Construction and Building Materials 180 (2018) 177–187

Contents lists available at ScienceDirect

Construction and Building Materials

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

Surface-wave attenuation by periodic pile barriers in layered soils

Xingbo Pu, Zhifei Shi *

Institute of Smart Materials and Structures, School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, China

HIGHLIGHTS

- This work provides a new insight into the design of periodic piles as wave barriers.
- Passive isolation of surface waves by periodic pile barriers in layered soil deposits is studied.
- Attenuation zones for surface waves in periodic pile barriers are obtained.
- The influence of various parameters on isolation efficiency is comprehensively discussed.
- The 3D numerical simulations both in frequency and time domain are provided.

ARTICLE INFO

Article history:
Received 7 March 2018
Received in revised form 24 May 2018
Accepted 29 May 2018

Keywords:
Rayleigh wave
Attenuation zone
Periodic structure
Pile barrier
Vibration isolation

ABSTRACT

The purpose of this study is to investigate surface-wave isolation by periodic piles from the perspective of attenuation zones. There are three major components. The first is the dispersion equation, which is derived based on periodic theory of solid-state physics. The second component is the main new part of this paper. Finite element method is adopted to calculate the dispersion relation and attenuation zones for surface waves in a periodic pile and layered soil system. Moreover, effects of geometric parameters on attenuation zones and the amplitude reduction spectra are thoroughly investigated. As a result, harmonic responses show that the isolation region on amplitude reduction spectra is consistent with the theoretical attenuation zone. The third component is the feasibility of ground vibration isolation by periodic pile barriers, which is verified in the time domain by investigating train-induced ground vibrations. Using the concept of attenuation zone, one can manipulate the propagation and attenuation of surface waves artificially. This work provides a new insight into the design of periodic piles as wave barriers.
© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Ground vibrations caused by trains, machine foundations and construction blasting can adversely affect adjacent facilities and the operation of nearby sensitive equipment [1]. Such vibrations propagate in the forms of body waves and surface waves. Surface waves, which carry most of vibratory energy and decay much more slowly along the free surface of a half-space, are of primary concern in vibration isolation engineering [2,3]. Installing wave barriers in the ground before the protected structures are known as passive isolation [4]. Passive isolation diffracts the surface waves and thus makes it possible to reduce the unwanted ground vibrations [5]. These barriers may be open trenches, in-filled trenches, sheet pile walls, or rows of piles. Sometimes, however, difficulties of using trench barriers will increase in practice for the reason that the construction becomes very difficult in soft ground or high water table level locations [6,7]. Use of piles as wave barriers are likely to be preferred for they can be driven into the ground at any depth, and can also be arranged in any desirable configuration.

The idea of vibration isolation by pile barriers was initially given by Richart et al. [8]. Since then, a good deal of research has been carried out both experimentally and numerically to investigate the isolation effectiveness of pile barriers. Woods et al. [9] performed a series of holographic experiments on Rayleigh wave screening by several types of piles. Effective isolation was found when the pile diameter is greater than 1/6 Rayleigh wavelength. Using a two-dimensional (2D) plane strain model, Avilés and Sánchez-Sesma [10] presented an approximate analytical approach to investigate the screening of incident SH, SV, and P waves by a row of rigid piles embedded in an elastic, isotropic and homogeneous unbounded space. The theoretical analysis was later extended to three-dimensional (3D) models by a row of elastic piles as barriers for Rayleigh waves [6]. They concluded that the pile spacing and diameter play major roles in vibration isolation, which is similar to what was found in the 2D model. In addition,

* Corresponding author.
E-mail address: zfshi178@bjtu.edu.cn (Z. Shi).

https://doi.org/10.1016/j.conbuildmat.2018.05.264
0950-0618/© 2018 Elsevier Ltd. All rights reserved.

although increase of pile length can improve the vibration isolation efficiency, the pile length appears not to be a governing parameter because Rayleigh waves are confined in a thin layer near the free surface. Kattis et al. [7,11] employed 3D frequency-domain boundary element method (BEM) to study the vibration-isolation problem by a row of piles. Moreover, they also analyzed the same problem by an effective trench to reduce the modelling complexity [11]. Their results showed that the general vibration screening behavior of pile barriers is similar to that of trenches, but the latter always tend to perform better. Another finding was that pile spacing seems to govern the screening effectiveness, while the cross-sectional shape of piles has little effect on vibration isolation. Tsai et al. [12] also utilized 3D BEM in frequency domain to investigate the screening effectives of pile barriers, and found isolation efficiency is most related to pile length and material. Using a Fourier-Bessel series expansion technique, Cai et al. [13] studied the screening of plane waves by a row of piles embedded in a homogeneous unbounded poroelastic soil. Assuming that the piles are modeled by Euler-Bernoulli beams, they further investigated the isolation of Rayleigh waves by a row of piles in a poroelastic half-space [14]. They concluded pile spacing is a key parameter for wave attenuation. Besides, increase of pile length can result in a better isolation performance, but this effect appears to be less obvious for very long piles. The aforementioned works centered on the passive isolation by a row of piles; however, recently certain interest has been focused on multi-rows of piles as wave barriers with the latter being always more effective than a row of piles. These studies have been carried out in frequency domain for the isolation of plane waves [15], Rayleigh waves [16,17], and moving-load induced vibrations [18,19].

Although the preceding literatures published some interesting findings, two aspects have not been fully emphasized. First, dispersion property of surface waves in rows of piles has not been studied. For pile and soil systems, surface waves are dispersive. Dispersion properties can help to understand the physics of surface wave propagation and attenuation. Second, these studies focused only on the amplitude reduction at a single frequency. The amplitude reduction spectra as well as time-domain analysis has not been performed.

The research effort towards vibration isolation based on periodic structures, termed *phononic crystals*, has drastically increased during the past two decades. A major reason for this is the existence of *attenuation zones* (AZs), or called band gaps, in which wave propagation becomes prohibited. Such a novel property leads to a good deal of research, both numerical and experimental, on vibration mitigation or even seismic isolation [20–23]. The first large-scale experimental verification of periodic pile barriers should be attributed to Brûlé et al. [24], but the parameters that affect the isolation efficiency of periodic piles deserve further study. Huang and Shi [25,26] systematically investigated the screening effectiveness of periodic pile barriers, and also found that waves can be strongly reduced if the excitation frequencies are located in AZs. Very recently, the periodic pile barriers are extended to saturated soil for ambient vibration isolation [27]. Although many achievements have been made, the current research mainly focuses on the isolation of body waves, and the investigation of surface-wave mitigation is very limited. Since surface waves are of primary concern in ground vibration isolation, the main contribution of this study is therefore to provide a thorough investigation of surface-wave isolation by periodic pile barriers, from the view of surface-wave AZs. Given the complexity of the geological conditions, the soil is modeled as a layered half-space, which is very common in many areas of southeast China.

An outline of this paper is as follows. Based on Bloch-Floquet theory, the dispersion equation is derived in Section 2. In Section 3, the surface-wave identification method is verified through comparison with published results. Then, the AZs for surface waves in periodic pile barriers are studied. In particular, a 3D numerical simulation for Rayleigh-wave attenuation is performed, which confirms the attenuation coefficient predicted by Bloch-Floquet theory. In Section 4, the numerical modelling scheme and degree of isolation are presented. The effects of geometric parameters on AZs and on amplitude reduction spectra are thoroughly discussed in Section 5. In Section 6, the performance of finite rows of pile barriers to train-induced ground vibrations is investigated in time domain. Finally, some summarized remarks are provided in Section 7.

2. Dispersion theory for periodic structures

2.1. Governing equation

For a homogeneous linear elastic medium without consideration of damping as well as body force, the governing equation can be expressed by the displacement vector $\mathbf{u}(\mathbf{r})$

$$\nabla \cdot (\mathbf{C}(\mathbf{r}) : \nabla \mathbf{u}(\mathbf{r})) = \rho(\mathbf{r}) \frac{\partial^2 \mathbf{u}(\mathbf{r})}{\partial t^2} \tag{1}$$

where ∇ is a differential operator, $\mathbf{r} = (x, y, z)$ is the position vector, t is the time parameter, $\mathbf{C}(\mathbf{r})$ and $\rho(\mathbf{r})$ are the position-dependent elastic stiffness tensor and mass density, respectively. For the convenience of calculation, the nonlinear and viscoelastic nature of soil are not considered. This simplification can also be found in related studies [28,29]. It is assumed that piles and soil are bonded perfectly at the interfaces. The hysteretic, slip and nonlinear behaviors between the interfaces may happen in practical engineering [30,31]. However, the related discussion is beyond the scope of this study.

2.2. Bloch-Floquet theory and periodic boundary condition

Periodic structures, which are artificially constituted by composite materials whose elastic coefficients vary periodically in space. Specifically, if $\mathbf{R}$ is a constant vector which gives the repetition of a periodic structure, the material parameters can be expressed as $\rho(\mathbf{r}) = \rho(\mathbf{r} + \mathbf{R})$ and $\mathbf{C}(\mathbf{r}) = \mathbf{C}(\mathbf{r} + \mathbf{R})$. According to the periodic theory of solid-state physics (i.e., Bloch-Floquet theory), the displacement vector $\mathbf{u}(\mathbf{r})$ of a periodic structure in Eq. (1) can be written as

$$\mathbf{u}(\mathbf{r}, t) = e^{i(\mathbf{k}\cdot\mathbf{r} - \omega t)} \mathbf{u}_{\mathbf{k}}(\mathbf{r}) \tag{2}$$

in which $\mathbf{k}$ is the Bloch-Floquet wave vector in the first *Brillouin zone*, $i = \sqrt{-1}$, ω is the angular frequency, $\mathbf{u}_{\mathbf{k}}(\mathbf{r})$ is a modulation function of the displacement vector. For a considered periodic structure, the modulation function is a periodic function defined in the elementary unit cell, which means:

$$\mathbf{u}_{\mathbf{k}}(\mathbf{r}) = \mathbf{u}_{\mathbf{k}}(\mathbf{r} + \mathbf{R}) \tag{3}$$

Substituting Eqs. (3) into (2), the periodic boundary condition (PBC) can be obtained,

$$\mathbf{u}(\mathbf{r} + \mathbf{R}, t) = e^{i\mathbf{k}\cdot\mathbf{R}} \mathbf{u}(\mathbf{r}, t) \tag{4}$$

2.3. Dispersion equation

Combining the governing equation of Eq. (1) and the PBC of Eq. (4), the dispersion relation of an infinite periodic system can be transferred into an eigenvalue problem of an elementary unit cell. The dispersion equation is an implicit function of wave vector $\mathbf{k}$ and angular frequency ω in mathematics,

$$(\Omega(\mathbf{k}) - \omega^2 \mathbf{M}) \cdot \mathbf{U} = \mathbf{0} \tag{5}$$

Download English Version:

https://daneshyari.com/en/article/6712493

Download Persian Version:

https://daneshyari.com/article/6712493

Daneshyari.com