Value Engineering Results in Successful Precast Railroad Bridge Solution

A value engineering study for the Arbor Rail Line Bridge replacement in Nebraska City, Nebraska, resulted in an innovative precast concrete design solution that was accepted over a proposed steel superstructure, saving $70,000 in the project costs. The precast superstructure comprises five box girder sections that create the same profile as the original steel solution. By using a detailed analysis to design the diaphragms and transverse post-tensioning, the five boxes worked together as a single unit to resist the design loads. Additionally, since the entire superstructure consisted of only five precast components, the box-girder system allowed the new bridge to be erected and opened to traffic within 72 hours. This article provides the design considerations and construction highlights of the project.

A precast, prestressed concrete bridge alternate to an already bid steel project has demonstrated convincingly that value engineering can provide significant engineering benefits and cost savings to owners and taxpayers.

In the case of the Arbor Rail Line Bridge 5.90 near Nebraska City, Nebraska, the value engineering analysis by Tadros Associates, LLC, resulted in a bridge replacement structure that was not only more economical to build, but also one that could be constructed faster and safer than the steel proposal. Furthermore, precast concrete provided a very durable structure and one that will require very little maintenance over the life of the structure.

Owned by the Omaha Public Power District (OPPD), one of the largest publicly owned electric utilities in the United States, the Arbor Rail Line is a major spur for transporting coal to OPPD’s Nebraska City Power Station. A series of engineering inspections revealed that the existing bridge was structurally deficient and would need to be replaced. The new project was originally designed as a steel bridge and let for bid, with the construction contract being awarded to L.G. Barcus & Sons of Kansas City, Kansas.
VALUE ENGINEERING STUDY

After the construction drawings were released, Tadros Associates carried out a value engineering analysis, working with the owner and contractor, with the objective of finding ways to cut construction time and cost. One of the conditions of the contractual agreement was that the rail line could be shut down for only 72 hours. Furthermore, any new superstructure design would have to keep within the existing bridge profile parameters. This meant that modifications to the profile grade line, vertical clearance limits, bridge width, or substructure design would not be acceptable.

The most challenging aspect of the bridge design was that the roadway clearance was very shallow, even for a structural steel solution. Engineers would have to be creative in developing structurally a precast concrete alternate that would fit within the same geometric parameters as the steel scheme. It would also have to use the latest in concrete materials technology.

Working closely with CSR Wilson Concrete (now Rinker Materials) of Omaha, Nebraska, Tadros Associates devised a precast concrete superstructure configuration that would work as an alternative to the steel design solution. The precast design was proposed to the contractor, who in turn proposed it to the owner and original designer. The precast option was ultimately ac-
cepted by all concerned, and the contractor directed Tadros Associates to develop the necessary construction documents.

**PRECAST DESIGN**

The bridge design was governed by AREMA Cooper E80 loading. The original steel design consisted of five rolled W40x324 steel girders as the principal load carrying members. In addition, there were two rolled W35x150 steel girders that were used to support walkways on either side of the tracks.

These girders were not designed to carry any of the train loads. The walkways, which were elevated to avoid interference with the tracks, created a nonuniform cross section, but it did provide the much needed advantage of additional structural depth. Figs. 1 and 2 show the elevation and cross section, respectively, of the original steel solution.

For the precast concrete option, two alternatives were considered. One system consisted of five modified NU I-girders with an integral precast deck; the second was a box girder system. The span length was set at 65 ft 10 in. (20.1 m), the same as for the steel design. A preliminary design of both systems revealed that the box girder system was the more efficient of the two and was, therefore, accepted as the chosen solution.

The box girder system is unique in that it consists of two different sized box sections. The two exterior boxes are 3 ft 8 in. (1.11 m) wide and 5 ft 0 in. (1.52 m) deep, and the three interior boxes are 4 ft 4 in. (1.32 m) wide and 3 ft 4 1/2 in. (1.03 m) deep. The five box girders were post-tensioned transversely at five locations along the span.

Fig. 3 shows the cross section of the precast concrete solution. This precast concrete system matched the profile of the proposed steel structure. The deeper exterior boxes created the elevated walkways, and the interior boxes were sized to match the depth of the five W40x324 steel girders. The concrete compressive strength for the box girders was 8500 psi (59 MPa) at 28 days and 6000 psi (41 MPa) at strand release. The combined
width of the three interior box girders provided the bed for the railroad tracks and ballast.

The key element in the design of the precast solution that allowed it to compete favorably with the steel design was the detailed analysis for the design of the diaphragms and transverse post-tensioning. The goal of the analysis was to have the five box sections work together as a single structural unit to resist the design loads. The rigidity that the post-tensioning provided allowed this to happen.

The exterior boxes were an integral part of the structural system. Without structurally designed rigid diaphragms and post-tensioning, only the three interior boxes would have carried the majority of the design load, and much of the capacity of the two deeper exterior boxes would have been wasted. The concrete box system had a span-to-depth ratio of approximately 20, which resulted in perhaps one of the most slender concrete railroad bridge ever built in the United States for this span.

The structural analysis of this system was complicated by the fact that the cross section was nonuniform and the loading would occur in two distinct phases. In the first loading phase, prior to transverse post-tensioning, the boxes had to be designed as individual elements to resist longitudinal pre-stressing and self-weight during handling and erection.

For the second phase of loading, the five boxes acted as a single structural unit. Second phase loads included the weight of the ballast, railroad tracks, and train load. Because of these design complexities, most commercial software packages, such as those typically used for highway bridge design, could not be used. Instead, the design engineers combined a number of design tools, including a three-dimensional modeling program, and hand calculations to carry out the design.

To account for the structural contribution of the transverse diaphragms and post-tensioning, the bridge system was modeled as a three-dimensional space frame. From this model, the load distribution among the five boxes was determined.

The flexural capacity of the system

Fig. 7. Arrival of a box girder by truck-trailer.

Fig. 8. Girder No. 2 in place.

Fig. 9. Placement of Girder No. 3.
was determined using strain compatibility analysis. The current code equations for flexural capacity lump all of the prestressing steel together, which does not accurately account for tensioned strands in the compression zone near the top face of the box. By performing a detailed strain compatibility analysis, the multi-layered strands could be accounted for accurately. Code equations for flexure also limit the ultimate capacity of a member if the section is over-reinforced. By using strain compatibility, the engineers were able to more accurately determine the ultimate flexural capacity of the system, and assign the proper strength reduction factors.

For the concrete diaphragms and transverse post-tensioning, the three-dimensional modeling program was used to determine the maximum moments and stresses in the diaphragm. Post-tensioning was designed to overcome the maximum tensile stresses in the diaphragms and provide an additional 250 psi (1.72 MPa) of contact pressure between adjacent beam diaphragms. The result was the use of four 1 3/4 in. (45 mm) diameter post-tensioning bars per diaphragm, with a force of 292 kips (1300 kN) per bar.

**FABRICATION AND ERECTION**

Because of the 72-hour limit on rail down time, fabrication and erection speed was a critical issue. Tadros Associates worked closely with the contractor and the precast producer to make the fabrication and the construction sequence as efficient as possible. Because the entire superstructure consisted of only five precast pieces, the box girder system could be produced and erected very quickly. This efficiency of construction of the precast concrete alternate could not be matched by the original steel solution.

Figs. 4 to 11 show some of the fabrication details and erection highlights for the bridge. Fig. 4 illustrates the production setup at the end diaphragm, showing the post-tensioning ducts inside the diaphragm, grout key blockout, reinforcement, and lifting loops. Fig. 5 shows the end of a completed girder stored at the precaster’s...
yard, and Fig. 6 shows the alignment of two adjacent girder ends in place at the job site.

The girders were delivered from Rinker’s LaPlatte, Nebraska, plant to the site by truck-trailer and erected by the contractor (see Figs. 7 to 10). Post-tensioning was also executed by the contractor (see Fig. 11).

Views of the completed structure are shown in Figs. 12 to 14.

CONCLUDING REMARKS

This project is an excellent example of how a precast concrete superstructure can compete with steel, even when conditions call for a very shallow structural depth. The value engineering study provided immediate benefits to the owner and the contractor in terms of construction time and cost savings.

At an overall project cost of $2.5 million and a precast package cost of $75,000, the precast concrete alternative resulted in an overall reported cost savings of approximately $70,000, which was distributed among OPPD, L.G. Barcus, and Tadros Associates. Long-term benefits will be realized through lower maintenance costs over the life of the structure.

This project recently won the 2002 PCI Design Award for “Best Nonhighway Bridge.” The jury citation was as follows:

“This project is an excellent example of the speed and efficiency in which a precast concrete bridge can be erected. The existing bridge was demolished and the new bridge erected and opened to traffic within 72 hours. The shallow vertical clearance, which was a design challenge even for the original steel design, was accommodated by precast concrete through the use of modern concrete materials and accessories and innovation in design. The concept of transverse post-tensioning to make the five box girders act as a singular unit provided the means to maximize the structural capacity of the superstructure system. This value engineering project, which saved over $70,000 over the steel proposal, resulted in a rapid replacement of the existing bridge and provided a low cost, durable, and virtually maintenance-free structure.”

Fig. 13. Top view of completed bridge with rails and ballast in place.

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CREDITS

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Engineer of Record: Tadros Associates, LLC, Omaha, Nebraska
Contractor: L.G. Barcus & Sons, Kansas City, Kansas
Precast Concrete Manufacturer: Rinker Materials Corporation, Prestress Division, LaPlatte, Nebraska

Fig. 14. Elevation view of completed bridge.