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Dynamic response of a laterally loaded fixed-head pile group in a transversely isotropic multilayered half-space

Zhi Yong Ai *, Zhi Xiong Li, Li Hua Wang

Department of Geotechnical Engineering, Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, College of Civil Engineering, Tongji University, Shanghai, China

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ABSTRACT

The time-harmonic response of a laterally loaded fixed-head pile group embedded in a transversely isotropic multilayered half-space is investigated using a finite element and indirect boundary element coupling method. The piles are solved by the finite element method (FEM), while the soil can be modeled by the indirect boundary element method (BEM) with the aid of the fundamental solution for a transversely isotropic multilayered half-space in a cylindrical coordinate system. The governing equation of the pile-soil-pile dynamic interaction is established by applying the FEM-BEM coupling method. Numerical examples are carried out to validate the presented theory and to investigate influences of the soil's anisotropy and layering on the dynamic response of pile groups.

1. Introduction

Pile groups of super high-rise buildings, bridges, offshore structures are usually subjected to heavy lateral dynamic loads due to earthquake, wind, wave, etc. Therefore, the researches on the dynamic response of pile groups are of great importance in academia. Over the past several decades, numerous researchers have been concerned about this issue.

Elastic analysis of pile groups in continuum medium started with the pioneering work of Poulos [1] in 1968. After that, quite extended researches of static analysis of pile groups were published in the literature [2–9]. As to the dynamic analysis of pile groups, the earliest contribution to this subject was presented by Wolf and Von Arx [10]. Up to now, numerous methods have been developed for the dynamic analysis of piles and pile groups [11–23]. Among these references, the works of Kaynia [11], Kaynia and Kausel [12] were generally-accepted standard solutions for the dynamic response of pile groups in viscoelastic media. By virtue of Muki and Sternberg Method, Pak and Jennings [13], Jin et al. [14], Gharahi et al. [15] analyzed single piles embedded in different soils under transverse excitations, while Zhou and Wang [16] extended the solutions to pile groups in a poroelastic medium. Kuhlemeyer [17], Wu and Finn [18] used the finite element method to investigate the dynamic responses of single piles and pile groups. Sen et al. [19], Mamoon et al. [20] examined the pile-soil-pile dynamic interaction by employing the boundary element method. Based on the BEM-FEM coupling method, Padrón et al. [21], Millán and Domínguez [22] derived the solutions for dynamic responses of piles and pile groups in viscoelastic or poroelastic soils. Shi et al. [23] utilized the thin layer element method and the flexible volume method to compute the

* Correspondence to: Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China. Fax: +86 21 65985210.

E-mail address: zhiyongai@tongji.edu.cn (Z.Y. Ai).

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dynamic impedances and free-field vibrations of rigidly-capped pile groups embedded in saturated ground. However, few papers concerned the soil properties of transverse isotropy and stratification simultaneously. As we all know, natural soils are usually layered because of the long-term sedimentation process and have different properties in the horizontal and vertical directions [24–26]. Since the dynamic behavior of laterally loaded pile groups is closely related to the horizontal direction properties of the soil, it is meaningful to study the dynamic behavior of laterally loaded pile groups in the transversely isotropic multilayered half-space.

Recently, the authors [27] presented a finite element and indirect boundary element coupling method to obtain the solutions for dynamic response of a floating pile in a transversely isotropic multilayered half-space subjected to horizontal excitations. In this paper, the FEM-BEM coupling method [27] is extended to analyze the dynamic behavior of a laterally loaded fixed-head pile group in a transversely isotropic multilayered half-space. The piles are assumed to be one-dimensional bars and discretized by the FEM. Supposing that the soil is not altered by the presence of piles, so it can be treated as a three-dimensional transversely isotropic multilayered half-space continuum with the assumption of damping term, which can be modeled by the indirect BEM based on the dynamic analytical layer-element solution presented in Ref. [28]. The governing equations of the pile-soil-pile interaction are obtained by virtue of the FEM-BEM coupling method. Then, the solutions for the governing equations are further carried out by considering boundary conditions. Finally, some numerical examples are performed to compare with existing solutions and to investigate the influence of the soil's anisotropy and layering on the dynamic response of pile groups.

2. FE equations for the pile group

As is illustrated in Fig. 1, m randomly distributed piles connected to a rigid free standing raft are embedded in a transversely isotropic multilayered half-space. A pile i in the pile group has a circular section with diameter d_i and length L_i. A horizontal time-harmonic load $Fe^{i\omega t}$ with the amplitude F and circular frequency ω is applied to the raft. It is assumed that there is no contact between the rigid raft and the multilayered half-space, and the rigid raft moves horizontally without any vertical displacement; besides, the vertical displacement of the pile is also neglected.

According to Ref. [27], the piles can be discretized by three-node elements. With the elimination of the harmonic time factor $e^{i\omega t}$, the equilibrium equation of pile i in the pile group can be expressed as

$$(\mathbf{K}_i - \mathbf{M}_i\omega^2)\mathbf{u}_i^p = \mathbf{F}_i^H + \mathbf{T}_i\mathbf{q}_i^p \tag{1}$$

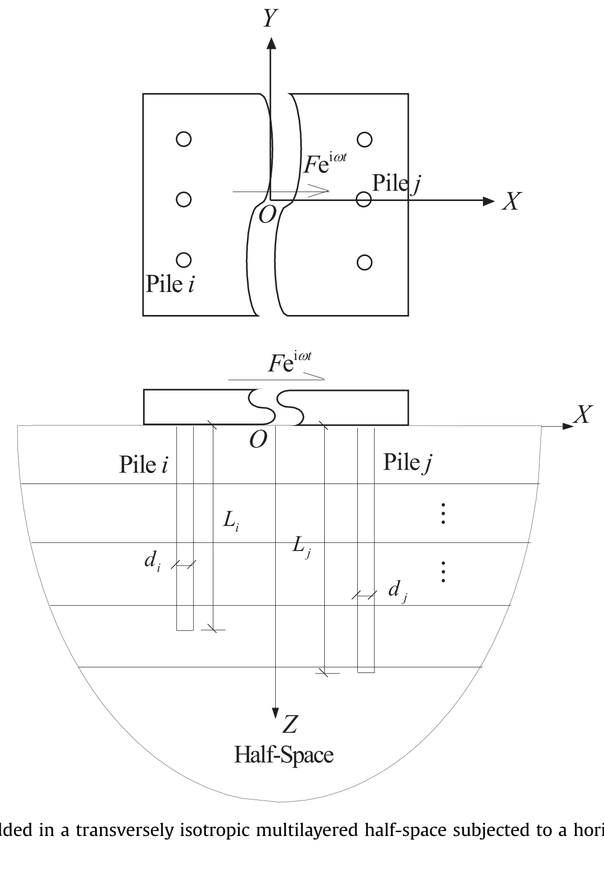

Fig. 1. A pile group embedded in a transversely isotropic multilayered half-space subjected to a horizontal time-harmonic load.