

Contents

Abstract	<i>i</i>
Resumen	<i>iii</i>
Resum	<i>v</i>
Acknowledgements	<i>vii</i>
Contents	<i>ix</i>
1 INTRODUCTION	15
1.1 Motivation and background.....	15
1.2 Objectives.....	16
1.3 Outline.....	17
2 CURVE SQUEAL.....	19
2.1 Introduction	19
2.2 Curving behaviour.....	22
2.2.1 Insertion of a free wheelset in a curve.....	24
2.2.2 Insertion of a bogie in a curve.....	26
2.3 Frictional excitation mechanisms	27
2.3.1 Negative friction slope model	28
2.3.2 Constant friction mechanism.....	30
2.4 Other types of excitation	32
2.4.1 Excitation by roughness	32
2.4.2 Excitation by discrete irregularities.....	33
2.5 Conclusions	34
3 REVIEW OF THE MODELLING OF THE VEHICLE/TRACK DYNAMIC INTERACTION	35
3.1 Introduction	35
3.2 Wheelset models.....	38

3.3	Track models	39
3.4	Contact models	41
3.4.1	Normal contact problem.....	42
3.4.2	Tangential contact models.....	45
3.4.3	Transient contact conditions during squeal.....	49
3.5	Train/track dynamic interaction models	50
3.5.1	Frequency-domain models	50
3.5.2	Time-domain models	55
3.6	Conclusions	57
4	WHEEL/RAIL ROLLING CONTACT MODELLING	59
4.1	Introduction	59
4.2	Wheel/rail rolling contact model	61
4.2.1	Elastic model.....	63
4.2.2	Kinematic model	66
4.3	Numerical algorithm.....	71
4.3.1	Algorithm for solving the normal contact problem.....	72
4.3.2	Algorithm for solving the tangential contact problem	75
4.4	Numerical issues.....	82
4.4.1	Numerical errors due to spatial/temporal discretisations	82
4.4.2	Numerical errors due to a falling friction coefficient.....	86
4.5	Regularisation of Coulomb's law on a steady-state tangential contact problem	90
4.5.1	Introduction of the regularisation of Coulomb's law	90
4.5.2	Regularisation on a steady-state tangential contact problem	93
4.6	Study of falling friction effect on rolling contact parameters.....	95
4.6.1	Introduction	95
4.6.2	First analysis through a 2D approach.....	97
4.6.3	Parameters of the rolling contact model.....	102

4.6.4	Comparison to experimental data.....	104
4.7	Conclusions	109
5	VEHICLE/TRACK DYNAMIC INTERACTION MODEL IN THE TIME DOMAIN.....	113
5.1	Introduction	113
5.2	Generation of the train/track interaction model through substructuring techniques	114
5.3	Flexible and rotating wheelset model.....	115
5.4	Cyclic and flexible track model based on the Moving Element Method....	123
5.4.1	Formulation of the 1D Moving Element Method.....	125
5.4.2	3D Moving Element Method	131
5.4.3	Rail support models.....	138
5.4.4	Pseudo-static deformation of the track based on MEM	141
5.5	Method for the temporal solving of the train/track interaction.....	143
5.5.1	Modal approach for reducing the dimension of the problem	143
5.5.2	Static modal correction	145
5.5.3	Method for decoupling the system after a modal approach	147
5.5.4	Simpson and Magnus integrators for solving the modal system.....	150
5.5.5	Magnus expansion for periodic interaction forces	152
5.6	Calculation of interaction forces.....	159
5.6.1	Calculation of wheel/rail contact forces.....	159
5.6.2	Calculation of forces in the rail supports	164
5.7	Conclusions	165
6	APPLICATIONS OF THE WHEELSET/TRACK INTERACTION MODEL	167
6.1	Introduction	167
6.2	Contributions of the 3D MEM track model in the high-frequency domain for a single wheelset	168
6.2.1	Introduction.....	168

6.2.2	Vehicle model	168
6.2.3	Track model	171
6.2.4	Wheel/rail contact model	172
6.2.5	Results.....	173
6.2.6	Discussion	177
6.3	Linear stability analysis and non-linear time-domain simulation for a single wheelset negotiating a curve	178
6.3.1	Introduction.....	178
6.3.2	Wheel and track models	179
6.3.3	Wheel/rail contact model	182
6.3.4	Solution procedure	183
6.3.5	Results.....	185
6.3.6	Discussion	190
6.4	Investigation of stick/slip oscillations in curving conditions for constant friction	191
6.4.1	Introduction.....	191
6.4.2	Wheelset, track and contact models	191
6.4.3	Results.....	193
6.4.4	Discussion	206
6.5	Conclusions	207
7	CONCLUSIONS AND FUTURE WORK.....	211
7.1	Conclusions	211
7.2	Future work	217
APPENDIX A: Influence coefficients for the elastic half-space		219
APPENDIX B: Hertzian model for normal contact		223
APPENDIX C: Published articles linked to the Thesis		229
References		257