Investigation of Exterior Girder Rotation and the Effect of Skew during Deck Placement

tech transfer summary

This project investigated exterior girder rotation, girder and formwork deflection, and the effect of skew during bridge deck placement through a field review of construction practices and both a numerical, analytical study and a parametric, sensitivity study using calibrated finite element models.

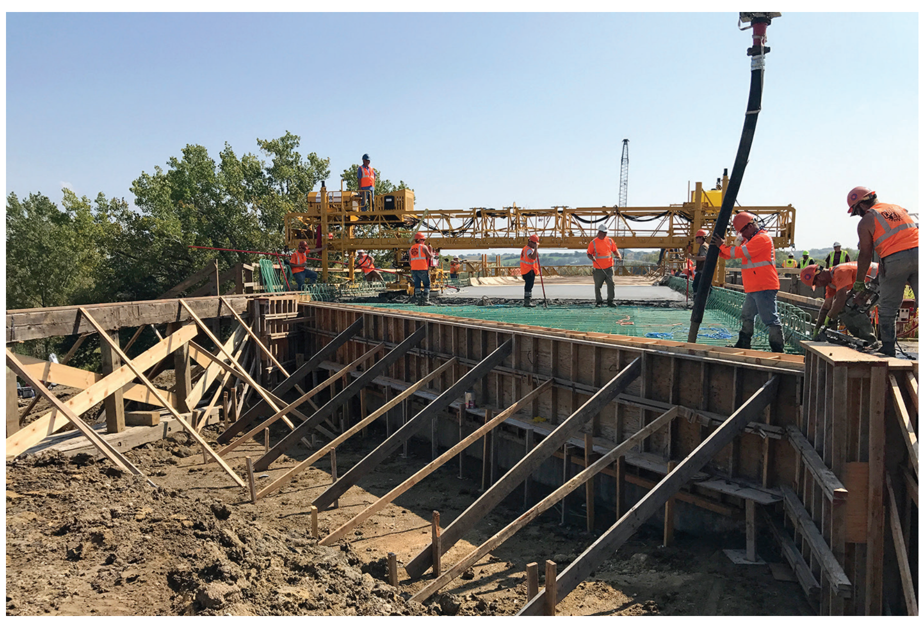
Objectives

The objectives of this work were to investigate exterior girder rotation and the effect of skew during bridge deck placement.

Background

The practice of using common girder sizes for all girder lines limits the bridge designer's ability to economically design the fascia girder to withstand bridge deck construction loads. In general, large eccentric deck placement loads come from two sources: large overhangs and deck finishing equipment typically positioned at the edge of the overhang. Combined, the resulting torsional loads have resulted in issues in both steel and concrete superstructures.

It has been observed that current construction practices associated with placing bridge decks sometimes result in excessive out-of-plane and torsional loads on the exterior girders. Structurally, this can result in decks that are too thin or girders with excessive (and unintended) internal stresses. Functionally, this can result in bridges that are difficult to maintain or have rideability issues. In some cases, the most extreme situations have occurred during bridge widening projects.



Screed orientation perpendicular to the roadway for the 45° skew BNSF Railway Bridge during deck placement

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RESEARCH PROJECT TITLE

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SPONSORS

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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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Various previous research efforts have focused on the effect of bridge deck overhangs on exterior girders and the effectiveness of bracing elements to resist girder twist. Girder buckling capacity is a function of cross-frame diaphragm spacing, strength, and stiffness.

For completed bridge structures, the in-place concrete deck provides continuous structural lateral bracing for bridge girders. Whereas, during construction, the deck is not present to provide the lateral bracing for the girders and can result in lateral torsional buckling of the exterior girders. Therefore, alternative means of bracing may need to be provided during deck placement.

Problem Statement

Although bridge designers commonly use rules-of-thumb with regard to the geometry of the bridge deck overhang, these rules-of-thumb generally consider only the deck strength and deflection limits, and the effect due to construction loads during deck placement is often overlooked.

Research Description

Three bridge construction projects were selected for field evaluation of bridge behavior during deck placement. Two of the projects were new construction and one was a widening project. The projects were selected for their representation of variables of interest that included skew, relative girder depth, and span length.

All three bridges were instrumented before deck placement using a combination of strain gages, tiltmeters, and deflection transducers. For a typical field instrumentation setup, the tiltmeter was mounted to the web of the girder, strain gages were placed on the girder flange and formwork support bracket, and deflection chains were mounted to the girder flange and deck formwork and attached to transducers stabilized on the ground beneath them.

Maple Bridge instrumentation and temporary timber blocking and diagonal cross-bars for the east (left) and west (right) spans during the braced deck pour

Screed traveling over an instrumented cross-sectional location of the 15° skew Cedar Fork Bridge

Strain, rotation, and deflection data were captured throughout the duration of each deck pour and also during two dry runs with the screed on the Maple Bridge before its deck pour. The researchers then analyzed and summarized the results.

Field-reviewed bridge construction projects

Bridge	County	Project Type	Span Lengths	Deck Overhang	Skew	Girder Sizes	Temporary Deck Bracing
Cedar Fork	Des Moines	Widening	45 ft 9 in., 58 ft 6 in., and 45 ft 9 in.	34 in.	15°	W24×84, W27×102	None
Maple	Ida	New Construction	102 ft, 136 ft, and 102 ft	37 in.	0°	W44×230, W44×290	None for first dry run with screed Temporary for braced dry run with screed and actual pour*
BNSF Railway	Adams	New Construction	78 ft, 104 ft, and 78 ft	37 in.	45°	W40×199, W40×167	Temporary timber blocking in exterior bays

** Data collection for the Maple Bridge included an unbraced dry run with the screed, a braced dry run with the screed with temporary timber blocks at the exterior bay diaphragm locations as well as diagonal pipes between the diaphragms, and the actual braced deck pour using the same temporary bracing with additional span instrumentation for data comparison purposes*

To provide supplemental data while also validating the field observations, the researchers created analytical models that incorporated a variety of variables thought to affect girder rotation. This analysis helped to provide an understanding of the effects caused by the loads when applied over the portion of overhang on the exterior girder in terms of deflection and rotation using finite element analysis (FEA) by correlating the results with the field data.

Upon calibration, the researchers conducted a parametric study to expand upon the understanding of the structural behavior of bridges when different loads, such as concrete weight and screed load, are acting on them.

Actual field testing provides a realistic estimation of the rotation and deflection of girders and overhang, respectively. The FEA, however, plays an important role in providing estimation of the contributing mechanisms, while also allowing for the study of various other parameters. This is not feasible during field investigations due to the nature of testing, project timeframe, site-specific issues, construction schedule, and other restrictions.

The three-dimensional (3D) FEA was performed using the structural analysis and design software for bridges, CSiBridge. The numerical study included the investigation of effects of different combinations of bracing, including cases of no timber blocking, only timber blocking, only temporary bracing, and temporary bracing with timber blocking—on three different bridges.

Finite element models (FEMs) for the Maple Bridge in Ida County and the BNSF Railway Bridge in Adams County were developed and used to compare with results from their field investigations, while a 160 ft bridge with 0° skew from Iowa Department of Transportation (DOT) bridge standards was also modeled and studied for various configurations.

To investigate the parameters that affect the rotation and deflection of exterior girders, as well as the deflection of brackets, the researchers modeled and used the Iowa DOT 260 ft Standard Bridge. The goal of the parametric study was to identify the parameters for which the rotation and deflection of the exterior girders and brackets were most sensitive.

The parametric study involved six different parameters that were identified to investigate: brace strength, skew angle, diaphragm spacing, girder spacing, span ratio, and girder flange thickness. Three load cases were studied for each of the six parameters. The load cases were applied at the mid-span of the interior and each exterior span.

Timber blocking and diagonal compression struts as temporary bracings were modeled using compression-only elements by providing the axial stiffness of the members. This modeling technique is expected to simulate the actual situation of the bridge, as these members are expected to participate when subjected to a compression load.

Key Findings

Field Review of Construction Practices

- Concern for exterior girder rotation increased with an increase in skew. This is due to the unequal loading of the exterior girders when the screed is not oriented along the skew.

- The field review showed that the concrete is being placed right in front of the screed to keep up with placement, rather than placing the concrete unequally in front of the screed to combat the unequal loading of concrete caused by the skew during placement.

- While exterior girder rotation was evident for all instrumented deck placements, differential deflections were also present and seemed to have a greater effect on the deck thickness deficiencies that were observed at the Maple Bridge.

- The greatest exterior girder rotation observed for the three instrumented bridges was just over 1°, with a residual rotation of 0.75°. The greatest deflection observed during placement was approximately 2.5 in., with a residual deflection of just over 1 in.

- Temporary bracing of the exterior bays is not common practice based on conversations with contractors and field observations. Contractors mentioned that for other projects, if bracing was used by the contractor but was not called for in the plans, timber blocking was most often used. While this is an effective means for reducing girder rotation, it does not protect against differential deflection, and alternate bracing methods to better reduce differential deflections would be advantageous.

- Of the three deck placements that were monitored in the field, deck thinning was only noticed at one site

Analytical and Parametric Study

- The models confirmed that both differential deflection and exterior girder rotation can lead to deck thickness deficiencies during deck placement, with the largest contribution coming from the differential deflection.

- Diagonal bracing in the exterior bays, combined with timber blocking in the adjacent bay, greatly reduced the exterior girder rotation for straight bridges. This bracing system also reduced the deflections, although to a limited extent.

- The skew angle influences the deflection and rotation of exterior girders, as deflection and rotation of the two exterior girders are not equal. Unsymmetrical load distribution due to skewness increases the deflection and rotation of exterior girders, depending on the skew angle.

- The temporary bracing system was highly effective in reducing rotation of the 0° bridge. However, for a skew angle 30° and greater, the temporary bracing system became increasingly ineffective in reducing rotation.

260 ft Standard Bridge percentage of reduction in rotation with temporary bracing system during deck placement depending on skew angle

Skew Angle	No Temporary Bracing	Temporary Bracing*	Reduction in Rotation
0°	0.29	0.12	58.9%
30°	0.34	0.26	25.5%
45°	0.33	0.32	2.9%

** Timber blocking and compression struts as temporary bracing were modeled using compression-only elements by providing the axial stiffness of the members*

Overall

Based on the modeling and field investigation efforts, it appears that the predominant cause of any possible deck thinning (or the greatest rotation and/or deflection of the girders) is a result of differential deflections, not from the rotation of exterior girders.

While differential deflections during deck placement are not surprising due to the screed loading location, the field data showed that, while the bridge does begin to return to its original location, there is permanent differential deflection of the bridge cross-section even after the screed load is off the bridge.

While the bracing methods considered in this research were effective at restraining girder rotation for straight bridges or those with low skew, they were not as effective at reducing differential deflections caused by the concentrated screed load. Alternate bracing methods or construction techniques (such as reducing the moment arm of the screed load) should be utilized where possible.

While reducing the moment arm of the screed load would be more effective at combating rotation rather than deflection, this reduction would still improve differential deflections to some extent, especially if diagonal cross bracing is used.

Recommendations for Future Research

Further work is needed to address concerns regarding differential deflections and their impact on the long-term behavior and performance of bridges. While not modeled in this research, the feasibility and performance of cross bracing is something to consider to combat differential deflections and would be beneficial to include in future research efforts.

In addition to differential deflection concerns, more work is also needed to address the effect of skew. Of particular interest is determining what level of skew necessitates the positioning of the screed parallel to the skew, rather than perpendicular to the roadway, as is often the current practice.

Implementation Readiness and Benefits

It is vitally important that, when new bridges are constructed (or when existing bridges are widened), the most current and best bridge construction practices are followed so that the final product has a high likelihood of achieving the target design life.

Implementation of this work will help the Iowa DOT Office of Bridges and Structures develop both design guidance and construction procedure recommendations that are aimed at reducing girder rotation (and especially for exterior girders) due to eccentric loads during deck placement. The goal is for the bridge designers to be able to provide guidance on the stiffness and/or bracing details for various configurations before the design is finalized.

The results of the proposed future work will also help the Office of Bridges and Structures to determine a skew threshold for which the finishing machine should be oriented parallel to the skew as opposed to the more common position perpendicular to the bridge centerline. When structural details cannot be provided that counteract the eccentric loads, the office can prescribe under which circumstances the deck placement equipment can be used in various orientations.