Research Report
KTC 95-8

PERFORMANCE OF SHRINKAGE COMPENSATING BRIDGE DECK CONCRETE (CLASS S) I-75, KENTON COUNTY

by

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16. Abstract

Shrinkage Compensating Concrete (Class S) is made with an expansive cement in which the expansion, if restrained, induces compressive stresses that approximately offset tensile stresses induced during drying shrinkage, thereby eliminating or significantly reducing the occurrence of shrinkage cracking in concrete. The objectives of this study were to evaluate the construction and performance of the Shrinkage Compensating Concrete (Class S) and to compare these characteristics to previous Class S concrete data and to conventional Class AA bridge deck concrete. This report summarizes construction activities and provides final performance evaluations and recommendations relative to experimental decks and barrier walls constructed of shrinkage compensating concrete during the widening and reconstruction of I-75 in Kenton County, Kentucky.

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EXECUTIVE SUMMARY

In an effort to minimize the amount of shrinkage cracking occurring in Portland cement concrete bridge decks and gain further experience with the use of expansive cements, the Kentucky Department of Highways made use of a shrinkage compensating concrete for the I-75 widening and realignment project in northern Kentucky. Shrinkage compensating concrete is made with a Type K cement in which the expansion, if restrained, induces compressive stresses that approximately offset tensile stresses induced by drying shrinkage. The objectives of this study were to evaluate construction and performance aspects of shrinkage compensating concrete used in bridge decks and barrier walls and to compare the performance to conventional, Class AA, concrete that is normally used in bridge decks and barrier walls.

Placement of Class S concrete began in September 1991 and continued sporadically through April 1992. Approximately 960 cubic meters (1,256 cubic yards) of Class S concrete were placed. Placement of the Class S concrete was excellent and the concrete finishing crew did outstanding work on the deck surfaces. Both workability and finishing characteristics of the Class S concrete mixture were superb. The Class S concrete was wet cured for seven days using a combination of burlap, water tanks, and soaker hoses.

During placement activities, University Kentucky Transportation Center personnel cast specimens for freeze/thaw durability testing and specimens for compressive strength and modulus of elasticity determinations. Expansions of the Class S concrete mixture during the freeze/thaw durability test averaged 0.01 percent. Specimens cast from the Class AA concrete had an average expansion of 0.05 percent. Compressive strength and modulus of elasticity tests indicated average compressive strengths and modulus of elasticity at 28 days of 38.61 MPa and 24.82 x 10^3 MPa (5,600 psi and 3,600,000 psi), respectively.

Regular visual inspections of the experimental and control decks were performed over a three-year period following completion of placement activities. Confirmation that the Class S concrete has significantly less shrinkage cracking comes from observing the concrete barrier walls. Barrier walls constructed of Class S concrete have exhibited very few cracks and the observed cracking occurs only randomly. However, far more cracks were observed in comparison barrier walls constructed of Class AA concrete. The Class AA concrete barrier walls typically have cracks at 1.22-meter (four-foot) intervals. This pattern has been observed in numerous other barrier walls constructed of Class AA concrete as well. The limited amount of cracking observed on the deck surfaces and from beneath those decks that are attached to existing structures appears to be stress related and probably not due to drying shrinkage of the concrete. The independent bridge structures constructed of Class S concrete are virtually crack free while the Class AA concrete bridge decks exhibit numerous shrinkage cracks. Cost comparisons for this project revealed an in-place concrete cost of $461.76 per cubic meter ($353.04 per cubic yard) for the Class S concrete and $487.24 per cubic meter ($372.52 per cubic yard for the Class AA concrete. The purpose for the use of the Class S concrete by the Kentucky Department of Highways was to significantly reduce the occurrence of shrinkage. Due to the relative absence of shrinkage cracking in the Class S concrete decks and barrier walls and the presence of significantly more shrinkage cracking in the comparison bridge decks and barrier walls, it may be concluded the performance of the Class S concrete is superior to the conventional Class AA bridge deck concrete and future use is warranted.

INTRODUCTION

Type K cement is an expansive cement and is designed to relieve internal tensile stresses in concrete and therefore minimize shrinkage cracking. Type K cement expands significantly during the seven-day moist curing period but then returns to a zero expansion/contraction level. Type K cement meets the specifications detailed in ASTM C 845, [1]. Concrete containing Type K cement is shrinkage compensating concrete and has been designated as Class S by the Kentucky Department of Highways (KDOH). Kentucky Department of Highways personnel proposed that Class S concrete be used in lieu of Class AA concrete in the bridge decks and barrier walls for the I-75 widening project from the Dixie Highway to 4th Street in Kenton County. The bridge decks and barrier walls where the Class S concrete was used are located on Northbound I-75. Bridge decks and barrier walls containing Class AA concrete are located opposite the experimental decks on Southbound I-75. Construction activities, materials characteristics, and initial performance of the experimental bridge decks and barrier walls have been documented in a previous report, [2].

There were only three stand alone bridge decks; Ramp G over Ramp Y, Ramp G over 9th Street (both Class S concrete), and Ramp C over 9th Street (Class AA concrete). The remainder of the bridge decks were attached to existing decks; Spans 1 - 12 (Class S concrete and Class AA concrete), Ramp Y over 9th Street (Class S concrete), and Ramp X over 9th Street (Class AA concrete). The Class AA concrete bridge decks and barrier walls served as the control for comparison purposes. Figure 1 contains a site map for the experimental project.

The objectives of this study were to evaluate the construction of the Class S bridge decks and barrier walls, evaluate materials characteristics of the Class S mixture, and compare the performance of Class S concrete to the performance of conventional Class AA concrete in bridge decks and barrier walls relative to the presence of shrinkage cracking.

MATERIALS INFORMATION

The Class S concrete mixture was required to conform to all the requirements for conventional Class AA bridge deck concrete with a few exceptions noted herein. The cement content was established at 9.94 bags/m^3 (7.6 bags/yd^3). The maximum water/cement ratio was set at 22.71 L/bag (6.00 gal./bag). The maximum slump of the concrete mixture at the time of placement was established at 152.4 mm (6.0 inches). There were no chemical admixtures permitted in the concrete mixture except water

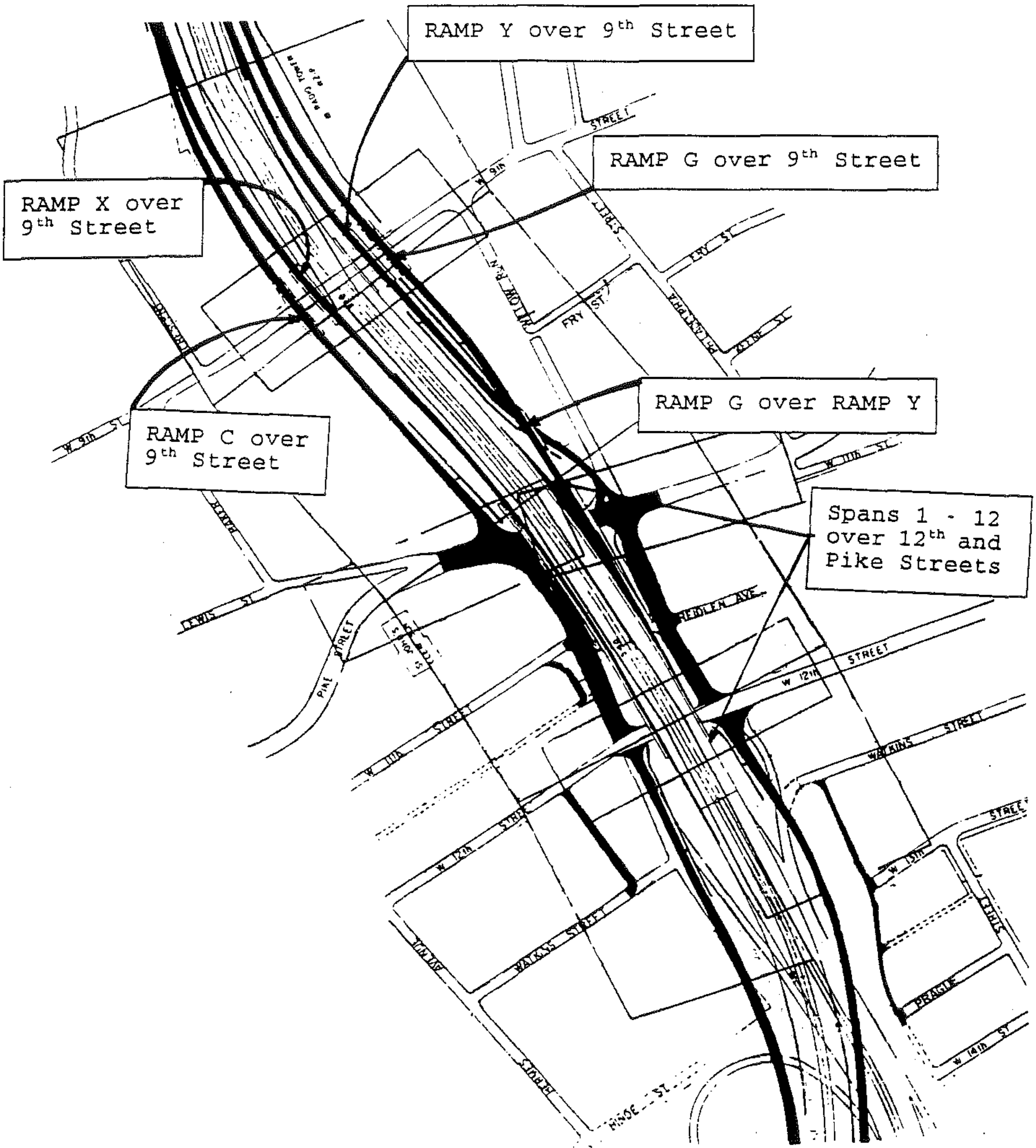

Figure 1. *Location of experimental and control bridge decks on I-75.*

reducing and retarding, and air entraining admixtures. The admixtures that were used had to be approved for compatibility with Type K cement by the cement manufacturer. The maximum ambient daytime temperatures during placement could not exceed 26.7°C (80°F). The contractor or concrete producer was required to make trial batches and tests as necessary to ensure that the mixture met the requirements for air content, slump, cement content, water/cement ratio, and compressive strength.

Furthermore, additional special considerations were given to construction requirements for the Class S concrete. The forms had to be thoroughly wetted immediately before placing the Class S concrete. Special precautions were taken to reduce delay in placing the concrete. Additional water could be added at the jobsite to compensate for slump loss, but in no instance could the maximum water/cement ratio be exceeded. Mixtures with temperatures exceeding 32.2°C (90°F) were rejected. The Class S concrete was wet cured in accordance with Section 601.25 of the Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction. Membrane-forming curing compounds were not permitted.

Information contained in Table 1 details the submitted mix design for a one cubic meter (cubic yard) batch. The fine and coarse aggregate source was American Aggregates Corporation, North Dayton Station, Ohio. The cement source was Southwestern Portland Cement Company, Fairborn, Ohio. The concrete was batched at Plainville Concrete, Cincinnati. The contractor for the job was Incisa U.S.A., Incorporated.

TABLE 1. DESIGN FOR A ONE CUBIC METER (CUBIC YARD) TRIAL BATCH

	CUBIC METER	(CUBIC YARD)
Type K Portland Cement	*324.3 kilograms*	*(715 pounds)*
Natural Sand	*476.3 kilograms*	*(1,050 pounds)*
No. 57 Gravel Aggregate	*852.7 kilograms*	*(1,880 pounds)*
Water (171.9 kilograms maximum)	*+/- 136.1 kilograms**	*(+/- 300 pounds*)*
Retarder (Hy-Kon 2000R)	*609.5 grams*	*(21.5 ounces)*
Air Entrainment (Hy-Kon AE260)	**	**
Sand to Coarse Aggregate Ratio	*0.36*	*0.36*
Maximum w/c ratio	*0.53*	*0.53*
Assumed "wet" Weight	*2,546.6 kg/m^3*	*(146 lbs/ft^3)*

* *As required to provide a six-inch maximum slump at the point of placement.*

** *As required to provide 5.5% +/- 1.5% air content.*

CONSTRUCTION

Two trial batches of Class S concrete were made prior to actual placement of the experimental concrete in the bridge decks and barrier walls. The trial batches conformed to all provisions contained in the Special Note for this project. Placement of Class S concrete began September 6, 1991 and continued sporadically through April 15, 1992. Control decks were placed for comparison using conventional Class AA concrete. A concrete pump was used during the placement of all concrete in decks and barrier walls. A Gomaco C-450 single drum finisher and a Bidwell dual drum finisher were used interchangeably for deck finishing. The Class S concrete was wet cured using an elaborate system of burlap, water tanks, and soaker hoses. Incisa U.S.A., Incorporated job foreman, Don Markesbury, expressed complete satisfaction with both the workability and finishability of the Class S concrete. The concrete finishers stated that the Class S concrete was sometimes "sticky" and a fog spray was applied to the surface during bull floating. A desirable finish was achieved on the majority of Class S decks. An isolated case of an undesirable finish occurred on Ramp G over 9th Street. The finish on this deck is rough and has a large number of displaced aggregate particles and aggregate pull-outs due to deep tyning.

TESTING

The experimental Class S concrete was evaluated relative to freeze/thaw durability, compressive strength, and static chord modulus of elasticity. All test specimens were cast and cured in accordance with ASTM C 31, [3]. Concrete prisms (76.2 mm x 101.6 mm x 406.4 mm) (3" x 4" x 16") for evaluation of freeze/thaw durability were cast during deck placements. Freeze/thaw tests were performed in accordance with ASTM C 666, Method B, Freezing in Air and Thawing in Water, [4]. The rapid freeze/thaw test is used to determine the susceptibility of coarse aggregates to freezing and thawing while confined in a concrete mixture. The average durability factor (based on 350 cycles) for 17 Class S prisms was 87.7 percent. The average expansion was 0.01 percent for the experimental Class S concrete specimens. The Class S concrete prisms met the Kentucky Department of Highways' Standard Specifications for concrete pavement, subsection 805.04.01(B). Subsection 805.04.01(B) requires that concrete for portland cement concrete pavement (PCCP) have no more than 0.06 percent expansion after 350 cycles of rapid freezing and thawing.

Four concrete prisms were cast Class AA concrete during the placement of Ramp X. Durability testing procedures were the same for the Class AA concrete as for the Class S concrete. The average durability factor was 75.8 percent for the four Class AA concrete prisms. The expansion of the four prisms averaged 0.05 percent. One of the four Class AA prisms failed to meet the requirements set forth in subsection 805.04.01(B) for durable concrete pavements.

Compressive strength and static chord modulus of elasticity tests were performed at ages of three, seven, 14, and 28 days. Compressive strength tests were performed in accordance with ASTM C 39, [5]. Cylindrical test specimens were capped in accordance with ASTM C 617 prior to testing [6]. Static chord modulus of elasticity tests were performed in accordance with ASTM C 469, [7]. Figure 2 graphically illustrates the strength gain as a function of time for average values obtained at the different test ages. The 28-day compressive strength requirement of 27.58 MPa (4,000 psi) for the Class S concrete was easily achieved. The static chord modulus of elasticity values appear to be somewhat low when compared to their corresponding compressive strength values.

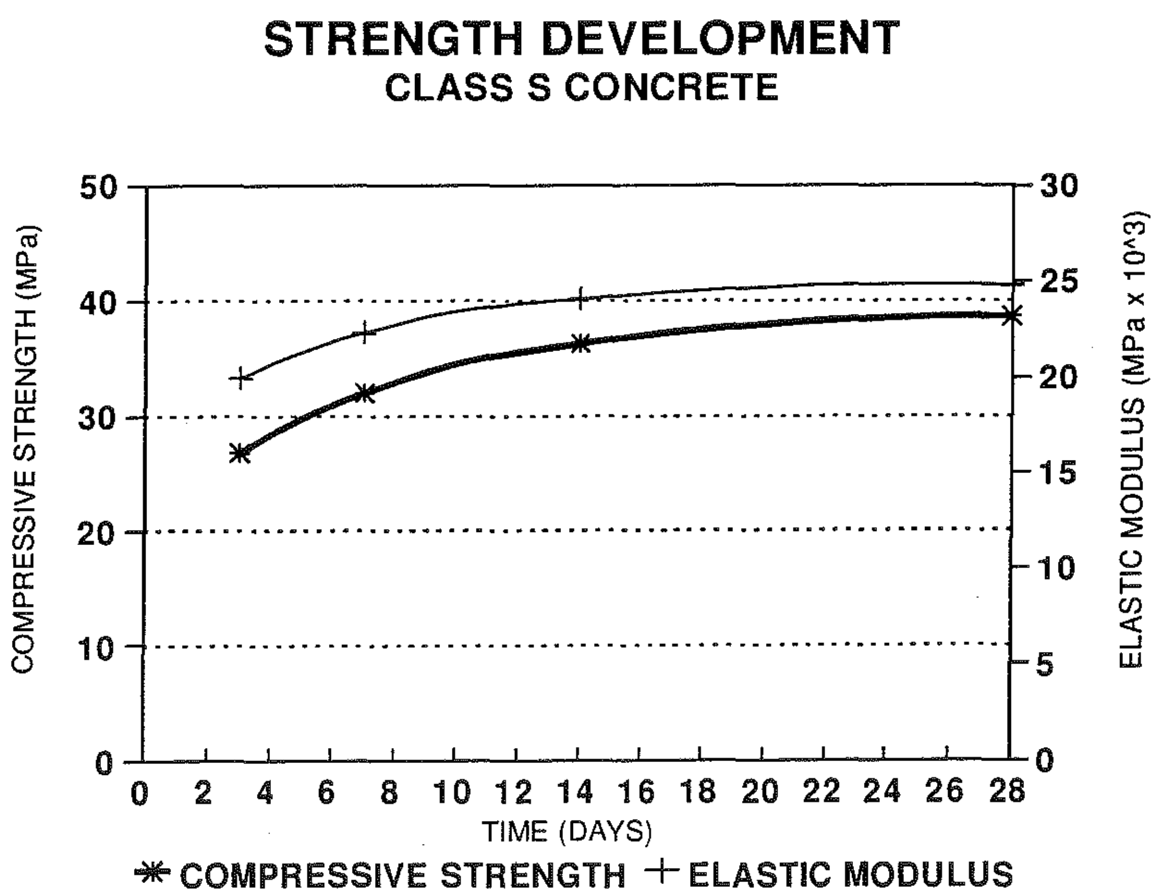

Figure 2. *Strength development properties of the Class S concrete mixture.*

PERFORMANCE COMPARISONS

Regular visual inspections to observe and document the development of deck cracking were performed. The initial inspection, covering Spans 4, 5, 6, and 7, was conducted in October, 1991. There was no cracking in the Class S bridge decks or barrier walls observed during the initial inspection. Visual inspections on all concrete structures under this study (experimental and control) continued throughout the three-year evaluation period. A visual inspection performed in April, 1992 also revealed no cracking in the Class S concrete decks. However, cracking was detected in the Class AA decks during this inspection. Also, a definitive cracking pattern was observed along the barrier walls containing Class AA concrete. The Class AA concrete barrier walls generally had very obvious shrinkage cracks every 1.22 to 2.44 meters (four to eight feet) with the majority occurring at 1.22-meter intervals (four-foot intervals). The barrier walls constructed of Class S concrete exhibited only occasional shrinkage cracks and the cracking that had occurred was random in occurrence.

A visual inspection of the barrier walls was performed again in April, 1993. This survey revealed several aggregate popouts in the barrier walls constructed of Class S concrete. The nature of the popouts was not extreme, but did occur with some regularity. There was no evidence of this problem observed on the barrier walls containing Class AA concrete. Also during this inspection, it was again observed that barrier walls containing Class AA concrete exhibited many shrinkage cracks that generally occurred in a strict pattern. Barrier walls constructed of Class S concrete had relatively few shrinkage cracks that occurred randomly.

Another visual performance survey was performed in September, 1993. All observations were made from beneath the bridge decks during this inspection. Inspection personnel were able to observe the undersides of some decks at very short distances, where the bridge abutments made this possible. Many small, hairline cracks were detected in both the Class S concrete decks and the Class AA concrete decks while inspecting the undersides of the bridge decks. The cracks did not appear to be shrinkage cracks and may be stress related due to their location. The small, hairline cracks did not exhibit any evidence of efflorescence, did not appear to go through the full depth of the deck slab, were minute in width, and appeared random in nature (see Figure 3). Figure 4 is illustrative of a typical shrinkage crack in a concrete deck.

The amount of deck cracking appeared to increase proportionately closer to the existing decks, in both Class S and Class AA concrete decks. The observed cracking appeared

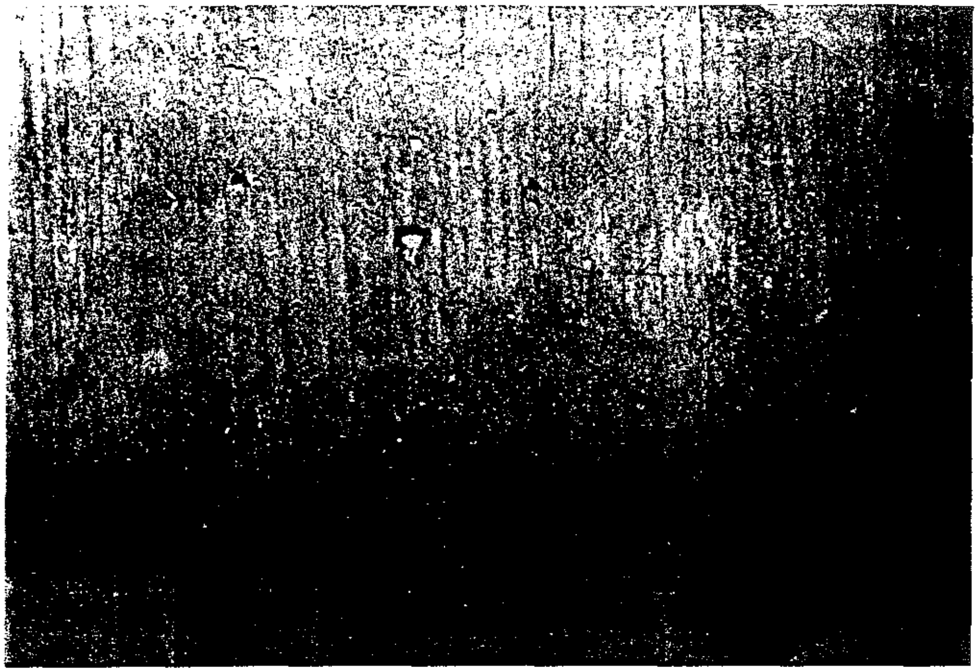

Figure 3. *Cracking of the Class S concrete bridge deck as viewed from beneath the deck.*

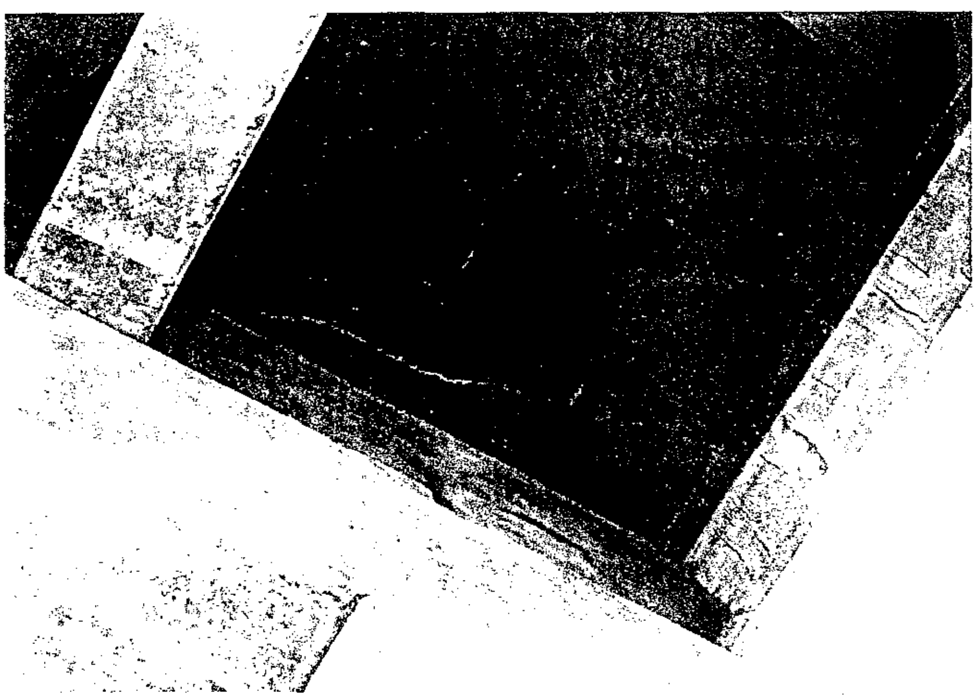

Figure 4. *A typical shrinkage crack in a concrete bridge deck.*

more severe where the new concrete decks were tied to existing decks. Also during this survey, there were shrinkage cracks observed in both concrete types. However, it was readily apparent that there were more shrinkage cracks in the Class AA concrete decks. The cracks in the Class AA decks were also more severe than those observed in the Class S decks. There were fewer shrinkage cracks observed in the Class S concrete decks and they were much more difficult to detect. This was due to the fact that they were not as large and did not exhibit the amount of calcium efflorescence as did the cracks observed in the Class AA concrete decks. Again, the greatest amount of shrinkage cracks in the newer concrete decks was observed nearer the old, existing bridge decks. Also, many of the cracks on the existing decks appeared to have extended into the new concrete decks, both Class S and Class AA. It was quite apparent upon observing the cracking patterns, that much of the cracking in the newly constructed concrete decks was related to sympathetic-type cracking or resulted from vibrations caused by the large volume of traffic traveling on the existing concrete bridge decks.

The final visual survey was conducted in March, 1995. Inspectors returned to the underneath side of the decks to count the number of observable full-depth cracks in the experimental Class S and Class AA control decks. The inspection team numbered the cracks in the control decks at over 140. The experimental Class S decks had only 13 observable cracks. Figures 5 and 6 illustrate the differences between the Class S and Class AA concrete decks. Figure 5 shows the bottom of the Class S bridge deck of Ramp Y over 9th Street. The Class S deck is entirely free of any observable cracking. Figure 6 is a photograph of a Class AA deck located within Span 2 of I-75 over 12th Street and shows significant cracking of the deck. The small extent of shrinkage cracking observed within the experimental Class S concrete bridge decks contrasted with those observed in the Class AA decks serves as positive evidence to the effectiveness of the Class S concrete at minimizing shrinkage cracking.

Shrinkage cracking of the Class S barrier walls remained random with only minimal occurrences. The Class S barrier walls were measured to be 492.25 meters (1,615 feet) in length. The Class S barrier walls contained 52 shrinkage cracks, or about one crack every 9.47 meters (31 feet) on average. The Class AA concrete barrier walls along the southbound side of I-75 were measured to be 356.62 meters (1,170). There were 250 shrinkage cracks identified, or about one crack every 1.43 meters (5 feet) on average. Figures 7 and 8 demonstrate the stark contrast between the two concrete types relative to shrinkage cracking. Figure 7 is a photograph of the west side barrier wall of Ramp Y over 9th Street. The Class S concrete barrier wall has no shrinkage cracks present in the photograph. However, there were six shrinkage cracks identified along the 48.77-meter (160-foot) barrier wall. Figure 8 is a photograph of the west side barrier wall of

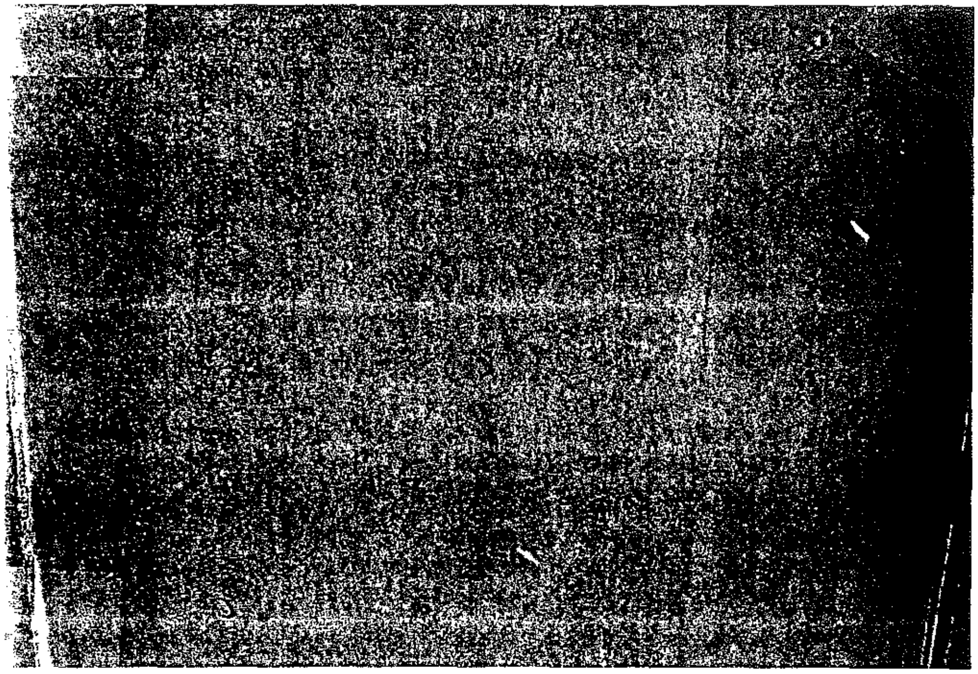

Figure 5. *Class S concrete bridge deck as viewed from beneath the deck (Ramp Y over 9th Street).*

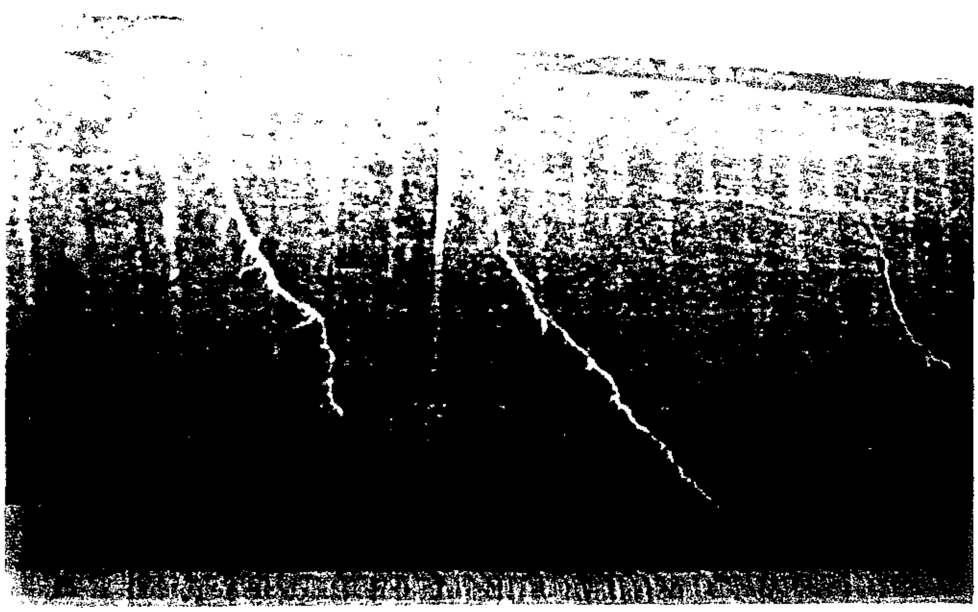

Figure 6. *Class AA concrete bridge deck as viewed from beneath the deck (Span 2 of I-75 southbound over 12th Street).*

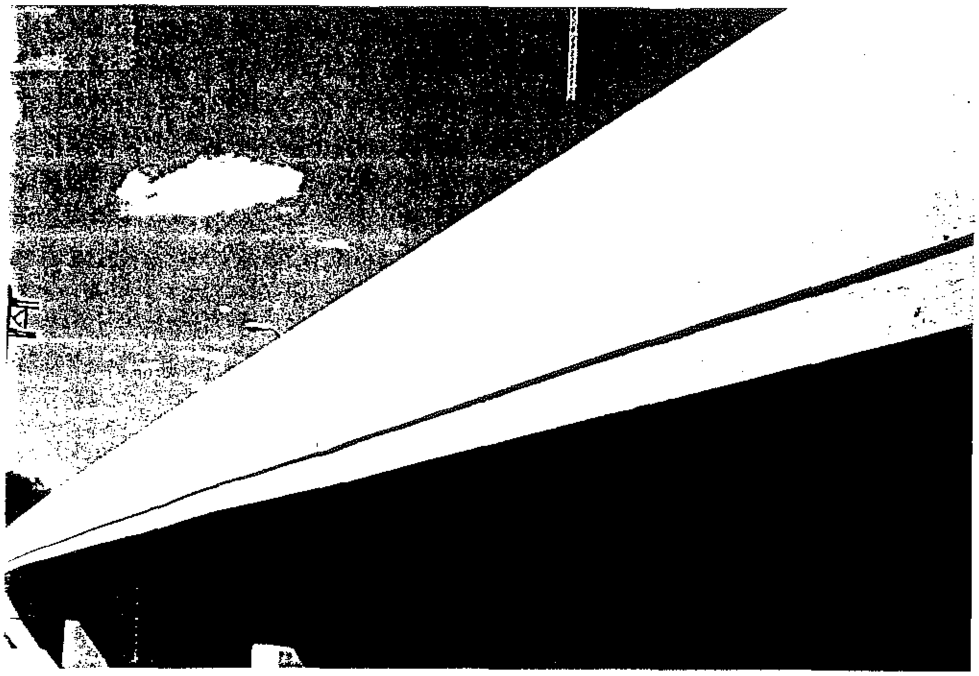

Figure 7. *Class S concrete barrier wall contains no shrinkage cracking (west side of Ramp Y over 9th Street).*

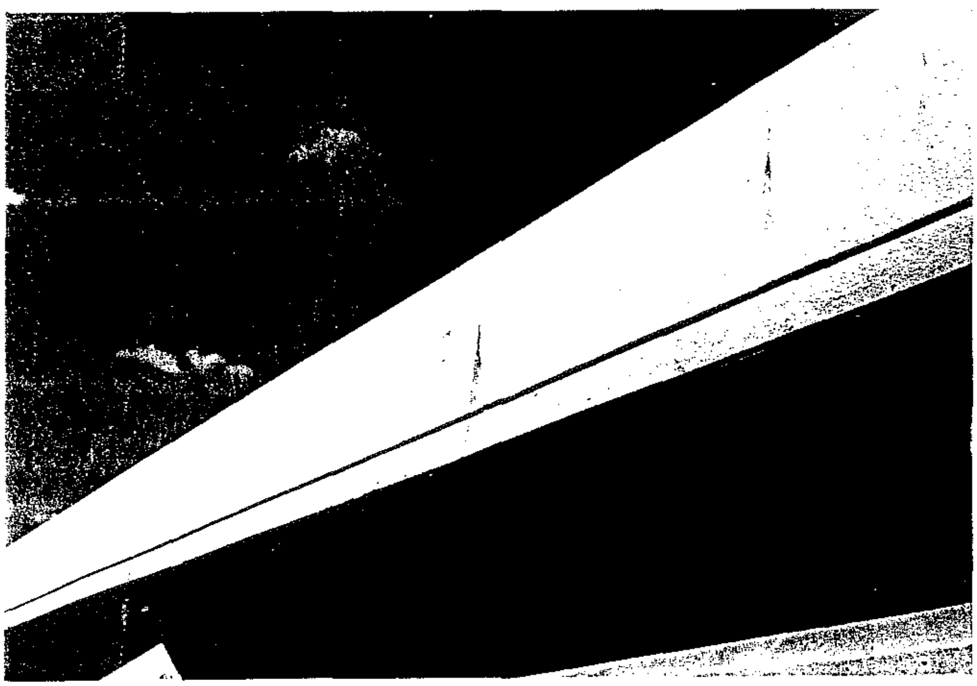

Figure 8. *Class AA concrete barrier wall exhibits shrinkage cracking at 1.22-meter intervals (west side of Ramp X over 9th Street).*

Ramp X over 9th Street. There were 34 shrinkage cracks identified in the 48.77 meter (160 foot) Class AA barrier wall of Ramp X over 9th Street, or an average of one crack every 1.43 meters (5 feet). The absence of significant shrinkage cracking in the Class S concrete barrier walls provides further confirmation of the effectiveness of shrinkage compensating concrete to minimize tensile stresses caused by drying shrinkage.

COST ANALYSIS

Payment for the completed structures described herein was in accordance with the plans and specifications and in the prescribed units for the several pay items. The work was paid for at the contract unit price bid for the several pay items and was for full compensation for furnishing, hauling, and placing all materials, as specified on the plans, and for all labor, equipment, tools and all incidentals necessary to complete the work. Costs provided to the University of Kentucky Transportation Center by Kentucky Department of Highways' personnel were in terms of a unit bid price for concrete, i.e., cost per unit volume. However, that cost included several pay items and was not a true cost for the materials. The unit bid price for work containing Class S concrete was $461.76 per cubic meter ($353.04 per cubic yard) for the I-75 widening and realigning project. The unit bid price for work containing Class AA concrete materials was $487.24 per cubic meter ($372.52 per cubic yard). The portion of the project containing Class S concrete was bid about 5.5 percent less per unit volume than the Class AA portion of the project. Because the Class S concrete mixture was an experimental mixture, it was thought that it would cost slightly more than a conventional mixture. Recent conversations with the Resident Engineer for the project and the concrete producer have established that a Class S concrete mixture would typically cost about $25.18 per cubic meter ($19.25 per cubic yard) more than a conventional Class AA concrete mixture. In terms of a percentage, the concrete producer estimated that the Class S concrete mixture would cost about 35 percent more than a conventional Class AA mixture, due primarily to the cost of the Type K cement versus the cost of Type I Portland cement.

SUMMARY

In an effort to reduce the amount of shrinkage cracking associated with Portland cement concrete bridge decks and gain further experience with the use of an expansive cement, the Kentucky Department of Highways utilized a shrinkage compensating concrete on the I-75 widening and realignment project in northern Kentucky from the Dixie Highway to 4^{th} Street. A previously issued report contains documentation of construction activities, materials properties, and interim performance assessments of the I-75 project, [2].

Shrinkage compensating concrete is made with an expansive cement in which the expansion, if restrained, induces compressive stresses that approximately offsets 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 [8]. 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.

The objectives of this study were to evaluate the construction and performance of shrinkage compensating concrete used in bridge decks and barrier walls and compare the performance to conventional, Class AA, concrete used in bridge decks and barrier walls. The Class S, shrinkage compensating concrete, conformed to all requirements for conventional Class AA concrete with the following exceptions: the cement content was raised to 9.94 bags per cubic meter (7.6 bags per cubic yard), the maximum water to cement ratio was 0.53, the maximum slump of the mixture at the time of placement was 152.4 mm (six inches), no chemical admixtures other than water reducing and retarding and air entraining admixtures were allowed, the maximum ambient temperature during placement could not exceed 26.7°C (80°F), and the use of a membrane-forming curing compound was not permitted.

Placement of Class S concrete began in September 1991 and continued sporadically through April 15, 1992. Approximately 960 cubic meters (1,256 cubic yards) of Class S concrete were placed in the experimental decks and barrier walls. A concrete pump was used during the placement of all concrete in decks and barrier walls. A single drum finisher and a dual drum finisher were used interchangeably for deck finishing. The finishing crew did outstanding work on the Class S concrete decks. The foreman for the job indicated complete satisfaction with both the workability and finishability of the Class S concrete. The concrete finishers stated that the Class S concrete was sometimes "sticky" and water needed to be applied to the surface during bull floating the surface. Placement of the Class S concrete went very well and good deck finishes were obtained with the exception of the Ramp G over 9th Street bridge deck. The Class S concrete was wet cured for seven days using an elaborate system of burlap, water tanks, and soaker hoses.

University of Kentucky Transportation Center personnel observed the placement and deck finishing operations for both the Class S and Class AA concretes. During placement activities, University of Kentucky Transportation Center personnel cast specimens for freeze/thaw durability testing and specimens for compressive strength and modulus of elasticity determinations. The concrete aggregate durability test indicated expansions of the Class S mixture to be about 0.01 percent. The Class AA mixture had an average expansion of 0.05 percent during the test. Compressive strength and modulus of elasticity tests were performed on the Class S concrete cylinders at various ages. The results of these strength tests indicated average compressive strengths and modulus of elasticity at 28 days of about 38.61 MPa and 24.82×10^3 MPa (5,600 psi and 3,600,000 psi), respectively. The Kentucky Department of Highways' Class AA concrete is designed to achieve a minimum compressive strength of 27.58 MPa (4,000 psi) at 28 days. Generally, concrete having a compressive strength of approximately 27.58 MPa (4,000 psi) will have an elastic modulus of about 24.82×10^3 MPa (3,600,000 psi). Results of the strength tests on the Class S concrete demonstrate that the 28-day compressive strength requirement of 27.58 MPa (4,000 psi) was easily met. Previously reported research relative to the use of Class S concrete in Kentucky indicated that the Class S concrete did not achieve the required compressive strength of 27.58 MPa (4,000 psi) in 28 days [9].

Regular visual inspections of the experimental and control decks were performed throughout the three-year evaluation period. The best evidence that the Class S concrete has reduced the amount of shrinkage cracking comes from observing the barrier walls on the decks. Barrier walls constructed of Class S concrete have exhibited very few cracks and the observed cracking is random in occurrence. However, many cracks have been detected in the barrier walls constructed of Class AA concrete. In addition to the large number of shrinkage cracks observed in the Class AA barrier walls, a distinct pattern was also noticed. The Class AA concrete barrier walls typically had cracks every 1.22 meters (four feet). This pattern has been observed in numerous other barrier walls constructed of Class AA concrete.

CONCLUSIONS AND RECOMMENDATIONS

The limited amount of cracking observed on the Class S concrete deck surfaces and from beneath the decks that are attached to existing structures appears to be stress related and not due to drying shrinkage of the concrete. The independent bridge structures constructed of Class S concrete are virtually crack free while the Class AA concrete bridge decks exhibit numerous shrinkage cracks. Overall, with the absence of significant shrinkage cracking in the Class S concrete decks and barrier walls and significantly more shrinkage cracking evident in the comparison bridge decks and barrier walls containing Class AA concrete, it may be concluded that the performance of the Class S concrete is superior to that of the conventional Class AA bridge deck concrete relative to reducing drying shrinkage cracking.

Payment for the completed structures described herein was in accordance with the plans and specifications. Costs provided to the University of Kentucky Transportation Center by Kentucky Department of Highways' personnel relative to this project were in terms of a unit bid price for concrete, i.e., cost per unit volume. However, that cost included several pay items and was not a true cost for the concrete mixtures. For the I-75 widening and realigning project the unit bid price for work containing Class S concrete was $461.76 per cubic meter ($353.04 per cubic yard). The unit bid price for work containing Class AA concrete materials was $487.24 per cubic meter ($372.52 per cubic yard). The portion of the project containing Class S concrete was bid about 5.5 percent less per unit volume than the Class AA portion of the project. However, recent conversations with the Resident Engineer for the project and the concrete producer have established that a Class S concrete mixture would typically cost about $25.18 per cubic meter ($19.25 per cubic yard) or about 35 percent more than a conventional Class AA concrete mixture.

Based upon the data and observations obtained during this study, it is recommended that Shrinkage Compensating Concrete, Class S, be included in the 1996 Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction as an alternate to Class AA concrete to be used in all reinforced concrete in bridge substructures and superstructures above the tops of caps where a reduction in the quantity of shrinkage cracking is desirable.

REFERENCES

1. American Society of Testing and Materials, ASTM C 845-90, 1992 Annual Book of ASTM Standards, Cement; Lime; Gypsum, 04.01, pp. 417-418.

2. Stone, M.D. and Hunsucker, D.Q., "Construction and Interim Performance of a Shrinkage Compensating Concrete (Class S) Bridge Deck Concrete," Research Report KTC 94-7, University of Kentucky Transportation Center, College of Engineering, University of Kentucky, February 1994.

3. American Society of Testing and Materials, ASTM C 31-91, 1992 Annual Book of ASTM Standards, Concrete and Aggregates, 04.02, pp. 5-9.

4. American Society of Testing and Materials, ASTM C 666-90, Method B, 1992 Annual Book of ASTM Standards, Concrete and Aggregates, 04.02, pp. 322-327.

5. American Society of Testing and Materials, ASTM C 39-86, 1992 Annual Book of ASTM Standards, Concrete and Aggregates, 04.02, pp. 20-24.

6. American Society of Testing and Materials, ASTM C 617-87, 1992 Annual Book of ASTM Standards, Concrete and Aggregates, 04.02, pp. 302-305.

7. American Society of Testing and Materials, ASTM C 469-87a, 1992 Annual Book of ASTM Standards, Concrete and Aggregates, 04.02, pp. 245-248.

8. Beckman, P.A. and Gulvas, R.J., "Design and Construction with Shrinkage Compensating Concrete," Construction Materials for Civil Engineering Projects, American Society of Civil Engineers, New York, New York, April 1986.

9. Hunsucker, D.Q., "Performance of a Shrinkage Compensating Deck Concrete (KY 1974 Bridge over West Hickman Creek) Final Report," Research Report KTC 89-30, University of Kentucky Transportation Center, College of Engineering, University of Kentucky, April 1989.