ILLINOIS CENTER FOR TRANSPORTATION

CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 22-002
UILU-ENG-2022-2002
ISSN: 0197-9191

Longitudinal Cracking Investigation on I-72 Experimental Unbonded Concrete Overlay

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Research Report No. FHWA-ICT-22-002

A report of the findings of
ICT PROJECT R27-SP48
Longitudinal Cracking Investigation on
I-72 Experimental Unbonded Concrete Overlay

https://doi.org/10.36501/0197-9191/22-002

Illinois Center for Transportation

February 2022

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-ICT-22-002	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A
4. Title and Subtitle Longitudinal Cracking Investigation on I-72 Experimental Unbonded Concrete Overlay		**5. Report Date** February 2022 **6. Performing Organization Code** N/A
7. Authors John DeSantis (https://orcid.org/0000-0002-3391-025X), Jeffery Roesler (https://orcid.org/0000-0001-6194-269X)		**8. Performing Organization Report No.** ICT-22-002 UILU-2022-2002
9. Performing Organization Name and Address Illinois Center for Transportation Department of Civil and Environmental Engineering University of Illinois at Urbana-Champaign 205 North Mathews Avenue, MC-250 Urbana, IL 61801		**10. Work Unit No.** N/A **11. Contract or Grant No.** R27-SP48
12. Sponsoring Agency Name and Address Illinois Department of Transportation (SPR) Bureau of Research 126 East Ash Street Springfield, IL 62704		**13. Type of Report and Period Covered** Final Report 5/1/21–2/28/22 **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

https://doi.org/10.36501/0197-9191/22-002

16. Abstract

A research study investigated longitudinal cracking developing along an experimental unbonded concrete overlay (UBOL) on I-72 near Riverton, Illinois. The project evaluated existing literature on UBOL (design, construction, and performance), UBOL case studies, and mechanistic-empirical design procedures for defining the mechanisms that are contributing to the observed distresses. Detailed distress surveys and coring were conducted to assess the extent of the longitudinal cracking and faulting along the longitudinal lane-shoulder joint. Coring over the transverse contraction joints in the driving lane showed stripping and erosion of the dense-graded hot-mix asphalt (HMA) interlayer was the primary mechanism initiating the longitudinal cracks. Cores from the lane-shoulder joint confirmed stripping and erosion was also occurring there and leading to the elevation difference between the driving lane and shoulder. Field sections by surrounding state departments of transportation (DOTs), such as Iowa, Michigan, Minnesota, Missouri, and Pennsylvania, with similar UBOL design features to the I-72 section were examined. Site visits were performed in Illinois, Michigan, Minnesota, and Pennsylvania, while other sections were reviewed via state DOT contacts as well as Google Earth and Maps. Evidence from other DOTs suggested that HMA interlayers, whether dense graded or drainable, could experience stripping, erosion, and instability under certain conditions. An existing performance test for interlayers, i.e., Hamburg wheel-tracking device, and current models reviewed were not able to predict the distresses on I-72 eastbound. Adapting a dynamic cylinder test is a next step to screen HMA interlayers (or other stabilized layers) for stripping and erosion potential. To slow down the cracking and faulting on I-72 eastbound, sealing of the longitudinal lane-shoulder joint and driving lane transverse joints is suggested. To maximize UBOL service life, an HMA overlay will minimize water infiltration into the interlayer system and significantly slow down the HMA stripping and erosion mechanism that has led to longitudinal cracking and lane-shoulder faulting.

17. Key Words Unbonded Concrete Overlay, Longitudinal Cracking, Stripping, Erosion, Faulting, Fiber-reinforced Concrete, Macrofibers	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 37 + appendices	**22. Price** N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGMENT, DISCLAIMER, MANUFACTURERS' NAMES

This publication is based on the results of **ICT-R27-SP48: Longitudinal Cracking Investigation on I-72 Experimental Unbonded Concrete Overlay**. ICT-R27-SP48 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

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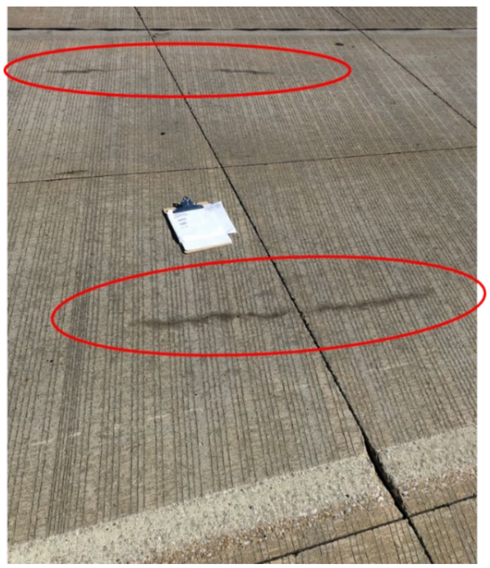
The authors also acknowledge Illinois Department of Transportation District 6 operations, drill crew, and lab employees for assisting in the findings of this report. This includes providing traffic control, coring operations, and hot-mix asphalt core testing.

EXECUTIVE SUMMARY

Concrete overlays are an accepted option to rehabilitate existing roadways. A research project was initiated to investigate an experimental short-jointed unbonded concrete overlay (UBOL) constructed in 2015 near Riverton, Illinois, that was exhibiting longitudinal cracking and lane-shoulder faulting. This concrete overlay on I-72 was supported by a dense-graded hot-mix asphalt (HMA) and nonwoven geotextile fabric (NWGF) interlayers in the eastbound and westbound directions, respectively. The purpose of the research was to assess the potential mechanisms causing the longitudinal crack development within the wheel paths and the lane-shoulder faulting in the eastbound direction only. The typical longitudinal cracking occurring on I-72 eastbound can be seen in **Figure S1**.



The research focused primarily on how the HMA interlayer may be contributing to longitudinal cracking and lane-joint faulting relative to the NWGF interlayer section. First, a literature review was conducted to identify the major distresses observed in other UBOLs, specifically short-jointed UBOLs (e.g., 6 × 6 ft [1.8 × 1.8 m] panels). This background review also included assessing the available UBOL design procedures for failure modes and distress predictions. Next, a field investigation of the I-72 HMA and NWGF interlayers was initiated, which included the type and extent of distresses and coring of the section. Several surveys of short-jointed UBOL sections in surrounding states were also conducted. Finally, previous laboratory testing on the specific HMA interlayer on I-72 eastbound was reviewed for its performance.

Studies and sections of short-jointed UBOLs from other states with and without longitudinal cracking in the wheel path were examined, particularly those with design features similar to I-72. Several DOTs with UBOLs (Iowa, Michigan, Minnesota, Missouri, and Pennsylvania) were also contacted for their experience and knowledge of the stripping and erosion potential within dense-graded HMA interlayers. Google Earth and Maps were explored to determine the existence and severity of longitudinal cracking in these short-jointed UBOLs. These investigations concluded that there were multiple mechanisms contributing to longitudinal crack development and not all sections had the same failure mechanism but stripping and erosion were potential failure modes identified in some sections.

The I-72 field investigation showed longitudinal cracking initiated at the transverse joint within 1 year after construction and has continued to develop over the past 5 years. Coring performed directly over the intersection of transverse joints and longitudinal cracking in the wheel path determined the dense-graded HMA interlayer was stripping and resulting in support erosion. The stripping and erosion caused nonuniform support beneath the overlay at the transverse joints and resulted in bottom-up tensile cracks. Because the overlay concrete has fiber-reinforced concrete (FRC), the longitudinal cracks have not extensively propagated longitudinally and have extremely small widths (≤ 0.02 in. [0.45 mm]). The combination of differential deflections at the undowelled joint, trapped moisture (no joint sealant and nonpermeable interlayer), and high traffic volumes and speed have resulted in high water pressure generated in the joint and at the interface of the new and existing concrete slab-HMA interface. The high-water pressures have increased the likelihood of stripping and erosion of the HMA interlayer despite it being an HMA mixture that passed performance testing with a Hamburg wheel-tracking device (HWTD). Longitudinal cracking was seen in sections in Michigan and Minnesota and was likely caused by similar stripping and erosion mechanisms of the dense-graded HMA interlayer, which was not verified with any coring during this study.

Longitudinal joint faulting has also developed along the driving lane's concrete shoulder joint. Coring performed directly over the lane-shoulder longitudinal joint determined the dense-graded HMA interlayer was stripping and eroding in a similar way to the interlayer mechanism in the driving lane. Unlike the transverse joints, the macrofibers have already been sheared off across this longitudinal contraction joint, resulting in the observed step faulting, i.e., shoulder is higher than the driving lane. Tie bars are not present at this lane-shoulder joint, which if used may have limited the fault development but likely would not have prevented stripping and erosion.

Several recommendations were provided on design, construction, and maintenance for new UBOLs and the existing experimental section on I-72. In the design phase, the interlayer must be resistant to stripping and erosion as well as accommodate lateral drainage beneath the surface to the shoulder and beyond. This means the cross slopes of the interlayer and UBOL surface must convey water to the shoulder, through the shoulders, or to the subsurface edge drains and ultimately to the ditches. One rehabilitation option for I-72 is to place an HMA overlay to minimize the water ingress into all joints, particularly on the driving lane. Another temporary maintenance or new design option is to seal only the transverse and longitudinal joints within the driving lane because stripping has not been observed in the passing lane. This includes sealing of the longitudinal lane-shoulder joint that has developed faulting. A performance test called the dynamic cylinder test has been suggested to assess stripping and erosion potential of HMA interlayers under higher porewater pressure conditions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

An unbonded concrete overlay (UBOL) is an optional rehabilitation strategy for existing concrete pavements that have reached the end of their service life. UBOLs consist of a new Portland cement concrete (PCC) or fiber-reinforced concrete (FRC) layer placed on an existing concrete or composite pavement. The new concrete layer is separated from the existing pavement by an interlayer system, allowing these overlays to be placed on distressed concrete pavements with limited pre-overlay repairs. The interlayer system usually consists of a thin drainable or dense-graded hot-mix asphalt (HMA) layer or a nonwoven geotextile fabric (NWGF). This interlayer acts as a shear-slip plane by inhibiting adhesive bonding between the two concrete layers, avoiding distressed areas in the existing concrete layer to impact the new overlay performance, and enhancing structural capacity of the new concrete overlay's composite action with the existing pavement.

UBOLs have been used since the 1910s to increase structural capacity and improve surface friction and ride quality (Taylor et al., 2007). They have proven to be durable, mitigate reflective cracking, require minimal pre-overlay repairs, and can be placed with traditional concrete paving methods (ERES, 1999). UBOLs have demonstrated excellent performance in many states over the past 30 years (Harrington et al., 2007).

UBOLs can vary in design and construction and can resemble conventional jointed concrete pavements, continuously reinforced concrete pavements (CRCP), or thin overlays. The overlay thickness can range between 4 to 12 in. (102 to 305 mm). The larger thicknesses can result in construction of conventional joint spacing (12 to 15 ft [3.7 to 4.6 m]). Thinner sections should be constructed with shorter joint spacing to reduce curling and warping stresses (4 to 8 ft [1.2 to 2.4 m]). A prevailing UBOL design is a 6 × 6 ft (1.8 to 1.8 m) joint spacing with a 6 in. (152 mm) overlay. The use of smaller panel sizes for UBOLs with a thin interlayer is a relatively new concept and only recently has been proposed within a design method (Khazanovich et al., 2020). Since unbonded concrete overlays with smaller panel sizes are designed for a 20-year service life, there is limited performance history that pavement engineers can review for expected distress development and field failure mechanisms. As more of these UBOLs are constructed, performance data become available that can assist in improving the existing design and material specification. One distress that has been observed on a few UBOL projects is longitudinal cracking (Figure 1) in the wheel path, as shown on I-72 eastbound near the Riverton, Illinois, exit. Likewise, a previous study documented the same longitudinal cracks initiating at the transverse joint (Alland et al., 2016; Souder et al., 2020). These cracks have developed in both the outside and inside wheel path of the driving lane and can initiate on both the leave and approach side of the transverse joint or crack. Researchers at the University of Pittsburgh hypothesized this distress originated from damage to the HMA interlayer from fatigue, localized stripping, and/or consolidation (Alland et al., 2016; Khazanovich et al., 2020).

UNBONDED CONCRETE OVERLAY INTERLAYER TYPES

The different interlayer types have advantages and disadvantages. When selecting, designing, and constructing an interlayer system, it is important to have a permeable, durable, and stable interlayer. The different interlayers that are typically employed and their characteristics are presented next.

Dense-graded HMA can be a durable and stable interlayer solution. This interlayer is typically between 1 to 2 in. (25 to 51 mm) and can either be newly placed or an existing overlay (surface defects can be milled to desired thickness). An important material characteristic to account for is its stripping potential. If preventative measures are not taken, then stripping may occur from built-up water pressures underneath the slab when moisture becomes trapped within the system. This stripping can lead to erosion and eventually cracking in the concrete overlay from loss of support. The erosion can also lead to faulting at the transverse and longitudinal joints from pumping of the interlayer material.

Open-graded or drainable HMA can be a permeable interlayer option that drains freely. This drainable interlayer is also between 1 to 2 in. (25 to 51 mm) and is placed prior to the concrete overlay. A potential concern for drainable interlayers is if the HMA is not sufficiently stable, then the aggregates may possibly dislodge and increase erosion potential in the interlayer. Therefore, the drainable HMA mixture needs to be stable and durable to prevent erosion in the interlayer and formation of distresses (i.e., longitudinal cracking from loss of support, faulting) in the concrete overlay.

NWGF interlayers are a potentially drainable and durable interlayer solution. NWGF come in multiple densities that can be used as a function of the existing pavement distress. A denser NWGF is recommended for more severely distressed existing pavements (Harrington & Fick, 2014). Additionally, different pigments are available to reduce solar absorption and heat storage in the NWGF prior to placing the concrete overlay. A white pigment option is available for higher temperature regions or during high construction temperature conditions. Additionally, when placing the NWGF, a glue adhesive, tack coat, or nail and washer system is commonly used to stick it to the existing pavement. To keep the permeability of the NWGF, the amount of adhesive or tack coat should not excessively impregnate the NWGF. Additionally, a portion of the cement paste from the concrete overlay will penetrate the surface of the NWGF and may further limit its maximum drainability. In general, NWGF have been shown to be erosion resistant for approximately 10 years of service life so far in US applications for concrete overlays (Cackler, 2017).

The Illinois Department of Transportation's (IDOT's) *Standard Specifications for Road and Bridge Construction* manual (2021c) documents the appropriate HMA (interlayer) construction practices (e.g., mix parameters and design, field compaction levels, etc.). Given the longitudinal distress in Figure 1, the interlayer system in combination with the existing and new concrete layers needs to be assessed further to determine the primary mechanism of this cracking, e.g., repeated loading in conjunction with moisture damage, debonding of interlayer, permanent deformation in the interlayer, delayed viscoelastic recovery, or another mechanism.

I-72 EXPERIMENTAL SECTION (RIVERTON, ILLINOIS)

The I-72 experimental section is located in IDOT District 6 in Sangamon County just east of Springfield, near Riverton. Current (2021) average annual daily traffic (AADT) volumes are 7,800 eastbound and 7,400 westbound, with 1,500 and 1,200 multiple-unit trucks, respectively. The 3.24 centerline mile (5.2 km) project (Contract 72G92) was constructed in 2015 using two different interlayer types (HMA and NWGF). The overlay design consisted of 6 × 6 ft (1.8 × 1.8 m) joint spacing with a 6 in. (152 mm) FRC overlay with 4 lb/cy (2.4 kg/m^3) synthetic macrofibers. The FRC overlay was cast on top of the two 12 ft (3.7 m) lanes and existing shoulders (10 ft [3 m] outer and 6 ft [1.8 m] inner) in each direction. The concrete overlay did not include dowel bars or joint sealant at transverse joints, and only the centerline longitudinal construction joint included tie bars and hot poured sealant. The existing pavement in both directions was an 8 in. (203 mm) CRCP originally constructed in 1976 with an HMA overlay from 1998 that was milled off prior to placement of the UBOL. The only difference in design between the two directions was interlayer type, with the eastbound direction employing a new 1.25 in. (32 mm) dense-graded HMA interlayer and the westbound direction using a 0.125 in. (3.2 mm) black NWGF interlayer. The initial design called for a binder grade of PG 64-22 for the eastbound HMA. However, due to the fractionated reclaimed asphalt pavement (FRAP) asphalt binder replacement (ABR) exceeding 20%, the binder grade needed to be lowered to a PG 58-28 (IDOT, 2021a). Therefore, PG 58-28 was the resulting binder grade used on the I-72 eastbound section.

Detailed distress surveying performed in August 2020 showed the prominent distress in the eastbound direction was longitudinal cracking in the wheel paths (inner and outer) of the driving lane, e.g., Figure 1. Distress surveys as early as 2016 showed signs of this distress just starting to develop on a limited number of transverse joints. The observed longitudinal cracking has not occurred in the westbound lanes that utilized a NWGF interlayer. Therefore, the main focus in this study is the HMA interlayer as a primary mechanism for the resultant concrete overlay distress. An additional distress observed in both westbound and eastbound directions is longitudinal joint faulting along the lane-shoulder joint. The edge of the driving lane is slightly lower than the elevation of the shoulder at some locations in each direction.

RESEARCH OBJECTIVE AND SCOPE

The objective of this research study was to determine the cause of longitudinal cracking in the eastbound direction of the I-72 UBOL experimental feature project (Figure 1). To reach the objective, this project evaluates existing literature, case studies, and design procedures (specifically mechanistic-empirical [ME]) for potential mechanisms that are contributing to the distresses. In addition, detailed visual distress surveys were conducted to assess the extent and development of the longitudinal cracking. Coring was performed in multiple locations to help determine the likely mechanisms. Falling weight deflectometer (FWD) testing was also performed and presented in greater detail in DeSantis and Roesler (2022). Additional field investigations were also conducted by examining similar designs constructed by surrounding state DOTs, such as Iowa, Michigan, Minnesota, Missouri, and Pennsylvania. They were investigated primarily through phone calls to the appropriate state DOT contacts as well as Google Earth and Maps. Site visits were only performed in Illinois, Michigan, Minnesota, and Pennsylvania. This research study also investigated previously published test data to assess the interlayer impact on UBOL response and performance. The research has led to suggestions on rehabilitation and maintenance strategies for existing concrete overlays with longitudinal cracking like I-72, as well as future design and construction considerations for short-jointed UBOLs. Finally, a future laboratory performance test is proposed to supplement the findings in the literature and to confirm the mechanism(s) causing the observed longitudinal cracking. This research will assist IDOT engineers, consultants, and contractors with information on interlayer selection, design, and construction practices for UBOLs to avoid premature failures as a function of the interlayer.

CHAPTER 2: BACKGROUND REVIEW OF LONGITUDINAL CRACKING FOR UNBONDED CONCRETE OVERLAYS

Traditional UBOLs have performed well in many states over the last 30 years (Harrington et al., 2007; Harrington & Fick, 2014). The use of smaller panel sizes for UBOLs with a thinner HMA interlayer or NWGF is still a relatively new design concept. Therefore, the performance of these newer UBOL structures was investigated to determine the failure mechanisms and corresponding design features that may contribute to their distresses. The extent of the distresses was primarily examined in surrounding states with similar climates. Additionally, ME design procedures capable of designing UBOLs were investigated to assess the prediction capabilities relative to current observations.

LITERATURE REVIEW AND CASE STUDIES

The primary failure mode for UBOLs with short slabs appears to be longitudinal cracking occurring directly in the wheel path, indicating repeated loading contributes to development and propagation. The longitudinal cracking initiates at the transverse joint and likely develops from damage within the HMA interlayer from fatigue, localized stripping and erosion, and/or consolidation (Alland et al., 2016; Khazanovich et al., 2020). This damage can result in a void, gap, or settlement beneath the overlay in the wheel path. As traffic accumulates, the deformation or gap increases and results in an increase in the tensile stress at the bottom of the concrete slab and eventually leads to a bottom-up crack to develop if the flexural capacity of the concrete is exceeded (Figure 2). Longitudinal cracking is less likely to occur prematurely as a function of erosion when a NWGF interlayer is employed, as this is an erosion-resistant material and unlikely to consolidate based on its initial density and thickness. Bonded concrete overlays of asphalt (BCOA) with 6 × 6 ft (1.8 × 1.8 m) panels experience a similar distress mechanism when the interfacial bond deteriorates over time and the longitudinal cracking initiates at the transverse joint (Li & Vandenbossche, 2013).

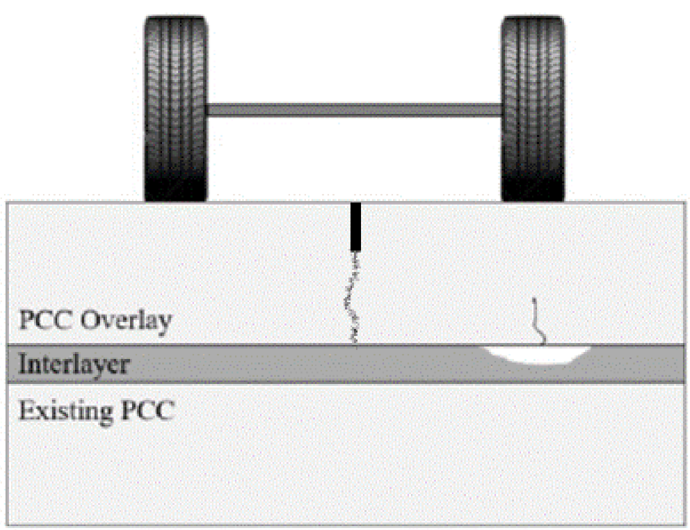


Figure 2. Schematic. Tensile crack development from void in HMA interlayer (Souder et al., 2020).

An investigation was performed to assess the extent of this longitudinal cracking distress for short-jointed UBOLs in surrounding states with similar climates. This effort mainly consisted of contacting state DOTs for information, background, and experience of UBOLs constructed within their respective agency or state. When concrete overlay sections were identified, Google Earth and Maps were used to explore their performance, e.g., presence of longitudinal cracking in the wheel path. Similar short-jointed UBOL projects were also found using the American Concrete Paving Association Overlay Explorer webtool. The states, provinces, and countries where short-jointed overlays were examined included Colorado, Iowa, Kansas, Michigan, Minnesota, Missouri, Ohio, Oklahoma, Ontario, Pennsylvania, Uruguay, and Wyoming. The overlays examined were primarily UBOLs; however, some BCOA sections were also examined for comparison.

In general, most of these sections had overlays of 6 in. (152 mm) or less. This resulted in most sections not including dowels. All sections examined had short-jointed overlays and likely used a dense-graded HMA interlayer, with only NWGF interlayers in Michigan and Missouri. The main focus was to determine sections with similar short-jointed overlays that were exhibiting signs of longitudinal cracking like the I-72 experimental section. The sections examined with some design information can be seen in Table 1. Pertinent technical information for each section can be found in Appendix A. Not all sections reviewed exhibited longitudinal cracking. However, when the section did exhibit longitudinal cracking, some possible mechanisms were from repeated loading (fatigue), localized stripping and erosion, and/or consolidation of the HMA interlayer. If the longitudinal crack was well defined and somewhat continuous in the lane, it is also possible the overlay extended wider than the existing pavement and a knife-edge condition was created causing the longitudinal reflective cracks to develop. Some sections also had relatively thin overlays, less than or equal to 4 in. (102 mm), which may have resulted in primarily concrete fatigue and not damage to the interlayer system.

Table 1. Concrete Overlays Examined Using Google Earth and Maps

State / Province	Section ID	Location	Year constructed	Joint spacing, ft	Overlay thickness, in.	Longitudinal cracking present (Yes/No)
Colorado	I-70	Grand Junction	2012	6 × 6	6	Yes
	SH 121 (Wadsworth Blvd)	Denver	2001	6 × 6	6	Yes
	SH 13	Craig	2016	6 × 6	6	No
Iowa	IA 3	Plymouth Co. to east of Cleghorn	2015	6 × 5–7	6	Yes
	US 65	Wayne County Line to US 34	2013	5 × 5.5	5	n/a[1]
	US 18	Fredericksburg	2011	4.5 × 4.5	4.5	Yes
	IA 13	Strawberry Point	2008	4.5 × 4.5	3.5–4.5	Yes
	IA 9	Ocheyedan	2015	5 × 5	5.5	Yes
	IA 14	Parkersburg	2013	5 × 5	4.5	Yes
	IA 175	Arthur	2013	7 × 7	4.5	Yes
Kansas	I-70	Wilson	2012	6 × 6	6	No
Michigan	South Boulevard East	Pontiac	2009	6 × 6	4	Yes
	Hall Road	Woodhaven	2008	6 × 6	4	Yes
	Gratiot Avenue	Detroit Metro Area	2004–2005	6 × 6	4	No
	Little Mack Avenue	St Clair Shores	2011	6 × 6	4	Yes
Minnesota	TH 53	Duluth	2008	6 × 6	5	Yes
Missouri	Route D	Kansas City	2008	6 × 6	5	No
	Route 24 / Business 63 Intersection	Moberly	2010	6 × 6	5.5	Yes
Ohio	Sprague Road	North Royalton	2014	6.5 × 6.5	7	No
Oklahoma	US 69 N	Kiowa	2007	6 × 6	5	Yes
Ontario	Bloor Street West at Aukland Road	Toronto	2003	5 × 5	6	No
Pennsylvania	SR – 50	Bridgeville	2016	6 × 6	6	No
Uruguay	Routa 24	Guyunusa	2011–2012	6 × 6	5.5	No
Wyoming	US 30	Cokeville	2012	6 × 6	6	Yes

[1] n/a = not available. US 65 in Iowa did not have updated Google Earth and Maps after construction. Last updated in August 2009.

Additional UBOL sections that had more conventional joint spacing with dense- or open-graded HMA interlayers were examined in Michigan using Google Earth (DeGraff, 2020). Most of these sections also showed evidence of longitudinal cracking within the wheel paths and are presented in Table 2. A few case studies on UBOLs have also been performed and documented (Yao & Weng, 2012; Hansen &

Liu, 2013; Alland et al., 2016; Sachs, 2017; Zhu, 2017). However, these published studies investigated conventional joint spacing not short-jointed UBOLs, but also showed evidence of longitudinal cracking within the wheel paths.

Table 2. Unbonded Concrete Overlays Examined in Michigan Using Google Earth and Maps (Conventional Joint Spacing)

Section ID	Location	Year Constructed	Joint Spacing, ft	Overlay thickness, in	Interlayer type	Longitudinal cracking in wheel path
US 131	Kalamazoo to Grand Rapids	2004	10 × 12	7	Open HMA (NB)/ Dense HMA (SB)	Yes
	M-89 to Martin	1997	10 × 12	7.5	Dense HMA	Yes
I-96	Portland	1983-1984	27 × 12	7.5	Dense HMA	No
	Eagle	1991	27 × 12	7.5	Dense HMA	Yes
US 10	Sanford	2010	10 × 12	6	Open HMA	Yes
	Coleman	2015	10 × 12	6	Open HMA	Yes
	Clare	2018	10 × 12	6	Open HMA	No
I-75	South of West Branch	2017	10 × 12	6	Dense HMA	No
	North of West Branch	2003	10 × 12	6	Open HMA	Yes

MECHANISTIC-EMPIRICAL DESIGN PROCEDURES

Several ME design procedures were reviewed to compare their recommended design with the I-72 UBOL. Historically, empirical pavement design methods base new designs on past observations of pavement performance relative to the initial inputs. An example of an empirically based design method is AASHTO (1993), which cannot provide valid design for short-jointed UBOLs. A ME approach starts with fundamental pavement responses (stresses, strains, and deflections) based on the proposed pavement structure and climatic inputs and predicts the expected performance based on calibrated models of cracking, faulting, and International Roughness Index (IRI). An example of a well-known ME approach is the AASHTOWare Pavement ME (ARA Inc., 2004). The major benefits of ME over empirical-based methods are the more confident extrapolation of designs for a wide array of inputs such as material properties, traffic (load levels, axle types, and axle distributions), climate (environmental effects), and pavement design features (e.g., joint spacing, shoulder type, joint details) without having extensive performance data.

TPF 5-269 UBOL-ME

Recently, a ME design guide has been proposed by Khazanovich et al. (2020) to account for longitudinal cracking in UBOL and to extend the existing AASHTOWare Pavement ME software (ARA Inc., 2004). However, this proposed model (Khazanovich et al., 2020) treats the interlayer as an elastic spring layer (Totsky model) and does not allow for friction or viscoelastic properties that are characteristics of HMA interlayers. The structural model used to train artificial neural networks (ANNs) for the cracking and faulting prediction models treats the interlayer as a constant stiffness, either 3,500 psi/in. (950 kPa/mm) for HMA (dense and open graded) or 425 psi/in. (115 kPa/mm) for a NWGF interlayer. A study determined this was appropriate for both HMA and NWGF interlayers as a function of temperature and stiffness (Sachs et al., 2018). However, this study only focused on deflections for model convergence and validation, not stress. This may be accurate for the faulting prediction model, purely based on deflections. Additionally, from the executed design factorial of the structural model, the resultant ANNs for short-jointed UBOLs when loaded at the transverse joint resulted in half of the data being greater than 750 psi (5,170 kPa) tensile stress at the bottom of the concrete overlay. This would result in failure of the overlay under one loading scenario and condition. In addition, due to limited performance data, the cracking model calibration did not include any short-jointed UBOLs.

The potential for erosion is accounted for within the cracking and faulting prediction models as a function of the interlayer material properties, effective binder content (%), air void content (%), and percent of fine material (percent of material passing the number 200 sieve, P200). Unfortunately, the permanent deformation model developed by Souder et al. (2020) has not been incorporated into the design procedure. Erosion susceptibility is an important component within the design; however, stripping susceptibility is not directly accounted for. Recommendations are provided within Khazanovich et al. (2020) and Harrington and Fick (2014) on different HMA interlayer material properties. More details would be beneficial as to providing an anti-stripping agent for dense-graded HMA interlayers.

AASHTOWare Pavement ME

In the AASHTOWare Pavement ME design guide, jointed plain concrete pavement (JPCP) UBOLs are designed using the same structural analysis and damage models used to design a new JPCP with some minor changes. The permeability, erodibility, and plastic deformation of the HMA interlayer are not considered. The primary distress considered in the AASHTOWare Pavement ME design guide is transverse cracking at mid-slab (ARA Inc., 2004) for conventional JPCP overlays. The recent addition of short-jointed concrete overlays is only for BCOAs but does consider longitudinal or corner cracking failure mechanisms (See “University of Pittsburgh BCOA-ME” below).

University of Pittsburgh BCOA-ME

The University of Pittsburgh developed a ME pavement design procedure for BCOA. This design procedure is specifically for bonded concrete overlays. The primary failure mechanism for short-jointed slabs (half-lane width, 6 × 6 ft [1.8 × 1.8 m]) is longitudinal cracking in the wheel path initiating at the transverse joint (Li & Vandenbossche, 2013). Although the BCOA structure is different than an UBOL, in that the overlay is typically thinner and requires structural support from the existing HMA, they both have the same primary distress. Similar to TPF 5-269, the faulting prediction model considers an erosion model as a function of the HMA material properties (effective binder content [%], air void content [%], and percent of fine material [percent of material passing the number 200 sieve, P200]) (DeSantis et al., in review; DeSantis, 2020). However, the cracking prediction model does not incorporate erosion into the model, as there has been little concern for this being the primary mechanism contributing to longitudinal cracking in the overlay. Therefore, the cracking prediction model is based on the bonding condition between the concrete overlay and the HMA layer, which provides additional structural support in conjunction with the overlay. This model is very sensitive to the stiffness of the HMA layer and thickness, as a decrease in stiffness or thickness results in an increase in tensile stress underneath the wheel load. Stress predictions are not sensitive to concrete elastic modulus and the modulus of subgrade reaction (k-value). Therefore, this design procedure could potentially be applicable as a second assessment. However, stripping and erosion potential are not directly considered within the procedure and within the cracking prediction model.

OptiPave 2.0

Another ME design procedure capable of designing an UBOL is OptiPave 2.0. Although OptiPave 2.0 is an ME design procedure for new JPCP with optimal slab geometry to limit any given slab to be subjected to only one set of wheels from a truck axle (Covarrubias & Covarrubias, 2008; Covarrubias & Binder, 2013), it is still capable of designing UBOLs. The short-jointed slab system concept adopted by UBOLs is based on the optimal slab geometry concept. The procedure was based on fatigue damage equations in NCHRP 1-37 and incorporated into the AASHTOWare Pavement ME (ARA Inc., 2004). The faulting model employs the same procedure in the AASHTOWare Pavement ME when accounting for the erodibility of the layer directly beneath the concrete pavement, using an empirical value between 1–5 (1 is erosion resistant and 5 is highly erodible). This system was based on recommendations by the Permanent International Association of Road Congresses (PIARC) (Christory, 1990). Therefore, stripping, erosion, and plastic deformation potential are not directly considered within the procedure and within the cracking prediction model.

CHAPTER 3: FIELD INVESTIGATION OF UNBONDED CONCRETE OVERLAYS AND INTERLAYERS

Longitudinal cracking was first observed approximately one year after construction in the eastbound direction of I-72 based on a visual survey completed by IDOT. These initial cracks were not necessarily deemed unusual or problematic at the time, as they were very short, tight cracks located infrequently along the experimental section. After visiting the site in the summer of 2020 and seeing a much larger extent of longitudinal cracking, this study was initiated to determine the mechanism and extent of this distress.

The project's goal for the distress survey and forensic investigation was to determine the likely mechanisms contributing to longitudinal cracking. Stripping or erosion within the HMA interlayer was a likely mechanism, and, thus, coring was performed on two separate dates. Based on the observed results from the second set of cores, the focus of this research was shifted to the stripping potential in short-jointed (e.g., 6 × 6 ft [1.8 × 1.8 m]) UBOLs with dense-graded HMA interlayers. Short-jointed UBOLs constructed within the past 10 years were also identified in surrounding states to conduct surveys and assess the stripping potential when a dense-graded HMA interlayer was used. In addition, Hamburg wheel-tracking device (HWTD) testing results were also examined to assess the stability and durability of the dense-graded HMA interlayer employed on I-72.

I-72 EASTBOUND DISTRESS SURVEYING

A detailed distress survey was performed in August 2020 and May 2021 to quantify the extent and severity of the longitudinal cracking developing along I-72 eastbound. The survey included three 1,000 ft (305 m) test sections near the beginning, middle, and end of the eastbound section. The full detailed distress survey and synopsis can be found in Appendix B. Longitudinal cracking was the major distress that was observed, on average, in every sixth panel, or 36 ft (11 m). It seems to initiate at the transverse joint and propagate from there. Longitudinal cracking was found in both the inner and outer wheel path of the driving lane. Longitudinal cracking does not always occur in both wheel paths at the same location. For instance, in the first 1,000 ft (305 m) section, it was common to observe longitudinal cracking in both wheel paths at the same transverse joint. However, in the second and third 1,000 ft sections (305 m), cracking was more likely to be observed only within the inner wheel path. This is possibly related to the cross-slope adjustments and thicknesses of the FRC and HMA interlayer. The cracking is developing on both the approach and leave side of the transverse joint and not always a continuous crack across the transverse joint. The average crack length extends 2 ft (0.6 m) on both approach and leave slabs for a total length of 4 ft (1.2 m). The distress is difficult to view without the presence of moisture, meaning the macrofibers are keeping the crack width tight and slowing propagation. Some examples of the observed longitudinal cracking are presented in Figure 3. Note, there is currently no measurable transverse joint faulting at these locations and throughout the project length. Ride quality remains very good with International Roughness Index (IRI) values of 50 and 66 in/mi (0.8 and 1.0 m/km) in the eastbound and westbound directions, respectively, in 2021.

A. Longitudinal cracking in inner wheel path only B. Longitudinal cracking in both wheel patl

Figure 3. Photos. I-72 eastbound longitudinal cracking at the transverse joints within the wheel path of the driving lane with longitudinal cracks in the (a) inside wheel path and (b) both wheel paths.

In addition to longitudinal cracking, longitudinal faulting along the lane-shoulder joint is also occurring in the eastbound direction at some locations. The shoulder-edge elevation is higher than the driving lane. A potential mechanism includes stripping and erosion, as several drain outlets were observed to be clogged and filled with water (Figure 4). This can also influence longitudinal crack development if moisture is being stored beneath the pavement and in the joints. Another potential contribution to the longitudinal faulting is the condition of the existing CRCP. Prior to placement of the interlayer and overlay, there was edge deterioration along this joint in the existing CRCP because of D-cracking. Areas with severe deterioration were repaired prior to placing the interlayer.

A. Longitudinal joint faulting B. Standing water in drain outlets

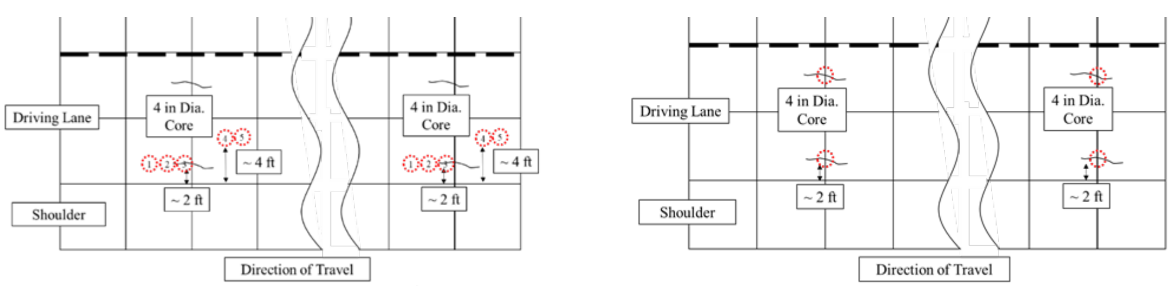
Figure 4. Photos. I-72 eastbound (a) longitudinal joint faulting along the driving lane and shoulder and (b) edge drain outlets with standing water.

Past distress surveys were also examined to estimate when longitudinal cracking was likely first observed. A distress survey conducted in 2016 by IDOT indicated some short longitudinal cracks were present in the eastbound direction just one year after construction. Additionally, a detailed distress survey was performed on the existing CRCP prior to placing the HMA interlayer and FRC overlay. This distress survey indicated a few locations with longitudinal cracking. However, the 2016, 2020, and 2021 distress surveys indicate the longitudinal cracking observed in the FRC is not reflective cracking from the existing CRCP.

I-72 EASTBOUND PAVEMENT CORING PLAN

Cores were extracted as part of the forensic examination of the HMA interlayer for erosion, permanent deformation, or debonding from the concrete overlay or existing concrete pavement. Two different coring plans were executed to examine the potential failure mechanisms. Cores were taken in December 2020 in the outer wheel path on the approach slab as well as on the leave slab adjacent to the wheel path (Figure 5-A). This coring strategy was selected to assess if any permanent deformation was occurring in the HMA in the wheel path and causing longitudinal cracking initiation to develop in the concrete overlay at the transverse joint. Coring was performed in three locations. Two locations had longitudinal cracking present, and the third location did not exhibit cracking. A total of 14 cores (4 in. [102 mm] diameter) were obtained. Coring during this site visit was near the joint, approximately 6 in. (152 mm) (on center) away from the joint but not directly over the transverse joint. Table 2 lists the stations for the 2020 coring plan shown in Figure 5-A.

A lack of clarity on the true mechanism resulted in a second set of cores being extracted in June 2021 to eliminate erosion in the interlayer as a primary mechanism. These cores were mostly taken directly over the transverse joints where longitudinal cracking was present. Three distinct stations along the section were cored directly over the transverse joint and in the inner and outer wheel path. A schematic of the coring can be seen in Figure 5-B. Each station location included two cores, resulting in a total of six 4 in. (152 mm) diameter cores in the driving lane. Cores within the first location had longitudinal cracks in both wheel paths, only longitudinal cracking was present in the inner wheel path in the second location, and cracking was only present in the outer wheel path in the third location. Coring was also performed directly over the lane-shoulder longitudinal joint in two eastbound locations to assess the observed longitudinal joint faulting. Table 3 also lists the stations for the 2021 coring plan shown in Figure 5-B.



A. 2020 coring plan

B. 2021 coring plan

Figure 5. Photos. Proposed coring plan over longitudinal cracking at the transverse joint in (a) 2020 and (b) 2021.

Table 3. I-72 Experimental Section Coring Information

Section ID	Date Cored	Pavement Type	Base Type	Stationing for Coring	Coring Location
I-72 Eastbound UBOL	12/10/2020	UBOL	HMA IL (new)	15+47 EB, 20+00 EB, 80+00 EB	Approach joint in outer wheel path; leave slab mid-lane (adjacent to wheel path)
I-72 Eastbound UBOL	6/10/2021	UBOL	HMA IL (new)	14+02 EB, 75+30 EB, 150+50 EB	Transverse joint inner and outer wheel path
I-72 Eastbound UBOL	6/10/2021	UBOL	HMA IL (new)	145+57 EB, 145+75 EB	Lane-shoulder longitudinal joint

Coring Outcomes

Coring results from December 2020 away from the transverse joint showed all cores having a fully bonded condition between the bottom of the PCC overlay and the HMA interlayer (Figure 6). There was no bond present between the bottom of the HMA interlayer and existing CRCP, or at least this was the weakest interface while extracting the overlay and interlayer materials. The core specimens over the longitudinal cracks in the wheel path had very tight cracks because of the engaged fibers. For the crack to be visible, moisture needed to be present. It was observed that water dissipated beneath the overlay in the core holes away from the transverse joint, but not in the core holes adjacent to the transverse joint. This indicated that potential consolidation or formation of a void or low point at the transverse joint that allows water to migrate and collect there is present. Table 4 presents the coring summary from December 2020.

Outer wheel path (approach joint):
Over longitudinal crack

Right edge panel (Leave slab):
NOT in wheel path

A. 15+47 EB

Outer wheel path (approach joint):
Over longitudinal crack

Right edge panel (Leave slab):
NOT in wheel path

B. 20+00 EB

Figure 6. Photos. Extracted cores from December 2020.

Table 4. Summary of Core Measurements from December 2020

Station (Eastbound)	Core location	Core ID#	PCC overlay thickness, in.	HMA Thickness, in.
15+47	Approach OWP (Crack)	3	6.75	1.50
	Approach OWP	2	6.63	1.50
		1	6.63	1.50
	Leave Non-WP	4	6.63	1.44
		5	6.63	1.38
20+00	Approach OWP (Crack)	3	6.56	1.38
	Approach OWP	2	6.63	1.38
		1	6.56	1.44
	Leave Non-WP	4	6.50	1.50
		5	6.50	1.50
80+00	Approach OWP (No Crack)	3	–	–
	Approach OWP	2	6.00	1.38
		1	6.00	1.38
	Leave Non-WP	4	6.00	1.63
		5	6.00	1.63
All cores	Average thickness, in.		6.43	1.46
	Standard deviation, in.		0.28	0.08
WP only	Average thickness, in.		6.47	1.43
	Standard deviation, in.		0.28	0.06
Non-WP	Average thickness, in.		6.38	1.51
	Standard deviation, in.		0.27	0.09

* Approach OWP=outer wheel path, Non-WP= non wheel path.

To investigate the potential mechanisms causing longitudinal cracking in the wheel path, additional laboratory testing was conducted on the obtained cores from December 2020. The additional testing of the HMA interlayer consisted of core density and conditioned split tensile (modified Lottman). The compressive strength of the concrete was also tested. The results of the density testing did not show anything unusual, and no correlation appears between test results and cracking. All HMA specimens exceeded 60 psi (415 kPa) conditioned tensile strength, which is the minimum acceptable for unmodified asphalt binders according to the contract provisions and updated standards (IDOT 2021b). All concrete compressive strengths were greater than 5,500 psi (38,000 kPa). Table 5 presents the material testing results for the HMA interlayer.

Table 5. I-72 (72G92) Eastbound Interlayer HMA Material Testing Results

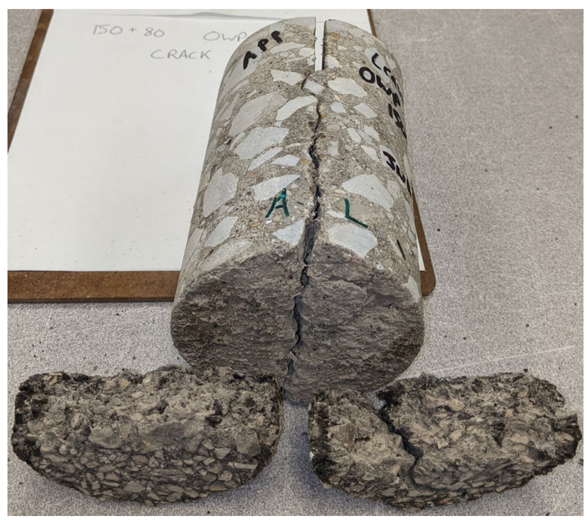
Station (Eastbound)	Core location	Core ID#	Core G_{mm}	Core density	Conditioned Tens. Str., psi
15+47	Approach OWP	2	2.464	96.3	101
		3		96.2	137
	Leave Non-WP	4		94.4	67
		5		94.2	86
20+00	Approach OWP	2	2.470	96.3	122
		3		96.4	131
	Leave Non-WP	4		96.5	118
		5		96.6	134
80+00	Approach OWP	2	2.470	96.0	90
		3		96.0	112
	Leave Non-WP	4		95.8	129
		5		95.9	137
All cores	Average		2.468	95.9	114
	Standard deviation		0.003	0.75	21.9
WP only	Average		–	96.2	115
	Standard deviation		–	0.15	16.3
Non-WP	Average		–	95.6	112
	Standard deviation		–	0.94	26.3

The results from coring in June 2021 directly over the transverse joint and longitudinal crack intersection showed evidence of stripping and erosion in the HMA layer. Some of the cores showed bonding between the HMA interlayer and FRC overlay, but only on the approach side of the joint. No bond was observed for five of six cores on the leave side of the joint. This likely indicates the longitudinal cracking is initiating on the leave side of the joint. Only one core (75+30 EB #4) was fully bonded between the HMA and FRC. This location also did not have a longitudinal crack, although the HMA showed early signs of stripping. For all core locations, no bonding was observed between the HMA and existing CRCP, which is where the stripping and erosion likely initiated. The layer thicknesses for each core, as well as bond condition can be seen in Table 6. All cores showed deterioration of the propagated PCC joint crack through the HMA layer. The cores remained together in the FRC overlay, as the fibers were bridging the transverse joint and working properly. Some of the cores exhibited stripping, as seen in Figure 7.

A. 14+02 EB OWP longitudinal crack on leave; stripping on leave only

B. 14+02 EB OWP crack deterioration in HMA at transverse joint

C. 75+30 EB IWP longitudinal crack on leave; stripping on leave only



D. 150+80 EB OWP longitudinal crack on leave; stripping at bottom of HMA interlayer

Figure 7. Photos. Extracted cores from June 2021.

Table 6. Coring Summary from June 2021

Station (Eastbound)	Core location	Core ID#	PCC overlay thickness, in	HMA thickness, in.	Total core thickness, in.	Bond condition[1]
14+02	OWP (Crack)	1	6.38	1.125	7.50	No bond on Leave, Bond on Approach
	IWP (Crack)	2	6.25	1.50	7.75	No bond
75+30	IWP (Crack)	3	6.25	1.44	7.69	No bond
	OWP (No Crack)	4	6.00	1.00	7.00	Good bond, Stripped HMA at bottom
150+50	IWP (No Crack)	5	6.13	1.50	7.63	Partial bond
	OWP (Crack)	6	6.00	1.31	7.31	No bond on Leave, Bond on Approach
All cored	Average thickness, in.		6.17	1.31	7.48	
	Standard deviation, in.		0.15	0.21	0.28	
OWP only	Average thickness, in.		6.13	1.15	7.27	
	Standard deviation, in.		0.22	0.16	0.25	
IWP only	Average thickness, in.		6.21	1.48	7.69	
	Standard deviation, in.		0.07	0.04	0.06	

[1] Bond condition is at the FRC-HMA interface. There was no bond at the HMA-CRCP interface when extracting the cores.

The coring results from directly over the lane-shoulder longitudinal joint also indicated stripping and erosion was occurring. The stripping and erosion at this location appears to be more severe than the transverse joint, as the HMA crumbled during coring (see Figure 8). Thicknesses of the HMA interlayer were not able to be determined based on the asphalt stripping and erosion. The magnitude of longitudinal lane-shoulder faulting has caused all fibers to shear, resulting in only aggregate interlock between interfaces. Figure 8 shows the core location, inside the core hole, and the two halves of the core. It also appears as if there is some form of delamination within the HMA interlayer in the shoulder. It is difficult to determine if the shoulder is moving up a little, the driving lane moving down, or a combination of both.

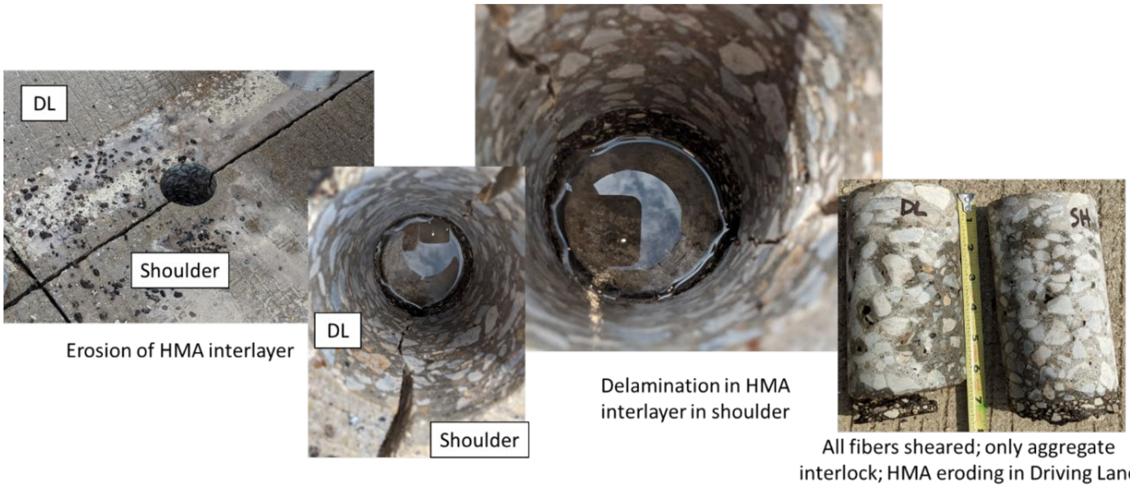


Figure 8. Photos. Core over the longitudinal lane-shoulder joint from June 2021.

I-72 FALLING WEIGHT DEFLECTOMETER ANALYSIS

FWD testing was performed in 2016 and 2020 on both the eastbound and westbound directions as a part of the research study by DeSantis and Roesler (2022). The testing included three 1,000 ft (305 m) test sections near the beginning, middle, and end of each direction. Test sections consisted of 1,000 ft (305 m), with the first 90 ft (27.4 m) consisting of 15 adjacent panels and then one panel every 100 ft (30.5 m) tested with the FWD. Test Sections 1 and 2 on the eastbound were tested with this protocol; however, time only permitted Section 3 to include the 15 consecutive panels to be tested and not the additional 9 locations spaced at 100 ft [30.5 m] within the 1,000 ft [305 m] section. All three sections in the westbound direction were tested with the intensive and intermittent FWD drops.

A summary of the FWD testing performed in 2016 and 2020 is provided for both eastbound and westbound. Table 7 presents the average normalized deflection (9 kip [40 kN]), D0* at the center of the right driving lane panel directly beneath the load plate. Figure 9 presents the normalized deflections, D0* for the different dates of testing for both directions along the length of each section. Joint load transfer efficiency (LTE) across the transverse joints (leave joint) was also examined and averages are presented in Table 8. Figure 10 presents the LTE for the different dates of testing for both directions along the length of each section.

Table 7. I-72 eastbound and westbound center panel FWD testing summary (Adapted from DeSantis and Roesler 2022).

	October 11–12, 2016		August 5–6, 2020	
	Center		Center	
	D0* (mils)	D0* (mils)	D0* (mils)	D0* (mils)
Direction	EB	WB	EB	WB
Average	2.40	3.93	3.54	4.48
Std. Dev.	0.28	0.48	0.58	0.53
COV	11.6	12.3	16.2	11.8

Tested 10/11–12/16 Temperature: Average Air = 67°F, Pavement Surface = 68°F, Pavement @ 3 in. depth = 70°F

Tested 8/5–6/2020 Temperature: Average Air = 85°F, Pavement Surface = 74°F, Pavement @ 3 in. depth = 72°F

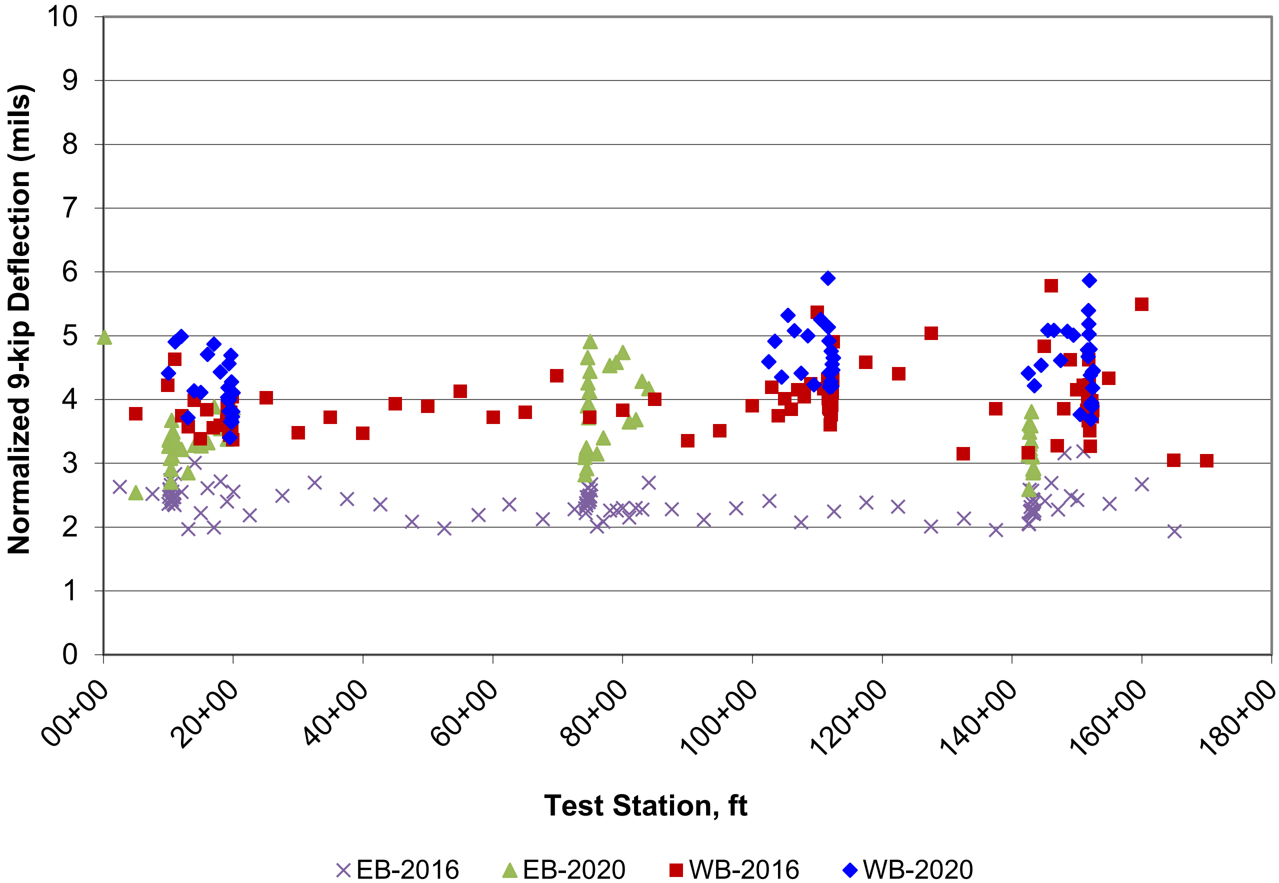


Figure 9. Graph. I-72 normalized 9-kip center deflections.

The first observation in Table 7 and Figure 9 is the westbound deflections are greater than the eastbound despite no observed cracking in the westbound. These increased deflection responses are linked to the compressibility of the NWGF interlayer on the westbound, which will increase the magnitude of deflection relative to the eastbound. I-72 eastbound has developed a significant increase in deflections in all locations. This can be a function of the stiffness of the HMA interlayer. However, evidence of stripping and erosion of this interlayer from the coring results could be the reason for the increase in deflections and decrease in LTE. Center deflections have increased from 2.4 mils (61 microns) in 2016 to 3.5 mils (89 microns) in 2020. I-72 westbound has also shown an increase in deflections as compared to shortly after construction (3.9 mils [99 microns] in 2016 and 4.5 mils [114 microns] in 2020).

Table 8. I-72 Eastbound and Westbound FWD Testing Summary (Adapted from DeSantis and Roesler 2022)

	October 11–12, 2016				August 5–6, 2020			
	Leave joint				Leave joint			
	D0* (mils)	LTE (%)	D0* (mils)	LTE (%)	D0* (mils)	LTE (%)	D0* (mils)	LTE (%)
Direction	EB	EB	WB	WB	EB	EB	WB	WB
Average	2.52	90.5	4.88	78.2	3.54	88.2	5.63	74.3
Std. Dev.	0.44	5.72	1.27	13.9	0.62	6.35	1.38	14.9
COV	17.6	6.32	26.1	17.8	17.7	7.20	24.6	20.1

Tested 10/11–12/16 Temperature: Average Air = 67°F, Pavement Surface = 68°F, Pavement @ 3 in. depth = 70°F

Tested 8/5–6/2020 Temperature: Average Air = 85°F, Pavement Surface = 74°F, Pavement @ 3 in. depth = 72°F

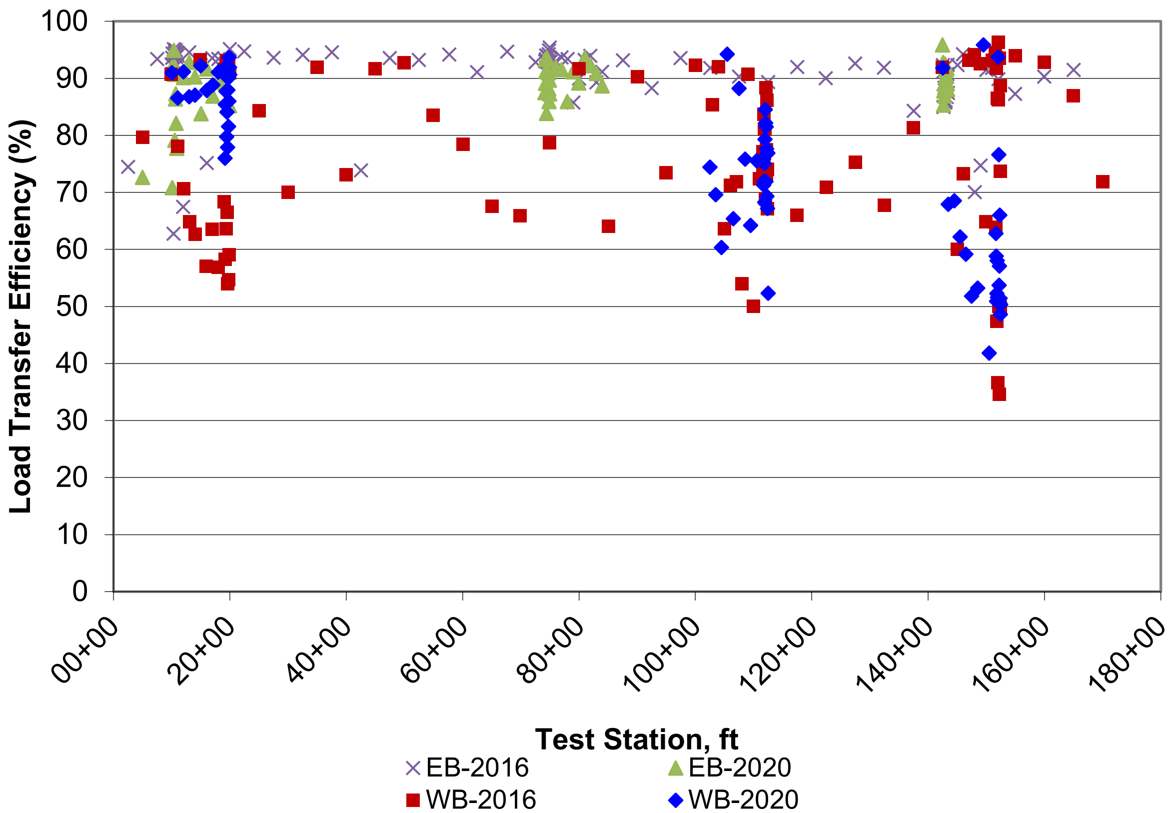


Figure 10. Graph. I-72 transverse joint load transfer efficiency.

The average LTE values are consistent between the two dates of testing for both eastbound and westbound and are approximately 90% and 75%, respectively. However, the transverse joint LTE along the westbound is much more variable. This difference in joint LTE behavior is likely due to the NWGF and its effect on the initial joint formation as well as compressibility during testing at the joint. Additionally, both eastbound and westbound sections are exhibiting some longitudinal faulting across the lane-shoulder longitudinal joint (shoulder greater elevation than driving lane). The LTE across this joint is highly variable and on average was 75% and 45%, respectively, from testing in 2020. The macrofibers present in the concrete and across the longitudinal contraction joint are mostly sheared or pulled out and not contributing to keeping the joint tight or aligned anymore (DeSantis & Roesler 2022).

UNBONDED CONCRETE OVERLAY SITE VISITS

To assess the extent of stripping potential in other short-jointed UBOLs with similar design features, short-jointed UBOLs constructed in the past 10 years were identified. Three different states were visited—Michigan, Minnesota, and Pennsylvania—to assess if similar failure mechanisms were occurring on those project sections.

The first state surveyed was Michigan. Three UBOL sections examined in Michigan near the Detroit Metropolitan Area included Little Mack Avenue in St. Clair Shores, Gratiot Avenue in Detroit, and Hall Road in Woodhaven. The first section, Little Mack Avenue, was constructed in 2011 and has a 6 × 6 ft (1.8 × 1.8 m) short-jointed UBOL with a 4 in. (102 mm) slab thickness. The existing PCC was experiencing joint deterioration and resulted in milling 4 in. (102 mm), placing a NWGF interlayer and then the 4 in. (102 mm) PCC overlay. This is a 2 mile (3.2 km) project with four total lanes, two lanes in each direction. The section is in an urban area with curb and gutters. This section did not include dowels or tie bars, but included sealed joints. The average annual daily traffic reported prior to design in 2010 was 13,400 with 2.3% trucks. From the visual survey, the southbound lanes had distress present, including faulting, spalled cracks, shattered slabs with transverse and longitudinal cracking, longitudinal faulting, and a potential longitudinal reflective crack spanning a quarter of the length of the project in the southbound direction. Additionally, a clicking sound was observed when vehicles drove in the southbound direction over the faulted joints. Since construction, numerous slabs have been replaced. The northbound lanes are exhibiting significantly less distress, even though the PCC overlay thickness was approximately the same according to the ultrasonic tomography device, MIRA. It is possible that there is directional truck traffic, i.e., heavy vehicles traveling south towards Detroit and resulting in higher fatigue in the southbound direction versus the northbound. Overall, this section is very thin; with surface drainage only with the curb and gutter, a bathtub effect likely exists underneath the thin slabs leading to the numerous fatigue cracks. Figure 11 shows the severely distressed southbound driving lane of Little Mack Avenue.

Figure 11. Photo. Little Mack Avenue (southbound) in St. Clair Shores, Michigan (UBOL with NWGF interlayer).

The second section visited within the Detroit Metropolitan Area was Gratiot Avenue. This was originally a pilot project within the metro area constructed in 2004 and 2005 and was an existing composite pavement that included milling the existing surface and placing an HMA interlayer. Two separate HMA interlayer mixes were used, open graded in the southbound direction and dense graded in the northbound direction. This urban curb-and-gutter roadway section is seven lanes wide (three 12 ft [3.7 m] lanes in each direction and a continuous two-way left-turn lane [TWLTL]) with 6 × 6 ft (1.8 × 1.8 m) panels and a 4 in. (102 mm) PCC overlay. This design was an UBOL without dowels and joint sealant. This is a heavily trafficked arterial that leads directly into Detroit's downtown. The southbound lanes appear to be performing well with minimal observed distress and no joint deterioration along contraction joints. However, the construction joints had more severe joint deterioration. The northbound direction had severe joint deterioration, faulting, observed panel replacement, and overfilled joints with excessive joint sealant from maintenance work. It is possible the open-graded interlayer system is contributing to the better performance in the southbound direction relative to the dense-graded interlayer in the northbound direction. No truck traffic was observed during the site visit in June 2021, which was on a Saturday. Figure 12 shows the southbound driving lane of Gratiot Avenue.

Figure 12. Photo. Gratiot Avenue (southbound) in Detroit, Michigan (UBOL with open-graded [southbound] and dense-graded [northbound] interlayer) (Google Maps 2019).

The third and final UBOL section visited within the Detroit Metropolitan Area was Hall Road in Woodhaven, Michigan, which was constructed in 2008. This section is also a 6 × 6 ft (1.8 × 1.8 m) panel design with a 4 in. (102 mm) PCC overlay with curb and gutters. The interlayer is a 1 in. (25 mm) dense-graded HMA placed on an existing JPCP. This section contains two 12 ft (3.7 m) lanes in each direction separated by a grass median. The traffic is moderate to low in this section (average annual daily traffic = 10,000 with 2% trucks) and is also within a school zone that has a speed limit of 25 mph (40 km/h). In the UBOL, there are no dowels or sealed joints. Longitudinal cracking is more common and very clear within the northbound direction and is the likely lane on which buses travel. Slab migration has occurred with transverse joint faulting present in both directions. Signs of pumping along longitudinal cracks, longitudinal joints, and transverse joints were also observed and can be seen in Figure 13. Some vegetation was observed to be growing within deteriorated longitudinal joints and is evidence of trapped moisture within the system. Additionally, deteriorated joints show signs of black silty-sandy material with high number of fines. It is likely this is the material being pumped and potentially the HMA interlayer is eroding away.

Figure 13. Photo. Hall Road (northbound) in Woodhaven, Michigan (UBOL with dense-graded interlayer).

Trunk Highway (TH) 53 near Duluth, Minnesota, had one concrete overlay section surveyed. Dr. Manik Barman of the University of Minnesota Duluth assisted on the site visit and visual confirmations for the TH-53 performance. TH-53 is northwest of Duluth and was constructed in 2008. The northbound and southbound lanes were constructed with 12 × 12 ft (3.7 × 3.7 m) panels with a 5 in. (127 mm) PCC overlay. There was an experimental portion of the southbound direction that included a 1,500 ft (457 m) section with 6 × 6 ft (1.8 × 1.8 m) panels, which was the main focus of this investigation. The interlayer consisted of a minimum 1 in. (25 mm) dense-graded HMA but had variable depth to account for the cross-slope. Each direction consisted of two 12 ft (3.7 m) lanes with HMA shoulders. TH-53 did not use dowels, joint sealant, fibers, or retrofitted edge drains. The estimated traffic was much less than I-72 at 3.6 million equivalent single axle loads (ESALs). The initial performance survey reported early signs of premature distress, mainly consisting of transverse cracking from poor joint activation, late sawcutting, and potentially reflective cracking, as the existing pavement had severe joint deterioration prior to the UBOL (Watson et al., 2010). The major distress observed from Google Maps (September 2018) was severe longitudinal cracking in the driving lane, specifically the outer wheel path. Corner breaks were common along the outer edge of the driving lane, as it appears erosion must be occurring beneath the slab in the HMA interlayer. The 6 × 6 ft (1.8

× 1.8 m) section consisted mainly of longitudinal cracking within the inner and outer wheel paths, spanning multiple slabs. The southbound section of TH-53 started undergoing rehabilitation and reconstruction starting in summer 2021 and, thus, no higher resolution photographs of the current distresses were available. Figure 14 presents the observed longitudinal cracking on TH-53 within the 6 × 6 ft (1.8 × 1.8 m) section.

Figure 14. Photo. TH-53 (southbound) near Duluth, Minnesota (Google Earth 2021).

The third state survey was conducted in Pennsylvania on a similar UBOL design to I-72 eastbound and was located on route 50 near Bridgeville, Pennsylvania, just south of Pittsburgh. PA SR-50 is a 3.5 mile (5.6 km), 6 × 6 ft (1.8 × 1.8 m) short-jointed slab design with an undoweled 6 in. (152 mm) concrete overlay on a 1 in. (25 mm) dense-graded HMA interlayer over an 8 in. (203 mm) existing jointed reinforced concrete pavement (JRCP). The outer shoulders are 8 ft (2.4 m) tied PCC (6 × 8 ft [1.8 × 2.4 m] panels). Unlike the I-72 project, PA SR-50 had sealed transverse and longitudinal joints, slightly lower traffic volume (average daily traffic = 8,000 with 8% trucks) and traffic speed (55 mph speed limit), and the transverse and longitudinal slopes were greater because PA SR-50 was in a mountainous region. There were no macrofibers added to the concrete mixture. The UBOL was originally constructed in September 2015 with four total lanes (two in each direction). Sachs et al., (2017) investigated the frictional characteristics of the HMA interlayer and the impact on joint activation and joint widths of PA SR-50 but did not investigate cracking. An initial survey using Google Maps (July 2019) revealed longitudinal cracks occurring in the outer and inner wheel paths of the driving lane. However, the field site visit to PA SR-50 showed less cracking than the Google Map images with only five cracks observed. The weather conditions during the site visit were poor with rain and could have influenced the observed distress. If cracks were as tight as the cracks observed on I-72, it would be difficult to visualize while driving and conducting the survey. Out of the five observed cracks, only one showed similarity to the distress occurring on I-72. Figure 15 illustrates the longitudinal crack that initiated at the transverse joint in the outer wheel path of the eastbound driving lane.

Figure 15. Photo. Pennsylvania SR-50 (eastbound) UBOL longitudinal cracking.

After potential evidence of stripping was observed for some UBOLs with dense-graded HMA interlayers, there was concern for a recently constructed UBOL with conventional JPCP design in southern Illinois. Therefore, an additional site visit was conducted to assess the stripping and longitudinal cracking potential. The UBOL section on I-57 in Union and Johnson Counties was constructed in 2015 and 2016. This section was thicker than I-72 with a 9.75 in. (248 mm) overlay and a 3.25 in. (83 mm) dense-graded HMA interlayer on an existing 10 in. (254 mm) JRCP. This UBOL had 1.5 in. (38 mm) dowels at transverse joints, centerline tie bars, tied concrete shoulder, sealed longitudinal joints, and conventional joint spacing of 15 × 12 ft (4.6 × 3.7 m). The longitudinal cracking observed is located within both wheel paths of the driving lane. From the site visit and MIRA device, cracks were determined to be directly over the dowel bars, given they were spaced 12 in. (305 mm) on center, directly over the dowels. A dowel bar inserter was used on this project and potentially resulted in some form of vertical tilt of the dowels in some locations, leading to high stress concentrations and eventually crack development. Another potential mechanism causing the longitudinal cracks to develop could be related to poor consolidation of the concrete during dowel insertion. The longitudinal cracking is likely directly related to the dowel bars. This cracking was only observed at a few locations in the southbound direction in the driving lane.

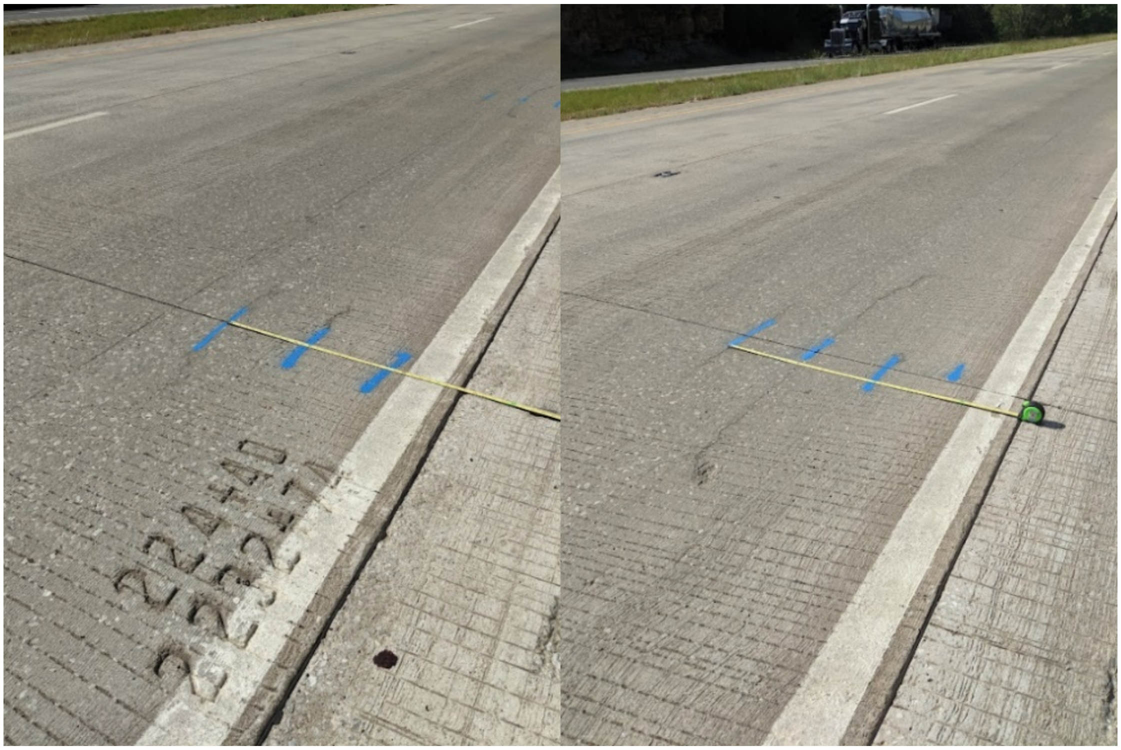
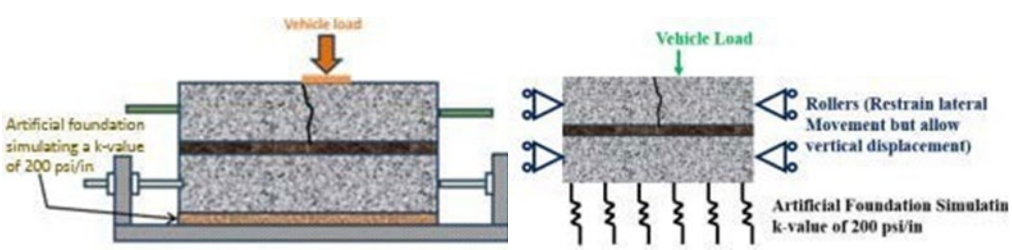


Figure 16. Photos. I-57 longitudinal cracking in the outer wheel path directly over dowel bars.

LABORATORY INVESTIGATION LITERATURE REVIEW

Laboratory testing performed by Sachs (2017) for the development of the UBOL design guide (Khazanovich et al., 2020) was re-evaluated to determine the mechanisms likely contributing to I-72 longitudinal cracking. The UBOL fatigue testing setup by Sachs (2017) is shown in Figure 17. This performance test was primarily designed to compare different interlayer systems for UBOLs, i.e., HMA versus NWGF, HMA mixture designs (open versus dense graded), HMA thickness, milling HMA surface, etc. This idealized UBOL testing was performed at a single test temperature and under plane stress conditions but did provide concrete fatigue and interlayer permanent deformation performance of different interlayer types.



A. Schematic of composite beam test B. Boundary conditions of test setup

C. Composite beam setup with HMA interlayer

Figure 17. Photos. Composite concrete beam test setup with HMA interlayer (Sachs, 2017).

The laboratory experimental results were used to develop a ME permanent deformation model for HMA interlayer systems. Souder et al. (2020) developed a prediction model for one-dimensional densification as a function of temperature, traffic, mixture design, and vertical strain similar to the model presented in the AASHTOWare Pavement ME (ARA Inc., 2004). The model was calibrated with UBOL section data exhibiting longitudinal cracking in the wheel path. The developed ME model was used to assess the repeated loading performance and potential permanent deformation for the I-72 eastbound mixture design and can be seen in Figure 18. The failure criteria threshold established by Souder et al. (2020) is when permanent strain levels reach 0.06 in/in. The permanent deformation failure criteria is the product of the thickness of the HMA interlayer and the permanent strain level criteria. The I-72 eastbound case permanent deformation failure criteria is 0.075 in. (1.9 mm), as the thickness of the HMA interlayer is 1.25 in. (32 mm). With this model, longitudinal cracking of the I-72 HMA interlayer is predicted as a result of permanent deformation after 3 million ESALs. The largest levels of predicted deformation occur during the summer, when the HMA interlayer is at its lowest stiffness. Other mechanisms may have been contributing to the longitudinal cracking in addition to permanent deformation in the sections used for calibration of this model, such as stripping and erosion. No coring was performed for verification of the failure mechanism of the sections used for calibration as they were no longer in-service when the study was performed.

Before the I-72 EB construction, the HWTD was used to evaluate the rutting potential of the HMA interlayer. The HWTD was also proposed as a performance test under project ICT-R27-193-6 for assessing the erosion potential of different stabilized base layers under concrete pavements and concrete overlays (DeSantis & Roesler, 2022). Figure 19 presents the I-72 HMA interlayer test results for PG 58-28. According to IDOT standards, a specified plan binder grade of PG 64-22 (as was specified in Contract 72G92) needs to pass a minimum of 7,500 wheel-load cycles and not exceed a rut-depth greater than 0.5 in. (12.5 mm) even though a PG 58-28 binder was substituted to account for FRAP in the mixture. The results indicated the mixture passed 20,000 wheel-load cycles and did not reach the failure criterion of 0.5 in. (12.5 mm) rut depth. Subsequently, there was no concern on using this HMA mixture as an interlayer in terms of rutting or permanent deformation.

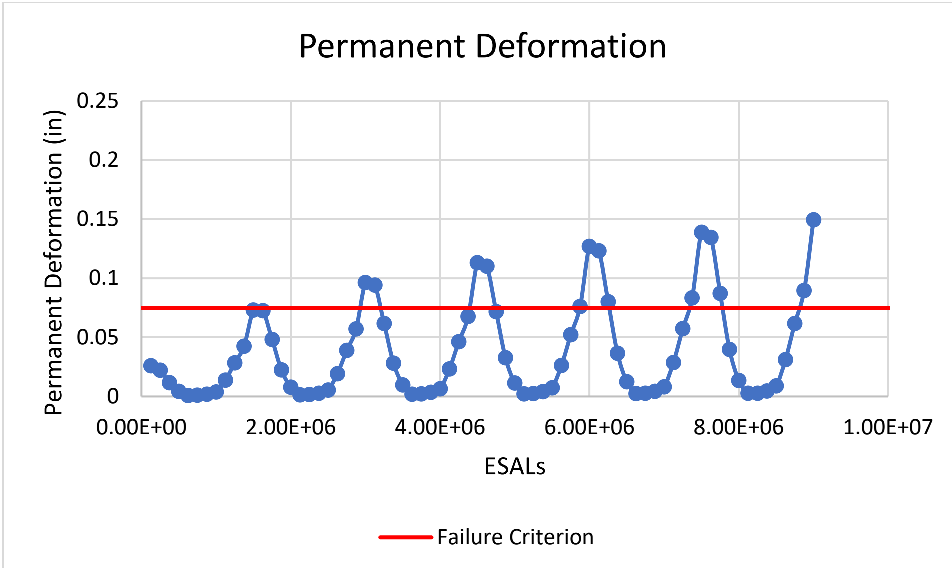


Figure 18. Graph. I-72 HMA permanent deformation prediction (failure criterion is equal to 0.075 in.).

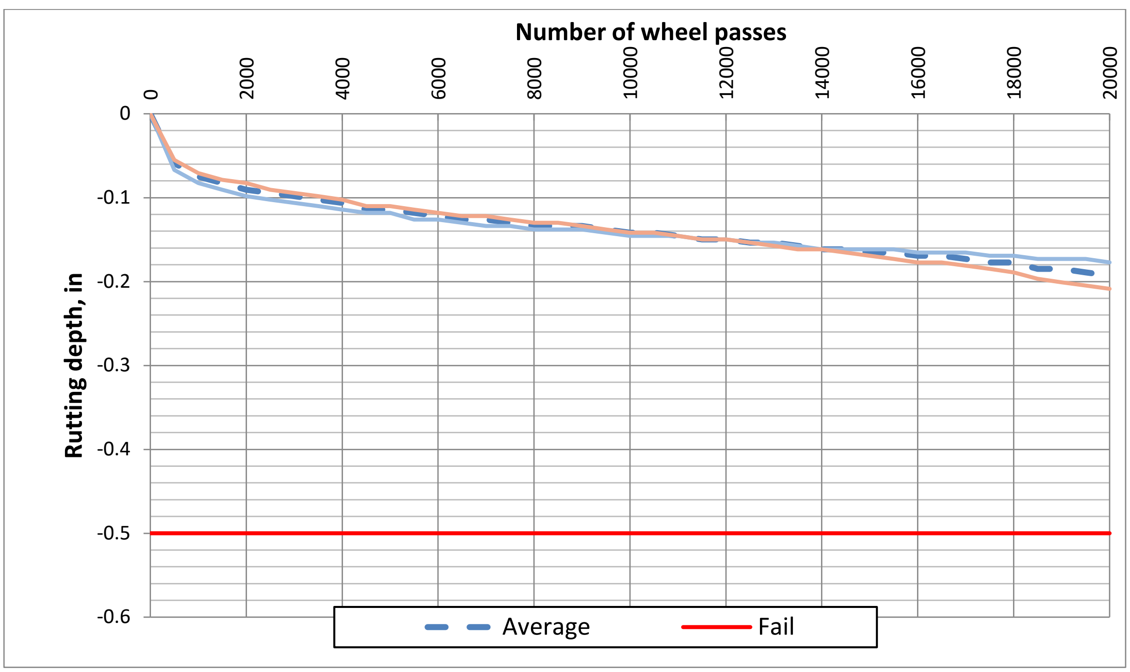


Figure 19. Graph. Hamburg wheel-tracking device I-72 HMA interlayer results (PG 58-28).

CHAPTER 4: REHABILITATION AND MAINTENANCE STRATEGIES FOR LONGITUDINAL CRACK PROGRESSION

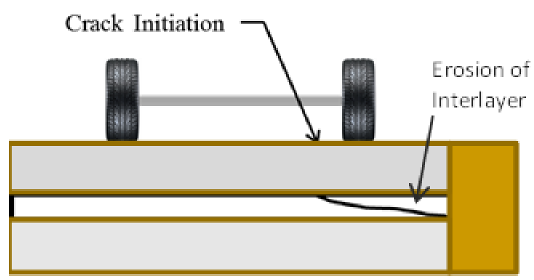
The primary mechanism for longitudinal crack formation in the concrete overlay of I-72 eastbound is the stripping and erosion of the HMA interlayer at the transverse joints and longitudinal lane-shoulder joint of the concrete overlay. This chapter focuses on providing recommendations and considerations for design, construction, and maintenance practices of UBOL. The focus of this chapter is to prevent stripping and erosion within the HMA interlayer for UBOL designs. Additional considerations include rehabilitation and maintenance strategies for I-72 eastbound to limit crack growth and deterioration, as well as potential adjustments for future and other UBOLs in Illinois. A performance test is also presented that may be a future option for predicting the stripping and erosion potential of HMA interlayers susceptible to high porewater pressures.

DESIGN AND CONSTRUCTION ADJUSTMENTS FOR UNBONDED CONCRETE OVERLAY IN ILLINOIS

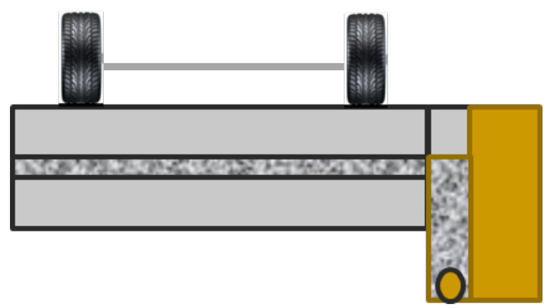
The first recommendation regarding the interlayer type and design for UBOL is to use erosion-resistant materials. This same characteristic is important for conventional HMA paving mixtures to be resistant to stripping and erosion. However, the HMA interlayer is sandwiched between two rigid plates and the potential water pressure build-up can result in stripping or erosion of the HMA that may not exist at the pavement surface. For this reason, the HMA layer should be made more resistant to stripping (Khazanovich et al., 2020; Vandenbossche & DeSantis, 2021). Strategies for improving the stripping resistance of dense-graded HMA interlayers include polymer modification, mixtures with increased binder contents, utilizing anti-strip additives, or finer graded aggregate mixture compositions. Open-graded HMA interlayers are also still vulnerable to erosion and have lower strength/stiffness, which can lead to stability issues. Other state DOTs have reported performance issues with drainable HMA interlayers to a similar degree as dense-graded mixtures. For drainable HMA interlayers, it is important to balance permeability with strength and stability and erosion resistance when designing an HMA interlayer. In some UBOL projects, a NWGF interlayer can replace an HMA interlayer and provide a lateral drainage pathway and erosion-resistant interlayer system (Cackler, 2017). NWGF also have the potential to reduce the pore water pressure build-up during repeated loading at the joints.

The second important factor for HMA interlayer performance is ensuring target density is reached during construction. Achieving the HMA interlayer target density will minimize any type of consolidation or shearing under traffic loading. Improper densities can lead to potential consolidation within the wheel paths, which can result in high tensile stresses at the bottom of the concrete layer and bottom-up longitudinal cracking.

The third component to consider with UBOL design and construction is minimizing moisture infiltration and/or ensuring a clear drainage path for infiltrated water to exit the system. Regardless of interlayer type, drainage beneath the concrete overlay is important for long-term performance. To minimize erosion potential of the interlayer, sealing of the longitudinal and transverse joints may be a worthwhile strategy. A properly constructed and installed joint sealant will reduce water infiltration and minimize the condition of a fully saturated joint and interface condition. By providing a drainage path and outlet for water that does infiltrate and contact the interlayer, the stripping and/or erosion susceptibility of the interlayer decreases significantly. Figure 20-A illustrates the effects if there is no lateral pathway for water to escape the system. The water remains trapped and can develop hydraulic pressures under moving traffic loads that can result in loss of support. Figure 20-B illustrates one way a connected interlayer/drainage pathway allows for infiltrated water to escape the system. The I-72 project utilized the existing pipe underdrains and required cleaning of outlets. The other lateral drainage factor is making sure the interlayer/interface has 1.5%–2% cross slope that matches the cross slope of the pavement surface.



A. Lateral drainage outlet is not provided, resulting in stripping and erosion.



B. Interlayer connected to an edge drainage system to limit stripping and erosion.

Figure 20. Schematic. Interlayer and lateral drainage system configuration that can lead to erosion or positive drainage condition (Khazanovich et al., 2020; Vandenbossche & DeSantis, 2021).

For future UBOLs, reducing the differential deflections across the transverse joints is another design factor to limit stripping and erosion of the interlayer. Lower differential deflections will reduce water velocities and overall stripping and/or erosion of an HMA interlayer. To reduce differential deflections, the primary remedies are to specify load transfer across the transverse joints and tie bars across contraction or construction longitudinal joints. The overlay thickness can be increased slightly to reduce differential deflection and increase bending capacity, but if the slab thickness increases too much then a conventional JPCP overlay can be designed. Tied concrete shoulders, if not present, can also reduce deflections.

MAINTENANCE AND REHABILITATION SUGGESTIONS FOR I-72

I-72 eastbound continues to develop new and propagate existing longitudinal cracks and longitudinal joint faulting along the lane-shoulder joint. Given these continuing distress developments, a plan for maintenance and rehabilitation to extend the life of this UBOL is necessary. The ongoing concern with I-72 eastbound is stripping and erosion of the dense-graded HMA interlayer. FRC in the overlay has kept all longitudinal cracks together (≤ 0.02 in. [0.51 mm]) and transverse joints tight. One potential rehabilitation strategy is to place an ultra-thin bonded wearing course or HMA overlay over the PCC overlay to minimize water ingress into the system. Because of how tight the longitudinal cracks remain, reflective cracks from the wheel path distress will likely not occur. The longitudinal lane-shoulder is deteriorating more rapidly from loading and water infiltration, so more immediate action is needed at this location. One maintenance strategy that can be taken almost immediately is sealing the joints in the driving lane and the lane-shoulder longitudinal joint, which should lead to slowing down the deterioration. With a 6 × 6 ft (1.8 × 1.8 m) design, the amount of joint sealant required is large; therefore, only the driving lane should be sealed.

FUTURE PERFORMANCE TEST

A potential method to assess the stripping and erosion potential of HMA interlayers is using a dynamic cylinder test developed by Caro et al. (2010). This test more accurately simulates the movement of high velocity water across the stabilized material's surface. This is an accelerated performance test that can better represent the porewater pressures that can develop beneath the concrete overlay and dense-graded HMA interlayer. The dynamic cylinder test (Caro et al., 2010) was developed to capture the effect of shear forces that develop at the interface between a concrete surface layer and a stabilized subbase layer. These forces are a function of deflections and the velocity of water. The device developed for this testing is shown in Figure 21 and requires an actuator, accelerometers, and water pressure sensors. Typically, the water velocities induced in the field range between 5–16 mph (2–7 m/s) (Hansen et al., 1991). The dynamic cylinder test analyzes three different loading frequencies to target three distinct horizontal water velocities. In the field, different water velocities will be caused by differential deflections, traffic load, and traffic speed. The type of stabilized materials, e.g., dense-graded versus open-graded HMA interlayer, will respond differently as these test variables are changed. This test could be part of future work for designing stripping- and erosion-resistant HMA interlayers, especially for UBOLs.

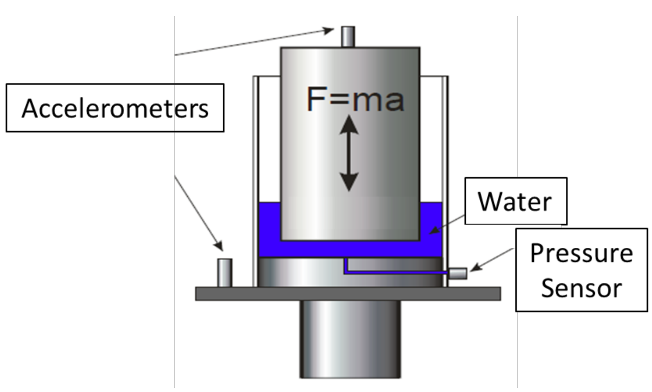


Figure 21. Schematic. Dynamic cylinder testing device (Caro, 2010).

CHAPTER 5: CONCLUSIONS

The experimental section of a short-jointed (6 × 6 ft [1.8 × 1.8 m]) unbonded concrete overlay (UBOL) of an existing continuously reinforced concrete pavement (CRCP) on I-72 in Sangamon County near Riverton, Illinois, is exhibiting longitudinal cracking in the wheel paths of the eastbound direction and faulting along the longitudinal lane-shoulder contraction joint. Both directions have concrete shoulders (no tie bars), no dowel bars in the transverse joints, unsealed contraction joints, and macrofiber-reinforced concrete (FRC) in all lanes and shoulders. The eastbound direction has a dense-graded hot-mix asphalt (HMA) interlayer, while the westbound direction inserted a nonwoven geotextile fabric (NWGF) as an interlayer.

A literature review was conducted on state departments of transportation (DOTs) that have experience with UBOLs and previous studies reviewing longitudinal cracking on short-jointed UBOLs. Iowa, Michigan, Minnesota, Missouri, and Pennsylvania DOTs were reviewed for UBOLs, particularly their insight on stripping and erosion potential within the dense-graded HMA interlayer. Google Earth and Maps were used in conjunction with contacting state DOTs to assess the severity of longitudinal cracking in short-jointed UBOLs. Current mechanistic-empirical (ME) design procedures that are applicable for designing UBOLs were reviewed, including TPF 5-269 UBOL-ME, AASHTOWare Pavement ME, and BCOA-ME. The first two methods are primarily for UBOLs and the third is primarily for bonded concrete overlays of asphalt pavements (BCOA). UBOL-ME is a new design procedure that incorporates short-jointed panels within the design framework including accommodation of HMA and NWGF interlayers.

To assess the quantity and severity of the longitudinal cracking, a detailed distress survey was performed in August 2020. This distress survey indicated cracking was developing in both the inner and outer wheel paths of the driving lane and likely initiating at the leave side of the transverse joints. Coring was performed directly over the transverse joints and intersecting longitudinal cracks to help define the potential failure mechanisms. These cores demonstrated that the dense-graded HMA interlayer was stripping and resulting in interlayer erosion. The stripping and erosion caused nonuniform support beneath the overlay at the transverse joints and resulted in a bottom-up tensile crack initiation. This mechanism is likely to continue to develop throughout the entire eastbound UBOL pavement section. Because the overlay concrete was FRC, the longitudinal cracks have remained extremely tight (≤ 0.02 in. [0.51 mm]). The combination of differential deflections (no dowels), moisture (no joint sealant, nonpermeable interlayer), and high traffic volumes and speed resulted in high water pressures from water becoming trapped within the system to generate stripping and erosion of the dense-graded HMA interlayer. Hamburg wheel-tracking device (HWTD) testing was performed on the HMA interlayer mixture prior to construction, and the results indicated this mixture was very stable and had a rut-depth less than 0.25 in. (6.4 mm) after 20,000 wheel-load cycles (maximum allowable rut-depth is 0.5 in. [12.5 mm] at 7,500 cycles for the specified mixture).

To assess if stripping within the HMA interlayer is a common occurrence for short-jointed (e.g., 6 × 6 ft [1.8 × 1.8 m]) UBOLS constructed within the past 10 years, surrounding states' projects were examined. UBOL site surveys to Michigan, Minnesota, and Pennsylvania were made because of similarity to the I-72 design. Stripping was not observed in Pennsylvania, as all joints used a joint sealant and this pavement was constructed in a mountainous region with large longitudinal and transverse grades, which enables good surface drainage. Longitudinal cracking was observed in Michigan and Minnesota sections, which were hypothesized to be caused by stripping and erosion of the dense-graded HMA interlayer.

Due to the quantity of the longitudinal cracking and lane-shoulder joint faulting on I-72 eastbound, it is important to assess the different design, construction, and maintenance aspects that could be improved to minimize this from occurring in the future. The different considerations could be 1) application of sealant to contraction joints to minimize water infiltration, 2) provide an anti-stripping agent or strip resistant binder within the HMA mixture for dense-graded interlayers, and/or 3) establish minimum cross-slopes (e.g., 1.5%–2.0%) at the pavement surface and along the interlayer interface to ensure lateral drainage conveyance. The UBOL drainage design should transmit water to the edge drains or ditch and not become trapped underneath the driving lane or at the lane-shoulder joint. Because stripping has not been observed in the passing lane, rehabilitation and maintenance options for I-72 are to place an ultra-thin bonded wearing course or HMA overlay to minimize the water ingress or seal all joints within the driving lane and at the lane-shoulder joint. Further development of a dynamic cylinder performance test to test the stripping and erosion potential of HMA interlayers in the presence of high porewater pressures is suggested.

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APPENDIX A: CONCRETE OVERLAY SECTIONS

Table 9. Concrete Overlays Examined with Google Earth and Maps

State/ Province	Section ID	Location	Year Constructed	Joint Spacing, ft	Overlay thickness, in.
Colorado	I-70	Grand Junction	2012	6x6	6
	SH 121 (Wadsworth Blvd)	Denver	2001	6x6	6
	SH 13	Craig	2016	6x6	6
Iowa	IA 3	Plymouth Co. to east of Cleghorn	2015	6x5-7	6
	US 65	Wayne County Line to US 34	2013	5x5.5	5
	US 18	Fredericksburg	2011	4.5x4.5	4.5
	IA 13	Strawberry Point	2008	4.5x4.5	3.5-4.5
	IA 9	Ocheyedan	2015	5x5	5.5
	IA 14	Parkersburg	2013	5x5	4.5
	IA 175	Arthur	2013	7x7	4.5
Kansas	I-70	Wilson	2012	6x6	6
Michigan	South Boulevard East	Pontiac	2009	6x6	4
	Hall Road	Woodhaven	2008	6x6	4
	Gratiot Avenue	Detroit Metro Area	2004-2005	6x6	4
	Little Mack Avenue	St Clair Shores	2011	6x6	4
Minnesota	TH 53	Duluth	2008	6x6	5
Missouri	Route D	Kansas City	2008	6x6	5
	Route 24 / Business 63 Intersection	Moberly	2010	6x6	5.5
Ohio	Sprague Road	North Royalton	2014	6.5x6.5	7
Oklahoma	US 69 N	Kiowa	2007	6x6	5
Ontario	Bloor Street West at Aukland Road	Toronto	2003	5x5	6
Pennsylvania	SR - 50	Bridgeville	2016	6x6	6
Uruguay	Routa 24	Guyunusa	2011-2012	6x6	5.5
Wyoming	US 30	Cokeville	2012	6x6	6

Table 10. Concrete Overlays Examined with Google Earth and Maps (Additional Information)

State/ Province	Section ID	Structure Type	Interlayer type	Interlayer thickness, in	Longitudinal cracking
Colorado	I-70	BCOA	Existing HMA	Unknown	Yes
	SH 121 (Wadsworth Blvd)	BCOA	Existing HMA	Unknown	Yes
	SH 13	BCOA	Existing HMA	Unknown	No
Iowa	IA 3	UBOL	Dense HMA	1.5	Yes
	US 65	UBOL	Dense HMA	1	Inconclusive
	US 18	UBOL	Milled dense HMA	5-8	Yes
	IA 13	UBOL	Milled dense HMA	3	Yes
	IA 9	UBOL	Milled dense HMA	3	Yes
	IA 14	UBOL	New dense HMA	1	Yes
	IA 175	UBOL	Milled dense HMA	3.5	Yes
Kansas	I-70	BCOA	Existing HMA	14	No
Michigan	South Boulevard East	UBOL	Dense HMA	1	Yes
	Hall Road	UBOL	Dense HMA	1	Yes
	Gratiot Avenue	UBOL	Dense (NB)/ Open HMA (SB)	1-2	No
	Little Mack Avenue	UBOL	NWGF		Yes
Minnesota	TH 53	UBOL	Dense HMA	1	Yes
Missouri	Route D	UBOL	NWGF	16.2 oz	No
	Route 24 / Business 63 Intersection	UBOL	NWGF	NA	Yes
Ohio	Sprague Road	UBOL	Dense HMA	1	No
Oklahoma	US 69 N	UBOL	Dense HMA	1	Yes
Ontario	Bloor Street West at Aukland Road	UBOL	Dense HMA	1	No
Pennsylvania	SR - 50	UBOL	Dense HMA	1	No
Uruguay	Routa 24	BCOA	Existing HMA	10	No
Wyoming	US 30	BCOA	Existing HMA	3+	Yes

APPENDIX B: I-72 DISTRESS SURVEY

I-72 (CONTRACT 72G92):

I-72, east of Springfield (from 0.48 miles [0.77 km] east of Overpass Rd to 0.15 miles [0.24 km] east of Dawson Road overpass) (STA 0+00 to 171+09)

I-72 EB – District 6 (Sangamon Co.):

- 6.0-in. (152-mm) JPCP on 1.25-in. (32-mm) HMA interlayer on 8-in. (203-mm) CRCP

I-72 WB – District 6 (Sangamon Co.):

- 6.0-in. (152-mm) JPCP on 0.125-in. (3.2-mm) NWGF interlayer on 8-in. (203-mm) CRCP

Both directions:

- 6-ft [1.8-m] x 6-ft [1.8-m] panels (two lanes with 10-ft [3-m] outside shoulder and 6-ft [1.8-m] inside shoulder)
- Transverse joints:
    - Undoweled
    - 0.125-0.250 in. (3.2-6.4 mm) wide saw cuts to 1.50 in. (38 mm) depth with no joint sealant
    - #4 x 24 in. (610 mm) tie bars at 15 in. (381 mm) spacing at construction joints only (end of a day's paving)
- Longitudinal joints:
    - 0.125-0.250 in. (3.2-6.4 mm) wide saw cuts to 1.50 in. (38 mm) depth with no joint sealant
    - #4 x 24 in. (610 mm) tie bars at 36 in. (914 mm) spacing at construction joints only (centerline) with hot poured joint sealer
- Constructed 2015

Test sections - EB:

- 10+00 to 20+00, 74+15 to 84+15, 142+50 to 152+50

Test sections - WB:

- 10+00 to 20+00, 102+50 to 112+50, 142+50 to 152+50

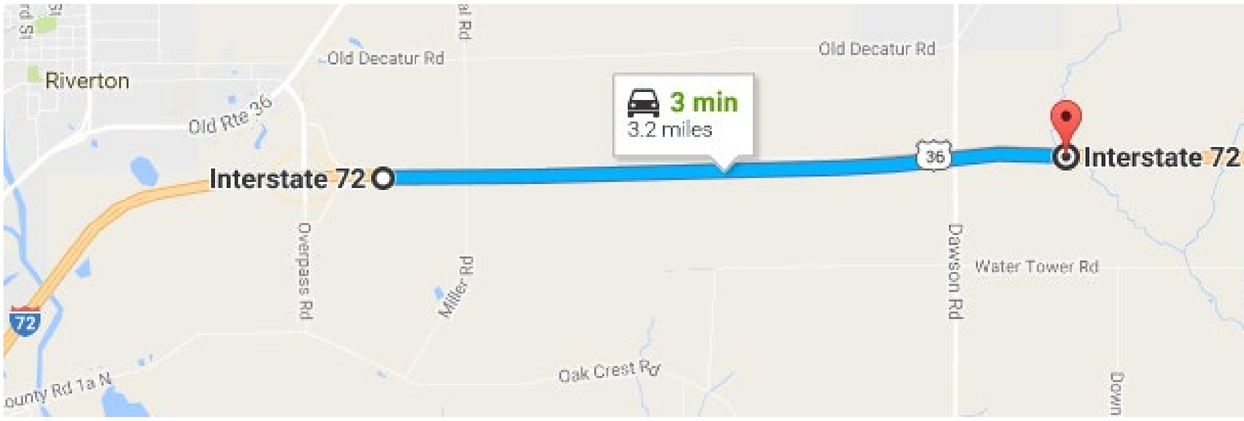


Figure 22. Photo. I-72 (Contract 72G92).

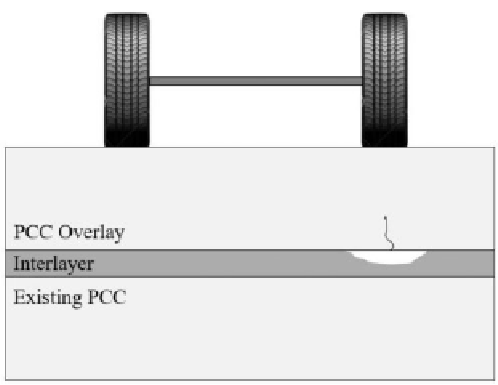
I-72 (Contract 72G92) Synopsis of Testing – 08/05-06/2020

*Synopsis of distress in **Eastbound** (HMA interlayer):*

The prominent distress in the EB direction was longitudinal cracks in the wheel paths (WP) of the driving lane (each panel). On average, cracks appear to be 2 ft [0.6 m] in length on each panel and a total of 4 ft [1.2 m] across transverse joints. Longitudinal cracking spanning a full slab or greater was not observed. Approximately 30 locations had longitudinal cracking occurring across the transverse joint (tested two sections of 1,000 ft [305 m] and 3rd section of 100 ft [30.5 m]). This distress has been commonly seen in UBOL with HMA interlayers (Alland et al. 2016 and Souder et al. 2020). A possible mechanism for this distress is permanent deformation in the HMA layer (densification or shear flow) resulting in a void, gap, or settlement beneath the PCC in the wheel path. As traffic accumulates the deformation or gap increases, resulting in an increase in the tensile stress at the bottom of the PCC and eventually leads to a bottom-up crack to develop if the flexural stiffness and strength of concrete is not sufficiently high (See Figure 23-C below). With the lower vertical pressure reaching the HMA interlayer, this mechanism is less likely. The vertical pressure on the interlayer is likely less than 25 psi (172 kPa) if the joint is ignored.

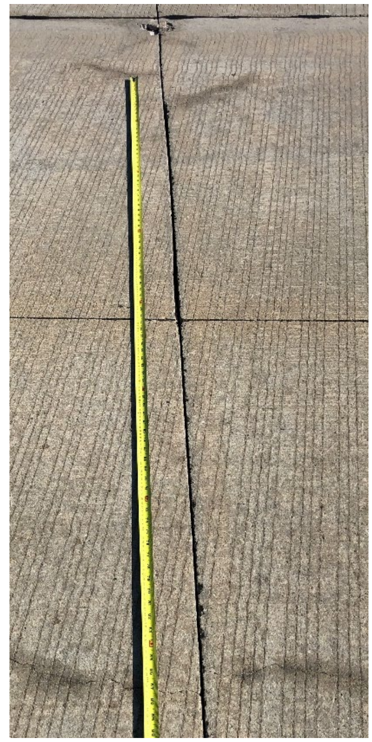
A. Long. cracking in the inner wheel path

B. Long. cracking in both wheel path (inner and outer)



C. Hypothetic mechanism of permanent deformation in HMA resulting in 1D densification or shearing that enables tensile crack to initiate at bottom of PCC overlay

Figure 23. Photos. Short-jointed unbonded concrete overlay (UBOL) on HMA interlayer.



A. Length of long. crack (approx. 4 ft [1.2 m] across the trans. jt.)

B. Distance between long. cracks at the trans. jt. (approx. 7.5-8 ft [2.3-2.4 m])

Figure 24. Photos. Distress photos of longitudinal cracking on I-72 (72G92) eastbound.

- Proper compaction of the HMA interlayer is still very important, even though it is not the surface layer. This mixture should be examined under the Hamburg Wheel Testing Device (HWTD) to check rutting and stripping potential prior to construction. The interlayer is only 1.25 in. [32 mm] currently so coring is needed to review its condition and participation in the mechanism.

- There are several proposed ways to mitigate this potential distress mechanism, which are not verified yet. Increasing the thickness of the concrete overlay will decrease the stress on the interlayer, and therefore decrease the risk of degradation and/or consolidation. Reducing differential deflections and minimize any potential water pressure by using load transfer devices may be helpful. Finally, using an interlayer system which is not prone to consolidation or stripping, will help minimize this distress as well (Alland et al. 2016).

- To assess if consolidation is occurring, the design information and mixture designs can be put into the newly developed permanent deformation of HMA interlayers model for UBOL (Souder et al. 2020). In addition, cores can be taken from the HMA interlayer to assess the density of the HMA in the wheel path versus mid-lane where the HMA is less trafficked.

- At the project start on the eastbound, the left panel in the driving lane is shattered. This is likely from the construction process when starting the UBOL versus the existing HMA surface layer. This panel needs to be replaced with a full-depth repair.

Figure 25. Photo. Distress photo of shattered slab in I-72 (72G92) eastbound.

- Clumping of the fibers was observed once. It appears the mixing was done very well and fibers were distributed evenly throughout concrete material production and construction.

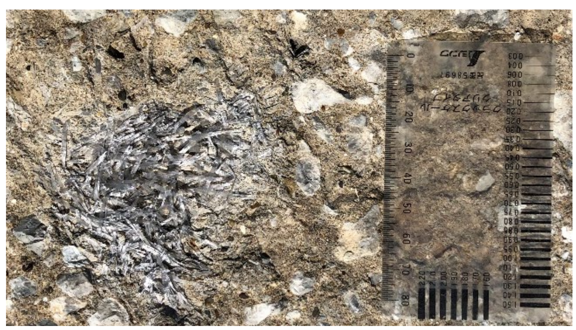
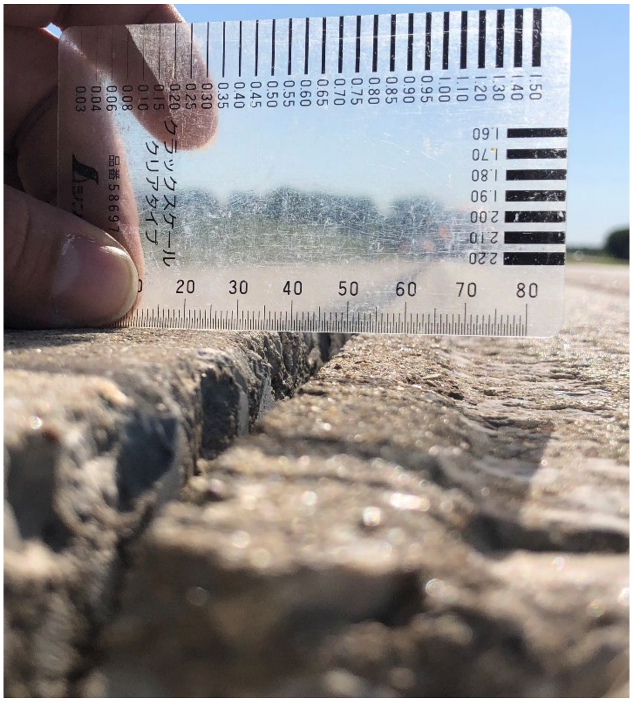


Figure 26. Photo. Clumping of fibers in I-72 (72G92) eastbound.

*Synopsis of distress in **Westbound** (Nonwoven Geotextile Fabric interlayer):*

- No longitudinal cracking was observed in the westbound direction. The main observation made from the westbound lane was a difference in elevation across the lane-shoulder joint in the outer wheel path (OWP). This difference in elevation was consistent along the test section, with an average difference of 0.16 in. (4 mm). There are two possible hypotheses behind this observation.
    1. The fabric interlayer in the driving lane has been vertically compressed from the truck traffic in addition to slab's self-weight, whereas no traffic is occurring on the shoulder and the fabric is only compressed due to slab's self-weight.
    2. There is a cross-slope change between the driving lane and outside shoulder, and it is possible that the shoulders have separated from the mainline since there are no tie bars at that joint. This joint was observed to be wider than the initial 0.25 in. (6.4 mm) longitudinal saw cut. It seems that it is also possible that it is a combination of these two potential reasons, such that the heavy truck traffic compresses the fabric in the driving lane and not in the shoulder (assumes fabric is continuous across the lane-shoulder joint). The compressed driving lane fabric settles slightly relatively to the shoulder. There may be some upheaval in the shoulder as well but only coring may determine this.
- Without incompressible fines getting in the joint or under the shoulder slab, this difference in elevation should not increase because there is a maximum compression thickness of the fabric interlayer. In addition, the macrofibers in the concrete are engaged and should be contributing to keeping the joint together. However, if differential movement is too high then joint width across the lane-shoulder joint increases and macrofibers are less effective.
- If this joint had a steel tie bar, the separation and differential elevation may have been limited and potentially negated. It is also possible that separation could have occurred along the longitudinal joint within the driving lane (6 ft [1.8 m] offset from shoulder). There is a construction joint in the centerline between the passing and driving lane with steel tie bars. This joint was remaining tight.



A. Lane/shoulder jt. elevation difference (shoulder = approx. 0.16 in. [4 mm] higher than driving lane)


B. Potential distress occurring from elevation difference

Figure 27. Photos. Distress photos of longitudinal faulting in I-72 (72G92) westbound.

- Corner spalling is also occurring on the leave joint in the driving lane along the centerline longitudinal joint. It appears to be a form of chipping or spalling with a radius of 4 in. (102 mm). No other signifcant distresses were observed over the test sections.


A. Corner distress on leave joint left panel in driving lane


B. Corner distress on leave joint left panel in driving lane

Figure 28. Photos. Distress photos of corner spalling in I-72 (72G92) westbound.

Both directions:

- All approach slabs have the distress shown in the figure below. It appears the grooving for recessed pavement marking operation resulted in spalling of the approach slab. This can result in small corner spalls to eventually occur.

A. Grooving effect on approach joint spalling

B. Grooving effect on approach joint causing corner spalling

C. Grooving effect on leave joint corner spalling

Figure 29. Photos. Distress photos of improper recessed pavement marking grooving on I-72 (72G92) eastbound and westbound.

Table 11. I-72 (72G92) Temperature Profile for Eastbound (8/5/2020)

	Temperature @ corresponding depths (°F)		
Time of measurement	1.5-in. depth	3-in. depth	5.5-in. depth
8:45 am	72	73	78
1:00 pm	93	90	82
2:45 pm[1]	96	95	95

[1]Temperature readings are possibly erroneous due to operating errors.

Table 12. I-72 (72G92) Temperature Profile for Westbound (8/6/2020)

	Temperature @ corresponding depths (°F)		
Time of measurement	1.5-in. depth	3-in. depth	5.5-in. depth
8:30 am	67	68	70
1:00 pm	88	86	81
2:45 pm[1]	98	95	95

[1]Temperature readings are possibly erroneous due to operating errors.

MIRA ultrasonic device scanning was performed with 50 kHz testing frequency across transverse joints to assess joint activation (optimal testing frequency is 35 kHz). All other locations were performed with 50 kHz testing frequency. During field surveying, the majority of joints appeared to be activated and working. Joint conditions were clear to be able to determine if the joint activated/cracked or by looking into the joint (both westbound and eastbound). This was not expected for the westbound with the NWGF interlayer because of the low level of friction it provides. However, this is a good result.

Table 13. I-72 (72G92) Testing Sections and Stationing

Intensive test sections	**Time @ start of section**	**Stationing**	
		Beginning of test section	**End of test section**
Intensive test sections	**Time @ start of section**	**Stationing**	**End of test section (Approx.)**
1 EB	8:45 am	10+00	20+00
2 EB	10:15 am	74+15	84+15
3 EB	12:45 pm	142+50	152+50
1 WB	8:30 am	152+50	142+50
2 WB	10:00 am	112+50	102+50
3 WB	1:00 pm	20+00	10+00

Test sections consisted of 1,000 ft [305 m], with the first 90 ft [27.4 m] consisting of 15 adjacent panels and then one panel every 100 ft [30.5 m] tested with the FWD and MIRA. Test Sections 1 and 2 on the eastbound were tested in full, however time only permitted Section 3 to include the 15 consecutive panels to be tested and not the additional nine locations spaced at 100 ft [30.5 m] within the 1,000 ft [305 m] section. All three sections in the westbound direction were tested in full.

Detailed distress surveying was conducted along the driving lane where FWD and MIRA testing was performed.

Table 14. I-72 (72G92) Detailed Distress Survey Notes (Eastbound)

Stationing	Detailed distress notes
Section 1 (10+00 EB)	
9+38	Long. crack driving lane (DL) outer wheel path (OWP) across trans. jt.; corner spall approach jt. along centerline
11+08	Long. crack DL OWP and inside wheel path (IWP) across trans. jt.
11+43	Long. crack DL OWP and IWP across trans. jt. (~0.02-in. [0.45-mm] width)
11+80	Long. crack DL OWP across trans. jt.
11+97	Long. crack DL OWP and IWP across trans. jt. (~0.016-in. [0.40-mm] width)
12+46	Long. crack DL OWP across trans. jt.
12+58	Long. crack DL OWP across trans. jt.
12+94	Long. crack DL OWP across trans. jt.; corner spall approach jt. along centerline
13+54	Long. crack DL OWP and IWP across trans. jt. (~0.014-in. [0.35-mm] width)
14+02	Long. crack DL OWP and IWP across trans. jt.; corner spall approach jt. along centerline
14+32	Long. crack DL OWP across trans. jt.
14+68	Long. crack DL OWP across trans. jt.
15+04	Long. crack DL OWP across trans. jt.
15+35	Long. crack DL OWP and IWP across trans. jt. (~0.012-in. [0.30-mm] width)
15+47	Long. crack DL OWP across trans. jt.
15+95	Long. crack DL OWP across trans. jt.
16+30	Long. crack DL OWP across trans. jt.
16+49	Trans. jt. spalling
16+54	Long. crack DL OWP across trans. jt.
16+84	Long. crack DL OWP across trans. jt.
17+32	Long. crack DL OWP and IWP across trans. jt.
18+04	Long. crack DL OWP and IWP across trans. jt. (~0.016-in. [0.40-mm] width)
18+35	Long. crack DL OWP across trans. jt.
18+47	Long. crack DL OWP across trans. jt.
18+59	Long. crack DL OWP across trans. jt.
18+72	Long. crack DL OWP across trans. jt.; corner spalling lane-shoulder long. jt.
18+84	Long. crack DL OWP and IWP across trans. jt.
19+08	Long. crack DL OWP across trans. jt.
19+44	Long. crack DL OWP and IWP across trans. jt.
19+99	Long. crack DL OWP across trans. jt.; end of Section 1 (20+00)
Section 2 (74+15 EB)	
74+63	Long. crack DL IWP across trans. jt.
75+18	Long. crack DL IWP across trans. jt.
75+36	Long. crack DL IWP across trans. jt.
78+85	Long. crack DL IWP across trans. jt.
80+60	Spalling/ raveling along trans. jt.
84+15	End of EB Section 2

Stationing	Detailed distress notes
Section 3 (142+50 EB) – 5/13/2021	
142+50-150+00	Longitudinal joint faulting: Shoulder elevation > driving lane; spanning entire section; ~0.5 in. (12.5 mm) difference in elevation
143+10	Long. crack DL IWP across trans. jt. (observed in 2020 survey)
143+47	Long. crack DL IWP across trans. jt.
143+50	End of FWD testing for EB Section 3
143+89	Excessive joint width from saw cut
144+24	Long. crack DL IWP across trans. jt. (observed in 2020 survey)
144+60	Long. crack DL IWP across trans. jt. (observed in 2020 survey)
145+72	Drain outlet location along shoulder edge; standing water pooling
145+86	Long. crack DL IWP at trans. jt. (observed in 2020 survey); Leave slab only
146+00	2020 distress survey ends due to time constraints
146+26	Long. crack DL IWP across trans. jt.
146+99	Long. crack DL IWP across trans. jt.
147+44	Long. crack DL IWP across trans. jt.
147+60	Long. crack DL IWP across trans. jt.
148+15	Long. crack DL IWP across trans. jt.
149+23	Long. crack DL IWP across trans. jt.; not connected across joint
149+71	Long. crack DL IWP across trans. jt.
150+25	Long. crack DL IWP across trans. jt.; not connected across joint
150+80	Long. crack DL OWP at trans. jt.; Leave slab only (~6 in. [152 mm])
151+33	Long. crack DL OWP at trans. jt.; Leave slab only (~6 in. [152 mm])
152+06	Long. crack DL IWP across trans. jt.
152+24	Long. crack DL IWP across trans. jt.; not connected across joint
152+43	Long. crack DL IWP across trans. jt.; not connected across joint

Table 15. I-72 (72G92) Detailed Distress Survey Notes (Westbound)

Stationing	Detailed distress notes
Section 1 (152+50 WB)	
151+29	Corner distress leave slab along centerline (~4-in. [102-mm] radius)
149+85	Corner distress leave slab along centerline (~4-in. [102-mm] radius)
148+34	Corner distress leave slab along centerline (~4-in. [102-mm] radius)
142+50	End of WB Section 1
Section 2 (112+50 WB)	
109+68	Corner distress leave slab along centerline (~4-in. [102-mm] radius)
108+05	Corner distress leave slab along centerline (~3-in. [76-mm] radius)
106+71	Corner distress leave slab along centerline (~1.5-in. [38-mm] radius)
102+80	Corner distress leave slab along centerline (~4-in. [102-mm] radius)
102+50	End of WB Section 2
Section 3 (20+00 WB)	
19+69	Corner distress leave slab along centerline (~4-in. [102-mm] radius)
16+61	Poor finishing of concrete surface across DL right edge panels
15+89	Corner distress and chip leave slab along centerline (~5-in. [127-mm] radius)
15+77	Corner distress and chip leave slab along lane-shoulder long. jt.
15+47	Corner distress and chip leave slab along centerline (~8-in. [203-mm] radius)
15+11	Corner distress and chip leave slab along centerline (~6-in. [152-mm] radius)
14+21	Corner distress and chip leave slab along centerline
13+01	Corner distress and chip leave slab along centerline
12+58	Corner distress and chip leave slab along centerline (~6-in. [152-mm] radius)
10+00	End of WB Section 3