Cold-Formed Steel Design

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PREFACE

This book has been prepared to provide readers with a better understanding of the analysis and design of the thin-walled, cold-formed steel structures that have been so widely used in building construction and other areas in recent years. It is essentially a revised version of my book, *Cold-Formed Steel Structures*, published by McGraw-Hill Book Company in 1973. All the revisions are based on the 1980 edition of the AISI specification and other publications.

The material was originally developed for my graduate courses and short courses in the analysis and design of cold-formed steel structures and is based on my experience in the design, research, and development of American Iron and Steel Institute (AISI) design criteria.

Descriptions of the structural behavior of cold-formed steel members and connections are given from both the theoretical and the experimental points of view, and the reasons and justification for the various design provisions of the AISI specifications are discussed at length. Consequently the text will not only be instructive for students but can serve as a major source of reference for structural engineers and researchers.

Of the earlier published book's 13 chapters, Chapters 1 through 4 and 7 through 9 have been completely revised, and the other chapters have been updated on the basis of available information.

Chapter 1 includes a general discussion of the application of cold-formed steel structures and a review of previous research, the development of design specifications, and the major differences between the design of cold-formed and hot-rolled steel structural members. Because of the many research projects in the field that have been conducted worldwide during the past ten years, numerous presentations have been made at various conferences and many articles have been published in a number of engineering journals. At the same time, new design criteria have been developed in several countries. These new developments are reviewed in this chapter.

Since material properties play an important role in the performance of structural members, the types of steels and their most important mechanical properties are described in Chapter 2. In addition to a revision of Table 2.1 and some figures, additional detailed information on the effects of cold forming and residual stress on mechanical properties has been included in Articles 2.8 and 2.11.

In Chapter 3 the strength of thin elements and design criteria are discussed to acquaint the reader with the fundamentals of local buckling and postbuckling strength of thin plates and with the basic concepts used in design. Recent research findings made it possible to add more information about effective design widths and the requirements for stiffeners.

Chapter 4 concerns the design of flexural members. Because the AISI design provisions for beam webs were revised extensively in 1980, Article 4.3 has been completely rewritten. In addition, two new articles (4.7 and 4.8) have been added to acquaint the reader with inelastic reserve capacity and torsional analysis of beams.

The design procedures for compression members and beam-columns are discussed in Chapters 5 and 6, respectively. These two chapters have been brought up to date to include data from the 1980 edition of the AISI specification. Some additional design examples and new design information on unsymmetrically loaded singly symmetric shapes have been included.

Chapter 7 covers the design of cylindrical tubes. This revised chapter also contains comparisons of available test data and design criteria with regard to column buckling and local buckling of cylindrical tubes.

In 1980 the AISI design provisions for welded connections and bolted connections were revised extensively. As a result, Chapter 8 has also been revised, and the research data used for developing the AISI design critera are included.

Because various types of structural systems, such as shear diaphragms and shell roof structures, have become increasingly popular in building construction, Chapter 9 contains design information on these types of structural systems. It also contains a design method for wall studs.

The sectional properties of standard corrugated sheets are discussed in Chapter 10, because they have long been used in buildings for roofing, siding, and other applications.

Steel decks are widely used in building construction. Consequently the review in Chapter 11 of their use in steel-deck-reinforced composite slabs and composite beams is timely.

In addition to a discussion of the design of cold-formed carbon steel structural members, Chapter 12 contains an introduction to the design of cold-formed stainless steel structural members. Data in the 1974 edition of the AISI specification for stainless steel design were used to update this chapter.

The increasing use of computers for design work warrants the brief introduction that is given in Chapter 13 for the computer-aided design of cold-formed steel structures.

It is obvious that a book of this nature would not have been possible without the cooperation and assistance of many individuals, organizations, and institutions. It is based primarily on the results of a continuing research program on cold-formed steel structures that has been sponsored by the American Iron and Steel Institute at Cornell University since 1939 and on the publications related to cold-formed steel structures issued by the institute and other establishments.

I am especially indebted to the late Professor George Winter of Cornell University, who made contributions of pronounced significance to the building profession in his outstanding research on cold-formed steel structures and in the development of AISI design criteria. A considerable amount of material used in this book is based on Dr. Winter's publications. In view of his lasting influence in this field of endeavor, this book is gratefully dedicated to Professor Winter's memory.

An expression of thanks is due to Dr. Albert L. Johnson of the American Iron and Steel Institute for permission to quote freely from the AISI specification and the commentary thereon, and for his review of the complete manuscript, to Professor Eric R. Bryan of the University of Salford in the United Kingdom, Professor Duane S. Ellifritt of the University of Florida, Dr. Samuel J. Errera of Bethlehem Steel Corporation, Dr. James M. Fisher of Computerized Structural Design, Inc., Mr. Richard B. Heagler of Nicholas J. Bouras, Inc., Mr. Donald L. Johnson of Butler Manufacturing Company, Professor Karl H. Klippstein of the University of Pittsburgh, Professors William McGuire and Teoman Pekoz of Cornell University, and Mr. Don S. Wolford for their individual reviews of various parts of the manuscript. Their suggestions and encouragement have been of great value in the preparation of this book.

My sincerest thanks go to the many organizations and individuals that granted permission for the reproduction of quotations, graphs, tables, and photographs. Credits for the use of such materials are given in the text.

The endeavors of Drs. Joseph H. Senne and William A. Andrews of the University of Missouri-Rolla, who made the arrangements that permitted me to teach the annual graduate course related to cold-formed steel structures since I joined the University's faculty in 1968, are appreciatively acknowledged, because most of the material in the book has been and is used in the course. My thanks to Mr. John W. Koenig of the Univesity of Missouri-Rolla for his editorial suggestions and to Mrs. DeAnne Larson for her careful typing and assistance. The financial assistance provided by the University of Missouri through the award to me of a Curators' Professorship is most appreciated.

This book could not have been completed without the help and encouragement of my wife Yueh-Hsin and my children, Julie, Dorothy, and Gordon. I am very grateful to them for their patience, understanding, and assistance.

WEI-WEN YU

Rolla, Missouri
June 1985

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CHAPTER 1 INTRODUCTION

1.1 GENERAL REMARKS

In steel construction, there are two main families of structural members. One is the familiar group of hot-rolled shapes and members built up of plates. The other, less familiar but of growing importance, is composed of sections cold-formed from steel sheet, strip, plates, or flat bars in roll-forming machines or by press brake or bending brake operations.[1.1,1.2,1.3,*] These are cold-formed steel structural members. The thickness of steel sheets or strip generally used in cold-formed steel structural members ranges from 0.0149 in. (0.4 mm) to about $\frac{1}{4}$ in. (6.4 mm). Steel plates and bars as thick as 1 in. (25 mm) can be cold-formed successfully into structural shapes.[1.1,1.4]

Although cold-formed steel sections are used in car bodies, railway coaches, various types of equipment, storage racks, grain bins, highway products, transmission towers, transmission poles, drainage facilities, and bridge construction, the discussions included herein are primarily limited to applications in building

*The references are listed at the back of the book.

construction. For structures other than buildings, allowances for dynamic effects, fatigue, and corrosion may be necessary.[1.4]

The use of cold-formed steel members in building construction began in about the 1850s in both the United States and Great Britain. However, such steel members were not widely used in buildings until around 1940. The early development of steel buildings has been reviewed by Winter.[1.5-1.7]

Since 1946 the use and the development of thin-walled cold-formed steel construction in the United States have been accelerated by the issuance of various editions of the "Specification for the Design of Cold-Formed Steel Structural Members"[1.4] of the American Iron and Steel Institute (AISI). The specification was based largely on the continuing research sponsored by AISI at Cornell University under the direction of George Winter since 1939 and to a lesser extent at some other institutions.

In general, cold-formed steel structural members provide the following advantages in building construction:

1. As compared with thicker hot-rolled shapes, cold-formed light members can be manufactured for relatively light loads and/or short spans.
2. Unusual sectional configurations can be produced economically by cold-forming operations (Fig. 1.1), and consequently favorable strength-to-weight ratios can be obtained.
3. Nestable sections can be produced, allowing for compact packaging and shipping.
4. Load-carrying panels and decks can provide useful surfaces for floor, roof, and wall construction, and in other cases they can also provide enclosed cells for electrical and other conduits.
5. Load-carrying panels and decks not only withstand loads normal to their surfaces, but they can also act as shear diaphragms to resist force in their own planes if they are adequately interconnected to each other and to supporting members.

Compared with other materials such as timber and concrete, the following qualities can be realized for cold-formed steel structural members.[1.8,1.9]

1. Lightness.
2. High strength and stiffness.
3. Ease of prefabrication and mass production.
4. Fast and easy erection and installation.
5. Substantial elimination of delays due to weather.
6. More accurate detailing.
7. Nonshrinking and noncreeping at ambient temperatures.
8. Formwork unneeded.
9. Termite-proof and rotproof.

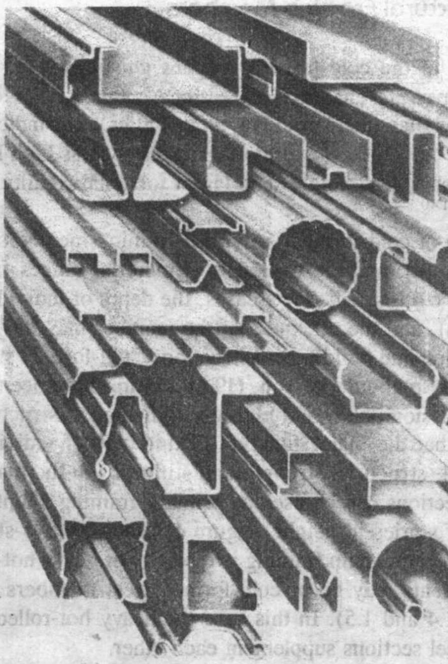

Fig. 1.1 Various shapes of cold-formed sections.[1.1]

10. Uniform quality.
11. Economy in transportation and handling.
12. Non-combustibility.

The combination of the above-mentioned advantages can result in cost saving during construction.

1.2 TYPES OF COLD-FORMED STEEL SECTIONS AND THEIR APPLICATIONS

Cold-formed steel structural members can be classified into two major types:

1. Individual structural framing members.
2. Panels and decks.

The design and the usage of each type of structural members have been reviewed in a number of publications.[1.5–1.39]

1.2.1 Individual Structural Framing Members

Figure 1.2 shows some of the cold-formed sections generally used in structural framing. The usual shapes are channels, Z-sections, angles, hat sections, I-sections, T-sections, and tubular members. Previous studies have indicated that the sigma section (Fig. 1.2*d*) possesses several advantages such as high load-carrying capacity, smaller blank size, less weight, and larger torsional rigidity as compared with standard channels.[1.40]

In general, the depth of cold-formed individual framing members ranges from 2 to 12 in. (51 to 305 mm), and the thickness of material ranges from 0.048 to about $\frac{1}{4}$ in. (1.2 to about 6.4 mm). In some cases, the depth of individual members may be 18 in. (457 mm), and the thickness of the member may be $\frac{1}{2}$ in. (13 mm) or thicker in transportation and building construction. Cold-formed steel plate sections in thicknesses of up to about $\frac{3}{4}$ or 1 in. (19 or 25 mm) have been used in steel plate structures, transmission poles, and highway-sign support structures.

In view of the fact that the major function of this type of individual framing member is to carry load, structural strength and stiffness are the main considerations in design. Such sections can be used as primary framing members in buildings up to three or four stories in height. Figure 1.3 shows a two-story building. In tall multistory buildings the main framing is typically of heavy hot-rolled shapes and the secondary elements may be of cold-formed steel members such as steel joists or panels (Figs. 1.4 and 1.5). In this case the heavy hot-rolled steel shapes and the cold-formed steel sections supplement each other.

As shown in Figs. 1.2 and 1.6 through 1.10, cold-formed sections are also used as chord and web members of open web steel joists, space frames, arches, and storage racks.

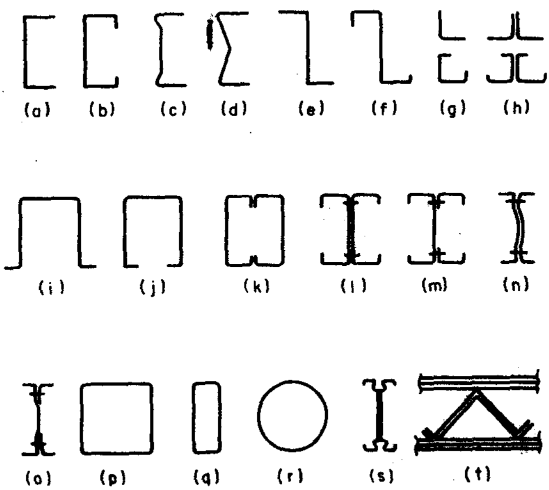

Fig. 1.2 Cold-formed sections used in structural framing.[1.6]

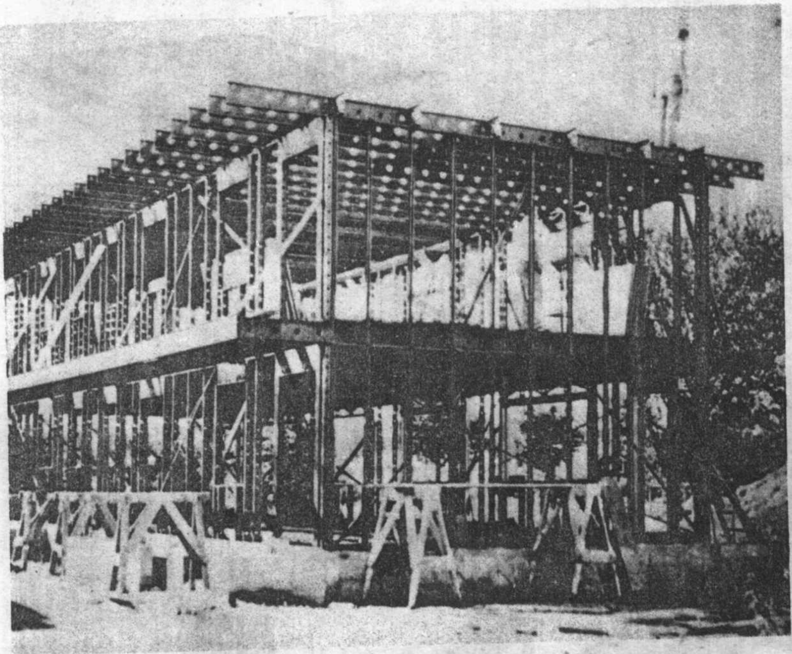

Fig. 1.3 Building composed entirely of cold-formed steel sections. (*Penn Metal Company.*)[1.7]

1.2.2 Panels and Decks

Another category of cold-formed sections is shown in Fig. 1.11. These sections are generally used for roof decks, floor decks, wall panels, siding material, and bridge forms.

The depth of panels generally ranges from $1\frac{1}{2}$ to $7\frac{1}{2}$ in. (38 to 191 mm), and the thickness of material ranges from 0.018 to 0.075 in. (0.5 to 1.9 mm). This is not to suggest that in some cases the use of 0.012 in. (0.3 mm) steel ribbed sections as load-carrying elements in roof and wall construction would be inappropriate.

Steel panels and decks not only provide structural strength to carry loads, but they also provide a surface on which flooring, roofing, or concrete fill can be applied, as shown in Fig. 1.12. They can also provide space for electrical conduits, or they can be perforated and combined with sound absorption material to form an acoustically conditioned ceiling. The cells of cellular panels are also used as ducts for heating and air conditioning.

During recent years, steel roof decks have been used in folded-plate and hyperbolic paraboloid roof construction,[1.13,1.22,1.26,1.30,1.34,1.35,1.41–1.48] as shown in Figs. 1.13 and 1.14. The world's largest light-gage steel primary structure using steel decking for hyperbolic paraboloids, designed by Lev Zetlin Associates, is shown in Fig. 1.15.[1.46] In many cases, roof decks can be curved to fit the shape of an

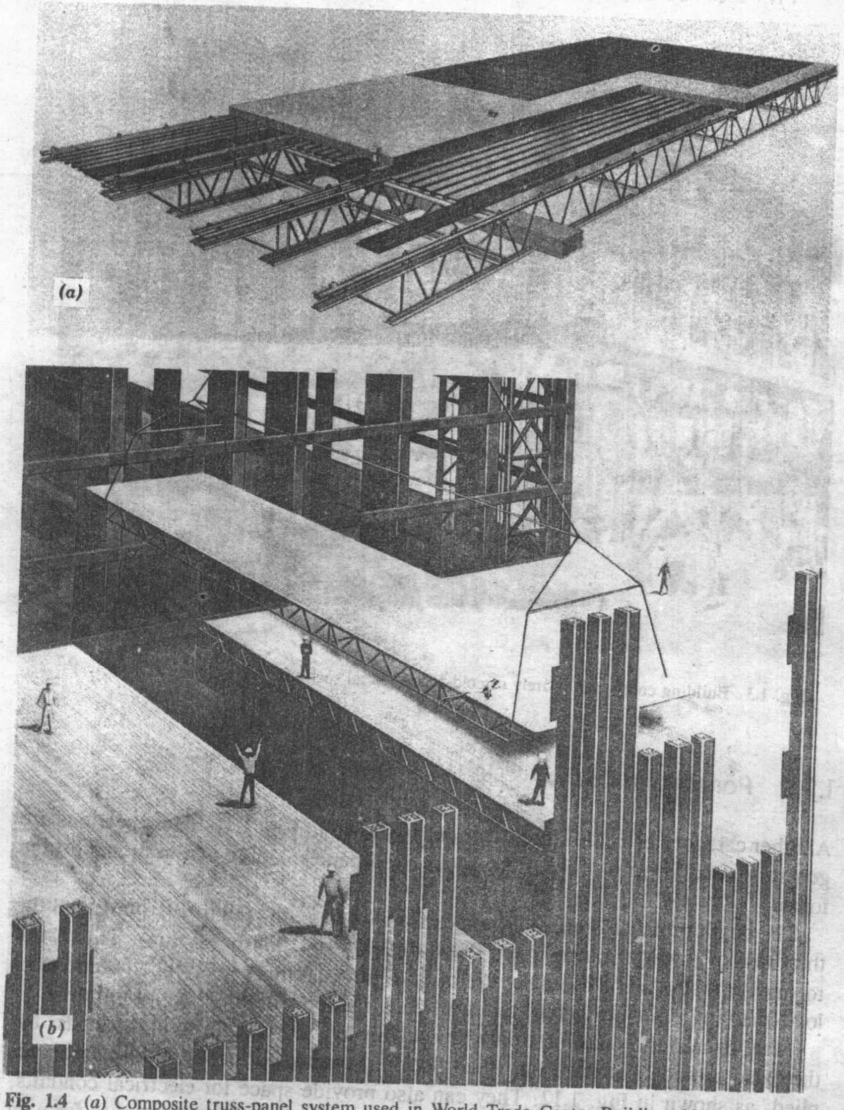

Fig. 1.4 (*a*) Composite truss-panel system used in World Trade Center Building, New York City; prefabricated by Laclede Steel Company. (*b*) Placement of prefabricated composite floor panel section in World Trade Center Building. (*Port of New York Authority.*)

arched roof without difficulty. Some roof decks are shipped to the field in straight sections and curved to the radius of an arched roof at the job site (Fig. 1.16). In other buildings, roof decks have been designed as the top chord of prefabricated open web steel joists or roof trusses (Fig. 1.17).[1.49,1.50] In Europe, TRP 200 decking (206 mm deep by 750 mm pitch) has been used widely.

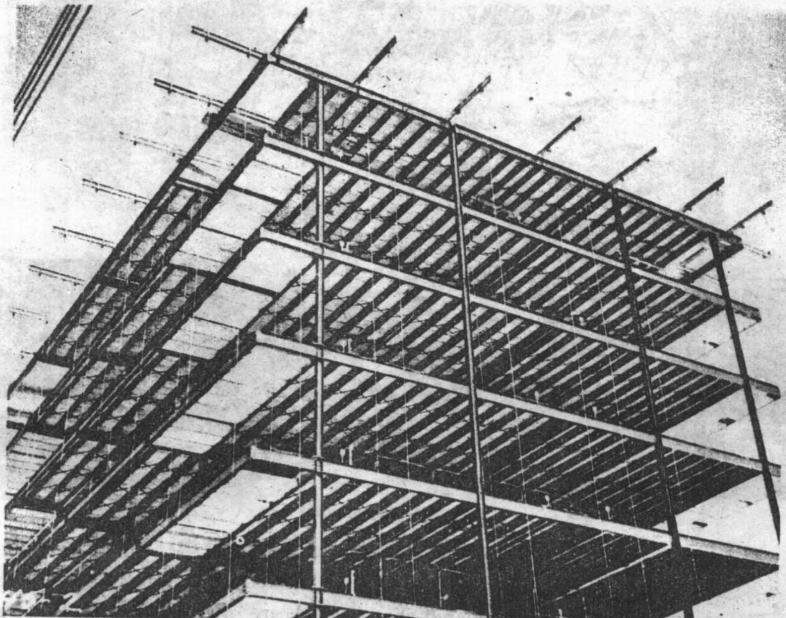

Fig. 1.5 Cold-formed steel joists used together with hot-rolled shapes. (*Stran-Steel Corporation.*)

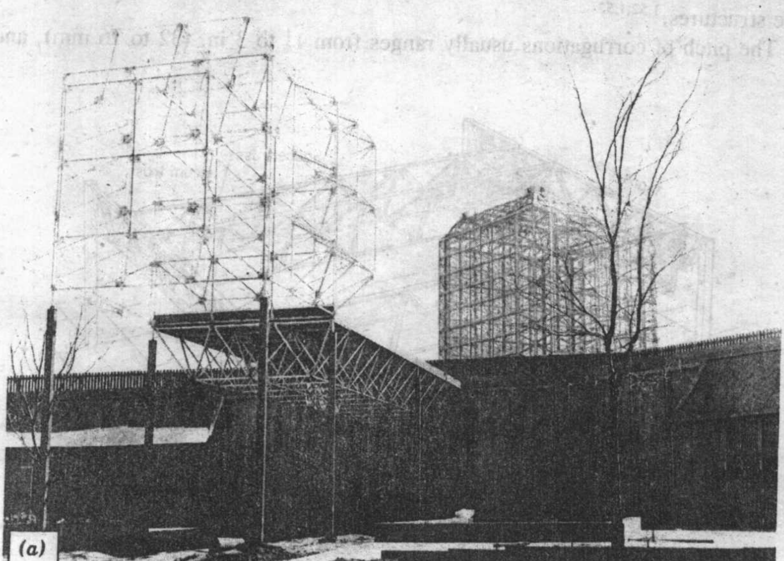

Fig. 1.6 Cold-formed steel sections used in space frames. (*Unistrut Corporation.*)