Bridge Views

Issue 56 July/August 2009

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The Evolution of HPC in Vermont

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The Vermont Agency of Transportation (VTrans) has been using high performance concrete (HPC) for approximately 7 years. Initially, HPC was incorporated into bridge structures to help combat the potential for alkali-silica reactivity.

HPC Mixes

VTrans uses three primary HPC mixes. Each mix contains a ternary blend of cementitious materials including Type II cement, 40 lb/yd^3 (24 kg/m3) of silica fume, and either fly ash at 20% or ground granulated blast-furnace slag at 25% of the total cementitious materials content. The superstructure mix, which is used in the deck and for all other cast-in-place concrete above the top of the bridge seats, is designated as HPC-A and contains 660 lb/yd^3 (392 kg/m^3) of cementitious materials. The substructure concrete mix is HPC-B and contains 611 lb/yd^3 (363 kg/m^3) of cementitious materials. The third mix is HPC-AA and is used for repairs and overlays. This mix contains 705 lb/yd^3 (418 kg/m^3) of cementitious materials and 3/8-in. (10-mm) coarse aggregate.

The first 2 years with these materials was a learning period for the contractors to understand the finishing characteristics of the mixes. Because VTrans' use of HPC is still relatively new, long-term durability studies are not available. So far, HPC has provided a good product. The permeability values for the HPC-A and HPC-B mixes typically range from 600 to 900 coulombs at 56 days. The compressive strengths are typically 70 to 100% above the specified values of 4000 and 3500 psi (28 MPa and 24 MPa) at 28 days for HPC-A and HPC-B mixes, respectively. Because of these excessive strengths, some VTrans field personnel feel there is excessive cracking in the bridge decks and ornamental concrete bridge rails. VTrans has not been able to quantify these perceptions because most of the bridge decks receive a waterproofing membrane and overlay. Plus VTrans has not studied previously constructed bridges built with the conventional cement only mixes to establish a baseline for comparison.

The curing specification for HPC concrete requires 10 days of wet curing for the superstructure and 7 days for other components. For bridge decks, curing must be applied within a maximum lag time of 10 minutes after the screed machine passes.

Modified HPC Mixes

One of the first HPC modifications by VTrans was to the HPC-B mix in 2006 for a 4-ft (1.22-m) thick by 34-ft (10.4-m) high by 34-ft (10.4-m) wide bridge pier. The contractor wanted to construct the pier in one concrete placement instead of four separate ones. We changed the size of the stone from a No. 67 to a No. 467 as specified in AASHTO M43 and decreased the cementitious materials content from 611 to 564 lb/yd^3 (363 to 335 kg/m^3). Approximately 170 yd^3 (130 m^3) of this concrete was successively pumped to complete the pier in one placement. We are not aware of any cracks in the bridge pier to date. This mix has been used for mass concrete placements on a few other jobs with good results.

One problem is cracking on the ornamental concrete bridge rails or "Texas rails." These rails, in the past, have used the standard HPC-A mix. VTrans feels that because of the high strength that this mix achieves, it becomes brittle and doesn't deflect with the bridge. The mix may also be susceptible to a higher amount of shrinkage. The shape of the rail may also contribute to the cracking because of all the reduced cross sections and blockouts. To reduce the cracking as much as possible, the cementitious content of the HPC-A mix was reduced from 660 to 611 lb/yd^3 (392 to 363 kg/m^3), the air content was maintained at 6% +/- 1.5%, and the same water-cementitious materials (w/cm) ratio of 0.44 was retained. By keeping the original w/cm ratio, the total water in the mix was reduced. This mix is labeled HPC-A Low Shrink. Shrinkage-reducing admixtures have been specified on a few projects. At this time, we do not have any official data to show if there is a reduction in cracking but our research section has been looking at these ornamental concrete rails and should have a report out later this year.

VTrans primarily puts membranes and overlays on the bridge decks as a waterproofing measure. We have built some exposed concrete decks in the past but their use has been sporadic. However, they still appear to be in good condition. VTrans structures section has begun designing more exposed bridge decks in the past two years. For these, we took our standard HPC-A mix, reduced the cementitious materials content from 660 to 611 lb/yd^3 (392 to 363 kg/m^3), reduced the maximum slump from 7 to 6 in. (180 to 150 mm), increased the air content from 6 to 7 +/- 1.5% and kept the w/cm ratio unchanged. This modified mix is labeled HPC-A Low Cement. The cement content was reduced in an effort to lower the total water in the mix to help reduce shrinkage and to reduce the actual 28-day compressive strengths. Three bridge decks were completed in the summer of 2008 using this mix with the most noteworthy being on I-89 northbound in Berlin, Vermont. This deck also received the first longitudinal grooving treatment in Vermont. This summer, the southbound bridge on I-89 is scheduled to be reconstructed in the same manner along with three to four other bridges with exposed concrete decks.

VTrans is developing specifications for a self-consolidating, cast-in-place concrete. It was used on one project in 2007 to encase a bridge pier. It was very successful and plans are underway to use it on another bridge project for the ornamental railing.

Vermont will continue to develop HPC mixes based on laboratory testing and field experience to get the most efficient and durable mixes that will maximize the life of our transportation structures for years to come.

Further Information

For more information about Vermont's HPC experiences, please contact the author at jim.wild@state.vt.us.

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Curing of concrete bridge decks requires saturated burlap for 7 days.

Experiences with Ohio HPC Bridge Decks with Warranty Program

Jim Welter, Ohio Department of Transportation

In October 2000, the Pennsylvania Department of Transportation (PennDOT) started its research and development of a high performance concrete (HPC) specification for bridge decks. This research was done in conjunction with the Pennsylvania Transportation Institute (PTI) at the Pennsylvania State University. Currently four out of the eleven Engineering Districts of PennDOT are using some aspect of the HPC concept for bridge decks. This article contains a timeline of events leading to our current status.

In 2001 and 2002, a PennDOT concrete mix for HPC bridge decks was developed. This mix had a water-cement ratio of 0.43, a design strength of 4000 psi (28 MPa), and an air content for the freshly mixed concrete of 6%.

In 2002 and 2003, several bridge decks were constructed using this concrete mix. During this time, 25 full-scale concrete mixes were produced and a full battery of tests was performed on them to determine the mixtures' workability, durability, and other parameters that would impact the long-term performance of the concrete. A Best Engineering Practices Guide for bridge decks was also developed. It included engineering guidelines and design aids on the following concrete properties: compressive strength, strength development, chloride penetration, shrinkage, alkali-silica reaction, freezing and thawing durability, scaling resistance, modulus of elasticity, creep coefficient, and tensile strength. Engineering long-life concrete highway structures was also included in the guide.

During 2004, PennDOT's specifications book (Publication 408) was revised to include the best practices as identified through the research at that time. Some of the revisions were as follows:

- Design cement-concrete mixes for bridge decks to meet a 28-day to 7-day compressive strength ratio greater than or equal to 1.33.
- Provide the necessary equipment and determine the evaporation rate before starting deck placement and every hour during the placement. Allowable evaporation rate for exposed finished concrete shall not exceed 0.15 lb/ft^2/hr (0.732 kg/m^2/hr) of exposed surface as determined by Fig. 2.1.5 of ACI 305R-91. Fog cure misting is an acceptable method to mitigate an excessive evaporation rate. Do not leave concrete exposed for an extended duration. Place concrete 5 to 8 ft (1.5 to 2.4 m) ahead of the finishing machine to prevent any premature concrete drying.
- Conduct finishing operations immediately behind the finishing machine or screed from work bridges or rigid construction that are not in contact with the surface of

the concrete, are set on rails, and are easily moved. Finish with a 10-ft (3-m) long-handle, straightedge to achieve a smooth, accurate surface. If the concrete surface remains open after the finishing machine operations, make one pass with the float. Do not over-finish the surface.

- Cure the deck as soon as possible. Minimal marking of the fresh concrete is permissible. Maintain wet burlap applications within 10 to 18 ft (3-1/2 to 6 m) of the finishing equipment at all times. Maintain the burlap in a saturated condition during the entire 7-day curing period.

The HPC specification was revised in 2005 based on the research performed and the data collected up to that time. A Best Construction Practices Guide for concrete bridge decks was developed also. The Guide contains the following information on construction practices: quality assurance and quality control, designing performance-based concrete mixes, site preparation, certification of ready-mixed concrete plants and trucks, producing and transporting concrete, placing and consolidating concrete, finishing concrete, and curing concrete. Information on hot weather concreting and successful early and late season placements is also included in this guide.

As part of the research done by PennDOT and PTI, 10 bridges were constructed on I-99 during the 2005 and 2006 construction season. Each bridge was instrumented with temperature sensors, strain gages, and grounding clamps for half-cell potential measurements. Instrumentation was placed on the girders, inside the deck, and in locations surrounding the deck. These instruments were used to monitor the short- and long-term performance of the bridge decks. A weather station was used to document ambient conditions. Construction of these decks was monitored and multiple early age deck condition surveys were conducted.

Between 2001 and 2007, 21 bridges, including the 10 on I-99, were constructed with HPC decks throughout Pennsylvania. Information and data collected from these bridge decks and future decks will be analyzed. These data and other industry data will be used to modify the existing HPC bridge deck specification. Some of the changes that are being considered are:

- Furnish a concrete mix with moderate heat of hydration
- Fineness modulus of the fine aggregate between 2.60 and 3.15
- Minimum 4% total air content according to ASTM C457 for the in-place hardened concrete
- Minimum design compressive strength of 4000 psi (28 MPa) at 28 days with the average 28-day design compressive strength, including overdesign, not to exceed 6000 psi (41 MPa)
- 14-day wet curing of the bridge deck

In conclusion, PennDOT is taking steps to improve the durability of the concrete used in its bridge decks in order to increase the service life of our bridges.

Further Information

For more information about PennDOT's experiences, see HPC Bridge Views Issue No. 45 or contact the author at pimiller@state.pa.us.

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Penobscot Narrows Bridge.

Introduction of HPC by the Maine DOT

Michael Redmond, Maine Department of Transportation

While the Maine Department of Transportation (DOT) may not use all the traditional definitions of a high performance concrete (HPC), Maine does incorporate and benefit from many of the improved performance characteristics realized from the use of HPC. This article contains a brief history of how Maine DOT came to incorporate HPC into its everyday concrete requirements.

In the early 1990s, Maine DOT was invited to participate in an alkali-silica reactivity (ASR) workshop sponsored by the Federal Highway Administration and hosted by the New Jersey DOT. At this conference, Maine DOT took the first step towards understanding the value of pozzolans and their beneficial effects when added to a standard concrete mix. While a good portion of the workshop focused on identification of ASR in concrete pavements and bridge structures, preventative measures were also presented. These included the use of ground granulated blast-furnace slag and pozzolans such as silica fume and coal fly ash. Following the workshop, Maine applied for and was granted research money from the Federal Highway Administration's Office of Priority Technologies and purchased the necessary equipment to screen the concrete aggregate sources. The following year (1993) Maine DOT implemented an ASR specification that required the use of pozzolans in all bridge concrete mixes containing potentially reactive aggregates.

During the same time frame, Maine also began to implement its first Quality Control-Quality Assurance (QCQA) specification. Initially the intent was to introduce this specification to the bridge construction general contractors and give them a greater role in the design and control of concrete mixes. However, it also enabled Maine DOT to reduce inspector staffing at concrete batch plants and inspector testing at jobsites. Under QCQA, these duties became the responsibility of the contractor's quality control personnel and enabled department engineers and inspectors to focus more on material and construction quality issues rather than the day-to-day testing of concrete.

Perhaps the most important aspect was the specification that was developed with the advent of QCQA. The DOT initially focused on test properties such as slump, water-cement ratio, entrained air content, compressive strength, and chloride permeability. Once QCQA was fully implemented in 1996, the test properties evaluated were reduced to entrained air content, compressive strength, and chloride permeability. Maine continued to specify these test properties until 2004 when a new version of QCQA was adopted known as Quality Level Analysis (QLA). Under QLA, the test properties remained the same but were all evaluated under the Standard Deviation Percent Within Limits Method, which generated a Composite Pay Factor (CPF). The current CPF consists of 20% compressive strength, 40% entrained air content, and 40% rapid chloride permeability. The resulting pay factor is then multiplied by the cubic yard quantity of concrete in the lot and the dollar value assigned per cubic yard for the concrete in question. This generates a penalty or bonus payment for the general contractor.

While there have been instances of contractors being penalized on QLA projects, most have been due to variations in control of the entrained air contents. Maine specifies an air content higher than most states due to its proximity to the Atlantic Ocean. Because of this proximity, Maine also experiences more freeze-thaw cycles than most states. This requires a higher quality and more durable concrete for use in bridge structures. Over the life of our QCQA program, the concrete industry in Maine has consistently provided better concrete year after year. The driving force behind this has been the use of pozzolans and blends of pozzolans in our everyday bridge concrete and also in concrete used at the many precast concrete plants providing products.

Recent blends of ground granulated blast-furnace slag and portland cement have resulted in cast-in-place compressive strengths approaching 10,000 psi (69 MPa), while limiting the total cementitious materials content to 660 lb/yd3 (392 kg/m3), and precast concrete girders with compressive strengths in excess of 13,000 psi (90 MPa). While these test results would suggest the ability to lengthen spans, design thinner sections, or use fewer beams, Maine is more focused on durability of structures, again due to the severe environmental conditions.

Perhaps the greatest benefit from the mixes utilizing pozzolans is the resistance to chloride penetration, which is a critical tool in the current QLA specifications. Because corrosion of reinforcing steel continues to be the number one cause for structures not achieving their design life expectations, the resistance to chloride penetration is very important. Maine DOT will remain committed to using HPC and any other technologies that extend the service life of concrete bridges.

Further Information

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