

**Technische Universität Darmstadt
Systemzuverlässigkeit im Maschinenbau (SzM)
Prof. Dr.-Ing. H. Hanselka
Magdalenenstr. 4, 64289 Darmstadt**

TU Darmstadt
FB Maschinenbau



60065683

Noise and vibration from high-speed trains

Edited by

V. V. Krylov

*Department of Civil and Structural Engineering
Nottingham Trent University*



Thomas Telford

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

19. 12. 2012

FACHGEBIETSBÜCHEREI
Systemzuverlässigkeit und Maschinenakustik
TU Darmstadt.

2407 Akus

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
<i>D. J. Thompson</i>	
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	27
	<i>P. J. Remington</i>	
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	65
	<i>J. D. van der Toorn</i>	
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	85
	<i>J. J. A. van Leeuwen</i>	
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 $L_{A, \max}$	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_{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
	<i>M. T. Kalivoda</i>	
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
<i>C. J. C. Jones and D. J. Thompson</i>	
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
<i>T. Maeda</i>	
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
<i>N. Sugimoto</i>	
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

8.4.	Analysis of the far field	223
8.4.1.	Formulation	223
8.4.2.	Non-linear wave equation for the far field	226
8.4.3.	Evolution of the pressure wave into a shock	228
8.5.	Shock-free propagation	229
8.5.1.	Linear dispersion characteristics	229
8.5.2.	Effects of the array of Helmholtz resonators	234
8.5.3.	Suppression of shock formation	236
8.6.	Experimental verification	241
8.6.1.	Experimental set-up	241
8.6.2.	Experimental results	243
8.7.	Conclusion	244
8.8.	References	245
Part 4. Generation of ground vibrations by surface trains		249
9.	Generation of ground vibration boom by high-speed trains	251
	<i>V. V. Krylov</i>	
9.1.	Introduction	251
9.2.	Quasi-static pressure mechanism of generating ground vibrations	252
9.2.1.	Dynamic properties of the track	253
9.2.2.	Forces applied from sleepers to the ground	255
9.3.	Green's function for the problem	256
9.3.1.	Homogeneous elastic half-space	257
9.3.2.	Effect of layered ground structure	258
9.4.	Calculation of generated ground vibrations	262
9.4.1.	Vibrations from a single axle load	262
9.4.2.	Vibrations from a complete train	262
9.5.	Trans-Rayleigh trains	263
9.5.1.	General discussion	263
9.5.2.	Ground vibrations from TGV and Eurostar trains	265
9.5.3.	High-speed trains travelling underground	270
9.5.4.	Waveguide effects of embankments on generated ground vibration fields	277
9.6.	Conclusions	281
9.7.	Acknowledgements	282
9.8.	References	282
10.	Free-field vibrations during the passage of a high-speed train: experimental results and numerical predictions	285
	<i>G. Degrande</i>	
10.1.	Introduction	285
10.2.	The <i>in situ</i> measurements	287
10.2.1.	The train	287
10.2.2.	The track	288

10.2.3.	The soil	288
10.2.4.	The experimental set-up	290
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
	<i>C. Madshus and A. M. Kaynia</i>	
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
	<i>H. Takemiya</i>	
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

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 $\{\sigma_{12} \sigma_{22} \sigma_{32}\}$	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
	<i>S. A. Kostarev, S. A. Makhortykh and S. A. Rybak</i>	
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
	<i>H. E. M. Hunt</i>	
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