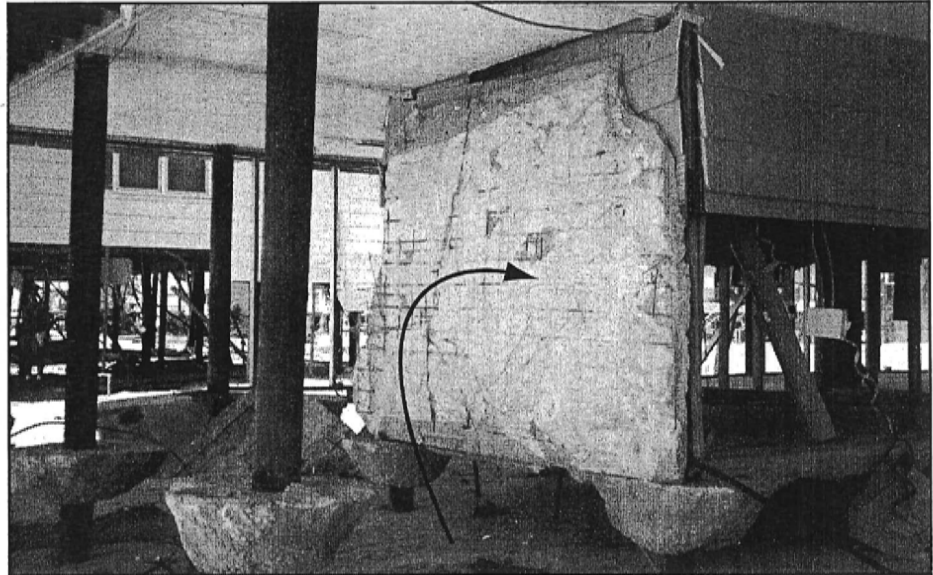


**Appendix Section 4**  
**FEMA Coastal Construction Manual**  
**Page 7-18 Floodborne Debris**  
**Cover & Table of Contents**

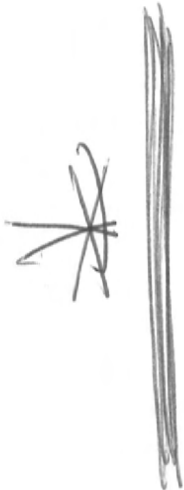
Shoaling waves beneath elevated buildings can lead to *wave uplift* forces. The most common example of wave uplift damage occurs at fishing piers, where pier decks are commonly lost close to shore, when shoaling storm waves lift the pier deck from the pilings and beams. The same type of damage can sometimes be observed at the lowest floor of insufficiently elevated but well-founded residential buildings and underneath slabs-on-grade below elevated buildings (see Figure 7-16).

**Figure 7-16**  
Hurricane Fran (1996).  
Concrete slab-on-grade  
flipped up by wave action  
came to rest against two  
foundation members,  
generating large  
unanticipated loads on the  
foundation.



### 7.3.4 Floodborne Debris

Floodborne debris produced by coastal flood events and storms typically includes decks, steps, ramps, breakaway wall panels, portions of or entire houses (see Figure 7-17), heating oil and propane tanks, vehicles, boats, decks and pilings from piers (see Figure 7-18), fences, destroyed erosion control structures, and a variety of smaller objects. Floodborne debris is often capable of destroying unreinforced masonry walls (see Figure 7-19), light wood-frame construction, and small-diameter posts and piles (and the components of structures they support). Debris trapped by cross bracing, closely spaced pilings, grade beams, or other components or obstructions below the Base Flood Elevation (BFE) is also capable of transferring flood and wave loads to the foundation of an elevated structure. Parts of the country are exposed to more massive debris, such as the drift logs shown in Figure 7-20.



Volume I + II + III

# Coastal Construction Manual

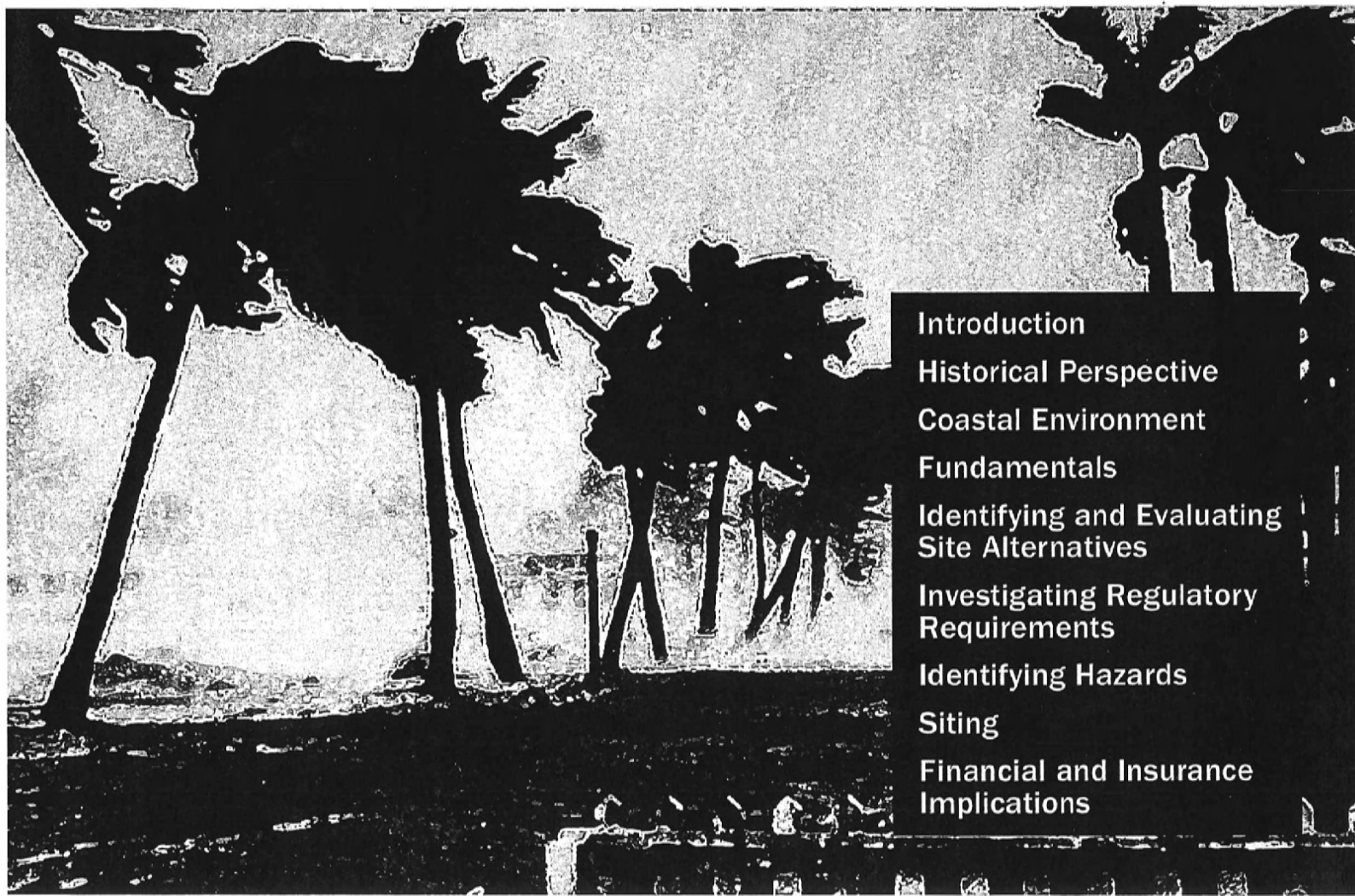
Principles and Practices of Planning, Siting, Designing,  
Constructing, and Maintaining Buildings in Coastal Areas

November 2003



**FEMA**

FEMA 55 – THIRD EDITION



Introduction  
Historical Perspective  
Coastal Environment  
Fundamentals  
Identifying and Evaluating  
Site Alternatives  
Investigating Regulatory  
Requirements  
Identifying Hazards  
Siting  
Financial and Insurance  
Implications

# Table of Contents

## Volume I

|                                                    | Page |
|----------------------------------------------------|------|
| Dedication .....                                   | i    |
| Foreword .....                                     | iii  |
| Acknowledgments .....                              | xlv  |
| Acronyms and Abbreviations .....                   | xlix |
| Metrification .....                                | liii |
| <br><b>Chapter 1</b>                               |      |
| <b>Introduction</b> .....                          | 1-1  |
| 1.1 Background .....                               | 1-1  |
| 1.2 Purpose .....                                  | 1-1  |
| 1.3 Organization .....                             | 1-3  |
| 1.4 Using the Manual .....                         | 1-6  |
| <br><b>Chapter 2</b>                               |      |
| <b>Historical Perspective</b> .....                | 2-1  |
| 2.1 Introduction .....                             | 2-1  |
| 2.2 Coastal Flood and Wind Events .....            | 2-1  |
| 2.2.1 Northeast Atlantic Coast .....               | 2-1  |
| 2.2.2 Southeast Atlantic Coast and Caribbean ..... | 2-8  |
| 2.2.3 Gulf of Mexico Coast .....                   | 2-21 |
| 2.2.4 Pacific Coast .....                          | 2-27 |
| 2.2.5 Hawaii and U.S. Pacific Territories .....    | 2-30 |
| 2.2.6 Great Lakes .....                            | 2-33 |
| 2.3 Lessons Learned .....                          | 2-35 |
| 2.3.1 Hazard Identification .....                  | 2-35 |
| 2.3.2 Siting .....                                 | 2-37 |
| 2.3.3 Design .....                                 | 2-38 |

|       |                    |      |
|-------|--------------------|------|
| 2.3.4 | Construction ..... | 2-40 |
| 2.3.5 | Maintenance .....  | 2-41 |
| 2.4   | References .....   | 2-41 |

## **Chapter 3**

|                                  |                                                        |            |
|----------------------------------|--------------------------------------------------------|------------|
| <b>Coastal Environment</b> ..... |                                                        | <b>3-1</b> |
| 3.1                              | Introduction .....                                     | 3-1        |
| 3.2                              | United States Coastline Characteristics .....          | 3-4        |
| 3.2.1                            | Atlantic Coast .....                                   | 3-5        |
| 3.2.2                            | Gulf of Mexico Coast .....                             | 3-6        |
| 3.2.3                            | Pacific Coast .....                                    | 3-6        |
| 3.2.4                            | Great Lakes Coast .....                                | 3-7        |
| 3.2.5                            | Coast of Alaska .....                                  | 3-7        |
| 3.2.6                            | Coast of Hawaii and Pacific Territories .....          | 3-7        |
| 3.2.7                            | Coast of Puerto Rico and the U.S. Virgin Islands ..... | 3-7        |
| 3.3                              | Coastal Flood Hazards .....                            | 3-8        |
| 3.3.1                            | Wave Heights and Wave Crest Elevations .....           | 3-10       |
| 3.3.2                            | Wave Runup .....                                       | 3-10       |
| 3.3.3                            | Erosion Considerations and Flood Hazard Mapping .....  | 3-11       |
| 3.4                              | References .....                                       | 3-13       |

## **Chapter 4**

|                                                         |            |
|---------------------------------------------------------|------------|
| <b>Fundamentals</b> .....                               | <b>4-1</b> |
| 4.1 Introduction .....                                  | 4-1        |
| 4.2 Hazards, Risk Assessment, and Risk Management ..... | 4-4        |
| 4.2.1 Risk Assessment .....                             | 4-5        |
| 4.2.2 Risk Management .....                             | 4-8        |
| 4.3 Cost Considerations .....                           | 4-12       |
| 4.4 References .....                                    | 4-14       |

## **Chapter 5**

|                                                           |                                                                        |            |
|-----------------------------------------------------------|------------------------------------------------------------------------|------------|
| <b>Identifying and Evaluating Site Alternatives .....</b> |                                                                        | <b>5-1</b> |
| 5.1                                                       | Introduction .....                                                     | 5-1        |
| 5.2                                                       | Identifying Suitable Property for Coastal Residential Structures ..... | 5-4        |

|       |                                                      |      |
|-------|------------------------------------------------------|------|
| 5.3   | Compiling Information on Coastal Property .....      | 5-6  |
| 5.3.1 | Sources of Information .....                         | 5-10 |
| 5.3.2 | Property Disclosure Requirements .....               | 5-12 |
| 5.4   | Evaluating Hazards and Potential Vulnerability ..... | 5-15 |
| 5.4.1 | Define Coastal Hazards Affecting the Property .....  | 5-15 |
| 5.4.2 | Evaluate Hazard Effects on the Property .....        | 5-16 |
| 5.5   | Decision Time .....                                  | 5-17 |
| 5.6   | References .....                                     | 5-18 |

## **Chapter 6**

|       |                                                                                           |            |
|-------|-------------------------------------------------------------------------------------------|------------|
|       | <b>Investigating Regulatory Requirements .....</b>                                        | <b>6-1</b> |
| 6.1   | Introduction .....                                                                        | 6-1        |
| 6.2   | Land Use Regulations .....                                                                | 6-1        |
| 6.3   | Building Codes and Standards .....                                                        | 6-3        |
| 6.4   | National Flood Insurance Program .....                                                    | 6-5        |
| 6.4.1 | Background .....                                                                          | 6-5        |
| 6.4.2 | Determination of BFEs and Flood Insurance Zones<br>in Coastal Flood Hazard Areas .....    | 6-7        |
| 6.4.3 | Minimum Regulatory Requirements Imposed by<br>Communities Participating in the NFIP ..... | 6-8        |
| 6.5   | Recommendations for Exceeding Minimum NFIP<br>Regulatory Requirements .....               | 6-15       |
| 6.5.1 | Non-Coastal A Zones .....                                                                 | 6-15       |
| 6.5.2 | Coastal A Zones and V Zones .....                                                         | 6-16       |
| 6.5.3 | Summary .....                                                                             | 6-17       |
| 6.6   | Coastal Barrier Resources Act of 1982 .....                                               | 6-22       |
| 6.7   | Coastal Zone Management Regulations .....                                                 | 6-22       |
| 6.8   | References .....                                                                          | 6-24       |

## **Chapter 7**

|       |                                               |            |
|-------|-----------------------------------------------|------------|
|       | <b>Identifying Hazards .....</b>              | <b>7-1</b> |
| 7.1   | Introduction .....                            | 7-1        |
| 7.2   | Natural Hazards Affecting Coastal Areas ..... | 7-1        |
| 7.2.1 | Tropical Cyclones and Coastal Storms .....    | 7-2        |

|     |        |                                                                          |      |
|-----|--------|--------------------------------------------------------------------------|------|
|     | 7.2.2  | Tsunamis .....                                                           | 7-9  |
| 7.3 |        | Coastal Flooding .....                                                   | 7-13 |
|     | 7.3.1  | Hydrostatic Forces .....                                                 | 7-13 |
|     | 7.3.2  | Hydrodynamic Forces .....                                                | 7-14 |
|     | 7.3.3  | Waves .....                                                              | 7-16 |
|     | 7.3.4  | Floodborne Debris .....                                                  | 7-18 |
|     | 7.3.5  | Sea-Level Rise and Lake-Level Rise .....                                 | 7-21 |
| 7.4 |        | High Winds .....                                                         | 7-23 |
|     | 7.4.1  | Speedup of Winds Due to Topographic Effects .....                        | 7-27 |
|     | 7.4.2  | Windborne Debris and Rainfall Penetration .....                          | 7-27 |
|     | 7.4.3  | Tornadoes .....                                                          | 7-27 |
| 7.5 |        | Erosion .....                                                            | 7-28 |
|     | 7.5.1  | Describing and Measuring Erosion .....                                   | 7-36 |
|     | 7.5.2  | Causes of Erosion .....                                                  | 7-39 |
| 7.6 |        | Earthquakes .....                                                        | 7-54 |
| 7.7 |        | Other Hazards and Environmental Effects .....                            | 7-61 |
|     | 7.7.1  | Subsidence and Uplift .....                                              | 7-61 |
|     | 7.7.2  | Landslides and Ground Failures .....                                     | 7-61 |
|     | 7.7.3  | Salt Spray and Moisture .....                                            | 7-63 |
|     | 7.7.4  | Rain .....                                                               | 7-66 |
|     | 7.7.5  | Hail .....                                                               | 7-67 |
|     | 7.7.6  | Wood Decay and Termites .....                                            | 7-67 |
|     | 7.7.7  | Wildfire .....                                                           | 7-67 |
|     | 7.7.8  | Floating Ice .....                                                       | 7-68 |
|     | 7.7.9  | Snow .....                                                               | 7-68 |
|     | 7.7.10 | Atmospheric Ice .....                                                    | 7-68 |
| 7.8 |        | Coastal Hazard Zones .....                                               | 7-68 |
|     | 7.8.1  | NFIP Hazard Zones .....                                                  | 7-70 |
|     | 7.8.2  | Examples of State and Community Coastal<br>Hazard Zone Delineation ..... | 7-78 |

|                  |                                                                                  |            |
|------------------|----------------------------------------------------------------------------------|------------|
| 7.8.3            | Other Risk Assessment Approaches .....                                           | 7-78       |
| 7.9              | Translating Hazard Information into Practice .....                               | 7-78       |
| 7.9.1            | Is an Updated or a More Detailed Flood Hazard<br>Assessment Needed? .....        | 7-79       |
| 7.9.2            | Updated or Revised Flood Hazard Assessments .....                                | 7-81       |
| 7.10             | References .....                                                                 | 7-84       |
| <b>Chapter 8</b> | <b>Siting .....</b>                                                              | <b>8-1</b> |
| 8.1              | Introduction .....                                                               | 8-1        |
| 8.2              | Siting Considerations .....                                                      | 8-1        |
| 8.3              | Raw Land Development: Infrastructure and Lot Layout .....                        | 8-4        |
| 8.3.1            | Introduction .....                                                               | 8-4        |
| 8.3.2            | Practices To Avoid and Recommended Alternatives .....                            | 8-7        |
| 8.4              | Infill Development: Siting a Building on an Existing Lot .....                   | 8-15       |
| 8.4.1            | Introduction .....                                                               | 8-15       |
| 8.4.2            | Practices To Avoid and Recommended Alternatives .....                            | 8-17       |
| 8.5              | Influence of Beach Nourishment and Dune Restoration<br>on Siting Decisions ..... | 8-20       |
| 8.6              | References .....                                                                 | 8-22       |
| <b>Chapter 9</b> | <b>Financial and Insurance Implications .....</b>                                | <b>9-1</b> |
| 9.1              | Introduction .....                                                               | 9-1        |
| 9.2              | Benefit and Cost Implications of Siting, Design,<br>and Construction .....       | 9-2        |
| 9.3              | Hazard Insurance .....                                                           | 9-10       |
| 9.3.1            | Flood Insurance .....                                                            | 9-11       |
| 9.3.2            | Wind Insurance .....                                                             | 9-18       |
| 9.3.3            | Earthquake Insurance .....                                                       | 9-20       |
| 9.4              | References .....                                                                 | 9-21       |

# Volume II

|                   |                                                                                        |       |
|-------------------|----------------------------------------------------------------------------------------|-------|
| <b>Chapter 10</b> | <b>Introduction to Volume II</b> .....                                                 | 10-1  |
| 10.1              | Purpose and Organization .....                                                         | 10-1  |
| 10.2              | Important Reminders .....                                                              | 10-4  |
| <b>Chapter 11</b> | <b>Determining Site-Specific Loads</b> .....                                           | 11-1  |
| 11.1              | Introduction .....                                                                     | 11-1  |
| 11.2              | Dead Loads .....                                                                       | 11-3  |
| 11.3              | Live Loads .....                                                                       | 11-3  |
| 11.4              | Concept of Tributary or Effective Area and<br>Application of Loads to a Building ..... | 11-4  |
| 11.5              | Snow Loads .....                                                                       | 11-4  |
| 11.6              | Flood Loads .....                                                                      | 11-6  |
| 11.6.1            | Design Flood .....                                                                     | 11-6  |
| 11.6.2            | Design Flood Elevation (DFE) .....                                                     | 11-6  |
| 11.6.3            | Design Flood Depth ( $d_s$ ) .....                                                     | 11-7  |
| 11.6.4            | Wave Setup ( $d_{ws}$ ) Contribution to Flood Depth .....                              | 11-9  |
| 11.6.5            | Design Wave Height ( $H_b$ ) .....                                                     | 11-9  |
| 11.6.6            | Design Flood Velocity ( $V$ ) .....                                                    | 11-9  |
| 11.6.7            | Hydrostatic Loads .....                                                                | 11-11 |
| 11.6.8            | Wave Loads .....                                                                       | 11-14 |
| 11.6.9            | Hydrodynamic Loads .....                                                               | 11-18 |
| 11.6.10           | Debris Impact Loads .....                                                              | 11-22 |
| 11.6.11           | Localized Scour .....                                                                  | 11-26 |
| 11.6.12           | Flood Load Combinations .....                                                          | 11-29 |
| 11.7              | Tsunami Loads .....                                                                    | 11-36 |
| 11.8              | Wind Loads .....                                                                       | 11-36 |
| 11.8.1            | Main Wind Force Resisting System .....                                                 | 11-39 |
| 11.8.2            | Components and Cladding .....                                                          | 11-42 |
| 11.9              | Tornado Loads .....                                                                    | 11-48 |

|       |                         |       |
|-------|-------------------------|-------|
| 11.10 | Seismic Loads .....     | 11-48 |
| 11.11 | Load Combinations ..... | 11-57 |
| 11.12 | References .....        | 11-61 |

## **Chapter 12**

|      |                                                                             |             |
|------|-----------------------------------------------------------------------------|-------------|
|      | <b>Designing the Building .....</b>                                         | <b>12-1</b> |
| 12.1 | The Design Process .....                                                    | 12-1        |
| 12.2 | Step 1 – Determining Loads .....                                            | 12-2        |
| 12.3 | Step 2 – Applying Loads to the Building .....                               | 12-3        |
|      | 12.3.1 Failure Modes .....                                                  | 12-4        |
|      | 12.3.2 Load Path .....                                                      | 12-14       |
|      | 12.3.3 Structural Building Systems .....                                    | 12-16       |
|      | 12.3.4 Construction Materials .....                                         | 12-22       |
|      | 12.3.5 Building Layouts and Architectural Shapes .....                      | 12-23       |
| 12.4 | Step 3 – Determine Forces at Connections and<br>Stresses in Materials ..... | 12-25       |
|      | 12.4.1 Getting Started .....                                                | 12-25       |
|      | 12.4.2 Analyze Load Path Links .....                                        | 12-32       |
|      | 12.4.3 Foundation Design .....                                              | 12-59       |
|      | 12.4.4 Other Important Load Paths .....                                     | 12-75       |
|      | 12.4.5 Bracing .....                                                        | 12-76       |
|      | 12.4.6 Breakaway Wall Enclosures .....                                      | 12-85       |
| 12.5 | Step 4 – Develop Connections at Each Link .....                             | 12-86       |
|      | 12.5.1 Connection Choices .....                                             | 12-86       |
|      | 12.5.2 Link #1 – Roof Sheathing to Roof Framing .....                       | 12-88       |
|      | 12.5.3 Link #2 – Roof Framing to Exterior Walls .....                       | 12-88       |
|      | 12.5.4 Link #3 – Top Wall Plate to Wall Studs .....                         | 12-90       |
|      | 12.5.5 Link #4 – Wall Sheathing to Window Header .....                      | 12-91       |
|      | 12.5.6 Link #5 – Window Header to Exterior Wall .....                       | 12-91       |
|      | 12.5.7 Link #6 – Wall to Floor Framing .....                                | 12-91       |
|      | 12.5.8 Link #7 – Floor Framing to Support Beam .....                        | 12-92       |
|      | 12.5.9 Link #8 – Floor Support Beam to Pile Foundation .....                | 12-92       |

|        |                                                                              |        |
|--------|------------------------------------------------------------------------------|--------|
| 12.6   | Step 5 – Select Building Materials .....                                     | 12-93  |
| 12.6.1 | Introduction .....                                                           | 12-93  |
| 12.6.2 | Selection of Materials for Foundations<br>and Enclosures Below the DFE ..... | 12-95  |
| 12.6.3 | Selection of Materials for Use Above the DFE .....                           | 12-97  |
| 12.6.4 | Material Combinations .....                                                  | 12-97  |
| 12.6.5 | Fire Safety Considerations .....                                             | 12-99  |
| 12.6.6 | Corrosion .....                                                              | 12-101 |
| 12.6.7 | Additional Environmental Considerations .....                                | 12-101 |
| 12.7   | Design of the Building Envelope .....                                        | 12-103 |
| 12.7.1 | Floors for Elevated Buildings .....                                          | 12-104 |
| 12.7.2 | Exterior Walls and Soffits .....                                             | 12-105 |
| 12.7.3 | Doors and Door Assemblies .....                                              | 12-108 |
| 12.7.4 | Windows, Shutters, and Skylights .....                                       | 12-112 |
| 12.7.5 | Roof Coverings .....                                                         | 12-120 |
| 12.7.6 | Roof Ridge Vents .....                                                       | 12-140 |
| 12.8   | Utilities/Mechanical Equipment .....                                         | 12-142 |
| 12.8.1 | Elevators .....                                                              | 12-142 |
| 12.8.2 | Design of Exterior-Mounted Mechanical Equipment ...                          | 12-143 |
| 12.8.3 | Design of Interior Mechanical Equipment .....                                | 12-146 |
| 12.8.4 | Electrical, Telephone, and Cable TV Systems .....                            | 12-147 |
| 12.8.5 | Water and Wastewater Systems .....                                           | 12-151 |
| 12.9   | Appurtenant Structures .....                                                 | 12-153 |
| 12.9.1 | Decks, Gazebos, and Covered Porches Attached<br>to Buildings .....           | 12-153 |
| 12.9.2 | Walkways, Sidewalks, and Other Ground-Level<br>Structures .....              | 12-154 |
| 12.9.3 | Access to Elevated Buildings .....                                           | 12-157 |
| 12.9.4 | Pools and Hot Tubs .....                                                     | 12-157 |
| 12.9.5 | Boat Houses .....                                                            | 12-158 |
| 12.9.6 | Storage Buildings .....                                                      | 12-159 |

|                   |         |                                                     |             |
|-------------------|---------|-----------------------------------------------------|-------------|
|                   | 12.10   | References .....                                    | 12-160      |
| <b>Chapter 13</b> |         | <b>Constructing the Building .....</b>              | <b>13-1</b> |
|                   | 13.1    | Introduction .....                                  | 13-1        |
|                   | 13.2    | Foundation Construction .....                       | 13-2        |
|                   | 13.2.1  | Layout .....                                        | 13-2        |
|                   | 13.2.2  | Soils .....                                         | 13-6        |
|                   | 13.2.3  | Pile Foundation .....                               | 13-9        |
|                   | 13.2.4  | Masonry Foundation Construction .....               | 13-15       |
|                   | 13.2.5  | Concrete Foundation Construction .....              | 13-17       |
|                   | 13.2.6  | Wood Foundation Construction .....                  | 13-19       |
|                   | 13.2.7  | Foundation Material Durability .....                | 13-20       |
|                   | 13.2.8  | Field Preservative Treatment .....                  | 13-25       |
|                   | 13.2.9  | Substitutions .....                                 | 13-26       |
|                   | 13.2.10 | The Top Foundation Issues for Builders .....        | 13-26       |
|                   | 13.2.11 | Inspection Points .....                             | 13-27       |
|                   | 13.3    | Structural Frame .....                              | 13-27       |
|                   | 13.3.1  | Floor Framing .....                                 | 13-31       |
|                   | 13.3.2  | Wall Framing .....                                  | 13-34       |
|                   | 13.3.3  | Roof Framing .....                                  | 13-38       |
|                   | 13.3.4  | The Top Structural Frame Issues for Builders .....  | 13-40       |
|                   | 13.4    | Building Envelope .....                             | 13-41       |
|                   | 13.4.1  | Substitution of Building Envelope Materials .....   | 13-42       |
|                   | 13.4.2  | Building Envelope Inspection Points .....           | 13-42       |
|                   | 13.4.3  | The Top Building Envelope Issues for Builders ..... | 13-43       |
|                   | 13.5    | Appurtenant Structures .....                        | 13-44       |
|                   | 13.5.1  | Decks .....                                         | 13-44       |
|                   | 13.5.2  | Storage Buildings .....                             | 13-46       |
|                   | 13.5.3  | Swimming Pools and Hot Tubs .....                   | 13-46       |
|                   | 13.5.4  | Walkways and Sidewalks .....                        | 13-48       |

|        |                                                      |       |
|--------|------------------------------------------------------|-------|
| 13.6   | Utility/Mechanical Equipment .....                   | 13-49 |
| 13.6.1 | Elevators .....                                      | 13-49 |
| 13.6.2 | Heating, Ventilating, and Cooling (HVAC) Systems ... | 13-50 |
| 13.6.3 | Electrical Systems .....                             | 13-53 |
| 13.6.4 | Water and Wastewater Systems .....                   | 13-53 |
| 13.6.5 | Tanks .....                                          | 13-54 |
| 13.7   | References .....                                     | 13-55 |

## **Chapter 14**

|        |                                                           |             |
|--------|-----------------------------------------------------------|-------------|
|        | <b>Maintaining the Building .....</b>                     | <b>14-1</b> |
| 14.1   | Introduction .....                                        | 14-1        |
| 14.2   | Effects of Coastal Environment .....                      | 14-3        |
| 14.2.1 | Corrosion .....                                           | 14-3        |
| 14.2.2 | Termites .....                                            | 14-3        |
| 14.2.3 | Moisture .....                                            | 14-3        |
| 14.2.4 | Weathering .....                                          | 14-5        |
| 14.3   | Building Elements That Require Frequent Maintenance ..... | 14-5        |
| 14.3.1 | Siding .....                                              | 14-5        |
| 14.3.2 | Roofs .....                                               | 14-6        |
| 14.3.3 | Glazing .....                                             | 14-7        |
| 14.3.4 | Outdoor Mechanical/Electrical Equipment .....             | 14-8        |
| 14.3.5 | Decks/Exterior Wood .....                                 | 14-8        |
| 14.3.6 | Metal Connectors .....                                    | 14-9        |
| 14.4   | Maintenance Techniques Required for Natural Hazards ..... | 14-10       |
| 14.4.1 | Flooding .....                                            | 14-10       |
| 14.4.2 | Seismic and Wind .....                                    | 14-10       |
| 14.5   | Retrofit Opportunities .....                              | 14-11       |
| 14.6   | Retrofit Costs .....                                      | 14-15       |
| 14.7   | References .....                                          | 14-16       |