DEVELOPMENT AND UTILIZATION OF FLOWING HIGH PERFORMANCE CONCRETE – A REVIEW OF INCORPORATING THIS TECHNOLOGY IN TWO FLORIDA PRECAST/PRESTRESSED BRIDGE PROJECT COMPONENTS

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ABSTRACT

Flowing Concrete (FC) is generally characterized by a slump greater than 7.5 inches that remains cohesive without excessive bleeding and segregation while maintaining normal setting characteristics and strength development. Unlike Self-Consolidating Concrete (SCC) FC employs conventional material proportioning and a minimized amount of consolidation by mechanical means. Since the year 2000, the Florida Department of Transportation (FDOT) has utilized high performance FC in the fabrication of precast/prestressed concrete beams for two bridge projects.

This paper presents an overview of lessons learned in implementing and applying FC. The results of the examinations and inspections of plastic and hardened FC properties indicate that FC provides the entire construction team with numerous advantages such as controlled rheology, much accelerated speed of placement, reduction in labor and equipment costs, optimized surface appearance, excellent engineering properties and overall structural integrity.

Keywords: Flowing Concrete, Cohesive, Non-segregating, High Slump, High Performance, Consolidation, Synthetic High Range Water Reducer, Slump Loss, Self-Consolidating Concrete.

INTRODUCTION

In use around the world since the mid 1980's, Flowing Concrete (FC) applications have been typically limited to very specialized commercial construction projects, where large volumes and fast-track production of high performance concrete were essential, and as such primarily applied in high-rise construction. The more recent rapid advancements in concrete admixture technology enticed Florida Department of Transportation (FDOT) in 1998 to further investigate the use of higher workability concrete and its suitability for precast/prestressed high-performance concrete production. A primary purpose of this investigation was to minimize honeycombing in the bearing areas of the beams with congested reinforcing steel and strands.

New generations of High Range Water Reducers (HRWR), a.k.a.-superplasticizers, introduced in the past two decades, and especially Synthetic High Range Water Reducers (SHRWR) introduced in the past five years, are capable of developing higher workability levels up to 11 inches of slump[1] for concrete that facilitates placement and consolidation around congested strands and other steel reinforcing areas. At the same time flowing high-performance concrete becomes less labor-dependent for optimum structural uniformity and concrete performance.

In this study the criteria for the use of the superplasticizing admixture in the fabrication of the precast/prestressed concrete was prepared. After an initial field demonstration, and a beam mock-up pour and subsequent satisfactory inspection thereof, FC laboratory and field mix verifications were performed on Class VI (8,500 psi) concrete designs for the fabrication of the beams of the Beaver Street project. This FC design was also used in the fabrication for precast/prestressed concrete U-beams of the SR 9-A project.

Beaver Street is the U.S. 90/ SR 10 project, which is located in Jacksonville, Florida. Bridgework for the Beaver Street project consisted of a viaduct bridge replacement over the SCL Railroad Bridge No. 7200004.

The second project consisted of the fabrication of Florida U-beams for the State Road 9A project, which is located from West of U.S. 1 to East of U.S. 1. The second part of the project is located at the SR 9A/I-295/I-95 interchange, also located in Jacksonville, Florida.

During this study the concrete mixing, delivery, placement and consolidation techniques are documented and the performances of FC, both in the plastic and hardened concrete states, were examined. The utilization of FC in the fabrication of bridge structures for these two experimental projects is a gradual approach to the use of SCC.

HISTORY

Flowing high-performance concrete, pioneering in the United States in the early 1980's as a ready-mix supplied cast-in-place concrete, became many contractors' preferred construction material of choice and since then has found multiple applications in fast-track and high-rise markets such as New York City, Philadelphia, Atlantic City, Houston and Dallas. In Florida, FC technology was instrumental in pioneering and perfecting 20% silica fume treated ultra-durable floors for the Solid Waste Authority (Delray Beach, 1993) and about a dozen additional such projects since then. Other examples of unique FC applications in Florida are a record residential mass pour of over 10,000 cubic yards which was placed in 22 hours for the Santa Maria project (Miami, 1995), an un-cooled 8,000 psi high-strength monolithic mass concrete foundation of 2000 cubic yards at the Portofino Tower (Miami Beach, 1995) and Florida's first major 12,000 psi concrete application for the Orange County Court House (Orlando, 1997), which yielded compressive strengths in excess of 15,000 psi.

Not to be confused with SCC which recently has generated much interest in the construction industry, FC does share many similarities but is distinct in that it employs conventional fine aggregate-to-total aggregate ratios (S/A) and the absence of viscosity-modifying additives. Consolidation, though much reduced, is still incorporated in the placement of FC, primarily to relieve entrapped air voids. At times, facilitated by a high fine materials ratio, FC performance does venture into SCC parameters as projects have in the past specified and utilized the "spread" or slump flow workability requirements (1991-Society Tower[2], Cleveland f'c = 14,000 psi). Furthermore, most recent (last five years) adaptation of the polycarboxilate chemistry to produce Synthetic High Range Water Reducers[3] (SHRWR), has in itself lowered the viscosity of high performance concrete incorporating such an admixture. By the addition of the SHRWR, the viscosity of high performance concrete can be lowered to such an extent that high-end FC and medium viscosity SCC merge into an indistinguishable "grey" area in the plastic state and provide very similar operational benefits. Such a self-leveling, high modulus of elasticity (6×10^6 psi) concrete was pumped for nearly 800 vertical feet and then flowed freely through extremely congested reinforcement steel at the recent Four Seasons project (Miami, 2001-2002). As all concrete ingredients, the SHRWR is plant-added and maintains a high level of workability due to thixotropy, has a neutral effect on setting times yet produces high early and ultimate strengths, and generally maximizes all engineering properties of high performance concrete.

INVESTIGATION

As in the ready-mix industry, the precast/prestressed industry is also employing more high performance concrete in more challenging structures with thinner sections, longer lengths, utilizing a higher degree of steel reinforcement complexity that ever increases the demand on professional concrete placement techniques to optimize concrete performance. FC adaptation to precast/prestressed concrete production generated significant interest with FDOT and was viewed as a complement to bridge component manufacturing technology[4] that could ultimately benefit not only the construction team but also the durability and longevity of the project in place.

DEMONSTRATION AND EXERIMENTAL TESTING (1998 - 1999)

The first demonstration of FC at Gate Concrete was observed during the placement of a Class V (Special), 6,000 psi concrete for experimental test piles on December 8, 1998. All concrete ingredients, including the SHRWR were added at the central-mix concrete plant and delivered to the placement site in three separate loads of non-agitating trucks (Tuckerbuilts). The purpose of this demonstration was to review the performance of FC and its use for the fabrication of FDOT precast/prestressed concrete piles and beams. The slump ranges observed were between 8.5 and 11.0 inches, varying with applied SHRWR dosage rates between 5 and 6 oz/cwt. The slump loss of FC treated with 5.5 oz/cwt of SHRWR was approximately 2 in/hr. Other plastic concrete parameters measured during this demonstration were an average air content of 4.5 %, unit weight of 141.4 pcf, concrete temperature at 82°F, and ambient temperatures around 80°F. As with any low water content mix design, finishability of concrete improved at the higher SHRWR dosage, i.e. higher workability spectrum. There was no visible segregation of the aggregates. During the concrete placement some grout leakage through the strand form holes was noticed. The uniformity of the field demonstration concrete during its plastic state was determined in accordance with ASTM C 94 by taking samples of concrete at different locations of the delivered batch or from in-place concrete and results of the tests met the uniformity test requirements of ASTM C 94. Two 4 x 8-in cylinders were cast to determine the rapid chloride permeability, resulting in 3414 and 3341 coulombs at the age of 28 days.

In a larger application, experimental testing was performed on a 10-ft prestressed concrete mock-up beam (Fig. 1). External form vibrations, approximately one minute per cubic yard, were used during concrete discharge and then hand-held vibrators were used to consolidate subsequent layers of concrete deposits, as needed. Upon completion of casting with FC (Fig. 2), it was saw-cut to determine the presence of any voids in the concrete, especially around the reinforcing steel and prestressing strands. The saw cut sections of the mock-up (Fig. 3) were observed for the aggregate distribution and core samples were taken from different locations of this experimental structure (Fig. 4). In order to determine the aggregate distribution in the hardened concrete, the principal author initiated the following test method:

A line was drawn along the surface of the core sample. The size of each piece of aggregate along the line, greater than or equal to 0.1 in [2 mm] was measured. The total length of the aggregates along the straight line was determined by adding the measured sizes of all pieces. The coarse aggregate (C.A.) content along the straight line was determined by calculating the ratio of the total length of aggregates along the line, to the length of the drawn line. The average C.A. ratio of at least 8 lines (4 measurements along the lengths and 4 measurements along the diameter) for each core samples was reported as the C.A. ratio of the core sample.

Fig. 1 Beam mock-up section

Fig. 2 Casting with flowing concrete

Fig. 3 Saw-cut cross section

Fig. 4 Some of the core locations

Figure 5 and Figure 6 show the measurements of aggregate sizes along the length and diameter of a core samples, respectively. Table 1 shows the C.A. measurement data of four core samples. All measurements are taken in millimeters (mm). The samples have been identified as ET-L1, EB-D1, WT-L1, etc. The following are sampling identifications:

1- Letters (E) and (W) show if the samples are taken from the East or West end of the mock-up beam, respectively.
2- The second letter shows if the core has been taken from top (T) or bottom (B) of the mock-up beam.
3- The letters (L) and (D) show if the measurements are taken along the length or diameter of the core sample, respectively.
4- The last number of the designation shows the serial number of the measurements along the length or diameter of each core sample.

For example, in a 6.9-in [175- mm] line (Serial No. ET-L1), the lengths of the aggregate pieces were 24, 2, 2, 13, 2, 14, 5, and 10, with a total length of 2.8 in [72 mm]. The C.A. content along this line would be:

$$\text{C. A.} = 72/175 \times 100 = 41\ \%$$

The results of the average of eight measurements, comprising of four measurements along the length and four measurements along the diameter, of each core sample are shown below:

C.A. Contents of End E: Top = 43 % Bottom = 51 %
C.A. Contents of End W: Top = 46 % Bottom = 47 %

Fig. 5 Coarse aggregate measurement along the length of the core sample

Fig. 6 Coarse aggregate measurement along the diameter of the core sample

The results of the measurements show that the C.A. content of the bottom part of End (E) of the mock-up beam had a higher amount of C.A. in comparison with the other locations. There is a difference of 8 % between the C.A. content of the top and bottom end of the mock-up beam. The average C.A. value of the cores was 47 %. The same average C.A. was obtained when calculating the values along the length or along the diameter. The standard deviations were 7.1% and 9.1% along the lengths and diameters of the cores, respectively. The overall standard deviation of all measurements was 8.0%.

The C. A. content of the concrete designed mix, based on its volume, was 42%. A review of the data indicates that the majority of the coarse aggregate distribution data of the hardened concrete for the mock-up, Class V[5] (Special) 6,000 psi concrete mix, were within close proximity of the actual C.A. content of the mix. There is a maximum difference of about 5 % between the average test results of the experimental C.A. content of all four production core samples and C.A. content of the designed mix. The difference might be due to the counting of aggregate size, which was 0.1 in [2 mm] or greater in lieu of No. 4 sieve size [4.75 mm].

Due to limited data, the aggregate distribution of hardened concrete method of this pilot test is considered to be a preliminary experiment. More tests and research work are needed to augment the validity of this test for the purpose of the field estimate of the aggregate content and distribution of the concrete mixture.

Table 1 Coarse Aggregate Measurement Of Hardened Concrete Core Samples

Serial No.	Measurements of the sizes of the coarse aggregate along the drawn line (mm)	Total length of C.A (mm)	Length of the line (mm)	C.A. (%)	Average C.A. (%)	Stand. Dev. (%)
ET-L1	24,2,2,13,2,14,5,10	72	175	41		
ET-L2	5,10,7,5,5,5,7,7,7,3,10	71	177	40		
ET-L3	5,5,13,8,2,13,2,7,4,10	69	170	41		
ET-L4	9,8,10,4,5,3,3,5,7,4,4,7	64	166	39	40	0.1
ET-D1	2,3,7,13,7,	32	70	46		
ET-D2	6,7,2,3,3,7	28	68	41		
ET-D3	3,5,6,3,5,3,10	35	70	50		
ET-D4	8,3,7,3,7,4	32	70	46	46	3.7
EB-L1	10,2,9,2,3,4,8,2,13,7,8,4,11,6,2	91	188	48		
EB-L2	18,5,7,2,4,2,7,12,2,3,5,10,22,10,12	121	188	64		
EB-L3	5,3,7,4,8,4,10,12,2,4,2,5,2,2,4	74	185	40		
EB-L4	7,3,3,5,6,7,7,7,3,4,12,10,3,2,2,9	90	190	47	50	10.1
EB-D1	7,2,4,5,10,5,7	40	70	57		
EB-D2	3,4,5,4,2,2,9,3,2	34	70	49		
EB-D3	10,9,5,10,4,3	41	70	59		
EB-D4	3,5,8,5,8,8,2	31	70	44	52	7.0
WT-L1	13,10,9,2,2,5,3,2,2,7,3,2,7,7,4	78	162	48		
WT-L2	6,3,2,2,10,2,4,2,20,14,2,2,2,	71	163	43		
WT-L3	6,8,8,2,5,10,2,2,4,4,13,8,4	76	160	48		
WT-L4	7,5,8,8,2,10,15,2,3,6	66	160	42	45	3.2
WT-D1	2,2,18	22	70	31		
WT-D2	4,4,14,7	29	70	41		
WT-D3	4,8,5,8,8,4,8	45	70	64		
WT-D4	5,12,3,15,2	37	70	53	47	14.3
WB-L1	8,12,2,8,5,10,2,6,6,9,2,5	75	147	51		
WB-L2	7,6,6,7,2,2,4,8,6,2,2,2,5,6	65	148	44		
WB-L3	8,10,7,11,2,5,3,3,2,9,2,10	72	148	49		
WB-L4	10,9,5,5,7,5,2,12,5,10,2,2,3,12	89	148	60	51	6.7
WB-D1	2,9,4,2,7,2,4,2,2,3	37	68	54		
WB-D2	6,2,7,5,4,2,2,3	31	68	46		
WB-D3	2,5,2,2,2,2,3	18	58	31		
WB-D4	3,6,2,2,5,3,3	24	56	43	44	9.5

Average Coarse Aggregate Content (C.A.) = 47% Average Standard Deviation = 8%.

SPECIFICATION AMENDMENT (1999 - 2000):

During 1999, FDOT started preparing the specification and guidelines for the use of FC. Based the subsequent laboratory trial batches and field demonstrations of the mock-up piles and beams, the specification was modified to allow the use of FC on the FDOT experimental projects.

During 2000, the criteria of materials used in the manufacture of FC were set forth in a specification amendment to facilitate FC experimental project status. Table 2 is an excerpt of a Table from the FDOT 346[5] specification, which describes the classification, strength, air content, and target slump of the concrete, with and without HRWR admixtures.

FLOWING CONCRETE SPECIFICATION

The technical special provisions have been included as part of the contract documents of the two experimental projects to allow the use of FC in the fabrication of precast/prestressed concrete beams. The following are FC related excerpts of a few paragraphs from the Supplemental Technical Special Provisions of FDOT Portland Cement Concrete, Section 346[7] specification:

"346-2.5.3 High Range Water Reducing Admixtures":

346-2.5.3.1 General: Use High Range Water Reducing (HRWR) admixtures in concrete mixes incorporating silica fume or metakaolin. The Contractor is allowed to use Department approved AASHTO M 194 Type F or G admixtures in all classes of concrete, except for concrete used in drilled shafts.

346-2.5.3.2 Flowing Concrete Admixtures: The Contractor is allowed to propose the use of a previously approved High Range Water Reducer admixture, either, ASTM C 1017 Type I (plasticizing) or Type II (plasticizing and retarding) to produce a flowing concrete mix with target slump of 9.0 inches [230 mm]. The use of these types of admixtures is limited to the construction of precast prestressed concrete products. Add the flowing concrete admixtures at the ready-mixed concrete batch plant.

Submit the proposed flowing concrete mix design, containing Type I or II admixture, and test data as specified herein and in 346-6.2.

Subsequent to the laboratory trial batch, perform a field demonstration of the proposed mix by production and placement of at least three batches (3 yd^3 [2.3 m^3] minimum size each) of concrete containing flowing concrete HRWR admixture. Take representative samples from each batch and perform slump, air content, and temperature tests on these samples. Cast specimens from each sample for compressive strength tests. Record the ambient air temperature during the test. Ensure that the concrete properties are within the required specification limits.

Determine the slump loss of the demonstration concrete batches by performing the slump tests on the samples taken at 30-min intervals from each batch. Continue sampling and testing until the slump measures 6 in [254 mm] or less. From the plot of slump versus time, determine the time for each batch when the slump is at 7.5 in. [190 mm]. The shortest time period determined from three consecutive batches, at 7.5 in [190 mm] slump, is considered the cutoff time of the proposed concrete mix. For production concrete, ensure that the time between the batching to the depositing of each load of concrete shall be less than the cutoff time of the mix and also it shall not exceed the allowable time limit specified in 346- 7.6.

Ensure that the demonstration concrete is mixed, delivered, placed, consolidated, and cured in accordance with the proposed method and sequence. Ensure that the flowing concrete batches are produced at the slumps between 7.5 in – 10.5 in [190 mm – 265 mm].

Perform inspection of the demonstration concrete during batching, delivery, placement, and post placement. During placement, ensure that the concrete batches meet all plastic property requirements of the specifications and maintain their cohesive nature without excessive bleeding, segregation, or abnormal retardation.

Ensure that the compressive strength test results of the demonstration concrete meet the strength requirements of the specifications. After removal of the forms, perform the post-placement inspection of the in-place concrete. Observe for any signs of the honeycombs, cracks, aggregate segregation, or any other surface defects during post-placement inspections and ensure that the hardened concrete be free from these deficiencies. The Engineer may require the saw-cut of the mock-up products to observe the uniform distribution of the aggregates within the saw-cut surfaces and around the reinforcing steel and prestressing strands. The saw-cut of the demonstration mock-up products is a requirement for the plants that are demonstrating the use of the flowing concrete for the first time. Also, obtain core samples from different locations of mock-up products to inspect the aggregate distribution within the mock-up surfaces and perform rapid chloride permeability tests.

Submit the laboratory and field demonstration test data, inspection reports, and certification statement to the Engineer. In the certification, state that the results of the laboratory and field demonstration tests indicate that the proposed concrete mix design meets the requirements of the specifications. For the proposed mix design, state the anticipated maximum time limit between the batching and when the concrete of each batch shall be deposited during the production.

Upon the Engineer's review and verification of the specification compliance of the laboratory trial batch, field demonstration test data, inspection reports and contractor's certification statement, the proposed mix design will be approved."

Table 2 Specified Strength And Plastic Properties Of FDOT Concrete

STRUCTURAL CONCRETE			
Class of Concrete	Specified Minimum Strength (28 day) (psi) [(MPa)]	Target Slump (a) (inches) [(mm)]	Air Content Range (%)
IV	5,500 [38]	3 [75]	1 to 6
V (Special)	6,000 [41]	3 [75]	1 to 5
V	6,500 [45]	3 [75]	1 to 5
VI	8,500 [59]	3 [75]	to 5

(a) The Engineer may allow a maximum target slump of 7.0 inches [180 mm], when AASHTO M 194 Type F or G admixture is used. A target slump of 9.0 inches [230 mm] is allowed when ASTM C 1017 Type I or II admixture is used to produce flowing concrete in construction of precast prestressed concrete beams.

CONCRETE MIX DESIGN

Based on the laboratory trial batches and field demonstrations, necessary adjustments were made in the design of the two FDOT Class VI (8,500 psi) FC mixes. Both of the mixes were designed for hot weather conditions with 28-day strength of 10,000 psi. The FDOT 346 specification defines hot weather concreting as the production, placing, and curing of concrete when the concrete temperature at placing is between 85 to 100 degrees Fahrenheit. The specification required a minimum total cementitious materials content of 752 pounds with Type II cement, including 18 to 22 % Class "F" fly ash.

Gate Concrete designed two FC mixes with water-to-cementitious materials ratios of 0.28 and 0.25, total cementitious materials contents (incl. 20% class F fly ash) of 1,000 and 1,125 pounds respectively, local # 67 crushed limestone and silica sand with a coarse-to-total-aggregate ratio greater than 67.0 percent. The mixes contained a SHRWR that met the requirements of ASTM C 1017 Type I Plasticizing, as well as AASHTO M 194 Type D water reducing and retarding and AASHTO M 154 air entraining admixtures. The FDOT Class VI, 8500 psi mix design was design utilized in the fabrication of beams. The mix design ingredients are shown in Table 3. Figure 7 shows the average results obtained of the three 3-cubic yard batches of the pre-production field demonstration.

Table 3 FDOT Mix Design for FC Class VI 8,500 psi Concrete

Class VI - Flowing Concrete	1 cubic yard S.S.D.
Type II Cement	800 lbs
Class "F" Fly Ash	200 lbs
# 67 Crushed Limestone (Nom. Sizes 3/4"-3/8")	1650 lbs
Silica Sand	868 lbs
Water	280 lbs
Air Entraining Agent	2 ozs
Water Reducing Retarder	16 ozs
Synthetic High Range Water Reducer	52 ozs

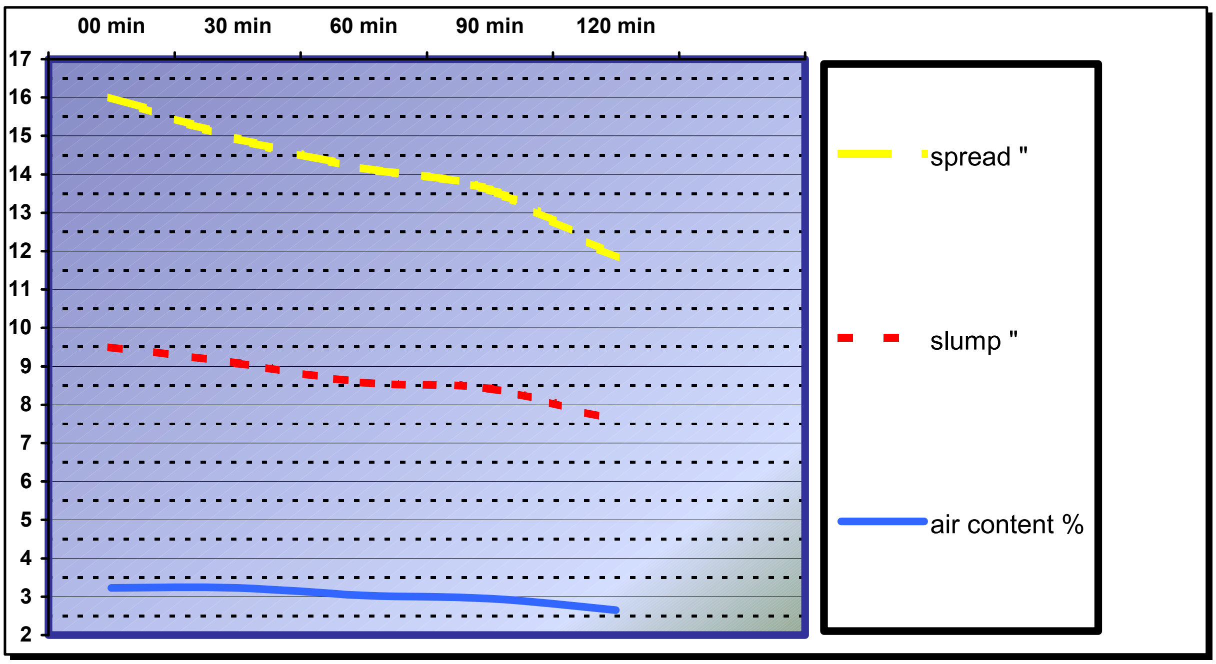

Fig. 7 Field verification examination, average of three 3 cubic yard batches sampled

FIRST APPLICATION (2000 - 2001) Beaver Street / US 1 overpass

The Beaver Street project (Fig. 8) is located at the State Road 10 with bridge number 720004. The 8500 psi Class VI[6] - FC mix was used to fabricate a total of 4120 linear feet (836 cu yards) of Type IV beams. The concrete mixes are designed for hot weather use of up to 100 degree Fahrenheit in accordance with FDOT Section 346 specification.

The 28-day compressive strength of the laboratory test data indicated compressive strength of over 10,000 psi. The maximum allowable lift thickness and the drop height[7] of the FC for these projects have been performed in accordance with the current specification, which is the same as the requirements of the conventional mixes.

The report of this project shows that fifty beams were cast without any sign of honeycombs (Fig. 9). The time for the consolidation of the concrete, by mechanical means, was reduced to almost half of the time used for the consolidation of the conventional of HRWR concrete. Five percent of the delivered concrete was rejected, exceeding the specified slump parameters. Three batches were rejected due to slump less than 7.5 inches and five batches due to slump greater than 10.5 inches. This rejection rate may be normal for a class of concrete with new admixtures that is attempted for the first time. Workability of the concrete mix has been considered to be good.

Fig. 8 The Beaver Street project site

Fig. 9 Beam produced with FC

Table 4 shows a compilation of plastic and hardened FC test results of the FDOT inspections during fabrication of the beams for the Beaver Street project.

SECOND APPLICATION (2002 - 2003) SR 9A/I-295/I-95 Interchange U-beams:

This project is located at Interstate 95 and 295 (9A) interchange. The 8500 psi Class VI[8] -FC mix was used to fabricate 54-in and 63-in Florida U-beams. In a total of 2416 linear feet (1088 cu yards) of 63-in U beams and 4,480 linear feet (1449 cu yards) of 54-in U beams, FC was used to cast these products. Table 5 shows the FDOT compilation of quality assurance test data of plastic and hardened properties of routine during fabrication of 63-in and 54-in U-beams.

Table 4 Compilation Of FDOT Quality Assurance Test Data For Fabrication Of Class VI 8,500 psi FC Beams For The Beaver Street – U.S.90/SR10 Project

Serial #	Date Cast	Concrete Temp (°F)	Slump (in.)	Slump Flow (in.)	(%) Air Content	28-Day Comp. Strength (psi)
BS 1- 5	12- 15- 00	81	9.00	---	5.0	
		84	10.00		2.2	11,050
		90	10.00		2.2	10,220
BS 6-10	12- 26- 00	70	9.25	---	1.7	
		70	9.25		1.2	11,280
		70	9.50		1.7	11,050
BS 11-14	1- 4- 01	64	9.25		3.7	
		64	10.25	17.25	2.0	11,400
BS 15-20	1- 11- 01	72	11.00	28.75		
		73	8.50	13.75	2.7	
		73	9.75	23.00	2.8	11,060
			9.25		3.2	11,010
BS 21-25	1- 18- 01	81	9.00	13.00	2.8	
		82	9.00	15.00	2.4	10,940
		84	7.50		2.4	11,040
BS 26-30	1- 26- 01	72	10.50	27.50	1.2	
		73	9.25	18.50	1.4	10,480
		73	10.00	24.00	1.2	10,680
BS 31-35	2- 3- 01	70	10.50		1.4	11,910
		72	10.50		2.0	10,500
		73	9.75	22.00	2.2	
BS 36-40	2- 8- 01	79	10.25	22.00	3.7	11,580
		81	10.25	25.00	2.2	11,860
		82	9.50	15.00	1.7	
BS 41-45	2- 16- 01	82	10.50	26.50	2.1	
		82	9.50	16.50	2.3	10,640
		84	8.50	12.00	2.2	10,690
BS 46-48	2- 23- 01	79	10.00		2.7	
		79	10.25		2.7	10,890
		79	8.00	23.00	2.2	12,040
BS 49-50	3- 2- 01	82	10.50	23.00	1.8	
		84	8.75	12.00	2.2	11,280

I-295 U-BEAMS/ EXPERIENCE:

The utilization of the FC is currently ongoing (Fig.10-14) in the fabrication of the U-beams for a whole year at Gate's Jacksonville, FL plant. This large application of about 3,000 cubic yards of FC (I- 295 and Palm Beach County projects) was a new venture for this producer into the never before attempted production of U-Beams. Known to be complex in properly

Table 5 Compilation Of FDOT Quality Assurance Test Data For Fabrication Of Class VI 8,500 psi FC Beams For The SR 9A – I-95 – I-295 Projects.

Serial #	Beam Size	Date Cast	Concrete Temp (°F)	Slump (in.)	(%) Air Content	28-day Comp. Strength (psi)
UB – 001	63 ″	4 - 22 - 02	95	10.50	1.9	11,040
UB – 002	63 ″	4 - 22 - 02	90	10.50	1.9	11,060
UB – 003	63 ″	5 - 3 - 02	95	10.50	1.4	11,000
UB – 004	63 ″	5 - 3 - 02	95	10.25	1.5	11,175
UB – 005	63 ″	5 - 17 - 02	82	10.50	0.3	10,680
UB – 006	63 ″	5 - 17 - 02	88	10.50	2.4	11,890
UB – 007	63 ″	5 - 17 - 02	92	10.50	1.0	11,620
UB – 008	63 ″	5 - 17 - 02	94	8.50	2.8	10,580
UB – 009	63 ″	5 - 30 - 02	90	9.50	3.6	9,440
UB – 010	63 ″	5 - 30 - 02	93	9.50	3.2	10,230
UB – 011	63 ″	5 - 30 - 02	92	10.00	3.3	9,440
UB – 012	63 ″	6 - 8 - 02	92	9.50	4.2	10,190
UB – 013	63 ″	6 - 8 - 02	94	9.50	4.2	10,990
UB – 014	63 ″	6 - 8 - 02	95	8.00	4.8	10,440
UB – 015	63 ″	6 - 14 - 02	95	10.25	3.8	10,670
UB – 016	63 ″	6 - 14 - 02	95	9.25	3.7	9,760
UB – 017	63 ″	6 - 14 - 02	95	8.75	7.2	10,180
UB – 018	63 ″	6 - 14 - 02	92	9.00	4.4	10,790
UB – 019	63 ″	6 - 25 - 02	89	8.75	2.3	10,720
UB – 020	63 ″	6 - 25 - 02	92	9.25	2.0	10,810
UB – 021	63 ″	6 - 25 - 02	91	9.00	2.3	10,850
UB – 022	63 ″	7 - 5 - 02	95	8.75	2.2	10,060
UB – 023	63 ″	7 - 5 - 02	94	9.75	1.2	10,670
UB – 024	63 ″	7 - 5 - 02	94	10.50	1.5	10,750
UB – 025	54 ″	12-14-02	69	8.50	1.6	10,130
UB – 026	54 ″	12-14 – 02	67	10.00	1.2	10,660
UB – 027	54″	12-20-02	80	9.50	3.0	9,510
UB – 028	54 ″	12-20-02	72	10.00	3.0	10,300
UB – 029	54 ″	12 -20-02	73	10.25	2.0	9,860
UB – 030	54 ″	1-3 - 03	74	10.00	2.0	11,170
UB – 031	54 ″	1-3 - 03	72	9.00	2.0	10,820
UB – 032	54 ″	1-16- 03	78	10.50	3.4	11,130

Table 5 is continued on the next page

Table 5 (continued) Compilation Of FDOT Quality Assurance Test Data For Fabrication Of Class VI 8,500 psi FC Beams For The SR 9A – I-95 – I-295 Projects.

Serial #	Beam Size	Date Cast	Concrete Temp (°F)	Slump (in.)	(%) Air Content	28 day (psi)
UB – 033	54″	1-16 - 03	80	9.50	3.7	10,980
UB – 034	54″	1-16 - 03	81	10.00	3.4	10,220
UB – 035	54″	1-17- 03	68	9.50	4.0	10,060
UB – 036	54″	1-17- 03	69	8.50	2.7	9,180
UB – 037	54″	1-17- 03	71	9.50	4.2	11,030
UB – 038	54″	1-28- 03	62	10.00	2.2	11,030
UB – 039	54″	1 - 28 –03	67	10.00	1.2	10,180
UB – 040	54″	1 –28 –03	69	10.00	4.2	10,390
UB – 041	54″	2 -5 – 03	73	10.00	1.6	11,550
UB – 042	54″	2 - 5 –03	75	10.50	1.7	11,870
UB – 043	54″	2–5–03	76	10.00	1.8	11,520
UB – 044	54″	2-14 – 03	70	9.50	2.9	11,510
UB – 045	54″	2 -14 – 03	73	9.50	2.2	10,550
UB – 046	54″	2 -14 – 03	72	10.00	2.2	10,290
UB – 047	54″	2- 20– 03	83	9.75	2.0	10,000
UB – 048	54″	3 - 21 –03	84	9.50	1.2	10,560
UB – 049	54″	2 – 27-03	83	8.75	2.2	10,470
UB – 050	54″	2 - 28 – 03	78	9.75	4.5	9,760
UB – 051	54″	3 - 8 – 03	77	10.00	2.8	9,890
UB – 052	54″	3 - 8 – 03	76	10.50	2.6	9,880
UB – 053	54″	3 - 14- 03	88	9.00	1.7	9,950
UB – 054	54″	3 –14-03	91	9.50	2.0	10,890
UB – 055	54″	3 – 14- 03	85	8.50	1.2	10,040
UB – 056	54″	3 - 21- 03	89	9.25	3.7	9,790
UB – 057	54″	3 - 21- 03	93	10.00	2.3	9,620
UB – 058	54″	3 - 28- 03	90	10.00	3.8	10,070
UB – 059	54″	3 - 28- 03	83	9.50	4.6	10,190
UB – 060	54″	3 - 28- 03	87	9.50	5.0	10,050
UB – 061	54″	3 - 29 – 03	89	9.00	4.2	10,140

placing concrete and obtaining acceptable uniformity consolidation and surface appearance, it proved to be an excellent application for FC. The conventional form release agents were used prior to the placement of concrete. The internal and external vibrations were used in the consolidation of concrete to eliminate maximum entrapped air, consolidate subsequent layers and primarily the U-Beam undersides which are completely inaccessible. The external vibration was continuously used during the discharge of concrete. Finished structures appeared free from defects (Fig. 12) and uniformity of consolidation seemed exceptional

(Fig. 13). Though no conventional concrete placement comparison in this specific application exists with this precaster, in accordance with Gate Concrete, the use Class VI, 8500 psi FC utilized in these up to 155 feet long U-Beams showed the following benefits:

1.) Much increased speed of placement, only limited by the rate of concrete production capability.

2.) Approximately 30 % decreased labor measured in total man-hours to place a line of these U-beams.

3.) About 60-80% reduction in consolidation efforts, both by internal and external mechanical vibration.

4.) Near perfect surface finish on all surfaces of the structure, greatly reducing or eliminating the need for post-placement touch-up (rubbing).

5.) Much reduced wear and tear on the formwork, facilitating re-setting for faster re-cycling as well as increased longevity of the formwork continuously providing good surface finishes.

6.) Optimizing concrete and material performance to a higher degree of uniformity throughout the project.

Gate Concrete has considered the above comparison and benefits based on measurements of the quantity of concrete placed in a given period of time (as much as 80 cubic yards per hour for U-Beams), as compared to other classes of FDOT concrete placement for miscellaneous applications, often down to 30 cubic yards per hour. Also, the fabrication of U-Beams with the class of concrete, used for the fabrication of U-Beams, are more complex and labor intensive compared to fabrication of the other prestressed concrete beams.

Fig. 10 Formwork for U-beam

Fig. 11 FC placement

Fig. 12 U-Beams for the SR 9A – I-95 – I-295 projects, inside and outside surface finish

Fig. 13 Exposed header of U-beam shows the uniformity of aggregate distribution

Fig 14 Florida U-Beam at Storage

SUMMARY / LESSONS LEARNED

The use of the FC concrete in the fabrication of beams of two FDOT projects indicated that both the producer and FDOT personnel were satisfied. The use of the FC concrete minimized the incidents of the honeycombs in the bearing areas of the beams.

The 9-in target slump FC was utilized in the fabrication beams of the FDOT projects. A few slump flow tests were also performed. At higher slump content, the slump flow was about 2 times the value of the conventional slump. For low slump concrete, this factor decreases. Due to limited test data a correlation between slump and slump flow was not established.

Flowing Concrete can be proportioned at high slump to be capable of attaining a level surface with little consolidation effort. FC placement may require consolidation of about 20-40 percent of a 2 to 4-in slump concrete. Improper vibration of concrete during its placement may result in localized excessive fluidity and segregation. The ambient temperature condition can affect FC workability retention and adjustment in supplemental set-controlling admixture may be necessary to achieve desirable results.

The initial strength development of FC is similar to conventional concrete. During the casting of the first few beams, honeycombing was observed on the surfaces of the beams. Fine tuning of SHRWR dosages employed and finishing and consolidation techniques resulted in satisfactory finished products. The decrease in the water-to-cementitious materials ratio in combination with lowest possible cementitious content of mix design will minimize the shrinkage cracking potential of the concrete.

Under influence of consolidation by mechanical means, the FC can leak through even small openings in form joints. It is important that form joints be nearly watertight and can withstand full hydraulic head. Over-vibration may cause leakage and segregation of concrete.

The concrete temperatures in Florida are generally above eighties, and during summertime well into the nineties. The change in the ambient/concrete temperatures requires change in the dosage rate of SHRWR or FC's resulting workability level may alter the entrained air content of the concrete. Very minor dosage adjustments in typically accompanying retarding admixtures can stabilize the loss of workability, which then in turn also stabilize air entrainment properties.

CONCLUSIONS

The results of the testing and inspection of the use of FC indicate that it can be specified for the fabrication of precast/prestressed concrete piles and beams of bridge structures. The use of a well-designed FC requires satisfactory demonstrations of laboratory and field trial batches prior to its utilization for the fabrication of precast/prestressed concrete structures. Admixture manufacturers should advise the concrete producers about the appropriate dosage rate of the SHRWR. The laboratory verification and field demonstration of the designed mixture shall ensure that the mixing, delivery, placement and consolidation of the production FC will achieve homogeneous concrete of the desired performance. A mock-up pour is recommended, and if feasible a saw-cut of the mock-up structure should be performed to ensure of the uniform aggregate distribution and absence of any unusual voids, especially around the prestressing strands and other reinforcing steel.

FC's fast placement properties accommodate much faster concrete production rates; to the extent that placement can outpace production capability. In such an event it is possible that already poured exposed concrete surfaces may "dry-out", sitting in, at times very hot, formwork. When subsequent layers of newly produced FC arrive, it is important that proper consolidation techniques address the entire flow distance of this newly placed concrete layer in order to avoid unsightly pour lines. The FC mix should be designed for the weather condition that concrete would be placed in. The laboratory and field demonstrations should simulate the expected weather condition during the concrete mixing, delivery, placement and curing process.

The forms should be tight to prevent any leakage of water or mortar through form joints or strand form-holes. It is important that formwork is stable and able to withstand the pressure of the rapidly placed flowing concrete. Also, special effort is required to avoid water or mortar leakage at the form joints and fittings. Primarily due to excessive consolidation efforts, it is possible that the structure exhibits aggregate segregation, bleeding, vertical sand streaking or even concrete shrinkage. Over-vibrating FC can result in poor aggregate distribution and vertical sand streaks adjacent to the vibrator penetration points. At deep structure placement, inspections should be made for any sign of the concrete settlement at all horizontal elevations.

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Gate Concrete furnished concrete materials, forms, equipment and quality control testing which made the utilization of FC in the fabrication of FDOT precast/prestressed concrete beams a success.

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