INVESTIGATION OF BRIDGE DECK CRACKING ON I-95 NORTHBOUND OVER POWELL CREEK

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TECHNICAL ASSISTANCE REPORT

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Transportation and the University of Virginia)

Charlottesville, Virginia

June 1994
VTRC 94-TAR6
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INTRODUCTION

Shortly after construction, many longitudinal cracks were noted by VDOT personnel in the concrete of deck span No. 6 of the bridge widening project on I-95 northbound over Powell Creek. Three cores were taken at crack locations. One full-depth core was obtained, in which the crack could be traced through the entire core. Because the cracks provided a direct path to the reinforcing steel for chloride ions, and in some cases went completely through the deck, the deck was quickly determined to be unacceptable. The VDOT asked the contractor to propose corrective measures such as removal and replacement of the deck, epoxy injection of the cracks, or other acceptable alternatives.

As often happens, the cause of the cracking became an issue. In preliminary discussions, it was suggested that vibrations from traffic traveling in the adjacent lanes during and after placement caused the cracking. The VTRC was asked to examine the cores to determine the cause of the cracking of the concrete.

PROCEDURES

Three 4-in cores were received and identified as follows:

<table>
<thead>
<tr>
<th>Core No.</th>
<th>VTRC No.</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P-2172</td>
<td>Partial to reinforcing</td>
</tr>
<tr>
<td>2</td>
<td>P-2173</td>
<td>Partial to reinforcing</td>
</tr>
<tr>
<td>3</td>
<td>P-2174</td>
<td>Full</td>
</tr>
</tbody>
</table>

Specimens P-2172 and P-2173 were in two pieces separated by the crack. After preliminary visual examination, the two halves of specimen P-2173 were epoxied together. Specimens P-2173 and P-2174 were sawed along two planes
parallel to the core axis and perpendicular to the crack trend to produce slabs. The slab from specimen P-2174 was sawed parallel to the top surface at mid-depth and epoxy was spread along the crack face to ensure that the specimen would remain intact through further processing and handling. The slabs were then finely lapped on one face to produce a smooth surface for microscopic examination.

A visit was also made to the construction site to observe the cracked deck.

RESULTS

The crack trend on the surface of each core was roughly parallel to traffic and perpendicular to the surface texture. The maximum crack width of sample P-2172 was 0.8 mm, that of P-2173 was 1.0 mm, and that of P-2174 was 1.5 mm. Several microcracks approximately 0.1 mm or less in width with transverse as well as longitudinal trends were also noted in the top surface of all three specimens. The trace of the crack on the top surface of P-2174 was discontinuous, exhibiting a feature termed "bridging" (Figure 1).

Figure 1. Core P-2174
A - Bridging of paste across crack.
The crack surfaces were examined on P-2172 and found to have the dull, powdery appearance of dried-out paste. Several large voids were noted (Figure 2). Many large voids were also found on the polished surfaces of P-2173 and P-2174 (Figures 3 & 4).

Microscopic examination of polished surfaces of P-2173 and P-2174 showed the cracks to be roughly vertical. The crack could be traced full-depth in P-2174. The cracks skirted around aggregate particles, followed large voids, and in P-2174 followed a path around both top and bottom reinforcing bars (Figure 4). In both P-2173 and P-2174 the crack path on the polished surface was discontinuous, broken by "bridging" of paste across the crack (Figure 3). Comparison of opposite sides of the cracks revealed areas where the opposite sides would not fit neatly back together (Figures 3 & 4).

Except for an excessive number of large voids, the general quality of the concrete appeared good. The coarse (crushed granitic stone) and fine (natural siliceous sand) aggregates were well distributed with good paste-aggregate bond showing only slight signs of coalescing air voids at the coarse aggregate boundaries. The paste was fairly hard and dense.

Figure 2. Core P-2172. Surfaces of crack are dull and powdery. A - Large voids.
Figure 3. Core P-2173. Polished surface.
A - Large voids;
B - Bridging of paste across crack;
C - Poor fit of crack surfaces indicates plastic deformation.

Because of the many large voids noted in the samples (Figures 2, 3, & 4), a linear traverse analysis of the air content was performed on P-2174. The results indicated a total air content of 6.6 percent, with 4.5 percent composed of voids less than 1 mm in diameter and 2.1 percent larger than 1 mm. The total length traversed was 2103 mm. The spacing factor derived from this analysis was 0.15 mm. A spacing factor less than 0.20 mm is considered to provide adequate resistance to damage from freezing and thawing and de-icer scaling. The percentage of air in large voids, 2.1 percent, is considered excessive\(^1\) and indicates that adequate consolidation was not achieved.

An inspection of the bridge deck revealed that most of the cracking occurred in the middle of the span, and seemed unrelated to the location of girders. The cracks were straight, parallel, and longitudinally oriented (Figure 5). The longest individual cracks were about 0.5 m in length. Cracks were often aligned end-to-end, separated by paste “bridges”, forming total lengths up to nearly 4 m. The average width of cracks at the surface was about 1.25 mm. The maximum crack width noted was 2 mm. Traffic-induced vibration and wind were noticeable in the middle of the span, especially when tractor trailers or buses crossed the bridge.
Figure 4. Core P-2174. Polished surface.
A - Large voids;
B - Trap rock aggregate;
C - Reinforcing bars;
D - Poor fit of crack surfaces indicates plastic deformation.
Figure 5. Deck surface. Cracks are essentially straight and parallel in the longitudinal direction. Rectangles identify full-depth cracks.

At the time of placement, a Jersey barrier had been used to separate traffic from the construction area. A liquid membrane curing compound had been sprayed on the concrete but coverage was very poor, especially where most of the cracking occurred (Figures 6 & 7). It was understood that no other curing method was used or precaution taken to prevent evaporation of water from the concrete during or after placement.

DISCUSSION

Certain features noted in the cores, specifically the dry powdery interior surface of the crack, the deformation of crack surfaces, and the "bridging" of paste across cracks, all indicate that the cracks formed while the concrete was in a plastic state as opposed to a hardened or brittle condition. Cracks which form in plastic concrete are generally ascribed either to rapid loss of moisture from the concrete or settlement.
Figure 6. Deck surface. Very poor coverage of white pigmented curing compound, especially in middle of span. Rectangles identify full-depth cracks.
Figure 7. Longitudinal crack in deck surface. Very spotty curing compound coverage.
Settlement cracking typically occurs after vibration and finishing when the plastic concrete continues to consolidate but is restrained locally by formwork or reinforcing bars. Because the cracking in this case was not located near the perimeter of the deck, settlement associated with formwork can be ruled out as a cause.

The cracks were spatially associated with reinforcing bars, and the poor consolidation indicated by the high number of large voids suggests that the concrete would have been prone to continued post-finishing settlement. However, the reinforcement in this bridge deck was laid out in a closely-spaced grid pattern while the cracking was oriented in the longitudinal direction. Furthermore, settlement cracking associated with reinforcing bars is most notably a problem when cover depths are shallow, while in this case the cover depth was a considerable 3 in. Settlement may have contributed to the severity of the plastic cracking in this deck but was not the primary cause.

As noted earlier, concern was expressed that the cracking of the deck may have resulted from traffic-induced vibrations because the new deck span was tied to the existing bridge and traffic was maintained on the bridge during construction of the new span. Similar concerns arose when the practice of maintaining traffic on adjacent lanes during bridge widening or reconstruction began in the mid-to-late 1970s. Research and general experience nationwide and here in Virginia indicate that these concerns are not warranted and that traffic-induced vibrations do not adversely affect the quality of the finished deck. This conclusion is supported by the fact that five deck spans constructed previously to the cracked deck on this project had no similar problems although constructed in the same manner.

An ACI report on consolidation mentions vibration of reinforcing as an acceptable means to consolidate concrete. That report discusses concerns about the effects of vibration of reinforcing on plastic or partially set concrete. Examinations of concrete consolidated in this manner revealed no detrimental effects on the concrete. In fact, the report indicates that the vibration of reinforcement while the concrete is plastic improves the concrete-to-steel bond by removing air voids and water pockets from the vicinity of the bars. Traffic-induced vibrations may have caused some additional post-finishing consolidation of the concrete, resulting in settlement. However, if such consolidation occurred, it was not sufficient to prevent the concrete from containing an excessive amount of large or entrapped voids. Had the concrete been adequately consolidated during placement, traffic-induced vibrations would have had no adverse effect.

The essential straight, parallel nature of these cracks and their tendency to have great depth, often completely through the deck, all correspond to features noted for plastic shrinkage cracks. The nature of the cracking, when coupled with the apparent inadequate curing which the concrete received, leads
to a finding that the cause of the cracking in this deck was rapid moisture loss and consequent shrinkage of the plastic concrete.

CONCLUSIONS

1. The cracks in this deck are essentially straight, oriented in the longitudinal direction, and in many cases full depth.

2. The cracking of the deck began while the concrete was in the plastic state.

3. The primary cause of the cracking was plastic shrinkage resulting from rapid loss of moisture from the concrete.

4. The cracked concrete was not adequately protected from the loss of moisture after placement and finishing.

5. The concrete had an excessive amount of large voids due to inadequate consolidation.

6. Settlement of the poorly consolidated concrete may have exacerbated the plastic cracking.

7. Traffic-induced vibrations may have contributed to settlement primarily because the concrete was not adequately consolidated during placement.
REFERENCES


