

MnROAD Lessons Learned

Thin and Ultra-thin Concrete Overlays

History at MnROAD

Thin and ultra-thin concrete overlays (also known as whitetoppings) are a pavement rehabilitation option that has been increasing in popularity in the U.S. over the past 15 years. One area of deficiency in the use of ultra-thin and thin concrete overlays is the lack of a rational design method. While several local (1,2) and industry (3,4) design methods have been formulated, few are based on mechanistic-empirical research born out of actual field performance. Fortunately, the Minnesota Road Research Project (MnROAD) has contributed significantly to the understanding of the field performance of thin and ultra-thin concrete overlays.

In 1997, three thin (TWT) and three ultra-thin (UTW) concrete overlay test sections were constructed on the interstate portion of the MnROAD facility. The objective in locating these thin concrete surface layers on the interstate was to accelerate traffic related distresses. In 2004, after enduring over 6 million concrete equivalent single axles loads (CESALs), the UTW test sections needed to be replaced due to severe surface distresses. Later that year, four new thin concrete overlay test sections were constructed in their place. Table 1 summarizes the experimental designs studied at the MnROAD facility.

The following sections highlight the lessons learned from the testing and monitoring of the MnROAD concrete overlay test sections.

Table 1. Thin (TWT) and ultra-thin (UTW) concrete overlay designs at the MnROAD project. All sections are subject to interstate traffic.

Cell #	Type	PCC thickness (in)	HMA thickness (in)	Panel size (ft)	Sealed joints	Fiber reinforcement type	Year Start-End
92	TWT	6	7	10 x 12*	Y	Polypropylene	1997- present
93	UTW	4	9	4 x 4	Y	Polypropylene	1997-2004
94	UTW	3	10	4 x 4	Y	Polypropylene	1997-2004
95	UTW	3	10	5 x 6	Y	Polyolefin	1997-2004
96	TWT	6	7	5 x 6	Y	Polypropylene	1997- present
97	TWT	6	7	10 x 12	Y	Polypropylene	1997- present
60	TWT	5	7	5 x 6	Y	None	2004- present
61	TWT	5	7	5 x 6	N	None	2004- present
62	TWT	4	8	5 x 6	Y	None	2004- present
63	TWT	4	8	5 x 6	N	None	2004- present

* Test Cell 92 contains doweled transverse joints.

Effect of Panel Size and Thickness

Panel size and thickness can have a major effect on the performance of a thin concrete overlay. As the panel thickness decreases, so too should the overall panel size. This ensures that the panels will have less of a tendency toward curling up, and instead simply deflect downward under heavy loading. To test this theory, the UTW test sections at the MnROAD facility studied two

panel sizes and two thicknesses. Test cells 93 and 94, consisting of 4 foot by 4 foot panels, both demonstrated corner cracking in locations near the wheelpaths. The concentration of heavy loads near the edge of the thin panels exceeded their load capacity. Cell 93, with a concrete surface thickness of 4 inches, exhibited approximately 75% less cracks than the 3 inch thick Cell 94. Photo 1 shows the typical crack pattern experienced by Cells 93 and 94.



Photos 1 & 2. MnROAD UTW test Cell 94 (left photo) and test Cell 95 (right photo) after 5 million CESALs (November 2003). Driving lane is on left side in photos.

Test Cell 95 (3 inch PCC), with the larger 5-foot long by 6-foot wide panels, also experienced about 75% less cracking than the 3 inch thick, 4 by 4 foot panels, in Cell 94. Surface distress in test Cell 95 occurred mostly in panels near the driving lane shoulder. See Photo 2. Cracking in Cell 95 was caused mainly by debonding of the thin concrete overlay from the hot-mixed asphalt (HMA) layer. Once a crack initiated, repetitive heavy traffic loading propagated further cracking, eventually resulting in a large area of distress.

Based on the performance of the UTW test sections at MnROAD, it is recommended that panel size should be chosen to keep the wheel loadings away from the edges of the thin panels. Also, there is a significant difference in performance between a 3 and 4 inch concrete surface layer for the same panel size. It needs to be reemphasized that MnROAD provides accelerated traffic loading, and that more typical UWT and TWT applications are located on lower volume roadways.

The thin concrete overlay test Cells 92 and 97, with their larger 10 foot long by 12 foot wide panel size, both experienced minor longitudinal cracking in several panels. The tendency of the larger panels to crack into 6 foot wide panels, supports current theory that a panel size of 6 foot by 6 foot is optimal for most thin concrete overlays. In fact, test Cell 96, with 5 foot long by 6 foot wide panels, demonstrates the best performance of the original concrete overlay test cells constructed in 1997.

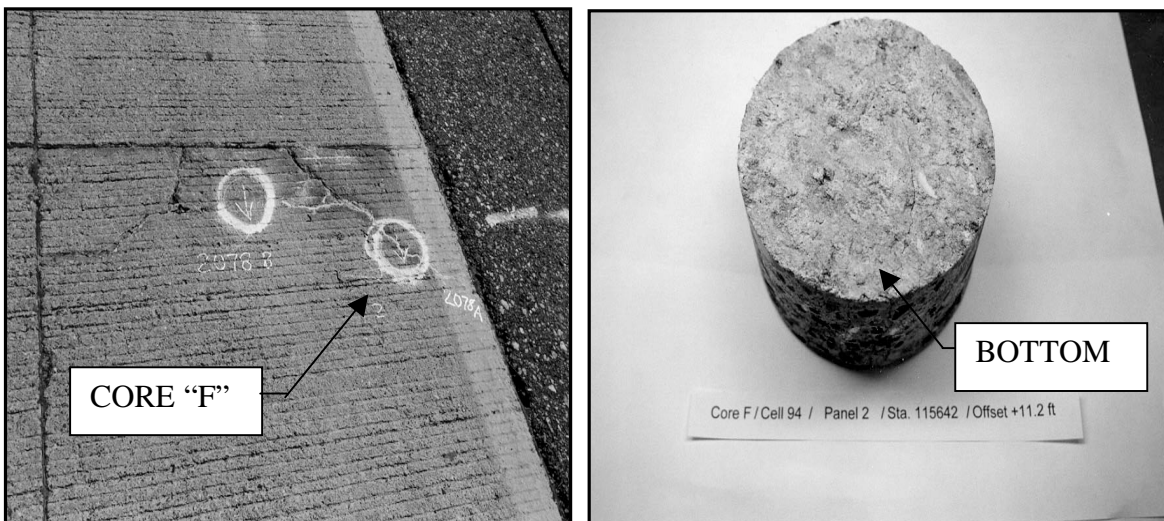
Reflective Cracking

Besides corner cracking, the phenomenon of reflective cracking was noticed at MnROAD for test sections with a concrete layer thickness less than 5 inches. This behavior was evident in both the original UTW test sections (Cells 93-95), and the 4 inch thick TWT test Cells 62 and 63 constructed in 2004. The cause for this difference in performance is still being studied.

Interlayer bonding

The performance of ultra-thin concrete overlays relies heavily on the composite action between the older HMA and the new concrete layer. Steps are taken during construction to enhance bonding of the layers through the techniques of HMA milling and careful surface cleaning. Understanding the strength and longevity of the layer bonding will be critical to forming rational design methods for UTW and TWT.

Forensic examination of core samples and test pits at MnROAD showed clear evidence that debonding of the ultra-thin whitetopping from the hot-mix asphalt layer led to cracking, and eventually surface distress(5). Photos 3 and 4 show a core sample demonstrating significant loss of interlayer bond. Debonding between the layers always occurred near panel edges or cracks, likely due to asphalt stripping and/or freezing and thawing action from the increased amount of available moisture.



Photos 3 and 4. Sample location (left photo) and bottom view (right photo) of Core “F”, showing loss of bond between the UTW and HMA layers. Core shown upside down.

Load Testing

Besides exposure to live interstate traffic and Minnesota’s extreme weather, the MnROAD test sections are periodically load tested by specific test vehicles (MnROAD truck) and non-destructive devices (FWD). Results of this testing can be found in references 6-9. Notable results include strain measurements indicating composite action between the layers, and the observation that as temperatures increase in the HMA layer (and therefore resilient modulus decreases), the strains measured in the concrete layer increase(9) .

Joint Faulting

Test Cell 97, which has large panels and undoweled transverse joints, has recently demonstrated significant joint faulting. This indicates TWT overlays can experience faulting, even when placed on a thick HMA base. The other test cells have experienced low levels of joint faulting.

Fibers in Concrete Mix

The original UTW and TWT test sections at MnROAD had concrete surface layers containing synthetic fibers. These fibers were inserted to strengthen the concrete, reduce shrinkage cracking, and provide reinforcement across cracks. The small polypropylene fibers in the MnROAD test sections seemed to provide little benefit to the performance of the concrete layer. The larger polyolefin fibers did not prevent cracking, but did appear to have the ability to retain small broken pieces of concrete. Reference 5 contains further information on the performance of the fiber-reinforced mixes in the MnROAD UTW and TWT test sections. Given their less than satisfactory performance, and substantially higher initial cost, fiber-reinforced mixes have not been used in the newer TWT test cells at MnROAD.

Best Design for Interstate Traffic

As previously mentioned, MnROAD TWT test Cell 96 demonstrates the best performance under interstate traffic loads. The design consists of 6 inch thick concrete over 7 inches of HMA, with 5 foot by 6 foot panels. This closely simulates the national trend toward “6 inch (thick) by 6 foot by 6 foot (panel)” designs for higher volume roads.

Future Plans

The original thin concrete overlay test sections at MnROAD are approaching their ninth year in operation. In addition, the test cells constructed in 2004 continue to be monitored and load tested. There exists a tremendous amount of valuable data from the MnROAD UTW and TWT test cells that could contribute to the development of a rational design method for thin and ultra-thin concrete overlays. Efforts toward that goal are currently underway.

References

1. Tarr,S.M., Sheehan,M.J., Okamoto,P.A. *Guidelines for the Thickness Design of Bonded Whitetopping Pavement in the State of Colorado*. Report No. CDOT-DTD-R-98-10. Colorado Department of Transportation, Denver. Dec, 1998.
2. *Development of a Design Guide for Ultra-thin Whitetopping*. SWK Pavement Engineering. Princeton, N.J., Jan. 1998.
3. Wu,C.L., Tarr,S.M., Refai,T.M., Sheehan,M.J. *Development of Ultra-Thin Whitetopping Design Procedure*. Report RD 2124. Portland Cement Association. Skokie, IL, 1998.
4. American Concrete Pavement Association, *Whitetopping – State of the Practice*. Engineering Bulletin EB210.02P. Skokie, IL, 2002.
5. Burnham, T.R.. *Forensic Investigation Report for MnROAD Ultrathin Whitetopping Test Cells 93, 94, and 95*. Minnesota Department of Transportation. St. Paul, MN. Sept., 2005.
6. Vandenbossche, J.M., Fagerness, A.J. *Performance, Analysis, and Repair of Ultrathin and Thin Whitetopping at Minnesota Road Research Facility*. Transportation Research Record No. 1809. 2002.
7. Vandenbossche, J.M. *The Measured Response Of Ultra-Thin and Thin Whitetopping to Environmental Loads*. Proceedings of Seventh International Conference on Concrete Pavements. Sept., 2001.
8. Vandenbossche, J.M., Rettner, D. *The Construction of US-169 and I-94 Experimental Thin and Ultra-Thin Whitetopping Sections in Minnesota*. Minnesota Department of Transportation. St. Paul, MN. April, 1998.
9. Vandenbossche, J.M., Rettner, D. *One-Year Performance Summary of Whitetopping Test Sections at the Mn/ROAD Test Facility*. CD_ROM Proceedings from 1999 International Conference on Accelerated Pavement Testing. Oct., 1999.