Ground vibrations from high-speed railways: Prediction and mitigation

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Prediction and mitigation

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Preface

Over the last two decades, high-speed railways have continued to be developed in many countries in Europe, Asia and North America. The main advantages of high-speed railways are low air pollution per passenger and, of course, very high operational speeds that cannot be achieved by any other means of surface transport. Because of this, high-speed railways have become a viable alternative to air transport for travelling short and medium distances, such as within Europe. Speeds close to or greater than 300 km/h are now typical for high-speed railways, and train speeds still continue to grow. For example, for the new proposed high-speed railway network HS2, which is planned to be built in the UK by the 2030s, operational speeds are to be increased even further, up to 400 km/h.

It has been known for a long time that increased train speeds are usually associated with increased levels of railway noise and vibration. This is especially true in the case of railway-induced ground vibrations that can propagate to nearby buildings and cause annoyance to local residents both directly and via associated air-borne noise. When train speeds become large enough (i.e. larger than certain velocities of elastic waves propagating in the supporting ground or in more complex systems involving tracks, ground and embankments), some specific vibration generation mechanisms can occur, in addition to those already existing for relatively low (conventional) train speeds. Such specific mechanisms may cause substantial increases in the levels of vibrations both in rail track systems and in the supporting ground. In particular, a very large increase in generated ground vibrations may occur if train speeds exceed the velocity of Rayleigh surface waves in the supporting ground, which is possible for relatively soft grounds. If this happens, a ‘ground vibration boom’ takes place, similar to a ‘sonic boom’ from supersonic aircraft. In addition to increased levels of generated ground vibrations, the effects of track critical velocities on rail deflections may result in train derailment – a matter of concern for high-speed railway operators. All these complex problems involving elastic wave propagation in track and ground systems, interaction of these coupled systems with moving trains as well as the final impact of generated elastic waves on nearby buildings should be studied in detail in order to be able to understand and control the associated dynamic phenomena. These studies should also include development of possible mitigation measures to reduce generated ground vibrations and their impact on the environment. This can be done in three ways: (*a*) by reducing the vibration at source by applying knowledge of track dynamics under the impact of moving trains; (*b*) by screening and dispersing generated ground vibrations (mainly Rayleigh surface waves) on their propagation from tracks to buildings; and (*c*) suppressing vibrations in building by applying special vibration-damping systems.

Although a variety of problems associated with ground vibrations from high-speed railways have been addressed in numerous journal papers and conference proceedings, there is still a lack of general reference books that could help the reader study these problems from different points of view and find answers to numerous theoretical and practical questions. The only existing book in this area, *Noise and Vibration from High-speed Trains* (edited by V. V. Krylov), was published in 2001 by Thomas Telford Publishing (now ICE Publishing). Since then, many new interesting and important investigations have been carried out in the field of railway-induced ground vibrations. In particular, substantial progress has been made in the study of critical velocities in realistic track–ground systems and their effects on generated ground vibrations. New theoretical and numerical approaches, including 2.5-dimensional (2.5D) approaches and hybrid methods, have been developed for prediction and possible mitigation of ground vibrations from underground and surface railways. The effects of layered soils and different types of embankments on generated ground vibrations have been thoroughly investigated both theoretically and experimentally. Therefore, there is a clear need for a new book to inform about the progress in this area. The present book addresses this need, reflecting recent developments in research into ground vibrations from high-speed railways.

Unlike the above-mentioned book *Noise and Vibration from High-Speed Trains* that covered both noise and vibration issues, the present book concentrates on ground vibrations only. The reason for this is the growing importance of vibration problems, both in tracks and ground, with the continuing increase of train speeds. The large rise in the number of journal publications on ground vibrations generated by high-speed trains indicates that there is a growing demand for guidance on this topic. This book aims to present in one volume the views of leading international experts in ground vibrations from high-speed trains on the current status of the problem of the generation and propagation of ground vibrations from high-speed trains and to discuss possible ways of reducing their environmental impact.

This book consists of 12 chapters, which can be read independently. Chapter 1 concentrates on fundamental problems of the dynamic behaviour of track–ground systems under the impact of high-speed trains. The authors consider numerical modelling of different types of tracks and soils as well as different train types. Chapter 2 starts by studying soil–structure interaction, echoing Chapter 1. The author then continues with a description of generated ground vibrations for different types of layered soil and train speeds. The obtained theoretical predictions are compared with the original measurements. The chapter finishes with a description of the proposed mitigation of train-induced ground vibrations due to vehicle–track interaction. Chapter 3 describes recently developed computational tools capable of predicting ground vibrations from surface and underground railways. The authors present several numerical models, and illustrate their operation with a number of practical examples. Chapter 4 presents semi-analytical approaches to the theory of track–ground interaction, echoing the developments described in Chapters 1 and 2 and paying special attention to critical velocities and instabilities of moving systems (trains). The author considers different types of elastic and viscoelastic foundations modelling the supporting ground as well as different types of moving loads considered as oscillating systems. The authors of Chapter 5 describe their studies of ground vibrations from high-speed non-ballasted railways. The investigations include numerical modelling and field experiments. Chapter 6 reports the results of numerical predictions of vibrations of high-speed railways using time-domain approaches. The author considers multibody system simulation involving railway vehicle–track dynamics. The chapter finishes by consideration of the supercritical phenomenon and of the effect of the track earthwork profile. Chapter 7 presents the 2.5D approach to modelling ground vibrations from high-speed railways. The author considers both the 2.5D finite-element and boundary element methods, which are then applied to different practical problems, including calculation of the ground vibration power spectrum for a given wheel–rail roughness power spectral density. The authors of Chapter 8 describe hybrid prediction methods for vibrations from high-speed railways. Reflecting the three main stages of generation, propagation and reception of railway-generated ground vibrations, the hybrid model implementation considers the source term, the propagation term and the receiver term, respectively. Different practical scenarios are then considered. Chapter 9 describes some benchmark solutions for vibrations generated by moving sources in tunnels, echoing Chapter 3. Field expansions and the application of boundary conditions are discussed, followed by numerical considerations. Chapter 10 describes the scoping assessment of ground and building vibrations generated by railway traffic. The authors consider track–soil forces, the track–soil transfer function, the free-field response and the building response. The author of Chapter 11 describes the finite-element method approach to train-induced vibrations of pile-supported embankments. Such embankments can be used for the mitigation of ground vibrations generated by high-speed trains. Vibration analysis of a pile-supported embankment is considered in detail, including the effect of critical speed. Finally, Chapter 12 presents the new proposed method of mitigation of railway-induced ground vibrations using the attenuation of Rayleigh surface waves propagating over areas of artificially created stochastically rough surfaces adjacent to railways.

This book describes mainly the results of recent academic research, and it is pitched largely at an advanced level. It is assumed that the ideal reader will have a university background in engineering, physics or applied mathematics. However, some of the chapters describe results of recent experimental investigations, and they are expected to be understood by a more general audience. The intended readership of the book is rather wide – scientists and engineers working on the prediction and remediation of railway-induced ground vibration, consultants dealing with environmental impact of railways, designers of new railway lines and so on. The book will be also useful for university students and railway enthusiasts.

Victor V Krylov