Texas's Totally Prefabricated Bridge Superstructures

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The Texas Department of Transportation (Texas DOT) has developed two new bridge superstructure systems that have maximum span lengths of 115 ft and a total superstructure depth of only 38 in. and are totally prefabricated: a steel tub girder and a prestressed concrete pretopped U-beam. The steel tub-girder system uses a conventional prefabricated trapezoidal steel girder, which is topped by a concrete slab before transport to the bridge site. To achieve the shallow superstructure depth of 38 in., shoring the beams during slab placement makes them composite for all loads. After slab placement, the beam is hauled to the bridge site and erected on the bridge piers. A simple cast-in-place closure pour joins the deck girder sections after they are in place. The prestressed concrete pretopped U-beams use a portion of the existing Texas U-beam form system. Each beam is fabricated as a closed U-beam and hauled to the contractor's yard, where a 4-in. topping is placed before beam erection. A cast-in-place closure pour joins the deck girder sections after erection. Texas DOT anticipates that these two systems will be used over the next 10 years for the rapid construction of nearly 150 bridges that cross I-35 in central Texas. Construction of the first four such structures begins in spring 2005. It is expected that girder erection and closure-pour placement will take less than 24 h and that bridges will open to traffic after as few as 4 days.

Prefabricated bridge elements and systems are typically constructed off-site and brought to the project location ready to erect. However, they also can be constructed adjacent to the project site, out of the way of traffic, and moved into position when needed. Prefabrication can be used for individual elements, such as beams or caps, and even complete bridges. Prefabricated bridge elements and systems benefit bridge owners, designers, and contractors by minimizing traffic disruptions, increasing safety in the work zone, reducing environmental impact, improving constructibility, and increasing quality while lowering cost.

BRIDGE ELEMENTS AND SYSTEMS

In 2001 the AASHTO Technology Implementation Group (TIG) selected prefabricated bridge elements and systems as a first-round focus technology. TIG champions the implementation of ready-to-use focus technologies that offer significant economic or qualitative advantages. The TIG Panel on Prefabricated Bridge Elements and Systems has developed a website (www.fhwa.dot.gov/bridge/prefab) to promote this technology and the advantages it offers.

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Minimize Traffic Disruption

The Interstate highway system is approaching the end of its service life at the same time that urban congestion is increasing. Meanwhile, the traveling public has lost patience with highway construction delays that impede commerce and slow progress to and from workplaces. Bridge construction can be a bottleneck because of its sequential nature—foundations are required before columns and caps, and columns and caps are required before beams and deck—and because concrete curing requirements can make the process excessively long.

The use of prefabricated bridge elements and systems allows portions of construction (such as component fabrication) to be moved away from the construction site and its traffic. Time-consuming tasks such as formwork erection and removal, steel reinforcement and concrete placement, and concrete curing no longer need to be accomplished in the work zone. Prefabricated components can be transported to the bridge site and quickly erected in place. Conventionally sequential processes can occur off-site concurrently with on-site construction.

Increase Work-Zone Safety

Construction sites often require workers to operate near moving traffic, over water, at high elevations, near power lines, or in other dangerous situations. Prefabrication allows bridge construction activities such as concrete placement and curing to occur in safer surroundings, greatly reducing the amount of time that workers must operate in potentially dangerous settings.

Reduce Environmental Impact

Conventional bridge construction requires significant access to the underside of the bridge for construction personnel and for equipment to erect formwork and place steel reinforcement necessary for construction. Using prefabricated bridge elements and systems gives contractors more construction options, including top-down construction in sensitive wetlands, and can reduce effects on adjacent landscapes. On-site construction time is also reduced. This flexibility facilitates bridge construction and can be especially beneficial in environmentally sensitive areas.

Improve Constructibility

Many job sites constrain the constructibility of bridge designs. Some problematic situations include heavy traffic on an Interstate highway that runs under a neighborhood bridge, high elevations, long stretches over water, and restrictions caused by development adjacent to the work zone. Using prefabricated bridge elements and systems to move much of the work off-site relieves constructibility pressures.

Increase Quality, Lower Life-Cycle Cost

Prefabrication can take bridge elements and systems out of the critical path of the project schedule. Bridge components can be fabricated in advance, using as much time as necessary and in a controlled environment such as an off-site fabrication plant or adjacent field plant. The controlled environment reduces dependence on weather and increases quality control over the resulting products. Established materials suppliers ensure consistent quality of materials. Plant operations are standardized, ensuring consistent quality of production. The curing of prefabricated concrete components can be more closely monitored, and quality inspection is easier in a plant than in a work zone.

If the cost of construction delays to bridge users is included in cost comparisons of conventional cast-in-place versus prefabricated construction methods, prefabricated elements and systems typically are much more cost-competitive because on-site construction time is significantly reduced. In addition, improving construction quality also increases bridge durability, resulting in a longer service life and even lower life-cycle cost.

I-35 CORRIDOR RECONSTRUCTION

Pressure to upgrade and expand its on- and off-system roadways is mounting as the aging infrastructure in Texas experiences increasing traffic volumes and loads. Rapid bridge construction has become increasingly important, particularly in urban areas. Texans demand faster construction, safer work zones, and more protection of environmentally sensitive areas.

The reconstruction of I-35, the main north–south corridor in the state, will include constructing numerous bridges in the coming decade. A primary goal for reconstruction is to reduce the time that traffic is disrupted by lane closures and detours. In the interests of efficiency, economy, and minimized traffic disruption, the Texas Department of Transportation (Texas DOT) desired a consistent prefabricated bridge system for the proposed I-35 reconstruction. Design engineers identified four representative bridges on Loop 340 over I-35 near Waco to use as prototype bridges for the I-35 corridor. These bridges exhibit reconstruction constraints typical to the I-35 project, allowing engineers to address these constraints in bridge design.

Project Constraints

Many site conditions for the proposed bridges over I-35 provide minimal available vertical clearance and require spans of up to 115 ft to traverse the proposed lower roadway. The I-35–Loop 340 project specifically required spans up to 115 ft with a total superstructure depth of 38 in. To speed construction, Texas DOT limited the use of site-cast concrete while ensuring that the ride quality of the finished bridge deck would not be compromised.

Although overlay may help meet finite geometric tolerances, it is also a significant critical-path activity before opening a structure to traffic. An attractive alternative to overlay is a diamond-grinding deck with sacrificial cover to obtain the desired surface profile. Such a method is faster and generally more cost-effective.

Project Solutions

To create a prefabricated bridge system that would satisfy the design constraints and be economical, designers created two competing designs. The first makes use of shallow steel tub girders that are shored during slab placement, making them composite for all loads. The second is a new precast, prestressed concrete beam: a pretopped U-beam. This U-beam section makes use of strand patterns and forms currently available in Texas for the fabrication of Texas U54 beams. However, the new beams will be only 34 inches deep, with a 4-inch topping slab added by the contractor off site. Both designs were developed by using *AASHTO LRFD Bridge Design Specifications: Customary U.S. Units* (*1*) with HL93 loading.

At first glance, one might assume that a box-beam bridge would provide a reasonable alternative to the proposed pretopped beams or steel tub-girder sections. However, a box-beam bridge of similar width would take considerably longer to erect because of the number of boxes to handle. Texas DOT box beams come in two widths, 4 ft and 5 ft, versus the nominal width of 8 ft for pretopped U-beams and 13.25 ft for steel tub girders. For a bridge with an overall width of 48 feet, eight 5-ft and two 4-ft-wide box beams would be required for a total of 10 box beams per span. Only six pretopped U-beams would be required for the same roadway width (40% fewer beams), and only four steel tub girders would be required (60% fewer beams). With fewer pieces to be handled, bridge erection would proceed more quickly, and traffic delays due to lane closures would be reduced.

Steel Tub-Girder Design

The steel tub-girder design has a 29.5-in.-deep steel section with an 8.5-in. slab, creating a section that is 38 in. in total depth (Figure 1). The girders are spaced at 13.25 ft on center. Figure 2 illustrates a typical transverse girder section that has a span capability of 115 ft.

The design makes use of ASTM A709 Grade 50W steel. A weathering steel has been specified for its durable performance with no maintenance costs. The finished girders are specified as unpainted. Drip tabs and other details are provided to reduce the potential for substructure staining from the weathering steel. The design of this element was challenging because the aspect ratio was around 48:1. The service level design of the girder was controlled not by allowable strength but by the Texas DOT–imposed live load deflection limit of L/800.

Furthermore, because of the unusually shallow section, the girder had to be proportioned so that the deck would not crush before the steel tub reached yield. This check is similar to the check for nonductile failure of an overreinforced concrete beam. In response to contractor feedback, the girder was designed to allow a wide range of lifting locations. The designers developed a lifting scheme that was flexible enough to allow the girder to be lifted up to 15 ft away from the bearing location; the contractor thus had several locations for crane setup to allow for a wide adjustment to local construction constraints.

Pretopped U-Beam Design

The pretopped U-beam design comprises a 34-in.-deep precast, prestressed beam with a 4-in. topping slab creating a section that is 38 in. in total depth (Figure 3). This girder section has a span capability of 115 ft. The design makes use of 0.6-in. strands on a 2-in. grid. The beams are spaced at approximately 8 feet on center, and

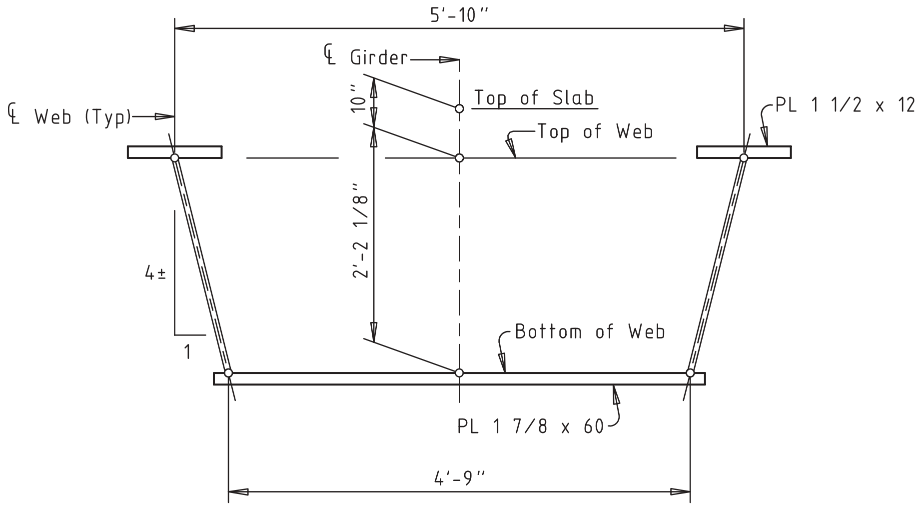


FIGURE 1 Typical steel girder section (PL = plate).

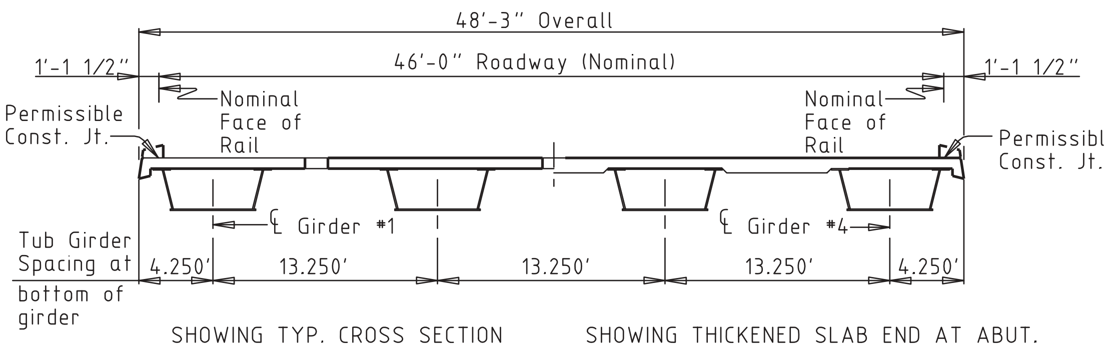


FIGURE 2 Steel girder superstructure.

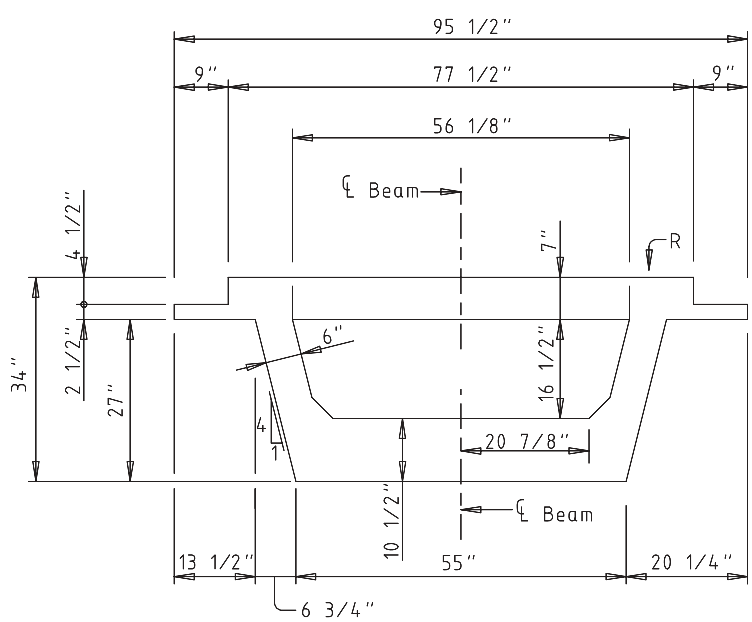


FIGURE 3 Typical pretopped U-beam section.

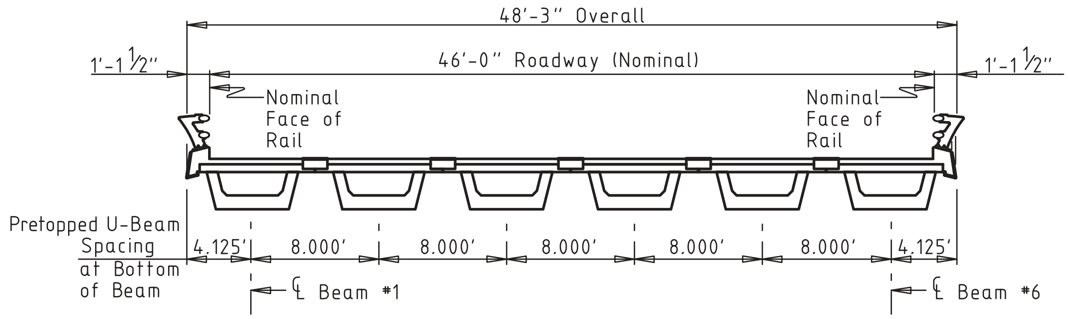


FIGURE 4 Pretopped U-beam superstructure.

each beam requires up to 77 of the 0.6-in. strands; concrete strength at release is 6.5 ksi, and final concrete strength is 7.4 ksi. Figure 4 illustrates a typical transverse section, and Figure 5 illustrates the construction sequence for these beams.

The design required debonding as much as 75% of the prestressing strands in the beam ends to satisfy the allowable tensile stresses at release in the beam ends. Although AASHTO limits debonding to no more than 25% of the total number of strands, Texas DOT has experience with prestressed beams in which as many as 75% of the strands were debonded successfully. The Texas DOT-sponsored research project Anchorage of Large Diameter Prestressing Stands in Pretensioned I-Beams, 1388-S, also confirmed the use of 75%

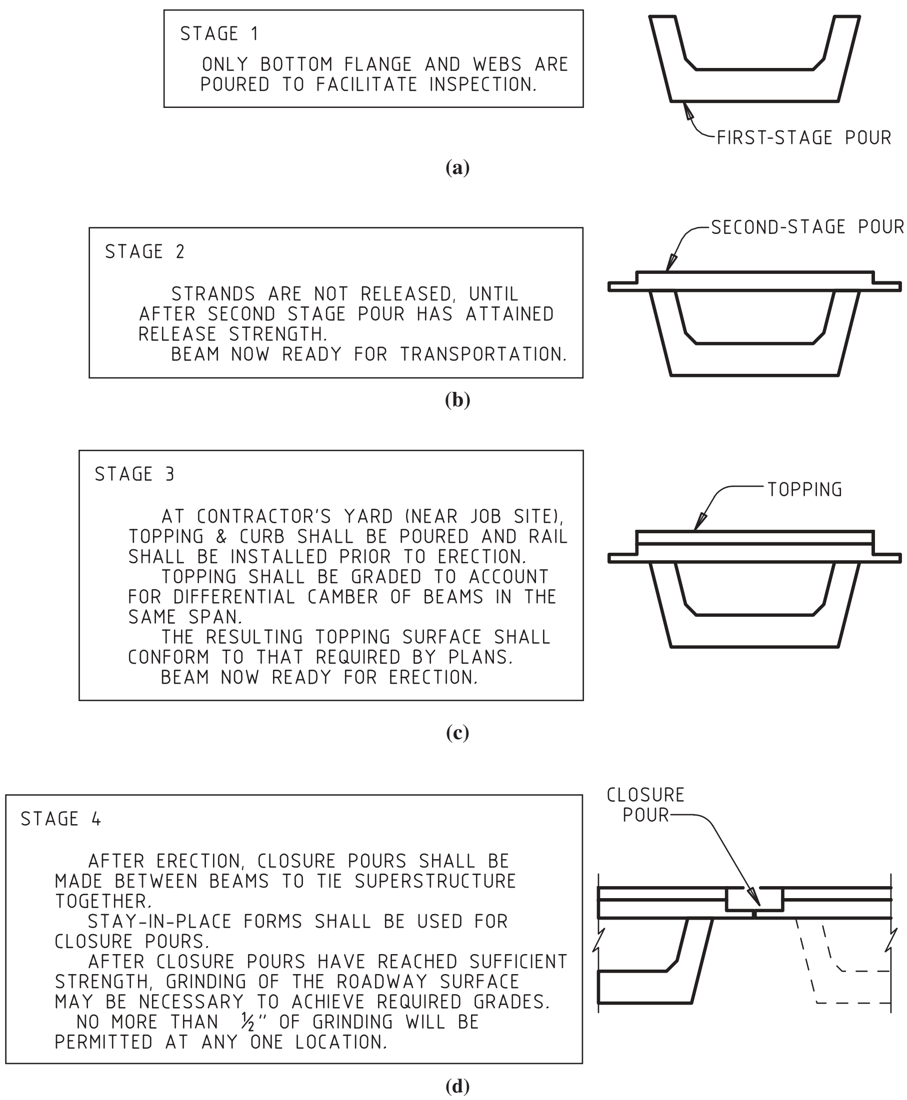


FIGURE 5 Pretopped U-beam construction sequence.

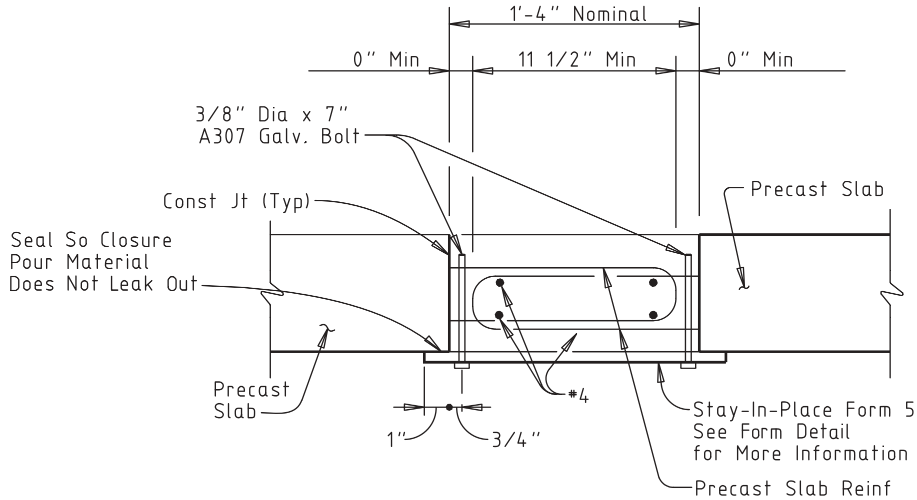


FIGURE 6 Steel tub-girder longitudinal closure pour detail.

debonding. Finally, the pretopped U-beams were determined to have adequate shear resistance when 75% debonding was used.

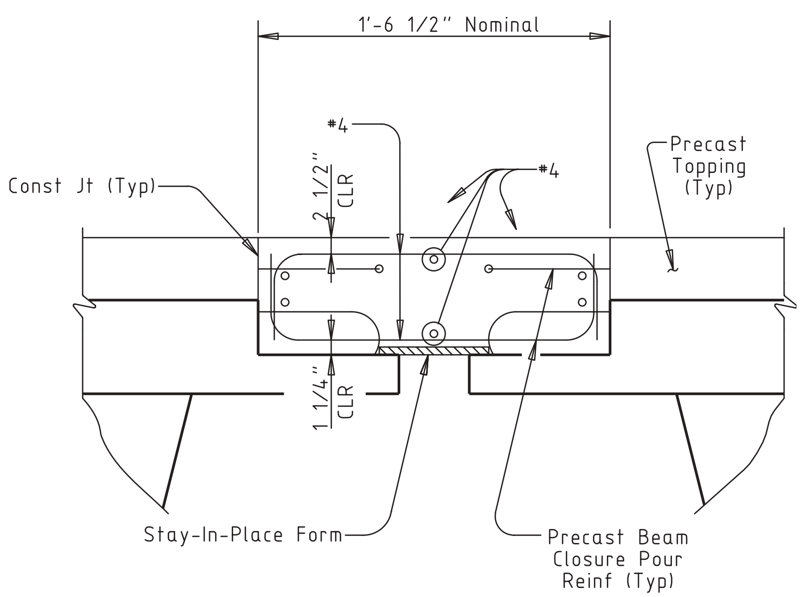
Research

The closure pour details for the steel tub-girder design and the pretopped U-beam design are currently being tested by the Texas Transportation Institute at Texas A&M University. The closure pour details are illustrated in Figure 6 for the steel tub-girder sections and in Figure 7 for the pretopped U-beams. Preliminary results on the steel tub-girder closure pour specimens indicate that the closure pour behaves as designed and develops the predicted moment and shear capacities. Failure is due to yielding of the reinforcement extending across the closure joints exhibiting ductile behavior. Researchers expect similar results for the pretopped U-beam specimens.

Durability of the longitudinal joints is a concern. Central Texas does not have weather that requires the frequent use of deicing salts or chemicals, so corrosion is not a major concern. Care has been taken to ensure that if cracks develop, they will be arrested by the reinforcing steel and remain small. Texas DOT plans to monitor the structure closely and inject any cracks that develop with epoxy.

Letting Results

The two competing prefabricated bridge designs were released for letting in August 2004. The winning bid was for a pretopped U-beam design at a total bridge cost of approximately $85/ft². For comparison, box-beam bridges in Texas are typically constructed for about $45/ft². The recent escalations in steel prices probably prevented the steel tub-beam design from being competitive.



Anticipated Fabrication Issues

Because the contractor selected the newly developed pretopped U-beam sections for this project, some fabrication issues may need to be resolved during construction. The main issues will likely relate to the measured versus predicted beam cambers and to the challenges presented by the shallow sections with fairly congested reinforcement in the end regions.

Schedule

Construction of the pretopped U-beam bridges has not begun as of this writing. However, it is expected to be under way in spring 2005 and estimated to be completed by September 2006. Texas DOT is also developing plans for several future structures to be constructed in the next few years that will use the pretopped U-beam and the steel tub-girder designs.

CONCLUSIONS

In 2001, Texas voters affirmed their interest in improving the state's transportation infrastructure by approving Proposition 15, which allows Texas more flexibility in paying for transportation projects through innovative financing alternatives. With additional financial alternatives on the horizon, the governor initiated a Trans-Texas Corridor Plan that outlines a new vision for transportation in Texas. Just as the Interstate highway system met transportation needs envisioned in the 1950s, the Trans-Texas Corridor addresses needs of the 21st century. The plan proposes a network of corridors designed to move people and goods faster and more safely than ever before. The corridors consist of separate vehicle and truck lanes, high-speed commuter and freight rail, and a utility zone that can accommodate the transmission of oil, natural gas, electricity, data, and water. Bridge construction with prefabricated bridge elements and systems is anticipated to play an important role in the construction of the Trans-Texas Corridor bridges.

To meet this challenge, Texas DOT has developed two new bridge superstructure systems that are totally prefabricated: a steel tub-girder construction with deck topping and a prestressed concrete pretopped U-beam. The first four of the U-beam structures will begin construction in spring 2005. It is expected that girder erection and closure pour placement will take less than 24 h and that bridges will open to traffic in as few as 4 days. Texas DOT anticipates that these two systems will be used during the next 10 years for the rapid construction of many of the approximately 150 bridges that cross over Interstate 35 in central Texas.

REFERENCE

1. *AASHTO LRFD Bridge Design Specifications: Customary U.S. Units,* 2nd ed. AASHTO, Washington, D.C., 1998.

The 6th International Bridge Engineering Conference Committee sponsored publication of this paper.