Use of High-Performance Concrete for Rapid Highway Pavement Repairs: An Overview of Five Field Installations

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The Strategic Highway Research Program awarded a contract to investigate the use of high-performance concrete in highway pavements and bridge structures. One of the primary objectives of this research effort was "to provide recommendations and guidelines for using these concretes in highway applications." As a result, the research program included an examination of the field performance of high-performance concrete. Field test sections were constructed in Arkansas, Illinois, Nebraska, New York, and North Carolina. Except in North Carolina, the installations consisted of full-depth and lane-width patches. Traffic and environmental exposure conditions differ for all locations. Each batch of concrete brought to a site was tested for its fresh concrete properties. Specimens were cast for long-term testing too. The field installations will continue to be monitored for at least 18 months after construction. Details about site locations, the type of concrete used, the construction process, and the testing plan are provided, and the most important lessons learned from the field trials are discussed.

In March 1989, Strategic Highway Research Program (SHRP) Contract C-205 was awarded to investigate the mechanical properties of high-performance concrete (HPC) for highway applications. A consortium of three universities—North Carolina State University (NCSU), the University of Arkansas, and the University of Michigan—make up the research team. The 4-year research effort has focused on an investigation of three classes of HPC. These concretes are intended for use in pavements and bridge structures where durability and strength development are critical.

Within the context of the NCSU study, HPC is defined as any concrete that provides substantially improved resistance to environmental influences, extraordinary properties at early ages, or enhanced long-term mechanical properties. The primary objective of this research effort has been to evaluate the mechanical properties and field performance of the concretes developed for the project. Major tasks have included establishing the proportions for three different classes of concrete, performing laboratory tests to determine the properties of these concretes, and constructing field installations to investigate the production and in-service performance of the concrete.

This paper will focus only on the field installations and is intended to provide guidance to prospective users of HPC in highway applications. General information about the construction of the test sections is presented. Limited data are provided regarding the results of field tests.

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PURPOSE OF FIELD INSTALLATIONS

One of the main tasks of the SHRP research effort was to determine how various field service conditions, such as traffic and climate, affect the behavior and properties of HPC. Actual field conditions often cannot accurately be simulated in the laboratory. Thus, to accomplish the stated task, several field test sections were constructed using HPC. The field installations also would provide an opportunity to determine if the HPC developed under controlled laboratory conditions could readily be produced and placed in the field. An important aspect of the SHRP study was that the production of HPC should be possible with locally available materials and methods.

DESCRIPTION OF FIELD INSTALLATIONS

Five separate field installations were constructed as part of this research. The installations are in Arkansas, Illinois, Nebraska, New York, and North Carolina. The candidate test sites were selected partly on the basis of their traffic and environmental exposure conditions. Variables considered in the selection process included expected traffic volume, percentage truck traffic, freeze-thaw potential, moisture potential, exposure to deicing agents, and site availability and convenience. A general description of the location, geometry, and exposure condition of the five sites follows.

New York

The first installation was constructed in June 1991. The site is located on I-88 about 80 km (50 mi) west of Albany near the town of Worcester. A single 18.5-m (61-ft) patch was placed in the passing lane of the eastbound highway. The patch is full depth and width, about 230 mm (9 in.) and 3.6 m (12 ft), respectively. Transverse joints are positioned every 6 m (20 ft). Insulation covered the entire patch until the morning after placement, when the patch was opened to traffic. The concrete is subject to a moderate level of traffic. The climatic exposure can be described as wet with a hard freeze in the winter.

North Carolina

The second field installation was placed in July 1991. The site is an approach to a new bridge located in the southbound lanes of US-17 just east of Williamston. Williamston is 96.5 km (60 mi) east of Raleigh and about 40 km (25 mi) west of Albemarle Sound on the Atlantic Ocean. The North Carolina installation was more extensive than the other four sites. Plain concrete pavement totaling 55 m (180 ft) was placed in two adjacent lanes. The pavement was roughly 230 mm (9 in.) thick. A number of insulated and noninsulated sections were constructed. Two coarse aggregates and two high-range water reducers (HRWRs) were used. The inside lane was constructed at a slow rate to allow for the best control and time for adjustments to the concrete mixture. The outside lane was placed at a more typical construction rate. Traffic in the area of the installation is light. Exposure is that of a mild marine environment so there is limited potential for freeze-thaw cycles to occur. Little to no deicer salt application is expected.

Illinois, Arkansas, and Nebraska

The remaining three installations have many similarities in terms of their geometry and construction. However, their traffic and climatic exposures are quite different. The third installation is located on I-57 about 8 km (5 mi) north of Effingham, Illinois. This installation was constructed in October 1991. Two 14-m (45-ft) patches are located in the right lane of the northbound traffic. The fourth installation was placed in Arkansas on I-40 about 5 km (3 mi) west of Forrest City. Forrest City is about 48 km (30 mi) west of Memphis, Tennessee. Two 14-m (45-ft) plain concrete patches were constructed in the passing lane of the westbound traffic. The fifth installation is in the eastbound lane of US-20 about 8 km (5 mi) west of Osmond, Nebraska. Osmond is northwest of Norfolk. A 29-m (96-ft) section of plain concrete was placed in July 1992, representing two 14-m (48-ft) patches.

Full-depth and lane-width repairs were made at all three sites. The slabs ranged in thickness from 200 to 250 mm (8 to 10 in.). Lane widths were 3.5 m (12 ft) in Illinois and Arkansas and 3.3 m (11 ft) in Nebraska. Transverse joints were positioned at intervals of roughly 4.6 m (15 ft). The same basic concrete mixture was used for all three installations. One of the two patches was insulated for 4 to 6 hr after placement of the concrete, and the other patch was left uncovered. Only the Nebraska installation was opened to traffic on the day of placement. The other two sites were opened the next morning.

Traffic levels in Illinois and Arkansas can be classified as moderate. However, the Arkansas site has a high percentage of truck traffic. Traffic in Nebraska is very light, yet the pavement is subjected to occasional heavy loads because of the many farms nearby. Like New York, the Illinois installation can be described as wet with a hard freeze. The Arkansas site can be considered wet with freeze-thaw cycling. In Nebraska, the potential for freeze-thaw cycles is very high and deicing salts are likely to be used after each snowfall.

MIX PROPORTIONS AND CHARACTERISTICS

Three classes of HPC were developed in the NCSU study. These concretes have been designated VES (very early strength), HES (high early strength), and VHS (very high strength). There are two categories of the VES mixture. Performance criteria for these mixes are as follows:

1. Water-cement ratio ≤ 0.35
2. Durability factor ≥ 80 percent after 300 freeze-thaw cycles (ASTM C666, Method A)
3. VES: 14 MPa (2,030 psi) in 6 hr using portland cement, 17 MPa (2,465 psi) in 4 hr using pyrament blended cement; HES: 34 MPa (4,930 psi) in 24 hr; VHS: 69 MPa (10,014 psi) in 28 days.

All three concretes were formulated to achieve their desired performance using the fewest ingredients possible and the least amount of each. In addition, the concretes can be produced using locally available materials and placed using standard construction practices.

Each of the three categories of HPC was developed for specific applications. The primary use for the VES mix is in rapid patch repairs, for which strength development is more critical than cost. The HES mix was designed for use in construction and repair of bridge decks, for which durability, especially corrosion of the reinforcement, is a significant concern. The HES mix can also be used in pavement patching when cost is an important factor. The VHS mix was developed for use in bridge construction, girders and piers being the prime focus. The primary material used in the field installations was the HES mixture. As explained later, the VES mixes were examined indirectly. The VHS concrete was not evaluated in the field trials.

There were two reasons for using the HES mix for the field trials instead of the VES patching material, as originally intended. First, at the time that the field installations were to be constructed (except Nebraska), performance criteria, approved materials, and proportions for the VES concrete had not been made final. Changes in each of these areas led to delays in developing a satisfactory VES mix. Because the field installations had been scheduled for completion in the summer of the third project year, these delays effectively removed the VES mix from consideration.

Second, in laboratory testing it was found that the HES mix, when insulated, would frequently satisfy the performance criteria of the VES mix. It was believed that both the HES and VES mixes could, in effect, be tested in the field by constructing two patches with the HES mix. One patch would be insulated and the other, noninsulated. Thus, the VES mix would be simulated by the HES mix and the insulation. A secondary benefit of using the HES mix for the installations was that the material could be examined under circumstances that were more forgiving in terms of strength development. If the performance of the HES concrete (intended for use on bridge decks) turned out to be less than anticipated, lower strength in a pavement section would be less serious than the failure of a bridge deck.

The general HES mix design used for the field installations is presented in Table 1. Given is a broad range for the aggregate contents. The coarse-aggregate content can be de-

TABLE 1 HES Mix Proportions

Material	Dry Weight (kg/m^3)	Dry Weight (lb/cy)
Cement	516	870
Water (1)	178	300
Coarse Aggregate	940 - 1020	1,580 - 1,720
Fine Aggregate	560 - 620	950 - 1,050
HRWR (Naphthalene)	6.1 L/m^3	18 oz/cwt
AEA (Vinsol Resin)	1.7 L/m^3	5 oz/cwt
Calcium Nitrite	20 L	4.0 gal

(1) Adjust for free aggregate moisture and water in Calcium Nitrite.

termined according to American Concrete Institute (ACI) guidelines for normal weight concrete (ACI 211.1-81). A fine-aggregate proportion adequate to produce the desired yield can then be determined. The proportions given in Table 1 are sufficient for both No. 57 and No. 67 nominal maximum-sized aggregate. The New York installation used an earlier version of this mix, but the general proportions were very similar to those in Table 1. In North Carolina, Illinois, and Arkansas the mixes used were based on Table 1 with adjustments only to the admixture dosages. When the Nebraska installation was constructed, it was decided to intentionally invert the coarse- and fine-aggregate quantities for the SHRP work. Conventional practice in the area of the installation calls for a 30 percent maximum coarse-aggregate fraction because of the potential for an alkali-aggregate reaction. Therefore, it was decided to impose the same restriction on the SHRP concrete since a prime objective of the field work was to determine if HPC could be produced using local materials and methods.

Several admixtures were used to produce the HES concrete, including an HRWR, an air-entraining agent (AEA), and a nonchloride set accelerator/corrosion inhibitor. An HRWR was chosen over a conventional water-reducing admixture, or combination of both, to minimize set retardation. So-called extended-life HRWRs were not used because they typically cause substantial increases in set times. Strength gain begins essentially at final set, so it was necessary to limit extension of the set time very closely in order to provide acceptable early age strengths. A calcium nitrite solution was used as the set accelerator/corrosion inhibitor. It must be added at the job site because workability is maintained for only about 15 min after addition in warm weather. The commercially available calcium nitrite solution used contained about 3.4 kg (7.5 lb) of water for each 3.8 L (1 gal) of product. This means that about 13.6 kg (30 lb) of water per 0.765 m^3 (1 yd^3) of concrete had to be held back during initial batching to maintain the intended water-cement ratio. The water-reducing admixture was added during initial batching to provide acceptable workability and, very importantly, entrained air content of these mixes with low water-cement ratios (no more than 0.35). Job-site addition of an HRWR to recover or enhance workability has been questioned when frost resistance is critical. Research by the Indiana Department of Transportation indicates problems with the frost resistance of concretes that have been redosed with an HRWR (*1*). The Arkansas research team is researching this issue.

CONSTRUCTION PROCESS

Construction of the patch sections in New York, Illinois, Arkansas, and Nebraska was similar in many respects. Figure 1 depicts a typical patch. A general discussion of the construction process is presented. When necessary, differences among the field sites will be highlighted. The North Carolina installation, being new pavement construction, will not be included in the following discussion. For more details on the North Carolina test installation, see the paper by Leming et al. in this Record.

The pavement that was to be replaced was removed by the lift-out method. Any subbase material disturbed during removal of the concrete was compacted using a hand-operated vibratory plate compactor. Sand was used in New York and Nebraska to return the subbase to the proper grade. Transverse joints are roughly spaced at 4.5-m (15-ft) intervals. Thus, a 14-m (45-ft) patch was separated into three sections of equal lengths. Joint spacing was 6 m (20 ft) in New York. Dowel bars were placed at all transverse joints and grouted into the existing concrete; all dowel bars were greased. New York and Illinois used welded wire mesh, placed on chairs, in constructing the patch. A bond breaker was placed along the longitudinal joint. The patches were also instrumented with thermocouples to monitor the temperature development in the slab.

The patch area was prepared on the morning of the placement in New York and Nebraska. The New York patch was small enough that all of the work could be completed in 1 day. In Nebraska, an overnight lane closure was not permitted because the highway has only two lanes.

Except in Illinois, where a central mixer was used, the concrete was dry-batched at a local ready-mix plant and transported to the job site. Each truck was charged with enough material to fill one 4.6- × 3.7-m (15- × 12-ft) section and cast the necessary test specimens. The basic batching sequence follows:

1. Wash out drum and discharge all water.
2. Add a fourth of total water and two-thirds of HRWR.

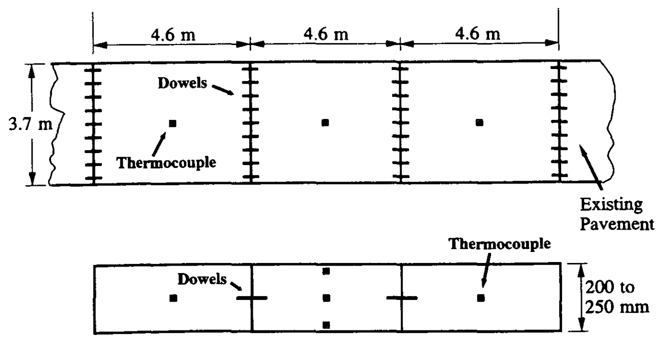

FIGURE 1 Typical field installation: *top*, plan view; *bottom*, cross section.

3. Add half of cement, coarse aggregate, and fine aggregate, and a third of AEA and mix while remaining material is weighed.
4. Add the other half of cement, coarse aggregate, and fine aggregate, and two-thirds of AEA.
5. Add three-fourths of total water less that held back for washing down the truck hopper.
6. Add the remaining third of HRWR.
7. Wash down hopper.
8. Mix for about 5 min.
9. Transport to site. (Drum at agitate speed.)
10. Add calcium nitrite.
11. Mix for 3 min.
12. Discharge concrete within 15 min.

Several points must be made with regard to batching the HES mixture, or any other HPC, in the field. First, the mix proportions given in Table 1 should be viewed as a first approximation for the mix. Differences in cement, aggregate, and admixture will most likely necessitate changes in the quantities and dosages of the constituent materials. Second, the order and split addition of the materials has been found necessary for three reasons. First, because of the dry nature of this mix, it is essential to add both water and HRWR to the drum of the truck. This will help to reduce the chance of head packing. Second, many batch plants do not have the capacity to weigh all of the required dry material at one time. Thus, batching can be done only by splitting the weights. Third, the effects of delayed addition of HRWR on the durability of this concrete had not been established when the installations were constructed.

Another critical point regarding the use of HPC in the field is the condition of the mixing trucks. Any truck likely to be used for a job involving HPC should be checked before any work is started. Inadequate mixing due to worn or coated blades will lead to dramatic problems as a result of nonuniformity of the concrete. Concrete that is not thoroughly mixed and uniform in consistency will be difficult to discharge, place, and finish.

Finally, all materials, except the calcium nitrite, were added at the batch plant. The calcium nitrite was added manually at the job site, which should not present any problems. In Nebraska this material was pumped into the mixing drum. At the other field sites the material was supplied in 210-L (55-gal) drums and was added manually using 19-L (5-gal) plastic buckets.

Once bathed and mixed, the concrete was placed, consolidated, finished, cured, and insulated according to the various state standards at each site. No special placement or finishing techniques were required or used. Two of the states used a vibrating screed as well as internal vibration, and the others used only internal vibration for consolidation. All states used a liquid curing compound. Insulation was placed on one of the two patches at each site except in New York, where the entire patch was covered. The type of insulating material used differed for each state. Forms of insulation included rigid foam, blankets, and asphalt-treated sheeting. Generally, the insulation remained on the one patch 4 to 6 hr after placement. Joints were sawed as soon as practical. All but the Nebraska installation were kept closed to traffic overnight as a precautionary measure; the Nebraska patch was opened the evening of the placement.

TESTING PLAN

Besides the evaluation of the ability to batch and place the HES concrete in the field, an extensive test program is continuing at each site. As with other aspects of the installations, the test program is essentially the same at each field site. The fresh concrete properties, internal temperature development, cylinder compressive strength, and core compressive strength are monitored at each site. Each site is visually inspected whenever specimens are retrieved or cores taken.

Each truckload of concrete brought to a site was sampled and tested for its fresh properties in accordance with AASHTO specifications and testing procedures. Slump, air content, unit weight, and as-placed concrete temperature were recorded. On the basis of experiences in the laboratory with the HES mix, an air content of 5 to 8 percent and a slump of greater than 51 mm (2 in.) was desired. In cool weather, a mix temperature of at least 27°C (80°F) was thought to be necessary for a sufficient rate of strength gain. Adjustments to the admixture dosages were made as necessary on the basis of the properties of the prior loads of concrete.

Each patch was instrumented with thermocouples in order to monitor temperature development. A short length of small-diameter PVC pipe was used to stabilize the position of the wires during placement of the concrete. All thermocouples were placed along the centerline of the patch. The outside sections of each patch had one thermocouple at mid-depth. The center section was instrumented with three thermocouples. One was placed about 25 mm (1 in.) from the top of the patch, one at mid-depth, and the third at about 25 mm (1 in.) above the subbase (Figure 1). Temperature readings were taken on a regular basis with a hand-held digital thermometer.

A large number of 100- × 200-mm (4- × 8-in.) compression cylinders were cast from each load of concrete. These cylinders were cast for both short- and long-term testing. The center section of each patch was identified as the representative section, and thus more specimens were cast from this concrete. The outside sections had cylinders cast for 1-, 7-, and 28-day testing. The center patch had additional cylinders cast for 6-, 12-, and 18-month tests. The insulated patch had still more specimens prepared. Cylinders were taken from the center section for testing at 4, 5, 6, and 7 hr after placement to study the rate of strength gain and early age properties of the mix.

The cylinders were cured for up to 1 day in a curing box constructed of extruded rigid foam insulation. The boxes provide a minimum of 50 mm (2 in.) of insulation around each specimen. The outside edge of the boxes are 150 mm (6 in.) thick. A thermocouple was placed in the cylinder in the center of the box. It has been found that the temperature history of this cylinder is very similar to that of the mid-depth thermocouple in the slab. Thus, it is believed that the cylinders are being cured in like manner to that of the slab. For the specimens taken from the insulated patch, a sheet of insulation is placed over the top of the curing box for as long as the slab is insulated. When the insulation was removed from the slab, the specimens in the curing box were uncovered but remained in the box. After curing in their boxes for 24 hr (except those tested earlier), the cylinders were removed and buried along the side of the road. The cylinders were buried so that their top surfaces are exposed to the environment and remain in their plastic molds until tested. Highway department personnel retrieve and test the specimens according to an established schedule.

The patches are also being cored at 6, 12, and 18 months of age. Three cores are taken at each test date from the center section of each patch. One core is taken from each of the outside sections. The first coring is done between the wheelpaths to correlate the strength with the field-cured cylinders. Later cores are taken from the wheelpath to evaluate any damage that may have occurred over the past 6 months.

RESULTS

Figures 2 and 3 and the following in-text table present selected data from the various field sites; space limitations do not permit data from all the field sites to be presented. Figure 2 shows the early strength development of test cylinders at the Arkansas and Nebraska sites. The concrete at the Arkansas installation nearly doubled in strength over a 3-hr period. In Nebraska the concrete started out at a high level of strength, which then increased by one-third. However, 7 hr after placement, the compressive strength of the concrete was essentially the same at both sites. Figure 3 shows the long-term compressive strength development of the test specimens cast in Arkansas. The strength of the insulated concrete, on the basis of cylinder specimens, is greater for the ages tested than that of the noninsulated concrete for the Arkansas site. Although this is typical, it is not universally true. Furthermore, it is important to note that these results are based on specimens that received no moist curing after being removed from their molds at 24 hr or less. The difference between the cylinder strengths has declined from 30 percent at 1 day to 7 percent at 6 months. At 6 months the difference is approximately 5 MPa (700 psi).

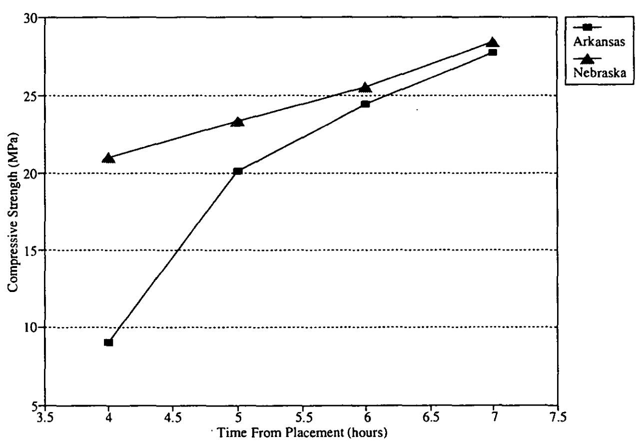

FIGURE 2 Early age compressive strength of insulated concrete.

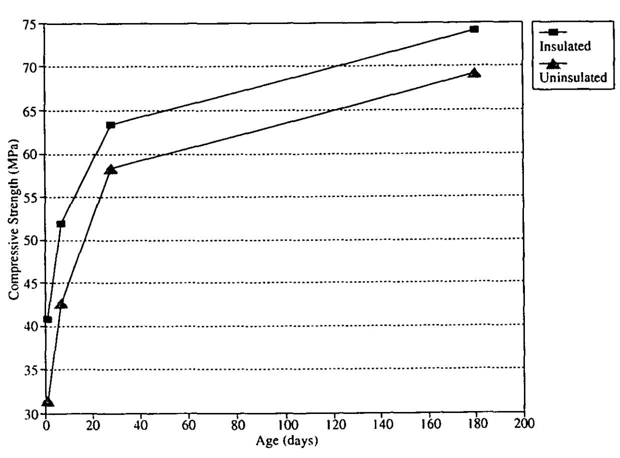

FIGURE 3 Long-term compressive strength.

The following table presents compressive strength data at 6 hr and at 1 day (1 MPa = 145 psi):

Site	*Insulated (6 hr) (MPa)*	*Noninsulated (1 day) (MPa)*
New York	10.3	No data
Illinois	10.8	34.5
Arkansas	24.4	31.4
Nebraska	23.3	30.8

These data were obtained from test cylinders cast from the second truck for both the insulated and noninsulated test sections at all sites but North Carolina. The table shows that the early strength of the insulated cylinders in Arkansas and Nebraska exceeded the minimum requirement of 14 MPa (2,000 psi) compressive strength in 6 hr for the VES mix. However, in these states, the noninsulated cylinders did not meet the requirement of 34 MPa (5,000 psi) in 1 day for the HES mix. The situation in New York and Illinois was reversed: the 1-day strength criterion of the HES mix was met, but the 6-hr strength criterion of the VES mix was not. It is important to note that the concrete should reach its target strength within the desired time frame and certainly before being loaded by traffic. The incremental rate of strength development up to this point, or the additional strength gained after this point, is not as important. Although the strength of this concrete at 28 days, and later, is much greater than that required for a pavement, it is an unavoidable side effect of requiring very high strengths at very early ages.

CONCLUDING REMARKS

After having placed HPC in the field on five occasions, much has been learned about the material and what it takes to produce and place it properly. To use this material successfully, certain aspects of the construction process require special attention. A brief discussion follows of what the authors believe to be a few of the more important lessons.

First, the calcium nitrite solution added at the job site must be thoroughly mixed into the concrete. This is critical even with central mix batching. Worn blades, fin buildup, or minimum drum rotation speed will hinder effective mixing. Chain-driven drums have proven susceptible to mixing problems with dry-batched HPC.

Because of the staged batching process, the low water-cement ratio, and limited mixing time available after addition of the calcium nitrite, it was found necessary to limit the size of the loads to no more than two-thirds of the truck's rated mixing capacity. This holds true for all truck mixers, even those in good operating condition. If adequate mixing is a problem, or if trucks in adequate condition (ASTM C94-90) are not available, it may be helpful to limit the load size to half the rated mixing capacity.

A preconstruction meeting should be held with the contractor; the concrete supplier, including the batch plant operator; and appropriate highway department personnel. Although important for any concrete construction, it is especially important when HPC is used. Topics to be discussed should include the mix proportions and needed materials; the batching sequence, including the site addition of calcium nitrite; travel time and route; placing, consolidation, and finishing procedures; the stiff and sticky nature of the mix; insulation; criteria for opening the patch to traffic; and field trial batching.

The batch plant should be made aware of the desire for tight control over water content. Excess water will harm the performance of the HPC more so than it will for conventional concrete. In addition, more care must be taken in the batching process to ensure that the correct materials are batched in the proper sequence. Drivers should be told that delays in transporting the concrete can cause serious problems. They must also understand that all wash water needs to be fully discharged before being charged with the HPC mixture and that the drum must be kept in constant rotation.

Contractor personnel should be informed of the stiff and sticky nature of the concrete. HPCs usually do not flow like the mixtures commonly used in patching, so more effort will probably be required to place the concrete. The mix will react well to vibration. However, a vibration should not be used to move the concrete to its final position, which may cause the mix to segregate. Usual finishing practice still applies to HPC, although the finishers may find the mix somewhat difficult to work. If possible, the finishers should have a chance to work with the mix during trial batching.

Enough laboratory and field trial batches should be produced to confirm the mix proportions, batching sequence, and workability of the mix. The basic proportions of the HPC mixture will have to be modified for the physical characteristics of the local aggregates and cement. It has been found that use of ACI's proportioning guidelines (ACI 211.1-81) for determining aggregate quantities will yield a satisfactory first approximation of the mix proportions. The brand, type, and time of addition of the admixtures will also affect the properties and performance of the concrete.

Laboratory batching of the constituent materials should be conducted as closely as possible to that expected in the field. Slump, air content, unit weight, and temperature of the fresh concrete should be determined. Several cylinders should be cast to evaluate the rate of strength gain and ultimate strength capacity. Curing of the cylinders should be as expected in the field. The mix proportions should be adjusted until the desired performance is achieved. At least one additional batch of a successful mix should be produced for confirmation.

After the mix has been adjusted in the laboratory, field trials should be conducted. Rarely does the mix not require further adjustments in the field to obtain the desired slump, air content, strength, and durability. The moisture content of the aggregate will play a significant role in adjusting the mix proportions. The best approach to the field trials is to produce a number of small batches to confirm the mix proportions and the time available to work the material. These batches can be used for patching, placed in temporary forms in the batch plant yard, or used as temporary working slabs on site. Between the preconstruction meeting and field trial batching, most potential problems can be addressed and remedied.

With small loads adequate mixing can be ensured, waste is minimal, a single patch can be filled by a single truck, and many trials can be conducted without excessive costs. If the concrete is used for patching, discontinuous patches are best. This will eliminate the potential for any cold joints due to construction delays. In addition, work can be stopped at just about any time. Only after the mixture has been successfully produced in field trials should any major construction be undertaken.

A final note on working with HPC in the field has to do with patience. The research team has found that a full day of production is typically required to bring all participants up to speed, and the learning curve costs during this first day can be appreciable. However, at field sites where multiple days of operation were possible, subsequent work went much more smoothly.

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This paper represents the views of the authors only and is not necessarily reflective of the views of the National Research Council, SHRP, or SHRP's sponsor. The results reported here are not necessarily in agreement with the results of other SHRP research activities. They are reported to stimulate review and discussion within the research community.

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