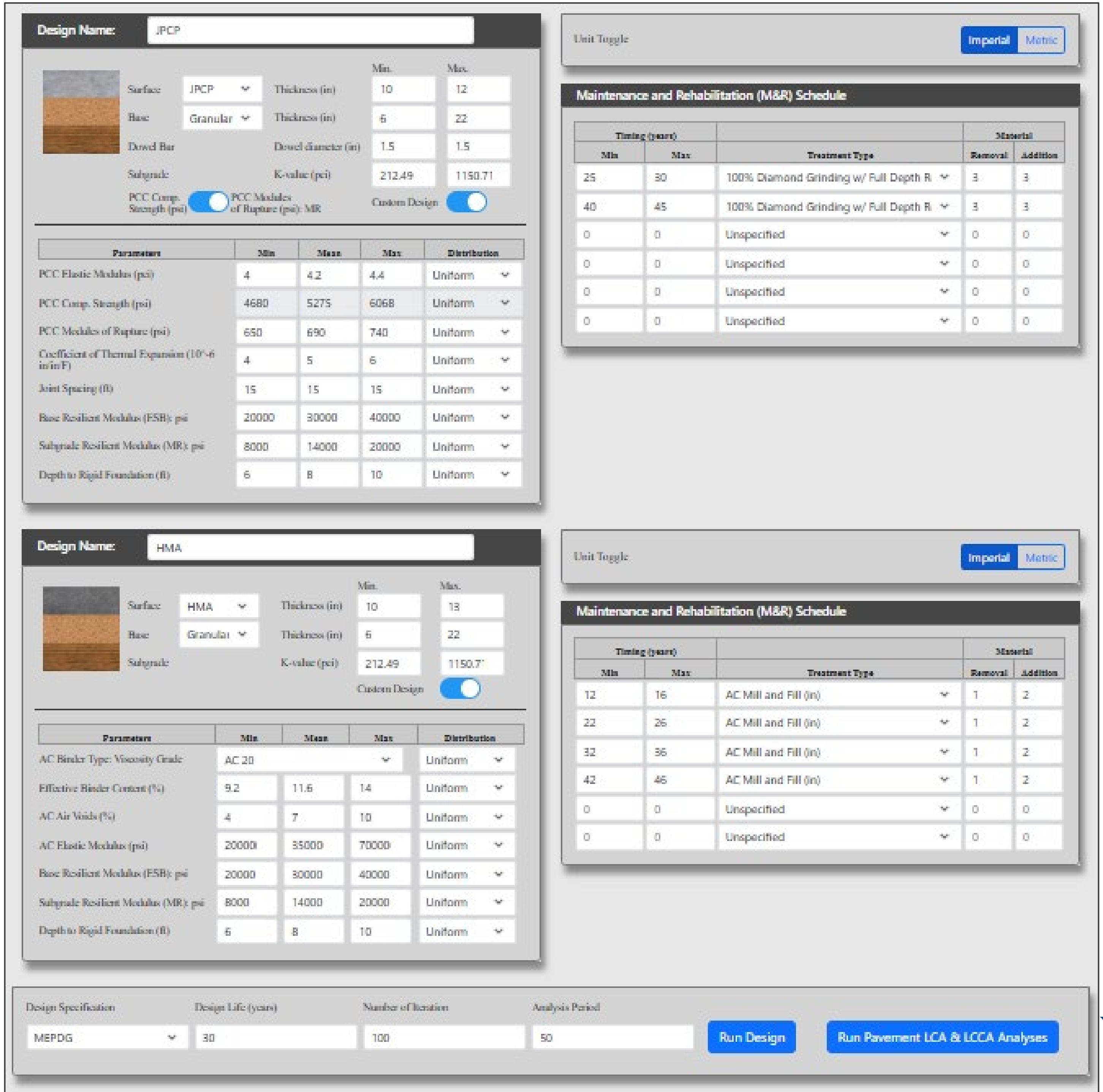
Pavement Desing sheets provide Initial & Rehab Activities

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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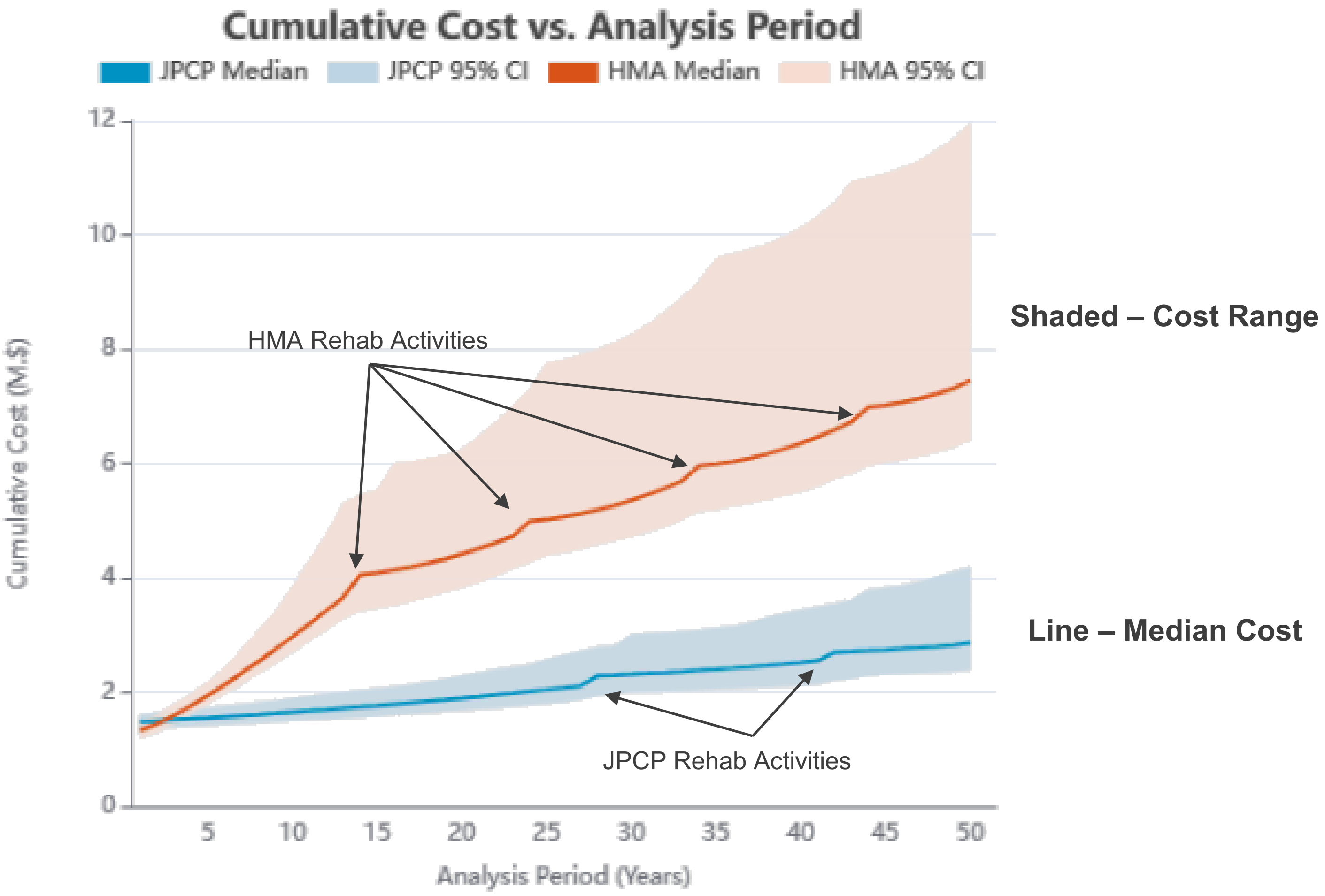
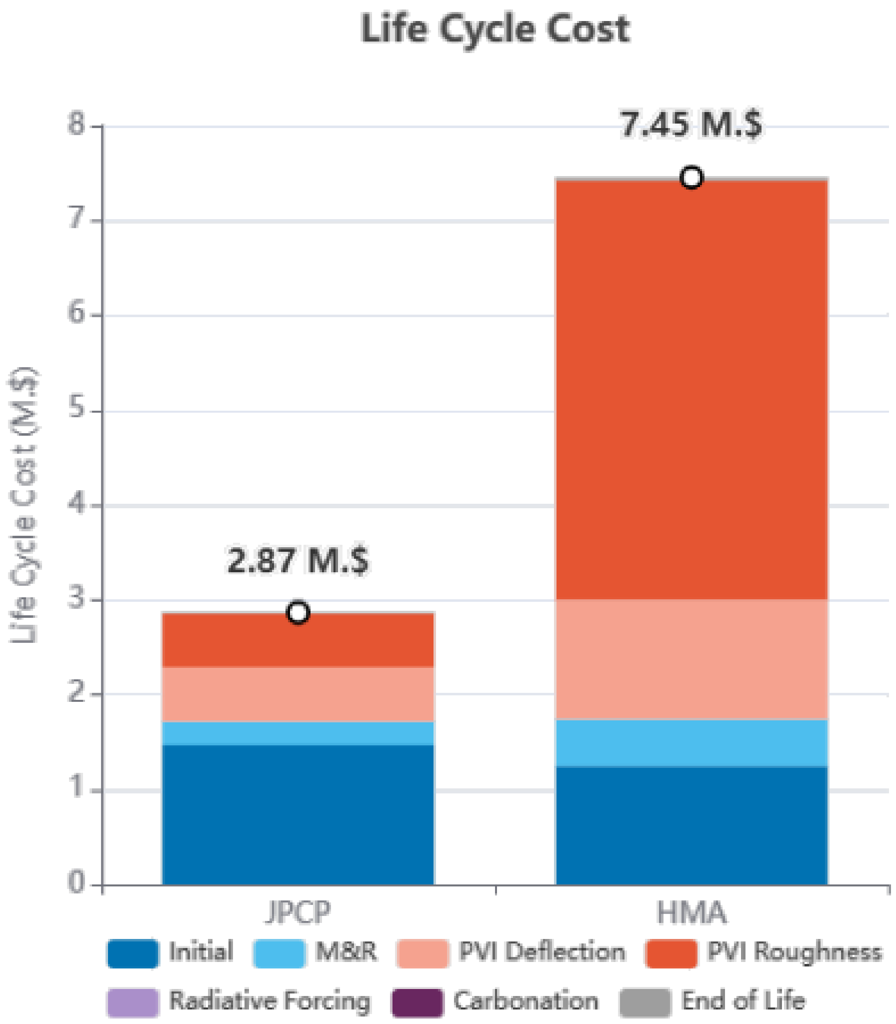
MIT STREAMLINED LCA & LCCA PLATFORM - OUTPUT

http://pavementlca.mit.edu





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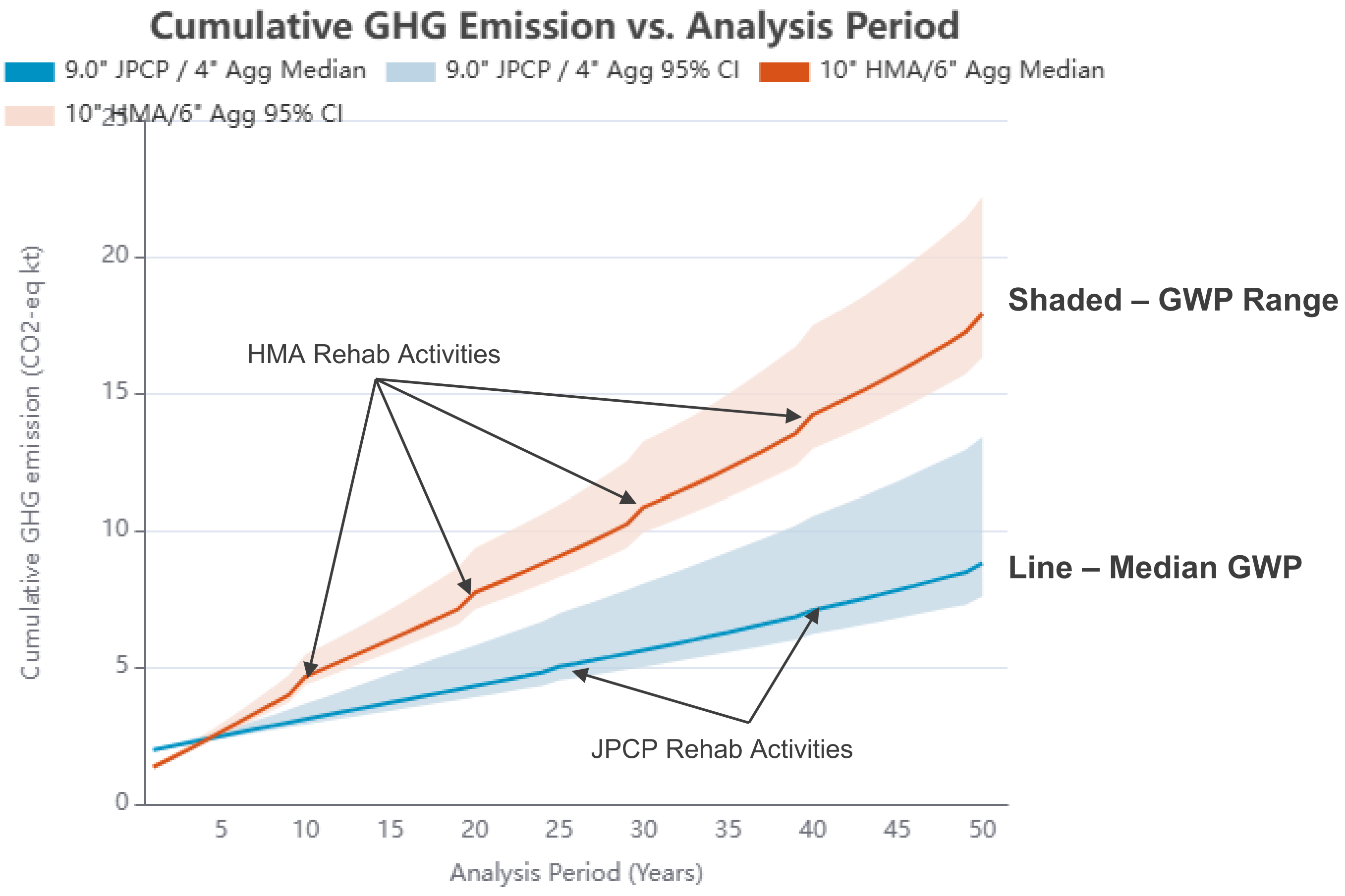

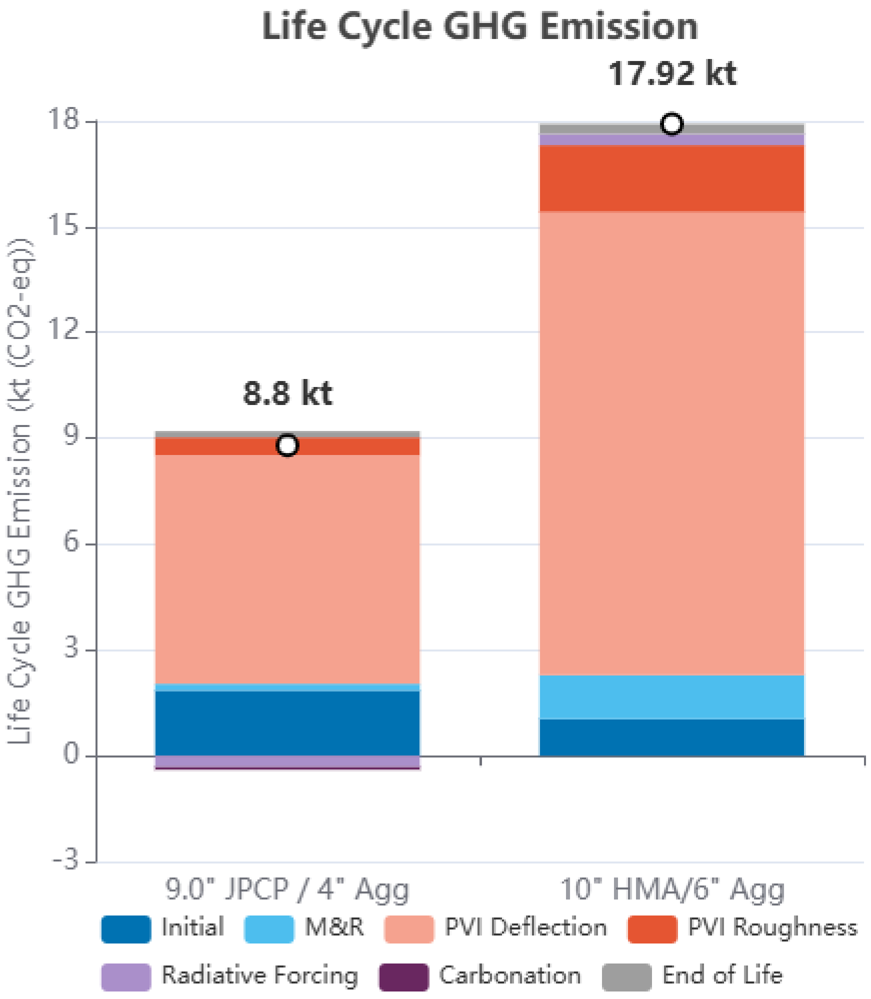

- Albedo
- Carbon Uptake
- End of Life
- Initial Emission
- M&R
- PVI Deflection
- PVI Roughness
- IRI for Asphalt Pavement
- IRI for Concrete Pavement

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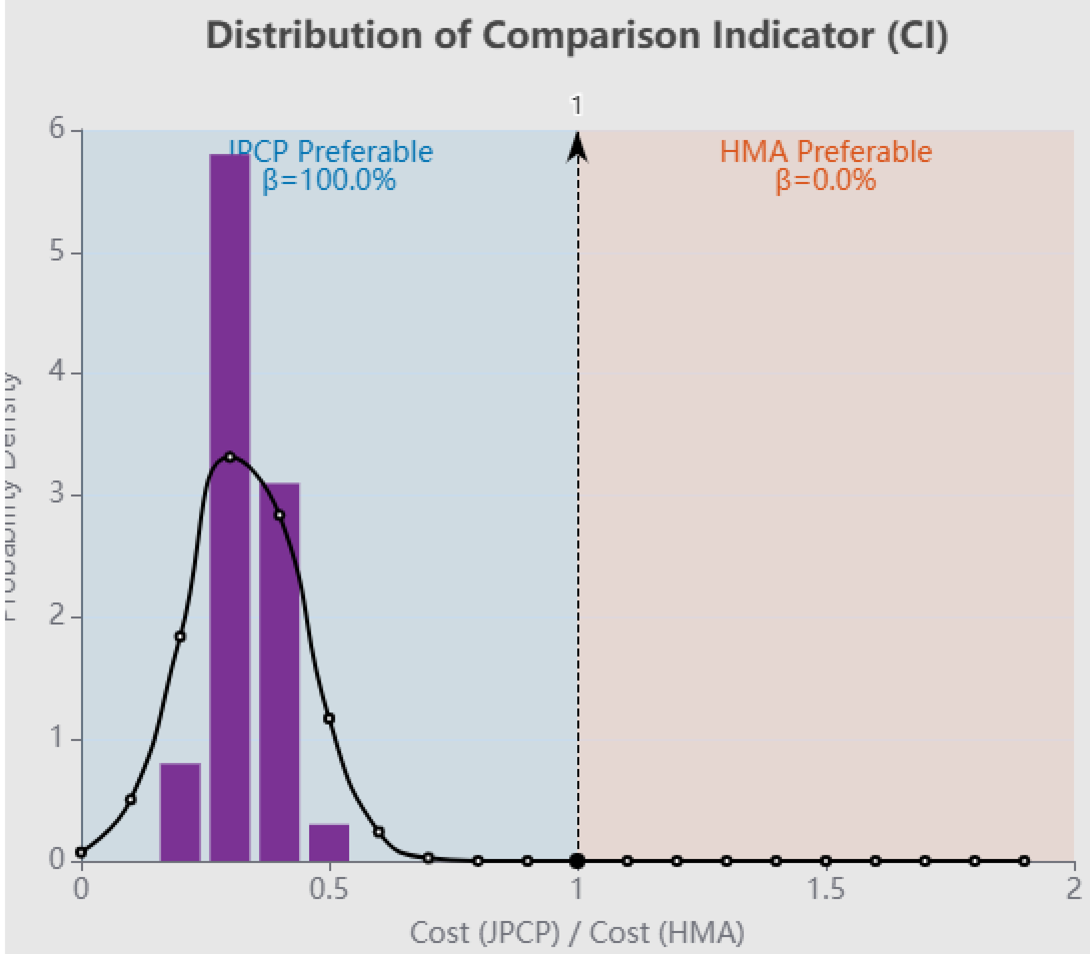

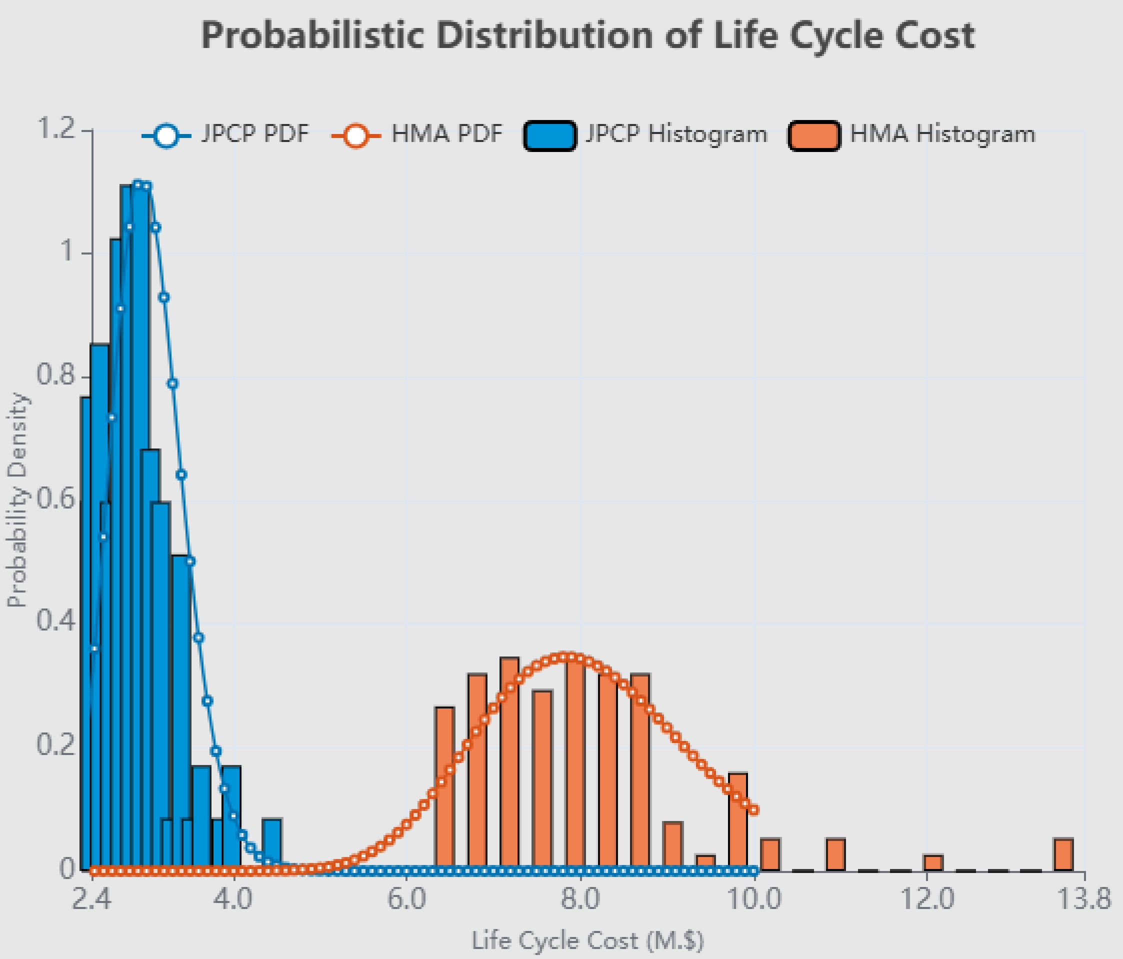

Thank you. Questions? Feedback?

Eric Ferrebee, P.E.

Senior Director of Technical Services

eferrebee@acpa.org | 847.423.8709

ACPA

Jim Mack, P.E.

Associate Principal

jmack@wje.com | 713.598.6669

WJE ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

Wiss, Janney, Elstner Associates, Inc.