Design and Detailing Requirements for Columns under Collision

tech transfer summary

The findings from this study will aid the Iowa DOT in making revisions and additions to its Bridge Design Manual in regards to vehicle collision design requirements for bridge frame piers and T-piers.

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RESEARCH PROJECT TITLE
Design and Detailing Requirements for Columns under Collision

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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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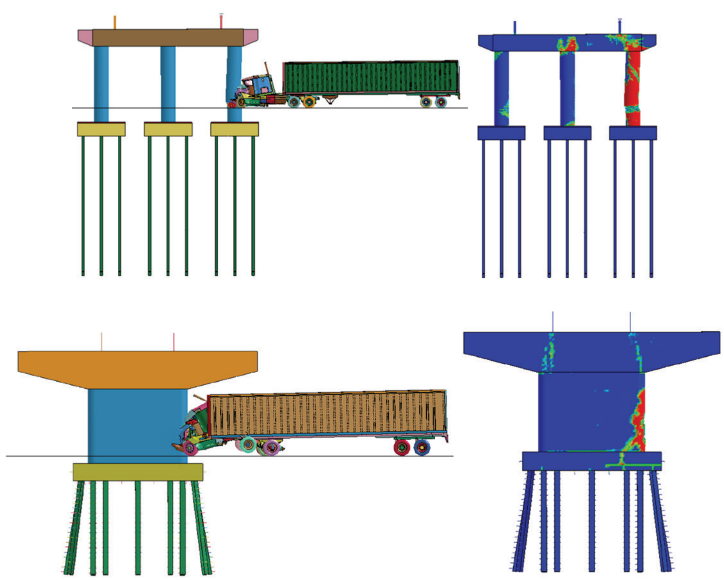
Objectives

The objectives of this project were to investigate how the vehicular collision section of the Iowa Department of Transportation's (DOT's) Bridge Design Manual could be improved by comparing it to the current American Railway Engineering and Maintenance-of-Way Association (AREMA) and American Association of State Highway and Transportation Officials (AASHTO) manuals, performing finite element simulations of vehicle collisions on representative bridge piers and conducting a parametric study.

Research Description

This study investigated the differences between AREMA, AASHTO, and Iowa DOT manuals concerning vehicular collisions with bridge piers. The research team investigated the differences in vehicle collision design requirements for bridge piers from the three design specifications and evaluated the performance of common Iowa bridges and their components when an 80 kip (36.287 metric ton) tractor-semitrailer collides into them. The researchers also performed a parametric study on a frame pier and T-pier that experience a vehicular collision.

To investigate the structural resistance of typical Iowa bridges to vehicular collision using the finite element method (FEM), two bridge pier types were modeled: a frame pier and a T-pier. Two other bridge pier models were developed to involve the typical pier protection strategies used by the Iowa DOT in cases where vehicular collision into a frame pier is likely.



Frame pier (top) and T-pier (bottom) models used to investigate the structural resistance to vehicular collision

One of the strategies used by the Iowa DOT for frame pier protection in urban areas is to construct a 54-in.-high median barrier that is routed around and directly adjacent to the frame pier. In such cases, each column of the frame pier is also supposed to be designed for the AASHTO-required 600-kip vehicular collision design force. The other main design strategy for frame pier protection against vehicular collision is to integrate a crash wall (or strut) into the frame pier.

Finite element modeling was conducted using the LS-DYNA software package. This software package is capable of performing nonlinear impact simulations, capturing various vehicle collision scenarios. The FEM process involved modeling the truck striking the bridge given the bridge frame or T-pier, foundation, and superstructure.

The parametric study that the researchers performed on the frame pier and T-pier investigated and evaluated the effect of different frame pier column diameters, the effect of the extension of frame pier spiral reinforcement into the pier cap and pile cap, the effect of different impact angles on the T-pier, and the effect of different tie reinforcement spacing in the T-pier. Various response measures were analyzed, and these included the damage pattern (plastic strains), impact force time history, shear force, bending moment, displacement, and internal energy.

One of the unique aspects of the project was to develop a damage ratio index (DRI) to allow for potential implementation of a performance-based design philosophy for design of columns under collision. As part of this effort, the DRI was determined for the various scenarios considered.

Key Findings

The researchers found a few differences between the three design manuals investigated in this study concerning pier protection for vehicular collisions and pier column detail requirements. However, for the most part, the requirements in all three are similar. Other findings include the following:

- The DRI values and damage description for the frame pier accurately predicted the damage observed in the frame pier due to vehicular collision.
- The T-pier commonly used in Iowa did not collapse under any of the three impact velocities considered when it was impacted along its longitudinal axis.
- The minimum requirements for a crash wall specified in the Iowa DOT Bridge Design Manual (2020) were able to keep the frame pier from failure when it was struck by a tractor-semitrailer traveling at the three impact velocities considered.
- The 54 in. (1.37 m) tall concrete barrier for the Iowa DOT successfully redirects a tractor-semitrailer and therefore prevents it from hitting the frame pier it is set up to protect.
- Extending the spiral reinforcement in the column of the frame pier to the pier cap and pile cap only slightly increases the stiffness of the pier and does not significantly increase the pier's resistance to vehicular collision loads.
- Greater impact angles on a pier from its longitudinal axis causes the pier to experience greater damage. It is important that there is no vertical region in the pile cap without steel reinforcement when considering vehicular collision design for impact velocities of 70 mph (112.7 km/h) and greater.

Implementation Readiness, Benefits, and Recommendations

The findings from this study will aid the Iowa DOT in making revisions and additions to its Bridge Design Manual.

Additional vehicular collision simulations can be conducted using finite element modeling to further refine requirements within the Iowa DOT's Bridge Design Manual.

Based on the modeling results and the parametric data, few modifications are recommended to bridge piers designed per the Iowa DOT Bridge Design Manual (2020). The one item of potential change would be lowering the bottom mat of reinforcing within frame pier footings to provide connection to the piles for better performance when vehicular impact occurs perpendicular to the long axis of the frame pier.

Other variances were present when the column or reinforcing was less than that recommended in the Iowa DOT Bridge Design Manual. Therefore, the results of this study have no direct impacts on the cost of bridge piers designed per the Iowa DOT Bridge Design Manual. Further recommendations include the following:

- Additional attention to the changes to Article 5.10.4.3 regarding tie reinforcing in a column upon adoption of the AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications (2019)
- Clarification of Iowa DOT guidance on the AASTHO LRFD detailing requirements for plastic hinging when the seismic design zone 1 (SD1 in AASHTO terms) is greater than or equal to 0.1

References

AASHTO. 2019. *AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications*. Ninth edition. American Association of State Highway and Transportation Officials, Washington, DC.

AREMA. 2014. *AREMA Manual for Railway Engineering: Volume 2–Structures*. American Railway Engineering and Maintenance-of-Way Association, Lanham, MD.

Iowa DOT. 2020. *LRFD Bridge Design Manual*. Iowa Department of Transportation, Ames, IA.