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, plate, or flat bar 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 sheet or strip generally used in cold-formed steel structural members ranges from 0.0149 in. (0.378 mm) to about $\frac{1}{4}$ in. (6.35 mm). Steel plates and bars as thick as 1 in. (25.4 mm) can be cold formed successfully into structural shapes.[1.1,1.4,1.314,1.336,1.345]

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 construction. For structures other than buildings, allowances for dynamic effects, fatigue, and corrosion may be necessary.[1.314,1.336,1.345]

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" of the American Iron and Steel Institute (AISI).[1.267,1.345] The earlier editions of the specification were based largely on the research sponsored by AISI at Cornell University under the direction of George Winter since 1939. It has been revised subsequently to reflect the technical developments and the results of continuing research.[1.267,1.336,1.346]

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.

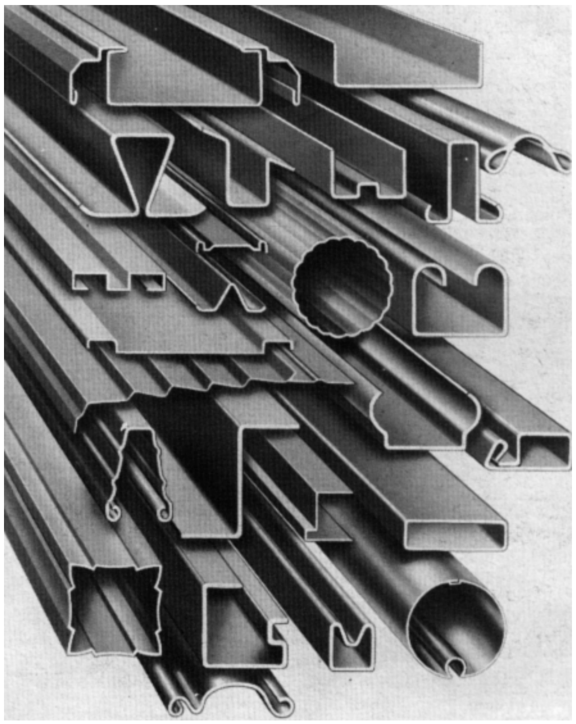

Figure 1.1 Various shapes of cold-formed sections.[1.1]

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

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 rot proof
10. Uniform quality
11. Economy in transportation and handling
12. Noncombustibility
13. Recyclable material

The combination of the above-mentioned advantages can result in cost saving in 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 and discussed in a number of publications.[1.5–1.75,1.267–1.285,1.349,1.358]

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 (C-sections), 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,

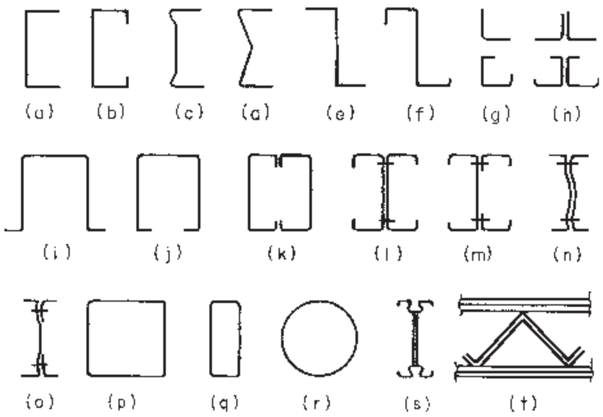

Figure 1.2 Cold-formed sections used in structural framing.[1.6]

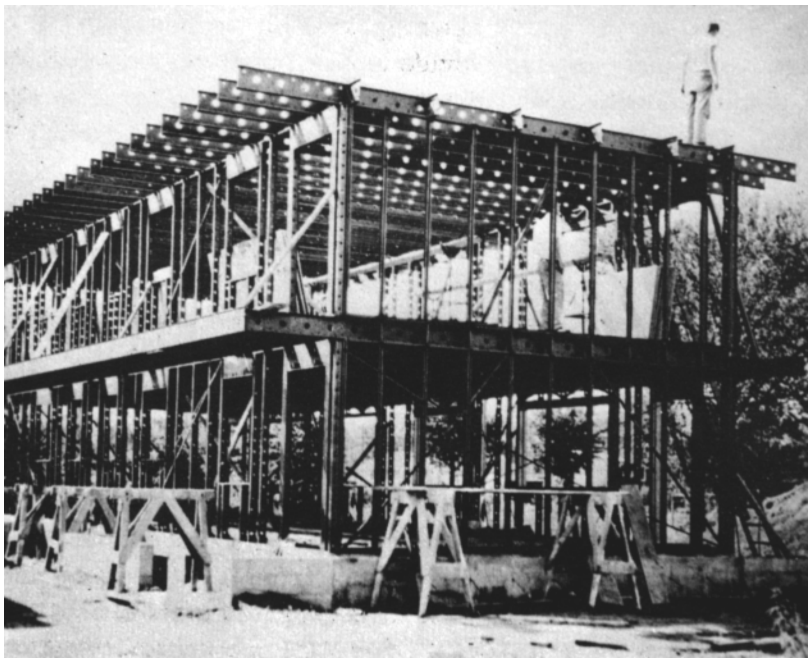

Figure 1.3 Building composed entirely of cold-formed steel sections. (Courtesy of Penn Metal Company.)[1.7]

and larger torsional rigidity as compared with standard channels.[1.76]

In general, the depth of cold-formed individual framing members ranges from 2 to 12 in. (50.8 to 305 mm), and the thickness of material ranges from 0.048 to about $\frac{1}{4}$ in. (1.22 to about 6.35 mm). In some cases, the depth of individual members may be up to 18 in. (457 mm), and the thickness of the member may be $\frac{1}{2}$ in. (12.7 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. (19.1 or 25.4 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 six stories in height.[1.278] In 2000, the 165-unit Holiday Inn in Federal Way, Washington, utilized eight stories of axial load bearing cold-formed steel studs as the primary load-bearing system.[1.357] 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, studs, decks, 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.[1.264]

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

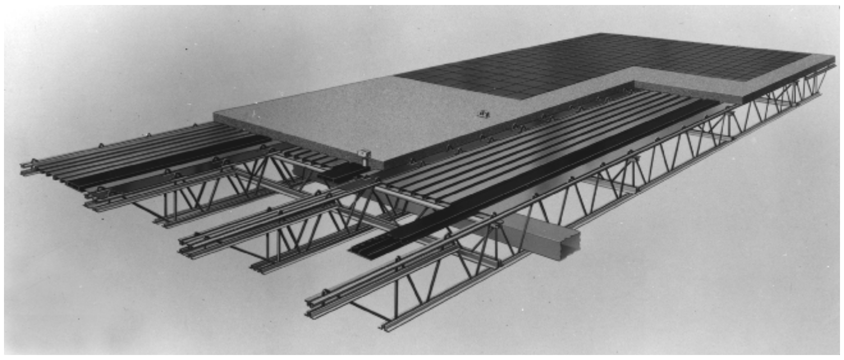

Figure 1.4 Composite truss–panel system prefabricated by Laclede Steel Company.

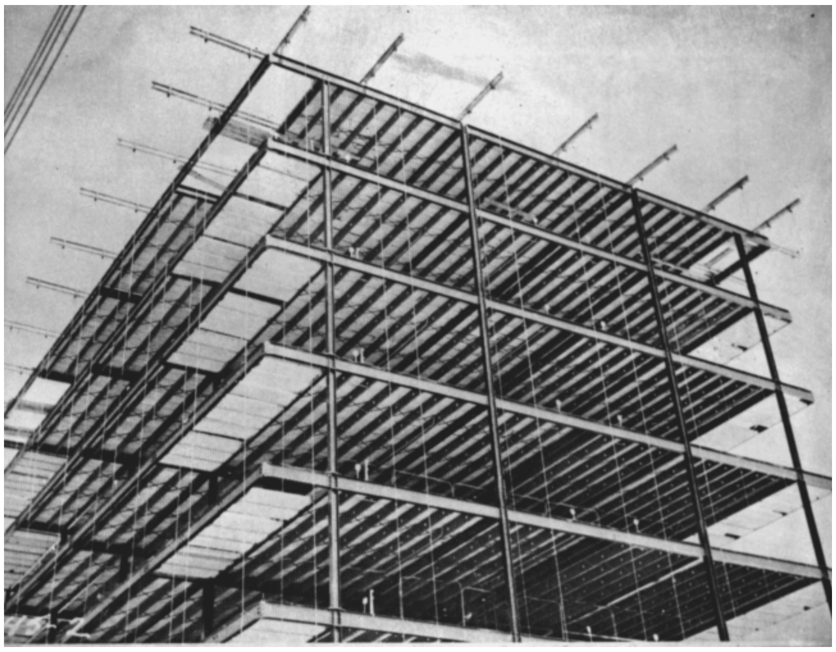

Figure 1.5 Cold-formed steel joists used together with hot-rolled shapes. (Courtesy of Stran-Steel Corporation.)

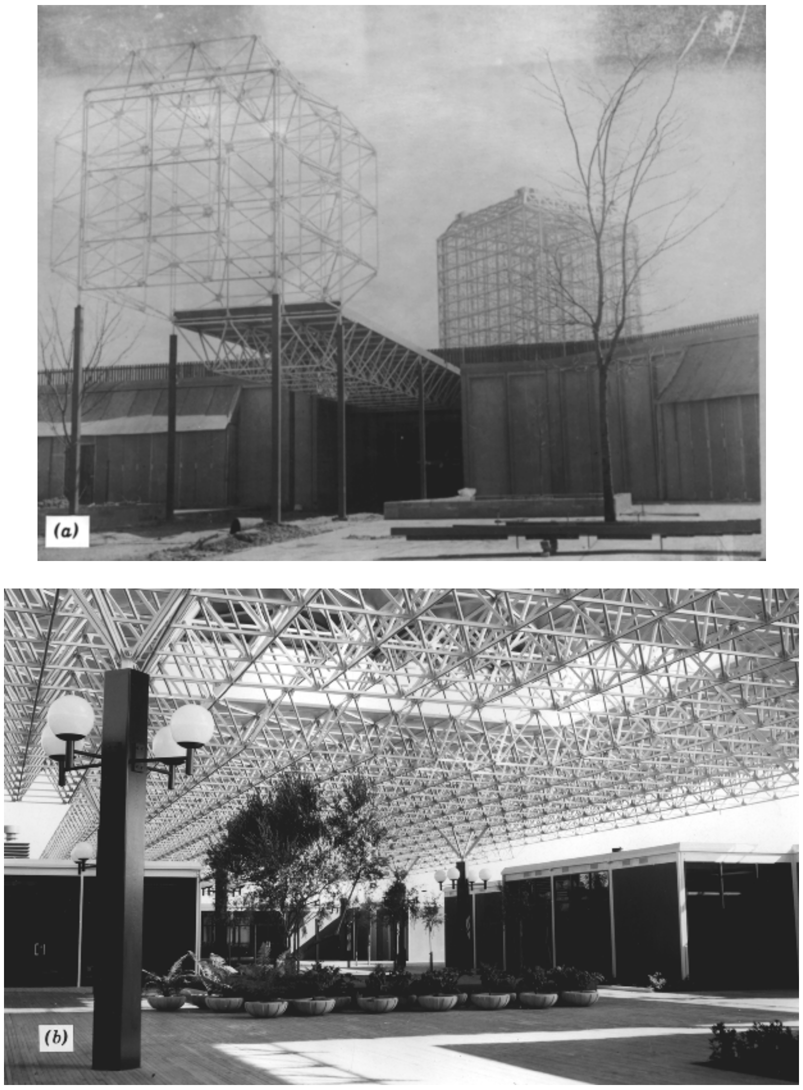

Figure 1.6 Cold-formed steel sections used in space frames. (Courtesy of Unistrut Corporation.)

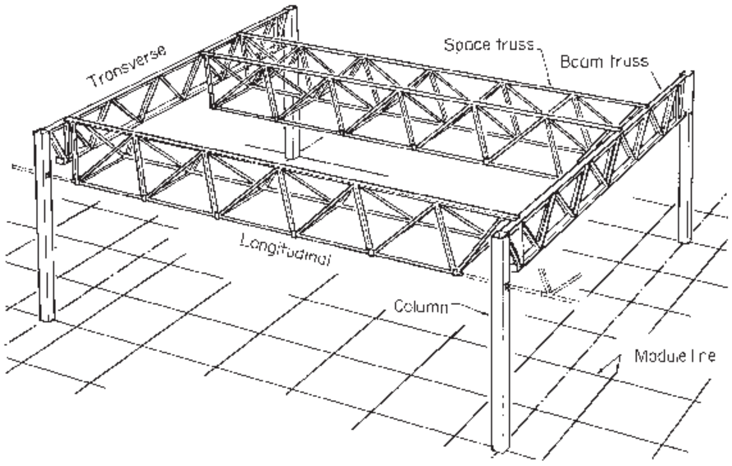

Figure 1.7 Cold-formed steel members used in space grid system. (Courtesy of Butler Manufacturing Company.)

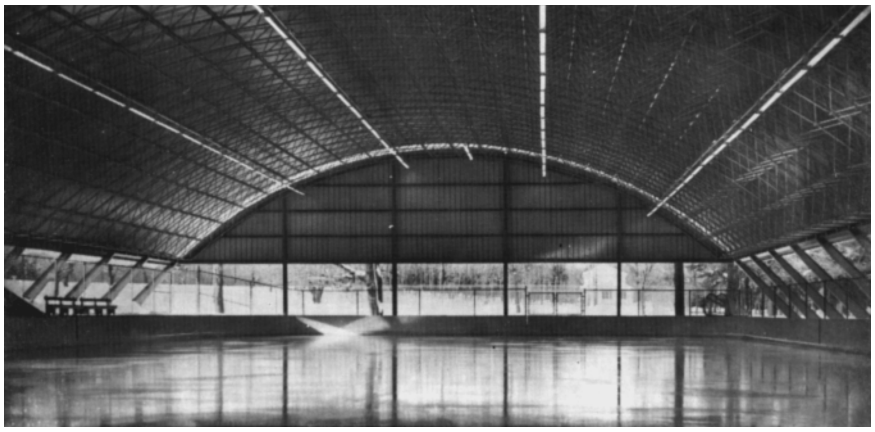

Figure 1.8 Cold-formed steel members used in a 100 × 220 × 30-ft (30.5 × 67.1 × 9.2-m) triodetic arch. (Courtesy of Butler Manufacturing Company.)

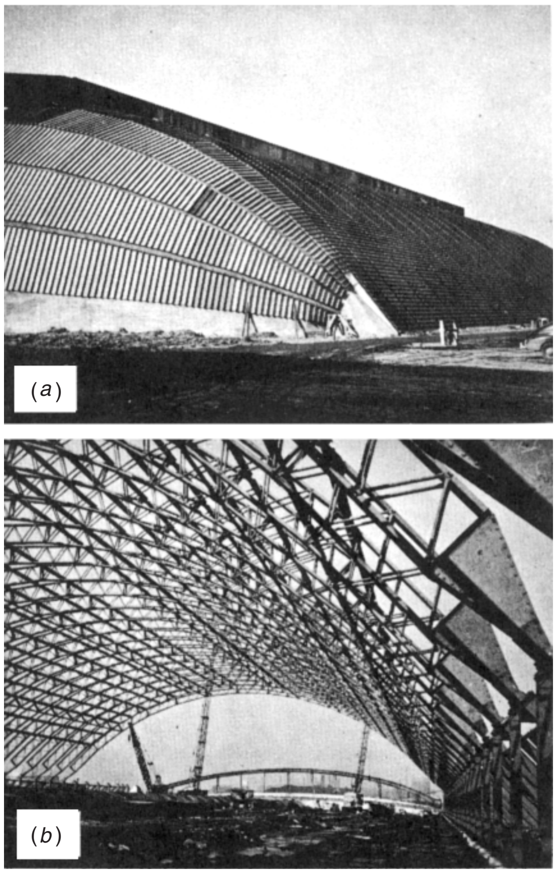

Figure 1.9 Hangar-type arch structures using cold-formed steel sections. (Courtesy of Armco Steel Corporation.)[1.6]

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. Some deeper panels and decks are cold formed with web stiffeners.

The depth of panels generally ranges from $1\frac{1}{2}$ to $7\frac{1}{2}$ in. (38.1 to 191 mm), and the thickness of materials ranges from 0.018 to 0.075 in. (0.457 to 1.91 mm). This is not to suggest that in some cases the use of 0.012-in. (0.305-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.

In the past, steel roof decks were successfully used in folded-plate and hyperbolic paraboloid roof construction,[1.13,1.22,1.26,1.30,1.34,1.35,1.72,1.77–1.84] as shown in Figs. 1.13 and 1.14. The world's largest cold-formed steel primary structure using steel decking for hyperbolic paraboloids, designed by Lev Zetlin Associates, is shown in Fig. 1.15.[1.82] In many cases, roof decks are curved to fit the shape of an 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).[1.85,1.86] In Europe, TRP 200 decking (206 mm deep by 750 mm pitch) has been used widely. In the United States, the standing seam metal roof has an established track record in new construction and replacement for built-up and single-ply systems in many low-rise buildings.

Figure 1.10 Rack structures. (Courtesy of Unarco Materials Storage.)

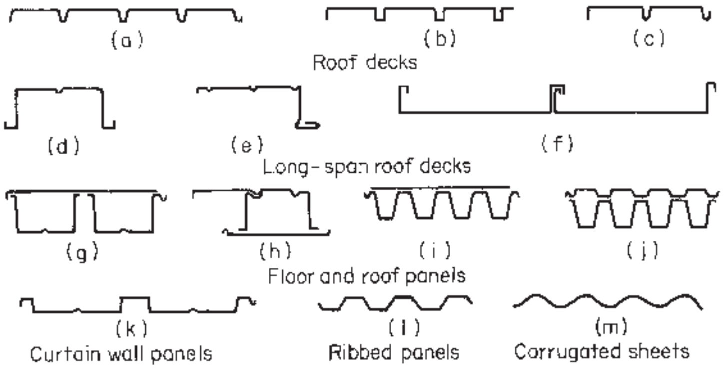

Figure 1.11 Decks, panels, and corrugated sheets.

Figure 1.11 also shows corrugated sheets which are often used as roof or wall panels and in drainage structures. The use of corrugated sheets as exterior curtain wall panels is illustrated in Fig. 1.18*a*. It has been demonstrated that corrugated sheets can be used effectively in the arched roofs of underground shelters and drainage structures.[1.87–1.89]

The pitch of corrugations usually ranges from $1\frac{1}{4}$ to 3 in. (31.8 to 76.2 mm), and the corrugation depth varies from $\frac{1}{4}$ to 1 in. (6.35 to 25.4 mm). The thickness of corrugated steel sheets usually ranges from 0.0135 to 0.164 in. (0.343 to 4.17 mm). However, corrugations with a pitch of up to 6 in. (152 mm) and a depth of up to 2 in. (50.8 mm) are also available. See Chapter 10 for the design of corrugated steel sheets based on the AISI publications.[1.87,1.88] Unusually deep corrugated panels have been used in frameless stressed-skin construction, as shown in Fig. 1.18*b*. The

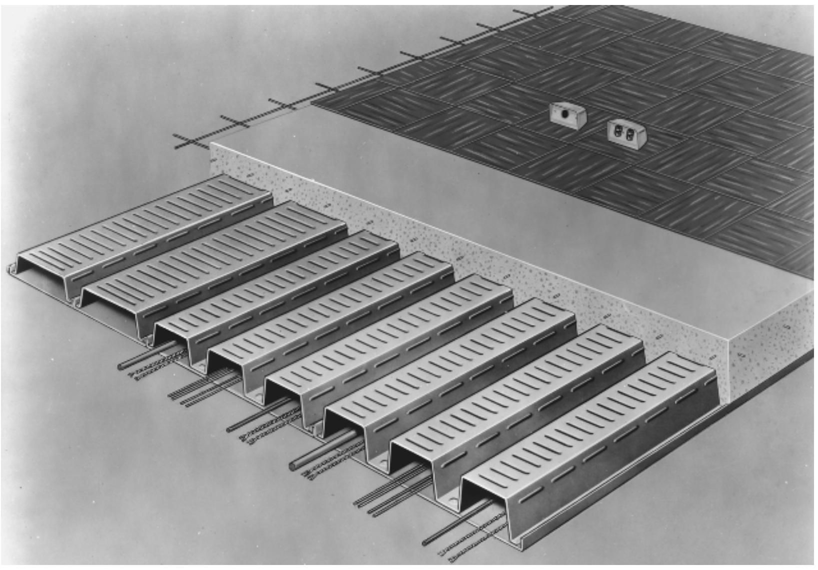

Figure 1.12 Cellular floor panels. (Courtesy of H. H. Robertson Company.)

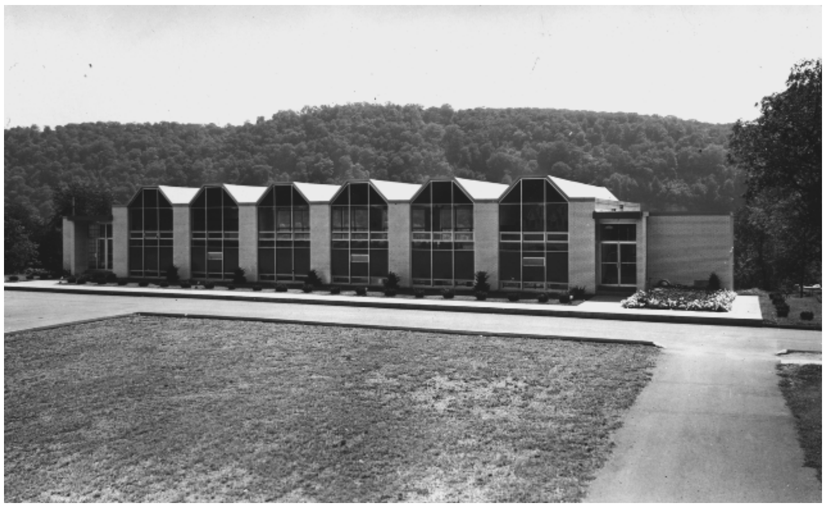

Figure 1.13 Cold-formed steel panels used in folded-plate roof. (Courtesy of H. H. Robertson Company.)

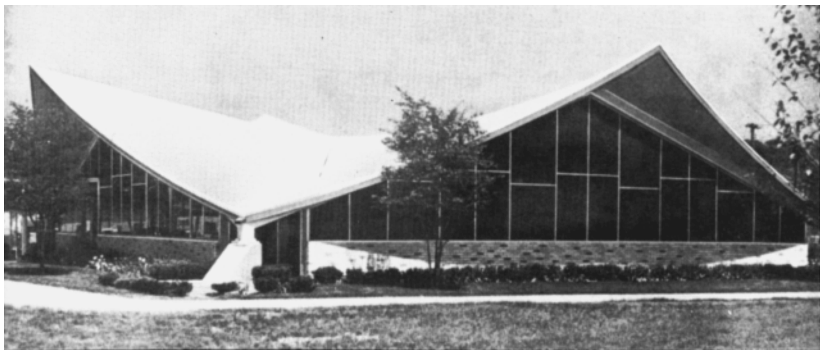

Figure 1.14 Hyperbolic paraboloid roof of welded laminated steel deck. (Reprinted from *Architectural Record,* March 1962. Copyright by McGraw-Hill Book Co., Inc.)[1.79]

Figure 1.15 Superbay hangar for American Airlines Boeing 747s in Los Angeles. (Courtesy of Lev Zetlin Associates, Inc.)[1.82]

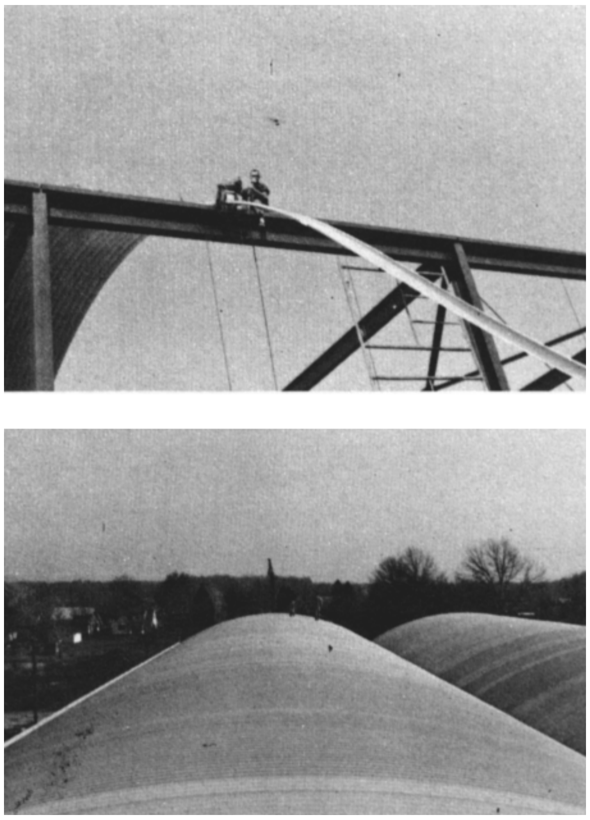

Figure 1.16 Arched roof curved at job site. (Courtesy of Donn Products Company.)

self-framing corrugated steel panel building proved to be an effective blast-resistant structure in the Nevada tests conducted in 1955.[1.90]

Figure 1.19 shows the application of standing seam roof systems. The design of beams having one flange fastened to a standing seam roof system and the strength of standing seam roof panel systems are discussed in Chapter 4.

In the past four decades, cold-formed steel deck has been successfully used not only as formwork but also as reinforcement of composite concrete floor and roof slabs.[1.55,1.91–1.103] The floor systems of this type of composite steel deck-reinforced concrete slab are discussed in Chapter 11.

1.3 STANDARDIZED METAL BUILDINGS AND INDUSTRIALIZED HOUSING

Standardized single-story metal buildings have been widely used in industrial, commercial, and agricultural applications. Metal building systems have also been used for community facilities such as recreation buildings, schools, and churches[1.104,1.105] because standardized metal building provides the following major advantages:

1. Attractive appearance
2. Fast construction
3. Low maintenance
4. Easy extension
5. Lower long-term cost

Figure 1.17 Steel deck is designed as the top chord of prefabricated open web steel joists. (Courtesy of Inland-Ryerson Construction Products Company.)

In general, small buildings can be made entirely of cold-formed sections (Fig. 1.20), and relatively large buildings are often made of welded steel plate rigid frames with cold-formed sections used for girts, purlins, roofs, and walls (Fig. 1.21).

The design of preengineered standardized metal buildings is often based on the *Metal Building Systems Manual* issued by the Metal Building Manufacturers Association (MBMA).[1.360] The 2006 edition of the MBMA manual is a revised version of the 2002 manual. The new manual includes (a) load application data [International Building Code (IBC) 2006 loads], (b) crane loads, (c) serviceability, (d) common industry practices, (e) guide specifications, (f) AISC-MB certification, (g) wind load commentary, (h) fire protection, (i) wind, snow, and rain data by U.S. county, (j) a glossary, (k) an appendix, and (l) a bibliography. In addition, MBMA also published the *Metal Roof Systems Design Manual*.[1.361] It includes systems components, substrates, specifications and standards, retrofit, common industry practices, design, installation, energy, and fire protection.

The design of single-story rigid frames is treated extensively by Lee et al.[1.107] In Canada the design, fabrication, and erection of steel building systems are based on a standard of the Canadian Sheet Steel Building Institute (CSSBI).[1.108]

Industrialized housing can be subdivided conveniently into (1) panelized systems and (2) modular systems.[1.109,1.278] In panelized systems, flat wall, floor, and roof sections are prefabricated in a production system, transported to the site, and assembled in place. In modular systems, three-dimensional housing unit segments are factory built, transported to the site, lifted into place, and fastened together.

In the 1960s, under the School Construction Systems Development Project of California, four modular systems of school construction were developed by Inland Steel Products Company (modular system as shown in Fig. 1.17), Macomber Incorporated (V-Lok modular component system as shown in Fig. 1.22), and Rheem/Dudley Buildings (flexible space system).[1.110] These systems have been proven to be efficient structures at reduced cost. They are successful not only for schools but also for industrial and commercial buildings throughout the United States.

In 1970 Republic Steel Corporation was selected by the Department of Housing and Urban Development under the Operation Breakthrough Program to develop a modular system for housing.[1.111] Panels consisting of steel facings with an insulated core were used in this system.

Building innovation also includes the construction of unitized boxes. These boxes are planned to be prefabricated of room size, fully furnished, and stacked in some manner to be a hotel, hospital, apartment, or office building.[1.25,1.112] For multistory buildings these boxes can be supported by a main framing made of heavy steel shapes.

In the past, cold-formed steel structural components have been used increasingly in low-rise buildings and residential steel framing. Considerable research

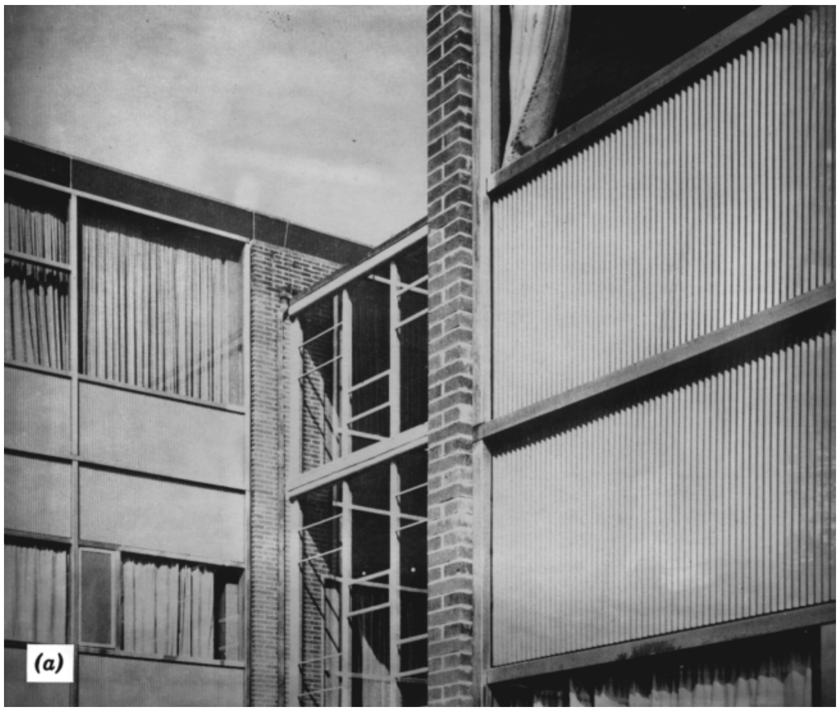

Figure 1.18 (*a*) Exterior curtain wall panels employing corrugated steel sheets.[1.87] (*b*) Frameless stressed-skin construction. (Courtesy of Behlen Manufacturing Company.)

Figure 1.19 Application of standing seam roof systems. (Courtesy of Butler Manufacturing Company.)

and development activities have been conducted continuously by numerous organizations and steel companies.[1.21,1.25,1.27,1.28,1.113–116,1.280–1.301] In addition to the study of the load-carrying capacity of various structural components, recent research work has concentrated on (1) joining methods, (2) thermal and acoustical performance of wall panels and floor and roof systems, (3) vibrational response of steel decks and floor joists, (4) foundation wall panels, (5) trusses, and (6) energy considerations. Chapter 13 provides some information on recent developments, design standards, and design guide for cold-formed steel light-frame construction.

In Europe and other countries many design concepts and building systems have been developed. For details,

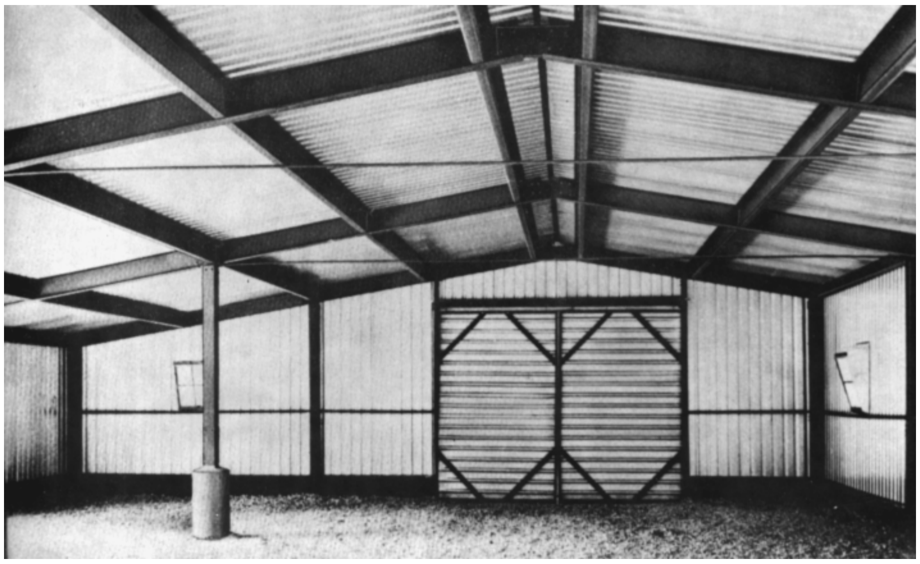

Figure 1.20 Small building made entirely of cold-formed sections. (Courtesy of Stran-Steel Corporation.)[1.6]

Figure 1.21 Standardized building made of fabricated rigid frame with cold-formed sections for girts, purlins, roofs, and walls. (Courtesy of Armco Steel Corporation.)

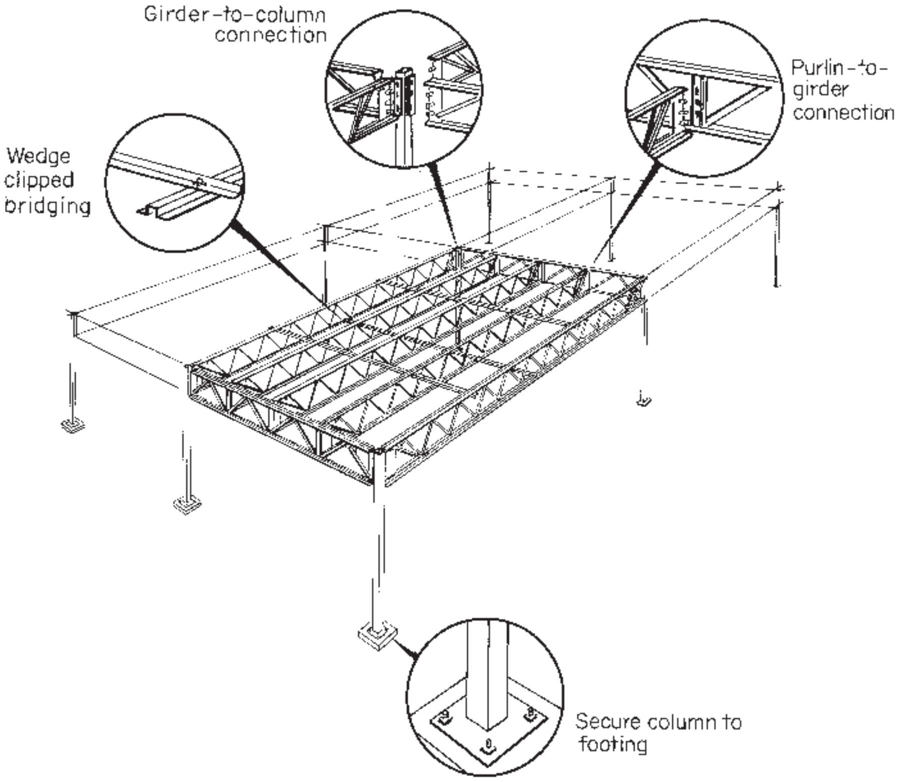

Figure 1.22 V-Lok modular component system. (Courtesy of Macomber Incorporated.)

see Refs. 1.25, 1.40–1.43, 1.117, 118, 1.268, 1.270, 1.271, 1.273, 1.275, 1.290, 1.293, and 1.297.

1.4 METHODS OF FORMING

Three methods are generally used in the manufacture of cold-formed sections such as illustrated in Fig. 1.1:

1. Cold roll forming
2. Press brake operation
3. Bending brake operation

1.4.1 Cold Roll Forming[1.1,1.119]

The method of cold roll forming has been widely used for the production of building components such as individual structural members, as shown in Fig. 1.2, and some roof, floor, and wall panels and corrugated sheets, as shown in Fig. 1.11. It is also employed in the fabrication of partitions, frames of windows and doors, gutters, downspouts, pipes, agricultural equipment, trucks, trailers, containers, railway passenger and freight cars, household appliances, and other products. Sections made from strips up to 36 in. (915 mm) wide and from coils more than 3000 ft (915 m) long can be produced most economically by cold roll forming.

The machine used in cold roll forming consists of pairs of rolls (Fig. 1.23) which progressively form strips into the final required shape. A simple section may be produced by as few as six pairs of rolls. However, a complex section may require as many as 15 sets of rolls. Roll setup time may be several days.

The speed of the rolling process ranges from 20 to 300 ft/min (6 to 92 m/min). The usual speed is in the range of 75–150 ft/min (23–46 m/min). At the finish end, the completed section is usually cut to required lengths by an automatic cutoff tool without stopping the machine. Maximum cut lengths are usually between 20 and 40 ft (6 and 12 m).

As far as the limitations for thickness of material are concerned, carbon steel plate as thick as $\frac{3}{4}$ in. (19 mm) can be roll formed successfully, and stainless steels have been roll formed in thicknesses of 0.006–0.30 in. (0.2–7.6 mm). The size ranges of structural shapes that can be roll formed on standard mill-type cold-roll-forming machines are shown in Fig. 1.24.

The tolerances in roll forming are usually affected by the section size, the product type, and the material thickness.

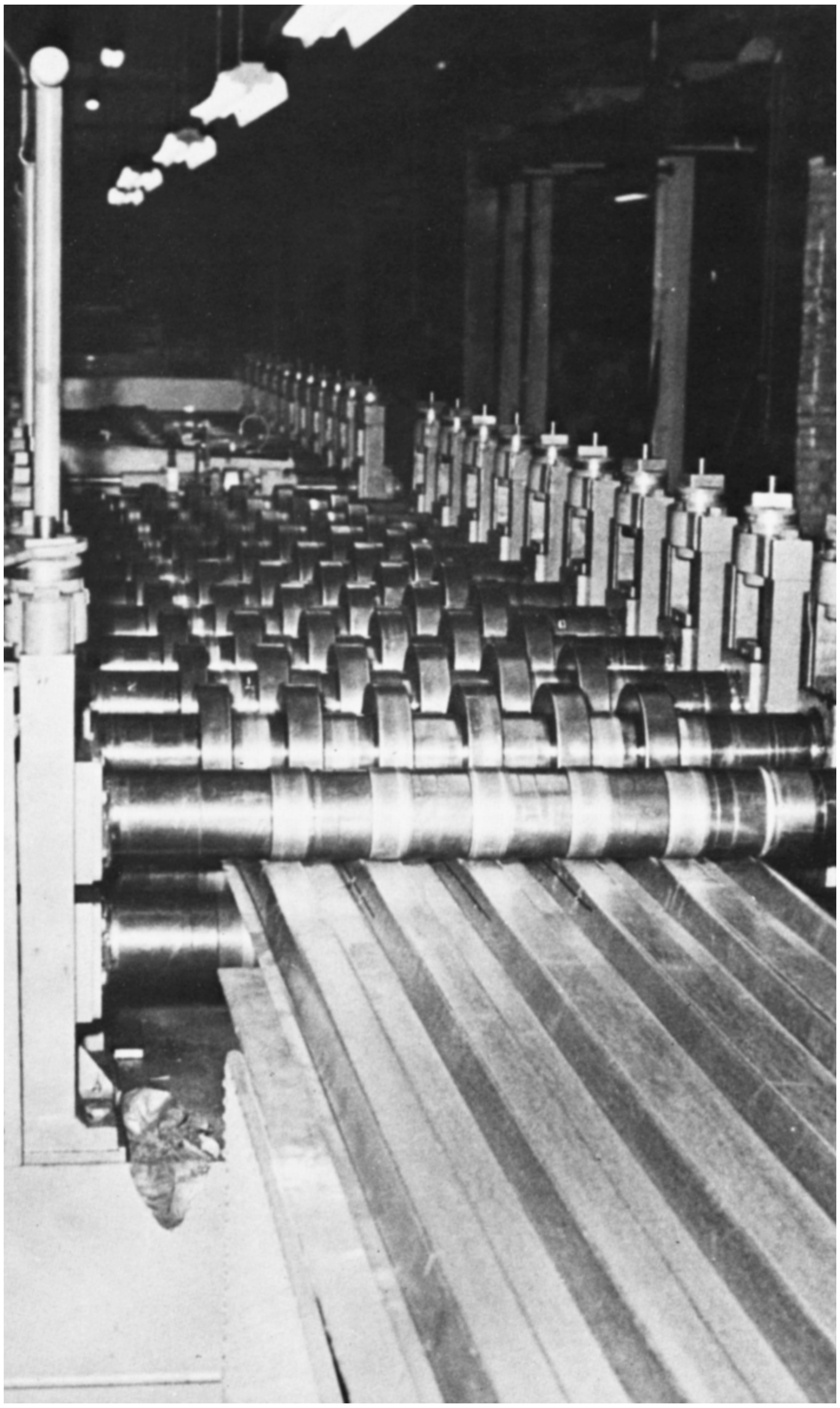

Figure 1.23 Cold-roll-forming machine.

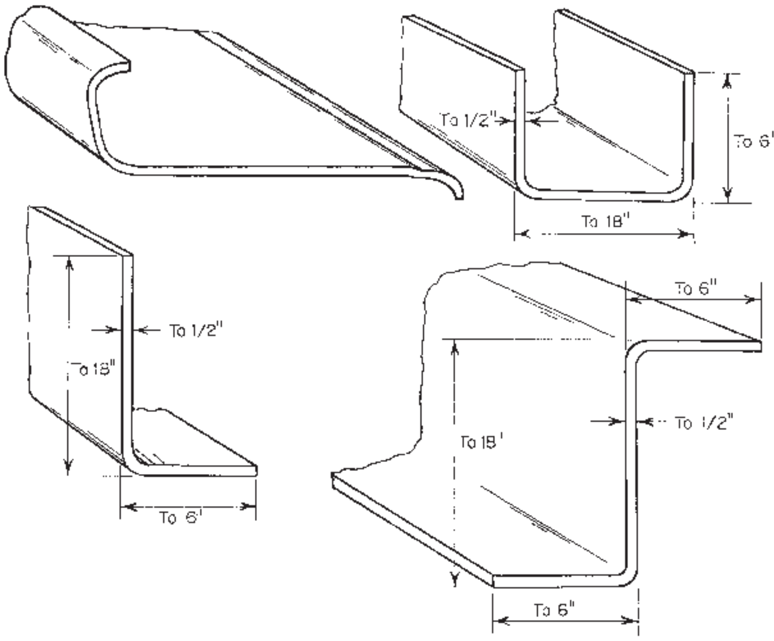

Figure 1.24 Size ranges of typical roll-formed structural shapes.[1.1]

The following limits are given by Kirkland[1.1] as representative of commercial practice, but they are not necessarily universal:

Piece length, using automatic cutoff	$\pm\frac{1}{64}$–$\frac{1}{8}$ in. (0.4–3.2 mm)
Straightness and twist	$\frac{1}{64}$–$\frac{1}{4}$ in. (0.4–6.4 mm) in 10 ft (3 m)
Cross-sectional dimensions	
Fractional	$\pm\frac{1}{64}$–$\frac{1}{16}$ in. (0.4–1.6 mm)
Decimal	±0.005–0.015 in. (0.1–0.4 mm)
Angles	$\pm 1^\circ$–2°

Table 1.1 gives the fabrication tolerances as specified by the MBMA for cold-formed steel channels and Z-sections to be used in metal building systems.[1.360] All symbols used in the table are defined in Fig. 1.25. The same tolerances are specified in the standard of the CSSBI.[1.108] For light steel framing members, the AISI framing standard S200-07 on general provisions[1.400] includes manufacturing tolerances for structural members. These tolerances for studs and tracks are based on the American Society for Testing and Materials (ASTM) standard C955-03. See Table 1.2 and Fig. 1.26. For additional information on roll forming, see Ref. 1.119.

Table 1.1 MBMA Table on Fabrication Tolerances[1.341]

	Tolerances, in.	
Dimension	+	−
Geometry		
D	$\frac{3}{16}$	$\frac{3}{16}$
B	$\frac{3}{16}$	$\frac{3}{16}$
D	$\frac{3}{8}$	$\frac{1}{8}$
θ_1	3°	3°
θ_2	5°	5°
Hole location		
E_1	$\frac{1}{8}$	$\frac{1}{8}$
E_2	$\frac{1}{8}$	$\frac{1}{8}$
E_3	$\frac{1}{8}$	$\frac{1}{8}$
S_1	$\frac{1}{16}$	$\frac{1}{16}$
S_2	$\frac{1}{16}$	$\frac{1}{16}$
F	$\frac{1}{8}$	$\frac{1}{8}$
P	$\frac{1}{8}$	$\frac{1}{8}$
L	$\frac{1}{8}$	$\frac{1}{8}$
Chamber, C	$\frac{1}{4}\left(\frac{\text{L ft}}{10}\right)$, in.	
Minimum thickness t	$0.95 \times$ design t	

Note: 1 in. = 25.4 mm.

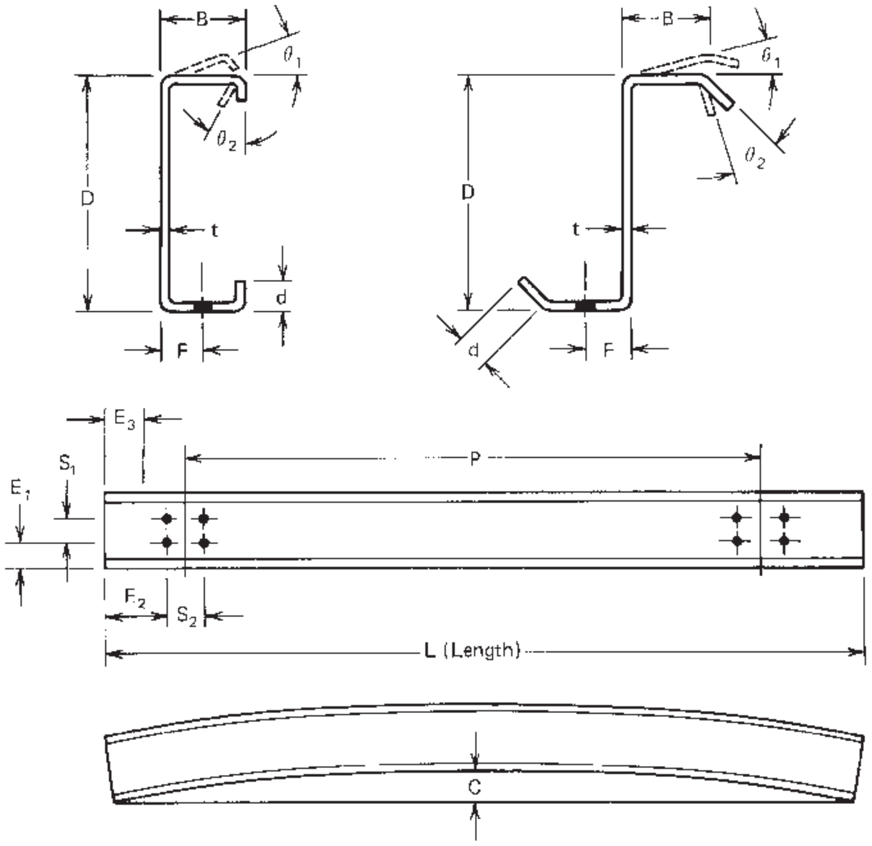

Figure 1.25 Symbols used in MBMA table.[1.360]

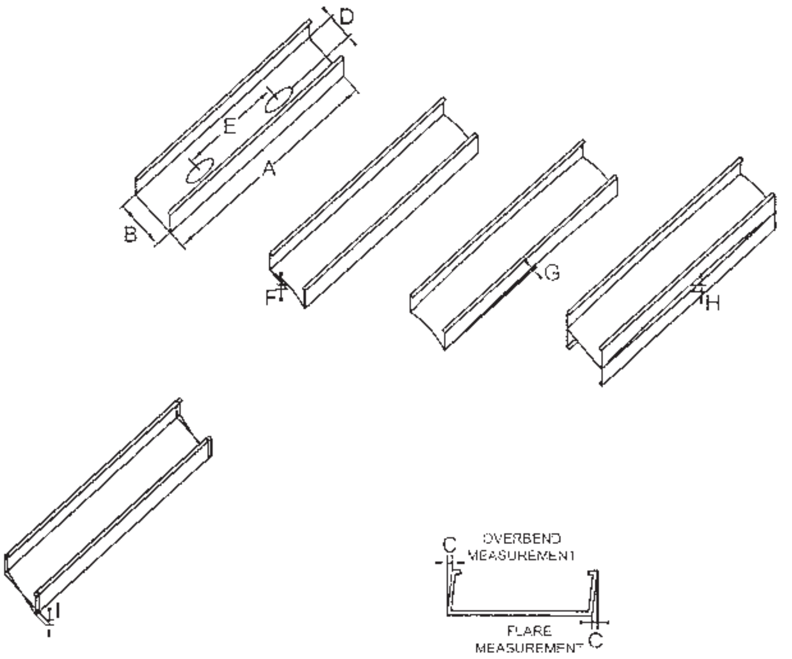

Figure 1.26 Manufacturing tolerances.[1.400]

Table 1.2 ASTM C 955-03 Manufacturing Tolerances for Structural Members[1.382,1.400]

Dimension[a]	Item Checked	Studs, In. (mm)	Tracks, In. (mm)
A	Length	$+\frac{3}{32}$ (2.38)	$\frac{1}{2}$ (12.7)
		$-\frac{3}{32}$ (2.38)	$-\frac{1}{4}$ (6.35)
B[b]	Web depth	$+\frac{1}{32}$ (0.79)	$+\frac{1}{32}$ (0.79)
		$-\frac{1}{32}$ (0.79)	$+\frac{1}{8}$ (3.18)
C	Flare	$+\frac{1}{16}$ (1.59)	+0 (0)
	overbend	$-\frac{1}{16}$ (1.59)	$+\frac{3}{32}$ (0.79)
D	Hole center	$+\frac{1}{16}$ (1.59)	NA
	Width	$-\frac{1}{16}$ (1.59)	NA
E	Hole center	$+\frac{1}{4}$ (6.35)	NA
	Length	$-\frac{1}{4}$ (6.35)	NA
F	Crown	$+\frac{1}{16}$ (1.59)	$+\frac{1}{16}$ (1.59)
		$-\frac{1}{16}$ (1.59)	$-\frac{1}{16}$ (1.59)
G	Camber	$+\frac{3}{32}\ \mathrm{ft}^{-1}(2.6\ \mathrm{m}^{-1})$	$+\frac{3}{32}\ \mathrm{ft}^{-1}(2.6\ \mathrm{m}^{-1})$
		$\frac{1}{2}$ max (12.7)	$\frac{1}{2}$ max (12.7)
H	Bow	$+\frac{3}{32}\ \mathrm{ft}^{-1}(2.6\ \mathrm{m}^{-1})$	$+\frac{3}{32}\ \mathrm{ft}^{-1}(2.6\ \mathrm{m}^{-1})$
		$\frac{1}{2}$ max (12.7)	$\frac{1}{2}$ max (12.7)
I	Twist	$+\frac{3}{32}\ \mathrm{ft}^{-1}(2.6\ \mathrm{m}^{-1})$	$+\frac{3}{32}\ \mathrm{ft}^{-1}(2.6\ \mathrm{m}^{-1})$
		$\frac{1}{2}$ max (12.7)	$\frac{1}{2}$ max (12.7)

Note: See Fig. 1.26.

[a] All measurements shall be taken not less than 1 ft (305 mm) from the end.

[b] Outside dimension for *stud*; inside for *track*.

1.4.2 Press Brake

The press brake operation may be used under the following conditions:

1. The section is of simple configuration.
2. The required quantity is less than about 300 linear ft/min (91.5 m/min).
3. The section to be produced is relatively wide [usually more than 18 in. (457 mm)] such as roof sheets and decking units.

The equipment used in the press brake operation consists essentially of a moving top beam and a stationary bottom bed on which the dies applicable to the particular required product are mounted, as shown in Fig. 1.27.

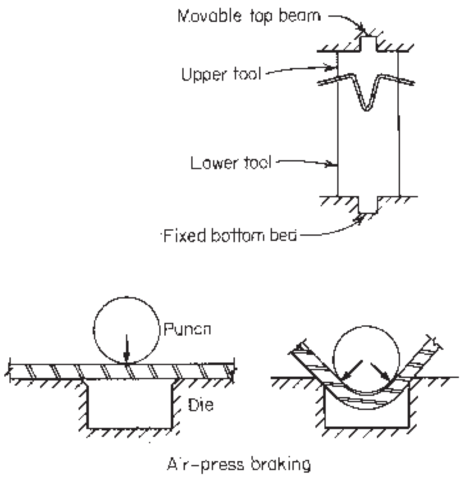

Figure 1.27 Press braking.[1.2.2.16]

Simple sections such as angles, channels, and Z-sections are formed by press brake operation from sheet, strip, plate, or bar in not more than two operations. More complicated sections may take several operations.

It should be noted that the cost of products is often dependent upon the type of the manufacturing process used in production. Reference 1.120 indicates that in addition to the strength and dimensional requirements a designer should also consider other influencing factors, such as formability, cost and availability of material, capacity and cost of manufacturing equipment, flexibility in tooling, material handling, transportation, assembly, and erection.

1.5 RESEARCH AND DESIGN SPECIFICATIONS

1.5.1 United States

1.5.1.1 Research During the 1930s, the acceptance and development of cold-formed steel members for construction industry in the United States faced difficulties due to the lack of an appropriate design specification. Various building codes made no provision for cold-formed steel construction at that time.

Since cold-formed steel structural members are usually made of light-gage steel and come in many different geometric shapes in comparison with typical hot-rolled sections, the structural behavior and performance of such thin-walled, cold-formed structural members under loads differ in several significant respects from that of heavy hot-rolled steel sections. In addition, the connections and fabrication practices which have been developed for cold-formed steel construction differ in many ways from those of heavy steel structures. As a result, design specifications for heavy hot-rolled steel construction cannot possibly cover the design features of cold-formed steel construction completely. It soon became evident that the development of a new design specification for cold-formed steel construction was highly desirable.

Realizing the need for a special design specification and the absence of factual background and research information, the AISI Committee on Building Research and Technology (then named Committee on Building Codes) sponsored a research project at Cornell University in 1939 for the purpose of studying the performance of light-gage cold-formed steel structural members and of obtaining factual information for the formulation of a design specification. Research projects have been carried out continuously at Cornell University and other universities since 1939.

The investigations on structural behavior of cold-formed steel structures conducted at Cornell University by Professor George Winter and his collaborators resulted in the development of methods of design concerning the effective width for stiffened compression elements, the reduced working stresses for unstiffened compression elements, web crippling of thin-walled cold-formed sections, lateral buckling of beams, structural behavior of wall studs, buckling of trusses and frames, unsymmetrical bending of beams, welded and bolted connections, flexural buckling of thin-walled steel columns, torsional–flexural buckling of concentrically and eccentrically loaded columns in the elastic and inelastic ranges, effects of cold forming on material properties, performance of stainless steel structural members, shear strength of light-gage steel diaphragms, performance of beams and columns continuously braced with diaphragms, hyperbolic paraboloid and folded-plate roof structures, influence of ductility, bracing requirements for channels and Z-sections loaded in the plane of the web, mechanical fasteners for cold-formed steel, interaction of local and overall buckling, ultimate strength of diaphragm-braced channels and Z-sections, inelastic reserve capacity of beams, strength of perforated compression elements, edge and intermediate stiffeners, rack structures, probability analysis, and C- and Z-purlins under wind uplift.[1.5–1.7,1.31,1.121,1.122,1.133–1.136]

The Cornell research under the direction of Professor Teoman Pekoz included effect of residual stress on column strength, maximum strength of columns, unified design approach, screw connections, distortional buckling of beams and columns, perforated wall studs, storage racks, load eccentricity effects on lipped-channel columns, bending strength of standing seam roof panels, behavior of longitudinally stiffened compression elements, probabilistic examination of element strength, direct-strength prediction of members using numerical elastic buckling solutions, laterally braced beams with edge-stiffened flanges, steel members with multiple longitudinal intermediate stiffeners, design approach for complex stiffeners, unlipped channel in bending and compression, beam–columns, cold-formed steel frame design, and second-order analysis of structural systems and others.[1..220,1.273,1.302–1.308,1.346,1.362,1.363]

In addition to the Cornell work, numerous research projects on cold-formed steel members, connections, and structural systems have been conducted at many individual companies and universities in the United States.[1.121–1.143,1.267,1.302–1.305,1.309,1.311,1.346,1.362–1.366] Forty-three universities were listed in the first edition of this book published in 1985.[1.352] Research findings obtained from these projects have been presented at various national and international conferences and are published in the conference proceedings and the journals of different engineering societies.[1.43,1.117,1.118,1.124–1.132,1.144–1.147,1.272–1.276,1.302–1.308,1.367–1.377]

Since 1975, the ASCE Committee on Cold-Formed Members has conducted surveys of current research on cold-formed structures and literature surveys.[1.133–1.136, 1.139–1.141] Thirty-eight research projects were reported in Ref. 1.136. In Ref. 1.141, about 1300 publications were classified into 18 categories. These reports provide a useful reference for researchers and engineers in the field of cold-formed steel structures.

In 1990, the Center for Cold-Formed Steel Structures was established at the University of Missouri-Rolla to provide an integrated approach for handling research, teaching, technical services, and professional activity.[1.312] In 1996, the Center for Cold-Formed Steel Structures conducted a survey of recent research. Reference 1.309 lists 48 projects carried out in seven countries. In October 2000, the center was renamed the Wei-Wen Yu Center for Cold-Formed Steel Structures (CCFSS) at the Fifteenth International Specialty Conference on Cold-Formed Steel Structures.[1.378]

1.5.1.2 AISI Design Specifications As far as the design criteria are concerned, the first edition of "Specification for the Design of Light Gage Steel Structural Members" prepared by the AISI Technical Subcommittee under the chairmanship of Milton Male was issued by the AISI in 1946.[1.5] This allowable stress design (ASD) specification was based on the findings of the research conducted at Cornell University up to that time and the accumulated practical experience obtained in this field. It was revised by the AISI committee under the chairmanships of W. D. Moorehead, Tappan Collins, D. S. Wolford, J. B. Scalzi, K. H. Klippstein, and S. J. Errera in 1956, 1960, 1962, 1968, 1980, and 1986 to reflect the technical developments and results of continuing research.

In 1991, the first edition of the load and resistance factor design (LRFD) specification[1.313] was issued by AISI under the chairmanship of R. L. Brockenbrough and the vice chairmanship of J. M. Fisher. This specification was based on the research work discussed in Ref. 1.248. In 1996, the AISI ASD Specification[1.4] and the LRFD Specification[1.313] were combined into a single specification[1.314] under the chairmanship of R. L. Brockenbrough and the vice chairmanship of J. W. Larson. The revisions of various editions of the AISI Specification are discussed in Ref. 1.267. In Ref. 1.315, Brockenbrough summarized the major changes made in the 1996 AISI Specification. See also Ref. 1.316 for an outline of the revised and new provisions. In 1999, a supplement to the 1996 edition of the AISI Specification was issued.[1.333,1.335]

The AISI Specification has gained both national and international recognition since its publication. It has been accepted as the design standard for cold-formed steel structural members in major national building codes. This design standard has also been used wholly or partly by most of the cities and other jurisdictions in the United States having building codes. The design of cold-formed steel structural members based on the AISI Specification has been included in a large number of textbooks and engineering handbooks.[1.13,1.149–1.158,1.269,1.277,1.318–1.320,1.350–1.358,1.412]

1.5.1.3 North American Specifications The above discussions dealt with the AISI Specification used in the United States. In Canada, the Canadian Standards Association (CSA) published its first edition of the Canadian Standard for Cold-Formed Steel Structural Members in 1963 on the basis of the 1962 edition of the AISI Specification with minor changes. Subsequent editions of the Canadian Standard were published in 1974, 1984, 1989, and 1994.[1.177,1.327] The 1994 Canadian Standard was based on the limit states design (LSD) method, similar to the LRFD method used in the AISI specification except for some differences discussed in Section 3.3.3.1.

In Mexico, cold-formed steel structural members have always been designed according to the AISI specification. The 1962 edition of the AISI design manual was translated into Spanish in 1965.[1.201]

In 1994, Canada, Mexico, and the United States implemented the North American Free Trade Agreement (NAFTA). Consequently, the first edition of *North American Specification for the Design of Cold-Formed Steel Structural Members* (NAS) was developed in 2001 by a joint effort of the AISI Committee on Specifications, CSA Technical Committee on Cold-Formed Steel Structural Members, and Camara Nacional de la Industria del Hierro y del Acero (CANACERO) in Mexico.[1.336] It was coordinated through the AISI North American Specification Committee chaired by R. M Schuster. This 2001 edition of the North American Specification has been accredited by the American National Standard Institute (ANSI) as an American National Standard (ANS) to supersede the AISI 1996 Specification and the CSA 1994 Standard with the approval by CSA in Canada and CANACERO in Mexico.

The North American Specification provides an integrated treatment of ASD, LRFD, and LSD. The ASD and LRFD methods are for use in the United States and Mexico, while the LSD method is used in Canada. This first edition of the North American Specification contained a main document in Chapters A through G applicable for all three countries and three separate country-specific Appendices A, B, and C for use in the United States, Canada, and Mexico, respectively.

The major differences between the 1996 AISI Specification and the 2001 edition of the North American Specification were discussed by Brockenbrough and Chen in Refs 1.339 and 1.341 and were summarized in the *CCFSS Technical Bulletin*.[1.338]

In 2004, AISI issued a Supplement to the 2001 Edition of the North American Specification that provides the revisions and additions for the Specification.[1.343,1.344] This supplement included a new Appendix for the design of cold-formed steel structural members using the direct-strength method (DSM). This new method provides alternative design provisions for determining the nominal axial strengths of columns and flexural strengths of beams without using the effective widths of individual elements. The background information on DSM can be found in the Commentary of Ref. 1.343 and Chapter 15.

The first edition of the North American Specification was revised in 2007.[1.345] It was prepared on the basis of the 2001 Specification,[1.336] the 2004 supplement,[1.343] and the continued developments of new and revised provisions. The major changes in the 2007 edition of the North American specification were summarized in Refs. 1.346–1.348. In this revised Specification, some design provisions were rearranged with editorial revisions for consistency. The common terms used in the Specification were based on the Standard Definitions developed by a joint AISC–AISI Committee on Terminology.[1.380] In addition to Appendix 1 on the DSM, Appendix 2 was added for the second-order analysis of structural systems. For the country-specific design requirements, Appendix A is now applicable to the United States and Mexico, while Appendix B is for Canada.

The North American specification has been approved by the ANSI and is referred to in the United States as AISI S100. It has also been approved by the CSA and is referred to in Canada as S136.

1.5.1.4 AISI Design Manuals In addition to the issuance of the design specification, AISI published the first edition of the *Light Gauge Steel Design Manual*[1.5] in 1949, prepared by the Manual Subcommittee under the chairmanship of Tappan Collins. It was subsequently revised in 1956, 1961, 1962, 1968–1972, 1977, 1983, 1986, 1996, 2002, and 2008.[1.349]

The 2002 AISI Design Manual was based on the 2001 edition of the North American Specification.[1.336,1.340] It included the following six parts: I, Dimensions and Properties; II, Beam Design; III, Column Design; IV, Connections; V, Supplementary Information; and VI, Test Procedures. Design aids (tables and charts) and illustrative examples were given in Parts I, II, III, and IV for calculating sectional properties and designing members and connections. Part I also included information on the availability and properties of steels that are referenced in the Specification. It contains tables of sectional properties of channels (C-sections), Z-sections, angles, and hat sections with useful equations for computing sectional properties. The development of this 2002 AISI Design Manual was discussed by Kaehler and Chen in Ref. 1.342.

Following the issuance of the 2007 edition of the Specification, AISI revised its Design Manual in 2008[1.349] on the basis of the second edition of the North American Specification.[1.345] As for previous editions of the Design Manual, the data contained in the AISI design manual are applicable to carbon and low-alloy steels only. They do not apply to stainless steels or to nonferrous metals whose stress–strain curves and some other characteristics of structural behavior are substantially different from those of carbon and low-alloy steels. For the design of stainless steel structural members, see Ref. 12.39 and Chapter 12.

It should also be noted that at the present time there are standardized sizes for studs, joists, channels, and tracks produced by member companies of the Steel Stud Manufacturers Association (SSMA).[1.379] The design aids for those frequently used members are included in the AISI Design manual. Except for the SSMA-designated sections, the sections listed in the tables of Part I of the AISI design manual are not necessarily stock sections with optimum dimensions. They are included primarily as a guide for design.

In some other countries, the cold-formed steel shapes may be standardized. The standardization of shapes would be convenient for the designer, but it may be limiting for particular applications and new developments.

1.5.1.5 AISI Commentaries Commentaries on several earlier editions of the AISI design specification were prepared by Professor Winter of Cornell University and published by AISI in 1958, 1961, 1962, and 1970.[1.161] In the 1983 and 1986 editions of the Design Manual, the format used for the simplified commentary was changed in that the same section numbers were used in the Commentary as in the Specification. For the 1996 edition of the Specification, the AISI Commentary, prepared by Wei-Wen Yu, contained a brief presentation of the characteristics and the performance of cold-formed steel members, connections, and systems.[1.310] In addition, it provided a record of the reasoning behind and the justification for various provisions of the AISI Specification. A cross reference was provided between various provisions and the published research data.

The Commentary on the 2001 edition of the North American Specification[1.337] was prepared on the basis of the AISI Commentary on the 1996 Specification with additional discussions on the revised and new design provisions. In the Commentary on the 2007 edition of the North American Specification, comprehensive discussions with extensive references are included for the new provisions, particularly for Appendices 1 and 2. For details, see Ref. 1.346.

In Refs. 1.62, 1.73, and 1.174, Johnson has reviewed some previous research work together with the development of design techniques for cold-formed steel structural members.

1.5.1.6 Other Design Standards and Design Guides In addition to the AISI Design Specifications discussed in Sections 1.5.1.2 and 1.5.1.3, AISI also published “Overview of the Standard for Seismic Design of Cold-Formed Steel Structures—Special Bolted Moment Frames”[1.381] and the ANSI-accredited North American standards for cold-formed steel framing, including (a) general provisions, (b) product data, (c) floor and roof system design, (d) wall stud design, (e) header design, (f) lateral design, (g) truss design, and (h) a prescriptive method.[1.387] These standards have been developed by the AISI Committee on Framing Standards since 1998. The uses of these standards for residential and commercial construction are discussed in Chapter 13. Furthermore, AISI also published numerous design guides: *Direct Strength Method (DSM) Design Guide*,[1.383] *Cold-Formed Steel Framing Design Guide*,[1.384] *Steel Stud Brick Veneer Design Guide*,[1.385] *A Design Guide for Standing Seam Roof Panels*,[1.386] and others. In addition, the Light Gauge Steel Engineers Association (LGSEA) and Cold-Formed Steel Engineers Institute (CFSEI) of the Steel Framing Alliance (formerly the Light Gauge Steel Engineers Association) have developed and published various technical notes and design guides on a broad range of design issues.[1.387]

In the past, many trade associations and professional organizations had special design requirements for using cold-formed steel members as floor decks, roof decks, and wall panels,[1.103,1.162,1.330–1.332] open web steel joists,[1.163] transmission poles,[1.45,1.48,1.164,1.321–1.323] storage racks,[1.165,1.166,1.407–1.410] shear diaphragms,[1.167–1.169,1.388,1.389] composite slabs,[1.103,1.170,1.324,1.325,1.390] metal buildings,[1.106,1.360,1.361] light framing systems,[1.171] guardrails, structural supports for highway signs, luminaries, and traffic signals,[1.88] and automotive structural components.[1.172,1.173] The locations of various organizations are listed at the end of the book under Acronyms and Abbreviations.

1.5.2 Other Countries

In other countries, research and development for cold-formed steel members, connections, and structural systems have been actively conducted at many institutions and individual companies in the past. Design specifications and recommendations are now available in Australia and New Zealand,[1.69,1.175,1.326,1.391] Austria,[1.176] Brazil,[1.392] Canada,[1.177–1.180,1.327,1.393] the Czech Republic,[1.181] Finland,[1.182] France,[1.183,1.184] Germany,[1.196–1.198,1.396] India,[1.185] Italy,[1.394] Japan,[1.186] Mexico,[1.397] the Netherlands,[1.187,1.395] the People’s Republic of China,[1.188] the Republic of South Africa,[1.189] Sweden,[1.191–1.193] Romania,[1.190] the United Kingdom,[1.49,1.72,1.194,1.195] Russia,[1.199] and elsewhere. Some of the recommendations are based on LSD. The AISI Design Manual has previously been translated into several other languages.[1.200–1.204]

In the past, the European Convention for Constructional Steelwork (ECCS), through its Committee TC7 (formerly 17), prepared several documents for the design and testing of cold-formed sheet steel used in buildings.[1.205–1.214] In 1993, the European Committee for Standardization published Part 1.3 of Eurocode 3 for cold-formed, thin-gage members and sheeting.[1.328] This work was initiated by the Commission of the European Communities and was carried out in collaboration with a working group of the ECCS. The design of cold-formed steel sections is also covered in Refs. 1.66, 1.69, 1.215, 1.216, 1.217, and 1.268.

With regard to research work, many other institutions have conducted numerous extensive investigations in the past. References 1.40–1.43, 1.71, 1.117, 1.118, 1.124–1.147, 1.158, 1.218, 1.237, 1.268–1.276, 1.302–1.309, and 1.362–1.377 contain a number of papers on various subjects related to thin-walled structures from different countries. Comparisons between various design rules are presented in Refs. 1.239 and 1.240.

1.6 GENERAL DESIGN CONSIDERATIONS OF COLD-FORMED STEEL CONSTRUCTION

The use of thin material and cold-forming processes results in several design features for cold-formed steel construction different from those of heavy hot-rolled steel construction. The following is a brief discussion of some considerations usually encountered in design.

1.6.1 Local Buckling, Distortional Buckling, and Postbuckling Strength of Thin Compression Elements

Since the individual components of cold-formed steel members are usually so thin with respect to their widths, these thin elements may buckle at stress levels less than the yield stress if they are subject to compression, shear, bending, or bearing. Local buckling of such elements is therefore one of the major design considerations.

It is well known that such elements will not necessarily fail when their buckling stress is reached and that they often will continue to carry increasing loads in excess of that at which local buckling first appears.

Figure 1.28 shows the buckling behavior and postbuckling strength of the compression flange of a hat-section beam with a compression flange having a width-to-thickness ratio of 184 tested by Winter. For this beam the

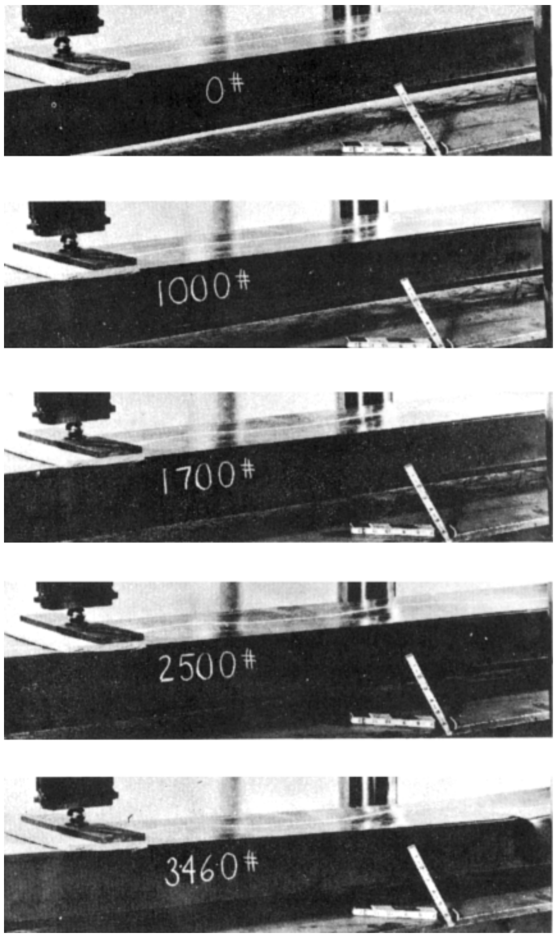

Figure 1.28 Consecutive load stages on hat-shaped beam.[1.7]

theoretical buckling load is 500 lb (2.2 kN), while failure occurred at 3460 lb (15.4 kN).[1.7]

Figure 1.29 shows the buckling behavior of an I-beam having an unstiffened flange with a width-to-thickness ratio of 46.[1.7] The beam failed at a load about 3.5 times that at which the top flange stress was equal to the theoretical critical buckling value. These pictures illustrate why the postbuckling strength of compression elements is utilized in design.

Prior to 1986, different procedures were used in the AISI Specification for the design of beams and columns with different types of compression elements. The current design methods for beams, columns, and beam–columns are discussed in Chapters 4, 5, and 6, respectively.

During recent years, distortional buckling has been considered as one of the important limit states for the design of cold-formed steel beams and columns having edge-stiffened compression flanges. New design provisions have been added in the current North American specification. For details, see Chapters 4, 5, and 15.

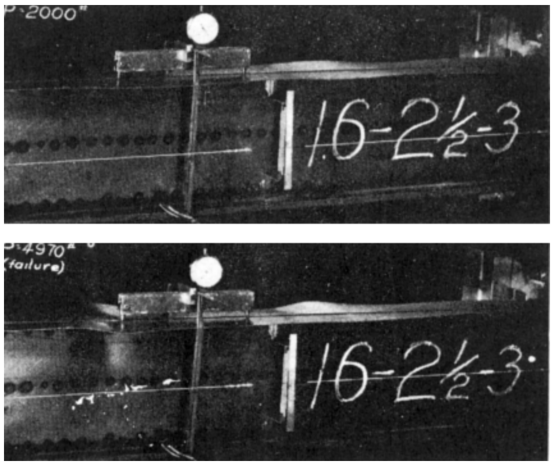

Figure 1.29 Consecutive load stages on I-beam.[1.7]

1.6.2 Torsional Rigidity

Because the torsional rigidity of open sections is proportional to t^3, cold-formed steel sections consisting of thin elements are relatively weak against torsion. Figure 1.30 shows the twist of a channel-shaped unbraced beam when it is loaded in the plane of its web. In this case, the shear center is outside the web and the applied load initiates rotation.

Since cold-formed steel sections are relatively thin and in some sections the centroid and shear center do not coincide, torsional–flexural buckling may be a critical factor for compression members. In addition, distortional buckling may govern the design for certain members used as beams or columns.

1.6.3 Stiffeners in Compression Elements

The load-carrying capacity and the buckling behavior of compression components of beams and columns can be improved considerably by the use of edge stiffeners or intermediate stiffeners. Provisions for the design of such stiffeners have been developed from previous research. However, this type of stiffener generally is not practical in hot-rolled shapes and built-up members.

1.6.4 Variable Properties of Sections Having Stiffened or Unstiffened Compression Elements

For a section having a stiffened, partially stiffened, or unstiffened compression element, the entire width of the element is fully effective when the width-to-thickness ratio of the element is small or when it is subjected to low compressive stress. However, as stress increases in the element having a relatively large width-to-thickness ratio, the portions adjacent to the supported edges are more

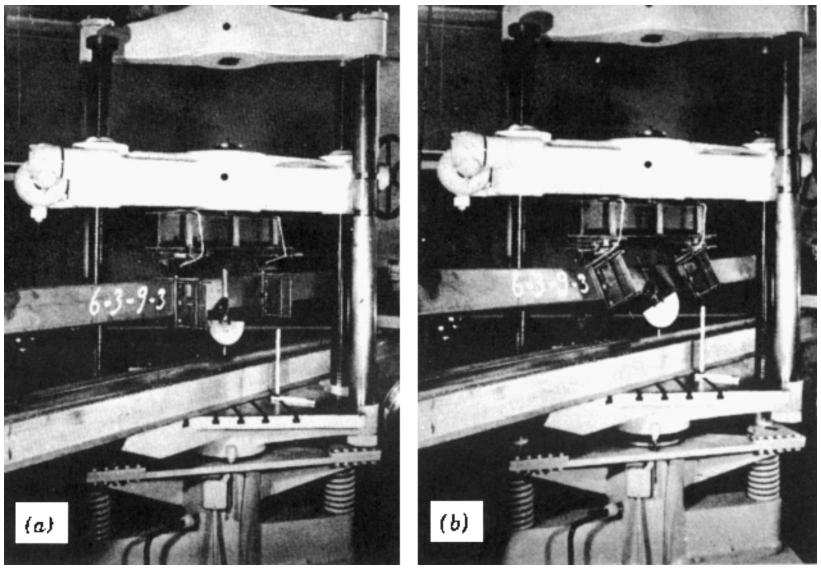

Figure 1.30 Twist of unbraced channel loaded in plane of its web[1.6]: (*a*) before loading; (*b*) near-maximum load.

structurally effective after the element buckles. As a result, the stress distribution is nonuniform in the compression element. In the design of such members the sectional properties are based on a reduced effective area.

The effective width of a compression element not only varies with the unit stress applied but also depends on its width-to-thickness ratio. For a given beam having a compression flange with a relatively large width-to-thickness ratio, the effective section modulus S_e decreases with an increase in the yield stress of steel used because the effective width of the compression flange becomes smaller when it is subjected to a higher unit stress. The strength of such a beam is therefore not directly proportional to the yield stress of the steel. The same is true for the compression members.

1.6.5 Connections

For bolted connections the thickness of connected parts is usually much thinner in cold-formed steel construction than in heavy construction. The steel sheet or strip may have a small spread between yield stress and tensile strength. These are major influences that make the behavior of the cold-formed steel bolted connection differ from that of heavy construction, particularly for bearing and tension stress. Modified design provisions have been developed in the Specification for cold-formed steel bolted connections.

In welded connections, arc welds (groove welds, arc spot welds, arc seam welds, fillet welds, and flare groove welds) are often used for connecting cold-formed steel members to each other as well as for connecting cold-formed sections to hot-rolled shapes. Arc spot welds without prepunched holes and arc seam welds are often used for connecting panels or decks to supporting beams or to each other.

In addition to bolted and welded connections, screws are often used for cold-formed steel construction. Design provisions for determining the shear and tensile strengths of screw connections are included in the current North American specification.

1.6.6 Web Crippling Strength of Beams

Web crippling is often a critical problem for cold-formed steel structural members for two reasons. First, the use of stamped or rolled-in bearing stiffeners (or stiffeners under concentrated loads) is frequently not practical in cold-formed steel construction. Second, the depth-to-thickness ratio of the webs of cold-formed steel members is usually large and generally exceeds that of hot-rolled shapes. Figure 1.31 illustrates the pattern of web crippling of an I-section.

Special design criteria for web crippling of cold-formed steel sections included in the North American Specification have been developed on the basis of extensive research.

1.6.7 Thickness Limitations and Corrosion Protection

The ranges of thickness generally used in various types of cold-formed steel structural members are described in Section 1.2. However, they should not be considered as thickness limitations.

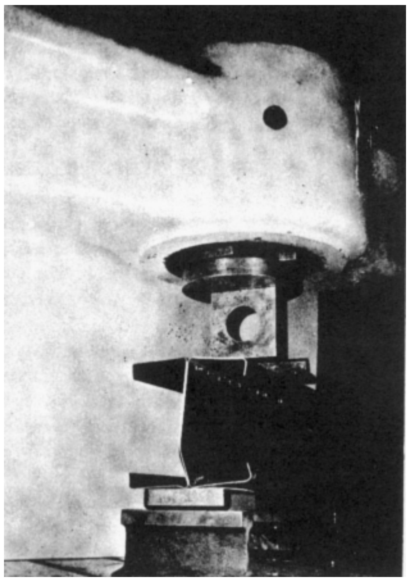

Figure 1.31 Test for web crippling strength of thin webs.[1.6]

For the design of cold-formed steel structural members the important factors are the width-to-thickness ratio of compression elements and the unit stress used; the thickness of the steel itself is not a critical factor. Members formed of relatively thin steel sheet will function satisfactorily if designed in accordance with the North American Specification.

The durability of lightweight steel construction has been studied by Cissel and Quinsey.[1.241,1.242] It was found that the durability of cold-formed steel sections is primarily dependent upon the protective treatment applied to the sheet and not necessarily upon the thickness of the sheet itself.[1.243] For galvanized cold-formed steel there is high corrosion resistance. Available data indicate that the corrosion rate of galvanized sheets in the atmosphere is practically linear; that is, for the same base-metal thickness a sheet having double the weight of coating of another sheet can be expected to last twice as long before rusting of the base metal sets in.[1.244–1.246] References 1.398 and 1.399 present a better understanding of how galvanizing provides long-term corrosion protection to steel members. It is therefore unnecessary to limit the minimum thickness for cold-formed steel sections merely for the purpose of protecting the steel from corrosion. The accepted methods of protection were discussed in Section 5 of Part III of the 1977 AISI design manual[1.159] and the minimum metallic coating requirements for framing members are specified in the AISI general provisions for cold-formed steel framing.[1.400] In addition, the LGSEA technical note outlines available corrosion-resistant materials for cold-formed steel framing members and makes recommendations for buildings at various distances from the ocean and for different exposure conditions within an individual building.[1.401] Tests of coil-coated steel panels are reported in Ref. 1.329.

1.6.8 Plastic Design

A complete plastic design method is not included in the North American specification because most cold-formed steel shapes have width-to-thickness ratios considerably in excess of the limits required by plastic design.[1.148] Such members with large width-to-thickness ratios are usually incapable of developing plastic hinges without local buckling or distortional buckling. However, since 1980 the AISI specification has included design provisions to utilize the inelastic reserve capacity of flexural members. The same requirements are retained in the North American specification. For details, see Section 4.2.2.3.

1.6.9 Linear Method for Computing Properties of Formed Sections

If the thickness of the formed section is uniform, the computation of properties of such sections can be simplified by using a linear or “midline” method. In this method the material of the section is considered to be concentrated along the centerline or midline of the steel sheet and the area elements are replaced by straight or curved “line elements.” The thickness dimension t is introduced after the linear computations have been completed. Thus the total area $A = L \times t$ and the moment of inertia of the section $I = I' \times t$, where L is the total length of all line elements and I' is the moment of inertia of the centerline of the steel sheet. The properties of typical line elements are shown in Fig. 1.32. Example 1.1 illustrates the application of the linear method.

Example 1.1 Determine the full section modulus S_x of the channel section shown in Fig. 1.33*a*. Use the linear method.

SOLUTION The midline of the cross section is shown in Fig. 1.33*b*.

1. *Flat width of flanges* (element 1):

$$L_f = 1.5 - 0.292 = 1.208 \text{ in.}$$

2. *Distance from x–x axis to centerline of flange*:

$$3.0 - \frac{0.105}{2} = 2.948 \text{ in.}$$

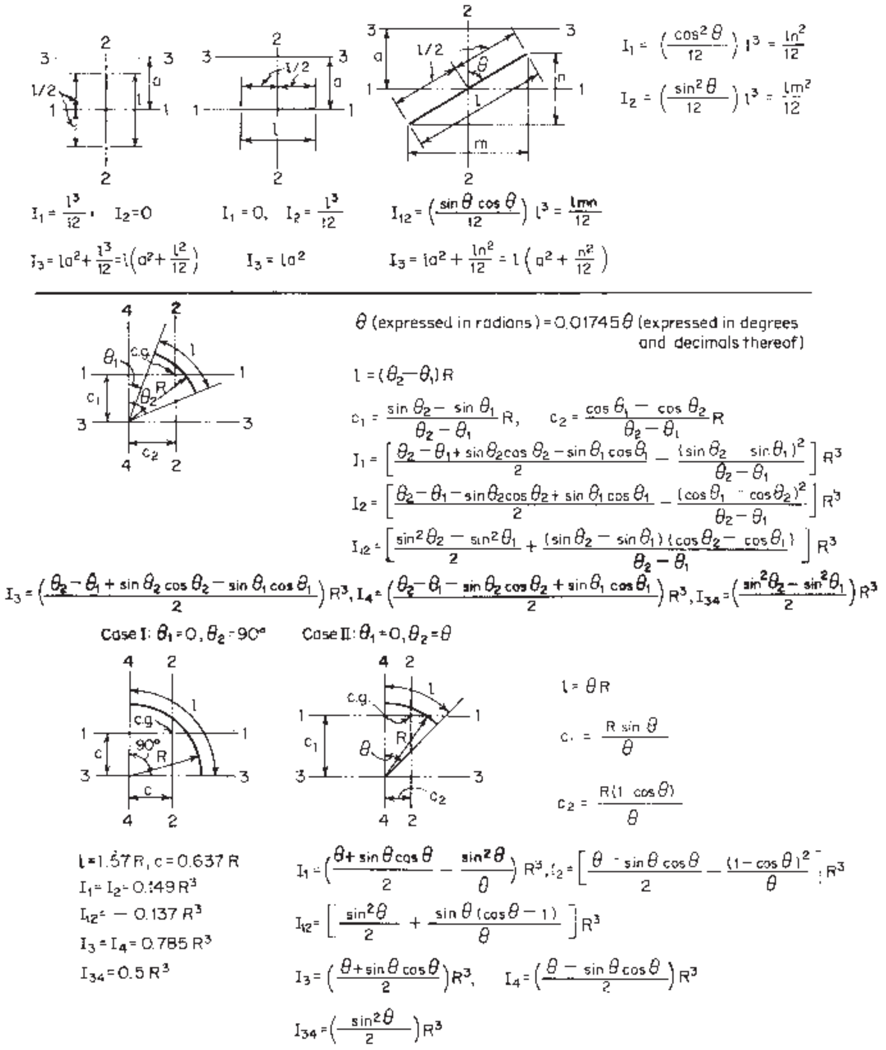

Figure 1.32 Properties of line elements.[1.159]

3. *Computation of properties of 90° corner* (element 2) (Fig. 1.33*c*):

$$R' = 0.1875 + \frac{0.105}{2} = 0.240 \text{ in.}$$

$$L_c = 1.57\ (0.240) = 0.377 \text{ in.} \quad \text{(Fig. 1.32)}$$

$$c = 0.637\ (0.240) = 0.153 \text{ in.} \quad \text{(Fig. 1.32)}$$

4. *Flat width of web* (element 3):

$$L_w = 6.0 - 2(0.292) = 5.416 \text{ in.}$$

5. *Distance from x–x axis to* center of gravity (*c.g.*) *of corner*:

$$y = \frac{5.416}{2} + 0.153 = 2.861 \text{ in.}$$

6. *Linear* I'_x, *moment of inertia of midlines of steel sheets*:

   Flanges: $2(1.208)(2.948)^2 = 21.00$

   Corners: $2(0.377)(2.861)^2 = 6.17$

   Web: $\frac{1}{12}(5.416)^3 = 13.24$

   Total: 40.41 in.^{3}

7. *Actual* I_x:

$$I_x = I'_x t = 40.41(0.105) = 4.24 \text{ in.}^4$$

8. *Section modulus*:

$$S_x = \frac{I_x}{d/2} = \frac{4.24}{3.0} = 1.41 \text{ in.}^3$$

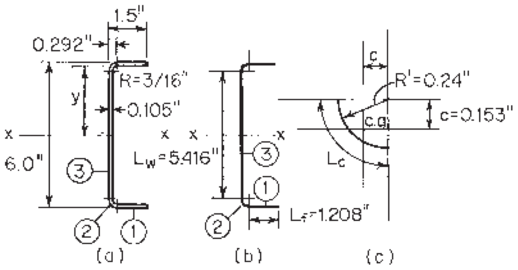

Figure 1.33 Example 1.1.

The accuracy of the linear method for computing the properties of a given section depends on the thickness of the steel sheet to be used and the configuration of the section. For the thicknesses of steel sheets generally used in cold-formed steel construction, the error in the moment of inertia determined by the linear method is usually negligible, particularly for relatively deep sections made of thin material. For example, as indicated in Table 1.3, the expected errors in the computed moment of inertia of the two arbitrarily chosen channel sections as shown in Fig. 1.34 are less than 1% if the material is $\frac{1}{4}$ in. or thinner.

Table 1.3 Expected Error in I_x

Channel Section	Thickness of Material (in.)	Expected in I_x (%)
A	0.50	3.3
	0.25	0.7
	0.10	0.1
B	0.50	0.6
	0.25	0.15
	0.10	0.02

Note: 1 in. = 25.4 mm.

For cylindrical tubes, the error in the computed moment of inertia about the axis passing through the center of the tube determined by the linear method varies with the ratio of mean diameter to wall thickness, *D/t*; the smaller the ratio, the larger the error. The expected errors in the moment of inertia are approximately 2.7 and 0.2% for *D/t* ratios of 6 and 20, respectively, if the wall thickness is $\frac{1}{4}$ in. Errors smaller than the above values are expected for materials thinner than $\frac{1}{4}$ in.

The *Direct Strength Method Design Guide*[1.383] indicates that the use of midline dimensions ignoring the corner is adequate for analysis unless the corner radius is larger than 10 times the thickness.

1.6.10 Tests for Special Cases

In Section 1.1 it was indicated that in cold-formed steel construction unusual sectional configurations can be economically produced by cold-forming operations. However, from the point of view of structural design, the analysis and design of such unusual members may be very complex and difficult. In many cases it may be found that their safe load-carrying capacity or deflection cannot be calculated on the basis of the design criteria presently included in the North American specification.[1.345] For this case the North American Specification permits their structural performance to be determined by load tests conducted by an independent testing laboratory or by a manufacturer's laboratory. It is not the intent of the North American provision, however, to substitute load tests for design calculations.

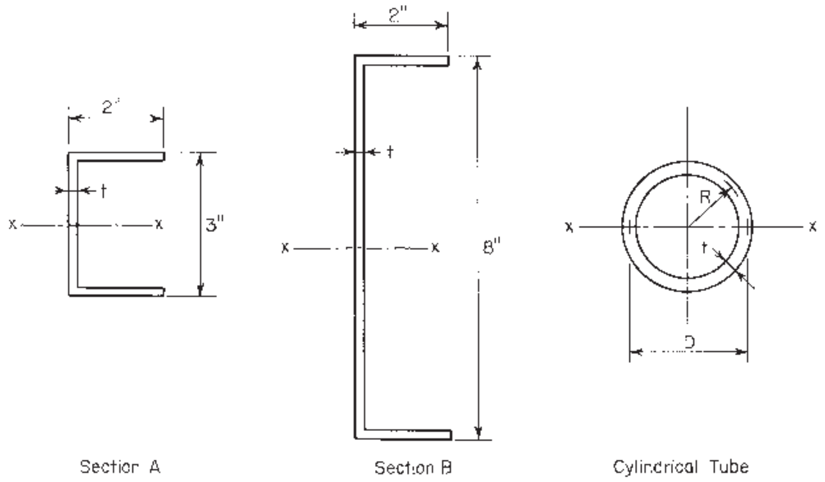

Figure 1.34 Sections used for studying the accuracy of the linear method.

A detailed discussion on the method of testing is beyond the scope of this book. However, when tests are found necessary to determine structural strength or stiffness of cold-formed sections and assemblies, Chapter F of the North American specification[1.345] and Part VI of the AISI Design Manual[1.349] should be used for the evaluation of test results and the determination of allowable load-carrying capacities. In some cases the test results may be evaluated by an experienced laboratory or consultant.

1.6.11 Cold Work of Forming

It is well known that the mechanical properties of steel are affected by cold work of forming. The North American specification permits utilizing the increase in yield stress from a cold-forming operation subjected to certain limitations. Sections 2.7 and 2.8 discuss the influence of cold work on the mechanical properties of steel and the utilization of the cold work of forming, respectively.

1.7 ECONOMIC DESIGN AND OPTIMUM PROPERTIES

The basic objective of economic design is to achieve the least expensive construction that satisfies the design requirements. One of the conditions required for the low cost of the erected structure is that the weight of the material be kept to a minimum, which is associated with the maximum structural efficiency.

It has been shown by numerous investigators that for a given loading system the maximum efficiency can be obtained when the member strengths for all the possible modes of failure are the same.

In practice, such ideal conditions may not be obtained easily because of unavoidable limitations, such as preselected shapes and specific dimensional limitations. However, it can be shown that in some cases there may be a possible mode of failure or limit state that will result in a maximum efficiency within the practical limitations.

The efficiency of the use of high-strength steel depends on the type of mode of failure. Under certain conditions, such as long columns having large slenderness ratios, the failure is usually limited by overall elastic buckling. For this case the use of high-strength steel may not result in an economic design because the performance of structural members under the above-mentioned conditions will be the same for different grades of steel. For this reason the use of high-strength steel for these cases may not be justified as far as the overall cost is concerned.

In any event the general aim should always be to utilize the full potential strength of the steel that can be used in fabrication by designing the detail outline of the section for maximum structural efficiency. Flexibility of the cold-forming process to produce an endless variety of shapes is ideal for this purpose.[1.225,1.247,1.402–1.406]