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Performance of Shoulders Adjacent to Concrete Pavements

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DISCLAIMER

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16. Abstract

The Wisconsin Department of Transportation (WisDOT) maintenance staff in both the Districts and Central Office discussed the less-than-optimum performance of the current asphalt shoulder design and standard being constructed adjacent to mainline concrete pavement projects. Problems associated with heaving of the shoulders during cold weather make snow removal operations more difficult and cause uneven wear on plow blades. Excessive cracking in both the longitudinal and transverse directions force maintenance crews to address these shoulders early in their life. In many cases, this is forcing continual maintenance crew exposure to high volume traffic roadways that are unwanted.

This report presents a set of guidelines for consideration in paved shoulder practice in Wisconsin. The set of guidelines was developed through a series of tasks including: a) review and synthesis of literature on paved shoulders, b) survey of seven Midwestern states (Illinois, Indiana, Iowa, Ohio, Michigan, Minnesota and Wisconsin) regarding their shoulder practices, and c) data collection and analysis of in-service paved shoulders adjacent to mainline concrete pavements in Wisconsin. On the basis of the analysis several recommendations are made regarding the design elements for two feasible shoulder alternatives to minimize the extent and/or severity of specific key distresses. The two feasible shoulder alternatives are a) Jointed plain concrete shoulder tied to the mainline concrete pavement and b) a composite shoulder (an extended PCC width beyond the white line plus a specified asphalt-surfaced width). In addition, recommendations are made regarding elements for consideration in the effective management of shoulders.

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EXECUTIVE SUMMARY

This report consists of a research study that was scoped to develop guidelines for consideration in paved shoulder practice in Wisconsin. The guidelines were developed to address concerns expressed by maintenance staff in both the districts and central office of the Wisconsin Department of Transportation (WisDOT) regarding the existing asphalt shoulder design and standard constructed adjacent to concrete mainline pavements. The concerns included the early appearance of excessive cracking, which forces maintenance crews to address the shoulders early in their life. This consequently, exposes maintenance crews to continual undesirable high volume roadways such as the interstate system. In addition, heaving of the shoulder occurs during the cold weather; this creates difficulty in snow removal operations and causes uneven wear on plow blades. The guidelines were developed through a series of tasks including: a) review and synthesis of literature on paved shoulders, b) survey of seven Midwestern states (Illinois, Indiana, Iowa, Ohio, Michigan, Minnesota, and Wisconsin) regarding their shoulder practices, and c) data collection and analysis of in-service paved shoulders adjacent to mainline concrete pavements.

The literature suggested that State Highway Agencies (SHA) pave shoulders for the purposes of accommodating stopped and emergency vehicles, and providing lateral support for the mainline pavement layers. According to the SHA, the decision to determine the paved shoulder type (flexible or rigid) to use is generally based on a combination of factors, such as the type of mainline pavement, traffic volume, proportion of heavy vehicles, the future use of the shoulder, and functional class. It was recommended however, that using the same type of material for both shoulder and mainline construction provides a number of advantages, including, ease of construction, reduced maintenance cost, and increased shoulder performance. In addition, field studies concluded that most flexible shoulders adjacent to mainline concrete pavements are under-designed and exhibit severe distresses such as horizontal and vertical separation of the longitudinal joint, fatigue cracking, rutting, frost heaving, raveling, potholes, and settlement. The joint separation was considered to be the source of most distresses on the flexible shoulder. The separation has been attributed to the differences in material properties between the concrete pavement and the flexible shoulder. It was strongly recommended that the longitudinal joint must always be sealed.

The survey to the seven Midwestern states addressed several elements including: policies and procedures for paved shoulder type selection, thickness determination and construction practices, maintenance practices, and functional interaction between maintenance, design, and construction units. An analysis of the survey data revealed considerable variation among the states on these elements. There was, however, an apparent lack of formal shoulder maintenance programs among the states. In addition, no formalized form of communication exists between maintenance staff and design and/or construction functional units when it comes to shoulder maintenance. Most state highway agencies (SHA) reported premature failures in both asphalt and concrete shoulders adjacent to mainline concrete pavements.

Field performance surveys of paved shoulders were conducted on 133 construction projects. A total of 289 one-mile project segments were surveyed from March to July 2002. Distress indicators recorded for concrete shoulders included slab breakup, distress joints/cracks, and

longitudinal joint distress. Distresses recorded for asphalt shoulders included various cracking forms (alligator, block, transverse and longitudinal), edge raveling, heave, settlement, and longitudinal joint deterioration.

The study used a more versatile approach of modeling individual distress modes to better explain the relationship between performance and design, environmental, maintenance, and construction variables. This is a significant shift from traditional methods, which use combined indices such as Pavement Distress Index (PDI) and Pavement Condition Index (PCI) in explaining performance. The combined index approach determines the average amount of distress from the many different combinations of distress types and tends to suppress the very effects of interest. The approach enabled various distress characteristics (extent, severity, and the combination of extent and severity) to be properly examined with respect to specific design, maintenance, and environmental variables. A comparative analysis regarding the performance of composite shoulders adjacent to dowel-jointed plain concrete pavements (Wisconsin Type 8) and composite shoulders adjacent to nondowel-jointed plain concrete pavements (Wisconsin Type 5) was conducted. In addition, a life cycle cost analysis was conducted for two feasible shoulder alternatives: a) jointed plain concrete shoulder tied to the mainline concrete pavement, and b) a composite shoulder consisting of a 2-ft concrete shoulder plus a specified asphalt shoulder width.

On the basis of the analysis, several observations and recommendations are made in the following areas:

<u>Jointed Plain Concrete Shoulder tied to the Mainline Pavement</u>

- Increase the minimum shoulder base thickness to 10 inches to minimize the occurrence of three primary distresses (longitudinal joint distress, distressed joints/cracks, and slab breakup) observed on concrete shoulders. A minimum thickness of 8 inches reduced the severity of the longitudinal joint distress while a minimum thickness of 10 inches reduced the extent of distressed joints/cracks. Thickness greater than 10 inches reduced the extent of slab breakup. The extent and severity of distressed joints/cracks reduced with base thickness of 12 inches or more.

- Field observations indicated that the majority of slab breakup occurred in the grooves of rumble strips. Hence, an investigation into the appropriate bar height for use with concrete rumble strips is warranted.

- The concept of mainline concrete pavement thickness reduction, in conjunction with a tied concrete shoulder, should be explored in terms of its life cycle cost and field performance implications. The literature indicated that the critical point for fatigue damage occurs on the outside edge of a concrete mainline pavement. The vertical shear support provided by a concrete shoulder tied to the mainline minimizes stress, and consequently, reduces fatigue damage in the adjacent outside lane. It was concluded that the increased edge support provided by the shoulder could result in a reduction of as much as one inch in the mainline thickness.

Composite Shoulders

- Mainline dowel-jointed plain concrete pavements (Wisconsin Type 8) significantly improved the performance of shoulders compared to nondowel-jointed plain concrete pavements (Wisconsin Type 5). The asphalt-surfaced component of composite shoulders adjacent to dowel-jointed plain concrete pavements (Wisconsin Type 8) showed significantly lower severity levels for all key distresses (longitudinal joint deterioration, transverse cracking, edge raveling, and settlement) compared to composite shoulders adjacent to nondowel-jointed plain concrete pavements (Wisconsin Type 5).

- A minimum width of 8 feet is recommended for the asphalt-surfaced component of a composite shoulder adjacent to Wisconsin Type 8 pavements to minimize the extent and severity of both transverse cracking and heave.

- Field surveys of paved shoulders found that longitudinal joints between PCC mainline pavement and the asphalt shoulder were not always sealed. A coherent policy regarding the treatment of the longitudinal joint is needed. The two main distresses observed on the asphalt-surfaced component of the composite shoulder adjacent to the Wisconsin Type 8 pavements were transverse cracking and longitudinal joint deterioration. The results of the analysis suggest that the extent for these two distresses reduced with filling of the longitudinal joint between the concrete and the asphalt shoulder. In addition, a model developed for the longitudinal joint deterioration distress in this study indicates that, in general, for a given level of truck traffic, a sealed joint can delay the occurrence of longitudinal joint deterioration by as much as 6 years.

- The current minimum recommended surface thickness of 2 inches (50 mm) should be increased to 4 inches (100 mm) to minimize the extent of transverse cracking, severity of edge raveling, and both the extent and severity of settlement.

- For shoulder base material, Crushed Aggregate Base Course (CABC) should be specified. Data analysis found that composite shoulders with CABC minimized the severity of transverse cracking and minimized both the extent and severity of heave. Filling the longitudinal joint can offset deterioration of the longitudinal joint with CABC.

Life Cycle Cost Analysis and Distress Models

- A life cycle cost analysis evaluating pavement options should continue to treat the mainline and the shoulder as a system. On the other hand, the type and timing of maintenance activities on the shoulder should be based on prescribed limiting levels of distress generated by models such as those developed in this research, rather than being controlled by the rehabilitation of the mainline.

Other Recommendations

- Set up formal performance/maintenance goals and expectations for shoulders for the various highway classifications. This provides an objective basis for identifying and addressing the current and future needs of shoulders within each functional classification system.

- Investigate the use and implementation of an appropriate automated data acquisition system for shoulders (similar to the existing system for mainline pavements) to be able to continually monitor shoulder performance at a reduced cost. All field data collection was done manually in this research and was very labor intensive.

- Develop a comprehensive database system to include design, construction, maintenance, and performance data for the pavement system. There was difficulty obtaining construction documents and records for this study, as well as design and maintenance data. A unified database system will, in the future, ensure that needed data is readily available for analysis and cut down cost.

- Establish formalized lines of communication between design, construction, and maintenance functional units. The maintenance surveys revealed that there are very little formalized lines of communication between functional units involved in the design, construction, and maintenance of the pavement system. Most feedback for example, is informal and occurs verbally and is often not documented. A formalized system of communication will be required in developing the database system described above.

- Investigate the practice of using the same type of material for both shoulder and mainline construction. This practice is reported to have several advantages including ease of construction, increased shoulder performance, and reduced maintenance cost.

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CHAPTER 1 INTRODUCTION

1.1 Background

At the present time, WisDOT has very little information on which to base the performance evaluation of paved shoulders adjacent to mainline PCC pavements. Past studies performed by other researchers have focused on design practices rather than evaluation of the field performance of the various paved shoulder alternatives. A broader perspective is needed to allow the performance of paved shoulder alternatives to be evaluated for cost effectiveness. This is only possible through a thorough investigation of all paved shoulder alternatives, including those that have been employed in other states and in Wisconsin, as well as an analysis of their cost effectiveness and applicability for Wisconsin.

The work contained in this research is significant since it will help guide WisDOT, and possibly other highway agencies, with a scientific understanding of the relationships between the performance and costs of concrete and asphalt paved shoulders abutting PCC mainline pavements. Such an understanding will enable WisDOT to validate shoulder design, construction and maintenance practices, and better predict paved shoulder performance. In addition, it will provide justification for WisDOT shoulder type selection procedures and designs based on life-cycle costs, constructability, and performance while also helping to develop a database for continuing evaluation and possible improvement.

1.2 Research Problem Statement

Shoulders form an essential component of a highway system. When properly designed and maintained, they promote safe traffic operations and provide lateral support for the adjacent mainline pavement.

The Wisconsin Department of Transportation (WisDOT) maintenance staff in both the Districts and Central Office have discussed the less-than-optimum performance of the current asphalt shoulder design and standard being constructed on concrete pavement projects. Problems associated with heaving of the shoulders during cold weather make snow removal operations more difficult and cause uneven wear on plow blades. Excessive cracking in both the longitudinal and transverse directions force maintenance crews to address these shoulders early in their life. In many cases, this is forcing continual unwanted exposure of maintenance crews to high volume traffic roadways. District maintenance staff is looking for cost effective maintenance alternatives for shoulders associated with high volume roadway shoulders, such as the interstate system.

1.3 Research Objectives

The objectives of this project are to:

1. Develop guidelines for the selection, design, and construction of shoulders adjacent to concrete pavements to achieve optimum performance;

2. Determine the cost effectiveness of paved shoulders; and
3. Broaden WisDOT's knowledge base on the design, construction, performance, cost and maintenance practices of shoulders adjacent to concrete pavements.

1.4 Research Approach

The project objectives were accomplished through the following set of tasks:

1.4.1 Literature Review

A literature review was conducted to identify, collect, review, and synthesize literature and research on the design, standards, performance, costs, and maintenance practices utilized by states. A survey was designed and mailed to midwestern states having climatic conditions similar to Wisconsin, particularly, Illinois, Iowa, Minnesota, Michigan, Indiana, Ohio, and Wisconsin itself. The survey sought information regarding the policies and procedures used in paved shoulder type selection, shoulder design, drainage treatment, shoulder condition evaluation method, maintenance practices and costs, freeze-thaw behavior, and effects of frost heave upon snowplow operations.

1.4.2 Identification and Review of Paved Shoulder Types in Wisconsin

A database of PCC projects was assembled to identify and review different paved shoulder types adjacent to mainline PCC pavements constructed in the last thirty years by WisDOT. Initial contacts were made with the Pavement Research and Management Unit of WisDOT to help in the PCC identification process. Then, individual districts were contacted to provide as-built plans. Jointed Reinforced Concrete Pavement (JRCP) was omitted from the identification process.

The information that was evaluated included the structural and geometric details, as well as construction placement information about each PCC pavement and adjacent shoulder. In addition, design and maintenance staffs from WisDOT district offices were contacted to determine if a PCC pavement had been overlayed.

1.4.3 Shoulder Condition Survey

Field surveys were conducted to evaluate the field performance of paved shoulders adjacent to mainline PCC pavements. This effort required considerable travel and field survey of existing paved shoulders from those projects in the database. Both JPCP and CRCP pavements were surveyed, however, JRCP pavements were omitted from the study. A phone conversation with WisDOT Pavement Management Unit staff indicated that shoulder condition monitoring did not start until 2000 and that only photolog images existed at the time of this study. Thus, a significant data collection effort was undertaken by the research team to perform a visual field survey of shoulder distresses on selected pavements.

1.4.4 Data Analysis

A comprehensive data analysis was conducted to understand key factors affecting the design, construction, and maintenance of paved shoulders. The analysis included the survey data from the midwestern states, and the analysis of the field performance and cost data of the various shoulder types in Wisconsin.

Survey data from Midwestern states, including Wisconsin, was analyzed and summarized for key design and construction criteria, such as structural design procedures, drainage systems, and construction policies. Survey results from maintenance personnel were analyzed and included such categories as types of shoulder maintenance practices in use and typical maintenance costs associated with each maintenance practice.

An analysis of the shoulder distress data collected during field surveys was conducted to determine the impact of factors such as shoulder type, highway functional classification, drainability, right shoulder relative to mainline pavement, and shoulder thickness range.

1.4.5 Development of Guidelines

Based on the literature, surveys, and data analysis, guidelines were developed to address key criteria related to paved shoulders adjacent to mainline PCC pavements. These guidelines focused on key elements, including criteria for selecting shoulder type, layer thickness determination, performance guide for maintenance intervention, and maintenance practices and costs guide.

CHAPTER 2 LITERATURE REVIEW

A literature and research review was conducted throughout the project to find all relevant information to paved shoulders adjacent to PCC mainline pavements. At the end of this review, it was concluded that there has been little documented research of paved shoulder design and performance.

2.1 General Literature

According to the FHWA, there has been minimal attention to the structural design of paved shoulders as compared to the mainline and no nationally recognized procedures exist for the design of paved shoulders [1]. The design procedures currently in use by some State Highway Agencies (SHAs) have developed gradually through experience rather than from a rational pavement design approach. Consequently, most shoulders may be considerably under-designed and have resulted in unsatisfactory performance.

The Federal Highway Administration (FHWA) [1] and the American Association of State Highway and Transportation Officials (AASHTO) [2] have thoroughly documented the functions of properly designed and well-maintained shoulders. These functions include, but are not limited to: promoting safe traffic operations, providing lateral support for the adjacent mainline pavement layers, facilitating water removal from the mainline pavement, enhancing roadway aesthetics, improving roadway capacity, providing space for routing traffic during construction and/or maintenance operations, providing space for snow removal and storage, and providing lateral clearance for signs and guardrails.

Shoulder design practices had been surveyed and studied at various times in the 1960s and 1970s. Those surveys and studies have been summarized in National Cooperative Highway Research Program (NCHRP) reports 63 and 202 [27, 9]. The surveys pointed to similar problems among various states; particularly, the joint between a concrete mainline pavement and a bituminous shoulder was found to be the cause of a considerable amount of shoulder distress. If this joint, however, is properly sealed and adequate drainage is provided, then shoulders structurally designed for the anticipated traffic will give satisfactory performance. The reports further indicated that the decision involving the type of shoulder to use for a specific mainline pavement is based on one or a combination of factors. These factors include the mainline pavement type and functional class, traffic volumes or percentages of heavy vehicles, engineering judgment, and availability of funds. Paved shoulders are, however, required on all interstate and major highways.

State highway agencies began using paved shoulders as a means to eliminate maintenance and safety problems brought about by increased traffic densities and axle loads. Various studies indicate that shoulder improvement in the form of widening or paving is generally the single most cost-effective action for improving safety; paved shoulders result in significantly lower accident rates [3,4,5,6,7]. Road test studies undertaken by the Western Association of State Highway Officials (WASHO) in the early 1950s indicated that without a paved shoulder, the outside wheel path of a pavement structure was inferior to the interior wheel paths in their ability to support test loads [5].

The main factors to consider in the thickness design of shoulders include, the type of mainline pavement, the future use of the shoulder, the amount of truck traffic encroachment on the shoulder, environment, planned maintenance strategy, and subgrade condition [3, 9]. It is however, recommended that shoulders should be constructed of the same material as the mainline pavement in order to facilitate construction, improvement of pavement performance, and reduction of maintenance cost [1]. Problems are found to occur at the mainline-shoulder joint when the pavement and shoulder are constructed with dissimilar materials (e.g. asphalt surface shoulders adjacent to mainline concrete pavements). Since the materials are of different thermal properties, they expand and contract at different rates; thereby introducing additional stresses into sealants already subjected to stresses from differential vertical deflections across the joints [9].

2.1.1 Width and Cross-Slope

The geometric elements of shoulders including, the width and cross-slope, have been published by FHWA [1] and AASHTO [2]. A desirable shoulder width according to AASHTO should be 10 feet to 12 feet for high-type facilities. This width provides 2ft clearance from the traveled lane for a stopped vehicle. A minimum shoulder width for low-type facilities is 2ft., however, 6ft to 8ft width is desirable. It is recommended that shoulder cross-slope be at least 1 percent more than that of the mainline pavement on tangent sections to facilitate drainage but should not be so steep as to be a hazard for the temporary use of the shoulder as a travel lane during future construction. A 2 to 6 percent cross-slope is recommended for asphalt and concrete shoulders, while 4 to 6 percent and 8 percent are, respectively, recommended for gravel and turf surfaced shoulders. The FHWA guidelines further suggest that the algebraic difference in cross-slope at the pavement edge should not be more than 8 percent in order to prevent any hazardous rollover effect.

2.1.2 Traffic Loads

Traffic loads are primarily responsible for shoulder fatigue. Traffic loading near the mainline-shoulder longitudinal joint can produce high stresses on the mainline pavement and can quickly reduce the fatigue life of the pavement [11]. Hence, shoulders should be structurally capable of withstanding wheel loading from encroaching truck traffic. Various methods have been proposed for estimating parked traffic and encroachment traffic for shoulder design. Hicks, et al [8] suggest an anticipated truck traffic encroachment of at least 2 to 2.5 percent of all mainline truck traffic. The suggested encroachment percentage range (2 to 2.5%) was established before the Transportation Assistance Act of 1982 where maximum truck width size was increased from 8 ft to 8.5 ft. This could deem the percentage estimates inaccurate. Where shoulders are expected to be used as additional traffic lanes during maintenance and construction operations, the additional traffic must be considered in the design. The shoulder is also used as a parking area for disabled vehicles. Since parked vehicles tend to move closer to the outer edge of the shoulder, it is essential that a uniform strong structural section be provided at the edge. Sawan et al [14], provide a detailed analysis for estimating traffic encroachment and parked traffic for use in design. The suggested analysis estimates that the proportion of truck encroachment varies between 1 to 8% of the adjacent outer lane truck traffic. If the shoulder may be used as temporary or permanent traffic lanes in the future, the ultimate case suggested is to design the shoulder using the mainline outer lane truck traffic. Surveys and calculations from in-service pavements suggest a range of 0.0005 to 0.005 percent for proportion of total truck traffic in one direction that parks on any random shoulder subsection.

2.1.3 Environmental Conditions

Environmental conditions including moisture and temperature, must be evaluated in the design process to determine what drainage systems are needed, the design considerations for frost effects, and the appropriate asphalt grade to select to meet the local climatic conditions. Environmental effects are generally more severe on shoulder performance than mainline because shoulders are generally constructed with less stringent specification standards compared to mainline (e.g., lower required compaction effort). Since shoulders are generally constructed of sections thinner than mainline pavement, the effects of frost penetration and freeze-thaw cycles are significant, especially for frost-susceptible soils [3]. Moisture infiltration and improper drainage are significant causes of premature shoulder deterioration. Moisture problems are best addressed by sawing and sealing the longitudinal shoulder joint and providing adequate drainage in the form of permeable foundation materials and/or subdrainage systems, or material less susceptible to the presence of moisture. Tables 2.1 and 2.2 respectively show the drainage practices and the gradation of granular base or subbases used as drainage layers reported by Barksdale and Hicks [9] for selected Midwestern states.

Design considerations for the effect of temperature variation impacts on asphalt concrete shoulder performance are the same as for mainline asphalt concrete pavements. Temperature related distresses are related to thermal cracking at low temperatures and pavement distortions (rutting, shoving, corrugations) at high temperatures. Both can be addressed by selecting the appropriate asphalt grade for the climate and layer thickness under consideration based on procedure developed by Basma and George [15].

Table 2.1 Drainage Practices in Selected Midwestern States (Adopted from [9])

State (1)	Surface Drainage		Subsurface Drainage Layer			Pipe Shoulder Drain	
	Pavement slope (2)	Shoulder slope (3)	Material (4)	Thickness, in. (5)	Extent (6)	Type location (7)	Size, in. (8)
Illinois	¼ in/ft	½ in/ft	Open graded aggregate base	4 - 6	Daylighted	Wet conditions during shoulder rehabilitation	-
Michigan	-	-	Granular base and subbase	14	Daylighted	Use edge drains where drainage path > 30 ft.	
Minnesota	3/16 in/ft	1 in/ft	Granular base	6	-	Cuts only	-
North Dakota	1/8 in/ft	1 in/ft	-	-	-	Seldom used	-
Ohio	3/16 in/ft (reverse slope)	½ in/ft	Granular base	7.5	Daylighted	For subgrade soils A-4, A-6, A-7-6	6 in. dia. clay or metal pipe

Table 2.2 Gradation of Granular Base/Subbase Drainage Layers used in Selected Midwestern States (Adopted from [9])

State (1)	Grain Size (% Passing)						
	2 in (2).	1 in. (3)	¾ in. (4)	3/8-in. (5)	#4 (6)	#100 (7)	#200 (8)
Type A		100			50-100	-	0-3
Illinois Type B		60-95			0-5	-	
Type C		95-100			0-10	-	
Michigan		100		60-85			3-7
Minnesota		100	90-100	50-90	35-80	-	3-10
North Dakota		100	76-100		35-80		0-20
Ohio		Stabilized Base					

2.2 Asphalt Shoulder Literature

During the mid-1970s, several state agencies experimented with various construction methods and cross-sectional areas of asphalt shoulders. The most significant and practiced change in design and construction was the use of full-depth asphalt shoulders. Full-depth shoulder pavements were found consistent with rigid pavement cross-sections. In an effort to reduce materials and cost, some agencies tapered the full-depth shoulder from equal depth at the mainline-shoulder longitudinal joint to 6-1/2 inches at the outside shoulder edge. This shoulder design performed favorably in Illinois, Ohio, Michigan, and North Dakota by reducing fatigue cracking near the longitudinal joint and limiting separation between the mainline and shoulder [5,8].

2.2.1 Types of Asphalt Shoulders

From the literature, the general types of flexible shoulders adjacent to mainline concrete pavements include:

a) Bituminous surface-treated shoulders;
b) Bituminous aggregate shoulders;
c) Full-depth asphalt shoulders; and
d) Widened lanes.

A *bituminous surface-treated* shoulder consists of an aggregate shoulder over which coats of liquid bituminous material and aggregate chips have been applied and rolled. A *bituminous aggregate shoulder* consists of asphalt or bituminous concrete on top of an aggregate base course. For *full-depth* asphalt shoulders, all layers consist of asphalt concrete mixtures placed directly on the prepared subgrade. *Widened lanes* consist of a 2 to 3-foot widening of the mainline structural section with the remaining width of shoulder composed of a bituminous surface treatment, bituminous aggregate section, aggregate or turf. For the widening to be effective, it is recommended that the widened lane be striped as a 12-ft travel lane [1,5].

Hicks et al [8] reported on a 1975 shoulder survey and indicated that paved bituminous sections adjacent to concrete mainline pavements varied from state to state. The survey revealed that most shoulder sections were under designed. This consequently, resulted in early deterioration of the bituminous shoulders studied. The main factors for the early deterioration were attributed to truck encroachment on the shoulder, water entering the longitudinal joint, and severe climatic conditions. Table 2.3 shows typical asphalt concrete shoulder sections constructed by Midwestern states in the early 1970s as reported by the study.

Table 2.3 Asphalt Concrete Shoulder Sections Constructed by Midwestern States (Adopted from [8])

	Surface Course		Base Course		Subbase	
State (1)	Material (2)	Thickness, in. (3)	Material (4)	Thickness, in. (5)	Material (6)	Thickness, in. (7)
Illinois	AC	1.5	CTB	6.5		
			LTB	6.5		
			ATB	6.5	ASB	4.0
Indiana	ST		ATB	6.0	ATSB	4.0
Michigan	AC	1.5	ATB	6.5 to 7.5	ASB	14.0
			CTB	5.0		
Minnesota	AC	1.5 to 2	AB	3.0	ASB	9.0 to 11.0
North Dakota	AC	4.0	ATB	4.0	LTS	
		2.0	Emulsion or cutback treated	6.0		
Ohio	AC	3.0	ATB	5.0 to 6.0	ASB	6.0
South Dakota	AC	2.0	ATB	6.0		
			LTB	6.0	AC	2.0
Wisconsin	AC	3.0	AB	6.0	ASB	15.0

AB = Aggregate Base
AC = Asphalt concrete
ASB= Aggregate subbase
ATB = Asphalt-treated base
ATSB = Asphalt -treated subbase
LTB = Lime-treated base
LTS = Lime-treated subgrade
ST= Surface treatment
CTB = Cement-treated base

2.2.2 Structural Performance

Other researchers have attributed the problems associated with asphalt concrete shoulders to be related mostly to structural performance. Insufficient asphalt concrete shoulder thickness or heavy traffic loading will create excessive stresses in the shoulder, especially when the foundation materials have softened under the mainline-shoulder area due to water infiltration and/or freeze-thaw cycles. This increased deformation will produce accelerated fatigue cracking in both the outside edge of the mainline pavement and in the shoulder. Poor drainage conditions can also accelerate the development of this distress. Field observations have shown that shoulder distress location is primarily within a 2-foot area of the longitudinal mainline pavement-shoulder joint [7,8,9,10]. In areas of severe winters, longitudinal cracking of shoulder pavements with relatively thin sections (2 in.) typically occurs during the first winter the pavement is loaded [8]. It has been concluded that the asphalt shoulder, generally, does not provide any structural support to the mainline PCC pavement [23].

2.2.3 Mainline-Shoulder Longitudinal Joint

The mainline-shoulder joint has been found to be the weakest part of the pavement-shoulder system [2,8,12]. Separation of the shoulder from the adjoining mainline pavement is common and is usually accompanied by vertical displacement or settlement. This problem occurs due to poor bonding between PCC and asphalt material, differences in the thermal properties, and insufficient compaction from equipment near the mainline-shoulder joint. Settlements in excess of ½ inch have occurred due to conditions such as unsuitable granular material in subbase, insufficient compaction of material beneath the shoulder or presence of soft soil material underlying the roadway embankment. Other factors found to contribute to shoulder settlements include: heavy truck traffic encroachment along the shoulder and pumping action of mainline pavement eroding base material from shoulder [9].

Large vertical movements have been observed in pavements with both sealed and unsealed joints where frost susceptible materials are present [12]. Within the first winter of construction, a shoulder was observed to heave as much as 3 inches [16]. The heave of the shoulder and pavement can open the longitudinal joint allowing incompressible materials and significant quantities of water to infiltrate the joint resulting in frost heave, cracking, and rapid shoulder deterioration [8]. Barksdale and Hicks [9] reported that the shoulder heaves more than the mainline pavement during frost action and presents a safety hazard of water retention along the mainline pavement. Maximum shoulder heaves were generally observed to be 3 to 12 inches away from the longitudinal pavement-shoulder joint with longitudinal cracking typically occurring in the midpoint of maximum heave. Shoulders constructed with different, or lesser, base and/or subbase than the mainline pavement can be subjected to frost heave different from that occurring on mainline pavements in some areas [11]. Most state agencies recommend avoiding the use of aggregate base courses having more than 6 percent minus 200 mesh sieve materials to prevent frost heaving, pumping, clogging of shoulder drainage system, and base instability [1].

Barksdale and Hicks [9] have reported the occurrence of various cracking forms at specific locations on asphalt shoulders. Transverse cracking has been found to develop at locations where the transverse pavement joints intersect the asphalt shoulder. The transverse cracking generally develops as a continuation of the pavement joint opening and appears to be related to the expansion and contraction of the PCC pavement. Again, the difference in material properties and the effects of weather on those properties create inconsistent movements and stresses resulting in transverse cracking. Longitudinal cracking on the other hand, was observed at areas with high concentration of wheel loadings from encroaching traffic, as well as in areas where significant quantities of water infiltrated beneath the pavement whether from unsealed mainline transverse joints or the pavement-shoulder longitudinal joint. In addition, the type of structural shoulder section was found to influence the occurrence of longitudinal cracking. Longitudinal cracking has traditionally been attributed to distress caused by local climate and construction materials [11].

It has been reported that severe cracking near the outside edge of the shoulder is due in part to inadequate thickness. Field inspections reported by McKenzie [13] revealed that at the outside edge of the shoulder where the cracking occurred, the constructed thickness was found to be ½ to $^2/_3$ of the design thickness; this resulted in premature cracking when loaded by traffic.

2.2.4 Full-Depth Asphalt Shoulders

Some states have attempted to improve the performance of asphalt concrete shoulders through the use of full-depth asphalt concrete shoulders. In the mid 1970s, as many as eleven states constructed full-depth asphalt concrete shoulder sections varying from 7 to 10 inches in depth. The full-depth asphalt shoulder was found to reduce cracking near the longitudinal joint and limit pavement-shoulder joint separation to approximately 1/8 inch during field studies in Illinois, North Dakota, Michigan, and Ohio [5,8]. The full-depth shoulder sections constructed by Michigan consisted of a deep asphalt concrete section equal to the thickness of the mainline slab at the inside edge, and tapering to 6-½ inches at the outside edge, all placed over a 14-inch sand subbase. Full-depth bituminous shoulders in North Dakota performed quite well considering the presence of expansive soils and a very severe climate. Transverse temperature cracking did occur in the shoulder and this was attributed to the extreme temperature variations. Shoulders used in North Dakota consisted of 4-inch asphalt concrete over 4-inch liquid or emulsified asphalt-treated base. Important factors contributing to the good performance in North Dakota appeared to be the use of continuously reinforced concrete mainline pavement, bituminous stabilized base, and sealed longitudinal pavement-shoulder joints.

McKenzie [13] reported on a comprehensive study in Illinois that showed that a full-depth bituminous aggregate shoulder section performed better than sections consisting of asphalt concrete on either cement-aggregate or a pozzolanic aggregate base. The bituminous aggregate base tapered in thickness from 8 inches at the pavement to 6 inches at the outside edge. A 1.5-in. bituminous concrete surfacing was placed over a 5.5-in. thick cement-aggregate base and also over a 6.5-in pozzolana-aggregate base. In the sections having cement and pozzolana-aggregate bases, longitudinal cracking occurred approximately 8 to 24 in. from the joint, with random cracking in between. The cement and the pozzolana-aggregate bases deteriorated significantly as a result of durability loss from freeze-thaw cycles and the presence of brine.

2.2.5 Maintenance

Shoulder maintenance practices have significant impact on shoulder performance. The level of maintenance required is dictated by the adequacy of the structural design, drainage type, and similarity of the materials used in the mainline pavement [16]. Routine maintenance of paved shoulders is expected to model the same practices of mainline pavement, including general rehabilitation or light re-construction. Generally, it is recommended that the shoulder be evaluated as part of the mainline pavement where evaluation and rehabilitation alternatives can be identified. Sealing of longitudinal joints is recommended approximately every 2 to 4 years [9]. The shoulder section should provide a safe, convenient, and reliable section for public use, which may require standard crack sealing practices, pothole repair and surface resistance improvements. Maintenance in moderately cracked shoulder areas in Illinois had generally been patched using a cold-mix patch. Michigan, and Minnesota use wedge patches to make a smooth transition from mainline pavement to the shoulder. The depth of these patches could be as great as 1-1/2 inches and span significant distances. Rehabilitation of AC shoulders should rely on the same rehabilitation options as AC pavements. Rehabilitation may include surface treatment or crack sealing, in addition to extensive patching, recycling, or complete replacement. Table 2.4 provides a summary of shoulder rehabilitation options for several key distress types [11]:

Table 2.4 Rehabilitation Options for Asphalt Shoulders (Adopted from [11])

Shoulder Distress (1)	Rehabilitation (2)
Pumping at shoulder lane joint	• Underseal concrete pavement and seal lane-shoulder joint. • Add concrete shoulder.
Alligator and Block Cracking	• Perform localized sealing or patching, including lane-shoulder joint. • Recycle or reconstruct with asphalt shoulder. • Add concrete shoulder.
Weathering and Raveling	• Rejuvenator or seal coat. • Chip seal or surface treatment. • Surface recycling.
Shoving	• Localized patching, and sealing of lane-shoulder joint. • Localized removal and replacement.
Potholes	• Localized patching, and sealing of lane shoulder joint. • Recycle or reconstruct with asphalt shoulder.
Settlements, Heaves, Dropoffs, or Shoulder Separation	• Localized patching, and sealing of lane-shoulder joint. • Localized removal and replacement. • Recycle or reconstruct with asphalt shoulder. • Add concrete shoulder.

2.3 Concrete Shoulder Literature

The construction of concrete shoulders adjacent to mainline concrete pavements began during the 1960s and 1970s. The first rural highway experimental concrete shoulders were built in Illinois in 1965. Since that time, many other states participated in the use of concrete shoulders in their highway systems. Between 1970 and 1974, approximately 5.7 million square yards of concrete shoulder contracts had been awarded in a total of 21 states [18,19]. Table 2.5 shows a summary of the different sections used or planned by Midwestern states in the 1970s.

Table 2.5 PCC Shoulder Designs in Selected Midwestern States (Adopted [8])

	Slab		Base		Tie Bars	
State (1)	Type (2)	Thickness, in. (3)	Type (4)	Thick., in. (5)	Size No. (6)	Spacing, in. (7)
Illinois	Plain	6 min.	Subgrade	-	4	30
Iowa	Plain	6	-	-	-	-
Michigan	Plain	9 taper to 6-1/4	Aggregate	4	Hook bolt	40
N. Dakota	CRC	8	Aggregate	2	5	48

2.3.1 Types of PCC Shoulders

Common rigid shoulder pavement types are jointed plain concrete (JPC), jointed reinforced concrete (JRC), and continuously reinforced concrete (CRC). Generally, the pavement type for rigid shoulders depends on cost, constructability, and type of mainline pavement. Only JPCP type shoulders are recommended with JPCP mainline because of cost effectiveness. It is feasible to use a JPCP shoulder with JRCP mainline; JPCP could be more cost effective to place and can be placed at the same time as the outside lane of the mainline pavement. JPCP shoulder can also be placed with CRCP mainline pavement as long as the joint spacing in the shoulder is short to reduce the potential of cracking the mainline pavement as a result of movement of the transverse shoulder joint. A 15-foot shoulder joint interval is recommended by the FHWA [1] for JPCP shoulders placed adjacent to mainline CRCP. Cracking of the mainline CRC pavement has occurred where long shoulder joint spacing (e.g., 100 ft) has been used [3].

2.3.2 Structural Performance

Concrete shoulders tied to the mainline PCC slab can significantly improve structural carrying capacity of the mainline pavement as well as its overall performance. Tied concrete shoulders have been found to reduce stresses and deflections in the mainline pavement [14, 17, 22]. This is due to the support provided by the tied shoulder to the edge. A width of at least 3ft is, however, needed for rigid shoulders to provide the greatest stress reduction in the traffic lane [10]. The 3-ft minimum width significantly reduces the effects of heavy truck traffic encroachment. The FHWA [1] recommends that Grade 40 steel be used if tiebars are to be bent and later straightened during construction since it better tolerates the bending. When using Grade 40 steel, No. 5 tiebars of length equal to 30 inches are recommended. For Grade 60 steel, 40-inch length No. 5 tie bars or 32-inch length No. 4 tie bars are recommended. According to the FHWA these lengths are necessary to develop the allowable working stress. Additionally, it is recommended that tie bars not be placed 15 inches away of transverse joints. For tie bar lengths in excess of 32 inches with skewed joints, the FHWA suggests that they should not be placed within 18 inches of transverse joints.

Field observations on the sections constructed in Illinois indicated that the concrete shoulders performed as well or better than asphalt shoulder sections. The following conclusions were reached on the basis of a comprehensive study performed in Illinois [20]:

a) A 6-in plain concrete shoulder gives good performance.
b) The shoulder should be tied to the mainline pavement by 30 in. long tie bars spaced at 30 in. on center.
c) Spacing of transverse joints of 20 ft. is desirable for control of intermediate cracking.
d) Use of a 6-in granular subbase under the concrete shoulder was found to reduce the amount of shoulder cracking by approximately 50%. However, the cracks that did develop in the sections without a subbase remained closed and did not significantly affect shoulder performance.
e) Sealing the longitudinal edge joint did not improve shoulder performance.

Several states followed the recommendations of the Illinois study and others made modifications such as increasing the shoulder thickness to equal the mainline pavement. The FHWA [1], recommends using the same pavement type and structural section for concrete shoulders as the mainline pavement to ensure adequate load capacity at the interface between the mainline and the shoulder while at the same time providing ease and economy of construction. Other advantages of having the shoulder section equal to the mainline slab thickness include improved subdrainage of the cross-section, differential frost heave is less likely between traffic lane and the shoulder if the cross-sections are matching. As an option, the FHWA recommends that the inside edge of the shoulder should be the same thickness as the adjacent mainline and then taper to at least 6 inches at the outside edge.

Performance data from JPCP concrete shoulders in Illinois showed significantly less punchouts on CRCP mainline pavement where the JPCP tied shoulders were located than where asphalt concrete shoulders were located [10]. Even after 20 years, the tied concrete shoulders did not show any tendency of edge drop-off; this distress type, however, is common to most flexible shoulders [16].

Studies by Darter [18, 22] and the Portland Cement Association [12] show that the critical point of fatigue damage for jointed concrete pavement is along the outside edge of the traffic lane. The concrete shoulder provides a presence of vertical shear support along the edge of the adjacent mainline slab reducing stress in the traffic lane and reducing fatigue damage. Various studies have estimated that the mainline slab thickness could be reduced by as much as one inch due to the increased edge support from the shoulder [10,17]. Experience has shown that a 6-inch concrete shoulder will perform without serious structural deterioration for over 15 years under heavy truck traffic in the mainline traffic lane [16]. Another consideration of shoulder thickness is that it can be tapered to a thinner section at the outer edge of the shoulder. The outer edge thickness is a function of the amount of parked trucks on the shoulder. The edge then acts as the critical point for fatigue damage from parking trucks.

Field tests further indicate that a rigid shoulder reduces corner and edge deflections. A reduction in corner and edge deflections consequently reduces the amount of potential pumping and corner breaks [10,16,17].

2.3.3 Distresses

PCC shoulder distresses are virtually the same as those found on mainline PCC Pavement [11, 23]. The most common include: Cracking, Pumping/Faulting, and Spalling. Pumping results in the loss of support under the pavement and faulting.

Cracking in the PCC shoulder can occur due to fatigue, poor support conditions at corners, and cracks, which propagate from the mainline pavement. Joints constructed in the shoulder pavement should match the mainline pavement. Intermediate joints in the shoulder have been found to encourage cracking in the mainline pavement. Therefore, this practice is discouraged.

2.3.4 Maintenance

Maintenance of PCC shoulders generally requires the same treatments as those required of mainline pavements. Many PCC performance problems have been traced to construction practice that produced a pavement outside design recommendations [21,23]. PCC shoulders are generally maintenance-free, with the exception of sealing the mainline longitudinal joint. However, full-width paving reduces maintenance operations and equipment needed due to the absence of a longitudinal joint. A routine maintenance schedule provides an agency with minimum rehabilitation cost, and longer pavement life [2,11]. Repairs of deteriorated cracks and spalls in the PCC shoulder are conducted using the same procedures as mainline pavement. If excessive spalling occurs along lane-shoulder joint, an evaluation of the tie bars should be performed to determine if the tie bars are contributing to the spalling. The lane-shoulder joint should be sealed, as should all unrepaired cracks to minimize water infiltration. Table 2.6 provides a summary of shoulder rehabilitation options for key distress types for concrete shoulders [11]:

Table 2.6 Repair Options for Key PCC Shoulder Distresses (Adopted from [11])

Shoulder Distress (1)	Rehabilitation (2)
Cracking	• Seal Cracks. • Localized repairs. • Recycle, reconstruction, or overlay.
Pumping / Faulting	• Underseal slab corners and seal lane-shoulder joint. • Underseal and overlay.
Spalling	• Partial-or-full-depth repairs. • Localized reconstruction.

Costs of repair options for the shoulder will be similar to those used in mainline repair. Actual patching and rehabilitation expenses must be evaluated on an individual level depending on equipment, labor, and average crew wage.

PCC shoulder-mainline joints are typically easily sealed and maintained. In the past 15 years, rubberized asphalt has become an industry standard. Rubberized asphalt sealants possess a greater working-range with respect to low temperature extensibility and resistance to high temperature softening and tracking. Within recent years, softer grades of asphalt cement have been used in rubberized asphalts to further improve low temperature extensibility; these sealants are used in most Northern States because of increased extensibility [11].

2.4 Literature Summary and Conclusions

There have been numerous recommendations from research papers and reports related to paved shoulders. Table 2.7 has been developed to synthesize key recommendations for design and construction. Key design criteria are provided, including width, cross-slope, base material, traffic encroachment, and drainage. Tables 2.8 and 2.9 provide specific recommendations for concrete and asphalt shoulders, respectively.

Significant findings in Tables 2.7 through 2.9 include the enumeration of important geometric dimensions, safety, traffic, and drainage considerations. These recommendations represent an assimilation of individual research efforts, with none comprehensively addressing all criteria directly in the respective studies. However, they serve as a basis for developing recommended practices for design and construction of asphalt and concrete paved shoulders.

A wide range of characteristics associated with paved shoulders has been examined in the literature. These characteristics include the functions, types, design considerations, construction, performance and maintenance. The following subsections further delineate these characteristics.

Table 2.7 Recommended Design and Construction Practices for Paved Shoulders

Year (1)	Paved Shoulder Criterion (2)	Specific Recommendations (3)
1976-1990	Safety	• Widening or paving is generally the single most cost-effective action for improving safety and significantly lowering accident rates [3,4,5,6,7].
1994	Width	• For high-type facilities, shoulder width should be 10 to 12 feet. This width provides a minimum 2-foot clearance from traveled lane for a stopped vehicle. • A minimum shoulder width for low-type facilities is 2 feet, however, a 6- to 8-foot width is desirable [2].
1994	Cross Slope	• Cross slope should be at least 1 percent more than that of the mainline pavement on tangent sections to facilitate drainage, but not so steep as to be a hazard as a temporary travel lane during future construction [2]. • A 2 to 6-percent cross-slope is recommended for asphalt and concrete shoulders [2].
1976 and 1990	Widened concrete travel lanes	• Widened concrete travel lanes, consisting of a 2 to 3-foot widening of the mainline structural section, with the remaining width asphalt shoulder, provide an effective paved shoulder. For the widening to be effective, it is recommended that the widened lane be striped as a 12-foot travel lane [1,5].
1990	Shoulder base material	• Avoid the use of aggregate base courses having more than 6 percent passing the #200 sieve to prevent frost heaving, pumping, clogging of shoulder drainage system, and base instability [1].
1990	Material Selection	• Construct shoulder with the same material as the mainline pavement in order to facilitate construction, improvement of pavement performance, and reduction of maintenance cost [1].
1976 and 1987	Traffic Encroachment	• Structurally capable of withstanding wheel loadings from encroaching truck traffic [11]. • An anticipated truck traffic encroachment of at least 2 to 2.5 percent of all mainline truck traffic is recommended during design [8].
1987	Moisture Infiltration and Drainage	• Moisture infiltration and improper drainage are significant causes of premature shoulder deterioration. Seal the longitudinal shoulder joint and provide adequate drainage in the form of permeable foundation materials and/or subdrainage systems, or material less susceptible to the presence of moisture [3].

Table 2.8 Recommended Practices for Paved Asphalt Shoulders

Year (1)	Paved Shoulder Criterion (2)	Specific Recommendations (3)
1976, 1979	Longitudinal Joint	• The joint between a concrete mainline pavement and asphalt shoulder is the cause of a considerable amount of shoulder distress. If this joint is properly sealed and adequate drainage is provided, then shoulders structurally designed for the anticipated traffic will give satisfactory performance [9]. • Full-depth asphalt shoulder was found to reduce cracking near the longitudinal joint and limit pavement-shoulder joint separation to approximately 1/8 inch during field studies in Illinois, North Dakota, Michigan, and Ohio [5,8].
1972	Base Material	• A full-depth asphalt shoulder on aggregate performed better than sections consisting of asphalt concrete on either cement-aggregate or a pozzolanic aggregate base [13].
1984	Transverse Cracking	• Temperature-related distresses are related to thermal cracking at low temperatures and pavement distortions (rutting, shoving, corrugations) at high temperatures. Both can be addressed by selecting the appropriate asphalt grade for the climate and layer thickness [15].
1997	Lateral Support	• Asphalt shoulders, generally, do not provide any structural support to the mainline concrete pavement [23].

Table 2.9 Recommended Practices for Paved Concrete Shoulders

Year (1)	Paved Shoulder Criterion (2)	Specific Recommendations (3)
1970, 1979 and 1982	Tied Shoulders	• Concrete shoulders tied to the mainline concrete slab can significantly improve structural carrying capacity of the mainline pavement and overall performance. Tied concrete shoulders have been found to reduce stresses and deflections in the mainline pavement [14, 17, 22]. • Performance data from JPCP concrete shoulders in Illinois showed significantly less punchouts on CRCP mainline pavement where the JPCP tied shoulders were located rather than asphalt shoulders [10]. • The shoulder should be tied to the mainline pavement by 30-inch long tie bars spaced at 30-inch on center [20].
1978	Width	• A width of at least 3 feet is needed for rigid shoulders to provide the greatest stress reduction in the traffic lane [10].
1978	Thickness	• A 6-inch plain concrete shoulder gives good performance [20]. • The mainline slab thickness could be reduced by as much 1 inch due to the increased edge support from the shoulder [10,17].
1978 and 1987	Corner and edge deflections	• A rigid shoulder reduces corner and edge deflections. Reduction in corner and edge deflections consequently reduces the amount of potential pumping and corner breaks [10,16,17].
1970, 1987, and 1997	Transverse Joints	• Joints constructed in the shoulder pavement should match the mainline pavement. Intermediate joints in the shoulder encourage cracking in the mainline pavement and should be avoided [23]. • Spacing of transverse joints of 20 feet is desirable for control of intermediate cracking [20]. • A 15-foot shoulder joint interval is recommended by the FHWA for JPCP shoulders placed adjacent to mainline CRCP [1]. • Cracking of the mainline CRC pavement has occurred where long shoulder joint spacing (e.g. 100 ft) has been used [3].
1970	Longitudinal Joints	• Sealing the longitudinal edge joint did not improve shoulder performance.
1970	Base Material	• Use of a 6-inch granular subbase under the concrete shoulder reduces the amount of shoulder cracking by approximately 50%. However, the cracks that did develop in the sections without a subbase remained closed and did not significantly affect shoulder performance [20].

2.4.1 Shoulder Functions

The literature suggests that SHAs pave shoulders for the purposes of accommodating stopped and emergency vehicles, and providing lateral support for the mainline pavement layers. Over the years, however, shoulder functions have been expanded considerably to include: providing added space for construction and maintenance activities, serving as temporary traffic lanes, expediting water runoff from the mainline pavement, improving roadway capacity, reducing edge stresses as well as edge and corner deflections. In addition, paved shoulders have been found to significantly reduce accident rates.

2.4.2 Paved Shoulder Types

Paved shoulders adjacent to mainline concrete pavements can be constructed as flexible or rigid. The decision to determine the shoulder type to use is based on a combination of factors, such as the type of mainline pavement, traffic volume, proportion of heavy vehicles, and functional class. It is however, recommended that using the same type of material for both shoulder and mainline construction provides a number of advantages including ease of construction, reduced maintenance cost, and increased shoulder performance.

2.4.3 Design, Construction, and Performance of Shoulders

The literature suggests that there are currently no nationally recognized procedures for the design of shoulders. Some states have developed their own procedures on the basis of experience rather than from a rational pavement design approach. Consequently, most shoulders are considerably under-designed and have resulted in poor performance.

The recommended factors to include in the thickness design process for shoulders are: truck traffic encroachment on the shoulder, environmental factors (temperature and moisture), subgrade condition, and planned maintenance strategy. Truck traffic encroachment estimates recommended for design is in the range of 2 to 2.5% of all mainline truck traffic. If shoulders are planned for future use as traffic lanes during construction and maintenance activities, the ultimate case is to design the shoulder using the mainline outer lane truck traffic.

During the mid-1970s, several state agencies experimented with various construction methods and cross-sectional areas of asphalt shoulders. The most significant and practiced change in design and construction was the use of full-depth asphalt shoulders. Full-depth shoulder pavements were found consistent with rigid pavement cross-sections. During construction, matching cross-sections between mainline pavement and the shoulder ensures equal compaction of base course material throughout the cross-sectional area reducing drop-off between mainline pavement and shoulder. Favorable performance of this design has also contributed to a reduction in differential frost heave, since temperature variations must reach the same depth. In favor of reducing materials and cost, some agencies tapered the full-depth shoulder from equal depth at the mainline-shoulder longitudinal joint to 6-1/2 inches at the outside shoulder edge. This shoulder design performed favorably in Illinois, Ohio, Michigan, and North Dakota reducing fatigue cracking near the longitudinal joint and limiting separation between the mainline and shoulder. Pavement widening has also been an effective construction procedure for improving asphalt shoulder performance. The effect of mainline pavement widening was studied in the state of Illinois. The rational for mainline pavement widening is to move the longitudinal mainline-shoulder joint outside of the 2-foot typical encroachment area while pavement markings remain at the standard 12-foot travel-lane location. In theory, the bulk of encroaching traffic will remain a sufficient distance from the mainline pavement edge reducing the high stresses created when encroaching traffic crosses from rigid to flexible pavements.

For concrete shoulder sections, the minimum recommended thickness is equal to the mainline-pavement for 3ft beyond the mainline-shoulder longitudinal joint, tapering to a thickness of $6\text{-}^{1}/_{2}$ inch to the outside edge. General PCC shoulder thickness ranges from 6 to 9 inches. Designing a concrete shoulder with the same requirements as adjoining mainline pavement enables the shoulder to be used as a temporary travel lane during maintenance or as a future permanent lane, construction is facilitated, water flow along base/slab plain is also enhanced and differential frost effects can be reduced.

Since concrete shoulder introduction to the United States during the mid-seventies, overall performance of various test sections has met or exceeded expectations of designers. After 20 years of use in the state of Illinois, performance data showed tied concrete shoulders improved structural capacity of mainline pavement. Concrete shoulders restrict the tendency of shoulder drop-off, limit vertical movement, and mainline pavement shows significantly lower punchouts and corner break distresses. Mainline PCC pavements with PCC shoulders can be reduced by as much as 1 inch in thickness due to the structural support provided on the outside edge by the PCC concrete shoulder. Despite the high performance of concrete shoulders adjacent to concrete mainline pavement; no state has implemented concrete shoulders as a design practice.

2.4.4 Maintenance

The level of maintenance required on a shoulder depends on the type, severity, and extent of distresses. Field studies show that most flexible shoulders adjacent to mainline PCC pavements are under-designed and exhibit severe distresses such as horizontal and vertical separation of the longitudinal joint, fatigue cracking, rutting, frost heaving, raveling, potholes, and settlement. The joint separation is considered to be the source of most distresses on the flexible shoulder. The separation has been attributed to the differences in material properties between the concrete pavement and the asphalt shoulder. It is strongly recommended that the longitudinal joint must always be sealed periodically (for example, every 2 to 4 years). In addition, crack sealing, patching, and surface treatment should be done when necessary. Past experience in the state of Illinois has found concrete shoulders adjacent to mainline PCC pavements to be virtually maintenance free, with the exception of longitudinal joint sealing.

2.5 Questionnaire Surveys to Midwestern States

Recommendations from previous literature papers and reports, as well as years of experience, have led several midwestern states to adopt a variety of design criteria, construction practices, and maintenance strategies for paved shoulders. To understand and evaluate the overall performance of paved shoulders, two sets of questionnaire surveys were designed and mailed to seven Midwestern states: Illinois, Iowa, Minnesota, Michigan, Indiana, Ohio, and Wisconsin. The reason for limiting the survey sample to the Midwest was research resources, and those states having similar climatic conditions to Wisconsin. The first set of surveys was sent to design personnel from each of the seven Departments of Transportation (DOT) main offices to seek information on policies and procedures used in paved shoulder type selection, design, construction, and drainage treatment. A copy of the design and construction survey is included in Appendix A of this report, while the summarized responses (Appendix B) can be accessed at www.whrp.org. All DOT offices except Ohio responded to the survey.

A second set of surveys was sent to maintenance personnel in all the SHA district offices in the seven states to seek information on maintenance practices for paved shoulders adjacent to mainline concrete pavements. Fifty-six SHA districts were targeted but two of them indicated that they did not have any mainline concrete pavements and, hence, could not participate in the survey. Twenty-two of the remaining 54 districts (40.7%) responded to the survey. The survey was designed to capture information regarding a comprehensive maintenance program. A copy of the maintenance survey is included in Appendix C of this report, while the summarized responses (Appendix D) can be accessed at www.whrp.org.

2.5.1 Criteria for Paved Shoulder Type Selection

Table 2.10 summarizes the factors considered in selecting paved shoulder type for mainline concrete pavements. Of the six states that responded to the survey, only Illinois has a stringent policy requiring Portland Cement Concrete (PCC) shoulders to be constructed adjacent to all mainline pavements constructed as PCC. A wide range of factors is considered by the other states in the shoulder type selection process. Minnesota uses construction and maintenance cost as the basis to determine the type of paved shoulder to be built adjacent to mainline PCC pavements. For the remaining states (Wisconsin, Iowa, Indiana, and Michigan), functional classification and traffic volume appear to be the most important factors for selecting shoulder type for PCC mainline pavements. Wisconsin, however, has the most factors in the selection process. Michigan is the only state that indirectly leaves the paved shoulder type selection decision for freeways to the contractor. The contractor is given the option of constructing either a plain PCC shoulder tied to the mainline or a full-depth asphalt concrete shoulder.

Table 2.10-Paved Shoulder Selection Guide for Concrete Pavements in Midwestern States

STATE (1)	Factors Considered in Paved PCC Shoulder Type Selection (2)	Specified Criteria (3)
Illinois	PCC only	PCC shoulders are required for all mainline PCC pavements
Indiana	Functional classification, truck traffic	• For high volume (HV) rural expressways and freeways (design year ADT >20,000), shoulders are constructed of bituminous surface with bituminous corrugations on bituminous base over compacted aggregate. • For medium volume (MV) rural non-freeways (5000 < design year ADT≤ 20,000) and HV non-freeways, shoulders are constructed of bituminous base over compacted aggregate base. • For HV and MV urban pavement sections, shoulders are constructed of PCC. • For low volume concrete pavement sections (design year ADT≤5000 for 2-lane roads, and ≤ 7,000 for 4-lane roads), shoulders are constructed of bituminous base over compacted aggregate base.
Iowa	Functional classification, traffic volume	• All interstate shoulders and shoulders for non-interstate roadways with design year ADT > 10,000 are paved. • The shoulder will be of full-depth PCC or full-depth AC if shoulder is subjected to traffic during the construction stage; otherwise, the shoulder will be 8 inches (200 mm) of AC or 7 inches (175 mm) of PCC over granular layer.
Michigan	Functional classification, truck traffic, construction and maintenance cost.	• For freeway shoulders on a project, the contractor has the option to construct it with either plain PCC or full-depth AC. If constructed with concrete, the shoulder is required to be tied to the mainline. • The shoulder is tapered towards the outside edge. The outside edge is 3 inches (75 mm) less in thickness than at the interface with the mainline. For concrete shoulders, the minimum thickness of the outside edge is 7 inches (175 mm)
Minnesota	Construction and maintenance cost	Lower cost alternative
Wisconsin	Functional classification, truck traffic, construction and maintenance cost, construction time, experience, and judgment.	• All rural state trunk highway (STH) shoulders are paved. • For 2-lane, 2-way STH with current ADT> 1250, pave with a 3-foot (900mm) monolithic concrete. • For 4-lane divided STH with current ADT> 1250, pave with a 2-foot (600mm) monolithic concrete on the right. • County trunk highways meeting the above current ADT criteria may be paved at the discretion of local officials.

2.5.2 Design Practices

The surveyed states were asked to provide information on the procedures for determining shoulder layer thickness. The information sought included design traffic estimation method for shoulders, type of joints and their characteristics, base layers, and tie bar design. Table 2.11 provides a summary of the general thickness practices. The data indicate that thickness determination practices vary from state to state for both concrete and asphalt shoulders. Thickness of concrete shoulders varies from a minimum of 6 inches (150 mm) to thickness equivalent to the mainline design thickness. The minimum thickness requirement for asphalt-surfaced shoulders is 2 inches (50 mm).

Table 2.11 Paved Shoulder Thickness Determination Practices in Midwestern States

State (1)	Concrete Shoulder (2)	Asphalt Shoulder (3)
Illinois	• For 20-year design period: Same thickness as mainline concrete at the pavement-shoulder interface tapering to 6 inches (150 mm) at the outside edge. • For 30-year design period: Same thickness as mainline concrete.	Not Applicable (N/A)
Indiana	• AASHTO • Same thickness as mainline for roadways with at least 30 million ESALs.	• A minimum thickness of 2 inches (50 mm) asphalt over compacted aggregate base for roadways with less than 30 million ESALs.
Iowa	• Same thickness as mainline if shoulder is used for construction staging or is anticipated to be used as a lane in the future; otherwise standard thickness of 7 inches (175 mm)	• Same thickness as mainline if shoulder is used for construction staging or is anticipated to be used as a lane in the future; otherwise standard thickness of 8 inches (200 mm)
Michigan	• AASHTO • Same thickness as mainline • Standard thickness consisting of same thickness at the pavement-shoulder interface and tapering to a minimum of 7 inches (175 mm) at the outside edge of the shoulder.	• AASHTO • Standard thickness consisting of a minimum of 5.5 inches (137.5 mm) for freeways.
Minnesota	• A 6-inch (150-mm) non-reinforced concrete surface tied to the mainline is required over aggregate base layers.	• A 3-inches (75 mm) minimum asphalt surface thickness required over aggregate base layers.
Wisconsin	• AASHTO (using 2.5% of mainline design ESALs/day); a 6-inch (150-mm) minimum surface thickness is required.	• AASHTO (using 2.5% of mainline design ESALs/day); a 2-inch (50-mm) minimum surface thickness is required.

Illinois and Michigan require tapers in their concrete shoulders; the taper begins at the mainline-shoulder interface and decreases to prescribed minimum thickness values at the outside edge of the shoulder. Illinois in addition, specifies the concrete thickness configuration on the basis of a 20- or 30-year design period. A taper is required for the 20-year design period only. Besides Illinois, which does not use asphalt shoulders for concrete mainline pavements, asphalt shoulder thickness for the surveyed states range from 2 inches (50 mm) to 8 inches (200 mm). The high-end thickness is used by Iowa and may be upgraded to the mainline thickness if the shoulder is anticipated as a travel lane in the future or for the purpose of construction staging.

Table 2.12 shows the general characteristics of the transverse contraction joints and tie bars used for concrete shoulders. Survey data indicate that jointed plain concrete (JPC) shoulders are popular among all midwestern states. In addition, Michigan also reported using jointed reinforced concrete (JRC) shoulders as well as JPC. Non-skewed joint spacing has varied from 15 feet (4.5m) to 20 feet (6m) for JPC shoulders. Typical joint spacing used for JRC in Michigan is 27 feet (8 m). For JPC shoulders adjacent to CRC mainline pavements, Illinois reported providing joint spacing at 20-foot (6-m) intervals. Joint width and depth also vary from state to state. The majority of the states specify the joint depth to be a quarter of the shoulder surface thickness (i.e., thickness / 4). If JRC is used as in Michigan, a 2-inch (50-mm) depth is required.

Table 2.12 further shows that typical tie bar size varies from No. 4 to No. 6 with spacing in the range of 24 inches (600 mm) to 36 inches (900 mm). Indiana on the other hand, specifies bar size on the basis of the shoulder thickness used. The No. 7 bar is used for thickness exceeding 12 inches (300 mm). The intermediate bar size (No. 6) is used for thickness in the range of 9 inches (225 mm) to 12 inches (300 mm), while the No. 5 bar size is used for thickness less than 9 inches (225 mm).

Table 2.12 Joint and Tie Bar Design Practices for PCC Shoulders

State (1)	Concrete Shoulder Type (2)	Joint				Tie Bars	
		Spacing (3)	Width (4)	Depth (5)	Shape (6)	Size, # (7)	Spacing (8)
Illinois	Jointed plain	Same as pavement	1/8 in.-1/4 in.	D/4*		6	24 in. (600 mm)
	Continuously reinforced	20 ft (6m)	1/8 in.-1/4 in.	D/4			
Indiana	Jointed plain	18 ft. (5.4m)	1/4 in.	D/4	Rectan -gular.	5 for D<9 in. 6 for D=9 to 12 in. 7 for D>12 in.	36 in. (900 mm)
Iowa	Jointed plain	20 ft (6m)	3/16 in. -5/16 in.	D/3 for D≥ 8 in. (200mm)	Rectan -gular.	5	30 in. (750 mm)
		20 ft. (6m)	3/16 in. -5/16 in.	D/4 for D<8 in. (200mm)	Rectan -gular.		
Michigan	Jointed plain	4-5 m	10 mm	38 mm	Rectan -gular.	6	36 in. (900 mm) max.
	Jointed reinf.	26 ft. (8 m)	14mm	50mm	Rectan -gular.		
Minnesota	Jointed plain	15 ft. (4.5m)				4	4 bars per 15-ft (4.5m) panel
Wisconsin	Jointed plain	15 ft. (4.5m) or 18 ft. (5.4m)	1/8 in.	D/3	No reservo ir	4	30 in. (750 mm)
*D = pavement thickness							

2.5.3 Base Layers and Subsurface Drainage

Base design and drainage systems are an integral component of pavement design. As shown in Table 2.13, base layers under paved shoulders adjacent to PCC pavements consist predominantly of granular materials. However, the thickness varies from state to state with a minimum thickness of 4 inches (100 mm) or 6 inches (150 mm) for PCC shoulders and a minimum of 3 inches (75 mm) for flexible shoulders. Illinois reported using asphalt and lime-treated bases in addition to untreated granular materials.

The gradation characteristics of the granular base layers are presented in Table 2.14. The gradation characteristics vary among states; where open-graded or drainable bases are used, the percent passing the #200 (75μm) is restricted to a maximum of 5%.

Two main subsurface drainage systems are commonly specified as shown in Table 2.15: (1) pipe in a geotextile-wrapped aggregate-filled trench, and (2) graded aggregate around pipe in the trench without a geotextile filter. These systems are generally required with drainable or open-graded base layers as reported by Wisconsin and Iowa. They intercept and remove infiltration water from a roadway section. Their general location is at the edge of the mainline pavement at an appropriate depth to intercept water from the granular base layers and the longitudinal joint at the pavement-shoulder interface. Illinois, however, reported placing the drainage system at the edge of the shoulder if the roadway has a 30-year design period, otherwise it is placed at the edge of the pavement. Michigan reported placing it at a distance of 2 feet (0.6 m) from the pavement-shoulder interface for roadways with no curb and gutter, or under curb and gutter if specified. The most commonly specified pipe is corrugated PVC.

Table 2.13 Base and Subbase Characteristics for Paved Shoulders Adjacent to Concrete Pavements

<table>
<tr><th rowspan="2">State
(1)</th><th colspan="2">Concrete Shoulders</th><th colspan="4">Asphalt Shoulders</th></tr>
<tr><th>Base type
(2)</th><th>Thickness
(3)</th><th>Base type
(4)</th><th>Thickness
(5)</th><th>Subbase type
(6)</th><th>Thickness range
(7)</th></tr>
<tr><td rowspan="3">Illinois</td><td>Aggregate</td><td>12-in. (300 mm) Minimum for 30-yr design</td><td colspan="4" rowspan="3">N/A</td></tr>
<tr><td>Asphalt-treated</td><td>4-in. (100mm) for jointed plain and 6-in (150 mm) for continuously reinforced concrete for 30-yr. design.</td></tr>
<tr><td>Lime treated</td><td>12-in. (300 mm) minimum for 20-yr design</td></tr>
<tr><td>Indiana</td><td>Aggregate</td><td>9-in. (225 mm)</td><td>Hot Mix Asphalt</td><td>3-in (75 mm)</td><td>Aggregate</td><td>7-12 in. (175-300 mm)</td></tr>
<tr><td>Iowa</td><td>Aggregate</td><td>6-in. (150 mm) minimum</td><td>Aggregate</td><td>6-in. (150 mm) Minimum</td><td>-</td><td>-</td></tr>
<tr><td>Michigan</td><td>Open-graded drainage course</td><td>4-in. (100-mm minimum)</td><td>Aggregate</td><td>6.5 in. (160 mm) Minimum</td><td>Sand</td><td>18 in. (460 mm) Minimum</td></tr>
<tr><td>Minnesota</td><td>Aggregate</td><td>Controlled by mainline thickness.</td><td>Class 5* dense – graded aggregate</td><td>3-in. (75 mm)</td><td>Class 3 aggregate*</td><td>Varies</td></tr>
<tr><td>Wisconsin</td><td>Aggregate</td><td>6-in. (150 mm) Minimum</td><td>Crushed Aggregate</td><td>6-in. (150 mm) Minimum</td><td>Non-typical</td><td>-</td></tr>
<tr><td colspan="7">* see gradation characteristics in Table 5</td></tr>
</table>

Table 2.14 Gradation Characteristics of Granular Base/Subbase Layers Under Shoulders Adjacent to Concrete Pavements

State (1)	Granular Material (2)	Percent Passing Sieve Size											
		2 in. (50 mm) (3)	1½ in. (37.5 mm) (4)	1 in. (25 mm) (5)	¾ in. (19 mm) (6)	½ in. (12.5 mm) (7)	3/8 in. (9.5 mm) (8)	#4 (4.75 mm) (9)	#8 (2.36 mm) (10)	#10 (2mm) (11)	#16 (1.18mm) (12)	#40 (425 µm) (13)	#200 (75µm) (14)
Illinois	Types A, B, or C [Gradation CA 6]	-	100	90-100	-	60-90	-	30-56	-	-	10-40		4-12
	Types A, B or C [Gradation CA 10]	-	-	100	90-100	65-95		40-60	-	-	15-45		5-13
Indiana	Type 8	-	-	100	75-95	40-70	20-50	0-15	0-10	-	-	-	-
	Type 53	-	100	80-100	70-90	55-80	-	35-60	25-50	-	-	-	5-10
Iowa	Crushed Stone	-	100	-	-	-	-	-	15-45	-	-	-	0-10
	Gravel	-	-	100	90-100	-	75-100	-	-	30-55	-	-	-
Michigan	Open-graded drainage course	-	100	85-100	-	40-70	-	-	15-35	-	-	-	0-5
	Dense graded aggregate	-	-	100	90-100		65-85	-	30-50	-	-	-	4-8

Table 2.14 (Cont.) Gradation Characteristics of Granular Base/Subbase Layers Under Shoulders Adjacent to Concrete Pavements

State (1)	Granular Material (2)	Percent Passing Sieve Size											
		2 in. (50 mm) (3)	1½ in. (37.5 mm) (4)	1 in. (25 mm) (5)	¾ in. (19 mm) (6)	½ in. (12.5 mm) (7)	3/8 in. (9.5 mm) (8)	#4 (4.75 mm) (9)	#8 (2.36 mm) (10)	#10 (2mm) (11)	#16 (1.18mm) (12)	#40 (425 µm) (13)	#200 (75µm) (14)
Minnesota	Class 5- dense graded aggregate for bases	-	-	100	90-100	-	50-90	35-80*, 35-70**	-	20-65*, 20-55**	-	10-35	3-10
	Class 3- aggregate for subbases	100	-	-	-	-	-	35-100	-	20-100	-	5-50	5-10

Table 2.14 (Cont.) Gradation Characteristics of Granular Base/Subbase Layers Under Shoulders Adjacent to Concrete Pavements

Wisconsin	Open-graded base course #1	-	-	100	90-100	-	20-55	0-10	0-5	-	-	-	-
	Open-graded base course # 2	-	-	100	-	-	45-65	15-45	-	0-20	-	0-10	0-5
	Crushed stone gradation #1 (for top layer of base course		100	-	-	-	30-65	25-55	-	15-40	-	-	2-12
	Crushed stone gradation #2 (for lower layer of base course			100	-	-	40-75	25-60	-	15-45	-	-	3-12
*Applies when the aggregate contains 60% or less of crushed quarry rock. **Applies when the aggregate contains more than 60% crushed quarry rock.													

Table 2.15 Subsurface Drainage Practices for Paved Shoulders Adjacent to Concrete Pavements

State (1)	Drainage System Type (2)	Type of Shoulder with Drainage System (3)	Conditions for use (4)	Location (5)	Pipe type (6)
Illinois	Geotextile wrapped aggregate with pipe	PCC	-	Edge of shoulder for 30-yr design and edge of mainline pavement for 20-yr design.	Corrugated polyethylene
Indiana	Graded aggregate around pipe	AC and PCC	Pavement length is greater than 600 m and ADT>3000 veh/day	Edge of mainline pavement	Corrugated PVC
Iowa	Graded aggregate around pipe	AC and PCC	Required with drainable bases	Edge of mainline pavement	Polyethylene
Michigan	Geotextile wrapped aggregate with pipe	AC and PCC	Recommendation comes from soils engineer and is dependent on soil conditions	2 ft. (0.6 m) off of mainline when no curb and gutter; under curb and gutter if present.	Stiff, smooth-walled PVC; Corrugated PVC
Minnesota	Geotextile wrapped aggregate with pipe; Graded aggregate around pipe.	AC and PCC	-	Edge of mainline pavement	Stiff, smooth-walled PVC; Corrugated PVC
Wisconsin	Geotextile wrapped aggregate with pipe	AC only if open-graded base course is specified	Required with open-graded base course	Edge of mainline pavement	Corrugated polyethylene; smooth-walled PVC

2.5.4 Maintenance Practices for Flexible Shoulders

A policy which ensures that all concerned parties are aware of the importance of providing adequate maintenance to the shoulder, and that necessary resources are made available to implement the required policy, are requisites for effective shoulder maintenance. A comprehensive maintenance program will include: routine inspection and monitoring, preventive maintenance strategies, spot detection of an actual or potential problem, repair, and continued monitoring as well as feedback to design and construction units. In the survey of selected midwestern states, responses regarding current policies and procedures for shoulder maintenance as they relate to each of these phases of maintenance are summarized.

2.5.4.1. Maintenance Policies

A routine maintenance policy enables shoulder problems to be identified prior to the occurrence of shoulder damage and/or early appearance of distress on the surface. A formal maintenance policy also implies that management is clearly aware of this importance and fully supports maintenance activities that are essential in achieving optimum performance of the shoulder and the roadway system.

The survey indicated that only 7 of the 22 (31.8%) responding SHA districts reported having a formal maintenance program. The remainder overwhelmingly reported that maintenance on an as-need basis was the norm. Only one SHA district (in Wisconsin) attributed the lack of funding as the main reason for not having a formal shoulder maintenance program. Of the 7 districts that reported having formal maintenance programs, 3 indicated that their programs are tied to the agencies' overall pavement management systems (PMS). They indicated that some measures of the following distresses are used as the indicator of shoulder performance: shoulder drop-off or settlement, edge raveling, potholes, cracking, and general surface deterioration. Districts in Minnesota, for example, have specified distress level criteria for triggering specific asphalt shoulder maintenance treatments. An average shoulder settlement of at least 1 inch (25 mm) occurring on roadways with at least 10,000 ADT will require shoulder work to be scheduled and the problem fixed within a year. The critical settlement level is set at a minimum of 1.6 inches (40 mm) for roadways with less than 10, 000 ADT.

The survey also indicated that SHA districts overwhelmingly recognize the significant functions of the shoulder. Yet, when asked to indicate the level of attention given to shoulder maintenance in comparison to mainline pavements, 18 (81.8%) of the districts indicated that little to very little attention is given to the shoulder. Only 2 (9.1%) reported equal attention given to the shoulder as the mainline. Regarding the allocation of highway maintenance resources, 7 (31.8%) of the districts reported allocating less than 5% of their agencies' highway maintenance resources to shoulders, 8 (36.4%) reported allocating between 5 and 10%, while the rest allocated at least 10%. The highest allocations came from two districts in Ohio where one district estimated a value of 28% and the other 37%.

2.5.4.2 Preventive Maintenance Programs

The main components of a preventive maintenance program include inventory, inspection survey, and scheduling. Fourteen districts (63.6%) reported having at least one component of a preventive maintenance program. Inspection survey was the most common component reported by the SHA districts. Only one district (from Illinois) reported having a complete program. Three districts had both inspection survey and scheduling but not inventory.

With regard to shoulder inspection surveys, the districts reported using visual methods. However, very few districts have inspection survey forms or instructions. The frequency of inspection survey varies from district to district even within the states. Frequencies reported ranged from intermittent to annually. Two districts reported conducting inspection surveys after heavy rainstorms.

2.5.4.3 Causes of Premature Failures in Paved Shoulders

Respondents were asked to indicate the causes of premature failures in paved shoulders. Table 2.16 shows that almost all districts reported that they experienced premature failure of concrete and asphalt shoulders to some degree. More than 50% of respondents did not attribute concrete shoulder failure to thickness. Only one district in Illinois indicated that concrete thickness inadequacy is always a cause of failure in its district. Shoulder drainage appears to be a primary concern to the districts, 14 (87.5%) of 16 respondents indicated that shoulder drainage has sometimes or always been a cause of premature failures in concrete shoulders.

For asphalt shoulders adjacent to concrete mainline pavements, all the factors identified in Table 2.16 generally result in premature failure as reported by the districts. Where frost heaving was a cause, districts reported an average heave of 1 to 2 inches (25 to 50 mm).

Table 2.16 Degree of Causes of Premature Failures in Paved Shoulders Adjacent to Concrete Pavements

Shoulder Type Adjacent to Mainline Concrete (1)	Cause of Premature Failure (2)	Number of Districts Responding		
		Always (3)	Sometimes (4)	Never (5)
Concrete	Inadequate thickness	1	5	9
	Inadequate treatment of mainline-shoulder joint system	0	13	2
	Poor shoulder joint construction	2	8	4
	Inadequate shoulder drainage	4	10	2
	Inadequate maintenance	1	10	2
Asphalt	Inadequate thickness	3	14	2
	Truck encroachment	4	13	1
	Inadequate treatment of mainline-shoulder joint system	1	17	1
	Poor shoulder joint construction	1	17	2
	Inadequate shoulder drainage	3	16	1
	Inadequate maintenance	0	17	1
	Frost	2	15	1

2.5.4.4 Maintenance Treatment Practices

Table 2.17 identifies shoulder maintenance treatment practices and their corresponding life expectancies reported by the districts. Patching and pothole repair for concrete shoulders seem to be popular among the districts. For asphalt surfaced shoulders, crack sealing and patching are the most common types of maintenance treatments performed by the districts. Life expectancies of the various treatments vary from state to state. Where overlays are used, the thickness range reported for the indicated life expectancies was 0.5 to 2 inches (13-50 mm).

Table 2.17 Life Expectancies of Paved Shoulder Maintenance Treatments

Shoulder Type (1)	Shoulder Maintenance Treatment Type (2)	Expected Service Life (years)						
		WI (3)	IL (4)	IA (5)	MN (6)	IN (7)	MI (8)	OH (9)
Concrete	Crack sealing	3-5	X	-	5-15	2-3	-	3
	Patching	5-10	5	-	X	X	X	0.5-5
	Pothole repair	1-2	.5-2	-	X	X	X	5-8
	Mainline-shoulder joint repair	3-5	X	-	X	-	-	3-5
	Diamond Grinding	6-8	-	-	X	-	-	3-5
Asphalt	Crack sealing	3-10	5-10	5	X	2-3	X	3
	Patching	3-10	5	-	X	X	X	0.5-1
	Pothole repair	1-2	-	-	-	-	-	-
	Mainline-shoulder joint repair	3-5	5	2	X	-	-	0.5-1
	Surface treatment	5-7	2-5	-	X	3-5	-	-
	Overlay	5-10	10	-	X	-	X	-
	Wedging	8-10	X	-	15	-	-	-
Note: An "X" indicates that the treatment is performed but the expected life was not reported								

2.5.4.5 Relationship of Maintenance and Design

To fully evaluate and establish the most appropriate shoulder system components, formalized lines of communications are necessary between functional units involved in the design, construction, and maintenance of the pavement system.

The survey found that more than one-half (17) of the 22 districts indicated that their maintenance groups are involved in design decisions, at least in the project scoping and review process. One district in Wisconsin reported that it is mandatory for the maintenance group to attend four project development meetings during the project design phase to provide input. When respondents were asked whether there is a regular feedback system between maintenance and design to report maintenance issues, 12 (54%) of the 22 districts responded "yes". The type of feedback systems reported by these districts included: verbal communication, e-mail, and completing a post-construction report. One district in Wisconsin reported documenting premature failures on a form called the “Report on Early Distress” (RED) and relaying that to the design office.

Maintenance districts were asked to report on design changes that have been made to facilitate or reduce shoulder maintenance. One district (in Wisconsin) reported that volume requirements for paved shoulders have been reduced, consequently, reducing the frequency of grading gravel shoulder. Another district in the same state also indicated that wherever possible, a 3 to 5-inch (75 to 125-mm) asphalt shoulders are used to facilitate shoulder maintenance. One district in Minnesota also reported that the installation of edge drains on all new and reconstructed roadways has resulted in reduced shoulder maintenance. In Ohio, one district reported the substitution of asphalt shoulders with concrete shoulders especially in areas of heavy truck traffic has reduced maintenance.

There does appear to be feedback between maintenance and construction units, with 13 of 22 districts reporting that methods exist to report maintenance issues with construction practices. However, most feedback was reported to be informal. One Wisconsin district reported that the maintenance group attends the final walk-thru on a project and then after one winter season, provide a quality index rating on the project to the construction unit. When respondents were asked to identify construction changes that have been implemented to reduce or facilitate shoulder maintenance, only 2 districts (from Minnesota) responded and indicated that the construction of thicker shoulders has minimized shoulder maintenance.

2.6 Survey Summary and Conclusions

From the survey questionnaires, various elements associated with current paved shoulder practices for concrete pavements were examined for seven midwestern states. These elements included: policies and procedures for paved shoulder type selection, thickness determination and construction practices, maintenance practices, and functional interaction between maintenance, design, and construction units. On the basis of the examination, the following observations are made:

- Policies and procedures for paved shoulder type selection for concrete pavements varied from state to state. The main factors considered include functional classification, traffic and/or truck volume, construction and maintenance cost, and engineering judgment. Illinois is the only state that has a stringent policy of requiring concrete shoulders to be constructed for all mainline concrete pavements.
- When concrete shoulders are specified, states recommend the jointed plain concrete (JPC) type tied to the mainline at the longitudinal joint. In addition to JPC, Michigan uses jointed reinforced concrete shoulders.
- Paved shoulder thickness determination is based on agency specified standard thicknesses that have been established from past field observations or some modified versions of procedures outlined by the American Association of State

Highway and Transportation Officials (AASHTO). Where the AASHTO procedure is used, a proportion of the mainline design traffic is considered. For example, Wisconsin reported using a value of 2.5% for the design of its paved shoulders. In general, reported thickness for concrete shoulders ranged from a minimum of 6 in. (150 mm) to thickness equivalent to the mainline thickness. For asphalt shoulders a minimum value of 2 in. (50 mm) was reported.

- Paved shoulder maintenance efforts vary considerably between state highway agency (SHA) districts. Most SHA districts do not have formal shoulder maintenance programs; maintenance on as-need basis is the norm. Almost all SHA districts reported premature failures of both asphalt and concrete shoulders to some degree. In addition, the majority of SHA districts reported that little to very little attention is given to shoulders in their pavement systems.

With regard to shoulder maintenance improvements, there are no formalized lines of communication between the maintenance staff and the design and/or construction functional units in the SHA districts, except for Wisconsin. Only one district (in Wisconsin) reported having a standard form for documenting premature failures and relaying it to design and construction when necessary. Feedback on maintenance issues to design and construction units predominantly takes the form of verbal communication with occasional e-mails.

CHAPTER 3 FIELD PERFORMANCE SURVEYS

An important phase of the study was to conduct field performance surveys of paved shoulders. The Wisconsin Department of Transportation (WisDOT) does not, at the present time, conduct any formal condition surveys for long-term performance evaluation of its shoulders. Only the mainline pavements are surveyed biennially. Therefore, it was necessary to conduct field surveys of existing shoulders in order to be able to evaluate shoulder performance. The field surveys involved: (1) identification and selection of shoulders to be surveyed, (2) distress types to be measured and how to quantify them, and (3) pilot and field surveys. The following sections describe the process to collect valid field performance data.

3.1 Identification and Selection of Shoulders for Field Surveys

The research team met with Mr. Bill Ducket and Mr. Dave Frederichs of the WisDOT Pavement Management unit on November 14, 2001 to examine the WisDOT database to identify all rural concrete pavement projects completed over the last 30 years in Wisconsin. Urban sections (having adjoining curb and gutter) were excluded in the search since they do not conform to the basic requirement of a paved shoulder – no structural concrete or asphalt on the side opposite the mainline pavement.

It was recognized that the WisDOT database uses a special reference point (RP) system to identify pavement segments. This RP system is not, however, linked to project identification numbers typically found on as-built construction plans that reside at the various WisDOT district offices. Geographic Information System (GIS) maps showing the general locations of PCC mainline pavements for each district were, therefore, generated by Mr. Frederichs to aid the research team in identifying the needed as-built plans based on the highway name and termini. In the database review process, jointed reinforced concrete pavements (JRCP) were excluded on the advice of the WisDOT Rigid Pavement Technical Oversight Committee (TOC).

Between January and March 2002, the research team visited all the districts and obtained copies of as-built plans for all PCC projects with age less than 30 years. It was very difficult collecting all the appropriate plans, and in some cases a follow-up email or phone call was made to secure the correct plans. It was not possible to obtain construction data from the Districts, so this important data was not included in the study. Table 3.1 shows projects identified by shoulder type, age, and mainline PCC type.

Table 3.1 Identified Projects having Paved Shoulders

Shoulder Type (1)	Age, years (2)	Number of Paved Shoulder Projects by Mainline PCC Pavement Type		
		JPCP without Dowels* (3)	JPCP with Dowels* (4)	CRCP* (5)
Asphaltic Concrete	<15	21	11	2
	15-30	38	0	10
Composite (AC and PCC)	<15	10	82	0
	15-30	0	0	0
PCC	<15	0	0	3
	15-30	3	0	14
Monolithic	<15	0	0	7
	15-30	1	0	0
*JPCP= jointed plain concrete pavement; CRCP = continuously reinforced concrete pavement				

A new database consisting of the PCC mainline and shoulder characteristics was created from a review of the as-built plans. (An electronic copy of the database will be made available upon request.) After reviewing the database, the research team considered factors such as mainline PCC type, paved shoulder type, pavement regional location, functional classification, and surface age as crucial factors influencing performance. Hence, those projects expected to capture these influential factors were selected to be surveyed. These projects were all located on Interstate, U.S., and State Trunk Highway systems.

3.2 Shoulder Distress Types and Measurement

The majority of distress types that occur on mainline pavements are similar to those occurring on shoulders. The WisDOT *Pavement Distress Manual* [24], currently used to survey mainline pavements, was reviewed to identify distress categories that will be appropriate for shoulders. For AC shoulders, the following distresses were considered: cracking (alligator, block, longitudinal, transverse), patching, and outside edge raveling. For PCC shoulders, the following distresses were considered: distress joints/cracks, slab breakup, and longitudinal joint distress.

There was no category in the present WisDOT manual for assessing the longitudinal joint between mainline PCC pavements and the adjacent AC shoulder. From the literature, it has been suggested that the longitudinal joint between a concrete mainline pavement and an AC shoulder is the cause of considerable amount of shoulder distress [1]. Hence, a new distress category called longitudinal joint deterioration (LJD) was proposed. The proposed LJD included distortion (in the form of heave and settlement) and pavement breakup/fracture/spalling in the vicinity of the joint. This new distress category was presented to the WisDOT pavement monitoring staff (Mr. Mike Malaney, Mr. Dwight Johnson, and Mr. Bill Duckert) for their review and comments. The staff indicated that, on the basis of their field experience, it would be appropriate to measure separately, the distress components at the joint. Hence, shoulder settlement, heave, and breakup/fracture/spalling were included as additional distresses to be measured.

Distress measurement and factors were derived from the existing WisDOT *Pavement Distress Manual* for longitudinal and transverse distortion. These categories were presented to the Rigid Pavement TOC for their comment; the research team received no feedback.

After working with the pavement monitoring staff, the research team considered the distress categories shown respectively in Tables 3.2 and 3.3 for the measurement on AC and PCC shoulders.

Table 3.2 Selection of Distress Indicators for AC Shoulders

Number (1)	Pavement Distress Indicator (2)	Pavement Area Measured (3)	Comments (4)	Use as a Shoulder Distress Indicator (5)
1a	Block Cracking	Total pavement area	Diagram excludes shoulder	Yes. Use existing procedure.
1b	Alligator Cracking	Total pavement area	Cracking which occurs in an area that is not subject to traffic loading should be rated as block cracking	Yes. Use existing procedure.
2	Transverse Cracking	Total pavement area	6 ft. in length to be counted	Yes. Modify crack length to 25% of shoulder width, to allow a survey of those shoulders less than 6 feet wide.
3	Longitudinal Cracking	Total pavement area		Yes. Exclude area 2 feet from mainline-shoulder longitudinal joint
4	Patching	Total pavement area		Yes. Use existing procedure.
5	Flushing	Total pavement area (no restriction to wheel path)	Severity rating only. Severity rated to affect traffic safety and pavement surface friction. Focus on wheel paths.	Yes. Use existing procedure.

Table 3.2 (Cont.) Selection of Distress Indicators for AC Shoulders

6	Edge Raveling	Outer pavement edge-time marking to a distance one-foot *inside the traveled way* (within one foot on traffic side)	Used to describe break up of edge of the pavement	Yes. Use existing procedure.
7	Surface Raveling	Total pavement area		Yes. Use existing procedure.
8	Rutting	No less than 5 feet from transverse crack and no less than 3 feet from roadway centerline.		No. There is minimal traffic on shoulders, and transverse distortion indicator will measure cross-section distortion.
9	Longitudinal Distortion	Total pavement area		Yes. Exclude area 2 feet from mainline-shoulder longitudinal joint
10	Transverse Distortion	Total pavement area		Yes. Exclude area 2 feet from mainline-shoulder longitudinal joint
11	Segregation	Total pavement area	Not a distress indicator. Information only.	Yes. Information only.
12	Seal Cracking	Total pavement area	Not a distress indicator. Information only.	Yes. Information only.
13	Crack Filling	Total pavement area	Not a distress indicator. Information only.	Yes. Information only.
14	Longitudinal Joint Deterioration	Two feet on the paved shoulder side of longitudinal joint	New distress indicator proposed and implemented for this research study.	Yes. New procedure.
15	Heave	Longitudinal joint	New distress indicator proposed and implemented for this research study.	Yes. New procedure.
16	Settlement	Longitudinal joint	New distress indicator proposed and implemented for this research study.	Yes. New procedure.

Table 3.3 Selection of Distress Indicators for PCC Shoulders

Number (1)	Pavement Distress Indicator (2)	Pavement Area Measured (3)	Comments (4)	Use as a Shoulder Distress Indicator (5)
1	Slab Breakup	Total pavement area		Yes. Use existing procedure.
2	Joint Crack Filling	None defined.	Not considered a distress.	Yes. Use existing procedure.
3	Distress Joints/Cracks	Within 2 feet on either side of a joint or crack.		Yes. Use existing procedure.
4	Patching	Total pavement area		Yes. Use existing procedure.
5	Surface Distress	Total pavement area.	Does not include distresses within 2 feet of crack or joint.	Yes. Use existing procedure.
6	Longitudinal Joint Distress	Distress within 2 feet on either side of longitudinal joint.	Evaluates PCC mainline panels and excludes PCC shoulders	**Yes.** Use existing procedure, but only measure within 2 feet on shoulder side of joint.
7	Transverse Faulting	2 to 3 feet from both the outside and inside pavement edge.	Evaluates PCC mainline panels and excludes PCC shoulders	Yes. Use existing procedure.

3.3 Pilot and Surveys

On March 19, 2002, the research team met with Mr. Malaney and Mr. Johnson of the WisDOT pavement monitoring unit to conduct trial surveys of paved shoulders on USH 151 near Sun Prairie, Wisconsin. The survey used new shoulder field survey forms created by the research team. The half-day training provided the research team the necessary tools to engage in a field survey encompassing several road networks. In addition, the research team had prior training in field surveys in the UW-Platteville CEE 4520 Pavement Rehabilitation course. The Principal Investigator, Dr. Samuel Owusu-Ababio, also has prior experience in conducting field performance surveys for a Connecticut DOT LTPP study.

Field surveys began late March 2002, and proceeded from the southern to northern regions of the state. Field surveys concluded on July 3, 2002. The research team was unable to obtain a formal frost detection procedure from WisDOT, thus, no physical measurements were made during field data collection. Frost determination was made by contacting local cemeteries, a common practice of WisDOT field staff. No cemetery reported frost in the ground.

During the data collection period, a total of 133 projects were surveyed. Table 3.6 provides the number of surveyed projects by shoulder type, age, and mainline PCC type.

The team realized during the pilot and field surveys inherent difficulties in collecting reliable and necessary data for all distress categories. Discussion with WisDOT pavement monitoring staff, and an internal evaluation by the research team, resulted in a reduced number of measurable distress categories and necessary modification of the survey forms. The revised forms used for all surveys are included as Appendix E in this report.

Distress indicators used by WisDOT for mainline PCC pavement performance, and omitted from the concrete shoulder performance analysis include surface distress, joint crack filling, and patching. Transverse faulting was not observed during initial field observations, and was subsequently omitted. Distress indicators excluded from the asphalt shoulder performance analysis were block and alligator cracking, flushing, surface raveling, rutting, longitudinal and transverse distortion, and segregation. Longitudinal and transverse distortions were evaluated with the new heave and settlement distress categories. The longitudinal joint deterioration category was added to evaluate a region 2 feet on the paved shoulder side of the longitudinal joint. Block and alligator cracking were omitted since 269 and 277 of a total 289 project segments (93% and 96%) had no observed distress, respectively. Patching was omitted since a near-equal low frequency was observed. For a complete description and sample photos of measured distresses, see Appendices F and G.

Table 3.6 Surveyed Projects

Shoulder Type (1)	Age, years (2)	Number of Paved Shoulder Projects by Mainline PCC Pavement Type		
		JPCP without Dowels* (3)	JPCP with Dowels* (4)	CRCP* (5)
Asphaltic Concrete	<15	10	4	1
	15-30	26	0	3
Composite (AC and PCC)	<15	10	62	0
	15-30	0	0	0
PCC	<15	0	0	2
	15-30	1	0	9
Monolithic	<15	0	0	4
	15-30	1	0	0
*JPCP= jointed plain concrete pavement; CRCP = continuously reinforced concrete pavement				

The following general field observations were made:

a) Significant joint openings overgrown with weeds are associated with PCC pavements having asphalt shoulders (see Figure 3.1). The AC component of this composite shoulder on Hwy 29 has no vertical displacement, but has separated horizontally from the PCC slab creating a wide joint opening partially covered with weeds.

Figure 3.1 An Open Joint Partially Covered with Weeds

b) Distresses on the PCC portion of a composite shoulder were observed to be a progression from the mainline (see Figure 3.2). In this instance, only general observations were made in the field and documented. No formal measurements were taken on the PCC portion of the composite shoulder. All effort was concentrated on the joint and the adjacent AC component. Figure 3.2 shows a composite shoulder with a slab breakup on the PCC portion of the shoulder. The breakup appears to be the result of the fracture that has occurred within the entire slab.

Figure 3.2 Composite Shoulder Distress – Migrating Longitudinal Crack

c) The majority of slab breakup in concrete shoulders involved the grooves of rumble strips (see Figure 3.3). A combination of reduced thickness and localized depression has provided an opportunity for crack propagation.

Figure 3.3 Concrete Shoulder Fracture in Groove of Rumble Strip

CHAPTER 4 PERFORMANCE DATA ANALYSIS

A comprehensive analysis was conducted on the collected data to understand relationships among key variables in paved shoulder performance and to provide the framework for developing guidelines for designing and maintaining paved shoulders. The data analysis focused on understanding responses in field shoulder performance indicators to design, traffic, environmental, and maintenance inputs.

4.1 Methodology

Traditionally, field survey data are used to compute the WisDOT Pavement Distress Index (PDI). The concept of a pavement performance index has been widely used by state highway agencies. Combined indices such as the pavement serviceability index (PSI), pavement condition index (PCI), and the WisDOT PDI have been established to measure pavement performance. There are, however, major concerns associated with the use of such combined indices of performance. These problems have been outlined by Paterson [25] and include:

a) Different types of maintenance are appropriate for different levels of each distress type.

b) The relative seriousness of different defects varies with the pavement type, environment, the rate of deterioration and the maintenance program in place.

c) Each distress type evolves at different rates in different pavement types and under different traffic and environmental conditions.

The problems outlined by Paterson [25] suggest that modeling the performance of shoulders using a combined index, such as the PDI, requires determining the average amount of distress effects from the many different combinations of distresses encountered on the shoulder. This method has the potential to yield results that have wide variances that, in turn, may suppress the very effects of interest. The modeling approach adopted in this study, therefore, is a shift from the combined index (PDI) approach to a more versatile approach in which major distress modes are individually modeled to better analyze and explain the relationship between distress progression and its influential factors.

The analysis of performance data began by creating separate extent and severity values for each of the individual distresses observed. This approach was used to allow a direct analysis of the subject distress without the confounding effect of the WisDOT Pavement Distress Index (PDI) approach. Then, using WisDOT procedures, the extent and severity values were combined to yield a Shoulder Distress Index Factor (SDIF) for the individual distresses observed. Thus, three performance indicators were created for each distress:

(1) Extent, (2) Severity, and (3) SDIF. The SDIF is identical to the mainline PDI factors used by WisDOT, with a separate designation exclusive for shoulders. For the new distresses (settlement, heave, longitudinal joint deterioration) introduced in this study, Table 4.0 shows the distress factors used. These factors were derived from WisDOT established factors pertaining to the following distresses: longitudinal distortion, transverse distortion, edge raveling, and transverse faulting. These distresses exhibit characteristics similar to those identified in Table 4.0.

Table 4.0 Distress Factors for Selected Distresses on AC Surfaced Shoulders Adjacent to PCC Pavements.

Distress	Severity	Extent		
		1-24%	25-49	50+
Settlement	1	0.877	0.605	0.364
	2	0.846	0.557	0.324
	3	0.766	0.504	0.270
Heave	1	0.925	0.731	0.514
	2	00.892	0.673	0.457
	3	0.808	0.609	0.380
Longitudinal joint deterioration	slight	0.987	0.958	0.783
	moderate	0.951	0.882	0.697
	severe	0.916	0.798	0.580

Equation 4.1 provides the basic model used to relate performance with the design, traffic, environment, and maintenance inputs. This equation provided the general framework for the statistical analysis. Construction, a key component of paved shoulder performance, was omitted from the model due to difficulty in securing construction data and records from the Districts.

$$\text{Performance} = \text{Design} + \text{Traffic} + \text{Environment} + \text{Maintenance} + \text{Interactive Effects} + \text{Unexplained Variability} \quad (4.1)$$

Performance was the dependent variable in the analysis, and was classified using the three categories described earlier (Extent, Severity, and SDIF). Tables 4.1 and 4.2 provide the associated levels of Extent and Severity for concrete and asphalt shoulders, respectively, that were observed. (Please see the WisDOT *Pavement Distress Manual* for full descriptions of the distresses and levels for extent and severity [24]).

Table 4.1 Levels of Concrete Shoulder Distress Indicators Observed in the Field

Distress (1)	Extent Levels (2)	Severity Levels (3)
Slab Breakup	0, 1, 2, 3, 4	0, 1, 2, 3, 4, 5, 6, 7, 8
Distress Joints/Cracks	0, 1-2, 3-4, 5+	0, 1, 2
Longitudinal Joint Distress	0, 1, 2	None

Table 4.2 Levels of Asphalt Shoulder Distress Indicators Observed in the Field

Distress (1)	Extent Levels (2)	Severity Levels (3)
Transverse Cracking	0, 1, 2, 3	0, 1, 2
Longitudinal Cracking	0, 1, 2	0, 1, 2, 3
Edge Raveling	None (severity measured only)	0, 1, 2, 3
Heaving	0, 1, 2, 3	0, 1, 2, 3
Settlement	0, 1, 2, 3	0, 1
Longitudinal Joint Deterioration	0, 1, 2, 3	0, 1, 2, 3

Tables 4.3 and 4.4 provide the levels for design, traffic, environment, and maintenance for concrete and asphalt shoulders, respectively. The selected variables were limited by collected data during field performance surveys. For both concrete and asphalt shoulders, the factors thought to affect performance are similar and include: shoulder layer characteristics (such as thickness, unbound layer and subgrade strength, material type, and drainage), traffic, highway functional classification, maintenance, and environmental factors such as age and shoulder regional location.

The regional location variable was used as a surrogate for climate. The state was broken into three distinct regions (North, Central, and South) as shown in Figure 4.0. These regional borders follow that established by the Wisconsin State Cartographers Office [28] for the Wisconsin State Plane Coordinate System. The average annual temperature varies from 39ºF in the north to about 50ºF in the south [29].

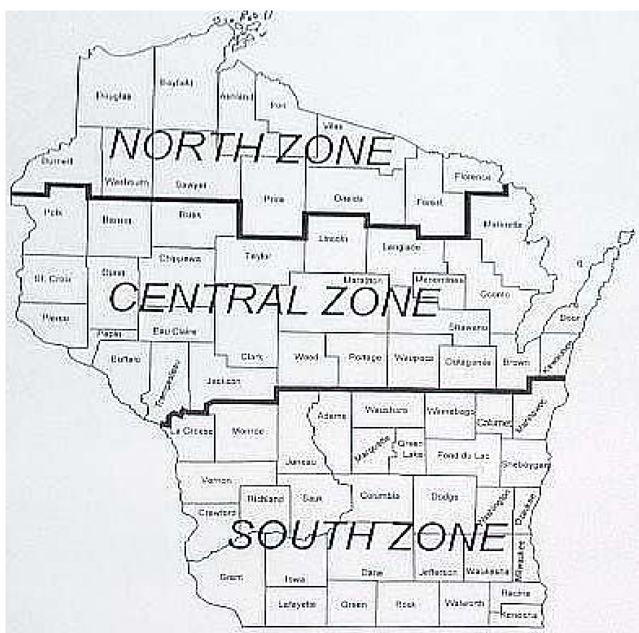

Figure 4.0 Shoulder Regional Location Map

Table 4.3 Observed Levels for Concrete Shoulder Input Variables

Category (1)	Variable (2)	Levels (3)
Design	Joint Spacing Modulus of subgrade reaction, K Shoulder Base Thickness Mainline PCC Thickness	15, 18, 20 feet 162.5, 175, 187.5, and 300 pci 8, 10, 19 inches 8 and 10 inches
Traffic	Functional Class 2002 ESALs 2002 AADT 2002 Truck Volume	Interstate, U.S., State Trunk Hwy. Random Levels Random Levels Random Levels
Environment	Regional Location Age	North, Central, South Random Levels
Maintenance	None	----

Table 4.4 Observed Levels for Asphalt Shoulder Input Variables

Category (1)	Variable (2)	Levels (3)
Design	Base Gradation Shoulder Type Shoulder Width Shoulder Thickness Shoulder base thickness PCC Mainline Thickness PCC Mainline Width PCC Mainline Type Soil Support Value (SSV) Edge Drain Edge Drain Offset	CABC, OGBC AC, Composite 3, 6, 8, 10 feet 3, 4 inches 4,6,7,8,9,10,11,12,13,14,15,16,17,18,19 8, 9, 10, 11, 12 inches 11, 12, 14, 15.5, 16 feet 5 (without dowels), 8 (with dowels) 4.0, 4.1, 4.3, 4.4, 4.5, 4.8, 5.4, 5.5 Yes, No 0, 2 feet
Traffic	Functional Class Estimated 2002 ESALs Estimated 2002 AADT Estimated 2002 Truck Volume	Interstate, U.S., State Trunk Hwy. Random Levels Random Levels Random Levels
Environment	Regional Location Age	North, Central, and South Random Levels
Maintenance	Longitudinal Joint Crack Filling	Filled, Not Filled Yes, No, Need More

Input variables for concrete shoulders having no change in levels that were omitted from the analysis were PCC mainline width (12 feet or 3.6 meters), PCC shoulder width (10 feet or 3.0 meters), PCC shoulder thickness (6 inches or 15 cm), and functional class (Interstate Highways only). Those input variables for asphalt shoulders with no change in levels included AC shoulder slope of 4%.

The modeling process consisted of two phases: a preliminary phase and a model-building phase. The former phase used an analysis of variance (ANOVA), scatter plots, and correlations to identify key input variables (design, traffic, environment, and maintenance) having an effect on the extent, severity, and SDIF of the major distresses predominantly observed on paved shoulders. The extent provides information on the frequency of occurrence while the severity indicates the seriousness of the distress. From a designer's point of view, the influential factors for the extent and severity can provide a basis for design modifications. For example, if a high frequency or severity level of cracking on asphalt shoulders is related to the environment, an investigation will be warranted and proper materials recommended. Such is the case with the new Superpave^{TM} technology where the asphalt binder is designed for anticipated low and high pavement temperatures. The combination of the severity and extent is also needed for determining the type and level of maintenance work to be performed, and consequently, aid in the life-cycle cost analysis associated with specific maintenance alternatives.

Two standard statistics were calculated and used to determine significance: (1) F-value and (2) p-value. The F-value was calculated from the ratio of variances, then the probability level of significance, or p-value, was calculated. Equation 4.2 shows how the F-value for each distress indicator was calculated from the ratio of variability in each input variable (design, traffic, environment, and maintenance) to the unexplained variability (error):

$$F_{\text{Ext, Sev, or SDIF}} = \frac{\text{MS (Input Variable)}}{\text{MS (Error)}} \tag{4.2}$$

The latter phase of model building consisted of simple and multiple regressions, using key input variables and distresses to build models that express the quantitative relationship among inputs and resulting performance output, as measured by the SDIF. For example, for concrete shoulders, the three major distress modes (slab breakup, distress joints/cracks, and longitudinal joint distress) were modeled separately to understand their dependence upon the independent variables of design, traffic, and environment.

The regression models were calculated using the method of ordinary least squares, where a relationship between the predictor and response variables was determined by minimizing the square of the difference between observed and fitted values. The overall quality of the regression equations was then measured by the coefficient of simple determination, or R-squared. The R-squared value was expressed as a percentage of explained variability to total variability.

Two stepwise procedures were used to formally select predictor variables that could potentially explain additional variation in the response variable: (1) forward selection procedure, and (2) backward selection procedure. Forward selection incrementally tested entering variables and retains significant variables in the regression equation using a p-value of 0.05. Backward selection started with a full equation of variables and eliminated insignificant variables based on the same p-value of 0.05. Models were considered stable if the forward and backward procedures yielded the same model.

The basic equation used in the multiple regression models in shown in Equation 4.3.

$$Y = \beta_0 + \beta_1 * X_1 + \beta_2 * X_2 + \ldots + \beta_{p-1} * X_{p-1} \tag{4.3}$$

Where,

Y = response variable (SDIF);

β_0 = regression constant (intercept for linear regression);

$\beta_{1, 2, p\text{-}1}$ = variable constant (slope for linear regression); and

$X_{1, 2, p\text{-}1}$ = predictor variables (design, traffic, region, age, and maintenance).

Multiple linear regression models were evaluated using the following criteria:

a) Test of significance of regression (F-test) to assess the overall significance of fitting the regression equation.

b) Test of significance of each variable (t-test) to determine the importance of each variable in the regression equation.

Where severe multicollinearity existed among regressor (independent) variables, ridge regression methods were used to combat the problem rather than eliminating key variables from the overall model. For example, multicollinearity may exist between regional location and AADT (more traffic in the southern region, and less traffic in the northern region). Multicollinearity can have serious effects on the estimates of the regression coefficients and on the general applicability of the estimated model [26]. Where multicollinearity was detected, a variance inflation factor procedure was applied to modify the regression coefficients and stabilize the model.

During development of each model, a key assumption was assessed: the residuals or errors were independently or identically distributed in a normal distribution with mean zero and some variance (IIDN). If this assumption was not met, as was the case with a majority of the runs, the model was rejected. In lieu of models, simple scatter plots or 95-percentile whisker plots were prepared to illustrate any potential relationship between the response (Extent, Severity, and SDIF) and independent variables (design, traffic, environment, and maintenance).

4.2 Concrete Shoulder Analysis

As previously mentioned, all concrete shoulders surveyed were jointed plain concrete (JPCP) type, 6-inch (150-mm) surface thickness, and adjacent to mainline continuously reinforced concrete pavements (CRCP). All sections were located on Interstate highways in the central and southern regions of Wisconsin. The estimated 2002 2-Way AADT ranged from 24,300 to 80,585 vehicles per day for the Interstate pavements. The pavement thickness ranged from 8 inches (200 mm) to 12 inches (300 mm) on a 6-inch (150-mm) crushed aggregate base course. The outside lane width consisted of 12-foot (3.6-m) lanes. A statistical summary of the shoulder characteristics is shown in Table 4.5.

Table 4.5 Statistical Characteristics of Concrete Shoulders

Shoulder Property (1)	Range (2)	Mean (3)	Standard deviation, σ (4)
Surface age (years)	14-23	18.2	2.6
Base thickness, in. (mm)	8-19 (200-475)	9.9	2.5
Joint spacing, ft. (m)	15-20 (4.5-6.0)	16.5	2.27
Modulus of subgrade reaction, K (pci)	162.5-300	175.8	40.0

4.2.1 ANOVA Results

Results of the ANOVA are provided in Table 4.6. Three levels of significance are provided in the table in an effort to assess the relative significance of each independent variable.

Table 4.6 ANOVA Results for Concrete Shoulders

Dependent Variable	Independent Variables								
	Design				Traffic			Environment	
	Joint Spacing	K	Base Thickness	PCC Thickness	ESALs Per day	Truck Volume	AADT	Regional Location	Age
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SLB_{Ext}	XXX	n/s	XXX	XXX	XXX	XXX	XXX	XXX	XXX
SLB_{Sev}	n/s	n/s	XXX	XXX	X	XX	XX	XXX	XXX
SLB_{SDIF}	n/s	n/s	XXX	XXX	X	X	X	XXX	XXX
DJC_{Ext}	n/s	n/s	XXX	XXX	XXX	XXX	XXX	XXX	XXX
DJC_{Sev}	n/s	XX	XX	XX	XX	XX	XX	XX	XXX
DJC_{SDIF}	n/s	n/s	XXX	XXX	XXX	XXX	XXX	XXX	XXX
LJD_{Sev}	n/s	n/s	XX	n/s	XX	XX	XX	n/s	XXX
LJD_{SDIF}	n/s	n/s	X	n/s	XX	XX	XX	n/s	XXX

DJC = Distress Joints/Cracks XXX = Highly Significant, p-value ≤ 0.01
SLB = Slab Breakup XX = Moderately Significant, 0.01 < p-value ≤ 0.05
LJD = Longitudinal Joint Distress X = Marginally Significant, 0.05 < p-value ≤ 0.1
n/s = Not Significant, p-value > 0.1
Ext = Extent; Sev = Severity level; SDIF = Shoulder Distress Index Factor

4.2.1.1 Slab Breakup

The design variables of shoulder base thickness and mainline outside-lane PCC thickness had a significant effect on both the extent and severity of slab breakup, while joint spacing only had an effect on the extent. All measures of traffic, as well as environmental measures of regional location and age, influenced the extent and severity of slab breakup. To support the ANOVA findings and help illustrate the relationships, simple plots were prepared as shown in Figures 4.1 through 4.5, that show the mean and range containing 95% of the observations. An interesting relationship was an increase in both the extent and severity with an increase in PCC mainline thickness (Figures 4.3 and 4.4). Figure 4.5 suggests a general trend where an increase in truck traffic caused an increase in the extent of slab breakup.

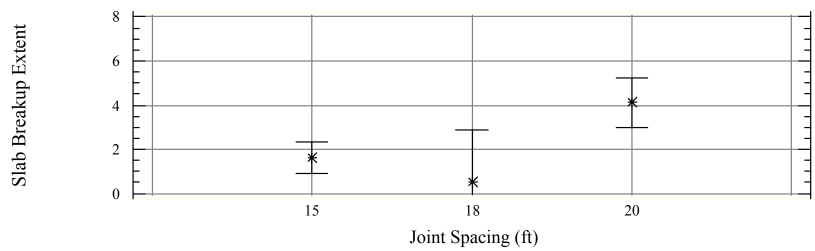

Figure 4.1 Slab Breakup Extent and Joint Spacing

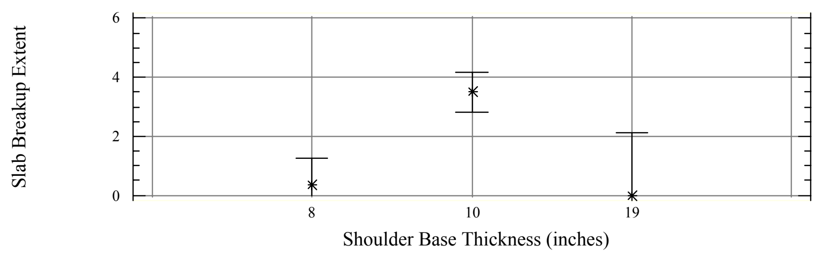

Figure 4.2 Slab Breakup Extent and Shoulder Base Thickness

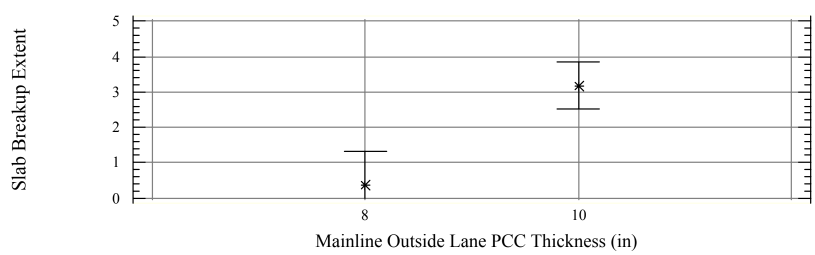

Figure 4.3 Slab Breakup Extent and PCC Mainline Thickness

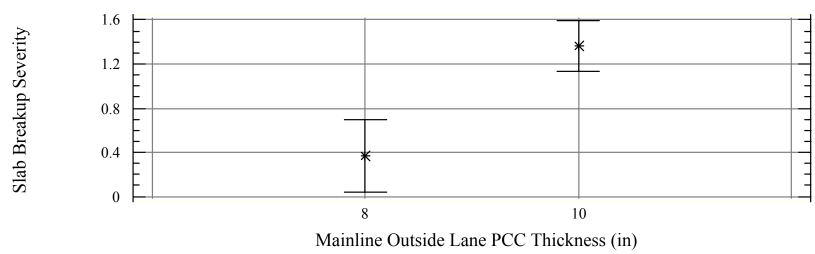

Figure 4.4 Slab Breakup Severity and PCC Mainline Thickness

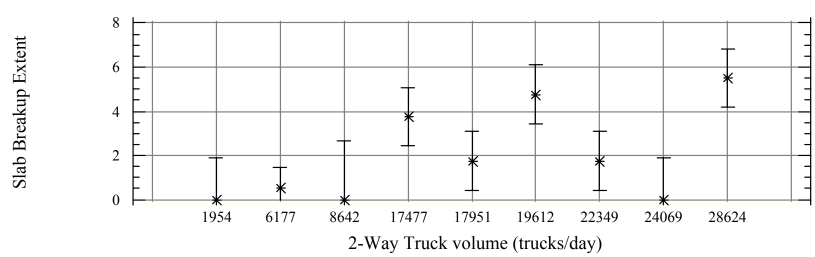

Figure 4.5 Slab Breakup Extent and Estimated 2002 Truck Volume

4.2.1.2 Distressed Joints/Cracks

Similar to slab breakup, the design variables of shoulder base thickness and PCC mainline thickness had a significant effect on both the extent and severity of distressed joints and cracks. Modulus of subgrade reaction was also significant, however, no trend was observed (see Figure 4.6). All traffic and environmental measures influenced the extent and severity of distressed joints and cracks. Simple plots were prepared as shown in Figures 4.6 through 4.10 to illustrate the relationships.

An interesting relationship was a decrease in extent and severity with an increase in traffic (Figure 4.9). Data also indicate a greater frequency of distress in the southern region of the state when compared to the central region (Figure 4.10).

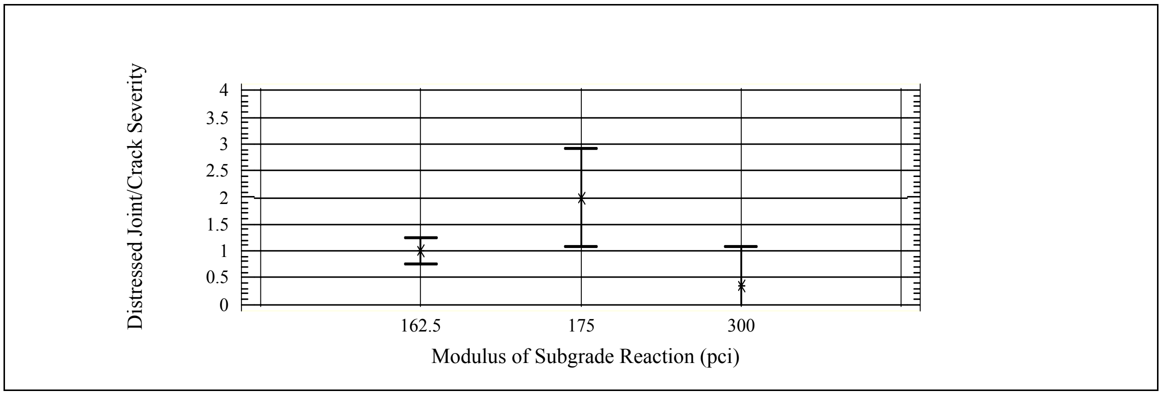

Figure 4.6 Distressed Joints/Cracks Severity and Modulus of Subgrade Reaction

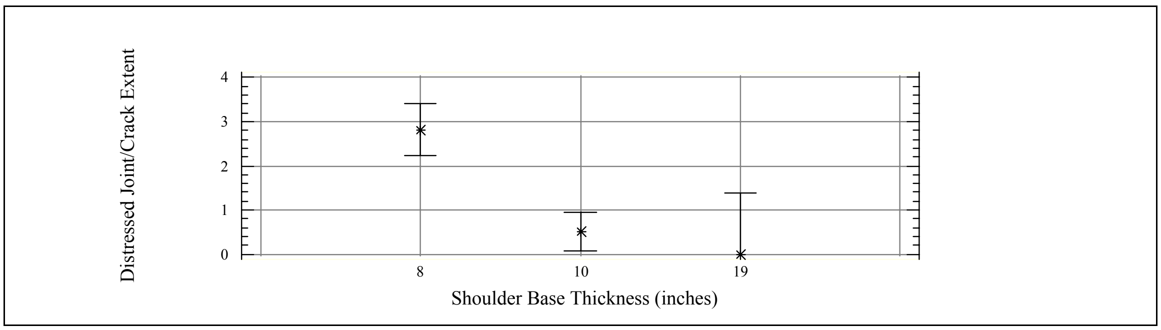

Figure 4.7 Distressed Joints/Cracks Extent and Shoulder Base Thickness

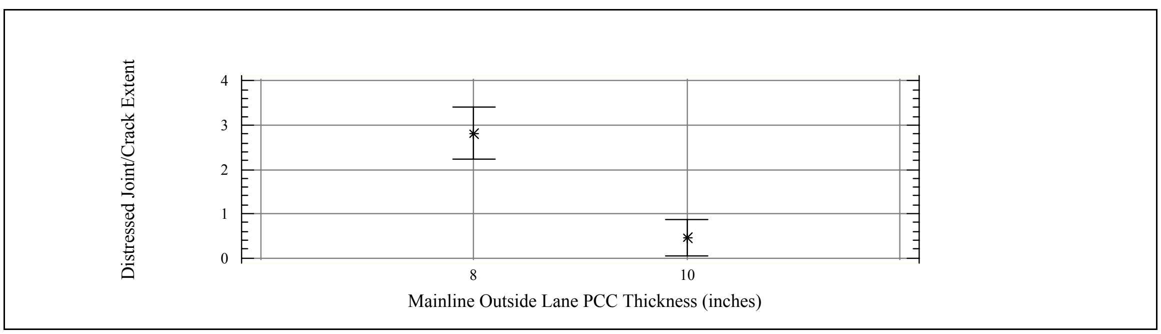

Figure 4.8 Distressed Joints/Cracks Extent and Mainline PCC Thickness

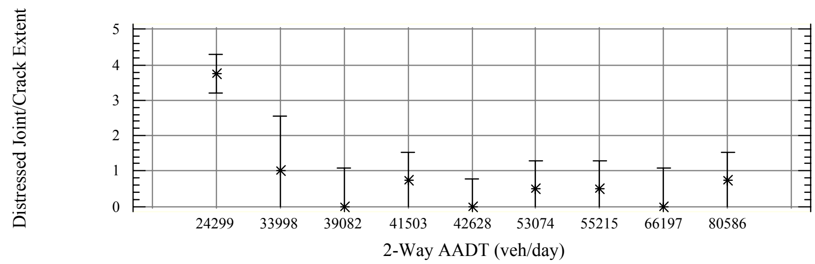

Figure 4.9 Distressed Joints/Cracks Extent and Estimated 2002 AADT

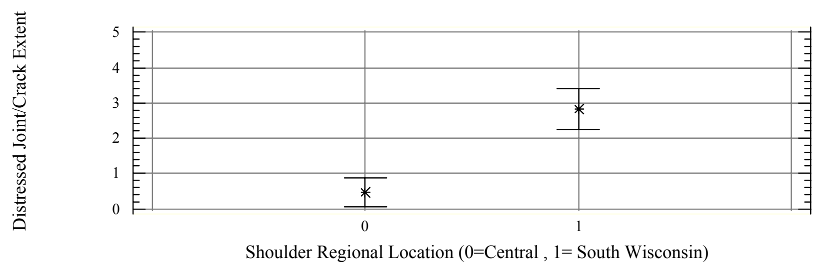

Figure 4.10 Distressed Joints/Cracks Extent and Regional Location

4.2.1.3 Longitudinal Joint Distress

Longitudinal joint distress, measured only by severity and the SDIF, was significantly affected by shoulder base thickness, all traffic measures, and age. However, Figures 4.11 through 4.13 illustrate that the change in mean levels, not a trend in the means, produced the significant effects. For shoulder base thickness, 8-inch and 10-inch thicknesses had similar severity levels, with a lower level for the 19-inch thick base (Figure 4.11). A random change in severity mean levels with traffic levels is shown in Figure 4.12. A positive trend was observed between severity and age (Figure 4.13).

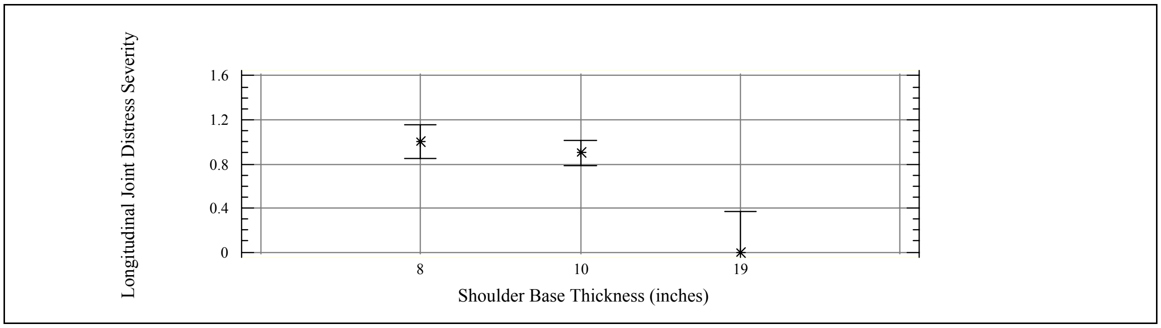

Figure 4.11 Longitudinal Joint Distress Severity and Shoulder Base Thickness

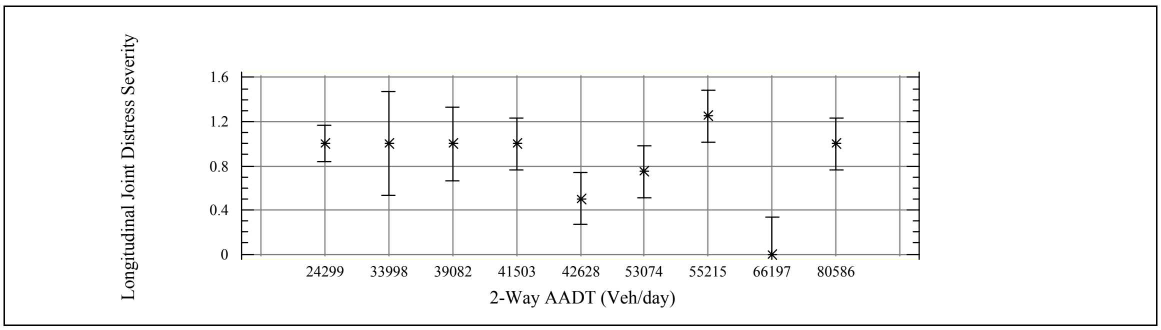

Figure 4.12 Longitudinal Joint Distress Severity and Estimated 2002 AADT

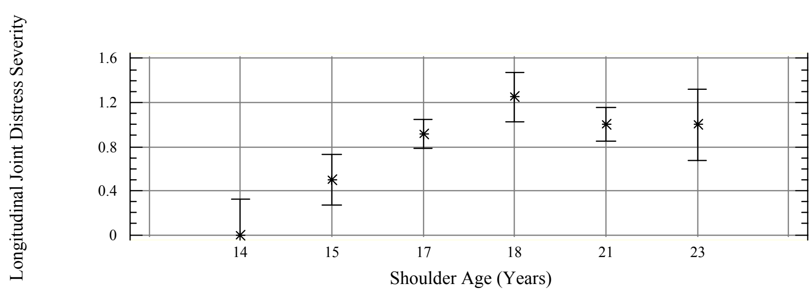

Figure 4.13 Longitudinal Joint Distress Severity and Age

4.2.2 Regression Models

Regression models were developed to numerically characterize the relationship of significant input variables with the computed SDIF for the three distresses. The developed models were then used to interface the performance relationship with design guidelines, life cycle costing, and maintenance policies in Chapter 5.

Table 4.7 provides regression models constructed from significant input variables having an effect on the measured SDIF. Several models were tested for each distress category to allow flexibility in model selection for development of guidelines. The coefficients for each input variable, accuracy (R^2), and degrees of freedom (df) are shown for each model. Standard diagnostic checks were made for each model, such as a plot of residuals versus fitted values to assess independence and normality of residuals. A test of outliers was also conducted and based upon this determination, the outlying data point was either accepted or removed from the model. Those models having a df less than 32 had an outlier removed from the model.

Table 4.7 Performance Models for Concrete Shoulders

Model # (1)	Form of Model (2)	Model R^2, % (3)	Df (4)
1	DJC_{SDIF} = 1.80045 – 0.0528554*Age	58.7	30
2	DJC_{SDIF} = exp (0.500624 – 6.287 / Base Thickness)	30.6	32
3	DJC_{SDIF} = 0.934636 – 0.205273 * Climate	38.6	32
4	LJD_{SDIF} = 1.02389 – 0.00345325* Age	28.1	31
5	LJD_{SDIF} = 0.920018 + 0.0041691 * Base Thickness	40.0	31
6	LJD_{SDIF} = 0.948081 – 0.0011162 * Age + 0.00337948 * Base Thickness	41.5	31
7	SLB_{SDIF} = 0.93576 + 0.0328227 * Climate – 0.00000146688 * AADT + 0.00849172 * Base Thickness	*53.5*	*31*

Regression modeling found that similar input variables had a significant effect on the three major distresses. The sign of the coefficients also supports the previous plots. Additional analysis of these equations can be found in Chapter 5.

4.2.3 Preliminary Recommendations for Concrete Shoulders

Findings from the ANOVA and simple plots yielded preliminary recommendations for enhancing the performance of concrete shoulders. Table 4.8 synthesizes design recommendations from the analysis, which were then used to develop the final guidelines in Chapter 5. Particularly, shoulder base thickness has a direct effect on the three shoulder distresses. Mainline PCC thickness had an effect, however, thicker pavements produced a higher extent and severity of slab breakup and distressed joints/cracks. Traffic levels had a random effect on distressed joints/cracks and longitudinal joint distress, while there was a clear positive correlation with slab breakup. Regional location and age had clear trends with all three distresses.

Table 4.8 Preliminary Design Considerations for Concrete Shoulders on Interstate Highways

Distress (1)	DESIGN OBJECTIVE IS TO MINIMIZE (2)	DESIGN ELEMENTS AND/OR VALUES FOR CONSIDERATION (3)	BASIS FOR SUGGESTED VALUES* (4)
Slab Breakup	Extent	a. Joint spacing: <20 feet b. Base thickness: >10 inches	a. Figure 4.1 b. Figure 4.2
	Severity	-	-
	Severity and Extent	Base thickness	Table 4.7(Model 7)
Longitudinal Joint Distress	Severity	Base thickness: ≥ 8 inches	Figure 4.11, Table 4.7(Model 5)
Distress Joint/Crack	Extent	a. Base thickness: ≥ 10 inches b. Mainline outside lane PCC thickness: ≥ 10 inches	a. Figure 4.7 b. Figure 4.8
	Severity	-	-
	Severity and Extent	Base thickness: ≥ 12 inches	Table 4.7, Model 2
* Table 4.6 for all parameters			

4.3 Asphalt Shoulder Component Analysis

Preliminary analysis of the asphalt data revealed the following shoulder configurations: (1) Asphalt-only shoulders adjacent to non-doweled jointed plain concrete pavements (Type 5), (2) Asphalt-only shoulders adjacent to dowel-jointed plain concrete pavements (Type 8), (3) Composite shoulders adjacent to Type 5, (4) Composite shoulders adjacent to Type 8, and (5) asphalt shoulders adjacent to Type 6 (CRC pavements). A composite shoulder consists of an extended PCC width beyond the striped white line plus a specified width of asphalt shoulder. The composite shoulders adjacent to Type 5 were similar in age to the composite shoulders adjacent to Type 8. Significant differences in age, however, existed between the asphalt-only shoulders adjacent to Type 5 and all Type 8 pavements. The significant age difference is due to a 1988 design policy change that exclusively specified Type 8 pavement construction [30]. Hence, a separate analysis was done for the asphalt-only shoulders adjacent to Type 5. In addition, since Type 8 is the recommended construction practice in Wisconsin, a comparative analysis was done regarding the composite shoulders adjacent to the Types 5 and 8 pavements for the purposes of validating the design policy regarding the Type 8 standard. Further analysis was conducted to compare Type 8 asphalt-only shoulders with Type 8 composite shoulders to check if the additional slab width (beyond the striped white line) for the latter has any impact on distress reduction. The analyses are described in the following sections.

4.3.1 Comparison of Asphalt-Surfaced Components of Composite Shoulders Bordering Type 5 and Type 8 Mainline PCC

Type 5 pavements have been built in Wisconsin for more than three decades. In 1988 however, a design policy that required Type 8 pavements to be built for better pavement performance went into place. Although Type 5 construction is gradually being phased out, a few have been built since 1988 with composite shoulders. The asphalt-surfaced components of composite shoulders built adjacent to Type 5 and Type 8 pavements were compared to validate the design policy regarding the Type 8 standard, rather than conducting detail analysis for the non-standard Type 5 pavement. The comparison was done by determining whether the differences in the means of the extent and severity levels of various key distresses (transverse cracking, edge raveling, longitudinal joint deterioration, and settlement) were significant. The basic statistical parameters for the two composite shoulder configurations are shown in Table 4.9. To check the significance of the difference in the means for the various distress levels, a t-test analysis was conducted and a summary of the t-test results is presented in Table 4.10.

Table 4.9 Descriptive Statistics for Composite Shoulders Bordering Types 5 and 8 Pavements.

Mainline PCC	Variable	Descriptive Statistic			
		Range	Mean	Std. Devia-tion	Observations, N
(1)	(2)	(3)	(4)	(5)	(6)
Type 5	Surface Age	1-14	10.9	4.6	25
	ESALs/day	99-685	336	205	25
	Shoulder surface thickness	2.5-3.0	2.9	0.2	25
	Mainline PCC thickness (in)	7-10	9.2	1.1	25
	Asphalt-surfaced width (ft)	5-8	6.0	0.7	25
Type 8	Surface Age	1-14	7.3	3.2	150
	ESALs/day	105-3646	718	816	148
	Shoulder surface thickness (in)	3-4	3.2	0.4	150
	Mainline PCC thickness (in)	9-12	10.2	0.9	150
	Asphalt-surfaced width (ft)	6-9	6.2	0.7	150

Table 4.10 T-test Results for Distresses on Composite Shoulders Bordering Type 5 and Type 8 Pavements

Distress Type and Property (1)	Significance of Difference in Means (2)
Transverse cracking extent	N/S
Transverse cracking severity	XXX
Outside edge raveling severity	XXX
Longitudinal joint deterioration extent	XX
Longitudinal joint deterioration severity	XXX
Settlement extent	XX
Settlement severity	N/S

XXX = Highly Significant, p-value ≤ 0.01
XX = Moderately Significant, 0.01< p-value ≤0.05
N/S = Not significant, p-value > 0.10

The analysis indicates that the difference in the mean severity levels for all the key distresses (except settlement) are highly significant (see Table 4.10). The mean severity levels for distresses on the shoulder bordering Type 5 are higher than those bordering Type 8 (see Figures 4.15, 4.16, 4.18, and 4.19). The differences in means for settlement extent and longitudinal joint deterioration are moderately significant. Longitudinal joint deterioration extent is higher for composite shoulders adjacent to Type 5 (see Figure 4.17). Although transverse cracking means are not significantly different as shown in Table 4.10, Figure 4.14 shows that higher extent levels do occur on shoulders adjacent to Type 5 than for those adjacent to Type 8. However, the extent of settlement is significantly lower for Type 5 shoulders than the Type 8 counterpart (see Figure 4.20). It is interesting to note from Table 4.9 that, the Type 8 carries a mean daily ESAL of 718, which is more than twice that of the Type 5, yet its overall shoulder performance supersedes that of Type 5. The superior performance of the Type 8 may be due to the presence of the dowels providing resistance to the damaging effects of traffic.

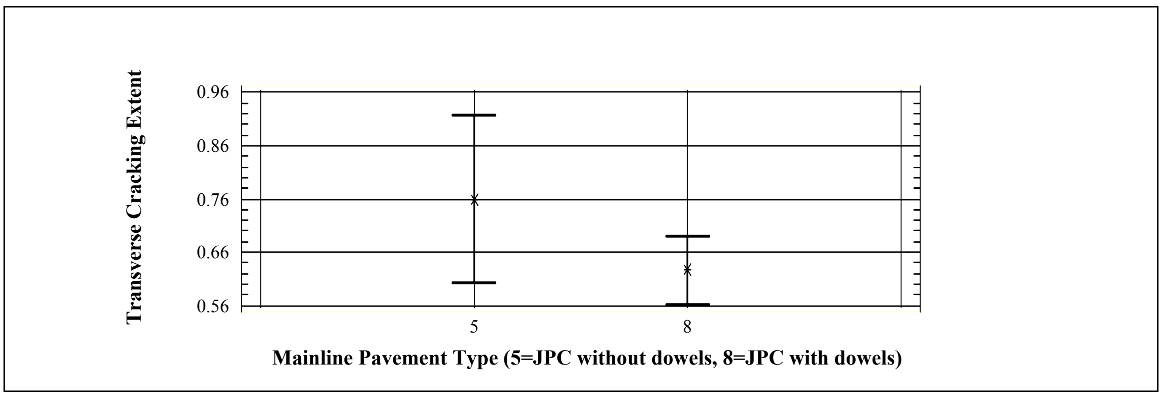

Figure 4.14 Transverse Cracking Extent Comparison for Composite Shoulders Adjacent to Type 5 and Type 8 Mainline PCC Pavements.

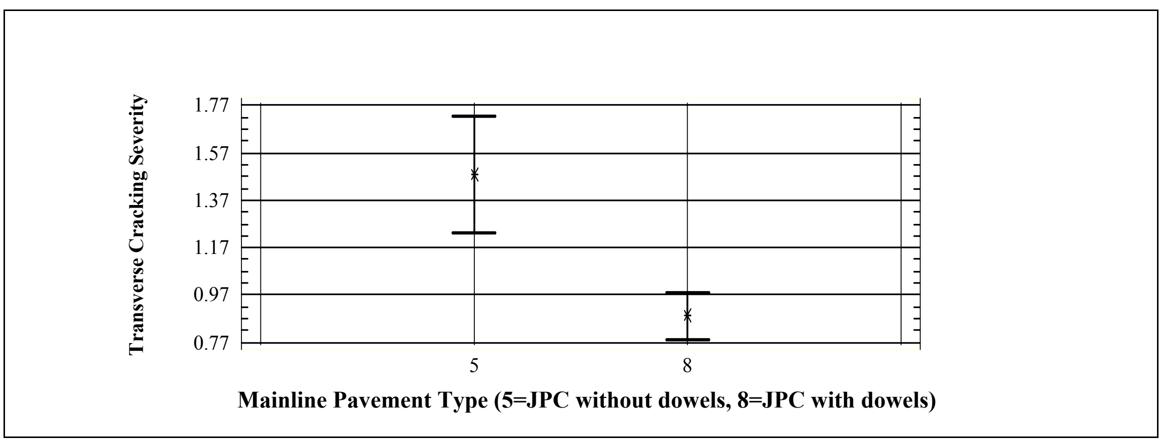

Figure 4.15 Transverse Cracking Severity Comparison for Composite Shoulders Adjacent to Type 5 and Type 8 Mainline PCC Pavements.

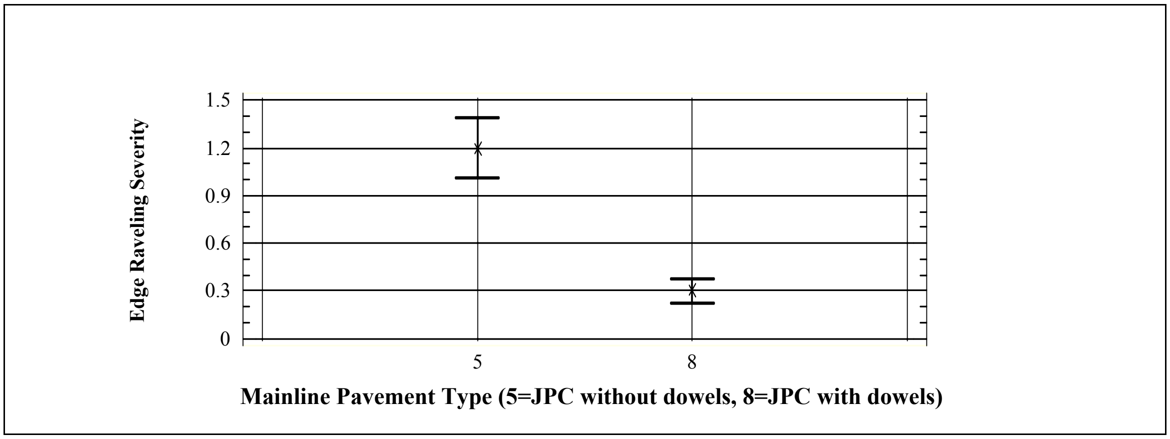

Figure 4.16 Edge Raveling Severity Comparison for Composite Shoulders Adjacent to Type 5 and Type 8 Mainline PCC Pavements.

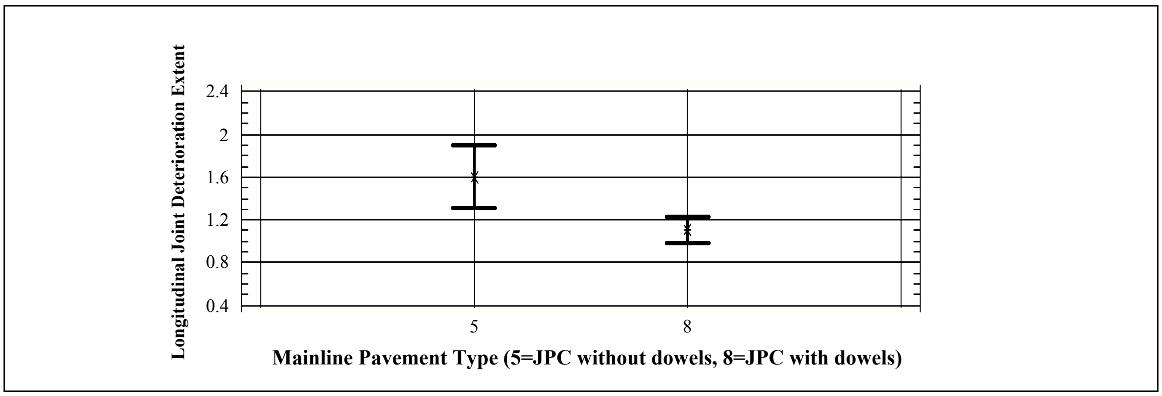

Figure 4.17 Longitudinal Joint Deterioration Extent Comparison for Composite Shoulders Adjacent to Type 5 and Type 8 Mainline PCC Pavements.

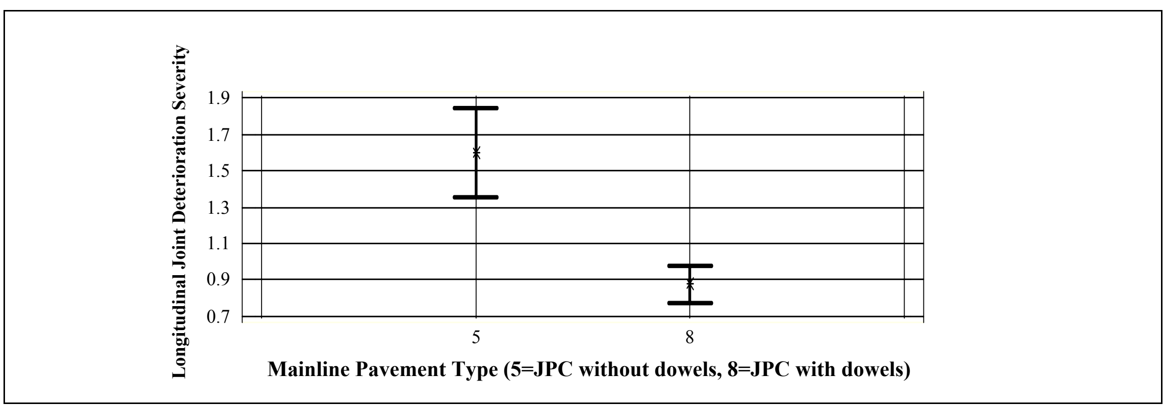

Figure 4.18 Longitudinal Joint Deterioration Severity Comparison for Composite Shoulders Adjacent to Type 5 and Type 8 Mainline PCC Pavements.

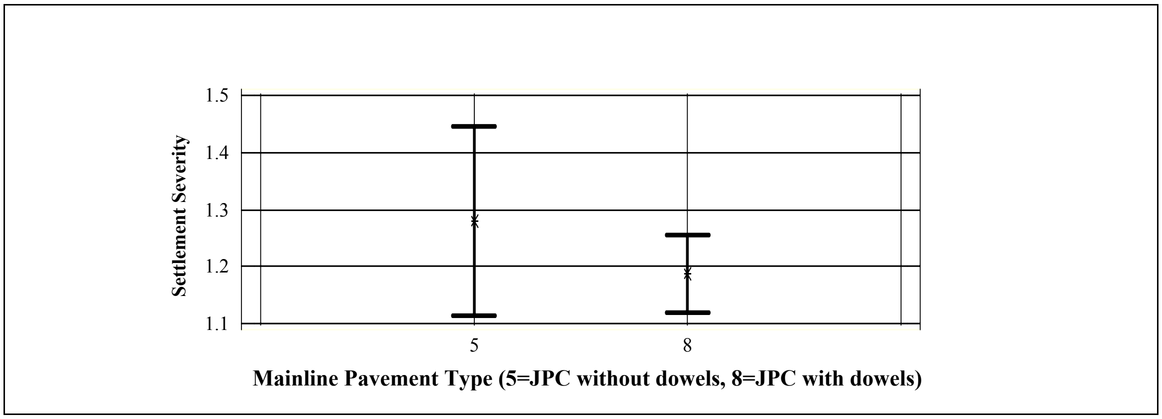

Figure 4.19 Settlement Severity Comparison for Composite Shoulders Adjacent to Type 5 and Type 8 Mainline PCC Pavements

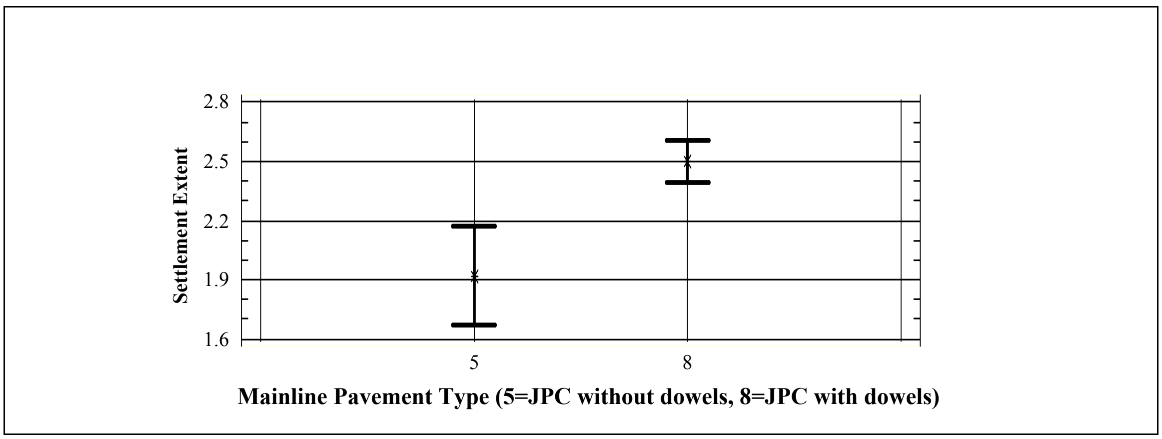

Figure 4.20 Settlement Extent Comparison for Composite Shoulders Adjacent to Type 5 and Type 8 Mainline PCC Pavements.

4.3.2 Comparison of Asphalt-Only Shoulders and Composite Shoulders Bordering Type 8 Mainline PCC Pavements

Type 8 pavements have been constructed since 1988 with both asphalt-only shoulders and composite shoulders (extended PCC slab plus a specified width of asphalt). The asphalt surfaces for these two shoulder configurations were evaluated for performance on the basis of various key distresses. The objective was to check if the presence of the extend PCC slab of the shoulder has any impact on the distress levels for the adjacent asphalt component of the shoulder. The key distresses included, transverse cracking, edge raveling, heaving, longitudinal joint deterioration, and settlement. The general descriptive statistics of the two shoulder configurations bordering the Type 8 pavements are shown in Table 4.11. A t-test analysis results conducted for the two shoulder configurations are also shown in Table 4.12, and Figures 4.21 through 4.29. Table 4.12 suggests that there are no statistically significant differences between distress level means for asphalt-only shoulders and composite shoulders bordering Type 8 pavements. Although these differences appear statistically insignificant, the extent and severity levels are higher for three primary distresses including, outside edge raveling (Figure 4.23), heave (Figures 4.26 and 4.27), and longitudinal joint deterioration (Figures 4.28 and 4.29). In addition, other studies have concluded that a widened PCC slab outside the striped 12-ft travel-lane location moves the weak longitudinal mainline-shoulder joint outside the 2-foot typical encroachment area [1,5]. This minimizes the high stresses created when encroaching traffic crosses from the rigid pavement to the flexible shoulder. This seems to suggest that composite Type 8 will be a more effective construction procedure to improve asphalt shoulder performance.

Table 4.11 Descriptive Statistics for Asphalt-only and Composite Shoulders Bordering Type 8 Pavements.

Shoulder Configuration (1)	Variable (2)	Descriptive Statistic			
		Range (3)	Mean (4)	Std. Deviation (5)	Observations, N (6)
Asphalt-only	Surface Age	5-15	10.7	4.4	12
	ESALs/day	112-1741	714	763	12
	Mainline PCC thickness (in)	9-12	10.3	1.1.3	12
	Asphalt-surfaced width (ft)	3-8	6.3	2.46	12
Composite	Surface Age	1-14	7.3	3.2	150
	ESALs/day	105-3646	718	816	148
	Mainline PCC thickness (in.)	9-12	10.2	0.9	150
	Asphalt-surfaced width (ft)	6-9	6.2	0.7	150

Table 4.12 T-test Results for Distresses on Asphalt-only and Composite Shoulders Bordering Type 8 Pavements.

Distress Type and Property (1)	Significance of Difference in Means (2)
Transverse cracking extent	X
Transverse cracking severity	N/S
Outside edge raveling severity	N/S
Longitudinal joint deterioration extent	N/S
Longitudinal joint deterioration severity	N/S
Settlement extent	N/S
Settlement severity	N/S
Heave extent	N/S
Heave severity	N/S
XXX = Highly Significant, p-value ≤ 0.01 XX = Moderately Significant, 0.01< p-value ≤0.05 X = Marginally Significant, 0.05< p-value ≤ 0.10; N/S = Not significant, p-value > 0.10	

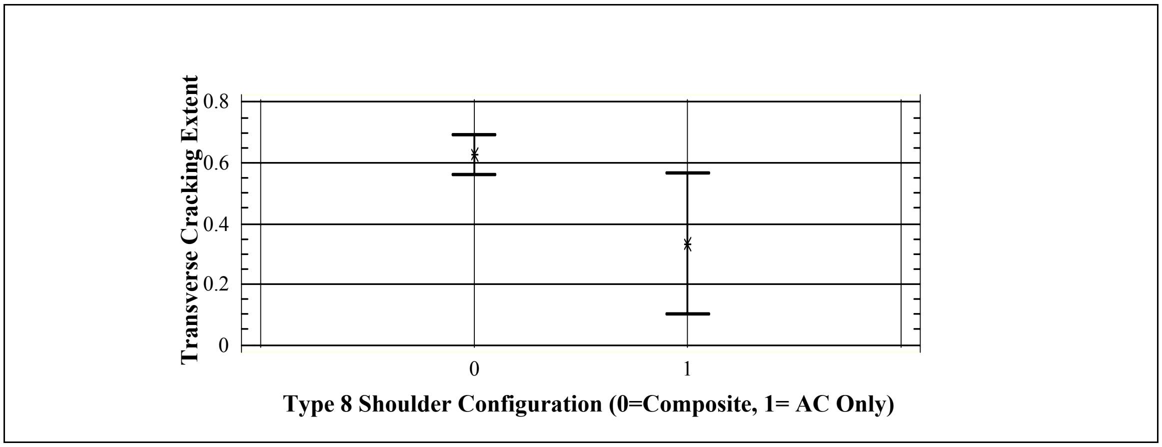

Figure 4.21 Transverse Cracking Extent Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

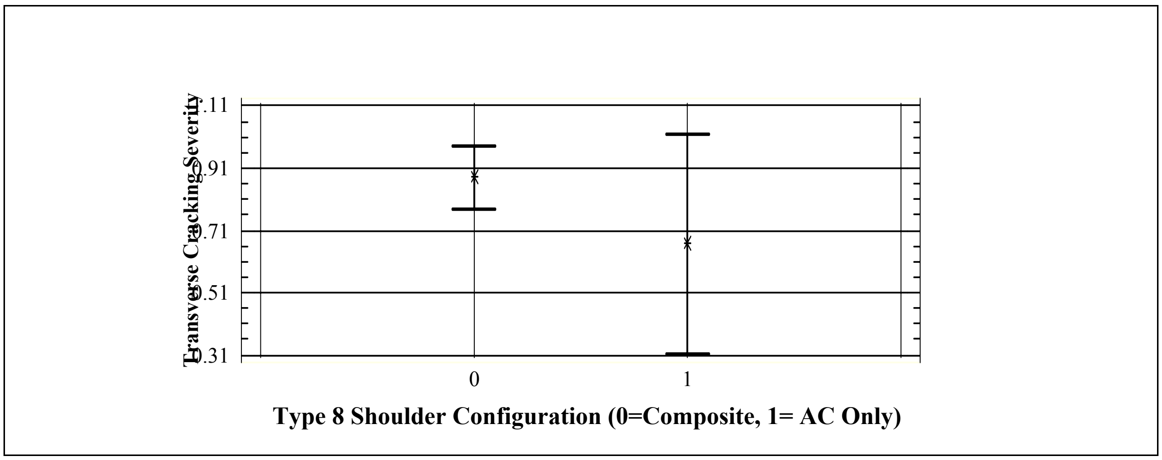

Figure 4.22 Transverse Cracking Severity Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

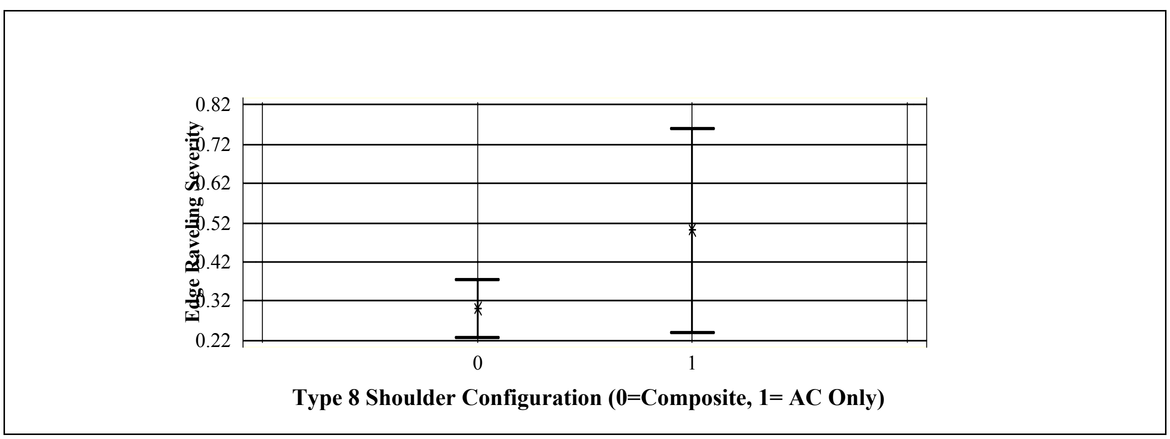

Figure 4.23 Edge Raveling Severity Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

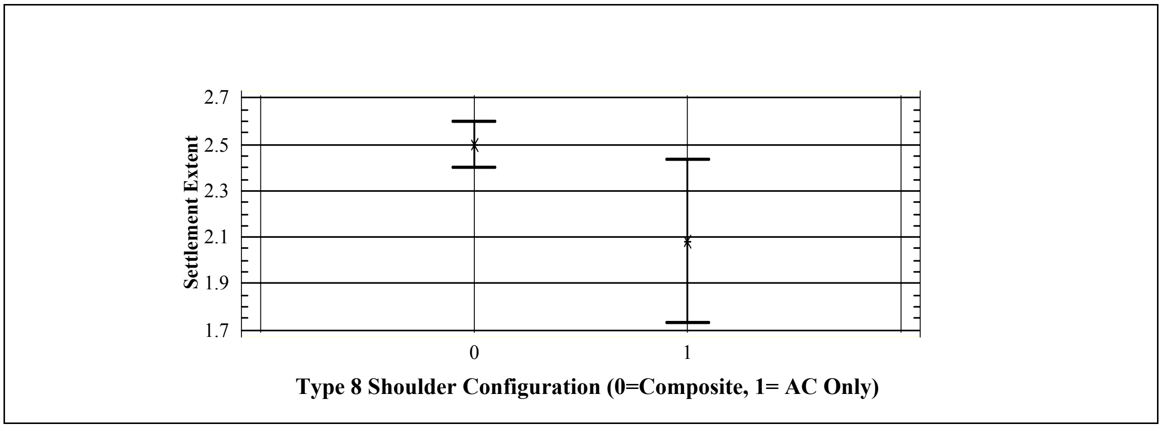

Figure 4.24 Settlement Extent Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

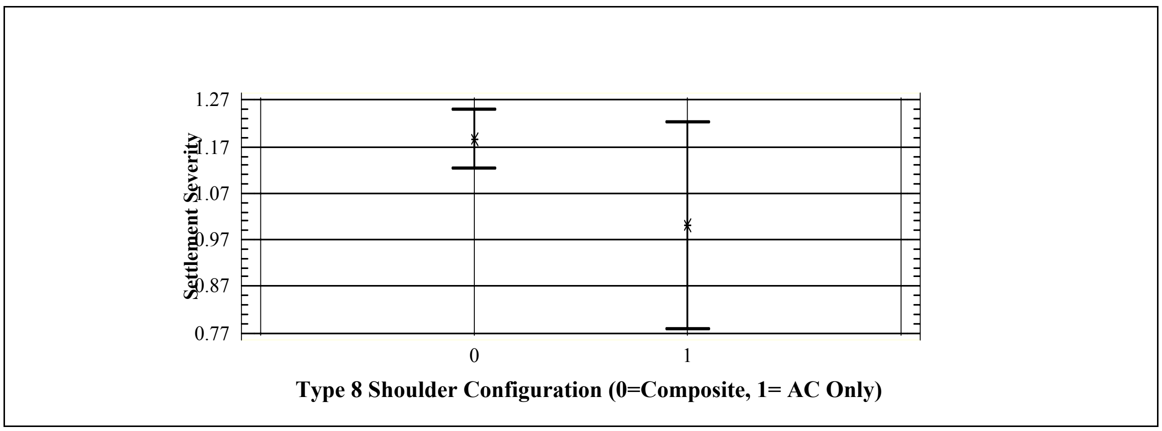

Figure 4.25 Settlement Severity Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

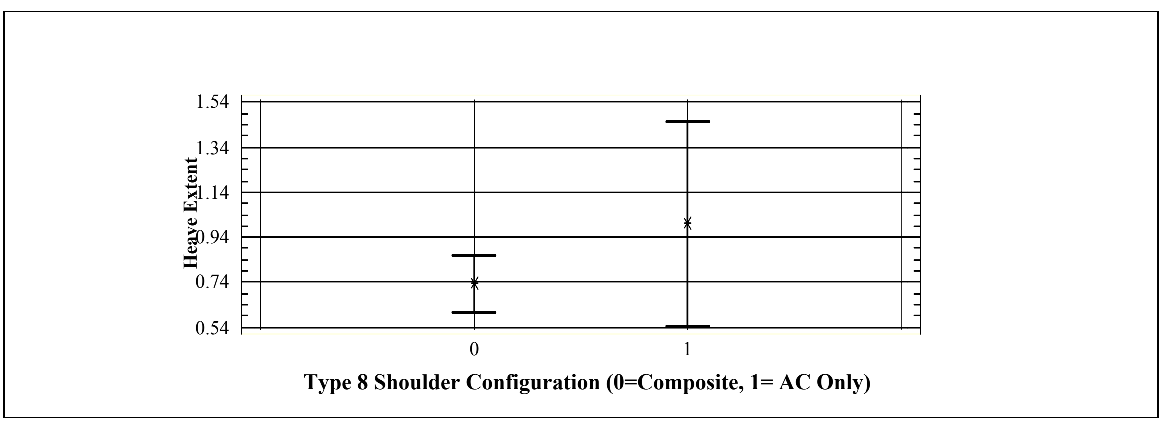

Figure 4.26 Heave Extent Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

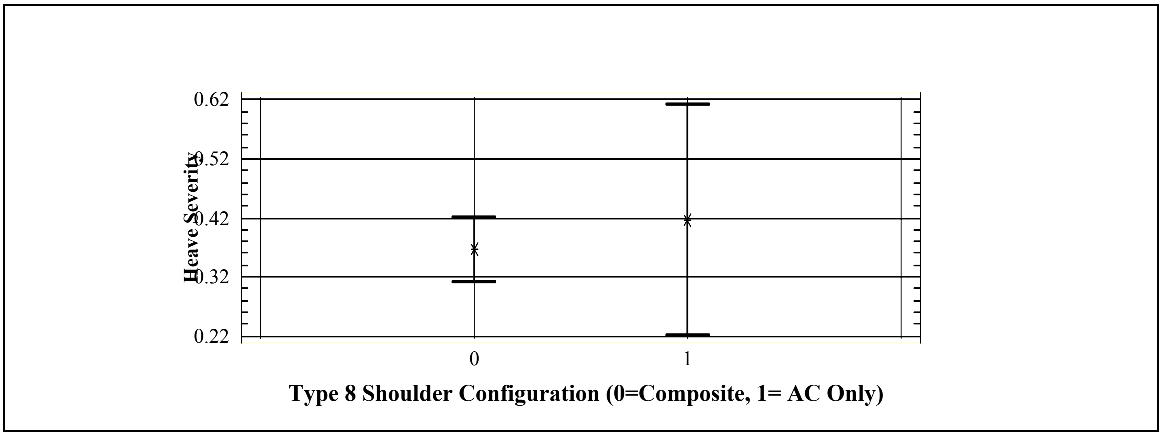

Figure 4.27 Heave Severity Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

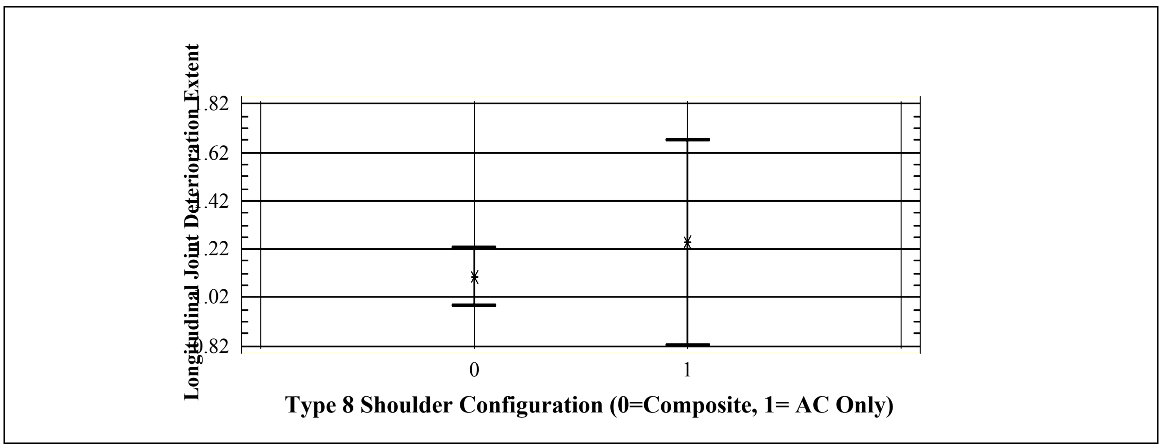

Figure 4.28 Longitudinal Joint Deterioration Extent Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements.

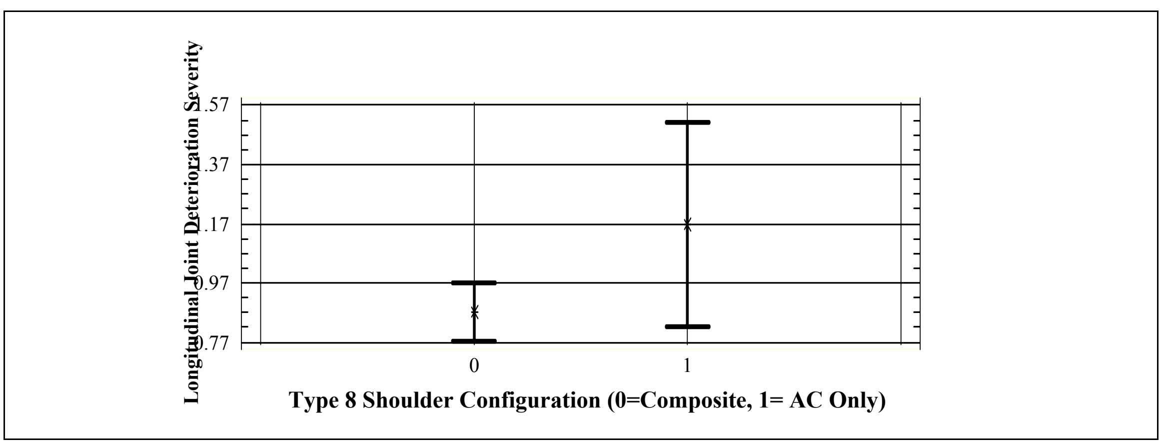

Figure 4.29 Longitudinal Joint Deterioration Extent Comparison for Asphalt-only and Composite Shoulders Adjacent to Type 8 Mainline PCC Pavements

4.3.3 Asphalt Surfaced Component of Composite Shoulders Adjacent to Type-8 PCC

The previous comparative analysis of composite shoulders adjacent to Type 5 and Type 8 PCC (see section 4.3.1) indicated superior performance of composite shoulders adjacent to Type 8. Hence, a more detailed analysis was conducted for the Type 8 composite shoulders to enable design and performance guides to be developed. ANOVA results for the asphalt-surfaced component of composite shoulders adjacent to Type 8 pavements are provided in Table 4.13. Similar to concrete shoulders, three levels of significance are provided in the tables to assess the relative significance of each independent variable. Degrees of freedom were 146 total, 112 error, and 34 model. A discussion and plots of each distress follows.

Table 4.13 ANOVA Results for the Asphalt Surfaced Component of Composite Shoulders Adjacent to Type-8 PCC

Dependent Variable (1)	Independent Variables										
	Design							Traffic	Environment		Maint
	Shoulder Base Gradation (2)	Shoulder Width (3)	Shoulder Surface Thickness (4)	Shoulder Base Thickness (5)	SSV (6)	PCC Thickness (7)	Edge Drain (8)	Functional Class (9)	Shoulder Regional Location (10)	Age (11)	Long. Joint Det (12)
TRAN$_{Ext}$	n/s	X	XX	XXX	XXX	XXX	X	XXX	XXX	XXX	XX
TRAN$_{Sev}$	XX	X	n/s	XXX	XXX	n/s	X	n/s	X	XXX	n/s
TRAN$_{SDIF}$	X	XX	n/s	XXX	XXX	n/s	n/s	n/s	XXX	XXX	XX
LONG$_{Ext}$	n/s	n/s	n/s	XX	n/s	XXX	n/s	XXX	n/s	XX	n/s
LONG$_{Sev}$	n/s	n/s	n/s	XX	n/s	XXX	n/s	XXX	n/s	XX	n/s
LONG$_{SDIF}$	n/s	n/s	n/s	n/s	n/s	X	n/s	XX	n/s	X	n/s
EDGE$_{Sev}$	n/s	n/s	XX	XXX	n/s	n/s	n/s	XXX	XX	XXX	n/s
EDGE$_{SDIF}$	n/s	n/s	XX	XXX	n/s	n/s	n/s	XX	XX	XXX	n/s
HEAV$_{Ext}$	XX	XX	XXX	XXX	n/s	n/s	n/s	XXX	XXX	XXX	n/s
HEAV$_{Sev}$	XX	XXX	XXX	XXX	n/s	n/s	n/s	XX	XXX	XXX	n/s
HEAV$_{SDIF}$	X	X	XXX	XXX	n/s	n/s	n/s	XXX	XXX	XXX	n/s
SETT$_{Ext}$	n/s	n/s	XX	XXX	n/s	n/s	n/s	XXX	XXX	XXX	n/s
SETT$_{Sev}$	n/s	n/s	XXX	XXX	X	n/s	n/s	XX	XX	XXX	n/s
SETT$_{SDIF}$	n/s	n/s	XX	XXX	n/s	n/s	n/s	XXX	XXX	XXX	n/s
LJD$_{Ext}$	n/s	n/s	n/s	XX	XX	n/s	n/s	n/s	n/s	XXX	XX
LJD$_{Sev}$	XX	n/s	n/s	XX	XX	XXX	n/s	n/s	XXX	XXX	n/s
LJD$_{SDIF}$	XX	XXX	n/s	X	XX	XXX	n/s	n/s	XXX	XXX	n/s

TRAN = Transverse Cracks XXX = Highly Significant, p-value ≤ 0.01
LONG = Longitudinal Cracks XX = Moderately Significant, 0.01 < p-value < 0.05
EDGE = Edge Raveling X = Marginally Significant, 0.05 ≤ p-value ≤ 0.1
HEAV/SETT= Heave/Settlement n/s = Not Significant, p-value ≥ 0.1
LJD = Longitudinal Joint Deterioration
Ext = Extent; Sev = Severity level; SDIF = Shoulder Distress Index Factor

4.3.3.1 Transverse Cracking for AC Surfaced Component of Composite Shoulders, Adjacent to Type-8 PCC

Transverse cracking was a function of several design variables, including shoulder base gradation, shoulder width, shoulder surface thickness, SSV, PCC thickness, and edge drain. Figures 4.30 through 4.38 show the relationships of transverse cracking with the design variables. Key findings were a reduced severity with CABC base material, as opposed to OGBC (Figure 4.30). Shoulder widths exceeding 8 feet had reduced extent levels, and widths of 6 and 8 feet had similar Index levels (Figures 4.31 and 4.32). Shoulder pavement thickness had lower extent with 4-inch thickness, when compared to the 3-inch thickness (Figure 4.33). SSV was significant due to random variation and a high mean level for SSV=5.0, however, no visible trend was observed for extent, severity, and index (Figures 4.34 though 4.36). PCC thickness of 12 inches had a lower extent than the other lesser range of thicknesses (Figure 4.37). The presence of edge drain increased the extent of transverse cracking (Figure 4.38).

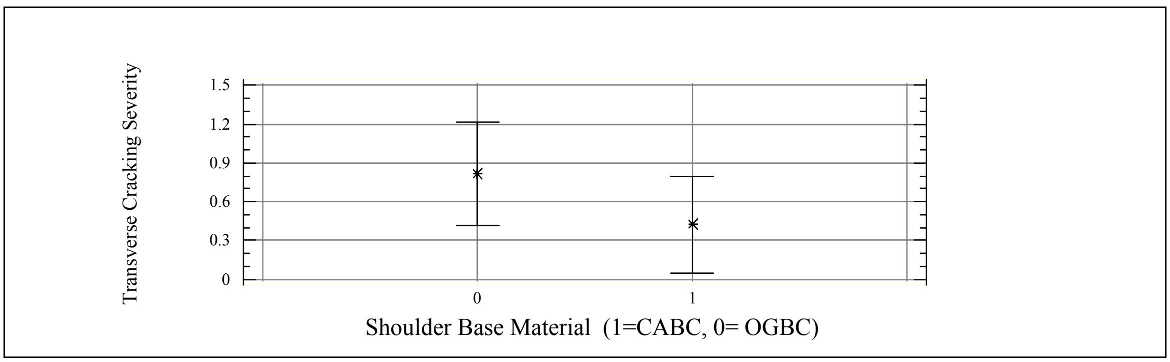

Figure 4.30 Transverse Cracking Severity and Shoulder Base Material (Composite Type-8)

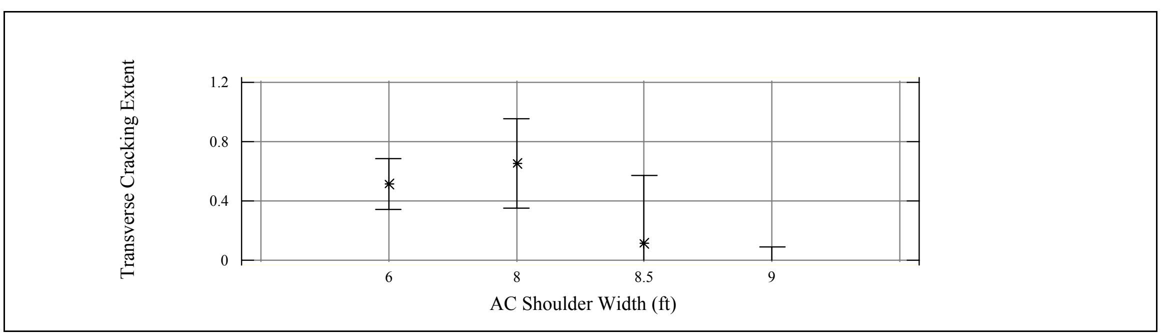

Figure 4.31 Transverse Cracking Extent and AC Shoulder Width (Composite Type-8)

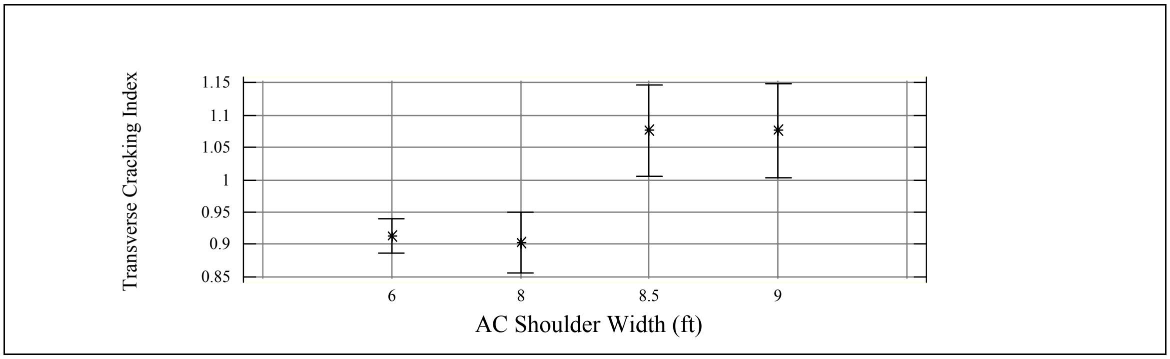

Figure 4.32 Transverse Cracking Index and AC Shoulder Width (Composite Type-8)

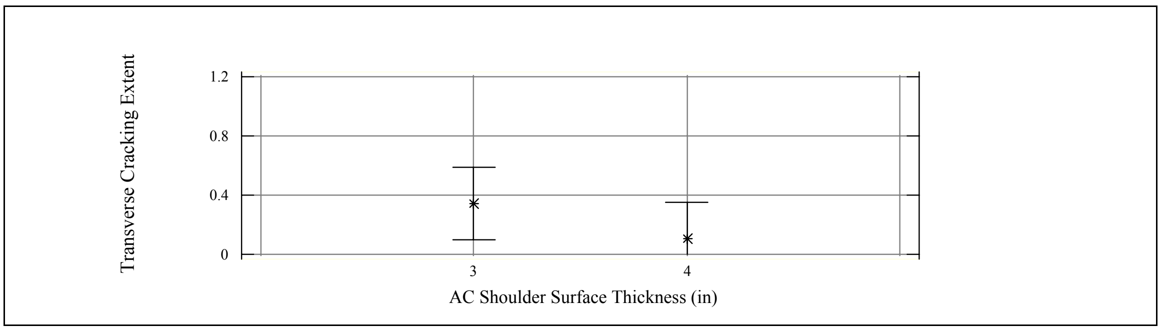

Figure 4.33 Transverse Cracking Extent and Shoulder Surface Thickness (Composite Type-8)

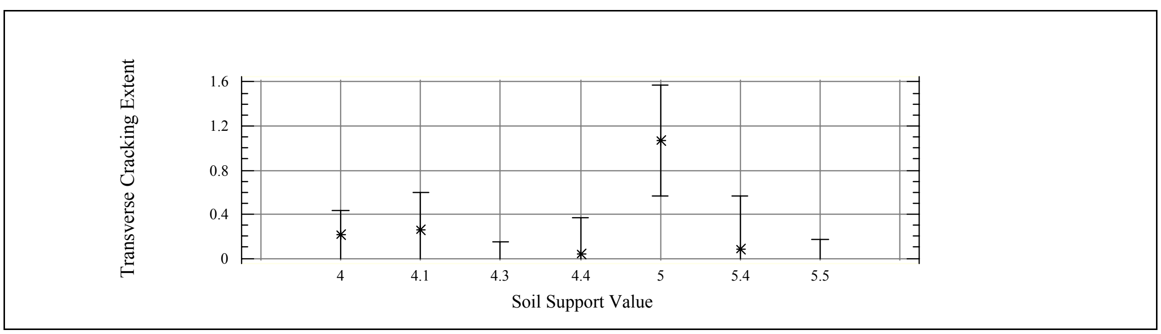

Figure 4.34 Transverse Cracking Extent and SSV (Composite Type-8)

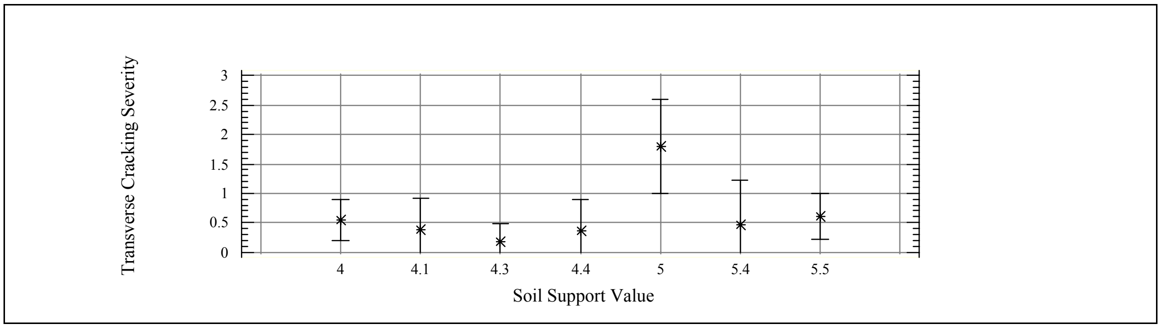

Figure 4.35 Transverse Cracking Severity and SSV (Composite Type-8)

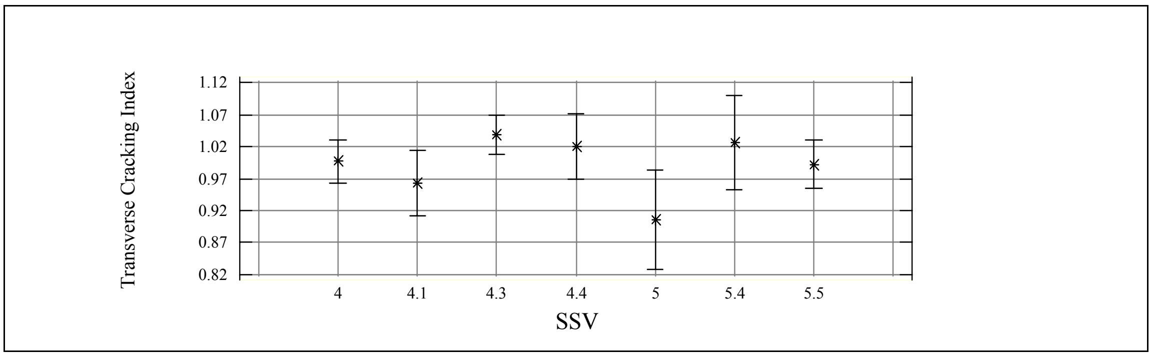

Figure 4.36 Transverse Cracking Index and SSV (Composite Type-8)

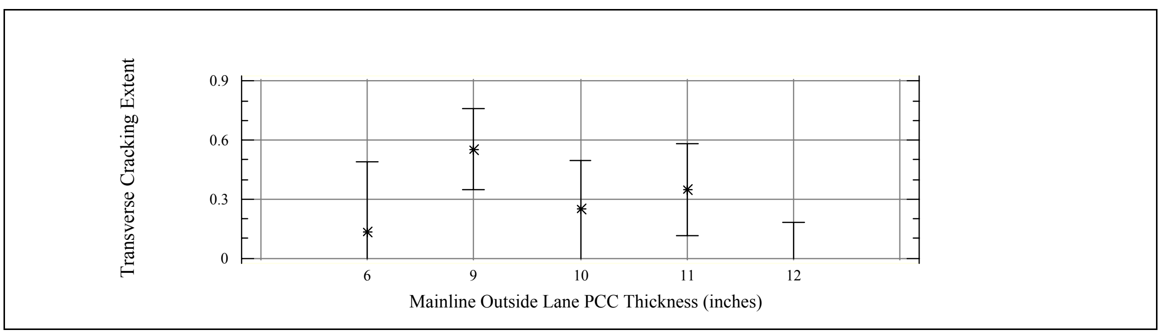

Figure 4.37 Transverse Cracking Extent and PCC Thickness (Composite Type-8)

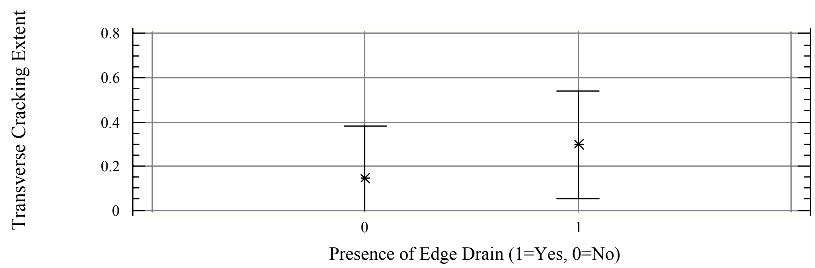

Figure 4.38 Transverse Cracking Extent and Edge Drain (Composite Type-8)

Figures 4.39 through 4.47 provide plots of transverse cracking with traffic, environment, and maintenance of the longitudinal joint. Traffic, as measured by the roadway functional classification, had a higher extent level for Interstate and U.S. Highways (Figure 4.39). Regional location had a significant effect, where the extent and severity levels were higher for central and southern regions, yielding a higher index for the northern region (Figures 4.40 through 4.42). An increase in age produced an expected increase in the extent and severity levels; however, there was variation in the trend line (Figures 4.43 through 4.44). Figure 4.45 also shows an expected decline in transverse cracking index (i.e. the combination of extent and severity) with increasing age. Filling the longitudinal joint reduced the extent of transverse cracking and increased the index value (Figures 4.46 and 4.47).

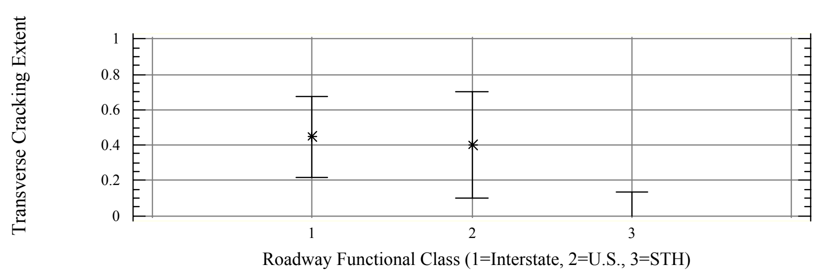

Figure 4.39 Transverse Cracking Extent and Roadway Functional Class (Composite Type-8)

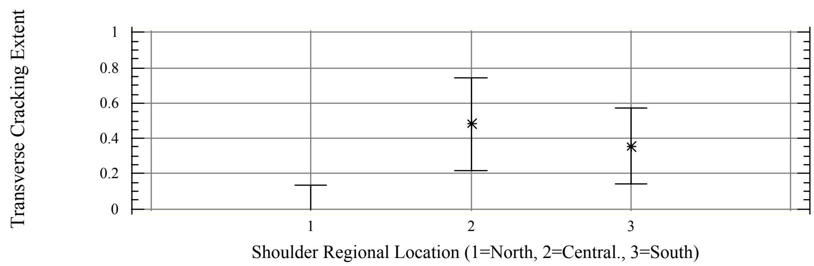

Figure 4.40Transverse Cracking Extent and Roadway Functional Class (Composite Type-8)

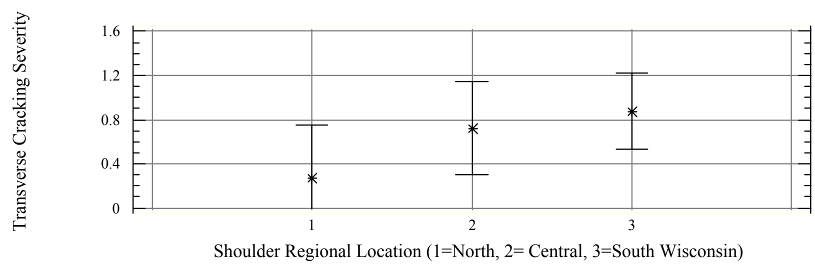

Figure 4.41Transverse Cracking Severity and Regional Location (Composite Type-8)

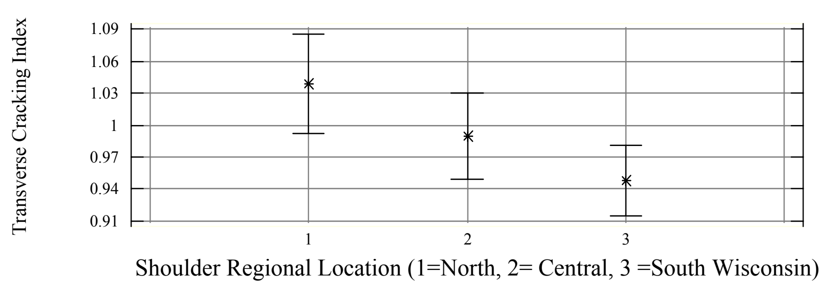

Figure 4.42 Transverse Cracking Index and Regional Location (Composite Type-8)

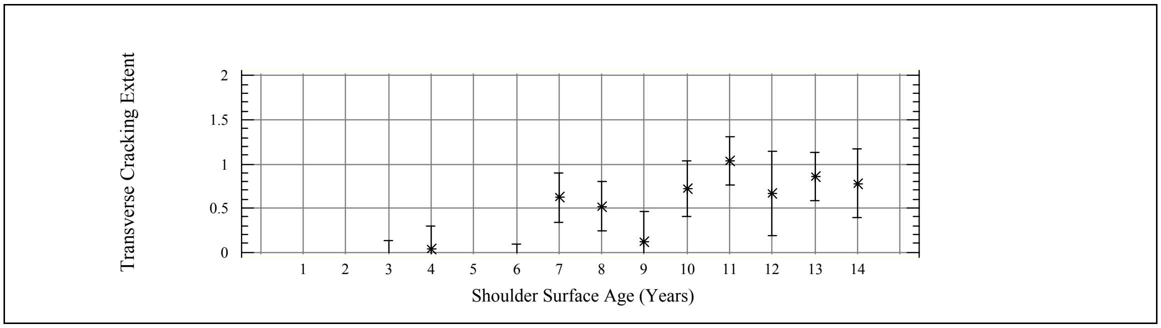

Figure 4.43 Transverse Cracking Extent and Age (Composite Type-8)

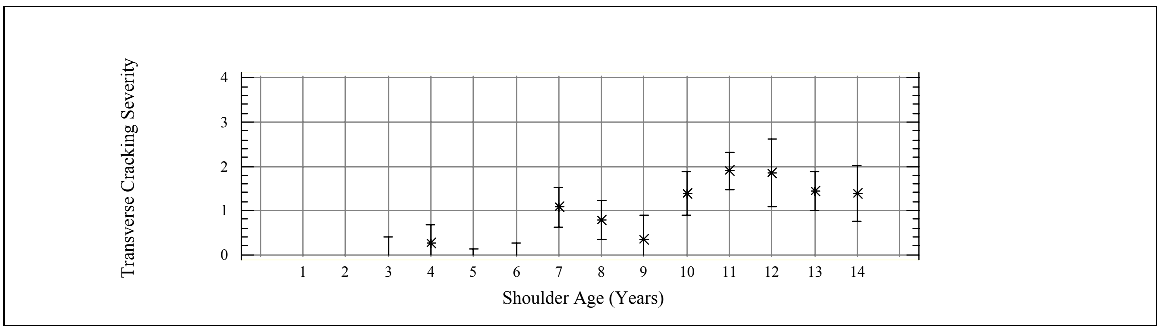

Figure 4.44 Transverse Cracking Severity and Age (Composite Type-8)

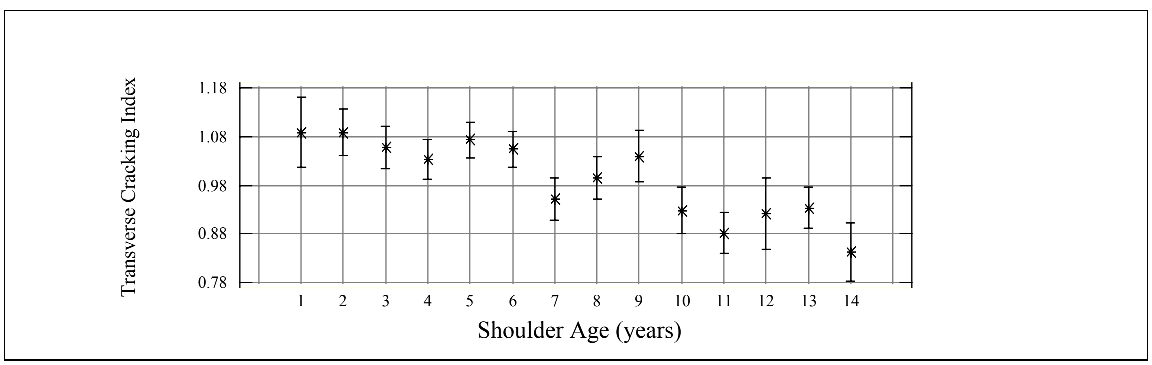

Figure 4.45 Transverse Cracking Index and Age (Composite Type-8)

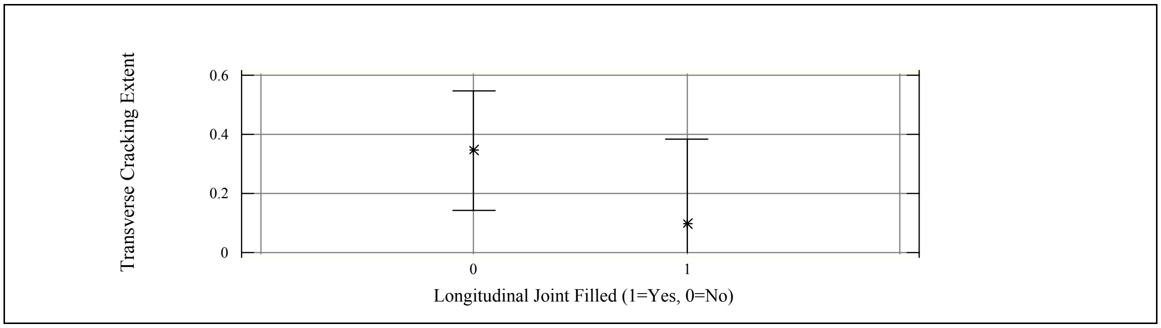

Figure 4.46 Transverse Cracking Extent and Longitudinal Joint Filling (Composite Type-8)

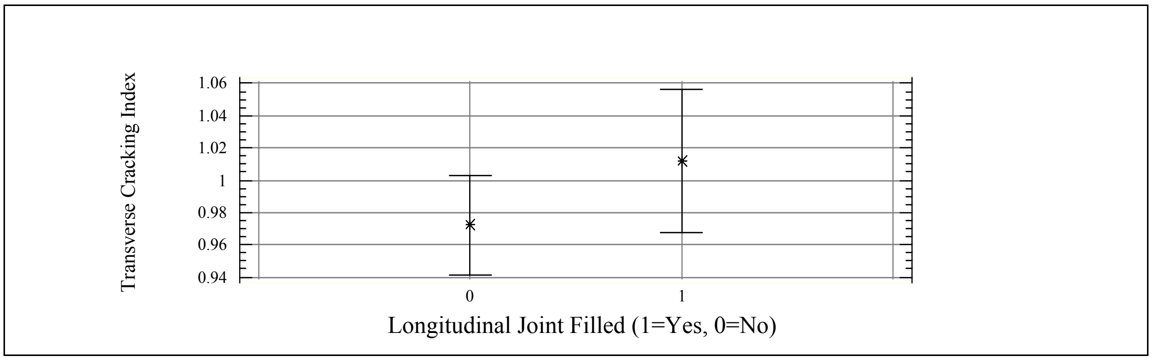

Figure 4.47 Transverse Cracking Index and Longitudinal Joint Filling (Composite Type-8)

4.3.3.2 Longitudinal Cracking for AC Surfaced Component of Composite Shoulders Adjacent to Type-8 PCC

Longitudinal cracking was a function of only one design variable, PCC thickness. Figures 4.48 and 4.49 show higher extent and severity levels with the 12-inch thick PCC pavement, respectively. For roadway functional class, there were higher extent and severity levels on U.S. and State Trunk Highways, and resulting higher index for Interstate Highways (Figures 4.50 through 4.52). An increase in age produced an expected increase in the extent and severity levels; however, there was some variation in the trend line (Figures 4.53 and 4.54).

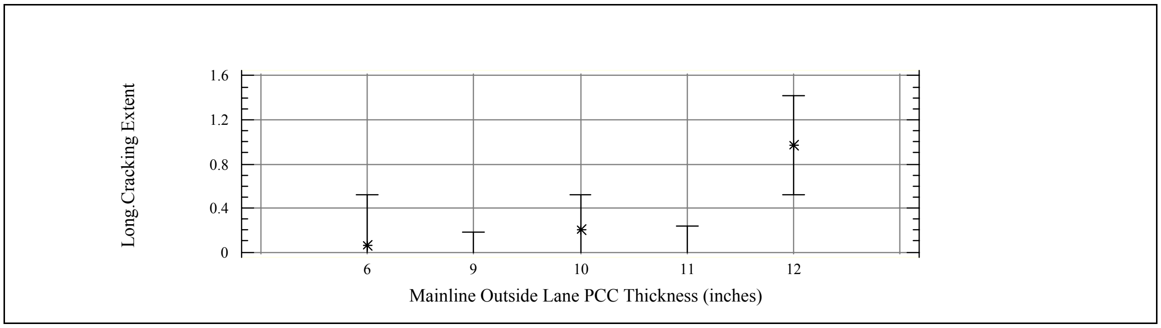

Figure 4.48 Longitudinal Cracking Extent and PCC Thickness (Composite Type-8)

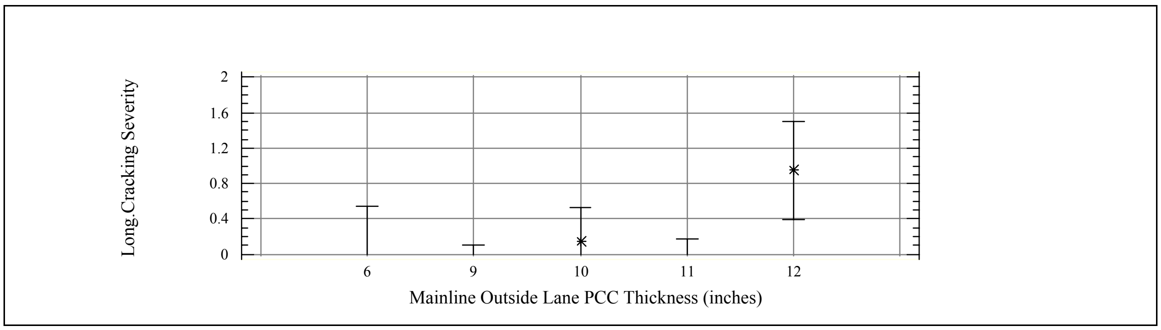

Figure 4.49 Longitudinal Cracking Severity and PCC Thickness (Composite Type-8)

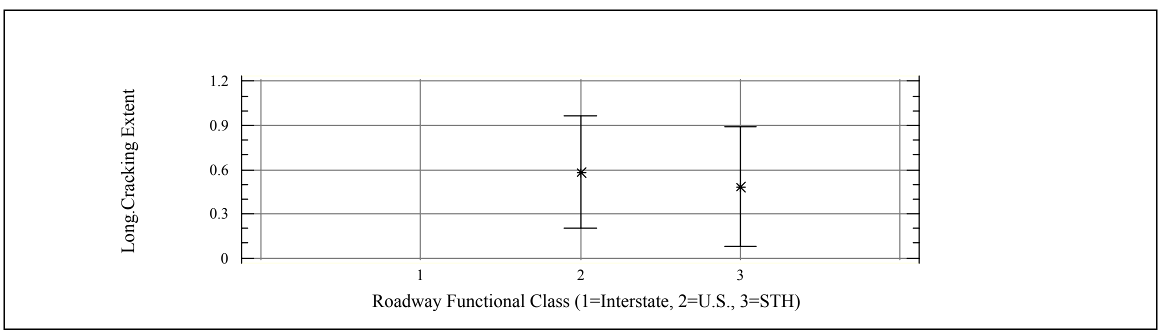

Figure 4.50 Longitudinal Cracking Extent and Roadway Functional Class (Composite Type-8)

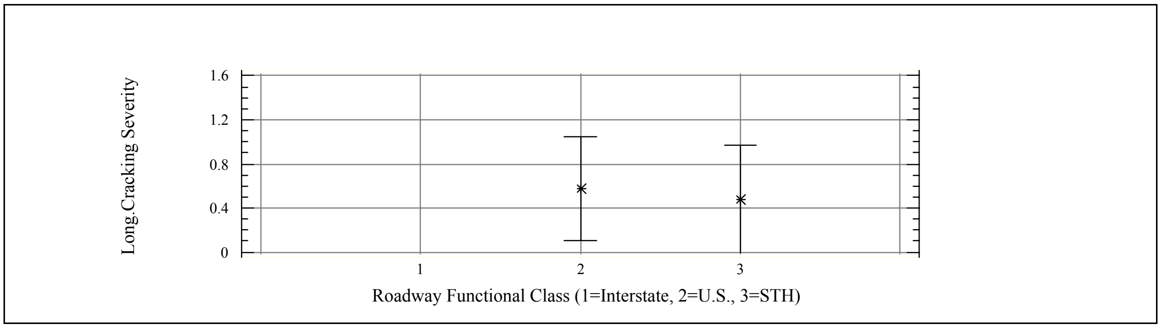

Figure 4.51 Longitudinal Cracking Severity and Roadway Functional Class (Composite Type-8)

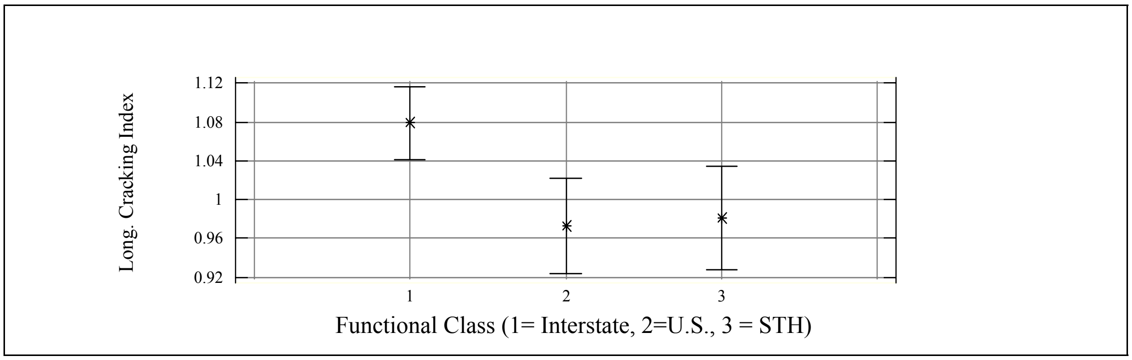

Figure 4.52 Longitudinal Cracking Index and Roadway Functional Class (Composite Type-8)

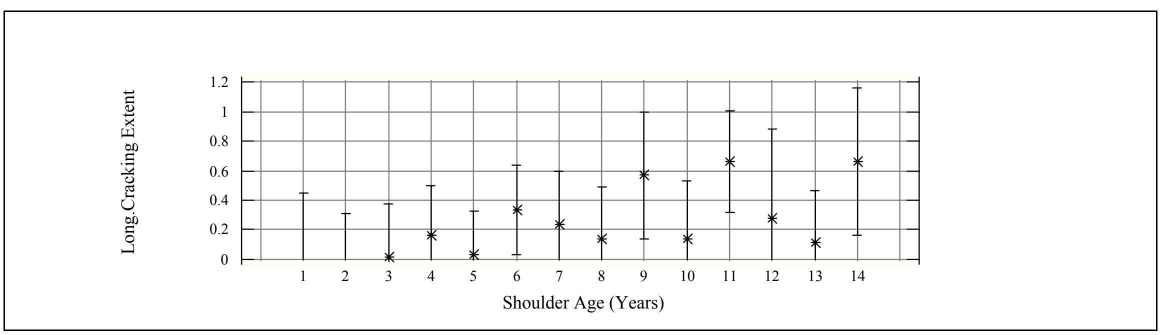

Figure 4.53 Longitudinal Cracking Extent and Age (Composite Type-8)

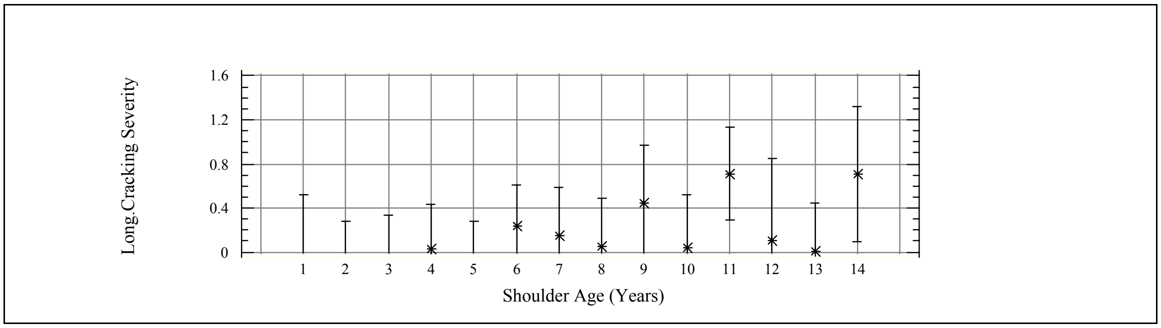

Figure 4.54 Longitudinal Cracking Severity and Age (Composite Type-8)

4.3.3.3 Edge Raveling for Composite Shoulders, Type-8 PCC

Edge raveling was only measured for severity and index, a common WisDOT practice. The data found a significant relationship between severity and shoulder surface thickness (Figures 4.55 and 4.56). Roadway functional class had an effect with a higher severity level on U.S. and State Highways, and resulting in a higher index for Interstate Highways (Figures 4.57 and 4.58). Regional location had an effect on the severity, where northern and southern regions had higher levels, and the central region had a higher index (Figures 4.59 and 4.60). An increase in age produced a slight increase in the severity level (Figures 4.61 and 4.62).

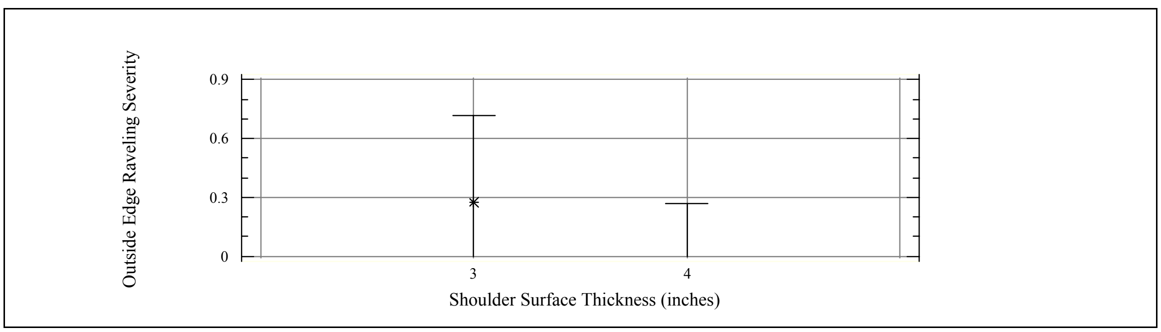

Figure 4.55 Edge Raveling Severity and Shoulder Surface Thickness (Composite Type-8)

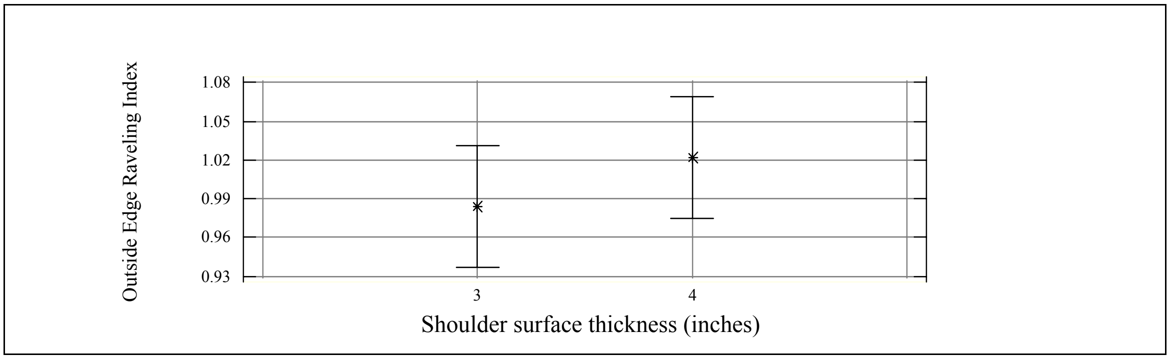

Figure 4.56 Edge Raveling Index and Shoulder Surface Thickness (Composite Type-8)

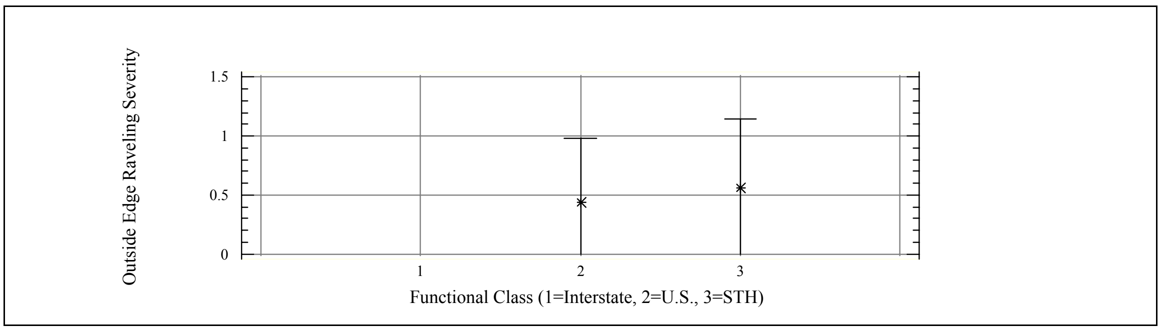

Figure 4.57 Edge Raveling Severity and Roadway Functional Class (Composite Type-8)

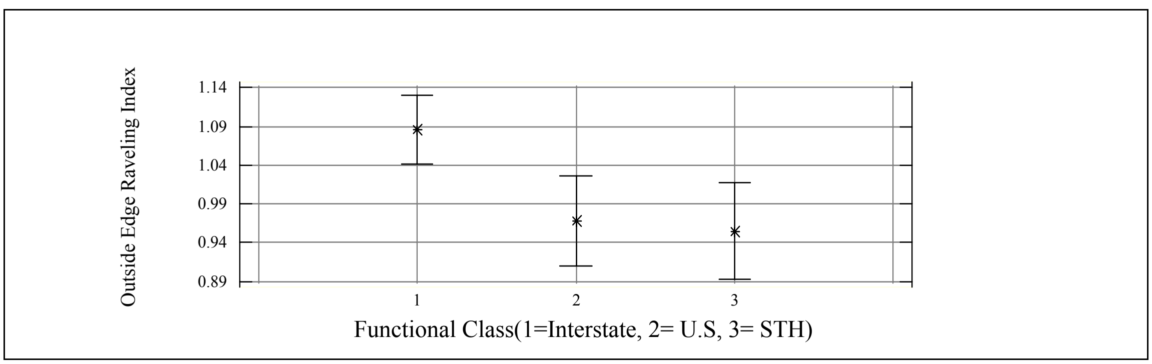

Figure 4.58 Edge Raveling Index and Roadway Functional Class (Composite Type-8)

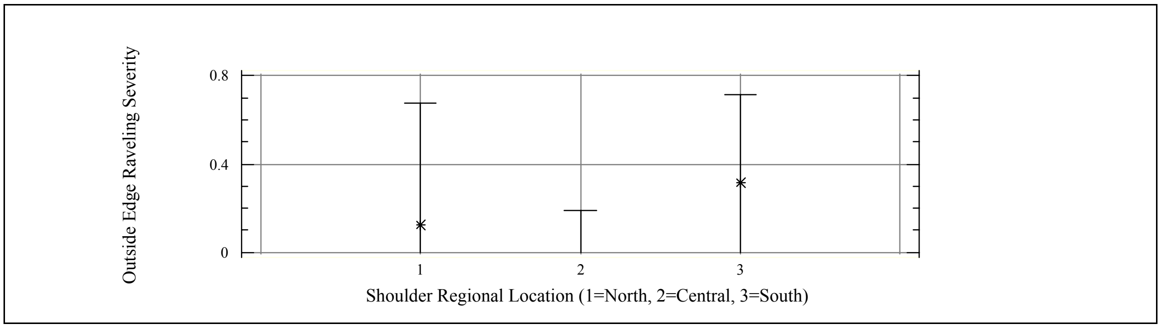

Figure 4.59 Edge Raveling Severity and Regional Location (Composite Type-8)

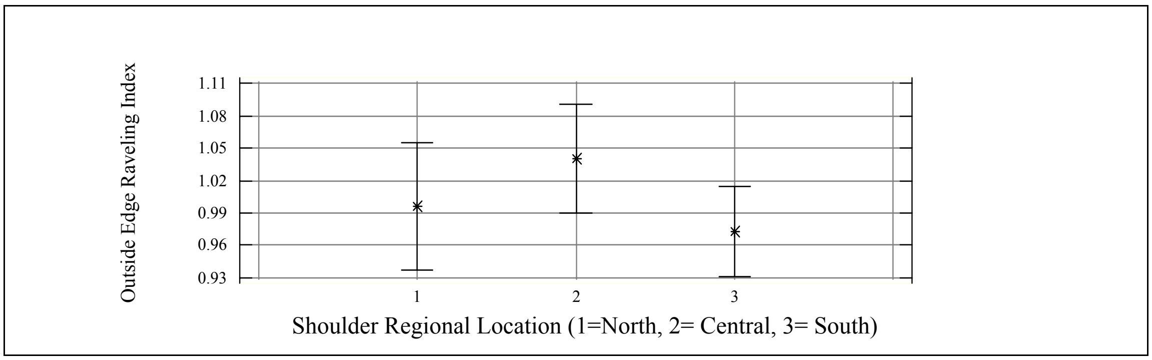

Figure 4.60 Edge Raveling Index and Regional Location (Composite Type-8)

Figure 4.61 Edge Raveling Severity and Age (Composite Type-8)

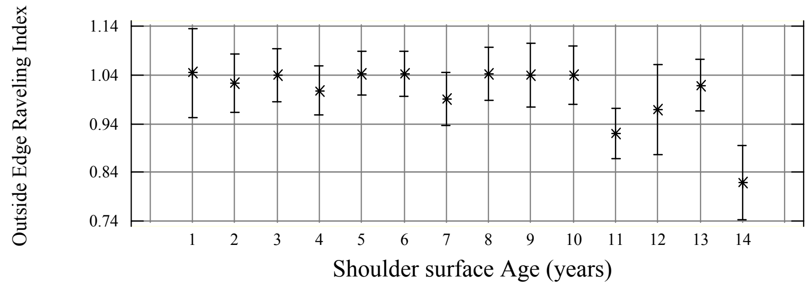

Figure 4.62 Edge Raveling Index and Age (Composite Type-8)

4.3.3.4 Heave for AC Surfaced Component of Composite Shoulders, Type-8 PCC

Heave was a function of several design variables, including shoulder base gradation, shoulder width, and shoulder surface thickness. Figures 4.63 through 4.70 show the relationships of heave with the design variables. Key findings were a reduced extent and severity with CABC base material, as opposed to OGBC (Figures 4.63 through 4.65). Shoulder widths exceeding 6 feet had reduced extent and severity levels (Figures 4.66 and 4.67). Shoulder surface thickness had lower extent and severity with 3-inch thickness, when compared to the 4-inch thickness (Figures 4.68 through 4.70).

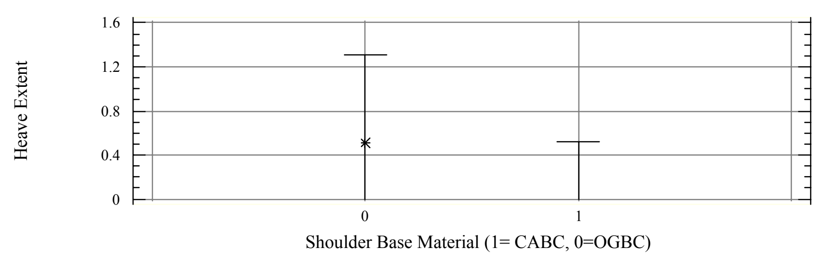

Figure 4.63 Heave Extent and Shoulder Base Material (Composite Type-8)

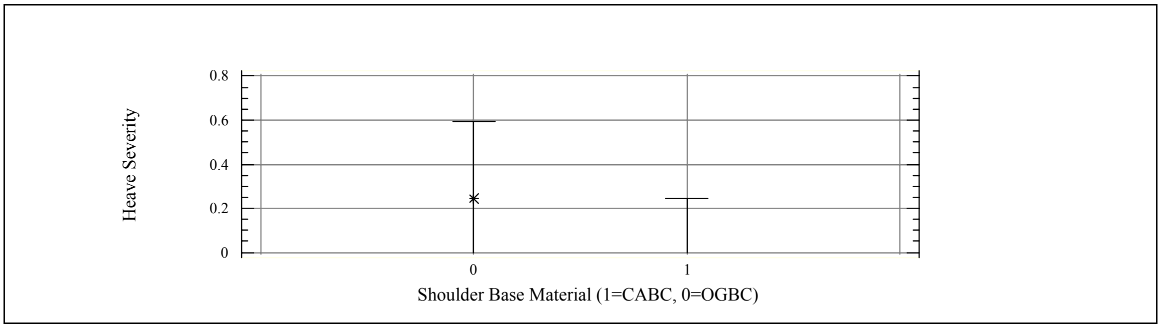

Figure 4.64 Heave Severity and Shoulder Base Material (Composite Type-8)

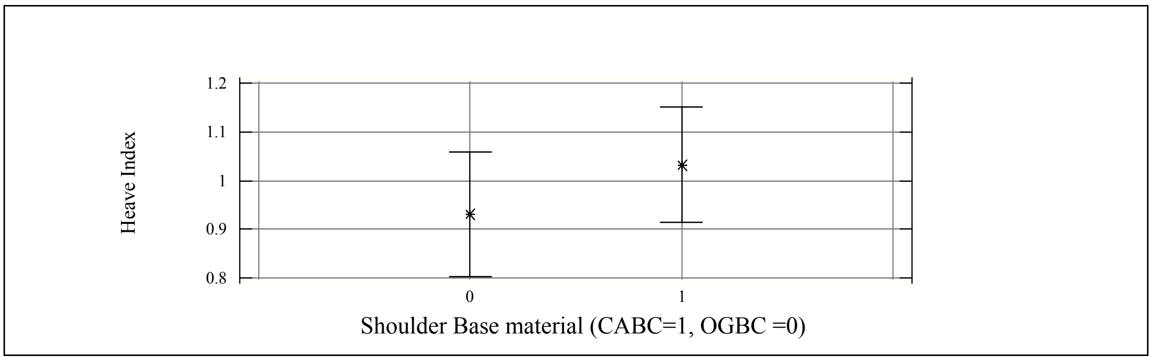

Figure 4.65 Heave Index and Shoulder Base Material (Composite Type-8)

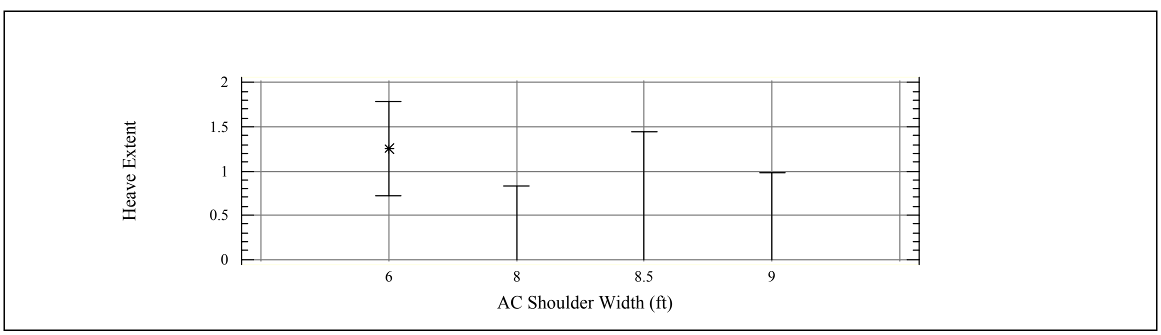

Figure 4.66 Heave Extent and AC Shoulder Width (Composite Type-8)

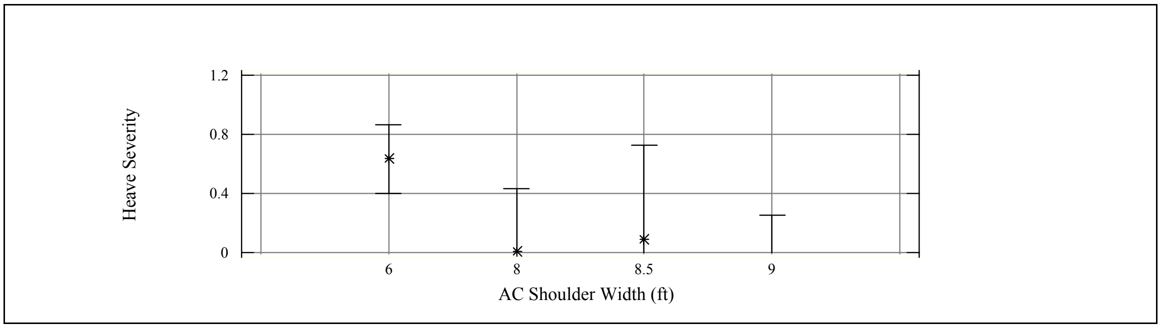

Figure 4.67 Heave Severity and AC Shoulder Width (Composite Type-8)

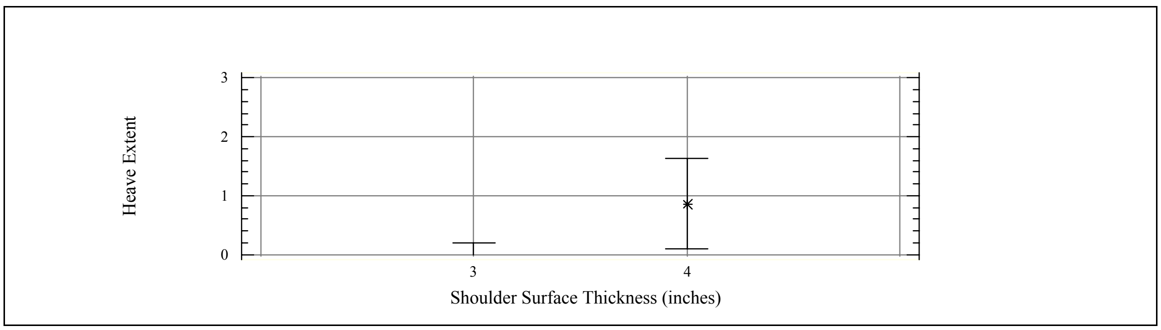

Figure 4.68 Heave Extent and Shoulder Surface Thickness (Composite Type-8)

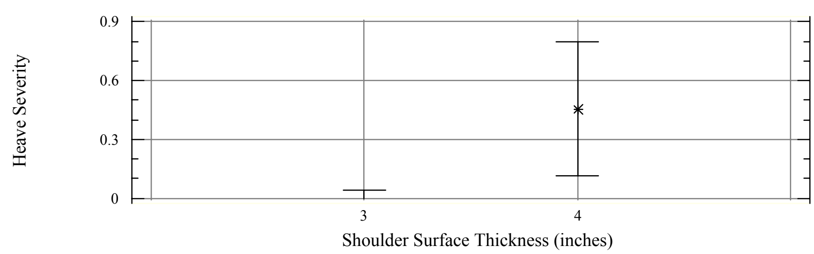

Figure 4.69 Heave Severity and Shoulder Surface Thickness (Composite Type-8)

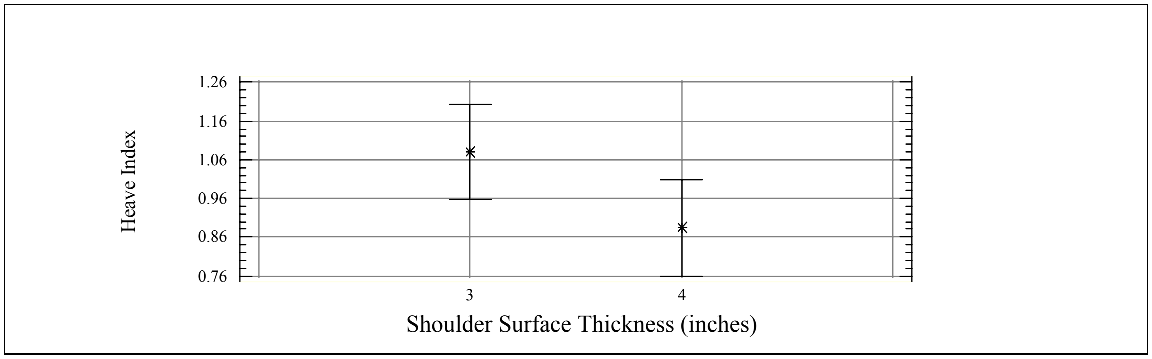

Figure 4.70 Heave Index and Shoulder Surface Thickness (Composite Type-8)

Figures 4.71 through 4.79 provide plots of transverse cracking with traffic, regional location, and age. Traffic, as measured by the roadway functional classification, had higher extent and severity levels for Interstate Highways (Figures 4.71 through 4.73). Regional location had a significant effect, having higher extent and severity levels for the central region (Figures 4.74 through 4.76). There was no visible trend in the relationship between age and the extent and severity levels for heave (Figures 4.77 through 4.79). This finding may suggest that other factors, such as construction, influence shoulder heave.

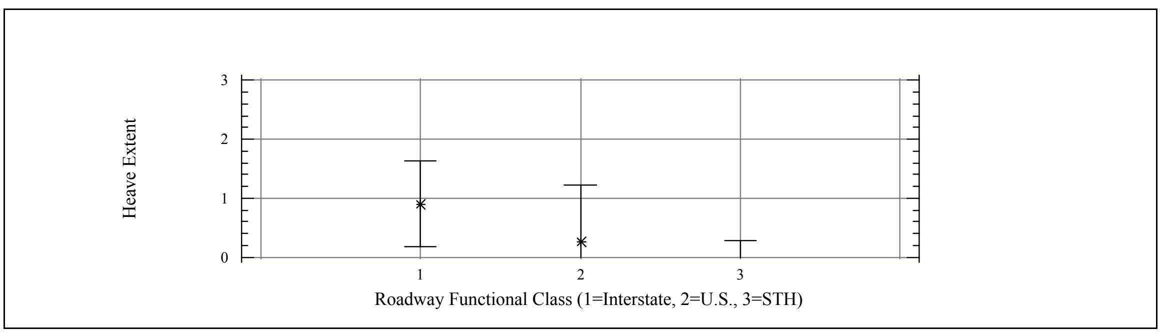

Figure 4.71 Heave Extent and Roadway Functional Class (Composite Type-8)

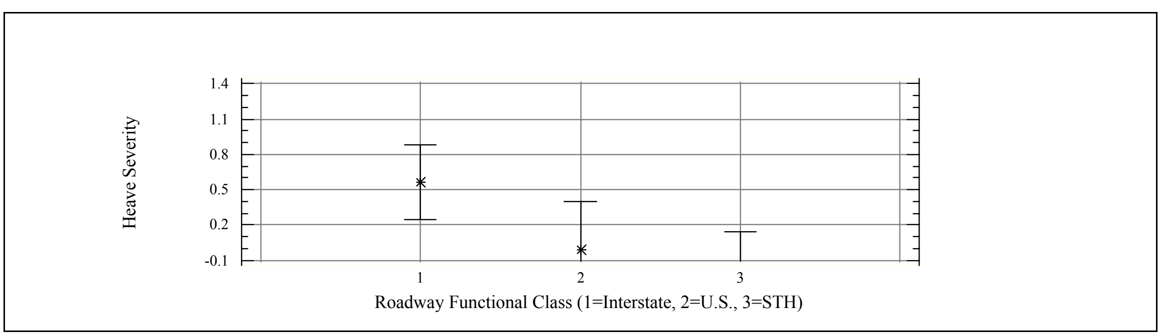

Figure 4.72 Heave Severity and Roadway Functional Class (Composite Type-8)

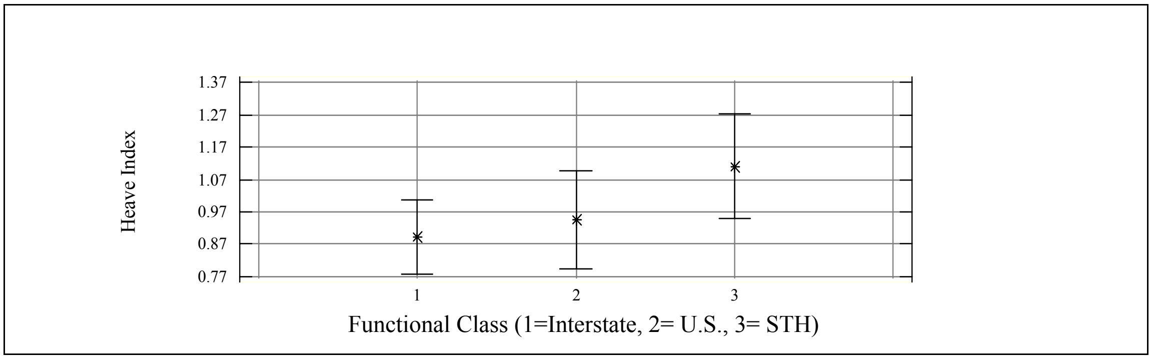

Figure 4.73 Heave Index and Roadway Functional Class (Composite Type-8)

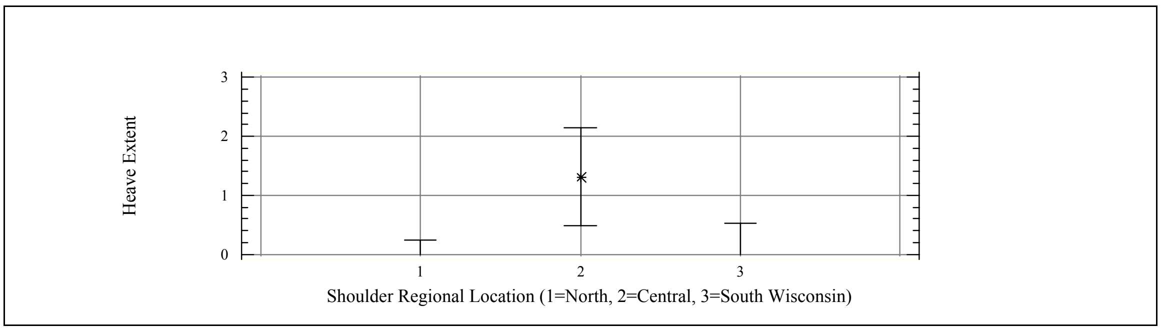

Figure 4.74 Heave Extent and Regional Location (Composite Type-8)

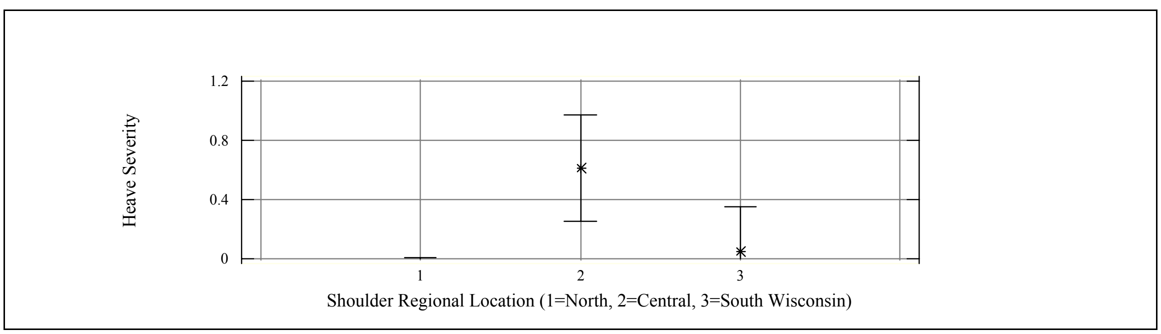

Figure 4.75 Heave Severity and Regional Location (Composite Type-8)

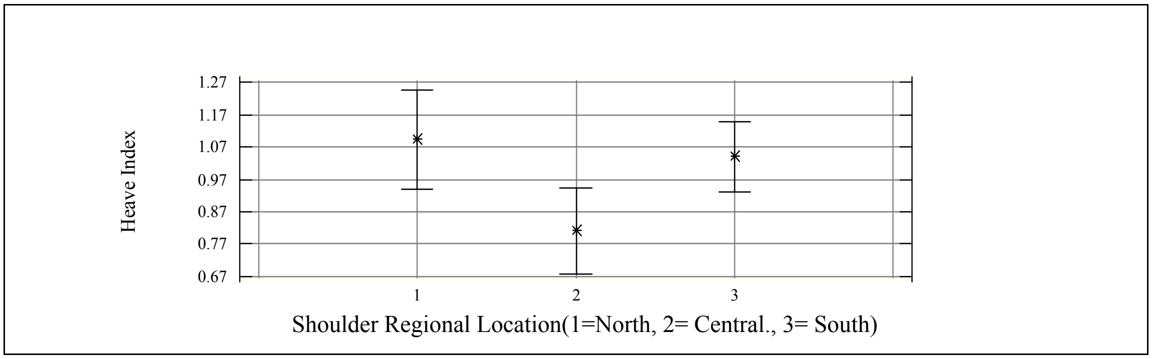

Figure 4.76 Heave Index and Regional Location (Composite Type-8)

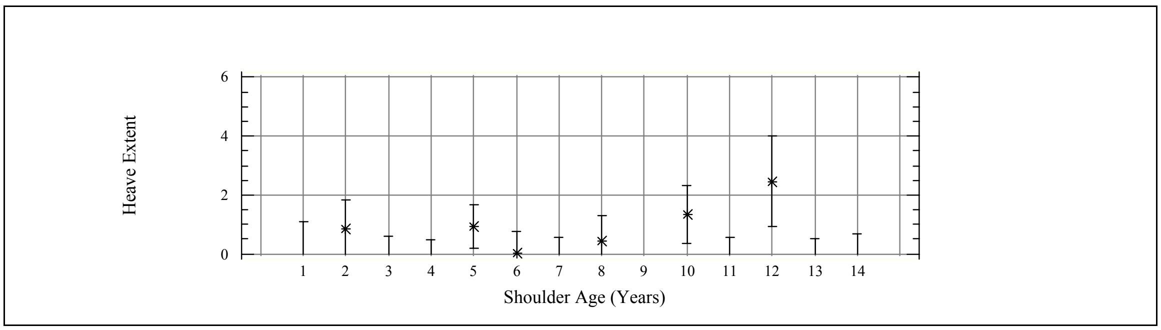

Figure 4.77 Heave Extent and Age (Composite Type-8)

Figure 4.78 Heave Severity and Age (Composite Type-8)

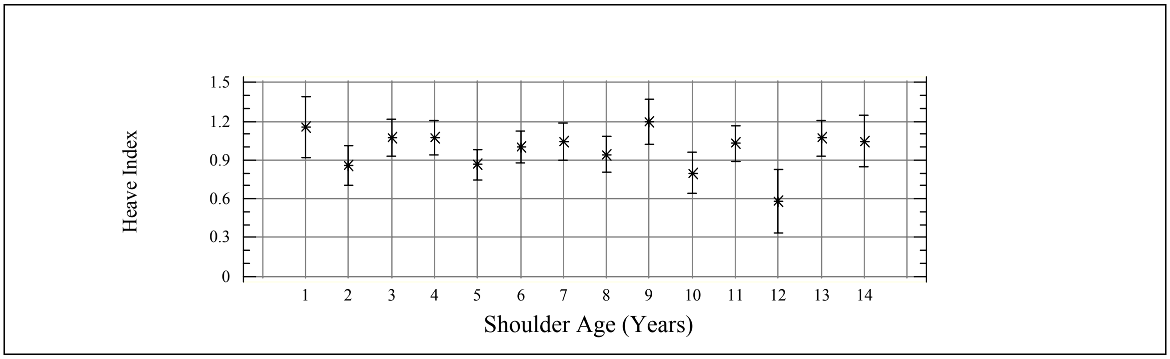

Figure 4.79 Heave Index and Age (Composite Type-8)

4.3.3.5 Settlement for AC Surfaced Component of Composite Shoulders, Type-8 PCC

Settlement was a function of only one design variable, shoulder surface thickness. Higher extent and severity levels were found for 3-inch thick shoulders (Figures 4.80 through 4.82). Traffic, as measured by the roadway functional classification, had higher extent and severity levels for State Trunk Highways (Figures 4.83 through 4.85). Regional location had a significant effect, having higher extent and severity levels for the northern and southern regions (Figures 4.86 through 4.88). There was no visible trend in the relationship between age and the extent and severity levels for settlement (Figures 4.89 through 4.91). Similar to heave, this finding may suggest that other factors, such as construction, influence shoulder settlement.

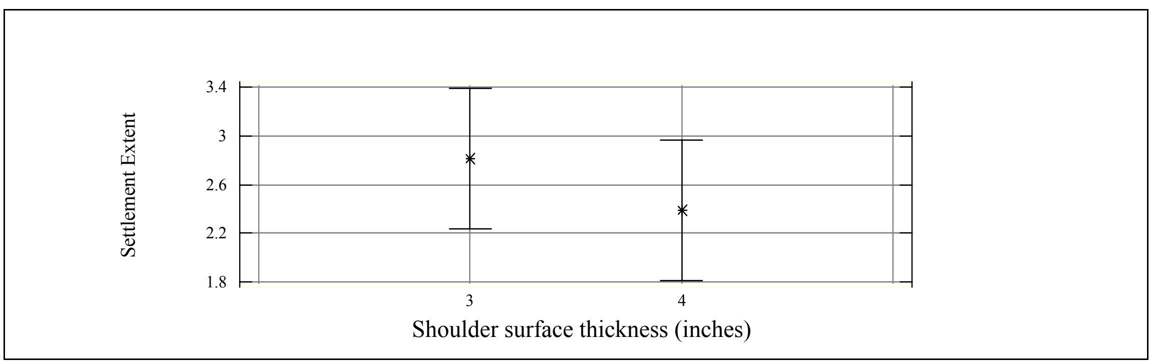

Figure 4.80 Settlement Extent and Shoulder Surface Thickness (Composite Type-8)

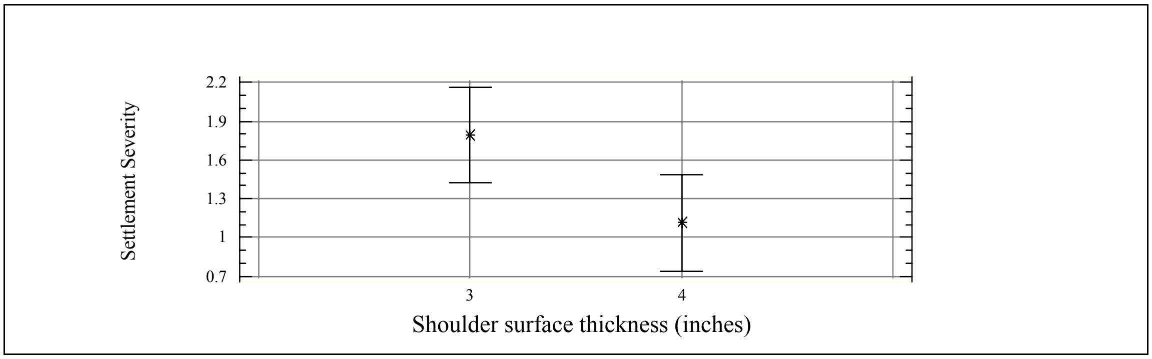

Figure 4.81 Settlement Severity and Shoulder Surface Thickness (Composite Type-8)

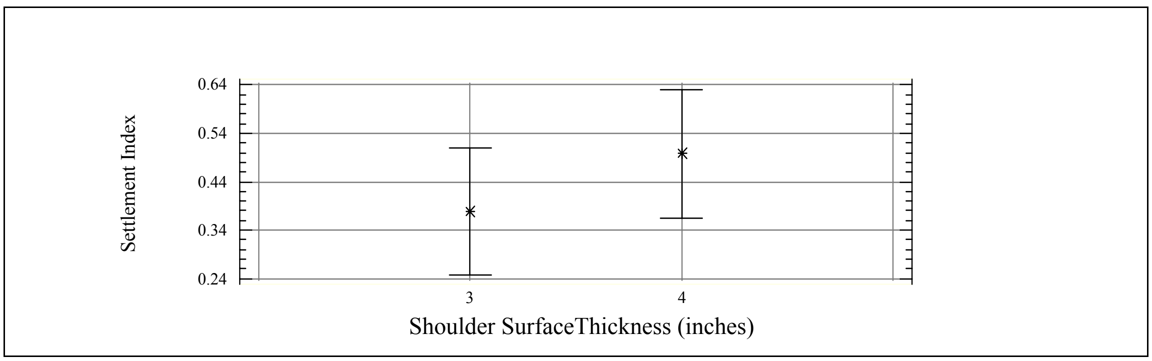

Figure 4.82 Settlement Index and Shoulder Surface Thickness (Composite Type-8)

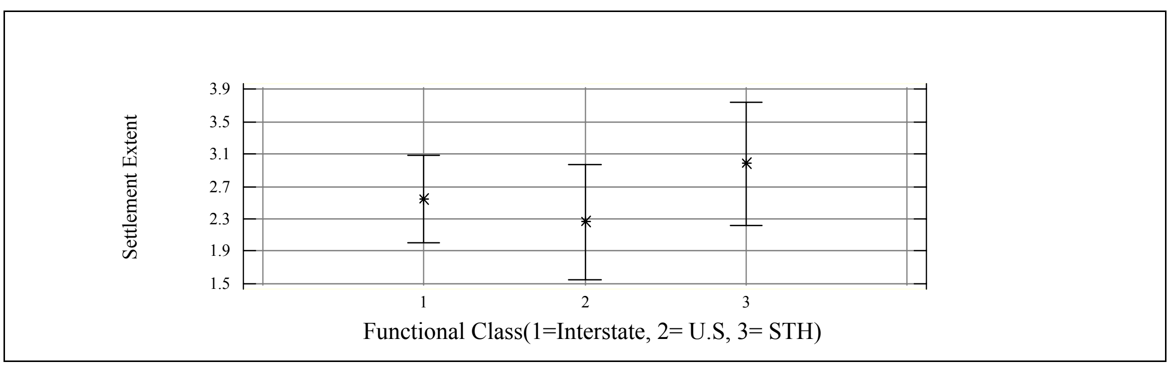

Figure 4.83 Settlement Extent and Roadway Functional Class (Composite Type-8)

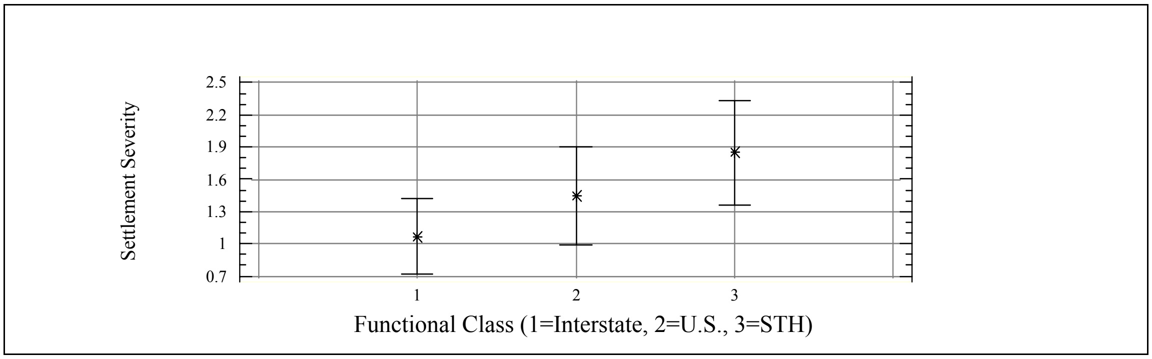

Figure 4.84 Settlement Severity and Roadway Functional Class (Composite Type-8)

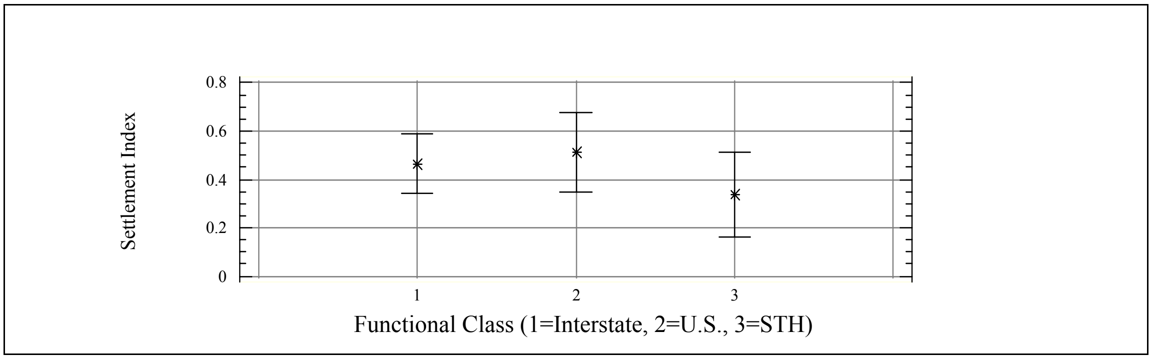

Figure 4.85 Settlement Index and Roadway Functional Class (Composite Type-8)

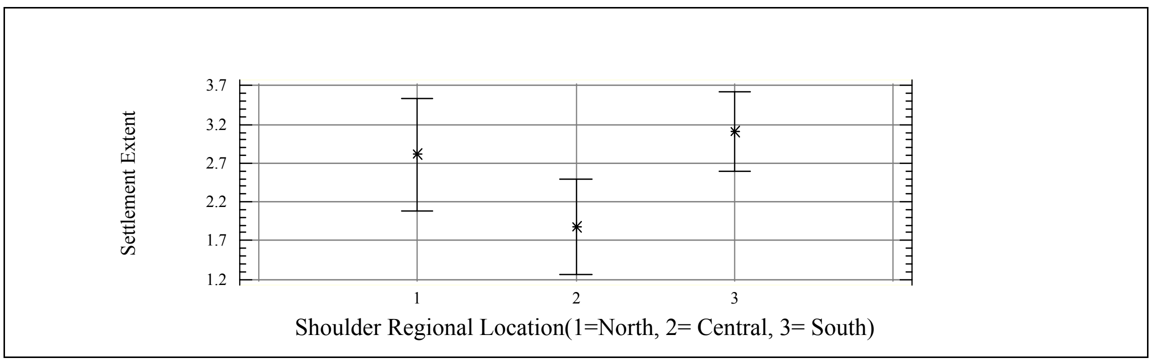

Figure 4.86 Settlement Extent and Regional Location (Composite Type-8)

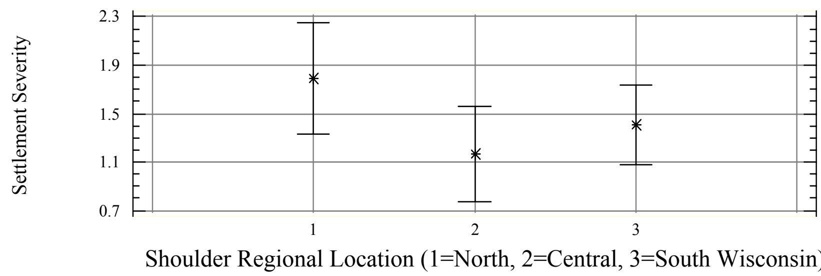

Figure 4.87 Settlement Severity and Regional Location (Composite Type-8)

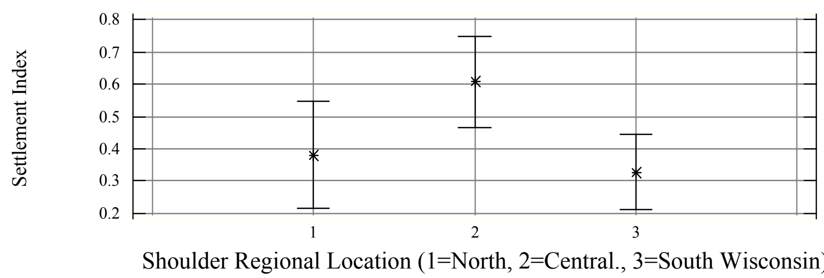

Figure 4.88 Settlement Index and Regional Location (Composite Type-8)

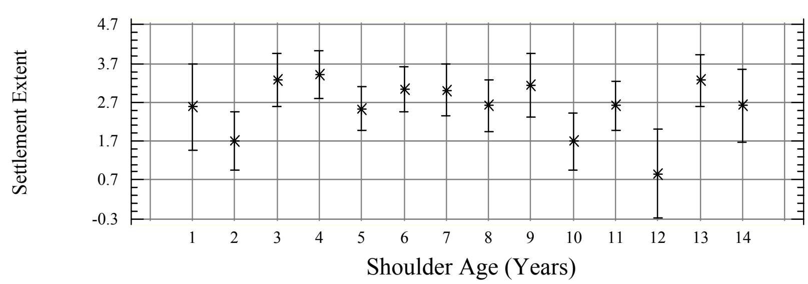

Figure 4.89 Settlement Extent and Age (Composite Type-8)

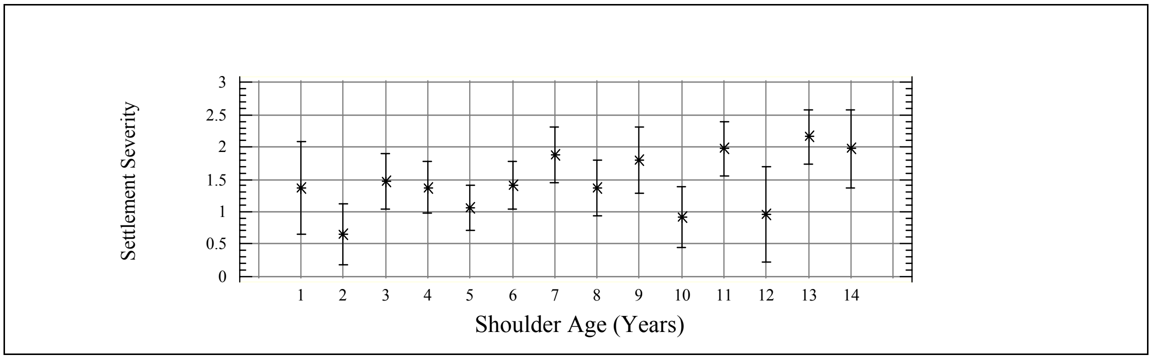

Figure 4.90 Settlement Severity and Age (Composite Type-8)

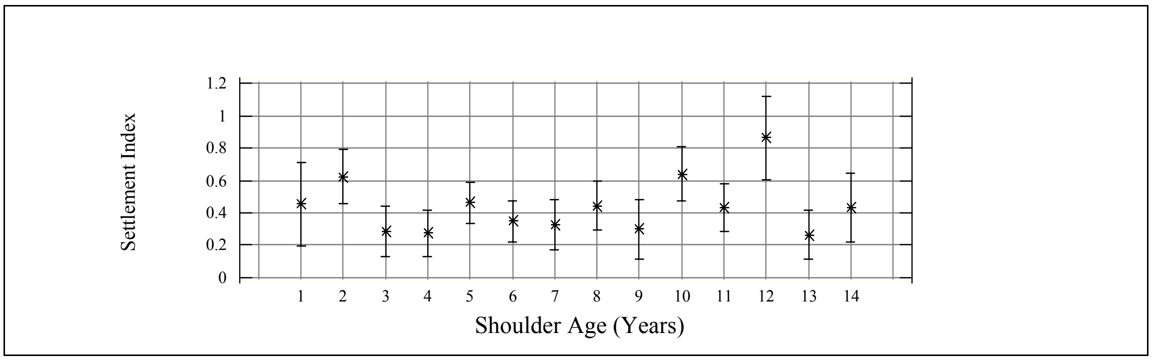

Figure 4.91 Settlement Index and Age (Composite Type-8)

4.3.3.6 Longitudinal Joint Deterioration for AC Surfaced Component of Composite Shoulders, Type-8 PCC

Longitudinal joint deterioration was a function of several design variables, including shoulder base gradation, shoulder width, SSV, and PCC thickness. Key findings were a reduced severity with OGBC base material, as opposed to CABC (Figure 4.92). Shoulder widths of 6 or 8 feet performed better than at 8.5 and 9 feet (Figure 4.93). SSV was significant due to random variation in mean levels with no visible trend observed, as shown by severity in Figure 4.94. PCC thickness was significant, however, this was attributed to random changes in the mean level among different thicknesses (Figure 4.95).

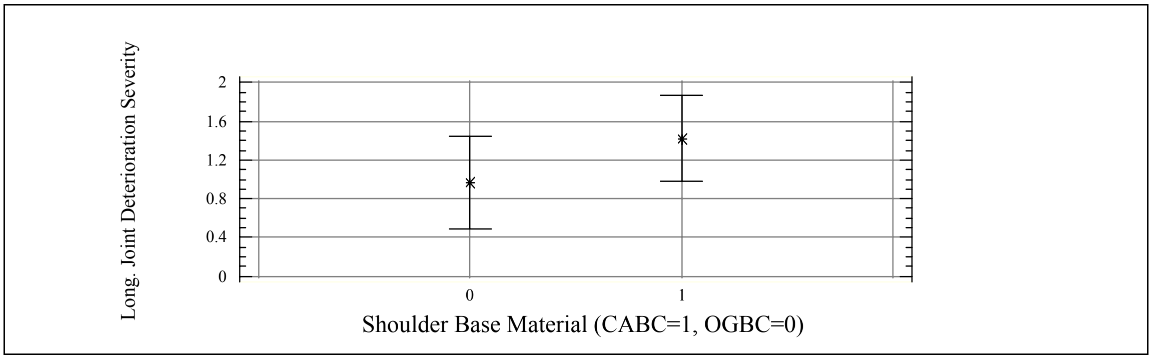

Figure 4.92 Longitudinal Joint Deterioration Severity and Shoulder Base Material (Composite Type-8)

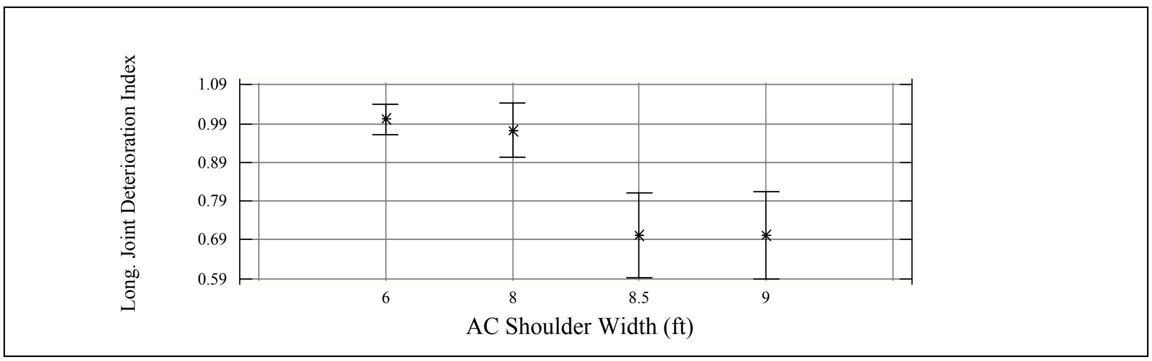

Figure 4.93 Longitudinal Joint Deterioration Index and AC Shoulder Width (Composite Type-8)

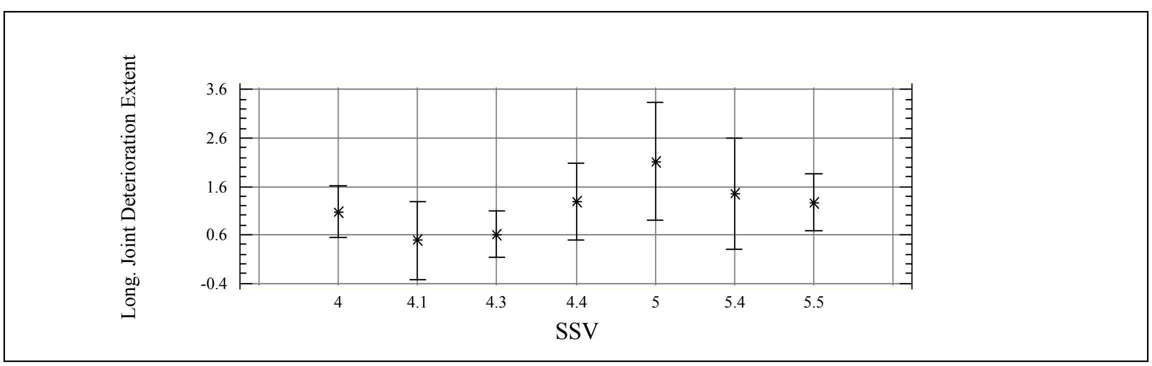

Figure 4.94 Longitudinal Joint Deterioration Extent and SSV (Composite Type-8)

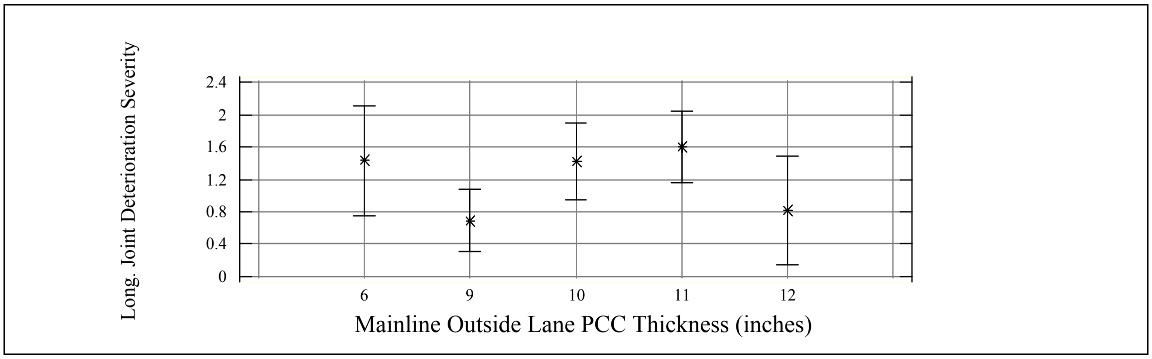

Figure 4.95 Longitudinal Joint Deterioration Severity and PCC Thickness (Composite Type-8)

Figures 4.96 through 4.100 provide plots of longitudinal joint deterioration with regional location, age, and filling of the longitudinal joint. Regional location had a significant effect, having higher severity levels for the northern and southern regions (Figure 4.96). There was slight trend in the relationship between age and the extent and severity levels (Figures 4.97 and 4.98). Filling the longitudinal joint reduced the extent of deterioration, as shown in Figure 4.100.

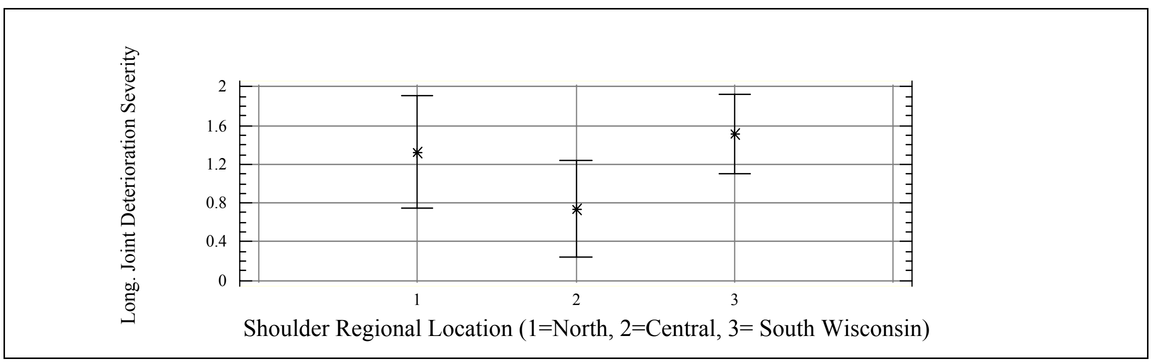

Figure 4.96 Longitudinal Joint Deterioration Severity and Shoulder Regional Location (Composite Type-8)

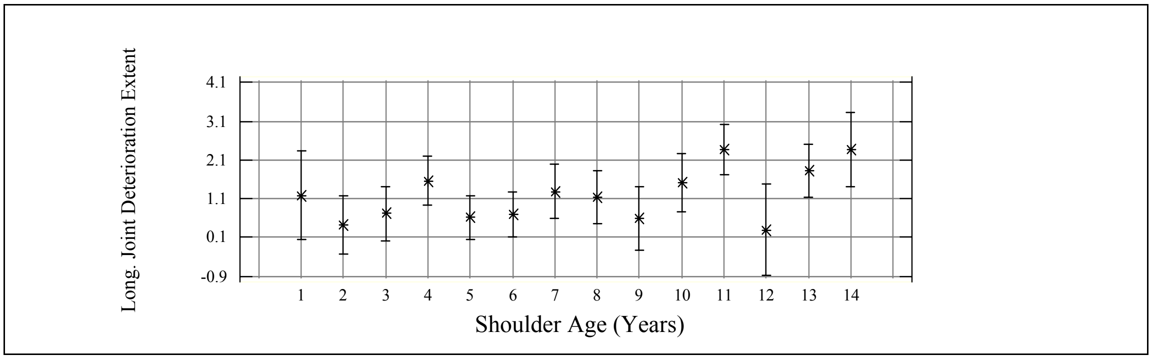

Figure 4.97 Longitudinal Joint Deterioration Extent and Age (Composite Type-8)

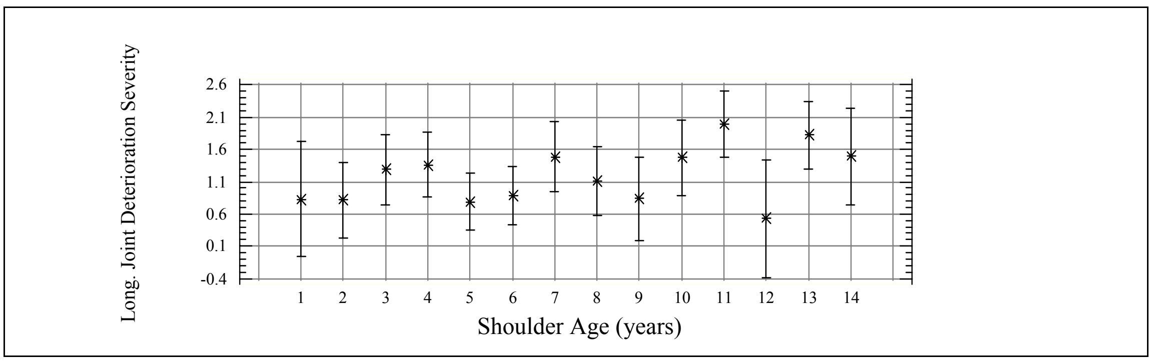

Figure 4.98 Longitudinal Joint Deterioration Severity and Age (Composite Type-8)

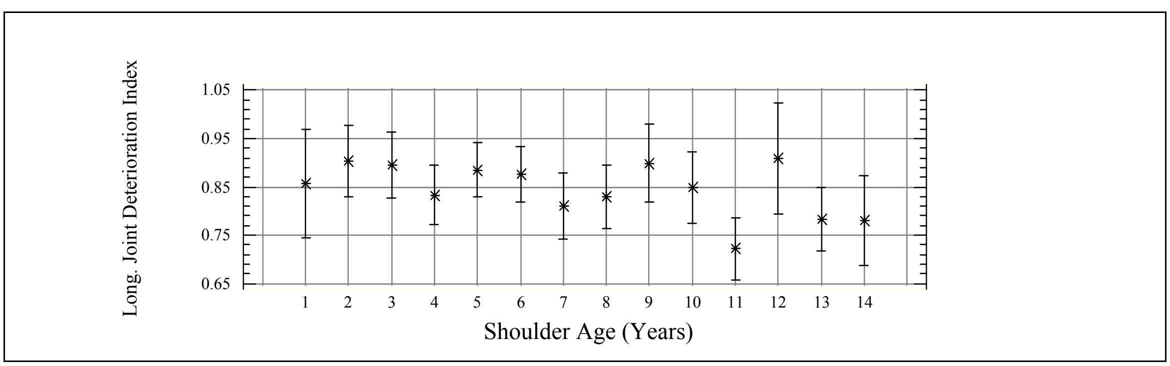

Figure 4.99 Longitudinal Joint Deterioration Index and Age (Composite Type-8)

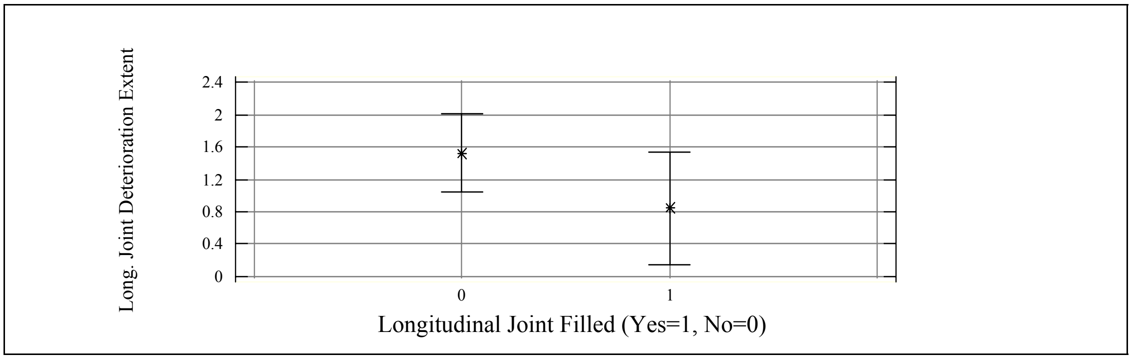

Figure 4.100 Longitudinal Joint Deterioration Extent and Filling the Longitudinal Joint (Composite Type-8)

4.3.4 Preliminary Recommendations for Composite Shoulders (Type-8 PCC)

Findings from the ANOVA and simple plots provided preliminary recommendations for enhancing the performance of composite shoulders adjacent to Type-8 PCC pavements. Table 4.14 synthesizes design recommendations from the analysis, while Table 4.15 provides data observations for planning maintenance activities. These preliminary recommendations were used to develop the final guidelines in Chapter 5.

Table 4.14 Preliminary Design Considerations for Asphalt Surfaced Component of Composite Shoulders (Type-8 PCC)

Distress (1)	DESIGN OBJECTIVE IS TO MINIMIZE (2)	DESIGN ELEMENTS AND/OR VALUES FOR CONSIDERATION (3)	BASIS FOR SUGGESTED VALUES* (4)
Transverse Cracking	Extent	a. AC surface thickness: 4 inches b. Longitudinal Joint Fill	a. Figure 4.33 b. Figure 4.46
	Severity	a. Base material: CABC	a. Figure 4.30
	Severity & Extent	a. Longitudinal Joint Fill b. AC shoulder width: >8ft	a. Figure 4.47 b. Figure 4.32
Longitudinal Cracking	Extent	-	-
	Severity	-	-
	Severity & Extent	-	-
Outside Edge Raveling	Severity	a. AC surface thickness: 4 inches	a. Figure 4.56
Heave	Extent	a. AC shoulder width: ≥ 8 feet b. Base material: CABC	a. Figure 4.66 b. Figure 4.63
	Severity	a. AC shoulder width: ≥ 8 feet b. Base material: CABC	a. Figure 4.67 b. Figure 4.64
	Severity & Extent	a. Base material: CABC	a. Figure 4.65
Settlement	Extent	a. AC surface thickness: 4 inches	a. Figure 4.80
	Severity	a. AC surface thickness: 4 inches	a. Figure 4.81
	Severity & Extent	a. AC surface thickness: 4 inches	a. Figure 4.82
Longitudinal Joint Deterioration	Extent	a. Longitudinal Joint Fill	a. Figure 4.100
	Severity	a. Base material: OGBC	a. Figure 4.92
	Severity & Extent	a. AC shoulder width ≤ 8 feet. b. Longitudinal Joint Fill	a. Figure 4.93 b. Table 4.16 (Model 3)
* See Table 4.13 for all parameters			

Table 4.15 Key Distresses for Maintenance Considerations in Composite Shoulders (Type-8 PCC)

Distress (1)	INFLUENTIAL VARIABLE(S) (2)	DATA OBSERVATION (3)	OBSERVATION SOURCE* (4)
Transverse Cracking	Functional Class	Extent is higher for Interstate and U.S. Highways	Figure 4.39
	Regional location	Extent and severity levels are higher for central and southern regions	Figures 4.40 & 4.41
	Age	Extent and severity increase with age.	Figures 4.43 & 4.44 Table 4.16 (Model 1)
	Longitudinal Joint Fill	Extent is lower for filled joints	Figure 4.46
Longitudinal Cracking	Functional Class	Extent is higher for and U.S. and State Trunk Highways	Figures 4.50 & 4.51
	Age	Extent and severity increase with age.	Figures 4.53 & 4.54
Outside Edge Raveling	Age	The severity (also denoted by the index) worsens after 10 years	Figure 4.62
	Functional Class	Severity is higher for and U.S. and State Trunk Highways	Figures 4.57 & 4.58
	Regional location	Severity levels are higher for the north and south regions	Figures 4.59 & 4.60
Heave	Regional location	Extent and severity levels are higher for central region	Figures 4.74 & 4.75
	Functional Class	Extent and severity are higher for Interstate highways	Figures 4.71 & 4.72
Settlement	Functional Class	Extent and severity are higher for State Trunk highways	Figures 4.83 & 4.84
	Regional location	Extent and severity levels are higher for the north and south regions	Figures 4.86 & 4.87
Longitudinal Joint Deterioration	Regional location	Severity levels are higher for the north and south regions	Figures 4.96
	Age	Extent and severity increase with age.	Figures 4.97 & 4.98 Table 4.16 (Model 3)
	Longitudinal Joint Fill	Extent is lower for filled joints	Figure 4.100
* Table 4.9 for all parameters			

4.3.5 Regression Modeling for Asphalt Shoulders Adjacent to Type-8 PCC

Table 4.16 provides regression models constructed from significant input variables for composite-shoulder adjacent to Type-8 PCC pavements. Several models were assessed for each distress category to allow flexibility in model selection for development of guidelines. Similar to concrete shoulders, a test of outliers was conducted. Those models having a df less than 149 had either outlier(s) removed from the model or missing data points. No regression models were developed for non-composite shoulders, primarily due to unstable models from small sample sizes (n=12 for Type-8 non-composite), or model estimates that were highly influenced by one or two data points. In addition, failures to meet important model assumptions (IIDN) were not met.

Table 4.16 Asphalt Shoulder Performance Models for Doweled Jointed Plain Concrete (Type-8 composite)

Model #	Model Form	R^2, %	DF
1	TRAN = 1.05845-0.0175711*Age	48.2	148
2	LJD=1/(0.958453+0.000023327*2-way Truck Volume)	48.3	147
3	LJD=1.0546-0.00762493*Age-0.0000119439*(2-way Truck Volume) + 0.0454722*Long Joint Filled[1=Yes, 0 = No]	48.0	147

4.3.6 Non-Composite Shoulders Adjacent to Type-5 PCC

The average age of non-composite shoulders adjacent to Type 8 was 10.5 years compared to 19.0 years for non-composite shoulders adjacent to Type 5. Given the significant age difference, no performance comparison was made between the two shoulder configurations. Instead the analysis focused on the non-composite Type 5.

ANOVA results for non-composite shoulders adjacent to Type-5 PCC pavements are provided in Table 4.17. Similar to previous analysis, three levels of significance are provided in the table to assess the relative significance of each independent variable. Degrees of freedom were 91 total, 59 error and 32 model. All project segments had CABC as shoulder base material. A discussion and plots of each distress follows.

Table 4.17 ANOVA Results for Non-Composite Shoulders Adjacent to Type-5 PCC

Dependent Variable	Independent Variables									
	Design						Traffic		Envir	Maint
	Shoulder Base Thickness	Shoulder Width	Shoulder Surface Thickness	SSV	PCC Thickness	Edge Drain	Functional Class	Region Location	Age	Long. Joint Filled
TRAN$_{Ext}$	XXX	n/s	n/s	n/s	XX	n/s	n/s	n/s	XX	n/s
TRAN$_{Sev}$	n/s	n/s	n/s	XX	XXX	n/s	XXX	n/s	X	n/s
TRAN$_{SDIF}$	XXX	n/s	n/s	n/s	XX	n/s	XXX	n/s	XX	n/s
LONG$_{Ext}$	XXX	X	n/s	X	XXX	n/s	n/s	n/s	XX	XXX
LONG$_{Sev}$	XX	XX	n/s	n/s	X	n/s	n/s	n/s	n/s	XX
LONG$_{SDIF}$	XX	XX	n/s	n/s	X	n/s	n/s	n/s	n/s	XX
EDGE$_{Sev}$	n/s	XX	XXX	XX	n/s	X	n/s	n/s	XXX	n/s
EDGE$_{SDIF}$	n/s	XX	XXX	XX	n/s	X	n/s	n/s	XXX	n/s
HEAV$_{Ext}$	XXX	n/s	n/s	n/s	n/s	n/s	n/s	n/s	XXX	n/s
HEAV$_{Sev}$	XXX	n/s	n/s	n/s	X	n/s	n/s	n/s	XX	n/s
HEAV$_{SDIF}$	XXX	n/s	n/s	n/s	n/s	n/s	n/s	n/s	XXX	n/s
SETT$_{Ext}$	n/s	XXX	XX	XX	XXX	n/s	XX	n/s	XXX	n/s
SETT$_{Sev}$	XX	N/s	n/s	n/s	n/s	n/s	n/s	n/s	XX	XX
SETT$_{SDIF}$	n/s	XXX	X	X	XX	n/s	X	n/s	XXX	n/s
LJD$_{Ext}$	XXX	n/s	X	n/s	XX	n/s	n/s	n/s	XX	n/s
LJD$_{Sev}$	XXX	n/s	XX	n/s	XX	n/s	X	n/s	XX	n/s
LJD$_{SDIF}$	XXX	n/s	X	n/s	X	n/s	n/s	n/s	n/s	n/s

TRAN = Transverse Cracks XXX = Highly Significant, p-value ≤ 0.01
LONG = Longitudinal Cracks XX = Moderately Significant, $0.01 <$ p-value < 0.05
EDGE = Edge Raveling X = Marginally Significant, $0.05 \leq$ p-value ≤ 0.1
HEAV/SETT= Heave/Settlement n/s = Not Significant, p-value ≥ 0.1
LJD = Longitudinal Joint Deterioration
Ext = Extent; Sev = Severity level; SDIF = Shoulder Distress Index Factor

4.3.6.1 Transverse Cracking for Non-Composite Shoulders, Type-5 PCC

Shoulder base thickness, SSV, PCC thickness, functional class, and age affected transverse cracking. Key findings were an increase in the mean level of extent with an increase in base thickness (Figures 4.101 and 4.102). A general reduction in severity level was observed with an increase in SSV (Figure 4.103). There was also a general reduction in extent and severity with increasing PCC thickness (Figures 4.104 through 4.106). Traffic, as measured by the roadway functional classification, had a higher severity level for Interstate and U.S. Highways (Figures 4.1107 and 4.108). An increase in age produced random variation in the mean level, with a slight increase in the extent (Figures 4.109 and 4.110).

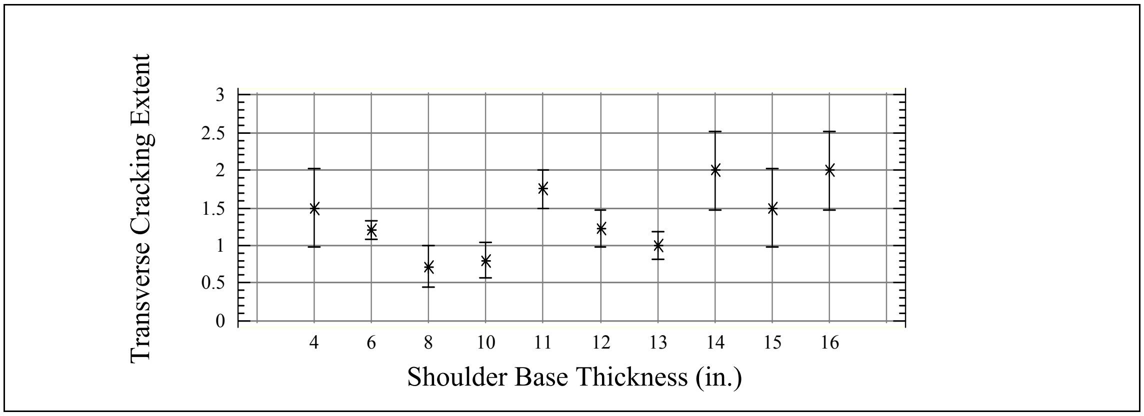

Figure 4.101 Transverse Cracking Extent and Shoulder Base Thickness (Non-Composite Type-5)

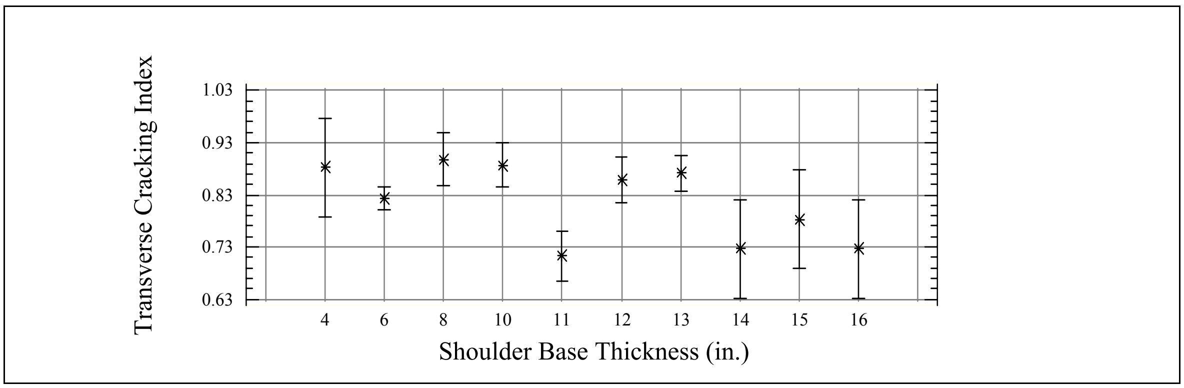

Figure 4.102 Transverse Cracking Index and Shoulder Base Thickness (Non-Composite Type-5)

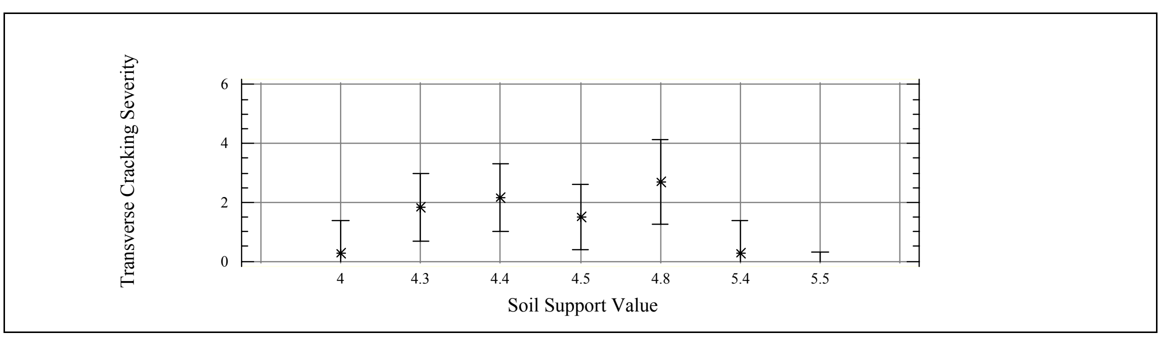

Figure 4.103 Transverse Cracking Severity and SSV (Non-Composite Type-5)

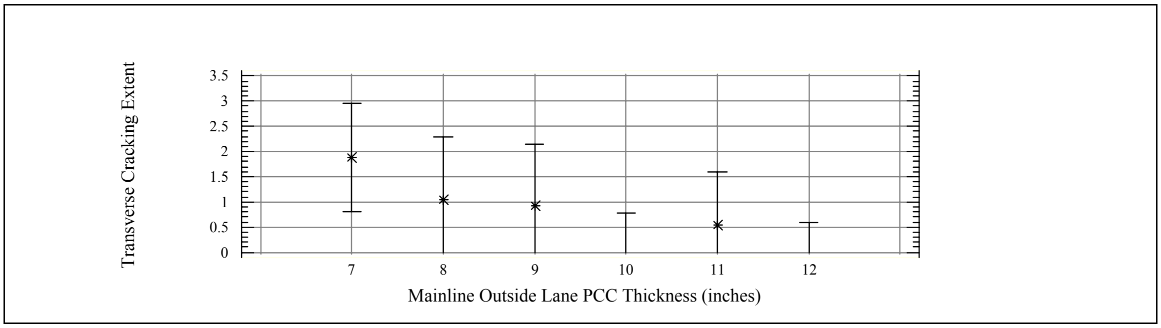

Figure 4.104 Transverse Cracking Extent and PCC Thickness (Non-Composite Type-5)

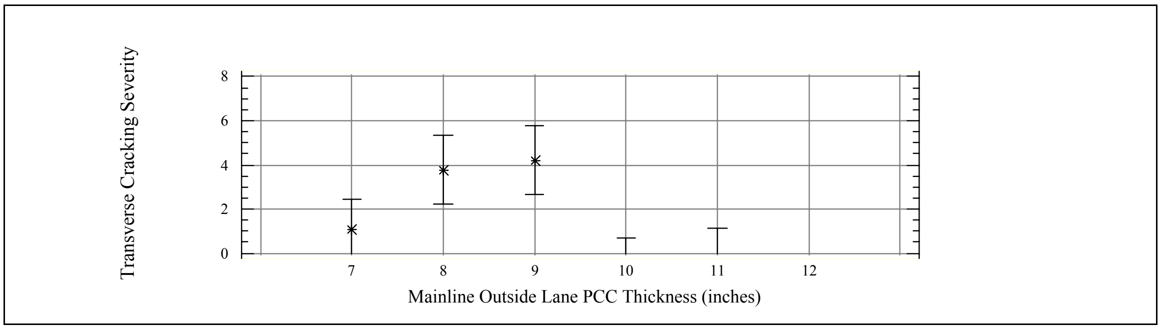

Figure 4.105 Transverse Cracking Severity and PCC Thickness (Non-Composite Type-5)

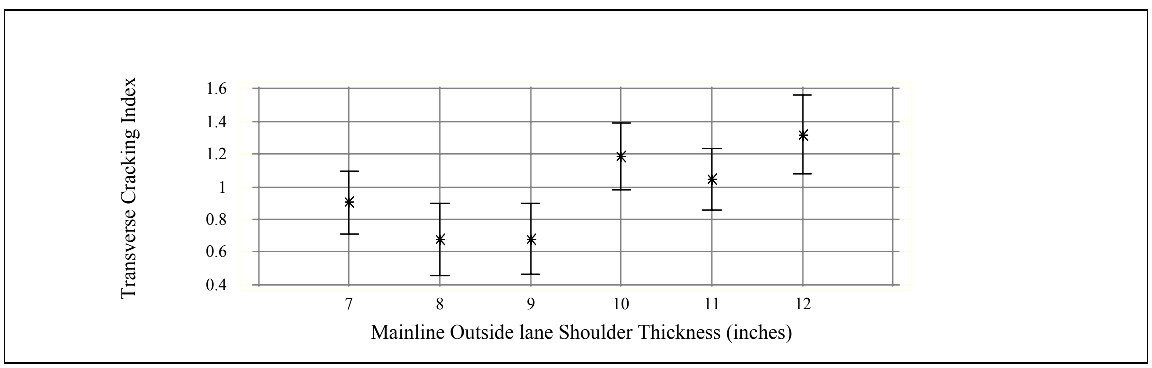

Figure 4.106 Transverse Cracking Index and PCC Thickness (Non-Composite Type-5)

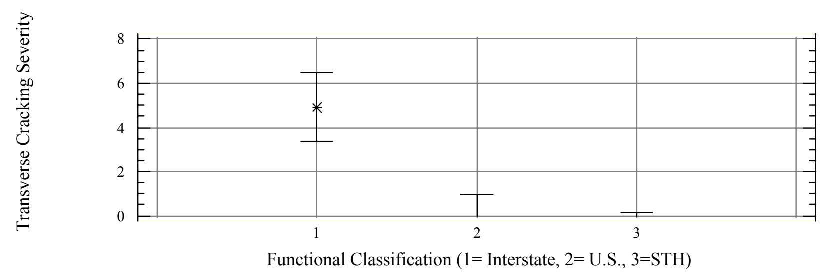

Figure 4.107 Transverse Cracking Severity and Roadway Functional Class (Non-Composite Type-5)

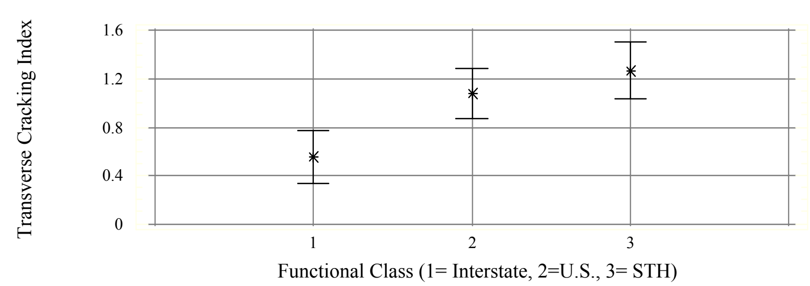

Figure 4.108 Transverse Cracking Index and Roadway Functional Class (Non-Composite Type-5)

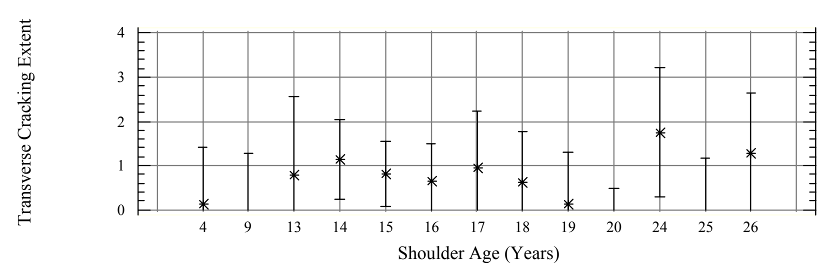

Figure 4.109 Transverse Cracking Extent and Age (Non-Composite Type-5)

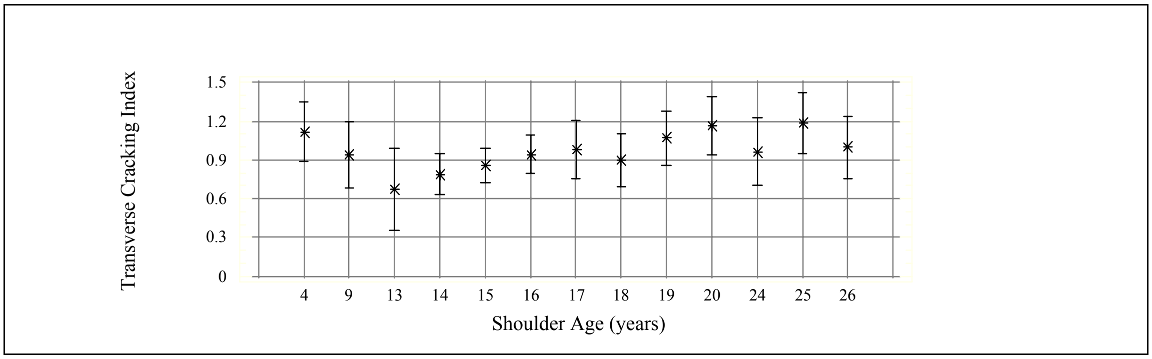

Figure 4.110 Transverse Cracking Index and Age (Non-Composite Type-5)

4.3.6.2 Longitudinal Cracking for Non-Composite Shoulders, Type-8 PCC

Longitudinal cracking was significant with shoulder base thickness, AC shoulder width, PCC thickness, age, and filling the longitudinal joint. There was random variation in the mean extent and severity levels for a range of shoulder base thicknesses (Figures 4.111 through 4.113). Severity levels increased with AC shoulder width (Figures 4.114 and 4.115). Figures 4.116 shows lower extent levels with thicker PCC pavement. An increase in age produced a gradual increase in extent levels, however, there was some variation in the trend line (Figure 4.117). Filling the longitudinal joint had an interesting relationship where an unfilled joint has lower extent and severity levels (Figures 4.118 through 4.120).

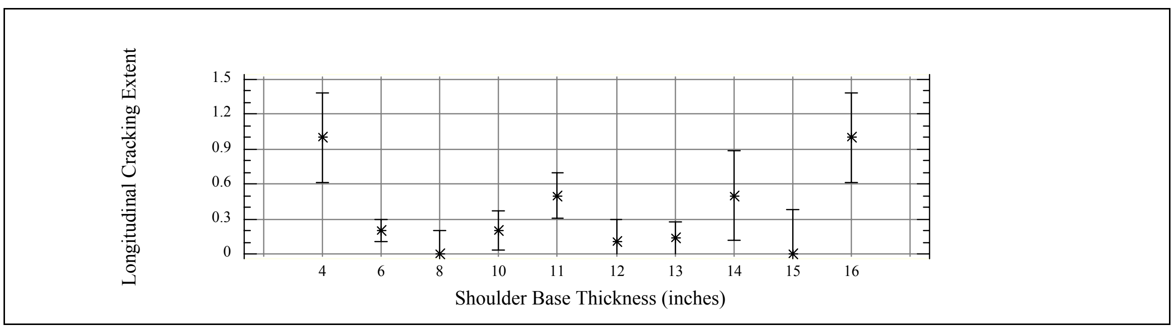

Figure 4.111 Longitudinal Cracking Extent and Shoulder Base Thickness (Non-Composite Type-5)

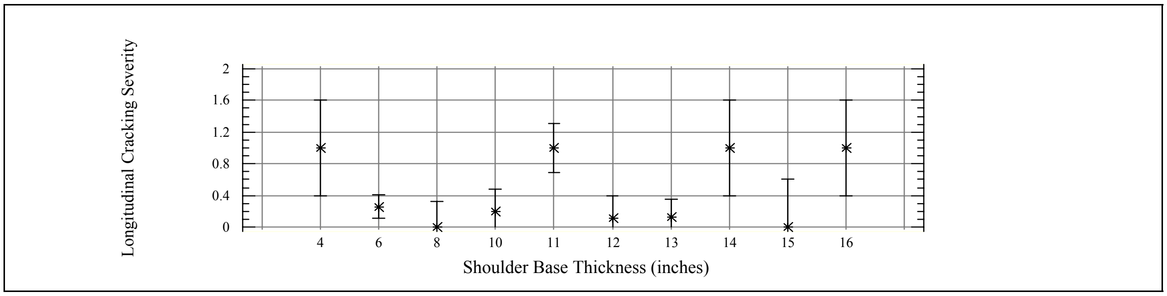

Figure 4.112 Longitudinal Cracking Severity and Shoulder Base Thickness (Non-Composite Type-5)

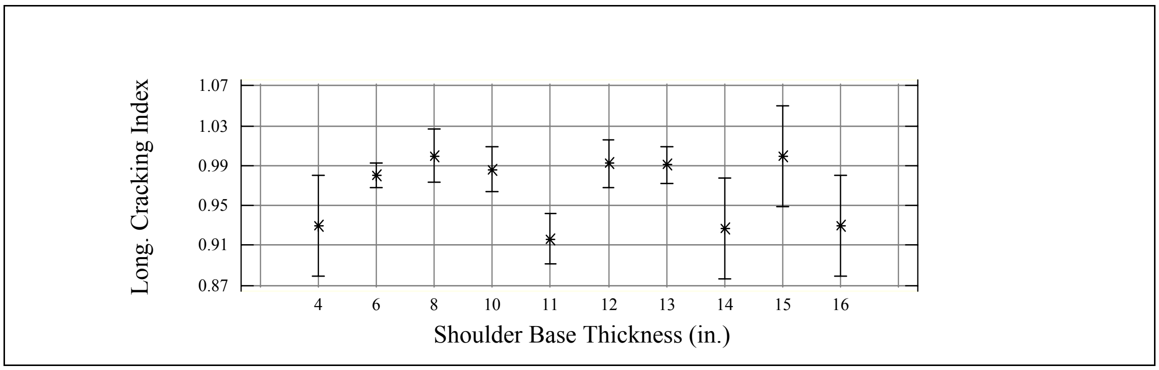

Figure 4.113 Longitudinal Cracking Index and Shoulder Base Thickness (Non-Composite Type-5)

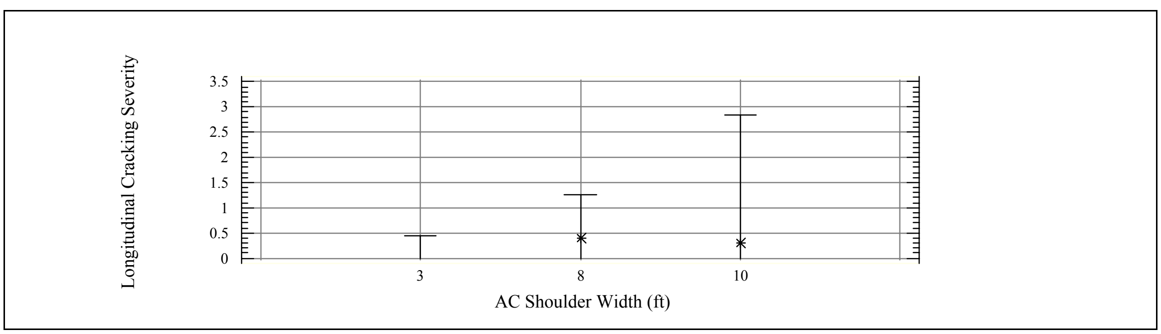

Figure 4.114 Longitudinal Cracking Severity and AC Shoulder Width (Non-Composite Type-5)

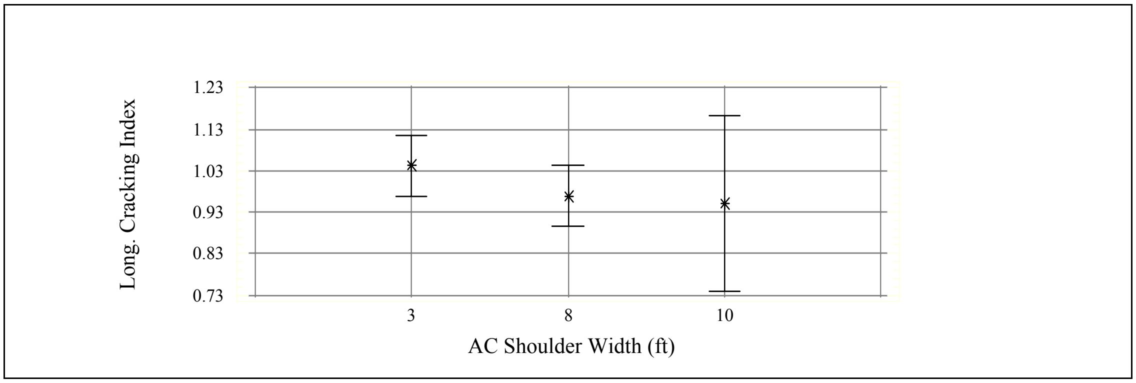

Figure 4.115 Longitudinal Cracking Index and AC Shoulder Width (Non-Composite Type-5)

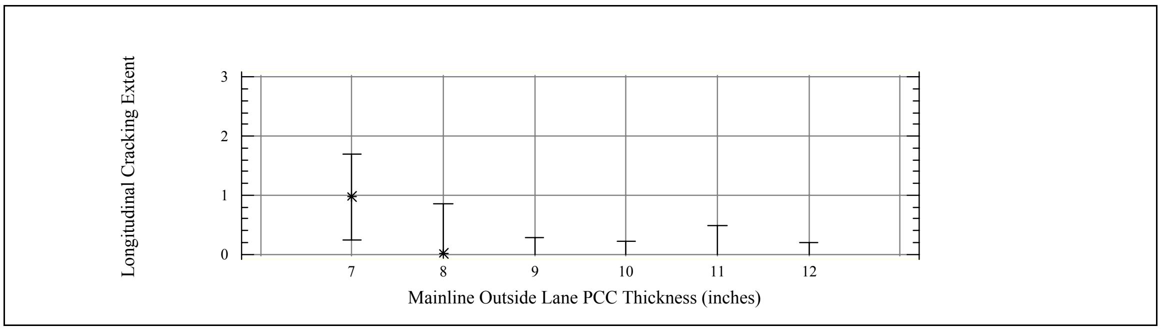

Figure 4.116 Longitudinal Cracking Extent and PCC Thickness (Non-Composite Type-5)

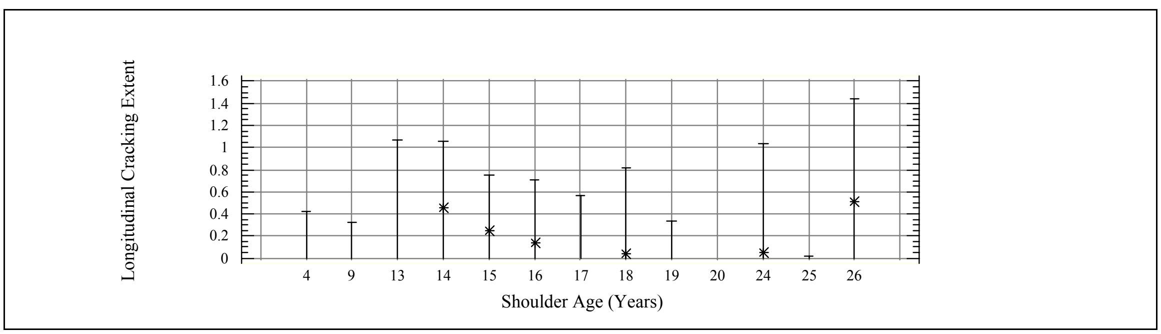

Figure 4.117 Longitudinal Cracking Extent and Age (Non-Composite Type-5)

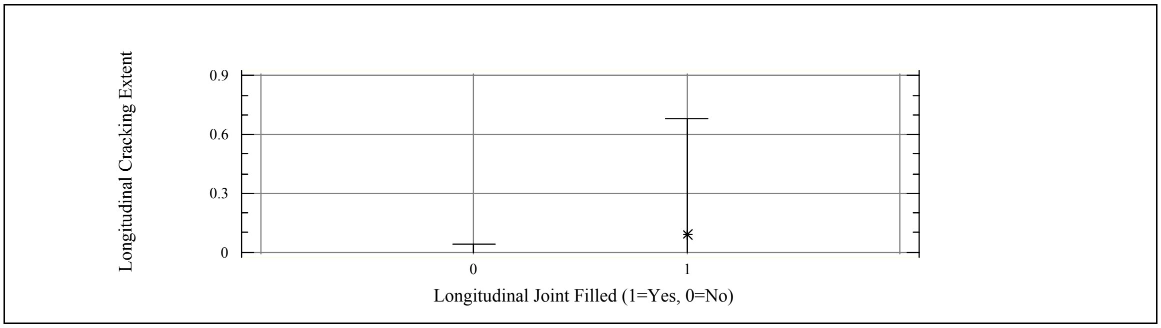

Figure 4.118 Longitudinal Cracking Extent and Filling Longitudinal Joint (Non-Composite Type-5)

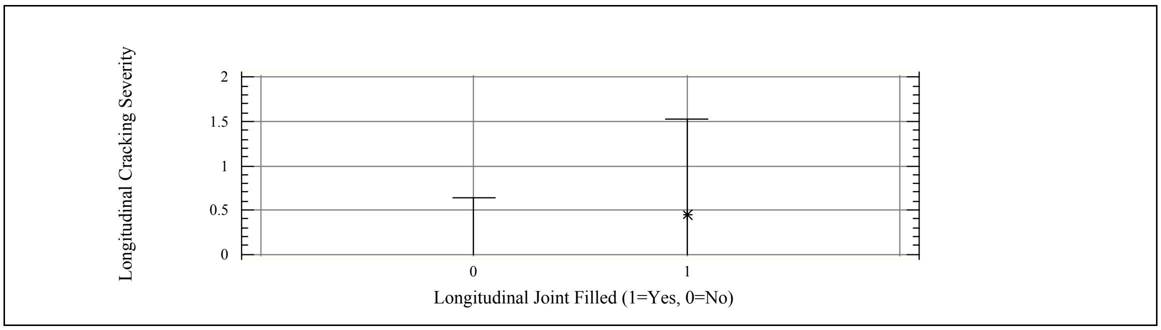

Figure 4.119 Longitudinal Cracking Severity and Filling Longitudinal Joint (Non-Composite Type-5)

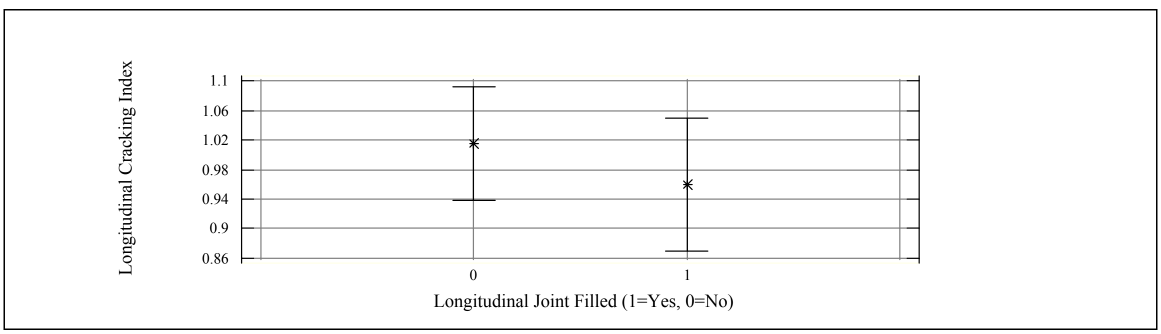

Figure 4.120 Longitudinal Cracking Extent and Filling Longitudinal Joint (Non-Composite Type-5)

4.3.6.3 Edge Raveling for Non-Composite Shoulders, Type-8 PCC

Four design variables affected edge raveling: shoulder width, shoulder thickness, SSV, and edge drain. Shoulder width produced a lower severity with increasing width (Figures 4.121 and 4.122). The severity of edge raveling was reduced with a thicker shoulder surface of 4 inches (Figures 4.123 and 4.124). SSV had a positive effect where an increasing value decreased the severity level (Figures 4.125 and 4.126). A random variation in severity mean levels occurred with increasing age (Figures 4.127 and 4.128).

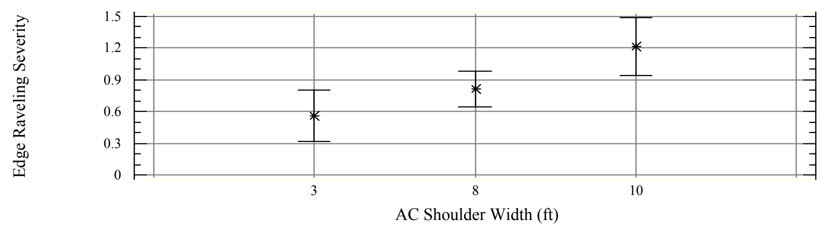

Figure 4.121 Edge Raveling Severity and Shoulder Width (Non-Composite Type-5)

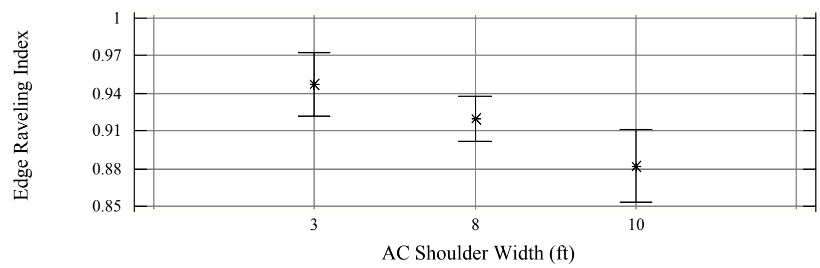

Figure 4.122 Edge Raveling Index and Shoulder Width (Non-Composite Type-5)

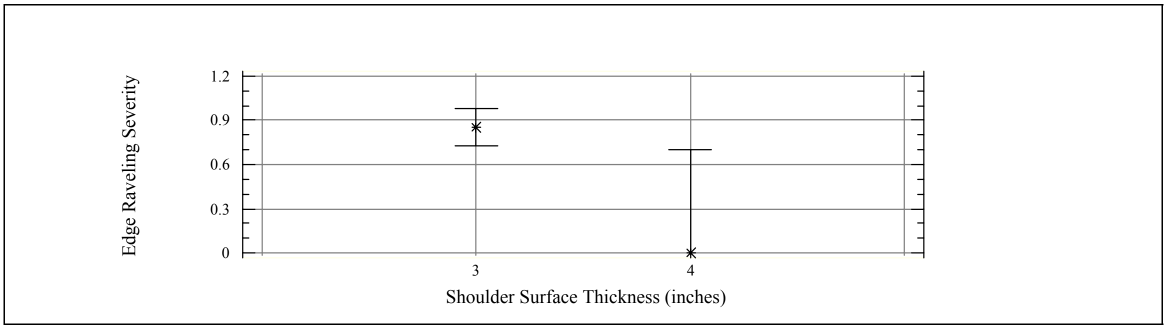

Figure 4.123 Edge Raveling Severity and Shoulder Surface Thickness (Non-Composite Type-5)

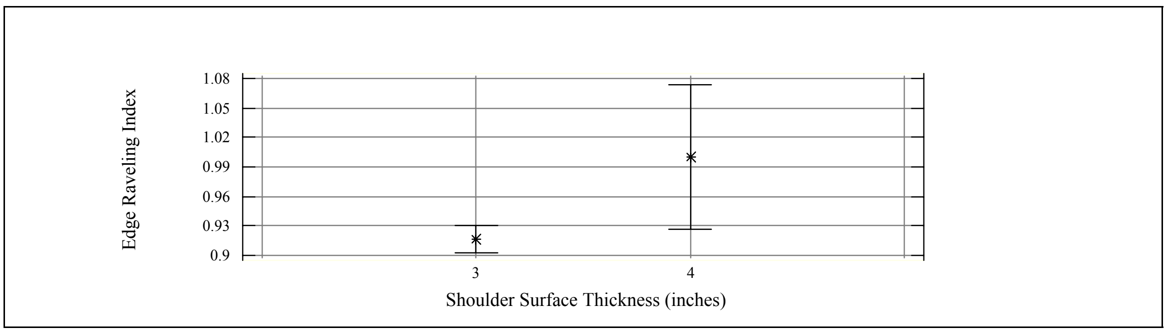

Figure 4.124 Edge Raveling Index and Shoulder Surface Thickness (Non-Composite Type-5)

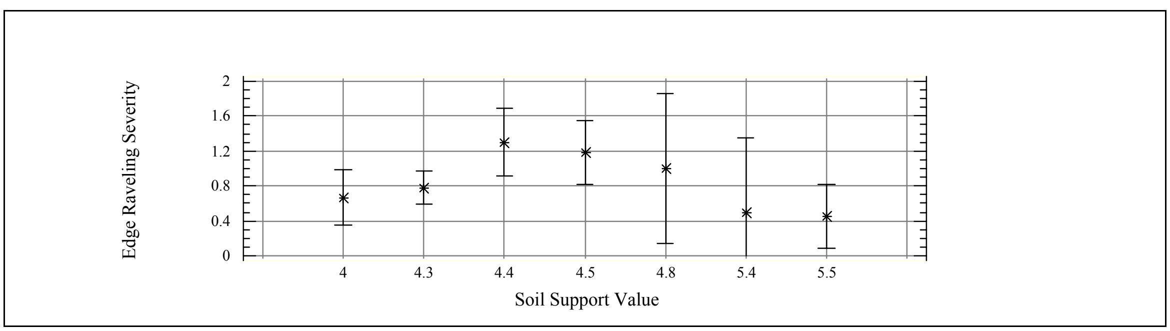

Figure 4.125 Edge Raveling Severity and SSV (Non-Composite Type-5)

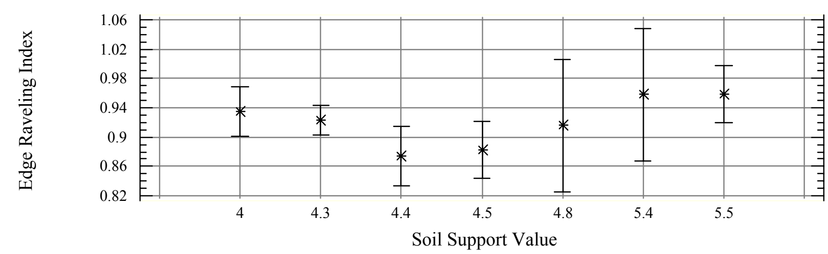

Figure 4.126 Edge Raveling Index and SSV (Non-Composite Type-5)

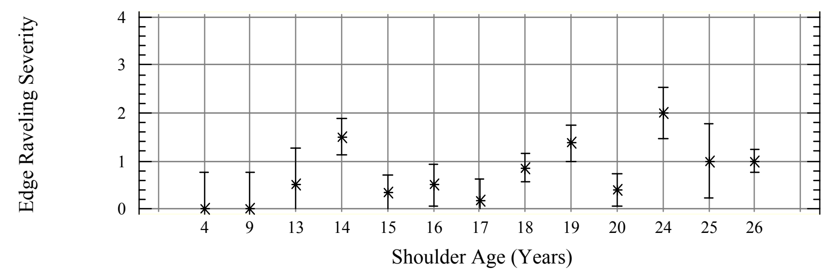

Figure 4.127 Edge Raveling Severity and Age (Non-Composite Type-5)

Figure 4.128 Edge Raveling Severity and Age (Non-Composite Type-5)

4.3.8.4 Heaving for Non-Composite Shoulders, Type-5 PCC

Heaving had a significant relationship with shoulder base thickness and age. The mean level for extent and severity was substantially higher for the 8-inch thick shoulder base, however, the other thickness values had similar means levels (Figures 129 through 131). Figures 4.132 through 4.134 show a gradual increase in extent and severity with age.

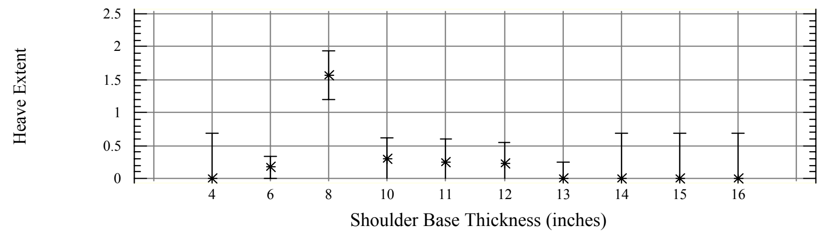

Figure 4.129 Heave Extent and Shoulder Base Thickness (Non-Composite Type-5)

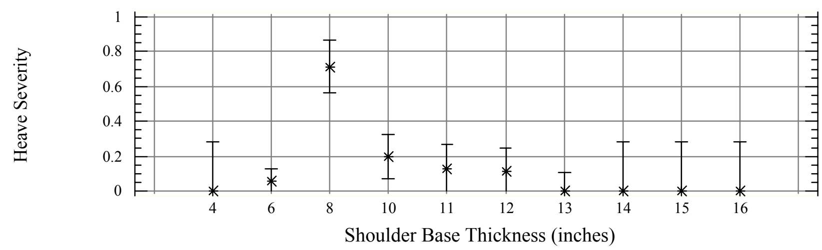

Figure 4.130 Heave Severity and Shoulder Base Thickness (Non-Composite Type-5)

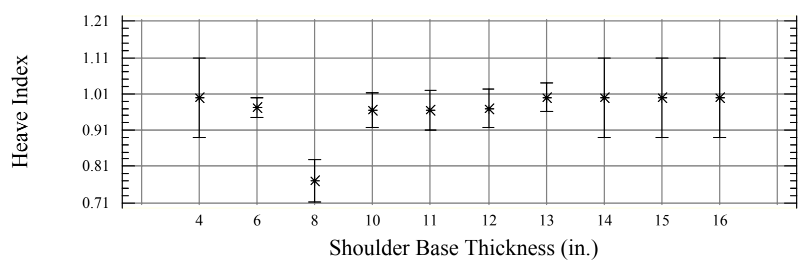

Figure 4.131 Heave Index and Shoulder Base Thickness (Non-Composite Type-5)

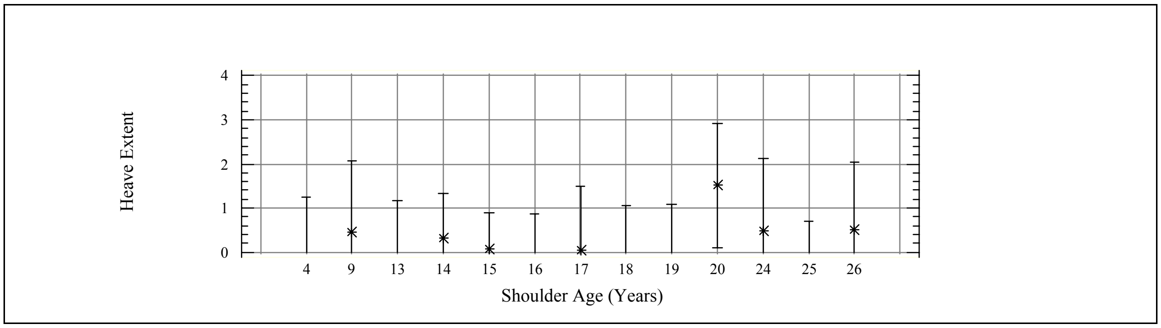

Figure 4.132 Heave Extent and Age (Non-Composite Type-5)

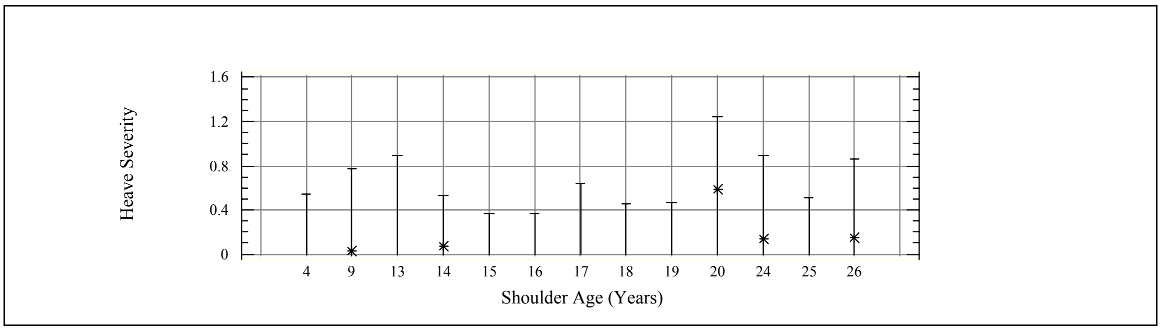

Figure 4.133 Heave Severity and Age (Non-Composite Type-5)

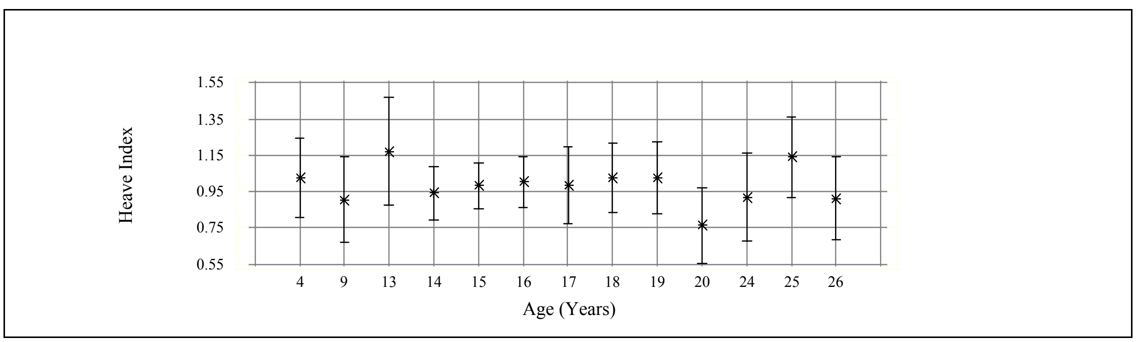

Figure 4.134 Heave Index and Age (Non-Composite Type-5)

4.3.6.5 Settlement for Non-Composite Shoulders, Type-5 PCC

Settlement was significant with five design variables including shoulder base thickness, shoulder width, shoulder surface thickness, SSV, and PCC thickness. Mean levels in shoulder base thickness were significant for severity, and a slight upward trend was observed (Figure 4.135). Figures 4.136 through 4.141 show the relationships of settlement with the design variables. Key findings were a reduced extent with increasing shoulder width (Figures 4.136 and 4.137). Shoulder width of 10 feet had lower extent and higher index levels. Shoulder surface thickness had lower extent with 4-inch thickness, when compared to 3-inch thickness (Figure 4.138). SSV had a consistent mean level near 2, but was reduced to zero with SSV= 5.5 (Figure 4.220). PCC thickness had random variation in the mean level, with no trend observed between the low and high thickness values (Figures 4.140 and 4.141).

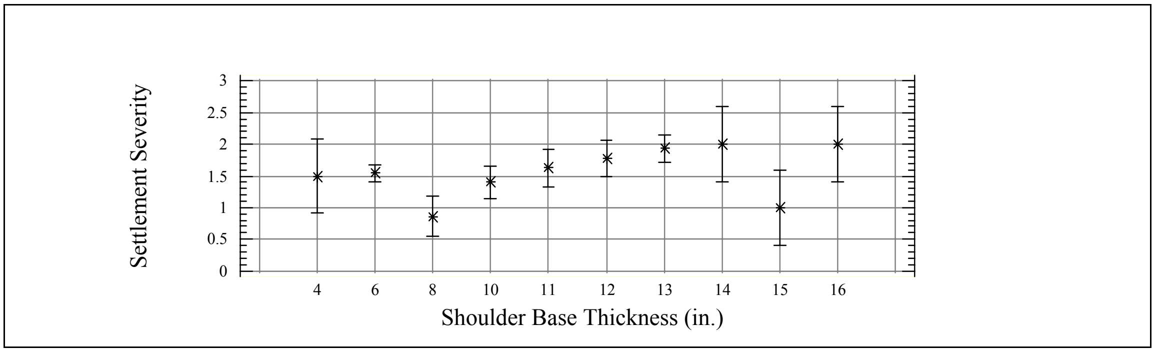

Figure 4.135 Settlement Severity and Shoulder Base Thickness (Non-Composite Type-5)

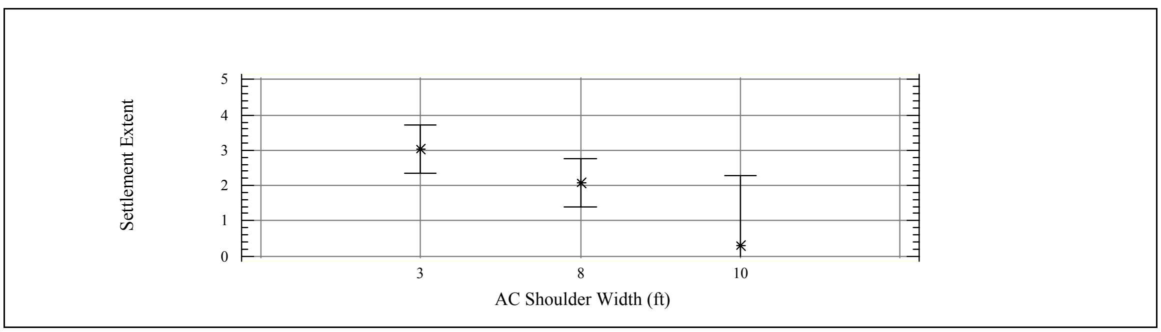

Figure 4.136 Settlement Extent and Shoulder Width (Non-Composite Type-5)

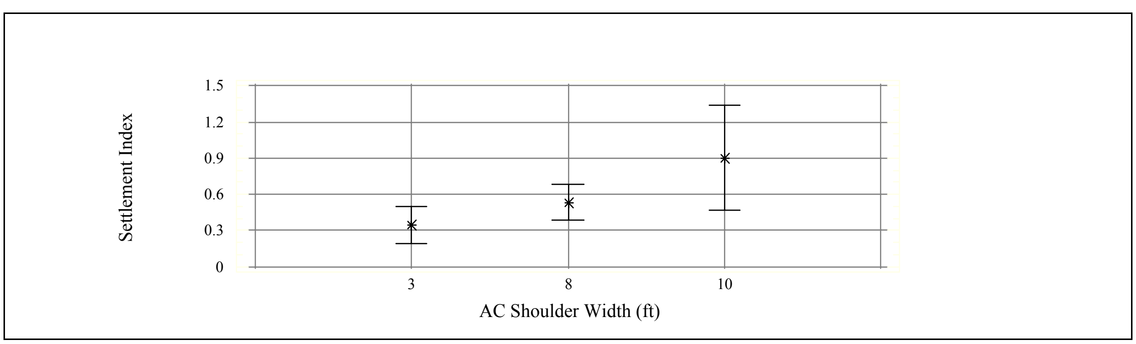

Figure 4.137 Settlement Index and Shoulder Width (Non-Composite Type-5)

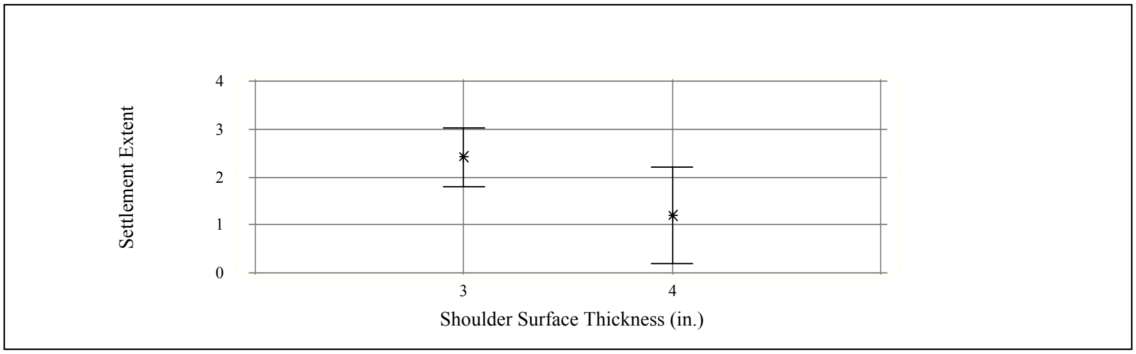

Figure 4.138 Settlement Extent and Shoulder Surface Thickness (Non-Composite Type-5)

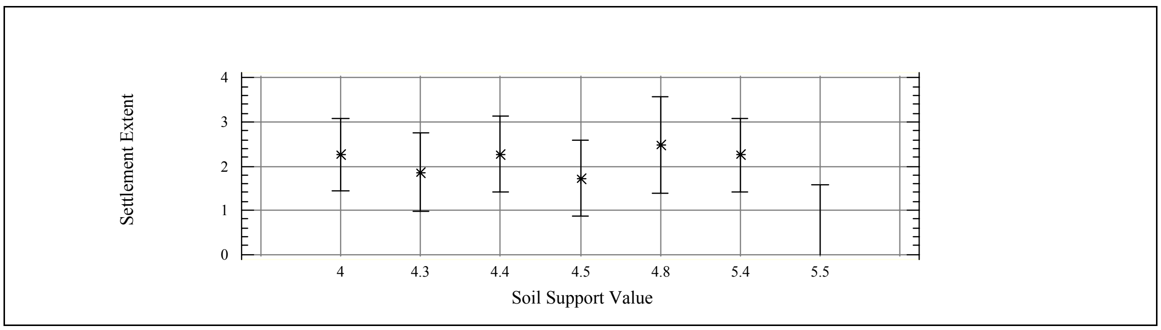

Figure 4.139 Settlement Extent and SSV (Non-Composite Type-5)

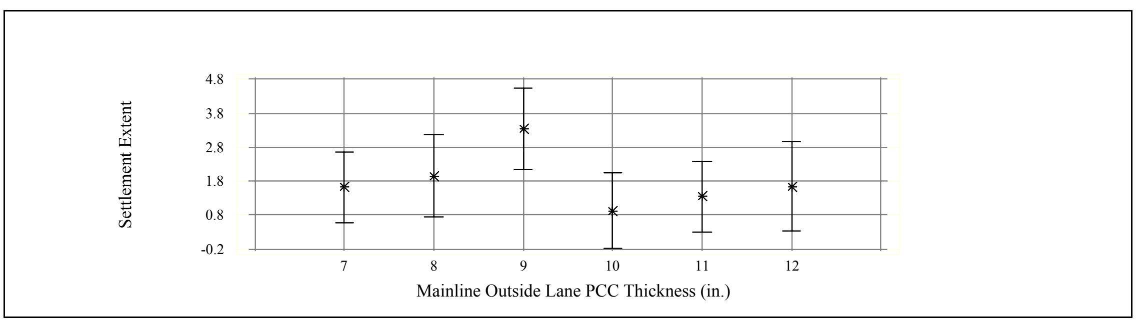

Figure 4.140 Settlement Extent and PCC Thickness (Non-Composite Type-5)

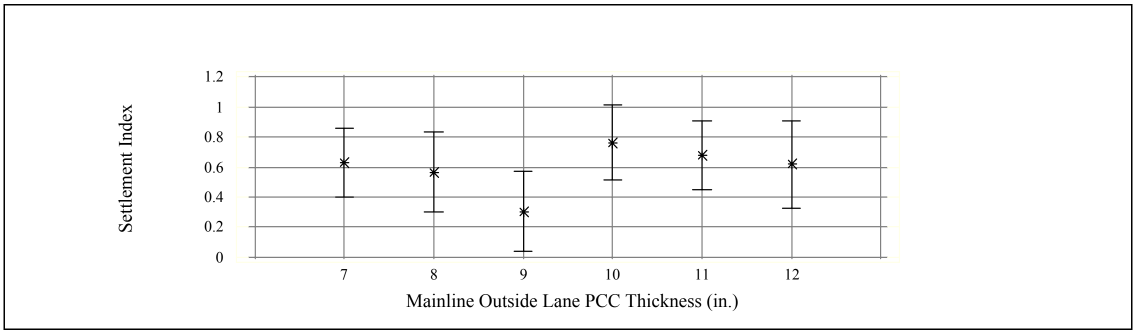

Figure 4.141 Settlement Index and PCC Thickness (Non-Composite Type-5)

Roadway functional class for Interstate Highways had a higher extent than U.S. and State Highways (Figure 4.142). The settlement extent showed an increasing trend with age (Figure 4.143), while the variations of severity and Index with age were random (Figures 4.144 and 4.145). Filling the longitudinal joint increased the severity level (Figure 4.146).

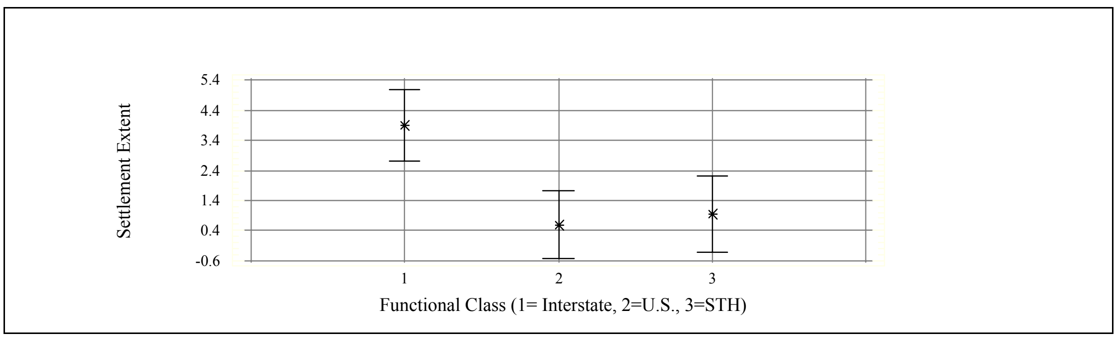

Figure 4.142 Settlement Extent and Roadway Functional Class (Non-Composite Type-5)

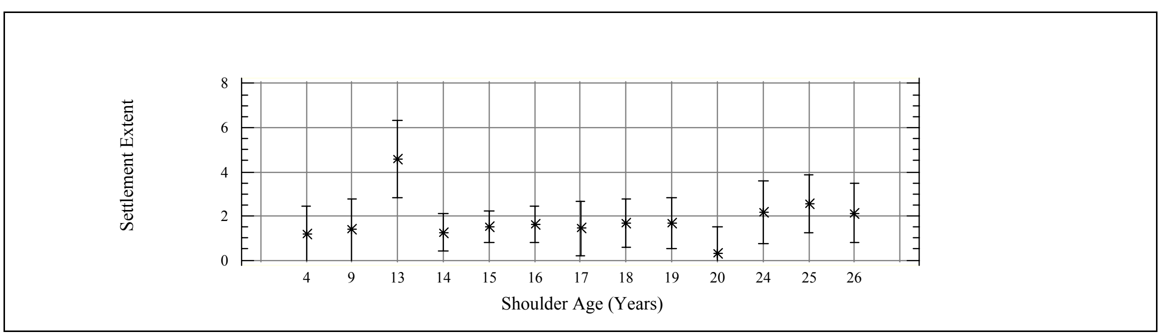

Figure 4.143 Settlement Extent and Age (Non-Composite Type-5)

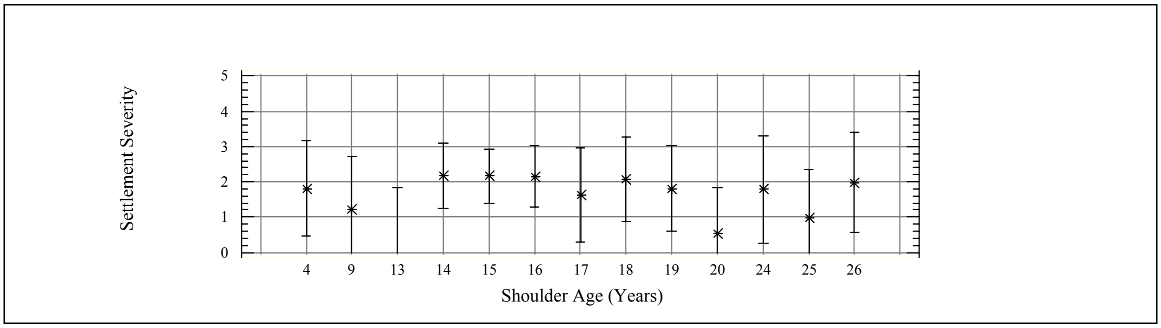

Figure 4.144 Settlement Severity and Age (Non-Composite Type-5)

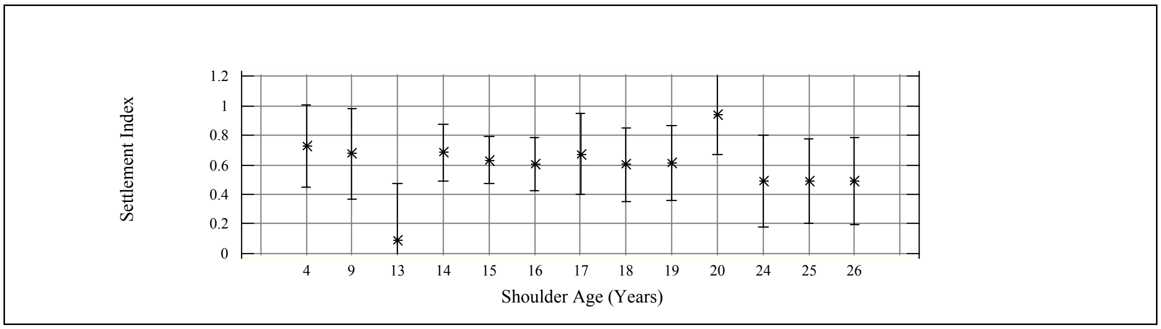

Figure 4.145 Settlement Index and Age (Non-Composite Type-5)

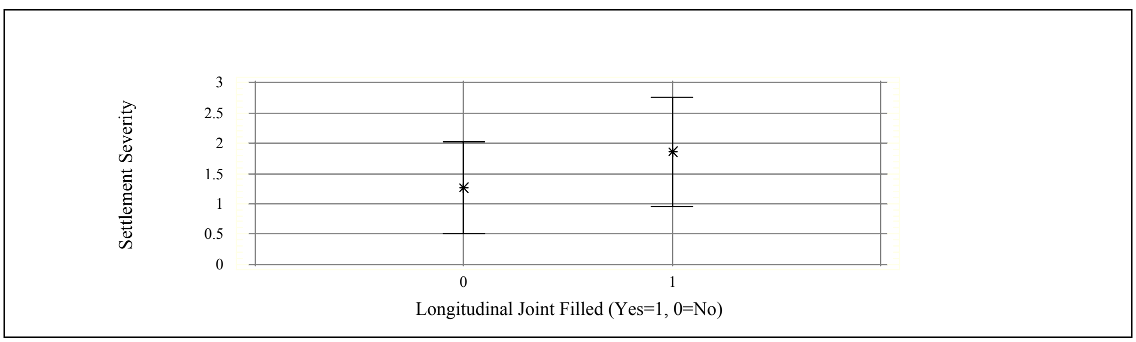

Figure 4.146 Settlement Severity and Filling Longitudinal Joint (Non-Composite Type-5)

4.3.8.6 Longitudinal Joint Deterioration for Non-Composite Shoulders, Type-5 PCC

Longitudinal joint deterioration had a significant relationship with four variables, including shoulder base thickness, shoulder surface thickness, PCC thickness, and age.

Key findings were no trend between shoulder base thickness and both extent and severity levels (Figures 4.147 through 4.149). Shoulder thickness had a direct effect, where 3-inch thickness had lower extent and severity levels (Figures 4.150 and 4.151). PCC thickness was significant, however, this was attributed to random changes in the mean level among different thicknesses (Figures 4.152 and 4.153). Age had random changes in the mean level for extent, however, a reduced severity level was observed with increased age (Figures 4.154 and 4.155).

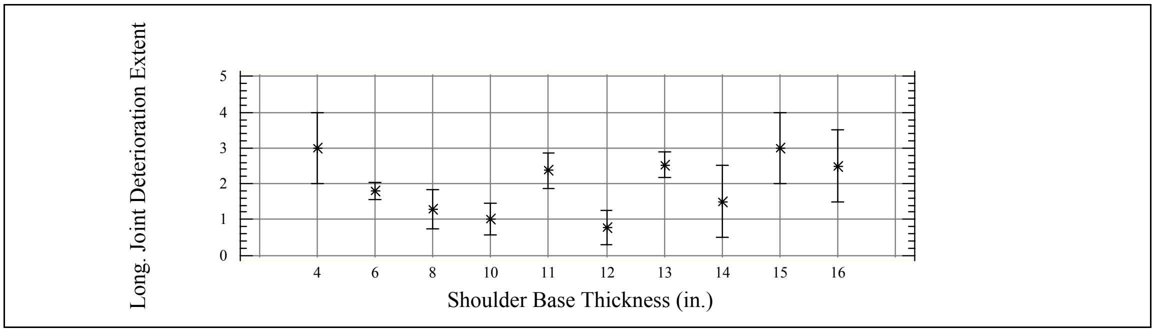

Figure 4.147 Longitudinal Joint Deterioration Extent and Shoulder Base Thickness (Non-Composite Type-5)

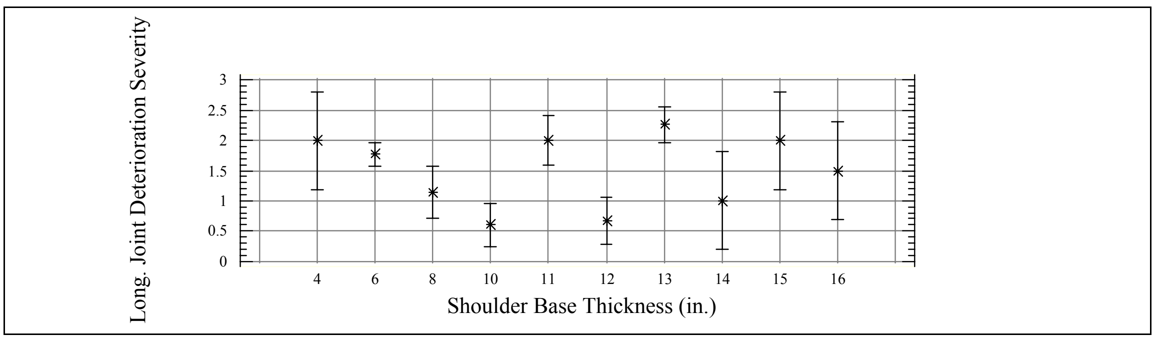

Figure 4.148 Longitudinal Joint Deterioration Severity and Shoulder Base Thickness (Non-Composite Type-5)

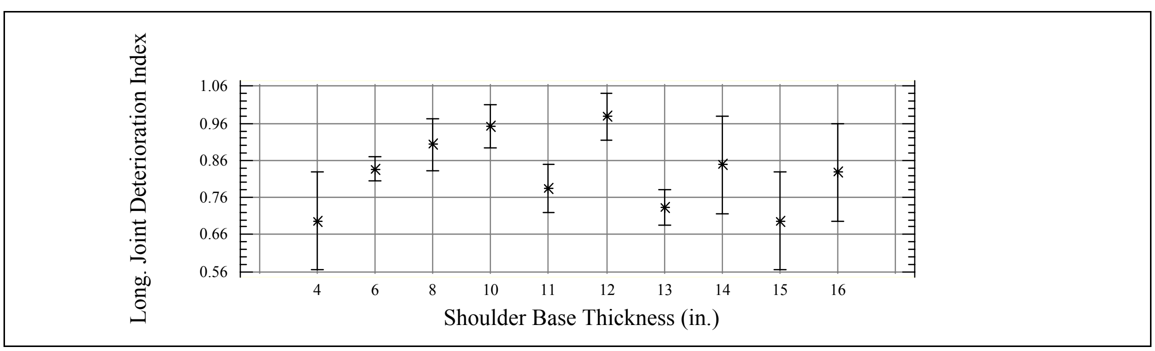

Figure 4.149 Longitudinal Joint Deterioration Index and Shoulder Base Thickness (Non-Composite Type-5)

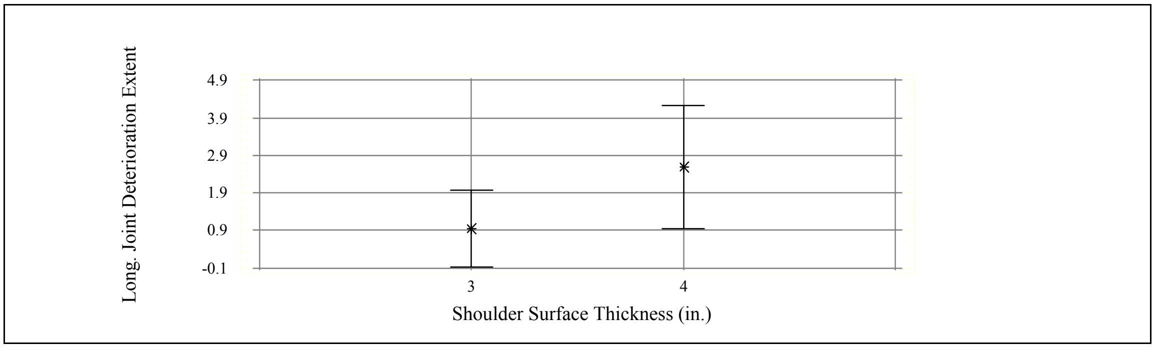

Figure 4.150 Longitudinal Joint Deterioration Extent and Shoulder Surface Thickness (Non-Composite Type-5)

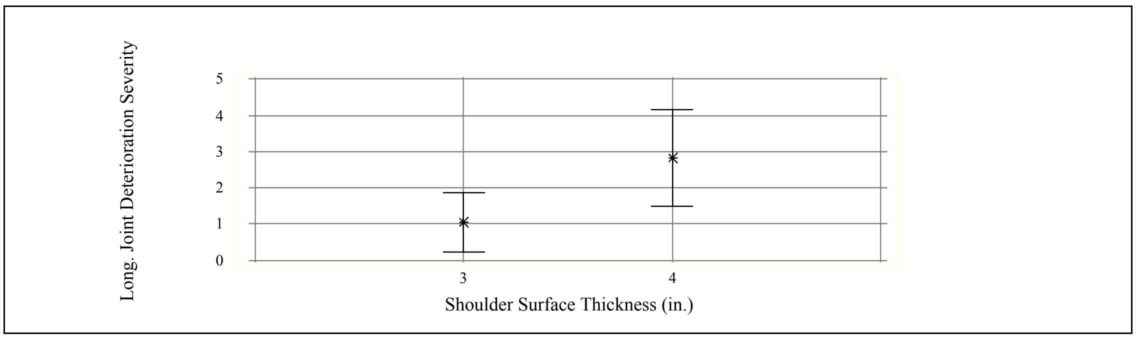

Figure 4.151 Longitudinal Joint Deterioration Severity and Shoulder Surface Thickness (Non-Composite Type-5)

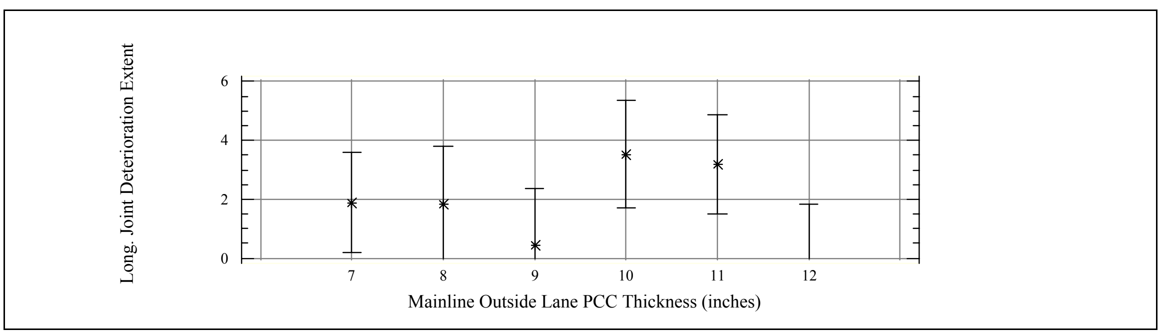

Figure 4.152 Longitudinal Joint Deterioration Extent and PCC Thickness (Non-Composite Type-5)

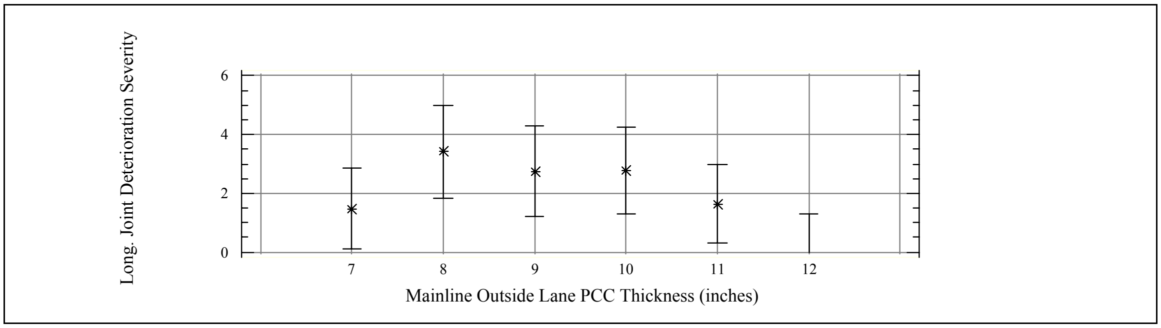

Figure 4.153 Longitudinal Joint Deterioration Severity and PCC Thickness (Non-Composite Type-5)

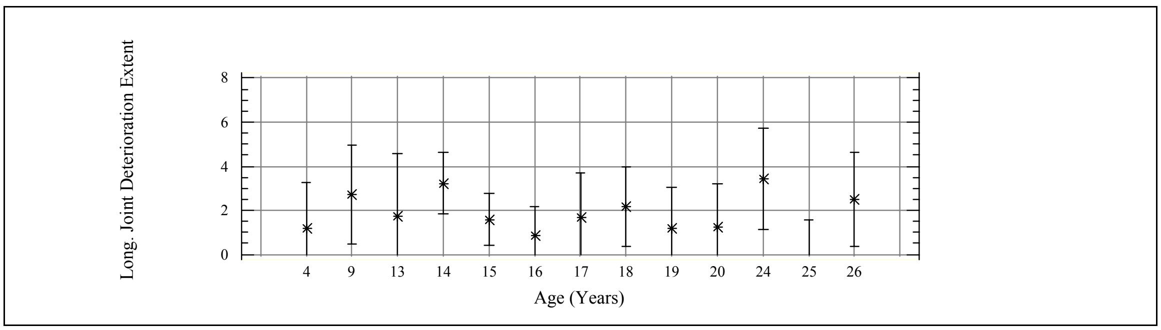

Figure 4.154 Longitudinal Joint Deterioration Extent and Age (Non-Composite Type-5)

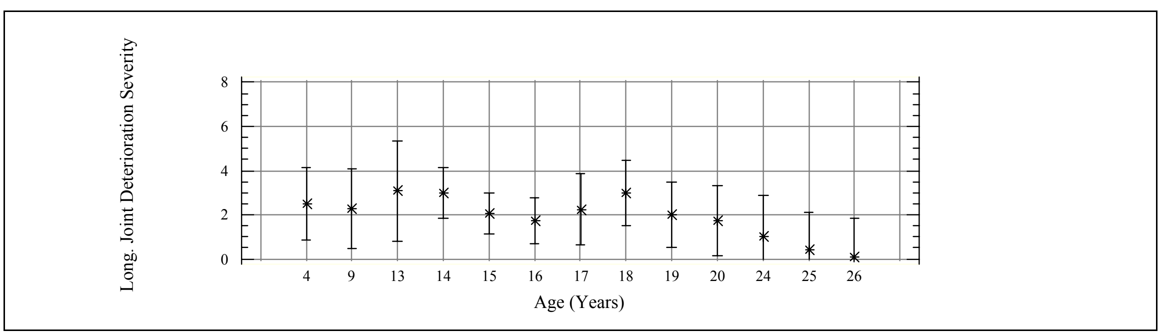

Figure 4.155 Longitudinal Joint Deterioration Severity and Age (Non-Composite Type-5)

4.3.7 Preliminary Recommendations for Non-Composite Shoulders (Type 5 PCC)

Findings from the ANOVA and simple plots provided preliminary recommendations for improving the performance of non-composite shoulders adjacent to Type 5 PCC pavements. Table 4.18 provides recommendations from the plots, while Table 4.19 provides data observations for planning maintenance activities. These preliminary recommendations were used to develop the final guidelines in Chapter 5.

Table 4.18 Preliminary Design Considerations for Non-Composite Asphalt Shoulders (Type-5 PCC)

Distress (1)	DESIGN OBJECTIVE IS TO MINIMIZE (2)	DESIGN ELEMENTS AND/OR VALUES FOR CONSIDERATION (3)	BASIS FOR SUGGESTED VALUES* (4)
Transverse Cracking	Extent	a. Mainline Outside lane PCC thickness: ≥10 in. b. Shoulder base thickness	a. Figure 4.104 b. Figure 4.101
	Severity	a. Mainline Outside lane PCC thickness: ≥10 in.	a. Figure 4.105
	Severity & Extent	Same as for extent	Figures 4.182, 4.106
Longitudinal Cracking	Extent	a. Shoulder base thickness b. Mainline Outside lane PCC thickness: ≥10 in.	a. Figure 4.111 b. Figure 4.116
	Severity	a. Shoulder base thickness b. AC shoulder width: 3 ft.	a. Figure 4.112 b. Figure 4.114
	Severity & Extent	a. Shoulder base thickness: 6-12 in. b. AC shoulder width: 3 ft.	a. Figure 4.113 b. Figure 4.115
Outside Edge Raveling	Severity	a. AC shoulder width: 3 ft. b. Shoulder surface thickness: 4 in	a. Figures 4.121 & 4.122 b. Figures 4.123 & 4.124
Heave	Extent	a. Shoulder base thickness	a. Figure 4.129
	Severity	Same as for extent	Figure 4.130
	Severity & Extent	a. Shoulder base thickness: ≥10 in.	Figure 4.131
Settlement	Extent	a. AC shoulder width: ≥8 ft. b. Mainline outside lane PCC thickness c. Shoulder surface thickness: 4 in	a. Figure 4.136 b. Figure 4.140 c. Figure 4.138
	Severity	a. Shoulder base thickness	a. Figure 4.135
	Severity & Extent	a. AC shoulders width: >8 ft. b. Mainline outside lane PCC thickness	a. Figure 4.137 b. Figure 4.141
Longitudinal Joint Deterioration	Extent	a. Shoulder base thickness b. Shoulder surface thickness: 3.0 in c. Mainline outside lane PCC thickness	a. Figure 4.147 b. Figure 4.150 c. Figure 4.152
	Severity	Same as for extent	a. Figures 4.148, 4.151, 4.153
	Severity & Extent	a. Shoulder base thickness: 12 in.	Figures 4.149
* Table 4.17 for all parameters			

Table 4.19 Key Distresses for Maintenance Considerations in Non-Composite Shoulders (Type-5 PCC)

Distress (1)	INFLUENTIAL VARIABLE (S) (2)	ISSUES FOR MAINTENANCE CONSIDERATIONS (3)	REFERENCE* (4)
Transverse Cracking	Functional Class	The combination of extent and severity is worse on Interstate highways	Figure 4.108
	Age	The extent increases with age.	Figure 4.109
Longitudinal Cracking	Longitudinal joint filling	The combination of extent and severity is better when longitudinal joint is not filled	Figure 4.120
Outside Edge Raveling	Age	The severity (also denoted by the index) worsens with age	Figures 4.127 &4.128
Heave	Age	The combination of extent and severity worsens with age.	Figure 4.134
Settlement	Functional Class	Extent is higher for Interstate highways	Figure 4.142
	Age	Extent increases with age.	Figure 4.143
Longitudinal Joint Deterioration	-	-	-
* Table 4.17 for all parameters			

4.3.8 Regression Modeling for Composite Shoulders (Type-5 PCC)

Table 4.20 provides regression models constructed from significant input variables for composite shoulders adjacent to Type-5 PCC pavements. Several models were assessed for each distress category to allow flexibility in model selection for development of guidelines. Similar to composite Type-8 shoulders, a test of outliers was conducted. Those models having a df less than 24 had either outlier(s) removed from the model or missing data points. No regression models were developed for non-composite shoulders adjacent to Type-5 pavements, primarily due to unstable models.

Table 4.20 Asphalt Shoulder Performance Models for Non-Doweled Jointed Plain Concrete (Type-5 composite)

Model #	Model Form	R^2, %	DF
1	TRAN = 1.03958- 0.0147516*Age	58.1	24
2	EDGE=1.05053-0.0000214481*(2-Way Truck Volume)-0.106753*Age	29.5	24
3	SETT = 0.943356 –0.0302861*Age	20.7	23
4	SETT = 0.389577 + 323.871/(2-Way Truck Volume)	45.1	24
All data points have "no joints filled" and base is CABC.			

CHAPTER 5 DEVELOPMENT OF GUIDELINES

A systematic process was employed to develop design and maintenance guidelines for two main types of paved shoulders adjacent to PCC pavements. The two main types of shoulders were:

a) Jointed plain concrete shoulder tied to the mainline pavement; and
b) Composite shoulder consisting of an extended 2-foot wide concrete pavement shoulder with adjacent asphalt-surfaced shoulder at a specified width.

The guidelines focused on these two shoulder configurations because of the availability of field data to support their feasibility.

5.1 Framework for Guidelines Development

A basic framework, consisting of the elements shown in Figure 5.1, was established to provide a systematic approach in the guidelines development process.

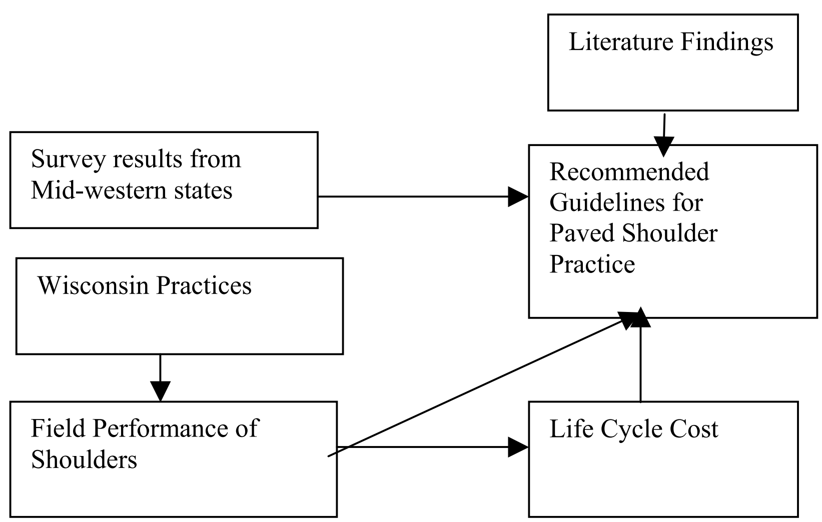

Figure 5.1 Framework for Developing Guidelines for Paved Shoulders Adjacent to Mainline PCC Pavements

Literature findings represent incremental advancements in pavement technology that provide the foundation for design and maintenance practices on a broader scale. The survey results from midwestern states provide practices with potential applicability to Wisconsin because of similarities in climate and traffic patterns. Current Wisconsin practices dictate the inputs, as well as the general performance of the paved shoulders. The results of the analysis of performance data yielded relationships found among key input variables (design, traffic, environment, and maintenance) and the output performance variables, as measured by the extent, severity, and the combination of severity and extent (denoted by the SDIF) of key distresses. In addition, the field performance data provide the basis for the life cycle cost analysis process.

The framework enabled existing WisDOT practice to be interfaced with important findings from the synthesized literature (Chapter 2), survey results (Chapter 2) and the field performance results (Chapter 4). Comparisons and recommended modifications to WisDOT practices are discussed in the following sections for the two shoulder configurations.

5.1.1 Design Practices for Composite Shoulders Adjacent to Type 8 PCC

Table 5.1 provides a comparison matrix of design criteria from existing WisDOT practice with findings from the literature review and surveys, and field performance data. The last column of the table provides recommended modifications to be made regarding current WisDOT paved shoulder practice.

Table 5.1 indicates that WisDOT shoulder design elements consistent with the literature findings include: paved shoulder width, cross-slope, and paved width configuration. Major differences, however, exist regarding other design elements including: surface type selection, shoulder base gradation, longitudinal joint treatment, and recommended minimum asphalt surface thickness. While the literature recommends using the same surface material for both mainline and shoulder, WisDOT practice uses asphalt shoulders adjacent to mainline PCC pavements. Besides Illinois, which does not use asphalt shoulders for PCC mainline pavements, the minimum recommended asphalt surface thickness from the surveyed Midwestern states ranged from 3 inches (75 mm) to thickness equivalent to the mainline thickness, compared to the 2-inch (50 mm) minimum thickness used in Wisconsin. WisDOT crushed aggregate base gradations #1 and #2 have a range exceeding 6 percent passing #200 sieve, contrary to the maximum value of 6 percent suggested by the literature findings. It is WisDOT practice not to seal the longitudinal joint during construction. The literature findings do not support this practice.

Modifications for consideration in current practices include:

a) A minimum width of 8 feet is required for the asphalt component of a composite shoulder to minimize the extent and severity of both transverse cracking and heave. However, a decision to increase the width from the engineered design standard must be made in the context of a life-cycle cost analysis (does a wider shoulder have lower life-cycle cost with higher construction cost and lower maintenance cost). Filling the longitudinal joint can offset minimizing deterioration of the longitudinal joint with a wider shoulder.

b) For shoulder base material (CABC or OGBC), it is recommended that CABC be specified. Data analysis found composite shoulders with CABC minimized the severity of transverse cracking and minimized both the extent and severity of heave. Filling the longitudinal joint can offset minimizing the deterioration of the longitudinal joint with CABC.

c) On the basis of the field performance, the current minimum recommended thickness of 2 inches (50 mm) should be increased to 4 inches (100 mm) to minimize the extent of transverse cracking, severity of edge raveling, and both the extent and severity of settlement. The recommended thickness is also consistent with thickness usage by most Midwestern states as indicated by survey data. In addition, one district in Wisconsin reported using surface thickness of 3-5 inches to facilitate shoulder maintenance. Similar to shoulder width, thickness decision must be made in the context of a life cycle cost analysis (does a thicker surface have lower life cycle cost with higher construction cost and lower maintenance cost).

The remaining design criteria had no recommended changes due lack of data, or variations in the levels of important design variables. Further research is needed on the edge drain system since OGBC is an integral component and has an effect on shoulder performance. In addition, lack of construction records and data to perform a comprehensive analysis for heave or settlement suggest they may be a function of transverse offset of the longitudinal joint at time of construction. Further research is needed where the construction transverse offset value is incorporated into a comprehensive analysis of heave and settlement.

5.1.2 Design Practices for Concrete Shoulders Adjacent to CRCP

Table 5.2 also provides a comparison matrix of design criteria from existing WisDOT practice with findings from the literature review and surveys, and field performance data. As shown in Table 5.2, WisDOT design elements for concrete shoulders comparable with findings from the literature are similar to those described previously for asphalt shoulders. In addition, transverse joint spacing and PCC surface thickness are consistent with literature findings. These elements, however, vary widely among the surveyed Midwestern states.

For concrete shoulders, recommendations are provided only for CRCP pavements since data were collected only from CRCP projects. There was only one recommended change to existing WisDOT design practice in Table 5.2, shoulder base thickness. An incremental increase in shoulder base thickness minimized the three primary shoulder distresses. A minimum thickness of 8 inches minimized the severity of the longitudinal joint distress while a minimum thickness of 10 inches minimized the extent of distressed joints/cracks. Thickness greater than 10 inches minimized the extent of slab breakup. The extent and severity of distressed joints/cracks reduced with base thickness of 12 inches or more. The decision to increase the thickness must be made in the context of a life cycle cost analysis (does a thicker shoulder base have lower life-cycle cost with higher construction cost and lower maintenance cost).

The remaining design criteria had no recommended changes due lack of data, or existing WisDOT practice designs against the subject distress. Further research is needed to evaluate the other design variables if there is a known change in levels.

Table 5.1 Recommended Design Practices for Composite Shoulders Adjacent to Type-8 PCC Pavements

Paved Shoulder Criterion (1)	Existing WisDOT Practice (2)	Literature Recommendations and Survey Inputs from Midwestern States (3)	Field Performance Analysis Results (4)	Recommended Changes to WisDOT Design Practice* (5)
Asphalt Surface Thickness	Based on AASHTO procedure using 2.5 percent of mainline design ESALs per day. A 2-inch (50-mm) minimum surface thickness is required.	--Design for an anticipated truck traffic encroachment of at least 2 to 2.5 percent of all mainline truck traffic [8]. --Minimum thickness of 3 inches used in other Midwestern states not including Indiana (Table 2.11).	4-inch surface thickness minimized: -Transverse cracking extent. -Edge raveling severity. -Settlement extent and severity.	Specify 4-inch surface thickness.
Longitudinal Joint Treatment	Longitudinal shoulder joint not sealed during construction, but sometimes sealed during service life.	-Seal the longitudinal shoulder joint [3]. -If longitudinal joint is sealed and adequate drainage is provided, then shoulders structurally designed for the anticipated traffic will give satisfactory performance [9]. -Full-depth asphalt shoulder reduces cracking near the longitudinal joint and limits pavement-shoulder joint separation to approximately 1/8 inch [5,8].	Sealing longitudinal joint minimized: -Transverse cracking extent and severity. -Longitudinal joint deterioration extent and severity.	Seal longitudinal joint.
Total Paved Width	10 feet for Interstate Highways. 8 feet for U.S. Highways.	10 to 12 feet for high-type facilities. 2 feet for low-type facilities, but 6 to 8 feet is desired [2].	Widths ≥ 8 feet minimized: -Transverse cracking extent and severity. -Heave extent and severity. Widths ≤ 8 feet minimized: -Long. joint deterioration extent and severity.	Specify width ≥ 8 feet and seal longitudinal joint to design against longitudinal joint deterioration.
Shoulder Base Material	--OGBC Gradation #2, 0 to 5 percent passing #200 sieve. --CABC Gradation #1, 2 to 12 percent passing #200 sieve. --CABC Gradation #2, 3 to 12 percent passing #200 sieve.	--Avoid CABC with more than 6 percent passing the #200 sieve [1]. --Full-depth asphalt shoulders on CABC performed better than sections consisting of asphalt concrete on either cement-aggregate or a pozzolanic aggregate base [13].	CABC minimized: --Transverse cracking severity. --Heave extent and severity. OGBC minimized: --Longitudinal joint deterioration severity.	Specify CABC and seal longitudinal joint to design against longitudinal joint deterioration.

Table 5.1 (cont.) Recommended Design Practices for Composite Shoulders Adjacent to Type-8 PCC Pavements

Paved Shoulder Criterion (1)	Existing WisDOT Practice (2)	Literature Recommendations and Survey Inputs from Midwestern States (3)	Field Performance Analysis Results (4)	Recommended Changes to WisDOT Design Practice* (5)
Paved Width Configuration	2-foot widening of the mainline structural section, with remaining width asphalt shoulder. Widened lane striped as a 12-foot travel lane.	--2 to 3-foot widening of the mainline structural section, with remaining width asphalt shoulder. Widened lane striped as a 12-foot travel lane [1,5]. --A width of at least 3 feet is needed for rigid shoulders to provide the greatest stress reduction in the traffic lane [10].	For composite shoulders, only 2-foot wide concrete shoulder sections were studied.	None.
Cross Slope	2 percent for mainline. 4 percent for paved shoulder.	--Minimum 1 percent more than mainline pavement [2]. --2 to 6-percent for asphalt and concrete shoulders [2].	All mainline sections had 2-percent slope, and all paved shoulder sections had 4-percent slope.	None.
Shoulder Base Thickness	Crushed aggregate. Minimum 6-inch thickness.	None.	No general trend was observed.	None.
Drainage Treatment	Subsurface drainage provided for asphalt shoulders having OGBC base material.	Provide adequate drainage in the form of permeable foundation materials and/or subdrainage systems, or material less susceptible to the presence of moisture [3].	None. Insufficient data in this study.	None. Further research needed to evaluate design and effectiveness of subsurface drainage system.
* Require continued data analysis and evaluation for highway improvement program, and life-cycle cost analysis for individual projects.				

Table 5.2 Recommended Design Practices for Concrete Shoulders Adjacent to CRCP Pavements

Paved Shoulder Criterion (1)	Existing WisDOT Practice (2)	Literature Recommendations (3)	Data Analysis Results (4)	Recommended WisDOT Design Practices* (5)
Shoulder base thickness	Aggregate. Minimum 6-inch thickness.	A 6-inch granular subbase under the concrete shoulder reduces the amount of shoulder cracking by approximately 50% (1970 study) [20].	Thickness ≥ 8 inches minimized: --Longitudinal joint distress severity. Thickness ≥ 10 inches minimized: --Distressed joint/cracks extent. Thickness > 10 inches minimized: --Slab breakup extent. Thickness ≥ 12 inches minimized: --Distressed joint/cracks extent and severity.	Specify thickness ≥ 10 inches.
Total Paved Width	10 feet for Interstate Highways. 8 feet for U.S. Highways.	10 to 12 feet for high-type facilities. 2 feet for low-type facilities, but 6 to 8 feet is desired [2].	No analysis. All PCC shoulders in the study had 10-foot width.	None.
Cross Slope	2 percent for mainline. 4 percent for paved shoulder.	Minimum 1 percent more than mainline pavement [2]. 2 to 6-percent for asphalt and concrete shoulders [2].	No analysis. All mainline sections had 2-percent slope, and all paved shoulder sections had 4-percent slope.	None.
Paved Shoulder Configuration	--For 2-lane, 2-way STH with current ADT > 1250, pave with a 3-foot (900-mm) monolithic concrete. --For 4-lane divided STH with current ADT> 1250, pave with a 2-foot (600mm) monolithic concrete on the right. --County trunk highways meeting the above current ADT criteria may be paved at the discretion of local officials.	A width of at least 3 feet is needed for rigid shoulders to provide the greatest stress reduction in the traffic lane [10].	No analysis. All 10-foot wide PCC shoulders were adjacent to 12-foot mainline PCC sections (no widened sections).	None.

Table 5.2 (cont.) Recommended Design Practices for Concrete Shoulders Adjacent to CRCP Pavements

Paved Shoulder Criterion (1)	Existing WisDOT Practice (2)	Literature Recommendations (3)	Data Analysis Results (4)	Recommended WisDOT Design Practices* (5)
Shoulder base material	OGBC Gradation #2, 0 to 5 percent passing #200 sieve. CABC Gradation #1, 2 to 12 percent passing #200 sieve. CABC Gradation #2, 3 to 12 percent passing #200 sieve.	Avoid CABC with more than 6 percent passing the #200 sieve [1]. A 6-inch granular subbase under the concrete shoulder reduces the amount of shoulder cracking by approximately 50% (1970 study) [20].	No analysis. All projects had CABC or CABC/gravel base.	None.
Surface Thickness	AASHTO procedure using 2.5 percent of mainline design ESALs per day. A 6-inch (150-mm) minimum surface thickness is required.	--Design for an anticipated truck traffic encroachment of at least 2 to 2.5 percent of all mainline truck traffic [8]. --A 6-inch plain concrete shoulder gives good performance [20]. --The mainline slab thickness could be reduced by as much 1 inch due to the increased edge support from the shoulder [10,17].	No analysis. All PCC shoulders in the study had 6-inch PCC thickness.	None.
Transverse Joints	Random spacing of 15 to 18 feet.	--Shoulder joints should match the mainline pavement joints [23]. --Spacing of transverse joints of 20 feet is desirable for control of intermediate cracking [20]. --A 15-foot shoulder joint interval is recommended by the FHWA for JPCP shoulders placed adjacent to mainline CRCP [1].	Joint spacing < 20 feet minimized: - Slab breakup extent	None.

Table 5.2 (cont.) Recommended Design Practices for Concrete Shoulders Adjacent to CRCP Pavements

Paved Shoulder Criterion (1)	Existing WisDOT Practice (2)	Literature Recommendations (3)	Data Analysis Results (4)	Recommended WisDOT Design Practices* (5)
Tied Shoulder	Tied shoulders with 30-inch long tie bars spaced at 30-inch on center.	--Tied concrete shoulders can significantly improve structural carrying capacity and overall performance of the mainline pavement [14, 17, 22]. --Significantly less punchouts on CRCP mainline pavement where the JPCP tied shoulders were located rather than asphalt shoulders [10]. --Tied shoulder should have 30-inch long tie bars spaced at 30-inch on center [20].	No data for analysis.	None.
Drainage treatment	No subsurface drainage system for PCC shoulders.	Provide adequate drainage in the form of permeable foundation materials and/or subdrainage systems, or material less susceptible to the presence of moisture [3].	No analysis. All PCC shoulder projects had no edge drain system.	None.
Longitudinal Joint Treatment	Longitudinal shoulder joint not sealed during construction.	--Seal the longitudinal shoulder joint [3]. --If longitudinal joint is sealed and adequate drainage is provided, then shoulders structurally designed for the anticipated traffic will give satisfactory performance [9]. --Sealing the longitudinal edge joint did not improve concrete shoulder performance (1970 study) [20].	No analysis. Insufficient data to determine effectiveness of sealing longitudinal joint.	None.
* Require continued data analysis and evaluation for highway improvement program, and life-cycle cost analysis for individual projects.				

5.2 Life Cycle Cost Analysis

Existing WisDOT design practice, as well as recommended changes to existing practices, must be made in the context of life-cycle costs. For that purpose, a life-cycle cost analysis was performed to (1) quantify costs of comparable sections for the various shoulder types, (2) identify the stage or time in shoulder life when maintenance and rehabilitation activities are performed, and (3) provide a life-cycle cost analysis (LCCA) for comparable sections. To conduct this analysis, several tools were used to yield proposed design guidelines and maintenance policies. The WisDOT LCCA methodology was used as the analysis tool, and recent construction and maintenance cost data were collected and applied to the program. The researchers attempted to use the WisPave Pavement Design and LCCA computer program [31], however, several attempts were unsuccessful since the software is configured for mainline pavements, and not paved shoulders. Thus, fundamental engineering economic methods were used.

In addition to these standard tools, the developed performance regression models from Chapter 4 were interfaced with the LCCA to reflect input levels of design, traffic, environmental, and maintenance variables with the observed performance level of the shoulder (SDIF). In essence, the models were able to predict the age of a certain maintenance treatment based on the distress level. The following sections describe the LCCA process.

5.2.1 Cost Data

The most recent construction and maintenance cost data were collected from several sources for the LCCA. Table 5.3 provides the input values and source for each cost item. An important stipulation in the LCCA, that was addressed during the analysis, is that the costs should take into account the quantity of materials, as well as the location and type of project being analyzed [31].

Table 5.3 Input Cost Values for Life-Cycle Cost Analysis

WisDOT Item Number (1)	Description (2)	Unit Price (3)	Source (4)
30404	Crushed Aggregate Base Course	$6.13/Ton	32
40203	Asphaltic Material for Tack Coat	$282.41/Ton	32*
40204	Asphaltic Material for Tack Coat	$1.17/Gal	32*
40501	Asphaltic Material for Plant Mixes	$157.15/Ton	32*
40721	Asphaltic Concrete Pavement, Type E-0.3	$19.10/Ton	32*
40722	Asphaltic Concrete Pavement, Type E-1	$16.07/Ton	32*
---	Asphalt Concrete Pavement, MV, Average for 2000	$28.58/Ton	33
---	Asphaltic Concrete Pavement, Shoulder	$28.00/Ton	**
41506	Concrete Pavement, 6-Inch	$13/SY***	35
41507	Concrete Pavement, 7-Inch	$10.35/SY	32
41508	Concrete Pavement, 8-Inch	$19.49/SY	32
41509	Concrete Pavement, 9-Inch	$19.20/SY	32
41510	Concrete Pavement, 10-Inch	$18.20/SY	32
41511	Concrete Pavement, 11-Inch	$19.93/SY	32
41512	Concrete Pavement, 12-Inch	$20.25/SY	32
41551	Continuous Concrete Pavement Reinforcement	$13.70/SY	32
41653	Pavement Ties	$5.28/Each	32
41654	Dowel Bars	$7.27/Each	32
41660	Concrete Pavement Repair	$164.79/CY	32
41670	Continuous Diamond Grinding	$2.41/SY	32
90315	Removing Concrete Surface, Partial Depth	$2.75/SY	32
90398	Joint and Crack Repair	$2.75/LF	32
---	Asphalt Pavement Crack Filling	$0.50/LF	34
---	Concrete Pavement Crack Filling	$0.50/LF	34
---	Asphalt Pavement Route and Seal	$1.20/LF	33

32. BidTabs Professional Software™, Oman Systems, Nashville, TN, 2001. Weighted average of 1997-2001 lettings of low bidders.
33. Wisconsin DOT, Asphaltic Pavement Warranties, Five-Year Progress Report, Madison, WI, June 2001.
34. Glen Clickner, Civil/Roadway Project Manager, Division of Facilities Development, Wisconsin Department of Administration, Madison, WI, Personal email correspondence, December 17, 2002.
35. Kevin McMullen, Executive President, Wisconsin Concrete Pavement Association, Personal Correspondence, April 30, 2003.

* Letting data from 2000 and 2001 only.

** $28.00/Ton used for AC paved shoulder analysis since there were unequal letting periods for concrete pavement and E-0.3 shoulder mix. ($28.00/ton = $19.10 mix + $8.65 binder @ 5.5% + $0.25 tack).

*** $12.00/SY to $14.00/SY range based on estimate from Kevin McMullen, WCPA. Accurate data does not exist in BidTabs software and WisDOT databases. Item 41506 is for small quantities and non standard construction practices that do not reflect larger quantities and slipform paving of 6-inch thick PCC shoulders.

Bid Tabs Professional Software™ was used to generate portions of the cost data [32]. Letting data of low bidders from 1997 to 2001 were used to calculate a weighted average for each bid item. A weighted average was used to minimize the effect of disproportionate units prices from small and large volume projects. Hence, a greater weight was given to larger volume projects having a lower unit price, and a smaller weight was given to smaller volume projects having a higher unit price. In addition, this approach proportionally reflected the monies expended by WisDOT for roadway improvements, where lower unit prices across larger volume projects have a greater influence. In some cases, a lesser product size had a higher unit price because of material price variation, and effects on labor and equipment productivity. For example, the 6-inch concrete pavement (placed as a shoulder) had a higher unit price than thicker concrete pavements because of potential effects from reduced productivity placing concrete in a more confined space, and labor and equipment costs spread across a smaller volume of work.

Crack filling unit prices were obtained from the Wisconsin Division of Facilities Development because no maintenance cost data was provided in the questionnaire surveys. Prices ranged from $0.32/LF to $0.59/LF, with a median value of $0.50/LF selected.

Items omitted from the life-cycle analysis included:

1. Rumble Strips. Design varies for PCC, Composite, and AC shoulders;
2. Edge Drain. Not specified for all pavement systems; and
3. Continuous Concrete Pavement Reinforcement. Not specified within shoulder region.

<u>5.2.2 Application of Regression Models</u>

A benefit of the developed regression models is in their ability to provide a quantitative approach to verifying a specific design methodology aimed at limiting specific distress levels. In addition, the models can be used as a tool to define a clear policy for maintenance and rehabilitation interventions.

The regression models from Chapter 4 were manipulated to yield the design or maintenance parameter(s) for each combination of extent and severity level. For example, the age at which transverse cracking achieves an Extent=1 (1 to 5 cracks per station) and Severity=2 (greater than ½-inch in width) was calculated. In this manner, maintenance staff can anticipate the age when these levels will be realized for maintenance intervention and planning purposes.

5.2.2.1 Concrete Shoulder Model Applications

Tables 5.4 through 5.7 provide the estimated age or AADT to reach the designated performance levels for PCC shoulders, with specified design and/or maintenance parameter if appropriate.

Table 5.4 Distressed Joints/Cracks (Model #1)

Age to reach Performance Level								
S1E1* (1)	S1E2 (2)	S1E3 (3)	S2E1 (4)	S2E2 (5)	S2E3 (6)	S3E1 (7)	S3E2 (8)	S3E3 (9)
16	18	20	19	22	23	25	27	29

**SiEi = Severity level i with extent level i. For description of distresses and levels, see Appendices F &G*

Table 5.5 Longitudinal Joint Distress (Model #4)

Age to reach Performance Level		
S1 (1)	S2 (2)	S3 (3)
20	47	-

Table 5.6 Longitudinal Joint Distress (Model #6)

Base Thickness (1)	Age to reach Performance Level		
	S1 (2)	S2 (3)	S3 (4)
6	13	-	-
8	19	-	-
10	25	-	-
12	31	-	-
19	52	-	-

Table 5.7 Slab Breakup (Model #7)

Perform-ance Level	AADT to Reach Performance Level							
	Central Wisconsin, Shoulder Base Thickness, inches				Southern Wisconsin, Shoulder Base Thickness, inches			
	6	8	10	19	6	8	10	12
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
S1E1	-	10,699	22,277	74,377	21,497	33,075	44,653	96,753
S1E2	5,256	16,834	28,412	80,513	27,632	39,210	50,788	102,889
S1E3	12,755	24,333	35,911	88,012	35,131	46,709	58,287	110,388
S1E4	20,254	31,832	43,410	95,511	42,630	54,208	65,786	117,887
S2E1	29,116	40,694	52,272	104,373	51,492	63,070	74,648	126,749
S2E2	37,979	49,557	61,135	113,235	60,355	71,933	83,511	135,611
S2E3	45,478	57,056	68,634	120,734	67,854	79,431	91,009	143,110
S2E4	61,839	73,417	84,995	137,096	84,215	95,793	107,371	159,471
S3E1	80,245	91,823	103,401	155,502	102,621	114,199	125,777	177,878
S3E2	100,015	111,593	123,171	175,272	122,391	133,969	145,547	197,648
S3E3	12,073	23,651	35,229	87,330	34,449	46,027	57,605	109,706
S3E4	29,798	41,376	52,954	105,055	52,174	63,752	75,330	127,431
S4E1	50,931	62,509	74,087	126,188	73,307	84,885	96,463	148,564
S4E2	72,065	83,643	95,221	147,321	94,441	106,019	117,596	169,697
S4E3	95,925	107,503	119,081	171,181	118,301	129,879	141,457	193,557
S4E4	119,785	131,363	142,941	195,042	142,161	153,739	165,317	217,417
S5E1	134,783	146,361	157,939	210,039	157,159	168,737	180,315	232,415
S5E2	185,912	197,490	209,068	261,168	208,288	219,866	231,444	283,544
S5E3	237,041	248,619	260,197	312,297	259,417	270,995	282,572	334,673
S5E4	290,897	302,474	314,052	366,153	313,272	324,850	336,428	388,529
S6E1	39,342	50,920	62,498	114,599	61,718	73,296	84,874	136,975
S6E2	87,744	99,322	110,900	163,001	110,120	121,698	133,276	185,377
S6E3	135,465	147,043	158,620	210,721	157,840	169,418	180,996	233,097
S6E4	192,047	203,625	215,203	267,304	214,423	226,001	237,579	289,680
S7E1	268,400	279,978	291,556	343,656	290,776	302,354	313,932	366,032
S7E2	320,892	332,470	344,048	396,149	343,268	354,846	366,424	418,525
S7E3	393,154	404,732	416,310	468,411	415,530	427,108	438,686	490,787
S7E4	393,154	404,732	416,310	468,411	415,530	427,108	438,686	490,787
S8E1	393,154	404,732	416,310	468,411	415,530	427,108	438,686	490,787
S8E2	393,154	404,732	416,310	468,411	415,530	427,108	438,686	490,787
S8E3	116,376	127,954	139,532	191,633	138,752	150,330	161,908	214,009
S8E4	263,628	275,206	286,784	338,884	286,004	297,582	309,160	361,260
S9E1	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948
S9E2	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948
S9E3	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948
S9E4	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948
SAE1	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948
SAE2	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948
SAE3	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948
SAE4	536,315	547,893	559,471	611,572	558,691	570,269	581,847	633,948

5.2.2.2 Composite Shoulder (Type-8 PCC) Model Applications

Tables 5.8 through 5.10 provide the estimated age or truck volume to reach the designated performance levels for PCC shoulders, with specified design and/or maintenance parameter.

Table 5.8 Transverse Cracking (Model #1)

Age to reach Performance Level								
S1E1 (1)	S1E2 (2)	S1E3 (3)	S2E1 (4)	S2E2 (5)	S2E3 (6)	S3E1 (7)	S3E2 (8)	S3E3 (9)
7	13	19	13	19	27	19	28	40

Table 5.9 Longitudinal Joint Deterioration (Model #2)

2-Way Truck Volume to reach Performance Level								
S1E1 (1)	S1E2 (2)	S1E3 (3)	S2E1 (4)	S2E2 (5)	S2E3 (6)	S3E1 (7)	S3E2 (8)	S3E3 (9)
2,346	3,660	13,662	3,990	7,516	20,417	5,712	12,633	32,824

Table 5.10 Longitudinal Joint Deterioration (Model #3)

Longitudinal Joint Filled	Truck Volume	Age to reach Performance Level								
		S1E1	S1E2	S1E3	S2E1	S2E2	S2E3	S3E1	S3E2	S3E3
No	1,000	7	11	34	12	21	45	17	32	61
	2,000	6	10	32	10	20	44	15	31	59
	3,000	4	8	31	9	18	42	13	29	58
	4,000	3	6	29	7	16	41	12	27	56
	6,000	-	3	26	4	13	38	9	24	53
	8,000	-	-	23	1	10	34	6	21	50
	10,000	-	-	20	-	7	31	3	18	47
	12,000	-	-	17	-	4	28	-	15	43
Yes	1,000	13	17	40	18	27	51	23	38	67
	2,000	12	15	38	16	25	50	21	36	65
	3,000	10	14	37	15	24	48	19	35	64
	4,000	9	12	35	13	22	47	18	33	62
	6,000	5	9	32	10	19	43	15	30	59
	8,000	2	6	29	7	16	40	12	27	56
	10,000	-	3	26	4	13	37	8	24	53
	12,000	-	-	23	1	10	34	5	21	49

5.2.3 LCCA Example

An example of the life-cycle costing process was prepared to show the interface of standard WisDOT practice with the results of the data analysis in this study. In the life cycle cost (LCC) illustration process, the shoulder was analyzed separately to highlight components and provide a clear evaluation of alternatives. The general inputs considered in the analysis included: design parameters and maintenance treatments, initial construction costs, maintenance and rehabilitation costs, analysis period, and discount rate. A 50-year analysis period and a discount rate of 5%, as defined by WisDOT policy, were used. Consider the following project parameters in Figure 5.2.

Given:
A 1-mile rural segment of a 4-lane interstate divided highway with the following characteristics is to be designed and evaluated on the basis of LCC:
Construction year: 2003
Construction year ADT = 25870 vpd
Design Year: 2023
Design Year ADT= 38430 vpd
Design Group Index =12

Truck classification

2D: 10.3%
3-SU: 1.2
2S-1, 2S-2: 13.1
3S-2: 0.7

Figure 5.2 Parameters for Example Project

Using the WisPave pavement design software, an 11-inch PCC thickness was determined. For the designed thickness, two shoulder configurations were evaluated as shown in Figure 5.3: (1) composite shoulder adjacent to 11-inch Type-8 PCC and (2) concrete shoulder adjacent to 11-inch Type-8 PCC. For asphalt shoulders, only composite Type-8 was analyzed since there was a design policy change where only Type-8 shoulders are specified [30]. The composite shoulder for Alternative #1 consists of a 2-foot extension of the PCC plus 8-foot wide AC surface where the outer slab of the roadway is 14-foot wide but the striped pavement edge is marked 12 feet from the centerline to indicate the limits of the travel lane. For the PCC shoulder, a 12-foot wide PCC pavement and 10-foot wide JPCP shoulder (without dowels) was used. A 6-inch base course was designed for each mainline pavement.

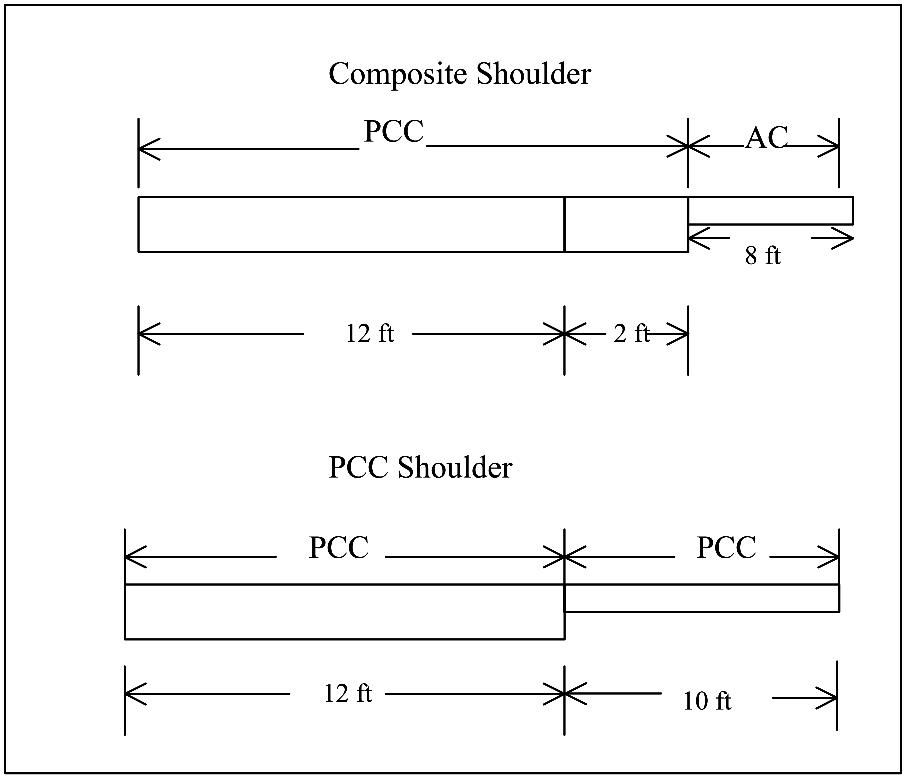

Figure 5.3 Pavement-Shoulder Cross Sections for LCCA

Details of the two alternatives are summarized in Table 5.11 for one direction of the 4-lane freeway. A 6-inch base thickness was designed for the entire 38-foot paved roadway width since a shoulder base thickness ≥ 10 inches was recommended to minimize PCC shoulder distresses. The remaining thickness is 5 inches from the difference between the 11-inch pavement slab and 6-inch shoulder slab. Similarly, 7 inches of base was added to the uniform 6-inch base to yield a 13-inch base for the asphalt surface.

Table 5.11 Cross-Section Details for each Shoulder Alternative

Cross-Section Element (1)	Alternative1 Composite Adjacent to Type-8 (2)	Alternative 2 Concrete Adjacent to Type-8 (3)
Paved Roadway Width	38 ft (4ft + 12ft + 12ft + 10 ft)	38 ft (4ft + 12ft + 12ft + 10 ft)
Pavement Structure	24-ft Type-8 PCC, 11-inch thick	24-ft Type-8 PCC, 11-inch thick
Left shoulder	4-ft wide AC, 3-inch thick	4-ft wide Type-5 PCC, 6-inch thick
Right Shoulder	2-ft Type-8 PCC 11-inch thick, plus 8-ft wide AC, 4-inch thick	10-ft wide Type-5 PCC, 6-inch thick
Shoulder Base	13-inch CABC: 6-inch CABC (from mainline), plus 7-inch CABC (11-inch PCC mainline minus 4-inch AC shoulder)	11-inch CABC: 6-inch CABC (from mainline), plus 5-inch CABC (11-inch PCC mainline minus 6-inch PCC shoulder)

The life-cycle sequences for each alternative are summarized in Figures 5.4 and 5.5 for composite and concrete shoulders, respectively. No life-cycle procedure exists for paved shoulders at the time of this research. Thus, the sequence for the paved shoulders was based on a combination of (1) WisDOT procedures for mainline pavements outlined in Chapter 14 of the Facilities Development Manual (FDM) [31], (2) distress regression models developed as part of this research, and (3) results of the shoulder maintenance surveys conducted for this research.

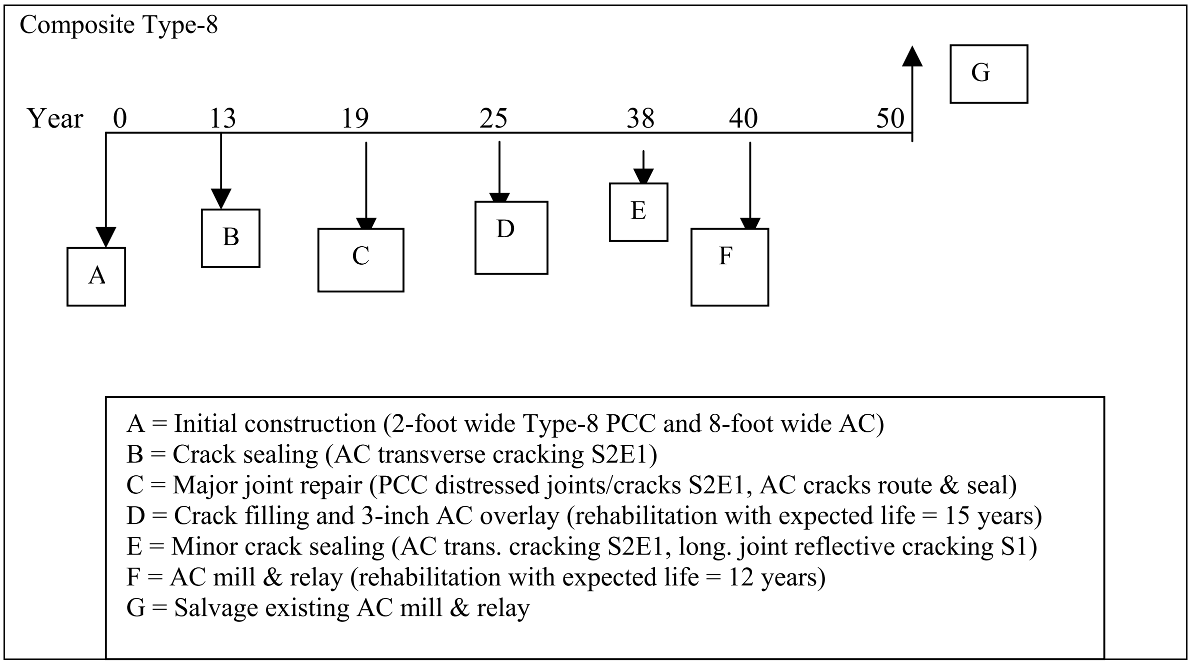

Figure 5.4 Life Cycle Sequence for Composite Shoulders Adjacent to Type-8 PCC

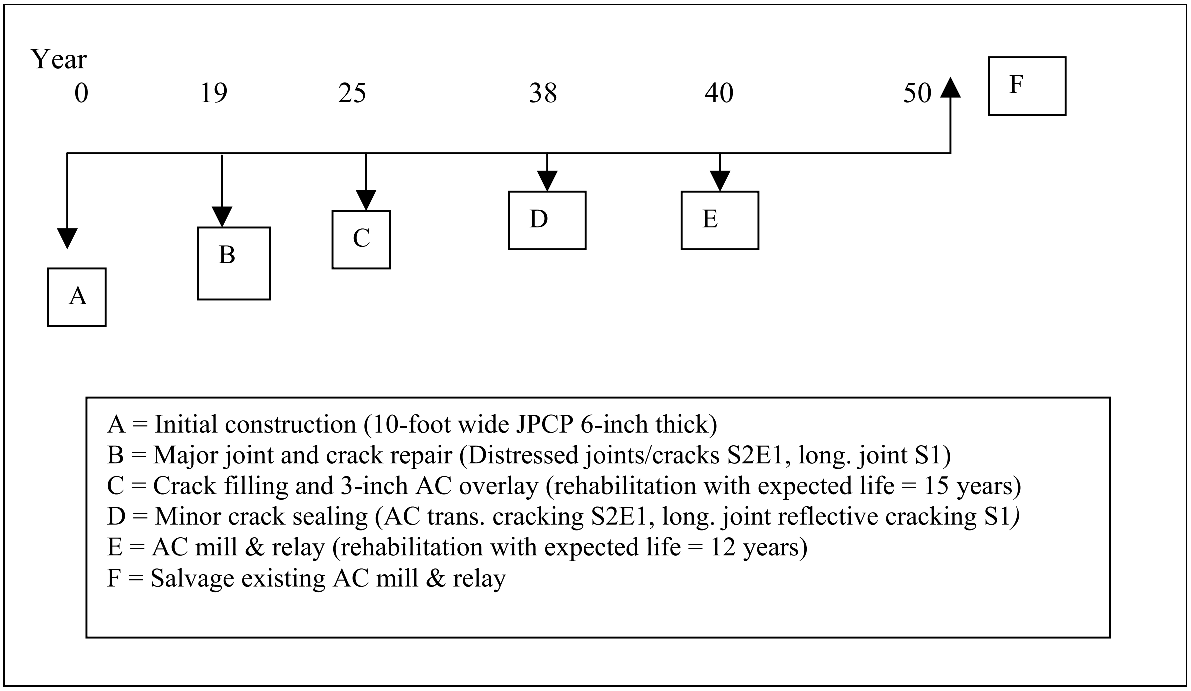

Figure 5.5 Life Cycle Sequence for Concrete Shoulders Adjacent to Type-8 PCC

In the composite shoulder example, Table 5.8 indicates that it takes 13 years for 1 to 5 transverse cracks of at least ½-inch in width to develop within 100 ft. length of shoulder. This corresponds to severity level 2 and extent level 1 condition (S2E1). Therefore, treatment was sequenced at Year 13. At Year 19, the PCC distressed joints/cracks reached the S2E1 performance level (Table 5.4), and the longitudinal joint distress was one year from reaching the S1 performance level (Table 5.5), both receiving treatment. In addition, previously treated transverse cracks, with an average treatment life of 3 to 5 years for mainline pavement, received route-and-seal treatment.

Crack filling and a 3-inch asphalt overlay were sequenced at 25 years, per the WisDOT FDM, with a life expectancy of 15 years [31]. The overlay was applied to both the mainline Type-8 PCC and the asphalt shoulder. At Year 38, the transverse cracks reached the S2E1 performance level (38 = 25 + 13) and these cracks were sealed along with reflective cracking from the longitudinal joint. An asphalt mill-and-relay was sequenced at the end of the overlay life, at Year 40. At Year 50, the service life of the pavement was terminated per WisDOT policy, and a 2/12 rehabilitation salvage value remained from the 12-year life of the mill-and-relay.

For the concrete shoulder example, distressed joints/cracks have reached the S1 performance level at Year 19 (Table 5.4), and the longitudinal joint was sealed, one year from reaching the S1 performance level (Table 5.5). Crack filling and a 3-inch asphalt overlay were sequenced at 25 years, per WisDOT FDM, with a life expectancy of 15 years [31]. Transverse cracking, and reflective cracking from the longitudinal joint, were sealed at Year 38. Model #1 for composite shoulders (Table 5.8) found that the S2E1 performance level was reached at 13 years. After a 2-year treatment life, a mill-and-relay was scheduled at Year 40, since the overlay at Year 25 had a 15-year useful life. The service life of the pavement was terminated at Year 50, per WisDOT policy, and a 2/12 rehabilitation salvage value remained from the 12-year life of the mill-and-relay.

Tables 5.12 and 5.13 provide the respective cost estimates for the two shoulders. Detailed estimates are provided so that all costs are traceable.

Table 5.12 Cost Estimates for Composite Shoulder LCCA

Cost Index (1)	Description (2)	$/shoulder-mile (3)
A	11-inch PCC, $19.93/SY x 1SY/9SF x 2ft x 5280ft	23,285
	4-inch AC, $28.00/ton x 1ton/2000 lb x 110-lb/SY/in x 4in x 1/9 x 8ft x 5280ft	28,911
	6-inch CABC, $6.13/ton x 1ton/2000 lb x 115-lb/SY/in x 6in x 1/9 x 2ft x 5280ft	2,482
	13-inch CABC, $6.13/ton x 1ton/2000 lb x 115-lb/SY/in x 13in x 1/9 x 8ft x 5280ft	21,506
B	Trans. cracks, S2E1, 5/100ft x 5280ft x 8-ft wide x $0.50/LF	1,056
C	Dist. joints/cracks, S2E1, 2/100ft x 5280ft x 2-ft wide x $2.75/LF	583
	Trans. cracks, route and seal, S2E1, 5/100ft x 5280ft x 8-ft wide x $1.20/LF	2,525
	Long. joint seal, S1, 5280ft x $0.50/LF	2,640
D	3-inch AC, $28.00/ton x 1ton/2000 lb x 110-lb/SY/in x 3in x 1/9 x 10ft x 5280ft	27,104
	Crack filling of "C", 5280ft x (2/100ft x 2ft + 5/100ft x 8ft + 1) x $0.50/LF	3,802
E	Trans. cracks, S2E1, 5/100ft x 5280ft x 8-ft wide x $0.50/LF	1,320
	Long. joint seal, S1, 5280ft x $0.50/LF	2,640
F	AC mill and relay, 10ft x 5280ft x 1/9 x $0.86/SY	5,046
G	Salvage, mill and relay, 2/12 x $5,046/shoulder-mile	841

Table 5.13 Cost Estimates for Concrete Shoulder LCCA

Cost Index (1)	Description (2)	$/shoulder-mile (3)
A	6-inch PCC, ($13/SY) x 1SY/9SF x 10ft x 5280ft	76,267
	11-inch CABC, $6.13/ton x 1ton/2000 lb x 115-lb/SY/in x 11in x 1/9 x 10ft x 5280ft	22,747
B	Joint crack and repair, S2E1, 2/100ft x 5280ft x 10-ft wide x $2.75/LF	2,904
	Long. joint seal, S1, 5280ft x $0.50/LF	2,640
C	3-inch AC, $28.00/ton x 1ton/2000 lb x 110-lb/SY/in x 3in x 1/9 x 10ft x 5280ft	27,104
	Crack filling of "B", (2/100ft x 5280ft x 10-ft wide + 5280ft) x $0.50/LF	3,168
D	Trans. cracks, S2E1, 5/100ft x 5280ft x 8-ft wide x $0.50/LF	1,320
	Long. joint seal, S1, 5280ft x $0.50/LF	2,640
E	AC mill and relay, 10ft x 5280ft x 1/9 x $0.86/SY	5,046
F	Salvage, mill and relay, 2/12 x $5,046/shoulder-mile	841

After estimating the cost inputs for both alternatives, engineering economic analysis with the net present worth (NPW) method was applied to estimate the overall costs and benefits throughout the life of each alternative. Thus, all future costs were converted to their equivalent present costs using the discount rate of 5%. The NPW was determined using Equation 5.1:

$$NPW = \sum F / (1+i)^N \qquad \text{(Equation 5.1)}$$

Where,

NPW = net present worth
F = cost at Year N
N = number of years
i = discount rate=5%

Tables 5.14 through 5.15 provide the cost per shoulder-mile of a 10-foot wide paved shoulder. Calculated values are provided for initial cost, each treatment, and the final NPW cost.

Table 5.14 Net Present Worth Estimates for Composite Shoulder LCCA

Cost Index (1)	Year (2)	Initial \$/shoulder-mile (3)	$(1+i)^N$ (4)	NPW \$/shoulder-mile (3)
A	0	76,284	1.0000	76,284
B	13	1,056	1.8856	560
C	19	5,758	2.5270	2,279
D	25	30,906	3.3864	9,127
E	38	3,960	6.3855	620
F	40	5,046	7.0400	717
G	50	-841	11.4674	-73
				Total = 89,513

Table 5.15 Net Present Worth Estimates for Concrete Shoulder LCCA

Cost Index (1)	Year (2)	Initial \$/shoulder-mile (3)	$(1+i)^N$ (4)	NPW \$/shoulder-mile (3)
A	0	133,393	1.0000	99,014
B	19	5,544	2.5270	2,194
C	25	30,272	3.3864	8,939
D	38	3,960	6.3855	620
E	40	5,046	7.0400	717
F	50	-841	11.4674	-73
				Total = 111,411

A direct comparison among alternatives is provided in Table 5.16. Both alternatives are compared by NPW cost item (initial construction, maintenance, rehabilitation, salvage, and total). In this example, the NPW ratio of concrete shoulder to asphalt shoulder was 1.24:1 (111,411/89,513 = 1.24). The results suggest that concrete has a larger initial construction cost, but slightly lower maintenance and rehabilitation costs when compared with the composite shoulder. This categorical cost comparison is recommended during an analysis of alternatives. It must be noted that user delay costs were not included in the analysis because of the absence of an appropriate user-delay cost model. It is therefore, recommended that some judgment be utilized in considering road user delay impacts in the final selection of an alternative especially where maintenance frequency is higher for one alternative.

Table 5.16 Categorical Cost Comparison of Shoulder Alternatives

Shoulder Type (1)	Net Present Worth ($/shoulder-mile)				
	Initial Construction (2)	Rehabilitation (3)	Maintenance (4)	Salvage (5)	Total (6)
Concrete	99,014	9,656	2,814	-73	111,411
Composite	76,284	9,844	3,459	-73	89,513

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Conclusions

A set of guidelines for consideration in paved shoulder practice in Wisconsin was developed in this research study. The guidelines were developed through a series of tasks including: a) review of literature on paved shoulders, b) survey of seven Midwestern states on shoulder practice, and c) data collection and analysis of in-service paved shoulders adjacent to mainline concrete pavements. On the basis of the study, the following summary and conclusions are provided.

6.1.1 Literature Review

1. The literature suggested that State Highway Agencies (SHAs) pave shoulders for the purposes of accommodating stopped and emergency vehicles, and providing lateral support for the mainline pavement layers. Over the years, however, shoulder functions have been expanded considerably to include: providing added space for construction and maintenance activities, expediting water runoff from the mainline pavement, improving roadway capacity, and reducing edge stresses as well as edge and corner deflections.

2. Paved shoulders adjacent to mainline concrete pavements can be constructed as flexible or rigid. The decision to determine the shoulder type to use was based on a combination of factors, such as the type of mainline pavement, traffic volume, proportion of heavy vehicles, and functional class. It was however, recommended that using the same type of material for both shoulder and mainline construction provides a number of advantages, including ease of construction, reduced maintenance cost, and increased shoulder performance.

3. There are currently no nationally recognized procedures for the design of shoulders. Some states have developed their own procedures on the basis of experience rather than from a rational pavement design approach.

4. Recommended factors to include in the thickness design process for shoulders were: truck traffic encroachment on the shoulder, environmental factors (temperature and moisture), subgrade condition, and planned maintenance strategy. Truck traffic encroachment estimates recommended for design were in the range of 2 to 2.5% of all mainline truck traffic. If shoulders are planned for future use as traffic lanes during construction and maintenance activities, the ultimate case is to design the shoulder using the mainline outer lane truck traffic.

5. The level of maintenance required on a shoulder depended on the type, severity, and extent of distresses. Field studies concluded that most flexible shoulders adjacent to mainline PCC pavements are under-designed and exhibit severe distresses such as horizontal and vertical separation of the longitudinal joint, fatigue cracking, rutting, frost heaving, raveling, potholes, and settlement. The joint separation was considered to be the source of most distresses on the flexible

shoulder. The separation has been attributed to the differences in material properties between the concrete pavement and the asphalt shoulder. It was strongly recommended that the longitudinal joint must always be sealed periodically (for example, every 2 to 4 years). Crack sealing, patching, and surface treatment should be done when necessary.

6.1.2 Questionnaire Surveys

Various elements associated with current paved shoulder practices for concrete pavements were examined for seven midwestern states (Illinois, Iowa, Indiana, Michigan, Minnesota, Ohio, and Wisconsin). These elements included policies and procedures for paved shoulder type selection, thickness determination and construction practices, maintenance practices, and functional interaction between maintenance, design, and construction units. On the basis of the examination, the following conclusions are made:

1. Policies and procedures for paved shoulder type selection for concrete pavements varied from state to state. The main factors considered include functional classification, traffic and/or truck volume, construction and maintenance cost, and engineering judgment. Illinois was the only state that has a stringent policy of requiring concrete shoulders to be constructed for all mainline concrete pavements.

2. When concrete shoulders are specified, states recommend tying the jointed plain concrete (JPC) type to the mainline at the longitudinal joint. In addition to JPC, Michigan uses jointed reinforced concrete shoulders.

3. Paved shoulder thickness determination was based on agency specified standard thicknesses that have been established from past field observations or some modified versions of procedures outlined by the American Association of State Highway and Transportation Officials (AASHTO). Where the AASHTO procedure was used, a portion of the mainline design traffic was considered. For example, Wisconsin reported using a value of 2.5% for the design of its paved shoulders. In general, reported thickness for concrete shoulders ranged from a minimum of 6 inches (150 mm) to thickness equivalent to the mainline thickness. For asphalt shoulders a minimum value of 2 inches (50 mm) was reported.

4. Paved shoulder maintenance efforts varied considerably between SHA districts. Most SHA districts did not have formal shoulder maintenance programs; maintenance on as-need basis was the norm. Almost all SHA districts reported premature failures of both asphalt and concrete shoulders to some degree. In addition, the majority of SHA districts reported that little to very little attention was given to shoulders in their pavement systems.

5. There were no formalized lines of communication between the maintenance staff and the design and/or construction functional units in the SHA districts. Only one district (in Wisconsin) reported having a standard form for documenting

premature failures and relaying it to design and construction when necessary. Feedback on maintenance issues to design and construction units predominantly was in the form of verbal communication with occasional e-mails.

6.1.3 Performance Data Analysis

Field performance surveys of paved shoulders were conducted on 133 construction projects. A total of 289 one-mile project segments were surveyed from March to July 2002. Distress indicators recorded for PCC shoulders included slab breakup, distress joints/cracks, and longitudinal joint distress. Distresses recorded for asphalt shoulders included transverse cracking, longitudinal cracking, heave, settlement, and longitudinal joint deterioration. A comprehensive analysis was conducted on the collected data to understand responses in field shoulder performance indicators to design, traffic, environmental, and maintenance inputs. Construction, a key component of paved shoulder performance, was omitted from the analysis due to difficulty in securing construction data and records.

This study used a more versatile approach of modeling individual distress modes to better explain the relationship between performance and design, environmental, maintenance and construction variables. This is a significant shift from traditional methods of using combined indices such as the Pavement Distress Index (PDI) and Pavement Condition Index (PCI) in explaining performance. The combined index approach determines the average amount of distress from the many different combinations of distress types and tends to suppress the very effects that are of interest. The approach used enabled various distress characteristics (extent, severity, and the combination of extent and severity) to be properly examined with respect to specific design, maintenance, and environmental variables. The combination of extent and severity for each distress type was denoted by the shoulder distress index factor (SDIF), which is similar to the WisDOT PDI factor used for the mainline. A summary of the results of the analyses is presented in the following sections.

6.1.3.1 Concrete Shoulders

1. Shoulder base thickness had a direct effect on the three PCC shoulder distresses.

2. Mainline PCC thickness had an effect, however, thicker pavements produced a higher extent and severity of slab breakup and distressed joints/cracks.

3. Traffic levels had a random effect for distressed joints/cracks and longitudinal joint distress.

4. Traffic and age had clear trends, where their increase caused a proportional decrease in shoulder performance.

6.1.3.2 Comparison of Composite Shoulders Adjacent to Type 8 and Type 5 PCC

1. The mean severity levels for various key distresses, including transverse cracking, edge raveling, longitudinal joint deterioration, and settlement were significantly lower for shoulders bordering Type 8 than for shoulders bordering Type 5 PCC. The results were the same regarding the extent of longitudinal joint deterioration and transverse cracking. However, settlement extent appeared higher in the shoulders adjacent to the Type 8 pavements.

6.1.3.3 Comparison of Asphalt-only and Composite Shoulders Adjacent to Type 8 PCC

1. Statistically significant differences did not occur in distress extent and severity levels between asphalt-only and composite shoulders adjacent to the Type 8 mainline. However, edge raveling severity, heaving severity and extent, longitudinal joint deterioration extent and severity reduced in the shoulders adjacent to Type 8.

6.1.3.4 Composite Shoulders Adjacent to Type 8

1. Crushed aggregate base course (CABC), as opposed to open-graded base course (OGBC), reduced the severity of transverse cracking and heave, but increased the severity of longitudinal joint deterioration.

2. Shoulder widths of 8 feet or greater reduced the severity of transverse cracking, and both the extent and severity of heave.

3. The severity of transverse cracking, edge raveling, and settlement were lower with a 4-inch thick shoulder surface, while heave had lower extent and severity with 3-inch thick shoulders.

4. The presence of edge drain increased the extent of transverse cracking.

5. Transverse cracking extent was higher for Interstate and U.S. Highways, and four distresses (longitudinal cracking, edge raveling heave, and settlement) had severity levels higher for U.S. and State Trunk Highways.

6. When the longitudinal joint was filled post-construction, the extent of transverse cracking and longitudinal joint deterioration was reduced.

7. Transverse cracking extent and severity were higher for central and southern regions of the state, while edge raveling severity levels were higher for northern and southern regions.

8. Heave extent and severity were higher for the central region, and settlement and longitudinal joint deterioration severity were higher for the northern and southern regions.

9. All distresses, except for heave, had an increase in extent and severity with age.

6.1.3.5 Non-Composite Shoulders Adjacent to Type 5 PCC

1. Transverse cracking extent increased with base thickness, and settlement severity was higher for base thickness greater than 10 inches.

2. Wider AC shoulders (8 and 10 feet) had higher severity levels of longitudinal cracking, and lower severity levels for edge raveling.

3. Shoulder surface thickness produced lower edge raveling severity at 4 inches, and lower extent and severity of longitudinal joint deterioration at 3 inches.

4. Higher soil support values (SSV) of 5.5 reduced the severity of transverse cracking and edge raveling, and reduced extent of settlement.

5. Edge drain offset had an effect; heave severity and extent together are reduced with edge drains at the edge of the travel lane. For settlement, a positive impact is achieved if the edge drain is placed at a 2-foot offset from the edge of the travel lane.

6. Transverse cracking severity was higher for Interstate and U.S. Highways, and settlement extent was higher for Interstate Highways.

7. All distresses, except longitudinal joint deterioration, increased with age.

8. Longitudinal cracking had lower extent and severity with unfilled longitudinal joint, and settlement severity increased with filling the longitudinal joint.

6.2 Recommendations

A systematic process was employed to develop design and maintenance guidelines for two types of paved shoulders adjacent to PCC pavements: (1) Jointed plain concrete shoulder tied to the mainline pavement; and (2) Composite shoulder consisting of an extended 2-foot wide concrete pavement shoulder with adjacent asphalt-surfaced shoulder at a specified width. Then, a life-cycle approach was developed for the design, construction, and maintenance of paved shoulders adjacent to PCC pavements. Based on this process, the following recommendations were made.

6.2.1 Concrete Shoulders

For jointed plain concrete shoulder tied to the mainline pavement,

1. Increase the minimum shoulder base thickness to 10 inches to minimize the occurrence of three primary distresses (longitudinal joint distress, distressed

joints/cracks, and slab breakup) observed on concrete shoulders. A minimum thickness of 8 inches minimized the severity of the longitudinal joint distress while a minimum thickness of 10 inches minimized the extent of distressed joints/cracks. Thickness greater than 10 inches minimized the extent of slab breakup. The extent and severity of distressed joints/cracks reduced with base thickness of 12 inches or more. The decision to increase the thickness must be made in the context of a life cycle cost analysis (does a thicker shoulder base have lower life-cycle cost with higher construction cost and lower maintenance cost). In addition, consideration must be given to the constructability of the shoulder base with respect to the thickness of the mainline base.

2. Field observations indicated that, the majority of slab breakup occurred in the grooves of rumble strips. Hence, an investigation into the appropriate bar height for use with the concrete rumble strips may be warranted.

6.2.2 Composite Shoulders

Recommendations for composite shoulders adjacent to Type-8 pavement include:

1. A minimum width of 8 feet is recommended for the asphalt component of a composite shoulder to minimize the extent and severity of both transverse cracking and heave. The decision to increase the width from the engineered design standard must be made in the context of a life-cycle cost analysis (does a wider shoulder have lower life-cycle cost with higher construction cost and lower maintenance cost). It may be possible to offset the deterioration of the longitudinal joint with a wider shoulder by filling the longitudinal joint.

2. Field surveys of paved shoulders found that longitudinal joints between PCC mainline pavement and the asphalt shoulder were not always sealed. A coherent policy regarding the treatment of the longitudinal joint is needed. The two main distresses observed on the asphalt-surfaced component of the composite shoulder were transverse cracking and longitudinal joint deterioration. The results of the analysis suggest that the extent for these two distresses reduced with filling of the longitudinal joint between the PCC and the asphalt shoulder. In addition, the model developed for longitudinal joint deterioration indicate that, in general, for a given level of truck traffic, a sealed joint can delay the occurrence of longitudinal joint deterioration by as much as 6 years (see Table 5.10).

3. For shoulder base material (CABC or OGBC), it is recommended that CABC be specified. Data analysis found that composite shoulders with CABC minimized the severity of transverse cracking and minimized both the extent and severity of heave. Filling the longitudinal joint can offset minimizing the deterioration of the longitudinal joint with CABC.

4. The current minimum recommended surface thickness of 2 inches (50 mm) should be increased to 4 inches (100 mm) to minimize the extent of transverse cracking, severity of edge raveling, and both the extent and severity of settlement. Similar to shoulder width, this decision must be made in the context of a life cycle cost analysis (does a thicker surface have lower life-cycle cost with higher construction cost and lower maintenance cost).

6.2.3 Life-Cycle Cost Analysis and Distress Models

1. The research team recommends that a life cycle cost analysis evaluating pavement options should continue to treat the mainline and the shoulder as a system. On the other hand, the type and timing of maintenance activities on the shoulder should be based on prescribed limiting levels of distress generated by models such as those developed in this research, rather than being controlled by the rehabilitation of the mainline.

6.2.4 Other Recommendations

1. Investigate the use and implementation of an appropriate automated data acquisition system for shoulders (similar to the existing system for mainline pavements) to be able to continually monitor shoulder performance at a reduced cost. All field data collection was done manually in this research and was very labor intensive.

2. Develop a comprehensive database system to include design, construction, maintenance, and performance data for the pavement system. There was difficulty obtaining construction documents and records for this study, as well as design and maintenance data. A unified database system will in the future, ensure that needed data is readily available for analysis, and will decrease cost.

3. Establish formalized lines of communication between design, construction, and maintenance functional units. The maintenance surveys revealed there are little formalized lines of communication between functional units involved in the design, construction, and maintenance of the pavement system. Most feedback for example, is informal and verbal and often not documented. A formalized system of communication will be required in developing the database described under recommendation 2 above.

4. Set up formal performance/maintenance goals and expectations for shoulders for the various highway classifications. This will provide an objective basis for identifying and addressing the current and future needs of shoulders.

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APPENDIX A-DESIGN AND CONSTRUCTION SURVEY

Dear Sir or Madam:

RE: SURVEY ON DESIGN AND CONSTRUCTION OF SHOULDERS ADJACENT TO MAINLINE CONCRETE PAVEMENTS

The Wisconsin Department of Transportation (WisDOT) is currently involved in a joint research project with the University of Wisconsin-Platteville aimed at developing guidelines for the selection, design, construction, and evaluation of the performance of paved shoulders adjacent to concrete pavements. The research team will be very grateful if you could complete the attached survey questionnaire and return it to the address below. The success of this study in part depends upon your input.

The survey is moderately extensive and will require patience and dedication from you. Please complete the following information.

Name of Organization:__________________________________

Address:____
____

City:____________ State:__________Zip:_______

Survey completed by:______________________________
Position /Title:______________________________________
Telephone:____
Fax:____
e-mail____

Survey results and final research report can be accessed free-of-charge at www.whrp.org.
Name of person completing the survey will be kept confidential.

RETURN SURVEY AND SUPPORTING DOCUMENTS BY **FEBRUARY 15, 2002** to:

Dr. Sam Owusu-Ababio, P.E.
Dept. of Civil & Environmental Engineering
University of Wisconsin-Platteville
1 Univ. Plaza
Platteville, WI 53818

For questions contact him by phone: 608-342-1554; fax: 608-342-1566; e-mail: owusu@uwplatt.edu

Section 1: Shoulder Type Selection

1. What criteria does your agency use in selecting shoulder types adjacent to Portland Cement Concrete (PCC) mainline pavements? *Mark all that apply.*

   ☐ Highway Functional Class
   ☐ Traffic Volume
   ☐ Truck Traffic

□ Construction & Maintenance cost
□ Construction Time
□ Experience & judgement
□ Other (please specify____)

Please supply copies of memoranda, policies, or guidelines pertaining to the criteria you have marked above.

<u>Section 2</u>: Design and Construction of PCC SHOULDERS adjacent to mainline PCC Pavements

2. What design method does your agency use for determining PCC shoulder thickness?
   □ AASHTO
   □ Same thickness as mainline PCC
   □ Agency-specified standard thickness (***please provide detail drawings for standards)***
   □ Other (specify, ***please include a copy***)___________________________

3. What method does your agency use in estimating the design traffic loading for PCC shoulders?
   □ Percent of mainline design loading (specify %)________
   □ AASHTO
   □ Other (specify:____________________________________, ***please supply a copy)***

4. Complete the table below for transverse joints used for the following PCC shoulders by your agency.

PCC TYPE	JOINT TYPE							
	Regular				Skewed			
	spacing	width	depth	shape	spacing	width	depth	shape
Jointed Plain Concrete								
Jointed Reinforced concrete.								

5. Does your agency tie PCC shoulders to the mainline?.

 Yes No

If no, please explain ____

If yes, please specify typical tie bar size and spacing: Size__________ Spacing__________

6. Complete the table below for the base/subbase material type and thickness placed under the following specified PCC shoulder thicknesses.

Base/Subbase Material type	*Base/subbase thickness under specified PCC Shoulder thickness*					
	6"	*7"*	*8"*	*9"*	*10"*	*Other (specify____*
Aggregate						
Cement-treated						
Asphalt-treated						
Lime-treated						
Other (specify__________						

Please supply copies of memoranda or specifications for gradation, density requirements, and material properties for the choices you have indicated above.

<u>Section 3</u>: Design and Construction of FLEXIBLE SHOULDERS adjacent to mainline PCC Pavements

7. What flexible shoulder types does your agency use adjacent to mainline PCC pavements? *Mark all that apply*

 Full-depth asphalt
 Asphalt over aggregate base course
 Seal coat
 Other (specify____________________________)

Please supply any guidelines/policies regarding the conditions for their use.

8. What design method does your agency use for determining thickness of flexible shoulders adjacent to mainline PCC pavements?

 AASHTO
 Asphalt Institute
 Agency specified standard thickness (please provide detail drawing for standards)
 Other (specify___________________________, *please include a copy*).

9. Does your agency consider frost effects in the paved shoulder thickness determination process?

 YES NO

If yes, ***please supply a copy of the procedure used***.

If no, please explain____

10. List material types commonly used as bases and/or subbases under flexible shoulders.

Base and Subbase Material Types commonly used under Flexible Shoulders			
Base Material	Thickness range (inches)	Subbase Material	Thickness range (inches)

Please supply copies of memoranda or specifications for gradation, density requirements, and material properties for the choices you have indicated above.

11. Does your agency require full specification compaction of shoulder material at the slab edge?
 Yes No

If no, please explain

____

If yes, please specify value as % of mainline compaction value:____

<u>Section 4:</u> Drainage

12. Does your agency use subsurface drains under both Flexible and PCC shoulders ?
 Both PCC only Flexible only None is used

If none is used, please explain____

If used, then please specify the following:

a. Location (e.g. edge of mainline pavement) ________________________________

b. Conditions for use:

c. Type of drainage system used
- Graded aggregate around pipe
- Geotextile wrapped aggregate with pipe
- Prefabricated geocomposite edge drain
- Other (explain)

d. Type of pipes used
- Stiff, smooth-walled PVC
- Corrugated PVC
- Composite

☐ Metal
☐ Other (specify)________________________

Please provide standard details and specifications for each subsurface drainage system used.

Section 5: Construction Cost

12. Does your agency have any information on construction costs (or bid tabs) for PCC and/or Flexible shoulders adjacent to mainline PCC?
☐ Yes ☐ No

If yes, please provide copies of construction costs for available projects and their cross-section details.

Comments:____
____
____
____
____

Note: Please remember to send the following information requested in the previous questions, if available, including:

- Guidelines/policies for selecting paved shoulder types for mainline PCC pavements.
- Summary of any special shoulder design procedure used only by your agency.
- Detail drawings of standard shoulder cross-sections used by your agency for the various classes of highways.
- Construction cost data for flexible and PCC shoulders adjacent to mainline PCC pavements. (Include cross-section information for all available projects for which costs are supplied).
- Standard details and specifications for type of subsurface drainage systems used by agency.
- Copies of memoranda or specifications for gradation, density requirements, and material properties for all base and subbase types used by your agency for paved shoulders adjacent to PCC mainline pavements.

Once again, thank you in advance for your time and consideration!!

APPENDIX B--RESULTS OF DESIGN AND CONSTRUCTION SURVEYS

(Can be accessed at ***www.whrp.org***)

<u>Section 1</u>: Shoulder Type Selection

3. What criteria does your agency use in selecting shoulder types adjacent to Portland Cement Concrete (PCC) mainline pavements?

STATE	Criteria for shoulder type selection for PCC pavements
ILLINOIS	PCC shoulders required for all mainline PCC pavements
WISCONSIN	Functional classification, Volume, Truck Traffic, construction and maintenance cost, construction time, experience and judgment.
INDIANA	Functional Class, Truck traffic
IOWA	Functional Class, Traffic volume (all interstate shoulders as well as shoulders for non-interstate roadways with ADT >10,000 veh/day are paved.
MINNESOTA	Construction and maintenance cost
MICHIGAN	Functional class, truck traffic, construction and maintenance cost.

<u>Section 2</u>: Design and Construction of PCC SHOULDERS adjacent to mainline PCC Pavements

4. What design method does your agency use for determining PCC shoulder thickness?

STATE	PCC shoulder thickness determination method
ILLINOIS	• 20-year design: Same thickness as mainline PCC at the pavement interface tapering to 6 inches at the outside edge. • 30-year design: Same thickness as mainline PCC.
WISCONSIN	AASHTO; minimum 6 inches
INDIANA	Same thickness as mainline , specified standard thickness*
IOWA	Same thickness as mainline , specified standard thickness*
MINNESOTA	Same thickness as mainline , specified standard thickness*
MICHIGAN	AASHTO, Same thickness as mainline , specified standard thickness*

7. What method does your agency use in estimating the design traffic loading for PCC shoulders?

STATE	Design traffic loading estimation method for shoulders
ILLINOIS	Not Applicable
WISCONSIN	AASHTO (2.5% of mainline design traffic is used)
INDIANA	AASHTO
IOWA	Not Applicable
MINNESOTA	Not Applicable
MICHIGAN	Local judgment is sometimes used in lieu of standard.

8. Complete the table below for transverse joints used for the following PCC shoulders by your agency.

STATE	PCC SHOULDER TYPE	JOINT TYPE							
		Regular				Skewed			
		spacing	width	depth	shape	spacing	width	depth	shape
ILLINOIS	Jointed Plain Concrete	Same as pavement	1/8-1/4	D/4					
WISCONSIN		15’ or 18’	1/8	D/3					
INDIANA		18 ft	¼	D/4	Rectangular				
IOWA		20’				20’			
MINNESOTA		15’							
MICHIGAN		4.5 m	10mm	38mm	rectangular				
ILLINOIS	Jointed Reinforced Concrete	-				-			
WISCONSIN		-				-			
INDIANA		-				-			
IOWA		-				-			
MINNESOTA		-				-			
MICHIGAN		8 m	14mm	50mm	rectangular	-			

5 & 6. Does your agency tie PCC shoulders to the mainline?.

State	PCC shoulder Slab	Base/Subbase		Tie Bars	
	Thickness	Type	Thickness	Size (#)	Spacing (in.)
ILLINOIS		a. Aggregate b. Asphalt-treated c. Lime-treated	a. Min. 12 in. for 30-year design. b. 4 in. for jointed plain concrete and 6 in for continuously reinforced concrete for 30-yr design. c. 12 in. minimum for 20-year design.	6	24
WISCONSIN		Aggregate		4	30
INDIANA	a. less than 9-in. b. 9 to 12 in. c. greater than 12 in.	Aggregate		a. 5 b. 6 c. 7	36
IOWA	7 in.	Aggregate	6 in.	5	30
MINNESOTA		Aggregate	Controlled by mainline thickness	4	4 bars per 15-ft panel
MICHIGAN		Open-graded drainage course	Min. 100mm; thickness generally controlled by mainline thickness.		

9. Complete the table below for the base/subbase material type and thickness placed under the following specified PCC shoulder thicknesses.

Please supply copies of memoranda or specifications for gradation, density requirements, and material properties for the choices you have indicated above.

<u>Section 3</u>: Design and Construction of FLEXIBLE SHOULDERS adjacent to mainline

PCC Pavements

What flexible shoulder types does your agency use adjacent to mainline PCC pavements?

STATE	Flexible shoulder types used for Mainline PCC Pavement
ILLINOIS	Not applicable
WISCONSIN	Asphalt over aggregate base course layers
INDIANA	Asphalt over aggregate base course layers
IOWA	Asphalt over aggregate base course layers, rare cases of full-depth asphalt
MINNESOTA	Asphalt over aggregate base course layers
MICHIGAN	Asphalt over aggregate base course layers

Please supply any guidelines/policies regarding the conditions for their use.

12. What design method does your agency use for determining thickness of flexible shoulders adjacent to mainline PCC pavements?

STATE	Flexible shoulder thickness determination method
ILLINOIS	Not applicable
WISCONSIN	AASHTO
INDIANA	Agency standard thickness
IOWA	Agency standard thickness
MINNESOTA	Agency standard thickness (min. 3 in. but thicker if planned traffic is to be supported)
MICHIGAN	AASHTO, agency standard thickness

13. Does your agency consider frost effects in the paved shoulder thickness determination process?

STATE	Consideration for Frost Effects in Flexible shoulder thickness Determination	
	YES	NO
ILLINOIS	Not Applicable	
WISCONSIN		X (traffic conditions on shoulder do not warrant consideration).
INDIANA		X (standard thickness is used)
IOWA		X
MINNESOTA		X
MICHIGAN	X (provide non-frost susceptible base/subbase layers	

14. List material types commonly used as bases and/or subbases under flexible shoulders.

STATE	Base Course		Subbase	
	Material	Thickness range (in)	Material	Thickness range (in)
ILLINOIS	Not Applicable			
WISCONSIN	Crushed Aggregate	Min. 6-in.	Non-typical	
INDIANA	Hot Mix Asphalt	3	Aggregate	7-12
IOWA	Aggregate	Min. 6-in.		
MINNESOTA	Class 5 dense –graded aggt.	3	Class 3	varies
MICHIGAN	Aggregate	160 mm minimum	Sand	460 mm minimum

Please supply copies of memoranda or specifications for gradation, density requirements, and material properties for the choices you have indicated above.

15. Does your agency require full specification compaction of shoulder material at the slab edge?

☐ Yes ☐ No

If no, please explain

____

If yes, please specify value as % of mainline compaction value:____

<u>Section 4:</u> Drainage

12. Does your agency use subsurface drains under both Flexible and PCC shoulders ?

STATE	Subsurface Drainage Utilization							
	Flexible Shoulders				PCC shoulders			
	Conditions for use	Drainage system type	Location	Pipe type	Conditions for use	Drainage system type	Location	Pipe type
ILLINOIS		Geotextile wrapped aggregate with pipe.	Edge of shoulder for 30-year design, Edge of mainline pavement for 20-year design	Corrugated polyethylene		Geotextile wrapped aggregate with pipe.	Edge of shoulder for 30-year design, Edge of mainline pavement for 20-year design	Corrugated polyethylene
WISCONSIN								
INDIANA	Pavement length > than 600m and ADT > 3000 veh/day	Graded aggregate around pipe	Edge of mainline pavement	Corrugated PVC	Pavement length > than 600m and ADT > 3000 veh/day	Graded aggregate around pipe	Edge of mainline pavement	Corrugated PVC
IOWA	Required with drainable bases	Graded aggregate around pipe	Edge of mainline pavement	Polyethylene	Required with drainable bases	Graded aggregate around pipe	Edge of mainline pavement	Polyethylene

MINNESOTA		Geotextile wrapped aggregate with pipe, Graded aggregate around pipe	Edge of mainline pavement	Stiff, smooth-walled PVC, Corrugated PVC.		Geotextile wrapped aggregate with pipe, Graded aggregate around pipe	Edge of mainline pavement	Stiff, smooth-walled PVC, Corrugated PVC.
MICHIGAN	Recommendation comes from soils engineer and is dependent on soil conditions	Geotextile wrapped aggregate with pipe	0.6 m off of mainline when no curb and gutter; under curb and gutter if present.	Stiff, smooth-walled PVC, Corrugated PVC.		Geotextile wrapped aggregate with pipe	0.6 m off of mainline when no curb and gutter; under curb and gutter if present.	Stiff, smooth-walled PVC, Corrugated PVC.

Please provide standard details and specifications for each subsurface drainage system used.

Section 5: Construction Cost

12. Does your agency have any information on construction costs (or bid tabs) for PCC and/or Flexible shoulders adjacent to mainline PCC?
☐ Yes ☐ No

If yes, *please provide copies of construction costs for available projects and their cross-section details.*

Comments:____

Note: Please remember to send the following information requested in the previous questions, if available, including:

- Guidelines/policies for selecting paved shoulder types for mainline PCC pavements.
- Summary of any special shoulder design procedure used only by your agency.
- Detail drawings of standard shoulder cross-sections used by your agency for the various classes of highways.
- Construction cost data for flexible and PCC shoulders adjacent to mainline PCC pavements. (Include cross-section information for all available projects for which costs are supplied).
- Standard details and specifications for type of subsurface drainage systems used by agency.
- Copies of memoranda or specifications for gradation, density requirements, and material properties for all base and subbase types used by your agency for paved shoulders adjacent to PCC mainline pavements.

Once again, thank you in advance for your time and consideration!!

APPENDIX C-- MAINTENANCE SURVEY

Dear Sir/Madam:

RE: SURVEY ON MAINTENANCE OF PAVED SHOULDERS ADJACENT TO MAINLINE CONCRETE PAVEMENTS

The Wisconsin Department of Transportation (WisDOT) is currently involved in a joint research project with the University of Wisconsin-Platteville aimed at developing guidelines for the selection, design, construction, and evaluation of the performance of paved shoulders adjacent to concrete pavements. The research team will be very grateful if you could complete the attached survey questionnaire and return it to the address below. The success of this study in part depends upon your input.

The survey is moderately extensive and will require patience and dedication from you. Please complete the following information.

Name of Organization:______________________________________

Address:____
____

City:______________ State:____________Zip:________

Survey completed by:_________________________________
Position /Title:____
Telephone:____
Fax:____
e-mail____

Survey results and final research report can be accessed free-of-charge at www.whrp.org.
Name of person completing survey will be kept confidential.

RETURN SURVEY AND SUPPORTING DOCUMENTS BY **FEBRUARY 15, 2002** to:

Dr. Sam Owusu-Ababio, P.E.
Dept. of Civil & Environmental Engineering
University of Wisconsin-Platteville
1 Univ. Plaza
Platteville, WI 53818

For questions contact him by phone: 608-342-1554; fax: 608-342-1566; e-mail: owusu@uwplatt.edu

Maintenance of PCC and Flexible Shoulders adjacent to mainline PCC pavements

1. Does your agency have a formal shoulder maintenance program?

     Yes   No

   Iif no, please explain____

   If yes, *please provide a copy of the maintenance policy*

2. Is shoulder maintenance a component of your agency's pavement management system?

     Yes   No

   If yes, please specify the indicator(s) used for describing the condition or performance of the shoulder:

   Do you have data to support the condition or performance indicator(s)?

     Yes   No

   If yes, ***please send any supporting data (study results, memoranda, reports)***

3. If you have a preventative shoulder maintenance program, which of the following components are included in the program? *Mark all that apply*.

    Inventory   Inspection Survey   Scheduling
    Other (specify)____

4. Is shoulder maintenance routinely performed?

     Yes   No

   If yes, ***please provide a copy of survey inspection/maintenance forms***.

   What is the frequency of shoulder condition survey?___________________

   Please describe survey inspection procedures:

5. Do you have any data on cost effectiveness of shoulder surveys?

    Yes   No

   If yes, ***please send any supporting data (study results, memoranda, reports***).

6. What types of maintenance activities are performed on **PCC** shoulders adjacent to PCC pavements? *Mark all that apply.*

Maintenance treatment type	Expected Life (years)
Crack sealing	
Patching	
Pothole repair	
Mainline-shoulder joint repair	
Other (specify______________	

7. What types of maintenance activities are performed on **FLEXIBLE (i.e. asphalt surfaced)** shoulders adjacent to PCC pavements? *Mark all that apply*

Maintenance treatment type	Expected Life (years)
□ Crack sealing	
□ Patching	
□ Mainline-shoulder joint repair	
□ Surface treatment	
□ Overlay(specify thickness range):	
□ Other (specify):_____________	

8. Do you have any maintenance costs for PCC and/or FLEXIBLE shoulders classified by traffic volume, percent trucks, and/or highway class?

□ Yes □ No

If yes, ***please provide a copy of shoulder maintenance costs for available maintenance practices.***

9. Which of the following are the causes of premature failures or poor performance of **PCC** shoulders adjacent to PCC pavements under your jurisdiction? *(Indicate: 1-always, 2-sometimes, 3-never)*

___ Inadequate thickness
___ Inadequate treatment of mainline-shoulder system joint
___ Poor construction of shoulder
___ Inadequate shoulder drainage
___ Inadequate maintenance
___Other (specify)____

10. Which of the following are the causes of premature failures or poor performance of **flexible** shoulders adjacent to PCC pavements under your jurisdiction? (*Indicate: 1-always, 2-sometimes, 3-never)*

___ Inadequate thickness
___Truck encroachments
___ Inadequate treatment of mainline-shoulder joint
___ Poor construction of shoulder
___ Inadequate shoulder drainage (e.g. water intrusion at the longitudinal joint)
___ Inadequate maintenance
___ Frost heave (specify in inches the average range of heave thickness above the mainline pavement:_________)
___ Other (specify)____

If shoulder is affected by frost heave, ***please send any available data (study results, memoranda, reports,) on frost heaving impacts on paved shoulders***.

11. Is the maintenance group in your agency involved in design decisions?

□ Yes □ No

If yes, please describe the interaction process:

12. Is there a regular feedback system between maintenance and design to report maintenance issues?

☐ Yes ☐ No

If yes, please describe and provide copies of any forms:

Please identify any design changes that your agency has implemented that have reduced and/or facilitated shoulder maintenance:

13. Is there a regular feedback system between maintenance and construction to report maintenance issues with shoulder construction practices?

☐ Yes ☐ No

If yes, please describe and provide copies of any forms:

Please identify any construction changes that your agency has) implemented that have reduced and/or facilitated shoulder maintenance.

14. What purposes do shoulders serve in your roadway system? *Mark all that apply*.
   - ☐ Parking area for disabled or stopped vehicles
   - ☐ Lateral support for mainline pavement structure
   - ☐ Added space for construction and maintenance activities
   - ☐ Other (specify)____

15. How much attention does your agency pay to shoulder maintenance in comparison to maintenance of mainline pavements?
   ☐ More ☐ Equal ☐ Little
   ☐ Very little ☐ Not considered

16. What percent of your agency's highway maintenance resources is generally allocated to shoulders?
   __________%

Comments:____
____
____
____
____
____
____

Note: Please remember to send the following information requested in the questions, if available, including:

- A copy of available policy on shoulder maintenance.
- Results, memoranda, or reports on assessment of performance or condition of paved shoulders adjacent to mainline PCC pavements.
- Study results, memoranda or reports on frost heaving impacts on paved shoulders.
- A copy of shoulder survey inspection/ maintenance forms
- Data or reports on shoulder maintenance costs for available maintenance practices.

Once again, thank you in advance for your time and consideration!!

APPENDIX D **–**RESULTS OF MAINTENANCE SURVEYS

(Can be accessed at www.whrp.org)

Summarized and Paraphrased Comments from DOT Districts on Maintenance of PCC and Flexible Shoulders adjacent to mainline PCC pavements

1. Does your agency have a formal shoulder maintenance program?

Number of districts responding YES: 7 NO: 15

If no please explain.

- Perform routine shoulder maintenance where needed and address special needs as they arise
- Looked at every year
- Performed when routine inspections dictate a need for corrective action
- WI DOT maintains the shoulders as needed
- Budget shortage
- Repair on as needed basis
- Maintenance performed as necessary
- Nothing formal
- Repair as needed
- Included in overall routine and capital preventative maintenance
- Look at pavement dropoffs and surface conditions in conjuction with mainline pavement
- PCC shoulders are maintained along with mainline PCC pavements, do not have any PCC pavements with flexible shoulders

2. Is shoulder maintenance a component of your agency's pavement management system?

Number of districts responding YES: 7 NO: 15

If yes, please specify the indicator(s) used for describing the condition or performance of the shoulder.

- Cross slope, ruts, drop offs
- Potholing, cracking, breakups along edge of pavement, surface deterioration
- Holes, depressions, irregularities, shoulder drop-offs
- Drop-off for unpaved shoulders and surface condition for paved shoulders
- Shoulder obstructions, drop-off, deterioration

3. If you have a preventative shoulder maintenance program (PSMP), which of the following components are included in the program? Mark all that apply.

PSMP Component	Number of districts having component in a PSMP
Inventory	4
Inspection Survey	10
Scheduling	4
Other	1

4. Is shoulder maintenance routinely performed?

Number of districts responding YES: 15 NO: 5

What is the frequency of shoulder condition survey? Please describe the survey inspection procedures.

- No formal survey at this time
- Every year, field observation
- 2-4 times a year as a minimum when needed, i.e. after a hard rainstorm
- Each spring or on as needed basis from field reviews
- County personnel inspects twice a week as part of their section maintenance
- Shoulder condition is observed as part of routine weekly visual surveillance by county and/or state personnel
- Observed on a weekly basis by county patrolmen.
- County personnel inspect at least once a year
- Each field technician from operations yards travels roads at least once per year and enters repair needs in his needs survey
- Annually, each subsection of pavement is surveyed each spring and needed repairs are scheduled
- Visual survey by maintenance supervisor as he travels thru his sub area, especially after heavy rainstorms
- Continuous survey by maintenance personnel, formal review at the time of a construction project
- Quarterly for 1/4 of each county, annually for entire county
- Quarterly

5. Do you have any data on cost effectiveness of shoulder surveys?

Number of districts responding YES: 0 NO: 21

6. What types of maintenance activities are performed on **PCC** shoulders adjacent to **PCC** pavements? *Mark all that apply.*

Shoulder Maintenance Treatment Type	Expected Service Life (years)						
	WI	IL	IA	MN	IN	MI	OH
Crack sealing	3-5	X		5-15	2-3		3
Patching	5-10	5		X	X	X	.5-5
Pothole repair	1-2	.5-2		X	X	X	5-8
Mainline-shoulder joint repair	3-5	X		X			3-5
Diamond Grinding	6-8			X			3-5

Note: Numbers represent the average reported expected life in years. An X represents that the activity is performed but the expected life was not reported.

7. What types of maintenance activities are performed on **FLEXIBLE (i.e. asphalt surfaced)** shoulders adjacent to PCC pavements? *Mark all that apply.*

Shoulder Maintenance Treatment Type	Expected Service Life (years)						
	WI	IL	IA	MN	IN	MI	OH
Crack sealing	3-10	5-10	5	X	2-3	X	3
Patching	3-10	5		X	X	X	.5-1
Pothole repair	1-2						
Mainline-shoulder joint repair	3-5	5	2	X			.5-1
Surface treatment	5-7	2-5		X	3-5		
Overlay	5-10	10		X		X	
Overlay thickness (inches)	.5-2						
Wedging	8-10	X					

Note: Numbers represent the average reported expected life in years unless otherwise noted. An X represents that the activity is performed but the expected life was not reported.

8. Do you have any maintenance costs for PCC and/or FLEXIBLE shoulders classified by traffic volume, percent trucks, and/or highway class?

Number of districts responding YES: 0 NO: 22

9. Which of the following are the causes of premature failures or poor performance of **PCC** shoulders adjacent to PCC pavements under your jurisdiction?
(Indicate: 1-always, 2-sometimes, 3-never)

Cause of PCC Shoulder Failure	Number of Districts Responding		
	Always	Sometimes	Never
Inadequate thickness	1	5	9
Inadequate treatment of mainline-shoulder joint system	0	13	2
Poor shoulder construction	2	8	4
Inadequate shoulder drainage	4	10	2
Inadequate maintenance	1	10	2

10. Which of the following are the causes of premature failures or poor performance of **flexible** shoulders adjacent to PCC pavements under your jurisdiction?
(*Indicate: 1-always, 2-sometimes, and 3-never)*

Cause of Flexible Shoulder Failure	Number of Districts Responding		
	Always	Sometimes	Never
Inadequate thickness	3	14	2
Truck encroachment	4	13	1
Inadequate treatment of mainline-shoulder joint system	1	17	1
Poor shoulder construction	1	17	2
Inadequate shoulder drainage	3	16	1
Inadequate maintenance	0	17	1
Frost heave (average. frost heave thickness: 1 – 2”)	2	15	1

11. Is the maintenance group in your agency involved in design decisions?

Number of districts responding YES: 17 NO: 5

If yes, please describe the interaction process.

- Scoping process, plan review
- Scoping meetings, informal discussions
- 6-8 years ago we were not really involved, but now we are
- Maintenance personnel attends four mandatory project development scheduling meetings during the design process to provide input
- Involved with concept definition of project and intermittent review of plans
- Involved in scoping projects, operational planning mtgs, and contact with designers during process
- Districts are sometimes involved with concept definition report
- In some building and open discussion, but design has their policies to follow
- Give advice and suggestions prior to the development of a project report, attend field check when plans are prepared
- Project scoping followed by "plan-in-hand: review for large projects, pre-final plan review for smaller projects

- scoping meetings where input is asked for and received
- Maintenance provides information to the scoping group and designers
- Make recommendations for repairs, have the ability to design maintenance contracts within the section
- Maintenance is part of scoping and review process
- Scope meetings during design phase
- Members of pavement relocation committee for project in their county are involved in the scoping of the project

12. Is there a regular feedback system between maintenance and design to report maintenance issues?

Number of districts responding YES: 12 NO: 10

If yes, please describe and provide copies of any forms.

- Have a program level scoping process
- Word of mouth
- Maintenance provides a design plan checklist to project development
- Post-construction report is filled out
- Recommendations by mail or face-to-face, premature failures are documented on the "Report on Early Distress" (RED) form
- Plan review
- Oral feedback and/or e-mail
- Verbal communication
- No formal forms

Please identify any design changes that your agency has implemented that have reduced and/or facilitated shoulder maintenance.

- Wherever possible use of 3-5" bituminous shoulders to facilitate shoulder maintenance
- Lowering volume requirements for paved shoulders has reduced the frequency of grading gravel shoulders to control dropoffs at edge of pavement
- See mechanistically designed pavement program
- Installation of edge drains on all new and reconstructed roadways
- Changed asphalt shoulders to concrete, especially in areas of heavy truck traffic

13. Is there a regular feedback system between maintenance and construction to report maintenance issues with shoulder construction practices?

Number of districts responding YES: 13 NO: 9

If yes, please describe and provide copies of any forms:

- Have a maintainability index
- Maintenance attends the final walk-thru on a project, provides construction a quality index rating after one winter season
- Part of the overall construction review
- During construction process
- Done with road reviews, drive roads together to look at problematic places
- Open verbal communication during life of contract
- No formal forms
- Maintenance employees do construction inspection

Please identify any construction changes that your agency has implemented that have reduced and/or facilitated shoulder maintenance.

- Thicker flexible pavement to facilitate farm equipment
- Thicker structure
- Try to catch all changes in design phase

14. What purposes do shoulders serve in your roadway system? *Mark all that apply.*

Purpose	Number of Districts
Parking area for disabled or stopped vehicles	21
Lateral support for mainline pavement structure	15
Added space	19
Other: Bicycles	5
Other: Farm equipment	3

Note: The following purposes, to provide a comfort zone for drivers, to provide space for emergency vehicles, to provide space for placement of rumble strips, and to eliminate pavement drop off, were each listed once by a district.

15. How much attention does your agency pay to shoulder maintenance in comparison to maintenance of mainline pavements?

Level of Attention	Number of Districts
More	0
Equal	2
Little	14
Very little	4
Not considered	1

16. What percent of your agency's highway maintenance resources is generally allocated to shoulders?

Percent	Number of Districts
<5	7
5-10	8
11-20	3
>20	3

APPENDIX E--FIELD SURVEY FORMS

AC SHOULDER SURFACE DISTRESS SURVEY FORM

HIGHWAY NAME:________________________ HIGHWAY DIRECTION: ☐ NB ☐SB ☐EB ☐WB
COUNTY NAME:__________________________ SHOULDER WIDTH (ft): ______ ☐ OUTSIDE SHOULDER ☐ INNER SHOULDER
DATE____________________________________ DRIVER/RECORDER:______________________________

REF. POINT (RP)				SECT. MILES	Mileage to Segment	Surface Year	1=BLOCK 2=Alligator	Cracking 0= None, 1= less than 1/2 inch, 2= greater than ½ inch; 3= Dislodgement; Block/Alligator (% of Area)					3= Band; Transverse (No./Sta)				Longitudinal (Lf./Sta)					0 = None 1= Good 2= Fair 3= Poor; Patching (% of Length)					Outside Edge Raveling 0= None 1= Slight	Distortion 0 : None 1: < ½ -inch 2: ½-1-inch 3: > 1 inch; Settlement (% of Length)				Heave (% of length)				0= None 1= Slight 2 = mod. 3= severe; Longitudinal Joint Deterioration (% Length)				Crack Filling [0= filled adequately, 1= need more filling; 2 =Never filled]
FROM	PLUS DIST.	TO	PLUS DIST					None	1-24	25-49	50-74	75+	None	1-5	6-10	11+	None	1-100	100-200	201-300	301+	None	< 1%	1-9 %	10-25%	>25%		None	1-24	25-49	50+	None	1-24	25-49	50+	None	1-24	25-49	50+	
FEATURE NAME																																								
					REMARKS																																			
FEATURE NAME																																								
					REMARKS																																			

PCC SHOULDER SURFACE DISTRESS SURVEY FORM

HIGHWAY NAME:________________________ HIGHWAY DIRECTION: ☐ NB ☐SB ☐EB ☐WB

COUNTY NAME:___________________________ SHOULDER WIDTH (ft) ______ ☐ OUTSIDE SHOULDER ☐ INNER SHOULDER

DATE___________________________________ DRIVER/RECORDER________________________________

REF. POINT (RP)				SECT. MILES	Mileage to Segment	Surface Year	PCC SHOULDER TYPE 5 =JPCP w/o d. 8=JPCP/d	JOINT SPACING (feet)	Doweled and Non-doweled JPCP Shoulders: SLAB BREAKUP* (% OF LENGTH)					JOINT/CRACK FILLING 0= Adequately filled; 1 = more filling needed	DISTRESSED JOINT/CRACKS (No. per station) 0= none; 1= Slight; 2=moderate; 3=Severe *(Evaluate within 2ft. of joint/crack)*				PATCHING (No. per segment) 0= None; 1=Good; 3 =Fair 4=Poor					LONGITUDINAL JOINT DISTRESS 0= None 1= Slight 2=Moderate 3 = Severe (Evaluate within 2 ft of joint on shoulder side only. faulting range for slight: <1/2", moderate ½-1", severe > 1")	TRANSVERSE FAULTING (no. per station) 0= None 1= Less Than ¼ in. 2= ¼ - ½ in. 3 = Greater Than ½ in.			
FROM	PLUS DIST.	TO	PLUS DIST.						0= None	1= 2-3 Large Blocks per slab	2= additional cracking	3= fragmented slabs	4 = level 3 plus slab movement		None	1-2	3-4	5+	None	1-3	4-6	7-9	10+		None	LT 1/STA	1 – 2 /STA	GT 3/STA
FEATURE NAME																												
						REMARKS																						
FEATURE NAME																												
						REMARKS																						

APPENDIX F--*Distresses Description and Photos for PCC Shoulders Adjacent to Mainline PCC Pavements*

Shoulder Distressed Joints/Cracks

Description
This is a distress item concerned with the deterioration of the concrete in the immediate vicinity of a crack or transverse joint on the shoulder. Distressed Joint/Crack includes any distress within two feet on either side of a transverse joint or crack on the shoulder.

Causes
Distresses at joints or cracks may be caused by a number of factors:

--D-cracking: a series of closely spaced crescent-shaped hairline cracks in the concrete surface usually paralleling a joint or major crack and usually curving across slab corners.

-- Spalling: a breakdown of slab edges at joints or cracks or directly over reinforcing steel, usually resulting in the removal of sound concrete.

--Dowel assembly problems: generally result from improper placement of dowel basket (or individual dowel bars in the case where dowel insertion is performed automatically by the paver) causing the joint to lock up.

--Longitudinal Cracks: are caused by lateral contraction, lateral movement and settlement of the roadbed.

SEVERITY

0 = none (no distress present)
1 = slight (early stages of distress and/or a slight loss of material within the joint/crack). Distress in wheel path is 2-4 inches wide.
2 = moderate (any of the following conditions may affect the rating; deterioration of the distressed area; moderate loss of material within the joint/crack and/or slight effect on safety of vehicles intending to use the shoulder). Distress in Wheel path is 6-10 inches wide.
3 = severe (significant breakup; loss of the material within the joint/crack resulting in a major effect on safety; at this severity level patching of the distressed joints/cracks is more frequent). Distress in the wheel path is greater than 10 inches.

EXTENT

Ratings for extent are different for longitudinal and transverse situations as defined below:
Distressed Joints/Cracks

0 = none
1 = 1 - 2 per station
2 = 3 - 4 per station
3 = more than 4 per station

Where random longitudinal cracking exists, the extent will be rated as follows:

Random Longitudinal Cracking

0 = none
1 = 1-48 feet per station
2 = 49-96 feet per station
3 = 97 or more feet per station

Figure F-1 Distress Joint/Crack Severity Level 1
[*Note that transverse crack shows spalling of the edges along most of its length*]

Figure F-2 Distressed Joint/Crack Severity Level 2
[*Note that crack shows spalling, moderate loss of pavement, and general surface deterioration in the immediate vicinity of the crack*]

Figure F-3 Distressed Joint/Crack Severity Level 2
[*Note the wide patch was probably due to moderate spalling of crack edges and significant loss of pavement material in the immediate vicinity of the crack*]

Shoulder Slab Breakup

Description
It is the fracturing of a shoulder slab due to crack development.

Cause
The breakup is caused by a combination of heavy load repetitions on a PCC shoulder with inadequate roadbed support, or from shrinkage, thermal, or moisture stresses.

SEVERITY

0 = intact slab
1 = two or three large block per slab
2 = level 1 severity plus the beginning of interconnecting cracks or additional transverse cracks dividing the slab into additional large blocks
3 = additional interconnecting longitudinal cracks resulting in fragmented slabs
4 = level 3 severity plus the lateral and/or vertical movement of the blocks.

EXTENT

Shoulder Slab Breakup is rated so that the approximate percent of the segment area affected by each severity level is recorded. Each of the five severity levels receive a single digit representing (nearest 10%), the percent of the segment area affected by that level of Slab Breakup; e.g., an entry of 3 represents 30%. Zeros must be placed in those columns that have no distress at that severity level. The letter "A" is used to represent 100 percent. The sum of all entries must equal 100%.

Figure F-4 Slab Breakup Severity Level 1
[*Note that the crack has broken the shoulder slab into two pieces along the groove of the rumble strip*]

Figure F-5 Slab Breakup Severity Level 1
[*Slab is broken up by two cracks; notice that cracks have been sealed, but not adequately]*

Figure F-6 Slab Breakup Severity Level 2
[*Slab is broken up into five parts by interconnecting cracks, which have been sealed]*

Longitudinal Joint Distress

Description
Failure at the Longitudinal Joint. Two factors are considered when rating Longitudinal Joint Distress, i.e. Longitudinal Joint Faulting and Longitudinal Joint Distress.

Cause
Longitudinal Joint Distress is caused by deterioration of the concrete in the immediate vicinity of the longitudinal joint. Longitudinal joint faulting is the difference in elevation at the longitudinal joint between the shoulder and the adjacent mainline outside traffic lane.

RATING

Longitudinal Joint Distress will be assigned severity levels only. Distress within two feet on shoulder side of a longitudinal joint should be rated as Longitudinal Joint Distress. At intersecting cracks and joints, the rater must determine whether the distress belongs primarily to the longitudinal joint or to the intersecting crack/joint. The amount of faulting is determined by measuring the difference in elevation between the shoulder and the mainline outside traffic lane slabs.

0 = none (no faulting or distress present)

1 = slight (faulting less than 1/2 inch; early stages of distress apparent; slight loss of surface). Distress less than 2 inches wide.
2 = moderate (faulting between 1/2 and 1 inch; a general deterioration of the distressed joint with a moderate loss of surface). There is a slight effect on safety. Distress ranges between 2 inches and 4 inches wide.
3 = severe (faulting greater than 1 inch; a significant breakup and loss of the surface resulting in a major effect on ride or safety). This severity includes significant patching. Distress greater than 4 inches wide.

APPENDIX G—*Distress Descriptions and Photos For Asphalt Shoulders Adjacent to Mainline Portland Cement Concrete Pavements*

Block Cracking

Description
Block cracking is the interconnecting of cracks forming a series of large polygons usually with sharp corners or angles.

Cause
Block cracking is generally caused by hardening and shrinkage of asphalt pavement. Block cracking is distinguished from other forms of cracking by pavement age, cause, and appearance and normally does not develop until late in the pavement's life.

Generally Block cracking does not occur Asphalt Pavements over Portland Cement Concrete. When Transverse cracks are intersected by a longitudinal crack, e.g., two transverse reflective cracks intersected by the longitudinal crack over an edge widening, the blocks thus formed are not block cracking.

1 = Block Cracking
2 = Alligator Cracking

SEVERITY

0 = None
1 = cracks less than 1/2-inch in width
2 = cracks greater than 1/2-inch in width (some loss of aggregate particles).
3 = cracks causing dislodgement of a significant number of pavement pieces.

EXTENT

The extent is based on the percentage of the area of the survey segment affected. Total area of the pavement surface affected is measured in square feet of surface area.

0 = None 3 = 50 to 74%
1 = 10 to 24% 4 = 75% +
2 = 25 to 49%

Alligator Cracking

Description
Alligator cracking is the interconnecting of cracks forming a series of small polygons that resemble an alligator's hide or chicken wire.

Cause
Alligator cracking is generally caused by an unstable base or roadbed. The cracks start at the bottom of the asphalt surface and propagate to the surface as longitudinal cracks. As traffic loading continues, the cracks form many-sided, sharp-angled pieces that develop a pattern resembling chicken wire or the skin of an alligator. The pieces are usually less than one (1) foot on the side.

1 = Block Cracking
2 = Alligator Cracking

SEVERITY

The main difficulty in measuring alligator cracking is that in many cases more than one type of distress exists at any given time and at varying levels of extent and severity. The predominant type of cracking (by surface area) should be rated.

0 = None
1 = cracks less than 1/2-inch in width (cracks are not spalled).
2 = cracks greater than 1/2-inch in width (some loss of aggregate particles).
3 = cracks causing dislodgement of a significant number of pavement pieces.

EXTENT

The extent of alligator cracking is based on the percentage of the surface area of the survey segment. Alligator cracking is measured in square feet of surface area.

0 = None
1 = 1 to 24%
2 = 25 to 49%
3 = 50 to 74%
4 = 75% +

Figure G-1 Alligator Cracking Severity Level 1
[*Note that crack widths are less than ½-inch and pavement pieces are still intact*].

Transverse Cracking

Definition
A crack running approximately at right angles to the centerline.

Cause
May be caused by shrinkage of the AC surface or by reflective cracks propagating upward from cracks running beneath the surface course. Cracks/Joints in underlying rigid pavements reflect to the pavement surface and cause transverse cracks.

SEVERITY

0 = None
1 = less than 1/2-inch in width
2 = greater than 1/2-inch in width
3 = band cracking (multiple cracks in close proximity resulting in a narrow band of cracks) with

or without dislodgement. A transverse crack is banded if the pavement area affected is within one (1 ft.) of the crack. Cracks beyond this limit are considered as either Block or Alligator cracking.

Hairline cracks are rated as category 1 cracks. Cracks that have been sealed and cracks that have been filled but have re-cracked will be included in the severity and extent ratings. Sealed and adequately filled cracks should be rated as severity level 1 unless one can tell that the cracks are severity level "2” or "3". All other cracks should be rated by severity and extent according to existing crack opening .

EXTENT

The extent of Transverse Cracking is determined from the average number of transverse cracks per station in the survey segment. A transverse crack length should be at least 25% of the shoulder width to be counted.

0 = None
1 = 1 to 5 cracks per station
2 = 6 to 10 cracks per station
3 = greater than 10 cracks per station

Figure G-2 Transverse Cracking Severity Level 1
[*This is a “sympathetic” transverse cracking developed as a continuation of the PCC joint from the mainline. Crack width is less than ½-inch with slight spalling at the edges*]

Figure G-3 Transverse Cracking Severity Level 2
[*Crack width is greater than ½-inch and exhibits some spalling at the edges*]

Figure G-4 Transverse Cracking Severity Level 3
[*Notice that there is some dislodgement of pavement material and band cracking also appear close to the longitudinal joint*]

Longitudinal Cracking

Definition
A crack running approximately parallel to the centerline of the roadway.

Causes
May be caused by shrinkage of the AC surface due to low temperatures or hardening of the AC. Reflective cracking due to cracks or joints beneath the surface course may also cause longitudinal cracking. It can also be caused by loading if found in the wheel path.

SEVERITY

The rules for determining severity are similar to those used for transverse cracks.

0 = None
1 = less than 1/2-inch in width
2 = greater than 1/2-inch in width
3 = band cracking (multiple cracks in close proximity resulting in a narrow band of cracks) with or without dislodgement. A Longitudinal crack is banded if the pavement area affected is within one (1 ft.) of the crack. Cracks beyond this limit are considered as either Block or Alligator cracking.

Hairline cracks are rated as category 1 cracks. Cracks that have been sealed and cracks that have been filled but have re-cracked should be included in the severity and extent ratings. Sealed and adequately filled cracks should be rated as severity level 1 unless one can tell that they are severity level "2" or "3". All other cracks should be rated by severity and extent according to the existing crack opening as indicated.

EXTENT

The extent of longitudinal cracking is determined from the average lineal foot of cracks per station.

0 = None
1 = 1 to 100 feet per station
2 = 101 to 200 feet per station
3 = 201 to 300 feet per station
4 = greater than 300 feet per station

Figure G-5 Longitudinal Cracking Severity Level 2
[*Crack width is greater than ½-inch*]

Figure G-6 Longitudinal Cracking Severity Level 3
[*Some dislodgment of pavement and band cracking at intersection of transverse crack]*.

Outside Edge Raveling

Definition
Edge raveling describes the breakup of the edge of the paved shoulder. The paved surface considered under this category extends from the paved shoulder edge to a distance one-foot inside from the edge of the paved shoulder.

Causes
A lack of vertical or lateral support, an unstable mix, or the effects of traffic loads cause edge raveling.

SEVERITY

Edge raveling is assigned severity levels only. Edge raveling is given a rating other than zero if the condition exists for over 10 percent of the paved shoulder length.

0 = distress not present (Edge raveling present, but < 10% of Segment length)
1 = visible cracking (slight)
2 = some dislodgement (moderate)
2 = breaking away and dislodgement of a significant quantity of the pavement (severe)

Figure G-7 Edge Raveling Severity Level 1
[*Cracking has occurred at the edge but pavement is still intact]*.

Figure G-8 Edge Raveling Severity Level 2
[*Some evidence of pavement dislodgement exists at the edge]*

Crack Filling

Definition: Crack Filling is not a distress indicator. However, it is included in this section to provide additional information. This indicator is used for reference purposes only, i.e., to explain changes in the computed PDI values over the life of a pavement surface. All types of crack filling, such as routing, should be rated under this distress category.

RATING

0 = filled adequately
1 = filled in past but in need of additional filling
2 = never filled

Longitudinal Joint Deterioration

Definition

A condition in which there is a horizontal separation between the PCC pavement and the AC shoulder, and the shoulder surface in the vicinity of the joint exhibits one or a combination of the following: various cracking forms, dislodgment, and loss of surface.

The paved surface considered under this category extends from the pavement-shoulder longitudinal joint to a distance two feet on the asphalt shoulder side of the joint.

Cause

Generally caused by the outward movement of the asphalt shoulder due to differences in thermal properties of the asphalt and PCC pavement materials. Traffic loads, an unstable mix, can cause the deterioration of the shoulder shrinkage of the shoulder surface, and an unstable base or roadbed.

SEVERITY

0 = None: joint opening is completely sealed and no distress is present

1= Slight: Joint opening is less than ½- inch and shoulder exhibits characteristics such as: some evidence of growth of weeds or grass in joint, low severity level cracking is apparent, and slight dislodgment.

2 = Moderate: Joint opening is between ½- and one-inch and shoulder exhibits characteristics such as some crack spalling, some cracking bands, some dislodgment, and minor pavement loss.

3= Severe: Joint opening is greater than one inch and shoulder exhibits characteristics such as: multiple cracking bands exist, significant dislodgment and loss of pavement, and some evidence of pumping.

EXTENT

The extent is measured according to the percentage of the length of the survey segment subjected to the distress. The extent categories are as follows:

0 = none,
1 = 1-24%
2 = 25-49
3 = greater than 50%.

Figure G-9 Longitudinal Joint Deterioration Severity Level 0
[*Joint is completely sealed and there are no distresses within 2feet of the joint on the shoulder side of the joint*]

Figure G-10 Longitudinal Joint Deterioration Severity Level 1
[*Joint opening is less than ½-inch and low severity level cracking exists within two feet of the joint on the shoulder side of the joint. The surface also appears slightly weathered*]

Figure G-11 Longitudinal Joint Deterioration Severity Level 1
[Note that *joint opening is filled with weeds and surface appears slightly weathered]*

Figure G-12 Longitudinal Joint Deterioration Severity Level 2
[*Bands in the form of alligator cracking appear here and seem to be the effect of encroaching traffic]*

Figure G-13 Longitudinal Joint Deterioration Severity Level 3
[*Significant dislodgment of pavement has created pockets filled with water.]*

Settlement

Description
A condition in which the AC shoulder section in the immediate vicinity of the longitudinal joint has become depressed causing a change in the intended profile of the longitudinal joint.

Causes
May occur as a result of the consolidation of the underlying granular base layers or subgrade under repeated traffic loads and/or voids created by pumping.

SEVERITY

Severity is determined by measuring the difference in elevation between the settled AC shoulder surface and the PCC slab surface at the longitudinal joint. The severity rating is based on an average elevation change within the survey segment.

0 = None
1 = AC shoulder surface is <u>lower</u> than the PCC pavement surface by less than ½ inch).
2 = AC shoulder surface is <u>lower</u> than the PCC pavement surface between ½ and 1 inch
3 = AC shoulder surface is <u>lower</u> than the PCC pavement surface by more than 1 inch

EXTENT

The extent of settlement is measured according to the percentage of the length of the survey segment subjected to the distress. The extent categories are as follows:

0 = none
1 = 1-24%
2 = 25-49
3 = greater than 50%

Figure G-14 Shoulder Settlement Severity Level 0
[*There is a horizontal separation here but no vertical separation or settlement*.]

Figure G-15 Shoulder Settlement Severity Level 1
[*The AC shoulder component of this composite shoulder is at a slightly lower elevation than the PCC slab. The slope of the pencil shows this. The measured average settlement was less than ½-inch*]

Figure G-16 Shoulder Settlement Severity Level 2
[*The AC shoulder component of this composite shoulder is at a lower elevation than the PCC slab. The measured average settlement was between ½ and 1-inch*]

Figure G-17 Shoulder Settlement Severity Level 3
[*The AC shoulder component of this composite shoulder is at a lower elevation than the PCC slab. The measured average settlement was greater than 1-inch*]

Heave

Description
A condition in which a portion of the AC shoulder in the immediate vicinity of the longitudinal shoulder joint has been elevated in relation to the intended profile of the joint.

Cause
May be caused by frost action or swelling soils.

SEVERITY
Heave severity level is determined by measuring the difference in elevation between the heaved AC shoulder surface and the lower PCC slab surface at the longitudinal joint. The severity rating is based on an average elevation change within the survey segment.

1 = AC shoulder surface is higher than the PCC pavement surface by less than ½ inch).
2 = AC shoulder surface is higher than the PCC pavement surface between ½ and 1 inch
3 = AC shoulder surface is higher than the PCC pavement surface by more than 1 inch

EXTENT
The extent is measured according to the percentage of the length of the survey segment subjected to heave. The extent categories are as follows:
0 = none,
1 = 1-24%
2 = 25-49
3 = greater than 50%

Figure G-18 Shoulder Heave Severity Level 2

[*The AC shoulder component of this composite shoulder is at a higher elevation than the PCC slab. The measured average heave was between ½ and 1-inch*]