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Project Summary Report 0-4148-S
Project 0-4148: Field Monitoring of Trapezoidal Box Girders with Skewed Supports
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PROJECT SUMMARY REPORT

Behavior of Trapezoidal Box Girders with Skewed Supports: Summary

Trapezoidal steel box girder systems are frequently used in Texas for the construction of highway interchanges and elevated expressways in urban areas. The closed shape of the box girder bridge provides not only aesthetic and maintenance advantages, but also structural advantages, particularly with respect to the torsional performance of the girders. The torsional stiffness of a box section is often more than 1000 times greater than that of a comparable I-shaped section. Based on these advantages, box girders have gained popularity in curved bridge applications.

Although they have significant structural advantages, curved box bridges are generally not understood as well as many other bridge systems are. TxDOT has funded several studies since the mid-1990s to improve understanding of the behavior of curved steel box girder bridges. These studies have focused on the behavior of the girders and bracing systems used in these bridges. Typical bracing systems (Figure 1) for the steel box girders include top flange lateral trusses and plate diaphragms at the supports, as well as K-frames both internal and external to the boxes.

A previous TxDOT study, Project 0-1395 *Field and Computational Studies of Steel Trapezoidal Box Girders*, resulted in design expressions for the internal bracing systems. Helwig and Fan (2000) presented these design expressions to predict the forces in the top lateral truss and internal K-frames. However, these expressions were based upon girders with radial supports and no intermediate (between supports) external K-frames.

What We Did…

The purpose of this investigation was to improve understanding of trapezoidal box girder systems with skewed supports. The impact of external K-frames on the behavior of the internal K-frames and top lateral truss was also studied. The research investigation included both field monitoring and computational investigations using finite element analytical (FEA) models. The field monitoring was conducted on a five-span twin box girder bridge with a skewed end support. The bridge was located at the intersection of Beltway 8 and Highway 59 in north Houston. For reference purposes in this report, the two girders of the bridge were labeled as the "interior" and "exterior" girder, respectively, based upon their location relative to the center of horizontal curvature of the bridge.

A total of 114 foil strain gauges were placed on the bridge to monitor the stresses during construction and subsequent load tests using dump trucks filled with sand. The instrumentation was placed at select locations near the

Figure 1 Box girder bracing systems

skewed end support of the bridge. The cross-sections of both the interior and exterior girders were instrumented at two locations. Instrumentation was also placed on bracing elements including select top lateral truss diagonals, two internal K-frames, and the external K-frame nearest the skewed end support.

To facilitate recording of strain from the instrumented twin girders, a wireless data acquisition system was used to obtain the field measurements. The data acquisition system included sensor and relay units. Individual sensors were connected to each strain gage and wirelessly transmitted the strain readings to three relay units. The relay units were used to store the data collected from the gages. A laptop with a special receiver unit was brought to the field as needed to download the data from the relay units. The laptop computer was also used to send commands to the individual sensor units such as the desired sample rate.

Data was recorded during girder erection, construction of the concrete bridge deck, and subsequent live loading using sand trucks. The truck-loading test was conducted twice before the bridge was opened to traffic. The truck loading was applied first with most of the external intermediate cross-frames still on the bridge and then again after they had been removed.

In addition to the field monitoring, a three-dimensional FEA model of the instrumented bridge was developed for verification of modeling techniques. After model validation, parametric FEA studies were conducted to improve understanding of the behavior of curved box girder systems. Parameters that were considered include the girder span, radius of curvature, support skew angle, panel size in the top truss, number and spacing between the internal and external K-frames, and also the bracing details. Results from the parametric studies were used to investigate the validity of the previous bracing design expressions that were developed for bridges without a skewed support or external K-frames. Modifications to the design equations were recommended for systems with a skewed support or external cross-frames. In addition, bracing details were suggested to improve the performance of the girder systems.

The results from the 3D FEA model were also compared to results from grid models. Since most designers employ a grid analysis, with the girders and diaphragms modeled using line elements, the accuracy of the grid approach was checked with both radial supports and skewed supports. The grid analyses were found to give good results for both radial and skewed systems; however, the grid analyses are very sensitive to the torsional constant that is used in systems with a skewed support. It is therefore important to properly evaluate the torsional constant used in an analysis. The parametric studies also were used to develop a simplified procedure to modify the results of a grid analysis to account for the impact of a skewed end support. The skew modification factor developed showed good agreement with results from 3D FEA models.

What We Found…

Measurements from the field studies provided valuable data that was used to validate the FEA models. However, obtaining meaningful data from the field measurements was a challenging task due to daily thermal gradients. The thermally induced stresses were often as large as or larger than the stresses due to the specific construction events that were to be monitored. To obtain meaningful data, readings were recorded in the early morning hours (~2:00 a.m.) the day before and the day after a specific construction event. During the early morning hours the temperature throughout the bridge had normalized and the change in strain between the two readings could be attributed to the stress caused by the construction activity.

The FEA parametric studies were used to examine a variety of factors in box girder systems with radial supports and also systems with a skewed end support.

- The details for the solid diaphragms at the supports were investigated. The girder system in the field studies had a "partial depth" solid diaphragm that did not frame into the girder top flanges. The height of the interior diaphragm was approximately 80% of the girder depth at the dapped end as shown in Figure 2.

Figure 2 Partial depth end diaphragm (soft end panel)

Since the interior solid diaphragm did not close the end of the box, the top flanges of the girder and the truss diagonal in the end panel were not properly restrained, producing a "soft" end panel. Consequently the forces in the top truss diagonals in the end panels were reduced, while more demand was put on the internal K-frame nearest the end support and the second truss diagonal because of the soft end panel. The girders also experienced larger rotations when a partial depth diaphragm was used.

- The details of the connection between the external solid diaphragm and the girders were investigated. Many engineers specify a connection between the girders and the top flange plate of the external solid diaphragm analogous to a "moment connection" that is usually required at the end of an I-shaped girder. However, in the case of a solid plate diaphragm, the predominant stiffness comes from shear, not flexural stiffness. Results from a 3D FEA analysis with and without a "moment" connection on the external solid diaphragm showed no significant differences. Therefore, there is no need to detail a connection between the "flanges" of the external diaphragm and the girders unless the span-to-depth ratio of the plate diaphragm between the two boxes exceeds approximately 3.

The Researchers Recommend…

- Top lateral truss panels should be laid out so that the angle formed between the top lateral diagonal and the top flanges of the girder is as close to 45 degrees as possible (no less than 40 degrees if at all possible). The researchers also recommend alternating a top strut only with a full internal K-frame (Figure 3).

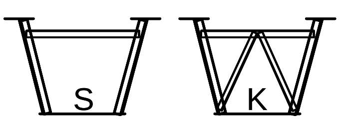

Figure 3 Alternate top strut only (S) and full internal K-frame (K)

The spacing between internal K-frames was varied from one to four panels of the top truss, and the optimal spacing in terms of distortional forces in the internal K-frames was found to be every two panels.

- A parallel top lateral truss layout, as shown in Figure 4, with internal K-frames every other panel, was found to be the best layout for bridges with radial supports (with or without external K-frames), and for bridges with a skewed support and no external K-frames. The first diagonal (adjacent to the support location) should be oriented to go into tension under torsional loads.

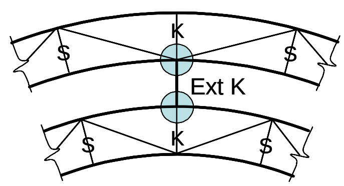

Figure 4 Parallel truss layout

- For systems with parallel truss layouts and skewed supports, the addition of external K-frame(s) caused increases of up to 80% in the strut force in the K-frames in the interior girder at the location of the external K. The reason for the very large increases in the strut forces in the interior girder is that with a parallel truss layout the diagonals of the top lateral truss in the interior girder do not meet at the external K as shown in Figure 4. Therefore with the parallel layout the top strut in the interior girder essentially resists the full reaction at the top of the external K-frame. If the top lateral truss of the interior girder is flipped so that the top diagonals in both girders meet at the external K-frame, as shown in Figure 5, there is a better distribution of the load from the external K and much less significant increases in the forces in the internal K-frames at that location. For systems with both skewed supports and external cross-frames, a layout like that shown in Figure 5 is recommended.

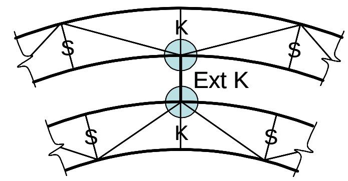

Figure 5 Flipped orientation of top truss in interior girder

A number of factors affect the forces that develop in the external K-frames; however, the researchers recommend that the primary role of the temporary external K's should be to control the girder twist so as to achieve a uniform slab thickness across the width of the bridge: a serviceability limit state. If the role of the external K's is designated as a serviceability issue, typical sizes can be used for these braces. However, with the designation of the external K-frames as elements to satisfy serviceability criteria, these braces should not be included in structural analyses. The box girders, internal bracing members, and end diaphragms should be designed to carry the full design construction loads. External K-frames should then be provided to control the relative twist of adjacent girders to maintain uniform deck thickness. To ensure ductile behavior, the connections between the box girders and the external K's should be designed to fully develop the K-frame members.

Reference:

Helwig, Todd A., and Fan Zhanfei, "Field and Computational Studies of Steel Trapezoidal Box Girder Bridges," Research Report 1395-3, Report for Texas Department of Transportation, August 2000.

For More Details…

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The research is documented in the following report:

0-4148-1 *Behavior of Trapezoidal Box Girders with Skewed Supports* (May 2004)

To obtain copies of reports please contact the research supervisor.

TxDOT Implementation Status
May 2004

This project produced recommendations for the design of box girder systems which have been implemented by TxDOT bridge designers (and their consultants) in the design of steel tub girder bridges. In the Houston District, steel tub girder bridges are now being designed with fewer external cross-frames, and the orientation of internal cross-frames will be optimized to better distribute the load transferred from adjacent girders. Also, actual loads carried by end diaphragms were shown by 3D Finite Element Analysis to be very sensitive to the torsional constant used in simpler grid models commonly employed by bridge designers. For designers who might still be using hand calculation methods, a load amplification factor was developed for use in the design of box girder systems with radial or skewed supports and with or without external cross-frames.

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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