Ground-borne vibrations and re-radiated noise in buildings from underground railways

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An efficient and modular numerical model is presented for the prediction of ground-borne vibrations and re-radiated noise in buildings due to underground railway traffic. The three-dimensional model covers the complete vibration propagation path including the generation of dynamic axle loads at the wheel-rail interface, dynamic track-tunnel-soil interaction, wave propagation in the soil, dynamic soil-structure interaction at the receiver and the calculation of the acoustic response inside rooms.

The three-dimensional dynamic track-tunnel-soil interaction problem is solved with a coupled periodic finite element-boundary element model of the track and the tunnel, embedded in a layered soil. The periodicity of the tunnel and the soil in the longitudinal direction is exploited using the Floquet transform, limiting the discretization effort to a single bounded reference cell. The track-tunnel-soil interaction problem is efficiently solved in the frequency-wavenumber domain; the wave field radiated into the soil is computed using an analytical formulation for the response of periodic media excited by moving loads. The dynamic soil-structure interaction problem at the receiver side is solved with a three-dimensional coupled boundary element-finite element formulation, allowing to determine vibration levels along structural elements. An acoustic spectral finite element method is used to predict the acoustic response in the rooms of the building, accounting for a weak coupling between the structural and acoustic vibrations.

The numerical model is validated by means of several experiments that have been performed at a site in Regent's Park on the Bakerloo line of London Underground. Vibration measurements have been performed on the axle boxes of a test train, on the rail, the tunnel invert and the tunnel wall, and in the free field, both at the surface and at a depth of 15 m. Prior to these vibration measurements, the dynamic soil characteristics and the track characteristics have been determined. The Bakerloo line tunnel has been modelled using the coupled periodic finite element-boundary element approach and free field vibrations due to the passage of the test train at different speeds have been predicted. The correspondence between the predicted and measured response in the tunnel is reasonably good, although some differences are observed in the free field. These discrepancies are explained on the basis of various uncertainties involved in the problem. The variation in the response with train speed is similar for the measurements as well as the predictions.

The methodology is subsequently applied to investigate the efficiency of various vibration mitigation measures. A case history of a three-story reinforced concrete portal frame office building on top of a bored concrete subway tunnel embedded in a layered halfspace is considered. The response in the free field due to a moving train on an uneven track is predicted in the frequency range between 1 and 150 Hz using the coupled periodic finite element-boundary element approach. Vibrations and re-radiated noise in the building are subsequently estimated. The efficiency of three vibration countermeasures such as a floating slab track in the tunnel, base isolation of the building and a box-within-box arrangement in the room is assessed by computing the insertion gain. It is demonstrated that track isolation is a very effective measure to mitigate vibrations and re-radiated noise in buildings close to metro lines.

This study demonstrates the applicability of the coupled periodic finite element-boundary element model to make realistic predictions of the vibrations from underground railways.

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