Development and Evaluation of Performance Measures to Augment Asphalt Mix Design in Idaho

University of Idaho
College of Engineering

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Outline

- Research Motivation
- Research Objectives
- Research Methodology and Tasks
- Research Findings
- Research Recommendations/Implementation

Research Motivation

- Superpave volumetric mix design is conducted without performance criteria to evaluate the mix resistance to cracking and rutting.

Performance Grade	PG 46-			PG 52-							PG 58-					PG 64-					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average seven-day Maximum Pavement Design Temperature, °C	<46			<52							<58					<64					
Minimum Pavement Design Temperature, °C	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
Original Binder																					
Flash Point Temp: Minimum °C	230																				
Viscosity, ASTM D4402: Maximum, 3 Pa.s, Test Temp, °C	135																				
Dynamic Shear: G*/sin δ, Minimum, 1.00 kPa Test Temp @ 10 rad/s, °C	46			52							58					64					
Rolling Thin-Film Oven Residue																					
Mass Loss, Maximum, Percent	1.00																				
Dynamic Shear: G*/Sin δ, Minimum, 2.20 kPa Test Temp @ 10 rad/s, °C	46			52							58					64					
Pressure-Aging Vessel (PAV) Residue																					
PAV Aging Temperature, °C	90			90							100					100					
Dynamic Shear: G* · sin δ, Maximum, 5000 kPa Test Temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Creep Stiffness: S, Maximum, 300 MPa, m-value, Minimum, 0.300 Test Temp @ 60s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Direct Tension: Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

Rutting criteria → (Dynamic Shear: G*/Sin δ, Minimum, 2.20 kPa)

Fatigue criteria → (Dynamic Shear: G* · sin δ, Maximum, 5000 kPa)

Low-temperature criteria → (Creep Stiffness)

Research Motivation

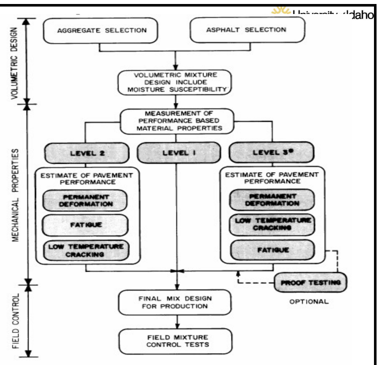
- Rutting and cracking have been observed in pavements that were designed using the Superpave method

Rutting

Fatigue Cracking

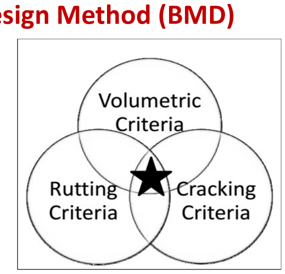
Moisture Damage

Research Motivation



Performance-Engineered Mix Design (PEMD) or Balanced Mix Design Method (BMD)

- PEMD incorporates performance assessment tests



PEMD concept

Research Objectives

1. Review and document performance tests and indicators used by various transportation agencies to evaluate the resistance of asphalt mixes to cracking and rutting.
2. Propose and develop new analysis method for monotonic cracking assessment test and dynamic cracking assessment test to overcome the limitations of existing indicators and tests
3. Select the most promising performance tests and indicators
4. Examine and evaluate selected tests and indicators to assess the resistance of asphalt mixes to cracking and rutting
5. Develop performance thresholds to ensure adequate resistance to cracking and rutting

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Research Methodology and Tasks

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Task 1: Literature review

Rutting assessment tests

Asphalt Pavement Analyzer (APA) rut test

Hamburg wheel tracking test (HWTT)

Performance indicators

- Maximum rut depth @ 8,000 loading cycles (APA_{8000})
- Maximum rut depth @ 15,000 loading passes ($HWTT_{15000}$)
- Maximum rut depth @ 20,000 loading passes ($HWTT_{20000}$

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Task 1: Literature review

■ **Performance thresholds**

APA rut test

State DOT	Additional Distinguish criteria (i.e., binder PG, traffic level. etc.)	Limits (Max. rut depth [mm])
Idaho	All mixes (SP3, SP5)	5.0
Alabama	SMA mixes and HMA with traffic ESALs between 1.0E7 and 3.0E7	4.5
Alaska	All mixes	3.0
Georgia	19.0 mm and 25.0 mm NMAS mixes	5.0

Others

HWTT

DOT	Rutting performance threshold (Minimum # of Passes)	
TXDOT	Additional Distinguish criteria (i.e., binder PG, traffic level. etc.)	Limits, @12.5mm rut depth tested at 50 °C
	<=PG 64	10000
	PG 70	15000
	=>PG 76	20000
Illinois	**PG 58-xx**	**5,000**
	PG 64-xx	7,500
	PG 70-xx	15,000
	PG 76-xx or higher	20,000
Oklahoma	**PG 64-xx**	**10,000**
	PG 70-xx	15,000
	PG 76-xx	20,000

Others

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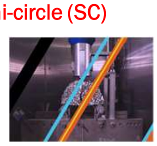
Task 1: Literature review

Documented testing standards to assess cracking

Specimen geometry		SC		IDT
Testing Standards		ASTM D8044	AASHTO TP 124	ASTM D6931 and D8225
Symbol		SCB-Jc	SCB-FI	IDT
Specimen geometry	Notch (mm) depth	25.4, 32, and 38	15	---------
	Diameter (mm)	150	150	150 or 101.6
Loading rate (mm/min)		0.5	50	50
Test output		Load-displacement curve		

Semi-circle (SC)



Circular

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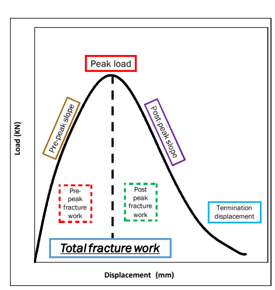
Task 1: Literature review

Performance indicators and PEMD specification to assess cracking



#	Formula	Research group	References
1	$G_{Fracture}^{Total} = \frac{W_{Fracture}^{Total}}{crack\ face\ area}$	-	(Zhu et al. 2017)
2	$\sigma_{tesnile}{}^{IDT} = \frac{2000xP_{Peak}}{\pi \times t \times D}$	-	Buttlar et al. (1996)
3	$IDT_{modulus} = \frac{\sigma_{Tensile}{}^{IDT}}{L_{Peak\ load}}$	Japan	West and Copeland (2015)
4	$J_c = -\left(\frac{1}{t}\right)\frac{dU}{da}$	Louisiana State University	Wu et al. (2005); Bayomy et al. (2006)
5	$FI = 0.01 * \frac{G_{Fracture}^{Total}}{\left\|m_{Inflection}^{Post-peak}\right\|}$	University of Illinois at Urbana-Champaign	Al-Qadi et al. (2015)
6	$N_{flex} = \frac{Toughness}{m_{inflection}^{Postpeak}}$	National Center for Asphalt Technology (NCAT)	West et al. (2017)
7	$IDEALCT_{\ Index} = \frac{G_{Fracture}^{Total}}{\left\|m_{75\%}^{Postpeak})\right\|} \times \frac{t}{62} \times \varepsilon_v{}^{tolerance}$	Texas A&M University	Zhou et al. (2017)
8	$CRI = \frac{G_{Fracture}^{Total}}{P_{Peak}}$	Texas A&M University	Kaseer et al. (2018)

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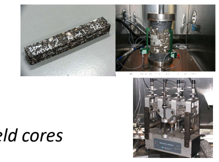
Task 1: Literature review

Identified limitations of cracking assessment tests

- Current monotonic performance indicators
  - *Lack the full description of the load-displacement curve*
  - *Provide illogical trend with air void content and thickness*
- Current dynamic assessment tests
  - *long or unknown testing time*
  - *Unknown stress/strain levels*
  - *Complex specimen shape*
  - *Costly equipment*
  - *Can not be used to evaluate extracted field cores*



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Task 2: Develop new and innovative cracking assessment tests

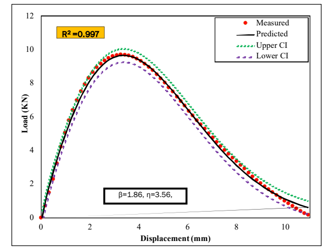
Innovative unified monotonic performance indicator

- Curve fitting

$$P = A \times \left(\frac{\beta}{\eta}\right)\left(\frac{u}{\eta}\right)^{\beta-1} \times e^{-\left(\frac{u}{\eta}\right)^{\beta}}$$

where

- P = the applied load or stress
- u = the measured displacement
- β = the *shape parameter*
- η = the *scale parameter*
- A = the *area parameter*



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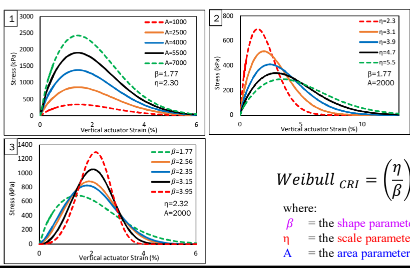
Task 2: Develop new and innovative cracking assessment tests

Innovative unified monotonic performance indicator

- Indicator derivation



Higher Weibull$_{CRI}$ Indicates *improved resistance* to cracking

$$Weibull_{CRI} = \left(\frac{\eta}{\beta}\right) \times log[A]$$

where:
β = the shape parameter
η = the scale parameter,
A = the area parameter

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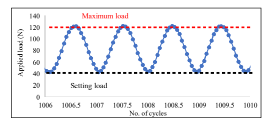
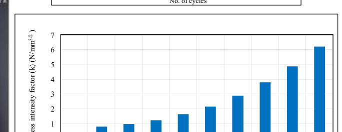
Task 2: Develop new and innovative cracking assessment tests

Develop a new dynamic loading cracking assessment

MSSD applies a series of different SIF factors

Ten different loading stages with different SIF are applied





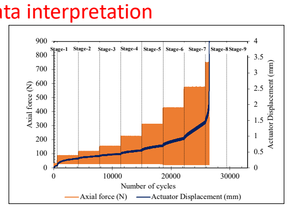
	Stage-0	Stage-1	Stage-2	Stage-3	Stage-4	Stage-5	Stage-6	Stage-7	Stage-8	Stage-9
ΔK	0.08	0.4	0.58	0.83	1.24	1.77	2.49	3.4	4.48	5.8
Kmax	0.20	0.60	0.78	1.03	1.44	1.97	2.69	3.60	4.68	6.00
Kmin	0.12	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

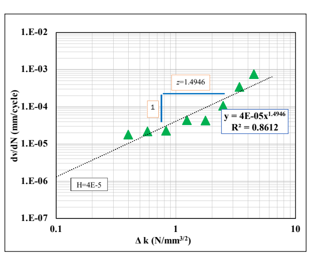
Task 2: Develop new and innovative cracking assessment tests

Develop a new dynamic loading cracking assessment test

$$\frac{dv}{dN} = H\,(\Delta K)^{Z}$$

Data interpretation





Lower slope (z) Value

Higher intercept value (Abs *log H*)

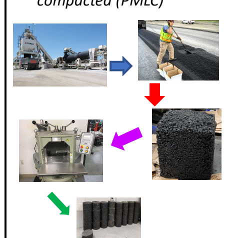
Improving in mix resistance to cracking

Task 3: Identify and select testing materials and conduct field performance evaluation

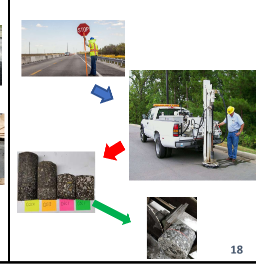
Identified test materials

Six Laboratory Mixed-Laboratory compacted (LMLC)

10 Plant Mixed-Laboratory compacted (PMLC)



17 Field Projects



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Task 3: Identify and select testing materials and conduct field performance evaluation

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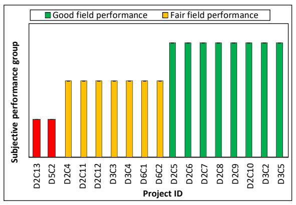
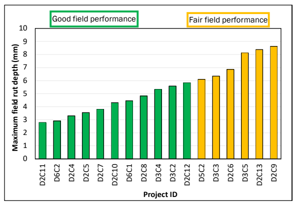
Observed field performance -

Observed cracking performance



Observed rutting performance



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Task 4: Conduct laboratory performance tests

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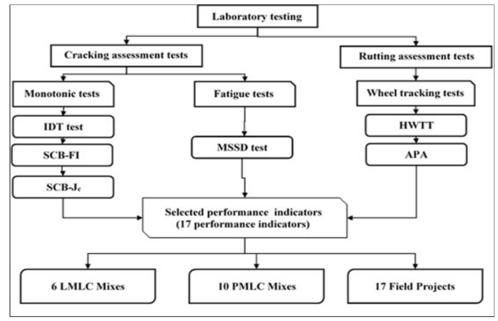
Selected testing standards and Experimental design



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Task 4: Conduct laboratory performance tests

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Selected performance indicators

Most promising rutting performance indicators

#	Assessment test	Assessment Indicator
1	APA	APA_{8000}
2	HWTT	$HWTT_{15000}$
3		$HWTT_{20000}$

Newly developed cracking performance indicators

#	Assessment test	Assessment Indicator
4	MSSD	Slope (z)
5		Abs log (H)
6	IDT	$Weibull_{CRI}$

Promising cracking performance indicators

#	Assessment test	Assessment Indicator
7	SCB-Jc	J_c
8	SCB-FI	$G_{Fracture}^{Total}$
9		CRI
10		FI
11	IDT	$G_{Fracture}^{Total}$
12		$\sigma_{tesnile}^{IDT}$
13		$IDT_{modulus}$
14		FI
15		CRI
16		$IDEAL-CT_{Index}$
17		N_{flex}

Task 4: Conduct laboratory performance tests

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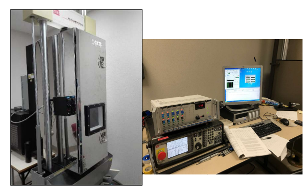
Testing devices

AMPT



MTS

APA Jr.

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Task 5: Conduct comprehensive evaluation of cracking and rutting performance of laboratory-prepared specimens

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1. Investigate fundamental understanding of variation in the load-displacement curve in terms of mix cracking resistance
2. Examine performance indicators sensitivity to the variation in binder content
3. Examine performance indicators sensitivity to the variation in binder grade
4. Examine performance indicators variability
5. Examine performance indicators correlation with each other
6. Examine performance indicators statistical grouping for mixes performance
7. Investigate the expected cracking and rutting resistance of currently produced asphalt mixes in Idaho

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Task 5: Conduct comprehensive evaluation of cracking and rutting performance of laboratory- prepared specimens

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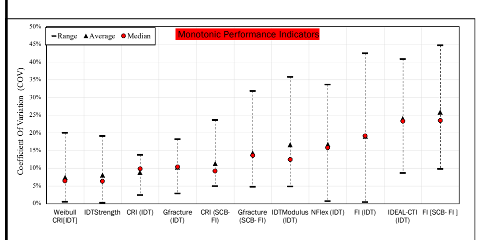
Performance indicators variability

Variability	Average COV
Low	<10%
Moderate	10% < COV < 30%
High	> 30%



Performance indicator	Variability
$G_{fracture}$ (IDT)	Moderate
$G_{fracture}$ (SCB-FI)	Moderate
CRI (IDT)	low
CRI (SCB-FI)	Moderate
FI (IDT)	Moderate
FI (SCB-FI)	***Highest***
$IDEAL-CT_{Index}$	Moderate
Nflex factor	Moderate
$IDT_{strength}$	low
$IDT_{Modulus}$	Moderate
J_c	NA
$Weibull_{CRI}$ (IDT)	***Lowest***

Task 5: Conduct comprehensive evaluation of cracking and rutting performance of laboratory- prepared specimens

Summary

performance indicator	LMLC mixes		PMLC mixes							PMLC and LMLC mixes
	Binder PG	Binder Content	D2L2 and D6L1 to have the best cracking resistance	D3L1 to have the worst cracking resistance	D1L1 to have better-cracking resistance than D3L3	D1L1 to have better-cracking resistance than D3L5	D2L1 to have better-cracking resistance than D3L1	D2L2 to have better-cracking resistance than D2L1	Number of Tukey Groups (PMLC)	Variability
$G_{fracture}$ (IDT)	↙	⇕	✓	✗	✗	✓	✓	✓	4	Moderate
$G_{fracture}$ (SCB-FI)	↙	⇕	✓	✓	✓	✓	✓	✓	4	Moderate
CRI (IDT)	↗	↗	✓	✓	✓	✓	✓	✓	4	low
CRI (SCB-FI)	↗	↗	✗	✗	✗	✓	✓	✓	3	Moderate
FI (IDT)	↗	↗	✓	✓	✓	✓	✓	✓	2	Moderate
FI (SCB-FI)	↗	↗	✗	✗	✗	✓	✓	✓	2	Highest
IDEAL-CT_{Index}	↗	↗	✗	✓	✓	✓	✓	✓	2	Moderate
Nflex factor	↗	↗	✓	✓	✓	✓	✓	✓	2	Moderate
$IDT_{strength}$	↙	↙	✗	✗	✗	✓	✓	✗	2	low
$IDT_{Modulus}$	↙	⇕	✗	✗	✓	✓	✗	✓	1	Moderate
J_c	↙	⇕	✗	✗	✗	✗	✓	✓	NA	NA
$Weibull_{CRI}$ (IDT)	↗	↗	✓	✓	✓	✓	✓	✓	4	Lowest

↙ indicates worse cracking resistance,

↗ indicates better cracking resistance,

⇕ shows both trends

✓ indicates agreements between indicator ranking and the expected ranking

✗ indicates disagreements between indicator ranking and the expected ranking

- Best test is IDT
- Best performance indicator is $Weibull_{CRI}$

Task 5: Conduct comprehensive evaluation of cracking and rutting performance of laboratory- prepared specimens

Evaluation criteria		Performance indicator		
		$HWTT_{15000}$	$HWTT_{20000}$	APA_{8000}
Sensitivity to	Binder content (increase binder content)	↙	↙	↙
	binder PG (using softer binder content)	↙	↙	↗
Statistical sensitivity		7	6	7
Variability		Moderate	Moderate	low/moderate
Advantages		Moisture damage	Moisture damage	N/A
Correlation based on ranking mixes resistance to rutting (Spearman rank correlation coefficient [r_s])		$r_s = 0.10$ (APA_{8000} VS $HWTT_{20000}$) $r_s = 0.14$ (APA_{8000} VS $HWTT_{15000}$) $r_s = 0.98$ ($HWTT_{15000}$ VS $HWTT_{20000}$)		

↙ indicates worse cracking resistance,

↗ indicates better cracking resistance,

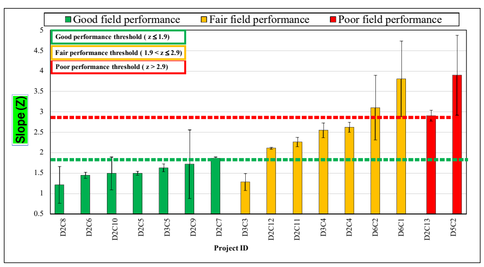
⇕ shows both trends

✓ indicates agreements between indicator ranking and the expected ranking

✗ indicates disagreements between indicator ranking and the expected ranking

Task 6: Develop PEMD specifications to assess mix resistance to cracking and rutting

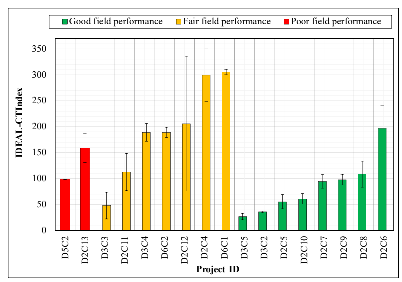
MSSD indicators and Observed field cracking



Lower slope (z) value indicates improved resistance to cracking

Task 6: Develop PEMD specifications to assess mix resistance to cracking and rutting

Monotonic indicators and observed field cracking

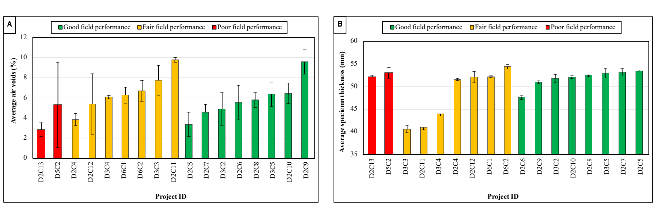


NONE of the monotonic indicators was able to distinguish between mix results

Task 6: Develop PEMD specifications to assess mix resistance to cracking and rutting

Monotonic indicators and Observed field cracking

- Explanation
  - It was reported that monotonic performance indicators to provide illogical trend with specimen air void content and thickness



Task 6: Develop PEMD specifications to assess mix resistance to cracking and rutting

Monotonic indicators and observed field cracking

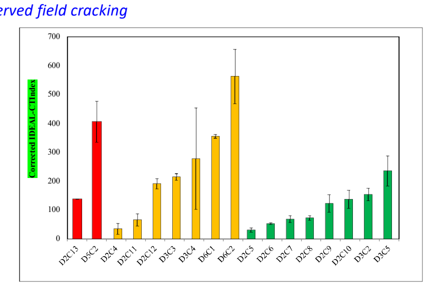
- Proposed solution

$$FI_{7\%} = FI_{AV} \times \frac{7\%}{AV\%}$$

$$FI_{7\%} = FI_{AV} \times \frac{0.0651}{AV - AV^2}$$

$$FI_{50} = FI_t \times \frac{t}{50}$$

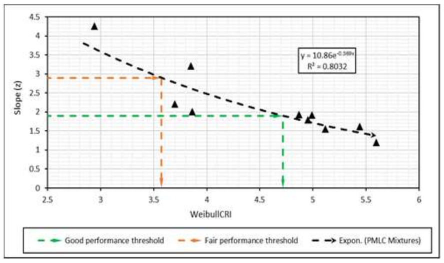
(Al-Qadi *et al.*, 2015a; Barry, 2016; Rivera, 2017; Kaseer *et al.*, 2018)



Task 6: Develop PEMD specifications to assess mix resistance to cracking and rutting

Monotonic indicators and observed field cracking

- Alternative New Solution



Task 6: Develop PEMD specifications to assess mix resistance to cracking and rutting

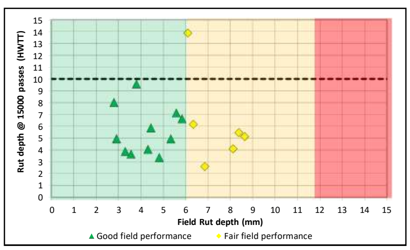
Monotonic indicators and Observed field cracking

Alternative New Solution

Monotonic indicators	MSSD (Slope)	Proposed Performance Thresholds (Minimum)		Literature	
	R^2	Fair	Good	Good	
$G_{fracture}$ (SCB-FI)	0.55	1546	2280	----	
CRI (IDT)	0.59	466	614	----	
FI (IDT)	0.57	11.38	22.55	27	Sreedhar et al., (2018)
IDEAL-CT_{Index}	0.55	26.4	73.7	80	Diefenderfer and Bowers, (2019)
Nflex factor	0.62	0.38	0.70	0.80	West et al., (2017)
J_c	0.46	0.21	0.61	0.60	LADOT, (2016)
$Weibull_{CRI}$	0.80	3.57	4.7	NA	

Task 6: Develop PEMD specifications to assess mix resistance to cracking and rutting

Rutting indicators and observed field rutting



Proposed threshold Maximum rut depth of 10 mm at 15,000 passes

Task 7: Develop recommendations and guidelines for PEMD

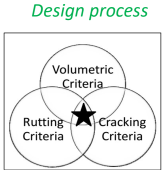
Recommended assessment tools to assess cracking and rutting

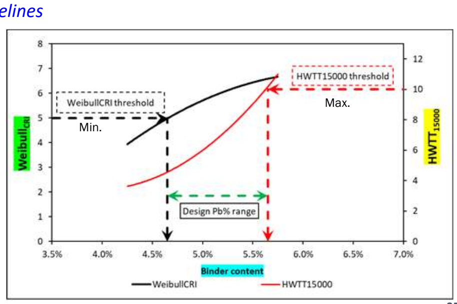
Distress	Test type	Test standard	Performance indicator	PEMD specifications	
				Performance	Thresholds
Cracking	Monotonic	-	$Weibull_{CRI}$	Good	$Weibull_{CRI}$ >4.7
				Fair	3.57 <$Weibull_{CRI}$ >4.7
				Poor	$Weibull_{CRI}$ <3.57
	MSSD	-	Slope (Z)	Good	Z< 1.9
				Fair	1.9 < z ≤ 2.9
				Poor	z > 2.9
Rutting	HWTT	AASHTO T 324	$HWTT_{15000}$	Good/Fair	Rut depth < 10 mm
				Poor	Rut depth >10 mm

Task 7: Develop recommendations and guidelines for PEMD

Implementation Guidelines

Design process





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- ITD Asset Management Team

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THANK YOU