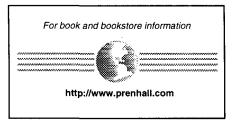
# BRIDGE STRENGTHENING AND REHABILITATION

Petros P. Xanthakos Consulting Engineer





Prentice Hall PTR Upper Saddle River, New Jersey 07458

# Contents

	PREF	ACE	xiii
CHAPTER 1	THE BRIDGE PROGRAM AND BRIDGE NEEDS		
	1.1	The Status of the Nation's Highways and Bridges: Conditions and Performance 1	
	1.2	The National Bridge Inventory (NBI) and Other Programs 7	
	1.3	Bridge Management Systems: An Overview 10	
	1.4	Recording and Coding Policies 13	
	1.5	Priority Ranking 22	
	1.6	Systemwide Analysis of Bridges 41	
	1.7	FHWA Ongoing Programs 42	
	'	References 49	
CHAPTER 2	COST	EFFECTIVENESS ANALYSIS AND SERVICE LIFE ESTIMATES	51
	2.1	Project-Level Analysis 51	
	2.2	Cost Effectiveness of Evaluation Method 61	
	2.3	Analytical Models 64	
	2.4	Sensitivity Analysis of Economic Model: Example 74	
	2.5	Incremental Benefit/Cost Ratio 77	
	2.6	Bridge Deterioration Studies and Service Life Estimates 91	
	2.7	Needs Prediction Models 101	
			vii

- 2.8 Network Level Analysis 111
- 2.9 Overview of FHWA Philosophy 115 References 121

#### CHAPTER 3 ASSESSMENT OF BRIDGE DEFICIENCIES

- 3.1 Inspection Policies and Procedures 123
- 3.2 Bridge Systems, General Overview 127
- 3.3 Defects and Definitions 146
- 3.4 Inspection of Bridge Members 152
- 3.5 Procedures for Detecting Defects and Deterioration 158
- 3.6 Assessment of Deficiencies Below the Waterline 187
- 3.7 Full-Scale Testing 190
- 3.8 Current Practice 192 References 196

### CHAPTER 4 STRUCTURAL CAPACITY ANALYSIS

- 4.1 Overall Structure Adequacy Appraisal 203
- 4.2 Specifications for Checking Capacities of Existing Bridges 205
- 4.3 Allowable Stress Design (ASD) 211
- 4.4 Load Factor Design (Strength Design) 215
- 4.5 Design Examples, Steel Beams: Load Factor 222
- 4.6 Design Examples, Concrete Superstructure: Load Factor Method 227
- 4.7 Special Considerations for Bridge Foundations 232
- 4.8 Design Example, Substructure Capacity Analysis Timber Pile Foundations 234
- 4.9 Assessment of Trusses and Truss Members 237
- 4.10 Design Example 4–5, Truss Bridge 241
- 4.11 Prestressed Concrete 249
- 4.12 Special Considerations for Columns 258
- 4.13 Design Example 4–7, Capacity Analysis: Pile Foundations and Spread Footings 262
- 4.14 Two-Girder Steel Bridges: Capacity Analysis and Rating 269 References 284

#### CHAPTER 5 METHODS OF STRENGTHENING EXISTING BRIDGES

- 5.1 Background and Objectives 286
- 5.2 Bridges in Need of Strengthening: Statistical Data 288
- 5.3 Composite Action Between Deck and Beams 292
- 5.4 Increasing the Strength of Bridge Members 305
- 5.5 Increasing the Geotechnical Capacity of Bridge Foundations 321
- 5.6 Strengthening Critical Connections 332
- 5.7 Modification of Transverse Stiffness 335

203

ix

406

5.8	The Use of Posttensioning to Improve Strength 349			
5.9	Design Example 5–3, Posttensioning of Steel Beam Bridge 363			
5.10	Design Example 5–4, Strengthening of Truss Members 371			
5.11	Design Example 5–5, Transverse Stiffness Effects 374			
5.12	Design Example 5–6, Addition of Steel Cover Plates 378			
5.13	Design Example 5–7, Prestressed Precast Box Beams 381			
5.14	Further Considerations of Posttensioning 384			
5.15	Epoxy-Bonded Steel Plates 393			
5.16	Strengthening Steel Beams by Testing Existing Steel 398			
	References 399			
REIRU	OFIT PROCEDURES AND ANALYSIS			
6.1	Background 406			

- 6.2Adding or Replacing Members 407
- **Retrofit to Provide Continuity** 6.3 409

Integral Conversions (Retrofitting) 419 6.4

- 6.5 Design Example 6–1: Modification of Simple Spans 426
- 6.6 Seismic Resistance of Bridges: General Principles 430
- **AASHTO** Requirements for Seismic Design 6.7 435
- Bridge Eligibility and Evaluation for Seismic Retrofitting 6.8 447
- 6.9 Capacity/Demand Ratio Analysis 452
- -6.10Seismic Retrofitting Concepts and Details 469
- 6.11 Design Example 6–2: Seismic Retrofit 485
- 6.12 Development of Column Vulnerability Rating 510
- 6.13 Simplified Restrainer Analysis, CalTrans Method 514 References 518

#### **CHAPTER 7** GENERAL REPAIR METHODS

**CHAPTER 6** 

- 7.1**Repair of Concrete Elements** 522
- 7.2Repair of Prestressed Concrete 532
- 7.3Repair of Steel Members 550
- 7.4The Use of Welding to Repair Cracks in Steel Members 566
- 7.5**Increasing the Fatigue Strength of Welded Joints** 580
- 7.6 Repair of Accidental Damage 584
- 7.7**Repair of Timber Members** 589 References 589

#### **CHAPTER 8 REPAIR OF SUPERSTRUCTURES**

- 8.1 **Concrete Bridge Decks—Typical Conditions and Repairs** 591
- 8.2 Long-Term Programs for Salt-Contaminated Bridge Decks 596
- 8.3 Wearing Surfaces 599
- Steel Beams and Girders-Problems and Repairs 601 8.4

522

**CHAPTER 9** 

8.5

х

8.6	Deck Joints 630				
8.7	Bearing Assemblies 639				
8.8	Curbs, Sidewalks, and Railings 648				
8.9	Geometric Deficiencies 649				
8.10	Effects of Overload on Deterioration of Concrete Bridges				
	References 663				
REPAIR OF SUBSTRUCTURES					
9.1	Substructure and Foundation Requirements 665				
9.2	Scour at Bridge Sites 668				
9.3	Collision Damage 678				
~ .					

621

- 9.4 Problems Caused by Foundation Settlement 690
- 9.5 The Option of Strengthening 700

Prestressed Concrete Beams

- 9.6 Substructures Below the Waterline: Problems and Deterioration 705
- 9.7 Substructure Below the Waterline: Procedures to Arrest Deterioration 708
- 9.8 General Repair Techniques 715 References 726

CHAPTER 10 REHABILITATION OF SPECIAL BRIDGES

- 10.1 Trusses, Problems and Repair Procedures 729
- 10.2 Examples of Truss Repairs 746
- 10.3 Arch Bridges 751
- 10.4 Grid and Orthotropic Decks 762
- 10.5 Suspension Bridges 769
- 10.6 Steel Railroad Bridges 795
- 10.7 Movable Bridges 807

References 816

#### CHAPTER 11 THE REPLACMENT OPTION

- 11.1 The Rationale of Analysis: Replacement Versus Repair and Strengthening 818
- 11.2 Repair and Replacement Resulting from Damage of Steel Members 826
- 11.3 Partial Replacement of Steel Members 833
- 11.4 Replacement of Prestressed Concrete Beams 838
- 11.5 Replacement of Deck Joints 842
- 11.6 Replacement of Bearings 844
- 11.7 Redecking and Widening 846
- 11.8 Overview of Replacement Systems 851

665

654

- 11.10 Example of Steel Replacement Systems for Superstructures 861
- 11.11 Example of Timber Replacement Systems for Superstructures 872
- 11.12 Lightweight Deck, Uses and Applications 873
- 11.13 Lightweight Decks, Technical and Economic Considerations 876
- 11.14 Prefabricated Bridge Elements, A Commentary 887
- 11.15 Permanent Bridge Deck Forms 891
- 11.16 Substructure Replacement Systems 893
- 11.17 State Replacement Policies and Examples 898
- 11.18 Removal of Existing Structures 905 References 906

#### CHAPTER 12 BRIDGE DESIGNS TO REDUCE MAINTENANCE AND REPAIR NEEDS

- 12.1 Background and Overview 910
- 12.2 Design and Use of Suitable Materials 912
- 12.3 Accessiblity 928
- 12.4 Provisions for Rehabilitation and Continuous Use 930
- 12.5 Preventive Maintenance, Case Study 939
- 12.6 Corrosion Protection 943 References 946

#### CHAPTER 13 TRAFFIC MAINTENANCE

- 13.1 General Requirements 949
- 13.2 Detours 951
- 13.3 Detour Plans 952
- 13.4 Traffic Control 954

## INDEX

949

910