EUROPEAN CONCRETE PAVING ASSOCIATION

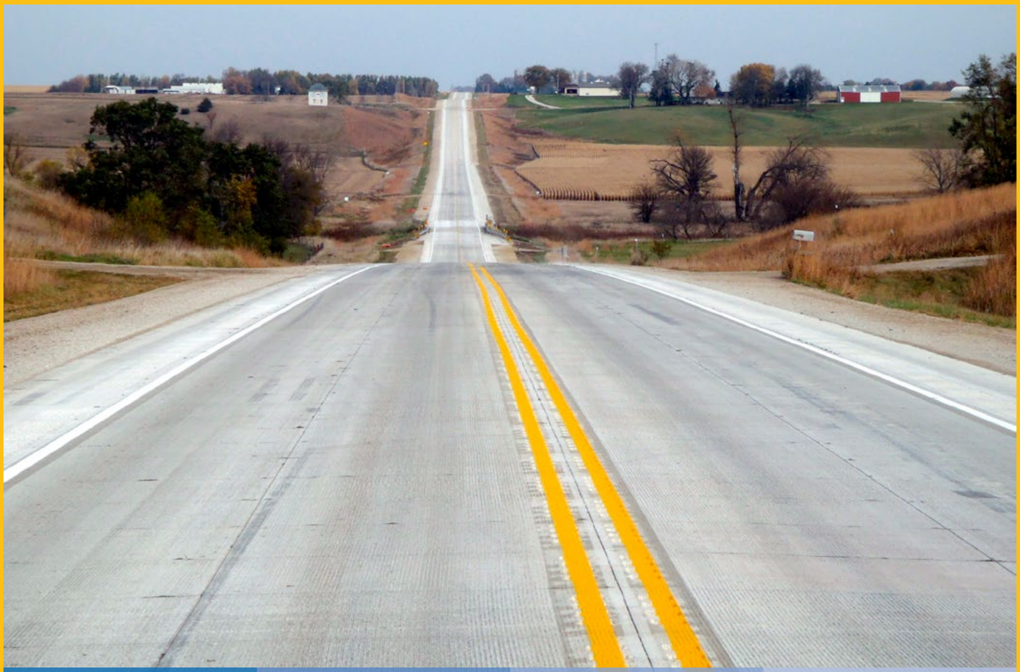
Guide for Design of Concrete Overlays

Cover image. Fiber-reinforced bonded concrete overlay of asphalt-surfaced pavement on Indiana State Route 3 near Delaware, Indiana, U.S., 2019, 11 cm thick, 2.4 kg/m^3 synthetic fibers. Photo: ACPA.

Guide for Design of Concrete Overlays

This publication provides an overview of the basic principles of concrete overlay design and construction on concrete and asphalt-surfaced pavements. It discusses the importance of many design parameters, including overlay bond (or separation), joint layout and design, material selection, overlay thickness, and other details. This document also describes recommended practices for overlay construction and construction staging. Performance histories and expectations are also discussed.

Bonded overlay of asphalt-surfaced pavement on U.S. Hwy 71 in Clay County, Iowa, U.S., 2018, 15 cm thick. Photo: ACPA.



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1 INTRODUCTION

WHAT ARE CONCRETE OVERLAYS?

A concrete overlay is simply a concrete paving layer that is placed over an existing pavement. When properly designed (materials, interface bond, panel dimensions, thickness, etc.) and constructed, concrete overlays provide cost-effective, long-life, sustainable pavement rehabilitation options for a broad range of pavement types, existing pavement conditions, and project needs (see Figure 1).

BENEFITS OF CONCRETE OVERLAYS

Well-designed and constructed concrete overlays offer many advantages and benefits over other types of overlays and rehabilitation strategies, including:

- Immediate improvement in pavement ride quality that lasts for many years.
- Cost-effective long-term (up to 40 years) extension of life for existing pavements near the end of their design lives. Even longer life has been documented in some cases.
- A technology proven through more than 100 years of experience to offer the potential for excellent performance.
- Can be constructed rapidly (compared with reconstruction) with effective traffic management and accelerated paving techniques.

Concrete overlays are a highly sustainable form of pavement construction. Their potential for long, low-maintenance service life makes them economical and reduces the frequency of traffic disruptions, vehicle emissions, resource consumption, and safety concerns associated with short maintenance and rehabilitation cycles.

Recent studies also point to the resiliency of concrete-surfaced pavements in the face of climate change and extreme weather events. Concrete pavement overlays offer resiliency by "hardening" flexible pavement systems against storm damage and allowing their rapid return to service without reducing long-term performance potential. For example, Gaspard et al. (2007) concluded that concrete pavement in the New Orleans (USA) area experienced little loss of strength after being submerged following Hurricane Katrina, while submerged asphalt pavement suffered strength loss equal to about 5 cm of thickness.

BRIEF HISTORY OF CONCRETE OVERLAY USE

According to the American Concrete Pavement Association's (ACPA's) National Concrete Overlay Explorer web tool (http://projects.acpa.org/concrete-overlays/), concrete has been used for pavement resurfacing in the U.S. since at least 1901, but this use began to increase rapidly in the 1980s with the re-introduction of thin and ultra-thin

Figure 1. Example successful concrete overlay project (Route D, Missouri, USA) in 2007 before overlay (left) and in 2020 after 12 years of service (right). Photos: Todd LaTorella, MO/KS Chapter ACPA.

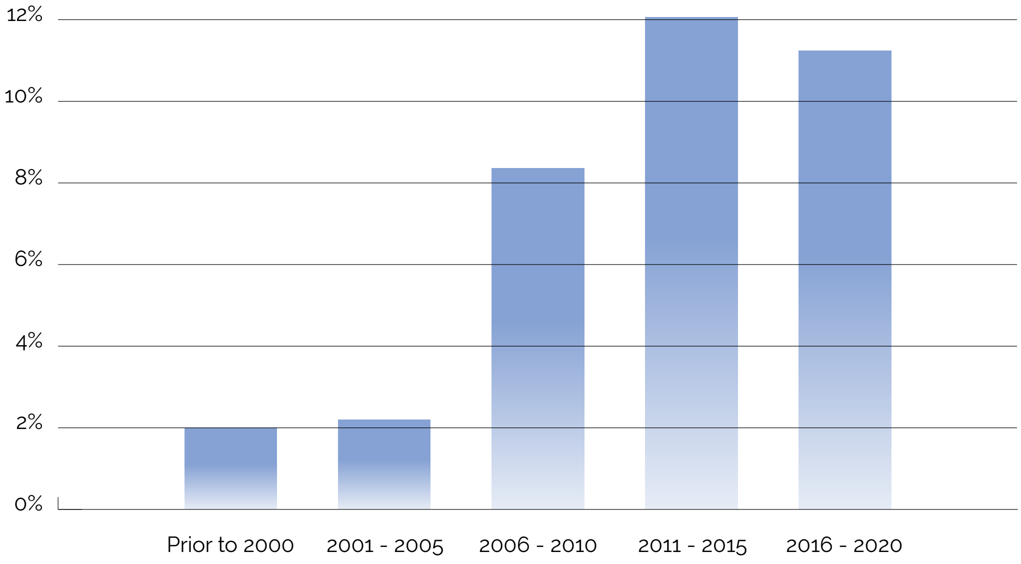
bonded concrete overlays of asphalt pavement. More than 1200 concrete overlay projects have been documented in the U.S. since 1901 (through 2017), with approximately 900 being constructed since 1980. Concrete overlays have been constructed in 46 of 50 states, including every state except Alaska and the extreme northeastern states of Maine, Vermont and New Hampshire (Fick, et al. 2021).

In Europe, a few concrete overlays were placed in the 1960s and 1970s (mainly in Belgium), but interest and use began to increase in the 1980s and 1990s with projects mostly in Austria, Belgium, France, and Sweden (Sion 1986, Rens 2016, Silfwerbrand 1998, Verhoeven 1990, Charonnat et al. 1998, Steigenberger 1997). Since 2000, Germany and Spain have also constructed concrete overlays while Austria, Belgium, and France have continued to use the technology (Rens 2016, Reeners and Jasienski 2004, Spalt 2015, Riffel 2010, Caestecker and Lonneux 2003, Ferrà and Rueda 2010). Concrete overlay applications for industrial pavements and other applications emerged in Italy and the Netherlands as well (Pasetto and Ursella 2004, Buitelaar, et al. 2006).

Almost all European concrete overlay projects have been designed and constructed as bonded overlays and inlays of asphalt-surface pavement. However, the construction of bonded and unbonded overlays of concrete in Austria, Belgium, and Spain has also been documented (Spalt 2015, Sion 1986, Ferrà and Rueda 2010, Reeners and Jasienski 2004), including jointed overlays of jointed concrete and continuously reinforced concrete (CRC) overlays of CRC pavement.

Concrete overlays current account for approximately 11 percent (by area) of the entire concrete paving market in the U.S. (see Figure 2). Historically, they have been used mostly for resurfacing existing concrete pavements, but far more have been applied to existing asphalt-surfaced pavements since the 1980s (see Figure 3). Fick et al. (2021) report that, between 2000 and 2017, approximately 29 percent of concrete overlays were placed over concrete pavement (including continuously reinforced concrete pavement [CRCP]) while 71 percent were placed over asphalt-surfaced pavement (including composite pavement). These trends reflect growing demand for a cost-effective, long-term solution to the impacts of higher volumes of heavy traffic on asphalt pavement: concrete overlays!

Figure 2. Historical U.S. national use of concrete overlays as a percentage of total concrete paving area as of November 2020 (Ferrebee, 2021).



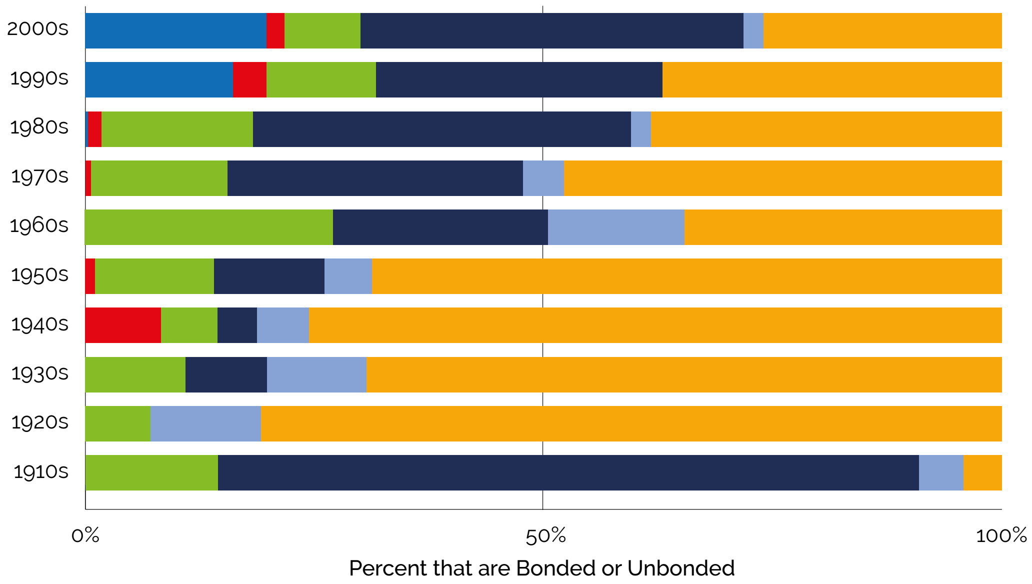


Figure 3. Historical distribution of concrete overlay types in the U.S. (CPTech 2015)

Figure 3 also shows the unbonded designs are currently far more common than bonded designs for concrete overlays of concrete pavement in the U.S. This is likely due to the ease of construction and good performance history of unbonded overlays of concrete pavement. Figure 3 shows that bonded overlays of asphalt and composite pavements have become much more common since the 1990s, but that unbonded designs are also the most common type of concrete overlay for asphalt-surfaced pavements.

2 TYPES OF CONCRETE OVERLAYS

NAMING SYSTEMS

Concrete overlays can be placed on any type of existing pavement system – asphalt, composite (asphalt over concrete), or any type of concrete (including jointed plain, jointed reinforced and continuously reinforced). The design details (including overlay thickness, joint layout, joint design, slab reinforcement, and bond between the overlay and existing pavement) depend on project-specific factors, such as condition of the existing pavement, traffic volume and load characteristics, geometric constraints, and design life.

Over the years, several descriptive overlay naming conventions based on the factors above have come and gone. These have included "whitetopping" (usually meaning a concrete overlay of asphalt), thickness-based descriptors (i.e., "conventional", "thin" and "ultra-thin" overlays, usually of asphalt pavement), "BCOA" (bonded concrete overlays of asphalt), "SJPCP" (short-jointed plain concrete pavement overlays) and others.

In recent years, the U.S. concrete paving industry began naming overlay types based on their assumed (in design) bond with the existing pavement and the type of pavement being overlaid. Prior to 2021, bond condition (bonded or unbonded) was named first, followed by pavement type (asphalt, concrete or composite). The 4th edition of the Guide to Concrete Overlays (Fick, et al. 2021) has changed this convention to place emphasis on the pavement type first and the assumed bond second. The naming was further simplified by combining "composite" and "asphalt" pavements into a single category of "asphalt-surfaced" pavements. The resulting four concrete overlay categories (with their industry-adopted acronyms) are:

- Concrete Overlays of Concrete pavement – Bonded (COC-B)
- Concrete Overlays of Concrete pavement – Unbonded (COC-U)
- Concrete Overlays of Asphalt-surfaced pavement – Bonded (COA – B)
- Concrete Overlays of Asphalt-surfaced pavement – Unbonded (COA-U)

This naming and acronym convention is used throughout this document for harmony and brevity.

These four main types of concrete overlay are illustrated in Figure 4 (Fick et al. 2021). The importance of overlay bond in design and construction is discussed below.

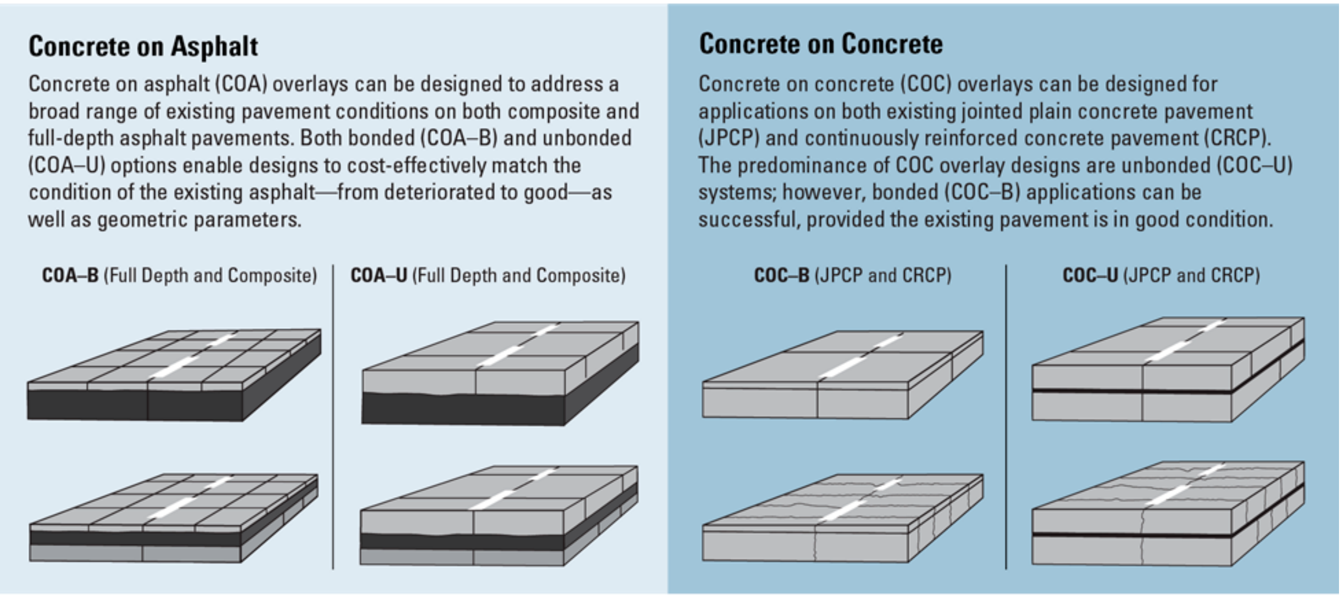


Figure 4. Four main types of concrete overlays (Fick, et al. 2021).

Concrete on Asphalt

Concrete on asphalt (COA) overlays can be designed to address a broad range of existing pavement conditions on both composite and full-depth asphalt pavements. Both bonded (COA–B) and unbonded (COA–U) options enable designs to cost-effectively match the condition of the existing asphalt—from deteriorated to good—as well as geometric parameters.

Concrete on Concrete

Concrete on concrete (COC) overlays can be designed for applications on both existing jointed plain concrete pavement (JPCP) and continuously reinforced concrete pavement (CRCP). The predominance of COC overlay designs are unbonded (COC–U) systems; however, bonded (COC–B) applications can be successful, provided the existing pavement is in good condition.

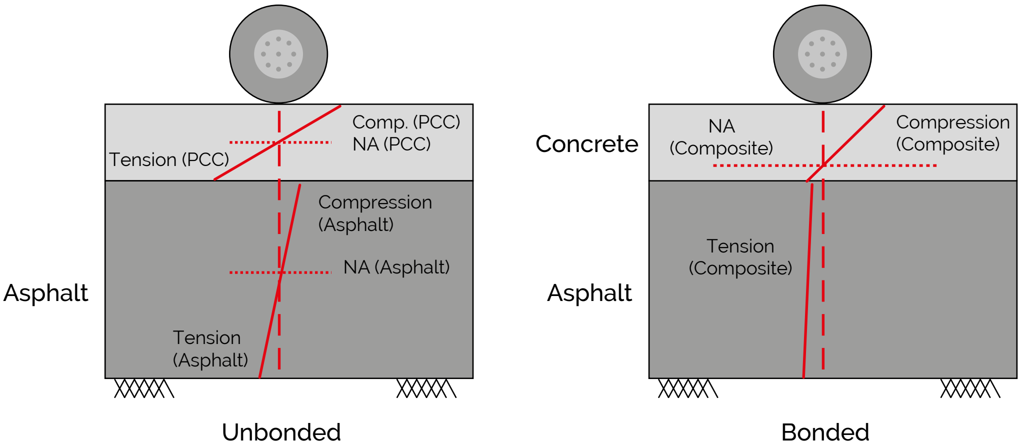


Figure 5. Behavior of (and flexural stress distribution through) the layers of unbonded (left) and bonded (right) overlay systems (Modified from Fick, et al. 2021).

CONSIDERING OVERLAY BOND IN DESIGN AND CONSTRUCTION

The degree of bond, interlock, or friction (hereinafter referred to simply as "bond") between a concrete overlay and the underlying pavement strongly affects the magnitude of stresses in both layers. When the overlay and existing pavement layers are well-bonded, they behave as a single layer with an effective thickness greater than that of either the overlay or the existing pavement. The bonded overlay-existing pavement system has a single neutral axis with respect to bending, which results in much lower flexural stresses in both the overlay material and the existing pavement than would develop in an unbonded pavement system with the same layer thicknesses (see Figure 5).

When no bond exists between the overlay and existing pavement layers, the two layers flex independently, with each layer having its own neutral axis and each layer experiencing both tension and compression (Figure 5, left). The magnitude of flexural stresses in each layer depends on their relative stiffnesses, which vary with the thickness and elastic modulus of each layer.

Deflections in the two systems will also be different. While both bonded and unbonded concrete overlays reduce deflections compared to that of the existing pavement, bonded overlays result in an overlaid pavement system with greater stiffness and have greater reductions in deflection (assuming the same overlay thickness in each case).

For design purposes, the overlay's bond with (or separation from) the existing pavement is an assumed condition that must be selected carefully in design to reflect expected service conditions. Note that some degree of bond or friction is always present between an overlay and an existing pavement, with the degree of bond in service depending in part on the efforts made to bond or separate the two layers during construction.

If a bonded condition is assumed in design but not achieved in construction, overlay flexural stresses will be higher than considered in design and the overlay will fail prematurely. On the other hand, if the overlay is assumed to be unbonded in design but actually develops some bond after construction, stresses will be lower than assumed and an improvement in performance may be realized over design expectations (i.e., the overlay thickness design will be more conservative). However, if a high degree of bonding is incidentally developed during construction for an overlay that was intended to be unbonded because of distress in the existing pavement, cracks and other distresses in the existing pavement may quickly reflect through the overlay. These examples illustrate the need to carry bond-related design assumptions through the construction process in most cases (unbonded overlays of asphalt are often an exception, as discussed later).

The structural impact of the overlay bond depends on the quality and integrity of both the overlay and the existing pavement, as well as the thickness of the existing pavement. *A bonded overlay should not be selected unless the existing pavement* (or the portion of that pavement that will remain after milling and other repairs) *is of sufficiently high quality and adequate thickness*. For example, 75 mm of sound asphalt pavement is usually considered the minimum acceptable existing pavement thickness for constructing a COA-B. The main reason for this limitation is that asphalt has a much lower elastic modulus than portland cement concrete (around 3 GPa vs 30 GPa), so there is little structural value to be gained by bonding to less than 75 mm of asphalt. A second reason for the minimum asphalt thickness is for the support of construction traffic and paving operations.

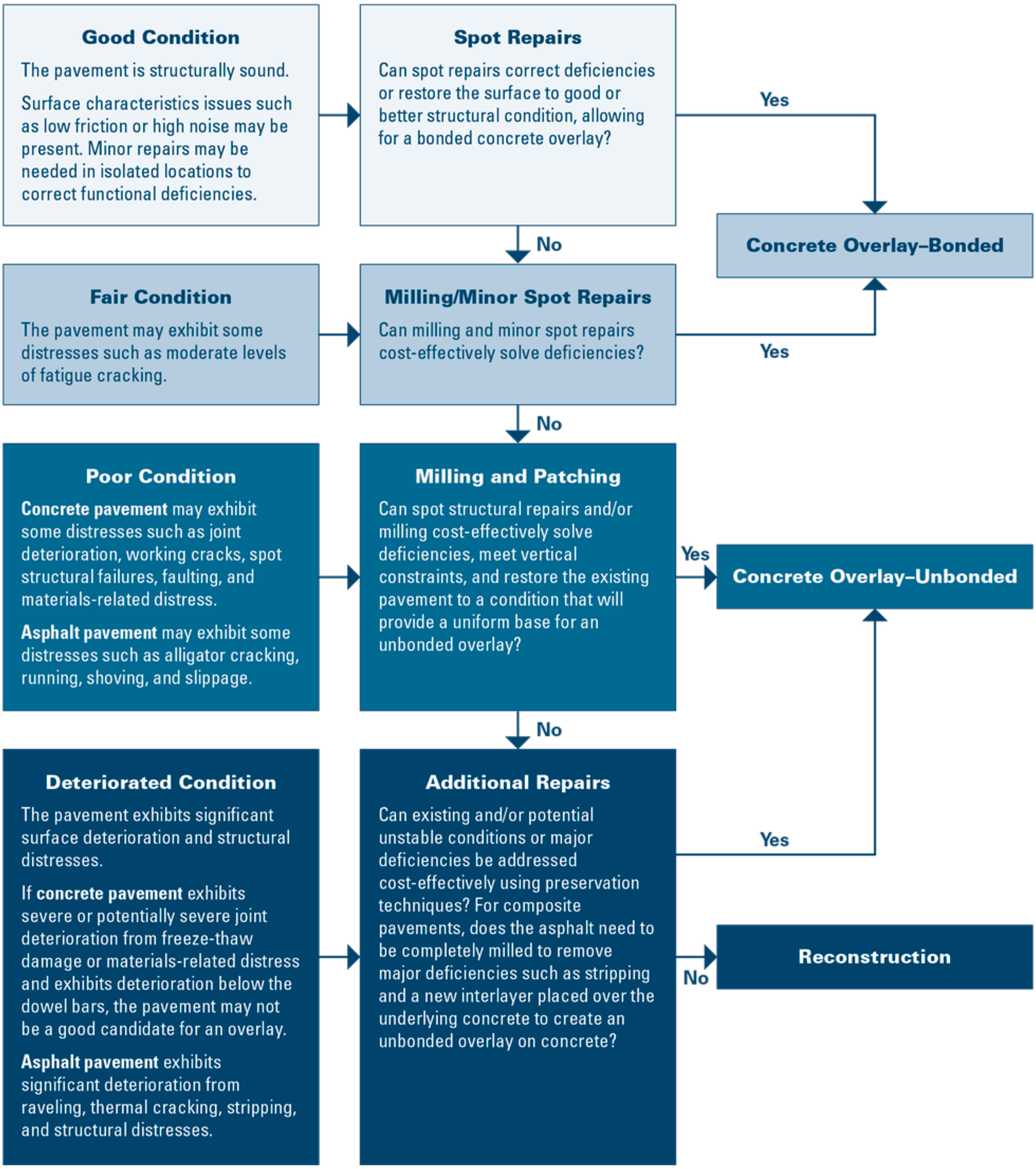
When overlaying thin (<75 mm thick) asphalt with concrete, it is usually better to design the concrete layer as a new pavement on an asphalt base rather than as bonded concrete overlay. The resulting concrete layer thickness may be slightly (up to 15 mm) greater for new pavement design than it would be for overlay design, but the design will likely be more reliable.

SELECTING OVERLAY TYPE FOR PROJECT CONDITIONS

While concrete overlays can be placed over any type of existing pavement structure, several factors should be considered in determining the *type* of concrete overlay best suited for a specific existing pavement. These factors include:

- Condition of the existing pavement
- Structural capacity (thickness and quality) of existing pavement layers
- Traffic volume and composition
- Geometric constraints (e.g., vertical clearance constraints, elevation of retained utility and drainage features, impact of pavement elevation on ditch slope and right-of-way limits, etc.)

In many cases, the most important factor for selecting overlay type is the condition of the existing pavement. Bonded overlays should only be placed on pavements that are in (or can be restored to) good structural condition. Bonding new concrete to cracked or unstable, poorly supported existing pavement often results in reflection of cracks through the overlay, loss of bond and delamination of the overlay, and a shortened overlay service life, especially for overlays of concrete pavement. In some cases, the existing pavement can be restored to good structural condition using full-depth repairs and other rehabilitation techniques before placing a bonded concrete overlay.



Good Condition

The pavement is structurally sound.

Surface characteristics issues such as low friction or high noise may be present. Minor repairs may be needed in isolated locations to correct functional deficiencies.

Spot Repairs

Can spot repairs correct deficiencies or restore the surface to good or better structural condition, allowing for a bonded concrete overlay?

Concrete Overlay–Bonded

Fair Condition

The pavement may exhibit some distresses such as moderate levels of fatigue cracking.

Milling/Minor Spot Repairs

Can milling and minor spot repairs cost-effectively solve deficiencies?

Poor Condition

Concrete pavement may exhibit some distresses such as joint deterioration, working cracks, spot structural failures, faulting, and materials-related distress.

Asphalt pavement may exhibit some distresses such as alligator cracking, running, shoving, and slippage.

Milling and Patching

Can spot structural repairs and/or milling cost-effectively solve deficiencies, meet vertical constraints, and restore the existing pavement to a condition that will provide a uniform base for an unbonded overlay?

Concrete Overlay–Unbonded

Deteriorated Condition

The pavement exhibits significant surface deterioration and structural distresses.

If **concrete pavement** exhibits severe or potentially severe joint deterioration from freeze-thaw damage or materials-related distress and exhibits deterioration below the dowel bars, the pavement may not be a good candidate for an overlay.

Asphalt pavement exhibits significant deterioration from raveling, thermal cracking, stripping, and structural distresses.

Additional Repairs

Can existing and/or potential unstable conditions or major deficiencies be addressed cost-effectively using preservation techniques? For composite pavements, does the asphalt need to be completely milled to remove major deficiencies such as stripping and a new interlayer placed over the underlying concrete to create an unbonded overlay on concrete?

Reconstruction

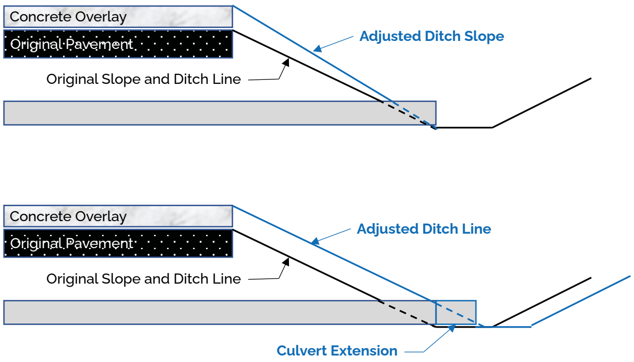
Figure 6. Example decision tree for determining concrete overlay options (Fick, et al. 2021).

However, it is often more cost-effective to perform fewer (or no) pre-overlay repairs and place a thicker, unbonded overlay than to perform extensive pre-overlay repairs for a bonded concrete overlay. Figure 6 presents an example decision tree for selecting bonded or unbonded overlay types (or reconstruction) based solely on the condition of the existing pavement.

When considering the use of a bonded concrete overlay, it is also important to consider whether bonding with the existing pavement will significantly increase the load-carrying

Figure 7. Example of asphalt pavement transverse crack reflecting through thin concrete overlay. Photo: J. Vandenbossche, University of Pittsburgh.

Figure 8. Schematic showing need to adjust ditch slopes (top) or ditch location (with culvert extension) due to overlay placement (Fick, et al. 2021).



capacity of the overlaid pavement system. For example, bonding with sound existing concrete pavement requires extra effort during construction (as is discussed later), but always results in reduced overlay thickness requirements to achieve a particular structural capacity or service life. Bonding with sound asphalt pavement, however, has relatively little impact on overlay thickness unless the asphalt layer is relatively thick (e.g., 10 cm or more) at the time of construction (i.e., after any pre-overlay milling has been performed). Further, some minimum thickness of existing asphalt pavement thickness is required for support of construction equipment, as discussed previously.

Caution: when thin bonded concrete overlays are placed on thick asphalt pavements, the stiffness of the asphalt layer may exceed that of the concrete layer, resulting in reflection of asphalt transverse cracks through the concrete overlay (see Figure 7). This mechanism is described by Vandenbossche and Barman (2010) and can be a performance factor when the asphalt layer thickness exceeds approximately twice the thickness of the concrete overlay. Such cracks must be repaired prior to overlay, or a joint must be placed in the overlay directly above the crack.

Geometric constraints can also drive overlay design. For example, it is often desirable to minimize the increase in pavement profile or elevation that can accompany the placement of any overlay. One reason to minimize changes in pavement elevation is reduced clearance at overpasses. However, profile changes can also be problematic even in areas without overpasses if they result in the need to adjust the elevations of appurtenant features (e.g., utility access covers, drainage inlets, guard rails, etc.) or require extension of ditch slopes and/or ditch relocations (see Figure 8). Such constraints may favor construction of bonded overlays (because they are thinner) if existing pavement conditions allow. Other options include reconstruction (rather than overlay) in the vicinity of overpasses, or the construction of an inlay (i.e., partial removal of the existing pavement layer, usually by milling, and placing concrete in place of the removed material, often at or near the original pavement elevation) instead of an overlay.

3 CONCRETE OVERLAY DESIGN AND CONSTRUCTION

Concrete overlay thickness is a major factor in determining overlay material and construction costs and, therefore, whether a concrete overlay is the selected rehabilitation strategy for a particular project. However, other factors, such as joint layout and construction material durability, sometimes have a greater impact on overlay performance than does thickness alone. In addition, decisions concerning panel dimensions, joint load transfer, edge support and bond condition directly affect thickness design, and should, therefore be determined concurrently with (and as an input to) overlay thickness.

Another factor that impacts concrete overlay performance is uniformity of support, which is actually far more important than strength of support. Overlay thickness can be adjusted for stronger or weaker foundations, but cannot cost-effectively protect against abrupt changes in support, such as may arise when the concrete overlay is used to increase lane widths or when milling of an existing asphalt pavement exposes local areas of thin or weak asphalt (see Figure 9). In these cases, uniform support must be restored with pre-overlay repairs or shoulder improvement, as required.

The overall goal of overlay design must be to design an overlay *system* that addresses all components of the overlay design (i.e., thickness, bond condition, joint layout and load transfer, uniformity of support, etc.) in a manner that balances cost considerations with the need to achieve the target service life with acceptable quality of service. Concepts and procedures for achieving this goal in design and construction are described herein.

Figure 9. Thin asphalt and base material exposed after milling (Fick, et al. 2021).

BONDED OVERLAYS OF CONCRETE PAVEMENT

Thin bonded overlays are not uncommon in bridge deck restoration, and concrete containing special bonding and shrinkage-reducing admixtures are commonly used. However, bonded overlays of concrete pavement are used far less often for several reasons:

- The existing pavement must be in very good condition, and such pavements are not typically programmed for rehabilitation.
- The good bond required between the overlay and existing pavement requires meticulous attention to detail during construction.
- Overlay cracking will almost certainly develop quickly if bond is lost, and repair will likely require expensive and time-consuming full-depth patches of the overlay (and possibly of the underlying pavement).

When properly designed and constructed, bonded overlays of concrete pavement can be expected to provide at least 15 years (and possibly 30 years or more) of service before requiring maintenance (Figure 10).

Figure 10. Example completed concrete overlay of concrete – bonded on US 56 in Kansas (USA). Photo: Todd LaTorella, MO-KS Chapter of ACPA

> **"The most common reason for COC–B overlays to develop distress prematurely is that the existing pavement was not a good candidate for this type of overlay or was not properly repaired prior to overlay placement. Trying to place a COC–B overlay on a pavement with significant distress is not recommended." Fick et al., 2021.**

Design Concepts and Procedures

Bonded concrete overlays are assumed to develop a full, complete bond with the underlying concrete pavement structure so that the two layers behave as a single monolithic layer. Therefore, thickness design for bonded overlays of concrete pavement is performed using new concrete pavement thickness design procedures. The overlay thickness is calculated as the difference between the required thickness for a new pavement and the effective thickness of the existing pavement (subject to some minimum constructable overlay thickness, typically 5 cm or more). COC-B rarely exceed 15 cm in thickness.

Conventional concrete mixtures are commonly used for bonded overlays of concrete pavement. The mixture components (aggregates, water, cementitious materials, and chemical admixtures) and proportions must be chosen to balance the need for ease of placement and finishing a thin paving layer with the need to maintain good bond in the long term (i.e., by minimizing the potential for overlay shrinkage and rates of thermal expansion/contraction that are significantly different from those of the existing pavement). The inclusion of steel or synthetic structural fibers (also called "macrofibers") may also be useful for slowing crack development and decreasing their width. The benefits of using fibers in bonded overlay design (and other concrete pavement designs) can be considered directly using PavementDesigner.org, a free web-based pavement design tool developed by U.S. concrete paving industry partners.

Figure 11. Example of the NÖBI - the "New Austrian Concrete Overlay Method" bonded concrete inlay of concrete on the A1 (Spalt 2015).

Joints in the overlay must be placed exactly over existing joints in the underlying pavement, as shown in Figure 4. Dowels and tie bars must not be included in the overlay as these would facilitate debonding. If they are present in the underlying pavement, they should be considered in the thickness design of the overlaid pavement system.

Jointed concrete is the most common type of concrete overlay on concrete pavement. However, CRCP overlays have been successfully designed and constructed over both jointed and continuously reinforced concrete pavements (also shown in Figure 4).

Appendix B of Fick et al. (2021) provides additional information on the design and construction of CRCP overlays in the U.S. and South Korea, and Ram et al. (2021) presents a case study and 20-year performance history of a bonded CRC overlay of CRCP in Texas. Sion (1986) describes the 1979 construction of a CRC overlay of CRCP in Belgium, and Spalt (2015) reports on Austrian techniques for constructing bonded jointed concrete overlays of jointed concrete pavement (JCP) - see Figure 11. Figure 12 shows a 16-year-old bonded CRC overlay of CRC pavement in Texas, USA.

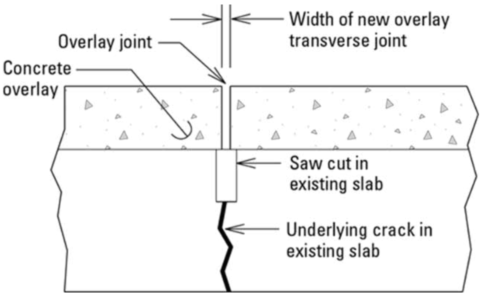
Figure 12. Bonded CRC over CRCP (US 281 in Texas, USA) – 2018 photo of 2002 construction. Photo: Mark Snyder, PERC, LLC.

Figure 13. Reflection of underlying pavement joint through bonded concrete overlay. Photo: Todd LaTorella, MO-KS Chapter of ACPA.

Joint Layout and Design

Joints in bonded overlays of concrete pavement must be cut or formed full-depth through the overlay and directly over the joints in the existing pavement. Failure to match the joint locations usually results in crack development over the original joint location (see Figure 13).

Figure 14. Schematic of joint construction for jointed bonded concrete overlays of JCP (Fick, et al. 2021).



In addition to being cut or formed through the full overlay thickness, overlay joints must also at least as wide as the narrowest part of the joint opening in the underlying pavement (see Figure 14). These depth and width requirements will allow the pavement to expand in warm weather and close the underlying pavement joint without causing the overlay joints to be compressed, which might initiate a shear failure of the overlay bond (and subsequent cracking and spalling) near the joint.

When a jointed concrete overlay is bonded to an underlying pavement with long panel lengths (e.g., > 6 m, such as with jointed reinforced or continuously reinforced concrete pavements), intermediate joints may be cut in the overlay to reduce overlay panel size, control overlay crack locations, and reduce the effects of overlay shrinkage and thermal contraction on the overlay bond.

Construction

There are several "keys" to successful construction of bonded concrete overlays on concrete. The first is restoring the existing pavement to very good condition by repairing all spalls and cracks prior to overlay placement. Tight, nonworking cracks can be left unrepaired, but they will likely reflect through the overlay. Reflective cracks may be prevented or mitigated if the overlay mixture contains macrofibers, as noted previously. The isolated use of reinforcing steel over tight cracks can also prevent their reflection (see Figure 15).

Figure 15. Use of reinforcing steel over tight longitudinal cracks in existing concrete before placing bonded concrete overlay. Photo: Brent Burwell, OK-AR Chapter of ACPA.

The second "key" is developing and maintaining good bond between the overlay and existing pavement. This is increasingly important as overlay thickness decreases and the overlay has less structural capacity when debonded. Some agencies have specified minimum required bond strength by pull-off or shear testing. For example, the Austrian NŐBI method recommends requiring an average 28-day tensile bond strength > 1.5 MPa (with no individual test value < 1.3 MPa) when tested in accordance with ONR 23303 point 9.5 (Spalt 2015). However, bond tensile and shear test results are often highly variable and there is little data available to relate specified values to bonded overlay performance.

Bond strength is not an input to current COC-B design procedures – it is assumed that construction will achieve adequate bond by whatever means are necessary. Emphasis in construction must be placed on preparation of the existing surface by (Fick, et al. 2021, Spalt 2015):

- water blasting, shot blasting, grinding or micromilling (to remove oil, paint and other bond inhibitors and provide texture for interlock with overlay materials) – see Figures 16 and 17,
- power sweeping and air blasting to remove dust just prior to overlay,
- *moistening* the surface (no standing water), and
- (optionally) spraying a neat cement grout (or other bonding agent) just ahead of the paver.

Figure 16. Concrete pavement shotblasting on US-281 in Texas (USA) prep for CRCP overlay of CRCP. Photo: Dr. Moon Won, Texas Tech University.

Figure 17. Milling concrete for bonded concrete inlay (Spalt 2015).

When using grout or other bonding agents, special care must be taken to ensure that the material does not dry or harden before the overlay is placed. Dried grout can act as a de-bonding layer and must be removed and the surface re-prepared before the overlay is placed. A very clean, saturated surface-dry surface is often preferred to bonding materials (Fick, et al. 2015, Spalt 2015),

A third "key" to thin overlay construction is timely and effective curing to prevent moisture loss and shrinkage that can overstress a young, weak interface bond. Water misting and wet burlap can be effective; spray-on membranes must have proven excellent moisture-retention characteristics and are often applied at rates greater than specified for conventional paving (up to double).

The final "key" is timely and accurate sawing of joints. Existing joint locations must be precisely located using techniques that will allow overlay joints to be re-established directly over the existing joints (within 25mm or less). To ensure that the overlay joints are cut through the full overlay thickness, saw cut depths are typically specified as overlay thickness plus 10-15mm. The minimum width of the overlay joint must be greater than the width of the crack below the sawcut in the underlying pavement, as discussed previously.

The timing of joint sawing is also crucial – too early results in joint raveling, too late results in uncontrolled cracks and spalled joints. Note that the joint sawing window is often smaller for thin concrete overlays than for thick overlays and conventional concrete paving. In addition, paving rates are often higher (more lineal meters per hour) with thin placements; therefore, more saws and operators may be required (or the paver may need to operate below capacity) to keep sawing operations within the sawing window.

Joint sealing or filling may be beneficial to long-term performance, especially in areas subject to freezing, by reducing the amount of water that can form ice in the joint, particularly at the bond interface (Fick, et al. 2021).

UNBONDED OVERLAYS OF CONCRETE PAVEMENT

Most concrete overlays of concrete pavement are designed assuming an unbonded condition between the overlay and existing pavement. They generally offer minimal need for pre-overlay repair, relative ease of construction, and high reliability.

A separation layer is always placed between the overlay and existing concrete to isolate the two layers, thereby preventing the reflection of cracks and other distresses in the original pavement. The separation layer may also serve as a drainage layer, leveling course, or other purposes.

When properly designed and constructed, unbonded overlays of concrete pavement can be expected to provide a service life that is comparable to that of a new concrete pavement (see Figures 1 and 18).

Design Concepts and Procedures

Unbonded concrete overlays are assumed in design to be supported by (but isolated from) the underlying pavement layer. Structurally, the two layers are assumed to flex independently, with both layers experiencing both tension and compression under applied loads (see Figure 5, left). Any friction or bond that does develop between the overlay and existing pavement will reduce stresses in the overlay (making the thickness design more conservative).

Unbonded overlays of concrete pavement should be designed directly using certain mechanistic-empirical overlay design procedures or software, such as UNOL Design (Khazanovich, et al. 2020) or AASHTOWare Pavement ME Design. They can also be designed indirectly using available procedures for conventional pavement design and a structural deficiency approach (i.e., the overlay design thickness is determined as a function of the difference between the required thickness for a new pavement design and the effective thickness of the existing pavement).

For example, the 1993 AASHTO Guide for the Design of Pavement Structures procedure for design of unbonded overlays of concrete pavements uses the following equation:

$$D_{overlay} = \sqrt{D_{new}^{2} - F * D_{existing}^{2}}$$

where D = pavement or layer thickness and F is an adjustment factor for the remaining life of the existing pavement (see AASHTO 1993 for details on determining F). Since the overlay is unbonded and performance is not strongly linked to distress in the existing pavement, the remaining life factor, F, does not greatly

Figure 18. Examples of completed COC-U projects – Left: Lorraine Avenue, Belgium – 2003 construction. Photo: FEBELCEM. Right: I-74 Illinois (USA) CRC overlay of CRC (1995 construction, 2018 photo). Photo: Applied Pavement Technology.

reduce the effective thickness of the existing pavement, even when it is badly distressed.

Pre-overlay repairs are typically few and are planned only for slabs or slab fragments that are unstable and move visibly under heavy traffic. Spalled areas are typically filled with cement grout or hot-mix (to prevent the overlay from "keying" into the spall area) rather than being repaired. The goal of pre-overlay work is to provide *reasonably uniform* support to the overlay, not to restore the original pavement. Doing extensive pre-overlay repair work is rarely cost-effective because it does not significantly increase the effective thickness of the existing pavement and, therefore, does not significantly decrease the overlay thickness.

Unbonded overlays are thicker than bonded overlays for any given project design, with a typical minimum thickness of 125 mm (100 mm for lightly trafficked pavement). For very heavy traffic and long service life, unbonded overlays may be almost as thick as a new concrete pavement.

Conventional concrete paving mixtures are commonly used for unbonded concrete overlays. Macrofibers (synthetic or steel) are finding increased favor in unbonded concrete overlays, especially in thinner overlays, where they enhance aggregate interlock load transfer and help to retain concrete fragments that may result from premature distress. Examples of macrofibers are shown in Figure 19. The use of macrofibers is directly considered in UNOL Design (Khazanovich et al., 2020) and PavementDesigner.org. Guidance for incorporating fiber impacts in other design procedures (for overlays or conventional pavement) is provided in Roesler et al. (2019).

A separation layer must be included in the design of unbonded overlays of concrete pavement. The separation layer is usually either hot-mix asphalt concrete (dense- or open-graded) or nonwoven geotextile fabric (see Figure 20). Factors to consider in the selection and design of the separation layer are discussed in the materials section of this Guide. An additional resource for the design and use of geotextile fabric separation layers is Cackler (2017).

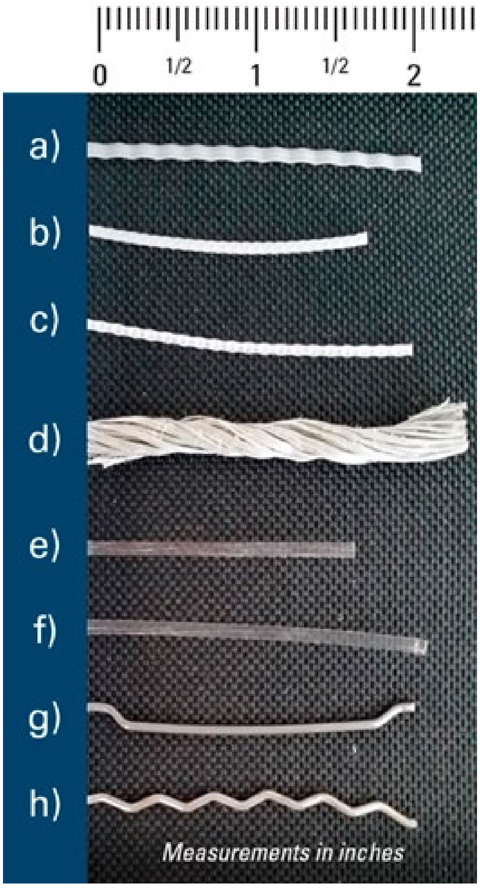


Figure 19. Example of macrofiber types: (a-c) crimped, embossed, or bi-tapered synthetic; (d) twisted synthetic; (e-f) straight fibrillated synthetic; and (g-h) hooked end and crimped steel. (Photo: Jeff Roesler, Univ of Illinois, USA).

Dowels and tie bars enhance structural behavior and are typically included in the design of unbonded concrete overlays that are thick enough to allow their use. Details of unbonded overlay joint design are included later in this Guide.

Jointed, unreinforced concrete is the most common type of concrete overlay. However, unbonded CRCP overlays have been successfully designed and constructed over both jointed and continuously reinforced concrete pavements. Appendix B of Fick et al. (2021) provides additional information on the design and construction of unbonded CRCP overlays in Belgium, France, South Africa, South Korea, Spain, the U.S., and the U.K.

Figure 20. Examples of nonwoven geotextile fabric (dark- and light-colored) and asphalt separation layers for unbonded concrete overlays. Photo: U.S. National Concrete Pavement Technology Center

Joint Layout and Design

Guidance for unbonded overlay joint layout is generally consistent with guidance for conventional concrete pavement joint layout. Representative guidance to prevent uncontrolled cracking in unreinforced conventional concrete pavement can be stated as:

- Maximum panel dimension ≤ 18-24 times slab thickness (lower values for higher foundation stiffness)
- Maximum panel aspect ratio (length/width or width/length) = 1.5
- Maximum panel length ~ 5m.

This guidance is typically applied directly to unbonded overlays with thickness ≥ 20 cm. When overlay thickness is 15 cm or less, small panels approximately 2m square are typically used. For overlay thicknesses between 15 and 20 cm, small panels offer a conservative approach to joint layout, but larger, full lane-width panels can be used successfully in mild climates (with low potential for slab curl and warp) and lower volumes of heavy traffic.

Small panel sizes result in smaller joint openings, lower curl/warp stresses, and fewer wheel loads per panel (smaller load-related stresses). These benefits often allow the use of significantly thinner overlays if they are considered in the selected pavement design procedure. Currently, only OPTIPAVE (Covarrubias, et al. 2014) and UNOL Design (Khazanovich et al., 2020) consider panel size in unbonded concrete overlay thickness design.

Unbonded overlay transverse joint locations generally can be selected without regard for the locations of transverse joints and cracks in the underlying pavement. The exception to this rule is that overlay joints should match the location and width of any expansion joints in the underlying pavement to avoid overlay blowups in warm weather when the underlying expansion joint closes.

Longitudinal overlay joints are usually located to match lane lines, regardless of the location of longitudinal joints in the underlying pavement. One possible exception is for widened lanes where overlay panels are designed to extend beyond the underlying lane-shoulder joint (to reduce load-related edge stress). Additional longitudinal joints, located away from the lane lines, are often required when the overlay is thin (<15 cm) or the width of widening exceeds 0.6 m (see Figure 21). These joints should not be located within wheel paths, where heavy traffic loads can produce high deflections, cracking and interior corner spalling).

All joint locations should be adjusted to reflect best practices for jointing around embedded utilities and drainage structures.

Unbonded overlay transverse joints are typically not doweled if the overlay thickness is less than 17 cm because minor errors in dowel alignment (especially vertical rotation) during construction can result in spalling near the joints. In such thin overlays, macrofibers have been shown to help ensure higher levels of load transfer through aggregate interlock, especially for smaller panel sizes. Thicker overlays are usually doweled, and the dowel system design is performed using the same tools and standards that apply to conventional concrete pavements. Overlay dowels are usually placed at mid-depth but, when the overlay includes cross-slope corrections, some dowels may be below mid-depth (for basket placements) or above mid-depth (for dowel bar inserter placements), as shown in Figure 22.

Figure 21. COC-U with widening, with and without tied longitudinal joint over old pavement edge on TH 212, Minnesota, USA. Photo: Matt Zeller, Concrete Paving Association of Minnesota.

Figure 22. Schematic of dowel placement using baskets or inserter when crowned section is overlaid as superelevation section

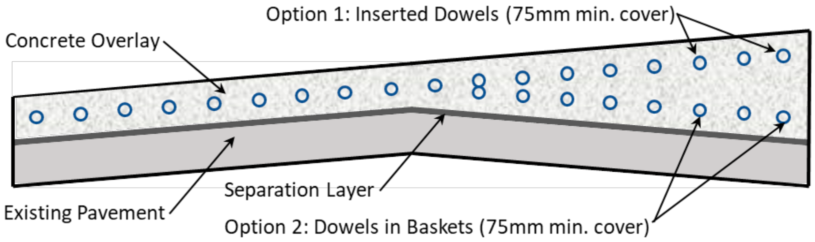


Figure 23. Examples pre-overlay repair of joint and crack spalling using cement-based mortar. Photos from Todd LaTorella, MO/KS Chapter of ACPA

Longitudinal joints in unbonded overlays are typically tied using deformed steel bars, although macrofibers may be adequate for holding joints tight in some cases. Tie bar systems should be *designed* with consideration of overlay thickness, expected frictional restraint on the interface with the underlying slab, climate conditions, distance of the joint from the nearest free edge, and other factors. Using a standard tie bar system developed for conventional pavement systems may result in over-reinforcing of the joints and the development of a longitudinal crack at some distance from the sawed or formed joint, especially when geotextile fabric separation layer is used.

Construction

Pre-overlay repairs are typically full-depth repairs and are limited to areas of the existing pavement with structural distresses that have the potential to reflect upward through the separation layer and cause distress in the overlay. These are usually only in areas exhibiting significant slab movement under heavy traffic. In areas that do require repair, foundation repairs should also be performed if necessary to stabilize the pavement system in that area. Spalled areas should be cleaned to remove loose material and filled with a stabilized material (typically asphalt patching material or cement grout) to provide a uniform surface profile for the separation layer and to prevent the overlay from "keying" into the existing pavement (see Figure 23).

If a geotextile separation layer will be used and joint faulting in the existing pavement exceeds 6mm, consider milling to reduce or eliminate the faulting before placing the fabric. Greater amounts of faulting can be accommodated with asphalt separation layers, especially if the separation layer thickness is increased.

Figure 24. Overlapping sections of nonwoven geotextile fabric, anchored with nails and washers. Photo: ACPA.

Asphalt separation layers should be constructed using high-quality, strip-resistant material and best practices for paving thin layers of asphalt. Geotextile separation layers should be rolled on the pavement surface, taking care to avoid tears and wrinkles in the fabric. Anchor the geotextile using geotextile spray adhesive, nails and thin galvanized washers (typically 5 – 7 cm diameter spaced less than 2m apart), or other suitable means (see Figures 24 and 25). Adjacent sections of geotextile should be overlapped 15 – 25 cm, with no more than 3 layers thickness in any overlap area.

Figure 25. Use of adhesive to anchor geotextile fabric. Photo: Dan King, Iowa Concrete Paving Association.

Figure 26. Example of geotextile fabric extending beyond pavement edge for drainage.

Drainable separation layers, whether asphalt or geotextile, must be extended to drainage inlets, the pavement edge, or other suitable outlet for the water (see Figure 26).

Concrete overlay placement should follow separation layer placement as closely as possible and using best practices for concrete paving. If dowel baskets and tie bar chairs are used, it is essential that they be properly anchored or secured to prevent movement during paving. Moisten the separation layer immediately before concrete placement to prevent absorption of water from the paving mixture. As always, concrete curing is important, especially if the overlay thickness is less than 20cm, because thin pavements are especially susceptible to the effects of drying shrinkage and curl/warp.

Transverse joint saw cut depths are typically ¼ to 1/3 the overlay thickness, but the depth may need to be increased further (without cutting any embedded bars) to ensure joint activation when geotextile fabric is used as the separator layer. Fabric separator layers result in very low friction at the interface between the overlay and existing pavement, so shrinkage restraint stresses are much lower – sometimes too low to cause cracking below the saw cuts at early ages, resulting in "dominant joints" that activate and open widely while other joints do not open at all.

Longitudinal contraction joints are usually formed or cut to 1/3 the overlay thickness. Deeper cuts can be made to ensure joint activation, but care must be taken to avoid damaging the tie bars.

The timing of joint sawing is important – too early results in joint raveling, too late results in uncontrolled cracks and spalled joints. Note that the joint sawing window is often smaller for thin concrete overlays than for thick overlays and conventional concrete paving. In addition, paving rates are often higher (more lineal meters per hour) with thin placements; therefore, more saws and operators may be required (or the paver may need to operate below capacity) to keep sawing operations with the sawing window.

Unbonded concrete overlay joints can be filled or sealed, or left unsealed, depending on anticipated traffic levels and vehicle speeds, local climate, and panel size. Joint sealant is increasingly recommended with larger panels, higher traffic levels, lower vehicle speeds, and colder climates (ACPA, 2018). Joint sealing/filling should be performed after all joints have activated and joint widths have stabilized, which can be weeks or months after construction in some cases.

BONDED OVERLAYS OF ASPHALT-SURFACED PAVEMENT

Bonded overlays of asphalt-surfaced pavements have become increasingly common, especially as a long-term, economical solution to chronic rutting and shoving of asphalt pavement surfaces (see Figure 27), particularly near intersections. They also offer potential for added load-carrying capacity and extended service. Bonded concrete overlays are best suited for existing pavements with: 1) at least 75 mm of asphalt surfacing (after any pre-overlay milling) and good foundation support; 2) structural distress (e.g., fatigue cracking) is minor or economically repairable before overlay placement, and 3) no stripping in any asphalt layer. The good bond assumed in design is easily achieved with good construction practices. Joint sealing will help to protect the bond in areas subject to freezing.

Bonded overlays can be designed and constructed for composite (asphalt over concrete) pavements if the asphalt layer meets the thickness and quality requirements described above and if there are no durability problems in the underlying concrete. In such cases, the concrete is considered to be a "very strong" foundation to the existing asphalt pavement. Alternatively, the overlay can be designed as an unbonded overlay of the concrete, with the existing asphalt layer acting as a separation layer (with an additional leveling course of asphalt or geotextile fabric layer, if necessary), or the asphalt can be removed and replaced with a new separation layer.

When properly designed and constructed, bonded overlays of concrete pavement can be expected to provide up to 30 years of service.

Design Concepts and Procedures

Bonded concrete overlays are assumed to develop a full, complete bond with the underlying pavement structure such that the overlaid pavement behaves as a single monolithic layer. Since asphalt and concrete have significantly different stiffnesses, bonded concrete overlays of asphalt cannot be designed using a structural deficiency approach (as bonded overlays of concrete are). In addition, the stiffness of asphalt varies with temperature and age, so the stiffness of

Figure 27. Examples of rutted, shoved asphalt pavement. Photos: Top - Cimbeton Publication T60; Bottom – pavementinteractive.org.

the overlaid pavement also varies accordingly. Special design procedures have been developed to account for these factors and should be used for bonded overlays of asphalt-surfaced pavement.

One of the most popular and commonly used procedures for COA-B in the U.S. is the free web-based program BCOA-ME (BCOA-ME (pitt.edu)); Li, et al. (2013) provides technical documentation for this procedure. AASHTO's PavementDesign ME also includes a module for designing "short-jointed plain concrete pavement" (SJPCP) on asphalt pavement, which is based on (but more limited than) the BCOA-ME program. BCOA-ME is currently the only design method that considers three modes of cracking and joint faulting as performance criteria. Thickness design inputs typically include structural, materials, panel geometry, traffic, climate inputs and failure criteria.

Cimbéton also provides tabulated design guidance for bonded concrete overlays of asphalt (called béton de ciment mince collé or "BCMC") in the publication T60 (Cimbéton 2004a). It provides consideration of various traffic levels, loading conditions, and material properties in recommending design thicknesses for several applications, including classic roadways, rotary intersections, rest areas, bus stops, industrial pavement, and airport applications. Cimbéton's T61 publication (2004b) documents information for several construction cases in each of these applications.

One challenge in COA-B design is often in determining an input value for the modulus of foundation support, k, for the overlaid pavement structure. The k value should represent the combined effect of all layers immediately below the asphalt, including the concrete for existing composite pavements. It is recommended that the effective k value of the materials below the asphalt be limited to 300 kPa/mm because very high values of k may result in unrealistic overlay thickness designs..

Bonded concrete overlays of asphalt typically range in thickness from 5 – 17 cm and design procedures limit design thicknesses to approximately this range. Overlays thicker than 17 cm may be bonded in practice, but the thick concrete layer is so stiff that the asphalt provides little structural contribution and is better considered a stabilized base for an unbonded system.

Conventional concrete mixtures are commonly used for bonded overlays of asphalt pavement. The mixture components (aggregates, water, SCMs and chemical admixtures) and proportions must be chosen to balance the need for ease of placement and finishing (especially for thin overlays) with the need to develop good bond. The inclusion of macrofibers is useful for slowing the development and decreasing the width of cracks (see Figure 28), for enhancing aggregate interlock load transfer at joints, and for preventing slab migration. The benefits of using macrofibers in bonded overlay design is considered directly in BCOA-ME and can be considered indirectly in other procedures using modifications of effective pavement strength described in the materials section of this Guide.

Figure 28. Reflective cracking in COA-B without fibers (left) and with macrofibers (right). Photos: Snyder and Associates.

Dowels and tie bars may be included in thick COA-B (>10 cm for tie bars, >13 cm for dowel bars) subject to constructability considerations (e.g., concrete cover requirements, alignment requirements, etc.). Short tie bars have been successfully used for thin overlays with small panels by anchoring them on the asphalt pavement surface before paving. Macrofibers may reduce or eliminate the need for dowels and tie bars, as noted previously.

Bonded overlays of asphalt pavement are exclusively designed as jointed pavement. CRCP overlays have been placed over asphalt pavement, but literature indicates that most are thicker overlays (> 15cm) that were likely designed as unbonded overlays (Appendix B of Fick et al. (2021)), including overlays in France (Tayabji et al. 1998), Belgium (Rens 2006), and South Africa (Brink and Pickard, 2008). However, Chen et al. (2016) describe the placement of thin bonded CRCP overlays on asphalt pavement in transition areas of between jointed bonded overlays and other pavement types in Texas.

Joint Layout and Design

Panel dimensions are a crucial factor in COA–B overlay behavior. Smaller panels experience smaller load-related bending stresses and can, therefore, be designed with less thickness. Similarly, thermal and drying shrinkage restraint stresses are reduced with smaller panel dimensions (see Figure 29). For these reasons, panel dimensions are typically an input in COA-B thickness design procedures.

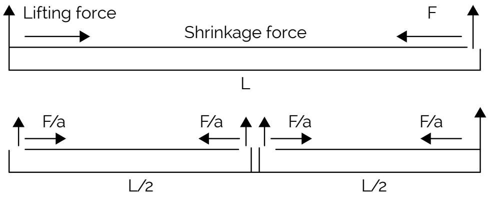


Figure 29. Effect of panel size on thermal (curl) and drying shrinkage stresses. Image: Fick, et al. 2021.

Panels are typically designed to be approximately square with maximum panel dimensions of 12 – 18 times the slab thickness for overlays up to 13 cm thickness, and 18-24 times the slab thickness for overlays between 13 and 17 cm thickness. Panel aspect ratio (the ratio of the longer side length to the shorter side length) should be approximately 1:1 and should never exceed 1.5:1.

Longitudinal joints in COA–B overlays should be located away from wheel paths because panel corners located within wheel paths often develop load-related cracks and spalls (see Figures 30 - 31). For this reason,

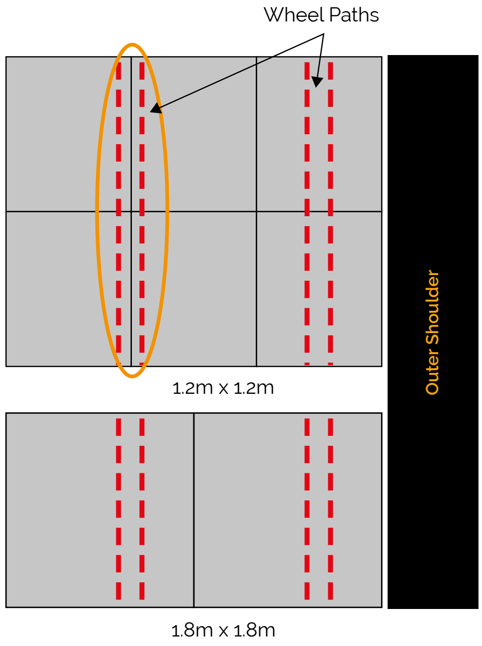


Figure 30. Schematic illustrating wheel path placement on different panel sizes. Image: Julie Vandenbossche, Univ. of Pittsburgh.

Figure 31. 7.5 cm bonded concrete overlay of 25 cm asphalt, 1.8m panels (left) and 1.2m panels (right), 6 years of service, ~6M 80-kN axle loads. Photos: Julie Vandenbossche, Univ. of Pittsburgh)

full-lane or half-lane panel widths generally perform better than (and are preferred to) other panel widths.

For COA–B overlays less than 15 cm thick, panels are typically 1.8 m squares. Joint locations should always be adjusted to reflect best practices for jointing around embedded utilities and drainage structures.

Construction

Preoverlay repairs are generally not required if rutting < 50mm and no major surface deterioration or asphalt layer stripping is present. In other cases:

- Small potholes with no base damage – remove loose material, fill with PCC during paving
- Potholes with base damage – full-depth repair of base and pavement
- Shoving, Rutting > 50mm - mill
- Fill wide transverse cracks with grout, sealant, or patch material. If potential for reflective cracking exists (e.g., if $T_{AC} \geq 2T_{PCC}$), reinforce existing transverse cracks (see Figure 32) or match transverse joint location in overlay (see Figure 33).
- Unstable concrete in existing composite pavement: Full-depth repair with base repair, if necessary

Figure 33. Example of reflective crack in COA-B caused by failure to match joint location or provide reinforcing steel over crack. Photo: Julie Vandenbossche, Univ. of Pittsburgh.

Figure 32. Deformed bars stapled over asphalt crack to prevent reflective cracking. Photo: James Cable, Iowa State University.

Milling of existing asphalt (see Figure 34) is typically done for one or more of several reasons, including:

- Minimize increases in elevation of the overlaid pavement surface
- Remove major distortions in the existing asphalt surface
- Reduce high spots to produce more uniform overlay thickness and reduce concrete overlay volume.
- Allow overlay surface to match elevations of curbs and adjacent structures.
- Enhance bond potential by increasing surface texture of very smooth existing asphalt surfaces.

Adequate bond between concrete and asphalt is usually achieved without milling if the above conditions do not require it.

After any required preoverlay repairs are complete, the existing pavement surface must be adequately protected from damage by service and construction traffic. Heavy loads and turning movements can delaminate or otherwise damage existing asphalt.

The prepared surface must be cleaned before paving. Power brooms and air-blasting are commonly used. The concrete should be placed on the clean, temperature-controlled (<50°C surface temperature), moistened (but free of standing water) surface. Conventional concrete placement and paving practices are used, with particular attention paid to curing (curing compound is often applied at 1.5-2x normal rates).

Figure 34: Milling of asphalt for profile and bond. Photos: Cimbeton 2004 (up) and U.S. National Concrete Pavement Technology Center (down)).

Figure 35. Many saws for sawing many joints. Snyder, 2019.

Joint sawing is typically performed as soon as the concrete has developed enough strength to allow sawing without significant raveling. Small panel sizes mean many more joints to saw, and thin overlays often have short sawing windows; therefore it is essential to have enough saws (including spares) and operators to complete all sawing within the sawing window (see Figure 35). The use of lightweight, early-entry saws is common (see Figure 36).

Figure 36. Using early entry joint saw (Cimbeton, 2004a).

COA-B joints are typically cut to 1/4 – 1/3 the overlay thickness. However, the presence of asphalt surface rutting or corrections in pavement profile, cross section, or super-elevation can increased overlay thickness in some areas, requiring increase saw cut depth in these same areas to ensure control of cracking.

Bonded concrete overlay joints should be filled with sealant material in wet-freeze climates to protect the bond interface from ice formation, which could cause delamination and cracking (see Figure 37). Joint filling should also be considered in other climates when there is risk of infilling with incompressible materials. Joint filling may require that the saw cut be at least 5mm wide. Self-leveling or hot-poured asphalt-based sealant materials are used for joint filling without backer rods..

Figure 37. Differences in COA-B performance in Minnesota (USA) for sealed and unsealed joints. Photo: Tom Burnham, Minnesota DOT.

UNBONDED OVERLAYS OF ASPHALT-SURFACED PAVEMENT

Most thick (> 15 cm) concrete overlays of asphalt pavements are designed assuming an unbonded condition between the overlay and existing pavement. Many thinner (10 – 15 cm) overlays on composite and thin asphalt pavement are also designed as unbonded. Thickness design for unbonded overlays of asphalt-surfaced pavements is effectively a new pavement design on a very stiff foundation. This design approach minimizes the need for pre-overlay repair, offers relative ease of construction, and provides high reliability. A separation layer is rarely placed between the concrete overlay and existing asphalt pavement; this is discussed further in the design concepts section below.

When properly designed and constructed, unbonded overlays of concrete pavement can be expected to provide a service life that is comparable to that of a new concrete pavement.

Design Concepts and Procedures

In design, COA-U are typically designed as new concrete pavement that is supported by a composite foundation layer comprising all layers below the overlay. The interface condition and structural support are usually modeled the way that an asphalt-treated base is modeled in new pavement design for the chosen design procedure. For example, AASHTOWare Pavement ME Design has a module to provide inputs for the mechanistic-empirical design of unbonded concrete overlays of asphalt pavement, but it uses the same structural analysis and performance models as for conventional concrete pavement design.

Because the overlay is unbonded and its performance is not strongly linked to distress in the existing pavement, pre-overlay repairs are typically few and are planned only for large areas of reduced support or (for existing composite pavements) where slabs or slab fragments are unstable and move visibly under heavy traffic. Doing extensive pre-overlay repair work is rarely cost-effective because it does not significantly increase the effective stiffness of the existing pavement and, therefore, does not significantly decrease the overlay thickness.

Unlike unbonded overlays of concrete pavement, a separation layer is rarely designed or selected for placement between the concrete overlay and existing asphalt pavement because the viscoelastic behavior of asphalt and the lower stiffness of asphalt material rarely allow reflection of existing pavement distresses through the concrete overlay. Further, any bond that does develop between the two layers reduces load-related stresses in the concrete, making the thickness design more conservative.

Unbonded overlays are thicker than bonded overlays for any given project design, with a typical minimum thickness of 125 mm (100 mm for lightly trafficked pavement). For very heavy traffic and long service life, unbonded overlays may be almost as thick as a new concrete pavement on a conventional foundation.

Conventional concrete paving mixtures are commonly used for unbonded concrete overlays. Macrofibers are finding increased favor in unbonded concrete overlays, especially in thinner overlays, where they enhance aggregate interlock load transfer and help to retain concrete fragments that may result from premature distress. The use of macrofibers is directly considered in PavementDesigner.org. Guidance for incorporating fiber impacts in other design procedures (for overlays or conventional pavement) is provided in Roesler et al. (2019).

Figure 38. Construction of doweled and tied COA on A99 near Munich, Germany (Riffel, 2010).

Dowels and tie bars enhance structural behavior and are typically included in the design of unbonded concrete overlays that are thick enough to allow their use (see Figure 38). Details of unbonded overlay joint design are included in the next subsection of this Guide.

Jointed, plain concrete is the most common type of concrete overlay of asphalt-surfaced pavement. However, unbonded CRCP overlays have been successfully designed and constructed over asphalt-surfaced pavements since the 1960s. These have been constructed mostly in the U.S., but also in Belgium, France, and South Africa (see Figure 39). Appendix B of Fick et al. (2021) provides additional information on the design, construction, and performance of unbonded CRCP overlays of asphalt-surfaced pavements.

Figure 39. Construction of CRC inlay of asphalt pavement in Belgium (Rens, 2006).

Joint Layout and Design

Guidance concerning panel dimensions, joint layout and design, and joint sealing for COA–U overlays is essentially identical to the guidance provided previously for COC–U overlays.

Design procedures that consider the impact of small panel size on overlay thickness design include the SJPCP module in AASHTOWare PavementME Design and OptiPave (Covarrubias, et al. 2014). In addition, PavementDesigner.org provides maximum recommended joint panel dimensions for doweled or undoweled overlay designs.

Construction

Unbonded concrete overlays of asphalt-surfaced pavement (COA-U) rarely require significant pre-overlay repair because the overlay will typically bridge intact, moderate-severity distresses such as fatigue cracking and raveling. Further, repair of such areas is unlikely to change the overlay thickness design, which is not sensitive to foundation stiffness. What is required is that the existing pavement provide reasonably uniform support to the overlay and that there are no large areas with significantly different support stiffness. For composite pavements, there should also be no unstable panels or panel fragments. Potholes, wide joints and cracks, and similar features should be filled or overlaid to prevent the overlay from interlocking with the existing pavement. The goal of the pre-overlay work is to provide *reasonably uniform* support to the overlay, not to restore the original pavement.

Milling of the existing asphalt surface may be performed to eliminate unstable or unsuitable asphalt layers or deep ruts. Milling may also be useful for changing pavement surface profile or cross-slope to address clearance issues, enhance surface drainage, or reduce the need to address safety and geometric issue (e.g., guardrail height, ditch slopes, etc.). At least 75mm of sound asphalt must remain after milling.

After any required preoverlay repairs (including milling) are complete, the existing pavement surface must be adequately protected from damage by service and construction traffic. Heavy loads and turning movements can delaminate or otherwise damage existing asphalt.

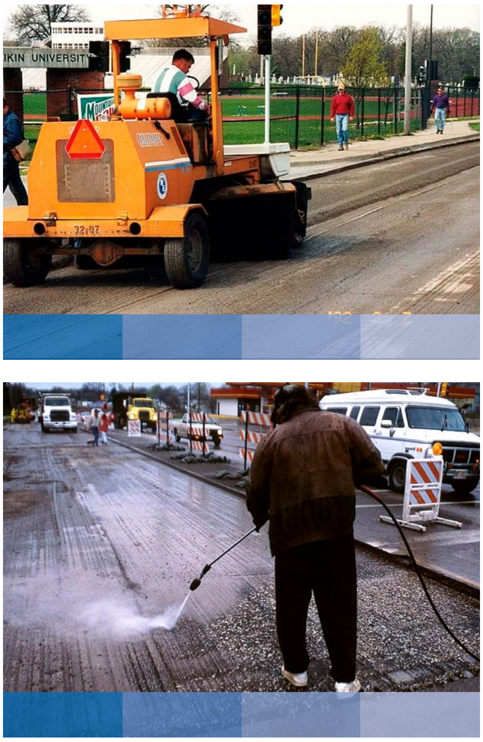


Figure 40. Cleaning milled surface with power broom (left) and water blasting (right). Images: U.S. National Concrete Pavement Technology Center, Iowa State University.

The guidance for surface cleaning (see Figures 40 and 41), concrete placement and paving, curing, and joint sawing for COA-U are the same as for COA-B. Unbonded concrete overlay joints can remain as narrow-width (~3mm) single saw cuts and be left unfilled, or can be widened sufficiently (~6mm) to allow joint filling with liquid asphalt or other self-leveling filling material (and no backer rod). The cost-effectiveness of sealing or filling COA-U joints has not been established.

Figure 41. Image of cleaned, milled asphalt surface (RIffel 2010).

4 CONCRETE MIXTURES AND OVERLAY MATERIALS

Concrete pavement overlays are typically constructed with conventional paving materials. The primary constituents of concrete overlay mixtures are cement, aggregate and water, but overlay mixtures may also include supplementary cementitious materials (SCMs), chemical admixtures, conventional steel reinforcing and/or macrofibers. Dowels, tie bars, separation layers and/or joint seals may also be a part of the overlay design. The proper selection and proportioning of concrete mixture components helps to ensure constructable fresh mixture characteristics, development of specified strength and durability characteristics, and long service life. Material selections for dowel, tie bar, separation layer and other overlay component materials must also be performed to ensure their durability and correct structural function. Discussion of concrete mixture components and overlay materials follows.

CONCRETE MATERIALS

Cementitious Materials

The same types of cement used for conventional concrete paving are used in concrete overlay mixtures. In Europe, the most common are Portland cement CEM I, Portland-composite cement CEM II, and blast furnace slag cement CEM III/A (EN 197-1). According to EN206, the addition of supplementary cementing materials (e.g., fly ash, granulated ground blast furnace slag, etc.) can be used in combination with the cement (most often with CEM I), taking into account the k-value (efficiency factor), the equivalent performance concept, and the national provisions in the place of use.

The types and quantities of cement and possible additions have an impact on set time and construction operations. Delayed set time can extend construction windows in hot weather, but may result in plastic shrinkage cracking in cool weather. Slower set and strength gain also impact the timing of sawing operations. The use of high early strength cements and high cementitious contents are not recommended because of their potential for increased cracking due to drying and thermal shrinkage.

Aggregates

The aggregates selected, whether comprising natural or recycled products, should generally conform to the physical, mechanical, and chemical requirements of applicable standards for concrete aggregate (e.g., ASTM C33, EN 12620). The aggregate top size should be limited to 1/3 the nominal overlay layer thickness. As with conventional paving mixtures, the use of a well-graded combined aggregate system will provide better workability (for improved placement, consolidation and finishing), reduced paste demand, and better aggregate interlock properties at joints and cracks. When less paste (water and cement) is used, permeability, shrinkage and costs also decrease, resulting in a more durable and economical mix.

For bonded overlays of concrete pavement, the coefficient of thermal expansion (CTE) of the overlay aggregate should be similar to that of the aggregate in the existing pavement. This will reduce the potential for debonding by helping to ensure that the two layers expand and contract similarly under temperature changes.

Water and Admixtures

The quality of water required to produce overlay concrete mixtures is identical to that required for conventional paving concrete: it must be free of any impurities that would adversely affect concrete set time, strength or durability. Water that is not potable (including water that is recycled from concrete production and washing operations) should be tested before use.

Chemical admixtures commonly used in conventional paving concrete are also used in concrete overlay mixtures. These include air-entraining admixtures (freeze-thaw and scaling resistance), water reducers (reduced water content and/or improved workability), set accelerators (for use in cool weather), and set retarders (to extend workability/finishability in warm weather). Chemical admixtures should be used with the same cautions in overlay concrete as for conventional paving mixtures, including assuring the compatibility of selected admixture combinations prior to use. Special care must be employed when using set retarding admixtures with thin concrete overlays, which can be particularly susceptible to shrinkage cracking in warm and/or windy weather.

In-depth discussions of water and admixture considerations in concrete mixtures can be found in Taylor, et al (2019).

Macrofibers

Fiber-reinforced concrete (FRC) has been successfully used for concrete overlays since the 1980s and especially in the last 15 years (Fick, et al. 2021). Using *macro*fibers in concrete overlays has been shown to:

- Provide additional structural capacity (extending service life or allowing thinner overlays);
- Reduce crack widths (see Figure 26);
- Increase and maintain load transfer efficiency across joints and cracks (compared with undoweled, unreinforced joints and cracks), thereby extending service life; and
- Reduce panel migration.

*Micro*fibers can also be used in concrete overlays to reduce the potential for plastic shrinkage cracking, but they provide no structural benefits and are not a substitute for *macro*fibers.

Macrofibers are typically synthetic or steel, measure 2.5 – 6 cm in length, and have an aspect ratio (length:width) of between 30 and 100. Figure 19 shows several examples of steel and synthetic macrofibers. The required macrofiber dosage rate depends on the fiber type and configuration, concrete strength, specified residual (post-cracking) strength, and more. In overlay applications, dosage rates typically range from 2 – 5 kg fibers/m^3 concrete for synthetic fibers and 15 – 45 kg fibers/m^3 concrete for steel fibers (about 0.2 – 0.5 percent by volume, but note that the most common use is 3-4 kg/m^3 for synthetic fibers and 25-35 kg/m^3 for steel fibers).

Concrete workability may decrease with the addition of macrofibers. Water-reducing admixtures can be used to compensate for slump loss and improve workability, consolidation and finishing characteristics. Concrete air content may also be indirectly affected by the use of macrofibers. Trial batches are recommended to verify plastic mix properties and determine the correct sequence for fiber addition during batching (Fick et al. 2021).

The compressive and flexural strengths of FRC are usually not significantly different from those of similarly proportioned plain concrete. The post-cracking strength, toughness and flexural fatigue performance of the concrete are generally improved, however (Roesler et al. 2019). ASTM C1609 recommends evaluating the residual strength (f_{150}) of FRC mixtures intended for use in concrete pavement overlays. See EN 14651 for guidance on determining the residual flexural strength of steel fiber-reinforced concrete. Another resource is the U.S. Concrete Pavement Technology Center's "Residual Strength Estimator" spreadsheet tool (Residual-Strength-Estimator-for-FRC-Overlays-April-19-2019_public.xlsx (live.com)), which was developed to assist pavement engineers in selecting a residual strength value for project-specific COA-B design conditions. Roesler et al. (2019) provides additional detail on the use of FRC for concrete overlays.

OTHER CONCRETE OVERLAY MATERIALS

Dowels and Tie Bars

Dowels are not typically used in concrete overlays less than 175 mm thick because of concerns about ensuring proper dowel position while maintaining adequate concrete cover for corrosion protection and shear load transfer (typically at least 75mm). Dowels are never used in bonded concrete overlays because their transfer of shear loads would likely cause loss of bond and delamination at the interface between the overlay and existing pavement.

When dowels are used in concrete overlays, they should conform to applicable specifications for pavement dowels (e.g., EN

13877-3, AASHTO M254, ASTM A1078, etc.) The size and layout of the dowels should be designed for the intended project structure and design traffic, and suitable dowel corrosion protection (or the use of corrosion-resistant materials) should be chosen to ensure proper function over the intended overlay service life. Snyder (2011) provides detailed information on dowel load transfer system design.

Tie bars are typically not recommended for concrete overlays with thickness less than 125 mm to ensure adequate concrete cover and avoid constructability issues. When tie bars are used, they are typically deformed bars, 14-20mm in diameter, and are typically spaced and are typically spaced about 75 cm apart (although greater or lesser spacings may be used). Suitable corrosion protection (or corrosion-resistant materials) should be used. Metallic bars conforming to EN 13877 (or ASTM A615 or AASHTO M31) are most common, usually with epoxy coating. Fiber-reinforced polymer (FRP) materials are increasingly being promoted for use in both dowel and tie bar applications; appropriate design modifications (i.e., size, length, spacing or layout, etc.) must be made to account for differences in the properties of FRP and steel.

Separation Layer

A separation layer is required for the construction of all unbonded concrete overlays of existing concrete pavement. Figure 20 presents photos of several types of common separation layer materials. Separation layers are rarely used (or needed) for unbonded overlays of asphalt pavement and are never used for bonded concrete overlays of any pavement (Fick, et al. 2021).

Until recently, asphalt concrete (either dense-graded or permeable) was the most common separation layer material. The layer thickness was generally 25 – 50 mm (thick enough to cover all irregularities in the existing pavement surface, including joint faulting). Aggregate top size was selected as a function of overlay thickness (typically 1/3 the layer thickness or less) and anti-stripping additives or other measures were employed for protection against moisture-related degradation. Potential issues with asphalt concrete separation layers include overlay settlement and cracking due to poor asphalt mix design, inadequate compaction during construction, secondary consolidation under traffic, and asphalt stripping.

Nonwoven geotextile fabrics have recently gained popularity as an overlay separation material in the U.S. (based on German use of fabric interlayers in new pavement constructed over cement-treated base, as documented by Leykauf and Birmann (2006). Geotextile fabrics offer the advantages of economy (often less than ½ the cost of asphalt concrete interlayer construction), excellent isolation/bond prevention properties, and reduced construction time. They also can provide effective drainage of entrapped water between layers if they are outlet to the pavement edge or a drainage system.

Separation layer fabrics are typically specified in terms of their weight and thickness (which vary with overlay thickness) and color. Guide specifications for geotextile separation materials can be found in Fick and Harrington (2016), and a broader overview of the performance of overlays constructed using geotextile materials is presented in Cackler (2017).

5 PLAN DEVELOPMENT, CONSTRUCTION DETAILS AND MANAGEMENT OF TRAFFIC

Chapter 7 of Fick, et al. (2021) provides extensive discussion of the development and assembly of plans for concrete overlay projects. The level of detail necessary in concrete overlay construction drawings varies greatly with the location, geometric features, and management of traffic (MOT) requirements for the project. For example, plan sets for pure overlay projects (i.e., with no profile grade and cross-section modifications) in rural applications may be comparable in size and scope to similarly scoped asphalt overlay projects, while urban projects and more complex rural situations often require additional drawing sheets and details.

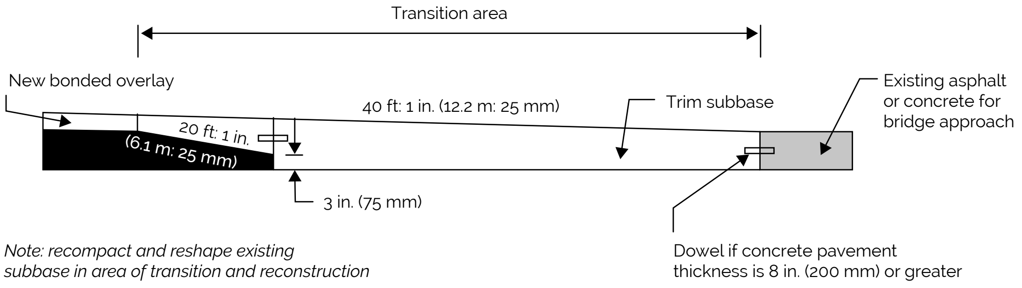
Gross and Harrington's 2018 *Guide for the Development of Concrete Overlay Construction Documents* provides example drawing sheets and construction details that are useful starting points for many overlay projects. A collection of typical overlay plan sheets (with explanatory notes) can be found at: Typical Overlay Construction Plans (iastate.edu).

The project plan set will need to include typical construction details concerning joint layout (as dictated by the overlay design processes described previously) and joint construction (i.e., saw cut depth and width, dowel and tie bar types, sealant, etc.), as well special details for transitions to intersecting side roads or driveways and adjacent pavement sections at the project ends. Figure 42 presents an example detail for transitioning from a bonded overlay of asphalt pavement to existing pavement at the project end.

Urban areas require additional special details, such as handling of existing curb and gutter, utility access, and intersection joint layouts. Additional discussion and details are provided in Fick, et al. (2021).

One of the most important aspects of overlay construction is the management of traffic through the duration of the project while providing a safe work zone for construction and access to residences and local businesses. Road closures, while favorable for work site safety and speed of construction, are often not possible or practical because detour options are inadequate. Other MOT options will depend on factors such as: overlay thickness, pavement width, edge drop-off limits (safety criteria), required number of lanes open to traffic during construction, available right-of-way (for construction activities and temporary lanes), etc.

Figure 42. Example COA-B transition detail (Fick, et al. 2021).



Note: recompact and reshape existing subbase in area of transition and reconstruction

Chapter 7 and Appendix D of Fick, et al. (2021) provide information on MOT options for various overlay types and project conditions, including various numbers of travel lanes in each direction, different shoulder types, and different paving configurations (conventional vs. zero-clearance) – see Figure 43, for example. Some of these options are also included in the "Typical Overlay Construction Plans" described above.

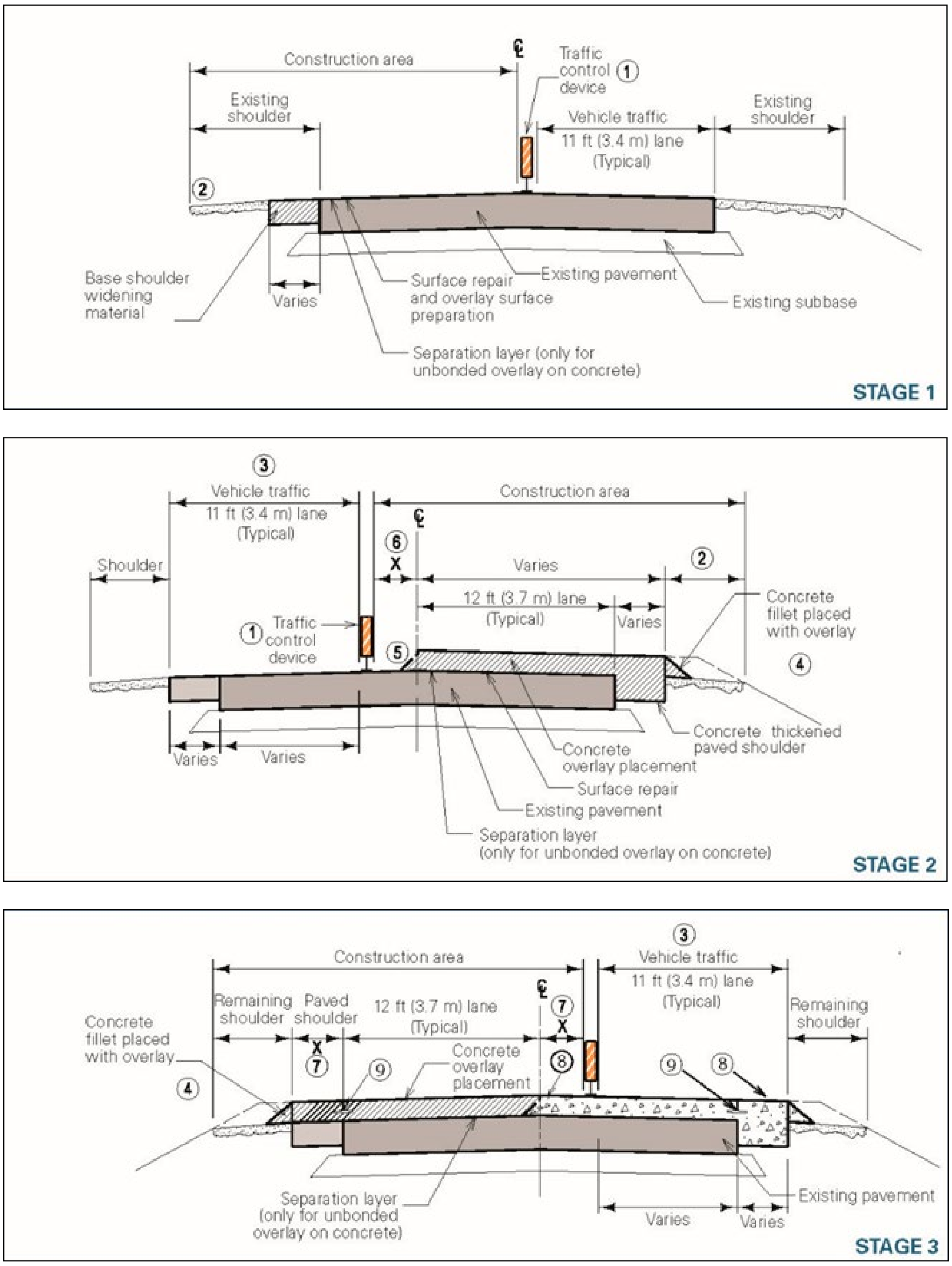


Figure 43. Example 3-stage MOT plan for concrete overlay construction on a two-lane roadway with paved shoulders (Fick, et al. 2021).

6 PERFORMANCE OF CONCRETE OVERLAYS

When properly designed and constructed with recommended practices and durable materials, concrete overlays reliably provide good ride quality and service life consistent with the expectations described for each overlay type in this guide. The most common causes of overlay performance issues have been:

1. inappropriate application (e.g., placing a bonded concrete overlay on a distressed or inadequately repaired pavement), and
2. inadequate construction quality (e.g., failure to adequately separate unbonded overlays, failure to adequately bond bonded overlays, etc.)

Several resources document the history and excellent performance of concrete overlays, including:

- *Technical Brief:Performance History of Concrete Overlays in the United States* (Fick and Harrington, 2014)
- *Concrete Overlay Performance on Iowa's Roadways* (Gross et al. 2017)
- *NCHRP Project 1-61: Evaluation of Bonded Concrete Overlays on Asphalt Pavements* (Pierce 2021)
- *Performance of Concrete Overlays on Illinois* Interstates, 1967 through 2016 (Heckel and Wienrank 2018)

Descriptions of many concrete overlay project in Europe (and performance histories of some) can be found in the numerous references cited in this Guide. Cimbéton (2004b) describes numerous "BCMC" (COA) projects constructed for a wide range of applications.

7 REPAIR OF CONCRETE OVERLAYS

Well-designed and constructed concrete overlays provide excellent performance and long life, as documented above. However, minor maintenance and rehabilitation may be necessary during an overlay's service life. Fortunately, concrete overlay repairs are similar to (and often easier to perform than) repair techniques for conventional concrete pavements.

Repairs of Thick (≥ 17 cm) Unbonded Overlays

Conventional repair techniques and procedures used for conventional concrete pavements are applicable to unbonded overlays that are 17 cm or more in thickness. Such techniques include: partial-depth repair, full-depth repair, dowel bar retrofit, cross-stitching, diamond grinding and grooving, and joint resealing (Fick, et al. 2021). Most pavement agencies have standard specifications and plan details for these repair techniques.

Figure 44. Techniques for removing thin concrete overlay panels. Photos: Julie Vandenbossche, Univ. of Pittsburgh.

Repairs of Unbonded Overlays Less Than 17 cm Thick and All Bonded Overlays

Repairs of bonded overlays of asphalt and any unbonded overlay are typically full-depth (of the overlay) and are performed after sawing full-depth around the perimeter of the panel to be removed, which facilitates removal by jackhammer or other construction equipment (see Figure 44). After panel removal, the material below the panel should be inspected and removed or replaced, if necessary, taking care to re-establish the required bond condition. For overlays of asphalt, it is common to replace deficient asphalt with concrete, usually placed in a single placement with the repair rather than as separate placements for the asphalt repair and the overlay replacement. In all cases, replacement panels are constructed, finished and cured using typical concrete materials and overlay construction methods (including techniques and materials for accelerated repair and return to service, if required).

Repairs of bonded concrete overlays of concrete are typically performed as full-depth repairs of the entire concrete pavement system (overlay and original pavement) in a single monolithic repair using conventional full-depth repair techniques.

Other common repair methods for thinner overlays include diamond grinding and grooving and joint resealing and crack sealing. Partial-depth repairs are not commonly performed on bonded and thin unbonded overlays (Fick, et al. 2021).

8 CONCLUSION

Concrete overlay options exist to provide cost-effective, long-life rehabilitation options for street and highway pavements in almost any condition. Concrete overlay design procedures and construction techniques have evolved over more than 100 years and have been proven to provide reliably good results. Table 1 provides a summary of typical applications and design parameters for various types of concrete overlays.

For thin concrete overlays, the importance of good curing and timely joint sawing cannot be overstated. Traffic control options have been developed to ensure safe construction zones for construction workers while maintaining traffic flow and access to businesses and residences.

When properly designed and constructed with durable materials, concrete overlays offer smooth, reliable, long-lasting pavement with much shorter construction time and much lower costs than conventional pavement reconstruction.

Table 1. Summary of typical applications and design parameters for various overlay types (Adapted from Fick, et al. 2021).

Overlay Type	Typical expected service life	Typical existing pavement condition	Typical concrete slab thickness	Typical maximum panel dimension	Dowels in transverse joints?	*Tied longitudinal joints?	Recommended design procedures	Macrofibers directly considered in design procedure?
Concrete on Asphalt–Bonded (COA-B)	Up to 30 years	Fair to Good	10–15 cm	Width: ½ lane; Length: 2m	Yes (only for thickness ≥ 18 cm)	Yes (when thickness ≥ 10cm).	AASHTOWare Pavement ME Design (SJPCP module), BCOA-ME	Yes for BCOA-ME. Modify concrete strength inputs for others.
Concrete on Concrete–Bonded (COC-B)	Up to 30 years	Fair to Good	5–10 cm	Match existing joints and cracks	Not in overlay	Not in overlay	AASHTOWare Pavement ME Design, PavementDesigner.org	Yes for PavementDesigner.org. Modify concrete strength inputs for others.
Concrete on Asphalt-Unbonded (COA-U)	Same as new pavement design	Deteriorated to Good	20-30 cm for heavy truck routes; 15-20 cm for others.	18-24 times slab thickness, 4.6 m maximum	Yes (only for thickness ≥ 18 cm)	Yes	AASHTOWare Pavement ME Design, PavementDesigner.org	Yes for PavementDesigner.org. Modify concrete strength inputs for others.
Concrete on Concrete–Unbonded (COC-U)	Same as new pavement design	Deteriorated to Good	20-30 cm for heavy truck routes; 15-20 cm for others.	18-24 times slab thickness, 4.6 m maximum	Yes (only for thickness ≥ 18 cm)	Yes	AASHTOWare Pavement ME Design, UNOL Design	Yes for UNOL Design. Modify concrete strength inputs for others.
Unbonded Concrete Overlays (COA-U and COC-U) with Small Panel Sizes	Same as new pavement design	Deteriorated to Good	12–18 cm	Width: ½ lane; Length: 2m	No	Yes (when thickness ≥ 10cm).	AASHTOWare Pavement ME Design, UNOL Design (only for COC-U)	Yes for UNOL Design. Modify concrete strength inputs for others.

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Concrete overlay of asphalt-surfaced road in Daviess County, Indiana, U.S., 2019, 15 cm thick.
Photo: ACPA.

Fiber-reinforced concrete overlay of asphalt-surfaced local road Grant County, Indiana, U.S., 2020, 15 cm thick.
Photo: ACPA.

Unbonded concrete overlay of asphalt pavement on U.S. Route 69 near Caddo, Oklahoma, U.S., 30 cm thick. Photo: ACPA.

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