15 STEEL DESIGN AND ANALYSIS[1]

Nomenclature

a	stiffener spacing	in
A	area	in^2
b	width	in
c	distance to extreme fiber	in
C	coefficient	–
C_c	critical slenderness ratio	–
d	depth or diameter	in
D	outside diameter	in
e	eccentricity	in
E	modulus of elasticity	psi
f	actual stress	ksi
F	strength or allowable stress	ksi
g	gage spacing	in
G	end condition coefficient	–
H	horizontal force	kips
I	area moment of inertia	in^4
J	polar moment of inertia	in^4
k	flange to web toe fillet distance, or spring constant	in, or lbf/in
K	end restraint coefficient	–
l	length between supports	in
L	length or distance	in
M	moment	ft-kips
n	modular ratio	–
N	bearing length	in
P	force	lbf
r	radius of gyration, radius, or distance	in
R_w	weld strength (resistance)	kips/in
s	pitch spacing	in
S	section modulus	in^3
SR	slenderness ratio	–
t	thickness	in
T	tension	kips
U	reduction coefficient	–
V	shear	kips
w	weld size	in
Z	plastic modulus	in^3

1 This chapter cannot serve as a complete substitute for the American Institute of Steel Construction's *Manual of Steel Construction* or its accompanying *Specifications*. Throughout this chapter, references to the *AISC Specifications*, 9th edition, are listed in bold, square brackets. For example, **[H1-3]** is a reference to equation H1-3 in the *Specifications*, not to equations in this book. Also, tables, figures, and appendices listed in italic are part of the *AISC Manual* or *Specifications*. Thus, the *Allowable Stress Design Selection Table* would not be found in this volume.

Subscripts

a	axial
b	bracing or bending
c	centroidal or concrete
cr	critical
e	effective or edge
f	flange
g	gross
n	net
p	bearing or plastic
s	secondary or steel
st	stiffener
t	tension
u	ultimate or unbraced
v	shear
w	web
y	yield

1 REVIEW OF STEEL NOMENCLATURE

It is traditional in steel design to use the upper case letter F to indicate strength or allowable stress. Furthermore, such strengths or maximum stresses are specified in ksi (i.e., 1000's of psi). For example, $F_y = 36$ would imply a steel with a yield strength of 36 ksi. Similarly, F_v is the allowable shear stress, and F_b is the allowable bending stress, both in ksi.

Actual or computed stresses are given the symbol of lower case f. Computed stresses are also specified in ksi. For example, f_t is a computed tensile stress in ksi. The symbol σ is never used.

2 CONVERSIONS

multiply	by	to obtain
ft-kips	1.356	kN-m
ft-lbf	1.356	N-m
in-lbf	0.113	N-m
kips	4.448	kN
kips	1000	lbf
kips/ft	14.59	kN/m
kips/ft^2	47.88	kN/m^2
kN	0.2248	kips
kN/m	0.06852	kips/ft
kPa	1000	Pa
ksi	6.895 EE6	Pa
lbf	0.001	kips
lbf	4.448	N
N-m	0.7376	ft-lbf
N-m	8.851	in-lbf
N-m^2	1	Pa
Pa	1.0	N/m^2
Pa	EE-6	MPa
Pa	0.001	kPa
Pa	1.45 EE-7	ksi
Pa	1.45 EE-4	psi
Pa	0.02089	psf
psf	47.88	Pa
psi	6.895 EE3	Pa

3 TYPES OF STEELS

ASTM A36 is the designation given to the all-purpose, carbon steel used for most projects. Most A36 shapes are hot rolled.

Other steels have higher strengths. Their use results in lower dead weights but higher material costs. The commonly available steels and their applications are listed in appendix A.

Table 15.1
Properties of A36 Steel

E, modulus of elasticity:	2.9 EE7 psi (up to 100°F)
G, shear modulus:	11.5 EE6 psi
α, coefficient of thermal expansion:	6.5 EE-6 1/°F
μ, Poisson's ratio:	0.30
ρ, density:	490 lbm/ft^3
F_y, yield strength:	36 ksi (to 8″ thickness inclusive)
	32 ksi (over 8″ thickness)
F_u, ultimate strength:	58 ksi (minimum)
F_e, endurance limit:	approximately 30 ksi

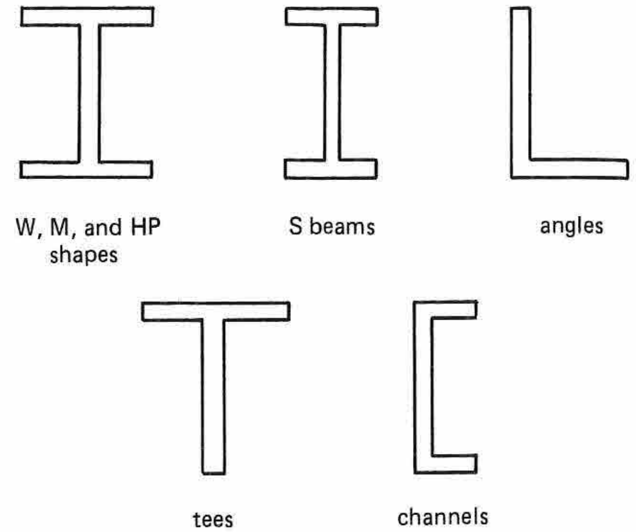


Figure 15.1 Structural Shapes

4 STEEL PROPERTIES

Some properties of steel (such as the modulus of elasticity and density) are essentially independent of the type of steel. Other properties (such as the ultimate and yield strengths) depend not only on the type of steel but also on the size or thickness of the piece.

5 STRUCTURAL SHAPES

Many different structural shapes are available. The identifying dimension and weight must be appended to the designation to uniquely identify the shape. For example, W 30×132 means a W-shape with an overall depth of approximately 30 inches and which weighs 132 pounds per foot.

Table 15.2 lists structural shape designations.

Table 15.2
Structural Shape Designations

shape	designation
wide flange beams	W
standard flanged beams	S
misc. flanged beams	M
American std. channels	C
bearing piles	HP
angles	L
tees	ST or WT (cut from S or W)
plate	PL
bar	bar
pipe	pipe
structural tubing	TS

6 STANDARD COMBINATIONS OF SHAPES

Figure 15.2 illustrates several combinations of shapes that are used in construction. The double angle combination is particularly useful for carrying axial loads. Combinations of W shapes and channels, channels with channels, or channels with angles are used for a variety of special applications, including struts and light crane rails. Properties for certain combinations have been tabulated in the *AISC Manual*.

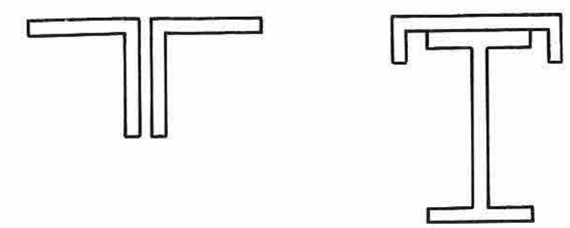


Figure 15.2 Typical Combination Sections

7 REINFORCEMENT OF MILL SHAPES

Occasionally, it will be desirable to provide additional bending or compressive strength to a shape by adding plates. It is generally easy to calculate the properties of the built-up section from the properties of the shape and plate. No stress calculations are necessary. The following characteristics can be used when it is necessary to specify plate reinforcement.

- Plate widths should not be the same as b_f, due to difficulty in welding. Widths should be somewhat larger or smaller. It is better to keep plate width as close to b_f as possible, as width-thickness ratios specified in the *AISC Manual* may govern.
- Width and length tolerances smaller than 1/8″ are not practical. Table 15.3 should be used when specifying the nominal plate width.

Table 15.3
Width Tolerance for Small Universal Mill Plates

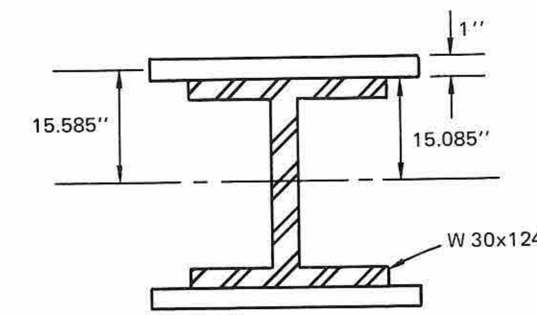
thickness (inches)	width (inches) 8–20, excl.	20–36 excl.	36 and above
0–3/8, excl.	1/8	3/16	5/16
3/8–5/8, excl.	1/8	1/4	3/8
5/8–1, excl.	3/16	5/16	7/16
1–2, incl.	1/4	3/8	1/2
2–10, incl.	3/8	7/16	9/16

- Not every plate exists in the larger thicknesses. Unless special plates are called for, the following thickness guidelines should be used:

1/32″	increments up to 1/2″
1/16″	increments from 9/16″ to 1″
1/8″	increments from $1\frac{1}{8}$″ to 3″
1/4″	increments for $3\frac{1}{4}$″ and above

Example 15.1

A W 30×124 shape must be reinforced to achieve the strong-axis bending strength of a W 30×173 shape by welding plates to both flanges. All steel is A36. The plates are welded continuously to the flanges. What size plate is required if all plate sizes are available?



The moments of inertia are 8200 in^4 and 5360 in^4 for the two beams. The difference in bending resistance to be provided by the plates is

$$I_{\text{plates}} = 8200 - 5360 = 2840\ \text{in}^4$$

For ease of welding, assume the plate thickness will be approximately the same as the flange thickness. $t_f = 0.930''$, so choose a plate thickness of 1.0″.

The centroidal moment of inertia of the two plates acting together is

$$I_{c,\text{plates}} = 2\left[\frac{w(1)^3}{12}\right] = \frac{w}{6}$$

The depth of the W 30×124 beam is 30.17″. Therefore, the distance from the neutral axis to the plate centroid is

$$\frac{30.17}{2} + \frac{1}{2} = 15.585''$$

By the parallel axis theorem, the moment of inertia of the two plates about the neutral axis is

$$I_{\text{plates}} = \frac{w}{6} + (2)(w)(1)(15.585)^2 = 486.0w$$

The required moment of inertia is 2840. Therefore,

$$w = \frac{2840}{486} = 5.84''\quad(\text{say } 6'')$$