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CURING FOR HPC BRIDGE DECKS — BRING ON THE WATER!

Michael F. Praul, Federal Highway Administration

As we take the next step in the evolution of concrete technology and move toward more widespread implementation of high performance concrete (HPC), we must realize that assuring successful application of concrete in bridge decks is largely dependent on timely and appropriate wet curing. The challenge is defining what is meant by "timely and appropriate" for HPC and how to specify it.

Due to the desire for low permeability, HPC for bridge decks usually contains pozzolanic material. These concretes are especially sensitive to water loss and poor curing practices. Essentially, HPC requires better curing than we use today. Which brings us back to defining "timely and appropriate."

In my opinion, "appropriate" is best defined as wet burlap or cotton mats for as long a duration as possible. "Timely" means as soon as possible after finishing; to put it in more definitive terms, place the burlap or mats 10-15 minutes after concrete placement. This requires the contractor to have wet burlap or mats on site and ready to be placed, prior to the start of concrete placement. Some may object to this approach because the burlap may leave indentations or impressions in the fresh concrete. However, achieving enhanced durability far outweighs the desire for a pristine appearance. Also, if the burlap is placed carefully, the effect on the surface is kept to a minimum.

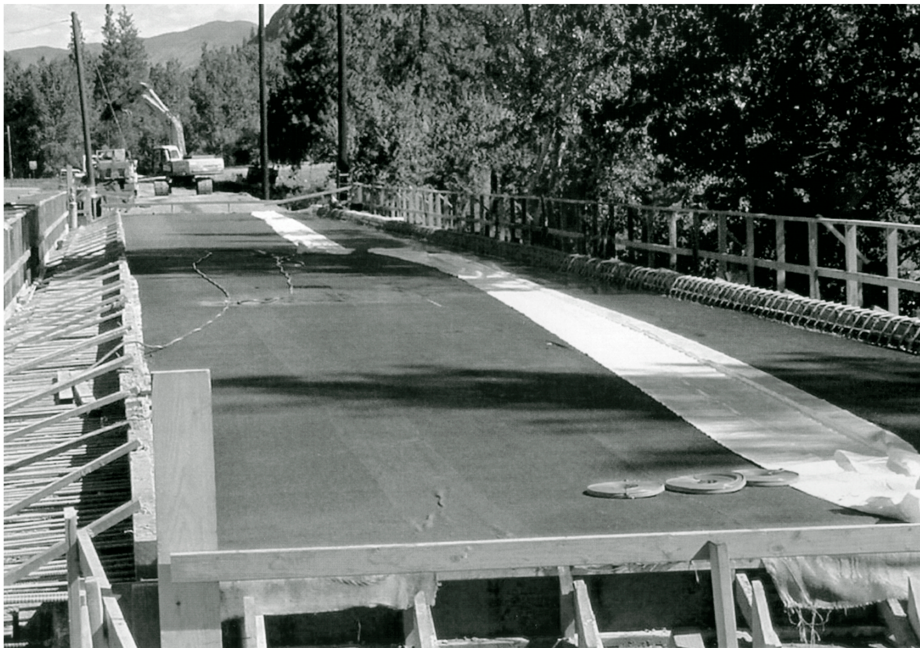
A tight operation must be maintained from start to finish. The desired sequence of operations is to place concrete, finish concrete, apply curing compound if necessary, apply tining grooves, apply wet curing material, keep wet and let sit undisturbed, remove wet curing materials, apply curing compound, and saw cut grooves (if not tined).

For HPC, the use of curing compounds should generally be restricted to after the burlap is removed. If they are placed on fresh concrete, it may be difficult to achieve the proper application rate in the limited time available and may lead field personnel to believe they have a time cushion before applying the burlap. If the evaporation rate is high, curing compounds may be placed if they can be applied properly and without delaying the start of wet curing.

The following two examples clearly demonstrate the benefits of "timely" curing. The Idaho Transportation Department (ITD) tried silica fume concrete on several approach slabs. Curing consisted of applying curing compound with burlap placed 45 minutes later. The slabs experienced severe cracking and ITD staff were understandably hesitant to use silica fume for deck applications. Before abandoning it entirely, ITD placed some additional slabs and cured them with wet burlap placed 10-15 minutes after concrete placement. Only minimal cracking was experienced. Today ITD routinely uses silica fume for bridge deck overlays.

The Maine Department of Transportation experimented with the use of concrete containing a pozzolan as a proposed replacement for granite curbing. Sections that were extruded, sprayed with curing compound, finished, and then covered with wet burlap exhibited cracks every 3 ft (0.9 m). Sections that were immediately covered and then finished by removing isolated areas of the cover exhibited cracks every 15 ft (4.6 m).

I will not dwell on "appropriate" curing, as it is well known that a longer period of wet curing produces a better quality concrete. Curing duration is even more significant for HPC. The New York State DOT, an acknowledged leader in HPC bridge decks, has recently incorporated specification language requiring the contractor to "Leave all burlap in place for 14 curing days. Provide continuous, uniform wetting for the entire curing period." This includes decks placed in New York City where the demands for an open bridge are tremendous. Nevertheless, they have realized the long-term benefits of extended curing. Perhaps we should all consider this as we progress toward more widespread HPC use and our desire to provide the best concrete decks for the traveling public.



Continuous wet curing is required for 14 days.

HPC BRIDGE DECKS IN WASHINGTON STATE

Bijan Khaleghi and Jerry Weigel, Washington State Department of Transportation

The need for a superior and durable concrete capable of resisting environmental distress resulted in the development of high performance concrete (HPC) for bridge decks. This article focuses on the Washington State Department of Transportation (WSDOT) standard practice of using HPC for bridge decks.

Construction Practices

Durability of concrete is one of the most important factors determining the service life of concrete decks. Fly ash has been incorporated into the HPC bridge deck mix to increase concrete's resistance to chloride penetration. Air-entrained concrete is required for all WSDOT concrete decks to provide the necessary freeze-thaw resistance when exposed to harsh environmental conditions.

For finishing, a self-propelled finishing machine is used to level the concrete and to pan drag the surface. If necessary, the concrete surface is floated by hand prior to combing it with metal tines.

Curing is one of the most important factors in achieving a superior and durable concrete. WSDOT requires two coats of curing compound, in accordance with AASHTO M 148, followed by continuous wet curing for 14 days. Two coats of liquid membrane-forming curing compounds are required immediately after finishing or as soon as the visible bleed water has evaporated. The surface is covered with pre-soaked, heavy, quilted blankets or pre-soaked burlap as soon as the concrete has hydrated sufficiently to support foot traffic. When wet curing was first initiated, we did not require the curing compound.

The length of time between concrete placement and start of wet curing was too long; hence, the need for the curing compound.

Wet curing is usually maintained by the use of soaker hoses placed between a clear plastic cover and the curing blankets. Intermittent use of the hose is sufficient to keep the blankets wet. Delayed application of curing results in unacceptable surface cracking and the potential for excessive deterioration at later ages.

Concrete temperature must be between 55 and 90°F (13 and 32°C) while it is being placed. The contractor is required to maintain the concrete temperature below 90°F (32°C) during the curing period.

The contractor cannot mix or place concrete while the air temperature is below 35°F (2°C) unless the water, aggregate, or both have a temperature of at least 70°F (21°C). Concrete placed when the air temperature is below 35°F (2°C), must be immediately surrounded with a heated enclosure. Air temperature within the enclosure must be maintained between 50 and 90°F (10 and 32°C) and the relative humidity must be above 80 percent. These conditions must be maintained for a minimum of 14 days.

Use of Fly Ash

Initially, contractors expressed concerns over the addition of fly ash and the required wet curing. These concerns diminished rapidly because the fly ash improved workability and the wet curing was not the problem originally envisioned.

The first benefits realized were improved workability, reduction of aggregate segregation, and less bleed water. Additional benefits include reduced alkali-silica reactivity and increased resistance to sulfate and seawater attack.

Specifications Enforcement

As we all recognize, once a concrete element is placed, corrective action is very costly and removal of substandard concrete can actually cause more damage than accepting the substandard element. For this reason, a preconstruction conference is required five to ten days before a scheduled deck slab concrete placement. The purpose of this meeting is to ensure that the contractor has appropriate supervisory personnel, that the concrete production and placement rates will be adequate to meet the placing and finishing deadlines, that an acceptable self-propelled finishing machine is available and properly set up, and that enough finishers will be provided.

Test Results

The deck concrete on the Washington State HPC Showcase Bridge* used the HPC bridge deck concrete, Class 4000D, with the following 28-day test results.

Property	Design	Test Results
Compressive Strength, psi	4000	4800 to 5800
Abrasion, %	4 to 8	3 to 6
Permeability, Coulombs	2000 to 3000	2338 2164 3434

Further Information

For further information, the lead author may be contacted at khalegb@wsdot.wa.gov or 360-705-7181.

**See HPC Bridge Views, Issue No. 2, March/April 1999*

ONTARIO'S HPC PERFORMANCE SPECIFICATION

Hannah C. Schell and Jana Konecny, Ontario Ministry of Transportation, Canada

The Ontario Ministry of Transportation's (MTO) current specification for high performance concrete (HPC) is intended to give contractors greater flexibility with respect to the selection of materials and mix design, while ensuring that the contractor bears the responsibility for the quality of the finished product and will be appropriately compensated for high or low quality concrete. Early work with HPC by the province took a prescriptive approach, to provide assurance that basic requirements could be met and to reduce contractor risk. As experience and confidence was gained, the ministry moved to an end-result based specification. Payment adjustment formulas for quality indicators included strength, permeability, and air-void parameters of the hardened concrete.

Background

Ontario experiences severe winters and, like other jurisdictions in northern climates, spends considerable amounts of money to repair and rehabilitate prematurely deteriorated concrete structures. In its search for longer lasting concrete, MTO began experimenting with silica fume concrete in 1992 to take advantage of its durability enhancing properties. The initial contracts involved overlays and bridge decks.

On these trial contracts, MTO relied on prescriptive construction and material specifications. At that time, there was little experience with silica fume concrete in the Ontario industry or MTO, and the prescriptive approach was appropriate. It provided assurance that basic requirements such as strength, permeability, and air-void system parameters were met and that contractors were not exposed to unnecessary risk.

As more experience was gained, MTO expanded the use of silica fume concrete. In 1995, MTO constructed a demonstration bridge to show that silica fume concrete could be used successfully utilizing technology and equipment commonly available to the construction industry. Conventional contracting methods were used. In this bridge, silica fume was used not only in concrete for the bridge deck but also in concrete for the barrier walls and substructure with the exception of girders and foundations. This demonstration project was carried out in cooperation with Concrete Canada, a technology transfer group funded by the Canadian federal government. Even here, a prescriptive approach to the specification was used. Following completion of the bridge, MTO had gathered enough experience to allow creation of an end-result type of specification for high performance concrete.

The first MTO end result specification for high performance concrete was implemented in 1998. It removed many of the prescriptive aspects and gave contractors more freedom with respect to mix design and more responsibility for quality control and testing of concrete.

HPC Specification

The specification defined high performance concrete as concrete containing silica fume and maybe other supplementary cementing materials, and having a specified 28-day compressive strength of at least 7250 psi (50 MPa) and a specified rapid chloride permeability (RCP) at 28 days of 1000 coulombs or less. Air-void parameter requirements for the hardened concrete are also specified. Interground cement Type 10E-SF(1) containing silica fume must be used. The contractor is allowed to replace a portion of preblended cement with Type 10 cement. Ground granulated blast-furnace slag, fly ash, or a combination of slag and fly ash, not exceeding 25 percent by total mass of the cementitious materials may be used to replace a portion of the preblended cement.

The end result specification removed the requirement for a minimum cement content; although, there are some restrictions, such as the requirement that commercially interground cement Type 10E-SF(1) containing silica fume must be used. MTO continues to prefer the use of Type 10E-SF cement to silica fume additions by other methods, because there are concerns that silica fume may not be uniformly distributed in the concrete when added at the point of making the concrete.

The use of a superplasticizer is specified. It may be added at the ready-mix plant or at the site. Slump and air content are not specified for the plastic concrete before the addition of the superplasticizer. The only requirements are that the slump immediately prior to placing or pumping be no more than 9 in. (230 mm) and that the concrete not segregate.

Contractor production of a trial batch and trial slab are still required by the specification. However, if a contractor has demonstrated ability to produce HPC

Fogging equipment attached to the finishing equipment.

meeting MTO specifications, the requirements for a trial slab and trial batches are waived. When a trial slab is required, it must be the same width and thickness as the bridge deck, and have a length of at least 33 ft (10 m). The contractor must use the same placing methods, finishing machine, and crew that will be used in the actual construction. Permission to place concrete in a bridge deck is based on the contractor's ability to adequately place, finish, and cure the concrete in the trial slab and on verification that adequate consolidation of concrete is obtained.

Curing requirements continue to be prescriptive and have become even more stringent. In addition to fog misting, application of wet burlap within 6-1/2 to 13 ft (2 to 4 m) of the pan or screed of the finishing machine and placement of polyethylene over burlap within 12 hours of placement of concrete is required. There is also a requirement for maintaining the burlap wet by means of a soaker hose throughout the 7-day curing period. Wet curing must be maintained even in cold weather.

Maximum allowable temperature of the plastic concrete at the time of placing is 77°F (25°C). In order to minimize thermal cracking, the contractor is now required to control the temperature of concrete and temperature difference within the concrete. For decks of slab-on-girder bridges and for substructure elements with at least one dimension of 2 ft (0.6 m) or greater, the contractor installs thermocouples in the center and on the surface of concrete. The temperature is monitored and recorded at least every 4 hours for the first 72 hours after placement or longer under hot or cold weather conditions. The temperature of the center of the concrete must not fall below 50°F (10°C) or exceed 158°F (70°C). At the same time, the temperature difference between the center and the surface of the concrete, on slab-on-girder bridges, must not be more than 36°F (20°C).

The presence of cracks in HPC bridge decks compromises the value of this premium concrete. Therefore, contractors are required to repair cracks of a specific width. In bridge decks that will be waterproofed and paved, any crack that is 0.039 in. (1 mm) wide or wider must be repaired. In exposed decks, sidewalks, and curbs, the contractor must repair cracks wider than 0.012 in. (0.30 mm).

The contractor is responsible for sampling and testing the fresh and hardened concrete, with the exception of compressive strength cylinders, which are tested in laboratories under contract to the ministry. All laboratory testing of hardened concrete is carried out by commercial laboratories, prequalified for use on MTO contracts via correlation testing programs and inspection of the testing facilities. Laboratories carrying out the compressive strength testing of high strength concrete, rapid chloride permeability testing, and air-void analysis of hardened concrete must demonstrate their ability to carry out testing properly before their names are added to a list of qualified firms (and in the case of air voids, operators) maintained by the ministry. Laboratories, except for strength testing, are hired directly by the contractor with the ministry playing an audit role in monitoring quality of testing.

For compressive strength, one test result is based on a set of three cylinders. Cylinders are prepared and cured in accordance with CSA A23.2-94.[2] All concrete of one specified strength level is considered to be one lot. Each lot is split into sublots varying from 13 to 130 cu yd (10 to 100 cu m) in size; one set of cylinders is cast per sublot. The mean and standard deviation of the strength results are used to calculate percent within limits, which results in payment adjustment factors. The contractor may be subject to a bonus payment up to $2.47/cu yd* ($CAN 5/cu m) of concrete or penalties ranging as great as $19.73/cu yd ($CAN 40/cu m), depending on the strength and variability of the concrete produced.

Analysis of the air-void system in the hardened concrete is carried out on cores removed from the structure. The cores are tested in accordance with ASTM C 457, with the modified point-count method typically being used. Concrete components of the structure are broken into lots of concrete bridge deck surface, or lineal feet of barrier wall, with two 4-in. (100-mm) diameter cores removed from each lot. Each core is split vertically to form two halves, and one half is forwarded to MTO for audit testing purposes. The contractor tests the remaining half and results are submitted to MTO. Samples must be retained by the contractor for a period of one year to facilitate retesting or comparison of samples should it be required.

Acceptance of the concrete is based on a minimum air-void content of 3 percent and a maximum allowable average spacing factor of 0.010 in. (0.25 mm) for the average result per lot, with no individual result greater than 0.012 in. (0.30 mm). Concrete that fails to meet these requirements is unacceptable and must either be removed or the contractor may propose a means of remediation.

Chloride permeability is assessed on the basis of 4-in. (100-mm) diameter cores removed from the structure. Cores are tested in accordance with ASTM C 1202, at 28 to 32 days of age, with two 2-in. (50-mm) long test samples cut from each core to improve the level of confidence in the result obtained. Testing is carried out by the contractor and reported to MTO.

The specification contains penalty provisions based on this test. A lot average of 1000 coulombs or less results in full payment, but results between 1000 and 2000 coulombs are subject to a payment reduction of up to $12.33/cu yd ($CAN 25/cu m) concrete. Results greater than 2000 coulombs are indicative of concrete that is unacceptable. As requirements for permeability of concrete have only been introduced to the industry very recently, the contractor is not required, at this time, to remove or repair such concrete. The contractor is subject only to reduced payment.

Strength

Mean strengths recorded for individual contracts, where 7250 psi (50 MPa) was the specified minimum strength, varied from 7510 psi (51.8 MPa) to 9410 psi (64.9 MPa). Standard deviation ranged from about 510 psi (3.5 MPa) to 870 psi (6.0 MPa). This is only slightly higher than would be considered typical for conventional concrete strengths on MTO contracts. Based on comments from contractors, it would appear achievement of strength is not generally viewed as a problem.

Air-Void Parameters

Considering some contract tests by MTO and later results from contractor testing, only a small number of results from cores have led to concrete being considered unacceptable. There has been

Conversion rates are based on $1.00 = $CAN 1.55

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Application of wet burlap within 6-1/2 to 13 ft (2 to 4 m) of finishing equipment.

concern for potential loss of air or degradation of the air-void system of the highly fluid mixes due to pumping, which is the typical method for MTO bridge deck placement. However, results to date generally appear very good. Based on 52 cores from contracts employing the 1998 specification, an average air-void content of 5.9 percent, with an average spacing factor of 0.006 in. (0.15 mm) has been achieved. The majority of results meet the more stringent spacing factor requirement of average spacing factor no more than 0.008 in. (0.20 mm) applied by MTO to conventional concrete. Accuracy of results submitted by testing laboratories remains a concern to both MTO and contractors, and changes in the qualification process for laboratories have been made, so that individual operators rather than companies are evaluated.

Rapid Chloride Permeability

Contracts employing the current specification had average RCP test values ranging from 380 to 1267 coulombs at a nominal test age of 28 days, with values of less than 600 being typical. A standard deviation of about 100 coulombs or less was observed on contracts with a significant number of samples.

Initially, industry expressed concern that mixes with high contents of slag or fly ash, or both, might not perform well in this test because of the early age of the concrete, and preferred to see a 56-day test age; it was felt this could not be accommodated because of contract time constraints, and was considered less realistic in that the concrete is exposed to the elements within a shorter period of placing in many cases. Several mixes to date included 25 percent slag as cement replacement. The average RCP results on those contracts ranged between 380 and 557 coulombs. These are excellent results and well within the specification limit of 1000 coulombs. This concern will continue to be monitored.

Storage of the test samples after removal and prior to testing has been an issue; the specification has recently been altered to ensure consistent age of removal of cores and consistent storage conditions prior to testing. Occurrence of results over 1000 coulombs on one contract has been traced to improper early storage in a dry condition. Long-term results after laboratory curing were excellent with values between 393 and 637 coulombs at an age of 46 days.

Curing

Although, initially, there was resistance to the introduction of fog misting and extended wet curing of HPC both from contractors and from MTO field staff responsible for enforcement, this appears to have been largely overcome. A number of contractors have modified their deck finishing equipment to provide machine-mounted fogging systems for deck placements. In some cases, and where it appears to work most effectively, these are augmented by hand-held equipment. With this arrangement, stoppages of the automatic system or redirection of the mist by wind can be compensated for, and fogging maintained by the hand-held equipment. Consideration is being given to making the presence of a hand-held fogging wand mandatory on site.

Finishing

Finishing of bridge deck surfaces has been an issue on several jobs. Grinding of a rough or uneven deck surface is sometimes necessary to produce a surface smooth enough to receive the normal hot-applied waterproofing treatment. The ministry's current specification for finishing is aimed more at elimination of high and low areas rather than dealing with roughness issues. To some extent, this appears to be a function of contractor experience as well as mix design. There appears to be little transfer of experience from one job to the next, as the contractor moves from one concrete supplier to another. The use of trial slabs has, unfortunately, not provided the intended effect of allowing the contractor to work out his finishing problems, prior to starting work on a structure.

Appropriateness of Mixes

Although the specification responded to industry's desire for increased allowable replacement of cement by supplementary materials, and greater flexibility in types and amount of cement used, this does not appear to have been exploited to any degree to date. Mixes are conservative; some more so than the original trial work, with extremely high cement contents, 758 to 809 lb/cu yd (450 to 480 kg/cu m), being typical. Slag at the 25 percent replacement level, commonly used in conventional MTO concrete, is being used in an increasing number of mixes, with good results. No contractors have chosen to utilize fly ash, or additional portland cement.

Costs

Based on recent contract figures, a premium of between 0 and 20 percent of normal costs is being paid for HPC. This is slightly less than the anticipated $29.60/cu yd ($CAN 60/cu m) premium based on assessment of costs related to special features such as trial batches and slabs, and additional curing requirements.

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Conclusions

The MTO specification for HPC has proven to be workable. Some excellent HPC has been produced. However, both MTO and contractors need to gain more experience with the use of this specification, and with HPC in general, before use of HPC can be optimized on a routine basis in MTO construction. Overall confidence in and acceptance of the material, both in the industry and MTO, vary.

It is anticipated that use of HPC will be gradually increased by MTO. However, to date, structures have been selected for use of HPC on an individual basis. It is necessary to develop clear guidelines for designers as to when HPC should be used, in order to facilitate its use throughout the province in the most cost-effective applications.

There is a need to develop fully a payment adjustment system, including all performance indicators, and consider increased use of bonuses as an incentive to the contractor to provide an exemplary product. The next step in this process will be development of a payment adjustment system for air voids in hardened concrete. Particular attention must be paid to workmanship issues, such as deck finishing, to ensure that the specification contains appropriate incentives to provide a good quality end product.

Further Information

For further information, Hannah Schell may be contacted at hannah.schell@mto.gov.on.ca or (416) 235-3708.

References

1. CSA A362-98, Blended Hydraulic Cement, Canadian Standards Association, Toronto, Canada, 1998.
2. CAN/CSA A23.2-94, Methods of Test for Concrete, Canadian Standards Association, Toronto, Canada, 1994.

LETTERS TO THE EDITOR

The following letter was received from Bryce Simons, State Concrete Engineer with the New Mexico State Highway & Transportation Department concerning the article on "Capping Cylinders for Testing High Strength Concrete" in Issue No. 14.

I find it extremely encouraging that all this work and the associated questions are being asked and researched. However, I do not understand why much of the information, and the associated "lessons learned" in the private construction sector (especially high-rise construction) during the mid to late 1980's are not being utilized. When we developed the very high strength concrete mixes with compressive strengths exceeding 20,000 psi (138 MPa) for use in Seattle, we had to deal with the issue of how to test the cylinders. At that time, the best sulfur capping compound that we could buy seemed to result in an apparent maximum compressive strength of approximately 16,000 psi (110 MPa), regardless of the quality of the concrete.

When we switched over to the use of pad-caps, we immediately removed the ceiling, and the identical mixes all of a sudden exhibited strengths of 18,000 and 19,000 psi (124 and 131 MPa). After we were able to develop an acceptable grinding system (none existed when we started this work), we also saw the ceiling disappear. When we finally issued the specifications, we allowed the testing laboratories to use either grinding only, pad caps only, or a combination of grinding and pad caps.

On the Two-Union Square project, the cylinders were ground only. On the Pacific First Center project, the cylinders were first ground, and then tested using the pad caps. Although there were some other basic differences between the two mixes, it was interesting to note that the test results between the two systems were remarkably similar. The results were also very consistent, and statistically sound. I believe that the coefficient of variation for each of the mixes was approximately 4 percent.

Consequently, when I see statements that indicate that these systems do not work with strengths above 12,000 psi (83 MPa), I can't help but discount these statements, since I tend to believe what I have seen with my own eyes.

NCBC WEB SITE

The National Concrete Bridge Council (NCBC) has announced its new web site at www.nationalconcretebridge.org.

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