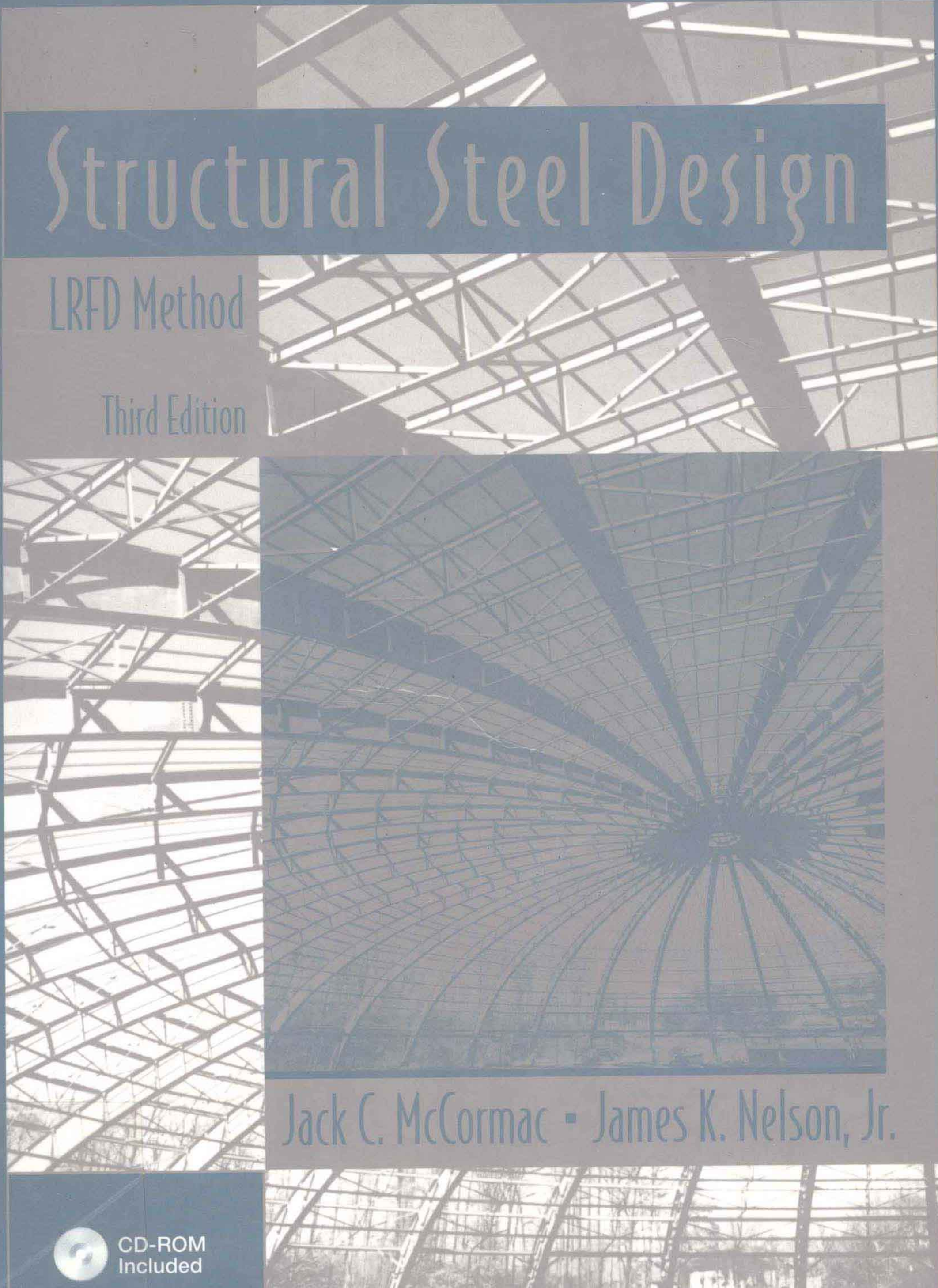
INTERNATIONAL EDITION

Structural Steel Design

LRFD Method

Third Edition



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CD-ROM Included

Structural Steel Design: LRFD Method

THIRD EDITION

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Preface

The authors' major objective in preparing this new edition was to update the text to conform to both the 1999 Load and Resistance Factor (LRFD) Design Specification and the 2002 edition of the LRFD Manual of Steel Construction.

Among the several changes made in the new specification and included in the steel manual are the following:

1. The inclusion of data and equations in both U.S. customary units and metric units.
2. The introduction of two new important ASTM steels, A913 and A992.
3. A few revisions in bolt criteria.
4. Revised design procedure for fatigue loadings.
5. A new section concerning the evaluation of existing structures.

In addition to the revisions in the Specification, several changes and additions have been made in the text concerning the enclosed computer programs. First, the program previously named INSTEP has been updated to the new specifications and has been changed from a DOS format to a Windows format. It is now named INSTEP32. Though the program was written specifically to solve many of the textbook-type problems presented in this book, it has often been used by professional engineers in their design practices.

Despite the practical applications of INSTEP32 and its value in teaching steel design, the authors feel that many professors would like their students to have some experience with at least one of the major commercial steel-design programs on the market today, in hopes that such experience would enable students to cross the bridge more quickly between the classroom and actual design practice. As a result, a student version of SAP 2000 has been included with INSTEP32 on the enclosed disk and presented herein. Use of this software will also enable the student to better understand the relationship between analysis and design.

Chapter 20, a new chapter in the text, presents an introduction to the subject of systems design. In this regard, recent requirements for "capstone" courses in our engineering schools have made the subject of "open-ended" problems a serious component of design studies. Therefore, the topic of systems design along with "open-ended" problems and an introduction to SAP 2000 are included in Chapter 20.

The authors wish to thank the following persons who reviewed this edition: Robert Abendroth, Daniel G. Linzell, Rolla Idriss, W. H. Walker, and Ahmad M. Itani.

They also thank the reviewers and users of the previous editions of this book for their suggestions, corrections, and criticisms. They are always grateful to anyone who takes the time to contact them concerning any part of their book.

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Contents

CHAPTER 1

Introduction to Structural Steel Design

1.1 ADVANTAGES OF STEEL AS A STRUCTURAL MATERIAL

A person traveling in the United States might quite understandably decide that steel was the perfect structural material. He or she would see an endless number of steel bridges, buildings, towers, and other structures. After seeing these numerous steel structures, this traveler might be surprised to learn that steel was not economically made in the United States until late in the nineteenth century, and the first wide-flange beams were not rolled until 1908.

The assumption of the perfection of this metal, perhaps the most versatile of structural materials, would appear to be even more reasonable when its great strength, light weight, ease of fabrication, and many other desirable properties are considered. These and other advantages of structural steel are discussed in detail in the paragraphs that follow.

1.1.1 High Strength

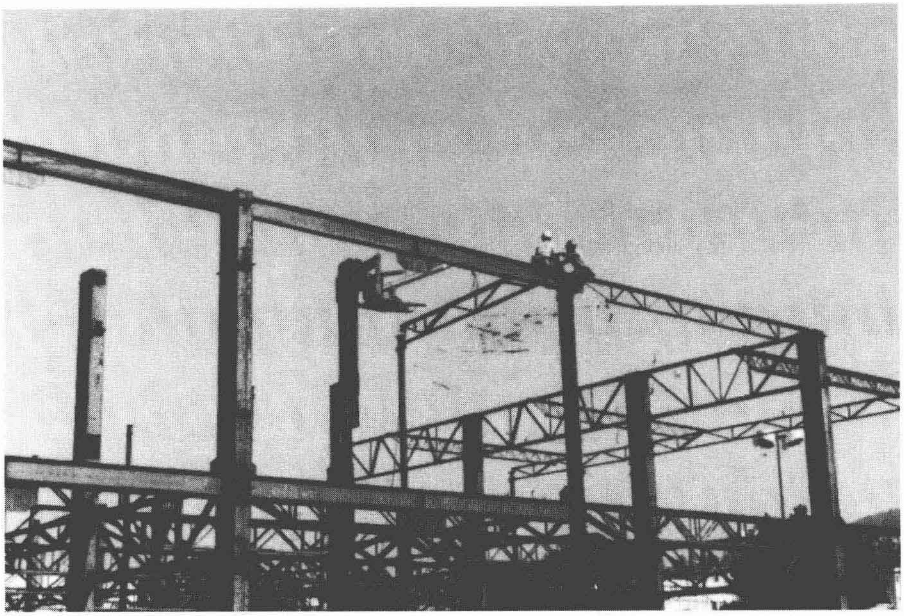
The high strength of steel per unit of weight means that the weight of structures will be small. This fact is of great importance for long-span bridges, tall buildings, and structures situated on poor foundations.

1.1.2 Uniformity

The properties of steel do not change appreciably with time, as do those of a reinforced-concrete structure.

1.1.3 Elasticity

Steel behaves closer to design assumptions than most materials because it follows Hooke's law up to fairly high stresses. The moments of inertia of a steel structure can be accurately calculated, while the values obtained for a reinforced-concrete structure are rather indefinite.



Erection of steel joists. (Courtesy of Vulcraft.)

1.1.4 Permanence

Steel frames that are properly maintained will last indefinitely. Research on some of the newer steels indicates that under certain conditions no painting maintenance whatsoever will be required.

1.1.5 Ductility

The property of a material by which it can withstand extensive deformation without failure under high tensile stresses is said to be its *ductility*. When a *mild* or *low-carbon* structural steel member is being tested in tension, a considerable reduction in cross section and a large amount of elongation will occur at the point of failure before the actual fracture occurs. A material that does not have this property is generally unacceptable and is probably hard and brittle, and it might break if subjected to a sudden shock.

In structural members under normal loads, high stress concentrations develop at various points. The ductile nature of the usual structural steels enables them to yield locally at those points, thus preventing premature failures. A further advantage of ductile structures is that when overloaded their large deflections give visible evidence of impending failure (sometimes jokingly referred to as "running time").

1.1.6 Toughness

Structural steels are tough—that is, they have both strength and ductility. A steel member loaded until it has large deformations will still be able to withstand large forces. This is a very important characteristic because it means that steel members can be subjected to large deformations during fabrication and erection without fracture—thus allowing them to be bent, hammered, sheared, and have holes punched in them without visible damage. The ability of a material to absorb energy in large amounts is called *toughness*.

1.1.7 Additions to Existing Structures

Steel structures are quite well suited to having additions made to them. New bays or even entire new wings can be added to existing steel frame buildings, and steel bridges may often be widened.

1.1.8 Miscellaneous

Several other important advantages of structural steel are as follows: (a) ability to be fastened together by several simple connection devices including welds and bolts, (b) adaptation to prefabrication, (c) speed of erection, (d) ability to be rolled into a wide variety of sizes and shapes as described in Section 1–4, (e) fatigue strength, (f) possible reuse after a structure is disassembled, and (g) scrap value, even though not reusable in its existing form. Steel is the ultimate recyclable material.

1.2 DISADVANTAGES OF STEEL AS A STRUCTURAL MATERIAL

In general, steel has the following disadvantages:

1.2.1 Maintenance Costs

Most steels are susceptible to corrosion when freely exposed to air and water and therefore must be painted periodically. The use of weathering steels, however, in suitable applications tends to eliminate this cost.

1.2.2 Fireproofing Costs

Although structural members are incombustible, their strength is tremendously reduced at temperatures commonly reached in fires when the other materials in a building burn. Many disastrous fires have occurred in empty buildings where the only fuel for the fires was the buildings themselves. Furthermore, steel is an excellent heat conductor—nonfireproofed steel members may transmit enough heat from a burning section or compartment of a building to ignite materials with which they are in contact in adjoining sections of the building. As a result, the steel frame of a building may have to be protected by materials with certain insulating characteristics, and the building may have to include a sprinkler system if it is to meet the building code requirements of the locality in question.

1.2.3 Susceptibility to Buckling

As the length and slenderness of a compression member is increased, its danger of buckling increases. For most structures the use of steel columns is very economical because of their high strength-to-weight ratios. Occasionally, however, some additional steel is needed to stiffen them so they will not buckle. This tends to reduce their economy.

1.2.4 Fatigue

Another undesirable property of steel is that its strength may be reduced if it is subjected to a large number of stress reversals or even to a large number of variations of tensile stress. (Fatigue problems occur only when tension is involved.) The present practice is to reduce the estimated strengths of such members if it is anticipated that they will have more than a prescribed number of cycles of stress variation.

1.2.5 Brittle Fracture

Under certain conditions steel may lose its ductility, and brittle fracture may occur at places of stress concentration. Fatigue type loadings and very low temperatures aggravate the situation.

1.3 EARLY USES OF IRON AND STEEL

Although the first metal used by human beings was probably some type of copper alloy such as bronze (made with copper, tin, and perhaps some other additives), the most important metal developments throughout history have occurred in the manufacture and use of iron and its famous alloy called steel. Today, iron and steel make up nearly 95 percent of all the tonnage of metal produced in the world.[1]

Despite diligent efforts for many decades, archaeologists have been unable to discover when iron was first used. They did find an iron dagger and an iron bracelet in the Great Pyramid in Egypt, which they claim had been there undisturbed for at least 5,000 years. The use of iron has had a great influence on the course of civilization since the earliest times, and may very well continue to do so in the centuries ahead. Since the beginning of the Iron Age in about 1000 B.C., the progress of civilization in peace and war has been heavily dependent on what people have been able to make with iron. On many occasions its use has decidedly affected the outcome of military engagements. For instance, in 490 B.C. in Greece at the Battle of Marathon, the greatly outnumbered Athenians killed 6400 Persians and lost only 192 of their own men. Each of the victors wore 57 pounds of iron armor in the battle. (This was the battle from which the runner Pheidippides ran the approximately 25 miles to Athens and died while shouting news of the victory.) This victory supposedly saved Greek civilization for many years.

According to the classic theory concerning the first production of iron in the world, there was once a great forest fire on Mount Ida in Ancient Troy (now Turkey) near the Aegean Sea. The land surface supposedly had a rich content of iron and the heat of the fire is said to have produced a rather crude form of iron which could be hammered into various shapes. Many historians believe, however, that human beings first learned to use iron that fell to the earth in the form of meterorites. Frequently the iron in meteorites is combined with nickel to produce a harder metal. Perhaps early human beings were able to hammer and chip this material into crude tools and weapons.

Steel is defined as a combination of iron and a small amount of carbon, usually less than 1 percent. It also contains small percentages of some other elements. Although

[1]American Iron and Steel Institute, *The Making of Steel* (Washington, D.C., not dated), p. 6.

some steel has been made for at least 2000–3000 years, there was really no economical production method available until the middle of the nineteenth century.

The first steel almost certainly was obtained when the other elements necessary for producing it were accidentally present when iron was heated. As the years went by, steel probably was made by heating iron in contact with charcoal. The surface of the iron absorbed some carbon from the charcoal, which was then hammered into the hot iron. Repeating this process several times resulted in a case-hardened exterior of steel. In this way the famous swords of Toledo and Damascus were produced.

The first large volume process for producing steel was named after Sir Henry Bessemer of England. He received an English patent for his process in 1855, but his efforts to obtain a U.S. patent for the process in 1856 were unsuccessful because it was shown that William Kelly of Eddyville, Kentucky, had made steel by the same process seven years before Bessemer applied for his English patent. Although Kelly was given the patent, the name Bessemer was used for the process.[2]

Kelly and Bessemer learned that a blast of air through molten iron burned out most of the impurities in the metal. Unfortunately, at the same time the blow eliminated some desirable elements such as carbon and manganese. It was later learned that these needed elements could be restored by adding spiegeleisen, which is an alloy of iron, carbon, and manganese. It was further learned that the addition of limestone in the converter resulted in the removal of the phosphorus and most of the sulfur.

Before the Bessemer process was developed, steel was an expensive alloy used primarily for making knives, forks, spoons, and certain types of cutting tools. The Bessemer process reduced production costs by at least 80 percent and allowed for the first time production of large quantities of steel.

The Bessemer converter was commonly used in the United States until after the turn of the century, but since that time it has been replaced with better methods, such as the open-hearth process and the basic oxygen process.

As a result of the Bessemer process, structural carbon steel could be produced in quantity by 1870, and by 1890, steel had become the principal structural metal used in the United States.

Today most of the structural steel shapes and plates produced in the United States are made by melting scrap steel. This scrap steel is obtained from junk cars, and scrapped structural shapes as well as from discarded refrigerators, motors, typewriters, bed springs, and other similar items. The molten steel is poured into molds which have approximately the final shapes of the members. The resulting sections, which are run through a series of rollers to squeeze them into their final shapes, have better surfaces and fewer internal or residual stresses than newly made steel.

The shapes may be further processed by cold rolling, by applying various coatings, and perhaps by the process of *annealing*. This is the process by which the steel is heated to an intermediate temperature range, held at that temperature for several hours, and then allowed to slowly cool to room temperature. It results in steel with less hardness and brittleness, but with greater ductility.

The term *cast iron* refers to materials with very low carbon content materials, while the very high carbon content materials are referred to as *wrought iron*. Steels fall

[2]American Iron and Steel Institute, *Steel 76* (Washington, D.C., 1976), pp. 5–11.