# TRADE-OFF ANALYSIS TO IMPROVE CONCRETE PAVEMENT SUSTAINABILITY BY OPTIMIZING DESIGNS

**April 2023**

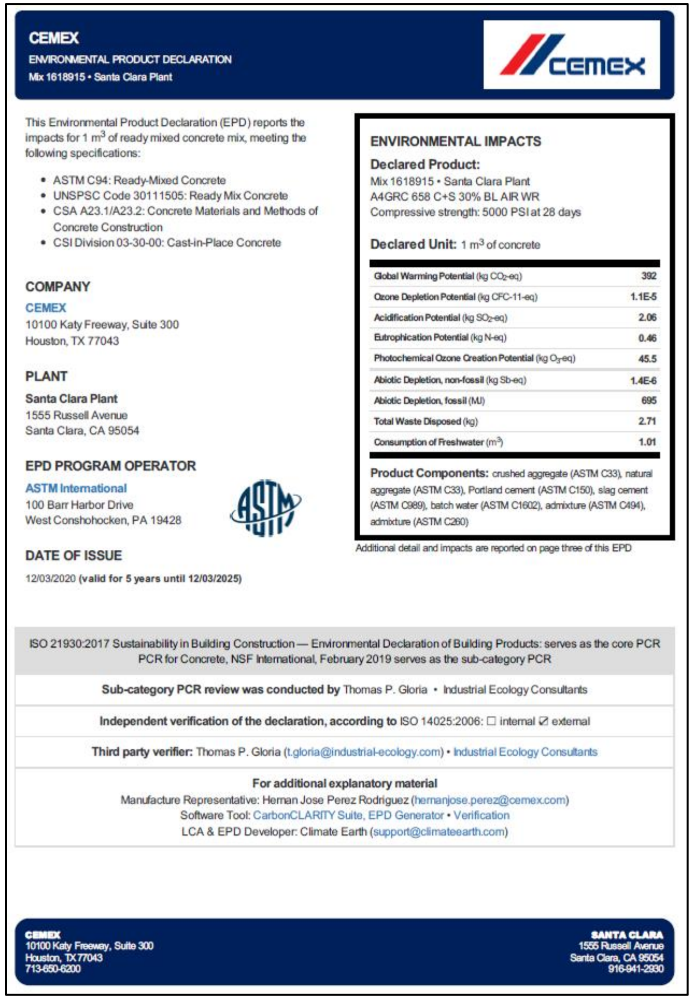
**ACI Concrete Convention, San Francisco, CA**


**James Mack, P.E.**

**Director, Market Development – Infrastructure**

**CEMEX**

# MUCH OF THE CURRENT SUSTAINABILITY FOCUS IS ON EPDs, REDUCING "EMBODIED EMISSIONS" & USING LOW CARBON CONSTRUCTION MATERIALS



CEMEX
ENVIRONMENTAL PRODUCT DECLARATION
Mix 1618915 • Santa Clara Plant

This Environmental Product Declaration (EPD) reports the impacts for 1 $m^3$ of ready mixed concrete mix, meeting the following specifications:

- ASTM C94: Ready-Mixed Concrete
- UNSPSC Code 30111505: Ready Mix Concrete
- CSA A23.1/A23.2: Concrete Materials and Methods of Concrete Construction
- CSI Division 03-30-00: Cast-in-Place Concrete

COMPANY
CEMEX
10100 Katy Freeway, Suite 300
Houston, TX 77043

PLANT
Santa Clara Plant
1555 Russell Avenue
Santa Clara, CA 95054

EPD PROGRAM OPERATOR
ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428

DATE OF ISSUE
12/03/2020 **(valid for 5 years until 12/03/2025)**

ENVIRONMENTAL IMPACTS

**Declared Product:**
Mix 1618915 • Santa Clara Plant
A4GRC 658 C+S 30% BL AIR WR
Compressive strength: 5000 PSI at 28 days

**Declared Unit:** 1 $m^3$ of concrete

| | |
|---|---|
| **Global Warming Potential** (kg $CO_2$-eq) | 392 |
| **Ozone Depletion Potential** (kg CFC-11-eq) | 1.1E-5 |
| **Acidification Potential** (kg $SO_2$-eq) | 2.06 |
| **Eutrophication Potential** (kg N-eq) | 0.46 |
| **Photochemical Ozone Creation Potential** (kg $O_3$-eq) | 45.5 |
| **Abiotic Depletion, non-fossil** (kg Sb-eq) | 1.4E-6 |
| **Abiotic Depletion, fossil** (MJ) | 695 |
| **Total Waste Disposed** (kg) | 2.71 |
| **Consumption of Freshwater** ($m^3$) | 1.01 |

**Product Components:** crushed aggregate (ASTM C33), natural aggregate (ASTM C33), Portland cement (ASTM C150), slag cement (ASTM C989), batch water (ASTM C1602), admixture (ASTM C494), admixture (ASTM C260)

Additional detail and impacts are reported on page three of this EPD

ISO 21930:2017 Sustainability in Building Construction — Environmental Declaration of Building Products: serves as the core PCR
PCR for Concrete, NSF International, February 2019 serves as the sub-category PCR

**Sub-category PCR review was conducted by** Thomas P. Gloria • Industrial Ecology Consultants

**Independent verification of the declaration, according to** ISO 14025:2006: ☐ internal ☑ external

**Third party verifier:** Thomas P. Gloria (t.gloria@industrial-ecology.com) • Industrial Ecology Consultants

**For additional explanatory material**
Manufacture Representative: Hernan Jose Perez Rodriguez (hernanjose.perez@cemex.com)
Software Tool: CarbonCLARITY Suite, EPD Generator • Verification
LCA & EPD Developer: Climate Earth (support@climateearth.com)

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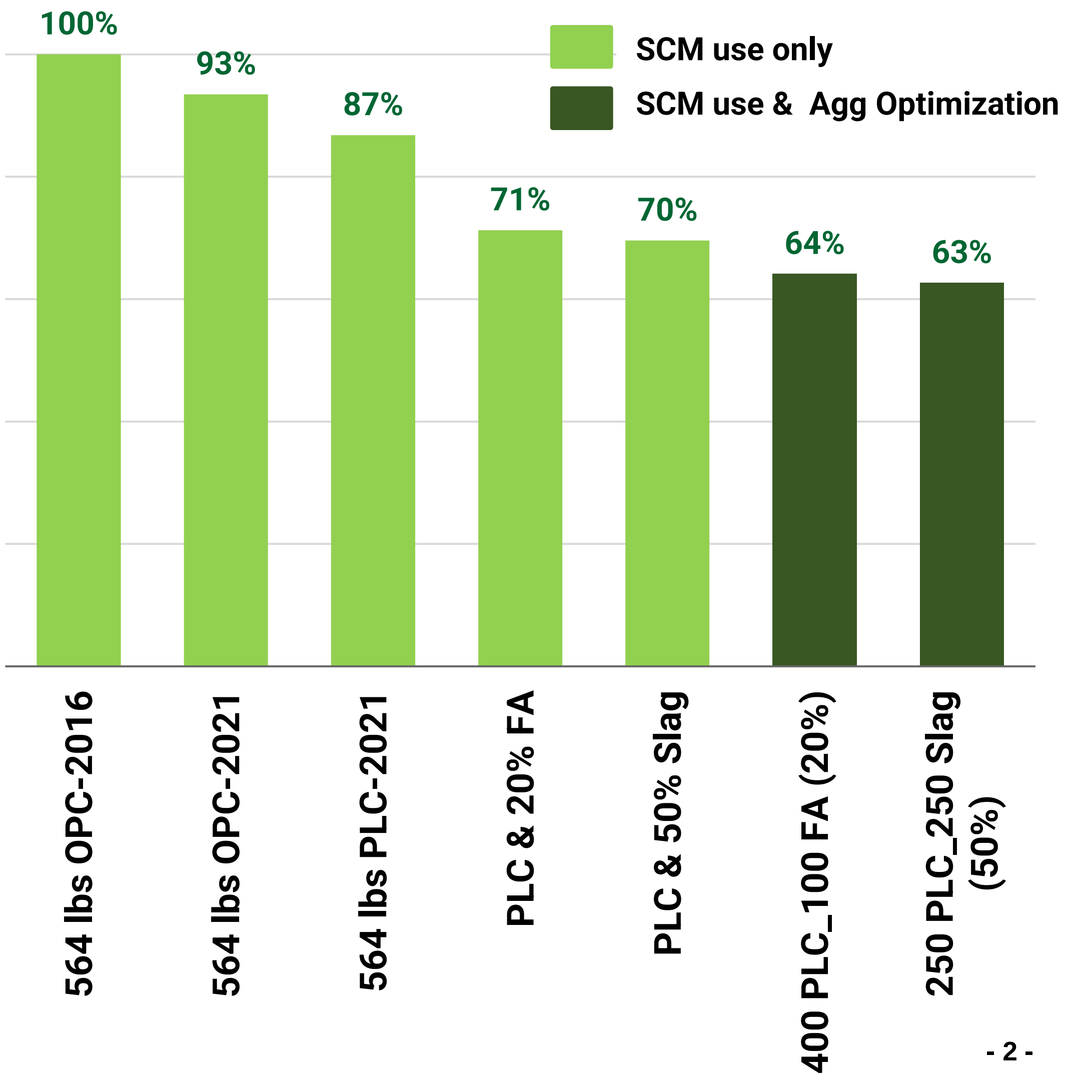
## Buy Clean Policies

Procurement policy that incentivize the purchase of construction materials and products with lower embodied greenhouse gas (GHG) emissions.

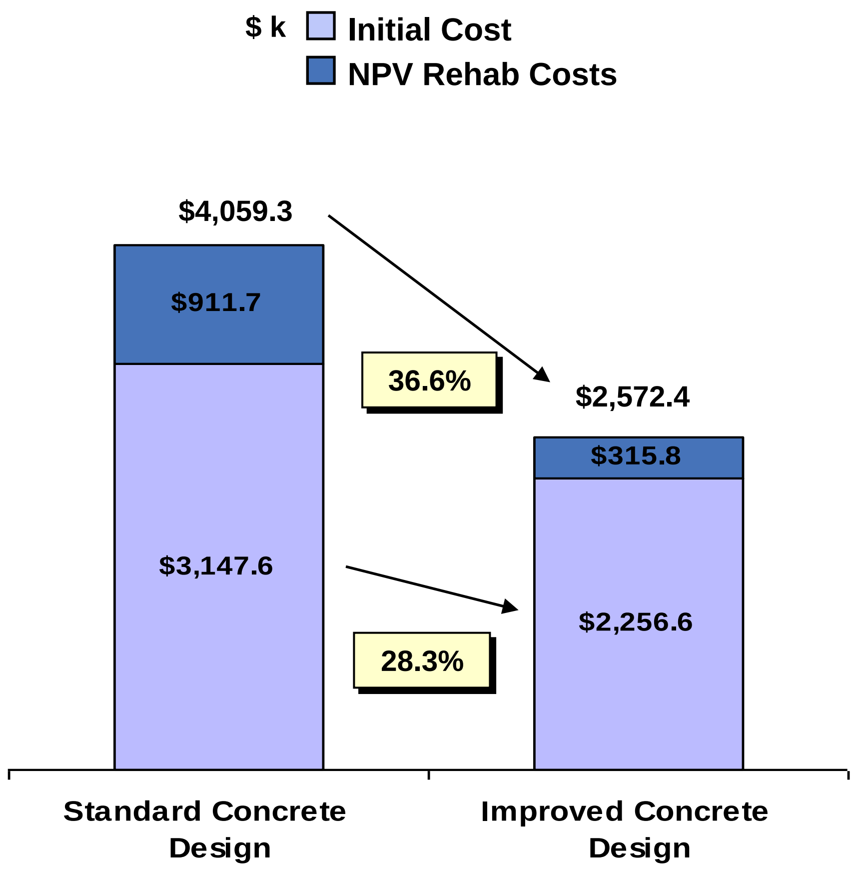
## Low $CO_2$ Concrete Mix Designs



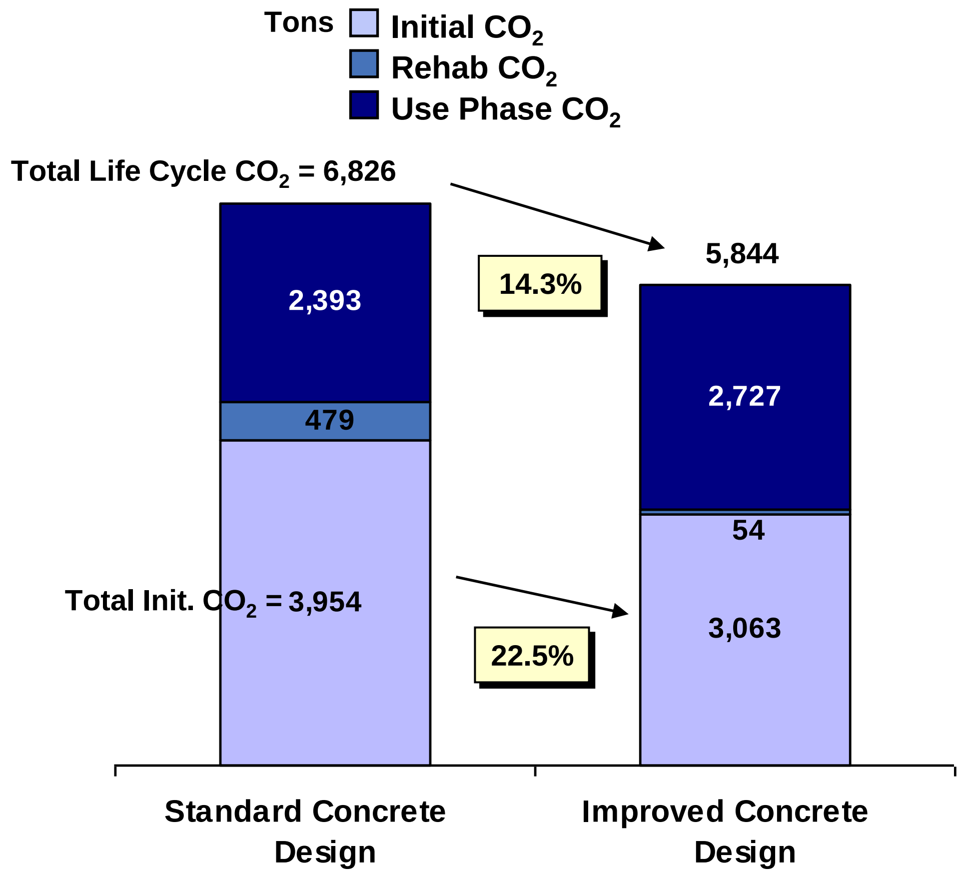
# JUST AS IMPORTANT IS WHAT WE BUILD

## Optimizing pavement designs can lowers costs and environmental impacts

### Lower Initial and Long-Term Cost




### Lower Initial & Long-Term $CO_2$ Emissions




**When done correctly, Optimizing Designs brings value to the project**

- Cost and $CO_2$ emissions for 1 mile of Pavement, 2 lanes in each direction (+ middle turn lane) and 2 inner/2 outer shoulders
- Original JPCP Rehabilitation schedule based on CALTRANS LCCA manual. Optimized JPCP Rehabilitation schedule based on Pavement-ME / MEPDG results

# TOOLS FOR OPTIMIZING DESIGNS FOR THE PAVEMENT SYSTEM

## Optimizing designs balances the initial costs/impacts, life cycle costs/impacts & performance

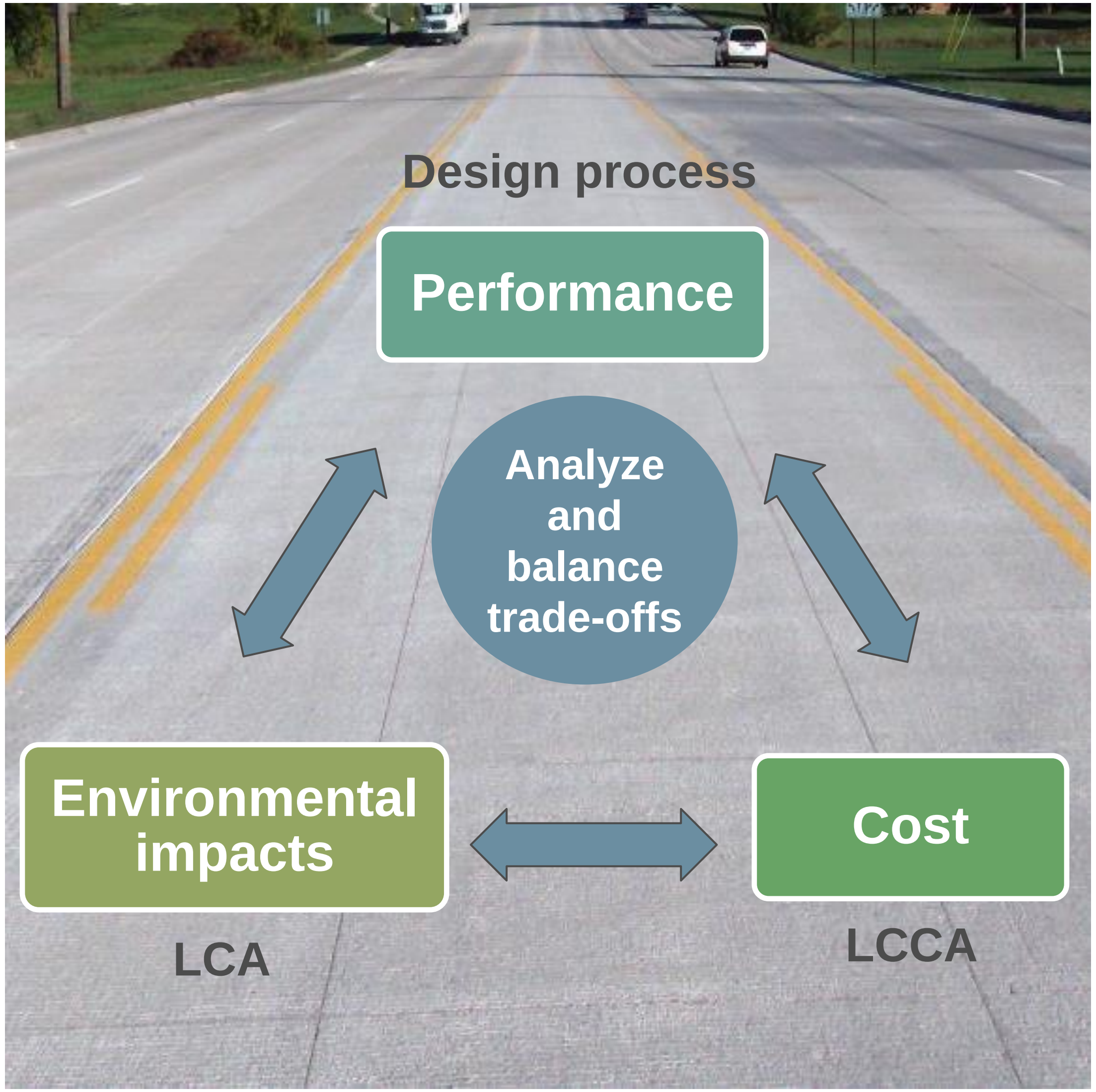
### TOOLS

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**

**Pavement ME tells how different pavements will perform & the LCCA / LCA helps designers make trade-offs to find cost-effective & environmentally responsible designs**



# 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

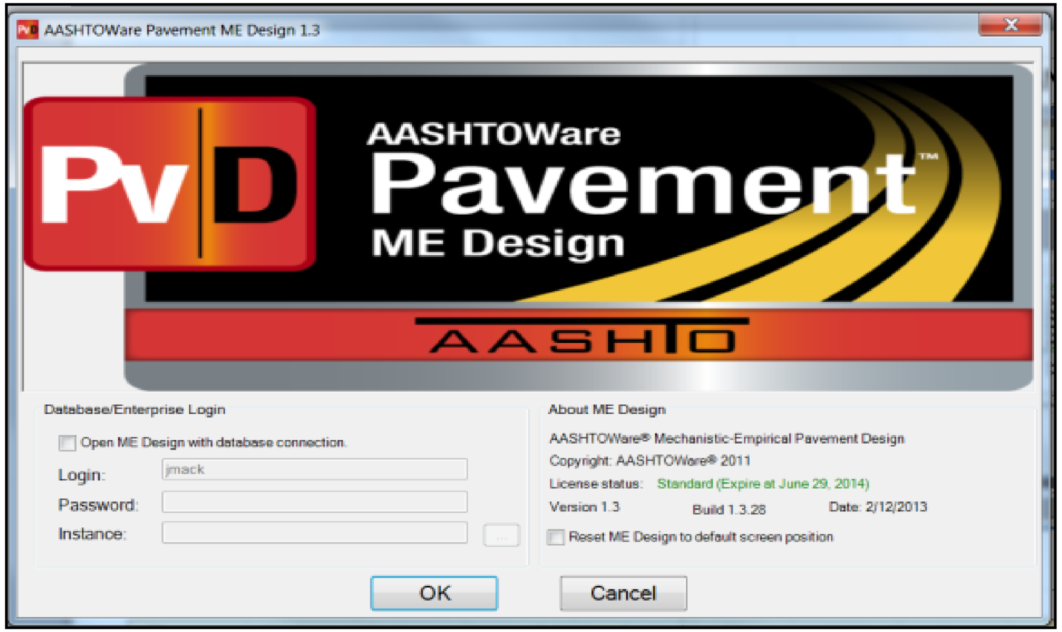
- Adopted by AASHTO in 2011
- Calibrated to more than 2,400 asphalt & concrete pavement test sections, ranging in ages up to ~40+ years

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




**New Pavement**

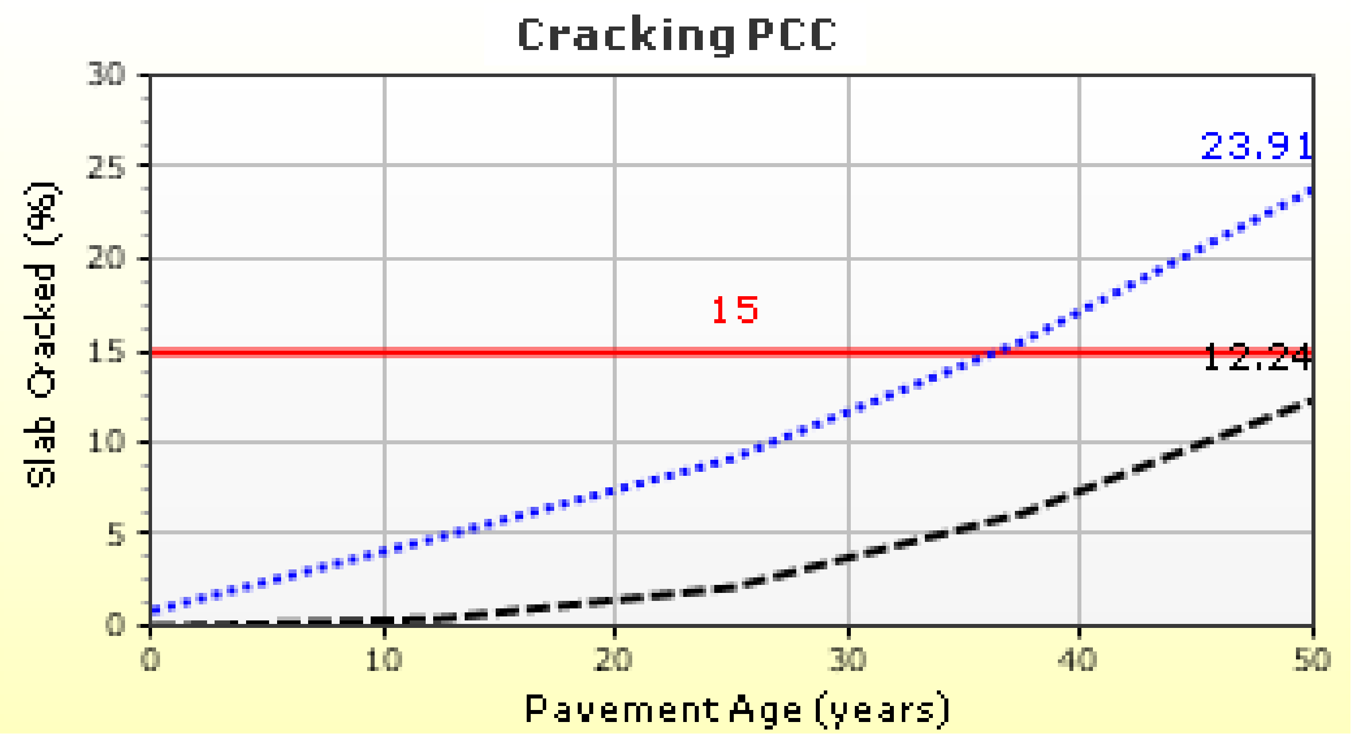
- Asphalt Concrete (AC)
- Jointed Plain Concrete Pavement (JPCP)
- Continuously Reinforced Concrete Pavement (CRCP)

**Overlays & Restoration**

- AC over AC
- AC over JPCP / CRCP (w/ & w/o fracture)
- Bonded PCC over JPCP / CRCP
- Unbound PCC over JPCP / CRCP
- JPCP /CRCP over AC
- JPCP Restoration

# PAVEMENT ME DEFINES A SPECIFIC PAVEMENT'S PERFORMANCE

## Predicting performance for key distresses allows for trade-off analysis of Features 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 (~33 years in this case)***

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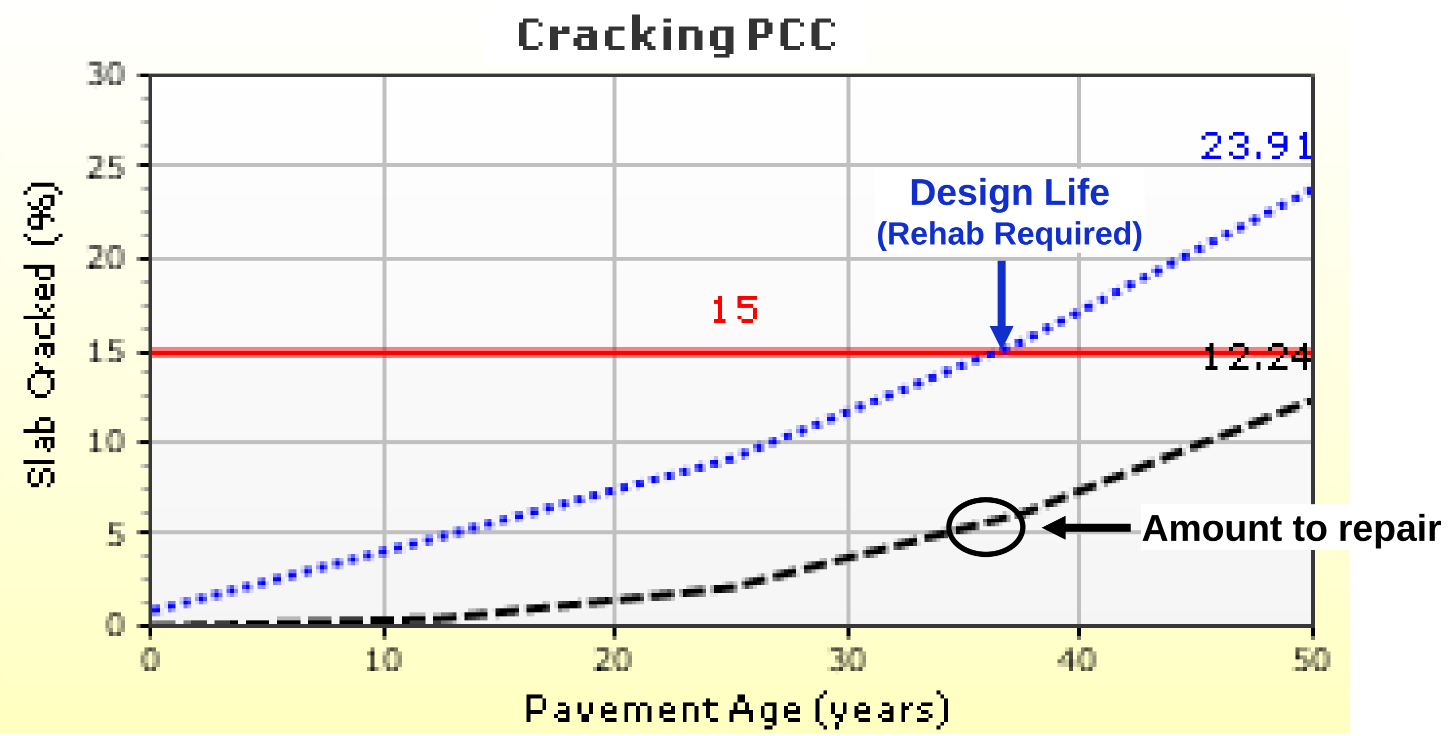


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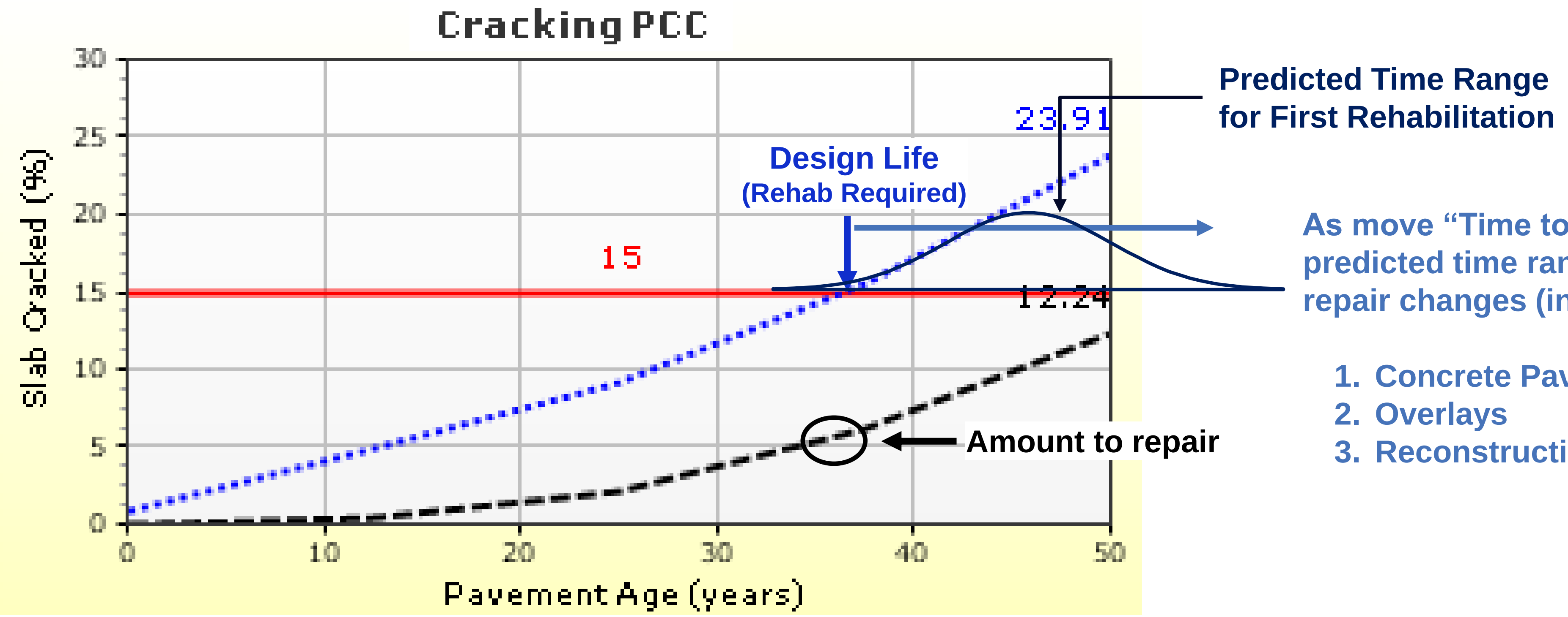


As move "Time to first Rehab" across predicted time range, category of repair changes (in order):

1. Concrete Pavement Preservation
2. Overlays
3. Reconstruction

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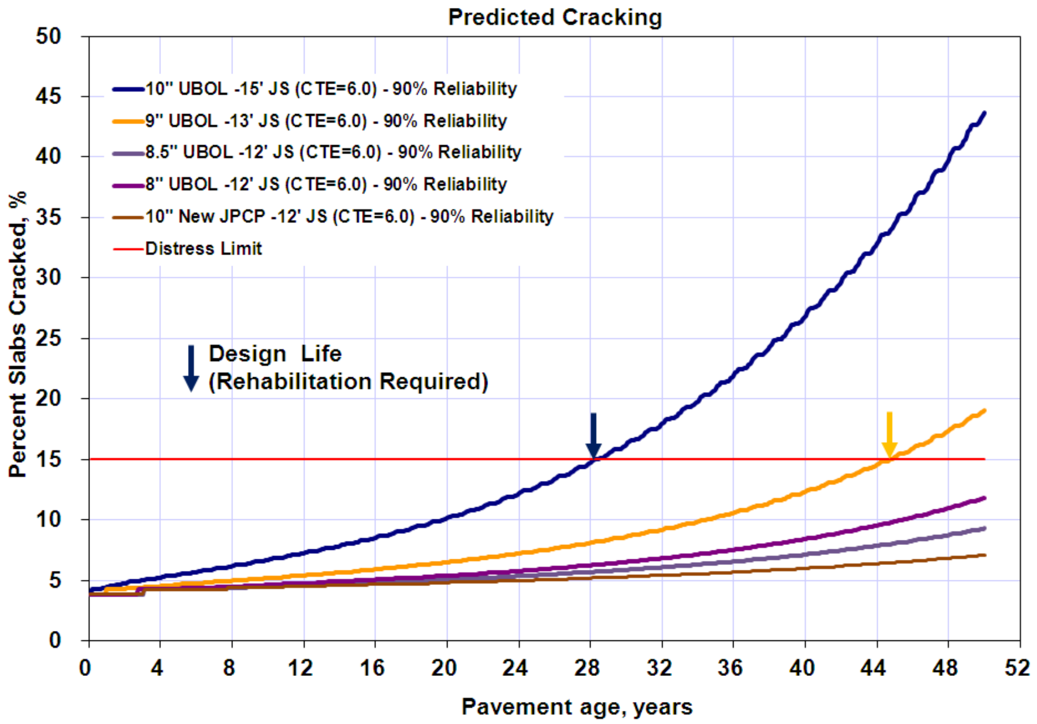
# PAVEMENT ME ALLOWS FOR COMPARISONS OF DIFFERENT DESIGNS

**Predicted Performance Curves for Pavement Designs**

- Many pavement designs will meet the design criteria
  - Pavement ME predicts what the actual performance could be
  - Allows for comparisons and evaluation of different design features / thickness
- Performance estimates help determine the "when" and "what" rehabilitation activities to perform



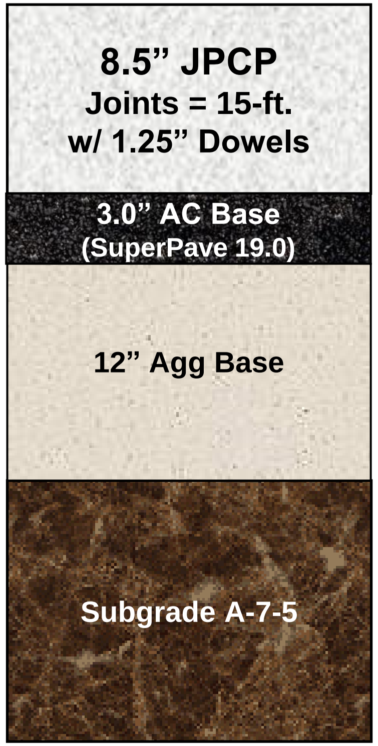

**Comparing Designs**

- Pavement ME output was set for 50 years to give long term performance for each design
- Pavement design must meet the "design criteria" (eg less than 15% cracking at year 30)

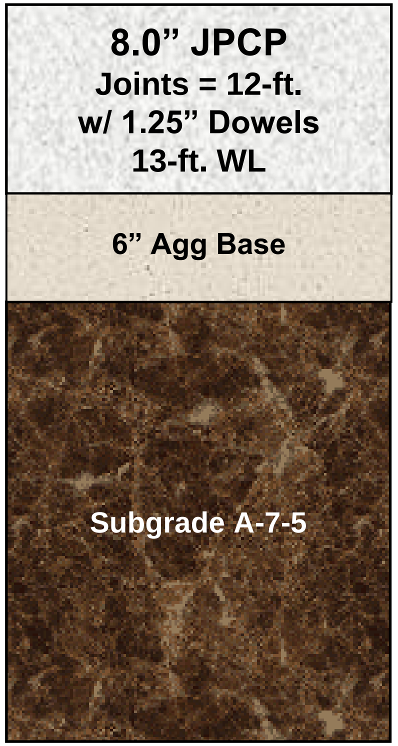
**Combining performance with the LCCA / LCA finds the design that best balances the costs, sustainability impacts, and performance over the full life cycle**

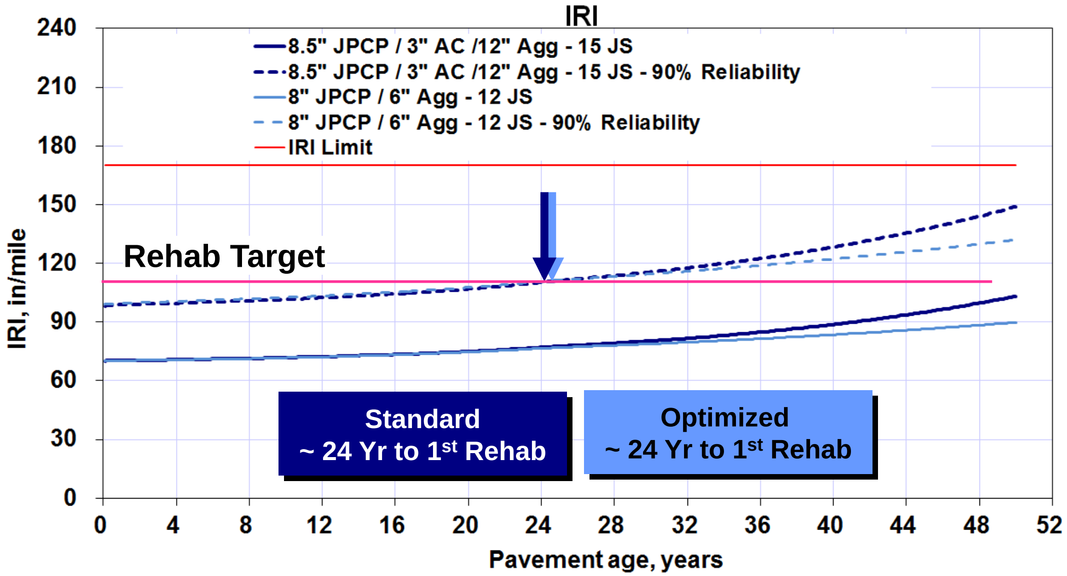
# PAVEMENT ME ALLOWS FOR COMPARISONS OF DIFFERENT DESIGNS

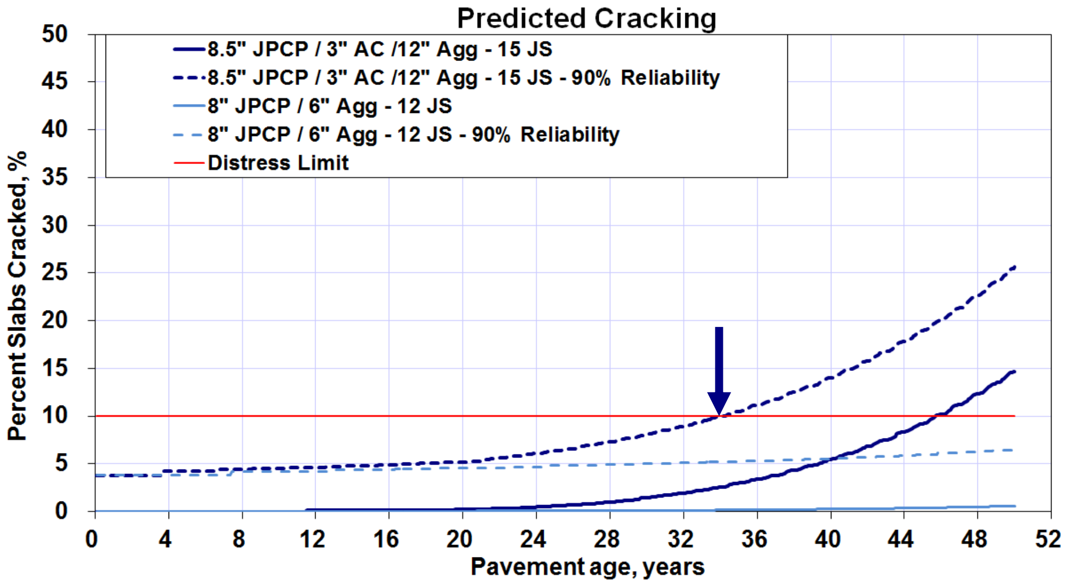
**Original Concrete Design**




**Optimized Concrete Design**




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

# DESIGN IMPROVEMENTS FOR CONCRETE PAVEMENTS

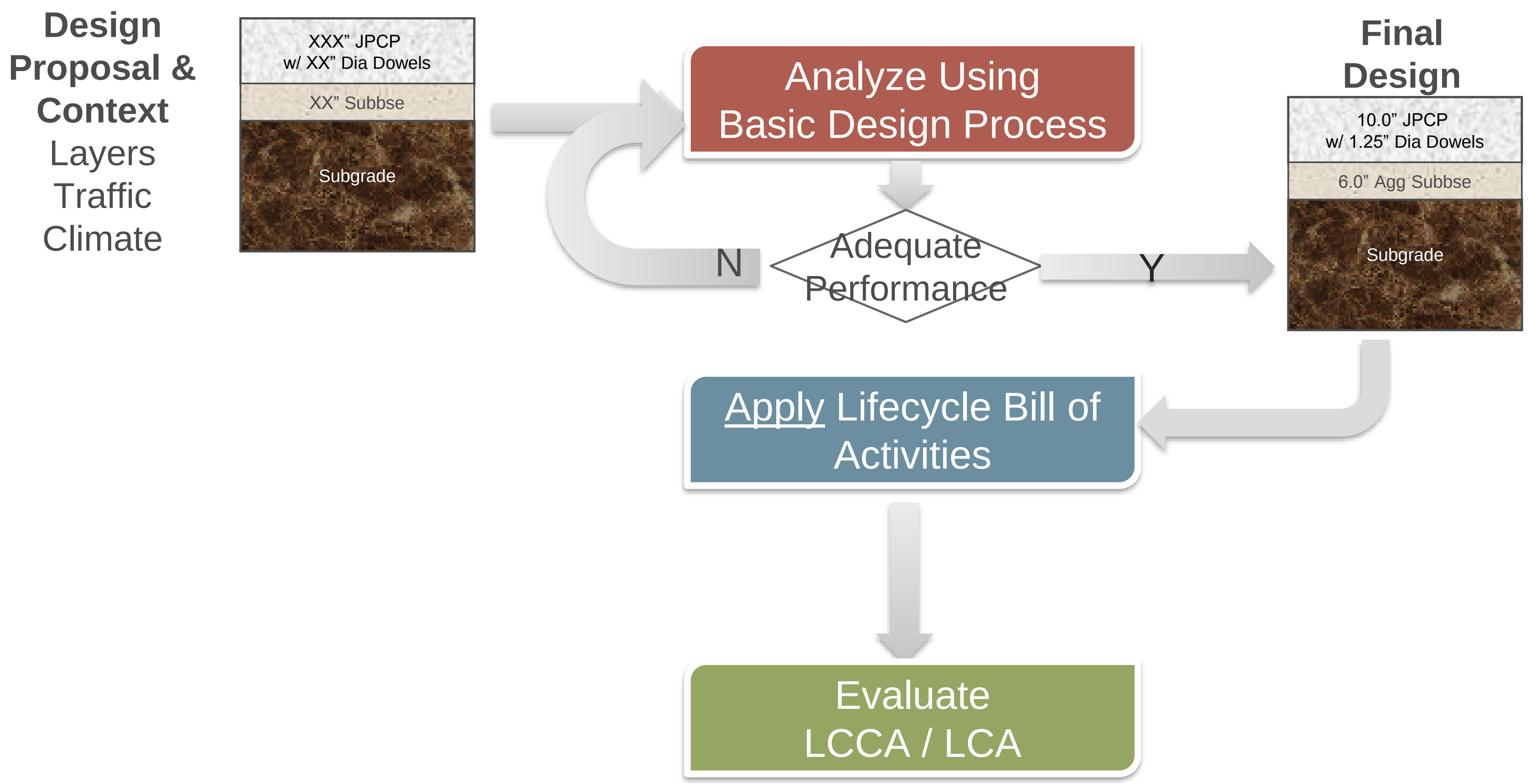
## Each Design Feature must balance Performance and Cost (both initial & long term)

| Feature | Benefit or Options |
|---|---|
| Shorten Joint Spacing | Reduces curling & warping stresses (reduces thickness but does increase joint sawing and dowel costs) |
| Use 13-ft Widened Outside Lanes | Shifts loading to “interior loading” (reduces thickness) |
| Use Dowels / Increase Dowel Size | 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 |

**“Features” have a significant impact on performance & cost**

# CURRENTLY DESIGN IS DONE IN A “STATIC” MODE

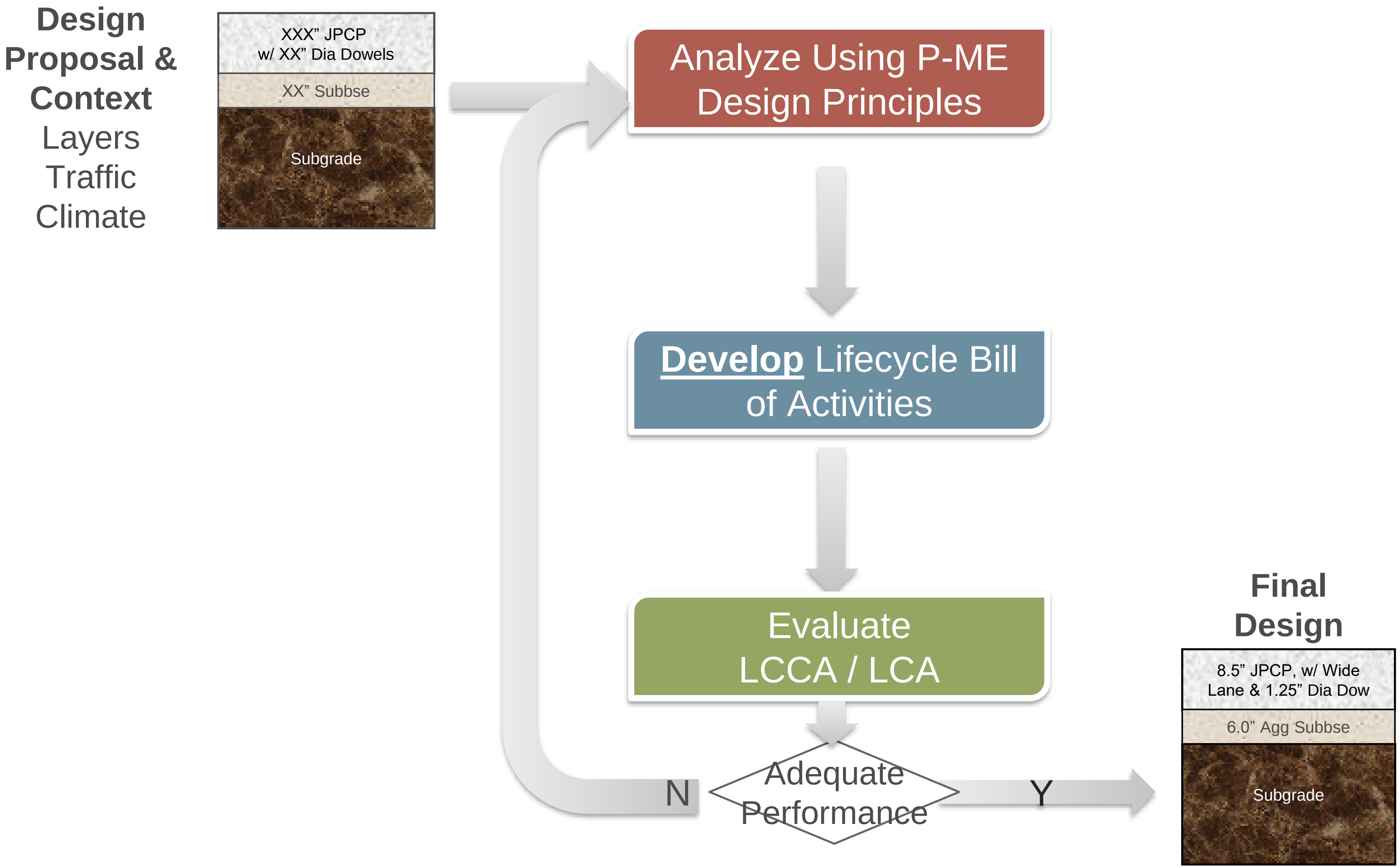
## Designs are developed and then compared to select the final pavement design




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

# TO IMPROVE THE PAVEMENT DESIGNS

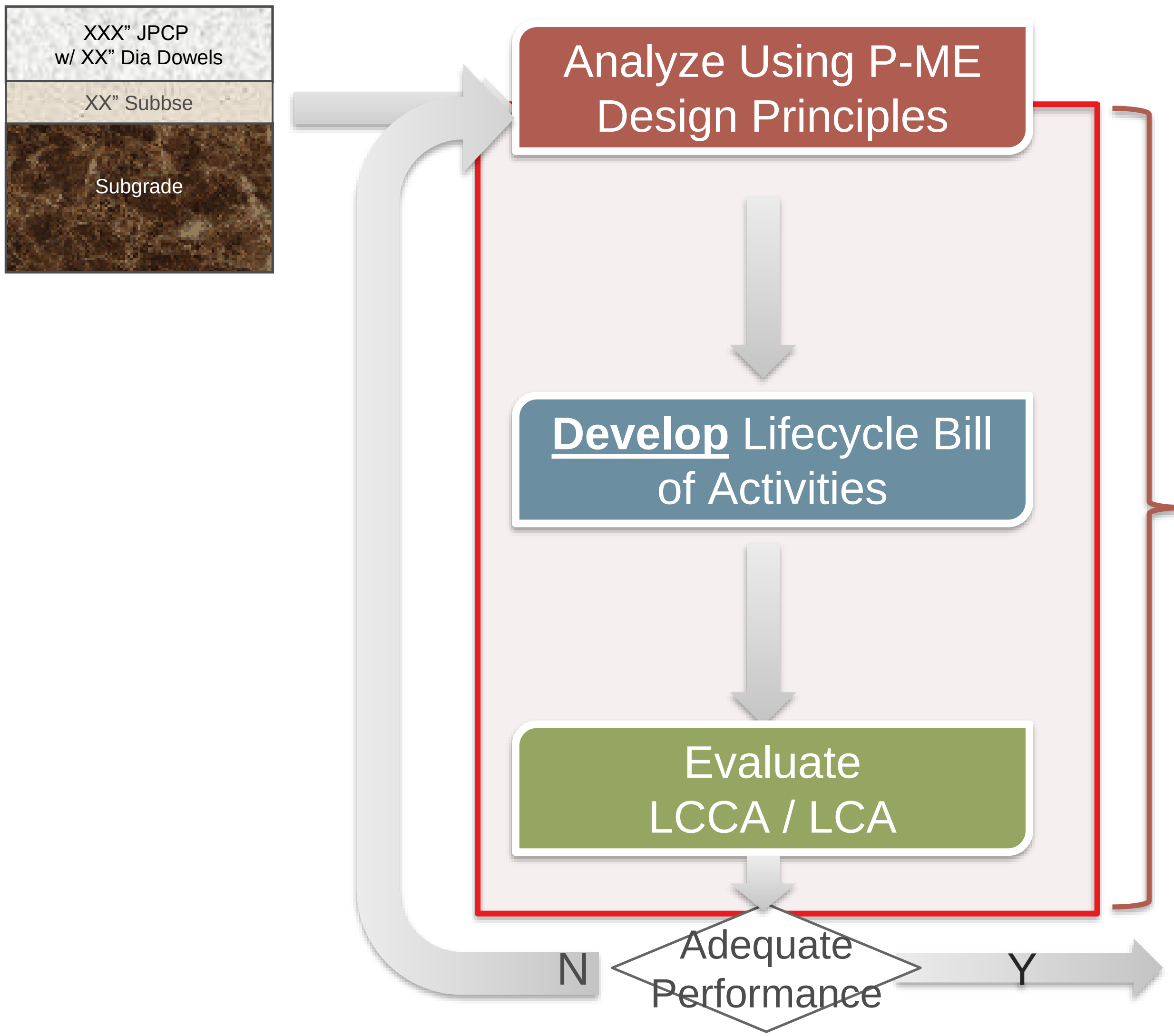
## Need to create a link between Design and Evaluation in an iterative design process



# TO IMPROVE THE PAVEMENT DESIGNS

## Need to create a link between Design and Evaluation in an iterative design process

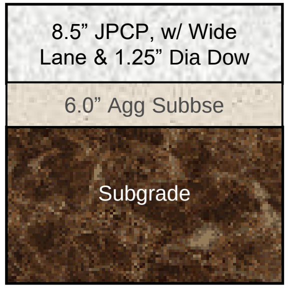
**Design Proposal & Context**
Layers
Traffic
Climate




**Designing pavements in an iterative procedure provides a Feedback Loop**

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

**Final Design**




Slide: Courtesy of MIT Concrete Sustainability Hub

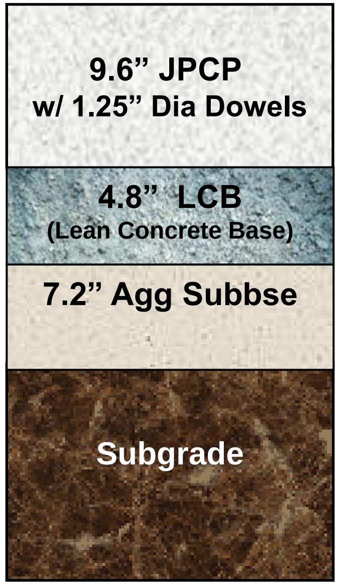
# ROUTE 67 IN RAMONA, CA

## 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

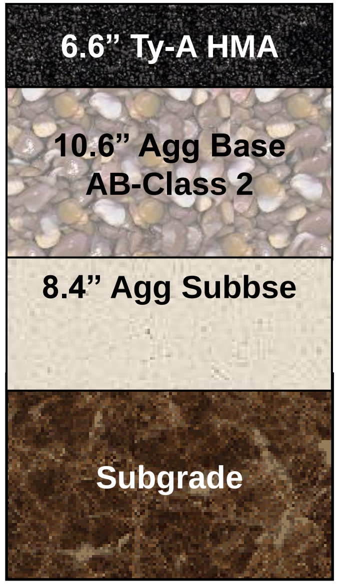
**CALTRANS Concrete Design**




**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**

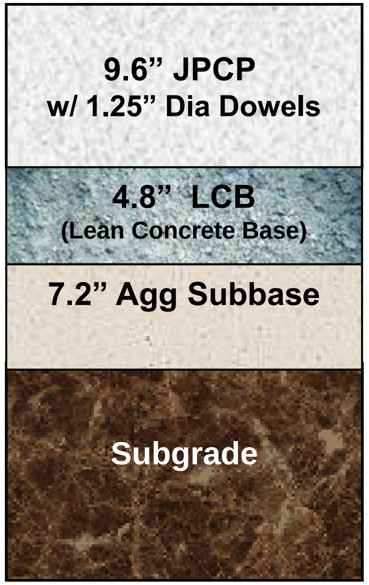
- 3” AC Overlay in years 20,
- Mill / 4" ACOL in year 25
- Mill / 3" ACOL in year 35
- Mill / 4" ACOL in year 45
- Mill / 3" ACOL in year 50 (5-year life)

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

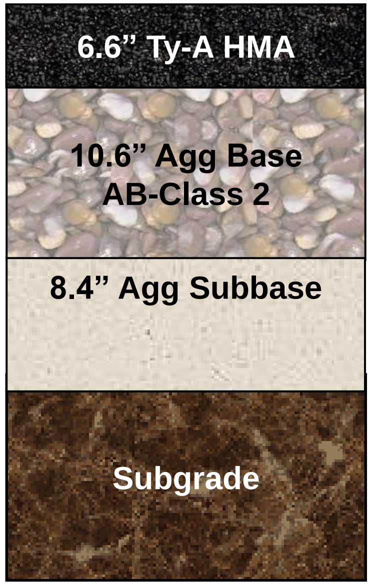
## Route 67 - Ramona, CA

### CALTRANS Concrete Design




| | LCCA (NPV $/mile) | LCA (tons $CO_2$e/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



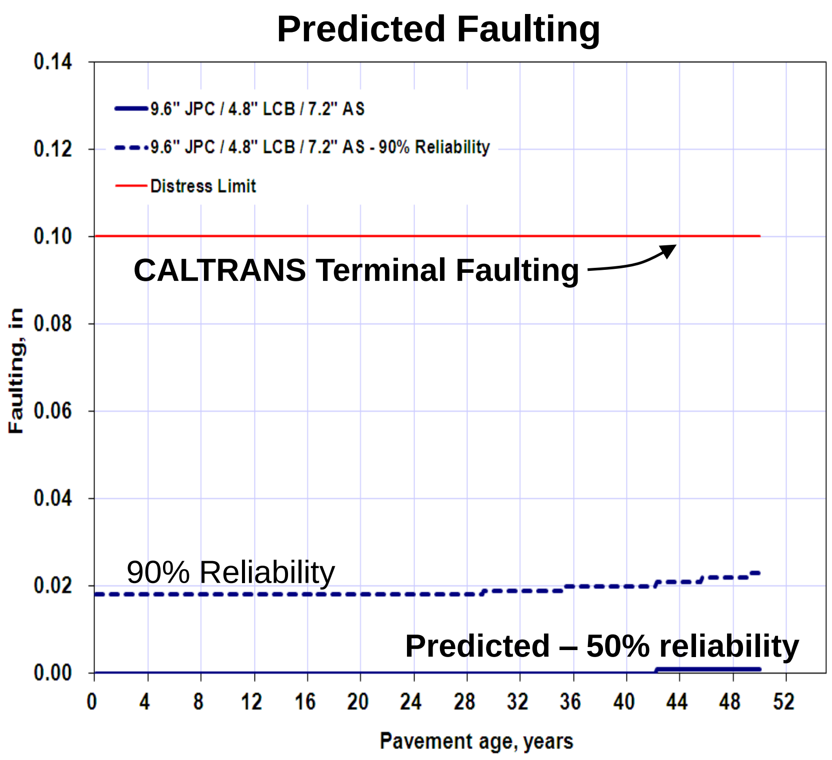

| | LCCA (NPV $/mile) |
|---|---|
| **Initial Const.** | **$2,278,102** |
| *Pavement* | *$1,437,480* |
| *AB-Class 2* | *$522,262* |
| *Agg Subbase* | *$318,360* |
| **Rehabilitation** | **$1,104,504** |
| **Total** | **$3,382,606** |

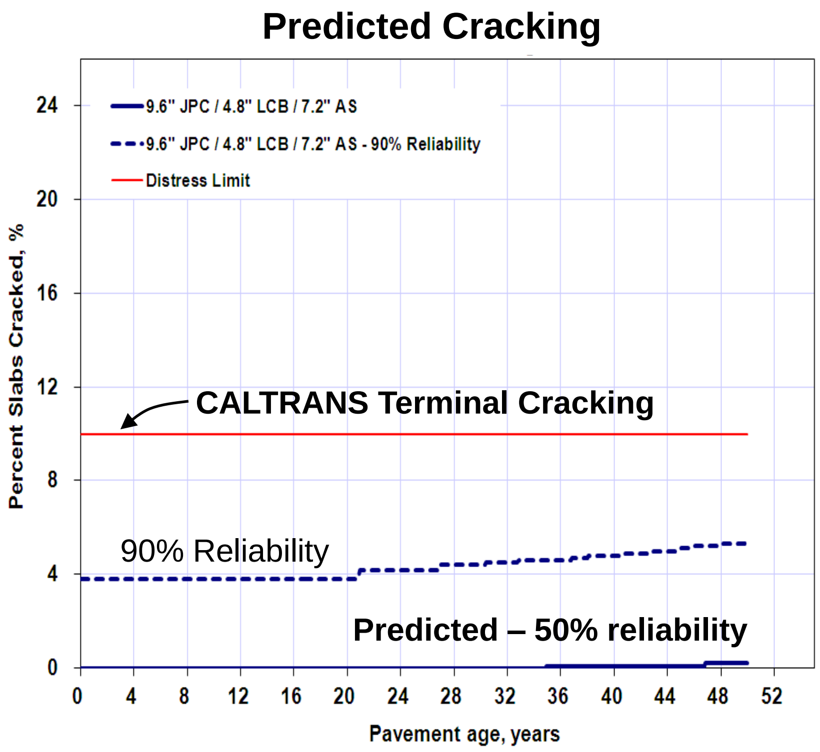
**Asphalt is 38% lower in Initial Costs and 20% lower in Life Cycle Costs**

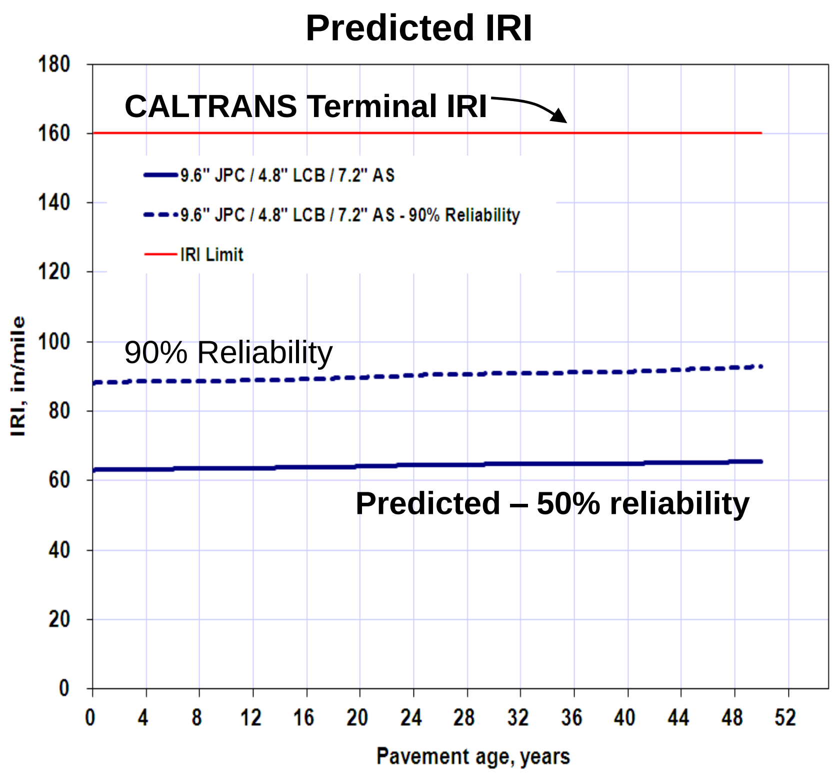
Caltrans Concrete Design: From Table 623.1E (South Coast/Central Coast, Type II SG
Initial AADTT = 1,357 / day, 4% Compound Growth (Initial ESAL = 335,000 / yr)
20 Yr ESALs = 10,650,000; 50 Yr ESALS = 51,151,000

# Route 67 PAVEMENT-ME PREDICTED PERFORMANCE IS HIGH

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



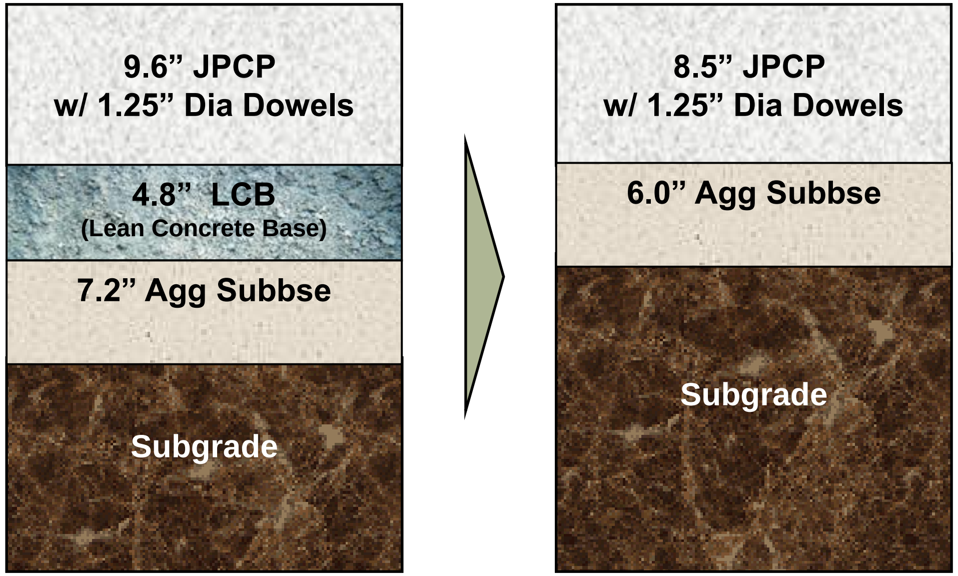

**Pavement is over-designed because it does not need rehabilitation for the entire 50-year analysis period**
**Creates the opportunity for project specific optimization**

# OVER-DESIGN CREATES THE OPPORTUNITY FOR OPTIMIZATION & POTENTIAL TO LOWER COST AND ENVIRONMENTAL IMPACT

## 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

# 8.5" JPCP MEETS PERFORMANCE CRITERIA

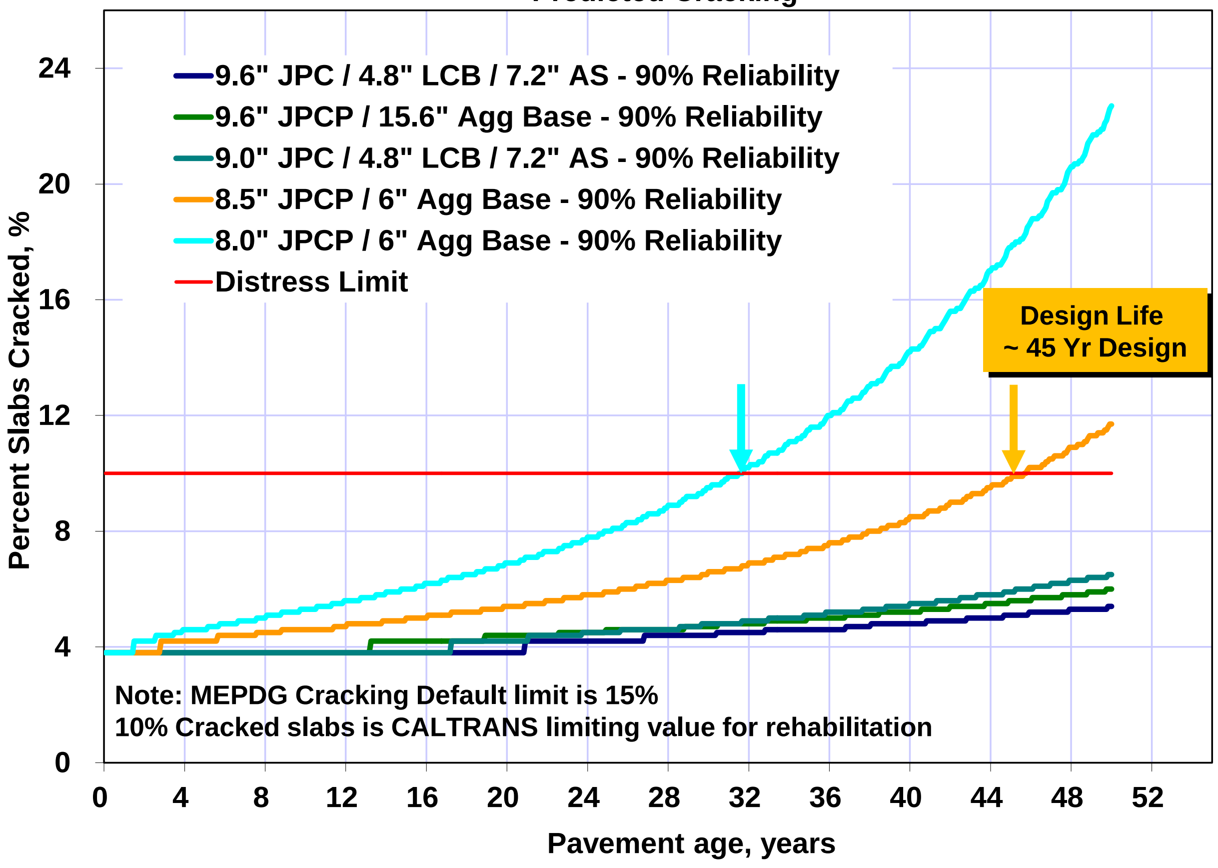
## Good balance between long term performance and low cost / low GWP

- 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**
**Its about selecting the most Effective**

### Pavement-ME Predicted Performance




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

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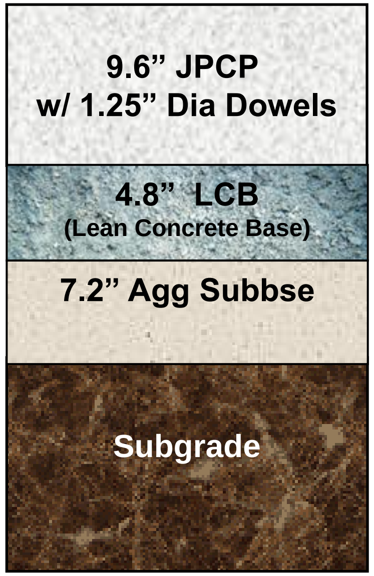
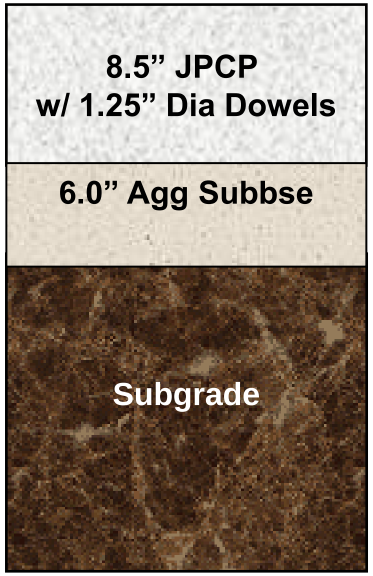
# PROJECT SPECIFIC PAVEMENT OPTIMZATION LOWERS COST AND ENVIRONMENTAL IMPACT

**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

# SUMMARY

1. Current Sustainability efforts focus on EPDs and using low carbon construction materials

2. Just as important is “what you build”
   - Over design raises Initial Embodied $CO_2$ levels
   - Under design will increase operational and maintenance $CO_2$ levels
     - Both making hitting US has Greenhouse Gas Emissions Targets difficult

3. Pavement Optimization can be used to lower Life Cycle Costs & Environmental Impacts
   - They will still have good long-term performance
   - When done correctly, they will have low Cost of Ownership & low Environmental Impacts

4. Pavement Optimization requires a “trade off analysis” that balances the costs, environmental impacts, and pavement performance / future rehabilitation activities
   - It is more than just cutting thickness
   - Other “features” have a significant impact on performance, cost and environmental impacts

# Thank You

## & Any Questions?

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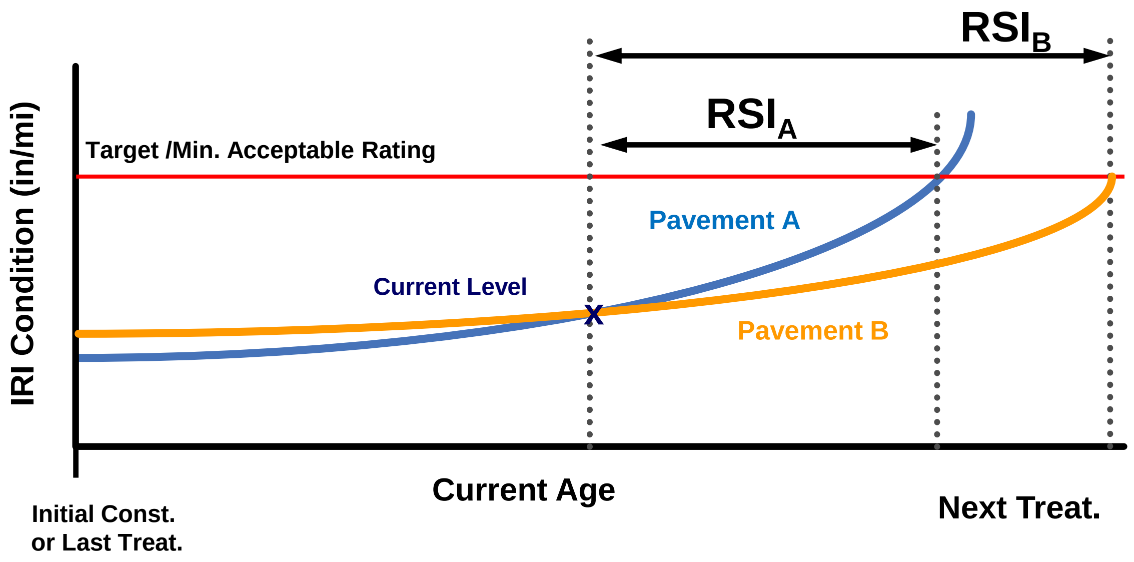
# NEED TO USE A FORWARD LOOKING INDICATOR TO DISTINGUISH HOW DIFFERENT PAVEMENT SEGMENTS ARE PERFORMING

## Remaining Service Interval (RSI) is one possible forward looking time element

| | |
|---|---|
| **Definition** | • RSI tells HOW LONG and HOW WELL the pavement will serve the public<br>  • A RSI=10 means 10 years to next construction treatment for that segment<br>  • A RSI=0 means that its condition is worse than the agency's defined trigger value<br>  *"Treatment" can be anything from preservation activities (i.e. crack sealing) to full reconstruction for the segment* |
| **What it does** | • Two pavement sections at the same condition are not necessarily equal<br>  • They will require different management strategies<br>  • RSI takes into account "rate of deterioration"<br>• Higher RSI pavements / networks deliver higher value than lower RSI networks |




**RSI provides insight into future conditions and impact of different investment strategies**