MONTANA
Department of Transportation
Research

Technical Brief

About This Research

Objectives

- Expand testing on pile-to-cap connection configurations under extreme lateral loads
- Enhance MDT's connection design and analysis methodologies

Benefits

- Greater understanding of how to strengthen connections against horizontal forces
- Validates the connection design methodology as a reliable tool to predict capacity.

ENHANCING MONTANA'S BRIDGE PILE CONNECTION DESIGNS

Understanding the capacity of the connections between concrete-filled steel tube piles and concrete caps will result in stronger bridges in Montana.

Research Need

Concrete-filled steel tube (CFST) piles are an economical and low-maintenance solution for the Montana Department of Transportation (MDT) to use when constructing short- and medium-span bridges. The steel tube provides a strong framework for the bridge supports, while the concrete within prevents the steel from buckling.

The critical connection point where the pile meets the concrete pile cap needs to withstand a variety of forces. While the performance of pile cap connections under the vertical pressures of traffic are well understood, impacts from lateral pressures – such as from seismic activity, ice jams, or even strong winds – are more challenging to predict and factor into design and analysis methodologies.

Past research projects have explored how half-sized models of pile cap connections behave under lateral loadings, providing support for MDT to develop a new design and analysis methodology that optimizes the performance of CFST-to-concrete-pile-cap connections. The methodology, however, relies on empirical assumptions that may not represent all cap configurations.

To enhance its design and analysis methodologies for concrete pile cap connections, MDT wanted to better understand connection behavior under lateral loads and identify any potential refinements to the design methodology.

About This Project

Project title: Concrete-Filled Steel Tube to Concrete Pile Cap Connections – Further Evaluation/ Improvement of Analysis/Design Methodologies (Phase 4)

Project number: 9630-628

Technical Panel

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"These results will allow MDT to adjust the design of our concrete-filled steel tube to concrete cap connections to ensure performance against varying levels of lateral forces across the state."

—Lenci Kappes, Project Champion

Research Process

A thorough review of previous research and published literature focused on the structural behavior of the connections between CFST piles and concrete pile caps under various lateral loadings. As previous projects did not vary parameters such as cap dimensions and loading configurations, researchers designed an experiment to address these shortcomings.

Four specimens, consisting of a portion of concrete-filled tubes connected to pile caps, were constructed and tested. One specimen was half-sized, as in previous experiments, following a typical MDT design to provide consistency for comparison purposes. The other three models were two-thirds sized, with the first having similar reinforcements as the half-sized specimen to isolate any effects of scale. The other two larger specimens had the same reinforcements, but one used a higher-strength concrete and the other added U-bars for additional reinforcement.

All models were set vertically and tested to their breaking points under continuously increasing horizontal force to failure to observe damage under varying lateral loadings. The tests produced measured force-deflection curves that show the correlation between pile-cap connection performance and lateral stress. Finally, an evaluation of the methodology for anticipating connection performance determined the effects of key parameters on predicted connection behavior.

Research Results

Observations of the movement, progression of damage, and failure from increasing horizontal force in all four specimens resulted in these findings:

- The inclusion of U-bars increased the cap capacity about 50%, causing the failure to occur in the CFST pile itself rather than the connection.
- The scale of the specimens affected their performance; the two-thirds sized model had greater stiffness and strength relative to the half-size models but both sizes experienced similar movement and patterns of damage progression.
- The increase in concrete strength was directly related to the increase in performance of the CFST-cap connection.

MDT's new design and analysis methodology for predicting the connection performance between CFST piles and concrete pile caps connections was highly accurate in predicting cap connection capacities. The evaluation showed that the embedded depth of the CFST piles into the cap was the most significant factor in the prediction of connection performance using MDT's new methodology, with an increase in embedment depth of 50% resulting in a 126% increase in strength.

Research Implementation

This research demonstrated that MDT's new design and analysis methodology for predicting the connection performance between CFST piles and concrete pile caps is highly accurate, though it slightly overpredicted capacity for designs without U-bars and underpredicted designs that included U-bars.

While additional research could explore small refinements to further improve the methodology, the design tool provides MDT with much-needed flexibility to tailor pile-to-cap connections for expected seismic or other lateral forces. MDT will consider creating a user-friendly interface or software to implement the design methodology and explore creating standardized details for predefined conditions to facilitate a consistent, reliable, and streamlined design process for high-performing pile cap connections.

MDT Project Champion

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Learn More About This Project

Final report is available in ROSA P.