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Improved analysis of ground vibrations produced by man-made sources

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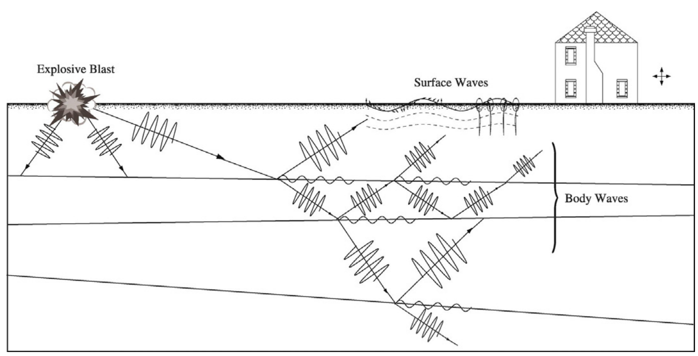
HIGHLIGHTS

- Study of ground vibrations due to blasting, rail, and road traffic
- Comparative evaluation of dominant frequency estimation methods undertaken
- Benefits of using time-frequency distributions investigated
- Improved localised approach presented to analyse complex ground vibrations

GRAPHICAL ABSTRACT



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ABSTRACT

Man-made sources of ground vibration must be carefully monitored in urban areas in order to ensure that structural damage and discomfort to residents is prevented or minimised. The research presented in this paper provides a comparative evaluation of various methods used to analyse a series of tri-axial ground vibration measurements generated by rail, road, and explosive blasting. The first part of the study is focused on comparing various techniques to estimate the dominant frequency, including time-frequency analysis. The comparative evaluation of the various methods to estimate the dominant frequency revealed that, depending on the method used, there can be significant variation in the estimates obtained. A new and improved analysis approach using the continuous wavelet transform was also presented, using the time-frequency distribution to estimate the localised dominant frequency and peak particle velocity. The technique can be used to accurately identify the level and frequency content of a ground vibration signal as it varies with time, and identify the number of times the threshold limits of damage are exceeded.

1. Introduction

Structures and occupants in urban areas are constantly subjected to ground vibrations due to various man-made activities. These ground vibrations can induce cosmetic and structural damage and can pose a nuisance to residents. Generally speaking, the term ground vibration is used when discussing man-made activities and excludes natural phenomena such as earthquakes, and associated topography amplification (e.g. the amplification of seismic waves due to ridges, slopes, and canyons (Srbulov, 2008)). Ground vibration encompasses most man-made sources of vibration, such as construction activities, or traffic

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loading. The various complexities associated with man-made sources (and ground characteristics) results in the generation and propagation of seismic waves, each with considerably different effects.

The generated ground vibrations are dependent on not only the type of excitation but also the attenuation characteristics of the medium (Auersch and Said, 2010; Kim and Lee, 2000). There are numerous seismic waves which can be generated due to a man-made source. The first type of waves is body waves, which travel through the medium itself. There are two types of body waves; the first is the compressional P-wave which produces longitudinal particle motion. The second body wave is the transverse S-wave, which has a particle motion perpendicular to the direction of propagation. Surface waves, such as the Rayleigh wave (R-wave), and the Love wave (Q-wave), travel along the surface at slower velocities in comparison to body waves and their amplitude rapidly decreases with depth. The particle motion of the R-wave is elliptic and retrograde, isolated in a small area near the surface and horizontal to the direction of wave propagation. While R-waves are always generated in the presence of a free surface, Q-waves are only observed when there is a soft superficial layer on top of a stiffer medium. Q-waves are produced by the interference due to multiple S-waves trapped in the soft layer and the particle motion is transverse. An illustrated example of the complex propagation of body and surface waves is presented in Fig. 1.

The International Organisation for Standardisation (ISO) outlined the typical ranges of frequency and particle motions of the ground-borne vibrations generated by man-made sources under ISO 4866 (Anon, 2010), given in Table 1. From the table, it is clear that the various man-made sources can produce high-level vibrations across a similar frequency range, with the exception of blasting which can produce ground vibrations with a higher level and broader frequency range. While there are many man-made activities which generate ground vibrations, this article focuses on the analysis from three different sources: explosive blasting, road traffic, and rail traffic.

Table 1
Typical ranges of particle motion, and frequency of ground vibrations produced by various man-made sources, from ISO 4866 (Anon, 2010).

Vibration source	Frequency range [Hz]	Particle velocity range [mm/s]	Particle acceleration range [m/s^2]
Traffic (road and rail)	1–100	0.2–50	0.02–1
Blasting	1–300	0.2–100	0.02–50
Pile driving	1–100	0.2–100	0.02–2
Outside machinery	1–100	0.2–100	0.02–1

- Blast-induced ground vibrations.
  Explosives used in the construction and mining industries are of growing concern due to the increasing number of mines and quarries located near urban areas. Explosive blasting is a considerably complex problem involving the detonation of explosives, the subsequent gas expansion in each borehole, the rock fragmentation, and even crack propagation and extension (Ainalis et al., 2017b). The total explosive energy is never entirely expended in the fragmentation of the medium, and the subsequent ground vibrations generated during each blasting sequence can travel great distances (Ainalis et al., 2017b).
- Traffic-induced ground vibrations.
  Ground vibrations produced by road and rail traffic are among the most extensively studied cases. In road transport, the complex dynamic interaction between heavy vehicles and irregular pavement surfaces can generate considerable vibrations in both the vehicle and ground (Ainalis et al., 2015; Hunaidi et al., 2000; Vogiatzis, 2013). The complexity in rail transport is mainly due to the difficulty in modelling the interaction between the sequential axle loads and the track and trackbed (Carels et al., 2012; Connolly et al., 2015; Connolly et al., 2016; Kouroussis et al., 2015; Kouroussis et al., 2014).

One common issue with the analysis of the ground vibrations generated by these sources is the short duration and highly transient nature. The amplitude and frequency content of the vibration records are expected to significantly vary with time and appropriate analysis techniques are required to interpret the rapid changes in frequency and amplitude. The research presented in this paper evaluates several techniques to analyse the ground vibrations generated by various man-made sources.

2. Ground vibration analysis methods

This section presents a brief state-of-the-art on the methods used to analyse ground vibrations, along with two time-frequency analysis techniques, that monitor and assess the likelihood of structural damage occurring due to the generated ground vibrations.

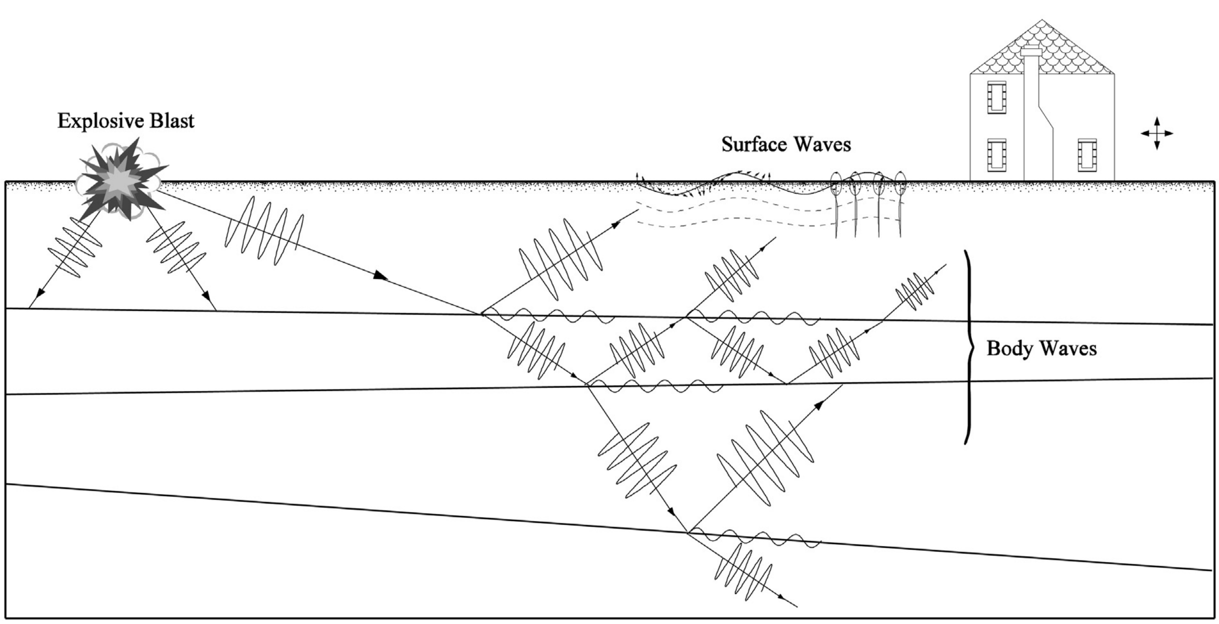

Fig. 1. Illustration of the complex propagation of the body and surface waves in the ground due to a man-made source, shown in this case due to an explosive blast.