Nebraska Department of Transportation
Funded Research
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Executive Summary, Research Readiness Level Assessment, and Technology Transfer

Feasibility Study: Application of Steel Sheet-Piles for the Abutment of Water-Crossing Bridges in Nebraska

Research Objectives

The overall goal of this study is to investigate the anticipated performance of steel sheet-pile bridge abutment to encourage its wider applications to not only new construction but also repair/replacement of existing water-crossing bridges in Nebraska. To achieve this goal, we set several objectives as follows:

- Suggest an improved analysis method that incorporates the combined effect of axial and lateral loads that are imposed on the sheet pile walls and considers the following aspects:
  - Skin frictional resistance in active/passive zones for either dry or submerged soil conditions
  - Soil plugging effects
  - Different cross-sections of the sheet piles
  - Design configurations (cantilever vs. anchored walls)
  - Effect of seasonal temperature variations
- Elucidate the moment generated by the forces between the horizontal movement of the superstructure of semi-integrals in Nebraska vs. loads caused by the soil behind (e.g., active/passive pressures, the friction of backfill on superstructure end or the shearing resistance of backfill, which could play a role if the bridge has skew and lateral bearings are not provided).
- Assess the feasibility of avoiding the tie-rod anchoring for various design parameters.
- Suggest a range of superstructure length and skew angle that can be supported by the axially loaded sheet pile abutment system.
- Provide the research summary and design recommendations that can be used by engineers and contractors for the water-crossing bridges in Nebraska.

Research Benefits

Anticipated benefits from the research findings are as follows:

- Experimental and numerical modeling data and improved analysis for the axially loaded sheet pile abutment systems, including the anchored design, will be provided.
- A better understanding of the earth pressure development, the mobilization of skin friction resistance, end-bearing capacity, and load transfer will be provided.
- Design recommendations to improve the performance of sheet pile abutment systems will be provided.
- Based on those outcomes, the research findings can help reduce the construction time and cost for both new and repair/replacement of water-crossing bridges in Nebraska.

Background

Sheet piles are recommended to be installed for most water-crossing bridges, along with load-bearing piles, to avoid the scouring problem and protect backfill soils in Nebraska. A specific design procedure related to the axially loaded sheet piling does not exist in most parts of the US. Accordingly, the research team perceived a lack of data and experience in the design and analysis of vertical and lateral load resistance of the axially loaded sheet piling. For example, there is insufficient confidence in the estimate of bending and lateral stresses induced by the axial loading and lateral soil pressure, respectively. There is also uncertainty on how lateral load could be transferred from the superstructure to the sheet pile during a seasonal temperature variation. In terms of the side frictional resistance, it is unknown how the skin frictional resistance of the sheet pile could be mobilized in the different passive and active zones. Moreover, the side frictional resistance could be noticeably different between the dry and submerged soil conditions. For the end bearing resistance, the soil plugging effect may improve the end bearing capacity. Those uncertainties may result in a too conservative design, and thus, an unnecessary increase in the construction cost. In addition to those general challenges, there are additional research needs perceived by engineers in Nebraska. First, the load transfer from the superstructure to the substructure could be substantially different depending on the connection design that is a unique design of Nebraska DOT compared to other states. The main difference with other states is that Nebraska is no longer using back walls behind the deck for semi-integral abutment bridges. If there is a back wall element, there will be a joint created at the end of the deck before the approach span starts. Nebraska moved from this design and had details which combines the deck, girder, and approach span and creates the joint far away from the end of the deck at the approach span. Due to the difference in details at the end of the deck, the total horizontal force created by temperature loading from the superstructure, which should interact with the lateral soil loads that will create a moment, will differ from other cases. Second, the tie-rod anchor may be avoided depending on the soil condition and bridge design. With that, the reduction or elimination of the anchor will bring the cost and time saving for the construction. Lastly, there is a research need that investigates the feasible length of the superstructure that is compatible with the concept of the axially loaded sheet pile abutment system of a short-span bridge for general geologic conditions and construction practices in Nebraska.

Conclusion

The overall goal of this study is to investigate the anticipated performance of steel sheet-pile bridge abutments to encourage its wider application to not only new construction but also repair and replacement of existing water-crossing bridges in Nebraska. For this purpose, this study first reviewed several bridge cases with axially loaded sheet pile abutments, as well as previous in-depth studies related to the bearing capacity of sheet piles. Then, this study conducted the large-scale direct shear tests to better understand the interaction between sheet pile and soil. As a result, about four-fifths of the internal friction angle of fill sand was obtained as the interface friction angle. After that, this study conducted the static pile loading test with a down-sized test sheet pile. The ultimate bearing capacity of sheet piles obtained from three separate static pile loading tests was consistent. Analysis showed that the pile shaft carried most of the load (70% to 75%), while the tip resistance contributed up to 25% of the total bearing capacity. The CPT-based method resulted in an adequate match with the field test data, while the analytical method and SPT-based method appeared to slightly over- and under-estimate the side frictional resistance, respectively. Nonetheless, all predictions were comparable to the static loading test results. Upon the validation of the numerical simulation model, an extensive parametric study was conducted to investigate how various parameters may affect the performance of the sheet pile abutment system under the combined axial and lateral loading. After that, a summary of parametric numerical study results, including the maximum horizontal deflection, maximum vertical settlement, the factor of safety against shear failure, and the factor of safety against bending failure was prepared. Based on the study results, recommendations were made for follow-up research.

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Final report is available:
HERE

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NDOT Recommendations Based Off Research Project – 2025 – RRL2

This research shows the NDOT the promising results of steel sheet-pile bridge abutments. This research provided some light by doing field and lab testing in addition to finite element 2D and 3D modeling for verification to quantify the bearing capacity of the sheet piles. Furthermore, examples and a practical protocol was developed to conduct static and quasistatic axial load tests on cantilever sheet piles. The NDOT has not allowed these elements to be used as vertical load bearing elements because of the inability to confirm bearing resistance during construction. For end abutments of small, short bridges, there is a potential for realizing savings if Bridge Division can verify the axial resistance of the sheet piling and eliminate the need for separate deep foundations. However, while this technology would provide cost savings associated with bearing piles, greater savings could be achieved by focusing on more important aspects of the bridge, such as improving the bridge deck and rail concrete mix design. Any future funding for this research would be better spent researching other aspects of bridge design. There may be a need to come back to this research if counties decide to pursue it.

- *As provided by Fouad Jaber, Lead TAC Member*

Research Readiness Level (RRL) Assessment

RRL 2

Level 2: Applied Research/Proof of Concept/Lab-Level

Research validated and demonstrated in a laboratory environment.

Technology Transfer

Principal Investigator did not have any technology transfer for this research project.

This brief summarizes Project SPR-FY22(010)
"Feasibility Study: Application of Steel Sheet-Piles for the Abutment of Water-Crossing Bridges in Nebraska"
Nebraska Department of Transportation Research Program