Simplified Continuity Details for Short- and Medium-Span Composite Steel Girder Bridges

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State departments of transportation are being requested to produce bridge designs that are cost-effective, require less maintenance over a projected 75- to 100-year lifetime, and are adaptable to rapid construction operations. Most continuous bridges in the United States constructed of pre-fabricated girders and high-quality materials meet these requirements. Some geographic areas, however, have steel beam girder bridges that are at a competitive disadvantage to precast, prestressed concrete in spans up to 150 ft. Tennessee is developing bridge systems for steel bridges that can be erected similarly to precast, prestressed beams made continuous, with cranes of the same or lower lifting capacity, and can be fabricated at a reduced cost to be competitively priced. This development, it is hoped, will lower prices for both concrete and steel bridges.

In 1995, the American Iron and Steel Institute (AISI) issued a set of standard rolled beam bridge designs, published as Short-Span Steel Bridges (1). During the development of these standardized designs, the Tennessee Department of Transportation (TDOT) was asked to review the draft versions. These standard designs served their stated purposes: provide local agencies, which had no design staff, with predesigned and detailed plans; provide efficient designs that could compete with standardized precast, prestressed simple-span concrete bridges; and promote the use of rolled steel beam bridges in general.

Although the AISI designs used the concept of continuous slab, known in Texas as the poor man’s continuous bridge details and in North Carolina as link slabs (Figure 1), TDOT’s assessment was that configurations more nearly achieving continuity would be more desirable. TDOT wanted to achieve designs with greater redundancy and more efficient use to the capacity of steel beams. The positive aspects of the AISI standards that TDOT wanted to maintain were simplicity in fabrication and ease of construction. Efforts at improvement have led incrementally to two approaches, tested through construction of prototype bridges.

SIMPLE SPAN FOR NONCOMPOSITE DEAD LOADS AND CONTINUOUS FOR COMPOSITE DEAD LOADS AND LIVE LOADS

The initial conceived and implemented approach was to design bridges in essentially the same way that TDOT had developed previously for precast, prestressed beams. This approach would involve designing the steel beams to support their self-weight and the weight of the cast-in-place slab in the noncomposite condition while retaining the reserve strength to carry subsequent superimposed dead and live loads on the resulting composite section. Continuity over interior supports was achieved through a cast-in-place 3,000-psi concrete diaphragm and mild steel reinforcement placed longitudinally within the deck slab, thus forming the resisting couple (Figure 2).

The development of the compressive reaction was the first topic of discussion. A fail-safe solution would be to join the bottom flanges of each line beam at the supports. This approach was rejected at the time because it required precise placement of the beams, allowing no error. The decision was to apply the compressive reaction of the bottom portion of the steel beam in such a way as to develop a compression stress in the concrete diaphragm not to exceed 0.6 f’c (the design 28-day compression strength of the concrete). The question of how to size the end plate for distribution of the beam flange forces could be solved through strain compatibility. However, it was decided to size the plate by setting its width equal to that of the beam flanges and its height approximately equal to the distance from the bottom flange base to the neutral axis of the composite section. The plate thickness was determined by applying a load to the plate as if it were a cantilever, fixed at the flange and free at the neutral axis, acting under a triangular pressure diagram. Although not an exact analogy, it sufficed as a conservative approach. A plate thickness resulting in a theoretical deflection at the free end of 1/48 in. was considered satisfactory. In actuality, an end plate equal in height to the beam was used to simplify forming and to provide additional connection strength in case of catastrophic loss of support.

The trial design was implemented for the construction of a bridge carrying SR-35 over Brown Creek and Harper Avenue in Maryville, Tennessee (Figure 3). As this was a bridge replacement project, phased construction was used. The new, lightweight design was selected for this site because the bent heights from the ground ranged up to 44 ft and only limited locations were available for placement of cranes.

The spans for the new bridge are 65.3, 71.3, 71.5, and 45.3 ft. The slab width varies from 75 to 87 ft and is supported by eight W36 × 150 grade 50W rolled beams varying in spacing from 9.36 to 11.55 ft. The weight of the longest beam was 35,000 lb, easily handled by a 20-ton crane (Figure 4).

As a final concession to simplicity, the beams did not have to be cambered to compensate for the expected dead load deflection of 2.6 in. Instructions were to place the beams with “natural camber” (out of straightness) up. The unit weight of structural steel was 18.3 lb/ft² at an in-place cost of $0.72/lb. This cost would not be competitive with precast, prestressed beam bridges at most sites in Tennessee.
Although the experiment of constructing SR-35 over Brown Creek and East Harper Avenue was a success, TDOT's Division of Structures was not completely satisfied that the best structural efficiency per unit cost had been achieved. The design minimized shop cost and erection effort. However, it was recognized that if simple details could be developed at modest cost, the steel beams erected as simple spans but made continuous for dead load of the wet slab could achieve additional economies in beam size and weight.

Important to the solution selected was the knowledge that, for most span arrangements of continuous bridges, the negative moment demands at interior supports are greater than the maximum positive moment demands. Three customary methods are used to satisfy this requirement:

1. Selecting a prismatic beam cross section that meets the maximum moment demand, sacrificing economy at other locations;
2. Sizing beams to just exceed the needs at interior supports spliced with smaller sections using welded plate girders with plate cutoffs or two or more prismatic, rolled-steel sections spliced together, usually at dead load inflection points; and
3. Using a prismatic, rolled shape supplemented with fatigue-sensitive, welded cover plates.

None of these options suited TDOT’s idea of simplicity with economy. After some discussion, TDOT’s designers compromised on details that are minimal in fabrication complexity, avoid cover-plate fatigue details, and enable simple span beam erection.

The design concept is to use a prismatic beam section full length, meeting the demands in the maximum positive moment region. The beam top flange is joined to its mating beam from the adjacent span by using a single shear bolted connection (Figure 5). The splice plate is extended in length as necessary to act as a bolted cover plate. The bottom compression flange is fitted with a welded cover plate run-

FIGURE 3  SR-35, general view.  
FIGURE 4  SR-35, side view.
ning from the beam end toward the cutoff point equal to the top cover plate.

The gap between the bottom compression flanges for adjacent beams ends at the interior supports that are joined by two mating trapezoidal plates is equal in thickness to the sum of the beam flange and cover plate (Figure 6). Being wedges, the trapezoidal plates can be driven to a tight fit and welded regardless of any reasonable gap tolerance between beams ends. The quality of the welds is not critical, because the joined wedges are in compression. After the wedge plates have been welded, the concrete diaphragm at the interior supports may be poured at the full height of the beams, locking the system in place and establishing continuity, before the deck slab is poured. Alternatively, the concrete diaphragms may be poured concurrently with the slab pour, because the wedge plates cannot buckle.

FIGURE 5 Continuity for dead load slab and composite load details.

FIGURE 6 Driven wedge plate details.
This concept was used to construct a two-span overpass replacement bridge at the DuPont Access Road over SR-1 in New Johnsonville, Tennessee (Figure 7). The bridge has spans of 87 and 76 ft and is 40 ft wide. Six W33 × 240 grade 50W rolled beams spaced approximately 7 ft 5 in. on centers and supporting an 8½-in. deck compose the superstructure. The unit weight of structural steel was 37.7 lb/ft². Although the DuPont Access Road bridge may appear to have less structural efficiency than the SR-35 bridge, the two are comparable. The reason is that the end spans controlled both designs and the ratio of maximum positive moments for the DuPont Access Road to that of the SR-35 bridge is about 1.57. The price of the steel from the low bidder was $0.56/lb in place. Two other bids averaged $0.74/lb.

Significantly, the total bridge was constructed in 90 calendar days, without incentives, using the details.

EXPANDING THE RANGE OF APPLICABILITY

TDOT now has two other bridges under construction that increase the limits on span length, using the simple span for dead load of beam, continuous for all other loads.

SR-210 over Pond Creek is an example of the upper limits of span length achievable with rolled-steel I-sections. The bridge is a five-span configuration with spans of 93.50, 103.25, 132.25, 132.25, and 118.33 ft (Figure 8). The bridge is jointless, having integral abutments (Figures 9 and 10). These features reduce maintenance and dampen seismic motions.

The substructures are skewed 35° from the longitudinal axis. The 42-ft-wide roadway is supported on five W40 × 248 ASTM A709 50W rolled beams, spaced 8 ft 6 in. on centers. Figures 11 and 12 show details of the continuity connections before the deck was poured. The structural steel density was 34.48 lb/ft². The beams were set in 30 calendar days.

Massman Avenue over I-40 in Nashville (Figures 13 and 14) is an experiment with welded plate girders erected as simple span for dead load girder and continuous for dead load of slab and all continuous composite loads. The 287-ft bridge has integral abutments and spans of 140 and 147 ft. Five 60-in. welded plate girders, spaced 9 ft 9 in. on centers, support a 46-ft roadway. The structural steel density is 36.73 lb/ft². This bridge will also be instrumented to verify the degree

FIGURE 7 DuPont Access Road, elevation view.

FIGURE 8 SR-210 under construction.

FIGURE 9 SR-210 integral abutment details.

FIGURE 10 SR-210 beam penetration details.
of continuity achieved. Traffic disruption from the erection will be compared with similar data on a more conventional continuous welded plate girder bridge being erected on the same project.

CONCLUSIONS

Bridges made from shallow steel rolled beams can be economically competitive to those made from deeper precast, prestressed beams for several reasons. Material costs and shipping costs are lower. Girder erection is less expensive because smaller cranes are required. The cost of road approaches is reduced because shallower fills are required.

A viable steel beam system with continuous composite concrete deck, constructed in the same way as precast, prestressed concrete bridges, designed as simple span for dead loads of beam and slab, and continuous for all subsequent loadings, is practical in spans up to 70 to 75 ft.

With only a modest increase in complexity details to splice the flanges at intermediate supports before pouring, the deck slab provides improved structural efficiency at little cost and is the recommended solution. This design will create viable options to deeper precast, prestressed beams relative to economic competitiveness and the option to reduce the cost of approach roadways where grade differentials matter.

Using continuity details at intermediate supports can reduce future maintenance and provide an extra measure of redundancy in case of catastrophic events.

Simple span for dead load of beam, continuous for all other loadings, increases construction speed and reduces traffic disruption over active roadways. The two continuity details are available for rapid construction and reduction of traffic disruption during erection.

REFERENCE