
Load and Resistance Factor Design Specification for Steel Hollow Structural Sections

November 10, 2000

Supersedes *Specification for the Design of Steel Hollow Structural
Sections* dated
April 15, 1997 and all previous versions.

Prepared by the
American Institute of Steel Construction, Inc.
under the direction of the
AISC Committee on Specifications and approved by
the AISC Board of Directors.



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PREFACE

The AISC *Load and Resistance Factor Design (LRFD) Specification for Structural Steel Buildings* is intended to cover the common design criteria in routine office practice. Accordingly, it is not feasible to also cover the many special and unique problems encountered within the full range of structural design practice. This AISC *Load and Resistance Factor Design Specification for Steel Hollow Structural Sections* is a separate document that addresses one such topic: the design and construction of building systems that utilize steel hollow structural sections (HSS). A list of Symbols and a non-mandatory Commentary with background information are provided.

The AISC Committee on Specifications, Task Committee 13—Hollow Structural Sections is responsible for its ongoing development. Additionally, the AISC Committee on Specifications has enhanced these provisions through careful scrutiny, discussion, suggestion for improvements, and endorsement.

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CROSS REFERENCE TO THE AISC LRFD SPECIFICATION

This table provides a cross reference from Sections in this Specification to the relevant Sections and related Appendices in the *LRFD Specification for Structural Steel Buildings* dated December 27, 1999.

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SYMBOLS

The section number in the right hand column refers to the section where the symbol is first used.

<u>Symbol</u>	<u>Definition</u>	<u>Section</u>
A	Area used to calculate A_e , in. ² (mm ²)	2.1
A_g	Gross area of cross-section, in. ² (mm ²)	2.1
	Chord gross area, in. ² (mm ²)	9.4
A_e	Effective net area for tension member, in. ² (mm ²)	2.1
A_n	Net area, in. ² (mm ²)	2.1
A_w	Web area, in. ² (mm ²)	5.3
B	Overall width of rectangular HSS, in. (mm)	1.3
B_b	Overall width of rectangular HSS branch member in a truss connection, in. (mm)	9.2
C	HSS torsional constant	6.
D	Outside diameter of round HSS, in. (mm)	2.1
D_b	Outside diameter of round HSS branch member in a truss connection, in. (mm)	9.4
E	Modulus of elasticity, ksi (MPa)	2.2.1
F_{cr}	Critical stress for column buckling, ksi (MPa)	4.2
F_n	Nominal stress for rectangular HSS shear resistance, ksi (MPa)	5.2
F_u	Specified minimum tensile strength of the HSS, ksi (MPa)	3.1
F_y	Specified minimum yield strength of the HSS, ksi (MPa)	2.2.1
F_{y1}	Specified minimum yield strength of plate or connecting element that is welded to an HSS, ksi (MPa)	8.1
F_{yb}	Specified minimum yield strength of HSS branch member in a truss connection, ksi (MPa)	9.4
H	Overall height of rectangular HSS, in. (mm)	1.3
H_b	Overall height of rectangular HSS branch member in a truss connection, in. (mm)	9.2
K	Compression member effective length factor	4.1
L_b	Unbraced length, in. (mm)	5.1
L_{pd}	Maximum unbraced length for plastic moment M_p in plastic analysis, in. (mm)	5.3
M_n	Nominal flexural strength, kip-in. (N-mm)	5.1
M_p	Plastic moment of section, kip-in. (N-mm)	5.1
M_r	Yield moment of section, kip-in. (N-mm)	5.1
M_u	Required flexural strength, kip-in. (N-mm)	7.1
M_{ur}	Resultant required flexural strength for round HSS, kip-in. (N-mm)	7.1
N	Bearing length of concentrated load along length of HSS, in. (mm)	8.1
P_n	Nominal axial strength, kips (N)	2.2.1
P_u	Required axial strength, kips (N)	4.2
P_y	Axial yield load, kips (N)	2.2.1
Q	Effective area factor	4.2



Q_f	Connection resistance reduction factor for compression in HSS, parameter used for truss connections	9.4
Q_q	Parameter used for truss connections	9.4
Q_β	Parameter used for truss connections	9.4
R_f	Reduction factor for wind forces on exposed HSS	1.3
R_n	Nominal resistance of connections to HSS, kips (N)	8.
S	Elastic section modulus, in. ³ (mm ³)	5.1
S_{eff}	Effective elastic section modulus for thin-walled rectangular HSS, in. ³ (mm ³)	5.1
T_n	Nominal torsional strength, kips (N)	6.1
T_u	Required torsional strength, kips (N)	7.2
U	Shear lag factor, parameter used for truss connections	2.1
V_n	Nominal shear strength, kips (N)	5.2
V_u	Required shear strength, kips (N)	7.2
Z	Plastic section modulus, in. ³ (mm ³)	5.1
a	Length of essentially constant shear in a beam, in. (mm)	5.2
b	Flat width of rectangular HSS flange or side, which is permitted to be taken as $B - 3t$, in. (mm)	2.2.1
b_1	Width of plate or connecting element that is welded to an HSS, in. (mm)	8.1
b_{eoi}	Parameter used for truss connections	9.4
b_{gap}	Parameter used for truss connections	9.4
c	Constant for bending in rectangular HSS branches of truss connections . . .	9.4
d	Bolt diameter, in. (mm)	9.1
f	Stress, ksi (MPa)	4.2
g	Gap between branch members in a gapped K-connection, in. (mm)	9.4
h	Flat width of rectangular HSS web or side, which is permitted to be taken as $H - 3t$, in. (mm)	2.2.1
k	Distance from point of application of concentrated force to critical section of HSS, in. (mm)	8.1
l	Member length, in. (mm)	2.3
l	Connection length, in. (mm)	2.1
r	Radius of gyration, in. (mm)	2.3
r_y	Radius of gyration about the y-axis, in. (mm)	5.1
t	Design HSS wall thickness as given in Section 1.2, in. (mm)	2.2.1
t_1	Thickness of plate or connecting element that is welded to an HSS, in. (mm)	8.1
t_b	Thickness of branch member in an HSS truss connection, in. (mm)	9.4
$\bar{x}$	Eccentricity for shear lag, in. (mm)	2.1
α	Parameter used for truss connections	9.4
β	Parameter used for truss connections	9.4
β_{eff}	Parameter used for truss connections	9.4
β_{eop}	Parameter used for truss connections	9.4
β_{gap}	Parameter used for truss connections	9.4
γ	Parameter used for truss connections	9.4
ϕ	Resistance factor	
η	Parameter used for truss connections	
λ	Wall slenderness	

λ_c Column slenderness 4.2

λ_p Maximum wall slenderness for compact section 2.2.1

λ_r Maximum wall slenderness for non-compact section 2.2.1

ζ Parameter used for truss connections 9.4



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Load and Resistance Factor Design Specification for Steel Hollow Structural Sections

November 10, 2000

1. GENERAL PROVISIONS

1.1. Scope

This Specification is intended for the design of round and rectangular hollow structural sections (HSS) that are used as structural members in buildings and for the design of connections to HSS. HSS are: (1) prismatic structural shapes; and, (2) products of a pipe or tubing mill that meet the geometric tolerances, tensile requirements, and chemical requirements of a standard specification. Rectangular HSS include square and rectangular cross-sections that have rounded corners within the tolerances of an appropriate product specification. Only unstiffened non-composite HSS in non-fatigue applications are considered in this Specification.

This Specification includes the list of symbols.

This Specification is based on the *AISC Load and Resistance Factor Design Specification for Structural Steel Buildings* (AISC, 1999), hereinafter referred to as the LRFD Specification. In some cases, criteria taken from the LRFD Specification have been modified to appear in non-dimensional form and to apply directly to rectangular HSS, which have two webs. For situations that are not covered in this Specification, the criteria in the LRFD Specification shall apply. In seismic applications, HSS shall be designed to meet the requirements of the *AISC Seismic Provisions for Structural Steel Buildings* (AISC, 1997) and the *Seismic Provisions Supplement No. 2* (AISC, 2000).

1.2. Material

1. Structural Steel

HSS material that meets the requirements in one of the following ASTM specifications is approved for use under this Specification:

Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc Coated, Welded and Seamless, ASTM A53/A53M-99b Gr. B

Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes, ASTM A500-99

Standard Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing, ASTM A501-99

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Standard Specification for Hot-Formed Welded and Seamless High-Strength Low-Alloy Structural Tubing, ASTM A618-99
 Standard Specification for Cold-Formed Welded and Seamless High-Strength, Low-Alloy Structural Tubing with Improved Atmospheric Corrosion Resistance, ASTM A847-99a

Certified mill test reports or certified reports of tests made by the fabricator or a qualified testing laboratory that meet the requirements in ASTM A370, Test Methods and Definitions for Mechanical Testing of Steel Products, and the governing specification shall constitute sufficient evidence of conformity with one of the above ASTM standards. If requested, the fabricator shall provide an affidavit stating that the structural steel furnished meets the requirements of the grade specified.

2. Design Wall Thickness

The design wall thickness t shall be used in calculations involving the HSS wall thickness. When the design wall thickness is not known, it is permitted to be taken as 0.93 times the nominal wall thickness.

1.3. Loads and Load Combinations

The nominal loads and factored load combinations shall be as stipulated by the applicable code under which the structure is designed or dictated by the condition involved. In the absence of a code, the loads and factored load combinations, including impact and crane loads, shall be those stipulated in ASCE 7. For design purposes, the loads stipulated by the applicable code or ASCE 7 shall be taken as nominal loads.

If permitted by the applicable building code, wind forces on the projected areas of exposed HSS are permitted to be reduced by the factor R_f from the forces on frameworks with similar configurations but using sections or shapes with flat elements. R_f shall be taken as follows:

- (a) For round HSS, $R_f = 2/3$.
- (b) For rectangular HSS with outside corner radii that are greater than or equal to 0.05 times the width B and wind force acting on the short side (B), $R_f = 0.4 + 0.6 B/H \leq 2/3$, where H is the depth of the HSS. For rectangular HSS under other conditions, $R_f = 1.0$.

2. DESIGN REQUIREMENTS

2.1. Effective Area of Tension Members

The effective area A_e of tension members shall be determined as follows:

$$A_e = AU \quad (2.1-1)$$

- (a) For a welded connection that is continuous around the perimeter, $A = A_g$, where A_g is the gross area and $U = 1$.
- (b) For connections with concentric gusset plates and slotted HSS, $A = A_n$, where the net area A_n at the end of the gusset plate is the gross area minus the product of the thickness and total width of material that is removed to form the slots and

$$U = 1 - (\bar{x}/l) \leq 0.9$$

In the above equation, $\bar{x}$ is the perpendicular distance from the weld to the centroid of the cross-sectional area that is tributary to the weld.

For round HSS with a single concentric gusset plate

$$\bar{x} = \frac{D}{\pi} \quad (2.1-3)$$

For rectangular HSS with a single concentric gusset plate

$$\bar{x} = \frac{B^2 + 2BH}{4(B + H)} \quad (2.1-4)$$

- (c) For connections with rectangular HSS and a pair of side gusset plates, $A = A_g$, where A_g is the gross area and U shall be calculated using Equation 2.1-2 with

$$\bar{x} = \frac{B^2}{4(B + H)} \quad (2.1-5)$$

where

l = length of the connection in the direction of loading, in. (mm)

D = outside diameter of round HSS, in. (mm)

B = overall width of rectangular HSS, in. (mm)

H = overall height of rectangular HSS, in. (mm)

Larger values of U are permitted to be used in the foregoing cases when justified by tests or other rational criteria. For other end-connection configurations, U shall be determined by tests or other rational criteria.

2.2. Local Buckling

1. Classification of Steel Sections

HSS are classified for local buckling of the wall in compression as compact, noncompact, or slender-element cross-sections according to the limiting wall slenderness ratios λ_p and λ_r in Table 2.2-1. For an HSS to qualify as compact, the wall slenderness ratio λ must be less than or equal to λ_p . If λ exceeds λ_p but is less than or equal to λ_r , the HSS is noncompact. If λ exceeds λ_r , the HSS is a slender-element cross-section. The wall slenderness ratio λ shall be calculated as follows:

- For round HSS, $\lambda = D/t$, where D is the outside diameter and t is the wall thickness. This Specification is applicable only to round HSS with λ less than or equal to $0.448E/F_y$, where E is the modulus of elasticity and F_y is the specified minimum yield stress.
- For flanges of rectangular HSS, $\lambda = b/t$, where b is the clear distance between webs less the inside corner radius at each web and t is the wall thickness. If the corner radius is not known, b is permitted to be taken as the overall flange width B minus three times the wall thickness t .
- For webs of rectangular HSS, $\lambda = h/t$, where h is the clear distance between flanges less the inside corner radius at each flange and t is the wall thickness. If the corner radius is not known, h is permitted to be taken as the overall web depth H minus three times the wall thickness t .

2. Design by Plastic Analysis

Design by plastic analysis is permitted when λ is less than or equal to λ_p and plastic analysis in Table 2.2-1.

TABLE 2.2-1 Limiting Wall Slenderness for Compression Elements			
Element	Wall Slenderness Ratio, λ	Limiting Wall Slenderness	
		λ_p (compact)	λ_r (noncompact)
Round HSS for axial compression for flexure for plastic analysis	D/t [a]	n.a. $0.0714 E/F_y$ $0.0448 E/F_y$	$0.114 E/F_y$ $0.309 E/F_y$ n.a.
Rectangular HSS wall for uniform compression for plastic analysis	b/t or h/t	$1.12\sqrt{E/F_y}$ $0.939\sqrt{E/F_y}$	$1.40\sqrt{E/F_y}$ n.a.
Rectangular HSS wall as a web in flexural compression	h/t	$3.76\sqrt{E/F_y}$	$5.70\sqrt{E/F_y}$
Rectangular HSS wall as a web in combined flexure and axial compression	h/t	[b]	$5.70\sqrt{E/F_y} \left(1 - \frac{0.74 P_u}{\phi_b P_y}\right)$
[a] D/t must be less than or equal to $0.448 E/F_y$ [b] For $P_u/\phi_b P_y \leq 0.125$ $3.76\sqrt{E/F_y} \left(1 - \frac{2.75 P_u}{\phi_b P_y}\right)$ For $P_u/\phi_b P_y > 0.125$ $1.12\sqrt{E/F_y} \left(2.33 - \frac{P_u}{\phi_b P_y}\right) \geq 1.49\sqrt{E/F_y}$			

3. Design in Seismic Applications

In seismic applications, λ shall also meet the requirements in the AISC *Seismic Provisions for Structural Steel Buildings* (AISC, 1997) and the *Seismic Provisions Supplement No. 2* (AISC, 2000).

2.3. Limiting Slenderness Ratios

For compression members, the slenderness ratio Kl/r preferably should not exceed 200.

For tension members, the slenderness ratio l/r preferably should not exceed 300. Members that are primarily tension members but that are subject to some compression under other load conditions need not satisfy the compression slenderness limit.

For bracing members in seismic applications, l/r shall meet the requirements in AISC *Seismic Provisions for Structural Steel Buildings* (AISC, 1997) and the *Seismic Provisions Supplement No. 2* (AISC, 2000).

3. TENSION MEMBERS

3.1. Design Tensile Strength

The design tensile strength $\phi_t P_n$ shall be the lower value obtained from the limit states of yielding in the gross section and fracture in the net section.

(a) For yielding on the gross area:

$$\begin{aligned}\phi_t &= 0.9 \\ P_n &= F_y A_g\end{aligned}\quad (3.1-1)$$

(b) For rupture on the net effective area:

$$\begin{aligned}\phi_t &= 0.75 \\ P_n &= F_u A_e\end{aligned}\quad (3.1-2)$$

where

A_e = effective net area, in.² (mm²)

A_g = gross area of HSS, in.² (mm²)

F_y = specified minimum yield strength, ksi (MPa)

F_u = specified minimum tensile strength, ksi (MPa)

P_n = nominal axial strength, ksi (MPa)

4. COLUMNS AND OTHER COMPRESSION MEMBERS

4.1. Effective Length and Slenderness Limitations

1. Effective Length

The effective length factor K for compression members shall be taken as follows or as determined by rational analysis:

(a) In trusses that are made with HSS branch (web) members that are welded around their full perimeter to continuous HSS chord members, the effective length factor K that is used to modify the length between panel points for in-plane buckling, or between locations of lateral bracing for out-of-plane buckling, shall be not less than:

$$\begin{aligned}K &= 0.75 \text{ for branch members} \\ K &= 0.9 \text{ for chord members}\end{aligned}$$

(b) In trusses that are made with HSS branch members that do not meet the requirements in Section 4.1.1(a) or with non-HSS branch members connected to continuous HSS chord members, the effective length factor K that is used to modify the length between panel points for in-plane buckling shall be not less than:

$$\begin{aligned}K &= 1.0 \text{ for branch members} \\ K &= 0.9 \text{ for chord members}\end{aligned}$$

(c) In frames for which lateral stability is provided by diagonal bracing, shear walls or equivalent means, K shall be taken as unity, unless a lesser value can be justified by rational analysis.

(d) In frames for which lateral stability is dependent upon the flexural stiffness of rigidly connected beams and columns, K shall be determined by rational analysis.

2. Design by Plastic Analysis

Design by plastic analysis is permitted if the column slenderness parameter λ_c is less than or equal to $1.5K$ and the axial force in columns of unbraced frames due to gravity loads plus factored lateral loads does not exceed ϕ_c times $0.75F_y A_g$.

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4.2. Design Compressive Strength

The design strength for flexural buckling of compression members is $\phi_c P_n$.

$$\begin{aligned}\phi_c &= 0.85 \\ P_n &= F_{cr} A_g\end{aligned}\quad (4.2-1)$$

F_{cr} shall be determined as follows:

(a) For $\lambda_c \sqrt{Q} \leq 1.5$,

$$F_{cr} = Q(0.658^{Q\lambda_c^2}) F_y \quad (4.2-2)$$

(b) For $\lambda_c \sqrt{Q} > 1.5$,

$$F_{cr} = \left[\frac{0.877}{\lambda_c^2} \right] F_y \quad (4.2-3)$$

where

$$\lambda_c = \frac{Kl}{r\pi} \sqrt{\frac{F_y}{E}} \quad (4.2-4)$$

Q shall be determined as follows:

(a) For $\lambda \leq \lambda_r$ in Section 2.2, $Q = 1$

(b) For $\lambda > \lambda_r$ in Section 2.2,

(i) For round HSS with $\lambda < 0.448E/F_y$,

$$Q = \frac{0.0379E}{F_y(D/t)} + \frac{2}{3} \quad (4.2-5)$$

(ii) For rectangular HSS,

$$Q = \frac{\text{effective area}}{A_g} \quad (4.2-6)$$

where the effective area is equal to the summation of the effective areas of the sides using

$$b_e = 1.91t \sqrt{\frac{E}{f}} \left[1 - \frac{0.381}{(b/t)} \sqrt{\frac{E}{f}} \right] \leq b \quad (4.2-7)$$

with $f = P_u/A_g$

5. BEAMS AND OTHER FLEXURAL MEMBERS

5.1. Design Flexural Strength

The design flexural strength $\phi_b M_n$ shall be determined as follows:

$$\phi_b = 0.90$$

(a) For round HSS, for $\lambda \leq \lambda_p$ in Section 2.2,

$$M_n = M_p = F_y Z \quad (5.1-1)$$

(i) For $\lambda_p < \lambda \leq \lambda_r$,

$$M_n = \left(\frac{0.0207 E}{D/t} \frac{F_y}{F_y} + 1 \right) F_y S_x \quad (5.1-2)$$

(ii) For $\lambda_r < \lambda \leq 0.448E/F_y$,

$$M_n = \frac{0.330E}{D/t} S \quad (5.1-3)$$

(b) For rectangular HSS, for $\lambda \leq \lambda_p$ in Section 2.2,

$$M_n = M_p = F_y Z \quad (5.1-4)$$

(i) For $\lambda_p < \lambda \leq \lambda_r$,

$$M_n = \left[M_p - (M_p - M_r) \left(\frac{\lambda - \lambda_p}{\lambda_r - \lambda_p} \right) \right] \quad (5.1-5)$$

where

$$M_r = F_y S$$

(ii) For $\lambda > \lambda_r$,

$$M_n = F_y S_{eff} \quad (5.1-6)$$

where S_{eff} is the effective section modulus with the effective width of the compression flange taken as

$$b_e = 1.91t \sqrt{\frac{E}{F_y}} \left[1 - \frac{0.381}{(b/t)} \sqrt{\frac{E}{F_y}} \right] \leq b \quad (5.1-7)$$

L_b is not limited for HSS structures designed by elastic analysis.

5.2. Design Shear Strength

The design shear strength of unstiffened HSS $\phi_v V_n$ shall be determined as follows:

$$\phi_v = 0.9$$

(a) For round HSS,

$$V_n = F_{cr} A_g / 2 \quad (5.2-1)$$

where F_{cr} shall be the larger of

$$\frac{1.60E}{\sqrt{a/D}(D/t)^{5/4}} \quad \text{and} \quad \frac{0.78E}{(D/t)^{3/2}} \quad (5.2-2)$$

but shall not exceed $0.6F_y$ and a is the distance from maximum to zero shear force.

(b) For rectangular HSS,

$$V_n = F_n A_w \quad (5.2-3)$$

where

$$A_w = 2Ht \quad (5.2-4)$$

F_n shall be determined as follows:

(i) For $h/t \leq 2.45\sqrt{E/F_y}$,

$$F_n = 0.6F_y$$