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Modified Sheet Pile Abutments for Low-Volume Road Bridges

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IOWA STATE UNIVERSITY
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Modified Sheet Pile Abutments for Low-Volume Road Bridges

tech transfer summary

Several improvements and further research are necessary before sheet pile bridge abutment systems similar to the Boone County project are economically feasible.

Background and Problem Statement

Iowa has about 22,936 bridges on low-volume roads (LVRs). Based on the National Bridge Inventory data, 22 percent of the LVR bridges in Iowa are structurally deficient, while 5 percent of them are functionally obsolete.

The substructure components (abutment and foundation elements) are known to be contributing factors for some of these poor ratings. Steel sheet piling was identified as a possible long-term option for LVR bridge substructures; but, due to lack of experience, Iowa needed investigation with regard to vertical and lateral load resistance, construction methods, design methodology, and load test performance.

This project was initiated in January 2007 to investigate use of sheet pile abutments.

Objectives and Scope

- Investigate a design approach for sheet pile bridge abutments for short-span LVR bridges including calculation of lateral stresses from retained soil and bearing support for the superstructure
- Formulate an instrumentation and monitoring plan to evaluate performance of sheet pile abutment systems including evaluation of lateral structural forces and bending stresses in the sheet pile sections
- Produce a report and technology transfer materials that provide an understanding of the associated costs and construction effort as well as recommendations for use and potential limitations of sheet pile bridge abutment systems



Bridge replaced for Boone County demonstration

Research Methodology

A total of 14 different project sites were investigated in several different Iowa counties as potential sites for demonstration projects. Three sites, located in Black Hawk, Boone, and Tama Counties, were selected based on site conditions for demonstration projects.

Each of the bridge replacements utilized different alternative sheet pile abutments. Each bridge project was instrumented and data have been collected and analyzed from load tests. Post-construction monitoring was also carried out.

Since axially-loaded sheet piling is relatively new in the US, a specific design procedure does not currently exist. Because of this, the design approach taken for this research was a hybrid between sheet pile retaining walls and driven piles.

To determine the lateral forces experienced by the abutment (and thus the bending stresses), the structure is analyzed as a retaining wall. However, bending stresses induced by axial load in the piling must also be considered.

To determine the bearing capacity of the pile elements, the structure is analyzed as driven piling according to the American Association of State Highway and Transportation Officials (AASHTO) 1998 load and resistance factor design (LRFD) bridge design specifications.

This research presents case histories for each of the demonstration projects constructed. Detailed information regarding site investigation, design, construction, load testing, data analysis, overall analysis of the applicability of the design methods used, as well as conclusions and recommendations for additional research, are included in the final report.



Cofferdam placement and alignment

Key Findings and Conclusions

The demonstration project in Black Hawk County (BHC) investigated the viability of axially-loaded sheet pile bridge abutments. The project involved construction of a 40 ft, single-span bridge utilizing axially-loaded steel sheet piling as the primary foundation component. An instrumentation system (consisting of strain gages, deflection transducers, earth pressure cells, and piezometers) was installed on the bridge to obtain live load test data as well as long-term performance data.

Live load testing of the bridge structure was performed on November 3, 2008 by placing two loaded trucks (approximately 24 tons each) at various locations on the bridge and recording data. Maximum axial stresses occurring in the piles were approximately 0.5 ksi and were comparable to estimates made by analysis for a load distribution width of 10 ft.

Flexural stresses, in general, were significantly less than those estimated by analysis and maximum values were approximately 0.2 ksi. Earth pressures recorded during live load testing (with maxima of approximately 100 lbs/ft²) were also significantly lower than earth pressures estimated by analysis.

These results suggest the method of analysis for lateral earth pressures applied to the sheet pile wall was conservative. Post-construction monitoring of the bridge from November 2008 through February 2009 was also performed; the datalogging system was damaged by flooding in March 2009 and subsequent long-term monitoring was terminated.

Variations in earth pressure over time were observed with the largest variations in earth pressure occurring behind



Geogrid material for Boone County west abutment



Driving of sheet pile sections with vibratory plate-equipped excavator boom

the abutment cap. The earth pressures experienced cycles that varied in magnitude from 50 lbs/ft² to 1,500 lbs/ft², suggesting long-term loading due to freeze/thaw cycles of the soil and the thermal deformation of the superstructure elements may be the critical factors in the design of sheet pile abutment and backfill retaining systems, rather than vehicular live loads.

Through the construction and structural monitoring of the demonstration project, axially-loaded steel sheet piling have been shown to be a feasible alternative for bridge abutments with site conditions similar to BHC (i.e., shallow bedrock). Although the project required approximately 10 weeks for construction, the construction time could be shortened significantly if critical to the project timeline.

According to the BHC Engineer's Office, the total cost of the project (including labor and materials) was \$151,230. The BHC Engineer's Office believes that a significant portion of the cost can be attributed to the labor and equipment time involved in developing a new method of construction for this type of bridge, as well as the many associated equipment breakdowns.

The demonstration project in Boone County (BC) was designed using a geosynthetically-reinforced soil (GRS) backfill with a steel sheet pile backfill retention system for the bridge abutments. The bridge superstructure, a 100 ft, three-span, J30C-87 standard continuous concrete slab, was supported by reinforced concrete spread footings at each end bearing on the geosynthetically-reinforced backfill.

Analyses of the live load test results concluded that the design methods used, in general, were conservative when compared to the stresses and deflections experienced due to vehicular traffic loading.



Sheet pile abutment and foundation cap with instrumentation placement

Maximum flexural stress experienced in the sheet pile elements were only 3 percent of the expected value by analysis. Vertical and horizontal earth pressures in the backfill were also lower than expected and were 73 percent and 28 percent of estimated values, respectively. The maximum lateral earth pressure experienced at the face of the sheet pile wall was 10 percent of the value estimated without including the geosynthetic reinforcement in the analysis; and, these results indicate a significant contribution of the geosynthetic reinforcement in reducing lateral earth pressures on the wall.

The anchorage system, which increased the overall cost of the project significantly due to extra construction time, special materials (about \$70,000), etc., was determined to be resisting negligible loads during live load testing (4 percent of expected load); this suggests there are potential cost savings with a reduced (or eliminated) permanent anchorage system.

The stresses due to Load 1 on the anchorage system, however, were significant and, thus, the system (or some alternative method of providing lateral restraint) was necessary for construction of the bridge superstructure.

Stresses in the wingwall tie rod (from live load only and Load 1) were negligible and thus provide potential for reduced material costs. The total cost of the construction of the BC demonstration project was approximately \$591,000, with a typical 100 ft, three-span county road J30C-87 standard bridge (with steel H-pile abutments) expected to cost \$397,000 and total construction time required to be about 18 weeks.

Finally, the Tama County (TC) demonstration project utilized a geosynthetically-reinforced sheet pile abutment system similar to BC with the exception that, instead of using a large reinforced concrete deadman for anchoring the sheet pile wall, the tie rods were anchored to the superstructure (two 89 ft railroad flatcars bolted together).

The railroad flatcars are supported by 10 ft by 20 ft spread footings constructed with several 10 in. thick timbers; each spread footing was designed to bear on the geosynthetically-reinforced backfill. The TC project completed construction in August 2010 with subsequent live load testing in October 2010.

Recommendations

Several improvements for sheet pile bridge abutment systems were determined during the construction and load testing of the demonstration projects. It is recommended that pile lengths determined from site investigation results be ordered a minimum of 5 ft longer than expected as splicing of sheet pile sections will result in greater costs (associated with materials and construction delays) if the subsurface profile is more variable than predicted.

Although the tie rod stresses were shown to be negligible once the superstructure is constructed, the use of some form of lateral restraint is needed to resist the loads developed during abutment construction. Tie rods are one alternative and will also provide overall system stability during large lateral loading events that may occur.

If tie rods are used, they must be attached to a relatively stiff deadman to provide adequate anchorage to the wall; the use of a driven pile as a deadman is not recommended, as it may be too flexible to develop sufficient resistance without excessive movement of the wall.

When driving piles into bedrock, the use of a forged pile driving cap for sheet piling is another recommendation, as significant time and labor were spent repairing the custom-made, welded cap used by BHC. The width of guide racks for setting and driving of sheet pile sections should be minimized to reduce the potential for misalignment; a width of 0.25 in. to 0.5 in. greater than the width of a sheet pile section is recommended.

Instrumentation of sheet pile sections should be protected by welding steel angles on the inside of the sheet pile flanges to minimize the influence on flexural stress (by minimizing the increase in flexural stiffness of the pile) as well as improve constructability of the sheet pile wall.

Redundancy of instrumentation is important for all critical information desired; damage to some instrumentation should be expected during construction.

For all projects utilizing steel sheet piling, the use of PZC sections are recommended. PZC sections have a greater flexural resistance and require less steel per ft of wall compared to traditional PZ sections.

Implementation Readiness

In addition to the three counties selected for these demonstration projects, several other Iowa counties expressed their willingness to participate in these projects and are very interested in the results of the investigation.

Future projects utilizing a similar design and construction method as Black Hawk County's with comparable site conditions could be performed at a reduced cost.

Additional research is recommended to investigate the development of an economical anchorage system. Recommendations for such research include testing of a full-scale, field-constructed model with no anchorage system (or temporary construction bracing) that could be tested to determine ultimate strength and behavior under load of a GRS sheet pile bridge abutment system; the presence of an anchorage system significantly alters the behavior of sheet pile wall systems.

Although the bridge test results showed significantly lower stresses and deflections than expected, further testing is recommended to determine the nature of earth pressure development behind sheet pile abutments.

Due to the inherent potential for settlement of spread footings, utilization of a GRS sheet pile bridge abutment system in multiple span (statically indeterminate) structures must include strict requirements for compaction and reduction of voids in the backfill material (such as the flooding technique used for the abutments in the Boone County bridge); use in simple-span bridges is ideal, as significant differential abutment settlements are not detrimental to the superstructure.

Implementation Benefits

Development of a more accurate analysis method for sheet pile wingwalls has the potential for significant cost savings through the reduction in sheet pile resistance as well as the anchorage systems required.

Through the construction and structural monitoring of the Boone County demonstration bridge, geosynthetically-reinforced earth steel sheet pile bridge abutment systems were shown to be a potential alternative for LVR bridge abutments.