Research Report
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PERFORMANCE OF A
SHRINKAGE COMPENSATING DECK CONCRETE
(KY 1974 Bridge over West Hickman Creek)
FINAL REPORT

by

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This report summarizes performance monitoring activities and evaluation in conjunction with the experimental use of shrinkage compensating bridge deck concrete (Class S). Two bridges of similar design but constructed using Class AA concrete were monitored for comparison purposes. Due to the absence of significant shrinkage cracking on the comparison bridge decks and the presence of minor shrinkage cracking on the Class S bridge deck, no conclusions were apparent at this time. Further study may quantify the reduction of shrinkage cracking due to the use of shrinkage compensating concrete in bridge decks.
INTRODUCTION

In an effort to reduce the amount of shrinkage cracking on concrete bridge decks, the Kentucky Department of Highways has experimented with shrinkage compensating concrete. Shrinkage compensating concrete is made with an expansive cement in which the expansion, if restrained, induces compressive stresses that approximately offset tensile stresses induced by drying shrinkage. Concrete produced with an expansive cement will expand initially and later shrink. Complete shrinkage compensation is obtained if expansion slightly exceeds shrinkage.

Expansion against internal (or external) restraint results in the development of early compression rather than early tension. Because tension is delayed, the concrete can gain higher compressive strengths without being subjected to the early tensile stresses associated with the drying shrinkage of concrete. Internally restrained shrinkage compensating concrete will always develop a lower level of negative strain than normal portland cement concrete because of the initial expansion (1). The development of lower levels of negative strain in shrinkage compensating concrete reduces the possibility of drying shrinkage cracking. Portland cement concrete however, will develop only net shrinkage strain thereby producing tension in the concrete. Since the tensile capacity of concrete is low, cracking of portland cement concrete may occur.

BACKGROUND

The objectives of this study were to evaluate the construction and performance of shrinkage compensating bridge deck concrete and compare the performance to conventional bridge deck concrete. The bridge under study is located on KY 1974 (Tates Creek Road) over West Hickman Creek in Lexington, Fayette County, Kentucky. The subcontractor for the bridge construction was R. R. Dawson Bridge Company. The experimental shrinkage compensating concrete was batched at W. T. Congleton Company in Lexington. Expansive cement meeting the requirements of ASTM C 845, Type K, was supplied by the Southwestern Portland Cement Company, Fairborn, Ohio. Fine aggregate for the mix was obtained from Harrison Sand and Gravel Company and coarse aggregate was obtained from Lexington Quarry. A maximum water/cement ratio of 0.63 gal./bag was specified. Maximum slump was limited to 7 inches. It was specified that Class S concrete meet all requirements for Class AA concrete with the exceptions as given in the concrete was utilized in all portions of the structure normally constructed of Class AA concrete except for the barrier walls and intermediate diaphragms.
The shrinkage compensating deck concrete was placed in the eastbound lanes on Wednesday, March 26, and in the westbound lanes on Friday, March 28, 1986. An estimated total of 212.6 cubic yards of Class S concrete was placed in the decks. Interviews with Kentucky Department of Highways' personnel revealed that, during initial placement, the Class S concrete had experienced considerable loss of slump when compared to slump taken at the plant and that proper finishing of the concrete was difficult due to rapid evaporation of free water. The Class S concrete also was quite sticky and obtaining a good finish was further compounded by the fact that the bridge was on a skew and the tyning machine was not skewed. Results were perceived to be much better during placement of the westbound deck. The amount of free water necessary for a good finish was adequate and workers appeared to have gained experience from the previous pour. Construction activities have been documented previously (2).

The experimental Class S concrete has been characterized in terms of freeze/thaw durability, compressive strength, and elastic modulus. Briefly, results of freeze/thaw testing of four prisms cast at the job site indicated an average durability factor of 56 based upon 350 cycles. The average percent expansion was 0.071 for the set. Kentucky Standard Specifications for Road and Bridge Construction require that Class AA concrete have no more than 0.050 percent expansion when tested in accordance with ASTM C 666, Method B. Concrete having more than 0.050 percent expansion is generally considered non-durable.

At the jobsite, and during placement of the eastbound and westbound decks, the shrinkage compensating concrete was tested by applicable Kentucky Department of Highways' Standard Test Methods for slump and air content and 6" x 12" concrete cylinders were cast for compressive strength tests at a later date. The Kentucky Department of Highways' Division of Materials tested the cylinders at ages of 6, 7, 28 and 30 days. The results are given in Table 1. Compressive strengths at 28-days, as determined by the Kentucky Transportation Center in accordance with ASTM C 39, for two cylinders cast at the job site indicated an average of only 3,080 psi. Elastic moduli of the two cylinders at 28 days, as determined by ASTM C 469, averaged $3.16 \times 10^6$ psi which is within the normal range for concrete having a compressive strength of 3,080 psi. Kentucky Standard Specifications for Road and Bridge Construction require that a Class AA concrete have a minimum compressive strength of 4,000 psi at 28 days.

Because the 28-day compressive strengths were low, cores were obtained from the westbound and eastbound bridge decks and tested at 52 and 54 days, respectively. The compressive strengths of those cores averaged 3,720 psi and 4,270 psi for the westbound and eastbound decks, respectively. Additional cores were obtained and tested at 96 and 98 days.
TABLE 1. COMpressive STrength, Slump, and AiR CONTENT OF FIELD SPECIMENS CAST AT THE JOBSITE

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Age at Test (Days)</th>
<th>Compressive Strength (psi)</th>
<th>Slump (in.)</th>
<th>Air Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1E</td>
<td>6</td>
<td>2,940</td>
<td>6.00</td>
<td>5.3</td>
</tr>
<tr>
<td>2W</td>
<td>7</td>
<td>3,440</td>
<td>6.00</td>
<td>4.5</td>
</tr>
<tr>
<td>3E</td>
<td>28</td>
<td>3,940</td>
<td>6.00</td>
<td>5.3</td>
</tr>
<tr>
<td>4E</td>
<td>28</td>
<td>4,895</td>
<td>3.00</td>
<td>4.0</td>
</tr>
<tr>
<td>5E</td>
<td>28</td>
<td>3,990</td>
<td>6.00</td>
<td>5.6</td>
</tr>
<tr>
<td>6E</td>
<td>28</td>
<td>3,560</td>
<td>5.75</td>
<td>6.0</td>
</tr>
<tr>
<td>7W</td>
<td>30</td>
<td>3,395</td>
<td>4.75</td>
<td>6.5</td>
</tr>
<tr>
<td>8W</td>
<td>30</td>
<td>4,055</td>
<td>6.00</td>
<td>4.5</td>
</tr>
<tr>
<td>9W</td>
<td>30</td>
<td>4,150</td>
<td>5.50</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Note: E and W denote eastbound and westbound, respectively.

for the westbound and eastbound lanes, respectively. The average compressive strength for the westbound-deck cores was 4,040 psi while the average of the eastbound-deck cores was 4,115 psi. The Division of Materials recommended the concrete be considered acceptable and the bridge was opened to traffic on December 22, 1986.

PERFORMANCE MONITORING

Monitoring of the development of shrinkage cracking in the experimental Class S concrete bridge deck was by visual methods. Inspections were proposed daily during the first week after placement, weekly during the first month, monthly during the first six months, quarterly during the first year and semi-annually for two years thereafter. Additionally, two bridges of similar design but constructed using conventional Class AA concrete also were inspected for cracking patterns for comparison purposes. One comparison bridge, constructed in 1982, is located in Scott County, Kentucky, on KY 227 over LeComptes Run. The prime contractor was Judy Construction Company. The other bridge, constructed in 1984, is located in Jefferson County, Kentucky, on KY 2052 over Buechel Branch. The prime contractor was Shamrock International Corporation.
Initial inspections of the comparison bridge decks were made during June 1985. The Scott County bridge deck exhibited two slight longitudinal cracks three feet in length in the southbound lane and one longitudinal crack about 3-feet long in the northbound lane. None were attributed to shrinkage stresses. The Jefferson County bridge deck had shrinkage cracking near drain inlets in the outer westbound lane, and corner cracking was evident at both ends of the outer westbound lane.

The initial inspection of the experimental Class S bridge deck was made within one week after placement of the concrete. No shrinkage cracks were evident on the surface of either eastbound or westbound decks. Visual inspections continued through the months of April, May and June, and no cracking was observed.

Very small shrinkage cracks were observed during the July 1986 inspection near the center of the deck. The cracks were traced with a lead pencil so they might be visible in photographs (see Figures 1 and 2). Also, corner cracking was observed in the northeast corner of the westbound deck. These cracks were generally radial and extended from the west end of the bridge to the north barrier wall. Five cracks were observed (see Figure 3). Inspections conducted in August, September and December, 1986, revealed little additional cracking.

![Figure 1. Shrinkage Cracking near Center of Class S Concrete Deck.](image-url)
Figure 2. Shrinkage Cracking near Center of Class S Concrete Deck.

Figure 3. Corner Cracking; Class S Concrete Deck.
The Class S deck was inspected again in March and September, 1987. Corner cracking first observed during the July 1986 inspection appeared to have widened appreciably (see Figure 4). Those cracks generally appeared where reinforcing steel had been placed radially in acute corners. Experience has shown that similar cracking patterns often occur in conventional Class AA concrete decks at these locations and may be related to the amount of steel placed there. Additional cracking also was observed in the outer eastbound lane (see Figure 5). No additional cracking was observed during inspections conducted in March and September, 1988.

Final inspections of the comparison bridges were conducted during March 1989. The Scott County bridge deck was in excellent condition. In addition to the small longitudinal cracks noted previously, one transverse crack about 6-feet long was observed in the northbound lane (see Figure 6). There were no shrinkage cracks detected near any of the six deck drains.

Final inspection of the Jefferson County bridge deck revealed considerable cracking of the Class AA concrete. In addition to the corner cracking noted previously at both ends of the outer westbound lane, similar cracking had occurred at both ends of the outer eastbound lane. Longitudinal cracking was observed in both eastbound and westbound lanes. The cracking occurred at somewhat regular intervals and appeared to be directly above the upper reinforcing mat (see Figures 7 and 8).

The final inspection of the Class S concrete deck also was conducted in March 1989. Little additional cracking had occurred since the previous inspection. Figure 9 shows cracking in the northeast corner of the deck. Figures 10 and 11 are typical of minor shrinkage cracks observed on the deck surface. Figure 11 also illustrates another problem associated with concrete deck surfaces, that of aggregate popouts.

**SUMMARY AND CONCLUSIONS**

The majority of drying shrinkage cracking of concrete occurs early. Typically, one-third of the total amount of drying shrinkage occurs during the first two weeks after moist curing ceases. Furthermore, 40 to 80 percent of the total drying shrinkage occurs within the first three months and generally, 85 percent of all drying shrinkage will occur during the first year (3). The shrinkage compensating concrete placed in the Tates Creek bridge exhibited minor shrinkage cracking within four months after placement and moist curing. Relative to the amount of surface area of the deck, about 6,720 square feet, the amount of shrinkage cracking appears insignificant.
Figure 4. Corner Cracking; Class S Concrete Deck.

Figure 5. Cracking of Class S Concrete Deck in Eastbound Lane.
Figure 6. Transverse Cracking of Class AA Concrete Deck; Scott County.

Figure 7. Longitudinal Cracking of Class AA Concrete Deck; Jefferson County.
Figure 8. Longitudinal Cracking of Class AA Concrete Deck; Jefferson County.

Figure 9. Corner Cracking of Class S Concrete Deck.
Figure 10. Shrinkage Cracking in Class S Concrete Deck after Three Years.

Figure 11. Shrinkage Cracking and Aggregate Popouts in Class S Concrete Deck after Three Years.
In reviewing the comparison decks for shrinkage cracking patterns, significant amounts of shrinkage cracks were not encountered. The Scott County bridge deck had few discernible cracks but none that were attributed to shrinkage stresses. The Jefferson County bridge deck exhibited numerous cracks. However, the majority of those cracks appeared to be load associated and not due to shrinkage of the concrete. Minor shrinkage cracking was detected around drain inlets in the westbound lane.

Due to absence of significant shrinkage cracking on the comparison bridge decks and the presence of minor shrinkage cracking of the Class S concrete deck, no conclusions can be drawn at this time concerning the effectiveness of using expansive cement in concrete mixtures to reduce shrinkage cracking. Other factors may have contributed to the amount of shrinkage cracking detected on the Class S concrete deck, i.e., early drying of the concrete surface and below expected compressive strengths.

Further study of shrinkage compensating concrete is warranted and currently being conducted in Franklin County, Kentucky, by the Kentucky Department of Highways' Division of Materials. Additionally, shrinkage compensating concrete is being considered for use in a bridge deck located in Northern Kentucky. Hopefully, the results of these trials will quantify the reduction of shrinkage cracking due to the use of shrinkage compensating concrete.
REFERENCES


APPENDIX A
SPECIAL NOTE FOR
SHRINKAGE COMPENSATING BRIDGE DECK CONCRETE, CLASS S
(EXPERIMENTAL)

I. DESCRIPTION

This Special Note covers requirements for bridge superstructure concrete produced using expansive cement, to be placed in structures at locations designated elsewhere in the contract.

II. MATERIALS

Concrete, Class S shall be produced using expansive cement meeting the requirements of ASTM C 845 for Type K. The concrete mixture shall conform to all requirements for Concrete Class AA with the following exceptions:

(1) The maximum water/cement ratio shall be 6.30 gal./bag

(2) Maximum slump at the time of placement shall be 7 inches.

(3) No chemical admixtures will be permitted except water reducing and retarding, and air entraining. The admixtures used shall be approved for compatibility with Type K cement by the cement manufacturer.

(4) Maximum ambient daytime temperature during placement of concrete shall be 80°F.

(5) The Contractor or concrete producer shall make trial batches and tests as necessary to ensure that the mixture used will meet the requirements for air content, slump, cement content, water/cement ratio, and compressive strength. The trial mixtures shall be made using ingredients to be used on the job, and shall be mixed at the approximate temperature anticipated for actual job mixtures. A report of test results for the above listed properties for all trial batches and for the proportions of the mixture the Contractor proposes to use shall be submitted to the Engineer for approval before placement begins.

III. CONSTRUCTION REQUIREMENTS

Mixing, hauling, placing, and curing of Concrete, Class S shall conform to all requirements for Concrete, Class AA with special attention to the following items:

(1) Forms shall be thoroughly wetted immediately before placing Concrete, Class S.

(2) Special precautions shall be taken to reduce delay in placing concrete after arrival at the jobsite.
(3) Additional water may be added at the jobsite to compensate for slump loss, but the maximum allowable water, as calculated from the maximum water/cement ratio, shall not be exceeded.

(4) Any mixture with a temperature exceeding 90°F shall be rejected.

For the structures indicated, Concrete, Class S shall be used in all portions of the structure normally constructed of Concrete, Class AA except barrier walls and intermediate diaphragms. Concrete, Class S may be used in barrier walls and intermediate diaphragms in lieu of Concrete, Class AA at the Contractor's option; however, concrete in these items will be measured and paid as Concrete, Class AA.

IV. MEASUREMENT AND PAYMENT

Method of measurement and basis of payment will be the same as for Concrete, Class AA. The accepted quantity will be paid for at the contract unit price per cubic yard for Concrete, Class S.

November 2, 1984