DEVELOPMENT OF P-Y CURVES FOR LARGE DIAMETER PILES/DRILLED SHAFTS IN LIMESTONE FOR FB-PIER

PROBLEM STATEMENT

Due to lateral loads (wind, ship impact, etc.), deep foundations transfer significant lateral forces to surrounding soil and rock. The current software (FB-Pier, Lpile, etc.) used for the design of drilled shafts, piles, etc., that are subject to lateral loads models the soil/rock material with axial and lateral nonlinear springs; the lateral nonlinear springs are referred to as P-Y curves, and the axial nonlinear springs are referred to as T-Z curves. A number of P-Y curves exists for soil; however, Florida Limestone has few if any representations and is usually characterized as clay. The P-Y curves for Florida Limestone in the case of large deformation or failure do not exist.

In addition, the axial load transfer is modeled (i.e., using FB-Pier) with nonlinear T-Z springs attached to the centerline of shaft/pile, not at the perimeter of pile/shaft. For small piles/shafts, the error is small; however, in the case of larger foundation elements (i.e. 6 to 12 ft diameters) embedded in strong material (i.e. Florida Limestone), the moment contribution or error from skin friction may be as high as 30%. This inaccuracy is a result of attaching the axial nonlinear springs (i.e. T-Z curves) to the centroid of the pile/shafts instead of the perimeter of the pile/shafts.

OBJECTIVES

The overall goals of the project are to develop nonlinear lateral springs (i.e., P-Y curves for Florida Limestone) and to modify FB-Pier to allow for representations that will provide a more accurate moment distribution along the pile/shaft with depth than current practice of the pile/shaft. Specific objectives included the following: (1) to transfer the axial skin friction, i.e. TZ curves from the center of the pile/shaft to its perimeter; (2) to account for axial skin friction in moment equilibrium on a pile/shaft cross-section; (3) to develop PY curves for Florida Limestone as a function of laboratory strength, unconfined compression; and (4) to validate new axial and PY models from experimental results. To accomplish the objectives, the following work was carried out:

FINDINGS AND CONCLUSIONS

For axial loading, T-Z curves characterize the axial skin friction on a pile/shaft as a function of its vertical load and displacement. For many pile/shaft programs, i.e., FB-Pier, LPILE, etc., the side Friction, T is assumed to act through the center of the shaft. Therefore, in the case of lateral loading, the shear, V, and moment, M, in a segment of shaft is assumed to resisted by the soil/rock lateral resistance, P (force/unit length) with no contribution of T. In the case of large pile/shaft diameters, or strong rock, the side shear, T, may develop a significant couple depending on rotation, θ, of the cross-section on both the Moment, M, and the back computed P-Y curve for a laterally loaded pile/shaft.

Nineteen instrumented centrifuge tests were conducted: 12 lateral and 7 axial (on drilled shafts embedded in Florida Limestone). Strengths varied between 10 tsf, 20 tsf, and 40 tsf; shaft diameters varied from 6' to 9', and shaft embedment, L/D, ranged from 2 to 4. The axial centrifuge tests were used to determine axial T-Z curves for later use with the lateral load tests. The axial TZ curves compared very favorably with reported field results.

From the instrumented lateral load tests, the P-Y curves were back-computed for Florida Limestone, with the assumption that axial skin friction was acting either at the center or at the perimeter of the shafts. Researchers found that the back-computed PY curves were 20% to 30% lower when axial skin friction was modeled on the side instead of at the center of the pile/shaft. Similarly, lateral load tests in the field, which do not account for axial side shear on the side of the pile/shaft in a lateral test may be unconservative by 20% to 30%.

Subsequently, the P-Y curves were normalized for Florida Limestone for a range of shaft diameters and rock strengths. None of the curves were found to be a function of the shaft's embedment depth, only the rock's unconfined compressive strength, qu, and the pile/shaft diameter. Prior employed P-Y curves (i.e., Reese & Nyman) and the stiff and soft clay models were found to be very conservative. FB-Pier was subsequently modified to include both skin on the perimeter of pile/shaft and the normalized PY curves. The modified program successfully predicted all of the measured deflections, and moments of the different diameter shafts, embedment lengths, and rock strengths. The report recommends that further field-testing of drilled shafts be undertaken to validate the proposed P-Y curves.

BENEFITS

This study developed (1) a more realistic model of axial side shear for FB-Pier for large diameter piles/shafts typically used in Florida and (2) normalized PY curves for Florida Limestone as a function of rock strength, qu, and pile shaft/diameter. The latter may be used in FB-Pier, LPILE, or other software to model single or lateral group behavior. The research also points to the need to account for axial skin friction when conducting lateral load tests in the field when back computing PY curves. Thus, the research should result in improved safety and cost savings (i.e., due to the lack of a well-defined P-Y curve for limestone, large safety factors (ASD) or small resistance factors (i.e. LRFD) are currently employed to represent Florida Limestone P-Y curves). With the proposed P-Y curves, smaller FS or higher Resistance Factors may be used, resulting in cost savings. Similarly, the improved mathematical model will result in more accurate (improved safety) moment distribution in large diameter pile/shafts that are being used more and more in Florida.

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