Power Transmission Foundation Design

Fifty-Percent Report

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By

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Introduction

MDT Engineering is currently in the process of designing foundations for power transmission towers located in East Hanover, New Jersey. The scope of this project consists of a lattice tower located in the meadowlands and a monopole tower located in the CSX South Kearney rail yard. This report contains progress made thus far concerning plans for completing the project. The current designs and ideas discussed are subject to change as the project nears completion. Currently MDT is in the process of designing pile caps for the lattice tower foundation.

Site Description

Each site presents unique challenges due to their locations and soil stratification. The lattice tower is expected to be placed in the meadowlands of the Richard W. De Korte Park, and the monopole is expected to be placed at the CSX South Kearney rail yard. The location of the lattice tower is surrounded by water. Access to the site is possible via Saw Mill Creek Trail which traverses the meadow and water and connects the tower with adjacent towers. The monopole at the rail yard is in a parking lot.

Geotechnical Analysis

Work began by analyzing CPT (cone penetration test) data for the lattice tower site. CPT results were provided by the project sponsor for each tower site. The soil stratification was divided into 4 foot layers. These layers were then individually calculated to find the undrained shear strength and effective stress. The soil at the meadowlands location was found to be mostly normally consolidated to under consolidated silts and clays with the water table located about four feet below the surface. The soil at the rail yard location was found to be much sandier with traces of clays. The water table at this location was about 8 feet below the surface.

Lattice Tower Pile Design

Based on pile design recommendations found in the National Highway Administration (NHWA) manual, *Design and Construction of Driven Pile Foundations – Volume I (2016)* floating steel pipe piles have been chosen for the foundation of the lattice tower. Calculations for bearing capacity and sleeve resistance were conducted per the alpha method, found on page 245 of the NHWA pile design manual.

The total axial load each pile cap is required to hold is 450 kips, which is a combination of the demand of 415.8 kips for the tower and 34.2 kips for a rough estimation of the weight of the pile cap. Using the calculated undrained shear strength of the soil and charts found in the NHWA manual, shaft resistance and nominal shaft resistance were calculated. Figure 1 shows a plot of shaft resistance (R_s) versus depth this design. A pile depth of 100 feet using a steel pile diameter of 20 inches provided the nominal shaft resistance of 449.7 kips per pile. This depth was chosen because it allows the design to operate at a factor of safety of 4, which was chosen because of the sensitivity of the soil, the degrading effect piles have when in proximity of the other piles, and the natural ambiguity of soils. The current design places each pile 10 feet center to center to allow for the smallest chance of interaction between piles as shown in Figure 2.

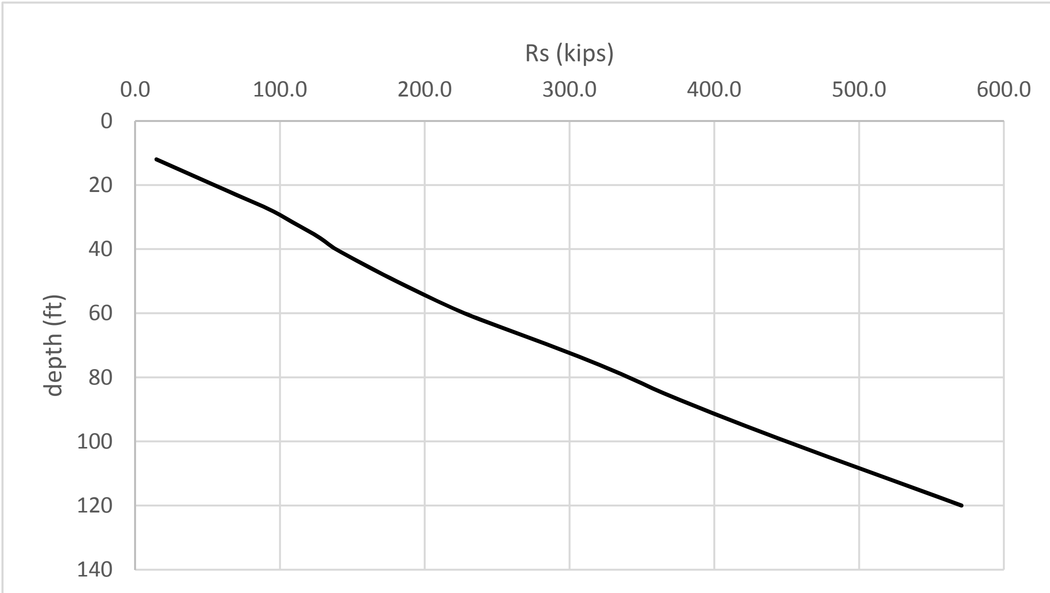

Figure 1. Nominal sleeve resistance versus depth for a single pile at the meadowland

Ensoft programs, LPILE and GROUP, were used to analyze the expected lateral loads. Individual pile reactions were analyzed using LPILE and the reactions for the pile groups were analyzed using the GROUP program. Plots generated in LPILE showing the lateral pile deflection, bending moment, shear force, and pile-head deflection can be found in the appendix of this report. These values are all within the required tolerance of 1 inch settlement for the project. Plots generated in GROUP showing resultant deflection, shear in y and z, and moment in y and z can also be found in the appendix of this report. Resultant deflection is less than one inch as required by the project specifications.

Equations for calculating the settlement of each pile group were found in the U.S. Army Corps of Engineers *Design of Pile Foundations* manual on page 4-21. Overall settlement for the designed pile group was found to be 0.57 inches. Per the given maximum settlement of one inch, the calculated values for settlement are within the allowable tolerances.

Lattice Tower Pile Cap Design

The pile cap design consists of a pile with a width of 13 feet in each direction and a depth of 4 feet shown in Figure 2. The depth was determined by simplifying the load distribution between piles into simple beams and using equations found in *Design of Reinforced Concrete* (McCormac 2016) and *Foundation Analysis and Design* (Bowles, 1996). The calculations determined that 3 feet would be sufficient for the pile cap to contain all the shear, punching shear, and moment loads. This size was altered to 4 feet to make sure there is enough room for development lengths in the rebar. This design was checked using GROUP, which showed no effect on the settlement. The design of the simple beams required at least 3 bars of #9 rebar on the bottom side of the beam. Because the loading within the cap could be reversed as uplift is created, the minimum 3 - #9 bars will be placed along the top as well. The exact layout of rebar enforcement is yet to be determined. The plate that the structure will be welded on is anchored into the slab by using a HP18X135 with 1.5-inch-wide and 0.5-inch-thick bars welded along the outside edges. These bars are positioned every 6 inches between the top of the plate to the bottom of the steel H-pile to transfer the load from the plate to the concrete as shown in Figure 3. The bottom of the H-pile will have a plate welded to the bottom to create a complete transfer of loads.

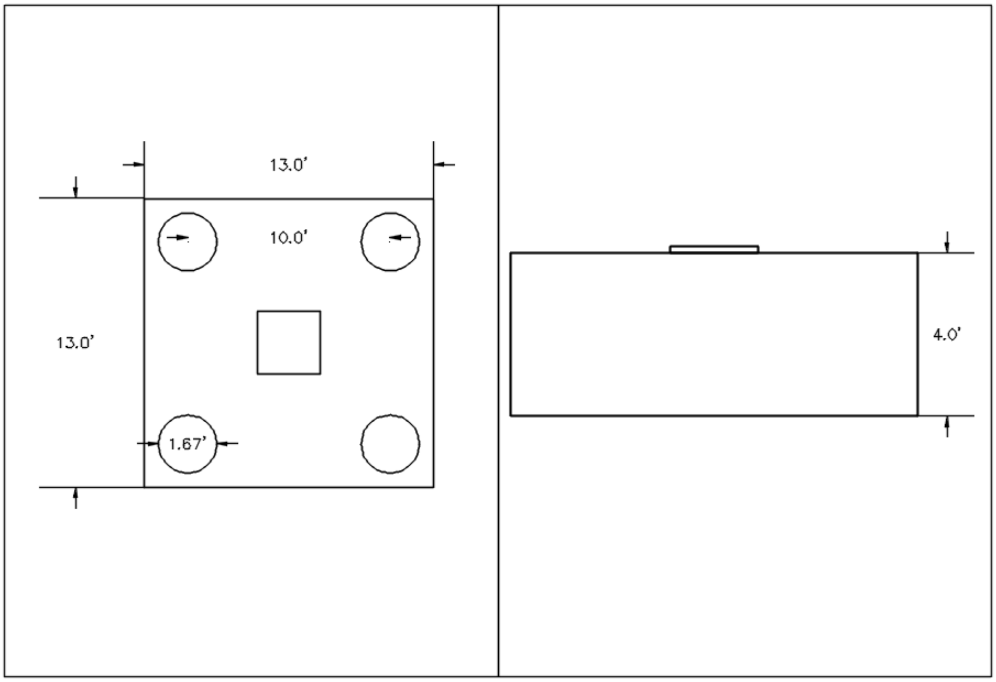

Figure 2. Sketch of the pile cap design for the meadowlands lattice tower.

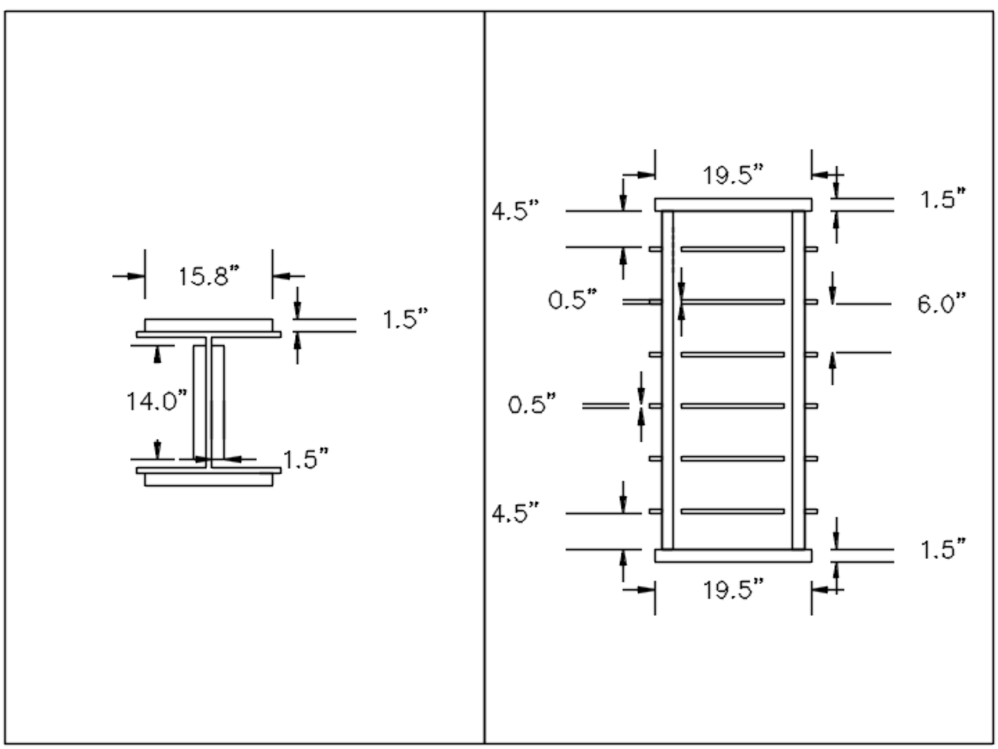

Figure 3. Sketch of the anchor for the meadowlands lattice tower.

Monopole Pile Design

CPT results revealed layers of sands, silts and clays at the railyard location. Higher levels of cone tip resistance at this location indicate that end-bearing piles may be effective for the monopole foundation. At a depth of 22 feet nominal sleeve resistance was found to be 373.4 kips for a single pile. End bearing resistance for a single pile, at that depth, was found to be 238.5 kips. Nominal sleeve resistance and end bearing resistance were calculated by following the Norland method found on page 242 of the NHWA manual, *Design and Construction of Driven Pile Foundations.* To meet the loading requirements, it has been estimated that an array of piles that sit on the sand layer at 22 feet deep will be needed. Analysis for this pile group is planned to begin in early March to determine the number of piles required, pile layout, settlement, and lateral load considerations. The same programs used to analyze the pile groups for the lattice tower foundation will be used for the monopole foundation analysis.

Concrete Mixture Design

The proposed concrete plan is still undergoing changes, and will be more finalized once the spacing of the reinforcing steel is found. The design is following the method listed in Chapter 10 of *Concrete* by S. Mindess et al. The proposed mixture will utilize an optimum mix (Mindess et al, pg. 225), and aggregate will be collected from a local site. The cost of the aggregate will be included upon further design, along with the total cost of the concrete. For the designed structures, the concrete temporarily will have a slump of 3 in. (Mindess et al, pg. 227). The maximum aggregate size will be no more than three-fourths of the minimum clear spacing for the reinforcing bars. Since the local of the design takes place where freezing and thawing occur, the concrete will need to have 6% air entrainment (Mindess et al, pg. 229). The temporary water-cement ratio is 0.45 (Mindess et al, pg. 230), and since sulfate resistance is required, Type V cement will be used. Two different designs will be considered to see if there will be savings by using fly-ash or silica fume as a replacement for up to 20% of the cement, and the strength differences will be calculated later.

Conclusion

Analysis of load cases and pile design for the lattice tower foundation have been completed. Design of the reinforced concrete for the lattice tower pile caps is close to completion and preliminary calculations for the monopole tower foundation have been completed. Computer analysis for the pile group is underway and pile cap design will begin with shortly for the monopole foundation. Progress has been maintained as close to the previously established timeline as possible. Delay caused by challenges and learning curves at the beginning of the project has been mostly made up by this point in the project. Designs for the meadowland pile caps are underway and the railyard pile cap design will follow shortly. Considerable amount of time has been spent studying manuals and researching design processes for this project to be completed correctly. It is expected that this project will be completed on schedule, by April 10th, 2017.

Appendix

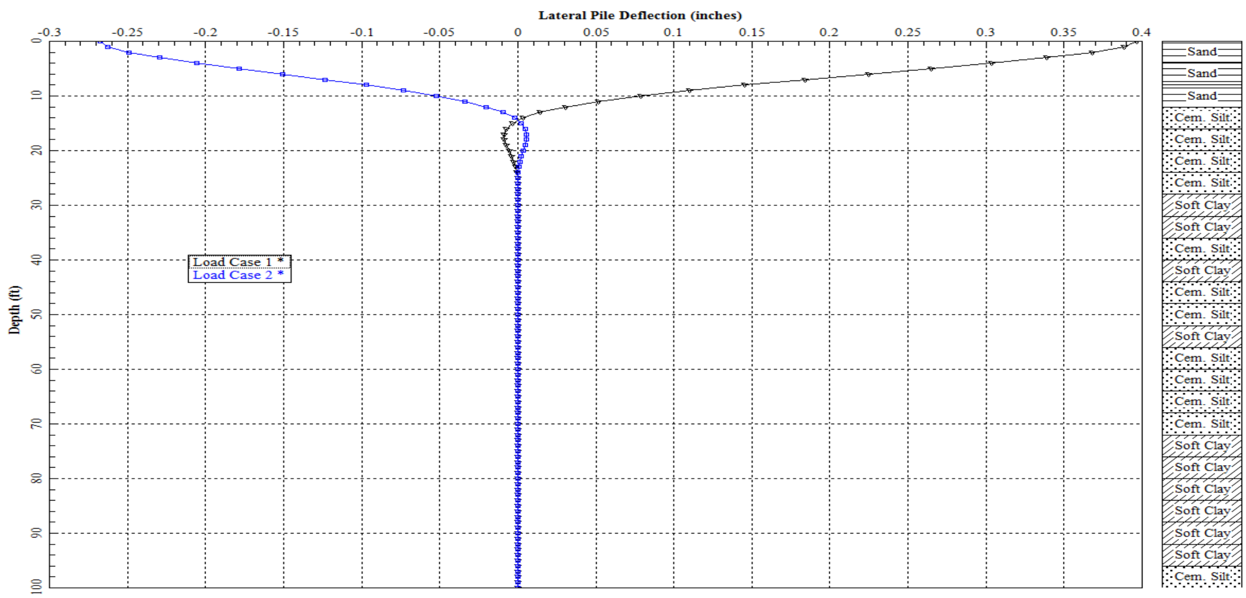

Figure 4. Lateral pile deflection for a single pile at the meadowland location.

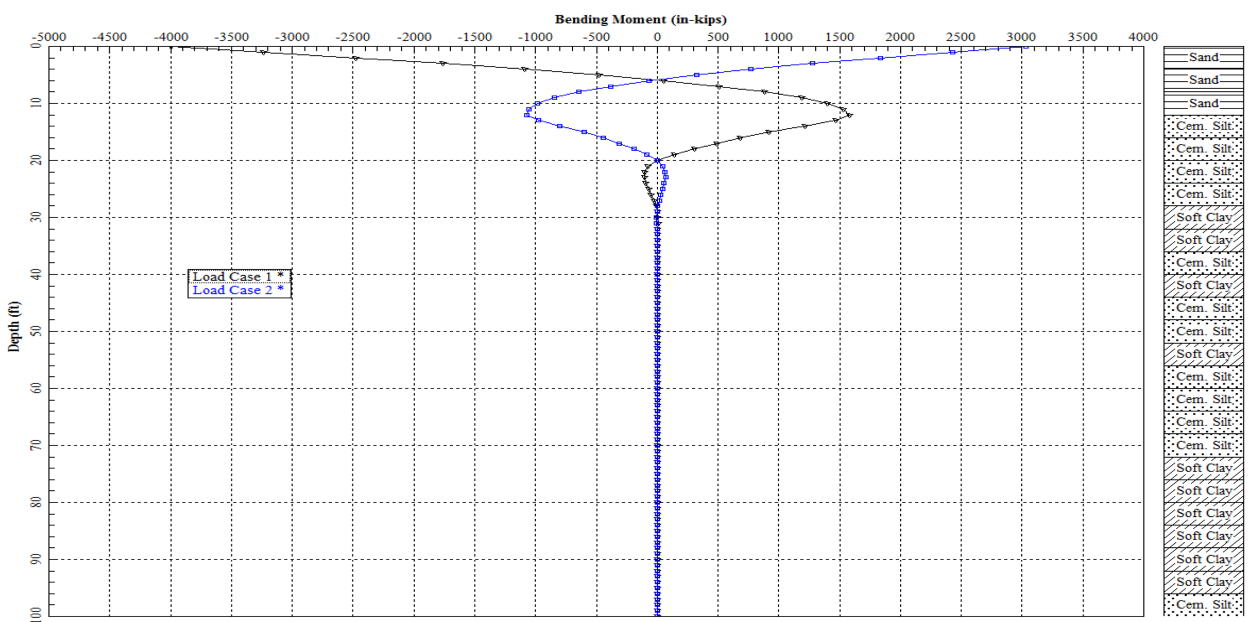

Figure 5. Bending moment reaction for a single pile at the meadowland location.

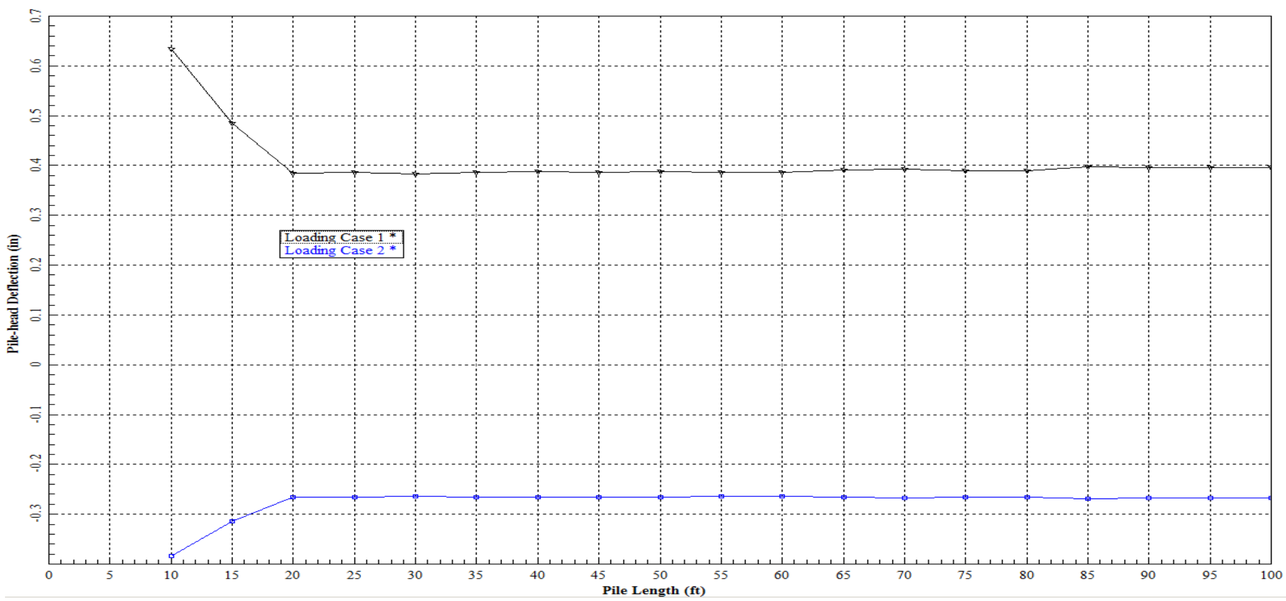

Figure 6. Pile head deflection for a single pile at the meadowlands location.

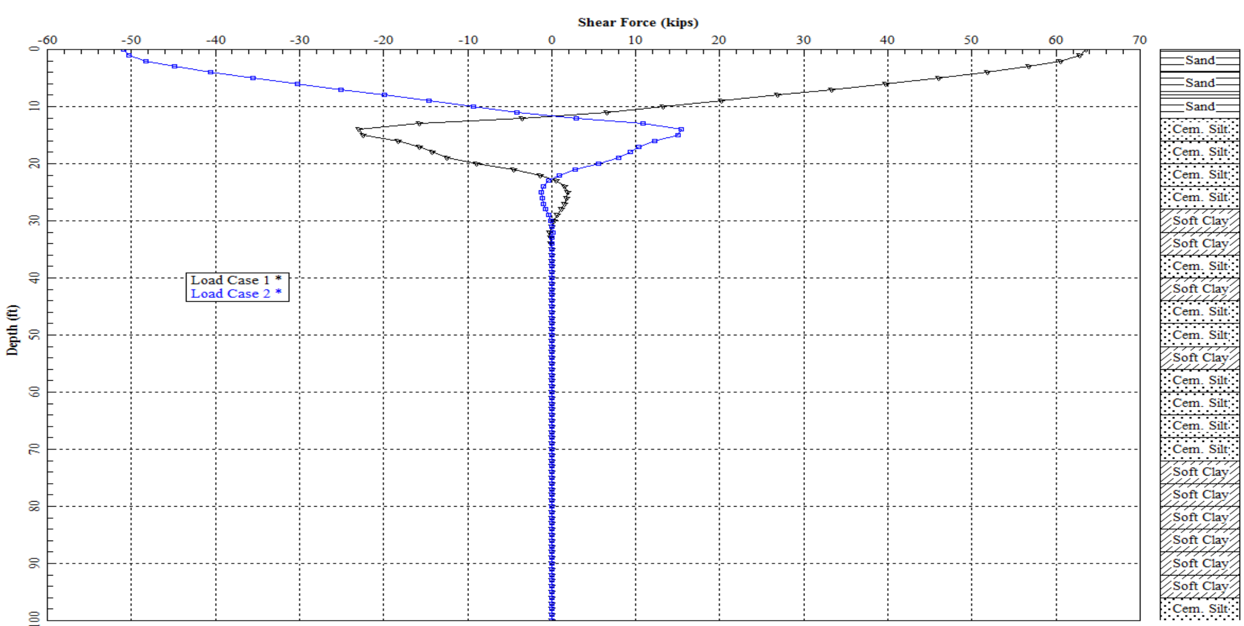

Figure 7. Shear force reaction for a single pile at the meadowland location.

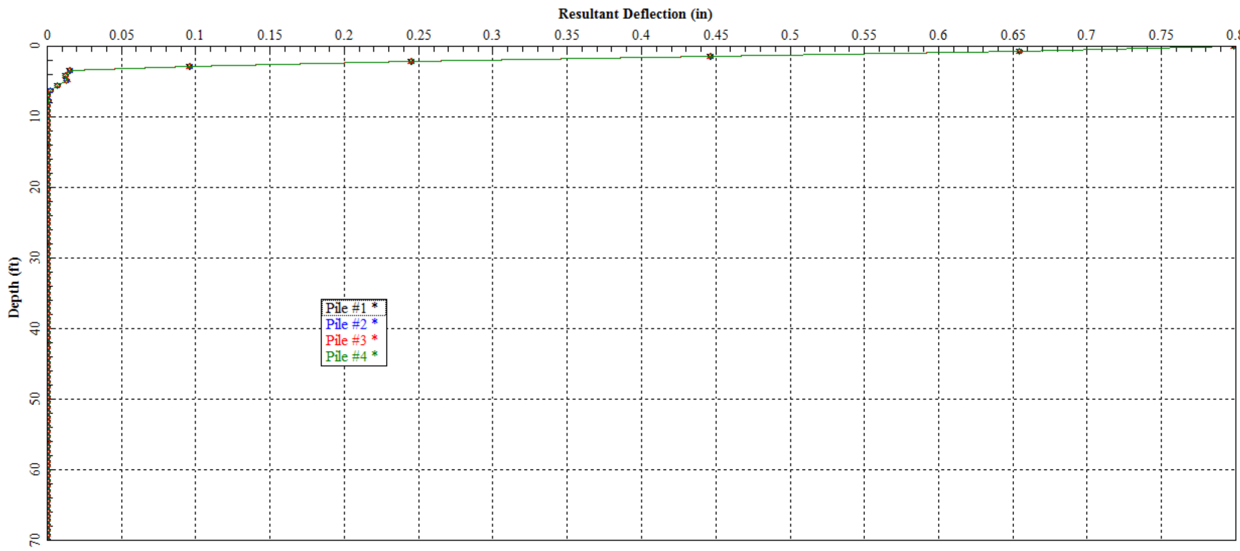

Figure 8. Resultant deflection for one pile group at the meadowland location.

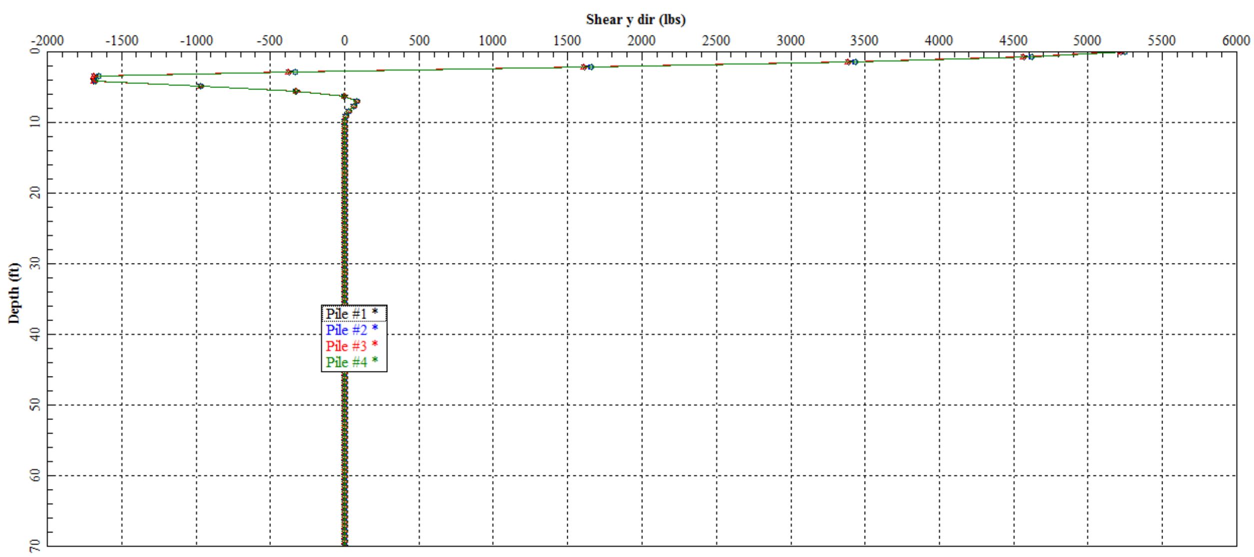

Figure 9. Reaction for shear in y direction for one pile group at the meadowland location

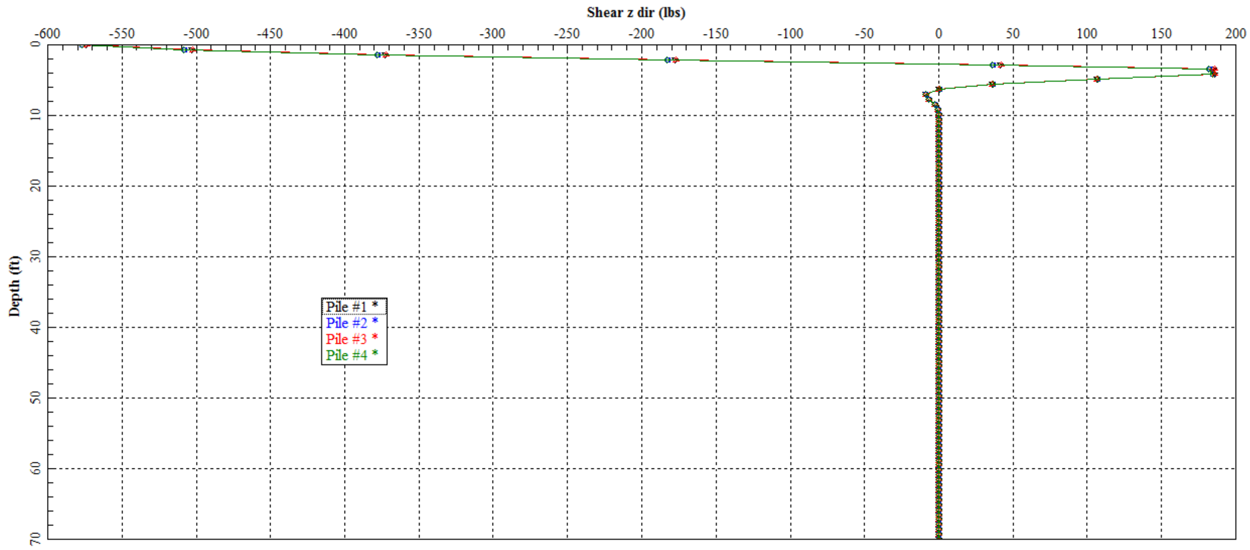

Figure 10. Shear reactions in z direction for one pile group at the meadowland location.

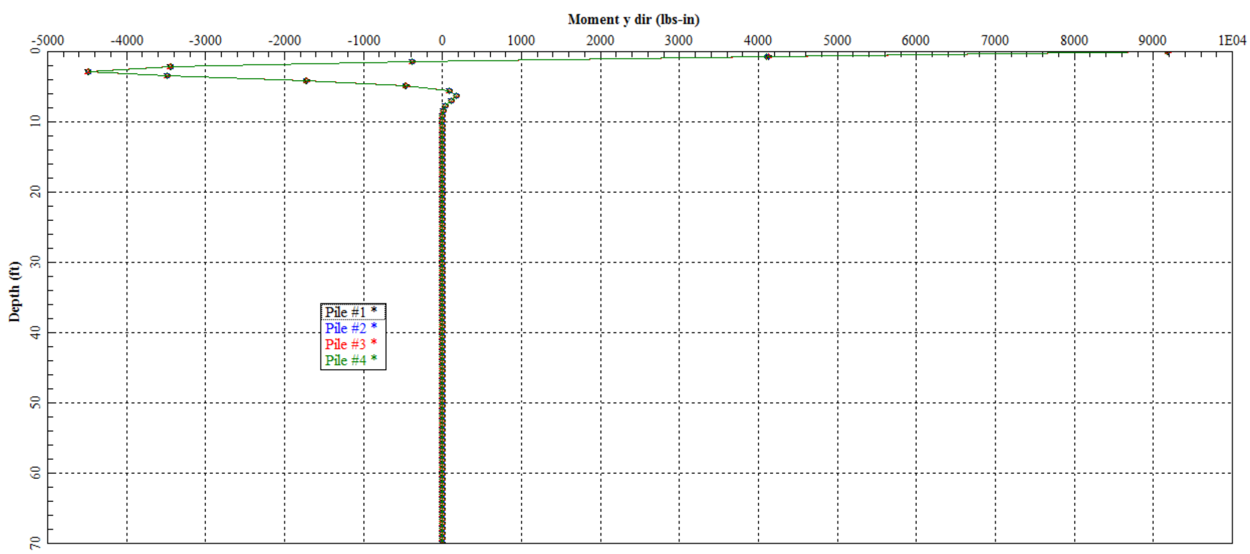

Figure 11. Moment reaction in y direction for one pile group at the meadowland location.

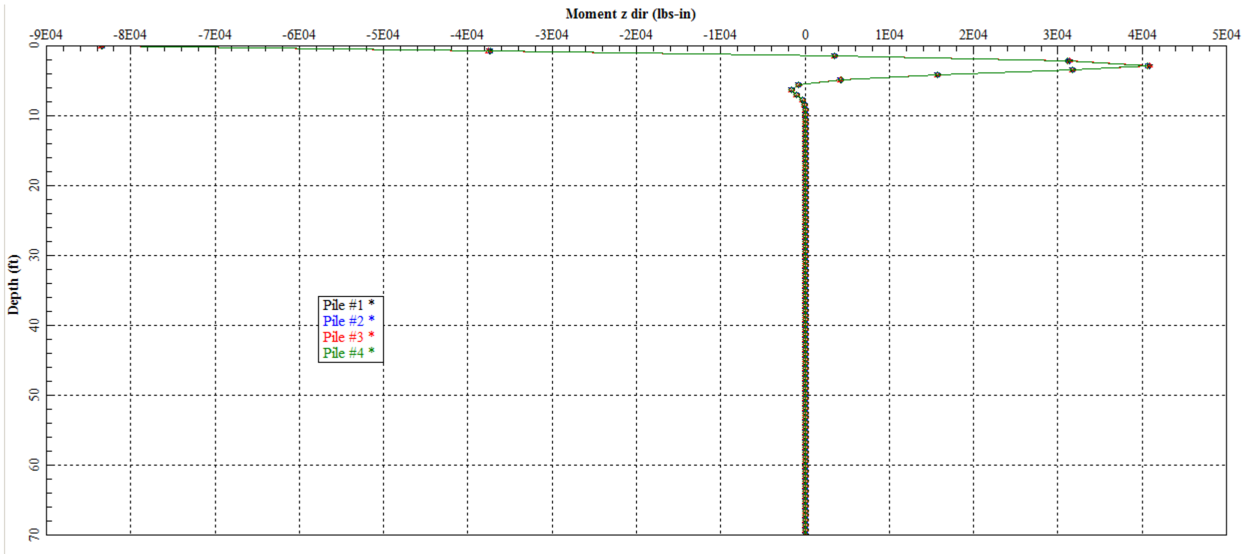

Figure 12. Moment reaction in z direction for one pile group at the meadowland location.

Sources

Bowles, J. E. (1996). *Foundation analysis and design*. New York: McGraw-Hill

McCormac, J. C., & Brown, R. H. (2016). *Design of reinforced concrete*. Hoboken, NJ: Wiley

Mindess, S., Young J. F., & Darwin D. (2003). *Concrete*. Upper Saddle River, NJ: Prentice Hall