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A response-based simplified model for vertical vibrations of embedded foundations

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ABSTRACT

A simplified damped oscillator model is proposed to simulate unbounded soil for the vertical vibration analysis of rigid embedded foundations. Based on the dynamic responses of a foundation–soil system, an optimal equivalent model is determined as the best simplified model. Magnification responses of a foundation–soil system simulated by the optimal equivalent model are well consistent with those obtained by the half-space theory and by a widely used computer program even as embedment depth or vibrating mass increases. The optimal equivalent model utilizing only three parameters can result in responses as accurate as the existing models, which use more parameters. This proposed method uses much simpler procedure than optimization techniques used by most existing discrete models. This proposed method may also be easily and accurately applied to practical soil–structure interaction analysis.

1. Introduction

Dynamic behavior of soil–structure interaction systems has been extensively studied over past few decades. The early developments in soil–structure interaction have been reviewed by Kausel [1]. A substructure method can be utilized to analyze the response of soil and superstructure separately. The core of the substructure method is using a dynamic impedance function to represent unbounded soil. Several studies [2–8] proposed numerical values, charts or simple formulas of impedance functions for practical engineering applications. The dynamic impedances are usually frequency-dependent so that they may not be used directly in time domain for the nonlinear structural analysis. Hence, numerous studies developed simplified models to establish frequency-independent impedances for simulating the dynamic soil behavior.

Most studies [9–18] used a lumped-parameter model, which comprises masses, springs and dashpots to simulate the unbounded soil. Parameters of those models were frequency-independent. Lysmer and Richart [19] and Whitman and Richart [20] used a simple mass-spring-dashpot model to simulate the elastic half-space. Through adjusting the three parameters of the lumped-parameter model, the impedance function of the model would be tuned to approach the solutions obtained by the use of a half-space model. In addition, several studies [21–24] developed a cone model to simulate the unbounded soil for foundation vibration analysis. These cone models were shown to be dynamically equivalent to certain simple lumped-parameter models. One of the earliest works was proposed by Meek and Veletsos [25], which showed that the impedance function for each cone model in lateral and rocking motion is identical to that for a simple discrete model with frequency-independent parameters. Similar studies were also proposed by Veletsos and Nair [26] and Wolf [27].

In general, existing lumped-parameter models use more parameters and degrees of freedom to enhance the accuracy. One of the most widely used approaches was to establish a simplified model and calculate the associated impedance functions. Then, through an optimization process, the modeling parameters were determined by minimizing the discrepancy between the impedance functions for the model and that obtained from the rigorous theory. This approach was used in the following studies: Wolf [27] and Wolf and Somaini [28] developed a two-degree-of-freedom model with five parameters to simulate the dynamic impedance functions for a circular foundation rested on or embedded in a uniform half-space. de Barros and Luco [29] proposed a modified two-degree-of-freedom model with five parameters to simulate the elastic half-space for surface and embedded foundations undergoing vertical vibrations. Jean et al. [30] established a three-degree-of-freedom model with ten parameters to simulate vertical, horizontal, rocking and torsional vibrations of rigid surface disks. Moreover, Wu and Chen [31] developed a series of lumped-parameter models to simulate the compliance functions for rigid surface and embedded foundations.

Another category of method assumed that the impedance function or compliance function for a lumped-parameter model can be expressed by the ratio of two polynomial functions in terms of complex frequency parameters. Through an optimization process, the unknown function parameters were then determined so

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