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PUTTING RESEARCH TO WORK

BRIEF

Performance of Pile Supported Sign Structures

Sign structures in Wisconsin are typically supported by drilled shaft foundations or spread footing foundations. However, when the soil conditions are not suitable to be supported on drilled shafts or spread footings, a group of piles could support the foundation. Large sign structures are subject to large lateral wind loads, which result in large lateral forces and overturning moments. These lateral forces and overturning moments produce both uplift loads and downward loads on the pile foundation. However, published methods for designing driven pile groups only address groups subjected either to compression or uplift, not both simultaneously. This research project investigated the behavior of the group of piles under both compression and uplift loads.

What is the Problem?

AASHTO Allowable Stress Design (ASD) requirements indicate that these uplift loads can be resisted by the smallest of the following three different methodologies:

1. The skin friction on one pile multiplied by the number of piles, divided by a factor of three.
2. The effective weight of the soil located within the perimeter of the piling times two, divided by three.
3. The effective weight of the soil located within the perimeter of the piling divided by two, plus the shear strength of the soil perimeter divided by two.

However, it is unclear what the uplift loads should be to compare to the pile group resistance or how the overturning loads are shed from one pile to the next pile.

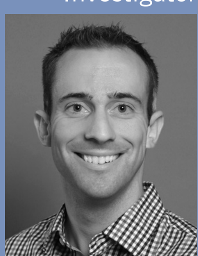
Objectives

1. Conduct field tests on two instrumented pile foundations for sign structures to evaluate the reaction to the uplift loads caused by a simulated wind load.
2. Develop and evaluate a model that demonstrates how sign-supported foundation piles react to the lateral wind load.
3. Calibrate the model based on the field test evaluations.
4. Provide recommendations with respect to the current state of practice of WisDOT's pile supported sign structures.

Methods

Researchers conducted a lateral load test of two four-pile groups to evaluate load transfer among the piles and to evaluate potential design implications. The load test was performed in Warrensburg, Missouri, at a test site with 10 to 15 feet of stiff clay overburden above shale. The test consisted of pulling together two four-pile groups: one constructed with HP10×42 H-piles and the other with 10.75-inch diameter closed-end steel pipe piles backfilled with concrete [cast-in-place (CIP) piles]. Loads were applied nine feet above the ground surface to simulate the overturning loads experienced by sign foundations. Test piles were instrumented with strain gages and Shape Array Accel (SAA) devices to monitor axial loads and bending moments. Displacements and rotations of the sign structures were monitored with linear variable differential transformers (LVDTs), dial gages and wireline devices. Construction of the two pile groups was completed over the course of one week. The load test was performed two weeks later, after the concrete had cured sufficiently.

Investigator



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Pile structures during final load step. CIP pile cap is at left and H-pile cap is at right

Results

- The displacement data collected at 11 points on each pile structure offer confirmation of three main observations from the pile load test: the tension piles had reached their uplift capacity when the test was terminated, the H-pile structure experienced more significant displacement and rotation than the CIP pile structure, and both pile caps rotated rigidly. The strain gage and SAA data were useful for characterizing the axial and bending moment behavior of the piles.
- Interpretation of the measured loads and displacements suggests overturning load transfer for the four-pile groups, typically employed by WisDOT for sign foundations, is reasonably predicted from simple consideration of static equilibrium up to loads where the uplift capacity of the tension piles is approached. Design capacity for overturning of four-pile groups can, therefore, be calculated using (1) pile loads corresponding to the axial force couple that satisfies moment equilibrium of the rigid sign structures and (2) pile capacities from appropriate design methods for axial and lateral loading of driven piles.
- Additional load-carrying capacity, beyond that attributed to the axial force couple alone, can potentially be mobilized from pile head bending moments that develop as the force couple approaches the tension pile uplift capacity. The test measurements support the potential for mobilizing this additional resistance, and numerical modeling with Ensoft GROUP lends confirmation as well. Contributions from pile bending resistance would be accompanied by significant inelastic displacement. However, some design efficiency could be realized by considering additional capacity for extreme event loading cases if the structural capacity of the piles is sufficient.

Recommendations

Results of the load test indicate the strength limit state resistance factors for single piles in uplift (ranging from 0.2 to 0.4) are likely to be inappropriately low for pile groups subjected to overturning loads. The observed failure was ductile, and the structures likely could have withstood greater loads had the test continued. A more appropriate resistance factor for the four-pile groups could be established based on probabilistic analysis of the groups. Such a study could also consider and quantify the additional resistance offered by pile head moments.

The WisDOT bridge manual may be revised to require the evaluation of only the entire pile group, rather than the individual pile, for sign structures supported on fully reinforced and encapsulated pile foundations.

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This brief summarizes Project 0092-14-02,
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