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# HIGHWAY RESEARCH REPORT

# INVESTIGATION OF UNBONDED PCC OVERLAYS

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...S AND TRANSPORTATION AGENCY
...ARTMENT OF PUBLIC WORKS
...VISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 635165

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

September, 1971

M&R No. 635165
FHWA No. D-5-29

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is the final report for the research project titled:

INVESTIGATION OF UNBONDED PCC OVERLAYS

Donald L. Spellman
Principal Investigator

James H. Woodstrom
and
B. F. Neal
Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachment

Reference: Spellman, D. L.; Woodstrom, J.H.; and Neal, B. F. "Investigation of Unbonded PCC Overlays", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 635165, FHWA D-5-29

Abstract: An investigation of unbonded PCC overlays placed over old PCC pavements is reported. Test sections were constructed to compare the effect of various materials as bond breakers. Performance was measured by the ability of the overlay system to prevent reflective cracking. It was concluded from these tests that an asphalt, such as MC-250, with a light sand cover to prevent pickup, reduces bond sufficiently to prevent reflective cracking, even when joint spacing is different from that of the base pavement. Wax base curing compound, specified as a bond breaker on one project, did not perform as well as anticipated. At a considerably higher cost, asphalt concrete also performs very well and is particularly worth consideration when leveling of the base pavement is necessary.

Key Words: Portland cement concrete, overlay, test sections, pavement construction, bond breaker

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Mr. J. R. Stoker was a co-investigator during the early stages of this project. Mr. Douglas Howard and Mr. Frank Kinsman performed the crack surveying and mapping throughout the project.

This project was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration, under agreement D-5-29. The opinions and conclusions expressed in this report are those of the investigators and are not necessarily those of the Federal Highway Administration.

# INVESTIGATION OF UNBONDED PCC OVERLAYS

## INTRODUCTION

The progressive deterioration of rideability or structural integrity of some portland cement concrete pavements eventually necessitates corrective action. While various corrective methods are available, there are times when a "second story" or PCC overlay is desirable.

Overlays may be bonded, partially bonded, or unbonded. To obtain good bond, considerable preparation of the base surface is necessary - removal of loose concrete, sandblasting and/or acid etching, and the application of a bonding agent. The cost of the preparatory work may approximate the cost of the overlay itself. Partial bond is considered to exist when no special steps are taken to prevent bond. Particular care must be taken with the overlay to match existing joints and cracks of the base pavement, otherwise reflective cracking is likely to occur over the joints on the underlying pavement. When a separator or bond breaking course is applied to the top of the base pavement, the overlay is considered to be unbonded and greater thickness is required than for the other types[1,2].

The PCC pavements in California now receiving overlay consideration have joints spaced at 15 feet and normal to the centerline. Present jointing practice is to randomize the spacing (13, 19, 18, 12 feet, then repeat) and to place at a skew of 2 feet in 12. To utilize the new joint spacing in overlays without reflective cracking, a bond breaking or stress relief course is considered necessary. The purpose of the study reported here was to determine the adequacy of unbonded overlays and the effectiveness of thin separator blankets in preventing reflective cracking.

From a review of the literature, it was found that a considerable number of materials have been used for breaking bond. Other than building paper or a sand layer, however, practically all the materials have been some type of bituminous product. Most investigators have reported adequate performance with unbonded pavements, but a few have noted adverse performance and recommended against the use of separator courses[3].

In reviewing overlay projects constructed in recent years in California, most were found to be reconstruction rather than overlays. The base pavement had been broken up with a pavement breaker, a cushion course placed over that, then cement treated base and a new concrete pavement. One project was found where a one to four-inch variable depth of asphaltic concrete had been placed over the base concrete before the PCC overlay. None of these projects were considered satisfactory for further investigation under this study, so new projects were selected.

The number of overlay projects in a given year is normally very limited; however, three were available which were to be paved in 1968 or early 1969. Before construction, surveys of the base pavements were made and joints and cracks mapped. The same survey sheets were used in post-construction surveys to determine whether or not new cracks were reflective.

## CONCLUSIONS

1. Just as is the case with new pavement, the time of forming weakened plane joints in an overlay pavement is an important factor in the occurrence of random cracks. These joints should be constructed as early as possible.

2. When existing joints or cracks of the base pavement can conveniently be matched in the overlay pavement, or if reflection and random cracking would be acceptable, a bond breaker could be omitted.

3. If a moderate amount of random cracking can be tolerated, a thick application of a wax based curing compound should be satisfactory as a bond breaker. It should be placed sufficiently ahead of the paving operation to allow enough drying to prevent pickup by truck traffic.

4. Asphalt (MC-250 or 60-70 Pen.) with a light sand cover is satisfactory as a bond breaker. Only enough sand should be sprinkled on to prevent tracking, as loose sand under the pavement could accelerate faulting.

5. Polyethylene sheeting will also work very well as a bond breaker. Consideration should be given to possible placing difficulties under windy conditions however, and problems in dumping fresh concrete on a loose layer.

6. Excellent results were obtained with an asphalt concrete blanket. It is especially attractive for old pavements where a leveling course is needed. It should be borne in mind, however, that if placed too far ahead of overlay construction, reflective cracks could occur in the AC, then be transmitted to the new pavement.

7. Slurry seal was satisfactory as a bond breaker. While unrealistically high in cost under the experimental conditions, it still would not normally be considered economically feasible for general use as a bond breaker.

## RECOMMENDATIONS

1. For overlaying PCC pavements which are structurally sound, a separation course of asphalt with a light sand cover should be used. Excess sand is to be avoided.

2. For pavements with numerous cracks or those needing leveling, an AC course should be used. The maximum size of aggregate to be used is dependent on the minimum thickness to be placed.

# OVERLAY CONSTRUCTION

## I-80 in West Sacramento

This heavily traveled section of highway, approximately three miles in length, was constructed to 4-lane freeway standards in 1954. An early 1968 contract was awarded to widen to eight lanes and upgrade the existing pavements. Plans called for overlaying the westbound lanes with a nominal 0.67-foot of concrete and grinding the eastbound lanes to provide a smooth ride. A proposal by the contractor to overlay the eastbound lanes in lieu of grinding (at no increase in cost) was accepted by the State.

In the westbound direction, widening was accomplished by adding a lane on each side of the existing 24-foot pavement. In the eastbound direction, the two new lanes were added to the outside of the existing pavement. A wax based concrete curing compound was specified as a bond breaker on this project. For purposes of comparison, several other materials were used as bond breakers in test sections of varying lengths.

Joints in the base pavement were normal to the centerline and at 15-foot spacing. Those in the overlay were skewed and at random spacing with no effort made to avoid crossing existing cracks or joints. The following tabulation compares the performance of overlays over experimental bond breakers with adjacent sections where the control bond breaker (white pigmented curing compound) was used.

### Westbound

No. 1 Control - 1200 feet; bond breaker consisted of curing compound

| No. 1A North (No. 3 Lane) | | No. 1B South (No. 2 Lane) | |
|---|---|---|---|
| 9-25-68 | Paved - Cool, sunny | 10-17-68 | Paved - Warm, overcast |
| 10-23-68 | No cracks | 10-23-68 | 5 cracks |
| 10-30-68 | 5 cracks | 10-30-68 | 3 additional |
| 11-6-68 | No additional | 11-6-68 | No additional |

(Table continued)

Table continued

| North (No. 3 Lane) | | South (No. 2 Lane) | |
|---|---|---|---|
| 1-6-69 | No additional | 1-9-69 | 6 additional |
| 12-9-70 | No additional | 12-9-70 | No additional |
| Total | 5 cracks - all reflective* | Total | 14 cracks<br>9 reflective* |

(2 of the reflective cracks extend across both lanes.)

Cracks per mile - 22 | Cracks per mile - 62

*Cracks and joints in the base pavement considered "reflective" by the surveyor.

No. 2 Bond breaker consisted of 60-70 Pen. asphalt with sand cover - 1500 feet

| No. 2A<br>Lane No. 3 | | No. 2B<br>Lane No. 2 | |
|---|---|---|---|
| 9-25-68 | Paved | 10-17-68 | Paved |
| 10-23-68 | No cracks | 10-23-68 | No cracks |
| 10-30-68 | No cracks | 10-30-68 | No cracks |
| 11-6-68 | No cracks | 11-6-68 | 4 cracks |
| 1-9-69 | No cracks | 1-9-69 | No additional |
| 12-9-70 | No cracks | 12-9-70 | No additional |
| Total | None | Total | 4 cracks,<br>1 reflective |
| Cracks per mile - 0 | | Cracks per mile - 14 | |

Eastbound - Lanes 1 and 2 (Inside)

No. 3 Control - 2000 feet; bond breaker consisted of curing compound

| | |
|---|---|
| 10-9-69 | Paved - cool, sunny |
| 10-14-68 | 2 cracks, full 24-ft. width |
| 10-23-68 | 3 additional, full width,<br>1 in No. 2 lane only** |
| 10-30-69 | No additional |
| 11-6-68 | No additional |
| 1-9-69 | 3 additional, full width |
| 12-9-70 | 1 additional, full width |
| Total | 9 full width, 6 reflective<br>1 half width, reflective |
| Cracks per mile | 25 |

Table continued

Table continued

**There were also five partial cracks at the outside edge of the No. 2 lane, 6 feet or less in length. Although these appear to be reflective in nature, no change in length has been noted since their appearance in 1968.

No. 4 Bond breaker consisted of 6 mil Polyethylene Sheeting, 500 feet

| | |
|---|---|
| 12-9-70 | No cracks |
| Cracks per mile | 0 |

No. 5 MC-250 Asphalt with Sand Cover - 1500 feet

| | |
|---|---|
| 12-9-70 | No cracks |
| Cracks per mile | 0 |

No. 6 No bond breaker; no sawn joints - 124 feet (7 joints omitted), Lanes 1 and 2

| | |
|---|---|
| 10-11-68 | Paved - cool, cloudy |
| 10-14-68 | 2 cracks, full width |
| 10-23-68 | 1 additional, full width |
| 10-30-68 | 1 additional, full width |
| 11-6-68 | No additional |
| 1-9-69 | No additional |
| 12-9-70 | No additional |
| Total | 4 full width cracks, all reflective |
| Cracks per mile | 170 |

No. 7 No bond breaker; joints sawn at random spacing - 1375 feet, Lanes 1 and 2

| | |
|---|---|
| 10-11-68 | Paved |
| 10-14-68 | 3 cracks, full width |
| 10-23-68 | No additional |
| 10-30-68 | 2 additional |
| 11-6-68 | 1 additional |
| 1-9-69 | No additional |
| 12-9-70 | No additional |
| Total | 6 full width cracks all reflective |
| Cracks per mile | 23 |

No. 8 Bond breaker consisted of asphalt concrete, 1/2" max., approximately 3/4" depth - 1500 feet

| | |
|---|---|
| 12-9-70 | No cracks |
| Cracks per mile | 0 |

No. 9 Slurry Seal - 1100

| | |
|---|---|
| 12-9-70 | No cracks |
| Cracks per mile | 0 |

No. 10 Control No. 2 - 800 feet (Curing compound)

| | |
|---|---|
| 10-11-68 | Paved - cool, cloudy, some rain, slight damage to surface texture |
| 10-14-68 | 1 crack, full width |
| 10-23-68 | No additional |
| 10-30-68 | No additional |
| 11-6-68 | No additional |
| 1-9-69 | No additional |
| 12-9-70 | 2 additional, full width |
| Total | 3 full width cracks, 2 reflective |
| Cracks per mile | 20 |

## Summary

| Bond Breaker | Cracks Per Mile Total | Cracks Per Mile Reflective |
|---|---|---|
| No. 1A, Curing Compound | 22 | 22 |
| No. 1B, " " | 60 | 40 |
| No. 2A, 60-70 Pen. Asph. + Sand Cover | 0 | 0 |
| No. 2B, 60-70 Pen. Asph. + Sand Cover | 14 | 4 |
| No. 3, Curing Compound | 25 | 17 |
| No. 4, 6 mil Polyethylene | 0 | 0 |
| No. 5, MC-250 Asph. + Sand Cover | 0 | 0 |
| No. 6, None - no sawn joints | 170 | 170 |
| No. 7, None - Joints at random spacing | 23 | 23 |
| No. 8, 1/2" max. Asph. Conc. approx. 3/4" thick | 0 | 0 |
| No. 9, Slurry Seal | 0 | 0 |
| No. 10, Curing Compound | 20 | 20 |

I-8, West of San Diego

The PCC base pavement was constructed in 1951 as part of a two-lane highway, 24 feet wide with centerline crown. Reconstruction was begun in 1968 to bring this section of highway to interstate standards. Plans called for utilizing most of the existing pavement by overlaying. As a result of some realignment, about one mile of the original alignment is part of the westbound lanes and about 2 miles are in the eastbound lanes.

Since traffic is relatively light on this highway (ADT of about 6000 vehicles with a small percentage of trucks), a 6-inch PCC overlay was deemed adequate. Except as noted later, an asphalt concrete blanket was placed to break bond between the two layers and to remove the existing crown so that the overlay would be of uniform thickness. The blanket was AC of 3/8-inch maximum size aggregate placed at a minimum depth of 1/2-inch, but varied up to about 4 inches. Joints of the new pavement were to be sawn on a skew, at random spacing of 13'-19'-18'-12'.

Before paving in January 1969, a survey was made on portions of the base pavement making note of existing joints and cracks. In the westbound lanes, 2500 feet was surveyed, and in the eastbound lanes, 5600 feet. A post-construction survey in March 1969 showed the following:

| | |
|---|---|
| Westbound lanes: | 6 full width random cracks, one of which was reflective.<br><br>All six cracks occurred within a 600-foot section of the pavement. |
| Cracks per mile: | 13 |
| Eastbound lanes: | 13 full width random cracks, two reflective.<br><br>All cracks occurred within a 1000-foot section of the pavement. |
| Cracks per mile: | 11 |

There have been no new cracks found since the March 1969 survey.

The leveling course was omitted for 200 feet at the beginning of the overlay in the westbound lanes. Joints in the new pavement were skewed and randomized, but were spaced so that no crossing of joints in the base pavement occurred. By May of 1969, five random cracks, all reflective, were present, but no new cracks have formed since that time.

US 99 - North of Bakersfield

This overlay project is somewhat different from the others reported here. The PCC base pavement was constructed in 1914 to a width of 15 feet and a depth of 4 inches. Over the years, the pavement was widened and resurfaced with AC several times. At the time of reconstruction in 1968, the depth of AC varied considerably but was probably a minimum of 12 inches. Since there were numerous reflective cracks in the AC, a 2800-foot section was surveyed before the new 36-foot PCC Pavement (0.67-foot thickness) was placed. An AC leveling course was placed on the inside, or median lane to remove crown before paving. Four random cracks were found in a post-construction survey, none of which were reflective. After three years, no new cracks have been found.

Base Pavement Condition

The original pavement in the West Sacramento project had some faulting ranging up to 0.20-inch. In the test sections, there were 50 random transverse cracks (including both partial and full width cracks), 8 daily construction joints, 5 corner breaks, and 4 small AC patches. The project near San Diego was relatively free of faulting and had very few random cracks and patched areas. At Bakersfield, all cracks were in the AC and were probably reflecting joints or cracks in the very old concrete beneath.

Of all the defects found in the base pavements during preliminary surveys, not one appeared to result in a reflective crack in the overlay. The reflective cracks developed only over planned transverse joints in the base pavement. Practically all of the joints in the original pavement had been sawn. The exceptions were due to single lane paving where cracks occurred in the second lane as an extension of a joint before the planned sawing was done. These were considered as planned joints in the survey rather than random cracks.

## DISCUSSION

All of the experimental bond breakers used in this study are considered to have performed satisfactorily. The wax based curing compound used on the West Sacramento project, however, did not work quite as well as was expected. While the surveys show practically no difference in cracking between the control sections with curing compound and those without a bond breaker, the curing compound appears to have performed better when the portions of the project outside of the test sections are included. One factor which affects random cracking other than the presence or absence of a bond breaker is the time of sawing the planned joints. A number of cracks occurred before sawing of all joints was completed, thus resulting in what had to be considered as random cracks. Weakened plane joints formed in the fresh concrete by joint inserting machine (now in fairly wide use) would probably have eliminated most of the random cracks. The superior performance of an asphalt application over that of a curing compound is undoubtedly a function of the thickness of layer. The asphalt is about four times thicker than the curing compound.

Unless considerable random cracking can be tolerated on an unbonded overlay project, some type of bond breaking or stress relief layer should be applied to the base pavement. The selection of material type, in addition to expected performance, would normally be based on economic considerations. Following are the prices paid for the various materials used on the West Sacramento project. They are based on a 24-foot width and extrapolated to equivalent one mile lengths. Some of the costs would be expected to be lower when placed on a nonexperimental basis.

| Bond Breaker | Cost per Mile (24 ft. wide) |
|---|---|
| Wax based curing compound (15 sq.yd./gal.) | $ 550 |
| MC-250 with sand cover (4 sq.yd./gal.) | 800 |
| 60-70 Pen. Asph. with Sand Cover (4 sq.yd./gal.) | 1150 |
| Polyethylene Sheeting | 1900 |
| 1/2" maximum Asph.Conc. (1/2" min. depth) | 2850 |
| Slurry Seal (1/8" min. depth) | 2500* |

*Estimated, since special charges were involved on this project.

Due to the experimental nature of these trials and the relatively short lengths involved, the quoted prices should be considered as only rough approximations. The cost of slurry seal, for example, was exceptionally high due to the lack of ready availability of necessary equipment at the particular time needed. However, the use of slurry seal would not be normally recommended since there are other equally satisfactory products at lower cost.

While the curing compound is apparently the least expensive and might be satisfactory on some projects, the use of asphalt should be considered since there is every expectation that fewer reflective cracks would occur. A light sand application is advisable to prevent tracking by construction traffic, but excess sand should definitely be avoided. Loose materials under slabs are a major source of the buildup which results in joint faulting.

An AC course should be used where leveling is needed or where the base pavement is badly cracked. Very few, if any, true reflective cracks were found in the concrete overlays placed over an AC leveling or separation course. During this study, the AC was placed just prior to concrete paving, and as far as could be determined, no reflective cracks had formed in the AC.

## REFERENCES


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## APPENDIX

### Pavement Surveys (Aerial Photographs)

Making detailed pavement surveys under heavy traffic conditions can be very hazardous. The I-80 project in West Sacramento presented a particularly difficult situation; not only was there a considerable amount of traffic, but the overlain pavement was not adjacent to the wider outside shoulder after freeway construction was completed. The use of aerial photographs was considered as a possible substitute to on-site surveys.

The first trial pictures were taken by plane, at around noon on a sunny day. The sun reflection on white pavement tended to blur many of the details. Clearer areas were examined steroscopically, by magnifying glass, and by placing the negatives over a light table. Results were very disappointing - very few random cracks could be seen even when the location of cracks was known.

For the next trial the flight was made about mid-afternoon to reduce glare. Clarity was significantly improved on most of the prints although some glare was still evident. All of the sawn joints and many random cracks could be readily seen. By surveying the test sections from the photographs and checking in the field, however, it was discovered that several errors were made. What appeared to be a crack in the photograph could turn out to be some type of mark on the pavement made by the burlap drag, the curing equipment, or other means. Some of the tighter cracks or those without spalled edges were missed entirely. It appears that without further refinements, aerials taken from a plane are not satisfactory for closely detailed surveys.

Photographic samples taken by helicopter indicated excellent possibilities; however, the equipment needed was not available locally and the cost of obtaining the service was considered excessive. The conclusion was that for this project, lane closures would be utilized for the surveys.

As a matter of possible interest, a 9x18-inch camera with 24-inch focal length was used. Photo coverage was at a scale of 1" = 50' with 20% forward overlap, and centered on the median of the freeway. Flight was made at a height of approximately 1200 feet.

## Bond Tests

When a new PCC pavement is placed in direct contact with an old PCC pavement and no special effort is made to prevent or secure bond, it is assumed that partial bond exists. To check this, cores were taken in the unbonded area of the West Sacramento project after about one year of traffic. No bond could be detected on any of four cores taken. While the torque of the coring machine may have been sufficient to break existing bond, the interface of the new and old pavements did not show any shear damage and it is believed that very little, if any, bond was present.

A few direct pull-off tests were made in the laboratory to compare relative bond achieved with various agents. Base slabs were cast, finished with a wooden float to provide minimal texture, then cured. Overlays were simulated by placing 3-inch diameter by 2-inch high molds on the base slabs and filling with concrete, with and without bonding agents. Agents used in the test were cement paste, sand mortar, two commercial bonding agents, and epoxy. After curing for 7 days, pull rings were epoxied to the top of the specimens and pull-off tests made. Load limitation of the equipment was equivalent to slightly more than 200 psi so loading was stopped if 200 psi was reached and results reported as 200+. Following are the results of the tests.

| | No. of Tests | Average Bond Strength, psi |
|---|---|---|
| No bonding agent | 6 | 117 |
| Cement paste | 6 | 129 |
| Sand Mortar | 9 | 144 |
| Commercial Agent A | 3 | 96 |
| Commercial Agent B | 3 | 87 |
| F-43 Epoxy | 6 | 200+ |

These tests indicate considerable bond can be developed even without a bonding agent. Why there was apparently none present on the West Sacramento project is not readily explainable, but movement due to deflections and temperature changes no doubt adversely affect bond.

In private correspondence with another state, reference was made to their trial of a 4-inch minimum thickness overlay. The old pavement was flushed clean and kept moist in an attempt to create a bond between the slabs. They reported this procedure ineffective. After three years, there was considerable longitudinal cracking between the wheel tracks and some disintegration in the wheel tracks at the transverse joints. While overlays thinner than 6 inches might be desirable, they would appear to be unsatisfactory unless adequate bond could be assured.