Project Summary Report 0-4145-S
Project 0-4145: Lateral Bracing of Bridge Girders by Permanent Metal Deck Forms
Authors: Todd A. Helwig, O. Ozgur Egilmez, and Charles A. Jetann

PROJECT SUMMARY REPORT

Lateral Bracing of Bridge Girders by Permanent Metal Deck Forms: Summary

Lateral torsional buckling is a failure mode that often controls the design of steel bridge girders during construction. Bracing in the form of cross-frames and diaphragms is often provided at locations along the bridge length to reduce the unbraced length and increase the buckling capacity.

Although they are not currently relied upon for bracing, permanent metal deck forms (PMDF) are frequently used to support the wet concrete for the bridge deck during construction. Figure 1 shows the underside of a bridge with steel bridge girders that have PMDF used to support the wet concrete during construction. Similar forms used in the building industry are commonly relied upon for beam bracing.

Figure 1 Steel bridge with PMDF

The forms typically behave as a shear diaphragm that restrains the warping deformation in the top flange. The main difference between the forms used in the building and bridge industries is the method of connection. In the building industry, the forms are typically fastened directly to the top girder flange by the shear studs, puddle welds, or other mechanical connections. In the bridge industry, the forms are supported on cold-formed angles that are fastened to the top flange using intermittent fillet welds. The angles allow the contractor to adjust the form elevation to account for variations in the flange thickness or differential camber between adjacent girders. While the support angles provide the ability to adjust the form elevation, they lead to eccentric connections that substantially reduce the in-plane stiffness of the PMDF systems.

The objective of this research investigation was to improve the understanding of the bracing behavior of PMDF systems used in the bridge industry as well as developing improved connection details between the support angles and the girder flanges. The use of PMDF for bracing will reduce the number of cross-frames or diaphragms that are required for stability bracing on the bridge.

What We Did…

The research investigation included both laboratory tests and computational investigations using finite element analytical (FEA) models. The laboratory tests were divided into three phases. The first phase consisted of tests conducted in a frame that subjected the PMDF system to pure shear deformations. Figure 2 shows an overall view of the testing frame. The frame consisted of two "rigid" beams that simulated the top flanges of two adjacent girders.

Figure 2 Shear frame

A load was applied at one end of the frame while the other end was anchored to the reaction floor. Steel plates (2.5 in. thick) were used to simulate the weight of wet concrete.

A variety of panel sizes and connection details were tested in the frame. Panel widths of 8 ft., 12 ft., and 16 ft. were tested for forms with metal gages of 16 ga., 18 ga., 20 ga., and 22 ga. The connection details that were tested included both conventional details as well as proposed details. The proposed details utilize "stiffening angles" that significantly improve the stiffness of the PMDF system.

The second and third phases of the laboratory testing were conducted on a twin girder system with W30 x 90 rolled sections that had a span of approximately 50 ft. The top flange of the rolled section was reduced from a width of approximately 10 in. to 6 in. to simulate a singly-symmetric section similar to those found in steel bridge construction.

The twin girder system was subjected to lateral loads that simulated the types of deformations that the system may be subjected to during girder buckling. The lateral loads were applied using turnbuckles that were positioned at the quarter points and midspan. A variety of deflection profiles were applied to obtain the stiffness characteristics of the PMDF with conventional details as well as the proposed stiffened details. The lateral loads and resulting deflections were measured during the tests so that a measure of the stiffness could be obtained.

The final phase of testing consisted of buckling tests on the twin girder system using the PMDF for bracing. Twist was prevented at the ends of the specimen. Aside from the bracing at the supports, the only bracing provided along the 50 ft. length was from the PMDF system. Figure 3 shows a view of the twin girder setup that was used in the lateral load and buckling tests. The concrete blocks were used to simulate concrete loading on the forms and achieve connection friction between adjacent sheets as well as the sheets and support angles.

Figure 3 Twin girder tests

In addition to the laboratory tests, parametric FEA studies were conducted using the three-dimensional finite element program ANSYS. The results from the lateral load tests were used to validate the finite element model. Results from the buckling tests were also used to ensure that the system was being properly modeled. The FEA model was then used to study the effect of a number of parameters on the bracing behavior of PMDF systems for bridge applications.

What We Found…

Shear Frame Tests

• Tests on the conventional forms showed that the support angle eccentricity dramatically reduces the stiffness of the PMDF system. The majority of the deformation occurs in the support angle as demonstrated in Figure 4 where the angle simply rotates about the fillet weld.

Figure 4 Support angle deformation at failure (unstiffened)

• The stiffened connection provides much better stiffness and strength characteristics than systems with the conventional connection details. A tee-shaped section was built up from the support angle material to allow the stiffening angle to have the same eccentricity as the bottom leg of the support angle. Figure 5 shows that the stiffening angle prevents excessive support angle deformation at the ultimate load. In tests the failure often consisted of excessive bearing deformation around the fastener locations.

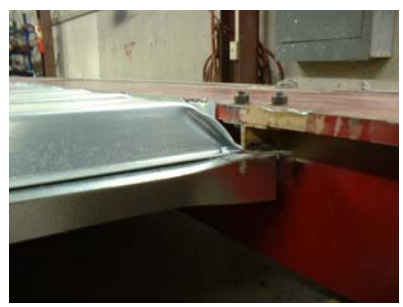

Figure 5 Stiffening angle at failure

Lateral Load and Buckling Tests

• The lateral load tests were conducted to measure the stiffness characteristics of the PMDF when subjected to deflection profiles that were similar to what they would be subjected to during buckling. Tests on the unstiffened deck (conventional details) showed that the shear diaphragm model often underestimates the stiffness of the PMDF system since this model doesn't reflect the in-plane flexural contributions of the formwork.

• The tests on the twin girder system provided the data necessary to calibrate the FEA models so that the bracing behavior of PMDF systems could be studied on a variety of girder systems. Comparisons of the tests and FEA results showed that the shear diaphragm model often underestimated the actual system stiffness.

• Lateral load tests were conducted on systems with stiffening angles spaced at 8 ft., 16 ft., and 24 ft. The stiffening angle significantly improved the lateral stiffness of the PMDF system. The lateral stiffness was not dramatically affected by the spacing between the stiffening angles. Figure 6 shows the graphs of the buckling moment versus the midspan twist for the twin girder system. Results are shown for cases with no bracing as well as bracing provided by 20 ga. PMDF with the maximum support angle eccentricity. Also shown in the graph are results from FEA buckling analyses with unbraced lengths of 25 and 50 ft. For the case with no intermediate bracing the test results compared well with the predicted buckling load. The PMDF provided a significant amount of bracing.

The Researchers Recommend…

• PMDF for bracing with the proposed stiffening angles can substantially reduce the number of cross-frames or diaphragms required during the construction phase. The spacing between the cross-frames should be determined based upon the stability requirements during girder erection. During this stage the load on the girders consists of the girder self-weight plus a nominal construction live load of approximately 5-10 lb/ft^2. The PMDF can then be designed to provide the stability bracing during the construction of the concrete bridge deck.

• The spacing between the support angles will often be in the range of 10-20 ft. (20 ft. max.). Expressions for determining the strength and stiffness requirements for the permanent metal deck forms are presented in TxDOT Report 0-4145-1.

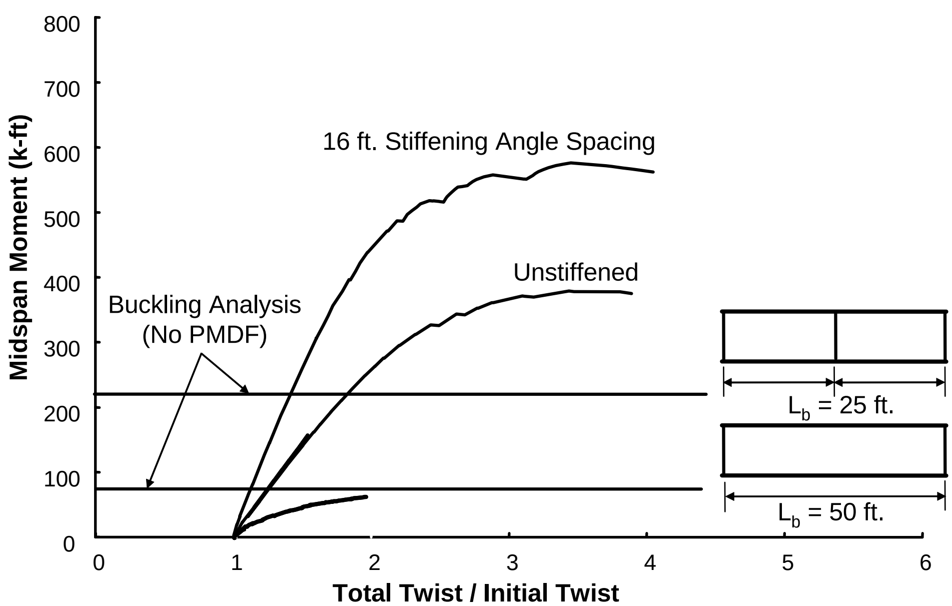

Figure 6 Graph of test results from buckling tests on twin girder system

For More Details…

Research Supervisor: Todd A. Helwig, Ph.D., (713) 743-4284, thelwig@uh.edu

TxDOT Project Director: John Vogel, P.E., (713) 802-5235, JVOGEL1@dot.state.tx.us

The research is documented in the following report:

0-4145-1 *Lateral Bracing of Bridge Girders by Permanent Metal Deck Forms* (January 2005)

To obtain copies of reports please contact the research supervisor.

TxDOT Implementation Status
January 2005

The Houston District is in the process of implementing the results from this research project. The IH 610 superstructure reconstruction of the Fulton Street and Irvington Street Overpasses is being designed to utilize permanent metal deck forms as construction bracing. Implementation project 5-4145 is currently active and is providing funding for the University of Houston to assist Houston District bridge 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.

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