Field Performance Review of Unbonded Jointed Concrete Overlays

G. F. Voigt, Michael I. Darter, and Sam Carpenter

This paper describes a nationwide pavement survey and evaluation of 14 unbonded concrete overlays. A comprehensive distress survey was performed, past traffic equivalent single-axle loads were estimated, and design, subgrade, and climatic data were obtained. The data were evaluated, and the results are summarized. Overall, unbonded overlays have performed quite well with little deterioration to date. Specific conclusions are presented to aid in the future design of unbonded overlays.

Portland cement concrete unbonded overlays are designed with an interlayer between the new overlay and the existing slab to isolate the overlay from distress in the underlying pavement and, thereby, eliminate reflective cracking (1,2). This type of overlay has been used effectively over both concrete and bituminous pavements (2-5). Particular economic and performance advantage is gained when used on existing pavements that have become significantly deteriorated. Until recently, no effort has been made to document the performance of this technique nationwide. However, increased attention focused on rutting and reflective cracking of bituminous overlays (and the steady increase in the cost of bituminous materials) has led to further review of this and other alternative concrete resurfacing methods.

CONCRETE OVERLAY PLACEMENT—STATE OF THE ART

Several advancements in the concrete pavement field should work as a catalyst to increase the use of unbonded, and other types, of concrete overlays. Advances in construction time required and the ability to construct adjacent to traffic lanes are two of the advantages of asphalt concrete overlays. However, fast track paving and zero-clearance pavers have allowed concrete overlays to be constructed competitively in terms of these variables.

Since 1985, several states have constructed overlays, both bonded and unbonded, using high early strength (fast track) concrete mixes. Mix designs have consisted of Type I cement with admixtures, Type II with admixtures, and also proprietary cementitious materials (6,7). Strengths have been developed that will allow the pavement to be opened to traffic in as few as 24 hours, and success has been obtained in rural, semi-rural, and urban conditions (7). No fast-track concrete overlays are contained in the data base, however.

Recent developments by several paving equipment manufacturers will have a profound effect on overlay selection. Zero-clearance paving machines will allow the placement of overlay concrete adjacent to lanes carrying traffic. Because of this, lane closure and traffic control measures under conventional concrete placement standards will no longer be required. When used in combination with fast track concrete mix designs, the placement of unbonded and other concrete overlay types using zero-clearance pavers will be even more competitive.

UNBONDED OVERLAY DESIGN AND PERFORMANCE—REPRESENTATIVE PROJECTS

Fourteen unbonded overlay sections were identified by state highway agencies and included in the data base. The following describes the location, original pavement design, overlay construction techniques, traffic, environmental conditions, and performance for four representative projects. Several of these projects contain more than one uniform section, which is defined as an original pavement and overlay containing uniform design factors (such as surface preparation, thickness, reinforcement, and traffic). Table 1 summarizes the design and construction factors for each unbonded concrete overlay contained in the data base.

Illinois: East-West Tollway (1-5)

Location

The project begins on the East-West Tollway near Naperville at approximately Milepost 142 and extends 5 miles to Milepost 147.

Original Pavement Design

The original pavement, built in 1958, was a four-lane, jointed, reinforced concrete pavement (8). The slabs were 10 inches thick and placed on 4 inches of gravel-sand subbase and 10 inches of select subgrade. The transverse contraction joints were spaced 50 feet apart and were dowelled with 1.0-inch diameter dowels spaced 12 inches on centers (8). The original design made no provisions for subsurface drainage.

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TABLE 1 DESIGN AND CONSTRUCTION DATA FOR UNBONDED CONCRETE OVERLAYS

<table>
<thead>
<tr>
<th>PROJECT CODE</th>
<th>PROJECT DESCRIPTION</th>
<th>DEBONDING LAYER MATERIAL</th>
<th>DEBONDING LAYER THICKNESS (inches)</th>
<th>OVERLAY OVERLAY THICKNESS (inches)</th>
<th>OVERLAY PAVEMENT TYPE</th>
<th>JOINT SPACING (feet)</th>
<th>JOINTING ARRANGEMENT</th>
<th>YEAR OF OVERLAY CONSTR.</th>
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<td>MIS</td>
<td>1985</td>
<td></td>
</tr>
</tbody>
</table>

* Indicates Random Joint Spacing (Average Shown).
** MIS = Mismatched Jointing.
*** Overlay Included Tied Concrete Shoulders.

Unbonded Overlay Rehabilitation Design

Considerable effort was spent on pre-overlay repair and concurrent improvements. The pavement was overlayed in 1969 with a 3-inch course of asphalt concrete (8). Prior to the placement of the unbonded overlay in 1981, the asphalt overlay material was removed with a cold milling machine. Once exposed, the concrete pavement was patched full depth at various locations where prior failures, such as blow-ups and joint deterioration had been previously patched by maintenance crews, or at unpatched joints showing severe deterioration (8). The design of the unbonded overlay section consisted of an 8-inch plain-jointed overlay constructed on an approximately 0.5-inch bond-breaking layer, which was placed directly on the existing concrete pavement (8). In general, the following design and construction procedures were used for the typical section (8):

1. After removing the existing overlay and placing full-depth patches, the exposed concrete pavement was surfaced with a bituminous prime coat and then a sand-asphalt bond-breaking layer, which was intended to provide a slip plane for the overlay pavement.

2. A nominal 8-inch lift of portland cement concrete followed the application of the bond-breaking layer. Early observation during the construction of pressure relief joints showed evidence that the overlay concrete was bonding to the sand-asphalt layer. To counteract this bonding action, the bond-breaking layer was sprayed with water just ahead of the paving operation. When, after a few days, no signs of reflection cracking were found on the areas in which the bonding was initially discovered, the application of water was discontinued for subsequent paving.

3. Perpendicular contraction joints were sawed into the overlay pavement at random intervals from 12 to 18 feet. Placement of these joints was made to ensure that no overlay contraction joint would occur within 2 feet of cracks and joints in the underlying pavement. This effectively created sleeper slabs beneath each overlay contraction joint. The designers relied on this for load transfer and did not use dowels in these joints.

Traffic

The average daily traffic (ADT) and percent trucks in the survey year was given as: ADT = 30,500, percent trucks = 24 (8). Accumulated 18-kip equivalent single-axle loads (ESALs) on the outer lane of the overlay at the time of survey were estimated to be 4.516 million.
Observed Distress

The pavement was surveyed in July 1985 and, after 4 years of service, the overlay was performing well. Surveys were performed in both the eastbound and westbound lanes and the pavement appeared to be in slightly worse condition in the westbound direction. No transverse fatigue cracking occurred in the lanes of either direction; however, some longitudinal cracking was found in the outer lane in the westbound direction. This cracking, located in the outer wheelpath, was tight and showed no signs of deterioration. No corner breaks were observed, indicating no loss of support beneath the overlay slabs. The joints, which did not contain dowels, showed no signs of significant distresses (such as corner or transverse spalling). The mean faulting of the overlay joints in the eastbound drive lane was 0.05 inches while the westbound drive lane exhibited a mean faulting of 0.08 inches. The differing conditions between the eastbound and westbound lanes may be most likely attributed to the joint sealant conditions. A 75 percent failure occurred in the sealant on the first 500-foot sample unit and a 25 percent failure rate occurred on the second 500-foot sample unit. The failure mode of the sealant was adhesion failure with the joint reservoir walls. Although the sealant performed poorly, no evidence of pumping was found in either sample unit. This is a significant finding that exhibits the beneficial effects of mismatching joints in the overlay with those in the underlying slab. Through mismatching the joint locations, no direct access is available for the subbase and/or subgrade fines to come up to the overlay.

Georgia: I-85

Location

The project is located on I-85 in Gwinnet County near the town of Braselton about 30 mi north of Atlanta. The project extends from Milepost 123 to approximately Milepost 123.25.

Original Pavement Design

The original pavement was built in 1960. The design consisted of 9-in. thick, jointed plain concrete slabs placed over a 3-in. premixed bituminous stabilized crushed aggregate base course and a soil-aggregate subbase (9). Transverse contraction joints were spaced at 30-ft centers and relied on aggregate interlock for load transfer (9). Slotted 6-in. diameter drainage pipes were placed beneath the shoulder in all cut areas (9).

Unbonded Overlay Rehabilitation Design

Subsealing of the existing pavement slabs was performed (9). Shattered slabs were removed and replaced with undowelled full-depth patches. The overlay consisted of a 6-in. plain jointed pavement. One section included 30-ft joint spacings, where joints were constructed directly over existing joints. Another section included 15-ft joint spacings, where joints were matched with the existing joints and also constructed at the midpoint between existing joints. The overlay joints that matched the existing joints were dowelled with 1%-in. dowels. Dowels were not placed in joints constructed at the mid-slab location (9). Ten-foot plain tied concrete shoulders on the outer lane and 4-ft plain tied concrete shoulders on the inner lane were also included in the design. The following design and construction procedures were used in constructing this overlay in 1975 (9):

1. Just before paving operations began, the exposed concrete pavement was given a coat of curing compound. The application of this compound was to be used as the bond-breaking layer between the new overlay concrete and the existing surface.
2. A 6-in. lift of portland cement concrete followed the application of the bond-breaking layer.
3. Shoulder paving followed mainline paving. The shoulder was not keyed, but was tied with tiebars spaced on 30-in. centers.
4. Contraction joints were sawed into the mainline overlay pavement in the locations described above. Transverse joints in the shoulders were sawed at 30-ft intervals.
5. Transverse joints were sealed with an open-cell neoprene joint sealant and the longitudinal shoulder joint was sealed with hot-pour asphalt sealant.

Traffic

The ADT and percent trucks in the survey year was given as ADT = 10,922, percent trucks = 25 (10). Accumulated 18-kip ESALs on the outer lane of the overlay at the time of survey were estimated to be 6.736 million.

Observed Distress

The pavement was surveyed in January 1986 in both of the southbound lanes on both the 30-ft joint spacing and 15 ft joint spacing sections. A 645-ft sample unit was taken on the 15-ft joint spacing section, and a 630-ft sample unit on the 30-ft section. After 10 years of service, both sections contained significant cracking—the 30-ft section contained 180 ft per 1,000 ft of low severity cracking and the 15-ft section contained 285 ft per 1,000 ft of cracking. On the 30-ft section, 53 percent of the slabs were cracked near the midslab region. Typically only one crack formed at this location, but two cracks in the midslab region were also noted. This cracking is attributed to differential curling of the overlay over the stiff underlying pavement. None of the cracks, however, had deteriorated into working cracks. The cracks noted on the 15-ft section were also only low severity, tight hairline cracks. The cracking was mostly located near the joints where problems were encountered during the paving of the overlay. Although little longitudinal cracking was noted on the outer lane of the 30-ft section, just 16 ft per 1,000 ft, the inner lane contained just over 100 ft per 1,000 ft of pavement. Not nearly as marked a difference was noted on the 15-ft section where the inner lane exhibited 145 ft per 1,000 ft and the outer lane only 96 ft per 1,000 ft of pavement. The longitudinal cracking may be attributed to the curling phenomena and an inadequately formed centerline joint. The average faulting was not significant, as it involved just 0.01 in. on the 30-ft section and 0.03 in. on the 15-ft section. No other structural-related problems
were evident. The surface on both sections showed some wear in isolated areas but, in general, was showing good performance.

**Colorado: I-25**

**Location**

The project is located north of Denver near the town of Mead. The overlay extends from approximately Milepost 246 to Milepost 253.

**Original Pavement Design**

The original pavement was built in 1964. The pavement was plain jointed with an average contraction joint spacing of 20 ft. These joints were not dowelled and, thus, relied on aggregate interlock for load transfer (personal communication with Hutter, Werner, Kiljin, John of Colorado Department of Transportation, DOT 1986). Slabs were constructed 8-in. thick and were placed over a 6-in. crushed granular base course. This pavement system was placed on a coarse-grained subgrade soil, with no provision of subsurface drainage (personal communication, Hutter et al., 1986).

**Unbonded Overlay Design**

Within the locations described previously, three overlay sections were constructed with differing designs in the summer of 1985. Two overlay thicknesses were used, 6.25 in. and 7.75 in. (personal communication, Hutter et al., 1986). Tied concrete shoulders were also used. The sections will herein be referred to as sections A, B, and C. Section A consisted of a 6.25-in. overlay with tied shoulders. On section B, a 7.75-in. overlay was constructed without tying the shoulders, and Section C consisted of a 7.75-in. overlay with tied shoulders. Joint spacing on the overlay was a random 14, 13, 15, 12 ft, skewed, and did not contain dowels. The following procedures were used to construct the overlay (personal communication, Hutter et al., 1986):

1. The surface of the existing pavement was swept of debris prior to placing an asphalt concrete bond-breaking layer. This layer was constructed 0.5 in. thick.
2. The overlay was paved to the thicknesses described above. The lanes were tied with 30-in. No. 4 tiebars spaced 30-in. on centers.
3. Where tied shoulders were used, the shoulders were also tied to the mainline pavement with 30-in. No. 4 tiebars spaced 30 in. on centers. Shoulders were constructed 10 ft wide on the outer lane and 4 ft wide on the inner lane. The shoulders were paved at a steeper cross slope than the mainline pavement.
4. Joints were sawed in the overlay and shoulders at a skew of 2 ft per lane (12 ft). The overlay joints were constructed as weakened plane joints and were sawed to match those on the lanes.

**Traffic**

The ADT and percent trucks in the survey year was ADT = 25,100, percent trucks = 16 (personal communication, Hutter et al., 1986). Accumulated 18-kip ESALs on the outer lane of the overlay at the time of survey were estimated to be 0.920 million.

**Observed Distress**

The surveys on this pavement were performed in late June 1986. In each section, one 500-ft sample unit was taken. The overlay had been in service for only one year at that time; therefore, the development of significant fatigue and environment-related distress was limited.

<table>
<thead>
<tr>
<th>Section</th>
<th>Overlay Thickness (in.)</th>
<th>Shoulder</th>
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<tbody>
<tr>
<td>A</td>
<td>6.25</td>
<td>Tied</td>
</tr>
<tr>
<td>B</td>
<td>7.75</td>
<td>Untied</td>
</tr>
<tr>
<td>C</td>
<td>7.75</td>
<td>Tied</td>
</tr>
</tbody>
</table>

No evidence of cracking was found in any of the three sections. The faulting in the outer lane ranged from 0.00 in. on Section B to just 0.01 in. on Sections A and C. On the inner lane, the faulting was 0.01 on both Sections B and C, and 0.00 in. on Section A. The joints were not spalled, and the concrete showed no sign of surface or mix-related defects. The shoulders on Sections A and C had performed well, although on Section C three transverse cracks had developed at the location of joints in the mainline pavement. It was apparent that these cracks had developed prior to the joint sawing operation and were left to perform as contraction joints, because no reservoir had been sawed in these locations.

**Pennsylvania: I-376**

**Location**

The project is located in eastern Pittsburgh. The overlay extends from Milepost 4.5 to Milepost 12.0.

**Original Project Design**

The original pavement constructed in 1946, was a four-lane jointed reinforced concrete pavement (personal communication, Grambling and Wade, Pennsylvania DOT, 1985). The slabs were 10 in. thick placed on 8 in. of crushed aggregate subbase. Load transfer was provided in the transverse contraction joints by 1.25-in. diameter dowels spaced 12 in. on centers. The slabs were 90 ft long and reinforced with welded wire fabric. Longitudinal drainage pipes were provided at the shoulders continuously along the project.

**Unbonded Overlay Design**

The overlay was constructed in 1983. Full-depth retrofit concrete shoulders were designed as part of the overlay. The overlay slabs were 8 inches thick with a joint spacing of 30.75 ft. The overlay joints contained 1.25-in. diameter dowels on 12-in. centers. The following procedures were used to construct the overlay (personal communication, Grambling, 1985).
• Onto the surface of the existing pavement, an asphalt concrete bond-breaking layer was applied to a thickness of approximately 1.0 in. As a further means by which to break the bond between the existing pavement and the new overlay, polyethylene sheeting was placed on top of that layer.
  • The overlay was paved to a thickness of 8 in. The lanes were tied with 30-in. No. 5 tiebars spaced 30 in. on centers.
  • The shoulders were also tied to the mainline pavement with 30-in. No. 4 tiebars spaced 30 in. on centers. Shoulders were constructed 10 ft wide on the outer lane and 4 ft wide on the inner lane. The shoulders were paved at a steeper cross slope than the mainline pavement.
  • Joints were sawed in the overlay and shoulders at a skew of 2 ft per lane (12 ft). Sealant was placed in the joints prior to opening to traffic.

Traffic

The ADT and percent trucks in the survey year was given as ADT = 67,500, percent trucks = 8 (personal communication, Grambling, 1985). Accumulated 18-kip ESALs on the outer lane of the overlay at the time of survey were estimated to be 1.822 million.

Observed Distress

The overlay on this route was surveyed in late August 1985. Surveys were conducted in both directions. At that time, the overlay contained a significant amount of cracking. In the eastbound lanes, two 1,000-ft sample units were taken, both located in sections of cut of between 16 and 40 ft. There was an average of 162 ft of low severity transverse cracking per 1,000 ft of pavement in the outer lane, and 60 ft per 1,000 ft in the inner lane. In the westbound direction, two sample units were taken, one in a similar cut section to those in the eastbound direction, and one in a section at grade. The amount of transverse cracking in the cut section was 110 ft per 1,000 ft of low severity in the outer lane and 90 ft in the inner. This is similar to that found in the eastbound lanes. In the section built at the in situ gradeline, there was slightly more low severity transverse cracking—384 ft per 1,000 ft in the outer lane and 30 ft per 1,000 ft in the inner lane. The cracks were almost exclusively located at midslab and were not found on the outer lane, which indicates that they had developed due to curling stresses. In either direction, the transverse joint faulting of the outer lane joints was only 0.04 in. The shoulders experienced tremendous movement, heaving between 0.07 and 0.63 in. and settling 0.18 and 0.52 in.

Although no direct correlation could be made to any of the measurements and observations of other distresses or conditions, the nonuniform movement of the shoulder slabs indicated a frost heave problem. The tiebars along the lane/shoulder joint are most likely failed due to the movement as well. Low severity longitudinal cracking on the average of 20 ft per 1,000 ft of pavement was found on the sample units in the eastbound direction, while an average of 62 ft per 1,000 ft of pavement of low severity transverse cracking was found in the westbound direction.

OVERALL UNBONDED OVERLAY PERFORMANCE

The performance of any rigid pavement rehabilitation technique can be measured by three basic factors (I):

1. The ability of that technique to correct the problems for which it was designed,
2. The ability of the materials used in constructing the technique to withstand the environment and maintain durability and structural integrity, and
3. The ability of the technique to serve future traffic loadings.

Table 2 gives a summary of unbonded concrete overlay distress observed on each uniform section.

Transverse Cracking

Field Observation

Only 2 of the 14 unbonded overlay uniform sections contained deteriorated (medium to high severity) transverse cracking. These sections are located on the two Georgia I-85 joint plain concrete pavement (JPCP) overlays. Less than 24 ft per 1,000 ft of traffic lane was measured on each section. These overlays were placed over a debonding layer of curing compound. Figure 1 shows the distribution of transverse cracking for each unbonded overlay surveyed. In each case, most of the cracking was located in the center region of the slab.

Development

Transverse cracking on unbonded overlays can develop from at least three major causes (or a combination of these): reflection cracking, thermal curling, and traffic load fatigue damage (1). Reflection cracking on unbonded overlays may result when the overlay is built over a thin and/or stiff debonding medium (1). However, the typical interlayer of AC or other type of asphaltic materials, such as slurry seal, usually prevents the development of reflection cracking. The Georgia I-85 6-inch thick overlay contained, on average, nearly 330 ft of outer lane transverse cracking per 1,000 ft of roadway. Almost all of this was low severity, tight-hairline cracking. Georgia Department of Transportation (DOT) officials reported that the curing compound, used as a debonding medium, was not effective (9). Thus, the probable cause of some of this cracking was reflection from the underlying slabs.

Thermal curling may be an even more severe problem in unbonded overlays. Figure 2 illustrates the temperature differential through a standard unbonded overlay section (11,12). The unbonded overlay and debonding medium will dampen virtually all of the temperature variation in the underlying slab. Thus, the overlay slabs, which will experience a significant temperature differential from surface to base, will tend to curl over the existing pavement slabs.

The curling action of the unbonded overlay slab is not significantly restrained at the interface, as it is on a bonded concrete overlay; therefore, the slab may actually lift off the underlying slab. Lifting will cause a void between the overlay
TABLE 2 SUMMARY OF UNBONDED CONCRETE OVERLAY FAULTING AND CRACKING OBSERVED ON EACH UNIFORM SECTION SURVEYED

<table>
<thead>
<tr>
<th>PROJECT CODE</th>
<th>AGE (yr)</th>
<th>ADT</th>
<th>% TRUCKS</th>
<th>ACCUM. 18 kip ESAL (millions)</th>
<th>MEAN FAULTING (inches)</th>
<th>LOW SEV. TRANS. CRACK (ft/1000 ft)</th>
<th>MEDIUM SEV. TRANS. CRACK (ft/1000 ft)</th>
<th>LOW SEV. LONG. CRACK (ft/1000 ft)</th>
<th>MEDIUM SEV. LONG. CRACK (ft/1000 ft)</th>
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* For two lane roads, data for both drive lanes (directions) are shown.
** Overlay Included Tied Concrete Shoulders.

For two lane roads, data for both drive lanes (directions) are shown.
Overlay Included Tied Concrete Shoulders.

slab and existing pavement surface (Figure 3). When this void develops from curling during the daytime, the void will be at the center region of the slab. Tensile stresses at the bottom of the overlay will occur as a result of the curl (due to the weight of the slab pulling down). The tensile stresses from curling in addition to load-induced tensile stresses (which will be greater than normal because of the loss of support beneath the slab) will create a critical stress. The typical location of the initiation and propagation of transverse cracking is from the longitudinal outer slab edge where resultant stresses will be the highest.

Other factors that contribute greatly to this problem are the increased effective (composite) foundation k-value of the portland cement concrete (PCC) and interlayer, and the transverse joint spacing used in the overlay. It is well documented that cracking is more likely to occur on slabs that have a longer joint spacing.

This is well illustrated on Georgia I-85 in which the original pavement joint spacing was 30 ft. Joints were matched at 30 feet on one overlay section and intermediate joints were sawed at mid-slab for an effective spacing of 15 ft on the other overlay section. Many of the 30-foot overlay panels had developed mid-panel cracks; significantly fewer cracks were observed in the 15-ft panels (9).

Two strategies can be used against cracking due to thermal curling in the overlay: preventive design and expected maintenance. Expected maintenance does not attempt to inhibit cracking, but instead uses steel reinforcement to hold cracking together once it has developed. Preventive design, on the other hand, attempts to limit crack development through design considerations.
FIGURE 2  Temperature profile (for mid-May) through an unbonded overlay cross section for 16-in. pavement.

FIGURE 3  Development of void under unbonded concrete pavements from the differential curling phenomenon.
The typical procedure that has been used to design against the development of cracking due to curling stresses has been to limit the joint spacing (in feet) to less than twice the pavement depth (in inches). However, this rule of thumb was based on limiting curling stresses in slabs placed on foundation k-values below about 300 pounds per cubic inch (pci). Experience has shown that slabs constructed using the $2 \times h$ rule of thumb on stiff foundations, such as treated base courses or existing pavement structures, may indeed still crack. This has led to consideration of an alternate procedure, the $L/l$ ratio, for determining joint spacing on stiff foundations (13).

Unlike the $2 \times h$ rule, this ratio does consider the effective slab support directly through the radius of relative stiffness. The $L/l$ ratio is the length of slab (in inches) divided by the radius of relative stiffness (13).

$$L/l = \frac{L}{(E \times h^2/12 \times (1 - \mu^2) \times k)^{1/4}}$$

where:

- $l =$ radius of relative stiffness (in.),
- $L =$ length of slab (in.),
- $E =$ modulus of elasticity of the pavement,
- $h =$ thickness of the pavement,
- $\mu =$ Poisson’s ratio, and
- $k =$ modulus of subgrade reaction (pci).

Analysis of the overlay sections, and additional projects revealed a critical $L/l$ ratio of about 7 (7). These have been plotted on a graph of $L/l$ envelopes and are shown in Figure 4. The critical $L/l$ ratio ($L/l = 7$) results in joint spacing determinations of approximately 1.9 to 1.6 times the overlay thickness, as overlay thickness varies from 6 inches to 12 in.

The $L/l$ ratio will vary dependent on the effective foundation support ($k$-value) used in determining the radius of relative stiffness. For this analysis, the effective $k$-value used was 500 pci. Although it is likely that the effective support from an underlying rigid pavement system is probably much higher, many design procedures limit foundation $k$-values at 500 pci; therefore, this was the value adopted.

![Slab Thickness, in.](image)

**FIGURE 4** $L/l$ ratio envelopes (unbonded overlays) for slabs on a stiff foundation ($k = 500$ pci, $E = 4 \times 10^6$ psi, Poisson’s ratio = 0.15).

FIGURE 5 shows the sensitivity of joint spacing to overlay thickness maintaining the critical $L/l$. It is interesting to note that as slab thickness increases, the $L/l$ ratio induces a larger constraint on maximum allowable joint spacing.

Where using a preventive design approach, it is recommended that a maximum $L/l$ of 7 be maintained. Where longer joint spacing is used, cracking will likely develop and slabs should be reinforced heavily to hold the discontinuities together.

### Longitudinal Cracking

#### Field Observation

Only two projects contained a significant amount of longitudinal cracking. Figure 6 shows the longitudinal cracking distribution for the unbonded overlay sections contained in the data base.

The Georgia I-85 6-in.-thick overlay contained, on average, approximately 180 ft of outer lane longitudinal cracking per 1,000 ft of roadway. All of this was low severity, tight-hairline cracking. The probable cause of the longitudinal cracking was reflection from cracking in the underlying slabs that was not arrested by the curing compound debonding medium (9).

The Illinois East-West Tollway also contained longitudinal cracking in the westbound direction. That cracking was attributed to late sawing of the longitudinal joint as reported by the resident engineer (8).

#### Development

The development of longitudinal cracking on unbonded overlays can be attributed to curling stresses, reflection cracking, and late sawing of the longitudinal lane joints (1).

The thermal gradient problem described earlier could possibly contribute to the development of longitudinal cracks. However, the development is less likely because the effective slab width is only 12 ft (one lane width), which may not be enough to develop large curling stresses.

Longitudinal cracks in the existing pavement will reflect through the overlay if the debonding medium is not adequate. The movements of the overlay and existing pavements must...
be separated by the debonding medium for proper performance of the overlay. Proper sawing depth (at least \( \frac{1}{2} \) the slab thickness) and timely sawing of the longitudinal joint are probably most critical.

Faulting and Pumping

Field Observation

Excellent load transfer efficiency and protection against pumping, loss of support, and faulting stems from the ability to mismatch the joints in an unbonded overlay from those in the underlying pavement. Mismatching provides a sleeper slab type arrangement (see Figure 7). The deflection profile under load is altered as the sleeper slab arrangement dampens deflections at the base of the underlying slab. Figure 8 illustrates the dampening effect. Most importantly, good assur-

![Diagram of 3 ft minimum clearance](image)

**A. Placement of Overlay Joints over Existing 20 ft JPCP Pavement.**

![Diagram of 3 ft minimum clearance](image)

**B. Placement of Overlay Joints over Existing 60 ft JRCP Pavement.**

**FIGURE 6** Distribution of severity of longitudinal cracking in the outer lane on unbonded concrete overlays.

**FIGURE 7** Details for mismatching overlay joints with joint in the existing pavement.
development of faulting and pumping.

The deflection at the bottom of the existing slab or where the erodible base materials are found is reduced significantly after the overlay is in place. This limits the potential for pumping erosion to create voids and loss of support, which cause faulting development (1).

Development

Faulting and pumping in unbonded overlays are reduced by several factors (1):

1. Nonerodible layers (existing PCC slabs and bond-breaker material) beneath the overlay slabs,
2. Dowels providing some load transfer in the overlay, and
3. The mismatching of the overlay joints.

The deflection at the bottom of the existing slab or where the erodible base materials are found is reduced significantly after the overlay is in place. This limits the potential for pumping erosion to create voids and loss of support, which cause faulting development (1).

Distress Potpourri

Other distresses and deterioration may develop in unbonded overlays such as D-cracking, reactive aggregate deterioration, or scaling. These distresses, however, are material or construction related. If an overlay should develop distresses of this nature, it is not a design problem. Proper specifications and inspection should prevent the occurrence of these problems. However, where the use of aggregates susceptible to D-cracking is unavoidable, recent studies in Ohio have shown that reducing the maximum coarse aggregate size used in the concrete mix to ½ in. should eliminate the development of aggregate durability problems (14).

Joint deterioration in unbonded overlays, while a possibility, is not likely to occur because of the short joint spacings specified (1). Very little joint deterioration existed in the pavements surveyed.

UNBONDED CONCRETE OVERLAY FAULTING MODEL

Although considerable analysis on the data base for unbonded concrete overlays was conducted, only one model (joint faulting) could be developed from the data. The analysis on other performance indicators was limited by the small number of occurrences of these problems and the limited number of uniform sections of this overlay type.

The model, developed using SHAZAM statistical analysis software, for joint faulting in unbonded concrete overlays is as follows (15):

$$\text{FAULT} = 0.28615 \times \text{ESAL}^{0.39654} \times [0.0987 (1 + \text{DOWEL})^{-0.51083}]$$

where

- \text{FAULT} = the mean faulting at the overlay joints (in inches),
- \text{ESAL} = equivalent single-axle loads accumulated on the overlay (in millions), and
- \text{DOWEL} = diameter of dowel bars placed in the overlay (in inches) (0 if no dowel bars were used in the overlay). Note that all dowel bar spacing was 12 inches on centers.

Statistics:

$$R^2 = 0.51$$

SEE = 0.02 inches (standard error of estimate)

$$n = 23$$ sample units

Equation Range of Applicability:

- \text{ESAL}—equivalent single-axle load data ranged from 0.73 million to 7.0 million accumulated on the overlay.
- \text{DOWEL}—the diameter of the dowel bars in the existing pavement ranged between 0 (no dowels) and 1.625 in.

A sensitivity plot for the faulting equation is given in Figure 9. It is evident that faulting in unbonded overlays is not...
a significant problem. Faulting typically becomes detrimental when it is more than 0.13 in. for JCP and 0.25 in. for joint reinforced concrete pavement (JRCP) (16).

An interesting point arises when considering the differences among dowel diameters. As was also discovered with bonded overlays (17), the effects of dowel diameter are not as great on unbonded overlays as on new pavement sections. This may be attributable to the increased slab support from the underlying pavement, mismatched joint arrangement, and the more erosion-resistant asphalt concrete (AC) and PCC beneath the overlay. Figure 10 compares new pavement faulting predicted with the COPES model (19) to faulting modeled by the unbonded overlay model. Without dowels, new pavements fault far more than unbonded overlays. However, with dowels, the predicted faulting is quite similar for both.

OTHER PERFORMANCE INDICATORS

The one major concern for cracking, is that the stiff base would increase thermal curling stresses to a detrimental point. This effect was seen on the Georgia 1-85 sections where the original pavement had a 30-ft joint spacing. The unbonded overlay cracked in the middle region of the 30-ft slabs. Where a 15-ft joint spacing was used, no cracks occurred in the overlay (9). Thus, shorter joints must be provided in the overlay to control cracking.

CONCLUSIONS

Unbonded concrete overlays have been used successfully to resurface existing concrete pavements with extensive deterioration. The performance of practically all of the 14 uniform sections of unbonded concrete overlays was very good, with no significant deterioration. No special construction techniques are needed in the construction of unbonded overlays. The following are overall conclusions and recommendations.

1. Thermal curling stresses are critical in unbonded concrete overlays because the temperature gradient through the overlay becomes large during many days and nights of the year, and because of the very stiff support from the existing slab. At these times, curling may cause the overlay slab to lift from the underlying slab and create voids between the slabs, which (when combined with traffic load stresses and the stiff foundation of the underlying slab) can cause transverse cracking. It is highly recommended that the overlay joint spacing be kept short. Maintaining an L/l of between 6 and 7 should ensure that cracking will not develop in the overlay. Short joint spacing will also reduce the need for dowel bars, because the linear movement from thermal contraction and expansion will be small and aggregate interlock should be maintained. If, however, longer slabs are used, reinforcement must be included to keep the cracks tight.

2. When a debonding medium that is not efficient in separating the overlay from the existing slab is used, reflective cracking may result. This has been due mainly to inadequate materials and insufficient debonding layer thickness. It is recommended that where joint and crack faulting is significant, and slabs are highly deteriorated, a minimum one inch of hot-mix asphalt concrete should be used as the debonding medium. Slurry seal has also been effective as a debonding medium; however, only where faulting in the existing slab is not significant and can be covered by this material.

3. Unbonded overlays without dowels fault very little (maximum measured was 0.04 in.), which is far less than new pavements without dowels for the same number of ESALs. The development of faulting in unbonded overlays is not reduced much by the use of dowels in the transverse joints. This has been attributed to fairly nonerodible and stiff foundation support from the underlying slab and mismatched joint locations. It is suggested that under normal traffic conditions (less than 0.8 million 18-kip ESAL per year) dowels are probably not needed in the transverse overlay joints for short-jointed JCP. It is still recommended that they be placed in log-jointed JRCP overlays, however. The predictive model for faulting can be used to predict faulting for a recommended overlay design to determine whether substantial faulting will occur.

4. Visual pumping was not observed in the field distress surveys. This is attributed to lack of erodible materials beneath the overlay slab, greatly reduced deflections of the slabs, and mismatched joints that alter the deflection basin developed under load. With these effects, there is very little potential for pumping in unbonded overlays.

5. Longitudinal cracking can be attributed mainly to the late sawing or improper depth of the longitudinal centerline
joint. To help control the cracking and provide a significant weakened plane, it is recommended that the centerline joint be sawed at least one-third the thickness of the slab. Timing is very critical in formation of this joint; sawing should be started as soon as possible after overlay placement.

6. Although matching the overlay joints to the existing pavement joints is not recommended, joint placement is not a critical concern in unbonded overlays. It is recommended that the joints be placed at least 3 ft from existing transverse joints or working cracks. This will ensure the load transfer benefits mentioned.

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