

SHRP2 R21 Project Implementation: Two-Lift Concrete Paving on I-65, Nashville

Linda M. Pierce, Mark B. Snyder, Kurt D. Smith, and Jamie L. Waller¹

Abstract

Under Strategic Highway Research Program 2 (SHRP2) Project R21, detailed design and construction guidelines were developed for new composite pavement systems. These systems, consisting of either a hot-mix asphalt (HMA) or portland cement concrete (PCC) wearing course over a structural concrete layer (i.e., HMA/PCC or PCC/PCC), are promising technologies for providing sustainable roadways that can be constructed rapidly and rehabilitated (or renewed) with minimal disruption to the traveling public. New composite pavement systems have proven to provide long service life, excellent surface characteristics, exceptionally smooth ride quality, and high durability.

As part of the SHRP2 Implementation Assistance Program, the Tennessee Department of Transportation (TDOT) integrated a two-lift (wet-on-wet) concrete composite pavement into a full-depth shoulder adjacent to a mainline reconstruction project on I-65 in Nashville. TDOT's interest in the two-lift concrete pavement was driven by a recent specification change requiring a higher quality surface aggregate, and the I-65 project offered the opportunity to evaluate the viability and cost-competitiveness of the two-lift system. This paper describes the construction of the TDOT two-lift composite pavement, including critical aspects of the batching, transport, placement, and post-construction aspects of two-lift composite pavement construction.

Acknowledgements

This paper is made possible through funding from the SHRP2 Implementation Assistance Program. Special recognition is given to Mr. Steve Cooper, Federal Highway Administration, SHRP2 Renewal Pavement Engineer for his support and guidance with the New Composite Pavement System (SHRP2 R21) Implementation project. In addition, the authors appreciate the information and support provided by Mr. Jagan Gudimetla and the FHWA Mobile Concrete Laboratory.

Introduction

The Strategic Highway Research Program 2 (SHRP2) R21 project, *Composite Pavement Systems*, focused on the design and construction of sustainable, renewable composite pavements (Rao et al. 2013a; 2013b). The SHRP2 R21 composite pavement systems can provide agencies with additional pavement type options for rapidly constructing and reconstructing sustainable roadways with minimal traffic disruptions.

In 2014 the Federal Highway Administration initiated a SHRP2 Implementation Assistance Program (IAP) to provide agency support for fostering the sharing of experiences and lessons learned between highway agencies in the deployment and implementation of SHRP2 products. Specific to the SHRP2 R21 product, the IAP included (among other tasks) providing technical support and documentation of agency processes during the planning, design, and construction phases of the composite pavement system.

¹ Linda M. Pierce, NCE, lpierce@ncenet.com; Mark B. Snyder, mbsnyder2@gmail.com; Kurt D. Smith, Applied Pavement Technology, Inc., ksmith@appliedpavement.com; Jamie L. Waller, Tennessee Department of Transportation, Jamie.Waller@tn.gov.

As part of the SHRP2 IAP (Round 4), the Tennessee Department of Transportation (TDOT) constructed a two-lift (wet-on-wet) composite pavement as a shoulder section of an existing concrete pavement reconstruction project. One of the primary TDOT motivations for evaluating the two-lift concrete composite pavement was to identify approaches for addressing a recent concrete pavement specification change. The TDOT concrete pavement specification changes include:

- “Coarse aggregate in portland cement concrete pavements for finished riding surfaces of travel lanes including mainline pavements and ramps shall consist of Size No. 467. Ensure that either the Size No. 4 or Size No. 67 fractions meet TDOT surface aggregate requirements.” Surface aggregate requirements are shown in Table 1.
- “Coarse aggregate in portland cement concrete bridge decks on interstates and four or more lane highways consisting of Size No. 57 shall meet TDOT surface aggregate requirements.”

Table 1. TDOT surface aggregate requirements.

Aggregate Property	Test Method	Aggregate Type			
		1	2	3	4
Silica Dioxide Content, % min	ASTM C25	40	30	20	10
Calcium Carbonate Content, % max	—	32	N/A	N/A	N/A
Acid Insoluble Residue, % min	ASTM D3042	50	35	25	N/A
British Pendulum Number, min ¹	AASHTO T 278	30	30	25	22
	AASHTO T 279				

¹ After 9 hours of accelerated polishing using the British Wheel (AASHTO T 279).

The construction of the two-lift composite pavement was performed to provide TDOT an opportunity to evaluate the cost-effectiveness of using polish-resistant aggregate in the top lift of the composite pavement only (versus in a single-lift, full-depth pavement) to ensure that the concrete plant can produce and supply two concrete mixtures and to assess the ability of a contractor to manage two paving crews while maintaining the logistics of concrete placement. If successful, two-lift concrete pavements can provide TDOT with an additional cost-effective concrete pavement construction alternative that is able to utilize local, and possibly recycled, materials.

Project Overview

The two-lift composite pavement was constructed in October 2014 on the outside shoulder in the northbound lanes of Interstate 65 just north of downtown Nashville, Tennessee between Trinity Lane and Dickerson Road. Placement included approximately 5,000 lineal feet of a 10-foot wide two-lift concrete pavement section.

The shoulder cross-section was placed to match the total thickness of the adjacent travel lane pavement section and included a 10-inch bottom lift, paved 9 feet wide, and an encapsulating 3-inch top lift paved 1 foot wider than the bottom lift (see Figure 1). The existing subgrade was prepared in accordance with TDOT specifications (grade and compact to 100 percent of maximum density). The base layers include 6 to 10 inches of aggregate base (crushed stone or slag, crushed or uncrushed gravel or chert with a maximum aggregate size of 1.5 inch) and 4 inches of asphalt-treated permeable base material (maximum aggregate size 1.5 inch, 3 percent by weight of liquid asphalt).

The two-lift composite pavement was included on an existing concrete reconstruction project by change order. The cost of the two-lift composite pavement

change order included \$67,500 for the two-lift composite paving plus \$23,000 for mobilization, for a total cost of \$90,500.

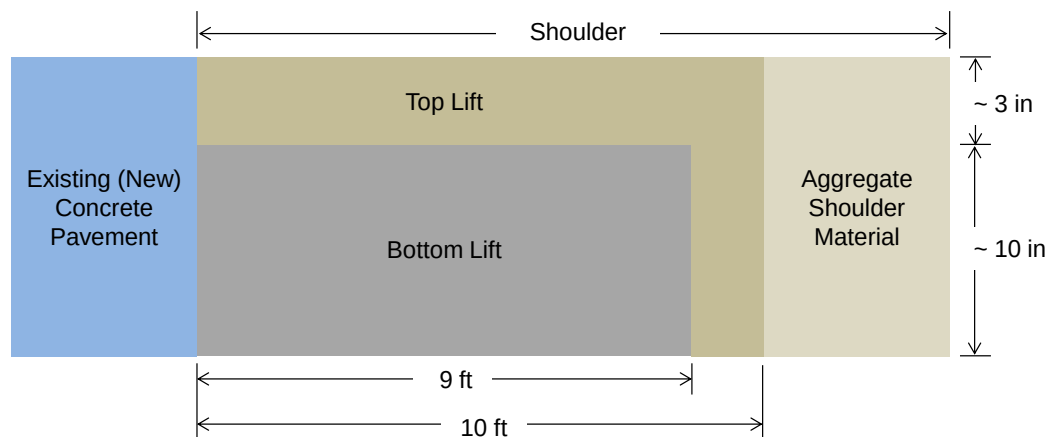


Figure 1. TN I-65 two-lift pavement cross section (Smith et al. 2015).

Change Order Requirements

Specifics of the change order for the composite pavement include (TDOT 2014):

- Placement of a two-layer fresh concrete pavement as wet-on-wet construction using a slip-form paver.
- Two-lift concrete pavement construction should be in accordance with TDOT conventional concrete paving except as follows:
 - Dowel bar baskets and tie bars to be placed at the mid-depth of the finished concrete pavement section. Internal vibration is required on the lower lift. Lower lift does not require curing or finishing.
 - Top lift should be placed while the bottom lift is still plastic and within 45 minutes of lower lift placement. Cold joints are not allowed. External vibration is allowed as long as the contractor can demonstrate uniform and satisfactory consolidation and finishing. Top lift to be cured using white pigmented curing compound immediately after finishing. Saw and seal joints to a depth of $D/3$ (where D is the combined top and bottom lift thickness).

Mix Proportions

The mix proportions for the TDOT conventional, bottom lift, and top lift concrete are shown in Table 2.

Construction Process

The following provides a summary of the TDOT two-lift concrete composite pavement construction process.

- Concrete mixes were wet-batched in 6.5-cubic yard batches at a ready-mixed concrete production facility located within 15 minutes of the project site. Plant operations included clearly labeled aggregate stockpile bins to minimize cross-contamination and aggregate mix-ups, state-of-the-art production monitoring equipment, and efficient truck clean-out and wash water recycling facilities. To ensure the correct mix was delivered for use in each layer, different haul vehicle types were used for each mixture. End-dump trucks were used to transport concrete for the bottom lift (Figure 2a) and front-discharge ready-mix trucks were used to transport concrete for the top lift (Figure 2b). This different layer thicknesses resulted in the

use of one front-discharge truck (top lift concrete) for every four dump trucks (bottom lift concrete).

Table 2. Concrete mix design (Smith et al. 2015).

Material	Conventional	Bottom Lift	Top Lift
Cement (lb/yd ³)	289	289	289
	(Type I/II)	(Type I)	(Type I)
Fly ash (lb/yd ³)	105	105	113
GGBFS ¹ (lb/yd ³)	132	132	169
AASHTO No. 4 Limestone (lb/yd ³)	940	765	—
AASHTO No. 67 Limestone (lb/yd ³)	940	1,150	1,800
Natural Sand (lb/yd ³)	1,283	1,290	1,244
Water (lb/yd ³)	210	220	240
Chemical admixtures	²	²	²
Theoretical unit weight (lb/ft ³)	146.4	146.4	143.1
W/C ratio	0.40	0.42	0.42
Air content (%)	5	5	6
Min. 28-day compressive strength, (lb/in ²)	3,000	3,000	3,000

¹ Ground Granulated Blast Furnace Slag

² Air-entrainer and water-reducer, dosage in accordance with manufacturer's recommendations.



a. Dump trucks (bottom lift).



b. Front-discharge trucks (top lift).

Figure 2. Concrete mix delivery (Smith et al. 2015).

- Transverse joints were placed at 15-foot intervals and included 1.5-inch epoxy-coated cylindrical steel dowels, placed on 12-inch centers, and mounted on baskets to position the dowels at the mid-depth of the pavement section. Deformed No. 5 tie bars were drilled and anchored into the adjacent concrete travel lane (positioned at mid-depth of the pavement section, 30-inches in length, and spaced at 18 inches on center).

- The bottom lift concrete was placed using a Gomaco Model 9500 Belt Placer, paved using a Gomaco GHP 2800, and finished with a burlap drag (Figure 3). The top lift concrete was placed using the truck-mounted discharge chute and paved using a Gomaco Commander II (Figure 4). The top lift concrete was generally placed within 30 minutes of bottom lift placement.

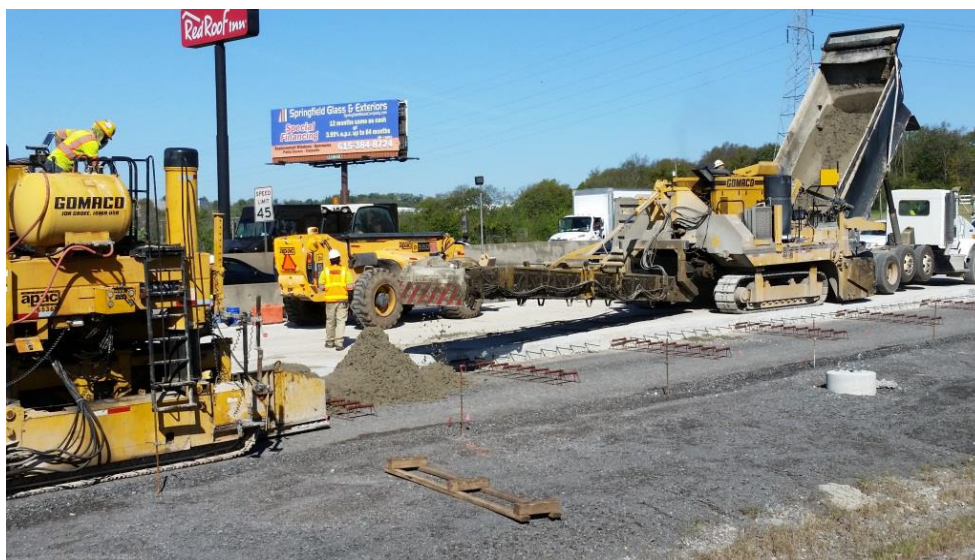


Figure 3. Bottom lift paving (photo courtesy of TDOT).



Figure 4. Top lift paving (photo courtesy of TDOT).

- The top lift was finished by transverse tining using a hand rake (Figure 5a). Curing included the application of a white-pigmented, membrane-forming curing compound, which was manually sprayed onto the concrete surface (Figure 5b). Transverse joints were sawed to match adjacent travel lane joint spacing and sawed to a depth of $D/3$ using a walk-behind saw (Figure 5c). As recommended, the minimum saw cut should be the greater of $1/3$ the total concrete thickness (lower lift plus upper lift) or the thickness of the upper lift plus 0.5 inches (Rao et al. 2013b). Figure 5d illustrates the propagation of a crack from the bottom of the saw cut in a sawed transverse joint (typical).



a. Transverse tining.



b. Curing compound application.



c. Saw cutting equipment.



d. Saw cut and resulting crack.

Figure 5. Concrete finishing, curing, and joint sawing (Smith et al. 2015).

- Testing was conducted during concrete placement and including slump, air, and the casting of beams and cylinders for determination of flexural strength and compressive strength. A summary of results for these tests is shown in Table 3. In addition, the FHWA Mobile Concrete Laboratory (MCL) was on site during concrete placement, and a number of additional tests were conducted. Testing conducted by the MCL staff included unit weight, air void system measurements (Air Voids Analyzer and Super Air Meter), modulus of elasticity, Poisson's ratio, coefficient of thermal expansion, heat signature, permeability, dowel alignment (MIT Scan 2-BT) and slab thickness (MIT Scan T2). Additional details regarding MCL tests and TDOT project results can be found in the project field report (Smith et al. 2015).

Table 3. Concrete mixture test results (Smith et al. 2015).

Date	Bottom Lift				Top Lift			
	Slump (in)	Temp (°F) ¹	Air (%)	Comp. Strength (psi) ²	Slump (in)	Temp (°F) ¹	Air (%)	Comp. Strength (psi) ²
Spec.	< 3	< 90/ 50-85	5 ³	> 3,000	< 3	< 90/ 50-85	6 ³	> 3,000
10/17/14	1.00	57/68	4.1	5,230	2.25	70/78	4.6	5,260
10/18/14	1.00	65/68	4.9	6,215	1.50	57/52	4.6	6,250
10/20/14	1.50	57/51	4.4	6,455	1.50	60/75	5.0	5,265
10/20/14	1.00	68/67	5.1	5,680	—	—	—	—
10/21/14	1.00	58/65	4.5	6,585	1.25	60/70	6.1	4,920

¹ Ambient air temperature/concrete temperature.

² 28-day compressive strength.

³ Design air content; 3 to 8 percent is allowed during production.

Costs

One of several potential benefits of the new composite pavement systems is the ability to use higher quantities of locally available, lower quality and/or recycled materials in the bottom concrete layer, and higher quality materials in the upper layer (Rao et al. 2013a; 2013b). The use of higher quality materials in the upper lift, and the equipment, mobilization, and labor often increase the total paving costs for composite pavements. However, a portion of the increased cost may be offset by reduced haul and aggregate costs. For example, the Illinois Tollway determined that roadway widening projects resulted in an average bid cost of \$56.37/yd² (approximately 1.2 million square yards of 12 inch JPCP placed between 2006 and 2009) compared to a comparable two-lift composite pavement of \$44.41/yd² (approximately 1.7 million square yards of two-lift JPCP placed in 2013 and 2014) (Beckemeyer and Gillen 2014).

For the TDOT project, an aggregate and aggregate hauling cost comparison was conducted by the TDOT. As previously noted, the TDOT specification change requires the use of polish-resistant aggregate in the finished pavement surface. The cost comparison is based on the use of the higher quality aggregate in a full-depth conventional concrete pavement versus just the upper lift of a two-lift concrete composite pavement. Table 4 summarizes the typical haul distance and drive time between the quarry and the concrete plant for the standard and higher quality aggregate, the additional total haul cost (difference in cost for hauling from standard aggregate quarry to concrete plant and higher quality aggregate quarry to concrete plant), and the additional total aggregate cost (difference in cost for standard aggregate and higher quality aggregate) in each of the TDOT regions.

Table 4. Typical haul and aggregate costs (adapted from FHWA 2015a).

Region	Standard Aggregate Haul ¹	Higher Quality Aggregate Haul ¹	Added Haul Cost	Added Aggregate Cost
Knoxville	5.5 miles 9 minutes	40.6 miles 60 minutes	\$238	\$477
Chattanooga	19.4 miles 25 minutes	25.7 miles 36 minutes	\$1,155	\$10,760
Nashville	8.0 miles 14 minutes	53.9 miles 50 minutes	\$1,932	\$5,405
Jackson	52.2 miles 51 minutes	98.2 miles 95 minutes	\$924	\$2,076

¹ Distance and time between quarry and concrete plant.

Table 5 provides a comparison of estimated hauling and aggregate costs for the conventional and the two-lift composite concrete pavements. The total estimated additional aggregate haul costs for the higher quality aggregate for the composite pavement is approximately \$23,000 less than the haul cost for the conventional pavement, the standard coarse aggregate costs for the composite pavement is approximately \$158,000 higher, and the coarse aggregate for the top lift is approximately \$262,000 less for the composite pavement. For this cost comparison the estimated aggregate material and haul cost savings of \$127,010 would be seen if a composite pavement had been utilized throughout the entire project length.

Table 5. Material cost comparison (adapted from FHWA 2015a).

Pavement Option	Total Added Haul Cost	Cost of Standard Coarse Aggregate	Cost of Higher Quality Top Lift Aggregate	Total Cost
Conventional	\$31,835	—	\$363,828	\$395,663
Composite	\$8,908	\$157,944	\$101,801	\$268,653
Difference ¹	-\$22,927	\$157,944	-\$262,027	-\$127,010

¹ Negative values indicate material cost savings for using composite pavements.

Discussion

The following summarizes the observations and the findings from the TDOT two-lift construction project (Smith et al. 2015):

- Construction observations. The ready-mix plant was well-managed and operated. The use of different truck types was effective for delivering the right mix to the right paver. The top lift was generally delivered and placed within the required 45-minute window after placement of the lower lift, but in one instance the time period reached nearly 90 minutes between lift placements. Some edge slump blowouts were observed in some areas where the top lift encapsulated the bottom by the planned 12 inches, but not when the encapsulation width was 6 inches or less. Over-spraying of water on the mixture at the back of the paver was noted and may result in a reduced surface durability, as well as a higher potential for map/shrinkage cracking.

- Field test results. The fresh concrete test results indicated that both mixtures met applicable TDOT specification requirements (except for one slump test on the top lift and one slump test on the bottom lift). All compressive strength test results exceeded the required 3,000 psi at 28 days. The air void distribution, as measured using the AVA and SAM, indicated good air void distribution in both lifts. The MIT Scan 2-BT test results indicated that all dowel bars were properly aligned and that three of the transverse joints appeared to have shipping wires that were not cut prior to concrete placement. The maximum thickness difference between the MIT Scan T2 results and measurements from the TDOT-obtained cores was less than 0.1 inches.

- MCL test results. The measured results for modulus of elasticity, Poisson's ratio, and coefficient of thermal expansion can be used by TDOT in the AASHTOWare Pavement ME Design™ software. Heat signature evaluation indicated that there were no significant changes in material sources during paving, no batching issues, and no material compatibility issues. The bottom lift mixture was categorized as having low-to-very low resistivity and the top lift was categorized as having low resistivity (i.e., lower permeability, indicating improved durability).

Based on the results of this project, TDOT noted that the placement of the two-lift composite pavement was a success and determined that it would be a viable alternative to the placement of full-depth concrete pavements that require the use of polish-resistant aggregate. TDOT is also considering adding some of the testing procedures demonstrated by the FHWA MCL into their concrete pavement program.

Keys to Success

Tables 6 and 7 includes key design and construction practices for PCC/PCC composite pavements, respectively (FHWA 2014).

Table 6. Key design practices (adapted from FHWA 2015b).

Design Input	Characteristics
Upper PCC Layer	• Durable • Meet agency surface characteristics (e.g., noise, polishing, conventional texturing) • Layer thicknesses of 1.5 to 3.0 inches have been successful
Lower PCC Layer	• Structural layer to meet design requirements (e.g., climate, traffic) • Jointed plain concrete pavement (JPCP) or continuously reinforced concrete pavement (CRCP) • Layer thickness: total required thickness minus the surface layer
Joint Design (JPCP)	• Transverse joint spacing: 12 to 15 feet • Limit joint faulting to 0.15 to 0.20 inches • Saw joints 1/3 of total concrete thickness or upper layer thickness + 1/2 in (whichever is greater)
Base and Sublayers	• Minimize erosion • Maximize ease of construction/cost effectiveness • Do not reduce friction between slab and base, unless cement-treated base is used (in which case friction should be minimized using plastic sheeting or other materials)

Table 7. Key construction practices (adapted from FHWA 2015b).

Construction	Characteristics
Sublayer Preparation	• Follow agency practices for conventional concrete pavements • In dry conditions, watering of base layer prior to placement of lower concrete lift may be necessary to minimize loss of moisture
Doweling	• Dowel diameter and placement should follow agency practices • Dowel baskets or dowel bar inserters may be used • Dowels should be placed at mid-depth of combined concrete layer thickness (the depth may need to be slightly increased to ensure that the dowel is completely encapsulated in the lower lift, while maintaining at least 2 to 3 inches of bottom cover)
Concrete Mix Design	• Upper lift: high quality aggregate • Lower lift: lower cement content, supplementary cementitious materials, coarse aggregate replacement (local and recycled materials), low-risk, high-reward opportunities for economics and sustainability
Batching and Deliver	• Single or multiple plants • Delivery time matters; placement time between lifts should be within 15 to 90 minutes, ideally < 60 minutes

Table 7. Key construction practices (continued).

Construction	Characteristics
Placing Concrete Layers	• Lower lift: similar to conventional concrete paving, place 0.75 to 1.5 inches (per side) narrower than intended paving width, vibrate if dowel baskets are used • Upper lift: place mix using belt placer or other methods, vibration should be handled delicately to prevent issues at interface
Shoulders & Tie Bars	• Follow agency practices for conventional concrete paving
Surface Texturing & Joint Saw Cutting	• Lower lift: no treatment applied • Upper lift: conventional surface texture and curing methods

References

Beckemeyer, C. A. and S. Gillen. “Innovations in Pavement Rehabilitation at the Illinois Tollway.” *Maintenance & Roadway Operations Workshop*, Jersey City, New Jersey. Illinois Tollway, Downers Grove, IL.

Federal Highway Administration (FHWA). 2015a. *SHRP2 Round 6 Pavements, Implementation Assistance Program Webinar, Precast Concrete Pavement (R05) and New Composite Pavement Systems (R21)*. Federal Highway Administration, Washington, DC.

Federal Highway Administration (FHWA). 2015b. *Workshop on New Composite Pavement System (R21)*. Federal Highway Administration, Washington, DC.

Rao, S., M. Darter, D. Tompkins, M. Vancura, L. Khazanovich, J. Signore, E. Coleri, R. Wu, J. Harvey, and J. Vandenbossche. 2013a. *Composite Pavement Systems, Volume 1: HMA/PCC Composite Pavements*. SHRP2 Report S2-R21-RR-2. Transportation Research Board, Washington, DC.

Rao, S., M. Darter, D. Tompkins, M. Vancura, L. Khazanovich, J. Signore, E. Coleri, R. Wu, J. Harvey, and J. Vandenbossche. 2013b. *Composite Pavement Systems, Volume 2: PCC/PCC Composite Pavements*. SHRP2 Report S2-R21-RR-3. Transportation Research Board, Washington, DC.

Smith, K. D., Snyder, M. B., Pierce, L. M., and Waller, J. L. 2015. *Tennessee DOT Two-Lift Concrete Pavement Construction Project: I-65 NB Shoulder*. Federal Highway Administration, Washington, DC.

Tennessee Department of Transportation (TDOT). 2014. *Special Provisions Regarding Two Lift Portland Cement Concrete Pavement*. TDOT Contract CNL264. Tennessee Department of Transportation, Nashville, TN.