Development of Multimedia Resource and Short Courses for LRFD Design

Final Report for:

Alabama Department of Transportation
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Development of Multimedia Resource and Short Courses for LRFD Design

Executive Summary

Multimedia technology is an essential instrument in the development of graduate engineers. This multimedia package provides an exclusive background and an in-depth understanding of the new technological advances in the design of concrete, steel and prestressed concrete bridges. It gives guidelines and step-by-step instructions for the design of different types of bridges using the LRFD specifications. It also includes an introduction of comparing three rating procedures (ASR, LFR, and LRFR). One of the advantages of the package is that it can be conveniently updated and modified to add future changes and procedures necessary for today's structural demand.

The LRFD specifications were created with a conservative point of view, applying almost exclusively the limit states of strength. It is consistent with other major bridge codes adopted or being adopted in many other countries such as Canada and the European countries. Because of this many states throughout the United States have changed their specifications and are currently implementing LRFD. It incorporates deep analysis and design methods with different kinds of loads and resistance factors, which are based on the known variability of applied loads and the material properties. This multimedia package includes the basis in which an engineer can design a concrete bridge using LRFD specifications. It includes some PDF documents containing explanatory examples and an overview of the strategic development of this structural code.

This project has a main focus to be a self-training tool for inexperienced engineers who are interested in learning about the implementation of LRFD specifications in the design of concrete bridges. It is a valuable tool because it contains procedures and specifications for each possible situation together with detailed examples and illustrations. This package is a time saving, user-friendly, reliable way of learning.

The CD multimedia package will be periodically updated by the principal investigator.

1.0 Introduction

The main goal of the LRFD multimedia package is to provide a practical introduction and an in-depth understanding of the new technological advances in the designing of bridges. This package can be used to train engineers, architects, designers, and personnel who are in charge of the design, construction, maintenance, and reconstruction of bridges because it is a self-training, time-saving tool. The complete package includes instructions of how to design concrete, steel and prestressed concrete bridges with AASHTO load and resistance factor design recommendations and specifications and six examples from which the user can have a generic overview of the design process.

Load and Resistance Factor Design (LRFD) specifications is a method of proportioning structures such that no applicable limit state is exceeded when the structure is subjected to all appropriate design load combinations. The LRFD specifications, like all other structural specifications, treat almost exclusively the limit states of strength because of the overriding considerations of public safety for people and property. LRFD specifications are among the many publications developed and maintained by the American Concrete Institute (ACI). Since the first edition of LRFD was published in 1994, many states have been diligently developing plans and taking steps to fully implement LRFD. The Federal Highway Administration (FHWA) has established a goal that the LRFD standards shall be used in all new bridge designs in the United States after 2007.

For bridges and total replacement bridges designed by LRFD Specifications using HL-93, after October 1, 2010 Method used to determine Operating Rating, Operating Rating, Method used to determine Inventory Rating and Inventory Rating are to be computed and reported to the NBI as a RF based on LRFR methods using HL-93 loading. An introduction comparing the three rating procedures (ASR, LFR and LRFR) is included in the CD.

The CD package will offer a tutorial that employs a wide range of multimedia, including hyperlinks and high-resolution graphics. To ensure the use of this multimedia package, it will be machine adaptable and design to run on different operating systems. The advantage of this package is that it can be accessible for updating and adding information whenever necessary. It is a self-training and time-saving tool.

2.0 Methodology

An extensive review of the existing literature and information available on LRFD was done. Since LRFD is an upcoming topic, step-by-step procedures were included in the package for better understanding.

The package is divided into twelve chapters accompanied with six design examples and various technical definitions. Each chapter contains specific equations, tables, and diagrams of relevance. To utilize the benefits of a multimedia product to the fullest, hyperlinks were created in all the chapters as well as the design examples to quickly access the required details. There is also display boxes that provide the instantaneous definitions to technical terms, a feature designed for a new engineer. This package was created with the Macromedia Dreamweaver MX software for creating dynamic HTML pages.

For further updates of the multimedia package according to the LRFD specifications including any recommendation by ALDOT (Alabama Department of Transportation), the contact information of the principal investigator is included in the package.

3.0 Website/CD-ROM Description

This multimedia package includes a homepage together with twelve chapters and some basic theory concepts. It also provides the user with five concrete bridge design examples and several other helpful links for designing concrete bridges. It also includes a link providing some concept definitions. The following is a description of these sections.

3.1 Home Page

The home page is a welcoming page explaining the goal and advantage of the package. This page also provides an overview of its contents. This multimedia package is a self-training tool providing information on LRFD specifications (See Figure 1).

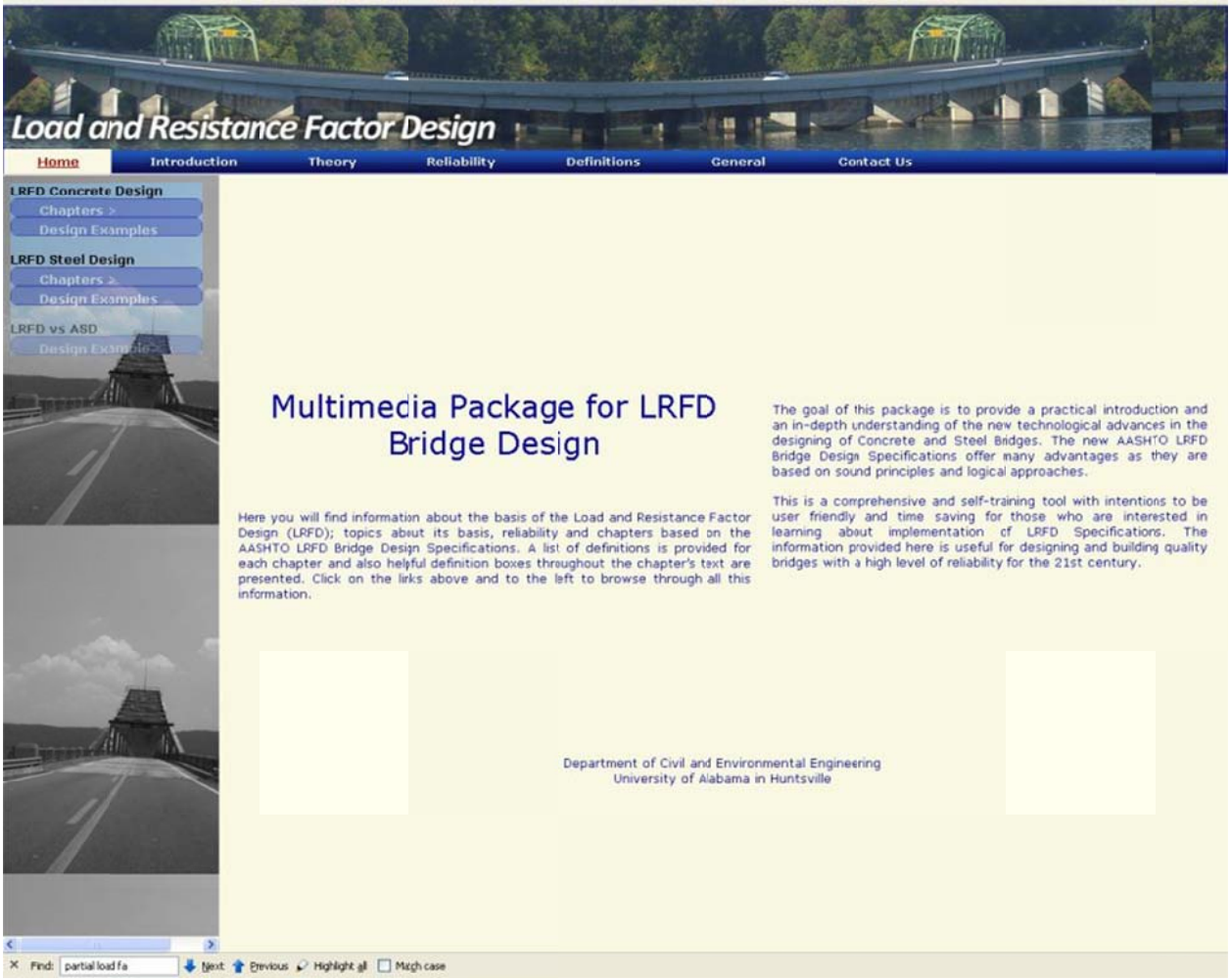


Figure 1: Home Page of the Multimedia Package for LRFD Concrete Bridge Design

3.2 Introduction

The introduction page provides the user a brief description of LRFD specifications. This page explains why these specifications are needed and are better for bridge design. It introduces the user to the benefits of LRFD. This page projects the idea of LRFD being implemented for all bridge designs in the United States (See Figure 2).

Figure 2: Introduction Page Explain what are LRFD Specifications

3.3 Description of Chapters

3.3.1 LRFD Concrete Design:

The following twelve chapters and their descriptions are from the AASHTO LRFD Specification Manual-Interim Revision 2005.

3.3.1.1 Chapter 1: Introduction

Chapter 1 introduces the concept of limit states and load modifiers that are required in the design specifications of Load and Resistance Factor Design (LRFD).

According to LRFD design philosophy, bridges are designed for specific limit states that fulfill the security, service, aesthetic, economy, and constructability objectives. The following limit states are considered:

1. *Service Limit State* – It is taken as restrictions on stress, deformations and crack width under the regular service conditions.

2. *Fatigue and Fracture Limit State* - It intended to limit the crack growth under repetitive loads in order to prevent fracture under the design life of the bridge.

3. *Strength Limit State* – It is used to ensure that the bridge receives the statistically significant *load* combinations without affecting its stability and strength in a local and global form. Structural integrity is expected to be always maintained.

4. *Extreme Event Limit State* – It is used to ensure structural survival of the bridge under extreme conditions like earthquakes, floods, vehicle collision, tidal waves, etc.

The following are the three load modifiers considered in LRFD specifications:

1. *Ductility* – At strength and extreme event limit states, the structure system of the bridge will undergo significant and visible inelastic deformations before failure.

2. *Redundancy* – Main elements and components whose failure is expected to cause a collapse of a bridge shall be designated as failure critical and the associated structural system as non-redundant.

3. *Operational Importance* – The owner may declare a bridge or any structural component and connection to be of operational importance.

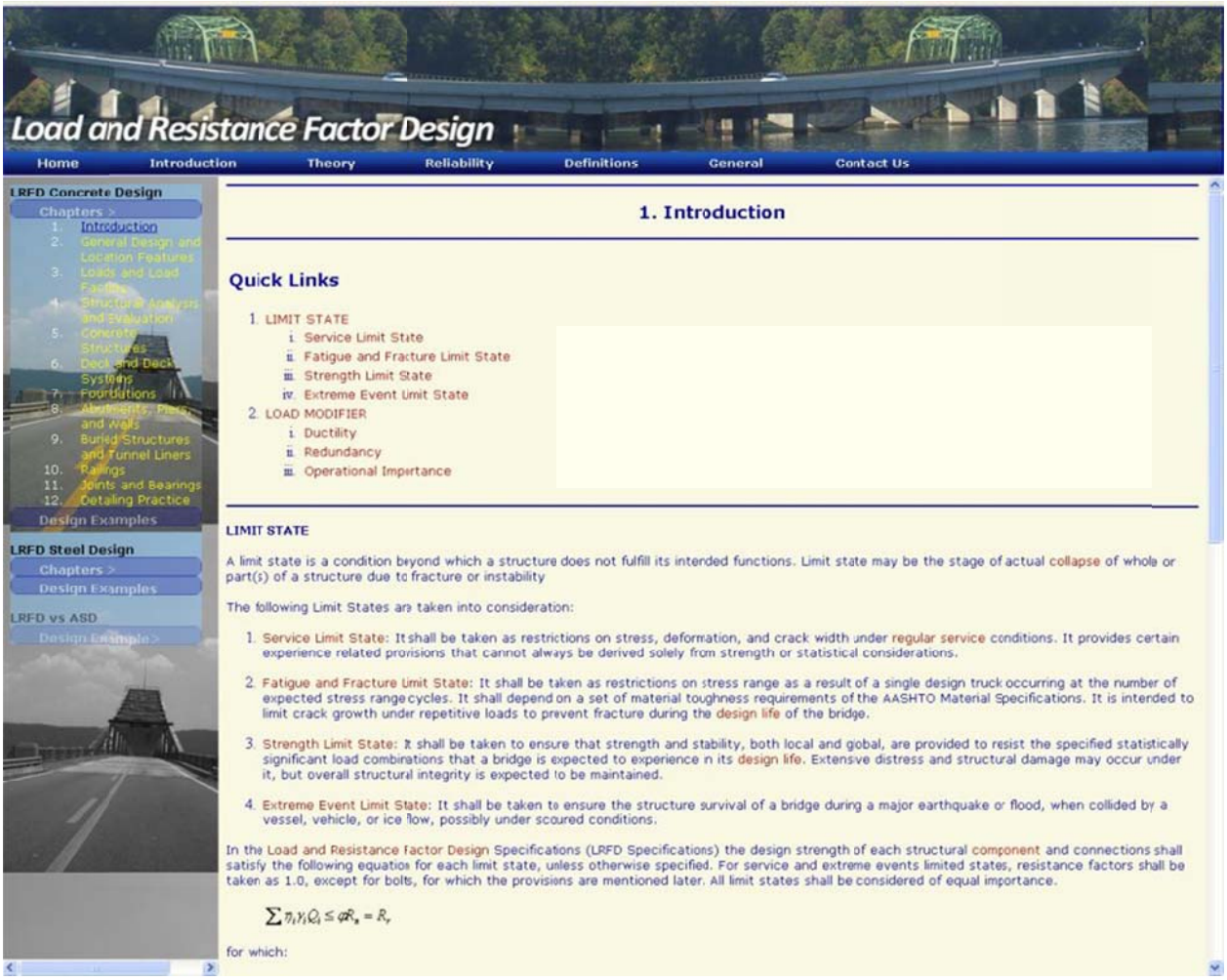


Figure 3: Chapter 1: Introduction Page Explains the Limit State and the Load Modifier

3.3.1.2 Chapter 2: General Design and Location Features

This chapter provides minimum requirements for clearances, environmental protection, aesthetics, geological studies, economy, rideability, durability, constructability, inspectability, and maintainability. Traffic safety is also considered in this section.

Chapter 2 also involves the minimum requirements for drainage facilities and self-protecting measures from ice, water, and water-borne salts. Scour, hydrology, and hydraulics that have caused bridge failure are included.

The configuration and overall dimensions of a bridge should be able to be determined from this chapter.

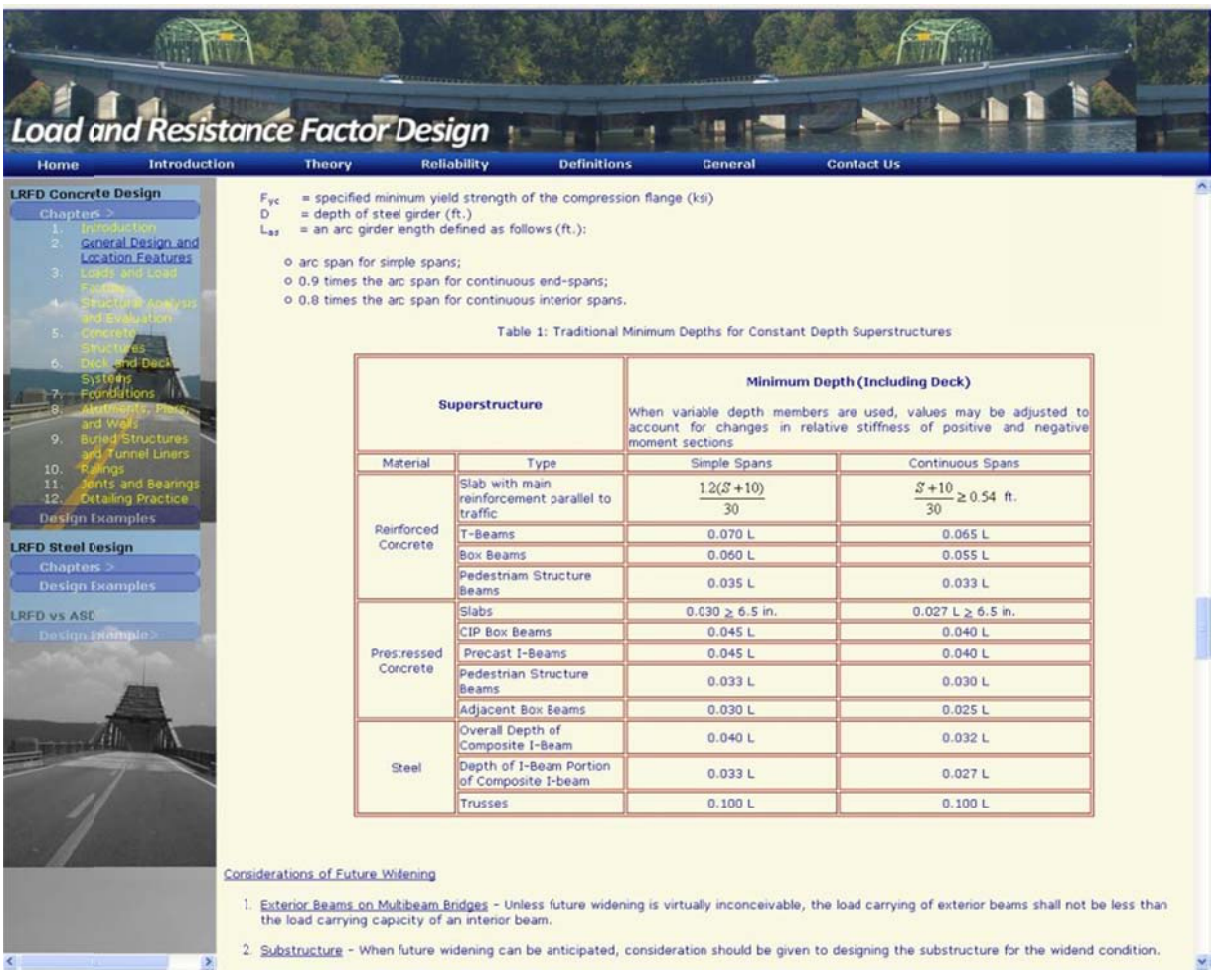


Figure 4: Chapter 2: Table of Traditional Minimum Depths for Constant Depth Superstructures

3.3.1.3 Chapter 3: Load and Load Factors

Chapter 3 defines minimum requirements for loads and forces, the application's limits, load factors, and load combinations used for the design of new bridges. The load provisions can also be used for the structural evaluation of existing bridges. This chapter also includes the force effects due to collisions, earthquakes, and settlement and distortion of the structure.

Force effects that develop during construction have a specified minimum load factor. Construction loads are not included in this section.

The following loads are discussed in the section:

Permanent Loads – The weight of all components of the structure, appurtenances and utilities attached thereto, earth cover, wearing surface, future overlays, and planned widening.

Live Loads – Forces that are variable within the bridge's normal operation cycle (Example: load exerted by a vehicle).

Water Loads (WA) – Loads that include static pressure, buoyancy, stream pressure, and wave load.

Wind Loads (WL and WS) – The loads in this section are horizontal wind pressure, vertical wind pressure, and aeroelastic instability.

Earthquake Effects (EQ) – Loads that shall be taken to be horizontal force effects determined on the basis of the elastic response coefficient and the equivalent weight of the superstructure, and adjusted by the response modification factor.

Earth Pressure (EH, ES, LS, DD) – Loads that consider compaction, presence of water in the earth, and the effect of earthquakes.

Force Effects due to Superimposed Deformations (TU, TG, SH, CR, SE) – Internal force effects in a component due to creep and shrinkage and the effect of a temperature gradient are considered. Force effects resulting from resisting component deformation, displacement of points of load application, and support movements should also be included.

Friction Forces (FR) – Forces due to friction shall be established on the basis of extreme values of the friction coefficient between the sliding surfaces.

Vessel Collision (CV) – A bridge constructed in a navigation channel is designed for a vessel collision.

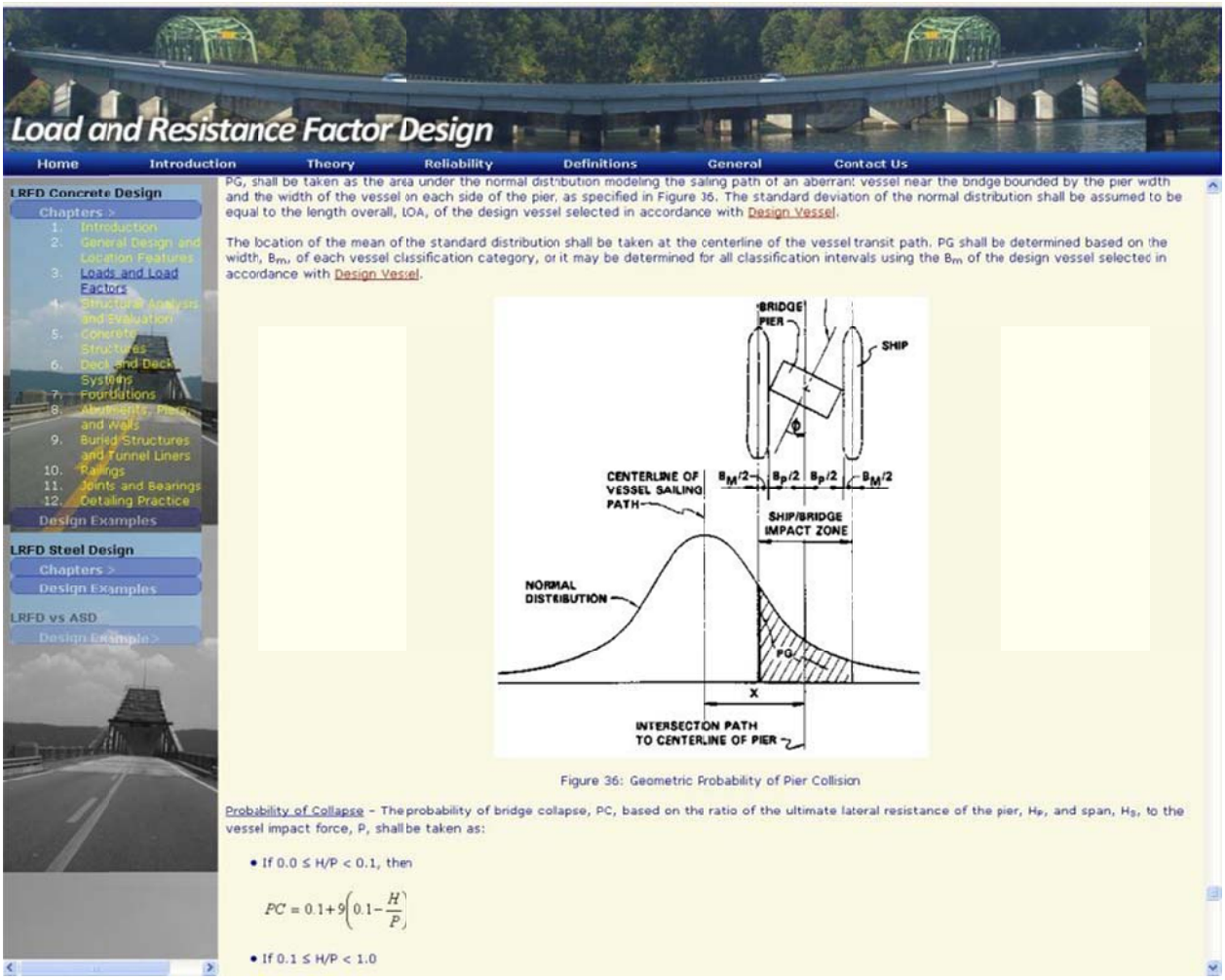


Figure 5: Chapter 3: Geometric Probability of a Pier Collision

3.3.1.4 Chapter 4: Structural Analysis and Evaluation

This chapter defines methods of analysis suitable for the design and evaluation of bridges and is limited to the modeling of structures and the determination of force effects.

Bridge structures are to be analyzed elastically; however, this section permits the inelastic analysis or redistribution of force effects in some continuous beam superstructures. It specifies inelastic analysis for compressive members behaving inelastically and as an alternative for extreme event limit states.

The loads, load factors, and resistance factors specified throughout the specifications were developed using probabilistic principles combined with analyses based on linear material models.

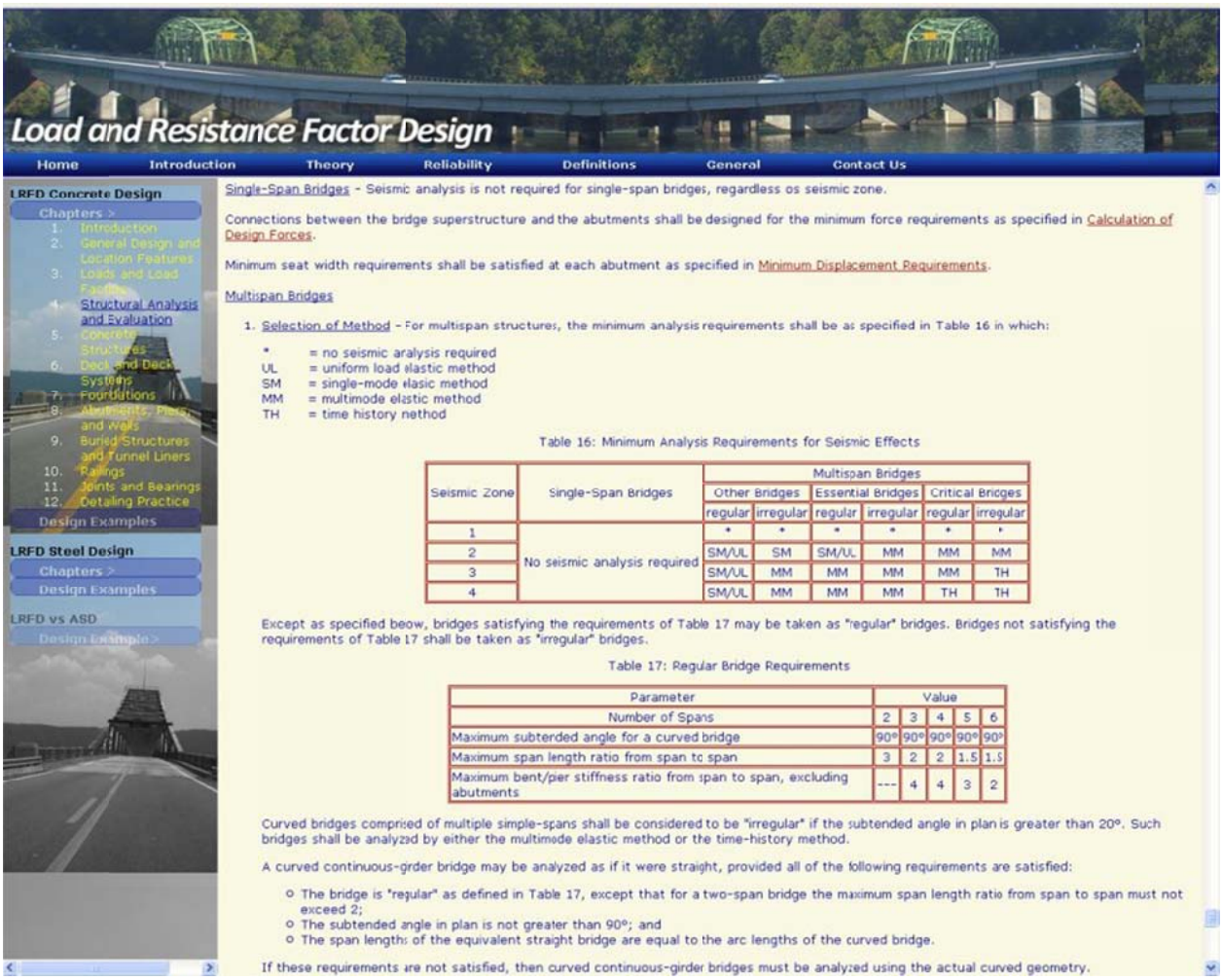


Figure 6: Chapter 4: Tables on Minimum Analysis Requirements for Seismic Effects and on Regular Bridge Requirements

3.3.1.5 Chapter 5: Concrete Structures

This chapter discusses the design of bridge structures in concrete. The provisions in this section apply to the design of bridge and retaining wall components of normal weight or lightweight concrete and reinforced with steel bars, welded wire reinforcement, and/or prestressing strands, bars, or wires.

The provisions combine and unify the requirements for reinforced, prestressed, and partially prestressed concrete, including seismic design, analysis by the strut-and-tie model, and design of segmentally constructed concrete bridges and bridges from precast concrete elements.

Figure 7: Chapter 5: Concrete Structures Page

3.3.1.6 Chapter 6: Deck and Deck Systems

This section contains provisions for the analysis and design of bridge decks and deck systems of concrete, metal, or their combination subjected to gravity loads. Implicit is a design philosophy that prefers jointless, continuous bridge desks and desk systems to improve the weather and corrosion-resisting effects of the whole bridge, reduce inspection efforts and maintenance costs, and increase structural effectiveness and redundancy. This chapter is divided into five parts covering the following areas: the general design requirements, the limit states, the proper structural analysis, and its application to concrete deck slabs and metal slabs.

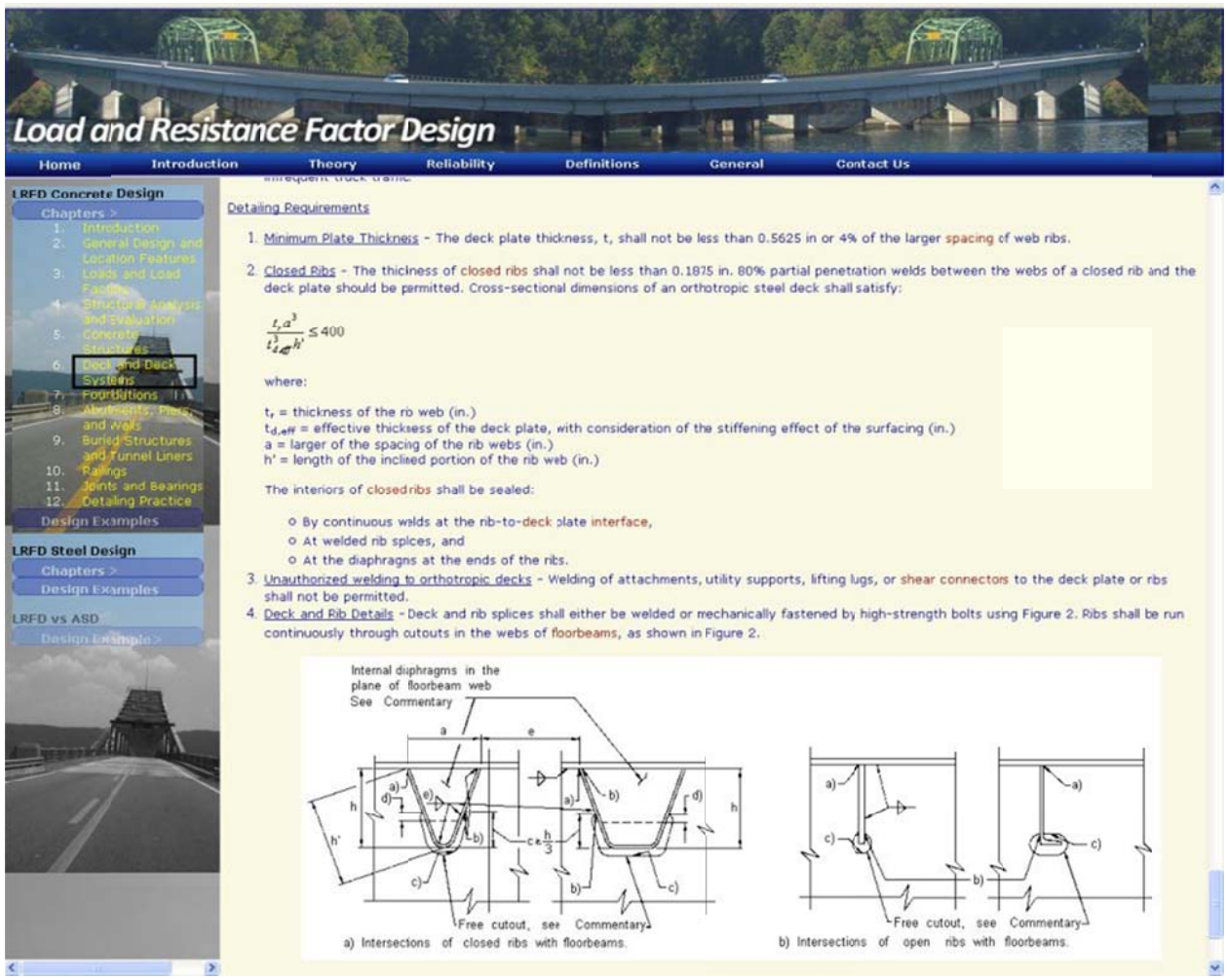


Figure 8: Chapter 6: Detailing Requirements for Orthotropic Decks

3.3.1.7 Chapter 7: Foundations

This chapter provides the LRFD specifications for the design of spread footings, driven piles, and drilled shaft foundations. In case of spread footings the general considerations shall apply to the design of isolated footings and, in some cases, to combined footings. Footings should be designed so that pressure under the footing is as nearly uniform as practical.

In some cases, positive anchorage should be provided between the rock and footing such as that provided by rock anchors, bolts, or dowels. In case of inclined load, failure by sliding shall be investigated for footing that supports this condition.

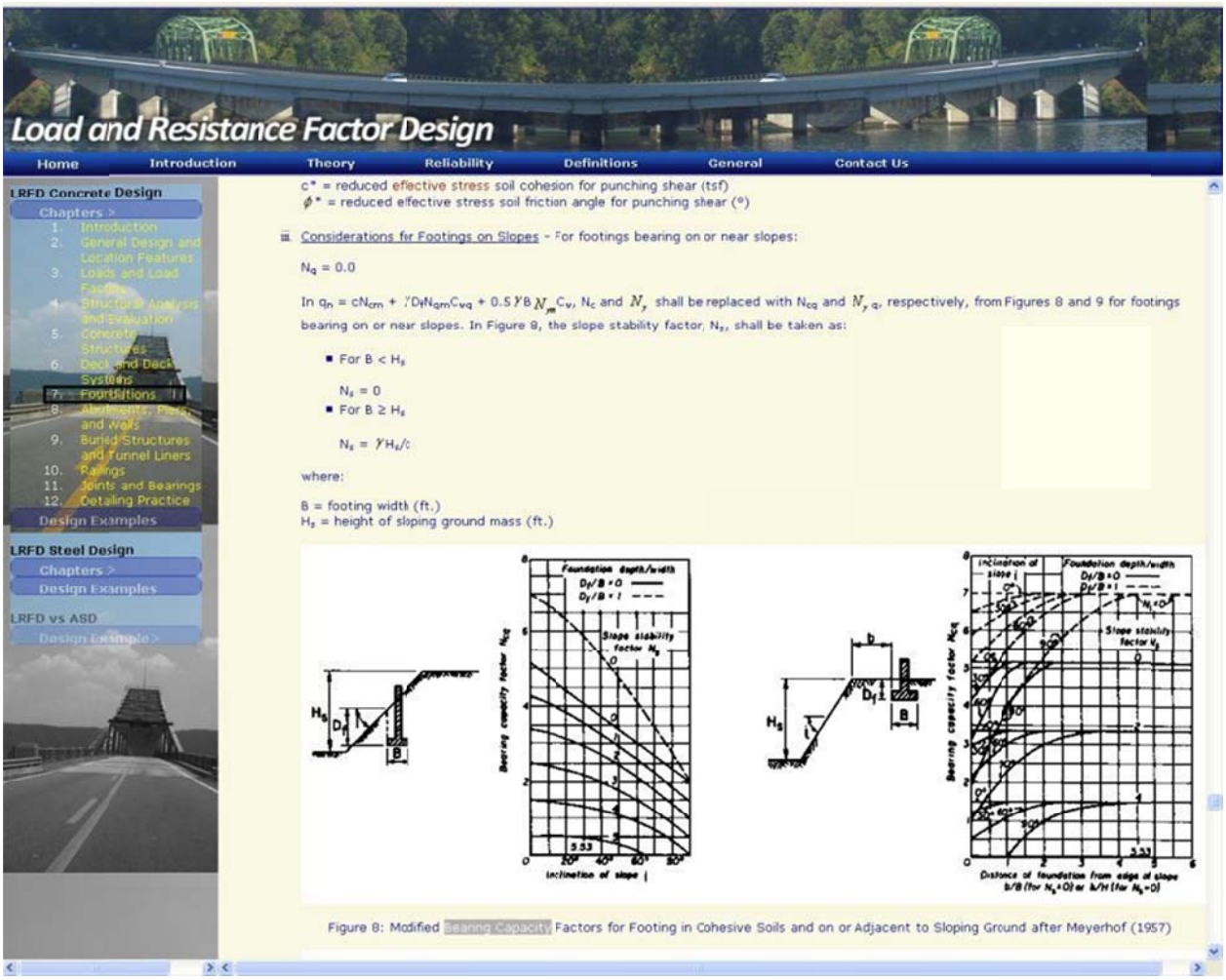


Figure 9: Chapter 7: Modified Bearing Capacity Factors for Footing in Cohesive Soils

3.3.1.8 Chapter 8: Abutments, Piers and Walls

This chapter provides requirements on the design of abutments, piers, and walls. These shall be designed to resist water pressure, the self weight of the wall, any live and dead load along with temperature and shrinkage effects.

In accordance with LRFD concrete bridge design specifications the design should be able to resist any vertical and lateral deformation or displacement. In addition this section provides the general considerations for the abutments and conventional retaining walls: loadings, wing walls, and reinforcement.

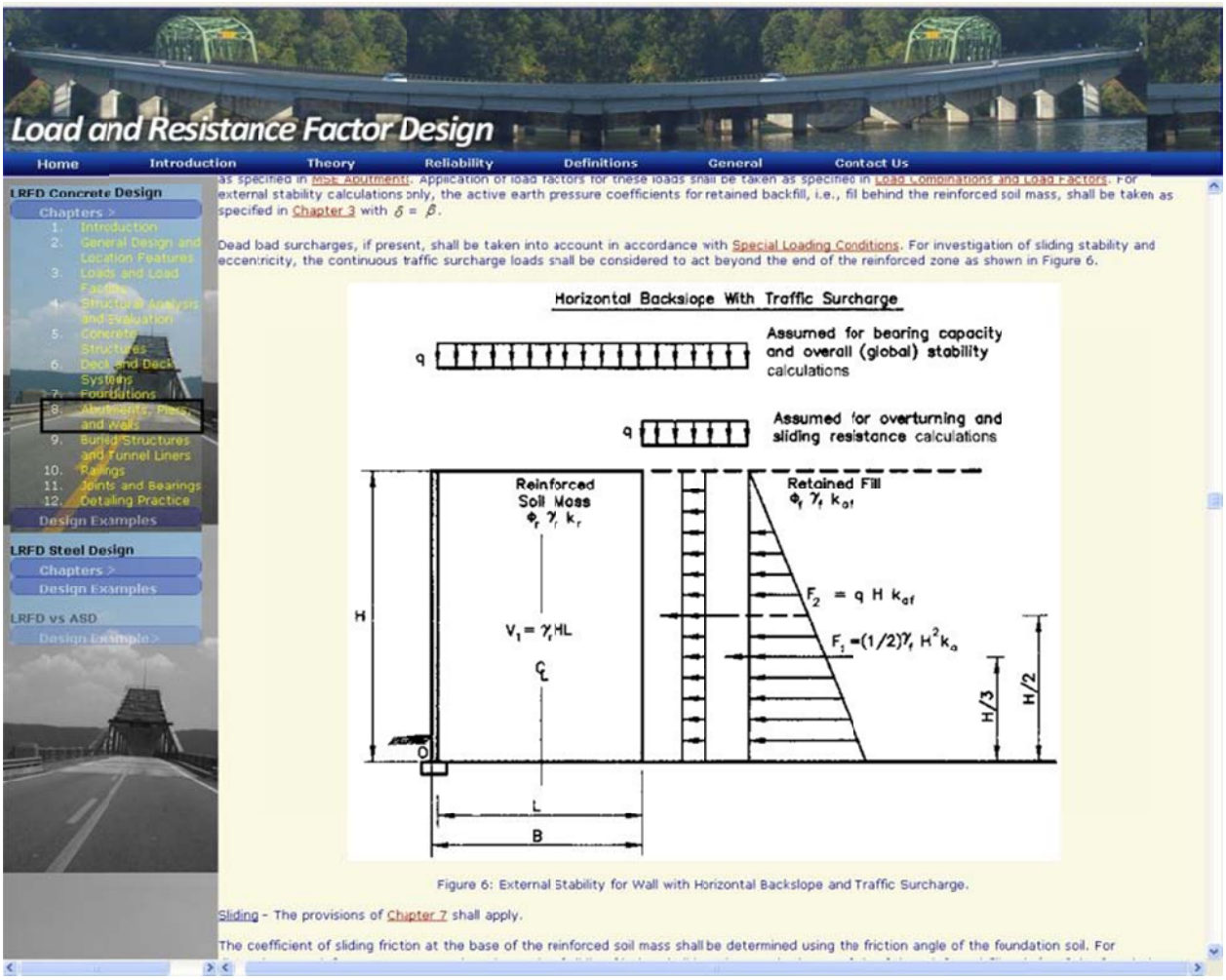


Figure 10: Chapter 8: External Stability for a Wall with Horizontal Back-Slope and Traffic Surcharge

3.3.1.9 Chapter 9: Buried Structures and Tunnel Lines

This chapter gives the requirements for the selection of structural properties and dimensions of buried structures such as culverts and steel plates used to support tunnel excavations in soil. It discusses the terms and characteristics of buried structure systems used in the designs such as metal pipes, structure plate pipes, box and elliptic structures, long-span structural plate, structural plate box, and thermoplastics pipes.

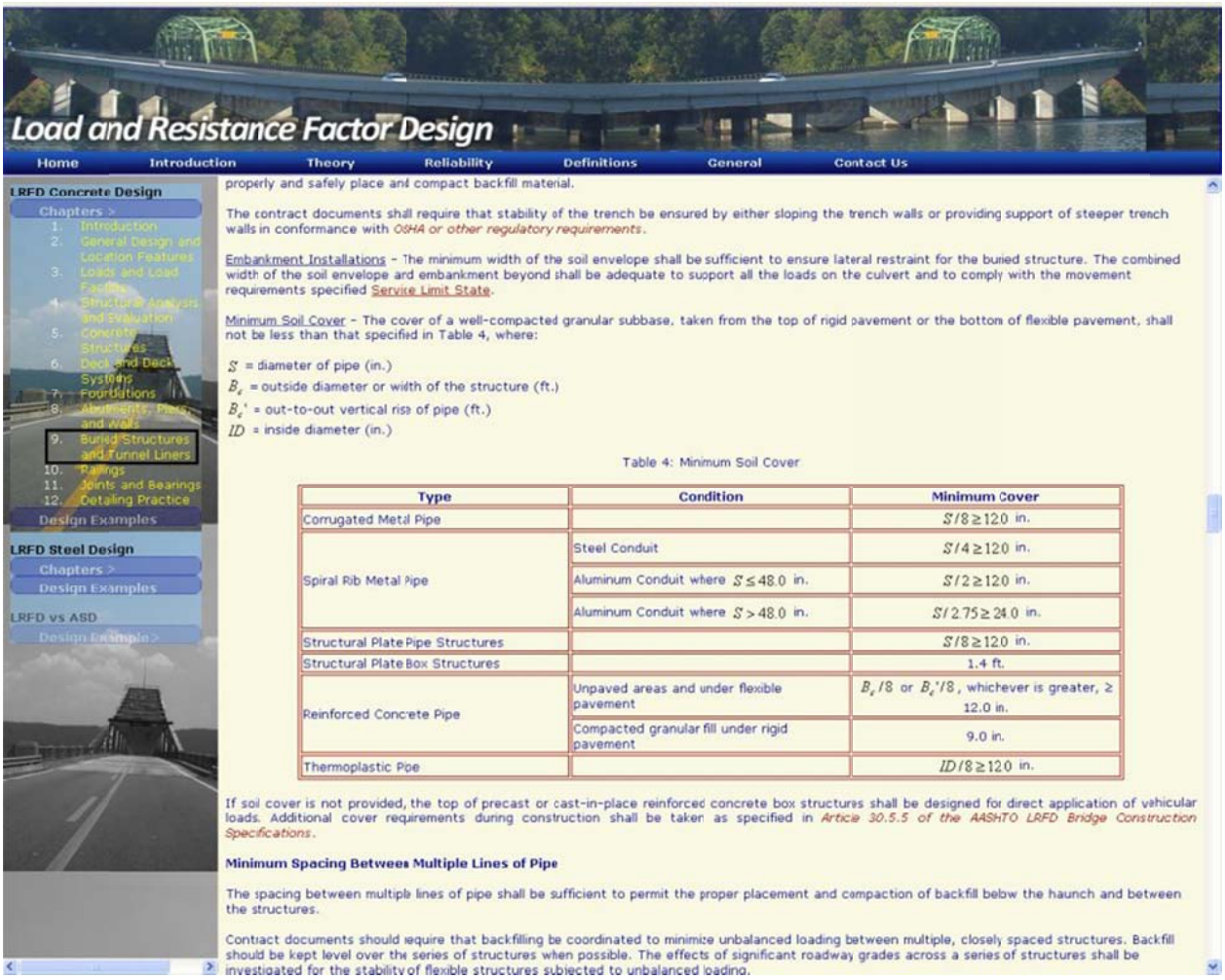


Figure 11: Chapter 9: Minimum Soil Cover Table Depending on the Different Types of Pipes or Pipe Structures

3.3.1.10 Chapter 10: Railings

This section provides six bridge railing test levels and their associated crash test requirements. This chapter applies to railings for new bridges and for rehabilitated bridges to the extent that railing replacement is determined to be appropriate. The process for the design of crash test specimens to determine their crash worthiness is described. There are three types of railings discussed in this section: traffic railings, pedestrian railings, and bicycle railings. Curbs and sidewalks are also considered in this section.

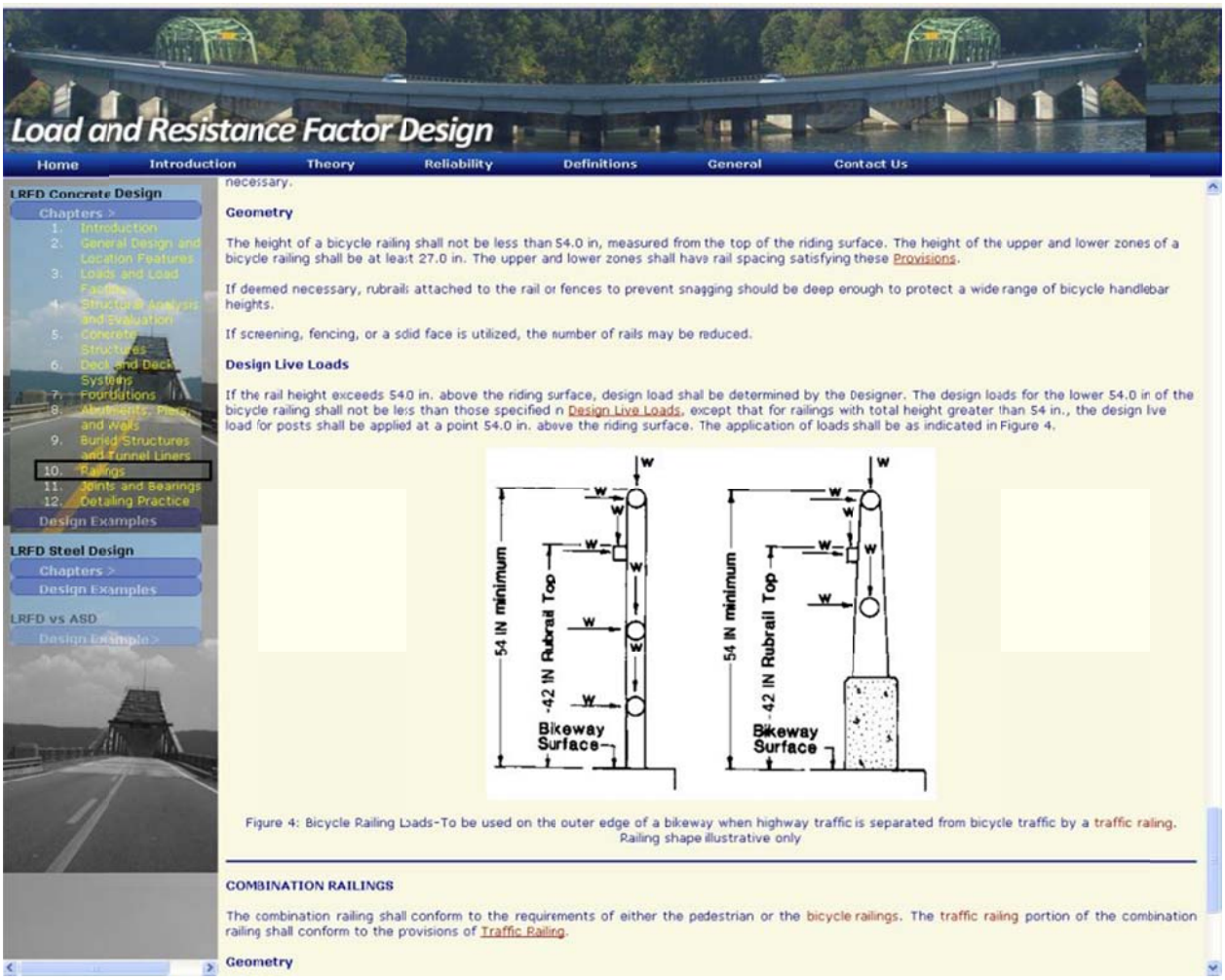
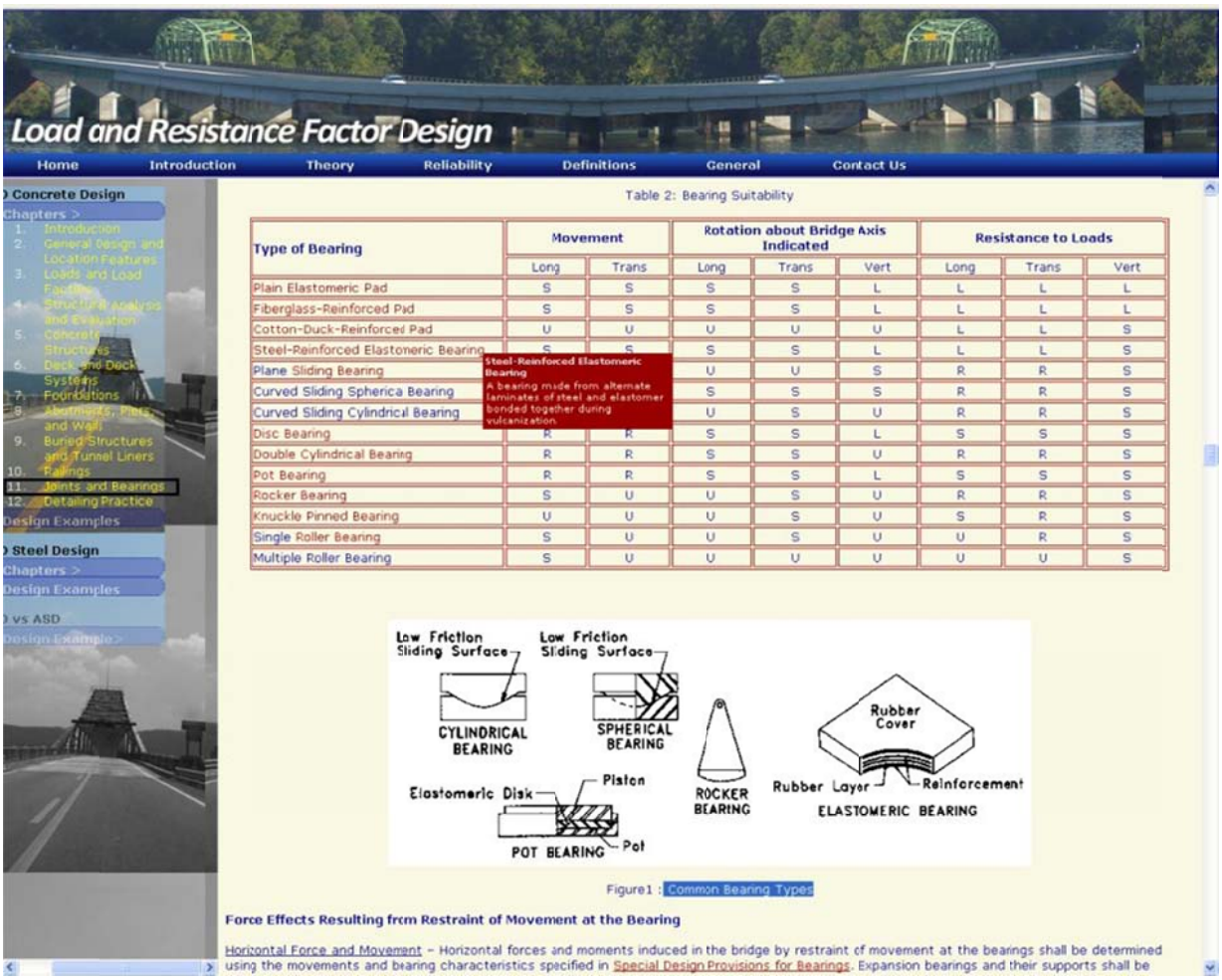


Figure 12: Chapter 10: Bicycle Railing Loads

3.3.1.11 Chapter 11: Joints and Bearings

In this section, requirements for the design and selection of structural bearings and deck joints are outlined. The design specifications for joints and bearings are stated separately.

Selection and layout of joints and bearings shall allow for deformations due to temperature and other time-dependent causes and shall be consistent with the proper functioning of the bridge. Deck joints and bearings shall be designed to resist loads and accommodate movements at the service and strength limit states and to satisfy the requirements of the fatigue and fracture limit state. Design loads for joints, bearings and structural members shall be based on the stiffness of the individual elements and the tolerance achieved during fabrication and erection. At service limit state no damage due to joints or bearing movement shall be permitted. At strength limit or extreme event states no irreparable damage shall occur.



Type of Bearing	Movement		Rotation about Bridge Axis Indicated			Resistance to Loads		
	Long	Trans	Long	Trans	Vert	Long	Trans	Vert
Plain Elastomeric Pad	S	S	S	S	L	L	L	L
Fiberglass-Reinforced Pad	S	S	S	S	L	L	L	L
Cotton-Duck-Reinforced Pad	U	U	U	U	U	L	L	S
Steel-Reinforced Elastomeric Bearing	S	S	S	S	L	L	L	S
Plane Sliding Bearing			U	U	S	R	R	S
Curved Sliding Spherica Bearing			S	S	S	R	R	S
Curved Sliding Cylindrical Bearing			U	S	U	R	R	S
Disc Bearing	R	R	S	S	L	S	S	S
Double Cylindrical Bearing	R	R	S	S	U	R	R	S
Pot Bearing	R	R	S	S	L	S	S	S
Rocker Bearing	S	U	U	S	U	R	R	S
Knuckle Pinned Bearing	U	U	U	S	U	S	R	S
Single Roller Bearing	S	U	U	S	U	U	R	S
Multiple Roller Bearing	S	U	U	U	U	U	U	S

Figure 13: Chapter 11: Common Bearing Types

3.3.1.12 Chapter 12: Detailing Practice

This chapter states the procedure that should be done according to the standards of the Load and Resistance Rating (LRFR) manual for any design of a bridge structure. It goes step-by-step on everything that should be done. The areas covered are:

1. Bridge Records
2. Bridge Management Systems
3. Inspection
4. Material Testing
5. Load and Resistance Factor Ratings
6. Fatigue Evaluation of Steel Bridges
7. Nondestructive Load Testing
8. Special Topics
    - Evaluation of Unreinforced Masonry Arches
    - Direct Safety Assessment of Bridges
    - Historic Bridges

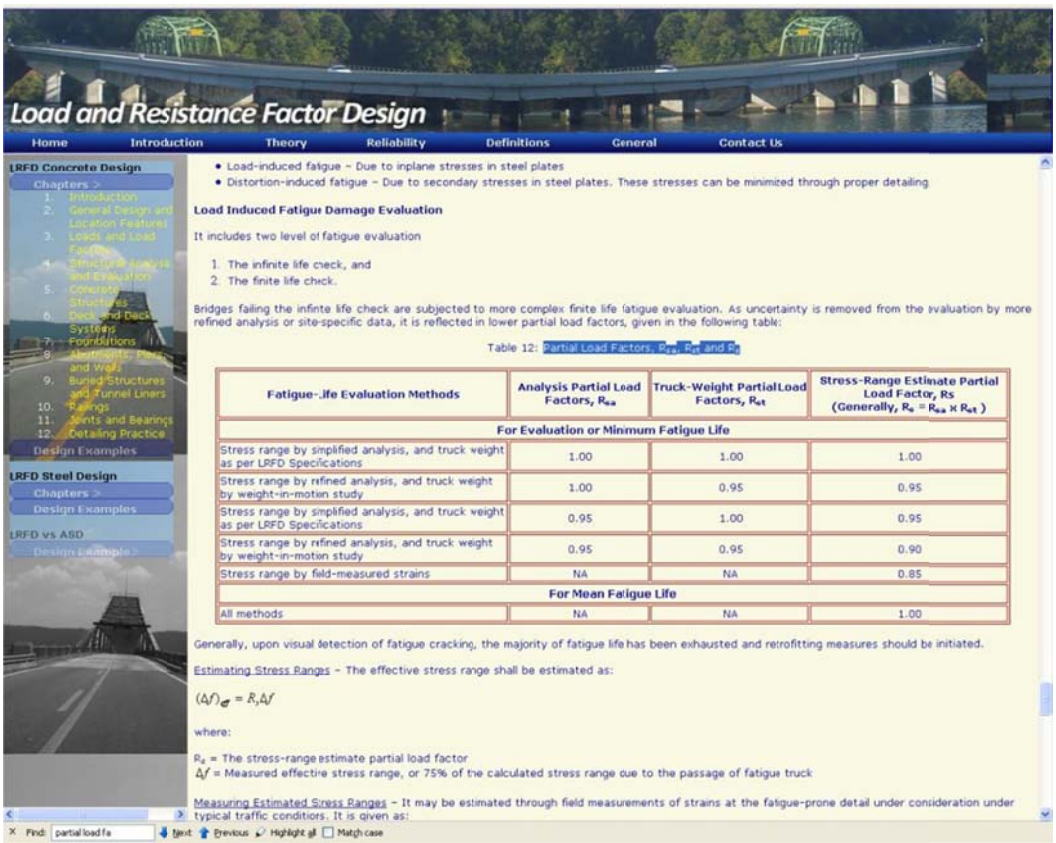


Figure 14: Chapter 12: Partial Load Factors, R_{sa}, R_{st} and R_s

3.3.2 LRFD Steel Design:

The following twelve chapters and their descriptions are from the AASHTO LRFD Specification Manual-Interim Revision 2005.

3.3.2.1 Chapter 1: Introduction

"Details are similar to the LRFD Concrete Design Section-Chapter 1."

3.3.2.2 Chapter 2: General Design and Location Features

"Details are similar to the LRFD Concrete Design Section-Chapter 2."

3.3.2.3 Chapter 3: Load and Load Factors

"Details are similar to the LRFD Concrete Design Section-Chapter 3."

3.3.2.4 Chapter 4: Structural Analysis and Evaluation

"Details are similar to the LRFD Concrete Design Section-Chapter 4."

3.3.2.5 Chapter 5: Steel Structures

This chapter discusses on design of steel bridges. Steel structures are a very important module in the design of a bridge. This section covers the design of steel components, splices and connections for beams and girder structures, frames, trusses and arches, cable-stayed and suspension systems, as applicable.

Curved girder structures are not included. Division I-A of the AASHTO Standard Specifications contains some limited information on seismic behavior of steel structures, which may be utilized where applicable.

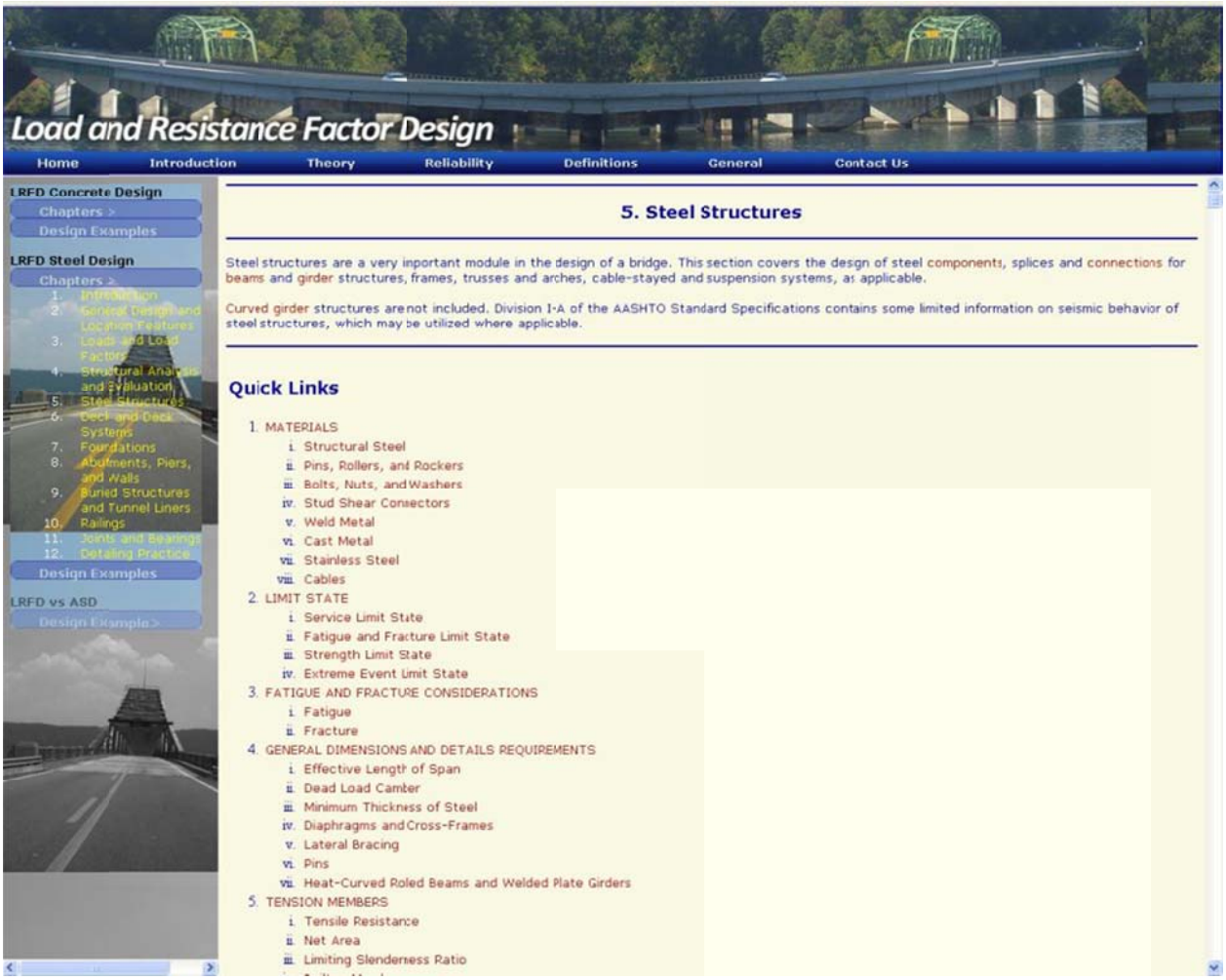


Figure 15: Chapter 5: Steel Structures Page

3.3.2.6 Chapter 6: Deck and Deck Systems

"Details are similar to the LRFD Concrete Design Section-Chapter 6."

3.3.2.7 Chapter 7: Foundations

"Details are similar to the LRFD Concrete Design Section-Chapter 7."

3.3.2.8 Chapter 8: Abutments, Piers and Walls

"Details are similar to the LRFD Concrete Design Section-Chapter 8."

3.3.2.9 Chapter 9: Buried Structures and Tunnel Lines

"Details are similar to the LRFD Concrete Design Section-Chapter 9."

3.3.2.10 Chapter 10: Railings

"Details are similar to the LRFD Concrete Design Section-Chapter 10."

3.3.2.11 Chapter 11: Joints and Bearings

"Details are similar to the LRFD Concrete Design Section-Chapter 11."

3.3.2.12 Chapter 12: Detailing Practice

"Details are similar to the LRFD Concrete Design Section-Chapter 12."

3.4 Theory

This page introduces the user a basic theory of LRFD specifications, providing basic equations of its methodology and definitions (See Figure 16).

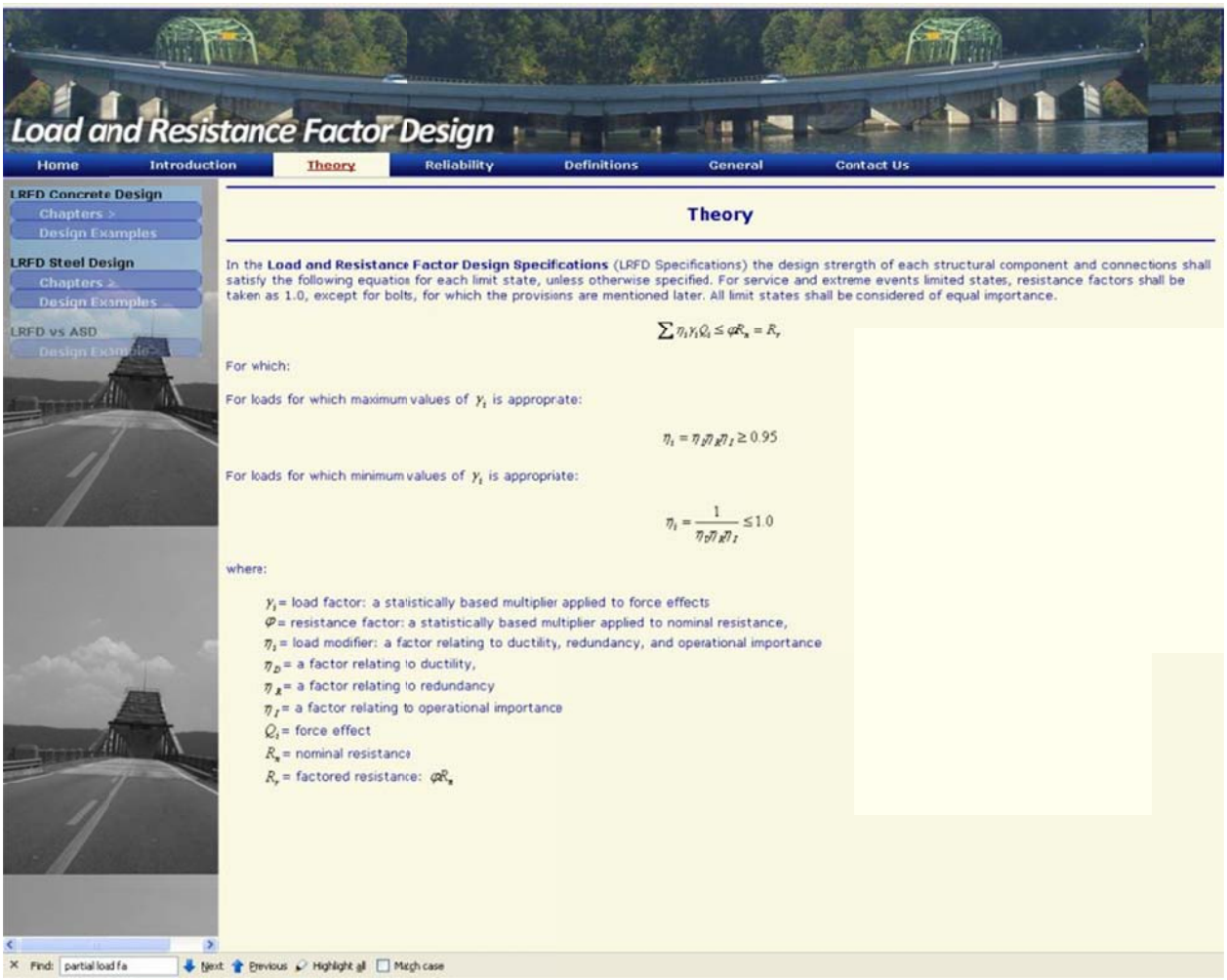


Figure 16: Theory Page Shows Basic Equations in LRFD

3.5 Reliability

The main idea of this page is to give the user a background of why AASHTO adopted LRFD Specifications in 1994. There is a comparison of the three design philosophies: elastic design / working stress design (allowable stress design), plastic design, and Load and Resistance Factor Design (LRFD).

For a better understanding about the reliability of LRFD Specification, the following graphs show the progress of implementing LRFD.

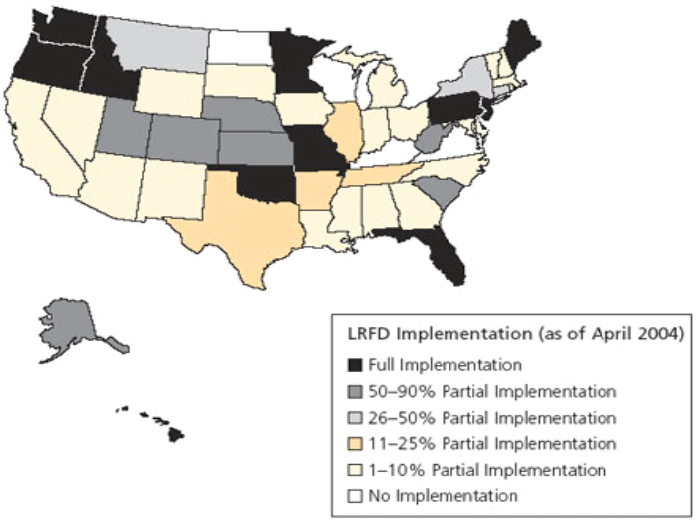


Figure 17: LRFD Implementation by States and Local Governments as of April 2004

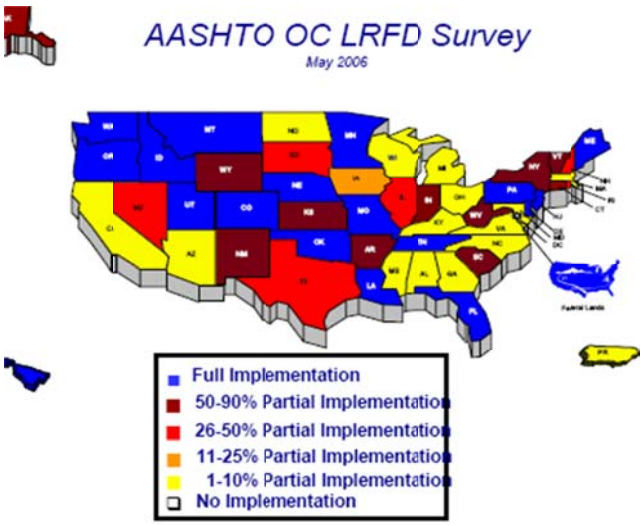


Figure 18: LRFD Specifications Implementation by States and Local Governments as of May 2006

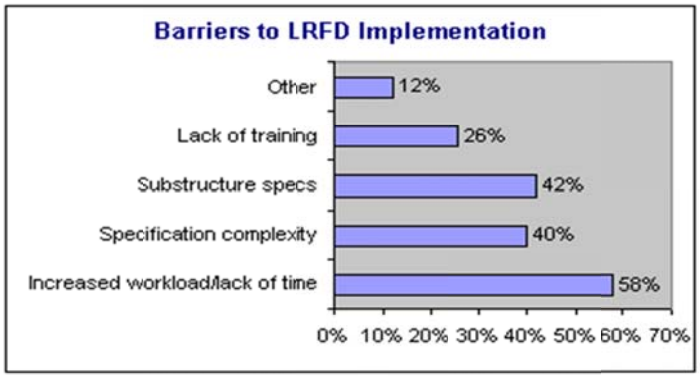


Figure 19: Barriers to LRFD Implementation

Every year more of the new bridges are being designed using LRFD. The barriers to LRFD implementation are illustrated in Figure 19.

Figure 20: Reliability Concepts Page Describes the Three Principal Design Philosophies

3.6 Design Examples

This section contains six typical concrete beam and girder superstructure designs. The first design example is a deck of a reinforced concrete T-beam bridge. The second example is a simply supported solid slab bridge. The third example is a reinforced concrete T-beam bridge. The fourth example is a simply supported pretensioned prestressed concrete girder bridge. The fifth example is a concrete box-girder bridge. And the sixth example is a stub abutment design. For the simplification of design procedure, a general outline is also presented. It is intended to be a generic overview of the design process. It should not be regarded as fully complete, nor should it be used as a substitute for a working knowledge of the provisions.

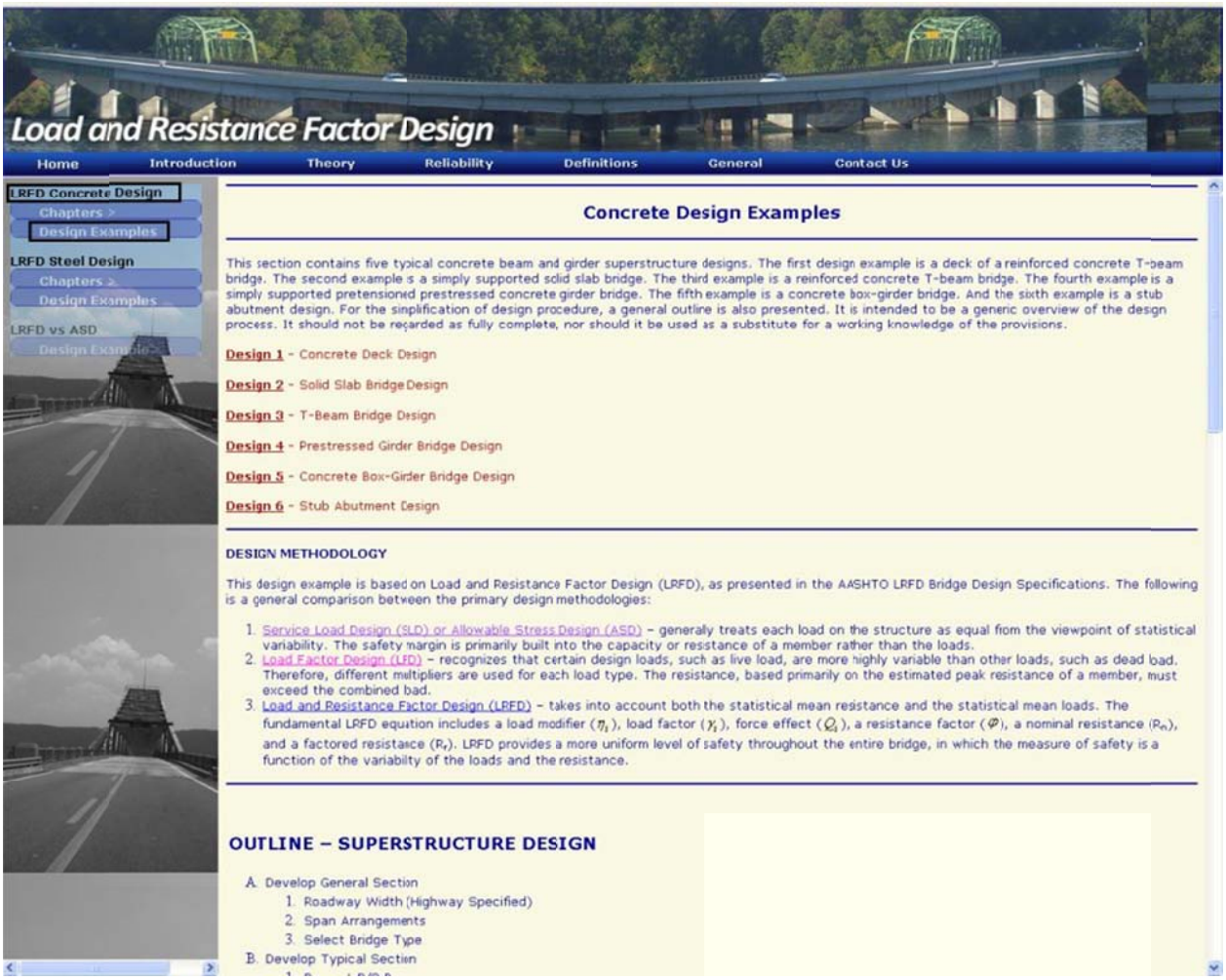


Figure 21: Design Examples Page Show Six Different Examples Step-by-Step

3.6.1 LRFD Concrete Design:

3.6.1.1 Design Example #1 – Concrete Deck Design

Use the approximate method of analysis to design the deck of the reinforced concrete T-beam bridge section of Figure 22 below for a HL-93 live load and a PL-2 performance level concrete barrier. The T-beams supporting the deck are 96 in. on centers and have a stem width of 14 in. The deck overhangs the exterior T-beams by 39 in. The concrete density is 0.150 kcf. Allow for a wearing future wearing surface of 3 in. thick bituminous overlay. Use f'_c = 4.5 ksi and f'_c = 60 ksi.

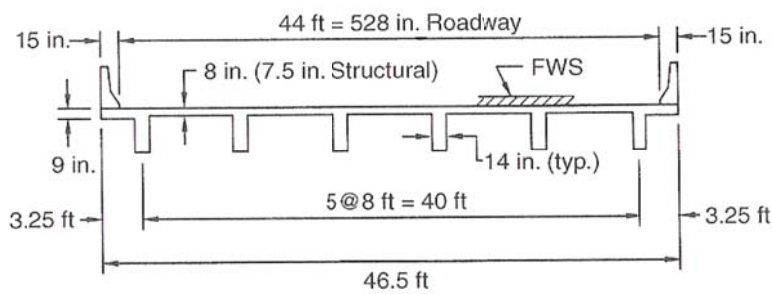
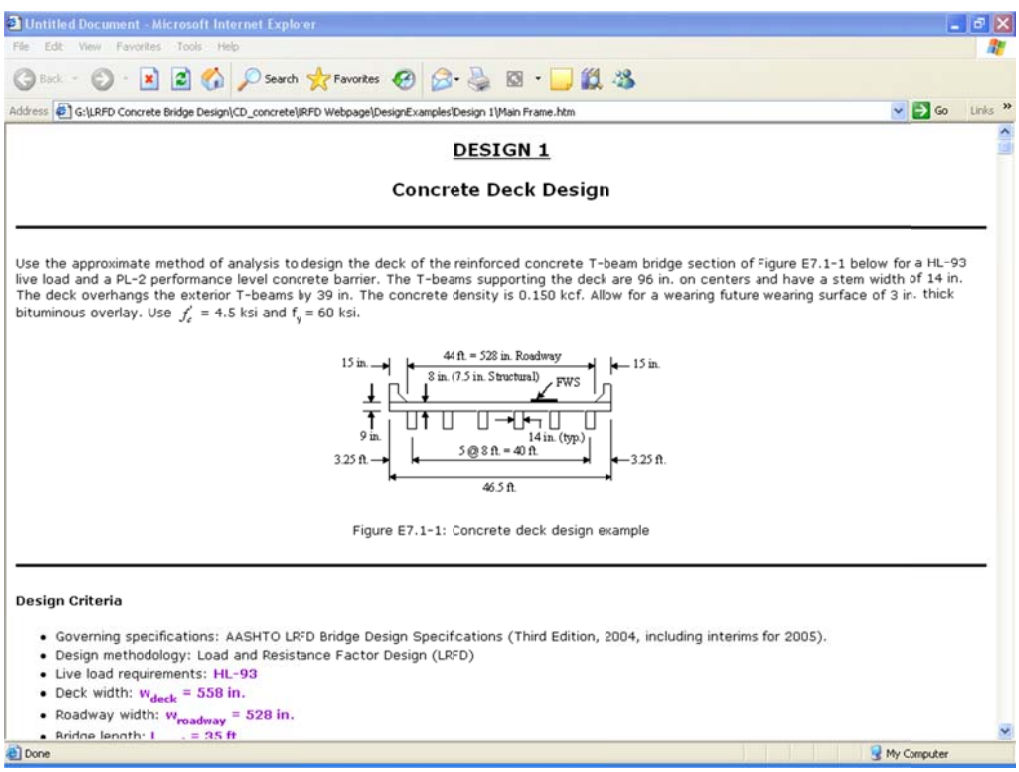


Figure 22: Beam for Concrete Design Example #1



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Address G:\LRFD Concrete Bridge Design\CD_concrete\LRFD Webpage\DesignExamples\Design 1\Main Frame.htm

DESIGN 1

Concrete Deck Design

Use the approximate method of analysis to design the deck of the reinforced concrete T-beam bridge section of Figure E7.1-1 below for a HL-93 live load and a PL-2 performance level concrete barrier. The T-beams supporting the deck are 96 in. on centers and have a stem width of 14 in. The deck overhangs the exterior T-beams by 39 in. The concrete density is 0.150 kcf. Allow for a wearing future wearing surface of 3 in. thick bituminous overlay. Use f'_c = 4.5 ksi and f_y = 60 ksi.

Figure E7.1-1: Concrete deck design example

Design Criteria

- Governing specifications: AASHTO LRFD Bridge Design Specifcations (Third Edition, 2004, including interims for 2005).
- Design methodology: Load and Resistance Factor Design (LRFD)
- Live load requirements: HL-93
- Deck width: w_{deck} = 558 in.
- Roadway width: $w_{roadway}$ = 528 in.
- Bridge length: L = 35 ft

Done

My Computer

Figure 23: Page for Concrete Design Example #1

3.6.1.2 Design Example #2 – Solid Slab Bridge Design

Design the simply supported solid slab bridge of Figure 24 with a span length of 35 ft. center to center of bearings for a HL-93 live load. The roadway width is 528 in. curb to curb. Allow for a future-wearing surface of 3 in. thick bituminous overlay. A 15-in.-wide barrier weighing 0.32 k/ft. is assumed to be carried by the edge strip. Use f'_c = 4.5 ksi and f_y = 60 ksi. Use exposure class 2 for crack control.

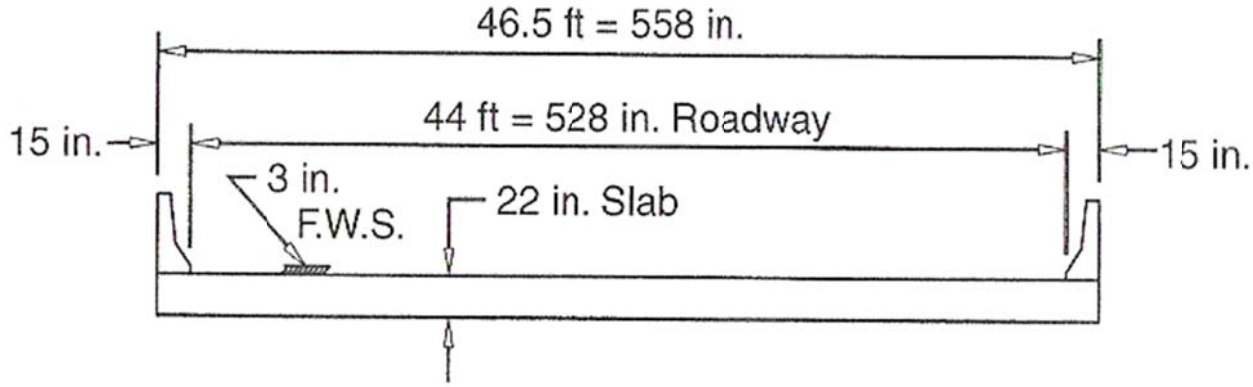


Figure 24: Concrete Deck Preliminary Details for Example #2

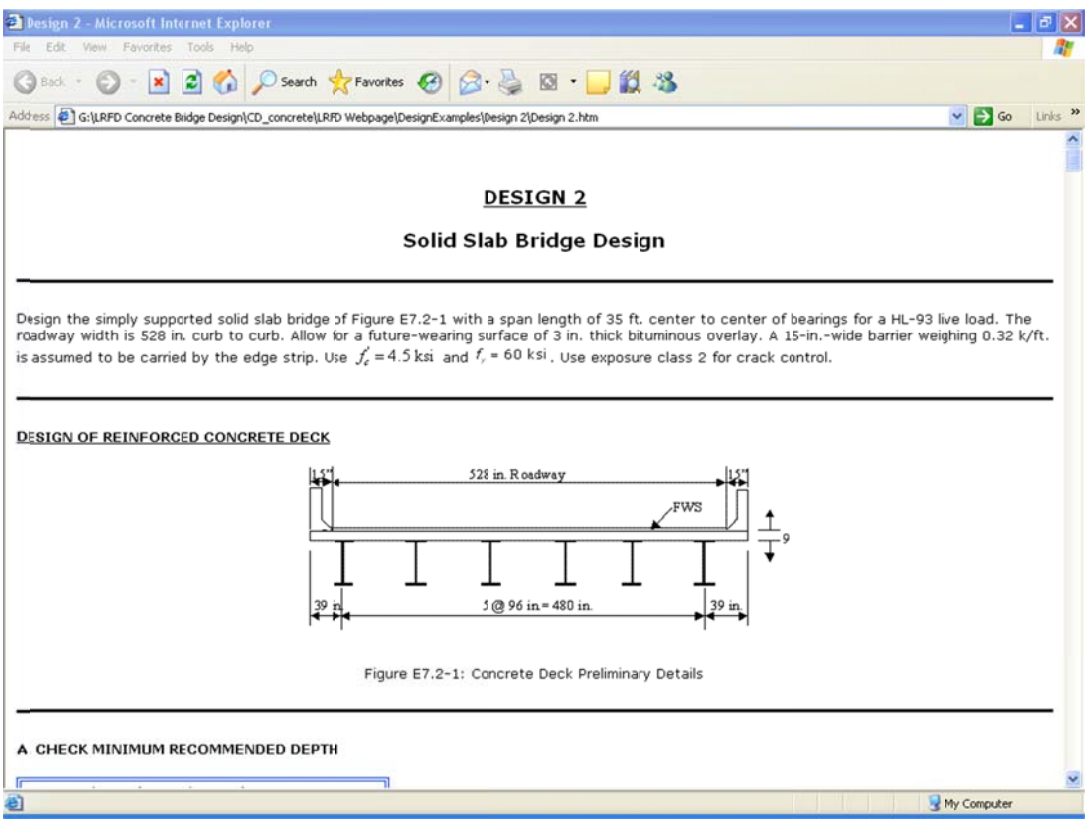


Figure 25: Page for Concrete Design Example #2

3.6.1.3 Design Example #3 – T-Beam Bride Design

Design a reinforced concrete T-beam bridge for a 44-ft. wide roadway and three-spans of 35 ft.-42 ft.-35ft. with skew of 30° as shown in Figure 26 Use the concrete deck of Design Example #1 previously designed for an HL-93 live load, a bituminous overlay, and an 8 ft. spacing of girders in Design Example #1. Use $f'_c = 4.5$ ksi and $F_y = 60$ ksi.

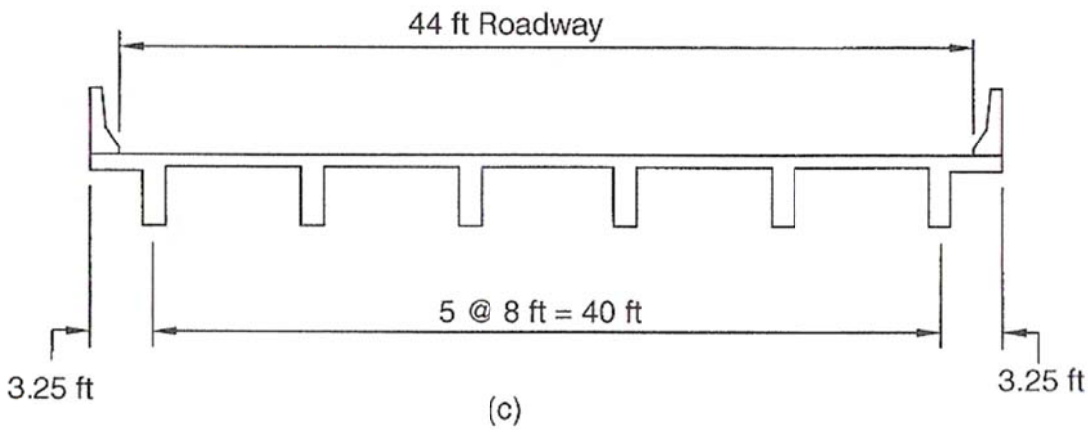
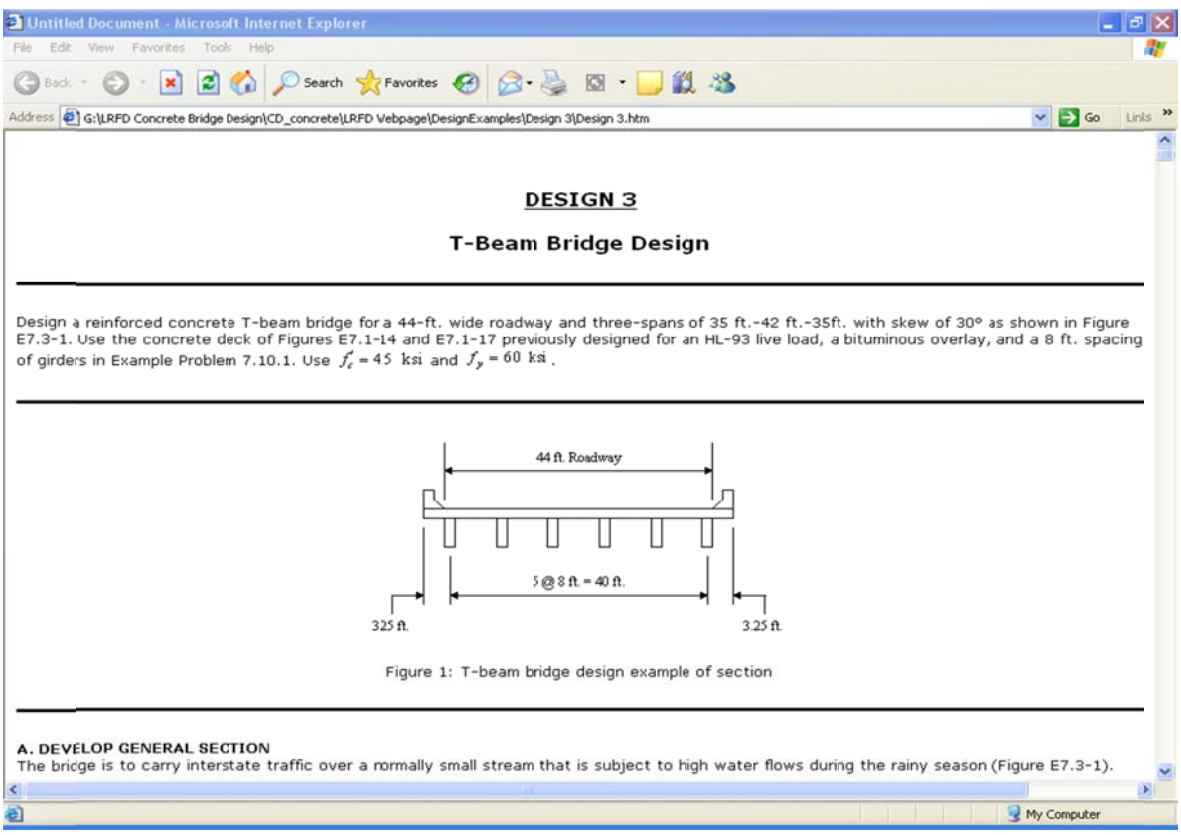


Figure 26: T-Beam Bridge Section



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DESIGN 3

T-Beam Bridge Design

Design a reinforced concrete T-beam bridge for a 44-ft. wide roadway and three-spans of 35 ft.-42 ft.-35ft. with skew of 30° as shown in Figure E7.3-1. Use the concrete deck of Figures E7.1-14 and E7.1-17 previously designed for an HL-93 live load, a bituminous overlay, and a 8 ft. spacing of girders in Example Problem 7.10.1. Use $f'_c = 4.5$ ksi and $f_y = 60$ ksi.

Figure 1: T-beam bridge design example of section

A. DEVELOP GENERAL SECTION

The bridge is to carry interstate traffic over a normally small stream that is subject to high water flows during the rainy season (Figure E7.3-1).

My Computer

Figure 27: Page for Concrete Design Example #3

3.6.1.4 Design Example #4 – Prestressed Girder Bridge Design

Design the simply supported pretensioned prestressed concrete girder bridge of Figure 28 with a span length of 100 ft. center to center of bearings for a HL–93 live load. The roadway width is 44 ft. curb to curb. Allow for a future wearing surface of 3-in. thick bituminous overlay and use the concrete deck design of Design Example #1 (f'_c = 4.5 ksi). Follow the beam and girder bridge outline of the AASHTO (2004) LRFD Bridge Specifications. Use f'_c = 8 ksi. Use f'_{ci} = 6 ksi, f_y = 60 ksi, and 270 ksi, low-relaxation 0.5 in., seven wire stands. The barrier is 15 in. wide and weighs 0.32 kips/ft. The owner requires this load to be assigned to the exterior girder.

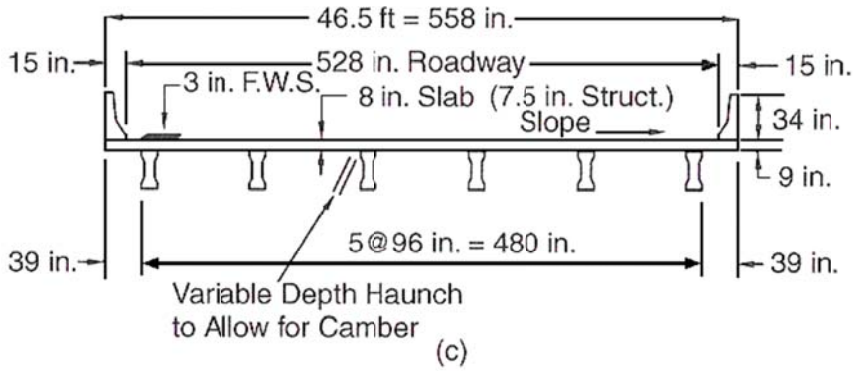

Figure 28: Prestressed Concrete Girder Bridge Section

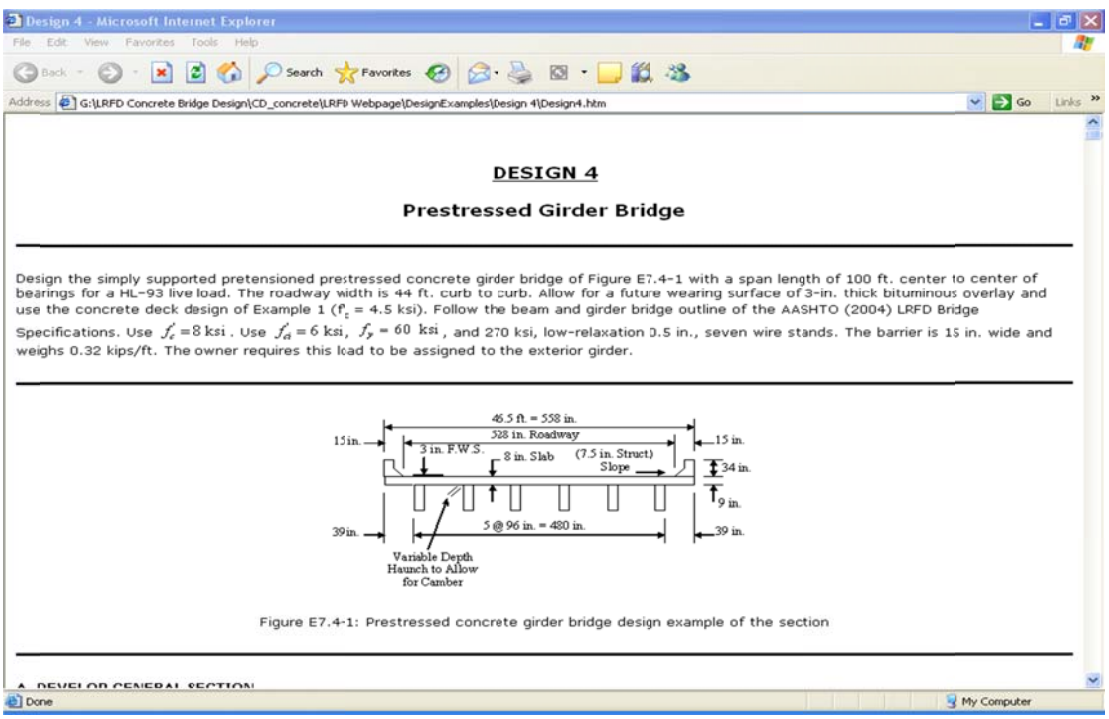

Figure 29: Page for Concrete Design Example #4

3.6.1.5 Design Example #5 – Concrete Box-Girder Design

Design of the deck of the reinforced concrete T-beam bridge with 98 ft. -118 ft. -98 ft. spans for a HL–93 live load. The roadway width is 44 ft. curb to curb. Allow for a future wearing surface of 3-in. thick bituminous overlay and. Use empirical method for overslabs to design the top flange of the box girder. Use f'_c = 5 ksi, f_y = 60 ksi, and 270 ksi, low-relaxation 0.6 in., 7- wire stands.

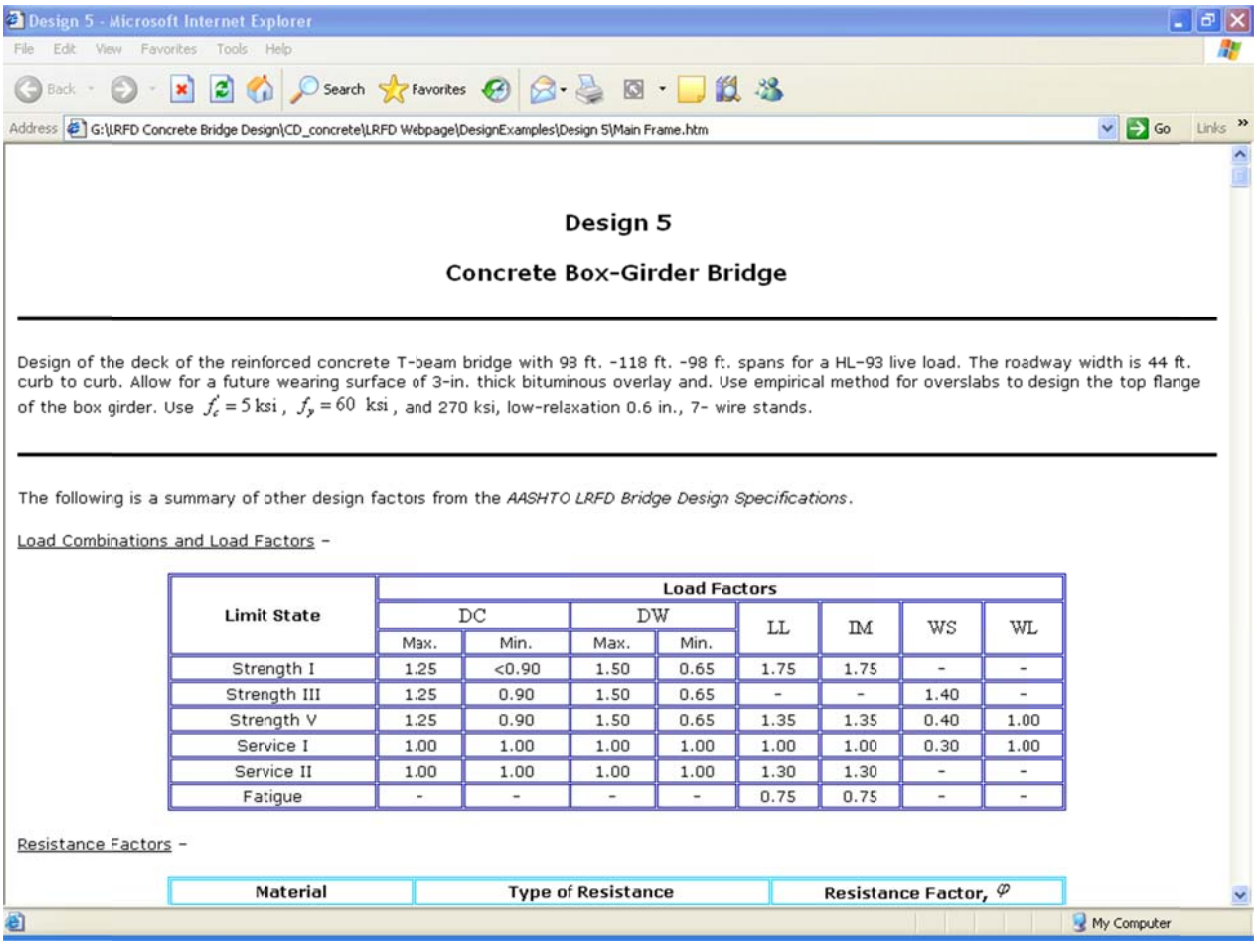

Figure 30: Page for Concrete Design Example #5

3.6.1.6 Design Example #6 – stub Abutment Design

Design a stub abutment to accommodate the given reactions from a composite steel superstructure.

1. A 3 span (29’-63’-29’) essential bridge crossing a highway
2. 1’-0” diameter concrete piles – 40 ft long. Capacity = 30 tons
3. 18 pairs of piles at 6’-8” center-to-center along length of footer
4. Concrete strength f_c’ = 3,000 psi
5. Grade reinforcement f_s = 24,000 psi
6. Total reaction from all stringers R = 315 k
7. Deck Weight = 21.74 k/ft.
8. Geographic area has acceleration coefficient: A = 0.19
9. Soil tests indicate stiff clay with angle of friction: ϕ = 30°

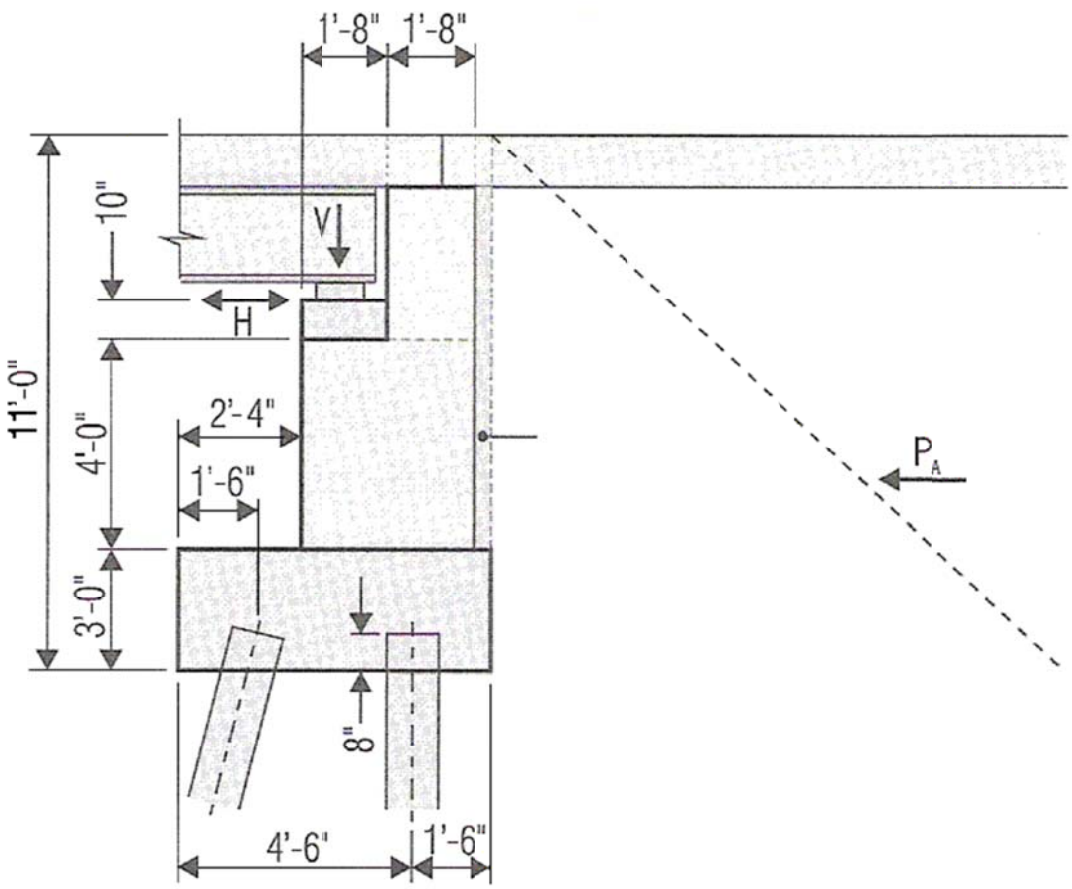

Figure 31: Stub Abutment for Design Example #6

3.6.2 LRFD Steel Design:

3.6.2.1 Design Example #1 – Non-composite Steel Beam Bridge

Design the simple-span non-composite rolled steel beam bridge of Figure 32 with 35-ft. span for a HL–93 live load. Roadway width is 44 ft. curb to curb. Allow for a future-wearing surface of 3 in. thick bituminous overlay. Use f_c'= 4 ksi and M270 Grade 50 steel. The fatigue detail at midspan is category A. The barrier is 15 in. wide and weighs 0.5 k/ft.

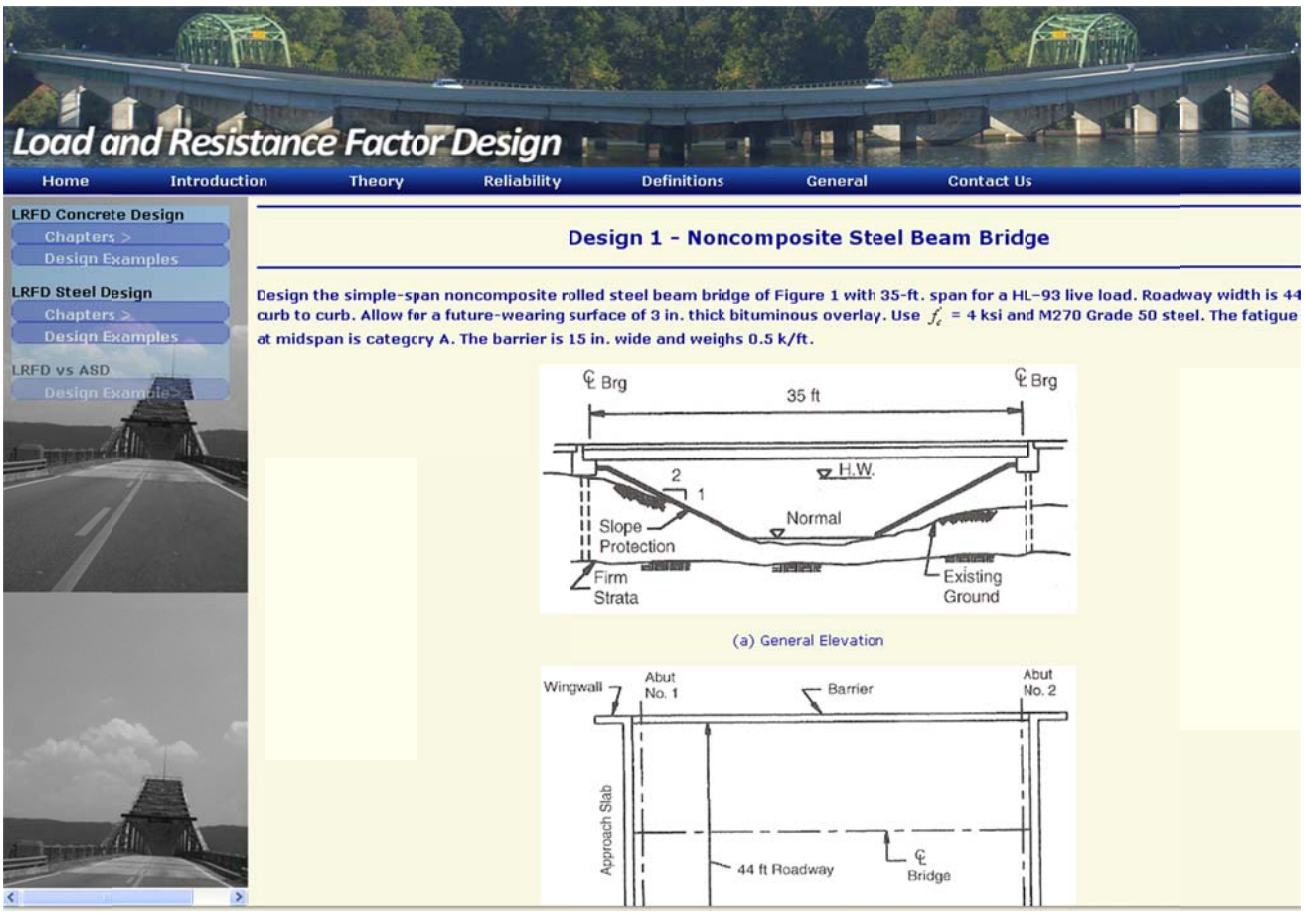

Figure 32: Page for Steel Design Example #1

3.6.2.2 Design Example #2 – Composite Steel Beam Bridge

Design the simple-span composite rolled steel beam bridge of Figure 33 with 35 ft. span for a HL–93 live load. Roadway width is 44 ft. curb to curb. Allow for a future wearing surface of 3 in. thick bituminous overlay. Use fc'= 4 ksi and M270 Grade 50 steel.

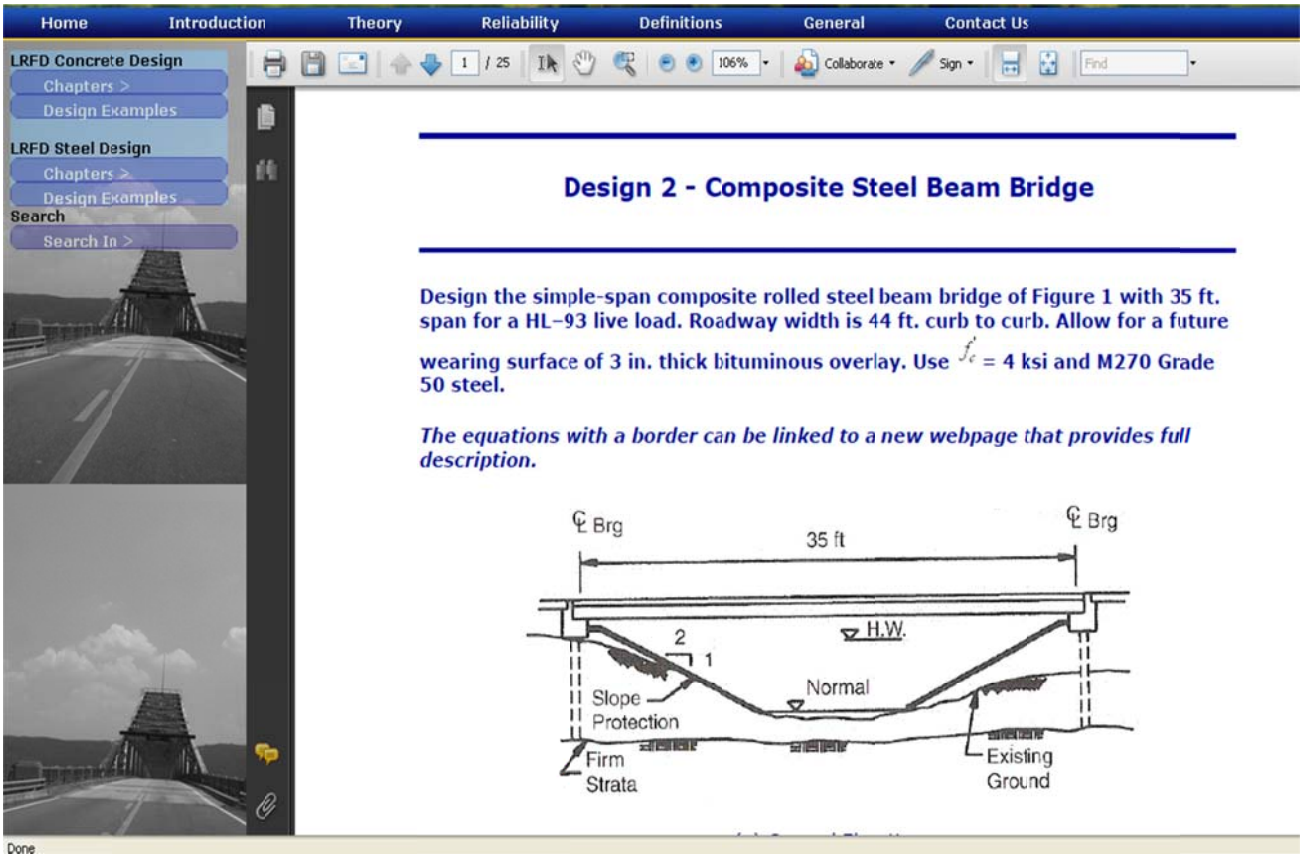

Figure 33: Page for Steel Design Example #2

3.6.2.3 Design Example #3 – Continuous Composite Girder Bridge

Design the continuous steel plate girder bridge of Figure 34 with 30 m, 36 m, and 30 m (100 ft., 120 ft., and 100 ft.) spans for a HL–93 live load. Roadway width is 13,420 mm curb to curb (44 ft.) and carries an interstate highway. Allow for a future wearing surface of 75 mm (3 in.) thick bituminous overlay. Use fc'=30 MPa (4 ksi) and M270 Grade 345 steel (50 ksi). Note that the computer program BT-Beam was used to generate the actions. The sample computations are presented to illustrate the hand and computer computations. The computer results are slightly different due to a refined live load positioning as compared to the hand-based critical position estimates. The primary unit systems for this example is SI.

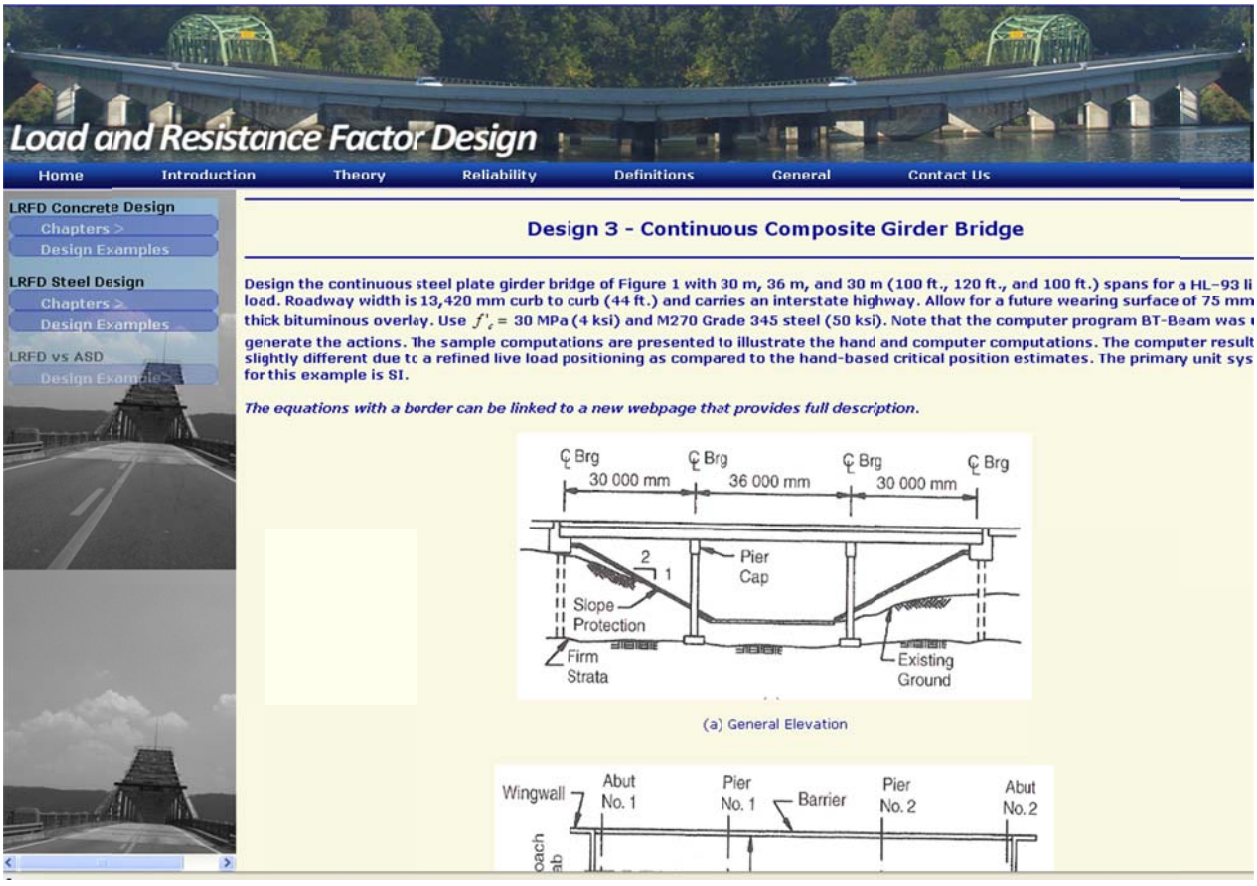

Figure 34: Page for Steel Design Example #3

3.6.3 LRFD Vs ASD: Bridge Substructure Design Example

3.6.3.1 Table of Contents

Page with table of contents on LRFD Vs ASD Bridge substructure Design example is shown below:

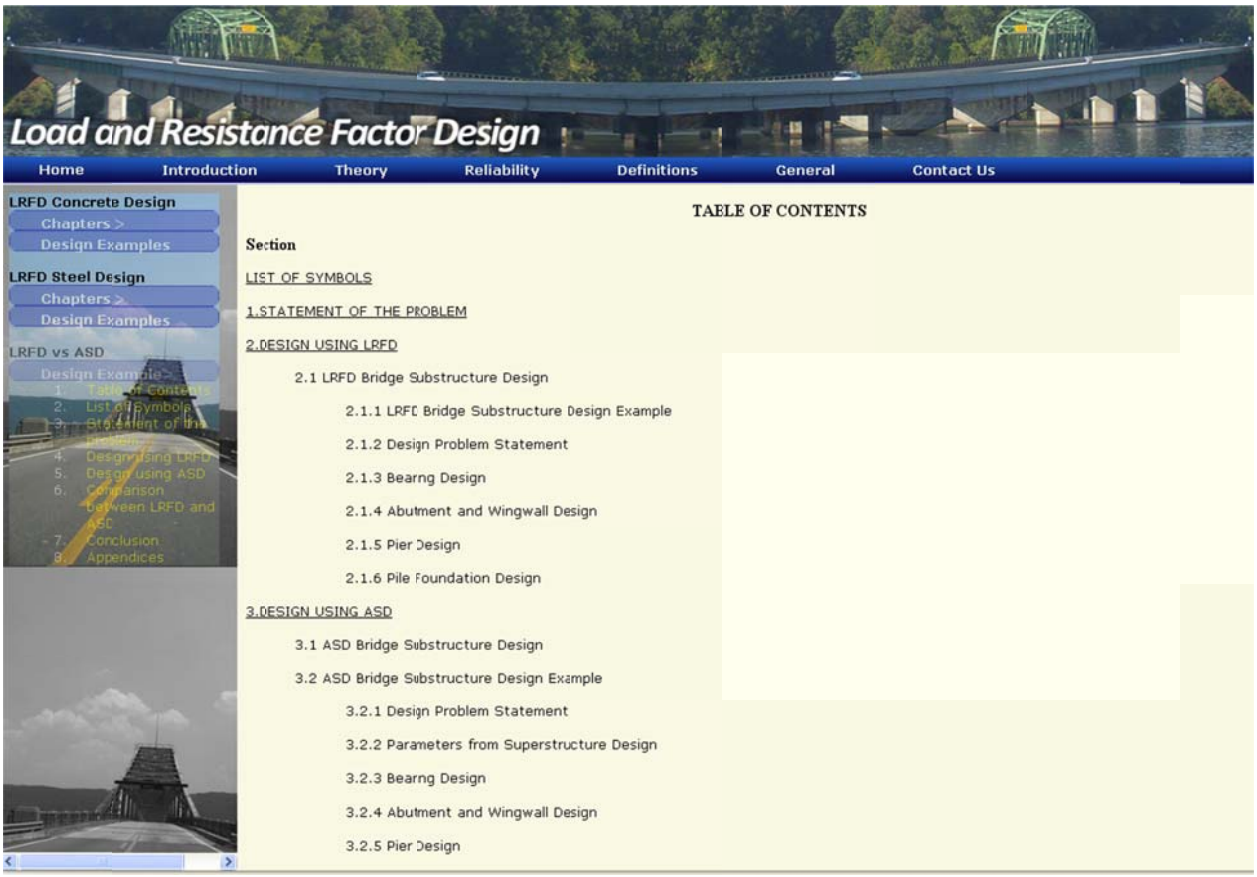

Figure 35: Page showing Table of Contents for LRFD Vs ASD Substructure Design Example

3.6.3.2 List of Symbols

Symbols used in design example of substructure are listed and the page with list of symbols and their description is shown below:

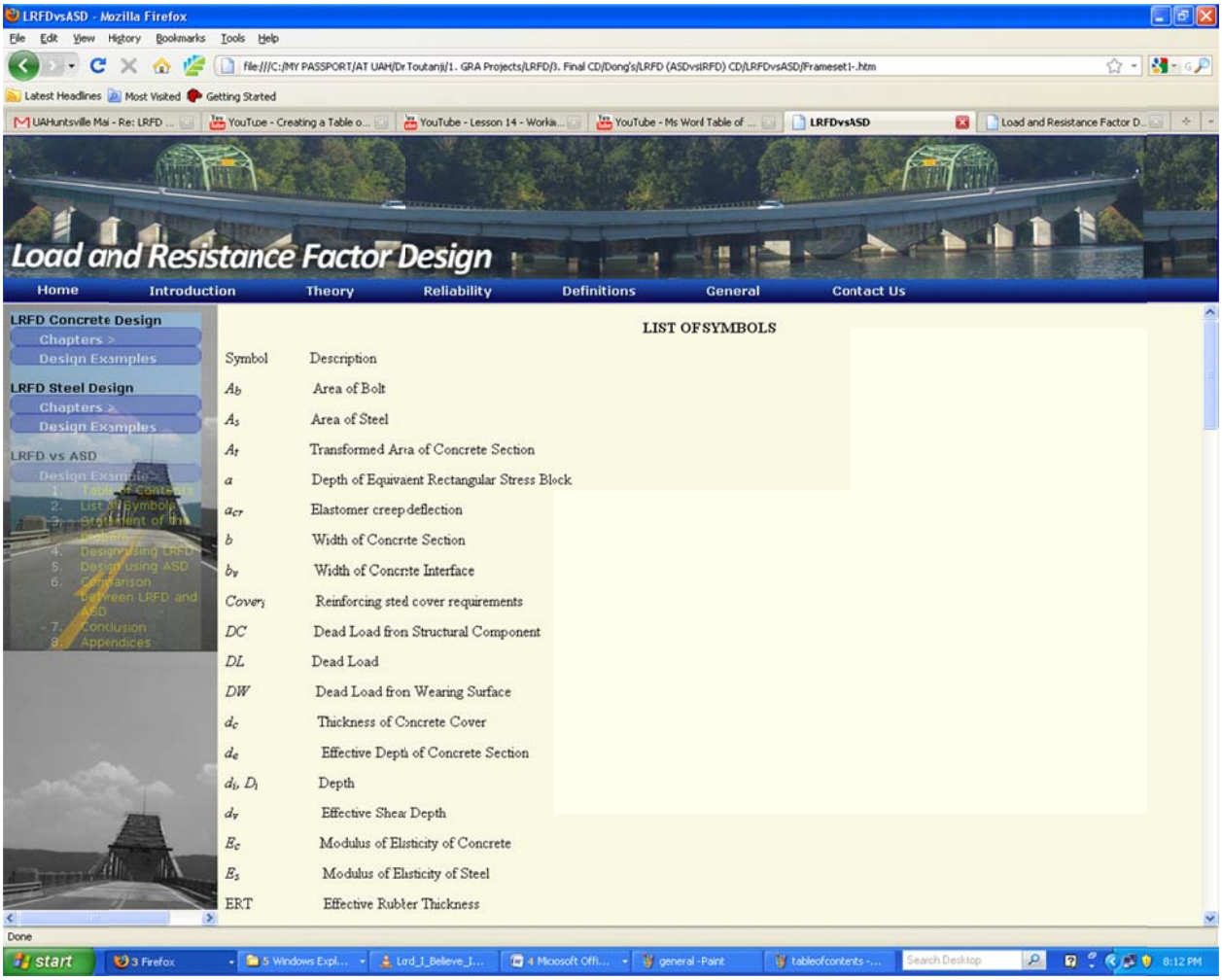

Figure 36: List of Symbols used in LRFD Vs ASD Substructure Design Example

3.6.3.3 Statement of the Problem

Using the LRFD&ASD methods, we will design a superstructure with a 44 ft wide (curb to curb) concrete deck with an overhang (two 12 ft lanes and 2 10 ft lanes). We will have two 120ft span lengths, and will use F-shape barriers, grade 50 steel, and composite for the deck. The deck is to transmit the HL-93 live load. The page showing superstructure cross-section is shown below:

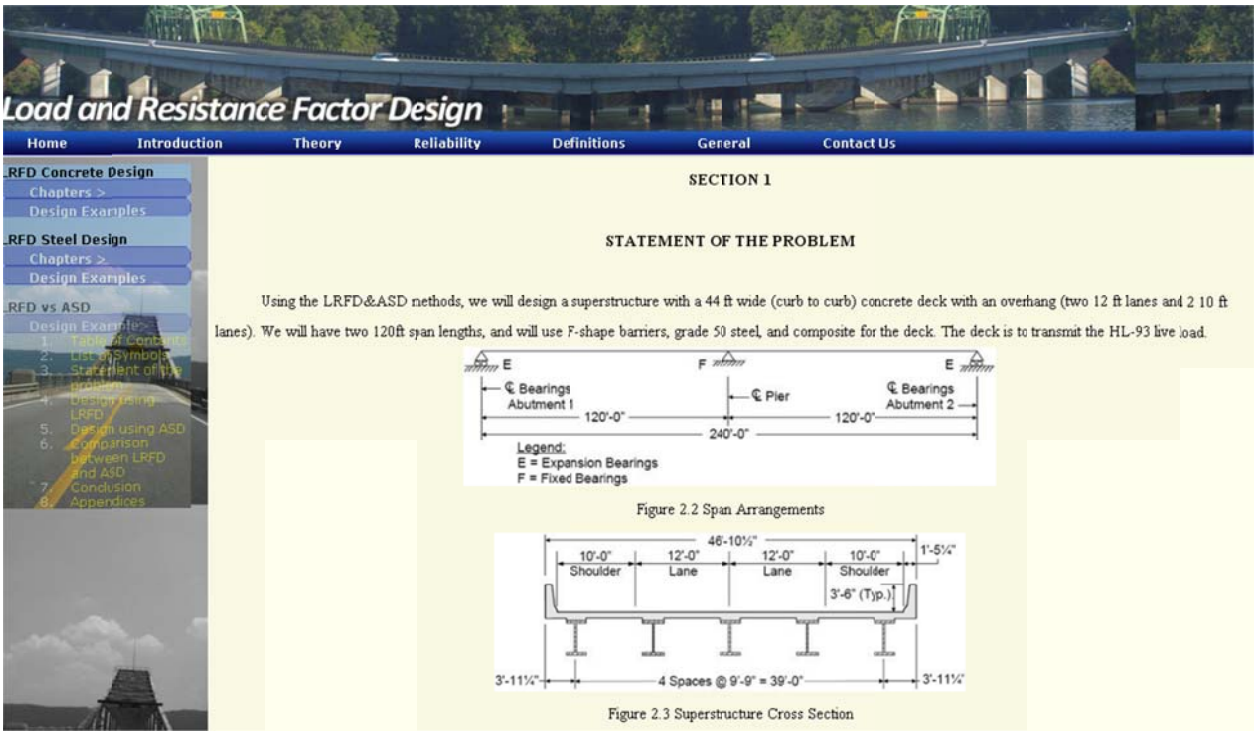

Figure 37: Page showing statement of problem for LRFD Vs ASD Substructure Design Example

3.6.3.4 Design Using LRFD

The design example of the bridge substructure is presented. The substructure is supporting the reinforced concrete deck bridge sitting on steel beams. The design methodology for the design is the load and resistance factor design (LRFD) method is AASHTO LRFD Bridge Design Specifications. For the purpose of this report, the example focuses on only the substructure design procedures. The material parameters and the numbers for the calculations, such as the superstructure dead load effects on the substructure, come from the superstructure design, which is not presented here. This design example is based on the example, originally provided by the Federal Highway Administration (FHWA) [14], as the supplemental material for engineers to understand LRFD. This example follows the latest LRFD Specifications for the most parts. As an aid to see the design procedure, a flowchart was developed for a substructure design, as shown in Figure 38.

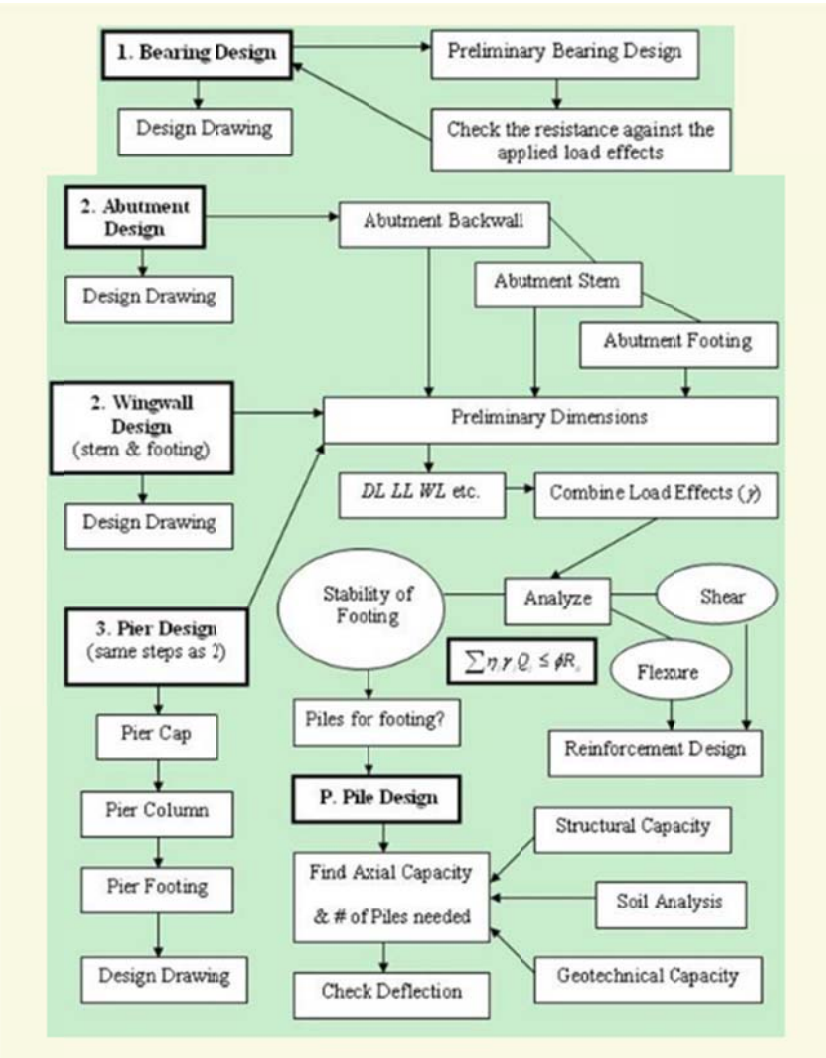

Figure 38: Flowchart for LRFD Bridge Substructure Design

3.6.3.5 Design Using ASD

The bridge substructure design example is presented in detail. It is designed basically according to ASD methodology, AASHTO Standard Specifications for Highway Bridges (11th Edition, 1973) and ACI 318-05 Building Code Requirements for Structural Concrete and Commentary. As the example by LRFD, the example by ASD also focuses on the substructure design procedures. The properties of material and the load effects are the same values as the LRFD example uses and are based on the superstructure design [14]. For the purpose of comparison with LRFD, the same load effects from the superstructure are applied for the ASD substructure as well. As an aid to follow the design procedure, a flowchart for a substructure design with ASD was developed, as shown in Figure 39.

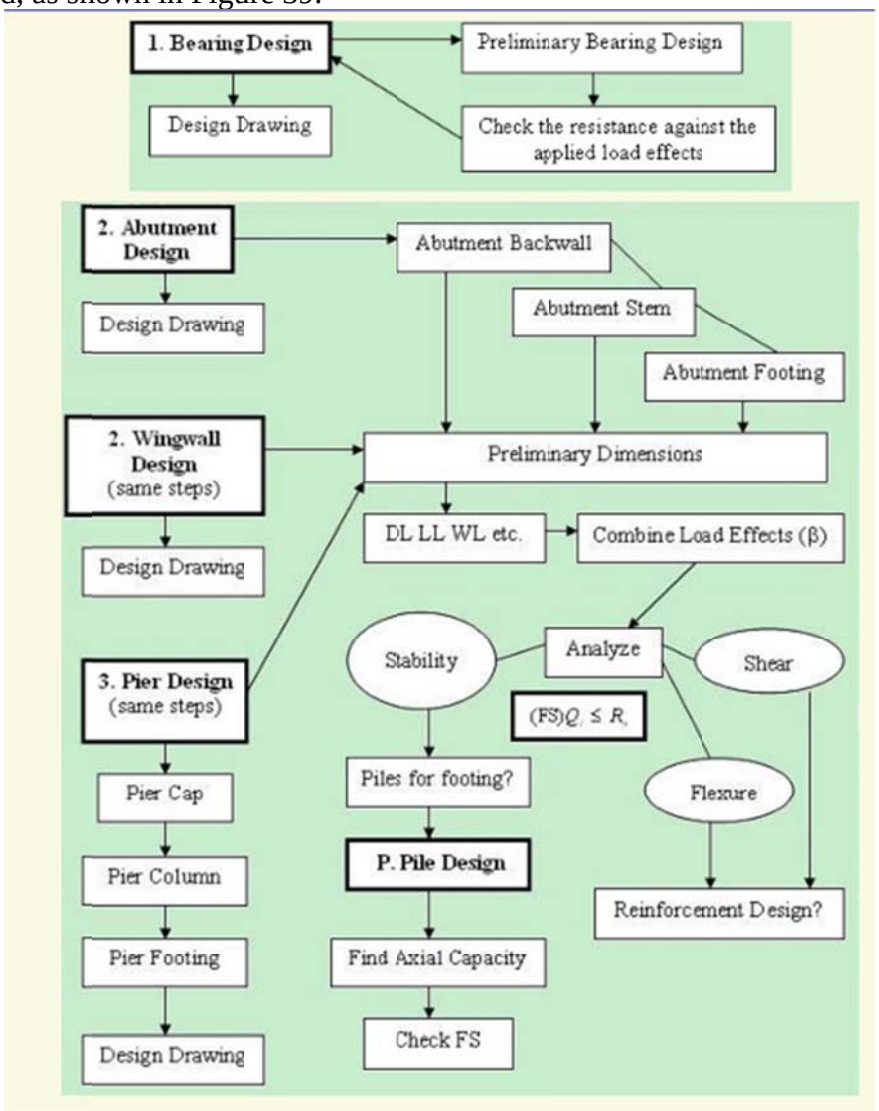

Figure 39: Flowchart for ASD Bridge Substructure Design

3.6.3.6 Comparison Between LRFD and ASD

Overall, LRFD shows more reliability of safety and efficiency of design compared with ASD, which is contributed by main equations and factors to evaluate load effects on bridge substructures, although in the design examples, there cannot be recognized the significant difference in the required amount of reinforcing steel bars and concrete since the design required resistances for both methods turns out to be closed values. However, in terms of design procedures, the main design flows for LRFD and ASD are almost identical as the flowcharts for both design methods represent.

In LRFD, concrete density for normal weight material takes 145 pound per cubic foot (145 lb/ft^3 = 0.145 kcf) while ASD adopts 150 pound per cubic foot (150 lb/ft^3 = 0.150 kcf). This difference directly results in the difference of structure self-weights, nominal dead load effects, which is the important factor not only for bridge substructures but also other structures. In the design examples, the differences in dead loads due to substructures can be seen. Web page showing summary of dead loads of substructures, including abutment back-wall, stem, footing, and wing-wall, and pier cap, column, and footing, are presented in a table is in the following Figure 40.

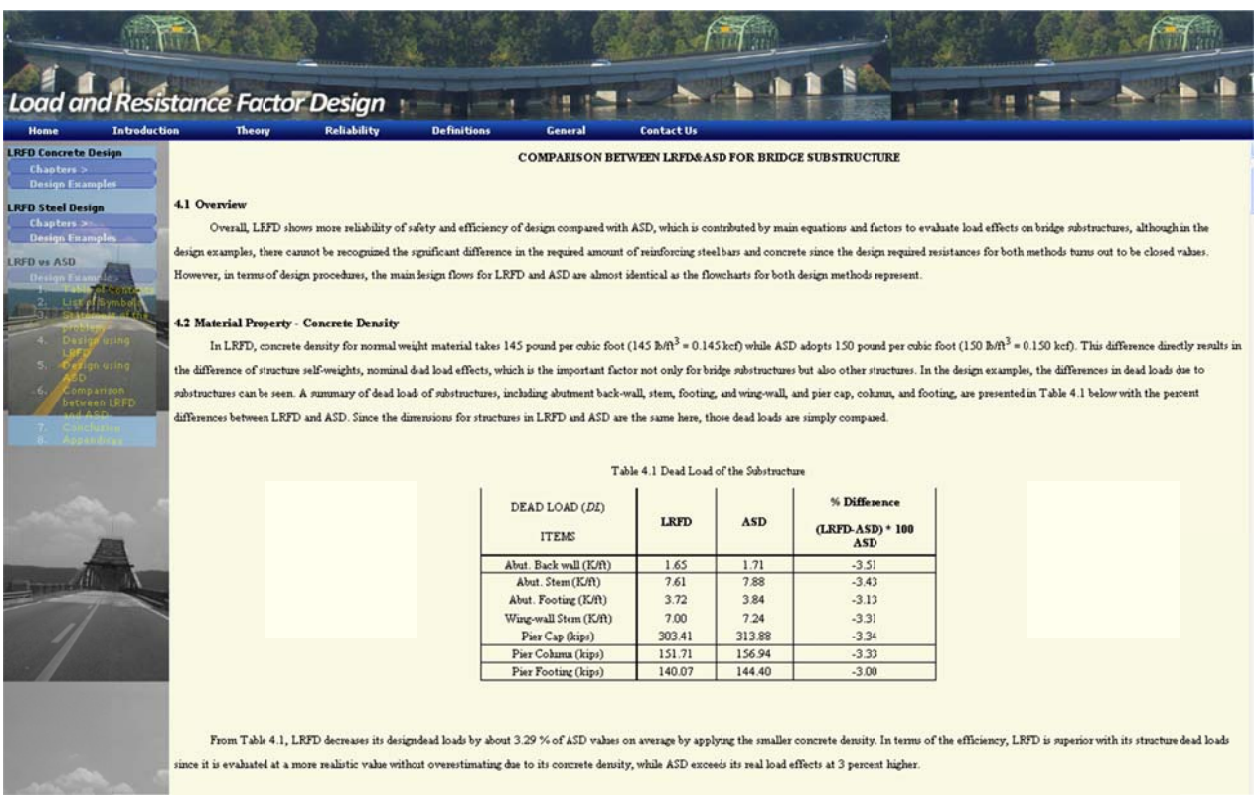

Figure 40: Summary of dead loads of substructure for LRFD and ASD

3.6.3.7 Conclusion

LRFD for bridge substructures is a relatively new method for the bridge industry compared with the design method for bridge superstructures, and it is still in the changing and developing stage. There seem to be some obstacles to fully adopting LRFD, such as the lack of familiarity with it and the initial introducing costs of it. In other words, it has not been implemented successfully even though the use of LRFD for state-aid bridges is regulated. However, there are several benefits to using LRFD over ASD for substructure designs, one of which is a more reliable and uniform level of safety against the risks of failure, contributed by the theory of probability and a variety of load factors. From the analysis and comparison of the substructure design examples of both LRFD and ASD, there are some conclusions derived:

- The LRFD procedures and design flow charts are similar to those of ASD even though there are more detailed criteria that must be satisfied in LRFD.
- More load combinations, such as Strength Limit States and Service Limit States, with more variety of factors, whose values are usually higher than those of ASD, applied to nominal loads, are evaluated and analyzed in LRFD.
- More detailed geotechnical data and analysis are required to determine load resistance capacities in LRFD, and more research is needed for the complete package of LRFD for substructures.
- LRFD potentially provides an efficiency and economy to structure constructions contributed by in-depth predictions of load effects with a variety of load factors derived from probability-based theory and statistical analysis.

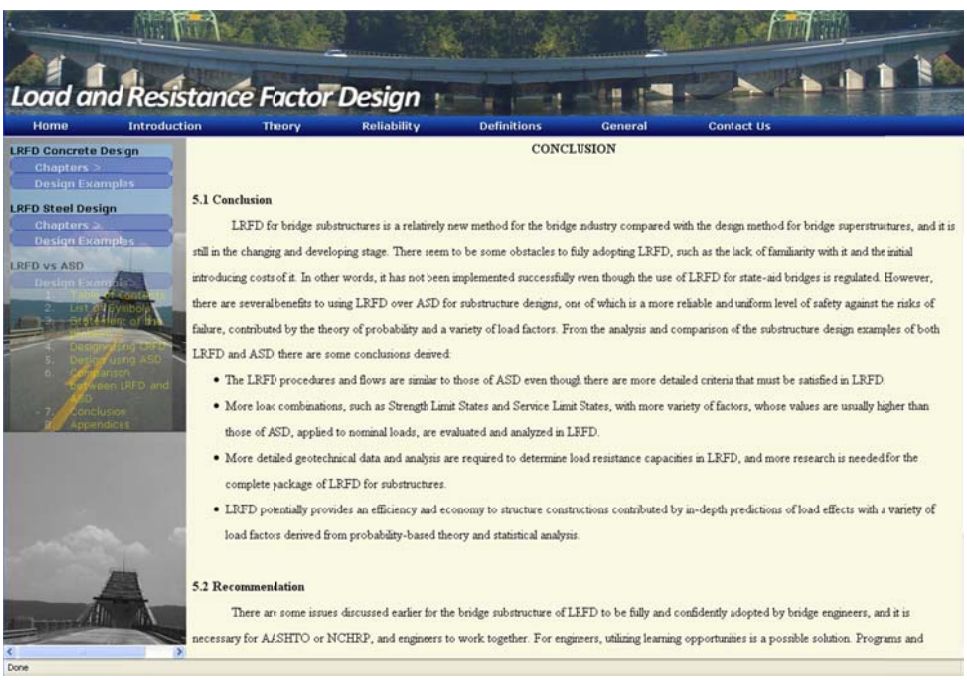

Figure 41: Page showing Conclusion for LRFD Vs ASD Substructure Design Example

3.6.3.8 Appendices

The appendix section lists out the tables of AASHTO LRFD Load combinations and factors, load factors for permanent loads, AASHTO ASD load group and factors, steel reinforcement information for reference. It also includes FHWA computer program (DRIVEN 1.0) output for steel design example and references used to design the substructure using LRFD.

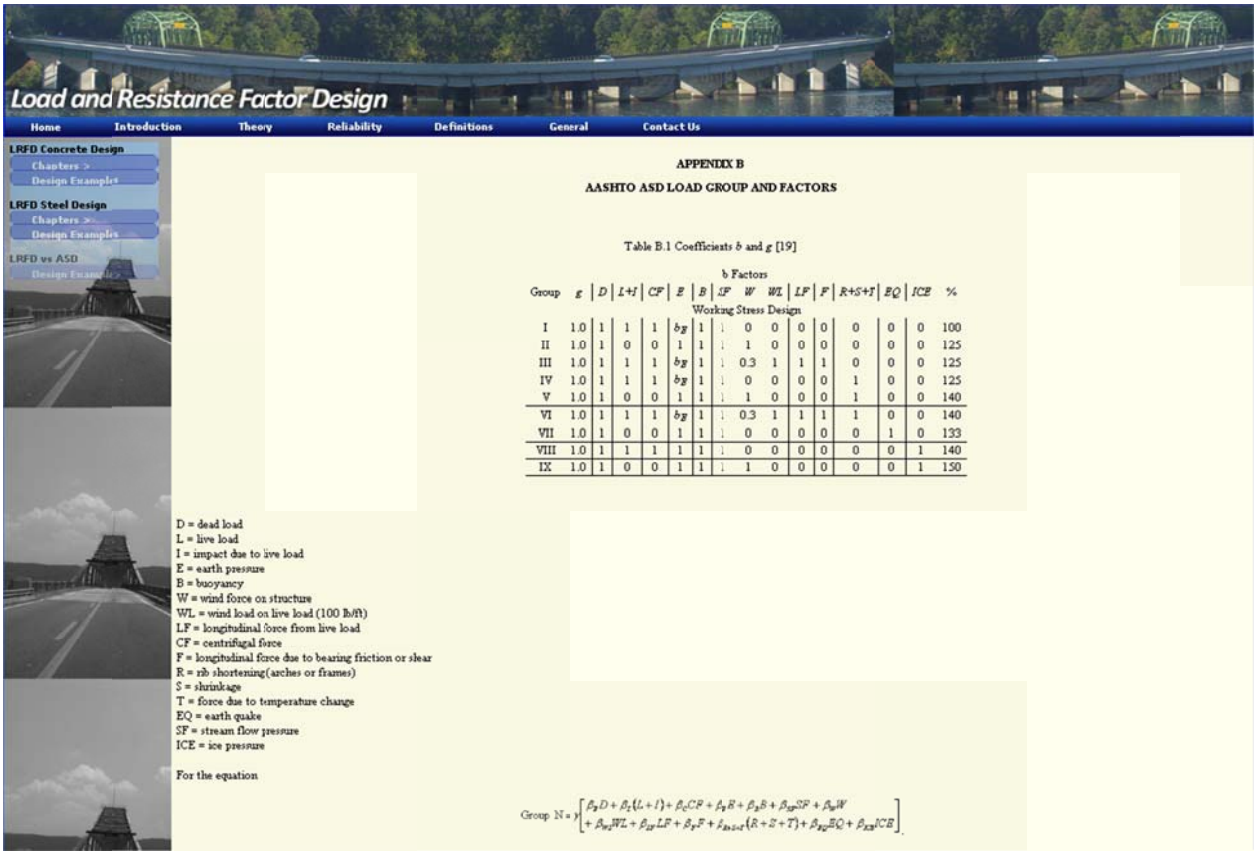

Figure 42: Appendices page for LRFD Vs ASD Substructure Design Example

3.7 Search Options

Search engine with three components is included in the CD. Figure 43, 44, 45 shows the results generated when searched for a keyword in theory, in definitions and in design examples respectively.

3.7.1 Search In: Theory

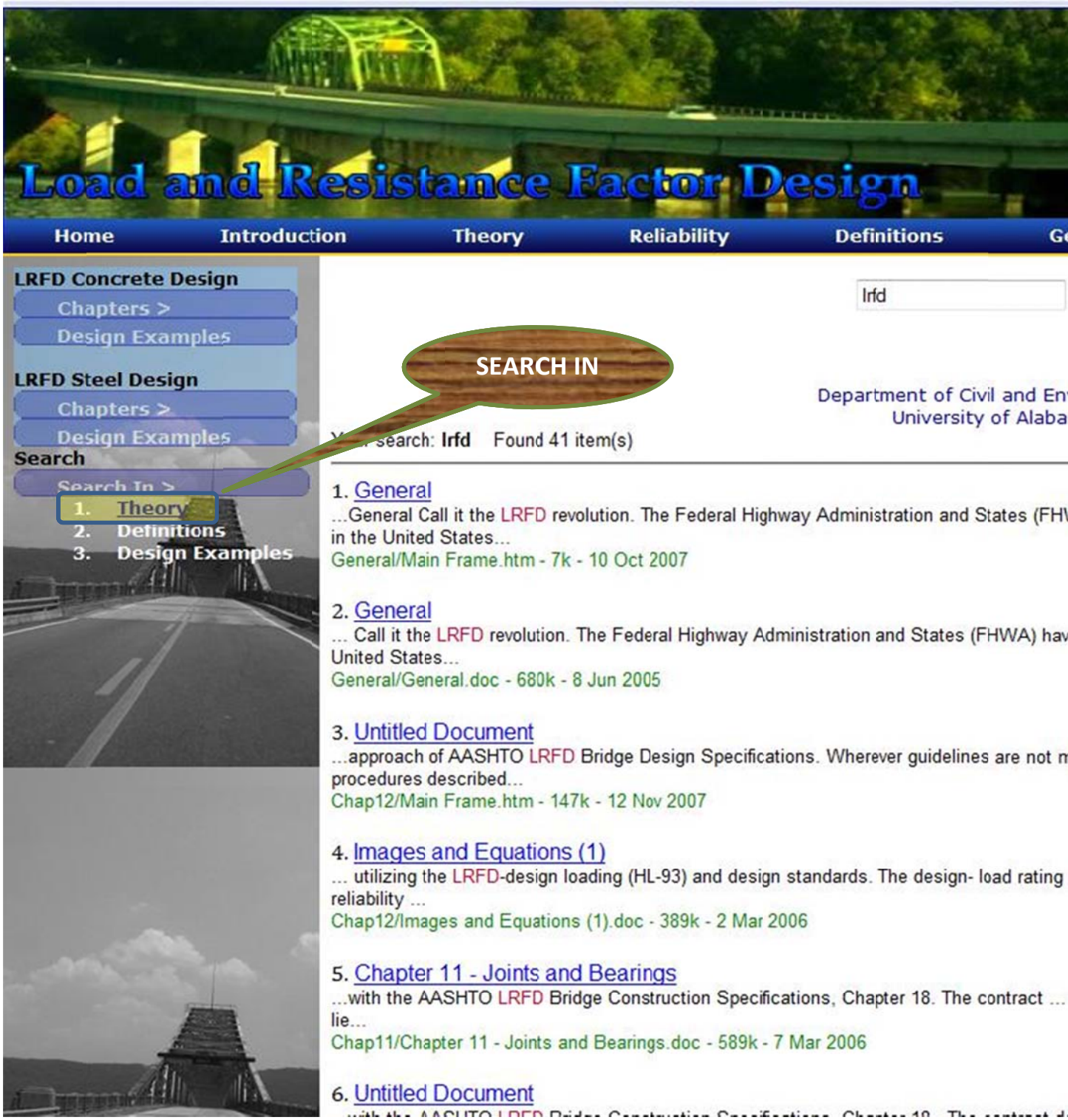

Figure 43: Page Showing Search Results for a keyword in Theory

3.7.2 Search In: Definitions

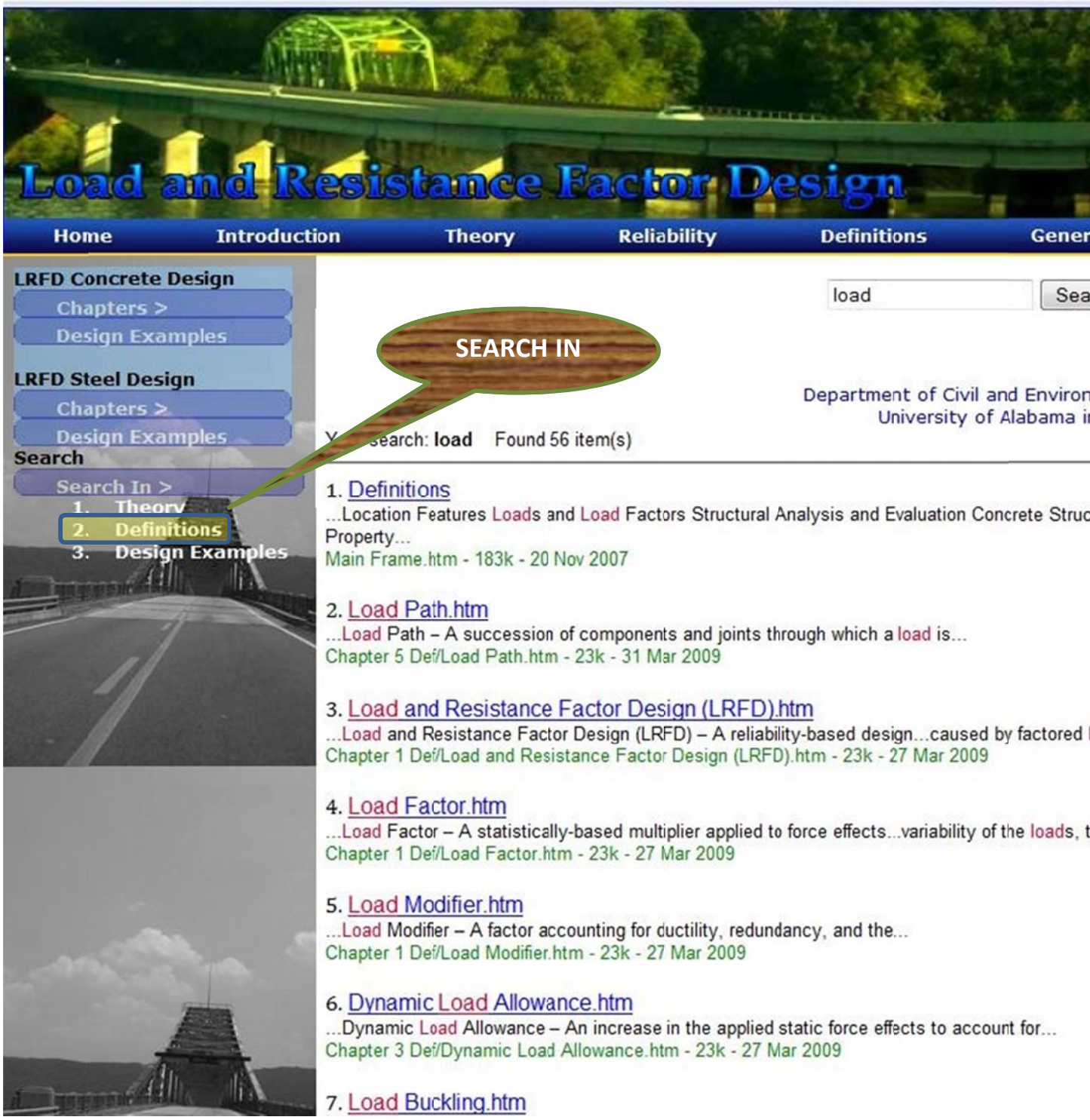

Figure 44: Page Showing Search Results for a keyword in Definitions

3.7.3 Search In: Design Examples

Figure 45: Page Showing Search Results for a keyword in Design Examples

3.8 Definitions

Alphabetized list of definitions is provided in this page and it is grouped according to chapters.

Figure 46: The Definition Page Defines Some of the Hardest Words Used in the Lecture

3.9 General

The general page provides information about the origin and the background of LRFD Specifications. This section also shows the progress of states adopting and implementing the specifications through diagrams.

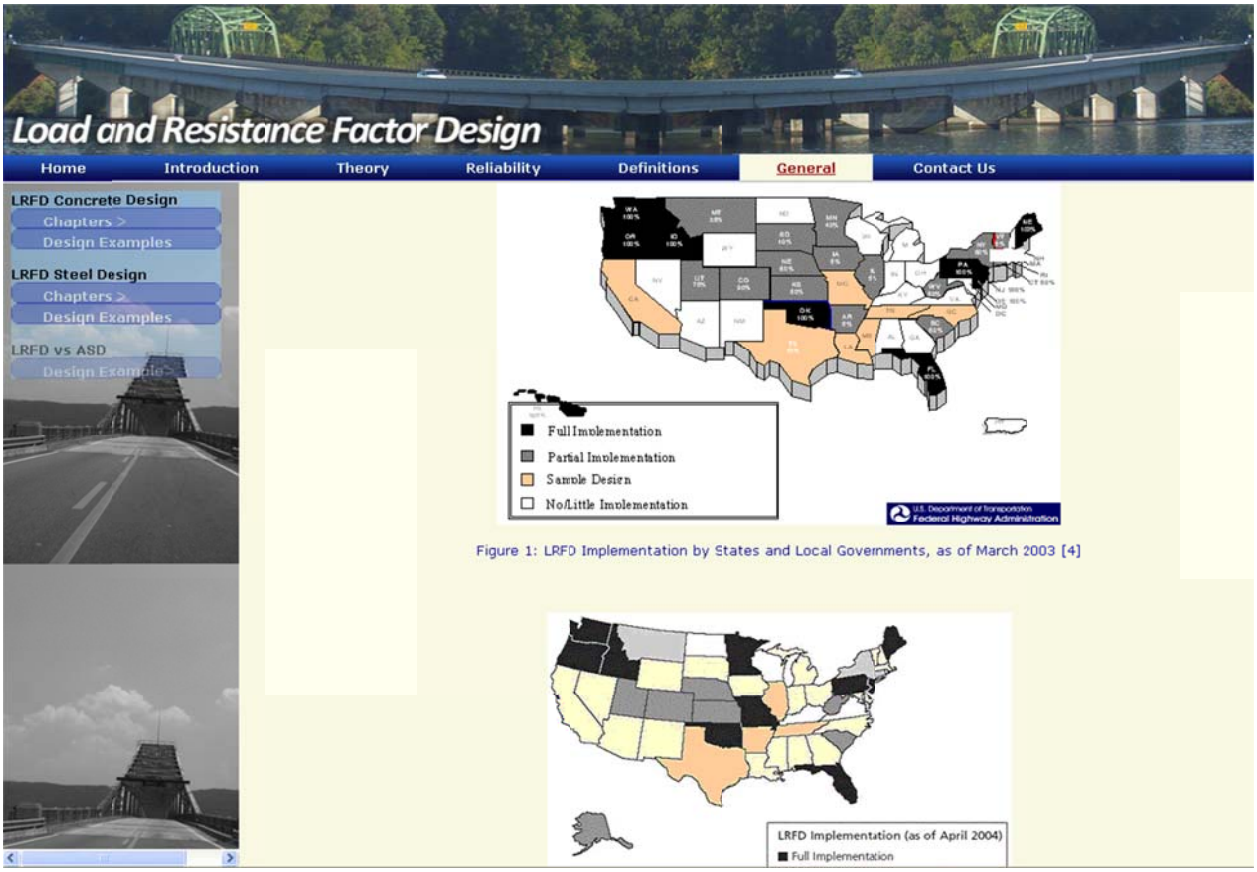

Figure 47: General Page Contains Basic Information about LRFD Specifications

3.10 Contact Us

This page provides the contact information of the principal investigator of the multimedia package.

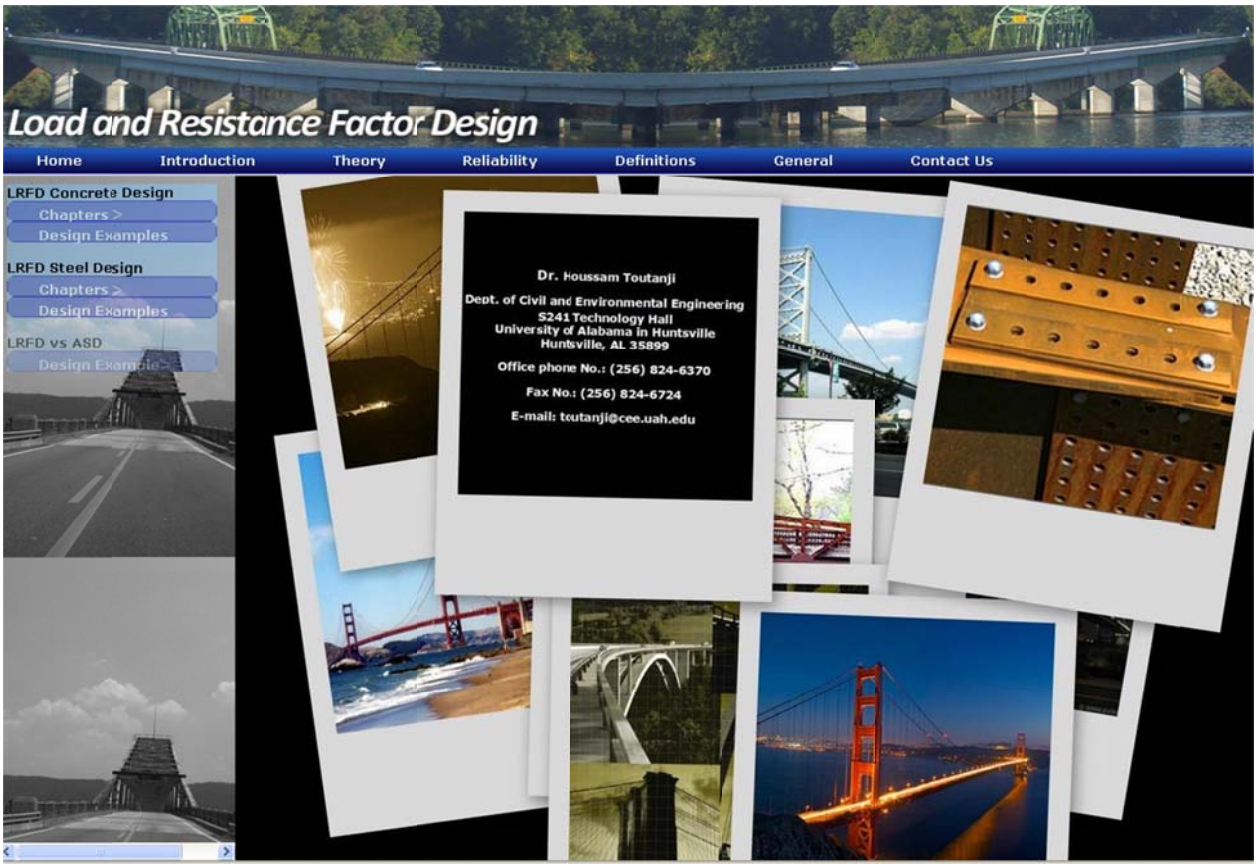

Figure 48: Contact Page Containing Dr. Toutanji's Information

4.0 Introduction to LRFR

For the past few years, various researches have compared the LRFR with LFR with regards to implementation. Few of initial comparative studies emphasizing the implementation of LRFR are explained briefly in the table below:

Researcher	Brief Description
Lichtenstein Consulting Engineers (2001)	In their National Cooperative Highway Research Program (NCHRP) project C12-46 report, they compared 37 bridges (among which one bridge is from State of Alabama) rated at both the Design and Legal ratings levels. Each bridge was analyzed at the Design, Inventory and Operating levels of rating under the HL-93 and HS-20 load models for the LRFR and LFR, respectively. The LFR analysis was performed according to the AASHTO Manual for Condition Evaluation (MCE)-1994.
(Mertz 2005)	In his NCHRP project 20-07 Task 122, the PI compared 74 bridges (all of the bridges in his study were provided by either NYSDOT or WYDOT). The Comparative study is made using AASHTO Bridgeware's Virtis Version 5.1 software.
(Rogers and Jáuregui 2005)	In this report, they had a comparative study on 5 simply supported prestressed concrete I-girder bridges (all of the bridges in his study were provided by NMDOT). They performed analysis only for interior girders of the bridges.

Based on this research, the need to implement LRFR is stimulated. Thus, The American Association of State and Highway Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) have set a transition date of October 1, 2007 after which all new bridges shall be designed in accordance with the AASHTO LRFD Bridge Design Specifications. FHWA memorandum dated October 30, 2006 on subject - "Bridge Load Rating For The National Bridge Inventory (NBI)"[19] emphasis on following policies:

1. For bridges and total replacement bridges designed by LRFD Specifications using HL-93 loading, prior to October 1, 2010, Items 63, 64, 65 and 66[20] are to be computed and reported to the NBI as either a Rating Factor (RF) or in metric tons. Rating factors shall be based on LRFR methods using HL-93 loading[19] or LFR methods using MS18 loading[19]. Metric ton rating values shall be reported in terms of MS18 (32.4 metric tons) loading derived from a RF calculated using LRFR methods and HL-93 loading, or LFR methods using MS18 loading[19].
2. For bridges and total replacement bridges designed by LRFD Specifications using HL-93, after October 1, 2010 Items 63, 64, 65 and 66[2] are to be computed and reported to the NBI as a RF based on LRFR methods using HL-93 loading[19].

The Manual for Bridge Evaluation (MBE-2008) discusses on three load rating procedures

Design Load Rating (First level Evaluation):
The Design loads used to design a bridge are used to evaluate the Rating Factor (RF).

The difference in load models, strength load factors for LFR and LRFR at Design Load Rating Level are shown below:

		Load Factor Rating	Load Resistance and Factor Rating
	Rating Factor:	$RF = \frac{C - A_1 D}{A_2 L(1 + I)}$	$RF = \frac{(C - \gamma_{DC}\, DC - \gamma_{DW} DW \pm \gamma_P P)}{(\gamma_{LL}\, (LL + IM))}$
DESIGN LOAD	**INVENTORY LEVEL:**		
	Design Load:	HS20 Truck/Tandem/Lane Load (0.64K/Ft. + Concentrated Load) in all lanes.	HL-93 Design Load: Case 1: Check HS20-44 Truck load along with lane load in all lanes Case 2: Check Tandem load along with lane load in all lanes Maximum of the above two cases is considered.
	Impact percentage:	30% maximum	33% on Truck or Tandem loads only
	Load Factors:	1.3DL +2.17LL	1.25DL1+1.5DL2+1.75LL DL1: Dead load of Components and attachments DL2: Dead load of wearing surface
	OPERATING LEVEL:		
	Design Load:	HS20 Truck/Tandem/Lane Load (0.64K/Ft. + Concentrated Load) in all lanes.	HL-93 Design Load: Case 1: Check HS20-44 Truck load along with lane load in all lanes Case 2: Check Tandem load along with lane load in all lanes Maximum of the above two cases is considered.
	Impact percentage:	30% maximum	33% on Truck or Tandem loads only
	Load Factors:	1.3DL +1.3LL	1.25DL1+1.5DL2+1.35LL DL1: Dead load of Components and attachments DL2: Dead load of wearing surface

Legal Load Rating (Second level Evaluation):

AASHTO Legal Load models (Type 3 Unit, Type 3S2 Unit, Type 3-3 Unit, Lane type model, NRL, SU4, SU5, SU6, SU7) and State Legal Load models are used to evaluate the Rating Factor.

Permit Load Rating (Third level Evaluation):

Permits are issued by states on a single trip, multiple trip or annual basis. Load factor are considered based on Table 6A.4.5.4.2a-1 of MBE Manual. Permit load rating is used only if the bridge rating factor is greater than 1.0 when evaluated for AASHTO legal loads.

The following figures show the introductory web pages on LRFR rating:

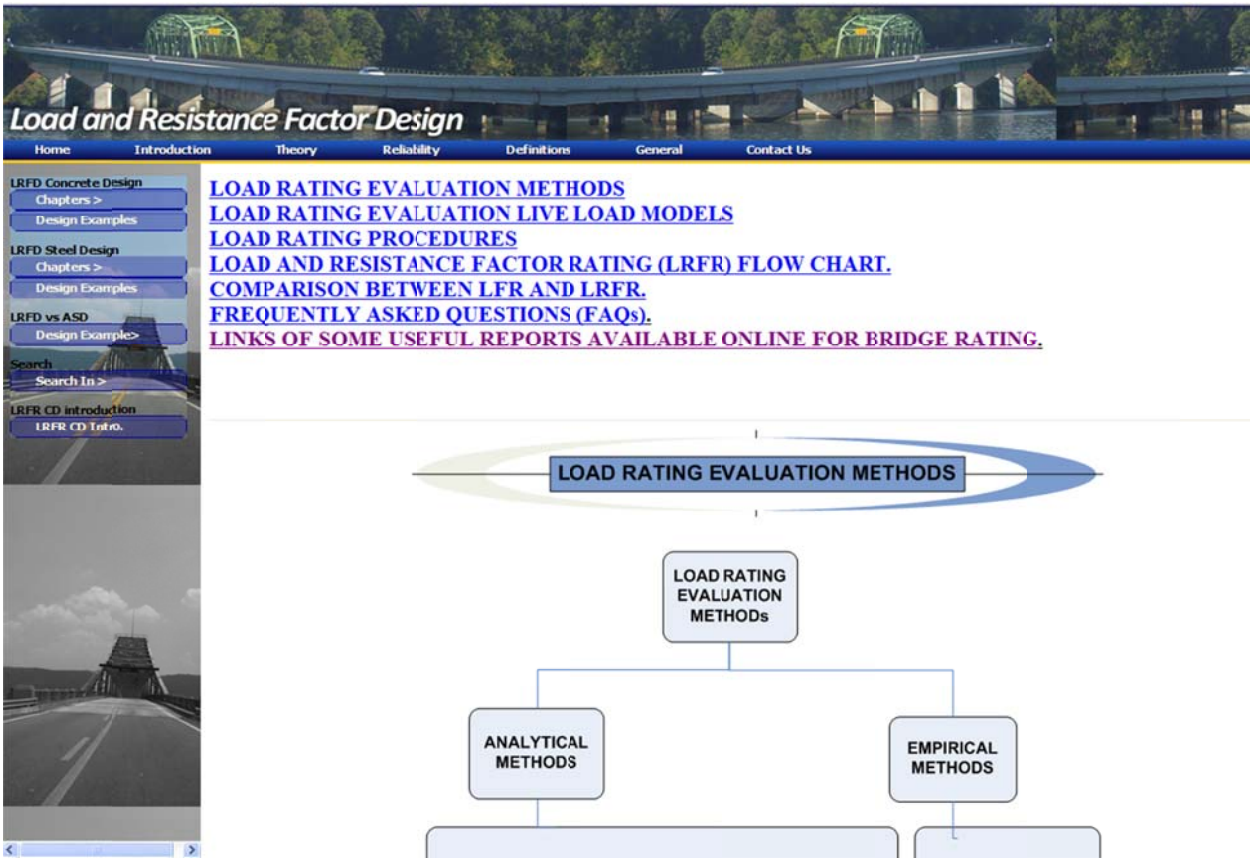

Figure 49: Page Showing Introduction to LRFR

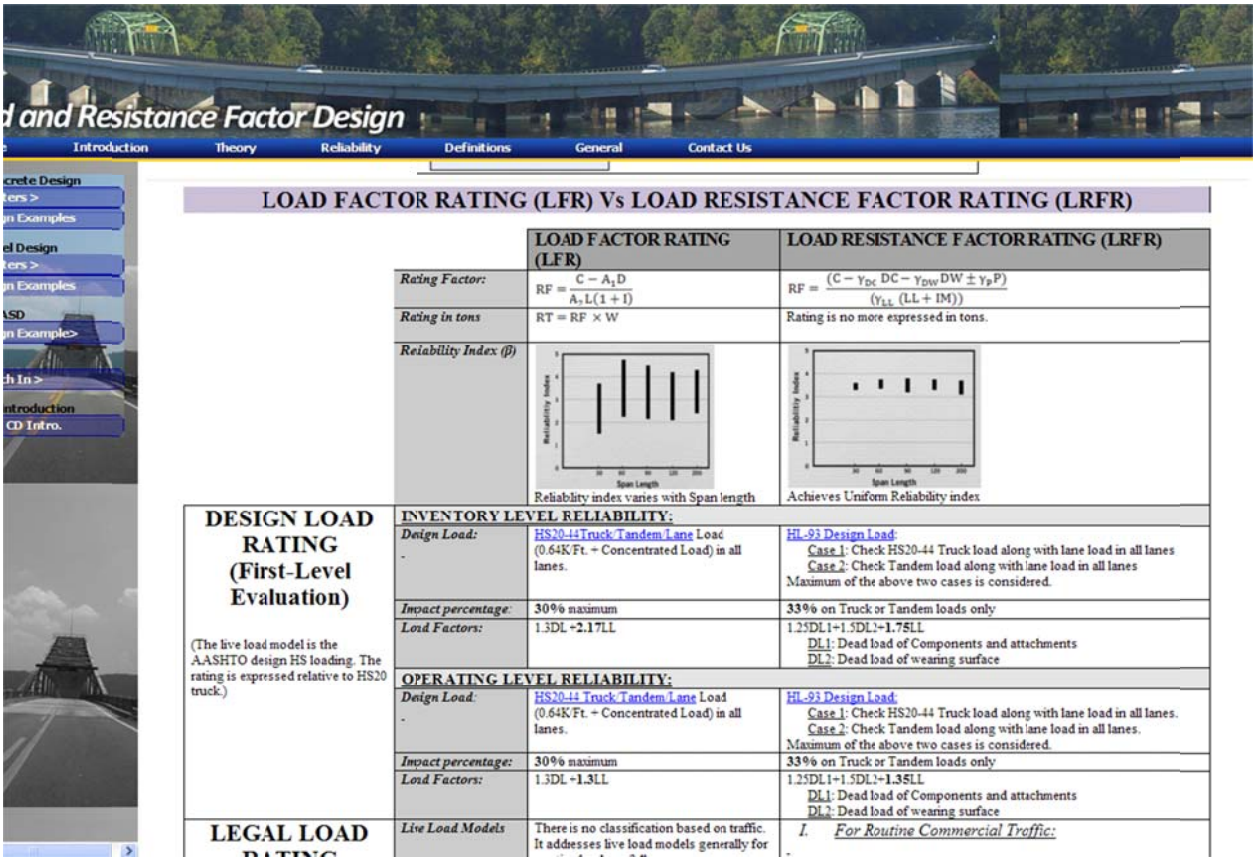

Figure 50: Page Showing Comparison between LFR and LRFR

5.0 Conclusion

The purpose of this project was to create a user-friendly multimedia package that brings the user full information about LRFD specifications. This tool can be used as a trainer for the study of the LRFD specifications that today's engineers and designers are using in the United States, and it can be updated to maintain the quality of its service to the highest level.

The multimedia CD-ROM has many advantages, namely: step-by-step details with diagrams, equations, examples, tables, definition, and theory. This multimedia package can be used like a reference tool for people trying to learn the complicated language of LRFD specifications. Another advantage is that the information can be modified whenever it is desired, able for updating the new requisites, and for including more examples.

This complete package will be available in ALDOT, the Bureau of Research and Development and the Civil and Environmental Engineering Department at the University of Alabama in Huntsville. Its main purpose is to facilitate the labor to many inexperienced designers and engineers in the innovative field of LRFD specifications for bridge designs. The Principal Investigator, Dr. Houssam Toutanji, is responsible for updating this multimedia package periodically or when it is necessary.

6.0 References

List of references used for developing the CD are listed.

[1] http://www.tfhrc.gov/focus/july04/01.htm

[2] http://training.bossintl.com/html/highway-bridge-design.html

[3] http://www.lrfd.com/Implementation_Status.htm

[4] http://lrfd.aashtoware.org/?siteid=34

[5] http://www.normas.com/AISC/PAGES/325-01.html

[6] http://www4.trb.org/trb/crp.nsf/0/6306c417bc81d2758525674800561ad4?

[7] http://www.nabro.unl.edu/events/fall1998/index.asp

[8] http://www.enm.bris.ac.uk/research/nonlinear/tacoma/tacoma.html

[9] http://lrfd.aashtoware.org/?siteid=34&pageid=229

[10] http://www.transportation.org/sites/bridges/docs/concrete%20examle%20us.pdf

[11] https://txspace.tamu.edu//bitstream/1969.1/3096/1/etd-tamu-2005C-CVEN-Adnan.pdf

[12] http://www.pupr.edu/pdf/civilpusp06.pdf

[13] http://www-personal.umich.edu/~nowak/Papers/Mertz,%20abs1,%204-19-02.pdf

[14] http://www.fhwa.dot.gov/bridge/lrfd/examples.htm

[15] *https://txspace.tamu.edu/bitstream/1969.1/4841/1/etd-tamu-2005C-CVEN-Mohammed.pdf*

[16] AASHTO LRFD Bridge Design Specifications, Customary U.S. Units, 3rd Ed. with Interim Revisions 2005. ISBN: 1-56051-272-5.

[17] AASHTO, Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges. October 2003. ISBN: 1-56051-283-0.

[18] Design of Highway Bridges, an LRFD Approach. Second Edition. Richard Barker, Jay Pucket.

[19] Federal Highway Administration Memorandum dated October 30, 2006. Subject: "Bridge Load Ratings for the National Bridge Inventory" http://www.fhwa.dot.gov/BRIDGE/nbis/103006.cfm

[20]. Federal Highway Administration "Recording and Coding Guide for the Structure Inventory and appraisal of the Nation's Bridges". http://www.fhwa.dot.gov/bridge/mtguide.pdf

Item 63 – Method used to determine Operating Rating.
Item 64 – Operating Rating.

Item 65 – Method used to determine Inventory Rating
Item 66 – Inventory Rating