Architecture 324

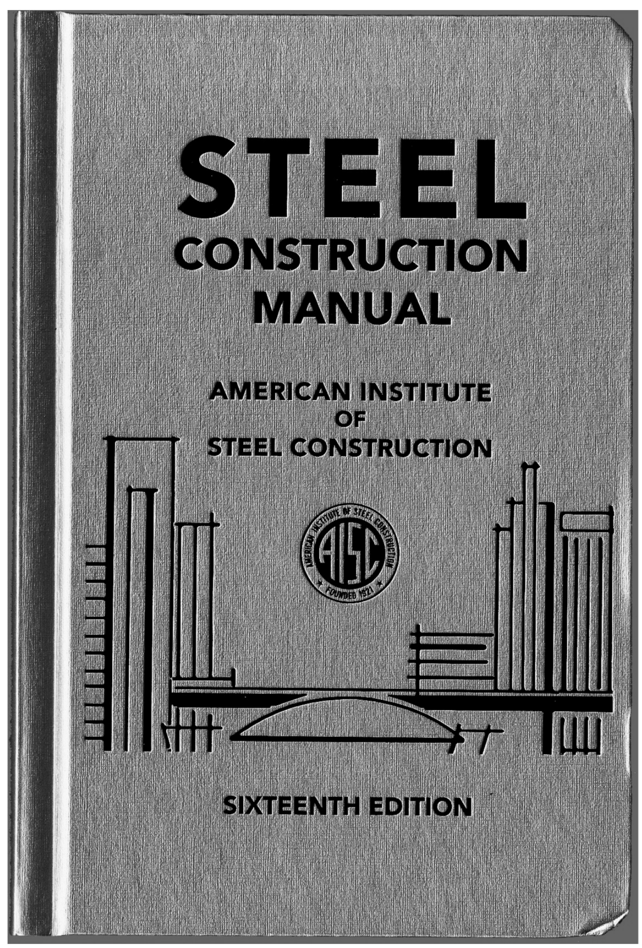
Structures II

Properties of Steel

- Steel Properties
- Steel Profiles
- Steel Codes: ASD vs. LRFD

Current AISC Manual

Specification and Manual for both ASD and LRFD



Cold Form Sections

Photos by Albion Sections Ltd, West Bromwich, UK

Cold Form Sections

From:

Building Design Using Cold Formed Steel Sections: Structural Design to BS 5950-5:1998. Section Properties and Load Tables. p. 276

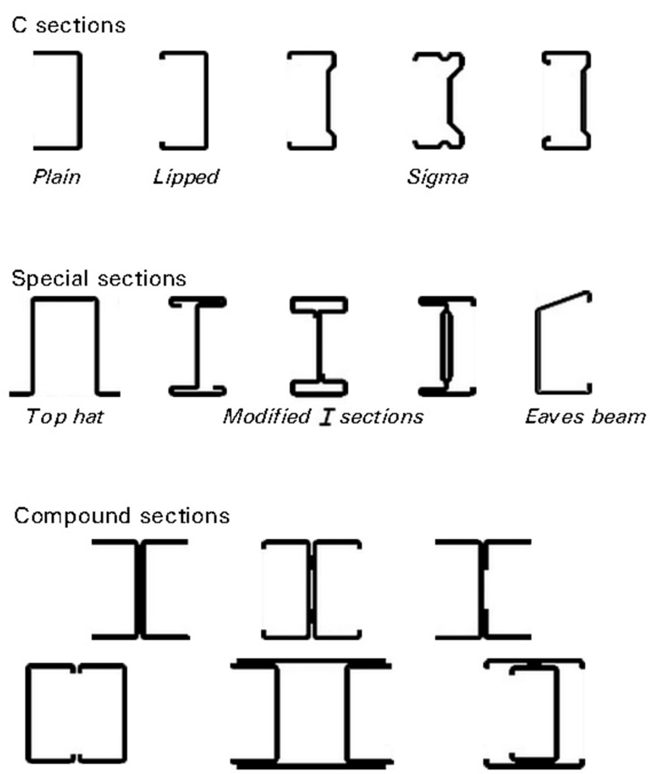
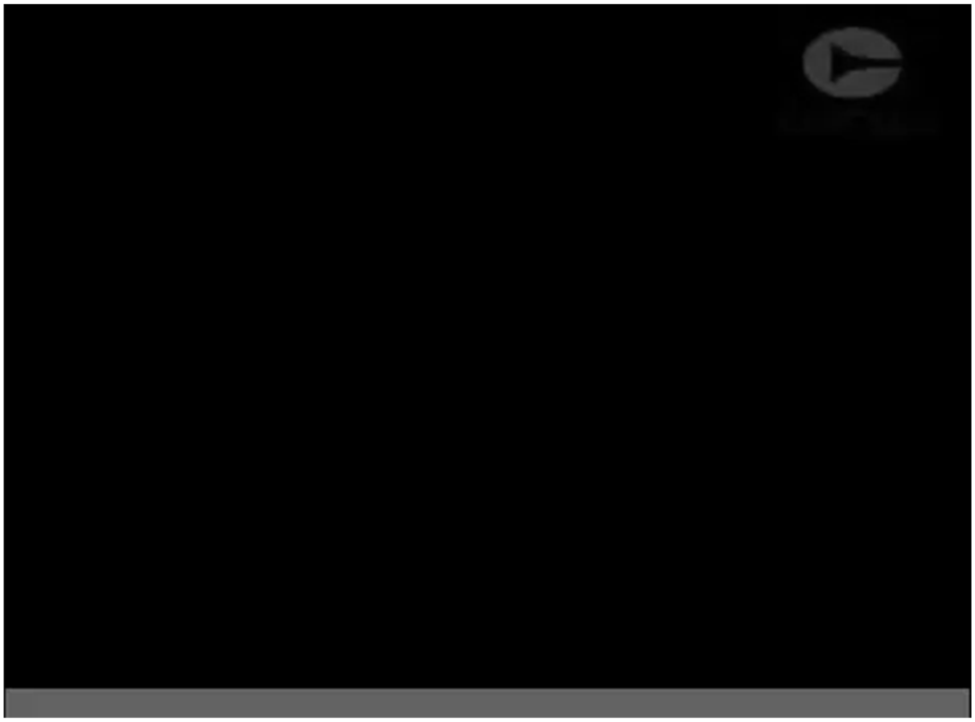
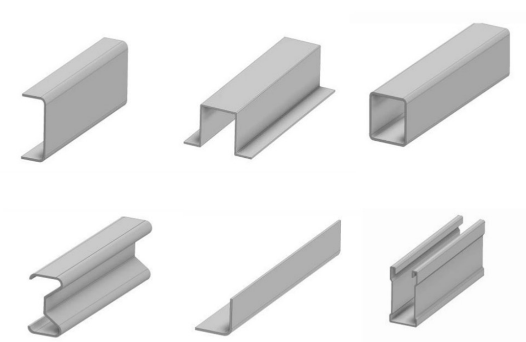


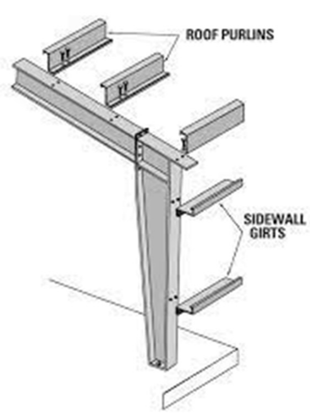
Figure 2.3 *Examples of cold formed steel sections*

Cold Form Sections

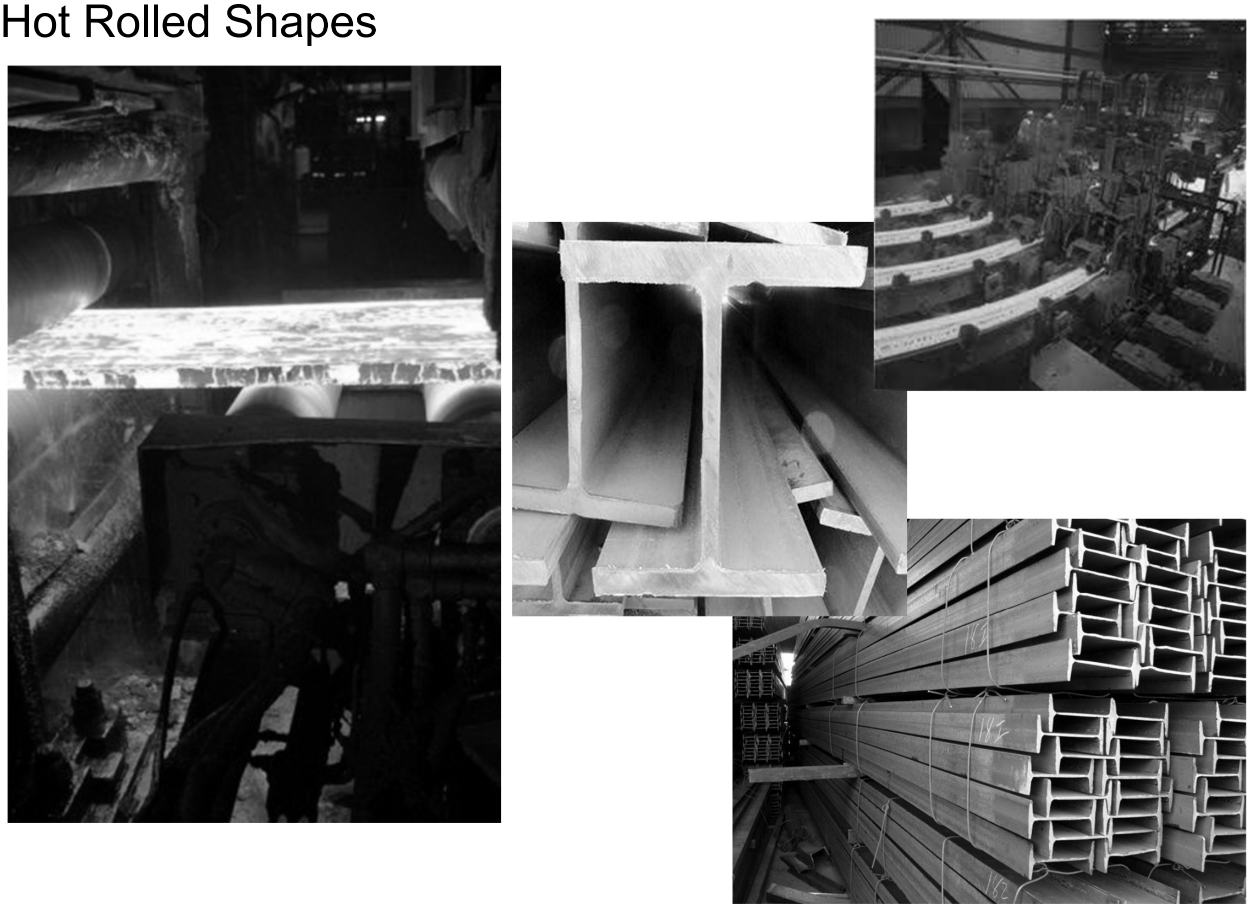


Cold Form Sections

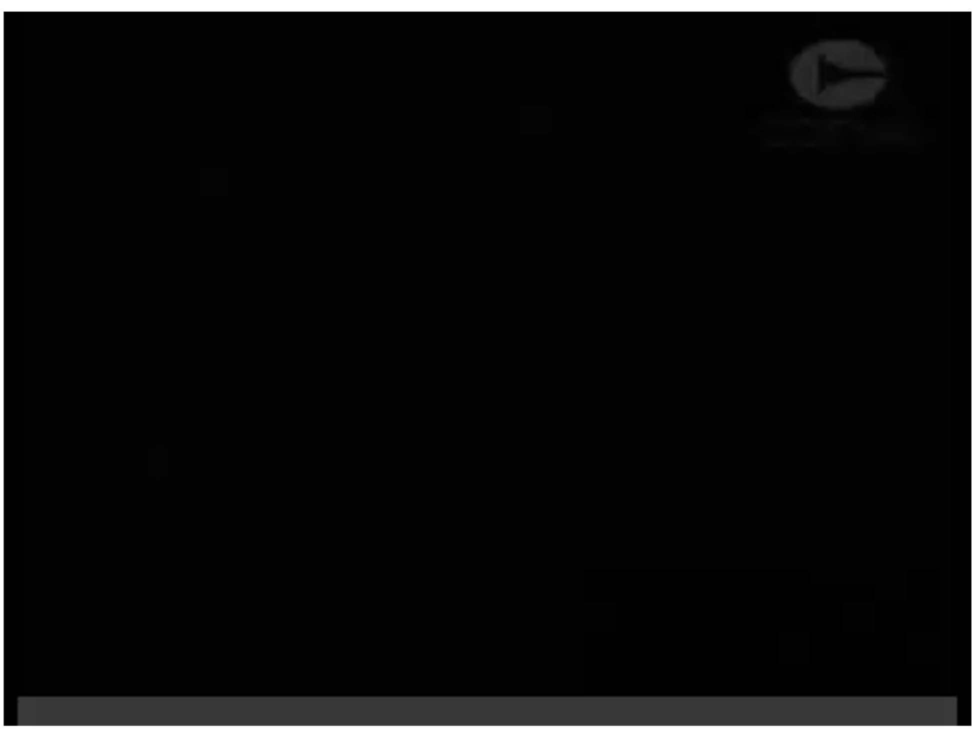




Hot Rolled Shapes



Hot Rolled Shapes



Corten Steel

Develops a rust layer on the surface that protects it from further corrosion.

Developed in the 1930 for rail cars

Used in the 1960 for architecture

John Deere Headquarters in Moine, Illinois. Arch Eero Saarinen, 1962

Nomenclature of steel shapes

Standard section shapes:

W – wide flange

S – American standard beam

C – American standard channel

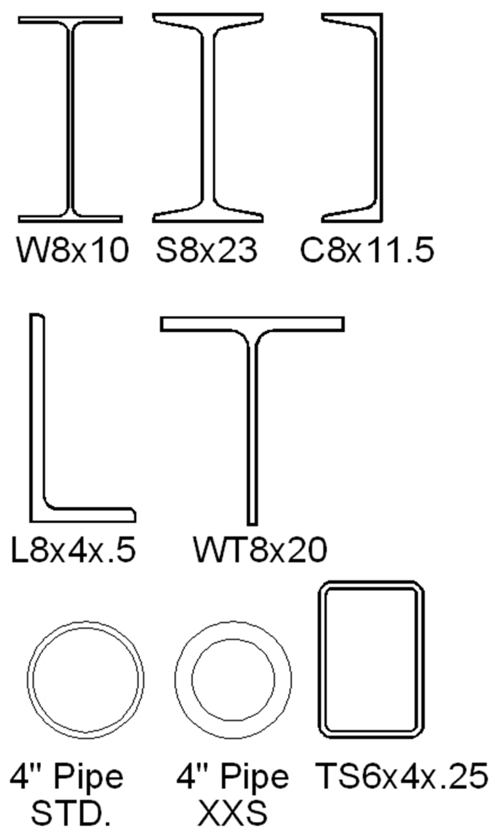
L – angle

WT or **ST** – structural T

STD, **XS** or **XXS** – Pipe

HSS – Hollow Structural Sections
  Rectangular, Square, Round

LLBB , SLBB - Double Angles



Steel Grades – Rolled Sections

Different sections are made with different grades of steel.

Most structural shapes are:
Gr. 50 Steel with Fy = 50 ksi

Older sections were made with:
A-36 Steel with Fy = 36 ksi

Table 2-4
Applicable ASTM Specifications for Various Structural Shapes

Steel Type	ASTM Designation		F_y, Yield Stress[a], ksi	F_u, Tensile Stress[a], ksi	Applicable Shape Series: W	M	S	HP	C	MC	L	HSS: Rectangular	Round	Pipe
Carbon	A36/A36M		36	58–80[b]	▒	▒	▒	▒	▒	▒	▒			
	A53/A53M Gr. B		35	60										■
	A500/A500M	Gr. B	46	58								▒	▒	
		Gr. C	50	62								■	■	
		Gr. D	36	58								▒	▒	
	A501/A501M[c]	Gr. B	46	65								▒	▒	
	A529/A529M[d]	Gr. 50	50	65–100	▒	▒	▒	▒	▒	▒	▒			
		Gr. 55	55	70–100	▒	▒	▒	▒	▒	▒	▒			
	A709/A709M	Gr. 36	36	58–80[b]	▒	▒	▒	▒	▒	▒	▒			
	A1043/A1043M[e],[f]	Gr. 36	36–52	58	▒									
		Gr. 50	50–65	65	▒									
	A1085/A1085M	Gr. A	50–70	65								▒	▒	
High-Strength Low-Alloy	A572/A572M[g]	Gr. 42	42	60	▒	▒	▒	▒	▒	▒	▒			
		Gr. 50	50	65	▒	■	■	■	▒	▒	■			
		Gr. 55	55	70	▒	▒	▒	▒	▒	▒	▒			
		Gr. 60[h]	60	75	▒	▒	▒	▒	▒	▒	▒			
		Gr. 65[h]	65	80	▒	▒	▒	▒	▒	▒	▒			
	A618/A618M[c]	Gr. Ia[f], Ib & II	50[i]	70[i]								▒	▒	
		Gr. III	50	65								▒	▒	
	A709/A709M	Gr. 50	50	65	▒	▒	▒	▒	▒	▒	▒			
		Gr. 50S	50–65	65	▒	▒	▒	▒	▒	▒	▒			
		Gr. 50W	50	70	▒	▒	▒	▒	▒	▒	▒			
	A913/A913M	Gr. 50	50	65	▒	▒	▒	▒	▒	▒	▒			
		Gr. 60	60	75	▒	▒	▒	▒	▒	▒	▒			
		Gr. 65	65	80	▒	▒	▒	▒	▒	▒	▒			
		Gr. 70	70	90	▒	▒	▒	▒	▒	▒	▒			
		Gr. 80	80	95	▒	▒	▒	▒	▒	▒	▒			
	A992/A992M		50–65	65	■	▒	▒	▒	■	■	▒			
	A1065/A1065M[f]	Gr. 50	50	60								▒		

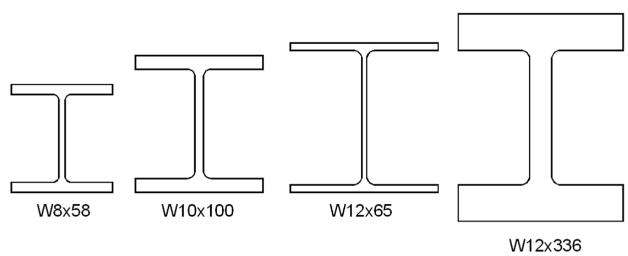
■ = Preferred material specification
▒ = Other applicable material specification, the availability of which should be confirmed prior to specification
□ = Material specification does not apply

Footnotes on facing page.

Steel W-sections for beams and columns

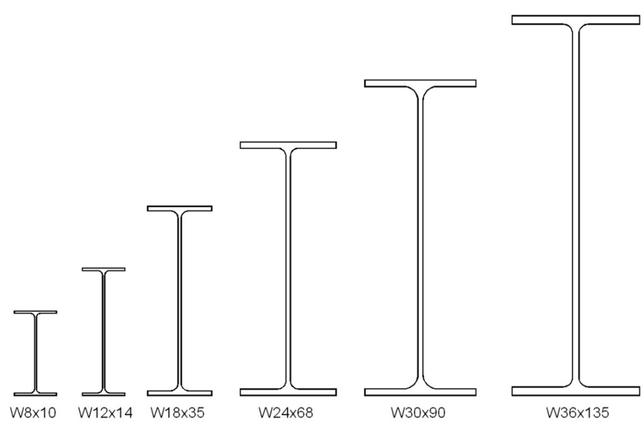
Columns:

Closer to square
Thicker web & flange



Beams:

Deeper sections
Flange thicker than web



Steel W-sections for beams and columns

Columns:

Closer to square
Thicker web & flange

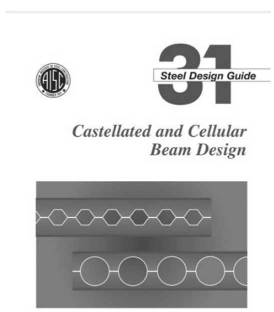
Beams:

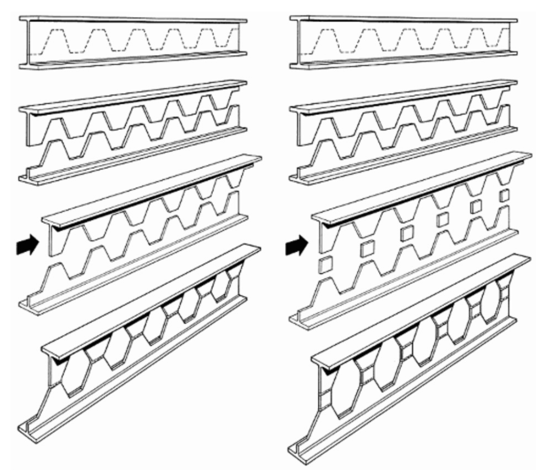
Deeper sections
Flange thicker than web

Photo by Gregor Y.

Modified Sections

- Castellated Sections:
- “Boyd beam”
- round, hexagonal, rectangular, sinusoidal
- extendable (added depth)
- cost-efficient
- lightweight





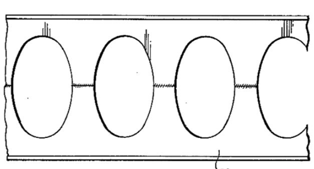


Fig.2A.

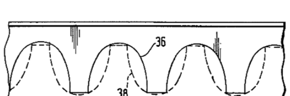


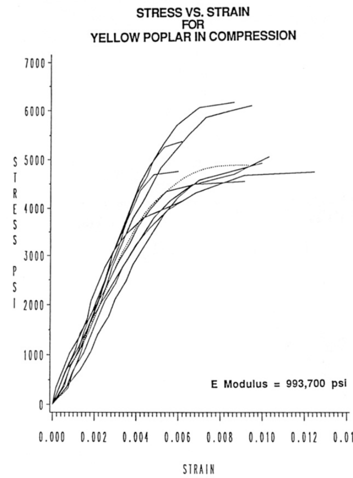
Fig.2B.

Young's Modulus

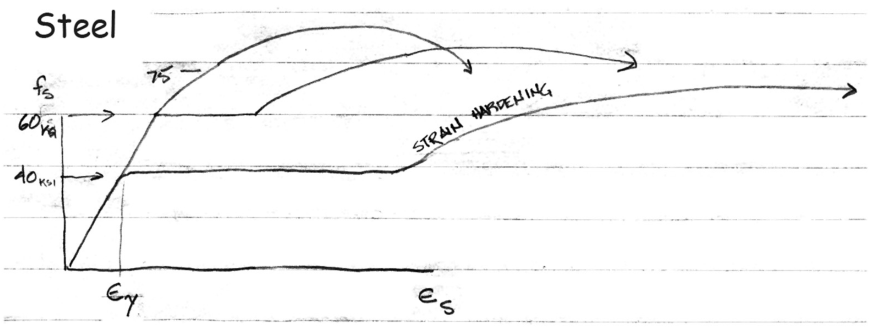
Young's Modulus or the Modulus of Elasticity, is obtained by dividing the stress by the strain present in the material. (Thomas Young, 1807)

$$E = \frac{P/A}{D/L} = \frac{\sigma}{\varepsilon}$$

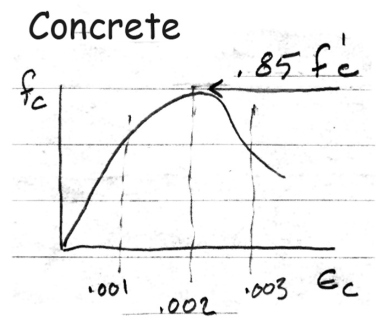
It thus represents a measure of the stiffness of the material.



E = 1000 ksi

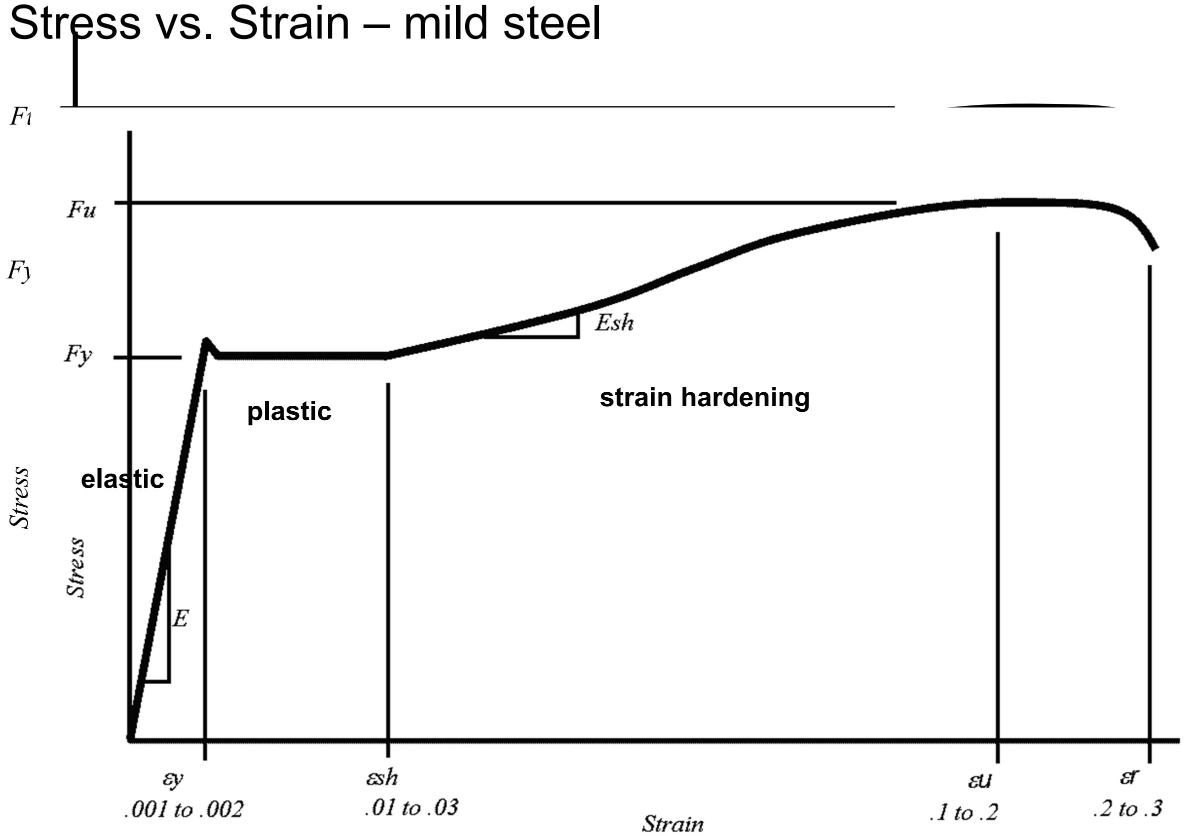


E = 29000 ksi



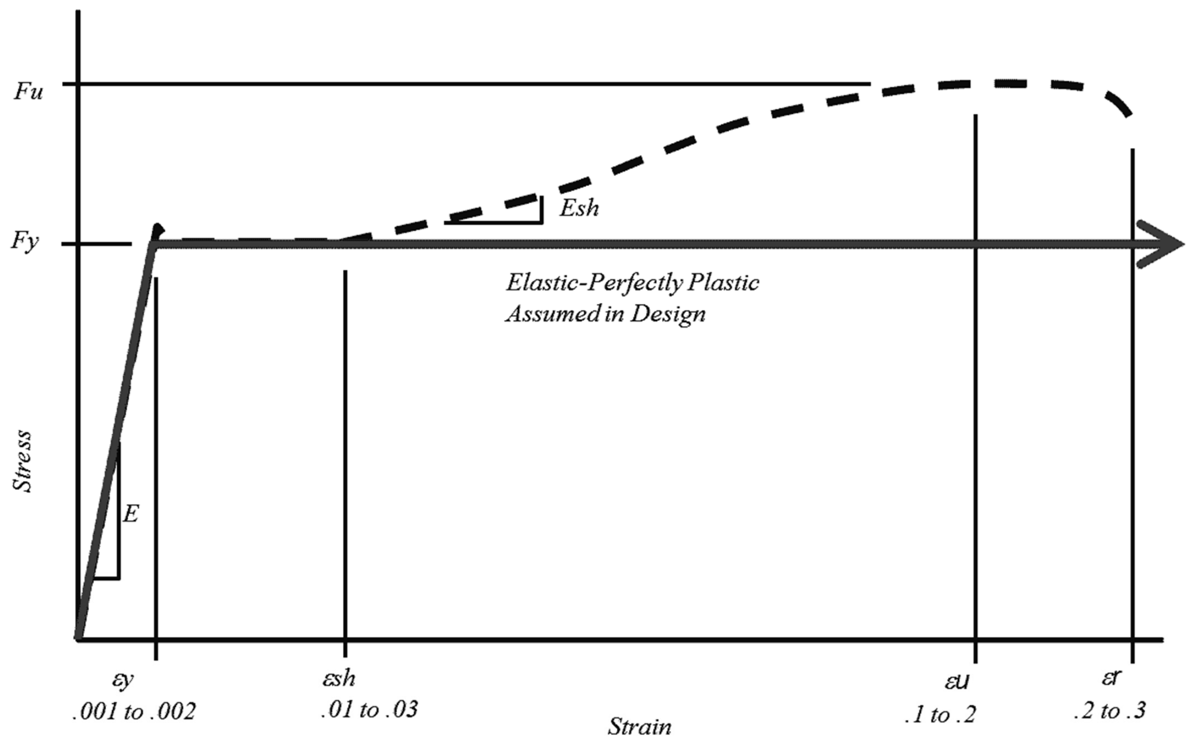
E = 3500 ksi

Stress vs. Strain – mild steel



Developed by Scott Civjan
University of Massachusetts, Amherst

Stress vs. Strain – AISC design curve



Stress Analysis – Two Methods

Allowable Stress Design (ASD)

- use design loads (no F.S. on loads)
- reduce stress by a Factor of Safety F.S.

$$f_{actual} = \frac{P}{A}$$

$$f_{actual} \leq F_{allowable}$$

$$F_{allowable} = F.S. \cdot f_{yield}$$

Load & Resistance Factored Design (LRFD)

- Use loads with safety factor γ
- Use factor on ultimate strength ϕ

$$P_{load} = \gamma \cdot P_{applied\_load}$$

$$P_{load} \leq P_{resisting}$$

$$P_{resisting} = \phi \cdot P_{material\_strength}$$

LRFD Analysis

Load & Resistance Factored Design (LRFD)

- Use loads with safety factor γ
- Use forces with strength factor ϕ

$$P_{load} = \gamma \cdot P_{applied} \qquad P_{load} \le P_{resisting} \qquad P_{resisting} = \phi \cdot P_{material}$$

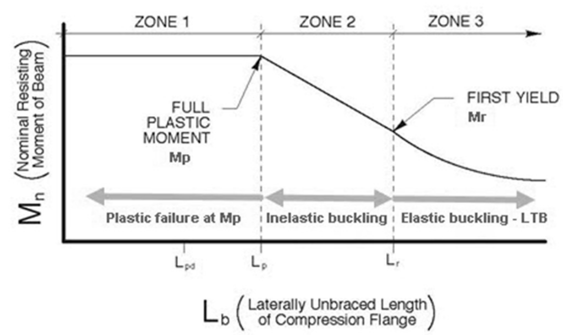
Design Strength $\quad P_u \le \phi \; P_n \quad$ Required (Nominal) Strength

2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN

1a. $1.4D$
2a. $1.2D + 1.6L + (0.5L_r \text{ or } 0.3S \text{ or } 0.5R)$
3a. $1.2D + (1.6L_r \text{ or } 1.0S \text{ or } 1.6R) + (L \text{ or } 0.5W)$
4a. $1.2D + 1.0(W \text{ or } W_T) + L + (0.5L_r \text{ or } 0.3S \text{ or } 0.5R)$
5a. $0.9D + 1.0(W \text{ or } W_T)$

ASCE 7 - 2022

Beam Strength vs Unbraced Length

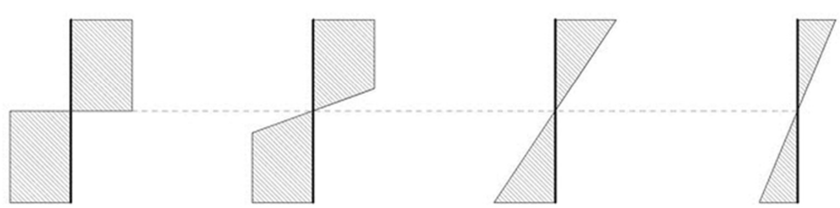


ZONE 1 — Plastic Behavior, Full Plastic Moment

ZONE 2 — Inelastic Buckling, More than First Yield, Less than Full Plastic Moment

First Yield

ZONE 3 — Elastic Buckling



$M_n = M_p = F_y Z \le 1.5 M_y$; $M_u = \emptyset_b M_n$

$M_n = C_b\left(M_p - (M_p - M_r)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right) < M_p$; $M_u = \emptyset_b M_n$

$M_r = 0.7 F_y S_x$; $M_u \le \emptyset_b M_r$

$M_{cr} = C_b \frac{\pi}{L_b}\sqrt{E I_y G J + \left(\frac{\pi E}{L_b}\right)^2 I_y C_w}$; $M_u \le \emptyset_b M_{cr}$ (for doubly symmetric sections)

$\phi_b = 0.90$

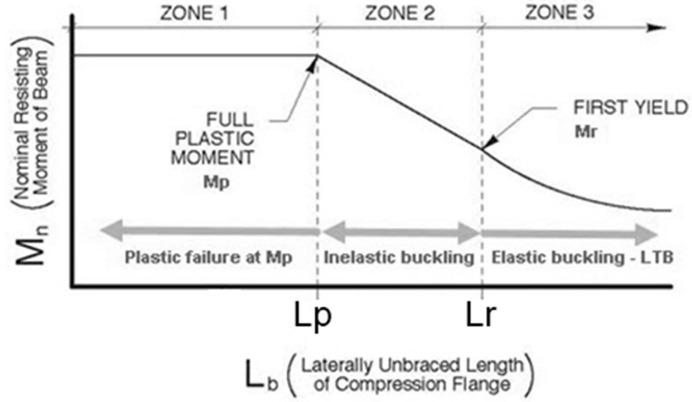
Steel Beams by LRFD

Yield Stress Values

- A36 Carbon Steel F_y = 36 ksi
- A992 High Strength F_y = 50 ksi

Elastic Analysis for Bending

- **Plastic Behavior (zone 1)**
  $M_n = M_p = F_y Z < 1.5 M_y$
  - Braced against LTB ($L_b < L_p$)
- **Inelastic Buckling "Decreased" (zone 2)**
  $M_n = C_b (M_p-(M_p-M_r) [(L_b-L_p)/(L_r-L_p)] < M_p$
  - $L_p < L_b < L_r$
- **Elastic Buckling "Decreased Further" (zone 3)**
  $M_{cr} = C_b * \pi/L_b \sqrt{(E*I_y*G*J + (\pi*E/L_b)^2 * I_y C_w)}$
  - $L_b > L_r$

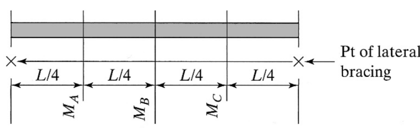


$$L_p = 1.76\, r_y \sqrt{E/Fy}$$

$$M_p = F_y Z_x$$

$$M_r = 0.7 F_y S_x$$

C_b is LTB modification factor



$$C_b = \frac{12.5\ \text{Mmax}}{2.5\ \text{Mmax} + 3\ \text{MA} + 4\text{MB} + 3\text{MC}}$$

Steel Beams by LRFD

Analysis for Bending

AISC 16th ed.

- Plastic Behavior (zone 1)
  $M_n = M_p = F_y Z < 1.5 M_y$
  - Braced against LTB ($L_b < L_p$)
- Inelastic Buckling "Decreased" (zone 2)
  $M_n = C_b(M_p-(M_p-M_r)[(L_b-L_p)/(L_r-L_p)] < M_p$
  - $L_p < L_b < L_r$
- Elastic Buckling "Decreased Further" (zone 3)
  $M_{cr} = C_b * \pi/L_b \sqrt{(E*I_y*G*J + (\pi*E/L_b)^2 * I_y C_w)}$
  - Lb > Lr

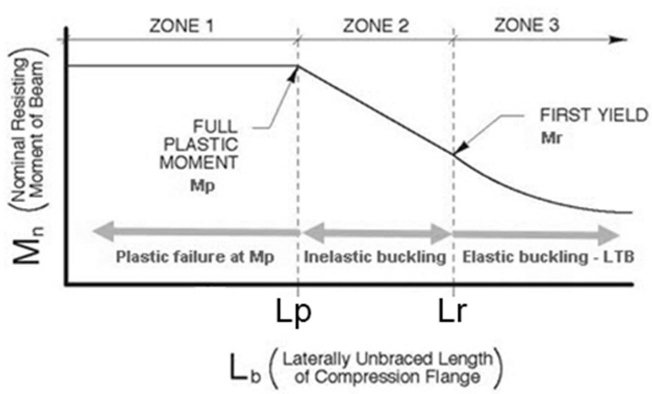


Table 3-2 (continued)
W-Shapes
Selection by Z_x

$F_y = 50$ ksi

Z_x

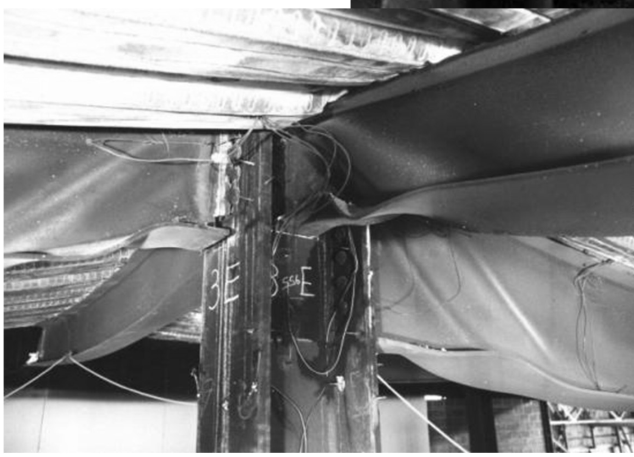
Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W21×55	126	314	473	192	289	10.8	16.3	6.11	17.4	1140	156	234
W14×74	126	314	473	196	294	5.31	8.05	8.76	31.0	795	128	192
W18×60	123	307	461	189	284	9.62	14.4	5.93	18.2	984	151	227
W12×79	119	297	446	187	281	3.78	5.67	10.8	39.9	662	117	175
W14×68	115	287	431	180	270	5.19	7.81	8.69	29.3	722	116	174
W10×88	113	282	424	172	259	2.62	3.94	9.29	51.2	534	131	196
W18×55	112	279	420	172	258	9.15	13.8	5.90	17.6	890	141	212
W21×50	110	274	413	165	248	12.1	18.3	4.59	13.6	984	158	237
W12×72	108	269	405	170	256	3.69	5.56	10.7	37.5	597	106	159
W21×48[f]	107	265	398	162	244	9.89	14.8	6.09	16.5	959	144	216
W16×57	105	262	394	161	242	7.98	12.0	5.65	18.3	758	141	212
W14×61	102	254	383	161	242	4.93	7.48	8.65	27.5	640	104	156
W18×50	101	252	379	155	233	8.76	13.2	5.83	16.9	800	128	192
W10×77	97.6	244	366	150	225	2.60	3.90	9.18	45.3	455	112	169
W12×65[f]	96.8	237	356	154	231	3.58	5.39	11.9	35.1	533	94.4	142
W21×44	95.4	238	358	143	214	11.1	16.8	4.45	13.0	843	145	217
W16×50	92.0	230	345	141	213	7.69	11.4	5.62	17.2	659	124	186
W18×46	90.7	226	340	138	207	9.63	14.6	4.56	13.7	712	130	195
W14×53	87.1	217	327	136	204	5.22	7.93	6.78	22.3	541	103	154
W12×58	86.4	216	324	136	205	3.82	5.69	8.87	29.8	475	87.8	132
W10×68	85.3	213	320	132	199	2.58	3.85	9.15	40.6	394	97.8	147
W16×45	82.3	205	309	127	191	7.12	10.8	5.55	16.5	586	111	167
W18×40	78.4	196	294	119	180	8.94	13.2	4.49	13.1	612	113	169
W14×48	78.4	196	294	123	184	5.09	7.67	6.75	21.1	484	93.8	141
W12×53	77.9	194	292	123	185	3.65	5.50	8.76	28.2	425	83.5	125
W10×60	74.6	186	280	116	175	2.54	3.82	9.08	36.6	341	85.7	129
W16×40	73.0	182	274	113	170	6.67	10.0	5.55	15.9	518	97.6	146
W12×50	71.9	179	270	112	169	3.97	5.98	6.92	23.8	391	90.3	135
W8×67	70.1	175	263	105	159	1.75	2.59	7.49	47.6	272	103	154
W14×43	69.6	174	261	109	164	4.88	7.28	6.68	20.0	428	83.6	125
W10×54	66.6	166	250	105	158	2.48	3.75	9.04	33.6	303	74.7	112

ASD	LRFD
$\Omega_b = 1.67$	$\phi_b = 0.90$
$\Omega_v = 1.50$	$\phi_v = 1.00$

[f] Shape exceeds compact limit for flexure with $F_y = 50$ ksi; tabulated values have been adjusted accordingly.

Design for Shear

Steel



Design for Shear

Shear stress in steel sections is approximated by averaging the stress in the web:

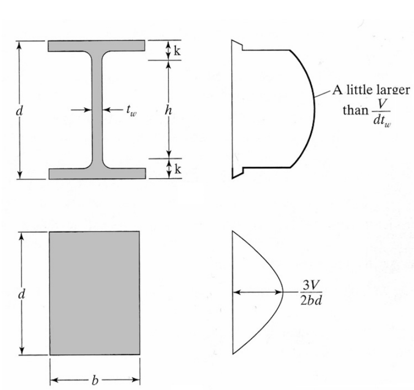
$F_v = V / A_w$

$A_w = d * t_w$

To adjust the stress a reduction factor of 0.6 is applied to F_y

$F_v = 0.6\ F_y$

so, $V_n = 0.6\ F_y\ A_w$ **(Zone 1)**



The equations for the 3 stress zones:
(ϕ in all cases = 1.0)

Zone 1:
WEB YIELDING (Most beam sections fall into this category)

if $\frac{h}{t_w} \le 2.45\sqrt{E/F_y} = 59$ (for 50 ksi steel)

then: $V_n = 0.6\ F_y\ A_w$

Zone 2:
INELASTIC WEB BUCKLING

if $2.45\sqrt{E/F_y} < \frac{h}{t_w} \le 3.07\sqrt{E/F_y} = 74$ (for 50 ksi steel)

then: $V_n = 0.6\ F_y\ A_w\ (2.45\sqrt{E/F}\ ) / \frac{h}{t_w}$

Zone 3:
ELASTIC WEB BUCKLING

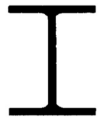
if $3.07\sqrt{E/F_y} < \frac{h}{t_w} \le 260$

then: $V_n = A_w \left[\frac{4.25\ E}{\left(\frac{h}{t_w}\right)^2}\right]$

Design for Shear

<u>No</u> W, M, S or HP section has $h/t_w > 59$

W-Shapes
Properties



W30-W27

Nom-inal Wt.	Compact Section Criteria		Axis X-X				Axis Y-Y				r_{ts}	h_o	Torsional Properties	
	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	I	S	r	Z	I	S	r	Z			J	C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
391	3.19	19.7	20700	1250	13.4	1450	1550	198	3.67	310	4.37	30.8	173	366000
357	3.45	21.6	18700	1140	13.3	1320	1390	179	3.64	279	4.31	30.6	134	324000
326	3.75	23.4	16800	1040	13.2	1190	1240	162	3.60	252	4.26	30.4	103	287000
292	4.12	26.2	14900	930	13.2	1060	1100	144	3.58	223	4.22	30.2	75.2	250000
261	4.59	28.7	13100	829	13.1	943	959	127	3.53	196	4.16	30.0	54.1	215000
235	5.02	32.2	11700	748	13.0	847	855	114	3.51	175	4.13	29.8	40.3	190000
211	5.74	34.5	10300	665	12.9	751	757	100	3.49	155	4.11	29.6	28.4	166000
191	6.35	37.7	9200	600	12.8	675	673	89.5	3.46	138	4.06	29.5	21.0	146000
173	7.04	40.8	8230	541	12.7	607	598	79.8	3.42	123	4.03	29.3	15.6	129000

Zone 1:

WEB YIELDING (Most beam sections fall into this category)

if $\frac{h}{t_w} \le 2.45\sqrt{E/F_y} = 59$ (for 50 ksi steel)

then: $V_n = 0.6\, F_y\, A_w$

Zone 2:

INELASTIC WEB BUCKLING

if $2.45\sqrt{E/F_y} < \frac{h}{t_w} \le 3.07\sqrt{E/F_y} = 74$ (for 50 ksi steel)

then: $V_n = 0.6\, F_y\, A_w\,(2.45\sqrt{E/F}\,)\,/\,\frac{h}{t_w}$

Zone 3:

ELASTIC WEB BUCKLING

if $3.07\sqrt{E/F_y} < \frac{h}{t_w} \le 260$

then: $V_n = A_w \left[\dfrac{4.25\,E}{\left(\frac{h}{t_w}\right)^2}\right]$