IMPLEMENTING HIGH PERFORMANCE CONCRETE ON TEXAS BRIDGES

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ABSTRACT

Success constructing durable concrete bridges depends on proper design and detailing, but even the best design is affected by the fact that for state transportation contracts the lowest bidder gets the work. Therefore, crafting precise specifications to instruct contractors is critical. This paper presents the experience of the Texas Department of Transportation (TxDOT) specifying the use of High Performance Concrete (HPC) for bridges. Currently, TxDOT specifications that accompany contracts with special emphasis on durability are mostly prescriptive. TxDOT believes that when contractors clearly understand project requirements, they have less uncertainty, resulting in better prices and fewer project delays.

Keywords: Bridges, Durable, High Performance Concrete, Prescriptive, Specifications, Supplementary Cementitious Materials

INTRODUCTION

The Texas Department of Transportation (TxDOT) is responsible for constructing, operating, and maintaining the 79,361 centerline miles of highways and 32,561 bridges (as of 2002) on the Texas highway system. TxDOT is a centralized organization that includes 25 districts aligned in unique geographic regions of the state, and within these districts are 122 individual offices that coordinate plan preparation and oversee construction. State geographic regions vary significantly, and the varying climate where highways and bridges reside poses challenges that engineers and planners must address. In general, the state has a climate conducive to long-lasting concrete structures. However, in some regions weather-related events, environmental conditions, and geological conditions affect the life of a structure, and deterioration of concrete structures occurs at a more rapid rate than is acceptable. Most climate-related distress can be attributed to reinforcing steel corrosion caused by chlorides and moisture penetrating the concrete to a depth of the steel. In the past ten years, despite the measures requiring use of non-reactive aggregates, significant occurrences of alkali-silica aggregate reactivity (ASR) have resulted in distress in several concrete structures. Also, TxDOT has known since the 1960’s that sulfates in the soil and groundwater were attacking concrete, and it has taken measures to resist this attack by requiring Type II cement in the concrete.

High performance concrete (HPC) can go a long way to address the need for more durable and longer lasting concrete as well as to meet strength and other performance-related criteria. HPC is specialized. In some instances—such as when concrete can obtain high early strength, obtain high final strength, be placed under water without segregating, or self-consolidate without the use of mechanical vibrators—it is specialized to meet requirements of a particular application. Specifications to obtain specialized concrete can be made performance-based by requiring certain minimum performance measures—such as strength, slump, and air content—that can be readily tested. However, when HPC is specified to address durability concerns, methods of testing and verification are not as direct. The durability of concrete is discovered over time. Tests can indicate how concrete may perform over time, but typically they take a long time to conduct, and some of their results may not hold up under scrutiny. Therefore, engineers should rely on the latest technologies, the best information available at the time, and good engineering judgment to craft specifications that will provide concrete that will meet the needs of the transportation community.

FIRST USES OF HPC IN TEXAS

The Louetta Road Overpass on State Highway 249 northwest of Houston, completed in 1994, and the two bridges constructed on US 67 over the North Concho River near San Angelo in 1997 were the first two HPC bridge project in Texas. These projects emphasized the use of HPC to obtain high strengths. Highlights of these projects are shown in Table 1[1,2].

In addition to the high strengths attained by the concrete in these bridge structures, TxDOT expects more durability than conventional concrete. The higher strengths specified for the concrete required a lower water-to-cementitious-material (w/cm) ratio, which produces lower concrete permeability. The permeability of the concrete was tested in accordance with AASHTO T 277, "Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration." This test is also known as the rapid chloride permeability (RCP) test. All HPC cast-in-place concrete used on these projects had permeability less than 2,000 coulombs, which is considered low or very low chloride penetration according to this test and which also correlates to FHWA HPC performance grade of 2[3]. The RCP test predicts how well the concrete will perform in keeping water and chlorides from penetrating the concrete and reaching the reinforcing steel.

TABLE 1 Geometry and Strength Summary.

	Louetta		**San Angelo**	
Maximum Values	**Northbound**	**Southbound**	**Eastbound**	**Westbound**
Span length, ft.	136.5	134.0	157.0	140.3
Beam spacing, ft.	12.94	16.62	11	8.26
Beam f′c, psi (Dsn/Act)	13,100/14,440	13,100/14,550	14,000/15,240	8,900/10,130
Deck thickness, in.	7.25	7.25	7.5	7.5
Deck f′c, psi	4,000/5,700	8,000/9,100	6,000/7,345	4,000/6,120

These two bridge projects focused on using HPC for high strength as well as for improved durability. The span lengths, beam spacings, and thickness of the decks were optimized to take advantage of the higher strengths attainable using HPC. From these two projects TxDOT learned the following[4]:

- High strength concrete is attainable using local materials.
- Longer spans reduce the amount of substructure needed but necessitate larger capacity hauling systems and cranes, adding concerns about transporting the beams to the job site and about stability of long slender beams. Longer spans require the beam fabricator to modify or construct new prestressing beds to handle the increased prestressing force.
- The use of high strength concrete allows wider beam spacing.
- Specifying higher strengths for bridge deck concrete in order to increase durability is not effective. The higher strengths require a significant change in the typical construction practice: high-range water reducers are often required to produce concrete with a w/cm ratio below 0.4, which makes concrete placement and finishing more difficult in Texas' typically hot, dry, and windy conditions. In addition, low w/cm ratios result in low-bleedwater concrete, which is more susceptible to plastic shrinkage cracking. Cracked concrete is less durable when exposed to moisture and deicing chemicals.

DURABILITY

The first uses of HPC in Texas demonstrated that concrete can be designed to possess a variety of properties. Durability is the HPC property TxDOT most values, and TxDOT is expending significant effort to implement it throughout the state. Although TxDOT recognizes the three main threats to concrete bridges—alkali-silica aggregate reactivity (ASR), sulfate attack, and reinforcing steel corrosion—it is convinced that the use of supplementary cementitious materials (SCM) in the concrete will manage these threats.

ALKALI-SILICA AGGREGATE REACTIVITY

In the early 1990's, several structures, primarily prestressed concrete beams, began to show cracking patterns not previously seen that could not be adequately explained by structural analysis. The cracking was attributed to ASR. This discovery initiated retesting of all fine and coarse aggregates used in concrete following the ASTM C 1260, "Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)." This testing showed that 80% of the fine aggregates and 60% of the coarse aggregates exhibited a potential for ASR[5]. In its search for ways to mitigate the potential for ASR in future concrete without drastically restricting the use of the majority of the commonly used aggregates, TxDOT developed six options and drafted them into a special provision that now accompanies the standard concrete specification for structural concrete. Four of the options require inclusion of an SCM to replace a portion of the cement, and a fifth requires use of a Type IP or IS cement. Only one of the options allows use of cement as the only cementitious component, traditionally the case for most concrete produced in the state.

Subsequently, even though five of the six options required use of an SCM, most concrete continued to be produced using the option allowing low-alkali cement without an SCM. Only one district in the state mandated use of an SCM in all cast-in-place concrete, and this district is in the westernmost part of the state where local aggregates are highly reactive. Replacement of 50% of the cement with ground granulated blast furnace slag (GGBFS) is required for all cast-in-place concrete in that district. GGBFS has also helped reduce the heat of hydration and improve the workability of the concrete in this hot, dry, and windy environment.

Thus, TxDOT's solution to mitigate ASR included a prescriptive specification addressing the concrete mix design, but it gives options easily met.

SULFATE ATTACK

TxDOT has not seen significant signs of concrete deterioration related to sulfate attack in recent years, probably because of its 40-year-old requirement to use Type II cement in the concrete wherever sulfates in the soil or water are thought to be present. Thus, TxDOT has prescriptively specified a known solution to mitigate sulfate attack.

REINFORCING STEEL CORROSION

Deterioration of concrete bridges in Texas is due primarily to corrosion of reinforcing steel, which results in concrete cracking, delamination, and spalling. Until recently, measures taken to construct structures more resistant to this type of deterioration included: increasing the concrete clear cover to reinforcing steel, using a lower water-to-cement ratio in the concrete, using epoxy-coated reinforcing steel, and applying penetrating sealers. Texas has many 50-to-70-year-old concrete bridges that are still in good condition. However, in some parts of the state increasing numbers of less-than-40-year-old bridges need significant repair or replacement. This problem has generated experimentation on how best to obtain more durable concrete structures.

PERFROMANCE VERSUS PRESCRIPTIVE SPECIFICATIONS

For early HPC bridge projects, TxDOT did not specify how the contractor was to obtain durable high performance concrete other than requiring adherence to the *Standard Specifications*[6] accompanying all projects. Contractors were alerted that these bridge projects were part of a research program and that concrete mix designs would be developed by TxDOT and the researchers to meet strength requirements and durability guidelines. A by-product of this research was an HPC specification to be used on future projects requiring HPC. The specification required that mix designs be formulated and verified to meet strength and permeability requirements before work started. This type of specification relies on the contractor's knowledge and experience to supply concrete to meet the contract requirements. However, several projects demonstrated that the contractors, the concrete suppliers, and TxDOT personnel lacked experience necessary to efficiently design concrete that would meet performance-based specification requirements for durability.

In order to gain experience and better understand the role that concrete constituents have on the permeability results, TxDOT initiated prescriptive specifications that require the use of SCM at a prescribed rate. Concrete specimens are sent to a central laboratory for testing. The contracting community has expressed minimal opposition to the use of prescriptive HPC specifications even though some of the projects require SCM in regions where they have never been used.

TxDOT's experience in several projects using prescriptive specifications encouraged adding more flexibility to the specifications, so more options were added to the prescriptive recipes, and the contractor was allowed to provide concrete meeting performance-based requirements.

PRESCRIPTIVE-ONLY SPECIFICATION PROJECT SUMMARIES

Several contracts awarded in the past three years have included HPC specifications requiring SCM in the concrete. TxDOT's HPC specification is a special provision to the *Standard Specifications*[6] that identifies other requirements for hydraulic cement concrete. The standard specification allows but does not require use of fly ash, silica fume, and GGBFS as partial replacement for cement. Many concrete suppliers actually have been using fly ash as a partial replacement for cement because the state has significant quantities of this material and fly ash costs one-third as much as cement. However, not all regions of the state are taking advantage of this material, and most areas are not maximizing its use.

TxDOT is aware of concerns about prescriptively specifying the use of SCM when the materials supplier and the contractor are not experienced with the materials, specifically with how inclusion of SCM affects strength gain of concrete. To address these concerns, TxDOT HPC specifications require the contractor to develop time-versus-strength curves for the concrete at 4, 7, 28, and 56 days during mix design approval. Inclusion of fly ash and

GGBFS can slow strength gain, especially in cooler weather, and having the contractor plot this curve facilitates synchronization of the concrete mix with the construction schedule. Additional concrete test specimens are provided and sent to the central laboratory for chloride ion penetrability testing using the RCP test. It is also intended that AASHTO T 259, salt ponding, testing be performed for verification of the RCP test.

Moist-curing requirements for AASHTO T 277 have been modified from 28 days at 73º F to 56 days at 73º F to allow for hydration to progress in mixes incorporating SCM and to produce better repeatability of test results. TxDOT is also allowing the curing to be changed to moist curing for 7 days at 73º F and 21 days at 100º F to expedite test results. Higher temperature curing has been shown to produce chloride ion penetrability results similar to specimens cured for 6 months[7].

Lubbock District

Just north of the city of Lubbock, two bridges constructed in 1967 were showing signs of significant reinforcing steel corrosion damage to both the superstructure and the substructure. This district routinely uses salt to keep ice from accumulating on the roadway, and tests performed on the concrete indicated a high concentration of chlorides at the level of the reinforcing steel. Based on the degree of corrosion damage to the structure and need for additional clearance at this location, TxDOT chose to replace these bridges, specifying HPC for the substructure and deck concrete for increased durability.

The substructure concrete was designated as Class C (HPC) concrete. Ordinarily, Class C concrete has a minimum specified compressive strength at 28 days (f′c) of 3,600 psi and a maximum w/cm ratio of 0.53. The HPC provision required 4% of the cement to be replaced with silica fume and 26% to be replaced by Class F fly ash with a maximum w/cm ratio of 0.47. It also required air entrainment of 5 to 8%. This concrete is expected to resist chloride intrusion as well as sulfate attack. In this region of the state, all concrete exposed to the ground must be resistant to sulfate attack. Testing performed to measure resistance to chloride ion penetration using the RCP test showed that this concrete tested at an average of 676 coulombs.

Concrete used in the bridge deck was designated as Class S (HPC) concrete. Class S concrete normally has a minimum f′c of 4,000 psi with a maximum w/cm ratio of 0.44. The HPC provision required 30% of the cement to be replaced with Class F fly ash. It also required air entrainment of 5 to 8%. Because of concern about attaining the 4,000 psi compressive strength at 28 days due to slower strength gain with Class F fly ash in cold weather, the 28-day strength was lowered to 3,000 psi and an additional requirement of 4,000 psi at 56 days was added to the plans. In terms of structural design, 3,000 psi is sufficient to resist the forces created by loading this type of structure, but 4,000 psi for deck concrete is required to meet FHWA requirements.

The RCP test performed on this concrete averaged 1,057 coulombs. RCP testing was also performed on concrete that had previously been used in this district that did not contain fly ash. The average of the actual values was 3,926 coulombs. Thus, the improved resistance to chloride ion penetration is dramatic. The mix design information for the Class C (HPC) and the Class S (HPC) with and without fly ash is shown in Table 2.

TABLE 2 Mix Design Information for Lubbock Concrete.

Mix Constituents (lbs/yd)	**Class C (HPC)**	**Class S (HPC) 30% Fly Ash**	**Class S w/o Fly Ash**
Cement Type I/II	367	397	588
Fly Ash (Class F)	137	181	-
Silica Fume	25	-	-
Coarse Aggregate	1,854	1,854	1,960
Fine Aggregate	1,241	1,174	1,133
Water	250	260	260
W/cm	0.47	0.45	0.44
RCP test (56 days)	676 coulombs	1,057 coulombs	3,962 coulombs

Corpus Christi District

The Corpus Christi District in south Texas borders the Gulf of Mexico. TxDOT advocates use of HPC in this district to combat the damage caused by chloride-induced corrosion attributed to the coastal environment. A bridge project awarded in late 2001, crossing from the mainland of Corpus Christi to North Padre Island, presented an opportunity to use HPC in both cast-in-place concrete and prestressed/precast concrete.

HPC was specified for the substructure, which consisted of prestressed concrete piling with cast-in-place bent caps. Specifications required 25% of the cement to be replaced with Class F fly ash for Class C (HPC) concrete used in the cast-in-place bent caps. This requirement provides concrete with reduced permeability and increased resistance to sulfate attack. TxDOT also requires use of Type II cement in concrete for structures in the Gulf of Mexico coastal environment. This project also used standard Class C concrete in members not directly exposed to the salt spray conditions, providing an opportunity to compare the two concretes using the RCP test. The results show a value of 1,243 coulombs for the standard Class C concrete and a value of 750 coulombs for the Class C HPC. These results were obtained from specimens cured for 16 days at 73º F and for 21 days at 100º F. See Table 3 for design mix information.

The prestressed concrete piling for this project was specified to be fabricated with Class H (HPC) concrete with a minimum compressive strength at release of the prestressing of 4,000 psi and a minimum 28-day compressive strength (f'c) of 5,000 psi. The maximum w/cm ratio of this concrete is 0.49. The specifications required that the concrete mix contain silica fume and Class F fly ash at a 5% and 19% replacement of the cement.

TABLE 3 Mix Design Information and Test Results for Corpus Christi Class C Concrete.

Mix Constituents (lbs/yd)	Class C (Standard)	Class C (HPC)
Cement Type II	451	395
Fly Ash (Class F)	84	128
Coarse Aggregate	1,850	1,900
Fine Aggregate	1,204	1,158
Water	186	188
W/cm	0.35	0.36
RCPT (56 days)	1,243 coulombs	750 coulombs

Initial mix designs—Class H (HPC) #1 and Class H (HPC) # 2—did not provide the early release strength that the fabricator needed to maximize the use of the stressing beds. The relatively slow-acting Type II cement and an insufficient amount of cement to react initially with the pozzolans may have contributed to this problem. The amount of cement was increased for mix design #3, Class H (HPC) #3, and has consistently obtained release strengths in 17 hours. The average RCP test results for mix design #1 are 317 coulombs. The test results for mix designs #2 and #3 are not available at this time. See Table 4 for mix design information.

TABLE 4 Mix Design Information and Test Results for Corpus Christi Class H HPC.

Mix Constituents (lbs/yd)	Class H (HPC) #1	Class H (HPC) #2	Class H (HPC) #3
Cement Type I/II	488	540	586
Fly Ash (Class F)	137	149	161
Silica Fume	42	42	49
Coarse Aggregate	1,872	1,872	1,869
Fine Aggregate	1,231	1,122	981
Water	228	248	271
W/cm	0.34	0.34	0.34
fc @ 17-19 hours	3,000 psi	3,790 psi	4,760 psi
f’c @ 28 days	8,320 psi	8,690 psi	9,138 psi
RCP test (56 days)	317 coulombs	315 coulombs	1,102 coulombs
RCP test (180 days)	180 coulombs	182 coulombs	1,021 coulombs

The RCP test values for mix #3 were significantly higher than for mixes #1 and #2, so the sample was examined using a petrographic microscope. The examination exposed micro-cracks that could explain the higher results. An additional mix design was recently developed, similar to mix #3 but with different aggregates, with RCP testing results equal to 212 coulombs at 29 days with specimens curing using the elevated temperature method.

Adding a prescriptive requirement to use SCM in concrete produced by the prestressed/precast industry raised another issue. The prestressed/precast industry that supports TxDOT depends on rapid turn-around of forms for its products. The usual requirement for fabricating beams or piling is for the concrete to obtain the required release strength in 16 to 19 hours to facilitate production of product on a daily cycle. Figure 1 shows

RCP test results compiled from the concrete produced by the main TxDOT fabricators. This chart clearly shows the trend for SCM on this test, which is favorable.

Figure 1. Effects of SCM and w/cm on RCP test results.

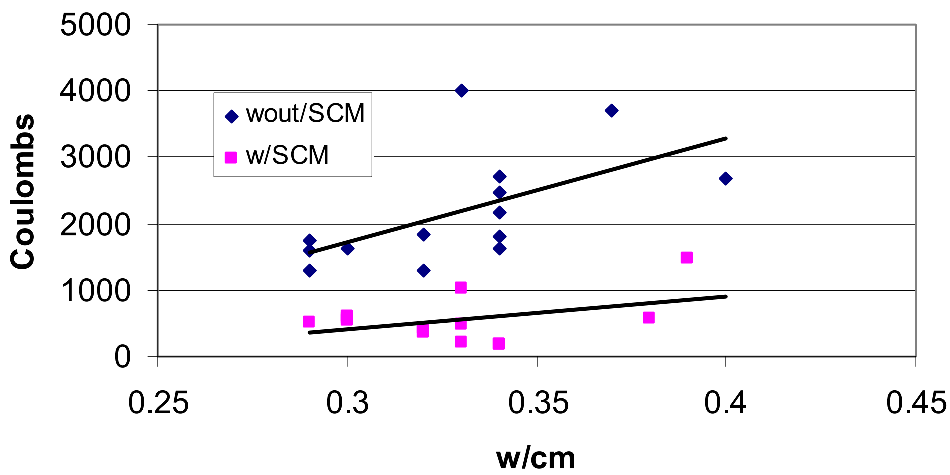
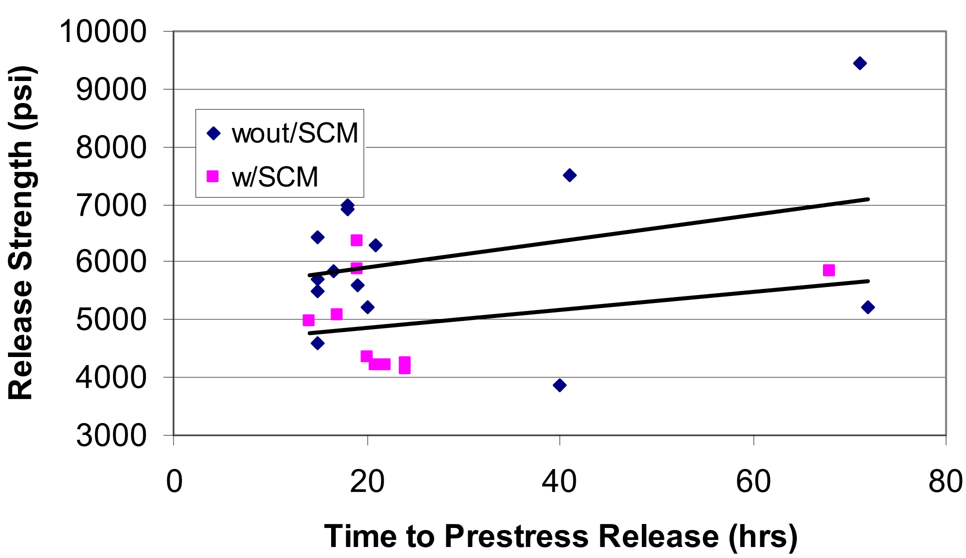


Figure 2 shows the downside to using SCM for production. It takes longer to obtain the required minimum release strengths, so either the cost of the product goes up or the amount of cement must be increased. Mix #3 required 98 more pounds of cement than the initial mix used. Although the cause of the micro-cracking is not definite, TxDOT suspects the high amount of cement contributed.

Figure 2. Effects of SCM and w/cm on strength.



PRESCRIPTIVE SPECIFICATION WITH MORE OPTIONS

After using a prescriptive HPC specification that allowed only one option for a particular class of HPC on several projects, TxDOT developed a new specification to provide additional prescriptive options. Multiple options enable the contractor to choose an option for the situation. The new specification allows a range of amounts of SCM to be substituted for cement—for example, 25 to 35% Class F fly ash. The Corpus Christi project demonstrated that requiring the use of Type II cement for increased sulfate resistance, in addition to requiring SCM, contributes significantly to low early-age strengths.

The low-early-age-strength problem was solved by increasing the cement content, which was not desirable. ACI 201.2R-01, “Guide to Durable Concrete,”[8] offers options for obtaining equivalent sulfate resistant concrete by using a combination of SCM and cement in place of a low tricalcium-aluminate cement. This option is now included in the prescriptive specification, provided ASTM 1012 testing is performed and verifies that an equivalent level of sulfate resistance is attained using SCM. The use of silica fume has increased since the prescriptive specification started requiring it. Problems have arisen with the use of silica fume. These include, silica fume bags not disintegrating and poor dispersion of the silica fume. A slightly higher amount of an ultra-fine fly ash (UFFA) is being allowed as an alternative to silica fume. UFFA has been shown to effectively mitigate ASR, provide sulfate attack resistance, and reduce the concrete permeability[9]. Also, newer versions of the HPC specification are requiring the contractor to verify complete dispersion of the silica fume within the concrete.

PRESCRIPTIVE SPECIFICATIONS WITH PERFORMANCE OPTIONS

In June 2003, TxDOT awarded a contract for the removal and reconstruction of a bridge connecting Galveston Island to the Texas mainland at a total contract cost of $136 million, about 2% over the engineers’ estimate. The current bridge has deteriorated as a result of chloride-induced reinforcing steel corrosion, and ASR was found in the prestressed concrete beams. Also, the bay that this bridge crosses contains high amounts of sulfates.

The Houston District requested that the new bridge have a minimum design life of 75 years, and the request was accommodated in several ways:

- Concrete clear cover to the reinforcing steel was increased for all structural components subject to salt spray.
- Steel casings are required to be left in place around the drilled shaft foundations.
- HPC was specified for most of the bridge members.

Developing the HPC specification for this job involved much discussion. The concept of using HPC in this is district was somewhat new, even though the initial work TxDOT did was in Houston, this particular area did not routinely use it. Time to complete this project was part of the discussion. The contract allows for 1250 days to complete the two 8,592 foot long bridges. Milestones were set at the completion of each bridge as well as the total completion of the project. Each bridge completion milestone carries an incentive bonus for early completion and a liquidated damage penalty for late completion of $20,000 per day. Requiring SCM in the HPC could slow some of the construction procedures and could result in higher bid costs which did have some bearing on the way the specification was worded.

The two bridges are identical, with one carrying northbound traffic and the other southbound traffic. Each bridge consists of 62 prestressed concrete AASHTO Type VI beam approach spans sandwiching a three span cast-in-place post-tensioned segmental structure. The substructure consists of reinforced concrete piers supported on drilled shafts for the approach spans and round steel piling on the main spans.

The concrete for the 126,000 feet of prestressed concrete beams and the 10,000 cubic yards of cast-in-place post-tensioned segmental concrete required extra consideration related to how HPC was specified in relation to the use of SCM. The final specification for this concrete allowed several options on the use of SCM but it also allowed the contractor provide a mix design meeting performance criteria based on the RCP test. If the contractor decides to provide concrete based on the performance criteria, the beam and segmental concrete must meet a maximum of 1,500 coulombs. The concrete will also be subject to quality assurance RCP tests periodically throughout the project to verify the concrete that it is in conformance to the performance requirement. The beam concrete also has a requirement to include three gallons of a calcium nitrite corrosion inhibitor per cubic yard. It is not the habit for TxDOT to use a corrosion inhibitor, but this application seems appropriate.

A brief review of bid items associated with constructing the two bridges on this project revealed a cost of $78/SF. This number is difficult to compare to with typical cost information, but it is higher than a similar project constructed several years for $50/SF. A look at the individual bid prices reveals that the beams were bid at $94/LF compared to $70/LF that was estimated and the concrete for the segmental was bid at $890/CY compared to the $700/CY estimated. The average bid price for the HPC used on the piers came in lower than what was estimated, $311/CY compared to $526/CY estimated. It is difficult to know how much HPC increased the cost of this project, but with the expected increase in structure life the costs seem reasonable.

FUTURE DIRECTION

TxDOT expects its promotion of HPC to have a long-term positive effect on the quality of structures in the state. Research continues on the first HPC structures constructed in the 1990's, and findings reveal no significant concern about performance thus far. Long-term monitoring of the bridges constructed using increased durability HPC is being conducted to ensure that TxDOT is achieving more durable, longer lasting structures. TxDOT continues to test concrete for performance-related criteria that can eventually be correlated with actual field conditions of the bridges.

The use of fly ash, silica fume, and GGBFS in Texas is increasing, and bridge designers and contractors are seeing the benefits of using these materials. TxDOT is continuing to examine methods to specify the use of HPC. As contractors gain experience providing concrete that meets prescriptive specification requirements, TxDOT will move toward performance-based specifications.

REFERENCES

1. Ralls, M.L., “Texas HPC Bridge Decks”, ACI *Concrete International*, V. 21, No. 2, Farmington Hills, MI, 1996, pp. 63-65.
2. Ralls, M.L., R. L. Carrasquillo, and N. H. Burns, “Optimization of Structural Design for High Performance Concrete Bridges,” *Transportation Research Record*, No. 1624, 1998, pp. 132-139.
3. Goodspeed, C. H., Vanikar S., and Raymond, A. C., “High-Performance Concrete Defined for Highway Structures,” ACI *Concrete International*, Vol. 18, No. 2, Farmingtion Hills, MI, 1996, pp. 62-67.
4. Ralls, M.L., “Louetta Road Overpass-Lessons Learned”, *HPC Bridge Views*, Issue No. 1, www.portcement.org/br/newsletters.asp.
5. Lankes, G. D., Lukefahr, E. J., and Won, M., “The Texas Dot Specifications for Mitigating ASR,” *Center For Aggregates Research 9th Annual Symposium Proceedings,* April 22-25, 2001, Austin, Texas.
6. Texas Department of Transportation, *Standard Specifications for Construction of Highways, Streets, and Bridges*, 1993 edition.
7. Ozyildirim, C. “Permeability Specifications for High-Performance Concrete Decks,” TRR 1610, Concrete in Construction, TRB, National Research Council, Washington, DC, 1998, pp. 1-5.
8. ACI Committee 201, “Guide to Durable Concrete,” ACI 201.2R-01, *ACI Manual of Concrete Practice*, Part 1. American Concrete Institute, Detroit, 2001.
9. Obla, K. H., Hill, R. L., Thomas, D. A., Shashiprakash, S. G., and Perebatova, O., “Properties of Concrete Containing Ultra Fine Fly Ash,” ACI Materials Journal, Vol. 100, No. 5, Sept.-Oct. 2003.