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DETERMINATION OF OPTIMUM DEPTHS OF DRILLED SHAFTS SUBJECT TO COMBINED TORSION AND LATERAL LOADS USING CENTRIFUGE TESTING

PROBLEM STATEMENT

FDOT high mast lighting and sign structures within coastal zones are now designed with mast arms attached to poles connected to drilled shaft foundations. For single pole mast arm systems, significant lateral and torsional loads may develop on the foundation. Current Geotechnical Design practice is to uncouple the torsion from lateral loading. Typically, for lateral loading, Broms design approach is applied, and, for torsion, one of four general FDOT methods is employed. Recently, however, both FDOT field-testing and the open literature has suggested that the lateral resistance of a drilled shaft is reduced when subject to torque. Consequently, both experimental data and an integrated torque/lateral design method for drilled shaft design are needed.

OBJECTIVES

The purpose of this project was threefold: (1) conduct multiple centrifuge tests on a mast arm/pole drilled foundation system subject to torque and lateral loading; (2) from the experimental results, evaluate current FDOT design practices for drilled shafts; and (3) if necessary, modify current FDOT design practice for drilled shaft foundations subject to torque and lateral loading. The objectives of the experimental work included the following:

- Investigate the influence of torque on the drilled shaft lateral capacity.
- For different construction practices: wet-hole or casing, identify and characterize any changes in the drilled shaft capacity.
- Identify the influence of soil properties (i.e. density and strength) and water table on the foundation's lateral and torsional resistance.
- Characterize the effect of shaft's geometry (i.e. length to diameter (L/D) ratio on its lateral and torsional capacity).

The final design (Mathcad file) was to be capable of sizing (length and diameter) a drilled shaft founded in one or two soil layers with variable depth water tables, supporting a single mast arm/pole with point loading anywhere on the mast arm.

FINDINGS AND CONCLUSIONS

Eighty centrifuge tests were conducted on high mast sign/signal (mast arm, pole, drilled shaft) structures subject to combined lateral and torsional load. The foundations (drilled shafts) were constructed in both dry and saturated sands under different densities (loose, medium, and dense) and different construction methods: casing and wet-hole (bentonite slurry). The shafts, constructed from cement grout with steel reinforcement, were installed and spun up in the centrifuge while still fluid, allowing the soil stresses around the shafts to equilibrate to field (prototype) values. The sign/signal structures were laterally loaded at one of three different locations: (1) top of pole; (2) middle of mast arm; and (3) mast arm tip. Loading on the pole applied no torque to the foundation, whereas loading along the mast arm applied increasing values of torque.

In the case of loading on the pole (i.e. no torque: 30 tests), soil failure was observed for short shafts (length to diameter: L/D ratio < 5), whereas long shafts (L/D > 5) exhibited shaft failure (flexure). Broms predicted the long shafts lateral capacities well, but overpredicted (unconservative) the short shaft response.

For torsional loading, i.e. loads on the mast arm, torsional resistance was predicted quite satisfactorily through the FWA axial skin friction model. The torsional resistance was also found to be independent of lateral load magnitude, as well as soil properties (i.e., sand density, strength, etc.). However, the lateral resistance of the shafts was found to be significantly affected by the applied torque on the foundation. General monographs for the reduction of lateral resistance as a function of torque to lateral load ratio were developed. Subsequently, Broms lateral soil pressure distribution model was modified to include (1) limit pressure as suggested by Reese, et al., and (2) a reduction in soil pressure based on torque-to-lateral load ratio. Based on the new model, all of the experimental results were predicted within twenty percent.

Finally, the centrifuge tests revealed that the wet-hole method of construction using bentonite slurry had little influence on the lateral or the torsional response of the shaft, if the slurry cake thickness was restricted to 0.5 in. However, if the cake was allowed to thicken, reductions in torsional resistance by as much as fifty percent were noted for thicker cake (3.0 in).

BENEFITS

The results of this study showed that the torsional resistances of drilled shafts are independent of any applied lateral load and that the current FDOT design for such loading is conservative. However, the lateral resistance of a drilled shaft subject to torque may be significantly reduced (depending on the torque-to-lateral load ratio), and the current FDOT (Broms) design approach maybe unconservative. A new modified method (i.e. Broms modified: Mathcad format) based on significant experimental work will result in much safer high mast lighting/sign structures in Florida under hurricane loads.

This research project was conducted by Michael C. McVay, Ph.D., at the Department of Civil and Coastal Engineering, University of Florida. For more information, contact Peter Lai, Project manager, at (850) 414 4306, peter.lai@dot.state.fl.us.