Project Summary

Texas Department of Transportation

0-1898: Simplified Details for Trapezoidal Steel Box Beams

Background

The steel tub of a trapezoidal box girder has a top flange lateral truss system for torsional strength during construction. Current design guides provide little or no guidance for the design of top-lateral bracing systems, which has led to either overly conservative or, in some instances, inadequate bracing designs. Since the top flange lateral system serves no function after hardening of the concrete bridge deck, perhaps the permanent metal deck forms (PMDF) used for the concrete deck could also function as the top flange lateral system.

Temporary intermediate external cross-frames are installed during the construction phase to maintain alignment, yet bridges have been successfully erected without them. When intermediate diaphragms are specified, they are usually removed for aesthetics after the deck has hardened. There is no formal design method for proportioning external intermediate diaphragms.

The main initial objectives of this research were to develop design procedures for both top flange lateral systems and intermediate cross frames, and to investigate the use of PMDF as an alternative for the top lateral truss system. Data from field tests, laboratory tests and analytical studies were used in support of these objectives. After some initial field tests were completed showing more than a 50% discrepancy between some measured and expected brace forces, assuming non-composite behavior during the deck pour, an additional objective was added to evaluate the development of composite action at early concrete ages.

What the Researchers Did

In the field test, a crane applied load before and after the PMDF was attached directly to the top flange. In the laboratory, a 54 inch deep straight trapezoidal steel box-girder specimen with either PMDF or various diagonal bracing arrangements was subjected to torsion and bending tests. The tests with PMDF entailed loading up to deck failure. The capabilities and limitations of metal-deck bracing systems were examined and design recommendations for top lateral bracing were developed.

Two intermediate external diaphragms on a bridge were monitored during the concrete deck pours and live load tests, to evaluate the accuracy of a design method developed for intermediate external diaphragms.

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Laboratory tests were performed to investigate the shear transfer between the concrete deck and steel girder at early concrete ages (hours, not weeks). An equation for predicting design strength and load-slip behavior for shear studs was developed. A finite element program, UTrAp, with a simple input format was developed to evaluate the bracing forces, girder stresses, deflections and rotations in single and twin curved trapezoidal box girder bridges during the deck pour. Various degrees of composite action can be specified during the construction sequence.

What They Found

Laboratory and field tests revealed that composite action develops at very early concrete ages because the concrete achieves 70% of its 28-day stiffness after only eight hours of curing and the stud strength is at 40%. The UTrAp software provided reasonable correlation between measured field data and computed results.

The conservative manual design procedure for intermediate diaphragms was found inapplicable after the slab has hardened. The highest diaphragm stress measured during the live load tests was only 0.9 ksi, thus justifying the TxDOT decision to remove all intermediate diaphragms from the completed bridge. The UTrAp finite element program, which was developed in the later stages of this project, can perform this function more easily and accurately.

Top flange brace forces predicted using the equivalent flat plate approximation showed reasonable agreement with measured values. Brace forces with decking present were between 23% and 34% smaller than the forces measured with no decking present. This significant reduction in the truss bracing forces demonstrated the potential of the metal deck forms as a lateral bracing system. The fasteners limit the shear strength of PMDF. For even moderately curved bridges, the shear forces induced by torsion will exceed the shear strength of PMDF.

The proposed top flange design specification, including PMDF, is based on satisfying both strength and stiffness criteria. Stiffness requirements are based on three criteria: control of girder rotations, control of warping stresses, and providing lateral stability for the top flanges.

What This Means

A structural analysis program, UTrAp, specifically developed for checking the construction stage of curved trapezoidal steel box girder bridges, is now available. Last-minute requests by contractors for changes in the pouring sequence can be quickly and accurately evaluated. The need for intermediate cross frames can also be determined, instead of being merely specified. Since it was proved that composite action commences after just a few hours of concrete curing, it may be beneficial to consider this fact when designing the bracing systems. It is suggested that the draft specification for top lateral bracing systems be transmitted to AASHTO for possible implementation into the standard steel bridge specification. For relatively straight bridges PMDF could be used to replace the top diagonal system.

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