Premature Joint Deterioration in Indiana Concrete Pavements

J. Olek, M. Arribas, M. Radlinski and N. Whiting
Purdue University

T. Nantung - INDOT

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Background

Premature joints deterioration observed in some relatively new (5-10 years old) PCC pavements

Visible signs include cracking, spalling and erosion of concrete in the vicinity of both **longitudinal** and **transverse joints**

I-65

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I-65

I-65

Examples of Deterioration

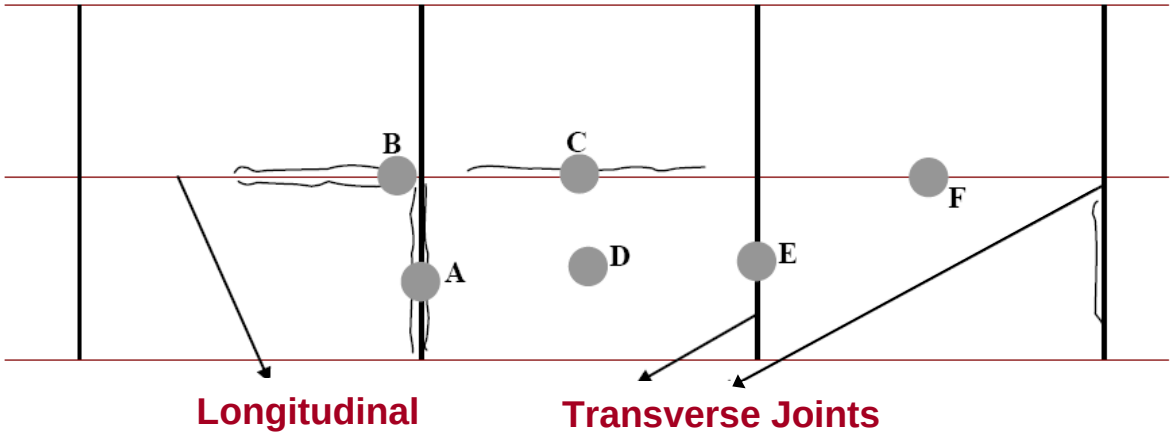
Coring Locations

Pavements included in the investigation:

- Ramp from **US 67** to **I-465E** in Indianapolis, IN
- **W 86th Street** (BL, AL) in Indianapolis, IN
- SB **I-65** in Indianapolis, IN
- **SR 933** near South Bend, IN

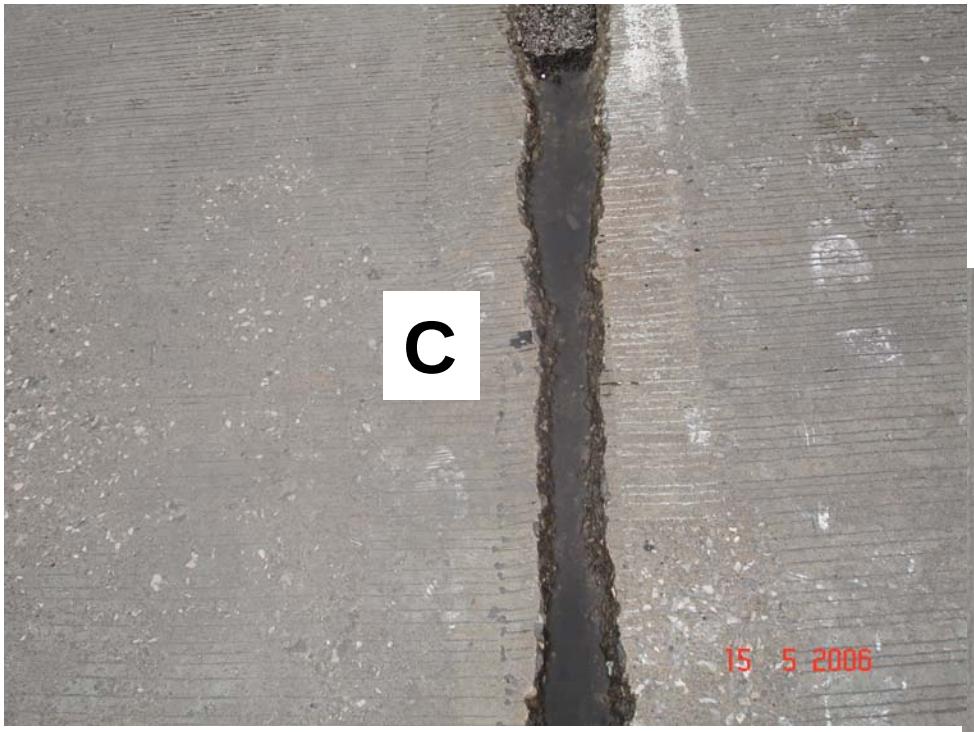
Types of Cores Collected

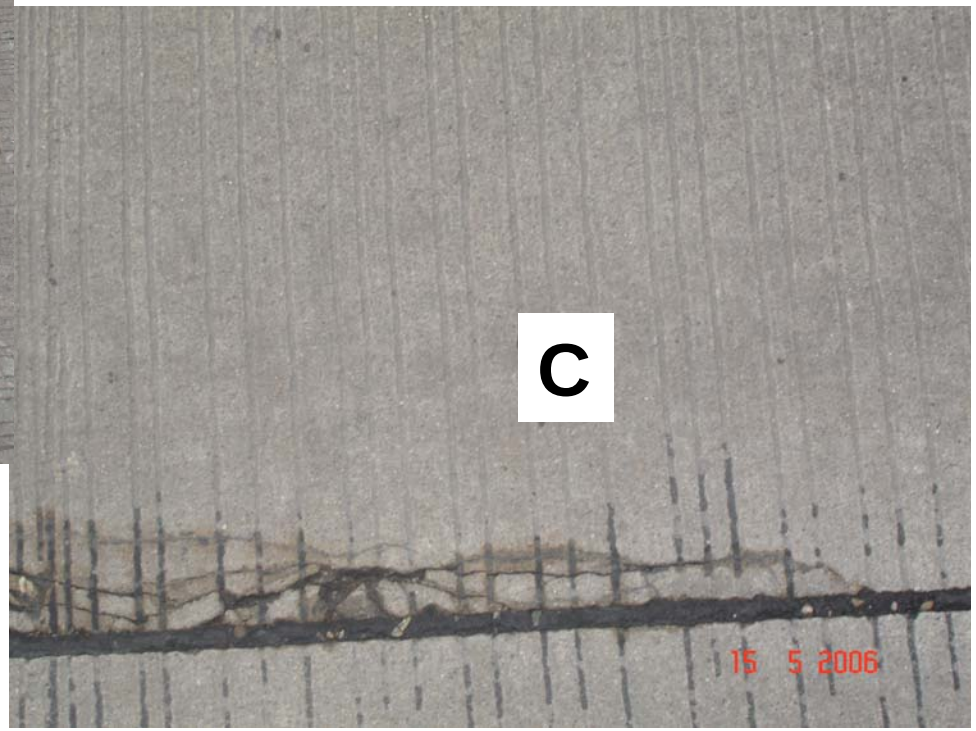
- Several types of cores were obtained:



- Total of **35** ϕ 6 in. cores were extracted
- To simplify the analysis, the cores grouped in 3 categories:
  - Damaged (A, B or C)
  - Undamaged (E or F)
  - Mid-span (D)

Types of Cores Collected





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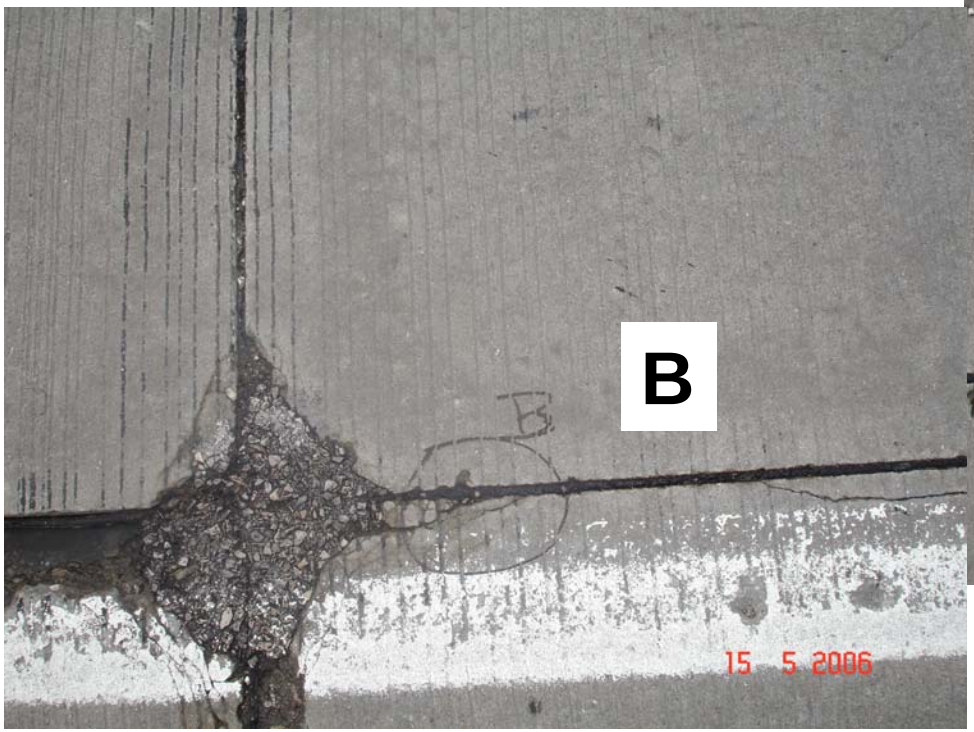
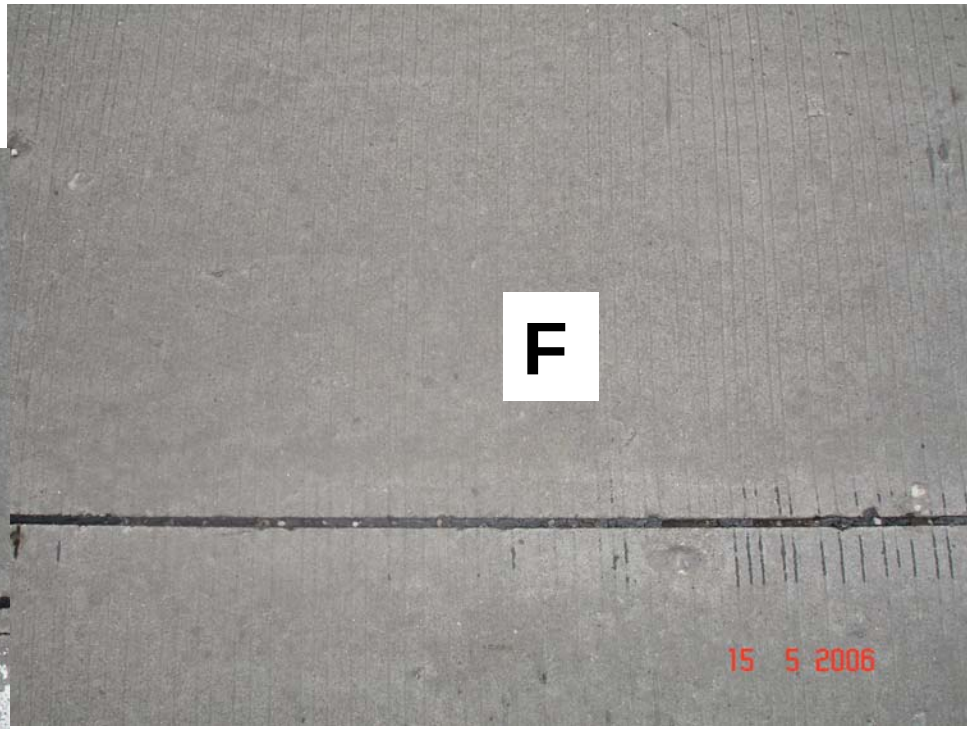
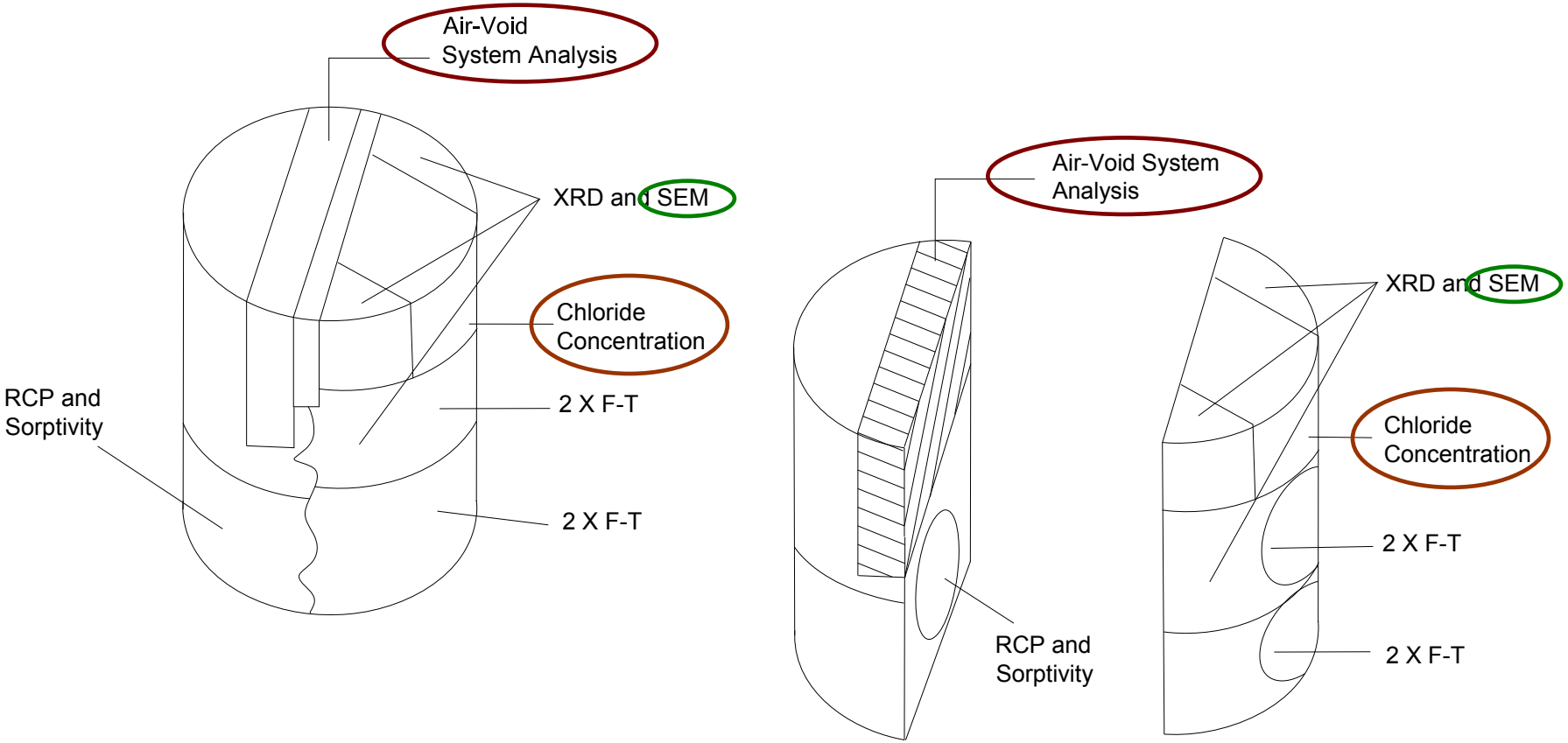




Types of Cores Collected

Test Specimens

From each core a number of specimens were obtained:



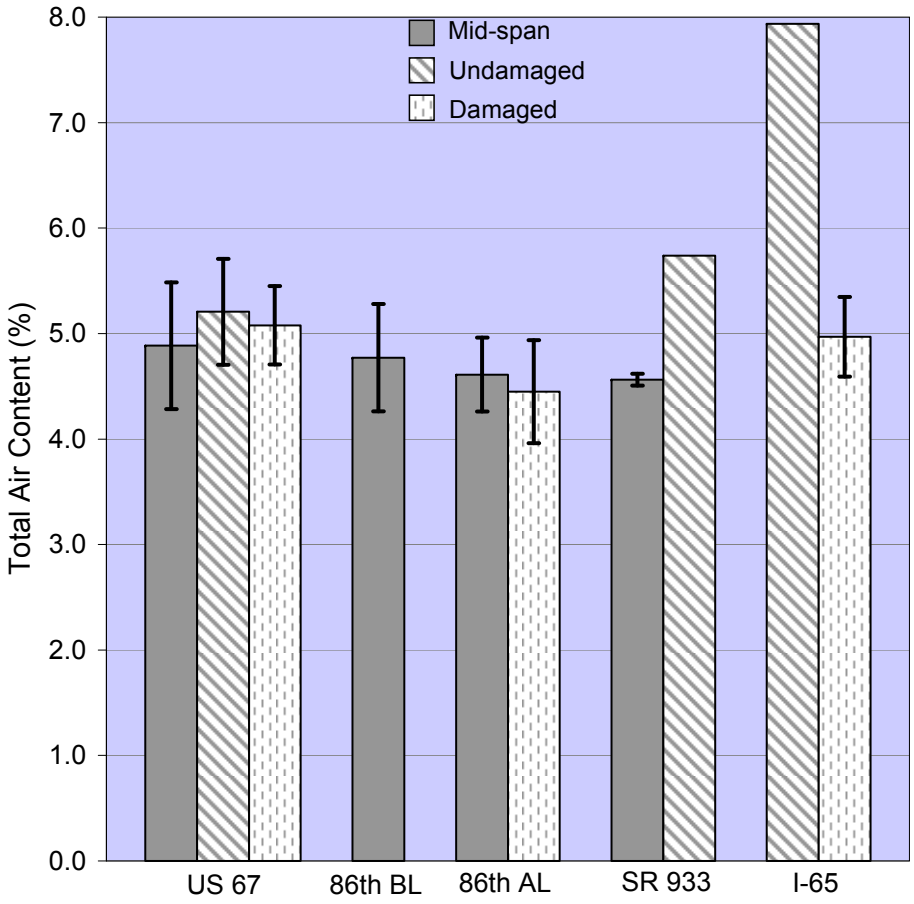
Scope of the Investigation

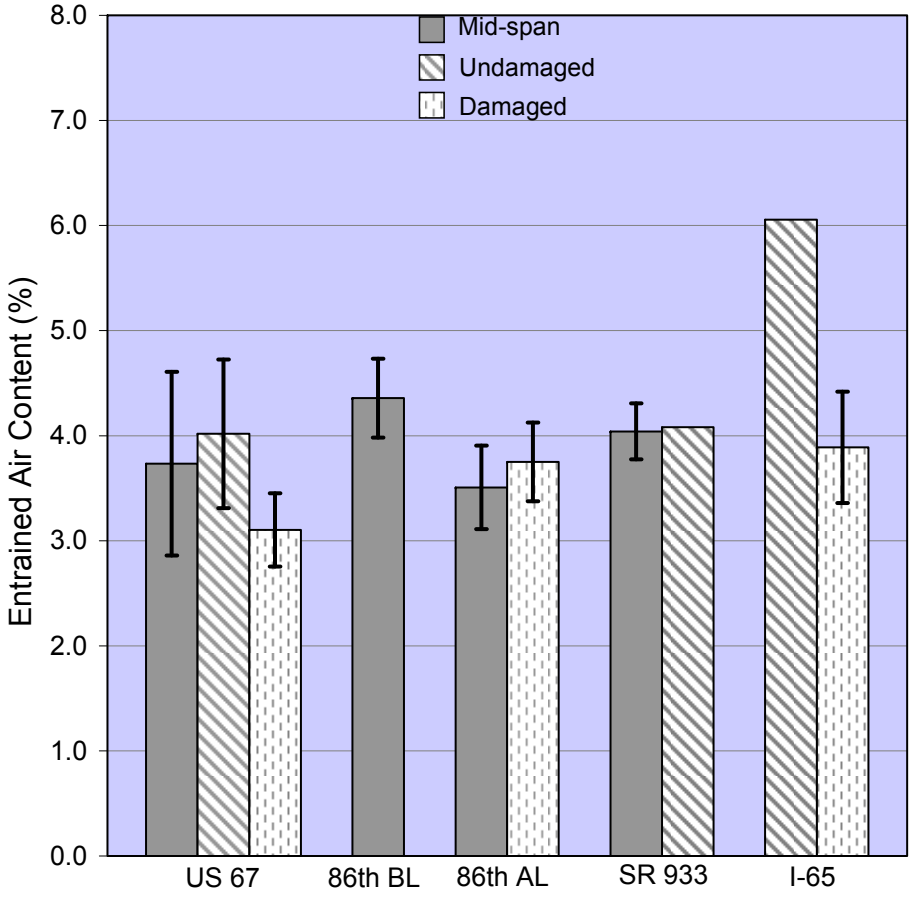
- Laboratory evaluation of the pertinent parameters (quality) of the air-void system
- Examination of microstructure to determine the chemical and morphological changes
- Evaluation of transport-related properties of concrete
- Development of proposed deterioration mechanisms

Testing Plan

Test	Specimen Location				
	SR 67	W 86th BL	W 86th AL	SR 933	I 65
Air Void System Analysis	A, D, E, F	D	A, B, C, D, E	D,E	B,C,F
SEM	A,D,F	D	C, D, E	D,E	B, F
XRD	A, D, E, F	D	A, B, C, D	D,E	B, C, F
Sorptivity	D,F	D	A, B, C, D	D,E	B, F
F-T	A, D,F	D	A, B, C, D	D,E	B, F
RCP	D,F	D	A, B, C, D	D,E	B, F
Chloride Profile Determination	A,D,F	D	A, B, C, D	D,E	B, F

Air-Void System in Relation to Pavement Condition





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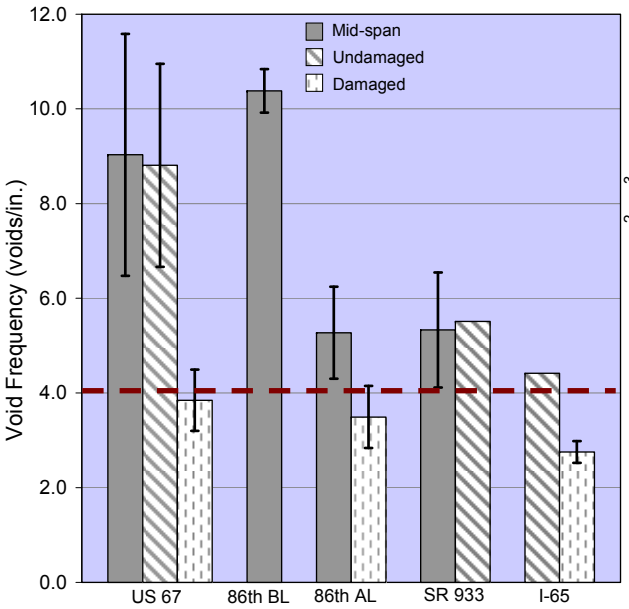
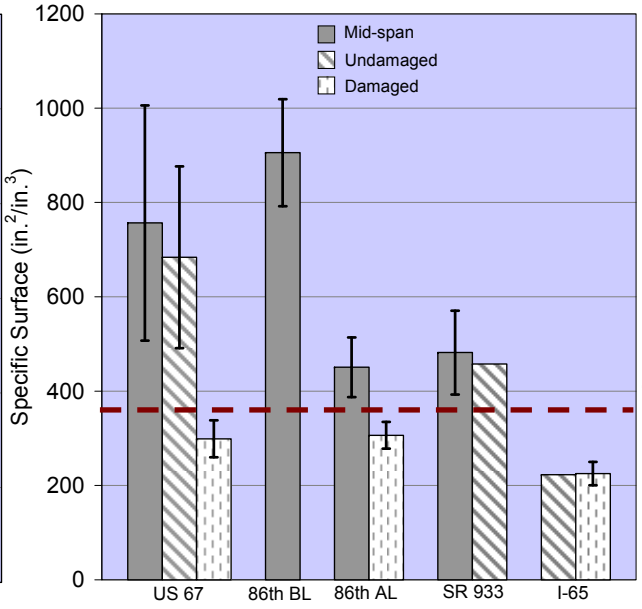
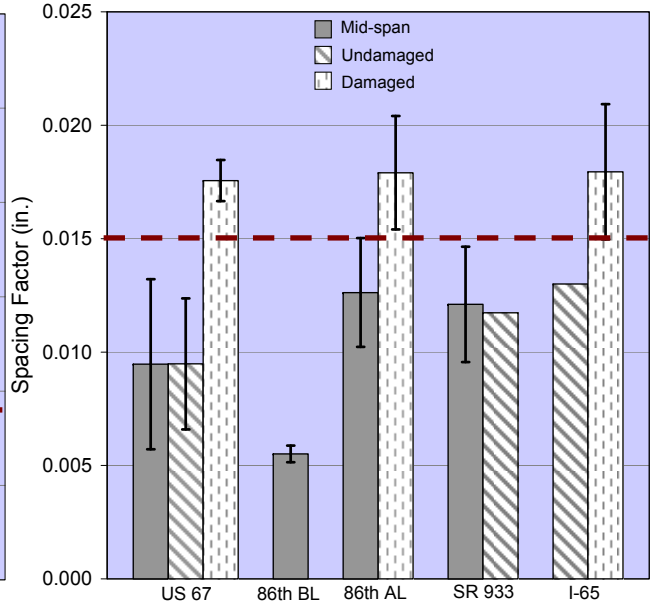


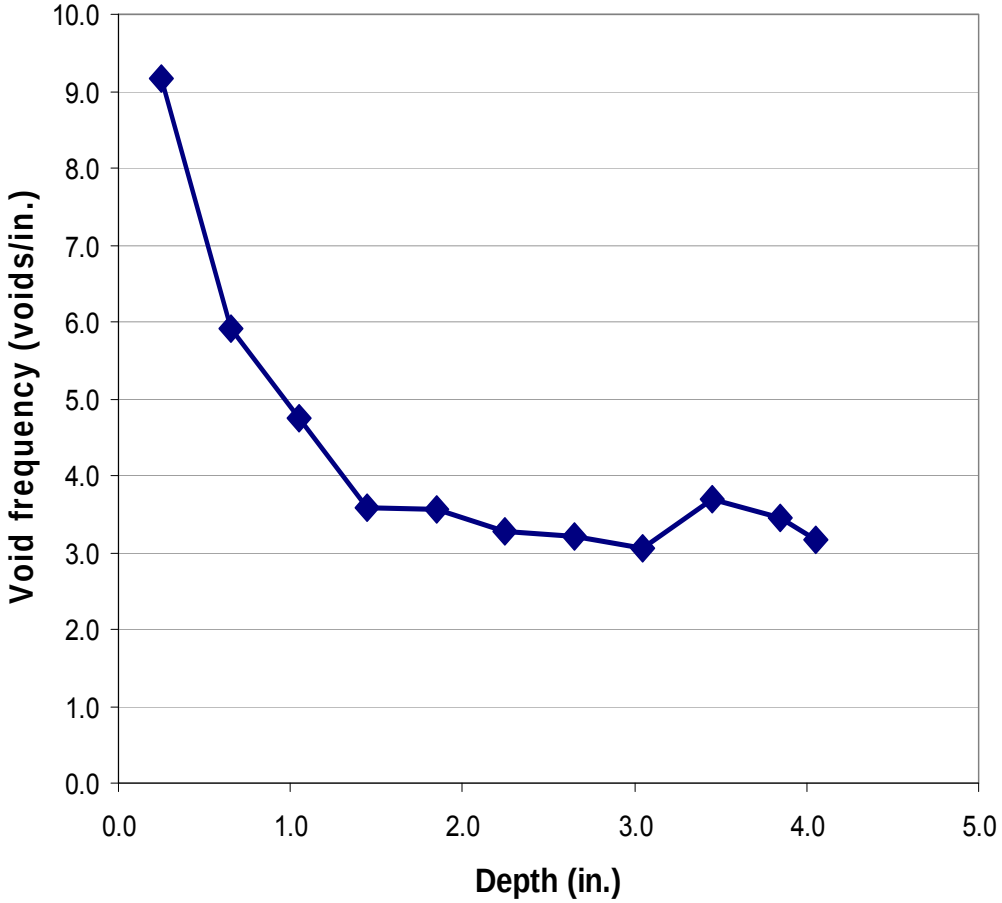




F-T Durable Concrete	Void frequency (voids/in.)	Specific Surface (in^2/in^3)	Spacing Factor (in)
Based on Field Performance	4.0	350	0.015
Recommended as per Hover (1994)	(1.0-1.5)×Air Content	400-600	≤ 0.008
Recommended as per ASTM C 457 (ASTM 2006)	8.0	600-1100	0.004-0.008

Observations from Air-Void System Analysis

- **Decreasing Void Frequency with depth** (12 samples):



- Sample from US 67:

0-1.0 in.

> 1 in.

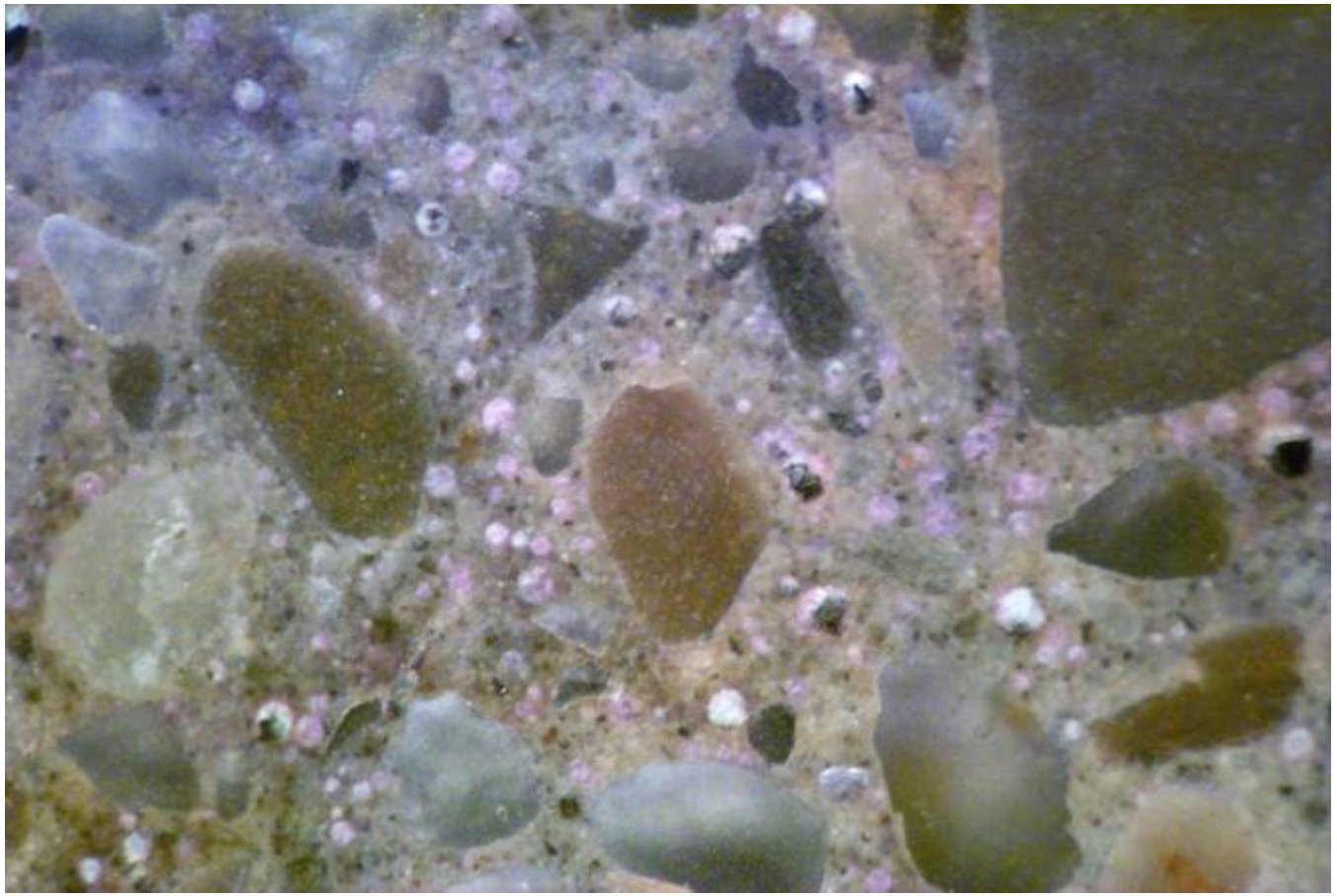
Observations from Microscopical Examination

Mid-Span Slab Core
(US67-D core; **Spacing Factor = 0.008 in.**)

Observations from Microscopical Examination

Damaged Longitudinal Joint

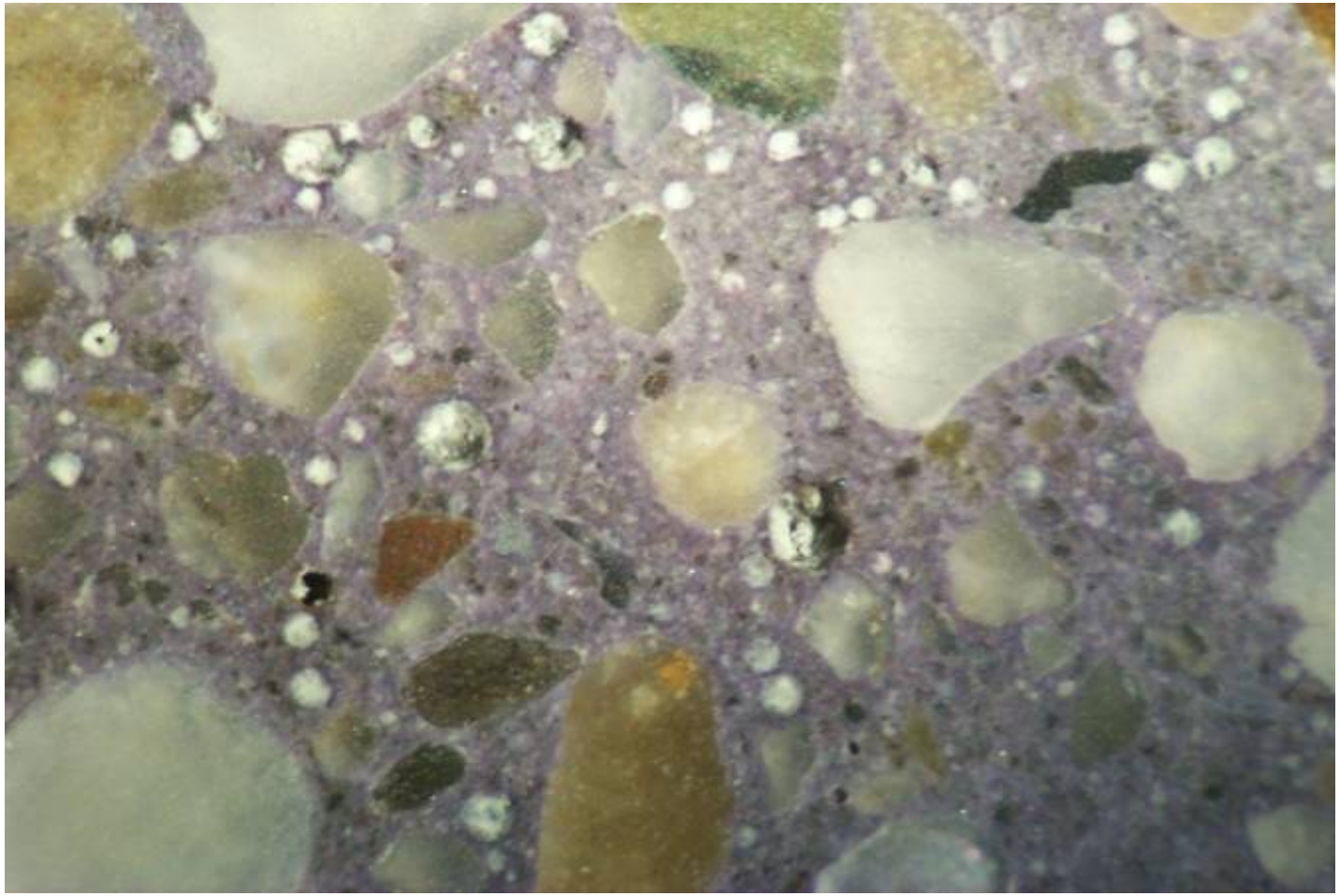
(86th Street AL-C core; **Spacing Factor = 0.021 in.**)



Observations from Microscopical Examination

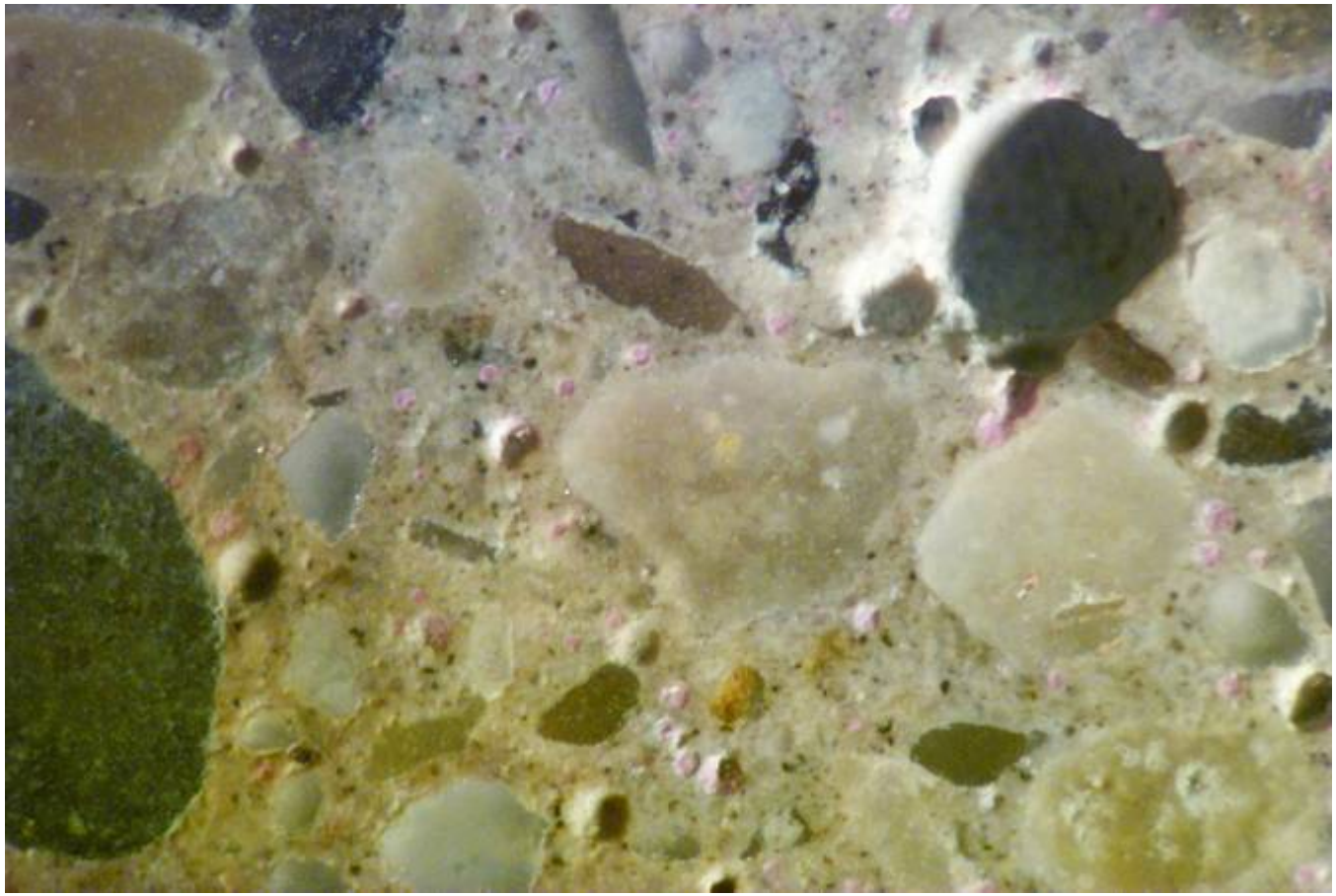
Damaged Longitudinal Joint

(86th Street AL-C core; **Spacing Factor = 0.015 in.**)



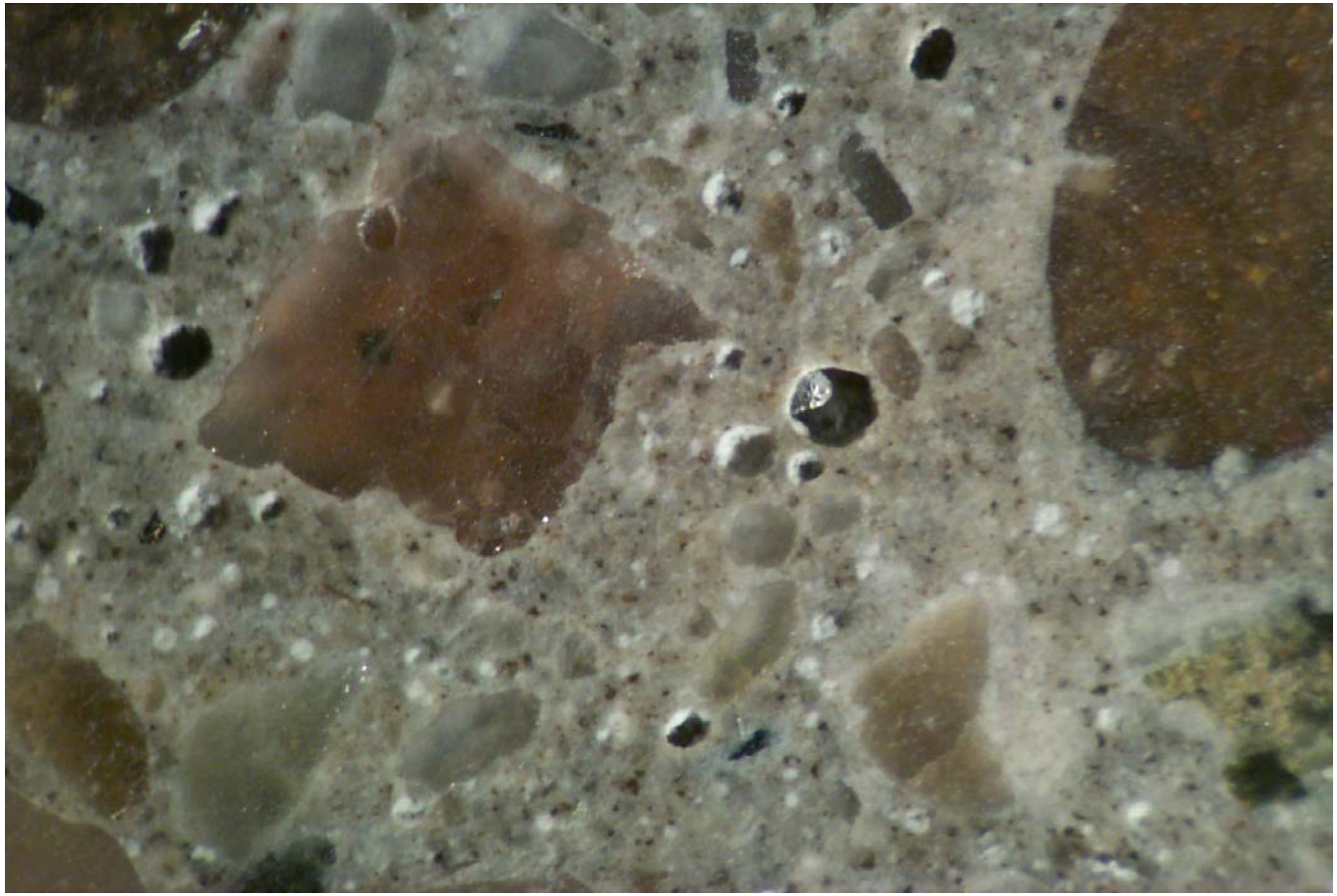
Observations from Microscopical Examination

Damaged Longitudinal near Transverse Joint
(86th Street, AL-B; **Spacing Factor = 0.016 in.**)



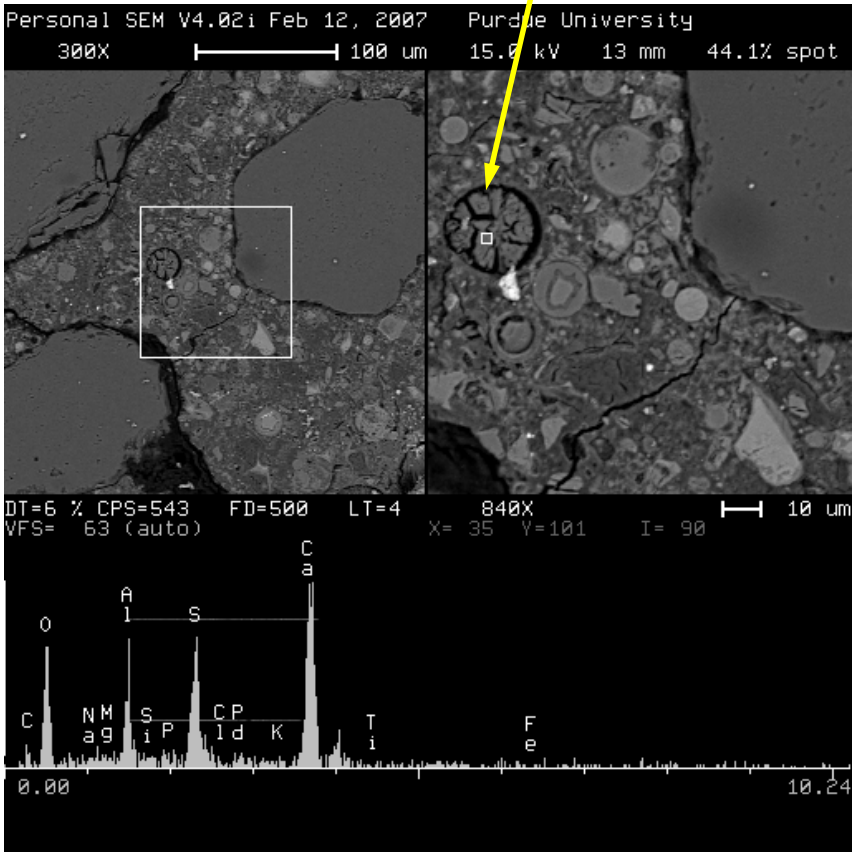
Observations from Microscopical Examination

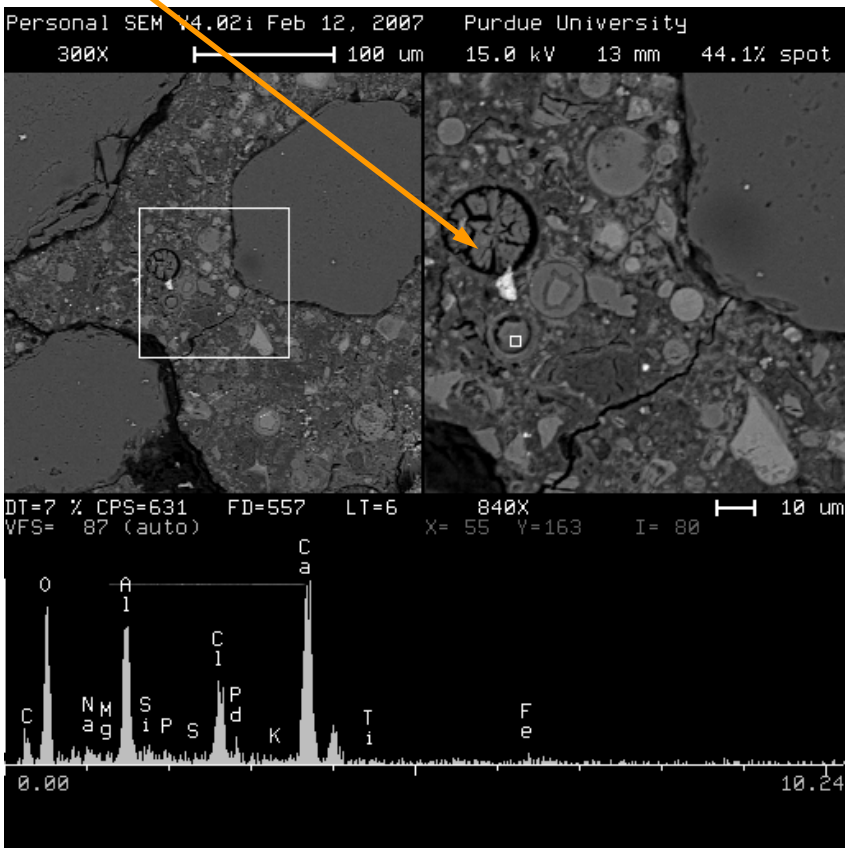
Damaged Transverse Joint
(86th Street AL-A; **Spacing Factor = 0.025 in.**)



Observations from SEM Analysis

Air voids filled with products of secondary reactions:
Ettringite and **Friedel's salt**



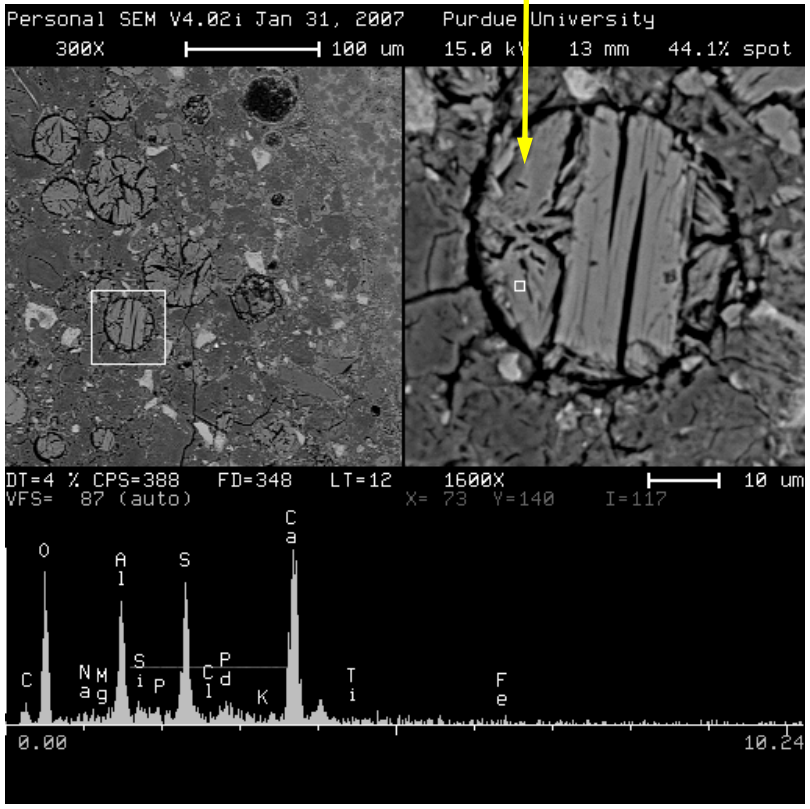


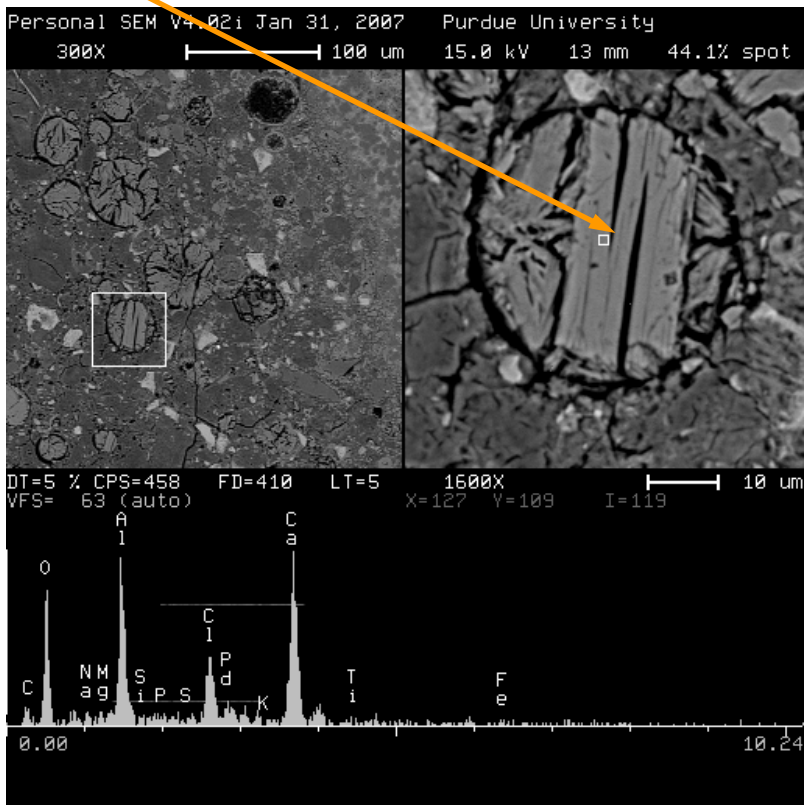
Sample from undamaged joint on I-65

Observations from SEM Analysis

Air voids filled with products of secondary reactions:

Ettringite and **Friedel's salt**





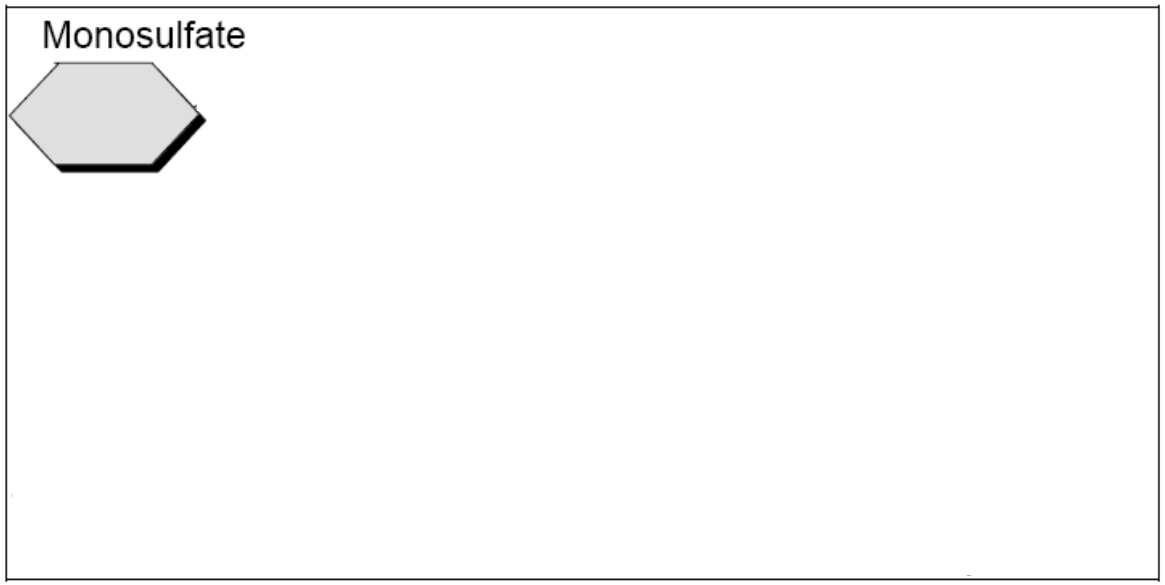
Sample from damaged joint on US 67

Observations from SEM Analysis

Core	Feature			
	Ettringite in Paste	Friedel's salt in Paste	Voids Filled with Ettringite	Voids Filled with Ettringite and Friedel's salt
US-67_#1	x	x	x	x
US-67_#4			x	
US-67_#5			x	
86th-BL_#1	x	x	x	
86th-AL_#1	x	x	x	
86th-AL_#10	x	x	x	
86th-AL_#11	x	x	x	x
SR-933_#0	x	x	x	
SR-933_#1		x	x	
SR-933_#2	x	x	x	x
I-65_#3	x	x	x	x
I-65_#4	x	x	x	x

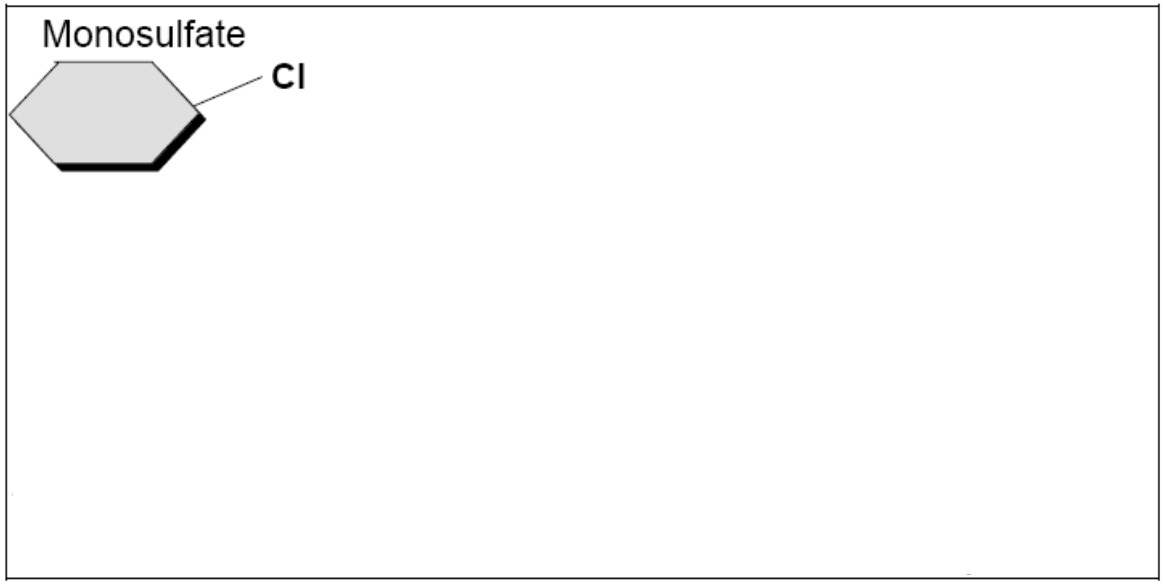
- All Samples had Voids Filled with Ettringite
- 10 of 12 Cores had Friedel's Salt in the Matrix
- 5 of 12 Cores had Voids Filled with both Friedel's Salt and Ettringite

Potential Mechanism of Voids In-Filling



(Stark J. i Bollmann K.)

Potential Mechanism of Voids In-Filling



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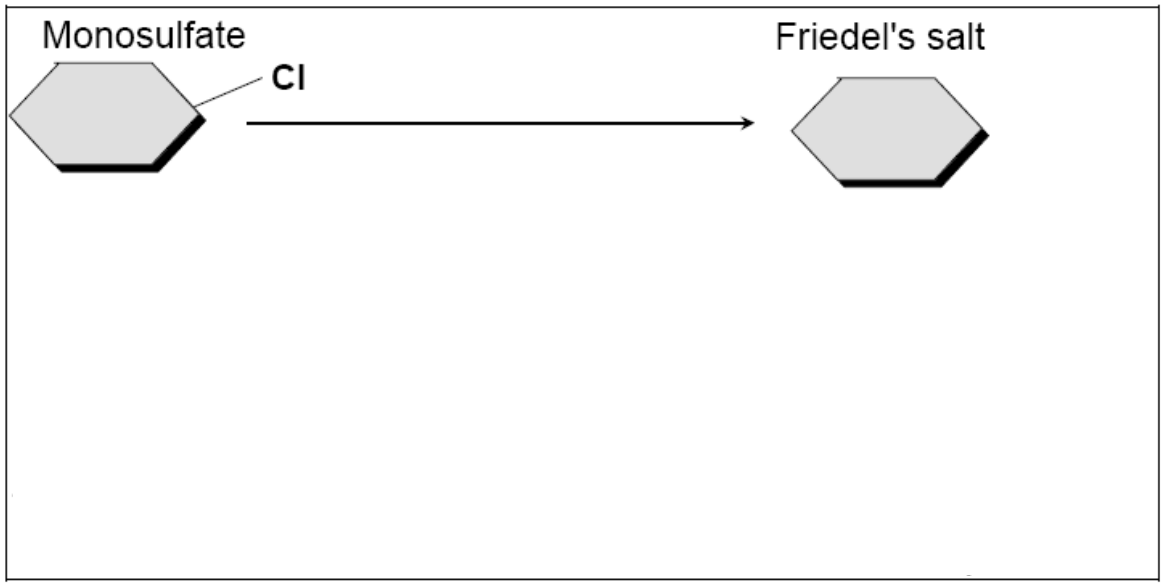

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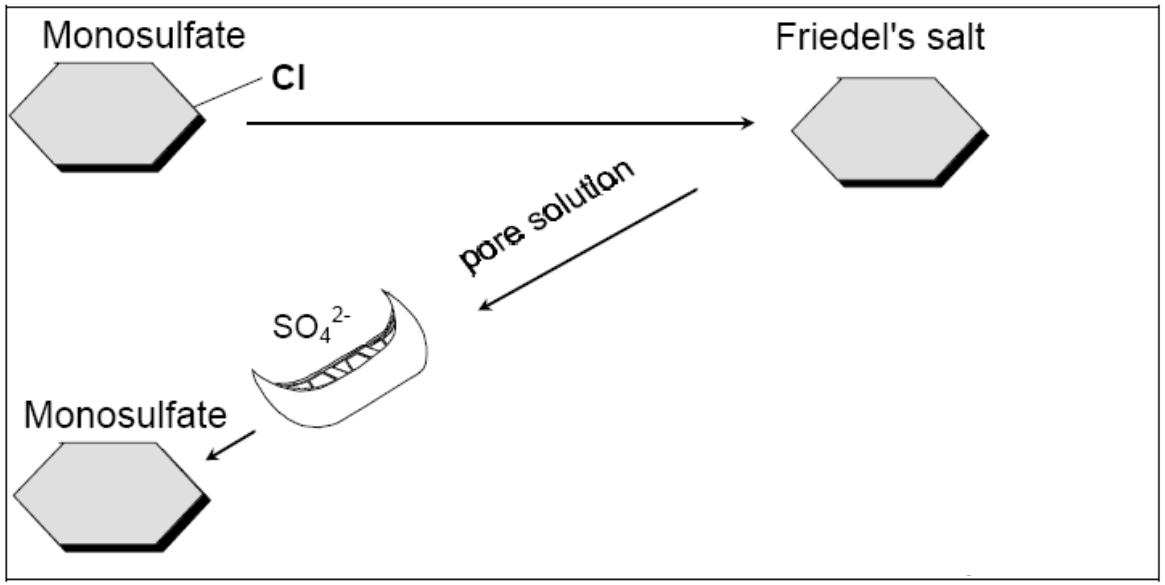
$$C_4A\overline{S}H_{12} + 2Cl \longrightarrow C_3A{\cdot}CaCl_2{\cdot}10H + C\overline{S}H_2$$

Potential Mechanism of Voids In-Filling



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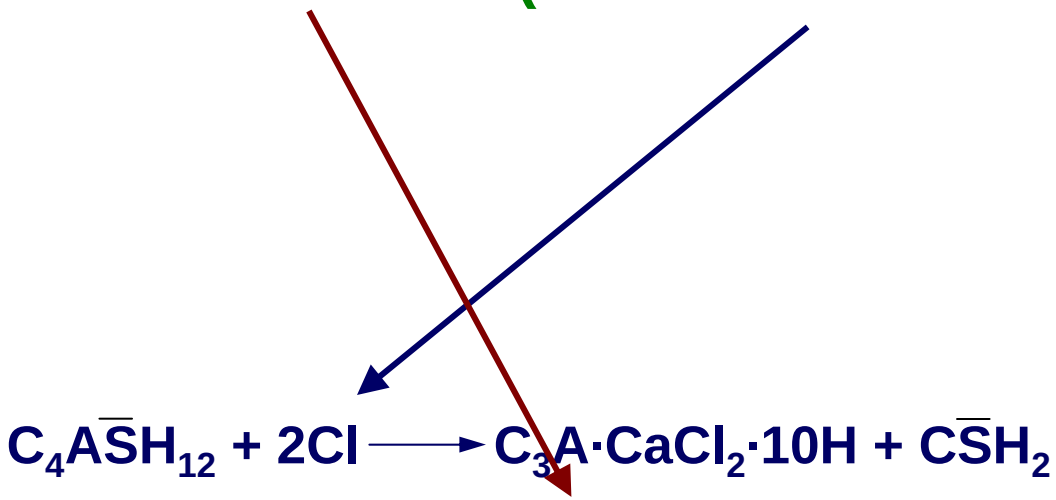
$$C_4A\bar{S}H_{12} + 2Cl \longrightarrow C_3A{\cdot}CaCl_2{\cdot}10H + C\bar{S}H_2$$

Potential Mechanism of Voids In-Filling

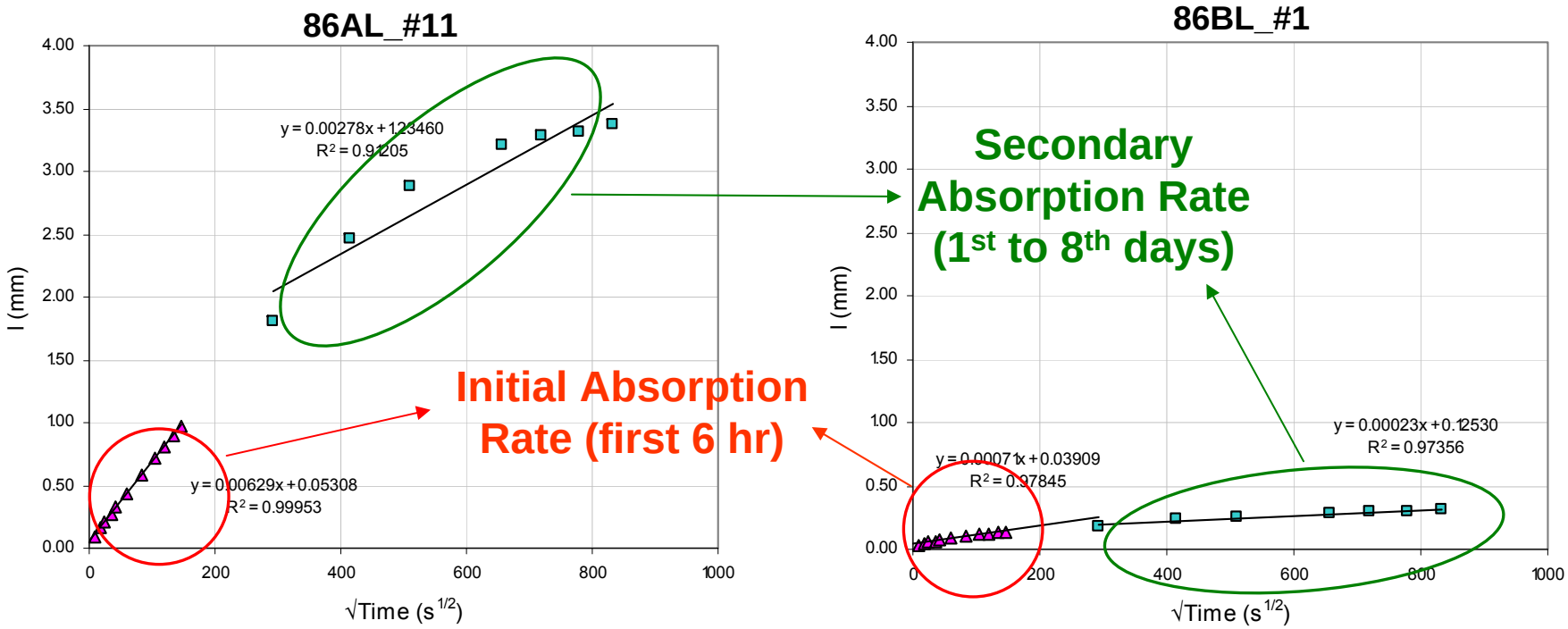
Solution?

KEEP WATER (AND CHLORIDES) OUT!



Sorptivity Test

Results of Sorptivity Test



Damaged joint

Location C

Mid-span

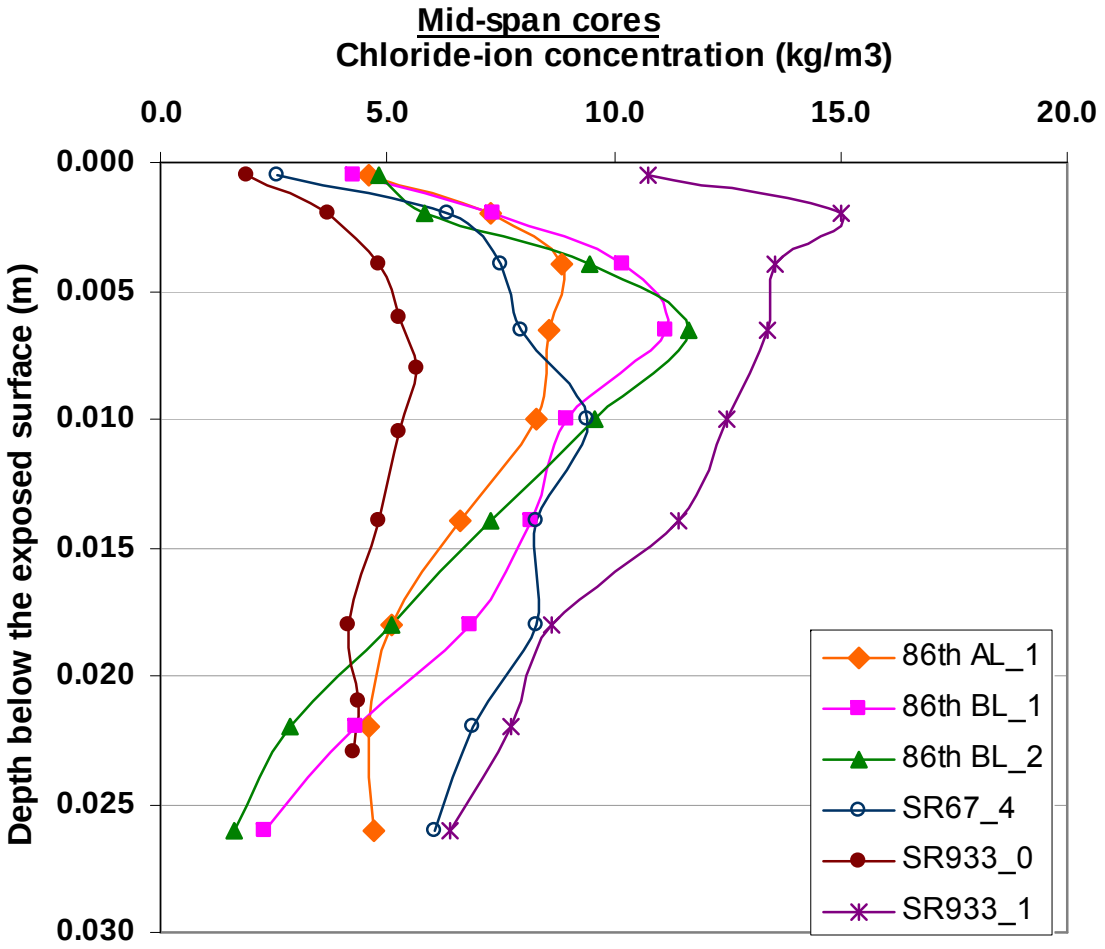
Location D

Summary of Sorptivity Data

Core #	Location	Final Labeling	Initial Absorption Rate x 10^{-4} ($mm/s^{1/2}$)	Secondary Absorption Rate x 10^{-4} ($mm/s^{1/2}$)
4	US 67	SR67-4D	19.2	12.9
5	US 67	SR67-5F	28.4	15.8
1	W 86th St. BL	86BL-1D	7.1	2.3
1	W 86th St. AL	86AL-1D	14.2	7.6
7	W 86th St. AL	86AL-7A	11.4	9.2
8	W 86th St. AL	86AL-8B	39.6	24.9
9	W 86th St. AL	86AL-9F	52.5	28.0
11	W 86th St. AL	86AL-11C	62.9	27.8
0	SR 933	SR933-0D	48.1	27.3
1	SR 933	SR933-1D	8.7	4.8
2	SR 933	SR933-2E	16.5	7.7
3	I-65	I65-3B	32.3	26.1
6	I-65	I65-6F	49.2	32.3

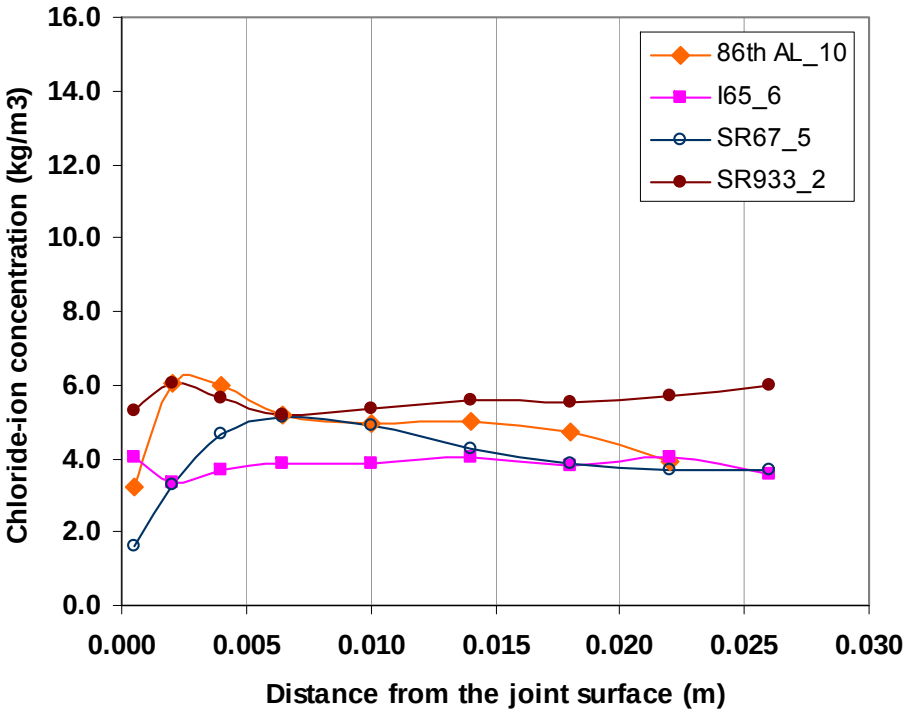
Slag aggregate

Chloride Concentration Profiles

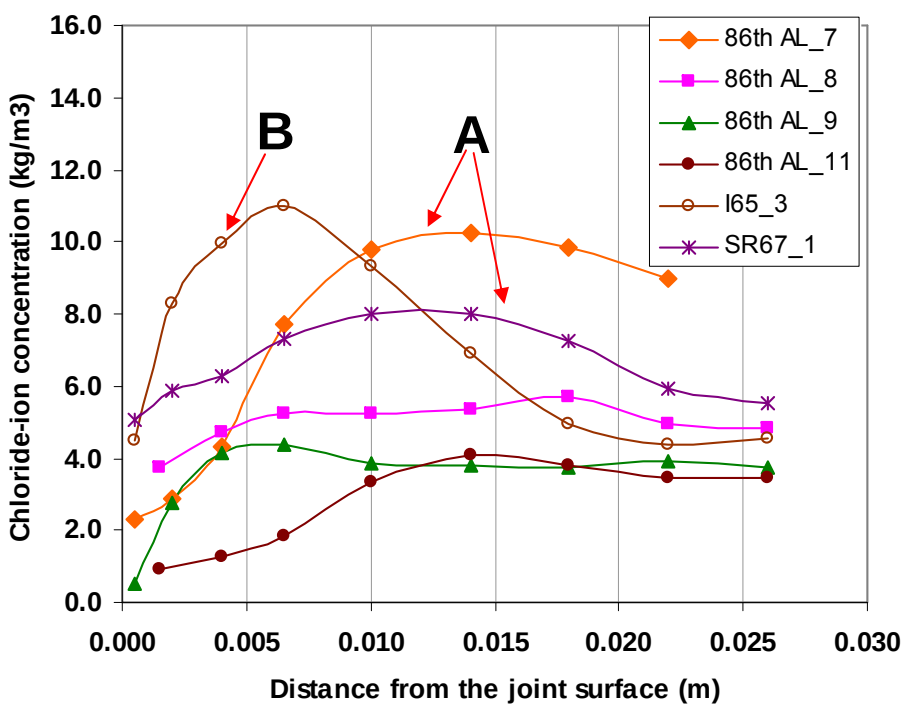


Chloride Concentration Profiles

Undamaged cores (joint location)



Damaged cores (joint location)



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Summary

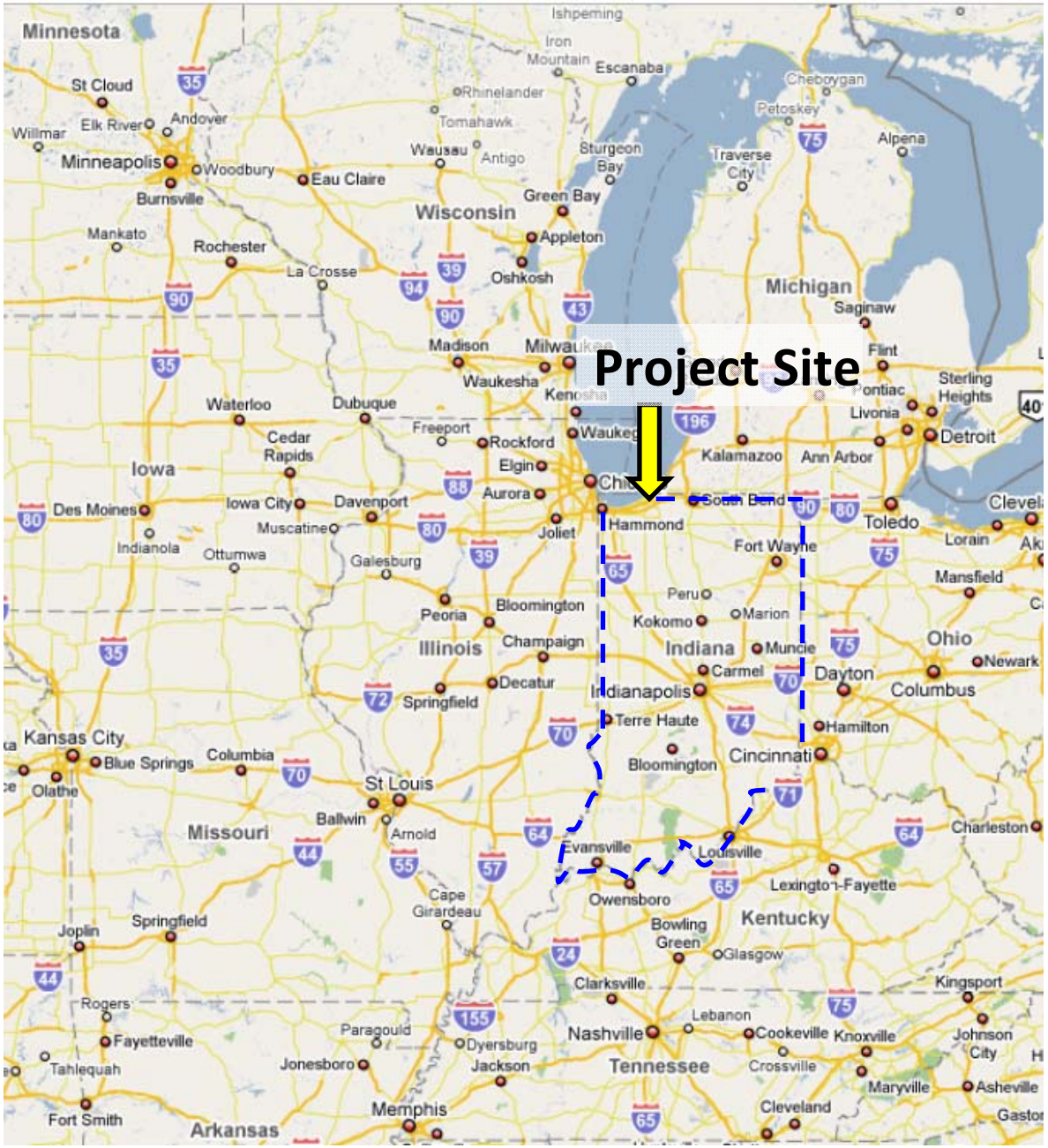
- Many of the original air bubbles have been in-filled with secondary reaction products thus compromising the ability of the air-voids system to offer effective FT protection
- Since the formation of these deposits requires water, most likely the voids were progressively filled with secondary deposits as a result of moisture accumulation in the joints
- The in-filling was particularly apparent in the vicinity of the damaged joints

Critical Saturation

- Water entering joints, particularly longitudinal saw joint, is trapped
- Longitudinal saw cut joints not cracking or if cracking – no sufficient opening of crack – as a result water can not drain out to drainable subbase under PCCP
- Silicone sealant and backer rod prevent any evaporation or air drying of trapped water

Joint Efforts to Solve the Joint Deterioration Issue

- FHWA core evaluations in 2005
- INDOT-Purdue-Industry evaluations in 2006
- Gatheing data from INDOT-JTRP-Industry
  - SPR-3016: Investigation of Air Void Systems
  - SPR 2472: Interaction Between Micro-Cracking, Cracking, and Reduced Durability in Concrete
  - SPR-2941: “Relating Exposure Conditions to Service Life Performance”
  - SPR-3093: Permeability of Concrete Pavements and Relation to Performance
  - SPR-3200: Saw Cutting and Curing of Concrete Pavement – Relation to Durability
  - PFS - Test Methods for Transport & Development of Performance Guidelines for Durability



I-94 near Michigan City, IN

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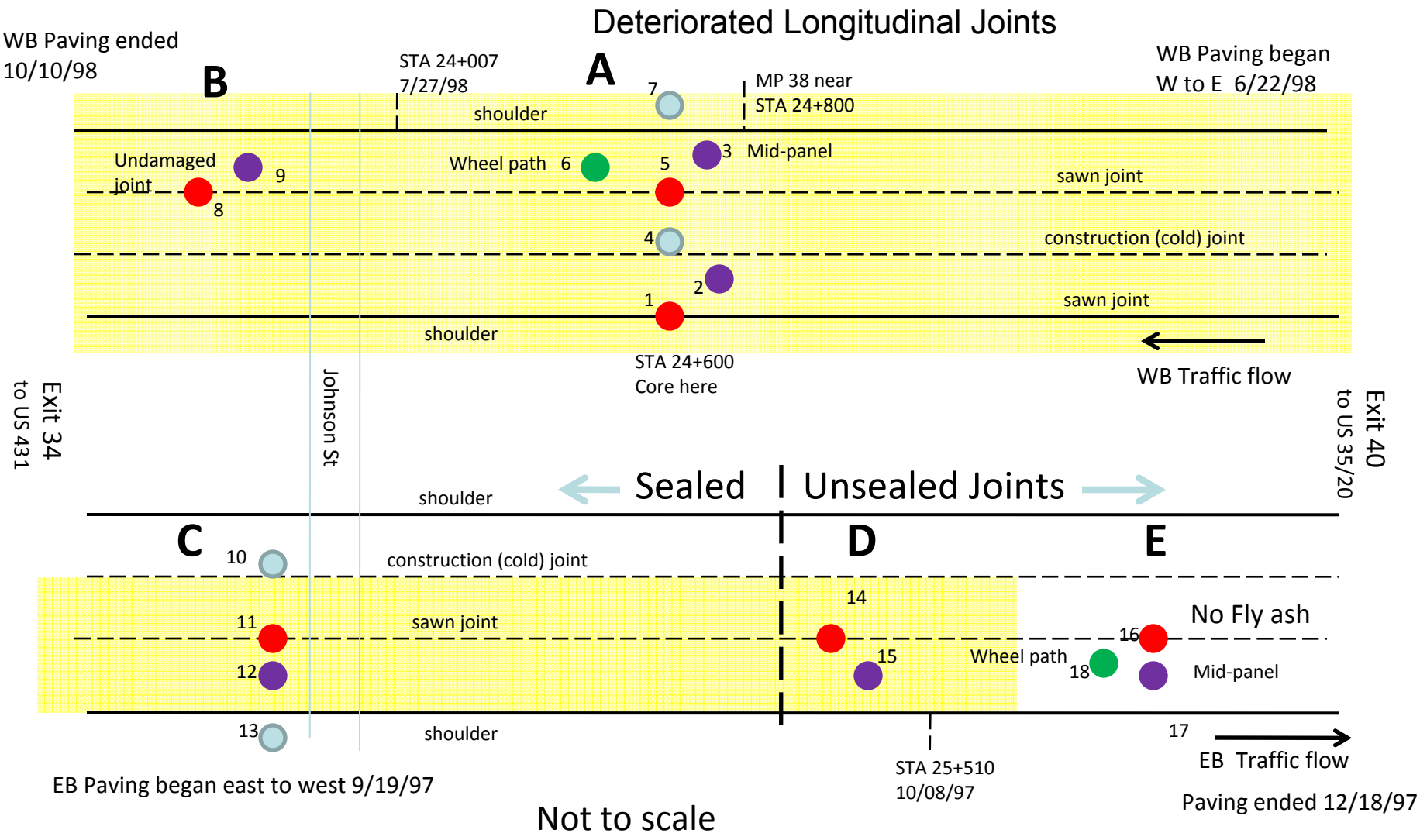


All of the WB lanes are Mix 1. EB lanes were paved with Mix 1 until 10/10/97. Extent of Mix 1 is approximated by shaded area

Mix 2 and Mix 6 did not contain fly ash and were used to pave the EB lanes from 10/16/97 until 12/18/97.

Section A
Core #1
Sawn shoulder joint

Slag Base fused to bottom of core

Fused slag base

Water ponding at joints

Coring at deteriorated joint Section A Core #5

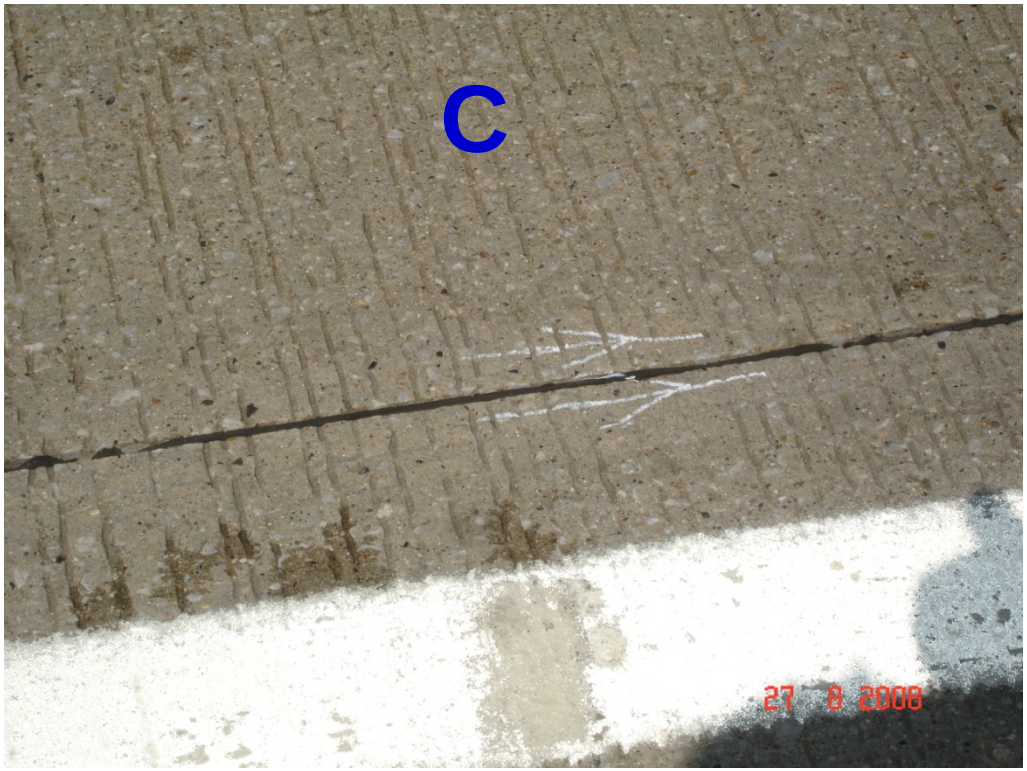
Coring at deteriorated joint Section A Core #5

Unsealed Joints

Section D (w/flyash)

Section B & Section C

Little to no surface deterioration



Unsealed Joints

Section E w/o (flyash)

Edge drains (Section C)