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Understanding seismic waves generated by train traffic via modelling

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Trains have recently been recognised as powerful sources for seismic imaging and monitoring based on the correlation of continuous noise records, but the optimal use of these signals still requires a better understanding of their source mechanisms. In this study, we present a simple approach for modelling train-generated seismic signals inspired from early work in the engineering community, which assumes that seismic waves are emitted by sleepers regularly spaced along the railway and excited by the passage of the train wheels.

As already known in the engineering literature, we exemplify the importance of the spatial distribution of each axle load over the rail track on the high-frequency content of the corresponding source time functions, and therefore of the final seismograms resulting from the contributions of all sleepers. In practice, this high-frequency content mainly depends on ground stiffness beneath the railway.

Furthermore, we identify two end-member mechanisms to explain the two types of observations documented in the seismological literature. The first is the case of a single stationary source (fixed sleeper) excited by successive wheels of a train. This generates a harmonic spectrum characterised by a narrow spacing between frequency peaks related to a fundamental frequency $f_1 = V_{train} / L_w$ controlled by train speed and wagon length. The second is the case of a single moving load (single wheel) exciting all sleepers along the railway. This also yields a harmonic spectrum, but with a larger spacing between frequency peaks, related to a fundamental frequency $f_2 = V_{train} / \Delta_{sleeper}$ controlled by train speed and sleeper spacing. This moving source also generates a clear Doppler effect.

In more realistic cases, considering all wheels and all sleepers, our modelling well reproduces the observations, both in the frequency domain (harmonic spectra) and in the time domain (tremor-like emergent shapes). The dominance of the previously-identified end-member mechanisms depends on sleeper regularity: perfectly-regular sleepers generate signals dominated by the signature of a single moving load with fundamental frequency f_2 and a clear Doppler effect, while slightly-irregular sleepers generate signals dominated by the signature of stationary sources with fundamental frequency f_1 . We speculate that our modelling parameter of sleeper regularity actually depends on the properties of the railway infrastructure in real cases.

Finally, we discuss the perspectives of this work in view of using train-generated signals for seismic imaging and monitoring. In this regard, an important conclusion is that the frequency content of the signals is dominated by interferences between harmonic waves. Therefore, the exact value of the fundamental frequency at play matters less than the generation and preservation of the high frequencies, which depend on the distribution of the train load over the rail track and on propagation effects (medium heterogeneities, scattering and attenuation). Therefore, most of train traffic worldwide is expected to generate signals with a significant frequency content in the band [1 - 50] Hz of interest for seismic applications, in particular in the case of trains travelling at variable speeds which are expected to produce truly broadband signals.