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Pile–soil–pile interaction in pile groups with batter piles under dynamic loads

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ABSTRACT

A simple analytical solution is developed for computing the dynamic interaction tensor for floating pile groups with batter piles. For this purpose, the governing differential equations are derived for an unloaded batter floating pile closely spaced to another loaded pile with the same properties. The reaction of soil against pile deformation is modeled by the springs and dashpots along the length of the pile. The soil is assumed linear viscous elastic and the pile behavior is linear elastic. The closed form solutions of governing equations are obtained using appropriate boundary conditions. The results are verified and compared with rigorous and approximate analytical solutions for vertical piles. The proposed method can be readily applied by engineers in the design of pile groups with batter piles.

1. Introduction

In structures to support lateral dynamic loads like platforms, bridges and machinery foundations batter piles are usually used. Since the piles are used in groups, it is necessary to consider the effect of each pile on another pile in the group. For this purpose the pile–soil–pile interaction factor can be used in the form of the ratio of the displacement of an unloaded pile to the displacement of a loaded pile because of soil deformation and oscillation. Dynamic behavior of piles is far from completely understood as the soil–pile interaction is very complex. Due to complexity of pile–soil–pile interaction, there are no readily applicable methods available that would include values of dynamic interaction factors especially in the presence of batter piles.

Poulos [1,2] introduced the concept of 'interaction factors'. Interaction factors for each degree of freedom of the pile head have been obtained by resource to integral equation-based methods [3–5] and finite element formulations [6,7], as well as by using simple but physically sound approximations [8,9].

Static interaction factors are not applicable to the dynamic analysis of pile groups, except perhaps at very low frequencies of oscillation. Indeed, dynamic studies of pile groups have demonstrated that the dynamic response of pile groups may differ substantially from their static response. Nevertheless, Kaynia and Kausel [10,11] have shown that even for dynamic loads, Poulos' superposition procedure remains an excellent engineering approximation, provided of course that dynamic interaction factors are used for each frequency of interest. Dobry and Gazetas [12] have developed a simple analytical solution for computing dynamic impedances of floating rigidly capped pile groups with consideration to pile–soil–pile interaction. Despite its simplicity, the results of that method were in reasonable agreement with more rigorous solutions. Cairo et al. [13] method makes use of the closed-form stiffness matrices derived by Kausel and Roesset [14] to analyze pile groups under vertical harmonic vibration in layered soil.

Today several numerical methods have been done for dynamic analysis of piles and pile groups [15–18].

Mylonakis and Gazetas [19,20] have developed a new analytical method in order to determine pile–soil–pile interaction factor for axially and laterally loaded vertical piles in layered soil by considering the presence of receiver pile, which is also done by Ghadimi [21] for axially loaded piles and by Ravanshenas [22] for piles under lateral harmonic vibrations. It is obvious that these methods present smaller interaction factors and economical design than other approaches. Despite the significant progress in understanding dynamic pile group behavior, in all methods mentioned above for calculating dynamic interaction factors, piles are vertical whereas using batter piles in some pile groups is inevitable. In case of batter piles, there is an interaction tensor of second order and four interaction factors should be determined. Therefore, in this research a practical and simple method has been developed for calculating dynamic interaction tensor in pile groups with batter piles. The presence of receiver pile and interaction of receiver pile with the soil around it is also considered.

2. Pile model

To calculate dynamic pile–soil–pile interaction factor of pile groups with batter piles an one dimensional continuous model is developed in which the reaction of soil is modeled by springs and

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