Experimental Validation of a Rapid Assessment Tool for Pile Capacity and Stability in Response to Scour Situations

tech transfer summary

This research validated the findings of the rapid pile assessment tool that was developed in the first phase of this research to help ensure accurate pile capacity determination, both for bare piles and those encased in concrete.

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RESEARCH PROJECT TITLE
Experimental Validation of a Rapid Assessment Tool for Pile Capacity and Stability in Response to Scour Situations

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Research Goal

The goal of this research project was to validate the previously developed rapid pile assessment tool's findings to help ensure accurate pile capacity determination, both for bare piles and those encased in concrete.

Background and Problem Statement

Concrete encasements are commonly used for bridge substructure piles that are exposed to the ground to protect them. This practice also provides bracing to the piles. The unbraced length of the piles increases when scour reduces the presence of soil surrounding the piles. The resulting increase in the unbraced length has a negative impact on the capacity and stability of the piles.

On the other hand, the stiffness contributions of concrete encasements around piles is typically ignored during pile bent design and in specifications and manuals, despite the stiffness of the concrete encasement having a positive contribution to pile capacity and stability.

The Iowa Department of Transportation (DOT) rating engineer is sometimes asked by field personnel to make quick decisions regarding pile capacity and stability when scour is identified around bridge pile bents.

To help rating engineers provide timely, realistic estimations of pile capacity, Deng et al. (2018) developed a rapid assessment tool to quickly assess pile capacity, also taking into account both the unbraced pile lengths and the stiffness contribution of the concrete encasements.

A numerical evaluation program was developed and implemented to offer a user-friendly assessment tool that could be used to quickly evaluate pile strength. The numerical program consisted of finite element (FE) models established for steel H-piles with or without concrete encasement and with consideration of linear and non-linear buckling and behavior.

The FE models were validated against capacities calculated based on the provisions outlined in the American Institute of Steel Construction (AISC) Steel Construction Manual (2017). After that, a parametric study was conducted to understand the influence of concrete encasements on pile buckling strength. Various combinations of the unbraced pile lengths and concrete encasement lengths were investigated. The relationships between buckling strength of the steel H-piles with concrete encasements under concentric and eccentric loading conditions were derived from the results of the parametric studies.

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For the user's convenience, the researchers developed a graphical user interface for the tool, which requires the input of four parameters: loading eccentricity, H-pile section type, unbraced pile length, and concrete encasement length. This pile assessment tool can be utilized to quickly calculate pile capacity and assist state rating engineers in making rapid decisions regarding pile capacity.

However, this rapid pile assessment tool was developed and verified using provisions and theoretical modeling approaches. Experimental data to validate the tool's results were not available at that time.

Research Description

To provide sufficient data for the validation of the rapid assessment tool developed during the Phase I research, a series of experimental tests were conducted. Four specimens with different pile lengths and concrete encasement lengths and ratios were constructed and tested with concentric axial loading in the laboratory.

With the intent to cover all three mechanisms of failure for members under axial load—yielding, inelastic, and elastic buckling—three different lengths of pile were chosen to represent short, medium, and long lengths. Laboratory tests were performed on four ASTM A572 Grade 50 HP10×42 steel pile sections, as summarized in the table.

The first and second specimens were 16 ft long, representing the short member. The third member had a medium length of 30 ft, and the fourth specimen was the longest specimen with a length of 38 ft, while the common length for the piles used in Iowa is between 16 and 40 ft.

All members had concrete encasement except for the first specimen. The second, third, and fourth specimens had 10 ft, 20 ft, and 30 ft long concrete encasement, respectively. The details of the encasements were based on the Iowa DOT standard.

All four piles were tested with a fixed-pin support condition as assumed in the Phase I research and loaded via concentric loading. During the tests, three types of measurements were obtained via strain gauges, load cells, and displacement transducers.

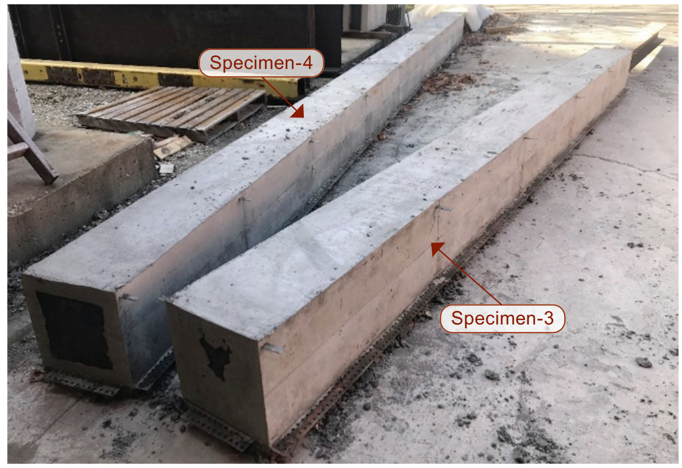
The load cell recorded the axial load reached at the pin end of the pile. The deformation of the piles was measured using the transducers, and the strain values on the steel or concrete encasement surfaces at critical locations were measured using the strain gauges. In general, 15 to 20 strain gauges and 10 to 14 displacement transducers were used for each specimen.

Data were observed and collected during the experiments and exported and post-processed using MATLAB.

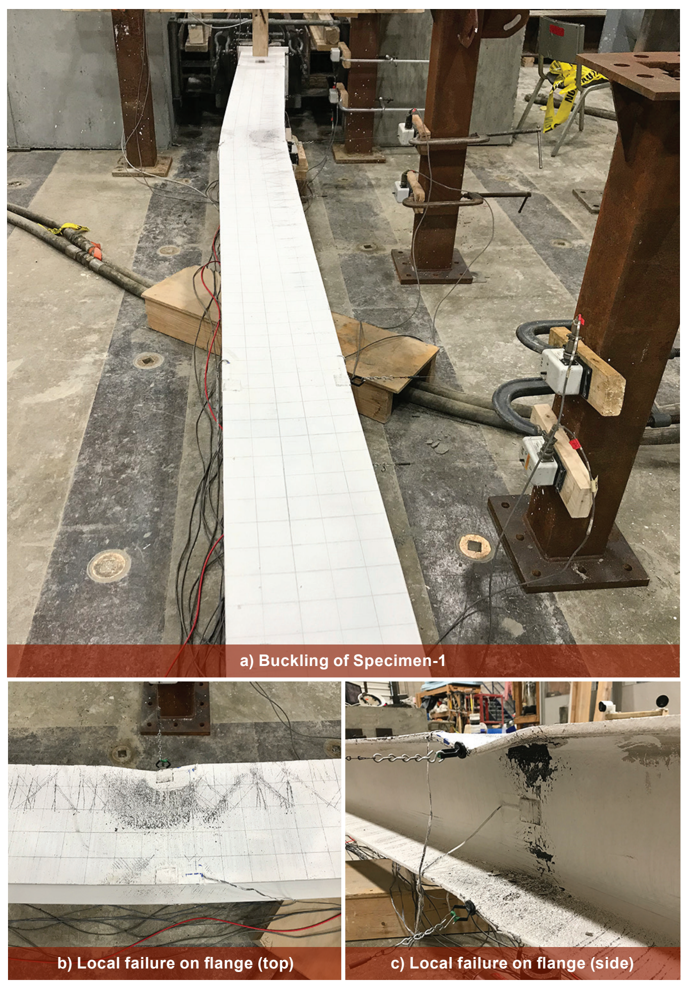
The results from the experimental tests were then compared to the predictions from the assessment tool.

HP10×42 specimen details

Specimen	Pile length (ft)	Encasement length (ft)
1	16	N/A
2	16	10
3	30	20
4	38	30



Concrete encased Specimen-3 and Specimen-4



Deformed shape of Specimen-1

Key Findings

Comparing the results from Specimen-1 and Specimen-2, the concrete encasement increased the initial stiffness and maximum axial capacity of the pile. For Specimen-1 with no concrete encasement, the load-displacement was completely linear until it reached the critical buckling load. In the other three specimens, with encasements, the displacement curves were not perfectly linear. This was because cracking occurred in the concrete encasement and reduced the cross-sectional stiffness.

The table provides comparisons between the buckling test results for the four specimens.

Experimental buckling test results for all specimens

Specimen	Pile length (L) (ft)	Concrete encasement length (Lc) (ft)	Ratio (Lc/L) -	Buckling load (kips)	Buckling displacement (in.)
Specimen-1	16	0	0	612	0.4013
Specimen-2	16	10	0.625	715	0.4087
Specimen-3	30	20	0.667	563	0.4283
Specimen-4	38	30	0.789	606	0.4913

- Based on the data, Specimen-1 and Specimen-2 showed a similar axial displacement when buckling occurred. However, the maximum capacity of Specimen-2 was 715 kips (about 103 kips higher than that of Specimen-1) given its concrete encasement.
- Although Specimen-4 was longer than Specimen-3, it showed a higher maximum capacity than Specimen-3. This is probably because of the concrete encasement given the ratio of encasement length over total length (L_c/L) for Specimen-3 was less than that for Specimen-4.
- Concrete encasement increases the initial axial stiffness of the piles and has a significant effect on the axial capacity of the steel HP piles. However, this contribution is ignored in current design procedures.
- The prediction results from the tool were about 8% to 24% lower than those from the experimental results, indicating that the pile assessment tool provides conservative estimation of the axial capacity of these piles.

Comparison between experimental and assessment tool results

Specimen	Experimental (kips)	Assessment tool		AISC equation	
		Result (kips)	Difference (%)	Result (kips)	Difference (%)
Specimen-1	612	493	24	493	24
Specimen-2	715	606	18	493	46
Specimen-3	563	519	8	278	102
Specimen-4	606	556	9	179	238

- In general, the assessment tool results are more conservative for the pile without encasement than that for the encased pile.
- Comparing the results between the experimental tests and AISC equations, the results indicated that the AISC equations predict the capacity of the pile about 24% to 238% less than the results from the experimental tests. This significant difference is caused by ignoring the contribution of the concrete encasements.

Implementation Readiness and Benefits

- Ignoring the effect of the concrete encasement, as with the use of the equations suggested by the AISC, can result in a significantly conservative prediction, especially for a long and encased pile scenario.
- While the tool provides conservative estimations, the calculated capacities are still significantly higher than specification-based values, thus providing greater accuracy and capacity to rating engineers. As such, valuable additional capacity can be seen when including the contribution from concrete encasements using the tool.

References

AISC. 2017. *AISC Steel Construction Manual*, 15th Edition. American Institute of Steel Construction, Chicago, IL.

Deng, Y. ("J."), B. M. Phares, and P. Lu. 2018. *Development of a Rapid Assessment Tool for Pile Capacity and Stability in Response to Scour Situations*. Bridge Engineering Center, Iowa State University, Ames, IA. https://intrans.iastate.edu/app/uploads/2018/03/pile_assessment_tool_w_cvr.pdf.