## CONTENTS

Preface xi  
Preface to the Second Edition xiii  
Preface to the First Edition xv  

**PART I  GENERAL ASPECTS OF BRIDGE DESIGN**  

**CHAPTER 1  INTRODUCTION TO BRIDGE ENGINEERING**  

1.1 A Bridge Is the Key Element in a Transportation System 3  
1.2 Bridge Engineering in the United States 3  
  1.2.1 Stone Arch Bridges 3  
  1.2.2 Wooden Bridges 4  
  1.2.3 Metal Truss Bridges 6  
  1.2.4 Suspension Bridges 8  
  1.2.5 Metal Arch Bridges 10  
  1.2.6 Reinforced Concrete Bridges 12  
  1.2.7 Girder Bridges 13  
  1.2.8 Closing Remarks 14  
1.3 Bridge Engineer—Planner, Architect, Designer, Constructor, and Facility Manager 14  
References 15  
Problems 15  

**CHAPTER 2  SPECIFICATIONS AND BRIDGE FAILURES**  

2.1 Bridge Specifications 17  
2.2 Implication of Bridge Failures on Practice 18  
  2.2.1 Silver Bridge, Point Pleasant, West Virginia, December 15, 1967 18  
  2.2.2 I-5 and I-210 Interchange, San Fernando, California, February 9, 1971 19  
  2.2.3 Sunshine Skyway, Tampa Bay, Florida, May 9, 1980 21  
  2.2.4 Mianus River Bridge, Greenwich, Connecticut, June 28, 1983 22  
  2.2.5 Schoharie Creek Bridge, Amsterdam, New York, April 5, 1987 24  
  2.2.6 Cypress Viaduct, Loma Prieta Earthquake, October 17, 1989 25  
  

CONTENTS

2.2.7 I-35W Bridge, Minneapolis, Minnesota, August 1, 2007 26
2.2.8 Failures During Construction 30
References 30
Problems 31

CHAPTER 3 BRIDGE AESTHETICS 33

3.1 Introduction 33
3.2 Nature of the Structural Design Process 33
3.2.1 Description and Justification 33
3.2.2 Public and Personal Knowledge 34
3.2.3 Regulation 34
3.2.4 Design Process 35
3.3 Aesthetics in Bridge Design 36
3.3.1 Definition of Aesthetics 36
3.3.2 Qualities of Aesthetic Design 37
3.3.3 Practical Guidelines for Medium- and Short-Span Bridges 47
3.3.4 Computer Modeling 55
3.3.5 Web References 56
3.3.6 Closing Remarks on Aesthetics 59
References 59
Problems 60

CHAPTER 4 BRIDGE TYPES AND SELECTION 61

4.1 Main Structure below the Deck Line 61
4.2 Main Structure above the Deck Line 61
4.3 Main Structure Coincides with the Deck Line 64
4.4 Closing Remarks on Bridge Types 66
4.5 Selection of Bridge Type 66
4.5.1 Factors to Be Considered 66
4.5.2 Bridge Types Used for Different Span Lengths 69
4.5.3 Closing Remarks 72
References 72
Problems 73

CHAPTER 5 DESIGN LIMIT STATES 75

5.1 Introduction 75
5.2 Development of Design Procedures 75
5.2.1 Allowable Stress Design 75
5.2.2 Variability of Loads 76
5.2.3 Shortcomings of Allowable Stress Design 76
5.2.4 Load and Resistance Factor Design 77
5.3 Design Limit States 77
5.3.1 General 77
5.3.2 Service Limit State 79
5.3.3 Fatigue and Fracture Limit State 80
5.3.4 Strength Limit State 81
5.3.5 Extreme Event Limit State 81
5.4 Closing Remarks 82
References 82
Problems 82
CHAPTER 6  PRINCIPLES OF PROBABILISTIC DESIGN  83

6.1 Introduction  83
   6.1.1 Frequency Distribution and Mean Value  83
   6.1.2 Standard Deviation  83
   6.1.3 Probability Density Functions  84
   6.1.4 Bias Factor  85
   6.1.5 Coefficient of Variation  85
   6.1.6 Probability of Failure  86
   6.1.7 Safety Index $\beta$  87

6.2 Calibration of LRFD Code  89
   6.2.1 Overview of the Calibration Process  89
   6.2.2 Calibration Using Reliability Theory  89
   6.2.3 Calibration of Fitting with ASD  93

6.3 Closing Remarks  94
References  94
Problems  94

CHAPTER 7  GEOMETRIC DESIGN CONSIDERATIONS  95

7.1 Introduction to Geometric Roadway Considerations  95
7.2 Roadway Widths  95
7.3 Vertical Clearances  96
7.4 Interchanges  96
References  97
Problem  97

PART II  LOADS AND ANALYSIS  101

CHAPTER 8  LOADS  101

8.1 Introduction  101
8.2 Gravity Loads  101
   8.2.1 Permanent Loads  101
   8.2.2 Transient Loads  102
8.3 Lateral Loads  114
   8.3.1 Fluid Forces  114
   8.3.2 Seismic Loads  118
   8.3.3 Ice Forces  122
8.4 Forces Due to Deformations  127
   8.4.1 Temperature  127
   8.4.2 Creep and Shrinkage  129
   8.4.3 Settlement  129
8.5 Collision Loads  129
   8.5.1 Vessel Collision  129
   8.5.2 Rail Collision  129
   8.5.3 Vehicle Collision  129
8.6 Blast Loading  129
8.7 Summary  130
References  130
Problems  131
# CONTENTS

12.2.3 Temperature Effects 222
12.2.4 Shrinkage and Creep 225
12.3 Closing Remarks 225
References 225

## PART III  CONCRETE BRIDGES

### CHAPTER 13  REINFORCED CONCRETE MATERIAL RESPONSE AND PROPERTIES 229

13.1 Introduction 229
13.2 Reinforced and Prestressed Concrete Material Response 229
13.3 Constituents of Fresh Concrete 230
13.4 Properties of Hardened Concrete 232
13.4.1 Short-Term Properties of Concrete 232
13.4.2 Long-Term Properties of Concrete 238
13.5 Properties of Steel Reinforcement 242
13.5.1 Nonprestressed Steel Reinforcement 242
13.5.2 Prestressing Steel 244
References 246
Problems 246

### CHAPTER 14  BEHAVIOR OF REINFORCED CONCRETE MEMBERS 249

14.1 Limit States 249
14.1.1 Service Limit State 249
14.1.2 Fatigue Limit State 252
14.1.3 Strength Limit State 255
14.1.4 Extreme Event Limit State 256
14.2 Flexural Strength of Reinforced Concrete Members 257
14.2.1 Depth to Neutral Axis for Beams with Bonded Tendons 257
14.2.2 Depth to Neutral Axis for Beams with Unbonded Tendons 259
14.2.3 Nominal Flexural Strength 260
14.2.4 Ductility, Maximum Tensile Reinforcement, and Resistance Factor Adjustment 262
14.2.5 Minimum Tensile Reinforcement 264
14.2.6 Loss of Prestress 265
14.3 Shear Strength of Reinforced Concrete Members 270
14.3.1 Variable-Angle Truss Model 271
14.3.2 Modified Compression Field Theory 272
14.3.3 Shear Design Using Modified Compression Field Theory 278
14.4 Closing Remarks 289
References 289
Problems 290

### CHAPTER 15  CONCRETE BARRIER STRENGTH AND DECK DESIGN 291

15.1 Concrete Barrier Strength 291
15.1.1 Strength of Uniform Thickness Barrier Wall 291
15.1.2 Strength of Variable Thickness Barrier Wall 293
15.1.3 Crash Testing of Barriers 293
15.2 Concrete Deck Design 293
References 311
Problems 311