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Reduction of train-induced building vibrations by using open and filled trenches

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Abstract

A numerical investigation on the effectiveness of open and in-filled trenches in reducing the building vibrations due to passing trains is presented. Particularly, a two-dimensional soil-structure system containing the cross-section of a railway embankment, the underlying soil, a trench barrier and a nearby six-storey building is considered. For the analysis, a time domain coupled boundary element-finite element algorithm is employed. Unlike most of the previous formulations, this model completely considers the soil-structure interaction effects and directly determines the effect of the wave barrier on the structural response. The effects of geometrical and material properties of the trench and its backfill material on the structural response are investigated. The results point out that using a trench barrier, a reduction level up to 80% of the building vibrations and internal forces can be achieved. Increasing the depth or the width of a trench may improve its reduction effect and a softer backfill material results in a better isolation effect.

Keywords: Vibration reduction; Trench barrier; Wave propagation; Building vibrations; FEM; BEM

1. Introduction

Due to train traffic, machine operations, pile driving, or blasting, ground vibrations are generated that may cause distress to adjacent structures and annoyance to residents. For instance, most of the vibration energy generated due to a train passage is carried by Rayleigh waves that propagate close to the soil surface and transmit the vibrations to the structures via their foundations. These vibrations lie in the frequency range of 4–50 Hz and may bring some structures to resonance with their vertical modes [1–3]. This type of vibrations can be a major problem in densely populated areas and for structures, which are housing sensitive machinery. Therefore, in many countries new environmental regulations have been introduced placing some constraints on railway operations. Consequently, the isolation of the traffic-induced vibrations has become an important issue in recent years.

Generally, it is possible to prevent the adverse effects of these vibrations by providing a suitable wave barrier between the source and the structure to be protected. This system of vibration isolation can be classified into

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two categories, source isolation and receiver isolation. With source isolation barrier it is tried to reduce the vibrations at their source. It should be installed surrounding the vibration source or at close distance to it. The receiver isolation barrier, on the other hand, usually is built away from the source, surrounding the structure to be protected. Stationary sources of vibration, e.g. machines working with a certain frequency, can be effectively isolated by a source isolation barrier, whereas a receiver isolation barrier is effective for a wide variety of wave generating sources.

Different types of wave barriers, varying from very stiff concrete walls or piles to very flexible gas cushions, are discussed in [4–7]. Among them, both, open and in-filled trenches are the most common in practical application since they present effective and low cost isolation measures.

The published literature reveals that in early studies, efforts have been directed mainly towards analytical studies and some experimental works to investigate the problem of isolation by means of trench barriers. Only a few experimental studies present some design guidelines for particular cases, but they are rather limited in their scope. Woods [8] and Haupt [9,10], for instance, conducted a series of field tests, analytical studies and laboratory model experiments in order to study the screening performance of open trenches and concrete walls. Moreover, the wave diffraction by spherical and parabolic obstacles has been studied analytically by some researchers [11,12]. However, the closed form solutions were confined to simple geometries and idealized conditions.

For this reason, various numerical methods were used by many authors for solving wave propagation and vibration reduction problems. For example, Lysmer and Waas [13] employed the lumped mass method, while Segol et al. [14] applied finite elements along with special non-reflecting boundaries to investigate the isolation efficiency of open and bentonite-slurry-filled trenches in a layered soil. Frequently, also the finite difference technique was used to study the scattering of a Rayleigh wavelet by a rectangular open trench [15]. Nevertheless, an underlying bedrock has to be inevitably included in the analysis models along with some sort of artificial transmitting boundaries due to the numerical constraints of the above mentioned methods.

In the last two decades, the boundary element method (BEM) has been applied for a significant portion of the studies on wave propagation problems. In particular, this method is very well suited to investigate the wave propagation in soils, since the radiation into the ground (e.g. into a halfspace) is directly included in the formulation. Many authors adopted the BEM for the analysis of isolation effects of open and in-filled trenches, investigating different types of soils. Thus Emad and Manolis [16] considered shallow open trenches of semi-circular and rectangular shape in a two-dimensional soil profile, while Beskos et al. [17] and Leung et al. [18,19] investigated open and filled trenches in homogeneous and non-homogeneous soil, respectively. Ahmad and Al-Hussaini [20] and Al-Hussaini and Ahmad [21] concentrated on simplified design methodologies for wave barriers and vibration screens, also looking at an active isolation of machine foundations by open trenches [22]. Trenches filled with different materials are discussed in [23].

In all cases, however, it can be observed that the boundary element method is not well suited for the modeling of irregular geometries or a possible non-linear material behavior of soft soils and/or structural foundations. To overcome this drawback, several procedures for coupling finite with boundary elements or finite with infinite elements have been proposed, following the pioneering work of Zienkiewicz and his co-workers, who developed a FEM/BEM coupling scheme [24] as well as a combination of the FEM with infinite elements [25]. Thus von Estorff and Prabucki [26], for instance, used a FEM/BEM scheme for dynamic soil-structure interaction including trench problems, while Yang et al. [27,28] concentrated on a coupling of finite and infinite elements applied to study the reduction of train induced vibrations using different types of wave barriers.

With the exception of a few, most of the previous researches have mainly dealt with the development of different numerical methodologies as a tool for the analysis of vibration isolation problems. Parametric studies have been rather limited and mostly performed in the frequency domain. Moreover, the reduction of the nearby ground surface vibration amplitude was the major concern.

In this paper, the investigation is focused on the effects of using trench barriers for the reduction of nearby building responses through a parametric study directly in the time domain. The building is directly considered in the mathematical modeling and analysis. The coupled boundary element–finite element (BE–FE) algorithm developed earlier by Adam et al. [29] is extended to handle the building structure as frame elements [30,31] and employed for the numerical analysis of the current problem, some details are given in Appendix A. Therefore, different from others, the soil-structure interaction effect is automatically taken into account and the effect of the barrier on the structural response is obtained directly. The response of the building is given in terms of accelerations and internal forces, which represent the most important design parameters for structural engineers.

2. Numerical model and considered parameters

A reinforced concrete six-storey building frame, as shown in Fig. 1, shall be considered in detail. Its width