Anything but Redundant

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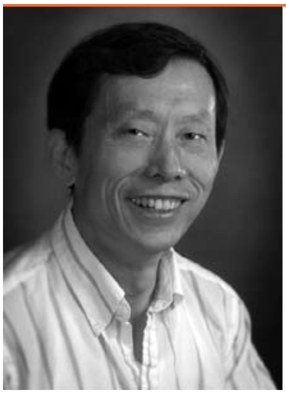
A Washington flyover curves through a tight construction window using a non-redundant steel plate girder system.

AS THE WASHINGTON State Department of Transportation (WSDOT) works to mitigate congestion, there is an increasing demand for grade-separated interchanges for the state's highways. Recent large design projects have demonstrated the need for cost-effective, single-lane structures. These structures are being located in previously developed, highly constrained urban settings, requiring long spans, thin superstructure depths and ease of construction over existing traffic.

SR522/US2 Interchange BNSF RR Flyover Ramp, which opened to traffic in December, is one of the ramp structures that was recently designed under such constraints and resulted in the use of a four-span steel-plate-girder bridge. The bridge is 27 ft wide with a total length of 712 ft and crosses over the BNSF Railroad near Monroe, Wash., northeast of Seattle. The main span over the railroad is 230 ft, and two-thirds of the bridge's length is curved with a 300-ft radius.

Because of this sharp curve, lateral instability caused by the torsional moment was a primary concern. A steel box girder was considered first because it is the most efficient structural type for resisting torsional moment. However, that would have meant shipping 120-ft-long, 28-ft-wide loads from the fabricator's facility in Oregon, which was not deemed practical. The alternative of using shorter sections would have increased the number of field splices, making construction both more difficult and more expensive, so that idea also was rejected.



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A concrete box girder was also ruled out because of the vertical clearance required over the railroad tracks. The bridge geometry would not have provided adequate space for falsework while allowing the railroad to remain in operation. The huge mass of the concrete box superstructure also would have created challenges for the drilled shaft substructure design of the bridge, which is located in a high seismic zone with the potential for soil liquefaction.

Redundant or not?

A steel plate girder bridge seemed to be the most feasible and cost-effective solution. The only question was how many girders to use. Decades ago, WSDOT defined girder bridges with less than four girders as non-redundant superstructures. In recent years, however, three-girder superstructures have been redefined as redundant superstructures.

In the preliminary design of the flyover ramp, all the piers, including those along the curve, were designed to be perpendicular to the alignment line. As the result of the radial bearings, the main span length of the exterior girder is 235 ft but the interior span is only 223 ft. Structural analysis of the bridge showed that the maximum flexural demand on the exterior girder was much higher than on the interior girder, but the shear demand on the interior girder was much higher than on the exterior one.

This meant that if a three-girder system was selected, it still would not provide complete load path redundancy due to the uneven load distribution resulting from the curvature of the bridge. On the other hand, a four-girder superstructure would provide redundancy but would result in a girder spacing of less than 7 ft, and would therefore not be cost effective.

A structure using two steel plate girders with a 16-ft spacing ended up being selected as the most cost-effective solution. Because a two-plate girder system is classified as fracture critical, due to the lack of structural redundancy, certain welding procedures and bridge inspection rules had to be applied.

In order to reduce the weight of the superstructure and ease the seismic demands on the substructure, the design used a two-way slab to reduce the slab thickness from 10½ in. to 8½ in.,

Two cranes hold the curved girder during erection.

The SR522 BNSF Flyover Bridge in November 2011, a month before it opened.

with shear studs installed on the top of the girders and the top of the cross frame members.

In the design of the SR522 RR Flyover, a cross-frame spacing of approximately 15 ft was designed on the curved portion and 25 ft for the straight portion. All cross frames were designed as primary members. Reinforced concrete end diaphragms were installed at both abutments to increase the fixity of the boundary condition and resist uplift on the outside girder, further stabilizing the two-girder system against the torsional moment.

Pinned disc bearings were designed on the intermediate piers to carry the vertical loads and to resist the lateral seismic loads. One-directional movable disc bearings at the end abutments allow free longitudinal movement.

A 3D finite element analysis was performed using GTSTRUDL and the results compared with the results of structural analysis using MDX to ensure correctness and accuracy. The analyses showed that the design of all the girders and the bracing frames met the requirements of the AASHTO *Bridge Design Specifications*.

Tracks and Wires

Constraints in terms of proximity to power lines and railroad tracks also had to be factored in. Two 120-KV power lines, one on each side of the railroad, posed a threat to both the shaft installations and girder erection. Through negotiations with both power line owners, one of the lines was temporarily shut down during construction and the other was rerouted. In addition, the railroad would not allow any temporary supports to be installed within 15 ft of their tracks. The designed field splicing points had to be adjusted to fit these constraints.

Under the circumstances, a "Suggested Girder Erection Plan" was provided on the design plan. This included the footprint of the temporary shoring towers, the locations where cranes should be set up and the calculated girder segment weight between splice points. A special notice was included in the plan, warning the contractor to consider the torsional rotation, warping and the differential vertical deflections between the two girders. The plan also recommended joining the two segments crossing the railroad together and then putting them on temporary support towers because it would be very challenging to anchor just one segment alone on the support towers. Of course, lifting two segments with the connecting cross frames would require a higher capacity crane, and the two segments together might also increase the difficulties of connecting to the other pieces on the temporary support towers simultaneously.

However, if choosing to put one piece at a time on the temporary tower as the alternative method, instead of providing required anchorages, the contractor would utilize one higher capacity crane to lift the segment between field-spliced points, while the other crane would hold the middle point of the segment as long as needed for connecting the adjacent girder segment to the first one with all the cross frames.

Under the dead load of the bridge deck, the curved bridge will not only experience differential vertical deflection between the interior girder and exterior girder, but will also experience the torsional rotation caused by the eccentric dead load. The torsional rotation will change the super elevation of the bridge deck. The cambers of the girders under the dead load of steel only and the dead load of the composite section were calculated and included in a table in the contract plans. But the calculated cambers in the table were based on the final stage of the construction, not for the falsework settings. The falsework settings had to be designed differently in order to match the designed final super elevation after the deck placement. MSC

*This project was discussed in the 2012 World Steel Bridge Symposium session "Bridge Potpourri II" (B16). You can watch a video of this session (and others) at **www.aisc.org/2012nascconline**.*

Owner, Structural Engineer and Architect
Washington State Department of Transportation, Olympia

General Contractor
Scarsella Bros., Inc., Kent, Wash.

Steel Team

Steel Fabricator
Fought and Co., Inc., Tigard, Ore. (AISC Member/AISC Certified Fabricator)