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Flexible Pavement Design (Full-depth Asphalt and Rubblization): A Summary of Activities

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16. Abstract

This report summarizes activities undertaken to support and ensure that the Illinois Department of Transportation utilizes the best demonstrated available technology for design and construction of full-depth hot-mix asphalt (HMA) pavements and HMA pavements on rubblized Portland cement concrete pavement (PCCP). To achieve this goal, the researchers reviewed pavement design and special provisions for full-depth asphalt and rubblization projects as well as full-depth asphalt and rubblization project performance via condition surveys and deflection measurements. They also modified design inputs as needed from the review of literature and responded to specific issues related to full-depth asphalt and rubblization design and construction. The researchers studied 32 rubblization projects on the interstate system and found this rehabilitation technique is providing good to excellent performance that exceeds design expectations. They provided input on proposed changes to full-depth hot-mix asphalt pavement on rubblized PCCP specifications as well as provided input on the RoadTec 1105e material transfer device. Analysis of traffic speed deflectometer data obtained on several hot-mix asphalt and rubblized pavements resulted in the development of analysis algorithms.

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Members of the Technical Review Panel (TRP) were the following:

- Charles Wienrank, TRP Chair, Illinois Department of Transportation
- Dennis Bachman, Federal Highway Administration, Illinois Division
- Mike Brand, Illinois Department of Transportation
- Kevin Burke, Illinois Asphalt Pavement Association
- Brian Hill, Illinois Department of Transportation
- Tim Peters, Illinois Department of Transportation
- LaDonna Rowden, Illinois Department of Transportation
- John Senger, Illinois Department of Transportation
- Heather Shoup, Illinois Department of Transportation

EXECUTIVE SUMMARY

Current Illinois Department of Transportation (IDOT) mechanistic-empirical (M-E) pavement design procedures for full-depth hot-mix asphalt (FDHMA), rubblized Portland cement concrete pavement (PCCP), and design of HMA pavement on rubblized PCCP are significantly based on previous University of Illinois at Urbana-Champaign research funded by IDOT. To maximize the impact of these M-E pavement design procedures and maintain their applicability and credibility, they should reflect current technology (as applicable for IDOT construction).

The focus of this project was to utilize the best demonstrated available technology (BDAT) as related to FDHMA pavements and HMA pavement on rubblized PCCP. The project's activities included the following tasks:

- Task 1: Review full-depth asphalt and rubblization projects identified by IDOT from the Transportation Bulletin and provide comments on pavement designs and special provisions.
- Task 2: Evaluate performance of existing full-depth asphalt and rubblization projects through pavement condition surveys and analysis of falling weight deflectometer (FWD) data collected by IDOT.
- Task 3: Review flexible pavement design literature and update/modify (as appropriate) previously provided inputs concerning mix design, testing procedures, thickness design, construction, and performance.
- Task 4: Respond to IDOT inquiries/questions concerning full-depth asphalt and rubblization-related issues.

A comprehensive performance study of rubblized Portland cement concrete interstates with HMA pavement was conducted (Lippert, Thompson, & Wienrank, 2021). The study considered 32 separate projects. The study concluded that, overall, rubblization is providing good to excellent performance and exceeding design expectations.

Project staff reviewed the plans and closely followed the construction of a rubblized PCCP with HMA pavement on I-74 west of Normal, Illinois (Contract 68A79). The project was unique in the use of a granular layer over the rubblized PCCP. The granular layer was utilized to achieve grade control. Prior to the placement of the 2 in. stone-matrix asphalt (SMA) surface, falling weight deflectometer (FWD) testing was conducted.

Project staff provided inputs to IDOT concerning several issues. Two of the most important inputs were the evaluations of the proposed specification for FDHMA pavement on rubblized PCCP and the RoadTec 1105e material transfer device (MTD). The rubblization specification will be included in the 2022 Standard Specifications for Road and Bridge Construction after being a special provision for many years. The MTD was evaluated by IDOT and was conditionally added to the group of MTDs currently allowed by IDOT. This device fills a gap where MTDs are desired on the lower construction lifts where heavy devices are not allowed.

An analysis was conducted of FWD and traffic speed deflectometer (TSD) data for several FDHMA pavements and rubblized PCCP with HMA pavement. Table 3 and Table 4 present the results. Because TSD loading is not like FWD loading, new ILLI-PAVE analysis algorithms were developed for analyzing the TSD data for FDHMA pavements and rubblized PCCP with HMA pavement.

A fatigue study was completed in 2019 for a significant National Cooperative Highway Research Program Project 9-59 (NCHRP 9-59) (Christensen, 2019). The project's final report has not been published, but a comprehensive paper was published in 2019 (Christensen & Tran, 2019). The draft NCHRP final report and the paper were reviewed by the lead author of this report, Marshall Thompson. Particularly relevant findings from the paper are as follows.

The fatigue performance of asphalt mixtures is primarily dependent on the applied strain relative to the strain capacity of the binder used in the mix as well as on the fatigue exponent. Note that the fatigue exponent is the exponent in the HMA fatigue algorithm, shown below.

$$N = K1\left(\frac{1}{\varepsilon_{HMA}}\right)^{K2}$$

Where, N is the number of load repetitions to "failure" (50% reduction in modulus), ε_{HMA} is the engineering flexural strain at the bottom of the HMA layer, and *K1* and *K2* are the intercept and slope, respectively, of regression. The fatigue exponent of asphalt mixtures is 180 divided by the binder phase angle in degrees (at the fatigue testing temperature).

The study confirmed the relation between *Log K1* and *K2* in the HMA fatigue algorithm. The relation is shown as follows:

$$Log\ K1 = 4.24 - (3.11 * K2)$$

The relation is similar to the one utilized by IDOT, shown below:

$$Log\ K1 = 3.43 - (3.4 * K2)$$

The key inputs in the current IDOT M-E thickness design procedures are HMA modulus-temperature algorithms, the HMA fatigue algorithm, and the fatigue endurance limit (FEL). The current inputs are based on the properties of HMAs utilized several years ago and do not consider the use of reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) in the mixtures or the use of asphalt modifiers.

The HMA modulus algorithms were established for consensus HMAs with virgin asphalt binders. Currently, most HMA binder mixes utilize grade bumping to accommodate the presence of recycled materials.

The current HMA fatigue algorithm used by IDOT is shown below:

$$N = 8.78 * 10^{-8}\left(\frac{1}{\varepsilon_{HMA}}\right)^{3.5}$$

The current Fatigue Endurance Limit (FEL) used in IDOT's design procedure is 70 microstrain.

The BDAT for establishing/estimating the FEL is not robust, particularly for HMAs with RAP and RAS. The project's staff kept these key inputs under continuous review and evaluated against BDAT. TRP meeting presentations have emphasized the importance of utilizing inputs representative of the HMAs currently utilized. To illustrate the impact of the FEL, a 10 microstrain increase in the FEL (to 80 microstrain) would typically decrease the HMA thickness by approximately 1 in.

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CHAPTER 1: INTRODUCTION

Current Illinois Department of Transportation (IDOT) mechanistic-empirical (M-E) pavement design procedures and policies for full-depth hot-mix asphalt (FDHMA), rubblized Portland cement concrete pavement (PCCP), and HMA pavement on rubblized PCCP are significantly based on previous University of Illinois at Urbana-Champaign research funded by IDOT. To maximize the impact of these M-E pavement design procedures as well as maintain their applicability and credibility, they should reflect current technology (as applicable for IDOT construction).

The focus of this project was to utilize best demonstrated available technology (BDAT) as related to FDHMA pavements and rubblized PCCP with HMA pavement.

Project activities included the following tasks:

- Task 1: Review full-depth asphalt and rubblization projects identified by IDOT from the Transportation Bulletin and provide comments on pavement designs and special provisions.
- Task 2: Evaluate performance of existing full-depth asphalt and rubblization projects through pavement condition surveys and analysis of falling weight deflectometer data collected by IDOT.
- Task 3: Review flexible pavement design literature and update or modify (as appropriate) previously provided inputs concerning mix design, testing procedures, thickness design, construction, and performance.
- Task 4: Respond to IDOT inquiries and questions concerning issues related to full-depth asphalt and rubblization.

Major activities pertaining to the tasks are presented in the following chapters of this report.

CHAPTER 2: REVIEW OF FULL-DEPTH ASPHALT PAVEMENT DESIGNS AND PROJECT SPECIAL PROVISIONS

The work under Task 1 was to review full-depth asphalt and rubblization projects identified by Illinois Department of Transportation from the Transportation Bulletin and provide comments on pavement designs and special provisions. This chapter details the activities and accomplishments under this task.

CONSTRUCTION PROJECT REVIEWED: I-74 RUBBLIZATION

Rubblization of the westbound lanes of the I-74 project west of Normal, Illinois (Contract 68A79), was initiated in 2019 (IDOT, 2018). Westbound traffic was moved to the eastbound lanes. The existing pavement was a 7 in. continuously reinforced concrete pavement (CRCP) with a 4 in. aggregate subbase. The existing HMA overlay thickness on the westbound lanes was a maximum of 13.9 in. with an average of 6.9 in. For the eastbound lanes, the maximum was 12.8 in., and the average was 5.7 in. The proposed pavement section was rubblization of the CRCP followed by an 11.25 in. HMA overlay (a limiting strain criterion design).

During a review of the bid plans, the project's staff noted that a Type A granular subbase, minimum Illinois bearing value (IBV) of 40, was to be utilized in many areas to achieve the required profile grade. A granular subbase over the rubblized CRCP has never been constructed on an IDOT interstate project. A previous project on I-55 in District 8 originally included a granular base, but the plans were amended prior to bidding and the granular base was eliminated. The granular subbase on the I-74 project was constructed per the original design. Figure 1 shows the resulting granular subbase during construction.

Figure 1. Photo. Granular subbase placed on passing lane vs. rubblized driving lane of I-74.

Paving of the westbound lanes was partially completed in 2019 with the construction of the 9.25 in. HMA binder course. The 2 in. SMA surface course was placed in 2020 following the completion of the eastbound lanes. Deflection testing using a falling weight deflectometer (FWD) was conducted upon the 9.25 in. binder course of the westbound section in the fall of 2019. Table 1 presents the results of the FWD data analyses. The profound effect of temperature on deflection and calculated HMA strain is noted in the data. For the location of this project, the maximum (July) pavement temperature is 87°F. Two deflection data groupings were collected below the maximum pavement temperature of 87°F and indicate the estimated strain from field deflections is just at the limiting strain criterion fatigue endurance limit (FEL) of 70 microstrain. The project was completed in 2020.

Table 1. I-74 Rubblized PCCP + HMA Pavement—FWD Analyses

Station	Pavement Temp (°F)	Max Deflection (mils)	AUPP	HMA Strain (microstrain)
971-1261	105	10.0/2.3/23*	11.1/2.5/22*	118/26/22*
1263-1375	94	8.3/2.2/26	8.4/2.2/26	89/24/27
1377-1411	85	6.9/0.9/13	6.7/0.9/14	70/9.9/14
1413-1459	76	7.2/1.1/15	6.8/1.0/15	71/11/16

* Average/standard deviation/coefficient of variation (%)

SPECIAL PROVISION REVIEW EFFORTS

Material Transfer Device Review

Current IDOT specifications for construction of HMA lifts for full-depth pavements and HMA pavement on rubblized PCCPs require the use of a “tracked” material transfer device (MTD) on partially completed segments where the thickness of binder in place is less than 10 in. (IDOT, 2014). Track pressure is limited to under 25 psi. In 2019 the RoadTec 1105e, shown in Figure 2 below, was utilized on the 2019 I-74 rubblized PCCP with HMA pavement project in District 4. ILLI-PAVE analyses conducted by the project’s principal investigator (Thompson) indicated the track pressure was less than 25 psi, thus allowed for use on lower lifts. IDOT reviewers expressed segregation concerns about the RoadTec 1105e device, which does not have the ability to mix upstream and downstream material. The principal investigator participated in IDOT segregation discussions concerning the issue. After the discussions and review of available thermal imaging data and on-site visual inspections, the RoadTec 1105e was conditionally added to IDOT’s approved MTDs in August 2020.

Figure 2. Photo. Paving train utilizing the RoadTec 1105e tracked material transfer device.

Hot-mix Asphalt Pavement (Full-depth on Rubblized PCC)

The principal investigator participated in an online meeting led by IDOT's LaDonna Rowden held in July 2020, concerning the development of an updated specification for FDHMA pavement for rubblized PCCP. The resulting specification, "Hot-Mix Asphalt Pavement (Full-Depth on Rubblized PCC)," will be included in Section 441 of the 2022 Standard Specifications for Road and Bridge Construction.

CHAPTER 3: PERFORMANCE EVALUATIONS

The work under Task 2 was to evaluate the performance of existing full-depth asphalt and rubblization projects through pavement condition surveys and analysis of falling weight deflectometer (FWD) data collected by IDOT. This chapter details the activities and accomplishments under this task.

DEFLECTION ANALYSIS OF I-39 RUBBLIZATION

The project's staff reviewed and analyzed IDOT's falling weight deflectometer (FWD) 2018 data for the I-39 rubblized pavements north of Normal, Illinois. The southbound and northbound lanes were constructed in 2013–14 and 2014, respectively. The I-39 sections are 8 in. of HMA over either 10.75 in. of hinge-jointed PCCP or 10 in. of continuously reinforced concrete pavement (CRCP). The project was designed as a staged construction experimental features project, with less than the full HMA design thickness placed in the first stage. The July mean monthly pavement temperature (MMPT) for the projects is approximately 87°F. Table 2 shows relevant FWD response data. The HMA strains for the sections with pavement temperatures of 97°F are less than the limiting strain criterion fatigue endurance limit (FEL) of 70 microstrain. If the HMA strain corresponding to the 78°F pavement temperature section was adjusted (increased) to capture the difference between the 78°F pavement temperature and the MMPT of 87°F, then the HMA strain would still be less than 70 microstrain. The data indicate the sections are meeting the limiting strain criterion.

Table 2. I-39 Falling Weight Deflectometer Data (2018)

Section	Pavement Temp (°F)	Avg. Deflection (Mils)	Avg. AUPP	Avg. HMA Strain (Microstrain) (1E-6)
Southbound Hinge-jointed*	80	3.4	2.8	28
Northbound Hinge-jointed**	97	3.4	2.8	29
Northbound CRCP**	97	4.0	3.6	37
Southbound CRCP**	78	3.6	2.7	28

* Contract 70634

** Contract 70A28

EVALUATION OF TRAFFIC SPEED DEFLECTOMETER

IDOT is participating in the Federal Highway Administration's traffic speed deflectometer (TSD) pooled-fund study. Several full-depth HMA and rubblized PCCP + HMA projects were tested in the 2019 and 2020 programs (see Table 3). The project's principal investigator participated in the Australian Road Research Board (ARRB) 2019 and 2020 test result briefings. Of particular importance to the ICT project R27-193-2 is the surface deflection data. The TSD operates at approximately 50 mph, and the surface deflections are averaged over 0.01 mi (~53 ft) increments. The data were analyzed for selected projects. Pavement response parameters, max deflection (D0), and area under pavement profile (AUPP), as shown in Figure 3, were analyzed to establish HMA flexural strains (the design criterion for HMA fatigue). Table 3 and Table 4 present the analysis results for full-depth HMA and rubblized PCCP with HMA pavement sections.

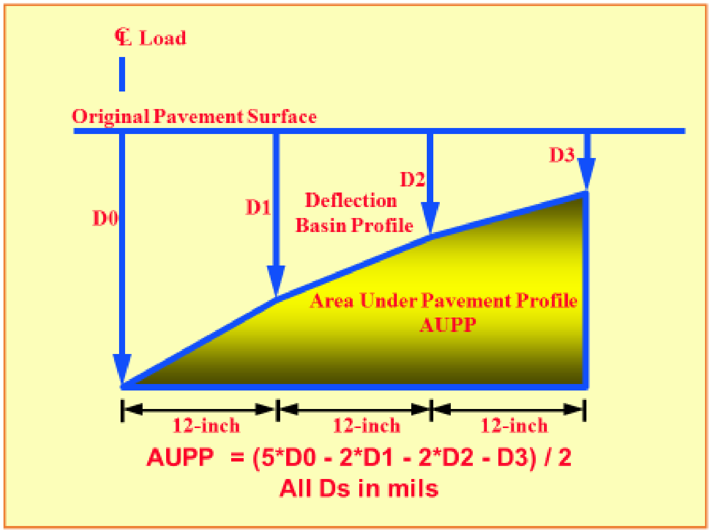

Figure 3. Drawing. The AUPP basin parameter.

Source: Hill (1988)

Table 3. Traffic Speed Deflectometer Projects (2020)

Location	HMA Thickness (in.)	Rubblized PCCP Thickness (in.)
Champaign I-74 / Full-depth (Eastbound—Section 1)	17.0	
Champaign I-74 / Full-depth (Eastbound—Section 2)	17.0	
Lincoln—I-155 Full-depth	15.0	
Madison Co. I-55 Rubblized PCCP (Section 1)	11.5	10.0
Madison Co. I-55 Rubblized PCCP (Section 2)	11.5	10.0
McLean Co. I-39 Rubblized PCCP	8.0	10.0
Champaign I-57 Rubblized PCCP	11.25	7.0

Table 4. Traffic Speed Deflectometer Data Analyses (2020)

Location	Pavement Temp (°F)	Max Deflection* (mils)	AUPP*	HMA Strain* (Microstrain) (1E-6)
Champaign I-74 / Full-depth (Eastbound—Section 1)	69	3.4/1.4/40	3.3/1.3/41	44/18/41
Champaign I-74 / Full-depth (Eastbound—Section 2)	69	3.7/1.5/42	3.4/1.4/41	46/19/41
Lincoln—I-155 Full-depth	86	9.6/2.8/29	8.7/2.8/34	118/37/31
Madison Co. I-55 Rubblized PCCP (Section 1)	95	3.3/1.2/36	2.8/0.9/34	37/9.9/27
Madison Co. I-55 Rubblized PCCP (Section 2)	95	4.1/1.4/35	3.6/1.3/36	46/14/30
McLean Co. I-39 Rubblized PCCP	95	4.2/1.6/38	3.4/1.3/38	40/16/40
Champaign I-57 Rubblized PCCP	76	3.7/1.2/31	3.7/1.0/26	47/11/24

*Average/standard deviation/coefficient of variation (%)

Traffic speed deflectometer loading is dual tires at 5 kips and a tire pressure of 125 psi. Several analysis algorithms were established based on ILLI-PAVE modeling. The algorithms relate AUPP to HMA strain. Figures 4–7 present the various algorithms.

$$Log\ \mu\varepsilon_{HMA} = 1.113 + 1.0018\ (Log\ AUPP)$$

Figure 4. Equation. HMA microstrain AUPP relationship for 15–16 in. full-depth HMA.

Where, $\mu\varepsilon_{HMA}$ is HMA strain in microstrain, and *AUPP* is the area under the pavement profile from FWD deflection basin.

$$\mu\varepsilon_{HMA} = 10.024 + 9.454AUPP + 0.164(AUPP^2)$$

Figure 5. Equation. HMA microstrain AUPP relationship for Madison County rubblized PCCP.

$$Log\ \mu\varepsilon_{HMA} = 1.038 + 1.052(Log\ AUPP)$$

Figure 6. Equation. HMA microstrain AUPP relationship for McLean County rubblized PCCP.

$$Log\ \mu\varepsilon_{HMA} = 1.151 + 0.917(Log\ AUPP)$$

Figure 7. Equation. HMA microstrain AUPP relationship for Champaign County rubblized PCCP.

For full-depth pavements, the ILLI-PAVE HMA strain predictions compared favorably to predictions based on recent FHWA activities (Nasimifar et al., 2020). The FHWA algorithm for 15–16 in. full-depth pavement is presented in Figure 8.

$$\mu\varepsilon_{HMA} = 5.248\left(SCI^{0.7285}\right)$$

Figure 8. Equation. HMA microstrain SCI relationship for 15–16 in. full-depth HMA.

Source: Nasimifar et al. (2020)

Where, surface curvature index (*SCI)* is $D_0 - D_1$, (in microns) D_0 is deflection at a 0 in. offset, and D_1 is deflection at a 12 in. offset.

PERFORMANCE STUDY OF INTERSTATE RUBBLIZED SECTIONS

Since the first experimental section in 1990, Illinois has developed and refined their rubblizing design policy and procedures. After thirty years of usage, there exists a variety of original rubblized cross-sections with HMA pavements in service. Monitoring and evaluations of early projects aided in the refinement of IDOT's design policy and procedures resulting in the processes in use today.

Illinois' current rubblized design process not only determines the thickness of the HMA pavement, but also evaluates the supporting structure under the pavement to be rubblized. The result is that for areas with weak soils, the breakage equipment may be limited to the multi-head breaker. For stronger sections, the contractor is given the option between resonant breakers and multi-head breakers. Most Illinois rubblizing projects have utilized a multi-head breaker similar to the one seen in Figure 9.

Figure 9. Photo. Version of multi-head breaker common on Illinois projects.

After pavement breakage, the surface is further conditioned with a “Z” patterned steel wheel roller, a rubber tire roller, and a steel wheel roller to prepare the surface for overlay. Figure 10 shows the final pass of the steel-wheeled roller before placing the HMA pavement directly upon the prepared surface. Note that a prime coat is deemed unnecessary and not used prior to HMA placement.

Figure 10. Photo. Final compaction of rubblized pavement with a steel wheel roller.

A study was undertaken to provide a timely look at factors that impact the performance of rubblized sections and what, if any, improvements might be adopted. Thirty-one HMA pavement on rubblized PCCP projects were included in the study. IDOT’s construction and performance information were assembled and analyzed. The performance study of interstate rubblized PCCPs was completed and resulted in several recommendations that can future improve the performance and life cycle cost effectiveness of rubblizing (Lippert et al., 2021). The data available to date indicate excellent performance.

Findings

As a result of this study, several findings can be made as to the current state of the practice of rubblizing design, construction, and performance in Illinois, as follows:

- Overall, rubblization is providing good to excellent performance and exceeding design expectations.
- The design process is conservative. Fatigue cracking has not been observed in the original rehabilitation, which is providing service beyond the design traffic. Overlays that result in no additional structure (mill and fill) are not experiencing fatigue cracking.
- Rutting is not excessive and is similar to full-depth HMA. The exception is one project on I-57 (mile post 29.6–32.1 southbound) in which rutting was attributed to a level binder layer being added under the surface to make up for thin pavement.

- The selected HMA surface mix greatly impacts the CRS performance of the section, with SMA and softer PGXX-28 grade mixes providing increased life over PGxx-22 grades and IL-9.5 surfaces.

- The current conservative limiting strain criterion (10.5 in. to 11.75 in.) is controlling design thickness on many projects.

- Some plans have included exceptionally long non-rubblized areas to protect underground structures that are overly conservative.

Recommendations

While rubblizing has demonstrated good to excellent performance to date, the data suggest that key policy and materials selection choices can greatly and consistently improve performance. The following factors are recommended to achieve this end:

- Select SMA with PGXX-22 or IL-9.5 with PGXX-28 for the surface mix to increase performance at limited additional cost. These combinations showed trends of an approximately 50% increase in life over IL-9.5 with PGXX-22.

- Limited data suggest that SMA with PGXX-28 could increase pavement life even more and may be the ultimate surface for HMA over rubblized pavement. Additional sections using this combination should be utilized to verify this trend, evaluate cost, and adopt as practical.

- Adopt an 8 ft buffer to rubblizing for structures with less than 8 ft of cover. The goal is to rubblize as much of the section as possible. Do not leave “islands” of intact pavement that may drive long-term performance issues of the section due to reflective cracking. To resolve any concerns, one may need to instrument and monitor culverts to define buffer distance needs and depth limits as well as how to break the pavement over culverts with modified multi-head breaker (MHB) operations or a skid steer with a stinger.

- Current modulus and fatigue outcomes of recycled material specifications are not known for HMA mixes in use. Some modulus and fatigue work in this area would help define the impacts of these materials for both rubblized and full-depth HMA pavements.

- The limiting strain criterion of 70 microstrain warrants revisiting, especially in connection to expected usage.

CHAPTER 4: LITERATURE IMPACTS ON DESIGN PROCEDURES

The work under Task 3 was to review flexible pavement design literature and update or modify (as appropriate) previously provided inputs concerning mix design, testing procedures, thickness design, construction, and performance. This chapter details the activities and accomplishments under this task.

ITEMS OF SIGNIFICANCE

Several reviewed publications were considered of particular interest to this study. As a result, they are summarized below.

The Federal Highway Administration has sponsored extensive research at North Carolina State University (Dr. Richard Kim's research group) in the development of a "simplified viscoelastic continuum model" (S-VECD) for characterizing HMA fatigue resistance. The current approach is summarized in an FHWA tech brief (FHWA, 2019) on cyclic fatigue index parameter (S_{app}) for asphalt performance engineered mixture design. Per the tech brief:

> "S_{app} accounts for the effects of a material's modulus and toughness on its fatigue resistance and is a measure of the amount of fatigue damage the material can tolerate under loading. Higher S_{app} values indicate better fatigue resistance of the mixture." The S_{app} value of an asphalt mixture can be obtained via cyclic fatigue tests using 100 mm diameter specimens (AASHTO TP 107) or 38 mm diameter small specimens (AASHTO TP 133) cored from gyratory-compacted samples. (Note: The cyclic testing is "direct tension".)"

Walbeck and Horan (2019) summarize the excellent performance of rubblized PCCPs in West Virginia's state highways and the West Virginia Turnpike. Antigo's multiple-head-breaker (MHB) has been exclusively utilized on projects in West Virginia. Hot-mix asphalt (HMA) overlay thicknesses varied from 7 to 10 in., depending on the traffic. In 2018, 12 West Virginia Division of Highways interstate rehabilitation projects were constructed. Six of the projects were designated to be rubblized. Contractors had the option of choosing the rehabilitation procedure (rubblization or "any other procedure wanted") for the remaining six projects. The six projects required a 9-year warranty. Contractors chose rubblization on all six projects. The article indicates that warranty pavements using rubblization outperformed full-depth new construction pavements and that West Virginian contractors received the process well.

A very significant NCHRP 9-59 project fatigue study was completed in 2019 (Christensen, 2019). The final report has not been published but a comprehensive paper was included in the 2020 Association of Asphalt Paving Technologists (AAPT) Journal (Christensen & Tran, 2019). Some relevant findings from the paper are:

- The fatigue performance of asphalt mixtures is primarily dependent on the applied strain relative to the strain capacity of the binder used in the mix as well as on the fatigue exponent.

Note: The fatigue exponent referenced here is the exponent (*K2*) in the HMA fatigue algorithm shown in Figure 11.

$$N = K1\left(\frac{1}{\varepsilon_{HMA}}\right)^{K2}$$

Figure 11. Equation. General HMA fatigue equation form.

Source: Thompson (1987)

Where, *N* is the number of load repetitions to "failure" (50% reduction in modulus), ε_{HMA} is the engineering flexural strain, and *K1* and *K2* are the intercept and slope, respectively, of the regression.

- The strain capacity of asphalt binders is primarily a function of modulus, with higher modulus values being associated with lower failure strains.
- The fatigue exponent of asphalt mixtures is 180 divided by the binder phase angle in degrees.
- The study confirmed the relationship between *Log K1* and *K2* in the HMA fatigue algorithm shown in Figure 12.

$$Log\ K1 = 4.24 - (3.11 * K2)$$

Figure 12. Equation. NCHRP 9-59 project relationship of *K1* and *K2*.

Source: Christensen (2019)

The relation is similar to the one utilized by IDOT, shown in Figure 13.

$$Log\ K1 = 3.43 - (3.4 * K2)$$

Figure 13. Equation. IDOT relationship of *K1* and *K2*.

Source: Carpenter (2006)

The AAPT Journal paper (Christensen & Tran, 2019, p. 462) indicates: "Also relevant to practice is the GFTAB model, which is a novel way of analyzing fatigue damage in asphalt binders and mixtures and is useful in understanding the fatigue phenomenon in these materials, and also in relating mixture fatigue performance to asphalt binder properties." Details concerning the general failure theory for asphalt binders (GFTAB) model are presented in the AAPT Journal paper (Christensen & Tran, 2019). The NCHRP 9-59 final report should be available in the near future. A significant shortcoming of the NCHRP 9-59 study is the lack of any HMAs containing RAP or asphalt modifiers. The findings of this study will be helpful to IDOT in evaluating the current HMA fatigue algorithm and asphalt binder characteristics.

A recent National Center for Asphalt Technology (NCAT) report concerning the benefits of rehabilitating concrete pavements with slab fracturing and asphalt overlays was reviewed (West et al., 2020a). The report documents the successful utilization of slab fracturing techniques. Rubblization was found to be a widely used and very effective procedure. The project's principal investigator participated in a National Asphalt Pavement Association/NCAT webinar on June 4, 2020, that summarized the major findings of the study (West et al., 2020b).

CHAPTER 5: RESPONSE TO DESIGN AND CONSTRUCTION ISSUES

The work under Task 4 was to respond to Illinois Department of Transportation inquiries and questions concerning issues related to full-depth asphalt and rubblization. This chapter details the activities and accomplishments under this task.

TRACKED MATERIAL TRANSFER DEVICE

Current IDOT specifications for construction of HMA lifts for full-depth pavements and HMA pavement on rubblized PCCPs require the use of a "tracked" material transfer device (MTD) on partially completed segments where the thickness of binder in place is less than 10 in. (IDOT, 2014). Track pressure is limited to be under 25 psi. In 2019, the RoadTec 1105e was utilized on the I-74 rubblized PCCP with HMA pavement project in District 4. ILLI-PAVE analyses conducted by the project's principal investigator (Thompson) indicated the track pressure was less than 25 psi, thus allowed for use on lower lifts. IDOT reviewers expressed segregation concerns about the RoadTec 1105e device, which does not have the ability to mix upstream and downstream material. The principal investigator participated in IDOT segregation discussions concerning the issue. After the discussions and review of available thermal imaging data and on-site visual inspections, the RoadTec 1105e was conditionally added to IDOT's approved MTDs in August 2020.

MONITORING OF HMA MODULUS-TEMPERATURE, FATIGUE, AND FATIGUE ENDURANCE LIMIT INPUTS

The key inputs in the current IDOT mechanistic-empirical thickness design procedures are HMA modulus-temperature algorithms, the HMA fatigue algorithm, and the fatigue endurance limit (FEL). The current inputs are based on the properties of HMAs utilized several years ago and do not consider the use of RAP and RAS in the mixtures or the use of asphalt modifiers.

The HMA modulus algorithms were established for consensus HMAs with virgin asphalt binders. Currently most HMA binder mixes utilize grade bumping to accommodate the presence of recycled material. The current HMA fatigue algorithm is shown in Figure 14.

$$N = 8.78 * 10^{-8} \left(\frac{1}{\varepsilon_{HMA}}\right)^{3.5}$$

Figure 14. Equation. Current IDOT HMA fatigue algorithm.

Source: Carpenter (2006)

Where, *N* is the number of load repetitions to "failure" (50% reduction in modulus), and ε_{HMA} is the engineering flexural strain.

The fatigue algorithms established for the HMAs tested in the ICT I-FIT study (Al-Qadi et al., 2017) showed the exponents in the fatigue algorithm ranged from 4 to 6.

The current FEL used in IDOT's design procedure is 70 microstrain. The best demonstrated available technology (BDAT) for establishing and estimating the FEL is not robust, particularly for HMAs with RAP and RAS.

The project's staff kept these key inputs under continuous review and evaluated them against BDAT. TRP meeting presentations have emphasized the importance of utilizing inputs representative of the HMAs currently utilized. To illustrate the impact of the FEL, a 10 microstrain increase in the FEL (to 80 microstrain) would typically decrease the HMA thickness by approximately 1 in.

CHAPTER 6: RECOMMENDATIONS

From the efforts of this project, two areas are recommended for additional research that would develop more economical designs, increase performance, and/or lower the life-cycle costs of both full-depth HMA and HMA (full-depth) on rubblized PCCP. These recommendations are as follows:

- Limited data to date indicates that HMA pavements on rubblized PCCP that utilized a stone-matrix asphalt (SMA) surface course with performance grades (PG) of 70-28 or 76-28 asphalt binder are providing superior performance compared to IL-9.5 surfaces or SMA surfaces using PG XX-22 asphalt binders. Additional projects utilizing SMA with PG XX-28 asphalt binder are encouraged so that additional performance data can be collected to make these trends clear.

- Because of increased traffic on the interstate system, the fatigue endurance limit (FEL) is controlling the design thickness of more and more full-depth hot-mix asphalt and HMA pavement on rubblized pavements. While the current factors utilized in determining the FEL thickness are resulting in conservative designs, designs that are overly conservative result in wasted resources. A study of typical mixes with recycled materials and related PG grade adjustments currently in use would be helpful to determine modulus and fatigue properties that need adjusting in order for the FEL factors to be more representative of current practices.

REFERENCES

Al-Qadi, I. L., Lippert, D. L., Wu, S., Ozer, H., Renshaw, G., Murphy, T. R., Butt, A., et al. (2017). *Utilizing lab tests to predict asphalt concrete overlay performance* (Report No. FHWA-ICT-17-020). Illinois Center for Transportation. http://hdl.handle.net/2142/98920

Carpenter, S. H. (2006). *Fatigue performance of IDOT mixtures* (Report No. FHWA-ICT-07-007). Illinois Center for Transportation. https://apps.ict.illinois.edu/projects/getfile.asp?id=2971

Christensen, D. (2019). Relating asphalt binder fatigue properties to asphalt mixture performance (Project No. NCHRP 9-59). https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3862

Christensen, D., & Tran, N. (2019). Relationships between mixture fatigue performance and asphalt binder properties. *Journal of the Association of Asphalt Pavement Technologists*, *88*. https://www.destechpub.com/product/asphalt-paving-technology-2019/

Federal Highway Administration. (2019, August 29). *Cyclic fatigue index parameter (S_{app}) for asphalt performance engineered mixture design* (Tech Brief FHWA-HIF-19-091). https://www.fhwa.dot.gov/pavement/pubs/hif19091.pdf

Hill, H. J. (1988). Early life study of the FA409 full-depth asphalt concrete pavement sections. PhD dissertation, University of Illinois at Urbana-Champaign. http://hdl.handle.net/2142/69984

Illinois Department of Transportation. (2014). Special provision for material transfer device [Memorandum]. Revised August 1, 2014. https://idot.illinois.gov/Assets/uploads/files/Doing-Business/Specialty-Lists/Highways/Design-&-Environment/BDE-Special-Provisions/Nov-7-2014-Letting/80045.pdf

Illinois Department of Transportation. (2018, April 27). Contract 68A79, Letting Item No 158. https://apps.dot.illinois.gov/eplan/desenv/042718/158-68A79/

Lippert, D. L., Thompson, M. R., & Wienrank, C. J. (2021). *Performance of interstate rubblization in Illinois* (Report No. FHWA-ICT-21-005). Illinois Center for Transportation. https://doi.org/10.36501/0197-9191/21-005

Nasimifar, M., Chaudari, S., Thyagarajan, S., & Sivaneswara, N. (2020). Temperature adjustment of surface curvature index from traffic speed deflectometer measurements. *International Journal of Pavement Engineering*, *21*(11). https://doi.org/10.1080/10298436.2018.1546858

Thompson, M. R. (1987). ILLI-PAVE based full-depth asphalt concrete pavement design procedure. In *Proceedings of the Sixth International Conference on the Structural Design of Asphalt Pavements*, Vol. 1. http://asphalt.org/publications/conference-proceedings/6th-conference/

Walbeck, T., & Horan, R. (2009, Summer). Rubblizing to rehabilitate existing pavements. *Asphalt, The Magazine of the Asphalt Institute*, *34*(2) https://www.antigoconstruction.com/wp-content/uploads/Asphalt-Asphalt-Insitute-Summer-2019-WV-rubblization.pdf

West, R., Gu, F., & Bowers, B. (2020a). *Benefits of rehabilitating concrete pavements with slab fracturing and asphalt overlays* (Report No. NCAT 20-03). National Center for Asphalt Technology. http://www.eng.auburn.edu/research/centers/ncat/files/technical-reports/rep20-03.pdf

West, R., Gu, F., & Bowers, B. (2020b). *Benefits of rehabilitating concrete pavements with slab fracturing and asphalt overlays* (Webinar June 4, 2020). National Center for Asphalt Technology. https://member.asphaltpavement.org/Shop/Product-Catalog/Product-Details?productid={B778CD8D-ADC2-EA11-A812-000D3A4DF348}

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