

56th Idaho Asphalt Conference

October 27, 2016
University Inn, Moscow, Idaho

the 2016 Presentations

Welcome Note, Dr. Patricia Colberg, Chair Dept of Civil Engineering on behalf of Dean of Engineering

- 1 Characterizing the Effectiveness of Recycling Agents and its Evolution with Aging in Binders and Mixtures with High RAP and/or RAS Contents, Dr. Amy Epps-Martin, PE, Professor, Texas A&M University, College Station, TX
- 2 Performance Graded (PG) Asphalt Binder Modification - Lessons Learned With the Hamburg and MSER Tests, Mr. Joe DeVol, PE, WSDOT, Olympia, WA
- 3 e-Construction: How Technology is Changing Project Delivery, Mr. George White, Pavia Systems, Inc., Seattle, WA
- 4 Speeding Construction Process using 3D Modeling - Case Study at Thornton Interchange, Mr. Mike McKee, PE Idaho Transportation Dept, District 6, Rigby, ID
- 5 Development of a Prediction Model for Skid Resistance of Asphalt Pavements, Dr. Emad Kassem, Assistant Professor, University of Idaho Moscow, ID
- 6 Asphalt Pavement Construction: Best Practices, Wayne Jones, PE The Asphalt Institute Lexington, KY
- 7 Guidelines to Evaluate 129k Truck Route Requests for Local Roads, Dr. Ahmed Ibrahim, PE Assistant Professor, University of Idaho Moscow, ID
- 8 Balanced Mix Design, Dave Johnson, PE The Asphalt Institute, Billings, MT

(Presentation #7 Unavailable)

56th Idaho Asphalt Conference

October 27, 2016
University Inn, Moscow, Idaho



Speakers of the 56th Idaho Asphalt Conference, October 26-27, 2016

From Left: Fouad Bayomy, George White, Mike Santi, Joe DeVoi, Amy Epps-Martin, Emad Kassem, Patricia Colberg, Wayne Jones, Dave Johnson and Mike McKee.

Not Pictured: Ahmed Ibrahim

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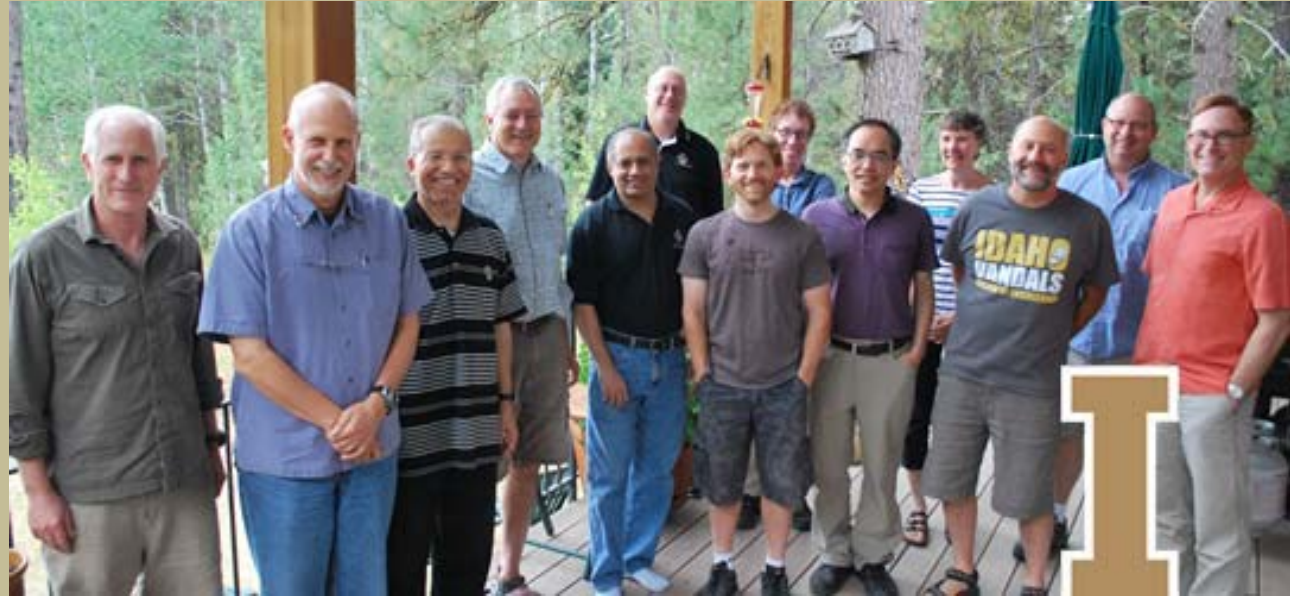
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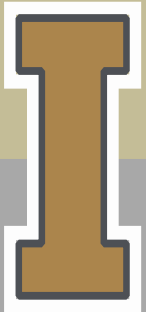
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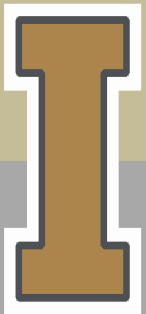
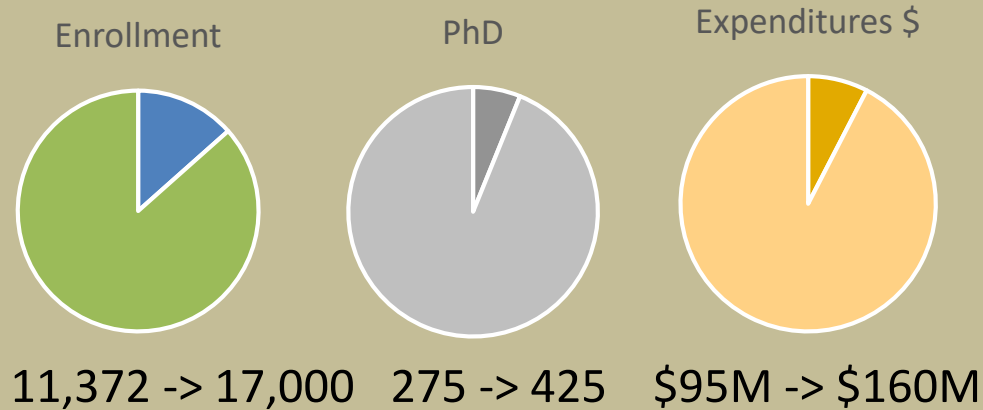
Greetings from Dean Larry Stauffer and the COE Leadership Team



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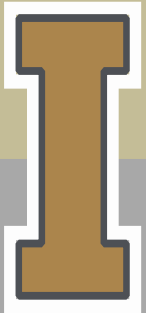


STRATEGIC PLANNING 2015 - 2025



COLLEGE PRIORITIES

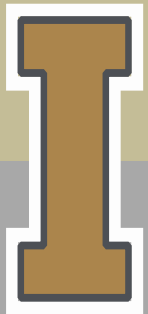
- Increase collaborations with industry, alumni, and other friends of the College
- Focus and grow our research and graduate programs
- Continue to provide an exceptional experience for our undergraduate students



WHAT MAKES OUR PROGRAMS

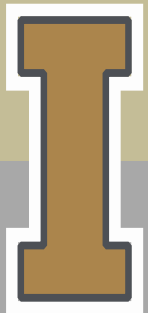
SPECIAL?

- Low student:faculty ratios
- Our world-class faculty teach our courses and advise our majors
- We have 1 of 7 nationally recognized senior design programs
- 20+ clubs and competition teams
- Emphasis on engineering fundamentals
- Lot of 'hands-on' and practical experiences for undergraduates
- A commitment to helping our students successfully transition to careers



NEW FACES AT UI

- 28 new faculty hired in past two years
- Over past 5 years, 50% of our faculty are new to UI
- 10 new faculty searches this year



NEW LEADERSHIP IN COE

All Department Chairs new in 2015



**Biological
Engineering**

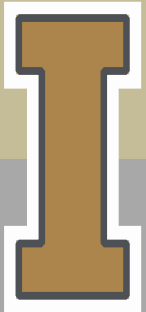
**Civil
Engineering**

**Chemical
and Materials
Engineering**

**Computer
Science**

**Electrical
and
Computer
Engineering**

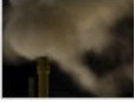
**Mechanical
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NAE GRAND CHALLENGES SCHOLARS PROGRAM

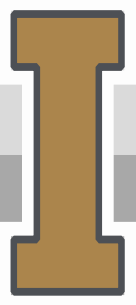
Engineering's Grand Challenges

WHAT DO YOU THINK? Click on the engineering challenge you think is the most important:

 Make solar energy economical	 Provide energy from fusion	 Develop carbon sequestration methods
 Manage the nitrogen cycle	 Provide access to clean water	 Restore and improve urban infrastructure
 Advance health informatics	 Engineer better medicines	 Reverse-engineer the brain
 Prevent nuclear terror	 Secure cyberspace	 Enhance virtual reality
 Advance personalized learning	 Engineer the tools of scientific discovery	

www.engineeringchallenges.org

- 122 universities signed original pledge
- UI is 28th program in USA approved by the NAE Steering Committee
- Financial assistance from Idaho Academy of Engineers
- First cohort selected this Fall



Welcome to the 56th Annual Idaho Asphalt Conference



26-27 October 2016
Moscow, Idaho



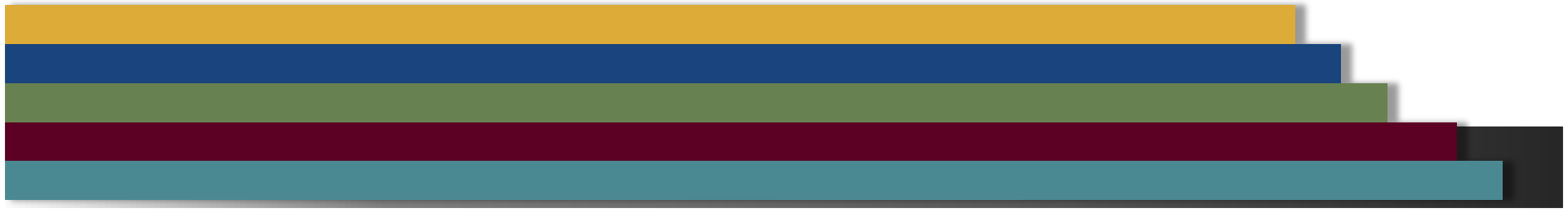
Characterizing the Effectiveness of Recycling Agents and their Evolution with Aging in Binders and Mixtures with High RAP and/or RAS Contents

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56th Idaho Asphalt Conference

Moscow, ID

October 27, 2016



NCHRP 9-58: The Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios

- Amy Epps Martin
- Fujie Zhou
- Edith Arambula Mercado
- Jon Epps
- Dave Newcomb
- Charles Glover
- Eun Sug Park
- Arif Chowdury
- Xue Luo
- Fan Yin
- Fawaz Kaseer
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- Elie Hajj
- Nathan Morian

UNR

- Jo Daniel

UNH

- Gayle King

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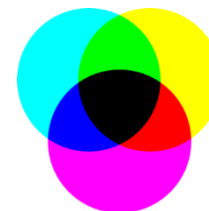
Motivation – High Recycled Binder Ratio (RBR) Mitigation – Recycling Agent (RA)

REMAINING ISSUES



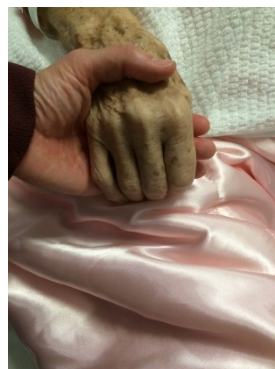
Engineering

- Embrittlement
- Aging
- Blending
- Mixture Performance

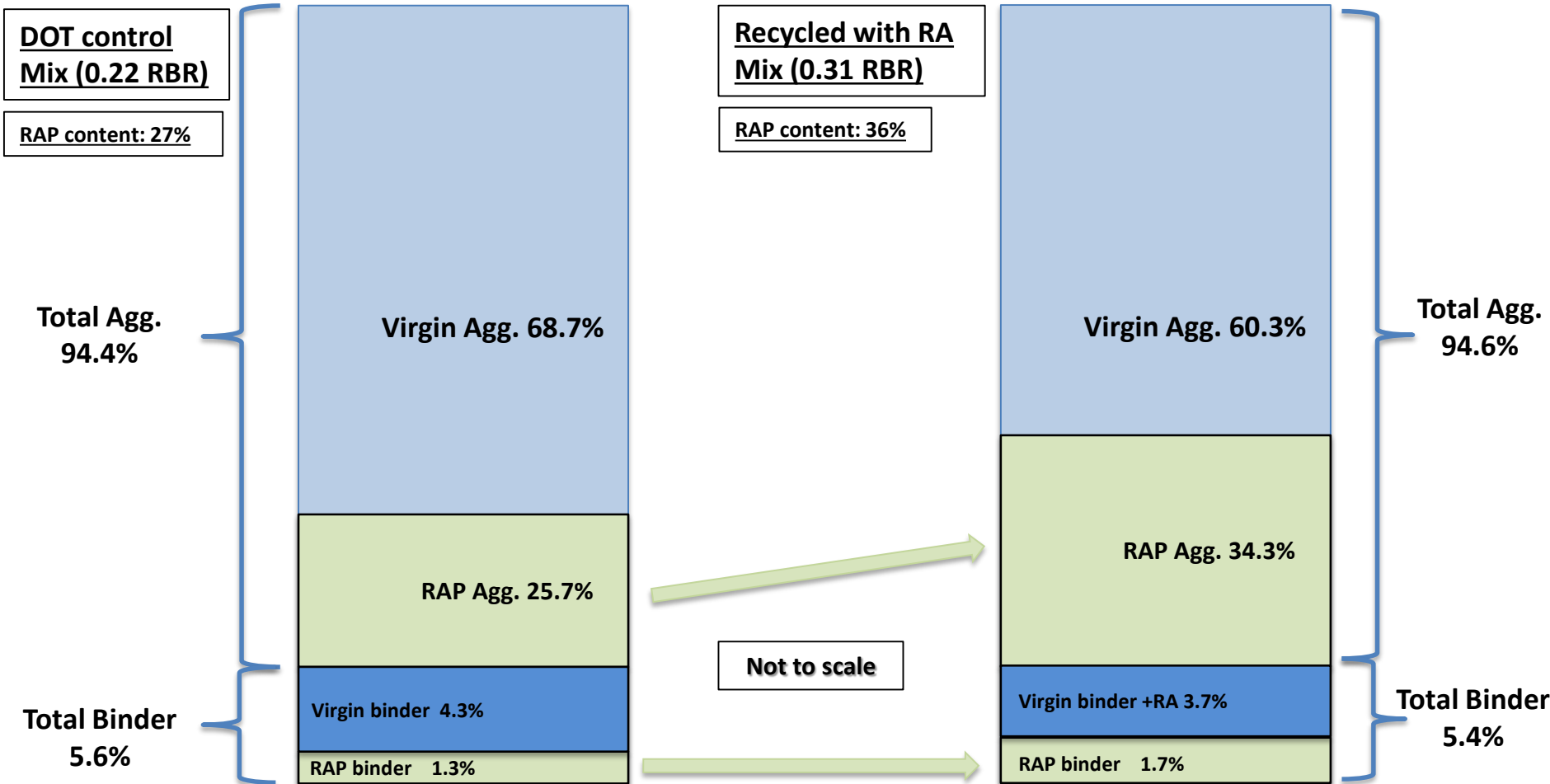


BENEFITS

- ✓ Economic
- ✓ Environmental
- ✓ Engineering



WI DOT & Recycled with RA



NCHRP 9-58 Research Plan

PHASE I

Identification of Gaps in
Knowledge on RA Use with High
RBRs

Task 1. Gather Information

Task 2. Design Laboratory
Experiment

Task 3. Document Results in
First Interim Report

PHASE II

Investigation of Effectiveness of
RAs in Restoring Binder Rheology,
Development of Blending
Protocol, and Associated Mixture
Performance

Task 4. Conduct Laboratory
Experiment

Task 5. Design Field
Experiment and Document
Results in Second Interim
Report

PHASE III

Validation of RA Use in Mixtures
with High RBRs

Task 6. Conduct Field
Experiment

Task 7. Propose Revisions to
AASHTO Specifications and
Test Methods

Task 8. Develop Training
Materials and Best Practices
and Deliver Workshop

Task 9. Document Results in
Final Report



Phase II Laboratory Tests – BINDER & MORTAR

□ PG - BOTH

$$\Delta T_c = (T_s - T_m)$$

□ Glover-Rowe

$$G-R = \frac{G^*(\cos\delta)^2}{\sin\delta} @ 15^\circ\text{C}, 0.005 \text{ rad/sec}$$

Rejuvenating Effectiveness

$$RE = \frac{(\log G-R_{DOT \text{ Control}} - \log G-R_{Recycled})}{\log G-R_{DOT \text{ Control}}} * 100$$

□ Carbonyl Area Growth by FT-IR



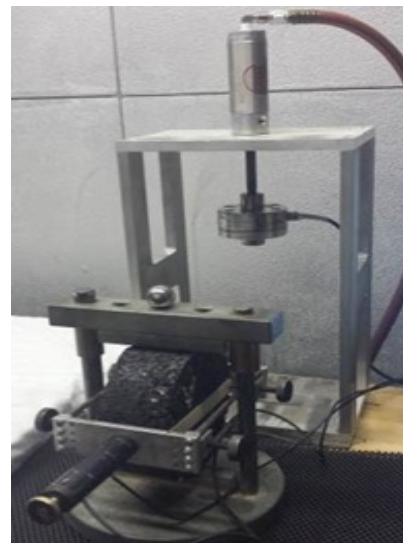
Phase II Laboratory Tests - MIXTURE

□ Stiffness

- $M_R @ 25^\circ\text{C}$
- E^*

□ Cracking Resistance

- FI by SCB
- N_f by S-VECD
- RI by UTSST



Phase II TX (Expanded) Materials

- ☐ TX: PG 64-22 + 0.28 RBR (0.1 RAP+0.18 MWAS)
+ 2.7% Tall Oil T1 (Target=PG 70-22)
- ☐ + **0.4 RBR** w/RAP only, **0.5 RBR** balanced RAP/RAS
- ☐ + **Aromatic Extract A1**
- ☐ + **NH PG 64-28 & NV PG 64-28P**
- ☐ + **TX TOAS**

RECYCLING AGENT (RA) DOSAGE SELECTION METHOD

1 Restore PGL/Check PGH

2 Restore ΔT_c

3 Restore PGH

**SELECT
MATERIALS**



**PREP
MATERIALS**



**CONDUCT LAB
TESTS**



**SELECT
DOSAGE**

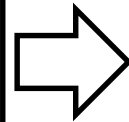
SELECT MATERIALS

**Target and base
binder PG grade**

RAP and/or RAS source(s)

Recycling Agent (RA)

**RAP and/or RAS Recycled Binder
Ratio (RAPBR/ RASBR)**



PREP MATERIALS

**Extract and recover binder from
RAP and/or RAS source(s)**



**Prepare recycled binder
blends:**

- **With no RA (control)**
- **With low RA dosage**
- **With high RA dosage**



CONDUCT LAB TESTS

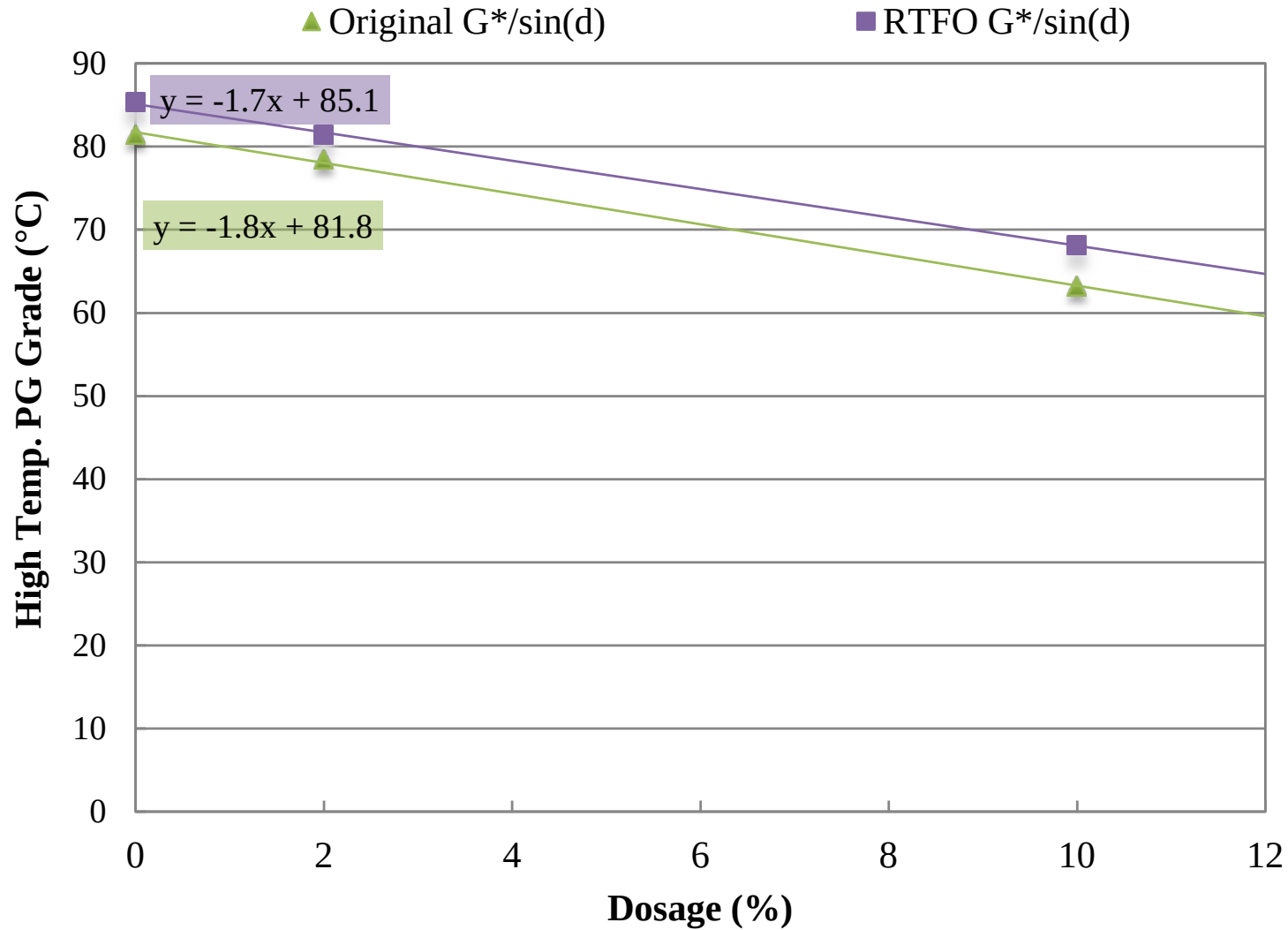
**Obtain high PG grade (PGH)
and low PG grade (PGL) per
AASHTO M320:**

- **Target binder**
- **Recycled binder blend with
no RA (control)**
- **Recycled binder blend with
low RA dosage**
- **Recycled binder blend with
high RA dosage**





0.3 RBR (PG 64-22 | 0.1 TxRAP | 0.2 TxMWAS | T1)



SELECT DOSAGE

Plot original & RTFO
PGH, S- & m-
controlled PGL vs. RA
dosage for all blends

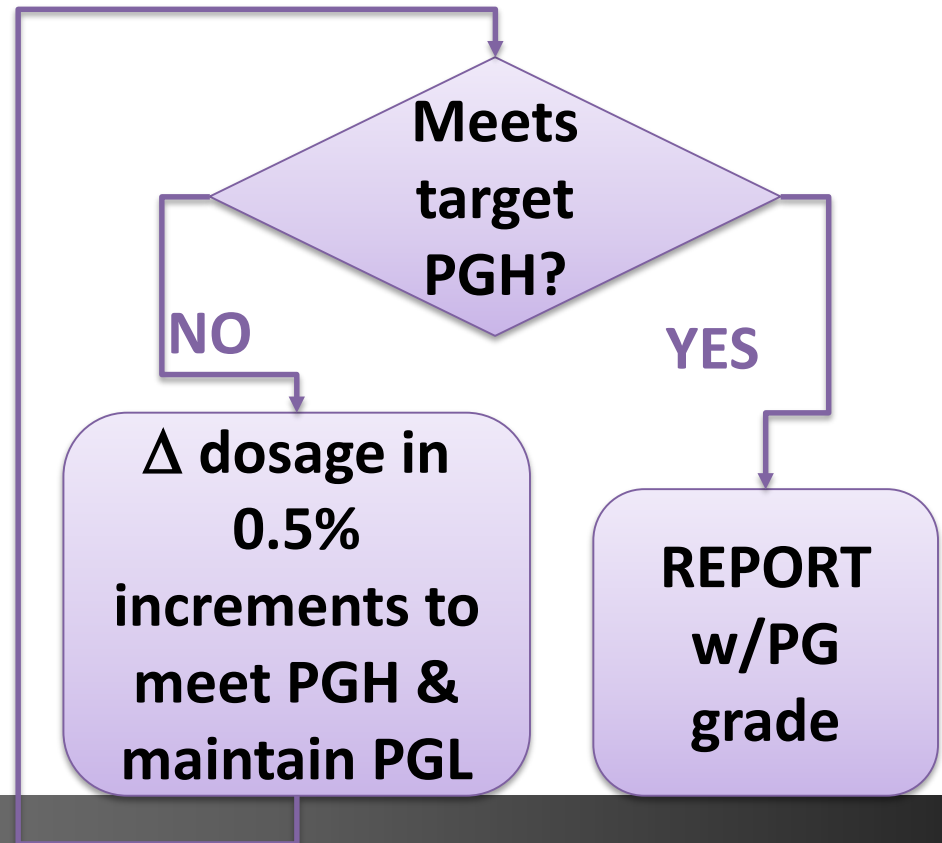
Establish linear
regression equations

Select RA dosage in
0.5% increments to
meet target binder
PGL using warmer
PGL regression line

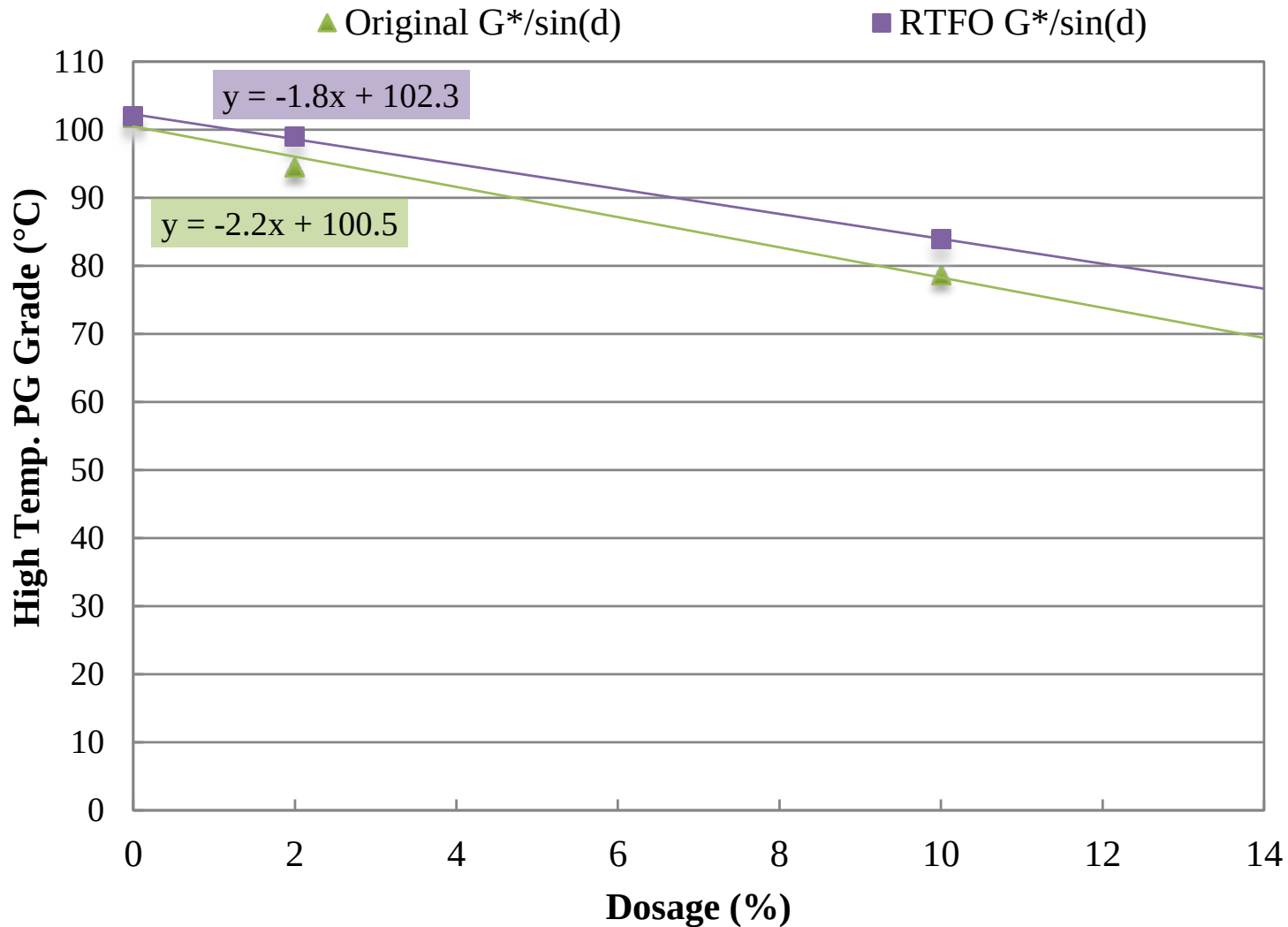
Verify PGH of
selected dosage vs.
target binder PGH
using colder PGH
regression line

**For RAS mixtures, if dosage >5.5%,
replace virgin binder with 50% RA
and add other 50%.*

1 Restore PGL/Check PGH

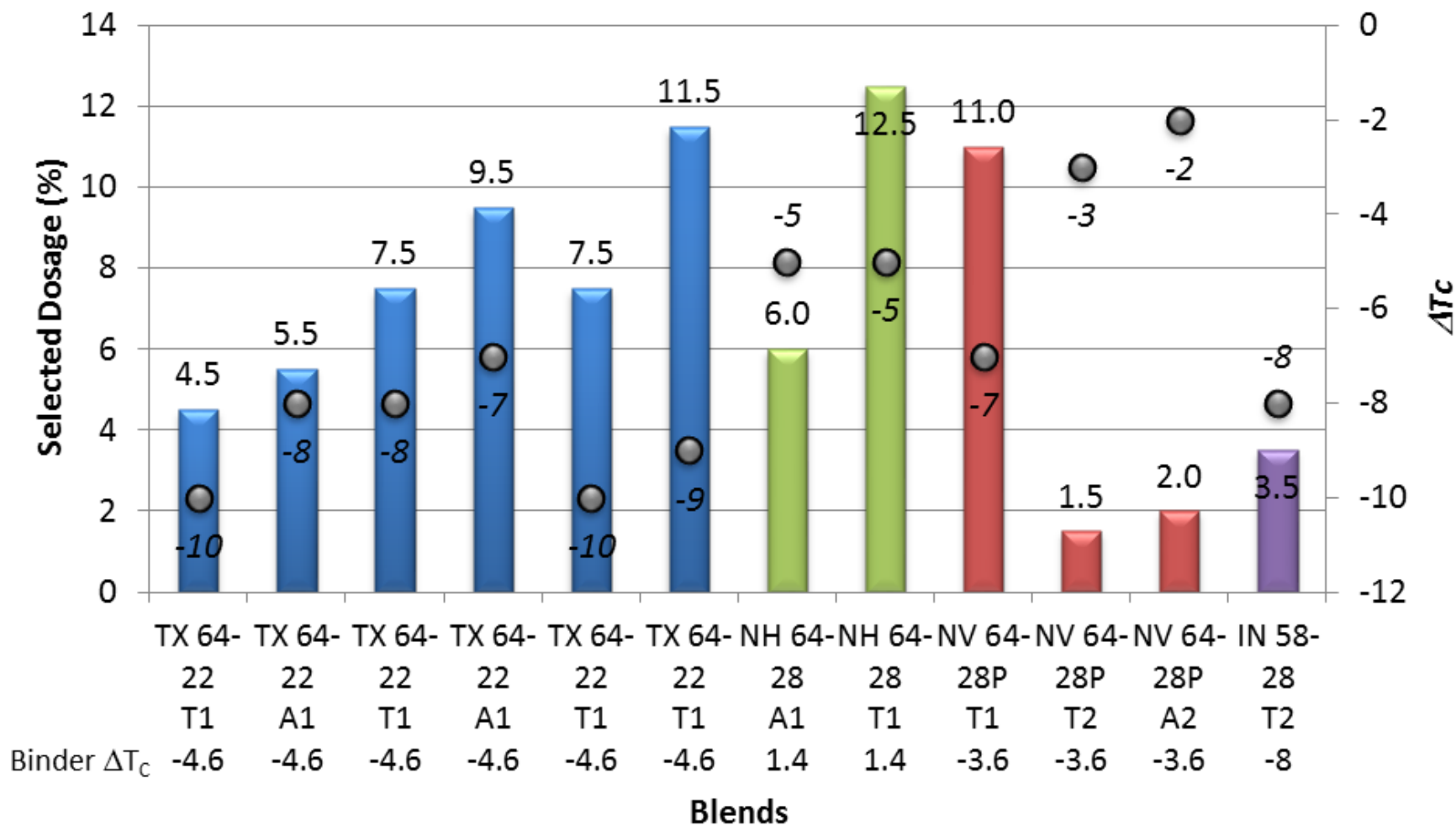


0.5 RBR (64-22 | 0.25 TxRAP | 0.25 TxTOAS | T1)



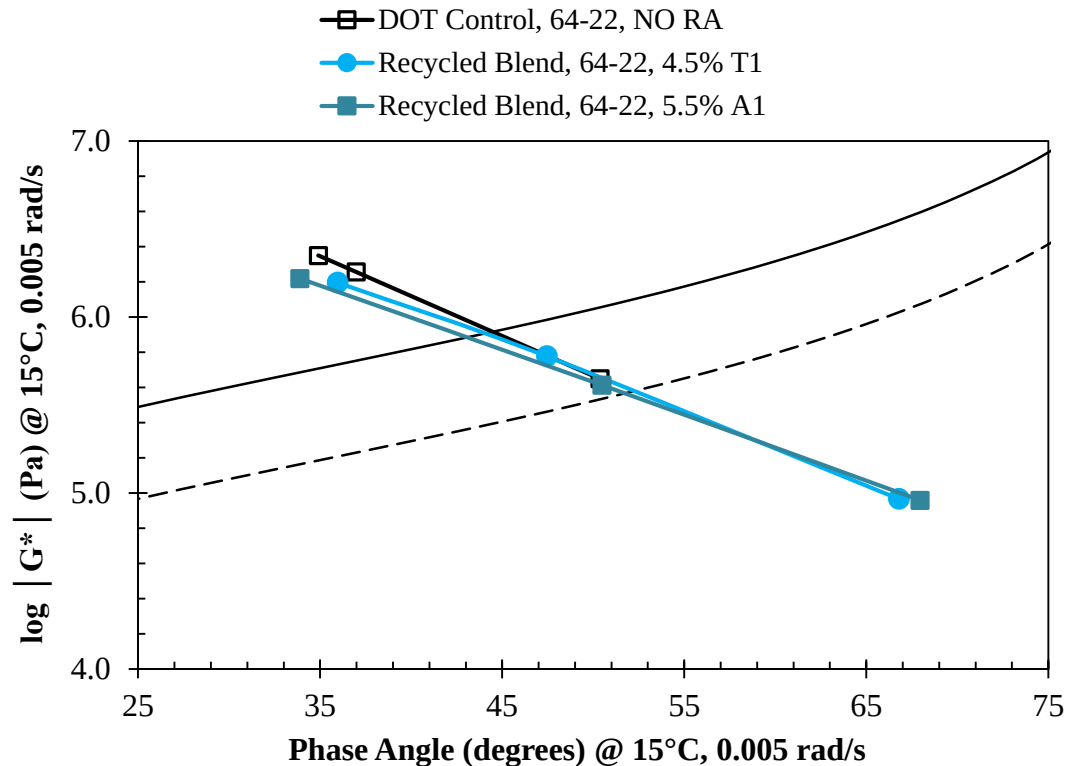
PHASE II DOSAGE SELECTION RESULTS

■ Restore PGL/ Check PGH ● Delta T_c



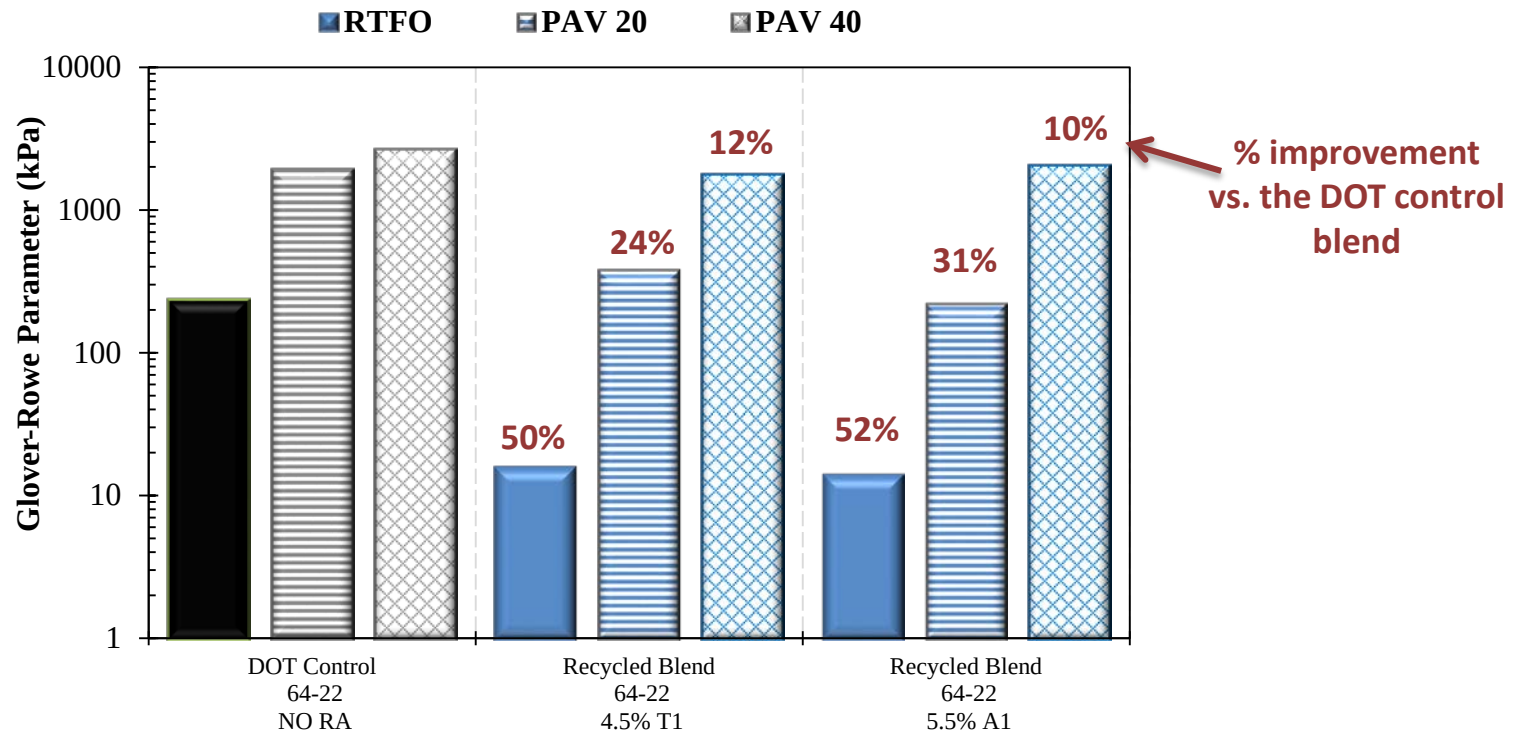
G-R Binder Black Space Diagram

0.3 RBR (0.1 RAP & 0.2 RAS)



G-R Results w/Aging

0.3 RBR (0.1 RAP & 0.2 RAS)

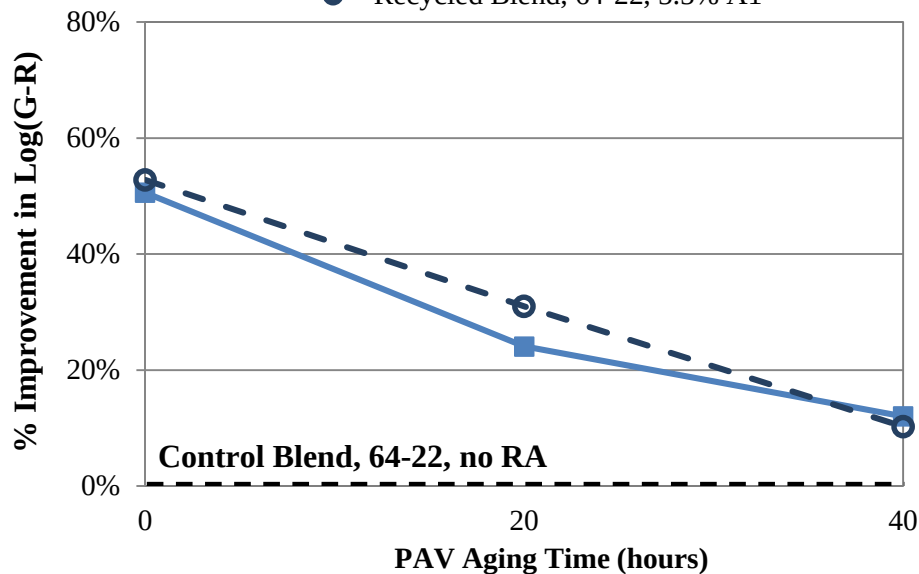


Recycled Blends @ opt RA < DOT control Blend no RA

Binder RE Evolution with PAV Aging

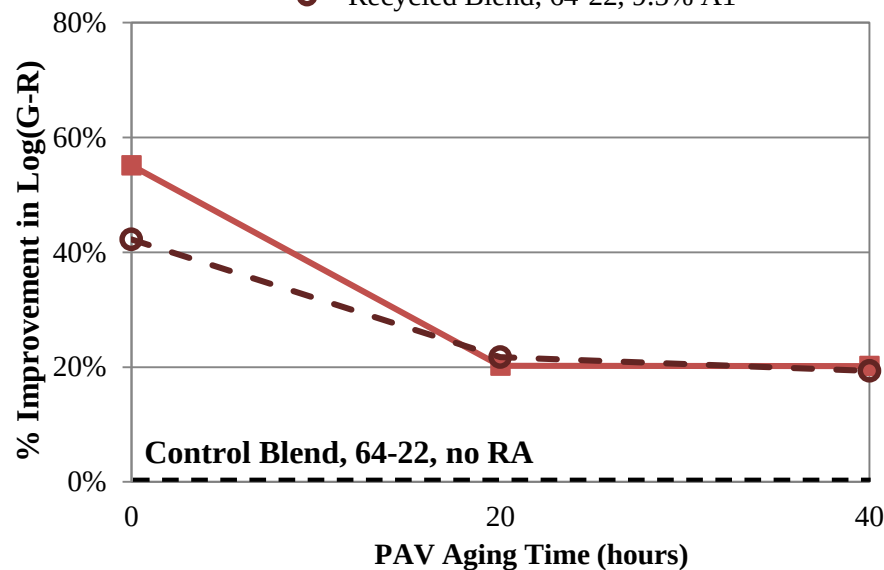
0.3 RBR (0.1 RAP & 0.2 RAS)

- Recycled Blend, 64-22, 4.5% T1
- Recycled Blend, 64-22, 5.5% A1



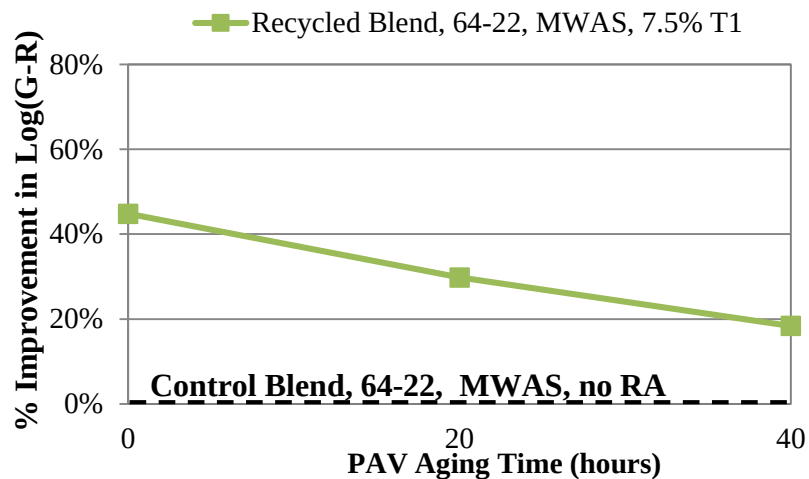
0.4RBR (0.4 RAP)

- Recycled Blend, 64-22, 7.5% T1
- Recycled Blend, 64-22, 9.5% A1

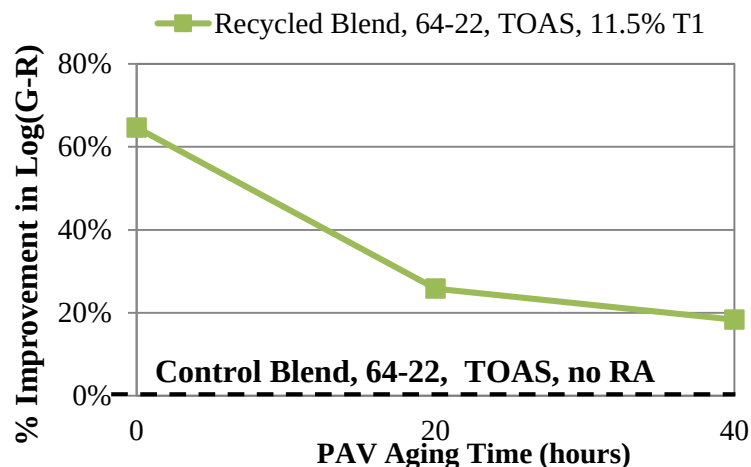


The “rejuvenating” effect of RA decreased with PAV aging

0.5 RBR (0.25 RAP & 0.25 RAS)

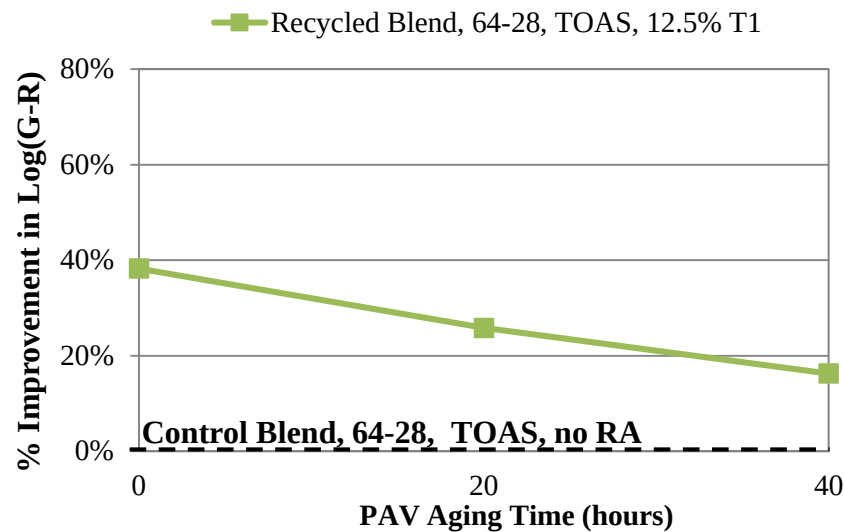


0.5 RBR (0.25 RAP & 0.25 RAS)

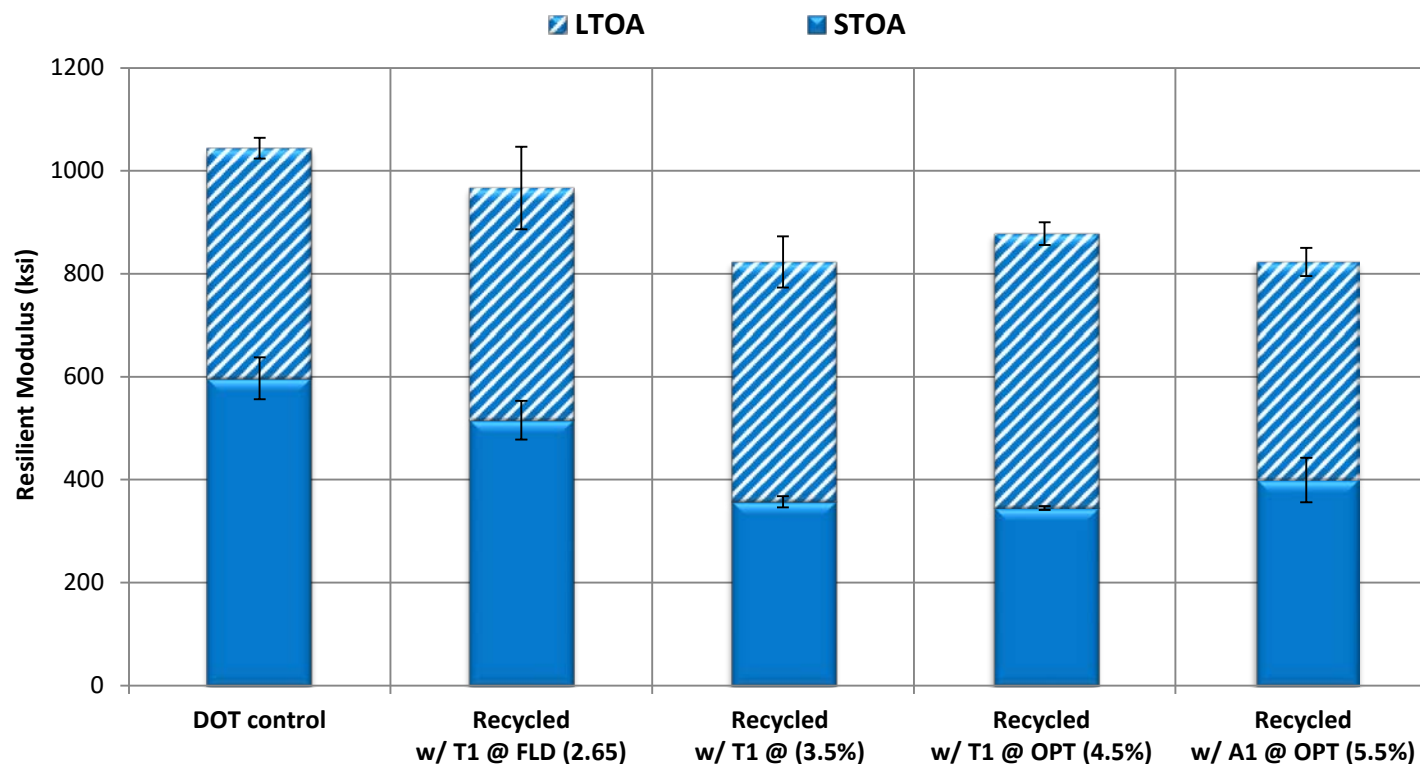


Binder RE Evolution with PAV Aging

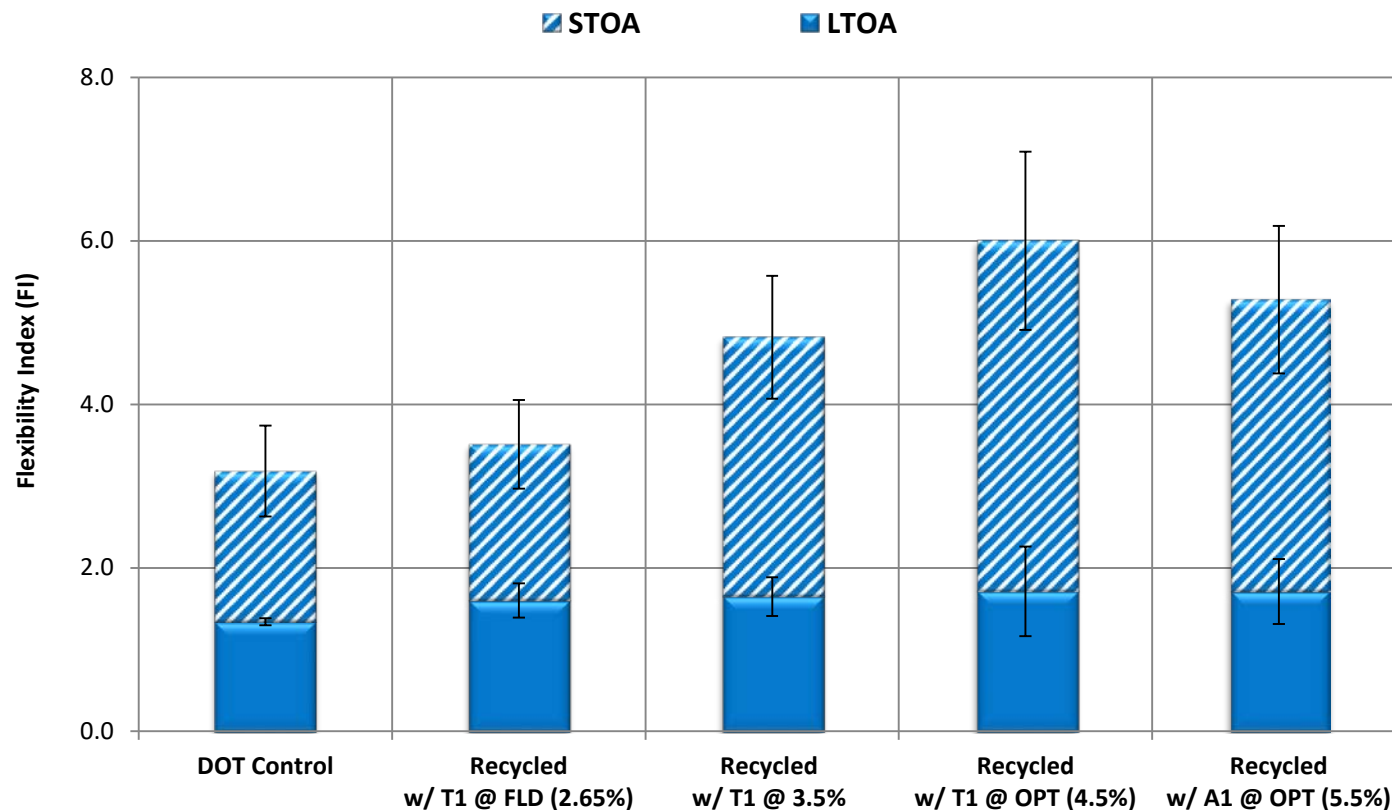
0.5 RBR (0.25 RAP & 0.25 RAS)



RA Dosage Selection – Mixture Validation - M_R



RA Dosage Selection – Mixture Validation - SCB

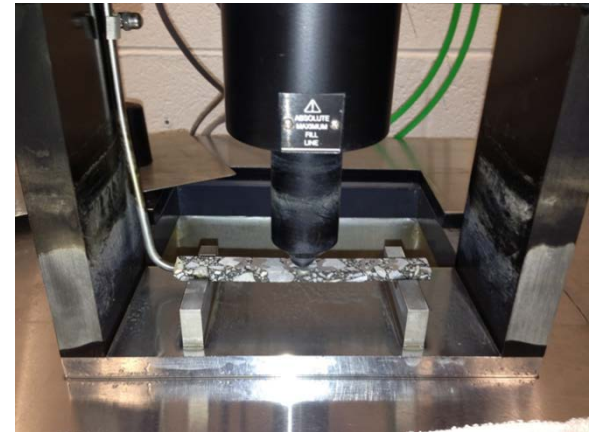


Phase IIB Materials

- ❑ **TX: PG 64-22 + 0.28 RBR (0.1 RAP+0.18 MWAS)
+ 2.7% Tall Oil T1 (Target=PG 70-22)**
- ❑ **+ Better Base Binder (less negative ΔT_c)**
- ❑ **+ Softer Base Binder**
- ❑ **+ Vegetable Oil V1, + Bio-Based Oil B**
- ❑ **+ 0.5 RBR** balanced RAP/RAS w/ **TX TOAS**
- ❑ Related Phase IIA results

Phase IIB

- ❑ RA Dosage Selection beyond restoring PGL/checking PGH by restoring ΔT_c to -5, restoring PGH
- ❑ + HWTT to preclude over-softening
- ❑ + BBR Sliver (AASHTO TP 125) for mixture Black Space
- ❑ + DSC (& UTSST) for onset of brittle behavior



SELECT DOSAGE

Plot original & RTFO
PGH, S- & m-
controlled PGL vs. RA
dosage for all blends

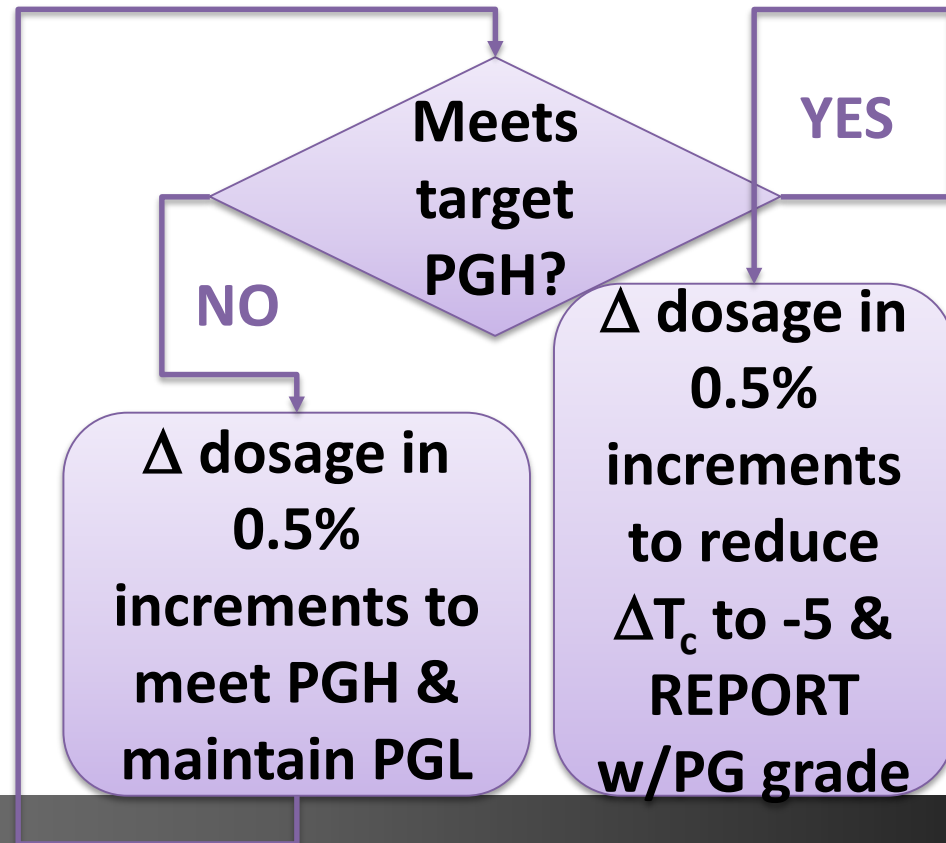
Establish linear
regression equations

Select RA dosage in
0.5% increments to
meet target binder
PGL using warmer
PGL regression line

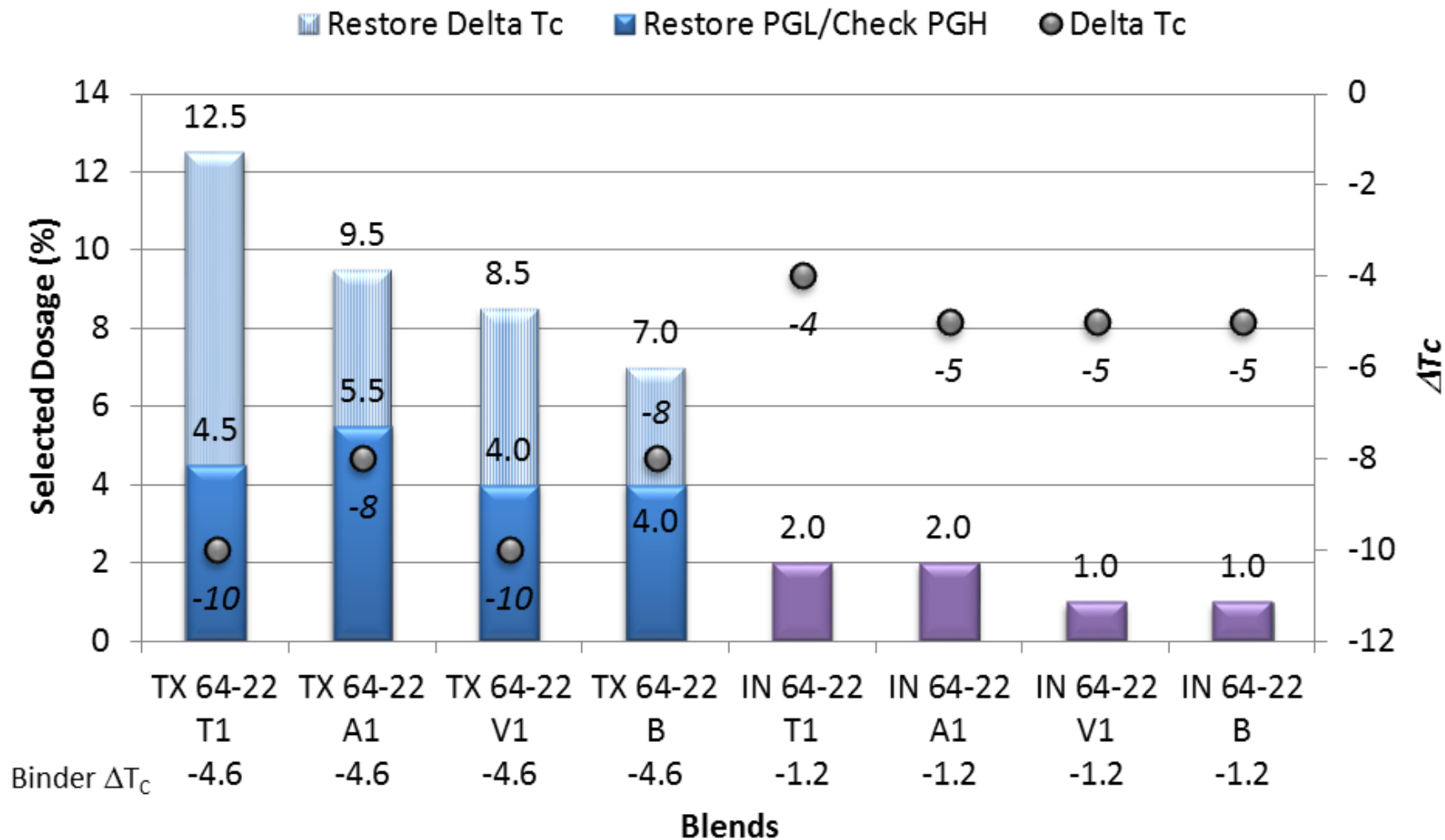
Verify PGH of
selected dosage vs.
target binder PGH
using colder PGH
regression line

**For RAS mixtures, if dosage >5.5%,
replace virgin binder with 50% RA
and add other 50%.*

2 Restore ΔT_c

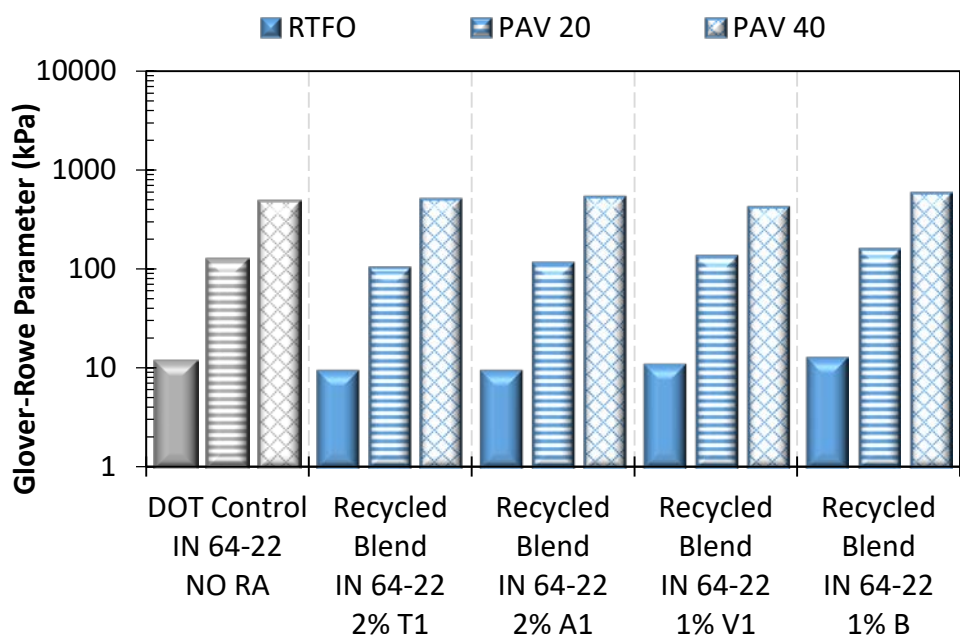
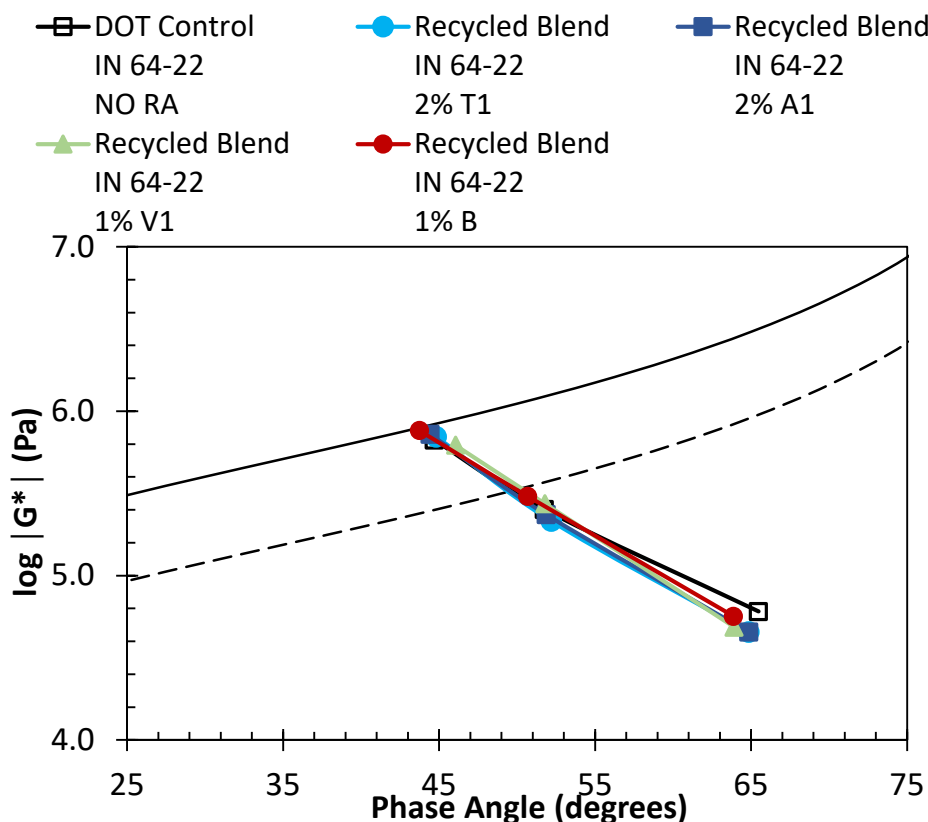


PHASE IIB DOSAGE SELECTION RESULTS 0.28 RBR (0.1 TX RAP + .18 TX MWAS)



G-R Results @ 21°C – (0.28 RBR) Blends w/ IN PG 64-22

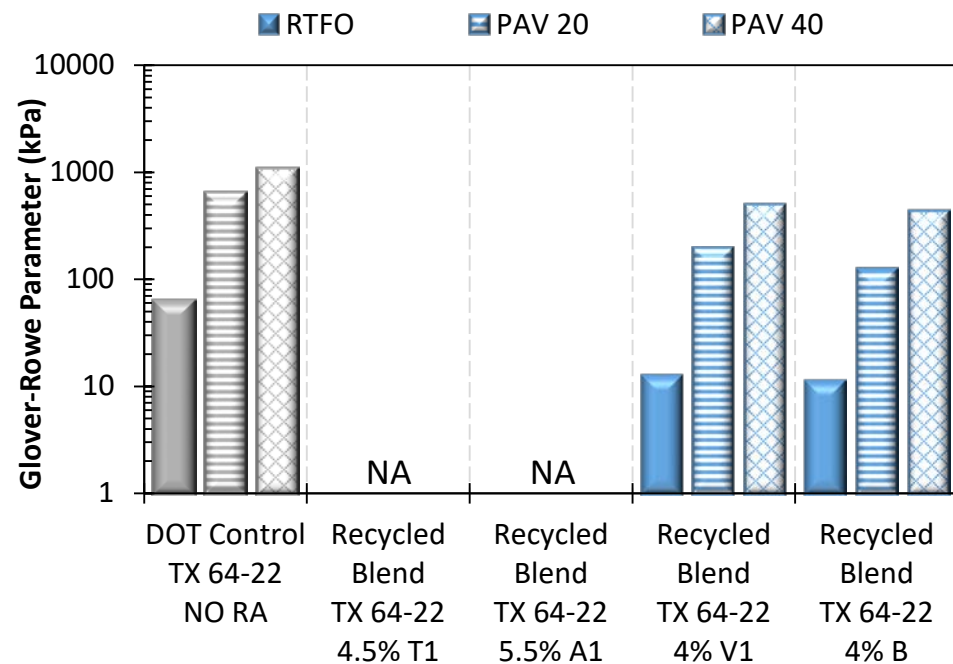
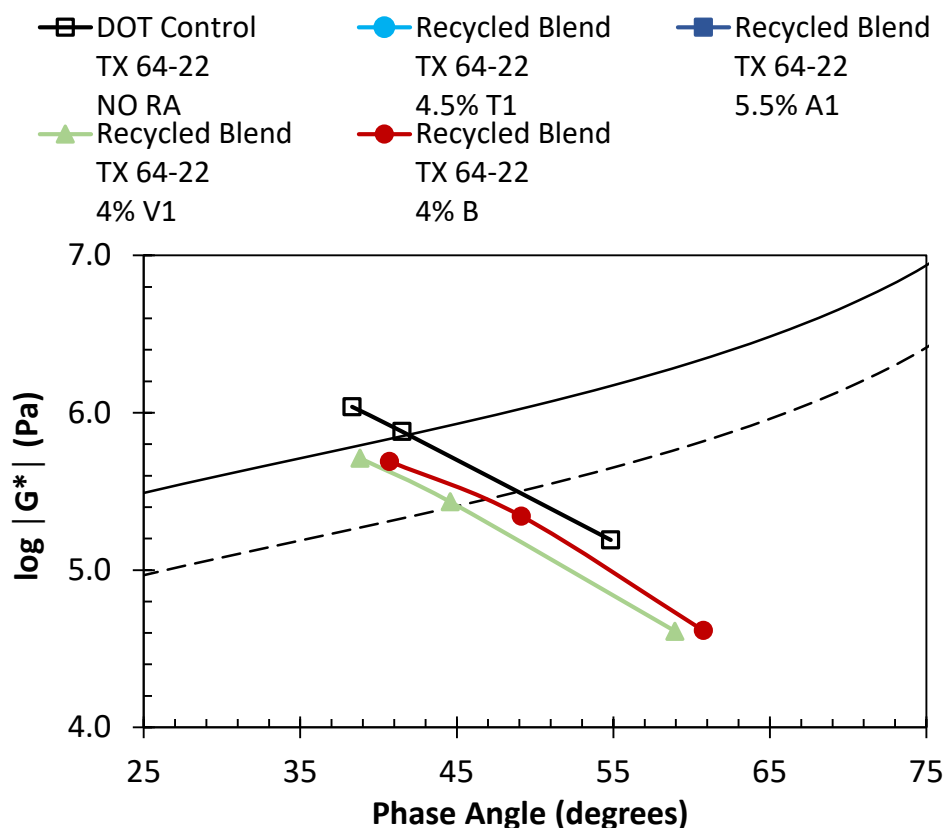
Restore PGL/Check PGH and Restore ΔT_c



G-R @ T= 21°C, same thresholds
RAs may not be needed with 0.3 RBR
and a better binder

G-R Results @ 21°C – (0.28 RBR) Blends w/ TX PG 64-22

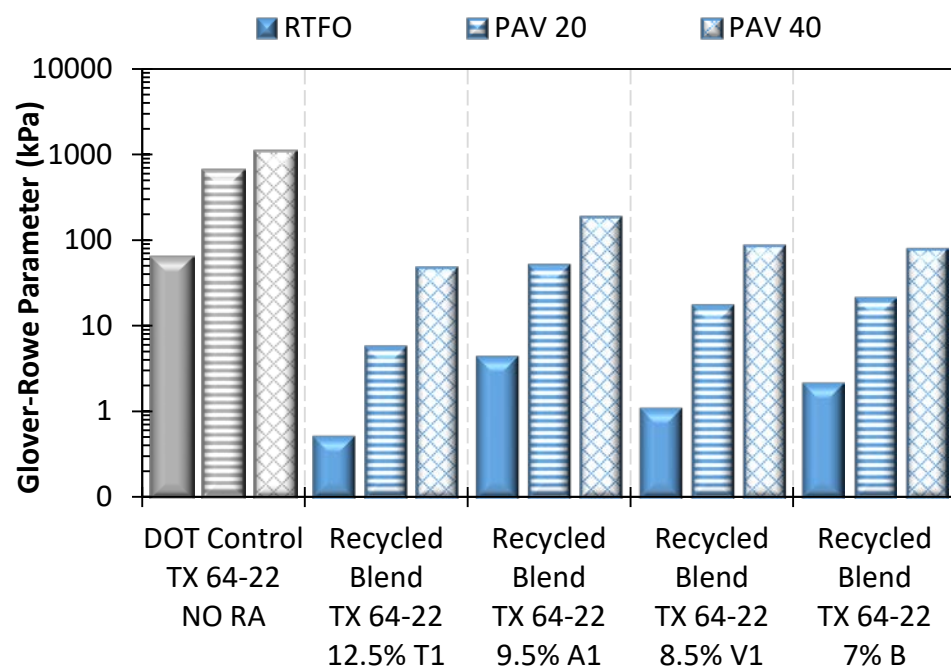
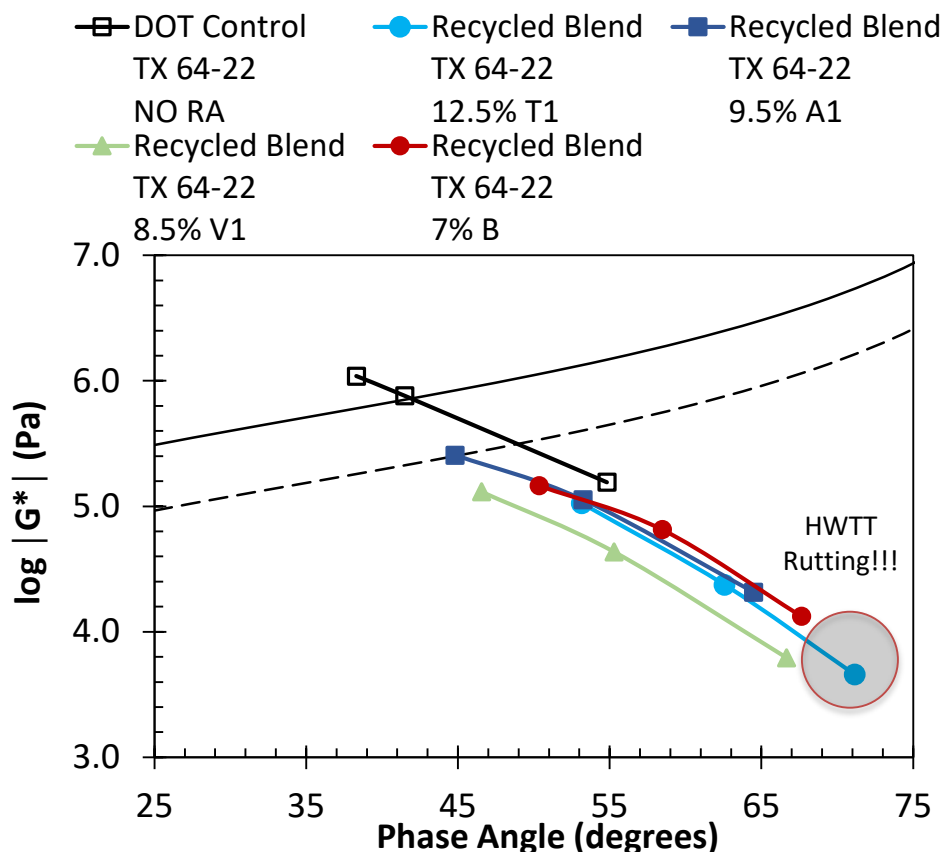
Restore PGL/Check PGH



G-R @ T= 21°C, same thresholds
Control blend ages beyond the thresholds
RAs improve the blends

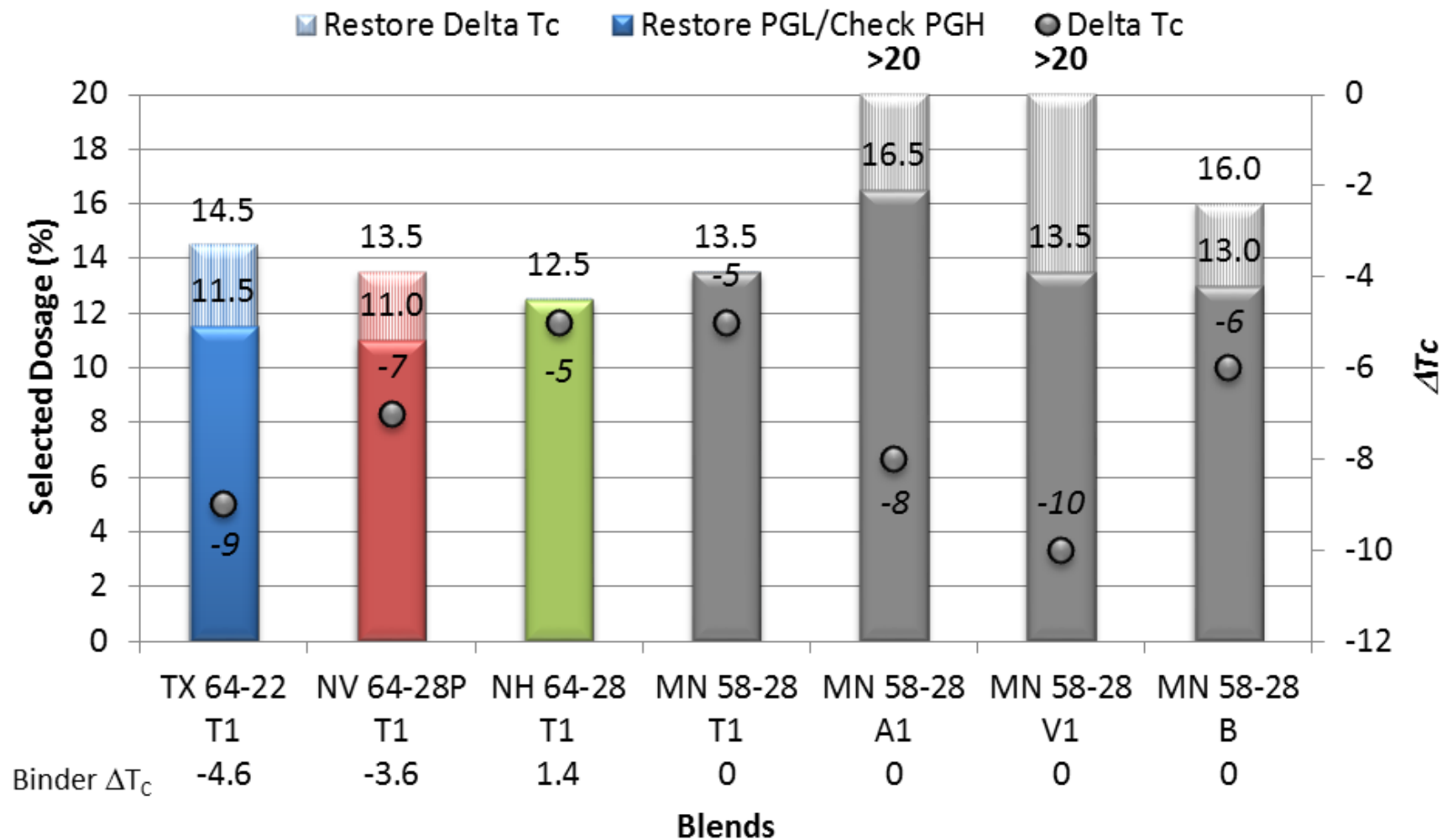
G-R Results @ 21°C – (0.28 RBR) Blends w/ TX PG 64-22

Restore ΔT_c



PHASE IIB DOSAGE SELECTION RESULTS

0.5 RBR (0.25 TX RAP + 0.25 TX TOAS)



SELECT DOSAGE

Plot original & RTFO
PGH, S- & m-
controlled PGL vs. RA
dosage for all blends

Establish linear
regression equations

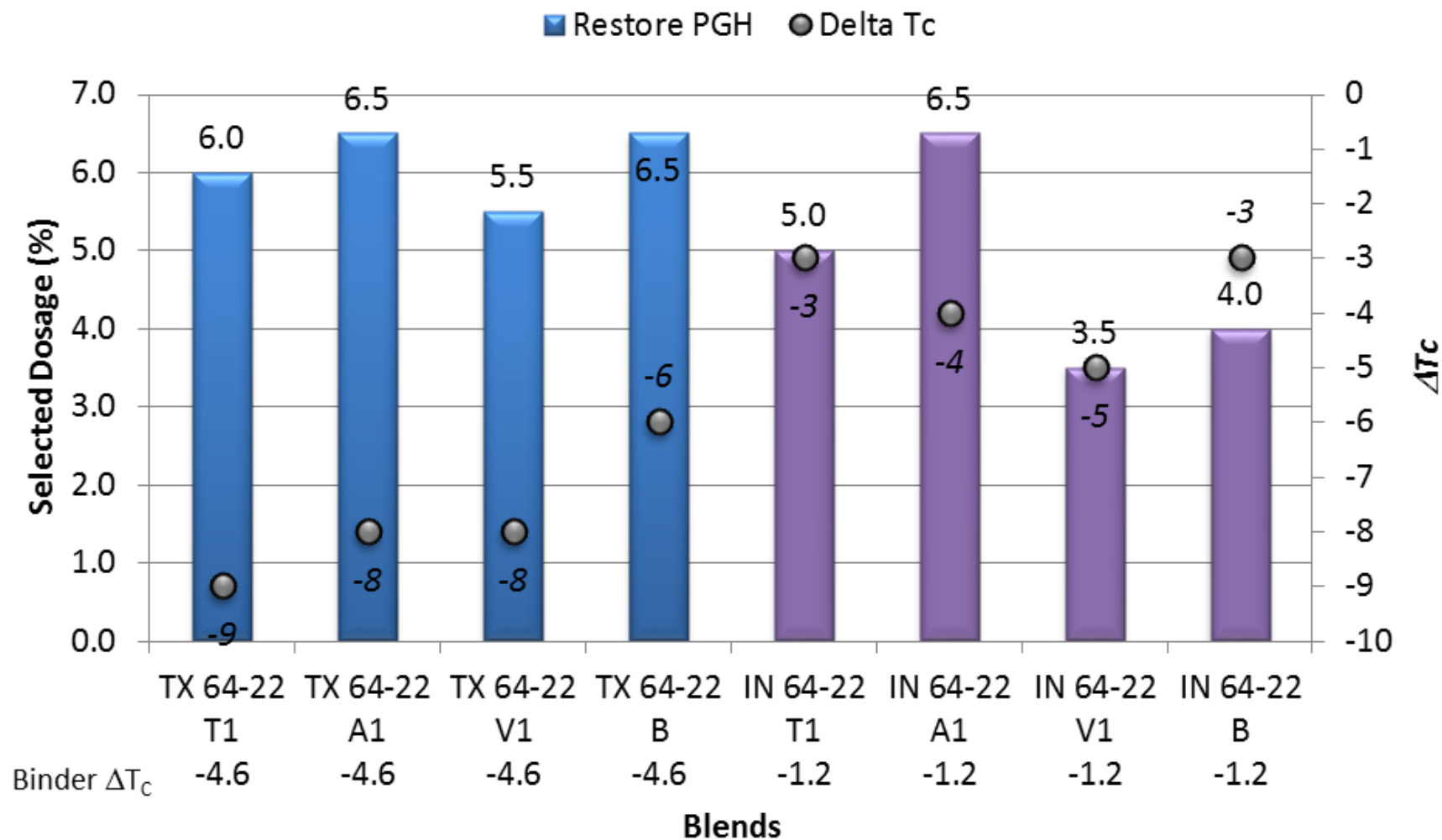
Select RA dosage in
0.5% increments to
restore PGH to
minimum that meets
target using colder
PGH regression line

**For RAS mixtures, if dosage >5.5%,
replace virgin binder with 50% RA
and add other 50%.*

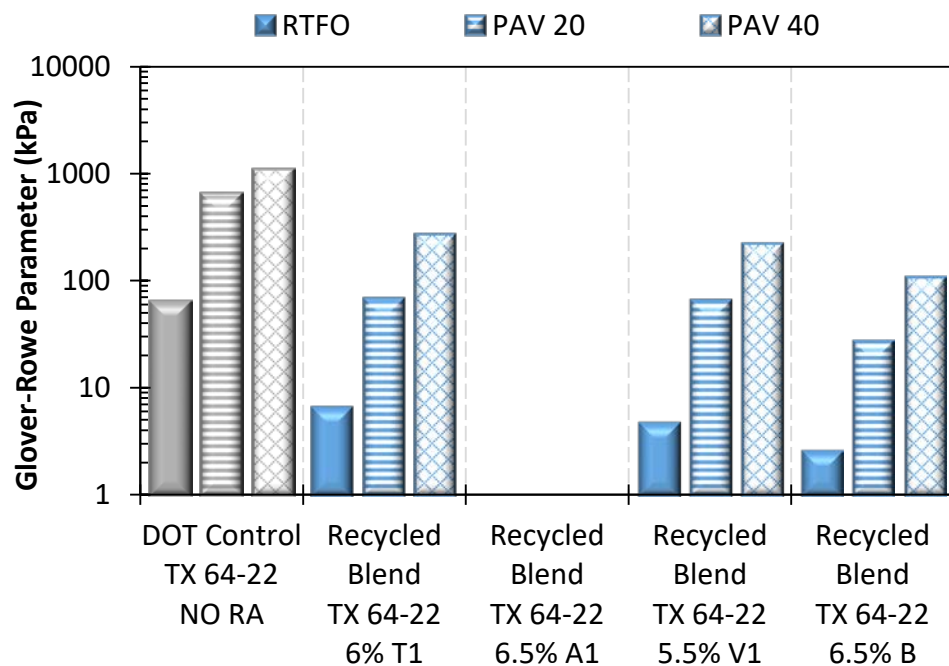
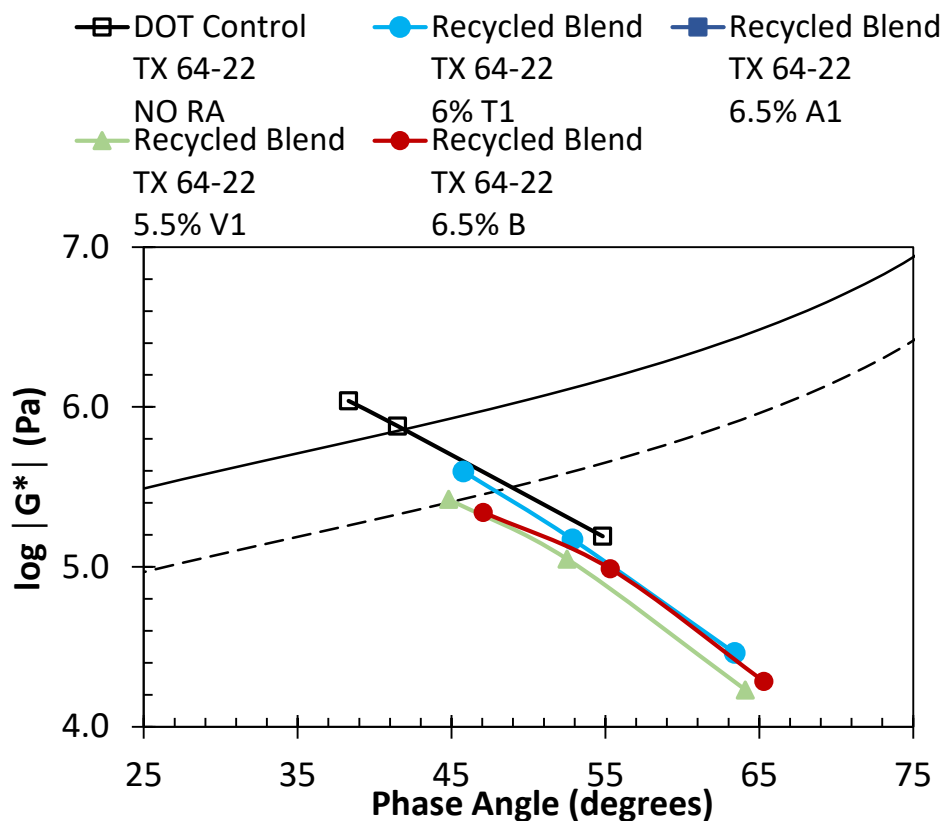
3 Restore PGH

REPORT w/ PG
grade & ΔT_c

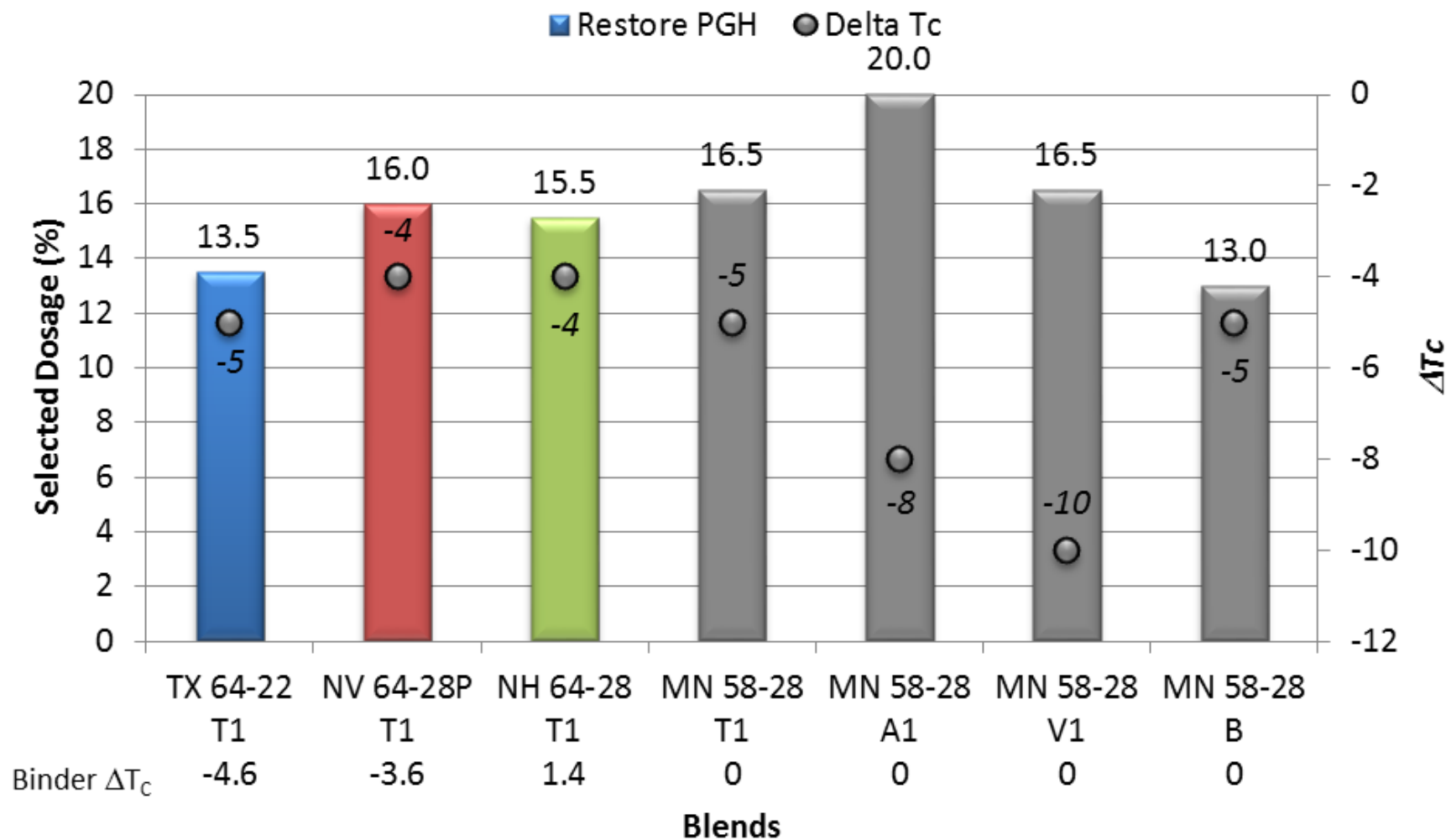
PHASE IIB DOSAGE SELECTION RESULTS 0.28 RBR (0.1 TX RAP + .18 TX MWAS)



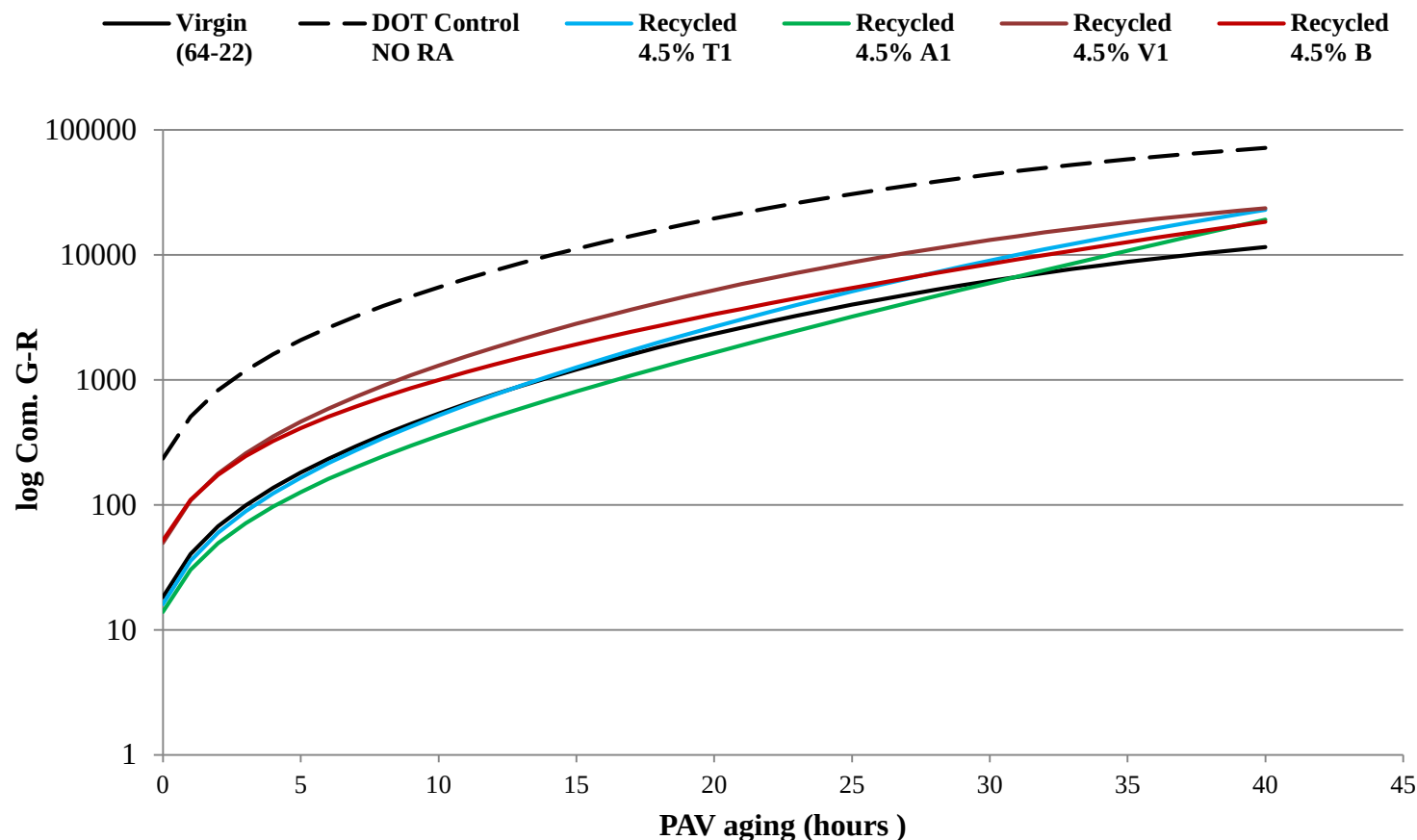
Estimated G-R @ 21°C (0.28 RBR) Blends w/ TX PG 64-22 Restore PGH



PHASE IIB DOSAGE SELECTION RESULTS 0.5 RBR (0.25 TX RAP + 0.25 TX TOAS)



Cumulative G-R





Next Steps

☐ Finalize **RA Dosage Selection Method**

☐ Consider **Incompatibility** by Chemical or Rheological Properties

☐ Complete **Aging Analysis** to explore oven vs PAV aging, chemical vs rheological properties

☐ Characterize **Mixtures**

☐ Cracking Resistance – FI by SCB, N_f by S-VECD, RI by UTSST

☐ Embrittlement - UTSST Viscous-Glassy Transition, Mixture Black Space with BBR Sliver and E^* , ϕ

☐ Evaluate **Phase III Field Projects** to set thresholds for **Rejuvenating Effectiveness w/Aging**

Environmental Zones

- - Wet-Freeze
- - Dry -Freeze
- - Dry -N Freeze
- - Wet-No Freeze

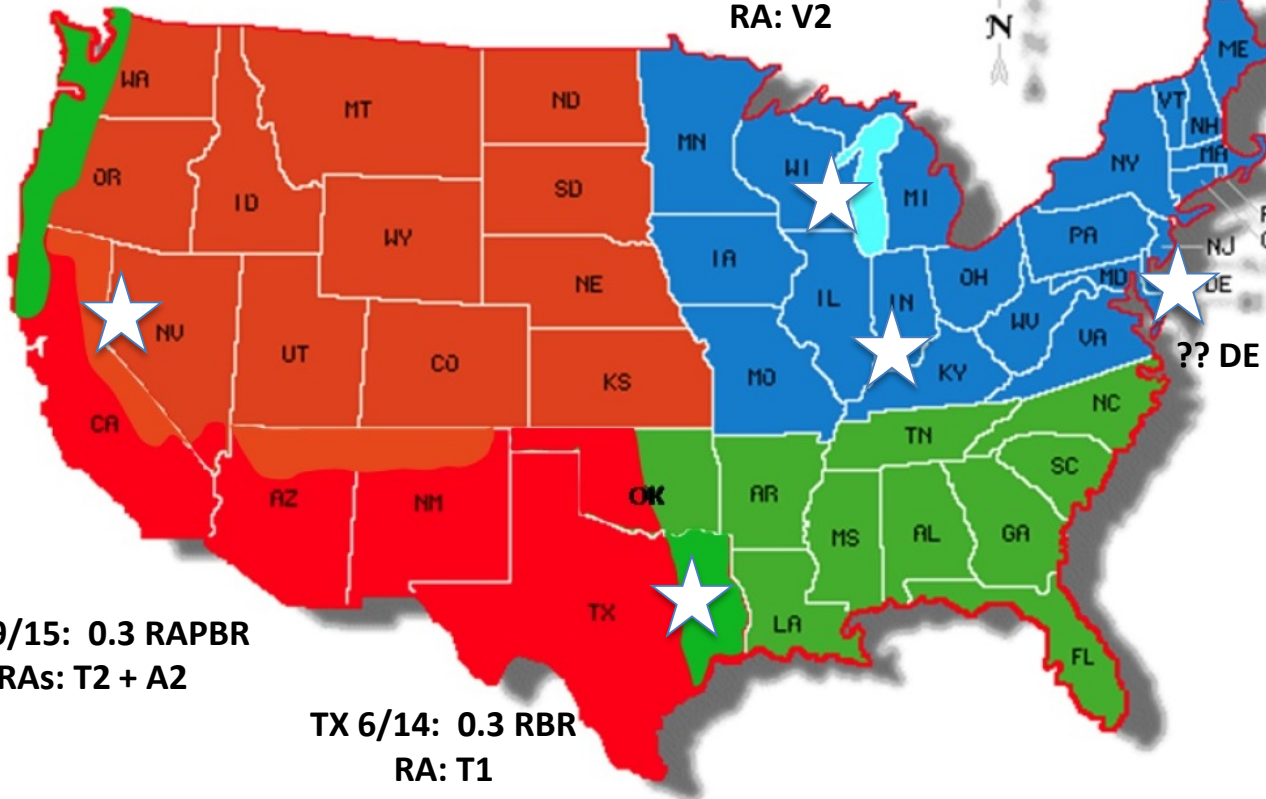
Phase III Field Projects

IN 9/15: 0.4, 0.5 RBR

RA: T2

WI 9/16: 0.3 RBR

RA: V2



NV 9/15: 0.3 RAPBR

RAs: T2 + A2

TX 6/14: 0.3 RBR

RA: T1

?? DE 2016: PG 64-28

RA: ??

NV Field Project

Laboratory Mixtures (LMMLC) & Field Mixtures (RPMLC, Cores)

Binder

Mixture

	Dosage Selection	RE & Evolution	HWTT	M _R & SCB (STOA & LTOA)	E* & UTSST (LTOA)	S-VECD (LTOA)
Target 64-28P	Mod Binder		✓	✓	✓	✓
Recycled (R) 64-28P (0.3 RAPBR)	—	—	✓	✓	✓	✓
(R) +T2@FLD (2%)	RA Type		✓	✓	✓	✓
(R) +A2@FLD (2%)	✓	✓	✓	✓	✓	✓
DOT Control 64-28P (0.15 RAPBR)	—	—	✓	✓	✓	✓

IN Field Project

Laboratory Mixtures (LMLC) & Field Mixtures (RPMLC, Cores)

	Binder		Mixture			
	Dosage Selection	RE & Evolution	HWTT	M _R & SCB (STOA & LTOA)	E* & UTSST (LTOA)	S-VECD (LTOA)
Target 64-22	—	—	—	—	—	—
DOT Control (58-28) (0.32 RBR) (0.25 RAP & 0.07 MWAS)	—	—	✓	✓	✓	—
Recycled (58-28) (0.42 RBR) (0.14 RAP & 0.28 MWAS + T2 FLD (3%))	High RAS		✓	✓	✓	✓

WI Field Project

Laboratory Mixtures (LMMLC) & Field Mixtures (RPMLC, Cores)

	Binder		Mixture		
	Dosage Selection	RE & Evolution	HWTT	M _R & SCB (STOA & LTOA)	E* & UTSST (LTOA)
DOT Control 58-28S (0.22 RAPBR)	—	—	✓	✓	✓
Recycled 58-28S (0.3 RAPBR)	—	—	✓	✓	✓
Recycled 52-34S (0.3 RAPBR)	—	✓	✓	✓	✓
Recycled 58-28S (0.3 RAPBR) + V2@FLD	V Type		✓	✓	✓

Mod Binders

Contact

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Professor and A.P. & Florence Wiley Faculty Fellow

Zachry Department of Civil Engineering

Research Engineer (TTI)

310D CE/TTI

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College Station, TX 77843-3136

(979)862-1750

a-eppsmartin@tamu.edu



56th Idaho Asphalt Conference

October 27th 2016

Performance Graded (PG) Asphalt Binder Modification - Lessons Learned With the Hamburg and MSCR

Joe DeVol

Assistant State Materials Engineer
State Materials Laboratory



**Washington State
Department of Transportation**



Washington State Department of Transportation

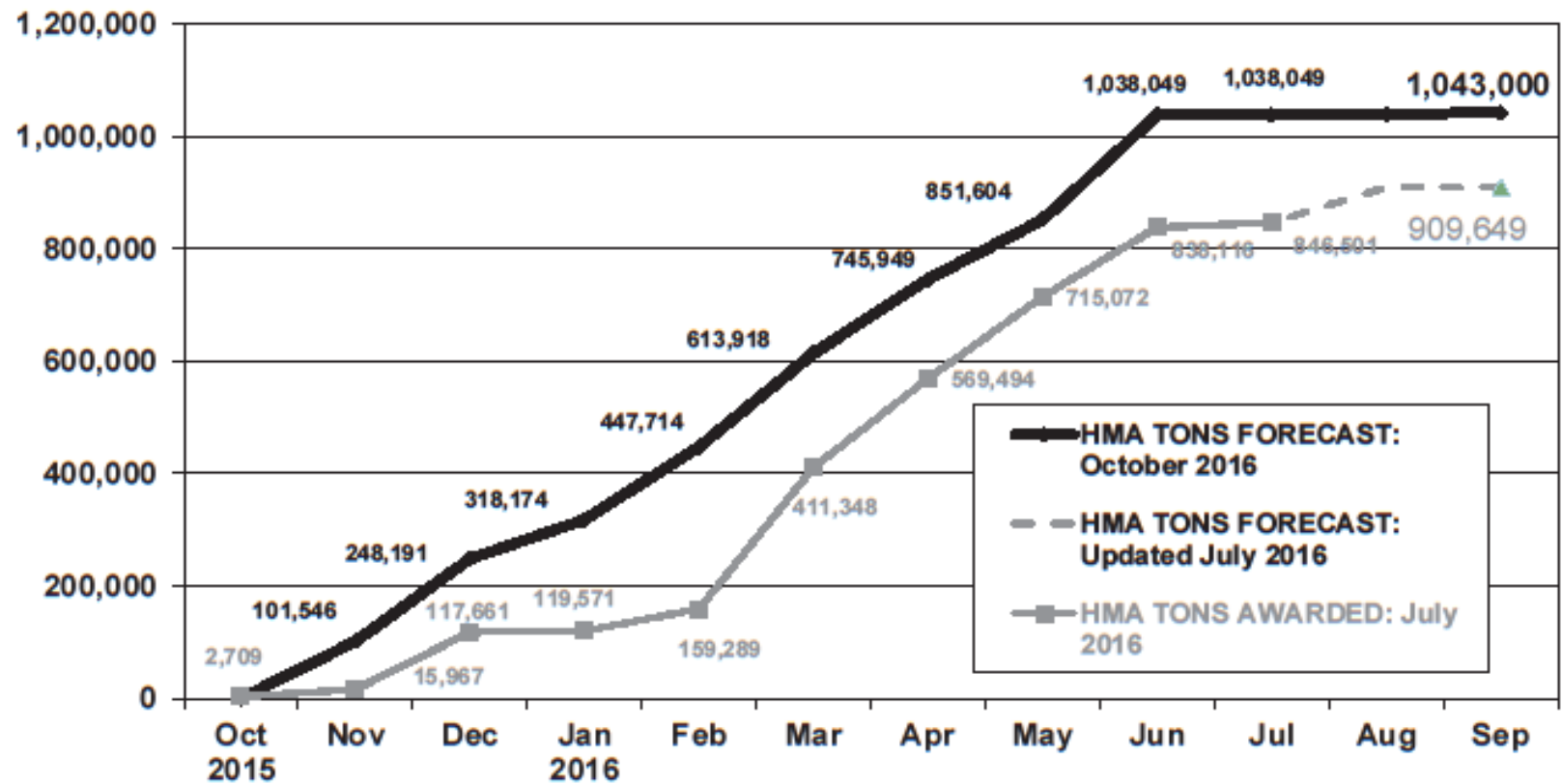
- Just the Facts
 - Connecting Washington Transportation Package
 - 16 Year, \$16 Billion Package
 - \$9.7 Billion, state and local road projects
 - \$1.4 Billion, highway maintenance, operations, preservation
 - 11.9¢ Gas Tax, phased in over next two years



Washington State Department of Transportation

- Just the Facts
 - WSDOT manages 18,500 lane miles
 - Smooth, safe and economical pavements
 - 2016 forecast
 - 1,043,000 tons HMA
 - 586,555 tons HMA - modified asphalt

2016 HMA TONS FORECAST VS. ACTUAL



Washington State
Department of Transportation



- Background

- How we got to where we are

- SHRP efforts - 1995
 - Implemented PG Binders - 2000
 - Superpave Volumetric Mix Design - 2004



- Hamburg & MSCR

- What have we learned?

- Asphalt and Anti-Strip Compatibility
- Asphalt Modification – Products and Processes
- Benefits of Polymer Modification
 - Note: Dual testing AASHTO M 320 & M 332 since 2008



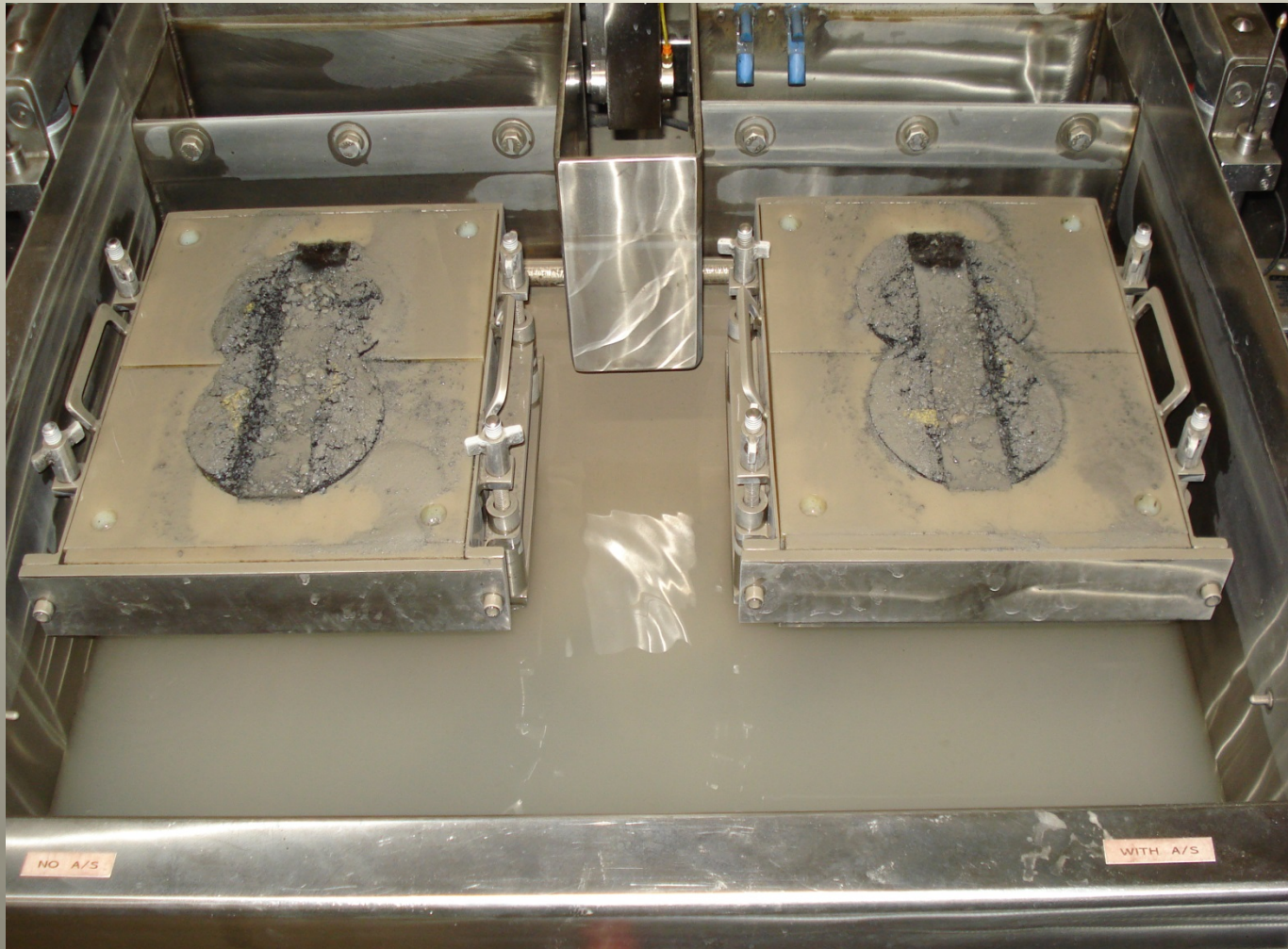
Shown with optional Crane Lift



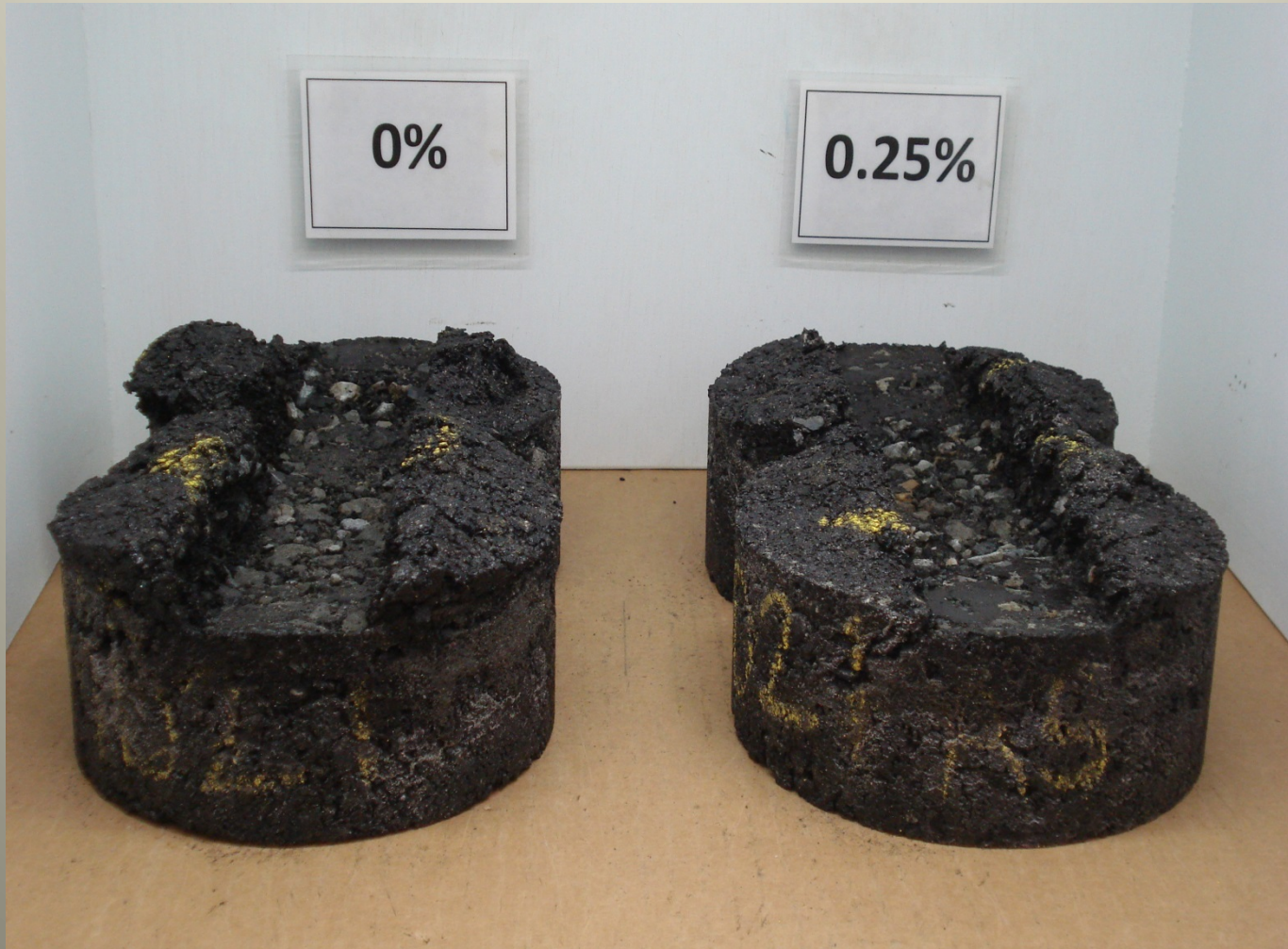
- Hamburg Testing



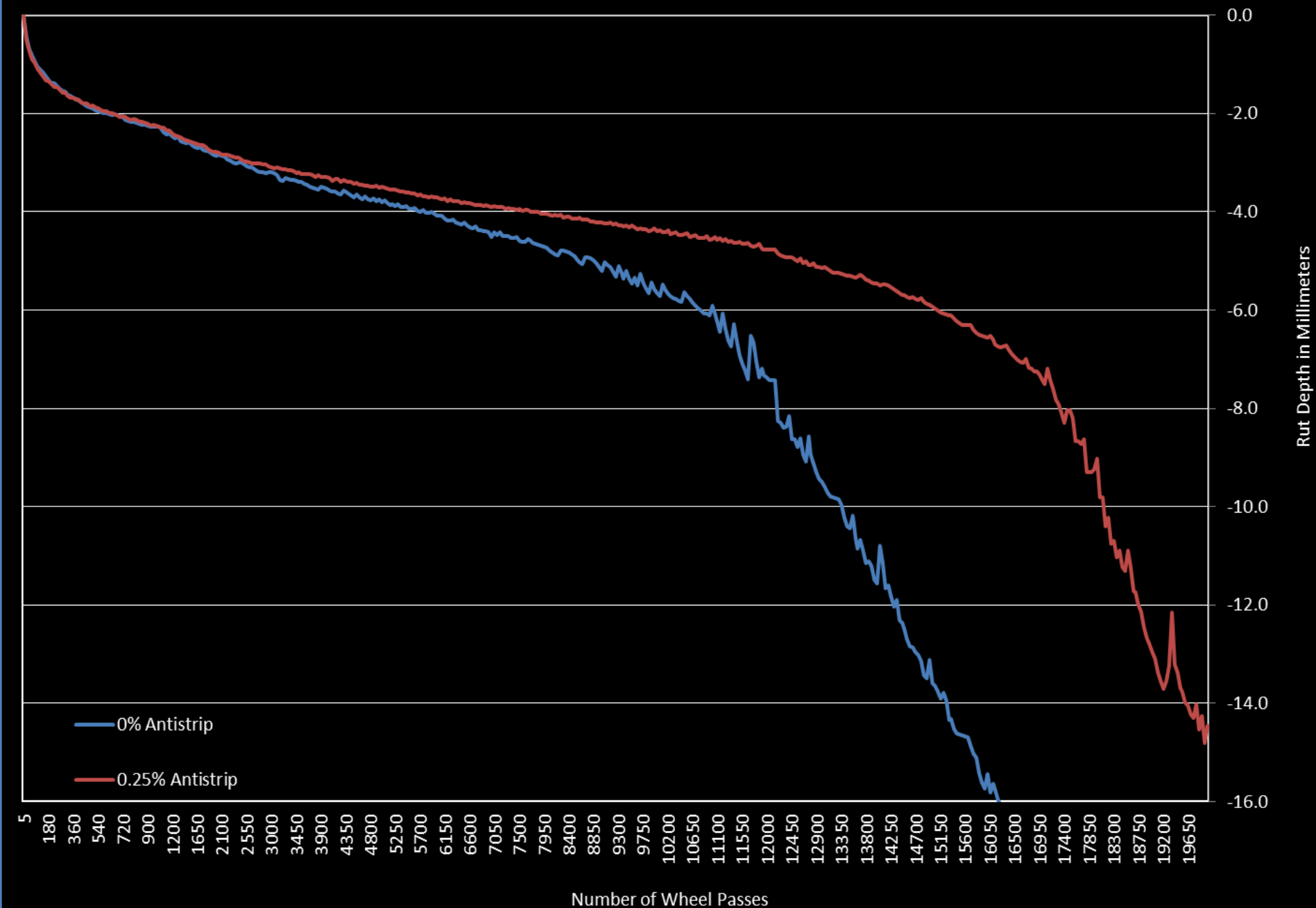
- Hamburg Testing



- Hamburg Testing

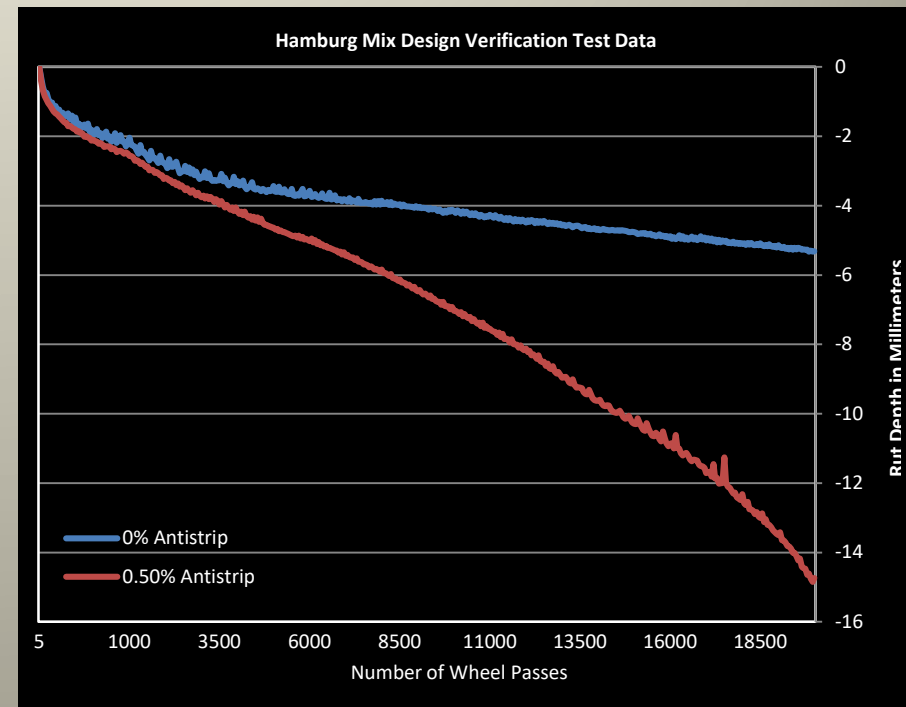


2011 Mix Design Hamburg Test Data (PG64-22)



• Hamburg Testing

➤ Asphalt & Anti-Strip Compatibility



Hamburg Samples with PG64-28 “Original Formulation”



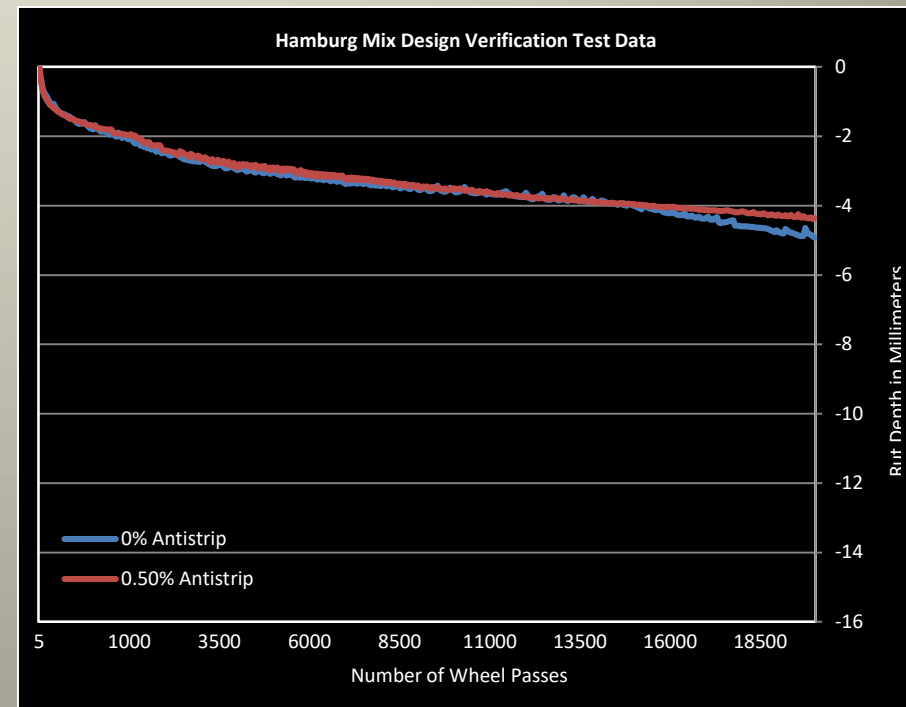
- Hamburg Testing

- Asphalt & Anti-Strip Compatibility

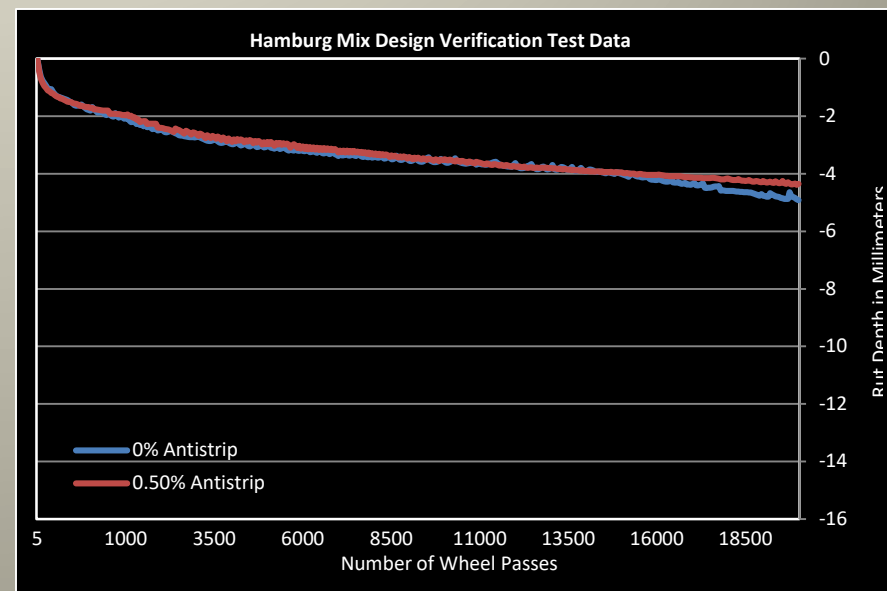
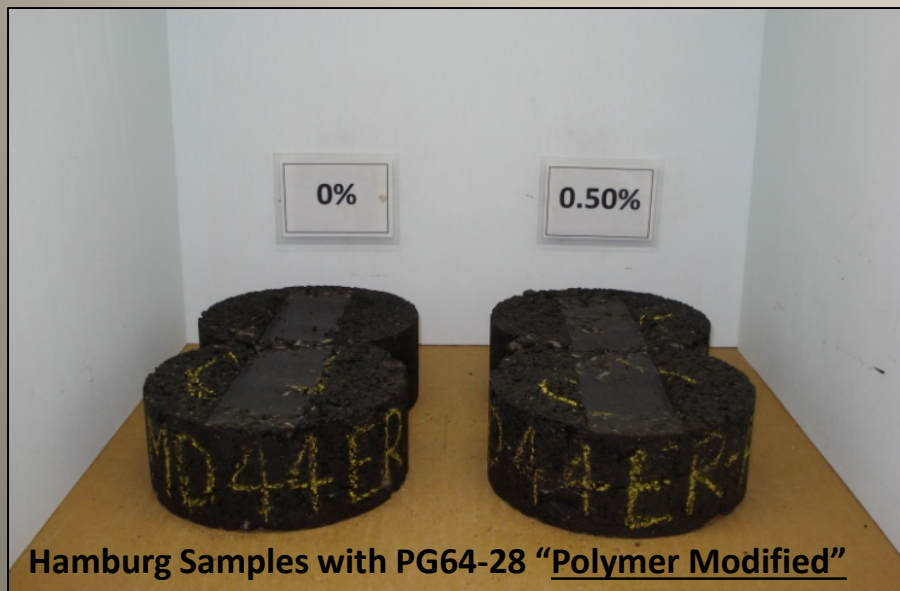
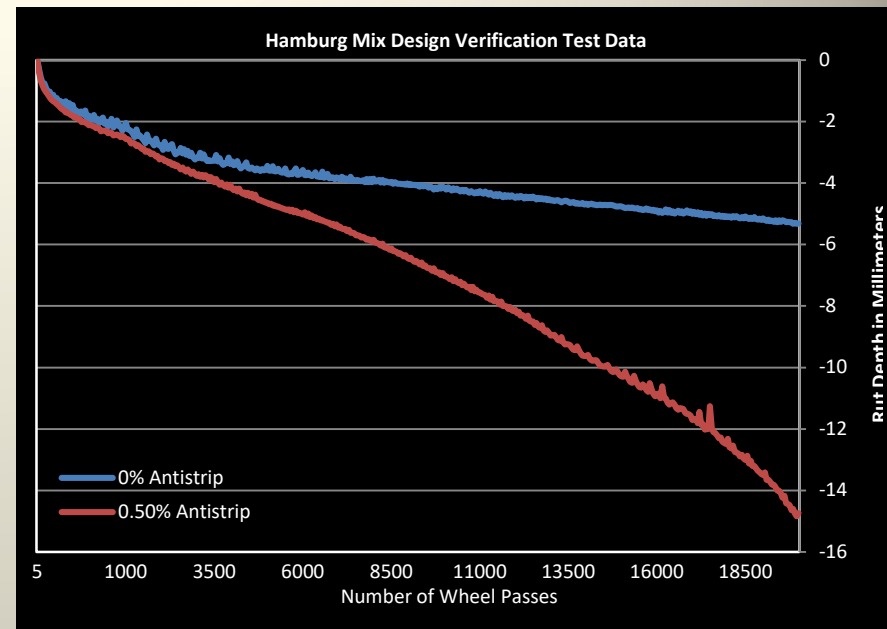
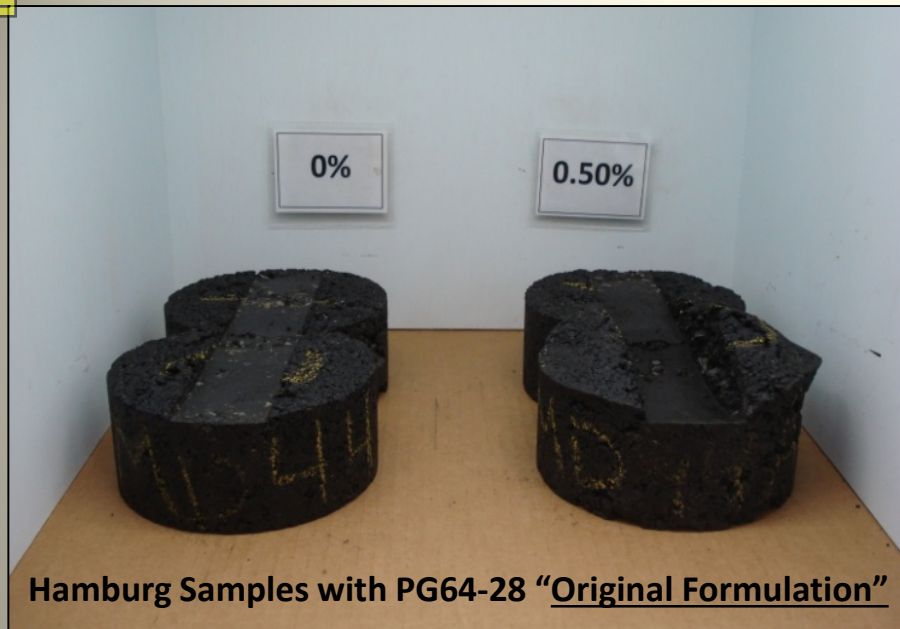
- Results of data analysis
 - AASHTO M 320 – binder meet specification
- Mix design
 - Lottman – improved TSR with anti-strip
 - Hamburg – significant rutting with anti-strip

• Hamburg Testing

➤ Asphalt & Anti-Strip Compatibility



Hamburg Samples with PG64-28 "Polymer Modified"



- Asphalt Binder Testing

- Data Analysis

Original Formulation

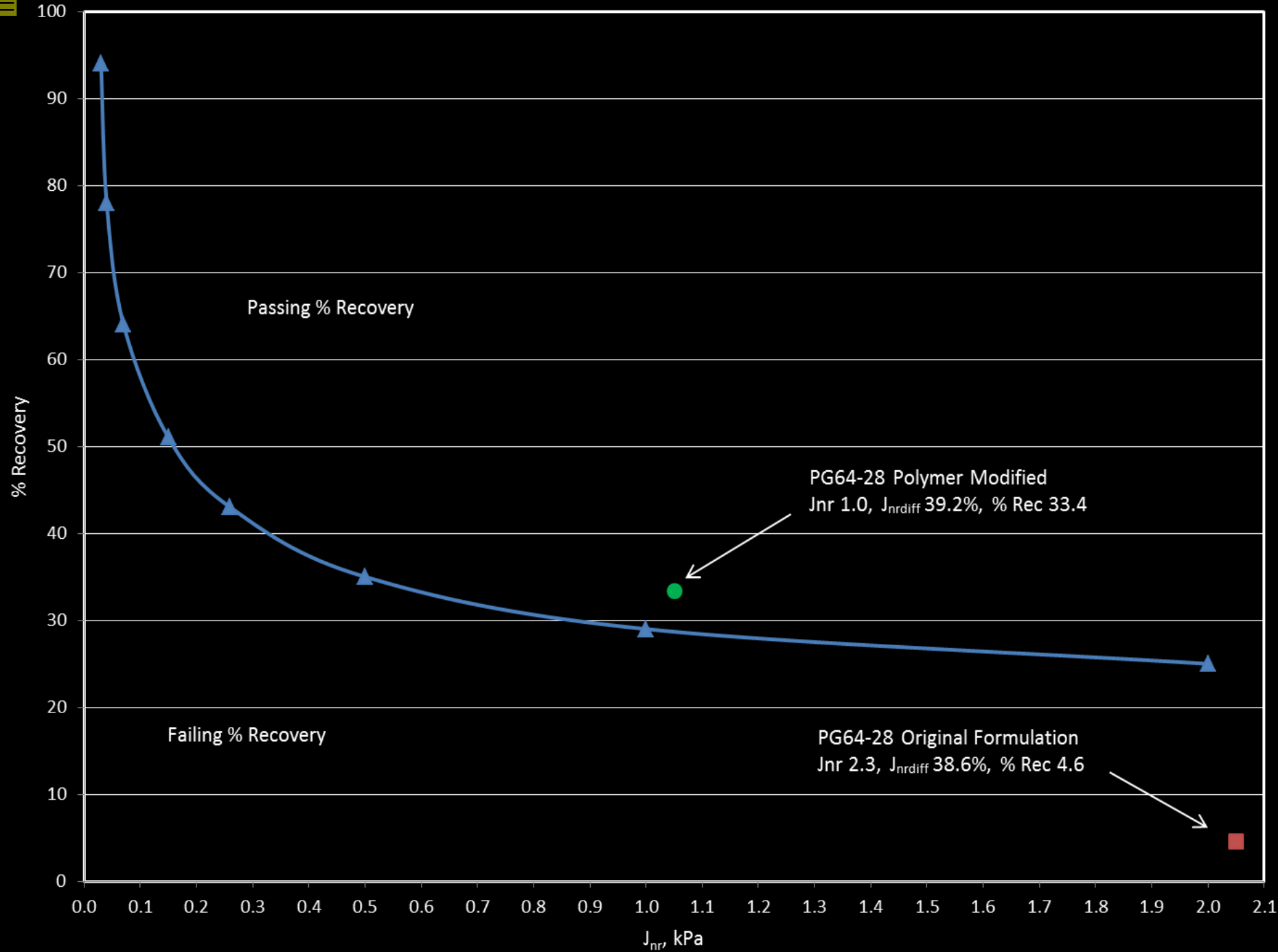
- Met Conventional PG Specs (AASHTO - M 320)
- Met MSCR Specs * (AASHTO - M 332)
- Elastic Recovery = 25% (AASHTO - T 301)

*Excluding Appendix X1

Polymer Modified

- Met Conventional PG Specs (AASHTO - M 320)
- Met MSCR Specs ** (AASHTO - M 332)
- Elastic Recovery = 74% (AASHTO - T 301)

**Including Appendix X1





- Asphalt Binder Testing

- Data Analysis

- Typical Modified PG Binders
 - Met all specifications requirements (AASHTO - M 320)
 - Passed MSCR (AASHTO - M 332) *
 - *Excluding Appendix X1 (% recovery)
 - Tested elastic recovery (AASHTO - T 301)

- Hamburg & MSCR

- Where are we today?

- Elastic Recovery Specification - 2012
 - Hamburg and IDT Specification - 2014
 - Multiple Stress Creep Recovery - 2018

Elastic Recovery Specification

Property	Test Method	Additional Requirements by Performance Grade (PG) Asphalt Binders					
		PG 58-22	PG 64-22	PG 64-28	PG 70-22	PG 70-28	PG 76-28
RTFO Residue:							
Elastic Recovery ¹	AASHTO T 301 ²	--	--	60% Min.	60% Min.	60% Min.	60% Min.
Notes:							

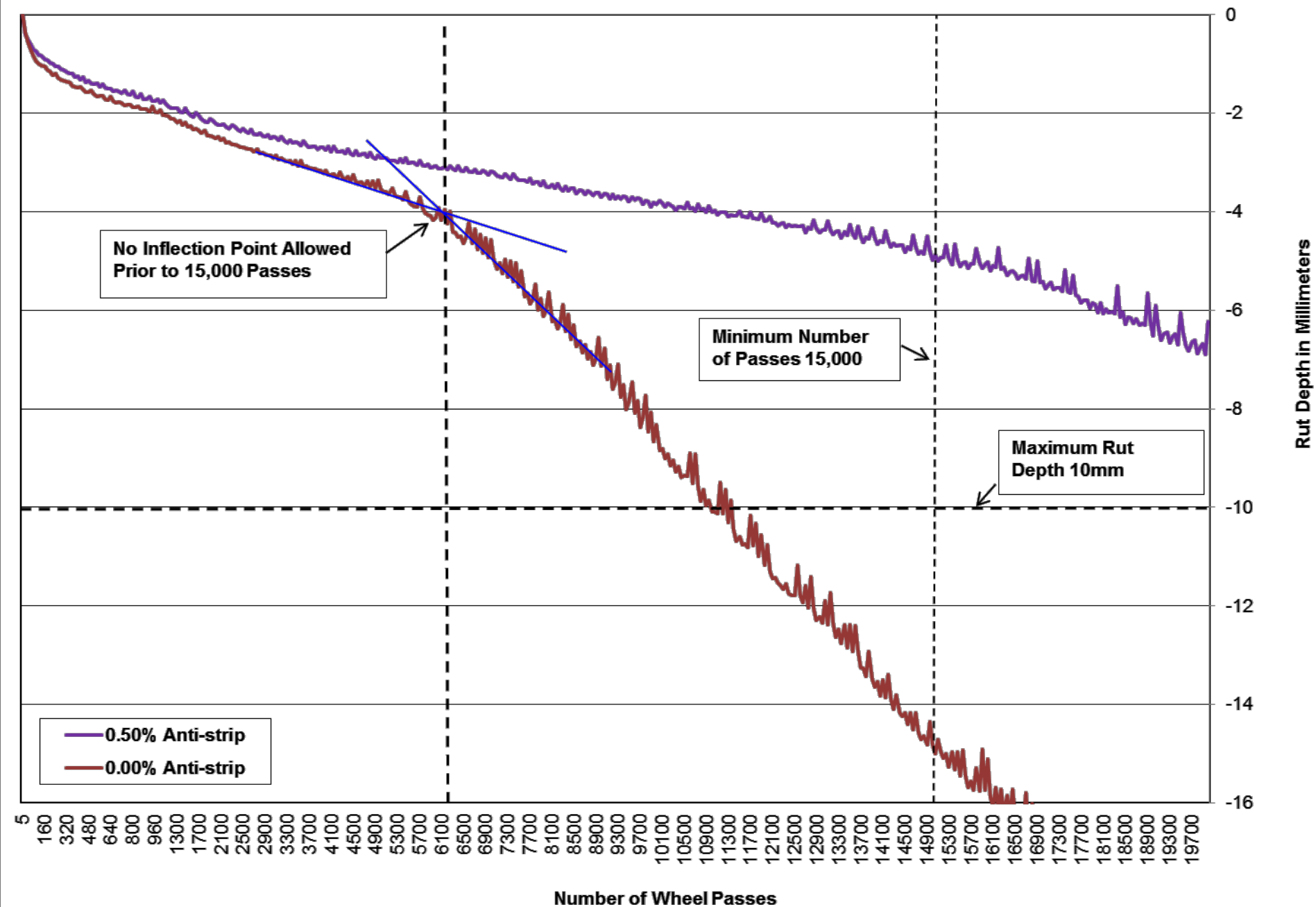
1. Elastic Recovery @ 25°C ± 0.5°C

2. Specimen conditioned in accordance with AASHTO T 240 – RTFO

Hamburg and IDT Specification

Mix Criteria	HMA Class							
	$\frac{3}{8}$ inch		$\frac{1}{2}$ inch		$\frac{3}{4}$ inch		1 inch	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Hamburg Wheel-Track Testing, WSDOT FOP for AASHTO T 324 Rut Depth (mm) @ 15,000 Passes		10		10		10		10
Hamburg Wheel-Track Testing, WSDOT FOP for AASHTO T 324 Minimum Number of Passes With no Stripping Inflection Point	15,000		15,000		15,000		15,000	
Indirect Tensile (IDT) Strength (psi) of Bituminous Materials WSDOT FOP for ASTM D 6931		175		175		175		175

Hamburg Mix Design Test Data

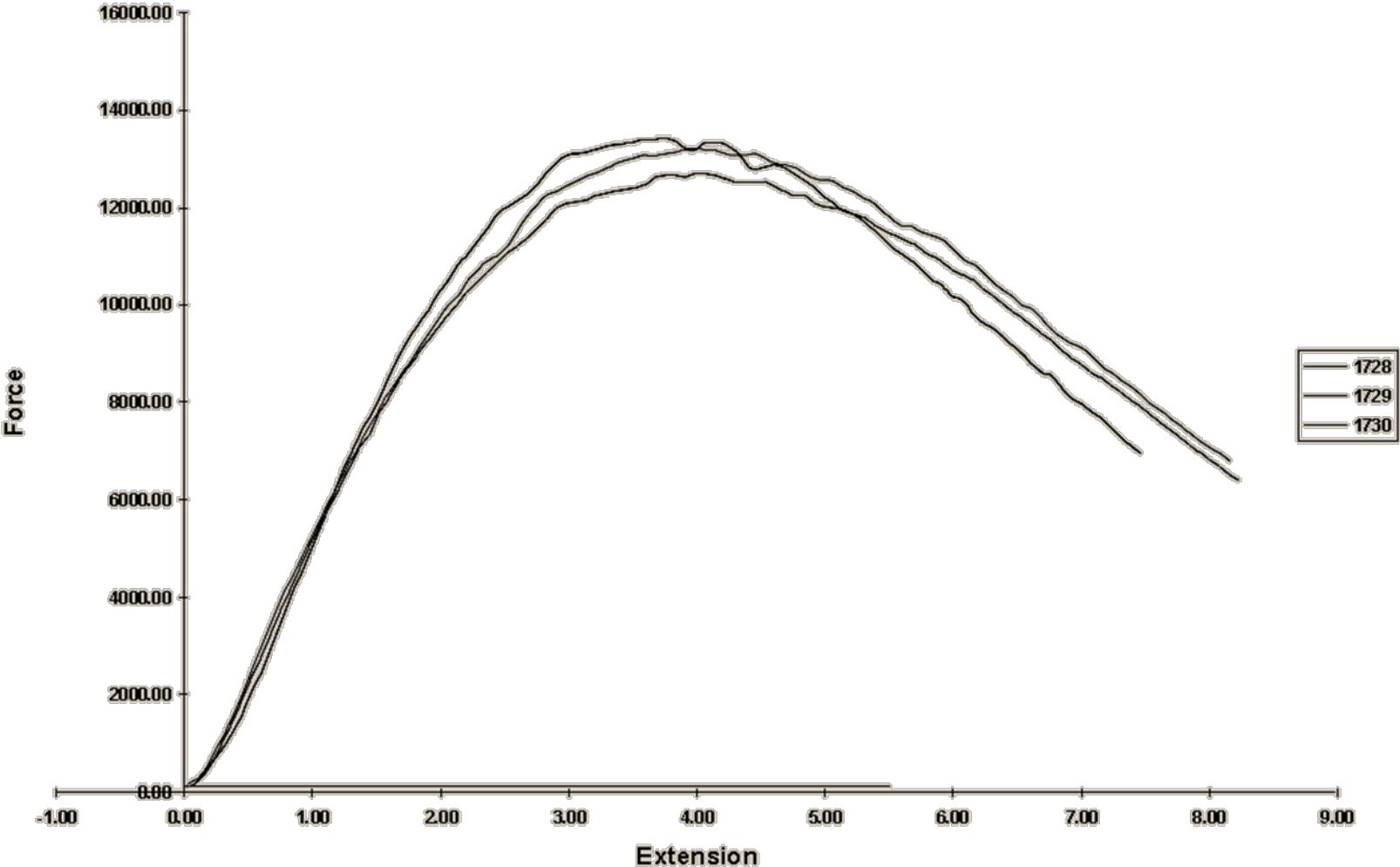




WSDOT HQ Materials Laboratory

Report No Indirect Tensile Strength (IDT) - Mix Design

Force (-N) vs Extension (%)



- Multiple Stress Creep Recovery

➤ Where we're headed next!

- Multiple Stress Creep Recovery - 2018

* Working with PCCAS, Regional Task Group & WAPA

- Would Replace Elastic Recovery
- New PG Grading Terminology

• Asphalt Binder Grading - 101

• Current Grading System

- Base grade (Environment)
- Grade bump (Traffic/Load)
- Bump = same stiffness at higher temperature
- Allows for products & processes that may affect performance

• MSCR Grading System

- Base grade (Environment)
- Grade bump (Traffic/Load)
- Bump = increase stiffness at service temperature
- Requires products & processes that ensure performance

- Asphalt Binder Grading - 101

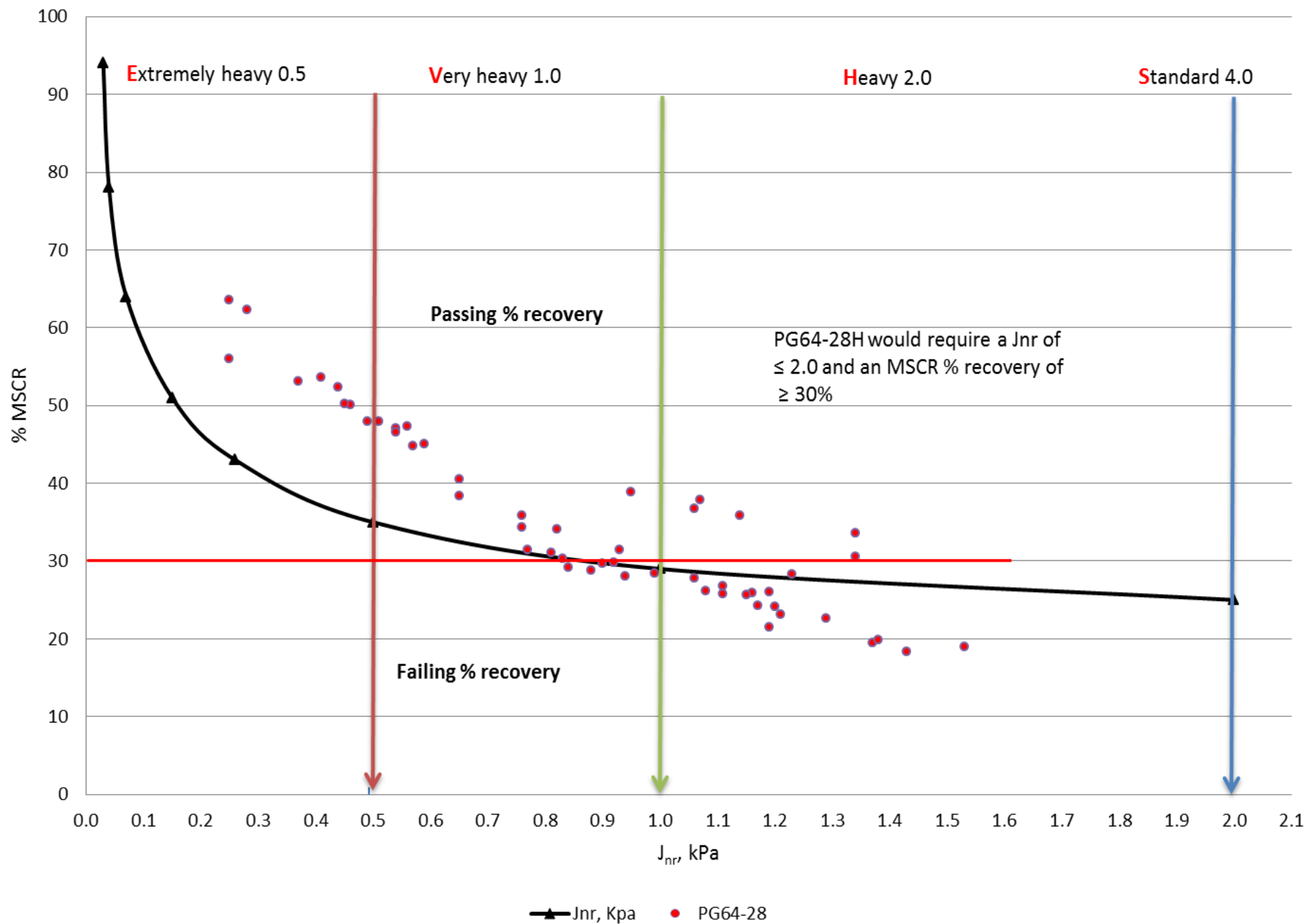
- Current Grading System

- PG58-22
- PG64-22
- PG70-22
- PG64-28
- PG70-28
- PG76-28

- MSCR Grading System

- PG58S-22 (Standard)
- PG58H-22 (Heavy)
- PG58V-22 (Very Heavy)
- PG64S-28
- PG64H-28
- PG64V-28

PG64-28 (PG64-28H) MSCR vrs Jnr 2013



56th Idaho Asphalt Conference

Questions?

devolj@wsdot.wa.gov

(360)709-5421

State Construction Office - Information

<http://www.wsdot.wa.gov/business/construction>



Washington State
Department of Transportation



**E-CONSTRUCTION:
HOW TECHNOLOGY IS CHANGING
PROJECT DELIVERY**

**George White
CEO, Co-Founder**

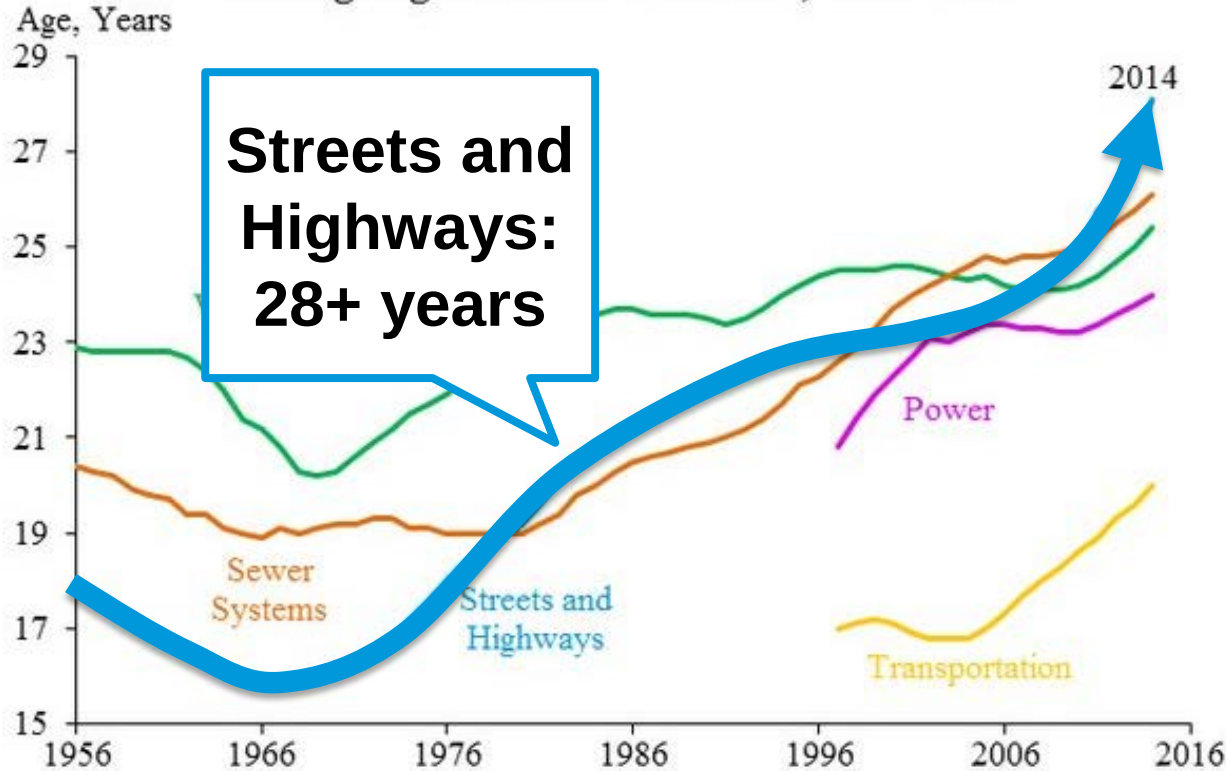


TRANSPORTATION INFRASTRUCTURE IS FUNDAMENTAL TO OUR WAY OF LIFE.

Why we do what we do...

Our infrastructure is aging...

Average Age of Public Structures, 1956–2014



Sources: Bureau of Economic Analysis, ASCE

AMERICA'S
G.P.A.

D+

ESTIMATED INVESTMENT
NEEDED BY 2020:

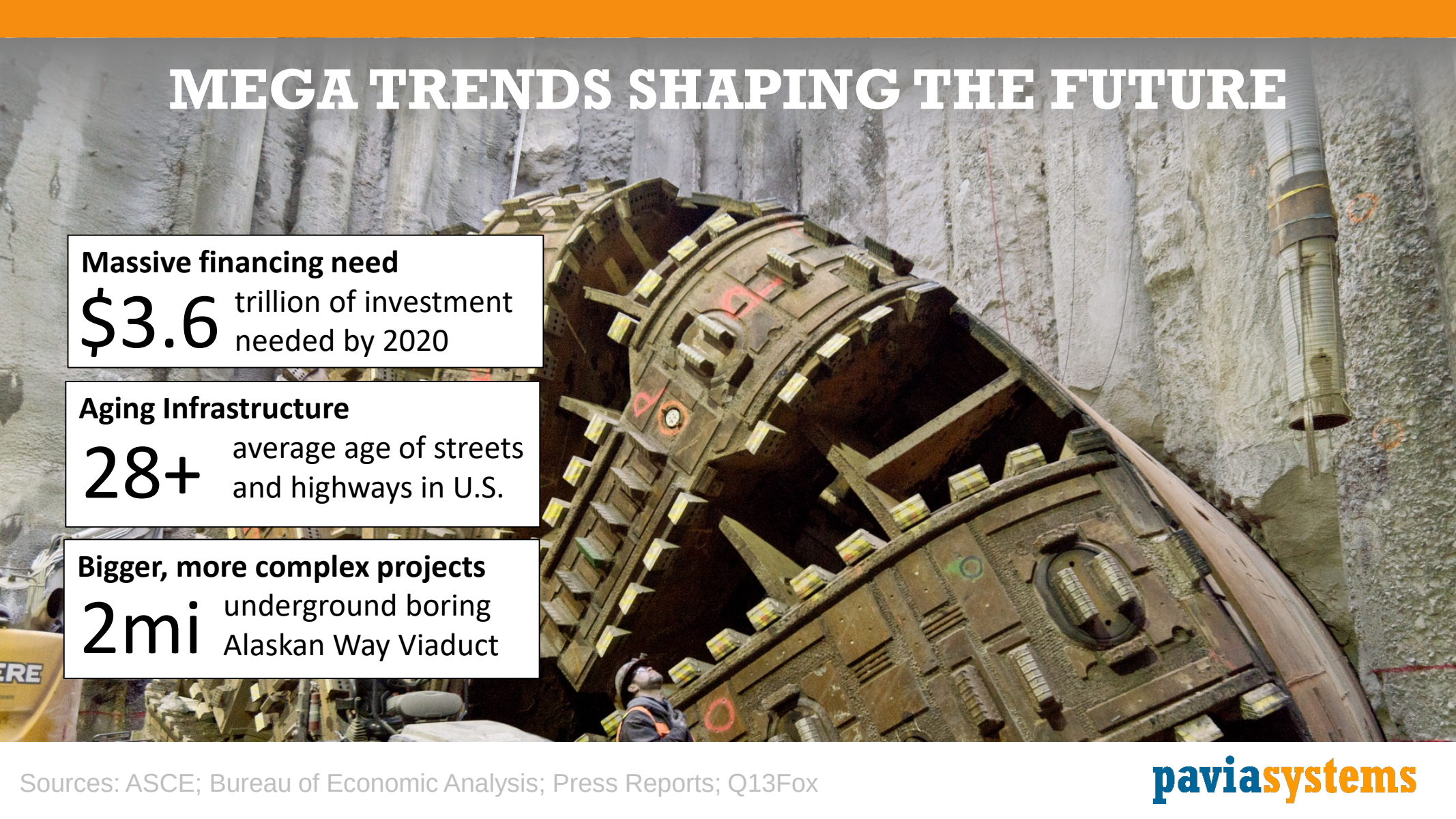
\$3.6
TRILLION

INFRASTRUCTURE GRADES FOR 2013

ENERGY	D+	SCHOOLS	D	PUBLIC PARKS & RECREATION	C-
TRANSIT	D	ROADS	D	RAIL	C+
PORTS	C	INLAND WATERWAYS	D-	BRIDGES	C+
AVIATION	D	WASTEWATER	D	SOLID WASTE	B-
LEVEES	D-	HAZARDOUS WASTE	D	DRINKING WATER	D
DAMS	D				

A: EXCEPTIONAL, B: GOOD, C: MODERATE, D: POOR, F: FAILING
Each category was evaluated on the basis of capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation

MEGA TRENDS SHAPING THE FUTURE



Massive financing need

\$3.6 trillion of investment
needed by 2020

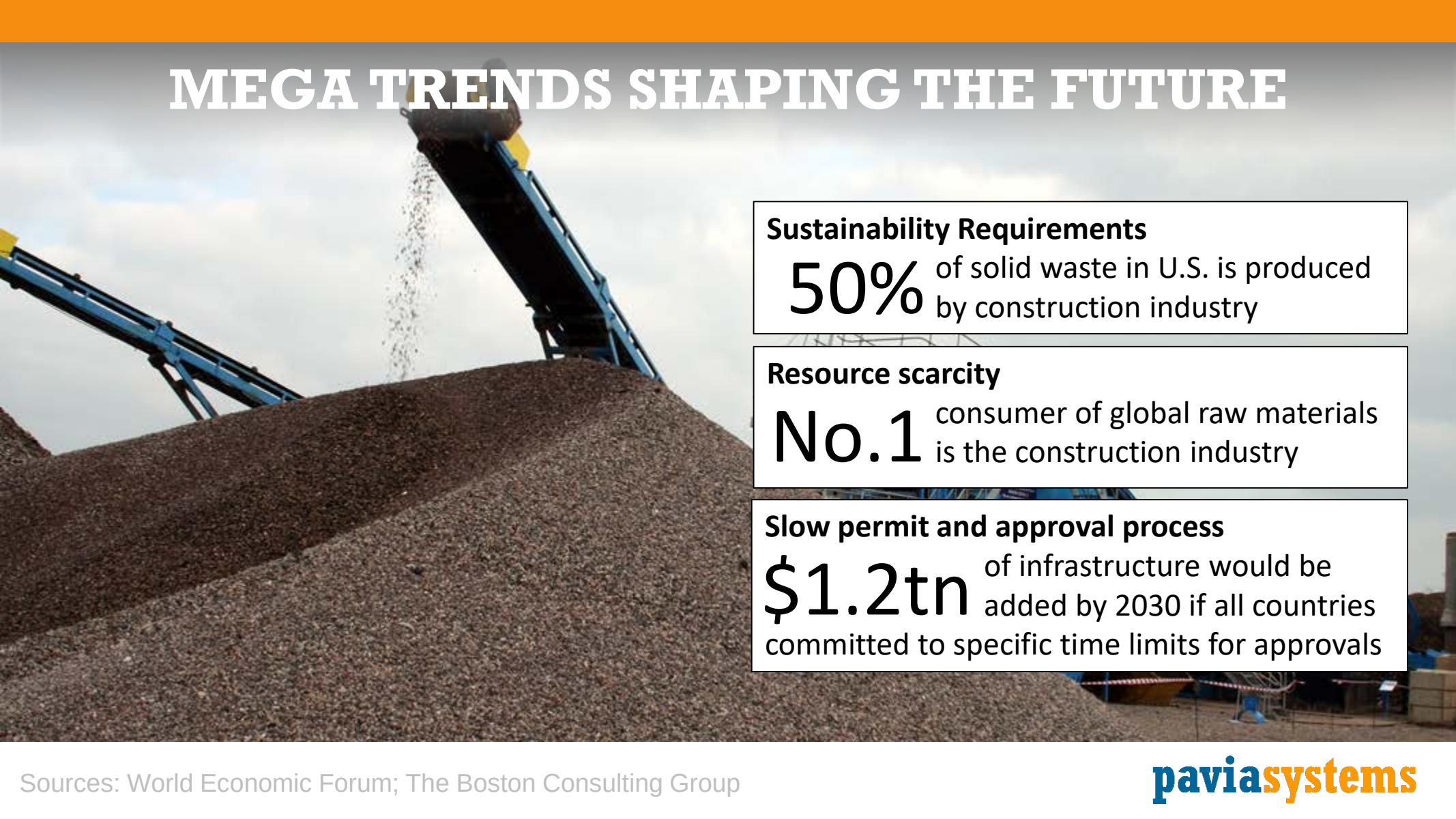
Aging Infrastructure

28+ average age of streets
and highways in U.S.

Bigger, more complex projects

2mi underground boring
Alaskan Way Viaduct

MEGA TRENDS SHAPING THE FUTURE



Sustainability Requirements

50% of solid waste in U.S. is produced by construction industry

Resource scarcity

No.1 consumer of global raw materials is the construction industry

Slow permit and approval process

\$1.2tn of infrastructure would be added by 2030 if all countries committed to specific time limits for approvals

MEGA TRENDS SHAPING THE FUTURE

Resilience Challenges

3x as many disasters reported
last year as in 1980

Talent and aging workforce leaving

50% of employees eligible for
retirement by 2018



Managing Risk Through Asset Life



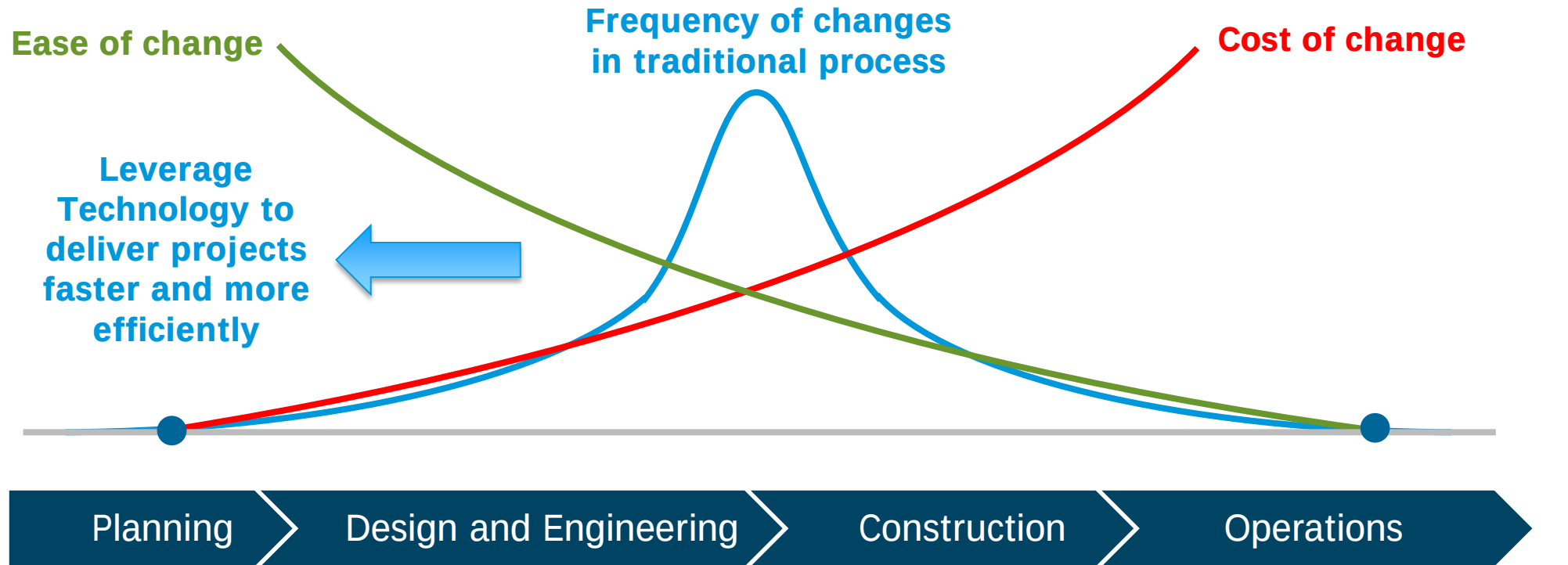
Planning

Design and Engineering

Construction

Operations

Managing Risk Through Asset Life (Time, Quality, Cost)



Source: Adapted from World Economic Forum; The Boston Consulting Group

OPPORTUNITIES TO EVOLVE

Mon: 98° - 79° P. CLOUDY 8 hrs
8/25 0800 - 5:00 pm Seq: 8

BASE: crew - Damians

① supvr. ② skill ③ UNSKILL

Equip: ① Loader ① Track Hog

BASE CONSTRUCTIONS EXCAVATING TRENCHES
FOR 24" RCB PIPE FOR ADJOINING STORM
WATER INLETS, THAT ARE ALSO BEING
INSTALLED ALONG EBFR US-290
AT APPROX. STA. 1176+00 → 1177+00

Tues: 92° - 77° P. CLOUDY / Seq: 8 2 1/2 hrs

8/26: 08:00 → 5:00 pm GAS: 054469

BASE: Damians crew

8/27 93° - 78° - P. CLOUDY Seq: 8
WED: 0800 -

BASE: chues crew

② skill ④ UNSKILL ① supvr.

Equip: ① Loader ① Track Hog
EXCAVATING SOIL FOR INSTALLATION

OF (36") RCB PIPE TO ADJOIN WITH
(5X5) STORM BOX LOCATED AT STA.
3143+50 FOR MH-1 TO 1-A15-1 16"
AND GRADED PIPE AND BOXES

: SEE PLAN SHEET 1141:

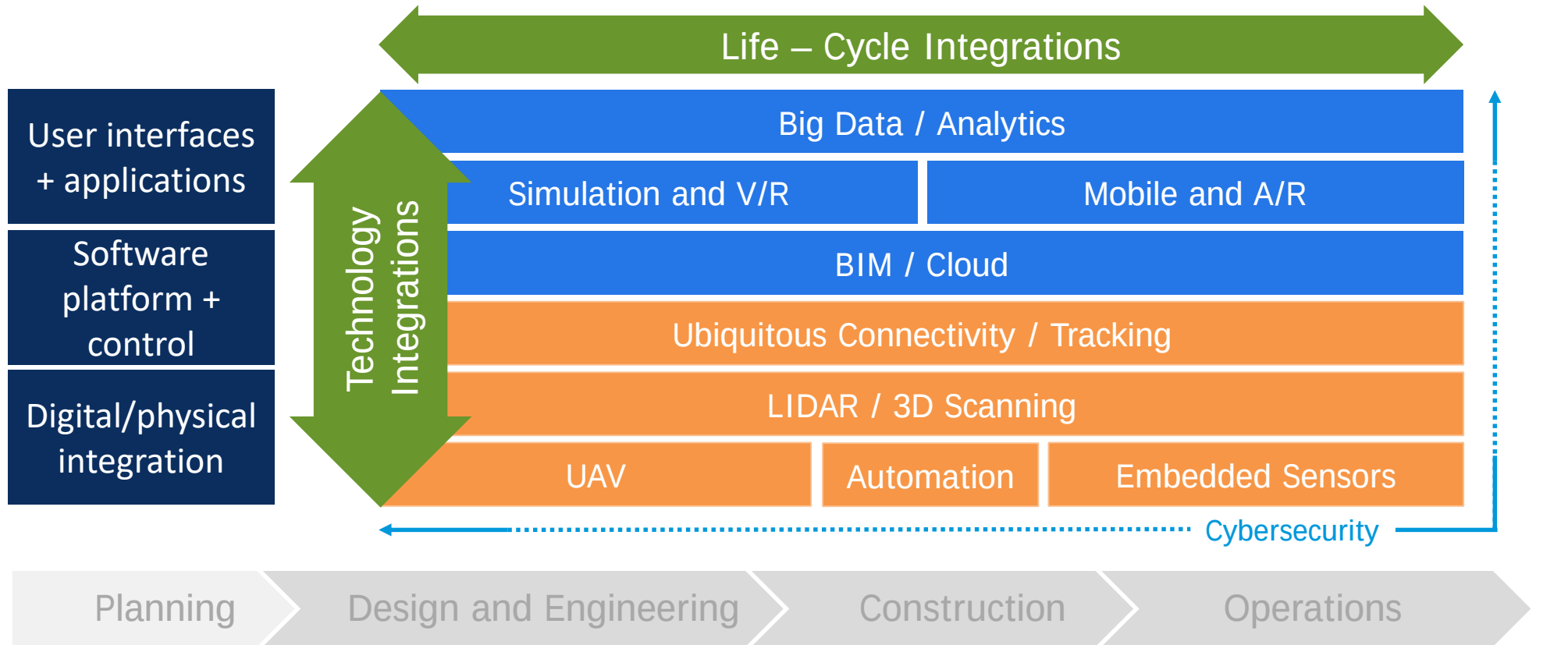
BASE: EXCAVATING SOILS FOR INSTALLATION
OF (36") RCB PIPE TO ADJOIN WITH STORM
BOX (5X5) LOCATION AT WBFR US-290

OPPORTUNITY TO CONNECT SILOS



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Core Enabling Technologies

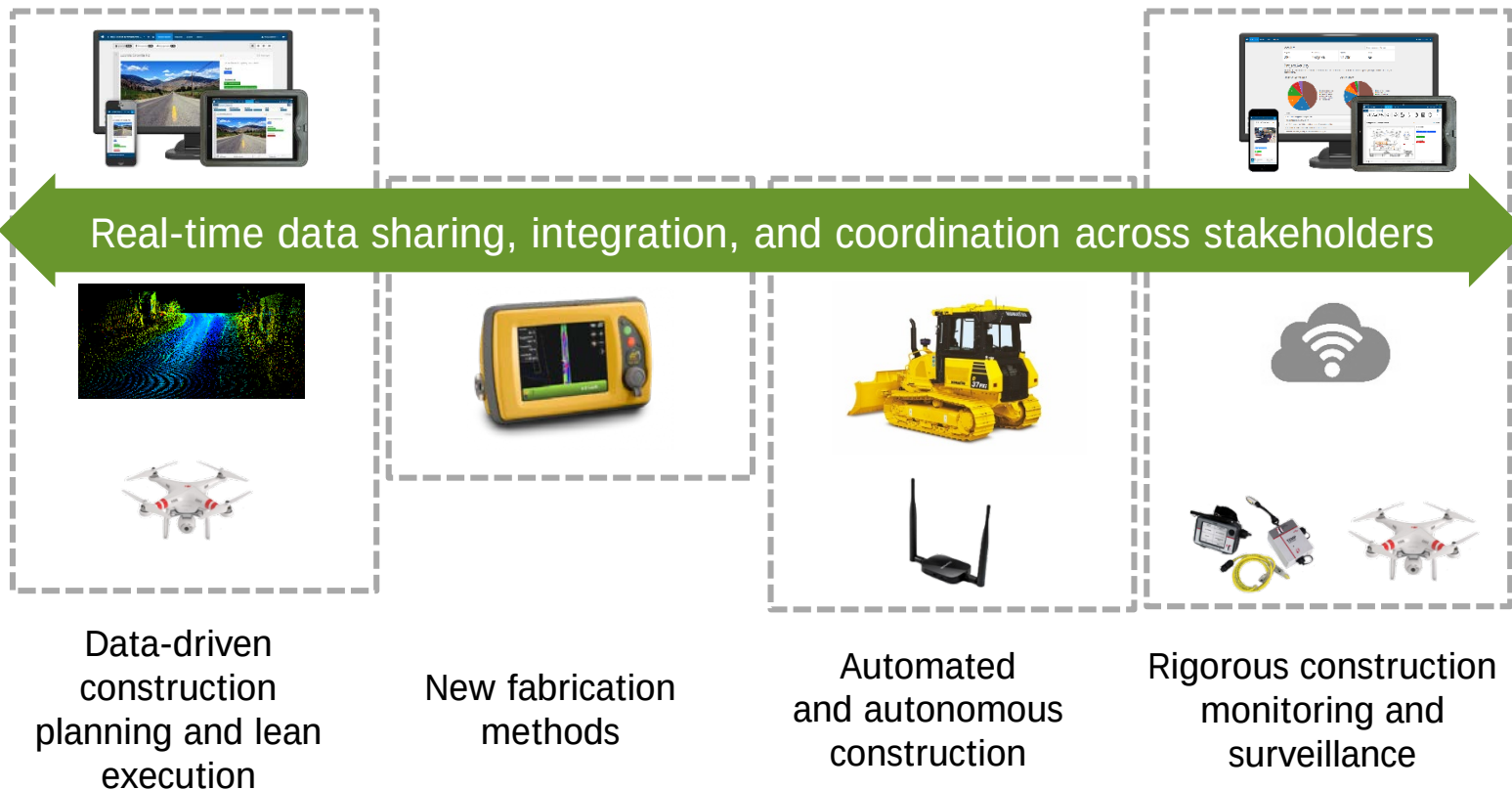


Opportunities Enabled By Digital

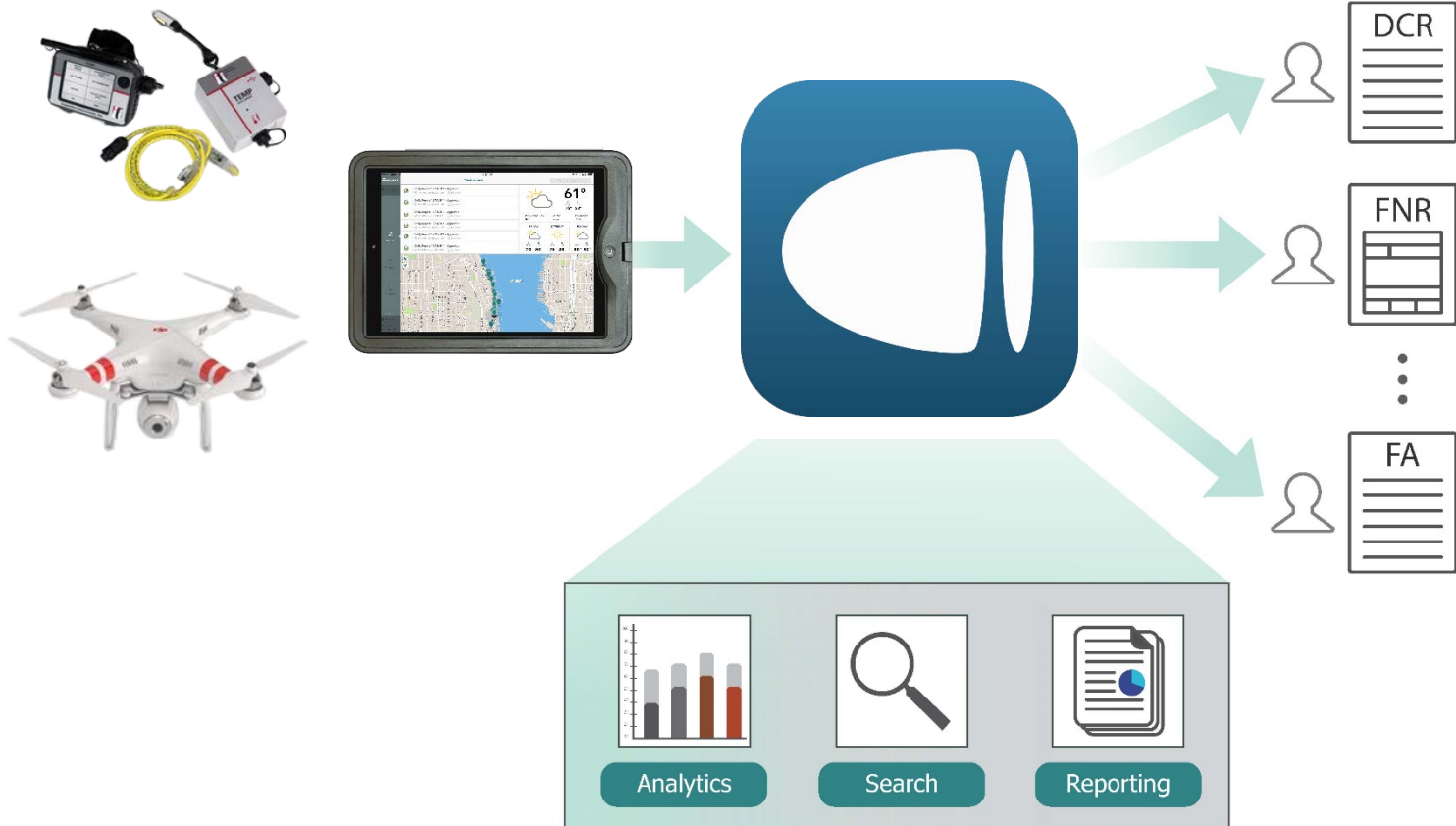
User interfaces
+ applications

Software
platform +
control

Digital/physical
integration



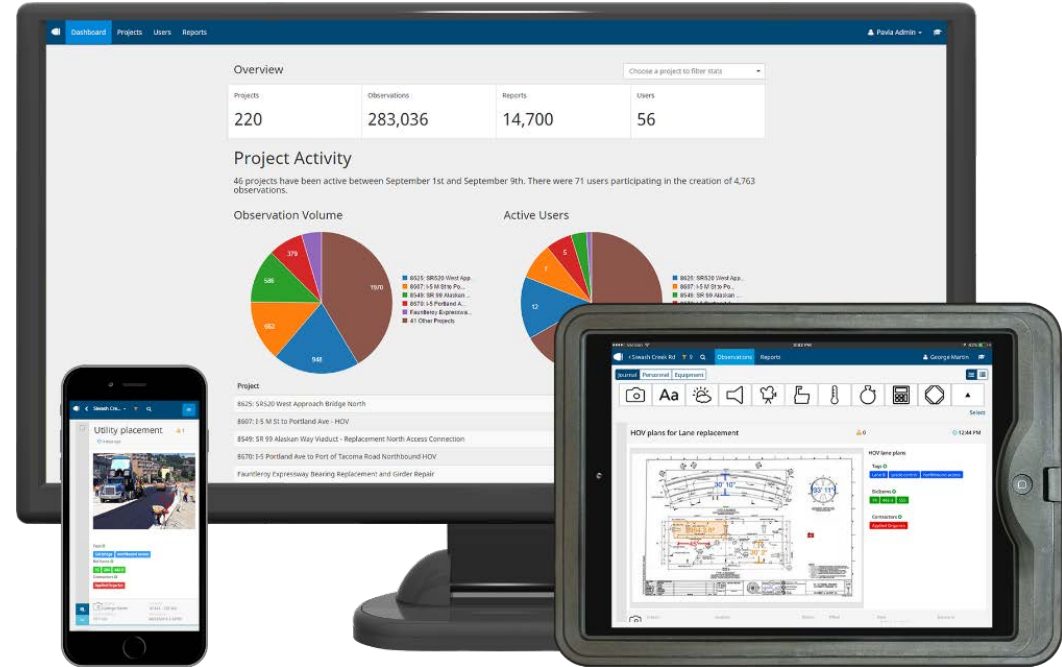
Collect Data Once, Use Many Times





A mobile first, purpose-built platform to reduce project delivery risk.

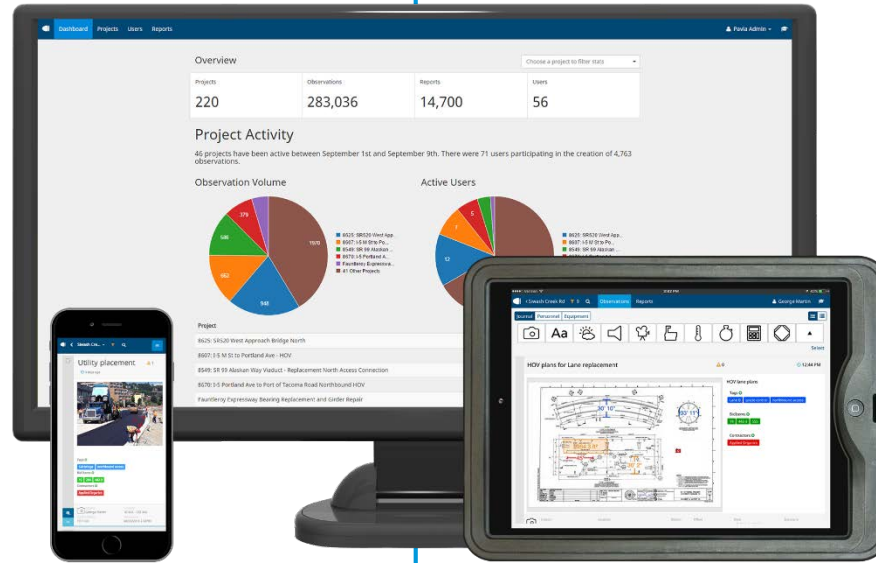
- ✓ Simplified project inspection
- ✓ Real-time communication
- ✓ Automated reporting
- ✓ Digitized workflows
- ✓ Information flow for collaboration



paviasystems

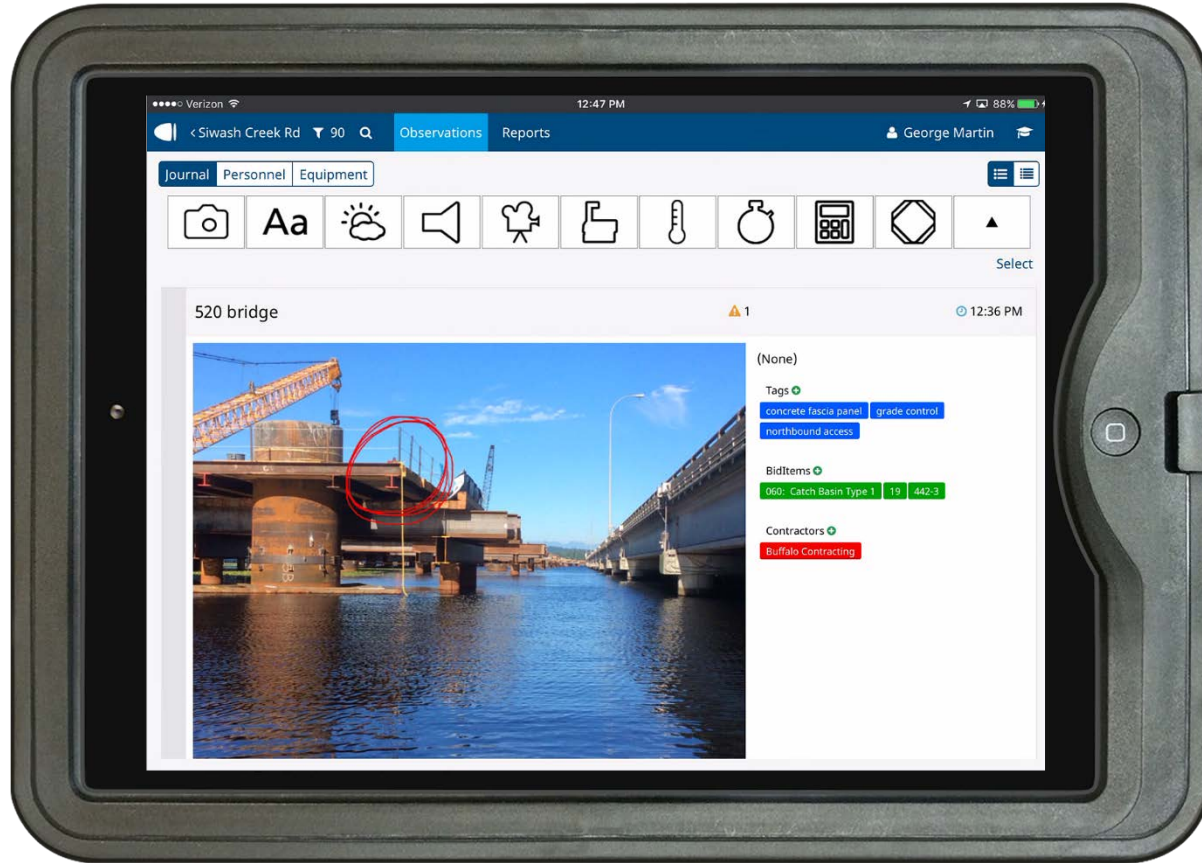
Real-Time Communication Among Stakeholders

Inspectors Field Staff

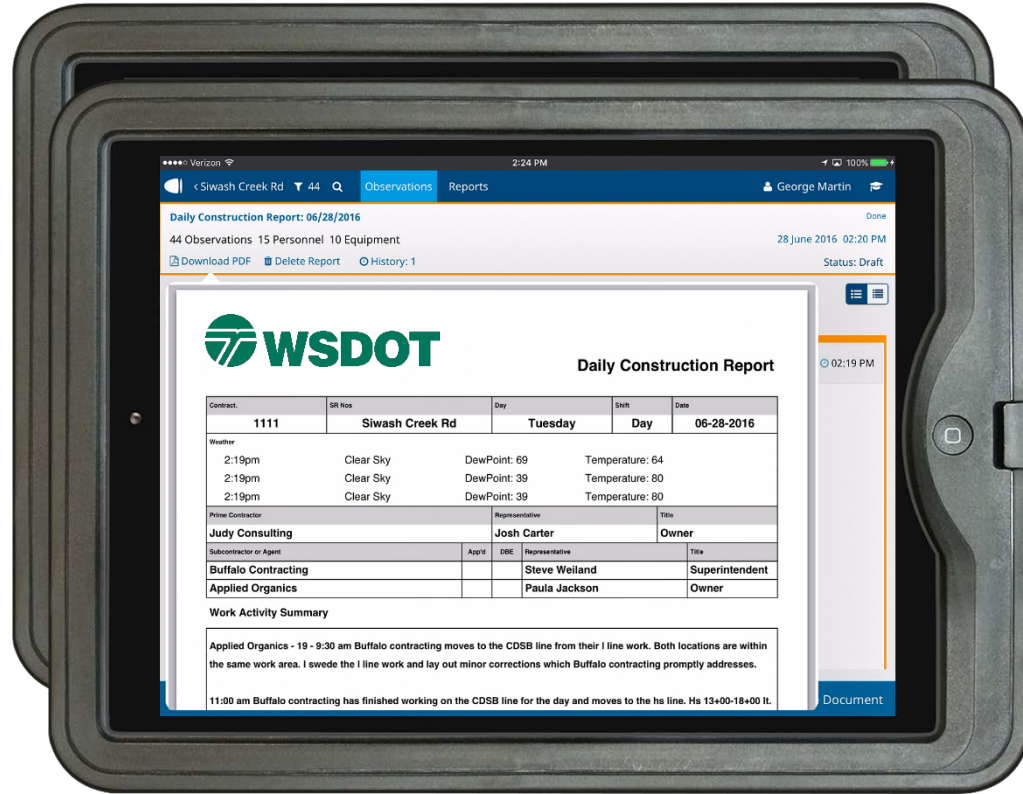


Design Engineers Project Engineers Resident Engineers Office Personnel

Simplify Data Collection

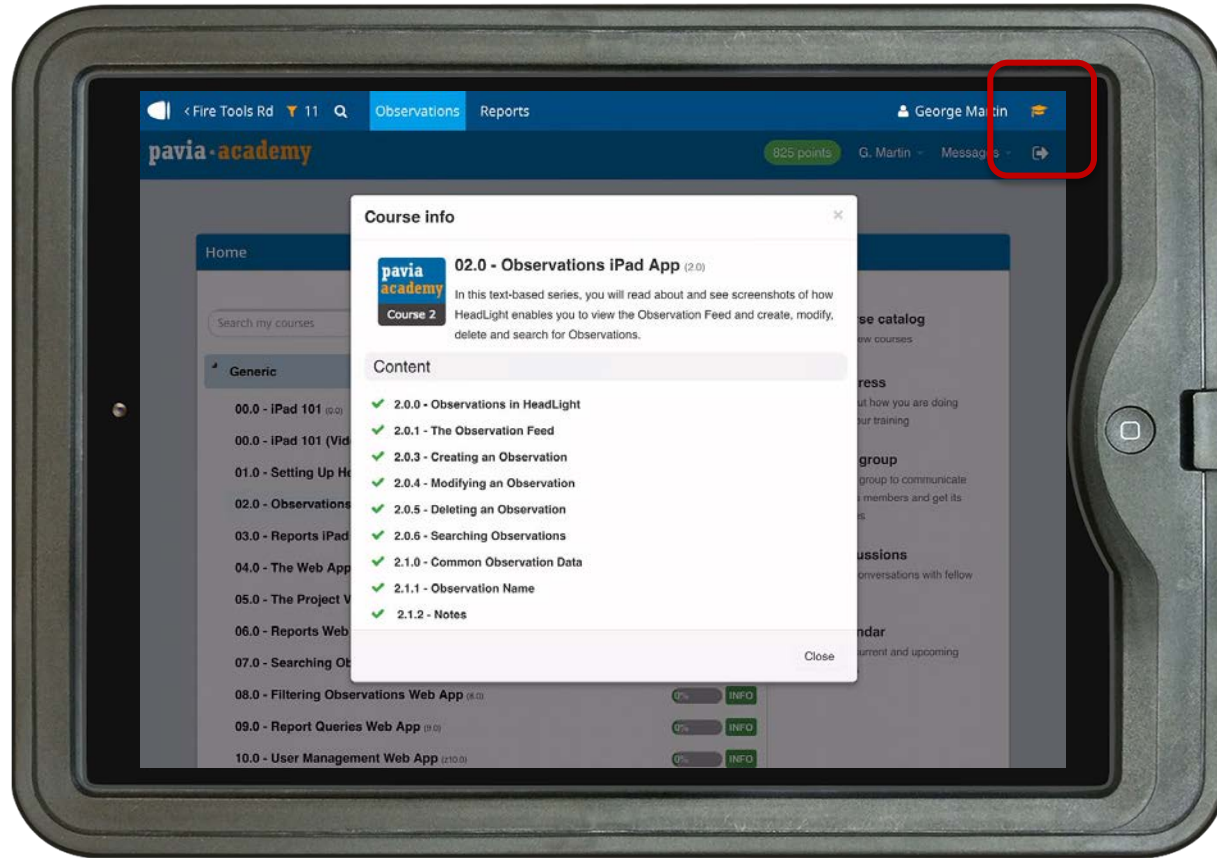


Automate Reporting and Enhance Workflows

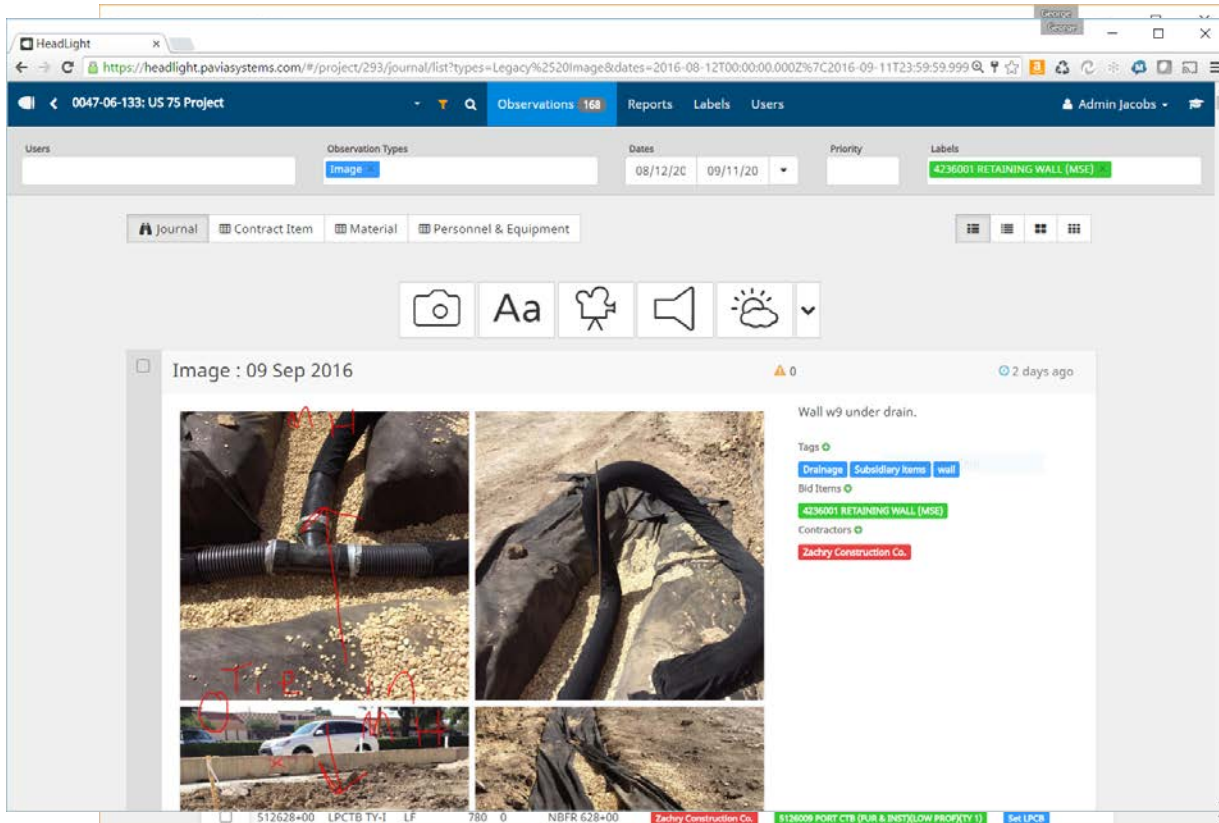


Final Records System

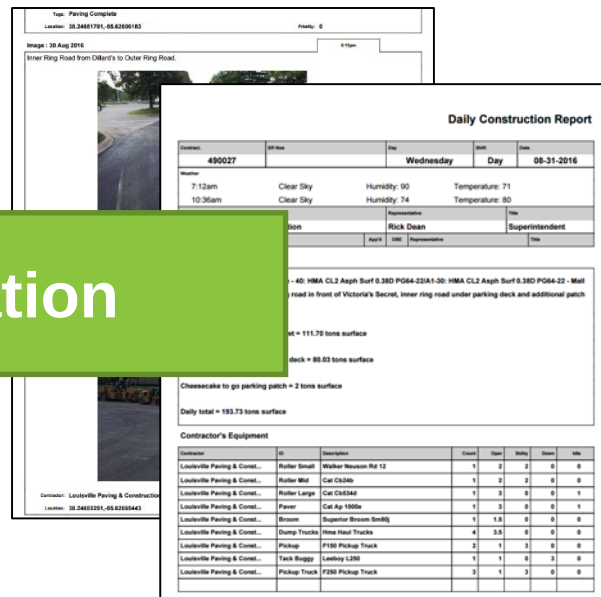
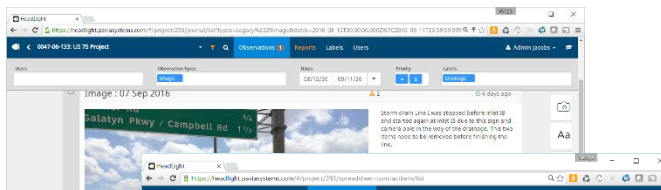
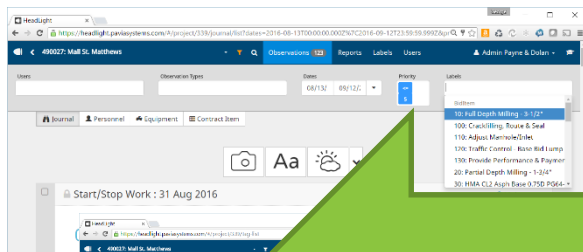
Improve Project Understanding



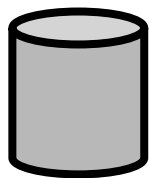
Collaboratively Track and Manage Issues



Discover Trends and Identify Potential Issues

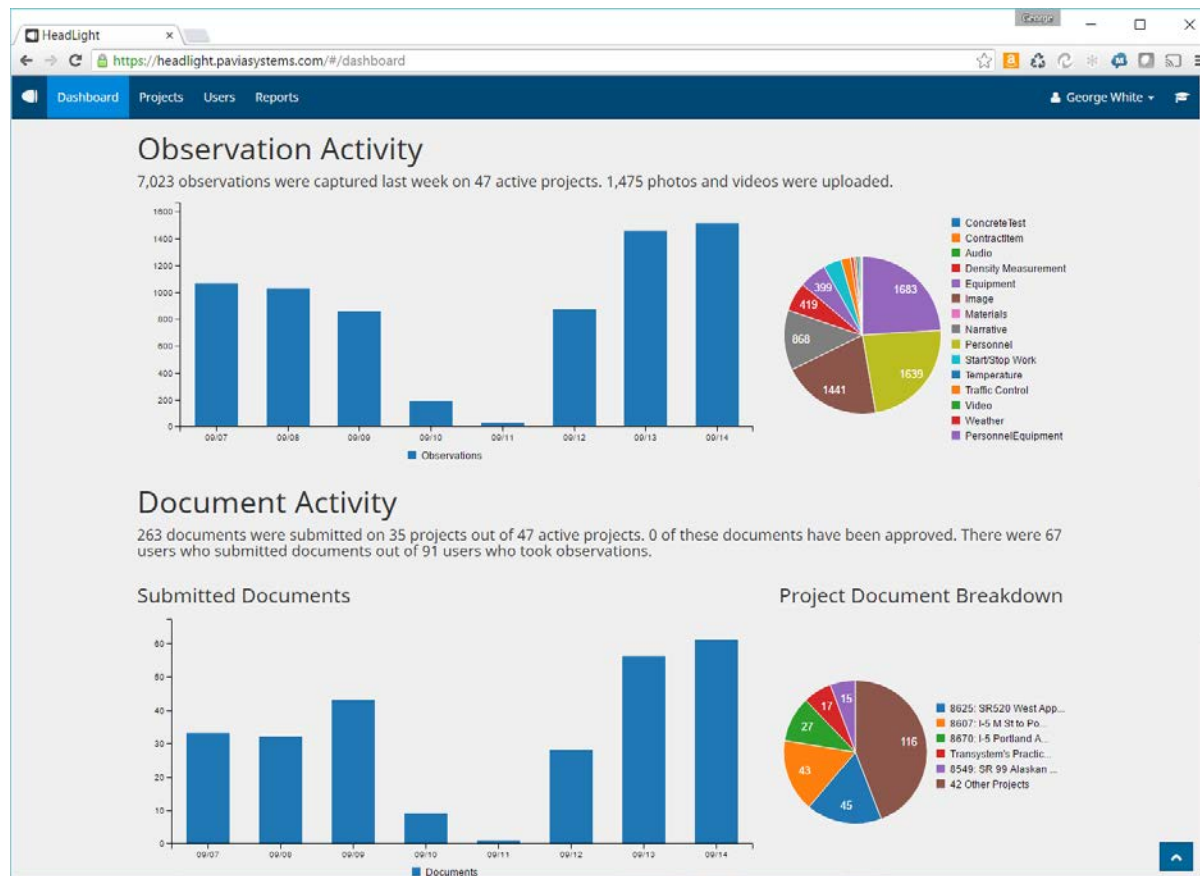


Turning Data Into Information

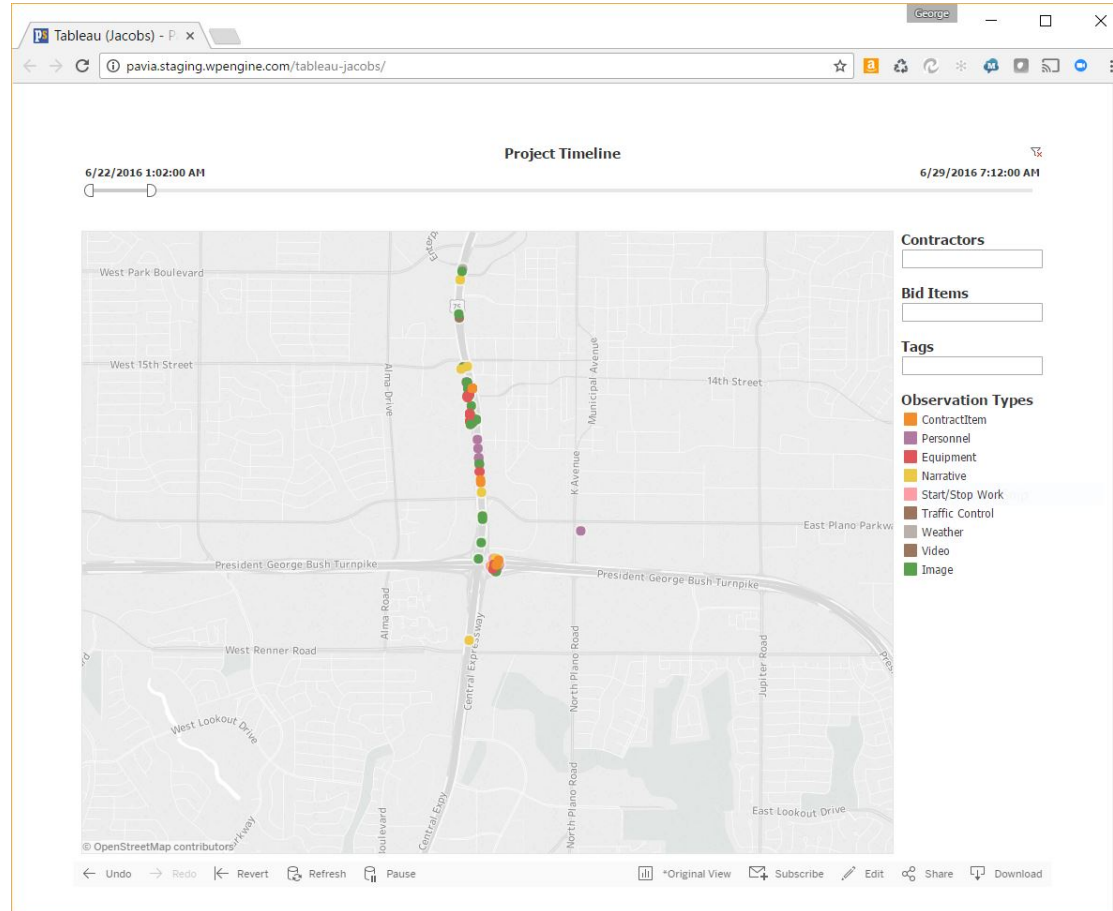


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Improve Project Intelligence



And turn into Asset Intelligence



Information Enabled By Digital



- Warehousing Collected Data
- Real-Time Access
- Communication\Collaboration



- Claims Abatement
- Risk Reporting
- Owner\Contractor Reporting



- Past Performance Analytics
- Real-time Data Analysis

Benefits To Be Realized

Office building



Highway



Power plant



Impact on life cycle cost (%)	-15%	-16 %	-12%
• Design and engineering	±0%	± 0 %	-5%
• Construction	-12%	-19 %	-14%
• Operations	-18%	-10 %	-10%
Impact on construction time (%)	-30%	-23 %	-15%



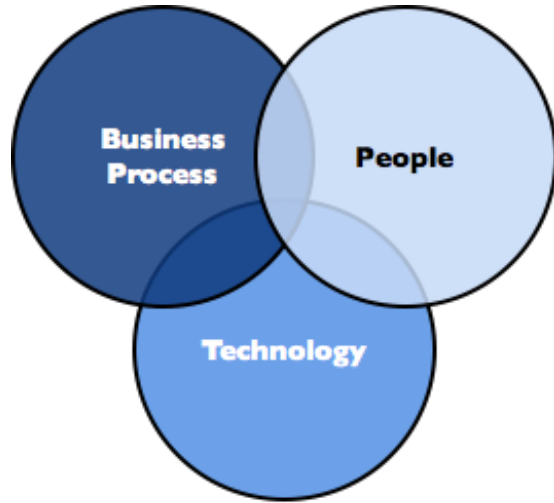
Benefits To Be Realized

Highway

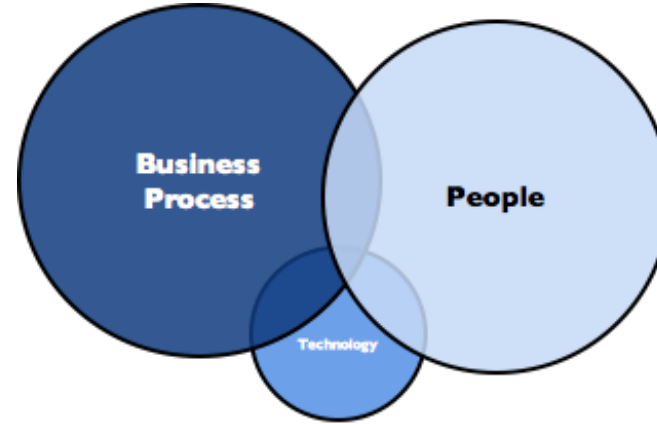


Impact on life cycle cost (%)	-16 %	\$24.1 Billion Annually
• Design and engineering	± 0 %	
• Construction	-19 %	
• Operations	-10 %	
Impact on construction time (%)	-23 %	

Innovation Requires Change



Perception



Reality

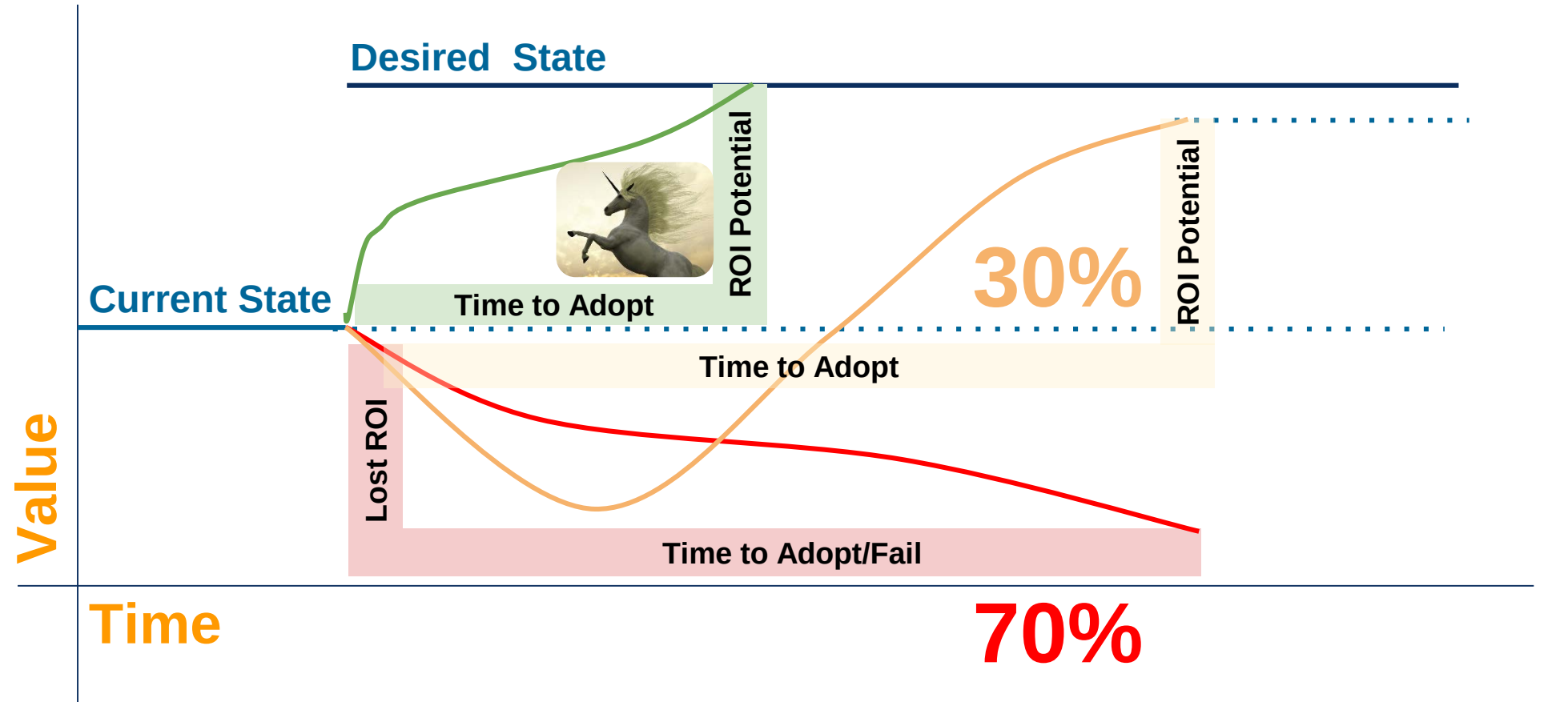
Most companies find the biggest innovation challenge is executing change to their people and processes.

Why Is Change Difficult?



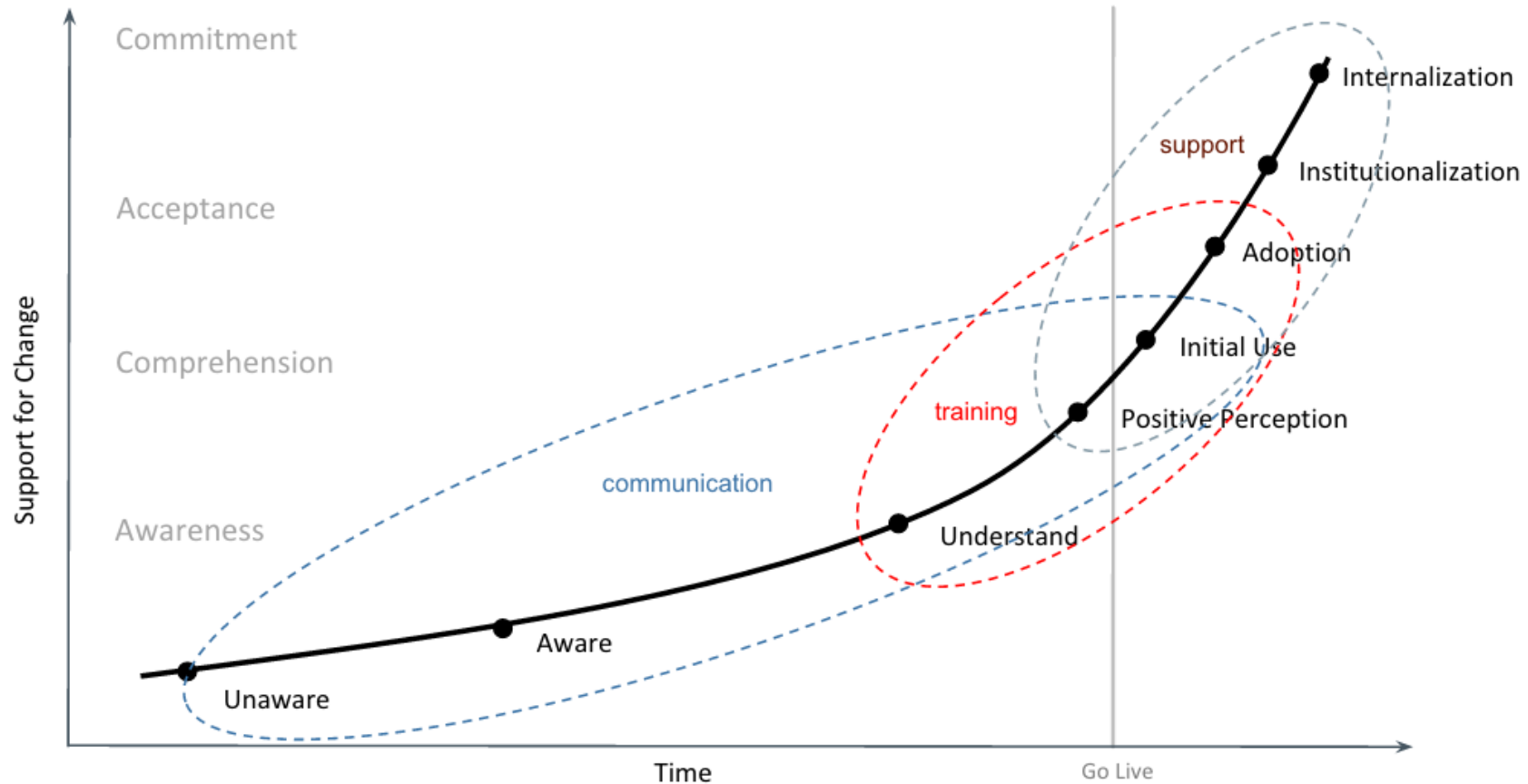


Expectations vs. Reality





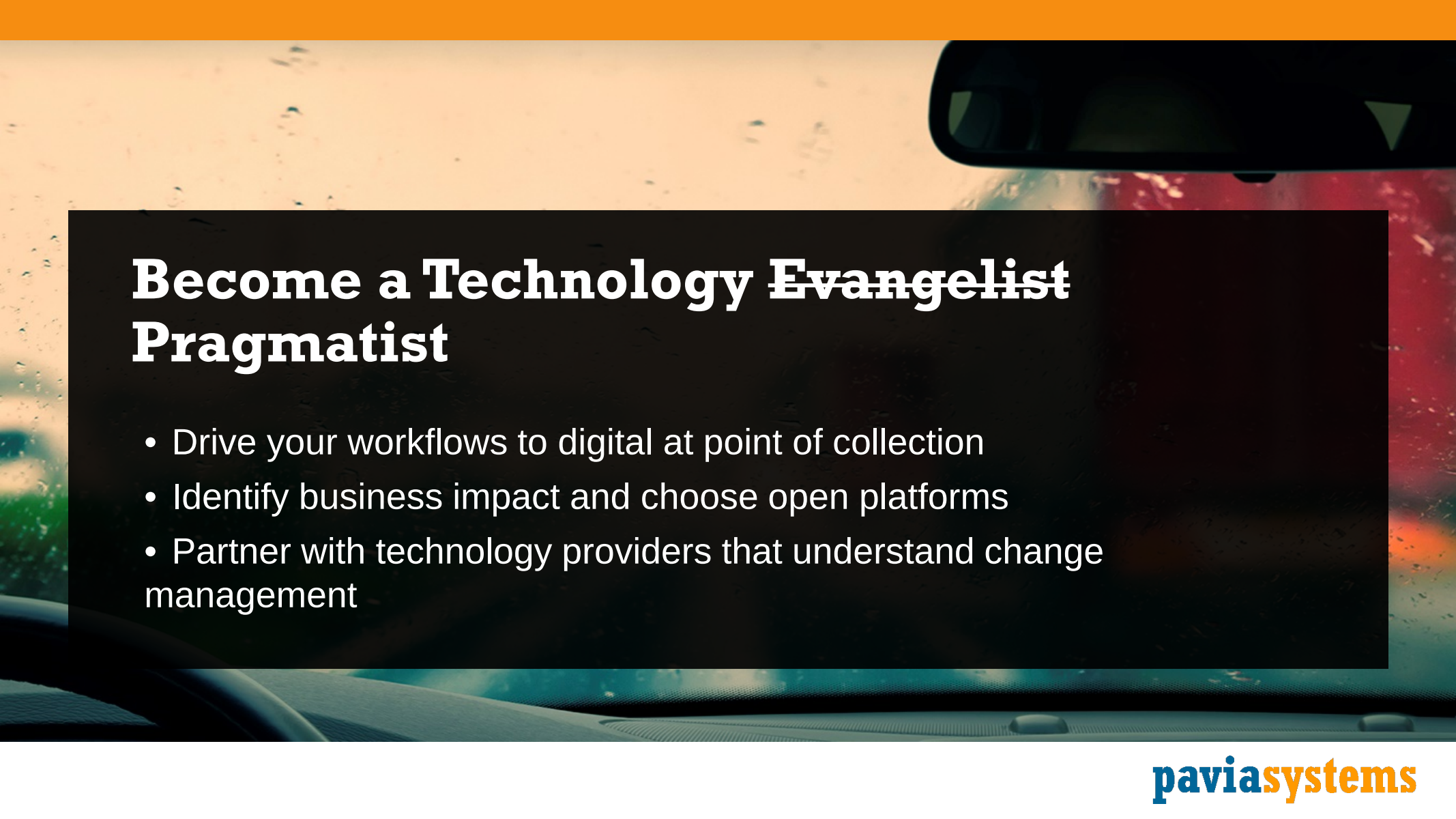
Managing Change: Shifting Focus of Activities





7 Critical Success Factors

1. Vision, value, and success metrics
2. Strong sponsorship (HQ and region-level)
3. Energy level
4. Thoughtful deployment
(planning, communication, training, and support)
5. Peer ambassadors
6. Feedback and responsiveness
7. Continuous improvement



Become a Technology Evangelist Pragmatist

- Drive your workflows to digital at point of collection
- Identify business impact and choose open platforms
- Partner with technology providers that understand change management

CHALLENGE THE STATUS QUO



George White george@paviasystems.com

paviasystems

Speeding Construction Process Using 3D Modeling

By Michael McKee

Questions



Text 208-932-5053



Thornton IC



- ▶ US-20
 - 20 Million Design/Construction
 - Eliminated 6 At grade intersections
 - Eliminated 5 RR Crossings
 - 500,000 CY of Material



Thornton IC



- ▶ Every Day Counts–3 (EDC–3) Initiative
 - Pilot Project
 - Deliver the Model Pre–Bid
 - New Survey Specification





Thornton IC Collaboration

- ▶ Multiple Sections – One Design File
 - Materials – gINT
 - Bridge – Existing/ Proposed Structure
 - Traffic – Traffic Control Plans

- ▶ Documentation
 - Design Specification
 - Pictures/Media
 - Design Calculations

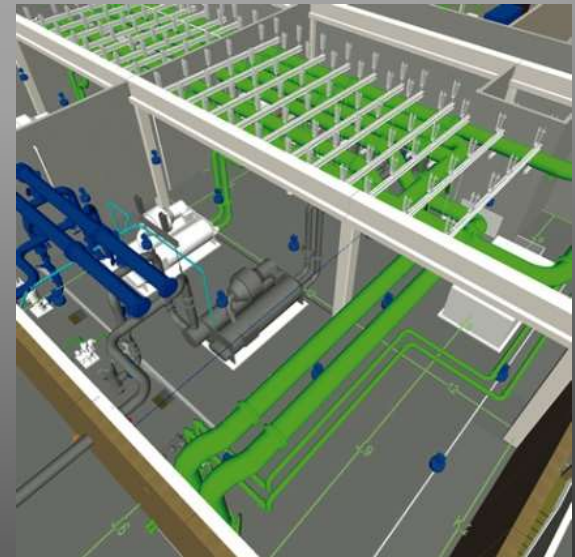


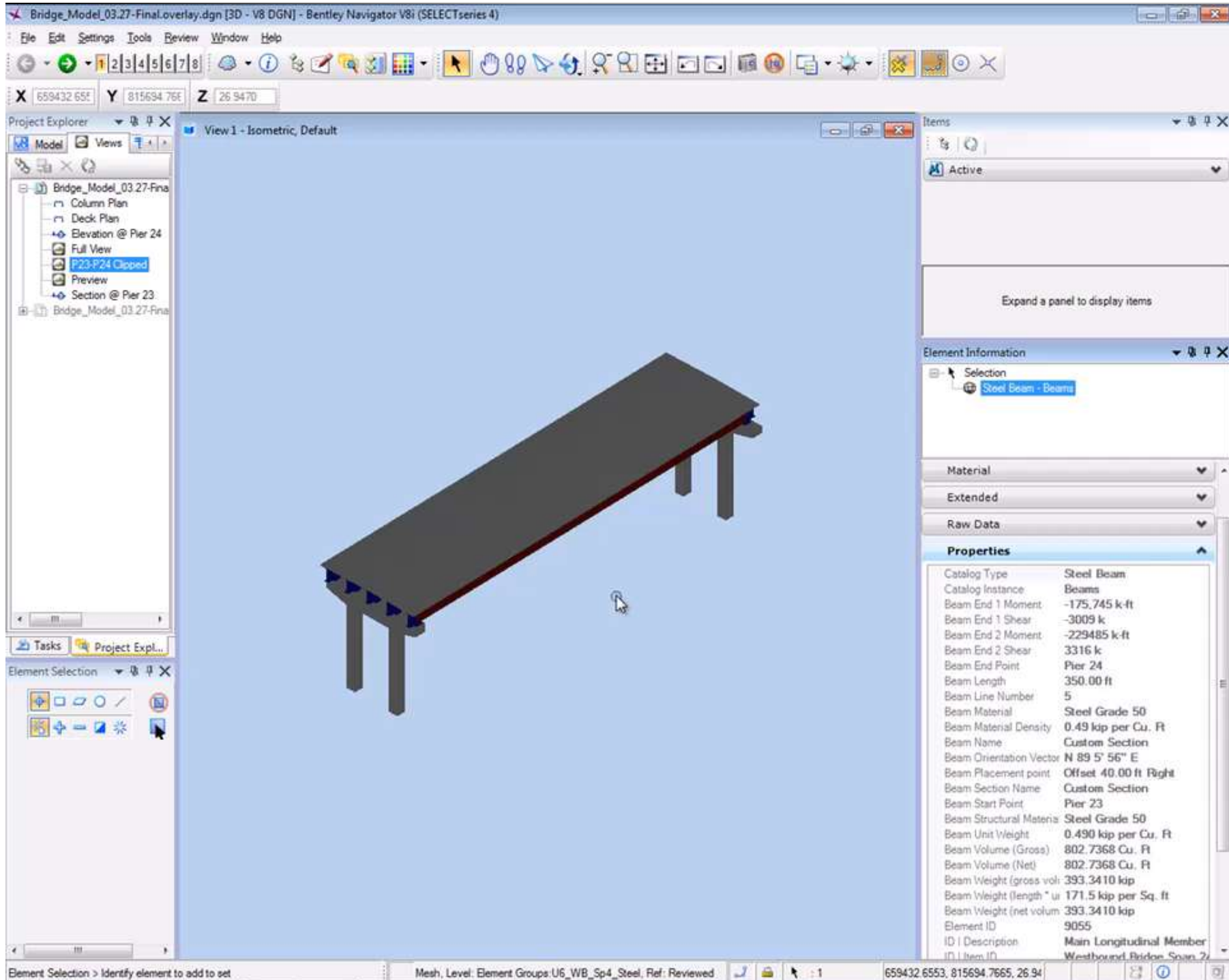
BIM (Information Modeling)

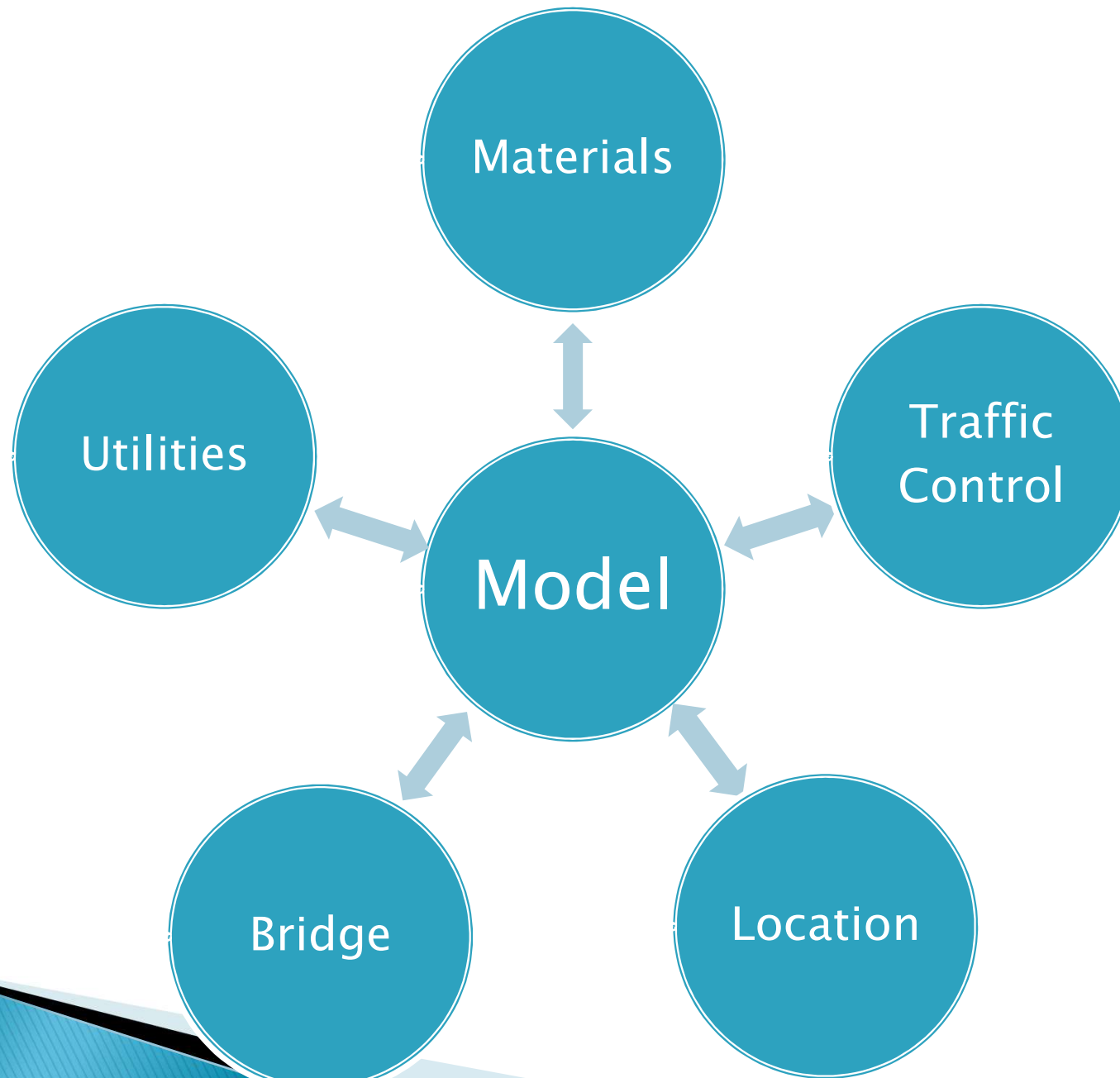
Information Modeling is the process of generating and managing building data during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction.

The process produces a model which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components.

i.e. all required information is in the model.









Thornton IC Layout

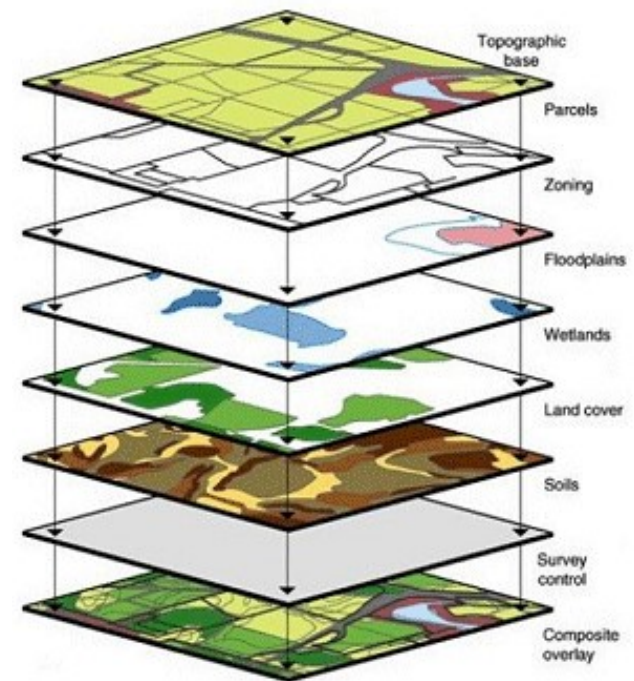
- ▶ 9 Corridors
- ▶ 9 Alignments
- ▶ 18 Templates



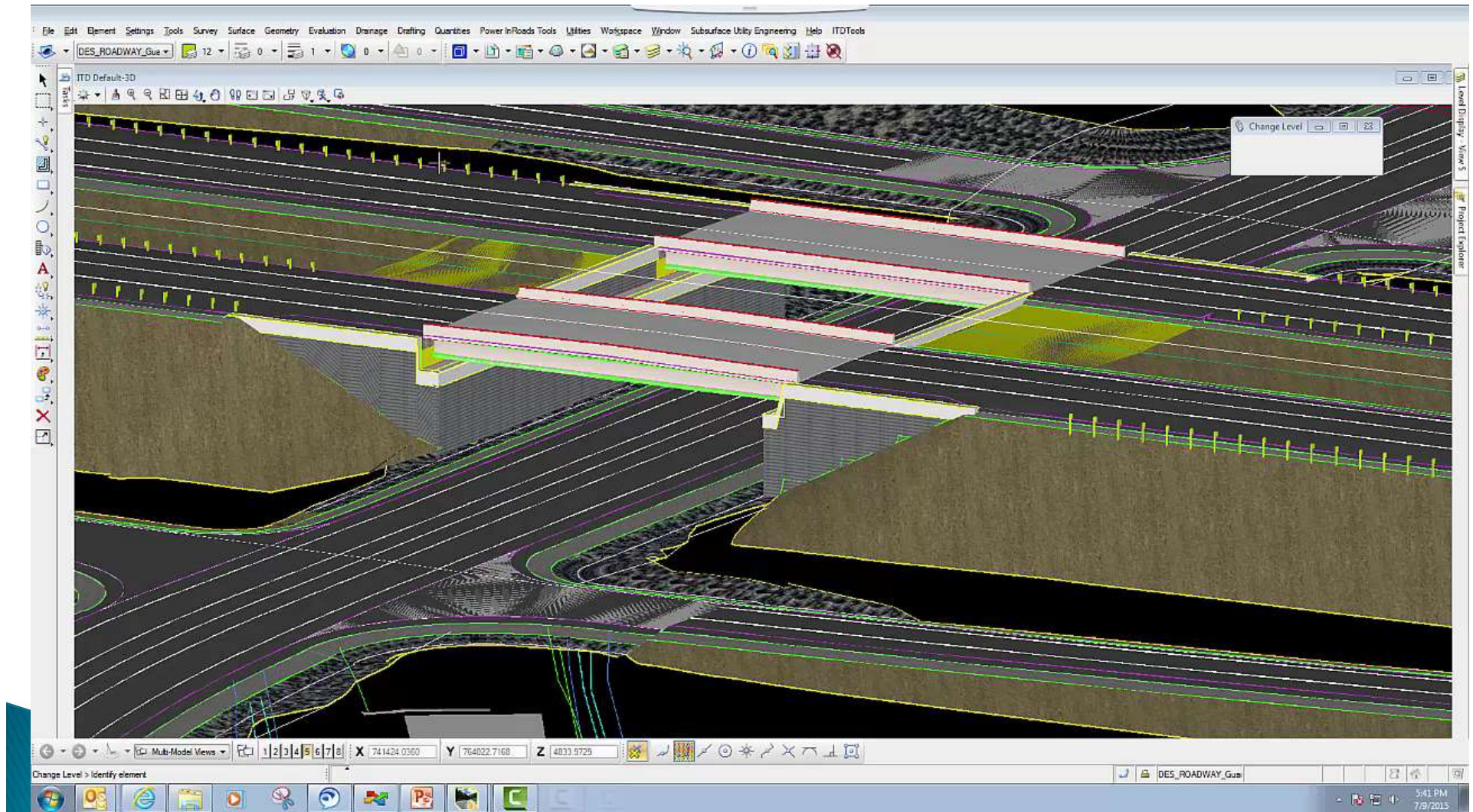


Power InRoad SS4 Layout

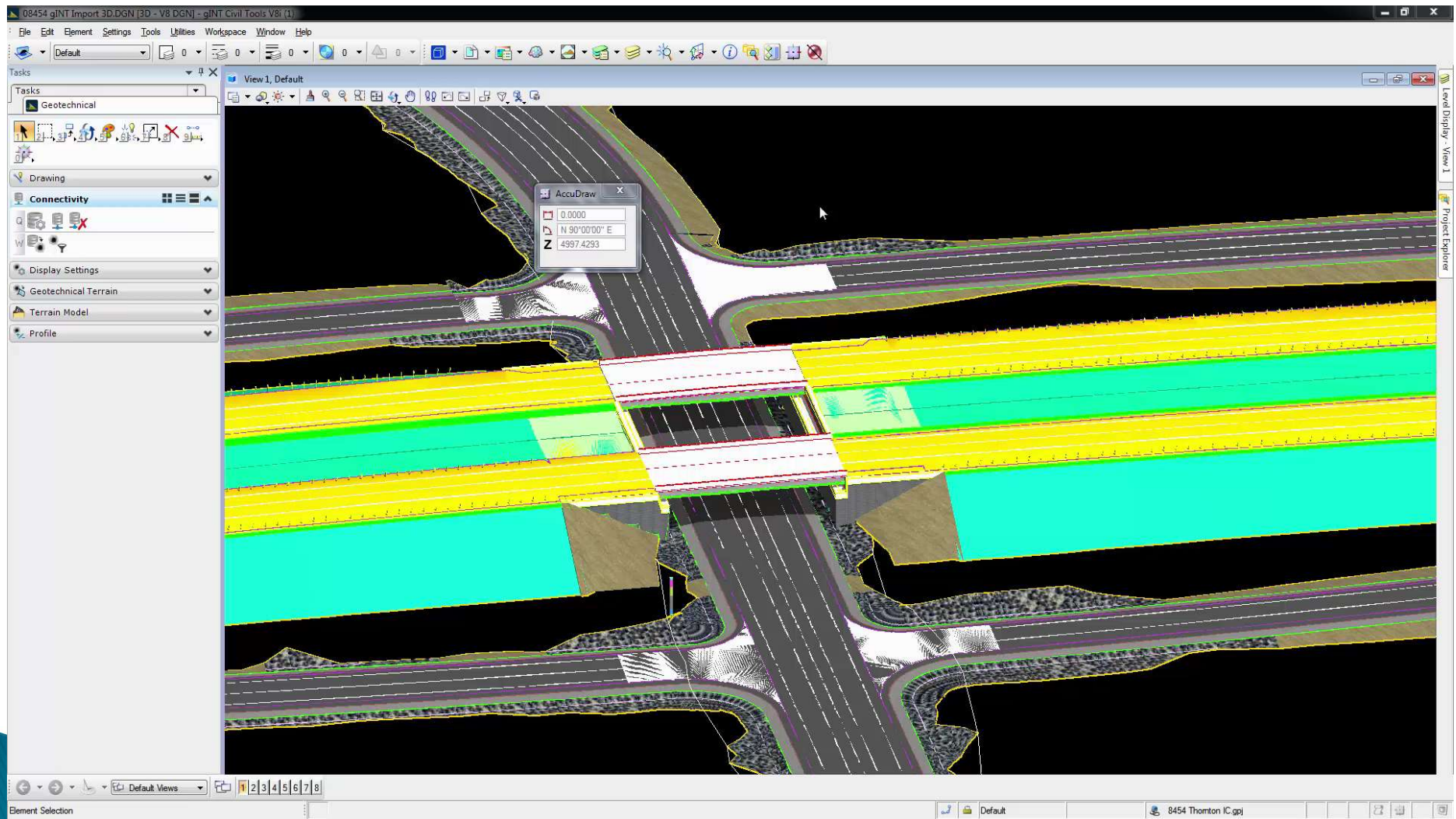
- ▶ Terrain Model – 3D
- ▶ Alignment – 2D
- ▶ Right of Way – 2D
- ▶ Utility File – 2D
- ▶ Retaining Wall (Bridge)– 2D
- ▶ Design File – 2D
- ▶ Traffic Control – 2D



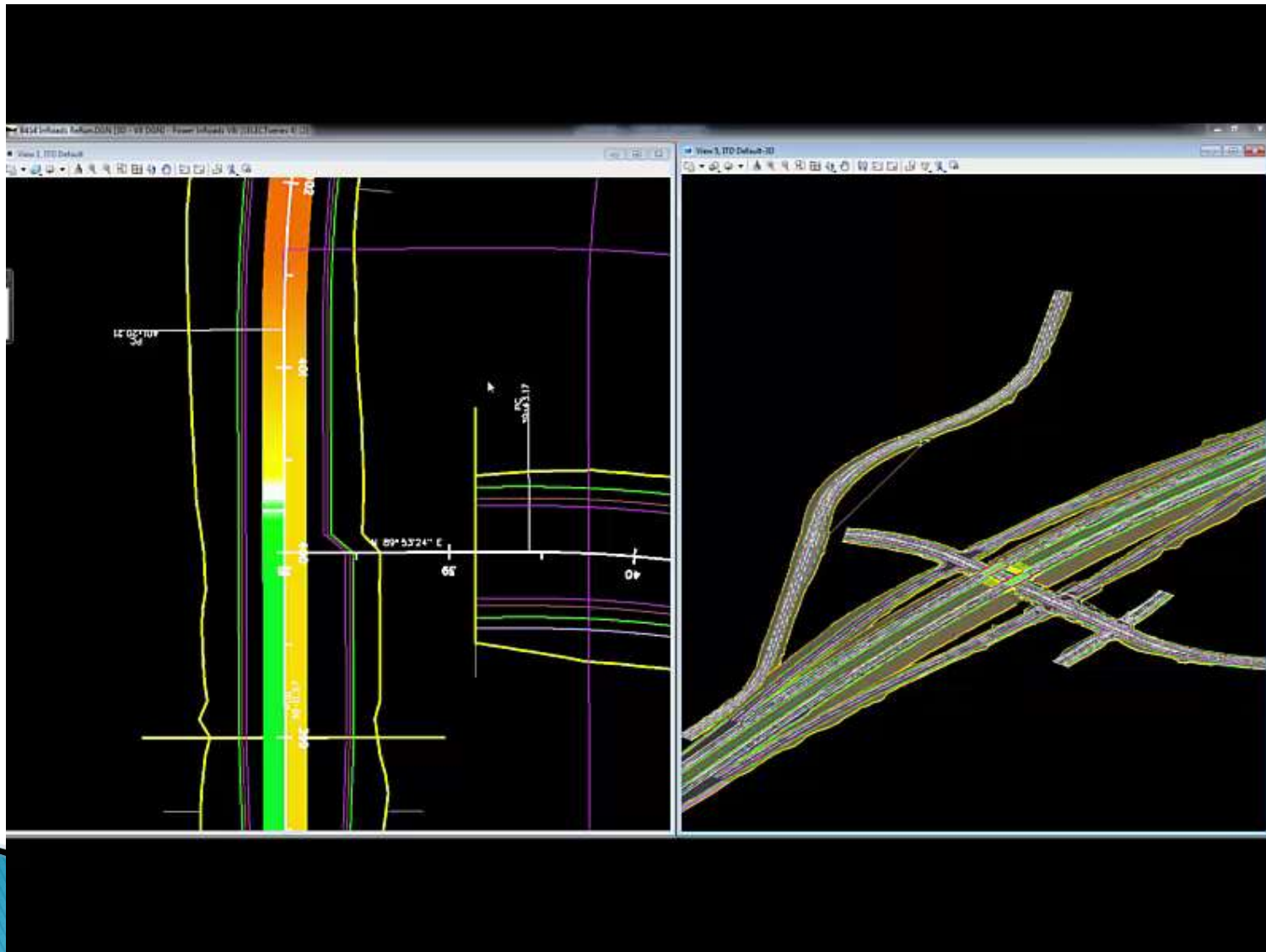
Thornton IC



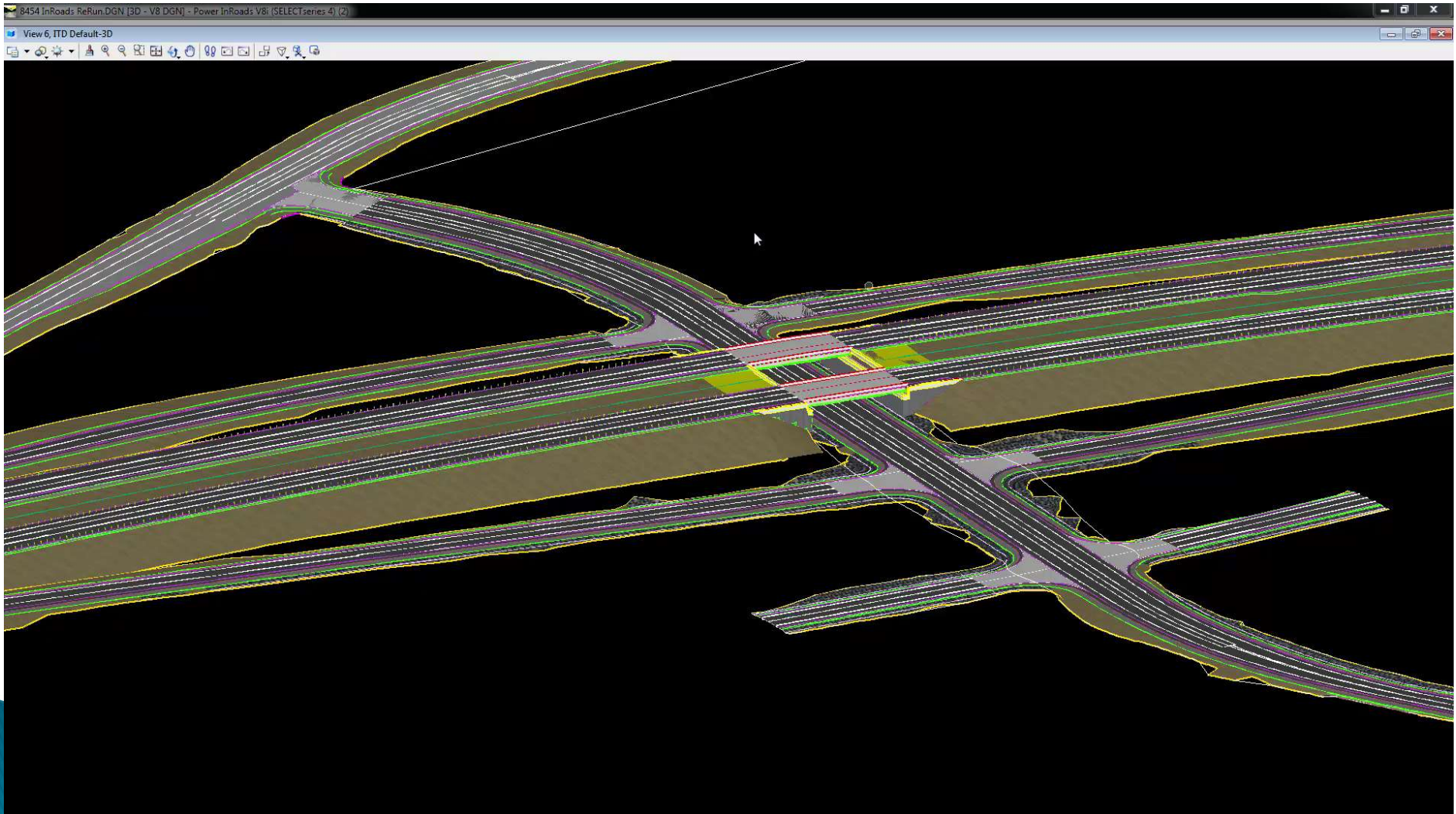
Thornton IC- gINT



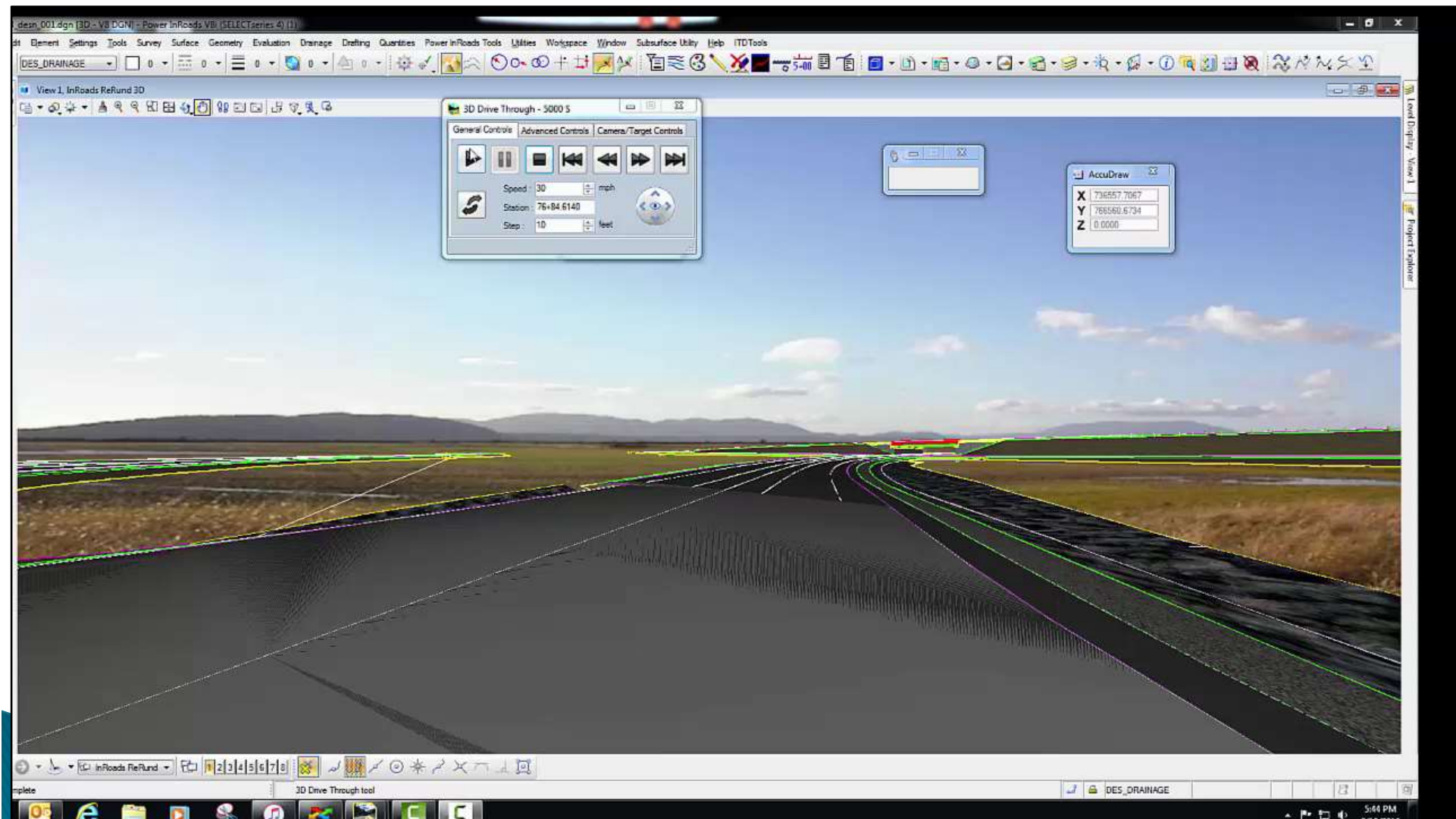
Thornton IC- Intersection



Thornton IC- 3D PDF



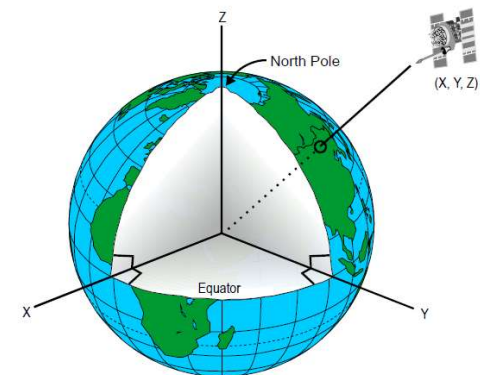
Thornton IC– Public Involvement

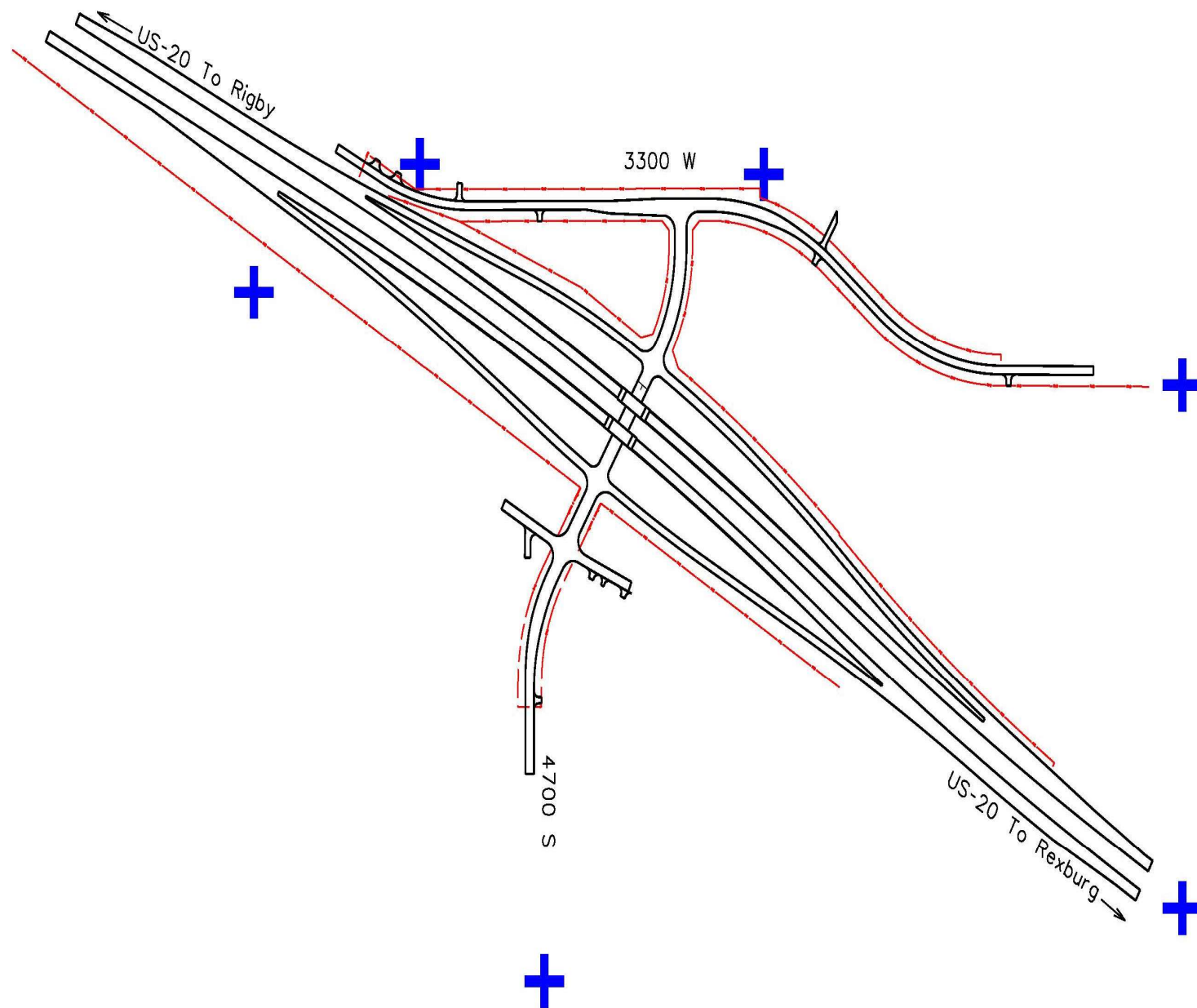
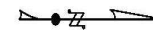




Model Check

- ▶ Export Model to XML format
- ▶ Vertical Surface lines (0.01 offset)
- ▶ Local Coordinate System
 - Scale Reduction in the model (ground to grid)

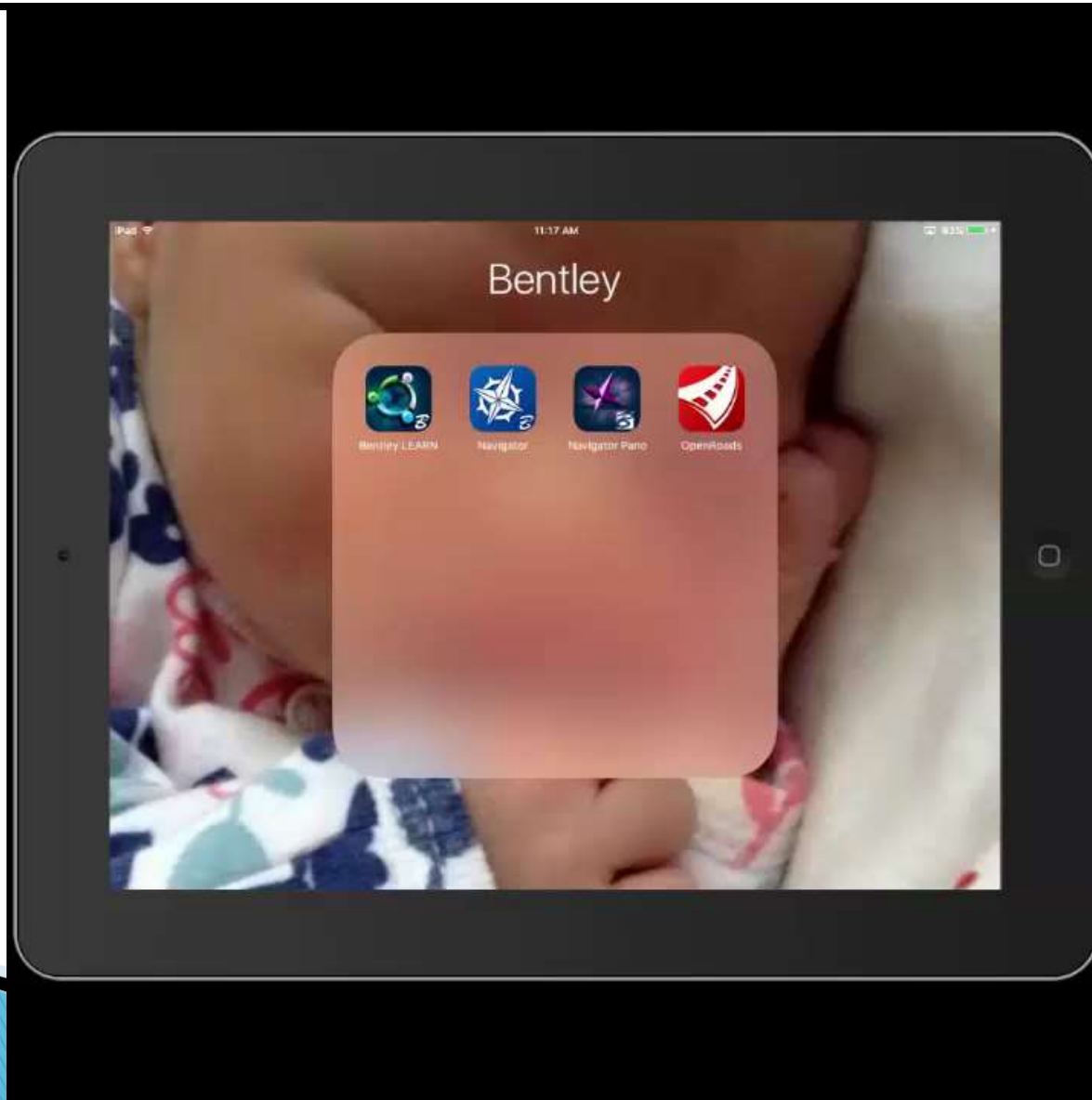








Thornton IC Testing



Questions



Development of Prediction Models for Skid Resistance of Asphalt Pavements



Emad Kassem, Ph.D.
Sanad Aldagari
Mohammad Al-Assi



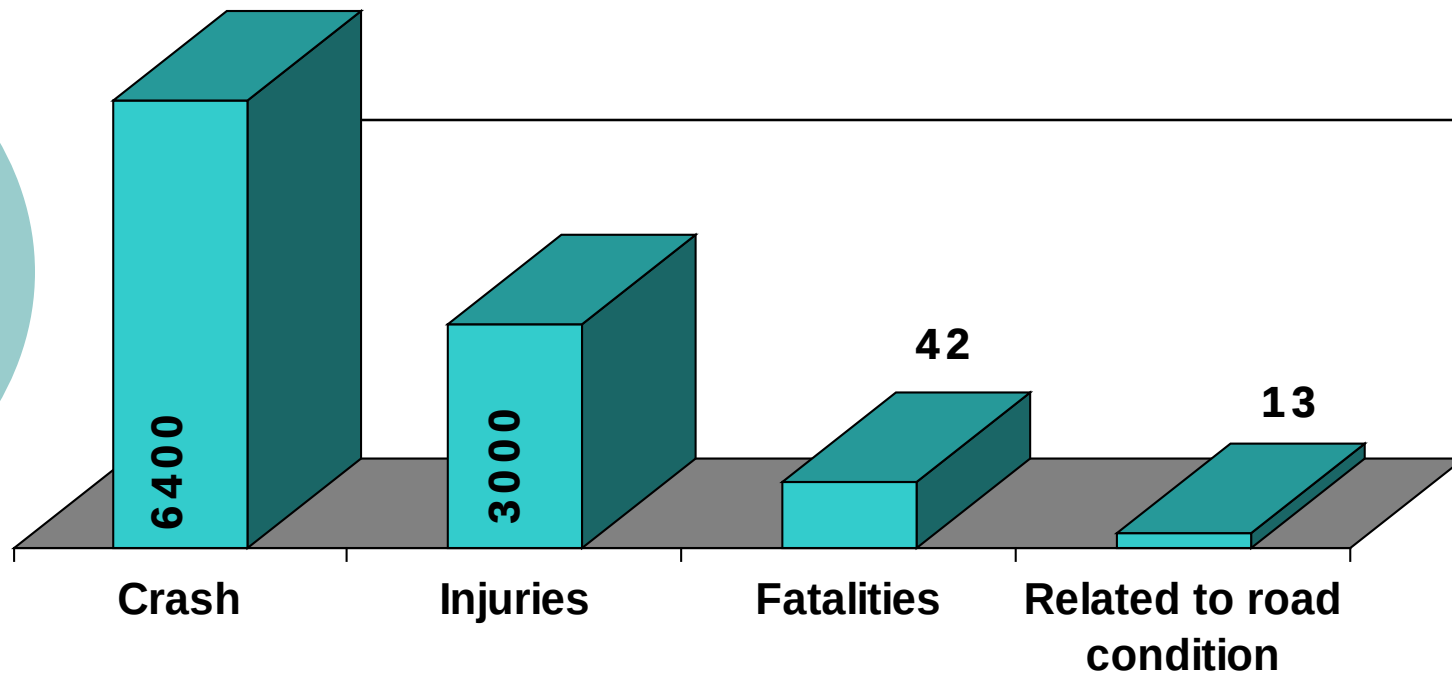
Arif Chowdhury, Ph.D.
Eyad Masad, Ph.D.

The 56th Annual Idaho Asphalt Conference, Moscow, ID
October 27, 2016



Introduction

- Pavement surface friction is a key component of road safety
- Approximately **14** percent of fatal crashes and **15** to **18** percent of all crashes occur on wet pavements [Smith, 1976; Davis et al., 2002; Chelliah et al., 2003].
- Providing acceptable level of friction leads to **50%** to **60%** decrease in wet weather accidents [Miller & Johnson, 1973; Kamel & Gartshore, 1982]

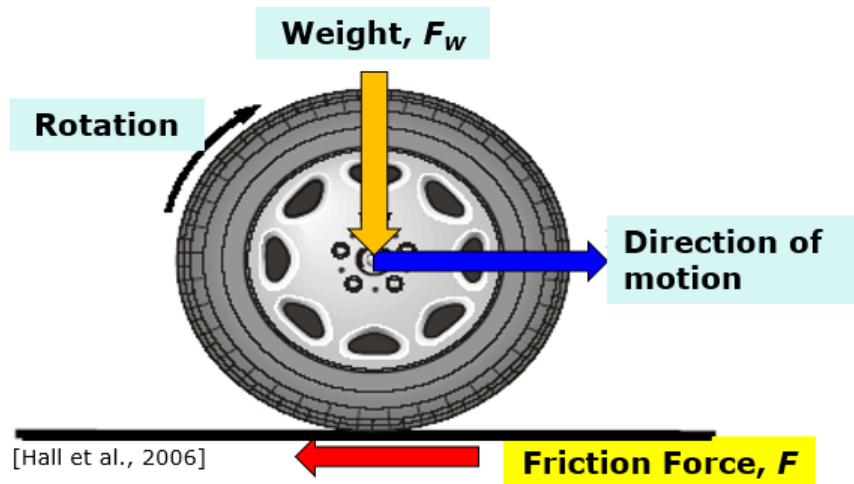


National Crash Statistics between 1993 and 2003 (thousands)

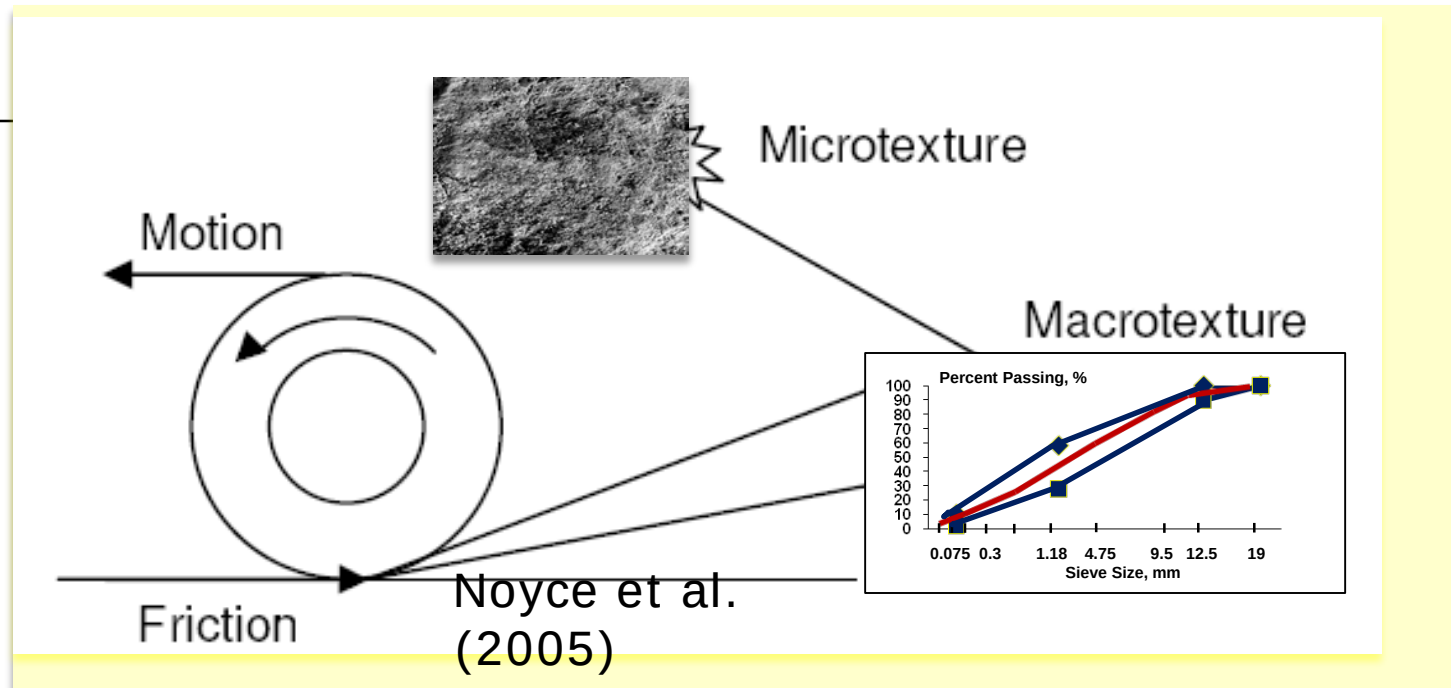
The cost of crashes is about \$231 billion

Introduction

- o **Friction**: The force that resists the relative motion between a vehicle tire and pavement surface.



$$\mu = \frac{F}{F_w}$$



Microtexture: irregularities in the surface of rock; dependent on aggregate petrography; smooth or rough when touch

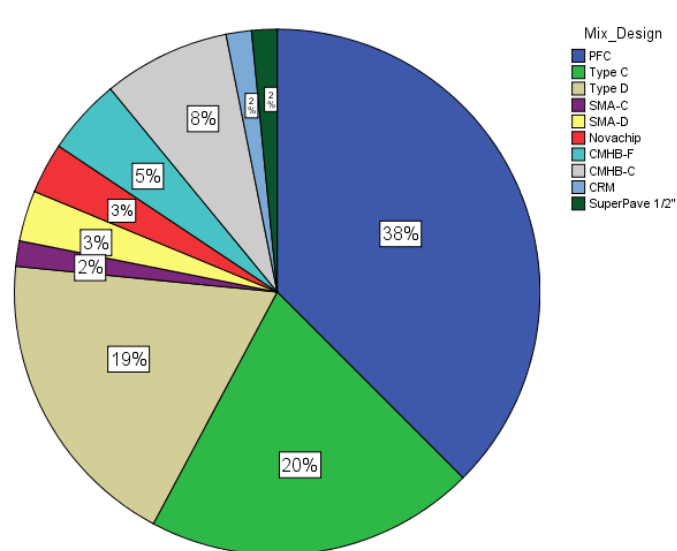
Macrotexture: larger irregularities in the road surface, dependent on aggregate gradation



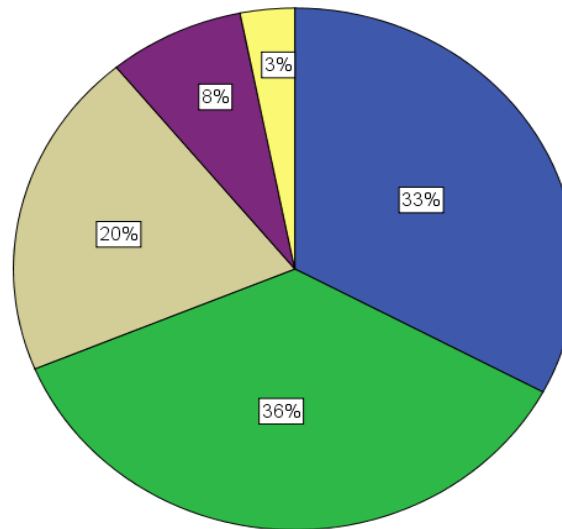
Objectives

- **Validate and revise** a prediction model for Skid Number of **asphalt pavements** as function of traffic level, aggregate characteristics, and aggregate gradation
- **Develop** a prediction model for Skid Number of **seal coat surfaces**
- Use the developed models to **classify road sections** based on their skid resistance

Field Experiments



Mix Designs



Traffic Levels

Fun_Class



Aggregate Sources

Field Friction Measurement

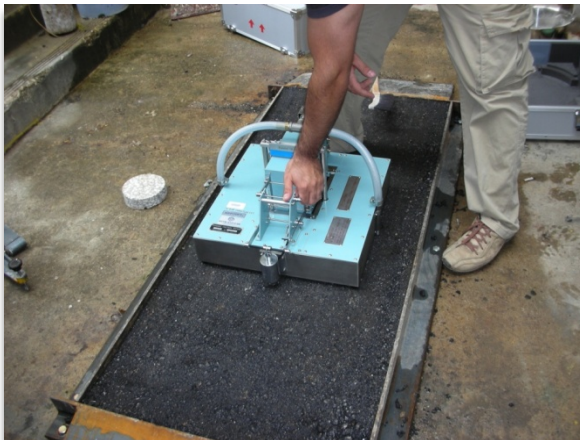
- o Locked-wheel Mode
 - o Skid trailer with one or two wheels are towed
 - o Water is applied in front of the wheel
 - o The **test wheel** is locked
 - o The friction force is recorded for a given distance
 - o The results is reported as **Skid Number (SN)**



Skid Trailer

$$SN = 100 \times \text{friction factor}$$

Laboratory Experiments



Task 1

Prepare laboratory asphalt mix slabs

Measure surface texture using CTMeter and DFT after different polishing cycles

Develop a model for the IFI of laboratory slabs

Acquire SN values for field asphalt pavement sections

Analyze asphalt pavement SN

Task 2

Measure pavement surface texture using the CTMeter and DFT

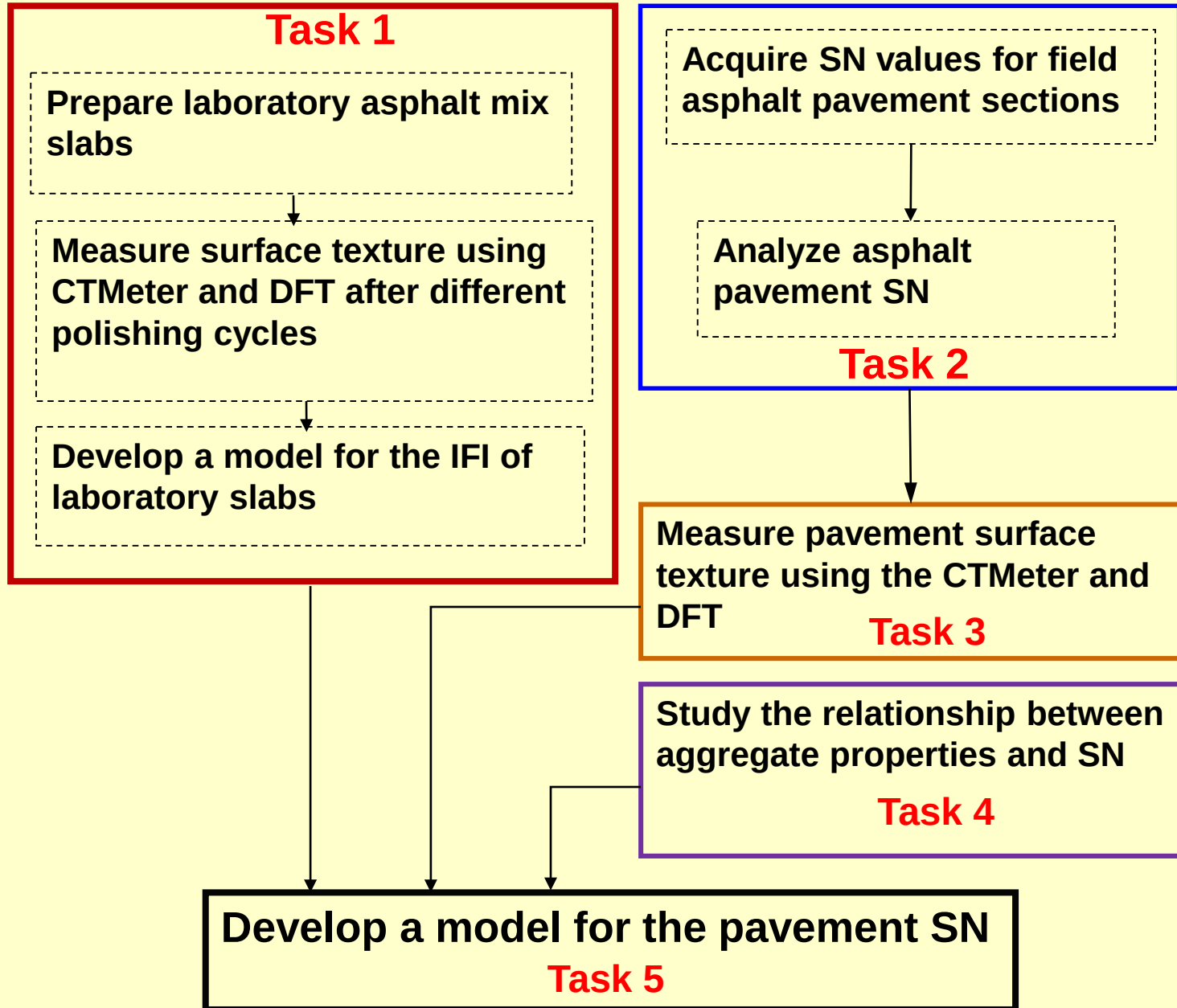
Task 3

Study the relationship between aggregate properties and SN

Task 4

Develop a model for the pavement SN

Task 5





International Friction Index

$$IFI = 0.081 + 0.732 DFT_{20} e^{\frac{-40}{S_P}}$$

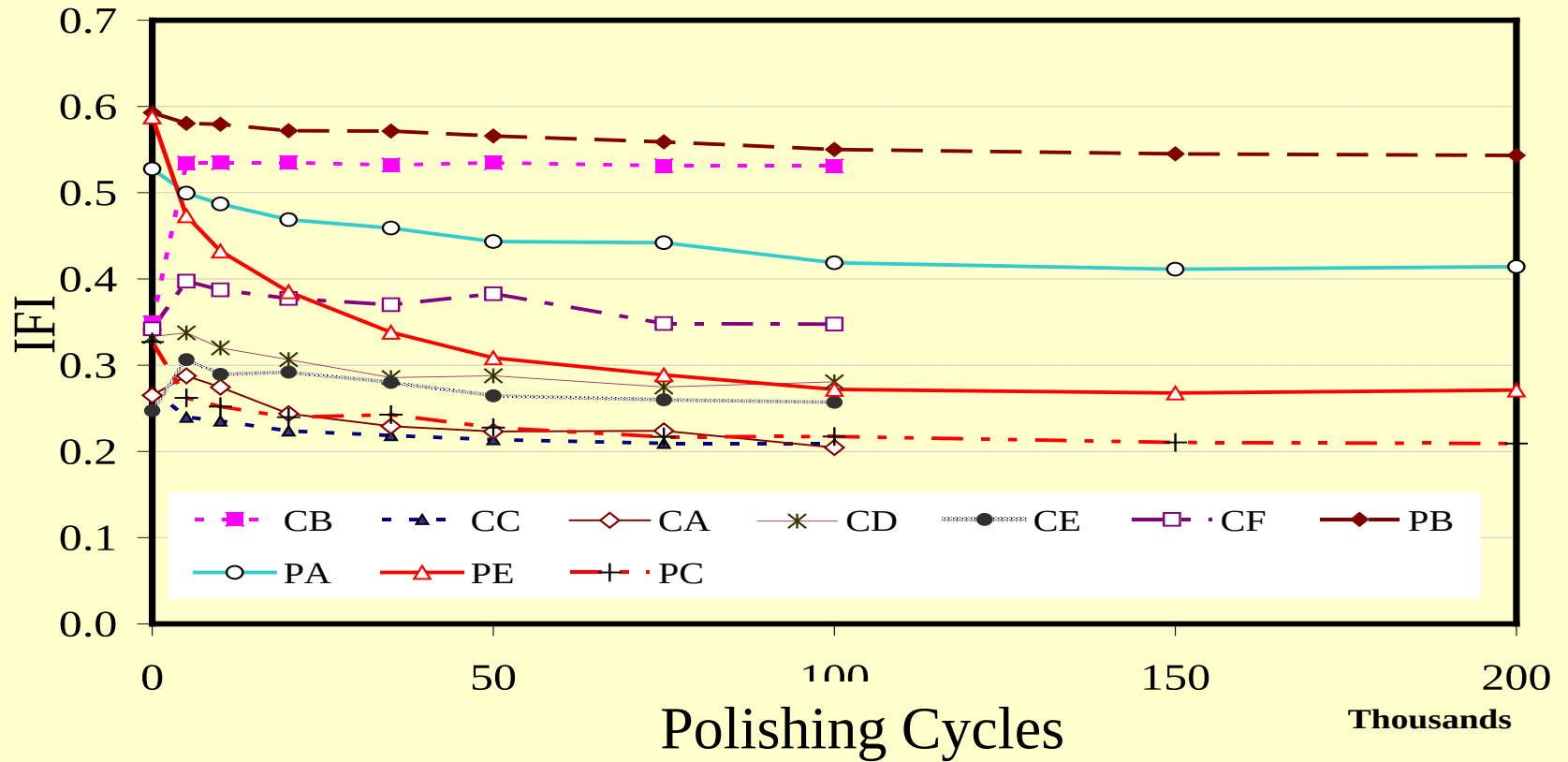
$$S_P = 14.2 + 89.7 MPD$$

$$IFI = 0.045 + 0.925 \times 0.01 \times SN(50) e^{\frac{20}{S_P}}$$

MPD is Mean Profile Depth Measured by CTMeter

DFT₂₀ is Dynamic Friction at 20 km/h Measured by DFT

SN(50) is measured skid number at 50mph using skid trailer



$$IFI(N) = a_{mix} + b_{mix} \cdot \exp(-c_{mix} \cdot N)$$

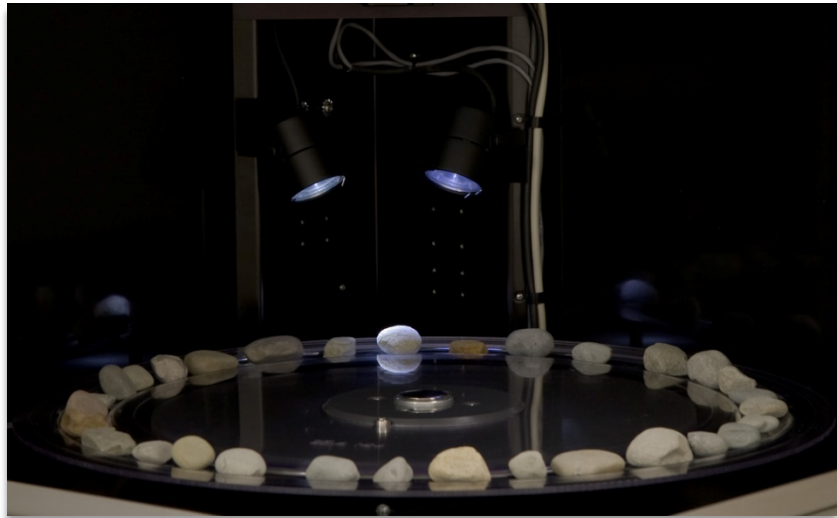
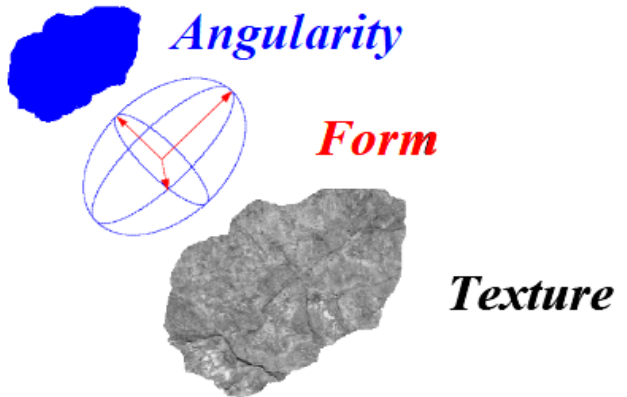
a_{mix} : Terminal IFI

$a_{mix} + b_{mix}$: Initial IFI

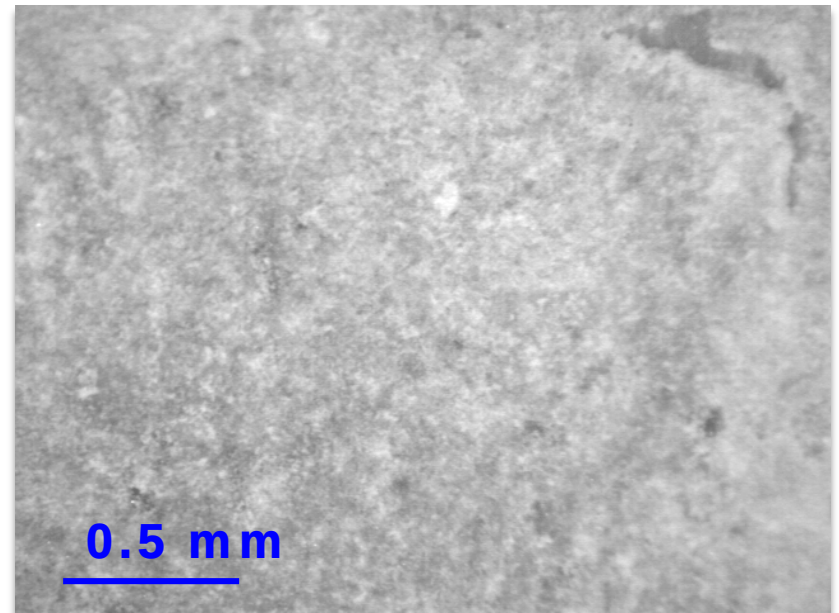
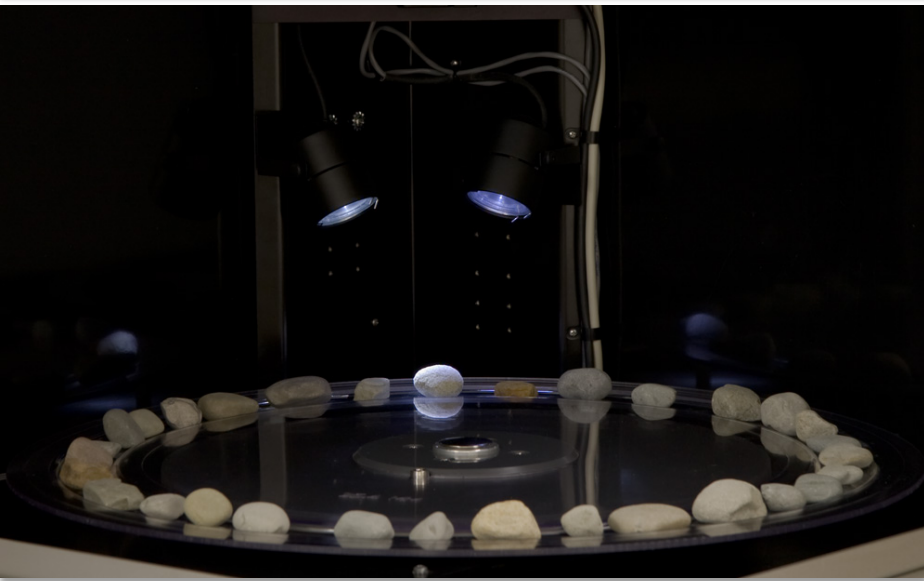
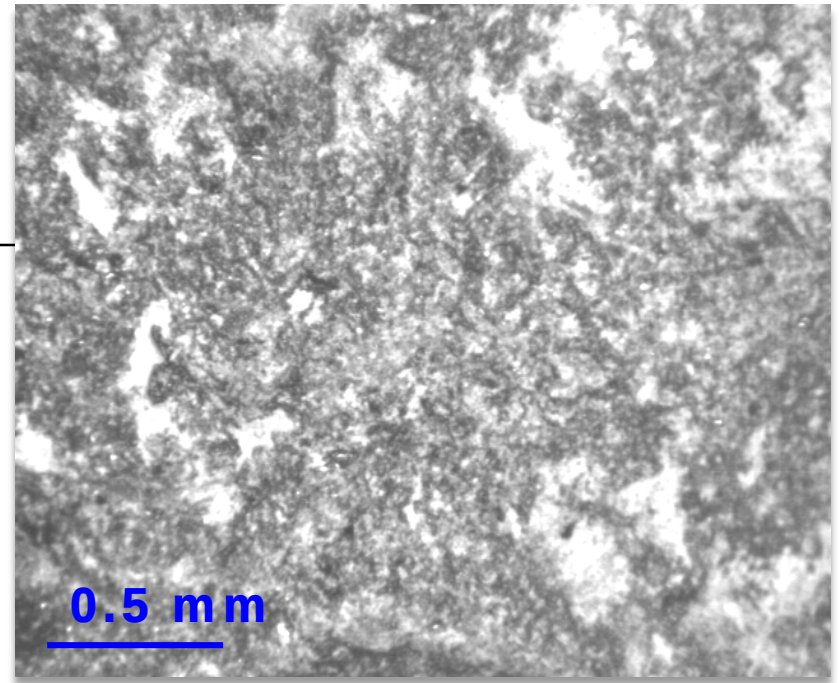
c_{mix} : Rate of IFI Change

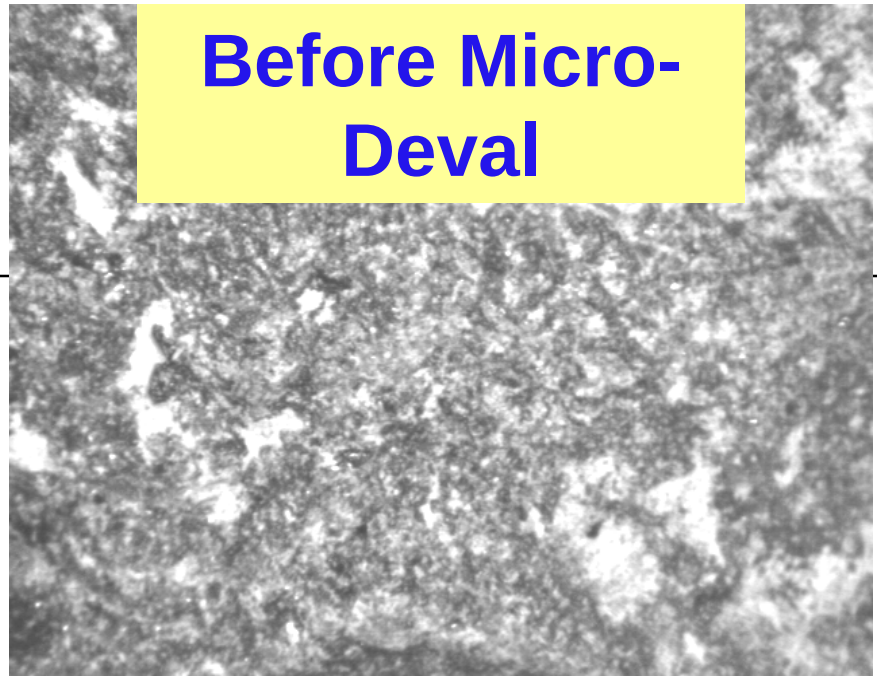
a_{mix}, b_{mix} and $c_{mix} = f$ (aggregate texture and gradation).

Measure Texture and Angularity before and after Micro-Deval Polishing



Aggregate Texture

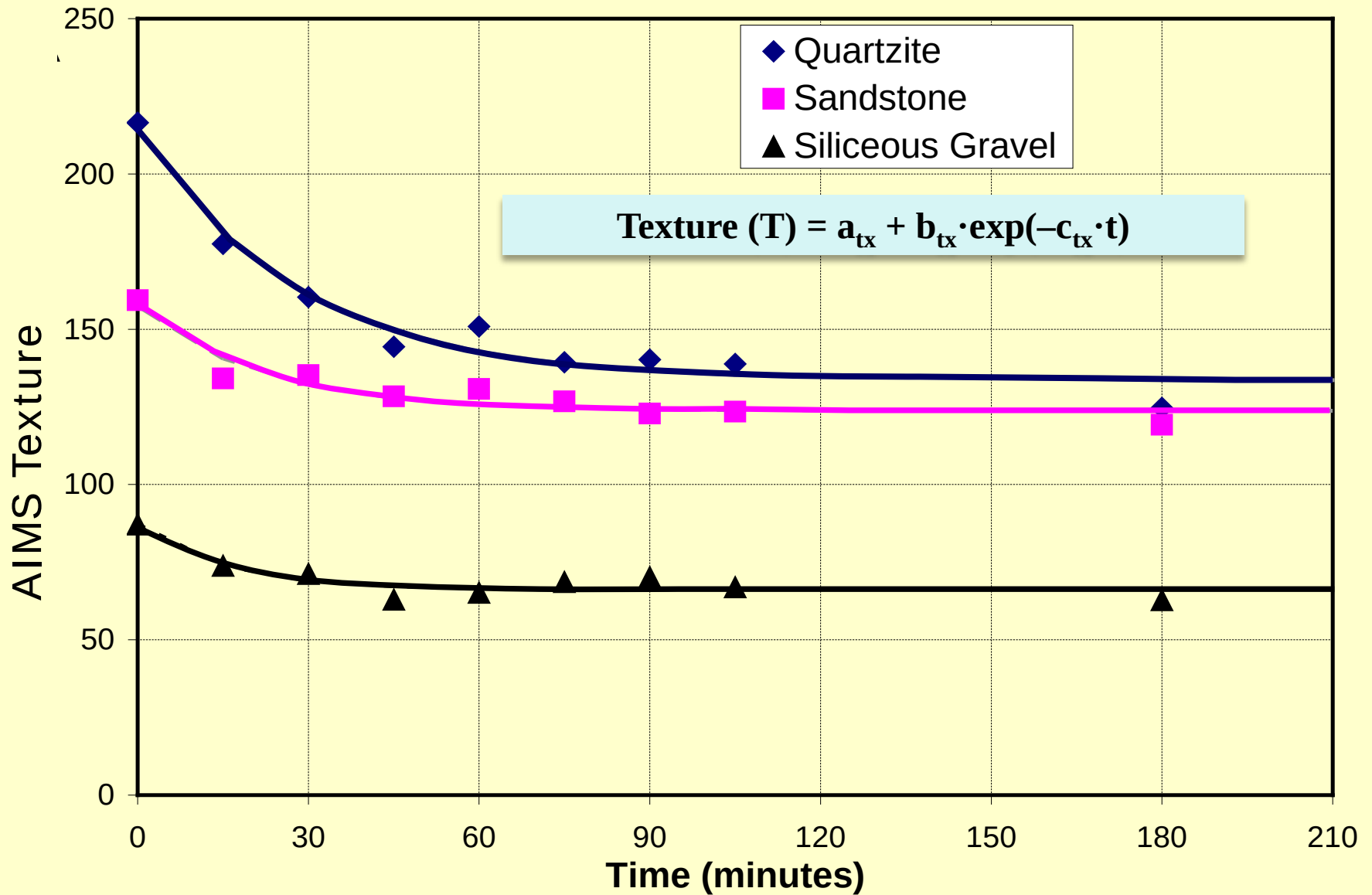




**Before Micro-
Deval**



**After Micro-
Deval**





List of HMA Test Sections

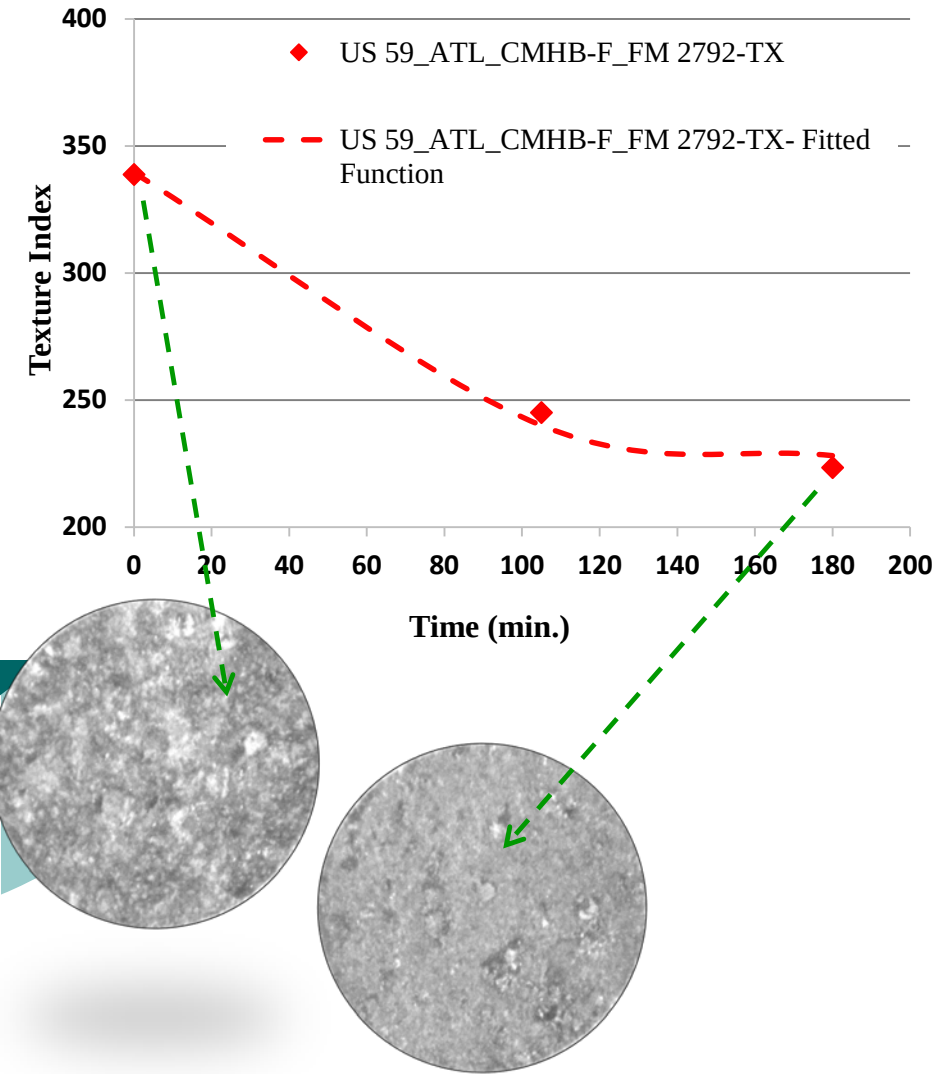
- **Locations:** ATL, BMT, ODA, SAT, YKM, HOU, LRD, PHR, LFK
- **Mix types:** SMA-D, SMA-F, CMHB-F, Type C, Type D, TOM, PFC, CMHB-C, CAM
- **Year of Construction:** 2006 to 2013
- **Aggregate Types:** Limestone, Gravel, Granite, Sandstone, Dolomite, Rhyolite, Traprock, Quartzite



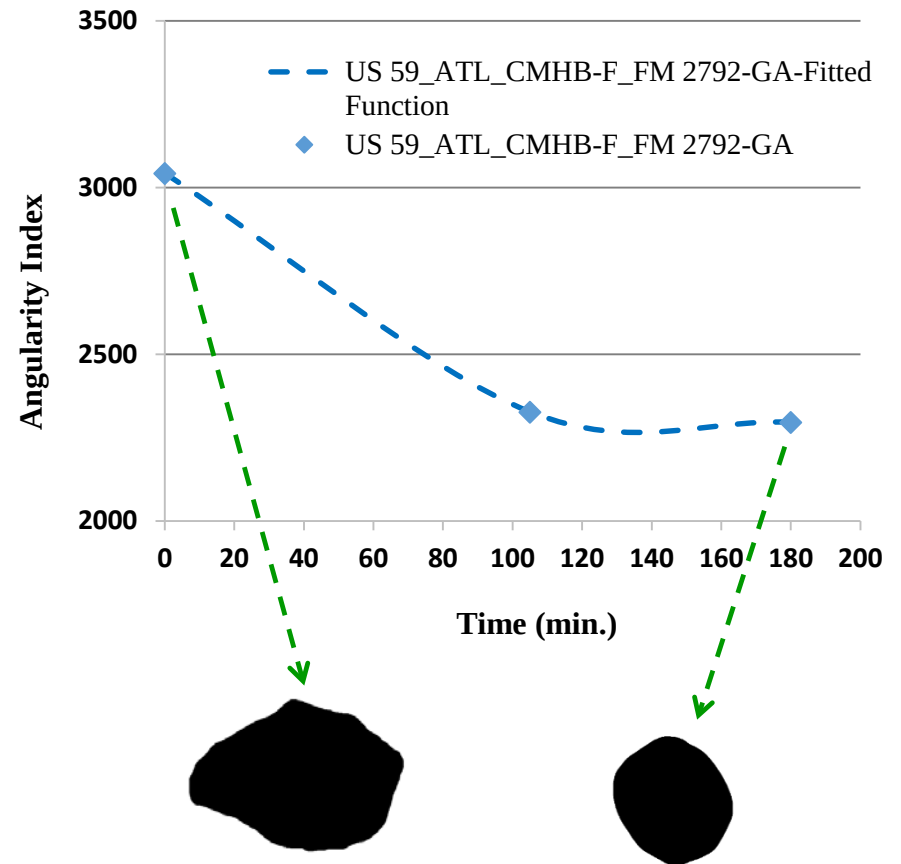
List of Seal Coat Test Sections

- **Locations:** ATL, BMT, ODA, SAT, YKM, LRD, PHR, LFK, BRY
- **Grade:** Grade 3, **Grade 4**, Grade 5
- **Year of Construction:** 2006 to 2013
- **Aggregate Types:** **Limestone**, Gravel, Traprock, Sandstone, Dolomite, Rhyolite, LRA, Lightweight
- **Coating:** **Pre-coated** and Virgin

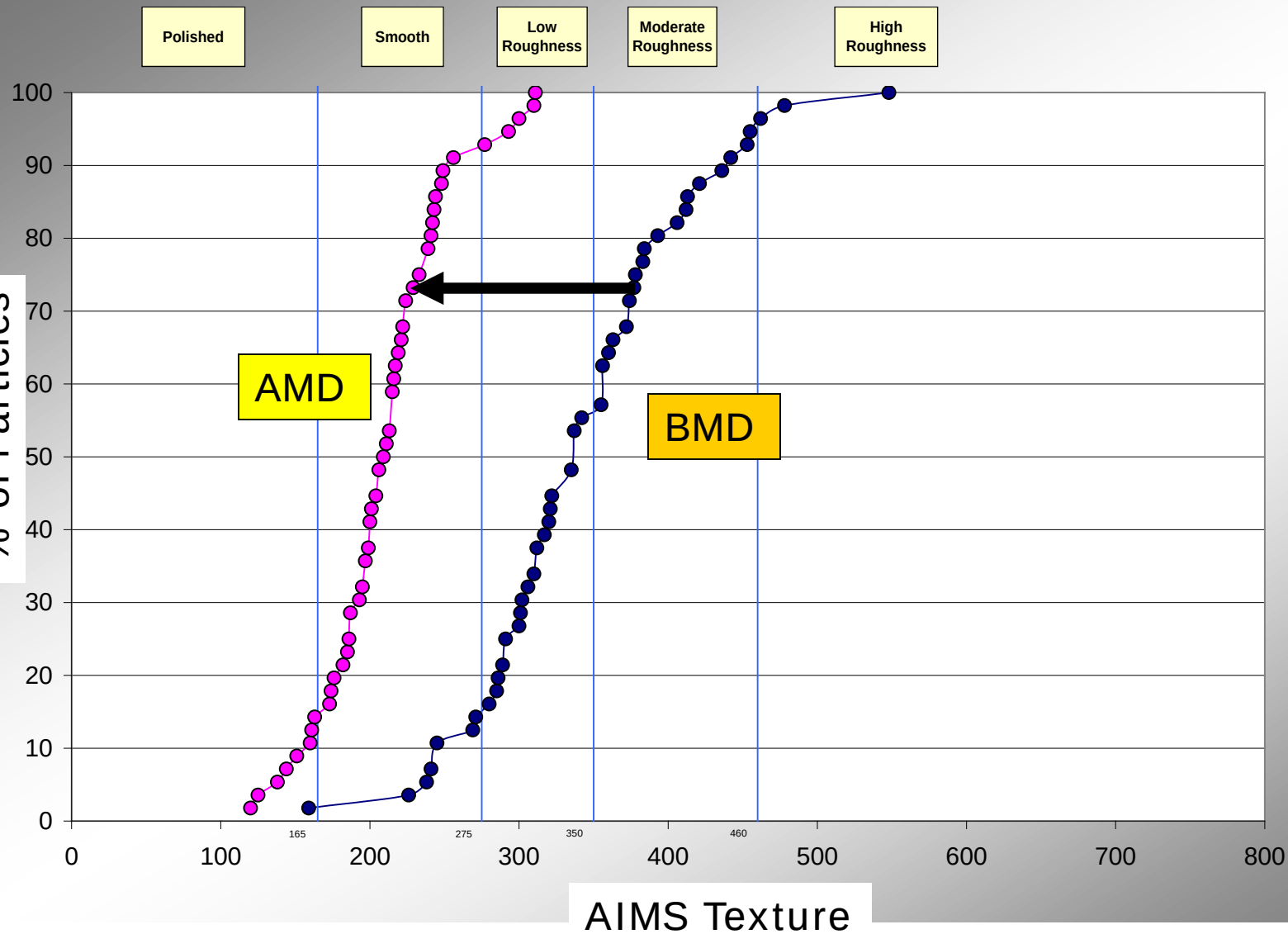
TEXTURE



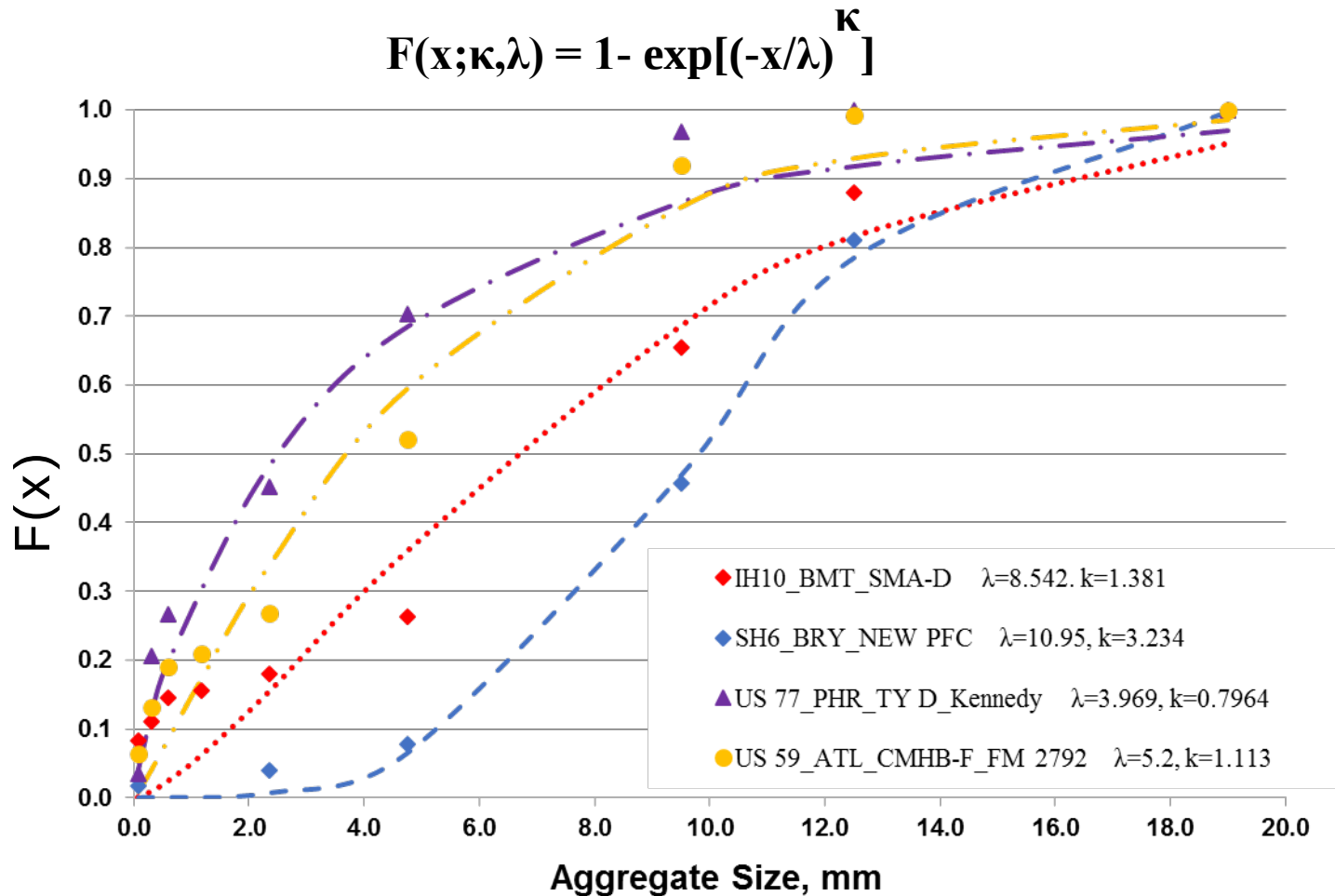
ANGULARITY



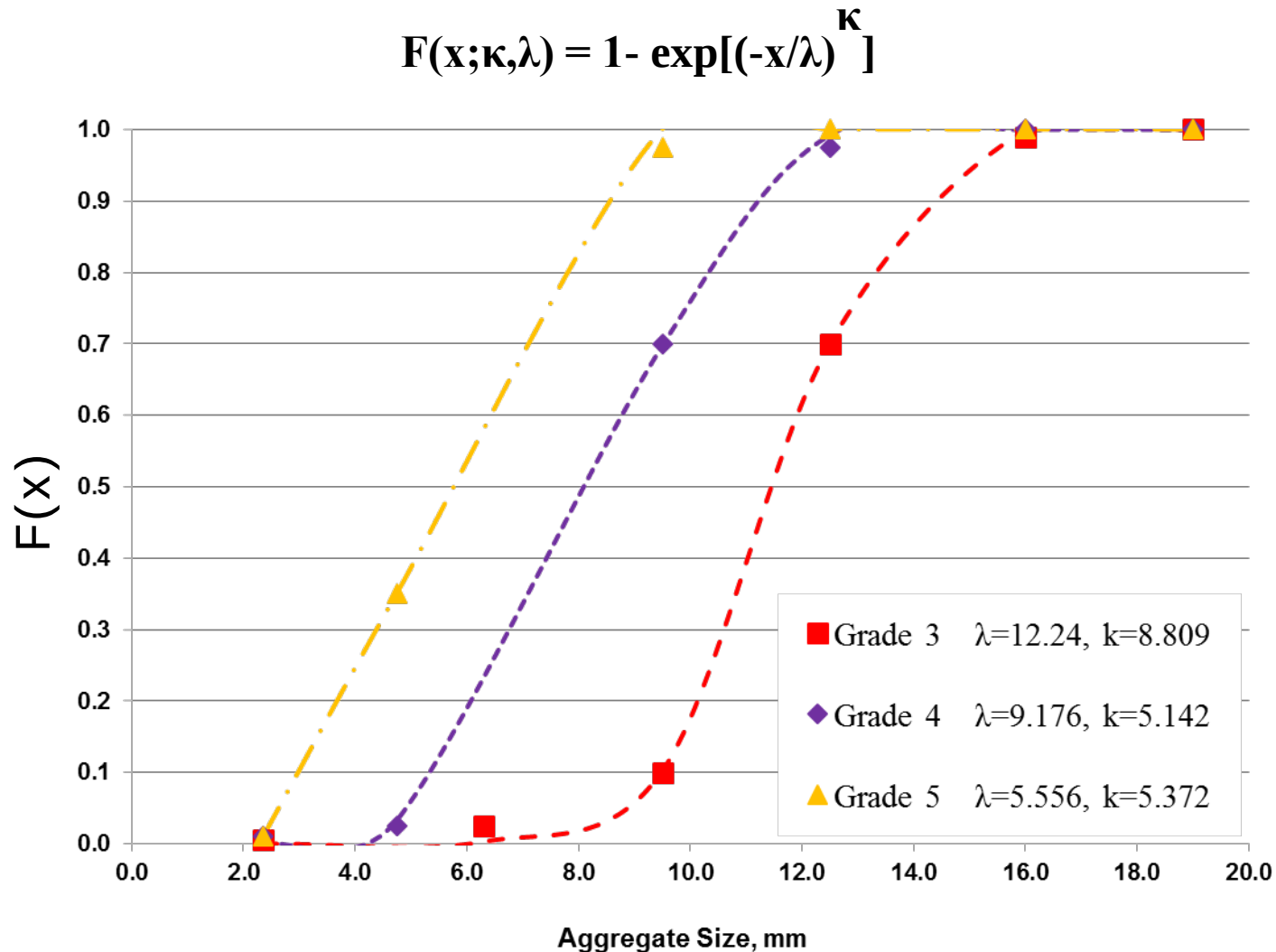
% of Particles



Aggregate Gradation for HMA (Weibull Distribution Function)



Aggregate Gradation for Sealcoat (Weibull Distribution Function)



Friction Model

Aggregate texture and angularity

$$\text{Texture (T)} = a_{tx} + b_{tx} \cdot \exp(-c_{tx} \cdot t)$$

$$\text{Angularity (T)} = a_{ga} + b_{ga} \cdot \exp(-c_{ga} \cdot t)$$

$$a_{tx}, b_{tx}, c_{tx}, \\ a_{ga}, b_{ga}, \text{ and } c_{ga}$$

Aggregate gradation

(cumulative Weibull distribution function)

$$F(x; \kappa, \lambda) = 1 - \exp\left[-\left(\frac{x}{\lambda}\right)^\kappa\right]$$

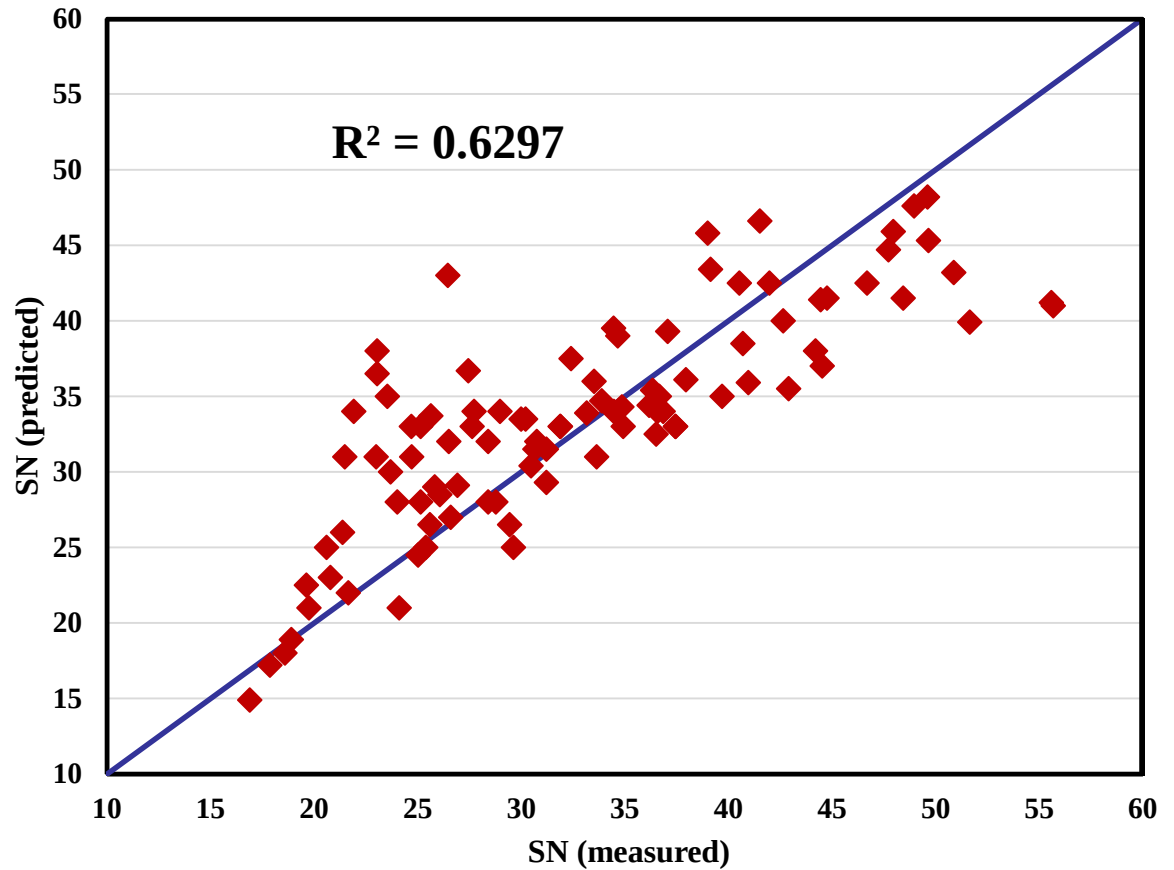
$$\lambda \text{ and } \kappa$$

Calculate a_{mix} , b_{mix} , c_{mix} from predictive models

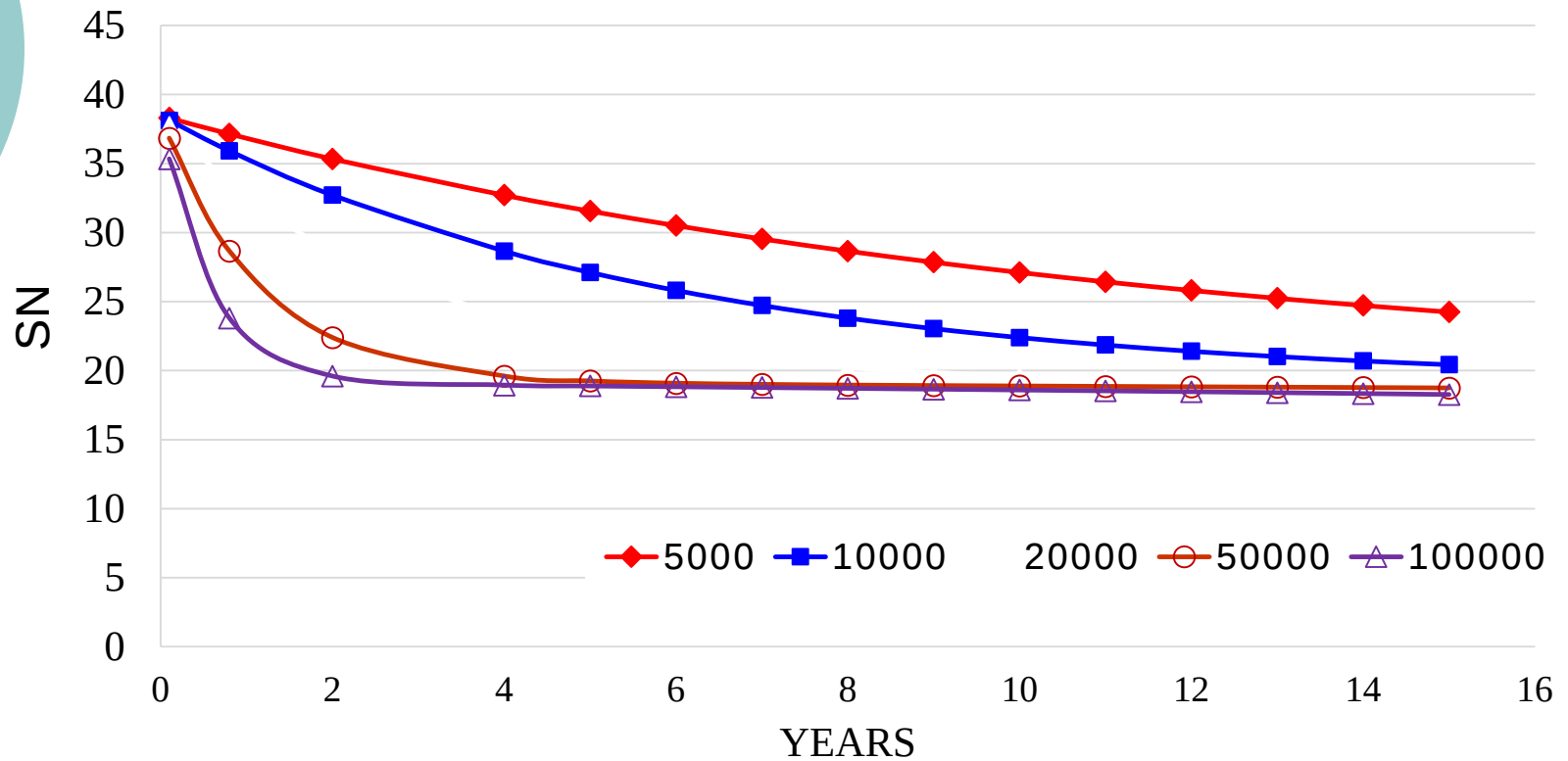
$$IFI(N) = a_{mix} + b_{mix} \cdot \exp(-c_{mix} \cdot N)$$

$$IFI = 0.045 + 0.925 \times 0.01 \times SN(50)e^{\frac{20}{S_p}}$$

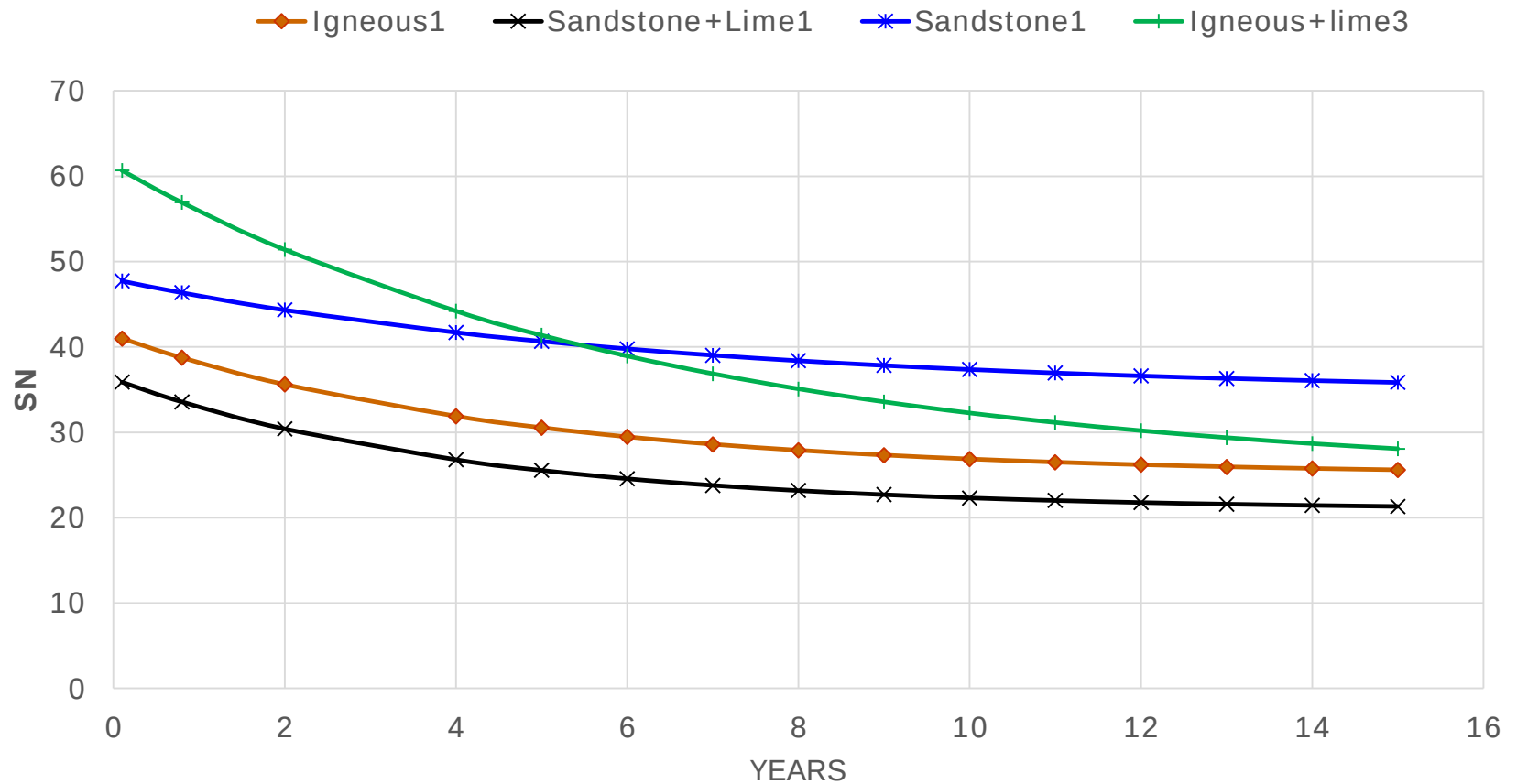
Skid Number for HMA



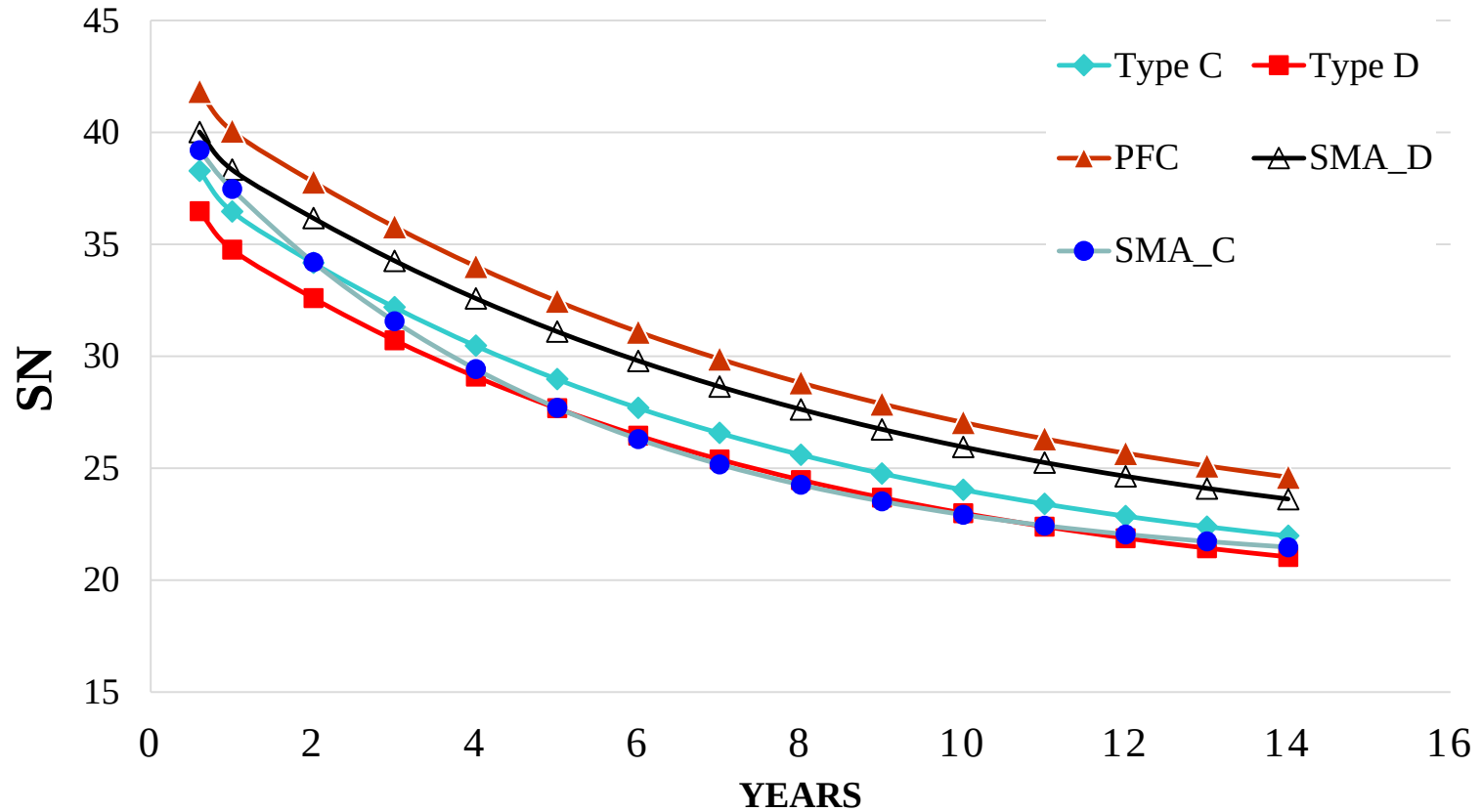
Effect of AADT on the Skid Number (SN)



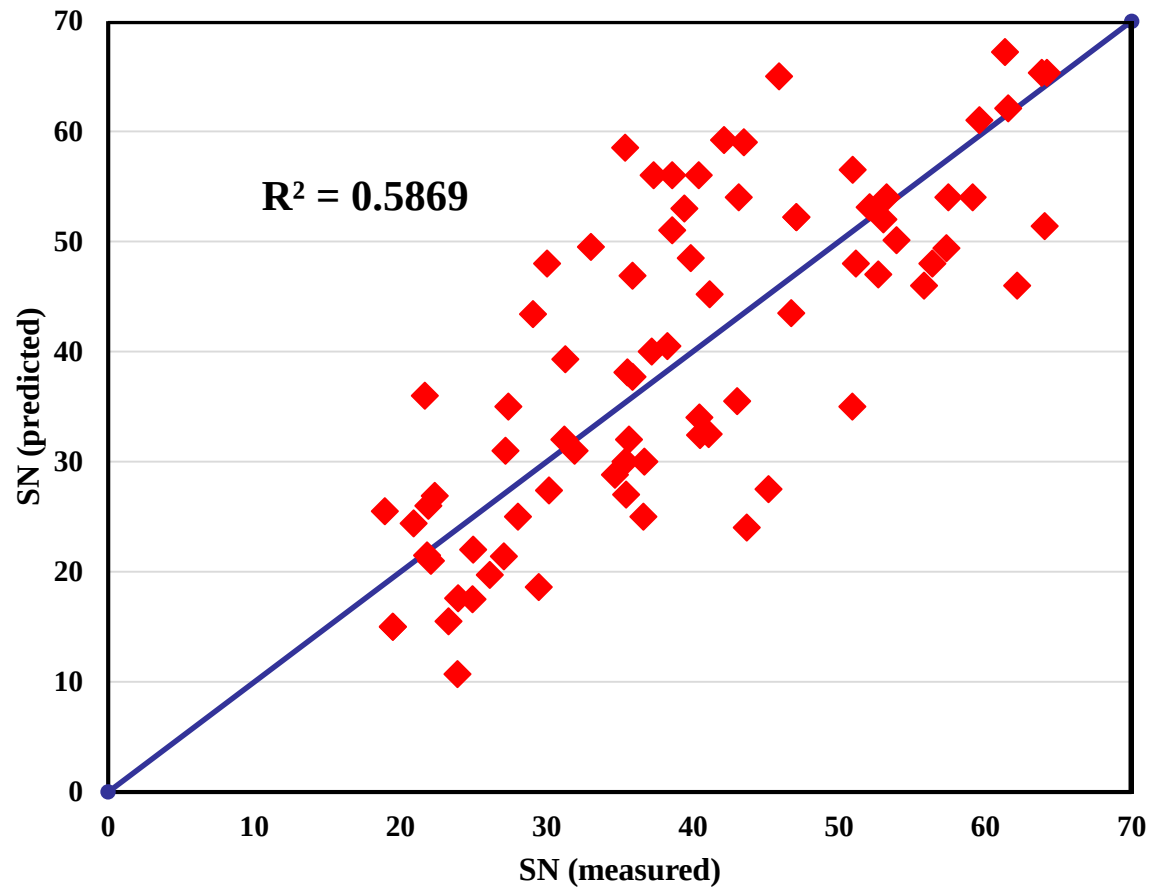
- **Effect of Aggregate Texture on the Skid Number (SN)**



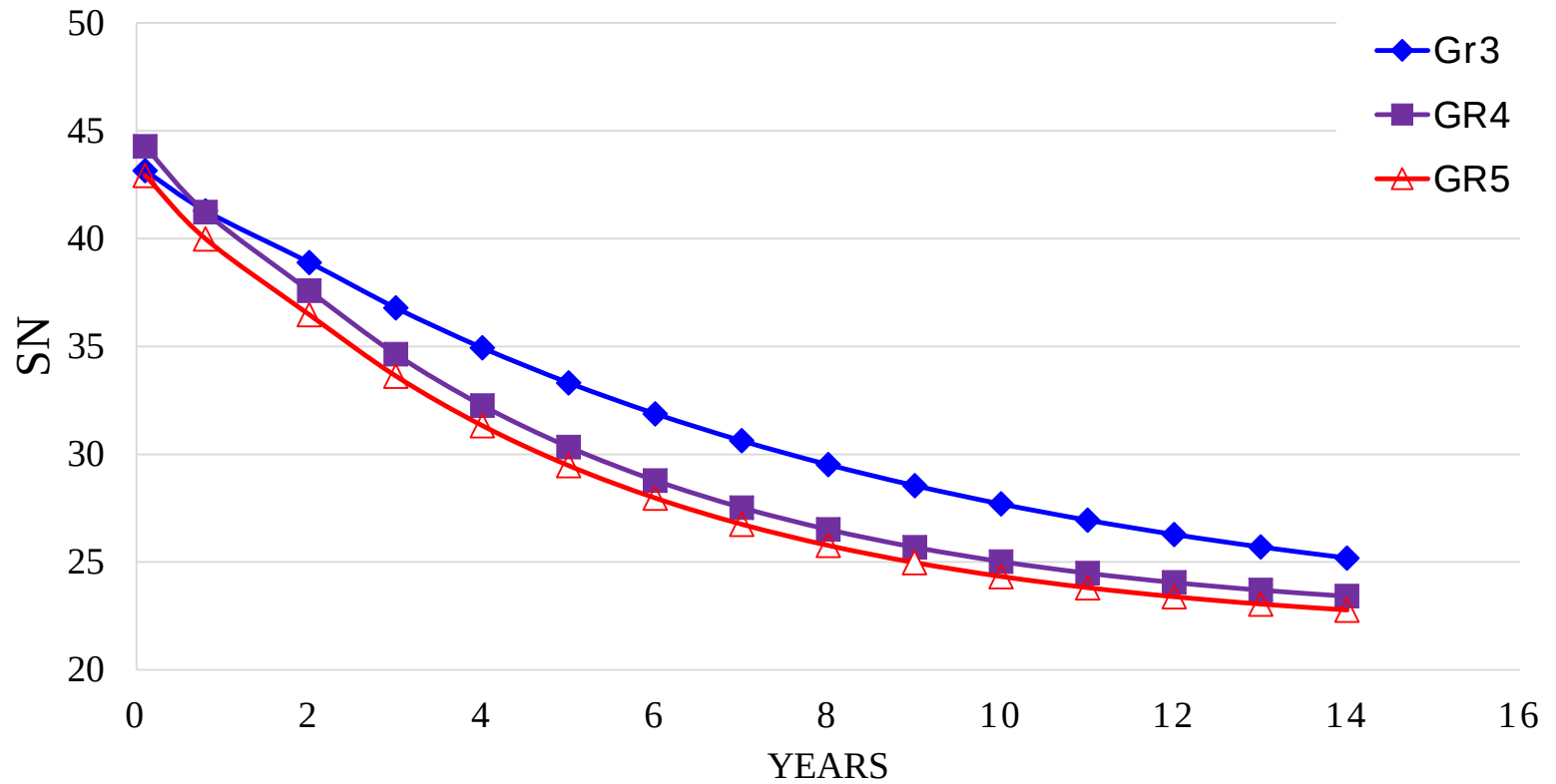
Effect of Mixture Gradation on the Skid Number (SN)



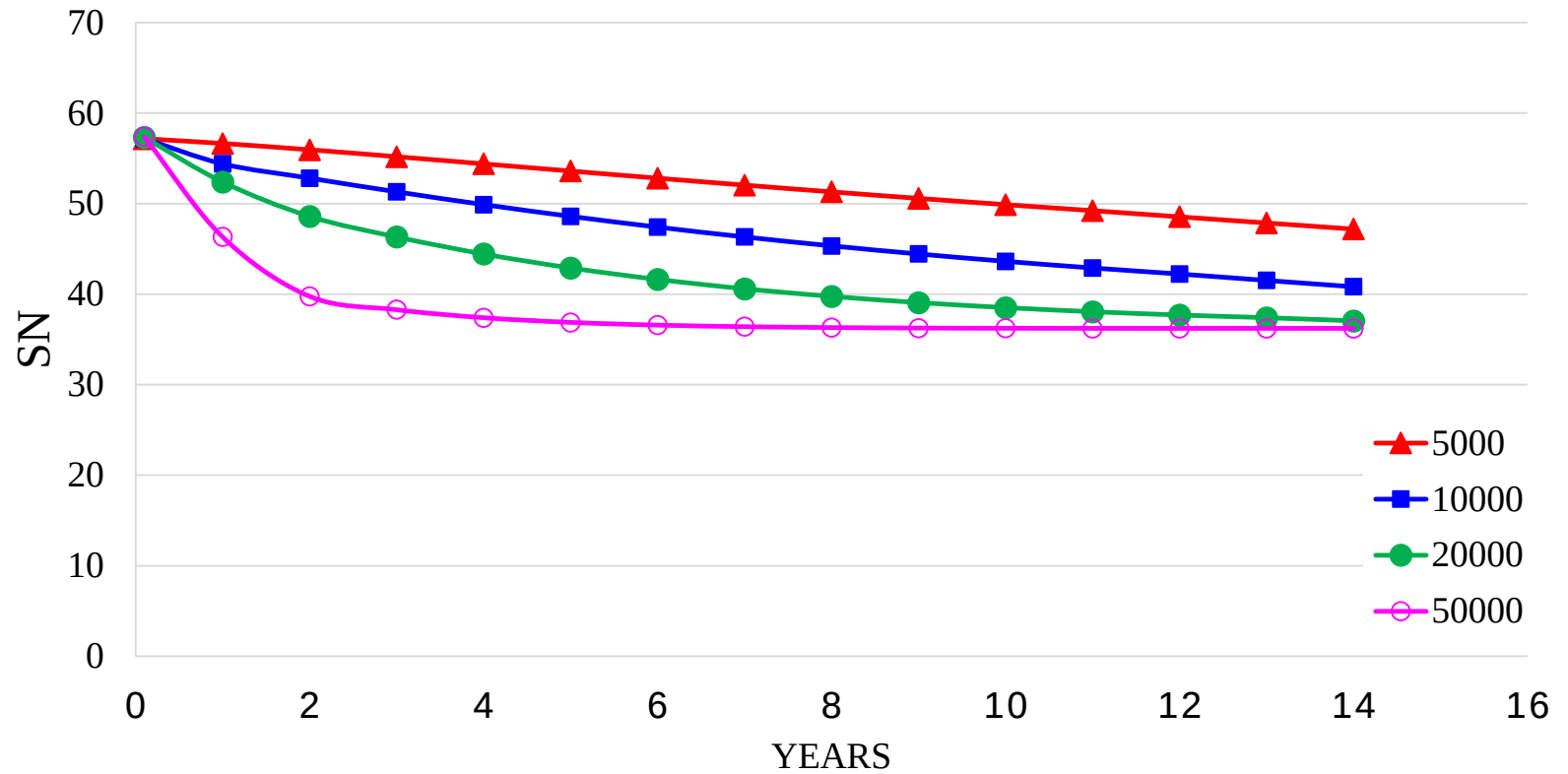
Skid Number for Seal coat



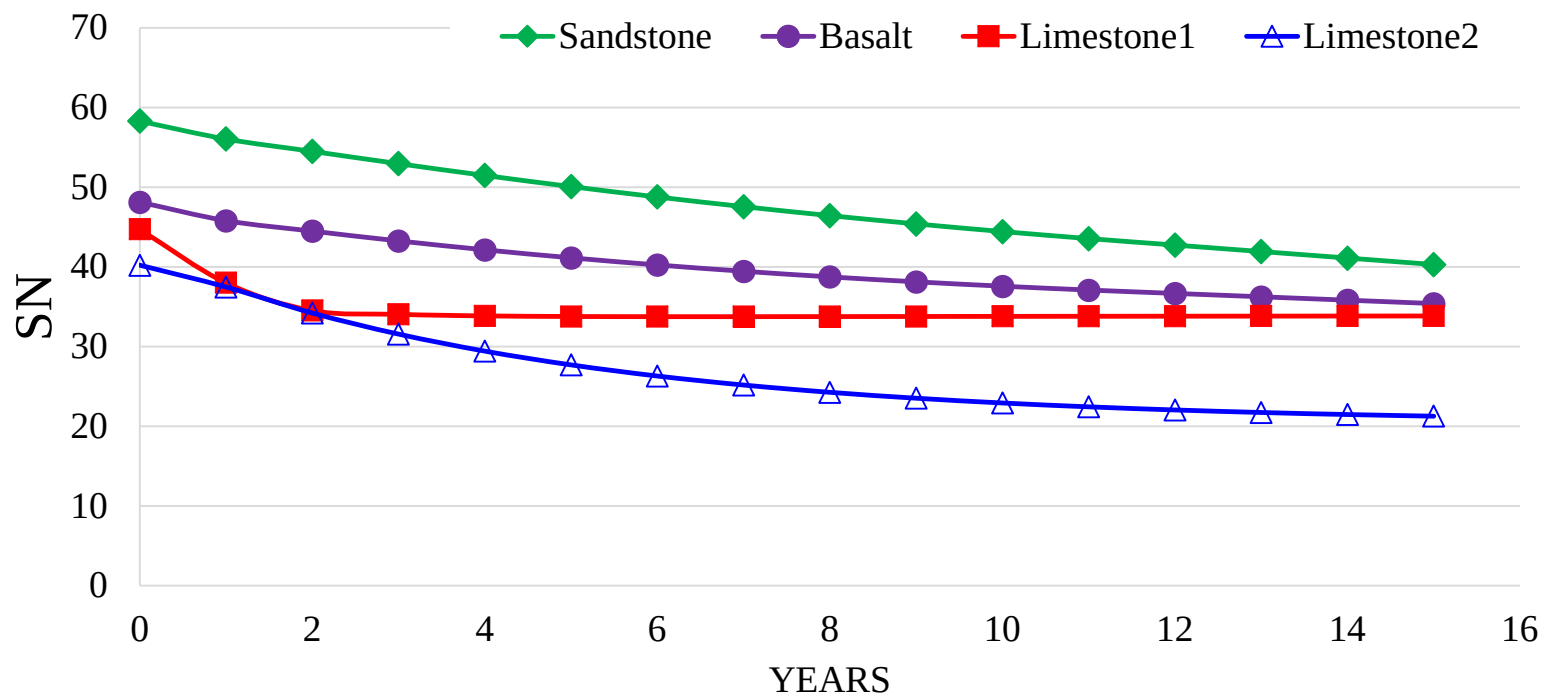
Effect of Seal Coat Gradation on the Skid Number (SN)



Effect of AADT on the Skid Number (SN)



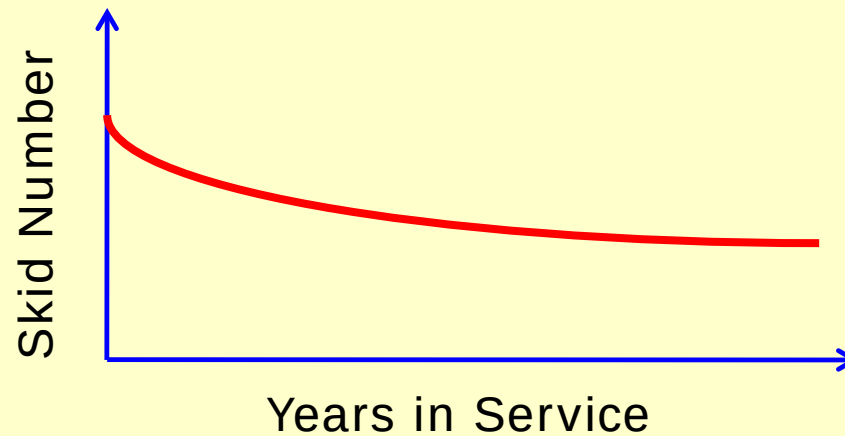
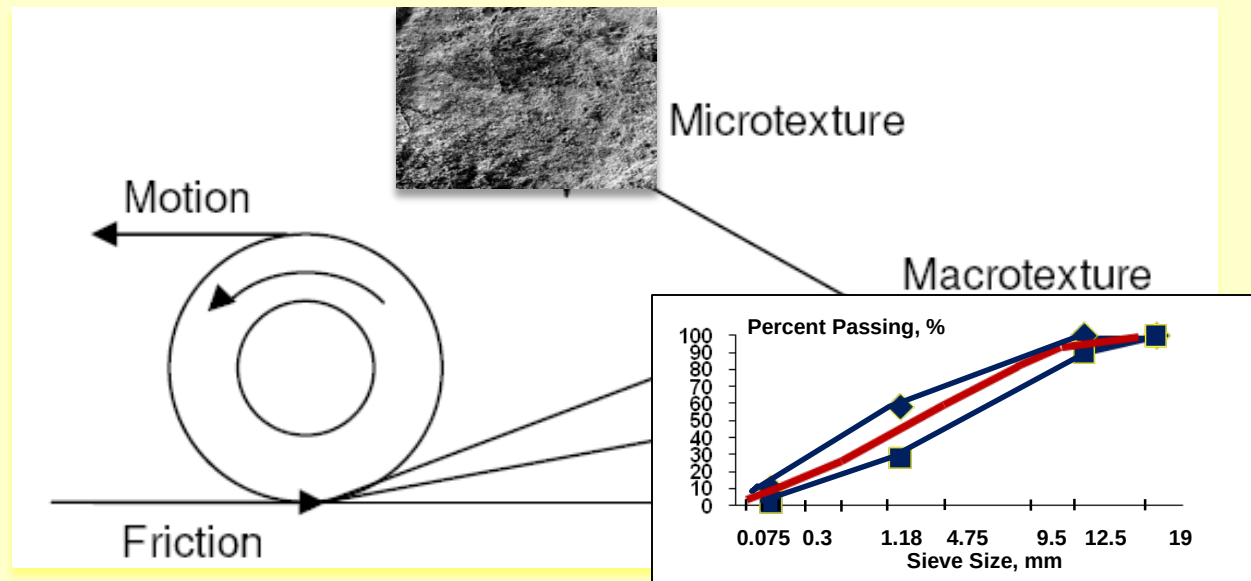
Effect of Aggregate Texture on the Skid Number (SN)



Example of Influence of Aggregate and Gradation on Skid Resistance

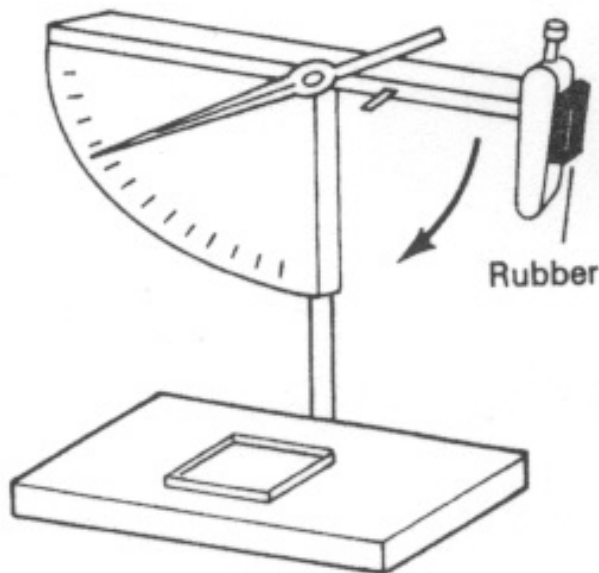
	Interstate		US Highway		State Highway	
AADT	64500	5700	34000	550	16800	150
Type C	21	29	23	31	26	31
Type D	12	15	12	15	12	15
PFC	29	47	34	51	40	51
SMA-D	29	54	36	60	45	60
SMA-C	29	57	37	63	47	63
CMHB-C	29	57	37	63	47	63
CMHB-F	7	11	7	11	7	11

Benefits



Benefits

- Replace the current time consuming methods
 - Polishing of aggregate coupons for 9 hours.
 - Measure the friction value of the specimens using the British pendulum tester.



AIMS Draft AASHTO Test Procedures

Standard Method of Test for

Determining Aggregate Shape Properties by Means of Digital Image Analysis

AASHTO Designation TP81

1. SCOPE

- 1.1. This standard covers the measurement of aggregate shape properties using the Digital Image Analysis techniques.
- 1.2. This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Standard Practice for

Determining Aggregate Source Shape Values from Digital Image Analysis Shape Properties

AASHTO Designation PP64

1. SCOPE

- 1.1. This standard covers the determination of aggregate source and source blend shape characteristics using gradation analysis and shape properties determined by means of digital image analysis.

AIMS Draft AASHTO Specifications

Determining Aggregate Shape Properties for Superpave Volumetric Mix Design

AASHTO Designation: MP zz-zz

1. SCOPE

- 1.1. This specification for Superpave volumetric mix design uses aggregate and mixture properties to produce a hot mix asphalt (HMA) job mix formula.
- 1.2. This standard specifies minimum quality requirements for aggregate shape properties measured using the Aggregate Imaging System (AIMS).
- 1.3. This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.



Thank You....

Asphalt Mixture Gradation

☐ Input Gradation

☒ Choose Gradation

Type C



Choose Type C

Cancel

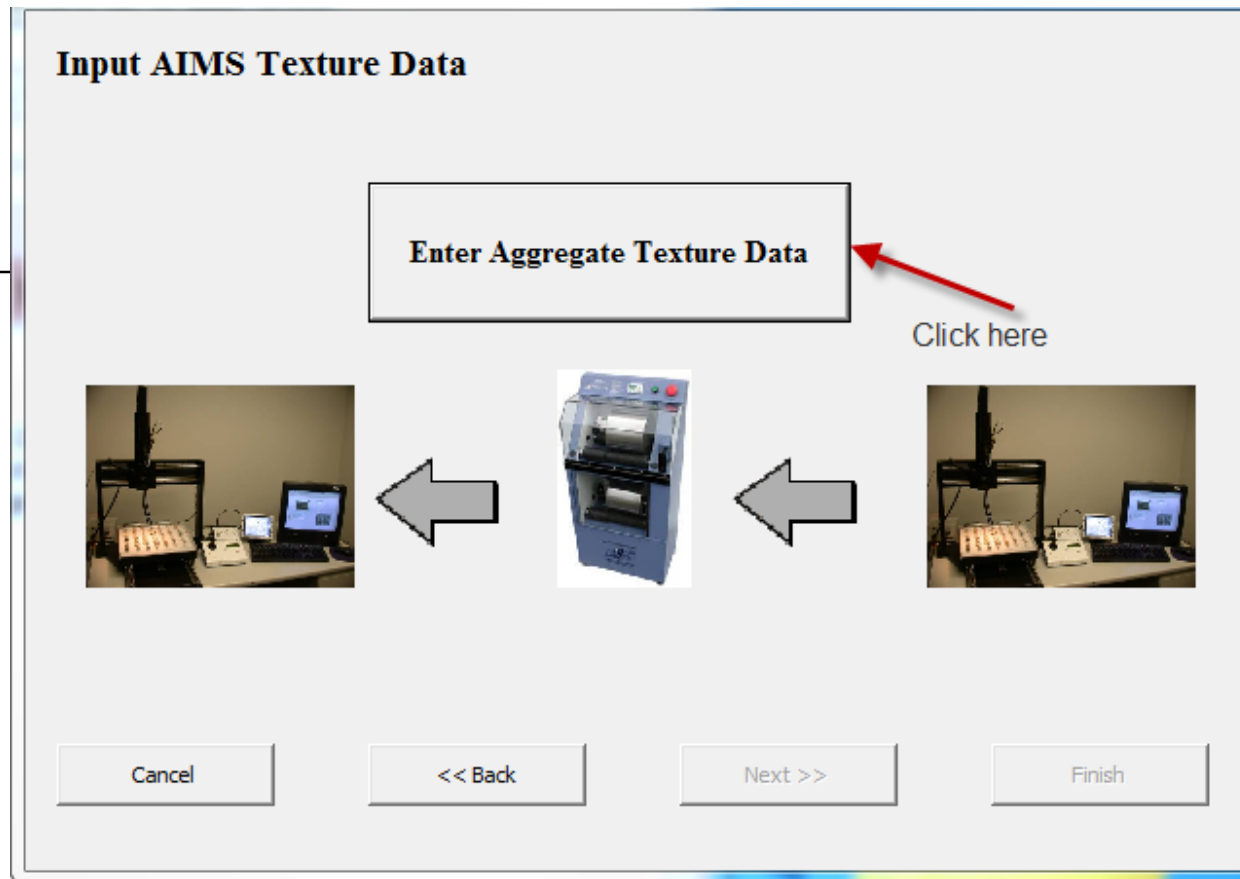
<< Back

Next >>

Finish

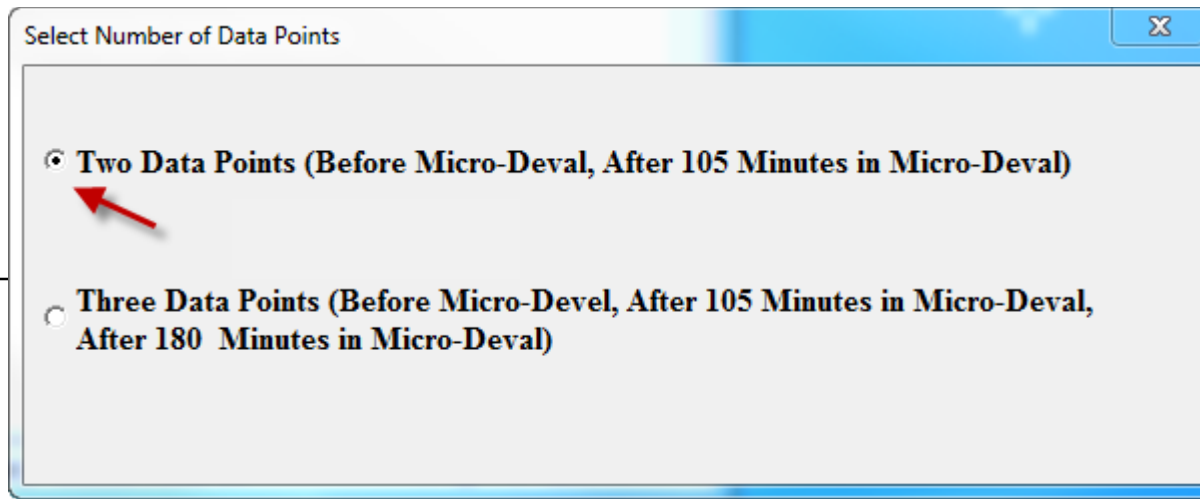
Step 1:

- Input gradation or choose standard TxDOT gradation.
- SAAP will calculate gradation parameters κ and λ .



Step 2:

- Click “Enter Aggregate Texture Data”



Step 3:

- Choose AIMS texture data at two points:
 - Before Micro-Deval Polishing.
 - After 105 minutes of Micro-Deval Polishing.

Or

- AIMS texture data at three points **(Note: more accurate than two points)**
 - Before Micro-Deval Polishing
 - After 105 minutes of Micro-Deval Polishing.
 - After 180 minutes of Micro-Deval Polishing.

Enter Texture Data

Enter Number of Aggregate Sources: 1

Enter Name of Aggregate Source 1: Text

Ok Cancel

Text

Proportion of Aggregate in the Mix (Percentage): N.A

Percent Passing #4: N.A

Texture Before Micro-Deval: 300

Texture After 105 minutes Micro-Deval: 50

Step 4:

- Choose number of aggregate sources used in preparing the mixture.
- Enter the proportion of each aggregate course in the mix.
- Percent Passing Sieve 4 for each source.
- Enter texture before and after Micro-Deval (**Note: typical texture is from 50 (low) to 600 (high)**).

Example:

Number of Aggregate Sources = 2.

Proportion of Aggregate in the Mix (Aggregate 1) = 30%

Percent Passing Sieve 4 (Aggregate 1) = 90%

Proportion of Aggregate in the Mix (Aggregate 2) = 70%

Percent Passing Sieve 4 (Aggregate 1) = 100%

Material	Agg. # 1		Agg. # 2		Blend
% Used	30 %		70 %		
U.S. Sieve	% Passing	% Batch	% Passing	% Batch	
3/8 "	100	30	100	70	100
No. 4	90	27	100	70	97
No. 8	30	9	100	70	79
No. 16	7	2.1	88	61.6	63.7
No. 30	3	0.9	47	32.9	33.8
No. 50	1	0.3	32	22.4	22.7
No. 100	0	0	24	16.8	16.8
No. 200	0	0	10	7	7

Input Pavement Texture Data

☐ Measured Mean Profile Depth (MPD) in mm

☒ Use SAAP Estimation of Mean Profile Depth (MPD) in mm Based on Mixture Gradation



Estimated MPD

 The Estimated MPD value is: 0.76

OK

Cancel << Back NEXT >> Finish

Step 5:

- Enter the MPD of a new road right after construction

Or

- Use SAAP to estimate MPD based on gradation.

Input Traffic data:

Highway Type

☒ Divided ☐ Undivided

Total Number of Through Traffic Lanes

☒ Two Lanes ☐ Four Lanes ☐ Six Lanes ☐ Eight Lanes or More

Average Annual Daily Traffic (AADT) for Both Directions

Percent Truck Traffic

5000

50

Cancel << Back Next >> Finish

Step 5:

- Enter road information and traffic data.
- SAAP will use this data to calculate Traffic Multiplication Factor (TMF).

$$TMF = \frac{AADT \times 365 \times \text{Years in Service}}{1000}$$

Skid Resistance Prediction Model Step 5 of 6

Choose Analysis Type:

 **Predict Skid Resistance as a Function of Years in Service**

Click here

Classify an Asphalt Pavement Section Based on its Skid Resistance

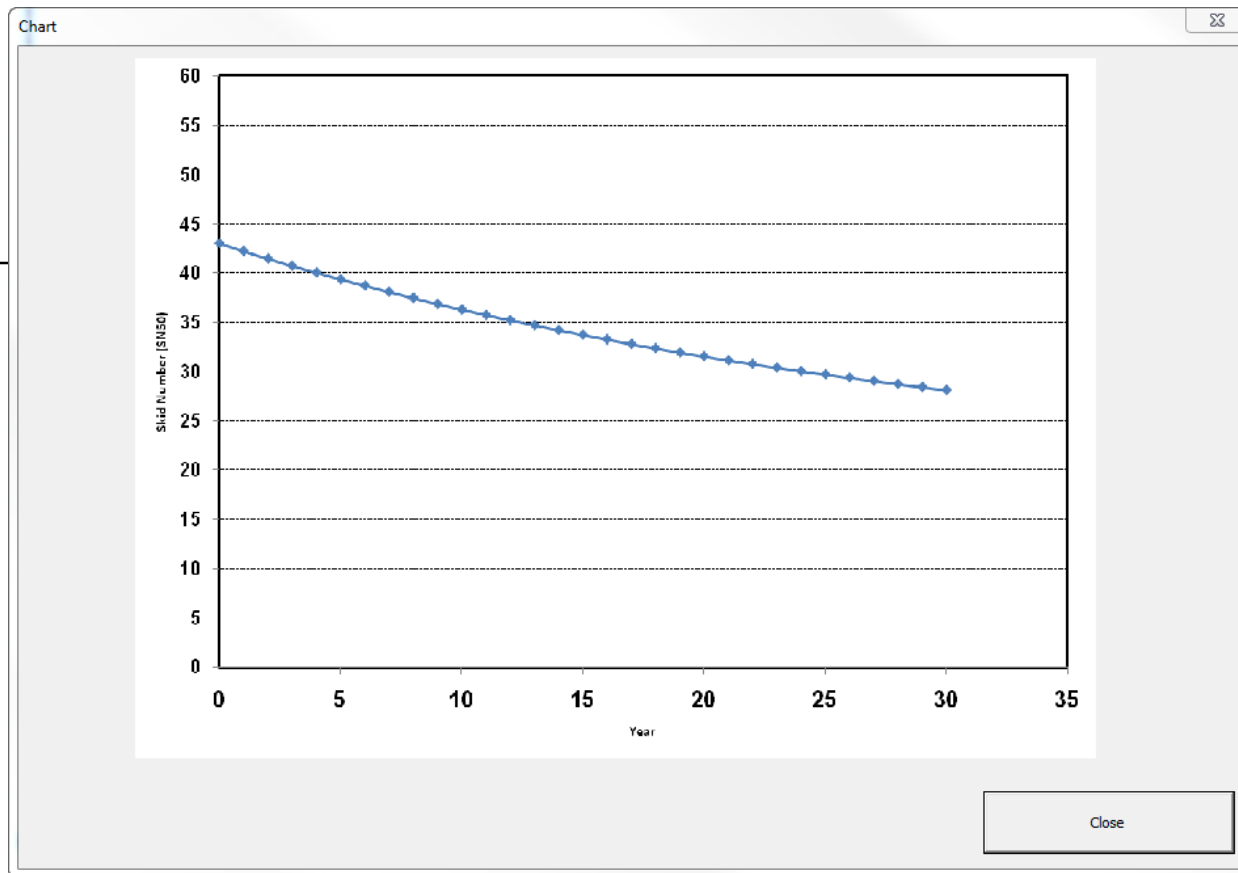
Cancel << Back Next >> Finish

Step 6:

- In this step, you can choose to plot skid resistance (SN) as a function of years in service.

Or

- You can choose to classify the pavement section based on the skid resistance after a certain number of years.



Step 7a:

- If you choose to predict skid resistance, the above chart will be plotted.

Set Classification Parameters:

Service Life: Years

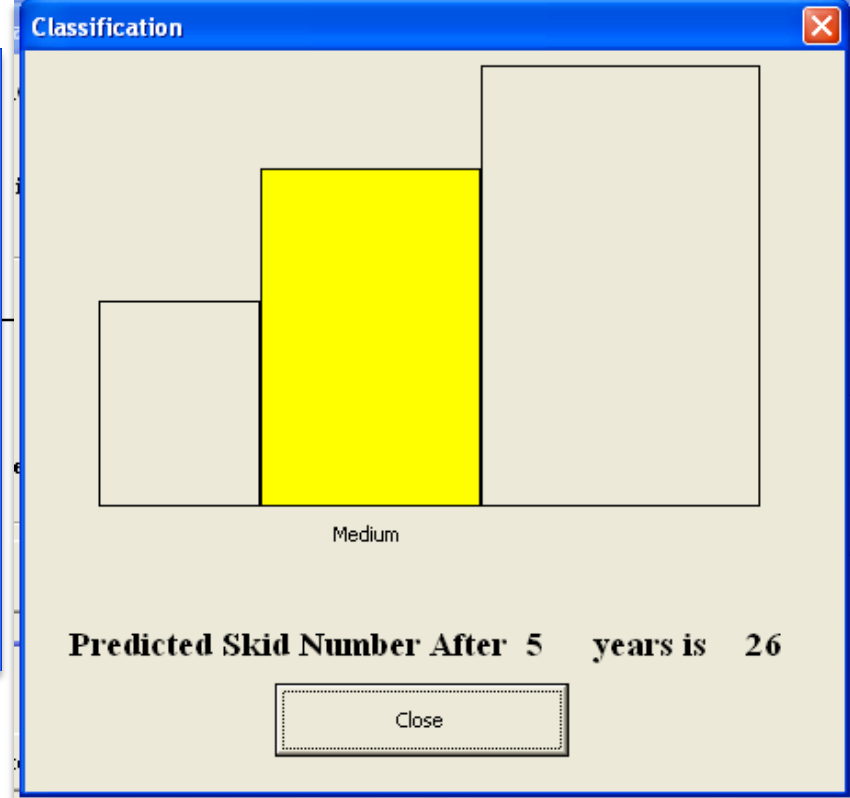
Thresholds

Accepted >

< Monitor Pavement Frequently <

Take Measures to Correct <

Cancel Set



Step 7b:

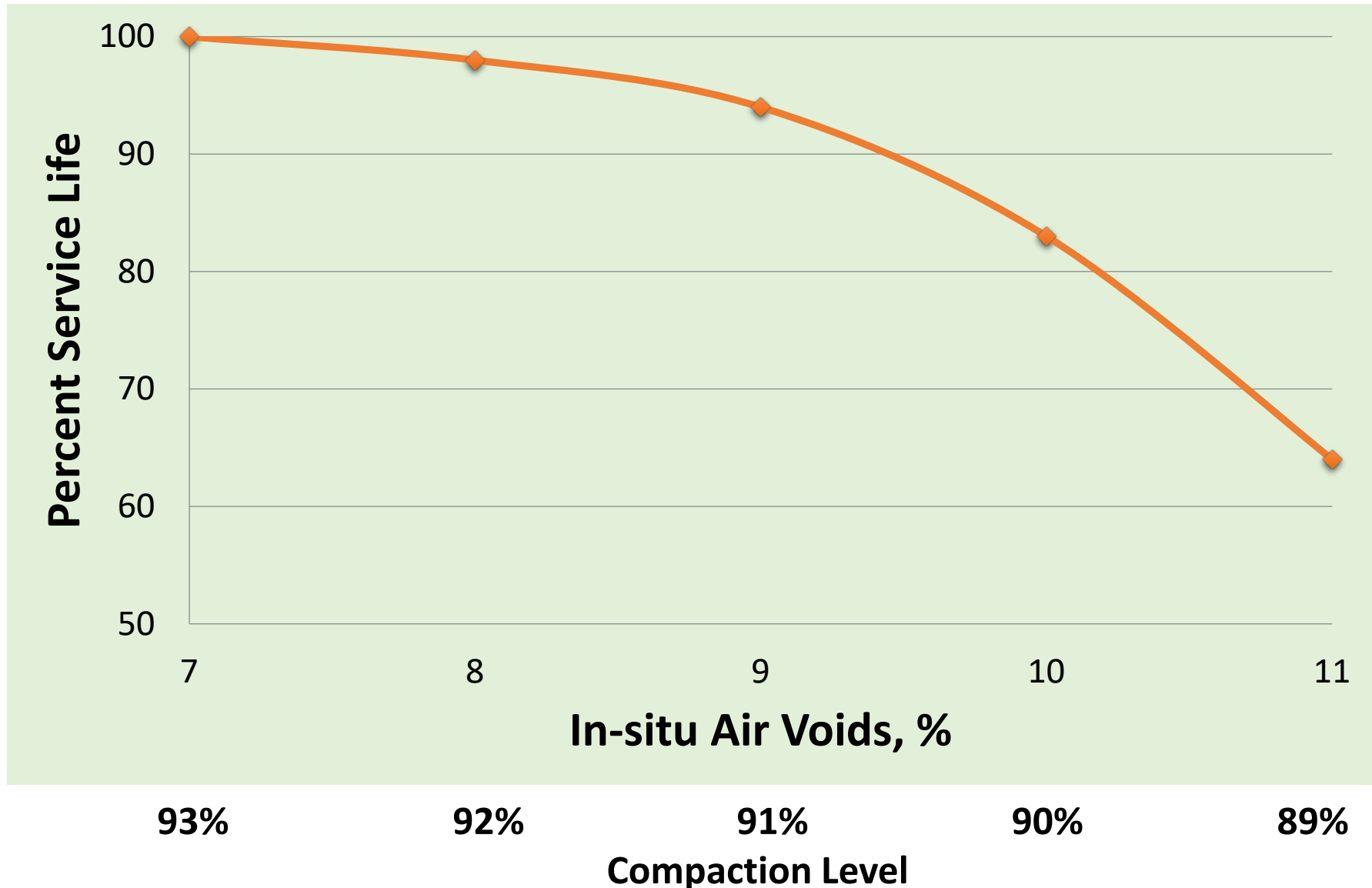
- If you choose to classify asphalt pavement section, you need to enter:
 - Number of years at which the skid number is monitored.
 - Thresholds for skid number for accepted performance, moderate performance (section is monitored), and low performance (surface rehabilitation is required)
- The result of this analysis is the classification of the pavement section after a certain number of years as shown in the screen on the right.

Asphalt Pavement Construction: Best Practices

**56th Annual Idaho Asphalt
Moscow, Idaho
October 26-27, 2016**

Effect of In-Place Voids on Life

Washington State DOT Study

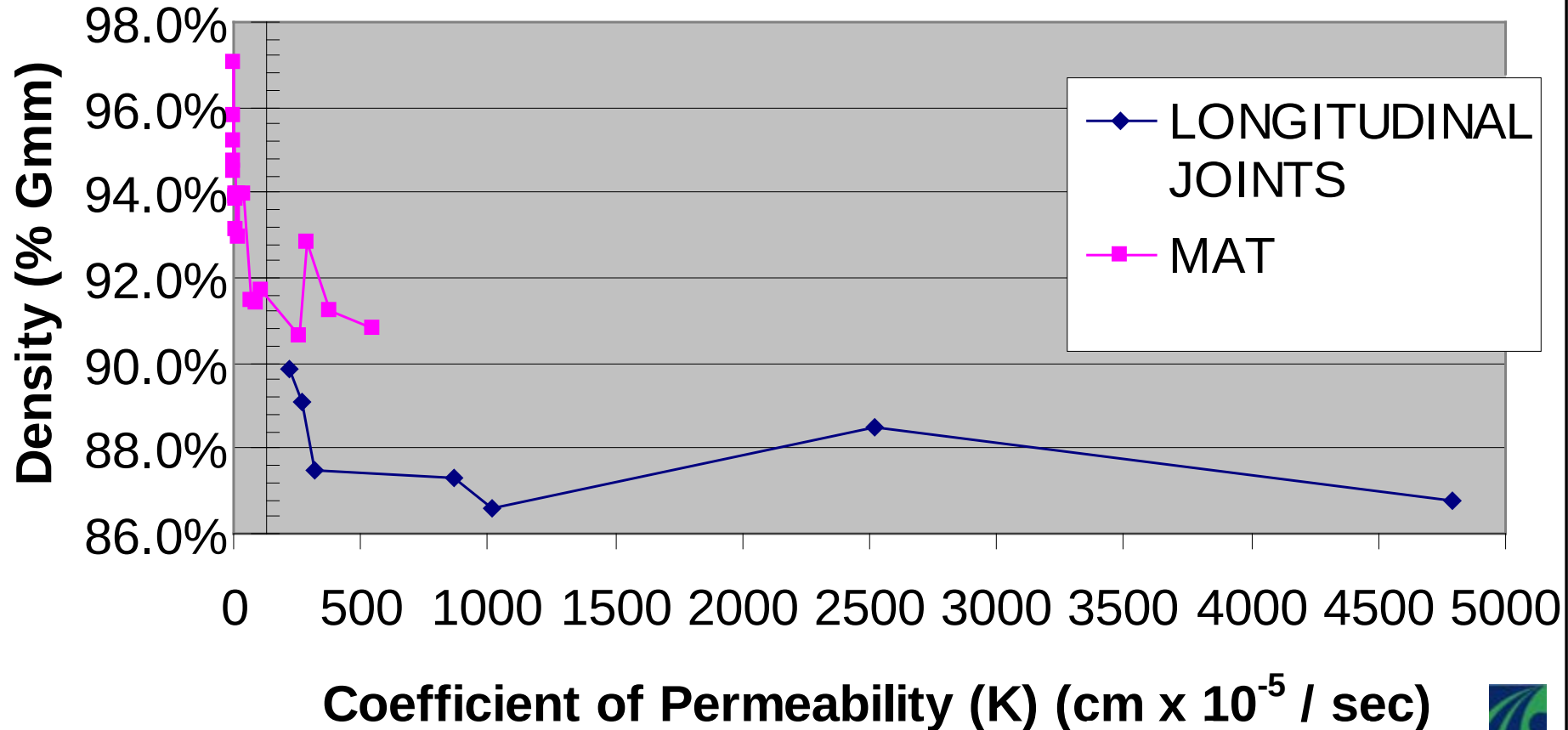


Enhanced Durability through Increased In-Place Pavement Density

- A 1% increase in field density can increase asphalt pavement service-life +10% (conservatively)
- Today's compaction target is typically 92% of maximum (G_{mm}) (8% air voids),
 - Varying requirements for longitudinal joints
- Increased Density Pavements target a 2% increase across the entire pavement!
 - Just 2% more... makes a huge difference!



DENSITY VS. PERMEABILITY 12.5 mm WEARING COURSE



“A 1% decrease in air voids was estimated to improve:

- Fatigue performance between 8.2 and 43.8%**
- The rutting resistance by 7.3 to 66.3%**
- Extend the service life by conservatively 10%.”**

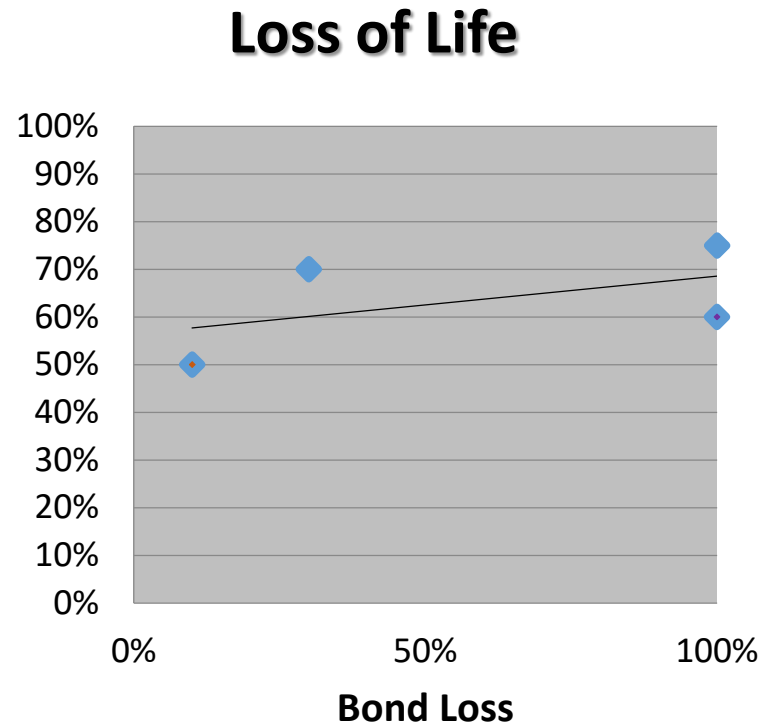
Importance of Tack Coats

- **Promotes the bond between pavement layers**
 - Prevents slippage between pavement layers
 - Vital for structural performance of the pavement
 - All layers working together
 - Seals all transverse & longitudinal vertical surfaces



Loss of Fatigue Life Examples

- **May & King:**
 - 10% bond loss = 50% less fatigue life
- **Roffe & Chaignon**
 - No bond = 60% loss of life
- **Brown & Brunton**
 - No Bond = 75% loss of life
 - 30% bond loss = 70% loss of life





What we are talking about:

- *Original Emulsion*—undiluted emulsion consists of a paving grade binder, water, and an emulsifying agent.
- *Diluted Emulsion*—an emulsion that has been diluted with additional water.
 - Critical to sprayed control
 - 1:1 typical (Original Emulsion:Added Water)
- *Residual Asphalt*—the remaining asphalt after an emulsion has set typically 57-70 percent of Original Emulsion

What difference does it make?

If the example spec *intended* 0.05 **gal/yd²** of residual asphalt:

*To receive **Residual Asphalt** at 0.05 gal/yd² using an emulsion with 60% residual asphalt, the contractor would need to apply:*

**0.083 gal/yd² of Original Emulsion or
0.167 gal/yd² of 1:1 Diluted Emulsion**

What is going on and why?





Days later!

8–10 years est. Interstate Pavement



Courtesy of MoDOT

Cost of Tack Coat

- New or Reconstruction
 - About **0.1-0.2%** of Project Total
 - About **1.0-1.5%** of Pavement Total Cost
- Mill and Overlay
 - About **1.0-2.0%** of Project Total
 - About **1.0-2.5%** of Pavement Total Cost



- Assume no inflation for materials
- Estimated traffic control
- Used project plans for thicknesses
- Used bid tabs for:
 - Milling
 - Material costs
 - Replaced pavement markings

**30-100% of Original
Pavement Costs**

Common Tack Coat Questions

- **What is the Optimal Application Rate?**
 - Surface Type
 - Surface Condition
- **Workshop Recommended Ranges**

Surface Type	Residual Rate (gsy)	Appx. Bar Rate Undiluted* (gsy)	Appx. Bar Rate Diluted 1:1* (gsy)
New Asphalt	0.020 – 0.045	0.030 – 0.065	0.060 – 0.130
Existing Asphalt	0.040 – 0.070	0.060 – 0.105	0.120 – 0.210
Milled Surface	0.040 – 0.080	0.060 – 0.120	0.120 – 0.240
Portland Cement Concrete	0.030 – 0.050	0.045 – 0.075	0.090 – 0.150

*Assume emulsion is 33% water and 67% asphalt.

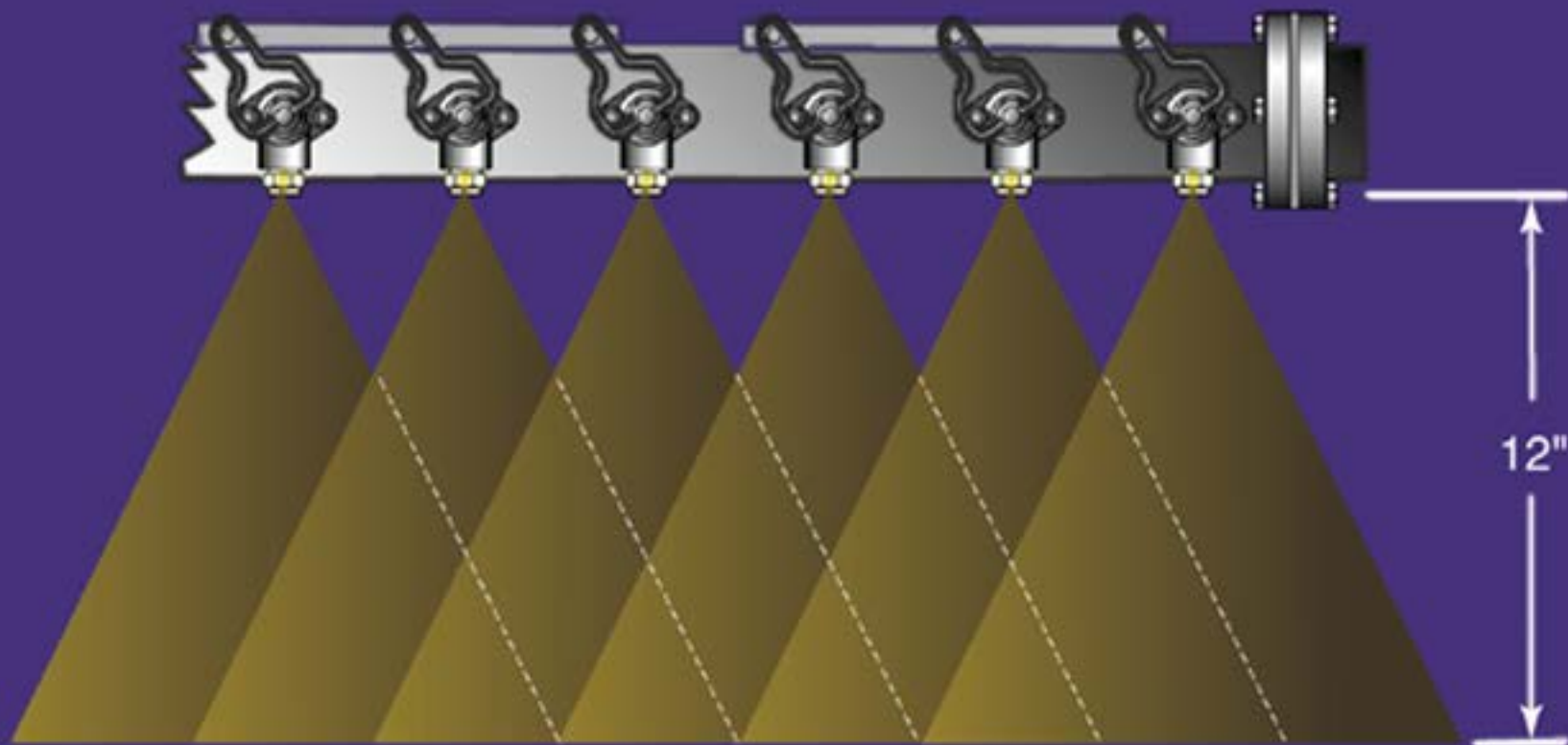
Tack Coat



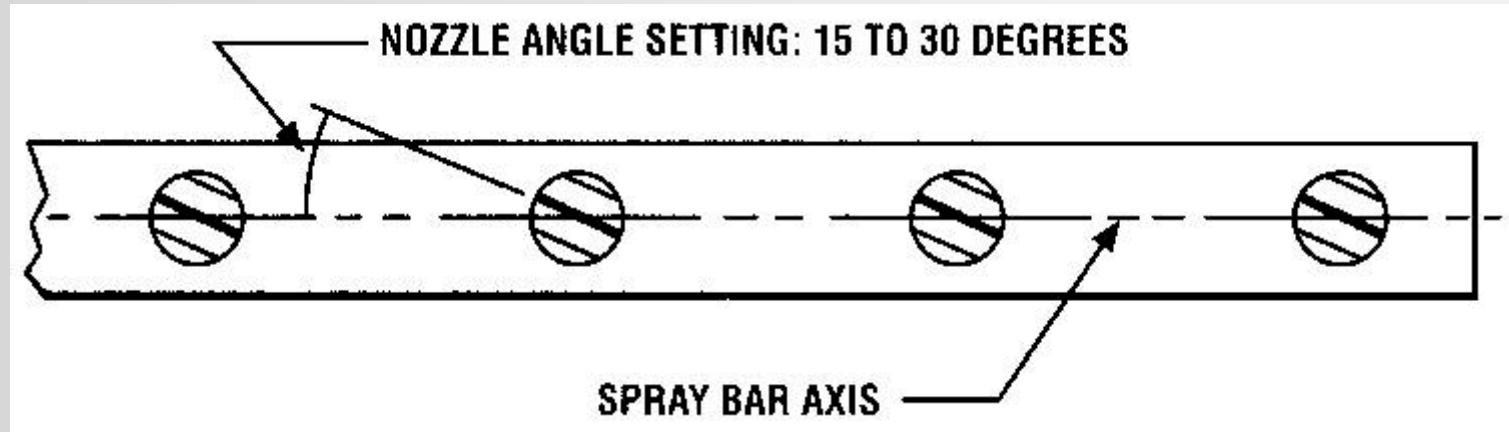
**Full width of mat to
minimize movement of
unsupported edge**



Triple Lap Coverage



Spray Bar/Nozzles



Nozzle Selection



Common Tack Coat Question

- **When to Re-Tack?**
 - Tracking
 - Contamination

**If in doubt ...
Re-Tack**







Longitudinal Joint Tacked

Dirty Surface

Light Application



Missed Line

Generally Uniform
Application



Filling it in

How To Build a Longitudinal Joint?





Photo: Carlos Rosenberger





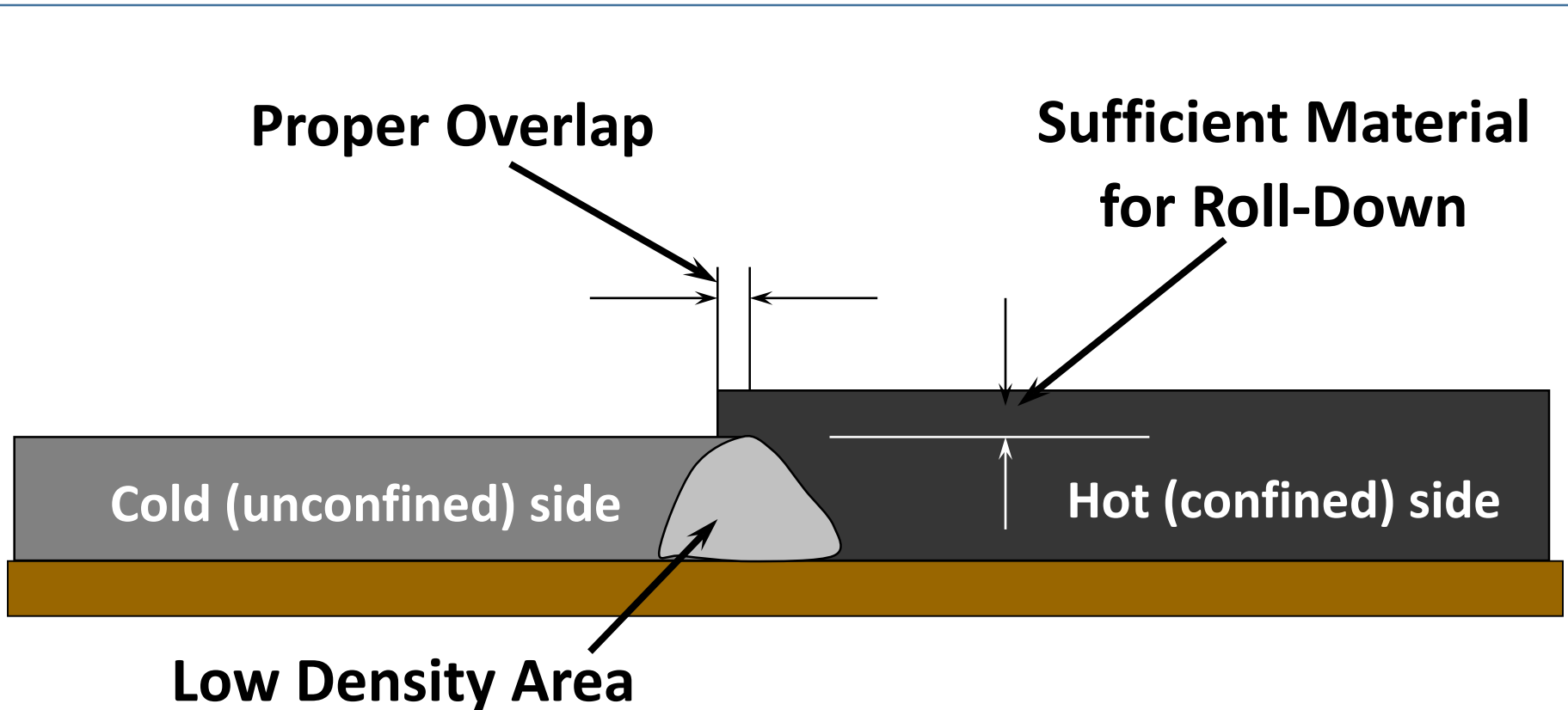
Photo: Carlos Rosenberger



I-71 in Columbus, OH

Longitudinal Joint Definitions

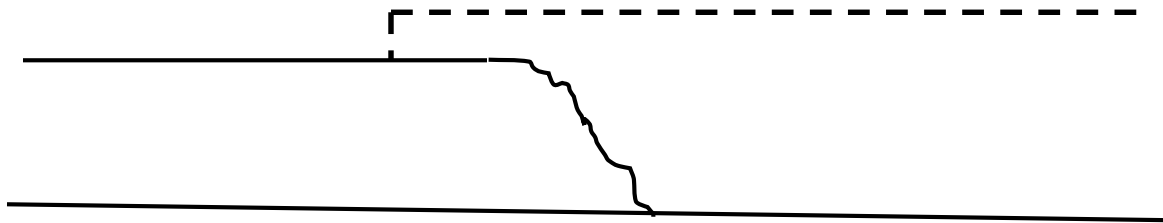
Unsupported Edge Will Have Lower Density



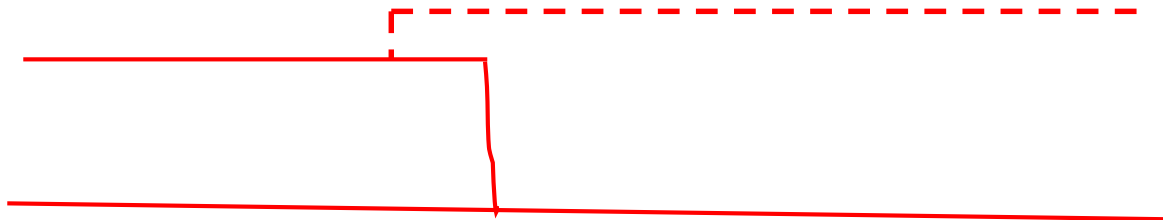
“Cold side” is the first paver pass and “Hot side” is the second

Different Types of Longitudinal Joints

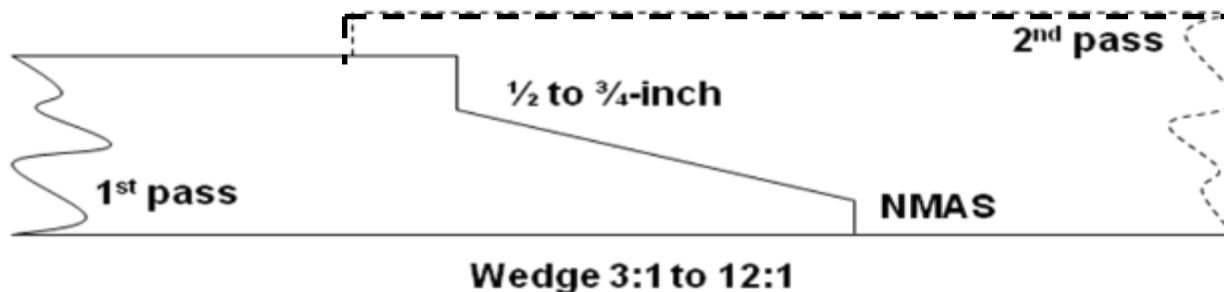
Butt (Vertical) Joint



Milled or Cutback Joint



Notched Wedge Joint



Mill & Pave One Lane at a Time



Photo in IL, Courtesy Hal Wakefield

The Best Longitudinal Joint: *Echelon Paving*



Echelon Paving Longitudinal Joint



Joint passes between the quarters

**But, the need to maintain traffic limits
the opportunities to pave in echelon**

**Consequently, most longitudinal joints
are built with a cold joint.**



First Pass Must be Straight





**Uniform head of material
across entire screed to joint**

...Do Not Overload Auger



Paint the Vertical Face

**Good: Double Tack with
Emulsion
Better: PG Binder
Best: Joint Adhesive**



Overlap By 1-inch +/- ½ Inch

- If milled or cutback joint, then 0.5-inch
- Keep end plate flat
- Set automation to **NEVER STARVE THE JOINT!**
- Joint Matcher best (versus ski) to match exact amount of material needed at joint



Do NOT Rake Away From the Joint

asphalt institute





Lute the Longitudinal Joint

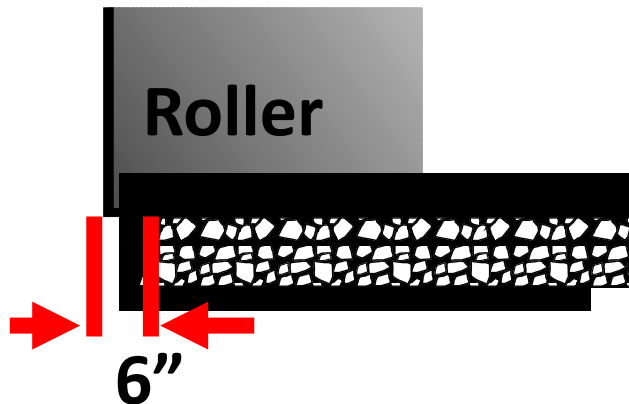


This lute person is
doing a great job

Rolling Unsupported Edge?

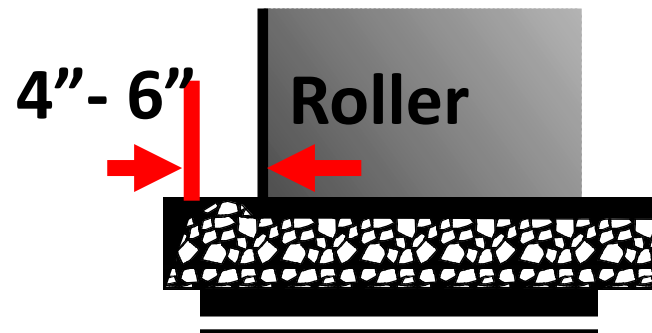
Option 1

Hang over 4-6"

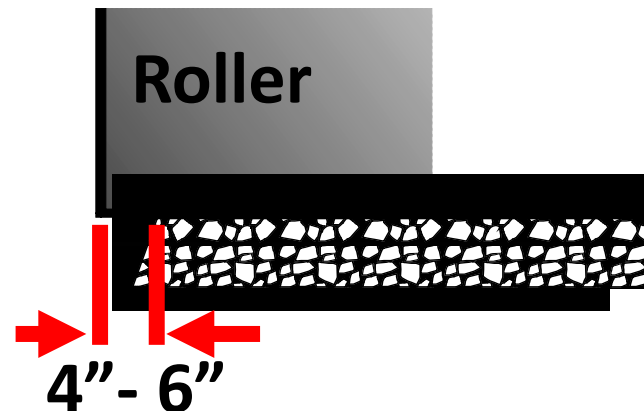


Option 2

1st Pass 4"-6" inside

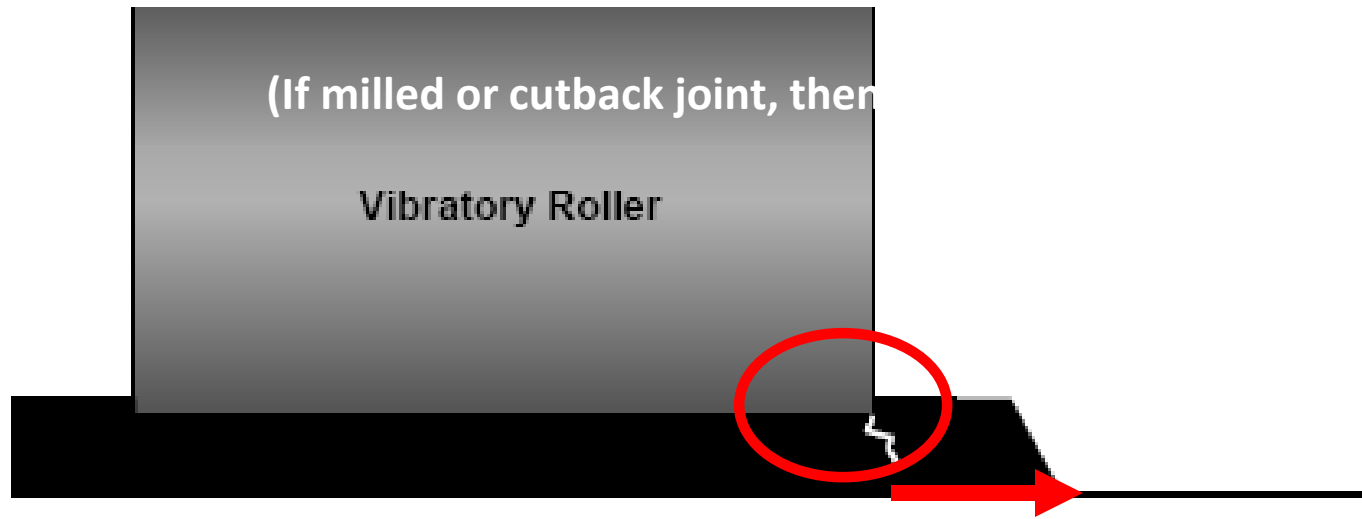


2nd Pass hang over 4"-6"



What We Don't Want

Rolling Unsupported Edge With First Roller Pass



If edge of drum is located just inside the unsupported edge, a stress crack can occur here.

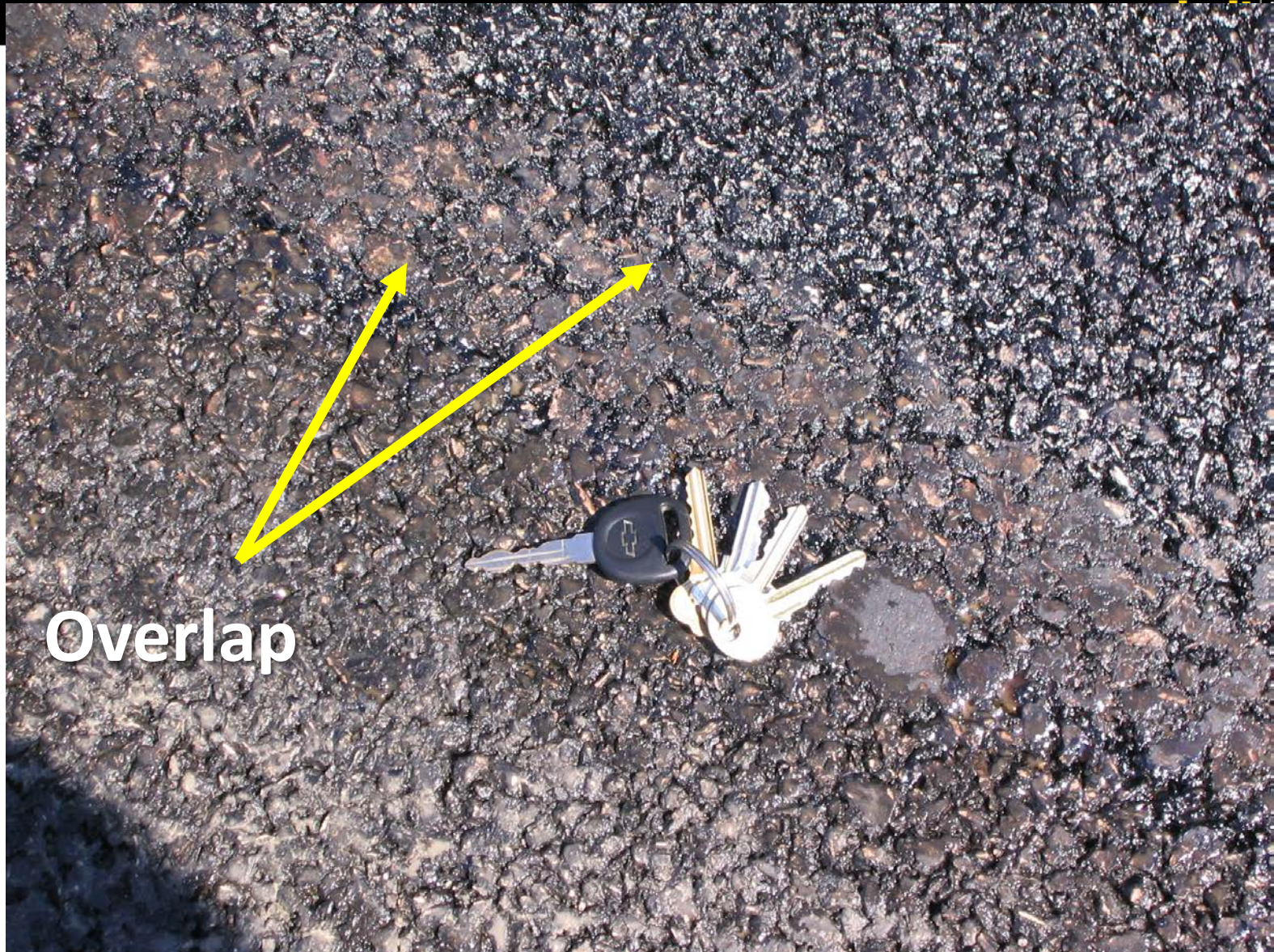
Rolling the Confined Edge:



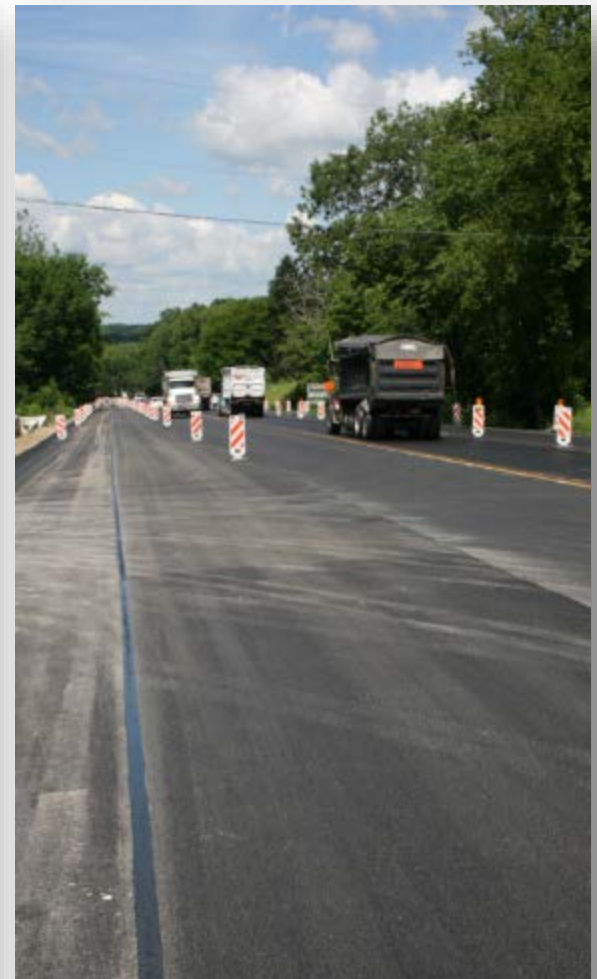
**1st pass all on hot mat
with roller edge off
joint approx 6-12 inches**



**2nd pass overlaps on
cold mat 3-6 inches**







**Frequently Done in
AK and PA**

Licensed Subcontractor $\approx$ 11 Trucks



Also Works as a Tack Coat



Balance the Mix Design

Smooth Quiet Ride
Skid Resistance

Strength/
Stability

Rut Resistance

Shoving

Flushing
Resistant

Durability

Crack
Resistance

Raveling

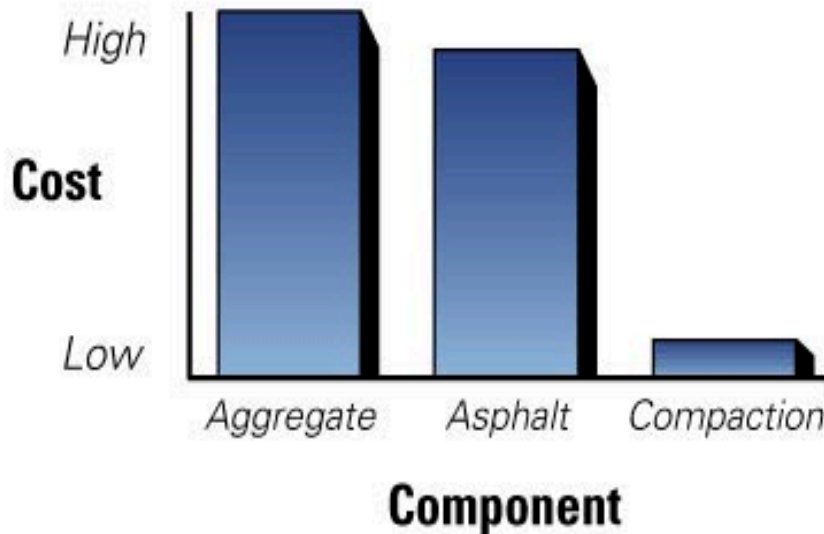
Permeabilit
y



DON'T ATTACK ONE HALF AT THE EXPENSE OF THE OTHER HALF!!

Cost of Compaction

**Relative cost comparison between
asphalt pavement components**

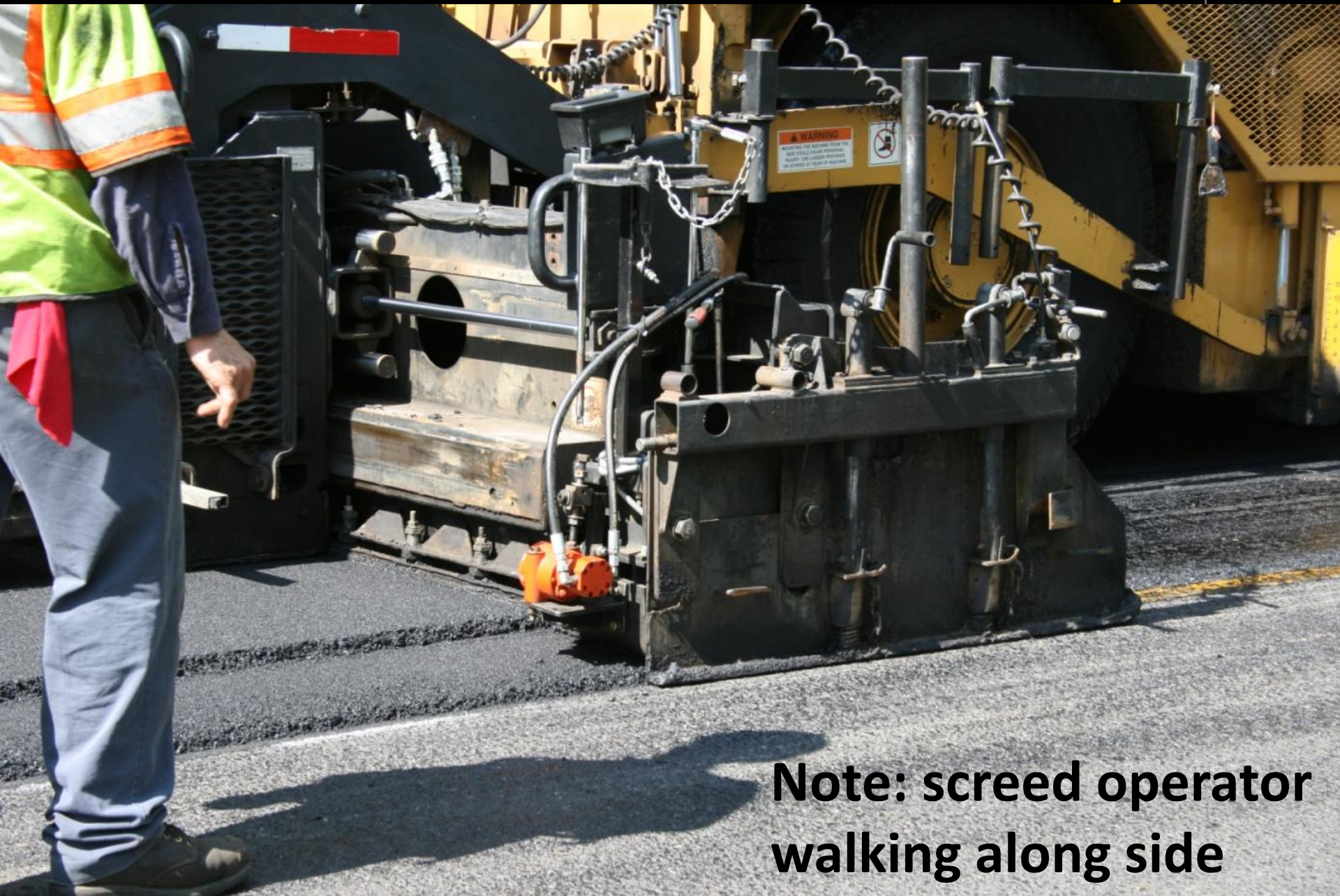


- Least expensive part of the paving process
- Aggregates and binders are expensive in comparison
- Compaction adds little to the cost of a ton of asphalt

- Aggregates need room to densify
- Too thin vs. NMAS leads to:
 - Roller bridging
 - Aggregate lockup
 - Aggregate breakage
 - **Compaction Difficulties**
- NCHRP Report 531 (2004)
 - Fine Graded Mix—Min Thickness = 3 X NMAS
 - Coarse Graded Mix—Min Thickness = 4 X NMAS
 - SMA Mix—Minimum Thickness = 4 X NMAS

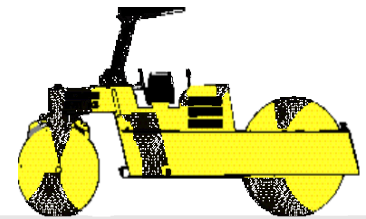
- **Thicker = More Time for Compaction**
- **Free tools for estimating compaction time**
 - **PaveCool—single lift (generation 1)**
 - PC
 - iOS App
 - Google App
 - **MultiCool—multiple lifts (generation 2)**
 - PC
 - Google App
 - Mobile Web

Vibratory Screed Should Always be “ON”



**Note: screed operator
walking along side**

Roller Operations - Temperature Zones



Temperature
Ranges

300° - 260°F

250° - 220° F

200 - 180° F

Breakdown

Intermediate

Finish

Paver Speed and Output

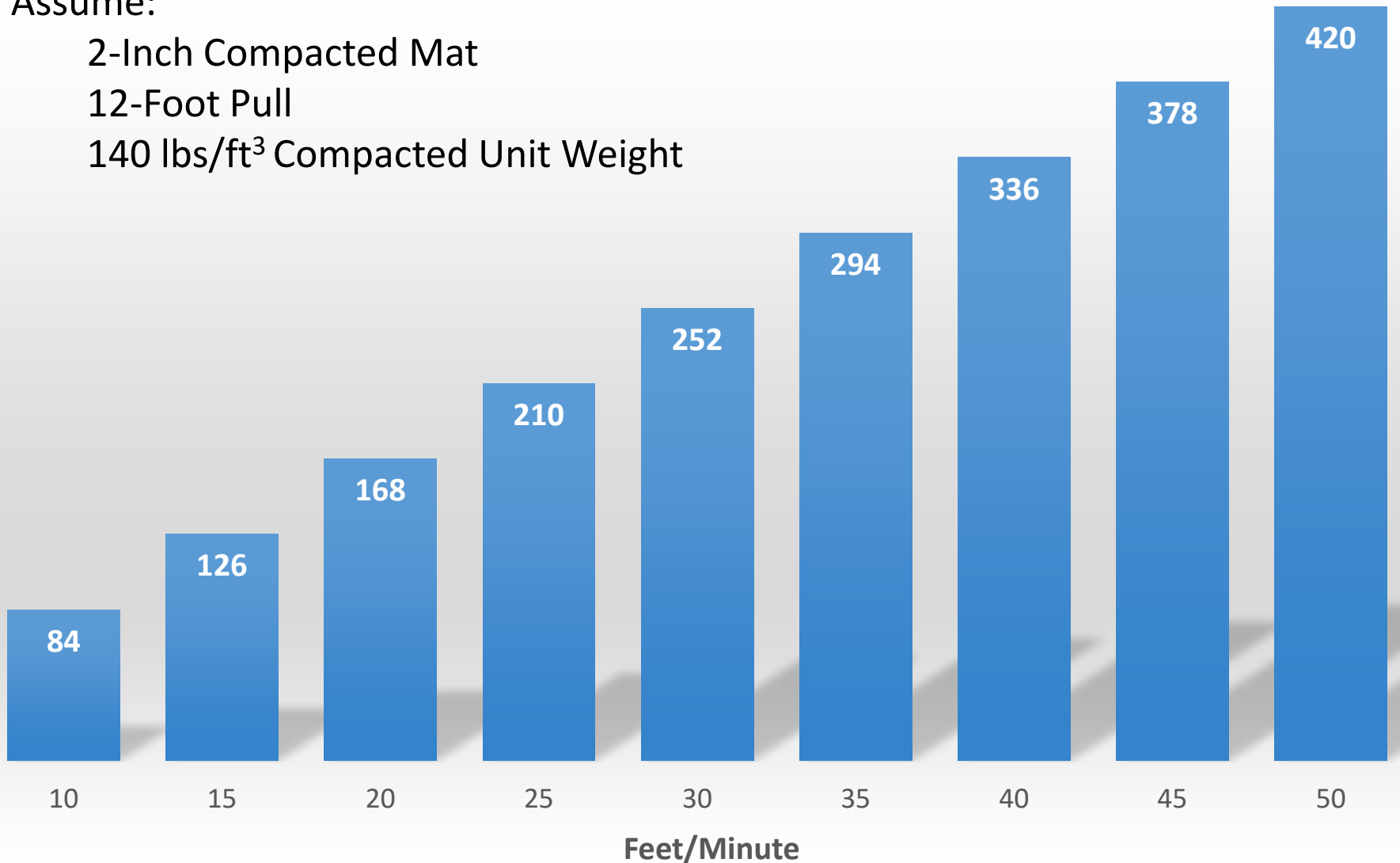
Assume:

2-Inch Compacted Mat

12-Foot Pull

140 lbs/ft³ Compacted Unit Weight

Tons/Hour

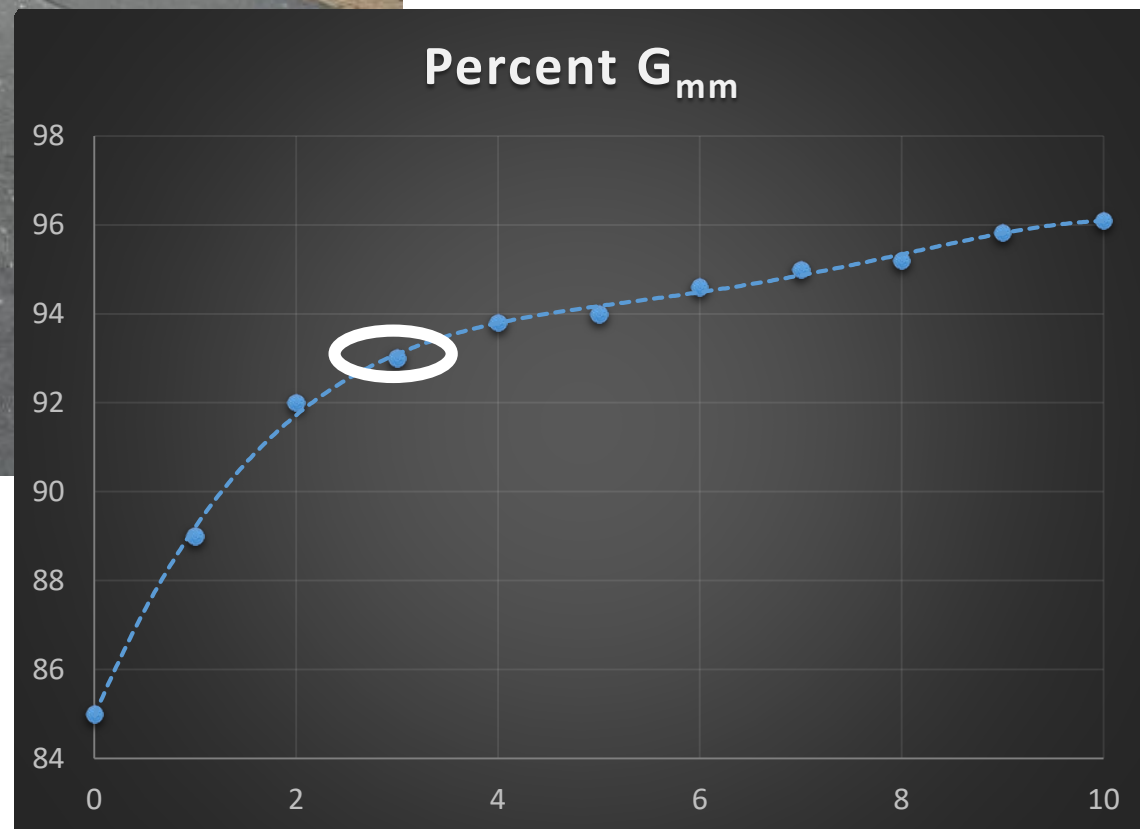


Establishing Rolling Pattern

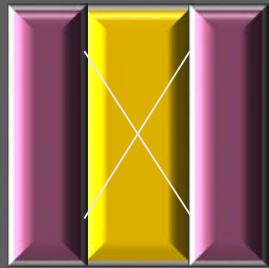


Goal: 93.5% G_{mm}

**Select: 3 Passes
(Intermediate will get
the rest of the density)**



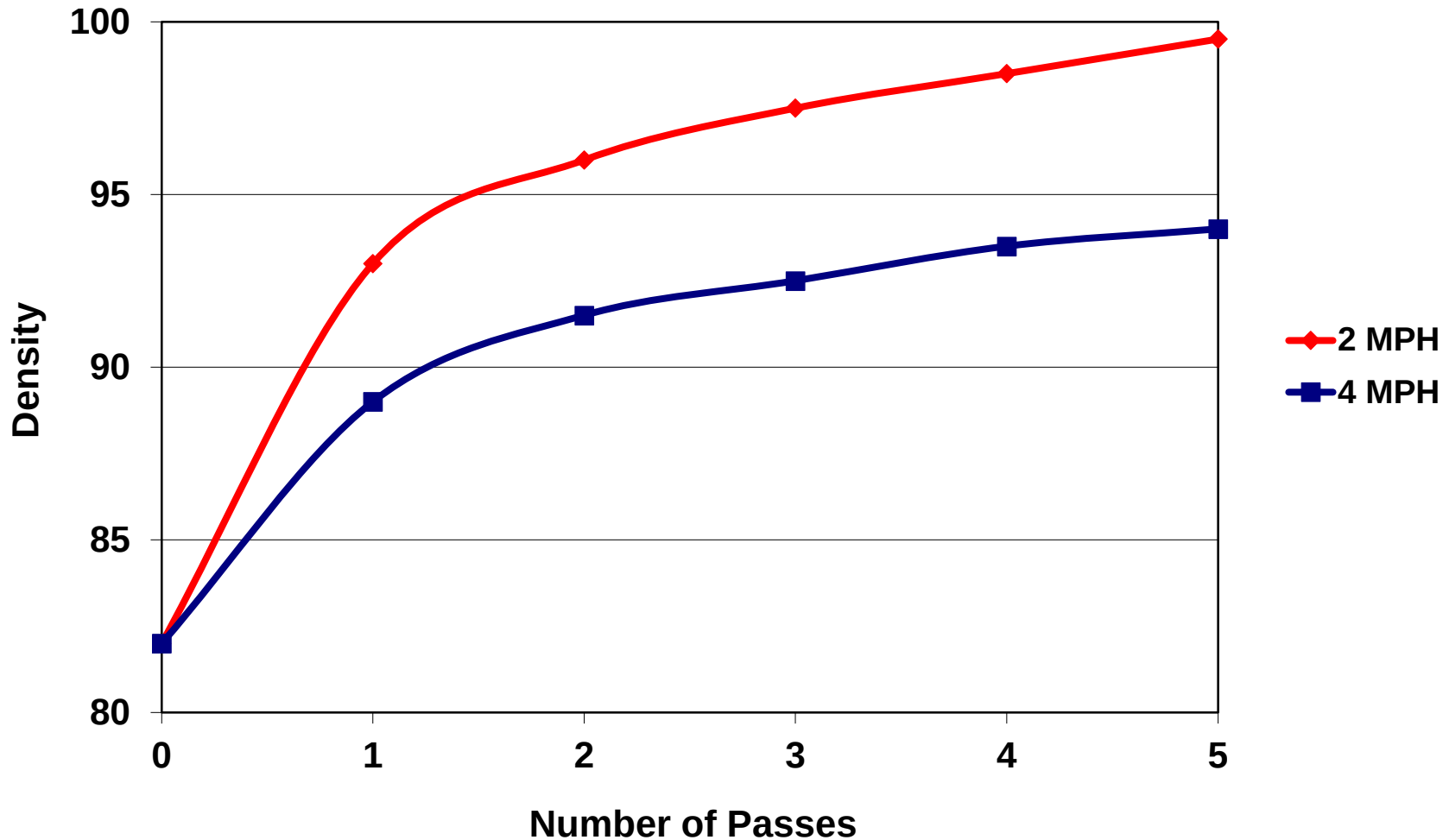
Rolling Pattern



← 100 - 170 ft →

- Roller width should overlap 6 inches
- Odd number of passes to advance
- Repeat uniformly

Roller Speed is Critical



Slower = More Compaction/Pass

Drum Impacts per Foot

Frequency	2 MPH	3 MPH	4 MPH	5 MPH
2000 vpm	11.36	7.58	5.68	4.55
2200 vpm	12.50	8.33	6.25	5.00
2400 vpm	13.64	9.09	6.82	5.45
2600 vpm	14.77	9.84	7.39	5.91
2800 vpm	15.91	10.61	7.95	6.36
3000 vpm	17.05	11.36	8.52	6.82
3200 vpm	18.18	12.12	9.09	7.27
3400 vpm	19.32	12.88	9.66	7.72
3600 vpm	20.45	13.64	10.22	8.18
3800 vpm	21.59	14.39	10.80	8.63
4000 vpm	22.72	15.16	11.36	9.10

Additional Vibratory Rollers



Vibratory Rollers - Amplitude

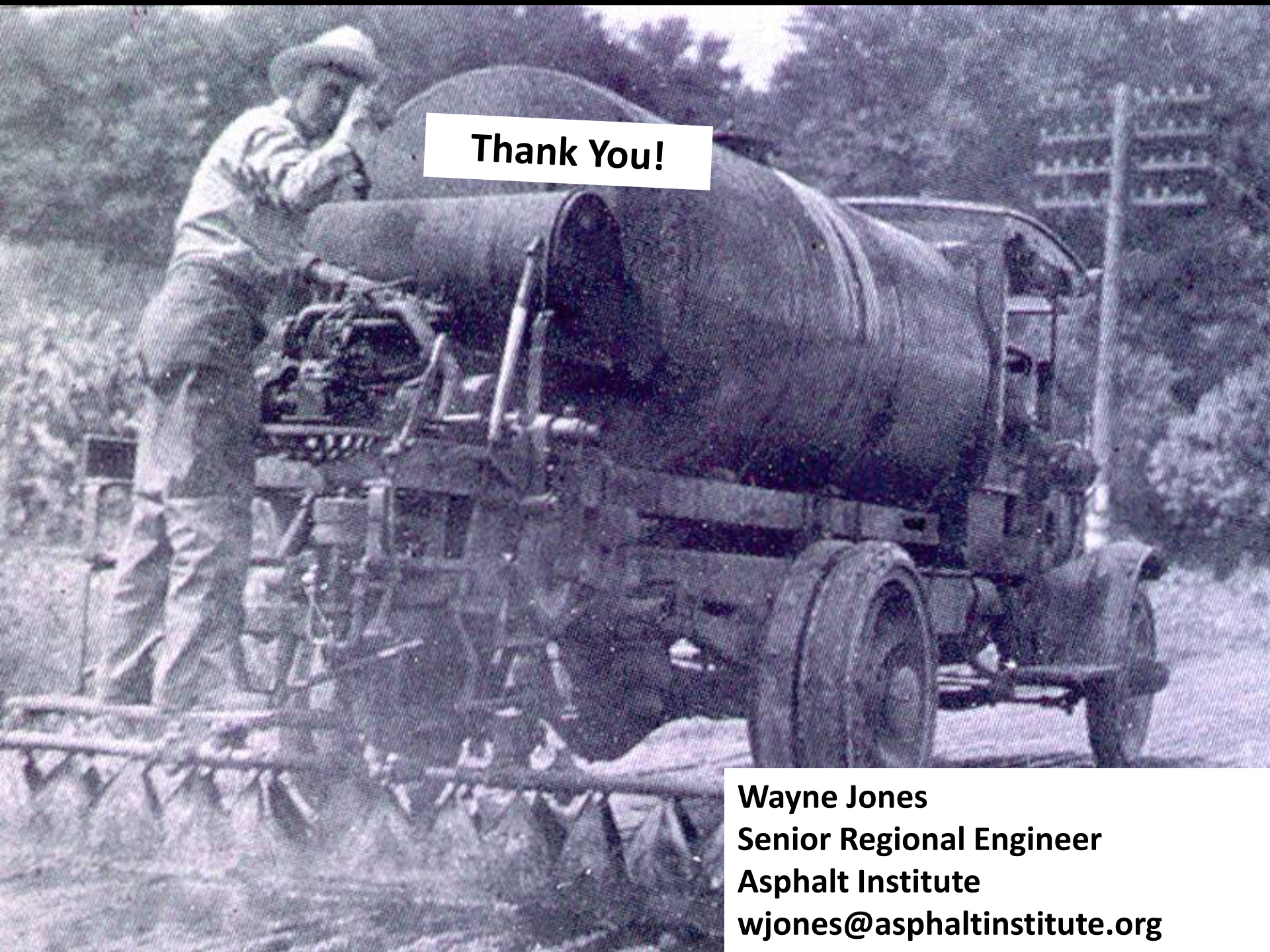


- **Amplitude too high**
- **Travel speed too fast**
- **Vibrating cool mat**
 - **Roll closer to paver**
- **Damaged gutter**
 - **Roll along interface**

Maximizing Our R.O.I.

- Infrastructure loads continue to rise
- Budget availability continues to fall
- Increased pavement life can be economically achieved
- Research shows a 10% increase in pavement life can be achieved by increasing compaction by 1%.

**What would a 3% increase in compaction
do for our industry?**



Thank You!

Wayne Jones
Senior Regional Engineer
Asphalt Institute
wjones@asphaltinstitute.org

Balanced Mix Design (BMD)



DAVE JOHNSON, P.E.

SENIOR REGIONAL ENGINEER, ASPHALT INSTITUTE

IDAHO ASPHALT CONFERENCE

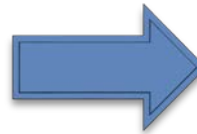
MOSCOW, IDAHO

Discussion Items

- Need for Balanced Mix Design
- Performance Testing Discussion
- Balanced Mix Design Examples
- FHWA Balanced Mix Design Task Force Efforts
- Next Steps



Need for Balanced Mix Design





Balanced Mix Design Definition

- *“Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.”*
- Basically, it consists of designing the mix for an intended application and service requirement.



Why the Need for a New Mix Design Approach?

- **Problems:**

- Relying on volumetrics along to provide performance
- Dry mixes exist in some (not all) areas

- **Solutions:**

- **Recognize performance issues** related to dry mixes in some areas. (Note: Many performance issues are caused factors outside the mix design)
- **Increase understanding** of the factors which drive mix performance
- **Design for performance** and not just to “the spec”.
- **Start thinking** outside of long held “rules and constraints”
- **Innovate!**



Mix Design Specifications

- Largely recipe driven
 - Aggregates and grading
 - Volumetrics (Va, VMA, VFA, D/A, etc.)
 - Binder grade and/or minimum %
 - RAP and/or RAS
 - WMA
- While this may work, there are problems
 - What happens when the recipe fails?
 - Specifications have become **convoluted and confounded**
 - ✦ Existing specified items compete against each other
 - ✦ New requirements get added and nothing gets removed
 - “Spec Book Creep”
 - Innovation has become stifled with our knowledge outpacing specifications



“Marshall method” pavement testing apparatus





Steps Must be Taken *Now* Towards Solutions

- **Each day**, approximately 1.4 Million tons of HMA are produced in the U.S. (M-F production basis)
 - *Equivalent to ~2500 lane miles @ 12' wide and 1.5" thick*
 - *Distance from New York to Las Vegas*



Long term research is certainly needed, but we must take steps
NOW towards a solution



Binder Content – Design vs. Optimum (There is a difference!)

- Design and optimum binder content are often used interchangeably
 - However, they mean two different things
- There can be many design binder contents for a mix, but only one truly optimum
- Optimum indicates the best binder content based **on intended application, performance requirements/needs, and ultimately economics**
- Goal is to get as close as possible to the true **optimum** for the mix



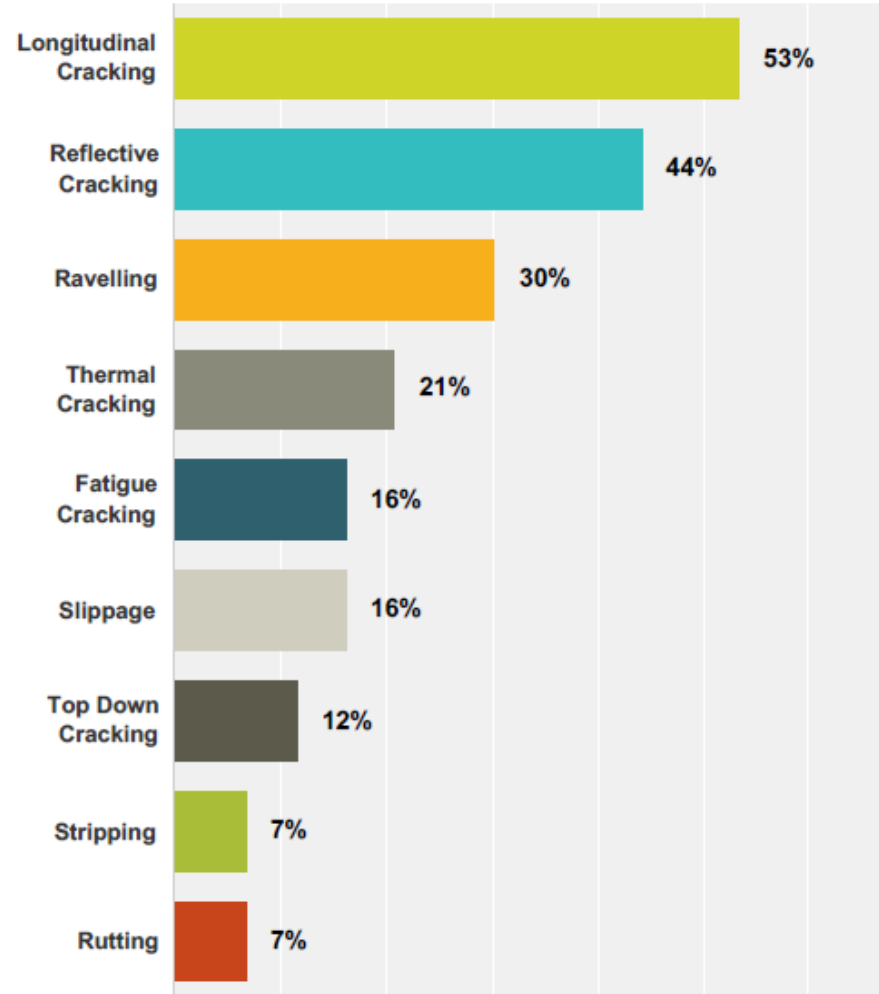


What Type Distress Is Occurring?

Oldcastle Survey Question:

Within the past 5 years, what type of mix performance related distress has been most evident in your mixes?

~40 companies responding from ~30 states



Balance the Mix Design

Smooth Quiet Ride
Skid Resistance

Strength/
Stability

Rut Resistance

Shoving

Flushing
Resistant

Durability

Crack
Resistance

Raveling

Permeability



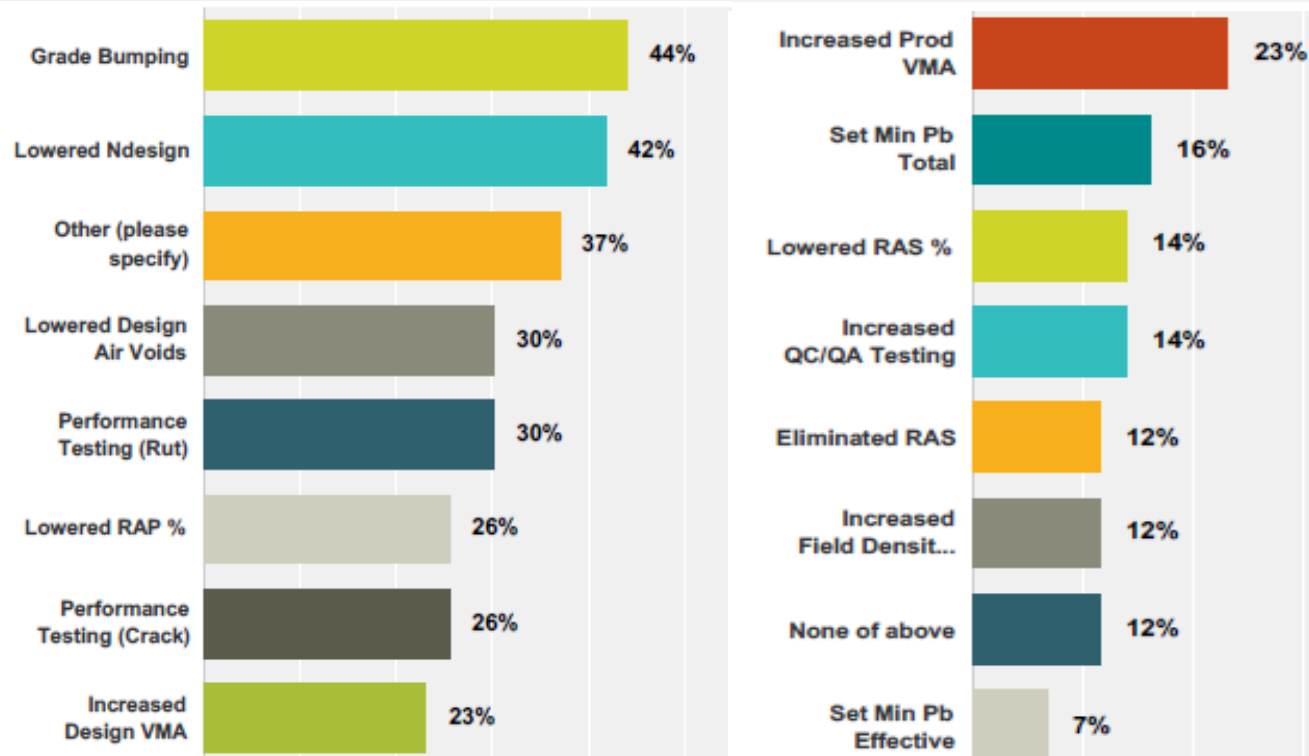
DON'T ATTACK ONE HALF AT THE EXPENSE OF THE OTHER HALF!!



Agencies Are Searching for Solutions: Spec Changes

- Superpave system is becoming unrecognizable with specifications changing rapidly as agencies search for ways to improve durability
- Establishing true “cause and effect” is impossible

Survey Question: Which of the following specification changes has your DOT implemented in the last 5 years?





Agencies are Searching for Solutions: Ndesign

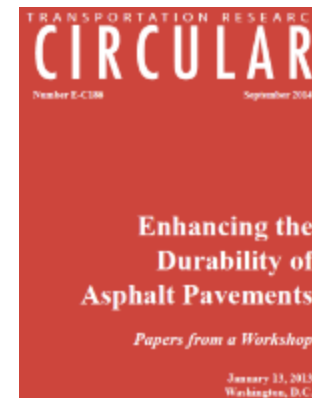
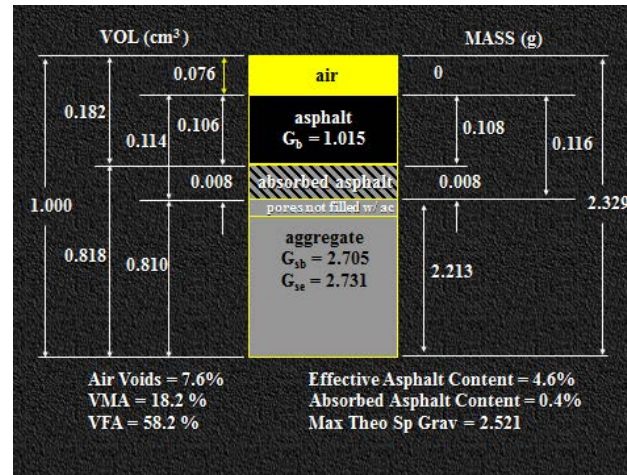
- Ndesign varies widely w/ levels being reduced with the *intent* of gaining more binder
- Problem:** Lower gyrations do not necessarily equate to more binder

State	Gyrations Level ¹	State	Gyrations Level ¹
Alabama	60	New Mexico	75, 100, 125
Arkansas	50, 75, 100, 125	New York	50, 75, 100
Colorado	75, 100	North Carolina	50, 65, 75, 100
Connecticut	75, 100	Ohio	65
Florida	50, 65, 75, 100	Oklahoma	64-22 (50), 70-28 (60), and 76-28 (80)
Idaho	50, 75, 100, 125	Oregon	65, 80, 100
Iowa	50, 60, 65, 68, 76, 86, 96, 109, 126	Pennsylvania	50, 75, 100
Kansas	75, 100	Rhode Island	50
Kentucky	50, 75, 100	Tennessee	65 or 75 Marshall
Maine	50, 75	Texas	50
Massachusetts	50, 75, 100	Utah	50, 75, 100, 125
Michigan	45, 50, 76, 86, 96, 109, 126	Vermont	50, 65, 80
Minnesota	40, 60, 90, 100	Virginia	65
Mississippi	50, 65, 85	Washington	50, 75, 100, 125
Missouri	50, 75, 80, 100, 125	West Virginia	50, 65, 80, 100
Montana	75		
Nebraska	40, 65, 95		
Nevada	Use Hveem		
New Hampshire	50, 75		
New Jersey	50, 75		

As of March 2015

Enhancing the Durability of Asphalt Pavements

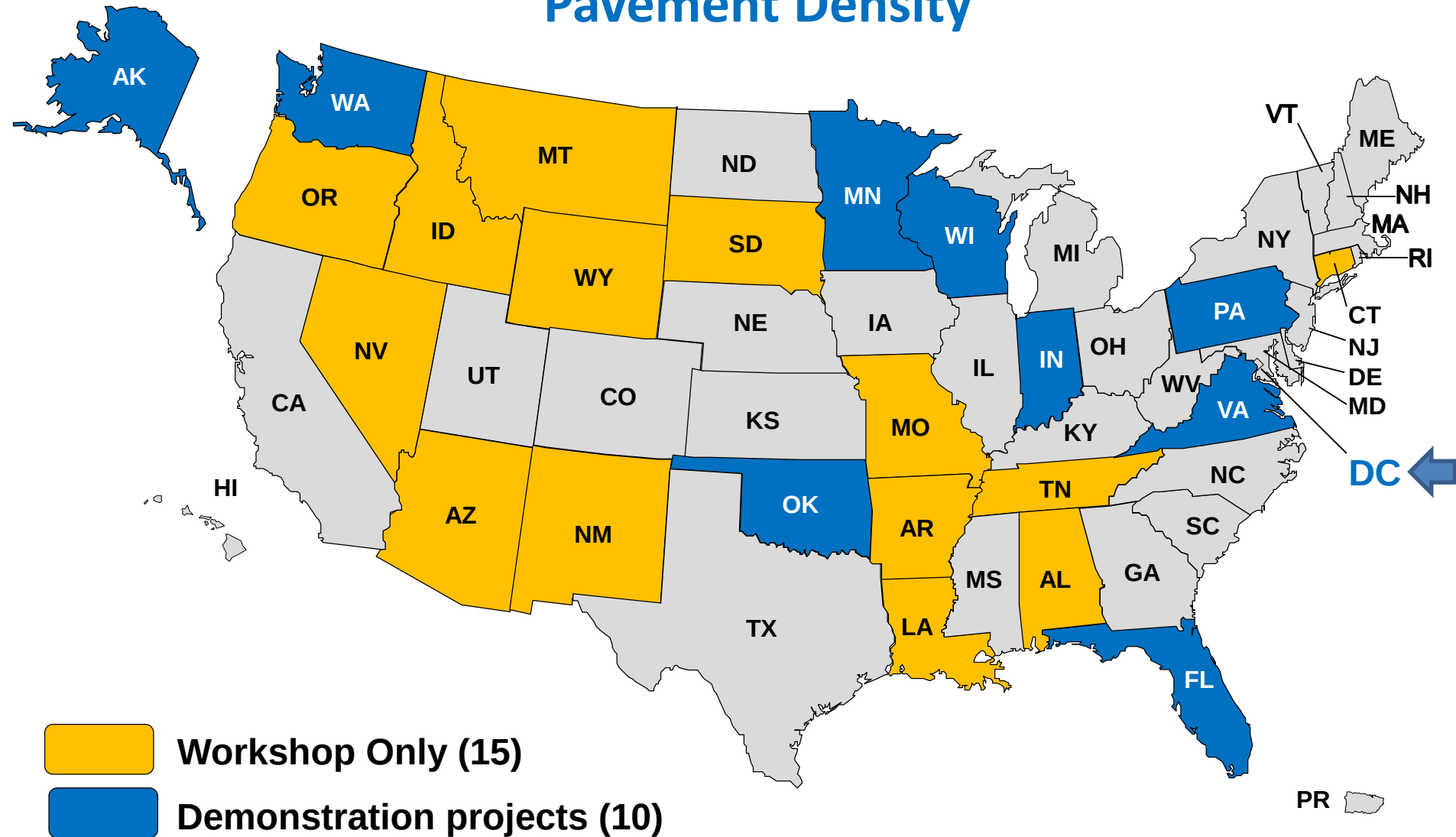
- **“Volume of Effective Binder (Vbe)** is the primary mixture design factor affecting both durability and fatigue cracking resistance.”
 - **$Vbe = VMA - \text{Air Voids}$**
- “A number of state highway agencies have **decreased the design gyration levels** in an attempt to increase effective binder contents. However, **decreasing the design gyrations may not always produce mixtures with higher Vbe.**”



Impact of Mix Design on Asphalt Pavement Durability

RAMON BONAQUIST
Advanced Asphalt Technologies, LLC

Enhanced Durability of Asphalt Pavements through Increased In-Place Pavement Density



History of Mix Design

1890

- **Barber Asphalt Paving Company**
- Asphalt cement 12 to 15% / Sand 70 to 83% / Pulverized carbonite of lime 5 to 15%

1905

- **Clifford Richardson, New York Testing Company**
- Surface sand mix: 100% passing No. 10, 15% passing No. 200, 9 to 14% asphalt
- Asphaltic concrete for lower layers, VMA terminology used, 2.2% more VMA than current day mixes or ~0.9% higher binder content

1920s

- **Hubbard Field Method** (Charles Hubbard and Frederick Field)
- Sand asphalt design
- 30 blow, 6" diameter **with compression test (performance)** asphaltic concrete design (Modified HF Method)

Stability

1927

- **Francis Hveem** (Caltrans)
- Surface area factors used to determine binder content; **Hveem stabilometer and cohesionmeter** used
- Air voids not used initially, mixes generally drier relative to others, fatigue cracking an issue

Stability + Durability

1943

- **Bruce Marshall**, Mississippi Highway Department
- Refined Hubbard Field method, standard compaction energy with drop hammer
- Initially, only used air voids and VFA, VMA added in 1962; **stability and flow** utilized

Stability + Durability

1993

- **Superpave**
- Level 1 (volumetric)
- Level 2 and 3 (performance based, but **never implemented**)

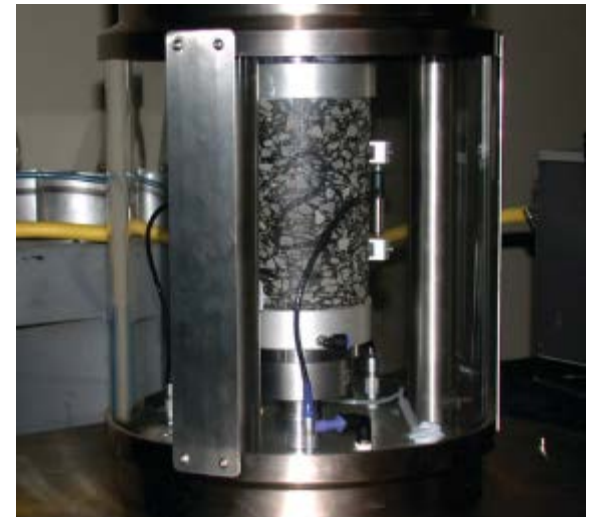
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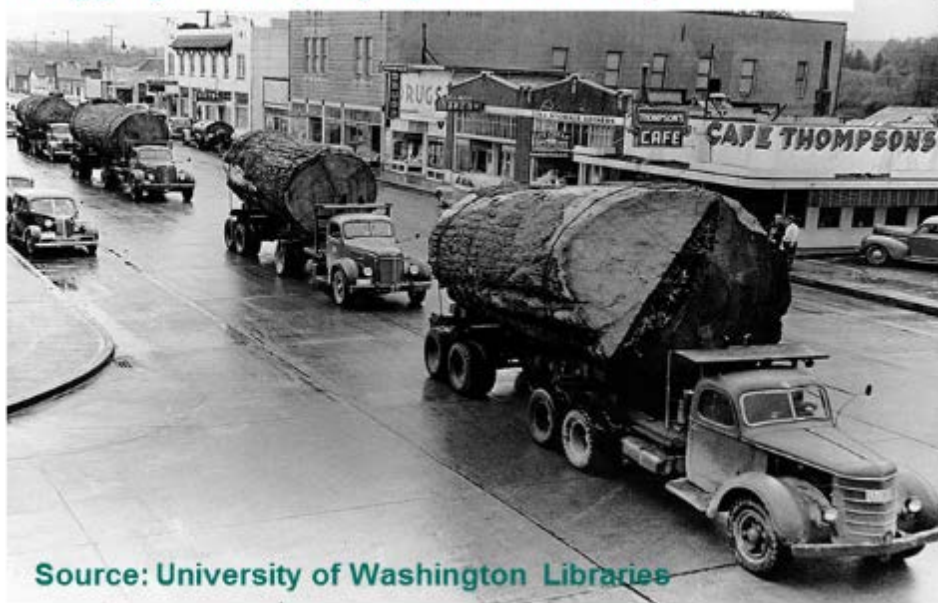
Idaho 2016

Performance Testing of Asphalt Mixes



Stability Testing

Logging Trucks, Olympic Peninsula, 1947



Source: University of Washington Libraries





Stability Evaluation

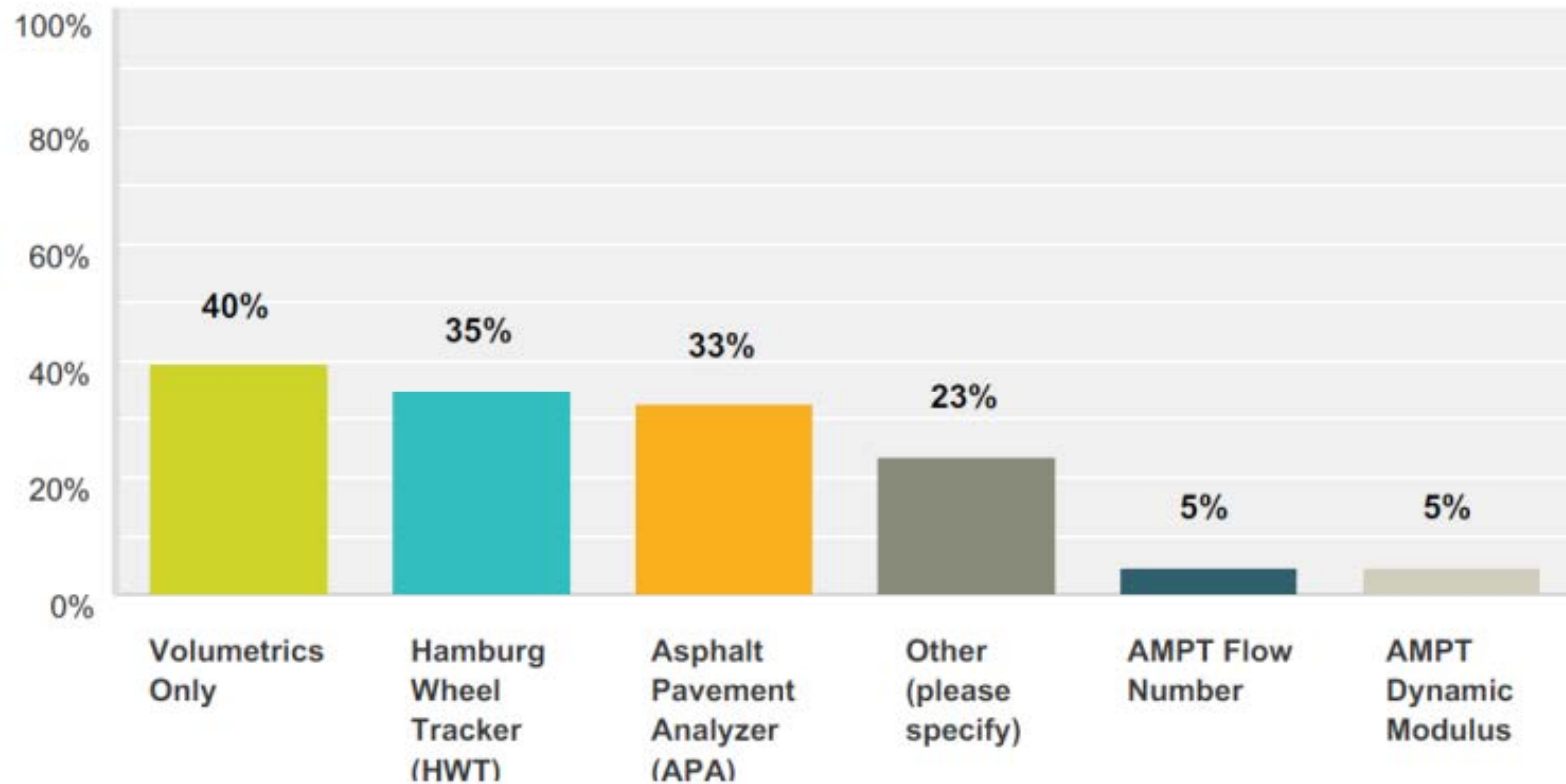
- Evaluate mix stability with one of several available “rutting” tools.
 - Hamburg, APA, AMPT Flow Number, etc.
 - Failure criteria
 - ✦ Based on best available research (local, regional, or national)
 - ✦ Function of traffic (e.g., low, medium, high) and/or mix end use applications





Stability Evaluation Survey

Survey Question:
How does your state DOT evaluate the rutting potential of designed dense graded asphalt mixes?



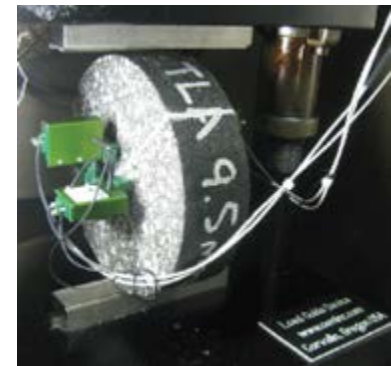
Durability Testing





Durability/Cracking Evaluation

- Durability/cracking evaluation is **substantially more complicated** than stability
 - What is the mode of distress?
 - What is the aging condition?
- Cracking prediction is a known “weak” link in performance testing
 - No general consensus the best test(s) or the appropriate failure threshold
- **GOALS**
 - **MATCH THE TEST TO THE DISTRESS**
 - **SET APPROPRIATE FAILURE THRESHOLDS**



Match the Test to the Distress

• Four-point Bending

• Disc Shaped Compact Tension

• Texas Overlay Test

Fatigue

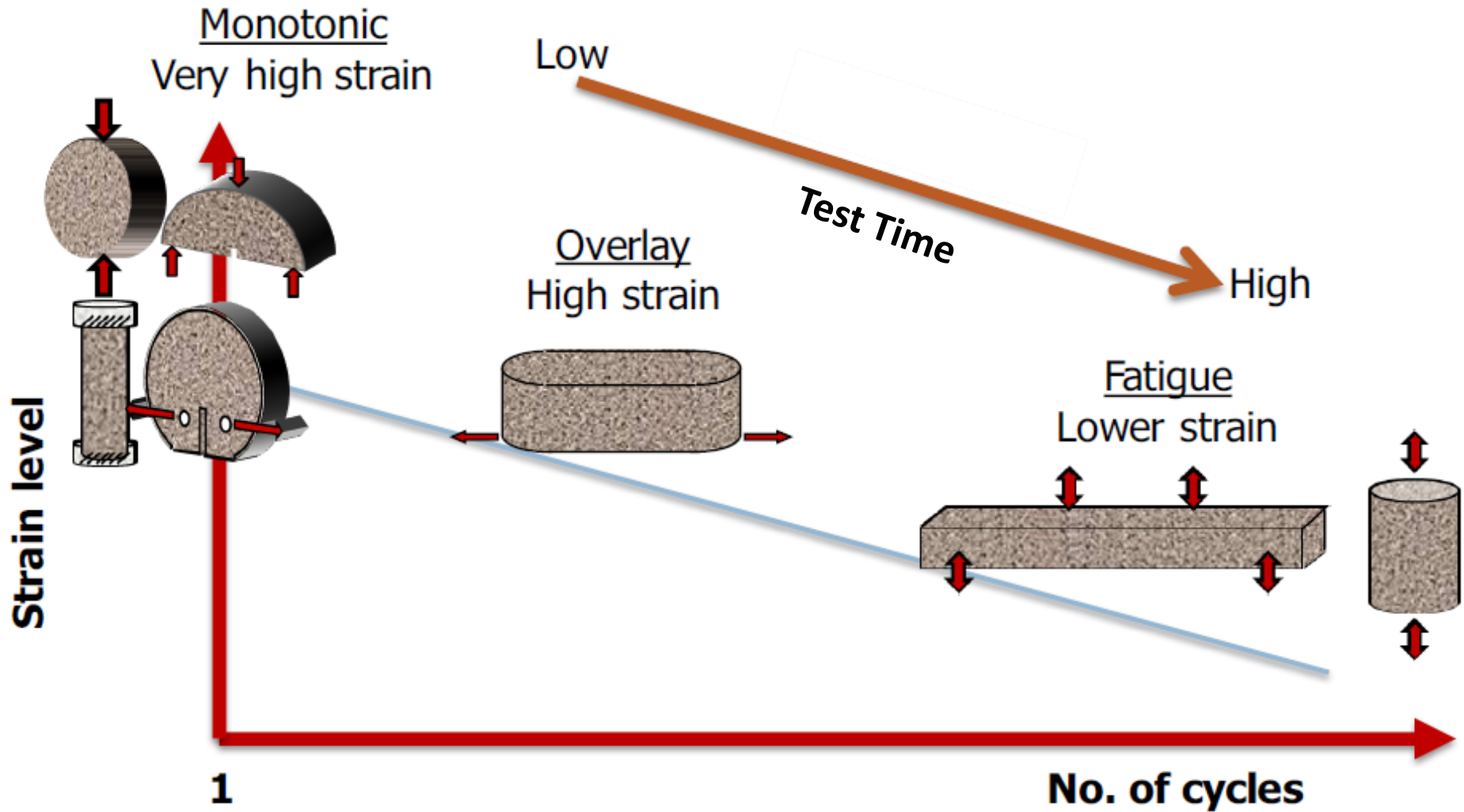
Thermal

Reflective

• Indirect Tension

• Semi-Circular Bending

Cracking Tests: Strain and Cycles Illustration





What is the Best Cracking Test? It Depends!

- NCHRP 9-57: Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures
 - Top tests for various distresses identified by national group of academia, agency, and industry representatives

August 2016

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Responsible Senior Program Officer:
Edward T. Harrigan

Research Results Digest 399

FIELD VALIDATION OF LABORATORY TESTS TO ASSESS CRACKING RESISTANCE OF ASPHALT MIXTURES: AN EXPERIMENTAL DESIGN

This digest summarizes key findings of research conducted in NCHRP Project 09-57, "Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures," by the Texas A&M Transportation Institute, Texas A&M University, College Station, Texas. This digest is based on the project final report authored by Dr. Fujie Zhou, Dr. David Newcomb, Mr. Charles Gurganus, Mr. Seyedamin Banihashemrad, Dr. Maryam Sakhaeifar, Dr. Eun Sug Park, and Dr. Robert L. Lytton. The complete project final report and three appendixes are available to download at <http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3644>.

Table 3 Cracking tests selected at the workshop.

Thermal Cracking Tests	Reflection Cracking Tests	Bottom-Up Fatigue Cracking Tests	Top-Down Cracking Tests
1. DCT	1. OT	1. Beam fatigue	1. IDT-Florida
2. SCB-IL	2. SCB-LTRC	2. SCB-LTRC	2. SCB-LTRC
3. SCB (AASHTO TP 105)	3. BBF	3. OT*	

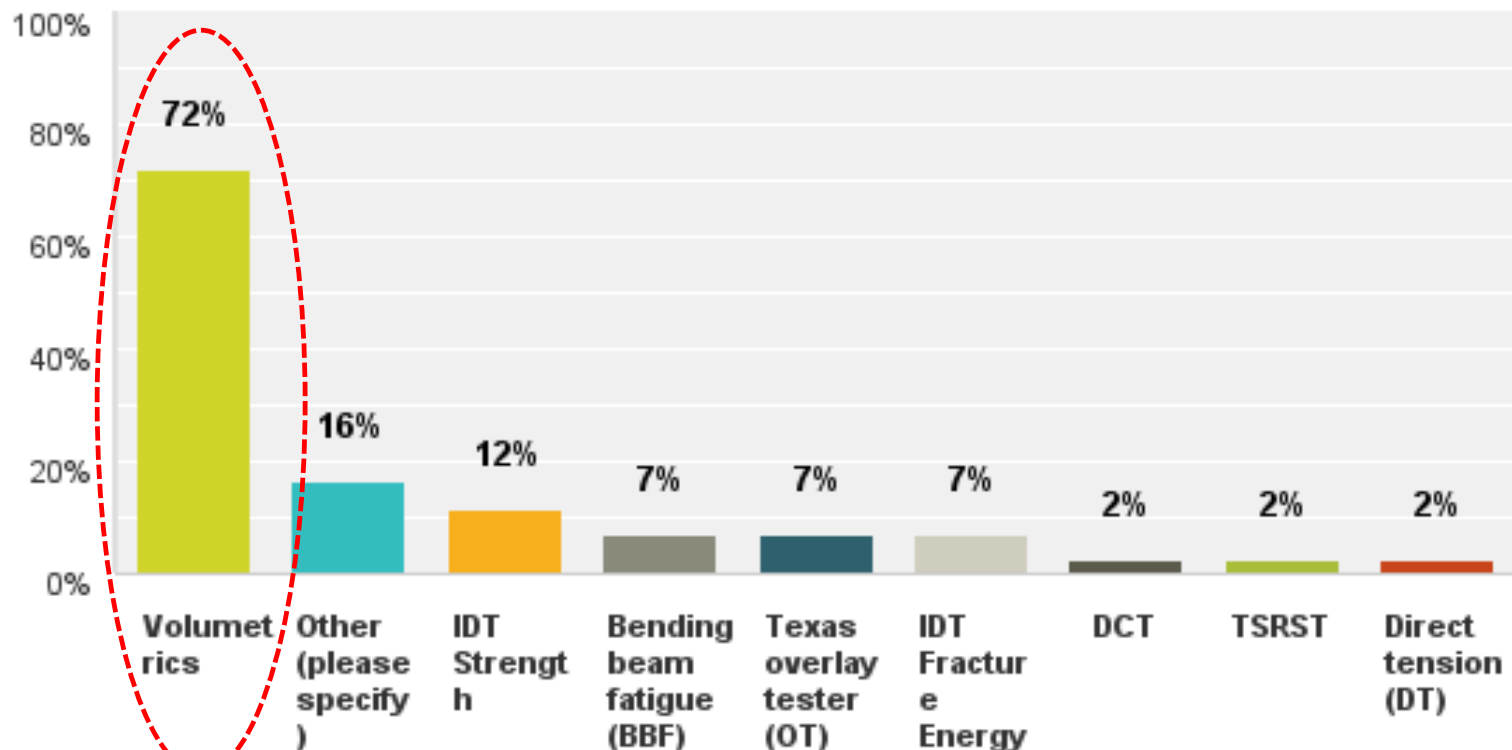
*OT for fatigue cracking was added later by request of the panel.

Note: SCB-IL is now I-FIT

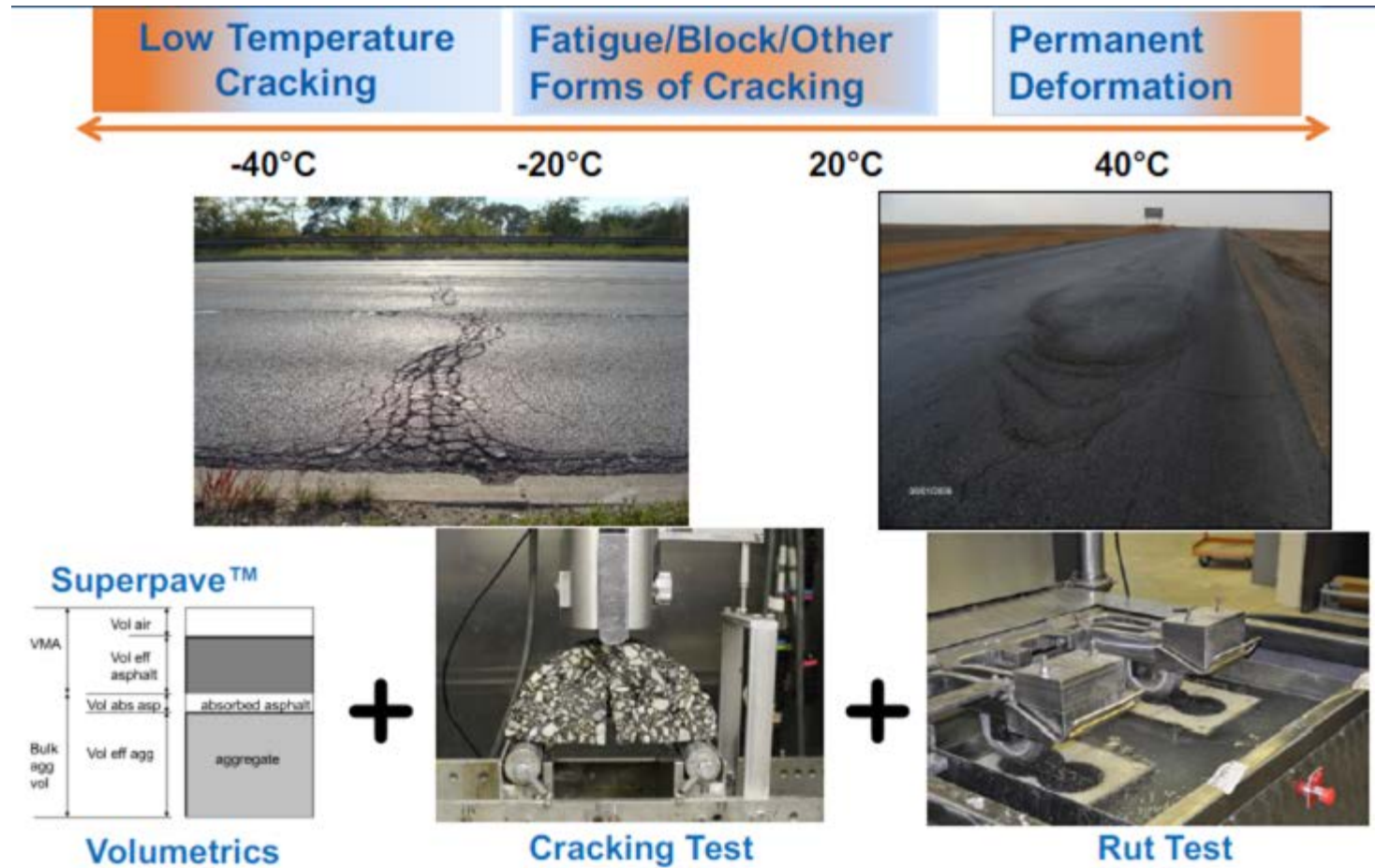
Durability/Cracking Evaluation Survey

Survey Question:

How does your state DOT evaluate the durability/cracking potential/of designed dense graded asphalt mixes?

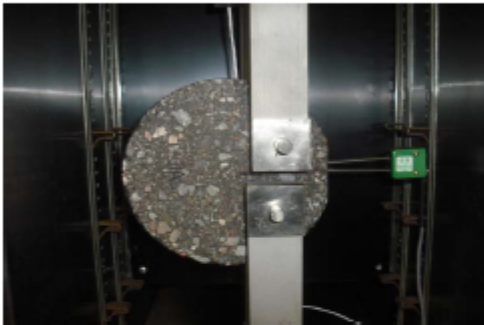


Use of Performance Testing in Design - Illinois



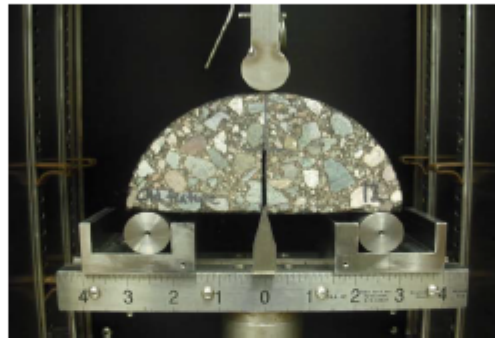
Use of Performance Testing in Design - Wisconsin

Thermal Cracking DC(t)



LT (-18 or -24°C)

Fatigue Semi-Circular Bend



IT (25°C)

Rutting Hamburg



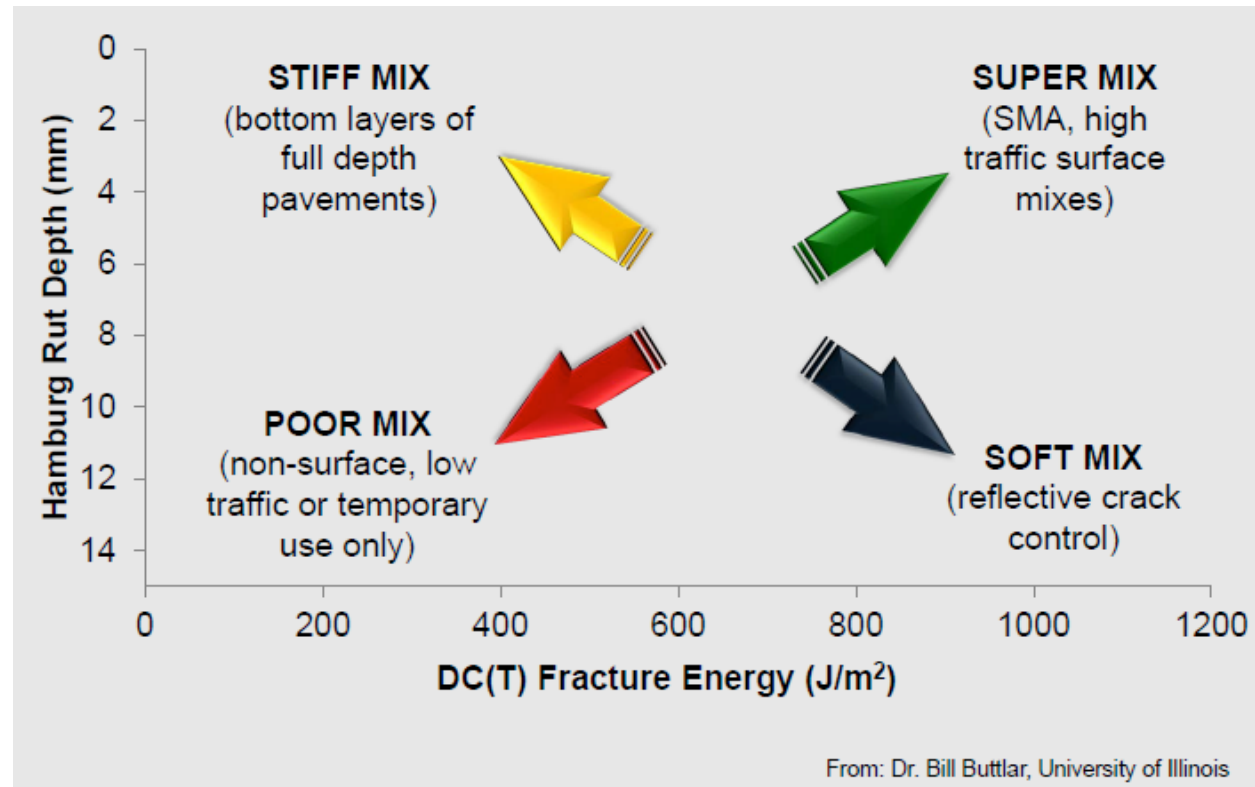
HT (50°C)

Long Term Aging – AASHTO R30 (5 days at 85°C)

- SCB and DCT
- Recovered binder grade and ΔT_c

Performance Space Diagrams

- Performance space diagrams show the performance of a mix related to multiple tests
- Allows the mix designer to visualize the mix performance and how to engineer the mix to provide the desired performance
- Illustrates the impact of varying mix factors on performance.



FHWA Performance Based Mix Design

	Fatigue Cracking	Rutting
Design Air Voids For every 1% increase	40% increase	22% decrease
Design VMA For every 1% increase	73% decrease	32% increase
Compaction Density For every 1% lower in-place Air Voids (Increasing Density Improved Both!)	19% decrease	10% decrease

Courtesy of Nelson Gibson

- Design at 5% air voids and compact to 5% voids in field (95% G_{mm})
- Lower design gyration to increase in-place density
 - No change in rutting resistance
 - No change in stiffness
 - Improve pavement life
 - Reduced aging
- Maintained Volume of Eff. Binder (V_{be})
 - Increased VMA by 1%

Balanced Mix Design Task Force

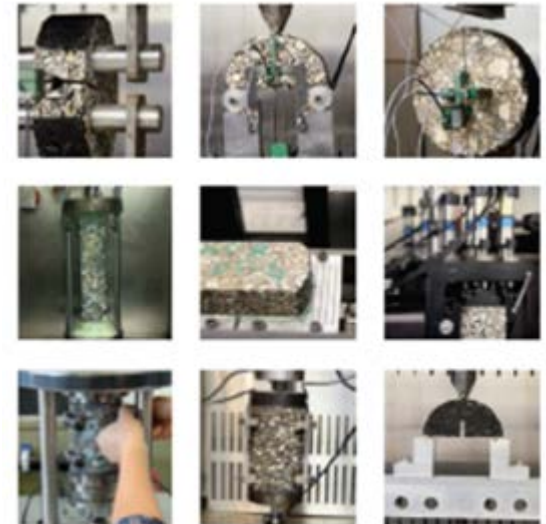
- Development and Work





Task Force Development

- At the request of the National Pavement Implementation Executive Task Group (PIETG) the Balanced Mix Design Task Force formed at the September 2015 FHWA Mixture and Construction ETG meeting
- Focus Areas
 - Define Balanced Mix Design
 - Determine the current “state of practice” of BMD
 - Present approaches/concepts for immediate use
 - Recommend future needs (potential research) to advance BMD approaches
 - Disseminate information



BMD Task Force Membership



Name	Affiliation	Category	e-mail
Dave Newcomb	Texas Transportation Institute	Academia/Research	d-newcomb@ttimail.tamu.edu
John Haddock	Purdue University	Academia/Research	jhaddock@purdue.edu
Kevin Hall	University of Arkansas	Academia/Research	kdhall@uark.edu
Louay Mohammad	Louisiana State University	Academia/Research	Louaym@Lsu.edu
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Bryan Engstrom	Massachusetts DOT	Agency	Brian.Pfeifer@illinois.gov
Charlie Pan	Nevada DOT	Agency	cpan@dot.state.nv.us
Curt Turgeon	Minnesota DOT	Agency	curt.turgeon@state.mn.us
Derek Nener-Plante	Maine DOT	Agency	derek.nener-plante@maine.gov
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Gerry Huber	Heritage Research	Industry	Gerald.huber@hrglab.com
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Anne Holt	Ontario Ministry of Transportation	Provincial Agency	Anne.Holt@ontario.ca
Randy West	NCAT	Research	westran@auburn.edu

Balanced Mix Design Definition





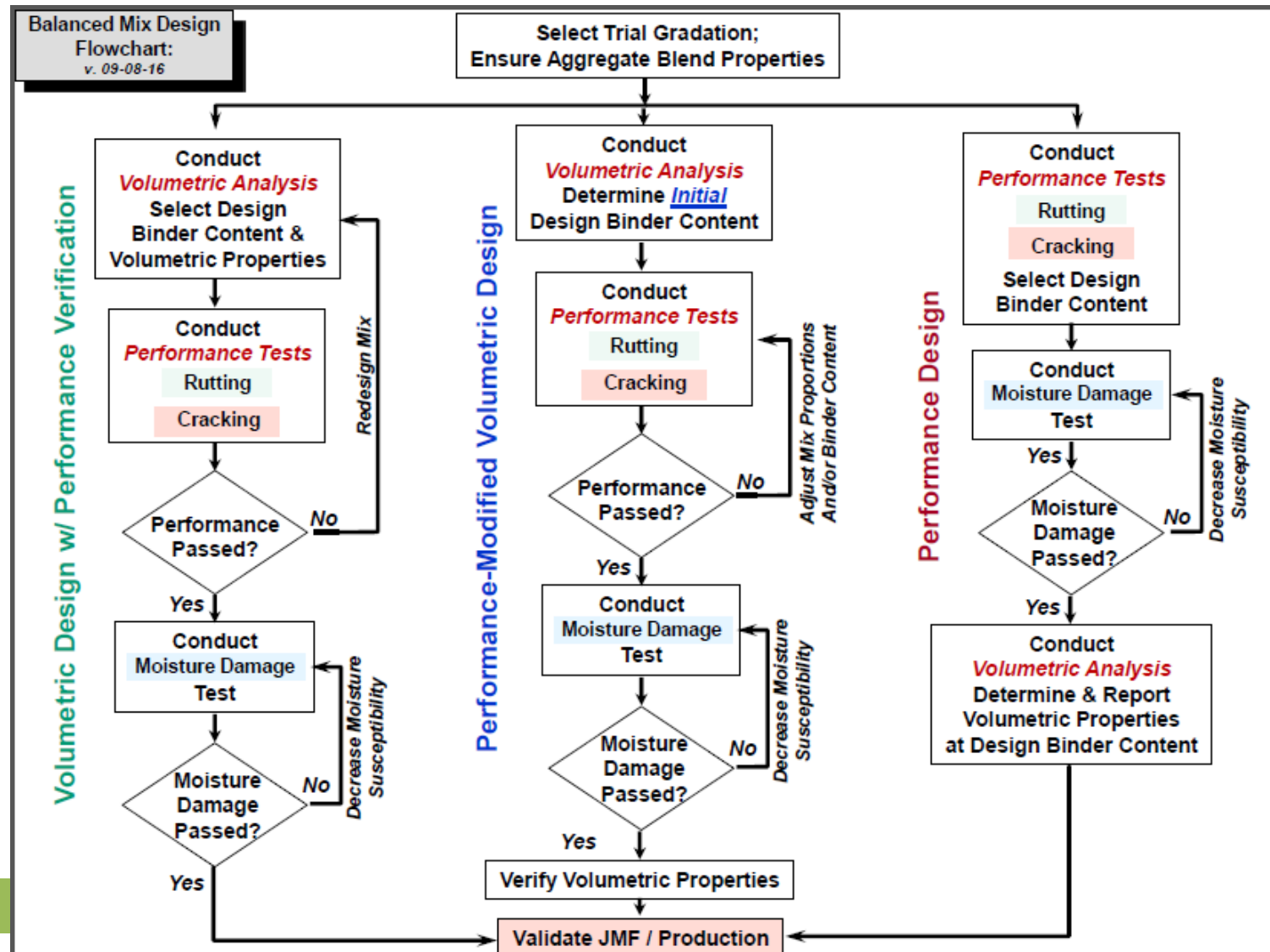
Balanced Mix Design Definition

- *“Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.”*
- Basically, it consists of designing the mix for an intended application and service requirement.

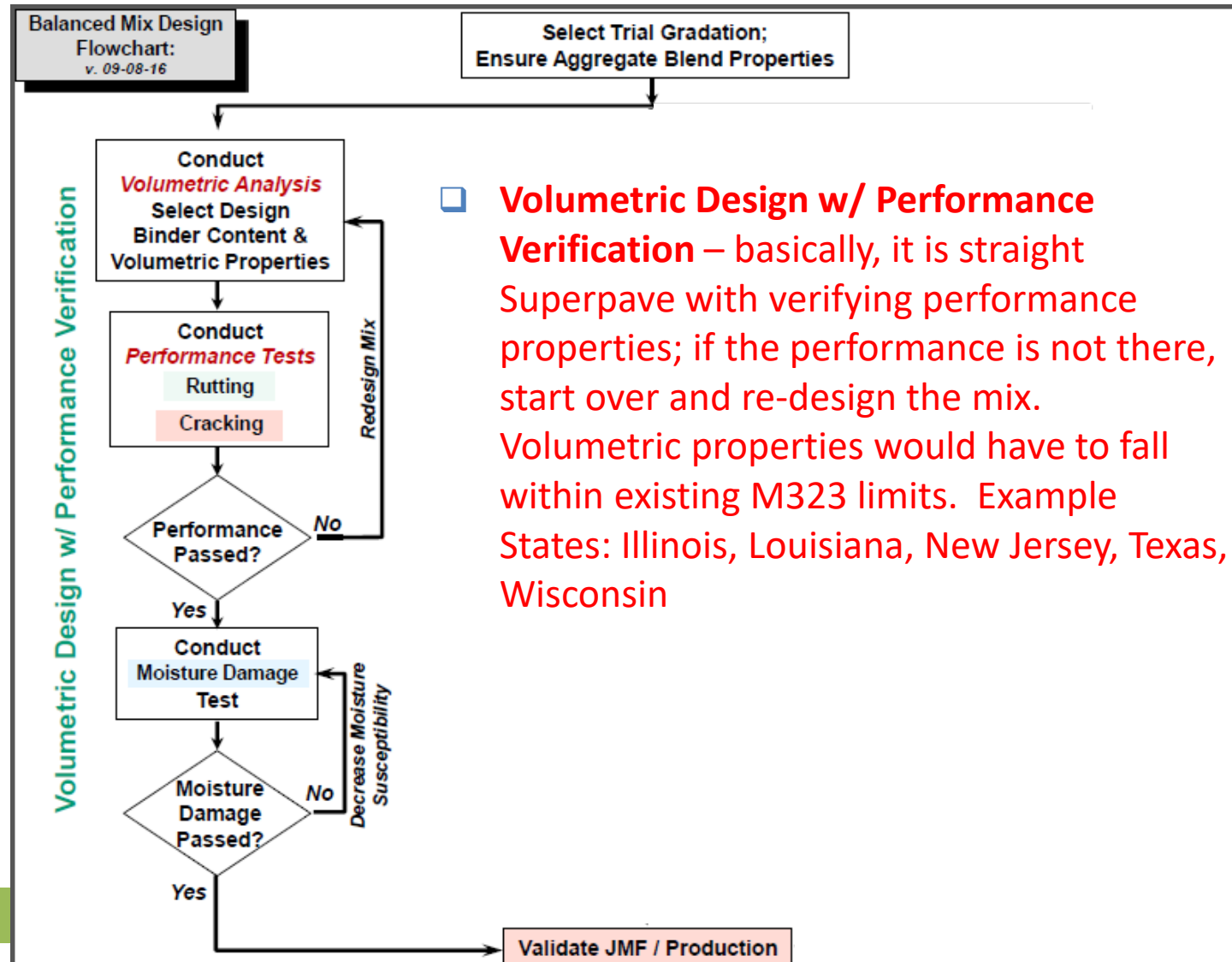
Agency Practices Related to BMD



Agency Approaches – 3 Main Approaches Identified



Volumetric Design w/ Performance Verification



Performance Modified Volumetric Design

Balanced Mix Design
Flowchart:
v. 09-08-16

Select Trial Gradation;
Ensure Aggregate Blend Properties

Conduct
Volumetric Analysis
Determine *Initial*
Design Binder Content

Conduct
Performance Tests
Rutting
Cracking

Performance
Passed?

No

Adjust Mix Proportions
And/or Binder Content

Yes

Conduct
Moisture Damage
Test

Moisture
Damage
Passed?

No

Decrease Moisture
Susceptibility

Yes

Verify Volumetric Properties

Validate JMF / Production

Performance-Modified Volumetric Design

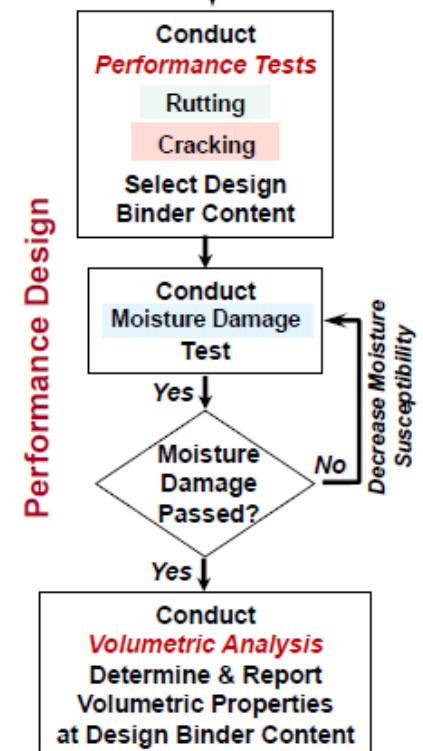
- Performance-Modified Volumetric Design – the initial design binder content is selected using M323/R35 prior to performance testing; the results of performance testing could ‘modify’ the mixture proportions (and/or) adjust the binder content – and the final volumetric properties may be allowed to drift outside existing M323 limits. Example State: California

Performance Design

Balanced Mix Design
Flowchart:
v. 09-08-16

Select Trial Gradation;
Ensure Aggregate Blend Properties

- **Performance Design** – this involves conducting a suite of performance tests at varying binder contents and selecting the design binder content from the results. Volumetrics would be determined as the 'last step' and reported – with no requirements to adhere to the existing M323 limits. Example States: New Jersey w/ draft approach

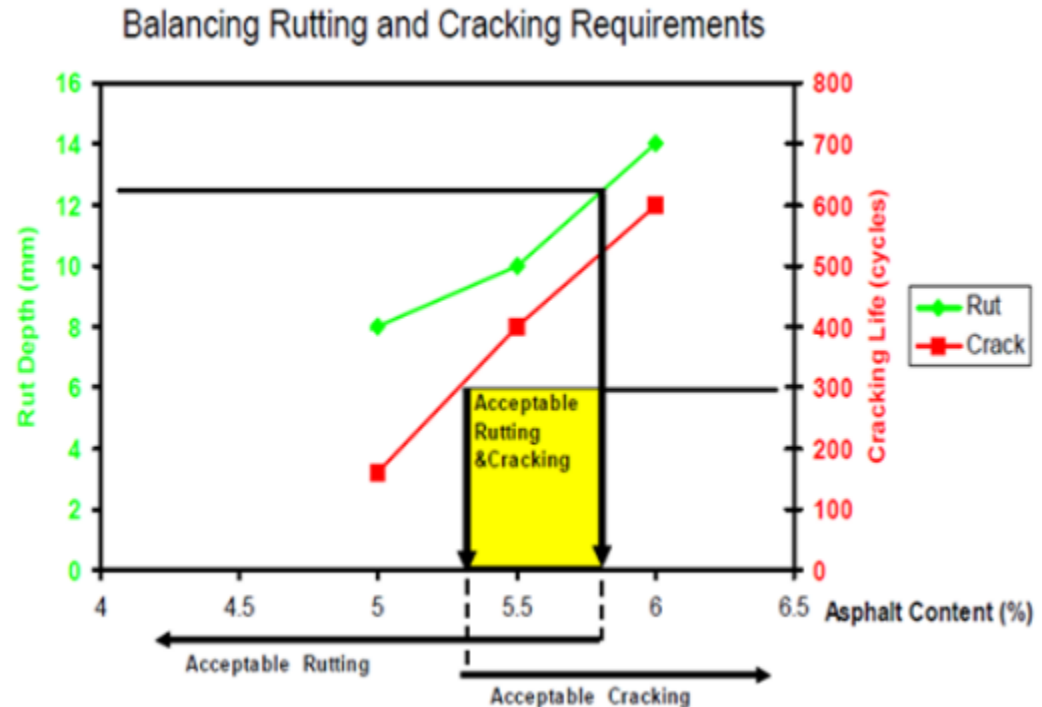


Validate JMF / Production

BMD Basic Example – Volumetric Design w/ Performance Verification

- **Texas DOT**

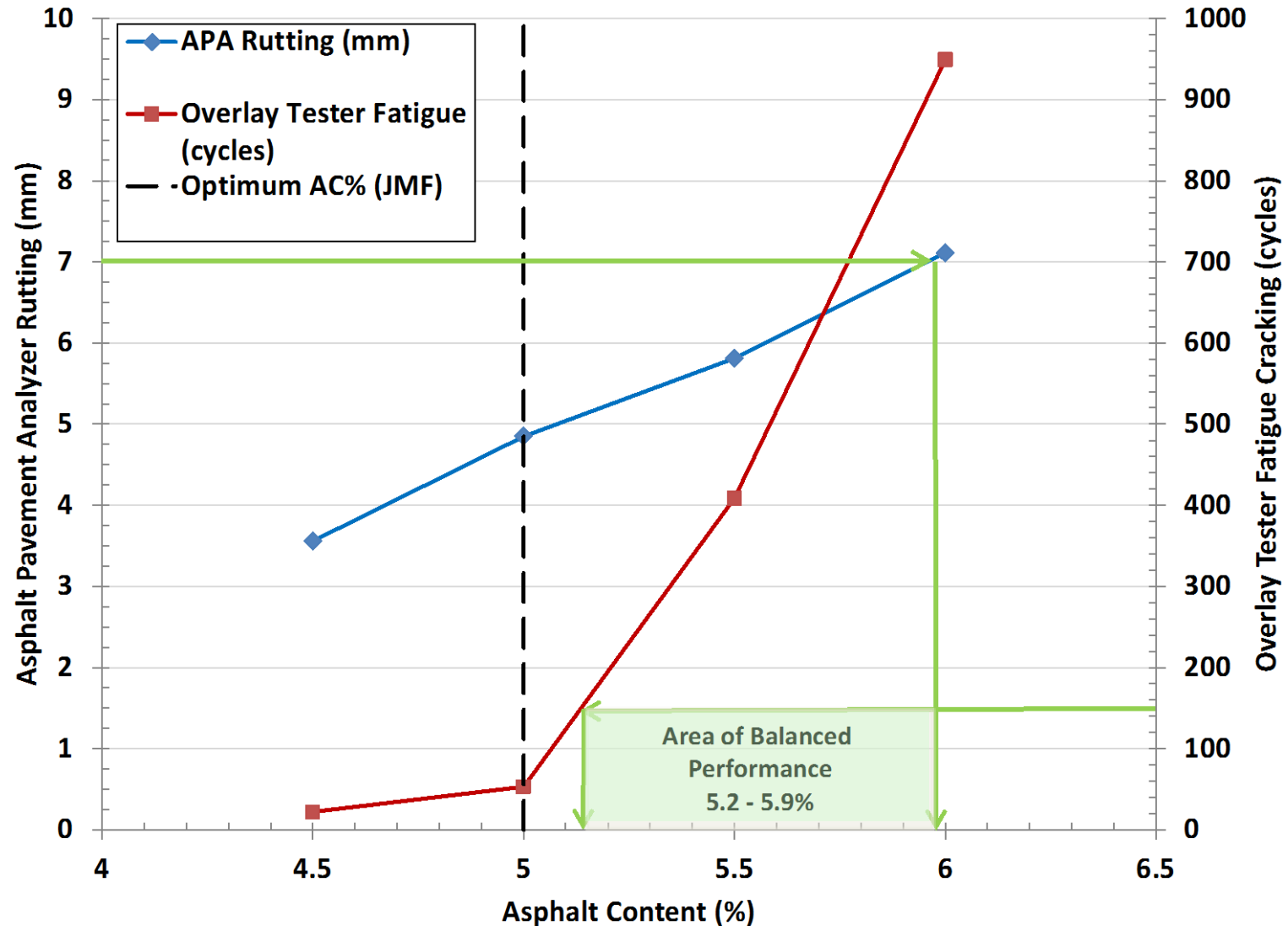
- Volumetric design conducted
- Hamburg Wheel Tracking Test (HWTT) AASHTO T 324
- Overlay Tester (OT) Tex-248-F
- Three asphalt binder contents are used: optimum, optimum +0.5%, and optimum -0.5%.
- The HWTT specimens are short-term conditioned.
- The OT specimens are long-term conditioned.



Within this acceptable range (5.3 to 5.8 percent), the mixture at the selected asphalt content must meet the Superpave volumetric criteria.

- Balanced Mixture Design Concept
- Mixes are designed to optimize performance
 - Not around a target air void content
- Take an existing virgin mix design
 - Start at a “dry” binder content
 - Add binder at 0.5% increments – measure rutting and cracking
 - Determine range where rutting and cracking are optimized
 - Conduct volumetric work
- Performance criteria (limits) already determined based on virgin mixes

New Jersey Balanced Design



Courtesy of Tom Bennert

- Most NJ mixes found to be below (dry) of the balanced area
- Plant QC air voids requirements need to be re-evaluated to account for the added binder
- Changes in production volumetrics are likely required to move the mixes in the right direction



FHWA Technical Brief - Draft

- Technical Brief being developed to provide a current summary of the BMD TF efforts.
- Target publication of end 2016 (or sooner).

TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the

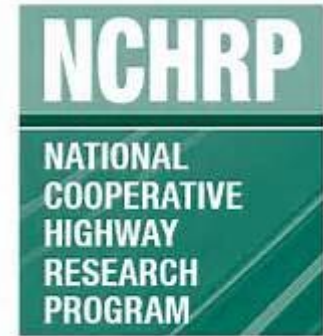
Balanced Mixture Design Approaches for Asphalt Pavement Construction

This *Technical Brief* provides an overview of balanced mixture design (BMD) approaches currently used by states in asphalt pavement construction. These approaches are still under development and this document will attempt to show the current status and some of the issues that will need to be addressed in the future.



Research Proposal: NCHRP 20-07 Project

- Research Problem Statement prepared and submitted last week to AASHTO for a NCHRP 20-07 Project.
 - ***Development of a Framework for Balanced Asphalt Mixture Design and Gap Analysis***
- Goals
 - Survey of all state highway agencies (SHAs) to determine the use and status of BMD practices
 - Review of literature for the development and state-of-the-practice for performance testing,
 - Develop a practice that is a framework for BMD for implementation of performance testing in the design of asphalt mixtures,
 - Develop research problem statements with funding needs based on gaps identified for development of a more detailed standard practice for BMD, and
 - Prepare a final report that documents results, summarizes findings, draws conclusions, and presents the (a) proposed practice and (b) research problem statements based on identified gaps with funding needs and a recommended plan for submittal.



NCHRP Project 20-07/Task ...

Project Title: *Development of a Framework for Balanced Asphalt Mixture Design and Gap Analysis*

Fiscal Year: 2016

Contract Time: 12 months

Funds: \$100,000

Staff:

Staff Phone:

Staff Email:

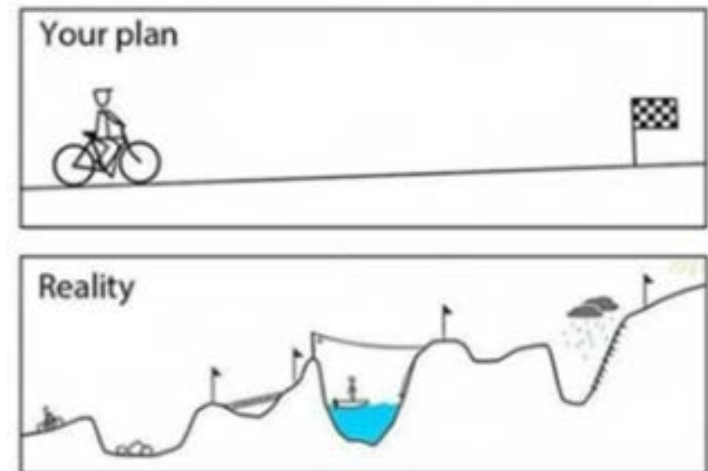
RFP Close Date (*proposal due date*):

Proposals must be submitted by email to:



The Path Forward for Balanced Mix Design

- Recognize the need and move incrementally in the appropriate direction to limit risk of mix performance issues.
- Must continue with theoretical research/modeling efforts, but not be afraid to utilize practical approaches to find solutions.
- **Recognize that this is a long term effort with ups/downs, but we must start now.**

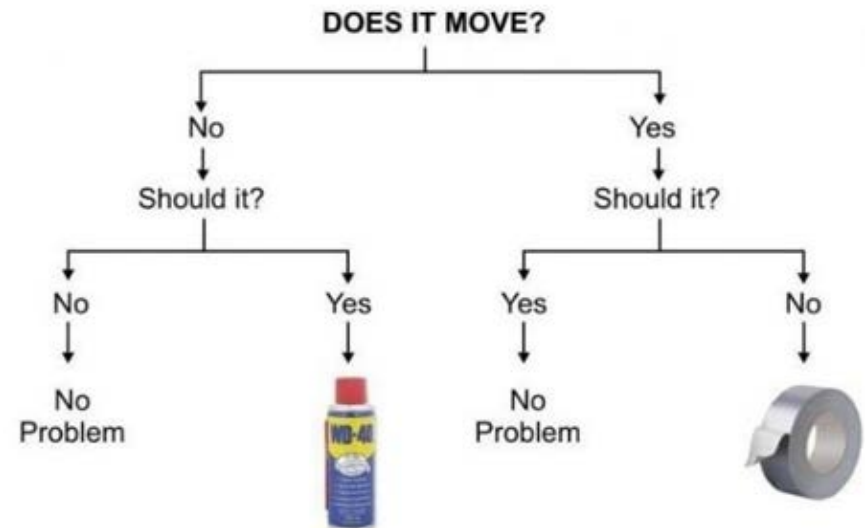


Final Thoughts on Mix Design

- Key Points to Keep in Mind
 1. **“Use What Works”**
 2. **“Eliminate What Doesn’t”**
 3. **“Be as Simple as Possible, Be Practical, and Be Correct”**



Engineering Flowchart



“Good doesn’t have to be complicated and complicated isn’t always good!”

What is Achievable?

