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NRRA LT1: Developing Best Practices for Rehabilitation of Concrete with Hot Mix Asphalt (HMA) Overlays related to Density and Reflective Cracking

Task -1: Literature Review

Task Memo

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1. Introduction

As pavement infrastructure is continuously aging and deteriorating, the preservation, maintenance and rehabilitation of pavements is of critical importance. Asphalt overlays are a relatively simple and cost effective maintenance solution for the extension of a composite pavement design life. However, the extension of the design life is dependent on the performance of the asphalt overlays. Reflective cracking is one of the most common distresses observed in asphalt concrete overlays and is the result of both load and non-load associated mechanisms. The formation of the cracks and rate of propagation is mainly due to the stress concentration located at the underlying joints in concrete pavement. Mechanical properties of the asphalt, layer thickness, composition and the condition of the existing pavement all contribute to reflective cracking performance.

Current state of practice of asphalt overlay design is policy-based and lacking an engineered design approach. The objective of this study is to develop a simple decision tree based tool for selecting suitable asphalt mixtures and overlay designs to extend the overlay lives by lowering reflective cracking and improving in-situ density. To develop the decision tree, laboratory testing and field performance data will be incorporated into a predictive performance model to assess varying overlay alternatives using a life cycle cost analysis approach.

In fulfillment of Task-1, a comprehensive literature review was conducted by the research team concentrating on the methods and approaches that are being implemented in the MnROAD test sections. The review is presented in Section 2 of this report and focuses on (a) impact of in-situ density, (b) reflective cracking performance prediction and evaluation, and (c) life cycle cost benefit analysis.

2. Impact of In-situ Density on Performance

While there are several factors that impact the overall performance of an asphalt pavement, in-place density is one of the most important to consider (Asphalt Institute, 2007). Throughout the development of pavement design, starting in the early 1800's with the basic notion to select an aggregate gradation and a suitable amount of bitumen, achieving a certain level of density has been a priority. Work done in the 1900's by individuals such as Clifford Richardson, Charles Hubbard and Frederick Field, Bruce Marshall, James Rice and Norman McLeod lead to the development of the Marshall mix design method. The Strategic Highway Research program (SHRP), developed in the late 1980's the empirically-based Superpave asphalt design method as an extension of the Marshall design method.

The Marshall method uses an air void design range of 3-5% while compaction specifications during construction result in approximately 8% in-place air voids. In comparison, Superpave requires a 4% design air void and typical in-place air voids are around 7%. The logic behind having higher in-place air voids after construction is that traffic would compact the asphalt mixture to the designed air void level over time. Superpave design focuses on the compactive effort to achieve density at the end of the pavement service life. Another method developed by the Laboratoire Central des Ponts et Chaussées (LCPC) focuses on achieving the desired density of asphalt at the beginning of the pavement in-service life. LCPC has shown that there is little to or no increase in density from traffic loading over the course of a pavement in-service life (Huber et al. 2016). Therefore, the design air void content should be consistent with that of the in-place air voids after construction as no post-construction densification is expected.

In recent years, there has been an interest by many states to adjust mixes to achieve higher in place field density to achieve better overall mixture performance. A demonstration project was sponsored by Federal Highway Administration (FHWA) and carried out by the National Center for Asphalt Technology (NCAT), to show that enhanced durability of asphalt pavements through increase in-place pavement density is achievable in the field and not only in the laboratory (Aschenbrener et al. 2017). A study by Tran et al. in 2016 performed a life cycle cost analysis (LCCA) on two pavement alternatives in which the same asphalt overlay would be constructed to 7% and 8% air voids. Results from the study showed that, "A 1% decrease in air voids was estimated to improve the fatigue performance of asphalt pavements between 8.2% and 43.8% and the rutting resistance by 7.3% to 66.3%. In addition, a 1% reduction in in-place air voids can extend the service life by 10% or more (Tran et al. 2016).

As part of this study, several cells of the MnROAD test facility have been dedicated to investigating how enhanced density may improve the performance of asphalt overlays. Permanent deformation is often focused on when considering improvements to the density of the asphalt layer, however there is a lack of research on the impact of in-situ density on reflective cracking or cracking performance in general. There are many approaches to achieving higher in-situ density such as, air void regression, film thickness, minimum asphalt contents, compaction additives, reducing the number of gyrations or modifying design air void targets. Two approaches are being investigated in this study, modifying the design air voids (Superpave5), and the regressed air void method. Further detail on the two approaches are given below.

2.1 Superpave5

Indiana recently developed the Superpave5 design (design at 5% air voids and compact to 5% in-place air voids), which is based off the LCPC approach. In comparison to the traditional Superpave (designed at 4% air voids), to achieve a 1% increase in design air voids while maintaining the same volume of effective binder (V_{be}), the Voids in the Mineral Aggregate (VMA) must be increased by 1% as well. In order to increase the design air void by 1% while holding V_{be} constant the aggregate proportions are adjusted to meet the new design criteria.

Hekmarfar et al. (2013) showed that using a 50 design gyration to evaluate Superpave5 that it was possible to compact to 5% air voids in the field without additional compaction effort and laboratory results indicate that the mixtures should have acceptable performance. Huber et al. (2016) concluded based on a laboratory study and two trial sections that an asphalt design at 30 gyrations with 5% air voids and compacted to 5% air voids will perform as well or better than asphalt designed using 100 gyrations and compacted to 7% air voids.

2.2 Regressed Air Void

Wisconsin developed the regressed air voids approach, which follows a conventional design (4% air voids) and then increases the amount of additional virgin asphalt binder to obtain 3% air voids.

Unlike the Superpave5 method which aims to hold the V_{be} constant while achieving higher in-situ density, the air void regression method typically increases the design asphalt content by up to 0.4%. The premise behind air void regression and increasing in-situ density of the mixture is that it will also decrease permeability, decrease porosity, increase durability and increase film thickness (WAPA 2016).

3. Reflective Cracking Laboratory Tests

Reflective cracking is one of the predominant distresses in asphalt overlays. The evaluation of reflective cracking to in-field and laboratory studies has been investigated extensively. Work done by Habbouche et al. (2017), Ahmed et al. (2013), Lytton (2010), Dave et al (2007) and (2010), Button and Lytton (2007), Baek and Al-Qadi (2006), Paulino et al. (2006), Blankenship et al. (2004), Cleveland et al. (2003), Eltahan and Lytton (2000), Buttlar et al. (2000), has been instrumental in determining methodologies to evaluate reflective cracking performance in overlays. While many of the previous studies have focused on the use of fabrics, grids and specialized asphalt mixtures to reduce or delay reflective cracking, the current study will evaluate asphalt overlay pavement structures without the use of proprietary products. To evaluate the reflective cracking performance of the test sections in this study, laboratory testing is to be carried out in addition to the collection of field data. The combination of this data will be used to develop prediction models and performance curves to accurately compare the laboratory and field performance.

Previous research has established various thresholds for lab performance test results to improve reflective cracking asphalt overlays by use of performance test based material selection process. Examples include works by Zhou et al. (2003, 2014), Hu et al. (2010) and Bennert et al. (2014) using Texas overlay tester, Al-Qadi et al. (2015) using Illinois-flexibility index test and Paulino et al. (2006) and Kim et al. (2009) for the disk-shaped compact tension test. Researchers will use these previous studies in Task 2 of the project to establish asphalt overlay performance and life curves. Using data from continued performance monitoring of the test sections, researchers will be able to validate viability of various lab performance tests in predicting reflective cracking performance.

The National Road Research Alliance (NRRA) flexible pavement group has undertaken a comprehensive laboratory evaluation of the MnROAD asphalt mixtures. All laboratory performance tests that are being conducted on the mixtures and pavements that are part of this study are summarized in Table 1.

Table 1: Planned laboratory tests and designated organization performing test on mixtures.

Mix Tests	Organization Conducting Tests
I-FIT (SCB)	Illinois DOT
Texas Overlay Tester	Illinois DOT
Disk-shaped Compact Tension (DCT)	Minnesota DOT
Indirect Tensile Strength and Creep (IDT)	Minnesota DOT
Dynamic Modulus Test (|E*|)	Minnesota DOT
IDEAL-CT	TTI / TAMU
Hamburg Wheel Tracking Test	Wisconsin DOT
Semi-Circular Bend (Low Temperature)	Univ. of MN
Mix Bending Beam Rheometer Test	Univ. of MN
Dynamic Modulus	Minnesota DOT / Univ. of NH
Direct Tension Cyclic Fatigue (S-VECD)	Univ. of NH

As part of the current study, two laboratory performance tests will be conducted by the research team: direct tension cyclic fatigue tests (AASHTO TP 107) and the compact tension (CT) fracture test. Simplified viscoelastic continuum damage (S-VECD) characterization using AASHTO TP 107 has been shown to capture fundamental fatigue characterization of asphalt mixtures in the lab (Kim et al. 2015, FHWA 2016). This procedure is currently being evaluated by FHWA for use in asphalt performance related specifications. A number of studies have employed this testing with Layered Viscoelastic for Critical Distresses (LVECD) analysis to predict field cracking performance, such as the North-East High RAP Pooled Fund Study (Daniel et al. 2015). It should be noted that while LVECD and S-VECD approaches are tests are not specifically designed for composite pavements, results from the direct tension cycle fatigue test can be used to assess the effects of density on pavement performance for the various MnROAD test sections.

The CT fracture test was co-developed by the PI of the current study to provide fracture characterization of composite asphalt overlays that result from use of spray paver construction (Ahmed et al. 2012). Since multiple MnROAD overlay test sections are comprised of spray paver construction as well as use of interlayers, the CT test will be able to capture fracture properties that are not possible with other currently available cracking tests such as IFIT, SCB, and DCT. The predictive models and laboratory tests that will be utilized in this study with statistical analysis are discussed in further detail in the subsequent sections.

3.1 Simplified Viscoelastic Continuum Damage (S-VECD) Fatigue Test

The direct tension cyclic fatigue test will be conducted following the AASHTO TP 107 procedure. The test typically consists of 4 replicates (1 at each strain level) and is run at a test temperature of ((PGHT-PGLT)/2)-3°C. The main output from this test is the damage characteristic curve (DCC) and energy dissipation for fatigue damage. These can then be utilized in a pavement structural analysis model such as FHWA Flexpave. Results from the S-VECD test are used to compare fatigue cracking resistance of the different mixtures by developing relationships between energy based fatigue failure criterion (G^R), pseudo stiffness based failure criteria (D^R) and number of load cycles to failure. Figures 1 (a) and (b) shows S-VECD test set up and required testing equipment.

(a) **(b)**

Figure 1: (a) S-VECD test set up in environmentally controlled chamber and (b) Asphalt Mixture Performance Tester (AMPT) equipment.

3.2 Compact Tension (CT) Facture Testing

While many other fracture tests have been developed to evaluate the cracking performance of mixtures such as indirect tension test, four-point bending beam, thermal stress restrained specimen test, disk-shaped compact tension, and semi-circular bend, these tests pose a challenge in acquiring appropriate sample geometries and thickness from the field. In addition to the geometry challenge, the direction of crack propagation varies compared to that observed from reflective cracking. Figure 2 illustrates the comparison of required geometry thickness for DCT and CT specimens and the direction of crack propagation. The CT specimen geometry is shown in Figure 3, and it should be noted that the CT test is run using a constant rate of crack mouth opening displacement (CMOD) of 0.017 mm/s, similar to that to the DCT test according to Wagoner et al. (2005b).

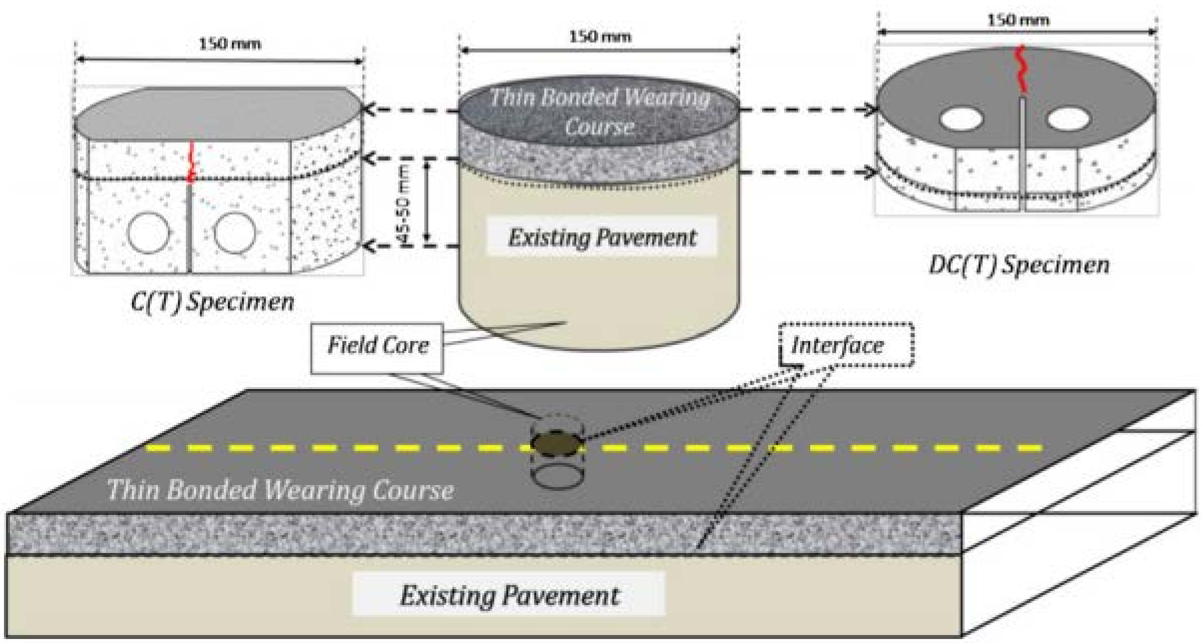

Figure 2: Comparison of DCT and CT specimen crack propagation orientation with respect to the pavement structure (Ahmed et al. 2012).

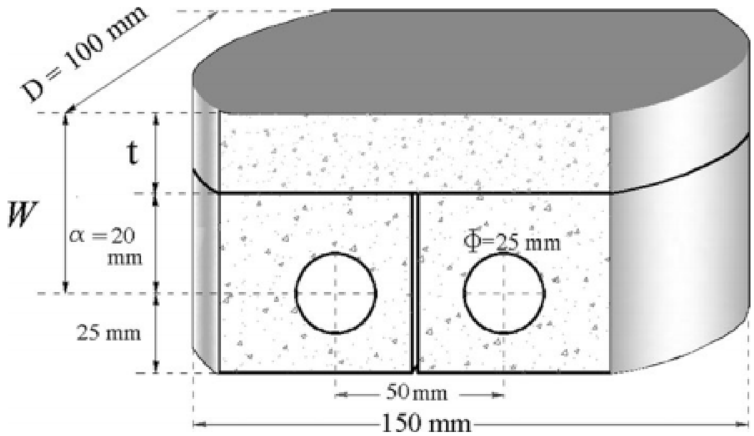

Figure 3: Compact tension specimen geometry and dimensions (Ahmed et al. 2012).

Many researchers such as Wagoner et al. (2005a) and (2005b), Li et al. (2006) and Song et al. (2008), have established that a fracture energy based approach for characterization of cracking performance for a quasi-brittle materials at low temperatures is more appropriate than using a linear elastic fracture mechanics (LEFM) approach. The CT fracture test is also beneficial because several MnROAD sections in this project were constructed to evaluate the effect of different tack coat application types, techniques and rates. Therefore, it is expected that the addition of running the CT test procedure will valuable in assessing the fracture resistance of the UTBWC sections.

3.3 Comparison of Field and Laboratory Results using Statistical Testing

Upon completion of the laboratory testing, comparisons will be made between the field and lab performance. Statistical testing methods such as regression, t-tests and Pearson's correlation matrix will be utilized to assess the MnROAD sections' field performance with the various laboratory performance tests. By conducting statistical testing, the goal is to gain an understanding of the effects mix design and pavement structure play on field performance as well as lab performance tests. In context of the MnROAD sections, variables such as layer thickness, density, tack coat application and mixture type may be evaluated in terms of crack resistance performance. The outcome of this analysis will not only provide insight into suitability of various lab performance tests for reflective cracking evaluation but will also generate necessary data to be utilized in the decision tree based overlay selection procedure that will be developed in later stages of this study.

4. Models for Reflective Cracking

4.1 NCHRP 1-41 Model

This mechanistic-based AC reflective cracking model was developed through NCHRP 1-41 study by Lytton et al. (2010) as a tool to predict the propagation of reflective cracks through the overlaying asphalt concrete layer due to bending and shearing traffic stresses and thermal stresses. During its initial development, the program included a finite element structural analysis for pavement response computation (stress intensity factors at the crack tip) and fracture mechanics approach based on Paris Law. Later, the finite element model was replaced by Artificial Neural Network (ANN) models to increase computational speed and efficiency for practical implementation in pavement design tools. The major input parameters to the program relate to the traffic, structure, climate, and material properties. The model was calibrated with field data obtained from more than 400 pavement sections in 28 states and the four climatic zones of the United States. This model was adapted into AASHTOWare Pavement ME software, and will aid researchers in making comparison beyond the 12 MnROAD field sections. The need for this additional simulated performance data is to ensure that the overlay life curves for life cycle cost analysis and decision tree are suitable for all overlay materials and structures beyond those installed at MnROAD.

4.2 Cohesive Zone Finite Element Reflective Cracking Model

Dave et al (2007, 2010a, 2010b and 2017) developed a finite element model for reflective cracking analysis of asphalt overlays on PCC pavements. The finite element model utilizes quasi-brittle asphalt behavior in the vicinity of the PCC joint through use of cohesive zone interface elements. Other attributes of the model include time dependent non-uniform temperature distribution through pavement thickness frictional interfaces between layers, time and temperature dependent viscoelastic response for asphalt layers, and stress dependent behavior for granular and subgrade layers. This modelling framework was used to simulate reflective cracking in 7 pavement sections through a national study (Paulino et al. 2006). Subsequently, the model was validated through an accelerated pavement testing study (Dave et al. 2008 and 2010) and has been utilized for mechanistic design of asphalt overlays (Dave 2013a) as well as to design thin bonded asphalt overlays for improved reflective cracking performance (Ahmed et al. 2011 and 2013, and Dave 2013b). The use of finite element reflective cracking models will help to develop a greater understanding of the mechanisms in which reflective cracking in asphalt overlays from both thermal and mechanical loading distresses occurs. The ability to make comparisons between not only the 12 MnROAD field sections but a series of combinations will also play a critical role in the development of simple and effective decision tree based tool.

Ultimately, the incorporation of field data, laboratory testing, predictive modeling and statistical testing will be used to develop performance curves of pavement sections. These performance curves will then be used to evaluate various overlay alternatives in a life cycle cost analysis. Further discussion on the current state of practice for the tools and benefits of performing a life cycle assessment is discussed next.

5. Life Cycle Cost Analysis (LCCA)

In order to analyze the cost effectiveness of each overlay section, life cycle cost analysis (LCCA) will be used in this study. LCCA is a technique that identifies and evaluates the costs associated with a piece of infrastructure (a pavement section in this case) during all of the various stages of its useful life. This includes, but is not limited to, costs such as initial construction, maintenance, rehabilitation, operation, and disposal/end of life. The main advantage of LCCA over traditional cost analysis is that LCCA incorporates all the costs endured by an agency throughout the life of the pavement section rather than the traditional way of focusing solely on the initial construction costs. Another significant advantage of LCCA is the ability to incorporate the performance of various sections and its impacts on user costs, which allows for a fair comparison to be made between the sections in terms of cost effectiveness. Through the review of previous research and current state of practice, the research team will follow the LCCA criteria and recommendations outlined below.

- Define realistic design alternatives to be consisted in the analysis
- Include all significant initial and future maintenance and rehabilitation costs (Agency costs, user costs, salvage value)
- For a fair comparison of future/predicted rehabilitation and maintenance, the discount rate and analysis period must be the same for all alternatives
- Analysis period over which future costs are evaluated is long enough to reflect cost difference (minimum of 3 full cycles)
- Cost effectiveness of each alternative shall be done in net present value (NPV) or equivalent uniform annual cost (EUAC)

It should be noted that there are two different computational approaches to perform an LCCA, deterministic and probabilistic. The more commonly performed deterministic approach involves assigning each LCCA input variable a fixed, discrete value based on historical data or engineering judgment. While sensitivity analysis may be performed to verify the robustness of the input values, the deterministic approach is unable to address simultaneous variations of multiple inputs at a time or convey the level of uncertainty associated with each life-cycle cost estimate. In comparison, a probabilistic approach assigns a probability function to each life-cycle cost estimate, therefore it is able to express both the range of likely inputs and the likelihood of their occurrence. In recent years, due to the improvement in computer processing capabilities, a probabilistic approach has become more practical to simulate and account for simultaneous changes in life-cycle cost inputs.

A study performed by Tran et al. (2016) illustrated the effect of in-place density on the LCCA of two alternative asphalt overlays (7% and 8% air voids). LCCA results showed that, “The state highway agency (SHA) would see a net present value (NPV) cost savings of $88,000 on a $1,000,000 paving project (8.8%) by increasing the minimum required density by 1% of G_{mm}” (Tran et al., 2016). However, this savings does not consider other costs such as operation, maintenance, and road user costs. Huang et al (2009) found that additional fuel consumption and pollutant emissions caused by traffic delays during roadwork periods (maintenance and rehabilitation) are significant and should not be ignored. The inclusion of user costs due to maintenance and operations is a complex task with room for improvement. The LCCA performed as part of this study will build off the LCCA study by Tran et al. (2016) and others such as, Lu et al. (2018), Yu et al. (2012), Zhang et al. (2010) and (2008) and Chan et al. (2008), to incorporate all relevant costs for each alternative to perform a holistic evaluation of the asphalt concrete overlay study.

The research team will use traditional LCCA techniques using a combination of FHWA’s RealCost software, which has the ability to perform both deterministic and probabilistic analysis, as well as current state of the art life cycle assessment framework developed by DeCarlo et al. (2017). This framework includes user costs in the life cycle cost calculation through use of pavement roughness as an input to fuel efficiency models developed by NCHRP 01-45 study (Chatti and Zaabar 2012). Overall, the incorporation of an LCCA approach to compare cost effectiveness of various asphalt overlay alternatives will be a critical step in the development of the simple decision tree based tool for the rehabilitation of concrete with HMA overlays.

6. Summary of Task-1

As part of Task-1, a comprehensive literature review was conducted to establish the current state of practice for the evaluation of asphalt concrete overlay performance related to density and reflective cracking. By review of literature and agency practices, data from previous and on-going studies, as well as relevant experience of the research team, the following can be summarized on the impact of in-situ density, modeling and laboratory testing to evaluate reflective cracking performance and conducting an LCCA:

- To investigate whether enhanced density may improve the performance of asphalt overlays two approaches are being examined; modifying the design air voids (Superpave5), and the regressed air void method. It is hypothesized that higher in-situ density will yield better performance in terms of cracking, rutting and durability.

- Reflective cracking is one of the most predominant distresses in asphalt concrete overlays. The combination of field data, laboratory testing, predictive modeling and statistical testing will be utilized to develop pavement life performance curves. A variety of laboratory tests will be performed including, S-VECD fatigue test to assess the effect of density and CT fracture test to assess the effect of tack coat application, rate and types. Reflective cracking models using mechanistic-based and finite element modeling will be utilized in addition to statistical testing to evaluate the reflective cracking performance of all mixtures within this study.

- As pavement infrastructure ages, there is an increasing rate of pavement maintenance and rehabilitation. Developing cost effective practices to maintain and repair roads is critical as the cost of construction rises. An LCCA approach is being adopted by the research team to evaluate the cost benefits for both agencies and users associated with varying asphalt concrete overlays in order to develop a simple decision tree tool to be used by practitioners.

7. References

AASHTO TP-107, "Determining the damage characteristic curve of asphalt concrete from direct tension cyclic fatigue tests." *American Association of State Highway and Transportation Officials, Washington, DC*, 2014.

Ahmed Sarfraz, Dave Eshan. V, William G. Buttlar & Marvin K. Exline, "Cracking resistance of thin-bonded overlays using fracture test, numerical simulations and early field performance," International Journal of Pavement Engineering, 14:6, 540-552, 2012.

Ahmed, Sarfraz, et al. "Compact tension test for fracture characterization of thin bonded asphalt overlay systems at low temperature." Materials and structures 45.8: pp 1207-1220, 2012.

Al-Qadi, I., Ozer, H., Lambros, J., Khatib, A., Singhvi, P., Khan, T., Rivera, J., Doll, B. "Testing Protocols to Ensure Performance of High Asphalt Binder Replacement Mixes Using RAP and RAS," Report FHWA-ICT-15-017, Illinois Center for Transportation, Rantoul, IL, 2015.

Aschenbrener, Tim, et al. "Demonstration Project for Enhanced Durability of Asphalt Pavements through Increased In-place Pavement Density". No. 17-05, 2017.

Asphalt Pavement Design Guide (2016). Wisconsin Asphalt Pavement Association (WAPA), Aug, 2016.

The Asphalt Handbook. Manual Series No. 4 (MS-4), Seventh Edition. Asphalt Institute, Lexington, Ky., 2007.

Baek, J. and Al-Qadi, I.L., "Finite-element method modeling of reflective cracking initiation and propagation: investigation of the effect of steel reinforcement interlayer on retarding reflective cracking in hot-mix asphalt overlay," *Transportation Research Record: Journal of Transportation Research Board,* Transportation Research Board of the National Academies, Washington, DC, Record No. 1949, 32 – 42, 2006.

Bennert, T, E. Sheehy, R. Blight, S. Gresavage, and F. Fee, "Implementation of Performance-Based Specifications for Asphalt Mix Design and Prediction Quality Control for New Jersey," Transportation Research Circular Number E-C189, Transportation Research Board, Washington DC, pp. 13-31, 2014.

Blankenship, P., Iker, N., and Drbohlav, J., "Interlayer and design considerations to retard reflective cracking," *Transportation Research Record: Journal of Transportation Research Board,* Transportation Research Board of the National Academies, Washington, DC, Record No. 1896, pp 177–186, 2004.

Buttlar, W.G., Bozkurt, D., and Dempsey, B.J., "Cost-effectiveness of paving fabrics used to control reflective cracking," Transportation Research Record: Journal of Transportation Research Board, Transportation Research Board of the National Academies, Washington, DC, Record No. 1730, pp 139– 149, 2000.

Button, J.W., and R L. Lytton, "Guidelines for Using Geosynthetics with Hot-Mix Asphalt Overlays to Reduce Reflective Cracking" ", Transportation Research Record: Journal of the Transportation Research Board, No. 2004, Washington D.C., pp 111-119, 2007.

Chan, Arthur, Gregory Keoleian, and Eric Gabler. "Evaluation of life-cycle cost analysis practices used by the Michigan Department of Transportation." Journal of Transportation Engineering 134.6, pp 236-245, 2008.

Chatti, K. and I. Zaabar, "Estimating the Effects of Pavement Condition on Vehicle Operating Costs," NCHRP Project 720, Project 1-45, Transportation Research Board, Washington DC, 2012.

Cleveland, G.S., Lytton, R.L., and Button, J.W., "Using pseudostrain damage theory to characterize reinforcing benefits of geosynthetic materials in asphalt concrete overlays," *Transportation Research Record: Journal of International Journal of Pavement Engineering*, Transportation Reserac Board of the national Academies, Washington, DC, Record No. 1849, pp202– 211, 2003.

Daniel, J.S., T. Bennert, Y.R. Kim, W. Mogawer, A. Comngalton, M. Ellwardany, D. Mensching, M. Sabouri, "Evaluation of Plant Produced RAP Mixtures in the Northeast," Phase II Report, TPF 5(23) Pooled Fund Study, 2015.

Dave, E.V., M.P. Wagoner, W.G. Buttlar, T. Lynn, and J. Bausano, "Integrated Testing and Modeling Approach to Develop Accelerated Testing Sections for Asphalt Overlay-Interlayer Systems over PCC," Proceedings of the 4th Eurasphalt & Eurobitume Congress, Copenhagen, ISBN: 978-90-802884-5-4 , pp. 625-637, 2008.

Dave E.V., S. Ahmed, W.G. Buttlar, J. Bausano, and T. Lynn, "Investigation of Strain Tolerant Mixture Reflective Crack Relief Systems: An Integrated Approach," Journal of the Association of Asphalt Paving Technologists, 79, pp. 119-156, 2010a.

Dave, E.V. and W.G. Buttlar, "Thermal Reflective Cracking of Asphalt Concrete Overlays," International Journal of Pavement Engineering, 11(6), pp. 477-488, 2010b.

Dave, E.V., "Sustainable Pavement Rehabilitation using Thin Bonded Overlay Constructed with High Taconite Mix," Project Number 2010-13, Local Operational Research Assistance Program, Local Road Research Board (LRRB), St. Paul, MN, April 2013a.

Dave E.V., "Design of Asphalt Overlays using Mechanistic Fracture Simulations," Final Report for MnDOT Agreement No. 02247, Minnesota Department of Transportation, June 2013b.

Dave E.V., C.E. Hanson, B. Helmer, J. Dailey, C.M. Hoplin, "Laboratory Performance Test for

Asphalt Concrete," Final Report for Work Order 40, Minnesota Department of Transportation, Research Services Section, 395 John Ireland Boulevard, MS 330, St. Paul, Minnesota 55155, 2015.

Dave, E.V., C. Hoplin, B. Helmer, J. Dailey, D. Van Deusen, J. Geib, S. Dai, and L. Johanneck, "Effects of Mix Design and Fracture Energy On Transverse Cracking Performance of Asphalt Pavements in Minnesota," Transportation Research Record, 2576, pp. 40-50, DOI: 10.3141/2576-05, 2016.

Dave, E.V., and B. Behnia, "Cohesive Zone Fracture Modeling of Asphalt Pavements with Applications to Design of High Performance Asphalt Overlays," International Journal of Pavement Engineering, 2017. (article in press)

DeCarlo, C., W. Mo, E.V. Dave, and J. Locore, "Sustainable Pavement Rehabilitation Strategy using Consequential Life Cycle Assessment: An Example of Interstate 95," Proceedings of the Tenth International Conference on the Bearing Capacity of Roads, Railways and Airfields (BCRRA 2017), Athens, Greece, 2017.

FHWA, "Testing for Fatigue Cracking in the Asphalt Mixture Performance Tester," Federal Highway Administration, FHWA-HIF-16-027, 2016.

FHWA, "Life-Cycle Cost Analysis: RealCost User Manual," Federal Highway Administration, May 2004.

Eltahan, A.A. and Lytton, R.L., "Mechanistic–empirical approach for modeling reflection Cracking," *Transportation Research Record: Journal of Transportation Research Board*, Transportation Research Board of the National Academies, Washington, DC, Record No. 1730, 132– 138, 2000.

Habbouche, J., E. Hajj, N. Morian, P. Sebaaly, M. Piratheepan, "Reflective Cracking Relief Interlayer for Asphalt Pavement Rehabilitation: From Development to Demonstration", Journal of the Asphalt Pavement Technology, 2017.

Hekmatfar, A., R. S. McDaniel, A. Shah, and J. E. Haddock, "Optimizing Laboratory Mixture Design as It Relates to Field Compaction in order to Improve Hot-Mix Asphalt Durability," Report SPR- 3624. Joint Transportation Research Program, Purdue University, West Lafayette, In., 2013.

Hu S., F. Zhou and T. Scullion, "Reflection Cracking-Based Asphalt Overlay Thickness Design and Analysis Tool," Transportation Research Record, Vol. 2155, pp. 12-23, 2010.

Huang, Yue, Roger Bird, and Oliver Heidrich. "Development of a life cycle assessment tool for construction and maintenance of asphalt pavements." Journal of Cleaner Production 17.2: pp 283-296, 2009.

Huber, Gerald, et al. "Adjusting Design Air Void Levels in Superpave Mixtures to Enhance

Durability.” 6th Eurasphalt & Eurobitume Congress, June 2016.

Kim, M., W.G. Buttlar, J. Beak, I.L. Al-Qadi, “Illinois Hot-mix Asphalt Overlay Mixtures,” Transportation Research Record, Vol. 2127, pp. 146-154, 2009.

Kim, Y.R., M. Guddati, H. Von Quintus, H. Lee, G. Huber, R. Bonaquist, N. Gibson, and J. Lee, “HMA Performance-Related Specification (HMA-PRS), Performance Specifications for Rapid Renewal,” SHRP R07 Workshop, 2015.

Li X, Marasteanu MO, Iverson N, and Labuz JF, “Observation of crack propagation in asphalt mixtures with acoustic emission,” Transportation research record, vol 1970, TRB, National Research Council, Washington DC, pp 171–177, 2006.

Lytton, R. L., Tsai, F. L., Lee, S. I., Luo, R., Hu, S., & Zhou, F., “Models for predicting reflection cracking of Hot-mix Asphalt Overlays,” NCHRP Project No. 01-41. National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2010.

Paulino, G.H., W.G. Buttlar, P.B. Blankenship, M.P. Wagoner, S.H. Song, and E.V. Dave, “Final Report for NSF-GOALI Project - CMS: 0219566,” National Science Foundation, Washington, DC, 2006.

Song SH, Wagoner MP, Paulino GH, Buttlar WG, “δ25 crack opening displacement parameter in cohesive zone models: experiments and simulations in asphalt concrete,” Fatigue Fract Eng Mater Struct 31(10):850–856, 2008.

Tran, N., P. Turner, and J. Shambley, “Enhanced Compaction to Improve Durability and Extend pavement Service Life: A Literature Review,” NCAT Report 16-02. National Center for Asphalt Technology at Auburn University, Auburn, Ala., 2016.

Wagoner MP, Buttlar WG, Paulino GH, “Development of a single-edge notched beam test for asphalt concrete mixtures.” ASTM J Test Eval 33(6):452–460, 2005b.

Wagoner MP, Buttlar WG, Paulino GH, “Disk-shaped compact tension test for asphalt concrete fracture.” Exp Mech 45:270–277, 2005a.

Yu, Bin, and Qing Lu. "Life cycle assessment of pavement: Methodology and case study." Transportation Research Part D: Transport and Environment 17.5: pp 380-388, 2012.

Zhou, F. and T. Scullion, “Upgraded Overlay Tester and Its Applications to Characterize Reflection Cracking Resistance of Asphalt Mixtures,” Report FHWA/TX-04/0-4467-1, Texas Department of Transportation, Austin Texas, 2003.

Zhou, F., Scullion, T., Walubita, L., and B. Wilson, “Implementation of a Performance-Based Mix Design System in Texas,” Transportation Research Circular Number E-C189, Transportation Research Board, Washington DC, pp. 32-50, 2014.

Zhang, H., G. A. Keoleian, and M. D. Lepech. "An integrated life cycle assessment and life cycle analysis model for pavement overlay systems." Proc., 1st Int. Symp. on Life-Cycle Civil Engineering. London: Taylor & Francis Group, 2008.

Zhang, H., Lepech, M., Keoleian, G., Qian, S.Z., Li, V., "Dynamic life-cycle modeling of pavement overlay systems: capturing the impacts of users, construction, and roadway deterioration," Journal of Infrastructure Systems 16, pp 299–309, 2010.