2011 Award of Excellence

Low-Rise Category

Baylor Cancer Hospital Concrete Strengthening for Collins Family Bridge of Hope

Dallas, TX

Submitted by Raymond L. Goodson Jr., Inc.

Building the new Charles F. Sammons Cancer Center on the Baylor University Medical Center campus in Dallas, TX, would require a connector to the newly renovated Baylor Cancer Hospital. The architect decided to make the connection with a sky bridge linking four buildings, including the Sammons Cancer Center and the Cancer Hospital. This bridge, the Collins Family Bridge of Hope, provides passage for both pedestrians and major utilities.

The architect chose a sweeping arc over Worth Street for the bridge layout, making it possible to connect four buildings in a smooth, continuous path with excellent sight lines for visitors. The north end of the bridge wraps over an underground garage and is supported by the Cancer Hospital's south plaza.

The south plaza deck is a conventionally reinforced cast-in-place concrete one-way system with a 5 in. (127 mm) slab spanning between 24 x 24 in. (610 x 610 mm) beams spaced at 6 ft (1.8 m) on center. It was originally designed in 1969 to support vehicular loading and landscaping.

The deck is the lid of a four-level underground parking garage. While the original design provided sufficient capacity for heavy vehicles, it was deficient in both strength and stiffness to support new sky bridge columns.

The underground garage is a multi-functional hub. The parking area is used by doctors, staff, and patients. It is also a hub for chilled water and steam lines for distribution throughout the campus. Primary telecommunications and fiber optics lines are routed through the garage. To add complexity, the south plaza is located directly above the primary garage exit. Any new constrictions to the exit lane height or width would have a significant negative impact.

With the garage being an integral part of daily operations, the owner set high expectations for the reinforcement project:

- The garage must remain in continuous use;
- Construction must have a minimal impact on daily operations;
- Reinforcement must not cause a permanent loss of parking spaces;
- Reinforcement must not cause a loss of headroom; and
- Reinforcing must be done in a way that minimizes rerouting mechanical, electrical, and plumbing (MEP) systems.

Condition of exiting garage with primary exit lane below the south plaza where the Bridge of Hope was to be located

Workers installing the formwork suspended from the slab above that allowed existing utilities to remain in place during strengthening

With these parameters, the owner defined how the overall cost of the project was driven not only by construction costs, but also by its impact on daily operations costs, nonstructural elements costs, and revenue losses. Phasing, clearance, flexible construction methodology, and material properties became integral parts of the equation.

The engineering diagnosis consisted of a thorough investigation of the existing structure per ACI 364.1 and ACI 437 using original construction documents and field evaluations. Detailed documentation was available for the original design and subsequent renovations. Despite its age, very few signs of deterioration were discovered. Analysis of the drawings revealed that most beams had significantly less shear capacity than flexural capacity.

Traditional methods of strengthening were first considered. These included installing supplemental steel beams under the existing concrete, extending new sky bridge columns down through the garage to new foundations, and removing and replacing existing beams and columns. These methods were all ruled out, as they could not conform to the owner's requirements for the project.

With traditional strengthening methods ruled out, the final solution was a synergistic combination of three distinct ideas with proven track records. It was recognized early on that the existing structure had reserve flexural capacity. While a single beam did not have sufficient capacity to support new columns, a combination of three or more beams would come reasonably close. So, the first step would be to bundle groups of beams together by installing new distribution ribs connecting three or more beams. The second step would be to use section enlargement to boost the stiffness and capacity of the bundled beams. The third step would use externally applied fiber-reinforced polymer (FRP) to boost the shear and flexural capacity of members not requiring additional stiffness.

It was important to determine if a high-early-strength concrete mixture could be designed with the high flow required to place a large quantity of concrete through holes in the existing slab. The selected mixture, a high-performance, high-flow concrete mixture, was a two-component, polymer-modified cementitous mortar with a penetrating corrosion inhibitor. The bagged mixture was extended with 25 lb (11.3 kg) of 0.5 in. (13 mm) river rock (not limestone) saturated surface-dry (SSD), 25 lb (11.3 kg) of 3/8 in. (9.5 mm) river rock SSD, and a high-range water-reducing admixture to improve flow and delay set.

Full-size mockups and strength tests were performed. The concrete for the mockups was placed manually as planned for the actual installation through 4 in. (102 mm) diameter holes. Based on the results of the mockups and experimentation with

Workers placing concrete through holes in deck

Installed CFRP on bottom of beam for flexural reinforcement and GFRP U-wrap for shear reinforcement

Workers installing reinforcing steel for section enlargement and distribution ribs with existing utilities still in place

mixers, a very controlled mixing sequence using only mortar mixers was specified. Concrete with a 10 to 11 in. (254 to 279 mm) slump, excellent aggregate distribution, and 5500 psi (37.9 MPa) 7-day strength was achieved.

Having chosen a suitable mixture design, the next step was developing a forming system that had minimal impact on the daily garage operations. A system was designed to suspend from the structure above. Formwork would fit between the structure and MEP systems to avoid costly re-routing. It would be partially prebuilt and raised into position in a few hours. Once the formwork was in place, the lanes beneath could be reopened.

Knowing the system was constructible, the engineer proceeded with the design of bundled transfer beams. The design crux was creating new distribution ribs between existing beams stiff enough to behave as beams on elastic foundations, distributing loads to existing beams proportional to their stiffness. A wide rib was selected and reinforced with both conventional reinforcing and post-tensioned tendons. Post-tensioned tendons were installed through holes cored through existing beams to provide a measure of continuity that would have been difficult to achieve with conventional reinforcing.

The analysis and design of distribution ribs and transfer beams was achieved through an iterative process of analysis of a beam on elastic foundations, design of section enlargement, recalculation of cracked section properties, and re-analysis with new properties until reasonable closure was achieved. With final sizes of enlarged sections determined, enlarged sections were reinforced with conventional reinforcing steel.

Composite action was achieved through mechanical and chemical bonding. In addition to using post-installed dowels with shear friction methodology, a chemical bond was achieved with a bonding bridge. A surface roughness of ICRI CSP-7 was achieved through mechanical profiling. For small pours where the placement window was relatively short, a high-modulus, high-strength epoxy bonding adhesive was used on a dry substrate. For larger pours where the bonding bridge required an extended life, an epoxy-modified cementitious bonding bridge over an SSD substrate was used. The SSD condition was achieved by soaking burlap, placing it against the prepared substrate, and tightly covering it with polyethylene sheets for 24 hours.

The third leg of the solution used externally applied FRP to reinforce beams not requiring additional stiffness. ACI 440 limits on strengthening were followed to ensure that structural members possessed sufficient strength during a fire. Members not meeting these requirements were reinforced by section enlargement. Glass fiber-reinforced polymer (GFRP) wet layup was selected for shear reinforcement. Concrete fiber-reinforced polymer (CFRP) wet layup and prepreg systems were used for flexural reinforcement. Cracks exceeding 0.010 in. (0.25 mm) were epoxy injected, and a CSP-3 surface profile was achieved by mechanical profiling. After installation, fabrics were covered with an intumescent coating to meet UL assembly standards for flame spread and smoke generation.

Scabbling was used to install CFRP strips in a modified system for top reinforcement. The entire deck was then covered with a waterproof membrane and a concrete topping for protection.

Multiple mortar mixers were used with a crew for each mixer. Large wood funnels were built to gravity-feed concrete through placement holes.

The deck slope affected concrete flow, making it important to start from the lowest point and work uphill. This minimized the potential for damming in the forms.

FRP systems were inspected and tested per ACI 440, Section 7.1, guidelines and by a special inspector with significant experience in both the design and testing of FRP systems.

The story of this project is one of innovation and collaboration. Innovative ideas were allowed to surface and mature. Out of this setting, the innovative idea to combine three unique solutions developed. Each leg of the solution was pushed beyond the limits of traditional reinforcement projects and rationally addressed to create a synergistic and innovative solution. This resulted in a very clean look to the garage. At a cost of $1.8 million, the owner was very pleased with the process and their new Bridge of Hope.

The completed Bridge of Hope

Collins Family Bridge of Hope

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