Failure Modes in Unbonded Concrete Overlays

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Abstract

Unbonded concrete overlays (UBOL) consist of a new Portland Cement Concrete (PCC) layer placed on an existing PCC pavement. The new concrete layer is separated from the existing pavement by an interlayer system, allowing these overlays to be placed on distressed PCC pavements. The interlayer system usually consists of a thin open graded or dense graded hot mix asphalt (HMA) layer or a non-woven geotextile fabric. An effort is currently being undertaken to develop a mechanistic-empirical design procedure for UBOLs. To develop this procedure it is necessary to identify the distresses that commonly develop in these pavement structures. Performance data from in-service pavements at the Minnesota Road Research Facility (MnROAD), in Michigan and Missouri, as well as data in the Long Term Pavement Performance (LTPP) database was reviewed. It was found that primary cracking mechanisms include longitudinal cracking in the wheelpath, at random locations and at mid-lane, and transverse cracking due to reflective cracking, reflective distress and erosion along the transverse joint. Many of these distresses appear to be at least partially caused by breakdown of the interlayer.

Introduction

An unbonded concrete overlay of an existing concrete pavement (UBOL) is a Portland cement concrete (PCC) overlay that is separated from the existing distressed concrete pavement with the use of an interlayer. The interlayer is commonly a hot mix asphalt (HMA) layer or a non-woven geotextile fabric. UBOLs have been used since the 1910's to increase structural capacity and improve surface friction and ride quality (Taylor et al. 2007). These overlay systems are becoming increasingly popular for PCC pavement rehabilitation. UBOLs are durable, mitigate reflective cracking, require minimal pre-overlay repairs, and can be placed with traditional concrete paving methods. Additionally, UBOLs have performed very well in many states over the last 30 years (Harrington et al. 2007). UBOLs can consist of jointed plain concrete pavements (JPCP), jointed reinforced concrete pavements (JRCP), or continuously reinforced concrete pavements (CRCP). Most UBOLs that are currently being constructed are JPCP, and will therefore be the focus of this study.

The interlayer is a critical component of the UBOL structure. The interlayer acts as a shear plane by inhibiting the mechanical bonding between the two pavement structures, which allows for the two slabs to move independently of one another (Harrington et al. 2007). The HMA interlayer can be newly placed or an existing aged layer and is typically 1 to 5 in thick (ERES Consultants 1999). If the existing PCC pavement was previously overlaid with HMA to create a composite pavement, surface defects in the existing HMA can be removed through milling. Milling will also act to increase the bond between the interlayer and the PCC overlay by increasing the surface area of contact. In addition to dense graded HMA, open graded HMA courses have been used in order to improve drainage characteristics of the interlayer and prevent pressure buildup. Recently, non-woven geotextile fabrics have become a popular alternative as an interlayer in these structures. The use of fabrics is an adaptation of the German application of using fabrics to separate newly constructed PCC pavements from cement stabilized bases (Rasmussen and Garber 2009). In the United States, non-woven fabrics were first used as an interlayer in UBOLs in 2008. These overlays have yet to experience significant distress. The three interlayer types each have advantages and disadvantages. Dense graded HMA is relatively resistant to breakdown and erosion since water is not flowing through the interlayer. However, it is not drainable and trapped water can lead to moisture related distresses. Open graded HMA allows water to drain, but the material is more susceptible to erosion due to stripping and raveling. Non-woven geotextile fabric is not erodible, and has sufficient in plane permittivity to allow drainage.

Research Objective

There is currently no mechanistic-empirical design procedure that was developed specifically for UBOLs. The Pavement ME design guide considers UBOLs but it is designed using the same structural analysis and damage models used to design a new JPCP with some minor changes (ARA 2004). To account for the load transfer through the existing slabs, the load transfer efficiency through the base layer is recommended to be 40-70%. The stiffness of the base layer in the structural analysis model is considered a composite of the interlayer and the existing PCC pavement. Finally, it is recommended that the base layer be considered non-erodible in the faulting model. The drainability and erodibility of the interlayer are not considered. Therefore, the primary distress considered in the design guide is transverse cracking at mid-slab (ARA 2004). Observations of field data have revealed that this is not the prevalent distress in UBOLs. In order to develop an appropriate design procedure for the design of JPCP UBOLs, the prevalent distresses and the mechanisms causing those distresses must first be identified. The objective of this research effort is to evaluate the failure mechanisms for UBOLs and identify the primary modes of failure.

Data Sources

Distress data from UBOL projects was examined from several sources in order to obtain as large of a data set as possible. These included pavements in the Long Term Pavement Performance (LTPP) database General Pavement Study (GPS) 9 experiment, overlays in Cells 105, 205, 305, 405, 505, and 605 from the Minnesota Road Research Facility (MnROAD), and other UBOLs in state highway systems.

LTPP GPS-9 Sections The LTPP GPS-9 experiment contains 14 JPCP UBOLs. One section did not use an interlayer system, instead separating the new and existing layers with a bond breaker. The specifics on the type of bond breaker used were not available and therefore this section was not included in the analysis. The design features for the sections considered are provided in

Table 1 (FHWA 2015). It is difficult to separate the effects of pavement thickness, dowel bars, and edge support from this data, as the variables are confounded. Manual distress surveys and automated distress surveys are performed on these sections regularly, and were aggregated to develop a time history of the distress development for this study. Falling weight deflectometer (FWD) testing is also performed regularly on these sections.

Table 1: LTPP and MnROAD Design Features

Location	Section	Overlay Thickness (mm)	Interlayer Thickness (mm)	IL Type	Dowel Dia. (mm)	Climate	Shoulder	Drains	Jt Spacing (m)
LTPP	6-9048(CA)	163	5	Chip Seal	None	W,NF	HMA	None	3.6,4.0,5.5,5.8
	6-9049(CA)	191	3	Chip Seal	None	W,NF	HMA	None	3.6,4.0,5.5,5.8
	6-9107(CA)	229	25	Dense Graded HMA	None	W,NF	HMA	Long.	3.6,4.0,4.3,4.6
	8-9019(CO)	229	5	Chip Seal	None	D,F	Untied PCC	None	4.0
	8-9020(CO)	203	3	Chip Seal	None	D,F	Tied PCC	None	4.0
	18-9020(IN)	254	5	Dense Graded HMA	None	W,F	HMA	X-Drains	4.7
	20-9037(KS)	153	51	Dense Graded HMA	12.7	W,F	Gravel	None	4.6
	27-9075(MN)	150	20	Dense Graded HMA	None	W,F	HMA	None	4.7
	28-9030(MS)	254	140	Dense Graded HMA	25.4	W,F	HMA	None	4.7
	31-6701[1](NE)	203	0	Bond-Breaker	None	W,F	Tied PCC	None	4.4
	42-1627(PA)	262	32	Dense Graded HMA	31.8	W,F	Tied PCC	Long.	6.2
	42-9027(PA)	305	94	Dense Graded HMA	38.1	W,F	Tied PCC	Long.	6.1
	48-9355(TX)	254	36	Dense Graded HMA	31.8	D,NF	Tied PCC	None	4.6
	48-9187(TX)	254	221	Dense Graded HMA	31.8	D,NF	Widened Lane	None	4.6
	89-9018(QC)	153	13	Chip Seal	None	W,F	HMA	None	5.0
MnROAD	Cell 105 and 205	102	25	Open Graded HMA	None	W,F	Widened Lane	None	4.6
	Cell 305 and 405	127	25	Open Graded HMA	None	W,F	Widened Lane	None	4.6
	Cell 505 and 605	127	4 (500 g/m^2)	Non-Woven Geotextile Fabric	None	W,F	Widened Lane	None	1.8

MnROAD Cells 105-605 Six Sub-Cells of UBOLs were built at MnROAD. Sub-Cells 105, 205, 305, and 405 were constructed in 2008 as overlays of the JPCP in Cell 5, a 191 mm thick JPCP pavement with 6.1 m joint spacing on what is considered the mainline. These sections are loaded with traffic from I-94. The large panel Sub-Cells 105 and 205 had larger panels which exhibited significant distress after three years of being in-service, and were replaced with Sub-Cells 505 and 605 in 2011, which had smaller panels. The interlayer in Sub-Cells 505 and 605 consists of a non-woven geotextile fabric with a unit weight of approximately 500 g/m^2 (approximately 4 mm thick). No significant distress has developed in these Sub-Cells to date. A 76-mm thick overlay was built on the low volume road (Cell 40) in 2013. This overlay is thinner than the UBOLs typically used in practice and experienced a decrease in serviceability due to slabs rocking under wheel loads. This section was not considered in this study since this thin slab is not representative of a typical UBOL. The design features for these sections can be seen in Table 1. Manual distress surveys and FWD testing are performed on these overlays twice a year. Manual distress surveys of the existing pavement prior to overlay construction are also available so comparisons can be made between the location of the distress in the overlay to the location of the joints and distresses in the existing pavement.

Other In-Service Pavements Michigan has a significant amount of experience using UBOLs, with the oldest overlays constructed in 1984. These overlays are typically between 152 mm and 203 mm thick. The UBOLs typically have dowel bars ranging between 25 and 38 mm diameter, and tied concrete shoulders. Prior to 2004, interlayer systems typically consisted of 25 mm of dense graded HMA. MDOT has identified drainage as a crucial aspect in the design of UBOLs and since 2004 they began using a 25-mm open graded HMA interlayer.

A survey of UBOLs in Michigan was performed in August and September 2014. Crack counts, faulting, and IRI were also evaluated. Michigan has recently experimented with using non-woven geotextile fabric as an interlayer. A test section in US-10 near Coleman, Michigan was constructed with both fabric and open graded HMA interlayer sections.

Missouri also has significant experience with UBOLs. Two different designs are used in Missouri. Overlays with 4.6 m joint spacing are typically 203 to 229 mm thick. Overlays with 1.8x1.8 m panels are typically 152 mm thick. The thicker overlays have dowels at the transverse joints, whereas the thinner design does not. Up until 2008, most of the interlayer systems were dense graded HMA. In 2008, Missouri built the first overlay on non-woven geotextile fabric in the United States on Route D near Kansas City. The department has built several 152 mm thick pavements with 1.8x1.8 m panels on non-woven geotextile fabric since then.

Observed Distresses

The performance data for the pavements described above was evaluated to determine what failure mechanisms commonly occur in UBOLs. The following distresses were determined to be the most prevalent in UBOLs.

Longitudinal Cracking

Longitudinal cracking in UBOLs can develop as a result of three mechanisms. These include 1. cracking in the wheelpath caused by deterioration of the interlayer due to fatigue, localized stripping, and/or consolidation, 2. cracking at random locations due to erosion “wash out” of the interlayer along the roadway length, and 3. cracking at mid-lane possibly due to high curling stresses.

Wheelpath Longitudinal Cracking A common location for the development of longitudinal cracks is the wheelpath. These cracks develop in both the outside and inside wheelpath, and can initiate on both the leave and approach side of the transverse joint or crack. Once these cracks initiate, they may propagate longitudinally to the adjacent transverse joint, or they may turn and propagate toward the adjacent longitudinal joint (lane-shoulder or centerline), appearing as a diagonal crack.

The high stress contributing to the initiation of this crack can be the result of a void or gap in the interlayer beneath the overlay. A void can form beneath the slab in the wheelpath in several ways. Consolidation in the HMA interlayer may occur in the wheelpath at the joint. Also, a portion of the interlayer may be pumped from beneath the joint resulting in faulting on the approach side of the joint and a void on the leave side of the joint. Finally, less stable interlayer systems, such as an open graded asphalt mix or a dense graded HMA where localized stripping has occurred in the vicinity of the transverse joint, may also fatigue and breakdown in the wheelpath. These can all lead to loss of support in the wheelpath starting at the joint, and eventually propagating the full length of the slab. When a wheel load is applied over this area, the slab must bridge this loss of support region, creating stress at the bottom of the slab and eventually bottom-up cracking in the wheelpath. This mechanism can be seen in Figure 1. Bonded Concrete Overlays of Asphalt (BCOA) with 1.8x1.8 m panels experience a similar distress mechanism (Li and Vandenbossche 2013).

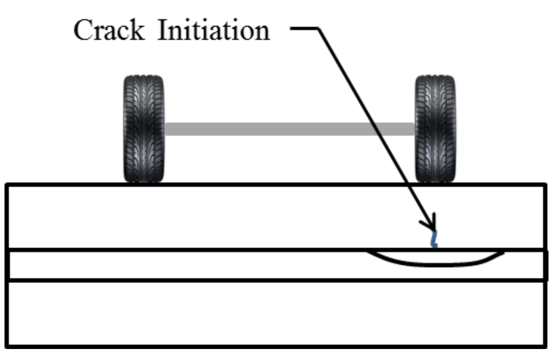
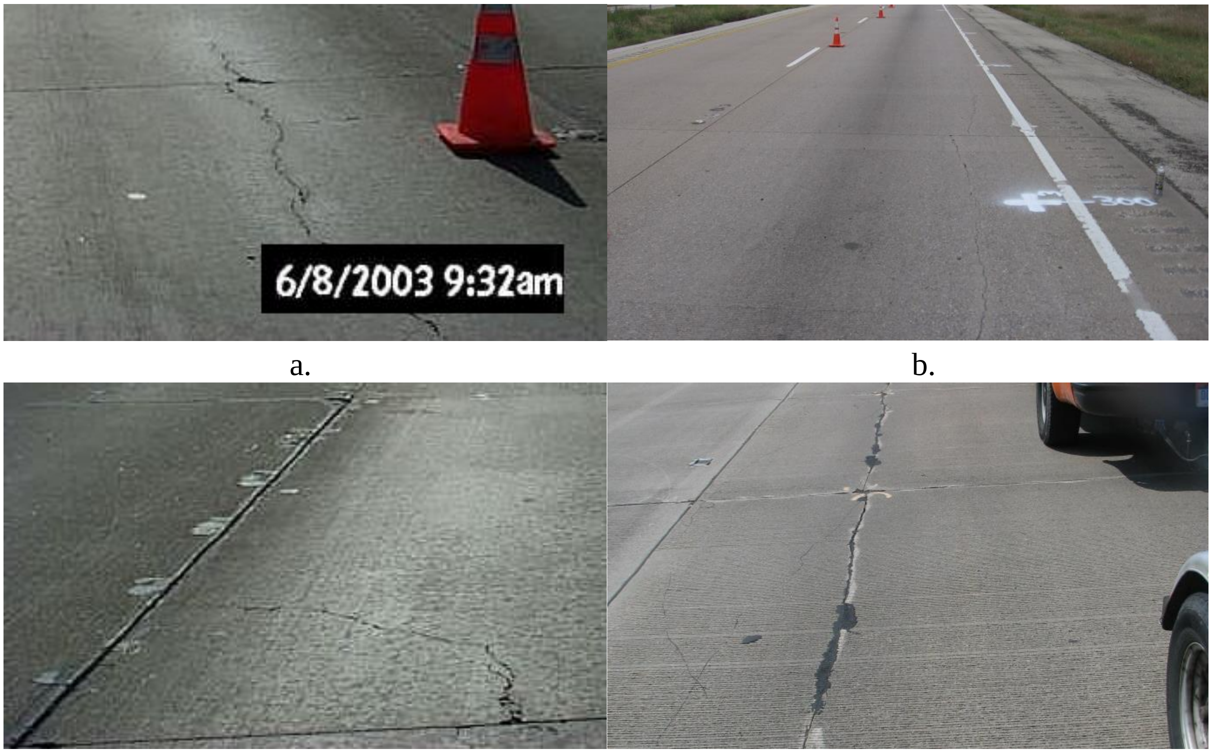


Figure 1: Longitudinal Cracking in the Wheelpath Mechanism

Longitudinal cracks were the primary distress mechanism observed in the UBOLs included in the LTPP database and in Michigan. They occur in 11 of the 13 JPCP LTPP sections, and in all of the Michigan sections reviewed. The undoweled sections in the LTPP database, which experience significant faulting of the transverse joints have developed more longitudinal cracks in the wheelpath than the doweled sections where faulting did not develop. However, it is worth noting the doweled sections in the LTPP GPS-9 were thicker than the undoweled sections as well. Figure 2 shows some examples of longitudinal cracking in the wheelpath.



a. b.

c. d.

Figure 2: a. Longitudinal Crack in Inside Wheelpath LTPP Section 06-9049, CA (Photo from Infopave.com), b. Longitudinal Crack in Outside Wheelpath LTPP Section 48-9167, TX (Photo from Infopave.com), c. Diagonal Crack Propagating to Adjacent Longitudinal Joint LTPP Section 06-9049, CA (Photo from Infopave.com), d. Longitudinal Cracks In Inside Wheelpath I-96 Near Walker, Michigan (Photo Courtesy of Andrew Bennett, Michigan Department of Transportation)

There are several ways to mitigate this distress mechanism. 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 pumping by using load transfer devices will also be helpful. Finally, using an interlayer system which is not prone to consolidation or stripping, will help minimize this distress as well.

Random Longitudinal Cracking In traditional JPCPs, longitudinal cracking can develop as a result of loss of support beneath the slab due to erosion of the underlying layer along the roadway. It is often the result of consolidation or transport of base layer materials due to poor drainage. Similar distress is found in UBOLs when the interlayer erodes away. These cracks usually occur on the shoulder side of mid-lane but do not necessarily occur in the wheelpath. This mechanism can be seen in Figure 3.

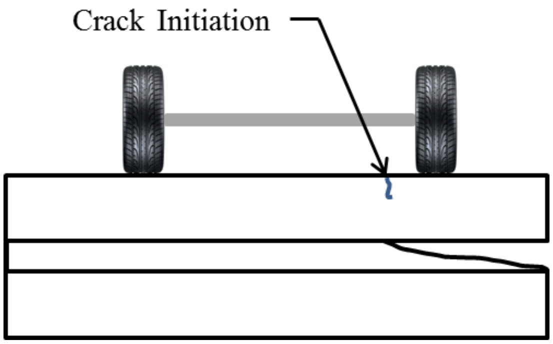


Figure 3: Loss of Support Mechanisms in UBOLs

A survey of Michigan UBOLs found these cracks often occurred in clusters, when proper drainage was not provided. MDOT has identified proper drainage as a crucial aspect necessary for good performing UBOLs. Without a means of escaping, water can become trapped along the interlayer. Figure 4 shows a random longitudinal crack on I-75 near West Branch, Michigan.

Figure 4: Random Longitudinal Crack, I-75 West Branch, Michigan

Careful attention to pavement drainage details are important for preventing random longitudinal cracking. A clear path must exist for any water entering the pavement to reach the drainage system. Proper maintenance of the drains and outlets is extremely important for these structures as well. The backup of water from a clogged drain can quickly strip and erode the interlayer. Drainable interlayers such as open graded asphalt or non-woven geotextile fabric will only improve drainage characteristics if there is a suitable method for removing the water from away from the pavement structure.

Longitudinal Cracking at Mid-Lane In pavements thinner than 205 mm thick, longitudinal cracking often develops at the transverse joint at mid-lane. Similar to the longitudinal cracks that develop in the wheelpath, these cracks sometimes propagate longitudinally to an adjacent transverse joint or crack, while other times will turn and propagate diagonally towards the lane-shoulder joint. For the mid-lane longitudinal cracks observed, albeit a small data set, all of the cracking appears to initiate on the leave side of the joint and propagate to a longitudinal joint or the approach side of an adjacent joint. Sometimes the crack would propagate on the approach slab, but only after the leave slab cracked. These cracks occurred primarily in thinner (less than 200 mm) sections. It is possible that higher curling and warping stresses may contribute to the development of these stresses. In a traditional JPCP, the less stiff base layer allows the pavement to "settle in," and the wheelpaths primarily fail near the rotation point (the point whose position is constant throughout the daily temperature gradient cycle) (Vandenbossche 2003)(Asbahan and Vandenbossche 2011). This results in the critical stress being in the middle third of the slab in the transverse direction, leading to longitudinal cracks. It is possible that with the stiff base provided by the existing pavement and interlayer, the rotation point is much closer to the center of the lane. If this is the case, an axle load when the slab is experiencing a negative gradient could cause a critical stress at the top of the slab in the transverse direction, as can be seen in Figure 5. UBOLs also tend to have full width panels with short (3.1-3.7 meters) transverse joint spacing. This further increases the likelihood that the critical stress causes longitudinal cracking at mid-lane, rather than transverse cracking at mid-slab (they are shorter than they are wide).

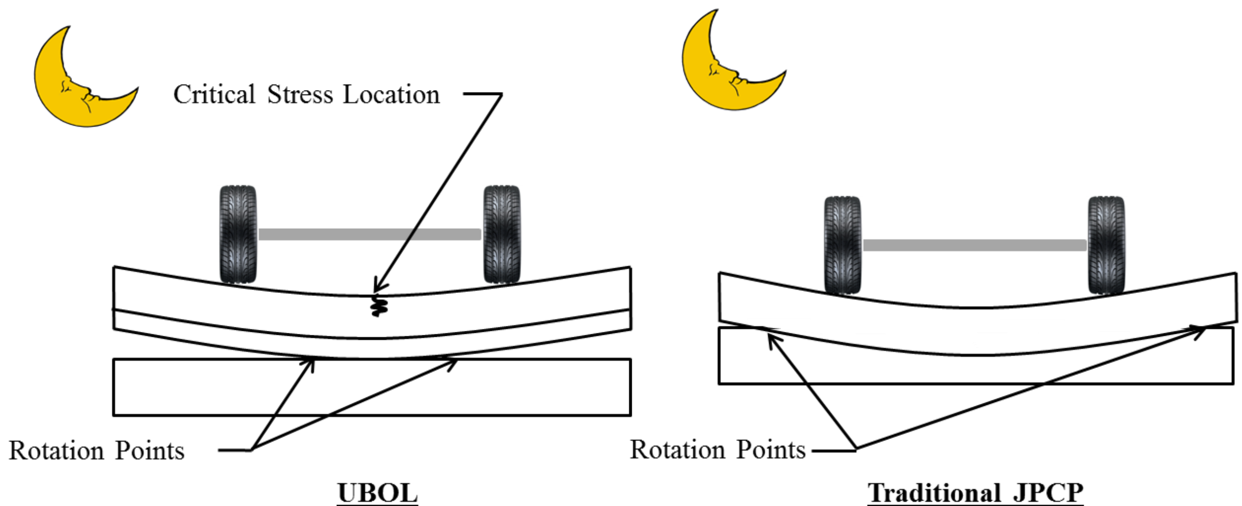
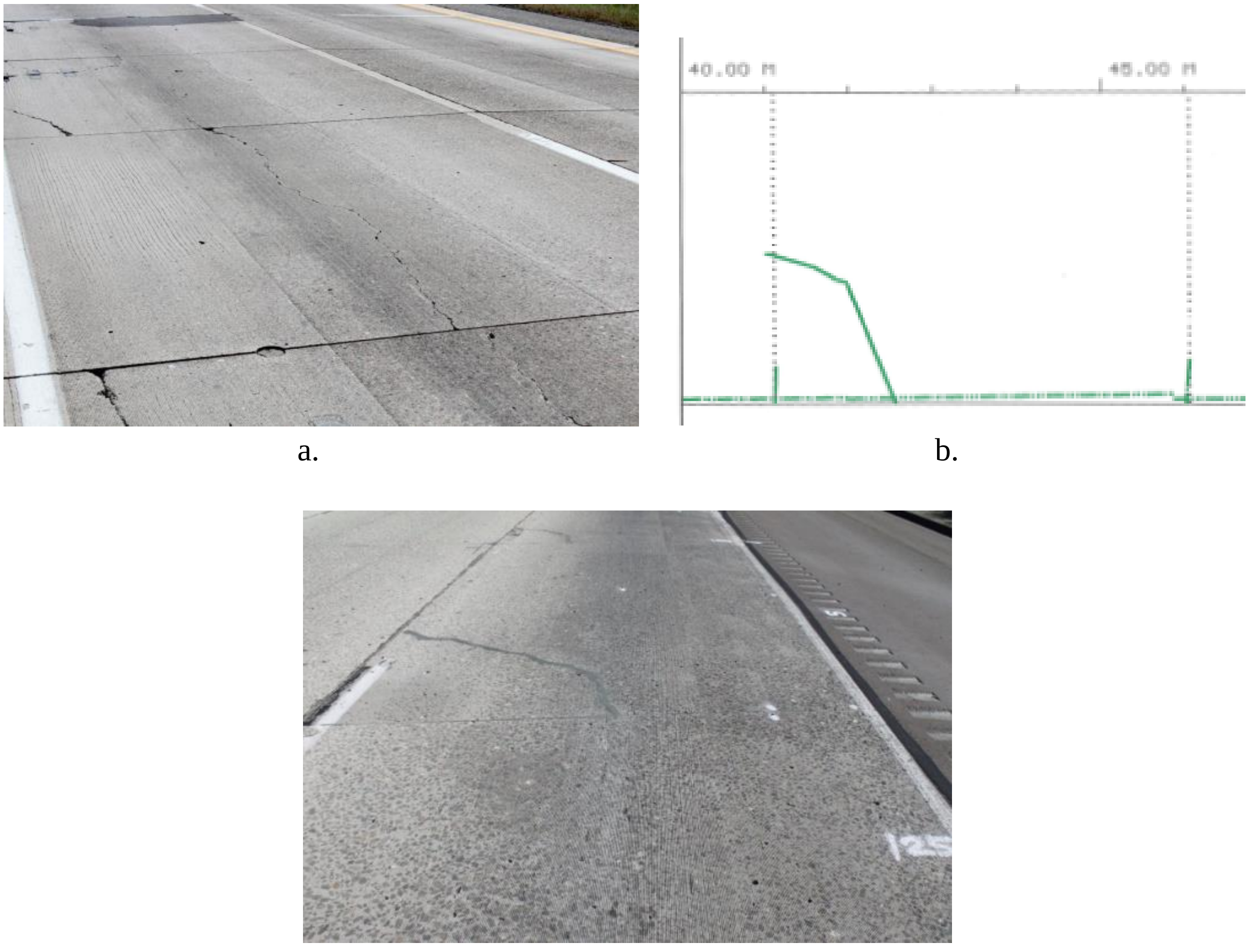


Figure 5: Mid-slab Longitudinal Cracking Mechanism

Mid-slab longitudinal cracks developed in MnROAD Cells 305 and 405, LTPP Sections 06-9048 and 06-9049 in California, 20-9037 in Kansas, and 89-9018 in Quebec. At MnROAD and LTPP Section 20-9037, the longitudinal cracks occurred only at mid-lane. It should be noted that LTPP Section 20-9037 experienced a significant amount of material related distress. In the other sections, the cracking at mid-lane was secondary to cracking in the wheelpath.



a. b.

c.

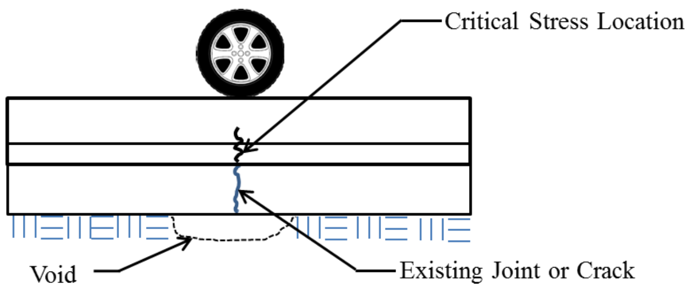
Figure 6: Longitudinal Crack at Mid-Lane at a. MnROAD Cell 305, b. LTPP Section 89-9018 Quebec (Automated Distress Survey From Infopave.com) c. LTPP Section 06-9048 California (Photo From Infopave.com)

An effective way to decrease the stresses due curling and warping in the slab coupled with wheel loads is to increase the thickness of overlay. A thicker pavement will experience lower flexural stresses from wheel loads, and smaller effective temperature and moisture gradients. A less stiff interlayer, such as a non-woven geotextile fabric or open graded asphalt should allow the pavement to sink into the interlayer more under its own self weight. This will decrease the portion of the slab which is unsupported when the slab is curled upward and thereby decrease curling stresses. Stress reductions can also be achieved by using smaller slab sizes, such as 1.8 x 1.8 m. This will both decrease the curling and warping stress, and eliminate the negative moment due to wheel loading, as the slabs would only be loaded by half the axle at a time.

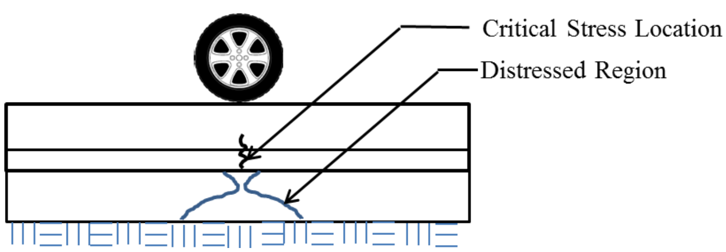
Transverse Cracking

Transverse cracks can develop in UBOLs due to three separate mechanisms: 1. reflective cracking, 2. reflective distress, and 3. erosion along the transverse joint. It is not common, since all sections with a slab length to thickness ratio less than 30, had less than 5% slabs cracked due to transverse cracking.

Reflective Transverse Cracking A discrete transverse crack or joint in the existing pavement can reflect into the overlay. This can be exacerbated by a lack of support underneath the joint. A laboratory study revealed that a discrete joint or crack in the existing pavement will not reflect up into the overlay under normal wheel loads if the existing pavement is fully supported. When a void is simulated under a crack or joint in the existing pavement, a reflective crack can develop (Sachs et al. In Review). A wheel load in the middle third of the slab will cause a tensile stress at the bottom of the slab. This stress will be higher if there is a loss of support area underneath the joint than if the slab is fully supported. The damage caused by this loading can be intensified by the stress concentration at the discrete crack in the existing layer. This mechanism is shown in Figure 7a.



a. Reflective Cracking



b. Reflective Distress

Figure 7: Reflective Cracking and Reflective Distress Mechanisms

At MnROAD, two mid-slab transverse cracks formed in the passing lane of Sub-Cell 305. These cracks both occurred when joints in the existing pavement aligned at mid-slab in the overlay. One of these transverse cracks can be seen in Figure 8. From the pre-overlay distress survey, these joints were not distressed and were not exhibiting faulting but FWD testing was not performed on either of the existing joints which reflected up to establish if a void was actually present. FWD testing was performed on a joint between the two reflective cracks. The LTE at the tested joint had been measured as low as 60%. This indicates that the existing joints may have been at risk for developing voids. No reflective cracks occurred in Sub-Cell 405, where the joints were distressed by a "Road Warrior" hammer prior to overlay construction. It is possible that the hammer drove the existing pavement into any voids that had developed, and actually helped provide uniform pavement support.

Figure 8: Reflective Transverse Crack at MnROAD Sub-Cell 405

When selecting a rehabilitation alternative it is important to consider the support conditions of the existing pavement. UBOLs are a good rehabilitation alternative for pavements which are distressed, but uniformly supported. If voids are present, uniform support should be restored by subsealing prior to the construction of the overlay.

Reflective Distress The long term performance of concrete pavements requires uniform support conditions. A distressed region in the existing slab can result in a reduction in support that must be bridged by the overlay. This will be referred to as reflective distress to differentiate it from a reflected crack that develops in the overlay above a discrete undeteriorated crack. An example of reflective distress can be seen in Figure 7b.

US 131 near Plainwell, Michigan had many deteriorated joints prior to overlay construction. MDOT performed little to no pre-overlay repairs so they could determine how severely deteriorated the distress can be in the existing pavement without adversely affecting the performance of the overlay. This overlay developed a significant number of transverse cracks, which were not prevalent in other sections in Michigan. Also, a tight mid-slab transverse crack on I-96 near Portland, Michigan was cored, and it revealed the crack was above a distressed region in the existing pavement (Andrew Bennett, Personal Communication, September 2014). The overlay at this location is a JRCP with a 12.5 m joint spacing, which may influence the development of reflective distress. It is also unknown if voids occurred beneath the distressed regions in the existing pavement, which would contribute to reflective distress.

Reflective distress does not always occur above deteriorated joints. In Missouri, a UBOL was placed in 2008 on a rural road with severe joint deterioration. Deteriorated joints were filled with grout or asphalt but were not repaired. The pre-overlay pavement can be seen in Figure 9. No reflective distress has occurred in the seven years since construction (John Donahue, Personal

Communication, August 2015). As previously mentioned, less cracking occurred in MnROAD Sub-Cell 405, where the joints were intentionally distressed with a "Road Warrior" hammer, than when the joints were not distressed.

Deteriorated sections of the existing pavement should be checked for uniform support. If any voids occur, uniform support should be restored by subsealing. Any large gaps in the existing pavement should also be filled.

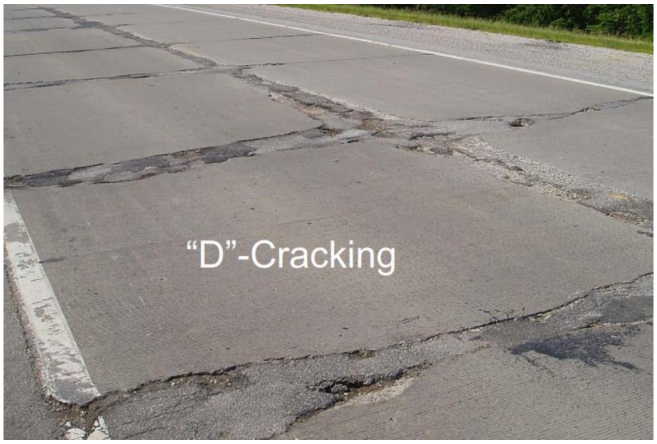
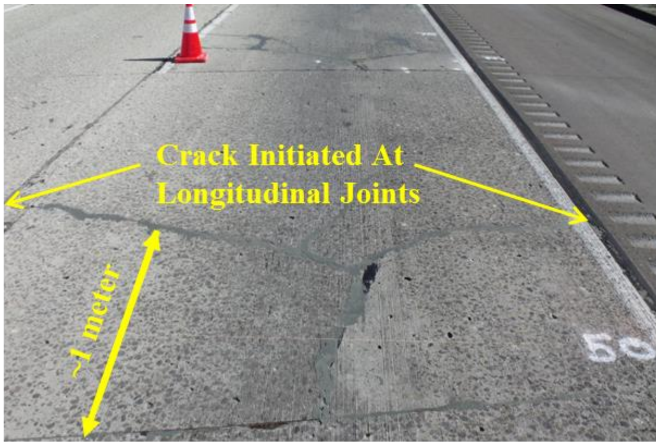


Figure 9: Condition of Route D in Missouri Prior To Overlay (Photo Courtesy of Todd LaTorella, ACPA)

Erosion Along the Transverse Joint Transverse cracks also form on the leave third of the overlay slabs, 0.5-1.5 m from the transverse joint. This is most likely due to the interlayer washing out due to water entering the transverse joint. Often a longitudinal crack will form between the crack and the adjacent joint and will look similar to that of a punch out in CRCP. Water entering the transverse joint due to lack of sealant or damaged sealant will drain slowly from the pavement structure, even when an open graded mixture is used. During periods of upward curling, water may even pool in the gap between the interlayer and the existing slab. If water only enters on part of the lane, a corner break may develop. This water will cause an asphalt interlayer to strip and ravel, leading to a loss of support. Images of this distress can be seen in Figure 10.



a. b.

c.

Figure 10: Transverse Crack Due to Erosion at a. LTPP Section 06-9048, California, b. MnROAD Cell 305, and c. a corner break on an UBOL in Michigan.

The LTPP Section 06-9048 seen in Figure 10 is experiencing spalling along the joint, which is likely compromising the effectiveness of the joint sealant. The joints at MnROAD in Sub-Cell 305, also shown in Figure 10, were not sealed, allowing water to enter (Watson and Burnham 2010). Preventing water from entering the joint with well-maintained joint sealant may prevent interlayer erosion along the longitudinal joint.

Deterioration of the interlayer between a transverse joint and an adjacent transverse crack have been observed in several locations. Repairs in Cell 305 at MnROAD revealed that the open graded HMA interlayer had broken down into gravel at these distress locations. Cores taken from the thin UBOL constructed on TH-53 near Duluth, MN (229 mm overlay on a 25-mm dense graded HMA interlayer) revealed deterioration of the dense graded HMA interlayer as well. The deteriorated interlayers from these sections can be seen in Figure 11. The Missouri Department of Transportation has also taken cores in similarly distressed locations, which again revealed the HMA interlayer had broken down (John Donahue, Personal Correspondence, August 2015).

a. MnROAD Cell 305 b. Core from TH-53 (Duluth, MN)

Figure 11: Deteriorated Interlayers Between the Transverse Joint and and Adjacent Transverse Crack

FWD testing was performed on LTPP Section 06-9048, where several of these voids developed. At each joint, deflection testing was performed near the 40 kN, 53 kN, and 71kN load levels, at the corner of the slab. The void parameter is calculated as the deflection intercept of a linear regression line drawn through the load vs. deflection data. The results can be seen in Figure 12. Of the seven joints which exhibit a void parameter greater than 50 microns, a transverse crack formed on the leave side of the joint four times, and a corner break formed three times. Transverse cracks or corner breaks did not occur at any location where a void was not detected. This confirms that the transverse cracks 0.5-1.5 m on the leave side of the joint are likely caused by a loss of support. .

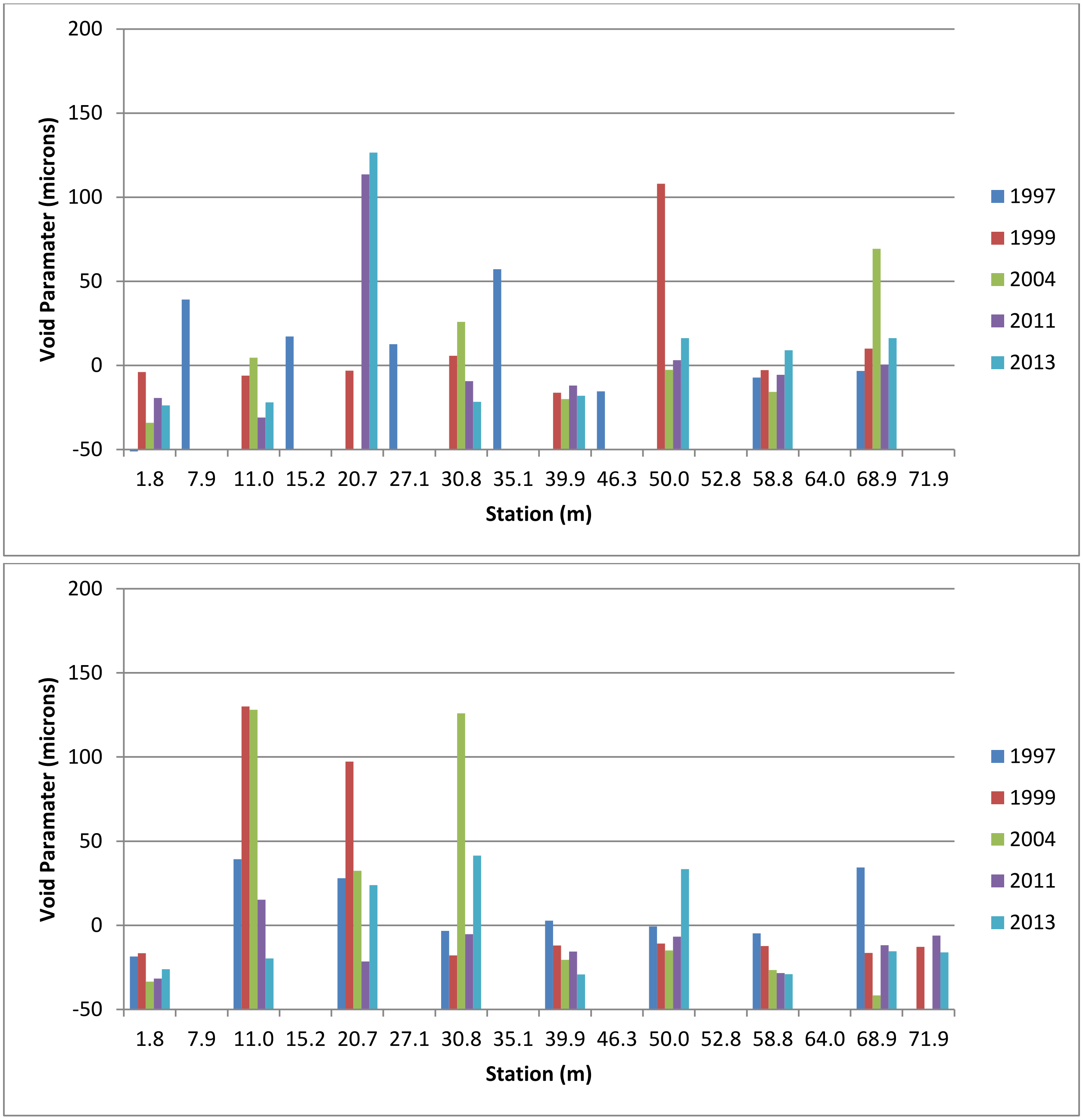


Figure 12 Deflection Intercept Corner Void Detection for LTPP Section 06-9048 in California

To prevent cracks from forming on the leave side of the joint, it appears to be important to keep joints properly sealed. Using a non-erodible interlayer, such as a non-woven geotextile fabric will also help mitigate this distress.

Conclusion and Recommendations

The type of cracking which was found to develop in UBOLs is longitudinal cracking in the wheelpath and at mid-lane, transverse cracking on the leave side of the joint, and transverse cracking due to reflective cracking, reflective distress, and erosion of the interlayer along the transverse joint. The current mode of failure addressed in the Pavement ME design guide, is transverse fatigue cracking. This does not appear to be a primary mode of failure.

A majority of the distresses observed, (wheelpath longitudinal cracking, random longitudinal cracking and transverse cracking on the leave side of a transverse joint) show some evidence of being caused by loss of support from erosion, consolidation, or general breakdown of the interlayer. This can be exacerbated by the presence of water, which can lead to stripping and raveling of the interlayer, especially when it is pumped back and forth under wheel loads. It is important to consider the durability and drainability of an interlayer system in addition to the stiffness and boundary conditions of the interlayer. Attaining both durability and drainability can be conflicting objectives, as the more drainable a HMA mixture is, the more prone it will be to stripping and raveling. Proper steps should be taken to avoid the development of these distresses by ensuring a durable interlayer system with a collection system that will facilitate positive drainage. Reflective cracking and reflective distress can also be prevented simply by subsealing and/or filling the distressed regions prior to the placement of the overlay.

In order to develop a mechanistic-empirical design procedure for UBOLs, the effect of the interlayer on the performance of the UBOL must be characterized. These characteristics must be incorporated in the development of structural response models to be used in predicting the development of longitudinal distresses at mid-slab and in the wheelpath. These interlayer characteristics, as well as how they might change over time, must also be considered when calibrating transfer functions to be used to relate damage to predict cracking. These steps will result in major improvements in providing a reliable method for designing UBOLs.

Acknowledgement

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