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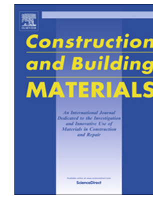

Benchmarking railway vibrations – Track, vehicle, ground and building effects

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HIGHLIGHTS

- A benchmark and review of over 230 technical railway vibration papers.
- Insights into holistic vibration prediction – from track to nearby buildings.
- Design guidelines for critical velocity based on site investigation data.
- Passenger comfort and railway track, ground vibration and structural vibration.
- Vibration effects, modelling, mitigation and future trends are synthesised.

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ABSTRACT

This paper reviews, synthesises and benchmarks new understandings relating to railway vibrations. Firstly, the effect of vibrations on passenger comfort is evaluated, followed by its effect on track performance. Then ground-borne vibration is discussed along with its effect on the structural response of buildings near railway lines. There is discussion of the most suitable mathematical and numerical modelling strategies for railway vibration simulation, along with mitigation strategies. Regarding ground borne vibration, structural amplification is discussed and how vibration mitigation strategies can be implemented. There is also a focus on determining how 'critical velocity' and 'track critical velocity' are evaluated – with the aim of providing clear design guidelines related to Rayleigh wave velocity. To aid this, conventional site investigation data is reviewed and related to critical velocity calculations. The aim is to provide new thinking on how to predict critical velocity from readily available conventional site investigation data.

1. Introduction

Over the last 50 years there has been increased demand for both passenger and freight railway carriage. One emerging way to satisfy this demand for increased capacity has been to create high speed passenger routes – thus freeing up capacity on the existing networks for classic rail serving urban conurbations and providing extra capacity for freight trains. Fig. 1 illustrates the evolution of railway train speeds since the 1960s.

With the creation of this extra capacity, much at high speeds – railway vibration is now a growing engineering challenge due to the higher speeds and heavier loads, in close proximity to densely populated urban environments. These faster or heavier trains impart greater forces into the track and can result in elevated vibration levels within both train and track, thus effecting passenger safety, maintenance costs and passenger comfort. In addition, when these vibrations propagate outward from the track they interact with their surrounding environment, which can cause negative side effects, particularly in urbanised areas.

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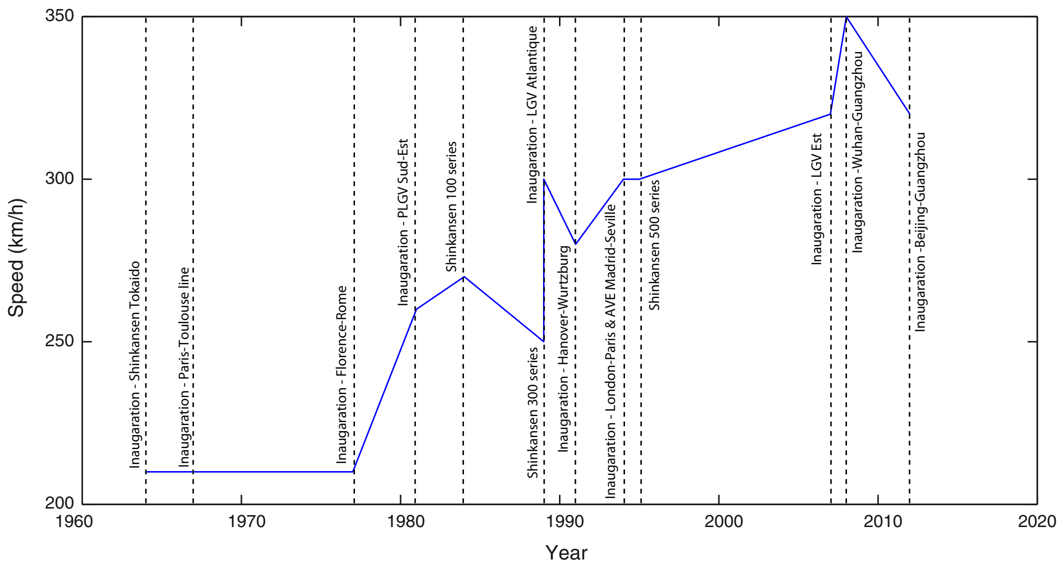

Fig. 1. Historical maximum train speed timeline (data taken from [1]).

This paper attempts to provide a comprehensive, detailed review of the vibrations generated within the train, track, ground and nearby structures, with each component being reviewed separately. For each element, vibration generation/propagation is described, along with practical considerations, mitigation possibilities and potential modelling approaches. It aims to do so in a manner that is useful for both academics and practitioners.

Firstly, as the wheel–rail interface is the source of vibration, the mechanisms that generate vibrations are discussed, along with general wave propagation theory. Then vibration propagation within the train vehicle is reviewed with a focus on passenger comfort which is becoming increasingly important on new lines. Next the role of the track is considered with a focus on numerical modelling and common vibration mitigation procedures. The role of the ground in the transfer of vibration from track to nearby structures is also analysed with a focus on modelling and critical velocity effects. Lastly, building vibration and the generation of re-radiated groundborne noise is reviewed. It should be noted that this work is complementary to other state of the art reviews into railway vibration, as listed in Table 1 below.

2. Background

2.1. Vibration generation

Railway vibration and noise arise from the forces generated at the contact point between train wheel and the rail. These forces can be broken down into their quasi-static and dynamic components [16]. Quasi-static forces arise from the train weight and are independent of train speed. They dominate the track response and near field, at distances up to one quarter of a wavelength [17]. If the track is considered as a Euler beam resting on an elastic foundation, the quasi static deflection of a typical track is shown in Fig. 2 and can be calculated analytically by

$$w(x,t) = w(x - v_0, t) = [\cos(\beta|x - v_0 t|) + \sin(\beta|x - v_0 t|)] \frac{P + m_w g}{8 E_r I_r \beta^3} e^{-\beta|x - v_0 t|}$$

where $w(x,t)$ is the track deflection at position x and time t. E_r and I_r are the Young's modulus and second moment of area of the Euler beam respectively. The train load is of constant force P, moving at a constant speed v_0, and K_f is the stiffness per unit length of the Winkler foundation. β is defined as:

$$\beta = \sqrt[4]{\frac{K_f}{4 E_r I_r}}$$

In contrast, dynamic excitation is speed dependent and arises from factors such as changes in stiffness due to sleeper placement, irregularities at the wheel/rail interface and the soil support

Table 1
Topics of previous review papers.

Topic of review paper	References
Railway vibration – modelling approaches	[2–4]
Track settlement	[5]
Track loading conditions	[6–9]
Vehicle dynamics	[10]
Track vibration mitigation	[11]
Tunnel vibration	[12]
Building vibration	[13,14]
Passenger comfort	[15]

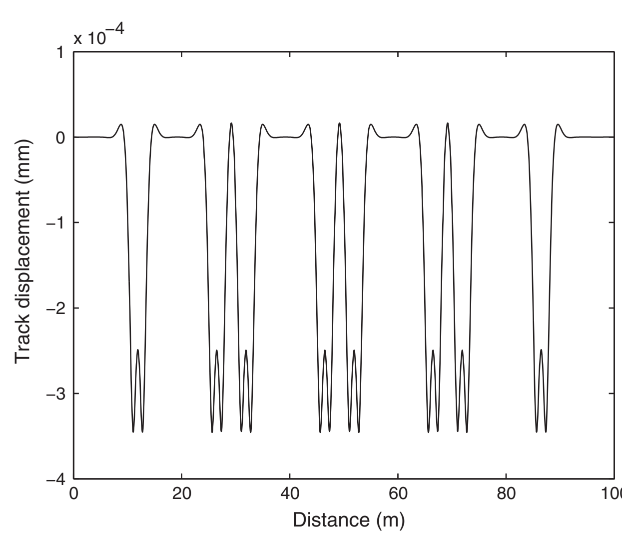

Fig. 2. Quasi-static track deflection.

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