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Project Summary Report 0-1772-S

Project 0-1772: Cross-Frame and Diaphragm Behavior in Bridges with Skewed Supports

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PROJECT SUMMARY REPORT

Cross-Frame and Diaphragm Behavior in Bridges with Skewed Supports: Summary

Lateral torsional buckling is a failure mode that is generally critical during the construction stages for steel bridges. Prior to curing of the concrete deck, the steel girders must support the entire load. The buckling capacity of the girders is improved by providing cross-frames and diaphragms, such as those shown in Figure 1, at locations along the length of the bridge to reduce the unbraced girder length.

Figure 1 Cross-frames used to reduce unbraced length of girders

Past AASHTO provisions limited the maximum spacing between cross-frames and diaphragms to 25 ft. The spacing limit was removed from the first edition of the AASHTO LRFD Specification (1994), which instead specified that the braces be designed based upon a rational analysis. One of the primary reasons for the removal of the spacing limit on the braces was the propensity for the cross-frame locations to experience fatigue cracks during the service life of the bridge. Although improved details such as welding the stiffeners at the brace locations to the bottom flange have improved the fatigue behavior, the design requirements and long-term behavior of the braces are not well understood. This is particularly true for systems with skewed supports in which live loads can cause large forces in some of the braces.

The behavior of the braces in systems with skewed supports are sensitive to the details that are used for the cross-frames or diaphragms. For systems with skew angles less than 20 degrees, the AASHTO specification permits the braces to be parallel to the skew angle. For skew angles larger than 20 degrees, AASHTO requires the braces to be positioned so that they are perpendicular to the longitudinal axis of the girders.

The objectives of this research investigation were to improve understanding of the bracing behavior of cross-frames and diaphragms in steel bridges and to develop details that would reduce the number of cross-frames on the bridge. Another goal for the recommended details was to minimize the forces induced in the braces by truck traffic.

What We Did…

The research investigation included both laboratory tests and computational investigations using finite element analytical (FEA) models. Figure 2 shows the test setup that was used for the laboratory investigations. The test setup consisted of a twin girder system using W14x22 members with a span of 33 ft.

Figure 2 Setup for laboratory shear frame

The loading that was used in the tests consisted of a point load applied at midspan through a gravity load simulator as shown in Figure 3. The gravity load simulator (Yarmici 1966) is a device that is utilized to minimize the lateral restraint provided at the transverse load points.

Calibration tests on the gravity load simulators showed that the apparatus provided less than approximately 20 lbs. of lateral restraint w a vertical load level of 10,000 lbs.

Figure 3 Gravity load simulator

The girders were designed to buckle elastically so that they could be reused with a variety of brace sizes. Cross-frames and diaphragms fit into the category of torsional bracing since they restrain twist of the girders. The torsional braces that were used consisted of square aluminum bars that were clamped to the top flange of the girders as shown in Figure 4.

Figure 4 Connection between braces and girder top flange

Brace sizes are often categorized relative to the "ideal stiffness," which is the stiffness required to force a perfectly straight member to buckle between the brace points. Four different sizes of the torsional braces were used, ranging from braces with a stiffness less than the ideal value to several times stiffer than the ideal value. The stiffness of the bracing system is a function of several parameters. The parameters include the brace stiffness, the stiffness of the cross-section (web/stiffener), and also the in-plane stiffness of the girders. Strain gages were applied to the braces so that brace forces could be measured in the laboratory.

The beams were simply supported at the ends. In addition to normal supports, cases were also checked with support skew angles of 26.6 degrees and 45 degrees. Braces oriented parallel to the skew angle as well as normal to the longitudinal axes of the girders were evaluated.

The laboratory tests were used to confirm that the FEA models adequately captured the behavior of the torsional braces. After the accuracy of the FEA models was confirmed with the laboratory tests, parametric studies were conducted to improve understanding of the behavior of cross-frame and diaphragm systems. The parametric studies were conducted on the steel girder systems simulating construction conditions. Although a variety of loading conditions were considered, the primary loading that was used consisted of a uniformly distributed load applied at the top flange of the girders. Both eigenvalue buckling analyses and large displacement analyses were conducted. The eigenvalue analyses provide an indication of the ideal stiffness requirements of the bracing system. Most design recommendations are based upon providing at least twice the ideal stiffness to control deformations and brace forces. The large displacement analyses are conducted on imperfect systems and provide an indication of the strength requirements for the braces.

A variety of parameters were considered in the investigation, including the following: girder system (two to four girder systems were considered); girder span (40 feet to 120 feet); girder cross section (singly and doubly symmetric sections with different depths); skew angle (0, 15, 25, 35, and 45 degrees); brace orientation (parallel to skewed support or normal to girders); loading condition (uniform moment, concentrated load, uniformly distributed load); and the number of intermediate braces.

In addition to considering the above parameters, a variety of cross-frame details were investigated in an attempt to reduce the number of cross-frames on the bridge. One detail that proved efficient was to "lean" several girders on a single cross-frame along a given bracing line. After the stiffness and strength expressions were developed for the recommended brace layout, analyses were conducted on a composite system with the concrete deck simulating truck loading on the bridge. These analyses demonstrated the behavior of the braces in the finished bridge so that the braces could be distributed in a manner to minimize live load forces.

What We Found…

Laboratory Tests

• The laboratory tests on the girders with normal supports showed that equations that had been developed from past computational investigations had good agreement with the test results. A difficult aspect of comparing the test results with the equations was measuring and determining the effective imperfection of the test girders.

• The tests on the girders with skewed supports and braces parallel to the skew angle also had good agreement with expressions that were developed in the FEA parametric studies.

• The tests on girders with skewed supports and the braces perpendicular to the skew angle showed that the equations were generally conservative with respect to the test results. The reason for the conservatism was that the expressions conservatively neglect (as do specification provisions) the warping restraint that develops in the beams due to the shorter unbraced length caused by the braces that frame into one of the girders near the supports.

Finite Element Results

• Based on the finite element results for systems with skewed supports and braces oriented perpendicular to the longitudinal axis of the girders, the researchers found the expressions were generally not a function of the skew angle. Therefore the expressions for the bracing were the same whether the supports were skewed or not.

• Based on the finite element results for systems with skewed supports and the braces oriented parallel to the skew angle, expressions were developed for the stiffness and strength requirements of the bracing. The expressions had good agreement with the FEA solutions. Although the AASHTO Specification generally limits the parallel orientation of the bracing to skew angles less than 20 degrees, the FEA results showed that the braces behaved well for all of the skew angles that were considered, which ranged between 0 and 45 degrees.

• A number of cross-frames could be eliminated utilizing the lean-on bracing concepts as shown in Figure 5. Expressions were developed for the stiffness and strength requirements for the braces. An important factor in laying out the cross-frames throughout the bridge is to distribute the braces across the entire bridge width to control the effects of the in-plane girder stiffness on the system brace stiffness. This is shown in Figure 5 at sections 1, 2, and 3 where the cross-frames are fully distributed across the width of the bridge, which therefore ties the entire bridge together. So as to minimize brace forces induced by truck traffic, along a given brace line the cross-frame should be positioned so that it is as far from the support as possible. In addition, bracing lines that might normally frame into the support should be offset by 4 or 5 feet from the support. This is done to "soften" the system so that the brace line isn't tied into the cross-frames or diaphragms near the support, which can cause large forces from the truck traffic.

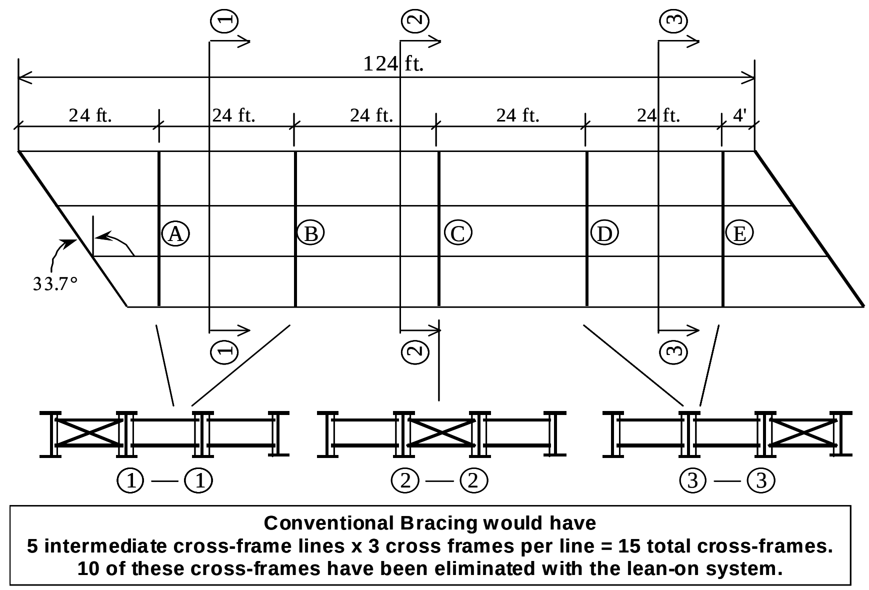

Figure 5 Proposed layout of cross-frames with lean-on bracing

The Researchers Recommend…

• The expressions for the stiffness and strength requirements for the cross-frame and diaphragms are relatively straightforward to apply. In many instances the "typical sizes" that are often used for the braces are larger than necessary, which can result in larger truck-induced forces induced in the braces. Several of the braces can be eliminated using the lean-on concepts; however, the braces should be positioned to minimize the forces induced. Figure 5 shows a typical layout that might be used with the lean-on concepts. Within a given brace line, the cross-frames have been positioned so that the cross-frame is as far from the support as possible. The other girders lean on the cross-frame using top and bottom lateral struts. The brace lines near the supports have been offset by approximately 4 or 5 feet so that these lines don't frame directly into a support. This was done to minimize truck-induced forces. It is also important to distribute the cross-frames across the width of the bridge to tie all the girders together. Otherwise the in-plane stiffness of the girders can negatively affect the brace system stiffness.

References:

Helwig, Todd A., and Wang, Liqun, "Cross-Frame and Diaphragm Behavior for Steel Bridges with Skewed Supports," Research Report 1772-1, Report for Texas Department of Transportation, July 2003.

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Yarmici, E., Yura, J.A., Lu, L., "Techniques for Testing Structures Permitted to Sway," Lehigh University, May 1966.

For More Details…

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The research is documented in the following report:

0-1772-1 *Cross-Frame and Diaphragm Behavior for Steel Bridges with Skewed Supports* (July 2003)

To obtain copies of the above report please contact the research supervisor.

TxDOT Implementation Status
January 2005

The TxDOT Bridge Division is in the process of implementing the results from this research project on three bridges in the Lubbock District. The bridges span US Highway 82 in Lubbock and have support skews of approximately 60 degrees. Utilizing the lean-on bracing concepts recommended in this research project has resulted in a substantial reduction in the number of cross-frames required on the bridges. Implementation project 5-1772 is currently active and is providing funding for the University of Houston to assist Bridge Division Engineers in this effort.

For more information, please contact Tom Yarborough, P.E., RTI Research Engineer, at (512) 465-7403 or tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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