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Screening effectiveness of open and in-filled wave barriers: A full-scale experimental study

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HIGHLIGHTS

- Field tests were conducted to evaluate the isolation performance of wave barriers.
- The effects of frequency, Rayleigh wave length and trench depth were investigated.
- Results of the experiments were compared with the published literature.
- Geofoam filled trench can be suggested to be used as an efficient wave barrier.

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ABSTRACT

The isolation of ground-borne vibrations caused by heavy traffic, construction activities and railway transportation has gained importance in recent years with rapid urbanization. Open or in-filled trenches have commonly been used as wave barriers in reducing unwanted vibrations. There only few experimental data concerning the effects of frequency of excitation, soil layering, material type and dimensions of the wave barrier on vibration control and isolation. In the present study, a series of full scale field experiments were conducted in order to investigate the screening efficiency of open, water filled and geofoam filled trenches. The attenuation of ground borne vibration was examined to determine the effects of frequency, distance and complex behavior of layering and irregular geometry of soil profile. Moreover, the results obtained from the experimental tests were compared with the numerical and experimental findings available in literature. Consequently, the field tests confirmed that the geofoam filled trench can be used as an efficient isolation system for reducing the transmission of ground-borne vibrations.

1. Introduction

Ground-borne vibration induced by traffic loading and construction operations has become a major urban environmental issue in recent years. Depending on its source and distance, ground-borne vibrations can be disturbing for urban dwellers and in the meantime harmful to the nearby structures containing sensitive equipment. Active (near the source) or passive wave barrier (farther from the source) is one of the efficient isolation techniques to reduce unwanted ground-borne vibrations [1]. These barriers can often be installed as trenches (open or filled with bentonite, concrete or geofoam) or sheet pile walls. Several factors including characteristics of waves and soil medium influence the isolation performance of wave barriers. Most of the energy produced by vibration propagates in the form of Rayleigh waves [2], [3]. Thus, the screening effectiveness of wave barriers depends on reflection, scattering and diffraction of Rayleigh waves [4]. The variation of the Rayleigh wave components with depth is mainly represented by the wavelength which is directly related to the operating frequency of vibration source and the dynamic properties of the ground. The amplitude of the wave components decreases by approximately 90% at a depth of $1.5\lambda_R$. [5].

Several experimental research studies [1,6–16] had been carried out to investigate the key parameters affecting the vibration isolation performance of wave barriers. These studies asserted that the trench depth and Rayleigh wavelength had a noteworthy influence on vibration screening. Woods [1] and Richart et al. [5] indicated that the ratio of trench depth to Rayleigh wavelength affected the performance of the vibration isolation. Based upon the experimental data Dolling [8], Haupt [9] and Kattis et al. [17] recommended that ratio of trench depth to Rayleigh wavelength should be at least 0.8. Çelebi et al. [11] conducted a series of field tests to investigate effectiveness of trenches filled with water, bentonite and concrete. The authors concluded that a higher level

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of attenuation was obtained in passive isolation when compared to active isolation.

The numerical techniques including finite element method (FEM) and boundary element method (BEM) have been widely used to understand the isolation mechanism of wave barriers. Beskos et al. [18], Al-Hussaini [19], Kattis et al. [17], Tsai and Chang [20], Wang et al [21], Zoccali et al. [22], Saikia and Das [23] employed numerical methods in order to evaluate the effect of both geometrical properties and type of wave barriers on screening performance. They concluded that open trenches provided better performance for vibration isolation compared to in-filled trenches. However, in-filled trenches are usually preferred in practice due to lack of stability in open trenches. Hamdan et al. [24] investigated the effectiveness of variously shaped wave barriers using FEM. The results showed that the reduction level was around 50% for rectangular-shaped, triangular-shaped and L-shaped wave barriers. Site experiments conducted by Woods [1] and numerical analysis performed by Al-Hussaini [19] presented that the width of trench had a negligible effect on the vibration isolation performance. However, Yang and Hung [25] and Murillo et al. [13] emphasized that this conclusion was not valid for shallow trenches. Andersen and Nielsen [26] developed a coupled FEM and BEM model of railway track to analyze the efficiency in-filled trenches. The authors concluded that shear wave velocity ratio between in-fill material and surrounding ground had a considerable influence on vibration isolation performance. Çelebi and Kırtel [27] and Massarsch [28] reported that the isolation performance of the wave barrier was strongly dependent on the relative stiffness between in-filled material and the surrounding soil (impedance ratio).

There are few studies directly analyzing screening effectiveness of the wave barriers made of Expanded Polystyrene (EPS) geofoam. Alzawi and El Naggar [14] conducted a series of full scale tests in order to examine the vibration isolation performance of geofoam wave barriers. The findings of the study show that a reduction of 68% or higher could have been achieved by using geofoam barriers. Besides, the authors stated that higher screening effectiveness could have been obtained when the depth of barrier was greater than $0.6\lambda_R$. Murillo et al. [13] performed centrifuge tests to investigate the influence of width and depth of the barrier and the source-barrier distance on isolation efficiency of in-filled geofoam trenches. Based on the results of the experiments, the barrier was found to be inefficient when the distance between the source and in-filled EPS barrier was smaller than $0.5\lambda_R$. Moreover, it was observed that adequate efficiency in active isolation could have been obtained if the depth and width of the barrier was larger than $1.5\lambda_R$ and $0.25\lambda_R$, respectively. Wang et al. [21], Qiu et al. [29] and Ekanayake et al. [30] used finite element method to examine the efficiency of EPS barriers under blast-induced ground shock. The authors reported that the geofoam barriers were very efficient in reducing the ground vibrations.

There have been only a few experimental studies focusing on the screening effectiveness of open and in-filled geofoam trenches. Thus, in the present study, a series of full-scale experimental tests were carried out to examine the isolation performance of wave barriers. The effect of excitation frequency and screening effectiveness of geofoam and water-filled wave barrier were evaluated under mechanical vibrations. The results were assessed in comparison with the findings published in literature.

2. Soil and material properties

A detailed site investigation was performed to evaluate the physical and dynamic soil properties of the local soil. Thus, results obtained from soil survey could be used to examine wave propagation and effect of relative stiffness between soil and barrier. A site located near a silent agricultural area in Bayir (Mugla, Turkey) was selected due to its feasible conditions for vibration tests. Five boreholes having varying depths of 10–30 m were drilled to obtain soil samples and to determine physical properties of the soil. The soil profile consists of 6 m clayey sand (SC) over 24 m clay with low and high plasticity (CL, CH) resting on very stiff clay. Standard penetration tests (SPT) were carried out in five boreholes at 1.5 m intervals and numbers of SPT blows (N_{60}) were recorded. Physical properties of the soil and average N_{60} values of stratified soil are presented in Fig. 1. The water table was observed 5 m below the ground surface.

Multichannel Analysis of Surface Waves (MASW) tests [31] were used to determine the dynamic properties of the subsoil. In the MASW method, a linear array of 24 geophones (4.5 Hz) with 3 m spacing was placed at the site in N–S and E–W direction. The surface waves were generated by the impact of sledge-hammer and the near-surface shear wave velocity profile (Fig. 2) was obtained through the inversion of those waves [32]. Furthermore, a series of microtremor tests were conducted in the study area to estimate the predominant period of the soil deposit. The measurements showed that the predominant period was approximately 0.32 s.

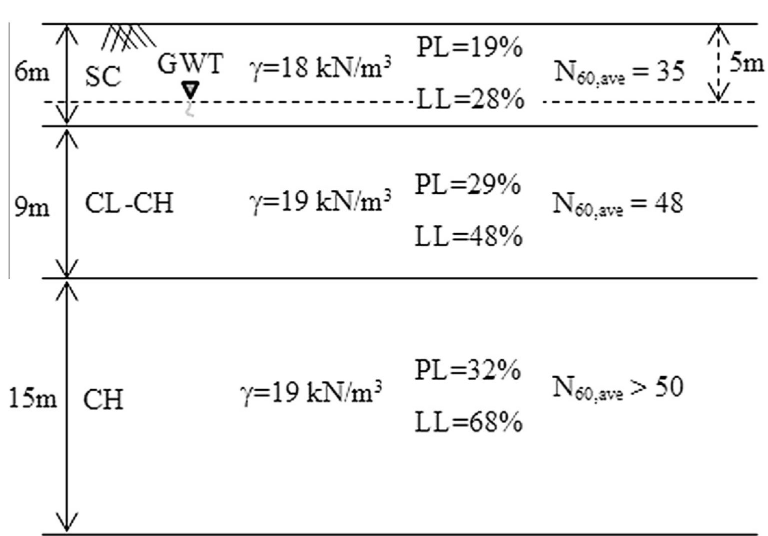

Fig. 1. Soil profile of the site.