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Final Report

Synthesis of Current Minnesota Practices Of Thin and Ultra-Thin Whitetopping

synthesis

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16. Abstract (Limit: 200 words)

This report documents the current practices of Minesota in rehabiliting Hot Mix Asphalt pavement with thin and ultra-thin Portland cement concrete overleys, i.e. thin and ultra-thin whitetopping.

The current practices of thin whitetopping (TWT) in Minnesota and its adjacent states have shown that TWT has been used successfully and is an important alternative for rehabilitating HMA pavements of medium-volume roads. If designed and constructed properly, TWT is also an important alternative for rehabilitating HMA pavements of highway volume roads with more requirements in HMA quality, bonding and fiber reinforcement.

The performance of ultra-thin whitetopping (UTW) projects in Minnesota ranges from very good to failing. The sections that perform poorly are short sections under stopping trucks or buses and over thin or poor condition HMA pavement. UTW has been used successfully in Minnesota when inlaid into thick and sound HMA pavements even in high-volume traffic. The quality of the HMA substrate, bonding, fiber reinforcement, and joint spacing all significantly affect the success of UTW. Great caution should be used when rehabilitating HMA pavements at bus stops, weigh stations, and intersections. The Minnesota Department of Transportation (Mn/DOT) does not recommend UTW for major highways and heavy traffic areas.

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Synthesis of Current Minnesota Practices Of Thin and Ultra-Thin Whitetopping

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Executive Summary

Thin whitetopping and ultra-thin whitetopping are alternatives for rehabilitation of flexible pavements and the optimization of pavement life. Many types of whitetopping projects have been completed locally, statewide, in adjoining states, and nationally. The experiences from these projects, and current research completed by the Local Road Research Board (LRRB) have been used for the development of this synthesis. The report describes what has been done and what has been learned:

- When and when not to use thin and ultra-thin whitetopping,
- Which type of whitetopping fits best,
- How to choose materials, thickness, joint spacing and other physical design features,
- How to choose construction techniques, and
- Risks associated with this rehabilitation process.

Whitetopping is a Portland Cement Concrete (PCC) overlay on Hot Mix Asphalt (HMA) layers. For the purposes of this report the three types of whitetopping commonly used in highway pavements are defined by Mn/DOT as follows:

- Conventional whitetopping is ≥ 6 inches thick.
- Thin whitetopping (TWT) is 4-6 inches thick.
- Ultra-thin whitetopping (UTW) is 2-4 inches thick.

(Note: These definitions are slightly different than definition listed in the National Cooperative Research Program (NCHRP) Synthesis 338.)

Conventional and thin whitetopping are typically used where the existing HMA pavement exhibits some structural deterioration and truck traffic is significant. These types have been used successfully for interstate and state highways.

UTW is typically used where the HMA is rutted or shoved but the underlying HMA layer(s) are structurally sound and where truck traffic is limited. These types are typically used on parking lots, residential streets and other low-volume roads, particularly at intersections where re-occurring rutting, asphalt is picked up by tires, oil spillage, and construction phasing are main concerns. The ultra-thin whitetopping needs to bond to the HMA for structural support.

This synthesis focuses on TWT and UTW and discusses the performance, use and cost of the various types of whitetopping. It provides guidance for evaluating the potential for use and selecting the design that has the best chance of being successful in Minnesota. A list of references is included at the end of the synthesis.

It should be noted that credit for bonding is given to various degrees in design of UTW. The thinner the whitetopping, the more efforts are needed to achieve bonding. Bond strength was perceived to be the key to determining an appropriate design and construction procedure for ultra-thin whitetopping. If adequate bond is achieved, a bonded PCC overlay technique can be used for design and construction. Otherwise, a PCC overlay procedure without bonding may be more appropriate.

The current practices of TWT in Minnesota and its adjacent states have shown that TWT has been used successfully and is an important alternative for rehabilitating HMA pavements of medium volume roads. If designed and constructed properly, TWT is also an alternative for rehabilitating HMA pavements of high volume.

The performance of current UTW projects in Minnesota ranges from very good to failing. The sections that performed poorly are short sections under stopping trucks or buses and over thin or poor condition HMA pavement. UTW has been used successfully in Minnesota when inlaid into thick and sound HMA pavements even in high-volume traffic. The quality of the HMA substrate, bonding, fiber reinforcement, and joint spacing all significantly affect the success of UTW. Great caution should be used when rehabilitating HMA pavements at bus stops, weigh stations, and intersections. The Minnesota Department of Transportation (Mn/DOT) does not presently recommend UTW designs.

Chapter 1
Introduction

This synthesis has been developed to present methods of design and construction of thin and ultra-thin whitetopping in Minnesota. The Local Road Research Board (LRRB) sponsored this report as a resource for local governments making decisions on the use of thin and ultra-thin whitetopping. It provides appropriate design information and construction practice that will lead to a successful pavement project.

Thin and ultra-thin whitetopping are Portland Cement Concrete (PCC) overlays that have become more widely accepted as rehabilitation alternatives for existing Hot Mix Asphalt (HMA) pavements in the United States:

- Thin whitetopping (TWT) refers to 4-6 inches of PCC overlay on a HMA pavement. TWT used for medium volume roads require a sound HMA substrate but does not require bonding to the HMA. TWT used for high volume roads depends on bonding to the HMA to ensure structural integrity.
- Ultra-thin whitetopping (UTW) consists of a 2-4 inch PCC overlay on a HMA pavement. UTW used for low volume roads require both sound HMA substrate and bonding to the HMA.

TWT has been defined as a 4-8 inch PCC overlay in the National Cooperative Highway Research Program (NCHRP) Synthesis 338 [1]. However, TWT in Minnesota is defined as a 4-6 inch PCC overlay, which the current practice shown is more appropriate for local applications.

In the past, placement and curing times of regular concrete have meant significant traffic disruption, limiting the use of TWT and UTW. However, with the advent of fast-track concrete pavement technologies that allow concrete pavement to be opened to traffic within 12 to 24 hours of initial paving, whitetopping technology has advanced. The NCHRP Synthesis 338 revealed that more than 52% of the agencies and contractors surveyed have used "fast-track" concrete materials in TWT and UTW projects [1]. Fast-track construction requires a higher early strength than can be achieved with conventional mixes. However, care should be taken with high early-strength mixes because of their greater potential for shrinkage and cracking [2].

Many TWT and UTW projects have been completed statewide, in adjoining states, and nationally. The use of UTW in the United States is continuing to steadily increase since its beginning in Madisonville, Kentucky, in 1989. In total, 313 projects comprise almost one million square yards of UTW in 35 states through the end of 2002 [3]. Minnesota placed its first TWT project in 1982 and first UTW project in 1995. So far, nine TWT and UTW projects have been constructed in Minnesota. Experience from these projects and others around the U.S., along with current research completed by the LRRB, have provided information for the development of this synthesis report. Because the use of UTW is relatively new, there will be emerging developments in materials and increased understanding of the design and construction of UTW. Thus, the report has been developed to be amenable to revision as pavement engineers learn from new experience.

UTW is a thin layer of concrete (2-4 inches thick) that usually has high strength and is fiber reinforced, placed over a prepared surface of sound HMA. This differs from conventional whitetopping because a substantial degree of bond is intentionally obtained between the concrete overlay and the existing asphalt pavement, and joint spacing is much shorter than normal.

The same factors that affect the performance of new PCC pavements affect the performance of TWT and UTW, and these include the following:

- Condition of the existing pavement (type, severity, and extent of distress)
- Pre-overlay repair (all areas of subgrade or base failures)
- Overlay design features (overlay thickness, joint spacing, load transfer design, bathtub section design, reinforcement design, and drainage design)
- Traffic (axle weights and number)
- Climate (temperature and moisture conditions)
- Construction quality and curing

An effective design procedure should account for the condition of the existing pavement and pre-overlay repairs, resulting in a design that will provide the desired performance. For the most part, existing design procedures have been effective in producing workable thicknesses for whitetopping. However, conventional design practices may be overly conservative in some cases because the bond effects have been ignored.

The goal of the synthesis is to summarize the use of TWT and UTW in Minnesota and the lessons learned from these projects. The basic approach used for developing this synthesis includes literature review, site visits, and personal interviews with respect to TWT and UTW projects in Minnesota. The literature was also reviewed for TWT and UTW projects in adjacent states and nationwide.

This synthesis report is organized into six chapters: this introductory chapter (chapter one); an overview chapter (chapter two); a chapter on whitetopping design (chapter three); one on construction (chapter four); a chapter on performance (chapter five); and a summary chapter with conclusions (chapter six).

Chapter 2
Overview of Current Practices

This synthesis provides a summary of current practices of thin and ultra-thin whitetopping. This chapter covers definitions of different types of whitetopping and distresses in the existing HMA pavements that affect the use of whitetopping. It provides an overview of whitetopping, its advantages and disadvantages, as well as the selection procedures and criteria for rehabilitating HMA pavements.

2.1 Definitions

Within the category of whitetopping, there are additional classifications of conventional whitetopping, TWT, and UTW, as defined in Chapter One. UTW differs from other whitetopping, PCC and HMA overlays in that bonding to the HMA is required. Table 2.1 defines these classifications based on existing HMA conditions, traffic, and design life. It is important to consider that the design life can be different for the same type of whitetopping.

Table 2.1 Types of Whitetopping

Purpose	**Structural and Functional Improvement**			
Design	**No Bonding is Assumed**		**Partial Bonding is Assumed**	
Construction	**No Intentional Bonding**		**Intentional Bonding**	
Name	Conventional Whitetopping	Thin Whitetopping	Thin Whitetopping	Ultra-thin Whitetopping
Traffic Volume*	High	Medium	High	Low
Application	Primary Roads and Interstate Highways	Secondary Roads and City Streets	Primary Roads and Interstate Highways	City streets, intersections, bus terminals, turning lanes, stopping zones, parking lots
Design Life (years)	30	20	20	20
Design Method**	AASHTO ACPA	AASHTO ACPA	ACPA CDOT	ACPA PCA
Thickness	≥ 8 inches	5-8 inches	4-6 inches	2-4 inches
Existing Pavement Conditions	Ruts < 2 inches Various types of cracks; Full of potholes.	Ruts < 2 inches Various types of cracks; Full of potholes.	Ruts > or = 2 inches No stripping.	Ruts > or = 2 inches No stripping.

(*) Traffic volume is high when Annual Average Daily Traffic Volume (AADT) >10,000 and low when AADT < 400.

(**) American Association of State Highway and Transportation Officials (AASHTO), American Concrete Pavement Association (ACPA), Colorado Department of Transportation (CDOT), or Portland Cement Association (PCA).

Table 2.2 provides a summary of their advantages and disadvantages. Whitetopping can also be "inlays," placed in a milled section so the surface is flush with the surrounding HMA pavement.

Table 2.2 Advantages and Disadvantages of Different Types of Whitetopping

Type	Advantages	Disadvantages
Conventional Whitetopping	• Requires minimal surface preparation because of concrete's ability to bridge deterioration. • Reacts structurally as if on strong base course. • The existing asphalt makes an excellent base course with the same advantages of other stabilized base materials, with reduced potential for pumping, faulting, and loss of support.	• Minimum overlay thicknesses tend to be in the range of 5-8 inches, which is quite thick and possibly unsuitable in situations where a specific elevation must be maintained such as in curbed areas or under bridges.
Thin Whitetopping	• Thinner than conventional whitetopping because of composite layer action when bonded.	• Slab size and joint location can complicate its use. • The need to ensure adequate bonding can also complicate its use. • If bonding is effective there maybe reflective cracks from the underlying HMA.
Ultra-thin Whitetopping	• Easiness to fit overhead clearance. • Easiness in phasing construction. • Broad range of application. • Commuters face fewer delays than with asphalt overlays because UTW requires minimal maintenance. • Over the service life, it is a cost-competitive option.	• Increased cost incurred from saw-cutting the overlay into panels and from the fibers sometimes added to the mix. • Not for use on mainline interstate highways and arterials. • Concern with the durability of the concrete-to-asphalt bond under freeze-thaw cycling. • Requires a substantial thickness of asphalt. • Susceptible to corner breaks and reflective cracks.

Most whitetopping projects have been constructed as jointed, plain concrete pavements (JPCP). Other pavement designs have been jointed reinforced (JRCP), continuously reinforced (CRCP), and fiber reinforced (FRCP). In recent years, FRCP has become popular in UTW [4].

Accurate evaluation of the existing HMA pavement is crucial to the success of TWT and UTW projects. The most common distresses of HMA that are related to the use of TWT and UTW, and their causes are defined as follows:

- Rutting: A longitudinal surface depression located in the wheel path. It may also have associated transverse displacement. Binder properties in HMA and moisture and high strains in subgrade and base are the main causes. Rehabilitation is needed when ruts are greater than ½ inches.

- Fatigue cracking: A series of interconnected cracks forming many-sided, sharp-angled pieces 6 inches or less in size, typically located in the wheel paths or where traffic loads are concentrated. Stiffening of the HMA and weak support are the main causes.
- Block cracking: A pattern of cracks dividing the pavement into approximately rectangular blocks. The size of the blocks range from 6 inches to approximately 3 feet. This type of distress normally covers the entire pavement surface. Shrinkage and oxidation of the HMA are the main causes. No repair is needed if 3-foot block cracking exists in HMA on a granular subgrade. Severe block cracks need repairs prior to the placement of TWT and UTW.
- Stripping: Separation of the asphalt binder from the aggregate owing to the presence of moisture. UTW and TWT requiring bonding to the HMA cannot be placed on stripped HMA.

2.1.1. Overview of Thin Whitetopping

Thin whitetopping (TWT) is divided into two types, depending on the requirements for bonding in design and/or construction: with bonding and without bonding. The TWT without bonding is the same as conventional whitetopping with a thickness between 5 and 8 inches.

TWT with bonding is a new technology and is intended for high-volume roadways carrying large numbers of heavy trucks. It deliberately uses various bonding methods and materials to bond a 4 to 6 inch thick PCC overlay to the HMA pavement [5]. As a result, the overlay and the underlying asphalt act as a composite section rather than two independent layers and the panel size is reduced to prevent curling.

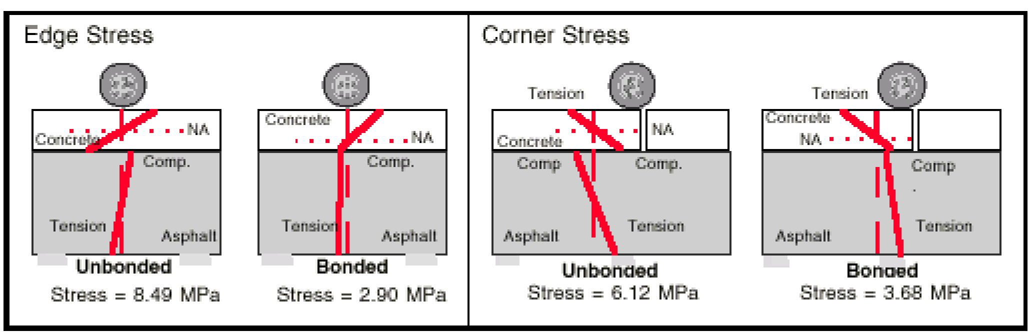

Figure 2.1 Effects of Bonding on Concrete Stress

2.1.2. Overview of Ultra-Thin Whitetopping

Ultra-thin whitetopping (UTW) is intended to bond to an existing asphalt pavement. Because the underlying HMA pavement is an integral part of the structural system for UTW, a minimum HMA thickness of 3 inches after milling is necessary [7]. Proper preparation of the existing HMA pavement is also essential to ensure good performance. This includes repair of any failed or severely deteriorated areas to provide adequate and uniform load-carrying capacity and milling of the HMA surface to promote good bond. Although long-term performance data are limited, the 5-year performance of UTW projects has generally been good nationally [8]. Some failures have been observed in Minnesota, generally contributed to unstable or insufficient HMA beneath.

As shown in Figure 2.1, the composite action results in substantially reduced maximum slab tensile stresses in the concrete, by a factor of 2 for corner stresses and 4 for edge stresses [5]. The whitetopping can thus be significantly thinner for the same loading as compared to a whitetopping with no bond to the underlying asphalt. In addition, bonding shifts the neutral axis in the concrete downward, reducing the tensile stresses at the bottom of the concrete layer. However, corner stresses are increased at the top of the concrete layer. If the neutral axis shifts low enough in the concrete, the critical load location will move from the edge to the corner. This stress can be decreased with an adequately thick asphalt layer to support the UTW slab [6].

2.2 Selection Procedures and Criteria

HMA pavements with surface problems are good candidates for TWT, while HMA pavements with rutting problems are good candidates for TWT and UTW. TWT and UTW provide the functional improvement and increase the structural capacity of HMA pavements without much change in profile to handle increased traffic loads.

Both bond and HMA strength are keys to determining an appropriate design and construction procedure for whitetopping. If adequate bond is to be achieved, a bonded PCC overlay technique can be used for design. The bond between the PCC and the HMA would be considered in the design and intentionally introduced during construction by means of texturing of the HMA before the overlay. When there is a sound bond, the concrete overlay can be thinner, and thus UTW is possible.

Effective techniques to enhance bond include power brooming and milling. A partial bond is usually realized as a result of a number of factors and the bond established during construction degrades over time [9].

2.2.1. Selection Procedures

The selection of a particular type of whitetopping as a possible rehabilitation alternative for an existing pavement is a subset of the overall pavement rehabilitation selection process. The basic principles of the overall process are summarized in several documents, including the 1993

AASHTO design guide [10], an ACPA engineering bulletin [11], and an APA position paper [12]. The process involves first identifying rehabilitation alternatives that are technically feasible, and then comparing the alternatives in terms of cost, performance, and benefit to identify the most appropriate option.

2.2.2. Benefits and Costs

2.2.2.1 Benefits

Research indicates that TWT and UTW can last two to three times longer than asphalt overlays with service lives of more than 20 years [13]. Whitetopping maintains serviceability and requires significantly less maintenance over its design life. With bonding and fiber-reinforced concrete, whitetopping has the following benefits:

- Improved safety from reducing chances of hydroplaning and elimination of distresses such as rutting, washboarding, shoving, and potholes.
- Traffic loop detectors have longer life because shoving is eliminated.
- Visibility is increased because it is a light-reflective surface.
- Street lighting costs may be reduced because of the light-reflective surface.
- With cure times of less than 24 hours for fast-track mixes, paving jobs such as intersection repairs can be completed in a day or two.
- A fuel consumption study shows a fuel savings up to 20% for concrete surfaces as compared with asphalt surfaces [14]. Since heavier traffic loads cause more deflections, absorbing more vehicle energy, the savings from whitetopping increase as truck weights increase.
- Since concrete is less affected by seasonal weakening of the subgrade, whitetopping can be used to reduce spring load restrictions.
- Whitetopping provides a cooler surface with environmental benefits. In urban areas, whitetopping combined with the effects of trees can reduce temperature by 10ºF, thereby conserving energy needed for air-conditioning.
- Eliminate asphalt picked-up by tires and resist damage from fuel spillage in parking lots.
- Eliminate the use of petroleum-based asphalt products.

2.2.2.2 Costs

A recent cost comparison study in Iowa on whitetopping showed that, although a 5- to 6-inch concrete overlay costs up to 50% more than a 2- or 3-inch asphalt overlay, it can last twice as long as asphalt. Likewise, UTW may be cost-competitive.

When calculating life-cycle costs, the user-delay costs of overlays are very important. With asphalt surfaces there are typically road closures for two overlays to the end of a 20-year design life. With whitetopping there are no subsequent overlays. Therefore, TWT and UTW are cost-effective in the long term because of the reduced user-delay and maintenance costs.

Chapter 3
Design

3.1. Design Overview

The design of TWT and UTW is similar to that of a new PCC overlay in many aspects. In fact, the design of the TWT for medium-volume roads or conventional whitetopping is the same as that of a new PCC overlay [7]. Because a relatively thick PCC surface is capable of bridging a significant amount of deterioration in the underlying HMA pavement, minimal pre-overlay repairs are often needed for Thicker TWT or conventional whitetopping. No bonding is assumed in design for conventional whitetopping, although in actuality some bonding does occur. Thicknesses for conventional whitetopping are greater than 6 inches.

In TWT and UTW construction, a bond is intentionally introduced by means of texturing. As described in Chapter 2, an emerging subset of whitetopping is TWT in which 4 to 6 inches thick PCC slabs are placed on a milled HMA. As in UTW, TWT joints are spaced at close intervals to reduce warping and curling stresses in the slab. The bonding between the layers is accounted for in the design process, and is expected to have a positive effect on the performance of the PCC overlay.

Mn/DOT has studied UTW but has not utilized it on a large scale. However, UTW is being used nationwide for local roads, streets, intersections, bus pads, and parking lots. UTW must be used only on appropriate applications where material conditions and design are carefully considered. The most important factors influencing the effectiveness of UTW are the existing asphalt thickness and condition, degree of bonding, and the amount of truck traffic.

Because milling is performed prior to the placement of UTW overlays, vertical overhead clearances, the matching of adjacent shoulder and traffic lane elevations, and curb elevation are generally not a concern. Often the UTW can be placed as an inlay, using adjacent (un-milled) HMA as side formwork, thereby lowering costs and facilitating the construction of a smooth pavement.

3.1.1. Design Procedures

The design procedures of TWT for medium-volume roads or conventional whitetopping include AASHTO [10], ACPA [7], and Mn/DOT [15] while the design procedures of the TWT for high volume roads or UTW include AASHTO [10] and ACPA [7]. This section briefly describes these two procedures for TWT and UTW design. Two additional design procedures from CDOT [16], and PCA [17] are not discussed in this report. (Note: At the time of this report Transtec (Austin, TX) was developing a more advanced procedures in an Innovative Pavement Research Foundation (IPRF)/Federal Highway Administration (FHWA) project however it had yet to be approved by FHWA).

3.1.2 Mix Design

The same PCC mixes used for new construction are generally used for whitetopping. For projects in congested urban areas, however, extended lane closures due to pavement rehabilitation may be highly undesirable. For those projects, the use of fast-track paving may minimize traffic disruptions. Numerous fast-track PCC mixes are available that can provide the strength required for opening to traffic in 12-14 hours, and the techniques for fast-track paving are well established [2,18,19]. Fast-track paving has been used successfully on a number of projects where traffic congestion or accessibility is critical [18,19]. However, little information is available on the long-term performance of pavements constructed using high-early-strength PCC mixtures.

As seen from the mix designs used on recent UTW projects in Minnesota, these mixtures have high cement contents, low water-to-cement ratios, smaller top size aggregate (typically ¾ inches), and synthetic fibers. The introduction of the fibers is expected to improve the toughness and post-cracking behavior of the PCC, as well as to help control plastic shrinkage cracking. Polypropylene and polyolefin fibers are the two most commonly used synthetic fibers in UTW overlays. On some projects higher-than-normal amounts of fiber have been used. However, fibers significantly increase the cost of the mix and may not be worth the cost. Experience at Mn/ROAD indicates that too high a percentage of fibers in the mix might actually cause more problems than it prevents. Aggregate interlock at the transverse joints seems to be degrading due to too many fibers in the mix. Further study is needed for proving the Mn/ROAD experience.

3.1.3 Thickness Design

Thicker TWT or conventional whitetopping is designed as a new PCC pavement, treating the existing HMA pavement as a stabilized base. The required overlay thickness is determined using any established PCC design procedure for new pavements, such as the 1993 AASHTO methodology [10] or the 1998 AASHTO Supplement procedure [20].

In the AASHTO design procedures, the overlay thickness is taken as the new PCC slab thickness required for the future traffic projections and for the given design conditions. The overlay is designed using an effective modulus of subgrade reaction (k_{eff}) of the existing flexible pavement, which can be determined from Falling Weight Deflectometer (FWD) deflection data or from the nomograph in the AASHTO guide and HMA thickness, HMA modulus, and subgrade modulus.

The effects of layer interaction are included in the Supplement to the AASHTO Guide [21]. The interaction between the PCC surface and stabilized base is handled through the use of a friction factor. The guide provides a range of recommended friction factors to account for a range of bonding conditions for different types of bases. Therefore, at least in principle, partial bonding can be considered by assigning an appropriate friction factor. However, the design thickness is insensitive to the friction factors in the range that is recommended for HMA base. Further validation of the design procedure is needed to ensure the reliability of the thickness design.

In addition to the design procedures described above, simple design charts have been developed for selecting PCC thicknesses for TWT and UTW [7]. In these charts, the slab thickness is selected based on the number of trucks per day, the design PCC flexural strength, HMA thickness, joint spacing, and the subgrade k-value.

Incorporating the effects of bonding in the thickness design produces a thinner overlay. However, it is important to note that the durability of the bond between the PCC overlay and the underlying HMA surface is not known. One study showed that PCC pavements constructed on a stabilized base nearly always exhibit bonded behavior initially (as indicated in FWD basin testing results), but long-term pavement performance (JPCP cracking) indicates unbonded behavior [22]. Debonding with time along the slab edges and corners (where the critical stresses occur in PCC pavements) could explain the poor long-term performance.

A Colorado DOT study of the load response of instrumented slabs in the field also showed that whitetopping can exhibit both bonded and unbonded behavior depending on the temperature and loading conditions, and that actual bonding between the pavement layers is not necessary for the pavement to show bonded response [23]. Therefore, further study is needed to ensure that the long-term benefits of partial bonding can be counted on to provide the satisfactory performance of whitetopping overlays of reduced thickness.

To take into account bonding, the CDOT TWT [16] and PCA UTW [17] design procedures were developed for TWT and UTW. Both procedures are mechanistic-empirical (M-E) in nature and calculate the pavement response under load.

3.1.4 Joint Design

Joint spacing has a significant effect on the rate of corner cracking. Short joint spacing, common on UTW and TWT, reduce load-related stresses, because the slabs are not long enough to develop as much bending moment [1]. The joint location is also important to avoid the concentrated loads. 4’ by 4’ panels on a 12’ wide lane would put truck tires on the edge of the panels, and significant distress would occur if the UTW became de-bonded from the HMA base layers. Based on Minnesota experiences the joint spacing as shown in Table 3.1 is recommended.

Table 3.1 Recommended Joint Spacing

Lane Width (feet)	Whitetopping Thickness	
	<5 inches	≥5 inches
10	5’x6’	10’x12’
12	6’x6’	12’x12’

Load transfer designs for thicker TWT and conventional whitetopping are identical to those for new PCC pavements. Dowels are recommended in 6-inch TWT for high truck traffic. Load transfer recommendations are summarized in Table 3.2. In general, load transfer is not required for TWT and UWT.

Table 3.2 Dowels Bar Size and Spacing

Slab Thickness (inches)	Dowel Diameter (inches)	Dowel Length (inches)	Dowel Spacing (inches)
< 6"	Dowels not required		
7" – 10"	1.25	15	12

Dowel bars, tie bars, and other embedded steel items are not used in UTW. This is because the thin UTW slabs make their installation impractical, and effective load transfer at joints is provided by aggregate interlock across the abutting joint faces, which is enhanced by short joint spacing and by the stiff support of the underlying HMA pavement.

3.1.5 Transition Area

Thickened slabs are recommended for UTW at transition areas between the PCC overlay and an adjacent HMA pavement. This is because impact loadings from traffic may induce high stresses in the UTW and cause cracking. Figure 3.1 shows a suggested transition detail [7]. The minimum thickness of 6 inches is recommended for the thickened slabs if whitetopping slabs are 3 inches thick.

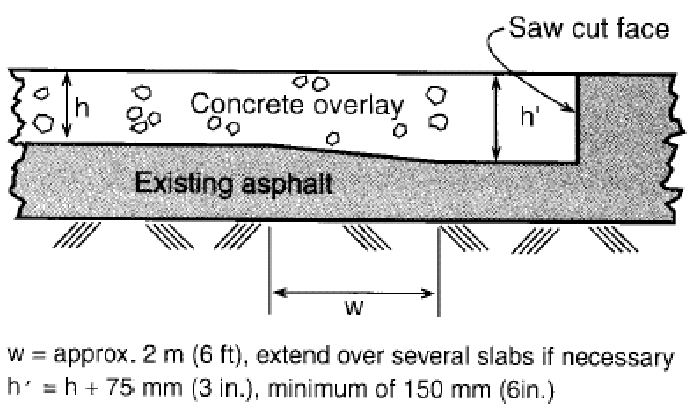

Figure 3.1 Transition from UTW to Adjoining HMA

3.1.6 Site Considerations

In terms of assessing the feasibility of whitetopping as a rehabilitation alternative, the following site factors should also be considered:

- Traffic control
- Shoulders
- Overhead clearance

In urban areas where traffic congestion is already a daily problem, management of detour traffic during construction can be a critical issue. At some point, pavement reconstruction is unavoidable; however, if rehabilitation alternatives with less severe lane closure requirements are still viable (e.g., an HMA overlay) the lane closure requirement can be a key factor that determines the feasibility of whitetopping. For projects in congested areas, the use of "fast-track" paving techniques may be appropriate to minimize lane closure times. Fast-track paving can be used to accomplish PCC pavement reconstruction and overlays with weekend lane closures [18].

The construction of a thin whitetopping may require new shoulders because of the increase in the elevation of the mainline pavement. The elevation change may also mean that interchange ramps have to be adjusted and guardrails raised, both of which affect the economic feasibility of whitetopping overlays.

Overhead clearances could also affect the feasibility of thin whitetopping. Because thin whitetopping adds significant thickness, short sections of reconstruction may be required at overhead structures such as bridge overpasses to ensure adequate vertical clearance. Raising the structure is a more costly alternative. Both of these alternatives increase complexity, time, and cost of pavement rehabilitation, making whitetopping overlays less feasible on projects that involve many overhead structures. Inlay whitetopping is only the solution to maintaining adequate overhead clearance.

3.2. Summary

Conventional whitetopping and TWT for medium-volume roads are viable alternatives for deteriorated HMA pavements, including those that exhibit such distresses as rutting, shoving, and alligator cracking. Their design is similar to that of new PCC pavement and is detailed in AASHTO Guide [10], ACPA Catalog Design [7], and Mn/DOT Design Manual [15]. Because whitetopping is capable of bridging significant deterioration in the underlying HMA pavement, no bonding is assumed in design and minimal pre-overlay repairs are needed.

Historically, the effects of bonding between the overlay and the underlying HMA pavement have been ignored in the design of conventional whitetopping and TWT for medium volume roads. However, since the early 1990s, the effects of bonding between the PCC surface and the underlying HMA pavement have been gaining more attention and design procedures have been developed that consider the effects of bonding in TWT for high volume roads and UTW projects.

There is an interim design procedure for UTW in which the load-carrying capacity of a specific UTW may be designed using mechanistic analysis [7]. In this catalog design, the asphalt thickness, joint spacing, flexural strength, and subgrade/subbase k-value are all needed to estimate the total number of trucks that the pavement can carry. If the truck traffic volume is known, the thickness and joint spacing of the UTW can be determined by comparing the actual truck volume with allowable truck volume.

Other design items such as joint spacing, fiber type and content, transition area, and site conditions become more important to the use of UTW and TWT for high volume roads than that of conventional whitetopping and TWT for medium volume roads. The ACPA catalog design is a good tool in determining these important design items.

Chapter 4
Construction

Current practices for constructing whitetopping are nearly identical to those for constructing any concrete pavement. This chapter emphasizes the unique features of TWT and UTW.

4.1 Construction Procedures

Construction of thin whitetopping involves limited pre-overlay repairs of the existing HMA pavement followed by placement of the PCC overlay with or without bonding agents. The PCC placement for whitetopping is similar to that for new construction, as briefly described in the following sections.

4.1.1 Pre-overlay Repair

Pre-overlay repair is critical in any whitetopping. Conventional whitetopping requires minimal pre-overlay repairs to provide uniform support. For inlay whitetopping, drainage repairs may be necessary. The ACPA guidelines for pre-overlay repairs for TWT and UTW are given in Table 4.1 [7]. The techniques for pre-overlay repairs are the same as the repair techniques for HMA pavements. Recommended practices for these techniques are summarized in several references by the ACPA [7] and in a National Highway Institute training course manual [24].

Table 4.1 Pre-Overlay Repair of Existing HMA

Pavement Conditions	Repairs	
	TWT	UTW
	Optional Milling* and Required Cleaning	Required Milling/Cleaning
Rutting/shoving < 2 inches	None (increasing joint sawing depth)	None
Rutting/shoving > 2 inches	Milling or leveling	None
Potholes	Fill with crushed stone, cold mix or hot mix, and compact	Patch
Subgrade failure	Replace subgrade	Replace subgrade
Alligator cracking	None	Full-depth patch
Block cracking	None	Crack filling
Longitudinal/Transverse cracking	None	Crack filling
Raveling	None	None
Bleeding	None	None

(*) HMA must be milled if bond is assumed for design.

As described above, some pre-overlay repair of the existing HMA pavement is required to obtain the desired level of performance because the existing HMA pavement will be carrying part of the traffic loading. Among the types of pre-overlay repair activities typically required for TWT and UTW overlays are [4,7]:

- Localized repair of failed areas caused by loss of base or subgrade support.
- Filling of medium- and high-severity potholes.
- Localized repair of medium to severe alligator cracking. If significant alligator cracking exists throughout the project, this suggests a structural inadequacy and the pavement may not be a suitable candidate for TWT or UTW.

These activities should follow conventional HMA patching practices. When patching alligator cracking it is important that the entire distressed area be removed and replaced through the entire depth of the HMA pavement.

4.1.2 Surface Preparation

If surface distortions on the existing HMA pavement are excessive (greater than 2 inches), either milling or a leveling course may be necessary to provide proper grading. The milling process should be controlled by a string line to prevent concrete quantity overruns.

Before whitetopping is placed, the temperature of the prepared asphalt surface should be considered. Placing PCC on a hot HMA surface can lead to cracking due to shrinkage, as well as excessive thermal restraint stresses resulting from the large temperature difference between the PCC at hardening and overnight low temperatures. Water fogging and whitewashing are two methods used separately to reduce the asphalt temperature. It is good practice to water fog if the asphalt surface heat makes it uncomfortable to touch with an open palm [7]. Water fogging is adequate for old and milled asphalt surfaces. Whitewashing can reduce the bond between the PCC overlay and the HMA.

Surface preparation (the surface after milling and bond) becomes critical to the performance of the UTW. Milling is a method to achieve the designed texture to help ensure bond. However, if the HMA strips or has been damaged at the level of milling, the bond will fail, which is why caution should be used when considering UTW. Grouting is not recommended because there is enough grout in the regular mix and a grout-bonding layer that dries will not properly perform its intended function of bonding.

4.1.3 Placement and Finishing

The procedures for placing and finishing PCC for thin whitetopping are the same as those for new concrete pavements. Standard practices apply, and the Mn/DOT Specifications and Concrete Manual on placement operations of PCC pavements [15,25] provides a good summary of recommended practices for PCC placement and finishing.

Special attention to temperature conditions during PCC placement may be warranted to avoid excessively high temperature gradients through the PCC during curing. Studies have shown that an excessive temperature gradient through PCC at the time of hardening can lock a significant amount of curling into PCC slabs, which can be deleterious to fatigue performance [22,23].

4.1.4 Texturing and Tining

Texturing of the finished PCC pavement surface is required to provide adequate surface friction of the roadway. Mn/DOT no longer tines concrete pavements; surface friction is provided by carpet drag or brooming, which also reduces noise.

4.1.5 Curing

Curing whitetopping is similar to curing new PCC pavements. Mn/DOT requires curing the entire pavement surface and edges as soon as surface conditions permit after the finishing operations using either blanket or membrane methods [25]. The most common practice is to spray liquid, white-pigmented, membrane curing compound [7]. A greater application of curing compound is recommended to help minimize moisture loss during the construction of TWT and UTW. A double coat of liquid, white-pigmented, membrane curing compound is common for curing whitetopping and is applied at twice the normal application rate for curing UTW.

4.1.6 Joint Sawing and Sealing

As with new PCC pavements, timely sawing is critical to avoid random cracking in whitetopping. Partial-depth saw cutting operations should commence immediately after the concrete has gained enough strength to prevent raveling and spalling of the joint. The same procedures and recommendations given for new pavements are applicable to whitetopping.

The saw-cut depth is of particular concern for whitetopping because the distortions in the underlying HMA pavement can effectively increase the slab thickness, as illustrated in Figure 4.1. A minimum saw-cut depth of one-third the PCC thickness is recommended [7]. A deeper cut should be made where the overlay thickness varies more than 2 inches from the nominal thickness. With early-age sawing techniques, a shallower saw cut may be allowable [7].

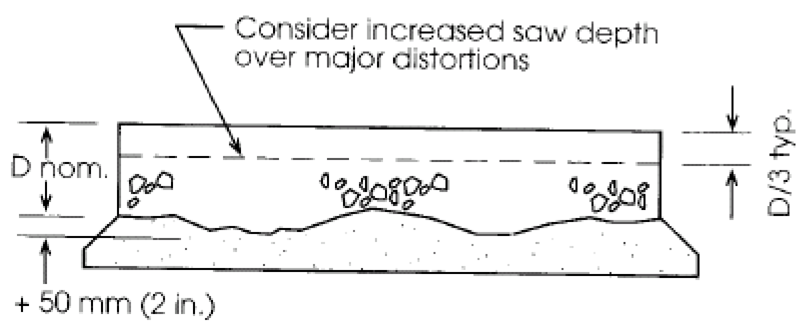

Figure 4.1 Deeper Sawing Where Distortions Exceed 2 inches

The purpose of joint sealants is to keep water and incompressibles (e.g., sand) out of the joint and the crack face. On some TWT construction, joint sealant is used, as it is in standard PCC pavement construction. UTW joints are usually placed at a short spacing and do not open as much as joints associated with longer slabs. For this reason, these joints are typically not sealed.

4.2 Summary

Construction of conventional whitetopping and TWT for medium-volume roads does not involve any special equipment or construction techniques. The whitetopping can be placed directly over existing HMA pavement without any surface preparation (direct placement), but pre-overlay repairs may be needed to address excessive distortions on the HMA surface.

However, the existing HMA pavement must be milled to the specified depth, repaired, and cleaned by sweeping prior to the placement of the TWT for high volume roads and UTW. Under extremely hot conditions, light water fogging is recommended. Standing water is not allowed on milled and cleaned surfaces.

Recommended practices for new PCC pavement are also directly applicable to TWT and UTW. Depending upon the size of the paving project, conventional fixed-form or slipform paving operations are used in TWT and UTW construction. Perhaps the significant differences are that the recommended saw cut depth for transverse joints must consider the rut depth on the underlying HMA surface. Timely and effective sawing of all joints is important in preventing random cracking.

A greater application of curing compound is recommended to help minimize moisture loss during the construction of TWT and UTW. A double coat of liquid, white-pigmented, membrane curing compound is common for curing whitetopping and is applied at twice the normal application rate for curing UTW. In rapid drying conditions, light water fogging is recommended prior to the application of curing compound.

Chapter 5
Performance

An understanding of whitetopping distresses is critical to performance evaluation, thereby resulting in proper design and construction. The definitions of distress types are discussed and followed by the performance of TWT and UTW projects in Minnesota.

5.1 Performance Evaluation

The most common method in performance evaluation is to survey pavement surface conditions, in which various types of distresses are identified and recorded. The results from the condition survey often lead to a set of possible repair or rehabilitation alternatives that can be assembled and ultimately the most appropriate process can be selected. The detailed evaluation and selection guidelines can be found in NCHRP Synthesis 338 [1].

5.1.1 Distress Types

The distress types observed in Minnesota are categorized into early-age and long-term distress types for TWT and UTW, respectively, as shown in Table 5.1. Early-age distresses are often related to the concrete mix properties, the environmental conditions, and methods during construction. Long-term distresses are attributed to the structural design, traffic loading, concrete quality, and environmental conditions after construction.

Table 5.1 Distress Types of Whitetopping

Types	Early Age	Long Term
TWT	Random Cracks Joint Spalling and Raveling	Corner Break Transverse/Longitudinal Cracks Faulting
UTW	Random Cracks	Corner Break Transverse/Longitudinal Cracks Delamination Shattered Slabs

5.2 Current Minnesota Practices

Table 5.2 lists the whitetopping projects in Minnesota since 1982. Appropriate engineering evaluation and design are critical to the success of any ultra-thin whitetopping project. For example, 3½-inch fiber reinforced whitetopping was used for bus pads and busy streets in St. Paul. Detailed engineering evaluation and design were not performed prior to installation. Some bus pads failed in two years. The post-failure thickness design of the pavement anticipated two to five years of service life for 800 buses per day, depending on the subgrade/subbase k-value. On the other hand, the other whitetopped streets have performed very well for five years with high volumes of traffic.

Table 5.2 Whitetopping Projects in Minnesota

General			Overlay				HMA			Performance		
Location	Use	Method	Built	Thickness (inch)	Spacing (feet)	Type	Built	Thickness (inch)	Type	Year	Condition	Reference
CSAH-10 Olmsted County	County Highway	Overlay	1982	6		JPCP			Full-depth	2005	Good	[26]
TH-30	Highway	Overlay	1993	6-7	12x12	JPCP	1973	4.25	6" soil-cement base	2002	Very Good	[27]
US-169, North Mankato	Intersection	Inlay	1995	3		FRCP		12	20" aggregate base	1996	Removed	[26]
Lor Ray Drive, North Mankato	Street	Inlay	1996	4.5 and 6	5x6 10x12	FRCP		11.5	Full-depth	2005	Fair	[28]
Lor Ray Drive, North Mankato	Street	Inlay	1996	3	5x6	FRCP		11.5	Full-depth	2005	Good	[28]
Service Drive and Dock Area, University of Minnesota	Street	Inlay	1996	3.5		FRCP						[29]
US-169, Elk River	Intersection	Inlay	1997	3	4x4 6x6	FRCP	1991	3.5	10" aggregate base	1999	Removed	[26]
I-94, Mn/ROAD	Highway	Inlay	1997	6	5x6 10x12	FRCP	1993	13.5	Full-depth	2001	Very Good	[30]
I-94, Mn/ROAD	Highway	Inlay	1997	3-4	4x4 5x6	FRCP	1993	13.5	Full-depth	2004	Removed	[30]
Bus Pads, St. Paul	Street	Inlay	1999	3.5	3.5x3.5	FRCP			Full-depth	2001	Various	[31]
Kellogg Blvd., St. Paul	Street	Inlay	2000	3.5	3.5x3.5	FRCP		8.25	Full-depth	2004	Very Good	[31]

Note: Two types of concrete overlays are jointed plain concrete pavement (JPCP) and fiber reinforced concrete pavement (FRCP).

5.3 Performance of Thin Whitetopping

5.3.1 Minnesota Field Performance

The field performance of TWT projects in Minnesota has generally been fair to very good [26,27,28,30,32]. Table 5.3 summarizes these projects and their performance at ages 7-22 years.

In 1982, the first TWT project in Minnesota was constructed on Olmsted County State Aid Highway 10 between the City of Chatfield and Interstate 90 [33]. The south 1.4 miles and north 1.1 miles of this project consisted of a concrete overlay placed over an existing HMA surface. The center 6.1 miles of this project was a 7-inch non-doweled concrete placed on a 4-inch layer of aggregate base. The existing HMA on this project was in a poor condition with substantial wheel rutting. A minimum of 6½ inches of concrete was placed over the HMA. Contraction joints were skewed with 15-foot effective intervals with no dowel bars. AADT on this portion of road is approximately 830. In 2005 there is some D-cracking in panels and some spalling and joint failures. Ride on these sections is good. The overall condition of the road would be considered good.

Two HMA and four TWT test sections were constructed in July 1993 over 11 miles on TH 30, approximately 35 miles southwest of Mankato, Minnesota. TH 30 is a very low traffic volume road with a 1992 AADT of 385 and 1992 HCADT of 90 (23%). It was constructed in 1955 with a 6-inch thick soil-cement treated base and 1.5 inches thick HMA wearing surface. A 2¾-inch thick HMA overlay was then placed in 1973, resulting in a 4¼-inch HMA pavement. The whitetopping thickness was 6 inches and panel size was 12 feet by 12 feet for all the whitetopping sections with skew joints. Dowel bars were installed in one of whitetopping sections and a bond breaker was introduced into another whitetopping section. Periodical performance evaluations included surface distress survey, rideability, joint faulting, and load responses. Final evaluation was performed in 2002. The TWT sections are performing very well without maintenance except for the section with dowelled joints that were distressed near the surface. The economic analysis indicated that a 6-inch thick bonded and undoweled TWT is the most economic design [27].

5.3.2 Iowa Field Performance

Iowa also has had very good performance from whitetopping overlays, many of which have been placed on county highways. For example, beginning in the late 1970s, three Iowa counties (Dallas, Boone, and Washington) began paving with whitetopping overlays, and since that time an average of 19 miles of county pavement are whitetopped each year [34]. In most cases, the PCC overlays are placed directly on the existing HMA with little preparation other than sweeping. In addition, the PCC overlays are constructed with 15-foot joint spacing and thickened-edge slab designs, in which the center of the pavement is constructed 5- or 6-inch thick and the outer edges are constructed 6- or 7-inch thick. The whitetopping projects in 1977 are all performing well after years of carrying heavy farm machinery and grain wagons. The 9-mile Washington County whitetopping receives 2,000 vehicles a day.

Table 5.3 TWT Projects in Minnesota

Route		TH 30					Lor Ray Drive		I 94		
Construction Year		1993					1996		1997		
TWT Thickness (in.)		6.5	6.5	7.0	6.5	7.0	4.5	6.0	6.0	6.0	6.0
Panel Length (ft.)		12x12					5x6	10x12	5x6	10x12	10x12
Load transfer		Undoweled	Doweled	Undoweled	Undoweled	Undoweled	Undoweled	Undoweled	Undowled	Undoweled	Doweled
Bonding		Direct	Direct	Milling	2 curing coats	Direct	Milling	Milling	Milling	Milling	Milling
Type		Bonded	Bonded	Bonded	Unbonded	Bonded	Bonded	Bonded	Bonded	Bonded	Bonded
Fiber		No					Polyolefin fibers		Polypropylene fibers		
Year of Survey		2002					2005		2005		
Survey Results		Low Spalling	Many transverse joints spalling and cracking	Low Spalling	Low spalling	Longitudinal cracks	Cracked panels	Some longitudinal cracks, corner breaks, and pumping	Very good	Beginning to fault	Very good
Faulting (mm)		0.61	0.16	0.81	0.53	0.02	Faulting		0.55	4.00	0.02
Changes in IRI (m/km)		0.26	0.06	0.19	0.06	0.06	N/A		N/A		
As-built $/mile		154,023	180,885	161,063	155,290	154,023	154,361	164,947	175,484	155,463	174,896
EUAC, $/year		10,353	12,158	10,826	10,438	10,353	N/A	N/A	N/A	N/A	N/A
Design Traffic	Year	1992					1995		1998		
	AADT	385					10,300		39,000		
	HCADT	90					N/A		5,100		
Future Traffic	Year	2002					2003		2002		
	AADT	650					14,500		48,000		
	HCADT	100					N/A		5,210		
Design Life (years)		20					20		20		
28-day Compressive strength (psi)		3852					N/A	N/A	6200	6300	6300
28-day Flexural strength (psi)		574					N/A	N/A	890	830	830
Project Section ID		3	4	5	6	7	NB	SB	96	97	92

Note: IRI stands for International Roughness Index; EUAC stands for Equivalent Uniform Annualized Cost; AADT stands for Average Annual Daily Traffic Volume; HCADT stands for Heavy Commercial Average Annual Daily Traffic Volume.

After 22 years of service, the oldest whitetopping overlays have required minimal maintenance and are performing well [34]. Because of the strong base on the original road (3-inch soilite and 6-inch rolled stone) the 1977 Dallas County whitetopping is expected to last 30 years. Since the 1977 job, Boone County has done 40 miles of PCC over HMA. Over the past 22 years, county engineers have worked to perfect the technique, experimenting with different surface preparations, overlay thickness, concrete mixtures, and joint spacing.

5.3.3 North Dakota Field Performance

The North Dakota Department of Transportation started experimenting with thin whitetopping on trunk highways in 1998 [35]. A 1,500-foot whitetopping test road was placed on U.S. 52, 20 miles north of Jamestown, North Dakota. Three 500-foot test sections were whitetopped with depths of 5, 6, and 7 inches of concrete. U.S. 52 was selected because of its good soil conditions, a thick section of existing asphalt (approximately 17 inches) and considerable truck traffic. The roadway was experiencing distresses, such as longitudinal and transverse cracking, rutting and shoving pavement, and depressed transverse cracks.

Approximately 5 to 7 inches of the original asphalt road was milled, swept, and blown with an air compressor to keep it clean. The concrete was then placed using a slip form paver. The width of the pavement measured 36 feet. It was poured as two 12-foot sections with two 6-foot shoulders. The concrete mix was based on North Dakota specification with compressive strength of 4,000 psi and slump of 1½ inch. The shoulder line was reinforced with #3 bars every 4 feet. Random tine spacing of the transverse texturing, North Dakota Specification 550.06, was applied using a texture/cure machine.

Three years later, in 2001, these test sections appeared to be performing very well. The first test section that was composed of 5-inch whitetopping and 12-inch HMA base, showed the most distresses along the joints. The second test section, which is composed of 6-inch whitetopping and 11-inch HMA base, was in very good condition. The third test section, which is composed of 7-inch PCC and 10-inch HMA base, was in very good condition with the exception of one panel. However, spalling has caused joint sealant to debond from several panels throughout each test section along both the longitudinal and transverse joints.

5.4 Performance of Ultra-Thin Whitetopping

This section describes some notable UTW projects that have been constructed since the early 1990s. Because this is a new technology, very little long-term performance data are available. However, the available data suggest that UTW is a viable pavement rehabilitation alternative for low-volume roadways. The UTW projects in Minnesota are summarized in Table 5.4.

A review of UTW projects indicates that the performance is various. Some problems with corner cracking have been noted and are often attributed to late sawing or to the placement of the longitudinal joints in the wheel path. Cracking of the approach and leave sides of UTW overlays has also been observed, and this is believed to be caused by impact loading as the wheel moves from the adjacent HMA pavement to the UTW. Using thickened edges at these locations is one

Table 5.4 UTW Projects in Minnesota

Route		I 94			US 169			Lor Ray Drive		St. Paul	
Construction Year		1997			1997			1996		1999	2000
UTW Thickness (in.)		4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5	3.5
Panel Size (ft.)		4x4	4x4	5x6	4x4	4x4	6x6	5x6	5x6	3.5x3.5	3.5x3.5
Bonding		Milling	Milling	Milling	Milling	Milling	Milling	Milling	Milling	Milling	Milling
Fiber		Polypropylene		Polyolefin	Polypropylene		Polyolefin	Polyolefin		Polypropylene	
HMA Thickness (in.)		9	10	10	6.25	6.25	6.25	8.5	8.5	Unknown	7.75
Base Thickness (in.)		No	No	No	5	5	5	No	No	Unknown	Unknown
Subbase Thickness (in.)		No	No	No	6	6	6	No	No	Unknown	Unknown
Subgrade		Silty Clay			Sandy			Silt Loam		Sandy	
2001 Survey		Corner breaks and transverse cracks			Corner breaks and transverse cracks		Corner breaks	No distresses		Various distresses	No distresses
Distress Severity		Moderate	High	Low	High	Moderate	Low	Low	Low	Low-High	None
2001 D IRI, m/km		1.74	1.71	0.31	N/A	N/A	N/A	N/A	N/A	N/A	N/A
As-built $/mile		146,630	128,963	145,923	154,716	154,716	171,924	117,008		N/A	N/A
Design Traffic	**Year**	1998			1997			1995		1999	1999
	AADT	39,000			32,000			10,300		Various	25,300
	HCADT	5,100			2,560			N/A			N/A
Future Traffic	**Year**	2002			1999			2003		2019	2019
	AADT	48,000			34,000			14,500		Various	37950
	HCADT	5,210			2,720			N/A			N/A
Design Life (years)		20			20			20			20
28-day Compressive strength (psi)		6,100	6,100	5,300	5,400	5,900	5,300	N/A	N/A	N/A	N/A
28-day Flexural strength (psi)		850	850	840	590	590	570	N/A	N/A	N/A	N/A
Project Section ID		93	94	95	98	99	91	NB	SB	Bus Pads	Kellogg Blvd.
2004 Status		Removed in 2004			Removed in 1999			Repaired	Repaired	Some removed	

way of addressing this problem. Continued performance monitoring is recommended in order to obtain a better indication of the actual service lives of these pavements.

5.4.1 ACPA Performance Evaluation Projects

In 1995 and 1996, the ACPA conducted detailed condition surveys on ten UTW projects: six in Tennessee, three in Georgia, and one in Missouri. The purpose of these surveys was to examine the early performance of UTW, and the ten projects were selected primarily because they are some of the older UTW [8]. The condition surveys were conducted in accordance with the pavement condition index (PCI) procedures developed by the Corps of Engineers and adopted by the American Public Works Association.

Based on the results of the condition surveys that represent about 4 to 5 years of performance data collected in 1997, the following conclusions were drawn [8]:

- Nine of the ten sections were rated in very good condition.
- Some cracks have occurred on the various PCC slabs, but most of these cracks are less than ¼-inch wide (low severity) and do not appear to be affecting pavement ride quality.
- The first and last panels (approach and leave ends) of the UTW contain a higher percentage of cracking than the rest of the project. This is believed to be the result of impact loading as the wheel crosses from the adjacent HMA pavement to the UTW.
- Sections with the highest PCI have the smallest panel size and a thicker underlying HMA thickness.

5.4.2 Lor Ray Drive, North Mankato, Minnesota

In 1996, a project was constructed on Lor Ray Drive, an arterial road in North Mankato, MN [28]. The existing pavement consisted of 11½ inches of full-depth asphalt over 3 feet of silty loam backfill. The bituminous surface was severely rutted due to heavy traffic moving at slow speeds. Three whitetopping test sections were inlayed over the existing bituminous surface by milling the pavement to the depth of the concrete overlay. A 6-inch overlay with 10-feet by 12-feet panels was constructed in the southbound lanes south of U.S. 14, a 4½-inch overlay with 5-feet by 6-feet panels was constructed on the northbound lanes south of U.S. 14, and a 3-inch overlay with 5-feet by 6-feet panels was constructed on the northbound and southbound lanes north of U.S. 14. The concrete contained polyolefin fibers at a rate of 25 lbs/yd^3. Panels were sized to match the joints in the curb adjacent to the pavement. This project is currently in poor condition with excessive faulting. Only a few corner cracks are present and most of these cracks are still very tight. There has been one minor pavement failure in the 3-inch section. It was subsequently discovered that the concrete thickness was only 1 inch at this location. The survey in 2005 indicates that the 4½-inch and 6-inch thick sections are faulting since 10 feet by 12 feet panels are used, and the 3-inch section is not.

5.4.3 US-169, Elk River, Minnesota

In 1997, a project was constructed on US-169 in Elk River [26]. The US-169 site represents a typical application for ultra-thin whitetopping. Most of the loads are static and the traffic is constantly starting and stopping. This section of US-169 carries approximately 400,000 Equivalent Single Axle Loads (ESAL) per year. The few cracks in the existing asphalt pavement were in good condition, but the asphalt itself was not, especially along the outer edge. A large amount of rutting (greater than 1 inch) was also present before milling.

The sections were located on the outer southbound lane of US-169 in Elk River at the intersections of Jackson, School, and Main Streets. The first 788 ft. north of each intersection was overlaid with 3 inches of fiber-reinforced concrete, and the following 12 feet was paved 8 inches thick as a transition. The original asphalt pavement had been constructed in 1961 on a sandy subgrade and consisted of a 4-inch asphalt surface on 5 inches of Class 5 aggregate base and 6 inches of Class 4 aggregate base. In 1991, 2 inches of asphalt was milled and the pavement was overlaid with 1.5 inches of asphalt. The average asphalt thickness based on a total of ten cores pulled April 8, 1997 between roadway post 159.080 and 160.367 was 6.25 inches.

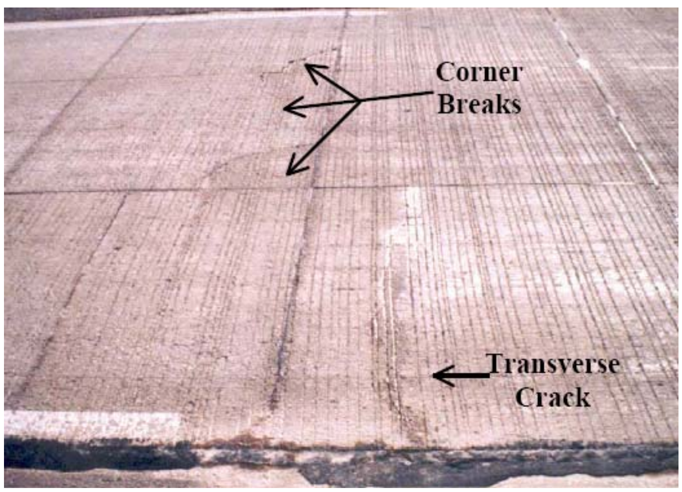

Figure 5.1 Jackson St. Sections on US-169, Elk River

Figure 5.2 Corner Breaks in the Wheelpath at Jackson St. Sections on US-169, Elk River

Distinct cracking patterns developed within each test section in 1998, as shown in Figure 5.1. The UTW test sections with a 4-foot by 4-foot joint pattern included corner breaks in the inside wheelpath (Figure 5.2) and transverse cracks. Corner breaks were the primary distress in the test section with 6-foot by 6-foot panels, although very little cracking was exhibited. The strain measurements emphasize the importance of the support provided by the HMA layer. A reduction in this support occurs when the temperature of the HMA is increased or when the HMA begins to ravel.

5.4.4 I-94 Mn/ROAD, Otsego, MN

In 1997, the Minnesota Department of Transportation constructed several thin and ultra-thin whitetopping overlays as part of the Minnesota Road Research (Mn/ROAD) test facility [28,30]. A 13-in full-depth asphalt pavement at the Mn/ROAD research site was whitetopped with fiber reinforced concrete overlays. This section of pavement was originally constructed in 1993 on a silty-clay subgrade. The sections were installed on 1,300 feet of westbound I-94 in the transition zone between 10-year design pavements and 5-year design pavements. These cells were instrumented with strain, temperature and moisture sensors.

The UTW thickness ranged from 3 to 4 inches, and joint spacing ranged from 4 foot by 4 foot to 5 foot by 6 foot. Two different PCC mix designs were also employed in this project, one with polyolefin fibers added at a dosage rate of 25 lb/yd^3 and one with polypropylene fibers added at a dosage rate of 3 lb/yd^3 [28]. Figure 5.3 shows the newly constructed sections.

The pavements were evaluated in 2001 after about 3½ years and 4.7 million ESAL applications. As shown in Figure 5.4, transverse and corner cracking had occurred in the UTW test sections, primarily in the truck lane [33]. An analysis of the performance data suggested that the selection of an effective joint pattern minimizing the number of joints in wheel paths would increase the performance of the UTW. Other factors noted to be important to the performance of the UTW are the quality of the HMA beneath the overlay and the HMA temperature and stiffness [30]. The UTW sections were replaced in 2004 after experiencing significant corner cracking distress.

Figure 5.3 Newly Constructed Sections on I-94

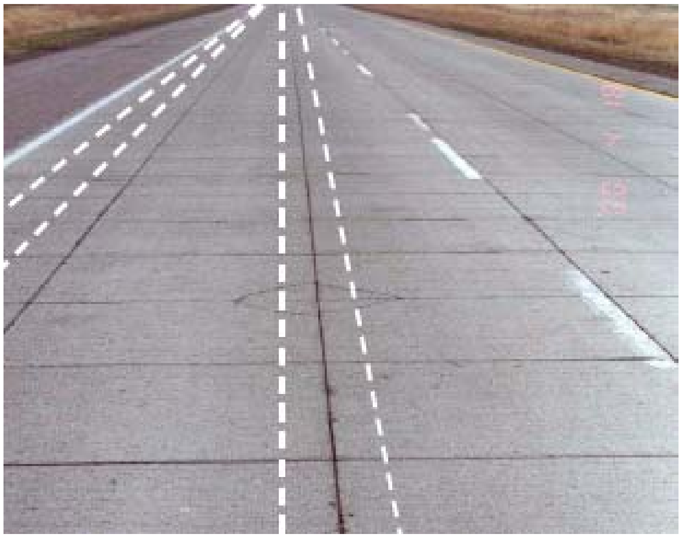

Figure 5.4 Corner Breaks on I-94

5.4.5 Bus Stops, St. Paul, MN

The City of St. Paul constructed a number of ultra-thin whitetopping projects on bus pads on major streets in 1999 and 2000 [31]. In 1999, 25 ultra-thin whitetopping bus pads were constructed along University Ave. between Rice Street and Vandalia Street and eleven were constructed in downtown St. Paul. Typical bus pads have a length of 60 to 300 feet and width of 10 to 12 feet. They are in the driving lane next to the curb. All existing pavements are asphalt concrete of various depths except for one PCC concrete pavement and one brick paver surface. The existing asphalt pavement was inlaid with a 3.5-inch fiber-reinforced concrete layer. In 2000, AADT on University Ave. ranged from 19,000 to 25,000 while AADT in downtown St.

Paul ranged from 4,600 to 10,000. In 2000, four westbound lanes (two travel and two turn lanes) on Kellogg Boulevard from 7th Street to STA 4+90.86 were inlaid with a 3.5-inch fiber-reinforced concrete whitetopping over an 8.25-inch HMA base. Kellogg Boulevard is an arterial road with AADT of 25,000 in 2000. The joint spacing ranges from 3.3 to 3.9 feet.

The performance of these sections varies from very good to failing. Some early cracking was observed on the concrete bus pads that were most heavily trafficked. Some pavement pads were rehabilitated in 2001 and some were scheduled for rehabilitation in 2004. The removed sections are located on 6th Street in downtown St. Paul, where daily bus traffic of 800 is reported. A majority of the panels in the failed bus pads were shattered into five or more pieces and were concentrated at the ends of the bus pads, as shown in Figure 5.5. A dramatic increase in the number of cracked panels was observed in 2004 when compared to the survey conducted in 2000. However, some sections, as shown in Figure 5.6 were in very good condition when surveyed in 2004.

Figure 5.5 Shattered Bus Pads in Downtown St. Paul

Figure 5.6 Intact Bus Pads in Downtown St. Paul

5.4.6 Route 21, Belle Plaine, Iowa

Iowa DOT constructed an experimental project evaluating thin and ultra-thin whitetopping overlays in 1994 [36,37]. This project is located on Iowa Route 21 on a 7.2-mile stretch of pavement near Belle Plaine, and represents one of the first uses of the technology in a highway application. A total of 41 test sections were established, ranging in length from 200 to 2,700 ft. Variables evaluated in the study include:

- HMA surface preparation: milled and patched, patched only, and cold in-place recycled (CIR)
- UTW slab thickness: 2 and 4 inches.
- Joint spacing: 2 foot by 2 foot and 4 foot by 4 foot on the 2-inch and 4-inch sections, and 6 foot by 6 foot on the 4-inch sections.
- Synthetic fibers: fibrillated polypropylene, monofilament polypropylene, and none
- Joint sealant: hot-poured and none.

The existing HMA pavement was 3 inches thick, not including a ¾-inch bituminous chip seal immediately beneath the HMA layer. Where the HMA pavement was milled, a layer ¼ inches thick was removed, leaving a nominal bituminous material thickness (HMA and chip seal) of 3.5 inches.

Performance monitoring of these experimental pavement sections is ongoing. Performance observations after five years of service include the following [9]:

- Milling of the existing HMA pavement provided the highest bond strength between the PCC and the HMA pavement. It also provided excellent control of longitudinal and transverse profiles, as well as overlay thicknesses.
- The 4-inch thick UTW sections performed well over the 5-year evaluation period.

- Some of the 2-inch UTW sections exhibited longitudinal and corner cracking, which often led to debonding of slab corners. Fibers were found to be beneficial to the performance of these sections.
- The 2-inch UTW sections with 2 foot by 2 foot joint spacing had less cracking than the 2-inch UTW sections with 4 foot by 4 foot joint spacing. However, the use of 2 foot by 2 foot joint spacing for the 2-inch UTW sections introduced a longitudinal joint in the wheel path that is believed to have been the source of cracking.
- The narrow, unsealed joints performed very well, with no signs of significant raveling or joint spalling.
- Deflection testing over the evaluation period indicated that traffic loadings and environmental conditions did contribute to increasing deflections over time, suggesting a reduction in the composite action of the pavement cross section.

Based on the results of the study, the researchers suggest the following design characteristics for good performing UTW overlays on highways [9]:

- Surface preparation: Milling the existing HMA pavement, leaving a minimum HMA thickness of 3 to 4 inches.
- PCC overlay thickness: UTW thicknesses between 3 and 4 inches, with fibers added to 3-inch overlays.
- Joint design: Joint spacing of 4 to 6 feet and narrow joints without joint sealant.

5.5 Maintenance and Rehabilitation

Maintenance and rehabilitation strategies for distressed TWT and UTW can be determined based on the distress survey, the analysis of their causes, as discussed briefly in Section 5.1 of this chapter, and the factors affecting performance, as discussed in Chapter 1.

For TWT, the rehabilitation recommendations resemble those for conventional concrete pavements. This is especially true for TWT 5 inches or thicker or where a bond with the HMA was not intentionally constructed. TWT overlays that are thinner, have short joint spacing, and are bonded to the HMA can be rehabilitated according to the guidelines recommended for UTW.

Full-panel replacement is common repair strategy for the distressed panels of UTW such as corner breaks. The use of a milling machine with tungsten carbide teeth to remove concrete can reduce repair times. The milling process also creates a ridged surface that improves the bonding between the HMA and new panel. Two repair strategies exist to deter reflective cracking in UTW, including placing a bond-breaking material over the cracks in the HMA and full-depth sawing along the longitudinal joints [26].

Little information is currently available regarding the optimal time for performing maintenance and rehabilitation of whitetopping. Research is needed to determine the most effective maintenance and rehabilitation treatments for whitetopping as well as the timing of such treatments for optimum benefit.

Chapter 6
Conclusions

Conventional whitetopping is identical to new PCC overlay in design and construction. It needs minimal pre-overlay repair and no surface preparation. However, for UTW more effort is needed to achieve a bond between the PCC overlay and HMA substrate. Since milling is the best way to achieve bond it is required in UTW projects. More engineering evaluation, more intensive pre-overlay repairs and surface preparation, better topping materials, and better HMA conditions are practiced in UTW, with the consequent cost increases.

In TWT and UTW the HMA substrate meets the following requirements:

- Distresses are concentrated on the surfaces, such as rutting resulting from unstable surface mix, top-down cracking resulting from surface shearing, oxidation and weathering.
- No stripping.
- Minimum thickness after milling of 3 inches.

The strength of the HMA substrate can be quantified by the modulus of subgrade reaction (k-value) in the conventional design procedure. The thickness of TWT and UTW can be determined with known traffic loading, HMA thickness, PCC flexural strength and k-value using the ACPA design catalog.

The current practices of TWT in Minnesota and adjacent states have shown that TWT has been used successfully and is an important alternative for rehabilitating HMA pavements of medium volume roads. If designed and constructed properly, TWT is also an important alternative for rehabilitating HMA pavements of high volume roads with more requirements in HMA quality, bonding and fiber reinforcement.

The performance of current UTW projects in Minnesota ranges from very good to failing. The sections that perform poorly are short sections under stopping trucks or buses and over thin or poor HMA pavement. UTW has been used successfully in Minnesota when inlaid into thick and sound HMA pavements under high volume traffic. Since there are inherent limitations of UTW in requiring high quality of the HMA substrate, bonding, fiber reinforcement, and short joint spacing, caution should be used when rehabilitating HMA pavements at bus stops, weigh stations, and intersections.

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