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Abstract:

As the primary focus of the Virginia Department of Transportation (VDOT) changes from highway construction to transportation maintenance, there is an increased need to extend the value derived from limited funding resources by increasing the service life of pavement rehabilitation treatments. In this regard, the development of a pavement warranty contract and a performance specification was considered in an effort to ensure that VDOT continues to deliver the highest quality pavement to the traveling public.

The concept of a pavement warranty allows for a department of transportation to specify either performance criteria or materials properties that are to be met at the time of project acceptance or throughout the warranty period. These criteria are to be met through the efforts of the contractor in performing periodic maintenance or rehabilitation if required. Reports from the literature suggest that implementing warranty specifications may improve the final quality of the pavement project, reduce the state inspection forces required, and shift some of the responsibility from the department to the contractor. Other reports suggest that disadvantages may include a potential for reduced competition and higher material bid prices during the initial stages of warranty implementation.

In an effort to help increase the overall quality of the roadway network and thus increase the service life of pavement resurfacings, VDOT sought to investigate the use of a warranty clause as part of an upcoming resurfacing contract. A performance-based warranty clause was developed in this pilot study to be included as part of the contract documents for a typical interstate resurfacing project. In this process, the bidding contractors would be given information about the condition of the pavement obtained from data collected through cores and the falling weight deflectometer and then the contractor would be responsible for developing the resurfacing pavement design that fulfilled the conditions of the warranty clause. The review of the submitted bids would be conducted in two stages where the technical merit of a proposal would be evaluated prior to the opening of a cost estimate.

Because of the extensive deterioration of the pavement, the warranty concept was not pursued for the pilot project. This report recommends that the warranty concept be applied in another location as part of a future study. Reports in the literature from other state departments of transportation indicate that although warranties have the potential to improve overall pavement performance and reduce life-cycle costs, they must be developed such that competition between contractors is not reduced.

FINAL REPORT

DEVELOPMENT OF A PAVEMENT WARRANTY CONTRACT AND PERFORMANCE SPECIFICATION FOR A HOT-MIX ASPHALT RESURFACING PROJECT

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Virginia Transportation Research Council
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ABSTRACT

As the primary focus of the Virginia Department of Transportation (VDOT) changes from highway construction to transportation maintenance, there is an increased need to extend the value derived from limited funding resources by increasing the service life of pavement rehabilitation treatments. In this regard, the development of a pavement warranty contract and a performance specification was considered in an effort to ensure that VDOT continues to deliver the highest quality pavement to the traveling public.

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INTRODUCTION

As the primary focus of the Virginia Department of Transportation (VDOT) changes from highway construction to transportation maintenance, there is an increased need to extend the value derived from limited funding resources by increasing the service life of pavement rehabilitation treatments. In this regard, the development of a pavement warranty was considered in an effort to ensure that VDOT continues to deliver the highest quality pavement to the traveling public.

The concept of a pavement warranty allows for a department of transportation (DOT) to specify either performance criteria or materials properties that are to be met at the time of project acceptance or throughout the warranty period. These criteria are to be met through the efforts of the contractor in performing periodic maintenance or rehabilitation if required. Prior to the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, the use of warranties was prohibited on federal-aid highway contracts as warranty provisions could be used to fund maintenance costs indirectly (Federal Highway Administration [FHWA], 2000). If the project is found not to comply with the specified performance criteria or desired materials properties, the contractor may be responsible for either providing financial restitution to the DOT or providing corrective action at no additional cost.

The National Cooperative Highway Research Program's (NCHRP) Project 451, *Guidelines for Warranty, Multi-Parameter, and Best Value Contracting*, reported on various projects using pavement warranties and found that warranty contracting appears to improve the final quality of the paving project, may reduce the state inspection forces required, and may shift some responsibility from the DOT to the contractor (Anderson and Russell, 2001). Other literature suggests that disadvantages include a potential for reduced competition and higher material costs during the early stages of implementing a warranty contract (Johnson, 1999; Aschenbrener and DeDios, 2001; Bayraktar et al., 2004; Cui et al., 2004).

Current data from VDOT's Asset Management Division indicate that the typical hot-mix asphalt (HMA) surface layer placed on the interstate network remains in service for approximately 8 to 9 years. In an effort to help increase the overall quality of the roadway network and thus increase the service life of pavement resurfacings, VDOT sought to investigate the use of a warranty clause as part of an upcoming resurfacing contract. A performance-based warranty clause was developed during this pilot study to be included as part of the contract documents for a typical interstate resurfacing project. The bidding contractors would be given information about the existing condition of the pavement, obtained from data from cores and falling weight deflectometer (FWD) deflection testing. The contractor would then be responsible for developing the resurfacing pavement design that fulfilled the conditions of the warranty clause. The review of the submitted bids was to be conducted in two stages where the technical merit of a proposal would be evaluated prior to a cost estimate being opened.

It was anticipated that the use of a warranty specification on a pavement resurfacing project would allow VDOT to transfer some of the liability for the performance of the end product to the contractor. It was thought that this would occur as the contractor would also have a financial interest in delivering a product with a low life-cycle cost. It was also anticipated that the contractor might be encouraged to develop or implement innovative techniques or procedures that could improve the quality of the final product. Details of pavement warranty implementation have been recently published by state DOTs in New Mexico (May et al., 2003), Texas (Chen et al., 2002), Colorado (Aschenbrener and DeDios, 2001), Wisconsin (Krebs et al., 2001; Dukatz et al., 2001), Minnesota (Johnson, 1999), and Indiana (Haddock and Ward, 1998).

PURPOSE AND SCOPE

The purpose of this research project was to develop and study the implementation of a performance-based pavement warranty clause for use in a typical HMA pavement resurfacing project.

The subject of this pilot study was a portion of I-66 in Prince William County, Virginia, located between mile posts 36.48 to 40.33 and 36.72 to 40.58 for the eastbound and westbound directions, respectively. This section of interstate was constructed between 1975 and 1978 and is a four-lane divided limited access facility.

This study directly applies to projects where HMA overlays are placed on existing flexible pavements. However, the methodologies and concepts described herein may be applied to the maintenance of other infrastructure assets through the use of warranties.

METHODOLOGY

To achieve the purpose of this study, the following tasks were conducted:

1. Conduct a literature review.

2. Establish a Pavement Warranty Task Group.

3. Develop a performance specification and identify an appropriate warranty period.

4. Conduct a field investigation to determine the existing condition of the pavement where the overlay warranty specification was to be applied.

5. Design a typical rehabilitation treatment for the pavement.

6. Study the implementation of the warranty and performance specification.

Literature Review

A literature review was conducted to determine the experiences of other state DOTs with regard to the implementation of similar warranty specifications. Documents were identified using the Transportation Research Information Services (TRIS) website, the Transportation Libraries Catalog (TLCat) website, and the WebSPIRS Transport database.

Establishment of Pavement Warranty Task Group

A Pavement Warranty Task Group was established to oversee the warranty development and implementation processes. The task group consisted of members of VDOT's Asset Management Division, Administrative Services Division, District Pavement Engineers, and Materials Division and the Virginia Transportation Research Council (VTRC). The members were assembled based on their interest in the project and particular expertise. The members of the group are as follows:

- James Bryant, Program Manager, Asset Management Division
- Kevin Chisnell, District Pavement Management Technician, Staunton
- Tanveer Chowdhury, Pavement Management Engineer, Asset Management Division
- James Cline, Assistant Division Administrator for Infrastructure Management, Asset Management Division
- Betty Cousins, Transportation Engineer, Asset Management Division
- Brian Diefenderfer, Research Scientist, VTRC
- Jim Gray, District Infrastructure Manager, Northern Virginia
- Mike Hall, Assistant Division Administrator, Administrative Services Division
- Garry Jarrell, Transportation Engineer, Asset Management Division
- Welford King, Transportation Technology Program Supervisor, Scheduling and Contracts Division
- Deborah Mintiens, District Pavement Manager, Staunton
- Albert Rollins, Interstate Maintenance Manager, Northern Virginia
- Don Silies, Assistant Division Administrator, Scheduling and Contracts Division

- Clinton Simpson, Senior Transportation Engineer, Asset Management Division
- Thomas Tate, Pavement Program Engineer, Materials Division.

Development of Warranty Contract and Performance Specification

Through the efforts of the task group, a warranty contract and a performance specification for the pilot study were developed. The warranty outlined the contractual obligation of the contractor and the methods with which payment for the construction and maintenance periods would be made. The specification focused on future annual measurements of items such as cracking, rutting, number of potholes, raveling, rideability, and skid resistance. As part of the contractual language, the contractor would be required to maintain the pavement in a condition such that severity levels for each criterion would not be exceeded.

Warranty Period

The task group selected an appropriate warranty period based on information reported by other state DOTs in the literature, data regarding typical performance of HMA pavements in Virginia, and consultation with representatives from local contractors and the surety industry.

Field Investigation

As stated previously, the subject of this pilot study was a portion of I-66 in Prince William County, Virginia, located between mile posts 36.48 to 40.33 and 36.72 to 40.58 for the eastbound and westbound directions, respectively. This section of interstate was constructed between 1975 and 1978 and is a four-lane divided limited access facility. This location was chosen because of its placement on VDOT's upcoming paving schedule and the willingness of the local district representatives to participate in the study.

The field investigation consisted of pavement coring, subgrade boring, and structural analysis using VDOT's FWD. This testing was undertaken to aid in establishing the conditions at the project site and to compare the pavement cross-section with that found in VDOT's Highway Transportation Records and Inventory System (HTRIS) database. The existing pavement cross-section for the eastbound and westbound lanes from the HTRIS database is shown in Tables 1 and 2, respectively. Table 2 shows several instances where incomplete pavement cross-section data exist in the HTRIS database. This is a typical problem encountered with historical pavement data at some locations.

Four pavement cores and subgrade borings from the pavement were obtained in the eastbound and westbound lanes in April 2005 to establish the existing pavement design and material conditions. FWD deflection testing was performed in April and May 2005 for the eastbound and westbound lanes, respectively.

Table 1. Pavement Design for Eastbound I-66 (Right Lane) from HTRIS Database

Milepost		Material	Thickness, in	Year Placed	Description
From	To				
36.59	37.21	SM-2A[a]	1.6	1995	PG 76-22, 5.2% binder content
		S-5[a]	1.2	1975	5.8% binder content
		B-3[b]	8.0	1975	4.5% binder content
		21A[c]	6.0	1975	
		Cement stabilized subgrade	6.0	1975	10% cement content
37.84	38.46	SM-2A	1.6	1995	AC-20, 5.2% binder content
		S-5	1.2	1975	5.8% binder content
		B-3	8.0	1975	4.5% binder content
		21A	6.0	1975	
		Cement stabilized subgrade	6.0	1975	10% cement content
38.77	38.94	SM-2A (modified)	1.6	1995	PG 76-22, 5.2% binder content
		S-5	1.2	1975	6.0% binder content
		B-3	6.0	1975	4.7% binder content
		21A	6.0	1975	
		Cement stabilized subgrade	6.0	1975	10% cement content
39.53	40.01	Experimental	1.6	1995	PG 76-22, 5.2% binder content
		S-8/PFC[d]	0.5	1982	6.3% binder content
		S-5	1.5	1975	6.0% binder content
		B-3	8.0	1975	
		Aggregate base, Type 1[e]	6.0	1975	
		Cement stabilized subgrade	6.0	1975	10% cement content

[a]HMA surface mix.
[b]HMA base mix.
[c]Dense-graded aggregate base.
[d]Permeable friction course.
[e]Locally available aggregate material.

Table 2. Pavement Design for Westbound I-66 (Right Lane) from HTRIS Database

Milepost		Material	Thickness, in	Year Placed	Description
From	To				
39.15	43.5	Latex emulsion, Type C	n/a	1993	
		S-8/PFC	0.7	1981	6.3% binder content
		S-8/PFC	0.8	n/a	6.5% binder content
		S-5	1.5	1980	5.4% binder content
		n/a	n/a	n/a	
38.67	39.15	Latex emulsion, Type C	n/a	1993	
		S-8/PFC	0.7	1982	6.5% binder content
		S-5	1.5	1980	5.4% binder content
		B-3	6.0	1980	4.5% binder content
		Aggregate base, Type 21A	6.0	1980	
36.8	38.67	Latex emulsion, Type C	n/a	1993	
		S-8/PFC	0.7	1980	6.5% binder content
		S-5	1.5	1979	5.8% binder content
		B-3	8.0	1979	4.5% binder content
		21A	6.0	1979	
		Type 1, Select material	6.0	1979	
		Aggregate base, Size 20	n/a	n/a	

PFC = permeable friction course.

FWD deflection testing is a common tool used by many DOTs to conduct nondestructive evaluations of the structural capacity and in-situ condition of in-service pavements. The FWD operates through the application of an impulse load through an 11.8-in-diameter loading plate. Through use of a series of geophones located at known radial distances from the center of the loading plate, the deflection attributable to the applied load is measured. The resilient modulus of the subgrade and a combined resilient modulus of the different pavement layers (in addition to the elastic moduli) can be calculated through a process known as backcalculation provided that the overall pavement thickness is known or estimated accurately. The FWD used by VDOT is a Dynatest Model 8000. This FWD is trailer mounted and is towed behind a van that includes an onboard data storage and processing computer. Loads, ranging from 1,500 to 24,000 lb, may be applied to the pavement by dropping known weights (110, 220, 440, or 660 lb) from heights ranging from 0.8 to 15 in.

During this study, FWD deflection testing was conducted at four load levels (6,000, 9,000, 12,000, and 16,000 lb). At each load level, three deflection basins were collected. This process resulted in a total of 12 deflection basins collected at each testing location. Two seating drops at 12,000 lb preceded the recorded FWD measurement as specified by Virginia Test Method 68 (VDOT, 2001). Testing spacing was set at 75-ft intervals to ensure that a representative statistical sample of the pavement sections was tested. MODTAG software was used to process the FWD data. The structural capacity of the existing pavement was determined from the results of the FWD deflection testing, pavement coring, and subgrade boring.

Design of Rehabilitation Treatment for the Pavement

To anticipate what responses might be received from potential contractors, members of the Pavement Warranty Task Group analyzed the core and FWD data to determine the "most likely" design of a rehabilitation treatment for the pavement. This most likely scenario would form the basis for analyzing the technical merit of received proposals by potential contractors and give the local VDOT district an idea of the cost for the warranty project. These steps were followed during this process: determination of existing conditions, estimation of future traffic levels, and calculation of pavement structure to carry future traffic.

RESULTS AND DISCUSSION

Literature Review

Following passage of ISTEA in 1991, FHWA created the Special Experimental Project No. 14 in an effort to investigate innovative contracting methods that could stretch the impact of funding and to promote the acceleration of highway construction and maintenance activities (FHWA, 2004). As a result, the following alternatives to traditional contract bidding were identified: design-build, multi-parameter bidding (cost plus time), lane rental, and warranty. The purpose of identifying these alternatives was to assist the state DOTs with developing choices that could minimize construction time, reduce life-cycle costs, and encourage innovative construction techniques/materials. Although warranty specifications were identified as a potentially beneficial method to improve the highway and construction maintenance activities, a major roadblock to successful implementation is the continued use of traditional prescriptive specifications by DOTs. Ultimately, specifications containing warranty language could stipulate the desired performance of the end product and relieve the DOT of constant quality assurance and inspection duties during construction.

Prescriptive specifications dictate to the contractor the type of materials to be used and the method in which they must be used. These prescriptive specifications also inherently assign any liability for premature failure or deterioration as a result of using the specified materials according to the specified methods to the DOTs. In contrast, warranty specifications differ from prescriptive specifications in that the contract is developed around the desired end product rather than the methods used to produce the end product. Warranty specifications may rely on quantitative measures of performance to indicate initial acceptance and functionality throughout the life of a particular construction or maintenance project. Examples of performance measures are ride quality, skid resistance, and rut/cracking measurements. Often, the limiting value of these performance measures varies during the course of the warranty period to account for expected pavement deterioration or unforeseen sudden increases in traffic levels.

Aschenbrener and DeDios (2001) defined four types of warranty specifications: prepaid maintenance warranties, workmanship warranties, materials and workmanship warranties, and performance warranties.

1. The *prepaid maintenance warranty* is a typical arrangement where the owner specifies the design, materials to be used, and prescriptive workmanship process. The contractors' responsibilities include the development of an estimate to maintain the pavement in accordance with the owner's construction requirements.

2. A *workmanship warranty* requires the contractor to correct any future defects that might arise from poor workmanship. As the owner is responsible for the design, the contractor does not carry any responsibility for defects that are a result of an inadequate design.

3. *A materials and workmanship* warranty requires the contractor to correct any future defects that result of either defective materials or poor workmanship. The owner is responsible for any future defects related to an inadequate design.

4. A *performance warranty* assigns full responsibility for the pavement performance to the contractor during the warranty period as the contractor prepares the design.

A potential fifth type that could be included is a *partial performance warranty* wherein the contractor is responsible for the pavement performance attributable to materials, workmanship, and design but the owner still retains control over the actual design.

Details of pavement warranty implementation have been published by many state DOTs including New Mexico (May et al., 2003), Texas (Chen et al., 2002), Colorado (Aschenbrener and DeDios, 2001), Wisconsin (Krebs et al., 2001; Dukatz et al., 2001), Minnesota (Johnson, 1999), and Indiana (Haddock and Ward, 1998). These projects represent some of the first efforts by state DOTs to implement warranties on newly built or rehabilitated roadways. Although the warranty concept is widely used in Europe, it is still regarded as innovative in the United States (Anderson and Russell, 2001). Initial pavement warranty efforts in the United States resulted from a desire to achieve longer lasting pavements by requiring contractors to warrant their work under a partial performance warranty for up to 5 years. However, some states have implemented longer warranty periods prior to studying their effectiveness.

From a paving contractor's perspective, a major drawback to these initial warranty projects was that the contractors had limited input in the design and performance specifications processes and thus were required to accept responsibility for subsequent failures attributable to the roadway design. As a result, the material bid prices for HMA on early warranty projects increased by 15% to 25% per ton (Bayraktar et al., 2004; R. Battey, personal communication, 2005). The increase in bid prices also reflected great uncertainty during early projects, as these were some of the first pavement warranty projects attempted in the United States. It is anticipated that as more warranty contracts are let, this uncertainty will be reduced as the industry becomes more comfortable with the warranty process and the DOTs have a better understanding of developing performance-based specifications.

To date, VDOT's only experience with a warranty specification for pavements was during the new construction of a portion of Route 288, west of Richmond. A private organization was given the freedom to design fully the pavement on a portion of the roadway to meet specific performance criteria for 20 years, a full performance warranty. As part of this contract, the private organization was even allowed to develop the performance specifications upon which the warranty was based. The benefits and/or consequences of this project are still under study by VDOT.

The difference in costs between warranted and non-warranted projects varies depending on the report cited, the duration of the analysis, and the methods in which projects are selected for implementation of the warranty process. Krebs et al. (2001) reviewed the cost of warranted pavement projects versus non-warranted pavement projects. They reported that the warranted projects constructed between 1995 and 1999 actually cost approximately 14% less than non-warranted pavements constructed at the same time in terms of life-cycle costs. Aschenbrener and DeDios (2001) reported that the differences in initial bid and maintenance costs were negligible after 3 years (if the cost of the weigh-in-motion scale, required by the Colorado DOT on warranted projects within this study, was disregarded). The Ohio DOT (2000) reported an increase in the material bid price of 8.5% for HMA projects involving 5-year warranties. As the result of a survey where state DOTs responded to a questionnaire, Bayraktar et al. (2004) reported that although initial bid prices increased 0% to 15%, changes in maintenance and project life-cycle costs were expected to be minimal.

Krebs et al. (2001) also performed an analysis based on distress and International Roughness Index surveys of 18 warranted pavement projects versus non-warranted pavement projects and found the warranted pavements to perform better initially and after 5 years. The warranted projects were approximately 30% smoother after construction than were the non-warranted projects, and the increase in roughness after 5 years for warranted pavements was approximately 16% versus approximately 30% for non-warranted pavements.

Krebs et al. (2001) attributed the reduced cost of warranted pavements to be due primarily to the selection process that the Wisconsin DOT uses to select projects to become eligible for inclusion in the warranty process. Included among the qualifications were verification of adequate subgrade support and inclusion of an accurate subgrade strength value in the design process. Although these steps may have biased the results in favor of the warranty, *these are concepts that ideally should already be a part of any overlay design process used by a DOT* (warranty or non-warranty). However, most overlay designs are not given such detailed analysis and the same typical rehabilitation treatment is often applied across many different conditions.

Warranty Contract and Performance Specification

The warranty contract developed in this project consisted of two phases: a resurfacing action and a maintenance period. The maintenance period was to begin on the date of the final acceptance of the resurfacing and extend for a period of 9 years. The project was to be bid at a lump sum price that included the cost of the resurfacing and maintenance. The contractor would be paid 80% of the lump sum upon acceptance and one-ninth of the remaining 20% annually provided that the pavement complied with the performance specification. Following discussions with representatives from local contractors and the surety industry, VDOT decided that the contractor would be required to obtain a performance bond for the initial 80% of the lump sum contract price to cover the actual resurfacing and annually renewable 1-year bonds, each in the amount of the remaining 20% of the lump sum contract price to cover the maintenance period. It was thought that this significantly reduced the risk to the surety and, therefore, the cost to the contractor.

The performance specification developed during this study defined allowable limits of deterioration on items such as cracking, rutting, number of potholes, raveling, rideability, and skid resistance that would be measured on an annual basis. As part of the contractual language, the contractor was required to maintain the pavement in a condition such that the severity level for each criterion would not be exceeded. The developed HMA overlay performance specification is provided in Appendix A.

Warranty Period

The previously cited reports by other state DOTs indicated warranty periods ranging from 2 to 20 years. In general, as the warranty period increases, so does the material bid price. This is a typical result of increased uncertainty on behalf of the contractor and surety (Johnson, 1999; Cui et al., 2004). As with any construction project, the contractor must secure a performance bond that assures that the contractor will perform the work within the contract. As a warranty involves a long-term contractual obligation, the surety assumes a greater risk with an increase in warranty period and passes along this risk in terms of cost to secure the bond to the contractor. Aschenbrener and DeDios (2001) stated that although the most cost-effective duration of the warranty period is still unclear, the warranty should be enforced long enough to ensure the desired performance over the service life of the project but not so long as to drive up the contract price artificially.

A warranty period of 9 years was set for this pilot study following an analysis of the annual visual condition survey data collected by VDOT's Asset Management Division. This information showed that the surface layer of flexible pavements on Virginia's interstate system had an average service life of between 8 and 9 years before resurfacing was required (based on a visual condition index rating). After discussion within the Pavement Warranty Task Group, it was decided to set the warranty period at 9 years for this pilot study. Selection of this time period was thought to be the most cost-effective means for improving the average (by reducing the number of premature failures) while not greatly increasing the risk to the contractor.

Field Tests

Field testing, consisting of pavement coring, subgrade boring, and FWD deflection testing, was performed between April and May 2005.

Pavement Coring and Subgrade Boring

The results of the pavement coring and subgrade boring are presented in Tables 3 and 4 for the eastbound and westbound directions of I-66, respectively. The results are given as a location, description, and depth from the surface for each material collected; any remarks based on the condition of the material found; and the results of standard penetration tests (SPT). The SPT results indicate the penetration resistance of the subgrade material by recording the number of blows required to drive the sample collector a distance of 6 in at depths of between 1 and 5.5 ft. Pavement coring and subgrade test borings were performed in the right-hand lane. The data show that stripping of the HMA was observed within the surface layer in two of the four cores from the eastbound direction and in three of the four cores from the westbound direction. In one core from the westbound direction, stripping was also noted at a depth of approximately 5 in. The SPT results generally indicated a stronger upper subgrade material (depths ranging from 1.5 to 3.5 ft) lying above weaker subgrade material (depths from 3.5 to 5.5 ft) in both directions. The average SPT values of the subgrade at depths from 1.5 to 3.5 ft were 11.3 and 10.1 for the eastbound and westbound directions, respectively. The average SPT values for the subgrade at depths of 3.5 to 5.5 ft were 8.3 and 6.9 for the eastbound and westbound directions, respectively.

The pavement structure in each direction can be separated into two sections: an eastern and a western section. The eastern section, including data from mile posts 37.0 and 38.0, consisted of approximately 9 to 11 in of HMA over approximately 8 to 10 in of crushed aggregate. The western section, including data from mile posts 38.9 and 39.8, consisted of approximately 10 to 12 in of HMA over approximately 3 to 5 in of crushed aggregate. Similar subgrade material, red-brown sandy silt with traces of clay, was found across the entire project.

Table 3. Existing Pavement Structure for Eastbound I-66 (Right Lane) from Core Data

Location, MP	Field Description	Depth, ft	Remarks	SPT Results	
				Depth, ft	Blows/ 6 in
37.0	10.25-in HMA	0.00-0.85	2.25-in HMA surface mix (1 layer) 8.00-in HMA base/intermediate mix (2 layers)	1.52-3.52 3.52-5.52	14-8-3-3 2-2-4-5
	9.25-in crushed aggregate	0.85-1.62			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.62-			
38.0	10.75-in HMA	0.00-0.90	2.38-in HMA surface mix (1 layer), mildly stripped 8.37-in HMA base/intermediate mix (2 layers), upper layer contains significant voids	1.69-3.69 3.69-5.69	17-9-3-4 4-6-8-9
	9.50-in crushed aggregate	0.90-1.69			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.69-			
38.9	11.50-in HMA	0.00-0.96	3.25-in HMA surface mix (2 layers) 8.25-in HMA intermediate/base mix (2 layers)	1.24-3.24 3.24-5.24	28-14-19-18 5-7-7-13
	3.31-in crushed aggregate	0.96-1.24			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.24-			
39.8	10.75-in HMA	0.00-0.90	2.75-in HMA surface mix (2 layers), lower layer moderately stripped 8.00-in HMA intermediate/fine base mix (2 layers)	1.16-3.16 3.16-5.16	11-6-10-13 4-5-24-27
	3.06-in crushed aggregate	0.90-1.16			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.16-			

f-m = fine-to-medium; f-c = fine-to-coarse.

FWD Deflection Testing

The results of the FWD deflection testing are summarized in Table 5. The average, standard deviation, and coefficient of variation of the backcalculated subgrade resilient modulus; effective structural number; deflection under the FWD load plate; and deflection at a distance of 72 in from the load plate for the eastbound and the westbound directions of I-66 are shown.

Table 5 shows that the summarized subgrade resilient modulus for the eastbound and westbound directions of I-66 is similar in terms of both average magnitude and variability. Table 5 also shows that the westbound lanes have a higher structural capacity than do the eastbound lanes. The average deflection under the load plate is higher for the eastbound direction. However, the average deflection at a distance of 72 in from the load plate is higher for the westbound direction. Because of the high coefficient of variation, there may be no statistical difference between the deflection measurements of the eastbound and westbound directions.

Table 4. Existing Pavement Structure for Westbound I-66 (Right Lane) from Core Data

Location, MP	Field Description	Depth, ft	Remarks	SPT Results	
				Depth, ft	Blows/ 6 in
39.8	10.50-in HMA	0.00-0.88	0.25-in thin surface overlay 2.25-in HMA surface mix (1 layer), top stripped 8.00-in HMA base/intermediate mix (2 layers)	1.30-3.30 3.30-5.30	17-15-11-14 6-14-12-12
	5.12-in crushed aggregate	0.88-1.30			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.30-5.30			
38.9	10.25-in HMA	0.00-0.85	0.25-in thin surface overlay 2.25-in HMA surface mix (1 layer), top stripped 7.75-in HMA base/intermediate mix (2 layers)	1.27-3.27 3.27-5.27	21-8-8-11 5-7-11-12
	4.94-in crushed aggregate	0.85-1.27			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.27-5.27			
38.0	9.00-in HMA	0.00-0.75	0.38-in thin surface overlay 1.75-in HMA surface mix (1 layer), moderately stripped 7.75-in HMA base/intermediate mix (2 layers), interface between layers moderately stripped	1.19-3.49 3.49-5.49	11-10-4-4 2-3-5-9
	8.88-in crushed aggregate	0.75-1.49			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.49-5.49			
37.0	10.25-in HMA	0.00-0.85	0.20-in thin surface overlay 2.00-in HMA surface mix (1 layer) 8.05-in HMA base/intermediate mix (2 layers)	1.52-3.52 3.52-5.52	14-8-3-3 2-2-4-5
	8.00-in crushed aggregate	0.85-1.52			
	Red-brown, micaceous f-m sandy SILT with f-c weathered rock fragments, trace clay	1.52-5.52			

f-m = fine-to-medium; f-c = fine-to-coarse.

Table 5. FWD Results Showing Subgrade Resilient Modulus, Effective Structural Number, Deflection Under Load Plate, and Deflection at Distance of 72 in for Eastbound and Westbound I-66

Statistic	Backcalculated Subgrade Resilient Modulus, psi		Effective Structural Number		Deflection Under Load Plate, mils		Deflection at Distance of 72 in, mils	
	EB	WB	EB	WB	EB	WB	EB	WB
Average	32,330	33,098	3.66	4.60	14.1	10.7	1.1	1.4
Standard Deviation	16,484	17,305	0.4	0.4	7.4	4.5	0.9	1.1
Coefficient of Variation	51.0%	52.3%	10.7%	9.2%	52.6%	41.5%	77.6%	80.6%

EB = eastbound; WB = westbound.

Additional details from the FWD testing are provided in Appendix B. Figure B1 presents the backcalculated subgrade resilient modulus for each direction by project mile post. This figure shows the subgrade conditions to be similar for each direction. It is also shown in Figure B1 that the subgrade is weak in both directions between mile posts 36.5 and 37.0. Figure B2 shows the effective pavement structure number as calculated from the FWD testing. The number is an empirical quantification of the structural capacity of the pavement. Figure B2 shows that the structural capacity of the westbound direction was higher than that of the eastbound direction.

Figures B3 and B4 present the deflection of the eastbound and westbound directions, respectively, as measured by the FWD during field testing. A lower deflection indicates a stronger pavement. The deflection from two sensors, D1 and D9, is shown in each figure. Sensor D1 is located at the load plate and is an indicator of the strength of all pavement layers. Sensor D9 is located at a distance of 72 in from the center of the load plate and is an indicator of the strength of the subgrade material. Figures B3 and B4 show a higher deflection between mile posts 36.5 and 37.0 than for the remainder of the project. In fact, the average deflection for both sensors in both directions between mile posts 36.5 and 37.0 is approximately twice the average deflection of the remainder of the project.

Design of Rehabilitation Treatment

To anticipate what responses might be received from potential contractors, members of the Pavement Warranty Task Group analyzed the data from the field investigation to determine the "most likely" design of a rehabilitation treatment for the pavement. The following steps were followed during this process: determination of existing conditions, estimation of future traffic levels, and calculation of pavement structure to carry future traffic.

The existing condition of the pavement was noted through a cursory visual survey, from the collection of pavement cores, and from analysis of the FWD deflection testing. The visual survey revealed that the condition of the eastbound lanes was worse than that of the westbound lanes. In each direction, fatigue cracking was evident at the surface of the pavement. In addition, pumping of fines from the subgrade was evident at the pavement surface in portions of the eastbound lanes. The collected pavement cores showed that the most recently applied HMA plant mix layer had stripped in five of the eight cores. Thus, it was suggested that any future rehabilitation would need to include milling of a minimum of 3 in of existing pavement to remove stripped material. It was also suggested that given the 9-year warranty period and the goal to keep existing traffic lanes open as much as possible, the likely rehabilitation effort would be to place an HMA overlay.

The anticipated future traffic was calculated in terms of the number of equivalent single axle loads (ESALs) using DarWin pavement design software and inputs from existing VDOT data. Based upon data from VDOT's Traffic Division, the ESALs the rehabilitation design would be required to carry was calculated using a current AADT of 38,000 with 10% trucks and a growth rate of 4%. The DarWin software calculated that the rehabilitation design would need to be capable of accommodating slightly more than 8.46 million ESALs (using a truck factor of

1.28) for the 9-year warranty period. Other assumptions, such as serviceability, percent traffic in the design lane, etc., were made following VDOT's *Guidelines for 1993 AASHTO Pavement Design* (VDOT, 2003).

The results of the FWD testing showed the average existing structural capacity of the pavement to vary depending on the direction; therefore, the analysis of the most likely rehabilitation design was conducted separately for each direction. The required structural number for the overlay was calculated based on future ESALs, existing subgrade resilient modulus, and current structure number of the pavement. The subgrade resilient modulus for each direction was calculated as 33% of the average backcalculated subgrade resilient modulus (M_r) from the FWD testing. Part III, Chapter 5.3.4, of the American Association of State Highway and Transportation Officials' (AASHTO) *Guide for Design of Pavement Structures* (AASHTO, 1993) states that this correction is necessary to make the backcalculated subgrade M_r value consistent with the subgrade from the AASHO Road Test (Highway Research Board, 1962). Following this methodology, the design subgrade M_r of the eastbound and westbound directions was calculated to be 10,600 and 10,900 psi, respectively. Based on this information, the structural numbers for future traffic were calculated as 5.15 and 5.10 for the eastbound and westbound directions, respectively. Therefore, the overlay structural numbers for the eastbound and westbound directions were 1.49 and 0.5, respectively.

The thickness of the pavement overlay was calculated based on the estimated structural coefficients of the existing pavement layers and the required design overlay structural number. The estimated structural coefficients for the existing pavement layers were based on the AASHTO guide (AASHTO, 1993). This guide provides typical coefficient values depending on the severity of deterioration at the pavement surface. Coefficient values for the eastbound and westbound directions were modified until the sum of the coefficient multiplied by the thickness for each layer was equal to the structure number of the existing pavement as determined by the FWD testing. This information is shown in Table 6.

Table 6. Estimated Structural Coefficients for Calculating Overlay Design Thickness

	Eastbound			**Westbound**		
	Average Existing Thickness, in (*A*)	**Estimated Layer Coefficient (*B*)**	**= A x B**	**Average Existing Thickness, in (*A*)**	**Estimated Layer Coefficient (*B*)**	**= A x B**
HMA	10.5	0.26	2.73	9.50	0.40	3.80
Aggregate	6.0	0.08	0.48	6.00	0.12	0.72
Treated subgrade	6.0	0.08	0.48	-	-	-
Estimated structure number			3.69			4.52
Average structure number from FWD testing			3.66			4.60

Based on the assumptions, shown in Table 6, the thickness of a new overlay was determined by subtracting the value of the layer coefficient of the existing HMA layers multiplied by the depth of the milled pavement from the existing structural number and then adding the value of the layer coefficient of the new overlay multiplied by the new overlay thickness. For typical HMA surface mixes, VDOT uses a structural layer coefficient of 0.44. The thickness of the new overlay was adjusted until the structural number of the rehabilitated pavement ($SN_{existing} - SN_{milled} + SN_{overlay}$) was equal to the required structural number as calculated by the DarWin software for the analysis period (5.15 and 5.10 for the eastbound and westbound directions, respectively).

Table 7 shows the resulting pavement design based on the methods described. The overlay thickness for the eastbound and westbound directions was calculated as 6.5 and 5.0 in, respectively. The existing HMA thickness for the eastbound and westbound directions, shown in Table 7, is based on a milled thickness of 5.5 and 4.0 in, respectively. There is a resultant increase in surface elevation of 1.0 in in each direction.

Prior to the analysis, the local VDOT district representatives had estimated that the scope of the project should consist of a 2-in milling operation followed by a 2-in HMA overlay, a decision that was not based on the analysis of the pavement structural capacity. This operation would not result in any increase in the elevation of the pavement surface. This was considered critical as the clearance to one overhead structure was already substandard and increasing the surface elevation by as little as 1 in would result in two more structures having a substandard overhead clearance. Calculations using the DarWin software showed this rehabilitation option to be associated with an expected service life of approximately 4.5 years.

Following the same analysis, a rehabilitation design that would meet the needs for future traffic (9 years) while not increasing the pavement surface elevation was found to be feasible in the eastbound direction using a combination of an 8.0-in milled thickness and an 8.0-in overlay; the resultant structure number for this design was calculated as 5.13. However, in the westbound direction, the maximum structure that could be achieved (without manipulating the aggregate base) was calculated to consist of a 9.5-in milled thickness (accomplished by milling all the existing HMA material) and a 9.5-in overlay, resulting in a structure number of 4.9. Analysis

Table 7. Rehabilitation Pavement Design for Eastbound and Westbound I-66

	Eastbound			**Westbound**		
	Thickness, in (*A*)	**Layer Coefficient (*B*)**	**= A x B**	**Thickness, in (*A*)**	**Layer Coefficient (*B*)**	**= A x B**
Overlay HMA	6.5	0.44	2.86	5.0	0.44	2.20
Existing HMA	5.0	0.26	1.30	5.5	0.40	2.20
Aggregate base	6.0	0.08	0.48	6.00	0.12	0.72
Treated subgrade	6.0	0.08	0.48	-	-	-
Rehabilitated structure number			5.12			5.12
Required structure number from DarWin analysis			5.15			5.10

showed that a structure number of 4.9 would be adequate for the pavement to carry the traffic for approximately 1.8 years less than a design based on the required structure number. It was assumed by the researchers that neither of these options would be feasible given the deep milling required and the desire to maintain traffic in this vital commuting corridor.

Warranty Implementation

Given the large difference in scope between the expected design of a 2-in mill and overlay and the calculated design for the 9-year warranty period, the researchers and other selected members of the Pavement Warranty Task Group recommended not pursuing implementation of the warranty concept at the location of this pilot study. This decision was based on the restricted overhead clearances and the fact that the contractor would not be allowed to apply a resurfacing treatment that increased the surface elevation. It is the intent of the Pavement Warranty Task Group to apply the pavement warranty concept at another location following a review of VDOT's upcoming pavement overlay schedule (including review of any associated overhead obstructions). Ideally, the warranty concept should be employed on a trial basis across several projects that represent a range of existing conditions rather than on one site, as was attempted within this study.

If the implementation of this concept moves forward again in the future, a materials and workmanship warranty should be considered in place of a performance warranty. The materials and workmanship warranty may be a better choice for warranty implementation in Virginia in that the DOT is still responsible for developing the design and the contractor is not held responsible if the design is found to be insufficient. This is a similar relationship as with the current practice; however, the contractor is typically held to a higher standard of quality control. Under a materials and workmanship warranty, contractors would be required to meet certain standards for items over which they have direct control; an example is a percent within limits specification on gradation, binder content, thickness, air void content, and density.

CONCLUSIONS

- *The use of core sampling and FWD deflection testing allowed for a thorough analysis of the existing condition of the pavement. This underscores the need for advanced nondestructive testing of pavements in order to design an effective rehabilitation treatment.*

- *Literature published by other state DOTs shows that implementation of pavement warranties on selected projects has the potential to improve quality and increase the service life of new and rehabilitated pavements. However, the specifications governing the warranty must be written such that the contractor is not so restricted that competition is stifled and benefits are gained by large contractors that are better able to absorb risk.*

RECOMMENDATIONS

1. *VDOT should pursue another pavement warranty pilot study for HMA overlays on multiple projects having varying deterioration conditions.*

2. *In future studies of pavement warranties, VDOT should consider a materials and workmanship warranty and include development of a set of criteria based on existing levels of accepted quality and typical rates of pavement deterioration.* Using this type of warranty specification, a shorter warranty period may be employed that reduces costs and risks to all parties.

3. *Sites for future pavement warranty pilot studies should be considered based on potential obstacles (such as substandard overhead clearances) that might negatively impact the ability to implement a cost-effective rehabilitation design.*

4. *VTRC and VDOT's Materials Division should work together to develop a set of materials and workmanship specifications for HMA paving that encourages the delivery of projects having high quality (such as percent within limits specifications).* This may achieve the same desired outcome of the warranty process without the need for future performance monitoring.

5. *VTRC and VDOT's Materials Division should work together to develop a mechanistic-based overlay design methodology using existing software for use prior to the acceptance of the Mechanistic-Empirical Pavement Design Guide (ARA, Inc., 2004).* This would allow for a realistic comparison among multiple pavement overlay designs.

6. *In future field testing involving core sampling and FWD testing, VDOT should consider conducting the FWD testing prior to core sampling.* This might be more beneficial to the pavement designer. As the FWD deflection is measured, rather than calculated based on existing pavement thickness, areas having high deflection can be identified such that cores may be collected from these locations. This method may offer additional input regarding the reasons for pavement failure through the collection of information at specific locations of interest rather than the use of a standard spacing.

7. *VTRC and VDOT's Materials Division should work together to implement the use of nondestructive methods to determine both the existing thickness (e.g., ground-penetrating radar) and structural condition of the pavement (e.g., FWD).* Jointly employing these technologies is already current practice in other leading state DOTs.

COSTS AND BENEFITS ASSESSMENT

According to the literature review, employing pavement warranties appears to be beneficial, although few reports are able to quantify the benefit. Aschenbrener and DeDios (2001) reported no difference in initial bid or maintenance costs after 3 years. However, Anderson and Russel (2001) stated that warranties have the potential to improve the long-term performance of pavements. Krebs et al. (2001) reported a life-cycle cost savings of approximately 14% after 5 years. Bayraktar et al. (2004) summarized a survey of state DOTs and industry representatives by stating that warranty contracts slightly increase the quality of projects as compared to non-warranted projects; however, the usage of warranties was reported to be worthwhile if used as an assurance against premature failures rather than as a way of achieving innovative practices.

In 2002 and 2003, VDOT spent an average of $120 million per year on pavement resurfacing. Assuming that use of the warranty concept in Virginia can effect a similar reduction in life-cycle costs as reported by Krebs et al. (2001), approximately 14%, the annual savings would be approximately $17 million per year. A similar percentage increase in the service life of HMA pavement overlays would increase the average life of the typical pavement surface by nearly 1 year.

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APPENDIX A

HMA OVERLAY PERFORMANCE SPECIFICATION

No pavement section shall contain the following pavement distresses in excess of the defined failure criteria (either severity or frequency). A pavement section is defined as an individual mainline or shoulder lane 528.4 feet (0.1 mile) in length, beginning at the limits of the project as defined within the contract. A pavement section is considered to have failed if the failure criteria (either severity or frequency) are exceeded for any of the following distresses during the time period stated.

Longitudinal Cracking - Cracks that are predominantly parallel to the pavement centerline, including longitudinal joints, but not within the wheel paths.

Time Period	Criteria
Years 1 - 4	Maximum unsealed crack length of 100 feet per section for cracks greater than 1/4-inch width but less than 1-inch width. No cracks greater than 1-inch width.
Years 5 - 9	Maximum unsealed crack length of 200 feet per section for cracks greater than 1/4-inch width but less than 1-inch width. No cracks greater than 1-inch width.

Transverse Cracking – Random cracks that are predominantly perpendicular to the pavement centerline, but not over joints in underlying layers.

Time Period	Criteria
Years 1 - 9	Maximum unsealed crack length of 100 feet per mile (for cracks greater than 1/4 inch width)

Alligator Cracking* - Usually found in the wheel paths, beginning as a single longitudinal crack, may form a series of interconnecting longitudinal and transverse cracks forming a series of blocks up to approximately 1foot each on a side in a complete pattern. Low severity may be seen as single longitudinal crack within the wheel path; medium severity may be seen as an area of interconnecting cracks.

Time Period	Criteria
Years 1 - 4	No more than 10% of the wheel path area containing low severity No more than 1% of the wheel path area containing medium severity
Years 5 - 9	No more than 50% of the wheel path area containing low severity No more than 10% of the wheel path area containing medium severity

*Criteria shall be waved at year 5 if the predicted total cumulative ESALs at year 5 are exceeded by more than 50%.

Block Cracking - A series of interconnecting longitudinal and transverse cracks forming a series of blocks greater than approximately 1foot each on a side in a complete pattern

Time Period	Criteria
Years 1 - 9	Existence

Slippage Cracking - Crescent or half-moon shaped cracks typically transverse to the direction of travel	
Time Period	**Criteria**
Years 1 - 9	Existence

Rutting*+ - A longitudinally-oriented surface depression	
Time Period	**Criteria**
Years 1 - 4	Maximum average depression of 1/4 inch per section per wheel path
Years 5 - 9	Maximum average depression of 1/2 inch per section per wheel path

*Criteria shall be waved at year 5 if the predicted total cumulative ESALs at year 5 are exceeded by more than 50%.
+Criteria shall be waved for shoulder areas.

Potholes – Bowl shaped depressions in the pavement surface	
Time Period	**Criteria**
Years 1 - 9	Existence

Raveling - Wearing away of aggregate particles due to loss of asphalt binder	
Time Period	**Criteria**
Years 1 - 9	Existence

Rideability*+ - Smoothness of the pavement measured by the International Roughness Index (IRI). Rideability testing shall be measured using equipment conforming to or exceeding the specifications outlined in VTM 106. Testing shall be performed following the procedures outlined in VTM 106.	
Time Period	**Criteria**
Years 1 - 4	No section shall be greater than 65 in/mile
Years 5 - 9	No section shall be greater than 90 in/mile

*Criteria shall be waved at year 5 if the predicted total cumulative ESALs at year 5 are exceeded by more than 50%.
+Criteria shall be waved for shoulder areas.

Skid Resistance+ - Measured by skid testing using a locked wheel device conforming to ASTM E274 and E524 specifications and procedures.	
Time Period	**Criteria**
Years 1 - 4	No section shall have a SN40S of less than 25
Years 5 - 9	No section shall have a SN40S of less than 25

+Criteria shall be waved for shoulder areas.

WHEEL PATH DEFINITION

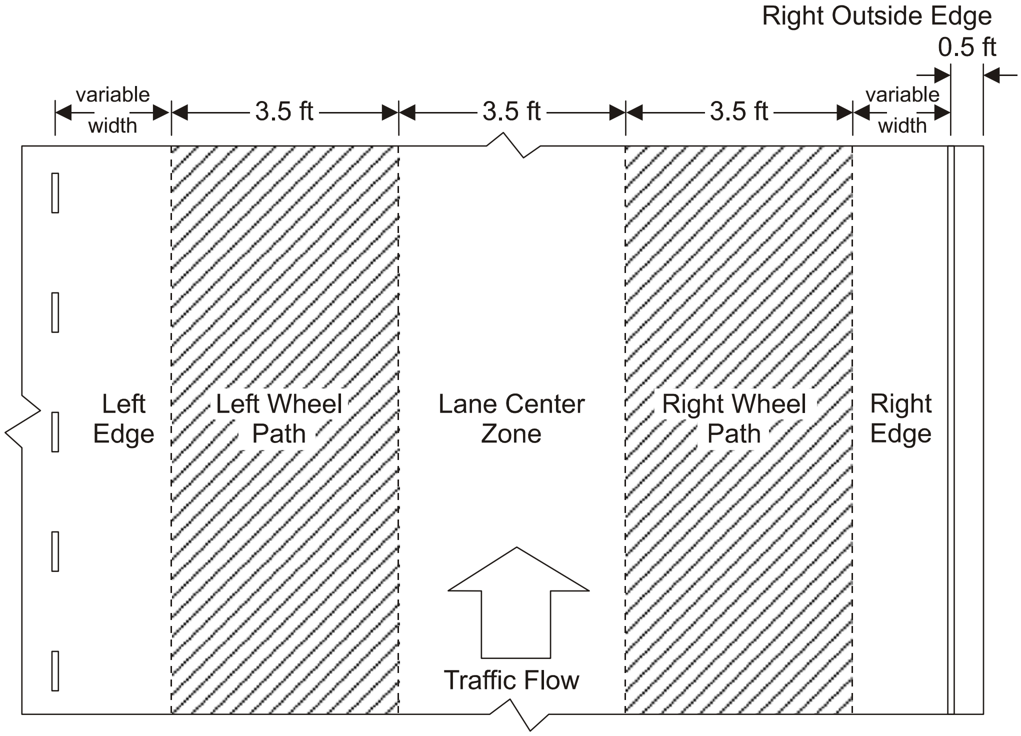

Figure A1. Definition of Location and Size of Left and Right Wheel Path and Center Lane. Average lane width was assumed to be 12 feet.

APPENDIX B

RESULTS OF FWD TESTING

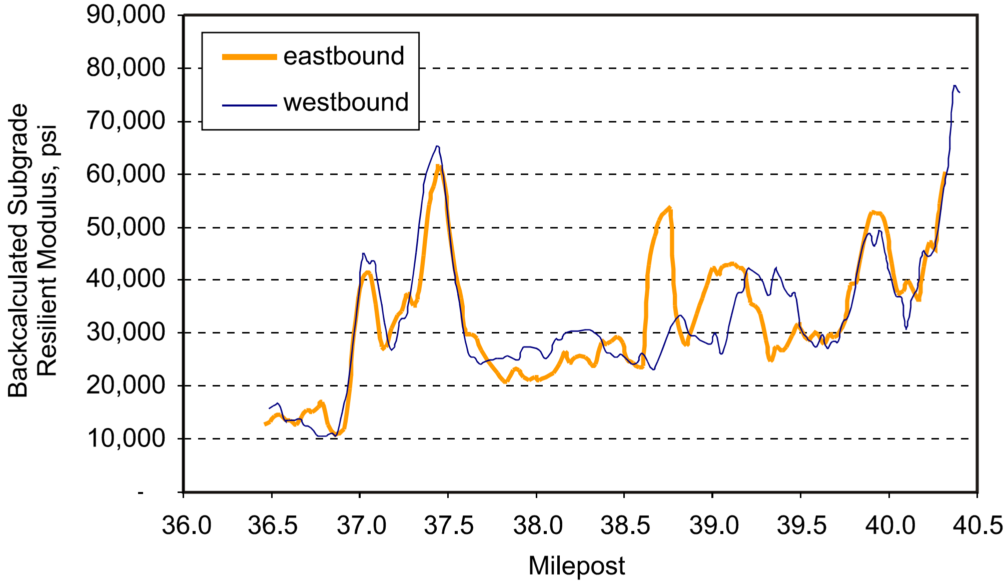

Figure B1. Backcalculated Subgrade Resilient Modulus from FWD Testing for Eastbound and Westbound Interstate 66

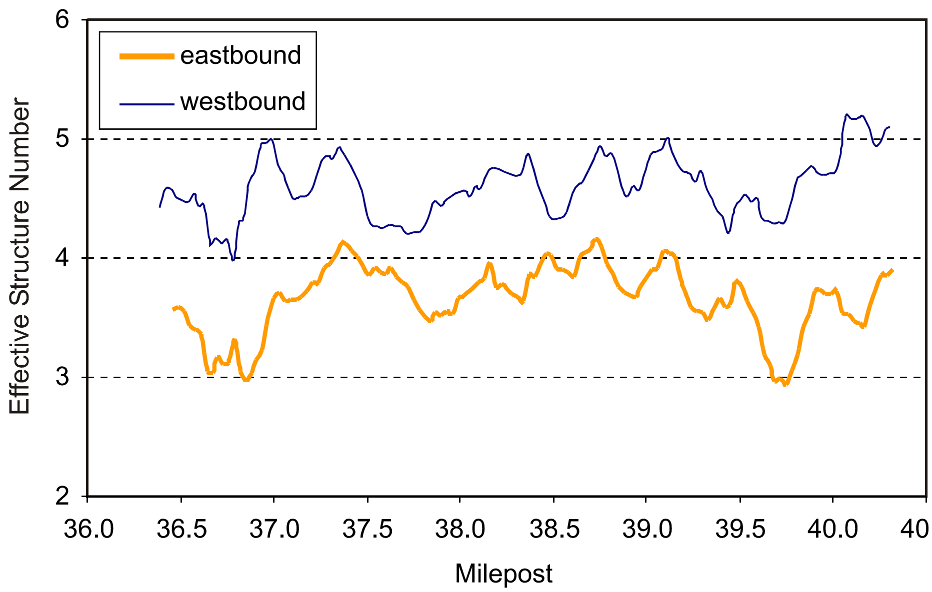

Figure B2. Effective Structural Number from FWD Testing of Eastbound and Westbound Interstate 66

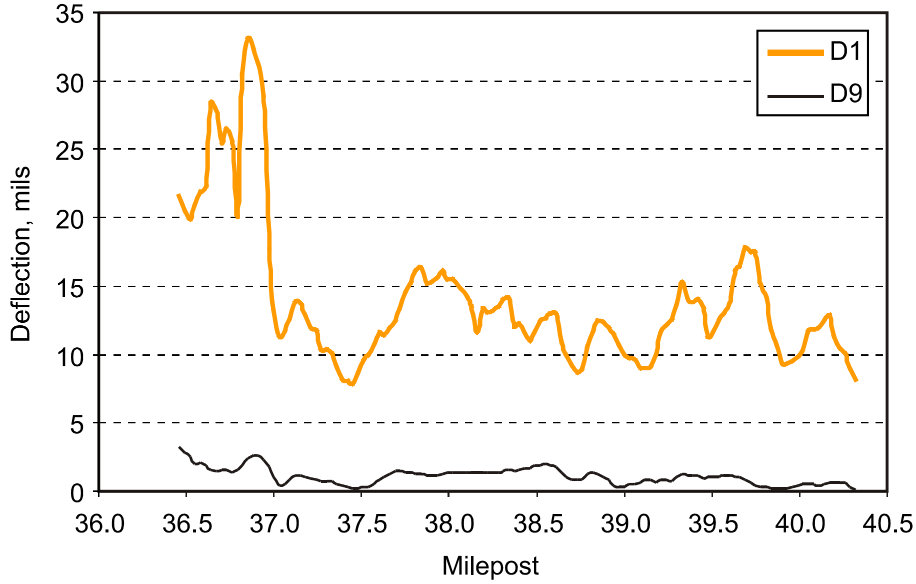

Figure B3. FWD Results Showing Deflection at D1 and D9 for Eastbound Interstate 66

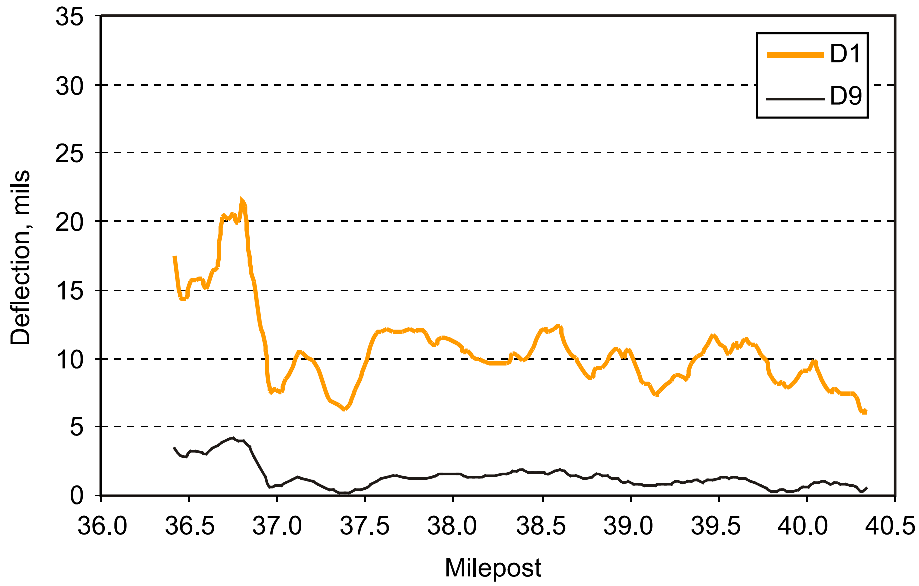

Figure B4. FWD Results Showing Deflection at D1 and D9 for Westbound Interstate 66