Research Report
KTC 94-7

CONSTRUCTION AND INTERIM PERFORMANCE OF A SHRINKAGE COMPENSATING (CLASS S) BRIDGE DECK CONCRETE

by

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in cooperation with
Kentucky Transportation Cabinet

and

Federal Highway Administration
US Department of Transportation

February 1994

Technical Report Documentation Page

1. Report No. KTC 94-7	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Construction and Interim Performance of a Shrinkage Compensating (Class S) Bridge Deck Concrete		5. Report Date 6. Performing Organization Code
7. Author(s) Michael D. Stone and David Q. Hunsucker		8. Performing Organization Report No. KTC 94-7
9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506-0043		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, KY 40622		13. Type of Report and Period Covered Interim 14. Sponsoring Agency Code
15. Supplementary Notes		

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 the construction activities and interim performance of experimental decks and barrier walls constructed of shrinkage compensating concrete.

17. Key Words	18. Distribution Statement
Pyrament Cement Concrete, Performance Evaluations, Mix Design, Compressive Strength, Elastic Modulus, Freeze/Thaw Durability, Chloride Permeability of Concrete, Bridge Deck Cracking	Unlimited with approval of the Kentucky Transportation Cabinet

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

Form DOT 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO METRIC UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in.	inches	25.40000	millimetres	mm
ft	feet	0.30480	metres	m
yd	yards	0.91440	metres	m
mi	miles	1.60934	kilometres	km
		AREA		
$in.^2$	square inches	645.16000	millimetres squared	mm^2
ft^2	square feet	0.09290	metres squared	m
yd^2	square yards	0.83613	metres squared	m
ac	acres	0.40469	hectares	ha
mi^2	square miles	2.58999	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57353	millilitres	ml
gal.	gallons	3.78541	litres	l
ft^3	cubic feet	0.02832	metres cubed	m
yd^3	cubic yards	0.76455	metres cubed	m
		MASS		
oz	ounces	28.34952	grams	g
lb	pounds	0.45359	kilograms	kg
T	short tons (2000 lb)	0.90718	megagrams	Mg
		FORCE AND PRESSURE		
lbf	pound-force	4.44822	newtons	N
psi	pound-force per square inch	6.89476	kilopascal	kPa
		ILLUMINATION		
fc	foot-candles	10.76426	lux	lx
fl	foot-Lamberts	3.42583	candela/m	cd/m^2
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	C

APPROXIMATE CONVERSIONS FROM METRIC UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.03937	inches	in.
m	metres	3.28084	feet	ft
m	metres	1.09361	yards	yd
km	kilometres	0.62137	miles	mi
		AREA		
mm^2	millimetres squared	0.00155	square inches	in.
m^2	metres squared	10.76392	square feet	ft
m^2	metres squared	1.19599	square yards	yd
ha	hectares	2.47103	acres	ac
km^2	kilometres squared	0.38610	square miles	mi
		VOLUME		
ml	millilitres	0.03381	fluid ounces	fl oz
l	litres	0.26417	gallons	gal.
m^3	metres cubed	35.31448	cubic feet	ft
m^3	metres cubed	1.30795	cubic yards	yd
		MASS		
g	grams	0.03527	ounces	oz
kg	kilograms	2.20462	pounds	lb
Mg	megagrams	1.10231	short tons (2000 lb)	T
		FORCE		
N	newtons	0.22481	pound-force	lbf
kPa	kilopascal	0.14504	pound-force per square inch	psi
		ILLUMINATION		
lx	lux	0.09290	foot-candles	fc
cd/m^2	$candela/m^2$	0.29190	foot-Lamberts ^{2}	fl
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	F

TABLE OF CONTENTS

PAGE

METRIC CONVERSION CHART i
LIST OF TABLES ii
LIST OF FIGURES ii
ACKNOWLEDGEMENTS iii
EXECUTIVE SUMMARY iv
INTRODUCTION 1
PROJECT LOCATION AND DESCRIPTION 1
MATERIALS INFORMATION 1
CONSTRUCTION 3
TESTING 6
PERFORMANCE 8
SUMMARY 11
REFERENCES 14
APPENDIX I 15
APPENDIX II 18
APPENDIX III 31

LIST OF TABLES

TABLE 1. MIX DESIGN FOR A ONE CUBIC YARD TRIAL BATCH 3
TABLE 2. TRIAL BATCH TEST DATA 4
TABLE 3. AVERAGE COMPRESSIVE STRENGTHS AND ELASTIC MODULI OF EXPERIMENTAL CLASS S CONCRETE 8

LIST OF FIGURES

Figure 1. *Location of experimental and control bridge decks on I-75.* 2
Figure 2. *Wet-cure techniques were employed to cure the shrinkage compensating concrete.* 5
Figure 3. *This figure illustrates the desirable finish obtained on the majority of the experimental Class S decks.* 5

LIST OF FIGURES (continued)

PAGE

Figure 4. *This Class S surface appeared to have been rained on prior to placement of the burlap curing cloth.* 6

Figure 5. *An undesirable finish was obtained on this Class S deck of Ramp G over 9th Street. Note the deep tyning and dislodged gravel aggregate particles on the deck surface.* 7

Figure 6. *A fractured aggregate particle dislodged from the Class S concrete barrier wall.* 9

Figure 7. *Cracking of the Class S concrete bridge deck as viewed from beneath the deck.* 10

Figure 8. *A typical shrinkage crack in a concrete bridge deck.* 10

ACKNOWLEDGEMENTS

The authors wish to express their appreciation and gratitude to those involved in the pre-construction, construction and post-construction monitoring of the experimental Class S concrete bridge decks and barrier walls including Mr. Larry Stoltz, P.E., Kentucky Department of Highways, Resident Engineer for the I-75 widening project; Mr. Mike Feinauer, P.E., Kentucky Department of Highways, District 6, Division of Materials; Mr. Gorman Shelly, P.E. and Mr. Jim Brannon, P.E., construction inspectors, Kentucky Department of Highways; Mr. Don Markesbury, Bridge Foreman, Incisia U.S.A. Incorporated; Mr. Ross Martin, P.E., Vice-President, Engineering and Technical Services, Bluegrass Concrete Incorporated; Mr. Leo J. Elsbernd, P.E., Technical Services, Southwestern Portland Cement Company, Eastern Division; Mr. Marcus Smalley, Marketing Representative, Southwestern Portland Cement Company, Eastern Division; and Mr. Donald Vrobel, Sales Representative, Southwestern Portland Cement Company, Eastern Division.

EXECUTIVE SUMMARY

In an effort to reduce the amount of shrinkage cracking in portland cement concrete bridge decks and gain further experience, the Kentucky Department of Highways utilized a shrinkage compensating concrete on the I-75 widening and realignment project in northern Kentucky. 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. 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 shrinkage compensating concrete conformed to all requirements for conventional Class AA concrete with the exceptions noted herein.

Placement of Class S concrete began in September 1991 and continued sporadically through April 1992. Approximately 1,256 cubic yards of Class S concrete were placed. 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 burlap, water tanks, and soaker hoses. Placement of the Class S concrete went very well and the finishing crew did outstanding work on the deck surfaces. The job foreman indicated complete satisfaction with both the workability and finishability of the Class S concrete.

During placement activities, Kentucky Transportation Center personnel made 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 5,600 psi and 3,600,000 psi, respectively.

Regular visual inspections of the experimental and control decks have been made. Evidence that the Class S concrete has reduced the amount of 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 is random in occurrence. However, many cracks have been detected in the barrier walls constructed of Class AA concrete. The Class AA concrete barrier walls typically had cracks every four feet. This pattern has been observed in numerous other barrier walls constructed of Class AA concrete. 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 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 the presence of significantly more shrinkage cracking in the comparison bridge decks and barrier walls, it appears that the performance of the Class S concrete is superior to the conventional Class AA bridge deck concrete.

INTRODUCTION

Type K cement is an expansive cement. It 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). The objectives of this study are to evaluate the construction and performance of shrinkage compensating concrete, Class S, in bridge decks and barrier walls and compare the performance to that of conventional Class AA concrete in bridge decks and barrier walls.

PROJECT LOCATION AND DESCRIPTION

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 Dixie Highway to 4th Street. 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. There were only three stand alone bridge decks; Ramp G over 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 serve as the control for comparison purposes. Figure 1 contains a site map for the experimental project. All bridges under study are located in Kenton County, Kentucky.

MATERIALS INFORMATION

The Class S concrete had to conform to all the requirements for conventional Class AA bridge deck concrete except the changes noted in Sections II and III of the Special Note for Shrinkage Compensating Concrete, Class S. The Special Note for Class S concrete has been reproduced in Appendix I of this report. Information contained in Table 1 details the submitted mix design for a one cubic yard batch.

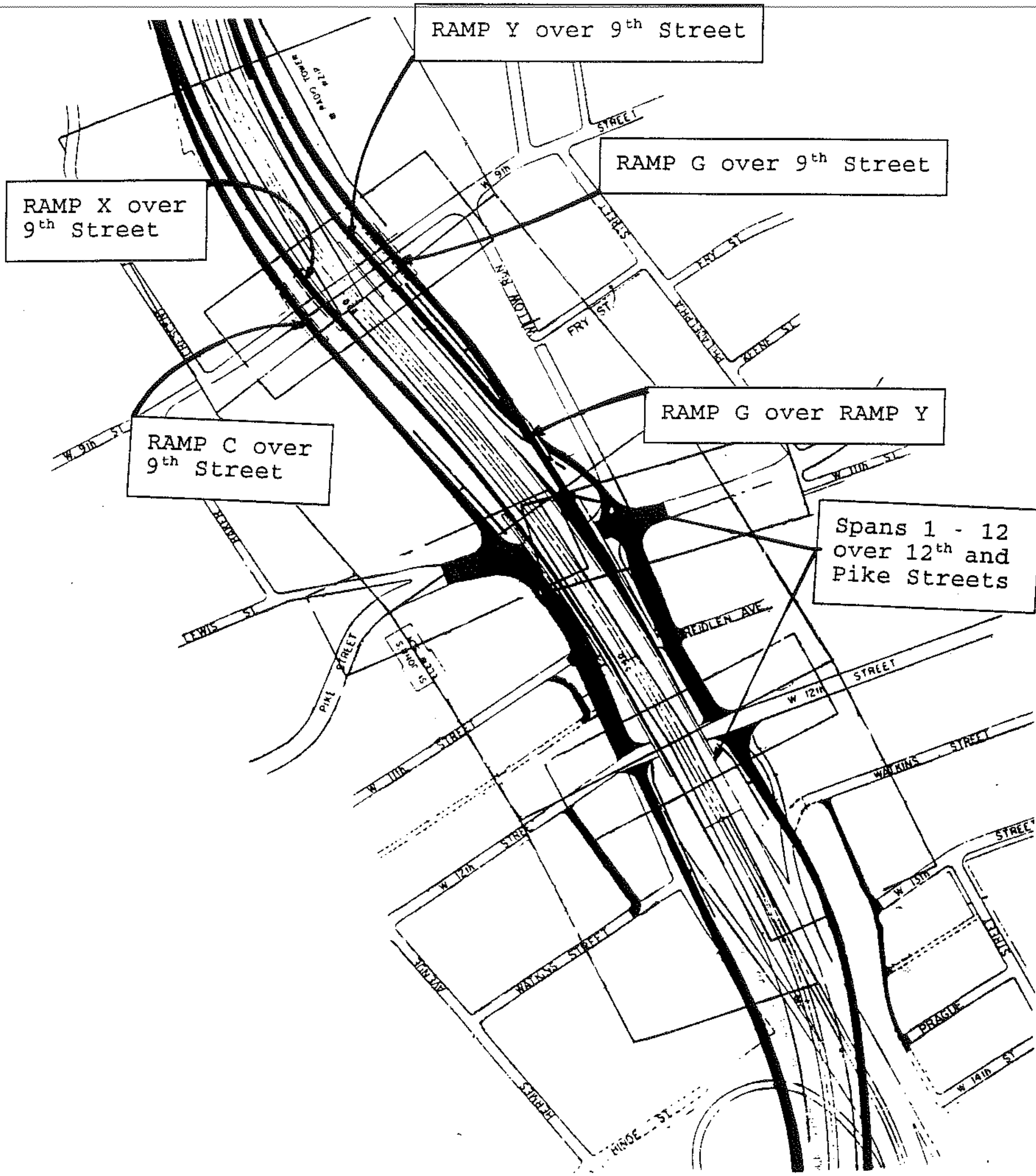

Figure 1. *Location of experimental and control bridge decks on I-75.*

TABLE 1. MIX DESIGN FOR ONE CUBIC YARD TRIAL BATCH

Type K Portland Cement	715 pounds
Natural Sand	1,050 pounds
No. 57 Gravel Aggregate	1,880 pounds
Water (379 pounds maximum)	+/- 300 pounds*
Retarder (Hy-Kon 2000R)	21.5 ounces
Air Entrainment (Hy-Kon AE260)	**
Sand to Coarse Aggregate Ratio	0.36
Maximum w/c ratio	0.53
Assumed "wet" Weight	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.

Compensation for free and negative moisture was made at the time of batching. As specified in the Special Note for Class S concrete, curing compound was not to be applied to the concrete. 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.

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. Test data for the trial batches are contained in Table 2.

Placement of Class S concrete began September 6, 1991 and continued sporadically through April 15, 1992. The following decks were placed with Class S concrete during that time period: Spans 1 - 12 over 12th Street and Pike Street, Ramp G over Y, Ramp G over 9th Street, and Ramp Y over 9th Street. Approximately 1,000 cubic yards of Class S concrete were placed in the experimental bridge decks. An additional 256 cubic yards of Class S

TABLE 2. TRIAL BATCH TEST DATA

	BATCH I	BATCH II
~~Initial Mix Temperature~~	~~85°F (8:50 am)~~	~~84°F (10:25 am)~~
Final Mix Temperature	90°F (9:10 am)	88°F (10:40 am)
Initial Slump	4.50 inches	5.25 inches
Final Slump	4.75 inches	6.00 inches
Initial Air Content	7.1%	8.0%
Final Air Content	5.1%	5.0%
Final Unit Weight	139.2 lbs/ft^3	140.8 lbs/ft^3
Average 28-day Compressive Strength = 4,230 psi		

concrete were placed in barrier walls, diaphragms, finger dams and bridge end bents. 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. According to the Special Note for Shrinkage Compensating Concrete, curing compound was not to be used on the Class S concrete. The Class S concrete was wet cured using burlap, water tanks, and soaker hoses (see Figure 2). Although a wet cure was specified in the Special Note for Shrinkage Compensating Concrete, curing compound was inadvertently applied to the Class S concrete in Spans 1, 2, and 3. This, however, did not have any apparent detrimental effects on the concrete. The 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 water was applied to the surface during bull floating. Water was applied with a fog sprayer. Overall, the placement of Class S concrete went smoothly.

One problem was encountered during the November 26, 1991 placement of Class S concrete on Ramp G over 9th Street. The finishing machine's rollers stopped working which forced the job to be shut down for that day. Approximately 30 yd^3 of Class S concrete had to be removed from the deck. This problem was obviously a mechanical difficulty and had nothing to do with the properties of the Class S concrete. A desirable finish was achieved on the majority of Class S decks. Figure 3 illustrates a desirable finish on a Class S concrete deck. However, Span 8 over Pike Street appears as though it was rained on before the concrete had time to set (see Figure 4). An isolated case of an undesirable finish

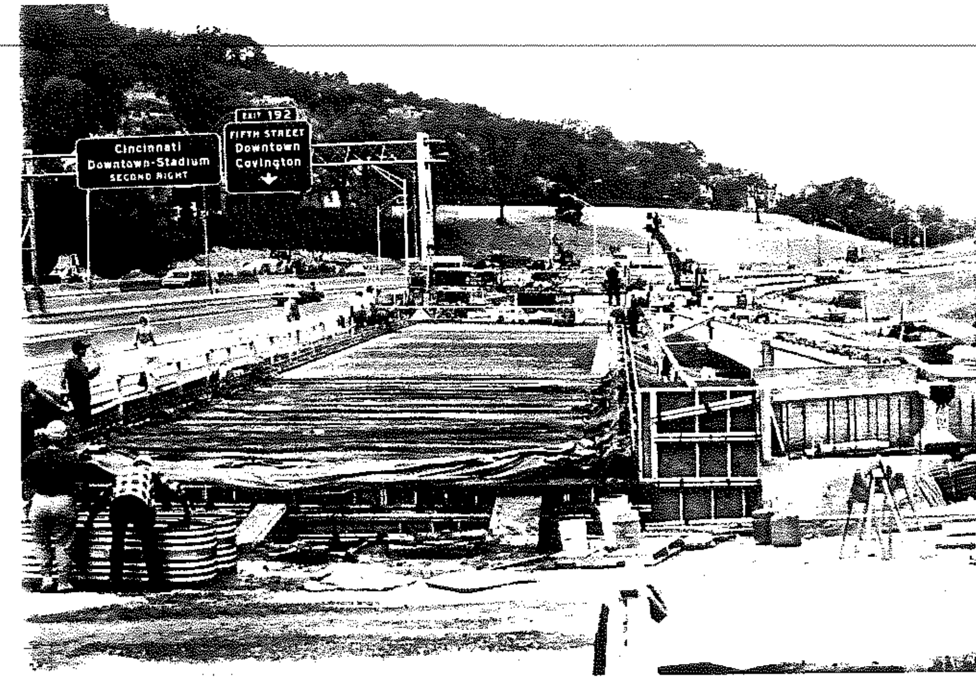

Figure 2. *Wet-cure techniques were employed to cure the shrinkage compensating concrete.*

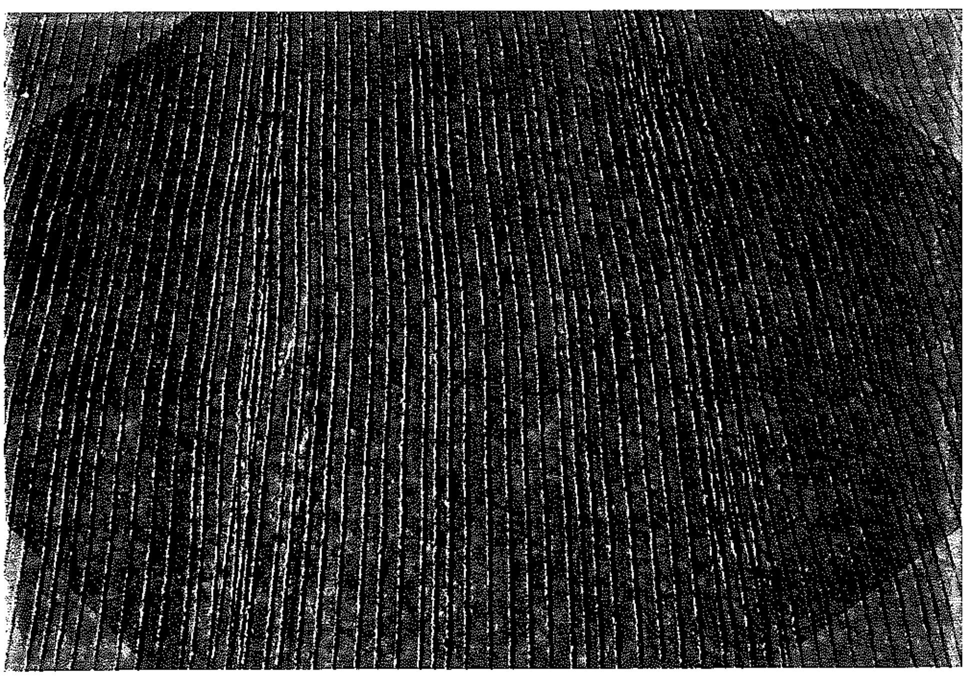

Figure 3. *This figure illustrates the desirable finish obtained on the majority of the experimental Class S decks.*

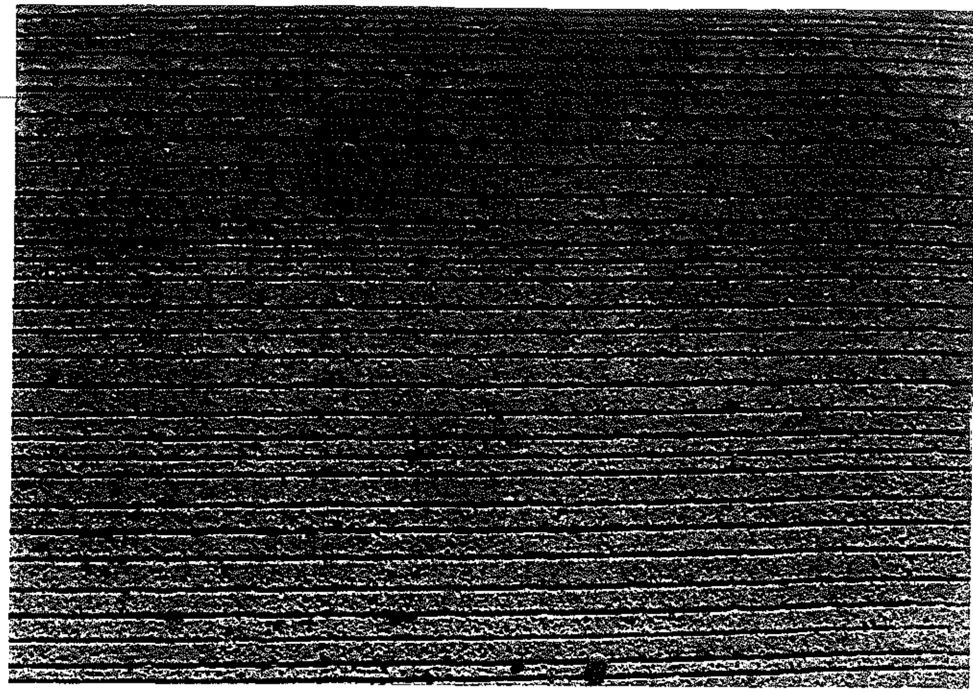

Figure 4. *This Class S surface appeared to have been rained on prior to placement of the burlap curing cloth.*

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. Figure 5 shows the poor finish on Ramp G. Unfortunately, it is not known why this particular deck received a substandard finish. Because there was inadequate space on the deck for sample preparation, the fresh concrete was sampled from the truck, before the pump, and Kentucky Transportation Center personnel did not adequately observe deck finishing activities in the deck area exhibiting the displaced aggregate particles.

TESTING

The experimental Class S concrete has been characterized in terms of freeze/thaw durability, compressive strength, and static chord modulus of elasticity. All test specimens were made and cured in accordance with ASTM C 31, [2]. Concrete prisms (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, [3]. The rapid freeze/thaw test is used to determine the susceptibility of coarse aggregates to freezing and thawing while confined in a concrete mixture. Results

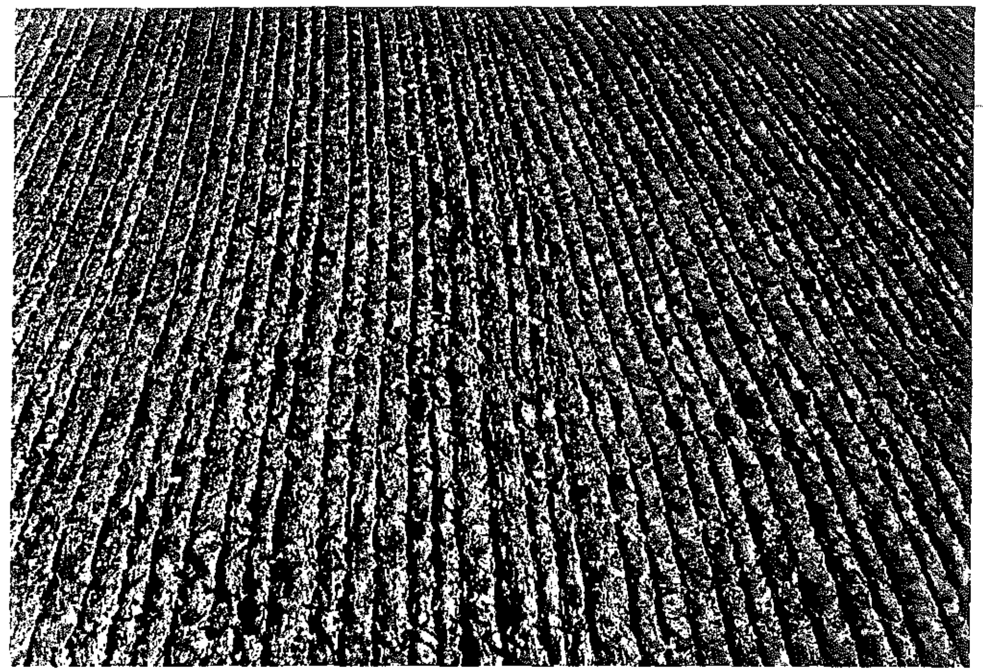

Figure 5. *An undesirable finish was obtained on this Class S deck of Ramp G over 9th Street. Note the deep tyning and dislodged gravel aggregate particles on the deck surface.*

of this testing activity are reported in Appendix II. 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, Specification 805.04.01(B). Specification 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 made of 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 Specification 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, [4]. Cylindrical test specimens were capped in accordance with ASTM C

617 prior to testing [5]. Static chord modulus of elasticity tests were performed in accordance with ASTM C 469, [6]. Results of these testing activities are contained in Appendix III. Average compressive strengths and elastic moduli of the Class S concrete specimens are reported in Table 3. The 28-day compressive strength requirement of 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.

PERFORMANCE

Regular visual inspections for deck cracking have been made. The initial inspection, covering Spans 4, 5, 6, and 7, was conducted on October 2, 1991. There was no cracking observed during the initial inspection. Visual inspections on all concrete under this study have continued on a regular basis since the initial inspection was conducted. A visual inspection performed on April 15, 1992 also revealed no cracking in the Class S concrete decks. However, some cracks were detected in the Class AA decks during this inspection. Also, a cracking pattern was observed on the barrier walls containing Class AA concrete. The Class AA concrete barrier walls generally had very obvious shrinkage cracks every four to eight feet. The majority of these cracks occurred at four-foot intervals. The barrier walls constructed of Class S concrete had very few shrinkage cracks and the cracking that had occurred was only random in occurrence.

A visual inspection of the barrier walls was performed again on April 23, 1993. This survey revealed several aggregate popouts in the barrier walls constructed of Class S concrete. This occurrence was not extreme, but did occur with some regularity. As shown in Figure

TABLE 3. AVERAGE COMPRESSIVE STRENGTHS AND ELASTIC MODULI OF EXPERIMENTAL CLASS S CONCRETE

AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psi x 10^6)
3	3,890	2.90
7	4,650	3.25
14	5,270	3.50
28	5,610	3.60

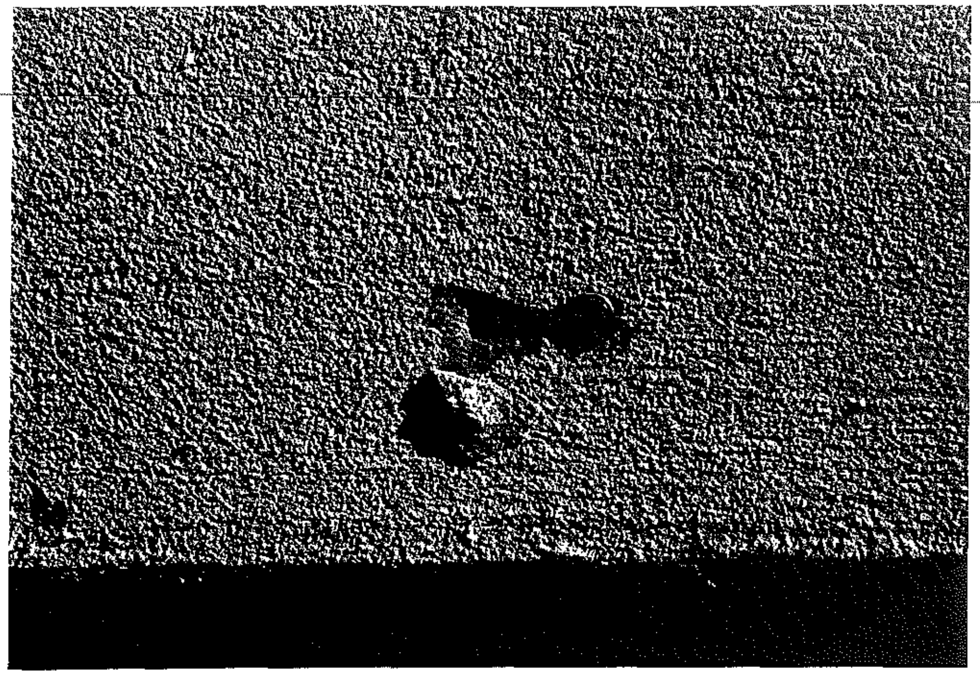

Figure 6. *A fractured aggregate particle dislodged from the Class S concrete barrier wall.*

6, the aggregate appears fractured and only a portion of the aggregate actually became dislodged from the concrete. There has been no incidence 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 only randomly.

Another visual performance survey was performed on September 14, 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 7). Figure 8 is illustrative of a typical shrinkage crack in a concrete deck.

Figure 7. *Cracking of the Class S concrete bridge deck as viewed from beneath the deck.*

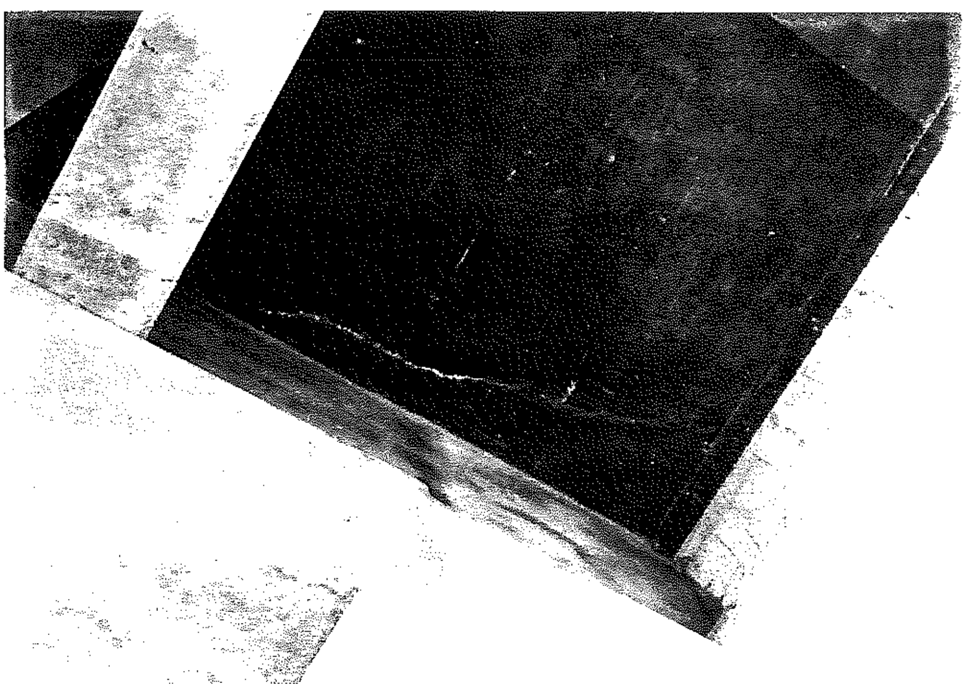

Figure 8. *A typical shrinkage crack in a concrete bridge deck.*

The amount of deck cracking appeared to increase, in both Class S and Class AA concrete decks, with decreasing distance from the existing decks. The observed cracking appeared more severe where the new concrete decks were tied to existing decks. Also during this survey, there were shrinkage cracks observed in both types of concretes. Overall, there was more shrinkage cracking observed in the Class AA concrete decks when compared to the Class S concrete decks. The cracks 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 is quite obvious upon inspection of the cracking patterns, that much of the cracking in the newly constructed concrete decks has been caused either as a result of sympathetic cracking or as a result of vibrations caused by the large volume of traffic traveling on the existing concrete bridge decks. A subsequent report will contain all data obtained during the visual inspections.

SUMMARY

In an effort to reduce the amount of shrinkage cracking in portland cement concrete bridge decks and gain further experience, 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 4th Street. 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 [7]. 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 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 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 80^0F, 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 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 noted exception of the Ramp G over 9th Street bridge deck. The Class S concrete was wet cured for seven days using burlap, water tanks, and soaker hoses.

Kentucky Transportation Center personnel observed the placement and deck finishing operations for both the Class S and Class AA concretes. During placement activities, Kentucky Transportation Center personnel made 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 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 4,000 psi at 28 days. Generally, concrete having a compressive strength of approximately 4,000 psi will have an elastic modulus of about 3,600,000 psi. Results of the strength tests on the Class S concrete demonstrate that the 28-day compressive strength requirement of 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 4,000 psi in 28 days [8].

Regular visual inspections of the experimental and control decks have been made and continue. 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 four feet. This pattern has been observed in numerous other barrier walls constructed of Class AA concrete.

The limited amount of cracking observed on the 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 to date and significantly more shrinkage cracking evident in the Class AA comparison bridge decks and barrier walls, it appears that the performance of the Class S concrete is superior to that of the conventional Class AA bridge deck concrete.

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

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

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

7. 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.

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

APPENDIX I

SPECIAL NOTE FOR

SHRINKAGE COMPENSATING BRIDGE DECK CONCRETE, CLASS S

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 cement content shall be 7.6 bags/cubic yard.

(2) The maximum water/cement ratio shall be 6.00 gal./bag.

(3) Maximum slump at the time of placement shall be 6 inches.

(4) 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.

(5) Maximum ambient daytime temperature during placement of concrete shall be 80^0 F.

(6) 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 proposed 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 90^0 F shall be rejected.

(5) For the structures indicated, Concrete, Class S shall be used in all portions of the structure normally constructed of Concrete, Class AA except intermediate diaphragms, unless otherwise noted elsewhere in the contract.

(6) Contrary to Section 609.15 of the Department's Standard Specifications, Concrete, Class S shall be wet cured in accordance with Section 601.25. Membrane-forming curing compound will not be permitted.

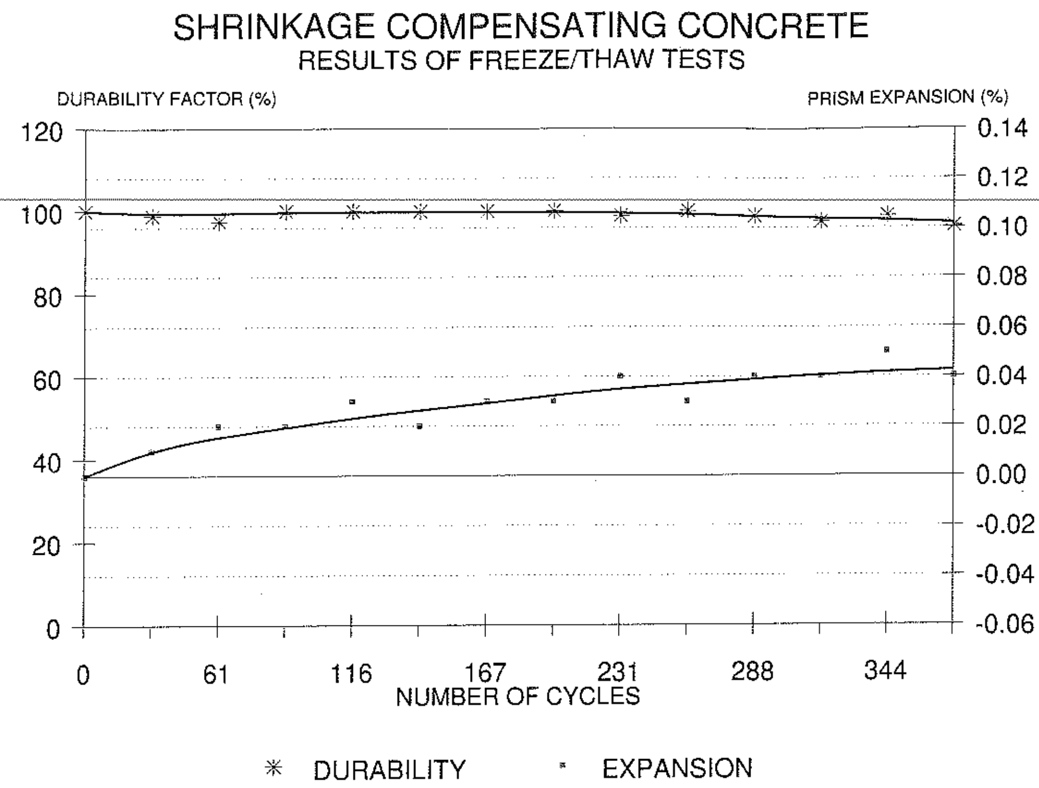
IV. MEASUREMENT AND PAYMENT

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.

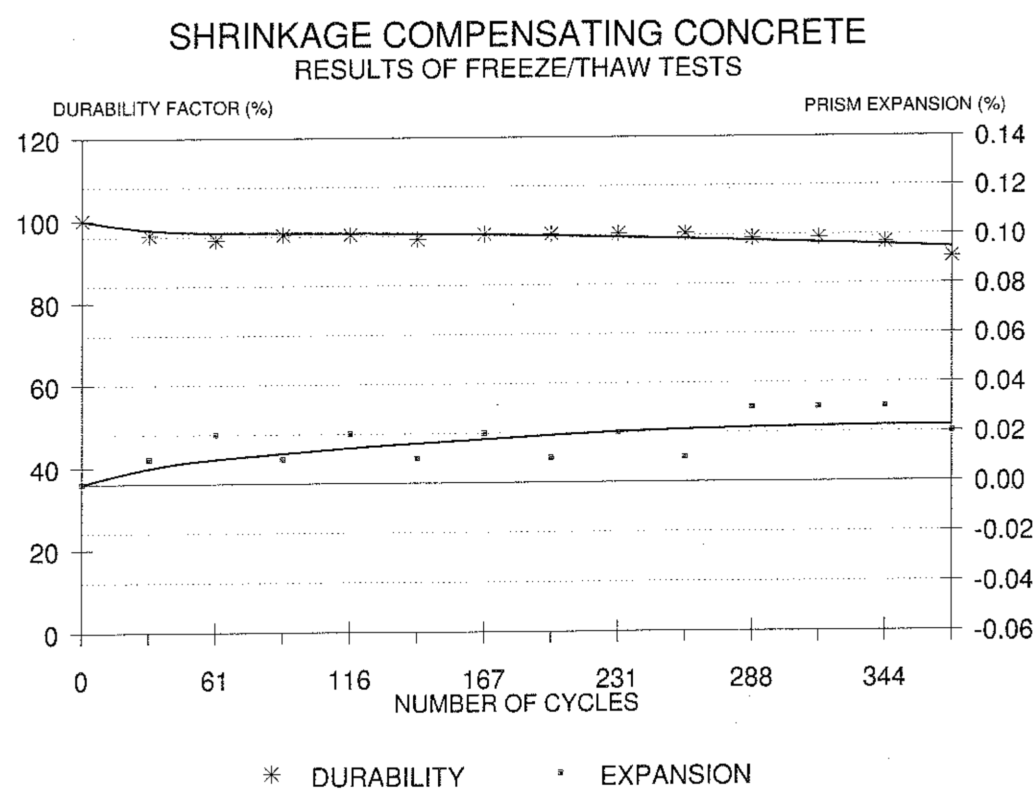
APPENDIX II

RESULTS OF FREEZE / THAW TESTING

CLASS S CONCRETE SPECIMENS



SPECIMEN NO. 2B, SPANS 4,5,6



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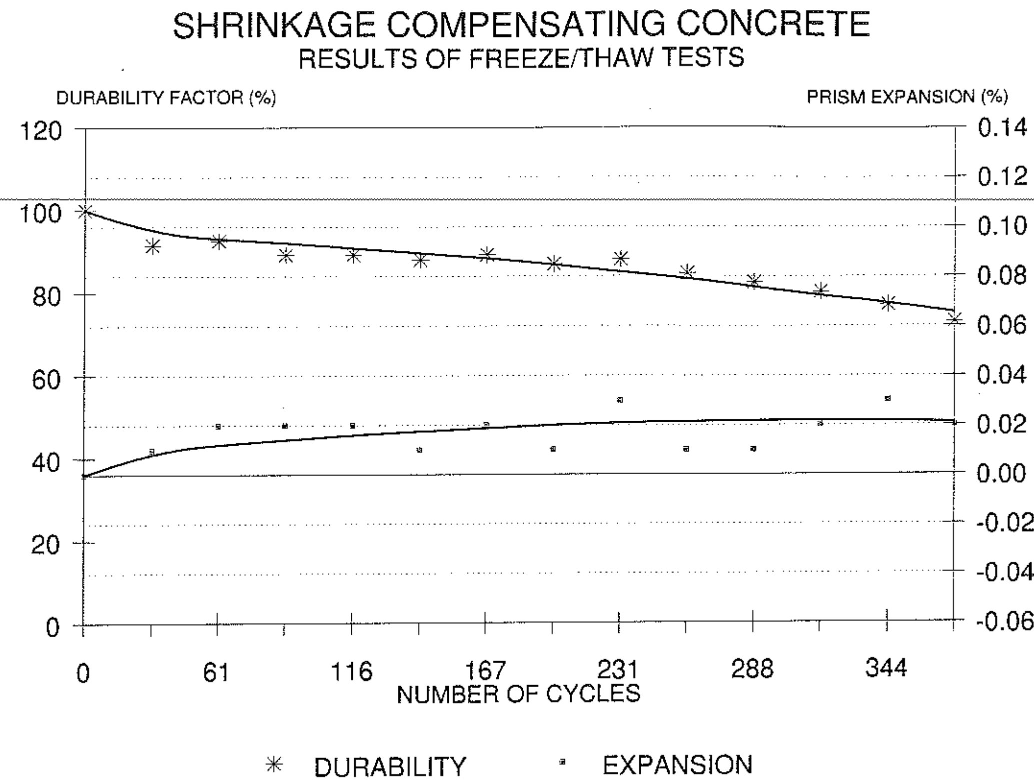
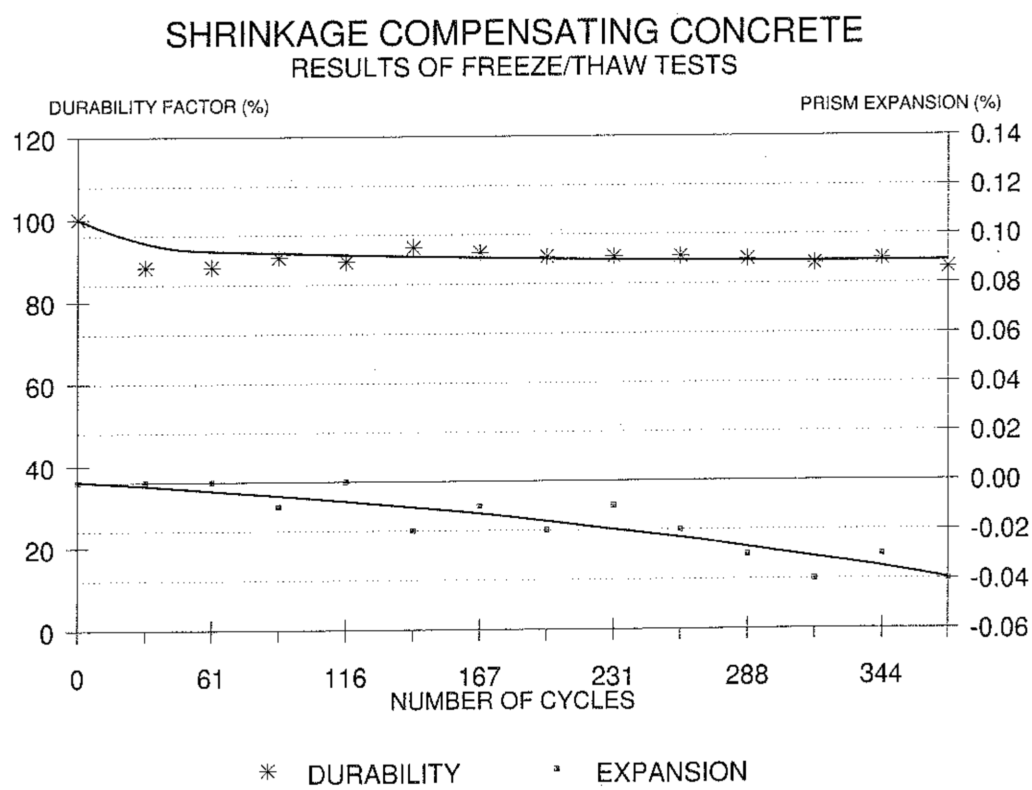


SPECIMEN NO. 2D, SPANS 4,5,6



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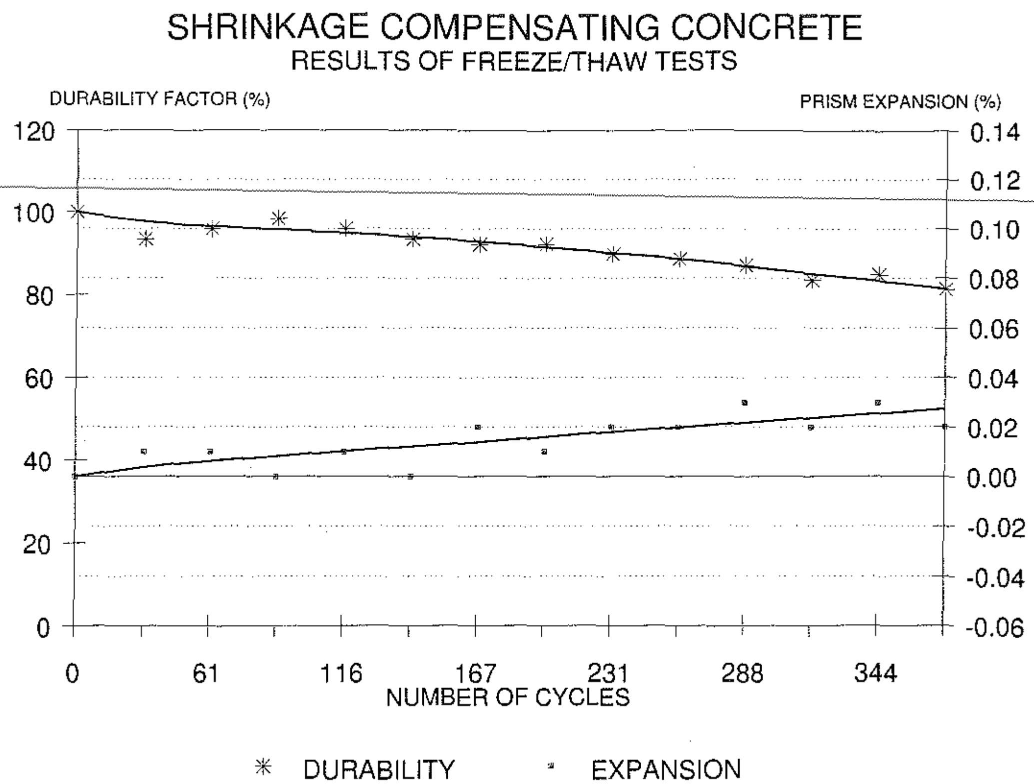

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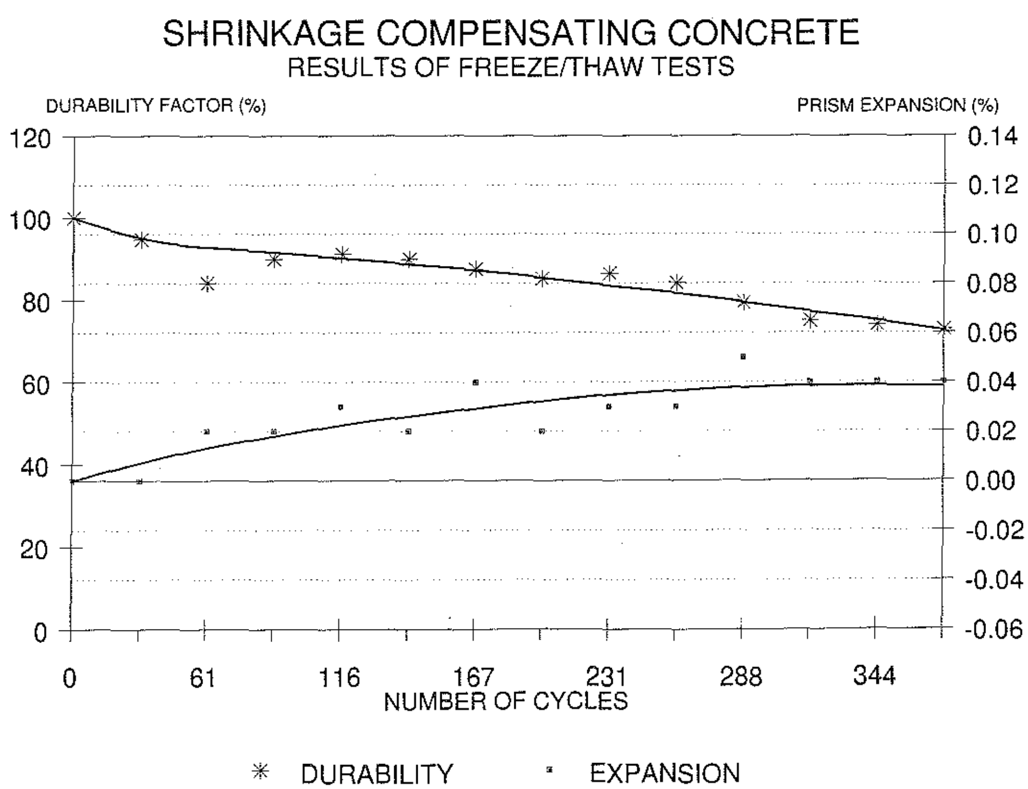

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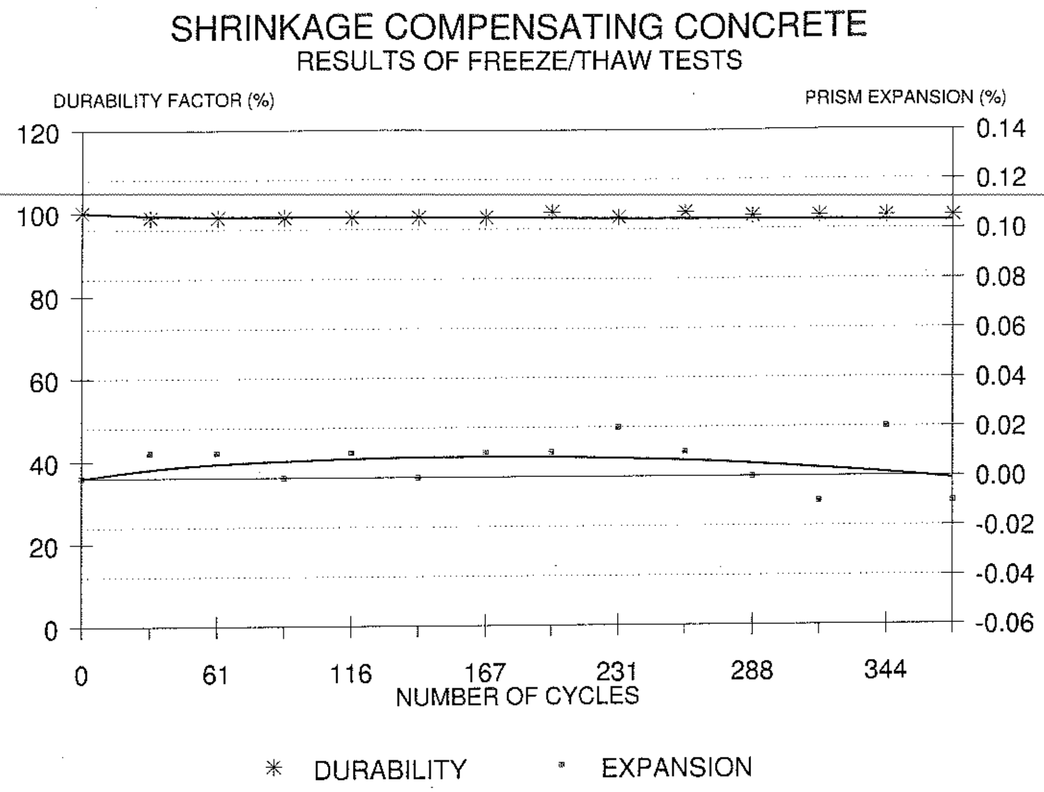

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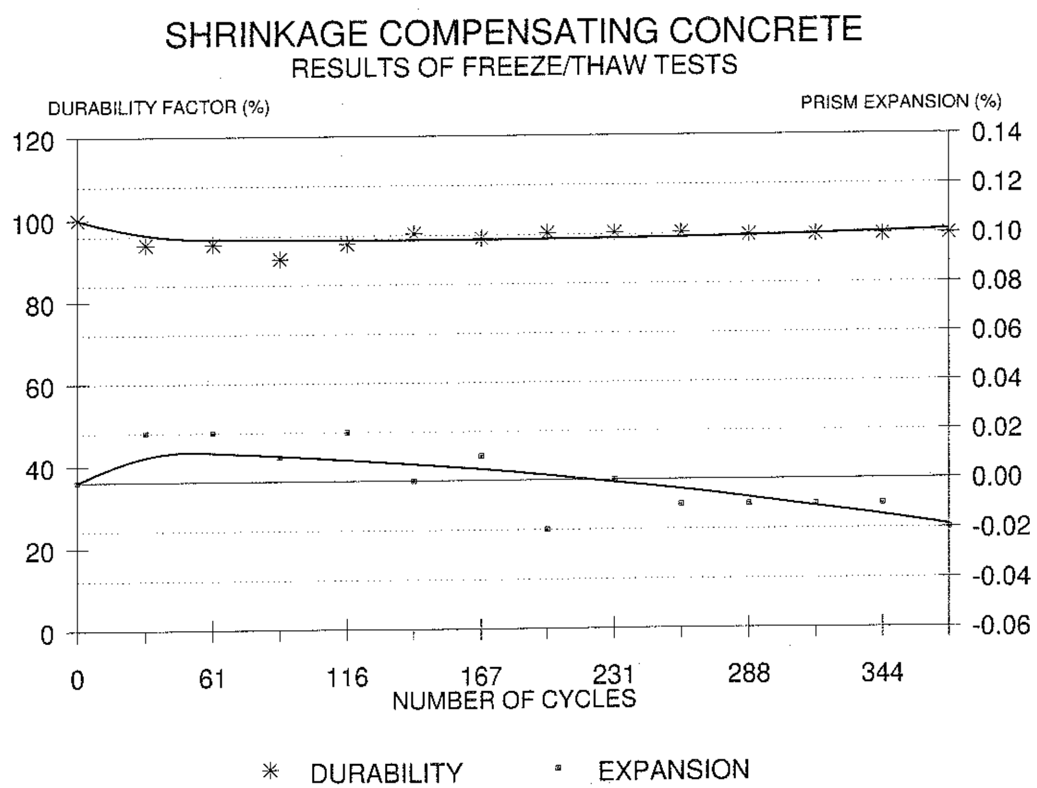

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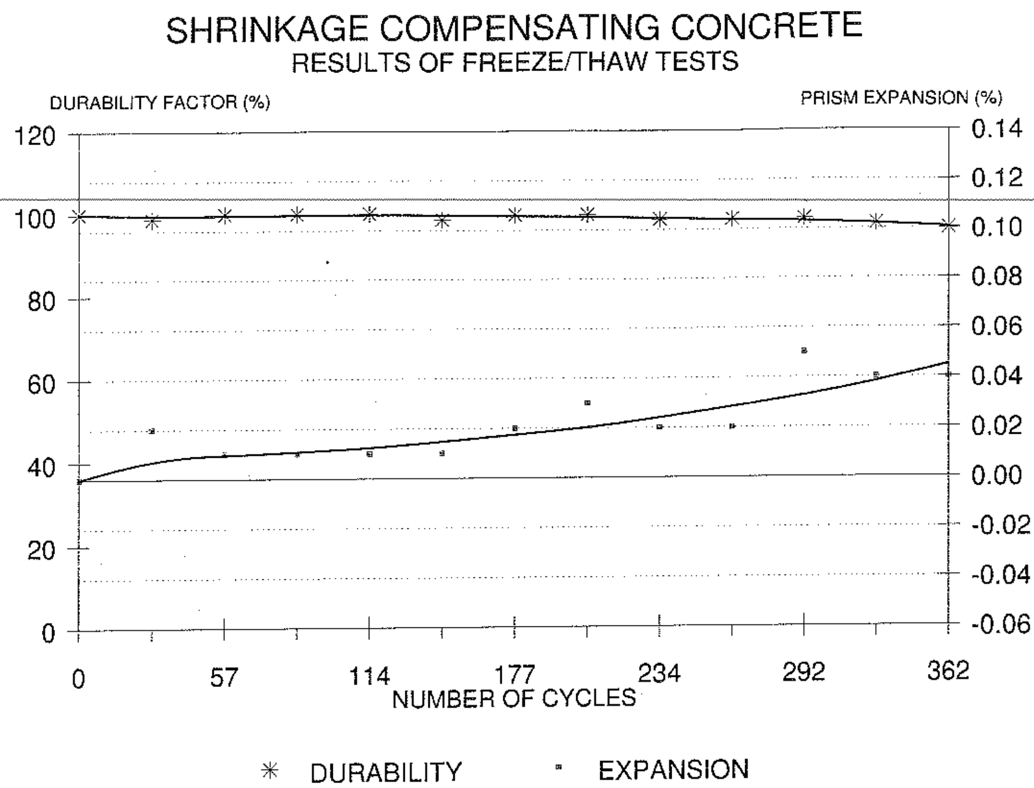
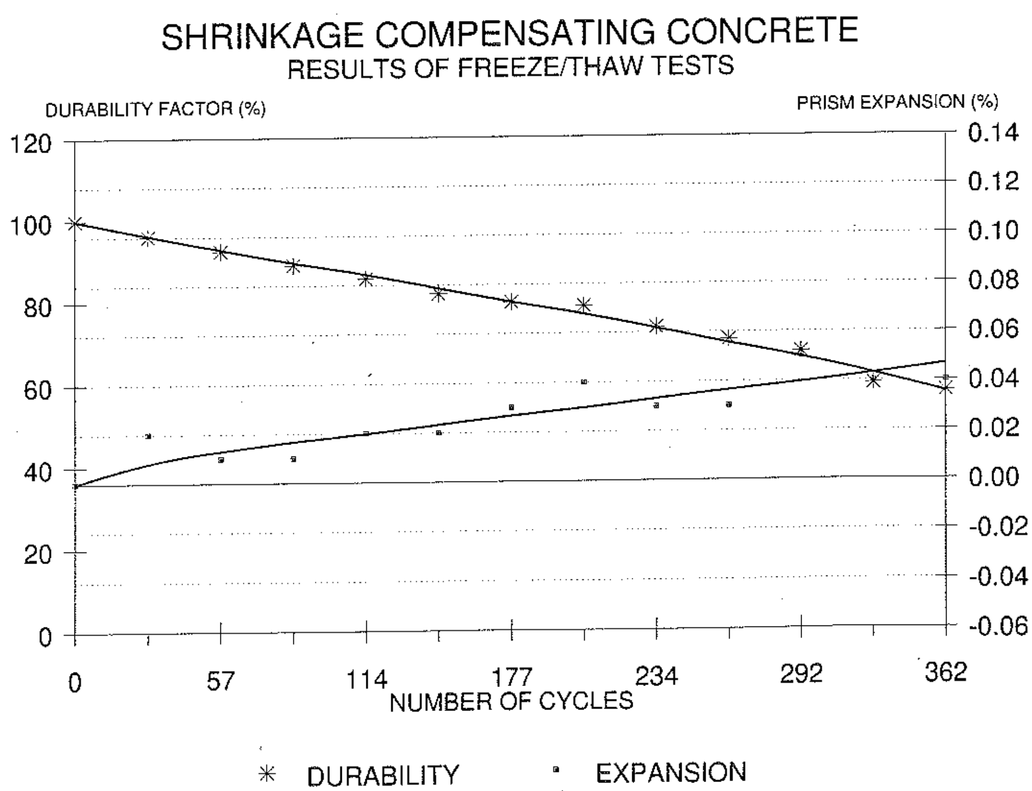


SPECIMEN NO. C1, SPAN 7



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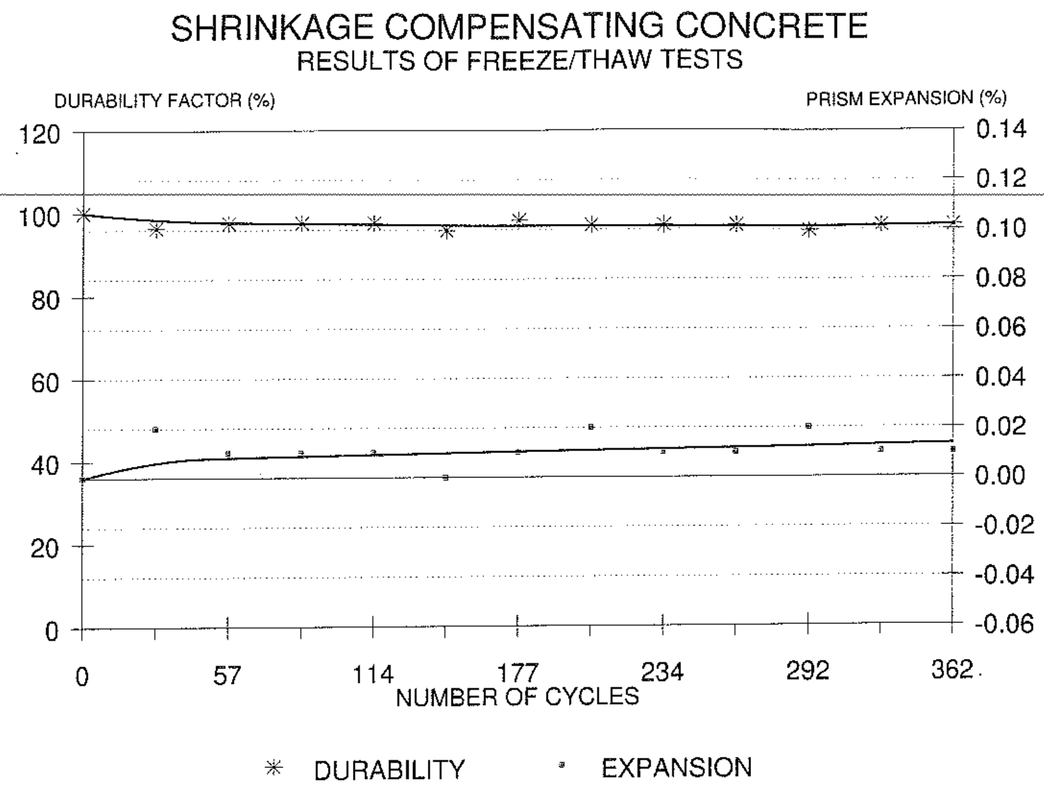

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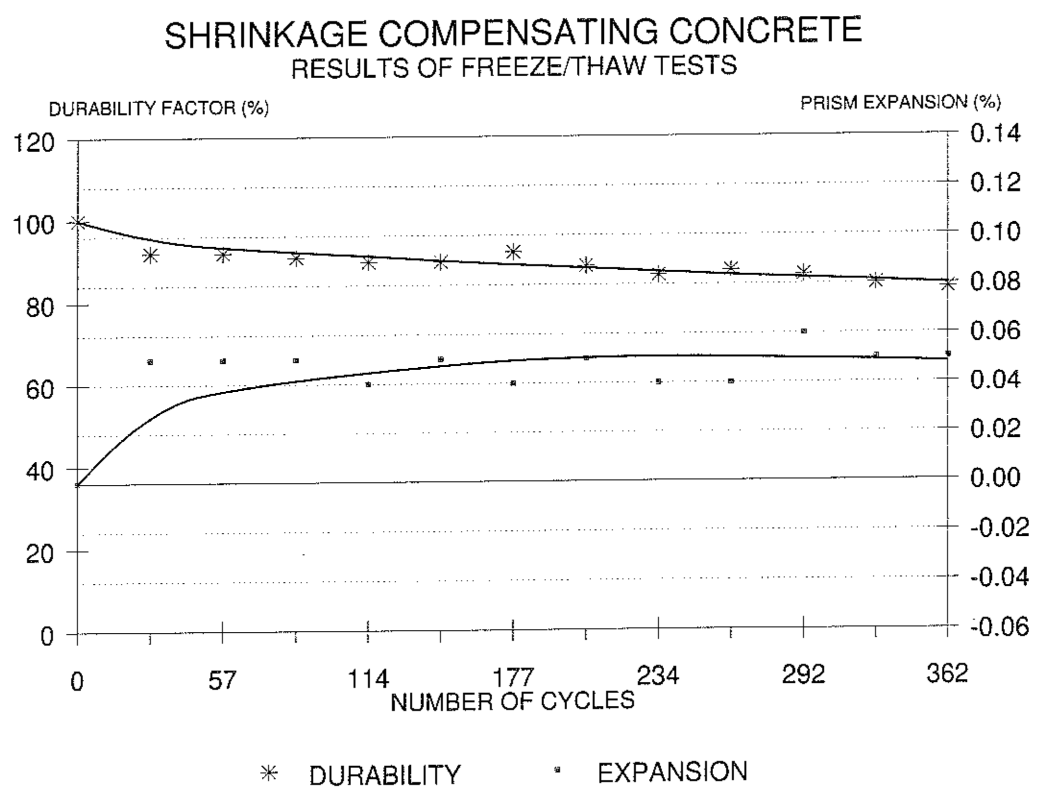

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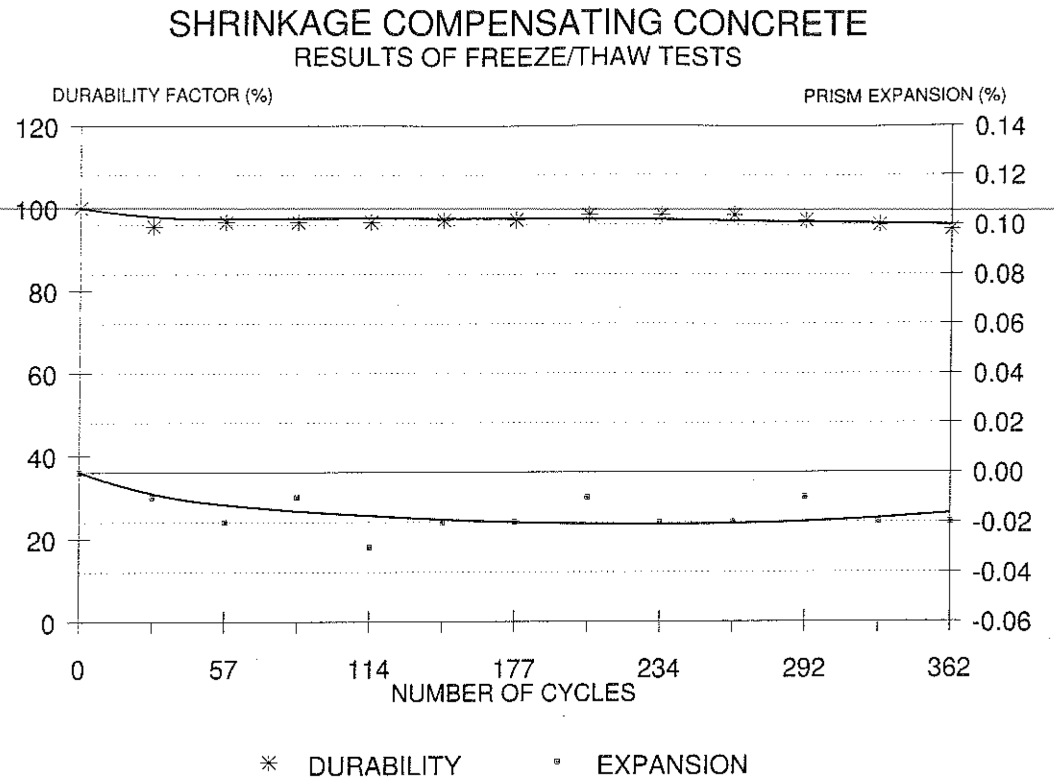

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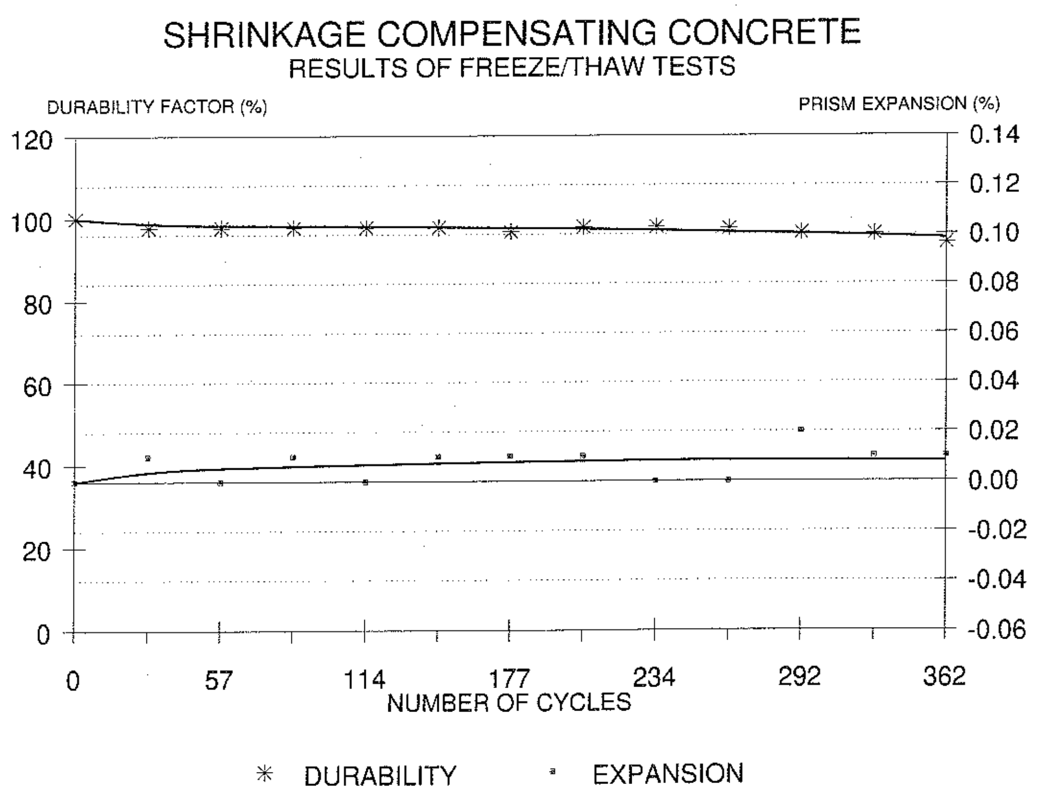
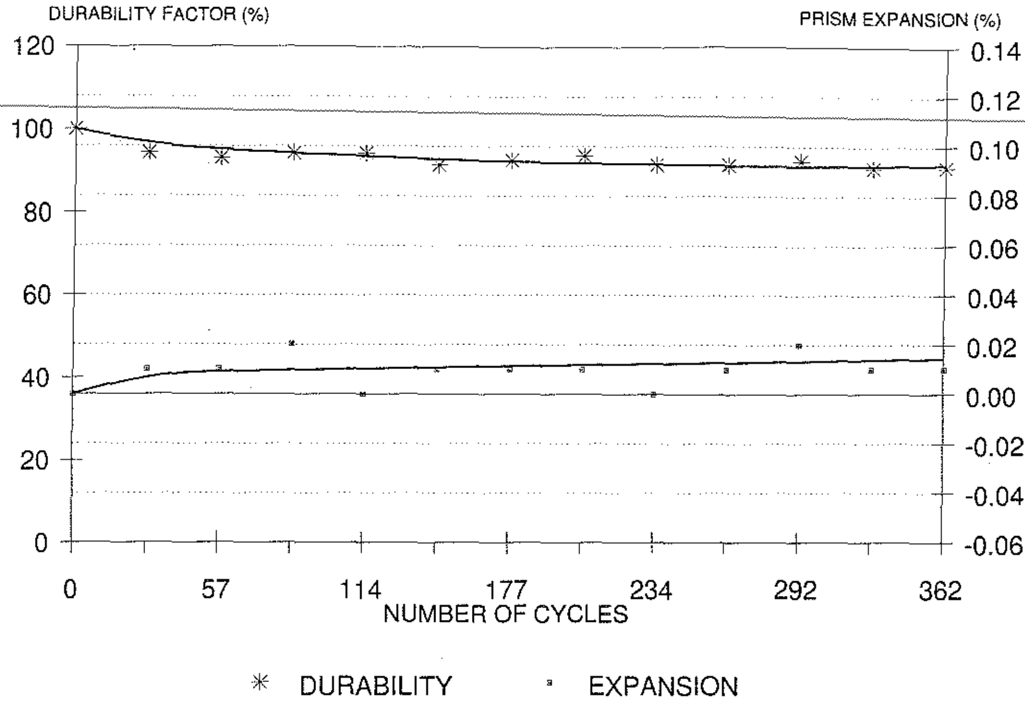


SPECIMEN NO. C6, SPAN 7

SHRINKAGE COMPENSATING CONCRETE
RESULTS OF FREEZE/THAW TESTS



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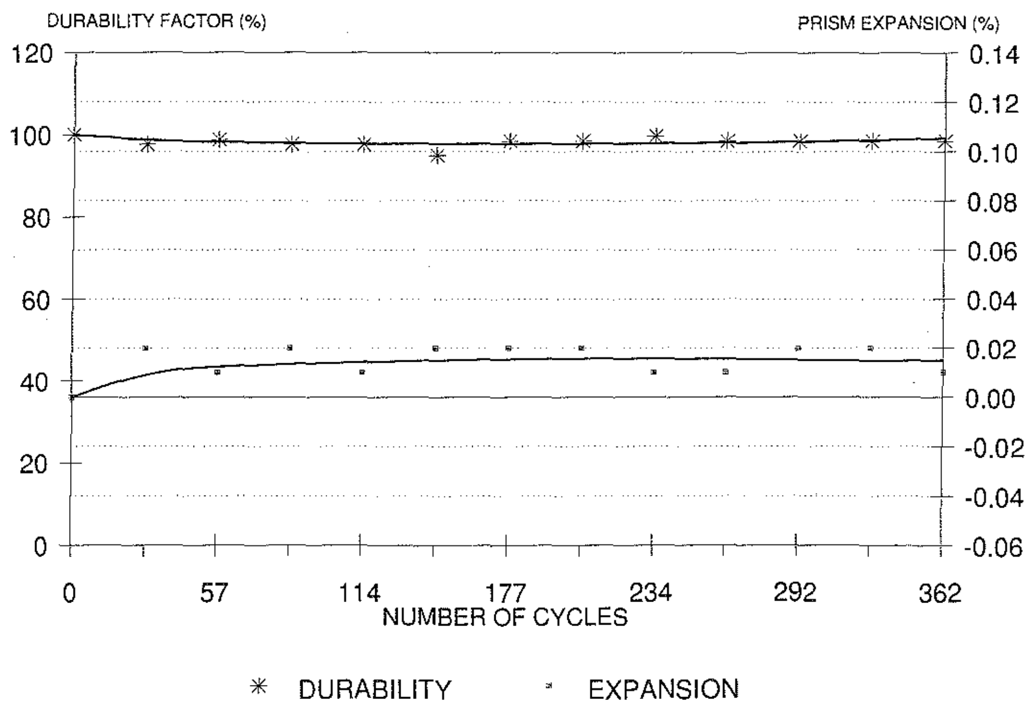
SHRINKAGE COMPENSATING CONCRETE
RESULTS OF FREEZE/THAW TESTS



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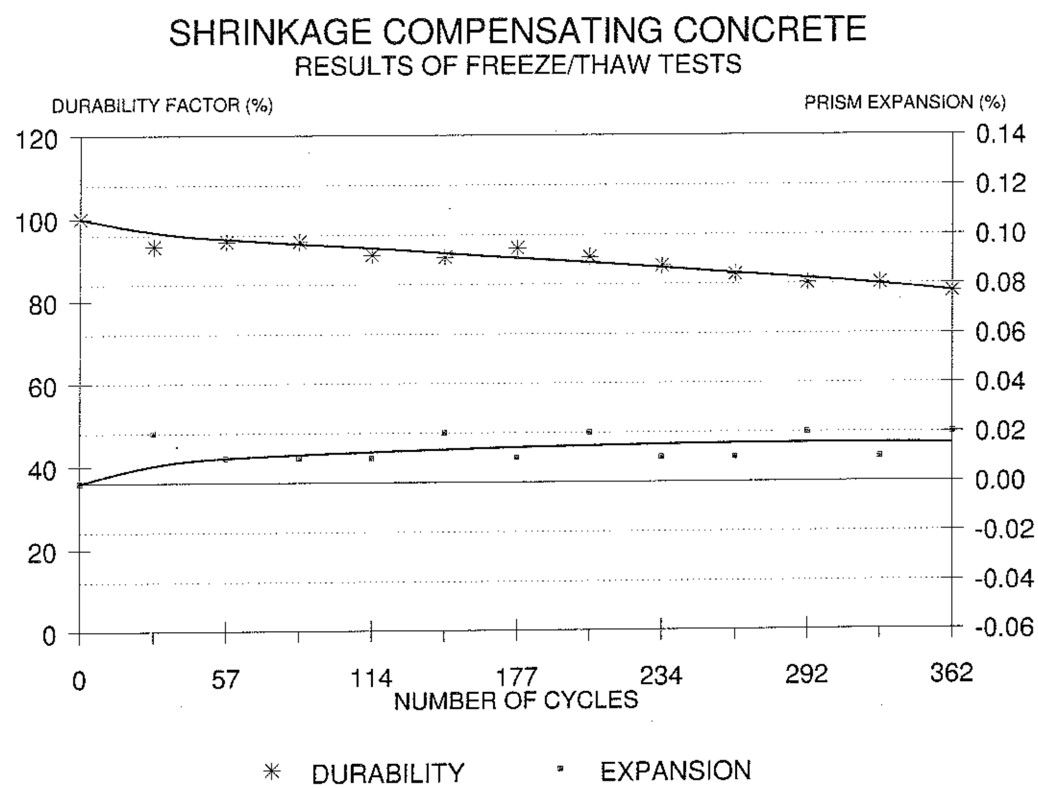
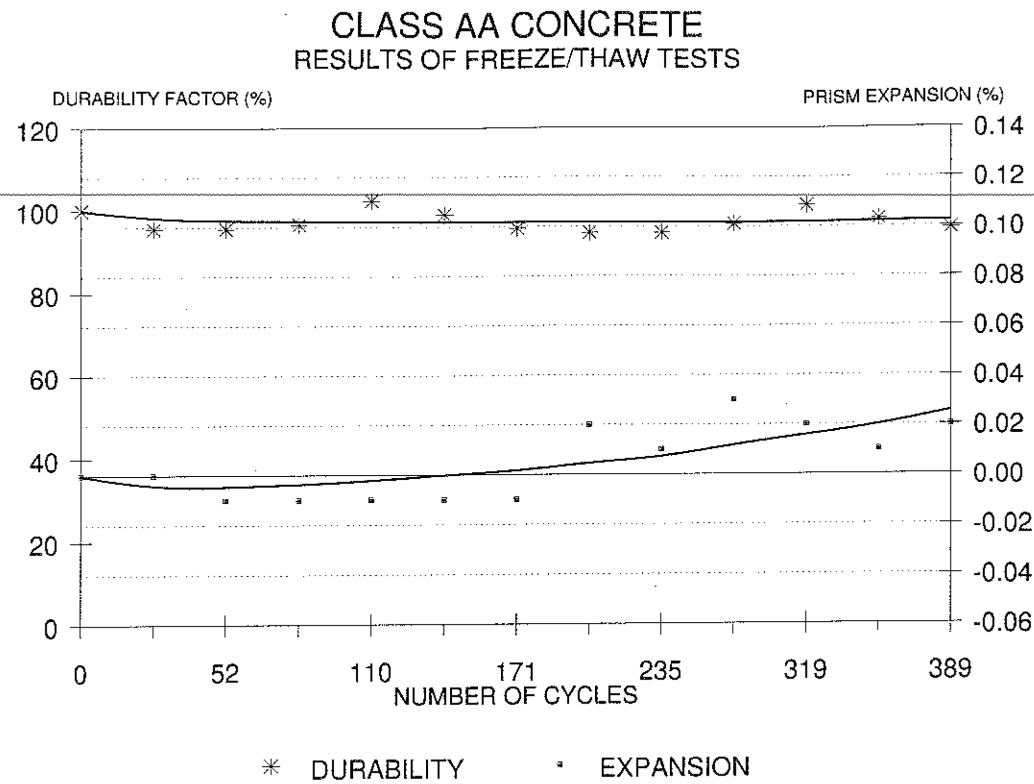


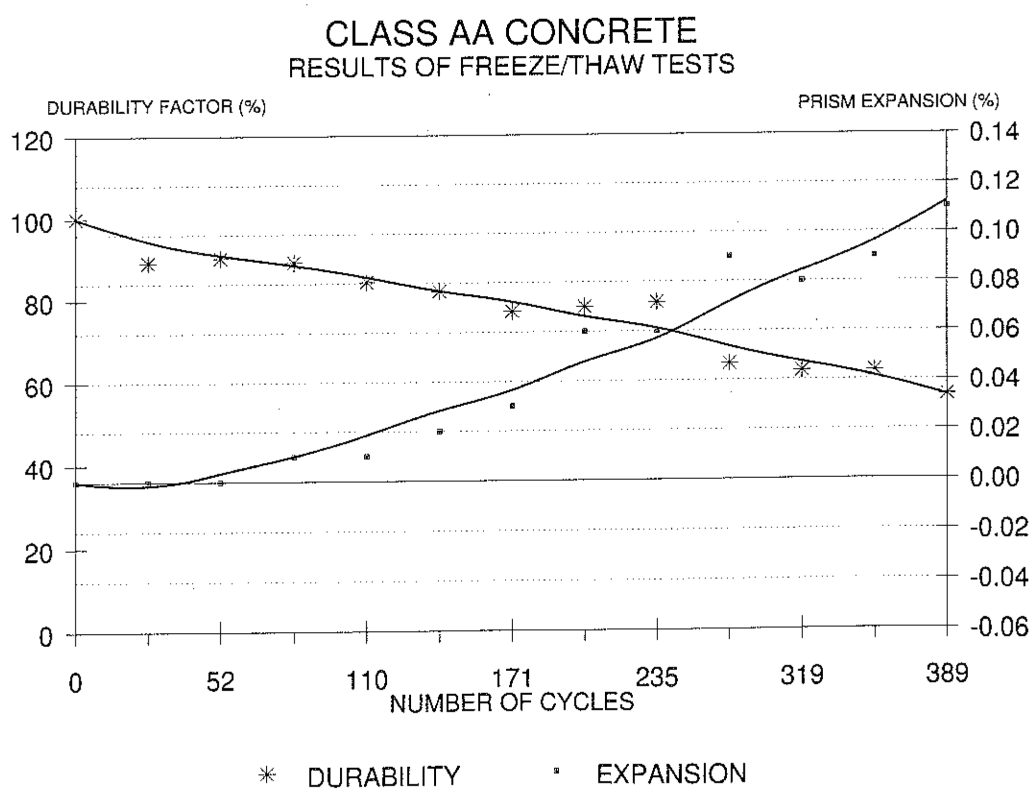
SPECIMEN NO. C10, SPAN 7

RESULTS OF
FREEZE / THAW TESTING

CLASS AA
CONCRETE SPECIMENS



SPECIMEN NO. X1, RAMP X



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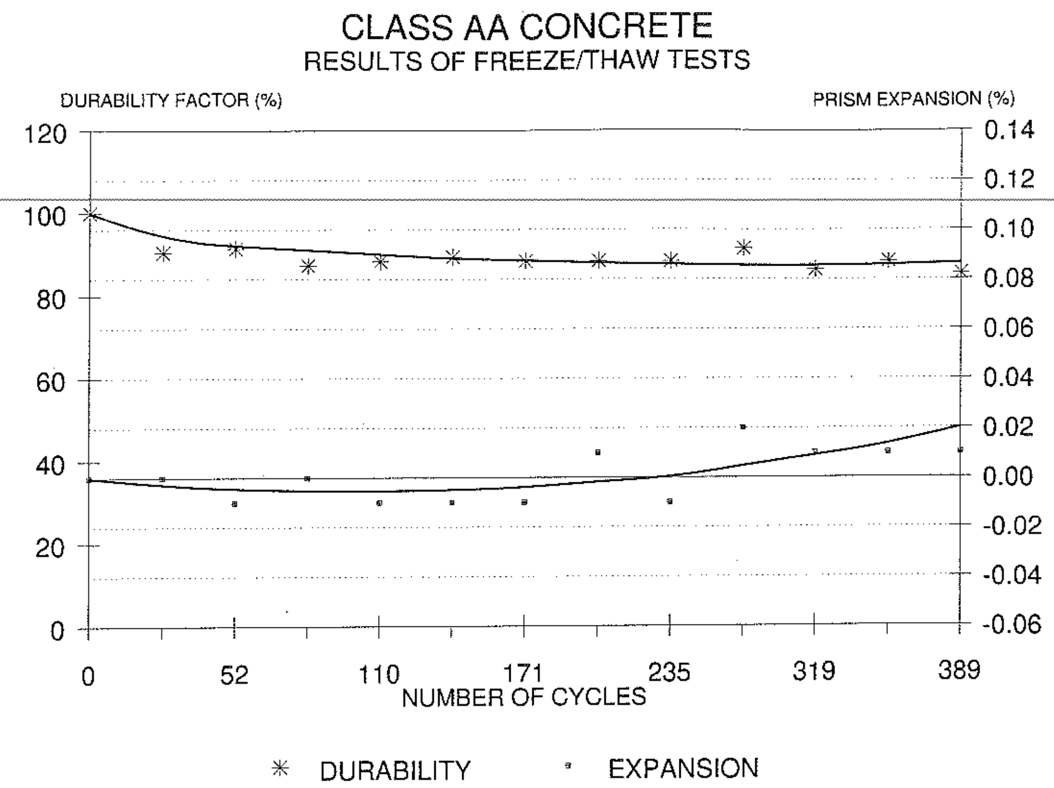

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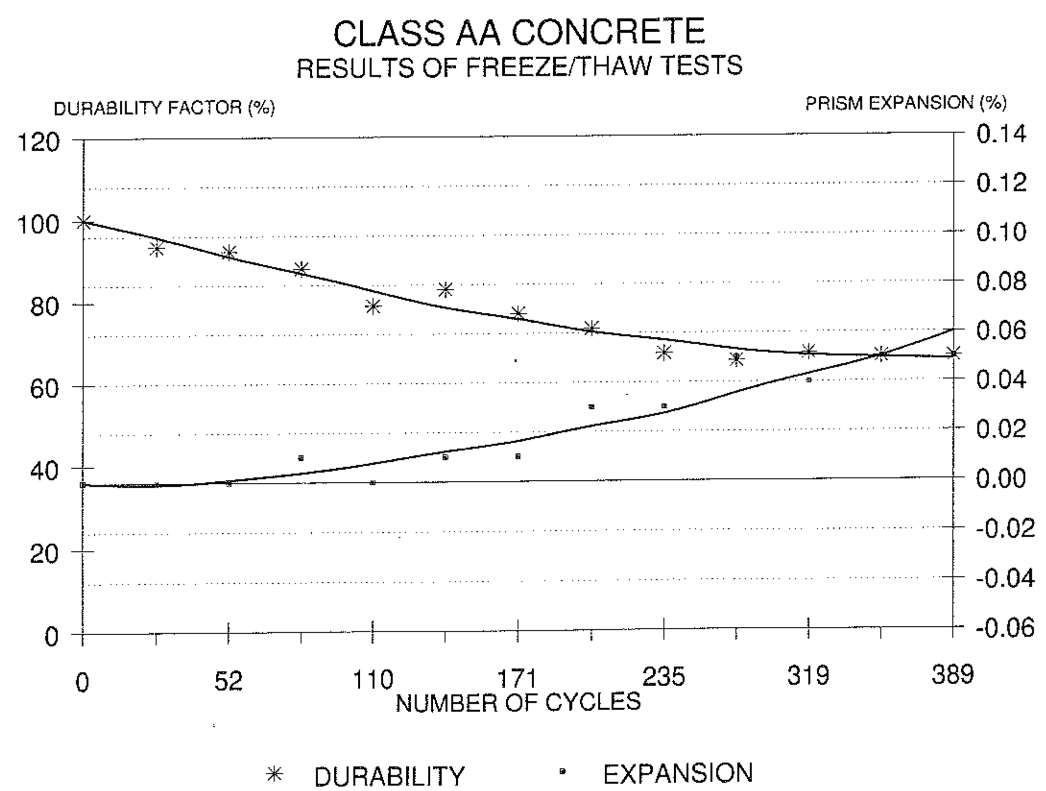

SPECIMEN NO. X4, RAMP X

APPENDIX III

COMPRESSIVE STRENGTH AND STATIC CHORD MODULUS OF ELASTICITY

CLASS S CONCRETE SPECIMENS

TABLE IIIa. CLASS S SPECIMENS: SPANS 4, 5, AND 6 (I-75 over 12th and Pike Streets)

SAMPLE NUMBER	AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psix10^6)	UNIT WEIGHT (lbs/ft^3)	AIR (%)	SLUMP (inches)
1-3	3	3,530	2.70	142.7	6.6	-
2-3	3	3,760	-	142.8	6.6	-
3-3	3	3,760	2.85	142.6	6.6	-
1-7	7	3,580	2.65	140.8	5.5	-
2-7	7	3,710	-	141.0	5.5	-
3-7	7	3,690	2.70	140.4	5.5	-
1-14	14	4,300	-	142.3	4.5	5.50
2-14	14	5,110	3.25	143.3	4.5	5.50
3-14	14	4,570	3.25	142.3	4.5	5.50
1-28	28	5,560	-	143.6	-	-
2-28	28	5,600	3.50	142.5	-	-
3-28	28	5,460	3.35	140.6	-	-

TABLE IIIb. CLASS S SPECIMENS: SPAN 7 (I-75 over 12th and Pike Streets)

SAMPLE NUMBER	AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psix10^6)	UNIT WEIGHT (lbs/ft^3)	AIR (%)	SLUMP (inches)
3-1	3	3,960	-	142.3	4.6	5.00
3-2	3	4,030	2.95	142.8	4.6	5.00
3-3	3	4,200	2.85	142.8	4.6	5.00
14-4	7	4,950	-	143.7	4.6	5.00
7-4	7	4,870	3.25	144.4	4.6	5.00
7-5	7	4,850	3.55	145.7	4.6	5.00
28-1	28	5,590	-	145.0	4.6	5.00
28-2	28	5,580	3.60	144.6	4.6	5.00
28-3	28	5,700	3.65	145.0	4.6	5.00

TABLE IIIc. CLASS S SPECIMENS: SPAN 8 (I-75 over 12th and Pike Streets)

SAMPLE NUMBER	AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psix10^6)	UNIT WEIGHT (lbs/ft^3)	AIR (%)	SLUMP (inches)
3-1	3	3,510	-	141.5	5.2	3.75
3-2	3	3,680	2.80	141.3	5.2	3.75
3-3	3	3,760	2.80	140.8	5.2	3.75
7-1	7	4,500	-	142.0	-	-
7-2	7	4,200	3.05	142.6	-	-
7-3	7	4,240	3.10	141.8	-	-
28-1	28	5,420	-	142.1	-	-
28-2	28	5,030	3.25	142.3	-	-
28-3	28	5,240	3.40	142.6	-	-

TABLE IIId. CLASS S SPECIMENS: Ramp Y over 9th Street

SAMPLE NUMBER	AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psix10^6)	UNIT WEIGHT (lbs/ft^3)	AIR (%)	SLUMP (inches)
1-3	3	4,120	-	143.2	5.5	4.50
2-3	3	4,050	3.10	143.5	5.5	4.50
3-3	3	4,280	3.10	144.3	5.5	4.50
7-4	7	4,230	-	142.9	4.8	-
7-5	7	4,560	3.20	141.8	4.8	-
7-6	7	4,460	3.25	142.9	4.8	-
7-7	7	4,430	3.20	144.1	4.6	-
7-8	7	4,090	3.25	143.8	4.6	-
7-9	7	4,430	3.35	143.2	4.6	-
28-10	28	4,220	-	141.6	6.2	-
28-11	28	4,340	3.30	141.9	6.2	-
28-12	28	4,380	-	142.4	6.2	-
28-13	28	5,280	3.35	143.7	4.8	-
28-14	28	5,230	3.30	142.1	4.8	-
28-15	28	5,500	3.30	142.7	4.8	-

TABLE IIIe. CLASS S SPECIMENS: Ramp G over Y

SAMPLE NUMBER	AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psix10^6)	UNIT WEIGHT (lbs/ft^3)	AIR (%)	SLUMP (inches)
A-1	7	4,970	-	145.3	4.3	5.00
A-2	7	5,030	3.45	144.2	4.3	5.00
A-3	7	5,220	3.50	146.0	4.3	5.00
A-4	7	5,270	3.45	145.9	4.3	5.00
A-5	7	5,230	3.40	145.1	4.3	5.00
A-6	7	5,150	3.40	143.4	4.3	5.00
B-1	14	5,520	-	144.4	3.7	-
B-2	14	6,120	3.70	147.1	3.7	-
B-3	14	5,360	3.65	144.1	3.7	-
B-4	14	6,220	3.80	146.6	3.7	-
B-5	14	6,250	3.75	146.6	3.7	-
C-1	28	5,760	-	145.4	4.0	5.00
C-2	28	6,470	3.90	146.5	4.0	5.00
C-3	28	6,660	3.85	143.9	4.0	5.00
C-4	28	7,090	3.85	145.1	4.0	5.00
C-5	28	6,200	3.80	146.8	4.0	5.00
C-6	28	7,210	3.95	149.1	4.0	5.00

TABLE IIIf. CLASS S SPECIMENS: SPANS 10, 11, AND 12 (I-75 over 12th and Pike Streets)

SAMPLE NUMBER	AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psix10^6)	UNIT WEIGHT (lbs/ft^3)	AIR (%)	SLUMP (inches)
1	7	4,810	-	142.6	4.7	4.50
4	7	4,810	3.25	143.0	5.5	5.25
7	7	4,350	3.10	141.6	5.8	6.00
10	7	5,500	3.60	145.8	4.0	4.75
13	7	5,720	3.55	144.3	4.8	4.50
16	7	4,930	3.45	143.9	5.5	5.50
17	14	5,240	-	143.3	5.5	5.50
2	14	4,910	3.25	-	4.7	4.50
5	14	4,530	3.45	143.1	5.5	5.25
8	14	4,550	3.15	141.3	5.8	6.00
11	14	5,820	3.75	144.1	4.0	4.75
14	14	5,960	3.70	145.1	4.8	4.50
3	28	5,480	-	143.8	4.7	4.50
6	28	5,480	3.75	144.2	5.5	5.25
9	28	4,860	3.50	145.0	5.8	6.00
12	28	6,220	3.85	145.8	4.0	4.75
15	28	6,760	3.85	143.6	4.8	4.50
18	28	5,620	3.75	143.3	5.5	5.50

TABLE IIIg. CLASS S SPECIMENS: Ramp G over 9th Street

SAMPLE NUMBER	AGE (days)	COMPRESSIVE STRENGTH (psi)	ELASTIC MODULUS (psix10^6)	UNIT WEIGHT (lbs/ft^3)	AIR (%)	SLUMP (inches)
1	7	4,430	-	139.6	Bad	6.00
4	7	4,030	2.75	138.8	7.5	7.00
7	7	5,230	3.40	142.3	6.0	6.00
2	14	4,960	-	140.9	Bad	6.00
5	14	4,520	3.05	140.4	7.5	7.00
8	14	5,670	3.45	142.9	6.0	6.00
3	28	5,330	-	141.2	Bad	6.00
6	28	4,980	3.15	140.4	7.5	7.00
9	28	6,010	3.65	143.4	6.0	6.00