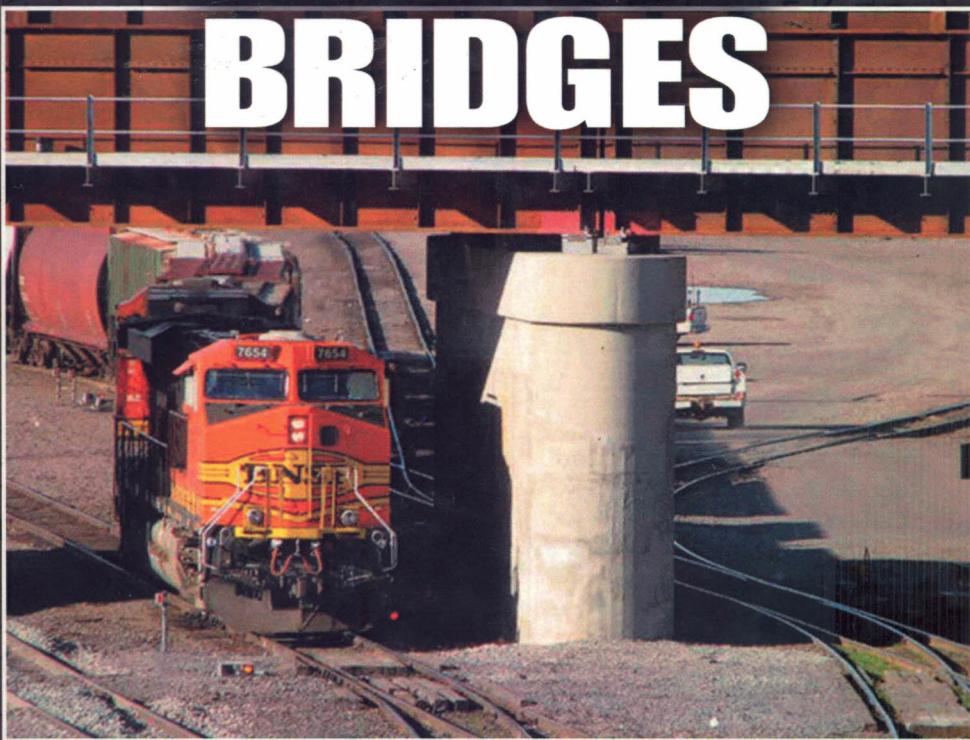
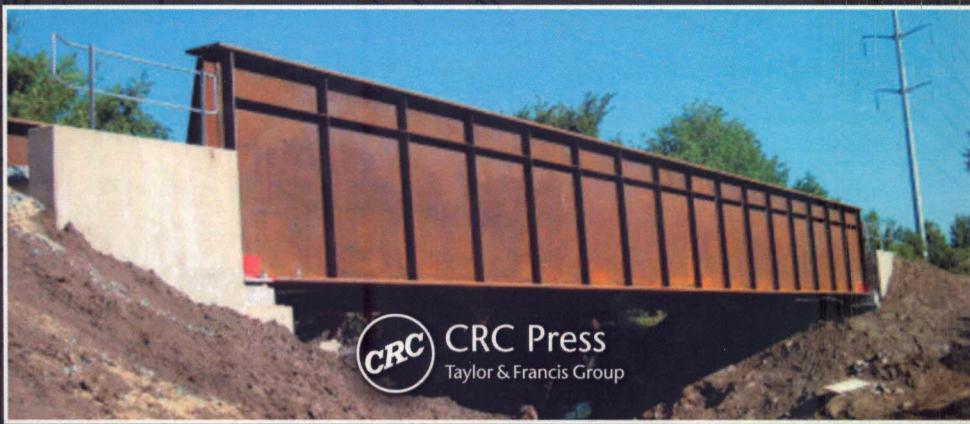


# DESIGN OF MODERN STEEL RAILWAY BRIDGES



**JOHN F. UNSWORTH**



CRC Press  
Taylor & Francis Group

---

# Contents

Preface .....	xiii
Acknowledgments .....	xvii
Author .....	xix
<b>Chapter 1</b> History and Development of Steel Railway Bridges .....	1
1.1    Introduction.....	1
1.2    Iron Railway Bridges .....	2
1.2.1    Cast Iron Construction.....	2
1.2.2    Wrought Iron Construction .....	8
1.3    Steel Railway Bridges .....	23
1.4    Development of Railway Bridge Engineering .....	32
1.4.1    Strength of Materials and Structural Mechanics ...	32
1.4.2    Railway Bridge Design Specifications .....	34
1.4.3    Modern Steel Railway Bridge Design .....	36
References .....	36
<b>Chapter 2</b> Steel for Modern Railway Bridges .....	39
2.1    Introduction.....	39
2.2    Engineering Properties of Steel.....	39
2.2.1    Strength.....	39
2.2.2    Ductility .....	41
2.2.3    Fracture Resistance .....	41
2.2.4    Weldability .....	43
2.2.5    Weather Resistance .....	43
2.3    Types of Structural Steel .....	47
2.3.1    Carbon Steels .....	47
2.3.2    High-Strength Low-Alloy Steels .....	47
2.3.3    Heat-Treated Low-Alloy Steels .....	48
2.3.4    High-Performance Steels .....	48
2.4    Structural Steel for Railway Bridges .....	49
2.4.1    Material Properties.....	49
2.4.2    Structural Steels Specified for Railway Bridges....	50
References .....	50

<b>Chapter 3</b>	Planning and Preliminary Design of Modern Railway Bridges .....	53
3.1	Introduction.....	53
3.2	Planning of Railway Bridges .....	54
3.2.1	Bridge Crossing Economics .....	54
3.2.2	Railroad Operating Requirements.....	55
3.2.3	Site Conditions (Public and Technical Requirements of Bridge Crossings).....	56
3.2.3.1	Regulatory Requirements .....	56
3.2.3.2	Hydrology and Hydraulics of the Bridge Crossing .....	56
3.2.3.3	Highway, Railway, and Marine Clearances.....	64
3.2.3.4	Geotechnical Conditions .....	65
3.2.4	Geometry of the Track and Bridge .....	66
3.2.4.1	Horizontal Geometry of the Bridge .....	66
3.2.4.2	Vertical Geometry of the Bridge .....	74
3.3	Preliminary Design of Steel Railway Bridges .....	74
3.3.1	Bridge Aesthetics .....	74
3.3.2	Steel Railway Bridge Superstructures .....	76
3.3.2.1	Bridge Decks for Steel Railway Bridges .....	77
3.3.2.2	Bridge Framing Details.....	80
3.3.2.3	Bridge Bearings.....	80
3.3.3	Bridge Stability .....	82
3.3.4	Pedestrian Walkways .....	82
3.3.5	General Design Criteria .....	83
3.3.6	Fabrication Considerations .....	83
3.3.7	Erection Considerations .....	85
3.3.8	Detailed Design of the Bridge .....	85
	References .....	85
<b>Chapter 4</b>	Loads and Forces on Steel Railway Bridges .....	87
4.1	Introduction.....	87
4.2	Dead Loads .....	87
4.3	Railway Live Loads .....	88
4.3.1	Static Freight Train Live Load .....	89
4.3.2	Dynamic Freight Train Live Load .....	92
4.3.2.1	Rocking and Vertical Dynamic Forces .....	92
4.3.2.2	Longitudinal Forces Due to Traction and Braking .....	107
4.3.2.3	Centrifugal Forces .....	115
4.3.2.4	Lateral Forces from Freight Equipment.....	118
4.3.3	Distribution of Live Load.....	119

4.3.3.1	Distribution of Live Load for Open Deck Steel Bridges .....	119
4.3.3.2	Distribution of Live Load for Ballasted Deck Steel Bridges .....	119
4.4	Other Steel Railway Bridge Design Loads.....	122
4.4.1	Wind Forces on Steel Railway Bridges .....	123
4.4.2	Lateral Vibration Loads on Steel Railway Bridges .....	127
4.4.3	Forces from the CWR on Steel Railway Bridges... 4.4.3.1 Safe Rail Separation Criteria .....	128 130
4.4.3.2	Safe Stress in the CWR to Preclude Buckling.....	131
4.4.3.3	Acceptable Relative Displacement between Rail-to-Deck and Deck-to-Span .....	132
4.4.3.4	Design for the CWR on Steel Railway Bridges .....	139
4.4.4	Seismic Forces on Steel Railway Bridges .....	139
4.4.4.1	Equivalent Static Lateral Force .....	139
4.4.4.2	Response Spectrum Analysis of Steel Railway Superstructures .....	140
4.4.5	Loads Relating to Overall Stability of the Superstructure .....	143
4.4.5.1	Derailment Load .....	143
4.4.5.2	Other Loads for Overall Lateral Stability .....	144
4.4.6	Pedestrian Loads .....	144
4.4.7	Load and Force Combinations for Design of Steel Railway Superstructures .....	144
	References .....	145

<b>Chapter 5</b>	Structural Analysis and Design of Steel Railway Bridges.....	149
5.1	Introduction.....	149
5.2	Structural Analysis of Steel Railway Superstructures .....	150
5.2.1	Live Load Analysis of Steel Railway Superstructures.....	150
5.2.1.1	Maximum Shear Force and Bending Moment Due to Moving Concentrated Loads on Simply Supported Spans .....	151
5.2.1.2	Influence Lines for Maximum Effects of Moving Loads on Statically Determinate Superstructures .....	162
5.2.1.3	Equivalent Uniform Loads for Maximum Shear Force and Bending Moment in Simply Supported Spans ...	182

5.2.1.4	Maximum Shear Force and Bending Moment in Simply Supported Spans from Equations and Tables .....	192
5.2.1.5	Modern Structural Analysis .....	192
5.2.2	Lateral Load Analysis of Steel Railway Superstructures .....	193
5.2.2.1	Lateral Bracing Systems .....	193
5.3	Structural Design of Steel Railway Superstructures .....	206
5.3.1	Steel Railway Superstructure Failure .....	207
5.3.2	Steel Railway Superstructure Design .....	208
5.3.2.1	Strength Design .....	208
5.3.2.2	Serviceability Design .....	210
5.3.2.3	Other Design Criteria for Steel Railway Bridges .....	224
	References .....	225
<b>Chapter 6</b>	<b>Design of Axial Force Steel Members .....</b>	227
6.1	Introduction .....	227
6.2	Axial Tension Members .....	227
6.2.1	Strength of Axial Tension Members .....	227
6.2.1.1	Net Area, $A_n$ , of Tension Members .....	228
6.2.1.2	Effective Net Area, $A_e$ , of Tension Members .....	230
6.2.2	Fatigue Strength of Axial Tension Members .....	232
6.2.3	Serviceability of Axial Tension Members .....	234
6.2.4	Design of Axial Tension Members for Steel Railway Bridges .....	238
6.3	Axial Compression Members .....	240
6.3.1	Strength of Axial Compression Members .....	240
6.3.1.1	Elastic Compression Members .....	240
6.3.1.2	Inelastic Compression Members .....	246
6.3.1.3	Yielding of Compression Members .....	251
6.3.1.4	Compression Member Design in Steel Railway Superstructures .....	251
6.3.2	Serviceability of Axial Compression Members .....	252
6.3.3	Axial Compression Members in Steel Railway Bridges .....	253
6.3.3.1	Buckling Strength of Built-up Compression Members .....	254
	References .....	272
<b>Chapter 7</b>	<b>Design of Flexural Steel Members .....</b>	273
7.1	Introduction .....	273
7.2	Strength Design of Noncomposite Flexural Members .....	273

7.2.1	Bending of Laterally Supported Beams and Girders .....	273
7.2.2	Bending of Laterally Unsupported Beams and Girders.....	275
7.2.3	Shearing of Beams and Girders .....	280
7.2.4	Biaxial Bending of Beams and Girders .....	282
7.2.5	Preliminary Design of Beams and Girders .....	282
7.2.6	Plate Girder Design .....	283
7.2.6.1	Main Girder Elements .....	284
7.2.6.2	Secondary Girder Elements .....	299
7.2.7	Box Girder Design .....	303
7.2.7.1	Steel Box Girders .....	303
7.2.7.2	Steel–Concrete Composite Box Girders .....	303
7.3	Serviceability Design of Noncomposite Flexural Members .....	303
7.4	Strength Design of Steel and Concrete Composite Flexural Members .....	311
7.4.1	Flexure in Composite Steel and Concrete Spans ...	313
7.4.2	Shearing of Composite Beams and Girders .....	316
7.4.2.1	Web Plate Shear.....	316
7.4.2.2	Shear Connection between Steel and Concrete .....	316
7.5	Serviceability Design of Composite Flexural Members....	318
	References .....	328
<b>Chapter 8</b>	<b>Design of Steel Members for Combined Forces .....</b>	<b>331</b>
8.1	Introduction.....	331
8.2	Biaxial Bending .....	331
8.3	Unsymmetrical Bending (Combined Bending and Torsion) .....	333
8.4	Combined Axial Forces and Bending of Members .....	346
8.4.1	Axial Tension and Uniaxial Bending .....	346
8.4.2	Axial Compression and Uniaxial Bending.....	347
8.4.2.1	Differential Equation for Axial Compression and Bending on a Simply Supported Beam .....	348
8.4.2.2	Interaction Equations for Axial Compression and Uniaxial Bending ....	353
8.4.3	Axial Compression and Biaxial Bending .....	356
8.4.4	AREMA Recommendations for Combined Axial Compression and Biaxial Bending .....	356
8.5	Combined Bending and Shear of Plates.....	357
	References .....	357

<b>Chapter 9 Design of Connections for Steel Members.....</b>	359
9.1 Introduction.....	359
9.2 Welded Connections .....	360
9.2.1 Welding Processes for Steel Railway Bridges .....	361
9.2.1.1 Shielded Metal Arc Welding .....	361
9.2.1.2 Submerged Arc Welding.....	362
9.2.1.3 Flux Cored Arc Welding.....	362
9.2.1.4 Stud Welding.....	362
9.2.1.5 Welding Electrodes .....	362
9.2.2 Weld Types.....	362
9.2.2.1 Groove Welds .....	363
9.2.2.2 Fillet Welds .....	363
9.2.3 Joint Types .....	365
9.2.4 Welded Joint Design .....	366
9.2.4.1 Allowable Weld Stresses .....	366
9.2.4.2 Fatigue Strength of Welds .....	367
9.2.4.3 Weld Line Properties .....	367
9.2.4.4 Direct Axial Loads on Welded Connections .....	369
9.2.4.5 Eccentrically Loaded Welded Connections .....	371
9.3 Bolted Connections .....	379
9.3.1 Bolting Processes for Steel Railway Bridges .....	379
9.3.1.1 Snug-Tight Bolt Installation.....	379
9.3.1.2 Pretensioned Bolt Installation .....	380
9.3.2 Bolt Types.....	381
9.3.2.1 Common Steel Bolts.....	381
9.3.2.2 High-Strength Steel Bolts .....	381
9.3.3 Joint Types .....	381
9.3.4 Bolted Joint Design .....	382
9.3.4.1 Allowable Bolt Stresses .....	382
9.3.4.2 Axially Loaded Members with Bolts in Shear .....	392
9.3.4.3 Eccentrically Loaded Connections with Bolts in Shear and Tension .....	400
References .....	420
<b>Index .....</b>	421