BRIEF HISTORY AND BACKGROUND OF PCC/PCC COMPOSITE PAVEMENTS

(ADAPTED FROM SHRP2 R21 Report) – Rao, S., M. Darter, D. Tompkins, M. Vancura, L. Khazanovich, J. Signore, E. Coleri, R. Wu, J. Harvey, and J. Vandenbossche, *Composite Pavement Systems – Volume B, PCC/PCC Composite Pavements*. SHRP2 Final Report, Transportation Research Board, Washington D.C., 2013.

HISTORY

The history of portland cement concrete over portland cement concrete (PCC/PCC) composite pavements in the United States dates back to the first concrete pavement constructed in the United States, located in Bellefontaine, OH, in 1891, shown in Figure 1.

Figure 1. The first PCC/PCC composite pavement in the United States in Bellefontaine, OH.

This experimental pavement section featured a 4-inch structural layer with w/c ratio 0.60 and a durable wearing course with w/c ratio 0.45 (Figure 2). Both layers were mixed by hand and placed during the same time. The initial construction cost of the pavement was $9000 and required only $1400 in maintenance costs over its first 50 years (Snell and Snell 2002).

Figure 2. A cross-section of PCC/PCC from Bellefontaine, OH (Snell and Snell 2002).

Prior to the pavement in Bellefontaine, New York City and other smaller towns and cities had experimented with a different sort of composite sidewalk, one that featured an aggregate wearing course on a solid PCC base. These composite sidewalks and the success of the Bellefontaine pavement led to the continued development of PCC/PCC pavements in the early 1900s that could withstand the traffic loading of the day (horse-drawn wagons). Some of these early composite pavements are listed in the National Register of Historic Places (Cable and Frentress 2004).

From roughly 1950 to the mid 1970s, two-lift paving for concrete pavements was very common in many American states. However, this manner of two-lift paving was simply halving what would now be considered a full slab (though a slab with much longer joints and reinforcement) and paving each half-slab lift at a time. Prior to paving the second-half slab, wire mesh reinforcement was placed on the first lift and dowel baskets were placed at the joints. These two-lift jointed reinforced concrete pavements (JRCP) began to disappear in the 1970s as state departments of transportation began to move toward what has become standard jointed plain concrete pavement (JPCP) design (Cable and Frentress 2004).

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 United States. 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). Figure 3 illustrates the Austrian JPCP design.

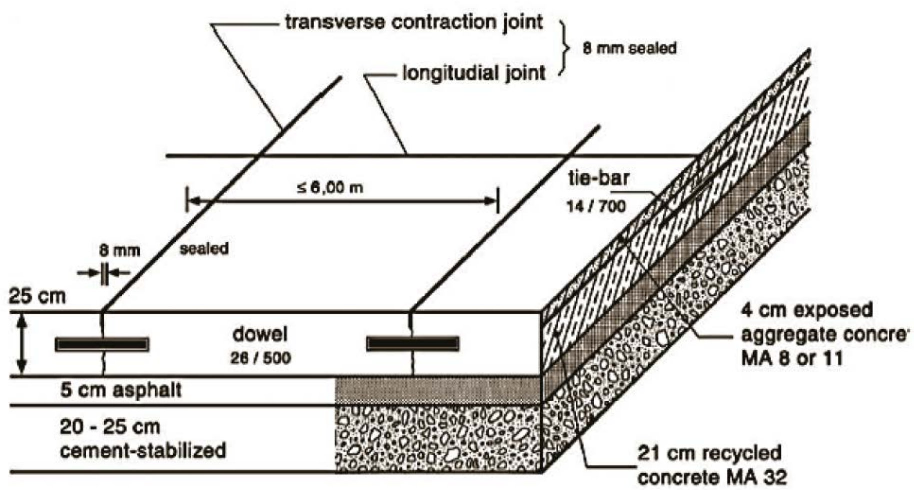

Figure 3. An illustration of JPCP as built in Austria—note two-layer construction (Hall et al. 2007).

Switzerland also has a number of JRCP designs featuring two-lift construction that have been implemented since the late 1950s. These two-lift JRCP pavements differ from their American counterparts in that the lifts are of different thicknesses and constituents. More information on the Swiss two-lift paving is available through the FHWA Concrete Pavement Evaluation System (COPES) database (ERES 1998).

Two-lift paving has been used for construction 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 roadways is motivating many countries to increase the frequency with which concrete pavements are constructed in two unique lifts.

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. Much of the current interest in two-lift paving stemmed from collaborative initiatives between the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP). These initiatives include:

- the 1992 United States Tour of European Concrete Highways;
- the High Performance Concrete Pavement (HPCP) Test and Evaluation Project 30 (TE-30), also started in 1992; and
- the 2006 International Technology Scanning Program tour of long-life concrete pavements in Europe and Canada.

The HPCP project in particular was responsible for the development of experimental two-lift sections in the 1990s in Michigan and Kansas (FHWA 2006, Larson 2006, Wojakowski 1998). 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. As a quick example of this new research, the goal of the experimental sections along I-75 in Michigan was to compare the performance of a European two-lift JPCP design to a traditional Michigan Department of Transportation (DOT) JPCP design.

EXPERIMENTAL SECTIONS

Florida Test Sections

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 sections were designed to observe performance and make comparisons between the different pavement constituents and design properties. The materials under investigation were three types of lean concrete and two subbases. The lean concrete lower-lifts differed in terms of the amount of cement (8.5, 7.3, and 5.5 percent by weight), while the subbases were either 6-in cement-treated subgrade (A-3) or 6-in shell-stabilized subgrade (A-3). The main sections consisting of PCC surfacing, three levels of PCC lower layers, and two joint spacings, performed very well over a 30-year period (ERES 1998, Green et al. 2010). 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."

Kansas Test Sections

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. The K-96 test sections look at three different factors of interest to Kansas DOT:

1. The use of recycled asphalt pavement (RAP) in the lower lift;
2. The use of a durable igneous rock with high alkali silica reactivity as aggregate in the upper lift instead of an abundant limestone in Kansas that has a tendency to polish and reduce skid resistance; and

3. The use of a lower w/c in the upper lift to investigate if the differential volume changes between the two lifts would lead to debonding.

More details on these sections are provided in Figure 4.

Researchers at Kansas DOT found that the replacement of 15 percent of total aggregates with RAP in a concrete mix did not affect the workability of the mix and resulted in a durable lower-lift for a PCC/PCC. In addition, the researchers were able to counteract the alkali-silica reactivity of the hard igneous rock in the second two-lift section by the replacement of cement with a locally available pozzolanic product. The innovative use of the materials was a success, as tests for expansion indicated showed volume changes far below what would have been expected had ASR occurred.

Finally, the low w/c ratio section showed no shrinkage cracking and/or evidence of debonding in spite of expectations of being difficult. It should be noted that 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. The K-96 project is one of a growing field of research that is aware of PCC/PCC as a potential cost savings and performance increase opportunity through the use of innovative materials (Wojakowski 1998).

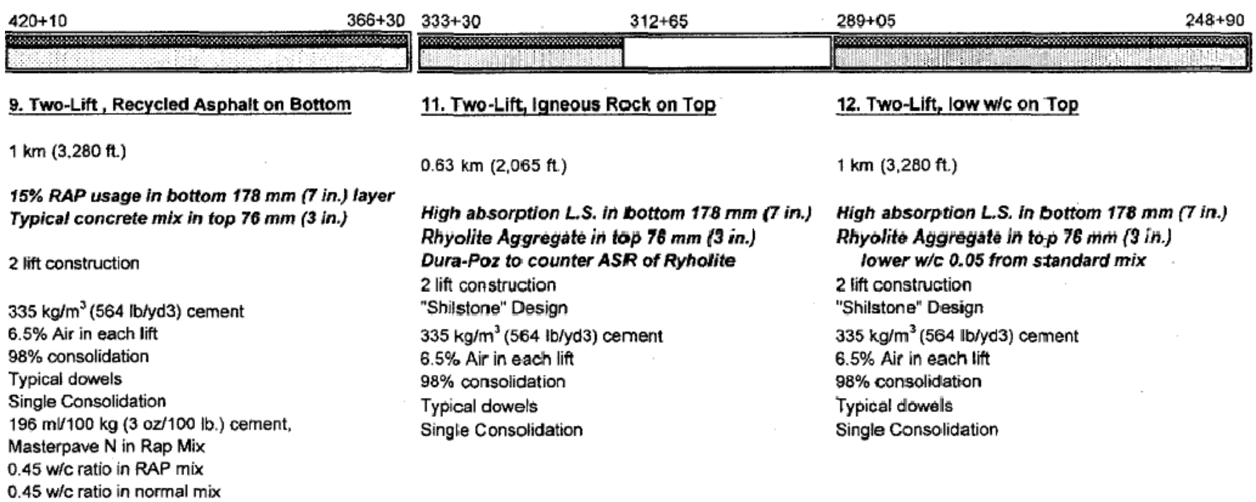

Figure 4. Two-layer test sections in Kansas utilizing innovative materials in different lifts (Wojakowski 1998).

Michigan Test Section

One of the first results of the 1993 U.S. TECH scanning tour of European concrete highways (Darter 1993) was the later development of the PCC/PCC new construction on I-75 near Detroit. The overall goal of the project was to compare the performance of a standard Michigan DOT concrete pavement with its structural PCC/PCC equivalent of European design. This comparison in design is shown in Figure 5.

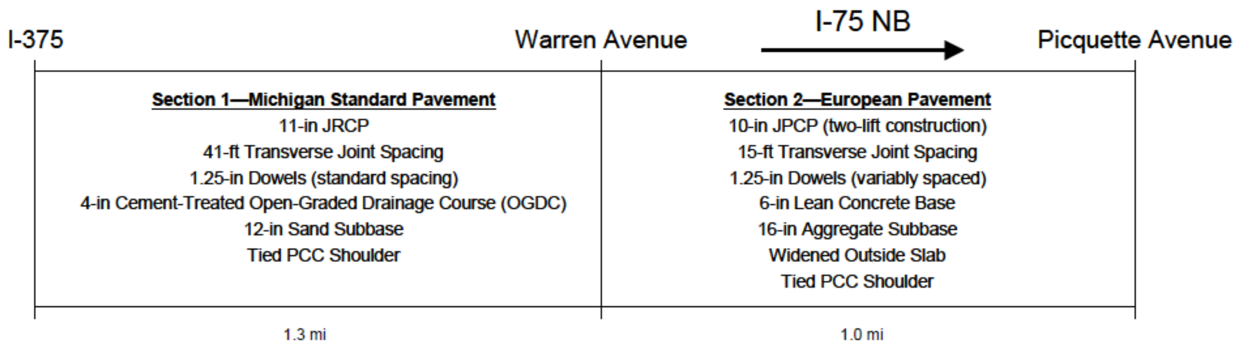

Figure 5. Comparison of design of Michigan DOT standard PCC and European PCC/PCC exposed aggregate pavements (FHWA 2006).

While the research project had this comparison of design performance as its goal, the project was also testing grounds for two-lift paving techniques that until I-75 had not been attempted in the United States. 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).

Kansas Test Sections, 2008

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.

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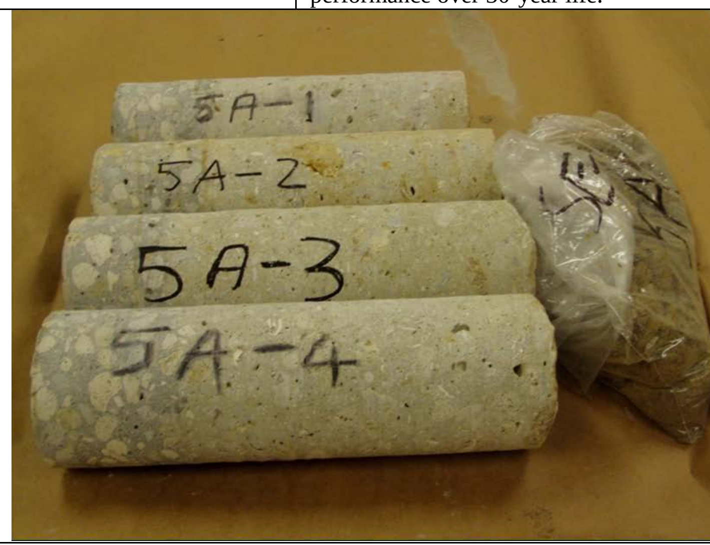
PCC/PCC composite pavements (from Rao et al. 2013).

Composite Pavement Type	Location	Construction Year & Traffic	Comments
3 in PCC over 9 in Econocrete (low-cement PCC with fc = 2000, 1250, or 750 psi) Undoweled, 15-ft Skew Joints	Fort Myers, FL US-41 12 Test Sections	1978 New construction 11000 ADT (12% trucks)	1992: Rigid pavement performance report does not indicate performance problems. 2010: Green et al. notes good bond & performance over 30-year life.
3 in PCC over 9 in Econocrete (low-cement PCC with fc = 2000, 1250, or 750 psi) Undoweled, 15-ft Square Joints	Fort Myers, FL US-41 12 Test Sections	1978 New construction 11000 ADT (12% trucks)	1992: Rigid pavement performance report does not indicate performance problems. 2010: Green et al. notes good bond & performance over 30-year life.
3 in PCC over 9 in Econocrete (low-cement PCC) with fc = 2000, 1250, or 750 psi 1" Dowel, 20-ft Square Joints	Fort Myers, FL US-41 12 Test Sections	1978 New construction 11000 ADT (12% trucks)	1992: Rigid pavement performance report does not indicate performance problems. 2010: Green et al. notes good bond & performance over 30-year life.

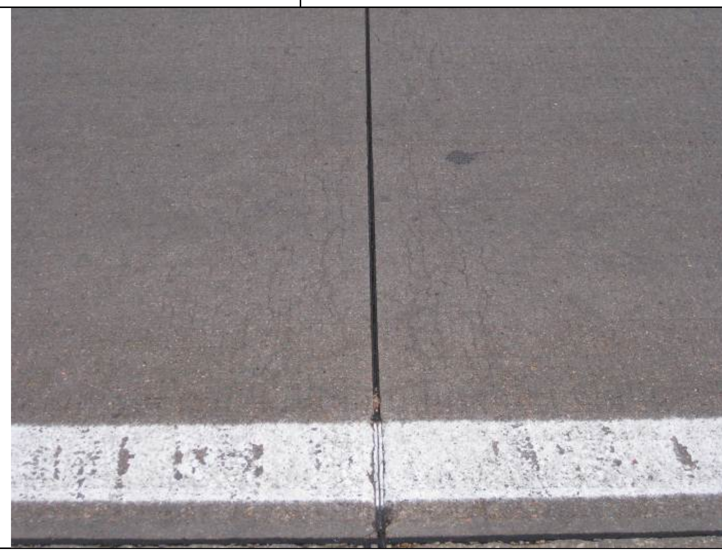
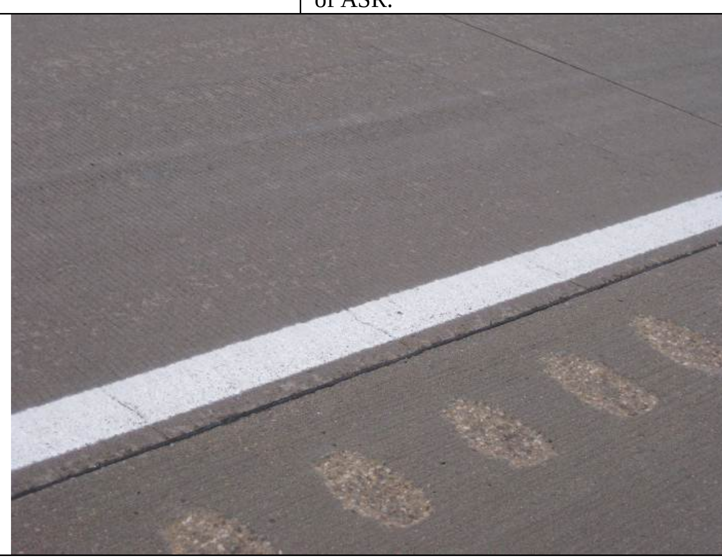
In front of surface layer paver

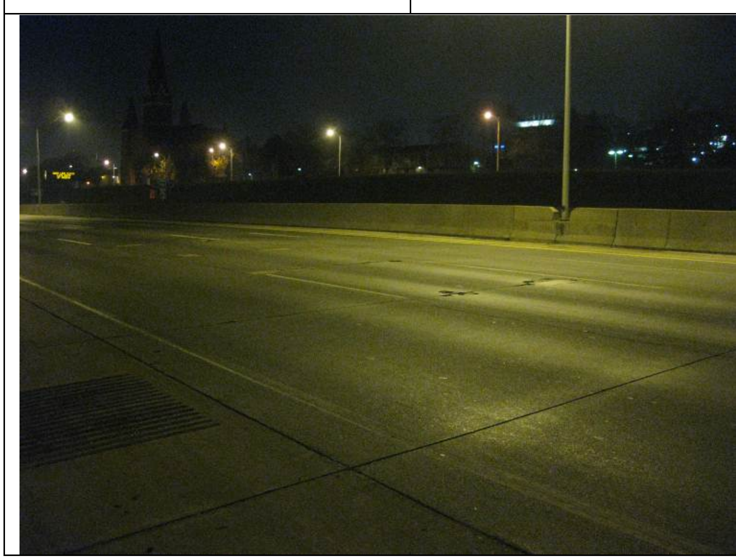


Roughened econocrete surface

Behind surface layer paver

3 in PCC over 7 in PCC (including slightly reduced cement content) 20-ft Joint Spacing	Rock Rapids, IA US-75	1976 New construction Traffic unknown Estimated 6000 ADT (13% trucks)	2004: Cable and Frentress indicate pavement performing well to date

Composite Pavement Type	Location	Construction Year & Traffic	Comments
3 in alkali-silica reactivity (ASR) susceptible PCC with lower water-cement ratio over **7 in high absorption limestone PCC** **15-ft Joint Spacing** **Section 12**	Haven, KS K96	1997 New construction 4800 ADT (11% trucks)	1998: Wojakowski reports no initial performance concerns 2011: Some evidence of ASR but overall the pavement performing exceptionally well with no other distresses.
			
3 in alkali-silica reactivity (ASR) susceptible PCC with 20% pozzolon (Dura-Poz) replacement for ASR mitigation over **7 in high absorption limestone PCC** **15-ft Joint Spacing** **Section 11**	Haven, KS K96	1997 New construction 4800 ADT (11% trucks)	1998: Wojakowski reports no initial performance concerns 2011: Some evidence of surface edge tearing/cracking (not fatigue) but overall the pavement performing exceptionally well with no other distresses. No evidence of ASR.
			

Composite Pavement Type	Location	Construction Year & Traffic	Comments
3 in normal PCC over 7 in PCC with 15% RAP 15-ft Joint Spacing Section 9	Haven, KS K96	1997 New construction 4800 ADT (11% trucks)	1998: Wojakowski reports no initial performance concerns 2011: No major distresses. Only two locations of minor spalling that have been covered with hot-mix asphalt near the longitudinal joint.
			
2.5 in PCC over 7.5 in PCC 15-ft Joint Spacing	Detroit, MI I-75	1993 New construction Traffic unknown Est. 120000 ADT (13% trucks)	1996: Smiley details early noise problems and localized distress, otherwise performing well. 2010: No longitudinal or transverse fatigue cracking. Wheelpath exhibits severe spalling, some of which have been patched. Spalling appears to originate from deterioration of the lower PCC at the joints. EAC texture looks good.
			

Composite Pavement Type	Location	Construction Year & Traffic	Comments
1.5 in PCC over **11.8 in PCC** **15-ft Joint Spacing** **8 different surface textures**	Salina, KS I-70	2008 New construction Opened Dec 2008 13000 ADT (31% trucks)	2011: Surveyed. No structural problems observed. Pavements performing well. Some popouts of longitudinal groove texture and minor surface edge tearing/cracking (not fatigue) observed at some locations. Minor ASR observed.

Composite Pavement Type	Location	Construction Year & Traffic	Comments
3 in PCC over **6 in PCC (incl. RCA)** **15-ft Joint Spacing**	MnROAD, Albertville, MN I-94	2010 New construction 25000 ADT (14% trucks)	2011: No performance issues. Section performing well with no distresses. Excellent bond between PCC layers.
3 in PCC over **6 in PCC (low-cost)** **15-ft Joint Spacing**	MnROAD, Albertville, MN I-94	2010 New construction 25000 ADT (14% trucks)	2011: No performance issues. Section performing well with no distresses. Excellent bond between PCC layers.

Composite Pavement Type	Location	Construction Year & Traffic	Comments
2 in PCC over **7.9 in PCC (incl. RCA)** **18-ft Joint Spacing**	Traun, Austria A1	1994 New construction 110000 ADT (13% trucks)	2010: R21 tour noted impressive structural performance and little wear in wheelpath. No distress existed after 16 years.

Composite Pavement Type	Location	Construction Year & Traffic	Comments

1.6 in PCC over **8.3 in PCC (incl. RCA)** **18-ft Joint Spacing**	Eugendorf, Austria A1	1993 New construction 56000 ADT (13% trucks)	2010: R21 tour noted impressive structural performance (no cracks) yet signs of wear in wheelpath due to tire chains, 17 years.

3 in PCC over **7.5 in PCC** **15-ft Joint Spacing**	Montreal, Quebec, Canada A15	2009 New construction Traffic unknown Est. 150000 ADT (13% trucks)	2011: Ministry of Transportation of Quebec indicates sections performing well with no major distresses.

Composite Pavement Type	Location	Construction Year & Traffic	Comments

2.8 in PCC over **7.5 in PCC** **18-ft Joint Spacing**	Bavaria, Germany A93	1995 New construction 70000 ADT (25% trucks)	2010: Test sections developed to investigate texturing (incl. EAC), overall impressive structural performance of sections given heavy traffic, 15 years.

3.5 in PCC **7 in PCC** **18-ft Joint Spacing**	Veghel, Netherlands N279	2000 New construction Traffic unknown Est. 25000 ADT (30% trucks)	2010: Test sections developed to investigate EAC texture depth, R21 tour noted good structural performance, 10 years.