Impact of RAS and RAP on Asphalt Mixtures' Fracture: The Need for a Cracking Potential Index

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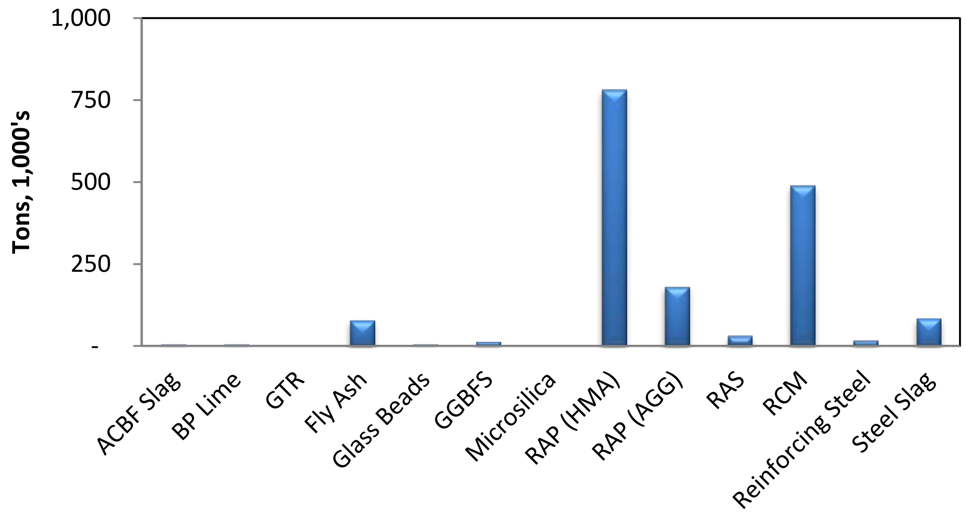
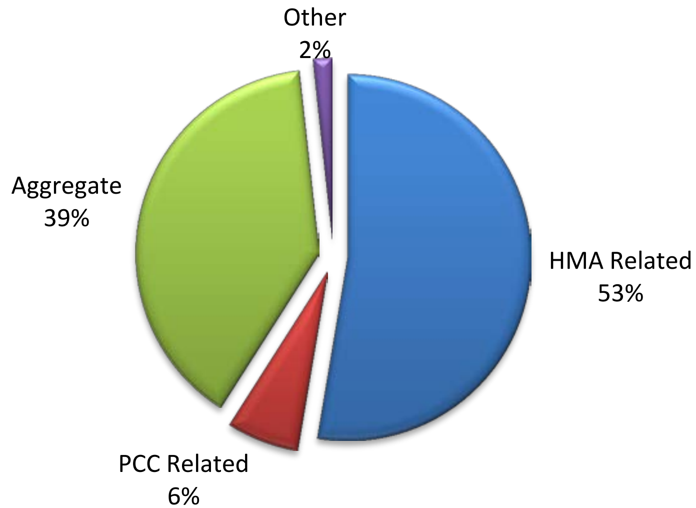
Increasing Use of RAP and RAS

- **43% increase in Illinois recycled tonnage from 2012 to 2013**
- **221% increase in Illinois RAS usage from 2012 to 2013**
- **Used 821,000 tons of RAP and RAS in 2013**
  - **About 19% of total asphalt mix produced**





Lippert et al. (2014). Illinois Highway Materials Sustainability Efforts

Challenges with RAP/RAS

- Currently recycle usage is allowed; specifications used are intended to limit risk of cracking by ABR limits and grade bumping, not actual mix performance
- Fatigue cracking issue: stiffer mixes with high ABR may exhibit early fatigue cracking
- Thermal/Block cracking issue: Stiffer mixes have reduced relaxation potential
- Selection of virgin binder of mixes with RAP/RAS is arbitrary

Research Goals and Overview

- Identify, evaluate, and develop protocols, procedures and specifications for testing engineering properties of asphalt mixtures (including ones w/ high ABR)
- Identify/develop an effective testing scheme to screen mixes (including ones w/high ABR) considering fatigue and thermal cracking
  - Develop specification requirements

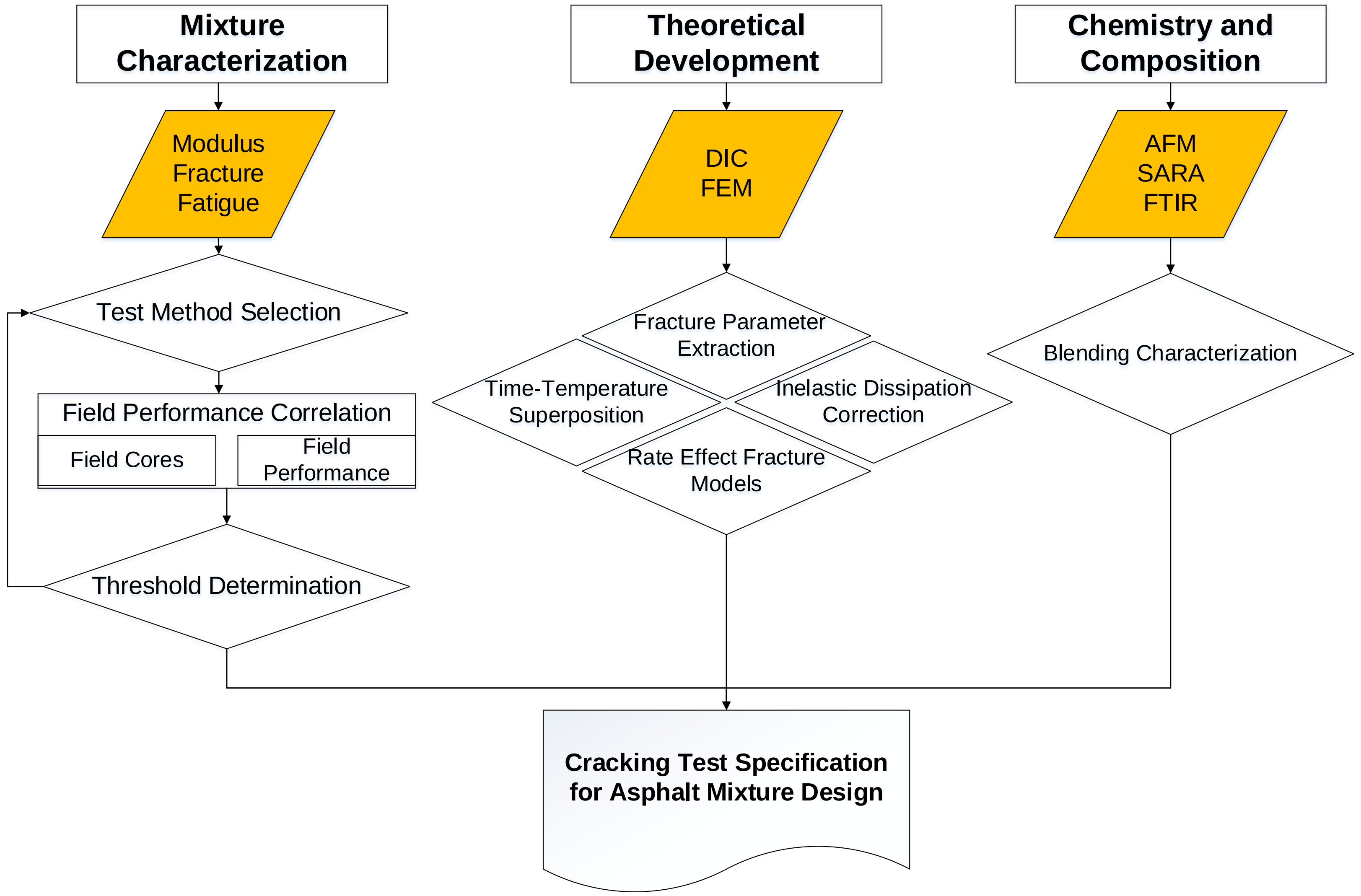
Research Approach

- Assessment of variety of plant mixes, lab design mixes, and field cores (25+ lab compacted, 25+ field cores)

Parameter	Variables
Material Source	Plant Mixes, Lab-Mixes, Field Cores
N-Design	N30, N50, N70, N80, N90
Nominal Maximum Aggregate Size	4.75 mm, 9.5 mm, 12.5 mm, 19.0 mm
Asphalt Binder	PG52-28, PG58-22, PG58-28, PG64-22, PG70-22, PG70-28, PG76-22
Recycled Materials	RAP, RAS, Recycled Concrete, and Steel Slag
Asphalt Binder Ratio	0 to 60
RAP Content (%)	0 to 53
RAS Content (%)	0 to 8.5

- Correlation to other tests (modulus and fatigue)
- Theoretical and numerical evaluation

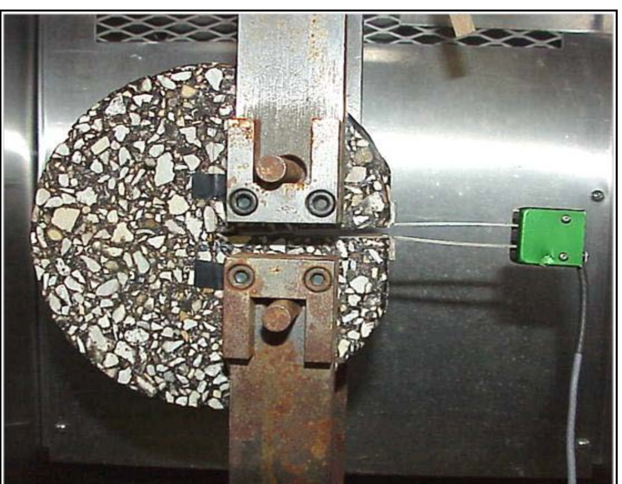
Research Approach



Mixture Tests Available


Beam Fatigue Test


Push-pull Fatigue


DCT (ASTM D7313)

SCB (AASHTO TP105)

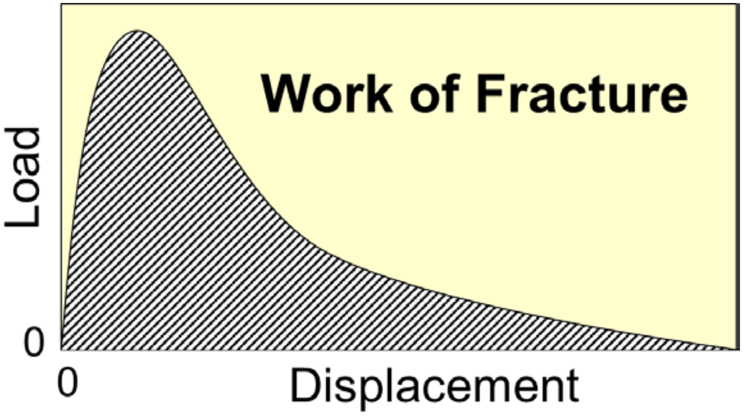

Texas Overlay Test

Test Method Selection

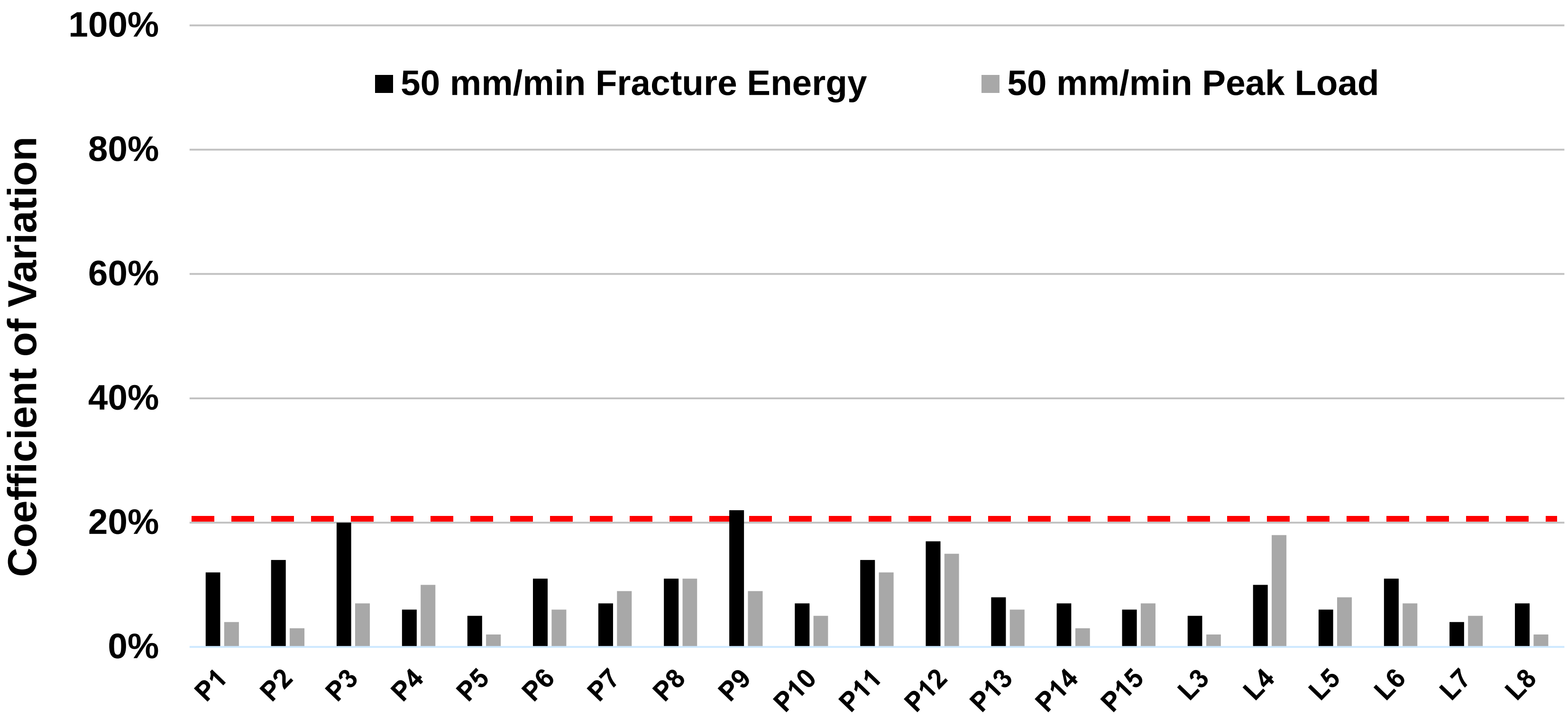
1. Feasibility, practicality, and repeatability
2. Meaningful spread in test output
3. Test parameters
4. Correlation to independent tests and engineering intuition
5. Correlation to field performance

1- Practicality of SCB

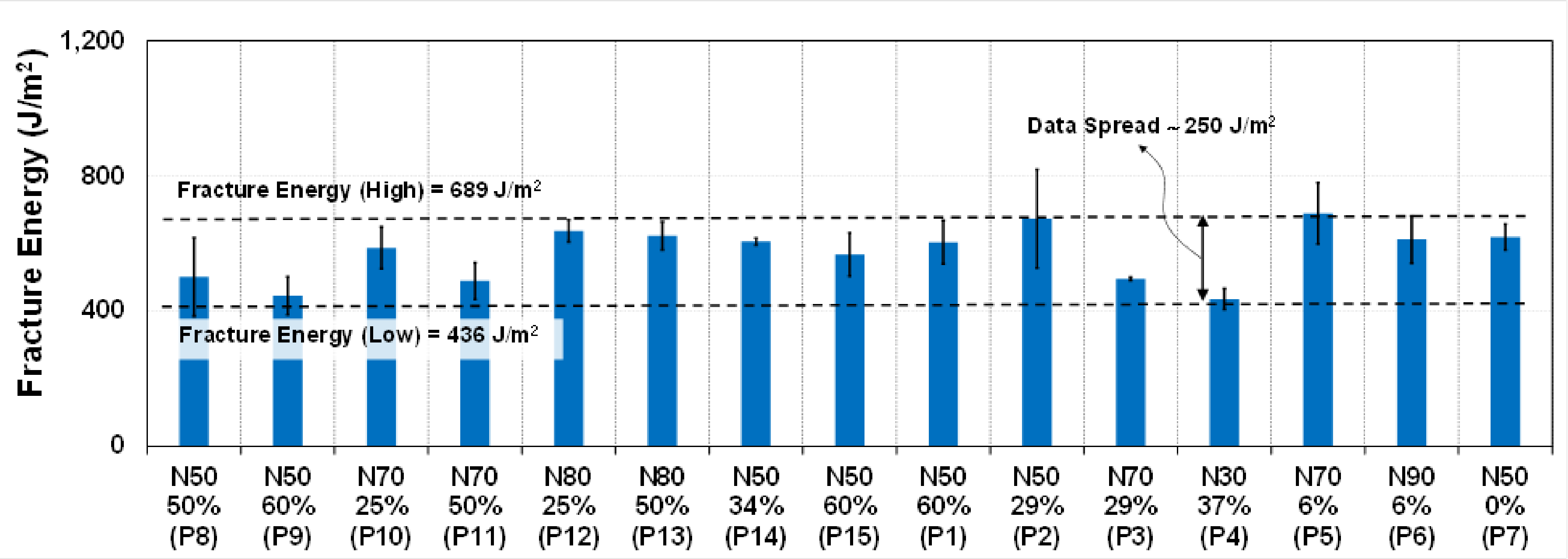
- Relies on simple three point bending
- Easy specimen preparation
- Can use AASHTO T283 equipment (like Humboldt frames)
- Conducted at 25˚C and 50 mm/min (LVDT)



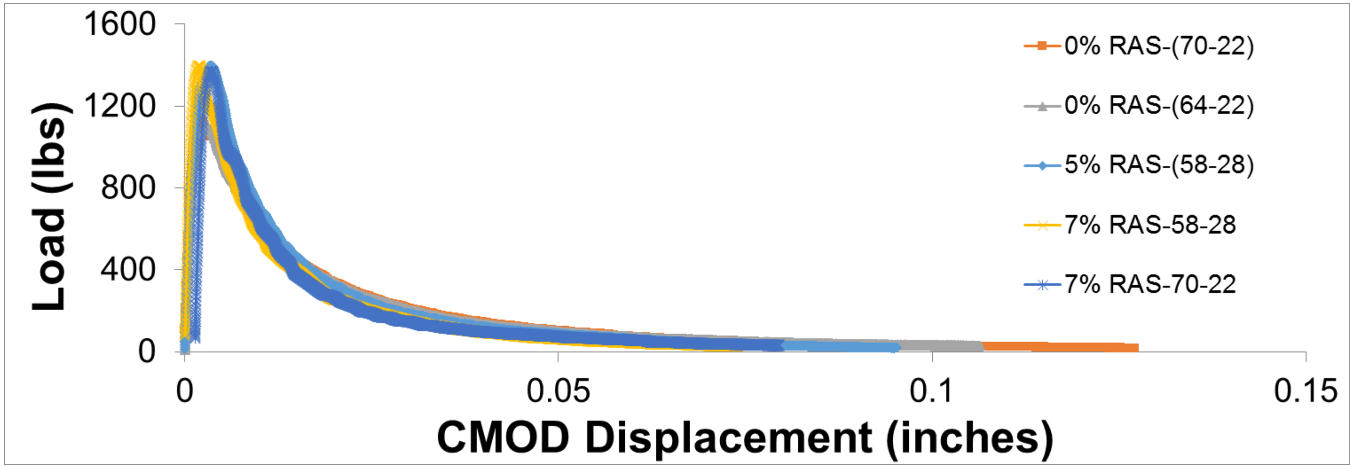
Test Repeatability



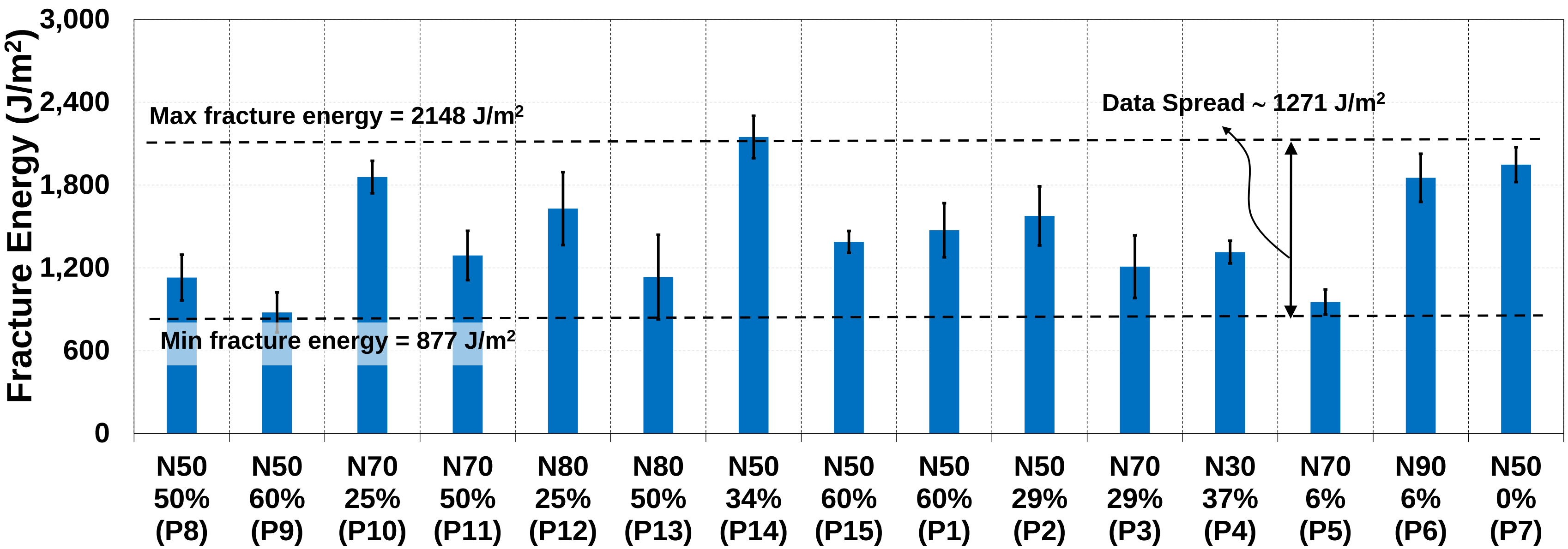
2- -12°C SCB Fracture Energy Spread



- **Limited data spread**



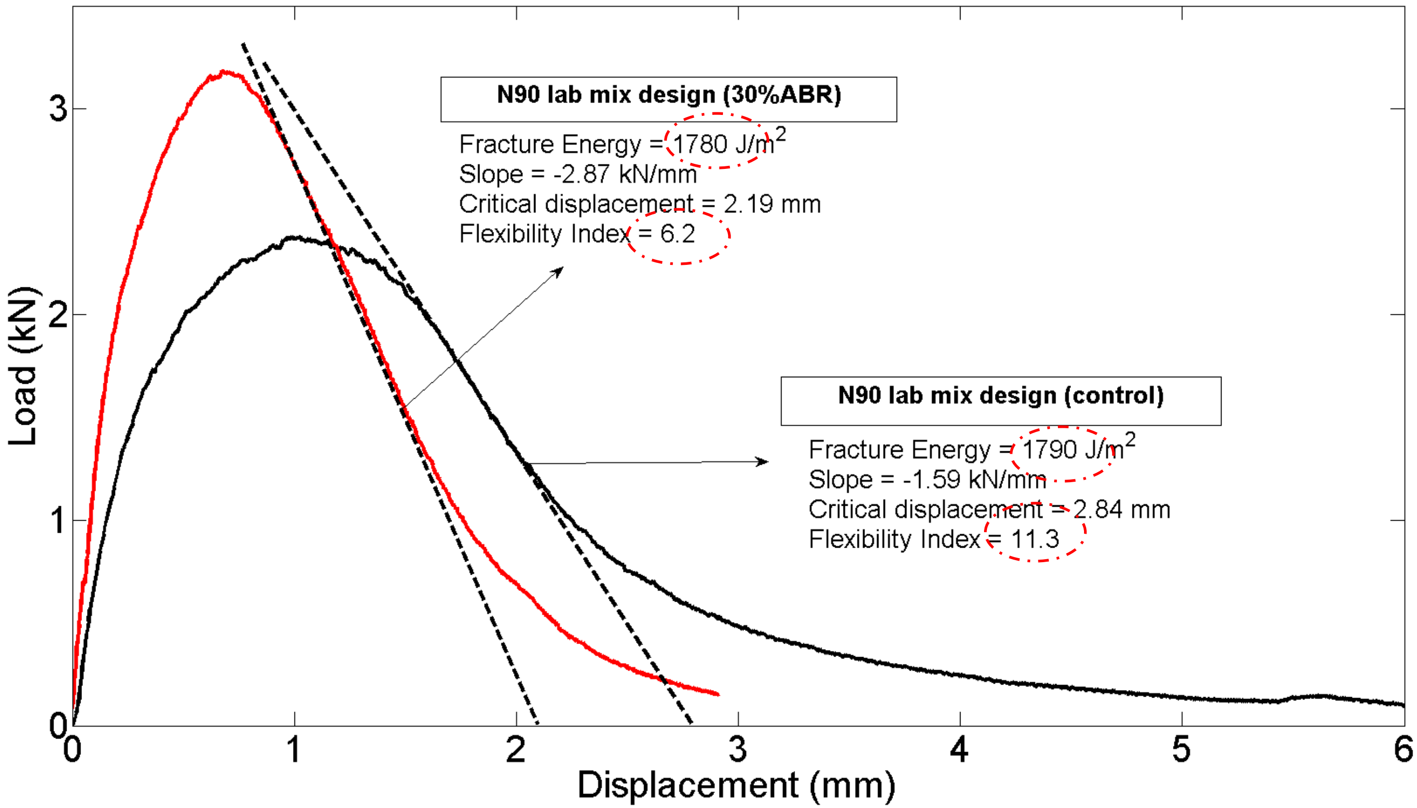
25°C SCB Fracture Energy Spread



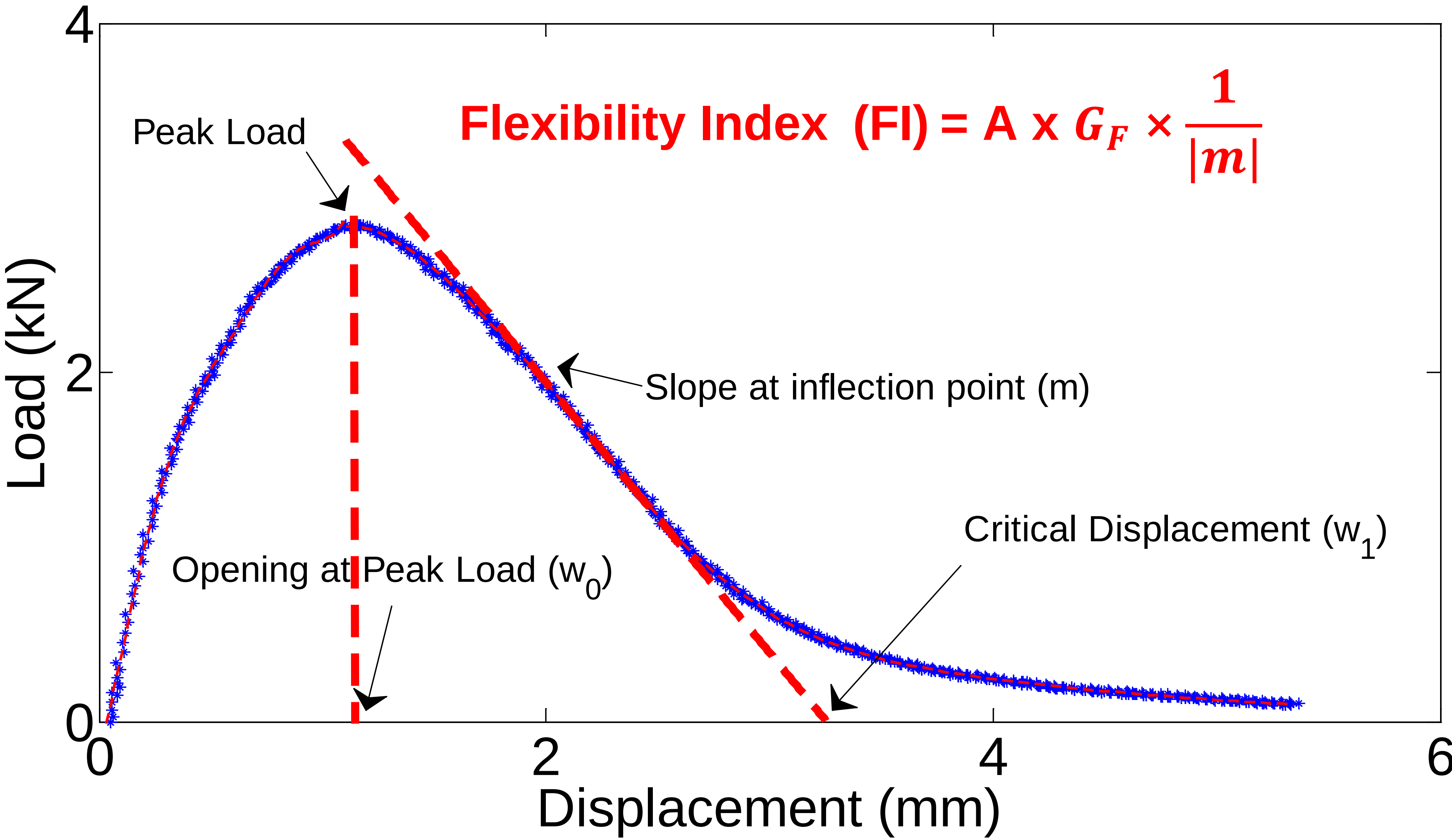
- SCB fracture energy results for the same mixes at 25°C using displacement control at 50 mm/min
- Significant spread in fracture energy

Contradiction of FE Results

- **Two different mixtures may have identical G_f**
- **Flexibility index is calculated for same two lab mix designs (N90): control and with RAS (7%)**

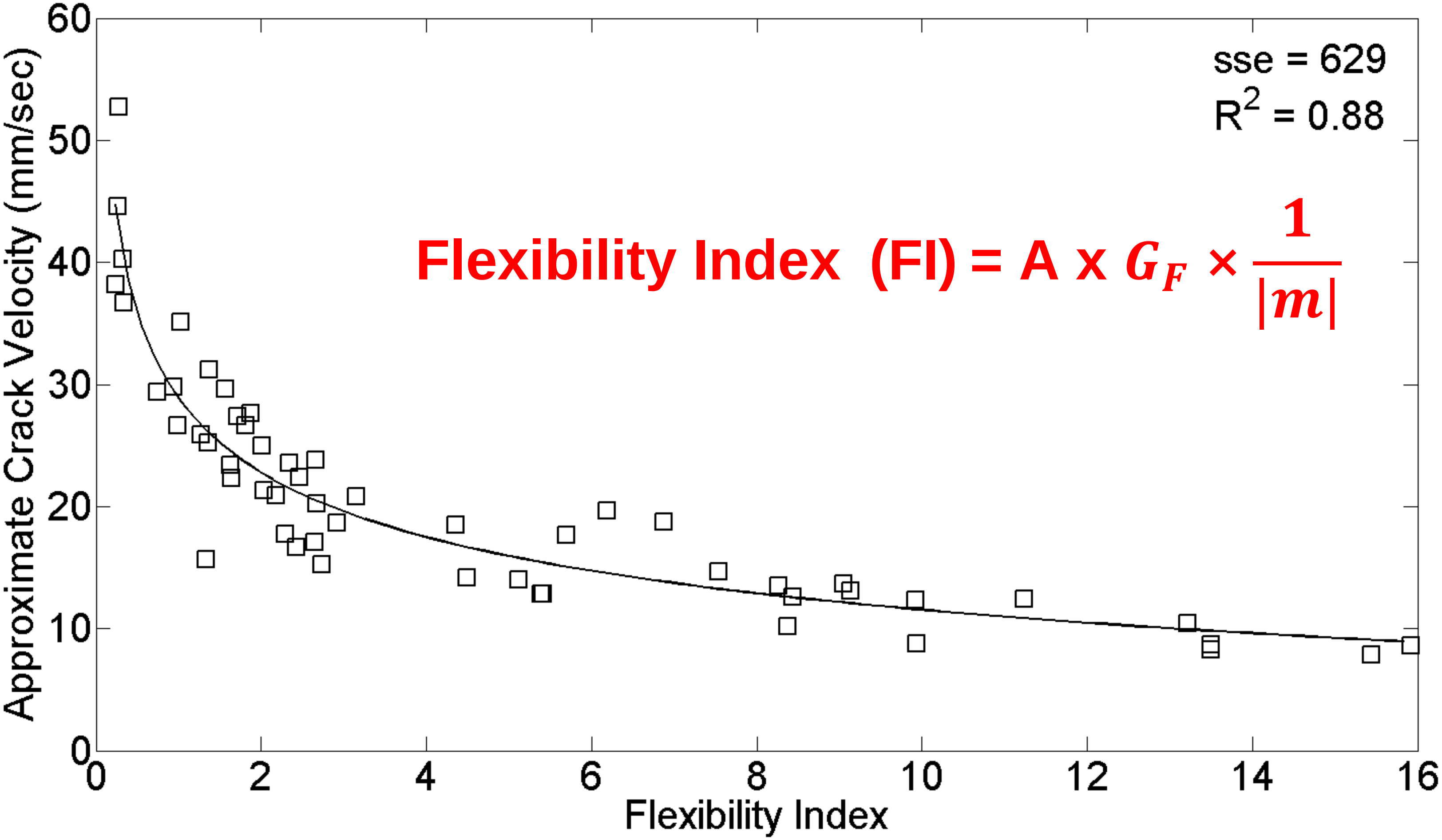


3- SCB Test Parameters



Development of Flexibility Index

- A theoretically-supported flexibility index (FI)

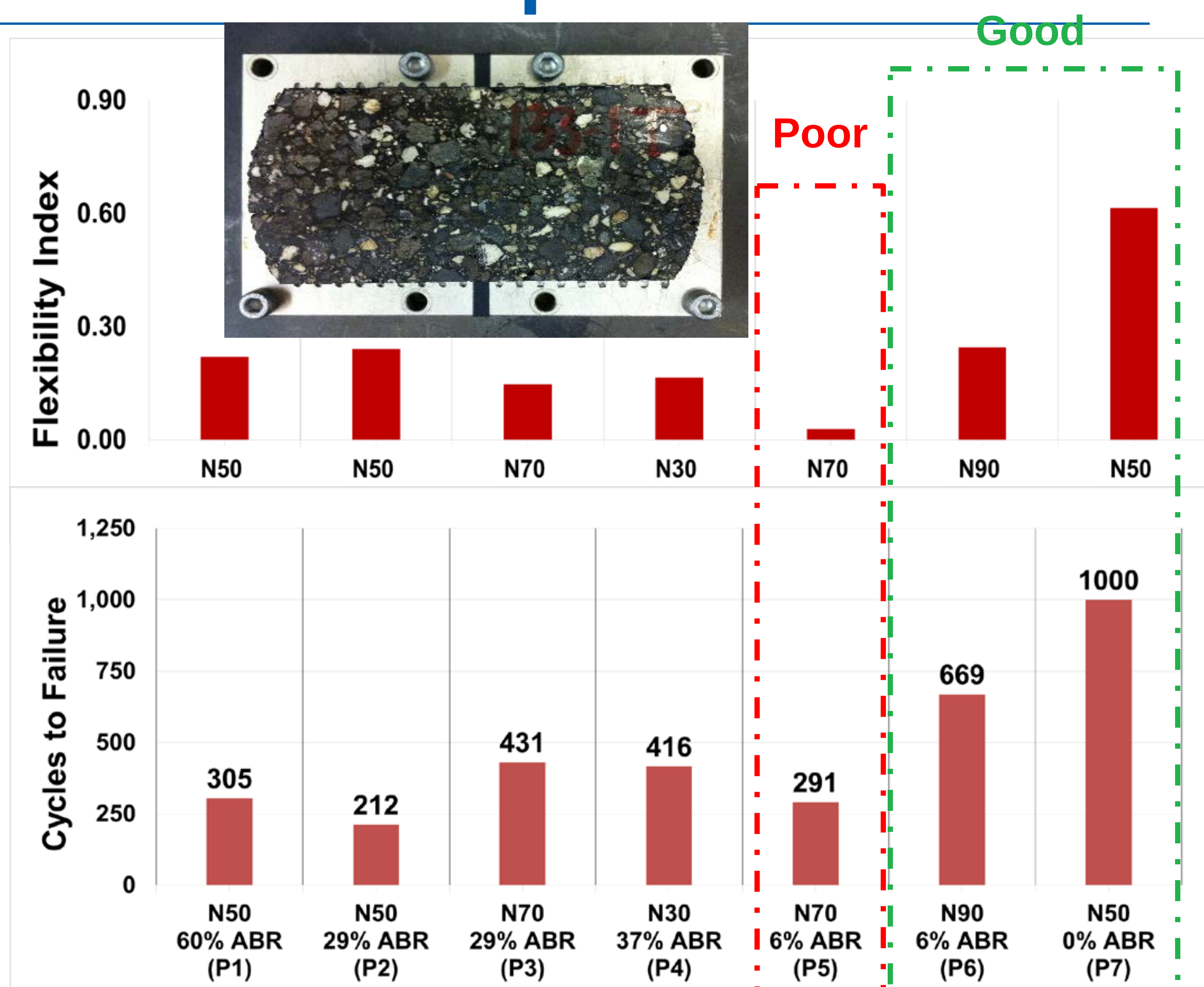


$$\text{Flexibility Index (FI)} = A \times G_F \times \frac{1}{|m|}$$

4- Correlation to Independent Tests: TOL-SCB Comparison

- SCB Flexibility Index:

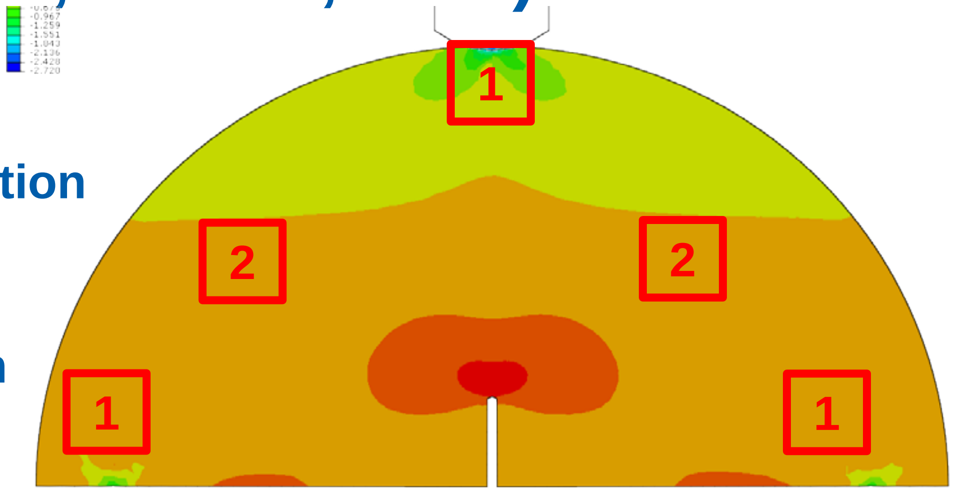
- TOL Cycles to Failure:



Finite Element Simulations

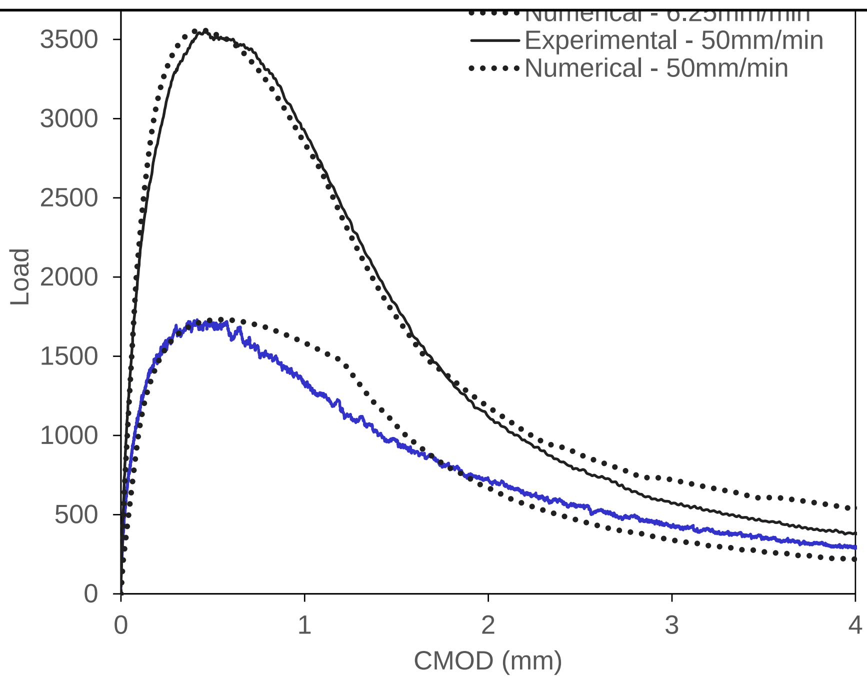
- Main objective of FEM simulations is to quantify **spurious inelastic energy dissipation**
- Spurious energy dissipation can cause an error in work of fracture calculations
- There are established procedures (analytical and experimental) to quantify spurious dissipations (Planas and Elices, 1993; Bazant, 1996)

- The sources are:
  1. Viscoplastic or friction dissipation under the loading head and supports
  2. Irreversible processes far from crack



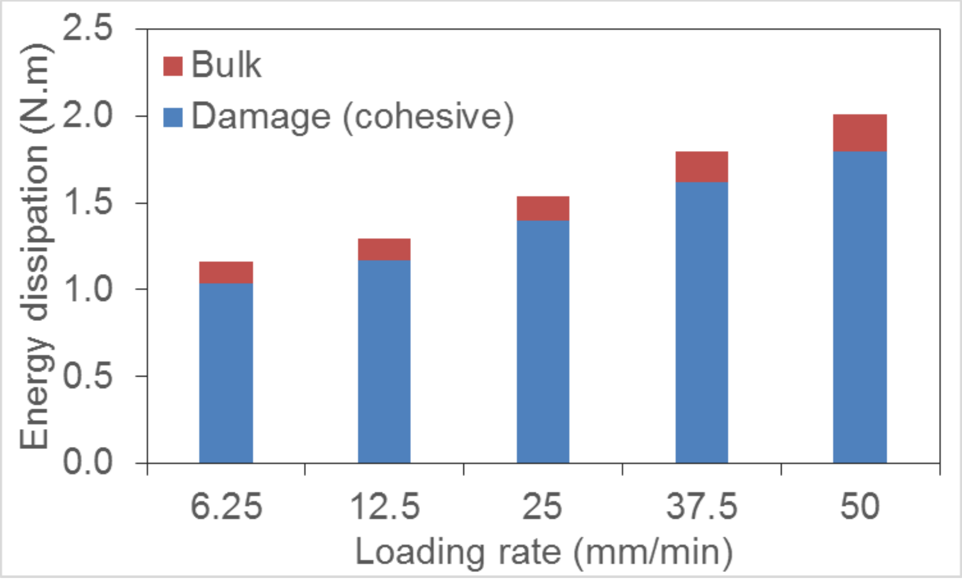
FEM Results

- FEM simulations of N80-25 mix

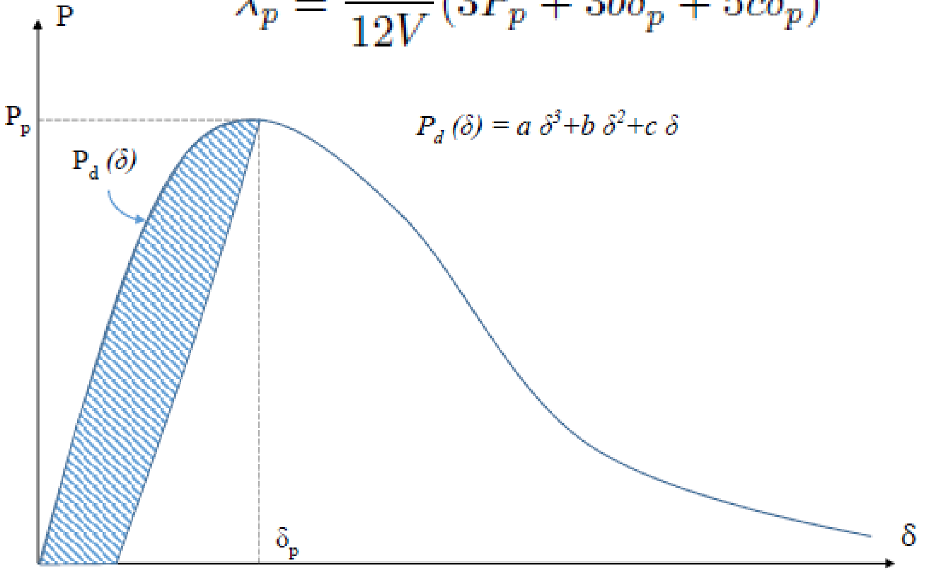


Spurious Inelastic Energy

- Viscoelastic farfield energy dissipation for an asphalt mix tested and simulated is 6-8% of total work of fracture at 25°C
- A semi-empirical model is developed

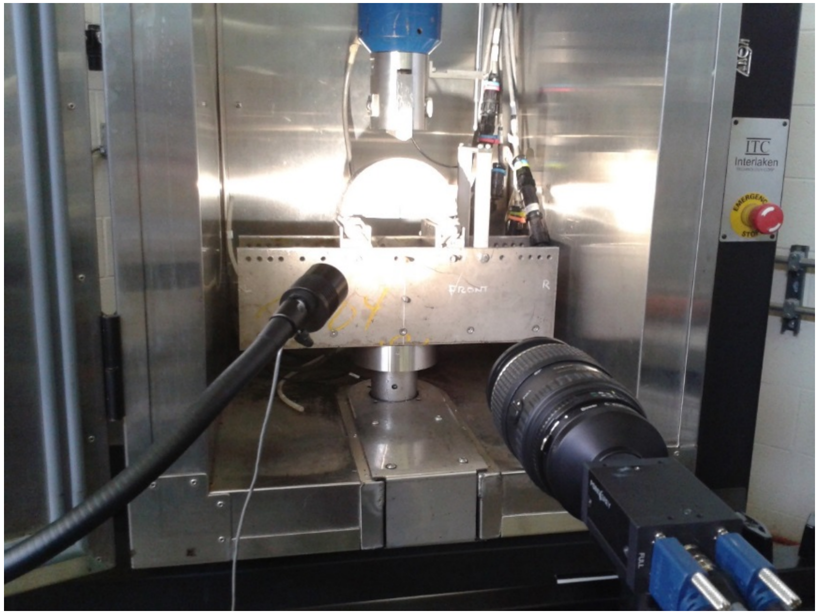


$$\lambda_p = \frac{\alpha_b \delta_p}{12V}(3P_p + 3b\delta_p^2 + 5c\delta_p)$$



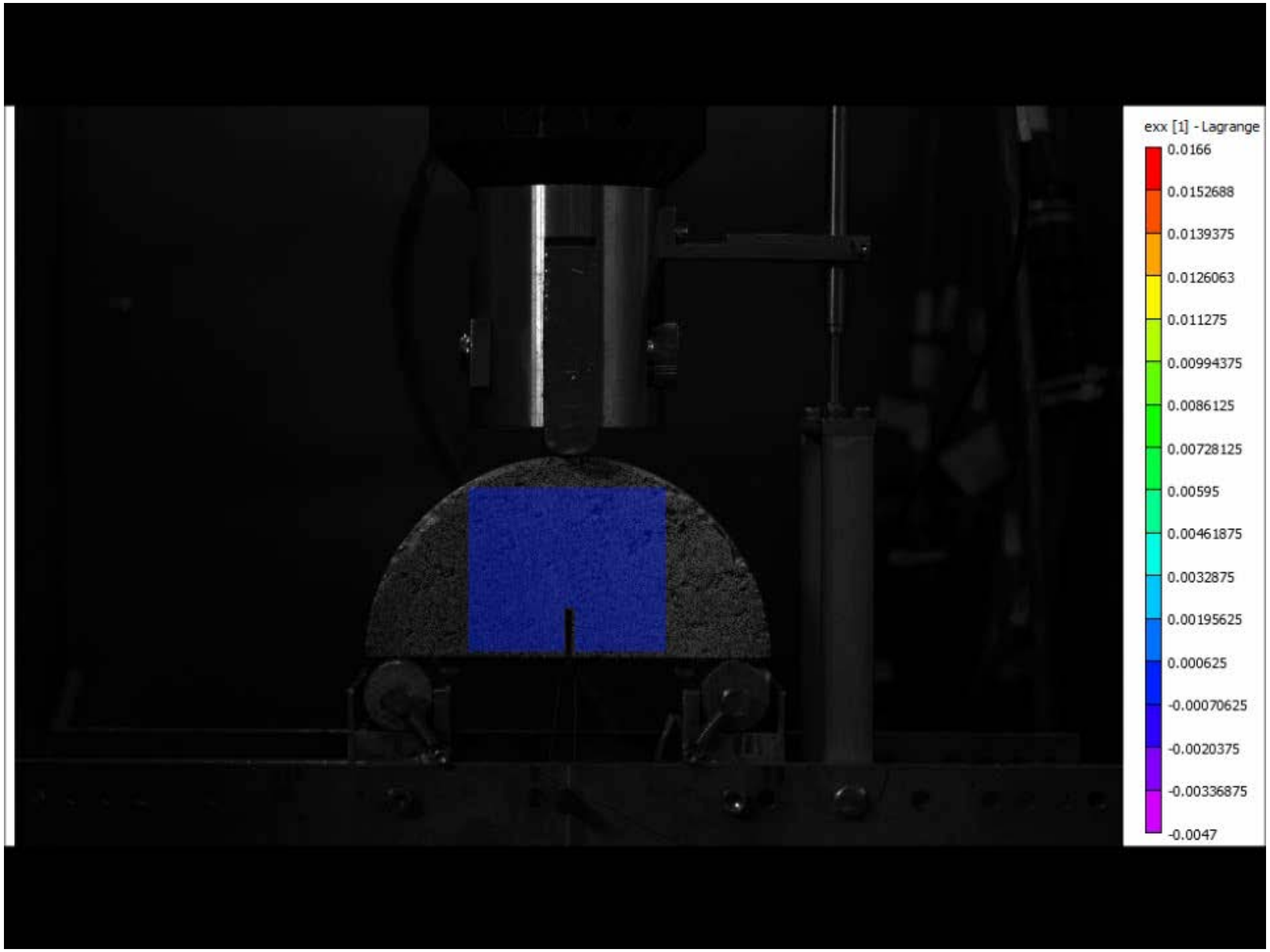
Digital Image Correlation (DIC)

- Using DIC allows us to study:
  1. Full displacement/strain fields
  2. Effect of bulk dissipation
  3. Damage under loading head
  4. Fidelity of the proposed test method (i.e. comparing variation between AASHTO standard and LVDT)
  5. Fracture process zone



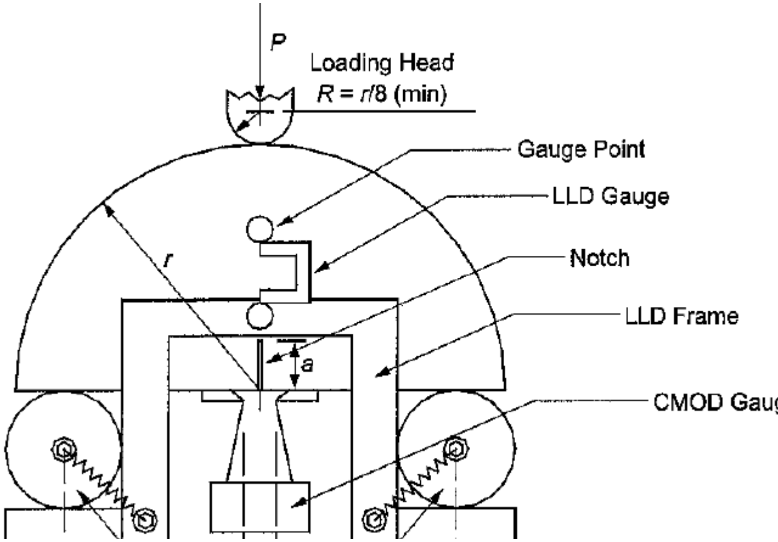
Dual camera set up with 29 MP @ 4 fps and 4 MP @ 150 fps

DIC: Full Field Measurements

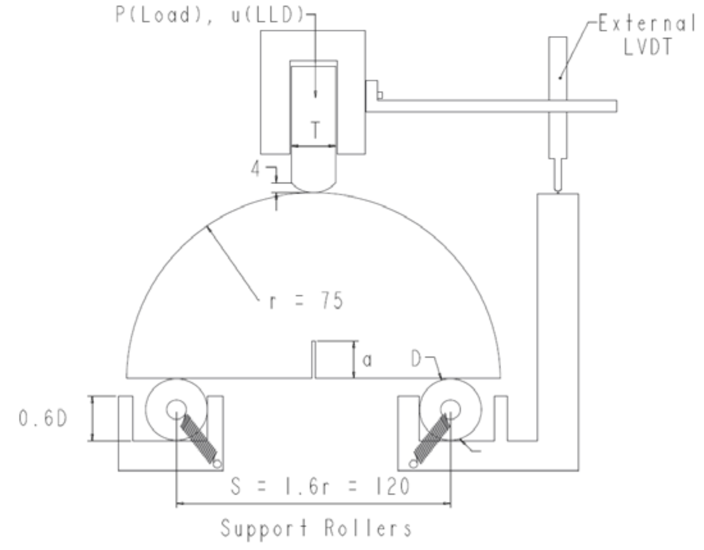


Machine Compliance and Fidelity of Results

- AASHTO TP105-13 uses LLD gauge on specimen in the middle of crack path

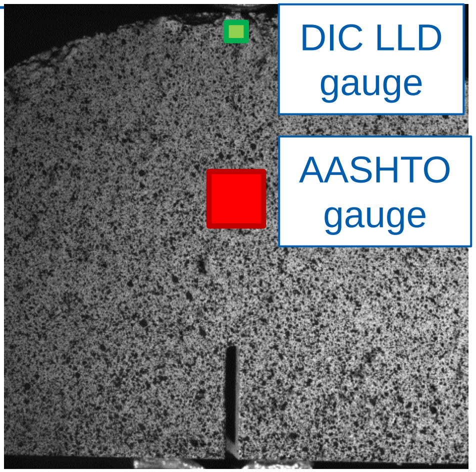


- We propose an external LVDT to measure load-line displacement

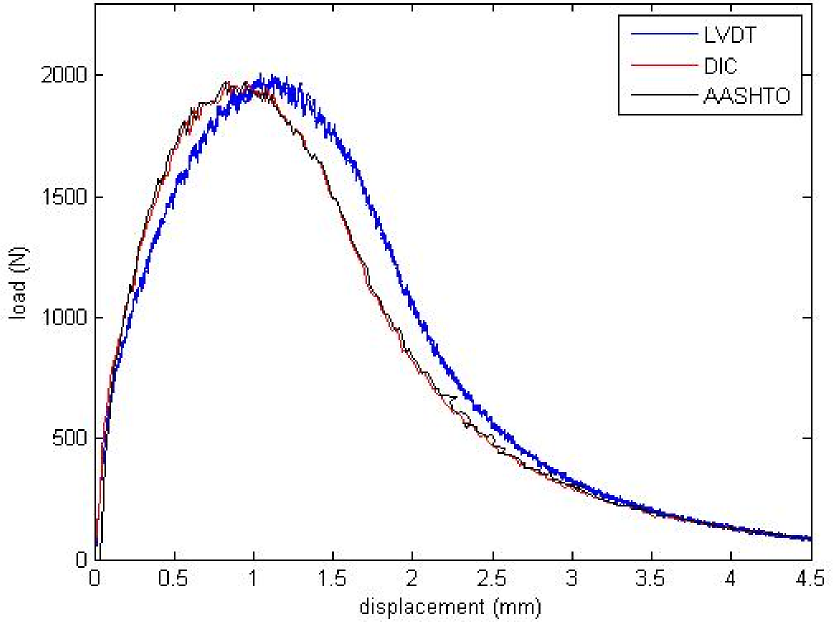


SCB Crack Propagation Measurements

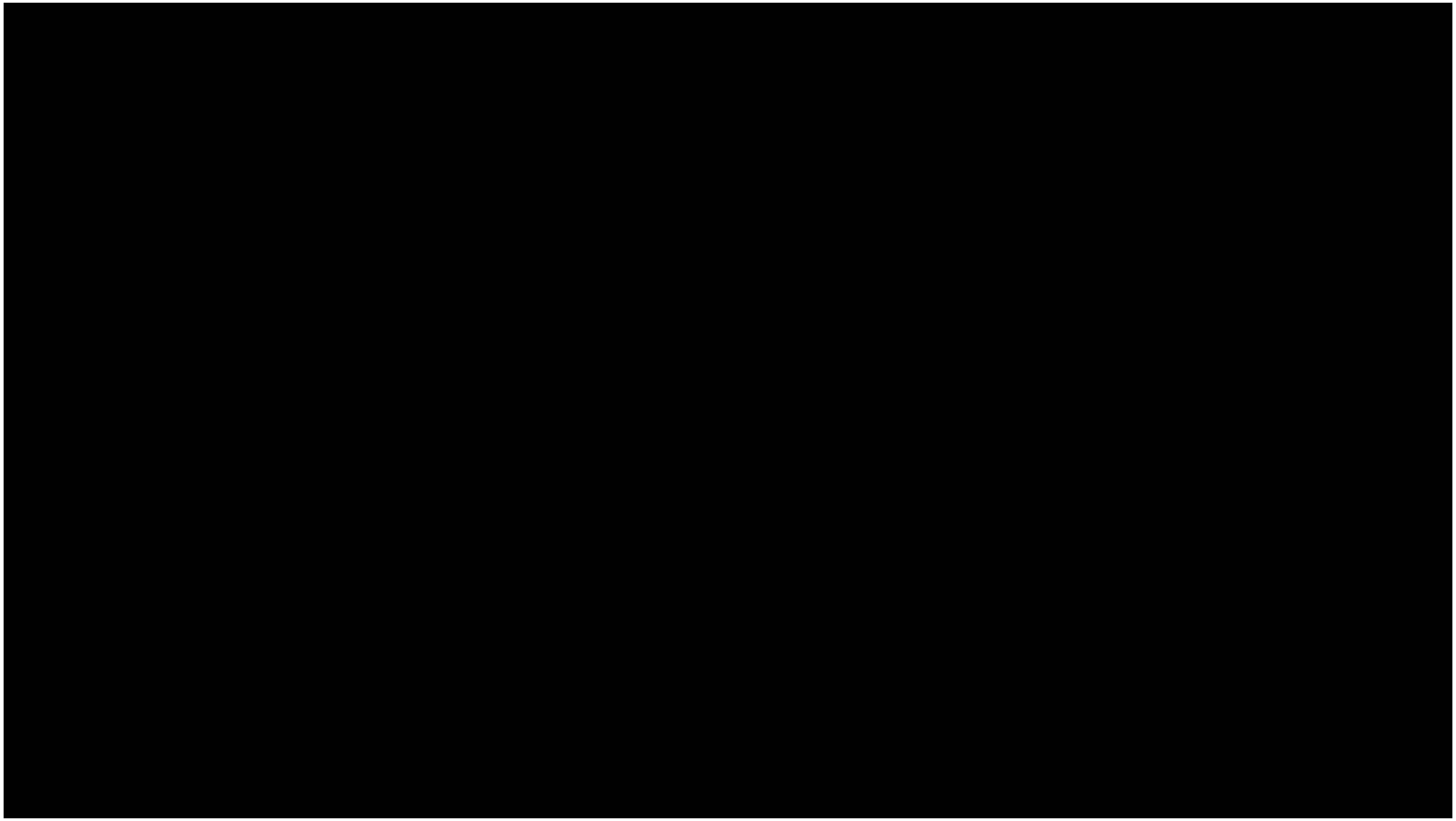
- Gauge location per AASHTO specification **(DIC-AASHTO)**
- Gauge under loading head **(DIC-LVDT)**
- LVDT measurements as in proposed SCB **(LVDT)**



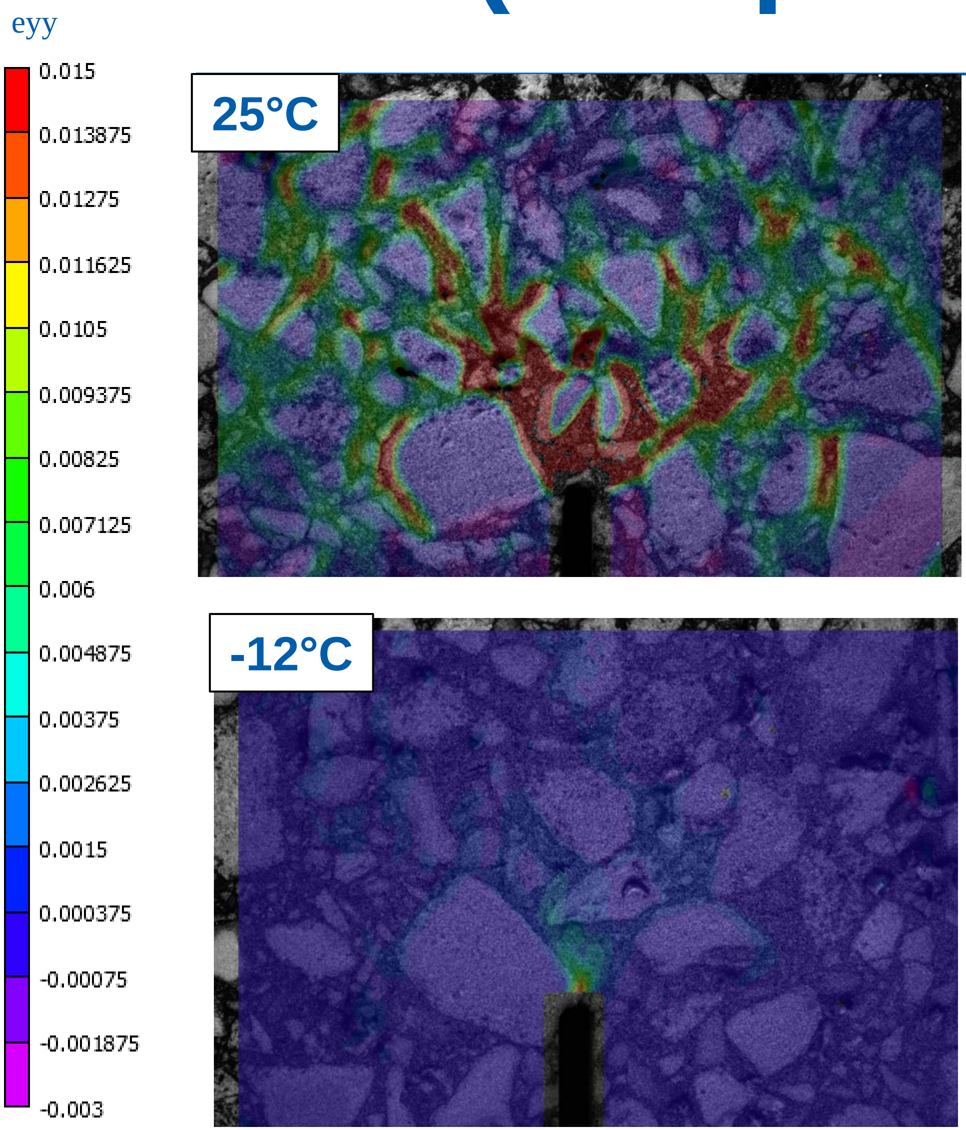
Specimen ID	Fracture Energy
Mix1 DIC	1.11E+03
Mix1 LVDT	1.12E+03
Mix4 DIC	1.11E+03
Mix4 LVDT	1.15E+03
Mix6 DIC	1.90E+03
Mix6 LVDT	1.84E+03
Mix7 DIC	1.26E+03
Mix7-LVDT	1.28E+03



Fracture Process Zone (FPZ)

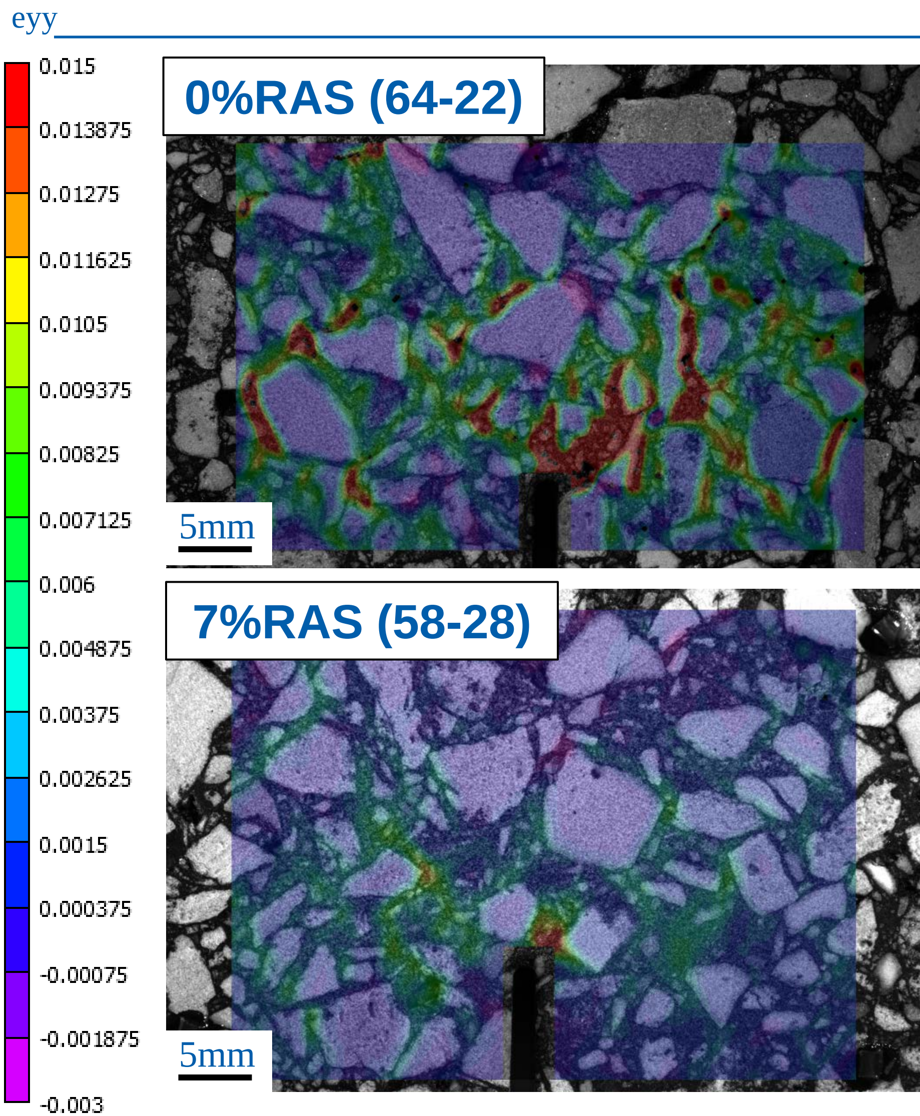


FPZ (Temperature Effect)

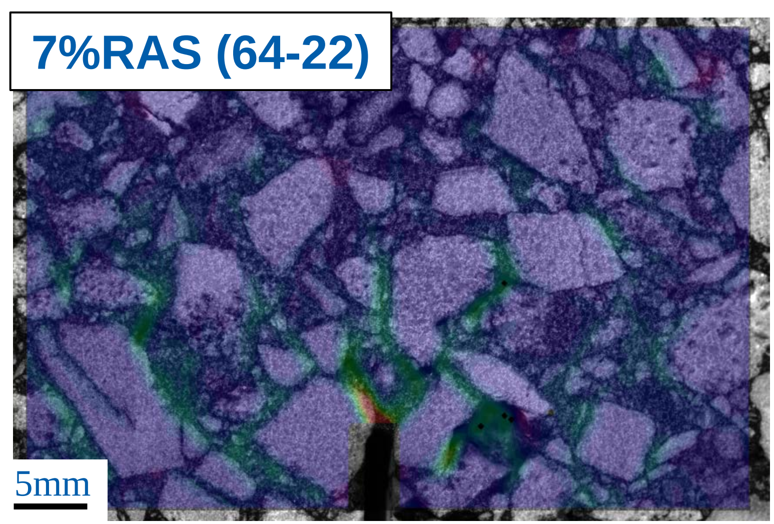


- Diffused damage at intermediate temperature
- Localization of crack initiation at low temperature

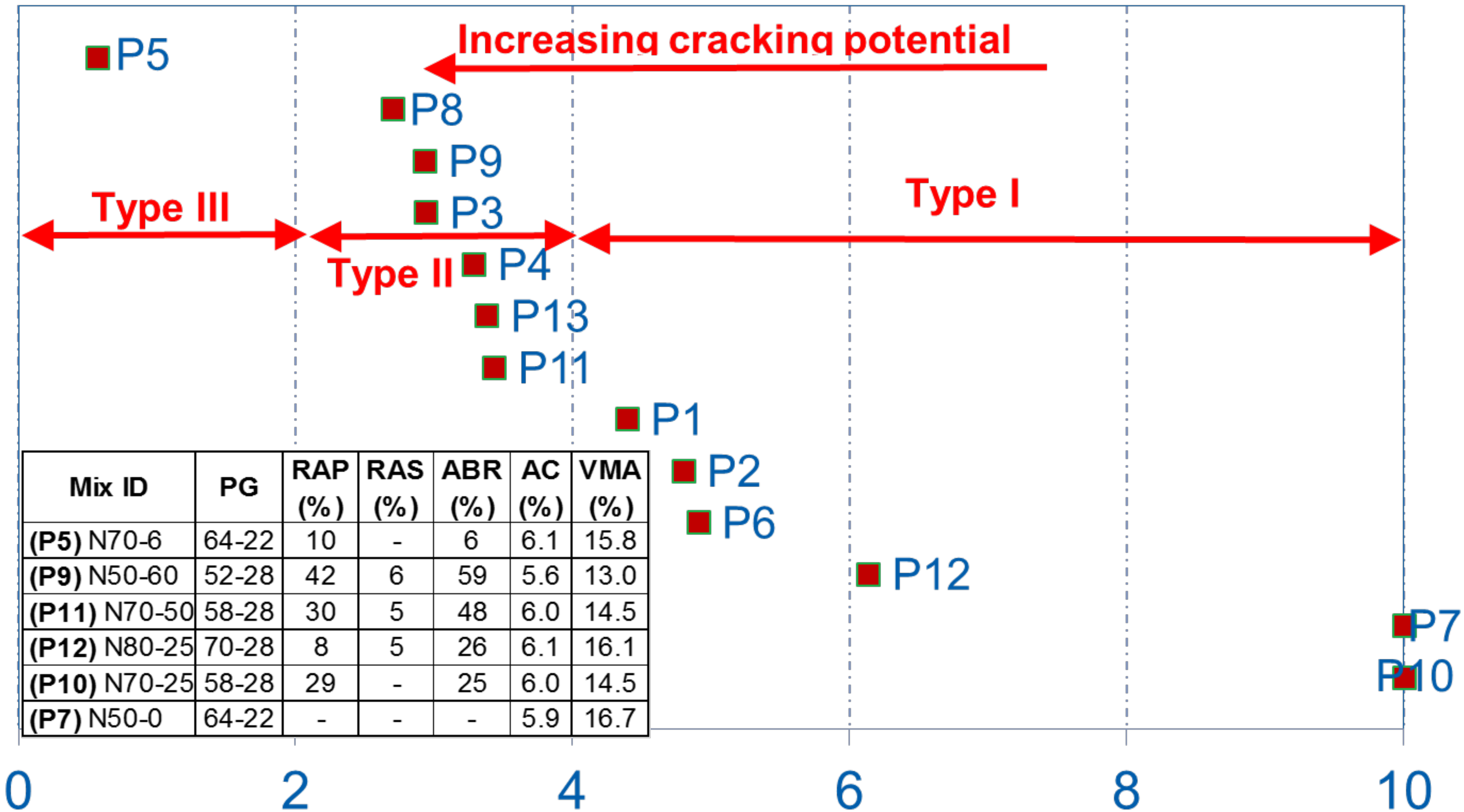
FPZ- Mix



- Decrease of the FPZ area with increasing RAS

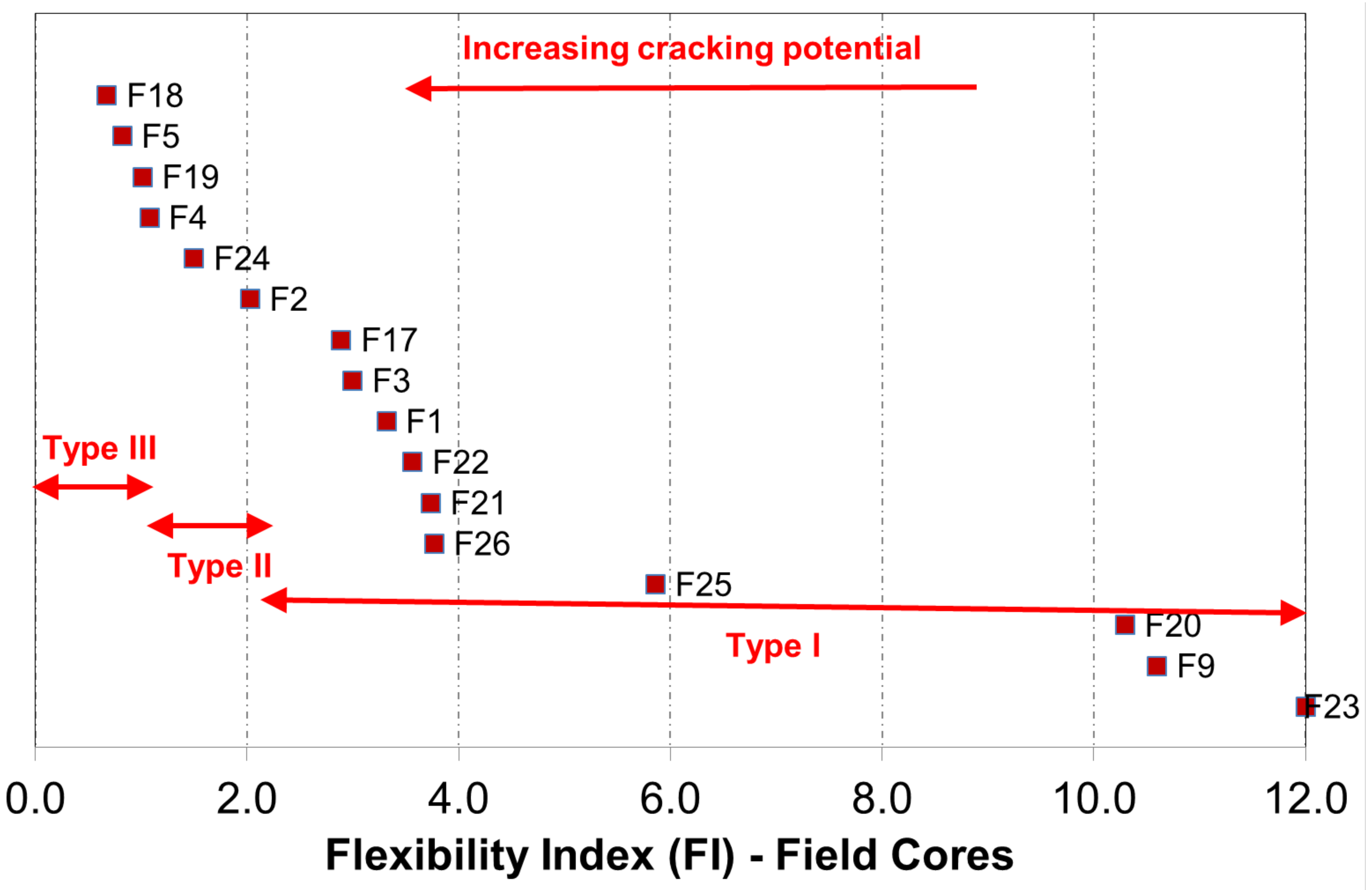


5- FI - Plant Mixes



Mix ID	PG	RAP (%)	RAS (%)	ABR (%)	AC (%)	VMA (%)
(P5) N70-6	64-22	10	-	6	6.1	15.8
(P9) N50-60	52-28	42	6	59	5.6	13.0
(P11) N70-50	58-28	30	5	48	6.0	14.5
(P12) N80-25	70-28	8	5	26	6.1	16.1
(P10) N70-25	58-28	29	-	25	6.0	14.5
(P7) N50-0	64-22	-	-	-	5.9	16.7

5- FI – Field Cores (ongoing work)



FI Categorization & Implementation

- Draft Categorization of Mixes Using Flexibility Index and Thresholds

Mix Category	Mix Type Based on Flexibility Index (FI)	Potential Actions and Remedies
Unacceptable Mix	Type III	Reject mix due to high early cracking potential. Redesign the mix.
Inferior Mix	Type II	Mix susceptible to cracking. Use the mix only in temporary application or redesign.
Acceptable Mix	Type I[1]	Accept the mix. Mix is expected to perform adequately. Use the mix in surface overlay or typical pavement applications.

***Mixtures having FI > 10 are considered high performance mix.**

R27-161 Construction and Performance Monitoring of Various Asphalt Mixes

Construction Year	Project	Contract	Length (mi.)	Mix	ABR %	RAS	RAP	Virgin PG
2014	Pulaski Rd./Crawford St. from 172nd to US	60Y03	1.7	N70-30% ABR	30	X	X	58-28
				N70-15% ABR	15	X	X	64-22
2014	US 52 From Chicaago St. (IL 53) to Laraway	60Y02	3.3	N70-30% ABR	30	X	X	58-28
				N70-30% ABR	30		X	58-28
2015	US 52 from Laraway Road to Gouger Road	60N07	1.6	TRA	TBD	5%	X	58-28
2015	US 52 from Gouger Road to Second Street	60N08	3.4	TRA	TBD	5%	X	52-34
2015	Washington Street from Bridggs Street to	60Y04	0.5	N70-30% ABR	30	X	X	58-34
				N70-30% ABR	30		X	38-34

June 13, 2014 Letting
Total Recycle Asphalt (TRA).
To be determined (TBD) by contractor as allowed by specification

Crawford/Pulaski

5 Lane Bare PCC - 2014 HMA Overlay

Center Section of Crawford Ave Looking North to 169th Street (Google)

US 52 - IL 53 to Laraway

March 26, 2015

Preliminary Laboratory Data

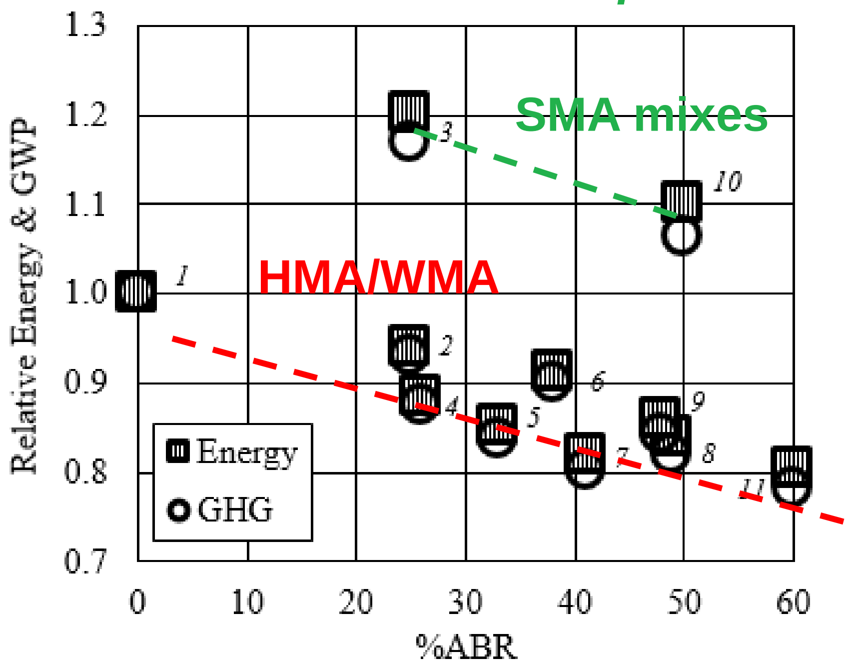
- **Initial SCB tests indicated lower Flexibility Index at Pulaski mixes**

Section	Mix ID	RD (mm) @ 20k passes	Fracture Energy (J/m^2)	Binder Grade	RAP (%)	RAS (%)	FI
Pulaski	141M	3.3	2016	70-28	30.0	4.0	5.1
	156M	3.0	2088	64-22	5.0	2.0	4.9
	157M	2.6	1885	58-28	10.0	4.0	3.5
52	147M	3.1	2190	70-28	25.0	4.5	5.3
	140M	3.8	1774	58-28	20.0	2.5	6.2
	159M	4.6	1963	58-28	34.0	-	8.8

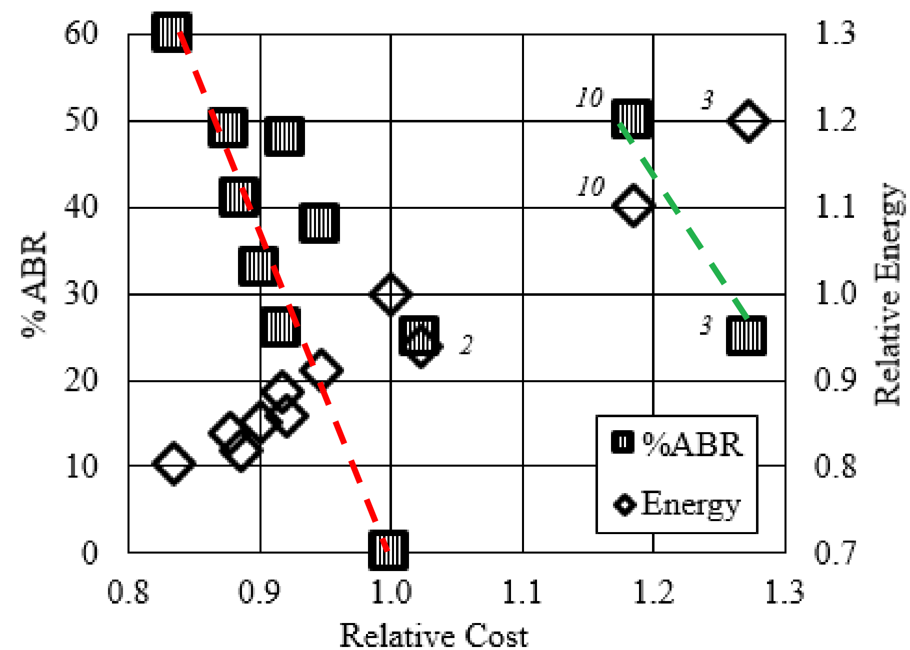
RAP/RAS Impact on Environment

- A net clear reduction in the energy and GHG of mix production with increasing RAP and RAS
- SMA have generally higher energy and GWP due to transportation of aggregates from longer distances

Environmental Impact

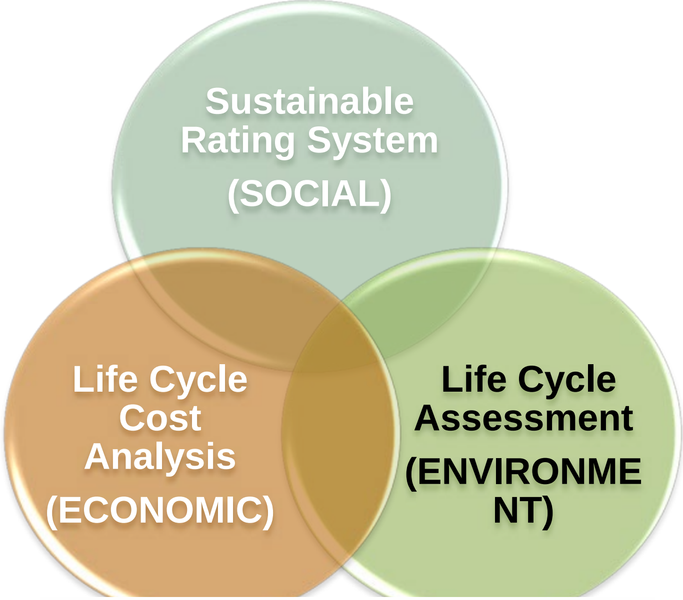


Cost of Production



Life-Cycle Assessment (LCA)

- **Quantify** environmental impacts
- **Evaluate** improvements in sustainability goals
- **Determine** where investment can be most effective

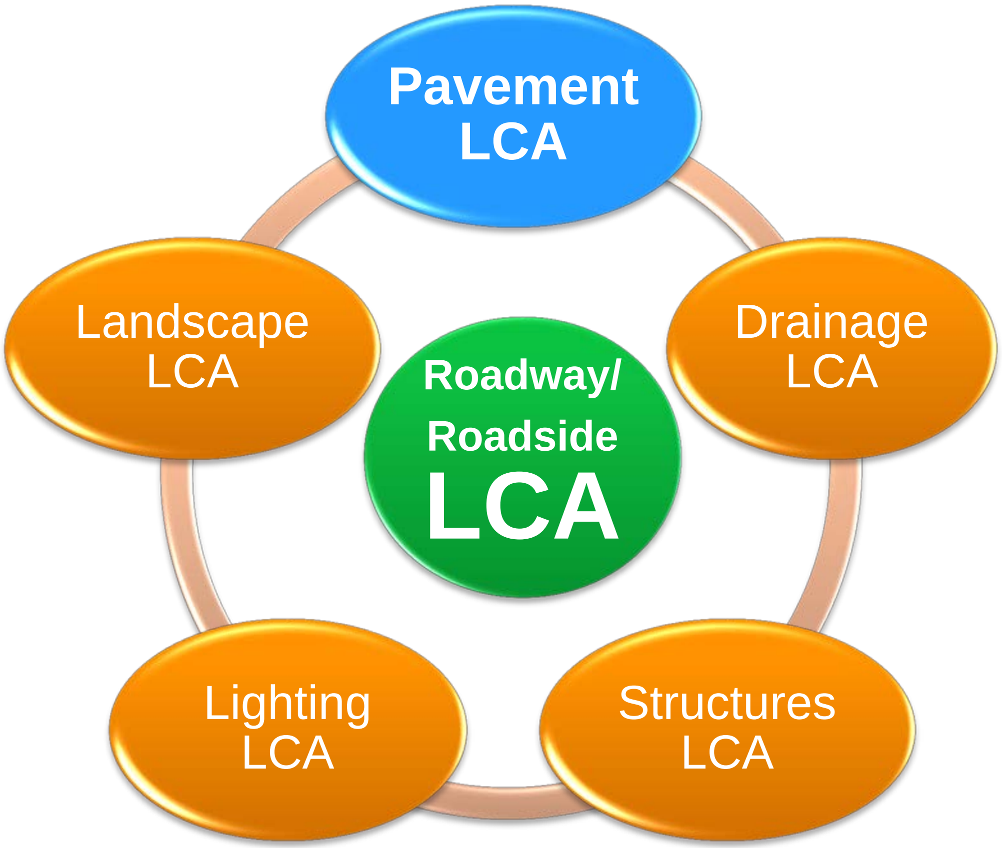


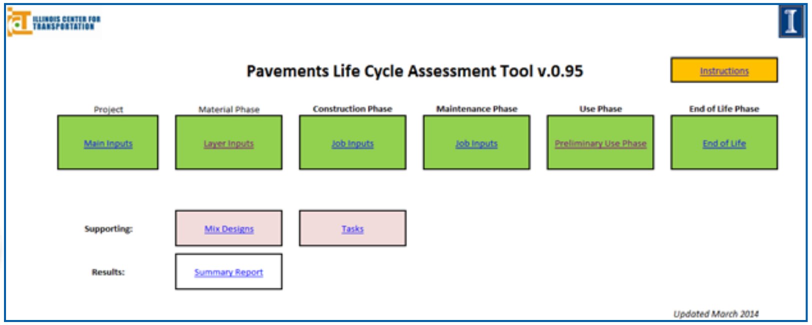
RAP/RAS Environmental Benefits

- Material acquisition and production phase
  - (↑) Replacing virgin binder and aggregates
  - (↓) Potential increase in plant energy consumption
- Construction
  - (↔) If same workability is achieved
- Maintenance/Rehabilitation
  - (↓) In the case of performance reduction resulting more frequent interference
- Use-phase
  - (↓) In the case of performance reduction, additional vehicle fuel consumption

ICT/UIUC LCA Tool

A roadway/roadside Life Cycle Assessment (LCA) toolkit was developed for Tollway in collaboration between UIUC, ARA, and theRightEnvironment

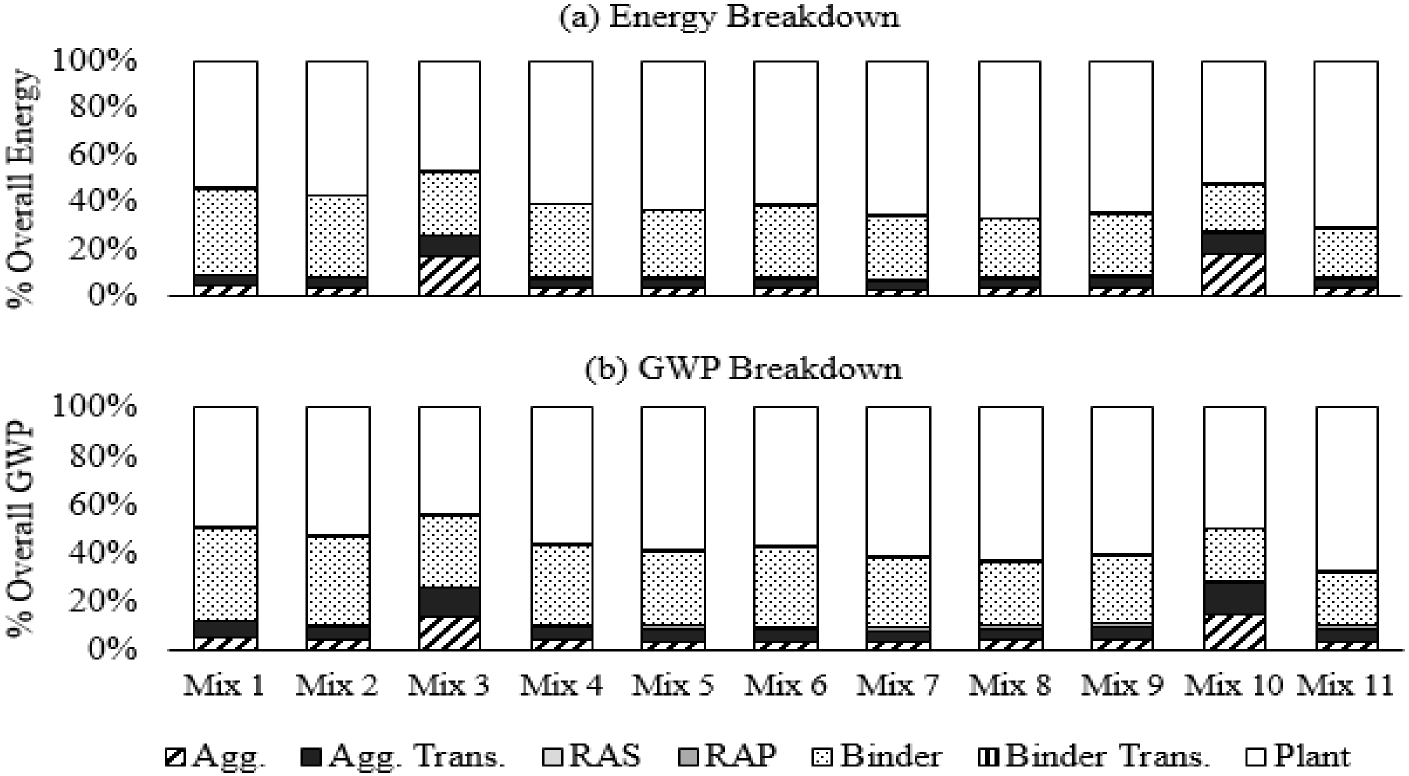




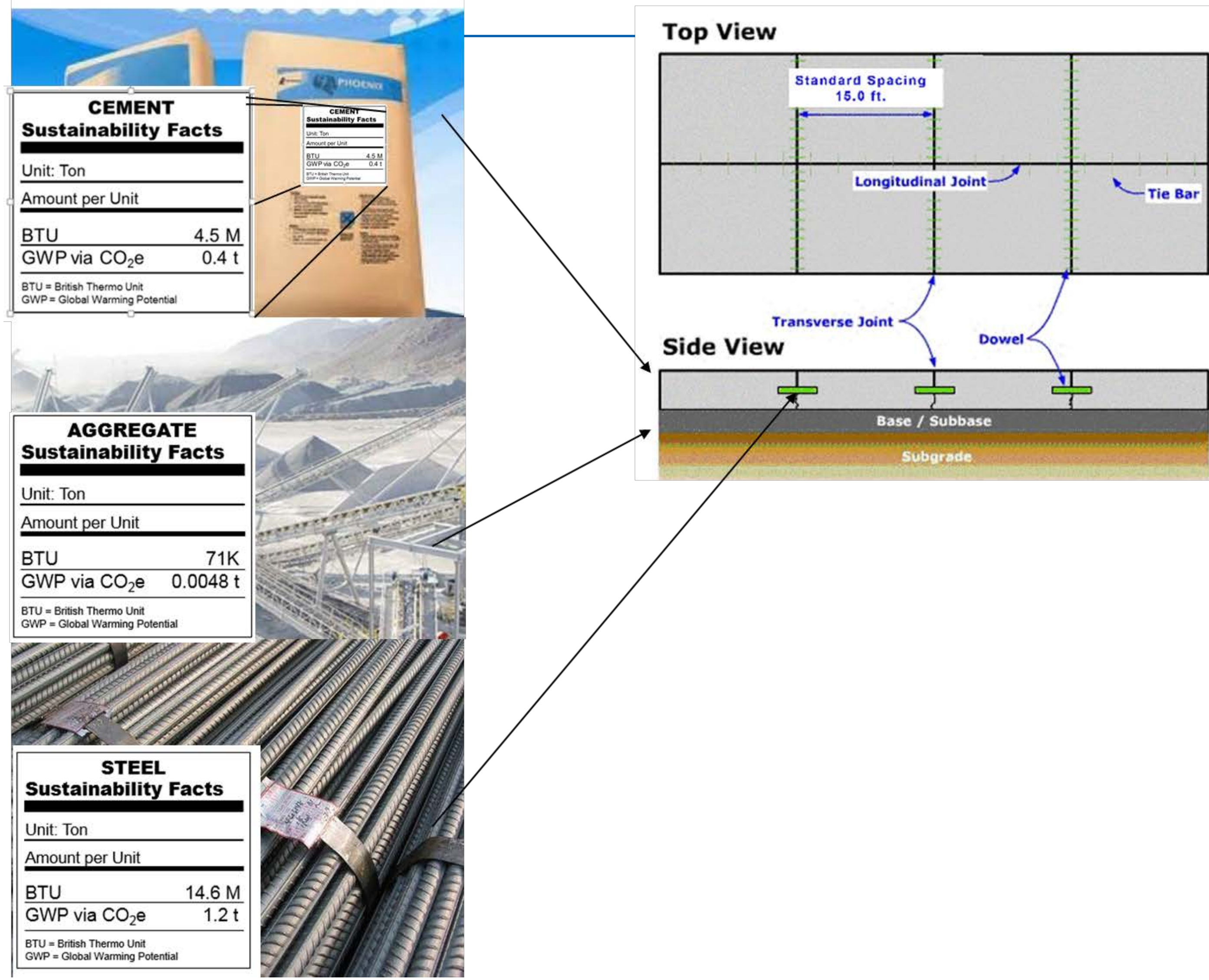
Spreadsheet based tool with inventory data collected for Midwest

Footprint of Mix Production

- Major processes contributing to GWP and energy consumption are binder, plant processes, and transportation



Materials

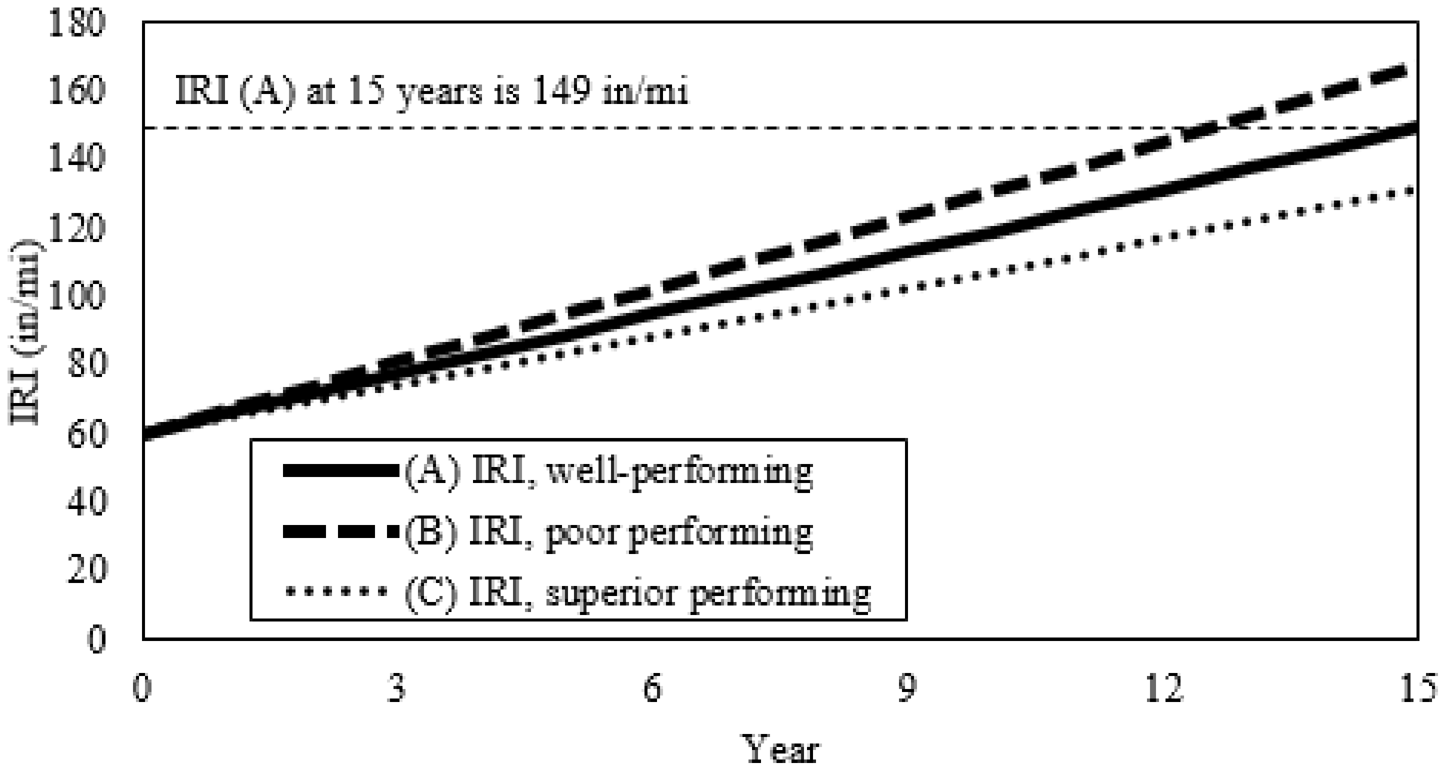

CEMENT
Sustainability Facts
Unit: Ton
Amount per Unit
BTU 4.5 M
GWP via CO_2e 0.4 t
BTU = British Thermo Unit
GWP = Global Warming Potential
AGGREGATE
Sustainability Facts
Unit: Ton
Amount per Unit
BTU 71K
GWP via CO_2e 0.0048 t
BTU = British Thermo Unit
GWP = Global Warming Potential
STEEL
Sustainability Facts
Unit: Ton
Amount per Unit
BTU 14.6 M
GWP via CO_2e 1.2 t
BTU = British Thermo Unit
GWP = Global Warming Potential
Top View
Standard Spacing
15.0 ft.
Longitudinal Joint
Tie Bar
Transverse Joint
Dowel
Side View
Base / Subbase
Subgrade

Use-Phase Impact

- Cost and environmental benefits are clear from the mix production phase
- Use-phase impact is calculated using a scenario-based analysis
  - Use of various mixes in 4-in overlay
  - Traffic varies from 6,000 to 60,000 ADT
  - Analysis period is 15 years
  - IRI performance is the key input to determine extra fuel consumption
  - IRI scenarios are developed to simulate different rates of deterioration

IRI Scenarios

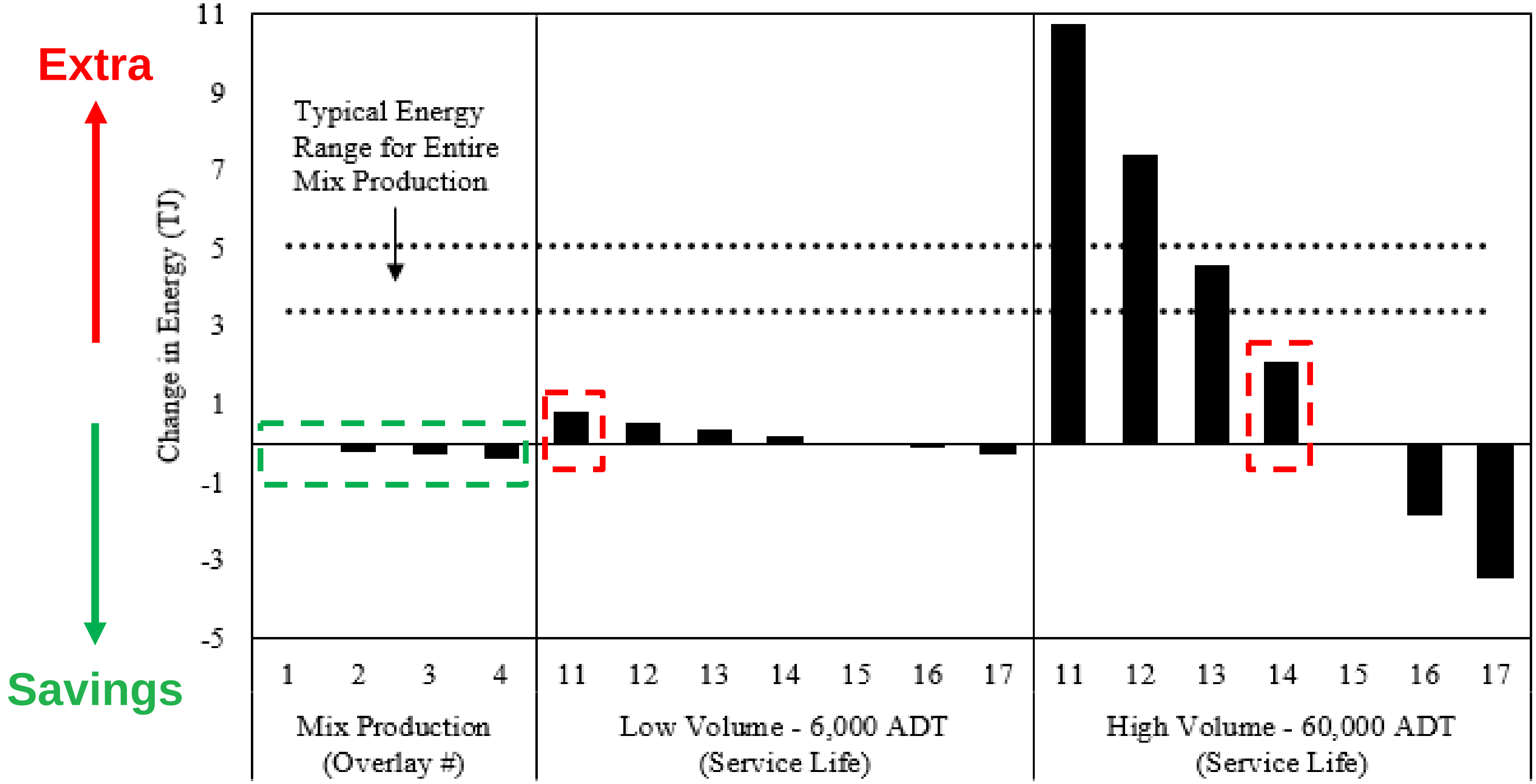
- Well-performing (standard from a network data), poor-performing, and superior performing overlays



Mix Production vs. Use-Phase

3-4 year reduction in service life can offset initial benefits for low volume roads

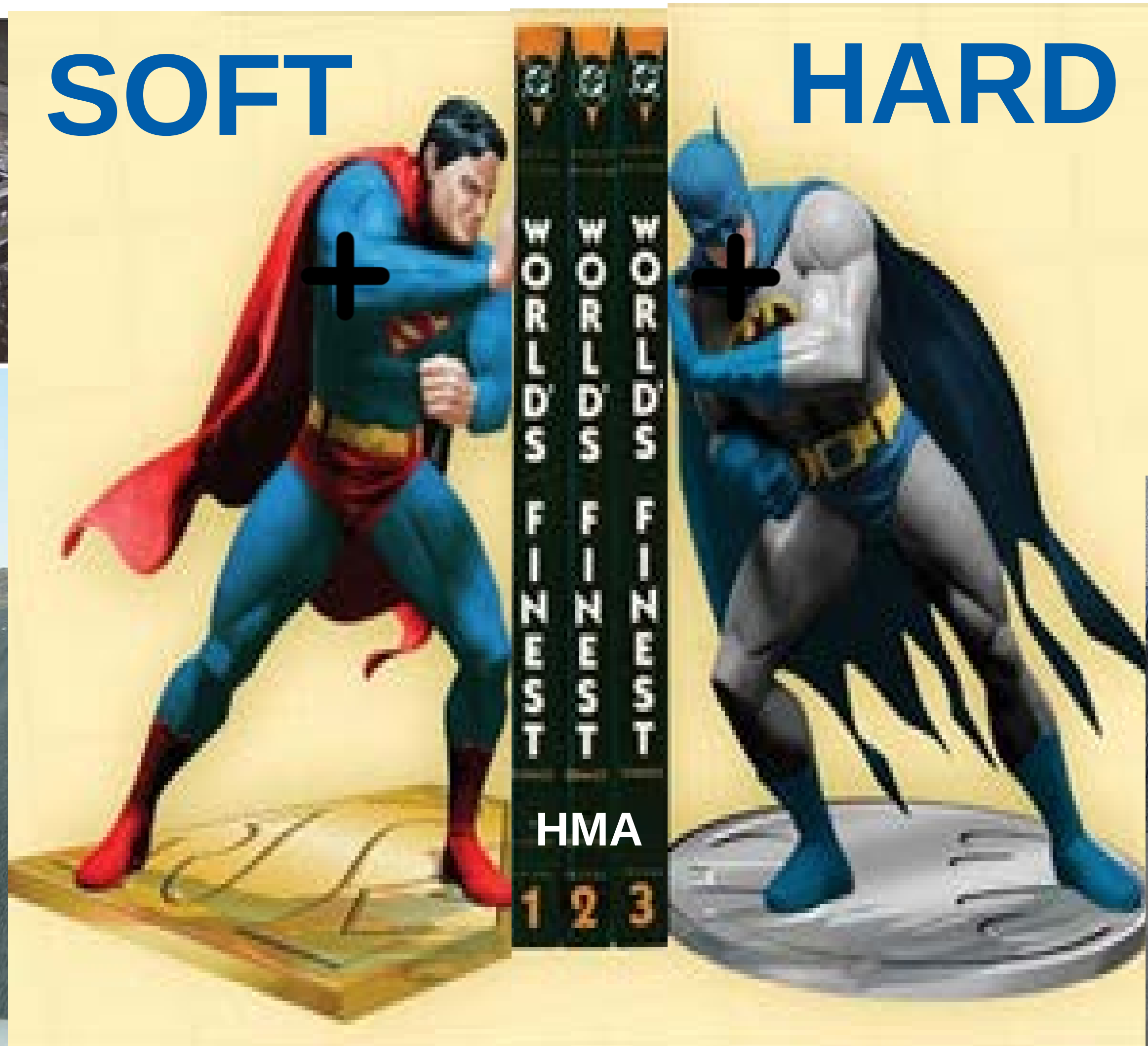
Less than 1 year reduction in service life can offset initial benefits for high volume roads



Final Remarks

- We need to engineer asphalt mixes
- Wheel Track, *Tensile*, and SCB
  - A simple, reliable, and scientifically sound test/methodolgy is introduced
  - Flexibility Index can discriminate between mixes
  - Good Validation; More is underway
- LCA is needed to assess sustainability impact
  - Pavement performance and traffic volumes are critical

HMA Testing “Book Ends”



Acknowledgements

- ICT R27-128 Project Technical Review Panel
- Undergrad and graduate students involved
- ICT research engineers

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