Investigation of Very Wide Cracks

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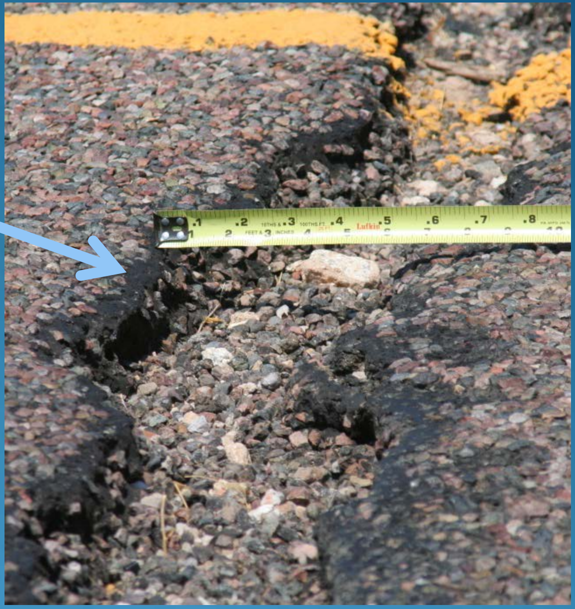
What is a Very Wide Crack?

- 2 inches or more wide cracks are considered **very wide cracks**
- Categorized as a **durability crack**
- May be referred to as a **working crack**
- May start as a **transverse thermal crack**



Sites with Very Wide Cracks

Maricopa County Roads

Sun Valley Parkway	Anthem Way	12th Street
North of McDowell Road	West of Independence Way	North of Circle Mountain Rd
Width = 7 inches	Width = 4 inches	Width = 2.5 inches
Age = 21 years	Age = 13 years	Age = 9 years

Examples of Very Wide Cracks

Non-County Pavements

Brown Road

West of 80th Street

Highway 89

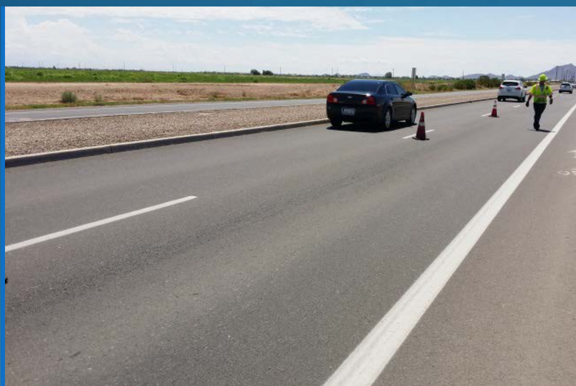
Near Mile Post 458

Private Parking Lot

Gilbert, AZ

Sites with No or Little Cracks

Maricopa County Roads



Ellsworth Road

North of Germann Road

Width = 1/8 in.
Age = 8 years

Ellsworth Road

South of McLellan Road

Width = 1/8 in.
Age = 10 years

Gilbert Road

North of Thomas Road

Width = 1/8 in.
Age = 9 years

Issues with Very Wide Cracks

- **Difficult to crack seal**—conventional crack seal material will not work
- **High maintenance cost**—if crack sealed, need frequent applications until it is not feasible any more
- **Cracking continues**—even other pavement preservations (overlay, rubber chip-seal) do not stop or slow down the cracking
- **Subgrade may fail**—may occur due to moisture penetration
- **Hazardous to motorists**—specially to cyclists and motorcyclists
- **Unpleasant ride**—noisy and bumpy

Very Wide Cracks—Observations

- Loss of volume—pavement loses significant amount of volume over the years
- Amount of volume loss—1% volume loss was estimated for pavements with cracks of 4” mean width appearing every 40 feet
- Average spacing of cracks—35 to 45 feet
- Lateral contraction—pavement separates even at gutters
- Crack width increases with time—no preservation method would stop the progress

Mechanisms of Very Wide Cracks

Known Factors Causing Volume Change

- Thermal Contraction and Expansion of pavement materials

Material	Thermal Expansion Coefficient, α
Aggregates	5.0×10^{-6} in / in / °F
Binder	1.0×10^{-4} in / in / °F
AC Mix	1.3×10^{-5} in / in / °F

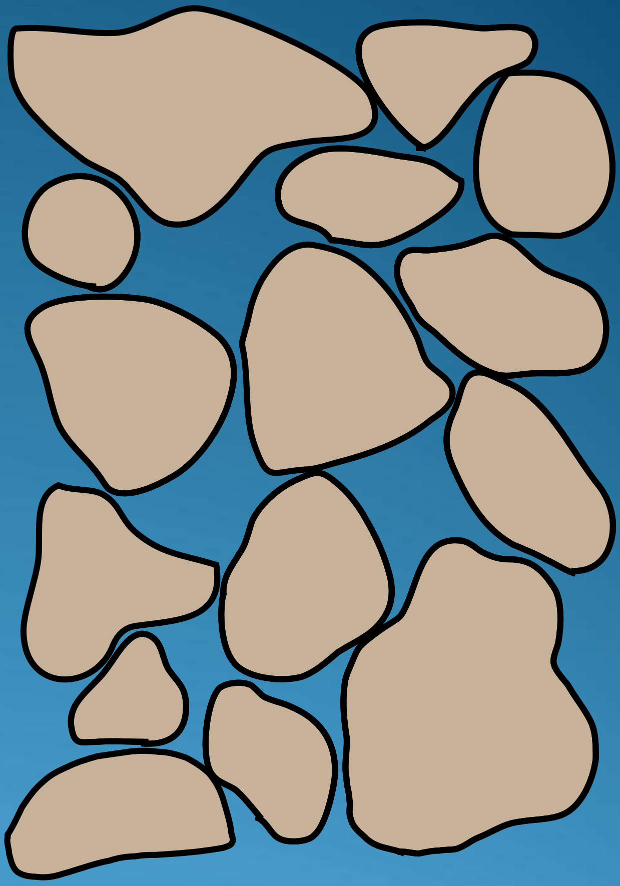
- Change in Air Voids—no internal stresses induced

- Evaporation and Oxidization—binder evaporates and oxidizes over time and causes volume loss

Investigation of Very Wide Cracks—Main Focus

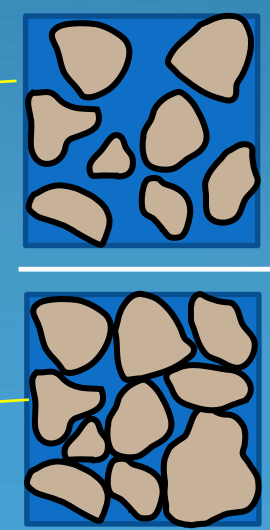
- **Main focus was given to the aggregate matrix**
- **Focused on aggregate interlocking**
- **Evaluated the nature of the mix used in the investigated pavements**
- **Attempted to answer the question:**

If a mix had good aggregate interlocking would that prevent cracking, or conversely, if a mix had poor aggregate interlocking would the pavement see more cracking?



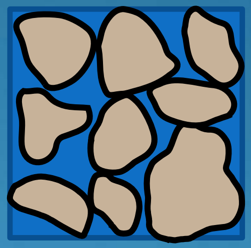
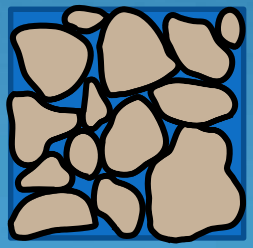
Investigation of Very Wide Cracks—Methodology

- The coarse aggregate (CA) interlocking was determined based on the **Loose Unit Weight (LUW)** concept in Bayley Method for AC mix design
- In Bayley Method, the interlocking is quantified as the ratio of volume of course aggregate in the AC mix to the volume of coarse aggregate when loosely packed
- This ratio is identified as **Degree of Interlocking (DOI)** for the purpose of this study
- $$\text{DOI} = \frac{\text{Volume of CA in 1 ft}^3\text{of mix}}{\text{Volume of CA based on LUW}} \times 100 =$$



Note: In Bayley Method DOI is referred to as % CA LUW

Investigation of Very Wide Cracks—Methodology

DOI	Mix Type	Matrix
< 85%	Fine-Graded	
95% to 105%	Coarse-Graded	
> 105%	Stone Matrix	

Investigation of Very Wide Cracks—Methodology

- Collect AC Core Samples from selected sites
- Perform binder and aggregate testing in the lab
- Determine DOI based on LUW
- Analyze DOI with respect to pavement crack width
- Check for any other noticeable factors affecting crack width

Investigation of Very Wide Cracks—Methodology

Collect AC Core Samples from selected sites

- Altogether, six sites were selected

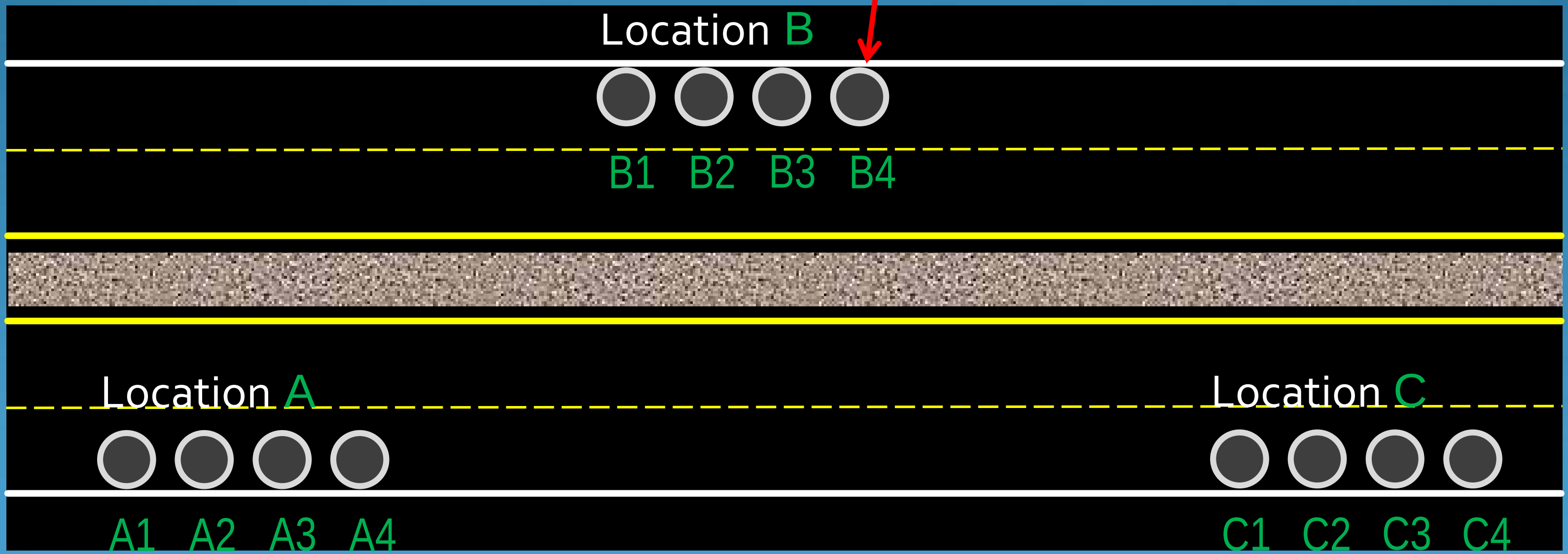
- Three sites with very wide cracks:
  - SV — Sun Valley Parkway north of McDowell
  - AW — Anthem Way west of Independence Way
  - TS — 12th Street north of Circle Mountain Road

- Three sites with no (or small) AC cracks
  - EG — Ellsworth Road north of Germann
  - EM — Ellsworth Road south of McClellan
  - GR — Gilbert Road north of McDowell

Investigation of Very Wide Cracks—Methodology

Collect AC Core Samples from selected sites

- **At each site, three locations (A, B, and C) representing cracked areas were selected**
- **Four 10-inch diameter cores were collected from each location**



Investigation of Very Wide Cracks—Methodology

Collect AC Core Samples from selected sites

Coring Gilbert Road Site

Investigation of Very Wide Cracks—Methodology

Perform binder and aggregate testing in the lab

- **Binder Testing:**
  - **Bulk Specific Gravity**
  - **Maximum Theoretical Specific Gravity (Rice)**
  - **Asphalt Binder Content**

- **Aggregate Testing:**
  - **Sieve Analysis of Aggregates**
  - **Loose Unit Weight (LUW) of Coarse Aggregates**
  - **LA Abrasion on Coarse Aggregates**

- **Calculations based on Test Results:**
  - **Determination of voids in the mix**
  - **Determination of Primary Control Sieve (PCS)**
  - **Determination of Degree of Interlocking (DOI)**

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

DOI

Volume of CA based on LUW

Volume of CA in 1 ft^3 of mix

$PCS = 0.22 \times NMAS$

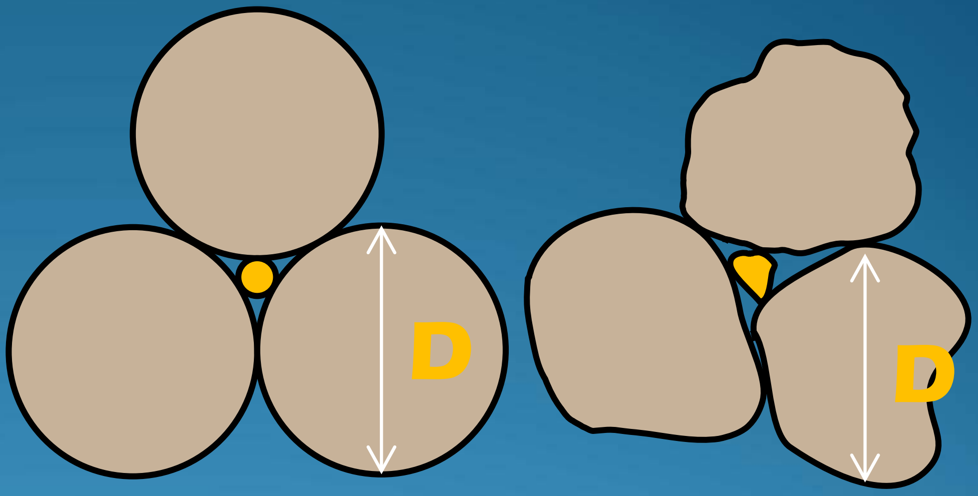
Nominal Maximum Aggregate Size (NMAS)

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

PCS —Primary Control Sieve

- PCS = 0.22 D
  where D = NMAS
  (from Bailey Method)
- PCS is the size that divides coarse aggregates from fine aggregates



Void Size for All Round Particles

0.15 D

Average Void Size for Aggregate Particles

0.22 D

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

Vol. of CA in 1 ft^3 of mix

Wt. of 1 ft^3 of mix (lbf) $= W_1 = G_{mb}\,\gamma_w$

based on bulk specific gravity, G_{mb}

unit weight of water

Wt. of binder in 1 ft^3 of mix (lbf) $= W_2 = bW_1/100$

based on binder content, b%

Wt. of fine & coarse aggregates in 1 ft^3 of mix (lbf) $= W_3 = W_1 - W_2$

based on W_1 and W_2

Wt. of coarse aggregates in 1 ft^3 of mix (lbf) $= W_c = pW_3/100$

based on % retained on PCS, p%

Vol. of coarse aggregates in 1 ft^3 of mix (ft^3) $= V_c = W_c / \gamma_s$

based on W_{c4}

unit weight of solids

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

Vol. of CA based on LUW

Wt. of coarse aggregates in the mold (lbf) $= W_{L1}$

based on loosely placed CA in modified Proctor mold

Loose Unit Weight of Coarse Aggregates (lbs/ ft^3) $= LUW = 13.33W_{L1}$

based on W_{L1} and volume of the mold, 1/13.33 ft^3

Wt. of CA in 1 ft^3 when in loose condition (lbf) $= W_L = LUW$

based on LUW

Vol. of CA when in loose condition (ft^3) $= V_L = W_L / \gamma_s$

based on W_L, which is actually LUW

unit weight of solids

Investigation of Very Wide Cracks—Methodology

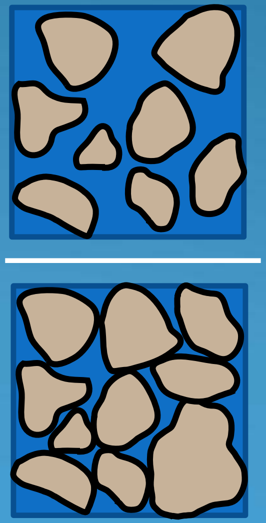
Determine DOI based on LUW

DOI based on LUW

$$DOI = \frac{\text{Vol. of CA in 1 ft}^3\text{ of mix, } V_c}{\text{Vol. of CA based on LUW, } V_L} \times 100$$

$$= \frac{W_c / \gamma_S}{W_L / \gamma_S}$$

$$= \frac{W_c}{W_L}$$

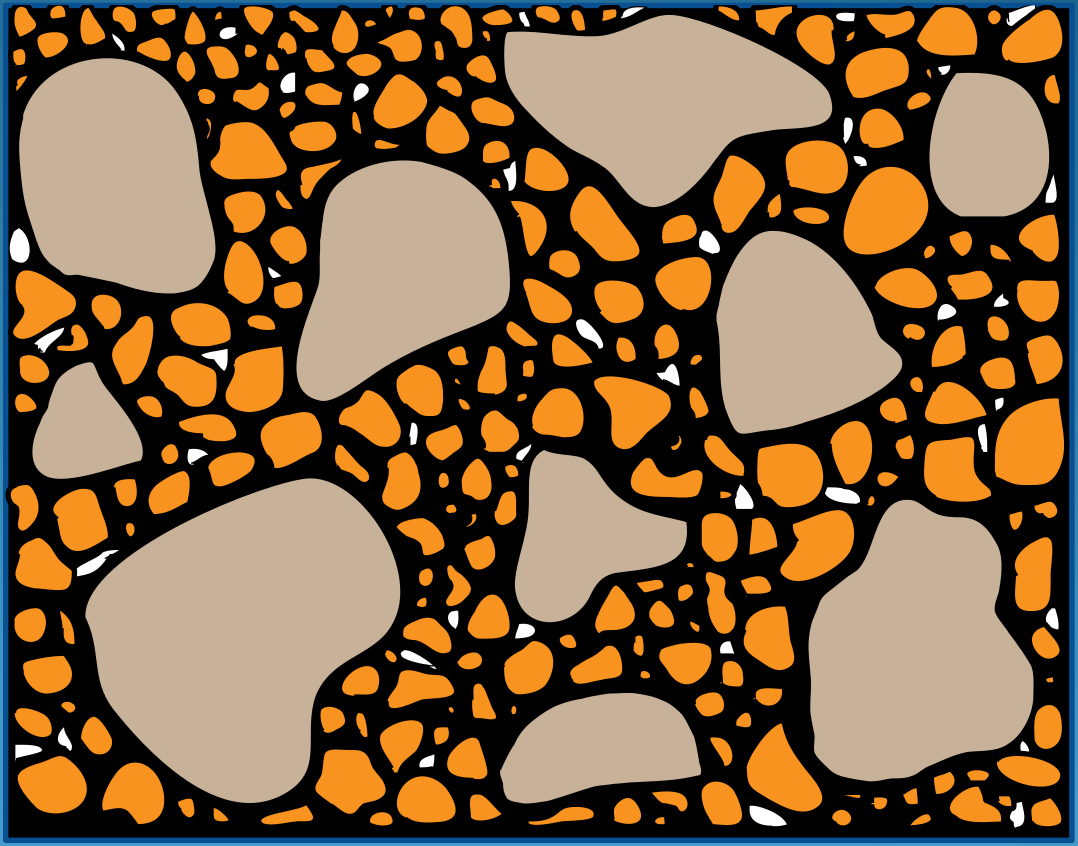


Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

DOI based on LUW

Fine
Graded
Mix



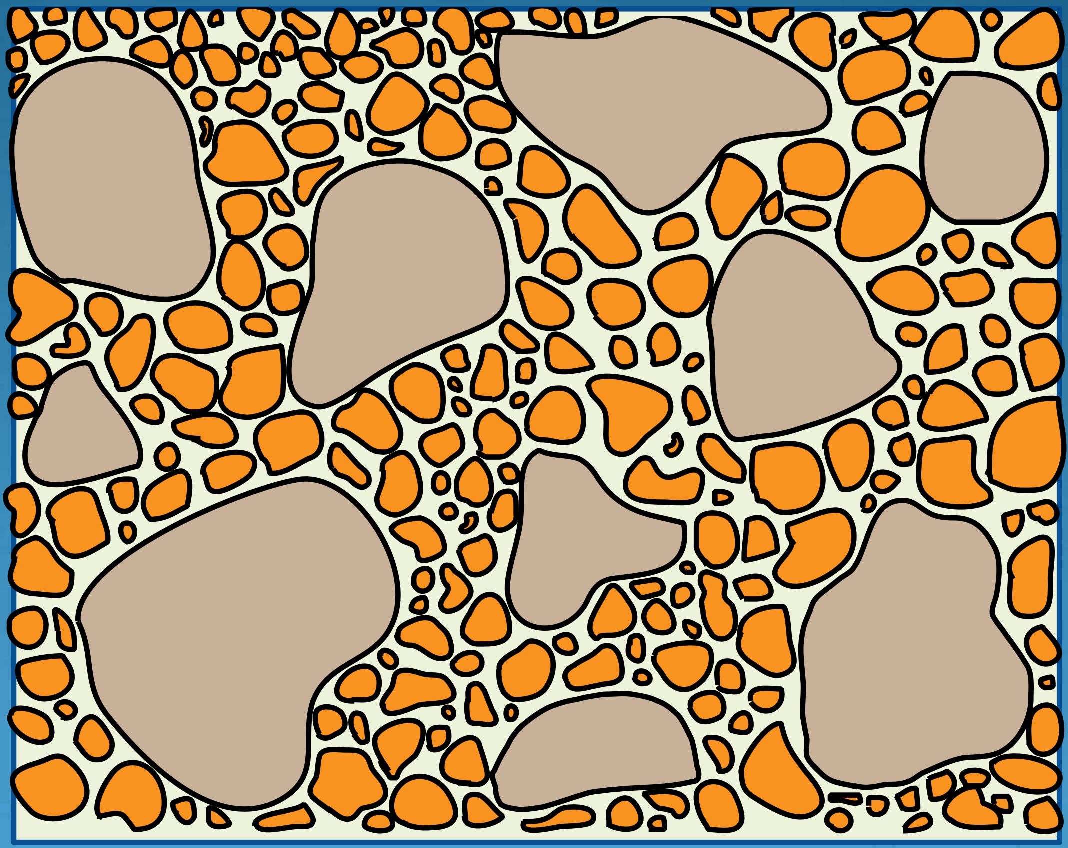
AC Sample

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

DOI based on LUW

Fine Graded Mix



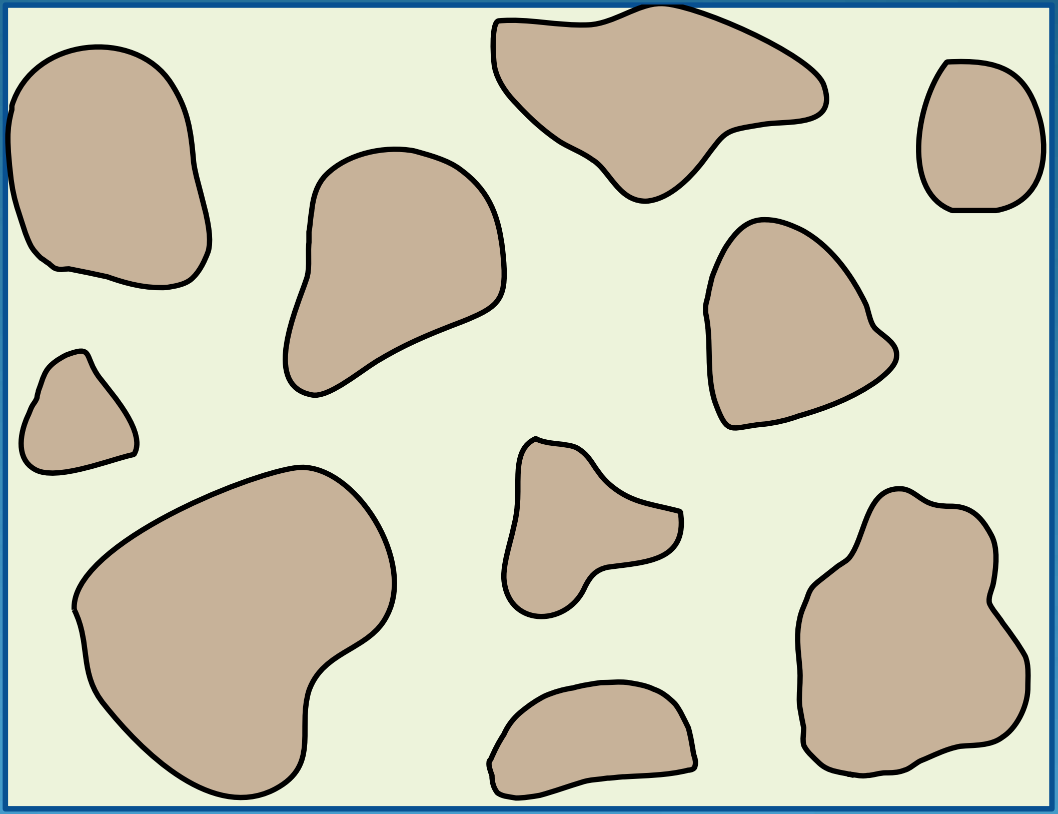
Binder Removed

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

DOI based on LUW

Fine
Graded
Mix



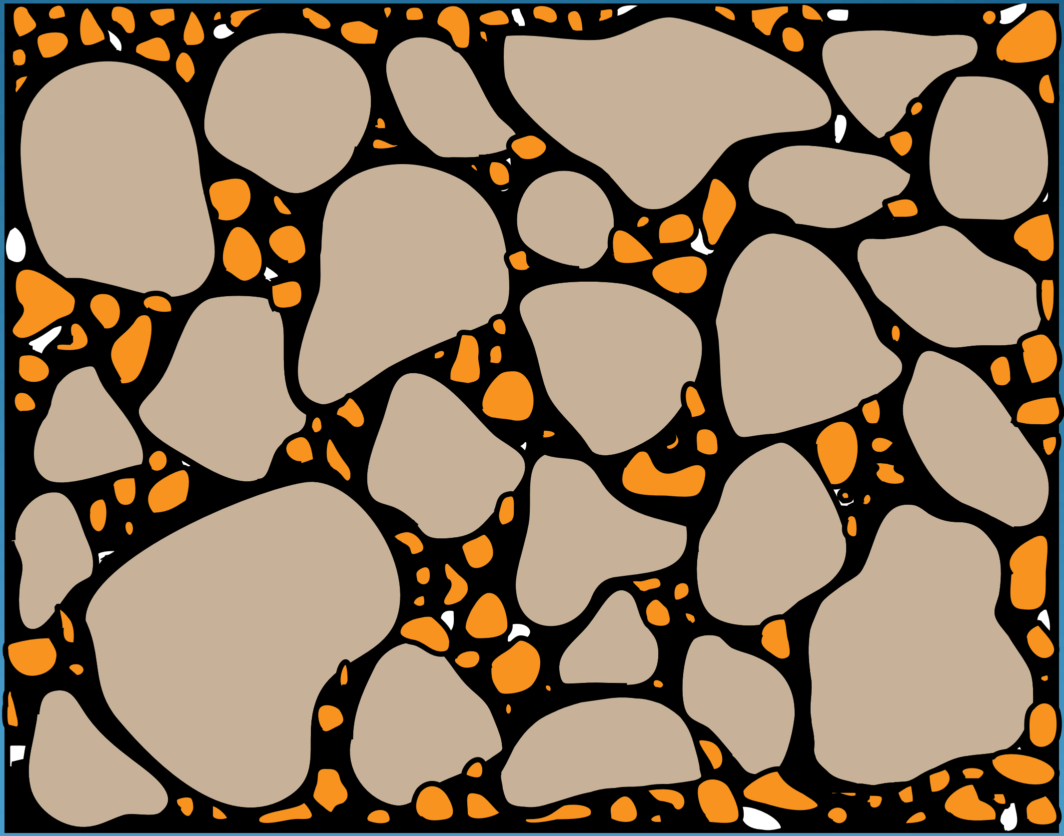
Fine Aggregates Removed

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

DOI based on LUW

Coarse
Graded
Mix



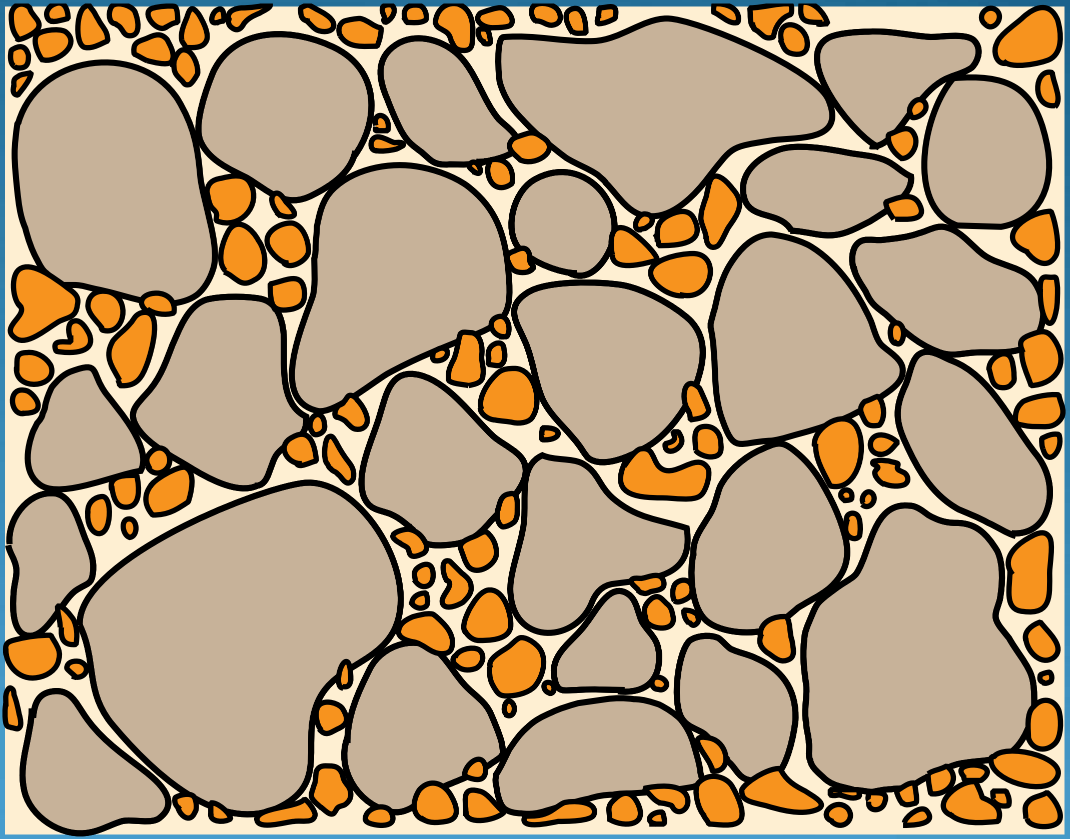
AC Sample

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

DOI based on LUW

Coarse Graded Mix



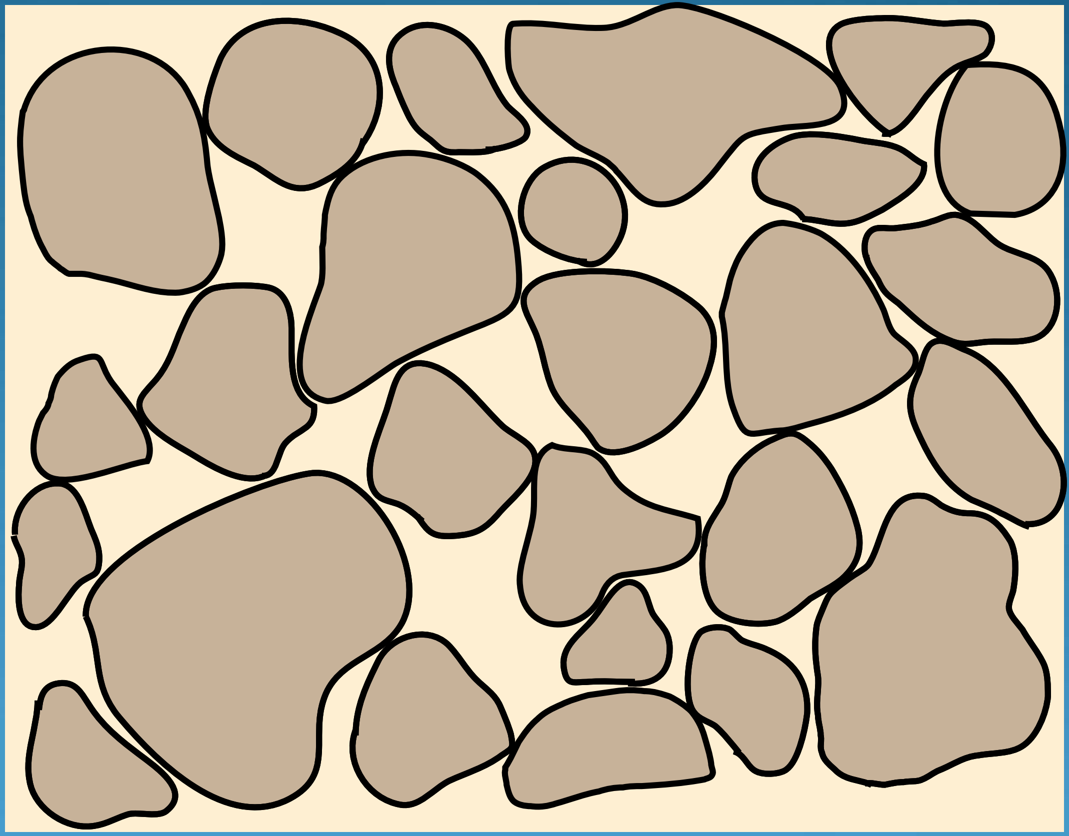
Binder Removed

Investigation of Very Wide Cracks—Methodology

Determine DOI based on LUW

DOI based on LUW

Coarse
Graded
Mix



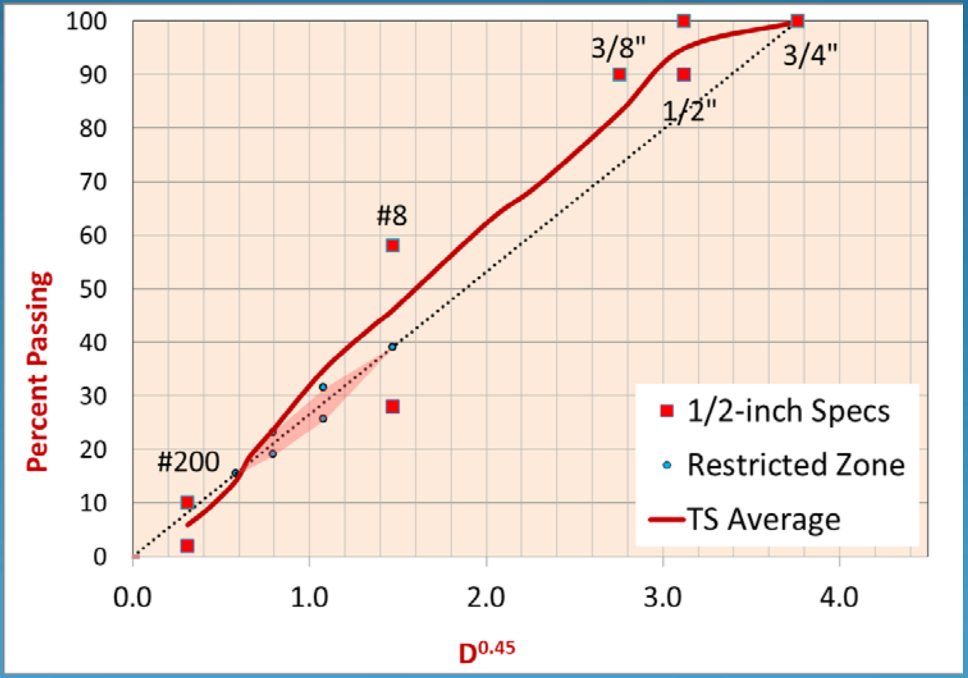
Fine Aggregates removed

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

TS

Single Layer



DOI

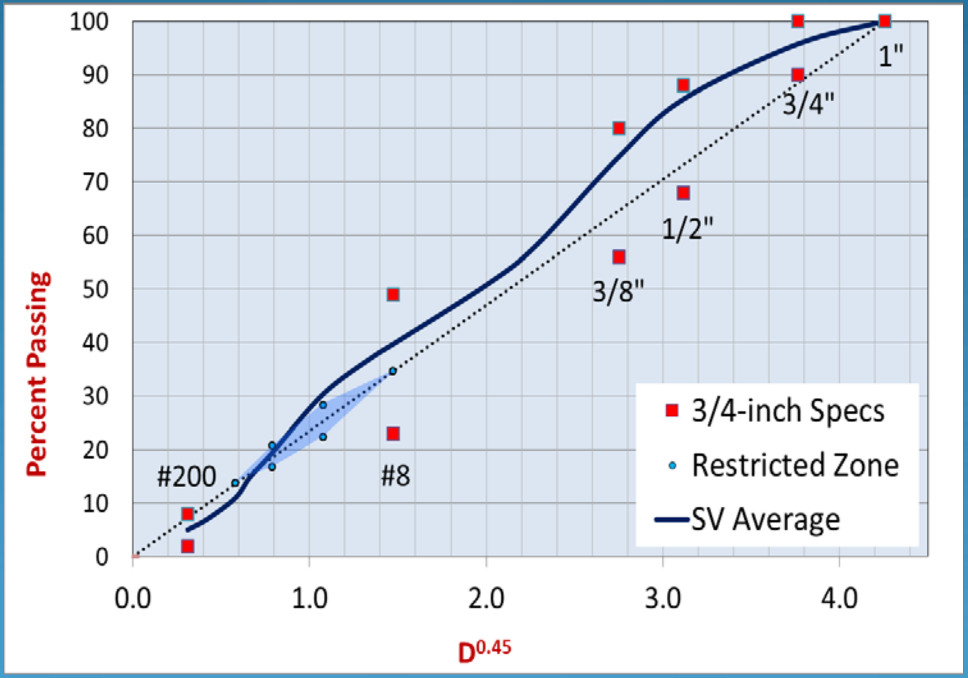
78%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect
to pavement crack width

SV

Single Layer



DOI

72%

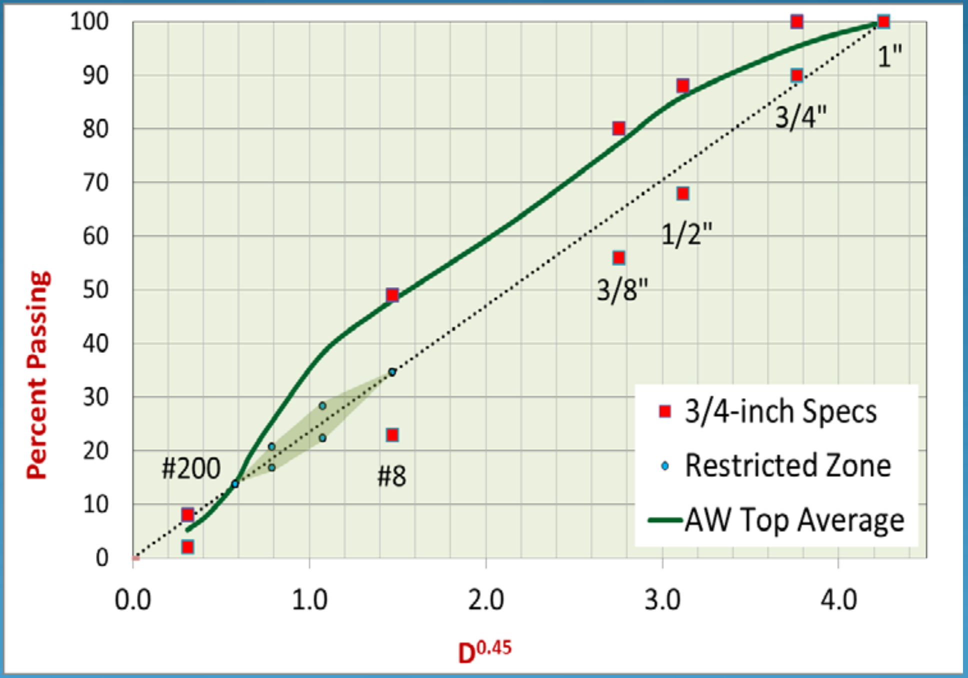
Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

AW

TOP

Layer



DOI

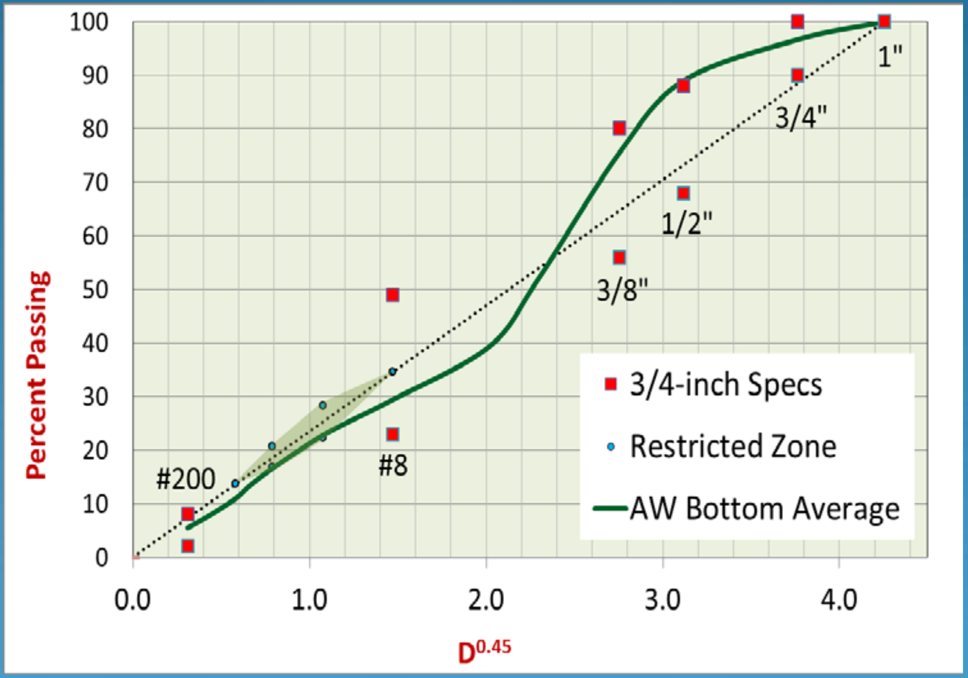
60%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

AW

Bottom Layer



DOI

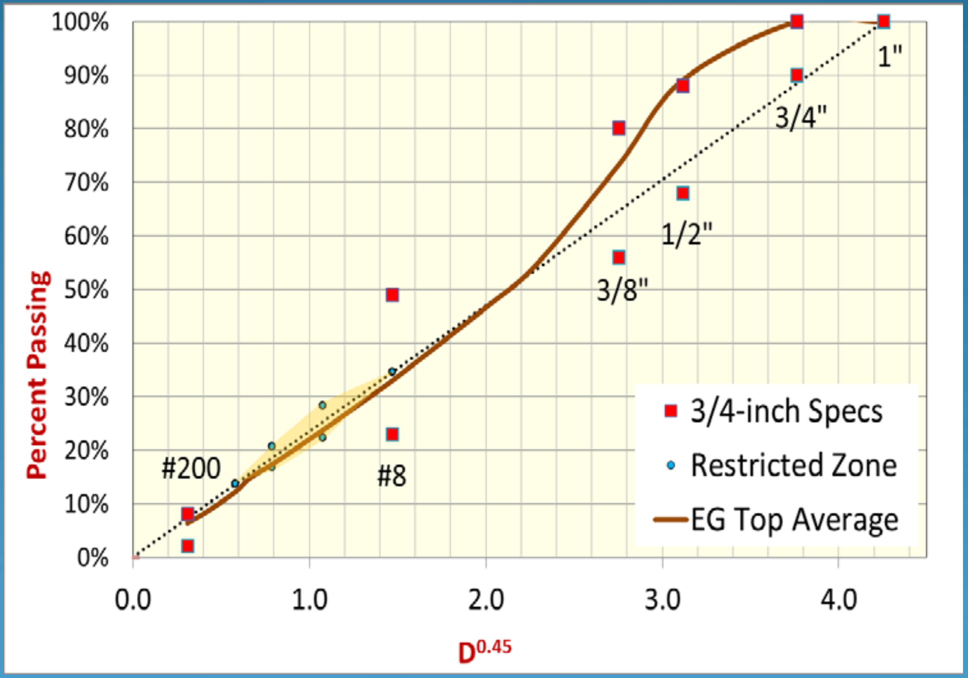
90%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

EG

Top Layer



DOI

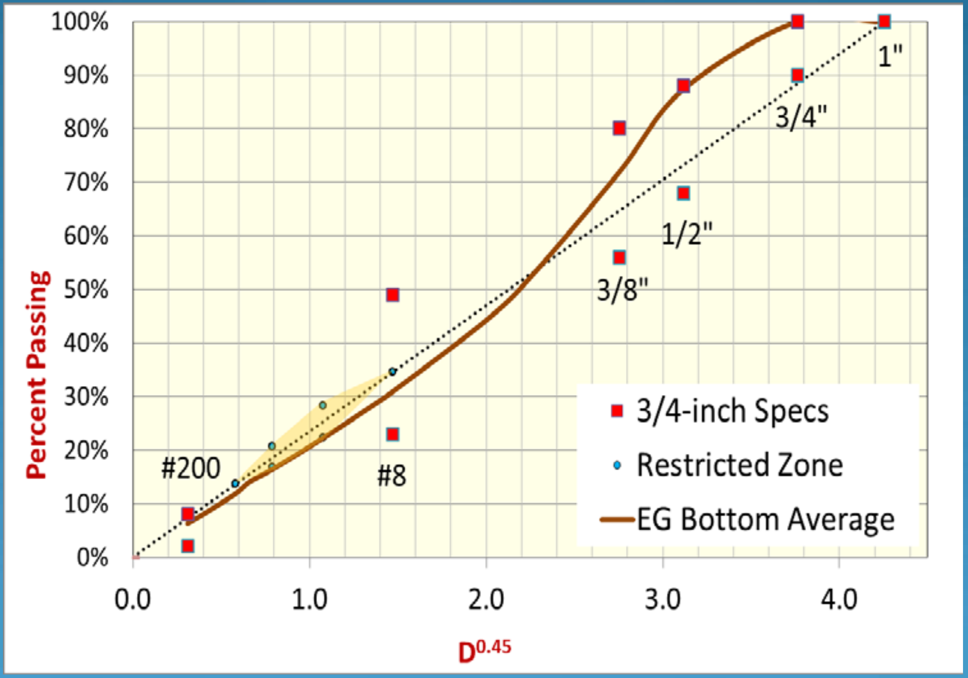
83%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

EG

Bottom Layer



DOI

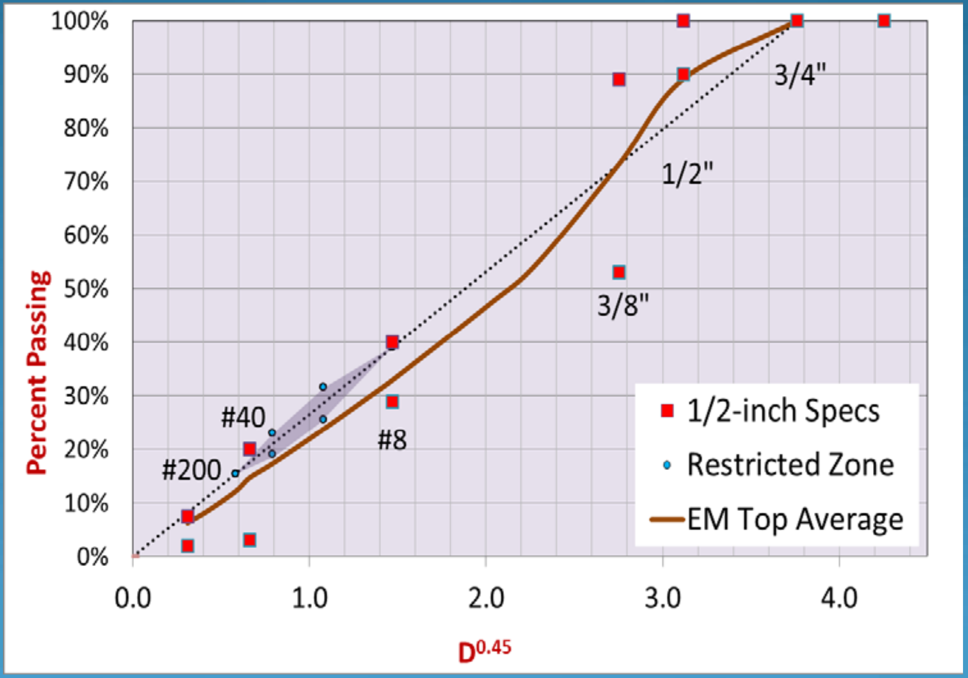
87%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

EM

Top Layer



DOI

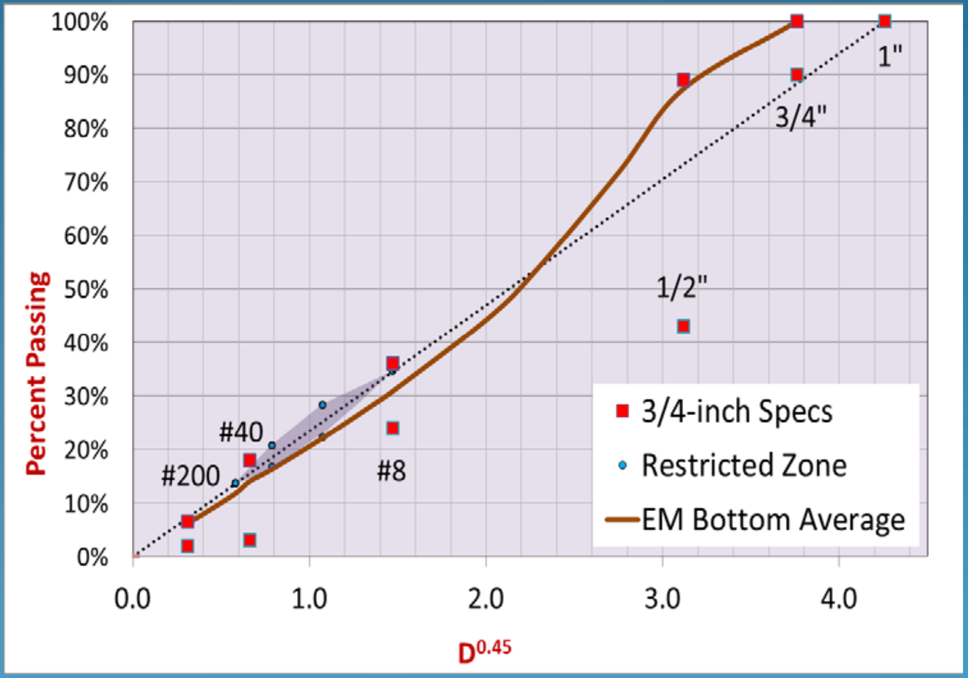
104%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect
to pavement crack width

EM

Bottom
Layer



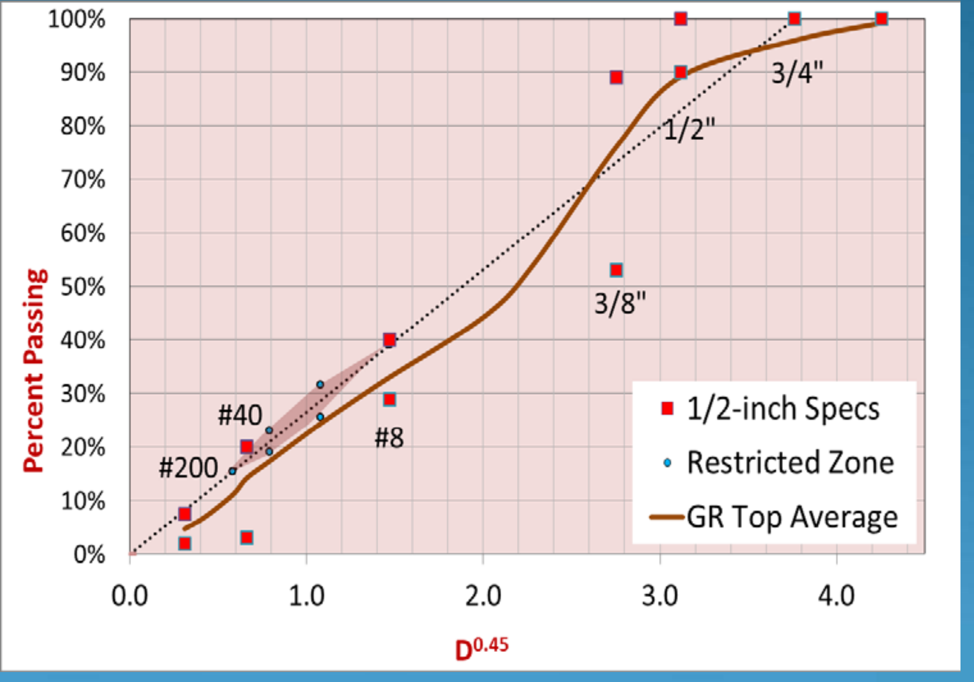
DOI
79%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

GR

Top Layer



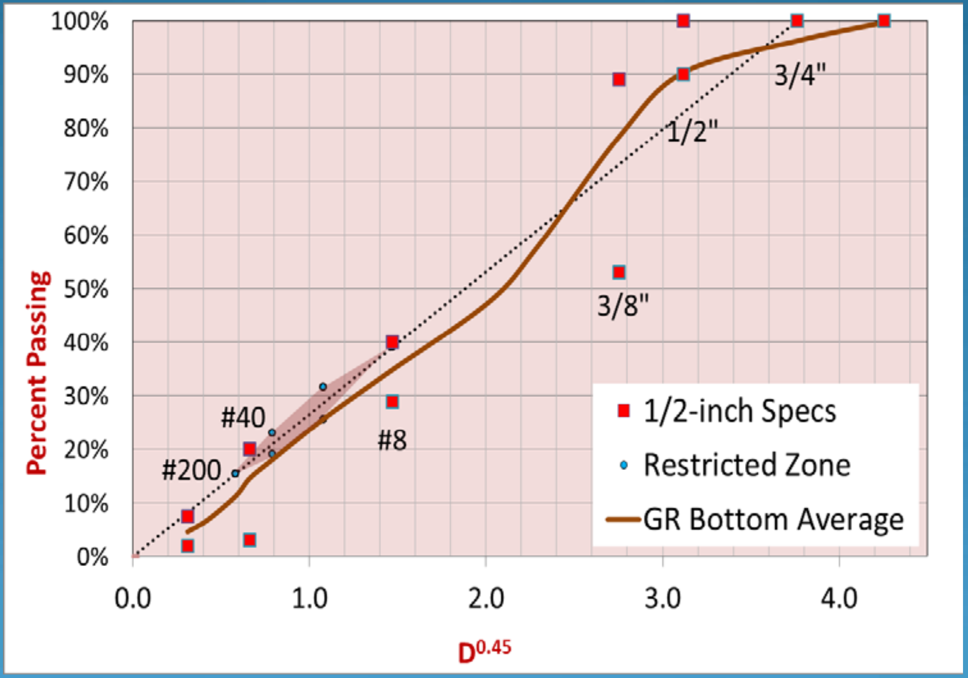
DOI
101%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

GR

Bottom Layer



DOI

98%

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

Site >		SV	AW		TS	EG		EM		GR	
Asphalt layer >		Single Layer	Top	Bottom	Single layer	Top	Bottom	Top	Bottom	Top	Bottam
Average Asphalt Thickness	inches	4.7	2.0	2.0	2.7	2.5	3	1.5	4	2.5	3
Thickness of AB	inches	10	10		NA	9		7.5		11.5	
Bulk Specific Gravity	--	2.337	2.333	2.329	2.362	2.471	2.445	2.213	2.327	2.366	2.364
Air Voids	%	5.35	5.50	6.72	4.76	4.99	6.00	5.33	4.15	4.57	3.75
Binder Content by weight	%	6.03	6.41	5.25	6.22	5.18	5.16	8.14	5.12	4.66	5.28
Nominal aggregate size	inches	¾	¾	¾	½	¾	¾	½	¾	½	½
Primary Control Seive (PCS)	#	#4	#4	#4	#8	#4	#4	#8	#4	#8	#8
Percent Retained on PCS	%	49	40	61	54	53	55	74	50	67	65
LUW	pcf	92.8	91.4	92.8	95.2	93.0	91.9	90.1	87.3	92.9	92.8
DOI	%	72	60	90	78	83	87	104	79	101	98
DOI (Average)	%	**72**	**75**		**78**	**85**		**91.5**		**99.5**	
Age of Maximum Crack	years	21	13		9	8		10		9	
Maximum Crack Width	inches	7.0	4.0		2.5	0.125		0.125		0.125	
Normalized Crack Width	inches	**3.33**	**3.08**		**2.78**	**0.16**		**0.13**		**0.14**	
LA Abration (500-Rev)	%	38	33	20	23	19	20	28	26	20	19
Shape of Aggregates	--	SRnd	SRnd	SRnd	SRnd	Ang	Ang	Ang	Ang	Ang	Ang

Investigation of Very Wide Cracks—Analysis

- Sub-Rounded
- Some particles crumble easily

- Sub-Rounded
- Some fracture faces

- Some Sub-Rounded particles
- Some fracture faces

Investigation of Very Wide Cracks—Analysis

- Angular particles
- Very high fracture faces

- Angular particles
- Very high fracture faces

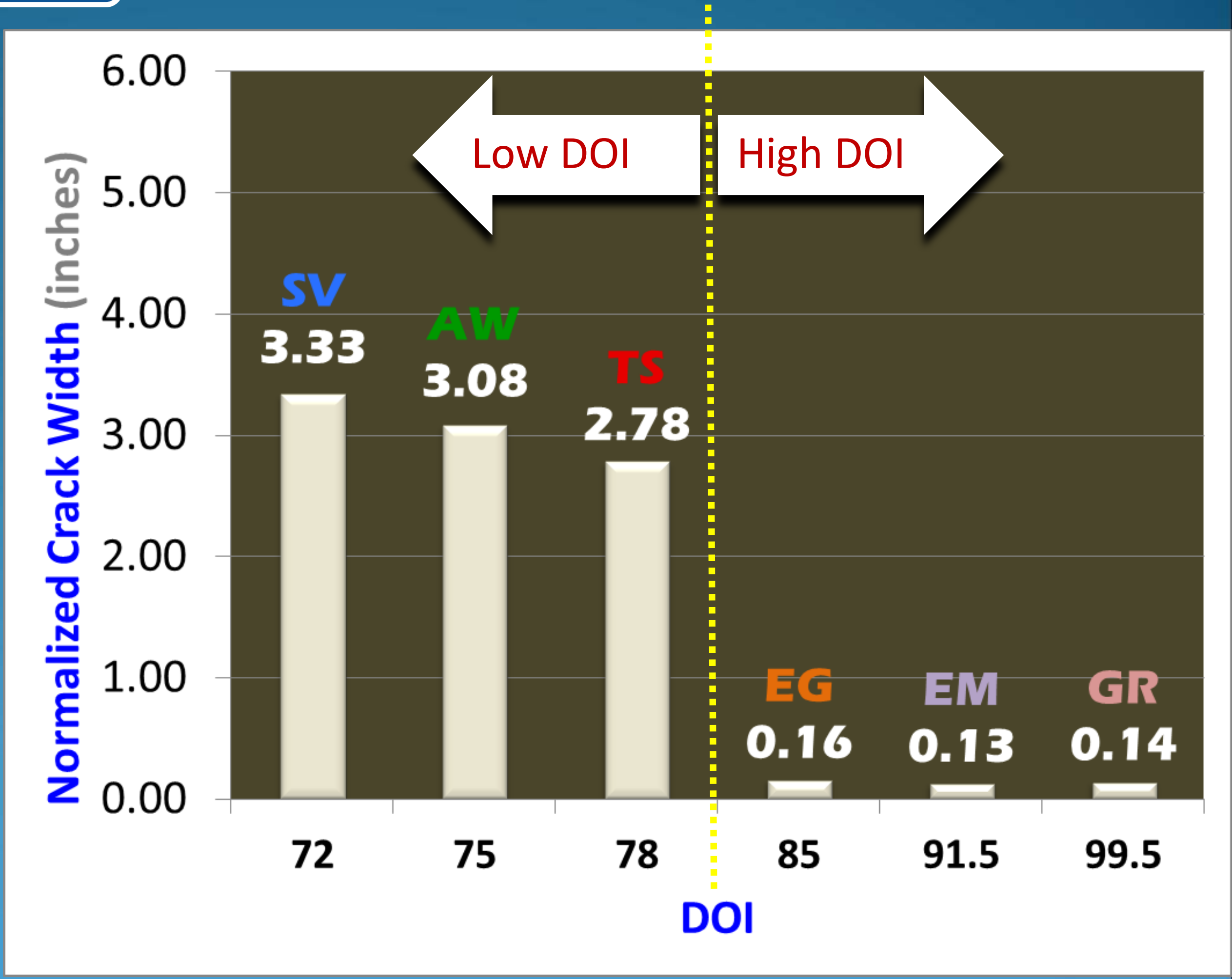
- Angular particles
- High fracture
- faces

Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width

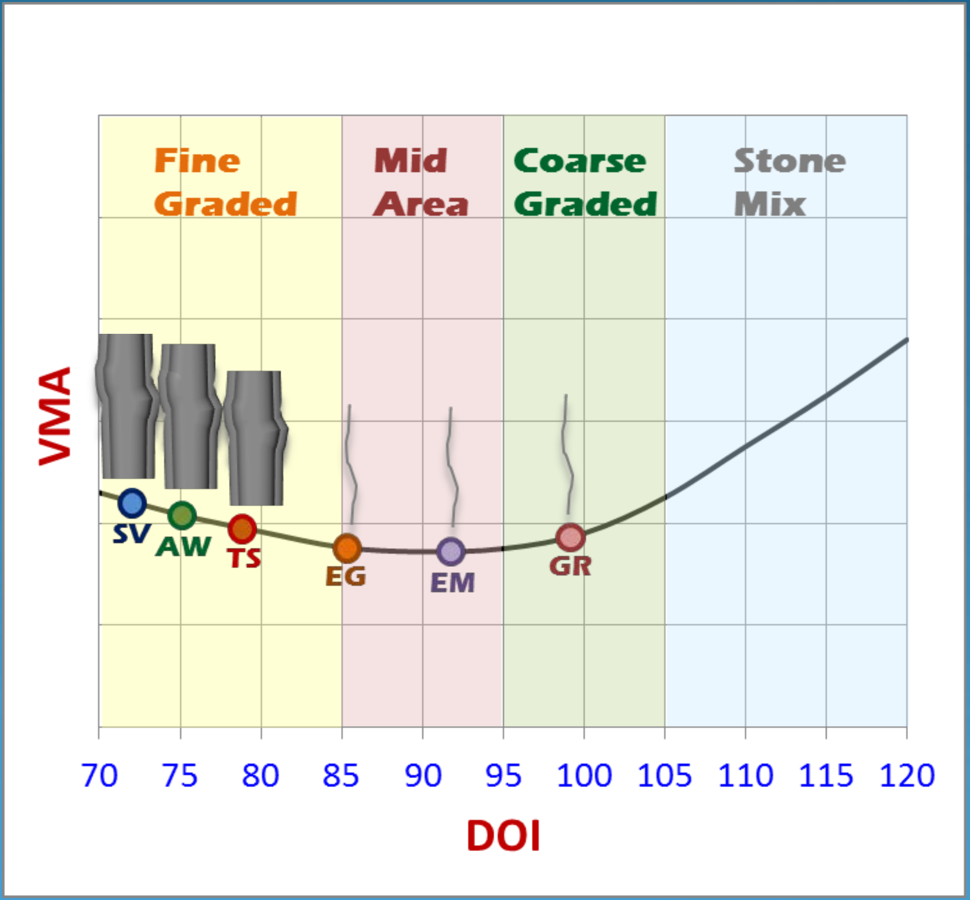
Normalized Crack Width

Maximum crack width was normalized for 10-year period based on the age of the crack



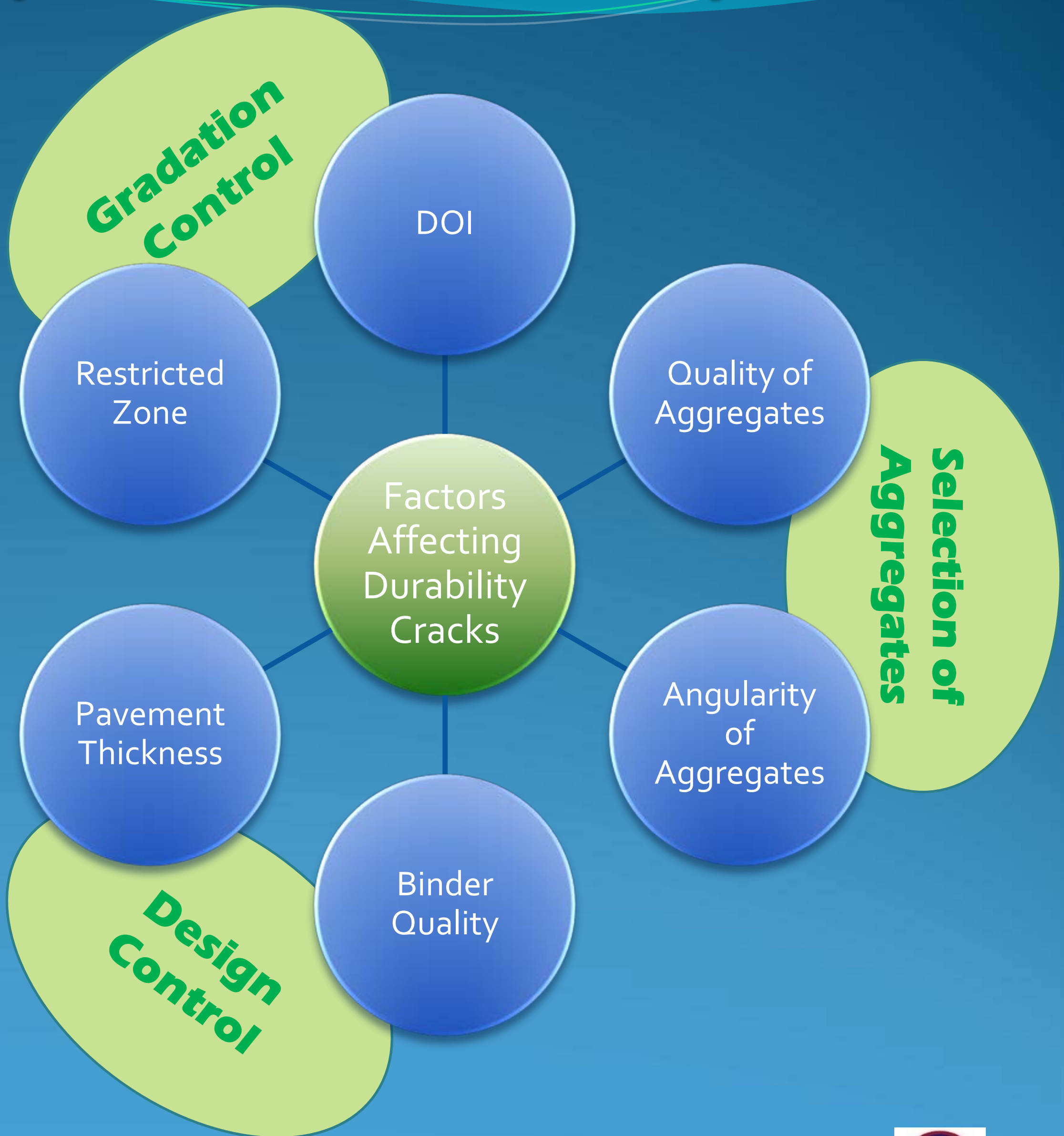
Investigation of Very Wide Cracks—Analysis

Analyze DOI with respect to pavement crack width



Investigation of Very Wide Cracks—Analysis

Check for any other noticeable factors affecting crack width



Summary of Findings

1. Coarse-Graded or Mid-Graded Pavements:
    - DOI > 85%
    - performed satisfactorily
    - exhibited only minor durable cracks

2. Fine-Graded Pavements:
    - DOI < 85%
    - performed unsatisfactorily
    - exhibited very wide durable cracks

3. Restricted Zone Comparison
    - Fine-Graded mixes plotted above the Restricted Zone
    - Coarse- or Mid-Graded mixes plotted below the Restricted Zone

4. Mixes with high angularity coarse aggregates:
    - perform better even with relatively low DOI
    - coarse aggregates with less angularity in mixes may exhibit prone to cracking if DOI is low

References

1. *Superpave Mix Design*, Superpave No. 2 (SP-2), Asphalt Institute, 3rd Edition 2001

2. *An Introduction to the Bailey Method for Achieving Volumetrics and HMA Compatibility*, Asphalt Institute, Mark D. Blow, PE and Robert P. Humer, PE, April 2007

3. *Bailey Method for Gradation Selection in Hot-Mix Asphalt Mixture Design*, Transportation Research Circular, Transportation Research Board, Number E-C044, October 2002

4. *Investigation of the Bailey Method for the Design and Analysis of Dense-Graded HMAC Using Oregon Aggregates*, Final Report, SPR 304-311, Asphalt Pavement Association of Oregon, Gary Thompson, PE, September 2006

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