

The Effect of AC Overlays on D-Cracking in PCC Pavements

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ABSTRACT

Durability cracking (D-cracking) is the progressive deterioration of portland cement concrete (PCC) and is normally caused by winter freeze-thaw cycling. The PCC coarse aggregate source has been identified as causing well-designed mixes to develop D-cracking. A common rehabilitation procedure for D-cracked PCC pavements is to overlay the PCC with asphalt concrete (AC). This renews the surface, but little is known about the long-term effect of AC overlays on D-cracked pavements. The primary climatic factors responsible for D-cracking are moisture and temperature. Finite-difference transient flow computer moisture movement modeling as well as field instrumentation and laboratory measurements indicate that AC overlays have a negligible effect on the PCC pavement moisture regime. The effect of AC overlays on the PCC temperature regime was evaluated by finite-difference heat transfer computer modeling. AC overlays were found to decrease the number of freeze-thaw cycles and the rate of cooling in PCC pavements. Laboratory freeze-thaw durability tests duplicating field conditions for Interstate 70 near Vandalia, Illinois, were conducted on PCC samples with AC overlays 0 to 6 in. thick. All the PCC samples cycled to the equivalent of 5 years of winter exposure showed strength loss as determined by split tensile tests. The samples with 4-in. overlays showed the most strength loss. It was concluded that AC overlays do not prevent the progression of D-cracking in PCC; instead some overlay thicknesses accelerate it. When AC overlays are designed for D-cracked PCC pavements, the effect of decreasing strength of the deteriorating PCC should be considered.

Durability cracking (D-cracking) in portland cement concrete (PCC) is the progressive deterioration of the concrete caused by environmental factors. It can occur even when the PCC has not been subjected to physical loading and is especially common in PCC pavements that are exposed to winter freeze-thaw cycling. Figure 1 shows a severely D-cracked PCC pavement. As D-cracking progresses in a PCC pavement, the load-carrying capacity and the ability of the pavement to resist deformation and cracking under repeated traffic loading gradually decrease. With time, this deterioration can lead to total structural failure of the pavement and loss of serviceability to the user.

Studies in Illinois (1), Ohio (2), and Iowa (3), among others, have identified coarse aggregate sources that lead to D-cracking in what would normally be considered good, durable mixes. The fine aggregate source has been found to have little significance in whether a mix develops D-cracking or not (4). Extensive testing programs (1-3) to identify aggregates susceptible to D-cracking have helped to ensure that new pavements are not likely to develop D-cracking in the future. But there remain many miles of D-cracked pavement that require some form of rehabilitation in order to continue to provide adequate serviceability to the user.

A common rehabilitation procedure is to overlay existing D-cracked PCC pavement with a thin layer of asphalt concrete (AC). These AC overlays provide immediate improvement in the riding quality of

D-cracked PCC pavements. Little is known about the long-term effects of AC overlays on the continued durability performance of the PCC. Can AC overlays perform well over D-cracked PCC pavements? Will the PCC continue to perform adequately? Although a layer of AC on top of the PCC will tend to decrease the number of freeze-thaw cycles that occur in the PCC, it also tends to decrease the rate of cooling. The literature differs on whether a faster cooling rate (5,6) or a slower cooling rate (7,8) is more detrimental to PCC. In addition, the AC overlay would form a barrier on top of the PCC that may prevent the evaporation of water. With evaporation reduced by an AC overlay, the PCC could be at a higher degree of saturation before winter freezing, which would lead to more severe damage (5). A thorough study to determine the effects of AC overlays on the moisture and temperature regimes in D-cracked PCC pavements is needed to predict the long-term effects of AC overlays on the progression of D-cracking in PCC pavements.

OBJECTIVES

The general objective of this project was to evaluate the influence of various thicknesses of AC overlays on the progression of D-cracking in PCC pavements. The specific objectives were as follows:

1. Determine the changes in the moisture and temperature regimes in D-cracked PCC pavements resulting from various AC overlay thicknesses,
2. Conduct laboratory freeze-thaw durability tests on D-cracked PCC samples with various AC overlay thicknesses and attempt to correlate any

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FIGURE 1 Severely D-cracked PCC pavement.

strength variations that occur with changes in sample moisture and temperature regimes, and

3. Make recommendations for design procedures that take into account the effects of the AC overlay on the continued durability performance of the PCC.

RESEARCH APPROACH

The important climatic parameters responsible for D-cracking are moisture and temperature. The PCC moisture regime was evaluated by computer modeling, laboratory moisture content measurements, and field moisture determinations. The PCC temperature regime was evaluated by computer modeling. The combined effects of changes in the temperature and moisture regimes on the progression of D-cracking were evaluated by laboratory testing that duplicated winter field conditions.

A necessary material property for moisture regime modeling is moisture characteristics, which is the relation between equilibrium moisture content and matric suction. Matric suction is the force that causes capillary rise. It is equivalent to the distance above the water table for equilibrium conditions when no flow is occurring. Detailed discussions of moisture characteristics and matric suction have been given by Janssen and Dempsey (9) and Hillel (10). Figure 2 is a moisture-characteristics curve for laboratory D-cracked PCC. It should be noted that there is very little decrease in moisture content for large increases in suction. This is due to the very fine pore structure of PCC.

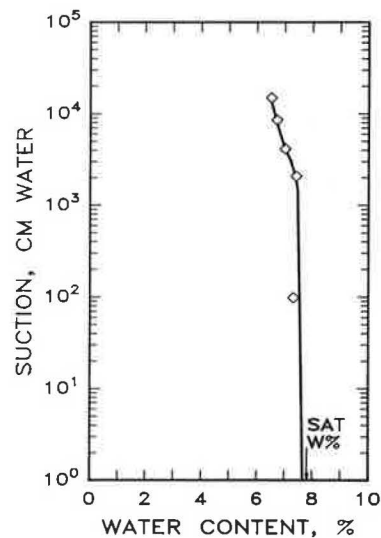


FIGURE 2 Moisture-characteristics curve for laboratory D-cracked PCC.

Figure 3 is a plot of unsaturated hydraulic conductivity versus moisture content for laboratory D-cracked PCC. This was determined from the moisture-characteristics curve and measured saturated hydraulic conductivity, or permeability (9). It should be noted that the unsaturated hydraulic conductivity decreases rapidly with a small decrease in moisture content. Details of the moisture characteristics and saturated hydraulic conductivity measurements have been given by Janssen (11).

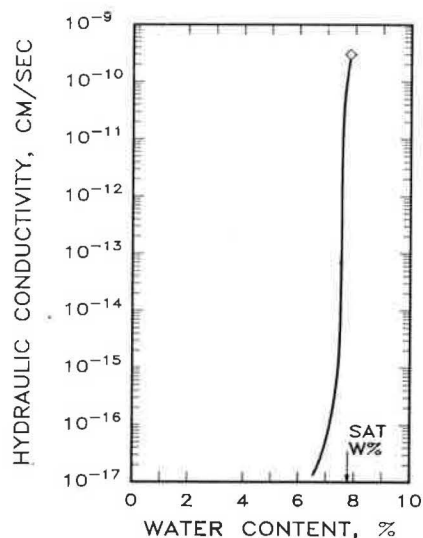


FIGURE 3 Unsaturated hydraulic conductivity curve for laboratory D-cracked PCC.

Moisture movement was modeled by means of a finite-difference transient flow computer program developed by Boast (12). The pavement section modeled was an 8-in.-thick PCC layer with free water at the bottom and a relative humidity of 50 percent at the top. The initial moisture content in the PCC was 5.7 percent. The results of moisture movement modeling for a period of 3 months are shown in Figure 4.

Field moisture contents were determined with psy-

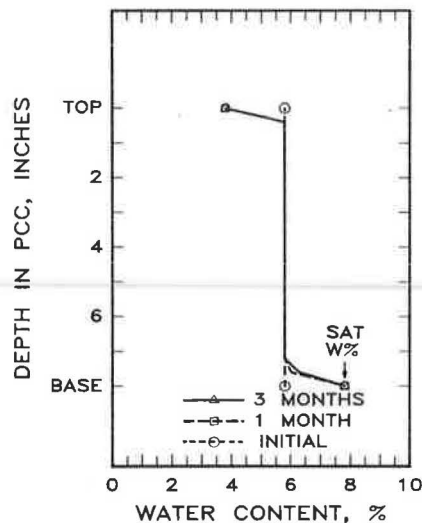


FIGURE 4 Moisture movement in PCC with 5.7 percent initial moisture content.

chrometers (13) installed in I-72 near Champaign, Illinois. Psychrometers, which have been used in the agricultural community for many years, actually measure matric suction, which is converted to moisture content with a moisture-characteristics curve. The psychrometers were installed at depths of 2 and 4 1/2 in. into the PCC for both overlaid and non-overlaid D-cracked PCC. Table 1 gives psychrometer moisture content determinations for March through

TABLE 1 Average Moisture Contents Determined with I-72 Psychrometers

| Date | Moisture Content (%) by Psychrometer Depth (in.) | | | |
|-------|--|-------|---------|-------|
| | No Overlay | | Overlay | |
| | 2 | 4 1/2 | 2 | 4 1/2 |
| 3/22 | 6.6 | 6.4 | 7.3 | 7.4 |
| 7/10 | 7.2 | 7.3 | — | 7.4 |
| 7/11 | 6.9 | 7.2 | 7.1 | 6.8 |
| 7/18 | 6.5 | 7.0 | 7.4 | — |
| 7/25 | 6.2 | 7.4 | 6.3 | 6.4 |
| 7/30 | 6.1 | — | 7.4 | — |
| 7/31 | 7.0 | 6.7 | — | — |
| 8/3 | 6.8 | 6.9 | 6.8 | 6.9 |
| 8/14 | 6.8 | 6.8 | 7.2 | 6.5 |
| 8/21 | 6.2 | 6.4 | 6.7 | 6.8 |
| 8/22 | 6.5 | 6.5 | — | — |
| 8/28 | 6.2 | 6.5 | 6.8 | — |
| 9/4 | 6.2 | 6.9 | 6.5 | 6.2 |
| 9/6 | 6.1 | 6.1 | 6.9 | 7.3 |
| 9/11 | 7.0 | 6.8 | 7.1 | 7.0 |
| 9/13 | 7.2 | — | — | — |
| 9/18 | 6.5 | — | 6.2 | — |
| 9/19 | 6.6 | 7.3 | — | 7.3 |
| 9/20 | 6.5 | — | 7.3 | — |
| 9/25 | 6.9 | 6.7 | 7.0 | 7.0 |
| 9/27 | 7.0 | — | — | — |
| 10/2 | 6.2 | — | 6.6 | — |
| 10/4 | 6.3 | — | 6.5 | — |
| 10/8 | 6.4 | 6.6 | 6.5 | 6.4 |
| 10/10 | 6.8 | 6.7 | 6.8 | 7.3 |
| 10/24 | 6.2 | 7.3 | 7.1 | 6.5 |
| 11/2 | 6.1 | 6.0 | — | — |
| 11/5 | — | — | 6.7 | 7.2 |
| 11/7 | — | — | 6.8 | — |
| 11/12 | 6.6 | 7.3 | 6.8 | — |
| 11/13 | 7.1 | — | 6.8 | — |
| 11/30 | — | — | 6.6 | 6.5 |

Note: Dashes indicate that no data were available.

November 1984. A moisture content of 7.6 percent was complete saturation.

Moisture content measurements were made on PCC samples that were freeze-thaw cycled in the laboratory. The samples were 4-in.-diameter by 8-in.-long cylinders, the bottoms of which were in contact with a moist crushed-stone base. Figure 5 gives moisture content distributions for samples with no overlay and Figure 6 for samples with 2-in. overlays. Saturation for these samples was at a moisture content of 7.8 percent.

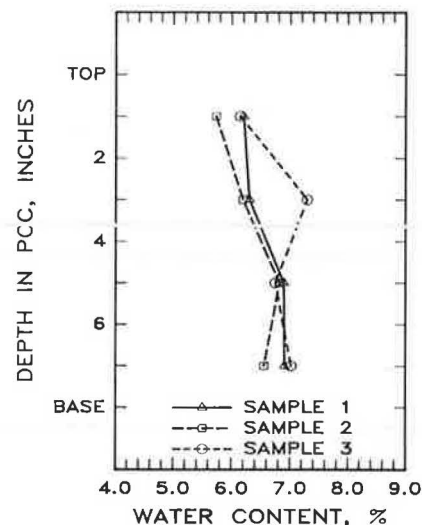


FIGURE 5 Moisture content distributions, 5-year samples, no overlay.

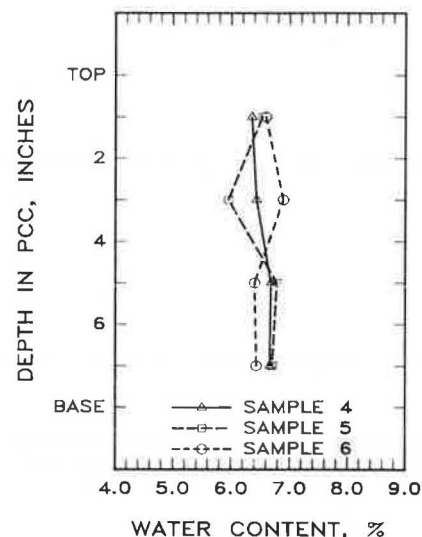


FIGURE 6 Moisture content distributions, 5-year samples, 2-in. overlay.

The temperature regime was modeled with a finite-difference heat transfer computer program developed by Dempsey (14). The modeled pavement section consisted of an 8-in. PCC surface on a 4-in. stabilized base with an AASHTO A-6 subgrade. Input consisted of climatic data including wind speed, cloud cover, daily high and low temperatures, and daily solar radiation. Climatic data from 1965 to 1980 were used to determine the average number of freeze-thaw cycles at the pavement surface for various locations

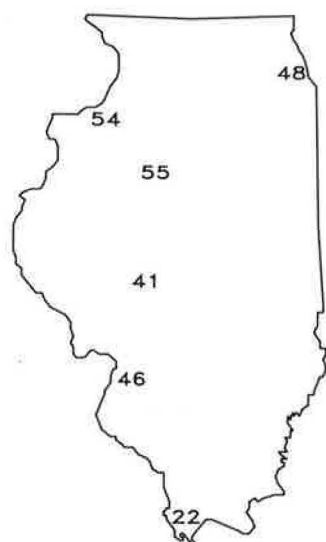


FIGURE 7 Number of freeze-thaw cycles in Illinois, top of PCC surface.

in Illinois (Figure 7). January 1971 was determined to be typical for winters in the St. Louis, Missouri, area. This time period was used to evaluate the effects of various AC overlay thicknesses on the cooling rate, the number of freeze-thaw cycles, and the minimum temperature below freezing (Table 2).

TABLE 2 Effects of AC Overlays on Freeze-Thaw Parameters, St. Louis, Missouri

| Parameter | Overlay (in.) | | | |
|--|---------------|------|------|------|
| | None | 2 | 4 | 6 |
| No. of freeze-thaw cycles | 19 | 7 | 4 | 2 |
| Cooling rate, avg (F°/hr) | 1.19 | 0.56 | 0.24 | 0.20 |
| Minimum temperature below freezing (F°) | 10 | 17 | 22 | 25 |

Freeze-thaw durability testing was performed in a programmable freeze-thaw durability testing unit developed by Dempsey (15). The specimens consisted of 4-in.-diameter by 8-in.-long PCC cylinders on dense graded crushed-stone bases (Illinois CA-6 gradation). The bottoms of the bases were in contact with water. The specimens had either no AC overlay or 2-, 4-, or 6-in.-thick overlays. The base-course thicknesses were adjusted depending on the overlay thickness in order to give a total specimen height of 18 in. (Figure 8). The sides of the specimens were

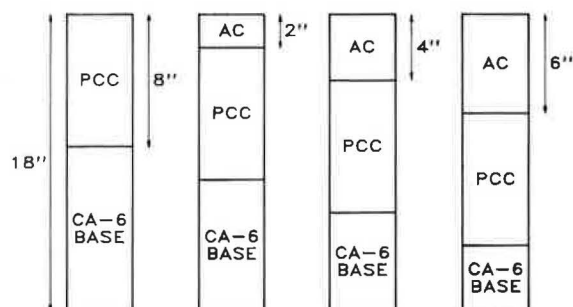


FIGURE 8 Schematic of freeze-thaw durability specimens.

wrapped with plastic, and insulation was provided between them to ensure that both moisture and heat flow were only vertical. The PCC samples were made from the same D-cracking susceptible coarse aggregate that was used in a D-cracked section of I-70 near Vandalia, Illinois.

The freeze-thaw cycle used in the laboratory was determined from heat transfer computer analysis of climatic data for St. Louis, Missouri, which included total daily sunshine, daily high and low temperatures, and daily average wind speed. This was the source of necessary climatic data closest to the Vandalia site being modeled. The values of pertinent freeze-thaw parameters for January 1971 for the St. Louis area, which were used to develop the laboratory freeze-thaw cycle shown in Figure 9, are given in Table 3, which also gives a summary of the freeze-thaw parameters for the laboratory freeze-thaw cycle.

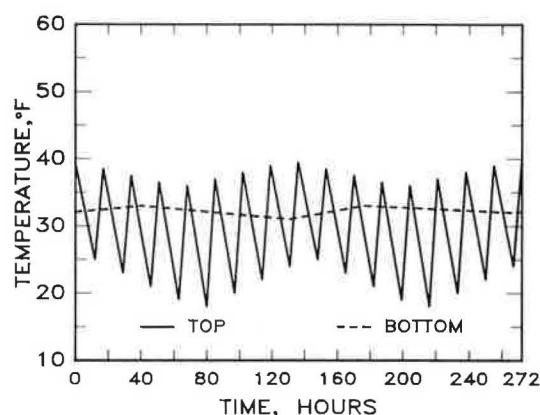


FIGURE 9 Laboratory freeze-thaw cycle: top and bottom of 18-in. specimen.

TABLE 3 St. Louis, Missouri, and Laboratory Freeze-Thaw Parameters

| Parameter | St. Louis Values | | Laboratory Values | | |
|--|------------------|---------------------------|-------------------|---------|---------|
| | Mean | Sample Standard Deviation | Mean | Minimum | Maximum |
| Cooling rate (F°/hr) | 1.2 | 0.40 | 1.35 | 1.21 | 1.50 |
| Minimum temperature below freezing (F°) | 22.8 | 4.31 | 21.5 | 18.0 | 25.0 |
| Difference between maximum and minimum temperature (F°) | 17.8 | 6.01 | 16.3 | 14.5 | 18.0 |

Results of split-tensile tests on the PCC samples that were freeze-thaw cycled to the equivalent of approximately 2 and 5 years of winter exposure are shown in Figure 10. Figure 11 shows split tensile strength loss versus overlay thickness for the 5-year samples.

DISCUSSION OF RESULTS

The moisture movement modeling (Figure 4) indicated that moisture movement in PCC is extremely slow. After 3 months, drying of the PCC extended less than 1 in. into the PCC. This is due to the extremely low unsaturated hydraulic conductivity of the PCC. Continued drying decreases the unsaturated hydraulic conductivity even further, which tends to minimize moisture loss at depths greater than 1 in. This im-

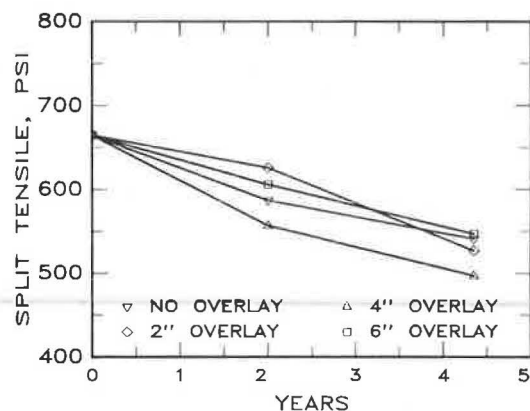


FIGURE 10 Split tensile strength versus years of freeze-thaw cycle.

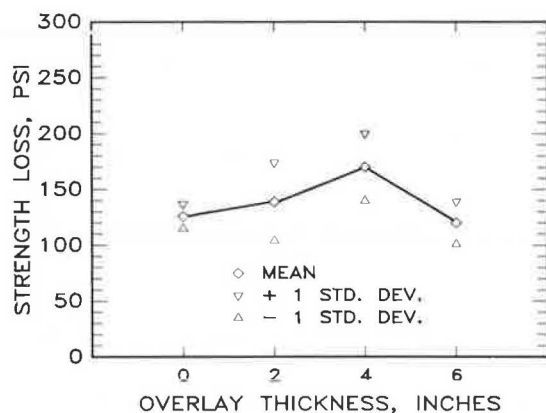


FIGURE 11 Strength loss versus overlay thickness, 5-year samples.

plies that AC overlays that prevent evaporation would have little effect on the PCC moisture regime, except near the surface where drying would be prevented.

The field moisture determinations (Table 1) show little difference between moisture contents at depths of 2 in. and depths of 4 1/2 in. There is also little difference between moisture contents of overlaid and nonoverlaid sections. This is possibly because the measurement at 2 in. is too deep to detect surface drying.

The laboratory moisture measurements (Figures 5 and 6) show drying at the tops of the nonoverlaid samples and no drying under the overlay. Actual drying at the top surface of the nonoverlaid PCC is probably of greater magnitude than is shown. Each measurement represents the average moisture content for 2 in. of sample and would not show any variation in that 2 in.

AC overlays have a definite effect on the temperature regime in PCC pavements. Table 2 indicates that an overlay decreases both the number of freeze-thaw cycles and the cooling rate at the PCC pavement surface. Although a decrease in the number of freeze-thaw cycles is beneficial, it is possible that a slower freezing rate could cause increased damage (8).

The results of the laboratory freeze-thaw durability tests indicate that none of the tested overlay thicknesses prevented D-cracking. Overlay thicknesses in the 2- and 4-in. range caused increased freeze-thaw damage to the PCC. Statistical analysis of the 5-year samples showed that there was a sig-

nificant strength difference between the 4-in. and the 6-in. overlay samples at α equal to 5 percent. At α equal to 7 percent there was a significant strength difference between the 4-in. overlay and the nonoverlaid samples. Figure 11 suggests that there is some overlay thickness greater than 6 in. that would prevent freeze-thaw strength loss. This would probably be due to the prevention of freezing in the PCC.

CONCLUSIONS AND RECOMMENDATIONS

The research conducted in this investigation has led to the following conclusions:

1. The PCC pavement moisture regime is unaffected by AC overlays except within the top 1 to 2 in. of the PCC. Most of the D-cracked PCC remains at a relatively high moisture content, and evaporative drying has little effect except at the surface.
2. AC overlays cause significant changes in the pavement temperature regime. These changes include slowing the cooling rate, decreasing the number of freeze-thaw cycles, and raising the minimum pavement temperature.
3. No common AC overlay thickness stops the progression of D-cracking. Thicknesses in the 2- to 4-in. range actually accelerate the rate of freeze-thaw damage. Although AC overlays decrease the number of freeze-thaw cycles, which is beneficial, they also decrease the cooling rate. The combined effect of decreased number of freeze-thaw cycles and decreased cooling rate was detrimental for PCC samples with 2- and 4-in. overlay thicknesses.

It is recommended that when an AC overlay is an alternative for D-cracked PCC rehabilitation, the following should be considered:

1. The structural design should take into account the continued deterioration of the PCC, and
2. The economic analysis should consider a shortened design life due to the decreasing PCC strength.

Further research should be conducted in the following areas:

1. The effect of various slow cooling rates (between 0.2 and 1.5°F/hr) on the progression of D-cracking;
2. The effect of different aggregates on the rate of D-cracking progression caused by slow cooling rates; and
3. The effect of reduced PCC strength on AC overlaid PCC pavement performance.

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