Contents

Foreword *xv*
About the Authors *xvii*
Acknowledgements *xix*

1 Introduction to High-Speed Railway Bridges *1*
José Romo
1.1 Book's Content *1*
1.2 What is Special About a High-Speed Rail Bridge? *2*
1.2.1 Dynamic Amplification and Resonance *2*
1.2.2 Rail Traffic Security *3*
1.2.3 Passenger's Comfort *3*
1.2.4 Track–Structure Interaction *4*
1.3 General Ideas on High-Speed Railway Bridges *4*
1.4 Evolution and Trends in High-Speed Bridge Design *6*
1.4.1 First High-Speed Bridges *6*
1.4.1.1 First-Generation German Bridges *6*
1.4.1.2 First-Generation French Bridges *8*
1.4.1.3 First-Generation Spanish Bridges *8*
1.4.2 Recent High-Speed Bridges *9*
1.4.2.1 Recent French Bridges *9*
1.4.2.2 Second-Generation German Bridges *9*
1.4.2.3 Recent Spanish HSRB *10*
1.4.2.4 Bridges for High-Speed Railway Lines in China *10*
1.4.2.5 British High-Speed Bridges *12*
1.4.2.6 High-Speed Railway Bridges in the USA *12*
1.4.3 Conclusions *12*
1.4.3.1 Viaducts *13*
1.4.3.2 Long-Span Bridges *13*
1.5 The Landscape and the Design of High-Speed Railway Bridges *13*
1.5.1 The Traveller's Experience *13*
1.5.2 The Bridge in the Landscape *15*
1.5.2.1 Long Viaducts with Low Vertical Level *16*
1.5.2.2 Long Viaducts with Medium or High Level *16*

1.6 Railway Bridges as Landmarks or Icons of a Line *22*
1.7 Railway Bridge's Legacy *23*
1.8 Building for the 21st Century *24*
1.9 Conclusions *24*
References *25*

2 Track for High-Speed Bridges *29*
Manuel Cuadrado
2.1 Introduction *29*
2.2 Specific Criteria for Railway Bridges *29*
2.2.1 General Criteria *29*
2.2.2 Specific Criteria for High-Speed Bridges *31*
2.3 Description of the Track Superstructure *31*
2.3.1 Track Components: Definitions, Functions, and Qualities *32*
2.3.1.1 Ballast *32*
2.3.1.2 Sleepers *32*
2.3.1.3 Fasteners *33*
2.3.1.4 Rails *33*
2.3.1.5 Switches and Crossings *34*
2.3.2 Most Important Conceptual Improvements *35*
2.3.2.1 Continuous Welded Rail (CWR) *35*
2.3.2.2 Track–Infrastructure Interaction: Better Understanding *36*
2.3.3 Evolution of the Different Components *36*
2.3.3.1 Ballast *36*
2.3.3.2 Sleepers *37*
2.3.3.3 Fastenings *39*
2.3.3.4 Rails *40*
2.3.4 Track Options Currently Available for High Speed *41*
2.3.4.1 Optimised Ballasted Track *41*
2.3.4.2 New Ballastless Track *43*
2.4 SLS Related to the Track *44*
2.4.1 Dynamic Interaction: Track–Vehicle *44*
2.4.2 Track Geometry Quality *46*
2.4.3 SLS Verifications Regarding Deformations and Vibrations *48*
2.4.3.1 Criteria for Traffic Safety *48*
2.4.3.2 Comfort Criteria *55*
References *57*

3 Conceptual Design of High-Speed Railway Bridges *61*
José Romo
3.1 Introduction *61*
3.2 Structural and Functional Specific Requirements for High-Speed Railway Bridges *62*
3.2.1 Introduction *62*
3.2.2 Control of Vertical Acceleration *62*

3.2.3 Rotation at Expansion Joints *62*
3.2.4 Horizontal Braking and Traction Forces and Relative Movements Between Deck and Infrastructure *62*
3.2.5 Track-Bridge Deck Interaction *63*
3.2.6 Expansion Joints *63*
3.3 Longitudinal Design Strategies *64*
3.3.1 General Concepts *64*
3.3.2 Ballasted Track *65*
3.3.3 Ballastless Track *66*
3.3.4 Actions to be Considered at the Fixed Point *66*
3.4 Design Situation of High-Speed Railway Bridges *66*
3.4.1 Short Crossing at Low Level *67*
3.4.2 Long Structures *67*
3.4.2.1 Low Profile *68*
3.4.3 High-Level Viaducts *71*
3.4.4 Long Span Structures *72*
3.5 Structural Types *72*
3.5.1 Straight Deck Solutions *72*
3.5.1.1 Simply Supported Deck *72*
3.5.1.2 Continuous Slab Concrete Decks *73*
3.5.1.3 Precast Beam Decks *74*
3.5.1.4 Concrete Box Hollow Sections *78*
3.5.1.5 Steel Beam Decks *80*
3.5.1.6 Steel Semi-through Decks *81*
3.5.2 Truss Bridges *82*
3.5.3 Arch Bridges *83*
3.5.3.1 Upper Deck Bridges *83*
3.5.3.2 Tied Arch Bridges *85*
3.5.4 Cable-Supported Bridges *85*
3.5.4.1 Extradosed Bridges *85*
3.5.4.2 Cable-Stayed Bridges *86*
3.5.4.3 Suspension Bridges *88*
3.5.4.4 Hybrid Bridges *89*
3.6 Structural Elements – Substructure *89*
3.6.1 Abutments *90*
3.6.1.1 Abutments with Expansion Joint in Structure Only *90*
3.6.1.2 Abutments with Expansion Joint in Structure and Track *90*
3.6.1.3 Fixed Abutments *91*
3.6.2 Piers *95*
3.6.3 Bearings *95*
3.6.3.1 General Bearing Layout *96*
3.7 Seismic Design *99*
3.7.1 Seismic Design Strategies *99*
3.7.2 Seismic Behaviour and Deck Articulation *99*
3.7.3 Longitudinal Behaviour *100*

3.7.3.1 Simply Supported Spans *100*
3.7.3.2 Continuous Deck *100*
3.7.4 Transversal Behaviour *101*
3.7.4.1 Introduction *101*
3.7.4.2 Fixed Transversal Support *101*
3.7.4.3 Transversal Damping Systems *102*
3.7.4.4 Damping Devices Plus Bearings *104*
3.8 Worked Example *106*
3.8.1 Introduction: Aim and Data *106*
3.8.1.1 Topography *106*
3.8.1.2 Plan and Elevation *106*
3.8.1.3 Railway Platform Section – Project Speed *106*
3.8.1.4 Water Flood Level *107*
3.8.1.5 Preliminary Geotechnical Data *107*
3.8.2 Methodology *107*
3.8.3 Critical Analysis of Existing Information *107*
3.8.4 Determination of the Length of the Viaduct, Selection of the Fixed Point *108*
3.8.5 Span Distribution *109*
3.8.6 Deck Pre-dimensioning *109*
3.8.7 Pre-design of the Infrastructure *112*
3.8.7.1 Fixed Point *112*
3.8.7.2 Bearings *112*
3.8.7.3 Abutments *112*
3.8.7.4 Piers *113*
References *115*

4 Design Basis *117*
José Romo
4.1 Introduction *117*
4.2 Design Situations *117*
4.3 Rail Traffic Actions and Other Actions Specific of Railway Bridges *118*
4.3.1 Permanent Loads *118*
4.3.1.1 Self-Weight *118*
4.3.1.2 Dead Loads *118*
4.3.1.3 Partial Ballast Removal *119*
4.3.2 Variable Loads *119*
4.3.2.1 Vertical Live Loads *119*
4.3.2.2 Traction and Braking Forces *121*
4.3.2.3 Centrifugal Forces *122*
4.3.2.4 Nosing Forces *123*
4.3.2.5 Aerodynamic Actions from Passing Trains *123*
4.3.2.6 Thermal Actions *123*
4.3.2.7 Bearing Friction *124*
4.3.3 Dynamics Effects *124*

4.3.3.1 Introduction *124*
4.3.3.2 Consideration of Dynamic Effects *125*
4.3.4 Railway Vehicle Derailment *125*
4.3.4.1 Railway Vehicle Impacts *125*
4.4 Application of Traffic Loads on Railway Bridges *126*
4.4.1 General *126*
4.4.1.1 Load Situations for Structural Design *127*
4.4.1.2 Load Situations for Limit State and Associated Acceptance Criteria *127*
4.4.2 Groups of Loads *127*
4.4.2.1 Characteristic Values of Multicomponent Action *127*
4.5 Traffic Loads for Fatigue *128*
4.6 Verifications Regarding Deformation and Vibrations for Railway Bridges *128*
4.7 Worked Example *129*
4.7.1 Introduction *129*
4.7.1.1 Calculation of Reactions at Bearings: Pre-dimensioning *130*
4.7.1.2 Calculation of Forces and Preliminary Design of the Fixed Abutment *130*
4.7.2 Actions *130*
4.7.2.1 Vertical Loads *130*
4.7.2.2 Horizontal Forces *131*
4.7.2.3 Wind Speed *132*
4.7.3 Calculation of Reactions at Bearings: Pre-dimensioning *133*
4.7.3.1 Vertical Forces *133*
4.7.3.2 Centrifugal Forces *134*
4.7.3.3 Wind at Unloaded State *135*
4.7.3.4 Wind with Live Load *135*
4.7.3.5 Reactions in Pier Heads *135*
4.7.3.6 Transversal Wind Bearings Reactions *136*
4.7.3.7 Loads per Bearings *136*
4.7.4 Fixed Abutment Loads *137*
4.7.4.1 Introduction *137*
4.7.4.2 Loads Transmitted by the Deck *137*
4.7.4.3 Forces Acting on the Abutment *138*
References *140*

5 Dynamic Behaviour of High-Speed Railway Bridges *143*
Alejandro Pérez-Caldentey
5.1 Introduction *143*
5.1.1 Resonance *143*
5.1.2 Envelope Dynamic Factor *144*
5.1.3 Dynamic Factor for Real Trains Obtained by Means of Analytical Formulations *145*
5.1.4 Dynamic Factor Obtained by Dynamic Analysis *147*

5.2 Methods for Dynamic Calculations and Structural Response *153*
5.2.1 Modal Superposition *153*
5.2.1.1 Matrix Formulation for Finite Element Analysis *153*
5.2.1.2 Formulation Based on Assumed Eigenforms *155*
5.2.2 Response to the Isolated Load *158*
5.2.3 Response to the Train Loads *162*
5.2.4 Effect of Damping *164*
5.2.5 Dynamic Interaction Between Vehicle and Structure *165*
5.3 Interoperability *167*
5.3.1 Introduction *167*
5.3.2 Universal Dynamic Train A *167*
5.3.3 Universal Dynamic Train B *167*
5.4 Application Examples *168*
5.4.1 Case Without Dynamic Analysis *168*
5.4.2 Case with Dynamic Analysis *169*
References *183*

6 Longitudinal Track–Structure Interaction *185*
Manuel Cuadrado and Alejandro Pérez-Caldentey
6.1 Introduction *185*
6.2 Problem Statement *185*
6.3 Model for Analysis *188*
6.3.1 General Considerations *188*
6.3.1.1 Rails *189*
6.3.1.2 Deck *189*
6.3.1.3 Interaction Between Rails and Track Base *189*
6.3.1.4 Bearings *189*
6.3.1.5 Columns *190*
6.3.1.6 Foundations *190*
6.4 Actions *191*
6.4.1 Temperature Variations *191*
6.4.1.1 Case Without Track Joint *191*
6.4.1.2 Case with Track Joint *191*
6.4.2 Traction and Braking Forces *191*
6.4.3 Vertical Loads *192*
6.4.4 Creep and Shrinkage *192*
6.4.5 Combination of Actions *193*
6.5 Verifications *194*
6.5.1 Verifications in Terms of Stresses *194*
6.5.2 Verifications in Terms of Displacements *195*
6.5.3 Criteria for Placing a Track Joint *196*
6.6 Rail Expansion Joints *197*
6.6.1 Design of REJs – Calculation of the Maximum Displacement *197*
6.6.2 Regulation *201*
6.6.3 Installation *201*
6.7 Longitudinal Schemes *203*

6.7.1 Continous Deck with a Single Fixed Point Located at One of the Abutments *203*
6.7.1.1 General *203*
6.7.1.2 Examples *204*
6.7.2 Continous Deck with the Fixed Point Located on One of the Central Piers *211*
6.7.2.1 General *211*
6.7.3 Simply Supported Spans Without Longitudinal Continuity, with a Fixed Point on Each Span *211*
6.7.3.1 General *211*
6.7.3.2 Example *212*
6.7.4 Fixed Points at the Two Abutments and a Structural Joint in the Middle *212*
6.7.4.1 General *212*
6.7.4.2 Example *214*
6.7.5 Deck Divided into Several Continuous Stretches, Each One Including Several Spans and One Fixed Point *216*
6.7.5.1 General *216*
6.7.5.2 Example *217*
6.7.6 Especial Situations *218*
6.7.6.1 Seismic Design *218*
6.7.6.2 Exceptional Geometries *226*
6.7.6.3 Example of Exceptional Geometry *226*
6.8 Example of Track–Structure Interaction *229*
6.8.1 Verification of Stresses in the Rails *229*
6.8.2 Verification of Horizontal Displacement at Abutment 2 Due to Braking and Traction Forces *231*
6.8.3 Verification of Horizontal Displacement at Abutment 2 Due to Vertical Train Loads *232*
6.8.4 Verification of Vertical Displacement at Abutment 2 Due to Vertical Train Loads and Temperature Variations *234*
References *235*

7 Conceptual Design for Maintenance *239*
José Romo
7.1 Introduction *239*
7.2 Accesses *240*
7.2.1 Decks *240*
7.2.2 Piers *240*
7.2.3 Abutments *241*
7.3 Bearings *242*
7.4 Expansion Joints *243*
7.5 Drainage *246*
7.6 Conclusions *248*
References *248*

Appendix A Basic Concepts of Dynamics *249*
Alejandro Pérez-Caldentey
A.1 Dynamics of Single Degree-of-Freedom Systems *249*
A.1.1 Dynamic Response to Moving Loads (Dynamic Load Factor) *249*
A.1.2 Basics of Resonance *257*
A.1.3 Solution of the Equation of Motion of a SDOF Damped System Subjected to a Triangular Load *258*
A.1.3.1 Auxiliary Expressions – Integrals I_1, I_2, and Their Derivatives *259*
A.1.3.2 Solution for the damped SDOF System Subjected to a Triangular Load *261*
Reference *262*

Appendix B Singular Bridges for High-Speed Railway Lines *263*
José Romo
B.1 Germany *263*
B.1.1 Gemünden Bridge *264*
B.1.1.1 Data Summary *264*
B.1.1.2 Description *264*
Further Reading *264*
B.1.2 Veitshöchheim Bridge *266*
B.1.2.1 Data Summary *266*
B.1.2.2 Description *266*
Further Reading *266*
B.1.3 Pfieffetal Bridge *268*
B.1.3.1 Data Summary *268*
B.1.3.2 Description *268*
Further Reading *268*
B.1.4 Nantenbach Bridge *270*
B.1.4.1 Data Summary *270*
B.1.4.2 Description *270*
Further Reading *270*
B.1.5 Unstruttal Bridge *272*
B.1.5.1 Data Summary *272*
B.1.5.2 Description *272*
Further Reading *272*
B.1.6 Gänsebachtal Viaduct *274*
B.1.6.1 Data Summary *274*
B.1.6.2 Description *274*
Further Reading *274*
B.1.7 Hämerten Bridge *276*
B.1.7.1 Data Summary *276*
B.1.7.2 Description *276*
Further Reading *276*
B.1.8 Filstal Bridge *278*
B.1.8.1 Data Summary *278*

B.1.8.2 Description *278*
Further Reading *278*
B.2 France *281*
B.2.1 Garde-Adhémar Viaduct *282*
B.2.1.1 Data Summary *282*
B.2.1.2 Description *282*
Further Reading *282*
B.2.2 Avignon Viaducts *284*
B.2.2.1 Data Summary *284*
B.2.2.2 Description *284*
Further Reading *284*
B.2.3 Mornas Viaduct *286*
B.2.3.1 Data Summary *286*
B.2.3.2 Description *286*
Further Reading *286*
B.2.4 Savoureuse Viaduct *288*
B.2.4.1 Data Summary *288*
B.2.4.2 Description *288*
Further Reading *288*
B.3 Spain *291*
B.3.1 Osera Bridge *292*
B.3.1.1 Data Summary *292*
B.3.1.2 Description *292*
Further Reading *292*
B.3.2 Llinars Del Vallès Viaduct *294*
B.3.2.1 Data Summary *294*
B.3.2.2 Description *294*
Further Reading *294*
B.3.3 Salto Del Carnero Railway Bridge, Saragossa *296*
B.3.3.1 Data Summary *296*
B.3.3.2 Description *296*
Further Reading *296*
B.3.4 Viaduct Over AP7 Riudellots de la Selva *298*
B.3.4.1 Data Summary *298*
B.3.4.2 Description *298*
Further Reading *298*
B.3.5 Contreras Bridge *300*
B.3.5.1 Data Summary *300*
B.3.5.2 Description *300*
Further Reading *300*
B.3.6 Viaduct Over River Ulla *302*
B.3.6.1 Data Summary *302*
B.3.6.2 Description *302*
Further Reading *302*
B.3.7 Almonte Bridge *304*

B.3.7.1 Data Summary *304*
B.3.7.2 Description *304*
Further Reading *304*
B.3.8 Alcántara Bridge *306*
B.3.8.1 Data Summary *306*
B.3.8.2 Description *306*
Further Reading *306*
B.4 Japan *309*
B.4.1 Yashiro Bridge *310*
B.4.1.1 Data Summary *310*
B.4.1.2 Description *310*
Further Reading *310*
B.4.2 Kumagawa Bridge *312*
B.4.2.1 Data Summary *312*
B.4.2.2 Description *312*
B.4.3 Sannai-Maruyama Bridge *314*
B.4.3.1 Data Summary *314*
B.4.3.2 Description *314*
Further Reading *314*
B.5 China *317*
B.5.1 Tianxingzhou Yangtze River Bridge *318*
B.5.1.1 Data Summary *318*
B.5.1.2 Description *318*
Further Reading *318*
B.5.2 Nanjing Dashengguan Yangtze River Bridge *320*
B.5.2.1 Data Summary *320*
B.5.2.2 Description *320*
Further Reading *320*
B.5.3 Tongling Yangtze River Bridge *322*
B.5.3.1 Data Summary *322*
B.5.3.2 Description *322*
Further Reading *322*
B.5.4 Beipanjiang Bridge *324*
B.5.4.1 Data Summary *324*
B.5.4.2 Description *324*
Further Reading *324*
B.5.5 Yachihe Bridge *326*
B.5.5.1 Data Summary *326*
B.5.5.2 Description *326*
Further Reading *326*
B.5.6 Wufengshan Yangtze River Bridge *328*
B.5.6.1 Data Summary *328*
B.5.6.2 Description *328*
Further Reading *328*

Index *331*