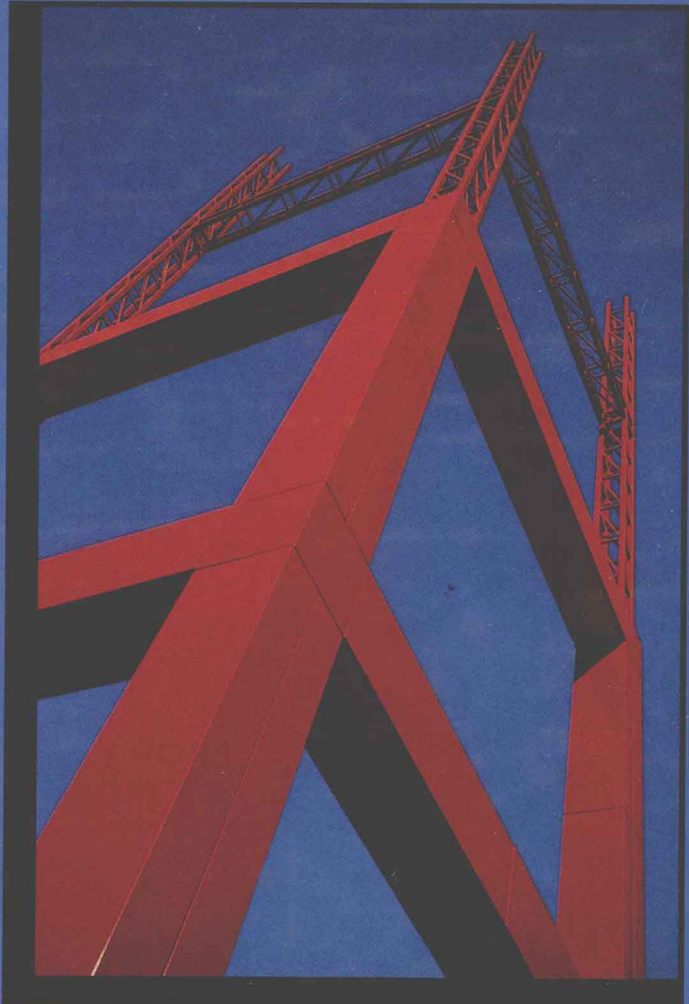
LRFD Steel Design

William T. Segui



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Uses the AISC's Latest LRFD Standards

LRFD STEEL DESIGN

WILLIAM T. SEGUI

The University of Memphis

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PREFACE

This book, which reflects the 1993 revisions to the AISC LRFD Specification, serves as a basic text in structural steel design for undergraduate civil engineering students at the junior or senior level. While the primary function of *LRFD Steel Design* is that of a textbook, practicing civil engineers who need a review of current practice and the current AISC Specification will find it useful as a reference. Students using this book should have a background in mechanics of materials and analysis of statically determinate structures.

Depending upon the level of competence of the students, *LRFD Steel Design* can be used for one or two courses of three semester hours each. A suggested two-course sequence is as follows: a first course covering Chapters 1 through 7 and a second course covering Chapters 8 through 10, supplemented by comprehensive design assignments. This division of topics has been used successfully for several years at The University of Memphis.

The emphasis of this book is on the design of building components in accordance with the provisions of the 1993 AISC LRFD Specification and the second edition of the *LRFD Manual of Steel Construction*. Although the text makes occasional reference to AASHTO and Area Specifications, no examples or assigned problems are based on these documents.

Prior to the introduction of the Load and Resistance Factor Design Specification by AISC in 1986, the dominant design approach for structural steel was allowable stress design. The trend today is toward load and resistance factor design, but because allowable stress design is still in use, students should have some familiarity with it. To that end, Appendix B provides a brief introduction to that topic.

It is absolutely essential that the student have a copy of the *Manual of Steel Construction*. In order to promote familiarity with it, material from the *Manual* is not reproduced in this book so that the reader will be required to refer to the *Manual*. All notation in this book is consistent with that in the *Manual*, and AISC equation numbers are used in tandem with sequential numbering of other equations according to the textbook chapter.

United States customary units are used throughout, with no introduction of S.I. units. Metric units can be incorporated easily into a basic mechanics text, but it is difficult to justify their use in a design text geared to industry standards that are based on customary units. Although metrication is inevitable and will be the basis of future AISC specifications and manuals, the change has not yet taken place in the steel construction industry.

As far as design procedures are concerned, the application of fundamental principles is encouraged. Although this book is oriented toward practical design, sufficient theory is included to avoid a "cookbook" approach. Direct design methods are used where feasible, but no complicated design formulas have been developed. Instead, trial and error with "educated guesses" is the rule. Tables, curves, and other design aids from the *Manual* are used, but they have a role that is subordinate to the use of basic equations. Assigned problems provide practice with both approaches, and where appropriate, the required approach is specified in the statement of the problem.

In keeping with the objective of providing a basic text, a large number of assigned problems are provided at the end of each chapter. Computer programming assignments are also included. These problems specify required input and output as well as the general algorithm. The requirements are completely machine-independent to give the instructor maximum flexibility. Most of these assignments can be done with spreadsheet software, and the instructor may wish to require this. Because of the wide range of hardware and programming languages available, program listings are not included in this book. This decision is based on the belief that students will benefit more from writing short programs to apply basic procedures than from running "canned" programs. Answers to selected problems are given at the back of the book, and a *Solutions Manual* is available.

A fairly comprehensive treatment of roof trusses is provided in Chapter 3, since components of trusses are dealt with in subsequent chapters. Column base plates are considered in the discussion of beams in Chapter 5 rather than in Chapter 4, which covers the topic of compression members. Because base plate design requires a consideration of bending strength, coverage of the topic is deferred until bending has been discussed.

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William T. Segui

CONTENTS

CHAPTER 4 COMPRESSION MEMBERS 73

CHAPTER 5 BEAMS 126

CHAPTER 6 BEAM-COLUMNS 206

1 INTRODUCTION

1.1 STRUCTURAL DESIGN

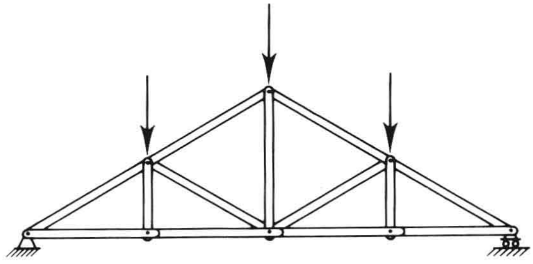
The structural design of buildings, whether of structural steel or reinforced concrete, requires the determination of the overall proportions and dimensions of the supporting framework and the selection of the cross sections of individual members. In most cases the functional design, including the establishment of the number of stories and the floor plan, will have been done by an architect, and the structural engineer must work within the constraints imposed by this design. Ideally, the engineer and architect will collaborate throughout the design process so that the project is completed in an efficient manner. In effect, however, the design can be summed up as follows: The architect decides how the building should look; the engineer must make sure that it doesn't fall down. Although this is an oversimplification, it affirms the first priority of the structural engineer: safety. Other important considerations include serviceability (how well the structure performs in terms of appearance and deflection) and economy. An economical structure requires an efficient use of materials and construction labor. Although this can usually be accomplished by a design that requires a minimum amount of material, savings can often be realized by using slightly more material if it results in a simpler, more easily constructed project.

A good design requires the evaluation of several framing plans — that is, different arrangements of members and their connections. In other words, several alternate designs should be prepared and their costs compared. For each framing plan investigated, the individual components must be designed. This requires the structural analysis of the frame(s) of the building and the computation of forces and bending moments in the individual members. Armed with this information, the structural designer can then select the appropriate cross section. Before any analysis, however, a decision must be made on the building material to be used; it will usually be reinforced concrete, structural steel, or both. Ideally, alternate designs should be prepared with each.

The emphasis in this book will be on the design of individual structural steel members and their connections. Although the structural engineer must select and evaluate the overall structural system in order to produce an efficient and economical design, this cannot be done without a thorough understanding of the design of the components (the "building blocks") of the structure. Component design is the focus of this book.

Before proceeding with a discussion of structural steel, we will examine the various types of structural members to be covered. Figure 1.1 shows a truss

FIGURE 1.1

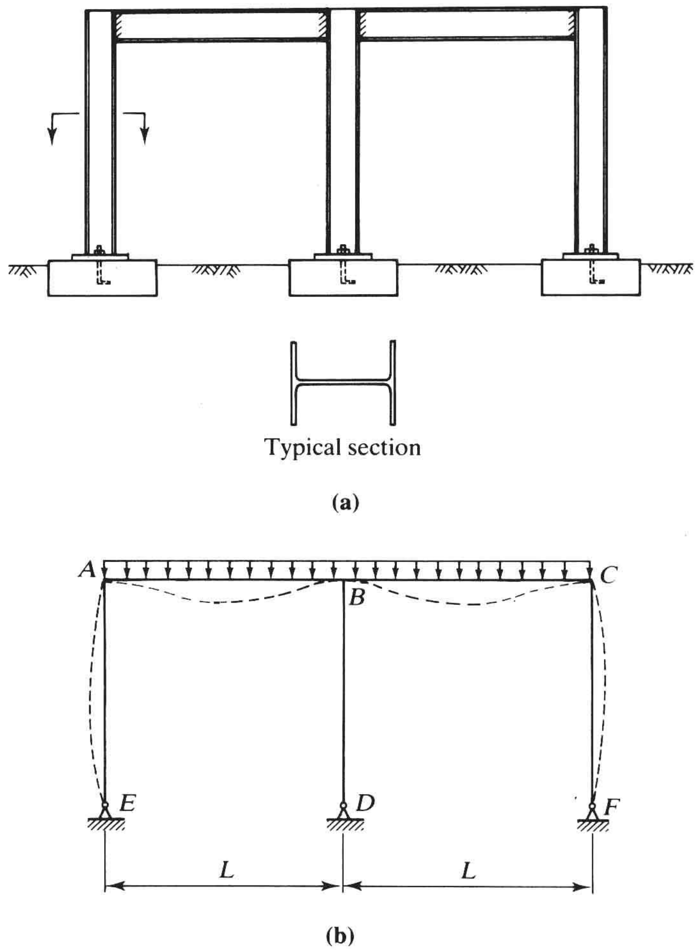


with vertical concentrated forces applied at the joints along the top chord. In keeping with the usual assumption of pinned connections, each member of the truss will be a two-force member, subject to either axial compression or tension. For simply supported trusses loaded as shown — and this is a typical loading condition — each of the top chord members will be in compression, and the bottom chord members will be in tension. The web members will either be in tension or compression, depending on their location and orientation and on the location of the loads.

Other types of members can be illustrated with the rigid frame of Figure 1.2a. The members of this frame are rigidly connected by welding and can be assumed to form a continuous structure. At the supports, the members are welded to a rectangular plate that is bolted to a concrete footing. If several of these frames are placed in parallel and connected with additional members that are then covered with roofing material and walls, we have a typical building system. Many important details have not been mentioned, but this is essentially the manner in which many small commercial buildings are constructed. The design and analysis of each frame in the system begins with the idealization of the frame as a two-dimensional structure as shown in Figure 1.2b. Because the frame has a plane of symmetry parallel to the page, we are able to treat the frame as two-dimensional and represent the frame members by their centerlines. (Although it is not shown in Figure 1.1, this same idealization is made with trusses, and the members are usually represented by their centerlines.) Note that the supports are represented as hinges (pins) and not as fixed. If there is a possibility that the footing will be able to undergo a slight rotation, the support must be considered to be pinned. One assumption made in the usual methods of structural analysis is that deformations are very small, and this means that only a slight rotation of the support is needed to qualify it as a pinned connection.

Once the geometry and support conditions of the idealized frame have been established, the loading must be determined. This is usually done by apportioning a share of the total load to each frame. If the hypothetical structure under consideration is subjected to a uniformly distributed roof load, the portion carried by one frame will be a uniformly distributed line load measured in force per unit length as shown in the figure. Typical units would be kips per foot.

FIGURE 1.2 ≡



For the loading shown in Figure 1.2, the frame will deform as indicated by the dashed line (drawn to a greatly exaggerated scale). The individual members of the frame can be classified according to the type of behavior represented by this deformed shape. The horizontal members *AB* and *BC* are subjected primarily to bending, or flexure, and are called *beams*. The vertical member *BD* is subjected to couples transferred from each beam, but for the symmetrical frame shown, they are equal and opposite, thereby canceling each other. Thus, member *BD* is subjected only to axial compression arising from the vertical loads. In buildings, vertical compression members such as these are referred to as *columns*. The other two vertical members, *AE* and *CF*, must resist not only axial compression from the vertical loads, but also a significant amount of bending. Such members are called *beam-columns*. In reality, all members, even those classified as beams or columns, will be subjected to both bending and axial load, but in many cases, one of the effects is minor and can be neglected.

In addition to the members described above, this book covers the design of connections and the following special members: composite columns, composite beams, and plate girders.

1.2 LOADS

The forces that act on a structure are called *loads*. They belong to one of two broad categories: *dead load* and *live load*. Dead loads are those that are permanent, including the weight of the structure itself, which is sometimes called the *self-weight*. Other dead loads in a building include the weight of nonstructural components such as floor coverings, suspended ceilings with light fixtures, and partitions. All of the loads mentioned thus far are forces due to gravity and are referred to as *gravity loads*. Live loads, which can also be gravity loads, are those that are not as permanent as dead loads. This type may or may not be acting on the structure at any given time, and the location may not be fixed. Examples of live load include furniture, equipment, and occupants of buildings. In general, the magnitude of a live load is not as well defined as that of a dead load, and it usually must be estimated. In many cases, a given structural member must be investigated for various positions of the live load so that a potential failure situation is not overlooked.

If the live load is applied slowly and is not removed and reapplied an excessive number of times, the structure can be analyzed as if the loads were static. If the load is applied suddenly, as would be the case when the structure supports a moving crane, we must account for the effects of impact. If the load is applied and removed many times over the life of the structure, fatigue stress becomes a problem, and we must account for its effects. Impact loading occurs in relatively few buildings, notably industrial buildings, and fatigue loading is rare, with thousands of load cycles over the life of the structure required before fatigue becomes a problem. For these reasons, all loading conditions in this book will be treated as static, and fatigue will not be considered.

Wind exerts a pressure or suction on the exterior surfaces of a building; because of its transient nature, it properly belongs in the category of live loads. Because of the relative complexity of determining wind loads, however, wind is usually considered a separate category of loading. Since lateral loads are most detrimental to tall structures, wind loads are usually not as important for low buildings, but uplift on light roof systems can be critical. Although wind is present most of the time, wind loads of the magnitude considered in design are infrequent and are not considered to be fatigue loads.

Earthquake loads are another special category and need to be considered only in those geographic locations where there is a reasonable probability of occurrence. A structural analysis of the effects of an earthquake requires an analysis of the structure's response to the ground motion produced by the earthquake. Simpler methods are sometimes used in which the effects of the earthquake are simulated by a system of horizontal loads, similar to those resulting from wind pressure, acting at each floor level of the building.

Snow is another live load that is treated as a separate category. Adding to the uncertainty of this load is the complication of drift, which can cause much of the load to accumulate over a relatively small area.

Other types of live load are often treated as separate categories, such as hydrostatic pressure and soil pressure, but the cases enumerated above are the ones ordinarily encountered in the design of structural steel building frames and their members.

1.3 BUILDING CODES

Buildings must be designed and constructed according to the provisions of a building code, which is a legal document containing requirements related to such things as structural safety, fire safety, plumbing, ventilation, and accessibility to the physically disabled. A building code has the force of law and is administered by a governmental entity such as a city, a county, or, for some large metropolitan areas, a consolidated government. Building codes do not give design procedures, but they do specify the design requirements and constraints that must be satisfied. Of particular importance to the structural engineer is the prescription of minimum live loads for buildings. Although the engineer is encouraged to investigate the actual loading conditions and attempt to determine realistic values, the structure must be able to support these specified minimum loads.

Although some large cities write their own building codes, many municipalities will adopt a "model" building code and modify it to suit their particular needs. Model codes are written by various nonprofit organizations in a form that is easily adopted by a governmental unit. Currently, there are three national model codes: the *BOCA National Building Code*,[1] the *Uniform Building Code*,[2] and the *Standard Building Code*.[3] A related document, similar in form to a building code, is ASCE 7-88, *Minimum Design Loads for Buildings and Other Structures*.[4] This standard is intended to provide load requirements in a format suitable for adoption by a building code.

1.4 DESIGN SPECIFICATIONS

In contrast to building codes, design specifications give more specific guidance for the design of structural members and their connections. They present the guidelines and criteria that enable a structural engineer to achieve the objectives mandated by a building code. Design specifications represent what is considered to be good engineering practice based on their latest research. They are periodically revised and updated by supplements or by completely new editions. As with model building codes, design specifications are written in a legal format by nonprofit organizations. They have no legal standing on their own, but by presenting design criteria and limits in the form of legal mandates and prohibitions, they can easily be adopted, by reference, as part of a building code.

The specifications of most interest to the structural steel designer are those published by the following organizations:

1. **American Institute of Steel Construction (AISC):**[5] This specification provides for the design of structural steel buildings and their connections. It is the one of primary concern in this book and will be discussed in detail.
2. **American Association of State Highway and Transportation Officials (AASHTO):**[6] This specification covers the design of highway bridges and related structures, and it provides for all structural materials normally used in bridges, including steel, reinforced concrete, and timber.
3. **American Railway Engineering Association (AREA):**[7] This document covers the design of railway bridges and related structures.
4. **American Iron and Steel Institute (AISI):**[8] This specification deals with cold-formed steel (see Section 1.6).

1.5 STRUCTURAL STEEL

The earliest use of iron, the chief component of steel, was for small tools in approximately 4000 B.C.[9] This material was in the form of wrought iron, produced by heating ore in a charcoal fire. In the latter part of the eighteenth century and in the early nineteenth century, cast iron and wrought iron were used in various types of bridges. Steel, an alloy of primarily iron and carbon, with fewer impurities and less carbon than cast iron, was first used in heavy construction in the nineteenth century. With the advent of the Bessemer converter in 1855, steel began to displace wrought iron and cast iron in construction. In the United States, the first structural steel railroad bridge was the Eads bridge, constructed in 1874 in St. Louis, Missouri.[10] In 1884 the first building with a steel frame was completed in Chicago.

The characteristics of steel that are of the most interest to structural engineers can be examined by plotting the results of a tensile test. If a test specimen is subjected to an axial load P as shown in Figure 1.3a, the stress and strain can be computed as follows:

$$f = \frac{P}{A} \quad \text{and} \quad \varepsilon = \frac{\Delta L}{L}$$

where

f = axial tensile stress
A = cross-sectional area
ε = axial strain
L = length of specimen
ΔL = change in length

If the load is increased in increments from zero up to the point of fracture, and stress and strain are computed at each step, a stress–strain curve such as the one in Figure 1.3b can be plotted. This curve is typical of a class of steel known as *ductile*, or *mild, steel*. The relationship between stress and strain is linear up to the proportional limit; the material is said to follow *Hooke's law*. A peak value, the upper yield point, is quickly reached after that, followed by a leveling off at the lower yield point. The stress then remains constant, even though the

FIGURE 1.3 ≣