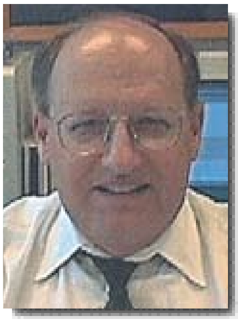
High Performance Concrete Extends Life of Charenton Canal Bridge



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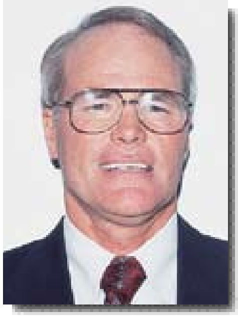

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The Charenton Canal Bridge in Charenton, Louisiana, is the state's first bridge built with High Performance Concrete (HPC) components. The 365 ft (111 m) long new bridge replaces a 55-year-old existing reinforced concrete structure. The structure has five spans each consisting of five Type III AASHTO girders made of precast, prestressed HPC. The bridge's piles also were cast with HPC. Casting these components with HPC required considerable advance testing and several adjustments to the required match-cast cylinder tests to ensure a consistent 10,000 psi (69 MPa) compressive strength was achieved. This article discusses the research work that led to the adoption of HPC, then describes the design features of the bridge together with the pile testing, batching procedures, and importantce of quality control in producing HPC components.

High Performance Concrete (HPC) is gaining acceptance among bridge engineers nationwide, the reason being that there are not only structural advantages to be gained but also long-term economic benefits. In the case of the recently completed Charenton Canal Bridge replacement project in Charenton, Louisiana (see Fig. 1), the project shows that while HPC can provide significant advantages in higher strength, its major advantage is the additional durability that can be achieved. This capability allows dramatically longer life spans, lessening maintenance and replacement costs far into the future. But the process also indicates that producing these higher strength concrete mixes requires increased quality control and rigorous surveillance of batching and casting operations by the precaster.

During the last 20 years, the Louisiana Department of Transportation and Development (LDOTD) has paid close attention to the potential benefits of using HPC. Engineers from the LDOTD have attended numerous seminars and workshops on the subject and have also conducted their own research for the department. In

Fig. 1. The Charenton Canal Bridge, Charenton, Louisiana. The 365 ft (111 m), five-span precast, prestressed concrete structure demonstrates the effectiveness of using HPC.

the 1980s, the LDOTD carried out a variety of tests on HPC using different concrete mix designs with silica fume admixtures. The test results convinced the LDOTD that further work on HPC should be pursued.

Additional research and design work from 1990 to 1994 included instrumentation and laboratory testing of precast, prestressed HPC bulb-tee girders with specified compressive strengths of 10,000 psi (69 MPa). These test girders were fabricated and then laboratory tested to validate their ultimate strength, fatigue strength, prestress losses and shear strength.

During the testing procedures for the Charenton Canal Bridge, a HPC precast, prestressed pile was driven and its behavior monitored. This included a steel casing with a removable plug insert that was driven before the pile due to the extensive scour conditions expected at the actual site. Soil and water tests also were done at the site to ensure there were no sulfates in the ground that would cause concrete deterioration when they came in contact with the Class C fly ash that would be used in the concrete mix.

In 1997, the LDOTD decided to test HPC in practice on a full-sized project. What was needed then was to find the appropriate bridge project that met the requirements for scheduling, application and location near researchers at Tulane University in New Orleans, Louisiana, who would perform ongoing monitoring and evaluation of the bridge's performance.

The new Charenton Canal Bridge replaces an existing 55-year-old deficient cast-in-place reinforced concrete bridge. The new structure comprises five precast, prestressed girder spans of 73 ft (22.3 m) made continuous for live load with a total bridge length of 365 ft (111 m). Fig. 2 shows a plan and elevation of the bridge. Fig. 3 is a half section of the girder showing the intermediate, end, and continuity diaphragms.

The spans each include five HPC AASHTO Type III girders, which were placed at 10 ft (3.1 m) spacings. They support an 8 in. (203 mm) thick HPC deck with a clear bridge width of 46 ft 6 in. (14.2 m) consisting of two 12 ft (3.66 m) lanes, one 12 ft (3.66 m) shoulder and one 8 ft (2.44 m) shoulder.

The structure also includes four 30 in. (762 mm) square, 116 ft (35.4 m) long HPC precast, prestressed piles for each of the four intermediate bents and six 24 in. (610 mm) square, 96 ft (29.3 m) long HPC precast, prestressed piles for each of the two end bents. Fig. 4 is a cross section of the

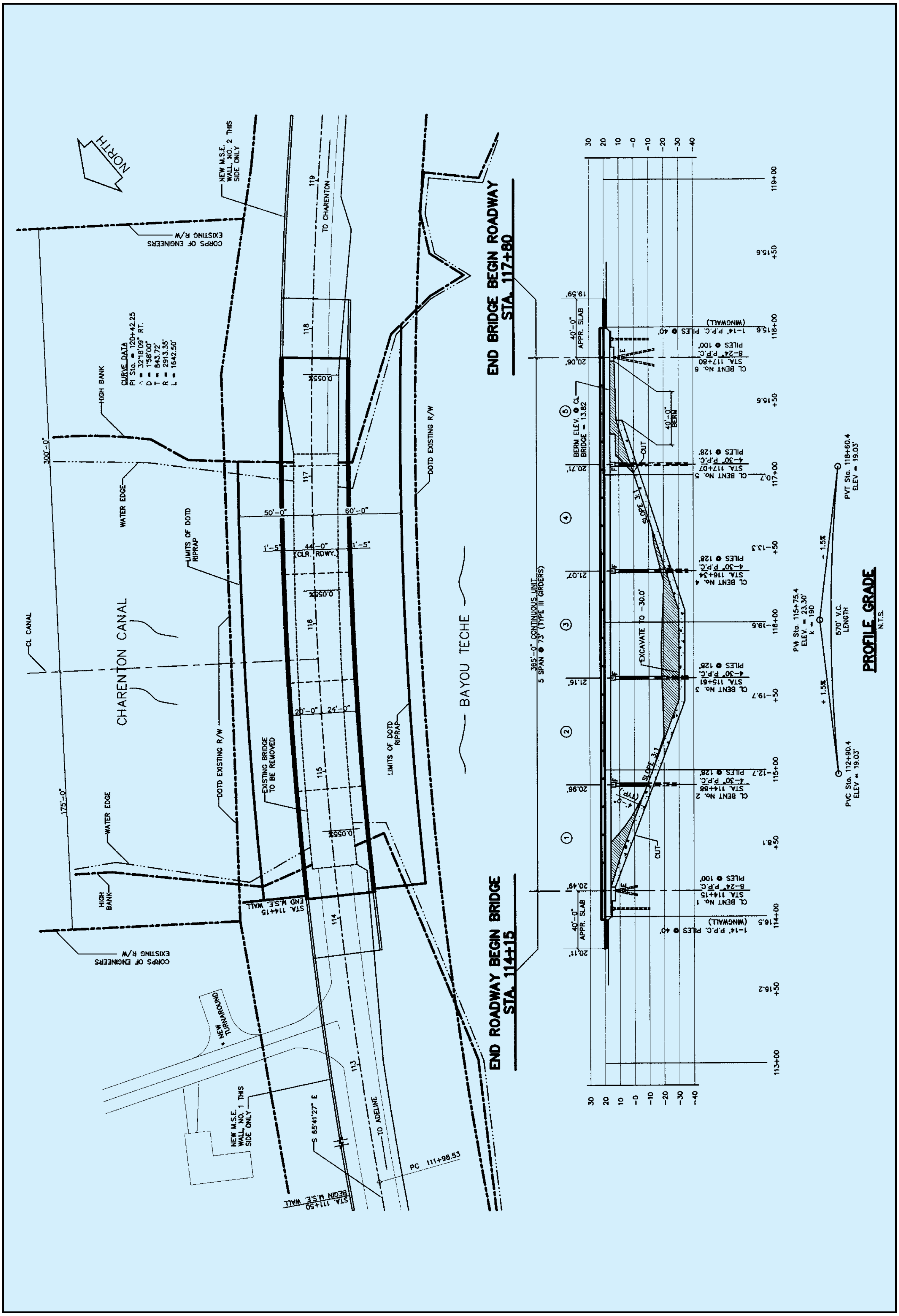
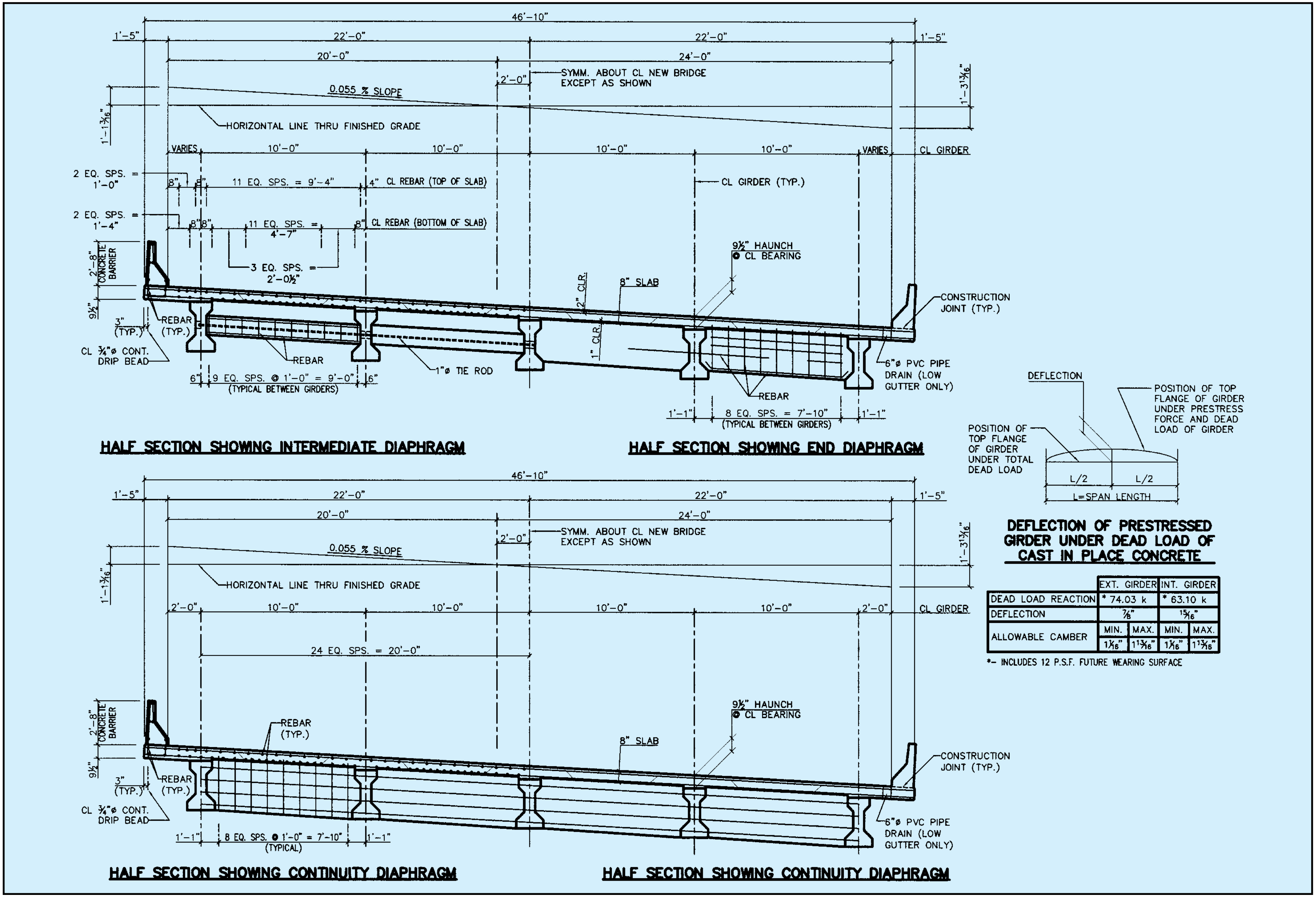


Fig. 2. Plan and elevation of bridge.



DEFLECTION OF PRESTRESSED GIRDER UNDER DEAD LOAD OF CAST IN PLACE CONCRETE

	EXT. GIRDER		INT. GIRDER	
DEAD LOAD REACTION	* 74.03 k		* 63.10 k	
DEFLECTION	7/8"		15/16"	
ALLOWABLE CAMBER	MIN.	MAX.	MIN.	MAX.
	1 1/16"	1 13/16"	1 1/16"	1 13/16"

*– INCLUDES 12 P.S.F. FUTURE WEARING SURFACE

Fig. 3. Half section of girder showing intermediate, end, and continuity diaphragms.

pile showing the prestressing steel and mild steel reinforcement. Fig. 5 shows the piles being stacked prior to shipping to the project site.

A key ingredient in designing the bridge was to meet the environmental concerns brought about by an adjacent landowner, whose site includes many 100-year-old oak trees. In addition, the bridge structure is viewed by commercial navigation traffic and by many recreational boaters that cross under and parallel to the bridge. The precast, prestressed concrete bridge components blended well with the area and made for an aesthetically pleasing design (see Fig. 6).

The bridge superstructure was specified with 7000 psi (48 MPa) release and 10,000 psi (69 MPa) final concrete compressive strengths for the precast, prestressed concrete girders. The use of these HPC girders allowed for wider girder spacings, which saved one row of girders when compared to a normal concrete strength design using 6000 psi (41 MPa) concrete. The girders contain 34 $^1/_2$-in. (12.7 mm) diameter prestressing strands with a minimum specified ultimate tensile strength of 270 ksi (1.86 GPa). Eight strands are debonded at various lengths from the girder ends.

The substructure consists of HPC concrete bent caps supported by two different sizes of piles using 10,000 psi (69 MPa) concrete (see Fig. 7). The use of HPC in the piles increased their resistance to compressive and tensile driving stresses during the pile-driving operation and allowed for casting and shipping of the typically long piles. The use of the long precast piles allowed the engineer to design for future channel scour that was predicted from the hydraulic analysis of the stream crossing.

In addition to the higher strength, all bridge members were required to have a permeability of less than or equal to 2000 coulombs using ASTM Specification C 1202. The permeability requirement was included to add durability and increase the structure's design life up to 75 to 100 years. This represents a significant improvement on the typical 50-year design life that is anticipated using normal concrete mixes. Ultimately, the HPC bridge components offered a 56-day permeability of 1079 coulombs in accordance with the trial mix design.

This bridge will benefit significantly from this durability and added life span. It crosses a river that supports navigational traffic and crosses a flood-control channel. Therefore, it was important to minimize the construction activity. In addition, the bridge is located in a coastal region that experiences appreciable amounts

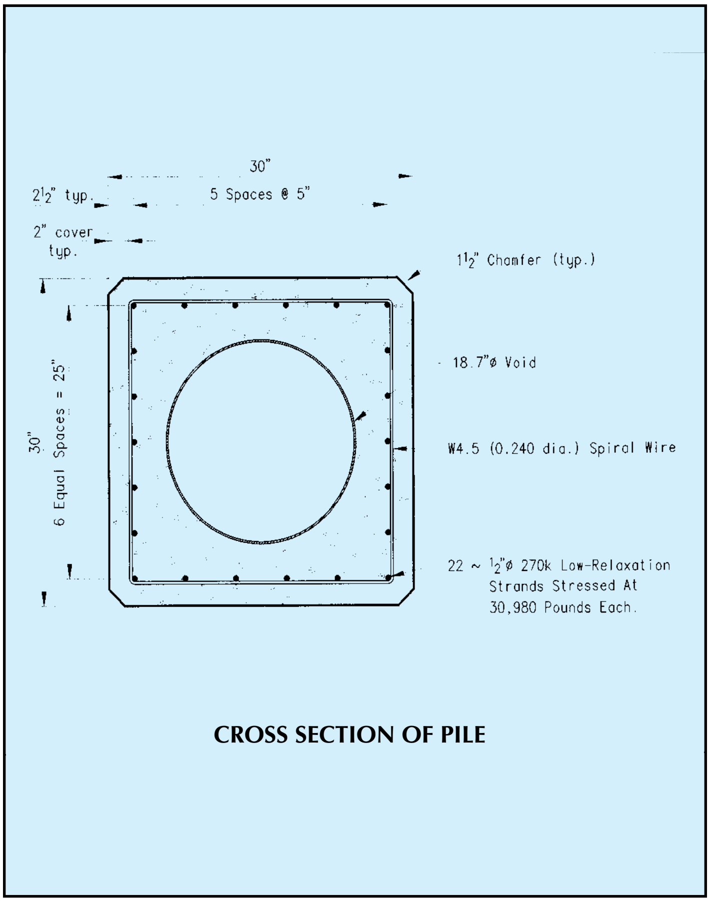


Fig. 4. Cross section of 30 in. (762 mm) square hollow prestressed concrete pile showing prestressing steel and mild steel reinforcement.

Fig. 5. Newly cast piles being stacked at precaster's yard.

Fig. 6. The use of HPC allowed the bridge engineers to eliminate one girder line thus saving on the cost of the superstructure.

of hurricane activity. The added durability of the bridge makes it more resistant to the harsh weather and more secure while reducing the long-term maintenance costs and the need for early replacement.

The precast, prestressed concrete specifications were designed primarily as performance specifications. In addition to the 10,000 psi (69 MPa) and maximum 2000 coulomb ratings, the HPC had to have a slump less than or equal to 10 in. (255 mm). In writing the specifications, no range tolerances were provided as typically is done for cast-in-place designs. The design actually was slightly conservative and was designed for 9000 psi (62 MPa) to provide a safety factor.

The specifications allowed for the use of a maximum of 35 percent fly ash by weight and 10 percent of silica fume by weight in the total combination of cement, fly ash and silica fume. The complete mix details for the concrete, which achieved a 56-day

Table 1. Mix proportions for precast, prestressed HPC.

Material	Quantities per cu yd
Portland cement Type III	691 lb
Fly ash	296 lb
Fine aggregate	1135 lb
Coarse aggregate	1803 lb
Water	247 lb
Water reducer, ASTM C 494	60 oz
Superplasticizer, ASTM C 494	150 oz
Air entrainment	None
Properties	
Water/cementitious material ratio	0.25
Slump	$7^3/_4$
56-day compressive strength	12,057 psi
Chloride permeability (56 days)	1079 coulombs

Note: 1 lb/yd^3 = 0.5933 kg/m^3; 1 oz/yd^3 = 36.68 ml/m^3; 1 in. = 25.4 mm; 1000 psi = 6.895 MPa.

Fig. 7. The substructure consists of HPC bent caps supported by two sizes of piles using 10,000 psi (69 MPa) concrete.

strength of 12,000 psi (83 MPa) are listed in Table 1. The number and description of precast components used on this project are listed in Table 2.

The precast concrete producer, Gulf Coast Prestress, Inc., Pass Christian, Mississippi, worked closely with LDOTD throughout the early testing stage, and was eager to help learn more about HPC in actual use. The company began looking at materials and performing tests as early as February 1997. From the tests, Gulf Coast Prestress and LDOTD determined the proper limestone aggregate needed to be selected. They secured a source and began laboratory tests to achieve the required 10,000 psi (69 MPa) strength.

Gulf Coast Prestress realized it had to change the way crews handled materials and batched concrete in the batch plant after discovering just how closely moisture content of the concrete mixes had to be controlled due to the small margin for error allowable when mixing 10,000 psi (69 MPa) concrete.

Note that in typical concrete mixes,

Table 2. Number and description of precast, prestressed concrete products.

Type of product	Total length Casting/shipping dates
30 in. square pile	
- 1 each at 128 ft long	128 ft
- Casting date:	8/24/1998
- Shipping date:	11/24/1998
14 in. square permanent pile	
- 2 each at 40 ft long	80 ft
- Casting date:	2/5/1999
- Shipping date:	6/11/1999
24 in. square permanent pile	
- 16 each at 90 ft long	1440 ft
- Casting dates:	1/13/1999 through 1/18/1999
- Shipping dates:	5/20/1999 through 7/2/1999
30 in. square permanent pile	
- 16 each at 116 ft long	1856 ft
- Casting dates:	1/28/1999 through 2/8/1999
- Shipping date:	5/20/1999
- 1 each at 134 ft long	134 ft
- Casting date:	2/11/1998
- Shipping date:	8/3/1999
AASHTO Type III girders	
- 25 each at 72.43 ft (avg)	1810.92 ft
- Casting dates:	11/16/1998 through 11/30/1998
- Shipping dates:	8/11/1999 through 8/19/1999

Note: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

a higher-than-needed cement factor can be supplied to provide a faster release strength and turn the beds for new casting the next day. Often, a 7000 psi (48 MPa) strength can be supplied even if 5000 or 6000 psi (34 or 41 MPa) is called for. But maximizing the strength into the 10,000 psi (69 MPa) level (and higher) is much more difficult and does not offer any leeway for overdesign. Every component in the mix plays a key role in ensuring that the level is achieved uniformly and consistently across each batch of concrete.

To ensure a consistent, high quality product, Gulf Coast Prestress performed several independent tests to produce the proper uniform batch. It also produced match-cured cylinders during the component-casting process.

Moisture control proved to be one of the most important factors. If more water than anticipated is present, the mix could end up several hundred psi short of the specified strength. This meant that Gulf Coast Prestress had to add new moisture-control equipment to its plant, tighten its already strict quality control procedures and carefully monitor and record its procedures at its automated batch plant. This allowed the batchers to retrace their steps to see what elements could have affected the outcome and then control those elements better to determine how they affected the batches.

The first attempt at casting a 20 ft (6.1 m) section of AASHTO Type III girder using HPC, 10,000 psi (69 MPa) concrete took place in the summer of 1997. Even though the batching and casting processes seemingly went well, the one-day compressive strengths fell well below the required 7000 psi (48 MPa). Since the plant's procedure was to keep sprinklers turned on the limestone aggregate stockpile at least 24 hours prior to batching, adjustments were made to this process to achieve a condition even closer to saturated surface dry (SSD).

A second specimen was cast two days later using this new technique, and a noticeable increase in release strength was achieved. The company continued to fine-tune this process. After this second test, it was concluded that water had migrated from adjacent aggregate bins used for normal strength concrete into the aggregate weigh-batcher.

Fig. 8. The five precast, prestressed girders for each span were cast in a line at the same time.

Fig. 9. Cylinder testing was done continuously to ensure compressive strengths were being met. In background, newly cast prestressed concrete piles can be seen.

Management decided to suspend all other batching operations during the HPC batching process to eliminate the possibility of any additional moisture. They concluded that since the mix proportion has a water-cementitious ratio of 0.25, it would be greatly affected by the slightest addition of water. Even though the first two tests resulted in 28-day strengths of 10,822 and 11,758 psi (75 and 81 MPa), respectively, the result of the third test exceeded their goal with a strength test of 12,780 psi (88 MPa).

Those procedures became the standard approach for producing HPC. This resulted in a more costly procedure, as all other operations had to be suspended during this batching process. Nevertheless, the operation achieved the goal and indicated how many factors can come into play

Fig. 10. Readying forms for casting girder.

Fig. 11. Concreting operation for casting girder.

when trying to maximize performance. The girders were cast in a line in the plant yard to save costs and ensure consistency (see Figs. 8 through 11). Reinforcing bars in the deck and girder segments were flagged to indicate where instrumentation would be placed (see Fig. 12).

Gulf Coast Prestress also produced cylinders using a match-cured cylinder mold system according to the specifications, which also limited the internal concrete temperature of all precast concrete members to 160˚F (71˚C). The company's research showed that internal concrete temperatures from the heat of hydration on the girder specimens reached 155˚F (68˚C). Research also showed that cylinders steam-cured in excess of 160˚F (71˚C) resulted in higher early-release strength but a lower 28-day strength.

The tests showed that the larger mass of the actual 10,000 psi (69 MPa) concrete components generated more heat than in the typical 6 x 12 in. (152 x 305 mm) or 4 x 8 in. (101 x 203 mm) molds. This meant the test cylinders were not replicating the characteristics of the actual components closely enough. By placing a thermocouple in the product, the match-cure system allowed the smaller cylinders to be cured at the identical time and temperature. This ensured the molds achieved the same characteristics and could be used as appropriate tests of the actual precast components.

These tests indicated that match-curing is imperative for high performance, high strength concrete, because the 28-day strength cannot be jeopardized by internal heat rising too high. Personnel from the Louisiana Transportation Research Center also made cylinder and modulus of rupture molds for on-going research purposes.

Ambient temperature changes through the seasons also can affect the rate with which HPC material sets up. Indeed, this becomes even more important as the strength increases. Particularly, in the summer and fall, fabricators and finishers have to be aware that they must work more quickly to avoid any surface cracking caused by premature drying.

HPC was used for both the piles and the girders. Before casting the piles, a test program was conducted to set the appropriate lengths. A 128 ft x 30 in. (39 m x 762 mm) square HPC precast, prestressed pile was driven and monitored with a pile-driving analyzer to verify its pile capacity and pile-driving stresses. The pile was driven through a casing to isolate it from the soil that would be removed by future scour.

Gulf Coast Prestress used match-cured cylinders to test these components before releasing the strands. During the casting, special attention was paid to the 30 in. (76.2 mm) square prestressed piles, which offered a greater surface area that had to be finished quickly due to the quick setting of the HPC.

The piles were produced hollow with an 18.7 in. (475 mm) diameter void. The precaster centered the sacrificed paper void in the form using steel yokes. After the concrete was placed in the form but not before it had a chance to set, the yokes were removed and the final finish was applied. With HPC, this has to be done fairly quickly because of the faster setting of the concrete.

The cast-in-place reinforced concrete deck has an 8 in. (203 mm) depth and a compressive strength of 4200 psi (29 MPa). The main reinforcement perpendicular to the supporting prestressed concrete girders consists of truss bars measuring $^3/_4$ in. (19 mm) and top and bottom straight bars measuring $^1/_2$ in. (13 mm) in diameter.

Longitudinal deck reinforcing steel included $^1/_2$ in. (13 mm) diameter top and bottom bars. Negative moment continuity for live loads over the piers was provided by the longitudinal reinforcing steel in the composite deck. No reinforcement was provided to resist a positive moment over the piers. Diaphragms were provided at the end bents, the piers and the midspans.

Construction of the bridge required the existing busy state highway route to be closed during work. However, the use of HPC precast girders and HPC precast piles allowed the construction to proceed much quicker and thus the bridge was reopened to vehicular traffic along this highway much sooner than other designs would have allowed (see Fig. 13).

Even though the bridge construction is complete, work on this project has not stopped. In conjunction with Tulane University, research is continuing on the structure through material testing, bridge instrumentation and bridge monitoring. The instrumentation will measure girder-curing temperatures, prestress forces during fabrication, prestress losses, camber and creep in the girders and girder deflection. These results will help propose new options for the AASHTO bridge design specifications for use on future HPC projects. Fig. 14 shows a completed view of the bridge.

Construction of Louisiana's next HPC bridge, which will feature a 10,000 psi (69 MPa) superstructure, is scheduled to begin in 2001. As the benefits of HPC become better known, state and private sources will fund development and construction of other HPC projects.

CONCLUDING REMARKS

The work on the Charenton Canal Bridge shows that HPC designs provide significantly higher strength that can lead to more efficient designs requiring fewer piers and, therefore, generate savings. However, the main advantage that many engineers and state organizations will find from using HPC members is not in the improved strength but rather in the increased durability. The initial savings from eliminating a girder is only a small portion of what can be saved overall if the larger picture is kept in mind.

Permeability is a key ingredient to HPC's success. Its ability to resist chlorides and protect steel reinforcement from corrosion will reduce maintenance costs on an on-going basis and help the bridge maintain a longer useful life. That durability combined with the higher strength lead to a structure life that will be in the range of 75 to 100 years versus a 50-year life achieved with conventional concrete. In essence, that will save the cost of an entire bridge replacement 50 years in the future, when costs will be considerably higher. It also ensures less disruption of traffic and impact on environmental features due to minimal construction or need for repairs.

To be sure, high permeability can be achieved in other more economical ways if that is the only criterion required. But when HPC's impermeability is combined with the added strength that is a byproduct of the mix, the performance and long-term advantages combined with the cost-saving aspects of the higher strength appear to make a compelling case.

One HPC project does not tell everything that needs to be known about this approach or the most advantageous situations for its use. As more projects are constructed, confidence in the process and the inevitable fine-tuning of design and production procedures will help produce an even more superior product. So too, as more precasters become aware of the processes and advantages, competition will help reduce costs. As more projects are built and more monitoring of the existing projects is completed, engineers and precasters will become more efficient at designing and producing HPC bridges.

The key lesson that was learned in this project in producing the HPC members was that all concrete is not the same. It varies depending on ambient conditions and the many factors that affect its batching, including the season of the year and the other ac-

Fig. 12. Sections of reinforcing bar were marked (with red flagging and green print) to indicate where the instrumentation would be placed.

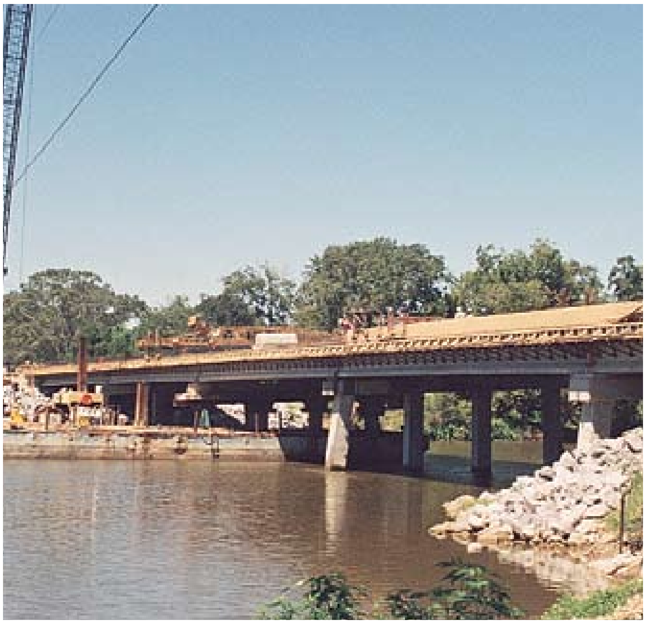


Fig. 13. Overview of bridge during construction.

Fig. 14. Finished bridge.

tivities underway at the same time.

It is vital to ensure the products are cast by a company that provides strict quality control standards and can retrace its steps to control and adjust every aspect of the production process. Engineers must be reassured that they are specifying a concrete quality that can be achieved on a routine, consistent basis. In those cases, HPC components offer a very intriguing application that may become more commonplace in the years to come.

CREDITS

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