A SHRP 2 Renewal Project Brief

PROJECT R21

Composite Pavement Systems

MAY 2014

SHRP 2 Renewal research project R21: Composite Pavement Systems investigated the design and construction of new composite pavement systems that could provide longer-lasting facilities with lower life-cycle costs. While composite pavements have been in use for many years, in almost all cases they are not designed as composite pavements initially but become composite pavements through maintenance overlays. This project developed design and construction methods for new composite pavements. Two composite pavement design strategies were determined to provide both excellent surface characteristics (low noise; very smooth, nonpolishing aggregates; and durability) that can be rapidly renewed and long-lasting structural capacity for any level of truck traffic:

- High-quality, relatively thin, hot-mix asphalt (HMA) surfacing—such as dense HMA, stone matrix asphalt (SMA), porous HMA, asphalt rubber friction course (ARFC), or Novachip gap-graded asphalt rubber hot mix—over a new portland cement concrete (PCC) structural layer—such as jointed plain concrete (JPC), continuously reinforced concrete (CRC), jointed roller compacted concrete (RCC), or a lean concrete base/cement-treated base (LCB/CTB) and
- High-quality relatively thin PCC surfacing atop a thicker, structural PCC layer.

These types of composite pavements give significant flexibility to the designer to optimize the pavement design in terms of life-cycle costs, reduction in future lane closures, and improved sustainability. They essentially exhibit the advantages of conventional HMA and PCC pavements while reducing their disadvantages.

Constructed and Field Survey Sections

The investigation of the composite pavement systems pursued three specific objectives:

1. Determine the behavior, material properties, design factors, and performance parameters for each type of composite pavement.
2. Develop and validate mechanistic-empirical (M-E) based performance prediction models and design procedures that are consistent with the Mechanistic-Empirical Pavement Design Guide (MEPDG).
3. Develop recommendations for construction specifications, techniques, and quality management procedures for adoption by the transportation community.

To achieve the objectives, experimental composite pavements were constructed at two major research sites--MnROAD, Minnesota, and the University of California Pavement Research

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Center [UCPRC] at Davis, California--and were instrumented and monitored under actual climate and heavy traffic loadings. In addition, the Illinois Tollway constructed an HMA/JPC composite pavement north of Chicago. Extensive field surveys were performed in the United States, Canada, and Europe of 64 sections of the two types of composite pavements and were used in the analysis and validation. Tables 1-3 provide examples of pavement performance reported in the surveys.

Composite Pavement Design

The design procedures in DARWin-ME for HMA overlay of jointed plain concrete pavement (JPCP) and continuously reinforced concrete pavement (CRCP) and in the MEPDG for bonded PCC overlay of JPCP and CRCP were found to be the most comprehensive and applicable for design of new composite pavements. Through use of appropriate inputs, the overlay procedure could be used for new com-

Table 1. Examples of HMA/PCC composite pavements in first performance period
(note: trucks given for heaviest lane, one direction only)

COMPOSITE PAVEMENT; AGE/TRUCKS	HMA LAYER	PCC LAYER	PERFORMANCE & MAINTENANCE	DESIGN, SUSTAINABILITY & LCCA
ARFC/JPC I-10, AZ; 17 years and 20 million trucks	1-in ARFC	14-in JPC 15-ft joints Dowels	Excellent performance; trans. joints refl. low severity; smooth; ARFC has lasted 20 years; no PCC cracks or repairs	DARWin-ME requires thinner slab design; low life-cycle cost over many years; no lane closures
SMA/JPC A93, Germany; 13 years and 47 million trucks	1.2-in SMA w/saw & seal joints	10.3-in JPC 16-ft joints Dowels	Good performance; trans. joints saw & seal; smooth; no PCC cracks; SMA spall repair	DARWin-ME gives same slab design; low life-cycle cost; few lane closures
HMA/CRC I-10, San Antonio, TX; 25 years and 24 million trucks	4-in HMA	12-in CRC HMA base	Excellent performance; no reflection cracks; smooth; no punchouts; no maintenance	DARWin-ME gives thinner slab design; low life-cycle cost over many years; no lane closures
HMA/RCC White Road. Columbus, OH; 7 years and 70,000 trucks	3-in HMA w/sealed cracks after cracking	8-in RCC 45-ft joints No dowels	Excellent performance; reflection cracks sealed just after cracked; smooth; no maintenance	DARWin-ME gives thinner slab design; short jt. space; low life-cycle cost; no lane closures
HMA/JPC I-94 MN; 1 year and 600,000 trucks	3-in HMA w/sawed & sealed joints	6-in JPC 15-ft joints Dowels	Excellent performance; sawed & sealed transverse joints good condition; no PCC cracks, smooth; no maintenance	DARWin-ME gives same design; PCC contains 50% RCA & 60% flyash

Table 2. Examples of "long-life" HMA/PCC composite pavements over several performance periods
(note: trucks given for heaviest lane, one direction only)

COMPOSITE PAVEMENT; AGE AND NO. OF TRUCKS	SURFACE AND REHABILITATION	BASE SLAB CHARACTERISTICS	PERFORMANCE AND MAINTENANCE	DESIGN, SUSTAINABILITY, AND LCCA
HMA/JPC I-5 Seattle, WA; 45 years and 35 million trucks	4-in. HMA original; 2-in. at 13 years; 2-in. at 16 years; 2-in. at 11 years; (some milling at times of resurfacing)	6-in. PCC No joints No dowels	Excellent performance; transverse cracks at 70 ft reflected medium severity after 8 years; smooth; replaced HMA at 11- to 16-year intervals; no additional transverse cracks; no PCC repairs	DARWin-ME would design thicker slab, add doweled transverse joints at 10 to 15 ft; saw and seal would extend life; low life-cycle cost over many years; few lane closures for rehabilitation
HMA/JPC I-294 Chicago, IL; 19 years and 30 million trucks	1992: 3.5-in. HMA original; 2001: Milled off and added 3-in. HMA; no additional rehabilitation after 10 more years	12.5-in. JPC 20-ft joint spacing Dowels	Excellent performance; transverse joints reflected medium severity; smooth; replace HMA at 9- to 10-year intervals; no transverse fatigue cracks in JPC; no PCC repairs	DARWin-ME gives thinner slab design; shorter joint spacing; saw and seal joints would extend life; low lifecycle cost over many years

posite pavement construction. Extensive testing and evaluations were performed, and many bugs related to composite pavements, as well as significant improvements, were identified and fixed in the MEPDG. A new version of the MEPDG (v. 1.3000:R21) was developed to use the Bonded-PCC-over-JPCP project to simulate newly constructed PCC/PCC and to address limitations of the existing structural and environmental models for PCC/PCC.

Table 3. Examples of PCC/PCC composite pavement characteristics, applications, and performance
(note: trucks given for heaviest lane, one direction only)

COMPOSITE PAVEMENT; AGE/TRUCKS	UPPER PCC LAYER	LOWER PCC LAYER	PERFORMANCE & MAINTENANCE	DESIGN, SUSTAINABILITY & LCCA
PCC/JPC I-75 Detroit, MI; 18 years and 72 million trucks	2.5-in EAC	7.5-in JPC 6-in LCB 15-ft jt. space Dowels	Fair performance; no transverse fatigue cracking; no joint faulting; smooth; only distress is joint spalling or debonding	Designed for very heavy traffic; low expected life-cycle cost; few lane closures
PCC/JPC FL-45, FL; 30 years and 5 million trucks	3-in PCC	9-in JPC Lower PCC Strength A, B, and C 15 & 20-ft joint spacing Doweled & Non-doweled	Excellent performance; low transverse fatigue cracking; low joint faulting	Pavement somewhat overdesigned; low life-cycle cost; no lane closures over 30-years; savings of cement; good sustainability
PCC/JPC A93, Germany; 13 years and 53 million trucks	2.8-in EAC	7.5-in JPC 16.4-ft jt. Space Dowels Tied PCC shoulders	Excellent performance; no transverse fatigue cracking; no joint faulting; smooth; low noise; pavement should last many more years	Designed for very heavy traffic; low life-cycle cost; no lane closures, good sustainability
PCC/JPC A1, Austria; 14 years and 47 million trucks	2-in EAC	7.9-in JPC (RCA materials) 18-ft jt. space Dowels ATB	Excellent performance; no transverse fatigue cracking; no joint faulting; smooth; low noise. Pavement should last many more years	Designed for very heavy traffic; low life-cycle cost; no lane closures; good sustainability
PCC/JPC K-96, Kansas; 14 years and 2.1 million trucks	3-in PCC	7 in JPC 15-ft Jt. Space Dowels PCC shoulders	Excellent performance (new pavement); no distress; smooth	Pavement over designed; low expected life-cycle cost; no lane closures
PCC/JPC N279, The Netherlands; 8 years and 11.9 million trucks	3.5-in EAC	7-in JPC 15-ft joint spacing Dowels	Excellent performance; no transverse fatigue cracks; smooth; low noise; no other distress	Well designed; low expected life-cycle cost; no lane closures
PCC/JPC I-70, Kansas; 4 years and 3 million trucks	1.5-in PCC 8 different surface textures	11.8 in PCC 15-ft Jt. Space Dowels PCC shoulders	Excellent performance (new pavement); no distress; smooth; low noise; Long life expected	Designed for very heavy traffic; low life-cycle cost expected
PCC/JPC I-94 MN; 1 year and 600,000 trucks	3-in EAC and diamond grinding	6-in JPC 15-ft joint spacing Dowels	Excellent performance; no transverse fatigue cracks; smooth; no maintenance	DARWin-ME gave this design for 15 year life, PCC 50% RCA, 60% fly ash, good sustainability

Recommendations for Composite Pavement Design

Based in part on these models and improvements made to the MEPDG/DARWin-ME software, the following can now be used in the design of new composite pavements:

- New HMA/JPC, HMA/RCC or LCB, and HMA/CRC can be designed using the overlay design feature in DARWin-ME.
- PCC/JPC and PCC/CRC can be designed using MEPDG (v. 1.3000:R21), which includes modifications to the allowable PCC layer thicknesses, representative PCC layer properties, slab and base interaction properties (full versus zero friction), PCC/PCC subgrade response modeling, and the distribution of the temperature nodes representing a thermal gradient through the composite pavement system.

Lattice Model for PCC/PCC Bonding

Extensive work was performed to more fully develop and use lattice models for composite slab simulations for debonding of the top PCC layer from the bottom PCC layer. Completed models coupled the lattice models with finite element models to provide a comprehensive model of the PCC/PCC interface bonding. For model simulations of realistic paving conditions in which newly constructed PCC/PCC pavements are placed in a reasonable time frame, debonding of the layers did not occur. Furthermore, additional simulations of layer behavior took into account unrealistic extreme thermal gradients and highly reduced shear strengths at the interface, and these simulations found failure at the interface in only the most extreme of cases, which would not be encountered in the field. This conclusion is supported by observations from the European PCC/PCC experience, as consultants to the R21 project were unable to cite an instance of PCC/PCC debonding. Based on these observations and model simulations, it was the assessment of the research team that debonding is only a concern in PCC overlays of existing PCC pavements, which was out of the scope of this project.

Research Products

The products from this research can be classified into five broad categories: (1) design, (2) construction and materials, (3) training, (4) informational, and (5) other. They are available online at http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Blurbs/168145.aspx.

Design Products

MEPDG (v. 1.3000:R21) developed under this study includes modifications to the allowable PCC layer thicknesses, representative PCC layer properties, slab and base interaction properties (full versus zero friction), PCC/PCC subgrade response modeling, and the distribution of temperature nodes through the composite pavement system. Many of these revisions specifically targeted the Enhanced Integrated Climatic Model (EICM) used by the MEPDG. This new program will be submitted to the American Association of State Highway and Transportation Officials (AASHTO) for consideration to incorporate the improvements into the DARWin-ME software. In addition, bug fixes and improvements related to both types of composite pavements were made to the MEPDG software throughout the R21 contract (e.g., crack opening error in HMA/CRC), and all of these modifications have been incorporated into the DARWin-ME software.

The structural fatigue damage and cracking models for both types of composite pavement were validated using all available data: MnROAD test sections, UCPRC test sections, and the existing 64 sections located in the United States, Canada, the Netherlands, Germany, and Austria. The existing global calibration factors were determined to be adequate. However, this does not mean that slab thickness will be the same for conventional or two-layer composite pavements.

- Various other structural and performance models for key distresses (rutting, joint faulting, smoothness) in new composite pavements were validated.
- Several detailed MEPDG design examples for composite pavements were prepared for guidance purposes. Comparisons of several examples with conventional JPCP or CRCP indicated a 1- to 3-in. reduction in required thickness for composite pavement. This reduction for HMA/JPC or HMA/CRC was attributable to a reduction in temperature gradients.
- Detailed recommended revisions were made to incorporate composite pavements into the MEPDG/DARWin-ME Manual of Practice.
- Guidelines and examples of life-cycle cost analysis were prepared. The life-cycle costs for composite pavement can be lower than those for conventional HMA or PCC pavements:

Construction and Materials Products

Construction specifications and guidelines were developed as part of construction at MnROAD and UCPRC for use by agencies considering constructing new HMA/PCC and PCC/PCC composite pavements. These include two-lift wet-on-wet construction of PCC/PCC pavements, timing and sequencing of operations, texturing procedures and related guidelines, guidelines for paving the stiffer lower lift PCC and the thin upper lift, saw cutting of joints, and the challenging exposed aggregate brushing technique. The MnROAD construction also involved the use of ultrasonic tomography to assess PCC/PCC layer thicknesses and bond quality at the PCC/PCC and slab/base interfaces. The PCC upper layer was diamond ground using a next-generation grind that produces a smoother and quieter surface.

Material specifications include those for recycled aggregate, cementitious materials such as cement and fly ash, aggregate type and gradation for EAC, and retarding/curing compound. Procedural specifications include those related to wet-on-wet construction, such as timing of paving operations, texturing, saw cutting, sealing of sawed and sealed joints, tack coat application for HMA/PCC, and others.

Concrete freeze–thaw durability is a major concern for pavements in many parts of the United States and Canada. The International Union of Testing and Research Laboratories for Materials and Structures (Paris) (RILEM) CIF concrete freeze–thaw standard was adopted based on European PCC/PCC experience, and the equipment was imported from Germany for use in SHRP 2 R21. RILEM CIF freeze–thaw testing and evaluations were conducted on all the concrete mixtures used at MnROAD and they all adequately resisted surface scaling and internal damage (modulus) caused by frost action. Compared with the decrease in relative modulus of other concrete samples studied with the RILEM CIF procedure, the loss of scaled material and the decrease in relative moduli of all of the samples were relatively small. The lack of scaling and internal damage n both lower PCC mixes after 56 freeze–thaw cycles indicated that these mixtures are suitable for use in long-life concrete pavements despite containing recycled concrete aggregates or having a 60% cement replacement with fly ash, respectively.

Training Products

Materials were prepared to promote the use and accelerate the adoption of new composite pavements. The training materials include both design and construction materials. Design examples for both major types of composite pavements are included.

Informational Products

This project produced three reports: *Composite Pavement Systems: Volume 1: HMA/PCC Composite Pavements* (S2-R21-RR-2); *Composite Pavement Systems: Volume 2: PCC/PCC Composite Pavements* (Report S2-R21-RR-3); and *2008 Survey of European Composite Pavements* (S2-R21-RR-1). A fourth document, *Composite Pavement Systems: Appendices,* (S2-R21-RR-4) provides additional detail, history, and context. All four reports are available online at http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/CompositePavementSystems.aspx. A database of test sections, including material properties, performance, traffic, structure, and location, which are all inputs required for use with the MEPDG/DARWin-ME.

Other Products

Three test sections (two PCC/PCC and one HMA/PCC) were constructed at MnROAD with various surface textures (exposed aggregate, conventional grind, next generation grind, HMA) and design features (doweled/nondoweled and with/without sawed and sealed joints for HMA/PCC) with two different PCC mixes in the lower lift. These are the only instrumented in-service composite pavement test sections in existence. The instrumentation includes static and dynamic gauges, moisture gauges, and temperature gauges, all of which are wired into a data acquisition unit for continuously collecting data. These sections were constructed in April through June 2010 and were opened to traffic in July 2010.

Instrumented UCPRC HVS test sections were constructed in May 2010 and loaded with the HVS equipment. The instrumented test cells can be used for future testing. Data were collected from rutting and reflection cracking tests at UCPRC (including laboratory testing). HMA/JPC full-scale fatigue cracking tests using the HVS were conducted to validate the MEPDG transverse cracking models, and the results provided validation. Additional testing may continue with other funding.