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## Contents

HPC for a Context Sensitive  
Bridge Replacement

Demonbreun Street Viaduct

Louisiana's First 10,000 psi  
Box Girder Bridge with U-  
Beams

Producer's Experience with  
10,000 psi Concrete and  
0.7-in. Diameter Strands

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Original Romeo and Juliette Bridge.



Replacement Collier's Promenade Bridge.

## HPC for a Context Sensitive Bridge Replacement

*Richard E. Hart, Oregon Department of Transportation*

Spring Creek in Klamath County, OR, is spring fed and is approximately 2-1/4 miles (3.6 km) in length from its source to its confluence with the Williamson River, at about 1/8 mile (0.2 km) downstream of the U.S. 97 overcrossing. The creek is about 60 ft (18 m) wide and is a favorite of fishermen and rafters regardless of its short length. The U.S. 97 highway bisects Collier Memorial State Park and Logging Museum grounds with a 160 ft (49 m) Oregon Department of Transportation right-of-way on each side of Spring Creek. Primarily due to the proximity of its source, the flow of Spring Creek fluctuates only a few inches between the low and high flow conditions.

The name of the original bridge was the Romeo and Juliette Bridge. However, local people referred to it as Collier's Promenade Bridge—originating from newspaper articles written during its construction. The replacement bridge is now known as Collier's Promenade Bridge.

The Romeo and Juliette Bridge was a reinforced concrete deck girder bridge with a 60-ft (16.29-m) long main span incorporating a radial girder haunch. This produced an arched appearance with 19-ft (5.79-m) long cantilevered approaches. It was constructed in 1946 and was unique among Oregon bridges. This bridge had walkways beneath the bridge that were cantilevered from the architecturally treated abutments. The walkways allowed park visitors access to each side of the Collier Memorial Park without crossing U.S. 97 at grade. The unique bridge design was due to the involvement of Conde B. McCullough of Oregon historic coastal bridge fame. This design is now believed, through documentation, to be one of the final bridge designs that Mr. McCullough may have influenced in the state.

Thus one can follow, or at least understand, why in mid 2003 the original idea of a simple precast, prestressed concrete slab bridge developed into something that would resemble the original structure, while incorporating modern concepts and methodologies.

### The Replacement Bridge

The new structure's general architectural appearance was developed by the preliminary design team in collaboration with the State Parks and Recreation Department and the State Historic Preservation Office to preserve the look and feel of the original bridge. Construction of the replacement structure was complicated by the proximity of the park and endangered aquatic species known to spawn within 1/4 mile (400 m) downstream. This led to the request from biologists, that the use of cast-in-place concrete over the stream be limited.

Collier's Promenade Bridge is 140 ft (42.7 m) long with a single main span of 82.5 ft (25.0 m). It has a width of 85.5 ft (26.1 m), which includes the northbound and southbound lanes of U.S. 97, a turning lane for the Park access, shoulders, and two 9-ft (2.75-m) wide walkways outside the modified F rail.

The bridge was constructed using staged construction while the original bridge continued to carry all the traffic. Once traffic was moved to the completed stage, the original bridge was demolished and the remaining section of the new structure completed. The total bridge cost was \$3.2 million.

### High Performance Concrete

High performance concrete (HPC) containing silica fume was specified for all concrete above the foundations. The inclusion of silica fume in the HPC is intended to extend the life of the structure by limiting the migration of chloride ions from deicing solutions. An added benefit of the HPC concrete in reference to the deck is the increased resistance to abrasion from the use of studded tires. The concrete used above the foundations can be further separated into the cast-in-place (CIP) concrete and the precast, prestressed concrete used only in the girders.

The following table provides the specified and average measured compressive strengths of concrete used for the different components of the bridge.

Application	Concrete Class, <sup>(1)</sup> MPa	Compressive Strength, <sup>(2)</sup> psi	Compressive Strength, <sup>(2)</sup> MPa
Precast, Prestressed Girders	50	12,363 7274 <sup>(3)</sup>	85.2 50.2 <sup>(3)</sup>
Deck and Approach Panels	35	8880	61.3
Bridge Rail Type F	25	6400	44.1
Other Cast-in-Place Elements	30	6240	43.0

1. Class of concrete represents the specified concrete strength at 28 days

2. Measured at 28 days except for release strength

3. Release strength specified as 6500 psi (44.8 MPa)

Other than the unique architectural treatment of the CIP concrete, the most striking item of interest on the bridge is the one-of-a-kind precast, prestressed concrete girder system. The 12 girders are radially haunched with a 42 in. (1.07 m) depth at midspan and 102 in. (2.59 m) depth at each bearing. The prestressing strand is symmetrically placed in the bottom quarter of the girder at midspan and continues horizontally to the ends of the girder. The radial haunch produces an effective strand eccentricity in the girder. The exterior three girders on each side of the structure have a 6-in. (150-mm) diameter standard steel structural pipe placed 1 ft (305 mm) from the top of the girder to accommodate utilities.

Originally, the girders were to be pretensioned for shipping and then post tensioned for live load. However, the precaster had installed a new high capacity casting bed so it was possible to apply all the prestressing force before casting.

### **Further Information**

For further information about this bridge, please contact the author at [richard.e.hart@odot.state.or.us](mailto:richard.e.hart@odot.state.or.us).

### **Acknowledgement**

The author acknowledges the assistance of Dr. Keith Kaufman, of Knife River Corp., Harrisburg, OR, and Denny Holm, owner of Holm II, the Bridge Contractor, Stayton, OR, for thinking this would be a fun project to cap his career.



**Girder System.**

# Demonbreun Street Viaduct

*Ed Wasserman, Tennessee Department of Transportation*



**High Strength concrete was used in the box beams to achieve a span-to-depth ratio of 29.**

On July 6, 2004, bridge inspectors advised the Metropolitan Government of Nashville and Davidson County to close a 60-year old viaduct crossing the rail yard of the CSX Railroad; thereby eliminating one of the three viaducts leading into downtown Nashville from the west. The new viaduct was opened to traffic 2 years and 7 months later, having started from the initial planning stage. High performance concrete (HPC) played a vital part in the execution of this successful project.

## **Design Considerations**

The viaduct to be replaced was 773 ft (236 m) long and 47 ft (14.3 m) wide and consisted of 13 spans of rolled steel beams supported on steel bents. The two maximum spans over the railroad were each 50 ft (15.2 m) long. As the railroad prohibited any at-grade crossing of the four tracks by construction equipment, it was decided that the replacement span over the tracks would be 130 ft (39.6 m) long. This provided for piers set at a clear distance of 25 ft (7.6 m) from the centerline of the outside tracks. The beams spanning the rail yard would have to be launched over the flanking piers. Because of the existing tie-ins of the viaduct deck with existing buildings at two critical locations, the proximity of the ends of the viaduct to intersecting streets, and the need to provide 23 ft 6 in. (7.2 m) of vertical clearance over the tracks, the substructure depth of the new bridge was critical.

## **Design Implementation**

The final configuration chosen for design was a seven-span continuous bridge 773 ft 7 in. (236 m) in length, jointless from back-to-back of the full height abutments. The superstructure uses

six lines of 48-in. (1.22-m) wide by 54-in. (1.37-m) deep box beams with a center-to-center spacing of 9 ft 8 in. (2.95 m) and a 58-ft (17.7-m) wide, 8-1/4-in. (210-mm) thick composite slab. The bridge is designed to be continuous for all loads applied to the composite section. The foundations for the integral abutment walls and the intermediate bents are composed of 42-in. (1.07-m) diameter drilled shafts, set in two pair clusters for the bents and three shafts for each abutment.

Depth restrictions necessitated the use of precast, prestressed concrete box beams 54 in. (1.37 m) deep over the rail yards for the 130-ft (39.6-m) long spans. The span-to-depth ratio of about 29 and the beam spacing required 10,000 psi (69 MPa) compressive strength HPC in combination with forty-six 0.6-in. (15.2-m) diameter, 270 ksi (1.86 GPa) low-relaxation strands with an initial jacking force of 2.02 million pounds (8.99 MN). The 54-in. (1.37-m) beam depth was used throughout the bridge.

The beam lengths varied from 73 ft 0 in. to 128 ft 3 in. (22.3 to 39.1 m) in the seven spans. Spans 1, 5, 6, and 7 required concrete with a compressive strength of 6000 psi (41 MPa) at strand release and a range from 7000 to 7750 psi (48 to 53 MPa) at 28 days. Span 2 with a beam length of 122 ft 3 in. (37.3 m) and spans 3 and 4 with beam lengths of 128 ft 3 in. (39.1 m) required concrete compressive strengths of 8000 psi (55 MPa) at strand release and 10,000 psi (69 MPa) at 28 days.

### Concrete Mix Proportions

The following mix proportions were used by the fabricator to obtain the required 10,000 psi (69 MPa) compressive strengths:

Material	Quantities (per yd <sup>3</sup> )	Quantities (per m <sup>3</sup> )
Cement, Type I	747 lb	443 kg
Fly Ash, Type C	249 lb	148 kg
Fine Aggregate	974 lb	578 kg
Coarse Aggregate No. 67	1439 lb	854 kg
Coarse Aggregate No. 11	481 lb	285 kg
Water	248 lb	147 kg
High-Range Water-Reducing Admixture	5-15 fl oz	193-580 mL

Retarder was required when the ambient temperature was 85°F (29°C) or higher and the maximum slump was not to exceed 8 in. (200 mm) after the addition of the high-range water-reducing admixture.

### Beam Production

Beams were produced on twin beds, on alternate days. The beams on the first bed were cast and the beams steam cured for 18 to 20 hours. During the curing period on the first bed, the

beams on the second bed were prepared and cast.

Twelve beams 128 ft 3 in. (39.1 m) long and six beams 122 ft 3 in. (37.3 m) long were cast with the 10,000 psi (69 MPa) mix. The highest measured release strength was 12,510 psi (86.3 MPa), the lowest was 8590 psi (59.2 MPa), and the average was 9950 psi (68.6 MPa). The 28-day strengths were 12,540, 11,350, and 11,860 psi (86.5, 78.3, and 81.8 MPa) for the highest, lowest, and average, respectively.

Because the bridge was designed to be continuous for dead and live loads applied to the composite section, the negative moment over the interior supports, combined with the effective prestressing force required that 21 of the 46 total strands be debonded, in order not to exceed the  $0.6 f'_c$  stress limit on beam compression. This led to concerns that the number of debonded strands might compromise the shear capacity at the beam ends. A check of the shear capacity using the disturbed region by strut-and-tie methods as well as the sectional method led to two decisions. To accommodate the tension in the strut, the prestressing strands were extended 30 in. (760 mm) outside the beam end and bent up to be anchored in the cast-in-place diaphragm that acted as the closure pour between beams at the supports. No supplemental reinforcement was used in the strut. Additionally, the end diaphragm of the beams was increased from the normal 18 in. (460 mm) thickness to 48 in. (1.22 m) and the shear reinforcement for the end region was designed as if the beams were not prestressed.

### **Closing Remarks**

Bids for the new viaduct were taken on October 14, 2005, and the bridge completed on October 14, 2006—5 months ahead of the predicted date and within the predicted budget. Costs for the bridge were \$111/ft<sup>2</sup> (\$1195/m<sup>2</sup>) for the superstructure and \$31/ft<sup>2</sup> (\$333/m<sup>2</sup>) for the substructure. The ability to accomplish the rapid construction within the specified budget and satisfy context sensitive issues led to the decision to construct the bridge from concrete components. The precast, prestressed concrete box beams met the critical clearance requirements and allowed for timely delivery that the schedule demanded.

### **Further Information**

For further information about this bridge, please contact the author at [ed.wasserman@state.tn.us](mailto:ed.wasserman@state.tn.us).

## Louisiana's First 10,000 psi Box Girder Bridge with U-Beams

*Rudy McLellan, Formerly HNTB Corporation*



High strength concrete was used in the U-beams of the North Boulevard Bridge.

The major benefit of the proposed North Boulevard project was to improve access for highway traffic to either enter or exit the downtown area of the city of Baton Rouge without railroad train operations constantly obstructing highway traffic. Public meetings were held for the proposed improvements resulting in the desire to construct a bridge that was aesthetically pleasing and would complement the existing recreational parks, an historic Temple, and a church with arch-type structures. The City of Baton Rouge and the East Baton Rouge Parish Department of Public Works promised the community that a visually pleasing bridge would be built.

The solution became Louisiana's first high performance concrete (HPC), 10,000 psi (69 MPa), precast, prestressed concrete (PPC) box girder bridge. Open to traffic in 2006, the new North Boulevard Bridge is a medium span bridge that is S-shaped in plan. The bridge aesthetics were provided by the smooth surfaces of the graceful and slender PPC U- beams, and the uniquely sculptured concrete arch-shaped piers. For this project, HPC was specified only for the concrete of the PPC U-beams.

### **HPC Girder Solution**

The bridge consists of nine spans of 120.0 ft (36.6 m) for a total bridge length of 1080 ft (329 m). The bridge superstructure is a single 58.8-ft (17.9-m) wide horizontally S-curved structure with a radius of 1146 ft (350 m). All spans contain a total of five straight PPC beam lines with beam spacing ranging from 11.3 to 11.7 ft (3.4 to 3.6 m). The straight beams in combination with the S-curve result in a variable length deck overhang.

The superstructure PPC members are 54-in. (1.37-m) deep U-beam shaped box girders having the same dimensions as the standard [Texas U54 beams](#). The PPC U-beams were designed for a concrete compressive strength of 6000 psi (41 MPa) at strand release and 10,000 psi (69 MPa) at 56 days. Ninety-two straight 0.5-in. (12.7-mm) diameter prestressing strands with a minimum ultimate tensile strength of 270 ksi (1.86 GPa) were used. The total prestress force was 3.0 million pounds (13.3 MN). There were 20 strands with different debonded lengths in the U-beam bottom flange. The U-beams are integral with a 7.5-in. (190-mm) thick cast-in-place concrete deck to create the box girders.

The box girder design using HPC materials resulted in an economical, much lighter, and thinner overall superstructure, which in turn required a smaller, less costly, substructure system and shorter approach lengths. The shorter approach lengths saved project costs, which included the reduced cost of expensive right-of-way acquisitions. The total construction cost of the bridge was \$5.1 million or about \$80/ft<sup>2</sup> (\$860/m<sup>2</sup>).

### HPC Girder Fabrication

The high strength concrete PPC U-beams were fabricated in nearby Pass Christian, MS. The precaster had previous experience with fabrication of 10,000 psi (69 MPa) PPC girders, which proved to be vital.

The HPC performance requirements from the Louisiana Department of Transportation and Development specifications were as follows:

Strength	Maximum 10,000 psi (69 MPa) at 56 days
Slump	Maximum 10 in. (250 mm)
Permeability	Maximum 2000 coulombs at 56 days
Silica Fume	Maximum 10.0% by weight*
Fly Ash	Maximum 35.0% by weight*
* by weight of the total cementitious materials (cement, fly ash, and silica fume)	

The HPC mix proportions developed by the precaster were as follows:

Materials	Quantities (per yd <sup>3</sup> )	Quantities (per m <sup>3</sup> )
Cement, Type III	691 lb	410 kg
Fly Ash, Class C	296 lb	176 kg
Fine Aggregate	1091 lb	647 kg
Coarse Aggregate <sup>(1)</sup>	1803 lb	1070 kg
Water	250 lb	148 kg
High-Range Water-Reducing Admixture	275 fl oz	10.6 L
Retarding Admixture	60 fl oz	2.32 L
Water-Cementitious Materials Ratio	0.25	0.25

1. Limestone size No. 78

These mix proportions produced a concrete with a unit weight of 153 lb/ft<sup>3</sup> (2450 kg/m<sup>3</sup>) and a 7 in. (180 mm) slump.

The measured concrete strengths based on test cylinders for 23 castings were as follows:

Age, days	Average, psi	Average, MPa	Range, psi	Range, MPa
1	6800	47	3990-8680	28-60
2	9900	68	9140-10,970	63-76
3	9300	64	3890-10,790	27-74
28	13,600	94	9790-15,840	68-109

The fabrication of the HPC high strength PPC U-beams did not pose any significant problems that could not be overcome with minor adjustments.

Each 120-ft (36.6-m) long, 10,000 psi (69 MPa), PPC U-beam weighed an average of about 80 tons (73 metric tons). A previous bridge project in Louisiana with similar type and length of PPC U-beams and designed using 6000 psi (41 MPa) concrete weighed an average of about 120 tons (109 metric tons) each because all cross-sectional dimensions had to be larger.

### Conclusion

The North Boulevard Bridge project shows that HPC is an efficient, cost effective material, which can be successfully used in Louisiana for visually appealing, slender, and elegant bridges with challenging geometric conditions.

### More Information

More information about this bridge is contained in the paper titled "Louisiana's First 10,000 psi Precast, Prestressed Concrete Box Girder Bridge," PCI National Bridge Conference 2007.

## Producer's Experience with 10,000 psi Concrete and 0.7-in. Diameter Strands

*George Schuler, Coreslab Structures (Omaha) Inc.\*



High strength concrete and 0.7-in. (17.8-mm) diameter strands were used in the precast, prestressed concrete beams.

The Pacific Street Bridge over I-680 in Omaha, NE, was constructed as the culmination of ongoing research to test the impact of using 0.7-in. (17.8-mm) diameter strands in NU I-girders. The objective of the project is to develop the quality control and design criteria required to introduce 0.7-in. (17.8-mm) diameter strands at 2-in. (50-mm) horizontal and 2.5-in. (64-mm) vertical spacing in NU I-girders. Compared to 0.5- and 0.6-in. (12.7- and 15.2-mm) diameter strands, only half and three quarters, respectively, of the total number of strands are needed. This results in immediate labor savings in precast concrete product costs. More importantly, having the ability to introduce almost twice the prestressing force, compared to 0.5-in. (12.7-mm) diameter strands and 135% of the prestressing force compared to 0.6-in. (15.2-mm) diameter strands, could result in a significant increase in the span capability of the current Nebraska Department of Roads (NDOR) NU I-girder without having to modify the sections or acquire new forms.

This research project was funded under the Innovative Bridge Research and Deployment (IBRD) program as a collaborative effort between the Federal Highway Administration (FHWA), NDOR, University of Nebraska-Lincoln, and the Transportation Research Board. As such, the FHWA reviewed the proposal, approved it, and provided the funding. In the proposal, the 0.7-in. (17.8-mm) diameter strand was to be demonstrated as an innovative idea. Hawkins Construction Company was the General Contractor for the project, and Coreslab Structures (Omaha) Inc. produced the precast, prestressed concrete bridge girders.

Twenty 98-ft 4-in. (30.0-m) long NU 900 bridge girders were constructed for the project. Each girder weighed 90,000 lb (41 metric tons) and included a partially thickened top flange. The girders were specified to include high performance concrete (HPC) with a compressive strength of 10,000 psi (69 MPa) at 28 days, and thirty 0.7-in. (17.8-mm) diameter strands per girder.

Full-scale testing performed prior to this project had shown that no unusual web cracking was observed at the girder ends, and the current provision for end zone reinforcement of the AASHTO LRFD Bridge Design Specifications was adequate. However, additional bottom flange reinforcement was needed to enclose the strands and confine the bottom flange concrete.

### **High Strength Concrete**

“We used a standard HPC mix design and were confident that we could deliver the specified compressive strengths for the project,” stated Michael Wilson, who serves as Coreslab Structures (Omaha) Inc.’s Quality Assurance Manager. Wilson, a 45-year veteran of the industry, is familiar with the special measures that must be employed to ensure the necessary workability of high strength, low water-cementitious materials ratio concrete mixes. “We used 865 lb/yd<sup>3</sup> (513 kg/m<sup>3</sup>) mix with 65% Type III cement, 20% slag, and 15% Class C fly ash at a 0.28 water-cementitious materials ratio,” said Wilson. “We also employed a three-stage mixing strategy to increase the consistency of the batches.” According to Wilson, all the water, cementitious materials, and half the aggregates were placed in the mixer in the first stage,

followed by the admixtures in the second stage, and finally the remaining aggregates were added for the third stage of mixing. Wilson went on to say, “Due to the extremely low water-cementitious materials ratio, we had to make sure we properly sequenced the addition of materials to allow the mixer to work efficiently.”

The average concrete compressive strength was 11,000 psi (76 MPa) at 28 days, exceeding the specified minimum strength of 10,000 psi (69 MPa). Overnight release strengths averaged approximately 7000 psi (48 MPa).

### **Production Challenges**

When asked if the combination of HPC and 0.7-in. (17.8-mm) diameter strands changed the normal dynamics of typical casting procedures, Wilson replied, “Not at all. The larger strand diameter didn’t seem to have an effect on our normal casting procedures. The biggest challenges had more to do with the handling of the strand itself.” Wilson referred to challenges associated with getting the strands out of the coils and flexibility issues when feeding the strands through the bulkheads. He went on to say, “This was a learning process for everyone involved. I’m sure once the use of 0.7-in. (17.8-mm) diameter strands becomes more common, many of these issues will be addressed and easier ways of handling the strands will be developed. It may be as simple as using a larger coil.” When asked about the aspects of the project that went smoother than anticipated, Wilson responded, “The tensioning process. We didn’t experience any tolerance issues, everything elongated properly as planned.”

The flame cutting process to release the strands went as normal. Despite the larger tensioning force, the 0.7-in. (17.8-mm) diameter strands seemed to have less reaction when cut than smaller diameter strands. There were no unusual cracks in the beams with the reinforcement provided. Dennis Drews, Project Consultant with Coreslab Structures, agreed with Wilson’s remarks regarding the larger strand size. “Strand availability was definitely a concern,” stated Drews, “We also experienced challenges acquiring the larger hold-down devices necessary to execute the draped strand pattern.” Drews went on to say, “Due to the fast-track nature of this project, the bridge designers responded immediately to this challenge and engineered an alternative strand pattern, eliminating the need to employ the draped strand approach.” “Everyone worked together to get the job done,” added Drews. “There was a great team in place for this project. We look forward to more opportunities to serve in the future and are excited to have played a role in producing the first bridge in the United States to utilize this unique strand size.”

### **More Information**

For more information regarding this research project, please visit <http://rip.trb.org/browse/dproject.asp?n=13599>.