1 Introduction

1.1 Bridge Engineering and Highway Bridge Network

Human beings have been constructing bridges for about four thousand years. The oldest and still existing bridge in the world is perhaps the Zhaozhou Bridge in Hebei Province in China, originally constructed approximately in A.D. 600. However, bridge design and construction then may not be considered bridge engineering practice by today’s definition. Instead, work was done based more on experience as opposed to quantitative planning as done now. Bridge engineering today uses calculus-based analysis and detailed planning.

Materials used in bridge construction have also changed noticeably through a good number of years, from mainly natural materials such as stones and wood then to mainly man-made materials such as steel and Portland cement concrete today. Due to great improvement in the strength and production quality control of these materials, bridge components have become smaller, thinner, skinnier, and lighter to reduce self-weight and be more economical.
1 Introduction

In 1866 Wayss and Koenen in Germany conducted a series of tests on reinforced concrete beams (Heins and Lawrie, 1984), which started the era of concrete for bridge construction. More tests and research work were done in the following decades. The first bridge using reinforced concrete in the world was credited to Monier in 1867 (Heins and Lawrie, 1984). The first bridges using steel are believed to be constructed in the United Kingdom and United States in the 1880s. These pioneering projects began what is known today as modern bridge engineering.

Another important aspect characterizing modern bridge engineering is the tools used to perform quantitative modeling and planning. They include calculus and calculus-based mechanics, acknowledged as the foundation of modern bridge engineering as practiced today. This knowledge was established in the seventeenth century. With the new materials and advanced analysis tools, fast development of modern bridge engineering had its technical strength.

The fuel for substantial developments of bridge engineering was the need or desire for economic development. For example, today’s highway bridge technology in the United States is largely a result of rapid development of the interstate highway system in the 1950s and 1960s after World War II. As a product, a comprehensive highway system has been established consisting of about 50,000 miles of roadways and about 600,000 bridges.

It is also interesting to mention that a number of developing countries are currently experiencing a similar “boom” in their surface transportation systems. This has become the driving force for bridge engineering development in those parts of the world.

1.2 Types of Highway Bridges

In highway systems bridges maintain the continuation of the roadway, for the traffic of vehicles and/or pedestrians as needed. The American Association of State and Highway Transportation Officials (AASHTO) design specifications include the following definition for highway bridges: any structure having an opening not less than 20 ft that forms part of a highway or that is located over or under a highway. Note that this definition actually covers a number of large culverts with a span longer than 20 ft, although structurally different from the highway bridges covered in this book because soil interaction is involved in the load-carrying behavior and performance.

Based on the superstructure type, highway bridges may be recognized as slab bridges, beam or girder bridges, arch bridges, truss bridges, cable-stayed bridges, and suspension bridges. These names directly refer to the main spanning structure of the bridges. Namely, slab bridges use a slab to span the opening, beam or girder bridges use beams, arch and truss bridges use arches and trusses, cable-stayed bridges use cable-stayed main girders, and suspension bridges use suspension-supported main girders.
1.2 Types of Highway Bridges

Figures 1.2-1 to 1.2-7 illustrate some of these bridge types. More details of these bridge types will be presented in Chapter 4 on highway bridge superstructure.

It also should be mentioned that, by number of bridges and by number of spans, beam or girder bridges represent by far the most popular highway bridges in the United States and the world. Their span lengths are usually within 300 ft to be cost effective. For longer spans, arch, truss, cable-stayed, and suspension spans may become more preferred due to cost consideration. Some examples for these spans are shown in Figures 1.2-6
Figure 1.2-3
Curved concrete box beam bridge.

Figure 1.2-4
Prestressed concrete I-beam bridge of single span.

to 1.2-9. Typically more than 90% of highway bridges are beam or girder bridges in the United States. This percentage is larger for number of bridge spans because very long bridges often consist of many short or medium beam spans. Therefore, this introductory book on highway bridge design and evaluation focuses on beam or girder bridges of short and medium spans covering a vast majority of current highway systems.
It is also very common to classify bridges into different groups according to their superstructure type. For example, classification according to superstructure material is a common one. Thus, there are steel bridges, prestressed concrete bridges, timber bridges, aluminum bridges, and so on, referring to the major material used to construct the superstructure. Another common classification is based on superstructure configuration, such as continuous bridges and simple span bridges, referring to spans made of continuous beams and simply supported beams, respectively. Sometimes they are used to refer to truss spans as well because trusses can
**Figure 1.2-7**
Steel arch bridge.

**Figure 1.2-8**
Cable-stayed bridge.
1.3 Bridge Construction and Its Relation to Design

It is essential for a bridge designer to understand the planned construction process of the bridge being designed. It is very important that the designer take into account the construction procedure in the design process because the construction procedure may subject bridge components to loading conditions not experienced in service and these conditions require special design. For example, lifting a prestressed concrete beam as a primary component for a beam bridge using a crane may cause a significant negative
moment that would never be induced in the service condition. Thus this negative moment needs to be carefully designed and detailed for. Otherwise, the beam may fail or be damaged during construction. This check in design is referred to as a constructability check in the AASHTO design specifications. Figures 1.3-1 to 1.3-3 show a few steps of highway bridge construction.

It is also worth mentioning that many bridge failure incidents occur when the bridge is under construction. Therefore, construction load is an important load to consider and to cover in design.

Figure 1.3-1
Concrete deck placement using a concrete pump.

Figure 1.3-2
Steel piles placed as the foundation for an abutment to be constructed.
1.4 AASHTO Specifications and Design and Evaluation Methods

Load factor design (LFD) and service load design (SLD) were the two traditional design methods used in the United States for highway bridge design over many decades and prior to the current AASHTO specifications. Sometimes SLD is referred to as allowable stress design (ASD) in the literature. In 1994, AASHTO adopted the first edition of the LRFD Bridge Design Specifications with the load and resistance factor design (LRFD) method. As mentioned in the preface, the latest sixth edition (AASHTO, 2012) is exclusively referred to in this book. This set of design specifications is also referred to hereafter as the AASHTO specifications, AASHTO design specifications, or AASHTO LRFD specifications.

For highway bridge evaluation, AASHTO has another set of specifications, the Manual for Bridge Evaluation, which references the design specifications for consistency. The latest second edition of the evaluation specifications (AASHTO, 2011) is referred to in this book as the AASHTO manual, evaluation manual, or evaluation specifications. Nevertheless, sometimes “AASHTO specifications” is also used to refer to both sets of specifications when the context is clear. Figures 1.4-1 and 1.4-2 show the cover pages of the electronic version of these specifications.

The articles of the two sets of AASHTO specifications are referred to in this book using italic Futura Condensed font, with an additional letter M for the AASHTO manual. For example, 1.3.1 means Article 1.3.1 in the AASHTO design specifications, and M6A4.2.1 refers to Article 6A4.2.1 in the AASHTO manual.
Figure 1.4-1
Cover page of AASHTO LRFD Bridge Design Specifications (electronic version). Used by permission.

Figure 1.4-2
1.5 Goals for Bridge Design and Evaluation

The AASHTO specifications set forth the following goals for highway bridge design in the United States: constructability, safety, serviceability, inspectability, economy, and aesthetics. Traditionally, the requirement on inspectability has not been adequately emphasized and is therefore worth special attention here. Apparently including this item as one of the design objectives in the design code is based on experience learned from maintaining the extensive network of bridges in the past several decades after its establishment. This has been seen as an issue because of the inadequate attention received.

It is important that the bridge designer focus on the above goals in the design process instead of merely trying to satisfy the provisions and/or equations in the specifications. Obviously the specifications cannot cover every situation that can possibly be encountered. These goals, however, should be targeted at all times during the design.

The AASHTO manual also serves as a standard and provides uniformity in the procedures and policies for bridge evaluation. Such evaluation is charged to determine the physical condition, maintenance needs, and load capacity of U.S. highway bridges. Chapter 7 addresses the determination of highway bridge load capacity or load rating as referred to in the community and in the specifications. While the topics of bridge inspection and scoping for renewing bridge condition are briefly mentioned there, their in-depth coverage is beyond the scope of this introductory book.

1.6 Preliminary Design versus Detailed Design

Highway bridge structures are part of a roadway for surface transportation. Accordingly, bridge structures need to meet the requirements for the roadway. These requirements may include but are not limited to roadway width, horizontal or vertical curvature profiles, elevation, cost effectiveness, maximized life span, and so on. In the first of the two stages of highway bridge design, or the preliminary design stage, these factors or issues are considered and covered. The factors accordingly determined are width, length, how many spans, types of the spans (suspension, cable stayed, truss, arch, or beams; simply supported or continuous), material type (steel, concrete, timber, etc.), construction method, and so on.

After the preliminary design is completed, the second design stage, or the detailed design stage, will begin. This stage includes determination of each member’s dimensions, location, connection with other members, quantity of steel reinforcement if any required, possible maintenance approaches, and so on. The detailed design works toward the goal of a set of plans for the contractor to build the bridge. Occasionally the construction may not take place, although the plans have been completed. For example, alternative
designs for a bridge may be required and performed using different materials to compare the costs (such as steel superstructure vs. concrete superstructure). Then the lower cost option is accepted and the higher cost one is eliminated, although both designs have been completed to the same level of detail so that construction could have been carried out for either option.

This book focuses on the detailed design of highway bridges in accordance with the AASHTO design specifications, while preliminary design is only briefly discussed when necessary. In addition, structural design is the main focus here since it is a major consideration in detailed design. In other words, detailed design covered in this book proceeds with given or already optimized structure type, span arrangement, span length, and so on. This situation is assumed so that the student will not have to be concerned with whether the being-designed bridge span has been optimized with respect to type, length, width, geometric parameters, and so on, which would unlock everything and leave no direction for the student to follow. On the other hand, the student needs to understand that determination of these factors may require additional information and/or knowledge not completely covered in this book, such as cost effectiveness of alternative span lengths and/or arrangements associated with different materials and climate conditions, and so on.

1.7 Organization of This Book

There are six more chapters beyond this introductory chapter. Chapter 2 covers the general and specific requirements in the AASHTO specifications for designing highway bridges. Some background information on the derivation of some of these requirements is also presented in this chapter, such as the structural reliability theory. This theory along with reliability analysis methods were used to derive or calibrate the load and resistance factors in the load combination formulas for both design and evaluation of highway bridges in both sets of AASHTO specifications.

Chapter 3 presents further detailed specific requirements of the AASHTO specifications for loads, load effects, and their combinations for highway bridge components. These items represent a major advance carried by the LRFD and load and resistance factor rating (LRFR) approaches in the specifications, as opposed to the LFD and SLD methods. The LRFD and LRFR concepts are distinctively based on probabilistic coverage of the risk involved in the entire life of the bridge. While the AASHTO specifications do not require the design or evaluation engineer to explicitly use the theory of probability and statistics in practice, it is definitely helpful to understand the background material in Chapter 2 to fully understand the concepts. This understanding would also be required when the engineer needs to extrapolate the concepts to cases not clearly covered in the current specifications, such as long bridge spans.
1.7 Organization of This Book

Not every load discussed in Chapter 3 may be critical or even present for every component that may be designed. However, these loads represent the most commonly observed ones that need to be considered in bridge design and evaluation. Note also that there may be loads that have not been explicitly covered in the specifications. The engineer needs to identify and estimate, spending the fullest effort, all possible governing loads at all stages of construction and operation of the bridge and have them covered in design. This book is unable to exhaustively identify all the loads given in the specifications. One example of such cases is the load that may be applied to bridge components during construction. Due to the wide variety of construction procedures that may be used, construction load may vary significantly from one bridge to another. It is the responsibility of the design engineer to exhaustively identify and quantify these loads and cover them in the design with an adequate safety margin. This concept is included in the specifications and covered in this book.

A bridge structure system may be divided into three major parts: the superstructure, the bearings (or connections between the superstructure and substructure), and the substructure. A more common classification includes only two parts: the superstructure and the substructure with the bearings included in the substructure. This book separates the bearings from the other two parts for an explicit understanding of the bearings. Chapter 4 of this book covers the superstructure part of bridge design, Chapter 5 the bearings, and Chapter 6 the substructure. Of course, these parts need to be integrated into a bridge structure system to function and last. Therefore, these three chapters are interrelated and will need to be so used during the course. It should also be noted that the order of these three chapters also represents a typical order of bridge design practice: from the top to the bottom of the structure system.

Chapter 7 shifts focus from design to evaluation (load rating) of the same bridges covered in the book. Since bridge load rating uses many provisions in the AASHTO design specifications, this topic is readily covered after these provisions are presented and learned in the previous chapters. It also should be noted that U.S. bridge engineers today often spend more of their time on bridge evaluation and maintenance than design in the United States. Therefore, this chapter should receive adequate attention in using this book.

The examples included in this book may be used without referring to the text. Such use can be particularly convenient for review after a level of understanding of the relevant text is established. Therefore, the examples may also serve as a helpful reference for junior engineers with limited familiarity with bridge design and/or evaluation and those who are preparing for a professional engineer license exam, particularly where bridge design is a required subject. A complete highway bridge will be visible to the student when several of these examples are integrated together, including its load rating of primary members. For instance, the following examples may make a typical highway commonly seen in one of today's bridge design offices:
the reinforced concrete deck designed in Examples 4.1, 4.3, and 4.4 plus the steel plate girders designed in Examples 4.9 to 4.11 plus the shear studs designed in Example 4.8 plus the abutment designed in Example 6.1 to 6.4. Examples 7.1 and 7.2 then provide the bridge’s superstructure member load rating. Of course, the deck design in Example 4.1 may be replaced by another deck design in Example 4.2. Furthermore, the superstructure steel beams in Examples 4.9 to 4.11 may be replaced by the prestressed concrete beams in Examples 4.12 to 4.14 or another steel beam superstructure in Examples 4.5 to 4.7. To minimize inconvenient cross reference between different examples, a few steps of calculation in these examples may have been repeated in other examples.

References


