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Mitigation of railway induced ground vibration by heavy masses next to the track

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ABSTRACT

The effectiveness of heavy masses next to the track as a measure for the reduction of railway induced ground vibration is investigated by means of numerical simulations. It is assumed that the heavy masses are placed in a continuous row along the track forming a wall. Such a continuous wall could be built as a gabion wall and also used as a noise barrier. Since the performance of mitigation measures on the transmission path strongly depends on local ground conditions, a parametric study is performed for a range of possible designs in a set of different ground types. A two-and-a-half dimensional coupled finite element–boundary element methodology is used, assuming that the geometry of the problem is uniform in the direction along the track. It is found that the heavy masses start to be effective above the mass–spring resonance frequency which is determined by the dynamic stiffness of the soil and the mass of the wall. At frequencies above this resonance frequency, masses at the soil's surface hinder the propagation of surface waves. It is therefore beneficial to make the footprint of the masses as large and stiff as possible. For homogeneous soil conditions, the effectiveness is nearly independent of the distance behind the wall. In the case of a layered soil with a soft top layer, the vibration reduction strongly decreases with increasing distance from the wall.

1. Introduction

Railway induced ground vibration can be a source of annoyance for lineside residents. Vibration in buildings (1–80 Hz) may cause malfunctioning of sensitive equipment and lead to discomfort of inhabitants. The vibrating walls and floors also radiate noise in the low frequency range (16–250 Hz). In case of excessive vibration levels, mitigation measures can be taken at the source, on the transmission path, or at the building where vibration problems occur [1,2]. The most effective way is to tackle the problem at the source [3]. Mitigation measures at the source for railway induced ground-borne noise and vibration include soft railpads [4], under-sleeper pads [5], ballast mats [6,7] and floating slab tracks [8] and are frequently used for new railway infrastructure. Vibration reduction measures at the receiver side, such as base isolation [9], are only effective for the structure to which the mitigation measure is applied.

Renewed attention has recently been paid to vibration reduction technologies in the transmission path, but installed close to the track so that they can still be regarded as part of the railway infrastructure [10]. These measures include open trenches [11], soft and stiff buried wall barriers [12–15], subgrade stiffening [16,17] and wave impeding blocks [18,19]. Interventions on the propagation path between source and receiver have the advantage that no modifications of the track are required. This paper focuses on the possible application of heavy masses next to the track as a feasible vibration mitigation measure on the transmission path.

Jones [1] investigated the effect of concrete masses placed in various configurations along the track. Krylov [20] studied the effect of individual masses such as concrete or stone blocks placed on the ground surface along the track. The reduction in transmitted vibration obtained by blocks at the surface is attributed to the scattering of the incident surface waves into surface and body waves. Similar studies of the scattering of waves by irregularities at the surface have been performed in the fields of solid state physics [21] and earthquake engineering [22–24]. The scattering turns out to depend on the spatial distribution and the number of irregularities per unit area [21]. In the case of soft soils, seismic wave fields are scattered when the excitation frequencies are close

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to the resonance frequencies of buildings on the ground stiffness [22]. Similarly, heavy masses next to the track are expected to be especially effective in reducing vibrations near the natural frequency of the mass coupled to the soil [1,20]. Two-dimensional (2D) calculations indicate insertion loss values up to 10 dB in a frequency range from about 20% below to about 20% above the natural frequency [20]. Tests with 600 kg concrete masses failed to give conclusive results [1].

More recently, Mhanna et al. [25] and Masoumi et al. [26] investigated the vibration mitigation effect of heavy masses by means of numerical simulations and experiments. Mhanna et al. [25] used a 3D time domain finite element (FE) model and compared simulations with test results for steel tanks filled with water. The observed reduction in vibrations was attributed to reflection of incident waves by the stiff irregularities, restriction of ground surface movements by the heavy masses and destructive interference between direct and secondary scattered waves. Masoumi et al. [26] investigated the effectiveness of a row of concrete blocks with a two-and-a-half-dimensional (2.5D) coupled finite element–boundary element (FE–BE) model. The model was validated with small scale tests performed in a test bench and full scale tests next to a railway line. Simulations showed an increased reduction for wider and heavier blocks. Including a resilient layer under the concrete blocks significantly reduced the effectiveness.

The reduction in transmitted vibration by heavy masses next to the track has been attributed to different phenomena. It is the aim of this paper to identify relevant physical phenomena that contribute to the vibration reduction and thus improve the knowledge necessary for the design of heavy masses as a vibration mitigation measure.

In this study, a continuous row of masses along the track is considered. Although the results of the theoretical analysis are generally applicable, gabion walls consisting of free standing stackable wire baskets filled with stones are considered in this paper. Gabion walls have been installed as noise barriers next to railway lines (Fig. 1). In this case, an acoustic nucleus is integrated within the wall to fulfill the acoustic requirements on sound transmission. The noise barriers consist of gabions with a width of 1 m and a height of 0.5 m or 1 m, possibly stacked next to or on top of each other. The length of the gabions forming the wall can vary between 1 m and 5 m. If the gabions would also lead to a significant reduction of ground-borne vibration, such a wall could be designed as a combined barrier for airborne noise [27] and ground-borne vibration. Because the stiffness of the gabions is of the same order of magnitude as the stiffness of typical soils, the gabion walls primarily act as an additional mass on the soils surface. The case of a continuous concrete wall next to the track is included in the present study to investigate the performance of a stiff barrier.

The outline of this paper is as follows. Section 2 describes the 2.5D model used for the analysis of the vibration reduction of heavy masses next to the track. Results for a benchmark reference case are presented in Section 3. To explain the observations made in the benchmark study, different idealized models with an increasing degree of complexity are set up. In Section 4, the underlying physical mechanisms are discussed in detail by comparing results from different simplified models. In Section 5, a comprehensive parametric study is performed to study the influence of the size of the wall and the soil characteristics. Concluding remarks are given in Section 6.

2. Methodology

Fig. 2 gives a schematic view of the problem considered in the parametric study. A continuous wall with height h and width w is placed on the soil's surface at a distance d from the centre of the track. The origin of the Cartesian frame of reference is placed at the soil's surface at the centre of the track. The x-axis is in the direction perpendicular to the track, the y-axis is parallel to the track and the z-axis is vertical.

The free field response due to a train passage can be calculated from the track–soil transfer function (impulse response function) $H_{ts}(\mathbf{x}, \mathbf{x}', t)$ that relates the response at a point $\mathbf{x}'$ to the load at a

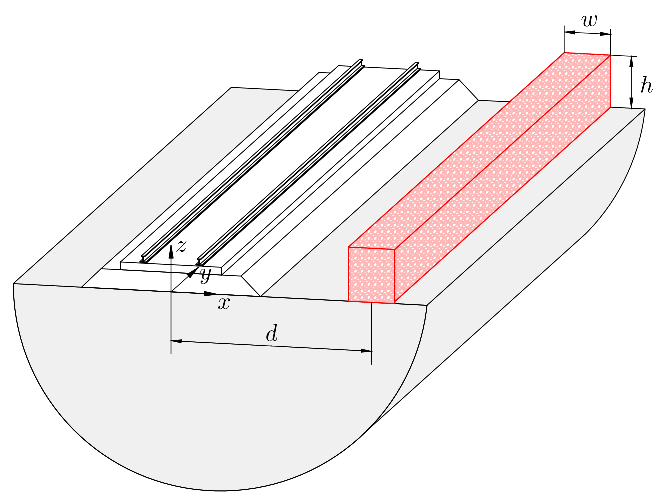

Fig. 2. Geometry of the 2.5D model for heavy masses next to a railway track.

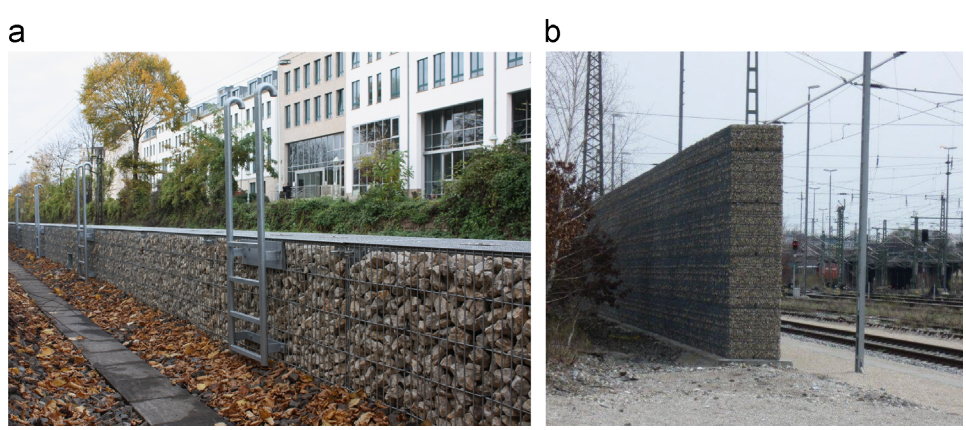

Fig. 1. Gabion walls installed as noise barriers next to railway tracks in (a) Bonn-Südstadt and (b) München Laim. Photos courtesy of (a) Deutsche Bahn AG, Gerd LeDosquet and (b) Deutsche Bahn AG, Hans-Jörg Terno.