Multiple Stress Creep Recovery (MSCR): State of the Practice

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MSCR Implementation

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- Purpose
- Basics
- Test Temperature
- Recovery
- Variability
- Why?

Purpose

- Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
  - AASHTO T350
  - ASTM D7405
- Uses the concepts of creep and recovery testing to evaluate an asphalt binder's potential for permanent deformation.

Purpose

- Persistent concern since the inception of the PG Asphalt Binder Specification (AASHTO M320)
  - G*/sin δ may not adequately characterize the performance properties of all modified asphalt binders
    - Testing to determine G* occurs in the small strain, linear viscoelastic region
    - In the LVE region, the stiffness properties of the base asphalt and modification will dominate the response
  - In the region of higher strain the modification plays a much more significant role
    - High strain region is where damage is expected to occur

Purpose

- Studies have shown that the MSCR test generates results for modified asphalt binders that better relate the contribution of the asphalt binder to the permanent deformation of the asphalt mixture than the G*/sin δ parameter generated from the DSR using AASHTO T315.
  - Higher strain in the MSCR than in T315

Purpose

- Studies have shown that the MSCR test generates results for modified asphalt binders that better relate the contribution of the asphalt binder to the permanent deformation of the asphalt mixture than the G*/sin δ parameter generated from the DSR using AASHTO T315.
  - Higher strain in the MSCR than in T315

- Meaning?
  - Rutting is dependent on more than the asphalt binder properties

MSCR Implementation

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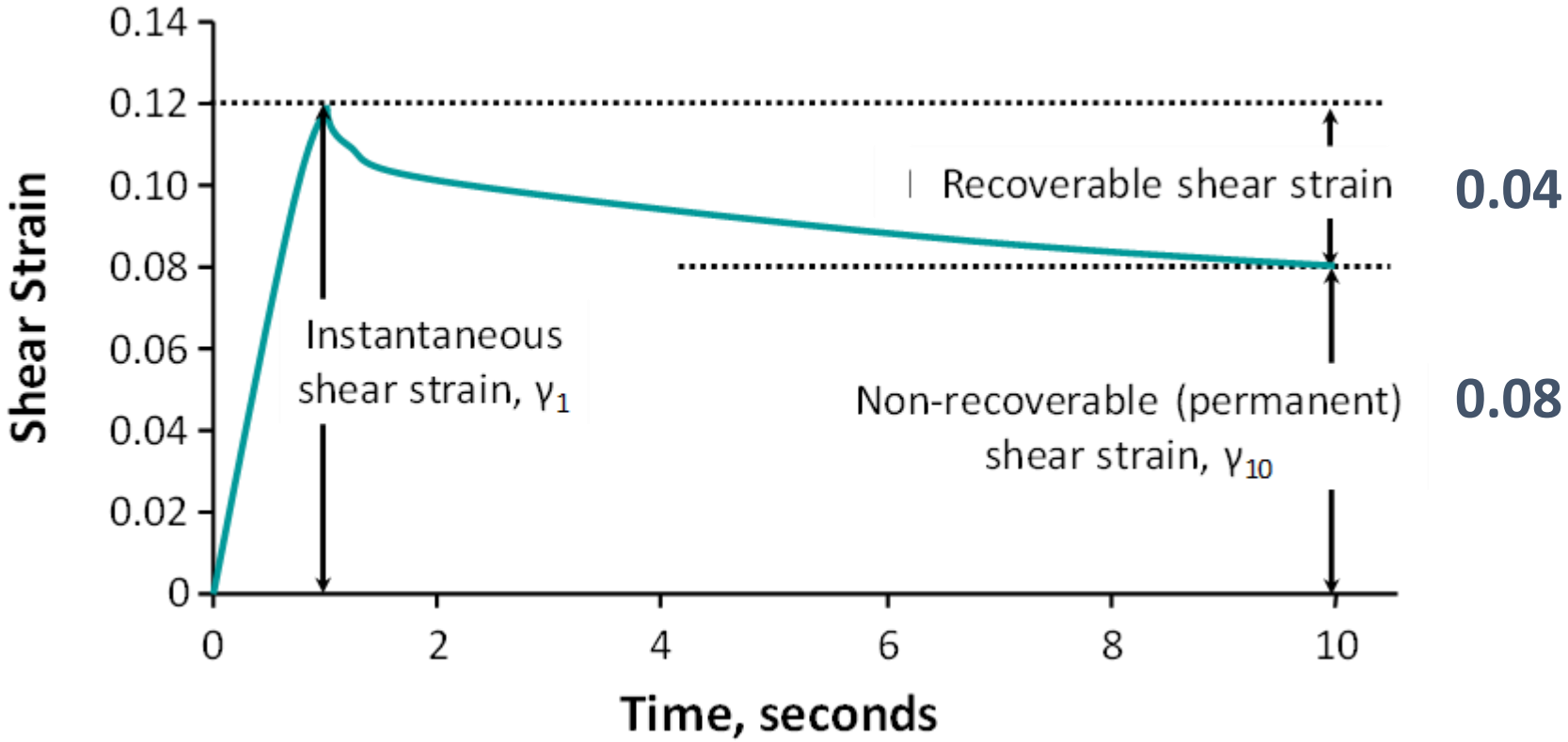
Performing the Test (AASHTO T 350)

- Typically performed on RTFO-aged Binder
- Same geometry as T315 testing
  - 25-mm parallel-plate geometry
  - 1-mm gap
- Test Temperature
  - Environmental Temperature
  - Not Grade-Bumped
- 10 cycles per stress level
  - 1-second loading at specified shear stress
    - 0.1 kPa
    - 3.2 kPa
  - 9-second rest period

Calculating and Understanding Test Output

- Calculate Non-recoverable Creep Compliance (J_{nr})
  - Non-recoverable shear strain divided by applied shear stress
    - "J" = "compliance"
    - "nr" = "non-recoverable"
- Calculate Recovery
  - Difference between strain at end of recovery period and peak strain after creep loading
- Calculate Difference in J_{nr} as a Function of Stress Level

Calculating and Understanding Test Output



Assume $\tau = 0.1$ kPa

$J_{nr0.1} = \gamma_{nr}/\tau$

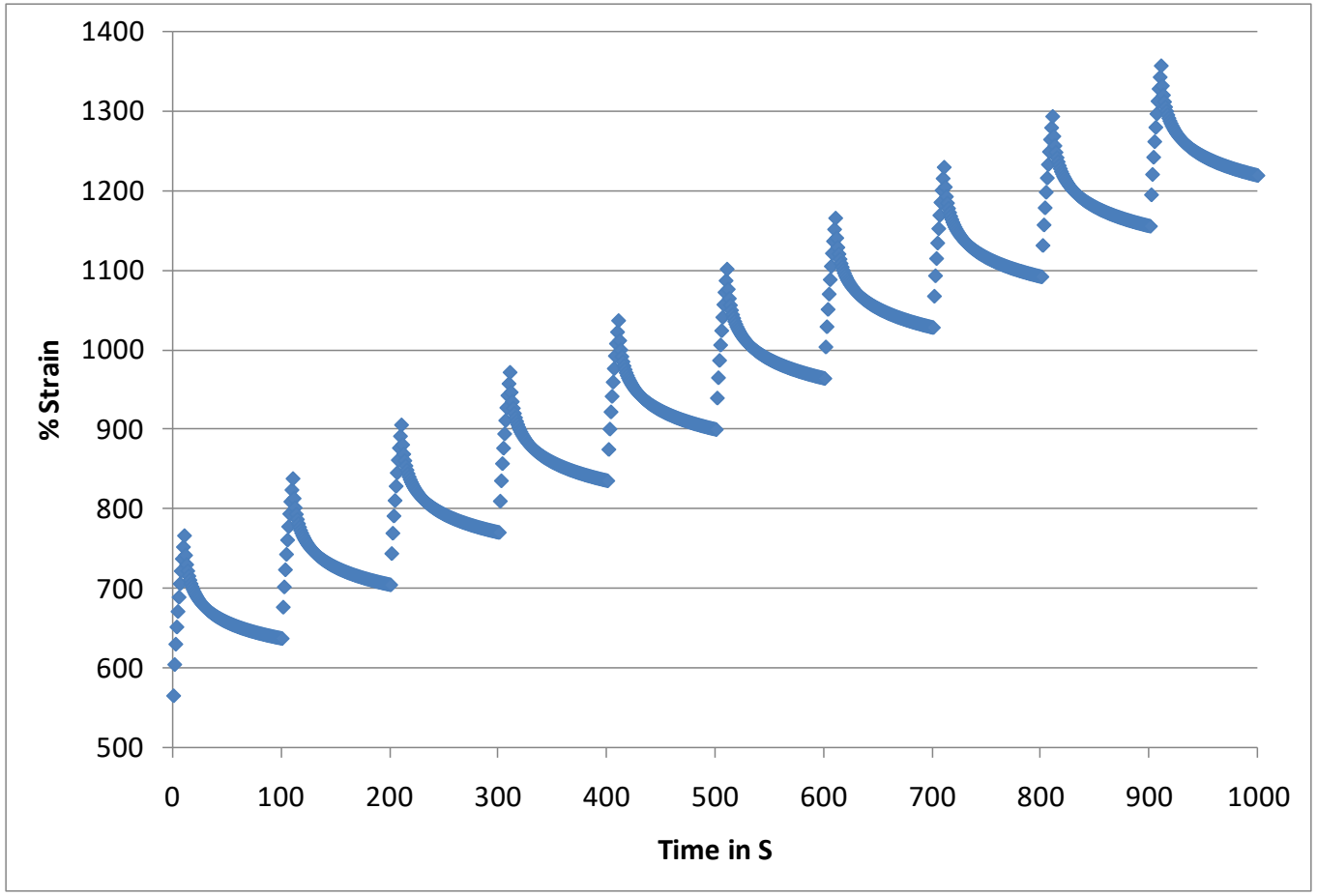
$J_{nr0.1} = 0.08/0.1$ kPa $= 0.8$ kPa^{-1}

Assume $\tau = 0.1$ kPa

$R_{0.1} = \gamma_r / \gamma_i$

$R_{0.1} = 0.04/0.12 = 0.33$ or 33%

Performing the Test – Ten Cycles



Performing the Test

- Some notes
  - Test uses high strains
    - Testing of RTFO-aged asphalt binder in T315 with a G*/sin δ value at the specification criterion uses 0.22 kPa shear stress
      - 10% shear strain
    - MSCR testing at 0.1 kPa is less than that strain (still small)
    - MSCR testing at 3.2 kPa is more than 14 times the T315 strain
  - Because of high strain, the sample cannot be re-used
    - Can perform MSCR after T315 but not T315 after MSCR
    - Cannot perform testing at more than one temperature on the same sample

Performing the Test

- Operations that are important to the T315 procedure are similarly important to the MSCR procedure
  - temperature verification
  - gap setting
  - trimming
  - equilibrium time to temperature

Calculating and Understanding Test Output

- Use and relevance of $J_{nr,Diff}$ as a specification requirement
  - Indicative of stress-sensitive binders
  - Problem for some current formulations
  - Not a problem for the majority of modified binders

Calculating and Understanding Test Output

- Use and relevance of $J_{nr,Diff}$ as a specification requirement
  - Can be a problem at very low Jnr values
    - Small differences can mean big ratios
  - If $J_{nr3.2} \leq 0.5$ kPa^{-1}, then $J_{nr,Diff}$ requirement is waived
    - Small values of J_{nr} should mean reduced contribution to rutting potential
    - Even a big change from 0.1 kPa to 3.2 kPa should not result in a significant increase in rutting potential

Example:

- $J_{nr,0.1} = 0.08$ kPa^{-1}
- $J_{nr,3.2} = 0.40$ kPa^{-1}

- $J_{nr,Diff} = (0.40 – 0.08) / 0.08 = 0.32/0.08 \times 100\% = 400\%$

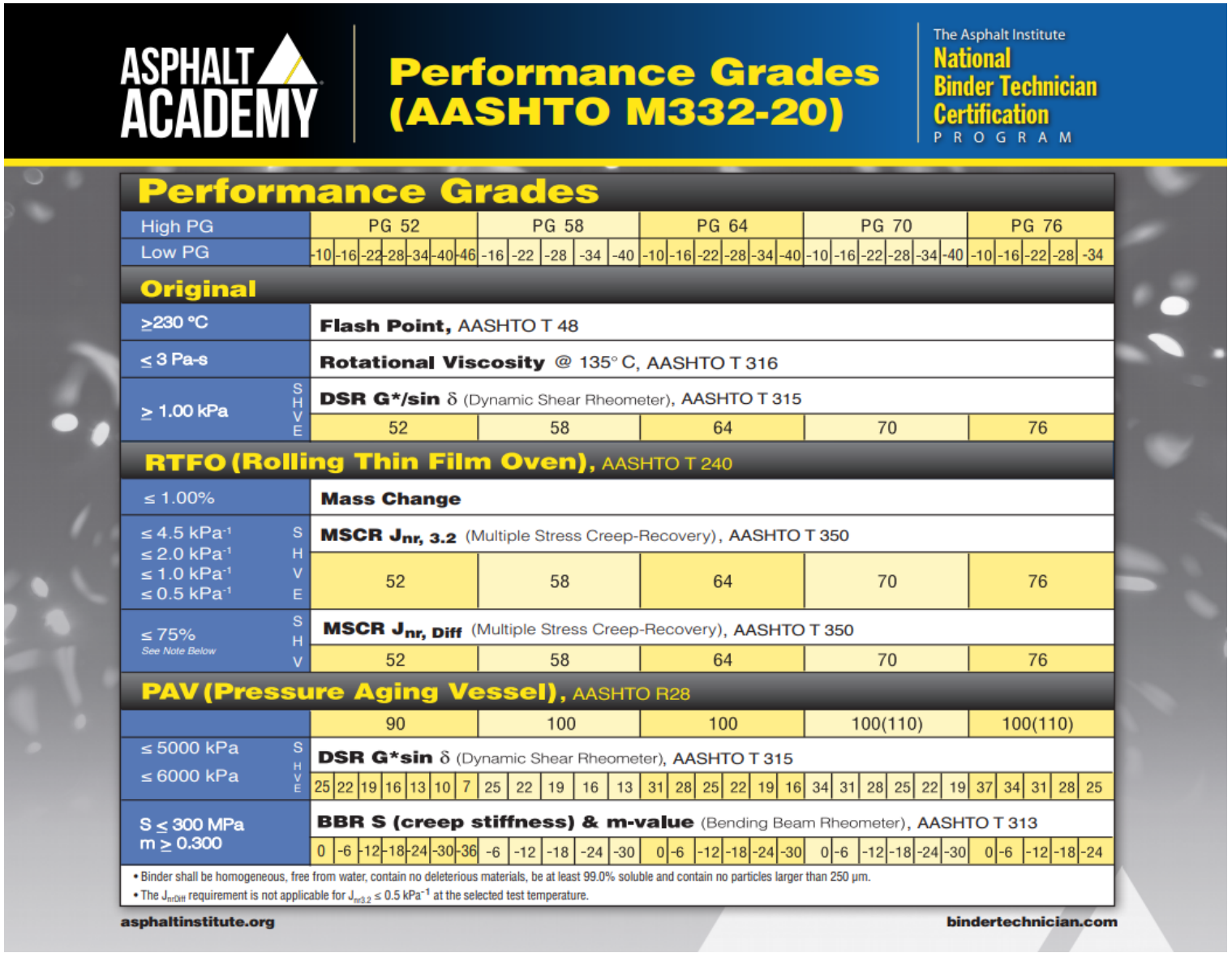
Test Conditions and Use

- MSCR testing intended for characterizing rutting potential
  - J_{nr} is an indication of the performance-based property of the asphalt binder related to permanent deformation (rutting)
  - Can be conducted at a wide variety of conditions, but
    - Most appropriately conducted at high temperatures on asphalt binder that has been aged to simulate its physical state early in the pavement life after mixing, laydown, and compaction
- Test temperature should always be selected based on actual high pavement temperatures with no grade bumping
  - Regardless of the traffic speed and loading
  - Higher traffic loading can be accounted for by increasing the stiffness (reducing the compliance) required for the asphalt binder at the grade temperature

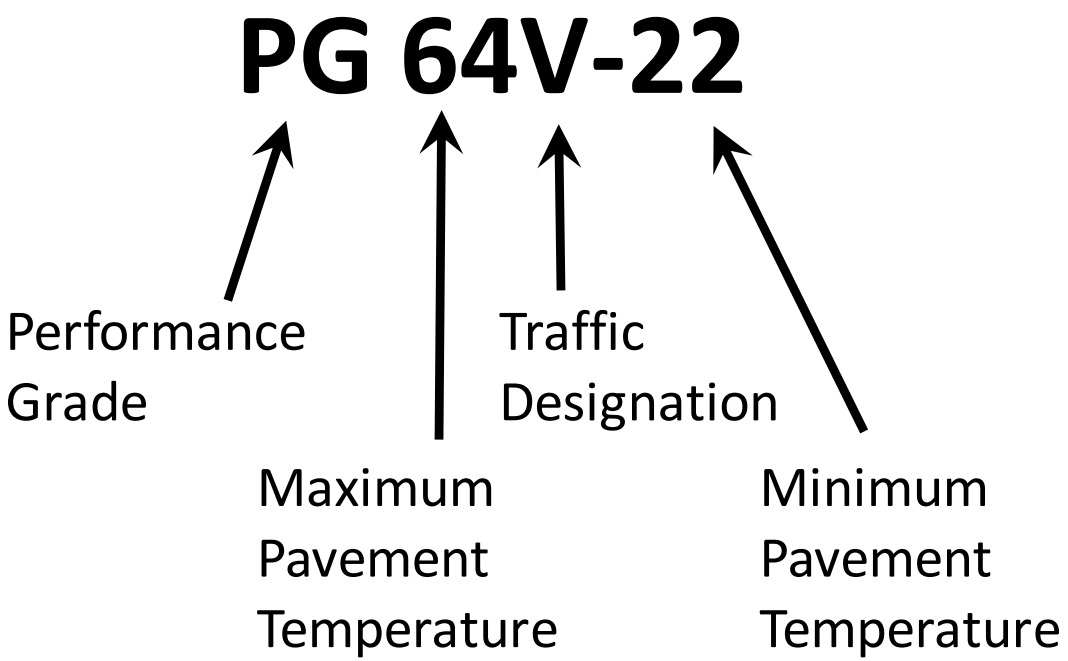
MTE Rutting Study: WI E10 Fine Mix

PG Grade (M320)	PG Grade (M332)	Test Temp, °C	$J_{nr3.2}$, kPa^{-1}	$R_{3.2}$, %	HWT Rut Depth (10,000 passes), mm
64-22	64S-22	64	3.40	3.4	7.1
70-22	64H-22	64	1.35	4.4	3.6
76-22	64E-22	64	0.24	55.8	1.7
82-22	64E-22	64	0.08	78.5	1.6

Specification



Grading



- Expected to perform in an environment where…
  - The maximum pavement temperature is no higher than **64°C**
  - Traffic loading is **very heavy**
  - The minimum pavement temperature is no lower than **-22°C**

Specification

- Comparing PG 64V-22 asphalt binder to a PG 64S-22 asphalt binder

	PG 64V-22	PG 64S-22
ORIGINAL		
COC Flash Point	≥ 230°C	≥ 230°C
Rotational Viscosity	≤ 3 Pa-s	≤ 3 Pa-s
DSR G*/sin δ	≥ 1.00 kPa @ 64°C	≥ 1.00 kPa @ 64°C
RTFO		
Mass Change	≤ 1.00%	≤ 1.00%
$J_{nr,3.2}$	≤ 1.0 kPa^{-1} @ 64°C	≤ 4.5 kPa^{-1} @ 64°C
$J_{nr,Diff}$	≤ 75%	≤ 75%
PAV		
DSR G*sin δ	≤ 6000 kPa @25°C	≤ 5000 kPa @25°C
BBR S	≤ 300 MPa @ -12°C	≤ 300 MPa @ -12°C
BBR m	≥ 0.300 @ -12°C	≥ 0.300 @ -12°C

Specification

- Notes on PAV DSR Criterion
  - In M320, intermediate temperature is determined as a function of the high and low temperature grades
    - Grade bumping – i.e. from a PG 64-22 to a PG 76-22 – would increase the intermediate temperature from 25°C to 31°C
  - No grade bumping in M332
    - PG 76-22 equivalent (PG 64V-22 or PG 64E-22) tested at 25°C
  - Higher allowable value of G*sin δ to account for test temperature difference
    - Not intended to disadvantage current-production modified asphalt binders
    - Consider strain tolerance of modified asphalt binders

MSCR Implementation

- Purpose
- Basics
- **Test Temperature**
- Recovery
- Variability
- Why?

Effect of Temperature and Stress on J_{nr}

- In neat binders a grade bump by temperature will more than double the J_{nr} value
- Some neat binders will maintain their compliance value well beyond the 3.2 kPa stress
- M320 Grade bumping (increasing PG grade temperature) often forced suppliers to use soft base binders and high degree of polymer modification to meet wide temperature ranges and the 2.2 kPa criterion for RTFO G*/sin δ

High PG Map (98%) Using LTPPBind 3.1

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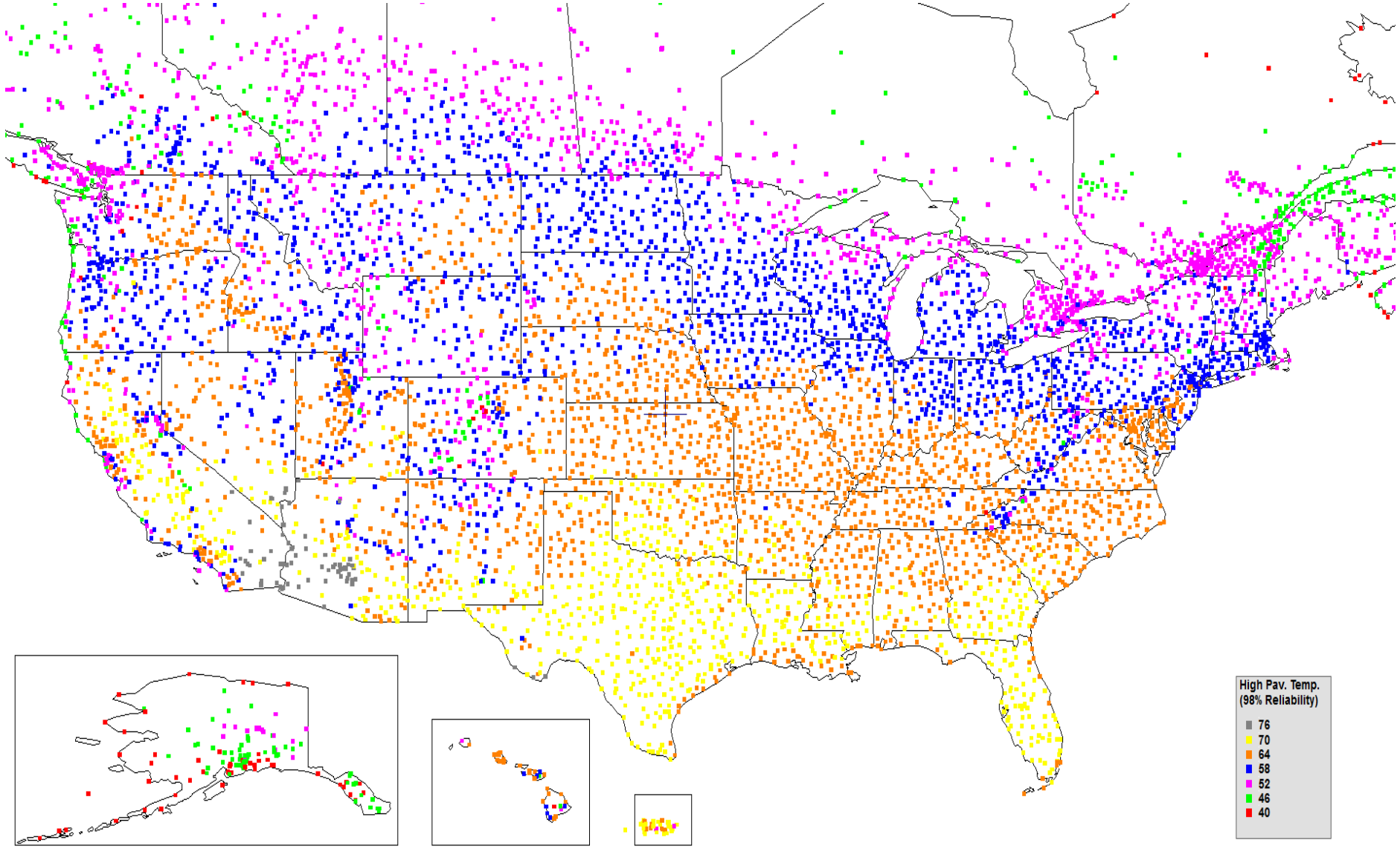

Test Conditions and Use

- AASHTO M332 Section 4.2 describes the traffic speed and loading conditions
  - Criterion for $J_{nr,3.2}$ is provided for each traffic loading designation

Designation	Traffic (ESAL)	Speed	$J_{nr,\ 3.2}$, kPa^{-1}
Standard Traffic Loading (S)	$< 10^6$	> 70 km/h (> 43 mph)	≤ 4.5
Heavy Traffic Loading (H)	10^6 to 30^6	> 70 km/h (> 43 mph)	≤ 2.0
	$< 10^6$	20-70 km/h (12-43 mph)	
Very Heavy Traffic Loading (V)	$> 30^6$	> 70 km/h (> 43 mph)	≤ 1.0
	$< 30^6$	< 20 km/h (< 12 mph)	
Extreme Traffic Loading (E)	$> 30^6$	< 20 km/h (< 12 mph)	≤ 0.5

MSCR Implementation

- Purpose
- Basics
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- **Recovery**
- Variability
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Recovery as an Indicator of Elastic Response

- Recovery
  - In addition to determining J_{nr} the MSCR test can be used to determine the amount of recovery in an asphalt binder during the creep-recovery testing
  - MSCR Recovery provides an indication of the elastic response of the asphalt binder
    - A high recovery is an indication that the asphalt binder has a significant elastic component at the test temperature
  - Not part of the criteria in AASHTO M323 Table 1
    - Not a true performance requirement

Implementation of the MSCR Test and Specification

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- Use of Recovery-J_{nr} curve for evaluating elastic response
  - D'Angelo Thesis
    - "A minimum MSCR %Recovery of somewhere between 20% and 40% would be a good indication of an effective polymer network in the binder. This range is based on the large increase in %Recovery seen between 2% SBS blend without cross-linker to 2% SBS blend with cross-linker."
    - "The %Recovery should also be tied to the Jnr value for the binder."
      - "To assure the %Recovery response is primarily from the polymer network and not from just a stiffening of the base binder, the minimum %Recovery should be increased as the Jnr value of the binder decreases."

Recovery as an Indicator of Elastic Response

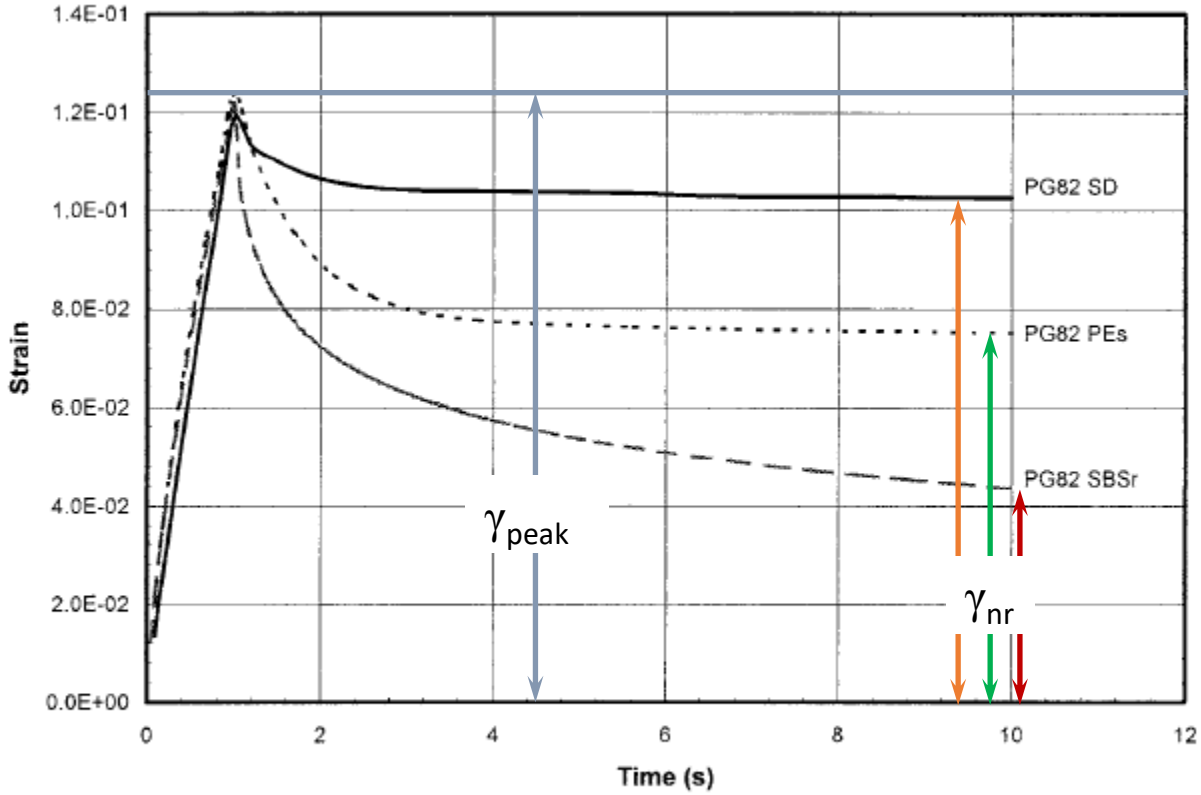


Figure 2.30 Creep and recovery of the first cycle for three PG 82 binders at 1 s loading and 9 s recovery (70°C, 300 Pa).

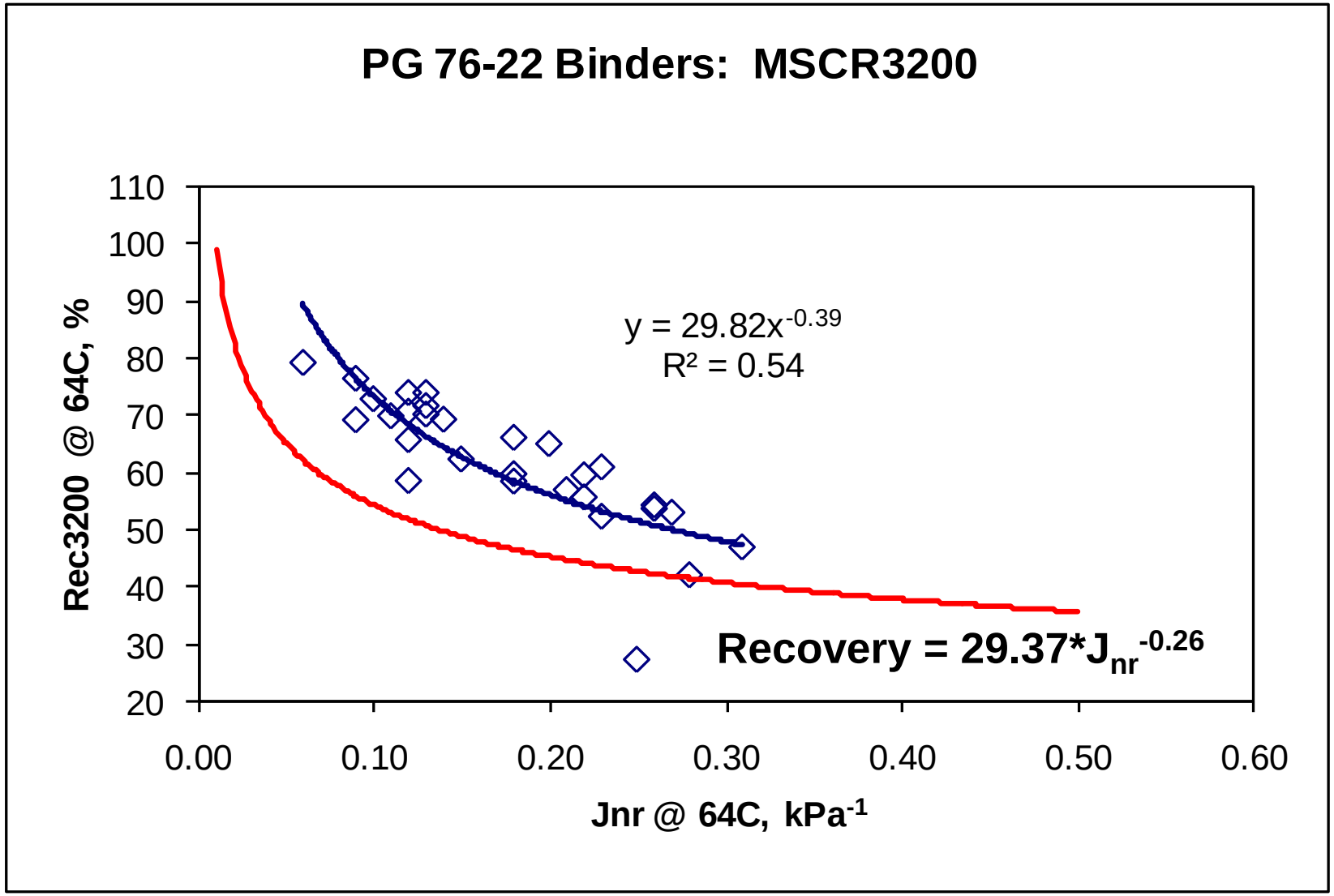
J_{nr} = 0.105 /0.3 kPa
= 0.35 kPa^{-1}
Rec = (0.125 – 0.105)/0.125
= 16%

J_{nr} = 0.075 /0.3 kPa
= 0.25 kPa^{-1}
Rec = (0.125 – 0.075)/0.125
= 40%

J_{nr} = 0.045 /0.3 kPa
= 0.15 kPa^{-1}
Rec = (0.125 – 0.045)/0.125
= 64%

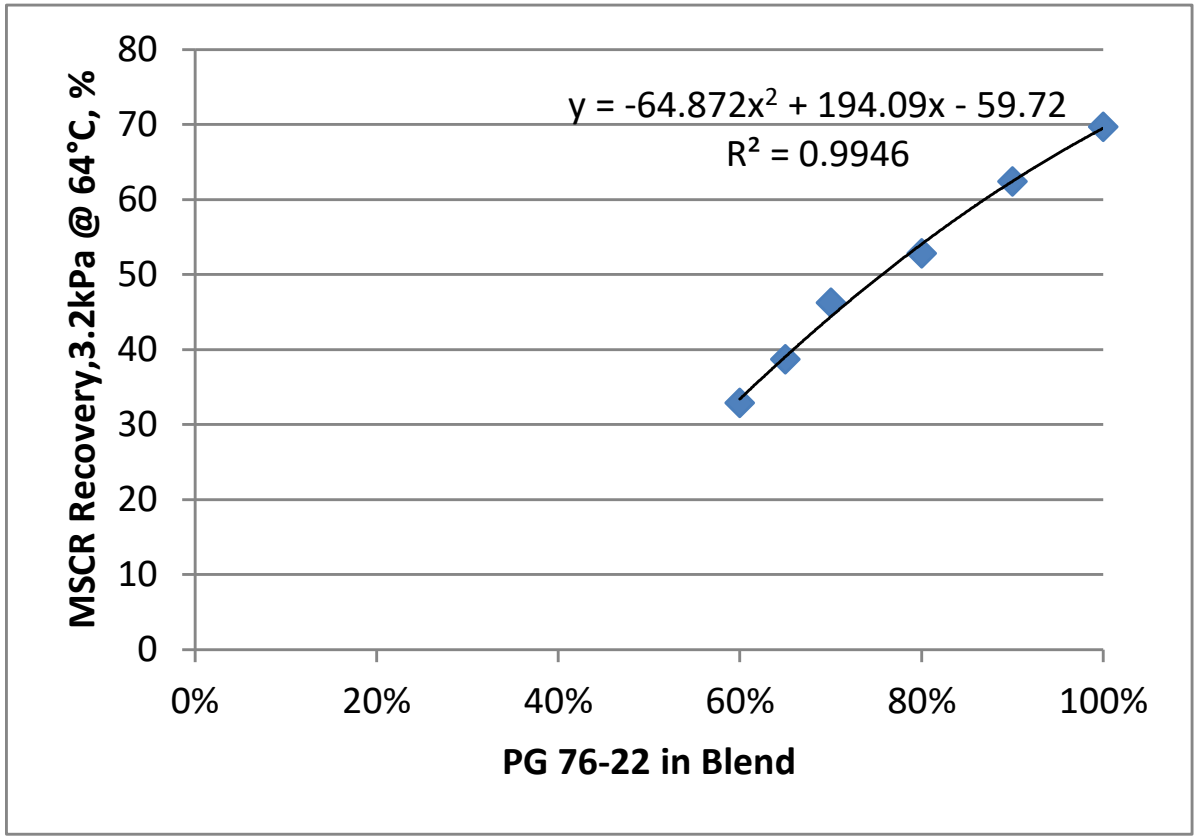
Excerpt from NCHRP Report 459, *Characterization of Modified Asphalt Binders in Superpave Mix Design*

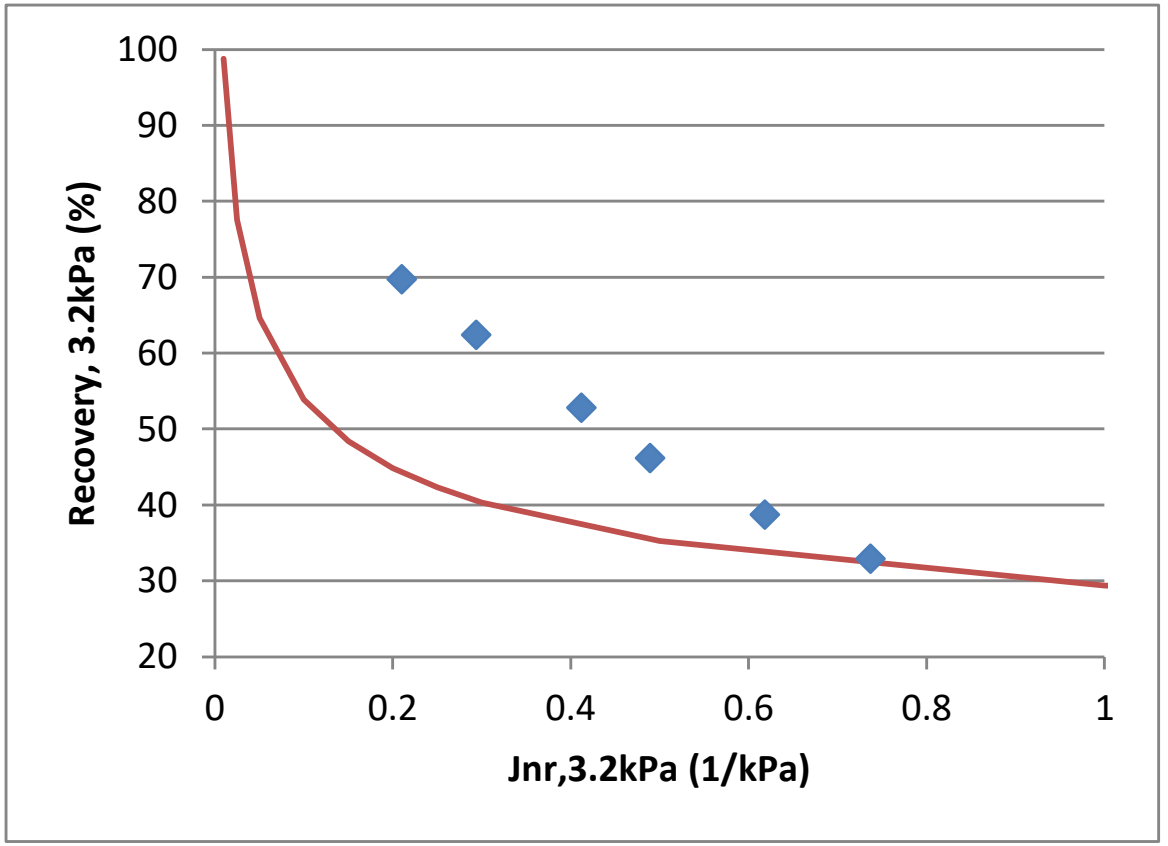
Recovery as an Indicator of Elastic Response



Implementation of the MSCR Test and Specification

- Use of Recovery-J_{nr} curve for evaluating elastic response





Implementation of the MSCR Test and Specification

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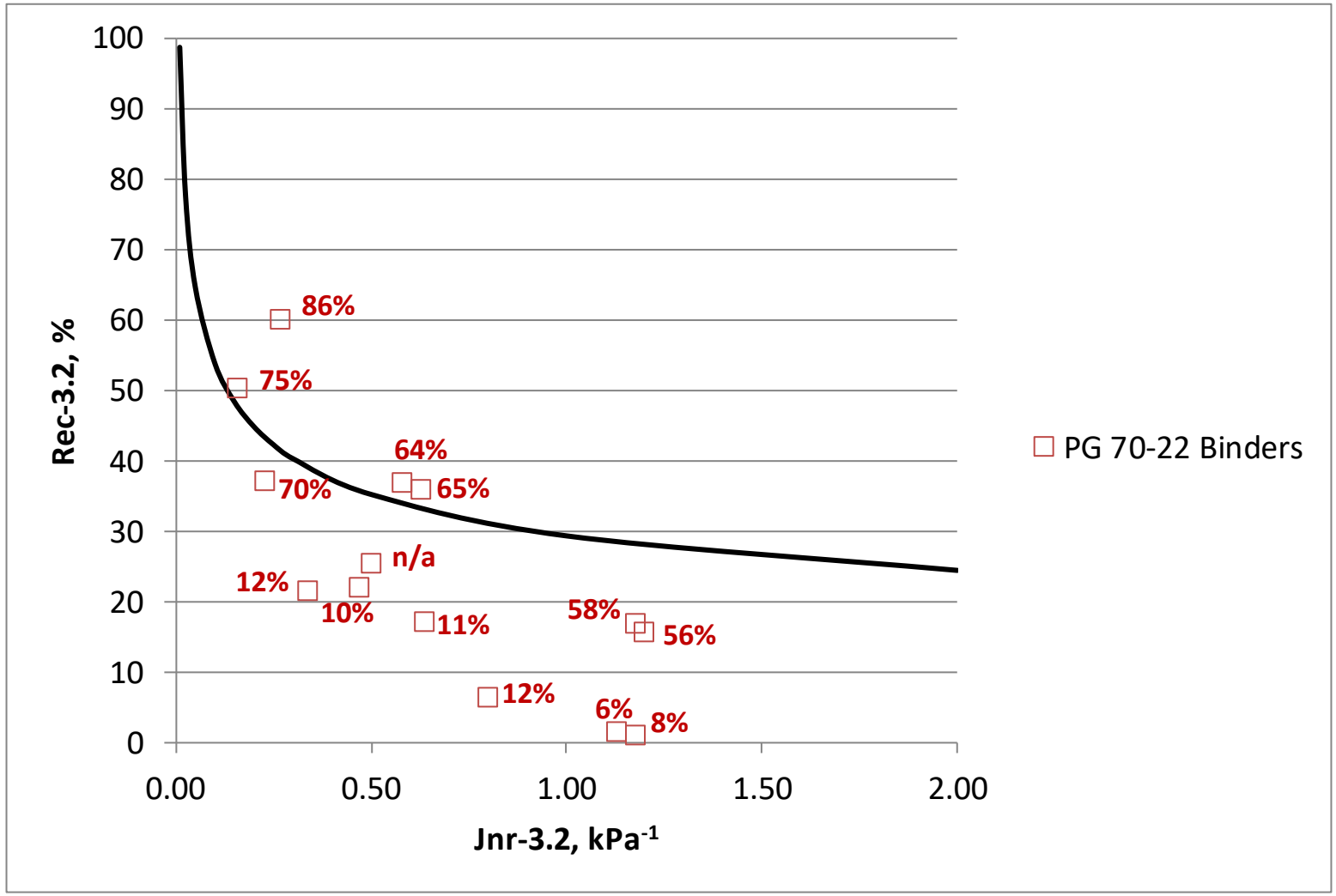

AASHTO MSCR Recovery Practice

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Standard Practice for

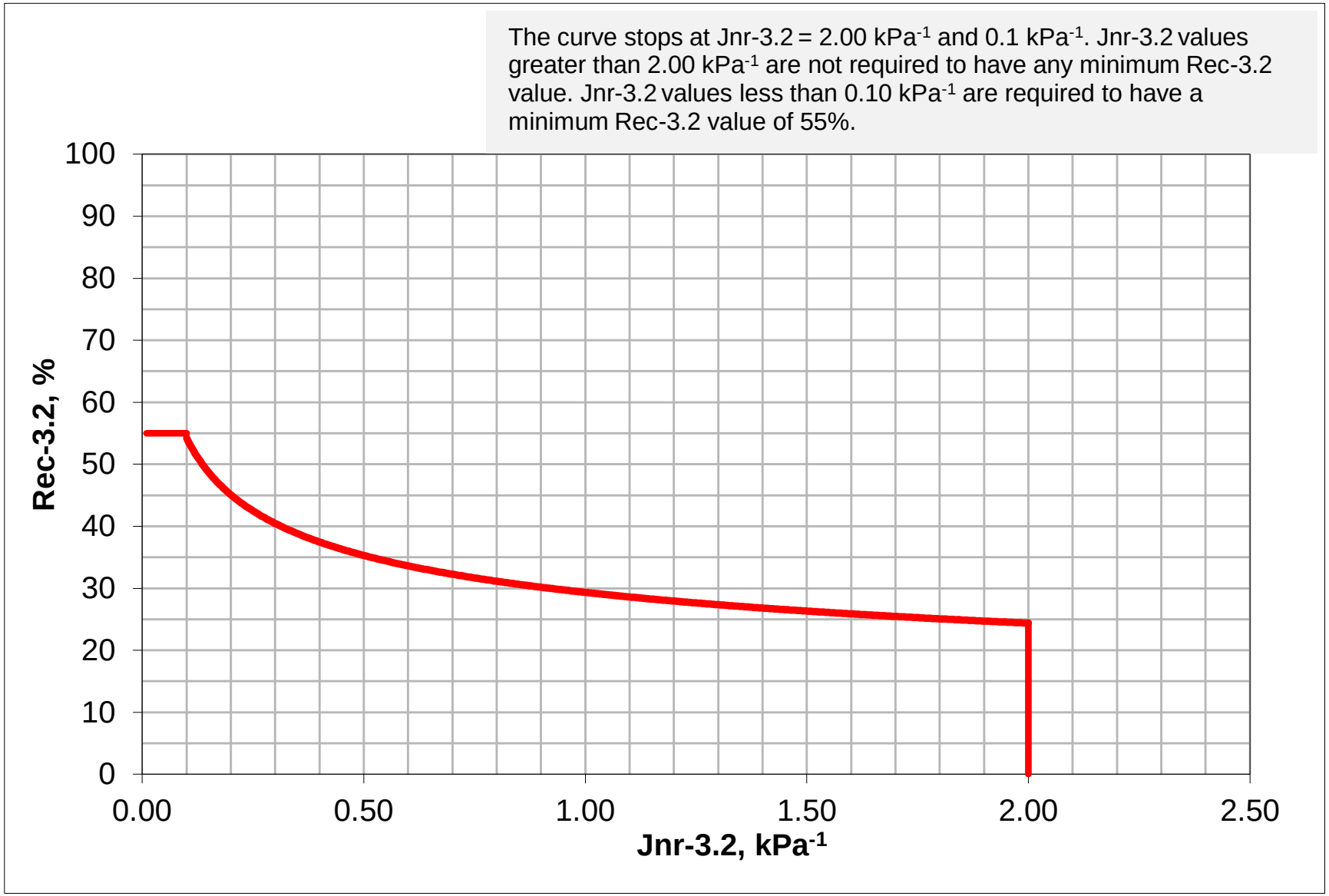
Evaluating the Elastic Behavior of Asphalt Binders Using the Multiple Stress Creep Recovery (MSCR) Test

AASHTO Designation: R 92-18

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

- Why Have a Separate Practice?
  - M320 and M332 are Performance-Based Specifications
    - No “PG Plus” tests, like ER, are included in M320
    - In M332 the parameter related to performance is Jnr
    - MSCR Recovery is like ER in that it identifies elastic response of modified asphalt binders

AASHTO MSCR Recovery Practice



Recovery as an Indicator of Elastic Response

- Notes on Use of MSCR Recovery
  - Curve developed for modified asphalt binders in production at the time
    - Many PG 76-22 asphalt binders and those modified with similar levels of polymer
    - Favors networked modification
  - Curve stops at 0.1 kPa^{-1} and 2.0 kPa^{-1}
    - $J_{nr,3.2}$ values above 2.0 kPa^{-1} would be classified as an **S** grade at the test temperature used and would not normally be a modified asphalt binder
    - $J_{nr,3.2}$ values below 0.1 kPa^{-1} would be classified as an **E** (Extreme) grade at the test temperature used
      - The $R_{3.2}$ value is sufficiently high (55%) that it would be extremely unlikely that any unmodified asphalt binder could have a Recovery exceeding the minimum

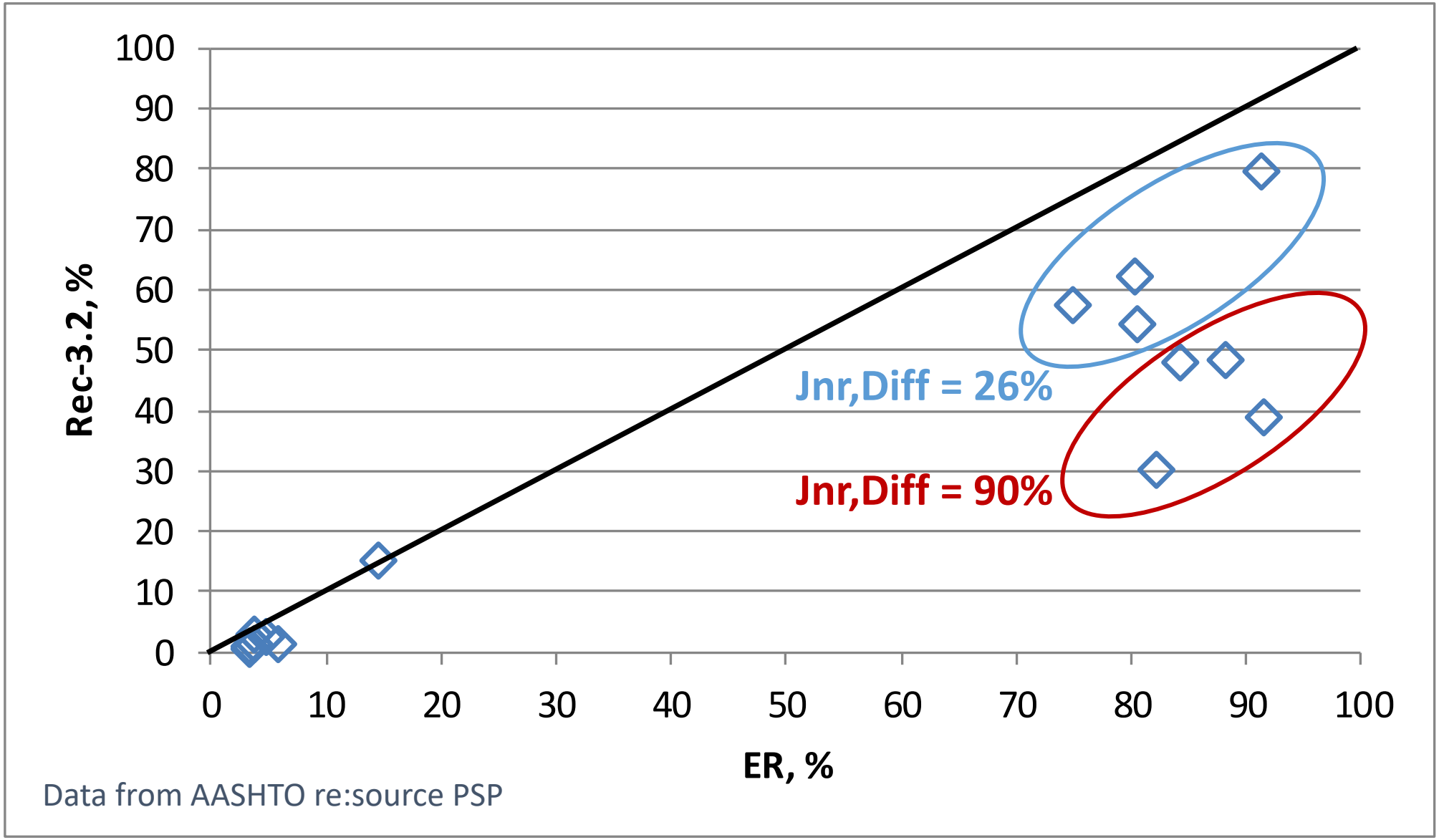
Recovery as an Indicator of Elastic Response

- Notes on Use of MSCR Recovery
  - High temperature binder specification parameter from M332 is $J_{nr,3.2}$
    - If the asphalt binder meets the appropriate $J_{nr,3.2}$ criterion, then it should be expected that the binder will minimize its contribution to permanent deformation (rutting) of the asphalt mixture.

Recovery as an Indicator of Elastic Response

- Notes on Use of MSCR Recovery
  - If a user wants to validate that an asphalt binder has been polymer-modified, specifically modified with an elastomer, then adding the appropriate MSCR Recovery ($R_{3.2}$) value as a minimum requirement is an option
    - MSCR Recovery could replace other PG Plus tests that are intended to have a similar purpose
      - e.g., Elastic Recovery, Force Ductility, and Toughness and Tenacity
    - Strong correlations should not be expected when conducting comparative testing between MSCR Recovery and other PG Plus tests
      - Purposes may be similar, but test conditions are sufficiently different

Implementation of the MSCR Test and Specification



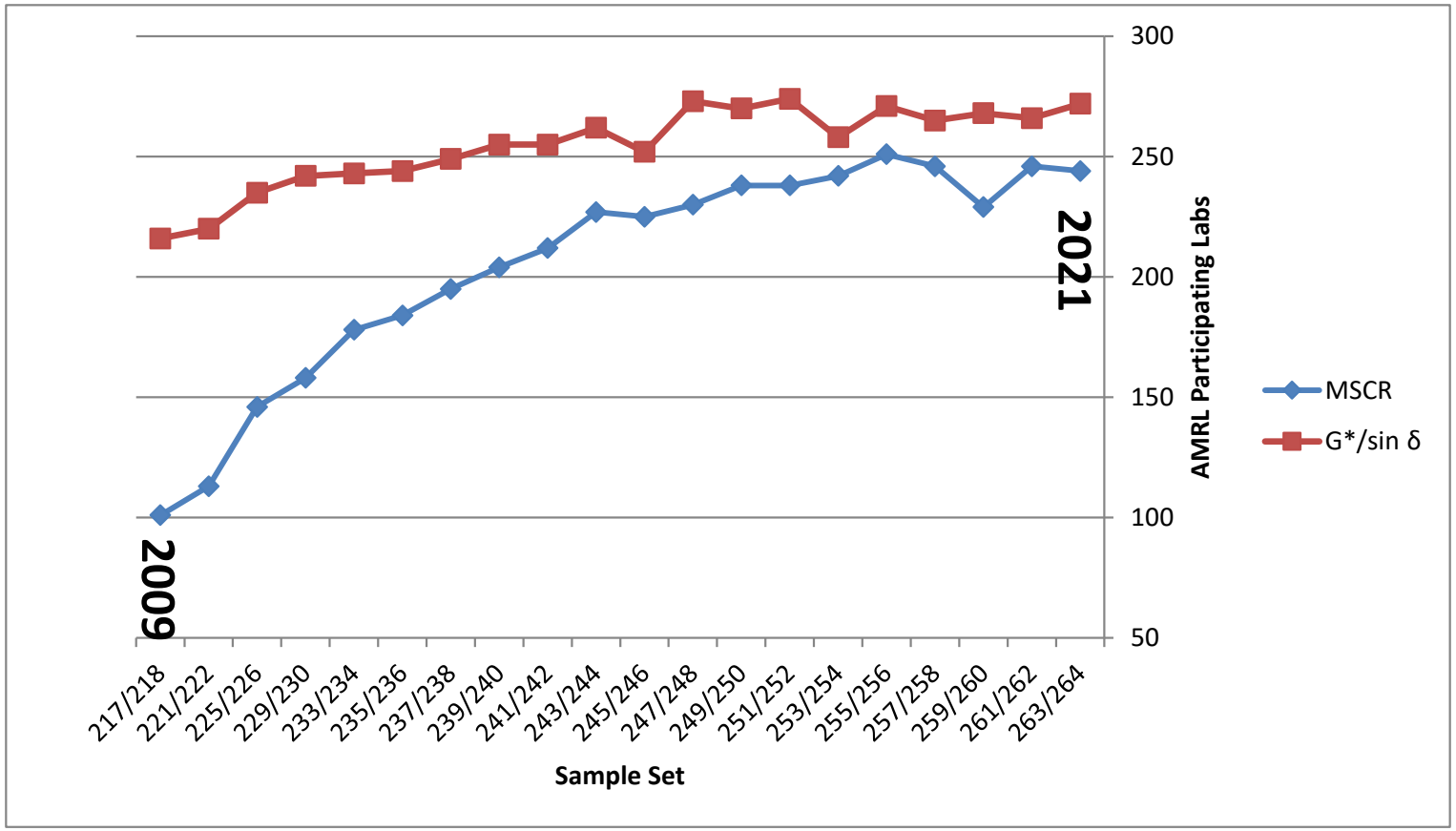
Data from AASHTO re:source PSP

MSCR Implementation

- Purpose
- Basics
- Test Temperature
- Recovery
- **Variability**
- Why?

Implementation of the MSCR Test and Specification

- Number of Participating Labs
  - AASHTO re:source PSP



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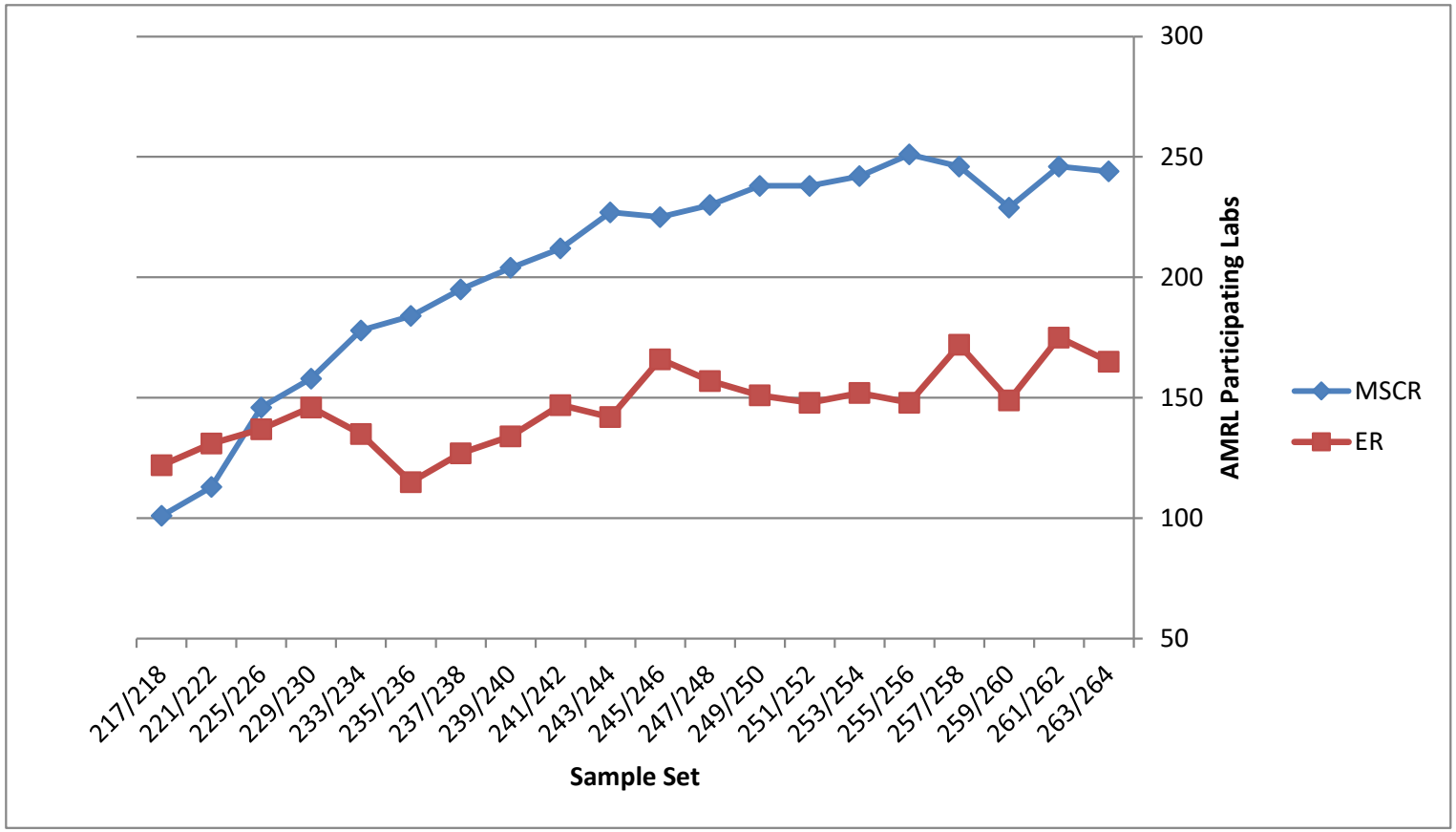

Implementation of the MSCR Test and Specification

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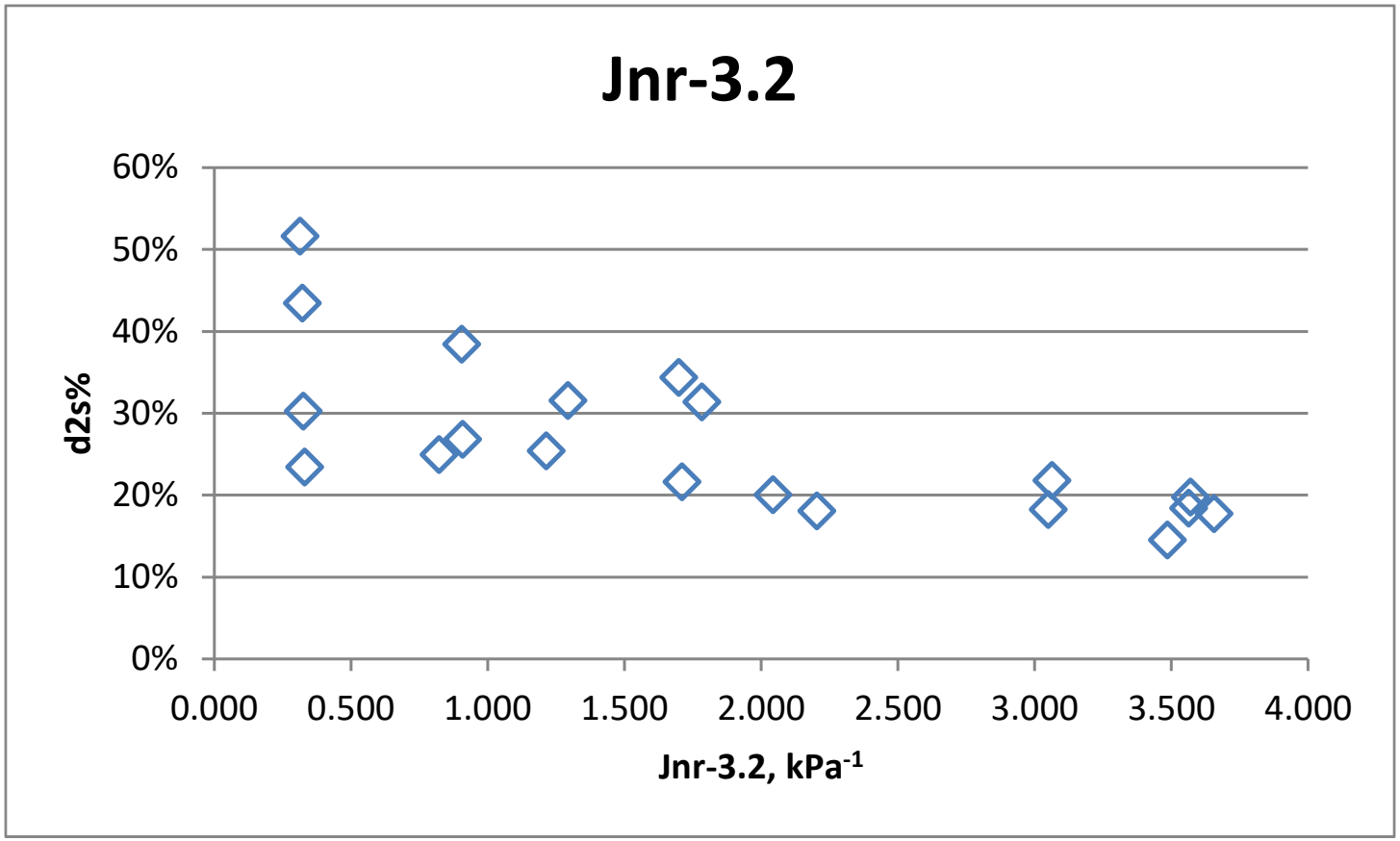
- Variability of MSCR test
  - AI-Coordinated ILS
    - d2s% shown for between lab (reproducibility)

ILS	Multi-Lab Rec-3.2	Multi-Lab Jnr-3.2
ETG 2009	18.1%	22.0-42.6%
NEAUPG 2010	18.7%	33.7%
SEAUPG 2011	9.8%	28.0%
NEAUPG 2012	7.6%	33.0%
PCCAS 2013	13.8%	36.8%

Implementation of the MSCR Test and Specification

- Variability of MSCR test
  - AASHTO re:source PSP



Implementation of the MSCR Test and Specification

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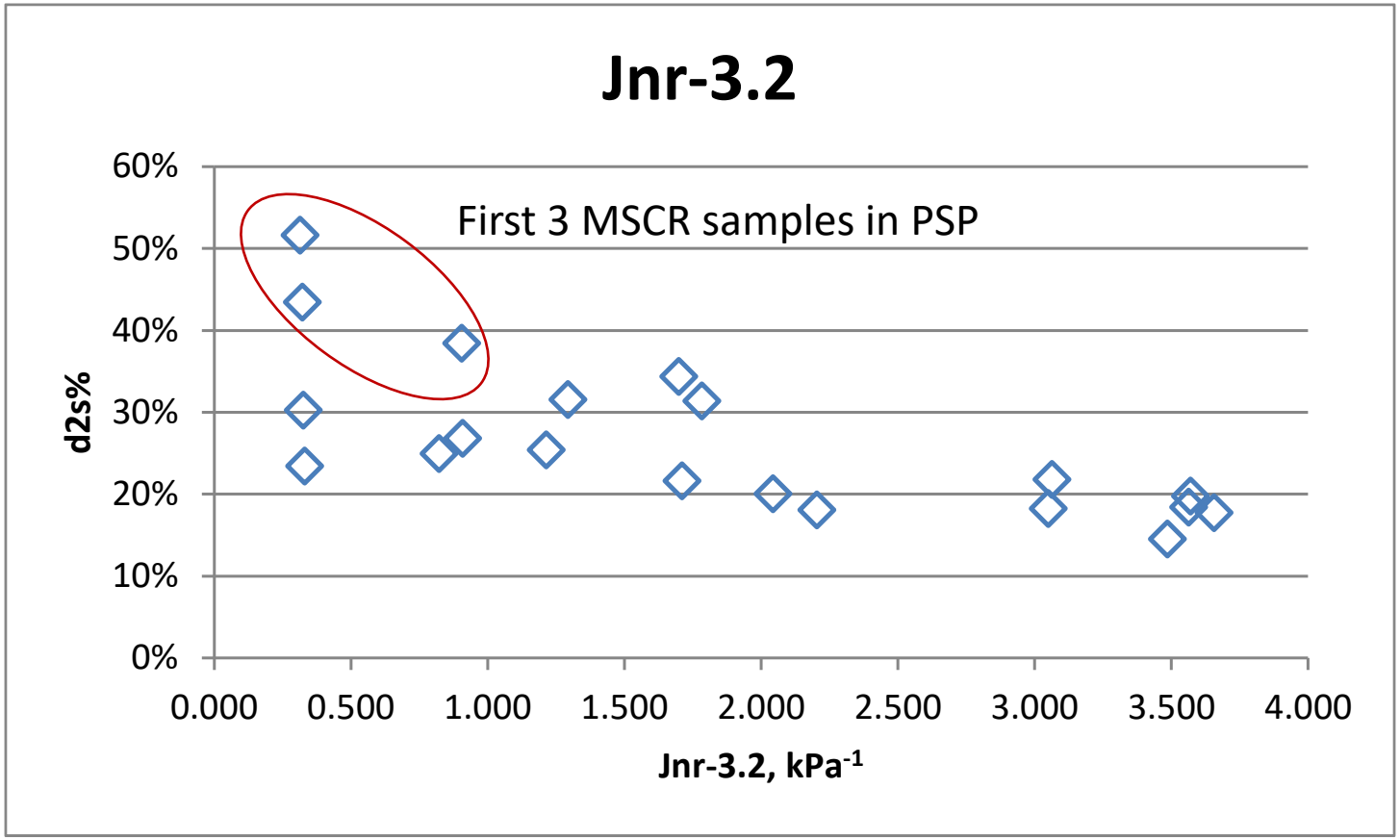

Implementation of the MSCR Test and Specification

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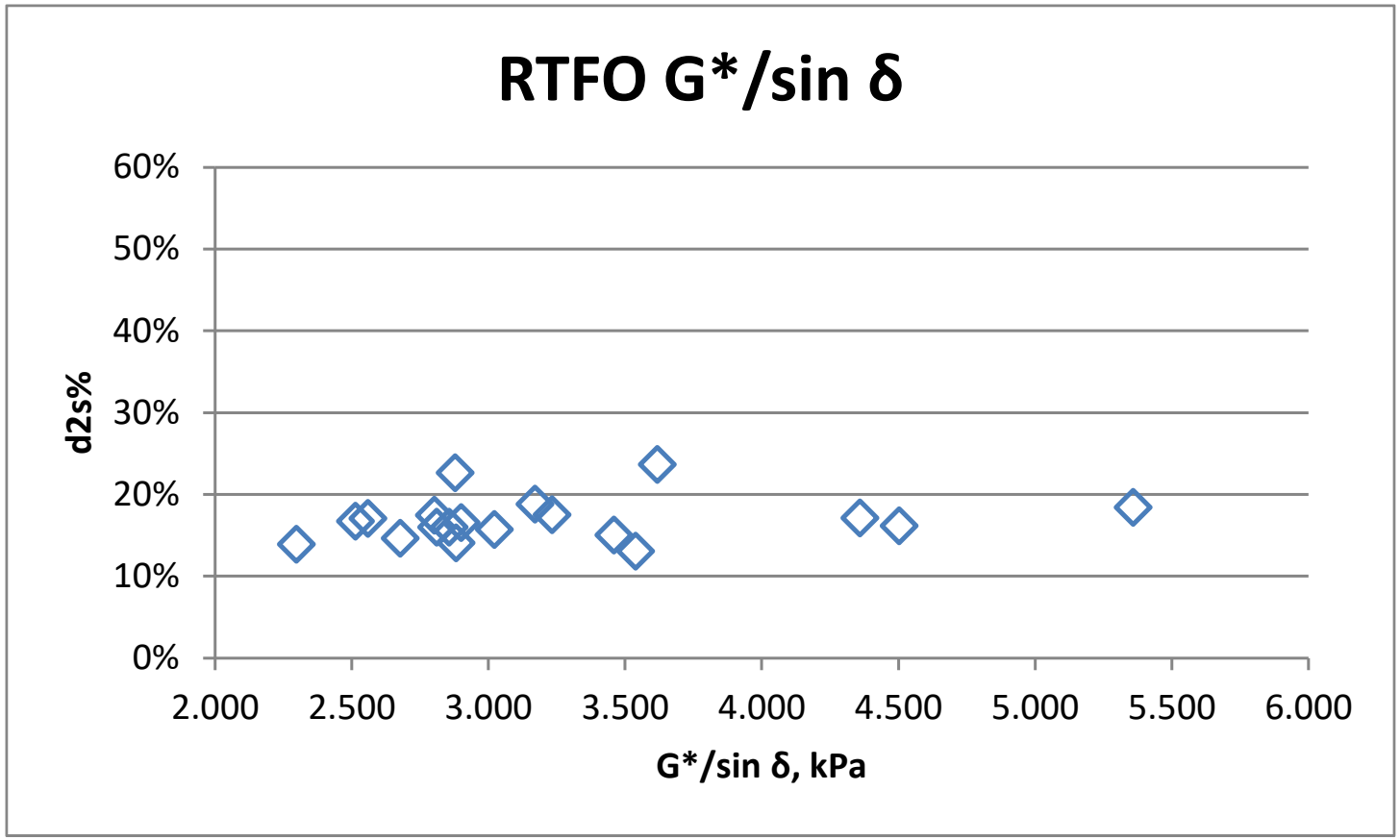

Implementation of the MSCR Test and Specification

- Variability of MSCR test
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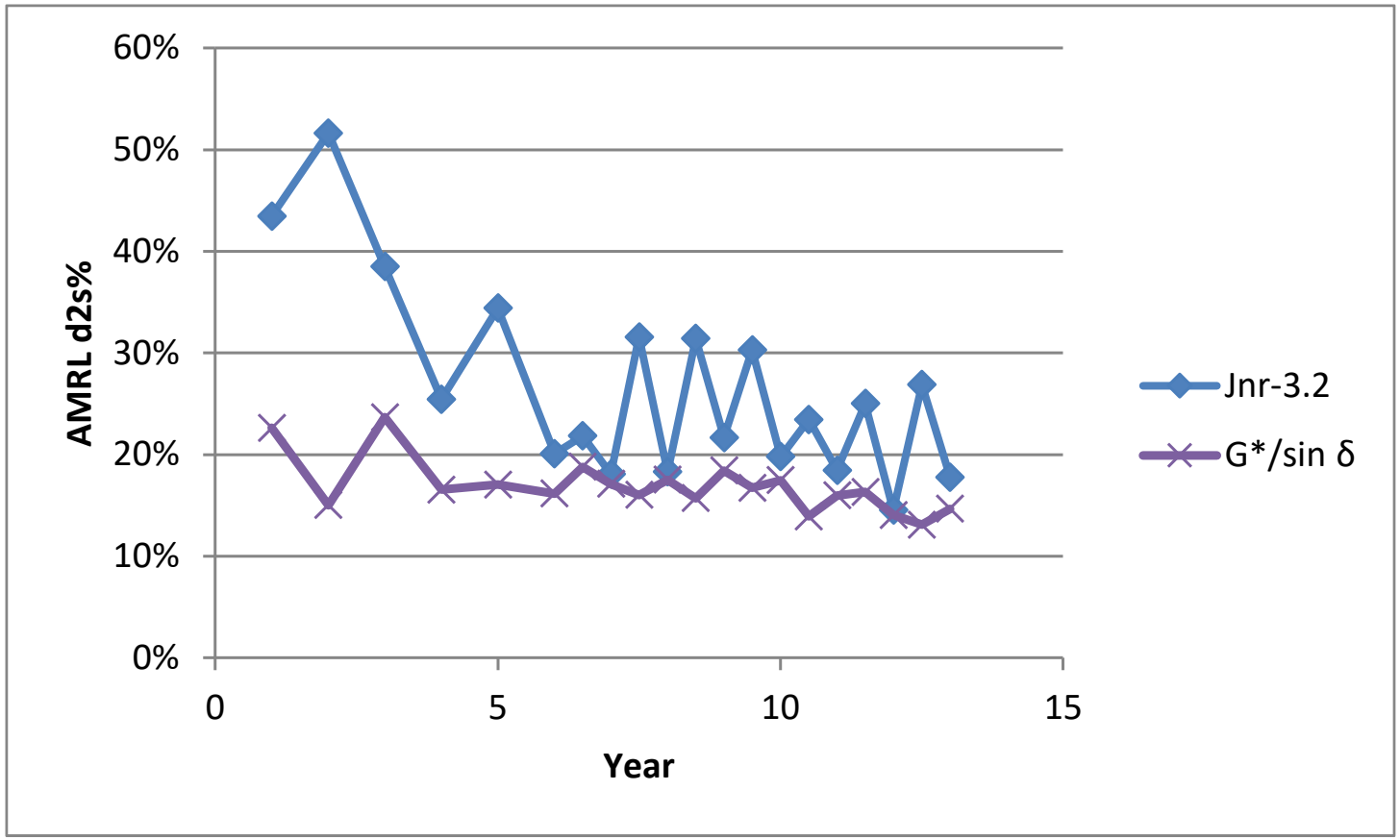


Variability

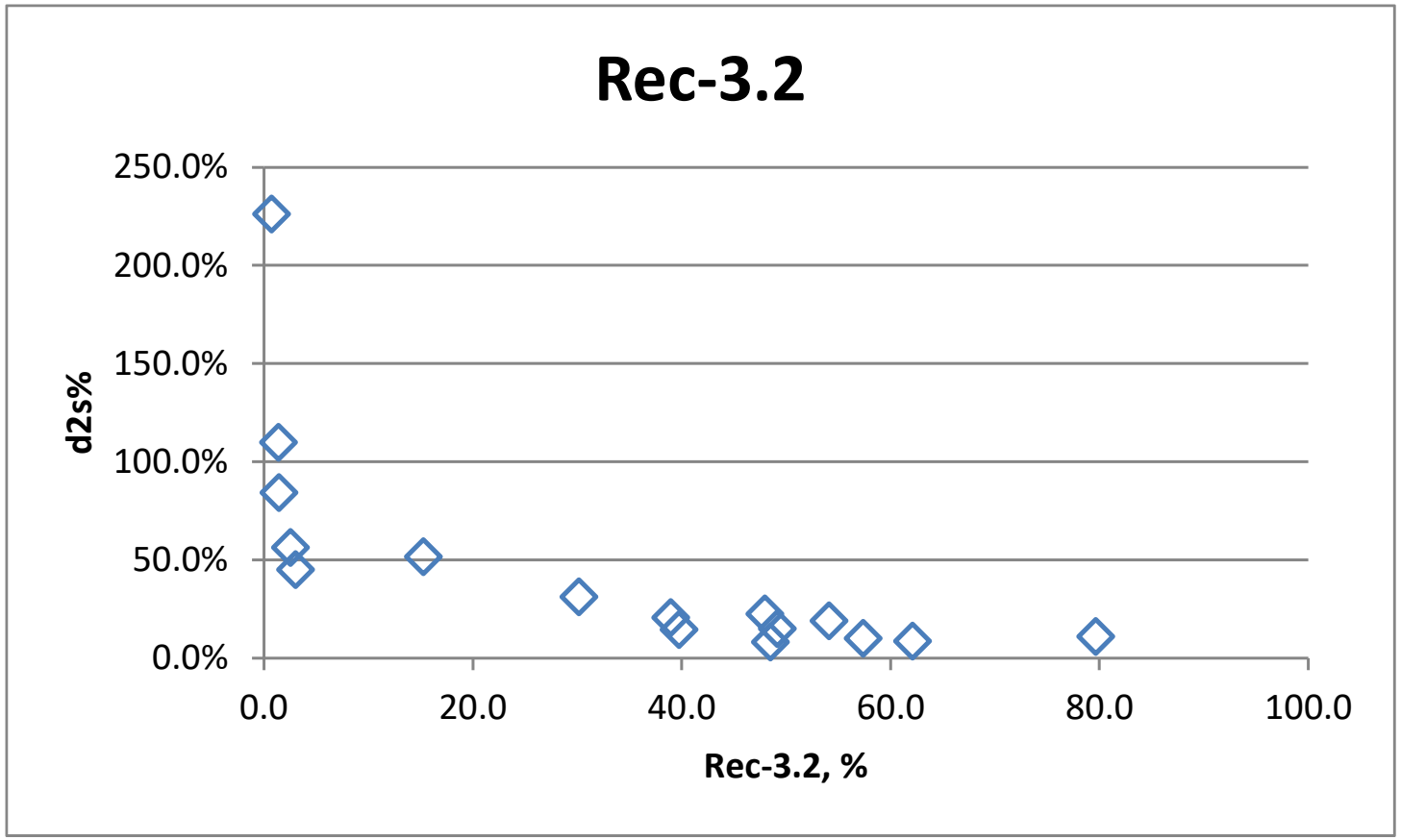
- AASHTO re:source has been analyzing data from the MSCR test in the Proficiency Sample Programs (PSP) since 2009
  - Since 2009, the average $J_{nr3.2}$ values for the samples have been in the range of 0.327 to 3.657 kPa^{-1}
  - For these 17 samples, the corresponding multi-laboratory d2s% values have been in the range of 14.5% to 34.4%, with an average value of 23.5%
  - Over the same time frame the multi-laboratory d2s% values for the RTFO G*/sin δ parameter (AASHTO T315) have been in the range of 13.1% to 18.8%, with an average value of 16.2%

Variability

- AASHTO re:source has been analyzing data from the MSCR test in the Proficiency Sample Programs (PSP) since 2009
  - Since 2009, eight of the asphalt binders appeared to be modified with average $R_{3.2}$ values for the samples in the range of 30.1% to 62.1%
  - For these eight samples, the corresponding multi-laboratory d2s% values have been in the range of 8.2% to 31.1%, with an average value of 16.2%

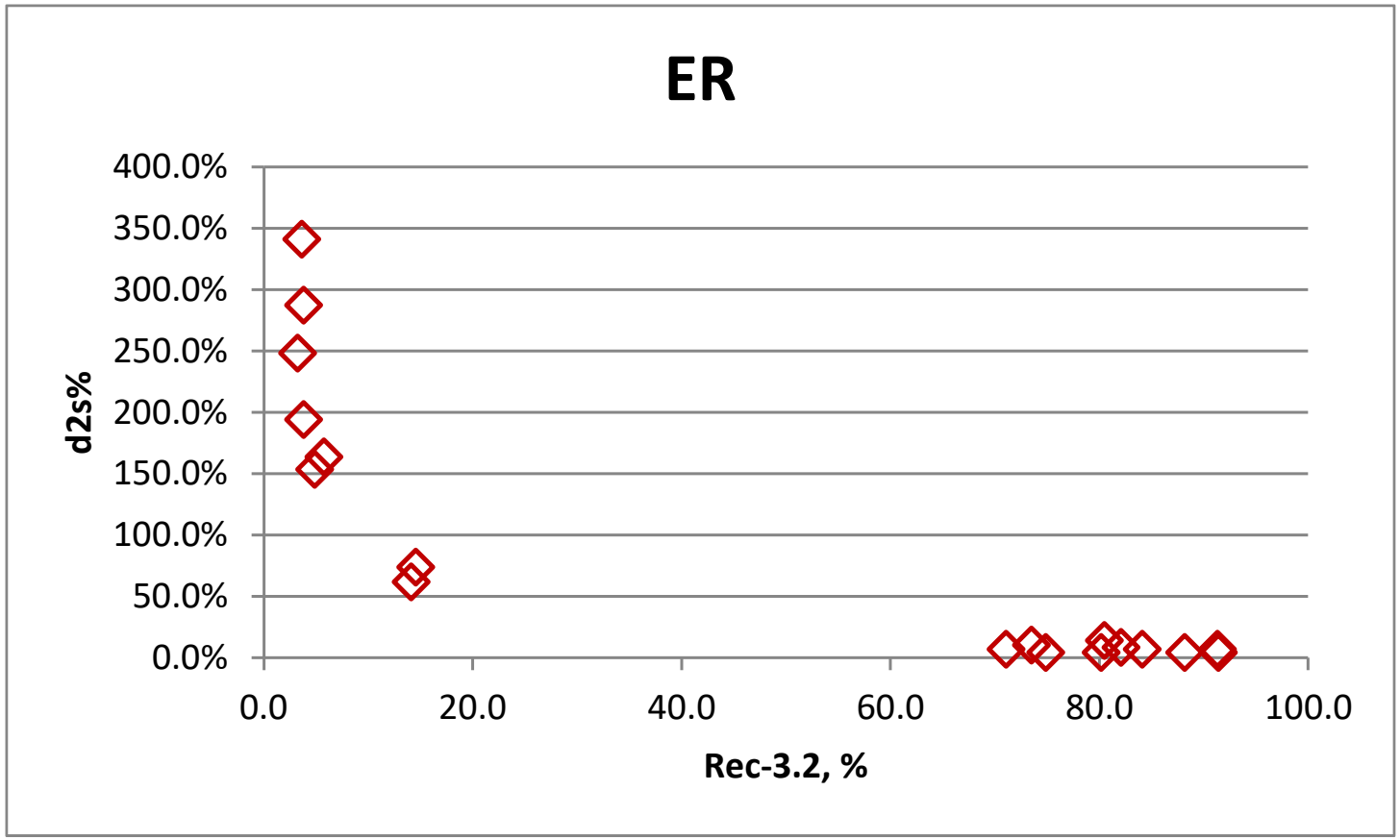
Implementation of the MSCR Test and Specification

- Variability of MSCR test
  - AASHTO re:source PSP



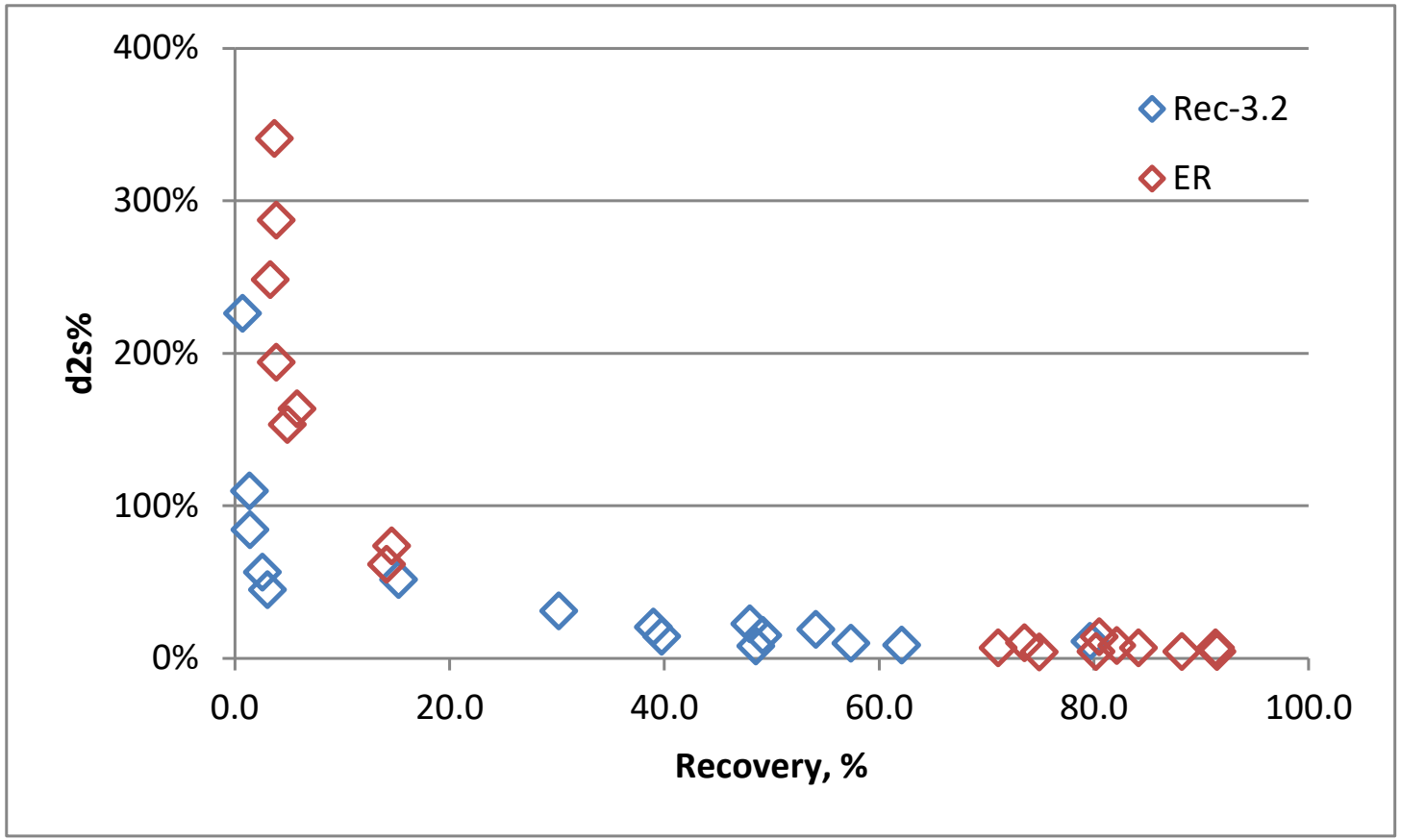
Implementation of the MSCR Test and Specification

- Variability of ER test
  - AASHTO re:source PSP



Implementation of the MSCR Test and Specification

- Variability of ER and MSCR Recovery tests
  - AASHTO re:source PSP



Implementation of the MSCR Test and Specification

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- Variability of MSCR test
  - PCCAS ILS (2013)

Table 20: Estimated Repeatability and Reproducibility from ILS

	Acceptable Range of Two Test Results (d2s%) 2013 PCCAS ILS	
Test	*Single Operator Precision*	*Multilaboratory Precision*
Elastic Recovery (RTFO) at 25°C	5.6%	9.2%
R&B Softening Point	2.8%	7.7%
Ductility (Original) at 4°C	17.9%	75.0%
Ductility (RTFO) at 4°C	19.5%	95.1%
Toughness at 25°C	15.3%	29.1%
Tenacity at 25°C	17.9%	30.0%
MSCR Rec-3.2	8.0%	17.3%

Implementation of the MSCR Test and Specification

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- Variability of MSCR test
  - AASHTO T 350-19

	Single Operator (Repeatability)		Multilaboratory (Reproducibility)	
	Coefficient of Variation (1s%)	Acceptable Range of Two Results (d2s%)	Coefficient of Variation (1s%)	Acceptable Range of Two Results (d2s%)
$R_{0.1}$ (%)	1.6	4.4	4.8	13.5
$R_{3.2}$ (%)	1.9	5.5	4.5	12.7
$J_{nr0.1}$ (kPa^{-1})	4.4	12.5	11.7	33.1
$J_{nr3.2}$ (kPa^{-1})	4.7	13.2	10.8	30.7

Precision estimates based on analysis of data from 4 pairs of AASHTO re:source proficiency samples representing 149-225 labs. Four modified asphalt binder grades – PG 58-28, PG 70-28, PG 76-22, and PG 82-22 – were used as samples in the analysis. Average range of values is as shown:

$R_{0.1}$: 54.6% to 71.6% $R_{3.2}$: 30.0% to 48.5%

$J_{nr0.1}$: 0.62 kPa^{-1} to 1.02 kPa^{-1} $J_{nr3.2}$: 1.22 kPa^{-1} to 1.79 kPa^{-1}

Implementation of the MSCR Test and Specification

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- Variability of MSCR test
  - AASHTO T 350-19

	Single Operator (Repeatability)		Multilaboratory (Reproducibility)	
	Coefficient of Variation (1s%)	Acceptable Range of Two Results (d2s%)	Coefficient of Variation (1s%)	Acceptable Range of Two Results (d2s%)
$R_{0.1}$ (%)	1.6	4.4	4.8	13.5
$R_{3.2}$ (%)	1.9	5.5	4.5	12.7
$J_{nr0.1}$ (kPa^{-1})	4.4	12.5	11.7	33.1
$J_{nr3.2}$ (kPa^{-1})	4.7	13.2	10.8	30.7
G*/sin δ (kPa), RTFO	2.5	7.2	5.9	16.8

Implementation of the MSCR Test and Specification

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- Variability of MSCR test
  - AASHTO T 350-19

	Single Operator (Repeatability)		Multilaboratory (Reproducibility)	
	Coefficient of Variation (1s%)	Acceptable Range of Two Results (d2s%)	Coefficient of Variation (1s%)	Acceptable Range of Two Results (d2s%)
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$J_{nr3.2}$ (kPa^{-1}) Unmod.	*8 samples from PSP (2009-2021)*		6.6	18.6
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Implementation of the MSCR Test and Specification

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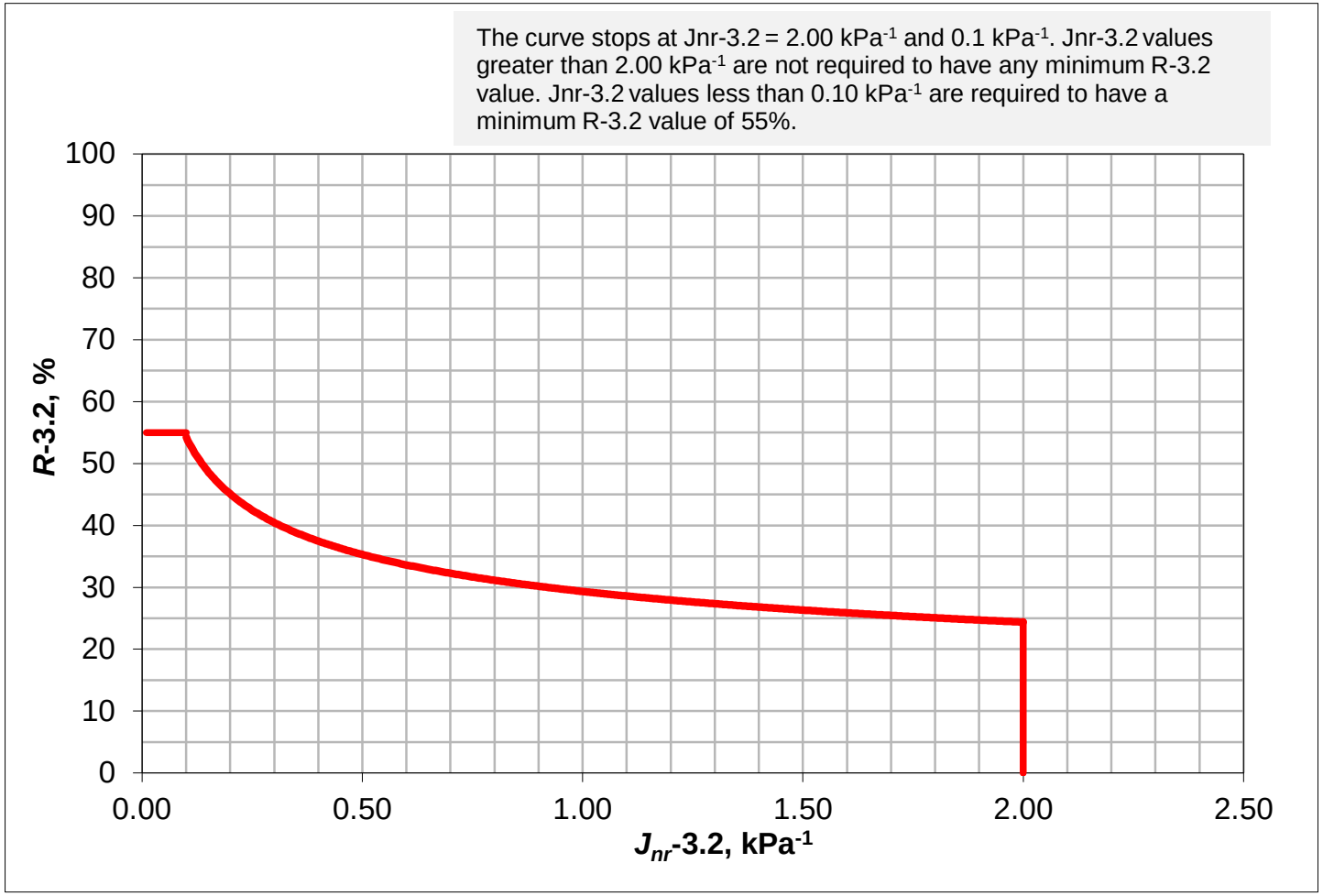
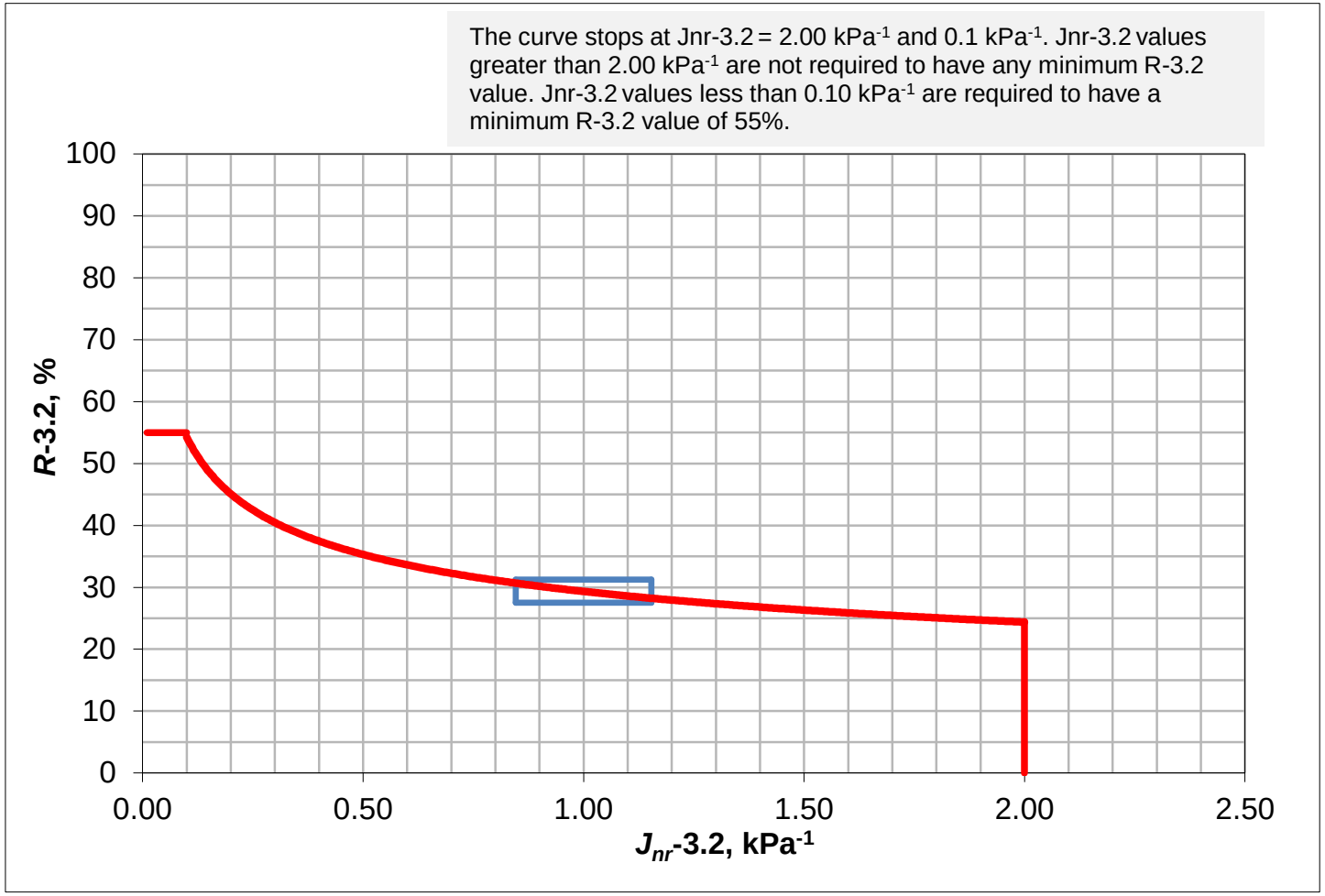
- Acceptable range of results for two labs
  - At specification value of 2.00 kPa^{-1}
    - $J_{nr3.2}$ range = 0.62 kPa^{-1}
  - At specification value of 1.00 kPa^{-1}
    - $J_{nr3.2}$ range = 0.31 kPa^{-1}
  - At specification value of 0.5 kPa^{-1}
    - $J_{nr3.2}$ range = 0.16 kPa^{-1}
  - At specification value of 2.20 kPa
    - G*/sin δ range = 0.37 kPa

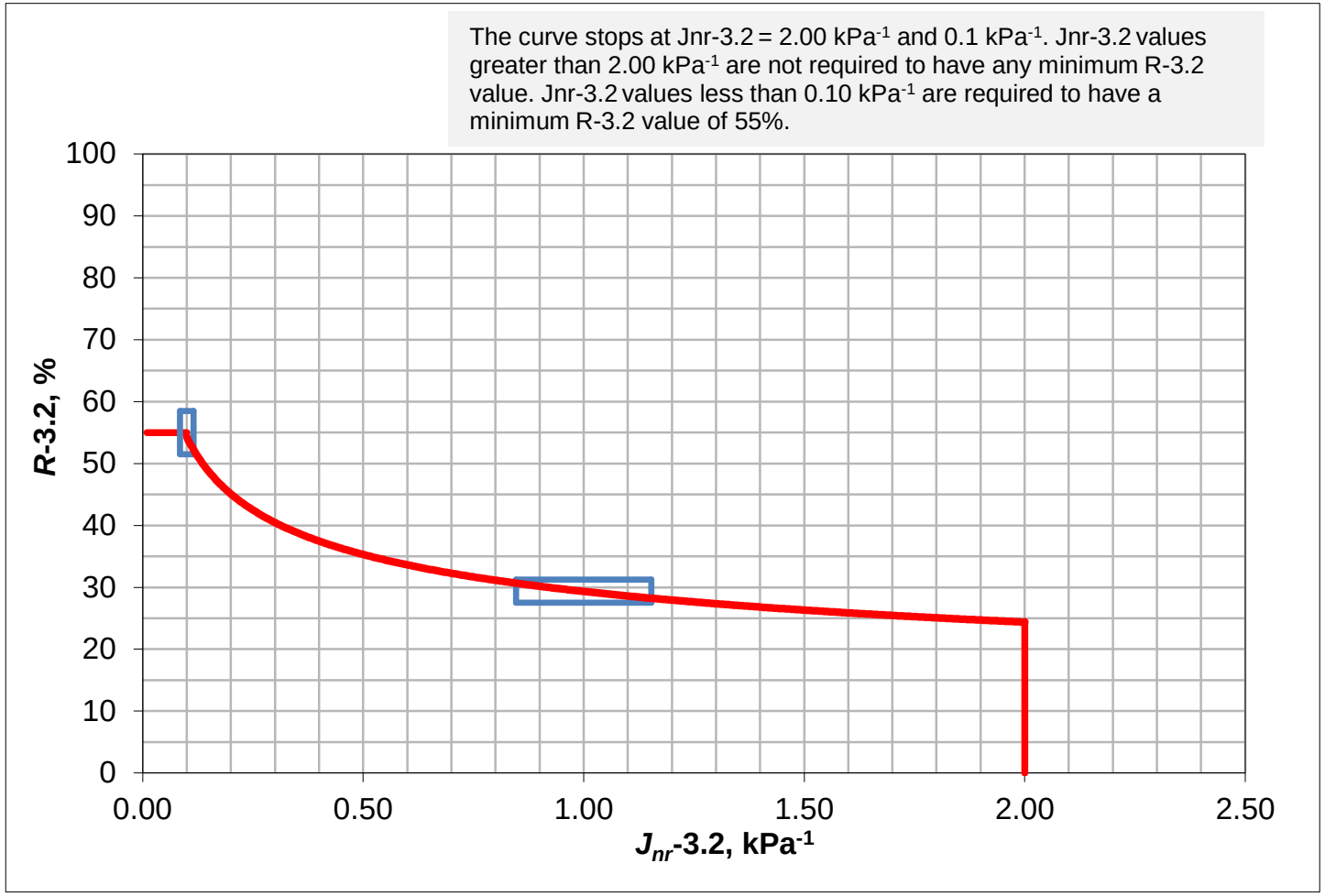
Evaluating Elastic Behavior



Evaluating Elastic Behavior: Variability



Evaluating Elastic Behavior: Variability



MSCR Implementation

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- Purpose
- Basics
- Test Temperature
- Recovery
- Variability
- **Why?**

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Multiple Stress Creep and Recovery (MSCR) Implementation and Transition

PREPARED BY:
GAYLON L. BAUMGARDNER, PH.D.
CO-PRINCIPAL INVESTIGATOR

FEDERAL HIGHWAY ADMINISTRATION (FHWA)
"DEVELOPMENT AND DEPLOYMENT OF INNOVATIVE ASPHALT PAVEMENT TECHNOLOGIES" COOP AGREEMENT WITH UNIVERSITY OF NEVADA, RENO

PRESENTED BY:
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U.S. Status of Implementation/Transition

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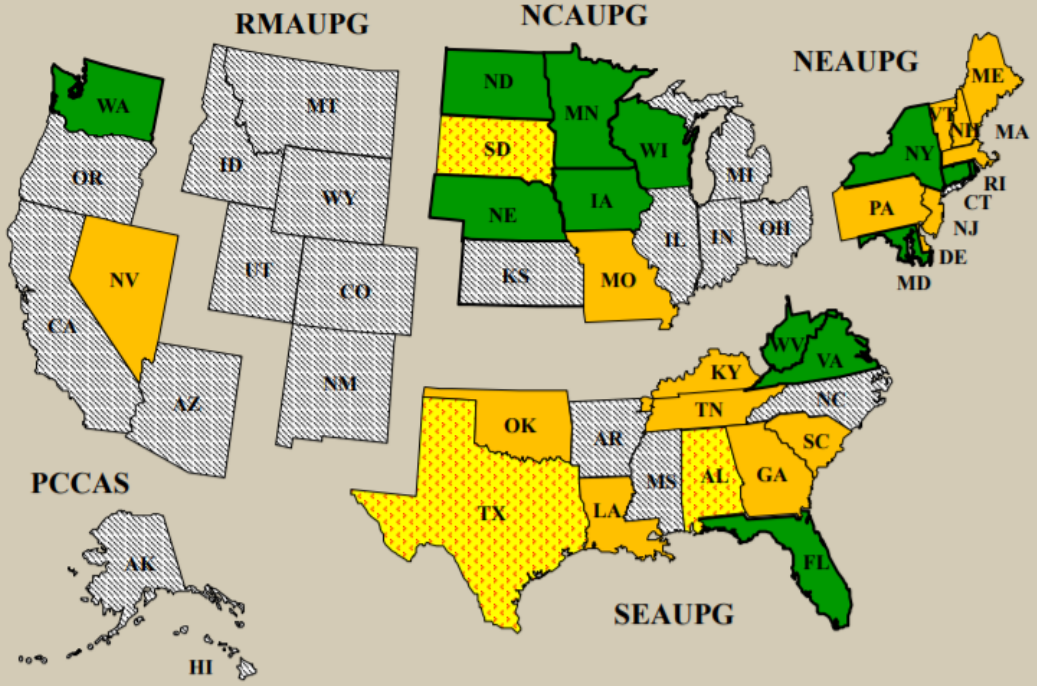

- 13 States Using M332
  - CT, FL, IA, MD, MN, NE, ND, NY, RI, VA, WA, WI, WV
- 15 States Using M332 for PMB only.
  - DE, GA, KY, LA, MA, ME, MO, NH, NJ, NV, OK, PA, SC, TN, VT
- 3 States Using M320 with M332 % recovery as a Plus test.
  - AL, SD, TX
- 19 States Using M320 and other Plus tests.
  - AK, AR, AZ, CA, CO, HI, ID, IL, IN, KS, MI, MS, MT, NC, NM, OH, OR, UT, WY

A Decade of MSCR Implementation

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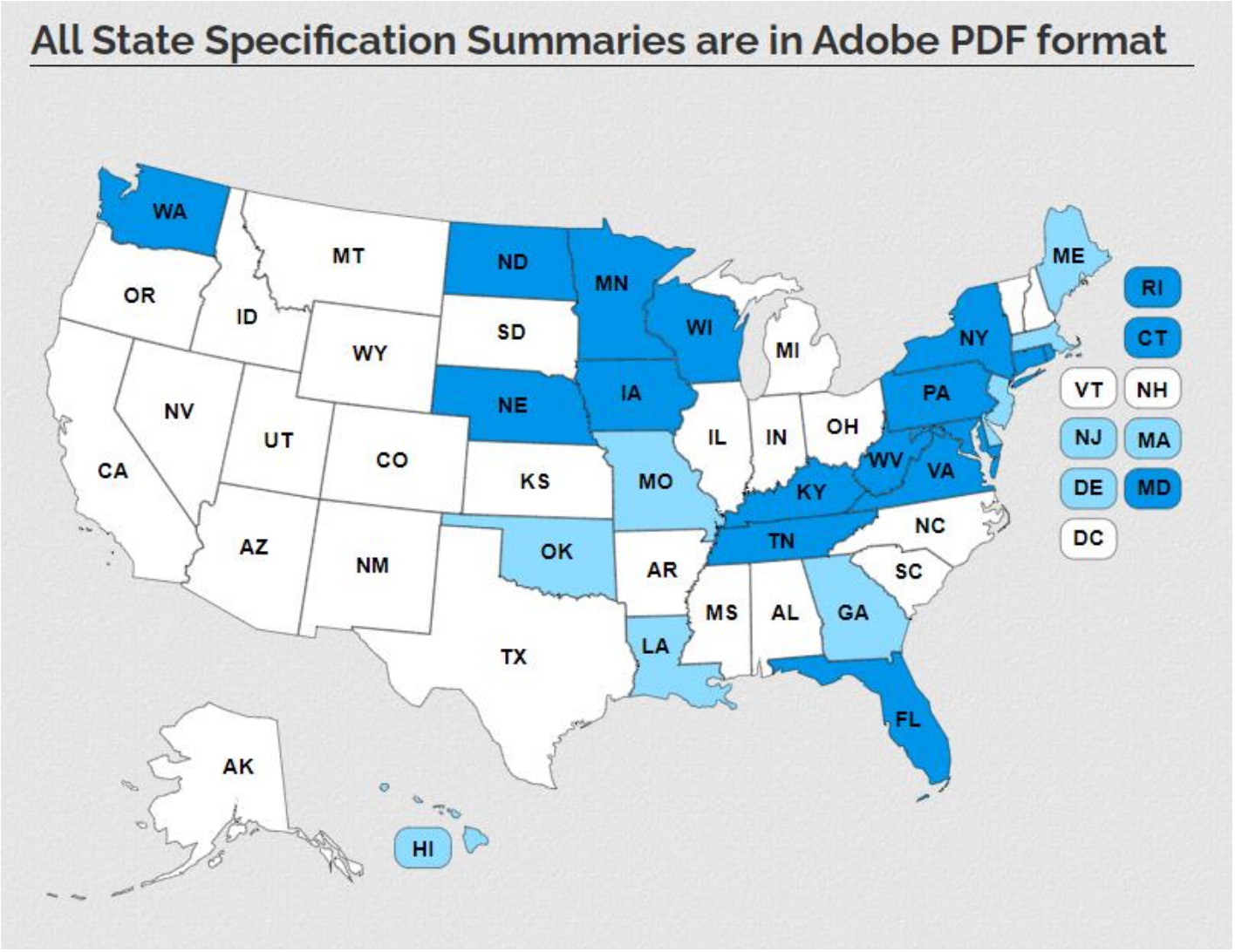
Current Status of MSCR Implementation in US



M320 Specifications

- Standard Specification for Performance-Graded Asphalt Binder
- Includes States still using M320
- Includes States that use MSCR Recovery only as a PG-Plus test

M320 / M332 Specifications

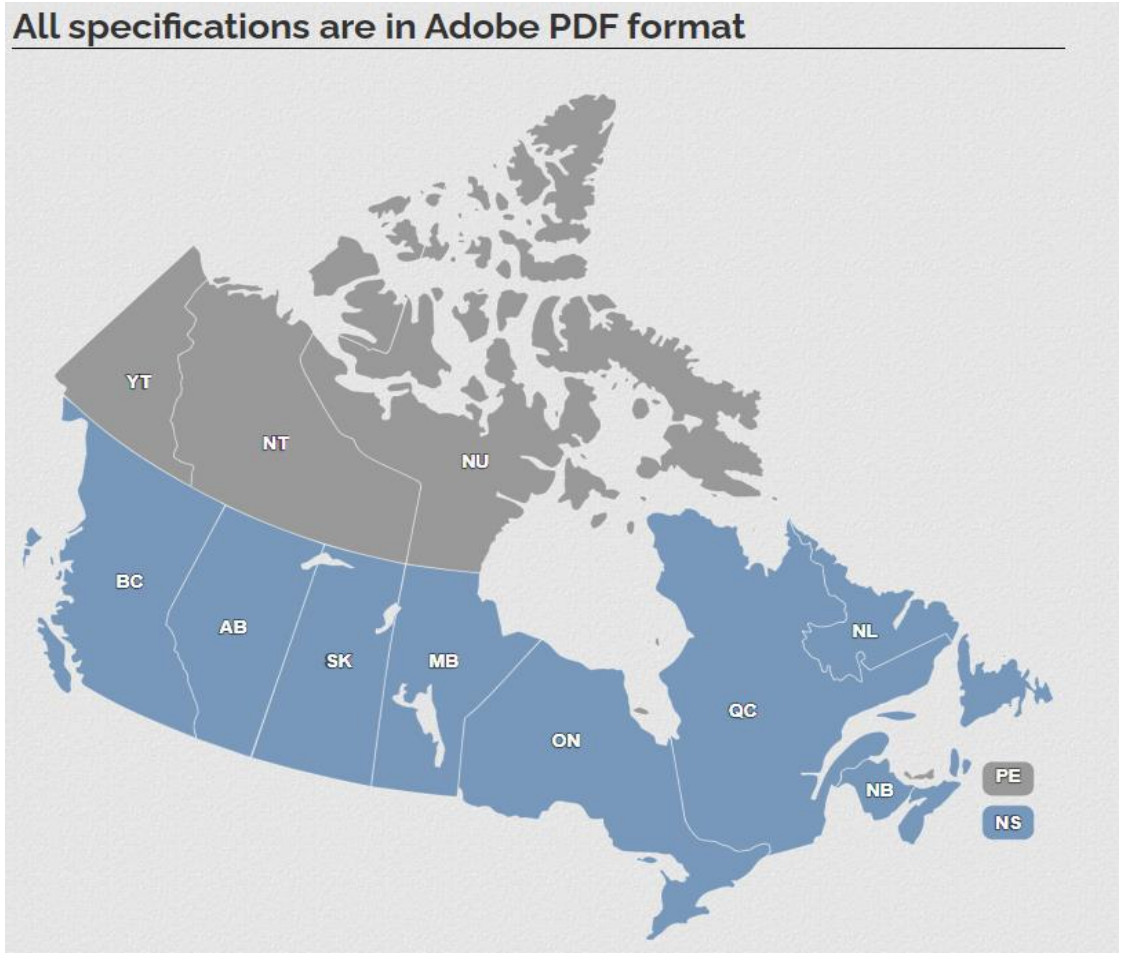
- States that specify M332 for some grades and M320 for other grades
- Includes States that allow a substitution of M332 for M320 grades

M332 Specifications

- Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) test
- Includes States that have adopted M332 for all grades
- Includes States that have adopted M332 for all grades, but retain the M320 nomenclature

A Decade of MSCR Implementation

Current Status of MSCR Implementation in Canada



- AASHTO M 320
  - Alberta
  - New Brunswick
  - Nova Scotia
  - New Foundland/Labrador
- AASHTO M 320 with MSCR %Recovery
  - British Columbia
  - Manitoba
  - Ontario
- AASHTO M 332
  - Quebec

Status of MSCR Implementation in US and Canada

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- United States
  - 25 of 50 states have implemented MSCR for all grades or some grades
  - A number of states use AASHTO M320 but also use MSCR %Recovery
  - Many DOTs have been doing M332 (MSCR) testing to gain knowledge
- Canada
  - 1 province has adopted MSCR (AASHTO M332)
  - 3 provinces use M320 but also use MSCR %Recovery

Why MSCR?

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- Why Use the MSCR Test and Spec?
  - Non-recoverable creep compliance (J_{nr}) is better correlated with pavement rutting than $G^*/\sin \delta$
    - The high temperature parameter is truer to the intent of the PG specification, that it be blind to method of modification

Why MSCR?

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- Why Use the MSCR Test and Spec?
  - MSCR Recovery can be used to identify elastomeric modification, thereby eliminating the need for many PG-Plus tests like Elastic Recovery
    - Much quicker test
    - Not directly tied to performance

Thanks!

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