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The 1996 AISI Specification

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Summary

The first edition of the AISI specification was adopted in 1946. Thus, the new specification represents fifty years of progress in the formal structural application of cold-formed steel. The continued efforts of the Committee on Specifications and the sponsorship of the American Iron and Steel Institute have made this fifty years of progress in cold-formed steel a reality. The new specification combines ASD and LRFD provisions in a single document. This affords the design engineer the opportunity to become familiar with both methods and facilitates the use of whichever method is preferred. In addition, the new specification includes a number of new or revised provisions based on the results of continuing research.

Introduction

For over five years, there have been two AISI specifications for the design of cold-formed steel members. The specification in load and resistance factor design (LRFD) format (AISI, 1991) was introduced in 1991 as an alternative to the specification in allowable stress design (ASD) format (AISI, 1989), which was last revised in 1989. Many parts of the two specifications were similar with common equations for nominal strength. The nominal strength was divided by a safety factor for ASD design or multiplied by a resistance factor for LRFD design. After careful consideration, it was decided to combine the two specifications into a common document, the 1996 AISI Specification (AISI, 1996). This greatly simplifies the process of maintaining and updating, and makes it convenient for the design engineer to use whichever method is preferred. Also, the drafting of the specification gave an opportunity to include various new developments and to coordinate certain provisions with those of the AISC specifications. The adoption of the new specification by the AISI *Committee on Specifications for the Design of Cold-Formed Steel Structural Members* will follow after the public review period and final balloting. A comprehensive Commentary drafted by Prof. Wei-Wen Yu will accompany the specification and facilitate its application.

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Fifty Years of Progress

The introduction of a new specification affords the opportunity to reflect briefly on the history of this document. The first edition of the AISI specification was adopted in 1946 (AISI, 1946). It was based on a considerable amount of research, most of which was conducted at Cornell University under the direction of Professor George Winter beginning in 1939 (Errera, 1990). With continuing research, additional information was developed that found its way into AISI specifications in 1956, 1960, 1962, 1968, 1980, 1986, and 1991. In addition to Cornell University, significant research activities that led to improved specifications have been conducted at the University of Missouri-Rolla, Virginia Tech, University of Florida-Gainesville, University of Waterloo, University of Sydney and at other institutions. Most of this work in North America has been sponsored by AISI, with co-funding on specific projects by the Metal Building Manufacturers Association (MBMA), the Steel Deck Institute (SDI), and the Metal Lath/Steel Framing Association (ML/SFA). The specifications are developed by the AISI Committee on Specifications, a consensus group of about 40 people with balanced representation from producers, manufacturers, users, researchers, and others. It is the continued efforts of this group and the sponsorship of the American Iron and Steel Institute that has made fifty years of progress in cold-formed steel a reality.

Format of New Specification

The new specification can be used with either English or SI units. Most equations are dimensionless, but equivalent SI values have been given in parenthesis where specific English units are encountered.

Following the organization of recent editions, the specification is organized under the following six major sections:

A. General Provisions
B. Elements
C. Members
D. Structural Assemblies
E. Connections and Joints
F. Tests for Special Cases

Section A deals with several important topics including materials, loads, and the basis of design (ASD or LRFD). Special efforts have been made throughout the specification to clearly indicate any provisions that apply only to ASD, such as safety factors, or only to ASD, such as load factors and resistance factors.

Equations for effective width, Section B, are the same for ASD and LRFD. Also, equations for nominal strength in Sections B through E are generally the same for ASD and LRFD.

Section A5 gives the general equation that must be satisfied for ASD:

$$R_a = R_n/\Omega$$

where

R_a = Required design strength
R_n = Nominal strength
Ω = Safety factor

The safety factors are given in Sections B through E of the specification. For ASD design, the loads in the basic load combinations are nominal (unfactored) loads.

Section A6 gives the general equation that must be satisfied for LRFD:

$$R_u = \phi R_n$$

where

R_u = Required strength
R_n = Nominal strength
ϕ = Resistance factor

The resistance factors are given in Sections B through E of the specification. For LRFD design, the loads in the basic load combinations are factored loads.

Throughout most of the specification, the equation for nominal strength is given and the appropriate Ω factor (ASD) and ϕ factor (LRFD) is given just below. However, for clarity, the provisions for combined effects are provided in separate sections for ASD and LRFD. This includes bending and shear (C3.3), bending and web crippling (C3.5), and combined axial load and bending (C5).

New Provisions

The significant new provisions that are included in the new AISI specification are summarized in Table 1 and reviewed below.

B4.2 - This section covers the effective width of uniformly compressed elements with an edge stiffener. It is divided into three cases depending on the ratio of the width between stiffeners to the thickness, w/t, and the parameter S, where S = $1.28(E/f)^{0.5}$. The effective width of the element is determined from the equations in Section B using the plate buckling coefficient k given in this section. For Case II, S/3 < w/t < S, the following new equation is given for k:

$$k = C_2^n(k_a - k_u) + k_u$$

where

$C_2 = I_s / I_a \langle 1$
$n = 1/2$
$k_u = 0.43$
$k_a = 5.25 - 5(D/w) \le 4$ for lip stiffener
$k_a = 4.0$ for stiffener other than simple lip
I_s = Moment of inertia of stiffener about its centroidal axis
I_a = Adequate moment of inertia of stiffener, so that each component element will behave as a stiffened element (see specification)
D = Depth of stiffener to center of bend (see specification)
w = Width of flange (see specification)

The depth-to-thickness ratio, d/t, of simple lip stiffeners should be limited to 14 because deeper stiffeners may give unconservative results.

C3.1.2 - This section, which addresses the lateral buckling strength of flexural members has been clarified and improved. Equations for calculating the critical moment, M_c, that previously applied only to I- or Z-sections bent about the x axis, now applies to singly-, doubly-, and point symmetric sections. The equations are:

For $M_e \ge 2.78 M_y$ $\qquad M_c = M_y$

For $2.78 M_y \rangle M_e \rangle 0.56 M_y$ $\qquad M_c = \frac{10}{9} M_y \left(1 - \frac{10 M_y}{36 M_e}\right)$

For $M_e \le 0.56 M_y$ $\qquad M_c = M_e$

where

M_y = Moment causing initial yield in compression
M_e = Elastic critical moment

Also, the following new equation for the bending coefficient C_b appears:

$$C_b = \frac{12.5 M_{max}}{12.5 M_{max} + 3M_1 + 4M_2 + 3M_3}$$

where

M_{max} =absolute value of maximum moment in unbraced segment
M_1 =absolute value of moment at quarter point of unbraced segment
M_2 =absolute value of moment at centerline of unbraced segment
M_3 =absolute value of moment at three-quarter point of unbraced segment

C_b is used to modify the elastic critical moment equation for a uniform moment to one that applies for moment gradients. The equation is derived from Kirby and Nethercott (1979) and agrees with that used in the AISC LRFD specification (AISC, 1993). Compared to the previous equation, it gives more accurate results when the moment diagram is non-linear.

C3.4 - This section, which treats the web crippling strength of flexural members, has been modified to include a special provision for calculating the end reaction of a Z-section bolted to the end support. Based on recent tests (Bhakta et al, 1992; Cain et al, 1995), the web crippling capacity is increased by 30 percent if certain additional criteria are met. Specifically, a depth-to-thickness ratio of h/t ≤ 150, a radius-to-thickness ratio R/t ≤ 4, a section thickness t ≥ 0.06 in. (1.5 mm), and a support member thickness ≥ 3/16 in. (4.8 mm).

C3.5 - This section addresses the strength of flexural members under combined bending and web crippling. Based on recent research (LaBoube et al, 1994), the following interaction equations have been added for nested Z-sections over a support:

$$\frac{M}{M_{no}}+\frac{P}{P_n}\leq 1.00 \quad \text{(ASD)}$$

$$\frac{M}{M_{no}}+\frac{P}{P_n}\leq 1.68\phi \quad \text{(LRFD)}$$

The equation applies for a bearing length-to-thickness ratio N/t ≤ 140, h/t ≤ 150, R/t ≤ 5.5, and F_y ≤ 70 ksi (483 MPa). Also certain connection requirements must be satisfied and the ratio of the thicker to thinner section must not exceed 1.3.

C4 - In the section on concentrically loaded compression members, the column equations have been revised to agree with those in the AISC LRFD specification (AISC, 1993). The new equations are included as follows:

The nominal axial strength, P_n, is calculated as

$$P_n = A_e F_n$$
$$\Omega_c = 1.80 \text{(ASD)}$$
$$\phi_c = 0.85 \text{ (LRFD)}$$

where A_e is the effective area at the stress F_n, which is determined from

$$F_n = \left(0.658^{\lambda_c^2}\right)F_y \quad \text{for } \lambda_c \le 1.5$$

$$F_n = \left[\frac{0.877}{\lambda_c^2}\right]F_y \quad \text{for } \lambda_c \rangle 1.5$$

where $\lambda_c = \sqrt{\frac{F_y}{F_e}}$

F_y = Yield point

F_e = Least of elastic flexural, torsional, and torsional-flexural buckling stresses.

The new column equations specifically include the effect of out-of-straightness. In contrast to the previous equations, the format enables the use of a single, constant safety factor. In a study that reviewed the results of 299 tests, Pekoz and Sumer (1992) showed that the new equations were more accurate than the previous ones.

The revisions to Section C4 also eliminated an additional equation for C- and Z-sections and single-angle sections with unstiffened flanges, which determined the strength based on the local buckling stress of the unstiffened element and the full cross-section area. Studies by Rasmussen (1994) and by Rasmussen and Hancock (1992) showed that the additional equation was unnecessary and gave excessively conservative results.

C5 - In the section on combined axial load and bending, equations were added to check combined axial tension load and bending.

D3.2.2 - This section provides for lateral bracing, of channel- and Z-section beams, with neither flange connected to sheathing. Under the previous provisions, bracing was required at quarter-points and at center of a loaded length if concentrated over a specified length. However, research by Ellifritt et al (1992) showed that the specification equations predict loads that are conservative for the case when one intermediate brace is used, but may be unconservative where more than one lateral brace is used. This is because the restraining nature of the braces may change the failure mode from lateral-torsional buckling to distortional buckling at the brace point. Although not a requirement, it is suggested that, minimally, a mid-span brace be used for channel- and Z-sections, because it may reduce horizontal deflection and rotation at service load by as much as 80 percent.

D4 - The section on wall studs and wall stud assemblies was expanded to include provisions for calculating the effective area of studs with non-circular web perforations. The provisions permit the effective area to be calculated in accordance with Section B, assuming the web to consist of two unstiffened elements, one on each side of the perforation. The method was verified in tests by Miller and Pekoz (1994). Based on those tests, certain limitations apply regarding perforation size and spacing, and web depth-to-thickness ratio. Alternatively, the effective area can still be determined by stub-column tests.

The table for determining the shear rigidity of sheathing was also revised. The values are now independent of the stud spacing.

D5 - This section on steel diaphragm construction (floor, roof or wall) was not included in the previous LRFD specification, and is revised from that in the ASD specification. It provides a table of safety factors for ASD and resistance factors for LRFD to be applied to the in-plane nominal shear strength established by calculation or test. Safety factors range from 2.0 to 3.0 and corresponding ϕ factors range from 0.65 to 0.50. Safety factors are about 20 percent higher for welded connections than for mechanical connections, because their strength is more difficult to predict. Also, safety factors for diaphragms subjected to earthquake loads are about 25 percent higher than for those subjected to wind loads because the ductility demand is higher.

E2.2.2 - New expressions for the strength of arc spot welds in tension are presented in this section., based on research by LaBoube and Yu (1993). The nominal tensile strength P_n is taken as the smaller of that limited by weld tensile failure and that limited by sheet tearing around the weld perimeter.

The expression based on weld failure is

$$P_n = 0.785 d_e^2 F_{xx}$$

where

d_e = Effective diameter of fused area

F_{xx} = Strength level designation in AWS electrode classification

Two expressions are given based on sheet tearing:

For $F_u / E \langle 0.00187$ $P_n = [6.59 - 3150(F_u / E)] t d_a F_u \le 1.46 t d_a F_u$

For $F_u / E \ge 0.00187$ $P_n = 0.70 t d_a F_u$

where

F_u = Tensile strength of sheet
E = Modulus of elasticity
t = Total thickness of steel sheets
d_a = Average diameter of arc spot weld

For eccentrically loaded arc spot welds, the nominal strength is reduced by 50 percent. At side lap connections in a deck, the strength is reduced by 30 percent.

E4 - This new section addresses the strength of screw connections in both shear and tension. It is based on a review by Pekoz (1990) of over 3500 tests worldwide. Because of the wide scope of application, the safety factor ($\Omega = 3.0$, ASD; $\phi = 0.5$ LRFD) is somewhat higher than typically used elsewhere in the specification.

The nominal shear strength P_{ns} is based on tilting and bearing failure modes. The minimum shear strength of the screw is specified as $1.25P_{ns}$ to preclude screw failure. The nominal shear strength is as follows:

For $t_2 / t_1 \le 1.0$, P_{ns} is the smallest of

$$P_{ns} = 4.2 (t_2^3 d)^{1/2} F_{u2}$$

$$P_{ns} = 2.7 t_1 d F_{u1}$$

$$P_{ns} = 2.7 t_2 d F_{u2}$$

For $t_2 / t_1 \ge 2.5$, P_{ns} is the smaller of

$$P_{ns} = 2.7 t_1 d F_{u1}$$

$$P_{ns} = 2.7 t_2 d F_{u2}$$

where

t_1 = thickness of sheet in contact with screw head
t_2 = Thickness of screw head not in contact with screw head
F_{u1} = Tensile strength of sheet in contact with screw head
F_{u2} = Tensile strength of sheet not in contact with screw head
d = nominal screw diameter

For $1.0 \langle t_2 / t_1 \langle 2.5$, the value of P_{ns} is determined by linear interpolation.

The nominal tension strength includes a check on pull-out strength (P_{not}, screw pulls out of sheet) and pull-over strength (P_{nov}, sheet pulls over head of screw or over washer if present). The tensile strength of the screw is specified as 1.25 times the lesser of these to preclude screw failure. The nominal tensile strength is the lesser of the following:

$$P_{not} = 0.85 t_c d F_{u2}$$

where t_c = lesser of depth of penetration and thickness t_2.

$$P_{nov} = 0.85 t_1 d_w F_{u1}$$

where d_w = larger of screw head diameter and washer diameter (max. = 1/2 in. or 13 mm).

Conclusions

The first edition of the AISI specification was adopted in 1946. Thus, the new combined specification represents fifty years of progress in the formal structural application of cold-formed steel. The continued efforts of the Committee on Specifications and the sponsorship of the American Iron and Steel Institute have made this fifty years of progress in cold-formed steel a reality.

Due to the foresight of those that developed the original documents, it was feasible to combine ASD and LRFD provisions in a single specification. This greatly simplifies the process of maintaining and updating the specification. Also, it affords the design engineer the opportunity to become familiar with both methods and facilitates the use of whichever method is preferred.

The new specification includes various new or revised provisions based on continuing research. These provisions affect a number of items including the design of edge stiffeners, lateral buckling strength, web crippling strength, column strength, wall stud compression strength, diaphragm strength, arc spot weld tension strength, and the strength of screw connections. The new column equations and the new equation for C_b, the moment gradient factor for the elastic critical moment, were adopted to agree with those of the AISC LRFD specification and to help unify design methods.

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Table 1

Significant New Provisions Included in the AISI Specification

B4.2- Effective Widths, Uniformly Compressed Elements with an Edge Stiffener

New equation for determining k for the effective width determination.

C3.1.2 Flexural Members, Lateral Buckling Strength

Equation for calculating the critical moment that previously applied only to I- or Z-sections bent about the x axis, now applies to singly-, doubly-, and point symmetric sections.

New equation for the bending coefficient C_b.

C3.4 Flexural Members, Web Crippling Strength

Web crippling capacity increased by 30 percent for the end reaction of a Z-section bolted to the end support and meeting other criteria.

C3.5 Flexural Members, Strength for Combined Bending and Web Crippling

Specific provisions have been added for nested Z-sections over a support.

C4 Concentrically Loaded Compression Members

New column equations. Applies also to cylindrical tubular members (C6.2).

Eliminated additional equation for C- and Z-sections and single-angle sections with unstiffened flanges.

C5 Combined Axial Load and Bending

New provisions for combined axial tension load and bending.

(Cont'd.)

Table 1 (Cont'd.)

Significant New Provisions Included in the AISI Specification

D3.2.2 Lateral Bracing, Channel- and Z-Section Beams, Neither Flange Connected to Sheathing

Eliminated provision for bracing at quarter-points and at center of loaded length.

D4 Wall Studs and Wall Stud Assemblies

New provisions for calculating the effective area of studs with non-circular web perforations.
Revised table for determining shear rigidity of sheathing.

D5 Floor, Roof or Wall Steel Diaphragm Construction

New table of safety factors (ASD) and resistance factors (LRFD) for diaphragms.

E2.2.2 Arc Spot Welds, Tension

New provisions for arc spot welds in tension.

E4 Screw Connections

New section on screw connections, including shear and tension.