December 2020

CTIP TECHBRIEF

Coordinated Technology Implementation Program

Internally Cured Concrete (ICC)

This Technical Brief provides an overview of the benefits, limitations, and applications of Internally Cured Concrete for bridge decks. Considerations for specifications, contracting, construction, and maintenance are discussed.

The Challenge

Minimizing cracking of concrete bridge decks is key to a long service life. Cracking provides a direct path for water and other ions to the interior of the concrete and the reinforcing steel of the structure that can jeopardize the structural capacity. Service life can be reduced by 50% depending on the depth and width of cracking. [1] Two options are then possible to address the deterioration – divert funding from other projects for repairs to keep the structure in service or allow deterioration until premature replacement is required. In summary, reduced service life means the unplanned expenditure of funds that could be used to address other infrastructure needs. .

Figure 1: Examples of Bridge Deck Cracking (All photos provided by FHWA Federal Lands)

Concrete mixtures take into account a fundamental property of concrete, pore structure, to meet service life targets. All concrete mixtures have a pore structure which allows for the transport of water and ions such as chlorides through the concrete. Concrete designed for longer service life structures reduce the size of the pores and amount in the concrete with the direct effect of slowing down the transport of deleterious substances into the concrete. However, a concrete mix optimized for durability has a greater tendency for cracking. This is due to the lower water-cementitious material (w/cm) ratio that is necessary to reduce the pore size and reduce the rate of transport in the concrete. The lowered w/cm ratio required for long term durability does not have enough water in the concrete mixture for complete cement hydration. This results in the concrete becoming desiccated as water is removed from internal pores during cement hydration. This removal of water from the pores causes autogenous shrinkage. This shrinkage is independent of any exterior environmental conditions and will occur even in a sealed environment. Autogenous shrinkage is one of the root causes of early age cracking of concrete. Therefore, despite the rigorous application of external curing, many bridge decks still experience some level of shrinkage cracking during curing.

Executive Summary

Innovation

The incorporation of lightweight fine aggregate into concrete mixtures provide internal curing and reduce cracking. Cracking short circuits concrete durability and can reduce expected service life up to 50% depending on depth and width of cracking.

Key Results

Internally Cured Concrete (ICC) significantly reduced cracking of test bridge decks.

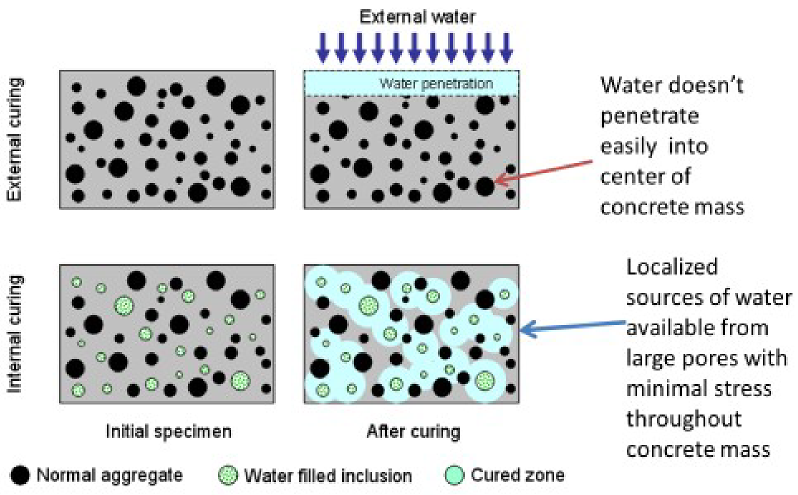
Potential Impact

Increase service life of bridge decks for minimal cost by reducing cracking.

U.S. Department of Transportation
Federal Highway Administration

The Solution

If an internal reservoir of water can be provided to the concrete that prevents desiccation through autogenous shrinkage, then this source of cracking can be reduced. This reservoir has to be evenly dispersed throughout the concrete, and cannot shrink when water leaves it. How is this accomplished? A reservoir of water is provided for internal curing by substituting highly absorptive lightweight fine aggregate for a portion of the normal fine aggregate in the concrete mix. The highly absorptive light weight fine aggregate retains and releases the water during concrete hydration and prevents internal desiccation of the concrete during the chemical reactions that occur during the hydration of concrete. Internal desiccation causes autogenous shrinkage with stresses that lead to early age cracking of the concrete at increased frequency. The autogenous shrinkage can significantly reduce the expected life cycle performance of the structural element. The technology associated with light weight fine aggregate is mature. Light weight fine aggregate has been used by the ready-mix concrete industry for many years; therefore, ICC is a new use for a well understood material. This represents a low risk / high benefit opportunity to improve concrete durability.



Water doesn't penetrate easily into center of concrete mass

Localized sources of water available from large pores with minimal stress throughout concrete mass

Reference: D. Bentz, Early Age Cracking

Figure 2: Autogenous Shrinkage and How ICC Mitigates Autogenous Shrinkage

The means of delivering the curing water into the concrete has been identified. The question is how to determine how much is sufficient? Previous research estimates that there is a 6.4% water demand caused by autogenous shrinkage. [2] Since there is some variance depending on the mixture composition, a value of 7% for water demand is used for the mixture development. How to adjust the concrete mixture to incorporate the lightweight fine aggregate (LWFA) will be demonstrated later in the Tech Brief.

The Journey

Internally Cured Concrete (ICC) has been deployed by several state DOT's, especially for concrete bridge decks. ICC is placed and handled just like any structural concrete mixture. ICC has been proven to work in its final form and under expected conditions. Results from the bridge decks placed using ICC and other structures show a reduction, as predicted, in the frequency and width

Topics

"Contract language required for ICC implementation is not extensive."

"Changes to placement and finishing properties are minimal."

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Maria Rosa, Eastern Federal Lands Highway Division, Technology and Engineering Coordinator, Maria.Rosa@dot.gov of any cracks that occur. The laboratory studies performed by Purdue University, National Institute of Standards and Technology (NIST), and others using highly absorptive lightweight fine aggregate to provide a means to deliver water for internal curing has been validated by the performance of structures placed in the field in various locations by several state DOT's.

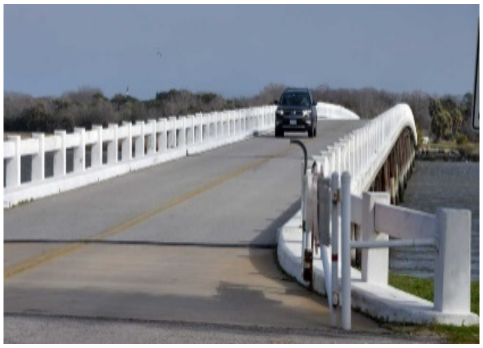
The goal of this technology implementation sponsored by CTIP and STIC was to evaluate how well the ICC could work for bridge projects delivered by FLH for our partner agencies. Remote locations and the smaller size of the projects are some of the challenges in the implementation of ICC by FLH.

Three projects were identified as candidates for using ICC. Two of the projects were administered by Western Federal Lands (WFL) and were in Idaho. The third project was administered by Eastern Federal Lands (EFL) and was in Georgia. The three bridges were of different designs to meet the traffic, site geometry, and environmental conditions. Climatic conditions of the projects varied from a humid subtropical climate to a semi -arid cold climate.

Site 1: Manning Crevice Bridge. The project was in Riggins, Idaho and consisted of the replacement of a one lane suspension bridge at the end of its service life that was built in 1934 over the Salmon River. The replacement structure is a 1 lane asymmetric suspension bridge with a 300-foot span and a cast in place concrete bridge deck. (All photos provided by FHWA Federal Lands)

Site 2: Williams Creek (Shoup) Bridge. The project was in Salmon, Idaho and consisted of the replacement of a 1 lane three span 60-year-old structure that provided access to mining, timber and emergency vehicles. Traffic accessing the bridge backed up on US 93, the main arterial road in the region. The structure was replaced with a 2-lane single span through arch bridge having a length of 220 feet with a cast in place concrete bridge deck. (All photos provided by FHWA Federal Lands)

Site 3: Fort Pulaski National Monument Bridge. The project was outside of Savannah, Georgia and consisted of the replacement of a 2 lane, 1285-foot multi-span bridge of timber pilings and pile caps with a concrete deck. The bridge provided the only access to Ft. Pulaski National Monument and a US Coast Guard Station facility. The bridge was replaced with a 1295-foot, 2 lane, multi-span concrete bridge that was a combination of precast prestress and cast in place elements. (All photos provided by FHWA Federal Lands)



The Results

For ICC, there are 3 major aspects that need to be reviewed: how easy was the technology to implement by ready mix producers, placement characteristics, and post-placement performance. For the ready-mix producer, how much extra work was required to adjust their typical concrete mixtures for bridge decks to implement an ICC mixture. For placement characteristics, how well did the concrete transport, maintain designed properties of slump and plastic air, place, consolidate and finish. Finally, did FLH's experience with ICC translate into reduced amounts of bridge deck cracking which was the end goal of implementing this technology. Post placement performance was evaluated in a laboratory setting and in the field by cracking surveys of the bridge decks. Laboratory testing was performed to get an understanding of several key properties of the original baseline mixture and subsequently compare with the modified mixture with LWFA replacement for ICC.

Ready Mix Implementation. The risk exists that the required mix adjustments and the extra bin of material to manage properly for ICC production for relatively small quantities of a few hundred yards of concrete can outweigh the benefits of a value-added pricing of the mix for the Ready-Mix producer. This can be a barrier to implementation. For the three projects, the local ready-mix producers were willing to accommodate the ICC production. The major aspects of incorporating LWFA after mix design adjustments is keeping them completely pre-wetted and manage the amount of free water to meet water/cementitious (w/cm) ratio requirements. The LWFA pile/ bin must be pre-wetted and continuously moist to ensure that the voids are filled when introduced to the mixture to provide the internal curing as it was discussed previously. As with any fine aggregate, capillary action in the voids between the fine aggregate particles will trap excess moisture. This excess free moisture needs to be accounted for during production. This is done by two methods the paper towel method (ASTM C1761) or the use of a centrifuge in a test method developed at Purdue University [3] of the type typically used in ASTM D2172. The paper towel method is simple, inexpensive and is an approved ASTM test method but relatively time consuming compared to the centrifuge method which at this writing is not a standard test method. ASTM

C1761 was used as the QC procedure by all 3 ready mix producers. FLH staff used a centrifuge on one of the projects as a shadow QC tool to investigate its performance relative to ASTM C1761. Free moisture contents and absorptions corresponded well with ASTM C1761 results. However, barriers to implementation of the more rapid centrifuge method is the equipment cost of around $2000 and a published ASTM or an AASHTO test method does not exist.

Figure 3: Centrifuge Used for Free Moisture Determination of LWFA

Placement Characteristics. A concrete mixture has to perform in a predictable manner after the teething problems of a new mix have been eliminated. If stable, predicable performance in terms of workability (slump), air content and handling during placement and finishing is not prevalent, then this will be a barrier to implementation. Large swings in mixture performance will make it impossible to place and finish the concrete to have a completed uniform deck with the same properties throughout. In the case of all 3 projects, stable performance of the ICC mixtures was noted after some initial issues. For Fort Pulaski – where the new bridge was being built adjacent to the existing bridge a pump truck was initially used working off the existing bridge in a single lane closure at the start of the first placement. The boom position required the concrete to be pumped straight up and back down. The boom orientation caused significant slump and air loss from the tests taken from the concrete truck prior to discharging in the pump truck hopper and the end of the discharge hose of the pump truck. When the contractor switched to a crane operated 3-yard bottom dump discharge hopper the problem was resolved. Production was adequate using this method and was used for the remaining 13 placements and 900 plus yards of ICC concrete for Fort Pulaski. Manning Crevice consisted of 2 days of placement to complete the bridge deck while 3 days were used for Shoup. For the two other projects, a concrete pump was used with no major loss of plastic properties for the placements of 200 and 280 cubic yards. Fort Pulaski and Shoup decks were placed and finished using a Bidwell, while Manning Crevice used a vibrating dual roller screed for placing and finishing.

Design w/cm ratios of the three concrete mixtures ranged from 0.37 to 0.39, with two out of three mixtures with a w/cm of 0.39. The in-place w/cm ratios were slightly lower, 0.36 to 0.37, due to the standard practice of having “hold back” water (allowable water being held prior to reaching the job site) that was not needed due to already having satisfactory workability and plastic properties.

There was no negative feedback from the finishing crews about the behavior of the concrete. Below shows data of the consistency of the mixes during construction.

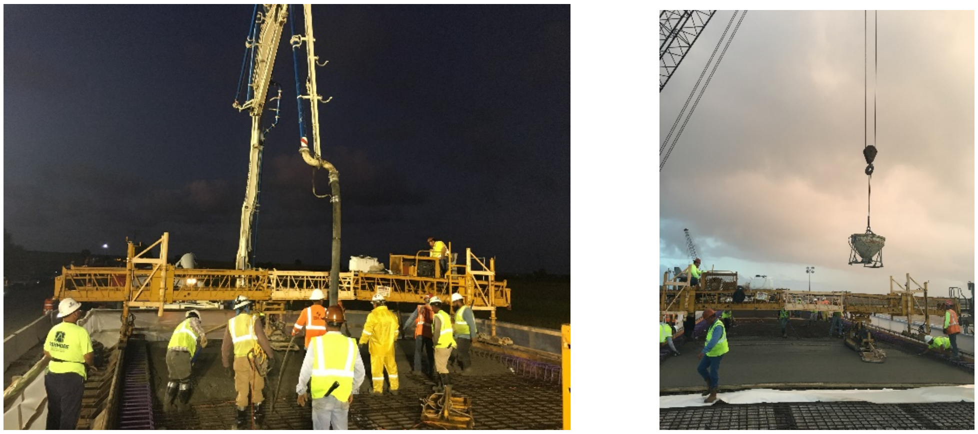


Figure 4: Initial Use of Pump Ft. Pulaski changed to 3 Yard Hopper Dump (All photos provided by FHWA Federal Lands)

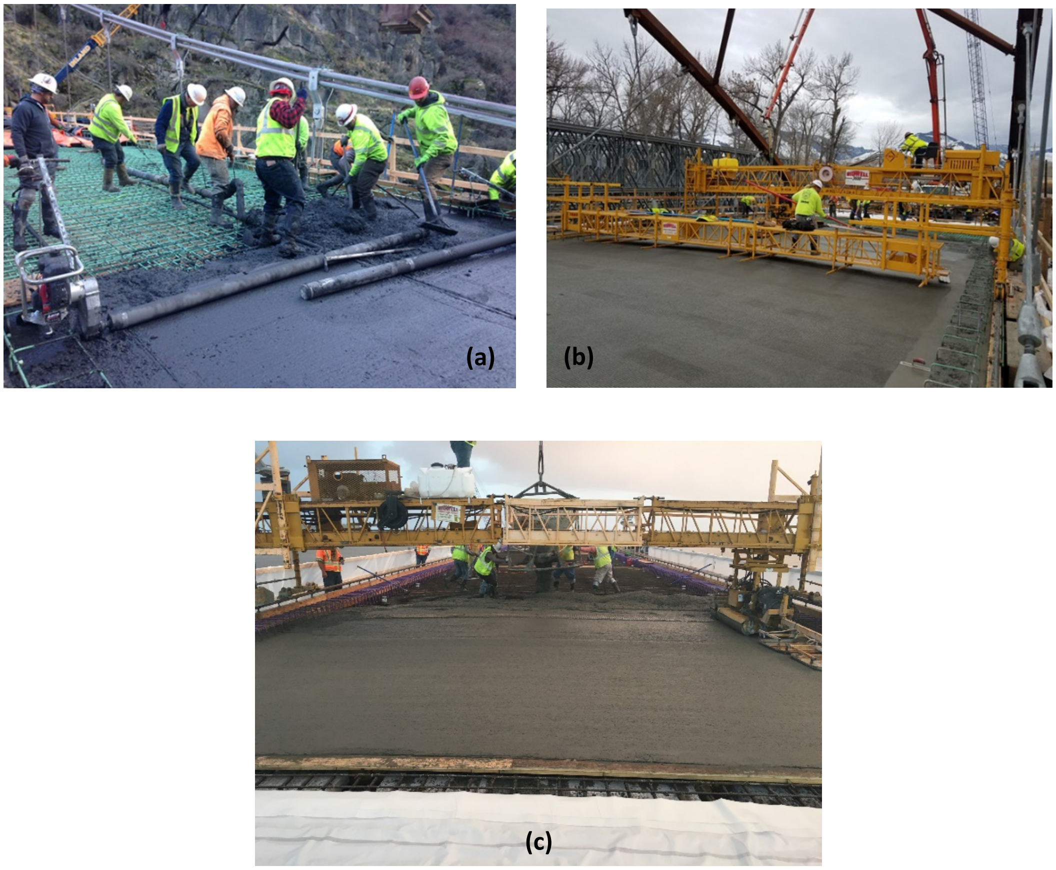


Figure 5: (a) Roller Screed Finishing - Manning Crevice, (b) Bidwell Finishing - Shoup, and (c) Bidwell Finishing - Ft. Pulaski (All photos provided by FHWA Federal Lands)

Table 1: Slump and Air Data from Project Concrete Placements

Project	Mean Slump (inches) To nearest (0.25”)	Standard Deviation Slump	Target Air Content (%)	Mean Air Content (%)	Standard Deviation Air Content (%)
Manning Crevice	5.0	0.7	6.5	8.6	0.7
Shoup	5.0	1.0	6.0	5.8	0.6
Ft Pulaski	7.0	1.0	6.0	5.6	0.6

Post Placement Performance. The three concrete mixtures in this study were also evaluated against the baseline concrete mixtures without ICC technology. This comparison highlighted of what changes in performance were attributable to ICC compared to the baseline performances of concrete mixtures. This was to also check the results against the work of previous researchers to see if the performance being reported by the study were similar. Post placement crack surveys were also performed periodically on the three structures to evaluate the actual performance of the bridge decks.

Laboratory Mixture Evaluation. After the concrete mixtures had been developed for the three projects, materials were evaluated in the laboratory for performance measured with several tests to assess cracking risk and mixture performance. The tests were as follows:

> ASTM C1698- Autogenous shrinkage is measured by ASTM C1698. The concrete mixture is wet sieved to remove coarse aggregate and a flexible plastic tube with bellows is used as the sample mold and subsequent sealed specimen surface. Measurements start immediately, prior to the concrete setting. This method captures volume change at early age, less than 24 hours, and before final set which is not captured by any other test method and in a sealed condition.

Figure 6: ASTM C1698 Autogenous Shrinkage
(All photos provided by FHWA Federal Lands)

Results for ASTM C1698 indicated a reduction in autogenous shrinkage that ranged from 45% to 75% for the 3 mixtures compared to their respective baseline concrete mixtures without the ICC technology. The mixture with a w/cm ratio of 0.37 exhibited the greatest reduction in autogenous shrinkage of 75%.

ASTM C157 – The volume change of hardened concrete is measured by ASTM C157. The initial reading is taken at 24 hours. The ends of the molds are loosened after specimen fabrication to prevent any restraint / debonding of the gauge pins. This process means that any early age (autogenous shrinkage) is not captured. A very low w/cm ratio mix will appear to have low drying shrinkage but in fact have high overall volume change (autogeneous + drying) that would cause the mix to be crack prone. This is measuring the volume change caused by water evacuating pores of hardened concrete.

Figure 7: ASTM C157 Molds and Specimen (All photos provided by FHWA Federal Lands)

Results for ASTM C157 drying shrinkage were similar for the control mixes and the mixes containing ICC at 120 days. ICC mixes did have a reduction up to 14 days after the end of curing. Since the purpose of ICC is to reduce autogenous shrinkage volume changes it would not be expected to reduce drying in the long term since this test measures the unrestrained volume change caused by water evacuating pores of hardened concrete.

ASTM C1581 - ASTM C1581 is a means to measure the cracking risk of a concrete mixture. This test method simulates the degree of restraint found in bridges. Specimens are cast around a strain gauge instrumented steel ring that provides the restraint. It is an accelerated test in as such that the standard test method has only 24 hours curing before stripping the specimen formwork and drying is initiated. The test can be considered a mixture of autogenous shrinkage initially and drying shrinkage after the stripping of specimen formwork. The age of cracking and the rate of tensile stress development is used by the test method to assign a relative cracking risk that ranges from low, moderate low, moderate high and high.

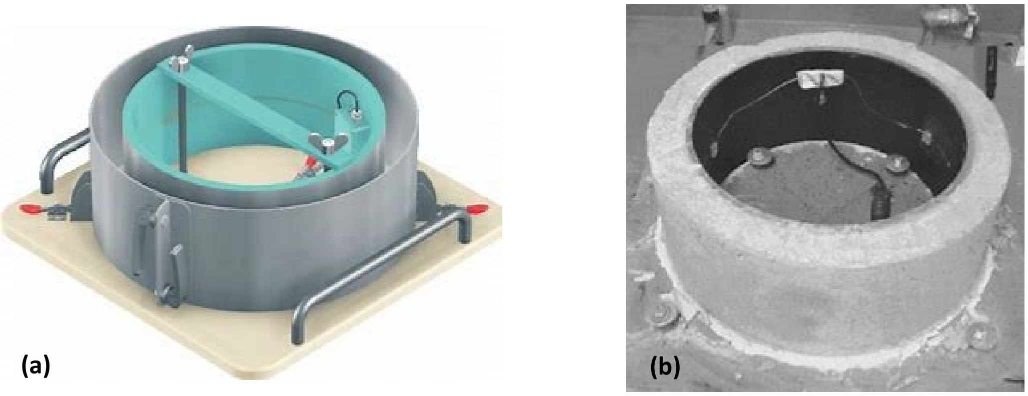


Figure 8: ASTM C1581 Restrained Shrinkage - (a) Specimen Mold (b) Test Specimen

Results for ASTM C1581 demonstrated that the three ICC mixtures improved in time to cracking compared to the respective baseline concrete mixtures ranging from 1 to 2.5 days. The cracking risk for the three baseline mixtures was moderate high, while two out of the three ICC mixtures were considered moderate low.

ASTM C1556 - ASTM C1556 measures the apparent chloride diffusion of a concrete mixture. This is a measure of the transport properties of concrete. It determines a rate of chloride diffusion after 28 days of curing which can be used to determine service life projections for structures exposed to chlorides. The intent is to ensure ICC mixtures utilized are at least neutral relative to the base mixture without LWFA for the apparent rate of chloride diffusion.

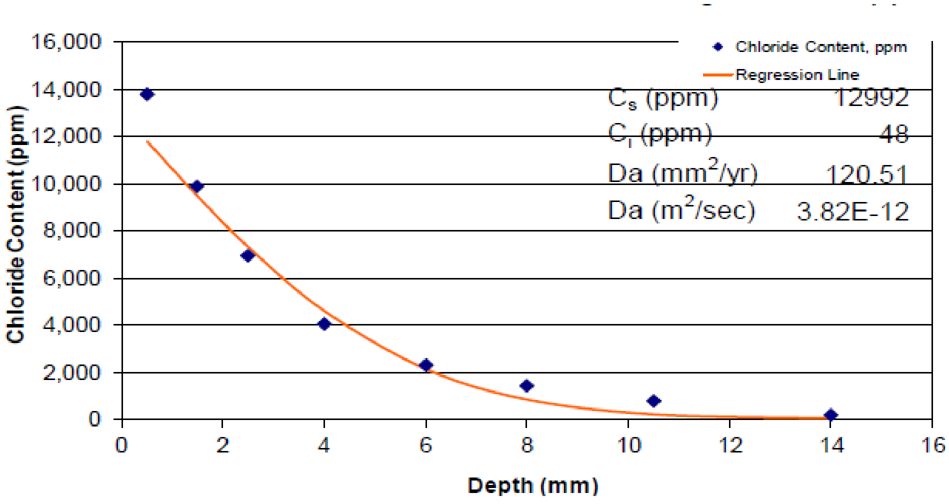


Figure 9: ASTM C1556 Data for Determination of the Apparent Chloride Diffusion Rate

Results for ASTM C1556 for two of the ICC mixtures containing Portland cement and type F fly ash indicated a slight decrease in the apparent chloride diffusion rate relative to the baseline mixture with an average of 3.8 x10^{-12} in/sec. The third mixture, used for Ft Pulaski to account for the severe chloride exposure, was a ternary blend of Portland cement, type F fly ash, and micro silica. The ternary ICC mixture did have an increase in the apparent chloride diffusion rate relative to the baseline mixture. But the ICC ternary blend had an apparent diffusion rate that was approximately 4.5 times lower (0.8x10^{-12} in/sec) than the mixtures containing only Portland Cement and fly ash. The values from the tests indicate that all three mixtures will perform well in meeting service life requirements.

Compressive strength was also evaluated in the laboratory study. 28-day compressive strength results indicated a decrease in compressive strength that ranged from 4% to 8% for the ICC mixes relative to the baseline mixtures at equal air contents. However, due to the service life requirements driving the mix design composition, they were overdesigned for compressive strength with even the lowest strength ICC mixture being almost 2000 psi over the f'c required for structural design. With service life requirements driving the mix process, an expected outcome of any strength reduction from incorporating LWFA into the mix for ICC would be overcompensated by the service life design providing excess compressive strength as a byproduct of the design.

Post Placement Bridge Deck Cracking Performance. All bridge decks in the study received 14 days of moist curing with either cotton mats or burlap with soaker hoses to keep the concrete surface moist with a polyethylene sheeting covering to prevent moisture loss. After the 14 days of curing the bridge decks were exposed to the environment. Cracking has been periodically monitored since the deck placements.

Manning Crevice Bridge. The Manning Crevice deck was placed in two pours. The sequence was that a half of the deck was placed from the abutment to about the centerline of the bridge and the rest placed subsequently in the second pour. The first day placement had many transverse cracks occur while curing which were immediately visible after curing was removed. The second day pour occurred the next day and did not exhibit any cracking during or after removal of curing. What made such a difference in performance in the two days of placement? Review of slump, air, unit weight and compressive strength indicated no change in mix properties from day 1 to day 2. However, the structure was very flexible to the point where construction elevation shots of the bridge by surveying instruments had to be done at the same time of day to avoid movements up to 1 foot in the structure. With understanding of the pour sequence, 1 day old concrete, and structure flexibility; the immediate appearance of the cracks indicated that the concrete placement sequence initiated the transverse cracking. The day 2 placement had no cracking after 6 months in service. Further site visits for crack surveys were not possible after an epoxy overlay was placed over the deck.

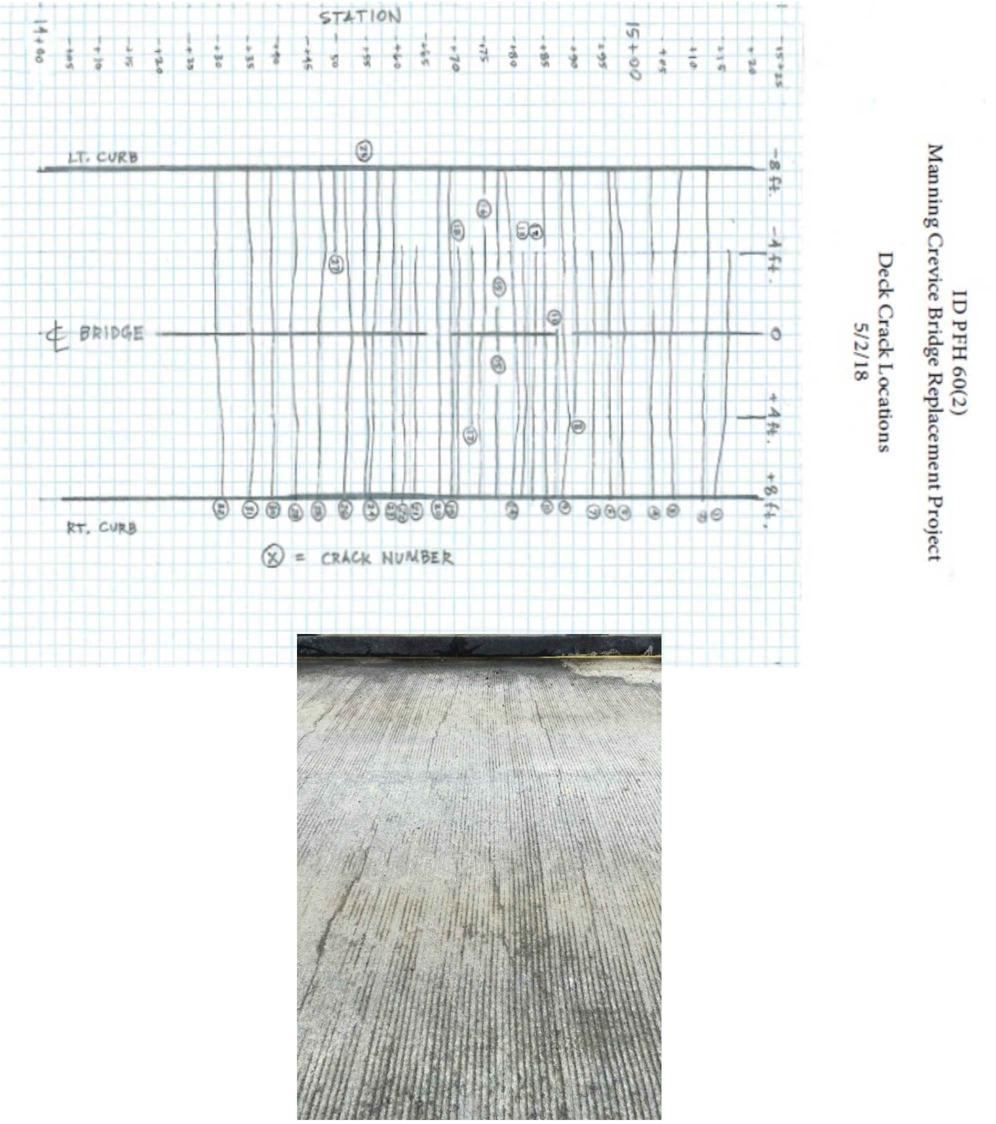


Figure 10: Manning Crevice – Crack map from first day placement 6-months survey (All photos provided by FHWA Federal Lands)

Shoup Bridge. Shoup deck was placed in 3 pours. After removal of curing there was no evidence of cracking. A survey of the deck a few months later revealed no cracking other than a hairline crack at the construction joints between the three with no cracking within the placements. A crack survey done 17 months after the deck placement did show some fine crazing cracks grouped together in random locations on the deck that were only visible after the deck being wet and subsequently drying out. No major cracking was reported on the approximately 8000 square foot bridge deck. An additional crack survey was conducted 34 months after the deck placement. The condition of the deck was similar to what had been observed at 17 and 34 months with no major cracking.

Figure 11: Shoup Bridge – 17 months Bridge Deck Cracking Survey, random fine crazing cracks parallel to span length (All photos provided by FHWA Federal Lands)

Figure 12: Shoup Bridge – 34 months Bridge Deck Cracking Survey, random fine crazing cracks parallel to span length (September 2020) **Fort Pulaski Bridge**.

Ft Pulaski deck was placed in 13 pours over a four-month period. There was one incident of plastic shrinkage cracking occurring during the first placement. Span 1 experienced plastic shrinkage cracking due to the curing mats and polyethylene sheeting being blown back by the wind before final set. Adjustments were made to the curing procedures and there were no more incidents of plastic shrinkage cracking. After removal of curing, there was no evidence of cracking other than the plastic shrinkage crack. (All photos provided by FHWA Federal Lands) previously noted. A crack survey done a few months after the completion on the deck placements only located about 4 linear feet of cracking with half of that attributed to the plastic shrinkage cracks discussed above and the rest on Span 2. A crack survey done at 14 months located an additional 3 feet of cracking for a total of 7 feet. A survey done at 28 months located some small cracks radiating from Span 11 joints with the cracks in Span 1 increasing in length and width. The total of crack length was approximately 10 linear feet. These crack surveys indicate there has been some crack growth over time, but not at a drastic rate. The total crack length of 10 feet for a bridge deck with 35,000 square feet of area is extremely low with a crack density of 0.0003 in/ square foot of deck.

Figure 13: Ft Pulaski – Plastic Shrinkage Crack, Placement #1 Span 1 (All photos provided by FHWA Federal Lands)

Figure 14: Ft Pulaski – 3 and 14 months Bridge Deck Cracking Survey, cracking on span 1 (All photos provided by FHWA Federal Lands)

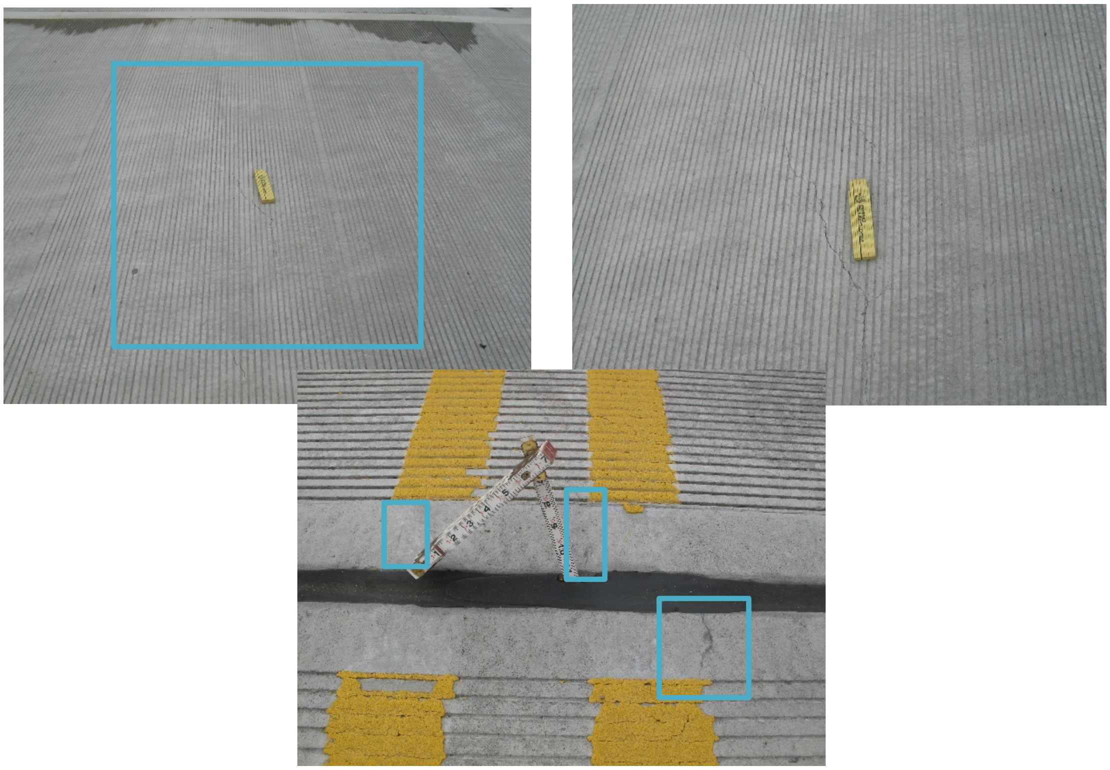


Figure 15: Ft Pulaski – 28 months Bridge Deck Cracking Survey, most cracking on span 1 and span 10 joint (All photos provided by FHWA Federal Lands)

The Implementation

Making the Mix Adjustments to Implement ICC. The implementation of ICC for the three projects was accomplished through minor additions to the Special Contract Requirements related to the substitution of LWFA for some of the normal weight fine aggregate in the baseline mix. Note that 7 pounds of water per each 100 pounds of cementitious material in the mix on a cubic yard basis is considered the baseline amount required to provide enough internal curing water to mitigate autogenous shrinkage. An example will be presented on how the baseline mixture is modified. The baseline concrete mixture example has 700 lbs of cementitious material per cubic yard that would need to be adjusted to become an ICC mixture. First, determine the amount of internal curing water required for the mix. This is determined by:

*7lbs water per 100lbs cementitious * (700/100) = 49 pounds of internal curing water*

The amount of LWFA needed for the mix to satisfy the amount of internal curing water would depend on the percent absorption of the source used. As an example, if a source of LWFA had 15% absorption then:

49 pounds internal curing water/ 15% absorption of LWFA = 327 pounds of LWFA would be needed in the mix

This assumes that all the water absorbed into the pores of the LWFA would be able to be 100% reabsorbed out of the LWFA to mitigate autogenous shrinkage. In most cases – some of the water will remain in the pores and the percentage that remains needs to be determined. This is done following procedures in ASTM C1761. By example, if 10% of the water is not available after testing, according to ASTM C1761, the efficiency would be 90% and the amount of LWFA needed has to be adjusted.

Adjusted LWFA = LWFA/ efficiency factor = 327/90% = 363 pounds

This is the value that will be used to complete the rest of the calculations to adjust the concrete mix. Determining the Saturated Surface Dry (SSD)specific gravity of the LWFA would then determine the volume of normal weight fine aggregate to replace. With the example above, if the SSD Specific Gravity of the LWFA was 1.75 then the volume of LWFA in the mix would be

*Weight LWFA/(SG*62.4) = 363/ (1.75*62.4) = 3.22 cubic feet*

If the baseline concrete mixture has 1000 pounds of normal weight fine aggregate (NWFA) in the baseline mixture with a SSD specific gravity of 2.60 then the volume of normal weight fine aggregate would be

*Weight of NWFA/(SG*62.4) = 1000/ (2.6*62.4) = 6.16 cubic feet*

Then, the adjusted volume for the NWFA would be

Volume(NWFA)- Volume (LWFA)= Adjusted NWFA   6.16- 3.22 = 2.94 cubic feet

The new batch weight for NWFA would be the adjusted volume multiplied by the specific gravity of the aggregate

*Adjusted NWFA Volume *(SG*62.4) =   2.94*(2.60*62.4) = 477 pounds of NWFA*

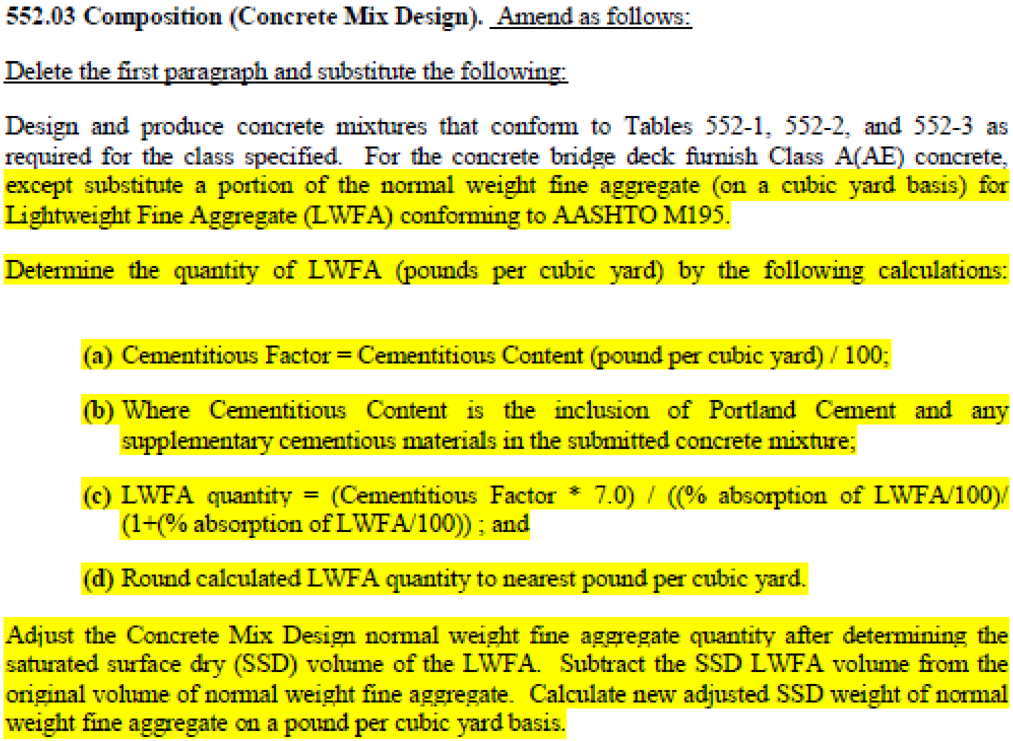
Therefore, the mix has been adjusted – keeping the same volume of NWFA in the baseline mix but incorporated LWFA. Subsequently, the new batch weights would be 477 pounds of NWFA and 327 pounds of LWFA per cubic yard of concrete. And a unit weight reduction of about 7 pounds per cubic foot in the ICC mixture. Here are the mixes used for the three projects:

Table 2: Project Mix Design

Material	Ft Pulaski	Manning Crevice	Shoup Bridge
Cement (pcy)	564	500	515
Fly Ash (pcy)	106	125	172
Silica Fume (pcy)	35		
Coarse Agg #1 (pcy)	1785	1662	1172
Coarse Agg #2 (pcy)			478
LWFA Absorption	12%	19%	19%
LWFA (pcy)	564	326	396
Fine Agg (pcy)	251	898	627

% Air	6	6.5	6
Water (pcy)	275	231	266
w/cm	0.39	0.37	0.39
(sand replacement)	786	499	563

Contract Language to Implement ICC. Language was inserted into each construction contract for ICC implementation. The goal was to make the changes required to the contract to implement ICC with sufficient clarity and with minimal verbiage. The major addition to the contract was the language to direct the contractor to use LWFA for ICC with the subsequent series of calculations based on internal curing water, LWFA absorption, and LWFA specific gravity to determine the baseline concrete mixture modifications for ICC. The second addition was language directing the contactor to keep the LWFA used for ICC fully saturated, and to perform daily moisture checks prior to batching, to control the w/cm ratio during mix production. The following was typical of the language inserted into the contract. This was used for the Shoup Bridge project:



552.03 Composition (Concrete Mix Design). Amend as follows:

Delete the first paragraph and substitute the following:

Design and produce concrete mixtures that conform to Tables 552-1, 552-2, and 552-3 as required for the class specified. For the concrete bridge deck furnish Class A(AE) concrete, except substitute a portion of the normal weight fine aggregate (on a cubic yard basis) for Lightweight Fine Aggregate (LWFA) conforming to AASHTO M195.

Determine the quantity of LWFA (pounds per cubic yard) by the following calculations:

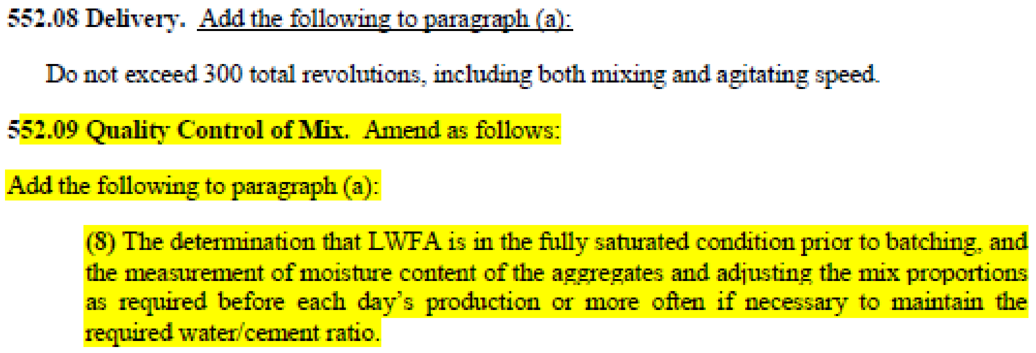
(a) Cementitious Factor = Cementitious Content (pound per cubic yard) / 100;

(b) Where Cementitious Content is the inclusion of Portland Cement and any supplementary cementious materials in the submitted concrete mixture;

(c) LWFA quantity = (Cementitious Factor * 7.0) / ((% absorption of LWFA/100)/ (1+(% absorption of LWFA/100)) ; and

(d) Round calculated LWFA quantity to nearest pound per cubic yard.

Adjust the Concrete Mix Design normal weight fine aggregate quantity after determining the saturated surface dry (SSD) volume of the LWFA. Subtract the SSD LWFA volume from the original volume of normal weight fine aggregate. Calculate new adjusted SSD weight of normal weight fine aggregate on a pound per cubic yard basis.



552.08 Delivery. Add the following to paragraph (a):

Do not exceed 300 total revolutions, including both mixing and agitating speed.

552.09 Quality Control of Mix. Amend as follows:

Add the following to paragraph (a):

(8) The determination that LWFA is in the fully saturated condition prior to batching, and the measurement of moisture content of the aggregates and adjusting the mix proportions as required before each day's production or more often if necessary to maintain the required water/cement ratio.

In terms of contract language, this was all that was required to modify the contract to incorporate ICC into the project. Like any concrete mixture submitted, the ICC mix would need to be evaluated for contract requirements such as compressive strength, air content and workability (slump) along with any other durability / service life performance testing that was stipulated in the contract. As discussed previously, there were no major issues with the ICC mixes for meeting these contract requirements.

Costs to Implement ICC. Costs associated with using LWFA for internally cured concrete included the cost of delivery of the LWFA to the ready-mix producer, amount of LWFA needed per cubic yard to provide the mix with the appropriate amount of internal curing water, and the extra work required to adjust and test the revised concrete mixture. All these costs are rolled up into a value-added upcharge to the cost of the baseline concrete mixture that was modified for ICC.

Costs for shipping the LWFA to the ready-mix plants ranged from 85 to 110 dollars per ton Freight On Board. Quantity used per cubic yard of concrete ranged from 326 pounds to 564 pounds per cubic yard. Thus, for each ton of LWFA would provide Internal Curing Water between 3.5 cubic yards and 5 cubic yards of concrete, which influenced the end cost and the amount of value added upcharge, relative to the baseline concrete mixture. Estimated upcharge costs per yard of concrete was approximately 100 dollars for both Shoup and for Ft. Pulaski. Since Manning Crevice used a Construction Manager/ Construction General (CM/CG) contract vehicle the extra cost associated from the use of ICC concrete was not readily available.

Additional costs associated with ICC utilization for the concrete bridge deck and the total project are important metrics since it can be another barrier to implementation. Typically, a concrete mixture is the only variable cost in a bridge deck since costs for formwork, reinforcing steel, concrete placement and curing will occur regardless what concrete mixture is used for the deck placement. There is incentive to keep costs down on the concrete mixture as a means to reduce the cost of the bridge deck. Any additional costs for a concrete mixture needs to be provide a significant benefit. Looking at the two projects where it was easy to estimate the cost increase from utilizing ICC, the cost increase for the bridge deck and the overall increase in project costs can be calculated. For Shoup Bridge, the increase worked out to be about $28,000 for using ICC concrete. This was 10% of the cost of the bridge deck and 0.5% of the overall project costs. For Fort Pulaski, the increase cost for ICC concrete was about $90,000. The increase worked out to be 8% of the cost of the bridge deck, and 0.9% of the total cost of the project.

Q&A

Q: Why the need for Internally Cured Concrete?

A: *Concrete mixes that are needed for extended service life undergo autogenous shrinkage (internal desiccation) at a very early age that cause stresses and can lead to early age cracking. External curing cannot address this.*

Q: What makes a concrete mix an Internally Cured Concrete mix?

A: *The substitution of some of the normal weight fine aggregate with fully saturated Light Weight Fine Aggregate provides a readily available reservoir of water for reducing autogenous shrinkage by internally curing the concrete.*

Q: What does the water in the fully saturated Light Weight Fine Aggregate do?

A: *It provides water that is readily available internally throughout the concrete to aid in curing and reduce autogenous shrinkage.*

Q: How do you determine how much internal curing water is needed?

A: *Previous research has determined that 7 pounds of water for each 100 pounds of cementitious material in the mix is sufficient.*

Q: How much Light Weight Fine Aggregate do you substitute in the mix?

A: *It will be 7 pounds per 100 pounds of cementitious material divided by the lightweight fine aggregate percent absorption. The lower the absorption of the fine aggregate the more needed.*

Q: What would be typical quantities in a mix?

A: *Depending on total cementitious content and percent absorption of the mix it would typically range from 300 to 600 pounds per cubic yard*

Q: What language was changed in the contract to incorporate Internally Cured Concrete?

A: *Minimal changes required. A few paragraphs in the Structural Concrete Section 552 of the contract was all that was required for making concrete mix modifications to incorporate Light Weight Fine Aggregate*

Q: How does substituting LWFA into the mix change mix handling, plastic properties, and placement?

A: *Not much. Admixture dosages might need to be adjusted a bit but other than that the only difference is a reduced unit weight of the concrete mix.*

Q: How much was the cost of using Internally Cured Concrete?

A: Added cost was about $100 per cubic yard of concrete. This included the shipping, batching and placement. Cost as part of the bridge deck averaged 9% and overall cost to the project was 0.7%.

Q: How much did it reduce bridge deck cracking?

A: T*wo bridge decks are still visible for surveys. After over two and one half years one deck has no* *visible shrinkage cracking, only some finish crazing on the surface of the 8000 square foot deck . The second deck had 10 linear feet of shrinkage cracking for a deck with 35,000 square feet of surface area.*

The Wrap-Up

The use of fully saturated Light Weight Fine Aggregate (LWFA) provides a means of reducing early age concrete bridge deck cracking from autogenous shrinkage by internally curing the concrete. Concrete mixtures used to meet the extended service life requirements used regularly for concrete bridge decks can be susceptible to early age cracking.

LWFA is substituted for a portion of the normal weight fine aggregate to provide internal curing water. Substitution rates vary from 300 to 600 pounds of lightweight fine aggregate depending on the concrete mix and the absorption of the LWFA.

Changes to placement and finishing properties are minimal. Contract language required for ICC implementation is not extensive. Overall cost averaged 9% of the total cost of bridge deck construction and 0.7% of total project costs for the projects in this CTIP Initiative. After more than two and one half years in service , bridge decks with the ICC technology show little if any cracking.

More Information

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Key Words—bridge deck cracking, autogenous shrinkage, internal curing of concrete, light weight fine aggregate

"The incorporation of lightweight fine aggregate into concrete mixtures to provide internal curing reduce cracking"

"Contract language required for ICC implementation is not extensive."

"Overall cost averaged 9% of the total cost of bridge deck construction and 0.7% of total project costs for the projects in this CTIP Initiative."