Louisiana Transportation Research Center

Final Report 569

Evaluation of Portland Cement Concrete with Internal Curing Capabilities

by

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16. Abstract
Proper curing is a key to durable and sustainable concrete structures. When a concrete mixture is designed, delivered, poured, and consolidated, curing is the last and the most critical part for a quality final product. Insufficient curing of concrete will cause cracking in the concrete and in turn leads to a non-durable and non-sustainable concrete structure.

The centrifuge test method for determining aggregate free moisture is superior to the paper towel test method in terms of expediency and repeatability of results. The laboratory results showed that the fresh concrete properties are unaffected by the use of lightweight fine aggregate for internal curing purposes. The compressive strength and modulus of elasticity results were determined to be the same or slightly higher when using lightweight fine aggregate for internal curing purposes. Flexural strength of concrete containing large amounts of lightweight fine aggregate was shown to be reduced slightly compared to the control. The surface resistivity values of the internally cured concrete (ICC) were shown to increase indicating better hydration of the concrete mixture.

Field trial placements showed that the ICC performs well. The West Congress project showed reduced cracking at one year over the control sections and the Ada project showed significantly less cracking over the control about nine months after placement of the ICC sections. The section placed without curing compound has yet to crack for the 150 pcy ICC mixture placement, and this is the worst case scenario. The reduced cracking will lead to longer service life and a more durable structure. In both cases, the contractor noted easier finishability characteristics and that, "ICC is just like normal concrete." Based upon the laboratory and field results, a standard lightweight fine aggregate replacement rate between 225 and 275 pcy is suggested for implementation.

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ABSTRACT

Proper curing is a key to durable and sustainable concrete structures. When a concrete mixture is designed, delivered, poured, and consolidated, curing is the last and the most critical part for a quality final product. Insufficient curing of concrete will cause cracking in the concrete and in turn leads to a non-durable and non-sustainable concrete structure.

The centrifuge test method for determining aggregate free moisture is superior to the paper towel test method in terms of expediency and repeatability of results. The laboratory results showed that the fresh concrete properties are unaffected by the use of lightweight fine aggregate for internal curing purposes. The compressive strength and modulus of elasticity results were determined to be the same or slightly higher when using lightweight fine aggregate for internal curing purposes. Flexural strength of concrete containing large amounts of lightweight fine aggregate was shown to be reduced slightly compared to the control. The surface resistivity values of the internally cured concrete (ICC) were shown to increase indicating better hydration of the concrete mixture.

Field trial placements showed that the ICC performs well. The West Congress project showed reduced cracking at one year over the control sections and the Ada project showed significantly less cracking over the control about nine months after placement of the ICC sections. The section placed without curing compound has yet to crack for the 150 pcy ICC mixture placement, and this is the worst case scenario. The reduced cracking will lead to longer service life and a more durable structure. In both cases, the contractor noted easier finishability characteristics and that, “ICC is just like normal concrete.” Based upon the laboratory and field results, a standard lightweight fine aggregate replacement rate between 225 and 275 pcy is suggested for implementation.

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IMPLEMENTATION STATEMENT

The results show that lightweight aggregate fines, when used for internal curing purposes, do not adversely affect the fresh or hardened concrete properties. Hardened properties of strength and surface resistivity are generally improved. The cracking potential has been shown to be reduced through the two document field applications, even where curing compound was inadvertently not applied. A standard replacement rate between 225 and 275 pcy of lightweight fines is suggested. Combining internal curing with a 7-day wet burlap cure is suggested. Implementation of internal curing technology will provide a benefit to the Department in terms of longer service-life structures with a lower life-cycle cost.

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INTRODUCTION

Proper curing is a key to durable and sustainable concrete structures. When a concrete mixture is designed, delivered, poured, and consolidated, curing is the last and the most critical part for a quality final product. Insufficient curing of concrete will cause cracking in the concrete and in turn leads to a non-durable and non-sustainable concrete structure. Current Louisiana specification requires all concrete decks to be water cured for 10 days. Based on the field experience, this is a very expensive operation and the most difficult one to enforce and monitor. Therefore, there is a great need to develop a new concrete mix that has the self-curing capability, which will reduce the time demand for water curing, minimize or eliminate cracks in the concrete deck, and help achieve durability and sustainability in concrete structures.

Literature Review

This section will detail past research work completed in Internally Cured Concrete (ICC) and the current state-of-the-practice. Case studies in the U.S. are also presented.

ICC is a concrete mixture that utilizes pre-wetted lightweight aggregates, pre-wetted crushed returned concrete fines, superabsorbent polymers, and pre-wetted wood fibers to aid in the hydration process. The only method studied in this report is a partial replacement using lightweight aggregate as it is the primary used method in the U.S. Replacement of normal weight aggregate with lightweight aggregate has been shown to extend hydration resulting in more evenly cured concrete. With extended hydration and a more even cure, cracking can be reduced significantly while increasing strength. Several states and private entities have implemented the use of ICC for applications including precast structural members, bridge decks, and mass concrete.

State-of-the-practice

A state of the art review was published in February 2011 by the National Institute of Standards and Technology. The report provides an excellent overview addressing the history and theory and then summarizes all existing published guidance on implementing internal curing in practice and its influence on the performance properties of concrete. The authors then proceed to discuss sustainability and provide an extensive bibliography of published resources. The main limitation of the report is that it primarily discusses prewetted lightweight fines as many of the other internal curing agents such as crushed returned concrete fines, superabsorbent polymers and pre-wetted wood fibers are in their infancy. The report states that internal curing has the potential to make a substantial impact on the durability and life-cycle costs of concrete structures. The report states that projects in New York and Indiana saw a 0 to 20 percent concrete cost increase, with a typical cost increase estimated to be in the 10-12 percent range compared with concretes typically used in these applications. This increased cost is offset by the reduced risk of cracking, reduced chloride ingress, and a more durable structure that has longer life and lower life-cycle costs. Another benefit is reduced disruption to the traveling public [*1*].

Case Studies

In January of 2005, one the largest to date ICC projects took place in Hutchins, TX. More than 250,000 yd^3 of ICC were placed for the Union Pacific Dallas Intermodal Terminal. Villarreal and Crocker reported in 2007 that 7-day flexural strengths were in the range of 90 to 100% of the required 28-day strength [*2*]. The project was surveyed almost 8 years later and showed excellent performance even with very heavy truck traffic [*3*]. The report states it was the largest known ICC project in the world at the time of publishing, the equivalent of 150 lane miles of ICC pavement. The survey showed virtually no shrinkage or plastic shrinkage cracks, spalls, or transverse and longitudinal cracks.

Rao and Darter provide several other examples of ICC being used in and around the Dallas area. These included two residential neighborhoods that were built in 2005 and, being surveyed in 2013, showed almost no shrinkage cracking or slab curling. Along with surveying the durability of in place ICC pavements, Rao and Darter analyzed the in place designs versus that of a conventional concrete design, showing that ICC pavements provide improved structural performance over their life span [*3*].

A publication in Concrete International outlined several field cases throughout Texas, including the use of more than 300,000 yd^3 of ICC pavement in the Fort Worth area. The average compressive strength was increased and cracking was minimal [*2*].

Denver Water successfully constructed a 10-million gallon water tank produced entirely of internally cured concrete. Strengths increased for the internally cured concrete mixture compared to control laboratory mixtures. Floors, walls, columns, and the roof were placed with concrete containing saturated lightweight fines as the internal curing agent. The Denver Water group was so pleased with the lack of cracking in their first internally cured water tank, they have since moved forward with several other construction projects specifying the use of internally cured concrete [*4*].

In an effort to show the benefit of internal curing, Purdue University documented the construction of nearly identical bridge decks, one with internal curing and one without internal curing. Their results showed improved strength and permeability characteristics. Their results also showed a significantly reduced cracking potential for the internally cured concrete bridge deck [*5*].

OBJECTIVE

The objective of this research was to investigate internally cured concrete produced for bridge structures in Louisiana's environment to improve the quality of concrete structures. This research investigated the use of differing percentages of lightweight aggregate for internal curing benefits as well as additional methods for determining available moisture on saturated lightweight aggregates.

SCOPE

To meet the objectives of this project, samples were produced in laboratory conditions at two water-to-cement (w/c) ratios and then tested. Fresh properties of slump, air content, and set time were measured for each mixture. Hardened concrete properties of compressive and flexural strength, modulus of elasticity, ring shrinkage, and surface resistivity were measured for each mixture. Samples were produced and cured in 50 percent relative humidity and 100 percent relative humidity conditions. Compressive strength was measured at 7- and 28-days of age. Flexural strength, surface resistivity and modulus of elasticity were measured at 28-days of age. Two field trial placements for bridge deck concrete were also conducted, one in North Louisiana on U.S. 80 near Ada and the other in Western Lafayette Parish on West Congress Street.

To meet the objective of alternative ways of measuring lightweight aggregate surface moisture, the research team conducted a series of paper towel tests, oven tests, and centrifuge tests.

METHODOLOGY

This section is divided into the materials and test methods used for the project. It also details the locations and results of the field trials.

Materials

The cementitious material used in the laboratory portion of the study was type I/II portland cement from Festus, MO. Mixtures incorporated No. 67 limestone and a natural sand as the coarse and fine aggregate, respectively. The coarse to fine aggregate ratio was kept near 60:40. These mixtures incorporated 600 lb. of total cementitious materials content with water to cementitious material (w/cm) targeted at 0.35 and 0.45. A polycarboxylate superplasticizer was incorporated to ensure workability of the mixtures and a minimum dose of a lignin based air entraining agent was used as required by DOTD specifications. A locally available lightweight expanded clay material was used for the saturated fines and was incorporated at 5, 10, 15, 20, and 25 percent replacement of the fine aggregate, by volume. Table 1 shows the mixture proportions for the laboratory study.

Table 1
Laboratory test matrix mixtures

LTRC Lab #	Description	#67 Limestone (lb.)	Sand (lb.)	Expanded Clay (lb.)	Type I/II Cement (lb.)	w/cm
C-4061	0.45 control	1935	1255	–	600	0.45
C-4062	0.45 5% LW	1935	1091	95	600	0.45
C-4124	0.45 10% LW	1939	934	186	600	0.45
C-4125	0.45 15% LW	1957	760	278	600	0.45
C-4126	0.45 20% LW	1915	644	371	600	0.45
C-4127	0.45 25% LW	1935	470	463	600	0.45
C-4128	0.35 Control	2004	1343	–	600	0.35
C-4129	0.35 5% LW	2032	1152	97	600	0.35
C-4130	0.35 10% LW	2022	991	195	600	0.35
C-4131	0.35 15% LW	2031	819	291	600	0.35
C-4133	0.35 20% LW	2035	657	385	600	0.35
C-4134	0.35 25% LW	2018	504	485	600	0.35

Test Methods

This section will detail the test methods used in characterizing the concrete properties. The section is divided into the fresh concrete properties and hardened concrete properties.

Fresh Concrete Property Test Methods

The following test methods were used in characterization of the fresh concrete properties of internally cured concrete.

- ASTM C138 [Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete] [*6*]
- ASTM C231 [Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method] [*7*]
- ASTM C403 [Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance] [*8*]

Hardened Concrete Property Test Methods

The following test methods were used in characterization of the hardened concrete properties of internally cured concrete. Note that samples were tested in triplicate and stored in both 50 and 100 percent relative humidity environments until the age of testing.

- ASTM C39 [Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens] [*9*]
- ASTM C78 [Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)] [*10*]
- ASTM C469 [Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression] [*11*]
- ASTM C1581 [Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage] [*12*]
- DOTD TR 233 [Test Method for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration] [*13*]

Other Test Methods

- ASTM C1761 [Standard Specification for Lightweight Aggregate for Internal Curing of Concrete [*14*]
- ASTM C566 [Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying [*15*]

Miller et al. proposed the centrifuge test method as a test method that utilizes a centrifuge to spin the excess surface water off of saturated lightweight fines while retaining the water for internal curing in the pores [*16*]. Specifics of the test method are given in Miller et al. [*16*]. Essentially a 600-gram sample of saturated fines is placed in the centrifuge for a period of 3 minutes at 2000 rpm and the mass loss is recorded. A series of equations are then used to determine the absorbed water versus the free water for mixing purposes. The proposed test method and equations can be found in the paper by Miller et al. [*16*].

West Congress Street Bridge Field Trial

The West Congress Street Bridge project is located on the parish line between Lafayette and Acadia parishes on West Congress Street. The location of the project is shown in Figure 1. The structure is a 13-in. thick slab span structure that consists of one 25-ft. center span and two adjacent 20-ft. spans one each side with a 10-ft. approach slab on each end of the structure. For this trial placement, each end slab placement was constructed using ICC as shown in Figure 2. Additionally, the east bridge approach section and the south railing were constructed using an ICC mixture.

The mixture proportions for this project included 519 pcy type I cement, 92 pcy class C fly ash, 847 pcy natural sand, 1711 pcy #57 river gravel, and 285 pcy of saturated lightweight expanded clay fines. Water reducing and air entraining admixtures were used to ensure the air content and slump values were in the acceptable range. All total, about 100 cubic yards of ICC were used in the construction of this project.

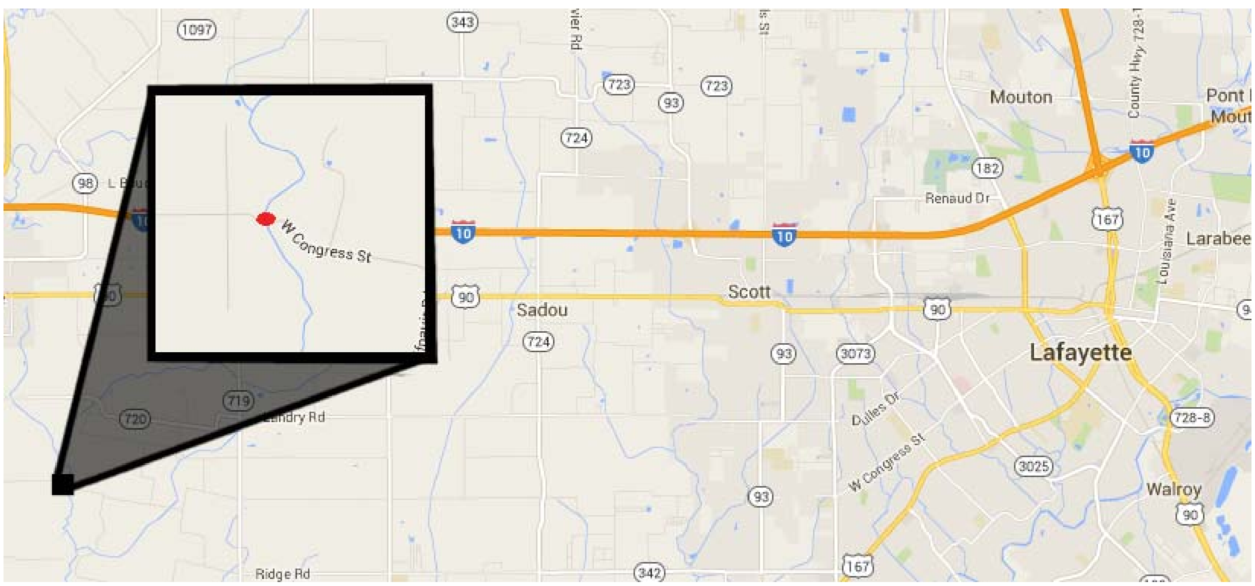

Figure 1
Location of West Congress Bridge, crossing Indian Bayou

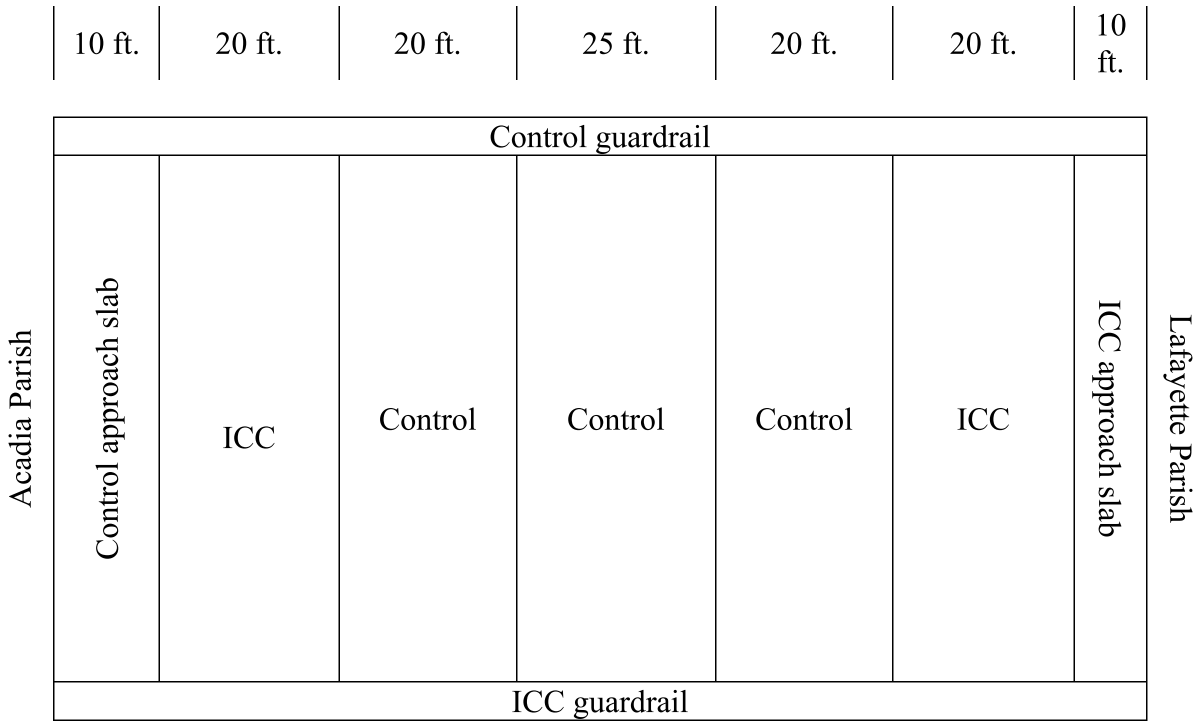

Figure 2
Bridge span layout for the West Congress project

U.S. 80 KCS Railroad Crossing near Ada, LA Field Trial

The U.S. 80 KCS Railroad crossing project is located in Bienville Parish just east of Ada, LA as shown in Figure 3. This project incorporated two different ICC mixture designs in the deck slab construction, the first containing 150 pcy of lightweight fines and the other containing 300 pcy of lightweight fines. Each placement is about an 8-in. thick section that is about 50-ft. wide and 270-ft. in length and comprises about 350 cubic yards of ICC. The mixture proportions for each ICC mixture and the control mixture are shown in Table 2. Water reducing and air entraining admixtures were incorporated to ensure adequate air content (2-7 percent) and slump (4-8 in.).

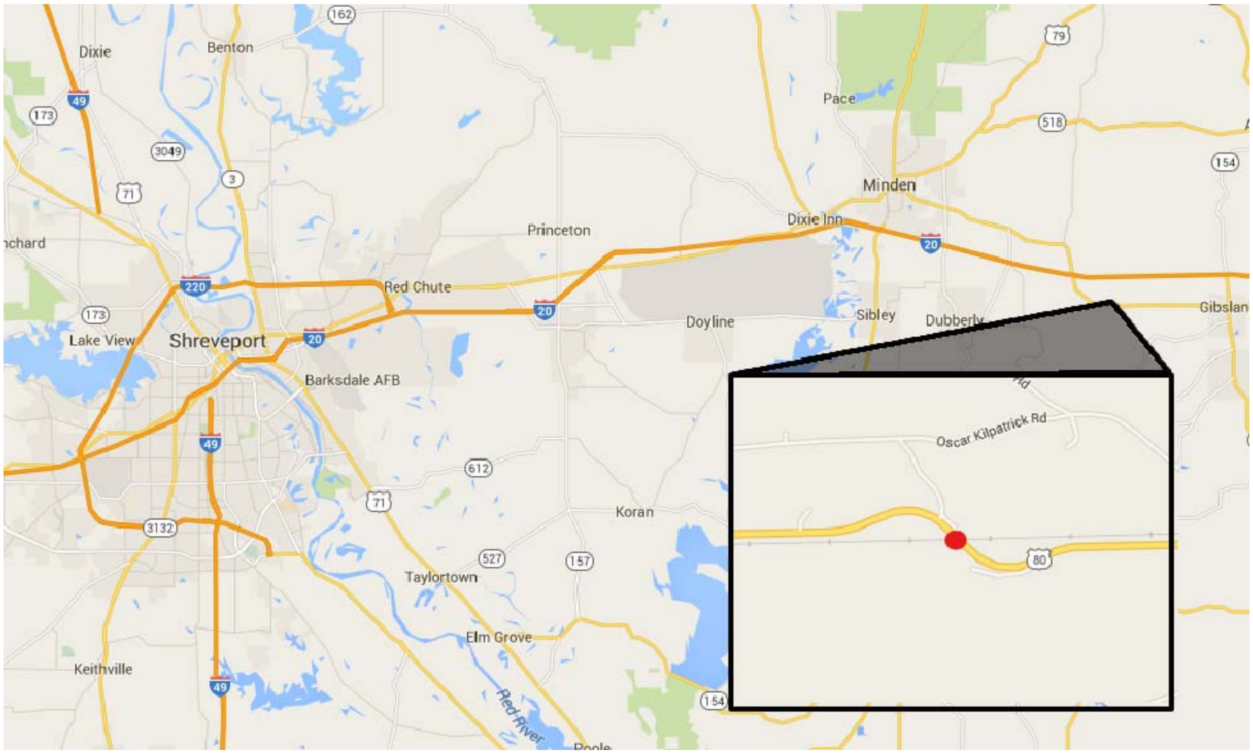

Figure 3
U.S. 80 KCS railroad crossing location

Table 2
U.S. 80 KCS railroad project mixtures

Description	#57 Gravel (lb.)	Sand (lb.)	Expanded Clay (lb.)	Type I/II Cement (lb.)	Class F Fly Ash (lb.)	w/cm
Control	1750	1113	–	553	98	0.44
150 PCY ICC	1748	870	150	553	98	0.44
300 PCY ICC	1550	810	300	553	98	0.44

DISCUSSION OF RESULTS

This section is divided into the laboratory fresh and hardened property results and the field results.

Aggregate Moisture Content

The research team conducted side-by-side comparisons for determining surface moisture using ASTM C1761 and quickly determined that the results were widely variable. In some instances the three results differed by as much as 4 percent [*14*]. The test method is vague when detailing the paper towel to be used in drying. No reference is made to absorptive capacity of the paper towel or the force to be applied to the aggregate with the paper towel. Differences in towels and force applied can lead to widely varying results as the team discovered. These results are reported by Miller et al. as well [*16*].

The team then turned to the centrifuge test method proposed by Miller et al. to determine viability and consistency [*16*]. After using the proposed test method, the team quickly determined that the results are more repeatable, representative, and remove the human factor that can lead to error. Once the team determined the results were acceptable for concrete batching purposes in the laboratory, it was determined that the proposed centrifuge test method would be used for the field trial batching purposes.

Fresh Concrete Properties

Table 3 shows the fresh concrete properties of slump, air content, unit weight, and initial and final set time for each mixture. The results are as expected for these mixtures, especially with the drop in unit weight as the lightweight aggregate content increases. Although the unit weight drops, the unit weights reported still classify this concrete as a normal weight concrete.

Table 3
Fresh concrete properties for the laboratory test matrix mixtures

LTRC Lab #	Description	Slump (in.)	Air (%)	Unit Weight (pcf)	Initial Set Time (hours)	Final Set Time (hours)
C-4061	0.45 control	3.00	2.2	150	3.87	5.13
C-4062	0.45 5% LW	1.00	2.0	148	3.47	4.78
C-4124	0.45 10% LW	6.50	2.6	147	4.47	5.82
C-4125	0.45 15% LW	2.50	2.5	143	2.62	3.78
C-4126	0.45 20% LW	2.00	2.3	141	3.30	4.80
C-4127	0.45 25% LW	1.00	2.2	139	3.30	4.63
C-4128	0.35 Control	0.50	2.9	151	3.33	4.62
C-4129	0.35 5% LW	3.50	2.3	151	3.88	5.53
C-4130	0.35 10% LW	1.75	2.7	149	2.95	5.72
C-4131	0.35 15% LW	0.50	2.8	147	3.08	5.02
C-4133	0.35 20% LW	0.25	2.3	146	2.02	4.73
C-4134	0.35 25% LW	0.25	2.7	140	1.10	3.47

Hardened Concrete Properties

The hardened concrete properties measured for all mixtures were as expected. The compressive strength results for the 0.45 w/cm are shown in Figure 4. Note that in a 50 percent relative humidity environment, the strengths were still adequate at all days of age, but increasing the lightweight fine aggregate content at 50 percent RH increased the strengths from 5500 psi to 6500 psi or greater. This shows the benefit of the ICC agent. Figure 5 shows the average compressive strength results for the 0.35 w/cm mixtures. Note that all mixtures exceeded 8000 psi compressive strength.

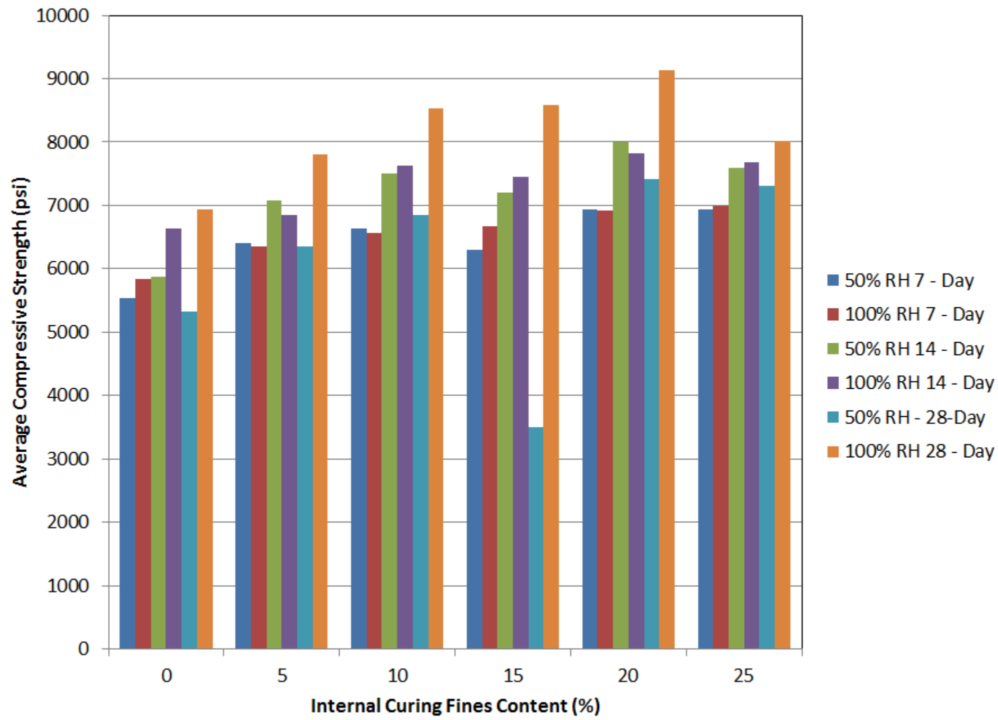

Figure 4
Average compressive strength results for the 0.45 w/cm mixtures

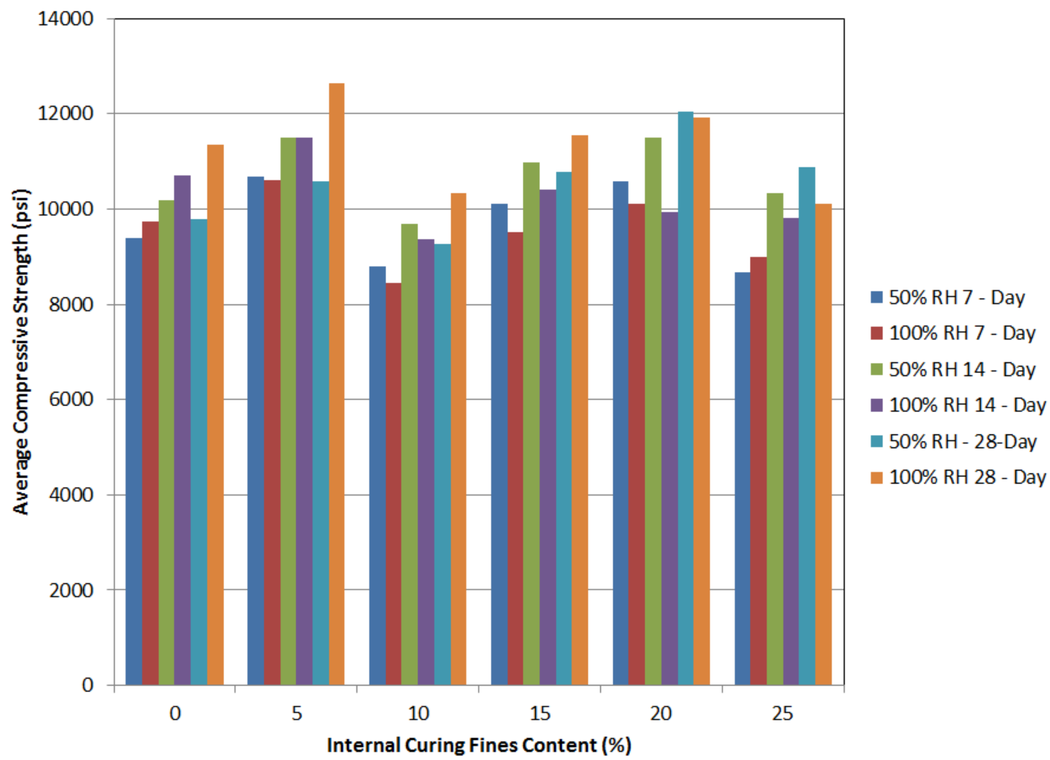

Figure 5
Average compressive strength for the 0.35 w/cm mixtures

The 28-day flexural strength results, shown in Figure 6, showed a slight decrease in flexural strength when incorporating large amounts of lightweight fine aggregate. Although a decrease was observed, the change in strength in a 100 percent RH environment is within the testing error for the standard test method.

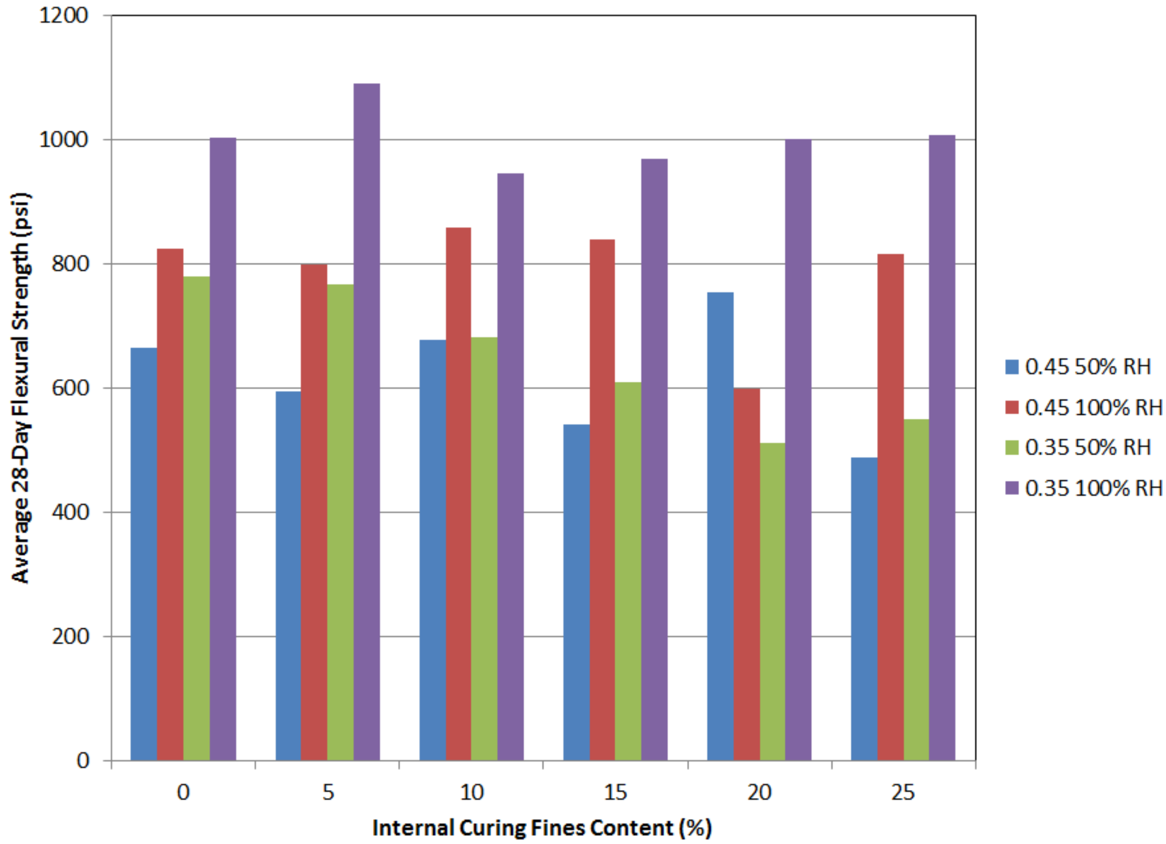

Figure 6
Average 28-day flexural strength for all mixtures

The modulus and Poisson's ratio results for the mixtures were slightly higher than expected with the average modulus of elasticity results being between 4.4 and 7.3 million psi. Traditionally, concrete moduli of elasticity results are between 4 and 6 million psi. The results show that the lightweight fine aggregate has no negative impact on the modulus of elasticity properties of the concrete. Table 4 shows the average modulus of elasticity and Poisson's ratio results for all mixtures.

The surface resistivity results for the laboratory mixtures were as expected. Figure 7 shows the average 28-day surface resistivity results for all mixtures. The results showed that as the w/c ratio is decreased, the surface resistivity is increased as expected. The results also show that for an increasing content of lightweight fine aggregate, the resistivity generally increases. This indicates better hydration of the portland cement within the concrete material as noted by other researchers [*1*].

Table 4
Average modulus of elasticity and Poisson's ratio results for all mixtures

		50% RH		100% RH	
LTRC Lab #	**Description**	**Modulus of Elasticity (millions psi)**	**Poisson's Ratio**	**Modulus of Elasticity (millions psi)**	**Poisson's Ratio**
C-4061	0.45 control	5.68	0.28	7.25	0.30
C-4062	0.45 5% LW	5.33	0.24	6.48	0.28
C-4124	0.45 10% LW	5.28	0.22	5.75	0.26
C-4125	0.45 15% LW	5.08	0.25	5.60	0.27
C-4126	0.45 20% LW	5.03	0.18	5.20	0.28
C-4127	0.45 25% LW	4.45	0.21	5.05	0.20
C-4128	0.35 Control	6.63	0.20	6.78	0.16
C-4129	0.35 5% LW	6.48	0.15	7.10	0.16
C-4130	0.35 10% LW	5.45	0.16	6.10	0.24
C-4131	0.35 15% LW	5.88	0.18	6.25	0.28
C-4133	0.35 20% LW	6.20	0.25	6.55	0.22
C-4134	0.35 25% LW	5.30	0.22	5.90	0.20

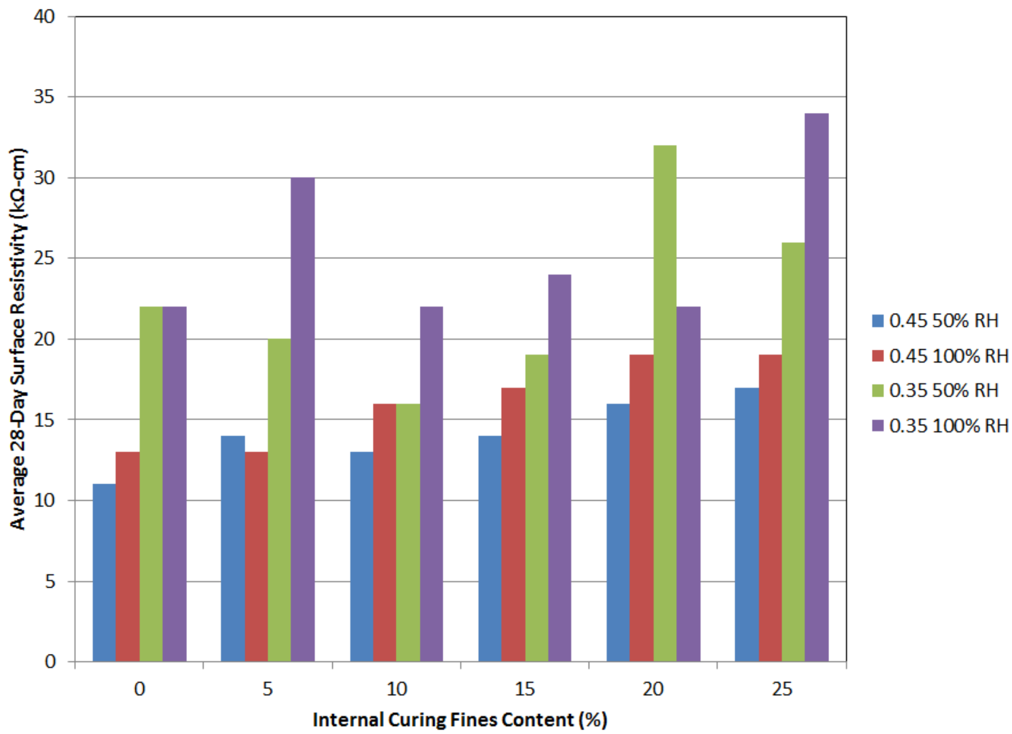

Figure 7
Average 28-day surface resistivity for all laboratory mixtures

The restrained ring shrinkage test was conducted for each mixture in triplicate, but the results were not repeatable and varied widely. Each mixture was then repeated to determine sources of error in the test method, sample preparation, etc. It was determined after seven months of unsuccessful testing that the research team could not count on the results of the test and a decision was made to abandon the method for the remainder of the study.

The Bentz equation is an equation used to determine the exact amount of internal curing water needed to satisfy chemical shrinkage demands due to hydration of the cementitous materials [*1*]. The authors discussed the implications of using the Bentz equation versus specifying a set replacement rate for Departmental purposes. The main drawback to the Bentz equation is that the exact mixture proportions must be known in order to predict accurately the amount of water needed. Also the desorption properties and absorption properties of the aggregate are required. The authors determined that for initial implementation of the technology, a standard replacement rate, or range of replacement rates, would be best suited if the Department were to implement the technology.

Field Results

West Congress Street Bridge Field Trial

Field samples were taken from one control bridge span and both ICC bridge spans. The fresh concrete properties are shown in Table 5 and compressive strength results are shown in Figure 8. The fresh concrete properties were not affected by the replacement of lightweight fines although more mixing water was added to the ICC trucks compared to the control due to the increase in ambient placement temperature. The compressive strength results showed that the control samples had the highest strength but the IC samples were still of adequate strength. Figure 9 shows the completed structure. The contractor noted, "It looks like regular concrete and finishes slightly better than regular concrete."

Table 5
West Congress fresh concrete properties

LTRC Lab #	Description	Date Poured	Slump (in.)	Air (%)	Outside Temp. (F)	Concrete Temp. (F)
C-4255	Lafayette Control	2/26/2015	2.25	5.5	40	50
C-4266	Lafayette Span 1	3/13/2015	4.25	4.0	70	75
C-4267	Lafayette Span 2	3/17/2015	4.00	4.4	70	77

A crack survey completed about 9 months after the bridge was put into service shows minimal cracking. Only two longitudinal cracks were discovered, both in the western control slab as seen in Figure 10, measuring 6 ft. and 16 in., respectively. The cracks are still small, measuring about 0.012 to 0.014 in. in width as seen in Figure 11 and Figure 12. This shows that the ICC is performing better than the control sections at this time. The excellent results from this project have pushed Lafayette Consolidated Government to bid and start construction of another structure, this one being fully constructed with ICC.

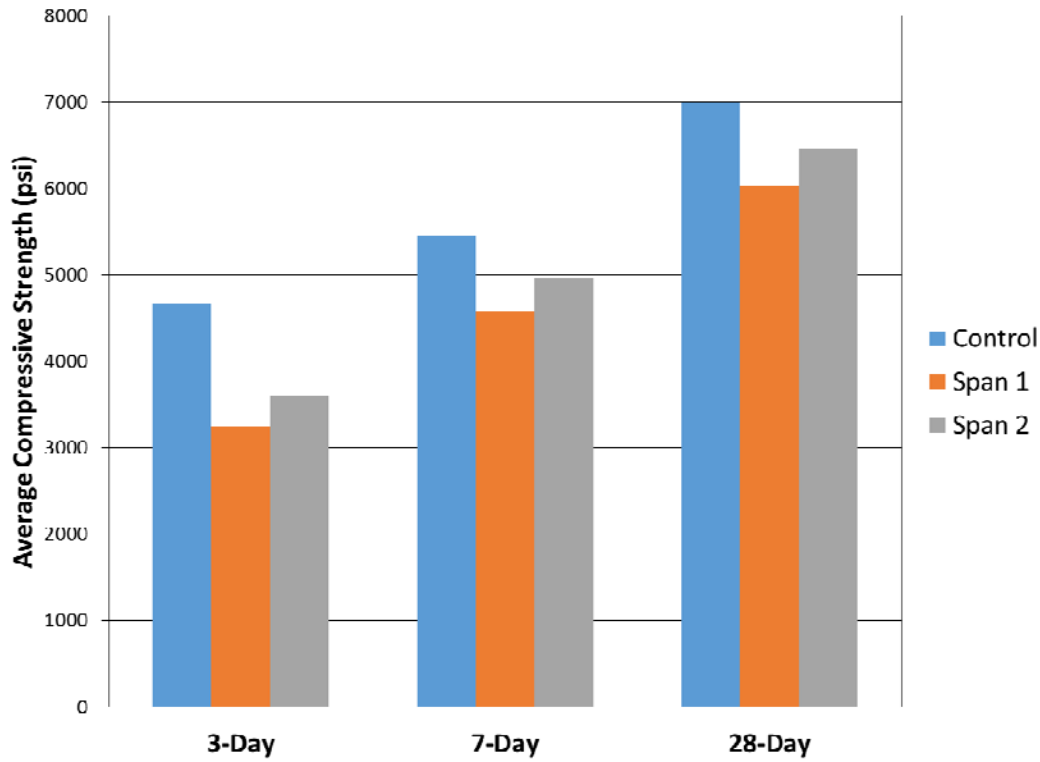

Figure 8
West Congress average compressive strength results

Figure 9
Completed West Congress Bridge looking east into Lafayette Parish

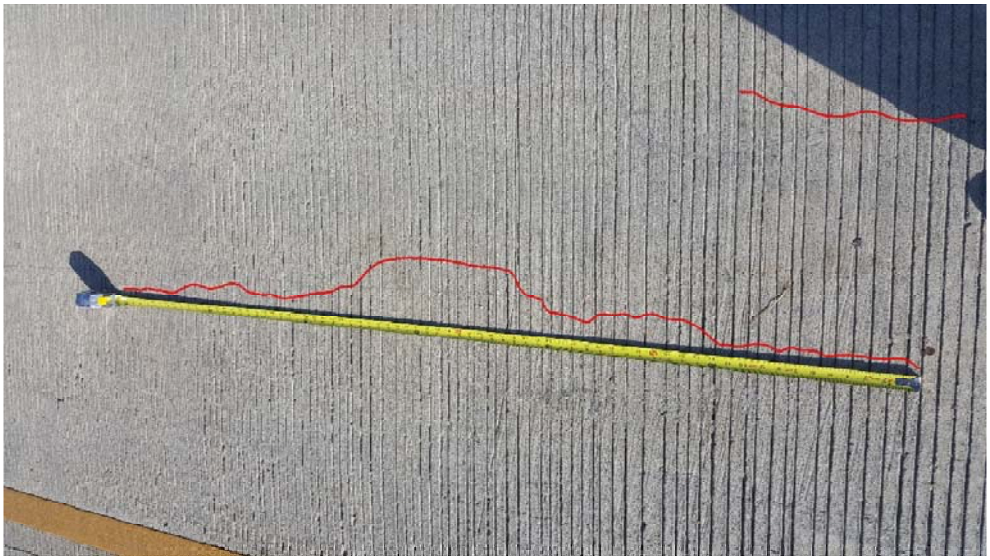

Figure 10
West Congress control span cracks

Figure 11
West Congress control span crack size

Figure 12
West Congress control span crack size

U.S. 80 KCS Railroad Crossing near Ada, LA Field Trial

Fresh and hardened properties were measured for the Ada project. Similar samples were obtained for both the 300 pcy and 150 pcy ICC spans. The fresh concrete properties are shown in Table 6. The results showed that the lightweight fines had no adverse effects on the fresh concrete. Laboratory testing for these samples included 7- and 28-day compressive strength testing and surface resistivity testing at 28 days (average results shown in Table 7). The average (six lots) compressive strength and surface resistivity results can be seen in Figure 13 and Figure 14, respectively. Compressive strength was adequate for all ICC samples and surface resistivity at 28 days was doubled for the 300 pcy mix when compared to the 150 pcy mix. It is important to note here that the 150 pcy ICC mixture does not meet the new specification of 22 kΩ-cm, but this construction effort was started prior to the enactment of the specification limits. The research team has had difficulty obtaining compressive strength results for the control section, but if past performance is accounted for on a statewide basis, the ICC mixtures perform equal to or better than the control mixtures. Results from others show that ICC can meet and exceed surface resistivity requirements. Figure 15 shows an aerial view of the completed sections. The ready-mix plant operator noted that the ICC mixture “looks and feels” like normal concrete. The contractor indicated that the ICC tended to finish with a little less effort than the control mixture.

Table 6
U.S. 80 fresh concrete properties

LTRC Lab #	Description	Slump (in.)	Air (%)
C-4290	300 pcy	5.25	2.0
C-4291		5.50	3.5
C-4292		4.00	2.2
C-4293		6.50	2.6
C-4294		6.50	3.0
C-4295		4.75	2.7
C-4309	150 pcy	6.50	1.9
C-4310		6.00	3.1
C-4311		6.00	3.1
C-4312		6.50	3.1
C-4313		6.25	2.9
C-4314		5.75	3.0

Table 7
U.S. 80 average hardened concrete properties

LTRC Lab #	Description	Average 7-day Compressive Strength (psi)	Average 28-day Compressive Strength (psi)	Average 28-day Surface Resistivity (kΩ-cm)
C-4290	300 pcy	5490	6694	21
C-4291		5179	6649	23
C-4292		5227	6280	23
C-4293		5306	6774	21
C-4294		4917	6049	22
C-4295		5203	6316	22
C-4309	150 pcy	6000	7348	11
C-4310		5350	6733	10
C-4311		5826	6944	11
C-4312		5886	6759	11
C-4313		5589	6619	11
C-4314		5366	6595	11

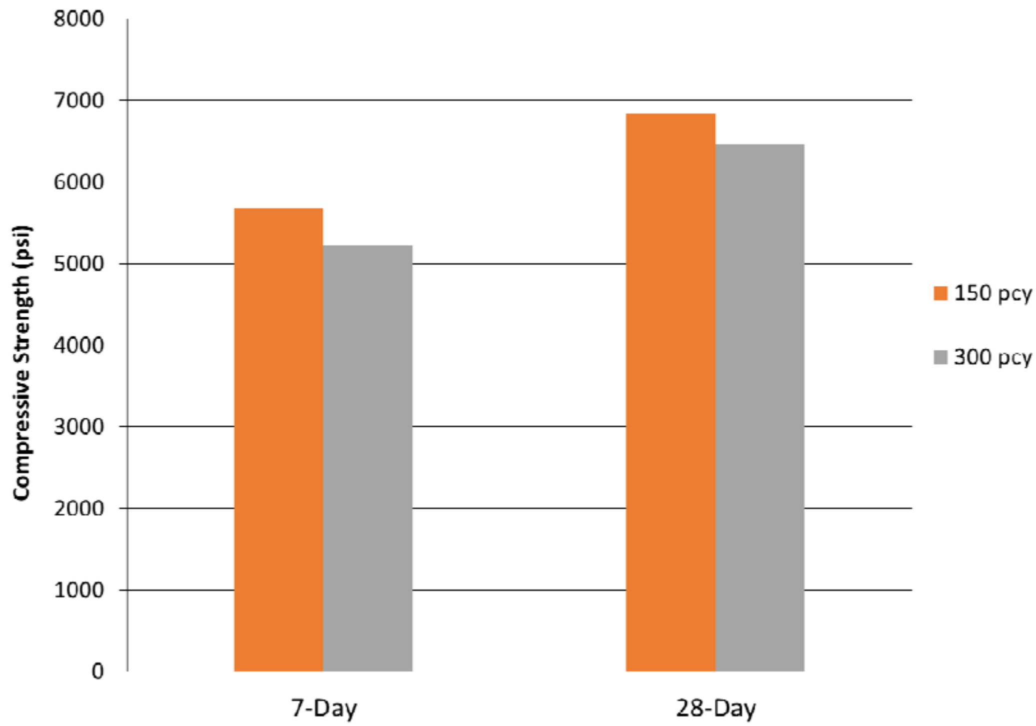

Figure 13
U.S. 80 average compressive strength results

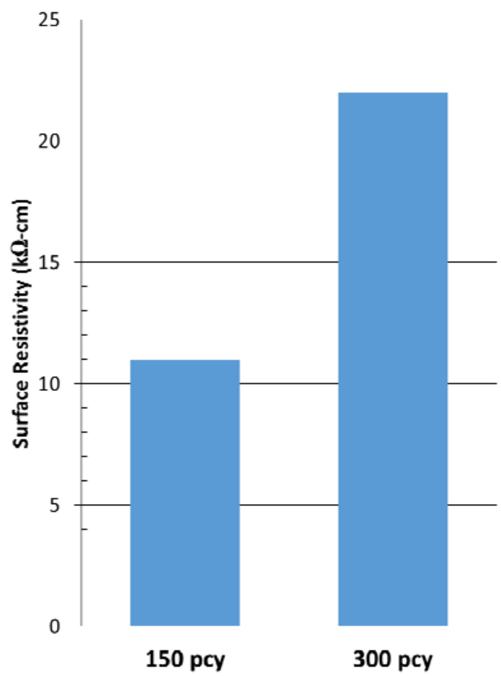

Figure 14
U.S. 80 Average 28-day surface resistivity results

Figure 15
Aerial view of the U.S. 80 KCS railroad crossing

As part of the ongoing study, a crack survey was completed in February 2016. Construction on the bridge was not completed at the time but the bridge was already showing several areas of cracking, as shown in Figure 16. Note the blue lines indicate the support columns structure.

In the first ICC section, the 300 pcy replacement, there were two sets of parallel cracks running all the way across the bridge deck located directly over the support columns. This is to be expected as this is the negative moment region of the structure. The total estimated crack length is about 200 ft.

The 150 pcy ICC section showed the least amount of cracking. It had one full width crack and one about 15 ft. long located at the east end of the section. This section is about 5 weeks younger than the 300 pcy ICC section; therefore, one should take extreme caution in directly comparing the two ICC sections.

The control section was placed latest and shows the most random cracking, with several sets of cracks located both above columns and between columns. Note the cracking in the negative moment region. The estimated total length of cracking is about 175 linear ft. Figure 17 and Figure 18 show two locations where the full width cracks extend over the edge and through the depth of the bridge deck.

The results show that incorporation of ICC into these spans is expected to reduce the cracking severity for the life of the structure since the control section is two months younger than the internally cured sections. The reduced crack severity will equate to longer service life of these spans compared to the control section.

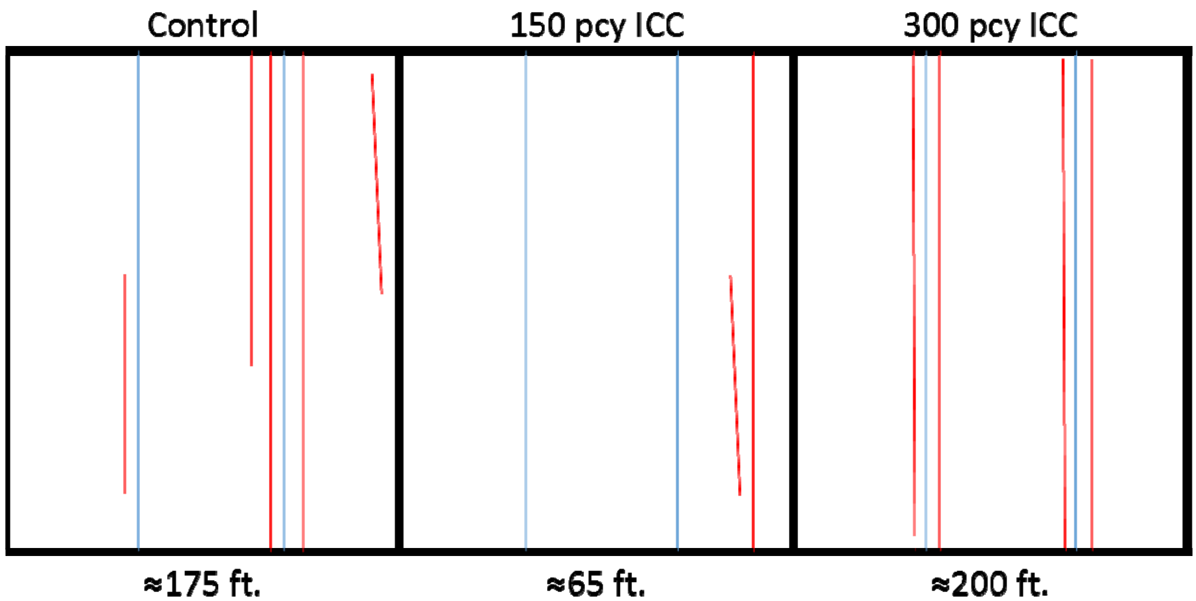

Figure 16
U.S. 80 Bridge deck layout with cracks (red) and support column locations (blue)

Figure 17
Picture of a mid-span crack on end of the U.S. 80 bridge deck

Figure 18
Picture of a crack over a column on the U.S. 80 bridge deck

Figure 19 shows the 150 pcy ICC mixture deck placement the following morning after the construction crew had left for the day. Note the absence of curing compound on the right side of the figure. This figure illustrates why ICC is a good option as the absence of cracking in this section (evidenced by Figure 16) indicates that the ICC will play a large role in the future durability of the short non-cured section. This also indicates that with the use of ICC, the wet burlap cure time may be reduced from the currently specified 10-day period to a 7-day period.

Figure 19
150 pcy ICC placement, note the lack of curing compound in the right of the picture

CONCLUSIONS

The results of this project warrant the following conclusions. The centrifuge test method is superior to the paper towel test method in terms of expediency and repeatability of results for determining free moisture and saturated surface dry condition. The laboratory results showed that the fresh concrete properties are unaffected by the use of lightweight fine aggregate for internal curing purposes. The compressive strength and modulus of elasticity results were determined to be the same or slightly higher when using lightweight fine aggregate for internal curing purposes. Flexural strength of concrete containing large amounts of lightweight fine aggregate was shown to be reduced slightly compared to the control. The surface resistivity values of the ICC were shown to increase indicating better hydration of the concrete mixture.

Field trial placements showed that the ICC performs well. The West Congress project showed reduced cracking at one year over the control sections, and the Ada project showed significantly less cracking over the control about nine months after placement of the ICC sections. The section placed without curing compound has yet to crack for the 150 pcy ICC mixture placement, and this is the worst case scenario. The reduced cracking will lead to longer service life and a more durable structure. In both cases, the contractor noted easier finishability characteristics and that, "ICC is just like normal concrete." Based upon the laboratory and field results, a standard lightweight fine aggregate replacement rate between 225 and 275 pcy is suggested for implementation.

RECOMMENDATIONS

The following recommendations are put forth as a result of this study. A study should be undertaken to determine the precision and bias of the centrifuge test method. Pending successful results, a TR procedure should be developed for the test method. Training materials for the test method include a half-day course with hands-on training and an instructional video. The Department should incorporate ICC into the specifications where appropriate and a standard 225 to 275 pcy replacement rate is suggested. A wet cure of 7 days is also still recommended. Although the Bentz equation can predict the quantity needed exactly, a standard replacement rate can be much more easily incorporated into Departmental specifications.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ASTM	American Society of Testing and Materials
DOTD	Department of Transportation and Development
FHWA	Federal Highway Administration
ft.	feet
ICC	internally cured concrete
in.	inch(es)
LTRC	Louisiana Transportation Research Center
PCC	portland cement concrete
pcf	pounds per cubic foot
pcy	pounds per cubic yard
QA	quality assurance
QC	quality control
w/cm	water to cementitious materials ratio

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