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# DETERMINE OPTIMUM DEPTHS OF DRILLED SHAFTS SUBJECTED TO COMBINED TORSION AND LATERAL LOADS FROM CENTRIFUGE TESTING

(SUPPLEMENTAL STUDY USING KB POLYMER SLURRY)

## PROBLEM STATEMENT

FDOT high mast lighting and sign structures near the coast 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 the 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 to expand the work on a previous project (BC354-09) that involved centrifuge lateral and torsional tests on drilled shafts installed in dry sands. This supplemental work included (1) repeating the lateral and torsional tests of shafts installed in saturated sands instead of dry sands, (2) installing the shafts with either mineral or polymer slurry, and (3) if necessary, recommending modifications to 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 lateral capacity of drilled shafts.
- For different wet-hole construction practices (i.e. use of mineral or polymer slurry), 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 the shaft's geometry [i.e. length to diameter (L/D) ratio on its lateral and torsional capacity].

As part of BC354-09, a Mathcad design program (Modified Broms) was developed to size (length and diameter) a drilled shaft installed in multiple layers, subject to lateral and torsional load. This work evaluated the design program for different types of construction (i.e. wet hole), as well as for water table locations.

## FINDINGS AND CONCLUSIONS

Sixteen centrifuge tests were conducted on high mast sign/signal structures (mast arm, pole, drilled shaft). The foundations, drilled shafts (25' and 35' embedment), were constructed in saturated sands under two different soil densities (loose and dense) using polymer slurry in their construction. The shafts were constructed with cement grout and steel reinforcement, and spun in the centrifuge while still fluid, allowing the soil stresses around the shafts to equilibrate to field (prototype) values. After hydration of the cement grout (i.e. shaft), the sign/signal structure was laterally loaded at one of three possible locations: (1) pole, (2) mid mast arm, and (3) mast arm tip. Loading on the pole applied no torque to the foundation, whereas loading on the mast arm and arm tip applied increasing values of torque.

All of the lateral load tests with torque (i.e. mid mast and arm tip) failed through foundation rotation (failure: $15^0$) instead of lateral deflection as observed with the dry sand experiments (BC354-09). The torsion failures of the shafts were attributed to the reduction in vertical and horizontal effective stresses as a result of the water table, in the saturated sands experiments. As with the earlier study (BC354-09), the torsional resistance in the saturated sands was found to be independent of point of lateral load application (i.e. torque/lateral load ratio) and soil strength (angle of internal friction), but dependent on the soil's unit weight (i.e. effective stresses). In the case of lateral resistance, the shafts were significantly affected by applied torque on the foundations. The reduction in lateral resistance as a function of torque to lateral load ratio graphs developed in BC354-09, predicted quite satisfactorily the shafts lateral response.

Researchers observed that no cake formation occurred with the polymer slurry shaft construction. Also, the torsional resistance of the shafts constructed with the polymer slurry was found to be from 15 to 25% higher than the mineral bentonite slurry in dense sands. The latter was attributed to the polymer slurry: (1) penetrating the borehole wall and bonding with shaft, and (2) reinforcing the soil.

Finally, the Mathcad file developed (in BC354-09) to design/analyze high mast sign/signal pole structures for both lateral and torsional loading predicted the experiments quite satisfactorily.

## 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.

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