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Ground-vibrations induced by trains: Filled trenches mitigation capacity and length influence

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HIGHLIGHTS

- In-situ railway vibration measurements for FE model calibration.
- Performance of trenches for different in-filled materials.
- Mutual influence between trenches length and in-filled material type.
- Filled trenches efficacy analysis in time and frequency domain.

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ABSTRACT

The use of trenches as vibration mitigation action is widespread in many countries. The complexity of the intervention design process depends on the high number of parameters that influence its efficacy, such as trench geometry size (width, depth, length), section shape, used in-filled material, distance among source-trench-receiver and frequency content of the source. This paper focuses on the study of the mutual influence between trenches length and in-filled material type considering several fixed observation points. The analysis was realized using a finite element model that was calibrated through comparison with in-situ measurements, and the evaluation of the effectiveness of each configuration taken into account was performed calculating the amplitude reduction index A_r and analyzing the vibration attenuation capacity both in time and frequency domain. As found by several other authors, it was found that increasing trenches length, a better isolation effect is performed, but the improvement amount seems to be strongly influenced by the kind of material to be used to fill trenches. This aspect must be taken into account in the optimization process of vibration isolation actions performed using trenches.

1. Introduction

In recent decades, many authors have studied the problem of vibrations generated by rail traffic and negative effects on the different types of receptor sites in the proximity of the railway infrastructure. The effects of vibrations is one of the most relevant themes, with regard to the railway externalities. An important research objective, in this sense, is to define possible interventions to be considered in the design phase of infrastructures, as actions able to prevent the environmental problems instead of mitigating them after the railway construction [1]. For this reason, it is important to evaluate the efficacy of the protective systems for vibrations, like the absorbing trenches here presented.

The study proposed in scientific literature, in fact, generally deal to the identification of appropriate forecasting models in order to use them for the predictive estimation of displacement, velocity or acceleration levels resulting from the construction of new railway lines, as well as in the assessment of the effects of any intervention on existing ones.

A further use of such models is the possibility to analyze and verify the effectiveness of different types of mitigation actions of ground-vibrations; among these, the use of trenches is widespread and their effectiveness has been studied by several authors [2–4] considering the insertion of open and filled trenches both in a homogeneous and non-homogeneous soil.

Traditionally, two of the main problems concerning the use of trenches are the choice of the size, with particular attention to width and depth of the elements to realize, and the optimal distance of the trench from the source and the site to protect; for that

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reason many parametric studies have been performed [5–8]. Since most of the vibration energy generated by the train transit is transmitted by Rayleigh waves, all parameters are normalized with respect to soil Rayleigh wavelength. Among these studies Ahmad and Al-Hussaini [5] considered both cases of open and filled trenches and for the last one they analyzed also the influence of the mechanical properties of the in-filled material with respect to soil ones, such as the velocity ratio V_{st}/V_{ss} between shear waves propagation velocities in the trench material and in the soil, and the density ratio ρ_t/ρ_s between them. The importance of these parameters is underlined by Yang and Hung [6], which analyzed the influence on the amplitude reduction ratio A_r of the impedance ratio IR defined as follows:

$$IR = \frac{\rho_t \cdot V_{st}}{\rho_s \cdot V_{ss}} \tag{1}$$

According to the IR value, barriers are defined as softer ($IR < 1$) or stiffer ($IR > 1$) trenches and the open ones are nothing else that a special case of filled trenches with $IR = 0$.

The open trenches present the most efficiency vibration reduction attitude but they can be used only when particular conditions are satisfied. In order to approach amplitude reduction ratio provided by open trenches, different in-filled material has been tested. In particular, in [9–11] geofoam (expanded polystyrene or extrude polystyrene) as in-filled materials has been studied, while in [12,13] the use of gas cushions trenches as wave barriers is analyzed, obtaining results very close to open trenches performances.

Depending on the trenches position, they provide an active isolation, if close to the source, or a passive isolation, if close to the receiver, and according to the type of the realized isolation the same barrier provides different vibration reduction capacity [14].

The trench mitigation capacity, in particular the efficacy of different in-filled material types, depends from the harmonic components of the source as presented in [14,15] where the vibration level reduction provided from trenches has been studied varying the load frequency.

The phenomenon of railway vibrations presents specific features because the source is moving with variable speed. Furthermore, the spectrum of the source includes a wide range of frequencies due to the different generation mechanisms. In fact, railway vibrations are wave motions generated by the dynamic interaction between different mechanical systems: the train, the track, the embankment and the ground surrounding the infrastructure. Given the complexity of the phenomenon, in order to facilitate the study of these topics, different mechanisms of generation were identified, according to the evaluation of the relative contribution to the response of the whole railway system as shown in Fig. 1.

Among the main contributions to vibration effects, there is the excitation produced by sleepers spacing, known as parametric excitation, because of the different vertical stiffness that wheels meet moving along the rail [17–20]. Another important generation mechanism, often analyzed in literature, concerns the irregularities of the contact wheel-rail surface [21,22]; these irregularities can consist, for example, in rail joints, faulty welds and facets of wheels. In addition, vibrations themselves generated by other generation mechanisms contribute to the degradation of rail geometrical features, as studied by Wu [23] who analyzed the effects of parametric excitation on rail corrugation.

The use of finite element models is widespread in trenches screening ability studies and, in order to contain the computational burden (reducing the effective time analysis), the train modeling is usually avoided, preferring to implement an appropriate loading function representative of the forces transmitted by the trains wheels to the track [24,25]. Through the development of a 2-D finite element model Adam and Von Estorff [26] studied the efficacy of open and filled trenches in reducing the stress actions on a building

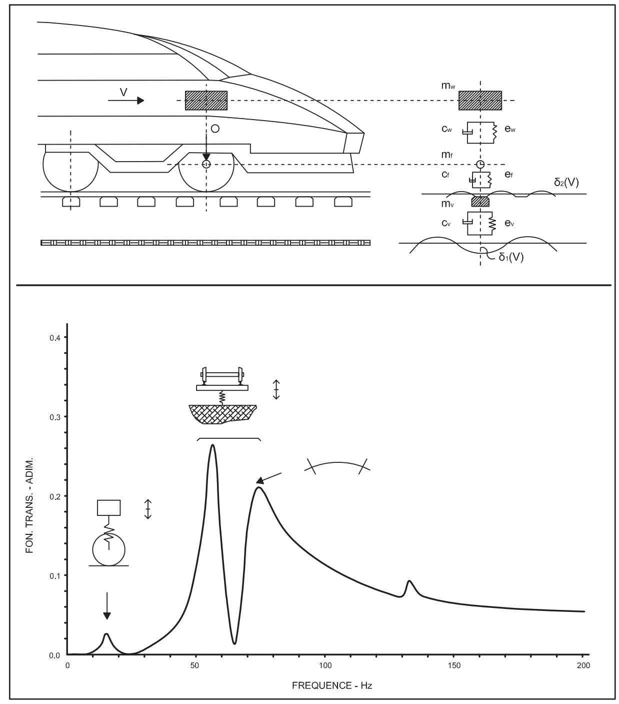

Fig. 1. Characteristic frequencies of the various mechanical systems [16].

structural elements (girders and columns), while Celebi and Kirtel [27] studied the screening performance of trench barriers considering the Mohr–Coulomb constitutive law (linear elastic model with post-failure plasticity) to better simulate the real soil behavior.

Several studies have underlined the better vibration reduction capacity of open trenches than the filled ones [2–5] but, considering the limited application of the first ones, in the present paper, through the development of a finite element (FE) model that represents a straight section of an high speed railway, the influence of the filled trench extension and the type of in-filled material on the reduction of perceived vibrations has been investigated. The model validation was achieved through comparison with in-situ measurements results performed during a previous experimental research.

2. Numerical modeling

In the study of dynamic phenomena, including vibrations, an useful tool can be represented by finite element models, that allow to explore the response of a mechanical system when external or internal actions are applied. However, these models need special attention in order to guarantee a correct representation of the real structural system and of its dynamic responses to applied actions. In particular, developing a FE model, a calibration phase is required, with the aim to correctly set the most relevant parameters and to verify the results provided. In the present study, the calibration has been performed using some experimental data, obtained from previous in-situ measurements. In particular, in order to contain the model size and to reduce the effective time analysis, in the early steps of the research the considered measures were referred only to a single bogie passage. As the rail profile is not known and considering the fact that the main contribution of these irregularities concerns above all high frequencies, this parameter has not be taken into account in the FE model.

2.1. In-situ measurements

The data for calibration process were obtained from a previous research, developed in the same department of authors [28]. The