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3-D Numerical Investigation of Piles under Monotonic and Cyclic Lateral Loads in Clay

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ABSTRACT

Two 3-D numerical procedures, Finite Element Method (FEM) and Finite Difference Method (FDM), are used to analyze laterally loaded piles in clay. Two field-measured case studies, one in soft clay and the other one in stiff clay, are modeled in this numerical study. The monotonically loaded pile in soft clay is modeled by both FEM and FDM, while the cyclically loaded pile in stiff clay is only modeled by the FDM. A strain hardening von Mises constitutive law is used in case of monotonic load, but a strain softening von Mises constitutive law is assigned for soil behavior in the case of cyclic load. FEM and FDM show the same displacements at the monotonically loaded pile head in soft clay. Both methods suggests that the soil shear strength, in case of soft clay, must be reduced up to 30% in order to match the numerical results with the field measured data. The displacements at cyclically loaded pile head in stiff clay are in good correspondence with the field-measured data.
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KEY WORDS: Laterally loaded pile, clay, monotonic load, cyclic load, Finite Element Method, Finite Difference Method, strain hardening von Mises constitutive law, strain softening Mohr-Coulomb constitutive law.

INTRODUCTION

Laterally loaded piles, either monotonically or cyclically loaded, can be analyzed by two methods; "p-y" curves and continuum based methods. The "p-y" curves method simulates the pile foundation as a beam on elastic foundation. The "p-y" curves, nowadays widely used by designers, are proposed by Matlock (1970) and Reese et al. (1975). Matlock (1970) conducted a test on a pile under both monotonic and cyclic loads in soft clay. In the monotonic load test, the resulted "p-y" curves showed severe nonlinear response of soil at shallow depths, while almost linear response was observed at lower elevations. In the cyclic load test, he concluded that after cycles, the soil-pile system reaches a stable condition and further displacements are not observed at the pile head. The main effect of cyclic load on pile-soil system is the gap that occurred behind and in front of the pile, leading to increase in pile bending moment.

Reese et al. (1975) carried out a test on a laterally loaded pile in over-consolidated stiff clay. The results showed that the soil shear strength degradation due to cyclic load is more than that in soft clay.

Rollin et al. (1998) showed that the major displacements occur during the first cycle. The pile head accumulative displacements during the 2nd through 15th cycles were just 15% of the displacement at the first cycle. In addition, they observed that pile-soil stiffness increases by loading during reloading. This is attributed to the gap in front of the pile, leading to more contribution of the pile to the equilibrium, and accordingly, stiffer response of the pile-soil system. Before the gap closes, the pile-soil system tends to have a linear response.

There are two main continuum-based approaches for a laterally loaded pile problem. The first approach suggests that the soil around the pile is treated as an elastic continuum. This approach is mainly based on a number of researches such as Douglas & Davis (1964), Spiller and Stoll (1964), Lenci et al. (1968), Mathewson (1969) and Polous (1971). The second approach applies non-linear numerical methods to better model the soil-pile interaction. Brown & Kumar (1989), Brown & Shie (1990), and Aristonous et al. (1991) have used 3-D FE analyses to model the laterally loaded piles. In these analyses, von Mises constitutive law was used to model the soil behavior.

In this study, FEM and FDM are employed to model laterally loaded piles in clay. FEM is used to model laterally loaded piles under monotonic load. The analysis results are compared with the results of a full-scale field measured case study in soft clay. FDM is employed to model laterally loaded piles under both monotonic and cyclic loads. The same case study used for FE analysis is used for FD analysis in case of monotonic load. Finally, the results of analyzed model of laterally loaded pile in soft clay by FEM and FDM are cross-compared. Another full measured case study in stiff clay is used to