

Composite Pavement Systems – A Sustainable Approach for Long-Lasting Concrete Pavements

S. Rao and M. Darter*

Abstract

This paper summarizes work performed under the Strategic Highway Research Program project R21 on developing MEPDG-compatible mechanistic-empirical design procedures, test methods, and construction guidelines and specifications, for two-lift PCC/PCC composite pavements and HMA/PCC composite pavements. Composite pavements consisting of high quality top layer(s) have been proven in Europe and in the United States to provide long lives with excellent surface characteristics and rapid renewal when needed. The lower PCC layer is a sustainable JPC or CRC pavement that utilizes recycled and lower cost locally available materials, thus reducing the need to haul aggregates over long distances.

As part of this research, three full-scale instrumented test sections on the MnROAD mainline roadway (I-94, west of Minneapolis) were constructed in Spring 2010. The sections include one HMA/JPC and two two-lift PCC sections subject to real highway traffic. Accelerated Pavement Tests (APT) using the Heavy Vehicle Simulator (HVS) were used at the University of California Pavement Research Center (UCPRC) at Davis to evaluate various HMA/PCC test sections. These test sections were constructed in Fall 2009. The research also includes evaluation of in-service composite pavement across the U.S., Canada, and Europe. The results from these experiments were used to develop performance models and procedures for designing HMA/PCC and PCC/PCC composite pavements.

Introduction

Two composite pavement design strategies were studied under the Strategic Highway Research Program 2 (SHRP2) that reflects SHRP2's Renewal philosophy of "get in, get out, stay out."

HMA/PCC composite pavement systems for the purposes of this research were defined as relatively thin HMA layer(s) over a newly placed, but sufficiently hardened, PCC layer. The term "HMA" is used to indicate all types of asphalt-based products, including stone matrix asphalt (SMA), dense and porous HMA (including polymer-modified asphalt [PMA]), asphalt rubber friction course (ARFC), and others. The wearing surface is a relatively thin high-quality type of HMA that could consist of one or more layers of HMA with or without special layers or materials to retard reflection cracks. The PCC layer can consist of jointed plain concrete (JPC) or continuously reinforced concrete (CRC). The PCC materials of this layer can consist of conventional PCC, roller compacted concrete (RCC), or could include a lower cost PCC (such as with a softer large aggregate or recycled PCC materials, or what has previously been called lean concrete base [LCB]).

PCC/PCC composite pavement systems for the purposes of this research were defined as a relatively thin high-quality concrete surface placed immediately on top of

* Shreenath Rao, Ph.D., P.E., Michael Darter, Ph.D., P.E.

Applied Research Associates, Inc., 100 Trade Centre Dr., Suite 200, Champaign, IL 61820, USA

plastic, less expensive concrete layer. The lower concrete layer may include increased amounts of recycled materials (recycled concrete aggregate [RCA], recycled asphalt pavement [RAP], and others), increased use of local and less expensive aggregates, and higher substitution rates for cementitious materials (fly ash or other supplementary cementitious materials [SCMs]) that may be less suitable for use in a surface layer at the higher substitution amounts. Construction is accelerated by placing the concrete surface layer on top of the lower concrete layer before the latter has set to facilitate a total bond (no slippage) between the two layers of concrete; this construction technique is commonly called “wet on wet” paving. The PCC can be constructed as jointed plain concrete (JPC) or continuously reinforced concrete (CRC).

Both types of composite pavements have strong technical, economical, and sustainable merit in fulfilling the key goals of the SHRP2 program including long lived pavements, rapid renewal, and sustainable pavements. A survey of US and international highway agencies conducted under SHRP2 R21 revealed considerable interest in both HMA/PCC and PCC/PCC composite pavements.

History

HMA/PCC Composite Pavements HMA/PCC composite pavements are by no means a recent development. They have been constructed since the 1950's using a cementitious base with an HMA wearing surface by various national, State/provincial, and local highway agencies such as New Jersey, Washington State, Ontario, the City of Toronto, New York City, Washington, D.C., and Columbus, Ohio. Columbus has constructed many composite pavements consisting of HMA over RCC on residential and collector streets in the past 15 or so years. Arizona has constructed many new composite pavements over the past 17 years consisting of an ARFC over a thick JPC or CRC layer. Several European countries, such as the Netherlands, the United Kingdom, Germany, and Italy have constructed major composite pavement projects with low noise HMA surfacing and either CRC or JPC as the lower layer. HMA/PCC composite pavements also are constructed routinely by many highway agencies when widening existing PCC pavements or existing overlaid HMA/PCC pavements.

Between the 1950's and the 1970's, several long-term studies on the performance of composite pavements were conducted in the US and Canada. These include the Ontario Highway 401 Study (Smith 1963, Ryell and Corkhill 1973), New Jersey Composite Pavement Study (Baker 1973), Federal Highway Administration (FHWA) Zero Maintenance Pavement Study (Darter and Barenberg 1976), which identified HMA/PCC composite pavement as one of the most promising low maintenance pavements, and FHWA Premium Pavements Study (Von Quintus et al. 1980). Transverse reflective crack deterioration was the major distress type observed on these composite pavements. Rutting was rated as only “minor” to “moderate” even under very heavy traffic (Darter and Barenberg 1976). The thinner HMA over a PCC slab seemed to have a definite effect on minimizing HMA rutting. Ryell and Corkhill (1973) concluded that better performance may be achieved if the wide transverse cracks were prevented from occurring, which may be accomplished by the use of “transverse crack inducers” (joints) in the concrete base at approximately 15-ft centers. The authors suggested that the extra cost of this could be offset through use of “lower quality” concrete in the slab.

Many European countries have been constructing HMA/PCC composite pavements on major projects for several decades and have substantial experience with the design and construction of composite pavements (Hassan et al. 2008). The

Netherlands has built porous HMA over recently placed CRC on a number of major projects over the past 13 years. These projects are all performing very well with very low noise levels and with no reflection cracking from the CRC despite their relatively thin HMA layer of about 2 to 3 in. Germany has built SMA surfaces on JPC and most recently over CRC. One SMA/JPC section was 15 years old under heavy traffic with sawed and sealed joints that had performed very well. More recently, Germany has constructed SMA over CRC. The United Kingdom also has constructed major projects and researched thin surface course systems (TSCS) over CRC and found significant technical and functional benefits (Hassan et al. 2008).

PCC/PCC Composite Pavements The history of PCC/PCC in the United States dates back to the first concrete pavement constructed in the United States, located in Bellefontaine, OH, in 1891 (Snell and Snell 2002). This experimental pavement section featured a 2-in surface and 4-in structural layer with water-to-cement ratio (w/c) of 0.60 and a durable wearing course with w/c of 0.45. From roughly 1950 to the mid 1970s, two-lift paving for concrete pavements was very common in many US States for the construction of jointed reinforced concrete pavements (JRCP), which began to disappear in the 1970s as agencies began to move toward jointed plain concrete pavement (JPCP) design.

In Europe, two-lift paving in the sense of constructing two layers with different properties for the sake of reducing noise, increasing skid resistance, lowering costs, etc. has been much more common than in the US. Austria in particular has been active in regular two-lift paving for concrete pavements, and the standard concrete pavement in Austria is constructed according to two-lift specification (Darter 1993; Hall et al. 2007, Tompkins et al. 2009). Two-lift paving has been used for special projects in countries such as Switzerland, Belgium, the Netherlands, France, and Germany with regularity since the 1930s and is becoming more common as the techniques are refined further. Germany has also used two-lift paving in airport pavements as a way of reclaiming recycled materials (Darter 1993). Overall, the desire for quieter, more economical and especially more sustainable roadways is motivating many countries to increase the frequency with which concrete pavements are constructed in two unique lifts (Tompkins et al. 2009, Vancura et al. 2009).

Much like their European counterparts, American pavement engineers have put a great deal of research, design, and construction effort into developing PCC/PCC. There were a limited number of experimental PCC/PCC projects in Iowa, Florida, and North Dakota during the late 1970s and 1980s. The High Performance Concrete Pavement (HPCP) project (FHWA 2006, Larson 2006, Wojakowski 1998) in particular was responsible for the development of experimental two-lift sections in the 1990s in Michigan and Kansas. These new two-lift experiments had as their larger research goals a desire to increase the service life of concrete pavements; lower life cycle costs; utilize innovative designs/materials; and improve construction practices.

Thirty-three composite PCC/PCC test sections on SR-45 near Ft. Myers, constructed in 1978, were designed with 3-in standard PCC in the top lift and 9-in lean concrete in the lower lift. The two-layer composite performed better than the one-layer conventional section. The project conclusions stated that “this experimental project has also demonstrated that a two-layer concrete system consisting of a relatively thin higher quality PCC surface over a lower quality econocrete layer and a granular subbase can be a sustainable and long-lasting pavement design alternative.” The desire to use more innovative materials, such as recycled aggregates, led to the creation of 3 two-lift test sections on K-96 in Kansas. All sections performed well in

the long term, though a large number of transverse cracks were observed on the sections with the igneous rock in the upper lift by Kansas DOT in a 2002 annual report. One of the first results of the 1992 U.S. TECH scanning tour of European concrete highways (Darter 1993) was the later development of the 1993 PCC/PCC new construction on I-75 near Detroit, Michigan. The I-75 European PCC/PCC sections were placed without serious problems but the placement went slowly due to the new techniques required for this composite pavement. In constructing these sections Michigan DOT and researchers from Michigan State University developed a number of recommendations for future two-lift paving. These recommendations include observations on appropriate sawing depths when forming joints, dowel bar spacing to save costs, minimal thicknesses of surface lifts, and improved techniques for brushing away cement in creating surface texture (Weinfurter et al 1994; Smiley 1995; Smiley 1996; Buch et al 2000).

The most significant two-lift concrete pavement project constructed in the United States was done in 2008 on I-70 near Abilene, Kansas (Fick 2008). The construction of this several mile long project is part of an innovative technology demonstration of two-lift concrete paving. Both “conventional” and “innovative” textures are included. The conventional includes longitudinal tining, burlap drag, longitudinal grooving, and diamond grinding surfaces. The innovative includes the “next generation” diamond grinding along with exposed aggregate concrete (EAC) texture.

SHRP2 R21 Research

The SHRP2 R21 research was conducted in three phases. Phase I consisted of a literature search, survey of various national and international highway agencies, field survey of composite pavements in three European countries, an evaluation of existing design procedures, development of database for full-scale applications, populating the database with information from available projects, and an initial evaluation of existing data. Phase II consisted of further completion of the databases, analyzing the databases, identifying failure mechanisms and other distresses relevant to new composite pavements, performance modeling, and conducting parametric evaluations of the performance models. Phase II also included the development of the detailed research plan for Phase III. Phase III consisted of implementing the research plan developed in Phase II. Full-scale roadway and accelerated pavement testing (APT) sections were constructed and tested at MnROAD (Tompkins et al. 2011, Rao et al. 2011) (figure 1) and the University of California Pavement Research Center (UCPRC) (figure 2), respectively. Field composite pavement sites with long-term performance were surveyed, and detailed information was collected in the US, Ontario, Canada, and three European countries (figure 3). The results of these investigations were used to refine and validate the performance models and develop the final design guidelines and procedures. Phase III also included the development of construction specifications, design guidelines, and a plan for long-term evaluation and validation of the design models, development of training materials, and delivery of the final report for this research.

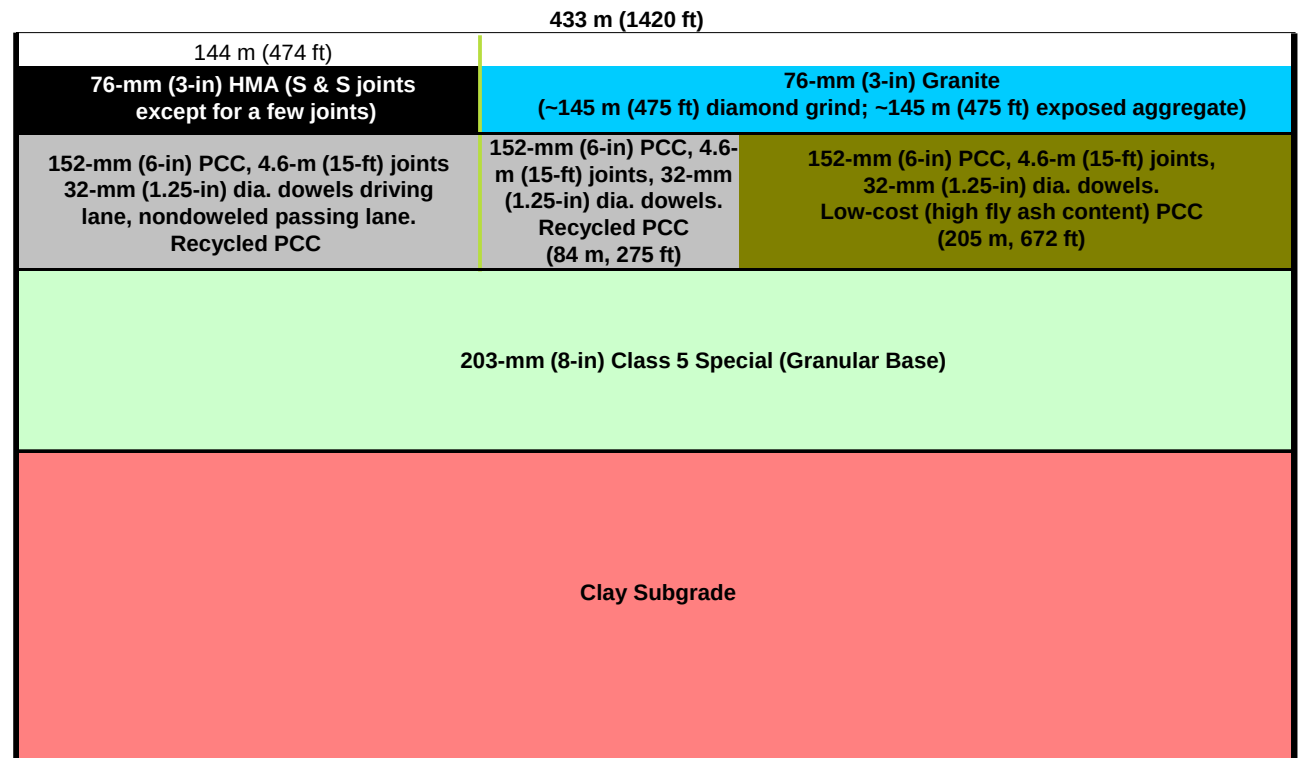


Figure 1. Layout of 3 instrumented test sections constructed on Interstate 94 at MnROAD.

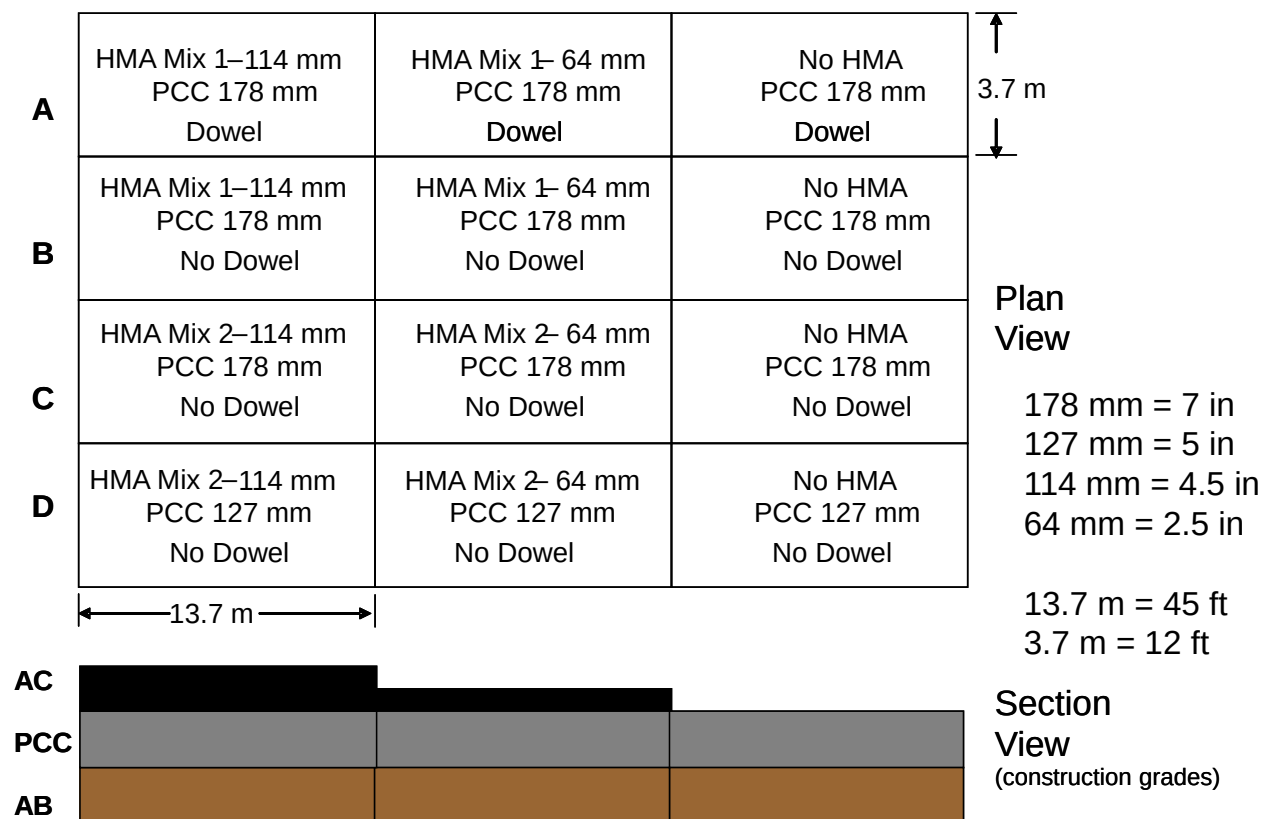


Figure 2. Layout of instrumented accelerated pavement testing sections constructed and tested at UCPRC.

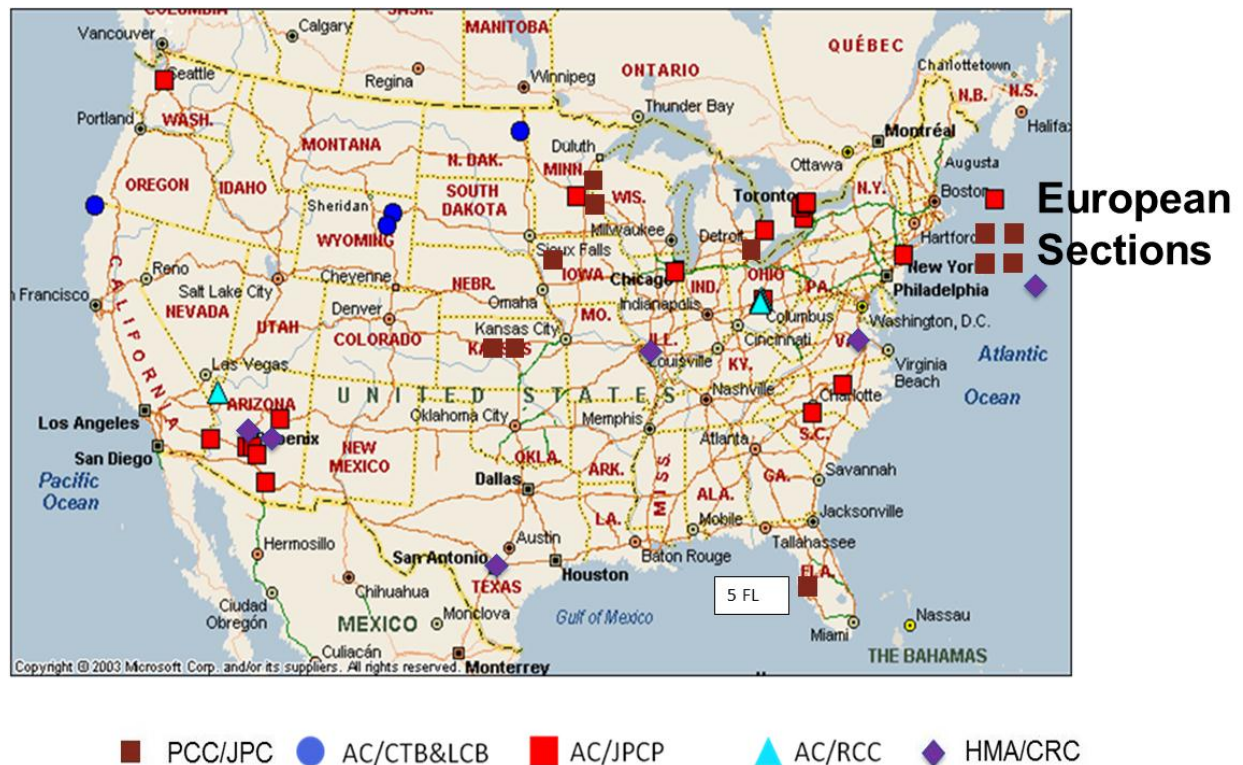


Figure 3. Field sections surveyed under SHRP2 R21.

Why Build Composite Pavements

A key question that often is asked with regards to composite pavements is: Where will composite pavements be used, and what will be the demand? Composite pavements allow the pavement designer to design pavements using the best qualities of two different materials to produce a more functional and economical structure that generally is more cost-effective in terms of service throughout its life. The fit in with SHRP2 Renewal mission of “Get in, Get out, Stay out” which comprises of three characteristics:

- Renewal that is performed rapidly.
- Minimal disruption to the community.
- Facilities which are long-lasting.

The goal is to achieve this consistently throughout the nation’s highway system and the key to achieving this is cost both initial and life-cycle. For HMA/PCC composite pavements, the PCC substructure is the primary load carrying layer and is designed to provide a durable, long-lasting pavement with low fatigue damage and a strong base, while the HMA layer is primarily a functional layer with excellent surface characteristics that can be renewed rapidly. For PCC/PCC composite pavements, both PCC layers provide structural capacity, but the lower PCC layer is the primary load carrying layer (because of the greater thickness) and is expected to provide a durable and strong base which is economical to construct and promotes the ideals of sustainability and energy efficiency. The upper PCC layer is expected to provide excellent surface characteristics over a long time period that can be renewed rapidly (through diamond grinding or other texturing methods).

Sustainability Benefits. The lower PCC in both types of composite pavements can be designed for minimal fatigue damage. This long-life “perpetual” design with lower maintenance and rapid renewal can result in reduced congestion, reduced energy

usage, and reduced emissions through the design life of the pavement. Composite pavements can also be built using recycled aggregates (Vancura et al. 2009) and local aggregates (in the lower PCC), thus reducing haul distances, energy usage, and emissions during construction. Supplemental cementitious materials (e.g. higher fly ash content) can also be used in the lower PCC lift. Composite pavements also benefit from upcoming and future technologies (e.g. WMA which has lower energy usage and lower emissions). The use of recycled materials offers environmental advantages by diverting the material from the waste stream, reducing the energy investment in processing virgin materials, conserving virgin materials, and minimizing pollution. Finally, composite pavements can be designed and constructed in urban areas where low pavement noise is desirable.

Performance Benefits. Composite pavements have several performance benefits as compared to conventional flexible and rigid pavements because they take advantage of the best characteristics of two different types of materials. Tables 1 and 2 summarize the performance benefits (with respect to key pavement distresses) of HMA/PCC and PCC/PCC composite pavements, respectively.

Table 1. Performance comparisons of HMA/PCC composite pavements with conventional flexible and rigid pavements with respect to key distresses.

Distress Type	Conventional HMA Pavement	Conventional PCC Pavement	Composite HMA/JPC & HMA/CRC
Bottom-Up Fatigue Cracking	Yes, major design concern.	Yes, major design concern.	Fatigue cracking does not occur in HMA layer since the HMA is almost always in compression. Bottom-up and top-down fatigue cracking in JPC and CRC (for punchouts) are reduced because of insulating effects of HMA.
Low Temperature or Shrinkage Transverse Cracking in HMA	Yes, this is major problem in many areas.	N/A	No, was not observed on any HMA/JPC or HMA/CRC composite projects surveyed. The bonded HMA layer does not move independently of the PCC layer.
Top Down Fatigue Cracking in Wheelpath	Yes, has occurred on some projects.	Yes, longitudinal cracking has occurred on some projects.	Top-down fatigue cracking does not occur in HMA layer since the HMA is almost always in compression. PCC longitudinal cracking in wheelpath of HMA/JPC may be reduced or eliminated due to insulating effects of HMA.
Permanent Deformation	Yes, rutting is major design concern.	N/A, however, wear from studded tires may occur.	Rutting minor on most HMA/PCC composite pavements due to high quality materials and thin layer. Also, the stiff PCC layer completely eliminates base/subbase/subgrade rutting.

Transverse Joint Reflection Cracks	No, does not occur.	N/A	Yes, occurs, for HMA/JPC. Control through saw and seal technique. No, does not occur with HMA/CRC.
Joint Faulting	N/A	Yes, major design concern.	Yes, can occur, but little faulting comes through the HMA surface. Faulting must be considered in design of HMA/JPC.

Table 2. Performance comparisons of PCC/PCC composite pavements with conventional rigid pavements with respect to key distresses.

Distress Type	Conventional JPCP & CRCP	Composite PCC/JPC & PCC/CRC Pavement
Bottom-Up Slab Fatigue Cracking	Yes, major design concern.	Yes, major design concern.
Top-Down Slab Fatigue Cracking and Top-Down Fatigue Cracking for Punchouts	Yes, major design concern.	Yes, major design concern. If higher strength PCC is used in the top surface this is less of a concern, and this damage mechanism may be reduced.
Top-Down Longitudinal Fatigue Cracking and Corner Breaks	Yes, has occurred on some projects.	No, was not observed on any PCC/PCC composite project. Higher strength PCC surface layer may be beneficial here.
Surface Wear Down (Rutting)	Yes, has occurred on projects in studded tire States/areas.	Minor on most composite pavements in over nearly 20 years in Austria due to high quality aggregates and high cement content.
Polishing of Surface (Poor Friction)	Yes, has occurred on many projects due to polishing aggregates. Higher quality aggregates are costly if used throughout the entire PCC slab thickness.	EAC surfacing in Austria and Germany where there is extensive snow and ice have shown only minor polishing in the wheel paths over 20 years. Use of the highest quality aggregates in the thin top layer would minimize polishing from occurring and lower construction costs.
Joint Faulting	Yes, major design concern.	Yes, major design concern.

Cost Benefits. In the SHRP2 R21 survey, Dutch, German, and Austrian researchers claim that composite pavements provide similar structural performance as an equivalently thick single layer at the same price in Europe, with the added benefits of higher quality and longer life friction and noise reduction due to the high-quality top layer (Tompkins et al. 2009). Furthermore, composite pavements allow for the optimization of costs and materials throughout the pavement cross-section because:

- High-quality materials can be used in lesser quantities in the upper layer, where they will be of the most benefit to the system.
- Lower quality (cheaper) materials can be used in greater quantities and in the lower layer, where they will contribute structurally without detracting from the quality and performance of the overall pavement.

HMA/PCC Composite Pavements. The analysis of the instrumented data at MnROAD (conducted by Dr. Vandenbossche at the University of Pittsburgh for this

research) and UCPRC (conducted by Dr. Harvey, Dr. Signore, Dr. Wu, and Mr. Coleri at the University of California for this research), showed that the thin HMA layer can reduce thermal and hygral gradients in the PCC layer. Figure 4 shows the relative frequency distribution of equivalent linear temperature gradients (ELTGs) in the PCC layer (Cell 70) of the HMA/PCC test section and the bare PCC pavement (Cell 71) of the PCC/PCC test section at MnROAD. The ELTG is a linear gradient that would produce the same curvature in the slab as the original nonlinear temperature gradient. The ELTG concept was developed by Thomlinson (1940), Choubane and Tia (1992), and Mohamed and Hansen (1997) to account for the nonlinearity of the temperature distribution in the slab. It was and later generalized for non-uniform, multi-layered slabs (Khazanovich 1994, Ioannides and Khazanovich 1998). The latter method in which the ELTG is established for an effective slab, with a thickness and stiffness equivalent to that of a composite multi-layer section, is employed in this study. The figure shows much greater frequency of both positive and negative extremes of temperature gradients for the bare PCC pavement. This reduction in gradients is adequately modeled in the MEPDG design procedure resulting in a PCC thickness reduction of 1-3 inches and corresponding cost savings for HMA/PCC composite pavements as compared to a bare PCC pavement. This was also confirmed through statistical analysis of one year of data from UCPRC (figure 5). Figure 5 shows that neither the thickness of PCC (7 inches vs 5 inches) nor the thickness of the HMA layer (4.5 inches vs. 2.5 inches) were major factors in this reduction of the temperature gradient. The key factors were existence of the HMA layer and HMA mix type. Figure 6 shows that relative humidity of the PCC following placement of the HMA layer is less affected by ambient conditions and longer term data shows that the PCC layer is almost always saturated resulting in near zero moisture gradients. Depths shown in the figure are from the top of the pavement so the sensors at 4.8 in depth are near the surface of the PCC layer and the sensors at 9.8 in depth are near the bottom of the PCC layer.

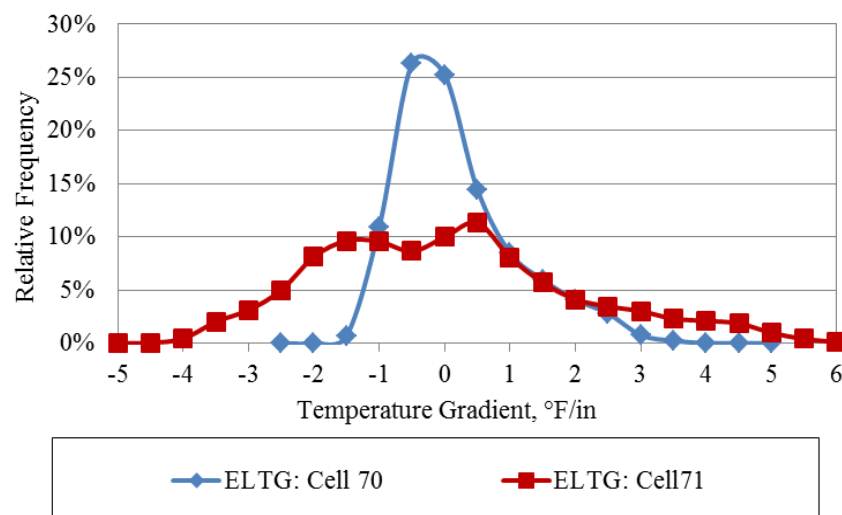


Figure 4. Relative frequency distribution comparison of equivalent linear temperature gradients in the PCC for HMA/PCC composite pavements (Cell 70) and bare PCC pavement (Cell 71). (Analysis conducted by Dr. Vandenbossche at the University of Pittsburgh for this research).

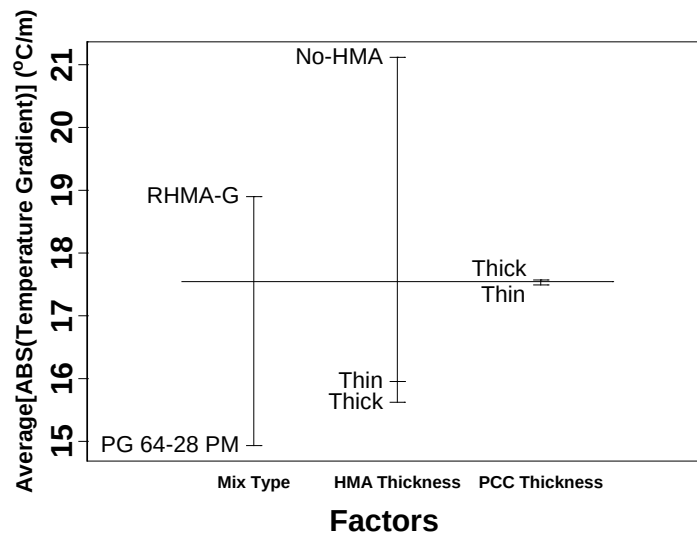


Figure 5. Design plot comparing the influence of variables HMA and PCC thickness and HMA type on the variation of the dependent variable PCC temperature gradient for 1 year of data. (Analysis conducted by Dr. Harvey, Dr. Signore, Dr. Wu, and Mr. Coleri at the University of California for this research).

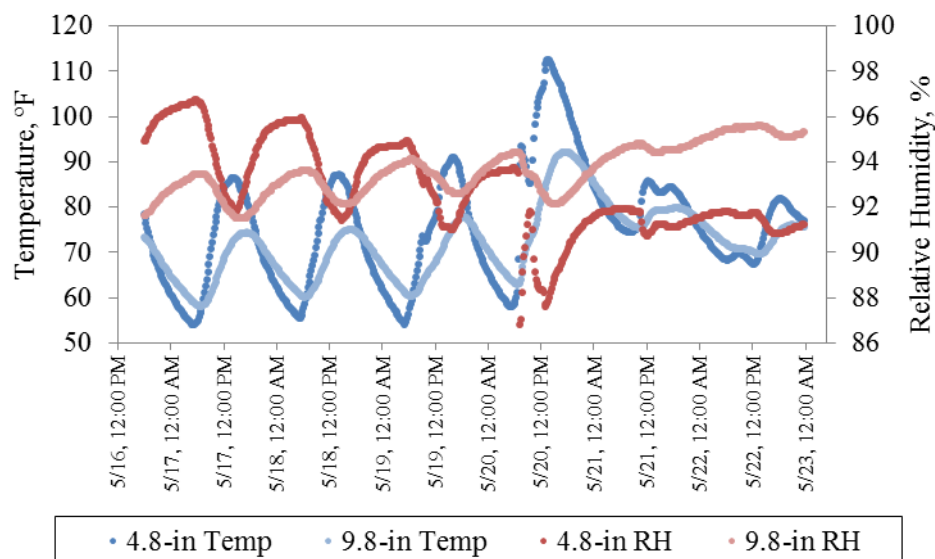


Figure 6. Daily variation in relative humidity and temperature in the PCC, 4 days before and 3 days after HMA overlay was placed in Cell 70. (Analysis conducted by Dr. Vandenbossche at the University of Pittsburgh for this research).

PCC/PCC Composite Pavements. As part of the construction at MnROAD, the construction contractor was asked to assess the feasibility of constructing PCC/PCC composite pavements with respect to initial costs. The contractor's assessment was that implementation of a 2-layer composite paving process would be a viable and competitive alternative to conventional paving, if Class A aggregates aren't readily available where long haul times drive the price of the aggregate too high. Also, it would be economically viable if recycled concrete could be produced on or near the site and haul times would have to be cut to minimal levels. Also in larger projects if producing and paving (with two pavers) could be done at an equal rate to conventional paving. With proper design and construction, PCC/PCC composite

pavements can be expected to have lower life-cycle costs because of its durability, rapid renewal, lower maintenance and rehabilitation, and long-life.

For both HMA/PCC and PCC/PCC pavements, the cost of the additional paver and paving crew needs to be offset by the reduced materials and hauling costs and lower long-term maintenance costs.

Application. Overall, composite pavements are ideal in the following situations:

- Urban areas with high congestion and high costs of lane closures.
- High-quality aggregates for PCC are not available.
- Recycling and sustainability are important considerations.
- Low pavement noise is desired.
- Rural low-volume roadways where low maintenance pavements are desired.
- Widening of existing PCC or HMA/PCC pavements.
- City streets where utility cuts are frequent.
- “Perpetual” pavement is desired.

The SHRP2 R21 database has examples of each of these applications.

Designing Composite Pavements

HMA/PCC Composite Pavements. HMA/PCC composite pavements can be designed using the AC overlay of PCC design procedure in DARWin-ME. As part of SHRP2 R21 the PCC fatigue cracking models in DARWin-ME were validated for designing composite pavements (see figures 7 and 8). Note that this does not mean that a composite pavement will be the same thickness for the same reliability and cracking criteria. This will depend on the thickness of the HMA surface among other factors. It only means that modified calibration factors are not required in DARWin-ME to use it for design of HMA/JPC or jointed RCC composite pavement. Table 3 shows the key distresses to be considered in the design of HMA/PCC composite pavements.

The empirical DARWin-ME transverse joint reflection model for HMA/JPC was not found to predict adequately. It is not recommended for usage. Instead, a fully calibrated model based on the results reported in NCHRP Report 669 (Lytton et al. 2011) is recommended to be implemented in DARWin-ME and used with caution. Also, alternatives such as sawing and sealing the HMA above the PCC joints (or use of CRC for the PCC layer) are strongly recommended. The rutting model included in the current version of DARWin-ME with the global calibration coefficients can be used to obtain reasonable predictions of rutting in HMA/PCC composite pavements. However, the updated NCHRP 9-30A (Von Quintus et al. 2011) research results are recommended to be implemented in DARWin-ME, following which, the updated calibrations coefficients are recommended for use.

Table 3. Distress considerations in design of HMA/PCC composite pavements.

Distress Type	Composite HMA/JPC
PCC Transverse Fatigue Cracking	Design using “AC/JPCP Overlay” procedure in DARWin-ME until software updated for composite pavements.
PCC Faulting	Although little faulting comes through the HMA surface, faulting check should be run with all the same inputs but without the HMA surface (new JPCP).
Reflection Cracking	Design using “AC/JPCP Overlay” procedure in DARWin-ME until software updated with fully-validated NCHRP 669 models. Ignore DARWin-ME output if saw and seal – recommended.
Permanent Deformation (Rutting)	Design using “AC/JPCP Overlay” procedure in DARWin-ME until software updated with NCHRP 9-30A models. Do not use NCHRP 9-30A coefficients in current DARWin-ME (v. 1.0.18).
Terminal IRI	Design using “AC/JPCP Overlay” procedure in DARWin-ME until software updated for composite pavements.
HMA Bottom-Up Fatigue Cracking	Does not occur in HMA layer since the HMA is almost always in compression. Ignore DARWin-ME output.
Top-Down HMA Fatigue Cracking in Wheelpath	Does not occur in HMA layer since the HMA is almost always in compression. Ignore DARWin-ME output.
Low Temperature or Shrinkage Transverse Cracking in HMA	Not observed on any HMA/JPC or HMA/CRC composite projects surveyed. The bonded HMA layer does not move independently of the PCC layer. Ignore DARWin-ME output.
	Composite HMA/CRC
PCC Punchouts	Design using “AC/CRCP Overlay” procedure in DARWin-ME until software updated for composite pavements.
Reflection Cracking	Not a concern for HMA/CRC pavements. Ignore until DARWin-ME software updated with fully-validated NCHRP 669 models.
Permanent Deformation (Rutting)	Design using “AC/CRCP Overlay” procedure in DARWin-ME until software updated with NCHRP 9-30A models. Do not use NCHRP 9-30A coefficients in current DARWin-ME (v. 1.0.18).
Terminal IRI	Design using “AC/CRCP Overlay” procedure in DARWin-ME until software updated for composite pavements.
HMA Bottom-Up Fatigue Cracking	Does not occur in HMA layer since the HMA is almost always in compression. Ignore DARWin-ME output.
Top-Down HMA Fatigue Cracking in Wheelpath	Does not occur in HMA layer since the HMA is almost always in compression. Ignore DARWin-ME output.
Low Temperature or Shrinkage Transverse Cracking in HMA	Not observed on any HMA/JPC or HMA/CRC composite projects surveyed. The bonded HMA layer does not move independently of the PCC layer. Ignore DARWin-ME output.

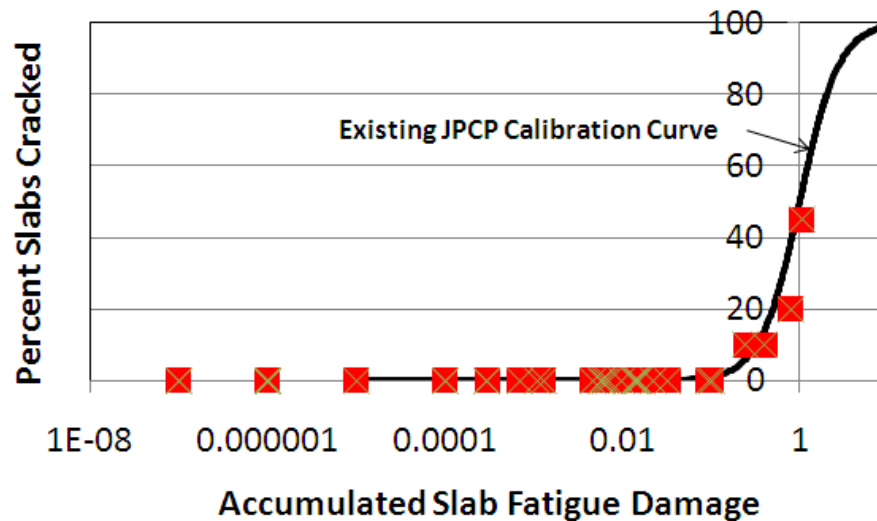


Figure 7. Fatigue damage versus measured transverse fatigue cracking (midslab) for all HMA/JPC or HMA/RCC composite pavements over their service life compared to existing JPCP calibration curve (derived in 2007 and used in the current version of DARWin-ME).

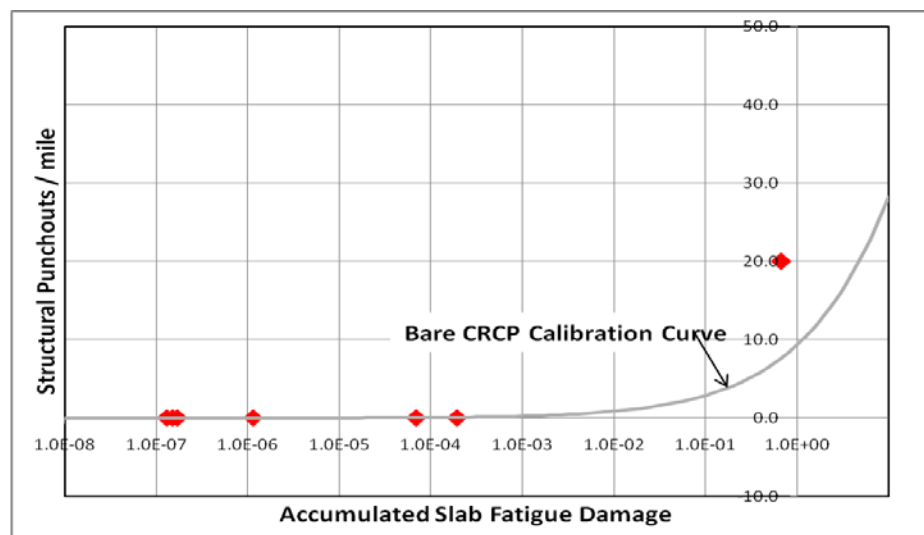


Figure 8. Plot of fatigue damage versus measured punchouts per mile for HMA/CRC projects in the R21 database. The DARWin-ME bare CRCP (national) calibration curve is shown for comparison.

PCC/PCC Composite Pavements. As part of SHRP2 R21, the AASHTO MEPDG software was modified for designing PCC/PCC composite pavements. This analysis was conducted by Dr. Khazanovich, Dr. Tompkins, and Ms. Vancura at the University of Minnesota for this research). PCC/PCC composite pavements can be designed using this MEPDG version (v.1.3000:R21) using the “Bonded PCC Overlay of PCC Pavement” procedure (Tompkins et al. 2012). The changes included bug fixes, modifications to PCC layer thicknesses and properties, slab-base interaction properties, subgrade response modeling, and distribution of temperature nodes representing a thermal gradient through PCC/PCC composite pavement system. Figure 9 illustrate the ability of the revised MEDPG to account for the damage of a pavement relative to its percentage of cracked slabs. All PCC/PCC sections were

used to make this important comparison. The s-shaped curves represent the national calibration curves obtained for JPCP one-layer slabs relating accumulated damage to transverse fatigue cracking of JPCP. The composite PCC/PCC pavements show good correspondence to these curves as shown. Thus, the national models used in JPCP design can also be used for PCC/JPCP design of composite pavement.

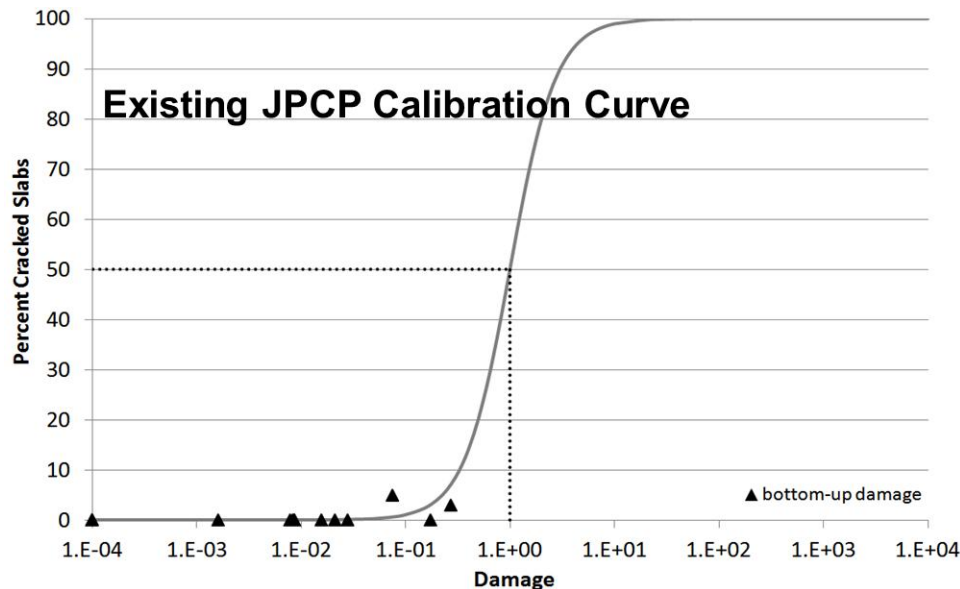


Figure 9. PCC/PCC measured cracking vs. MEPDG (v.1.3000:R21) predicted bottom-up damage. (Analysis conducted by Dr. Khazanovich, Dr. Tompkins, and Ms. Vancura at the University of Minnesota for this research).

A key concern for PCC/PCC composite pavements is the bonding between the two PCC lifts. As part of this research, a detailed finite element lattice modeling was performed at the University of Minnesota. The analysis concluded that wet on wet paving had only a very low chance (if any) to debond, which matched the field survey, survey of European agencies and contractors, and bond tests performed at MnROAD. Figure 10 shows the fractured cores from pullout tests where the PCC/PCC interface bond did not fail in any of the tests. All pullout failures were either in the lower PCC or the upper PCC layer.



Figure 10. Fractured cores– cell 72 (left) and cell 71 (right).

Constructing Composite Pavements

The construction of composite pavements does not require any new technologies or equipment that isn't already available in the US. HMA/PCC composite pavements are constructed by paving the PCC layer followed by paving the HMA layer after sufficient strength gain of the PCC layer. Steel reinforcement for HMA/CRC and dowel bars for HMA/PCC should be located at mid-depth of PCC slab. The PCC surface should be cured and textured (tined) to provide a mechanical interlock with the HMA surface. Prior to HMA paving, sufficient tack coat should be applied to the surface of the PCC layer for bonding between the HMA and PCC layers. Sawing and sealing the HMA at the location of the transverse and longitudinal PCC joints (for HMA/JPC composite pavements) is recommended.

The construction of PCC/PCC composite pavement requires an additional paver, careful planning to ensure production and placement of two PCC mixes; consistent delivery of mixes with proper identification; and special attention to width and alignment of the two pavers. Drift on the part of either paver can result in edge problems. The paving width of the lower layer is 1.5 to 2 inch less than final desired width. The lower layer should have low slump (~1 inch) and the vibrators should be higher than the top of reinforcing steel or dowel basket assembly (if used instead of dowel bar inserters). Steel reinforcement for HMA/CRC and dowel bars for HMA/PCC should be located at mid-depth of total PCC thickness. The upper PCC layer should be placed within 15-90 minutes (ideally within 60 minutes) of the lower PCC and is typically placed using a belt placer. Deformation of bottom PCC should be minimized by having a low drop height and discharge speed. The upper PCC lift should be placed with shallow vibrations and lower RPM to prevent comingling of layers. Saw cut depth should be 1/3rd total PCC thickness and at least 0.5 inch into lower PCC layer.

Conclusions

The products developed as part of SHRP2 R21 will result in improved design and life-cycle cost procedures for composite pavements. The guidelines, techniques, and specifications developed in SHRP2 R21 will greatly advance the state of the practice of constructing composite pavements. Composite pavements are congruent with the SHRP2 Renewal philosophy because they are designed to be long-lasting pavements that can be renewed rapidly. For highway engineers, designers, and agency decision makers, composite pavements provide a cost-effective alternative to conventional concrete and asphalt pavements over the life cycle of the pavement. Together, the R21 reports, software, and guidelines provide information for these technologies to become widely adopted by the transportation community.

Based on the comprehensive results achieved from this study, the key characteristics of composite pavements were determined as follows:

- Excellent surface characteristics from the thin, high-quality asphaltic or concrete top layers. These include low noise (especially for permeable mixtures), high friction, very good initial smoothness, minimal rutting, and reasonable durability over a 10- to 15-year period.
- Ability to rapidly renew a thin surface course as it wears under traffic and weather (removal and replacement of asphaltic materials, diamond grinding or retexturing of concrete materials).
- Long life “perpetual” structural design of the lower PCC layer (designed for minimal fatigue damage over a 40+ year period).

- Avoidance of certain distress types that occur regularly in conventional pavements but are rare or nonexistent in composite pavements. For example, HMA/JPC or HMA/CRC rarely show top-down HMA or PCC longitudinal cracking in the wheel paths (thermal gradients are reduced that lowers top down fatigue damage in PCC); these composites rarely show any low temperature transverse cracking (they are bonded to the PCC); and they show only minimal amounts of rutting. Transverse reflection from JPC joints can be controlled by the saw and seal procedure. Transverse reflection of CRC cracks rarely occurred in the HMA/CRC included in the database. PCC/JPC composite pavement has shown no longitudinal top-down cracking and only small amounts of fatigue transverse cracking. The durability of this surface has led to very little polishing in the wheel paths.
- Improved life-cycle costs due to both lower construction costs and lower maintenance and rehabilitation costs over time.
- Improved sustainability practices through structural and materials design of the lower PCC layer in both types of pavements. Increased use of recycled or alternative materials (RCA, RAP), increased use of more local and less expensive aggregates, and higher substitution rates for cementitious materials (higher contents of fly ash or other supplementary cementitious materials).

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