Research Report
KTC 95-21

USE OF CLASS AA CONCRETE MODIFIED WITH A HIGH-RANGE WATER REDUCING ADMIXTURE IN A FULL-DEPTH BRIDGE DECK SLAB US 127, LINCOLN COUNTY

by

David Q. Hunsucker
Research Engineer

and

Michael D. Stone
Former Engineering Technologist

Kentucky Transportation Center
College of Engineering
University of Kentucky

in cooperation with
Kentucky Transportation Cabinet

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Commonwealth of Kentucky
Transportation Cabinet
Frankfort, Kentucky 40622

Fred N. Mudge
›tary of Transportation

Paul E. Patton
Governor

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Mr. Paul E. Toussaint
Division Administrator
Federal Highway Administration
330 West Broadway
Frankfort, Kentucky 40602-0536

SUBJECT: Implementation Statement Kentucky Highway Investigative Task No. 22, "Use of Class AA Concrete Modified with a High-Range Water Reducing Admixture in Full-Depth Bridge Deck Slabs"

Dear Mr. Toussaint:

It is well known that the use of a high-slump concrete will enhance placement properties in areas of closely spaced reinforcing steel, such as in skewed bridge structures. Data obtained during this study indicate that a high-range water reducing admixture enhances both durability and strength properties of hardened concrete. However, the inability to adhere to the specified admixture rate compounded by undesirable finishing characteristics contributed to the poor results achieved with the experimental deck for this project. The admixture representative present during the experimental deck placement could not provide the suitable proportioning of admixtures necessary for both a good finishing mix that also met the requirements of the project. However, the positive attributes of the modified concrete identified in this project make it worthwhile to gain additional experience with the use of these admixtures.

The Kentucky Department of Highways will give appropriate consideration to the future use of high-range water reducers to modify conventional bridge deck concrete in situations where the placement properties can be enhanced or where it is desired to enhance strength and durability properties. Additional trial batches and placements will be performed in advance of construction. The bridge contractor for the project will be required to have those personnel doing the actual placement and finishing work at the trial placements so that

they may benefit from the exercise and gain the experience needed to produce acceptable results. Field personnel will participate during the planning phase of the project so that the goals and expectations of the project may be clearly defined to the field personnel. Additional guidelines and information in the area of admixtures will be sought to provide better mixture control. The appropriateness of conventional finishing equipment on this type of mixture, due to the stickiness of the concrete, will be determined prior to placement activities.

Sincerely,

J. M. Yowell, P.E.
State Highway Engineer

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ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Because it is desirable for bridge deck concrete to be strong and durable, the Kentucky Department of Highways chose to use a high-range water reducer to modify the properties of a conventional Class AA concrete mixture to be placed in a full-depth concrete bridge deck on US 127 in Lincoln County. A high-range water reducer is a chemical admixture that when added to low-to-normal slump concrete produces a high slump to flowing concrete. The higher slump enhances placement properties in areas of closely spaced and congested reinforcing steel such as that encountered in the corners of a skewed bridge structure. The addition of a high-range water reducer permits reductions in mix water in the range of 12 to 30 percent. The reduction in mix water lowers the water-to-cement ratio leading to increased strength properties. The Kentucky Department of Highways specified an admixture dosage rate of 10.42 mL per kilogram of cement (16.0 oz per 100 lbs of cement). Test results indicated that this dosage rate would facilitate the desired 15 percent reduction in the available mix water.

The use of a high-slump concrete enhances placement properties in areas of closely spaced reinforcing steel such as a skewed bridge structure. Data obtained during this study indicate that the high-range water reducing admixture also enhances durability and strength properties of concrete. The magnitude of cracking was slightly more for the experimental deck concrete but the severity of the cracks appeared to be higher in the control deck. The inability to adhere to the specified admixture rate compounded by the finishing characteristics of the concrete mixture contributed to the poor results achieved with the experimental deck. The admixture representative present during the experimental deck placement could not provide the suitable proportioning of the admixtures necessary for both a good finishing mix that also met the requirements of the project.

It is recommended that consideration be given again to the use of high-range water reducers to modify conventional bridge deck concrete in situations where the placement properties can be enhanced or where it is desired to enhance strength and durability properties. The positive attributes of the modified concrete identified in this project make it worthwhile to gain additional experience with the use of these admixtures. It is recommended the specifications be revised for any future projects to require that trial batches be performed until two separate batches conform to all specification requirements and that the bridge contractor have his intended placement and finishing personnel at the trial placements to gain experience.

INTRODUCTION

There have been many advances in the concrete construction industry that appear to be promising for improving the quality of concrete. These advances are of particular interest in the field of concrete bridge decks. It is desirable for bridge decks to be stronger, less permeable, and more durable without additional difficulty in placement. One possible means of improving bridge deck quality is through the use of a high-range water reducer. A high-range water reducer, or super plasticizer, is a chemical admixture that when added to low-to-normal slump concrete produces a high slump to flowing concrete. High-range water reducers may also be used to make low water/cement ratio, high-strength concrete with workability within the ranges normally specified for consolidation by internal vibration. The addition of a high-range water reducer permits a water reduction of 12 to 30 percent. Other benefits of a super-plasticized concrete are higher ultimate compressive strengths, high early strengths, and reduced chloride-ion penetration as well as other benefits attributed to lower water/(cement + pozzolan) ratios in concrete. The effectiveness of a high-range water reducer can be increased by increasing the amount of cement and the number of fines in the concrete mixture. The effectiveness also depends to some extent on the chemical composition of the admixture, concrete temperature, cement composition and fineness, and the presence of other admixtures. The Kentucky Department of Highways (KYDOH) proposed the experimental use of a high-range water reducer in a conventional Class AA concrete mixture that is typically used in full-depth bridge deck slabs. The high-range water reducer to be used was specified to be either a Type F or a Type G conforming to the requirements of Section 802 of the Kentucky Department of Highways Standard Specifications for Highway and Bridge Construction [1].

The KYDOH requested the University of Kentucky Transportation Center (UKTC) to participate in the experimental project. The overall objectives of the KYDOH and UKTC research study were to evaluate the construction and three-year performance of a concrete bridge deck constructed with a Class AA concrete containing a high-range water reducing admixture. The construction attributes and performance of the experimental concrete bridge deck were to be compared with those of a full-depth bridge deck constructed of a conventional Class AA concrete mixture. The comparison bridge, or control, was constructed on the same route and within eight days of the experimental bridge deck.

PROJECT LOCATION AND DESCRIPTION

Kentucky Department of Highways' engineers proposed both the experimental and the control bridge decks be located on US 127 in Lincoln County (see Figure 1). The experimental deck is a skewed, four-span bridge located at milepoint 3.7 spanning Baughman Creek. The control deck is a three-span structure and is located approximately 62 meters south of the experimental bridge and spans Hanging Fork Creek. The experimental concrete deck slab was poured on August 6, 1992. The control deck was placed on August 14, 1992. The subcontractor for both bridges was Hayden Bridge Company. The subcontractor had no previous experience using a super-plasticized concrete mixture in a full-depth bridge concrete placement.

A Special Note for Class AA concrete with a Type F or Type G high-range water reducer was developed for this experimental project. The Special Note has been reproduced in Appendix I of this report.

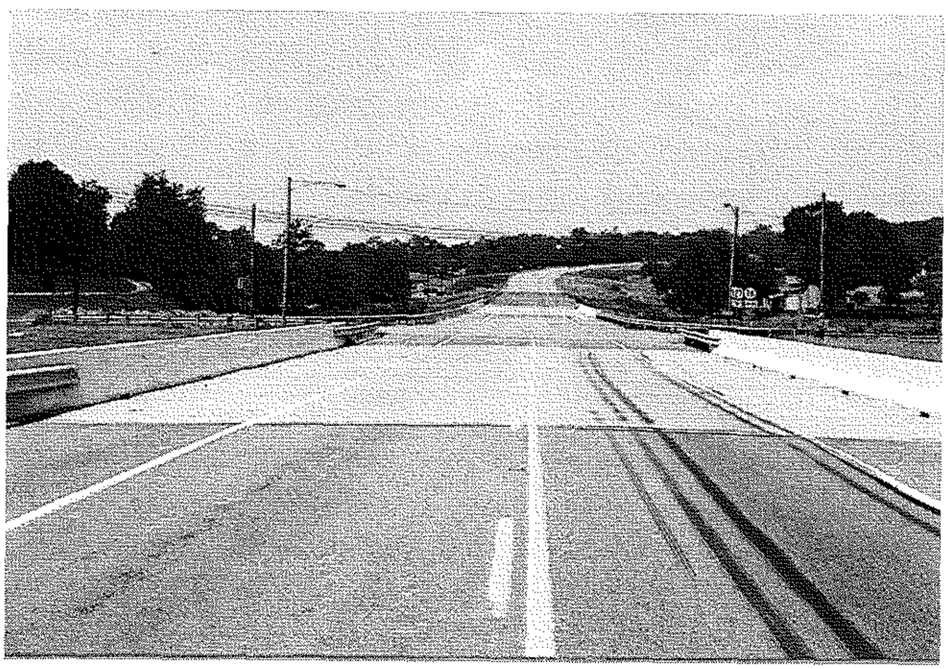

Figure 1. *Overview of experimental site looking north. The control bridge is in the foreground and the experimental bridge is in the background.*

MIXTURE DESIGN

The Type F or Type G admixtures that would be considered for use in this project had to adhere to the requirements set forth in Section 802 of the Kentucky Standard Specifications for Road and Bridge Construction [1]. It was required that the Type F or Type G high-range water reducer be an admixture with a minimum water reduction of 15 percent, as indicated by ASTM C 494 test data [2]. The Special Note for Construction is contained in Appendix I. The difference in Type F and Type G water reducing admixtures is that Type F is strictly a high-range water reducer while Type G is both a high-range water reducer and set retarder.

The bridge contractor was required to make a minimum of two, 2.28-cubic meter (3.00-cubic yard) trial batches to demonstrate that the mix would meet the requirements for slump, air content, water/cement ratio, and compressive strength specified in the Special Note for construction. The coarse aggregate source for the concrete mixture was Dix River Stone. The fine aggregate source was Nugent Sand. All concrete was batched at the Lincoln County Ready Mix concrete plant and transported to a site adjacent to the experimental bridge. The two trial mixtures for this project were batched on June 19, 1992 to demonstrate the ability of the mix design to meet the specified requirements. Specific masses of each component of the concrete mixture were not obtained during the trial batch operation. A Type D set retarder was required to be added to both batches because the ambient daytime temperature was above 22°C (71°F) at the time of batching. The Type D set retarder dosage amount was recommended to be 1,094 mL (37 ounces) per 2.28-cubic meter (3.00-cubic yard) trial batch. It was determined that the use of 75.7 L (20 gal.) of water per 0.76-cubic meter (1.0-cubic yard) would satisfy the desired 15 percent reduction in mix water for the batch. Air entrainment admixture was added at the rate of 118.3 mL (4.0 oz) per 0.76-cubic meter (1.0-cubic yard). The mixture design specified a Type F high-range water reducer to be used in the trial mixtures. The specified dosage rate was 10.42 mL of Type F high-range water reducer per kilogram (16.0 oz per 100 lbs) mass of cement. Type G high-range water reducer was not used during the trial batch operation. At the recommendation of the admixture representative, it was decided that the water reducer would be added at the jobsite due to the length of the haul from the concrete plant. A portable admixture dispenser was requested for this by KYDOH personnel, but the necessity was disputed by the admixture representative. The admixture representative's recommendation of using graduated containers for admixture dosage at the jobsite was accepted.

The first trial batch had 11.4 L (3.0 gal.) additional water added before leaving the concrete plant. The initial slump measured at the job site was 51 mL (2.0 in.). The air content of the first trial batch was 5.6 percent. Although KYDOH engineers specified a dosage rate of 10.42 mL per kilogram (16.0 oz per 100 lb) mass of cement for the batch based upon ASTM C 494 test data, a representative of the company supplying the high-range water reducing admixture advised the engineers that only 3.9 mL per kilogram of cement (6.0 oz per 100 lbs) of the Type F super plasticizer needed to be used. The admixture representative indicated that the dosage rate proposed by KYDOH engineers would make the concrete so watery that it would be useless. Engineers did not think the lower dosage rate would meet the requirements for water reduction but consented to the recommendation of the admixture representative. The Type F super plasticizing admixture was then added to the truck mixer along with 11.4 L (3.0 gal.) of water and mixed for 50 revolutions. The water added to the 2.28-cubic meter trial batch totaled 249.8 L (66 gal.) at this point. After adding the high-range water reducer, the slump was 83 mm (3.25 in.) and the air content was 5.7 percent. KYDOH personnel cast six test cylinders and UKTC personnel cast three cylinders from this first trial batch. Because the slump increased only 32 mm (1.25 in.) after the addition of the high-range water reducer at the dosage rate of 3.9 mL per kilogram (6.0 oz per 100 lb) mass of cement, the admixture representative agreed to use the dosage rate of 10.42 mL per kilogram (16.0 oz per 100 lb) mass of cement for the second trial batch.

The second trial batch arrived at the job site containing the specified amount of water 227.1 L per 2.28-cubic meter (60.0 gal. per 3.0-cubic yard). The initial slump of the second trial batch was 32 mm (1.25 in.). The initial air content was determined to be 2.1 percent. The specified amount of high-range water reducer was added, with no additional water, then mixed 50 revolutions. The slump of the trial mixture increased to 89 mm (3.50 in.) after the addition of the high-range water reducing admixture. The air content decreased slightly to 2.0 percent. The air content for the second trial batch was not within the 5.5 ± 1.5 percent range specified in the Special Note for construction. KYDOH personnel cast four test cylinders and UKTC personnel cast three test cylinders from the second trial batch. The contractor's finish personnel present at the time of the trial batching stated that the mix was very sticky and predicted that it would be difficult to finish.

Results of tests performed on the cylinders cast by UKTC personnel are contained in Table 1. One cylinder from each trial batch was tested for compressive strength in accordance with ASTM C 39 at seven, 14 and 28 days, [3]. The Special Note for

TABLE 1. HRWR Trial Batch Data

Sample/ Batch No.	Type F HRWR mL/kg cement	Type F HRWR oz/100 lb cement	Before HRWR Added Slump (mm)	Before HRWR Added Slump (in.)	Before HRWR Added Air (%)	After HRWR Added Slump (mm)	After HRWR Added Slump (in.)	After HRWR Added Air (%)	Compressive Strength (Mpa)	Compressive Strength (psi)	Age (days)
1-1	177.4	6	51	2.00	5.6	83	3.25	5.7	25.2	3,600	3
4-2	473.2	16	32	1.25	2.1	89	3.50	2.0	33.6	4,880	3
2-1	177.4	6	51	2.00	5.6	83	3.25	5.7	28.9	4,190	7
5-2	473.2	16	32	1.25	2.1	89	3.50	2.0	35.7	5,180	7
3-1	177.4	6	51	2.00	5.6	83	3.25	5.7	34.0	4,930	28
6-2	473.2	16	32	1.25	2.1	89	3.50	2.0	44.0	6,380	28

Construction required a minimum compressive strength of 41.35 MPa (6,000 psi) after 28 days. Based on the sample data shown, it may be noted that the specimen cast from the first trial batch failed to meet the required 28-day compressive strength requirement. The low strength likely resulted from the extra water that had been added to the mixture. The additional water affected the overall strength of the concrete by increasing the water/cement ratio. The specified maximum water to cement ratio was 0.40.

CONSTRUCTION

The experimental concrete deck was placed on August 6, 1992 and the control deck was placed on August 14, 1992. A Pioneer concrete pump was used to place both the experimental concrete and control concrete. A Bid-Well dual-drum concrete finishing machine was used at both sites to finish the concrete decks. Each concrete truck carried approximately 6.1 m^3 (8.0 yd^3) of concrete per truckload. The concrete mixture designs for the experimental and control bridge decks, with respect to specific masses of each component, was not made available to UKTC personnel. There was a water underrun of 23.8 L/m^3 (4.8 $gal./yd^3$) during construction of the experimental concrete bridge deck. There was a water underrun of 10.9 L/m^3 (2.2 $gal./yd^3$) throughout construction of the control deck. All fresh concrete tests were performed prior to the concrete being pumped. Also, test cylinders of the experimental and control concrete were cast prior to the concrete being pumped. More representative samples would have been obtained if the fresh concrete tests had been made and cylinders had been cast after the concrete had been pumped. This would have ensured that the concrete used for fresh and hardened concrete tests had the same characteristics as the concrete in the deck. Unfortunately, due to space limitations, these operations had to be performed below the decks. Typically, it has been observed that fresh concrete will lose about one percent air and 25 mm (1 in.) slump after being pumped.

Experimental Bridge Deck

The first truckload of Class AA concrete arrived at the experimental deck job site at 6:10 am. A representative of the admixture company was present at the job site to direct the addition high-range water reducer to the Class AA concrete mixture. A slump test was performed immediately after the concrete truck arrived. The slump before addition of the high-range water reducer was 38 mm (1.50 in.). An air content test was not performed at this time. After the slump test was performed the representative added the high-range water reducer at the rate of 10.43 mL per kilogram of cement (16.0 oz per 100 lbs of cement) by using a 18.9-L (5.0-gal.) bucket. The concrete was then mixed 50 additional revolutions in the concrete truck in accordance with specifications detailed in the Special Note for Construction for this project. After the additional 50 revolutions, a slump test was performed again, as well as an air content test. The slump increased to 9.00 inches. The measured air content was 2.1 percent prior to pumping the concrete. The Special Note for Construction permitted a slump ranging from 76 to 178 mm (3 to 7 in.) and a net air content ranging from 4.0 to 7.0 percent. The initial measurements for slump and net air content were not within the allowable tolerance for the mixture. However, this truckload was placed in the experimental deck. Actual placement of the concrete began at 6:35 am. KYDOH personnel cast 4 cylinders from the first truck.

The same general procedure for adding the high range water reducing admixture was followed throughout the placement of the experimental bridge deck concrete. The second truckload of concrete also received the specified amount of high-range water reducer and the slump was 178 mm (7.00 in.) after dosing. However, for the third truckload of concrete, the admixture company representative changed the high-range water reducer dosage to 6.52 milliliters per kilogram of cement (10.0 oz per 100 lbs of cement). The slump of the concrete after this amount of admixture was added measured 216 mm (8.50 in.), exceeding the 178 mm (7 in.) upper limit. Following this initial change in high-range water reducer dosage, the dosage amount changed several more times during placement of the remaining experimental concrete. Table 2 contains available information relative to dosage amounts for each truckload, the slump of the experimental concrete measured after addition of the admixture, and air content test results. Additional water was added six separate times, either at the job site or the concrete batch plant (see Table 2.) Three different high-range water reducing admixture dosage amounts were used at various times during placement. Those amounts were 10.43, 6.52, and 5.22 milliliter admixture per kilogram of cement (16.0, 10.0, and 8.0 oz per 100 lb of cement). The representative of the admixture company directed all modifications in the dosage rate of the high-range water reducing admixture. A Type D set retarder was added to the experimental concrete mixture at the rate of 475.8 milliliter per cubic meter (12.3 oz/yd^3) beginning with the seventh load of concrete and continuing throughout the remainder of the placement. Air entrainment was added at the rate of 386.9 milliliter per cubic meter (10.0 oz/yd^3) beginning with the tenth truckload and continuing. The last truck left the job site at approximately 12:20 pm. A total of 232.4 cubic meters (304 yd^3) of the experimental concrete were delivered to the job site (38 loads) and 227.1 cubic meters (297 yd^3) were placed in the bridge deck. Less than one cubic meter (1.0 yd^3) from the last truck was used to complete the placement operations.

Changing the specified dosage rate of the high-range water reducing admixture caused some confusion for personnel who were trying to keep record of the amounts used and corresponding slump measurements, air content readings, and preparations of test specimens. However, the concrete workers and finishers handled what appeared to be a fairly consistent product in terms of workability though measurements of the concrete's slump ranged from 108 mm to 289 mm (4.25 to 9.00 in.) As shown in Table 2, slump measurements were made by UKTC personnel on 19 of the 38 loads delivered to the job site. Of the 19 slump tests that were performed, only 14 were within the specified tolerances for slump as identified in the Special Note. Air content readings were made on 16 loads. The air content of the first load delivered to the job site measured 2.1 percent and was the only air content measurement not within the specified tolerances. The overall average of the air content readings was 5.0 percent and ranged from 2.1 percent to 6.2 percent.

The concrete was consolidated by using an immersion-type vibrator. Concrete finishers reported the experimental concrete to be quite sticky but the high slump of the concrete provided the experimental concrete with a high degree of workability. After the surface of the deck was finished by the Bid-Well finishing machine, it was bullfloated to

Table 2. Experimental Bridge Deck Construction Data

Load No.	HRWR Dosage (mL/kg cement)	HRWR Dosage (oz/100 lb cement)	Added Water (L)	Added Water (gal)	Slump (mm)	Slump (in.)	Air Content (%)
1	10.43	16	-	-	288.60	9.00	2.1
2	10.43	16	-	-	177.80	7.00	-
3	6.52	10	-	-	215.90	8.50	-
4	6.52	10	-	-	177.80	7.00	4.0
5	6.52	10	-	-	177.80	7.00	4.7
6	6.52	10	-	-	-	-	-
7*	6.52	16	-	-	203.20	8.00	6.2
8	10.43	16	-	-	-	-	-
9	10.43	16	-	-	203.20	8.00	6.2
10**	10.43	16	-	-	-	-	-
11	10.43	16	-	-	-	-	-
12	10.43	16	-	-	-	-	-
13	10.43	16	-	-	-	-	-
14	10.43	16	-	-	190.50	7.50	6.2
15	5.22	8	-	-	-	-	-
16	5.22	8	-	-	139.70	5.50	5.7
17	5.22	8	-	-	-	-	-
18	5.22	8	-	-	-	-	-
19	5.22	8	-	-	171.45	6.75	-
20	6.52	10	30.28 J	8 J	-	-	-
21	6.52	10	22.71 J	6 J	-	-	-
22	6.52	10	18.93 J	5 J	-	-	5.2
23	5.22	8	11.36 P	3 P	177.80	7.00	5.2
24	5.22	8		-	203.20	8.00	5.2
25	5.22	8		-	177.80	7.00	-
26	5.22	8		-	-	-	-
27	5.22	8		-	-	-	4.0
28	5.22	8		-	146.05	5.75	4.0
29	5.22	8		-	-	-	-
30	5.22	8	26.50 J	7 J	107.95	4.25	-
31	6.52	10		-	114.30	4.50	5.0
32	6.52	10		-	-	-	-
33	6.52	10		-	-	-	-
34	6.52	10		-	177.80	-	-
35	6.52	10		-	152.40	7.00	5.4
36	6.52	10		-	-	6.00	5.2
37	6.52	10		-	152.40	-	-
38	6.52	10	7.57 P	2 P	-	6.00	5.6

Notes * - Began adding Type D Set Retarder.
** - Began adding Air Entrainment admixture.
J - Water added at job site.
P - Water added at plant.

eliminate any high and low spots, tyned, sprayed with an approved curing membrane, and covered with curing blankets to prevent the loss of moisture.

Control Bridge Deck

The first truckload of concrete arrived at the job site at 6:05 am. The placement of the conventional Class AA concrete was excellent. There were no difficulties encountered and the concrete placers and finishers appeared quite accustomed to working with the conventional Class AA concrete mixture. The average slump and air content recorded by UKTC personnel were 76 mm (3.00 in.) and 5.4 percent, respectively. Approximately 135 cubic meters (176 yd^3) of concrete were placed in the control deck.

TESTING

The experimental Class AA concrete containing high-range water reducer and the conventional Class AA concrete have been characterized in terms of freeze/thaw durability, compressive strength, and static chord modulus of elasticity. All test specimens were cast and cured in accordance with ASTM C 31 [4].

Durability

Freeze/thaw durability tests on both experimental and control concrete prisms that were cast during construction were performed in accordance with ASTM C 666, Method B, Freezing in Air and Thawing in Water [5]. Twelve concrete prisms were evaluated; six of the experimental Class AA concrete containing the high range water reducing admixture and six conventional Class AA concrete. All prisms successfully met the Kentucky specification for durable concrete pavement (805.04.01 (B)) [1]. This specification requires that expansions of specimens subjected to the freeze/thaw test be no greater than 0.06 percent. The average durability factor based on 350 test cycles of the six experimental specimens was 97.3 percent. The same six specimens had a corresponding average expansion of (-)0.01 percent. The control specimens had a somewhat lower durability factor, averaging 91.0 percent. The average expansion was (+)0.02 percent for this set of specimens. The specimens cast of the experimental Class

AA concrete containing the high-range water reducing admixture performed slightly better in terms of greater durability and lower expansions than did the conventional Class AA concrete specimens.

Strength

Compressive strength and static chord modulus of elasticity tests of specimens made at the time of placement were performed by UKTC at ages of three, seven, 14, and 28 days. Test specimens were weighed and a unit mass (unit weight) was determined for each cylinder. Compressive strength tests were performed on 152-mm by 203-mm (6-in. by 12-in.) cylinders in accordance with ASTM C 39 [3]. Static chord modulus of elasticity tests were performed in accordance with ASTM C 469 [6]. Concrete cylinders were capped in accordance with ASTM C 617 except where use of pad caps is noted [7].

Results of compressive strength tests and static chord modulus of elasticity tests from the experimental and control concrete bridge decks are contained in Appendix II. UKTC data for the experimental concrete is arranged according to the dosage amount of the high-range water reducing admixture. The average unit mass (unit weight) of the 20 experimental concrete specimens was 2,387 kg/m^3 (149.0 lbs/ft^3). The average compressive strength at 28 days, without respect to dosage amount, was 46.00 MPa (6,670 psi). The 28-day compressive strength of the experimental concrete exceeded the specified 41.35 MPa (6,000 psi) minimum strength for the material. There were eight specimens cast from batches dosed at the specified 10.43 mL/kg of cement (16.0 oz per 100 lbs of cement). There were also eight specimens cast from batches dosed at one-half the specified amount, or 5.22 mL/kg of cement (8.0 oz per 100 lbs of cement). The four remaining specimens were cast from a truckload containing 6.52 mL/kg of cement (10.0 oz per 100 lbs of cement). There were two specimens tested at each age (three, seven, 14 and 28 days) for the specified 10.43 mL/kg of cement (16.0 oz per 100 lbs of cement) and the 5.22 mL/kg of cement (8.0 oz per 100 lbs of cement) dosage rate. There was only one specimen tested at each age for the 6.52 mL/kg of cement (10.0 oz per 100 lbs of cement). Because only one specimen was tested at each age for the 6.52 mL/kg of cement (10.0 oz per 100 lbs of cement) dosage rate, definitive conclusions may not be inferred with respect to the effect of dosage rate on the compressive strength of the experimental concrete mixture. Three-day strengths of the experimental mixture ranged from 28.80 MPa (4,180 psi) to 35.50 MPa (5,150 psi). These early strengths will permit removal of falsework and opening to traffic after only three-curing days. The average 28-day elastic modulus, without respect to the amount of high-range water reducer admixture added, was 35.25 x 10 ^{6} MPa (5.55 x 10^{6} psi).

KYDOH personnel obtained measurements of the fresh concrete properties and cast several specimens at the job site during placement of the experimental concrete. These data are also contained in Appendix II. The data are arranged with respect to dosage rate of the high-range water reducing admixture and age at the time of the test. The Department evaluated 30 test cylinders cast from the experimental concrete for compressive strength at ages of 28 and 56 days. There were five specimens tested from batches dosed at the specified rate of 10.43 mL/kg of cement (16.0 oz per 100 lbs of cement); all tested at an age of 28 days. There were 15 specimens tested from batches dosed at one-half the specified amount, or 5.22 mL/kg of cement (8.0 oz per 100 lbs of cement); six tested at 28 days and nine tested at 56 days. The ten remaining specimens were cast from truckloads containing 6.52 mL/kg of cement (10.0 oz per 100 lbs of cement); four tested at 28 days and six tested at 56 days. Compressive strength values reported by KYDOH at 28 days, without respect to dosage amount, were 45.55 MPa (6,610 psi). The five specimens cast from batches dosed at the rate of 10.43 mL/kg of cement (16.0 oz per 100 lbs of cement) averaged 42.10 MPa (6,400 psi). Compressive strengths of specimens cast from batches dosed at the rate of 6.52 mL/kg of cement (10.0 oz per 100 lbs of cement) averaged 45.60 MPa (6,615 psi) at 28 days and 52.30 MPa (7,580 psi) at 56 days. Compressive strengths of specimens cast from batches dosed at the rate of 5.22 mL/kg of cement (8.0 oz per 100 lbs of cement) averaged 46.80 MPa (6,780 psi) at 28 days and 49.65 MPa (7,200 psi) at 56 days. Based on the 28-day strengths, it appears that the lower dosage rate provided the highest strength. However, the dosage rate of 6.52 mL/kg of cement (10.0 oz per 100 lbs of cement) provided the highest strength gain after 56 days.

UKTC personnel obtained measurements of the fresh Class AA concrete properties and cast 16 specimens at the job site during placement of the conventional concrete mixture. These data are presented in Appendix III. The data are arranged according to the age of the concrete when the compressive strength test was performed. The average unit mass (unit weight) for the control concrete was 2,315 kg/m^3 (144.5 lbs/ft^3). Again, strength tests were performed at ages of three, seven, 14 and 28 days. The Class AA control concrete had an average three-day compressive strength of 24.40 MPa (3,540 psi) and an average modulus of elasticity of 28.30 MPa x 10 ^{6} (4.25 psi x 10^{6}). The Class AA concrete had a 28-day average compressive strength and elastic modulus of 35.30 MPa (5,120 psi) and 34.50 x 10 ^{6} MPa (5.00 x 10^{6} psi), respectively. All control concrete specimens passed the strength requirements for Class AA bridge deck concrete. KYDOH personnel reported the compressive strength test results for four specimens. The strength requirement for all specimens exceeded the minimum compressive strength requirements set forth in the specifications [1]. The average 28-day compressive strength reported by KYDOH for the four control specimens was 36.90 MPa (5,350 psi). From the data presented, it may be concluded that the addition of the high-range water reducing admixture to the conventional Class AA concrete mixture increased the overall compressive strength and elastic modulus of the concrete specimens.

COST ANALYSIS

The experimental and control bridges were both contained in the same bid document for this project. As such, there was no differentiation made between the two types of concrete. Placement of all concrete for this project was bid at $386 per cubic meter ($295 per cubic yard). Discussions with KYDOH Division of Materials personnel revealed that the addition of a good quality, high-range water reducing admixture at the dosage rates used for this experimental project would have added about $7.00 per cubic meter ($5.00 per cubic yard) to the overall cost of the concrete. The benefits of expected higher durability (longer life), higher early strengths, and higher ultimate strengths of the experimental concrete should more than offset the minor increase in cost over the useful life of the bridge.

PERFORMANCE MONITORING

Visual surveys to monitor the experimental and control decks were conducted periodically throughout a three-year evaluation period. The initial inspection revealed that the overall appearance of the surface of the experimental deck was extremely poor. The finish was not consistent and contained several rugged spots throughout the deck's surface. Tyning of the experimental deck's surface was very deep in many areas of the deck, displacing a significant number of coarse aggregate. Figure 2 shows one of the roughest spots in the deck's surface. It may be concluded, based on the experimental deck's appearance in these areas, that the surface of the experimental concrete was tyned too early. The early tyning allowed the rake to penetrate too deeply into the concrete

Figure 2. *The surface finish of the experimental deck was unsatisfactory.*

surface and displace the coarse aggregates. The high slump of the experimental concrete and the use of the Type D set retarder may have contributed to this situation.

There were also numerous areas of the experimental deck that exhibited cracks at a very early age (see Figure 3). The cracks in the experimental deck were perpendicular to the transverse grooves formed during the tyning operation but appeared to be very deep. KYDOH officials were very concerned with the appearance of these cracks and also with the rough texture of the deck's surface. Recommendations were made by KYDOH for two cores to be obtained from the experimental deck in the areas exhibiting cracking to investigate the depth of the cracks. KYDOH further recommended that the rough areas be milled and patched with an epoxy compound. Cores were obtained from the experimental deck and the depth of the cracks observed (see Figures 4 and 5). Although the widths of the cracks were quite large, the depths of the cracks were not deemed significant by KYDOH officials. It was concluded that the cracks were pull cracks caused by the tyning operation. The rough areas of the deck surface were patched on October 26, 1992. The roughest areas of the deck's surface were sandblasted, milled, and patched with an epoxy compound mix. A silica sand was spread over the spots for texture. A total of 10 rough spots were patched (see Figure 6).

Figure 3. *Surface cracking was apparent after the curing blankets were removed.*

Figure 4. *Core removed from the experimental deck demonstrated the extent of the surface cracking.*

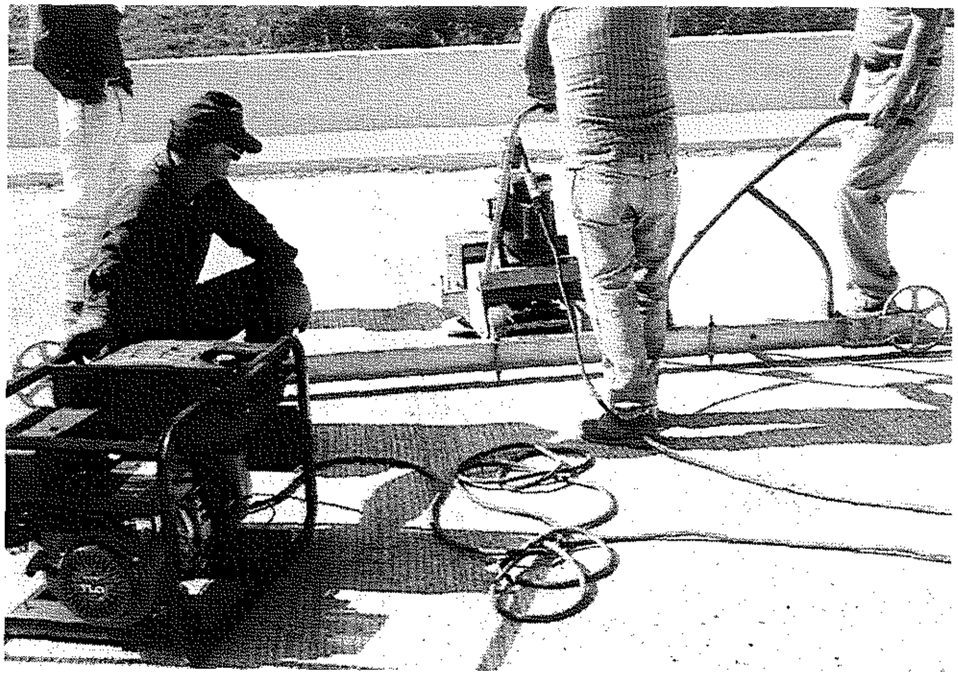

Figure 5. *Grinding the surface of the experimental deck to remove undesirable rough spots.*

Figure 6. *An epoxy compound was spread on the ground spots and sand was applied for surface texture.*

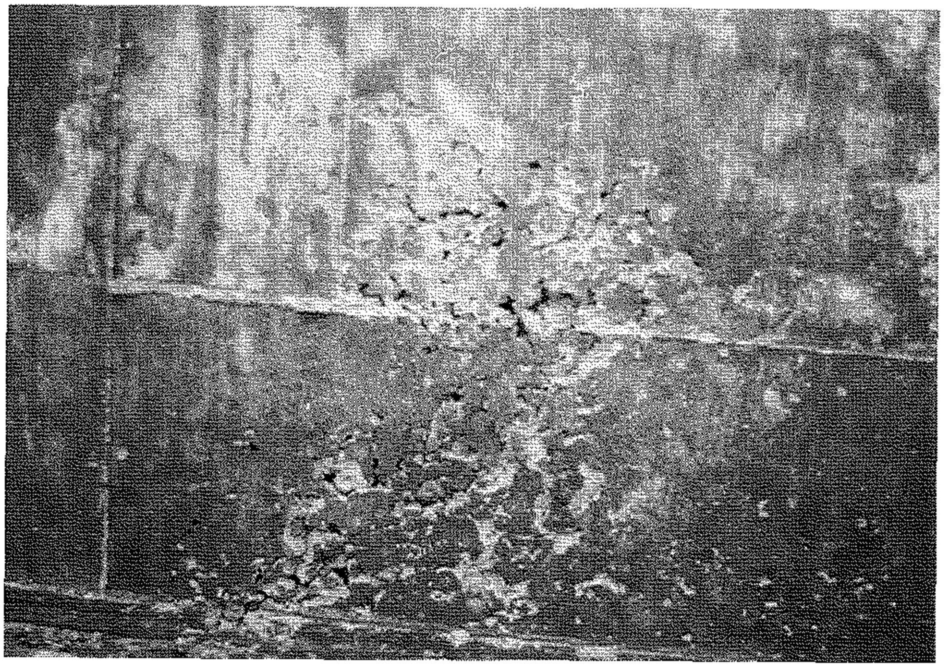

Figure 7. *Although the experimental concrete had a high slump, honeycombed areas were observed from beneath the deck.*

Also observed during the initial inspection were several honeycombed areas on the bottom of the experimental deck (see Figure 7). The subcontractor for the bridge work returned and made repairs to these areas using a mortar mix. Subsequent inspections showed that the areas had been repaired and appeared to be satisfactory.

Although the Class AA control concrete was not as workable as the experimental concrete during placement, as evidenced by an average 76-mm (3.00-in.) slump compared to the average 171-mm (6.75-in.) slump of the experimental concrete, there was a much more satisfactory finish on the deck. The transverse tyning was very consistent and at an ideal depth (see Figure 8). The control deck exhibited a few aggregate popouts and the appearance of some scarring of the deck. The scarring damaged the deck surface slightly but did not damage the integrity of the concrete.

Visual surveys were made periodically on both the experimental and control decks to monitor performance. The principal concern was the formation of full-depth cracks in the bridge decks. The experimental deck contained many more full-depth cracks and honeycombed areas (underneath the bridge deck) than the control deck. Cracking of the

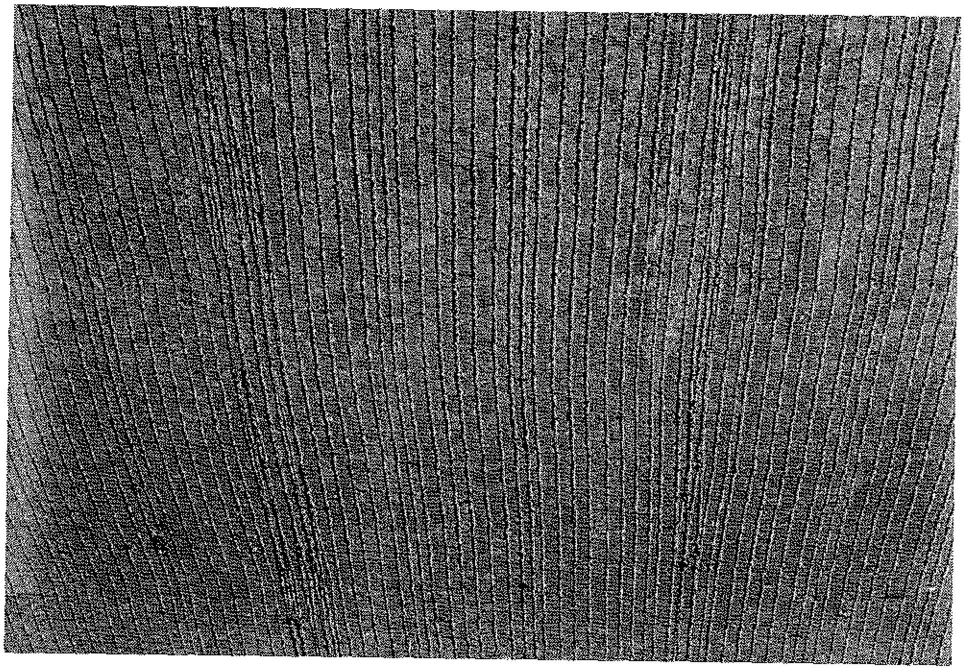

Figure 8. *The surface finish of the Class AA control deck was excellent.*

experimental deck was most prominent near the piers. The experimental deck contained 22 full-depth cracks exhibiting slight efflorescence. The control deck exhibited 12 full-depth cracks exhibiting slight to moderate efflorescence. Although the number of cracks is higher in the experimental deck, the severity of the cracks appears greater in the control deck. Figures 9 and 10 show a crack on the control deck's surface and from beneath the deck.

A discernible comparison of the short-term performance of the experimental and control decks can not be made at this time. With the exception of the extremely rough surface texture and pull cracks in the experimental deck that required remedial work, both decks appear to be providing acceptable service. The subcontractor for the project had not used a concrete mixture containing a high-range water reducer in a bridge deck pour prior to this project. A stronger familiarity with the product may have precluded the poor surface texture and pull cracks.

Figure 9. *Full-depth cracking of the control deck viewed from beneath the deck.*

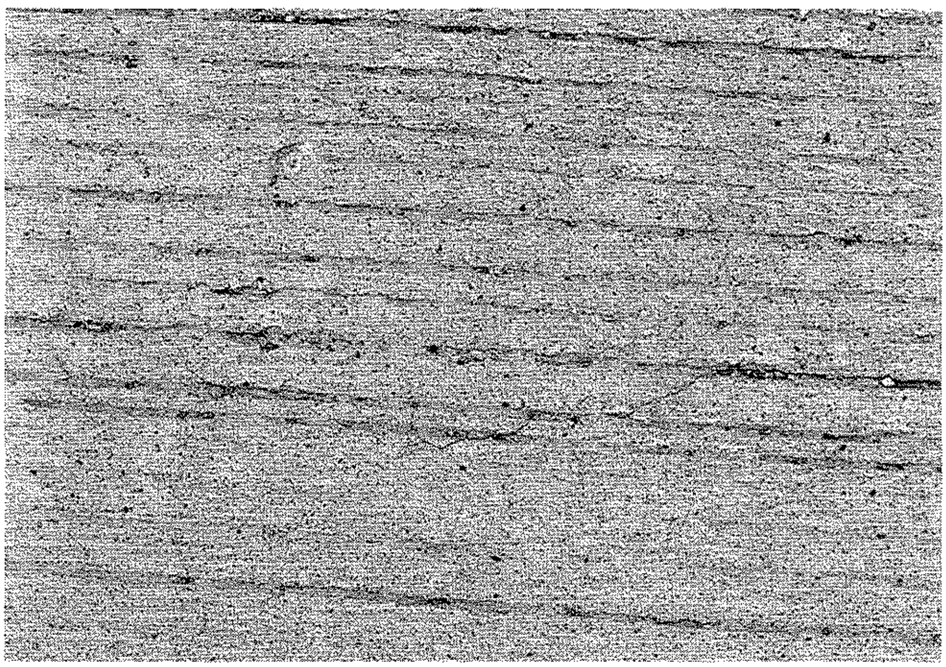

Figure 10. *Full-depth crack in the control deck viewed from the surface.*

SUMMARY

Because it is desirable for bridge deck concrete to be strong and durable, the Kentucky Department of Highways chose to use a high-range water reducer to modify the properties of a conventional Class AA concrete mixture to be placed in a full-depth concrete bridge deck on US 127 in Lincoln County. A high-range water reducer is a chemical admixture that when added to low-to-normal slump concrete produces a high slump to flowing concrete. The higher slump enhances placement properties in areas of closely spaced and congested reinforcing steel such as that encountered in the corners of a skewed bridge structure. The addition of a high-range water reducer permits reductions in mix water in the range of 12 to 30 percent. The reduction in mix water lowers the water-to-cement ratio leading to increased strength properties. The Kentucky Department of Highways specified an admixture dosage rate of 10.42 mL per kilogram cement (16.0 oz per 100 lbs of cement). Test results indicated that this dosage rate would facilitate the desired 15 percent reduction in the available mix water.

Trial batches of the modified Class AA concrete were in advance of placement of the experimental concrete mixture. During mixing the trial batches, a representative of the company supplying the admixture persuaded Department engineers that the specified dosage rate was too great and suggested a dosage rate of 3.9 mL/kg (6.0 oz per 100 lbs) of cement. One trial batch was made at each dosage rate. Results of the trial batch operation favored the use of the specified dosage rate.

During placement operations, the admixture company representative was present to direct all dosing activities. The specified dosage was added to the first and second loads. Thereafter, the dosage rate varied from the specified to one-half of the specified rate. A total of 38 loads of concrete, or approximately 227.1 cubic meters (304 cubic yards), were delivered to the job site. Nineteen slump tests were performed by UKTC personnel during placement operations. Of the 19 slump tests that were performed, only 14 were within the specified tolerances of 127 ± 51 mm (5 ± 2 in.). Air content readings were made on 16 of the 38 loads. The air content of the first load measured 2.1 percent and was the only air content measurement not within the specified tolerances of 5.5 ± 1.5 percent. The air content averaged 5.0 percent and ranged from 2.1 to 6.2 percent. After the concrete was pumped in place, it was consolidated using an immersion-type vibrator. Concrete finishers reported the experimental concrete to be quite sticky but the high slump of the concrete provided the experimental concrete with a high degree of

workability. After the surface of the deck was finished by the Bid-Well finishing machine, it was bullfloated to eliminate any high and low spots, tyned, sprayed with an approved curing membrane, and covered with curing blankets to prevent the loss of moisture.

The control bridge deck was placed using identical equipment. There were no difficulties encountered during placement operations. The average slump and air content recorded by UKTC personnel was 76 mm (3.00 in.) and 5.4 percent, respectively. Approximately 135 cubic meters (176 yd^3) of concrete was placed in the control deck.

Specimens cast during placement operations of the experimental and control bridge deck concretes were evaluated for freeze-thaw resistance, compressive strength development, and static chord modulus of elasticity. Results of the durability tests indicated the specimens cast of the experimental Class AA concrete containing the high-range water reducing admixture performed slightly better in terms of higher durability factors and lower expansions after exposure to 350 cycles of rapid freezing and thawing. Strength tests performed at 28 days by UKTC personnel indicated average compressive strengths and elastic moduli values of 46.00 MPa (6,670 psi) and 35.25 x 10^6 MPa (5.55 x 10^6 psi), respectively for the experimental concrete. All of the experimental concrete specimens exceeded the 28-day strength requirement for this project. Strength tests of the experimental concrete, completed after three days, indicated strengths ranging from 28.80 MPa (4,180 psi) to 35.50 MPa (5,150 psi). These early strengths are advantageous and permit removal of falsework and opening to traffic after only three-curing days. The control Class AA concrete had a 28-day average compressive strength and elastic modulus of 35.30 MPa (5,120 psi) and 34.50 x 10^6 MPa (5.00 x 10^6 psi), respectively. All control concrete specimens passed the strength requirements for Class AA bridge deck concrete. The addition of the high-range water reducing admixture to the conventional Class AA concrete mixture increased the overall compressive strength and elastic modulus of the concrete specimens.

Unfortunately, the experimental and control bridges were both contained within the same bid document for this project. As such, there was no cost differentiation made between the two concretes. Placement of all concrete for this project was bid at $386 per cubic meter ($295 per cubic yard). The addition of a good quality, high-range water reducing admixture at the dosage rates used for this experimental project would have added about $7.00 per cubic meter ($5.00 per cubic yard) to the overall cost of the concrete. The benefits of expected higher durability (longer life), higher early strengths, and higher ultimate strengths of the experimental concrete should more than offset the minor increase in cost over the useful life of the bridge.

The surface finish of the experimental bridge deck was very poor and required remedial work to improve rideability. Rough areas and areas with extensive pull cracks caused by transverse grooving operations required grinding and epoxy patching. Honeycombed areas beneath the deck also were required to be repaired with a mortar mixture. The surface finish of the control deck was excellent.

Visual surveys of the experimental and control bridge decks were made periodically to monitor performance. The principal concern was the formation of full-depth cracks in the bridge decks. The experimental deck contains many more full-depth cracks and honeycombed areas (underneath the bridge deck) than the control deck. The last inspection showed that the experimental deck contained 22 full-depth cracks exhibiting slight efflorescence. The control deck exhibited 12 full-depth cracks exhibiting slight to moderate efflorescence. Although the number of cracks are higher in the experimental deck, the severity of the cracks appear greater in the control deck.

CONCLUSIONS AND RECOMMENDATIONS

The use of a high-slump concrete enhances placement properties in areas of closely spaced reinforcing steel such as a skewed bridge structure. Data obtained during this study indicate that the high-range water reducing admixture also enhances durability and strength properties of concrete. The magnitude of cracking was slightly more for the experimental deck concrete but the severity of the cracks appeared to be higher in the control deck. The inability to adhere to the specified admixture rate compounded by the finishing characteristics of the concrete mixture contributed to the poor results achieved with the experimental deck. The admixture representative present during the experimental deck placement could not provide the suitable proportioning of admixtures necessary for both a good finishing mix that also met the requirements of the project.

It is recommended that consideration be given again to the use of high-range water reducers to modify conventional bridge deck concrete in situations where the placement properties can be enhanced or where it is desired to enhance strength and durability properties. The positive attributes of the modified concrete identified in this project gain additional experience with the use of these admixtures. It is recommended that additional trial batches and placements be performed in advance of construction and that the bridge contractor have those personnel expected to do the actual placement and finishing work be at the trial placements so that they may benefit from the exercise and gain the experience needed to produce acceptable results. On any future project it is recommended that more participation from field personnel be included during the planning phase of the project. Goals and expectations of the project need to be clearly defined to the field personnel. Additional guidelines and information are needed in the area of admixtures in order to provide better mixture control. There is some question about the suitability of conventional finishing equipment on this type of mixture due to the stickiness of the concrete.

REFERENCES

1. Kentucky Standard Specifications for Road and Bridge Construction, Edition of 1985, Kentucky Transportation Cabinet, Department of Highways, Frankfort, Kentucky.

2. ASTM C 494-92, Specification for Chemical Admixtures for Concrete, 1992 Annual Book of Standards, Concrete and Mineral Aggregates, Volume 4, Section 04.02, American Society for Testing and Materials, Philadelphia, U. S. A.

3. ASTM C 39-86, Test Method for Compressive Strength of Cylindrical Concrete Specimens, 1992 Annual Book of Standards, Concrete and Mineral Aggregates, Volume 4, Section 04.02, American Society for Testing and Materials, Philadelphia, U. S. A.

4. ASTM C 31-91, Practice for Making and Curing Concrete Specimens in the Field, 1992 Annual Book of Standards, Concrete and Mineral Aggregates, Volume 4, Section 04.02, American Society for Testing and Materials, Philadelphia, U. S. A.

5. ASTM C 666-90, Test Method for Resistance of Concrete to Rapid Freezing and Thawing, Method B, Freezing in Air and Thawing in Water, 1992 Annual Book of Standards, Concrete and Mineral Aggregates, Volume 4, Section 04.02, American Society for Testing and Materials, Philadelphia, U. S. A.

6. ASTM C 469-87a, Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, 1992 Annual Book of Standards, Concrete and Mineral Aggregates, Volume 4, Section 04.02, American Society for Testing and Materials, Philadelphia, U. S. A.

7 .ASTM C 617-87, Practice for Capping Cylindrical Concrete Specimens, 1992 Annual Book of Standards, Concrete and Mineral Aggregates, Volume 4, Section 04.02, American Society for Testing and Materials, Philadelphia, U. S. A.

APPENDIX I

SPECIAL NOTE FOR CLASS AA CONCRETE
WITH A TYPE F OR TYPE G
HIGH RANGE WATER REDUCER

SPECIAL NOTE FOR CLASS AA CONCRETE WITH A TYPE F OR TYPE G HIGH RANGE WATER REDUCER

(Experimental 3-20-91)

I. GENERAL

This work shall consist of furnishing, placing, finishing, and curing Class AA concrete containing a Type F or Type G high range water reducer. Class AA concrete with high range water reducer shall be used in those locations as specified on the plans.

II. MATERIALS REQUIREMENTS

1. Type F or Type G high range water reducers shall conform to Section 802 and shall be included on the Department's listing of approved admixtures. In addition, the Type F or Type G high range water reducer shall be an admixture with a minimum water reduction of 15% as shown by ASTM C 494 test data.

2. All other ingredients shall meet the requirements in Section 601 of the Department's Standard Specifications.

III. CONCRETE MIX REQUIREMENTS

1. Minimum compressive strengths shall be as follows:

A. For removing falsework	-- 24.15 MPa	(3,500 psi)
B. For opening to traffic	-- 27.60 MPa	(4,000 psi)
C. 28-day strength	-- 41.35 MPa	(6,000 psi)

2. Slump shall be within the range of 76 to 178 mm (3 to 7 in.)

3. The concrete mixture shall have a net air content, by volume, of 5.5 plus or minus 1.5 percent.

4. The water/cement ratio shall not exceed 17.0 L (4.50 gal.) per bag (0.40).

5. A minimum of 5 sets (2 per set) of 152-mm x 305-mm (6-in. x 12-in.) cylinders per 38.2 cubic meters (50 cubic yards) will be cast, cured, and tested by Department personnel.

6. When application of water to the surface of the concrete is permitted, it would be applied in accordance with Section 609.10.

7. The contractor shall make trial batches as necessary to demonstrate that the mix will meet the requirements for slump, air content, water/cement ratio, and compressive strength. The trial batches shall be made using the ingredients, proportions, and equipment (including batching, mixing, and delivery) to be used in the project. Department personnel shall observe all phases of the trial batching. At least two three yard batches meeting all specifications shall be made. A report of test results and mix proportions for all trial batches shall be submitted to the Engineer for review and approval.

8. If a slump loss occurs after addition and mixing of the superplasticizing admixture and before placement, the concrete mixture may be "re-tempered" with the admixture to restore plasticity. If superplasticizing admixture is added at the job site, the concrete shall be mixed an additional 50 revolutions at the specified mixing speed. The slump range and air content shall be rechecked to ensure conformance to the allowable values. If the consistency of the concrete mixture after "re-tempering" is such as to indicate segregation of the components, the load will be subject to rejection.

IV. COMPRESSIVE STRENGTH ACCEPTANCE REQUIREMENT

If the average strength of the 28-day cylinder test is less than 41.35 MPa (6,000 psi), two cores shall be taken from the concrete in question, and tested. If the cores average 41.35 MPa (6,000 psi), the concrete will be considered acceptable; but if the cores average less than 41.35 MPa (6,000 psi) the concrete will be paid for in accordance with the following table.

AVERAGE CORE STRENGTH		PERCENT OF CONTRACT UNIT PRICE
36.55 - 41.35	(5,300 - 5,999)	95%
31.70 - 36.55	(4,600 - 5,299)	90%
27.60 - 31.70	(4,000 - 4,599)	85%
24.15 - 27.60	(3,500 - 3,999)	80%
24.15 - 20.70	(3,000 - 3,499)	60%
Below 20.70	(Below 3,000)	Remove and Replace at Contractor's Expense.

Batching, mixing, hauling, placing, finishing, curing of concrete method of measurement, and basis of payment shall conform to the requirements of Section 601, 608, and 609 of the Department's Standard Specifications.

APPENDIX II

EXPERIMENTAL CONCRETE
STRENGTH DATA FROM
UKTC AND KYDOH

Experimental Bridge Deck Construction and Test Data (Reported by UKTC)

	HRWR Dosage			Slump			Unit Weight		Elastic Modulus		Compressive Strength	
Sample No.	(mL/kg cement)	(oz/100 lb cement)	Age at Test (days)	(mm)	(in.)	Air Content (%)	(kg/m³)	(pcf)	(kg/m³ x 10⁶)	(psi x 10⁶)	MPa	psi
1*	10.43	16	3	203	8.00	6.2	2,342	146.2	-	-	28.80	4,180
2	10.43	16	7	203	8.00	6.2	2,371	148.0	-	-	35.30	5,120
3	10.43	16	14	203	8.00	6.2	2,364	147.6	-	-	40.35	5,850
4	10.43	16	28	203	8.00	6.2	2,379	148.5	-	-	42.75	6,200
5*	10.43	16	3	190	7.50	6.2	2,329	145.4	31.05	4.50	31.30	4,540
6	10.43	16	7	190	7.50	6.2	2,353	146.9	32.40	4.70	36.45	5,290
7	10.43	16	14	190	7.50	6.2	2,376	148.3	35.15	5.10	40.80	5,920
8	10.43	16	28	190	7.50	6.2	2,384	148.8	36.55	5.30	45.65	6,620
17*	6.52	10	3	178	7.00	3.6	2,411	150.5	36.20	5.25	36.25	5,260
18	6.52	10	7	178	7.00	3.6	2,417	150.9	36.90	5.35	41.25	6,010
19	6.52	10	14	178	7.00	3.6	2,438	152.2	38.60	5.60	47.00	6,820
20	6.52	10	28	178	7.00	3.6	2,444	152.6	40.00	5.80	50.05	7,260
9*	5.22	8	3	203	8.00	5.2	2,395	149.5	33.10	4.80	30.40	4,410
10	5.22	8	7	203	8.00	5.2	2,348	146.6	33.45	4.85	35.85	5,200
11	5.22	8	14	203	8.00	5.2	2,387	149.0	34.45	5.00	38.60	5,600
12	5.22	8	28	203	8.00	5.2	2,345	146.4	36.55	5.30	42.55	6,170
13*	5.22	8	3	146	5.75	4.0	2,422	151.2	33.80	4.90	35.50	5,150
14	5.22	8	7	146	5.75	4.0	2,417	150.9	35.85	5.20	40.55	5,880
15	5.22	8	14	146	5.75	4.0	2,411	150.8	37.25	5.40	45.50	6,600
16	5.22	8	28	146	5.75	4.0	2,411	150.8	39.65	5.75	48.95	7,100

Notes * - Denotes use of pad caps during compressive strength test.

Experimental Bridge Deck Construction and Test Data (Reported by KYDOH)

Sample No.	HRWR Dosage (mL/kg cement)	HRWR Dosage (oz/100 lb cement)	Age at Test (days)	Slump (mm)	Slump (in.)	Air Content (%)	Compressive Strength MPa	Compressive Strength psi
A	10.43	16	28	178	7.00	3.5	47.35	6,870
C	10.43	16	28	178	7.00	4.7	42.05	6,100
D	10.43	16	28	178	7.00	6.2	42.35	6,140
E	10.43	16	28	178	7.00	6.2	43.15	6,260
F	10.43	16	28	178	7.00	6.2	45.70	6,630
						AVERAGE	**42.10**	**6,400**
B	6.52	10	28	178	7.00	4.0	46.05	6,680
L	6.52	10	28	171	6.75	6.1	43.85	6,360
M	6.52	10	28	171	6.75	6.1	45.10	6,540
N	6.52	10	28	171	6.75	6.1	47.35	6,870
						AVERAGE	**45.60**	**6,615**
G	5.22	8	28	140	5.50	5.7	39.85	5,780
H	5.22	8	28	140	5.50	5.7	48.70	7,060
I	5.22	8	28	140	5.50	5.7	49.10	7,120
J	5.22	8	28	140	5.50	5.7	49.15	7,130
K	5.22	8	28	140	5.50	5.7	47.85	6,940
O	5.22	8	28	178	7.00	5.2	46.00	6,670
						AVERAGE	**46.80**	**6,780**
Y	6.52	10	56	114	4.50	5.0	52.10	7,560
Z	6.52	10	56	114	4.50	5.0	54.45	7,900
AA	6.52	10	56	114	4.50	5.0	54.70	7,930
BB	6.52	10	56	114	4.50	5.0	51.00	7,400
CC	6.52	10	56	178	7.00	5.4	50.25	7,290
DD	6.52	10	56	152	6.00	5.2	51.15	7,420
						AVERAGE	**52.30**	**7,580**
P	5.22	8	56	178	7.00	5.2	42.95	6,230
Q	5.22	8	56	178	7.00	5.2	48.90	7,090
R	5.22	8	56	178	7.00	5.2	48.40	7,020
S	5.22	8	56	178	7.00	5.2	49.35	7,160
T	5.22	8	56	178	7.00	5.2	48.75	7,070
U	5.22	8	56	178	7.00	5.2	52.90	7,670
V	5.22	8	56	178	7.00	5.2	53.80	7,800
W	5.22	8	56	108	4.25	5.2	49.90	7,240
X	5.22	8	56	108	4.25	5.2	51.90	7,530
						AVERAGE	**49.65**	**7,200**

APPENDIX III

CONTROL CONCRETE STRENGTH
DATA FROM UKTC

Control Bridge Deck Construction and Test Data

Sample No.	Age at Test (days)	Slump (mm)	Slump (in.)	Air Content (%)	Unit Weight (kg/m³)	Unit Weight (pcf)	Elastic Modulus (kg/m³ x 10⁶)	Elastic Modulus (psi x 10⁶)	Compressive Strength MPa	Compressive Strength psi
21	3	83	3.25	5.4	2,289	142.9	-	-	22.55	3,270
25	3	76	3.00	5.9	2,294	143.2	28.60	4.15	23.70	3,440
29	3	89	3.50	6.2	2,289	142.9	28.25	4.10	23.25	3,370
33	3	51	2.00	4.1	2,372	148.1	31.00	4.50	28.15	4,080
22	7	83	3.25	5.4	2,300	143.6	-	-	27.25	3,950
26	7	76	3.00	5.9	2,302	143.7	31.00	4.50	28.70	4,160
30	7	89	3.50	6.2	2,295	143.3	31.00	4.50	26.95	3,910
34	7	51	2.00	4.1	2,388	148.6	33.45	4.85	33.80	4,900
23	14	83	3.25	5.4	2,279	142.3	-	-	29.65	4,300
27	14	76	3.00	5.9	2,297	143.4	32.05	4.65	32.00	4,640
31	14	89	3.50	6.2	2,302	143.7	31.00	4.50	30.35	4,400
35	14	89	2.00	4.1	2,368	147.8	35.85	5.20	35.80	5,190
24	28	83	3.25	5.4	2,292	143.1	-	-	32.80	4,760
28	28	76	3.00	5.9	2,295	143.3	34.15	4.95	34.90	5,060
32	28	89	3.50	6.2	2,297	143.4	32.40	4.70	33.45	4,850
36	28	51	2.00	4.1	2,376	148.3	36.90	5.35	40.00	5,800