Noise and vibration from high-speed trains

This item was submitted to Loughborough University's Institutional Repository by the/an author.


Additional Information:

- This is the contents page and preface to the book, Noise and vibration from high-speed trains [© V. V. Krylov and Thomas Telford Limited]. The definitive version is available at: http://dx.doi.org/10.1680/navfht.29637 and further content is available from Google Books.

Metadata Record: https://dspace.lboro.ac.uk/2134/10014

Version: Published

Publisher: © V. V. Krylov and Thomas Telford Limited

Please cite the published version.
This item was submitted to Loughborough’s Institutional Repository (https://dspace.lboro.ac.uk/) by the author and is made available under the following Creative Commons Licence conditions.

For the full text of this licence, please go to:
http://creativecommons.org/licenses/by-nc-nd/2.5/
Noise and vibration from high-speed trains

Edited by

V. V. Krylov

Department of Civil and Structural Engineering
Nottingham Trent University
Published by Thomas Telford Publishing, Thomas Telford Ltd, 1 Heron Quay, London E14 4JD
URL: http://www.t-telford.co.uk

Distributors for Thomas Telford books are
USA: ASCE Press, 1801 Alexander Bell Drive, Reston, VA 20191-4400
Japan: Maruzen Co. Ltd, Book Department, 3–10 Nihonbashi 2-chome, Chuo-ku, Tokyo 103
Australia: DA Books and Journals, 648 Whitehorse Road, Mitcham 3132, Victoria

First published 2001

A catalogue record for this book is available from the British Library
ISBN: 0 7277 2963 2

© V. V. Krylov and Thomas Telford Limited 2001

All rights, including translation, reserved. Except as permitted by the Copyright, Designs and Patents Act 1988, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of the Publishing Director, Thomas Telford Publishing, Thomas Telford Ltd, 1 Heron Quay, London E14 4JD

This book is published on the understanding that the authors are solely responsible for the statements made and opinions expressed in it and that its publication does not necessarily imply that such statements and/or opinions are or reflect the views or opinions of the publishers. While every effort has been made to ensure that the statements made and the opinions expressed in this publication provide a safe and accurate guide, no liability or responsibility can be accepted in this respect by the authors or publishers

Typeset by Helius, Brighton
Printed and bound in Great Britain by MPG Books, Bodmin
Contents

Preface xi

Part 1. Generation and propagation of railway noise 1

1. Theory of generation of wheel/rail rolling noise 3
   D. J. Thompson
   1.1. Introduction 3
   1.2. Wheel dynamics 6
   1.2.1. Modes of vibration of a railway wheel 6
   1.2.2. Frequency response functions 9
   1.2.3. Effects of rotation 10
   1.3. Track dynamics 11
   1.3.1. Models for track vibration 11
   1.3.2 Frequency response functions 11
   1.3.3. Propagation along the track 12
   1.3.4. Sleeper response 13
   1.3.5. Effects of preload 13
   1.4. Roughness and interaction 14
   1.4.1. Equations of wheel/rail interaction 14
   1.4.2. Contact receptances 15
   1.4.3. Wheel and rail roughness 16
   1.4.4. Roughness modification at the contact zone 17
   1.4.5. Effective damping of a rolling wheel 18
   1.5. Radiation of sound 18
   1.5.1. Radiation from the wheel 18
   1.5.2. Radiation from the rail 20
   1.5.3. Radiation from the sleepers 21
   1.5.4. Aerodynamic sources 21
   1.5.5. Contribution of various sources 22
   1.6. Validation 23
   1.6.1. Experimental set-up 23
   1.6.2. Results 23
   1.6.3. Sine wheel tests 25
   1.7. Summary 25
   1.8. References 25
2. Wheel and rail excitation from roughness
   P. J. Remington
   2.1. Introduction 27
   2.2. Roughness modelling 29
       2.2.1. Average roughness model 31
       2.2.2. Distributed point-reacting spring model 33
       2.2.3. Full elastic-interaction model 40
   2.3. Roughness measurement 45
       2.3.1. Accelerometer-based devices 45
       2.3.2. Displacement-based devices 46
   2.4. Wheel and rail roughness characteristics 48
   2.5. Controlling wheel/rail noise at the source 53
       2.5.1. Roughness amplitude reduction 54
       2.5.2. Contact stiffness reduction and contact area increase 56
   2.6. Summary and conclusions 61
   2.7. References 62

3. High-speed train noise barrier tests at reduced scale
   J. D. van der Toorn
   3.1. Modelling outdoor sound propagation 65
   3.2. Scale modelling 65
       3.2.1. Similarity 65
       3.2.2. Measurable quantities 66
       3.2.3. Sound sources 66
       3.2.4. Receiver 70
       3.2.5. Atmospheric absorption 70
       3.2.6. Ground plane 71
       3.2.7. Barriers 73
   3.3. Scale modelling of railway noise 73
       3.3.1. An acoustical 1:32 scale model of a high-speed train 73
       3.3.2. An acoustical 1:32 scale model of a railway track 75
   3.4. Design of sound-absorbing barriers at a scale of 1:32 76
       3.4.1. Reference absorption curve 76
       3.4.2. Absorption extracted from excess attenuation 79
   3.5. Barrier tests 79
   3.6. Concluding remarks 81
   3.7. Acknowledgements 82
   3.8. References 82

4. Generic prediction models for environmental railway noise
   J. J. A. van Leeuwen
   4.1. Introduction 85
   4.2. Noise indicators 85
       4.2.1. Annoyance 85
       4.2.2. The noise level and the A-frequency-weighted noise level 86
4.2.3. Root mean square average 86
4.2.4. The maximum sound level $L_{A,\text{max}}$ 87
4.2.5. The long-time average sound level and the equivalent sound level 87
4.2.6. Statistical indicators 87
4.2.7. The basic indicators: $L_{A,\text{day}}$, $L_{A,\text{evening}}$, $L_{A,\text{night}}$ and $L_{A,24\text{~h}}$ 87
4.2.8. The composite indicator $L_{\text{den}}$ 88
4.3. Background to environmental-noise predictions 88
4.3.1. Why noise predictions? 88
4.3.2. Noise predictions for where? 88
4.3.3. What do we want to calculate? 89
4.3.4. When to use prediction models 91
4.3.5. How do you provide your input? 92
4.3.6. Sequence of noise predictions 93
4.4. What is a noise prediction model? 94
4.5. Noise prediction methodology 95
4.6. Source description model 96
4.6.1. Sound radiation characteristics 98
4.7. Propagation models 98
4.7.1. Geometrical spreading 100
4.7.2. Atmospheric absorption 101
4.7.3. Absorption by the ground 101
4.7.4. Attenuation due to a barrier or another obstacle 102
4.7.5. Additional types of attenuation 104
4.7.6. Reflections 105
4.7.7. Meteorological correction 105
4.8. Calculation of the noise level 106
4.8.1. Calculating the noise level with monopole or dipole noise sources 107
4.9. The determination of the sound propagation paths 109
4.10. Accuracy of a generic prediction model 112
4.11. Conclusions 113
4.12. References 114

Part 2. Measurements and control of railway noise 117
5. Measurements of railway noise 119
M. T. Kalivoda
5.1. Introduction 119
5.2. Exterior noise 120
5.2.1. Diagnostics 122
5.2.2. Type testing 126
5.2.3. Monitoring 144
5.2.4. Non-acoustic factors influencing exterior rail noise 149
5.3. Interior noise 158
5.3.1. Diagnostics 158
5.3.2. Type testing 160
5.4. References 160
6. **Means of controlling rolling noise at source** 163

*C. J. C. Jones and D. J. Thompson*

6.1. Introduction 163

6.2. Wheel noise 164

6.2.1. Damping treatments 164

6.2.2. Wheel shape optimization 166

6.2.3. Resilient wheels 168

6.2.4. Reduced wheel radiation 169

6.3. Track noise 170

6.3.1. Rail pad stiffness 170

6.3.2. Damping treatments 173

6.3.3. Rail shape optimization 174

6.3.4. Track mobility 176

6.3.5. Ballastless track forms 177

6.4. Roughness 177

6.4.1. Effects of braking system 177

6.4.2. Rail corrugation 179

6.4.3. Changes to the contact zone 180

6.5. Shielding 180

6.6. Measures in combination 180

6.7. Summary 182

6.8. References 182

Part 3. **Bursting noise associated with non-linear pressure waves in tunnels** 185

7. **Micropressure waves radiating from a Shinkansen tunnel portal** 187

*T. Maeda*

7.1. Introduction 187

7.2. Generation of a compression wave by a train 189

7.3. The propagation of the compression wave through the tunnel 192

7.4. Radiation of the micropressure wave out of the tunnel portal 198

7.5. Measures to decrease the micropressure waves 203

7.5.1. Measures applied to Shinkansen tunnels 204

7.5.2. Measures applied to Shinkansen trains 206

7.6. References 210

8. **Emergence of an acoustic shock wave in a tunnel and a concept of shock-free propagation** 213

*N. Sugimoto*

8.1. Introduction 213

8.2. Overview of the problem 216

8.3. Analysis of the near field 219

8.3.1. Linear acoustic theory 219

8.3.2. Evaluation of the pressure field 220
10.3. Experimental results 291
10.3.1. The passage of a Thalys HST at a speed $v = 314$ km/h 291
10.3.2. The influence of the train speed 293
10.4. Krylov’s analytical prediction model 298
10.4.1. The force transmitted by a sleeper due to a single axle load 300
10.4.2. The forces transmitted by all sleepers due to a train passage 301
10.4.3. Response of the soil 302
10.5. Analytical predictions 303
10.5.1. Track response 303
10.5.2. Green’s functions 305
10.5.3. Free-field response 306
10.6. Conclusion 312
10.7. Acknowledgements 313
10.8. References 313

11. High-speed trains on soft ground: track–embankment–soil response and vibration generation 315

C. Madshus and A. M. Kaynia

11.1. Introduction 315
11.2. Case study 315
11.2.1. Test site and test programme 317
11.2.2. Observations 317
11.3. Measurements 323
11.4. Dynamic properties of soil and embankment materials 326
11.5. Numerical simulation 333
11.5.1. Simulations and comparisons 336
11.6. Countermeasures 337
11.7. Physical model 339
11.8. Environmental vibration 342
11.9. Conclusions 343
11.10. Acknowledgements 344
11.11. References 344

12. Ground vibrations alongside tracks induced by high-speed trains: prediction and mitigation 347

H. Takemiya

12.1. Introduction 347
12.2. Basic theory 349
12.2.1. Solution method for a moving load 349
12.2.2. Track–ground dynamic interaction 351
12.2.3. Modelling of a loading by train 354
12.2.4. Ground vibration due to a quasi-static moving load 355
12.2.5. Elastodynamic analysis 357
CONTENTS

12.3. Features of the response for a moving load 363
  12.3.1. Dispersion characteristics of layers 363
  12.3.2. Transient responses 364
  12.3.3. Ground surface motions 374
  12.3.4. Response of track–ground system 375
12.4. Field measurements, theoretical prediction and mitigation 377
  12.4.1. Measurement data 377
  12.4.2. Wave propagation at the site 380
  12.4.3. Prediction of ground motions 383
  12.4.4. Vibration mitigation measures – WIBs 385
12.5. Conclusion 387
12.6. Appendix: layer stiffness matrix 389
  12.6.1. The layer stiffness matrix with respect to stresses acting on the z plane \{\sigma_{1z}, \sigma_{2z}, \sigma_{3z}\} 389
  12.6.2. The stiffness matrix for a half-space with respect to stresses acting on the z plane 391
12.7. References 391

Part 5. Ground vibrations generated by underground trains 395

13. Prediction and measurements of ground vibrations generated from tunnels built in water-saturated soil 397
  S. A. Kostarev, S. A. Makhorykh and S. A. Rybak
  13.1. Introduction 397
  13.2. Waves radiated by a cylindrical oscillating shell 398
  13.3. Transmission of vibrations to the ground surface 405
  13.4. Two-level elastic system for vibration reduction 407
  13.5. Method of estimation of the elastic parameters and damping of layered ground 411
  13.6. Discussion 418
  13.7. Acknowledgements 421
  13.8. References 421

14. Measures for reducing ground vibration generated by trains in tunnels 423
  H. E. M. Hunt
  14.1. Introduction 423
  14.2. Tunnels with floating slabs 424
  14.3. Vibration from railway tunnels 425
  14.4. Conclusions 430
  14.5. References 430

Index 431
Preface

During the last decade, high-speed railways have become one of the most advanced and fast-developing branches of transportation. The reasons for this are the relatively low air pollution per passenger, compared with road vehicles, and the very high speeds achievable by the most advanced modern trains – French TGV, Eurostar, Thalys, the German ICE, British high-speed trains, the Italian Pendolino, the Swedish X2000, the Japanese Shinkansen, etc. For example, for French TGV trains a maximum speed of more than 515 km/h was achieved in May 1990, and speeds close to 300 km/h are now typical for commercially used TGV and Eurostar trains. Prospective plans for the year 2010 assume that the New European Trunk Line will have connected Paris, London, Brussels, Amsterdam, Cologne and Frankfurt by a high-speed railway service that will provide fast and more convenient passenger communications within Europe. Similar plans are being developed in the USA and Japan. All these make high-speed railways increasingly competitive with air and road transport at short and medium distances.

Unfortunately, when train speeds increase, the intensity of railway-generated noise and vibration generally becomes higher. And this represents a major environmental problem for nearby residents, schools and hospitals. Railway operators and local authorities need to be familiar with those new aspects of railway noise and vibration which are associated with high-speed trains. Almost all known mechanisms of generation of railway noise and vibration are speed dependent. These include both wheel/rail rolling noise and aerodynamic noise, the latter being important for train speeds higher than 300 km/h. This applies even more so for generated ground vibrations. For example, when train speeds exceed certain critical velocities of elastic waves propagating in the ground or in the track/ground system, new mechanisms of generation of ground vibrations may appear, in addition to those already known for conventional trains. In particular, a very large increase in generated ground vibrations may occur if train speeds exceed the velocity of Rayleigh surface waves in the ground. If this happens, a ground vibration boom takes place, similar to the sonic boom normally associated with supersonic aircraft. The first observation of a ground vibration boom took place on the recently opened high-speed railway line in Sweden. This line was built on very soft soil, with Rayleigh wave velocities as low as 45 m/s. This is why an increase in train speed from 140 to
180 km/h was sufficient for the phenomenon to be observed, thus indicating that ‘supersonic’ or (more precisely) ‘trans-Rayleigh’ trains have become today’s reality.

There are many other new physical effects and mechanisms of generation of noise and vibration which are specific to high-speed trains, for example the effects of train-induced non-linear pressure wave propagation in long tunnels, resulting in bursting noise radiated from the exit tunnel portals. In addition to these new effects, the ‘traditional’ mechanisms of generation of railway noise and vibration and their propagation from the source to a receiver demonstrate interesting new features and sometimes behave in a different way as train speeds increase. An example of this may be seen in the design of noise barriers for high-speed railway lines. Such barriers should take into account the spatial redistribution of noise generation mechanisms as train speeds increase.

Although some of the problems of noise and vibration from high-speed trains are being addressed in an increasing number of journal papers and conference proceedings, there is still no general reference book which could help a reader starting to study this problem to find answers to numerous theoretical and practical questions. The existing reviews concerning railway-generated noise and vibration deal largely with conventional trains and do not reflect specific high-speed problems. The present book, which consists of 14 chapters grouped into five parts, aims to fill this gap. It represents the views of leading international experts on the current status of the problems of generation and propagation of noise and vibration from high-speed trains and suggests possible ways of reducing their environmental impact. The book describes mainly the results of recent academic research and is pitched largely at an advanced level. In the light of this, it is assumed that the ideal reader will have a university background in engineering, physics or applied mathematics. At the same time, several chapters of the book have been written by railway noise and vibration practitioners. These chapters contain a lot of experimental data with interesting illustrations and can be understood by a less well-prepared audience.

The intended readership of the book is rather wide. It includes scientists and engineers working on the prediction and remediation of railway noise and vibration, environmental consultants investigating particular situations associated with the environmental impact of railways, local authorities, designers of new railway lines, etc. The book will also be useful to university students, railway enthusiasts and for members of the general public concerned with topical environmental issues.

Victor V. Krylov