Field Performance of Internally Cured Concrete Bridge Decks in New York State

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Synopsis: In an effort to improve the durability and the life cycle of infrastructure concrete, new advances have been made. These improvements have included the development of High Performance Concrete (HPC). HPC has utilized lower water cementitious ratios and supplementary cementitious materials (SCMs) in an effort to improve the durability of these structures. Unfortunately the use of SCMs and low water cementitious ratios have led to others problems including shrinkage cracking and cement that is not fully hydrated. To help improve these characteristics a supply of additional curing water is needed throughout the cement matrix. Water supplied from saturated pores of expanded shale, clay, and slate lightweight aggregates has shown promise in several research projects. New York State has developed a program to examine the benefits of internal curing and has utilized the technology on several bridges throughout the state. This paper will discuss the performance and construction of several of these bridges.

K**eywords**: Internal Curing, Internally Cured Concrete, Internally Cured Concrete Bridge Decks, Internally Cured High Performance Concrete Bridge Decks, Internally Cured HPC Bridge Decks, Concrete Durability, Concrete Bridge Deck Performance.

INTRODUCTION

New York State is home to more than 17,000 highway bridges, about 44 percent of them owned by the New York State Department of Transportation (NYSDOT), roughly 50 percent owned by municipalities, and the rest owned by state and local authorities, commissions, and railroads.[1] The American Society of Civil Engineers has reported that many of these bridges are structurally deficient or functionally obsolete in their Report Card for America's Infrastructure.[2] As these bridges are scheduled to be replaced new technology is always sought to improve the performance and life cycle of these structures.

New York State has a variety of climates and conditions over its 47,126 square miles of landmass. This exposes the state's bridges to a variety of severe environments caused by deicing chemicals, coastal conditions, freezing and thawing, wetting and drying, and heating and cooling. These factors, in addition to the loads imposed on the structures, present one of the most extreme conditions that concrete must endure.

In an effort to evaluate new technology that is available to improve the performance of bridge decks, NYSDOT developed a program to investigate internally cured concrete (ICC). This paper will discuss the findings to data and give examples of the use of this technology in the field.

NYSDOT INTERNAL CURING EVALUATION PROGRAM

The NYSDOT set out to evaluate ICC through the development of an experimental specification to reduce cracking in bridge decks. This specification can be found in Appendix 1. Cracking in bridge decks is the first step toward failure of the bridge deck, and over time leads to costly repairs. The goal was to improve the durability of the bridge deck and to dramatically reduce future maintenance and replacement costs.

Cracking in concrete is caused by tension. In this case, a significant source of tension comes from the opposing forces of the shrinkage and the restraint provided by reinforcement and the girders on which the concrete is cast. This is a very complicated process, and many other forces are at work, but shrinkage has been identified by research as one of the major forces, and relieving the stress caused by shrinkage would significantly reduce cracking in bridge decks.

Autogenous shrinkage has been identified as one of the primary stresses on freshly placed concrete during its first few days. The American Concrete Institute defines autogenous volume change as the change in volume produced by continued hydration of cement, exclusive of effects of applied load and change in either thermal condition or moisture content.[3] It is caused by self-desiccation, the process of using up the free water in the mix during the hydration process. The products of the chemical reaction have less volume than the components of the reaction, leaving behind a void. In traditional concrete mixes, keeping the concrete moist allowed water to be drawn into the concrete by the resulting vacuum. In today's low permeability mixes, the water is not able to easily pass through the concrete, and cannot relieve the vacuum. This vacuum is powerful enough to cause shrinkage of the concrete.

Internally Cured Concrete is concrete that has extra water in the concrete mix which is not available for hydration initially, and does not impact workability during placement, but becomes available as the free water in the mix is used up. This is accomplished by introducing materials into the concrete mix that initially absorb water or have absorbed water in them, keeping the water out of the mix, but release water to the mix after the mixing water is used up during the hydration process. This has several positive effects on the quality of the concrete. The most important, in terms of increasing bridge deck durability, is the reduction of shrinkage.

There are two types of materials currently being used for ICC. The first of these is lightweight aggregate, which typically is porous and therefore absorbs significant quantities of water. The lightweight aggregate is saturated with water prior to being added to the concrete mix, and releases the absorbed water when the vacuum begins to develop inside the concrete. The second material type is super absorbent polymers (SAPs). This is supplied as a dry powder which is mixed in with the fine aggregate and draws water from the concrete mix during the mixing process. It is necessary to over-supply water to make up for that anticipated absorption. Again, the water is released when the vacuum begins to form.

The advantage of the lightweight aggregate for this experiment is that it is already an approved product for NYSDOT, and there was some familiarity with it. There also were several sources available in New York State. A simple change in the mix design allows the lightweight aggregate to be incorporated with very little change in procedures.

NYSDOT had no experience with SAPs. The research on SAPs was at an earlier stage, and NYSDOT had not identified which of the many available SAPs might be best for use in concrete.

NYSDOT chose to use prewetted lightweight aggregate for this experiment. The advantages of familiarity with the product, similarity to current procedures, and that the material was State approved, made it a logical choice. [4]

WHAT IS INTERNAL CURING

Internal curing is a method of supplying additional curing water throughout the concrete mixture. Internal curing is often referred to as “curing concrete from the inside out.” This process is accomplished by using materials that absorb water such as lightweight aggregate or superabsorbent polymers to replace some of the fine aggregate in the freshly placed concrete mixture. By doing this, cement hydration and supplementary cementitious materials reactions are enhanced as the water is readily releasing from the absorbent materials as needed.

The American Concrete Institute in 2010 defined internal curing as “supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation”.[3]

MIX DEVELOPMENT

In an effort to improve the durability and life cycles of structures throughout the state, NYSDOT has utilized High Performance Concrete (HPC) for bridge decks. These HPC decks typically contain Supplementary Cementitious Materials (SCMs) such as flyash and silica fume to improve the deck's performance. Unfortunately, these materials, while reducing permeability, also increase cracking in the decks. Internal curing is one of methods that are being utilized to improve the performance of bridges. Various additional methods are being incorporated into the design and construction process to reduce cracking such as gradation optimization, sound structural design and good construction practices in the field.

Calculating the additional water demand for the HPC used in New York bridge decks needed to be investigated early in the specification development phase of this program. Utilizing research that had been previously conducted the following equation was used to evaluate the amount of internal curing needed for ICC.

$$M_{LWA} = \frac{C_f \; * CS \; * \alpha_{max}}{S \; * \boldsymbol{\phi}_{LWA}}$$

where

M_{LWA} = mass of (dry) LWA needed per unit volume of concrete (kg/m^3 or lb/yd^3);

C_f = cement factor (content) for concrete mixture (kg/m^3 or lb/yd^3);

CS = chemical shrinkage of cement (mass of water/mass of cement);

$\alpha_{\max}$ = maximum expected degree of hydration of cement (0 to 1);

S = degree of saturation of aggregate (0 to 1);

Φ_{LWA} = desorption of lightweight aggregate from saturation down to

93 % RH (mass water/mass dry LWA). [6]

After typical values were plugged into this equation, a demand of approximately 200 pounds of lightweight aggregate fines (LWAF) was calculated to meet the internal curing demand of mixes in the state. A specification was developed by modifying the Class HP concrete mixtures (*Table 1*) that were used on bridge decks.

Table 1 - Class HP Mix Criteria

Cement content (lbs./c.y.)	500
Fly ash content (lbs./c.y.)	135
Microsilica content (lbs./c.y.)	40
Sand percent total aggregate (solid volume)	40
Designed water/total cementitious content	0.40
Desired air content (%) Allowable air content (%)	6.5 5.0 - 8.0
Desired slump (inches) Allowable slump (inches)	4 3 -5
Type of coarse aggregate gradation	CA 2

NOTE: The criteria are given for design information and the data is based on a fine aggregate fineness modulus of 2.80. The mixture proportions shall be determined using actual conditions for fineness modulus and bulk specific gravities (saturated surface dry for aggregate). The proportions shall be computed according to Department written instructions.

It was determined that since the lightweight aggregates that are available throughout the region had similar absorption and desorption characteristics, a simplified specification could be developed for use in the field. This could be easily achieved by replacing 30% of the normal weight sand with the prewetted LWAF by volume. This replacement value has worked well for the three lightweight aggregates that have been used on projects in the state. The mix criteria for the internally cured concrete (*Table 2*) was identical to those found in the Class HP concrete with the exception of the addition of the LWAF and the corresponding reduction of sand.

Table 2 - Class HP-IC Mix Criteria

Cement content (lbs./c.y.)	500
Fly ash content (lbs./c.y.)	135
Microsilica content (lbs./c.y.)	40
Sand percent total aggregate (solid volume)	28
Lightweight fines percent total aggregate (solid volume)	12
Designed water/total cementitious content	0.40
Desired air content (%) Allowable air content (%)	6.5 5.0 - 8.0
Desired slump (inches) Allowable slump (inches)	4 3 -5
Type of coarse aggregate gradation	CA 2

NOTE: The criteria are given for design information and the data is based on a fine aggregate fineness modulus of 2.80. The mixture proportions shall be determined using actual conditions for fineness modulus and bulk specific gravities (saturated surface dry for aggregate). The proportions shall be computed according to Department written instructions.

After the materials had been accepted for a specific job, the proportions for concrete and the equivalent batch masses based on trials made with materials were established. Adjustments were made to the fineness modulus of the fine aggregate portion of the mix based on the percentages of normal weight sand and LWAF used in the mix design.

LIGHTWEIGHT AGGREGATE PREPARATION

The LWAF used in ICC can vary in moisture content based on the amount of time that the material was exposed to water. A component of the specification needed to address this subject and make sure that the LWAF were sufficiently prewetted. From prior experience with prewetting coarse lightweight aggregate for use in structural lightweight concrete, it was determined that the use of a sprinkler on the stockpile was the best method to prewet the LWAF. The developed specification stated:

Construct lightweight fine aggregate stockpile(s) at the production facility so as to maintain uniform moisture throughout the pile. Using a sprinkler system approved by the Materials Engineer, continuously and uniformly sprinkle the stockpile(s) with water for a minimum of 48 hours, or until the "Absorbed Moisture content" of the stockpile is at least 15% by weight (as determined by Test Method NY 703-19E). If a steady rain of comparable intensity occurs, turn off the sprinkler system at the direction of the Materials Engineer, until the rain ceases. At the end of the wetting period, or after the rain ceases, allow stockpiles to drain for 12 to 15 hours immediately prior to use, unless otherwise directed by the Materials Engineer.[7]

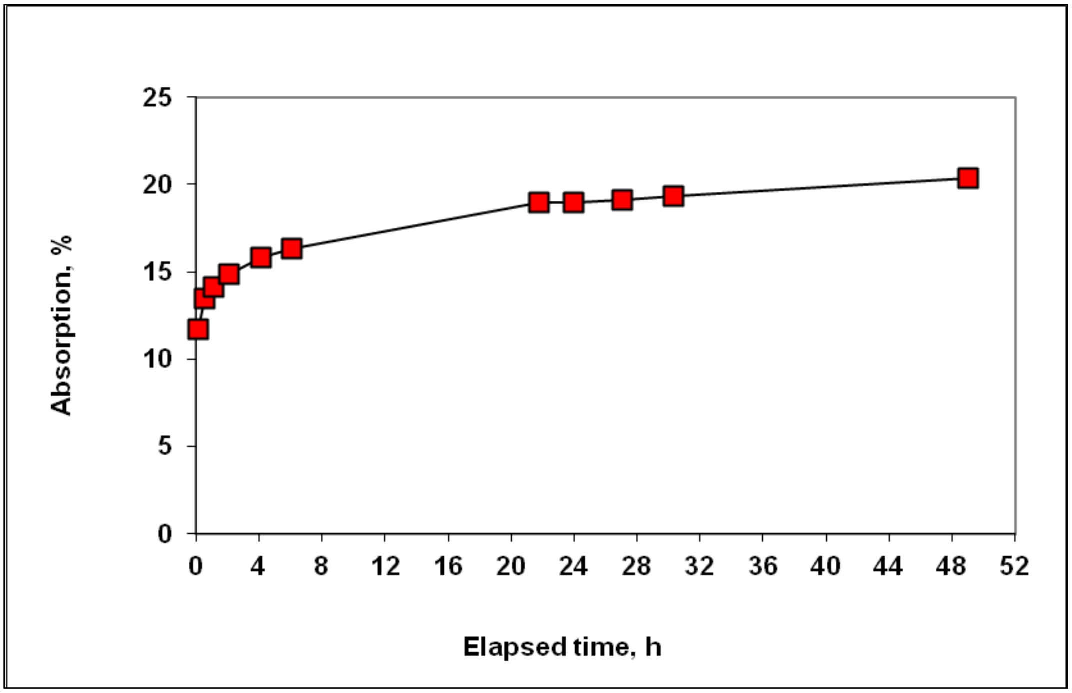
The minimum duration of applying water to the stockpile through the sprinkler was determined by evaluating absorption characteristics of regionally available LWAF (*Table 3*). The LWAF absorbed a large amount of moisture in the first 24 hours and then the curve flattened out (*Figure 1*). It was recommended to the concrete supplier to turn the piles several times during the soaking to ensure uniform wetting of the material. Most concrete suppliers kept the sprinklers on longer then the specified times and moisture contents were commonly at 20%.

Table 3 – Absorption of Lightweight Aggregate Fines

Time, hr	Average abs %	SD
0.09	11.70	0.00
0.53	13.47	0.20
1.07	14.10	0.17
2.06	14.83	0.19
4.08	15.79	0.16
6.05	16.34	0.27
21.76	18.95	0.20
23.99	19.00	0.15
27.09	19.15	0.19
30.30	19.35	0.19
49.01	20.39	0.21

Average absorption is the average of 3 samples
SD is the standard deviation of the 3 samples

Figure 1 – Absorption of Lightweight Aggregate Fines



After the stockpiles had been soaked the sprinklers were turned off to allow the stockpile to drain. The specification called for a drain time of 12 – 15 hours. This was achieved by shutting the sprinklers off at the close of business the day prior to the placement. Testing was run the next morning to determine moisture contents, the piles were sufficiently drained.

Determining the surface moisture content and the absorbed moisture content of the LWAF proved easy after a written test method was developed. Test Method NY 703-19E (Appendix 2) was written to standardize the methodology used to determine moisture content. This method involves the use of commercially available brown paper towels. A representative sample is taken and split into two parts. Part one is weighed, dried, reweighed after removal from the oven to determine the total moisture content.

Part two is placed on a 2 - 3 foot long sheet of clean, dry brown paper towel. The sample is spread uniformly across the paper towel while patting the sample with another paper towel. Replace the sheets of paper towel whenever the paper becomes too damp to absorb moisture. This process should be conducted as quickly and carefully as possible. This process is repeated until no further moisture appears on the clean brown paper towels. Part two is then weighed, dried, and reweighed after removal from the oven to determine its moisture content. Since the surface moisture has been removed, this sample represents only the moisture that has been absorbed into the sample.

The surface moisture can then be determined by subtracting the absorbed moisture content from the total moisture content. This value is used to adjust the mix water in the batch.

There were early concerns that the LWAF would have a difficult time flowing through the bins with a high moisture content. It was thought that prewetted LWAF would act similar to sand with a high moisture content. This proved not to be a problem since the majority of the moisture was absorbed into the aggregate.

BATCHING

No differences in batching were needed to accommodate ICC. Some of the concrete batch plants had an insufficient number of bins since they were batching two coarse aggregates. In this case, the coarse aggregates were pre-blended and placed into one bin. This left bin space to batch a normal weight and a lightweight sand. Batch pull weights were determined by aggregate testing the morning of the placement. The lightweight fine aggregate was batched first, followed by the fine aggregate, coarse aggregate, admixtures, cement, pozzolan, microsilica, and remaining mixing water and then mixed completely.

The NYSDOT required the lightweight aggregate manufacturer to supply a service representative at the site for the first day of concrete placement operations to assist in the control of ICC mixing and placement operations.

PLACEMENT

The concrete was placed in the same manner that a Class HP mix would be placed. Typically the concrete was pumped onto the deck. No differences were seen in the pumpability of the mix when compared to a similar mix without internal curing. Finishability was similar between Class HP-IC and Class HP concretes with some contractors commenting that the mixes with internal curing were less sticky than the traditional HPC mixes.

Testing was conducted in the same manner as HPC mixes. Air contents were determined in the field using a pressure meter. At the beginning of each job the engineer in charge usually wanted to see a comparison between the air content measured by ASTM C231 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method and ASTM C173 Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method. The results of this comparison were always within ½% of each other and the pressure meter was used throughout the pour.

CURING

Internal curing is meant to supplement conventional surface curing and is not a replacement for proper curing methods. After the decks were finished and textured, the concrete surface was completely covered with clean, prewetted burlap. The pre-wet burlap was placed within five minutes after the completion of texturing, and not longer than 30 minutes from the time of concrete placement. The burlap was thoroughly saturated in water troughs and drained of excess water prior to its application after which soaker hoses were applied. The burlap and soaker hoses were left in place for 14 curing days to provide continuous, uniform wetting for the entire curing period.

This described process follows typical NYSDOT practice that has been in place for over 15 years and specified for all bridge deck concrete curing. Key is the timely application of wet curing. It has proven to reduce the potential for drying shrinkage cracking compared to previous practices where curing application was greater than 30 minutes and the curing duration was only 7 days.

BRIDGE PERFORMANCE

The structures listed in *Table 4* were spread throughout the state of New York and had a variety of bridge types, numbers of spans, and construction methods. Different contractors, concrete suppliers and lightweight aggregate suppliers were utilized on these projects. The structures were exposed to a variety of climates, traffic loadings, and de-icing chemical exposures. While most of these structures were complete at the time of publication of this paper, evaluation of the performance of the ICC had only been conducted on a portion of the bridges. A few of the structures have been selected to look into in detail.

Table 4 – Structures Included in NYSDOT Internal Curing Study

Highway	Feature Spanned	Location
NY Route 9W	Vineyard Avenue	Lloyd
NY Route 96	Owego Creek	Owego
Interstate 81S	Tioughnioga River	Whitney Point
Interstate 81N	Tioughnioga River	Whitney Point
Court Street	Interstate 81	Syracuse
Bartell Road	Interstate 81	Cicero
Interstate 86	NY Route 415	Painted Post
Interstate 84	Route 6	Brewster
Interstate 290 Ramp B	Interstate 190	Tonawanda
Interstate 81N	East Hill Road	Lisle
Interstate 81S	East Hill Road	Lisle
NY Route 17 Exit 90 Ramp	East Branch Delaware River	East Branch
NY Route 38B	Crocker Creek	Endicott

NY Route 353	Allegheny River	Salamanca
Interstate 290 Ramp D	Interstate 190	Tonawanda
Interstate 87	Route 9 and Trout Brook	Chestertown
Goulds Corners Road	Fort Drum Connector	Watertown

Interstate 81 over East Hill Road - Lisle, New York

Internally cured concrete was supplied for this bridge on Interstate 81 over East Hill Road, in the town of Lisle, New York. The single span, straight steel girder bridge was 74.2 feet long and 42.4 feet wide. The bridge is located on a Interstate highway in rural South Central New York. The concrete supplied from C& C Ready Mix with the batch design shown in *Table 5*. The deck was placed relatively late in the construction season on November 3, 2010.

Figure 2 – Placing ICC on Interstate 81 over East Hill Road

Table 5 – Concrete Batch Designs - Interstate 81 over East Hill Road

	Class HP	Class HP-IC
Cement – Blended with 7% Silica Fume	538 lbs	548 lbs
Fly Ash – Type F	137 lbs	125 lbs
Fine Aggregate – Natural Sand	1187 lbs	810 lbs

Fine Aggregate – LWAF 22.2% moisture	0 lbs	250 lbs
Coarse Aggregate – No. 1 Stone	862 lbs	870 lbs
Coarse Aggregate – No. 2 Stone	849 lbs	840 lbs
Water	270 lbs	270 lbs
Air Entrainment - BASF MB-VR Standard	18.2 oz	17.5 oz
Retarder - BASF Pozzolith 100 XR	13.5 oz	34.0 oz
Water Reducer - BASF Polyheed 997	20.2 oz	

A companion Class HP mix without internal curing was batched at the same time of the bridge deck placement for comparison. Both batch proportions are shown in *Table 5* with the properties shown in *Table 6*.

Table 6 – Concrete Properties - Interstate 81 over East Hill Road

	Class HP	Class HP-IC
Average 7 day Compressive Strength	3,720 psi	3,335 psi
Average 28 day Compressive Strength	5,040 psi	5,273 psi
Average 56 day Compressive Strength	5,900 psi	5,853 psi
Concrete Density	137.8 pcf	133.0 pcf
Air Content	5.7%	7.2%
Slump	3.5”	4.5”

<u>Interstate 190 / Interstate 290 interchange - Tonawanda, NY</u>

Additional structures that utilized internally cured concrete were the Ramp B and Ramp D Bridges at the Interstate 190/ Interstate 290 Interchange. These bridges were 2 span curved steel girder structures both 42.4 feet wide. Ramp B was 376 feet long and Ramp D was 365 feet long with an integral pier cap that was cast at the same time the deck was placed. These bridges are located at a busy junction of 2 Interstate highways in a major metropolitan area, Buffalo, New York. The concrete was supplied by Buffalo Crushed Stone from their Gateway Trade Center Plant. The deck was placed early in the construction season in the Spring of 2011.

Figure 2 – Interstate 190/ Interstate 290 Interchange

Concrete was tested from an approach slab placement in September 2010. An additional companion Class HP mix without internal curing was batched at the same time of the approach slab placement for comparison purposes. Both batch proportions are shown in *Table 7* with the properties shown in *Table 8*.
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Table 7 – Concrete Batch Designs - Interstate 190/ Interstate 290 Interchange

	Class HP	Class HP-IC
Cement – Blended with 7% Silica Fume	540 lbs	540 lbs
Fly Ash – Type F	139 lbs	139 lbs
Fine Aggregate – Natural Sand	1150 lbs	813 lbs

Fine Aggregate – LWAF 22.0% moisture	0 lbs	244 lbs
Coarse Aggregate – No. 1 Stone	674 lbs	959 lbs
Coarse Aggregate – No. 2 Stone	1,038 lbs	792 lbs
Water	272 lbs	273 lbs
Air Entrainment - BASF AE-100	16.3 oz	17.7 oz
Water Reducer - BASF 100 Xr	20.4 oz	26.5 oz

Table 8 – Concrete Properties - Interstate 190/ Interstate 290 Interchange

	Class HP	Class HP-IC
Average 7 day Compressive Strength	3,040 psi	3,500 psi
Average 28 day Compressive Strength	4,677 psi	4,683 psi
Average 56 day Compressive Strength	5,343 psi	5,417 psi
Concrete Density	140.2 pcf	135.2 pcf
Air Content	5.5%	6.0%
Slump	5.0”	4.5”

When this deck was evaluated in September 2011, no cracking was found.

Court Street over Interstate 81 - Syracuse, New York

A unique project that involved numerous similar structures that were being replaced at the same time, offered an excellent setting to evaluate internally cured concrete. The project was the reconstruction of several bridges along Interstate 81 in Downtown Syracuse, New York. The structures evaluated had their decks placed within a few weeks of each other and the structures had similar designs and dimensions. The concrete for all the structures was supplied by the same concrete supplier, Robinson-Vitale Concrete. Additionally the same contractor placed the concrete on all of the structures evaluated. Two bridges, Butternut Street and Spencer Street, utilized Class HP concrete without internal curing, while Court Street (*Figure 3*) had Class HP-IC on the bridge deck. All of the bridges spanned Interstate 81 and were 2 span straight steel girder structures 65 feet wide located within ¾ mile of each other. Butternut Street and Court Street had similar lengths at 180 and 197 feet respectively, while Spencer Street had a shorter length of 125 feet. The decks were placed in the late Summer of 2009.

Figure 3 – Court Street Deck Placement

Table 9 – Concrete Batch Designs - Interstate 81 Reconstruction, Syracuse, NY

	Class HP	Class HP-IC
Cement – Blended with 7% Silica Fume	540 lbs	540 lbs
Fly Ash – Type F	135 lbs	135 lbs
Fine Aggregate – Natural Sand	1,130 lbs	782 lbs
Fine Aggregate – LWAF 22.0% moisture	0 lbs	239 lbs
Coarse Aggregate – Blended Stone	1,720 lbs	1,720 lbs
Water	270 lbs	262 lbs

The batch proportions for the Class HP mixes were from the two traditional HPC decks. The Class HP-IC data is from the Court Street Deck. Both batch proportions are shown in *Table 9* with the properties shown in *Table 10*.

The bridge decks were walked in Summer of 2010 after approximately 1 year of service. Both the Class HP and the Class HP-IC decks showed very good performance. All structures had only one crack on the structure. The crack was a small crack located only on the sidewalk directly over the pier. The cracking pattern was consistent among the structures at the time of the evaluation.

Table 10 – Concrete Properties - Interstate 81 Reconstruction, Syracuse, NY

	Class HP	Class HP-IC
Average 7 day Compressive Strength	4,727 psi	4,859 psi
Average 14 day Compressive Strength	5,917 psi	6,222 psi
Average 21 day Compressive Strength	6,077 psi	6,570 psi
Average 28 day Compressive Strength	6,309 psi	6,976 psi

CONCLUSIONS

In New York State ICC has shown to provide improvements by reducing the cracking associated with concrete shrinkage but has not eliminated all deck cracking. It presented no problems to concrete suppliers when batching concrete or to contractors placing and finishing concrete on bridges.

Internal curing is a helpful tool that can be used to improve concrete properties but, it is only a tool. It does not replace sound structural design and good construction practices in the field and it cannot be expected to make up for deficiencies in these areas. It should be used in combination with other technology available to improve concrete. Internally cured concrete is not self-curing concrete and it does not replace surface curing.

As we move ahead and replace our aging infrastructure we strive to get more out of our roadways and bridges. We now are designing bridges with expected service lives of 100 years. Time will tell how long the life span of a structure will be increased utilizing what are considered the progressive technologies of today. Hopefully we will not know the true effects of these technologies until at least 100 years from now.

REFERENCES

1. New York State Department of Transportation, (2011), New York State Highway Bridge Data, https://www.dot.ny.gov/main/bridgedata.
2. American Society of Civil Engineers, (2010), Report Card for America's Infrastructure, http://www.infrastructurereportcard.org/state-page/new-york.
3. American Concrete Institute, August 31, 2010, ACI Concrete Terminology, http://www.concrete.org/Technical/CCT/FlashHelp/ACI_Concrete_Terminology.pdf.
4. New York State Department of Transportation, (2008), Work Plan for Internal Curing Concrete Experimental Specification.
5. Bentz, D. P. and Weiss W. J., (2011) "A Internal Curing: A 2010 State-of-the-Art Review," NIST IR 7765; http://www.nist.gov/manuscript-publication-search.cfm?pub_id=907729
6. Bentz, Dale P., Lura, Pietro, and Roberts, John W., "Mixture Proportioning for Internal Curing," Concrete International, February 2005, pp. 35-40.
7. New York State Department of Transportation, Internal Curing Concrete Specification, September 18, 2008.

Appendix 1

NYSDOT Internal Curing Specification

Appendix 2

NYSDOT Test Method 703-19E