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Feasibility of ambient vibration screening by periodic geofoam-filled trenches

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ABSTRACT

Single in-filled trench barriers have been widely investigated to mitigate ground vibrations. However, investigations on the application of multiple rows of in-filled trenches are very limited. This paper investigates the attenuation of surface waves by periodic geofoam-filled trenches in single-phased elastic soil deposits. First, a field test of train-induced ground vibration is carried out, from which the corresponding acceleration record and main frequency are obtained. Second, attenuation zones for surface waves in periodic geofoam-filled trenches are studied based on the periodic theory of solid-state physics. Finally, a numerical model for ambient vibration isolation is built under the conditions of plane strain, and the responses are performed both in frequency domain and in time domain by finite element method. The screening effectiveness of the proposed wave barrier is studied by conducting an extensive dimensionless parameter investigation. Results show that the proposed periodic geofoam-filled trenches can attenuate surface waves effectively, when the frequencies of surface waves are located in the attenuation zones. The present study provides a new concept for designing periodic in-filled trench barriers to mitigate ground vibrations.

1. Introduction

Ambient vibration has become one of environmental issues and has been widely concerned. Vibrations induced by traffic loads, machine foundations and construction blasting can cause disturbances to nearby buildings and disrupt the performance of adjacent sensitive equipment [1,2]. Most of ambient vibration energy is carried by surface (Rayleigh) waves that propagate within a zone near the ground surface and decay more slowly than body waves. For this reason, attenuation of surface waves is of primary concern in ambient vibration reduction [3,4]. To prevent the unfavorable effects of surface waves, placing suitable wave barriers between the source and protected structures is very common in engineering [5–7]. These effective barriers include open or in-filled trenches and even rows of piles.

Several experimental studies have been carried out to investigate the isolation effectiveness of wave barriers. Woods [8] performed extensive field experiments to investigate the performance of open trenches in reducing the ground motion. According to those experimental findings, some design guidelines were suggested. For example, a minimum depth of 0.6 times Rayleigh wavelength is required for a trench to achieve a ground amplitude reduction of 75% or more. Celebi et al. [9] conducted a series of field tests on vibration reduction by installing open and four types of in-filled trenches. In their field experiments, the foundation vibration was produced by an electro-dynamic shaker and both active and passive isolation cases were studied. Their experimental results indicated that isolation efficiency of wave barriers depends on the vibration frequency, and use of in-filled trenches with softer materials can achieve a better performance but not as good as open trenches. Alzawi and El Naggar [10] carried out full scale experimental tests to investigate the effectiveness of open and geofoam filled trenches as wave barriers. In their experiments, barrier dimensions and location from vibratory source on screening efficiency were examined. Results showed that the geofoam filled trench can be used as an effective wave barrier to scatter the induced ground vibration. Moreover, a comparison was conducted between the field measurements and numerical results by a two-dimensional (2D) finite element model, and good agreement was found.

Since the analytical solutions are difficult to obtain, numerical techniques have been widely used by many researchers to study the vibration isolation problems. Beskos et al. [3,11] employed boundary element method (BEM) to investigate both active and passive isolation by open and in-filled trenches. The formulation and solution to this problem were accomplished in the frequency domain and time domain, respectively, and some very useful guidelines for design were provided. Based on the plane strain conditions, Ahmad et al. [12] used BEM to investigate various parameters on the vibration screening efficiency of

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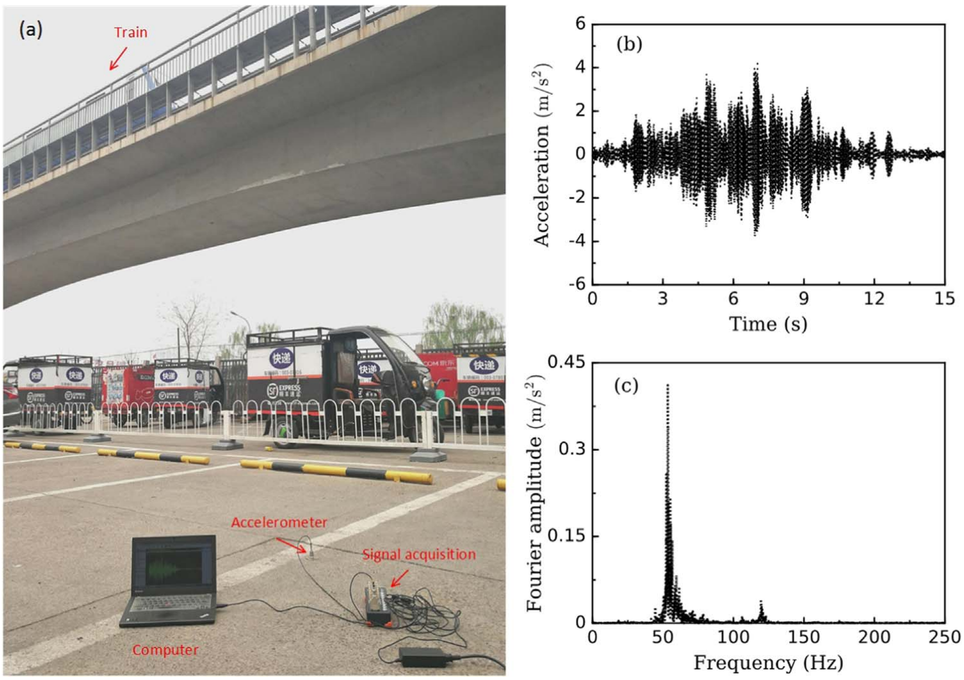

Fig. 1. A field test of ambient vibration: (a) test setup, (b) acceleration record, (c) Fourier spectra.

open and in-filled trenches, and simplified design formulas were presented. Using the coupled boundary element-finite element algorithm, Adam et al. [13] considered a 2D soil-structure system to investigate the isolation of train-induced building vibration by open and in-filled trenches. Results showed that increase of trench depth and width could improve isolation efficiency and that in-filled trenches with softer materials possess a better isolation performance. Celebi and Kirtel [14] studied the problem of thin-walled trenches on reduction train-induced ground vibrations. The soil-structure interaction effects and plastic deformations of soil were addressed by applying a non-linear 2D finite element model. The structural responses were discussed for different speeds of train loads as well as fill material properties. Ekanayake et al. [15] employed a three-dimensional (3D) finite element model to study the efficiency of in-filled wave barriers on the ground vibration attenuation. After verification with field data, the model was used to evaluate the screening capability of open trenches, water and geofoam filled trenches, respectively. Their simulation results indicated that compared to active isolation, geofoam in-filled trenches are found to be more effective in passive isolation. This conclusion is consistent with the experimental results in reference [9]. Very recently, Van hoorickx et al. [16] adopted a 2.5D finite element method to assess the performance of double wall barriers on ground vibration reduction, and the free field responses were considered for a point source and a train load at the surface, respectively.

In the past two decades, periodic materials or structures have attracted a lot of attention due to the unique dynamic property, i.e., elastic waves with some frequencies cannot propagate through periodic structures. These frequency domains are called band gaps or attenuation zones (AZs). Inspired by the concept of AZs, Shi and his coworkers [17–20] conducted a systematic investigation on seismic isolation and vibration reduction in the field of civil engineering from 1D to 3D periodic structures. Mo and his coworkers [21–23] carried out a series of experiments on seismic isolation by using periodic foundations. Their experimental results indicated that when the main frequency of excitation falls into the AZs, the response of the upper structure with mere five periodic foundations can achieve a reduction of 90% or more as compared to the same structure without periodic foundations.

Although the use of open trenches can achieve a better performance than using in-filled trenches, it is confined to the relatively shallow trench situation due to the instability problem [9,13]. Based on the above literature review, single in-filled trenches, especially with soft materials, due to possessing good screening behavior, have been accepted widely up to now. Only few studies, however, reported on the investigation of vibration isolation by double trenches [16,24]. Previous studies show that the periodic theory of solid-state physics opens a new window for designing wave barriers [19,20]. Therefore, the objective of this paper is to propose a new type of periodic in-filled trench and to use its surface wave AZs for ambient vibration isolation. The content of this paper is organized as follows. In Section 2, a field test of train-induced ground vibration is carried out, from which the corresponding acceleration record and main frequency are obtained. In Section 3, basic theory of surface waves in periodic structures is introduced. Based on the main frequency domain of the measured ground vibration, a new configuration of periodic geofoam-filled trenches is proposed and the corresponding AZs are calculated. Methodology of this paper is presented In Section 4. In Section 5, the screening effectiveness of the proposed periodic geofoam-filled trench is simulated by conducting an extensive investigation on geometrical parameters. Finally, some conclusions are summarized in Section 6.

2. Field test of train-induced ambient vibration

Design of proper wave barriers to mitigate vibrations depends on excitation frequencies. Hence, a test of ambient vibration is necessary to obtain the main frequency of excitations. In this paper, the ground vibration for free field induced by a railway in Beijing is considered. As is shown in Fig. 1(a), the train runs on the bridge, causing the ground vibration nearby buildings. An accelerometer is used to measure the ground accelerations. The measured acceleration record and its Fourier spectra are presented in Fig. 1(b) and (c), respectively. It can be seen that the main frequencies of this recorded ambient vibration lie in the range from about 50–60 Hz. For ambient vibration energy is principally carried by surface waves, the current study is performed to attenuate surface waves in this frequency range by periodic geofoam-filled trenches.