WISCONSIN
CONCRETE
PAVEMENT
ASSOCIATION

Moving forward with concrete results

Performance Engineered Mixtures Testing in Wisconsin

Kevin W. McMullen, P.E.
President
Wisconsin Concrete Pavement Association

The PEM Concept and Initiative

- A partnership of agency and industry to
  - Understand what makes concrete "good"
  - Specify the critical properties and test for them
  - Design the paving mixtures to meet those specifications

Performance Engineered Mixtures

Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: PP 84-17[1]

Tech Section: 3c, Hardened Concrete

Release: Group 1 (April 2017)

AASHTO

INTRODUCTION

Print

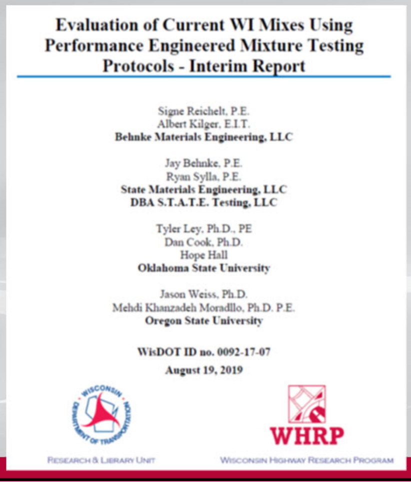
Specifications for concrete pavement mixtures have traditionally been prescriptive, with State Highway Agencies (SHA) specifying means and methods for both constituent materials and specific requirements for proportioning. This places the majority of the performance risk on the SHA and limits innovation. Recent trends of blending cementitious materials, reducing paste content, using modern additives and admixtures, and other innovations in the industry open the opportunity to move towards specifying the performance characteristics of concrete mixtures and allowing industry to design mixtures that address specific performance requirements. New methods to evaluate concrete performance have been developed, and others are being formulated, that can result in improved performance and economics. Shifting the responsibility for performance to the contractor provides an opportunity for innovation.

Performance Engineered Mixtures in Wisconsin

- More than a National priority, we have made it a state priority
- FHWA Pooled Fund Study – WisDOT and WCPA are both participating and funding.
- Our Joint Concrete Pavement Technical Committee is in the lead
  - We are getting beyond the decades old practice of blue book mixes, ACI 211 and tests of air, strength and slump.
  - WisDOT and contractors are supporting the emphasis on durability and performance based specifications
- Wisconsin Highway Research Program project to verify what we are doing

PEM Research in Wisconsin

- Evaluation of Current WI Mixes Using Performance Engineered Mixture Testing Protocols - Interim Report
- https://wisconsindot.gov/documents2/research/0092-17-07-interim-report.pdf



Evaluation of Current WI Mixes Using Performance Engineered Mixture Testing Protocols - Interim Report

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WisDOT ID no. 0092-17-07

August 19, 2019

RESEARCH & LIBRARY UNIT

WHRP
WISCONSIN HIGHWAY RESEARCH PROGRAM

Aggregate Quality and Stability

OUR FIRST PRIORITY

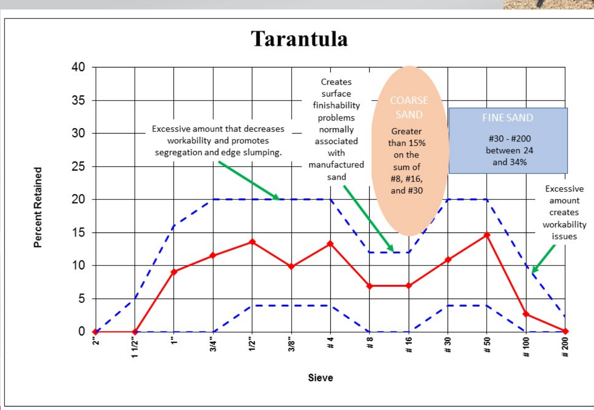
Optimized Aggregate Gradation and Concrete Mixtures

- National Research
- Tarantula Curve – Dr. Tyler Ley, OSU
- Promoted by NCPTC
- WisDOT and WCPA jointly developed the Standard special provisions (STSP) and specifications for WisDOT work
- Used on some construction projects in 2017 and has been incorporated into all concrete pavement projects by STSP since 2018.

Optimized Aggregate Gradation and Concrete Mixtures

- The GOALS
  - Stronger
  - More durable
  - Less permeable more dense concrete
  - Easier consolidated/workability
  - Improved ride

The *TARANTULA* curve!!!!



Optimized Aggregate Gradation Spec

TABLE 1 TARANTULA CURVE GRADATION BAND

SIEVE SIZES	PERCENT RETAINED
2 in.	0
1 1/2 in.	≤5
1 in.	≤16
3/4 in.	≤20
1/2 in.	4-20
3/8 in.	4-20
No. 4	4-20
No. 8[1]	≤12
No. 16[1]	≤12
No. 30[1] [2]	4-20
No. 50 [2]	4-20
No. 100 [2]	≤10
No. 200 [2]	≤2.3

[1] Minimum of 15% retained on the sum of the #8, #16, and #30 sieves.
[2] Conform to 24-34% retained of fine sand on the #30-200 sieves

Optimized Aggregate Gradation Spec

TABLE 2 JMF WORKING RANGE

SIEVE SIZES	WORKING RANGE[1] (PERCENT)
2 in.	±5
1 1/2 in.	±5
1 in.	±5
3/4 in.	±5
1/2 in.	±5
3/8 in.	±5
No. 4	±5
No. 8	±4
No. 16	±4
No. 30	±4
No. 50	±3
No. 100	±2
No. 200	≤ 2.3

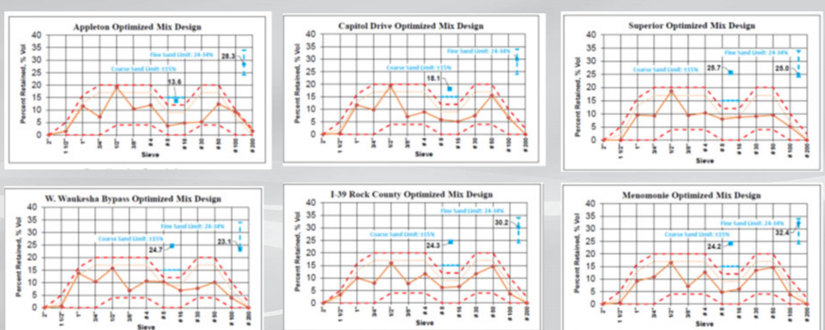
[1] Working range limits of composite gradation based on moving average of 4 tests.

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

PART 1

- Defines optimized gradation
- Outlines spec and testing requirements
- Contractor eligible for 3% incentive
- Sample on the belt leading to the weigh hopper
- Or, working face of the stockpile
- Test each component aggregate once per 1,500 CY of concrete production
- Moving average of four tests

What does the research project say?



Concrete Pavement Mixture Design and Analysis (MDA):
An Innovative Approach To Proportioning Concrete Mixtures

National Concrete Pavement Technology Center

Technical Report
March 2015

Sponsored through
Federal Highway Administration (DTFH61-06-H-00011 (Work Plan 25))
Pooled Fund Study TPF-5(205): Colorado, Iowa (lead state), Kansas, Michigan, Missouri, New York, Oklahoma, Texas, Wisconsin

IOWA STATE UNIVERSITY

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

PART 2

- Once aggregate gradation is optimized contractor can elect to go to mixture optimization
- Can reduce cementitious content to 520 lbs/CY.
- Utilizes new national design procedure
- Up to 30% replacement with fly ash, slag or combination
- Need to include the departments Flexural Strength for Mix Design STSP or the Concrete Pavement Flexural Strength SPV

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

1. Utilizes mix design procedure and spreadsheet developed by the National Concrete Pavement Technology Center
2. Utilize the spreadsheet to obtain an aggregate gradation system that fits within the Tarantula Curve and is relatively close to the power 45 curve.
3. Determine the volume of voids in the selected aggregate gradation system.
   a) Run ASTM C29 Specific Gravity on the proposed proportions of each aggregate.
4. Select the paste parameters; binder type, percentages, air content, w/cm.
5. **Select an Initial V_{paste} / V_{voids} value (1.25 – 2.00).**

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

6. Calculate the paste content utilizing the spreadsheet. WisDOT requires a **minimum cement content of 520 lbs** so the V_{paste} / V_{voids} value may need to be adjusted to meet this minimum cement content
7. Prepare trial batches and assess fresh properties and workability.
8. Prepare final trial batch and assess hardened properties.

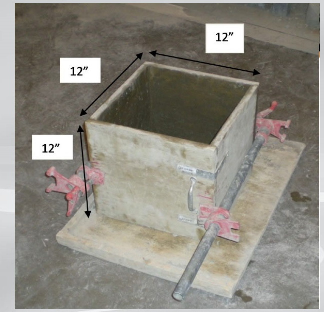
BOX TEST

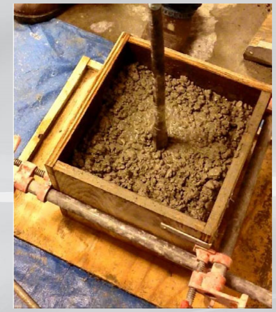
Workability

Assess Workability

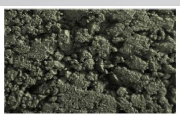
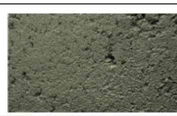
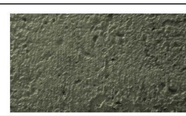
- Box Test
- V Kelly Ball

BOX TEST





BOX TEST

	
4	3
Over 50% overall surface voids.	30-50% overall surface voids.
	
2	1
10-30% overall surface voids.	Less than 10% overall surface voids.

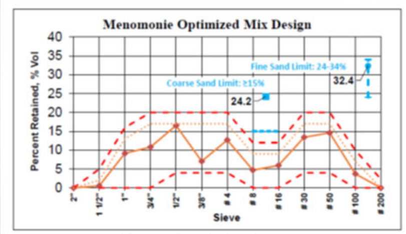


Figure 25: Menomonie Tarantula Curve.

Figure 26: Menomonie Box Test Photos.

From the research project

V-KELLY

WCPA

ASR Testing

- First time incorporated into the standard specifications

501.2.5.4.4 Alkali Silica Reactivity Testing and Mitigation Requirements

(1) If using coarse aggregate from sources containing significant amounts of fine-grained granitic rocks including felsic-volcanics, felsic-metavolcanics, rhyolite, diorite, gneiss, or quartzite; test coarse aggregate according to ASTM C1260 for alkali silica reactivity. Gravel aggregates are exempt from this requirement.

(2) If ASTM C1260 tests indicate a 14-day expansion of 0.15 percent or greater, perform additional testing according to ASTM C1567. Test mortar bars made with coarse aggregate and the blend of cementitious materials proposed for concrete placed under the contract. The department will reject the aggregate if ASTM C1567 tests confirm mortar bar expansion of 0.15 percent or greater at 14 days.

WCPA

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

- WisDOT Spreadsheet
- Originally developed at National Center for Concrete Pavement Technology
- Adapted for WisDOT use
- STSP requires use and submittal of this spreadsheet for approval
- http://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/qmp/default.aspx

WCPA

New Aggregate System

CONCRETE MIXTURE DESIGN — Date: 01/02/20

Project Information			
Construction Project ID	Contract ID	Highway	County
11223344	**123456**	**Highway A**	**County B**
Project Title		Project Limits	
Project Title C		**Project Limits D**	
Prime Contractor		Subcontractor (if applicable)	
Prime Contractor E		**Subcontractor (if applicable) F**	

AGGREGATE SOURCES

Type	Unique Aggregate ID #	Description	Quality #	S.G. (OD)	Absorp (%)	S.G. (SSD)
#1 Stone	55-47-008-QRY	Cookoo Quarry	225-0008-2020	2.493	3.836	2.589
Fine	53-32-001-PIT	Pipers Pit	162-0152-2020	2.648	0.847	2.670
#2 Stone	55-31-002-QRY	Cookoo Quarry	225-0008-2020	2.493	3.836	2.589
Other A - If Used				1.000		1.000
Other B - If Used				1.000		1.000

CEMENTITIOUS 520 — **AGGREGATE CORRECTION FACTOR** 0.3

SIEVE ANALYSIS DATA

Max nominal aggregate size inch (0.75, 1.0 or 1.5): 1.5 Inch

100.00	#1 Stone	Cookoo Quarry	Fine	Pipers Pit	#2 Stone	Cookoo Quarry	Combined: Percent Passing	Cum. Retained	Sieve Retained	Retained Volumetric	Fineness Modulus
Percent mass		37.61		42.73		19.66					
Percent vol.		38.57		41.26		20.16					
Sieve:	% Pass	% Mix	% Pass	% Mix	% Pass	% Mix	%	%	%	%	
2"	100.0	37.6	100.0	42.7	100.0	19.7	100.0	0.0	0.0	0.0	
1 1/2"	100.0	37.6	100.0	42.7	98.9	19.4	99.8	0.2	0.2	0.2	
1"	100.0	37.6	100.0	42.7	47.5	9.3	89.7	10.3	10.1	10.4	
3/4"	98.5	37.0	100.0	42.7	5.6	1.1	80.9	19.1	8.8	9.0	
1/2"	61.1	23.0	100.0	42.7	1.2	0.2	65.9	34.1	14.9	15.3	
3/8"	37.6	14.1	100.0	42.7	1.1	0.2	57.1	42.9	8.9	9.1	0.0
# 4	3.2	1.2	100.0	42.7	1.1	0.2	44.2	55.8	12.9	13.3	0.0
# 8	2.2	0.8	92.5	39.5	1.1	0.2	40.6	59.4	3.6	3.5	7.5
# 16	2.0	0.8	73.0	31.2	1.1	0.2	32.2	67.8	8.4	8.1	27.0
# 30	2.0	0.8	42.8	18.3	1.0	0.2	19.2	80.8	12.9	12.5	57.2
# 50	1.9	0.7	8.7	3.7	1.0	0.2	4.6	95.4	14.6	14.1	91.3
# 100	1.6	0.6	1.6	0.7	1.0	0.2	1.5	98.5	3.1	3.0	98.4
# 200	1.3	0.5	0.9	0.4	0.8	0.2	1.0	99.0	0.5	0.0	

TARANTULA CURVE LIMITS (percent retained chart)

Description	Sieves Retained on	Limit	Mix Retained (%)	Results
Fine	#30 - #200	b/w 24% and 34%	31.1	Pass
Coarse	#8, #16, and #30	>15%	24.9	Pass

Fineness Modulus 2.81

WisDOT Version 4.0
07/08/19

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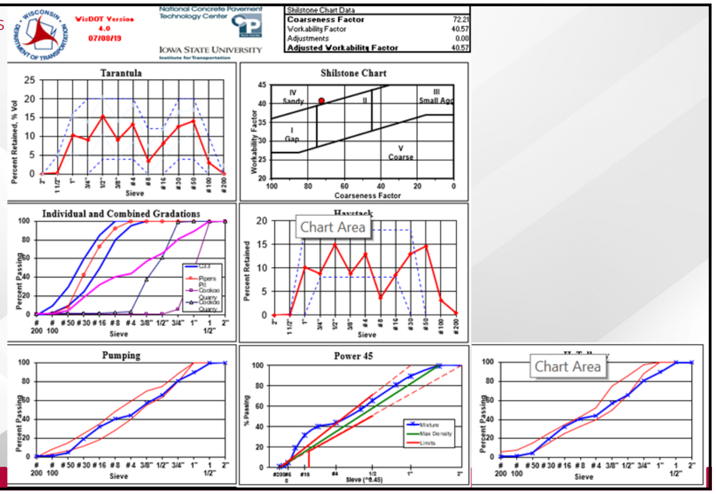
New Data Charts



New Paste Quality

CONCRETE MIXTURE DESIGN			Date	01/02/20
Project Information				
Construction Project ID **11223344**	Contract ID **123456**	Highway **Highway A**	County **County B**	
Project Title **Project Title C**		Project Limits **Project Limits D**		
Prime Contractor **Prime Contractor E**		Subcontractor (if applicable) **Subcontractor (if applicable) F**		

CEMENTITIOUS MATERIAL	Manufacturer	Source	Type/Class/Grade:	Specific Gravity (S.G.)
Cement				3.15
Fly Ash				2.65
Slag				1.00

WisDOT Version
4.0
07/08/19

CEMENTITIOUS	520

CONCRETE PROPERTIES		
w/cm	0.42	
Air %	7.0	%
SAM #	0.20	during trial batching
Fly Ash	30	%
Slag	0	%
Box Test Eval.	1	Rating #
Voids in Agg	19.0	%

= from Voids WS

AGGREGATE SOURCES	Unique ID #	Description	S.G. (OD)	S.G. (SSD)
#1 Stone	55-47-008-QRY	Cookoo Quarry	2.493	2.589
Fine	53-32-001-PIT	Pipers Pit	2.648	2.670
#2 Stone	55-31-002-QRY	Cookoo Quarry	2.493	2.589
Other A - If Used			1.000	1.000
Other B - If Used			1.000	1.000

WATER	Gal	Source
Water	26.19	

ADMIXTURE	Name	Dosage (oz/cwt)
1		
2		

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New Mix Design (Solver)

CONCRETE MIXTURE DESIGN			Date	01/02/20
Project Information				
Construction Project ID **11223344**	Contract ID **123456**	Highway **Highway A**	County County B	
Project Title **Project Title C**		Project Limits **Project Limits D**		
Prime Contractor **Prime Contractor E**		Subcontractor (if applicable) **Subcontractor (if applicable) F**		

MIXTURE PROPORTIONS					
Material	Manufacturer	Source	Weight (lbs)	Actual R.D.	Volume
Cement			364	3.15	1.85
Fly Ash			156	2.65	0.94
Slag			0	1.00	0.00
#1 Stone	---	Cookoo Quarry	1170	2.59	7.25
Fine	---	Pipers Pit	1330	2.67	7.98
#2 Stone	---	Cookoo Quarry	612	2.59	3.79
Other A - If Used	---		0	1.00	0.00
Other B - If Used	---		0	1.00	0.00
Water			218	1.00	3.50
Air %			7.0		1.89
	TOTAL		3851		27.20

Cementitious	520	520	pcy
Volume of paste		30.1	%
Volume of aggs		69.9	%
Volume of voids		13.3	%
vp/vv	>125	226.6	%
w/cm	0.42	0.42	
% SCM 1	30	30	%
% SCM 2	0	0	%
Mass aggs	3112	3112	pcy

WisDOT Version
4.0
07/08/19

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STRENGTH

Flexural Strength

- WisDOT basis for design is flexural strength in AASHTO pavement design procedure.
- Makes sense to assure we are achieving what was designed for

Special Provision Flexural Strength

Maximum resistance of a concrete specimen to bending.

- 6-inch x 6-inch x 21-inch concrete beams
- Third-point loading in accordance with AASHTO T 97.

Flexural Strength

- Two SPV's
  - SPV for mix qualification
  - SPV for strength acceptance
- Incentive/disincentive pay model for flexural strength is based on data from pilot projects over the last decade

Flexural Strength

- http://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/qmp/default.aspx
- Requires design of a mix using flexural strength
- Replaces all 28-day compressive strengths with flexural strengths
- New pay equations

Flexural Strength Challenges

- Molds
- Equipment – breakers
- Curing facilities to assure QC and QV are cured equally
- Sensitivity of flexural beams
- Risk Management (beam and mold can weigh as much as 110 pounds)

Flexural Strength Moving Forward

- Limited use
- Interstate/freeway only type projects
- Greater than 20,000 square yards
- Coordination with central office

From the research project:

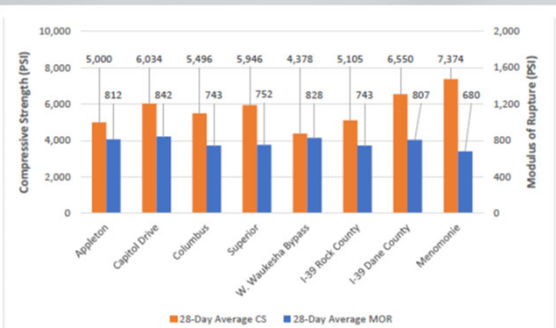

Figure 29: 28-Day compressive strength vs. 28-day modulus of rupture.

FREEZE THAW RESISTANCE

SUPER AIR METER (SAM)

SAM Moving Forward

- Incorporated into specifications in December 2017
- Requires doing SAM during Mix Design (715.2.3.1)
- Requires SAM test once per lot during concrete paving (715.3.1.1)
- Shadow specification to begin building database of where WI mixes are
- Does not impact acceptance
- Timeline to move to acceptance in 2021?
- WisDOT moving to structure specifications. Shadow testing begins in 2020

2021 SAM spec?

- 2 years of shadow specification
- 587 data points
- 72.7% </= 0.2
- 19.4% >0.2 and </=0.25
- 2.9% >0.25 and </=0.3
- 4.9% >0.3

- Acceptance Specifications
  - Draft Specs:
    - ≤0.2 – Accept
    - >0.2 to ≤0.25 – Corrective action.
    - >0.25 to ≤0.3 – Remain in place, consider price reduction.
    - >0.3 – Remove and Replace.
    - A minimum of 4% air would also be required.

From the research project:

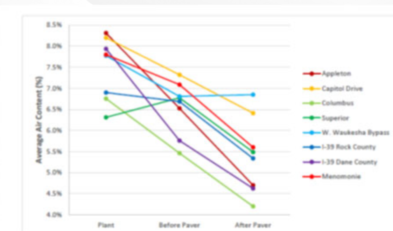

Figure 32: Air content changes throughout production and placement from the plant to before and after the paver.

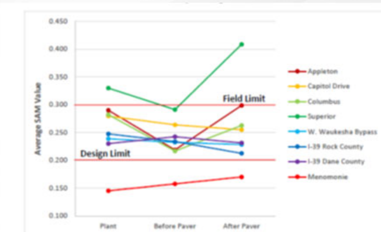

Figure 33: SAM value changes throughout production and placement from the plant to before and after the paver.

TRANSPORT PROPERTIES
(the next priority)

Electric Resistivity

- Durability measurement
- Correlates very well with Rapid Chloride Permeability.
- RPC 28-day test
- This can be used on any cylinder or concrete.

Formation Factor

- Resistivity
  - Store a cylinder in a fixed salt solution
  - Pull out at desired age
  - Read and put back
  - Repeat
  - Calculate formation factor (x10)
    - $F = \frac{\text{Resistivity (bulk)}}{\text{Resistivity (solution)}}$

From the research project:

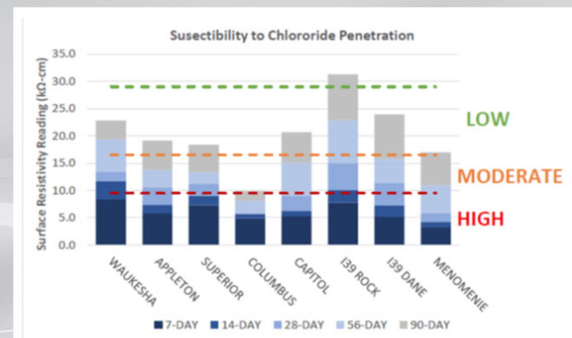

Figure 36: Surface resistivity gain by location with visual comparison.

After that?

- Resistance to deicing salt attack?
  - Calcium Oxychloride test
  - SCM use
- Shrinkage (the last piece of the puzzle)
  - Is this impacting pavement performance?

Shrinkage

- Paste content (read the batch sheet)
  - Easy
  - Fast

Project	**Gravel 1"**		**5/15/2017**		
Mixture Proportions					
		Targets		**Actual**	
			Pounds	R.D.	Volume
Cement	Type I		342	3.15	1.74
SCM 1	F Ash		86	2.65	0.52
SCM 2	Slag		0	1.00	0.00
Coarse Agg	A85006		1753	2.72	10.33
Fine Agg	A25518		1318	2.66	7.94
Intermediate	A85007		340	2.43	2.24
Water			180	1.00	2.88
Air %			5.0		1.35
			4019		27.00
Cementitious		428	428	pcy	
Volume of paste			24.0	%	
Volume of aggs			76.0	%	
Volume of voids			19.2		
vp/vv		125	125.0		
w/cm		0.42	0.42		
% SCM 1		20	20	%	
% SCM 2		0	0	%	
Mass aggs		3411	3411	pcy	
Excess paste, %			4.8	%	

Shrinkage Discussion To Date With WisDOT

- Pavements
  - Low priority
  - Short joint spacing
  - Early cracking not a performance problem/concern
- Structures
  - Higher priority
  - Reduction in bridge deck cracking is a high priority

QUESTIONS?

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