Concrete Overlays for Pavement Rehabilitation

Reported by ACI Committee 325

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This report provides information on the use of concrete overlays for rehabilitation of both concrete (rigid) and asphalt (flexible) pavements. Selection, design, and construction of both bonded and unbonded overlays are discussed. The overlay categories reviewed include bonded concrete overlays, unbonded concrete overlays, whitetopping overlays, and concrete overlays bonded to asphalt (ultra-thin and thin whitetopping). Information is also provided on selecting overlay alternatives. Significant portions of this document are based on a synthesis report prepared for the Federal Highway Administration (FHWA) by Applied Pavement Technology, Inc., under contract number DTFH61-00-P-00507. The report, "Portland Cement Concrete Overlays: State of the Technology Synthesis," is available from the FHWA as publication FHWA-IF-02-045.

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CHAPTER 1—INTRODUCTION

1.1—Background

Hydraulic cement concrete overlays are used as a rehabilitation technique for both existing concrete and asphalt pavements. Concrete overlays offer the potential for extended service life, increased structural capacity, reduced maintenance requirements, and lower life-cycle costs when compared with hot-mix asphalt overlay alternatives.

Concrete overlays have been used to rehabilitate existing concrete pavements since 1913 and to rehabilitate existing asphalt pavements since 1918 (Hutchinson 1982). Beginning around the mid-1960s, many highway agencies began to search for alternative means of rehabilitating existing pavements, and the use of concrete overlays increased significantly (McGhee 1994). In the 1990s, there was an even higher increase in the use of concrete overlays, spurred by improvements in concrete paving technology. For example, the use of zero-clearance pavers, fast-track paving concepts, and high-early-strength concrete mixtures greatly increased the ability of concrete overlays to serve as a viable rehabilitation alternative.

Parallel with the increased use of concrete overlays, significant research aimed at advancing the state of the knowledge of concrete overlays was conducted. One impetus for this research was the Intermodal Surface Transportation Act (ISTEA) of 1991, which included a provision under Section 6005 allocating designated funding for the assessment of thin bonded concrete overlays and surface lamination technology. The goals of the assessment were to evaluate the feasibility, costs, and benefits of the techniques in minimizing overlay thickness, initial laydown costs, and time out of service, and also to maximize life-cycle durability. As part of this effort, the Federal Highway Administration (FHWA) participated in funding 12 test-and-evaluation projects throughout the country (Sprinkel 2000).

Other examples of ongoing studies of concrete overlays are those being conducted under the FHWA's Long-Term Pavement Performance (LTPP) program. The LTPP program is divided into two complementary studies: the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). Under GPS-9, the performance of unbonded concrete overlays is being investigated; currently, 14 projects are being evaluated. Under SPS-7, the performance of four bonded overlay projects is being studied. The long-term monitoring of these GPS and SPS projects is expected to provide valuable information on the design and construction of concrete overlays. Additional information may be obtained by visiting the LTPP website at www.tfhrc.gov/pavement/ltpp/ltpp.htm.

Resurfacing asphalt pavements with concrete overlays, a process known as whitetopping, is another example of overlay research. In particular, several studies on the use of ultra-thin whitetopping (UTW), a very thin (2 to 4 in. [50 to 100 mm]) layer of concrete bonded to an existing asphalt pavement, have been conducted. In the 1990s, this technique evolved from a radical rehabilitation concept to a mainstream rehabilitation alternative. Several studies on whitetopping overlays are currently being conducted by the FHWA. Additional information may be obtained at www.tfhrc.gov/pavement/utwweb/utw.htm.

1.2—Purpose of report

Two ACI Committee 325 reports (ACI Committee 325 1958, 1967) discussed the pioneering work by the U.S. Army Corps of Engineers to develop design procedures for concrete overlays. The equations developed by the Corps for bonded, partially bonded, and unbonded concrete-on-concrete overlays are still used. The report suggested the design of concrete overlays on flexible pavement using the flexible pavement as a stiff base.

During the 1980s and 1990s, two National Cooperative Highway Research Program (NCHRP) syntheses were prepared on concrete overlays: "Resurfacing with Portland Cement Concrete" (Hutchinson 1982), and "Portland Cement Concrete Resurfacing" (McGhee 1994). There has been considerable work, however, in the area of concrete overlays since the most recent NCHRP synthesis.There is a need to assemble and synthesize information on the selection, design, and construction of concrete overlays for pavement rehabilitation.

This report discusses the selection, design, construction, and performance of concrete overlays. It is intended to provide the current state of the technology (as of 2004) of concrete overlays of both existing concrete pavements and existing asphalt pavements.

1.3—Definitions and notation

1.3.1 *Definitions*—This section presents definitions and notations unique to this report. Additional definitions for common concrete terminology can be found in ACI 116R. Definitions shown in italics are terms that may be found in ACI 116R, but have been redefined for this report.

break and seat—technique similar to crack and seat, except conducted on jointed reinforced concrete pavements and using higher impact energy; uses more impact energy to rupture the steel or break its bond with the concrete to ensure independent movement, and seating with a heavy roller.

crack and seat—technique involving fracturing the existing jointed plain concrete pavements into pieces 1 to 4 ft (0.3 to 1.2 m) on a side by inducing full-depth cracks using a modified pile driver, guillotine hammer, whip hammer, or other equipment, and seating with a heavy roller.

curling—concrete distortion, usually in a slab, resulting from differential temperatures.

drainage, subsurface—inclusion of specific drainage elements in a pavement structure intended to remove excess surface infiltration water from a pavement.

equivalent single-axle loads (ESALs)—summation of 18 kip (80 kN) single-axle load applications used to combine mixed traffic to design traffic during the analysis period.

falling weight deflectometer—device in which electronic sensors measure the deflection of the pavement as a result of an impact load of known magnitude; results can be used to estimate the elastic moduli of subgrade and pavement layers and the load transfer across joints and cracks.

faulting—difference of elevation across a joint.

fracturing, slab—technique in which an existing portland-cement concrete pavement is cracked or broken into smaller pieces to reduce the likelihood of reflection cracking.

hot-mix asphalt (HMA)—an asphalt cement-aggregate mixture that is mixed, spread, and compacted at an elevated temperature; also commonly referred to as "asphalt concrete" or "asphalt."

joint orientation—alignment of transverse joints in a concrete pavement with respect to the centerline of the pavement.

layer, separator—layer of hot-mix asphalt, bituminous material, or other stress-relieving material used at the interface between an unbonded concrete overlay and the existing concrete pavement to ensure independent behavior.

leveling course—thin layer of hot-mix asphalt or other bituminous material to produce a uniform surface for paving.

load transfer—means through which wheel loads are transferred or transmitted across a joint from one slab to the next.

life-cycle cost analysis (LCCA)—economic assessment of competing pavement design alternatives in which all significant costs over the life of each alternative are considered. LCCA is used to evaluate a design solution. Life-cycle costs may be measured for different designs to determine which design will meet the economic and performance goals.

mill—process using drum-mounted carbide steel cutting bits to remove material from a pavement and provide texture to promote bonding with an overlay.

overlay, bonded concrete—hydraulic cement concrete overlay bonded directly to an existing concrete pavement to form a monolithic structure.

overlay, partially bonded—hydraulic cement concrete overlay that is placed directly on an existing portland-cement concrete pavement with little or no surface preparation; consequently, partial bonding between the two pavements is expected.

overlay, unbonded concrete—hydraulic cement concrete overlay placed on an existing distressed concrete pavement such that the overlay is separated from the existing pavement through a separator layer.

pavement, continuously reinforced concrete (CRCP)—pavement with uninterrupted longitudinal steel reinforcement and no intermediate transverse expansion or contraction joints.

pavement, jointed plain concrete (JPCP)—hydraulic cement concrete pavement system characterized by short joint spacings and no distributed reinforcing steel in the slab, with or without dowels.

pavement, jointed reinforced concrete (JRCP)—hydraulic cement concrete pavement system containing dowels, characterized by long joint spacings and distributed reinforcing steel in the slab to control crack widths.

repair, preoverlay—repair or renovation activity performed on an existing pavement before the placement of an overlay.

roughness—irregularities in the pavement surface that adversely affect ride quality, safety, and vehicle maintenance costs.

rubblize, rubblization—breaking the existing pavement into pieces no larger than 6 in. (150 mm) on a side using a vibratory beam breaker or resonant frequency pavement breaker.

shotblasting—surface preparation technique in which steel shots are propelled against the surface of a portland-cement concrete pavement, effectively cleaning and preparing the surface to receive a bonded concrete overlay.

slab, shattered—concrete pavement with extensive longitudinal and transverse cracking.

slab, widened—concrete pavement slab that is paved wider (usually at least 18 in. [450 mm] wider) than a conventional 12 ft (3.7 m) traffic lane to increase the distance between truck tires and slab edge, thereby reducing edge stresses due to loading.

stripping—separation of asphalt cement from aggregate due to moisture attack.

user costs—in a life-cycle cost analysis, costs incurred by the user, such as delay costs, vehicle operating costs, and accident costs.

variable joint spacing—series of different joint spacings repeated in a regular pattern intended to reduce the rhythmic response of vehicles traveling over uniformly spaced joints.

warping—concrete distortion caused by differential moisture.

whitetopping—concrete overlay placed on an existing asphalt pavement. Whitetopping may be used in referring to conventional whitetopping, thin whitetopping, or ultra-thin whitetopping.

whitetopping, conventional—overlay placed on asphalt pavement, typically with a thickness higher than 8 in. (200 mm).

whitetopping, thin—bonded concrete overlay of thickness between 4 and 8 in. (100 and 200 mm) and typically having a joint spacing between 6 and 12 ft (1.8 and 3.7 m) that is placed on milled asphalt pavement.

Table 2.1—Recommended load transfer designs (Smith and Hall 2001)

Design feature	Recommendation	
Dowel diameter	Design catalog (Darter et al. 1997) <30 million ESALs 1.25 in. (30 mm) bar 30 to 90 million ESALs 1.5 in. (38 mm) bar >90 million ESALs 1.625 in. (41 mm) bar	Industry (ACPA 1991a) <10 in. (250 mm) slab 1.25 in. (30 mm) bar ≤10 in. (250 mm) slab 1.5 in. (38 mm) bar
Dowel length	18 in. (450 mm)	
Dowel spacing	12 in. (300 mm) center-to-center across the joint *Alternative*: cluster dowels in wheel path (Fig. 2.1)	
Dowel coating	Epoxy	

whitetopping, utltra-thin (UTW)—bonded concrete overlay of thickness less than 4 in. (100 mm) and typically having a joint spacing less than 6 ft (1.8 m) that is placed on a milled asphalt pavement.

whitewashing—application of a lime slurry to an asphalt pavement surface to reduce the surface temperature.

1.3.2 *Notation*—

CF = condition factor estimated based on remaining life (Section 4.2.3.1)
D = actual thickness of existing slab, in. (mm) (Section 4.2.3.1, 5.2.4)
D_{eff} = effective thickness of existing slab, in. (mm) (Section 4.2.3, 5.2.4)
D_f = required thickness of new concrete pavement for future traffic loadings, in. (mm) (Section 4.2.3.1, 5.2.4)
D_{max} = maximum thickness of slab, in. (mm) (Section 6.3.5)
D_{nom} = nominal thickness of slab, in. (mm) (Section 6.3.5)
D_{OL} = thickness of bonded or unbonded overlay, in. (mm) (Section 4.2.3.1, 5.2.4)
E_c = modulus of elasticity of concrete, psi (MPa) (Section 5.2.6)
F_{dur} = durability adjustment factor (Section 4.2.3)
F_{fat} = fatigue damage adjustment factor (Section 4.2.3)
F_{jc} = joint condition adjustment factor for bonded overlays (Section 4.2.3)
F_{jcu} = joint condition adjustment factor for unbonded overlays (Section 5.2.4)
k = modulus of subgrade reaction, psi/in. or lb/in.^{3} (MPa/mm) (Section 5.2.6, 6.2.2, 7.2.2)
ℓ = radius of relative stiffness, in. (mm) (Section 5.2.6)
L = joint spacing, in. (mm) (Section 5.2.6)
L_{max} = maximum joint spacing, in. (mm) (Section 7.2.5)
M_R = resilient modulus (Section 6.2.2, 7.2.2)
SC_{eff} = effective structural capacity of existing pavement (Section 4.2.3.1, 5.2.4)
SC_f = structural capacity of new pavement (Section 4.2.3.1, 5.2.4)
SC_O = original structural capacity when pavement was first constructed (Section 4.2.3.1)
SC_{OL} = structural capacity of new overlay (Section 4.2.3.1, 5.2.4)
μ = Poisson's ratio (Section 5.2.6)

CHAPTER 2—CONCRETE OVERLAY TYPES AND CONSTRUCTION MATERIALS

2.1—Introduction

This chapter presents general information on the different types of concrete overlays that are typically used in pavement rehabilitation and some of their common features. Concrete overlays for both existing concrete and existing asphalt pavements are described, including a summary of their defining characteristics. This chapter serves only as an introduction to the different concrete overlay types; detailed information is presented in later chapters.

Materials used in construction of concrete overlays are also described in this chapter. This includes a summary of concrete paving materials and mixture proportions, as well as interface materials and other aspects of construction.

2.2—Types of concrete overlays

2.2.1 *Concrete pavement types*—Concrete overlays and existing concrete pavements may be one of three basic types: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). Although in theory any type of concrete pavement could be used for an overlay, in practice, jointed plain concrete pavement (with and without dowels) is by far the most common.

2.2.1.1 *Jointed plain concrete pavement*—JPCP is a hydraulic cement concrete pavement system characterized by short joint spacings, no distributed reinforcing steel in the slab, and with or without dowels. Maximum slab length is typically 20 ft (6 m). Undoweled or aggregate interlock joints are generally used for short slabs, thin slabs, or both. For most pavements, however, adequately sized dowels should be provided to reduce faulting (Snyder et al. 1989; Smith et al. 1997). Dowel diameter is often selected based on slab thickness, but traffic may be a more important factor for consideration. Recommended load transfer designs are summarized in Table 2.1.

For concrete overlays, the recommended number and spacing of dowels is the same as those for new pavements. In general, uniform 12 in. (300 mm) spacing is recommended, but nonuniform spacing has also been used successfully. In the nonuniform dowel spacing design, the dowels are concentrated in the wheel paths (Darter et al. 1997). One recommended design for variable dowel bar spacing is illustrated in Fig. 2.1.

In general, joints perpendicular to the direction of traffic are recommended. On new JPCP, skewed joints can be effective in reducing faulting on nondoweled pavements, but have no effect when used on properly doweled pavements (Yu et al. 1998a; Khazanovich et al. 1998). Furthermore, JPCP designs with skewed joints constructed on a stiff base (treated cement or lean concrete) are prone to corner breaks.