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16. Abstract:

From 1990 to 1995 the department used recycled concrete pavement as open-graded drainage course (OGDC) base aggregate for thirteen concrete reconstruction projects. Overall, the JRCP projects with coated/stabilized OGDC have performed very well in contrast to other JRCP concrete projects constructed during that period that used an unbound, natural aggregate OGDC. The objectives of the joint UM-MDOT investigation was to determine whether the superior joint performance of JRCP projects on treated OGDC was tied to the OGDC stabilization, and whether those findings are transferable to current JPCP designs to benefit their long-term performance. The study included two JPCP projects (SHRP 260221 and 260223) on permeable asphalt-treated base (PATB).

Excellent long-term (>10 years) dowel-bar load transfer effectiveness was common. Pavement distress index curves showed little or no distress development with no upward trend. This is directly attributed to stable and uniform base support. Excellent long-term joint load transfer effectiveness (>85%) was found as well for the two JPCP SHRP test sections. A key factor in achieving excellent long-term performance is controlling base erosion and joint settlement by providing an adequate drainage system. In some cases, extensive base erosion and joint settlement of 0.10-0.2 inches from inadequate subsurface drainage lead to ineffective dowel-bar load transfer and mid-slab top-down cracking. In view of the varied performance that MDOT has experienced with JRCP/JPCP on untreated OGDC it is therefore recommended that MDOT use treated OGDC as the standard base, especially since the incorporation of crushed concrete pavement into the base provides long-term sustainability. However, the full, long-term benefits of using a treated OGDC are contingent on a well-draining pavement system.

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Final Report

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EXECUTIVE SUMMARY

From 1990 to 1995 the department used recycled concrete pavement as open-graded drainage course (OGDC) base aggregate for thirteen concrete reconstruction projects. Because the crushed concrete was known to form a leaching residue (calcium carbonate) that could clog drainage fabrics and pipes, the OGDC aggregate was coated with asphalt to assure that drainage system performance would not be adversely affected. Two of the thirteen projects used cement as a stabilizing material to compare with the eleven that used asphalt for a combined total of 115 lane miles. With coating, the OGDC remained highly permeable and provided a secondary benefit of excellent base support characteristics for the concrete pavement slabs. All of the reconstruction projects were constructed using jointed-reinforced concrete pavement (JRCP).

Overall, the JRCP projects with coated/stabilized OGDC have performed very well in contrast to other JRCP concrete projects constructed during that period that used an unbound, natural aggregate OGDC. Structural distress formation (transverse cracking, faulting, spalling) has been minimal with stabilized OGDC projects. Thus, it is expected their service life will exceed non-stabilized JRCP projects.

This study was a joint MDOT-UM investigation project to determine why these JRCP projects have shown superior performance. The objective was to find any ties to the OGDC stabilization, and whether those findings are transferable to current JPCP designs to benefit their long-term performance. The project was conducted over a twelve month period and the study approach was: (1) Compile design and condition data for JRCP projects with stabilized OGDC, and (2) from representative projects based on FWD testing, coring, profiling, distress surveying, determine the major reason for the improved performance of JRCP on stabilized OGDC. The study also included two JPCP projects (SHRP 260221 and 260223) on permeable asphalt-treated base (PATB) located on NB US-23 just north of the Ohio State line and one JRCP project on untreated OGDC just north of US-223, adjacent to MDOT's Aggregate Test Road on SB US-23 in Monroe County.

The major study findings are:

- Most JRCP projects with stabilized OGDC and the two JPCP SHRP projects on permeable treated base (PATB) have excellent joint load transfer effectiveness (less joint deflection and lower differential deflection) resulting from improved base support and bonding of the treated base to the concrete pavement.

- A key factor in achieving excellent long-term performance is to control base erosion by assuring a functioning drainage system. In some locations, base erosion lead to permanent joint settlement. Inadequate subsurface drainage combined with repeated truck loading caused the erosion. Over time, this condition has allowed a reduction of joint load transfer effectiveness that can ultimately lead to top-down, mid-slab transverse cracking.

- The two JPCP SHRP projects PATB with 15 ft joint spacing (SHRP 260221 and 260223) with concrete thicknesses of 8 and 11 inches respectively, were found to have excellent joint stability after fifteen years of service with low amounts of differential joint deflection, joint settlement and no transverse mid-slab cracking.

This investigation has demonstrated there are benefits for using a stabilized OGDC or PATB to achieve long term pavement performance. However, the full long-term performance benefits of this base type are contingent on sustaining a well-draining pavement system. Therefore, it is recommended that MDOT incorporate FWD and surface profiling as part of the Department's routine pavement management data collection activities. These data are vital to foresee impending erosion or other support deficiencies with the underlying OGDC/PATB base.

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CHAPTER 1. INTRODUCTION

Problem Statement: From approximately 1990 until 1995 a stabilized open-graded drainage course (OGDC) was used as a base for jointed reinforced concrete pavement (JRCP). This type of OGDC applied to only concrete pavement reconstruction projects. The primary purpose of the treatment was to coat[1] the aggregate particles, since crushed concrete from the old pavement was used by specification to promote recycling. The coating prevented the formation of a leaching concrete residue that could clog the drainage layer or the internal drainage system. A secondary benefit was to provide stability[2] to the aggregate matrix, which was a gap-graded gradation (5G) that was selected to enhance drainage. Since their construction, random condition surveys and MDOT's Pavement Management System (PMS) data have found mostly excellent performance with the JRCP projects that used a stabilized OGDC.

Project Objective: Determine why these JRCP projects have shown superior performance, particularly any ties to the OGDC stabilization, and whether those findings are transferable to current designs using Jointed Plain Concrete Pavement (JPCP) to benefit their long-term performance.

Project Description: Investigate the performance and design/construction factors of JRCP projects and two JPCP SHRP projects (260221 and 260223) that used a stabilized OGDC. Select representative projects for a detailed field evaluation after compiling and reviewing design and historical PMS distress data. The field evaluation of performance factors will include visual distress surveys, FWD testing for mid-slab and joint deflection, base/subbase support, joint faulting, and surface profiling. Determine the current physical characteristics of the stabilized OGDC by coring.

Organization of report:
Chapter 2– Background information for JRCP projects with stabilized OGDC.
Chapter 3 – Presentation of PMS condition data for the JRCP projects and LTPP performance trends for the JPCP projects.
Chapter 4 – Presentation and discussion of major findings from field testing.
Chapter 5 – Study Conclusions
Chapter 6 – Study Recommendations
Appendix A-E – MDOT specifications for stabilized OGDC, Special Provision for Permeable Asphalt Treated Base (PATB) (SHRP Test Sections), SHRP JPCP pavement cross sections, list of MDOT projects on OGDC.

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[1] If the OGDC aggregate was crushed concrete, only asphalt was used to prevent any leaching.

[2] Two projects used cement to stabilize the OGDC. The aggregate was made from crushed concrete pavement from the reconstruction project. The objective was to emphasize stability to compare with the stabilizing benefit from using an asphalt coating.

CHAPTER 2. JRCP PROJECTS with TREATED OGDC

2.1 Background

An open-graded drainage course (OGDC) became the standard base layer under concrete pavements in 1984 after several trial projects. Appendix E contains a partial list of projects, which studied various issues involving the use of an open-graded aggregate as a base under concrete pavement in lieu of a dense-graded aggregate.

From approximately 1990 until 1995 the department routinely specified asphalt or cement-stabilized OGDC when existing concrete pavement was reconstructed as new jointed reinforced concrete pavement (JRCP). Typically, the contractor was allowed to choose whether asphalt or cement was used to treat (stabilize) the OGDC. The primary purpose of the treatment was to coat the aggregate particles, since the specification stated that the old concrete pavement was to be crushed to make the needed aggregate. The treatment or coating was used to prevent any leaching concrete residue (calcium carbonate) from clogging the drainage layer or the underlying underdrain system. A secondary benefit was to provide stability to the aggregate matrix, which was a gap-graded gradation (5G), intended to maximize drainage potential. Table 2.1 contains the 5G OGDC gradation limits.

Table 2. 1 MDOT Gradation limits for 5G OGDC.

Sieve size	5G - % passing
1 ½”	100
1"	-
½”	0/90
No. 4	0/8
No. 8	-
No. 30	-
LBW	3.0 max

The Appendix (A) contains a typical project specification for stabilized OGDC from that time period.

Specification modifications were frequent, so a special provision (SP) was normally used. The primary construction concern was achieving the proper coating of the aggregate when asphalt was used. The SP allowed either an asphalt cement or emulsion to coat the aggregate. Being less expensive, the contractor selected an emulsion when asphalt was chosen. Two types of emulsion were allowed; an MS-2h or MS-2a. An MS-2h allowed cold mixing in a pug mill, which was the norm for projects. The SP typically required a minimum percentage of asphalt after water loss per aggregate weight to achieve the desired 90% particle coverage. Still, uniform coverage was difficult to achieve. The actual coverage of individual particles widely varied. Many particles also broke during rolling for compaction, exposing new uncoated surfaces. Still, the process overall was considered to be successful for fulfilling the objective.

There were also some difficulties in placing a stiff aggregate mass as a uniform layer to assure its specified thickness and avoid segregation. Contractors used varying techniques and equipment to meet the specified requirements. Once compacted in-place, they found that the base benefited the paving process more so than the unbound OGDC aggregate of preceding years.

Cement was used as a coating only twice during this period. Cement was considered more costly to use than asphalt. Also with cement, the specification required an upgrade to a 6” diameter underdrain pipe (std. 4”) to provide more capacity in case of infilling with leachate over time from the OGDC. Trench backfill quantities also increased, as the trench dimensions increased to account for the larger pipe. Cement was mixed at about 6% per weight of aggregate. Cement coating was found to be superior for stability than asphalt, but temporarily increased the potential for carbonate leaching versus using unbound crushed concrete. Placement had to usually avoid sunny, dry, windy days to prevent rapid water evaporation from the mixture causing a lack of bond among particles.

2.2 JRCP PROJECTS WITH STABILIZED OGDC

Table 2.2 is a list of the JRCP projects constructed with stabilized OGDC.

Route	CS	Job No.	General Location	Paved
US-23	25031	30798A*	south of Flint	1992
US-23	25031	31018A	south of Flint	1993
US-23	58034	32750A***	south of US-223	SB 1992, NB 1993
I-94	38102/13083	29508A	Albion	WB 1991, EB1992
I-94WB	82021	32147A**	Belleville	1992
I-94EB	82021	32148A	Belleville	1993
I-94	11015	29580A	Benton Harbor	1994
I-94	80023/11018	32517A	Hartford	1995
I-96	47065	28214A	Howell	1991/92
I-96	47065	28216A	Brighton	1994
I-75	58152	28352A	north I-275	1990
I-75	82191	29673A	Southgate	1991
I-75 ****	82251	30613A**	Detroit	NB 1993, SB 1994
I-69	19043	18632A**	Dewitt	1985

*JRCP reconstructed as JPCP in 2005. Poor condition caused by concrete MRD.
** Projects used cement as stabilizing material. All other projects used asphalt emulsion.

I-69 was a special project that used peastone as base aggregate and also the coarse aggregate for the concrete pavement. Therefore, this project was not included with this study performance evaluation.

*** SB US-23 contains MDOT's Aggregate Test Road.
NB US-23 includes SPS 2 SHRP project.

**** Comparison control section for 1993 European pavement study on NB I-75.

CHAPTER 3. PMS JRCP SUMMARY DATA AND DISTRESS INDEX GROWTH DEVELOPMENT

Table 3.1 summarizes project information for the JRCP projects on stabilized OGDC, including project location, design, cross section information, commercial traffic and pavement condition based on latest available pavement management system (PMS) pavement condition data for the latest year (2007). Distress index, DI, is MDOT's visual measure of a pavement's surface distress condition. Network wide, DI values are obtained every two years based on detailed visual pavement surface distress surveys. DI values start at 0 (a distress free pavement) and increase numerically as distress levels increase. A DI of 50 is the threshold value where reconstruction or major rehabilitation should be seriously considered.

As seen from Table 3.1, the latest year (2007) average project DI values for each traffic direction fall in the range of 0 to 10. This range corresponds to low severity cracking or joint deterioration. Also, the JRCP projects have maintained excellent ride quality as determined by the international roughness index (IRI) values. This property is an index of the smoothness of the longitudinal profile in the wheel-path. IRI includes a measure of joint and crack faulting. An average 2007 IRI value of 83 was obtained for all the JRCP projects. IRI values below 95 represent a good ride, while values in the range of 95 to 119 represent a fair ride. Two projects fall in the fair ride range with IRI values of 103-104 in one traffic direction, with IRI values of 90 -94 in the other traffic direction.

Previous MDOT research found that a logistic growth model describes well distress growth over time. Consequently, the results from this model are used by MDOT pavement engineers to quantify remaining service life (RSL) which is the time remaining in years for a pavement to reach a DI of 50.

It is currently not possible to accurately predict the RSL for the JRCP projects on stabilized bases due to insufficient growth in DI values versus pavement age. The low growth in pavement surface distress values and low variability is attributed to the stable and uniform support condition that the stabilized OGDC provides. DI values over time are shown in Figure 3.1 for all JRCP projects, except for NB US-23 MDOT special sections 2-5 due to insufficient pavement length (513 ft) per section.

Based on the DI results in Figure 3.1 it is probable that two JRCP projects (SB US-23, Aggregate Test Road Section B and the US-23 project South of Thompson Rd., Flint) may develop sufficient DI growth to necessitate concrete pavement repair (CPR) within their 20-year design life.

The performance of other JRCP and JPCP projects from the same time period were also assessed. The 1995 JRCP (CS 58034-32385A) on US-23 north of US-223 and two 1993 JPCP SHRP sections (260221 and 260223) on NB US-23 (CS 58034-32750A) were evaluated similar to the field testing done for the JRCP stabilized OGDC projects.

The US-23 JRCP has an unbound OGDC (3G) and the two SHRP JPCP sections have a permeable asphalt treated-base (PATB), which was a plant mix, placed hot over a dense-graded aggregate base on a clay soil subgrade without a subbase. The PATB project specification is in the Appendix (B) for reference.

Table 3.2 contains the summary project information for the JRCP project (CS 58034, JN 32385A) north of US-223 adjacent to the Aggregate Test Road. This project was constructed two years after the Aggregate Test Road sections. At the time of this investigation this pavement had developed major distress types with 98% of slabs showing mid-slab transverse cracking , some cracks had developed spalling and crack/joint faulting. The DI growth curves in Figure 3.2 show rapid distress development, with different growth rates between the two traffic directions. This project has undergone CPR in 2008. Considering that the only major difference between this project and the Aggregate Test Road sections is the OGDC, it is likely that the untreated OGDC has played a major role in distress development and that loss of joint support is the primary factor.

Table 3.1 Summary of project and design Parameters for JRCP on Stabilized OGDC.

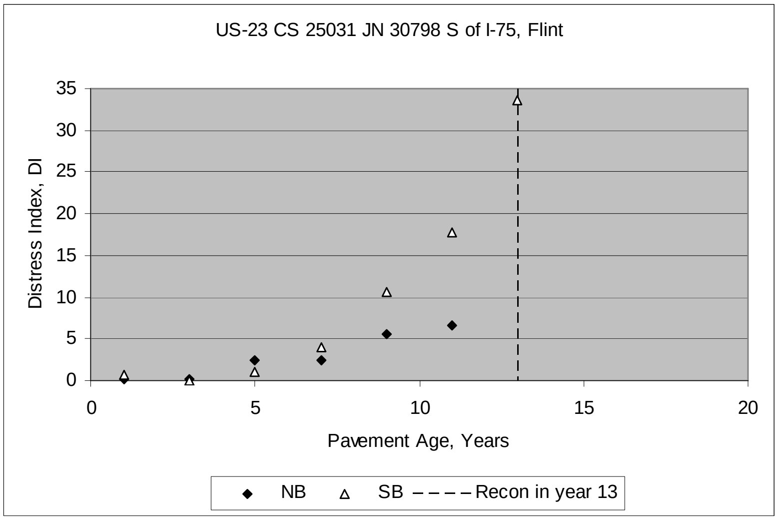
PROJECT				DESIGN PARAMETERS														CONDITION		
Route	CS	JN	General Location	Project Length miles	Year Opened	Begin CADT one direct.	2007 CADT one direct.	Slab L (ft)	T (in)	Widen Y	N	Coarse Agg. Type	Shld Type	OGDC Base	Separator/ Fabric	Drain Loc EOM	Subbase	2007 DI	2007 IRI	Remarks
US-23 NB	25031	30798A	South of I-75, Flint	6.789	1992	2500	2450	27	10.0		N	BF Slag	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	-	n/a	Recon as JPCP in 2005
US-23 SB	25031	30798A	South of I-75, Flint	6.894	1992	2500	2450	27	10.0		N	BF Slag	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	-	n/a	Recon as JPCP in 2005
US-23 NB	25031	31018A	South of Thompson Rd.,Flint	5.44	1993	2500	2450	27	10.0		N	BF Slag	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	8.9	93	
US-23 SB	25031	31018A	South of Thompson Rd., Flint	5.389	1993	2500	2450	27	10.0		N	BF Slag	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	5.8	85	
US-23 SB	58034	32750A	Agg Test Road Section A	1.089	1992	3000	3400	27	10.5		N	Dolomite (93-03)	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	n/a	93	
			Agg Test Road Section B	0.947	1992	3000	3400	27	10.5		N	Slag(82-22)	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	n/a	93	
			Agg Test Road Section C	1.231	1992	3000	3400	27	10.5		N	Gravel(30-05)	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	n/a	93	
			Agg Test Road Section D	1.231	1992	3000	3400	27	10.5		N	Dol(58-08)	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	n/a	93	
			Agg Test Road Section E	0.947	1992	3000	3400	27	10.5		N	Gravel(63-97)	Reinf Conc.	4in ATB-5G.	Agg.	2ft	Existing	n/a	93	
US-23 NB	58034	32750A	Ohio State line to North of Sterns Rd.	1.88	1993	3000	3400	27	10.5		N	Dolomite (93-03)	Reinf Conc.	4in ATB-5G.on 3in Asphalt membrane	Agg.	2ft	Existing	0.7	94	
			North of Consear Rd. to north of Labadie Creek	2.66	1993	3000	3400	27	10.5		N	Dolomite (93-03)	Reinf Conc.	4in ATB-5G.on 3in Asphalt membrane	Agg.	2ft	Existing	4.2	104	
US-23 NB	58034	32750A	North of Ohio State line	0.2	1993	3000	3400	27			N	Dolomite (93-03)	Reinf Conc.							
			Section #2 Sta 265+77 to 270+90 (513 ft)						10.5					4in ATB-5G.on 3in Asphalt membrane					n/a	
			Section #3 Sta 271+17 to 276+30 (Consear Bridge) (513 ft)						8.0					4in ATB-5G.on 3in Asphalt membrane					n/a	
			Section #4 Sta 276+30 to 281+43 (513 ft)						8.0					4in CTB-5G.on 3in Asphalt membrane					n/a	
			Section #5 Sta 281+70 to Sta 286+83 (513 ft)						10.5					4in CTB-5G.on 3in Asphalt membrane					n/a	
I-94 EB	38102	29508A	Albion	4.892	1992	2104	3650	27	11.0		N	Dolomite (93-03)	Reinf Conc.	4in ATB-5G.	Agg.	2ft	12 in. Class II	0.9	103	
I-94 WB	38102	29508A	Albion	4.887	1991	2104	3650	27	11.0		N	Dolomite (93-03)	Reinf Conc.	4in ATB-5G.	Agg.	2ft	12 in. Class II	0.5	90	
I-94 EB	82021	32148	Belleville	6.08	1993	5110	4800	27	11.0		N	Dolo (58-08)	Reinf Conc.	4in ATB-5G.	Agg.	Not Applica	10 in. existing	2.5	67	
I-94 WB	82021	32147	Belleville	5.96	1992	5110	4800	27	11.0		N	Dolo (58-08)	Reinf Conc.	4in CTB-5G.	Agg.	Not Applica	11 in. existing	3.8	69	
I-94 EB	11015	29580A	Benton Harbor	3.972	1994	4350	6850	27	11.5		N	BF Slag	Reinf Conc.	5 in ATB-5G.	Geotextile	3 ft	9 in existing	-	79	19 Full-Depth Repairs in Year 8
I-94 WB	11015	29580A	Benton Harbor	3.959	1994	4350	6850	27	11.5		N	BF Slag	Reinf Conc.	5 in ATB-5G.	Geotextile	2 ft	8 in existing	-	68	146 Full-Depth Repairs in Year 8
I-94 EB	80023	32517A	Hartford	1.336	1995	3300	4100	27	11.0	Y		Limestone (75-05)	HMA	4 in ATB-5G	Geotextile	2 ft	9 in Class II	1.7	75	
I-94 WB	80023	32517A	Hartford	3.59	1995	3300	4100	27	11.0	Y		Limestone (75-05)	HMA	4 in ATB-5G	Geotextile	3 ft	10 in Class II	2.2	63	
I-96 EB	47065	28214	Howell	5.223	1991	1980	2800	41	10.0		N	Dolomite (58-08)	Reinf Conc.	4 in ATB-5G	Geotextile	0 ft	10 in Class II	n/a	n/a	Full-Depth Repairs in 2007
I-96 WB	47065	28214	Howell	5.288	1992	1980	2800	41	10.0		N	Dolomite (58-08)	Reinf Conc.	4 in ATB-5G	Geotextile	0 ft	11 in Class II	3.1	85	Full-Depth Repairs in 2007
I-96 EB	47065	28216	Brighton	4.419	1994	2132	3400	41	10.0		N	Dolomite (58-08)	Reinf Conc.	4 in ATB-5G	Agg.	2 ft	10 in Class II	n/a	63	
I-96 WB	47065	28216	Brighton	4.477	1994	2132	3400	41	10.0		N	Dolomite (58-08)	Reinf Conc.	4 in ATB-5G	Agg.	2 ft	11 in Class II	1.8	65	
I-75 NB	58152	28352	North I-275	6.506	1990	n/a	6500	27	12.0		N	Dolomite (58-08)	Reinf Conc.	4 in ATB	Geotextile	0 ft	existing (thickne	2.7	92	inside lanes 11.0"
I-75 SB	58152	28352	North I-275	6.627	1990	n/a	6500	27	12.0		N	Dolomite (58-08)	Reinf Conc.	4 in ATB	Geotextile	0 ft	existing (thickne	n/a	89	inside lanes 11.0"
I-75 NB	82191	29673A	Southgate	4.814	1991	n/a	6500	27	11.0		N	Gravel (63-55)	Reinf Conc.	4 in ATB	exist. Agg.	0 ft	10 in Class II, m	n/a	91	Full-Depth Repairs in 2008
I-75 SB	82191	29673A	Southgate	4.561	1991	n/a	6500	27	11.0		N	Gravel (63-55) & Slag (63-55)	Reinf Conc.	4 in ATB	exist. Agg.	0 ft	10 in Class II, m	n/a	76	Full-Depth Repairs in 2008
I-75 NB	82251	30613A	Detroit	1.111	1993	6000	5500	41	11.0	Y		Limestone(71-47)	Reinf Conc	4 in CTB	Geotextile	2 ft	Existing	0.9	88	
I-75 SB	82251	30613A	Detroit	2.091	1994	6000	5500	27	11.0	Y		Limestone(71-47)	Reinf Conc	4 in ATB	Geotextile	2 ft	Existing	0.7	69	

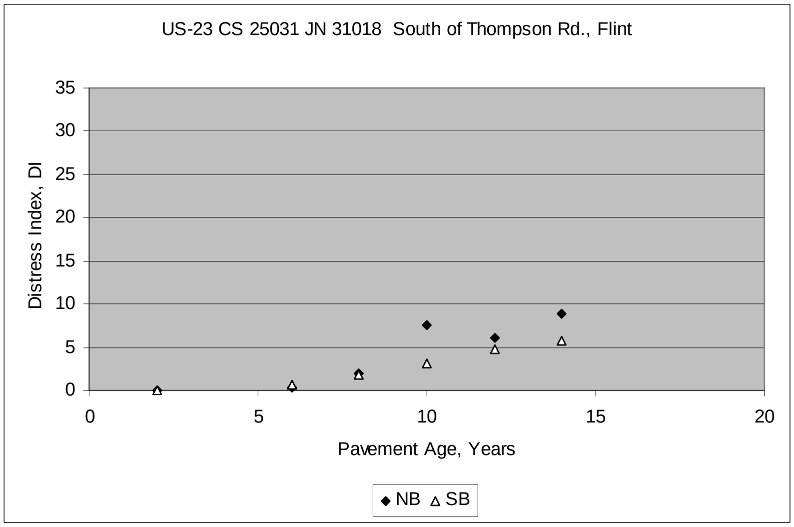
Table 3.2 Summary of project and design parameters for a 1995 JRCP project (CS 58034 JN 32385A) on US-23 north of US-223 on unbound OGDC (3G).

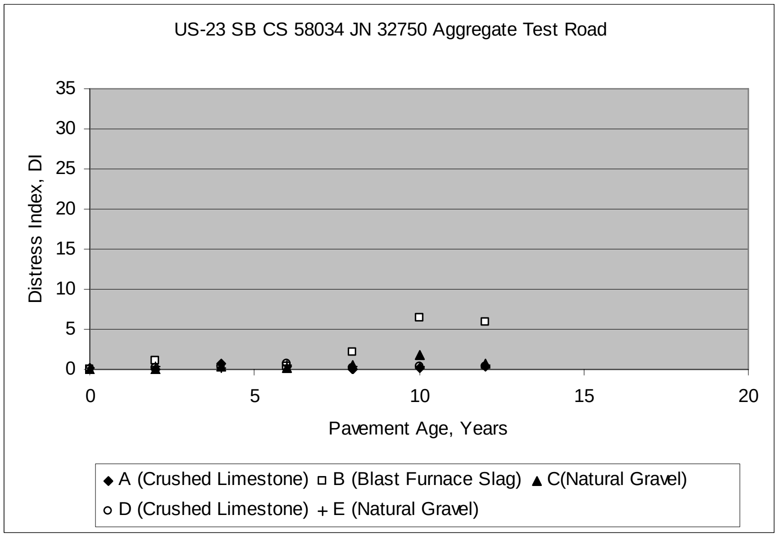
PROJECT								DESIGN PARAMETERS										CONDITION		
Route	CS	JN	General Location	Project Length miles	Year Opened	Begin CADT one direct	2007 CADT one direct	Slab L (ft)	T (in)	Widen Y	N	Coarse Agg. Type	Shld Type	OGDC Base	Separator/ Fabric	Drain Loc EOM	Subbase	2007 DI	2007 IRI	Remarks
US-23 SB	58034	32385A	US-23 north of 223	4.01	1995	3000	3400	27	10.5		N	Dolomite (58-03)	Reinf Con	4 in 3G-OGDC	Agg.	2 ft	Existing	n/a	n/a	CPR in 2008
US-23 NB	58034	32385A	US-23 north of 223	4.01	1995	3000	3400	27	10.5		N	Dolomite (58-03)	Reinf Con	4 in 3G-OGDC	Agg.	2 ft	Existing	17	n/a	CPR in 2008

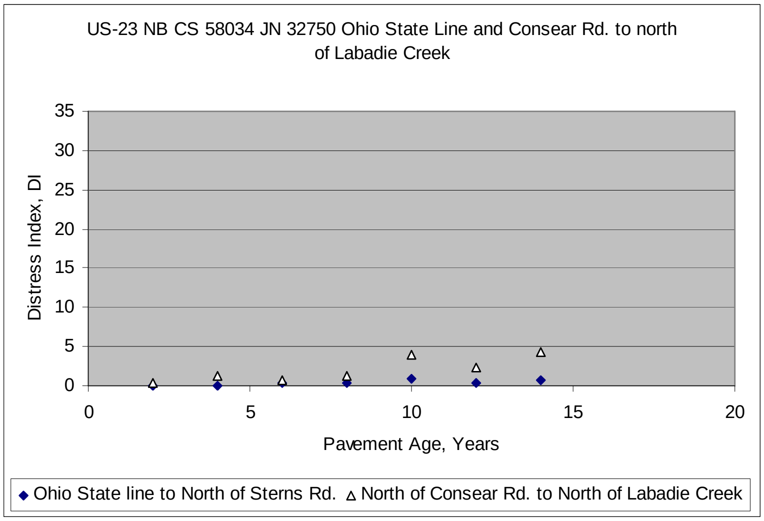
Table 3.3 Summary of project and design parameters for two 1993 JPCP SHRP sections (260221 and 260223) on NB US-23 (CS 58034-32750A).

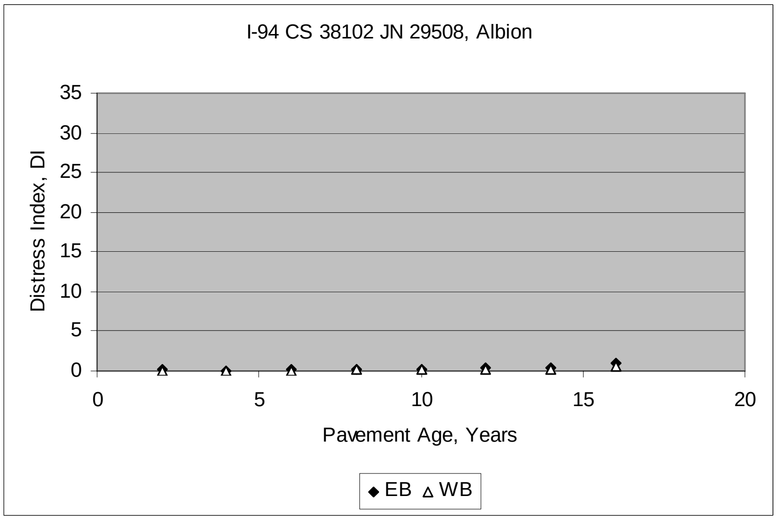
PROJECT								DESIGN PARAMETERS											CONDITION		
Route	CS	JN	General Location	Project Length miles	Year Opened	Begin CADT one direct	2007 CADT one direct	Slab L (ft)	T (in)	Widen Y	N	Concrete	Coarse Agg. Type	Shld Type	OGDC Base	Separator/ Fabric	Drain Loc EOM	Subbase	2007 DI	2007 IRI	Remarks
US-23 NB	58034 (SHRP 260221)	K21	South of Consear Rd. sta. 231+30 to Sta. 237+30	0.11 (600 ft)	1993	3000	3400	15	8.0	Y		Grade 550 (SHRP)	France Stone Silica (93-03)	Asphalt	4in ATB (Plant Mix)-6A.	Dense-graded Agg.	3ft		n/a	n/a	
US-23 NB	58034 (SHRP 260223)	K23	North of Consear Rd. sta. 304+70 to 310+70	0.11 (600 ft)	1993	3000	3400	15	11.0		N	Grade 550 (SHRP)	France Stone Silica (93-03)	Asphalt	4in ATB (Plant Mix)-6A.	Dense-graded Agg.	3ft		n/a	n/a	

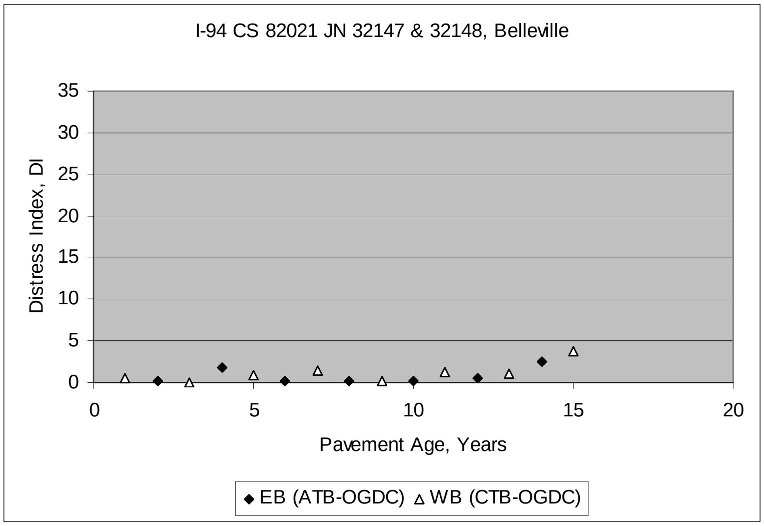

US-23 CS 25031 JN 30798 S of I-75, Flint


US-23 CS 25031 JN 31018 South of Thompson Rd., Flint


US-23 SB CS 58034 JN 32750 Aggregate Test Road


US-23 NB CS 58034 JN 32750 Ohio State Line and Consear Rd. to north of Labadie Creek


I-94 CS 38102 JN 29508, Albion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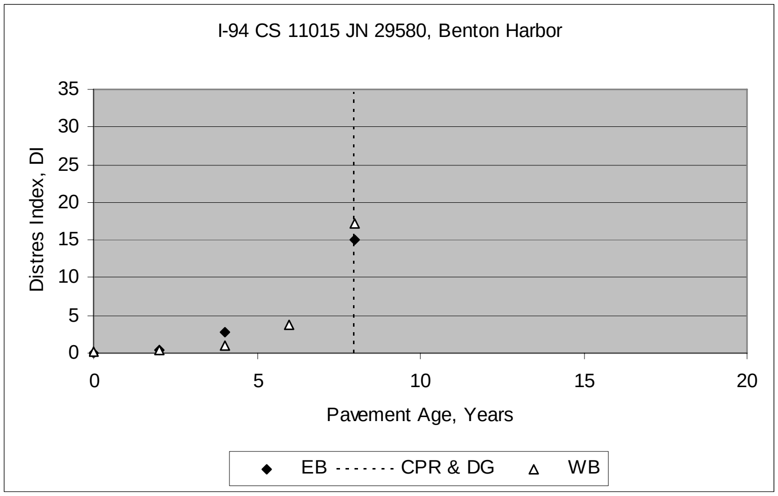
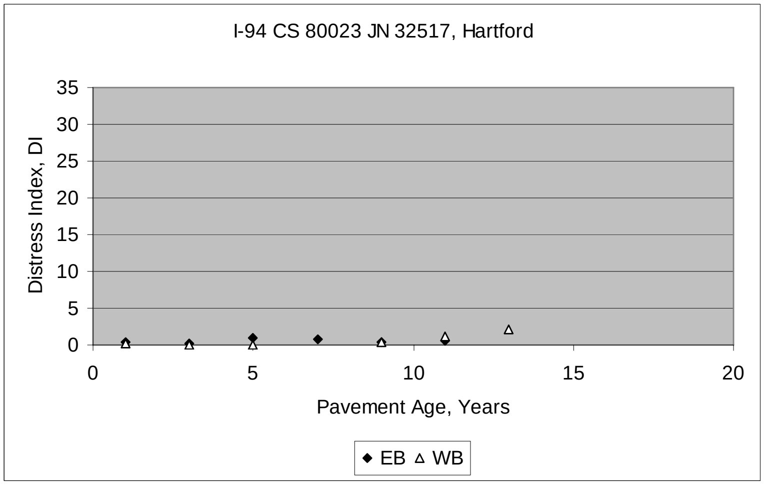

I-94 CS 11015 JN 29580, Benton Harbor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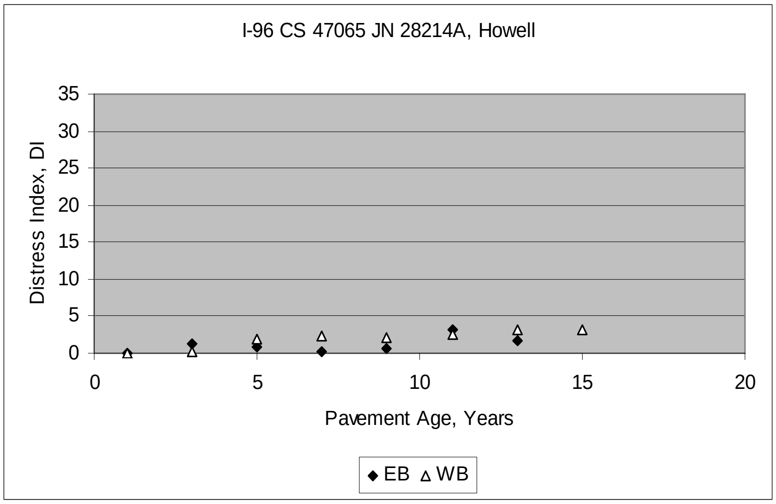
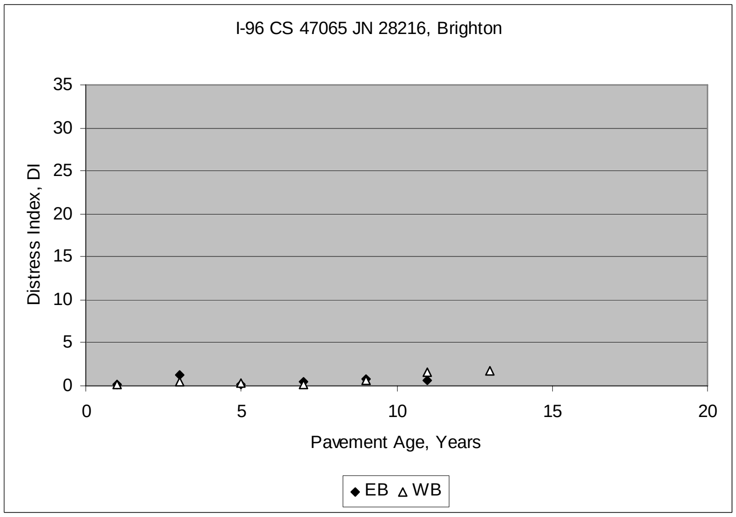

I-96 CS 47065 JN 28214A, Howell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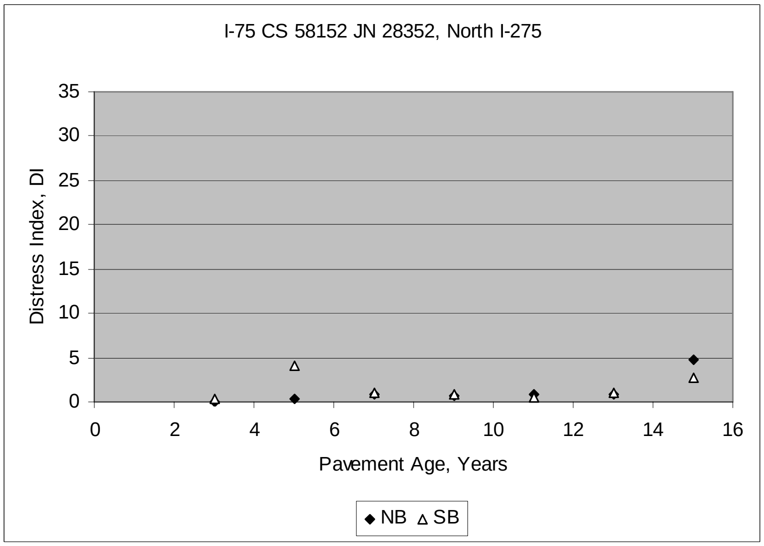
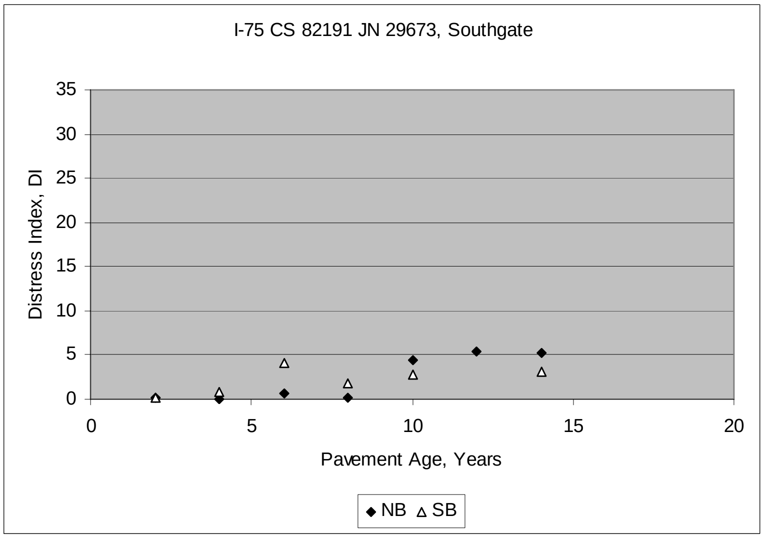

I-75 CS 58152 JN 28352, North I-275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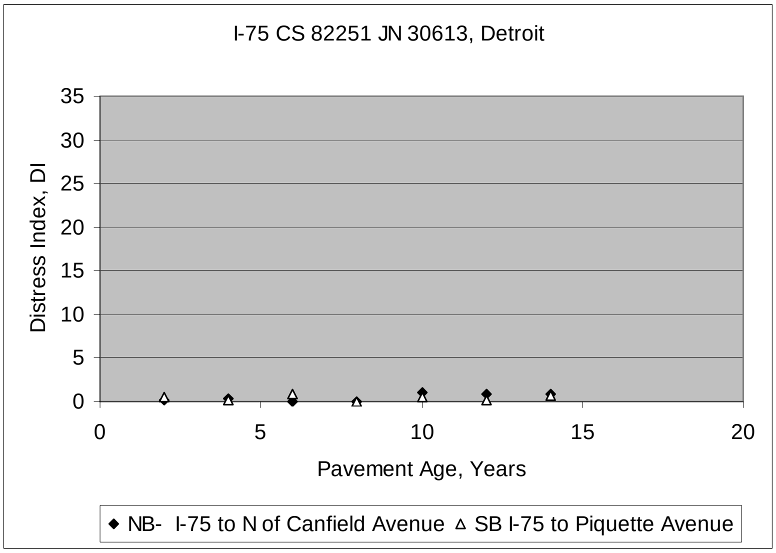


Figure 3.1 Distress development for all JRCP projects on stabilized OGDC

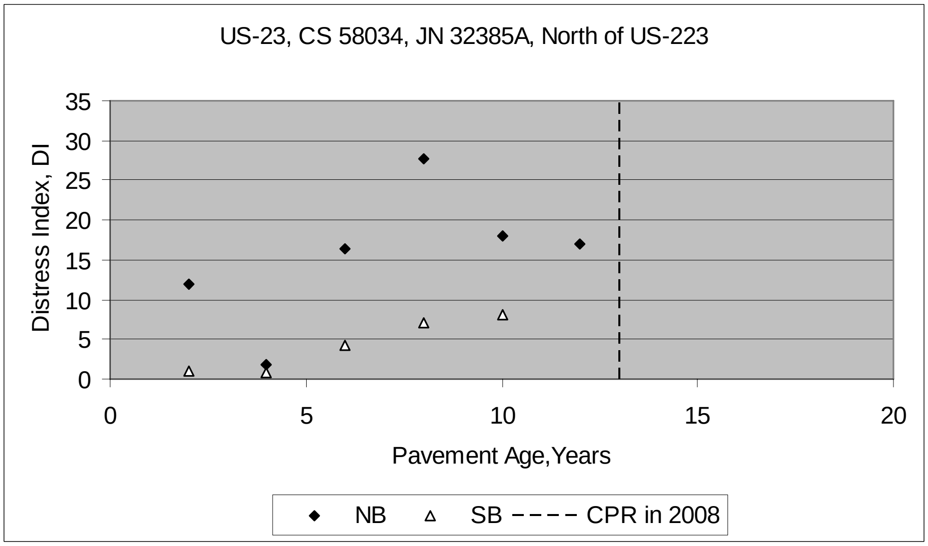


Figure 3.2 Distress development for the JRCP project (CS 58034 JN 32385A) on US-23 north of US-223 on unbound OGDC (3G).

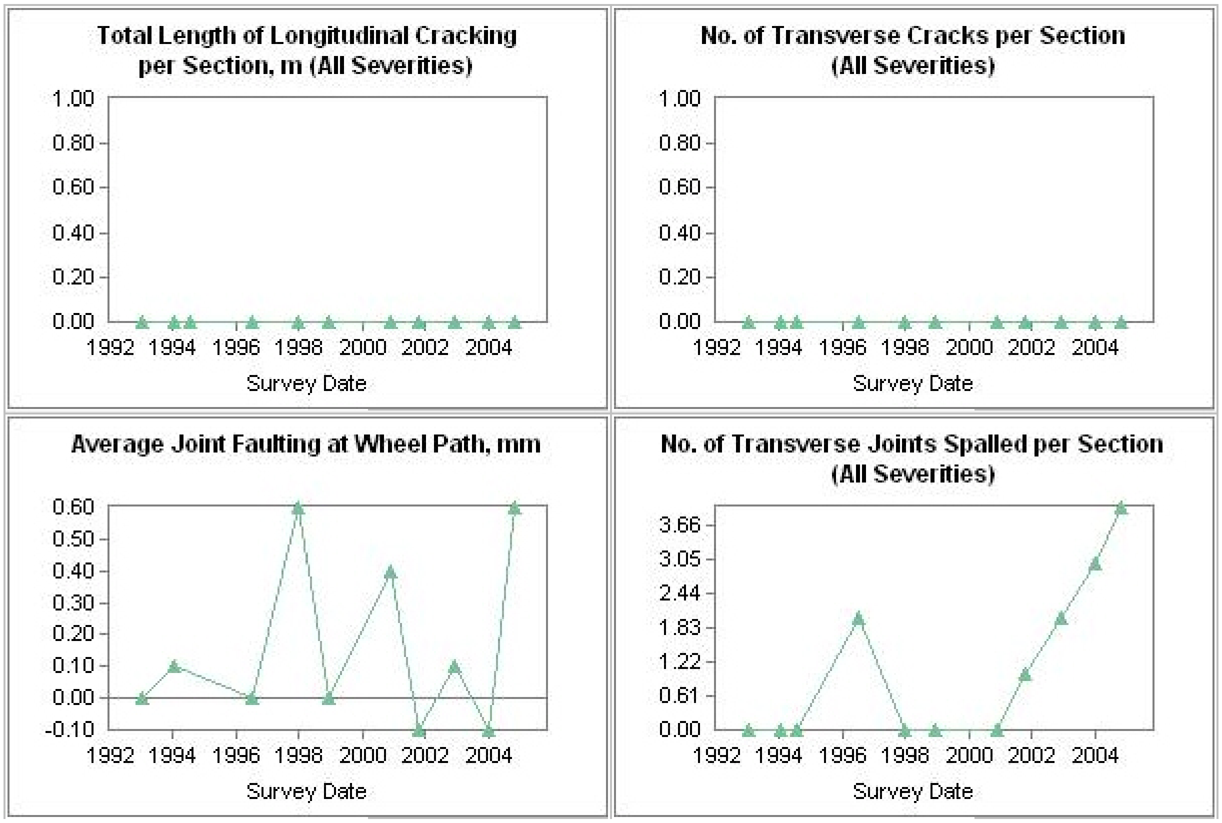


Figure 3.3 LTPP pavement performance trends for SHRP JPCP section 260221 on NB US-23 (CS 58034-32750A)

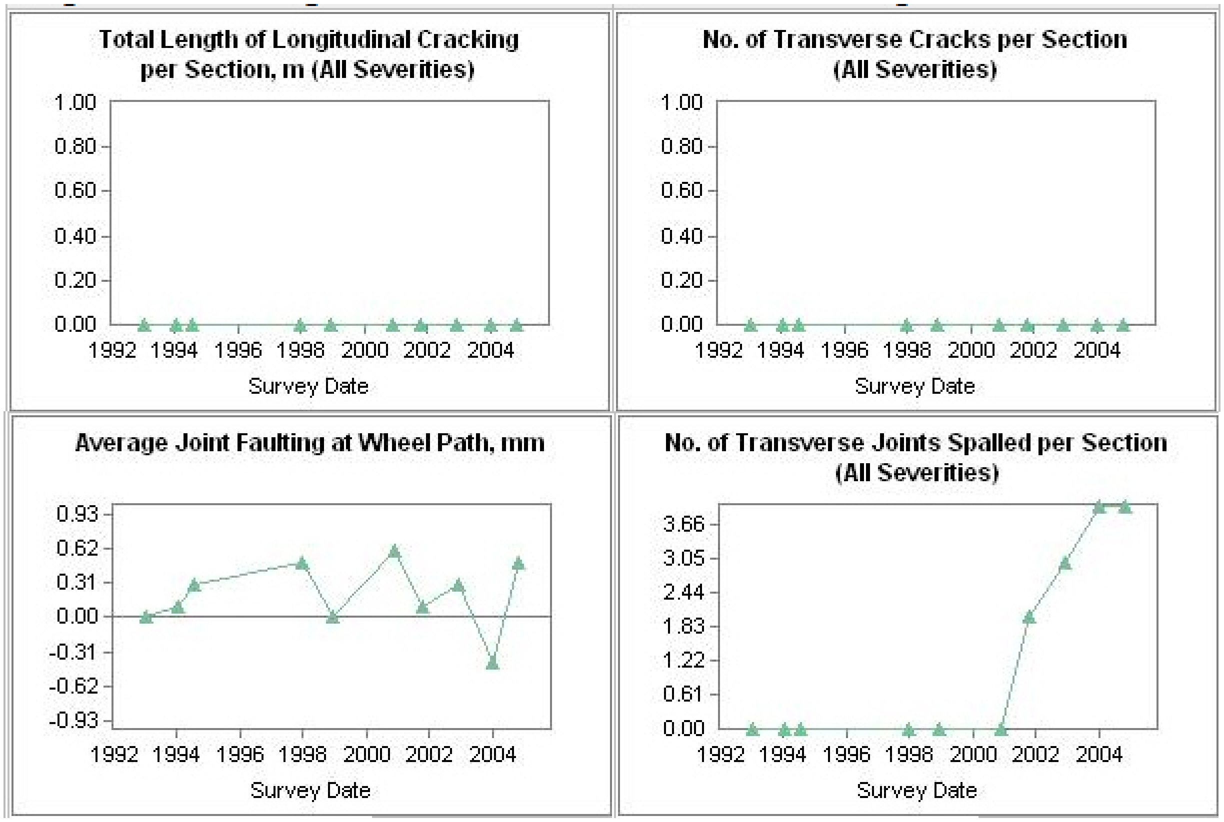


Figure 3.4 LTPP pavement distress development for SHRP JPCP section 260223 on NB US-23 (CS 58034-32750A)

The LTPP database values in Figures 3.3 and 3.4, show pavement performance trends (www.ltppproducts.com/DataPave/visualization/PerformanceTrends.asp) for the two SHRP JPCP sections constructed on a permeable asphalt treated-base (PATB). This suggests that loss of joint support is not a factor. Joint spalling however is developing at a rapid rate after 8 years. Joint spalling can be materials related distress (MRD) associated with frost durability. According to the LTPP database, the two JPCP sections have not developed any fatigue-related transverse cracking despite major differences in design. SHRP section 260221 is a thin slab (8 inch slab thickness) and 2 ft widened lane, while SHRP section 260223 is a 11 inch thick slab with standard 12 ft lane width. Table 3.3 summarizes project information for these two JPCP sections. The pavement cross section plans are shown in the Appendix (C & D).

It appears that the PATB has been a key factor in achieving excellent long-term performance. To further determine the role of the PATB on pavement performance these two SHRP sections were included in the field investigation.

CHAPTER 4. MAJOR FINDINGS FROM FIELD INVESTIGATION

The main objectives with this field investigation were (1) to determine the common major factor(s) for the excellent performance of the JRCP projects on stabilized OGDC as evident from the PMS/DI values presented and discussed in Chapter 3, and (2) whether these findings extend to JPCP on treated OGDC. The field investigation included visual distress surveys, coring, slab deflection measurements from FWD, and for some projects, surface profiling using the Dipstick profilometer.

4.1 Joint Load Transfer Effectiveness and Dowel-Bar Looseness.

For most projects the average FWD test section joint load transfer effectiveness, LTE, was found to be excellent for the outer wheel-path (OWP) as concluded from results in Figure 4.1 a and b. These values ranged between the mid seventies to the upper eighties. The two exceptions are Section B of the Aggregate Test Road on SB US-23 and the Michigan Sections 2-5 on NB US-23. The LTE values for the outer joint corner are lower due to base erosion effect.

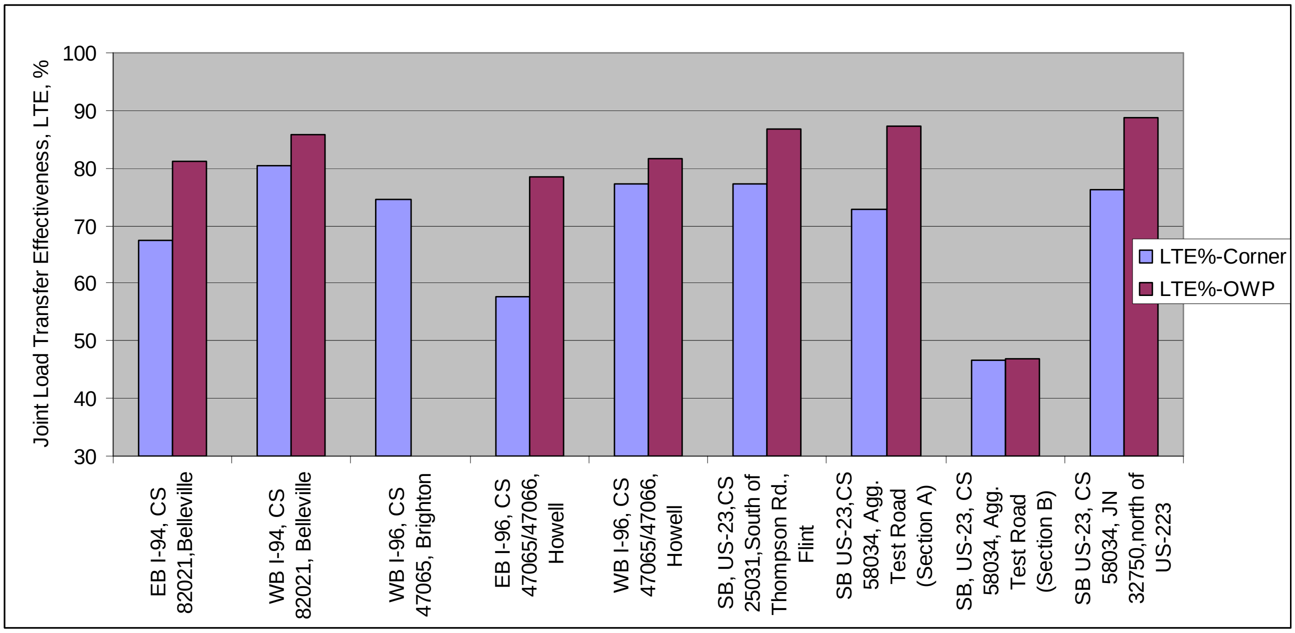
LTE was calculated using the PCA (Portland Cement Association) equation:
LTE (%) = 2D1/(D0+D1)*100
where, D0 is the slab deflection underneath the load plate before the joint (BJT) and D1 is the slab deflection on the unloaded joint, 12 inches ahead of the D0 load.

The test section average D0 and D1 values used to calculate LTE are shown in Figure 4.2a and b, along with mid-slab D0 values, where available. These curves illustrate that the magnitudes of joint or mid-slab D0 deflection are not good indicators of LTE. The difference in D0 and D1 values are good indicators of dowel-bar looseness and the joint damage at the outer corner from base erosion. Time-history curves, which are plots of increasing D0 and D1 values for increasing load for the D0 sensor, illustrate that dowel-bar looseness is the prime reason why LTE is reduced. Time-history curves are shown for the three sections on SB US-23 in Figure 4.3a, b and c. These curves provide a more detailed assessment of joint deflection behavior. For section A of the Aggregate Test Road, the D0 and D1 values are very close, and dowel-bar looseness is insignificant. Section B on the other hand has lost nearly all dowel-bar contribution to joint load transfer capability as a result of dowel-bar looseness. Dowel-bar looseness is the gap that has developed between the dowel and the concrete as a result of a degraded concrete-dowel-bar interface. This gap is conceptualized in Figure 4.5. A majority of the remaining joint load transfer capability for section B is mainly due to the elastic deflection-bowl from the foundation associated with joint loading. The JRCP section on untreated OGDC has maintained high load transfer effectiveness of the dowels despite much greater deflection values.

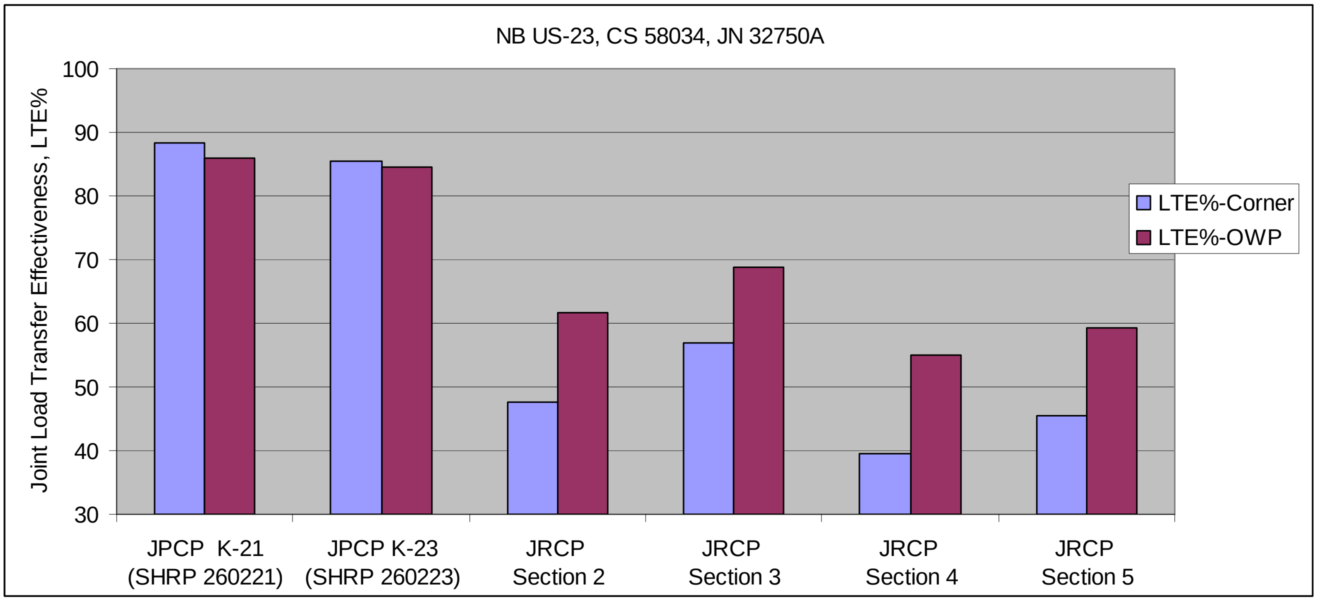
As coarse aggregate type is the only difference between Aggregate Test Road sections A and B it is likely that the cause for dowel-bar looseness in section B is due to a degraded concrete-dowel-bar interface.

Coring of the four Michigan Test Sections 2-5 showed that base water was not draining well beyond the outer slab edge, especially pronounced for Section 4. The impermeable separator layer consisting of a 3 inch bituminous membrane has likely trapped water in the CTB/OGDC, which has accelerated joint load transfer deterioration.

The two JPCP SHRP sections of same age (1993) and location as the Michigan Test Section have maintained excellent load transfer (>85%) without major differences in LTE results between the outer joint corner and OWP, suggesting that the plant mix of PATB has not developed significant erosion/degradation. Despite large differences in slab thickness (8 in. and 11 in.) the two SHRP sections have similar OWP deflections and LTE. The time-history curves for corner loading are identical as seen from Figure 4.4a and b.

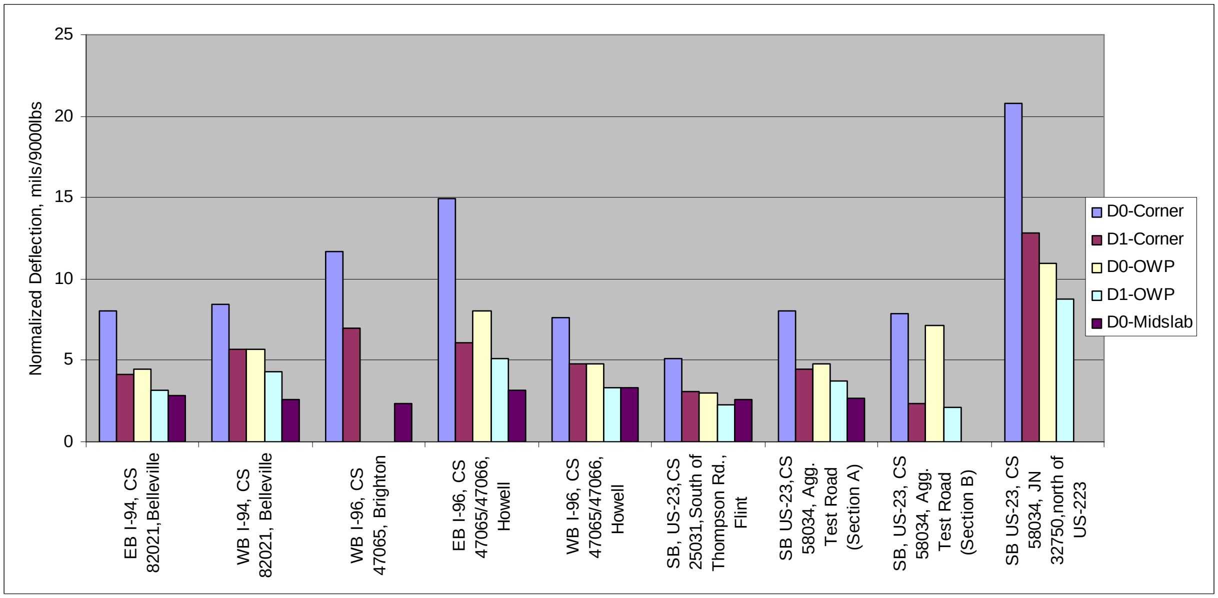


(a)

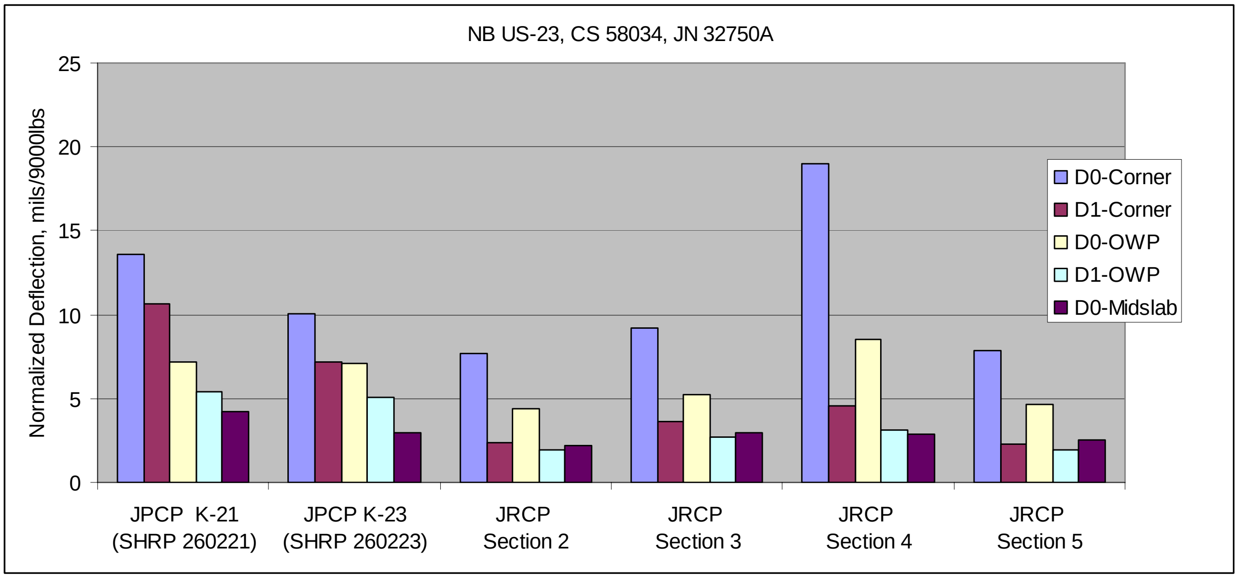


(b)

Figure 4.1 (a, b). Joint load transfer effectiveness.

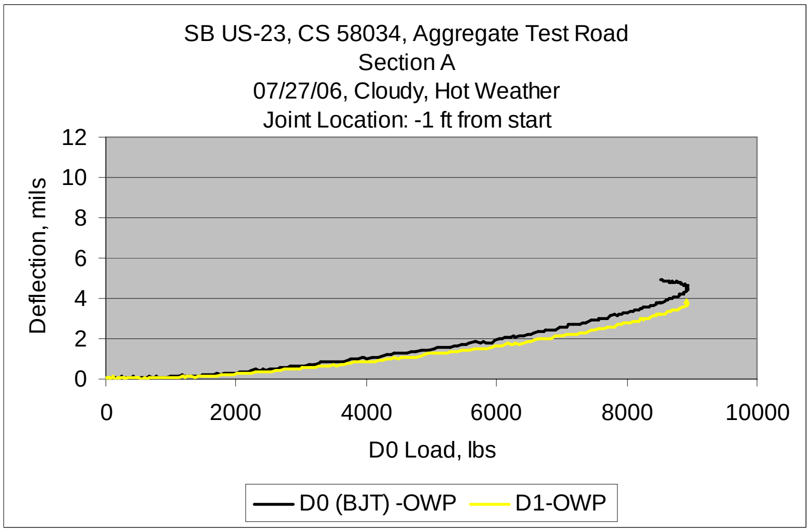


(a)

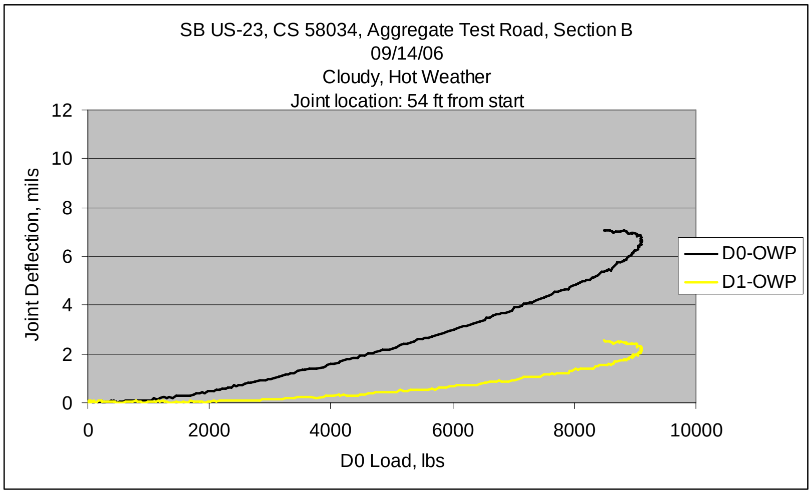


(b)

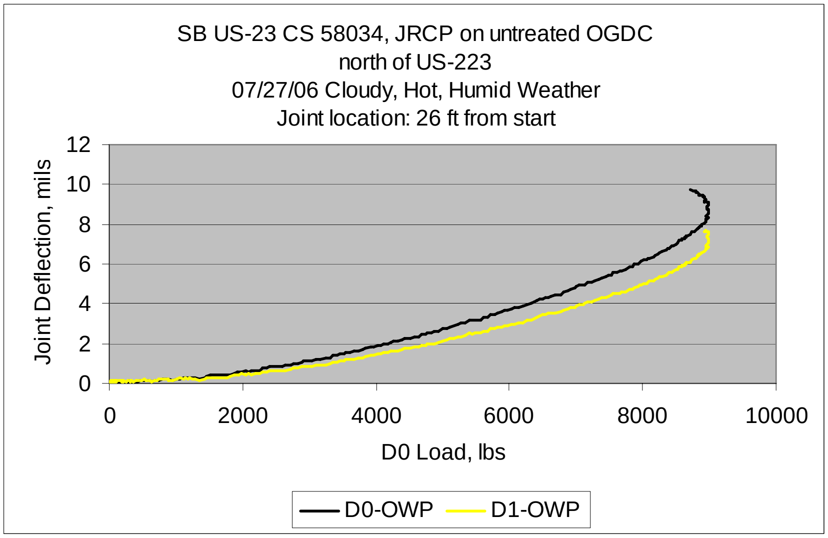
Figure 4.2 a and b. Normalized slab deflection



(a)

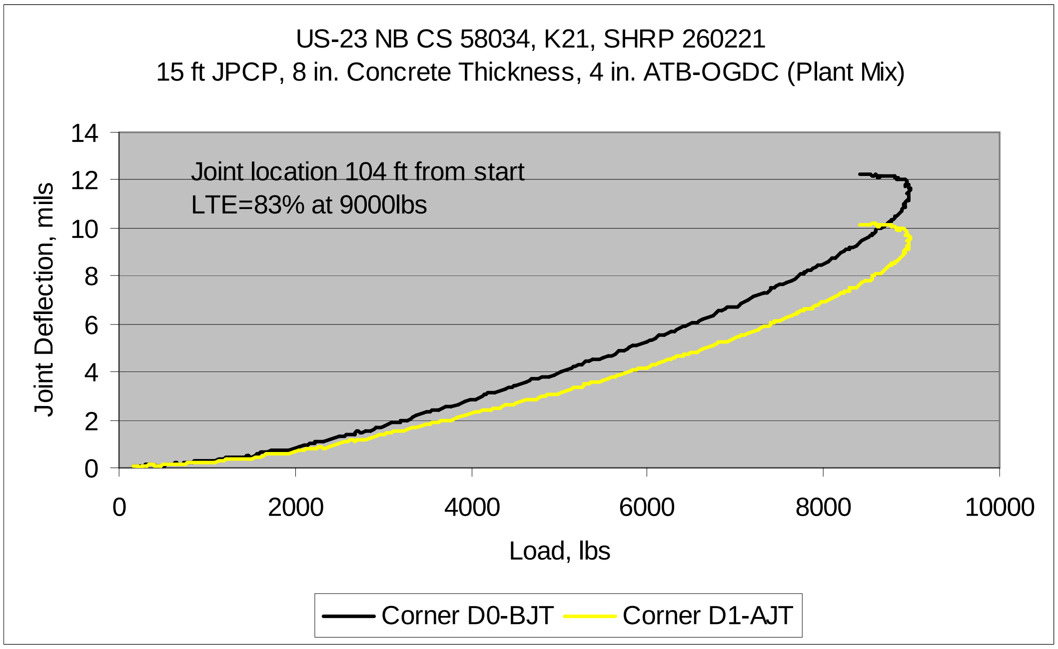


(b)

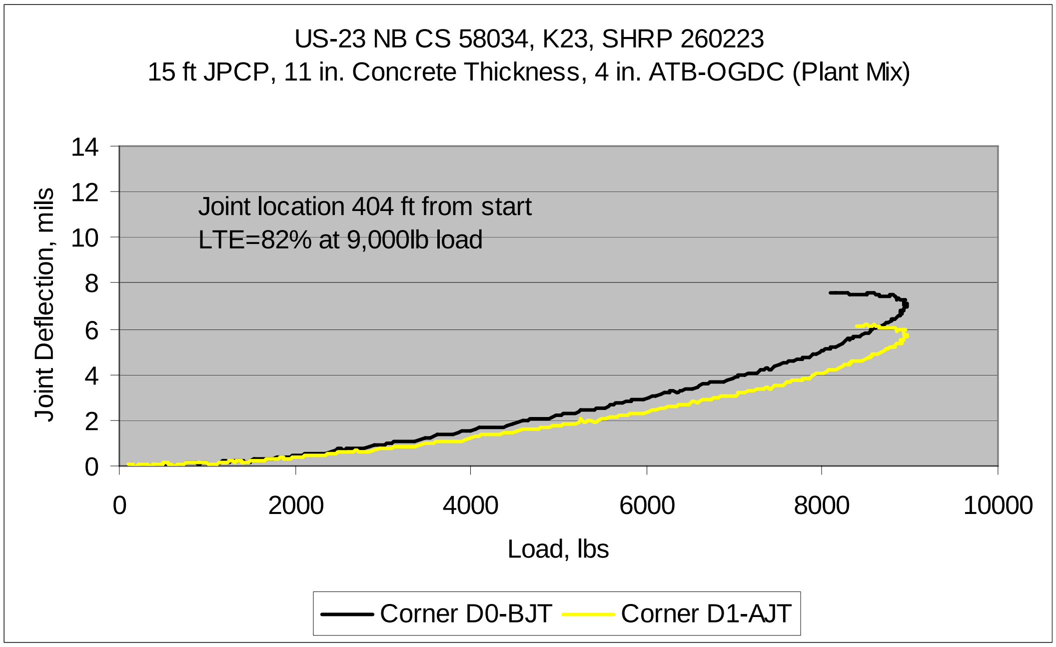


(c)

Figure 4.3 a, b, c. Time-history curves for the Aggregate Test Road Sections A (a), B (b) and the JRCP section on untreated OGDC north of US-223 (c).



(a)



(b)

Figure 4.4 a., b. Time-history curves for the JPCP SHRP sections.

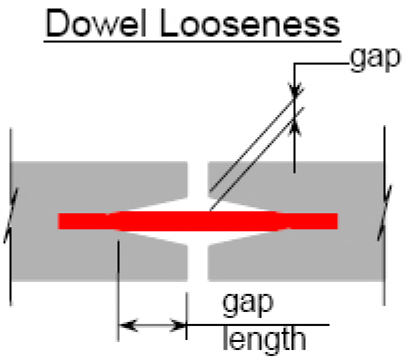


Figure 4.5 Conceptual illustration of dowel-bar looseness gap (Bill Davids, University of Maine, "EverFE Workshop".)

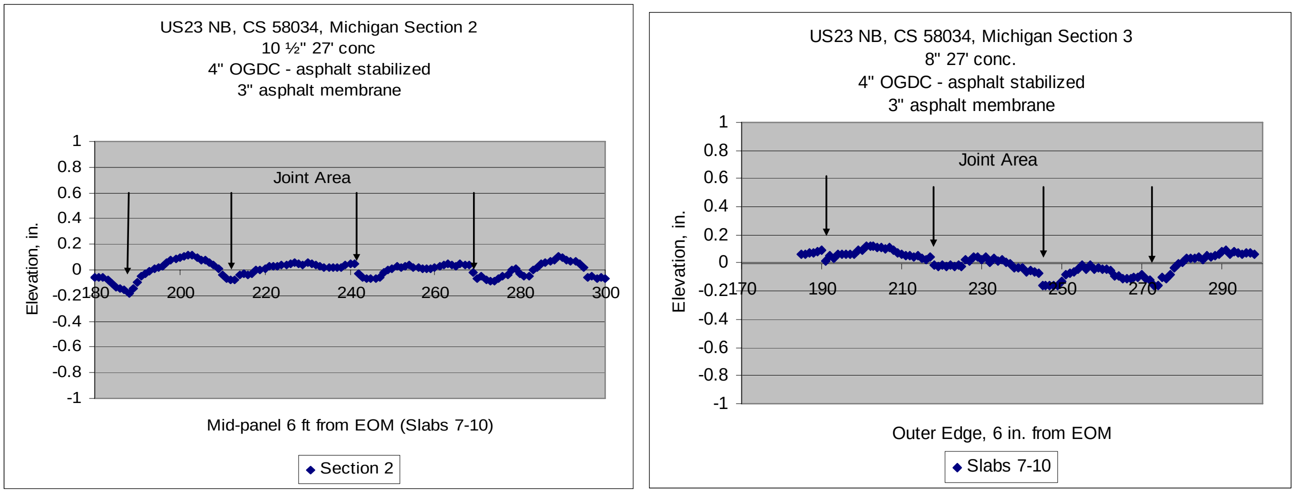
4.2 Top-Down Mid-slab Cracking due to Base Erosion/Joint Settlement

Two JRCP projects on treated OGDC were found to be in the beginning stages of mid-slab transverse cracking caused by joint settlement. The close-up photo (6a) of a mid-slab core in Figure 6b for Michigan Test Section 2 illustrates that top-down cracking is developing. Top-down cracking is normally associated with loss of joint support from an upward curl/warp condition. In this case, a permanent concave downward slab condition exists as seen from Dipstick Profilometer results in Figure 4.7. The magnitude is much larger than any curl/warp condition, and is due to joint settlement and base erosion. The joint settlement causes opposite slab rotation between the mid-slab and each transverse joint. Joint settlement and associated slab downward bending over time with a magnitude of 0.1 in. to 0.2 in. is promoting top-down mid-slab cracking.

(a)

(b)

Figure 4.6 a, b. Photograph is from Michigan Section 2, NB US-23.



(a) **(b)**

Figure 4.7 Joint settlement for JRCP Michigan Sections 2 and 3, NB US-23.

4.3 Materials Related Joint Spalling.

Although a detailed evaluation of materials related distress (MRD) factors were beyond the scope of this study, they affect pavement performance and ultimately can be the weakest link. Although the two SHRP test sections were found to have excellent structural performance (high joint load transfer effectiveness), MRD is developing at the joints. The hour-glass type joint spalling as seen in Figure 4.8 is reminiscent of salt scaling deterioration. The LTPP data presented in Figure 3.3 and 3.4 show that joint spalling is developing at a rapid rate after year 8.

a. b.

Figure 4.8 Joint spalling for test sections SHRP 260221 (a) and 260223 (b).

CHAPTER 5. MAJOR CONCLUSIONS

Starting in 1990 MDOT began using recycled crushed concrete as OGDC when the existing concrete pavement was reconstructed. The crushed aggregate was coated mostly with asphalt to prevent any leaching concrete residue from clogging the drainage layer or the internal drainage system. A secondary benefit was to provide stability to the aggregate matrix, which was a gap-graded gradation (5G) used to enhance drainage.

This study was a joint MDOT-UM investigation project to determine why these JRCP projects with stabilized OGDC have shown superior performance. The objective was to find any ties to the OGDC stabilization, and whether those findings are transferable to current JPCP designs to benefit their long-term performance. The study also included two JPCP projects (SHRP 260221 and 260223) on permeable asphalt-treated base (PATB) located on NB US-23 just north of the Ohio State line and one JRCP project with untreated OGDC just north of US-223, adjacent to MDOT's Aggregate Test Road on SB US-23 in Monroe County.

The major conclusions from this study are:

- Excellent long-term (>10 years) dowel-bar load transfer effectiveness was common. Pavement distress index curves showed little or no distress development with no upward trend. This is directly attributed to a stable and uniform base support. Excellent long-term joint load transfer effectiveness (>85%) was found as well for the two JPCP SHRP test sections.

- A key factor in achieving excellent long-term performance is controlling base erosion and joint settlement by providing an adequate drainage system. In some cases, extensive base erosion and joint settlement of 0.10-0.2 inches from inadequate subsurface drainage lead to ineffective dowel-bar load transfer effectiveness and mid-slab, top-down cracking.

- Two JPCP SHRP projects (260221 and 260223), constructed in 1993 using a plant mix of permeable asphalt treated (PATB) OGDC, were found to have excellent joint load transfer effectiveness (>85%) at a pavement age of 14 years. However, the LTPP database shows joint spalling is developing at a rapid rate since 2001 most likely from a concrete durability problem.

- One of the two sections investigated on the Aggregate Test Road on SB US-23 (Section B) has developed extensive dowel-bar looseness and associated loss of joint load transfer effectiveness after 13 years. This was concluded from FWD time-history measurements. Section B has also developed extensive mid-slab cracking in 98% of the panels, while about 4% of the panels in Section A were found to have mid-panel cracking. Given that the only difference between these two test sections is the concrete coarse aggregate, it is concluded that the concrete bearing resistance around the dowels for section B is a factor, and that this concrete is more crack sensitive than the concrete in Section A.

CHAPTER 6. RECOMMENDATIONS

- In view of the varied performance that MDOT has experienced with JRCP/JPCP on untreated OGDC it is therefore recommended that MDOT use stabilized OGDC as the standard base. The incorporation of crushed concrete pavement into the base further improves long-term sustainability. However, the full, long-term benefits of using a stabilized OGDC are contingent on a maintaining a well-draining pavement system.

- Current pavement performance measurements (cracking, faulting, IRI) do not capture adequately the joint settlement and base erosion. It is therefore recommended that MDOT incorporate FWD and surface profiling as part of the Department's routine pavement management data collection activities. These data are vital to foresee impending erosion or other support deficiencies with the underlying OGDC/PATB base.

APPENDIX

Appendix A: Special Provisions for Open-Graded Drainage Course, Stabilized, 4-inch In Place

SP3.01(C)

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION
FOR
OPEN-GRADED DRAINAGE COURSE,
STABILIZED, 4-INCH IN PLACE

M&T:DLS 1 of 3 01/15/92

a. **Description.**-This work shall consist of furnishing and placing an optional asphalt or portland cement stabilized (coated) aggregate on a prepared base/subbase in accordance with the details shown on the plans and as specified in Sections 2.11, 3.01, 7.01, 7.10, and 8.02 of the 1990 Standard Specifications with the exceptions and additions specified herein.

b. **Materials.**-The materials shall meet the requirements specified in the Section of the 1990 Standard Specifications designated and as specified herein:

Open-Graded Drainage Course (OGDC) Aggregate 5G	8.02
Asphalt Cement, Penetration Grade 85-100 or Viscosity Grade AC-10	8.04
Asphalt Emulsion, MS-2h or MS-2a	8.04
Portland Cement, Types I, IA, IP, IP-A	8.01
Water	8.11
Pozzolanic Admixtures	8.24

Open-Graded Drainage Course (OGDC) Aggregate 5G shall be obtained only from crushed portland cement concrete from this project. If there is not sufficient pavement quantities to complete the project, a 5G aggregate may be used to produce OGDC that meets the requirements of Section 8.02.

c. **Mix Preparation.**-The Contractor may select to coat the open-graded aggregate with either asphalt or portland cement as specified herein, as an option. Both types of coating can be used on the same project.

With either coating the Engineer may require the Contractor to construct a test strip of sufficient length to demonstrate that the mix proportions are acceptable prior to full production. If the test strip is required, it shall be constructed prior to any normal production. The following proportions for coating with cement are given as information.

1. **Cement.**-The approximate proportions to provide one cubic yard of cement treated open-graded aggregates are as follows:

Aggregate, 5G	- 27 x (dry rodded unit weight of aggregate, lb/ft^3), lb
Portland cement*	- 190 lb (approximately 6 percent by weight of aggregate)
Water (net)**	- 90 lb

* Pozzolanic admixture (fly ash) may be substituted for portland cement on a pound-for-pound basis, up to 15 percent by weight of cement. No fly ash substitution shall be made if the cement is a Type IP or IP-A portland pozzolan cement.

** Net water shall include any surface moisture on the 5G aggregate (total moisture less absorbed moisture) plus water added at the mixer.

The Contractor shall adjust the amount of cement and water depending on the characteristics of the aggregate resulting from the crushing operation, to provide a solid homogeneous mixture that will be stable after hardening in place.

The cement treated OGDC shall be mixed and transported according to applicable provisions of Section 7.01 of the 1990 Standard Specifications.

With the cement coating, 6-inch diameter underdrain pipe will be required.

2. **Asphalt.**-The Contractor may select either an asphalt emulsion or asphalt cement to stabilize the open-graded aggregate. When an asphalt cement or an MS-2a emulsion is used, the combined mixture shall be produced by plant-mixing. When an MS-2h emulsion is used, the mixture can be produced using a pug mill.

   The amount of asphalt emulsion or asphalt cement to use as a stabilizer will be dependent on the actual gradation of the 5G aggregate produced from the crushing operation. The relative proportions of fine and coarse size aggregate and the particle shapes will determine the total surface area and void content of the aggregate mass. From experience the required asphalt content should be a minimum 3.0% (after water loss from the emulsion) by weight of dry aggregate to provide sufficient stability and surface coverage of the particles. It shall be the Contractor's responsibility to use sufficient asphalt to coat the surface area of the aggregate.

d. Construction Methods.-The base/subbase shall be prepared in accordance with Section 2.11 or 3.01, whichever is applicable, prior to the placement of the OGDC. The plans will indicate the type of separation treatment for the OGDC or any base/subbase preparation work that will need to be performed prior to placement of the OGDC.

The cement stabilized OGDC shall be placed in a single layer by a spreader, auto grader or paver that is equipped with a vibrating screed. Internal vibration of the mixture is not permitted.

The asphalt stabilized OGDC shall be placed in a single layer using a machine spreader while the mixture is still workable and pliable. Two complete rollings with a steel drum roller are required immediately after placement. A complete rolling is down and back in the same path. The roller shall weigh a nominal 1.2 tons/ft. of total drum length, which is the weight of a 5-foot wide, 12 ton tandem steel-drum roller. The Engineer shall determine if an additional final rolling is needed after the OGDC is trimmed to grade.

The surface of either OGDC material shall be finished to the specified grade and cross-section within a tolerance of ±1/2 inch. The finished surface shall be smooth and uniform in appearance, and be free of holes, depressions, ruts, and ridges. The layer of OGDC should be solid and stable and be capable of supporting the paving equipment without crushing or settlement.

If a cement treatment is used, the Contractor shall be responsible for monitoring weather conditions and to provide any curing that may become necessary to insure against excessive water loss from the mixture during periods of hot, cry and windy weather. The Contractor shall also be responsible for preventing the fresh cement coating from washing off the aggregate from any rainfall.

No vehicle traffic or construction equipment shall be allowed to travel on the OGDC, whether cement or asphalt stabilized, except to place the subsequent concrete pavement. Any areas that become damaged or contaminated with fines from traffic or the Contractor's work operation shall be replaced or repaired to the Engineer's satisfaction, at no cost to the Department.

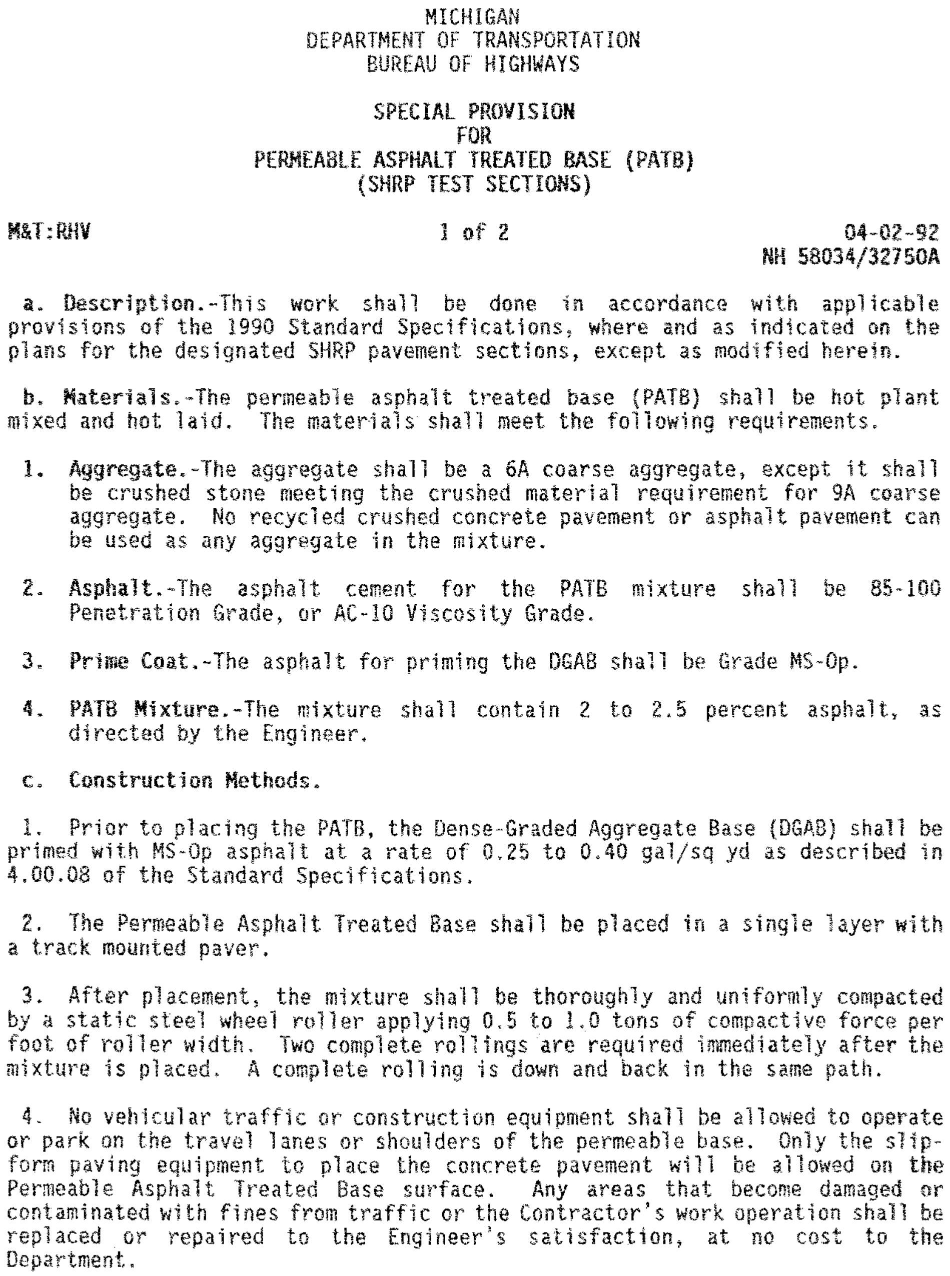
e. **Testing and Acceptance.**-The 5G aggregate will be sampled, tested and approved prior to coating. The asphalt content of the OGDC mixture will be verified at the discretion of the Engineer after mixing is completed and prior to placement. Any material that does not conform to the specifications shall be removed and replaced with acceptable material at the Contractor's expense.

f. **Measurement and Payment.**-The completed work as measured for OPEN-GRADED DRAINAGE COURSE, STABILIZED, 4-INCH IN PLACE will be paid for at the contract unit price for the following contract item (pay item).

Pay Item	Pay Unit
Open-Graded Drainage Course, Stabilized, 4-Inch In Place	Square Yard

Open-Graded Drainage Course Stabilized, 4-inch, In Place will be measured by area in square yards in place in accordance with the methods specified for measuring Aggregate Base Under Concrete in Subsection 3.01.10 of the 1990 Standard Specifications. Payment for the item Open-Graded Drainage Course, Stabilized, 4-Inch In Place includes payment for furnishing the crushed aggregate, coating materials, mixing with portland cement or asphalt (cement or emulsion), placing, spreading, shaping, compacting, and maintaining the OGDC, plus the difference in cost between 6-inch and 4-inch pipe when the cement coating option is selected. With either coating option, the pay item OPEN-GRADED UNDERDRAIN PIPE, 4 inch will be used in accordance with Subsection 6.02.10 of the 1990 Standard Specifications.

APPENDIX B: Special Provision for Permeable Asphalt Treated Base (PATB) (SHRP Test Sections)



MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION
FOR
PERMEABLE ASPHALT TREATED BASE (PATB)
(SHRP TEST SECTIONS)

M&T:RHV 1 of 2 04-02-92
NH 58034/32750A

a. **Description.**-This work shall be done in accordance with applicable provisions of the 1990 Standard Specifications, where and as indicated on the plans for the designated SHRP pavement sections, except as modified herein.

b. **Materials.**-The permeable asphalt treated base (PATB) shall be hot plant mixed and hot laid. The materials shall meet the following requirements.

1. **Aggregate.**-The aggregate shall be a 6A coarse aggregate, except it shall be crushed stone meeting the crushed material requirement for 9A coarse aggregate. No recycled crushed concrete pavement or asphalt pavement can be used as any aggregate in the mixture.

2. **Asphalt.**-The asphalt cement for the PATB mixture shall be 85-100 Penetration Grade, or AC-10 Viscosity Grade.

3. **Prime Coat.**-The asphalt for priming the DGAB shall be Grade MS-Op.

4. **PATB Mixture.**-The mixture shall contain 2 to 2.5 percent asphalt, as directed by the Engineer.

c. **Construction Methods.**

1. Prior to placing the PATB, the Dense-Graded Aggregate Base (DGAB) shall be primed with MS-Op asphalt at a rate of 0.25 to 0.40 gal/sq yd as described in 4.00.08 of the Standard Specifications.

2. The Permeable Asphalt Treated Base shall be placed in a single layer with a track mounted paver.

3. After placement, the mixture shall be thoroughly and uniformly compacted by a static steel wheel roller applying 0.5 to 1.0 tons of compactive force per foot of roller width. Two complete rollings are required immediately after the mixture is placed. A complete rolling is down and back in the same path.

4. No vehicular traffic or construction equipment shall be allowed to operate or park on the travel lanes or shoulders of the permeable base. Only the slip-form paving equipment to place the concrete pavement will be allowed on the Permeable Asphalt Treated Base surface. Any areas that become damaged or contaminated with fines from traffic or the Contractor's work operation shall be replaced or repaired to the Engineer's satisfaction, at no cost to the Department.

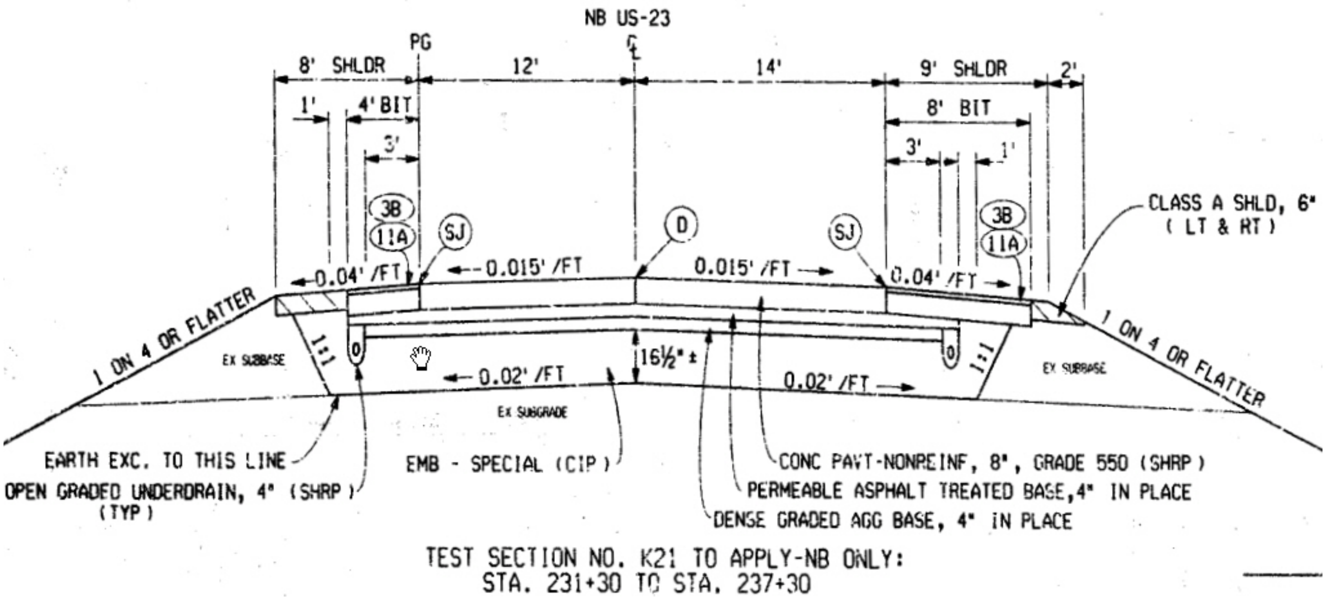
d. **Testing and Acceptance.**-The 6A aggregate will be sampled from the stockpile at the plant site, tested and approved for use prior to mixing. The asphalt content of the PATB mixture will be verified at the discretion of the Engineer by extraction testing. Any mixture that does not conform to the specifications shall be removed and replaced with acceptable material at the Contractor's expense.

e. **Measurement and Payment.**-The completed work as measured for PERMEABLE ASPHALT TREATED BASE will be paid for at the contract unit price for the following contract item (pay item):

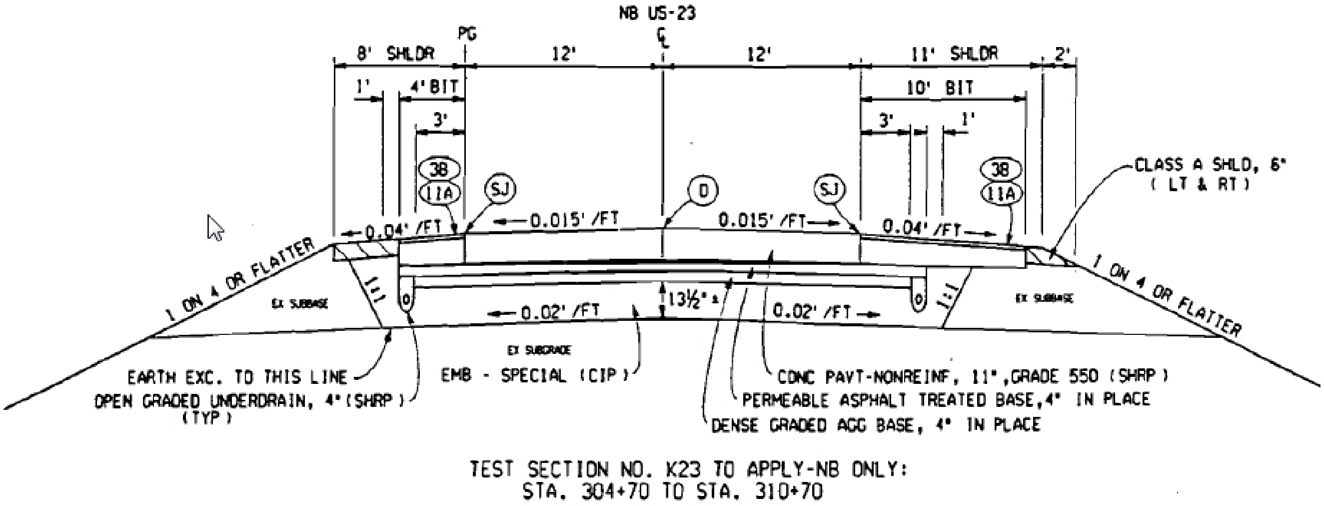
Pay Item	**Pay Unit**
Permeable Asphalt Treated Base, 4 Inch In Place	Square Yard

Permeable Asphalt Treated Base will be measured by area in square yards in place in accordance with the methods specified for measuring Aggregate Base Under Concrete in Section 3.01.10 of the 1990 Standard Specifications. Payment for the item Permeable Asphalt Treated Base includes payment for furnishing and applying the prime coat on the DGAB, furnishing the crushed aggregate, coating materials, mixing with asphalt cement, placing, spreading, shaping, and compacting the PATB.

Appendix C: JPCP SHRP (260221) Cross Section Plan



Appendix D: JPCP SHRP (260223) Cross Section Plan



Appendix E: MDOT Investigation studies for using Open-Graded Bases.

The following projects studied various issues involving the use of an open-graded aggregate as a base under concrete pavement in lieu of a dense-graded aggregate. The list is not necessarily inclusive. References are for microfilm (MF) storage.

80 TI-0678	Study of Possible Infiltration of Sand Subbase into Overlying Open-Graded Drainage Course Research Report No. R-1211 MF# 124, 70-71
80 TI-0705	Test of 21AA Gravel Material for Open-Graded Base MF#124, 92-93
87 TI-1276	Calcium Carbonate Precipitate from Crushed Concrete Open-Gradation 5G MF# 127, 183-184
89 TI-1393	Evaluation of Aggregates for Base Course under Concrete Pavements MF# 130, 90-91
90 TI-1513	Permeability Evaluation of OGDC Stabilization I-75 Monroe Co MF# 130, 183
91 TI-1583	Investigation of Cement Stabilized Open-Graded Drainage Course MF #129, 4-5