Design and Costs for Simple-Made-Continuous Rolled Steel Girder Bridges: Literature Survey

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Abstract: The method of simple-made-continuous for steel bridges is becoming more popular throughout the United States because it enables significant cost savings. Specifically, the method allows one to avoid steel bridge girder splices and design the steel sections for the self weight and the weight of the slab as simply supported and then the addition of live load and remaining dead loads as continuous. This balances the moments between the positive and negative regions allowing for a prismatic section and even adds speed of construction since the field splices are not needed. In 2006, the Colorado DOT sponsored a study to (1) review current approaches to simple-made-continuous using standard rolled sections and (2) develop design charts for rapid sizing of steel bridge beams and cost estimation for simple-made-continuous. This paper presents a state-of-the-art review up until 2007 for this type of construction and focuses on several of the most recent and successful transportation department projects.

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Introduction

Over the past 50 years in the mid-western United States, construction of short to medium span steel bridges has declined or, at best, remained constant, while prestressed concrete bridge construction has dominated the market (Azizinamini et al. 2003). The state of Colorado, in particular, has seen steel bridge construction virtually disappear and the market dominated by prestressed bridges [Wang, T. (2006) “Colorado Department of Transportation,” personal communication]. One reason for this sharp decline is the lack of steel mills in the region combined with a strong presence of precast concrete companies in the state. In addition, a lack of readily available economical and innovative procedures and tools to design and construct steel bridges has hindered the industry in certain areas such as Colorado.

During the bidding process for selection of the bridge type, it is mandated that accurate bidding of both steel and concrete be developed. The precast concrete industry has worked to develop tools to make this process easier and subsequently dominated the market in Colorado. These types of tools are not available for bidding steel bridges, thus more work by a design/build contractor is required for the steel option. The tendency is for bidders to go with the easier, and over time, more understood option and thus the type selection is routinely dominated by pre-stressed concrete.

Simple-Made-Continuous: Economical Steel Bridge Design Method

The conventional approach for constructing multispan steel bridges is to design them as continuous girders to distribute the load over all members. In that method, the rolled girders are fabricated and shipped to the job site where they are assembled by the contractor using a bolted or welded field splice at low stress points. There is a relatively recent method where simply supported beams are specified by the designer and beams are then made continuous at the piers using a concrete diaphragm or a connection plate (Azizinamini et al. 2005). In this approach, once the slab and diaphragm are poured, the simply supported beam accounts for its weight along with the wet concrete deck. As the concrete diaphragm hardens, making the girders continuous, all other loads (live, composite dead) are shared through the system of beams. This latter concept is called simple for dead load, continuous for live load, or simple-made-continuous (Azizinamini et al. 2005). Some of the major advantages of the simple-made-continuous method over the field splice method, hereafter referred to as the “conventional method,” are: (1) it eliminates the need for expensive field splices; (2) reduces the negative moment at the pier, while increasing the positive moment at mid span; (3) maintains a uniform cross section throughout span to reduce fabrication effort; leading to minimum detailing of the steel beam; (4) smaller cranes are required to assemble the beam system; (5) erection time is reduced without the need for field splices; and (6) there is minimal traffic interruption compared to the conventional method. As of 2007, several states have begun to implement this type of design and construction for some of their steel bridges. The list of states that have built simple-made-continuous steel girder bridges is becoming more popular throughout the United States because it enables significant cost savings.

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bridges includes Colorado, New Mexico, Nebraska, Ohio, and Tennessee. This paper presents a brief summary of these bridge projects, including a comparison of their approaches and costs.

**Nebraska**

The Nebraska Department of Roads recently teamed with the University of Nebraska to identify/develop an economical solution for short span (80–110 ft) steel bridges (Azizinamini et al. 2003). The two alternatives developed were to make the beam act as simple for the dead load and continuous for the live load, or to have the beam behave as continuous for both dead and live loading. After tests were conducted for both alternatives, it was shown that the beam acting as continuous for the live load only produced a lower negative moment at the pier, while also generating a higher positive moment at midspan (Azizinamini et al. 2003). This was attractive because as mentioned above a uniform cross section could be specified economically throughout the length of the girder. After comparing the alternatives, the University of Nebraska recommended the development of simply supported beams for the dead load and continuous for live load. The initial detail they designed for the connection at the pier can be seen in Fig. 1.

A research bridge was then constructed in Omaha, Neb. using the principles developed by the University of Nebraska and National Bridge Research Organization. The new steel bridge replaced a four-span bridge over Interstate 680, with two 97 ft spans (Azizinamini and Vander Veen 2004). The new rolled girder bridge, completed in August of 2004, uses four W40×249 grade 50W girders on its 32 ft width, plus a 7 ft cantilevered sidewalk. Girders are spaced at 10 ft 4 in. on center. The bridge contains integral abutments, which allows for no bearings or expansion joints in the deck. On the pier, the girders sit on a 1.75 in. bearing pad surrounded by a sponge rubber joint filler. Simple bent plate cross frames are attached to the bearing stiffeners on the girders. The negative moment at the pier creates large compressive forces in the bottom flanges that could crush the concrete diaphragm, therefore a 2 in. thick plate is welded to each bottom flange with no gaps to transfer the compressive forces through the steel instead of the concrete. Reinforcing rods are also run laterally through the girders to give extra support for the concrete diaphragm cast around them (Azizinamini and Vander Veen 2004). This bridge design calls for the concrete diaphragm to be poured two thirds full, making the beams partially continuous. The other third is filled in when the deck is poured, making the girders fully continuous. This process led to stability in the deck during the pouring phase. Reinforcing rods are also placed in the deck slab above the piers to provided extra continuity and handle the tension force. For this steel bridge, it was estimated that the simple-made-continuous design cut costs by one-third compared to using field splices to connect the girders, i.e., the conventional method. The cost for in-place erected steel for this bridge amounted to only $0.52/lb, compared to a rule of thumb estimate of $0.75/lb for rolled steel bridges having field splices (Azizinamini and Vander Veen 2004). Fig. 2 shows basic connection details for the research bridge spanning Interstate 680 in Omaha, Neb.

**Tennessee**

The state of Tennessee has also developed and applied this concept. In one of the Tennessee DOT’s (TDOT) initial designs for a simple-made-continuous bridge (Fig. 3), continuity was achieved by a cast in-place 3,000 psi concrete diaphragm with steel reinforcement at the interior supports (Talbot 2005). A 1/2 in. plate welded at the end of the girder distributed the compression forces in the flanges.

The trial bridge in Tennessee was built with four spans (65, 71, 71, and 45 ft) of W36×150 grade 50W steel with eight girders spaced between 9.3 and 11.5 ft. The varied spacing was due to the deck width changing from 75 to 87 ft over the length. The unit weight of structural steel was 18.3 psf at an in-place cost of $0.72/lb. While the concrete diaphragm was a technical success, the economics still did not compete well with precast concrete bridges at other sites in Tennessee (Talbot 2005). TDOT developed another method to create a full length beam with the same cross section (prismatic) throughout the span to meet the demands of the maximum positive moment. This was done by using a single shear bolted connection in the top flange. The bottom compression flange was fitted with a welded cover plate. Two trapezoidal wedges were tightly fit into the gap between the bottom flanges, similar to the Nebraska detail. A 12 in. steel channel frame was run from exterior beam to exterior beam along with a concrete diaphragm. This design was used in a two span, (87, 76 ft) 40 ft wide steel bridge in New Johnsonville, Tenn. Six W33×240 grade 50W beams were constructed at 7.5 ft on center.

![Fig. 1. Detail of connection designed by the University of Nebraska](image1.png)

![Fig. 2. Making a continuous beam with concrete diaphragm](image2.png)

![Fig. 3. Initial Tennessee beam connection](image3.png)
with a unit weight of structural steel of 37.7 psf. The price of the steel from the low bidder was $0.56/lb in place, significantly lower than their previous design. Construction of the total bridge took only 90 days, without incentives. TDOT also designed two similar bridges, which contained integral abutments. Advantages of the integral abutments include being jointless, reduced maintenance, and potentially dampening seismic motion. The first is a five span bridge, taking State Road 210 over Pond Creek. The substructure is skewed at 35° carrying spans of 94, 103, 132, 132, and 118 ft. Five W40×248 grade 50W girders support the 42 ft wide deck. The steel beams were set in 30 days. The second of the two was another large rolled beam bridge constructed in 2006, carrying Church Avenue over Route 158 and 71. It consisted of six spans measuring 80, 100, 100, 100, 93, and 90 ft. The 56 ft wide deck is supported by seven lines of W30×173 grade 50W girders, spaced at 8 ft 2 in. The engineers estimate for the bridge was $80/sq ft, totaling $2.82 million. The low contractor bid came in at $72.93/sq ft, or $2.55 million (Talbot 2005). Details of the connection at the pier along with the span of the concrete diaphragm can be seen in Fig. 4.

**Ohio**

The Ohio DOT installed a simple-made-continuous steel bridge as a replacement bridge in the summer of 2003. The existing structure was a six span (90 ft approaches with four 112 ft 6 in. main spans) 29 ft wide steel stringer bridge crossing the Scioto River in Circleville on U.S. 22 (Ohio DOT 2003). Because of time constraints, the state decided to make the project a design/build fast track job. Five girders, spaced at 9 ft, were required to support the bridge, which was widened to 44 ft. High performance steel girders, M270 grade 50W, were designed as simply supported and were made continuous in the field by integral concrete diaphragms. The concrete diaphragm was 3 ft wide and was cast across the pier comparable to the Nebraska and Tennessee diaphragms. The beams and diaphragm also sat on an elastomeric bearing pad and load transfer plate. The beams were constructed as plate girders with a 54 in. web depth and 18 in. flanges. The total construction time for the U.S. 22 Bridge, from demolition to the completed construction of the new bridge, was 48 days (Ohio DOT 2003). The bridge unit cost was $2.11 million, which equated to $75.6/sq ft. Design details obtained from the state of Ohio are presented in Fig. 5.

**New Mexico**

The New Mexico DOT used the simple for dead continuous for live method to design a five span 525 ft (105 ft/span), 34.5 ft wide replacement steel plate girder bridge (Barber 2006). The superstructure contained 4 lines of plate girders spaced at 7 ft 6 in. The plate girder dimensions were a 54 in. web depth, 13.8 in. top flange, and 17.3 in. bottom flange (Barber 2006). That bridge crosses the Rio Grande River on NM 187 and was completed in the summer of 2005. On an earlier project, the simple-made-continuous concept served in a dual-design analysis (steel versus prestressed concrete) for a bridge on U.S. 70 in southern New Mexico. A design consultant for the U.S. 70 project, Parsons Brinckerhoff, Inc. bid the two alternatives at a difference of only 0.2% out of a total project construction cost of $21 million (Barber 2006). An innovative feature on this project were the bolts being placed outside of the concrete diaphragm to allow for tightening after the deck and diaphragms were poured. Reinforcing bars were added to the concrete diaphragm to achieve the required negative moment capacity. Bars were also added above the pier to alleviate stresses on the continuity connection plate and are shown in Fig. 6. The cost of the bridge was $75 per sq ft. Bids for precast concrete girder bridges of comparable square footage were $68 and $88 per sq ft each (Barber 2006).

**Colorado**

The Colorado DOT designed and completed its first simple-made-continuous steel bridge in July 2006. The steel bridge replaced an out of date bridge on U.S. 36 that crossed Box Elder Creek outside of Denver (“Steel bridge uses simple-made-continuous construction.” 2006). The new superstructure was 470 ft long with six equal spans, 77 ft/span. The 44 ft wide concrete deck was supported by six lines of W33×152 grade 50W rolled beam girders spaced at 7 ft 4 in. The beams were supplied to the site in pairs with W27×84 diaphragms connected to the bearing stiffeners. These cross frames were spaced at 19 ft on the interior girders and 12 ft 4 in. on the exterior girders and provided stability during erection. Similar steel diaphragms were also designed to run over
the pier cap from exterior to exterior girder. The girders sit 6 in. apart on a 3/4 inch elastomeric pad along with a \(30 \times 14 \times 1\) in\(^3\) thick compression plate. The bottom flanges of each girder were welded to the compression plate to make the system continuous. A reinforcing rod was placed within the deck above the pier to take the tension of the negative moment. The total cost of the superstructure amounted to $1.1 million which equates to just $53/sq ft, or $0.97/lb of erected steel (“Steel bridge uses simple-made-continuous construction.” 2006). Details of the pier cap connections can be seen in Fig. 7.

### Comparison between States and Closure

Although the overall concept is similar for each of the simple-made-continuous bridge described herein, the details and costs are affected by many variables stemming from the requirements of the state and roadway. Table 1 presents a summary of the information for the rolled steel bridges discussed in this paper. General information on the bridge, along with beam size and cost is included.

Although each of these steel bridges were constructed using the simple for dead load, continuous for live load method, there are similarities and differences between each state. The primary similarities are: (1) all use grade 50 weathering steel; (2) all have concrete diaphragms that are cast from exterior to exterior beams to connect girders sitting on the pier cap, except in Colorado (steel diaphragm/welded connection plate); (3) integral abutments integrated in all bridges except initial designs in Tennessee; (4) none have an expansion joint due to integral abutments; (5) all have sufficient reinforcement placed in the deck above the pier in the negative moment section to provide extra continuity and take the tension force; (6) all the states placed an elastomeric pad along with a bearing plate between the pier cap and girders, except Tennessee; and (7) all were designed using the AASHTO LRFD bridge design specifications.

There were also some differences which can be summarized as follows: (1) the bridges in Tennessee and Nebraska both used a plate between the girders to transfer the compressive forces, whereas the Ohio, New Mexico, and Colorado bridges did not; (2) the cross frames varied from a wide flange section, to a bent plate, to a \(k\)-type cross frame; (3) Tennessee used a single shear bolted connection to connect the top flanges with a cover plate, along with a bottom plate, while New Mexico used a continuity connection plate on the top flanges; (4) Colorado welded the bottom flanges to the compression plate to create a continuous beam instead of using a concrete diaphragm; (5) the concrete diaphragm in the Nebraska bridge was poured two thirds full to make the beams partially continuous. The other third was filled when the deck was poured. This procedure was used to maintain the stability of the deck while it was cast.

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