Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(6) (2023) 277-280
DOI: 10.22060/ceej.2023.21261.7668

Surface waves attenuation using periodic buried soil-foam wave barriers

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ABSTRACT: Using wave barriers is one of the effective measures for seismic wave attenuation. The barriers have different geometries and are arranged in periodic configurations. Considering the complex barrier behaviors and their miscellaneous characteristics, much research has been conducted in recent years to find effective barriers. This paper proposes a new unit cell as a wave barrier to reduce the propagation of surface waves. Unlike the common practice in which harder and heavier materials are placed in the center and soil around it, the suggested unit cell consists of undisturbed soil as a core and a foam layer on both sides as a soft coating material. Firstly, a unit cell is considered in an infinite periodic lattice using solid-state physics concepts and periodic theories and is modeled using COMSOL Multiphysics FEM software. The dispersion curve can be obtained by changing the wave vector in the first irreducible Brillouin zone and calculating the corresponding eigenfrequencies. Then, the bandgaps are defined in the dispersion curves. Following that, because constructing an infinite lattice is impractical, a finite lattice of the unit cell is simulated to explore the unit cell efficiency in a more realistic setting. The time and frequency domain analyses are carried out using the finite lattices. The findings reveal that the proposed soil-foam unit cell with a height of four meters can effectively reduce the waves in the bandgap range in infinite and finite lattices. The obtained bandgap range is between 12.75 to 17.61 Hz.

Review History:

Received: Apr. 02, 2022
Revised: Mar. 10, 2022
Accepted: Apr. 13, 2023
Available Online: May, 31, 2023

Keywords:

Wave barrier
surface waves
periodic lattice
Bloch-Floquet theory
Finite element method

1- Introduction

Finding effective ways to mitigate the adverse effects of seismic waves has always been one of the most important topics of discussion among civil engineers in recent years. Among the various wave mitigation methods, using wave barriers is one of the most common and effective methods [1]. The use of solid-state physics theories, specifically the Bloch-Floquet theory, has gained attention in solving civil engineering problems [2]. This theory investigates the periodic wave barriers, creating a unique property that mitigates waves within a certain frequency range, known as the band gap [3].

In this regard, numerical modeling has been used to investigate buried piles in soil with infinite length and periodic arrangement [4]. Various other studies have explored the use of solid-state physics in designing wave barriers [5-9]. Researchers have introduced a new method of using periodic wave barriers to reduce surface wave propagation and proposed a method for separating bulk and surface waves [9]. Some researchers have investigated the use of planted trees as natural wave resonators [10]. The idea of using foam-filled corrugated sheets to reduce surface waves has also been examined [11]. This study proposes using a combination of soft and hard materials to create a local resonator wave barrier. The undisturbed soil remains in the center of the unit cell while softer materials are used around it to create a banded gap. This innovative method could be useful for designing wave barriers based on periodic concepts.

2- Methodology

In the present research, soil materials and seismic barriers are considered homogeneous and elastic. The wave propagation equation in a homogeneous linear elastic medium can be expressed as follows:

$$\nabla.(C(r):\nabla u(r)) = \rho(r)\frac{(\partial^2 u(r))}{(\partial t^2)} \quad (1)$$

Brillouin [12] found that in these periodic structures, only one repeating unit cell can be considered, and by changing the wave vector and frequency of wave propagation in this unit cell, an infinite repeating network of unitcells can be studied. This smallest repeating unit in the network is called the first Brillouin zone. Solid-state physics concepts and theories are used to study these periodic structures, including the Bloch-Floquet theory [13]. Finally, the periodic condition based on

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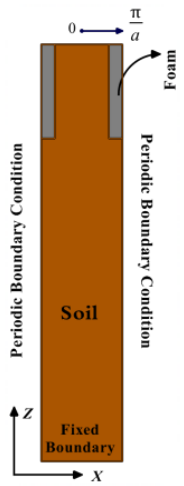

Fig. 1. Unitcell for infinite lattice

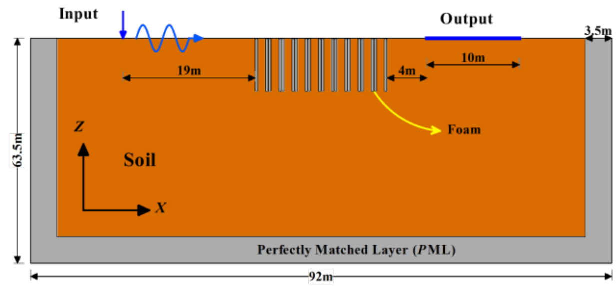

Fig. 2. Finite lattice

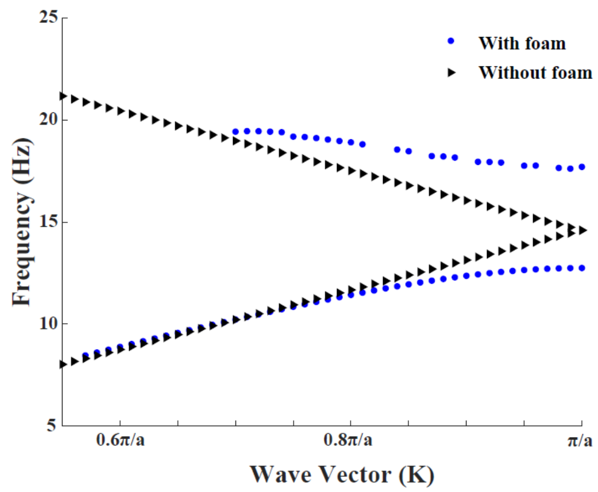

Fig. 3. Dispersion curve

this theory can be expressed as follows:

$$u(r+R,t)=e^{(ik.R)}u(r,t) \tag{2}$$

The dispersion curve originally includes both surface and bulk modes. In the modeling for obtaining band gaps for surface waves, post-processing is required to separate surface modes from bulk modes. A parameter ξ is defined to represent energy distribution in the studied eigenfrequency as follows:

$$\xi=\frac{\int_{0.1h}E_{\varepsilon}dA}{\int_{h}E_{\varepsilon}dA} \tag{3}$$

3- Problem definition

In this study, the main goal is to use a periodic wave barrier to protect sensitive structures against the adverse effects of seismic waves. Unlike the general trend in wave barrier design, which usually involves buried wave barriers like piles enclosed by soil, in this study, an innovation has been attempted to preserve the undisturbed soil core at the center of the barrier, surrounded by lighter and softer materials. Since modeling an infinite periodic network of wave barriers has a high computational cost, initially, only one unit cell of these wave barriers is examined. The unit cell or wave barrier under study in this research is composed of a foam layer on both sides of the soil. This unit cell can use the soil between the foams as a heavy core and the foams as a soft cover. The unit cell under study is shown in Figure 1.

After examining this unit cell and obtaining the dispersion curve and performing post-processing on this plot, band gaps are obtained for the unitcell. These band gaps indicate the regions where it is expected that the unit cell will not allow the propagation of waves with a frequency in this range. Since constructing an infinite network of these unit cells and wave barriers is practically impossible, a network with a limited number of these wave barriers is modeled according to Figure 2, and its performance is evaluated.

4- Results and discussion

Figure 3 shows the proposed unitcell dispersion curve. As can be seen in the range of 12.75 Hz to 17.61 Hz, there is no surface mode present. Therefore, this region is identified as a bandgap. Figure 3 clearly demonstrates the effect of the presence of barriers by comparing surface waves in the case of no obstacles and with obstacles. Initially, in the absence of barriers, two branches of surface waves are merged, and there is no empty space between them. As a result, finding a bandgap is impossible. However, after using wave barriers, the two branches of surface waves are separated, and a frequency range is created between them where no special frequency exists. Therefore, this range can be called a bandgap, and it is expected that waves with a dominant frequency in this range cannot propagate in the wave barrier network. The obtained bandgap has a width of about 5 Hz and is located in the region below 20 Hz, which is a desirable area for reducing seismic waves.

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HOW TO CITE THIS ARTICLE

K. Gholami, R. Rafiee-Dehkharghani, Surface waves attenuation using periodic buried soil-foam wave barriers , Amirkabir J. Civil Eng., 55(6) (2023) 277-280.

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