



Investigation of Unbraced Pile Height in Fully Encased Pile Bents of Bridge Structures

tech transfer summary

May 2026

RESEARCH PROJECT TITLE

Investigation of Unbraced Pile Height in Fully Encased Pile Bents of Bridge Structures

SPONSORS

Iowa Department of Transportation and Federal Highway Administration (SPR-RE23(008)-8H-00, InTrans Project 22-827)

PRINCIPAL INVESTIGATOR

Justin Dahlberg, Director
Bridge Engineering Center
Iowa State University
dahlberg@iastate.edu / 515-294-5664
(orcid.org/0000-0002-6184-4122)

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.

The sponsors of this research are not responsible for the accuracy of the information presented herein. The conclusions expressed in this publication are not necessarily those of the sponsors.

Understanding the additional capacity that concrete encasement contributes to steel H-piles in bridge foundations can improve bridge design and load rating practices.

Objectives

The primary goal of the research was to evaluate how concrete encasement affects the axial capacity of steel H-piles in bridge foundations, especially when scour exposes sections of the pile. Specific objectives were as follows:

- Assess the unbraced height limits of fully encased piles.
- Expand and validate previous pile capacity assessments carried out for the Iowa Department of Transportation (Iowa DOT) to include full encasement conditions.
- Compare the structural performance of fully encased and individually encased pile bents.
- Provide guidance for future design and load rating decisions based on experimental and analytical data.

Background

The steel H-piles used in bridge foundations throughout Iowa are often encased in concrete to protect against corrosion and mechanical damage. However, the state's current standard design for steel H-pile bents does not include the capacity contribution of the concrete encasement. This has become a notable issue when pile bents undergo scour and load rating engineers must determine actual pile capacities.

Iowa DOT projects in 2018 and 2021 investigated the additional capacity that standard P10L concrete encasements contribute to steel H-piles in scour-prone conditions. Finite element (FE) modeling and laboratory testing revealed that encasement considerably increases the capacity of individually encased piles.

It is often more cost-effective to fully encase a grouping of pier piles in a single concrete pier than to individually encase each pile. Currently, piles are fully encased when ice or debris in the waterway may be a concern, with the piles' weak axes placed parallel to the bridge's longitudinal direction.

Problem Statement

Ignoring the structural contribution of concrete encasement can result in significantly conservative pile capacity estimates, leading to oversized systems and missed opportunities for cost savings.

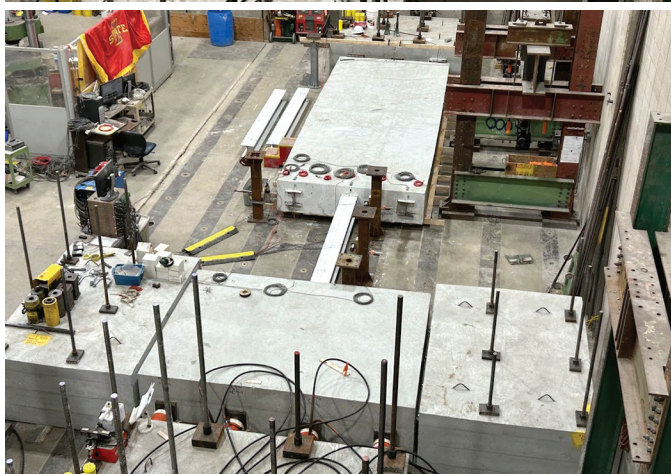
It is believed that the unbraced height limits of fully encased pile bents may be greater than those of individually encased piles under the same axial load, which may alleviate immediate capacity concerns when significant scour is observed. If this is the case, fully encased pile bents could become more widely used, resulting in cost savings for bridge projects. Reviewing the standard pile orientation may also reveal additional efficiencies.

Research Description

The research expanded the scope of the previous Iowa DOT studies to evaluate fully encased pile bents through a full-scale laboratory investigation and FE modeling.

The laboratory testing was designed to enable direct comparison with the results of the previous studies, which featured the P10L standard encasement for individual piles. A three-pile assembly and a single-pile assembly were evaluated:

- **Three-pile assembly.** Three HP10x42 piles with a 30 ft total length and a 20 ft encased length were embedded in a continuous concrete encasement, with a pile spacing and concrete cross-section simulating those of a fully encased pile bent. Load cells, strain gauges, and displacement transducers measured load distribution, stress, and deformation during axial loading under service loads.
- **Single-pile assembly.** To gauge the influence of the encasement and additional piles, the outer piles' unencased sections were removed from the specimen. The remaining central pile was then individually loaded in a manner similar to that used in the first test, but to failure.



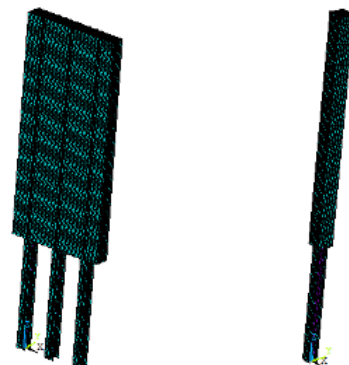
Three-pile (top) and single-pile (bottom) assemblies

To inform bridge design and load rating, the FE modeling approach was designed around a single-pile model that estimated the capacities of individually encased piles. To first validate the modeling assumptions and results against the laboratory data, an intermediate three-pile FE model replicating the laboratory-tested assembly was developed and subjected to axial loading with a slight eccentricity.

Once the modeling approach was validated, hundreds of single-pile models were developed to perform parametric studies across different combinations of pile orientations, pile section sizes, concrete encasements, and pile exposure lengths.

Key Findings

- The results for the three-pile laboratory assembly showed that load distribution across the three piles remained nearly equal (34%–35%–32%). The system remained in the elastic range throughout the loading, as evidenced by the linear stress-strain response and minimal flange displacement.
- The single-pile specimen yielded at around 620 kips and ultimately failed at 668 kips, confirming a capacity increase of about 18% over a standard P10L encased pile. Post-test inspections showed both local flange buckling and global lateral displacement, with clear indications of yielding and inelastic buckling modes.
- The updated pile capacity calculations developed through FE modeling and validated through experimental testing yield conservative estimations, 8% to 24% lower than actual test results.
- Increased encasement length consistently improves axial capacity.
- Weak-axis restraint (i.e., an orientation where the concrete encasement braces the more flexible axis) significantly outperforms strong-axis restraint in terms of capacity.
- Fully encased piles consistently outperform singly encased piles across nearly all configurations, sometimes by more than 50%, depending on the axis of restraint.



Three-pile (left) and single-pile (right) FE models

Conclusions

- Concrete encasement adds substantial stiffness and strength to the encased portion of a pile. Fully encased piles exhibit axial capacities exceeding those estimated by calculations that neglect the encasement.
- Capacity calculations provide conservative estimates but are still significantly more accurate than traditional methods that ignore encasement. The estimates are suitable for both design and load rating applications, particularly in scour-affected bridges.
- Fully encased pile bents behave as unified systems, distributing load evenly among piles and resisting axial loads effectively. The added stiffness from adjacent piles and continuous encasement walls enhances both capacity and durability.
- Orienting piles so that their weak axis is restrained by the encasement yields significantly higher axial capacity. Revising orientation practices in bridge design (i.e., rotating piles 90 degrees from standard practice) could optimize capacity and reduce material use.
- When scour is likely to remove surrounding soil and reduce lateral restraint, fully encased piles maintain their capacity more effectively than singly encased piles. The full encasement helps limit unbraced lengths and supports higher axial loads in vulnerable substructures.
- Designers can confidently include encasement in capacity calculations. This change can reduce the number of piles needed in a bent, shorten construction times, and lower costs, without compromising safety or durability.

Implementation Readiness and Benefits

This research demonstrates that concrete encasement should be considered as a contributing structural element when evaluating the capacity and unbraced height of steel H-piles in bridge foundations.

The findings support revisions to design practices, particularly for scour-prone areas, which can offer improved safety, structural performance, and potential cost reductions in bridge design. The implications of these findings are significant for both the load rating of existing bridges and the cost-effective design of new structures.

This research provides a significant step forward in understanding and leveraging the structural benefits of concrete-encased steel piles in bridge construction. It bridges a long-standing gap between practical field design and analytical assumptions, equipping engineers with better tools for resilient, efficient bridge foundation design.

Understanding the contribution of concrete encasement to the capacity of steel H-piles can improve bridge design and load rating practices.