Soil Dynamics and Earthquake Engineering 78 (2015) 175–188

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

A simplified method of calculating the impedance and foundation input motion of foundations with a large number of piles

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ARTICLE INFO

Article history:
Received 6 January 2014
Received in revised form
13 August 2014
Accepted 4 August 2015
Available online 25 August 2015

Keywords:
Impedance
Foundation input motion
Neighboring piles
Single equivalent pile
Soil–structure interaction

ABSTRACT

A new simplified method is developed for the analysis of the impedance and foundation input motion of foundations with a large number of piles. In this proposed method, the neighboring piles are replaced by a single equivalent pile. This process of replacement reduces the number of degrees of freedom, computer memory requirement, and calculation time. To validate the simplified method, the impedance and foundation input motion of a raft foundation and an embedded foundation supported by piles groups are calculated through both the simplified method and the rigorous numerical method. Results show that the proposed simplified method for the impedance and foundation input motion of a foundation with a large number of piles has sufficient accuracy and good computational efficiency.

1. Introduction

Numerous structures, such as offshore structures and nuclear power plants, are supported by piles arranged in groups. Each of these groups consists of a large number of piles. Several researchers have attempted to conduct frequency domain dynamic analysis of such pile groups embedded in the soil through the boundary element method in conjunction with the finite element method [1–7]. However, the use of both methods for soil and piles requires a large computer memory. Moreover, when the number of piles reaches several thousands, the dynamic response of the piles groups cannot be calculated even with the use of several mainframe computers. Thus, a high computational cost is an inevitable disadvantage associated with these models. Therefore, a method that reduces the number of degrees of freedom of the piles groups is desirable for the dynamic response analysis of such groups.

This study proposes approximate procedures that more efficiently obtain solutions by reducing the number of degrees of freedom of piles groups. Dobry et al. [8] proposed a simple analytical solution for the computation of the dynamic impedances of floating rigidly capped pile groups with due consideration of pile–soil–pile interaction. The impedance of the two individual piles is calculated through one equivalent pile using the dynamic interaction factor. The predictions of the vertical and rocking oscillations using the simple method compare extremely well with rigorous numerical solutions. Gazetas and Makris [9–10] discovered that an increase in the pile length leads to an error caused by the dynamic interaction factor, when the calculation of the impedance of the floating rigidly capped pile groups takes an unneglected step. Nozoe [11] proposed a simple quasi-dynamic method of computing the impedances of piles group installed in a homogeneous surface stratum lying on rigid bedrock. Asega [12] and Nogami [13] proposed analytical expressions for the soil stiffness of piles group obtained through the plan strain and Kelvin–Voight models. However, an *n*-times characteristic equation is required in the calculation procedure, so that computational difficulties arise with an increase in the number of the piles.

In previous studies, the dynamic interaction factor of two individual piles is typically employed to replace the two individual piles with an equivalent pile in calculating the response of the piles group foundation. However, the dynamic interaction factor of the piles is usually limited to the uniform soil condition. In contrast, a new simplified method is proposed in this paper, discretization of the piles in the vertical direction remain unchanged, the adjacent piles are aggregating to one equivalent pile in the horizontal direction. The response of the piles group is computed by the weighted average of the displacement of single piles in the group via the thin layer method

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http://dx.doi.org/10.1016/j.soildyn.2015.08.003
0267-7261/

[14,15]. Due to the thin layer method can calculate the response of the pile for layered soil condition. Thus, the proposed simplified method can analyze the impedance and the foundation input motion for both uniform and non-uniform soil conditions. The computational accuracy of the proposed simplified method was verified through the rigorous method for the foundation supported by piles groups.

2. Impedance and foundation input motion

The impedance and foundation input motion functions associated with massless rigid foundations (MRF) are utilized to incorporate the effect of soil structure interaction in the analysis based on the flexible volume substructure method [16,17] combined with the thin layer method [14,15] as shown in Fig. 1.

2.1. Rigorous method

The equation for the motion of the MRF–pile–soil system based on flexible volume substructure method is given by

$$([K]^G+[S]^S-[S]^E)\{u\}=\{F\} \tag{1}$$

where,$[S]=[K]-\omega^2[M]$, $[K]$, $[M]$ and $\{u\}$ are the stiffness matrices, mass matrices, and displacement vector, respectively. The foundation, and free field and excavated soil are identified by the superscripts S, G, and E, respectively. For the embedded foundation supported by piles groups, part of the embedded foundation is modeled by the solid element. The beam element is employed to form the stiffness matrices of the pile.

To calculate the impedance of the MRF, the subscripts F and O are used to denote the degrees of freedom of the foundation and the degrees of the freedom of the other part in the soil foundation system, respectively, as shown in Fig. 1(a). Thus, Eq. (1) can be rewritten as:

$$\begin{bmatrix}[S_{FF}] & [S_{FO}]\\ [S_{OF}] & [S_{OO}]\end{bmatrix}\begin{Bmatrix}\{u_F\}\\ \{u_O\}\end{Bmatrix}=\begin{Bmatrix}\{F_F\}\\ \{F_O\}\end{Bmatrix} \tag{2}$$

The decomposition of Eq. (2) leads to

$$\{u_O\}=-[S_{OO}]^{-1}[S_{OF}]\{u_F\}+[S_{OO}]^{-1}\{F_O\} \tag{3}$$

$$\{u_F\}=-[S_{FF}]^{-1}[S_{FO}]\{u_O\}+[S_{FF}]^{-1}\{F_F\} \tag{4}$$

Substituting Eq. (3) in Eq. (4), we obtain

$$([S_{FF}]-[S_{FO}][S_{OO}]^{-1}[S_{OF}])\{u_F\}=\{F_F\}-[S_{FO}][S_{OO}]^{-1}\{F_O\} \tag{5}$$

Converting Eq. (5) to an equation of motion with six degrees of freedom for the MRF, we obtain the following equation for the impedance of the foundation:

$$[K_F]=[T]^T([S_{FF}]-[S_{FO}][S_{OO}]^{-1}[S_{OF}])[T] \tag{6}$$

where $[T]$ is the coordinate transformation matrix relative to the centrality of the MRF.

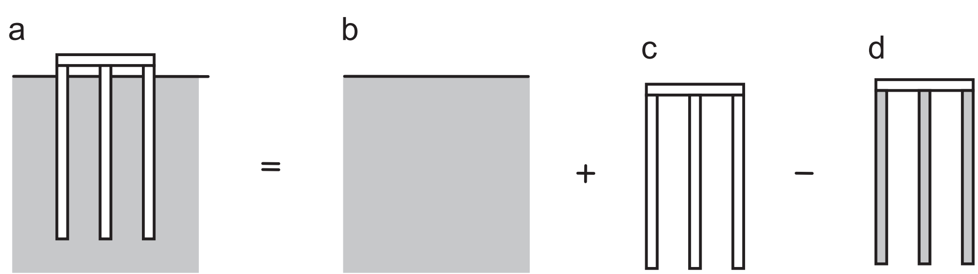

Fig. 1. Soil foundation model based on flexible volume substructure method. (a) Soil-foundation system, (b) free-field, (c) foundation and (d) excavated soil.

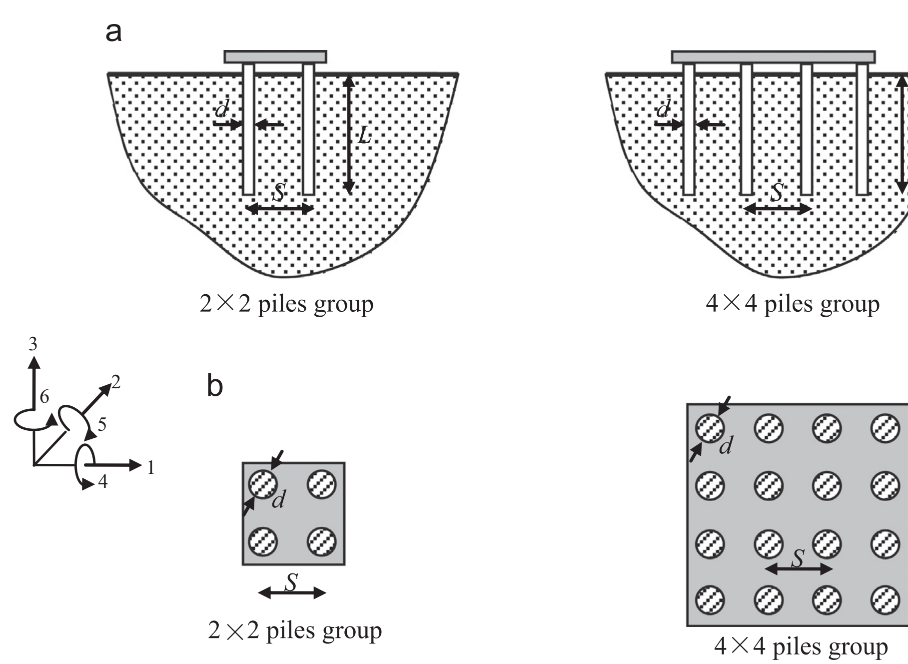

Fig. 2. Profiles and plans of piles group. (a) Profiles of piles group and (b) plans of piles group.