National Concrete Pavement Technology Center

Preservation and Rehabilitation of Urban Concrete Pavements Using

Thin Concrete Overlays

Solutions for Joint Deterioration in Cold Weather States

Iowa State University
Institute for Transportation

September 2014

On the Cover

Close-up of severe joint deterioration in a concrete pavement (Photo courtesy of Trinity Construction Management Services, Inc.)

Typical joint deterioration in transverse and longitudinal joints of concrete pavements, with asphalt patches (Photo courtesy of Trinity Construction Management Services, Inc.)

Milling existing concrete in preparation for an unbonded overlay (Photo courtesy of Randell Riley, IL chapter of American Concrete Pavement Association)

Close-up of milled concrete pavement (Photo courtesy of Dan DeGraaf, Michigan Concrete Paving Association)

Concrete curb overlay (Photo courtesy of Ron Youngman, CO/WY chapter of ACPA)

Thin unbonded concrete overlay after seven years of service (Photo courtesy of The Transtec Group)

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16. Abstract

The purpose of this guide is to provide a resource for pavement owners, designers, and contractors to design and construct successful thin (≤ 5-in.) concrete overlays, both bonded and unbonded, as a longer-term (15 years or more) preservation solution for concrete pavements with prematurely deteriorating joints. It covers topics such as selecting appropriate candidate pavements for such an overlay and designing and constructing thin overlays in urban areas. It also summarizes several case studies.

This guide is a companion document to the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, Third Edition (2014), and the *Guide to the Design of Concrete Overlays Using Existing Methodologies* (2012).

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Preservation and Rehabilitation of Urban Concrete Pavements Using

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Solutions for Joint Deterioration in Cold Weather States

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About This Guide

This guide is the product of a research project led by Iowa State University's National Concrete Pavement Technology Center (CP Tech Center): Investigation of Deterioration of Joints in Concrete Pavements. To date, this research has resulted in the publication of the *Guide for Optimum Joint Performance for Concrete Pavements* (July 2012) and now this *Preservation and Rehabilitation of Urban Concrete Pavements Using Thin Concrete Overlays: Solutions for Joint Deterioration in Cold Weather States*. The current guide also complements a series of publications about concrete overlays developed by the CP Tech Center to support the increased deployment of these useful solutions for a variety of pavement needs. These documents include, for example, the *Guide to the Design of Concrete Overlays Using Existing Methodologies* (October 2012) and the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd Edition (May 2014). The entire series of concrete-overlays related documents is on the CP Tech Center's website, www.cptechcenter.org/.

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Disclaimers

Mission

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, technology transfer, and technology implementation.

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1. Introduction

Although relatively few pavements are affected, premature joint deterioration has occurred on concrete pavements in several states, most commonly in northern states and in urban areas. See Figures 1 and 2.

Determining the causes of and preventing such deterioration is the focus of another document, the *Guide for Optimum Joint Performance for Concrete Pavements* (July 2012), developed by the National Concrete Pavement Technology Center (CP Tech Center) at Iowa State University. The 2012 document, in combination with the *Concrete Pavement Preservation Guide,* 2nd Edition (Smith et al. 2014), addresses several joint preservation techniques:

- Application of concrete surface sealers.
- Partial-depth repairs.

Figure 1. Typical joint deterioration in transverse and longitudinal joints of concrete pavements, with asphalt patches (Photo courtesy of Trinity Construction Management Services, Inc.)

Figure 2. Close-up of a failed asphalt patch and joint deterioration in a concrete pavement (Photo courtesy of Trinity Construction Management Services, Inc.)

- Full-depth repairs.
- Retrofit of underdrains.
- Thin (≤ 5-in.) concrete overlays, bonded and unbonded.

The last of these concrete preservation techniques—designing and constructing thin (≤ 5-in.) concrete overlays for concrete pavements with deteriorated joints—is the topic of this guide. Such overlays provide a longer term solution (15 years or more). The emphasis of this guide is on pavements in urban environments, but thin concrete overlays can be equally suitable for preserving rural pavements with open ditches.

This document provides up-to-date guidance for determining if a pavement is a candidate for a thin concrete overlay and, if so, offers recommendations on project details and implementation strategies.

One of the keys to thin concrete overlays is milling the existing pavement to remove a majority of the joint deterioration prior to constructing the concrete overlay. Milling has the advantage of retaining the existing elevation of curb and gutter and other structures in urban pavements after an overlay is placed. Many such projects have been constructed in the United States. Many "lessons learned" from these projects are incorporated into this guide as summaries of case studies. See section 7. As future projects are constructed and more is learned about implementing thin concrete overlays as solutions for pavements with deteriorated joints, design and construction guidance will be refined and updated.

Note that the existing pavement may be a composite; i.e., asphalt on concrete. Milling can remove the distressed asphalt layer; therefore, the design will be for a thin overlay on concrete pavement.

Water is the common factor in most premature joint deterioration in concrete pavements. For example, current deicing practices appear to be increasing the degree of concrete saturation at joints, making them more susceptible to freeze-thaw damage. Improper joint detailing, inadequate drainage, or poor construction practices may also allow the development of water-based joint distresses. Therefore, it is important to design and construct an overlay that addresses these issues so they do not recur.

Comprehensive guidance about concrete overlays can be found in the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd Edition (Harrington and Fick 2014).

2. Overview of Thin Concrete Overlays in Urban Areas

All concrete overlays are designed either to bond or not to bond to the existing pavement. In the case of *bonded* overlays, the existing pavement becomes a structural component of the overlaid pavement system. See Figure 3.

Unbonded overlays, on the other hand, utilize the existing pavement as a subbase layer. See Figure 4.

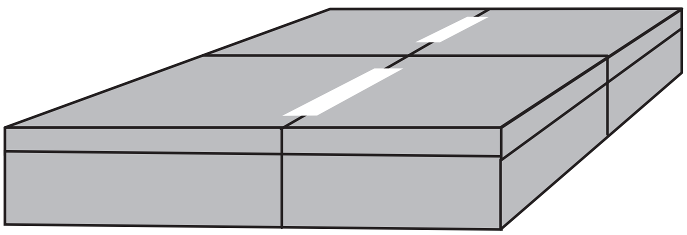


Figure 3. Illustration of thin bonded concrete overlay of concrete pavement

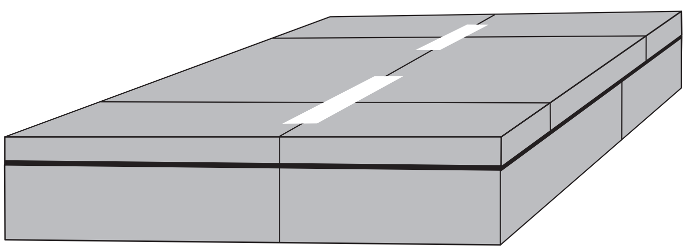


Figure 4. Illustration of thin unbonded overlay of concrete pavement with separation layer

The scope of this guide is limited to thin (≤ 5-in.) overlays. Thin bonded overlays are generally 2-in. to 5-in. thick. Thin unbonded overlays are generally 4-in. to 5-in. thick.

A concrete overlay is not recommended for a pavement experiencing fast-acting material-related distress, such as fast-acting D-cracking or alkali-silica reaction (ASR). Some states, however (particularly Kansas and Missouri), have demonstrated that unbonded overlays of fair- to poor-condition, slow-acting D-cracked or ASR pavements are possible. With pavements in this condition, proper measures must be taken to mitigate the propagation of these distresses, such as improving drainage so that the concrete is not exposed to high levels of moisture.

Such material-related distresses should be evaluated to assess the potential for future expansion, using approaches such as those described in Fournier, et al., 2010.

2.1 Key Concepts for Thin *Bonded* Overlays on Concrete Pavements

When a bonded concrete overlay is constructed, the existing pavement and the bonded overlay act as a monolithic pavement system, and the existing concrete pavement is considered a structural component of the system. Unless distresses are removed by milling and/or repaired, any distresses in the existing pavement will reflect up into the overlay.

2.1.1 Evaluating an Existing Concrete Pavement for a Thin Bonded Overlay

If an existing concrete pavement is in *good* condition but needs functional improvements such as increased albedo (reflectivity), smoothness, surface texture, etc., it is a good candidate for a thin bonded concrete overlay.

If an existing concrete pavement is in *fair* to *poor* condition, however, it is a good candidate for a bonded concrete overlay *only* if it can be restored, cost effectively, to good condition before the overlay is placed.

This is the major factor in determining the appropriateness of constructing a bonded concrete overlay on a concrete pavement in fair to poor condition.

For example, if a concrete pavement is in fair to poor condition and its major distress is joint deterioration in the upper half of the pavement, milling may cost-effectively remove the majority of unsound concrete and return the pavement to good condition in preparation for a bonded concrete overlay. See Figure 5.

If, after milling, isolated areas of deteriorated joints remain in the upper half of the slab, they should be repaired by partial-depth patching (or, if deterioration extends into the lower half of the slab, by full-depth patching); a few such repairs may still be cost effective. However, if, after milling, extensive partial- or full-depth repairs would be required, the pavement is not a good candidate for a bonded overlay. (Note: Such a pavement may be a candidate for an *unbonded* overlay. See section 2.2.)

Therefore, before a bonded concrete overlay solution is selected for an existing concrete pavement in fair to poor condition, a thorough evaluation of the existing pavement must be completed to determine the extent of joint distress. The evaluation should include the extraction of multiple cores at the joints.

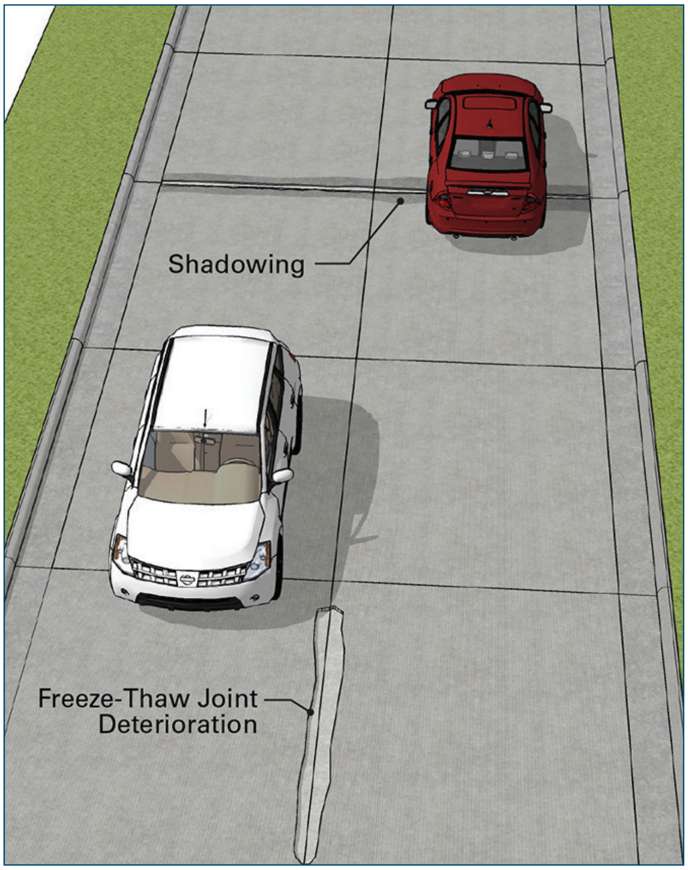


Figure 5. When considering a bonded overlay, evaluate condition of existing concrete pavement to determine if the majority of deterioration can be removed by milling (Illustration courtesy of Snyder & Associates, Inc.)

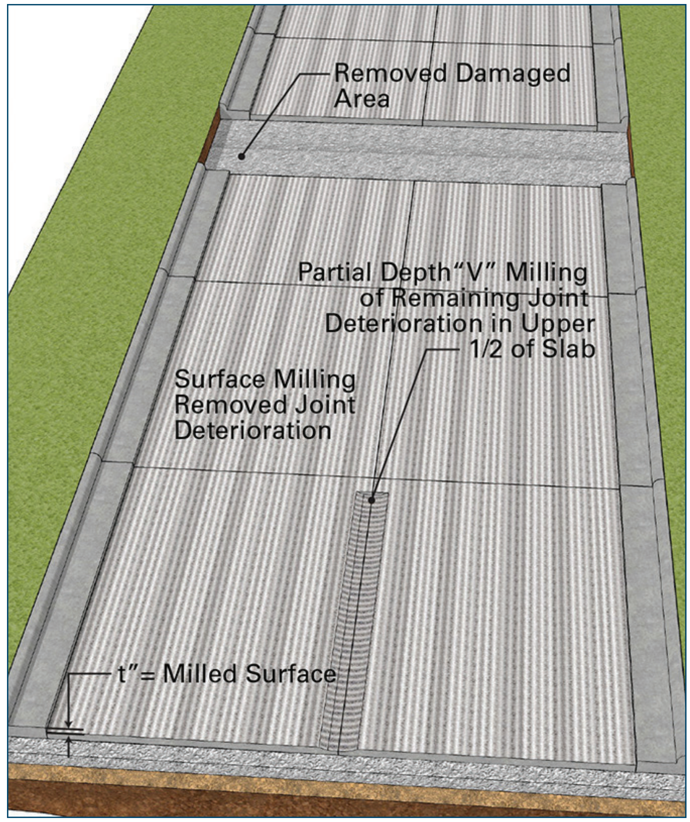


Figure 6. Mill full width of concrete pavement to a depth that removes a majority of deteriorated concrete (additional spot milling may be required in isolated areas) (Illustration courtesy of Snyder & Associates, Inc.)

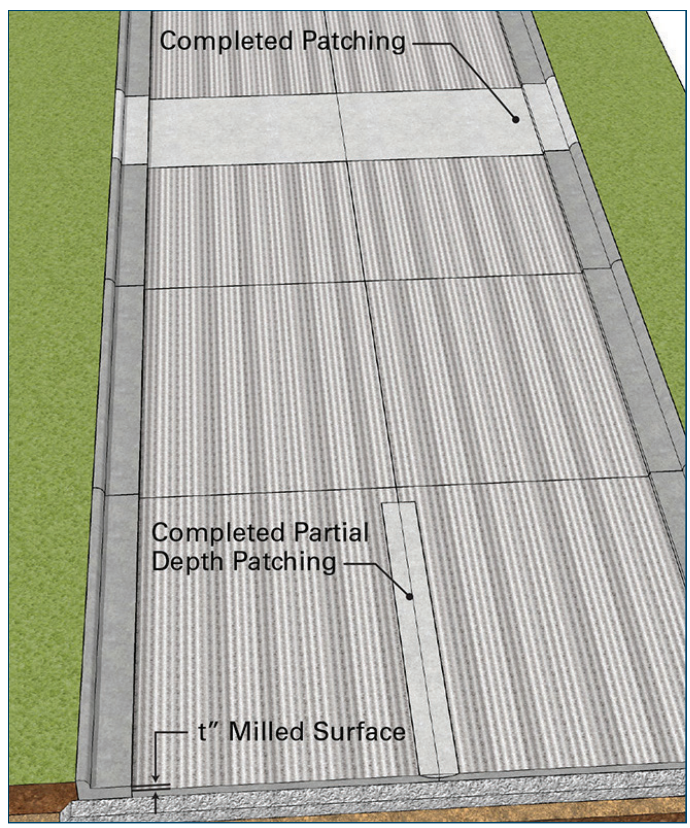


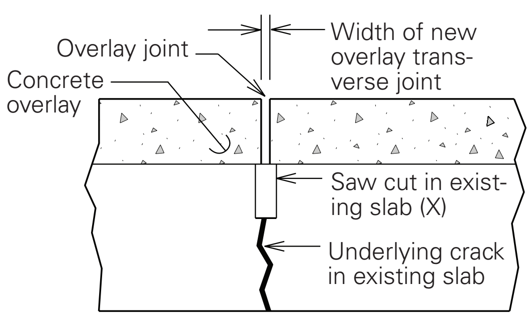
Figure 7. Construct partial- or full-depth repairs, if needed, in isolated areas where joint deterioration is excessive (Illustration courtesy of Snyder & Associates, Inc.)

2.1.2 Summary of Thin Bonded Concrete Overlay Construction

If, after evaluation, a bonded overlay is selected, the key points listed below should be followed. The primary steps in constructing thin bonded overlays are illustrated in Figures 6 through 8.

- Correct any and all drainage problems, making sure to address both top-down and bottom-up drainage.
- Mill the full width of the existing pavement to a depth that removes the majority of deteriorated concrete. See Figure 6.
- After milling, localized areas that still show signs of joint deterioration should be repaired by either partial- or full-depth patching, to complete the restoration of the existing pavement to good condition. See Figure 7.
- Any random cracks in the existing pavement that are open more than ⅛ in. should be filled with a hot poured joint sealant. This will prevent grout intrusion and potential locking of the crack.

- It is critical to establish and maintain a solid bond between the existing pavement and the overlay to ensure good performance of the overlaid pavement system. To minimize shear stress in the bond that can cause debonding, the thermal properties (i.e., the coefficient of thermal expansion) of the aggregate in the overlay mixture should be similar to or lower than the thermal properties of the aggregate in the existing pavement.
- Timing of joint sawing is especially critical for reducing stresses in thin concrete overlays. Contraction joints should be sawed as early as possible to account for movement in the underlying pavement due to temperature changes.
- To minimize cracking in the overlay, locations of the overlay joints should be matched exactly to the locations of joints in the underlying pavement. Matching joints allows the overlay and existing pavement to move monolithically.
- Matched joints should be sawed to a width equal to or greater than the width of the underlying crack in the existing pavement. See Figure 8.
- To help minimize curling and warping stresses in the bond, some agencies have used smaller panels (created by sawing additional transverse and longitudinal joints between the matched joints).
- Transverse joints must be sawed the full depth of the overlay plus ½ in.



Note: Overlay joint width shall be equal to or greater than crack in the existing slab.

If "X" is 0.50 in. (13 mm) or greater, the underlying crack width in the existing slab should be measured. If crack is 0.25 in. (6.4 mm) or greater, and existing pavement does not have dowel bars, the joints should be evaluated to determine if load transfer rehabilitation is required to eliminate faulting. If there are numerous joints of this type, the existing pavement may not be a good candidate for a bonded overlay.

Figure 8. Construct thin bonded concrete overlay with matched joints (Illustration courtesy of Snyder & Associates, Inc.)

- Longitudinal joints may be sawed to the same depth, although some agencies believe that T/2 is sufficient.
- Curing must be timely and adequate, especially near the overlay edges, due to thin overlays' high surface-to-volume ratio and the risk of early-age cracks.

Comprehensive guidance pertaining to bonded concrete overlays can be found in the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd Edition (Harrington and Fick 2014).

2.2 Key Concepts for Thin *Unbonded* Overlays on Concrete Pavements

As noted earlier, unbonded concrete overlays do not rely heavily on the underlying concrete pavement for structural support. Rather, the existing pavement serves as a subbase which must provide uniform support.

2.2.1 Evaluating an Existing Concrete Pavement for a Thin Unbonded Overlay

When evaluating an existing concrete pavement's suitability for a potential unbonded concrete overlay, note that, in general, unbonded overlays can be constructed on existing pavements that are in poor condition without extensive preoverlay repairs. See Figure 9.

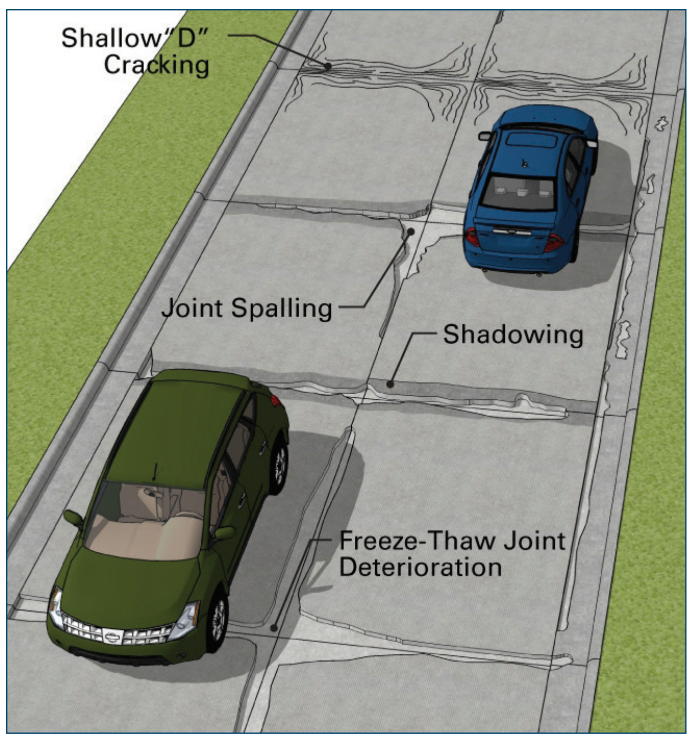


Figure 9. Evaluate an existing concrete pavement in poor condition with deteriorated joints to determine if it is a candidate for an unbonded concrete overlay (Illustration courtesy of Snyder & Associates, Inc.)

However, the existing pavement must be able to provide uniform and stable support for the overlay, and the overlaid system must be able to carry the expected traffic loads.

Also note that the existing pavement will serve as a subbase for the unbonded overlay and will be considered as such in the overlay design. That is, the thickness of the existing pavement should be considered when determining the modulus of subgrade reaction.

Finally, if a portion of unsound or deteriorated concrete in the existing pavement is removed through milling, the remaining concrete pavement must provide a stable, uniform base for the new overlay. Note, however, that designing an unbonded overlay to the same thickness as the thickness of the milled-off deteriorated concrete will not result in the same load-carrying capacity as that of the original pavement. In an unbonded overlay system, the existing pavement is considered a base and does not become a monolithic system with the overlay.

2.2.2 Summary of Thin Unbonded Concrete Overlay Construction

If, after pavement evaluation, an unbonded overlay is selected, the following key points should be followed. The primary steps in constructing thin unbonded overlays are illustrated in Figures 10 through 13.

- Correct any and all drainage problems, addressing both top-down and bottom-up drainage.
- Mill the full width of the existing pavement to a depth that removes the majority of deteriorated concrete, particularly when it is desirable to maintain the pre-overlay elevation. See Figure 10.
- After milling, remove loose material in the joint. Fill and level the joint with flowable mortar or grout. Some states use a regular concrete mixture if the removed pavement is full depth. Jointing is not necessary in the fill area because the separation layer prevents reflective cracking in the concrete overlay. See Figure 11.
- Place a separation layer (asphalt or geotextile fabric). This layer prevents bonding—i.e., isolates the concrete overlay from the existing underlying pavement—and

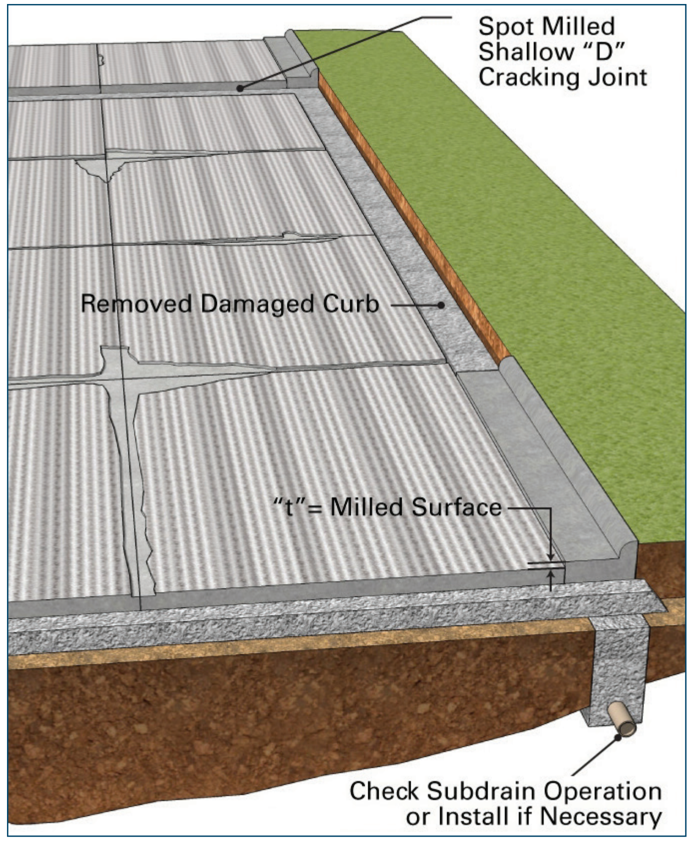


Figure 10. Mill the full width of the existing pavement to a depth that removes the majority of deteriorated concrete (Illustration courtesy of Snyder & Associates, Inc.)

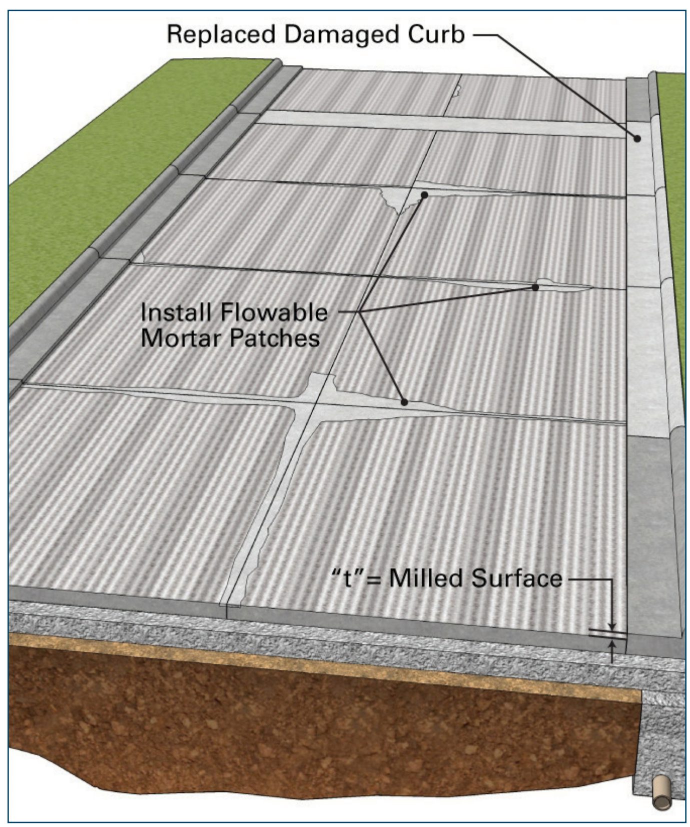


Figure 11. Level remaining areas of deterioration with flowable mortar or grout, and perform other repairs where necessary (Illustration courtesy of Snyder & Associates, Inc.)

minimizes reflective cracking. The separation layer is usually a geotextile fabric (see Figure 12) or, where there is vertical room and proper outlet, a 1-in. minimum asphalt layer.

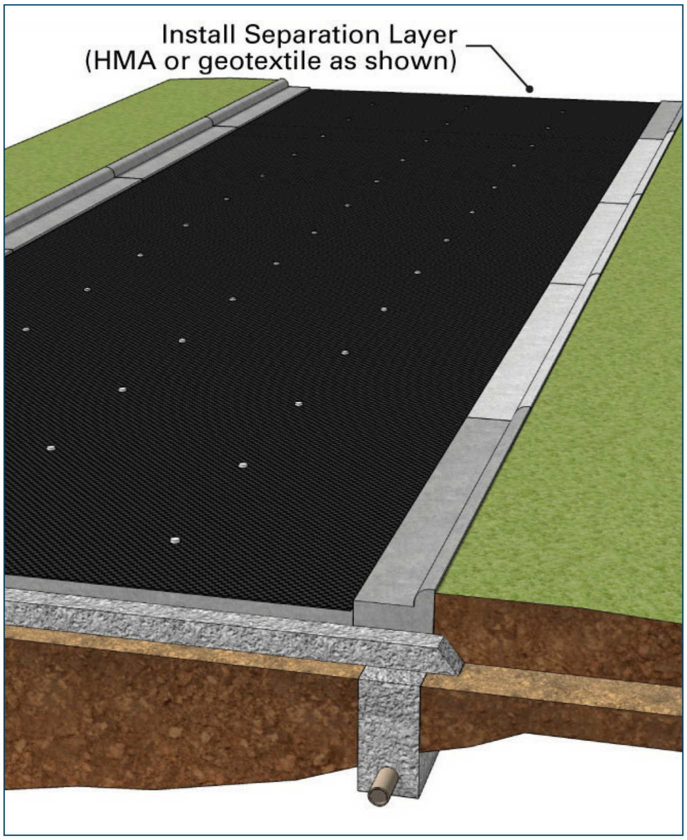


Figure 12. Place separation layer (geotextile fabric is shown) (Illustration courtesy of Snyder & Associates, Inc.)

- If geotextile fabric is used as a separation layer, heavy wrinkles and folds in the fabric should be eliminated before the overlay is placed.
- Make sure the separation layer is properly drained. Poor drainage can significantly shorten the life of the overlay. If an asphalt separation layer is used and the overlaid pavement system experiences heavy truck traffic, it is especially important to reduce the water pressure in the separation layer. If not properly drained, the asphalt layer can strip. Over time, the pavement will fail.

  Water pressure in a geotextile fabric separation layer can be reduced by draining the fabric into storm sewer inlets or into a subdrain if the curb is removed. See the discussion and photos on pages 11 and 12.
- The timing of joint sawing is critical for all thin concrete overlays.
- Joints should be saw-cut to the appropriate width and depth for a new concrete pavement.
- Expansion joints should be placed wherever they occur in the underlying pavement.
- The use of a separation layer eliminates the need to match or mismatch joints in the overlay to joints in the underlying pavement. However, in thin concrete overlays, shorter joint spacing minimizes curling and warping; therefore, transverse joint spacing should be based on overlay thickness. For overlays ≤ 6.0 in. thick, transverse joint spacing in feet should not exceed 1.5 times the thickness of the overlay in inches. For overlays > 6.0 in. thick, the transverse joint spacing in feet should not exceed 2.0 times the thickness of the overlay in inches and should not exceed 15 feet. Longitudinal joints should be sawed to provide nearly square slab dimensions where possible. See Figure 13.
- Attempt to keep joints out of wheel lanes, if possible.
- Curing should be timely and adequate, especially near the overlay edges, due to thin overlays' high surface-to-volume ratio and the risk of early-age cracks.

Comprehensive guidance pertaining to unbonded concrete overlays can be found in the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd Edition (Harrington and Fick 2014).

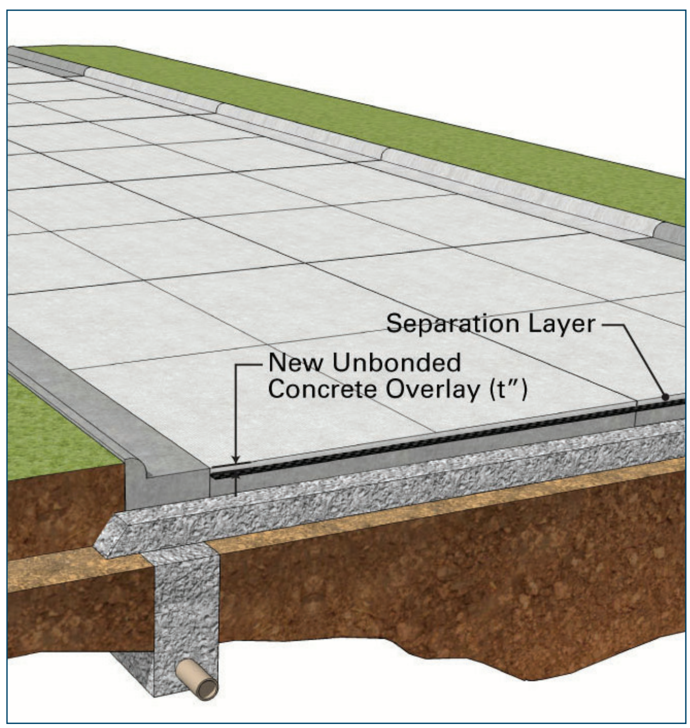


Figure 13. Joints should be cut so that slabs are nearly square in unbonded concrete overlays (Illustration courtesy of Snyder & Associates, Inc.)

3. Thin Concrete Overlay Performance Characteristics

Concrete overlays can address a host of pavement resurfacing requirements. In this guide, thin (≤ 5-in.) concrete overlays are discussed as a solution for pavements experiencing premature joint deterioration. It is important to note, however, that concrete overlays can also be used to improve pavement structural capacity and/or restore pavement function (especially smoothness, friction, noise, and albedo (reflectivity)).

When designing a concrete overlay, it is important to optimize the overlay's desired performance in three categories:

- Structural performance
- Functional performance
- Material performance

Following is a brief overview of concrete overlay performance characteristics in these three categories and the potential role of concrete overlays in improving the future performance of the overlaid pavement system.

3.1 Structural Performance

The first category of performance is structural. Strictly speaking, this is the ability of the overlay to resist excess joint degradation, slab cracking, and localized slab failures from loading. These distresses can possibly be affected by the underlying concrete pavement, but can also be mitigated accordingly.

Faulting of a concrete overlay is rare but can occur if certain construction practices are not followed carefully. For example, if the joints in bonded overlays are not sawed directly over, and at least as wide as, the joint cracks in the underlying concrete pavement, debonding and faulting can occur when the pavement system experiences expansion. See Figure 14.

Likewise, if the asphalt separation layer in an unbonded overlay system is not well drained, stripping of the layer can occur, leading to faulting.

3.1.1 Load Transfer (Bonded Overlays)

Joints will often be the first location of distress in any concrete overlay, particularly if the joints in the underlying pavement are in poor condition. Therefore, the condition of existing joints needs to be analyzed before placing an overlay.

If severe faulting exists (≥ ½ in.), a bonded overlay is a good solution only if the existing pavement can be milled (to prevent keying of the overlay) and if the overlay will provide adequate load transfer across the joints. If not, then a dowel bar retrofit may be a better solution.

Certain bonded overlay design choices can help reduce joint openings in the overlay and thus improve load transfer at the joints. For pavements subjected to heavy traffic that require a thicker (> 6 in.) overlay, improvements in load transfer can be made through the use of longitudinal tiebars at the centerline joint and shoulder joint (if shoulder is paved) or the use of fibers. As thickness of the overlay increases to ≥ 8 in., then dowels should be considered in the transverse joints.

A better choice to help with load transfer across joints in thin bonded overlays is the use of macro fibers in the mixture. In addition, the concrete mixture can be enhanced. For example, shrinkage stress can be minimized through reduced paste content, and temperature-related stress susceptibility can be reduced through use of a coarse aggregate with lower coefficient of thermal expansion. Larger aggregates can also be used to improve aggregate interlock at the joint.

Figure 14. Debonding due to mismatched joint widths (Photo courtesy of Jim Grove, FHWA)

3.1.2 Early-Age Cracking

Cracking is another common structural distress in concrete overlays. In some cases, cracking is directly attributable to conditions during construction that lead to excessive stresses in a young (and thus weak) concrete slab. Tools such as the FHWA HIPERPAV software (FHWA 2011) can help minimize this potential.

3.1.3 Structural and Fatigue Distresses

Cracking also develops because of fatigue stress caused by repetitive traffic loads, poor slab support, climate, and/or cumulative stress due to unfavorable combinations of these factors. To mitigate random cracking, the overlay design and construction activities should strive to reduce stresses and/or increase fatigue resistance in the concrete.

Areas of nonuniform support should be repaired through patching prior to constructing the overlay to prevent early-age cracking. Structural fibers may be used in the overlay to increase fatigue resistance.

If a high-strength mixture is used, care should be taken to mitigate potential undesirable characteristics such as increased shrinkage and brittleness, as well as potentially higher costs.

If a geotextile fabric is used as a separation layer in an unbonded overlay, it must be smooth and anchored firmly to the milled surface. Wrinkles in the fabric will lead to cracking of the overlay. See Figure 15.

Joint spalling and surface deterioration constitute other potential forms of structural distress in concrete overlays. See Figure 16.

While these distresses are aggravated by the abrasive action of tire wear and the expansive effect of freeze-thaw cycles, their primary cause is often linked to poor quality control during concrete overlay placement. Care must be taken to optimize mixture placement, jointing, and curing operations to minimize the development of these distresses.

3.2 Functional Performance

The second category of performance is functional performance. Until recently, specific functional performance requirements for pavements have been limited to smoothness and, indirectly, friction. On pavements experiencing joint deterioration, smoothness is commonly compromised due to the interaction of the vehicle with the deteriorated joints and/or patches.

Figure 15. Wrinkled geotextile fabric that resulted in overlay distress in Oak Park, IL (Photo courtesy of Randell Riley, IL chapter of ACPA)

Figure 16. Plastic shrinkage cracks caused by inadequate curing (Photo courtesy of John Cunningham, Iowa Concrete Paving Association)

Constructing a smooth concrete overlay is not difficult. Much guidance has been published in recent years on design and construction techniques that can lead to improvements in smoothness, most notably developed by the Federal Highway Administration (FHWA), National Concrete Pavement Technology Center (National CP Tech Center), American Concrete Pavement Association (ACPA), and various state departments of transportation (DOTs).

There will be some challenges, however, particularly in urban areas where driveways, inlets, and other features need to be matched, thus introducing deviations from an otherwise “smooth” surface.

Friction as a functional performance target is often not a design target per se. Instead, it is achieved through the proper selection of concrete materials (especially aggregates). The proper selection of the final surface texture on the concrete overlay will also affect friction.

More on better practices can be found in work recently published by the National CP Tech Center through the Concrete Pavement Surface Characteristics Program, *How to Reduce Tire Pavement Noise: Better Practices for Constructing and Texturing Concrete Pavement Surfaces* (Rasmussen et al. 2012) and by the American Association of State Highway and Transportation Officials (AASHTO) via its *Guide for Pavement Friction* (Hall et al. 2009).

Reduced tire-pavement noise is a relatively new functional performance requirement. It has gained much more attention in recent years, particularly in urban areas with speeds ≥ 45 mph. Fortunately, work at the National CP Tech Center, ACPA, International Grooving and Grinding Association (IGGA), and other organizations has resulted in surface textures that reduce noise and are still durable.

Other functional requirements can be realized from a new concrete overlay, including reflectance (a function of the concrete color), splash and spray (improved with adequate surface drainage capacity), and rolling resistance (optimized pavement texture that can improve fuel economy of the vehicles that travel that roadway).

3.3 Material Performance

The third kind of pavement performance is material. Designing and constructing a concrete overlay provides an opportunity to incorporate measures for improved material performance.

Proper selection of concrete constituents (aggregates, cementitious materials, and admixtures) can produce a concrete mixture that resists attack from both external and internal forces. For example, alkali-silica reaction (ASR) can be mitigated through proper aggregate selection, the use of supplementary cementitious materials (SCMs), and/or lithium-based admixtures.

D-cracking can be mitigated by proper selection (and possibly sizing) of coarse aggregates. Some states, particularly Kansas and Missouri, have demonstrated that overlays of D-cracked pavements are possible with proper measures to mitigate the propagation of this distress. These and other material-related distresses can be addressed as local experience dictates.

For more information, contact the Missouri-Kansas chapter of the ACPA, 913-381-2251, info@moksacpa.com.

4. Designing Thin Concrete Overlays to Meet Performance Requirements

Factors considered during thin concrete overlay design are thickness, drainage, joint design, fatigue resistance, and bond or, for unbonded overlays, separation layer.

4.1 Thickness

Concrete overlay performance requirements related to cracking and faulting can often be mitigated by proper thickness design. In general, thicker overlays experience less cracking and faulting than thinner overlays because they are more resistant to various stresses.

Concrete overlay thickness, however, is often limited by economics. Good overlay engineering includes cost considerations. Optimum thickness for a specific project is calculated based on the degree of risk that the overlay will achieve its specified design life, which is often quantified as “reliability.”

Other factors that affect thickness design include stiffness of the supporting layers, joint efficiency (load transfer), drainage, strength, and the design traffic (loading). Another factor, especially in urban settings, is restriction of grade at driveways, drainage inlets, and other features.

The most significant factor affecting design thickness, however, is the decision to design a *bonded* or *unbonded* overlay. See Table 1 on the following page.

With bonded overlays, the overlaid pavement system is monolithic and, therefore, some of the bending stresses are transferred to the underlying pavement. As a result, bonded overlays can be relatively thin.

Unbonded overlays, however, bend independently from the underlying pavement. Even though a thin unbonded overlay (as described in this document) can be the same thickness as the concrete removed by milling, the load-carrying structural capacity of the overlaid pavement system will be reduced. Grade restrictions in urban areas—due to driveways, drainage, inlets, and other features—limit the thickness of even unbonded overlays. Therefore, when designing an overlay for an urban area, it is critical to ensure that a relatively thin (≤ 5-in.) unbonded overlay can carry the expected traffic for the overlay design life. Note that retaining the pavement system’s pre-milling structural capacity requires constructing an unbonded overlay that is thicker than the layer removed and, thus, raising the grade.

Table 1. Typical Overlay Thickness Design and Software Parameters

	Overlay Type	Typical Design and Software Parameters							
		Traffic (Millions of ESALs)	Typical Concrete Slab Thickness	Maximum Joint Spacing (ft)	Range of Condition of Existing Pavement	Macro-fibers Option (in software)	Transverse Joint Dowel Bars	Mainline Longitudinal Tie Bars	Recommended Design Procedure
Bonded Overlays	**Bonded Concrete Overlay of Asphalt Pavement**	Up to 15	3–6 in.	1.5 times thickness (in.)	Fair to Good	Yes	No	No	1, 2, 8
Bonded Overlays	**Bonded Concrete Overlay of Concrete Pavement**	Up to 15	3–6 in.	Match existing cracks and joints and cut intermediate joints	Fair to Good	Yes	No	No	3, 4, 5
Bonded Overlays	**Bonded Concrete Overlay of Composite Pavement**	Up to 15	3–6 in.	1.5 times thickness (in.)	Fair to Good	Yes	No	No	1, 2, 8
Bonded Overlays	**Thin Fibrous Overlays of Asphalt Pavements**	Up to 15	2–3 in.	4–6 ft	Fair to Good	Yes	No	No	7
Unbonded Overlays	**Unbonded Concrete Overlay of Asphalt Pavement**	Up to 100	4–11 in.	Slab < 6 in.—use 1.5 times thickness (in.) Slab ≥ 6 in.—use 2.0 times thickness (in.) Slab > 7 in.—use 15 ft	Deteriorated to Fair	Yes	For slabs > 7 in.	T ≥ 6 in.—use agency standards	3, 4, 5
Unbonded Overlays	**Unbonded Concrete Overlay of Concrete Pavement**	Up to 100	4–11 in.	Slab < 5 in.—use 6 ft x 6 ft panels Slab 5–7 in.— use 2.0 times thickness (in.) Slab > 7 in.—use 15 ft	Deteriorated to Fair	Yes	For slabs > 7 in.	T ≥ 6 in.—use agency standards	3, 4, 5
Unbonded Overlays	**Unbonded Concrete Overlay of Composite Pavement**	Up to 100	4–11 in.	Slab < 6 in.—use 1.5 times thickness (in.) Slab ≥ 6 in.—use 2.0 times thickness (in.) Slab > 7 in.—use 15 ft	Deteriorated to Fair	Yes	For slabs > 7 in.	T ≥ 6 in.—use agency standards	3, 4, 5
Unbonded Overlays	**Unbonded Short-jointed Concrete Slabs**	Up to 100	> 3 in.	4–8 ft	Poor to Fair	Yes	For slabs > 7 in.	For ≥ 3.5 in. slabs at tied concrete shoulders or for T ≥ 6 in.—use agency standards	6

Recommended Design Procedures (see previous page for links)

1. *Bonded Concrete Overlay on Asphalt (BCOA) Thickness Designer* (ACPA 2012)
2. *BCOA ME* (Vandenbossche 2013)
3. *Guide for Design of Pavement Structures*. 4th ed. (AASHTO 1993)
4. *AASHTOWare Pavement ME Design* (no year)
5. *StreetPave* (ACPA 2012)
6. *Optipave V2.0.* (TCPavements 2010)
7. *Flowable Fibrous Concrete for Thin Pavement Inlays* (Bordelon and Roesler 2011) (see Appendix C)
8. Illinois DOT's spreadsheet for bonded concrete inlay/overlay of asphalt design (Roesler et al. 2008)

Over the years, concrete overlay design thickness procedures have been developed by a number of agencies: AASHTO, the National Cooperative Highway Research Program (NCHRP), the Portland Cement Association (PCA), ACPA, and various state DOTs. Each method addresses different types of concrete overlays and involves different inputs, software, strengths, and deficiencies.

To answer a call for simplicity from practicing engineers, the National CP Tech Center and FHWA have completed the *Guide to the Design of Concrete Overlays Using Existing Methodologies* (Torres 2012). This guide provides specific guidance about and examples of concrete overlay designs, with sample calculations and screen views. In addition, the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd edition (Harrington and Fick 2014), provides recommendations on design software programs for specific overlays.

4.2 Drainage

The presence of water within a pavement system will often accelerate the development of distress. Concrete overlays provide a unique opportunity to correct drainage deficiencies in a concrete pavement system.

Water can enter a pavement system from the top down or from the bottom up due to any of the following situations:

- Longitudinal joint trapping
- Tight, clay subgrade that does not drain
- Densely graded subbase that does not drain
- High water table capillary action
- No subdrains, or subdrains that are not working

All else being equal, improvements to pavement drainage can ultimately provide for longer pavement life. Such improvements have the additional benefit of facilitating the egress of water from the pavement system, which is often a key factor in mitigating joint deterioration with an overlay.

For example, a change in profile and/or cross-slope can be designed in the overlay so that water is more readily shed from the pavement surface. Joints in the overlay can be designed to resist excessive ingress of water. This can be done by constructing them with a narrow (single) saw cut and/or filling or sealing them appropriately.

Subdrainage can also be improved if measures are taken to retrofit edge drains.

For an unbonded overlay, either a nonwoven geotextile that meets certain transmissivity requirements (Harrington and Fick 2014) or an open-graded hot-mix asphalt (HMA) can be used as an impervious separation layer that promotes drainage. See section 4.6.

If an HMA separation layer is not designed and constructed properly, however, water may infiltrate and then become trapped in the HMA layer, resulting in stripping, or separation of the asphalt from the aggregate. If widespread, stripping of the HMA layer will eventually result in failure of the unbonded overlay. See Figure 17.

Curbs are common on urban pavements. If the curb is removed for construction of an unbonded overlay, the geotextile layer that separates the underlying concrete pavement from the overlay can be drained into an existing or retrofitted underdrain system. See Figure 18.

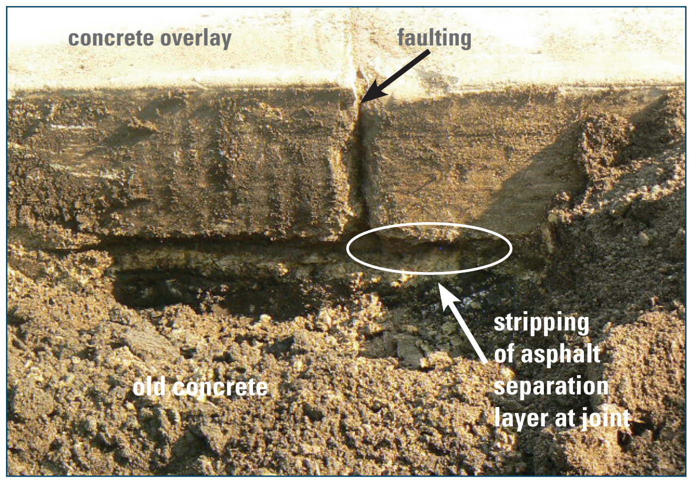


Figure 17. Stripping of asphalt separation layer (Photo courtesy of Dennis Gentz, City of Waterloo, IA)

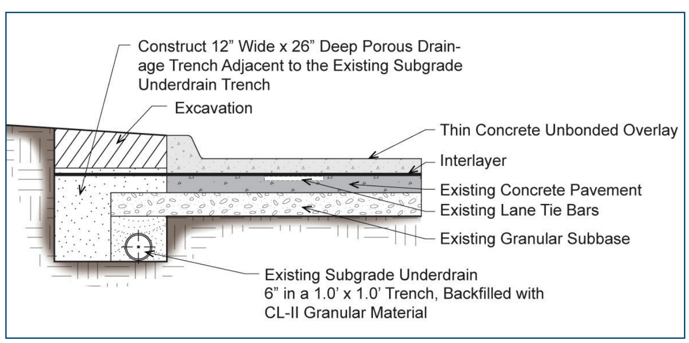


Figure 18. Drainage of separation layer (interlayer) into an existing underdrain system when existing curb is removed and replaced (Illustration courtesy of Snyder & Associates, Inc.)

If the curb is not removed, the geotextile separation layer will need to be tied into the wall of the intakes on the project. See Figure 19.

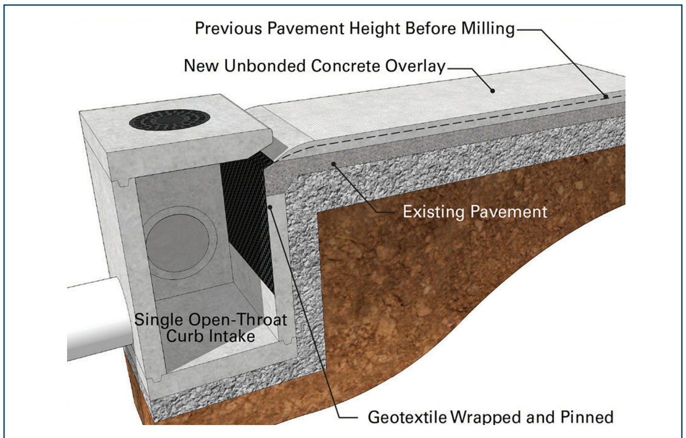


Figure 19. Drainage of separation layer fabric into intake when curb is not removed (Illustration courtesy of Snyder & Associates, Inc.)

4.3 Joint Design

Joint design is different for bonded and unbonded overlays.

4.3.1 Joint Design in Bonded Overlays on Concrete

Bonded overlay joint type, location, and width must match those of the existing concrete pavement in order to create a monolithic structure. Matched joints eliminate reflective cracking and ensure that the two layers of the pavement structure move together, helping to maintain the bond. To minimize curling and warping stresses in bonded overlays, some agencies have created smaller panels by sawing additional transverse and longitudinal joints between the matched joints.

An important factor in transverse joint design is joint dimensions. Joint depth should be full depth of the overlay plus ½ in. (13 mm) to cut through the bond line. For longitudinal joint depth, some agencies believe that T/2 is sufficient. Others recommend sawing longitudinal joints full depth plus ½ in. (13 mm) to cut through the bond line.

To prevent debonding, the width of the transverse joint should be equal to or greater than the width of the underlying crack beneath the matched joint in the existing pavement, which can be determined by spot-excavating along the pavement edge. See Figure 20.

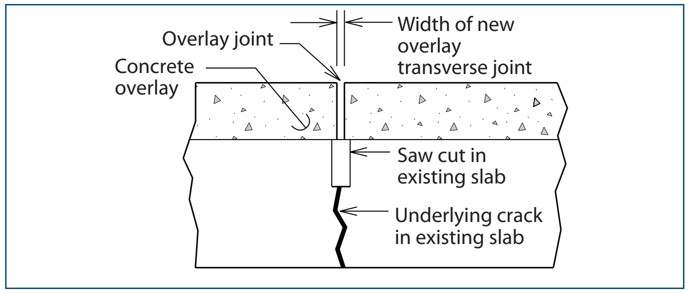


Figure 20. Joint width in bonded concrete overlays should be equal to or greater than the width of the crack in the underlying pavement

Note: If the pavement system experiences expansion and the overlay pushes against itself because the width of a transverse joint in the overlay is less than the width of the underlying existing pavement crack, debonding may occur.

Tiebars, dowel bars, or other embedded steel products are not normally used in thin (≤ 5 in.) bonded concrete overlays to minimize restraint forces in the bond.

4.3.2 Joint Design in Unbonded Overlays on Concrete

Load transfer is better in unbonded overlays of concrete pavements than in new jointed concrete pavements because of the load transfer provided by the underlying pavement and the unbonded overlay. However, shorter joint spacing (i.e., maximum 6 ft by 6 ft panels for overlays ≤ 5 in.) should be used to relieve overlay curling stresses that oppose the stiff support provided by the underlying pavement.

Some states intentionally mismatch joints in an unbonded overlay with joints in the existing pavement to maximize the benefits of load transfer. Many states, however, do not intentionally mismatch joints and have not experienced any adverse effects as long as there is no attempt to match joints.

Using longitudinal lane tiebars may be appropriate in unbonded overlays 5-in. thick or greater. When using tiebars for unbonded overlays, agency standards for full-depth pavements should be followed. Paved shoulders should be tied to the mainline with tiebars to allow load transfer to the shoulder. A sawed joint between a paved shoulder and the mainline is better for load transfer than a construction joint.

Doweled joints are used in unbonded overlays of pavements that will experience significant truck traffic, which are typically 7-in. thick or greater and are generally outside the scope of this manual.

Transverse joints can be sawed with conventional saws to a depth of between T/4 (minimum) and T/3 (maximum), but not less than 1¼ in. (31 mm). Transverse joint saw-cut depths for early-entry sawing should not be less than 1¼ in. (31 mm). Saw longitudinal joints to a depth of T/3.

4.4 Fatigue Resistance (Fibers)

To prevent the onset of many types of cracking, an increase of fatigue resistance in the concrete overlay can be designed. Fatigue resistance is a complex material property. An increase in concrete strength will increase fatigue resistance. However, there are other methods to achieve increased resistance. For example, the use of macro synthetic fibers in the concrete mixture is possible. The fibers can result in mixtures that are more ductile and thus commonly have improved fatigue resistance, in part because they develop lower stresses under the same traffic.

In general, the use of fiber reinforcement should be considered in thin concrete overlays (≤ 4 in). In situations where vertical restrictions limit overlay thickness, heavier traffic loads are expected, increased joint spacing is desirable, or conventional dowels cannot be used, the use of fibers may be warranted. In appropriate dosages, fibers can perform the following functions in a concrete mixture:

- Help increase concrete toughness (allowing thinner concrete slabs and/or longer joint spacing)
- Help control differential slab movement caused by curling/warping, heavy loads, temperatures, etc. (allowing longer joint spacing)
- Increase concrete's resistance to plastic shrinkage cracking (enhancing aesthetics and concrete performance)
- Hold cracks tightly together (enhancing aesthetics and concrete performance).

Although steel fibers have a long, successful history in paving applications, in the last two decades macro synthetic fibers have become predominant due to their ease of handling, better dispersion characteristics (i.e., less "balling"), and resistance to rust damage. Table 2 provides a summary of current categories of fibers, with general descriptions and application rates.

The volume of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed volume fraction (vf). Vf typically ranges from 0.1 to 3.0 percent. Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio.

Starting with a minimum dosage of macro synthetic fibers at 3 to 4 lb/yd^3 has worked well. For a typical concrete mix, this is about 0.26 percent volume. For comparison, the same volume of steel fibers would weigh about 34 lb/yd^3 but yield somewhat different characteristics in the concrete.

Various blends of fiber that combine steel and synthetic fibers are being introduced, and higher modulus synthetics are being developed. Fiber producers and suppliers can be of assistance since the technology is undergoing a rapid evolution.

The Illinois DOT's approved list of synthetic fibers is a good reference for minimum recommended dosages for a specific class of fiber; the list can be found at www.dot.state.il.us/materials/synthetic fibers.pdf.

Table 2. Summary of Fiber Types

Fiber Type	Size (D = dia.) (L = length)	Yrs Used in U.S.	Typical Rate (lb/yd^3)	Comments
Micro Synthetic	D < 0.012 in. (0.3 mm) L 0.50 to 2.25 in.	35	1.0 to 3.0	Reduces plastic shrinkage cracking and settlement cracking; limited effect on concrete overlay overall performance; more workability issues when using higher rates
Macro Synthetic	D > 0.012 in. (0.3 mm) L 1.50 to 2.25 in.	15	3.0 to 7.5	Increases post-crack flexural performance, fatigue-impact endurance; thinner concrete thickness; longer joint spacing; tighter joints, cracks; better handling properties, dispersion characteristics than steel fibers; not subject to corrosion
Macro Steel (carbon)	L 0.75 to 2.50 in.	40	33 to 100	Increases strain strength, impact resistance, post-crack flexural performance, fatigue endurance, crack width control, per ACI 544.4R (however, steel fibers are considerably heavier than synthetic fibers and can tend to settle to the bottom of the overlay)
Blended		15	Varies	Blend of small dosage of micro synthetic fibers and larger dosage of either macro synthetic fibers or macro steel fibers

Synthetic (polymer) fiber materials:
- Polypropylene
  - » Monofilament (cylindrical) – Fibers of same length
  - » Multifilament – Monofilament fibers of different lengths
  - » Fibrillated (rectangular) - Net-shaped fiber collated in interconnected clips
- Polyester
- Nylon

4.5 Bond (*Bonded* Overlays Only)

As implied in their name, bonded overlays are designed and constructed to bond to the underlying pavement. The bond will rarely be perfect, and current design procedures do not specifically address bond strength. However, a predetermined degree of bond is assumed for each overlay project design.

Achieving adequate bond strength is primarily a function of good construction practices, which are discussed in section 5. It is normally accepted that proper bond strength is achieved at opening strength of the overlay. Specific techniques can be found in the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd Edition (Harrington and Fick 2014).

If adequate bonding is not achieved or is prematurely lost due to material degradation, climate, or other factors, areas of distress will likely develop prematurely in the overlay. Furthermore, if portions of the underlying pavement in poor condition (e.g., deteriorated working joints) are not milled off and/or repaired, it is likely that those distresses will reflect through the bonded overlay and increase the likelihood of debonding. Mitigating this problem can be accomplished by milling the surface, removing the majority of joint deterioration and other distresses, and performing preoverly repairs.

4.6 Separation Layer (*Unbonded* Overlays Only)

An unbonded overlay is less susceptible to the condition of the underlying pavement, which can be particularly advantageous when the existing pavement is experiencing severe joint deterioration or other distresses.

To achieve the intended overlay performance, however, the design must include measures to ensure that the overlay does not bond to the existing pavement. This is generally accomplished by specifying an appropriate separation layer (sometimes referred to as an interlayer) between the existing pavement and the overlay.

The separation layer must balance at least three key properties:

- **Separation**. To prevent discontinuities (especially deteriorated cracks or joints) in the underlying pavement from reflecting through the overlay, the separation material must be thick enough to accommodate anticipated movements in the existing pavement.
- **Bedding**. To reduce bearing stresses and the effects of dynamic traffic loads, and ultimately prevent points of contact between the overlay and the underlying concrete, the separation material must be adequately thick and/or flexible.
- **Drainage**. The separation layer must either be impervious so that it prevents water from penetrating below the overlay, or it must channel infiltrating water along the cross-slope to the pavement edge. See section 4.2 on drainage design.

Common materials for separation layers are geotextile fabric, open-graded asphalt, and densely graded HMA.

4.6.1 HMA Separation Layer

An HMA separation layer should be 1- to 1½-in. thick. Scouring (stripping) of an asphalt separation layer may occur if the unbonded concrete overlay is poorly drained and experiences heavy truck traffic. To reduce scour pore pressure and increase stability, some states modify the asphalt mixture to make it more porous. In particular, the sand content is reduced and the volume of 0.38-in. (10-mm) chip aggregate is increased. This modified mixture has a lower unit weight and lower asphalt content and is comparable in cost to typical surface mixtures.

The Michigan DOT has designed an asphalt mixture with modified aggregate gradations to address stripping of separation layers. See Table 3.

Table 3. Modified Aggregate Gradations to Address HMA Stripping

Sieve Size	Percent Passing
½ in.	100
⅜ in.	85–100
No. 4	22–38
No. 8	19–32
No. 16	15–24
No. 30	11–18
No. 50	8–14
No. 100	5–10
No. 200	4–7

4.6.2 Nonwoven Geotextile Fabric Separation Layer

An alternative to an asphalt separation layer is a layer of nonwoven geotextile fabric.

According to Leykauf and Birmann (2006) of Munich University of Technology, geotextile fabrics provide uniform, elastic support for the concrete overlay and reduce stresses due to temperature and moisture gradients. Such fabrics also reduce pumping processes and prevent origination of reflected cracks from bonded base courses. However, the structural condition of the existing concrete pavement must be carefully assessed before selecting a geotextile instead of an asphalt separation layer.

Material specifications for geotextile fabric used as a separation layer for unbonded overlays are shown in Table 4.

According to German design practices and expertise, it is recommended that the concrete overlay design thickness calculated using the 1993 AASHTO Guide be increased by ½ in. when a nonwoven geotextile interlayer is used in lieu of asphalt. However, there is no accepted design proof that this is ncessary. Additional information about fabric separation layers can be found in sections 4.2 (drainage) and 5.5 (construction).

5. Construction of Thin Concrete Overlays to Meet Performance Requirements

Before constructing a thin concrete overlay, address any drainage issues. Then the key considerations for constructing thin concrete overlays, emphasizing issues related to urban projects, are as follow:

- Developing an optimum concrete mixture
- Milling the existing pavement to meet any profile requirements
- Conducting preoverlay repairs
- Treating existing structures
- Placing the overlay
- Curing
- Joint sawing

5.1 Concrete Mixture

This discussion is applicable to both bonded and unbonded overlays. Features that are listed as mixture constraints in urban areas are covered by the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and*

Table 4. Geotextile Separation Layer Material Properties (adapted from www.concreteontop) (The Transtec Group 2010)

Property	Requirements	Test Procedure
Geotextile Type	Nonwoven, needle-punched, no thermal treatment to include calendaring†	EN 13249, Annex F (Certification)
Color	Uniform/nominally same color fibers	(Visual Inspection)
Mass per unit area	≥ 450 g/m² (13.3 oz/yd²)* ≥ 500 g/m² (14.7 oz/yd²) ≤ 550 g/m² (16.2 oz/yd²)	ISO 9864 (ASTM D 5261)
Thickness under load (pressure)	[a] At 2 kPa (0.29 psi): ≥ 3.0 mm (0.12 in.) [b] At 20 kPa (2.9 psi): ≥ 2.5 mm (0.10 in.) [c] At 200 kPa (29 psi): ≥ 0.10 mm (0.04 in.)	ISO 9863-1 (ASTM D 5199)
Wide-width tensile strength	≥ 10 kN/m (685 lb/ft)	ISO 10319 (ASTM D 4595)
Wide-width maximum elongation	≤ 130 percent	ISO 10319 (ASTM D 4595)
Water permeability in normal direction under load (pressure)	≥ 1 x 10^{-4} m/s (3.3 x 10^{-4} ft/s) at 20 kPa (2.9 psi)	DIN 60500-4 (modified ASTM D 5493)
In-plane water permeability (transmissivity) under load (pressure)	[a] ≥ 5 x 10^{-4} m/s (1.6 x 10^{-3} ft/s) at 20 kPa (2.9 psi) [b] ≥ 2 x 10^{-4} m/s (6.6 x 10^{-4} ft/s) at 200 kPa (2.9 psi)	ISO 12958 (ASTM D 6574)* or ISO 12958 (modified ASTM D 4716)
Weather resistance	Retained strength ≥ 60 percent	EN 12224 (ASTM D 4355 @ 500 hrs exposure for grey, white, or black material only)
Alkali resistance	≥ 96 percent polyproplene/polyethylene	EN 13249, Annex B (Certification)

*Added to Material Specifications (The Transtec Group [no date]) for overlays

†Calendering is a process that passes the geotextile through one or more heated rollers during the manufacturing process. The surface of the geotextile is modified during this process. Calendering may reduce the absorption properties of the geotextile on the calendered side.

Rehabilitating Existing Pavements, 3rd Edition (Harrington and Fick 2014); some mixture constraints continue to be studied.

In general, conventional concrete paving mixtures are typically used for concrete overlays. Each of the components should be carefully selected so that the mixture is dense, relatively impermeable, and resistant to both environmental effects and deleterious chemical reactions. Today's deicing practices, for example, appear to be increasing the degree of saturation of concrete at the joints; thus, the concrete must be of high quality to be able to resist this environment.

Desirable concrete characteristics are best accomplished through the use of SCMs and water-reducing admixtures to control the water-to-cementitious materials (w/cm) ratio.

Some mixture considerations are especially specific to thin concrete overlays:

- The nominal maximum coarse aggregate size should be no greater than one third of the overlay thickness.
- The aggregate system must be well graded.
- Higher strength mixtures may be required, especially in the case of thin unbonded overlays. However, other properties such as shrinkage and permeability should not be compromised in the pursuit of strength.
- Design strength should be accomplished by optimizing the use of portland cement, SCMs, and admixtures to achieve a high-strength mixture that is durable.
- Concrete temperature at placement must be well controlled.
- A w/cm ratio of 0.40 to 0.42 is recommended to decrease permeability.
- With the high surface-to-volume ratio of thin overlays, thorough and timely curing is critical for overlay success.
- The use of high-modulus structural fibers can improve fatigue resistance, toughness, and post-cracking behavior of the concrete and help control plastic shrinkage cracking.

As an example, the concrete mixture specifications for a thin unbonded overlay project constructed in 2011 in Michigan are summarized below:

- Flexural strength of 550 psi at 7 days
- Minimum air content of 6 percent
- Total cementitious materials content between 470 lb/yd^3 and 564 lb/yd^3
- Fly ash substitution up to 25 percent of the cementitious material
- Slag cement up to 40 percent of the cementitious material
- Ternary mixtures allowed with up to 40 percent cement replacement with SCM
- "Shilstone" optimized gradation

5.2 Milling Existing Pavement

In many cases, raising the profile grade with a concrete overlay would result in adjustments to all of the existing features; often this proves to be cost prohibitive. A solution that maintains the existing gutter/curb elevation is preferable.

This can be accomplished by milling the existing pavement to a depth equal to the thickness of the new thin (≤ 5-in.) concrete overlay, allowing for the construction of a concrete overlay that returns the pavement to its original elevation. See Figure 21.

Figure 21. Milling existing concrete in preparation for an unbonded overlay (Photo courtesy of Randell Riley, IL chapter of ACPA)

While milling an existing pavement to this depth may seem unconventional, it has been done successfully in Iowa, Michigan, Illinois, and Texas. This approach also has the advantage of removing much of the distressed concrete. (Note: The existing pavement may be concrete, or it may be concrete overlaid with asphalt, which is called a composite pavement. In the case of a composite pavement, this document assumes that all asphalt will be removed by milling.)

When an unbonded overlay is constructed and the curb is not going to be removed, the existing pavement should be milled to a depth equal to the thickness of the new concrete overlay plus the thickness of the separation layer. See Figures 22 and 23.

Figure 22. Milled concrete pavement (Photo courtesy of Randell Riley, IL chapter of ACPA)

Figure 23. Milled concrete pavement (Photo courtesy of Dan DeGraaf, Michigan Concrete Association)

If a geotextile separation layer is used, the milled surface should be free from ridges that could either puncture the geotextile fabric or cause the unbonded overlay to "key-in" to the underlying pavement, resulting in restraint, which can cause cracking. Over-milling can result in exposing tiebars or dowel bars and should be avoided. See Figure 24.

Figure 24. Close-up of the milled surface showing where tiebars were located (Photo courtesy of Randell Riley, IL chapter of ACPA)

The following instructions are copied from a Michigan DOT special provision and are appropriate for milling concrete for unbonded overlays using a geotextile separation layer:

> The cold milling machine must consistently remove the concrete surface, in one or more passes, to the required grade and cross-section producing a uniformly textured surface. The cold milling machine must be equipped with all of the following:
>
> – An automatically controlled and activated cutting drum
>
> – Grade and depth reference and transverse slope control capabilities
>
> – An approved grade referencing attachment not less than 30 ft in length
>
> An alternate grade referencing attachment may be used if approved by the Engineer prior to use. The Contractor shall be solely responsible for controlling and monitoring the depth of all concrete cold milling to ensure that a uniform (insert thickness) inch depth is removed across the entire width and total length of the existing pavement structure.
>
> The absolute maximum "ridge height" of the milled concrete surface shall not exceed one-quarter inch (¼ in.) at any point across the entire width and total length of the existing pavement structure.
>
> If repeated passes of the cold milling equipment are required to achieve this mandatory requirement, the work shall be included in the "one-time" original measurement and payment per square yard for Cold Milling Concrete Pavement.

In summary, milling the existing pavement accomplishes three key objectives:

- The majority of the deteriorated pavement is removed down to a sound pavement structure.
- Curb and gutter profiles are maintained, which eliminates costly adjustments to adjoining and adjacent roadway features.

- For bonded overlay applications, isolated areas of severe joint deterioration can be identified and repaired with either partial- or full-depth patching techniques.

After milling the existing pavement, the type and extent of necessary repairs and surface preparation are different for bonded and unbonded overlays.

5.3 Preoverlay Repairs and Surface Preparation for *Bonded* Overlays

Preoverlay repairs of certain distresses may be necessary to restore the pavement to good condition, prevent distresses from reflecting up through the overlay, and achieve the desired load-carrying capacity and long-term durability.

After milling, the pavement surface should be inspected for remaining isolated pockets of deterioration that require repairs. Any movement in the underlying pavement that does not occur at matched joints can contribute to debonding and subsequent deterioration of the overlay.

Any random cracks in the existing pavement that are open more than ⅛ in. should be filled with a hot poured joint sealant. This will prevent grout intrusion and potential locking of the crack.

Asphalt patches should be removed and replaced with concrete patches (or simply filled with concrete at the time of overlay placement) to ensure bonding of the concrete layers.

Localized joint deterioration should be repaired by either partial-depth patches (if the deterioriation is in the upper half of the slab) or full-depth patching (if the deterioration extends into the bottom half of the slab) to complete the restoration of the existing pavement to good condition. See Figures 25 and 26. The details of partial-depth repairs can be found in *Guide for Partial-Depth Repair of Concrete Pavements* (Frentress and Harrington 2012). The details of full-depth repairs can be found in the *Concrete Pavement Preservation Guide*, 2nd edition (Smith et al. 2014).

Shot-blasting the existing concrete pavement surface is the most common method for roughening the surface to enhance bonding. If milling is used to lower the pavement elevation, any resulting micro-cracking should be removed by shot-blasting.

Figure 25. Milled joint for repair prior to placing bonded overlay (Photo courtesy of Kevin McMullen, Wisconsin Concrete Pavement Association)

Figure 26. Full-depth repair prior to placing bonded overlay (Photo courtesy of Kevin McMullen, Wisconsin Concrete Pavement Association)

The concrete surface should be cleaned to ensure adequate bonding between the existing concrete surface and the new concrete overlay. Cleaning may be accomplished by sweeping the concrete surface, followed by cleaning in front of the paver with compressed air. Water-blasting should be used only as a supplementary cleaning procedure to remove loose material from the surface after shot-blasting, milling, or sand-blasting joints. In no case should standing water or moisture remain on the pavement surface when the overlay is placed.

Paving should commence soon after cleaning to minimize the chance of contamination.

Vehicles should be limited on the existing surface after it is prepared. If it is absolutely necessary to have vehicles on the existing concrete, care should be taken that they do not drip oil or other contaminants that could compromise the bond.

5.4 Preoverlay Repairs and Separation Layer for *Unbonded* Overlays

Preoverlay repairs for unbonded overlays are normally not required unless a major loss of structural integrity exists. If even significantly distressed areas are not shifting or moving and the subgrade/subbase is stable, costly repairs are typically not needed, particularly with an adequately designed unbonded overlay.

Any areas of deteriorated joints or cracks that remain after milling should be cleaned. Any loose concrete must be removed and the joint or crack thoroughly sand- and air-blasted. Level any areas of joint deterioration with flowable mortar or grout. If the deterioration extends into the bottom half of the slab, some states fill the area with regular concrete mixture instead of mortar. See Figure 27. Jointing is not necessary because of the separation layer.

Figure 27. Full-depth distress filled with concrete mixture

After milling the existing pavement, the surface should be swept clean of loose material with either a mechanical sweeper or an air blower. Then conventional placement practices and procedures should be followed for placing the separation layer.

Both pervious separation layers (nonwoven geotextile fabric or open-graded asphalt) and impervious separation layers (densely graded HMA) must drain at the pavement edges or risk trapping water, which can be very damaging.

In general, the following construction practices have resulted in successful installations of geotextile separation layers:

- Place the fabric as soon as possible before paving (ideally no longer than 2 to 3 days) to reduce the potential for it to be damaged.
- Roll the material onto the existing pavement in sections that are no longer than the next intersecting street or 650 ft, whichever is shorter, keeping the nonwoven geotextile tight with no wrinkles or folds.
- Roll out sections of the fabric in a sequence that will facilitate good overlapping, prevent folding or tearing by construction traffic, and minimize the potential that the material will be disturbed by the paver.
- Overlap sections of the geotextile fabric a minimum of 6 in. and a maximum of 10 in., and ensure that no more than three layers overlap at any point. See Figure 28.

Figure 28. Overlap of nonwoven geotextile material sections

- Ensure that the edge of the material along drainage areas extends at least 4 in. beyond the pavement edge, terminating above, within, or adjacent to the drainage system.
- Secure the fabric with pins (nails) punched through 2.0-in. to 2.75-in. galvanized discs placed 6 ft apart or less, depending on conditions. See Figure 29. Some agencies have used asphalt tack rather than galvanized discs. No research has been completed on this method, however.

Figure 29. Fastening nonwoven geotextile fabric to existing concrete pavement

- Lightly dampen the geotextile fabric prior to concrete placement to prevent its drawing water from the mix. The fabric should be no more than "saturated surface dry." A simple test is to press on the fabric with a finger; the finger should be moist, but no free water should show.
- If concrete is being delivered in front of the paver, place no more than 650 ft of nonwoven geotextile material ahead of the paver at any time. See Figure 30.
- So as not to create wrinkles in the fabric, avoid unnecessary driving on the material during construction. If it is unavoidable (for example, to deliver concrete), brake slowly and never make sharp turns.

Figure 30. Geotextile fabric can be placed up to 650 ft ahead of the paver

5.5 Existing Features

Several pavement features that often exist in urban environments may dictate that the existing profile grade at the pavement edges be maintained when rehabilitating an existing pavement. See Figure 31.

Such features may include the following:

- Curb and gutter
- Storm sewer inlets and manholes
- Sewer manholes
- Sidewalks and driveways
- Sidewalks that comply with the Americans with Disabilities Act (ADA)
- Utilities
- Traffic signal loops

Figure 31. Examples of urban constraints: manhole, inlet, curb, sidewalk, and driveway (Photo courtesy of Kevin McMullen, Wisconsin Concrete Pavement Association)

5.5.1 Optional Curb Treatments

There are four options available for dealing with the existing curb:

- Leave the existing curb in place
- Remove the curb
- Remove the curb and gutter
- Overlay the curb

Project conditions should be reviewed to determine which of these options is appropriate.

5.5.1.1 Leaving the Existing Curb in Place

To leave the existing curb in place, the milling operation stops at the base of the curb, allowing for the thickness of the concrete overlay. See Figure 32.

There is a cost savings associated with leaving the existing curb in place, since driveways, sidewalks, and utility fixtures do not require raising. However, the condition of the curb should be evaluated and, if the concrete is showing signs of deterioration, it should be removed and replaced.

Also, when utility poles and other obstructions are in close proximity to the back of the existing curb, leaving the curb in place may limit the use of conventional slipform paving equipment.

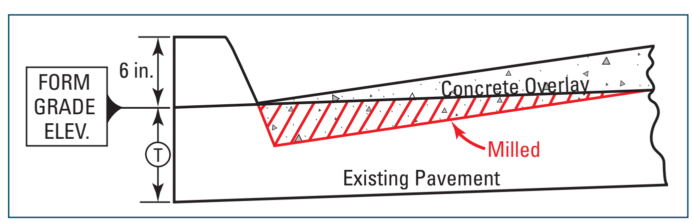


Figure 32. Milling detail when leaving the existing curb in place (Illustration courtesy of Snyder & Associates, Inc.)

5.5.1.2 Removing the Curb

The existing curb can be removed by sawing (see Figure 33) or by milling (see Figure 34).

This option allows for construction of the concrete overlay and curb integrally. Removing the curb does not alleviate potential interference from obstructions that are in close proximity to the back of curb.

Figure 33. Removing existing curb by sawing (Photo courtesy of Dan Frentress, Frentress Enterprises, LLC)

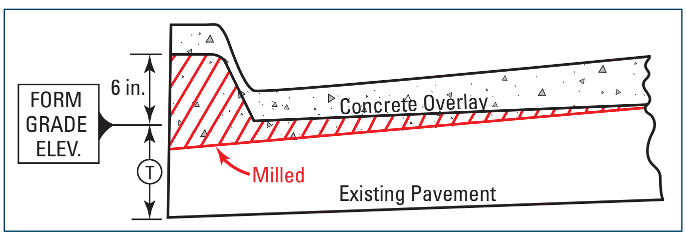


Figure 34. Milling detail when removing and replacing curb (Illustration courtesy of Snyder & Associates, Inc.)

5.5.1.3 Removing Curb and Gutter

When obstructions behind the curb prohibit the use of conventional slipform paving equipment, it may be advantageous to completely remove the curb and a portion of the gutter to allow placement of the concrete overlay a few inches higher than the existing curb. See Figure 35.

This full-depth section of curb and gutter could be milled. However, when there are obstructions behind the curb, a full-depth saw cut and traditional excavation methods are preferable to minimize disturbance of materials on the edges of the roadway. In this case, a new curb and gutter section can then be constructed after the overlay has been placed, using a curb paving machine.

Figure 35. Removing existing curb and gutter by milling (Photo courtesy of Dan Frentress, Frentress Enterprises, LLC)

5.5.1.4 Overlay Curb

It is possible to place a concrete overlay that encases the existing curb. See Figures 36 and 37.

It should be noted, though, that this option raises the profile grade of the existing curb and may require adjustment of adjoining and adjacent roadway features.

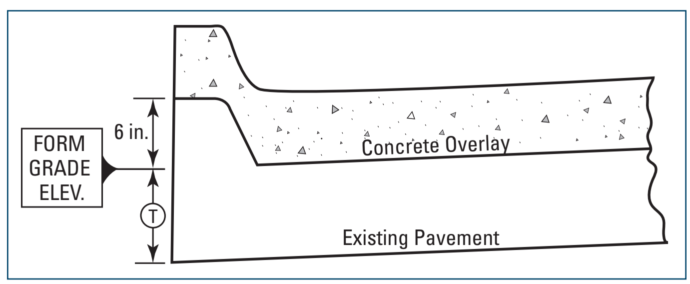


Figure 36. Detail of curb overlay (Illustration courtesy of Snyder & Associates, Inc.)

Figure 37. Concrete curb overlay (Photo courtesy of Ron Youngman, CO/WY chapter of ACPA)

5.5.2 Treatments for Manholes, Inlets, and Other In-Pavement Structures

When constructing a thin concrete overlay, the treatment of these structures is similar to their treatment when constructing a new pavement. The difference is that the existing structure is removed below the elevation of the overlay and then adjusted to the final overlay elevation.

Manholes can be fitted with telescoping rings which do not require a boxout for slipform paving. See Figures 38 and 39. Inlets and other structures typically require a boxout.

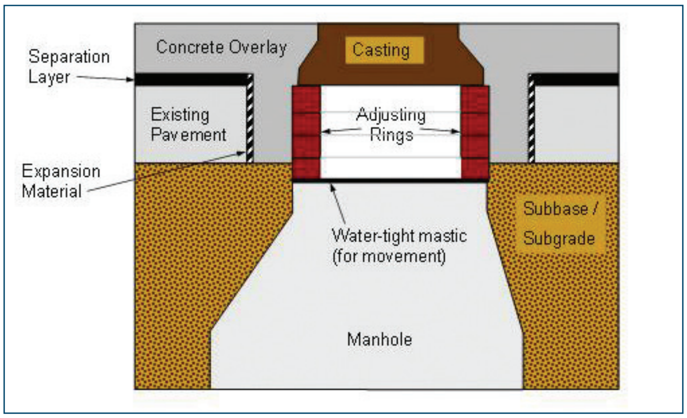


Figure 38. Detail of a manhole in an unbonded concrete overlay (Illustration courtesy of Snyder & Associates, Inc.)

Figure 39. Manhole removal (Photo courtesy of Dan DeGraaf, Michigan Concrete Association)

5.6 Concrete Placement

Conventional concrete paving procedures are followed for placing, spreading, consolidating, and finishing overlays. Minor grade adjustments may be made to ensure the required thickness of the concrete overlay.

When the surface temperature of a separation layer or the existing pavement is at or above 120°F (49°C), it should be sprinkled with water to reduce its temperature and minimize the chance of early-age shrinkage cracking. No standing water should remain on the surface at the time of overlay placement.

5.7 Curing

Good curing practices are especially critical for thin concrete overlays because of their high surface-area-to-volume ratio, which makes the thin concrete overlay more susceptible to rapid moisture loss. This is accomplished by applying a curing compound immediately after surface texturing. The finished product should appear as a uniformly painted solid white surface, with the vertical faces along the edges of the overlay also thoroughly coated.

5.8 Joint Sawing (*Bonded* Overlays)

Because the surface-area-to-volume ratio is higher for most bonded overlays, early random cracking can occur. Therefore, sawing should begin as soon as the concrete is strong enough that joints can be cut without significant raveling or chipping. Care must be taken to saw transverse joints full depth and at a width equal to or greater than the width of the existing crack in the underlying concrete joint.

Joints must be matched with those of the pavement below. To help match transverse joint locations, place guide nails on each edge of the existing pavement at the joints; after the overlay is placed, mark the joint with a chalk line connecting the guide nails. The width of transverse joints should be equal to or greater than the width of the associated cracks beneath the underlying joint. Saw transverse joints full depth plus ½ in., cutting through the bond line. (Refer back to Figure 20.) Longitudinal joints must be sawed to a depth of at least T/2.

If smaller panels are designed to reduce curling and warping stresses, saw additional transverse and longitudinal joints between matched joints.

5.9 Joint Sawing (*Unbonded* Overlays)

Timely joint sawing is necessary to prevent random cracking in front of the saw. Transverse joints can be sawed with conventional saws to a depth of between T/4 (minimum) and T/3 (maximum), but not less than 1¼ in. (31 mm). Transverse joint saw-cut depths for early-entry sawing should not be less than 1¼ in. (31 mm). Saw longitudinal joints to a depth of T/3.

6. Concrete Overlay Costs

In 2010, six state DOTs provided bid tabs for 33 concrete overlay projects. An analysis of the sampled bid tabs revealed that the average cost for concrete overlays is \$2.99 per square yard per inch of thickness, with bonded overlays = \$3.32/yd^2/in. and unbonded overlays = \$2.94/yd^2/in. This \$0.38 per square yard per inch difference in costs between bonded and unbonded overlay is negligible when compared to the total variability of the cost data set.

The average costs included furnishing concrete, placing the concrete overlay, dowels, tiebars, curing, sawing joints, and sealing joints. Because of the variation of the concrete thickness, the concrete material is bid on a volume (cubic-yard) basis. Some states include a bid item for placement, measured on a square-yard basis.

Items that are not included in the average costs are milling, pre-overlay repairs, and the separation layer for unbonded overlays. Surface milling costs vary depending on the aggregate type in the concrete, type of milling machine used, and width and depth of milling. A typical cost for a 4-in. milling depth of concrete with limestone aggregate is approximately \$3.00/yd^2. If milling is used for joints or curbs, the costs are typically as follows:

- Curbs \$8.00/lineal ft
- Transverse joints \$1.50/ft^2
- Longitudinal joints \$1.25/ft^2

If partial-depth repairs are required, the costs can vary greatly depending on the number of patches, typically \$25/ft^2 to \$30/ft^2 and higher for small quantities or \$55/ft^2 for nighttime work.

7. Lessons Learned from Case Studies

There is a robust performance history for both bonded and unbonded thin concrete overlays with a thickness of 5 in. or less. See Table 5. Case histories for the first four projects listed in Table 5 are provided on the following pages to demonstrate the potential for resurfacing pavements with joint deterioration or other distresses through the use of thin concrete overlays (unbonded and bonded).

Table 5. Examples of Thin Overlay Projects in the United States

Project	Type of Concrete Overlay	State	Year Constructed	Overlay Thickness
St. Clair Shores, MI; Little Mack Avenue (1)	Unbonded on concrete	MI	2011	4.0
Plano, TX; Alma Drive (1)	Unbonded on concrete	TX	2008	2.5–4.5
Harrisburg, PA; I-83 ramp (1)	Unbonded on concrete	PA	1995	3.5
Northwood, IA; Central Avenue (2)	Bonded on concrete	IA	2002	2.0
Chicago, IL; Western Avenue (various bus pads) (3)	Unbonded on concrete	IL	2003	4.0
Indianola, IA; City square (3)	Bonded on concrete	IA	1980	2.0
Shawnee, KS; Rehabilitation of I-435, Midland Drive to Holiday Drive (3)	Bonded on concrete	KS	1989	2.0
Richmond, VA: I-293 (3)	Bonded on concrete	VA	1995	2.0
Rock Falls, IL; I-88 westbound lane, east of Whiteside County line (3)	Bonded on concrete	IL	1996	3.0
Decatur, IL; U.S. 36, Country Club Road (3)	Bonded on concrete	IL	1998	3.0
Still, KS; U.S. 69 in northern 4 miles of Miami County	Bonded on concrete	KS	1999	3.0
Iola, KS; US 54 between Iola and La Harpe (3)	Bonded on concrete	KS	2000	2.8
Lawton, OK; I-44 (3)	Bonded on concrete	OK	2002	3.0
Numerous projects located in 23 states (4)	Bonded on concrete	23 states	1913–1990	1.0–4.0
Numerous projects located in 12 states (4)	Unbonded on concrete	12 states	1916–1992	3.0–4.0

Sources: (1) The Transtec Group, Inc.; (2) Iowa DOT; (3) American Concrete Pavement Association; (4) NCHRP Synthesis 204, Portland Cement Concrete Resurfacing

7.1 Thin Unbonded Concrete Overlay, St. Clair Shores, MI

A two-mile section of Little Mack Avenue in St. Clair Shores, Michigan, was rehabilitated in 2011 with a 4-in. unbonded overlay. This project successfully demonstrated many of the concepts for successful thin unbonded overlays. Little Mack Avenue is a five-lane urban arterial roadway. Originally constructed in 1995 at a cost of approximately $4 million per mile, the typical section consisted of a 9-in. thick jointed concrete pavement over a 6-in. thick aggregate subbase. Distress at the joints was observed within five years of construction. See Figure 40.

Figure 40. Five years after construction, early joint deterioration of Little Mack Avenue in St. Clair Shores, MI (Photo courtesy of Anderson, Eckstein and Westrick, Inc.)

After only 10 years (2005), joint deterioration was widespread and had progressed to the point that extensive partial-depth patches were required. See Figure 41.

Figure 41. After 10 years, deteriorated joints on Little Mack Avenue required partial-depth patching (Photo courtesy of Anderson, Eckstein and Westrick, Inc.)

While the partial-depth patches performed well, the pavement adjacent to the patches continued to deteriorate, and further distress developed at the lane/curb joint and around random cracks. See Figure 42.

In 2011, core samples of the 16-year-old pavement were analyzed. The cores revealed that the upper 3 in. of the existing pavement had a poor distribution of entrained air bubbles and reduced entrained-air content. However, the

Figure 42. After 16 years, severe joint deterioration in Little Mack Avenue (Photo courtesy of Anderson, Eckstein and Westrick, Inc.)

lower 6 in. of pavement and the subbase were sound and performing well. Rather than remove the entire pavement section, the designers opted to remove the upper 4 in. of deteriorated concrete and resurface the remaining pavement with a 4-in. unbonded concrete overlay.

A geotextile fabric separation layer was used in lieu of an asphalt layer. Because of its minimal thickness, the geotextile separation layer has many benefits in urban environments. The compromise between milling depth, concrete overlay thickness, and preservation of existing profile grade is easier to accommodate when using a thin geotextile separation layer.

Construction of the five-lane, 4-in. thick unbonded overlay commenced in April 2011. Two-way, two-lane traffic was maintained during construction. Construction was completed in September 2011 at an approximate cost of $1.15 million per mile.

The construction process consisted of the following steps:

1. Removal of manholes and inlet structures to an elevation below the depth of milling.
2. Milling 4 in. of the existing concrete. See Figure 43.

Figure 43. Milling the existing concrete on Little Mack Avenue (Photo courtesy of Dan DeGraaf, Michigan Concrete Assocation)

3. Removal of the existing curb and gutter.
4. Minimal preoverlay repairs.
5. Adjustment of manhole and inlet structures to final elevation.
6. Installation of the geotextile fabric separation layer. See Figure 44.

Figure 44. Geotextile fabric separation layer placed ahead of paving operations on Little Mack Avenue (Photo courtesy of Dan DeGraaf, Michigan Concrete Association)

7. Placement of the 4-in. unbonded concrete overlay. See Figure 45.

Figure 45. Placement of the 4-in. thick unbonded concrete overlay on Little Mack Avenue (Photo courtesy of Dan DeGraaf, Michigan Concrete Association)

8. Approximate joint spacing of 5 ft center-to-center.
9. Construction of new curb and gutter.
10. Final pavement markings and miscellaneous activities to finish the project. See Figure 46.

The project specifications stated that the maximum ridge height of the milled surface could not exceed ¼ in., primarily due to the use of a geotextile fabric as a separation layer. The ridge height needed to be controlled to prevent puncturing the geotextile.

Figure 46. Completed unbonded concrete overlay on Little Mack Avenue being prepared for opening to traffic (Photo courtesy of Dan DeGraaf, Michigan Concrete Association)

The contractor quickly discovered that meeting the specification could be accomplished only when the milling teeth were not worn too far down. They adjusted their milling into a two-step process: a first milling pass at a depth of 2 in., followed by a second pass to final grade with "new" milling teeth. Once the "new" teeth were worn to a point that results were not acceptable, the mill skipped ahead to resume the first pass. This process was repeated as new milling teeth were needed.

An optimized "durable" concrete mixture was used. Rather than repeating the same mistake that was made in 1995, a concrete mixture with adequate air entrainment properties and reduced permeability was used to enhance the performance of the unbonded overlay. This was accomplished through the use of a well graded mixture, reduced paste content, and the replacement of 30 percent portland cement with ground granulated blast furnace slag.

Soon after the northbound lanes were opened to traffic, noise began to radiate from the joints as traffic passed over them. This was especially noticeable in the early morning hours when the pavement was coolest and aggregate interlock was at its minimum. The noise was reduced and/or disappeared altogether as the temperature rose and the joints closed. No definitive cause for the noise was determined, and after less than a year the noise is no longer present. It is suspected that the noise occurred from the vertical movements of the slab grinding at the joint when the joints were open.

7.2 Thin Unbonded Concrete Overlay, Plano, TX

This project consisted of a thin (2.5 in. to 4.5 in.) unbonded overlay constructed on a portion of Alma Drive in Plano, Texas, in 2007. The project included a six-lane divided arterial roadway bounded by 15th Street to the north and Plano Parkway to the south. The pavement structure prior to overlay consisted of a 3- to 5-in. layer of HMA on top of 5 to 8 in. of concrete. There were localized HMA failures adjacent to the curb and gutter and reflective cracks. See Figures 47 and 48.

Figure 47. Typical reflective cracks on Alma Drive (Photo courtesy of The Transtec Group)

Figure 48. Localized HMA failures adjacent to curb and gutter on Alma Drive (Photo courtesy of The Transtec Group)

The soils on the project included both low and high plasticity clays, with some areas of shallow bedrock.

The overlay design specified that the existing HMA layer be removed and replaced with a new ½-in. thick HMA separation layer. The construction sequence was as follows:

1. Completely remove existing HMA overlay by milling.
2. Remove and replace heavily damaged areas of the existing concrete pavement layer, particularly on the approaches to the two signalized intersections and on the outside southbound lane.
3. Repair less damaged areas of the existing concrete pavement using various techniques.
4. Tack and pave a new thin (½-in.) HMA separation layer consisting of a fine-graded mixture.
5. Place a new (2½-in. to 4½-in.) unbonded, high-performance jointed concrete overlay.

To both mitigate risk and improve constructability, a number of features were recommended on this project:

- Payment of the concrete overlay as two bid items: 1) by volume for the concrete material and 2) by area for the placement. The intent of this is to accommodate for deviations from estimated quantities because of variability in the existing HMA thickness along the project.
- Use of a fine-graded mixture for the HMA separation layer. To minimize reflective cracking initiated by movement of the underlying concrete and to provide stability and uniform support for the concrete overlay, the separation layer could not be too flexible or too stiff.
- Use of a high-performance, high-strength concrete mixture for the overlay.

  The mixture included relatively small but well graded limestone coarse aggregate and siliceous fine aggregate, plus fiber reinforcement at the rate of 3 lb/yd^3. Strength specifications included a 28-day minimum requirement and a strength for opening to traffic that was not excessive (thus lowering the potential for the contractor to use too much cement, which could lead to problems with shrinkage cracking and wide joints).

- Use of zero-clearance paving equipment to overcome lateral constraints behind the curb and to facilitate maintenance of traffic through the project. See Figure 49.

Figure 49. Zero-clearance paver on Alma Drive (Photo courtesy of Duit Construction)

- Use of short joint spacing to minimize the formation of additional (natural) cracks that occur on thinner concrete overlays.

  As originally designed, a transverse joint spacing of approximately 3 ft was recommended, along with a longitudinal joint spacing equal to one-third the lane width (approx. 3.67 ft). These spacings were subsequently modified slightly to accommodate the paving equipment/operation. See Figure 50.

- Thorough planning and rigorous quality control during construction, particularly during the concrete paving operations.

The thin unbonded overlay has been in service for seven years and is in good condition. See Figure 51.

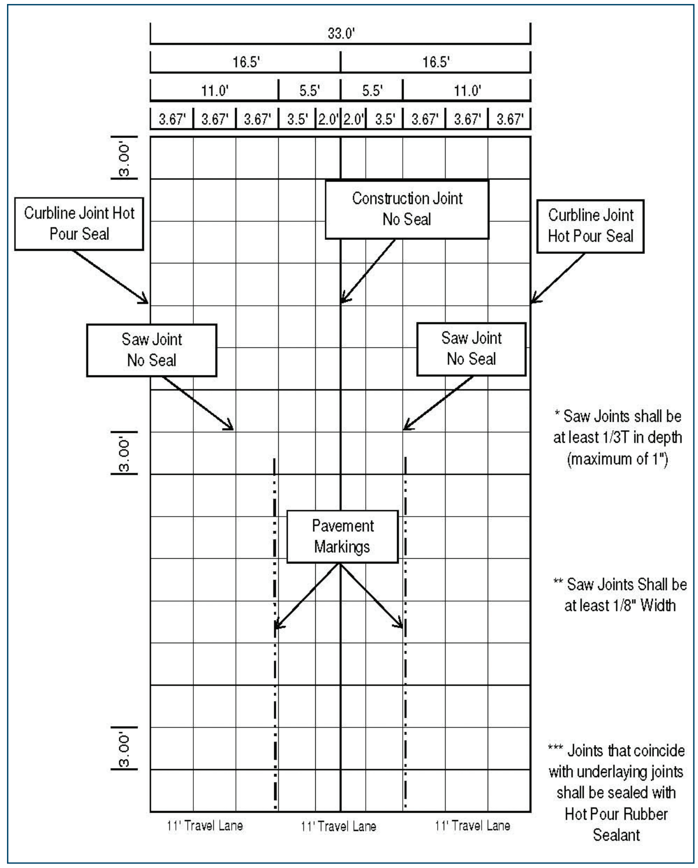


Figure 50. As-constructed joint spacing for three-lane, thin unbonded concrete overlay in Plano, TX (Image courtesy of Duit Construction)

Figure 51. After seven years of service, thin unbonded concrete overlay in Plano, TX (Photo courtesy of The Transtec Group)

7.3 Thin Unbonded Concrete Overlay, Harrisburg, PA

In 1995, the Pennsylvania Department of Transportation (PennDOT) constructed a thin unbonded concrete overlay on a ramp at the intersection of Interstate 83 and Route 22 near Harrisburg in Dauphin County, Pennsylvania.

The original pavement structure, constructed in 1960, consisted of 6 in. of special subbase underlying 10 in. of reinforced concrete pavement. In 1992, a 1½-in. HMA overlay was placed on the existing concrete. Due to repeated failures, additional HMA overlays had been constructed. In 1995, just prior to the concrete overlay construction, the average HMA thickness was 3.5 in. The HMA showed extensive distresses, including shoving, rutting, reflective cracking, raveling, weathering, and potholes.

Prior to construction of the concrete overlay, PennDOT milled the existing HMA layer to approximately 2 in. to act as a separation layer between the two layers of concrete. A 3½-in. unbonded, fiber-reinforced concrete overlay was then constructed over the milled asphalt in two days. The mixture included fiber reinforcement at the rate of 3 lb/yd^3. Joint spacing was designed as 3 ft by 3 ft and constructed between 2.9 ft and 3.3 ft.

The entire cost of the project was $214,411 (in 1995 dollars) for 769 ft of overlay, including incidentals such as transitioning to the existing grade at the acceleration ramps of the main lanes. It was reported shortly after construction that, based on a life-cycle cost analysis, at least a 10-year life would be needed before benefit would be realized from the concrete overlay at this site.

In April 1996, the new pavement section had experienced one winter season, which was particularly extreme. It included record-breaking snowfalls, rain, numerous freeze/thaw cycles, and flooding. During this time, the ramp was exposed to snow plows and deicing materials. By 1997, after experiencing two winters, the overlay was still performing well and had developed only one additional crack besides those that had appeared prior to opening to traffic, which were found to be associated with drainage inlets.

Figure 52 shows the project after nearly 16 years of service. While some isolated distress is evident near pavement transitions and at inlets, the majority of the project remains in good condition.

For a video of the project, visit www.youtube.com/watch?v=x6K-EMSqQAk.

Figure 52. After 16 years of service, thin unbonded overlay near Harrisburg, PA (Photo courtesy of John Becker, PA chapter, ACPA)

7.4 Thin Bonded Concrete Overlay, Northwood, IA

In 2002, the Iowa Department of Transportation (Iowa DOT) constructed a 2-in. thick bonded overlay in Northwood, Iowa. The existing pavement had been constructed in 1994 and consisted of 8 in. of dowel-jointed concrete pavement, which had severely deteriorated joints.

Sections of cores taken from the pavement were tested and showed inadequate air entrainment in the upper portion of the slab.

The Iowa DOT opted to mill 2 in. of the existing pavement and construct a bonded concrete overlay. The existing profile grade was maintained, which minimized the need for adjusting manholes, gutter inlets, and driveways. See Figure 53.

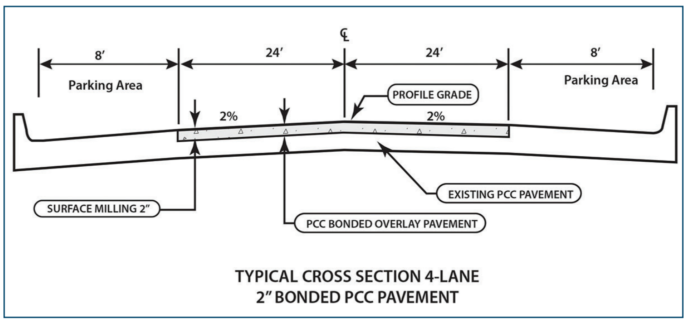


Figure 53. Typical section for Northwood, IA, thin bonded overlay (Photo courtesy of Iowa DOT)

The project consisted of the following:

- 21 partial- and full-depth patches completed prior to the overlay (396 square yards).
- 9,606 yd^2 of milling.
- 1,800 ft x 48 ft bonded concrete overlay.

Patching was followed by spot milling and then with shot-blasting and air-blasting to remove loose particles lodged in voids. The bonded concrete overlay was placed with a 24-ft wide slipform paver in two passes.

Traffic was restored to four lanes of operation within 24 days of the beginning of repair activities.

After 10 years of service, although there are some longitudinal cracks from lack of sawing, the concrete overlay is performing well. See Figures 54 and 55.

Future recommendations for similar projects include the following items:

- Place tiebars over existing mid-panel cracks to mitigate reflection of the cracks into the overlay.
- Saw all joints through the full thickness of the overlay.

Figure 54. After seven years of service, thin bonded concrete overlay in Northwood, IA; note the longitudinal joint was not sawed in the overlay (Photo courtesy of Iowa DOT)

Figure 55. After seven years of service, another view of thin bonded concrete overlay in Northwood, IA (Photo courtesy of Todd Hanson, Iowa DOT)

8. Conclusion

The suggestions in this guide will help agencies and contractors design and build thin (≤ 5-in.) concrete overlays as longer term solutions (15 years or more) for concrete pavements with deteriorated joints. As additional projects are constructed and new lessons learned, this guide will be revised and updated to reflect current best practices.

Comprehensive guidance about concrete overlays can be found in the *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, 3rd Edition (Harrington and Fick 2014).

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