Lateral Behavior of Pile Groups in Layered Soils

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Abstract: Assessment of the response of a laterally loaded pile group based on soil–pile interaction is presented in this paper. The behavior of a pile group in uniform and layered soil (sand and/or clay) is evaluated based on the strain wedge model approach that was developed to analyze the response of a long flexible pile under lateral loading. Accordingly, the pile's response is characterized in terms of three-dimensional soil–pile interaction which is then transformed into its one-dimensional beam on elastic foundation equivalent and the associated parameter (modulus of subgrade reaction E_s) variation along pile length. The interaction among the piles in a group is determined based on the geometry and interaction of the mobilized passive wedges of soil in front of the piles in association with the pile spacing. The overlap of shear zones among the piles in the group varies along the length of the pile and changes from one soil layer to another in the soil profile. Also, the interaction among the piles grows with the increase in lateral loading, and the increasing depth and fan angles of the developing wedges. The value of E_s so determined accounts for the additional strains (i.e., stresses) in the adjacent soil due to pile interaction within the group. Based on the approach presented, the $p-y$ curve for different piles in the pile group can be determined. The reduction in the resistance of the individual piles in the group compared to the isolated pile is governed by soil and pile properties, level of loading, and pile spacing.

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Introduction

The pile group analysis procedure commonly used today is the $p-y$ multiplier technique (Brown et al. 1988). Such a procedure is based on reducing the stiffness of the traditional (Matlock–Reese and others) $p-y$ curve by using a multiplier ($f_m<1$), as seen in Fig. 1(a). Brown et al. (1988) presented the overlap among the adjacent passive wedges [Fig. 1(b)] to explain the reasoning behind the adoption of a multiplier (f_m). The value of the $p-y$ curve multiplier is assumed based on the data collected from full-scale field tests on pile groups which are few in number (Brown et al. 1988). Consequently, a full-scale field test is strongly recommended in order to determine the value of the multiplier (f_m) appropriate for the soil profile under consideration. Moreover, the suggested value of the multiplier (f_m) is taken to be constant for each soil layer at all levels of loading.

In essence, the use of an f_m multiplier is somewhat similar to the traditional approach given in NAVFAC (1982) in which the modulus of subgrade reaction E_s is reduced by a factor (R_m) taken as a function of pile spacing ($R_m=1$ at 8 diameter pile spacing varying linearly to 0.25 at 3 diameters). The difference is that f_m has been found to vary with pile row (leading, second, third, and higher), and is taken to be constant with lateral pile displacement y. By contrast, Davisson (1970) suggested that R_m should be taken constant with pile head load such that displacement y increases. In any case, neither f_m, nor R_m reflects any change with load or displacement level, soil layering, pile stiffness, pile position (e.g., leading corner versus leading interior pile, etc.), differences in spacing both parallel and normal to the direction of load, and pile head fixity.

As seen in Fig. 1(b), the interaction among the piles in a group varies with depth, even in the same uniform soil, and increases with level of loading as the wedges grow deeper and fan out farther (the concept behind the strain wedge model). Therefore, the use of a single multiplier that is both constant with depth and constant over the full range of load/deflection would seem to involve significant compromise.

Based on full-scale experiments in submerged sand, Ochoa and O'Neill (1989) presented pile group interaction factors to determine the displacement and distribution of loads among the piles in a group. The technique exhibits good agreement with the analytical elastic approach developed by Randolph and Poulos (1982). More field tests are needed to extend the capability and to reduce the limitations of this technique.

The pile group analysis presented herein is based on the concepts and assumptions of the strain wedge (SW) model analysis for an isolated pile presented by Ashour et al. (1998a,b) and Ashour and Norris (2000). The SW model approach, developed to compute the response of a long flexible pile under lateral loading, is extended in this paper to analyze the behavior of a pile group in uniform or layered soil. Several field and experimental tests reported in the literature are used to calibrate and demonstrate the validity of the approach.

Strain Wedge Model Characterization for Single Pile

As presented by Ashour et al. (1998a,b), the assessment of single pile response to lateral loading using the SW model correlates

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