Highly skewed bridges now have a solution involving halved round HSS for improving fatigue performance, allowing better fit-up and facilitating easier installation of diaphragms and cross frames.

TWO HALVES are Better than None

BY YUAN ZHAO, P.E., PH.D., KARL FRANK, P.E., PH.D., AND JOHN HOLT, P.E.

WHEN IT COMES TO BRIDGES, the best skew is none at all.

Unfortunately, skewed supports for highway grade separation bridges are a reality when the alignment of the crossing roadway(s) cannot be oriented more favorably with regard to that of the bridge. Although highly skewed bridges—those with skew angles greater than 45°—are needed infrequently, they present significant challenges and difficulties to all parties involved with their design and construction.

Of their many challenges, one is the connection of cross frames to girders along the lines of support, such as bents or piers. A skewed stiffener cannot be used when the skew is significant due to the inability to make the weld on the acute angle side. The common approach for these connections on highly skewed bridges is to use a bent plate at each corner of the cross frame, with one leg of the plate bent parallel to the skew, or close to it, and the other leg attached to bearing stiffeners or connection plates installed square to girder webs. These bent plates are typically the most flexible component of a lateral bracing assembly, limiting a cross frame's ability to be fully engaged in girder bracing and introducing additional girder rotations at skewed supports.

A relatively new alternative to this traditional approach uses half of a round hollow structural section (HSS) in place of a conventional bearing stiffener on each side of a girder web. Attached to this round HSS section is a cross frame connection plate, placed in line with the support skew angle. This connection plate is radial to the half HSS regardless of skew and permits a conventional cross frame to be connected to the girder without any bent plates. This alternative solution is known as a split-pipe bearing stiffener (SPBS).

Research

The potential benefits of the SPBS led the Texas Department of Transportation (TxDOT) to fund research at the University of Texas at Austin to investigate cross frame connection details for skewed bridges. The research indicated that the SPBS provides a much stiffer cross frame connection detail than conventional details using bent plates, allowing more effective use of cross frames and providing better resistance to girder end twist.

Additionally, the researchers found that the SPBS provides significant warping restraint at the support bearings, which increases the torsional stiffness, and in turn, the elastic buckling strength of the girder. This allows for larger unbraced lengths, giving designers the opportunity to move the first interior cross frame locations further from the end bearings. Cross frames located close to end bearings on a highly skewed bridge tend to be more highly loaded than those further away. These highly stressed cross frames, which are too close to the end supports, can potentially create or experience fatigue problems later in the bridge's service life. Having the ability to move the first interior cross frames further from highly skewed end bearings helps reduce their forces and minimize future fatigue-related problems. The increased warping restraint provided by the SPBS will also help with girder stability during handling and lifting.

Design

The research report, "Cross-Frame Connection Details for Skewed Bridges" (available at **tinyurl.com/splitpipe**), provides design recommendations and an SPBS design example, including steps in selecting a half round HSS for providing

▲ Steel girders erected over a 60° skew interior bent.

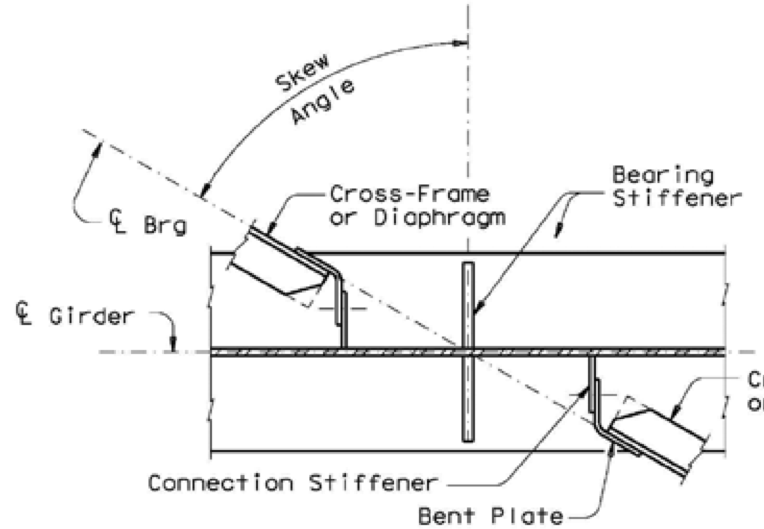
➤ A painted stiffener on a weathering steel girder with a weathering steel connection plate welded to the split pipe.

the required warping restraint based on the required girder buckling capacity.

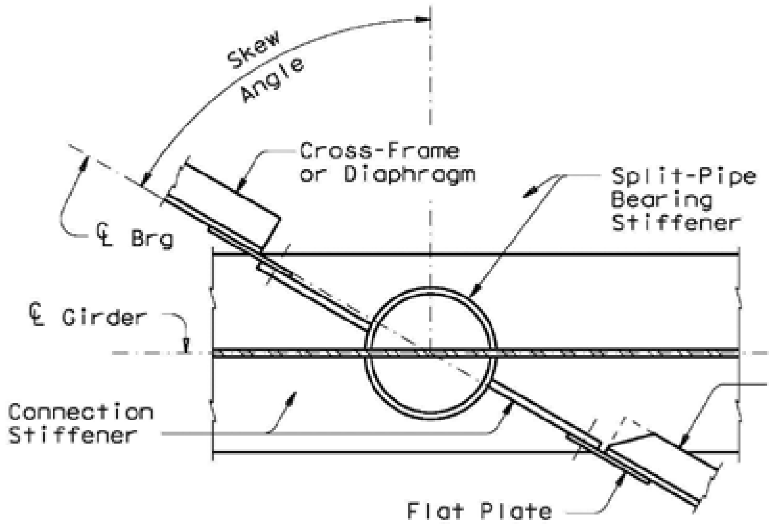
In their design recommendations, the researchers recommended the cross frame connection plate be welded to the HSS only and not welded to the girder flanges. This avoids a fillet weld partially along the length of the flanges, a weld that could not be classified as Category C' like conventional cross frame connection plate welds, which are normal to the web (or slightly skewed, up to about 20°). The lab tests showed that a skewed stiffener weld, partially along the flange's length, experienced a reduced fatigue life compared to that of a normal, Category C' stiffener weld.

However, not connecting the connection plate to the girder flanges contradicts the AASHTO LRFD *Bridge Design Specifications*. These specifications require that cross frame connection plates be connected to girder flanges, which is intended to reduce or eliminate damaging distortion-induced fatigue problems arising from the unstiffened web gaps. The welding of the split pipe to both flange and web eliminates the web gap and provides a stiffer connection between the web and flange than a welded plate stiffener. The stiffener can still be welded to the flange to provide additional restraint particularly for end diaphragm connections where the bending stress in the flange is nominally zero.

Yuan Zhao is a senior structural engineer with Burns and McDonnell (and was previously a bridge design engineer with TxDOT's Bridge Division), **Karl Frank** is a chief engineer with Hirschfeld Industries and **John Holt** is a senior bridge engineer with HDR (and retired as the design section director of TxDOT's Bridge Division).



A traditional bent plate connection.



A newly developed split-pipe bearing stiffener (SPBS) connection.

Based on commonly used girder flange widths for highway bridges—15 in. to 24 in.—most designers will find an SPBS that works by using round HSS of 11 in. to 20 in. in diameter, with wall thickness ranging from 0.50 in. to 0.75 in. Designers should verify that the section selected is available and can meet "Buy America" provisions.

The most oft-recommended material specification for round and rectangular HSS is ASTM A500. Thick-wall extra-strong or double-extra-strong ASTM A53 pipes are generally not available in large diameters or must be bought at a premium; the use of this material is therefore discouraged by fabricators. With the recent advent of the ASTM A1085 specification, improved HSS products are now available for structures subjected to dynamic loading. All HSS produced to A1085 has a minimum yield strength of 50 ksi and is required to meet the equivalent AASHTO Zone 2 CVN requirements for Grade 50 steels (minimum 25 ft-lb at 40 °F). Whenever availability is not an issue and its use can be justified economically, A1085 should be the recommended HSS specification for bridge applications.

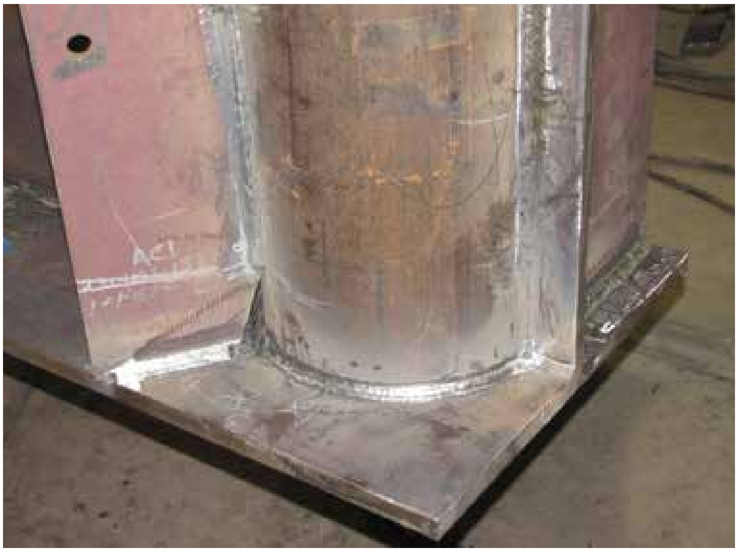
Both A500 and A1085 are suitable for bridges that will be painted. Some bridge owners, however, prefer the aesthetic benefits of weathering steel. Finding a round HSS section meeting ASTM A847 (a weathering steel grade) can prove challenging, especially in the diameters expected for a SPBS system. The quantity of round HSS needed to provide a SPBS system for a typical bridge project could be small, making availability even more elusive. An alternative for weathering steel is to allow for A1085 or A500 material in lieu of A847 and paint these components to provide an appearance similar to weathering steel. The downside to this approach is the inability of the selected color to match the weathering steel's appearance throughout its life. But instead of trying to match the color of weathering steel, this could be seen as an opportunity to enhance aesthetics and paint the component a contrasting color that complements the overall structure aesthetic.

Lastly, a SPBS is a bearing stiffener, so its design needs to satisfy the conventional bearing stiffener design specifications.

Fabrication

An SPBS offers much simpler and less congested cross frame fabrication than the conventional plate bearing stiffener due to the elimination of bent plates. The fit-up between the pipe and the flange, however, can be challenging. Slight distortion of the flange will cause fit of the pipe to be difficult over its full mating surfaces with the flanges. It is difficult to attain the 75% contact normally specified for bearing stiffen-

An SPBS used for a cross frame connection along a highly skewed bent line.



Cross frame connection details at highly skewed support bearings.

A weld detail at a web-to-flange connection (note that weld access is provided on the acute side).

ers. Due to the larger bearing area of the pipe stiffener relative to that of the normal plate stiffener, less area needs to be in contact in the case of the pipe stiffener. A maximum gap of 1⁄16 in., the limit for interior connection plates, can be used instead. This is based on findings of the research lab tests where larger gaps were used without yielding any adverse effect. The split pipe is tacked in place and then the connection plate is tacked to the pipe and flange.

The half-pipe is seal welded with fillet welds on all edges to prevent corrosion on the interior side. These welds will intersect the web-to-flange welds. As a result, it is recommended that the split pipe corners be clipped to clear the flange to web welds with a clearance of no more than ⅛ in.

Implementation

Due to its promising advantages, the SPBS system was adopted by bridge designers in several projects even before the University of Texas research was finished. While more jobs are now being designed and fabricated since the 2014 incorporation of SPBS into TxDOT's *Bridge Standards*, the authors are aware of at least four completed SPBS projects in Texas. In all four cases, the construction of all steel units went very smoothly, and no difficulties or challenges were experienced by the contractors in regard to girder erection and cross frame installation.

Based on the research findings and its successful implementation on the aforementioned projects, the SPBS is now incorporated into the TxDOT Bridge Division's standard drawings as a standard cross frame connection detail for future design of highly skewed steel bridges. When used in conjunction with a properly designed superstructure framing layout, the SPBS offers advantages over a simplified and streamlined connection for lateral bracings. With more designers specifying the use of SPBS, the cost of this system is also expected to compare favorably with that of the conventional stiffeners in future applications. ■