Bridge Views

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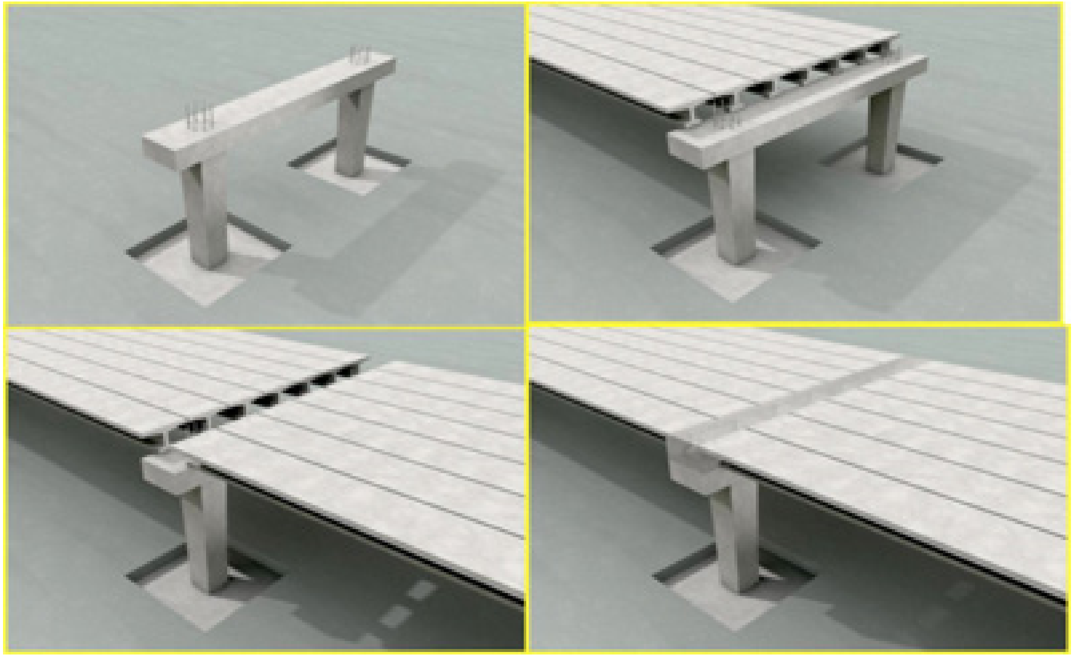
Welcome to *CONCRETE BRIDGE VIEWS!*

Alpa Swinger, Portland Cement Association

The photograph shows the bridge at sunrise with the piers illuminated using blue lights.

Welcome to Concrete Bridge Views! This is the first issue of a new bridge newsletter published jointly by the Federal Highway Administration and the National Concrete Bridge Council. It's sister publication, HPC Bridge Views, was first published in 1999 as a four- or six- page bimonthly newsletter and focused on high performance concrete. It's last issue was July/August 2011. This inaugural issue of Concrete Bridge Views features an expanded scope of concrete bridge longevity, preservation, materials, and innovation. Articles on concrete bridge durability, preservation strategies, new efficient beam shapes, accelerated bridge construction, materials and testing, non-destructive evaluation of bridges, designing for multi-hazard events, new types of reinforcement, how to achieve over 100-year service life, and upcoming materials like Ultra-High Performance Concrete (UHPC) will be featured. The new publication is designed to continue the tradition of disseminating valuable information to our readers. As such, the first issue number of Concrete Bridge Views will be a continuation of the HPC Bridge Views numbering, allowing our readers access to archived information. Read on and enjoy!



The photograph shows a model in four stages: the first stage is the bent cap by itself, the second stage is the bent cap supporting one span's beam, the third stage is the bent cap supporting two span's beams, and the fourth stage is concrete on top of the bent cap joining the spans together in an integral joint.

Fully Precast Bridge System used in Washington State Highways For Life Project, Part 1—Research

Bijan Khaleghi, Washington State DOT

The Washington State Department of Transportation (WSDOT) Highways For Life (HFL) project offers a precast concrete bridge system that is simple, rapid to construct, with excellent seismic performance. The WSDOT HFL project includes precast segmental columns, precast bent cap, and precast superstructure. The project is also known as the US 12 Bridge over I-5, Grand Mound to Maytown Interchange Phase 2 Bridge 12/118 Replacement. This article is the first in a two-part series on the bridge project, and it covers the research behind the project.

Precast connections are typically made at the beam-column and column-foundation interfaces to facilitate fabrication and transportation. However, for structures in seismic regions, those interfaces represent the locations of high moments and large inelastic cyclic strain reversals. Provisions must be made for bridges in seismic regions to transfer greater forces through connections and to ensure ductile behavior in both longitudinal and transverse directions. It was envisioned that a fully precast bridge system could be favorably used in accelerated bridge construction (ABC) projects in seismic regions*(1)*.

Monolithic action between the superstructure and substructure components is the key to seismic resistant precast concrete bridge systems. Lack of monolithic action causes the column tops to behave as pin connections resulting in substantial force demands on the foundations of multi-column bents. While the transverse stability of multi-column bents is ensured by frame action in transverse direction, stability in the longitudinal direction requires the column bases to be fixed to the foundation. Developing a moment-resisting connection between the superstructure and substructure makes it possible to develop plastic hinging at the column bases. Integral bent caps introduce moment continuity at the connection between the superstructure and substructure forcing columns into double-curvature bending, which tends to substantially reduce their moment demands at the foundation, affecting the sizes and overall cost of the adjoining foundations. The University of Washington*(2)* (UW) in two research project with WSDOT demonstrated the satisfactory performance of the column-to-cap connection. The first project performed pullout tests(2) of large size bars placed into corrugated galvanized standard post-tensioning ducts with cementitious grout, and the second project performed the testing of precast column to cap connection made with grouted ducts. The UW pullout tests demonstrated that the development lengths of bars grouted into ducts are significantly reduced compare to those development lengths required by the AASHTO LRFD Specifications *(3)* Article 5.11.2.1. The development length equation developed for the WSDOT Bridge Design Manual (BDM), *(4)* shown as Equation *(1)*, is based on the UW experimental tests, and shares the same dependencies on steel strength, bar diameter, and concrete or grout strength with the AASHTO LRFD development length equations.

$$L_d = 1.5\left[\frac{f_{ue}}{4\sqrt{f'_g}} d_b + \frac{d_{duct} - d_{bar}}{2}\right] \quad (1)$$

The second term in Equation (1) represents the effect of the pullout cone, and the difference between duct and bar diameters. AASHTO LRFD requires that the development length be increased by a factor of 1.25 for seismic applications *(3)* WSDOT BDM *(4)* recommends using a higher factor of 1.5 for field applications of grouted duct system. Table 1 shows the minimum embedment length of grouted bar-duct sleeves. The minimum development lengths are based on A706 Grade 60 deformed reinforcing bars with expected tensile strength (fue) of 95 ksi, and compressive strength (f'g) of 6.0 ksi.

As part of the HFL project, the UW has performed several tests of precast column-to-footing connections. To achieve proper interface shear transfer between the precast column and the cast-in-place concrete footing, the exterior of the column is roughened near the bottom to improve the transfer of shear stress. The shape of the lower column segment extending into the footing is changed to octagonal to provide more uniform interface surface. The precast column extends just below the footing, to assure that the force transfer at the bottom of the column bars can take place satisfactorily. The column-to-cap beam connection is made with a small number of large bars column grouted into ducts in the

Bar Size	Bar Outside diameter d_{bar}, in.	Duct diameter d_{duct}, in.	Theoretical Grouted Sleeve Develoment Length, L_d, in.	L_d/d_b Sleeve	Grouted Bar-Duct Develoment Length, L_d, in.
3	0.42	2	6.475	15.42	8.0
4	0.56	2	8.133	14.52	10.0
5	0.70	3	10.542	15.06	12.0
6	0.83	3	12.082	14.56	14.0
7	0.96	4	14.372	17.97	16.0
8	1.10	4	16.030	14.57	18.0
9	1.24	6	19.188	15.74	21.0
10	1.40	6	21.083	15.06	24.0
11	1.55	8	24.360	15.72	27.0
14	1.86	8	28.032	15.07	32.0
18	2.48	8	35.376	14.26	40.0

Table 1. Proposed Grouted Bar-Duct Development Length.

cap beam. Their small number, and the correspondingly large ducts sizes that are possible, lead to a connection that can be assembled easily on site.

References

1. Khaleghi, B. WSDOT Plan for Accelerated Bridge Construction. Journal of Transportation Research Board No 2200, Bridge Engineering 2010, Volume 1, pp 3-11.
2. Kyle P. Steuck Jason B.K. Pang, Marc O. Eberhard, John F. Stanton, Rapidly Constructible Large-Bar Precast Bridge-Bent Seismic Connection, WA-RD 684.2, October 2008
3. AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010.
4. Bridge Design Manual, Publication No. M23-50, Washington State Department of Transportation, Bridge and Structures Office, Olympia, Washington, 2010.

Further Information

For further information, readers are encouraged to contact the author at 360 705-7181 or khalegb@wsdot.wa.gov, and view project information at the Federal Highway Administration's Highways for Life website: http://www.fhwa.dot.gov/hfl/partnerships/bergerabam/index.cfm

Improving Concrete Bridge Decks with Internal Curing

Jason Weiss, Purdue University; Carmelo DiBella, Global Consulting, Inc., Turner-Fairbank Highway Research Center; and Dale Bentz, National Institute of Standards and Technology

The photograph shows internally cured concrete being cast in a bridge deck Monroe County, Indiana.

Transportation agencies strive to provide durable, long lasting concrete bridge decks. While high performance concrete is frequently desired due to its resistance to chloride ingress and corrosion, these mixtures are often accompanied with an increased risk of early age cracking due to the use of high cementitious contents, low water-to-cement ratios, and finer particle sizes. In fact it is often said that the 'high performance concrete' produced is durable, but only between the cracks. Internal curing is one method that has been developed to design concrete to be less prone to early-age cracking. Internal curing also reduces the rate of chloride (or fluid) ingress which can lead to corrosion. The fluid transport properties are reduced in three ways. First, internal curing supplies additional water that promotes increased hydration thereby reducing the porosity of the concrete. Second, internal curing reduces influence of the interfacial transition zone causing it to be 'almost nonexistent' at the lightweight aggregate (LWA) when compared with the interfacial transition zone around sand. Third, internal curing reduces unwanted cracking thereby reducing other paths for fluids to reach the reinforcing steel.

What is Internal Curing

Simply stated, the basic principle is to use prewetted fine LWA to provide moisture to the hydrating cement after the concrete sets. This prewetted LWA is used in place of a fraction of the conventional sand used in a mixture. While the water remains primarily in the prewetted LWA during mixing and transportation, the water can be drawn out of the LWA due to pressure that is developed in the pore fluid (e.g., 'water' in the concrete) after setting, or prior to setting in the case of evaporation. In the latter case, the prewetted LWA will assist in reducing plastic shrinkage, settlement, and its associated cracking.

This concept of internal curing is compared and contrasted with more conventional (external) curing in Figure 1. Conventional external curing places water at the surface of the concrete shortly after placement that can be absorbed over time. In practice, water curing is often difficult to perform and as such curing membranes or sealers are often used; however, these approaches do not add additional needed water to the system. Further, in lower water-to-cement ratio systems the external curing water cannot penetrate much beyond the surface (on the order of 3 mm of movement after 18 hours). Internal curing, however, uses the fine LWA to supply water uniformly across the cross section as shown in Figure 1. Proportioning procedures exist to determine the amount of lightweight aggregate to use considering both the volume of water that is to be supplied and the spatial distribution of the LWA.

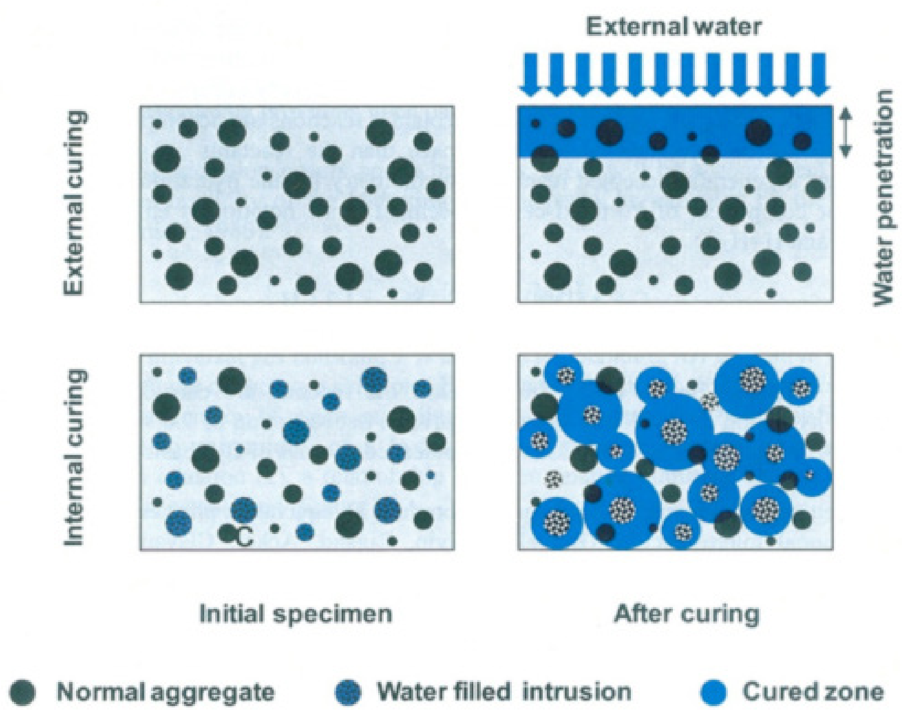


Fig. 1. Illustrating the concept of External and Internal Curing (Castro, 2011).

A Field Trial in Monroe County Indiana

Following up on a substantial amount of laboratory research that has been performed regarding internal curing, several recent bridge decks have been cast using these materials to transition the technology from the lab to the field. While several bridge decks have recently been cast by the New York State Department of Transportation (NYSDOT), this short article will report some observations from a pair of decks in Monroe County, Indiana (outside Bloomington) that were cast in September 2010. This pair of county bridges was similar in design and location. Both decks were cast using ready mix concrete. The first deck was cast using a conventional bridge deck concrete mixture, while the second was cast using an internally cured bridge deck concrete mixture that was made using the same raw materials. While the exact proportions will vary, the internally cured mixture had approximately 55% of the fine aggregate replaced with lightweight aggregate. It should be noted that this value will vary depending on the mixture proportions and the properties of the aggregate, however it is given as a point of reference.(1) The cover photo shows the casting of the internally cured deck where it was noted that the concrete was able to be placed and finished very similarly to the conventional concrete. In fact, it was noted by one finisher that it was less ‘sticky' and slightly easier to work with.

While research is underway to quantify the performance of the conventional and internally cured bridge decks, some preliminary observations have been made after the first year. First, while the one-day strength of the internally cured concrete was approximately 10% less than that of the conventional concrete, the conventional and internally cured concrete had equivalent strengths at approximately 10 days. After 3 months, the internally cured concrete was 20% stronger than the conventional concrete. Rapid chloride permeability testing (ASTM C1202) showed that the internally cured concrete had a 10% lower charge passed at 28 days and nearly 40% lower charge passed after 3 months. The internally cured mixture also had a lower shrinkage. Additionally, it was noted that cracks developed in the conventional deck after the first few months of service (Figure 2), while at the time of this article (nearly one year after placement), the internally-cured concrete has no visible cracking (Figure 3). While cracking can occur in bridges for a variety of reasons, the lack of visible cracking in the internally cured deck is consistent with the reduction in the concrete's autogenous and drying shrinkage.

The full report of results from this trial which include a wide range of additional tests will be available in late 2011 from the Indiana Local Technical Assistance Program.

Fig. 2. Cracking that occurred when using a “conventional bridge deck mixture” in Monroe County, Indiana.

References

1. Bentz, D. P. and Weiss W. J., A Internal Curing: A 2010 State-of-the-Art Review, NIST Interagency/Internal Report NISTIR-7765, National Institute of Standards and Technology, February 2011, http://www.nist.gov/manuscript-publication-search.cfm?pub_id=907729
2. Byard, B.E. and Schindler, A.K., Cracking Tendency of Lightweight Concrete, Highway Research Center, Auburn University, January 2011, 82 p. http://eng.auburn.edu/research/centers/hrc/reports/index.html
3. Database of Internal Curing Articles, National Institute of Standards and Technology, http://ciks.cbt.nist.gov/bentz/phpct/database/ic.html
4. Kovler, K., and Jensen, O. M., editors, Internal Curing of Concrete, RILEM Report 41, RILEM Publications S.A.R.L., 2007.
5. Schlitter, J., Henkensiefken, R., Castro, J., Raoufi, K., Weiss, J., and Nantung, T., Development of Internally Cured Concrete for Increased Service Life, Publication Number FHWA/IN/JTRP-2010/10, Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, October 2010. http://docs.lib.purdue.edu/jtrp/1120/.

Further Information

For more information about this project, contact W. Jason Weiss at wjweiss@purdue.edu or 765-494-2215.

Fig. 3. Currently ‘”crack free” internally-cured concrete bridge deck in Monroe County, Indiana after 1 year in service.

Planning, Design, Construction, Preservation, and Replacement are All Linked in a Bridge's Life.

Preserving Bridges—It Means More than You Think

Anwar Ahmad, Federal Highway Administration

Typically the term "bridge preservation" is associated with existing bridges. However, bridge preservation actions and strategies should be considered during all phases of a bridge's life, from the initial planning through design, construction, and its service life until the bridge is decommissioned. Considering preservation throughout these stages is essential to maximize the service life and minimize the overall lifetime cost of the bridge.

The advancement of bridge design, evolution of materials, and innovative construction techniques has facilitated the increase of bridge design life from 50 years to 100 years. Achieving 100 years life for bridges cannot be accomplished with improved design practices, high quality materials, and construction techniques alone. Proper inspection, maintenance, and preservation actions and strategies must be employed throughout the life of a bridge. So, what does all that mean? First let's start with defining bridge preservation.

Bridge Preservation

Bridge preservation is defined as "actions or strategies that prevent, delay or reduce deterioration of bridges or bridge elements, restore the function of existing bridges, keep bridges in good condition and extend their life. Preservation actions may be preventive or condition-driven."*(1)*

Although this definition may appear to be intended for bridges that are in service, a successful bridge preservation strategy will encompasses much more.

Following is a brief discussion of the core stages of bridge life as they relate to bridge preservation:

Planning

Effective bridge preservation strategy begins in the planning stage for a new bridge. It is crucial to select appropriate materials that suit the anticipated bridge environment. Thanks to advanced research, innovations and technology in materials science, we continue to see high quality and high performance bridge materials being produced. Each material type has its purpose and limitations. So, it's critical that the appropriate material for each bridge element is carefully evaluated and selected based on the intended service for that element in a given environment. Environmental factors include: type of service that will be provided by the bridge; type of crossing; drainage area; traffic volumes; and anticipated use of

Fig. 1. Planning for a Bridge Project.

anti-icing chemicals. Other environmental factors also include the potential for a bridge to be subjected to hazardous materials, vandalism, terrorist attack, or other extreme events. So, in essence, proper planning takes long term preservation and maintainability of the bridge into account.

Design

The bridge community continues to strive towards improving design practices to enhance bridge safety, facilitate materials fabrication, and take advantage of better construction and preservation techniques. In addition to the American Association of State Highway and Transportation Officials (AASHTO) design specifications, most State Highway Agencies (SHAs) have their own bridge standards, specifications, policies and procedures. Some SHAs have developed design check lists as part of their quality control and quality assurance efforts. Some SHAs are incorporating "maintenance and preservation friendly design details" in their design practices and policies. These details include facilitating access to bridge superstructure and substructure components for inspection and maintenance activities; eliminating expansion joints*(2)* when possible by using continuous span designs or by using integral and semi integral abutment designs; and considering construction sequences of future preservation and replacement activities. Another preservation related strategy that can be incorporated in the design stage is the development of a bridge maintenance and preservation check list or instruction manual for newly designed bridges. Such bridge manuals are currently being developed for signature bridges, but the same principle can be applied to common bridges. Manuals of this type assist bridge managers and engineers in planning and performing the necessary bridge inspection and preservation activities.

Fig. 2. Designing a Bridge.

Construction

There are a number of contracting methods available to construct bridges such as the conventional low-bid, design bid build, or performance based. Regardless of the contracting method used, ensuring full compliance with the design plans, specifications and materials' tolerances during fabrication, transportation, erection, and construction is the most critical component of a successful bridge construction project. High quality construction and materials will enable the bridge to function as intended and thus reduce or eliminate the need for premature repairs.

Similarly, good design plans and quality construction materials and practices don't guarantee a good bridge if not complemented with accurate construction plans and experienced construction personnel.

Inspection and Preservation

From the time the construction phase is completed to the time

Fig. 3. Bridge Construction.

the bridge is replaced, there are numerous preservation activities that are essential for keeping the bridge serviceable. In addition to conducting routine inspections and maintenance, it's critical that the appropriate actions and or treatments are applied to the bridge at the appropriate time. For example washing and cleaning the bridge on predetermined frequency is often a cost effective strategy for protecting the steel components from corrosion. However, washing becomes an ineffective strategy if it's not done regularly. Another example of an effective preservation strategy is selecting the appropriate candidate bridges for waterproofing decks with seals and or different types of overlays. Sealing a significantly deteriorated bridge deck may not be a cost effective strategy, where as sealing a bridge deck that is in good or fair condition on regular basis is a good strategy for protecting and preserving the structural integrity of bridge decks. The FHWA Bridge Preservation Guide -

Fig. 4. Inspecting a Bridge.

Maintaining State of Good Repair Using Cost Effective Investment Strategies provides additional examples of effective preservation treatments and strategies.

Recognizing the relationship of preservation to the core bridge life stages is important to achieving the desired service life of a bridge; therefore, achieving the desired service life depends largely on the level of collaboration and coordination with the stakeholders and disciplines that are involved in the various stages of the bridge life.

Further Information

For more information about bridge preservation, contact Anwar Ahmad at anwar.ahmad@dot.gov or 202-366-8501.

1. FHWA Bridge Preservation Guide - Maintaining State of Good Repair Using Cost Effective Investment Strategies
2. Many expansion joint materials if not properly designed, installed and maintained are susceptible to leaking which if left unchecked leads to accelerating deterioration of superstructure and substructure that are located below the joint.