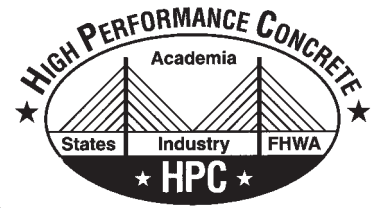




# Bridge Views



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## HPC FOR WACKER DRIVE RECONSTRUCTION

S.L. Kaderbek, Chicago Department of Transportation

Chicago's Wacker Drive is a two-mile (3.2-km) long, two level roadway originally built entirely of reinforced concrete, used by 60,000 vehicles a day, and bracketing the north and west sides of Chicago's downtown "Loop." The older east-west section was built in 1926 and the newer north-south section was built in the early to mid 1950s. In late 1998, as the Chicago Department of Transportation's (CDOT) Bureau of Bridges and Transit was beginning final design for the new Wacker Drive Viaduct, the specific characteristics of the materials to be used for the construction came under debate. The proposed replacement superstructure was designed to be a post-tensioned concrete slab resting on discrete concrete columns. There was also a strong consensus that a segmental type design might speed construction. Considering the cost of the replacement structure and the inconvenience that the reconstruction would cause, it was CDOT's desire to build a structure that would last for 100 years. The goal for the high performance concrete (HPC) was a minimum service life of 75 years.

CDOT strongly believed that the use of HPC in combination with the post-tensioned structural design would best ensure a long-lasting structure. Chicago's environment is extremely harsh, particularly in the winter. Temperatures vary widely above and below freezing. These freeze-thaw cycles, combined with an aggressive salting program to control snow and ice, reduce the life span for conventional concrete bridge structures. Developing a concrete mix that could resist chloride penetration, did not achieve excessively high compressive strengths, and could be used in both post-tensioned segmental and traditional cast-in-place construction was desired.

CDOT, using FHWA's Innovative Bridge Research and Construction (IBRC) Program funding, engaged consultants to research HPC mixes already in use around the country and, if necessary, to develop a mix design specifically for this project.

Constituent materials were screened to determine their durability and susceptibility to alkali-silica reaction. Accelerated testing was performed on "off the shelf" mixes provided by producers and new mix designs to ensure that long-term performance would be satisfactory. Finally, a full-scale mock-up of the superstructure was built to test actual performance under load and to refine construction techniques.

Research showed that previous HPC mixes did not have all the characteristics that CDOT was seeking. Consequently, a quaternary HPC mix using low-alkali cement, Class F fly ash, silica fume, and ground granulated blast-furnace slag as cementitious materials was developed.\* The concrete has a moderate compressive strength of 6,000 to 9,000 psi (41 to 62 MPa) at 28 days, develops strength quickly to allow stripping of formwork or post tensioning, has excellent placement and consolidation characteristics, and, for the most part, uses locally available materials. The mix stays workable without the addition of retarders over a wide range of temperatures. Concrete was placed with ambient temperatures as high as 80°F (27°C) without the use of a retarder. Attention was also paid to the curing of the concrete once it was in place. Wet cotton blankets, soaker hoses, and plastic sheeting were placed on the concrete and the concrete was kept wet for seven days. The result is a well-hydrated deck that is free of shrinkage cracks.

CDOT believes that the time and cost involved in the development of this HPC mix was a good investment. The HPC, combined with the post-tensioned deck design, will ensure that the new Wacker Drive Viaduct will be faithfully serving the citizens of Chicago into the twenty-second century.

### Editor's Note

This edition of HPC Bridge Views focuses on one project from the perspectives of the owner, construction manager, general contractor, and concrete supplier.

\*See HPC Bridge Views, Issue No. 19, January/February 2002.

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# THE OWNER'S REPRESENTATIVE'S PERSPECTIVE

Timothy P. Schmidt, Alfred Benesch & Company

The Chicago Department of Transportation (CDOT) retained Alfred Benesch & Company to provide construction management services for the Wacker Drive Viaduct Reconstruction Project. Our duty was to oversee the work of the contractors and the resident engineering (RE) consultants retained by CDOT on each of the three contracts used for the project. The RE consultants performed the quality assurance activities. For the high performance concrete (HPC), the general contractor and their concrete supplier performed the specified quality control activities.

The HPC used on the project possessed many good properties. The maximum slump of 8 in. (200 mm) after the addition of a high-range water-reducer (HRWR) produced a very workable mix that was easily pumped. A high degree of workability was essential for good consolidation of the concrete in areas of the bridge deck with highly congested reinforcing steel, post-tensioning ducts, and post-tensioning anchors. The concrete had little segregation during pumping. We achieved the minimum compressive strengths of 4200 psi (29 MPa) for post-tensioning at about 3 days and 6000 psi (41 MPa) at 28 days with few problems.

One aspect of the HPC specifications found to be very effective was the use of cotton mats and soaker hoses for concrete curing. For standard bridge decks in Illinois, the specifications require installation of wetted burlap and plastic sheeting for the curing materials. The contractor is then required to keep the burlap wet during

the curing period. Our specification allowed the contractor to install the cotton mats dry and saturate them with water immediately after installation. The contractor found the dry installation much easier to perform. Soaker hoses and plastic sheeting were then placed over the cotton mats. The cotton mats absorbed and retained a significant amount of water. It appeared that, even if the soaker hoses were not operating, the mats had absorbed enough water that they would always be wet. This specification saved both inspection time and potential confrontations with the contractor about installing and keeping the burlap wet.

When placement of HPC for the substructure units began, we found a high degree of variability in the air content of the plastic concrete. This occurred on days when small volumes of concrete were placed. There were instances when large fluctuations in the air content were found after the addition of the HRWR. Occasionally, truckloads were rejected due to high air content. After several months, the QC/QA team decided to add some of the HRWR during mixing at the concrete plant. The balance of the HRWR was then added on the jobsite. This practice helped to "condition" the load of concrete and decreased the amount of fluctuation in the air contents. Even after instituting the practice of conditioning the loads, the concrete still required a high level of QC/QA effort to ensure proper air content. Fortunately, the problem of fluctuating air content did not plague us during the large

deck placements. We attributed the decreased fluctuations to the fact that on days of large deck placements, the concrete supplier's plant produced concrete almost exclusively for the Wacker Drive Project.

In the future, we suggest using less HRWR for the substructure concrete. Substructure placements generally do not need a high slump concrete. The volume placed is also generally less than that for a deck placement. It appears that the amount of chemical admixtures in a concrete mix is directly proportional to air content fluctuations. On days when smaller volumes are placed, the expected decrease in air content fluctuations would save both time and money.

Despite the challenges of controlling air contents, we found the HPC to be a very workable mix with good strength characteristics. Based on our long-term test data, we believe that the HPC placed on the Wacker Drive Viaduct Reconstruction Project will perform well over its intended minimum 75-year service life.

After reflecting on the project history, we feel the key element to the success of our project was the teamwork of all involved in producing, placing, and testing the HPC. Without the critical teamwork, we would have moved from fixable minor problems, to major, irreparable ones. The QC/QA team required a learning curve to work past our normally adversarial relationships and to work together effectively. The key to our relationship was our shared goal: to provide our client with the best HPC product possible.

# THE CONTRACTOR'S PERSPECTIVE

Kyle Schultz, Walsh Construction Company of Illinois

The use of high performance concrete (HPC) on the Wacker Drive Reconstruction project presented several special challenges to the general contractor. Some of these resulted from the concrete mix proportions while others resulted from the special provisions.

The first challenge was the erratic air content following the addition in the field of the high-range water-reducer (HRWR). During the first weeks of production, the

addition of the HRWR would cause the air content to either increase or decrease, with no apparent pattern. Further, the required dosage of air-entraining admixture to achieve the specified 5.5 to 8.5 percent air content was not consistent from one day to the next. Not knowing which direction the air content was going following the addition of the HRWR would lead to rejected material. This problem was resolved by the concrete supplier trying different batching

sequences with the admixtures, and deciding to dose the concrete with a third of the HRWR during initial batching. This provided a predictable loss of air content after the balance of HRWR was added on site. However, the day-to-day required amount of air-entraining admixture remained erratic throughout the project.

The second issue was what to do when the air content was too high. Typically, high air content of concrete can be reduced



High performance concrete was used to provide a minimum service life of 75 years.

by additional mixing, or by stopping the truck's drum completely for a time. However, the HPC on this project seemed reluctant to release entrained air regardless of these, or any other techniques. It was believed that the four cementitious materials made for a very sticky mix and the entrained air was unable to escape from the cementitious materials. This problem persisted throughout the project, and was the primary cause of rejected concrete.

The concrete adhered aggressively to the formwork and made it necessary to strip bulkheads and pull keyway formwork as soon as possible. Delayed stripping tended to require the use of jackhammers and labor intensive prying to remove the formwork.

The mix proportions made it difficult for smaller concrete pumps to move the HPC through horizontal pipes or flexible lines. The larger 150- and 170-ft (46 and 52-m) long truck-mounted booms did not experience the same problems as the smaller pumps. The HPC was also susceptible to high air loss during pumping. Boom configurations were selected to minimize vertical drops. All superstructure placements required a "double 90° bend" at discharge to generate a constant stream and minimize air loss. It also became necessary to equip boom

lines with a reducer to minimize the air loss. Without a reducer or "double 90° bend," air loss could be as high as 5 to 6 percent; with the reducer, air loss at point of placement was typically limited to 2 to 3 percent.

Despite these minor problems, the HPC at Wacker Drive was relatively easy to work with. The design required the use of a HRWR with a maximum slump of 8 in. (200 mm). Though intended to provide for maximum workability while maintaining a low water-cementitious materials ratio, the flexibility for a higher slump allowed for adjustments when placing concrete around critical areas such as post-tensioning anchors and under horizontal bulkheads, or utilizing different placement and finishing methods. This played an important part on the night of July 24, 2002. On that night, four separate crews placed the largest and most complicated section of bridge deck utilizing a 170-ft (52-m) long boom concrete pump, two back-out conveyors, and two truck conveyors simultaneously. Slumps were easily adjusted to provide maximum workability and productivity for each crew.

The HPC required specific curing procedures. As soon as possible, cotton blankets were placed on the freshly cast deck. Soaker hoses were then placed atop the blankets to

keep the blankets saturated during the 7-day curing period. Finally, white polyethylene sheeting was placed on top of everything. The average bridge deck placement required about 4,500 sq ft (418 sq m) of blanket and polyethylene and 1800 ft (549 m) of soaker hose. During placement of bridge decks, weather conditions were monitored to calculate the rate of evaporation and minimize plastic shrinkage cracks. When conditions required, continuous fogging was maintained until conditions permitted its discontinuation or until the curing blankets were applied.

Though the start of HPC production was a little rough, we simply rode out the learning curve. After which, working with the HPC was no different from any other concrete. Everyone grew accustomed to the HPC with its special requirements and construction never seemed to be hampered due to the mix.

#### Concrete Mix Proportions for Substructure and Superstructure

Material	Quantities	
	per yd <sup>3</sup>	per m <sup>3</sup>
Portland Cement <sup>(1)</sup>	525 lb	311 kg
Fly Ash, Class F	53 lb	31 kg
Silica Fume	27 lb	16 kg
GGBFS	79 lb	47 kg
Total Cementitious	684 lb	405 kg
Fine Aggregate <sup>(2)</sup>	1140 lb	676 kg
Course Aggregate <sup>(3)</sup>	1800 lb	1068 kg
Water	246-260 lb	146-154 kg
Water Reducer	41 fl oz	1.59 l
HRWR	55-110 fl oz	2.1-4.3 l
Air Entrainment	As needed	
Water/Cementitious Materials Ratio	0.36-0.38	

<sup>(1)</sup> Type I/II

<sup>(2)</sup> Natural siliceous sand

<sup>(3)</sup> 3/4-in. (19-mm) maximum size limestone

## THE CONCRETE SUPPLIER'S PERSPECTIVE

Gary Hall, Prairie Material Sales, Inc.

**H**igh strength concrete for high-rise buildings, post-tensioned parking structures, and overlays or special repair concrete for existing structures has been produced in Chicago for many years. Most

major Chicago area ready-mixed concrete producers have quality control programs and procedures for production of such concrete. The Wacker Drive Reconstruction Project with its special concrete require-

ments, however, needed a much greater level of commitment of high quality materials, personnel, and time.

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An extensive prequalification process determined the raw materials and concrete mix proportions to achieve the desired properties.\* Some materials were locally available while others were brought in from out of state. The project specifications required a rigorous sampling and testing program. Samples of all admixtures and cementitious materials, along with their mill certifications were required weekly. Additional samples were also required for every bridge deck placement. Aggregate gradations, moisture contents, and absorptions had to be measured every time that HPC was produced, whether it was 1 or 2000 cu yd (0.7 or 1500 cu m). Materials that did not comply with project specifications were rejected.

To enable production of the quaternary mix, the two central mix plants at the production yard, located near downtown Chicago and less than 2 miles (3.2 km) from the project, were each set up to accommodate the four cementitious components of the mix. Mechanical adjustments for each cementitious material gate, as well as adjustments to the parameters of the batching software were necessary to compensate for the different flow characteristics of each material. The silica fume required close attention because, at an addition rate of only 27 lb/cu yd (16 kg/cu m), it could easily exceed the  $\pm 1$  percent tolerance. Even on a 9 cu yd (6.9 cu m) batch, the tolerance is only  $\pm 2.4$  lb (1.1 kg). Weighing times were increased considerably, due to each of the

four cementitious materials having to hit its target weight before the next could be weighed. The batching tolerance should be reconsidered when the batch weight of a cementitious material is relatively small. An increase in mixing time of about 50 percent was absolutely necessary in order to ensure optimal uniformity of the HPC mix.

The mix was typically batched with a water-cementitious materials ratio of 0.36, producing an initial slump of 3 to 4 in. (75 to 100 mm). Job site addition of high-range water-reducer (HRWR) increased the slump to approximately 7 to 8 in. (175 to 200 mm). Job site control of air entrainment was a problem encountered early in the project. After some discussion, it was decided to introduce a portion of the HRWR into the mix at the time of batching in an effort to reduce the variability of air content after final jobsite addition of HRWR. This approach seemed to mitigate the variation of air content, but constant attention was necessary for the duration of the project. Frequent sampling was done at the plant, and each batch of concrete was tested by the contractor at the jobsite for slump, air content, and concrete temperature.

Prior to every major deck placement, a pre-pour meeting was held at the jobsite field office and required attendance by personnel from our operations and quality control departments. That portion of the meeting directly involving the ready-mixed concrete producer addressed the rate of delivery, routing of trucks, location of concrete testing stations, and type and configuration of placing equipment. The latter was impor-

tant due to its impact on plastic air content of the concrete at the point of placement. At times, it was necessary to ship concrete exceeding the upper limit of the specified air content in order to be within specification at the point of discharge.

During the deck placements, a yard manager and quality control technician were required at the plant, while at least one operations and two quality control personnel were present on the jobsite. Air entraining and HRWR admixtures were at hand to provide field adjustment of mixes when required. Constant communication was always maintained between the plant and jobsite, allowing for reasonably quick adjustments to the mix or delivery rate. Due to the size of the deck placements, involvement and coordination of many people were required to make the placements go smoothly. An outstanding job was done by the City of Chicago, its engineering consultants, and contractors.

Production and delivery of HPC for the Wacker Drive Project was very challenging. Though representing only a small percentage of total concrete production at our plant serving downtown Chicago, the HPC mix required considerably more attention to materials testing and production. While at times difficult, it was not impossible. HPC is not only materials and finished product. It can also be considered an ideology that must be adhered to. As a result, the new Wacker Drive is an impressive structure that should not require reconstruction for many years to come.

\*See HPC Bridge Views, Issue No. 19, January/February 2002.

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