US-23 Aggregate Test Road
Long-Term Performance Evaluation

Final Report

Submitted to
Michigan Department of Transportation
Bureau of Field Services
Research Administration
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by

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16. Abstract The US-23 Aggregate Test Road was constructed in 1992 with the main purpose to determine the influence of coarse aggregate of varying frost susceptibility on long-term concrete durability. The pavement structure for the entire Test Road consists of a 10.5 inch, 27 ft. jointed reinforced concrete pavement (JRCP) constructed on a 4 in. asphalt-treated permeable base (ATPB) layer on top of a 3 in. gravel separator layer. Half of each test section was built on the original poorly-draining subbase with the other half constructed on a "select" well-draining permeable sand subbase. The report findings are based on latest field investigation in 2016 and previous year's field tests, aggregate properties, concrete mix proportions, periodic distress surveys, and IRI data collected by MDOT personnel. The main findings are: No joint durability distress was found. This is attributed to excellent air-void system, low concrete permeability and good drainage. Also, pumping erosion related distress has not developed. One section has developed full lane-width mid-panel cracking in over 75% of panels in the truck lane by year 5. These cracks turned into working cracks leading to spalling requiring full-depth concrete repairs in 29% of truck-lane panels, while between 0% and 4% of panels in the other four sections required full depth repair. Dowel looseness was pronounced in all sections since 2009 leading to low load transfer (30%-60%). Loss of load-transfer and excessive outer corner joint deflections (~ 40 mils/9000 lb by FWD) has resulted in a permanent transverse joint settlement of 0.1-0.2 inches. A downward slab bending combined with daily loss of slab support at joints from early morning curl has promoted top-down mid-panel cracking, which is developing in all sections. The information obtained from this study is helping MDOT pavement engineers design for 30 to 50 year pavement life for Michigan's severe traffic loading and environmental conditions.

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Executive Summary

Problem Statement

The Michigan Aggregate Test Road was constructed in 1992 to study the influence of different coarse aggregate types and their frost susceptibility on the long-term concrete pavement performance.

- Five PCCP test sections were constructed using varying degrees of freeze-thaw durable coarse aggregates.
- The pavement structure for the entire Test Road consists of a 10.5 inch, 27 ft. jointed reinforced concrete pavement (JRCP) constructed on a 4 in. open-graded asphalt-treated permeable base (ATPB) layer on top of a 3 inch gravel separator layer. Half of each test section was built on the original poorly-draining subbase with the other half constructed on a "Select" well-draining permeable sand sub-base.
- Current annual average daily traffic: approx. 20,000 vehicles per day; 18 percent commercial.

Major Findings from the Long-term Performance Evaluation are:

- At 23 years, four sections are performing very well with little or no cracking. One section (B) developed premature cracking based on distress surveys starting year 2. Within five years about 75 percent of truck-lane panels had developed full lane-width working cracks followed by crack spalling. This section required full-depth concrete repairs after 19 years in service in 29% of all panels, while crack repairs in the other sections ranged from 0% (Section A) to less than 5% (Sections C, D & E).
- No freeze-thaw related joint deterioration problems were reported in any section. Excellent frost resistance is attributed to a well-draining OGDC and concrete air-void system with an average of 5.4% total air and air-void spacing factor well within the range recommended by American Concrete Institute (0.004 to 0.008 in.) for frost protection. Sections D and E, containing high degree of frost suscep-

tible aggregate (Table 2.1.1) have experienced minor pop-out throughout the top surface region. However, this has not affected pavement performance.

- Some minor breakdown of the ATPB has developed at outside edge of transverse joints, as observed by coring.
- FWD joint (D0) deflections during early morning temperature conditions associated with cool clear mornings, were 10 times (~ 40 mils) greater than the mid-panel (3-4 mils) (D0) deflection at 9000 lb. loading. Substantial dowel looseness and low load transfer efficiency (40%-60%) is typical for all sections.
- Permanent joint settlement of 0.1-0.2 inches has developed for all sections. The downward slab shape explains why top-down, mid-panel cracking has developed in some of the test section panels.
- Joint faulting was insignificant (< 0.04 in.) after 23 years.
- Rigid pavement back-calculation based on mid-panel deflections of the 4 sensors at 0, 12, 24 and 36 inches from the impact load suggest that the effective modulus of subgrade reaction (k) is higher for the section constructed on the “Select” well-draining permeable sand subbase. The variation in mid-panel deflection is greater in the existing poorly-draining subbase sections compared to the “Select” well-draining subbase sections. However, the pavement distress in the existing subbase sections is no different from the “Select” subbase sections to date.

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1 INTRODUCTION

1.1 Objectives and Background

Five concrete test sections (Groups A through E) were constructed using varying degrees of freeze-thaw resistant coarse aggregates in order to determine their influence on pavement performance.

The pavement structure for the entire Test Road consists of a 10.5 inch, 27 ft. jointed reinforced concrete pavement (JRCP) constructed on a 4 in. open-graded asphalt-treated permeable base (ATPB) layer on top of a 3 inch gravel separator layer. Half of each test section was built on the original poorly-draining subbase with the other half constructed on a “Select” well-draining permeable sand subbase.

Current Annual Average Daily Traffic: approx. 20,000 vehicles per day; 18 percent commercial.

1.2 Layout of the Aggregate Test Road Sections A through E.

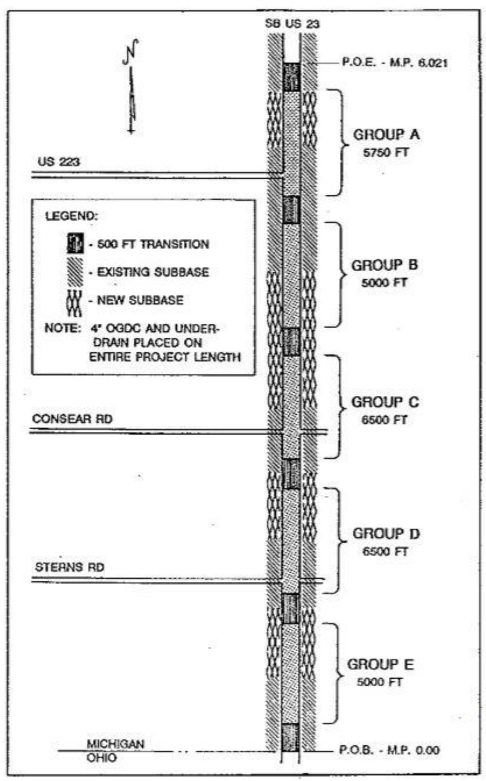


Figure 1.2. Layout of the Aggregate Test Road Sections (MATES, Issue No. 70)

1.3 Scope of Study

The findings from this study are based on a forensic investigation carried out jointly between MDOT's Construction Field Services Division and the UM Concrete Pavement Performance Center after 23 years in-service. Data evaluated are based on archival project information such as concrete proportioning, pavement design, construction period, distress surveys collected since 1993, MDOT Pavement Management System (PMS) database containing biennial international roughness index (IRI) results and information on repairs, as well as falling weight deflectometer (FWD) results from testing conducted in 2006, 2009 and 2016.

Concrete cores were extracted from the in-service pavement and evaluated at the UM for air-void parameters according to ASTM C 457 and permeability by the rapid chloride permeability test method (RCPT) according to ASTM C 1202.

2. Major Findings from Forensic Investigation of the Aggregate Test Road

2.1 Concrete Durability

The major focus of this test road was to evaluate in-service performance of concrete at joints with respect to D-cracking. D-cracking is the damage that occurs in concrete to excessive expansion of coarse aggregate particles from freezing of pore-water. D-cracking damage starts near joints forming a D-shaped crack. This distress type can be reduced either by selecting aggregates that are less susceptible to freeze-thaw deterioration in a water saturated state or by reducing the maximum aggregate size (Taylor et al., 2007). Saturation of the concrete is a necessary condition for D-cracking to develop. Five different test sections consist of two limestones and two natural gravels of low and high freeze-thaw dilation value, and one section containing blast-furnace slag of low dilation value. Aggregate characteristics and concrete mix proportions based on archived data are listed in Table 2.1.1

The photos in Appendix C from 2016 show that D-cracking has not developed in any section. The well-draining ATPB has been a major factor in avoiding D-cracking of Sections D (crushed limestone) and E (natural gravel) containing highly susceptible aggregate (Table 2.1.1).

An excellent air-void system of the paste combined with a low concrete permeability consistent with inclusion of pozzolans in the concrete mixture have provided salt-scaling resistance of the concrete in all five test sections. Test results for the 23-year old concrete are shown in Table 2.1.2 based on ASTM C 457 test, while permeability test results are found in Fig. 2.1. The air-void results illustrate that the current total air content of core samples of 4 inches diameter range between 3.8% and 8.6% with an average of 5.5%, and air-void spacing factor well below the 250 micron (0.0098 inch) threshold value. The average total aggregate content of 70% based on ASTM C457 results is in close agreement with MDOT's mix proportion requirements, which lists the value at 72% (Appendix A).

It is concluded that good joint drainage and a high frost resistant cementitious binder system are major factors for the excellent concrete joint performance after 23 years in-service. Minor pop-out development has not had any effect on the pavement performance.

Table 2.1.1 Concrete mix proportions, aggregate durability and physical properties (MDOT)

Section	Material	Option1 Weight	Option 2 Weight	Source	Pit Number	Class	Concrete Freeze-Thaw Dilation (%/100 cycles)	Specific Gravity	Absorption Percent
	Cement	480	517			I/IA		3.12	
All	Flyash	72	78	U.S. Ash Avon Lake		F		2.56	
	Water	195	218						
A	Coarse Agg.	1735	1735	France Stone Silica	93-3	6AA (Crushed Limestone)		2.57	2.57
	Fine Agg	1463	1365	Bundy Hill	30-35	2NS		2.59	1.71
	Concrete						0.006		
	Water	200	224						
B	Coarse Agg.	1446	1446	Levy Trenton Slag	82-22	6AA (Blast Furnace Slag)		2.29	3.34
	Fine Agg	1573	1473	Bundy Hill	30-35	2NS		2.59	1.71
	Concrete						0.001		
	Water	184	205						
C	Coarse Agg.	2059	2059	Bundy Hill	30-35	6A (Natural Gravel)		2.71	0.86
	Fine Agg	1241	1149	Bundy Hill	30-35	2NS		2.59	1.71
	Concrete						0.002		
	Water	195	217						
D	Coarse Agg.	1776	1776	Rockwood Stone	58-8	6AA (Crushed Limestone)		2.60	2.64
	Fine Agg	1445	1348	Bundy Hill	30-35	2NS		2.59	1.71
	Concrete						0.031		
	Water	187	208						
E	Coarse Agg.	1987	1987	American Agg. Milfc	63-97	6A (Natural Gravel)		2.66	1.24
	Fine Agg	1275	1182	Bundy Hill	30-35	2NS		2.59	1.71
	Concrete						0.075		

Table 2.1.2 Air-void results (ASTM C 457) at year 23

Core Location		**Modified Point Count Method**			**Linear Traverse**			
Section	Station	Paste %	Total Air %	Total Agg. %	Total Air %	Entrained Air %	Entrapped air > (1 mm)	Spacing Factor in. (mm)
A	389+01	23.3	4.6	72.1	5.1	4.1	1.0	0.0046 (0.117)
A	389+53	25.6	5.9	68.5				
B	341+70	21.4	6.9	71.7	8.7	6.2	2.5	0.0048 (0.121)
B	357+20	24.2	5.8	70.0				
C	307+08	27.8	6.6	65.6				
C	275+53	27.5	5.3	67.2	3.8	2.5	1.3	0.0076 (0.192)
D	238+29	24.2	4.3	71.5				
D	195+15	20.9	4.1	75.0	3.4	2.8	0.6	0.006 (0.152)
E	151+98	22.8	5.5	71.7	4.2	2.8	1.5	0.0062 (0.157)
E	148+02	24.3	5	70.7				
A(Shoulder)	413+72	25.3	6.9	67.8	6.6	5.9	0.7	0.003 (0.075)
A(Shoulder)	413+15	25.5	5.8	68.7				

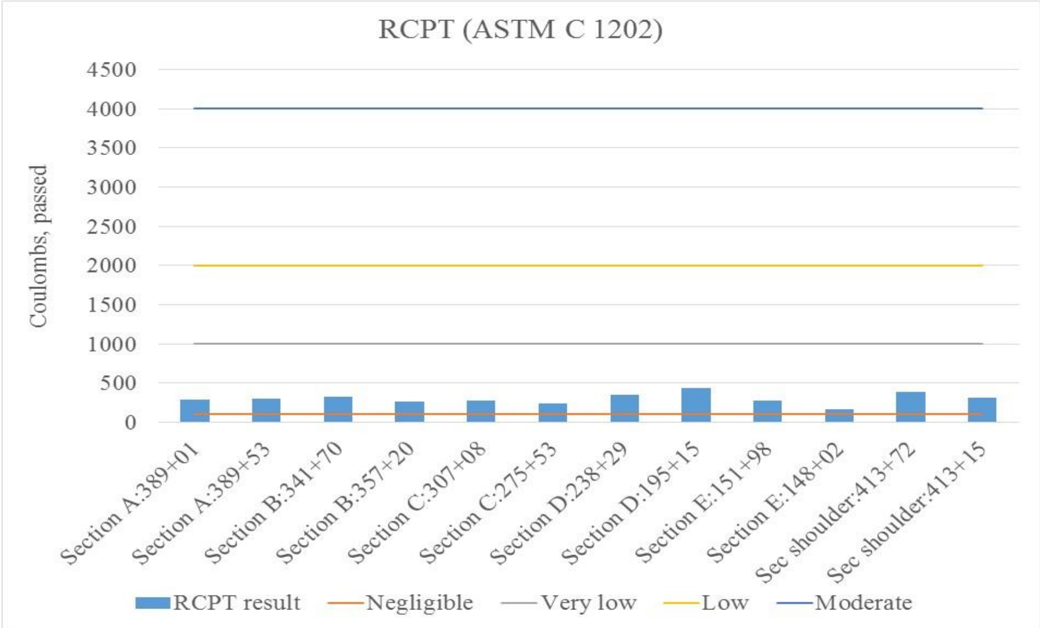


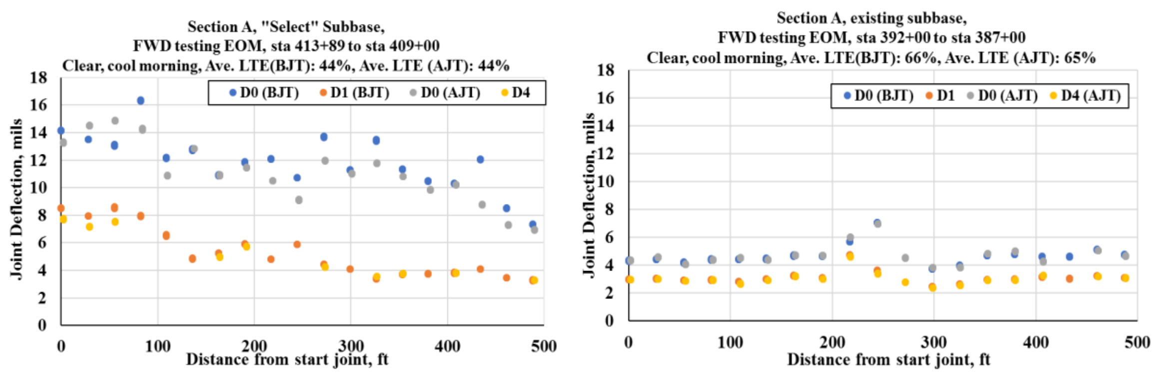
Figure 2.1. Rapid Chloride Test results (ASTM C 1202) Year 23

2.2 Joint Performance

2.2.1 Joint Deflection-Years 16 and 23.

Concrete joints subjected to heavy axle loads, erodible underlying base/subbase materials, and trapped water in the pavement system are prone to faulting and pumping erosion (Taylor et al., 2007).

Joint deflections for the FWD load-plate before the joint (BJT) and after the joint (AJT) are similar irrespective of load location (i.e. east of metal (EOM) and outer wheel-path (OWP)) and test section (A through E), subbase type ("Select" versus existing subbase), and time of day of testing (Figure 2.2). The uniform joint deflection values (BJT versus AJT) demonstrate that base erosion from pumping has not developed. However, load transfer efficiency (LTE) has decreased to the 30% to 60% range for all five sections as a result of dowel looseness. Dowel looseness was evaluated from FWD time-history data (Figure 2.3). Dowel looseness is the loss of contact between a dowel and the surrounding concrete as illustrated in the sketch by Bill Davids (Figure 2.4). Major factors for development of dowel looseness include bearing stress level, load magnitude and number of load cycles (Buch and Zollinger). Dowel looseness is especially noticeable during early morning temperature conditions where the joint is not in contact with the base/subbase due to curling effects (Figure 2.3a). No difference was found in joint deflection between 2009 (age 16) and 2016 (year 23) (Figure 2.5).



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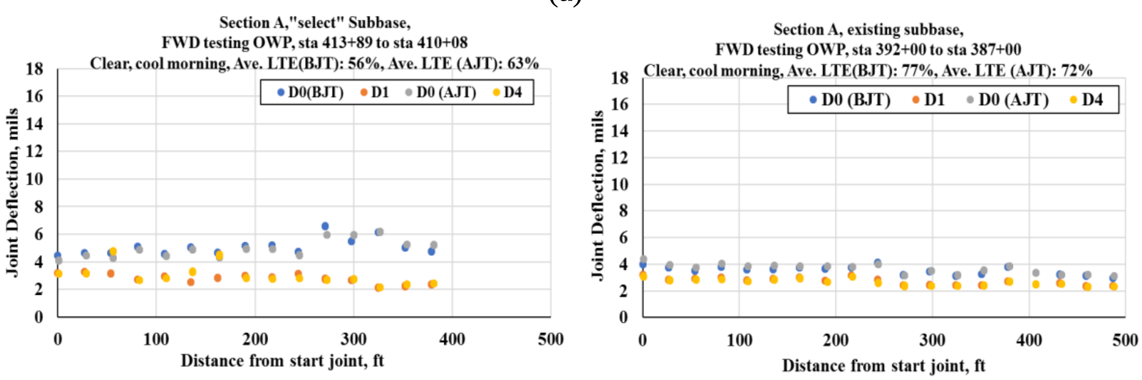

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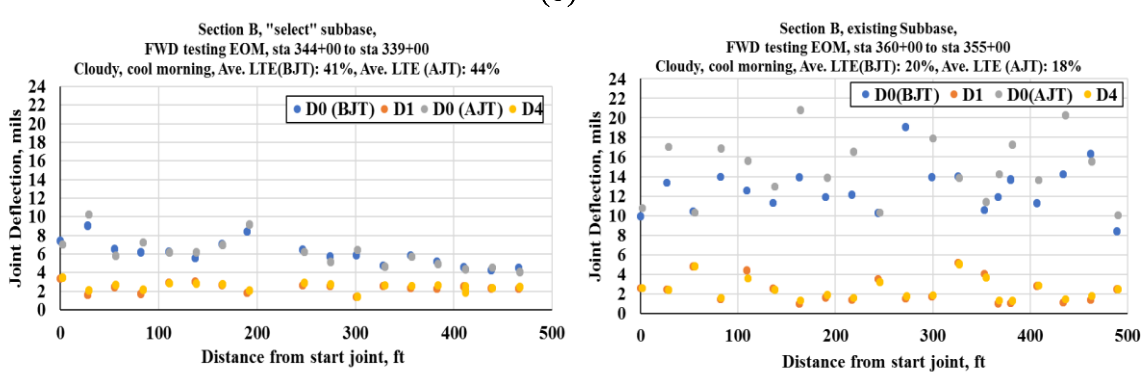

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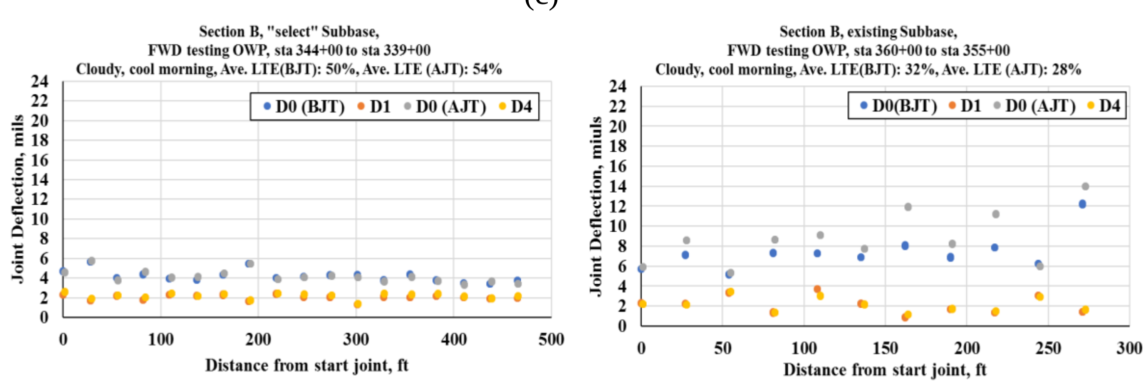
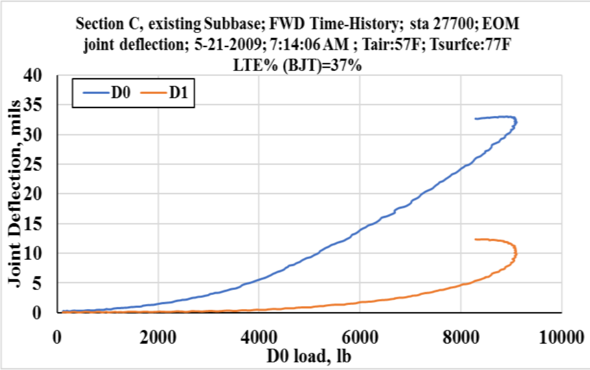
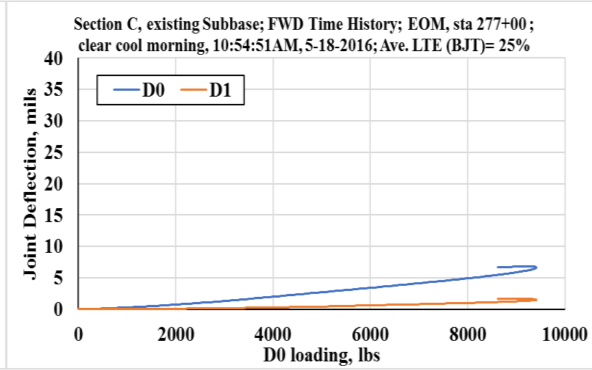


(d)

Figure 2.2 (a-d). Joint load deflections for the two subbase types for sections A and B in 2016.



(a)



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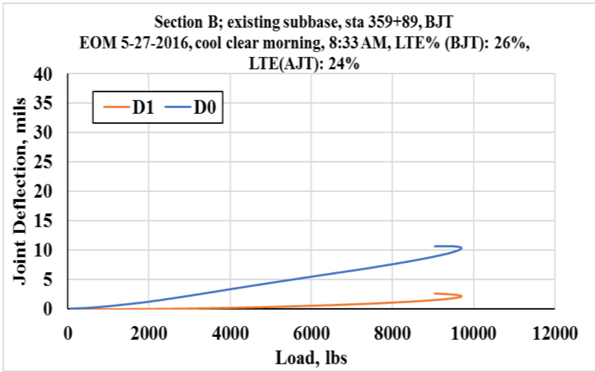

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Figure 2.3. Time-history for (a) early morning loading during high loss of joint support and mid-morning (b) nearing full contact in 2016 and (c) section B early morning in 2016.

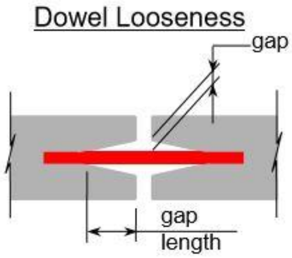
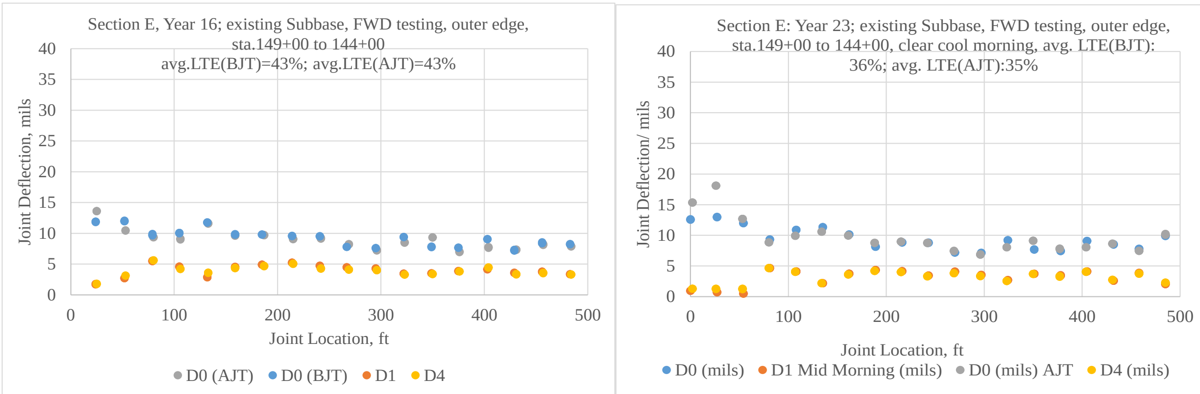


Figure 2.4. Sketch of dowel looseness (Davids)



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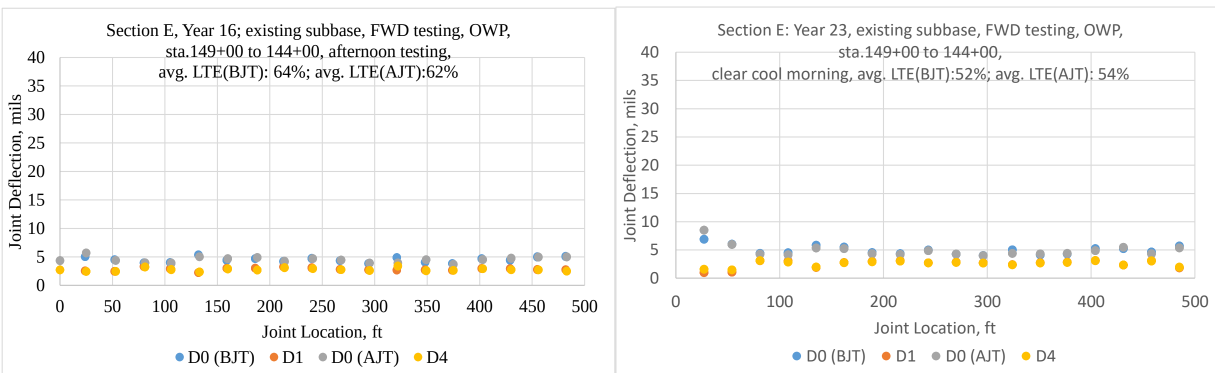


(b)

Figure 2.5 a and b. Effect of time of day on joint deflection at outer edge (a) and outer wheel-path (b) for year's 16 and 23 in Section E.

Early morning hour joint deflections at outer joint edge, were found to approach 40 mils/9000 lb during cool, clear days, settling down to below 5 mils later in the day when full base/contact was reached (Figure 2.5). It is likely that large joint deflections associated with loss of support has accelerated dowel looseness. Large joint deflections will increase mid-panel tensile bending stresses in the slab top. This is concluded from FWD deflection profiles (Figure 2.6).

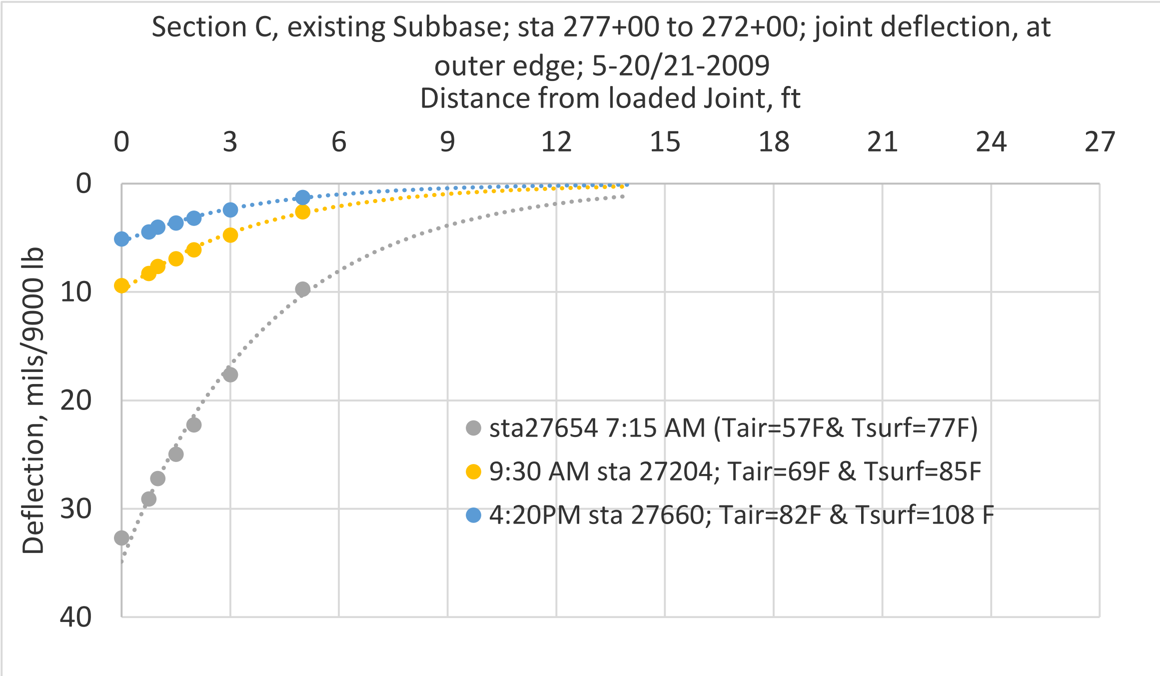
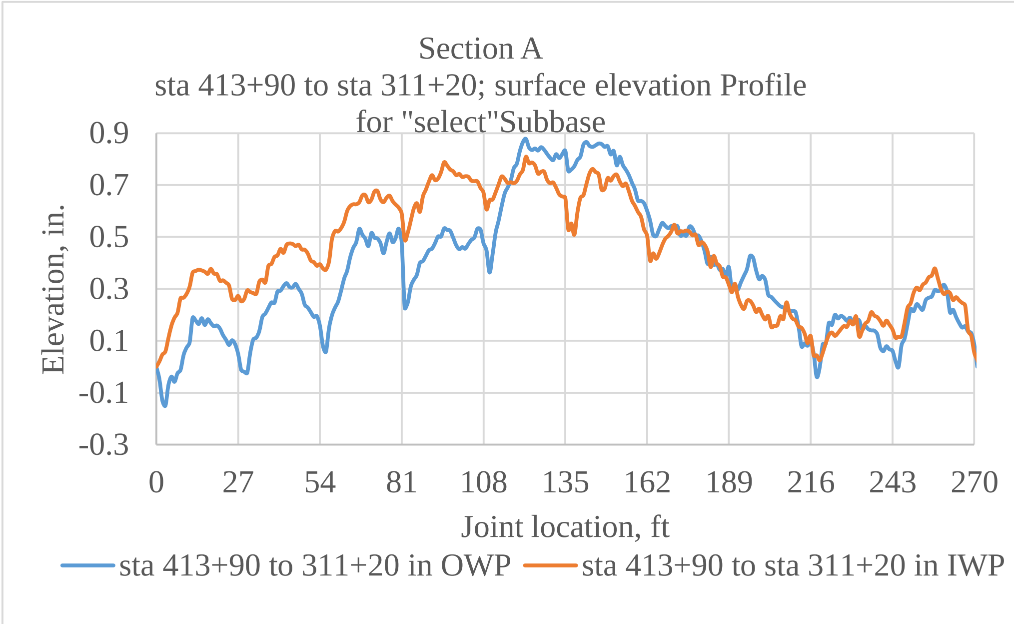


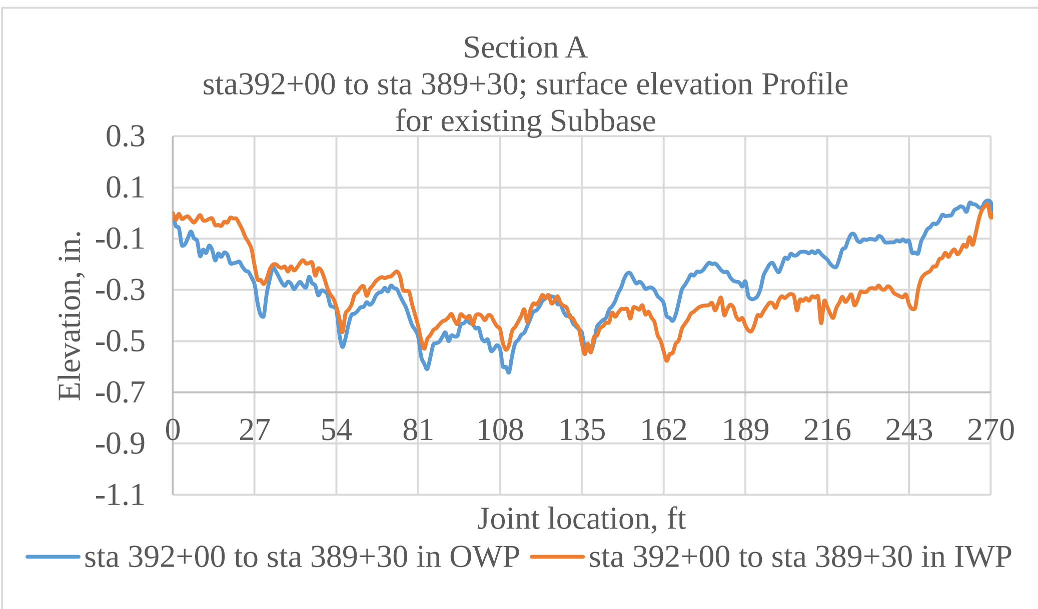
Figure 2.6. Slab bending from joint loading at different times of day.

2.2.2 Joint Settlement due to loss of load transfer.

Surface elevation results based on the Dipstick Road Profiler show that the transverse joints for sections A through E have settled by about 0.10-0.20 inch. Typical slab results are shown for Section A in Figure 2.7. The joint settlement has developed as a result of loss of joint load transfer at the contraction joints. Typical surface elevation profiles based on Dipstick measurements are shown in Figure 2.7 for profile results in the outer wheel-path (OWP) and inner wheel-path (IWP). Subbase type had no influence on joint settlement. The downward–curved slab shape creates maximum top tensile bending stress in the mid-panel region, which combined with early morning loss of support increase total slab bending stresses from joint loading. This condition promotes top-down mid-slab cracking consistent with observations from cores in 2006 (Figure 2.8).



(a)



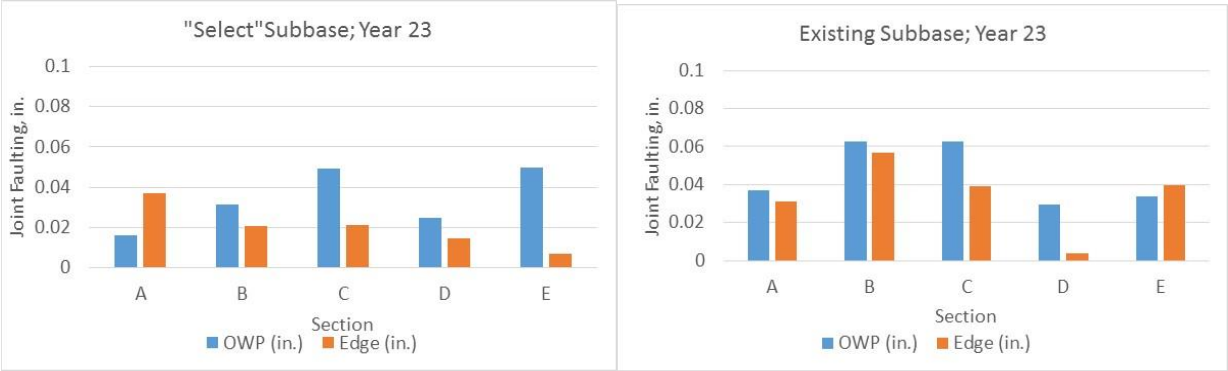
(b)

Figure 2.7. Permanent joint settlement is similar for "select" (a) and existing subbase (b) typical for all sections.

Figure 2.8. Partial-depth cracking (field core, Section A, 9-2006, station # 385+623, truck lane)

2.2.3 Joint Faulting

Pumping erosion leading to joint faulting has not developed in any of the five sections of the Aggregate Test Road after 23 years in service as the joint faulting is low (< 1mm), irrespective of subbase type (Figure 2.9).

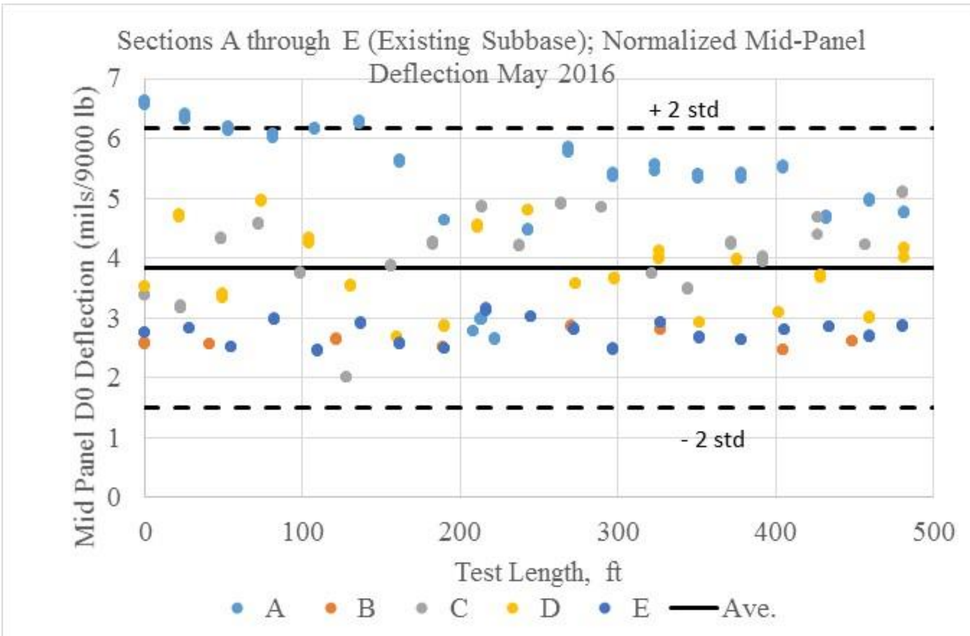


(a) (b)

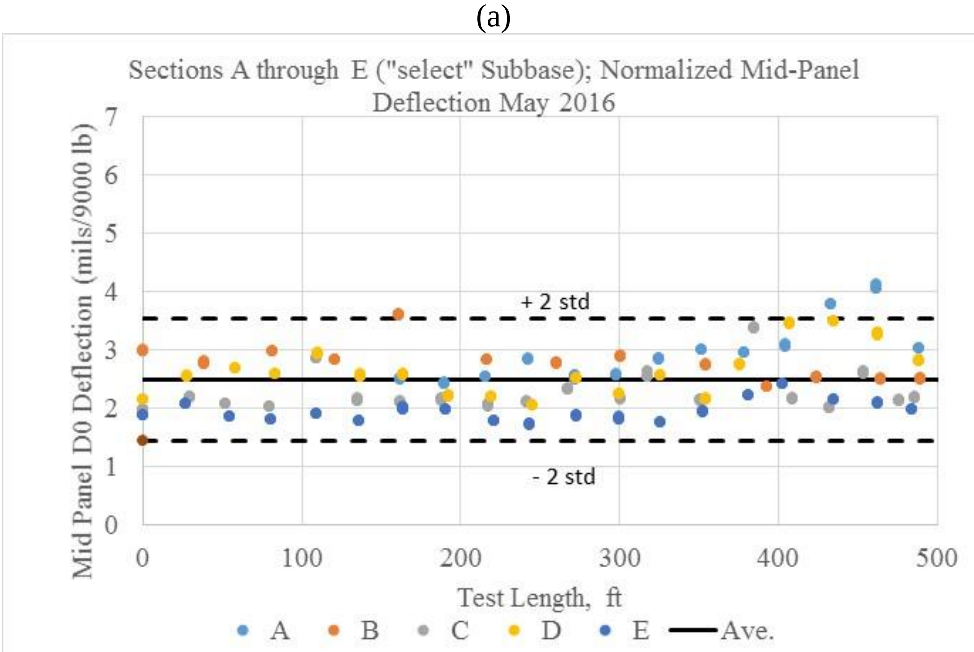
Figure 2.9. Average joint faulting for new (a) and old (b) subbase types

2.3 Effect of Subbase Type on Mid-Panel Deflection

Mid-panel deflections are lower in all section containing the "select" subbase compared to the existing poorly draining subbase, (Fig.2.10) and deflections are more uniform in the sections containing the "select" subbase. Mid-panel based back-calculation (Huang) for effective layer stiffness k (pci) using four FWD sensors D0, D4, D6 and D7 at distances (0, 12, 24 and 36 inch-es) from the D0 based on average D0 values result in static k-value of about 50 pci and 100 pci respectively for the existing and "select" subbase sections. These differences in average k-values do not have a significant effect on joint deflections. However, the large spread in deflections for the existing subbase is a concern. Backcalculation of k and E suggest that the effective slab thickness for the case of a 10.5 in. slab on a 4 in. bonded ATPB is slightly increased (approx. 11.5 inches) (Figure 2.11a). At the joint outer edge some erosion of the base is evident (Figure 2.11b).



(a)



(b)

Figure 2.10. (a) Mid-panel deflection on existing subbase and (b) "select" subbase

Figure 2.11. (a) Close-up of bonded ATPB away from joints and (b) and partly eroded ATPB at outer corners

2.4 Mid-Panel Crack Development and Full-Depth Slab Repairs

Test section B has developed premature mid-panel cracking early in its service life. Surface spalling developed which eventually required full-depth repairs in 29% of all slabs in the truck-lane after 19 years. Spalling is an indicator that aggregate interlock has been lost due to excessive crack opening. Premature mid-panel transverse cracking has developed rapidly (with first 5 years). Initially these cracks were tight, but quickly developed into working cracks, which then promoted spalling, while cracks in the other sections remained tight without spalling. Rapid development of mid-panel cracking is shown in Figure 2.12. Figure 2.13 shows a typical spalled mid-panel crack in section B from 2006. Figure 14 illustrates the large difference in full-depth repairs between Section B and the other sections.

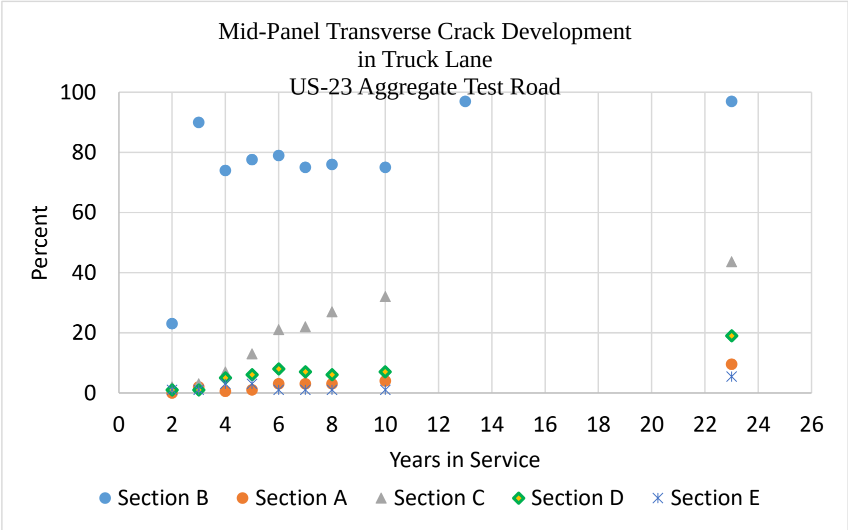


Figure 2.12. Mid-panel transverse crack development.

Figure 2.13. Typical crack spalling in section B (2006)

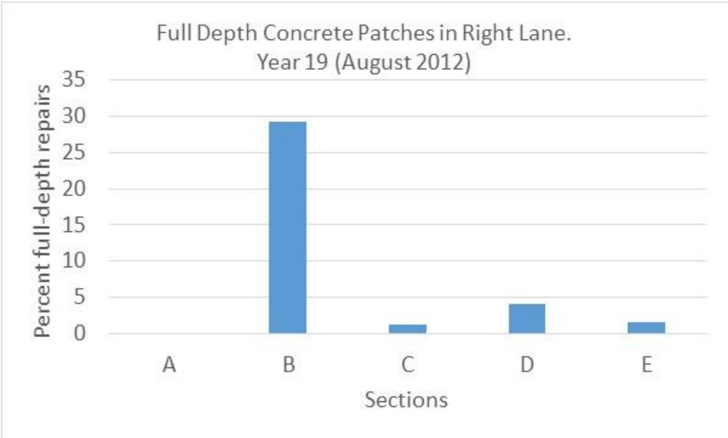


Figure 2.14. Full-depth repair history (Ben Krom, MDOT)

2.5 Pavement roughness

MDOT PMS database values for IRI (in./mile) development show the same gradual increase in pavement roughness for all sections and subbase types (Figure 2.15), (courtesy, Ben Krom, MDOT).

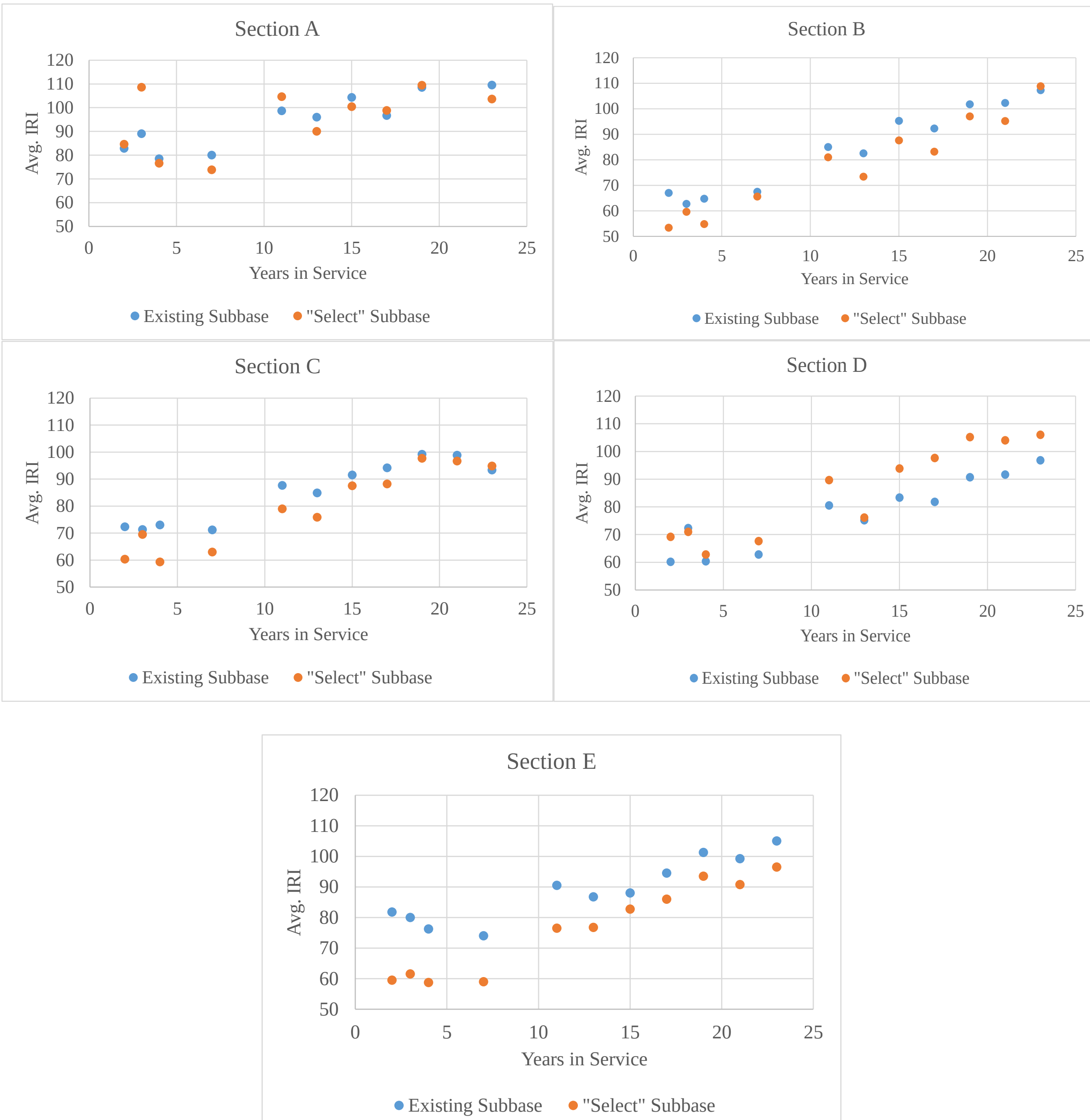


Figure 2.15. Increase in IRI versus Years in Service (Ben Krom, MDOT).

3. Conclusions and Recommendations

3.1 Major Findings after 23 Years in Service:

- Four sections (A, C, D & E) have developed little or no cracking, while one section (B) has developed premature mid-panel cracking with over 75 percent of panels in the truck lane within five years in service. These cracks became working cracks followed by spalling. Full-depth repairs were required in year 19 in 29% of all panels for this section, while little or no repairs were needed in the other sections.

- No freeze-thaw related joint durability problems were reported in any section. Excellent frost resistance is attributed to a well-draining ATPB and excellent concrete air-void system with an average of 5.4% total air and a spacing factor within the range recommended by ACI (0.004 to 0.008 in.) for good freeze-thaw resistance. Sections D and E have experienced minor coarse aggregate pop-out throughout the top surface region. However, this has not affected pavement performance.

- Some minor breakdown of the ATPB - outside edge at transverse joints, as observed by coring.

- FWD joint (D0) deflections during early morning temperature conditions associated with cool clear mornings were 10 times (approx. 40 mils) the mid-panel (3-4 mils) (D0) deflection at 9000 lb. loading. Substantial dowel looseness and low load transfer efficiency (40%-60%) is typical for all sections.

- Permanent joint settlement of 0.1-0.2 inches has developed for all sections. The downward slab shape explains why top-down mid-panel cracking may have occurred. Section B cracking occurred very early which most likely occurred prior to joint settlement.

- Pumping erosion at joints is not a factor and joint faulting is low (< 0.04 in.) after 23 years.

- Rigid pavement back-calculation based on mid-panel deflections of the 4 sensors starting with the D0, and 12, 24 and 36 inches behind the D0 sensor suggest that the bonded 4 inch stabilized ATPB increases the effective slab thickness slightly (approx.1 inch).

- Subbase type has not had any influence on pavement performance, to date, although the range of low to high mid-panel deflection is much higher in the original non-draining subbase sections than in the "Select" well-draining permeable sand subbase sections.

Recommendations:

- With the loss of load transfer from dowel bar looseness it is recommended to stabilize the joints with polyurethane undersealing prior to diamond grinding.

- The stabilized ATPB has prevented the pavement from becoming critically saturated thus avoiding freeze-thaw damage and moisture warping uplift. A stabilized base is therefore recommended for achieving excellent long-term pavement performance.

- A slight increase in dowel diameter from 1.25 inch to 1.5 inch reduces bearing load stress by approx. 30%. The reduced concrete stress may delay onset of dowel-bar looseness.

4. References

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Huang, Yang H. , “Pavement Analysis and Design,”2nd Edition, Pearson Education Inc. Prentice Hall, ISBN 0-13-142473-4, 2004, pp.419-422.

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Taylor, Peter C., Kosmatka, Steven H., Voigt, Gerald F. et al., “Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual”, National Concrete Pavement Technology Center, Iowa State University, FHWA Publication No. HIF-07, October 2007, pp. 350.

APPENDIX A: MDOT Concrete Proportioning Data for the Aggregate Test Road

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1824
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 8/31/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1684

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	FRANCE STONE SILICA	93-3	6AA	2.57	2.57
FLY ASH	U.S. ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 480 (SK/CU YD) :5.1 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 0.95
FLY ASH CONTENT, LB/CU YD: 72
THEORETICAL YIELD =99.96

WEIGHT OF COURSE AGG. (DRY, LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES, LB/CU YD OF CONCRETE		
	FINE AGG (OVER DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
82	1526	1594	266
83	1509	1613	266
84	1491	1632	265
85	1473	1652	265
86	1456	1671	264
87	1438	1691	264
88	1421	1710	263
89	1403	1730	262
90	1386	1749	262
91	1368	1769	261
92	1351	1788	261

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 87 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT, FLY ASH AND A WATER REDUCER

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1822 A
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 8/31/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1682

****

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	FRANCE STONE SILICA	93-3	6AA	2.57	2.57
FLY ASH	U.S. ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 517 (SK/CU YD) :5.5 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 1.02
FLY ASH CONTENT, LB/CU YD: 78
THEORETICAL YIELD =99.95

****

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVEN DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
82	1427	1594	289
83	1410	1613	288
84	1393	1632	287
85	1376	1652	286
86	1359	1671	286
87	1342	1691	285
88	1324	1710	284
89	1307	1730	283
90	1290	1749	283
91	1273	1769	282
92	1257	1788	281

****

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 87 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT AND FLY ASH

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: WH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1931 *Group B*
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 9/ 2/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1791

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		1/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	E.C.LEVY TRENTON SLAG	82-22	6AA	2.29	3.34
FLY ASH	N.M.C. AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 480 (SK/CU YD) :5.1 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 0.95
FLY ASH CONTENT, LB/CU YD: 72
THEORETICAL YIELD =99.94

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE FINE AGG (OVEN DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
67	1647	1302	276
68	1627	1321	275
69	1607	1341	275
70	1586	1360	275
71	1567	1380	274
72	1547	1399	273
73	1527	1419	273
74	1507	1438	272
75	1488	1458	272
76	1468	1477	271
77	1448	1496	271

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 72 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT, FLY ASH AND A WATER REDUCER

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1929 Group B
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 9/ 2/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1789

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	E.C.LEVY TRENTON SLAG	82-22	6AA	2.29	3.34
FLY ASH	N.M.C. AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 517 (SK/CU YD) :5.5 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 1.02
FLY ASH CONTENT, LB/CU YD: 78
THEORETICAL YIELD =99.96

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVER DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
67	1545	1302	299
68	1525	1321	299
69	1506	1341	298
70	1486	1360	297
71	1467	1380	297
72	1448	1399	296
73	1429	1419	295
74	1409	1438	294
75	1390	1458	294
76	1371	1477	293
77	1351	1496	292

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 72 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT AND FLY ASH

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1833 C
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 8/31/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1693

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		1/1A	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	BUNDY HILL	30-35	6A	2.71	0.86
FLY ASH	U.S.ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 480 (SK/CU YD) :5.1 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 0.95
FLY ASH CONTENT, LB/CU YD: 72
THEORETICAL YIELD =99.97

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVEN DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
100	1302	1944	228
101	1285	1963	227
102	1269	1982	226
103	1253	2002	225
104	1236	2021	224
105	1220	2041	223
106	1204	2060	222
107	1188	2080	221
108	1171	2099	220
109	1155	2118	219
110	1139	2138	218

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 105 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT, FLY ASH AND A WATER REDUCER

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1831 C
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 8/31/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1691

****

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	BUNDY HILL	30-35	6A	2.71	0.86
FLY ASH	U.S.ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 517 (SK/CU YD) :5.5 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 1.02
FLY ASH CONTENT, LB/CU YD: 78
THEORETICAL YIELD =99.97

****

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVER DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
100	1209	1944	248
101	1193	1963	247
102	1177	1982	246
103	1161	2002	244
104	1146	2021	243
105	1130	2041	242
106	1114	2060	241
107	1098	2080	240
108	1082	2099	239
109	1066	2118	238
110	1050	2138	236

****

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 105 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT AND FLY ASH

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1842 D
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 9/ 7/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1702-S

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	SUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	ROCKWOOD STONE GROUP D	58-8	6AA	2.60	2.64
FLY ASH	U.S.ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 480 (SK/CU YD) :5.1 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 0.95
FLY ASH CONTENT, LB/CU YD: 72
THEORETICAL YIELD =99.95

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVEN DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
84	1508	1632	267
85	1491	1652	267
86	1473	1671	266
87	1456	1691	266
88	1438	1710	265
89	1421	1730	265
90	1403	1749	264
91	1386	1769	264
92	1369	1788	263
93	1352	1807	262
94	1335	1827	262

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 89 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT, FLY ASH AND A WATER REDUCER.
SUPERSEDES MIX DESIGN NO. 92-1702 DATED 08-31-92.
CHANGED UNIT WEIGHT OF COARSE AGGREGATE.

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1840 Brovt D
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 9/ 7/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1700-S

****

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	ROCKWOOD STONE	58-8	6AA	2.60	2.64
FLY ASH	U.S.ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 517 (SK/CU YD) :5.5 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 1.02
FLY ASH CONTENT, LB/CU YD: 78
THEORETICAL YIELD =99.96

****

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVER DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
84	1410	1632	289
85	1393	1652	289
86	1376	1671	288
87	1359	1691	287
88	1342	1710	287
89	1325	1730	286
90	1308	1749	285
91	1291	1769	284
92	1275	1788	284
93	1258	1807	283
94	1241	1827	282

****

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 89 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT AND FLY ASH.
SUPERSEDES MIX DESIGN NO. 92-1700 DATED 08-31-92.
CHANGED UNIT WEIGHT OF COARSE AGGREGATE.

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1851 E
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 8/31/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1711

****

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	AMERICAN AGGREGATES MILFORD	63-97	6A	2.66	1.24
FLY ASH	U.S.ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 480 (SK/CU YD) :5.1 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 0.95
FLY ASH CONTENT, LB/CU YD: 72
THEORETICAL YIELD =99.96

****

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVER DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
96	1338	1866	237
97	1321	1885	236
98	1304	1905	235
99	1287	1924	234
100	1271	1944	233
101	1254	1963	232
102	1238	1982	231
103	1221	2002	231
104	1204	2021	230
105	1188	2041	229
106	1171	2060	228

****

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 101 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT, FLY ASH AND A WATER REDUCER

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

FORM 1830

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONCRETE PROPORTIONING DATA

FILE 300 -

CONTROL SECTION ID: NH-58034
JOB NUMBER : 32750A
LAB NUMBER : 92C-1849 F
GRADE OF CONCRETE : 35P
INTENDED USE OF CONCRETE : PAVEMENT (SLIPFORM)

DATE : 8/31/92
SPECIFICATION : 90 STD SPECS
MIX DESIGN NUMBER : 92-1709

****

CONCRETE MATERIALS

MATERIAL	SOURCE	PIT NUMBER	CLASS	SPECIFIC GRAVITY	ABSORPTION PERCENT
CEMENT	(SEE REMARKS)		I/IA	3.12	
FINE AGG.	BUNDY HILL	30-35	2NS	2.59	1.71
COARSE AGG.	AMERICAN AGGREGATES MILFORD	63-97	6A	2.66	1.24
FLY ASH	U.S.ASH AVON LAKE		F	2.56	

CEMENT CONTENT, LB/CU YD: 517 (SK/CU YD) :5.5 B/Bo : 0.72
AIR CONTENT (DESIGN) : 5.5 % (SPECIFIED): 6.5 % SPECIFICATION TOLERANCE (+ -): 1.5 %
R.W.C. : 1.02
FLY ASH CONTENT, LB/CU YD: 78
THEORETICAL YIELD =99.94

****

WEIGHT OF COURSE AGG. (DRY,LOOSE) LB/CU FT	AGGREGATE AND WATER PROPORTIONS QUANTITIES,LB/CU YD OF CONCRETE		
	FINE AGG (OVEN DRY)	COARSE AGG (OVEN DRY)	TOTAL WATER
96	1244	1866	257
97	1227	1885	256
98	1211	1905	255
99	1194	1924	254
100	1178	1944	253
101	1162	1963	252
102	1146	1982	251
103	1130	2002	250
104	1114	2021	248
105	1098	2041	247
106	1081	2060	246

****

THIS CHART FOR USE WITH CEMENTS OF THE CLASS SHOWN FROM APPROVED SOURCES.
TYPICAL UNIT WEIGHT (DRY,LOOSE) OF COURSE AGGREGATE AS DESCRIBED ABOVE IS 101 LB/CU FT.

SPECIAL MESSAGES:

THIS MIX DESIGN TO BE USED WITH THE COMBINATION OF PORTLAND CEMENT AND FLY ASH

CC: FILE
J.WEBER (2)
S.BARRETT-DIST.8 (2)

ROGER D. TILL
STRUCTURAL SERVICES - SUPERVISING ENGINEER

Project NH 58034/32750A
Special Requirements for Aggregates
(Research Project 92 A-0030)

	6AA	6AA	6A	6A	6A
Group	A	B	C	D	E
Pit Number	93-3	82-22	30-35	58-8	63-97
Grading, % passing					
1 1/2 in.	100	100	100	100	100
1 in.	95-100	95-100	95-100	95-100	95-100
3/4 in.	65-85	65-85	65-85	65-85	65-85
1/2 in.	35-60	35-60	35-60	35-60	35-60
3/8 in.	15-35	15-35	15-35	15-35	15-35
No. 4	0-5	0-5	0-5	0-5	0-5
Loss by Washing, max.	2.0	2.0	1.0	2.0	1.0
Deleterious Particles, %					
Soft	0.0-0.5	0.0-0.5	0.4-1.4	0.0-0.5	0.2-1.2
Chert	0.0-0.5	0.0-0.5	1.2-2.2	0.0-0.5	2.3-3.3
Bulk Specific Gravity	2.58-2.62	2.30-2.40	2.69-2.73	2.57-2.61	2.67-2.71
Absorption, %					
24 hr.	1.94-2.38	3.17-3.87	0.58-0.98	2.22-2.72	0.63-1.03
Vac Sat	3.13-3.83	----	0.88-1.28	3.05-3.73	0.87-1.27
Crushed Materials, %	100	100	0-25	100	0-28
Unit Weight, dry loose, lb/ft^3	83-93	69-79	102-112	83-93	100-110

APPENDIX B: Cores for ASTM C 457 and ASTM C 1202 analysis and Air-Void Microscopy Photos.

Section A	
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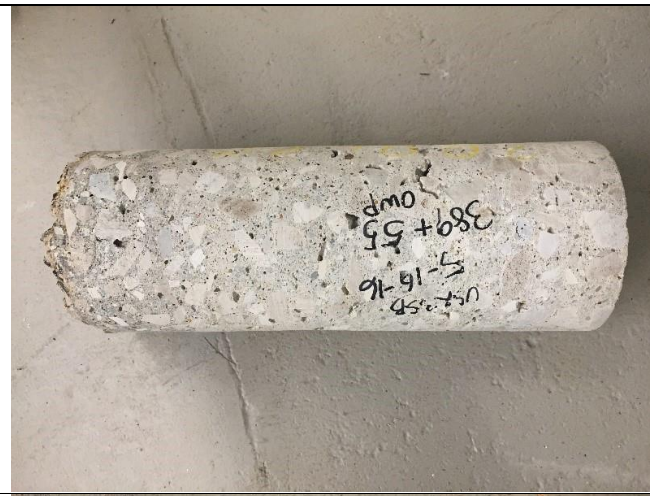
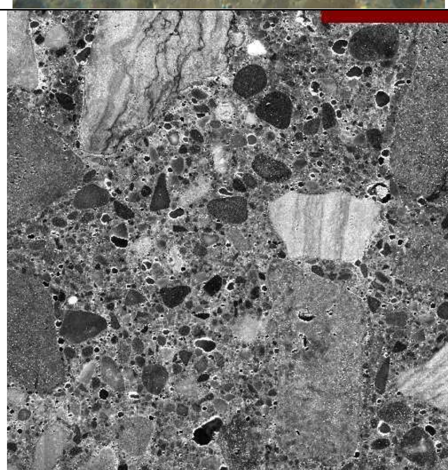
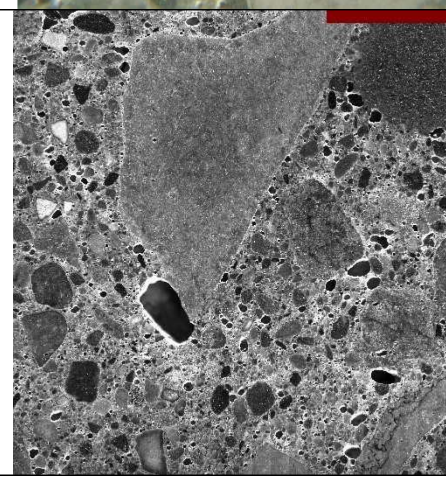
	
	
	

A-389(01)	A-389(55)
	
	
	

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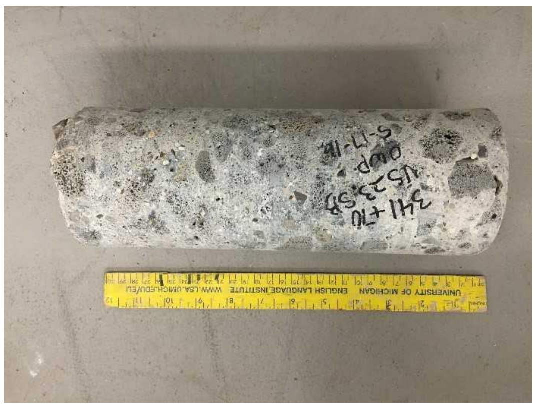
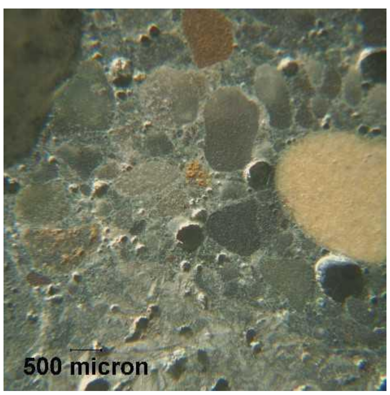
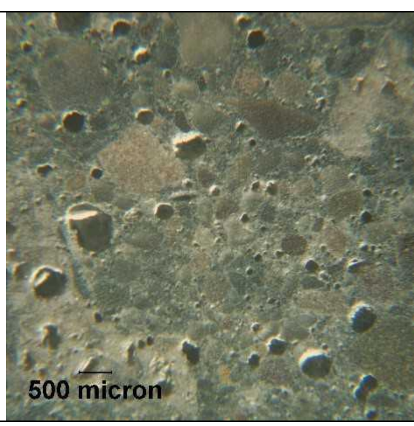
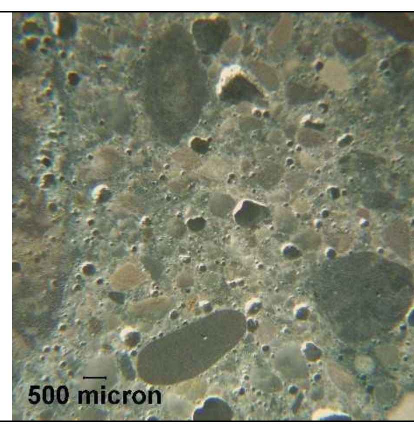
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
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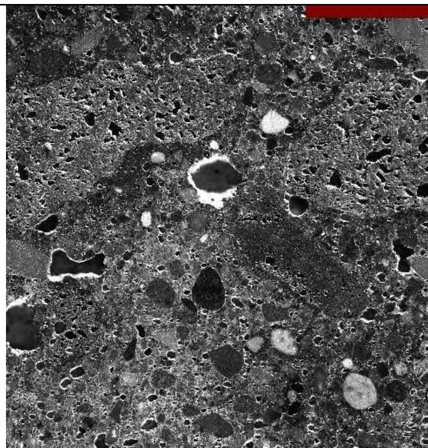	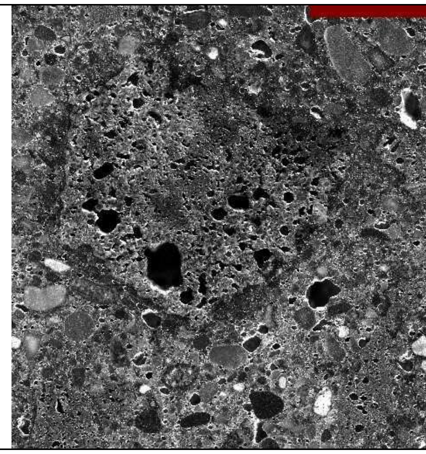
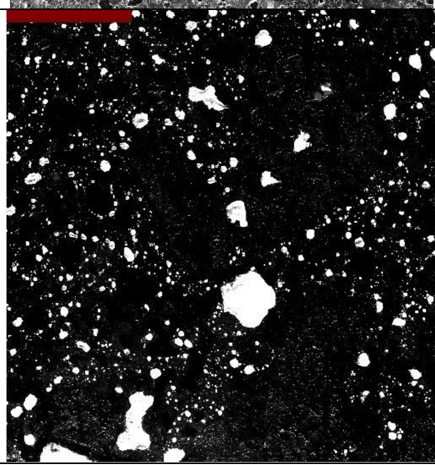	

Section C	
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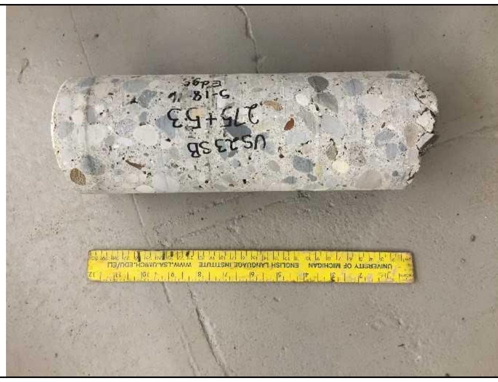
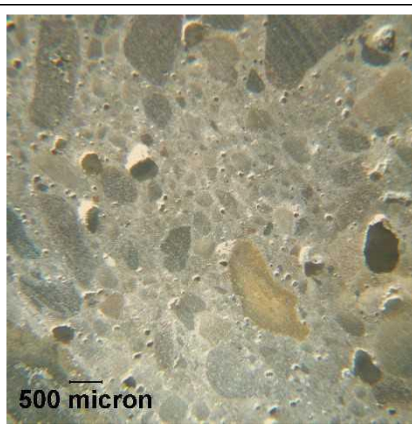
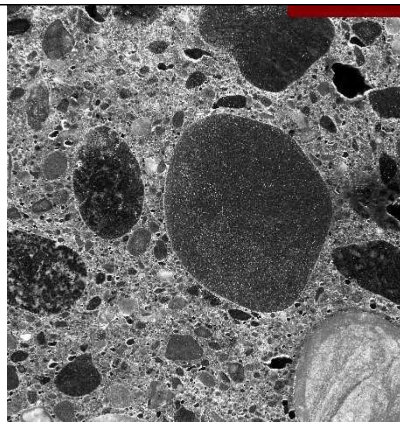
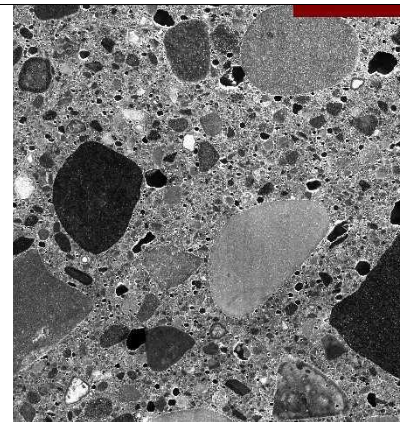
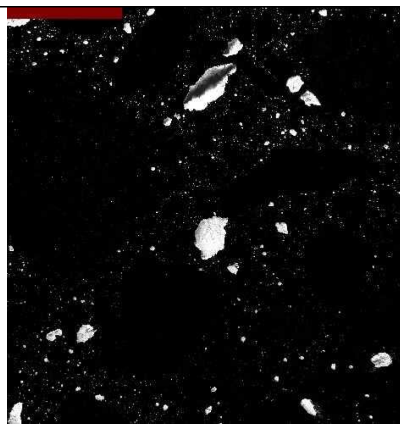
	
	
	
	

C-275(53)	C-307 (8)
	
	

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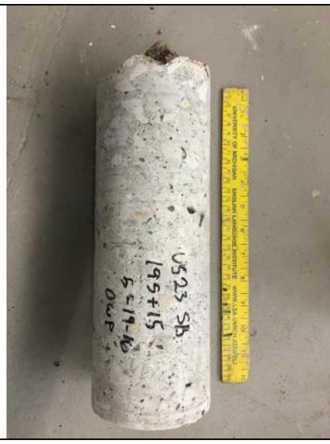
<tr><td></td><td></td></tr>
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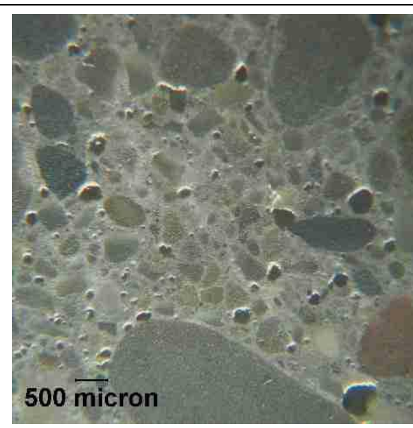
<tr><td></td><td></td></tr>
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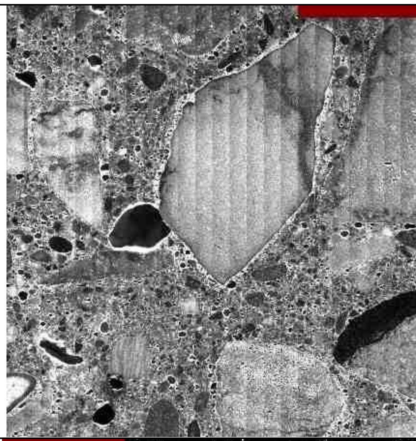	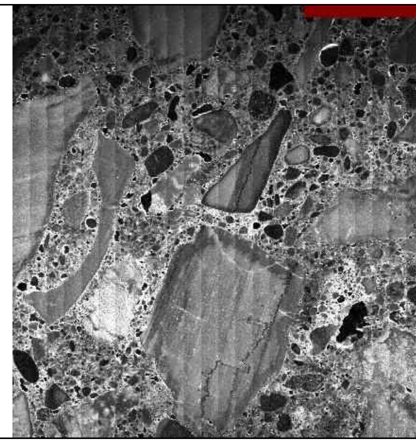
	

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	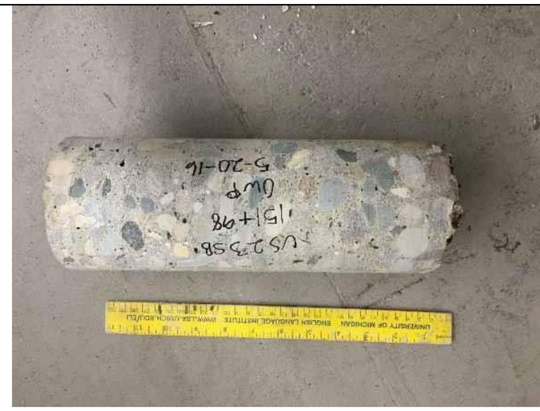
	
	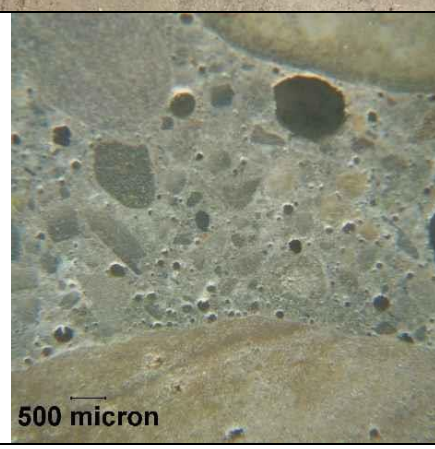

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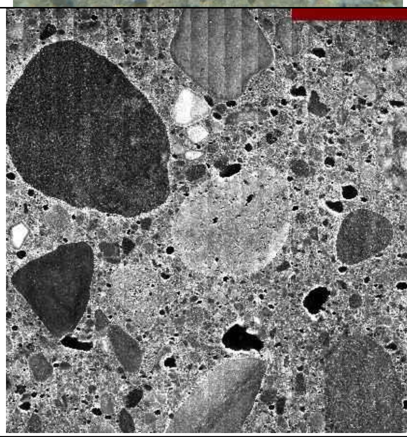	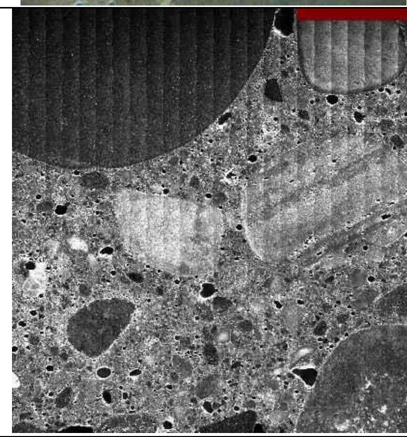
	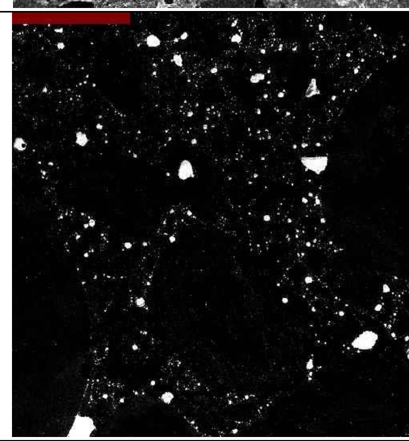

APPENDIX C: Aggregate Test Road Photos from 2016

Section A sta 414+00 to sta 409+00

Section B Sta 360+00 to sta 355+00

Section C Sta 277+00 to sta 272+00

Section D: Sta 244+00 to sta 239+00








Section E: sta 156+00 to sta 151+00