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Vertical dynamic impedance of the support plate of the Rod-less drilling rig in layered soil

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ABSTRACT

The vertical dynamic response of the support plate of the Rod-less drilling rig in layered soil is theoretically investigated. The soil layers are modeled as a set of viscoelastic continuous media, and the distributed Voigt model is proposed to simulate the dynamic interactions of the adjacent soil layers. Meanwhile, the support plate is regarded as an annular friction pile with a certain radian and can be divided into several plate segments allowing for soil layers. The governing equation of soil vibration is solved by virtue of the Laplace transform and the separation of variables method. Then the vertical dynamic impedance at the bottom of the support plate is derived by means of the impedance function transfer method as well as the force and displacement continuity conditions at the soil–plate interface. By means of the inverse Fourier transform and convolution theorem, the velocity response in the time domain can also be obtained. The reasonableness of the assumptions of the support plate and soil–layer interactions has been verified by comparing the present solutions with dynamic experiments on a full-scale plate in the field. It is shown that the solution derived in this study agrees better with the experimental one than the more limited solution of Novak. An extensive parametric study has been conducted to investigate the effects of major parameters.

1. Introduction

Considering the frequent occurrence of earthquakes, and the trend of increasing the weight and height of modern buildings all over the world, studies on how to improve the bearing capacity of pile foundations under dynamic excitations are of great importance. The Rod-less drilling rig [1] can improve the bearing capacity of pile foundation by increasing the diameter and depth of the pile hole for its special structure as shown in Fig. 1(a).

The Rod-less drilling rig replaces the drill pipe with the wire rope, and it can balance the torque and penetration resistances by using the support plate of the support device as shown in Fig. 1(b). For the analysis of dynamic interaction of the support plate regarding as a special structure and layered soil plays an important role in engineering practice, it has great theoretical and practical significance to study the vertical dynamical impedance of the support plate under dynamic excitations.

It is well known that dynamic soil–structure interaction (SSI) is a critical factor influencing response and damage in structures during dynamic excitations, which has been a subject of considerable interest over the years. Many researchers have addressed the problem of dynamic SSI using either rigorous analytical methods, simplified analytical methods, or numerical methods. Lamb [2] formed the basis for the study of oscillation of footings resting on a half-space by the solution of the dynamic Boussinesq problem. On the assumption that uniform stress distribution under the footing, Reissner [3] first developed the analytical solution for a vertically loaded cylindrical disk on elastic half-space. Later, Kaynia and many investigators [4–10] studied different models of vibrations with different contact stress distributions by extending Reissner's solution. Sawant [11] presented simple formulas for the dynamic response of pile groups in series and parallel configuration for various modes of vibration, which can be readily used by the practicing engineers.

In addition, Varun, Rui, Pradhan, Taha and Jaya et al. [12–21] used various models to compute the dynamic response of pile foundations for various modes. Due to its versatility and generality, finite element method (FEM) [22–24] or boundary element method (BEM) [25,26] have also been referred in dynamic response analysis of SSI. Padrón et al. [27,28] combined BEM with FEM to get the vertical dynamic analysis of piles and pile groups embedded in an elastic half-space. However, the high computational cost is a disadvantage of these models.

In most of the studies the soil medium was assumed to be a homogeneous elastic half-space. In reality, however, soil is rarely homogeneous and often shows a layered composition, and that

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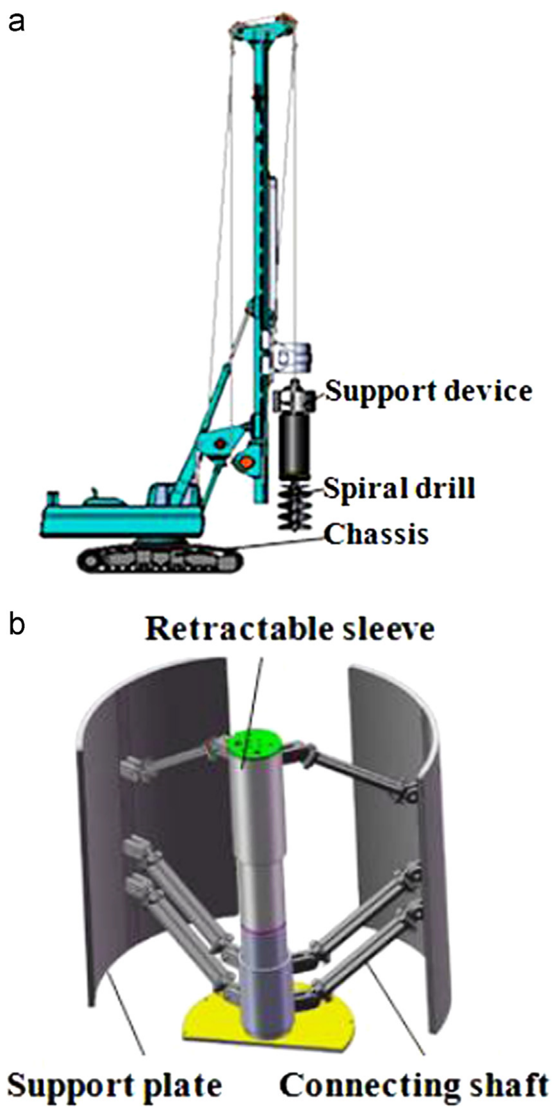

Fig. 1. (a) Structure of Rod-less drilling rig and (b) support device.

has a great influence on the dynamic behavior of structures. Gazetas et al. [29] have developed solutions for the vertical vibration responses of strip and circular footings on the surface of an elastic soil layer overlaying rock. They showed that the presence of a thin soil layer tends to increase the resonant frequency and amplitude compared to the half-space values. Luco et al. [30–32] also considered the effect of layering or non-homogeneity in their analyses. Novak et al. [33] proposed the plain-strain model to consider the effect of soil layer, which assumed that the gradient of strain and stress in the vertical direction is zero and the waves propagate only horizontally. Such assumption does not match well with reality. In order to improve this deficiency, a coupling mechanism has been introduced between the two adjacent thin layers by Nogami et al. [34]. Wang et al. [35] used Voigt model in consider the interaction of soil layers.

Even though the interaction of the support plate and layered soil is the key factor to affect the Rod-less drilling rigs normal work. However, to the extent of the authors' knowledge, the analytical solutions for dynamic impedance of structures supporting on the side of layered soil have never been reported in the literature. Due to similarity between piles and the support plate, the existing formulation for piles impedance functions can be extended to the support plate taking into account affecting parameters in a relatively simple manner.

In light of this, the primary purpose of this paper is to propose an analytical solution to investigate the vertical dynamic impedance of the support plate of the Rod-less drilling rig supporting on the side of layered soil considering the interaction of soil layers. The correctness and accuracy of the present solution are verified by comparing with the solution developed by Novak and the experimental one. A parametric study has been undertaken using the solution derived to evaluate the effects of the structural parameters of the support plate on its vertical dynamic impedance.

2. Mathematical model and assumptions

2.1. Calculation model

The dynamic interaction model of the soil–plate system is constructed, as shown in Fig. 2, in which the red area represents the support plate. $F(t)$ and $F_z(t)$ represent the penetration resistance and the exciting force acting on the plate bottom, respectively. Mechanical analysis of the Rod-less drilling rig can be seen in the literature [1]. According to the vertical inhomogeneous of the layered soil, the soil–plate system is divided into n equal thickness layers numbered by 1, 2,…, j, …,m, … n. The thickness of the jth soil layer is denoted by d_j, and the top positions of the jth soil layer and the jth support plate segment are denoted by h_j and h_p, respectively. h_s represents depth of the layered soil. H represents the length of the support plate. $or\theta z$ is the global coordinate

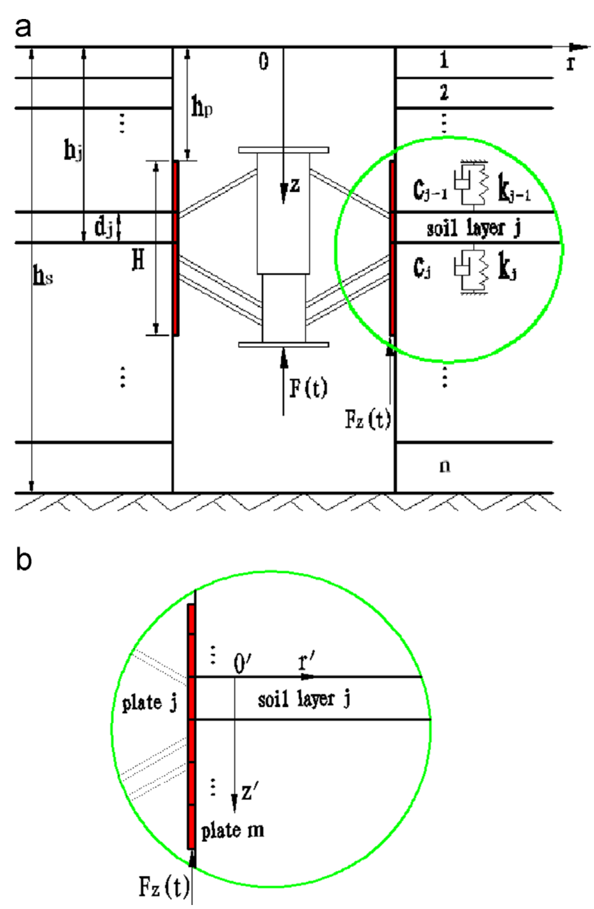

Fig. 2. Dynamic model of the plate–soil system (a) a sectional view, and (b) a local view. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)