Determination of the Forces in X-Frames in Curved Girder Bridges

tech transfer summary

Understanding the behavior of cross-frames in horizontally curved steel girder bridges can help improve the design of this important type of bridge.

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RESEARCH PROJECT TITLE
Determination of the Forces in Cross-Frames in Curved Girder Bridges

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PRINCIPAL INVESTIGATOR
Behrouz Shafei, Associate Professor
Bridge Engineering Center
Iowa State University
shafei@iastate.edu / 515-294-4058
(orcid.org/0000-0001-5677-6324)

CO-PRINCIPAL INVESTIGATOR
Brent Phares, Bridge Research Engineer
Bridge Engineering Center
Iowa State University
(orcid.org/0000-0001-5894-4774)

MORE INFORMATION
intrans.iastate.edu

Bridge Engineering Center
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103
www.bec.iastate.edu

The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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Goal and Objectives

The goal of this research was to understand the behavior of cross-frames in horizontally curved steel girder bridges during various stages of construction and over their service lives. Specific objectives included identifying critical locations on the bridge for instrumentation and evaluating the performance of cross-frames through long-term monitoring and live load tests.

Background

For decades, horizontally curved steel girder bridges have been a solution for constructing interchanges between state and Interstate highways. The cross-frames in these bridges are especially critical because, unlike in straight bridges, they are major load carrying elements.

The design and analysis of cross-frames in horizontally curved bridges is complex due to the complexities in how loads are transmitted throughout this type of bridge. Cross-frames have generally been configured based on standard designs that have depended principally on gross geometries, slenderness limits for tension and compression members, and other minimum requirements.

Problem Statement

Concerns remain regarding the design and construction of cross-frames in horizontally curved steel girder bridges. A unique opportunity exists to improve the design of these components using rigorous structural analyses paired with a short- and long-term monitoring program.

Research Description

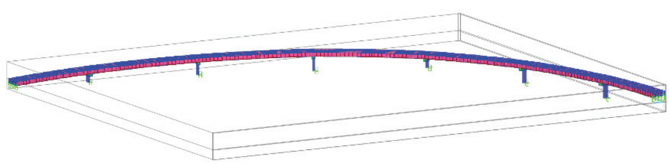
This project investigated a horizontally curved bridge located in Story County near Ames, Iowa, connecting northbound I-35 and westbound US 30. The project involved finite element analysis (FEA) to identify critical areas of the bridge for instrumentation and an evaluation of the bridge's cross-frames in the field using short- and long-term monitoring and live load testing.

Story County bridge

A detailed finite element model of the Story County bridge was developed using information from Iowa Department of Transportation (DOT) drawings. The axial forces and moments in the bridge's cross-frames were determined under various temperature and gravity load scenarios.

Based on the simulation results, the cross-frames critical for instrumentation were identified. A long-term instrumentation plan for the bridge was developed to measure changes in strains, displacements, and temperatures in the cross-frames during the monitoring period. To measure the maximum recorded forces within the cross-frames, the exterior cross-frame at the midspan of Span 4 and the exterior cross-frame near the span's fixed bearings were instrumented.

For live load testing of the bridge, selected cross-frames and flanges of the girders were instrumented with strain gauges. The bridge was tested using ambient traffic to observe the structural response of the elements under different truck loadings. As traffic passed over the full length of the bridge, the type of each vehicle was recorded and strain data were collected. Twenty load cases (LCs) were identified for analysis.



Story County bridge model

Strain gauge installation on a cross-frame of the Story County bridge for long-term monitoring

Installation of a strain gauge on the Story County bridge for live load testing

Key Findings

- From the numerical simulations, the maximum and minimum forces in the cross-frames were found within the third and fourth span of the bridge and near the interior supports. The girders were subjected to forces vertically as well as radially. This bidirectional translation confirmed that the displacement of girders does not follow a particular path.
- The simulation results showed that the load within the top chord of the cross-frames varies significantly at the two ends of each connection. The cross-frames in the interior bays were found to carry higher forces than those in the exterior bays.
- From the long-term monitoring data, the maximum compressive stress was found in the diagonal strut during the minimum temperature period.
- A stress difference of about 6 to 8 ksi was found within the top chord of the cross-frame located near the midspan, as also determined from the numerical simulations.
- From the live load testing, the maximum girder flange response in the longitudinal direction was 80 microstrain (2.4 ksi), measured in the bottom flange of Girder 5 during LC 12 (i.e., one semi-truck). In the transverse direction, the maximum response was -20 microstrain (-0.6 ksi), also measured in the bottom flange of Girder 5 during LC 12.
- No distress or anomaly was found in the field. The maximum stresses estimated from the strain gauge readings in the top chord and all of the other members were found to be minimal and consistently less than 36 ksi.

Conclusions

The cross-frames close to supports may experience high stress levels. Therefore, special attention is required for the design of these cross-frames, especially their top chords. The top chords and their connections may also become vulnerable to higher stress differences during extreme sustained and fluctuating temperatures.

The cross-frames within the interior bays were found to carry higher forces than those in the exterior bays. Additional analysis of these cross-frames is required during design to ensure the safety and performance of curved girder bridges.

Implementation Readiness and Benefits

Understanding the behavior of cross-frames in horizontally curved steel girder bridges can help improve the design and ultimately the longevity of this important type of bridge.

A key conclusion of this study is that cross-frames close to supports and those within the interior bays of a bridge can experience high stress and require special attention during design.

The Story County bridge has been instrumented for long-term monitoring, and additional data can be collected in the future to determine the performance and behavior of the cross-frames over time. Additionally, reconstruction of the Interstate system in western Iowa offers a unique opportunity to monitor the behavior of several yet-to-be-constructed horizontally curved steel girder bridges.