Architecture 324

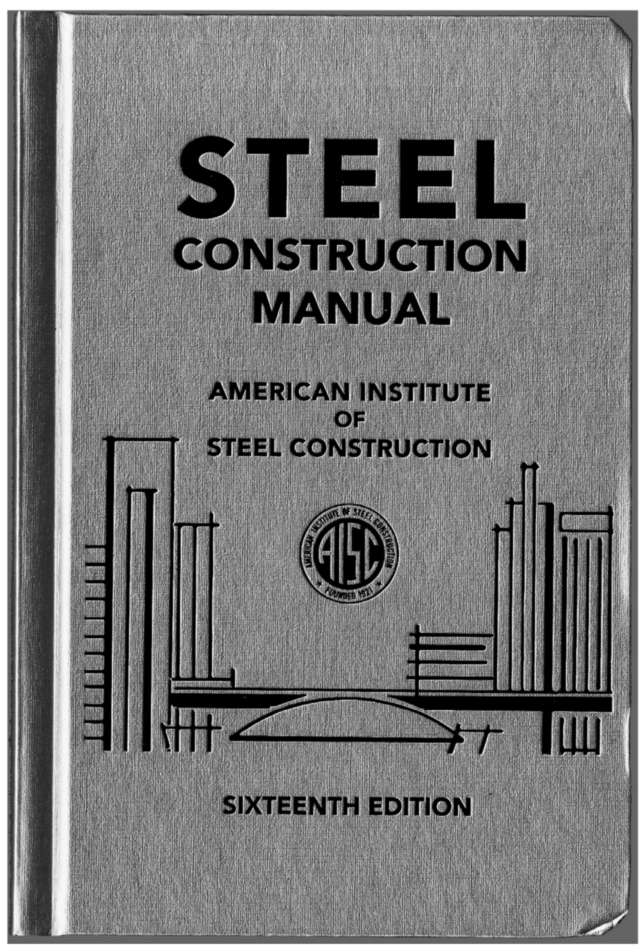
Structures II

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

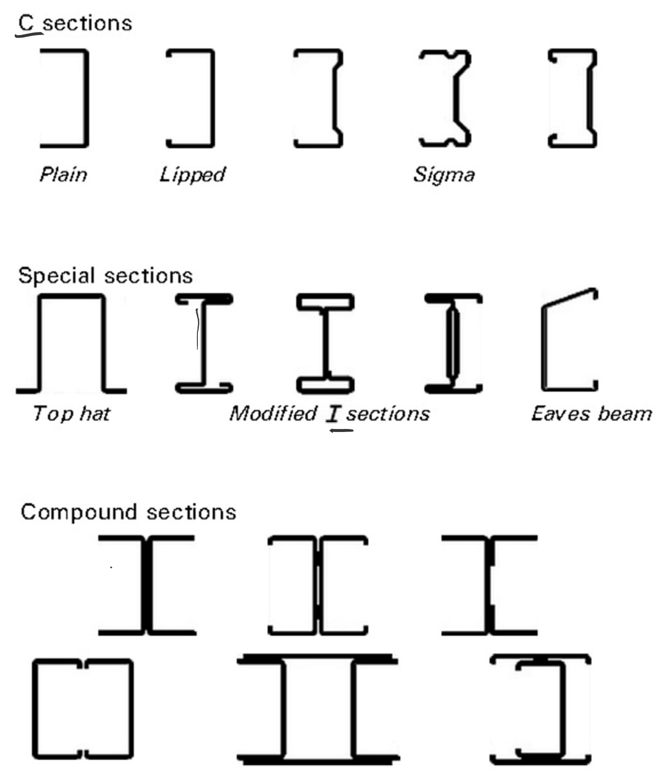
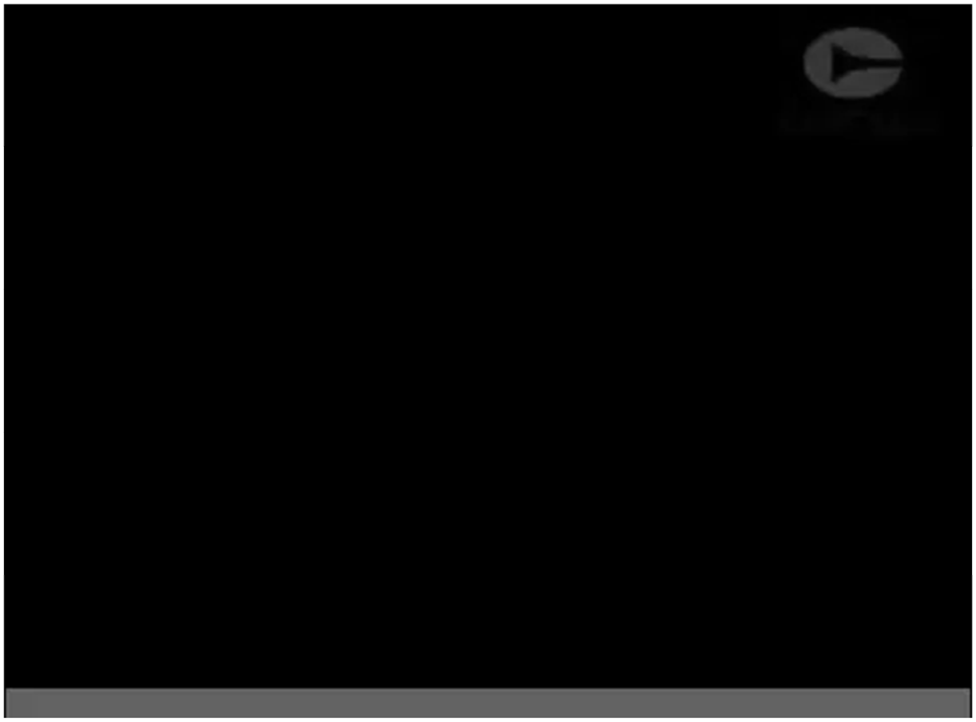
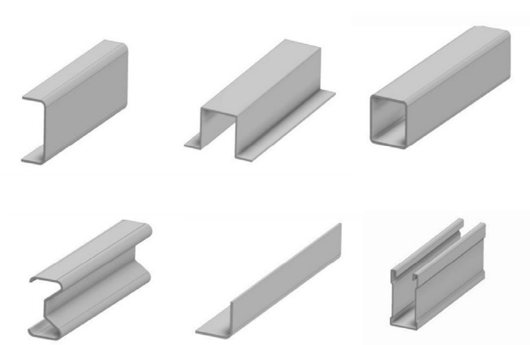


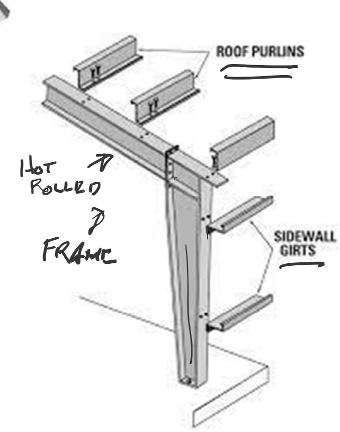
Figure 2.3 *Examples of cold formed steel sections*

Cold Form Sections

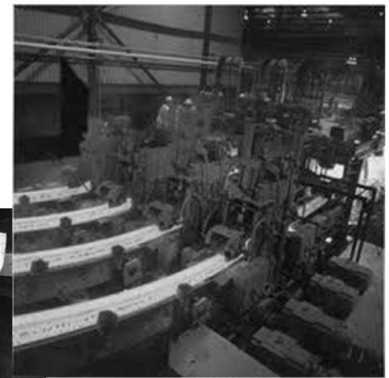


Cold Form Sections

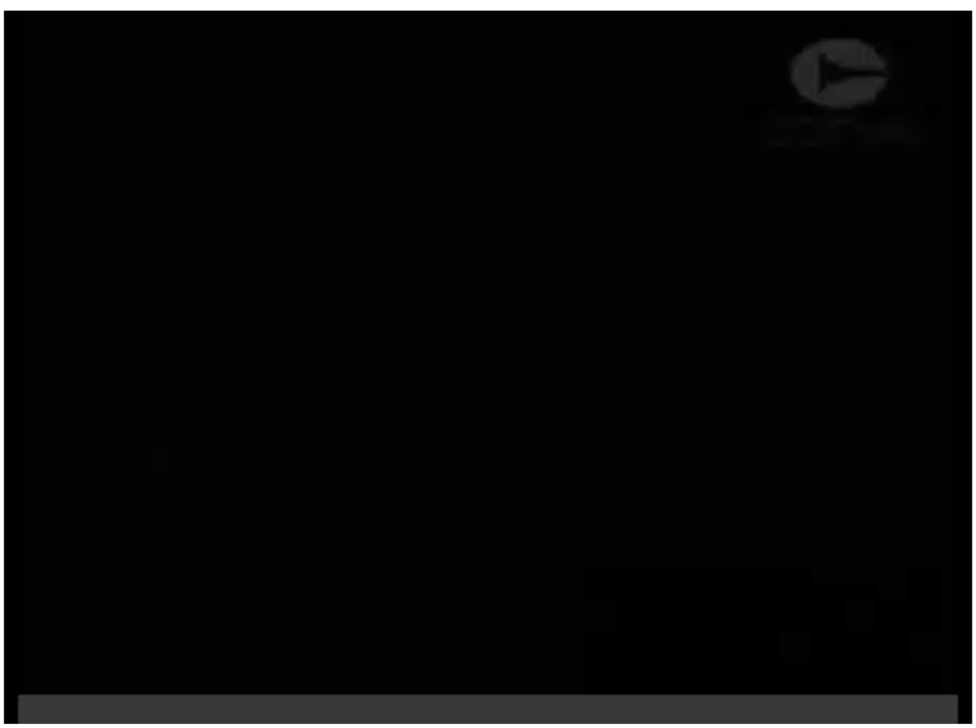




Hot Rolled Shapes



Hot Rolled Shapes



Nomenclature of steel shapes

Standard section shapes:

W – wide flange

S – American standard beam

C – American standard channel

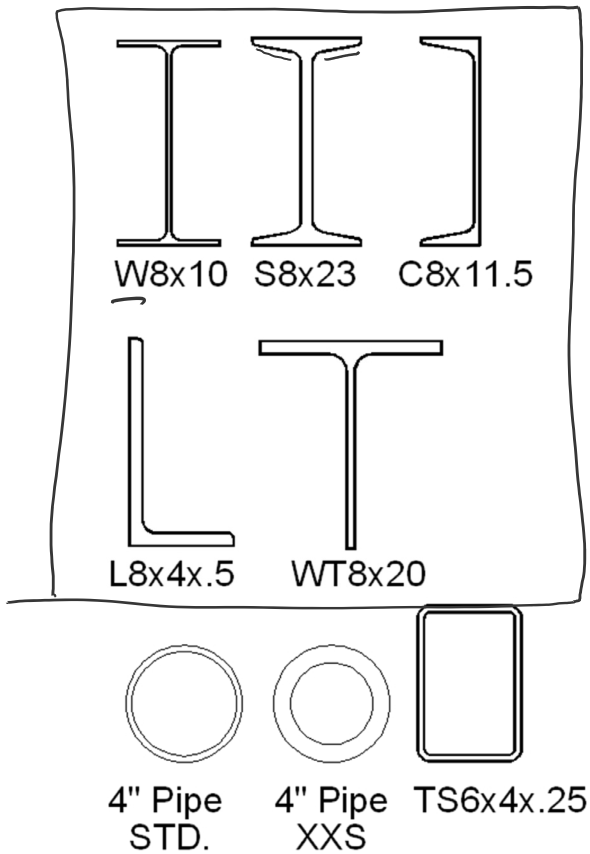
L – angle

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

AISC Manual - 16th ed.

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	W	M	S	HP	C	MC	L	HSS Rectangular	HSS 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								▨		

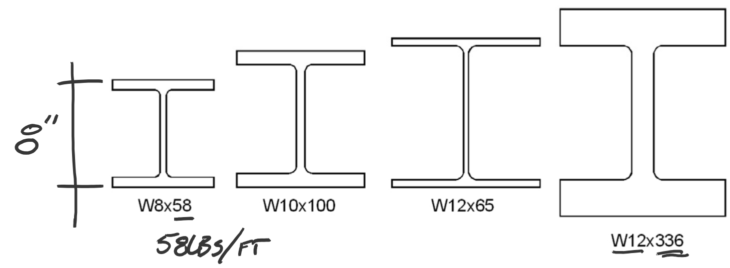
■ = Preferred material specification
▨ = Other applicable material specification, the availability of which should be confirmed prior to specification
□ = Material specification does not apply

Footnotes on facing page.

Steel W-sections for beams and columns

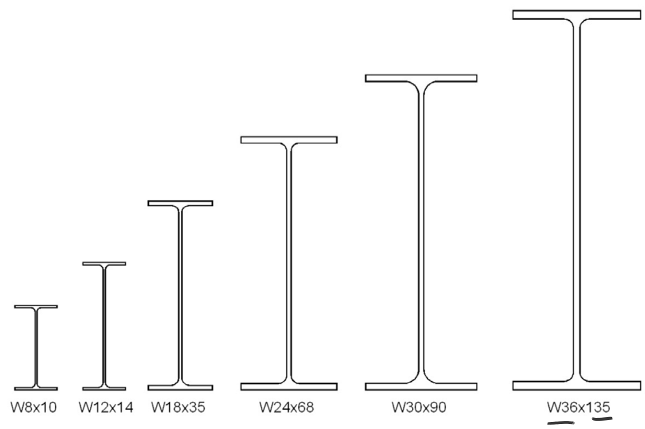
Columns:

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

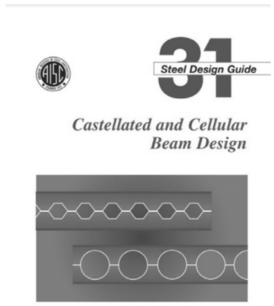
Beams:

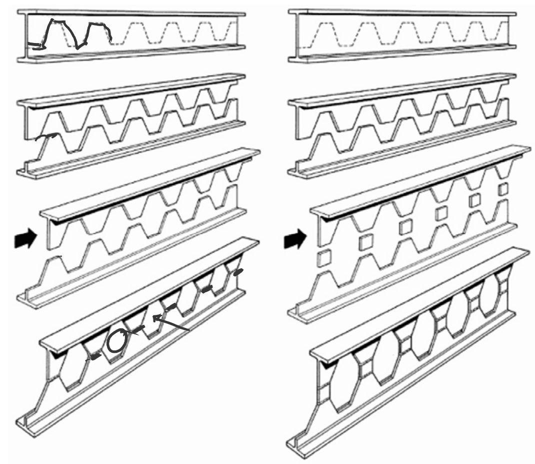
Deeper sections
Flange thicker than web

Photo by Gregor Y.

Modified Sections

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





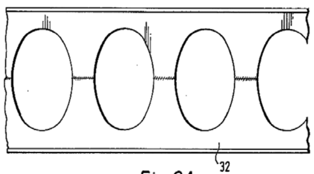


Fig.2A.

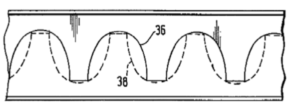


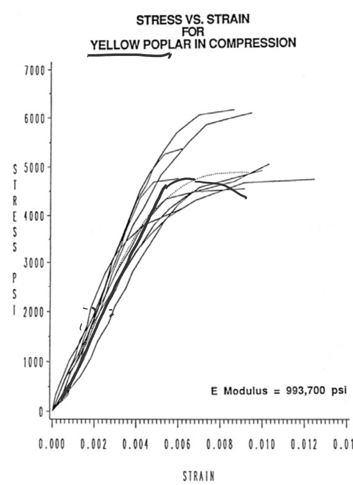
Fig.2B.

Young's Modulus

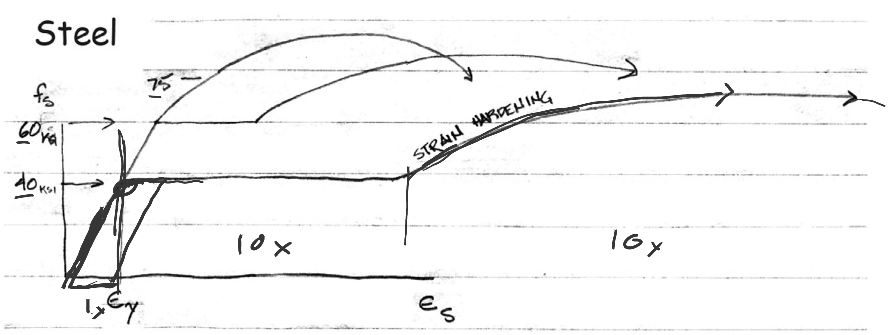
Young's Modulus or the Modulus of Elasticity, is obtained by dividing the stress by the strain present in the material. (Thomas Young, 1807)

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

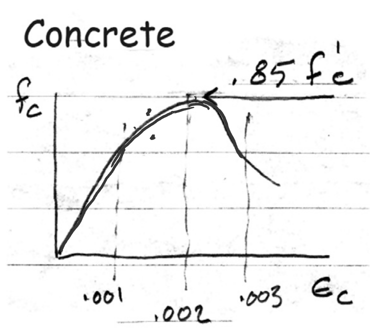
It thus represents a measure of the stiffness of the material.



E = 1000 ksi

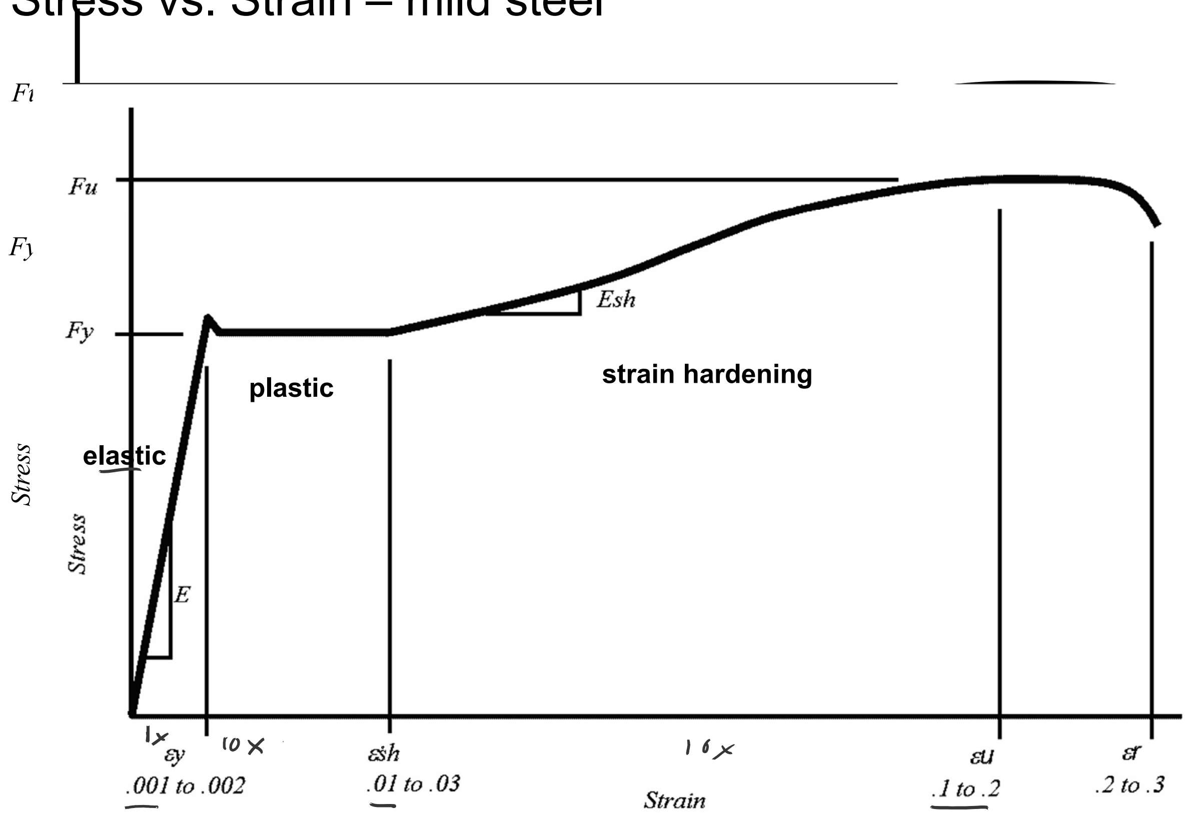


E = 29000 ksi



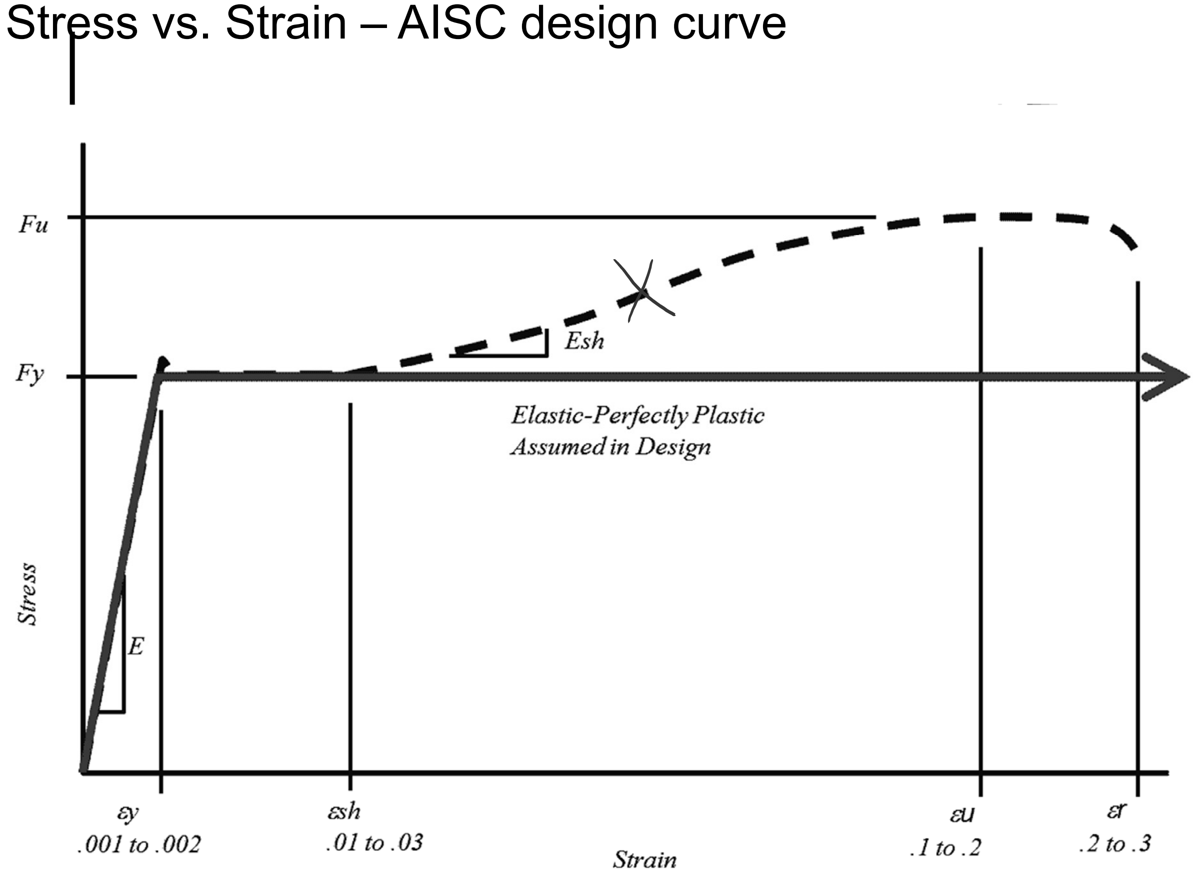
E = 3500 ksi

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

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

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

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

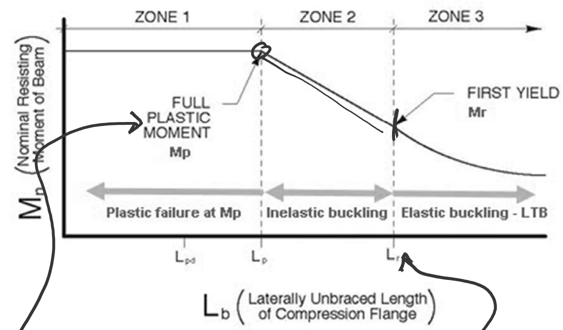
Design Strength $P_u \leq \phi \; P_n$ Required (Nominal) Strength

2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN

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

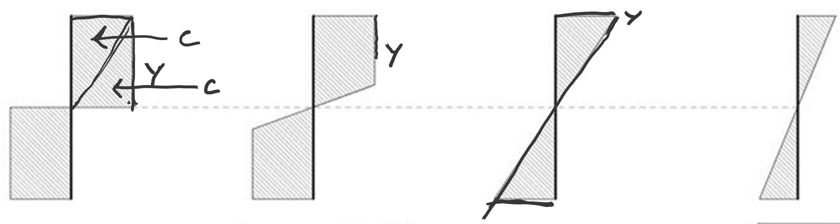
ASCE 7-2016

Beam Strength vs Unbraced Length



FULLY BRACED — NOT BRACED

ZONE 1	ZONE 2	First Yield	ZONE 3
Plastic Behavior Full Plastic Moment	Inelastic Buckling More than First Yield Less than Full Plastic Moment		Elastic Buckling



$Mn = Mp = Fy\,Z < 1.5\,My$	$Mn = Cb\left(Mp - (Mp - Mr)\left(\frac{Lb - Lp}{Lr - Lp}\right)\right) < Mp$	$Mr = 0.7\,Fy\,Sx$	$Mcr = Cb\frac{\pi}{L_b}\sqrt{E\,Iy\,G\,J + \left(\frac{\pi E}{L_b}\right)^2 Iy\,Cw}$
$Mu = \varnothing b\,Mn$	$Mu = \varnothing b\,Mn$	$Mu \le \varnothing b\,Mr$	$Mu \le \varnothing b\,Mcr$ (for doubly symmetric sections)

$\phi_b = 0.90$

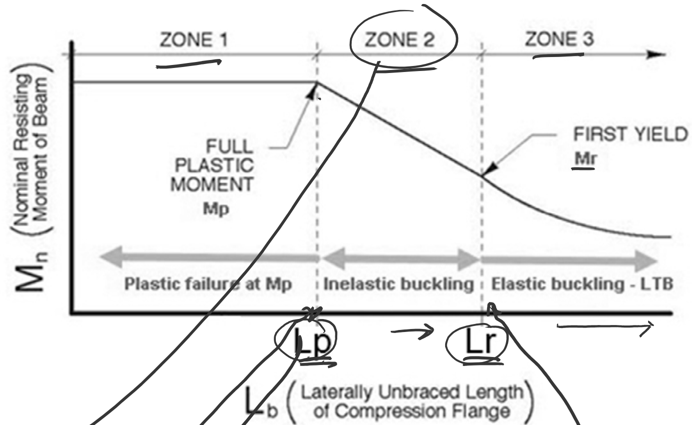
Steel Beams by LRFD

Yield Stress Values

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

Elastic Analysis for Bending

1. **Plastic Behavior (zone 1)**
   Mn = Mp = Fy Z < 1.5 My
   - Braced against LTB (Lb < Lp)
2. **Inelastic Buckling "Decreased" (zone 2)**
   Mn = Cb(Mp-(Mp-Mr)[(Lb-Lp)/(Lr-Lp)] < Mp
   - Lp < Lb < Lr
3. **Elastic Buckling "Decreased Further" (zone 3)**
   Mcr = Cb * π/Lb √(E*Iy*G*J + (π*E/Lb)^2 * IyCw)
   - Lb > Lr



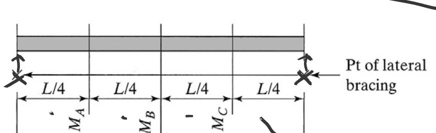
$Lp = 1.76\, r_y \sqrt{E/Fy}$

Mp = Fy Zx

Mr = 0.7 Fy Sx

Cb is LTB modification factor

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

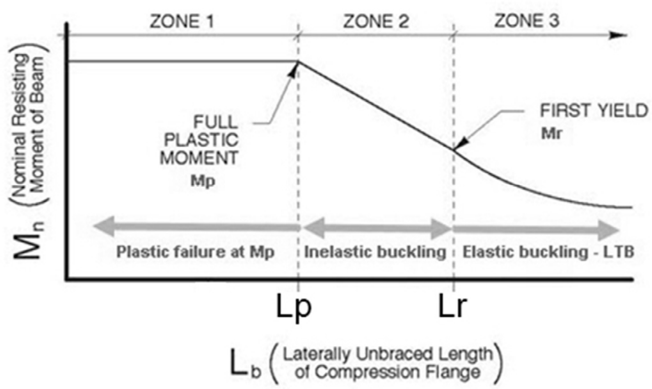


Steel Beams by LRFD

Analysis for Bending

AISC 15th ed.

- Plastic Behavior (zone 1)
  Mn = Mp = Fy Z < 1.5 My
  - Braced against LTB (Lb < Lp)
- Inelastic Buckling “Decreased” (zone 2)
  Mn = Cb(Mp-(Mp-Mr)[(Lb-Lp)/(Lr-Lp)] < Mp
  - Lp < Lb < Lr
- Elastic Buckling “Decreased Further” (zone 3)
  Mcr = Cb * π/Lb √(E*Iy*G*J + (π*E/Lb)^2 * IyCw)
  - Lb > Lr



Z_x ASD LRFD

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

F_y = 50 ksi

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
W21×44	**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
W18×35	**66.5**	**166**	249	**101**	151	**8.14**	12.3	**4.31**	**12.3**	**510**	**106**	159
W12×45	64.2	160	241	101	151	3.80	5.80	6.89	22.4	348	81.1	122
W16×36	64.0	160	240	98.7	148	6.24	9.36	5.37	15.2	448	93.8	141
W14×38	61.5	153	231	95.4	143	5.37	8.20	5.47	16.2	385	87.4	131
W10×49	60.4	151	227	95.4	143	2.46	3.71	8.97	31.6	272	68.0	102
W8×58	59.8	149	224	90.8	137	1.70	2.55	7.42	41.6	228	89.3	134
W12×40	57.0	142	214	89.9	135	3.66	5.54	6.85	21.1	307	70.2	105
W10×45	54.9	137	206	85.8	129	2.59	3.89	7.10	26.9	248	70.7	106
W14×34	**54.6**	**136**	205	**84.9**	128	**5.01**	7.55	**5.40**	**15.6**	**340**	**79.8**	120
W16×31	**54.0**	**135**	203	**82.4**	124	**6.86**	10.3	**4.13**	**11.8**	**375**	**87.5**	131
W12×35	51.2	128	192	79.6	120	4.34	6.45	5.44	16.6	285	75.0	113
W8×48	49.0	122	184	75.4	113	1.67	2.55	7.35	35.2	184	68.0	102
W14×30	**47.3**	**118**	177	**73.4**	110	**4.63**	6.95	**5.26**	**14.9**	**291**	**74.5**	112
W10×39	46.8	117	176	73.5	111	2.53	3.78	6.99	24.2	209	62.5	93.7
W16×26[v]	**44.2**	**110**	166	**67.1**	101	**5.93**	8.98	**3.96**	**11.2**	**301**	**70.5**	106
W12×30	43.1	108	162	67.4	101	3.97	5.96	5.37	15.6	238	64.0	95.9

ASD	LRFD
Ω_b = 1.67 Ω_v = 1.50	ϕ_b = 0.90 ϕ_v = 1.00

[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(a) with F_y = 50 ksi; therefore, ϕ_v = 0.90 and Ω_v = 1.67.

S.F.

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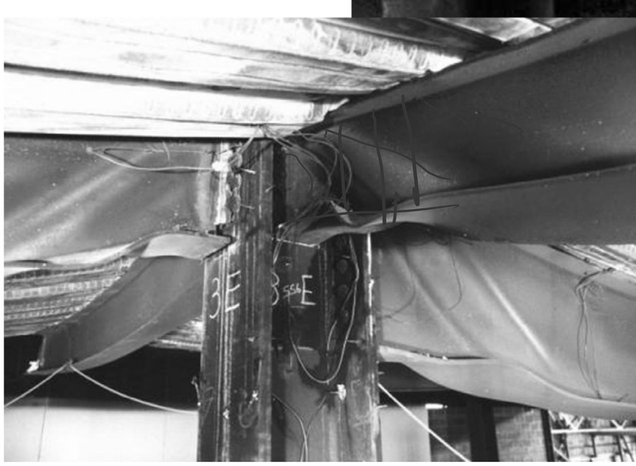
Design for Shear

Steel



Design for Shear

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

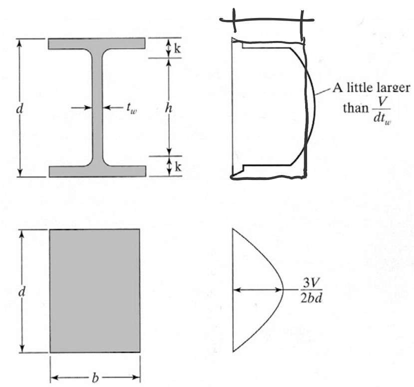
$F_v = V / A_w$

$A_w = d * t_w$

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