# Steel & Wood Column Design

#### **Design Aims**

If we know the loads, we can select a section that is adequate for strength & buckling.

If we know the length, we can find the limiting load satisfying strength & buckling.

#### **Design Code Methodologies**

Allowable Stress Design (ASD): the stress in a member must be less than an allowable stress which is equal to the yield stress divided by a factor of safety.

Load and Resistance Factor Design: more efficient method that factors loads for importance and compares the summation to a nominal strength that has been adjusted by a reduction factor.

## Allowable Stress Design - Steel

American Institute of Steel Construction (AISC) Manual of ASD, 9<sup>th</sup> ed:

 $\underline{Long \ and \ slender:} \ \ [ \ L_e/r \geq C_c, \ preferably < 200]$ 

$$F_{allowable} = \frac{F_{cr}}{F.S.} = \frac{12\pi^2 E}{23(KL/r)^2}$$

The yield limit is idealized into a parabolic curve that blends into the Euler's Formula at  $C_{\rm c}$ .

With 
$$F_y = 36 \text{ ksi}$$
,  $C_c = 126.1$ 

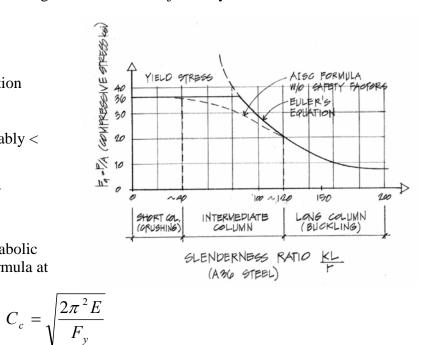
With 
$$F_v = 50$$
 ksi,  $C_c = 107.0$ 

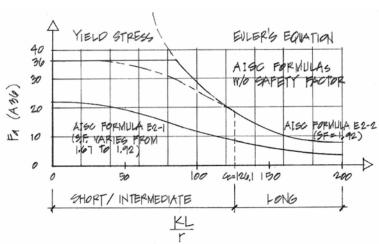
Short and stubby:  $[L_e/r < C_c]$ 

$$F_a = \left[ 1 - \frac{\left( \frac{KL_r}{r} \right)^2}{2C_c^2} \right] \frac{F_y}{F.S.}$$

with:

$$F.S. = \frac{5}{3} + \frac{3(KL/r)}{8C_c} - \frac{(KL/r)^3}{8C_c^3}$$





#### Procedure for Analysis

- 1. Calculate KL/r for each axis (if necessary). The largest will govern the buckling load.
- 2. Find  $F_a$  as a function of KL/r from Table 10.1 or 10.2 (pp. 361-364)
- 3. Compute  $P_{allowable} = F_a \cdot A$  or alternatively compute  $f_{actual} = P/A$
- 4. Is the design satisfactory?

Is 
$$P \le P_{\text{allowable}}$$
?  $\Rightarrow$  yes, it is; no, it is no good   
or Is  $f_{\text{actual}} \le F_a$ ?  $\Rightarrow$  yes, it is; no, it is no good

#### Procedure for Design

- 1. Guess a size by picking a section.
- 2. Calculate KL/r for each axis (if necessary). The largest will govern the buckling load.
- 3. Find F<sub>a</sub> as a function of KL/r from Table 10.1 or 10.2 (pp. 361-364)
- 4. Compute  $P_{allowable} = F_a \cdot A$  or alternatively compute  $f_{actual} = P/A$
- 5. Is the design satisfactory?

Is  $P \le P_{allowable}$ ?  $\Rightarrow$  yes, it is; no, pick a bigger section and go back to step 2. or Is  $f_{actual} \le F_a$ ?  $\Rightarrow$  yes, it is; no, pick a bigger section and go back to step 2.

6. Check design efficiency by calculating percentage of stress used =  $\frac{P_{actual}}{P_{allowable}} \cdot 100\%$  If value is between 90-100%, it is efficient.

If values is less than 90%, pick a smaller section and go back to step 2.

The critical load with respect to the slenderness ratio is presented in chart format in ASD, 8<sup>th</sup> ed, as well as the allowable stress charts for compression members.

#### Allowable Stress Design - Wood

National Design Specification for Wood Construction (1992):

Any slenderness ratio,  $L_e/d \le 50$ :

$$f_c = \frac{P}{A} \le F_c' \qquad F_c' = F_c(C_D)(C_M)(C_t)(C_F)(C_p)$$

The curve uses factors to replicate the combination curve:

where:

 $F_c$ ' = allowable compressive stress parallel to the grain

 $F_c$  = compressive strength parallel to the grain

 $C_D$  = load duration factor

 $C_M$  = wet service factor (1.0 for dry)

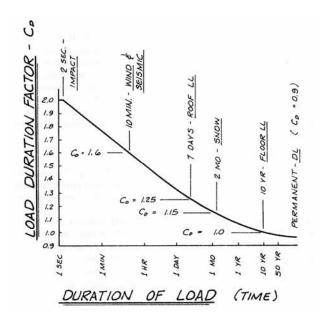
 $C_t$  = temperature factor

 $C_F$  = size factor

Cp = column stability factor off chart

For preliminary column design:

$$F_c' = F_c^* C_p = (F_c C_D) C_p$$



## Procedure for Analysis

- 1. Calculate L<sub>e</sub>/d<sub>min</sub>
- 2. Obtain F'<sub>c</sub>

compute 
$$F_{cE} = \frac{K_{cE}E}{\binom{l_c}{d}^2}$$
 with  $K_{cE} = 0.3$  for sawn, = 0.418 for glu-lam

- 3. Compute  $F_c^* \cong F_c C_D$  with  $C_D = 1$ , normal,  $C_D = 1.25$  for 7 day roof...
- 4. Calculate  $F_{cE}/F_c^*$  and get  $C_p$  from Appendix A, Table 14 (pp. 413-414)
- 5. Calculate  $F'_c = F^*_c C_p$
- 6. Compute  $P_{allowable} = F'_{c} \cdot A$  or alternatively compute  $f_{actual} = P/A$
- 7. Is the design satisfactory?

Is 
$$P \le P_{\text{allowable}}$$
?  $\Rightarrow$  yes, it is; no, it is no good   
or Is  $f_{\text{actual}} \le F'_{\text{c}}$ ?  $\Rightarrow$  yes, it is; no, it is no good

## Procedure for Design

- 1. Guess a size by picking a section
- 2. Calculate  $L_e/d_{min}$
- 3. Obtain F'<sub>c</sub>

compute 
$$F_{cE} = \frac{K_{cE}E}{\binom{l_c/d}{2}^2}$$
 with  $K_{cE} = 0.3$  for sawn, = 0.418 for glu-lam

- 4. Compute  $F_c^* \cong F_c C_D$  with  $C_D = 1$ , normal,  $C_D = 1.25$  for 7 day roof...
- 5. Calculate  $F_{cE}/F_c^*$  and get  $C_p$  from Appendix A, Table 14 (pp. 413-414)

- 6. Calculate  $F_c' = F_c^* C_p$
- 7. Compute  $P_{\text{allowable}} = F'_{c} \cdot A$  or alternatively compute  $f_{actual} = P/A$
- 8. Is the design satisfactory?

Is  $P \le P_{allowable}$ ?  $\Rightarrow$  yes, it is; no, pick a bigger section and go back to step 2. or Is  $f_{actual} \le F'_{c}$ ?  $\Rightarrow$  yes, it is; no, pick a bigger section and go back to step 2.

#### **Load & Resistance Factor Design**

American Institute of Steel Construction (AISC) Manual of LRFD, 3<sup>rd</sup> ed:

 $\sum \gamma_i Q_i \leq \phi P_n$  where

γ is a <u>load factor</u> Q is a <u>load</u> type

 $\phi$  is a <u>resistance factor</u>

P<sub>n</sub> is the <u>nominal load capacity (strength)</u>

Load combinations, ex:

1.4D (D is dead load) 1.2D + 1.6L (L is live load)

For compression,  $\phi_c = 0.85$  and  $P_n = A_g F_{cr}$ 

where:

 $A_{\rm g}$  is the cross section area and  $F_{\rm cr}$  is the critical stress shown below (in Compact Sections).

#### **Compact Sections**

Compact sections are defined as sections with flanges continuously connected to the web or webs and the width-thickness rations are less than limiting values given in the manual. This is to avoid local buckling of the flange or the web.

Formula parts depend on  $\lambda_c = \frac{Kl}{r\pi} \sqrt{\frac{F_y}{E}}$  where  $\frac{Kl}{r} = \frac{L_e}{r}$ ,

when  $\lambda_c \leq 1.5$ :

 $F_{cr} = (0.658^{\frac{2^2}{c^2}}) F_y$  where  $F_{cr}$  is the critical stress

when  $\lambda_c > 1.5$ :

$$F_{cr} = \left[\frac{0.877}{\lambda_c^2}\right] F_y$$

# Sample AISC Table for Allowable Axial Loads (ASD)

106   96   87   79   79   72   65	×		*	9	S ≥ 3	COLUMNS W shapes	NS				<b>m</b> <sub>y</sub>	= 20	ksi
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106   36   36   37   37   37   37   37   3	T											ľ	
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# Sample AISC Table for LRFD Design Strength in Compression

NIC   Stape   106   96   87   79   72   6511   58   53		×	
106   96   87   79   72   6511   56   56   1330   1200   1090   986   897   812   723   66   1140   1030   933   848   757   666   690   1120   11100   994   995   894   757   666   690   11210   11010   994   990   818   757   666   690   11210   11010   994   990   818   757   666   690   11210   11010   994   990   818   758   649   561   56		7	
106         96         67         79         72         6511         58           1330         1200         1090         986         897         812         723         66           1280         1150         1030         993         848         757         666         66           1240         11120         1010         994         861         757         666         661           1240         11120         1010         994         861         779         680         661           1110         1120         1010         994         861         779         669         661           1110         994         997         860         800         771         666         661         568         641         779         660         671         779         660         670         670         668         545         440         671         670         668         545         440         471         660         670         660         670         670         670         670         670         670         670         670         670         670         670         670         670         670         670 <th></th> <th></th> <th></th>			
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1260	623 562	504	450
1240         1120         1010         917         884         754         649         51           1120         1100         997         880         800         724         649         51           1150         1070         973         880         800         722         611         51           1110         995         990         814         740         668         545         61           1100         995         901         814         740         668         545         61           1100         996         901         814         740         668         545         61           1100         996         901         814         740         668         545         64           1000         904         817         790         771         647         521         496	0.02	486	434
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1190   1070   973   880   800   723   611   611   611   611   611   612   613   61		445	396
1160   1050   950   860   781   706   590   591   1130   1020   926   838   761   687   588   545   1170   995   901   814   740   688   545   541   1100   995   901   814   740   688   545   541   1040   995   901   814   740   688   545   541	559 472	422	376
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1100   995   901   814   740   668   545   446   1040   996   874   790   717   647   521   446   1040   996   817   794   717   647   521   446   998   871   788   771   645   581   447   446   992   882   882   822   883   822   822   822   822   823   822   823   822   823   8	518 418	374	332
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783         773         634         570         617         464         322         276         675         677         477         276         276         276         276         276         276         276         276         276         276         276         276         276         276         276         276         276         276         276         277         276         176         176         176         176         176         176         176         176         176         176         177         176         176         177         176         176         177         176         176         177 <td>334 208</td> <td>185</td> <td>163</td>	334 208	185	163
708 635 572 514 465 417 276 5 5 5 5 5 5 5 5 5 1 49 465 417 276 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	290 172	152	135
635 569 511 459 415 372 235 245 565 505 453 406 367 327 2255 225 443 443 397 305 321 287 282 202 144 443 397 305 321 282 222 155 145 245 202 147 110 279 249 223 221 157 110 279 249 223 221 157 110 279 249 223 221 157 110 279 249 223 221 157 110 279 249 223 221 157 110 279 249 223 215 156 149 110 110 110 110 110 110 110 110 110 11			113
565         905         497         443         397         365         367         378         202         202         406         367         378         202         202         406         367         378         202         202         176         176         176         176         176         176         176         176         176         176         176         176         177         172         172         176         179         170 <td></td> <td>_</td> <td>96.5</td>		_	96.5
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345 345 309 277 226 223 137 1 2 2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	139 81.2	2 72.1	63.7
345 308 276 247 223 199 122 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	123		
279   249   223   200   179   110   242   223   200   181   161   99.2   242   226   182   200   181   161   99.2   242   226   182   235   215   135   112   205   275   258   235   215   195   180   2276   228   185   152   156   103   115   226   238   103   103   237   231   191   170   231   232   231   191   170   231   231   232   231   191   170   231   231   232   231   2	110		
242         206         182         156         170penties           30.5         27.5         25.8         23.5         21.5         19.5         18.0           60.9         445         36.5         27.8         21.3         15.9         12.5           27.6         22.8         185         15.2         126         10.5         11.5           44.9         41.4         38.4         38.7         33.6         31.7         27.0           33.2         26.2         25.6         23.2         21.1         19.1         17.0           33.1         27.0         44.9         44.6         46.2         59.7         53.3         47.5           31.2         26.2         25.6         23.2         21.1         19.1         17.0           33.1         27.0         24.1         216         19.4         107         107           3.11         3.09         30.7         30.4         30.2         25.1           1.76         1.76         1.75         1.75         1.75         210	98.4		
242         206         182         156         137         117         112           305         275         258         235         215         195         180           609         445         365         278         213         159         125           276         228         185         176         105         115         115           449         414         384         357         336         317         270           3312         282         256         292         211         191         170           333         740         662         597         533         475           311         309         307         241         216         194         107           311         309         307         241         216         176         177         210			
30.5         27.5         25.8         23.5         21.5         19.5         18.0           60.9         44.5         36.5         27.8         21.3         15.9         12.5           27.6         22.8         18.5         12.6         10.9         11.5           41.0         10.9         10.7         11.9         27.0           31.2         28.2         25.7         33.6         31.7         27.0           33.2         28.2         25.1         19.1         17.0           33.1         28.0         24.1         26.5         53.3         47.5           31.1         39.9         30.7         30.9         30.4         30.7           31.1         17.6         17.5         17.5         17.5         17.7	101 105	90.5	75.2
609         445         365         278         213         159         125           276         228         185         152         126         103         115           110         110         108         108         107         119         270           449         414         384         357         336         317         270           312         282         286         282         211         131         170           933         833         740         662         597         533         475           311         270         241         216         196         174         107           311         309         307         341         266         530         475           176         176         175         175         175         175         210	17.3 18.5	16.8	14.8
276         228         185         152         126         103         115           11.0         16.9         10.8         10.8         10.7         11.9         887           44.9         41.4         384         35.7         33.6         31.7         27.0           31.2         28.2         25.6         23.2         21.1         19.1         17.0           33.1         27.0         66.2         597         593         475           31.1         3.9         30.7         241         216         196         174         107           176         176         175         175         175         175         210	110 133	98.6	67.4
11.0         16.9         10.8         10.8         10.7         11.9         8.87           44.9         41.4         38.4         35.7         33.6         31.7         27.0           31.2         28.2         28.2         21.1         19.1         17.0           93.3         83.3         740         68.2         59.7         53.3         475           31.1         270         24.1         216         194         107         107           3.11         3.09         30.7         30.8         30.4         261         107           1.76         1.76         1.75         1.75         1.75         210			74.6
449         414         384         35.7         33.6         31.7         27.0           31.2         28.2         25.6         23.2         21.1         19.1         17.0           933         833         740         662         597         533         475           301         270         241         216         196         174         107           311         309         307         305         304         302         251           176         176         175         175         175         175         210			6.85
31.2 28.2 25.6 23.2 21.1 17.0 933 833 740 662 597 533 475 301 270 241 216 195 174 107 3.11 3.99 3.07 3.05 3.04 3.02 2.51 1.76 1.76 1.75 1.75 1.75 1.75 2.10			19.2
933 833 740 662 597 533 475 301 270 241 216 195 174 107 3.11 3.99 3.07 3.63 3.04 3.02 2.51 1.76 1.76 1.75 1.75 1.75 2.10			771
3.11 3.09 3.07 3.65 1.75 1.75 1.75 1.75 1.75 1.75 1.75 1.7	6 22 6 26	0 00	444
1.76 1.75 1.75 1.75 2.10			1.94
			2.64
26700 23800 21200 18900 17100 15300 13600	57		8790
P, (KB)/104 8620 7730 6900 6180 5580 4980 3060 2740	2740 1610	1430	1260
"Flange is non-compact.			

### Example 1 (pg 367)

## Example Problem 10.10 (Figure 10.41)

A 24-ft.-tall, A572 grade 50, steel column (W14×82) with an  $F_y$  = 50 ksi has pins at both ends. Its weak axis is braced at midheight, but the column is free to buckle the full 24 ft. in the strong direction. Determine the safe load capacity for this column.

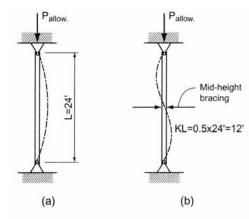
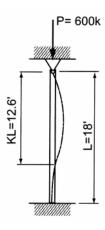


Figure 10.41 (a) Strong axis buckling. (b) Weak axis buckling.

### Example 2 (pg 371) + chart method Example Problem 10.14: Design of Steel Columns (Figure 10.48)

Select the most economical W12  $\times$  column 18' in height to support an axial load of 600 kips using A572 grade 50 steel. Assume that the column is hinged at the top but fixed at the base.

ALSO: Select the column using the ASD design charts, and the LRFD charts assuming that the load is a dead load (factor of 1.4)

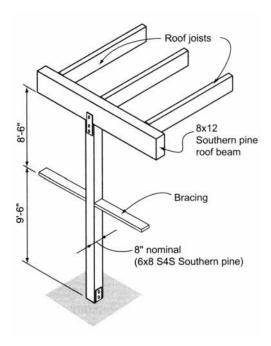


## Example 3 (pg 379)

## Example Problem 10.18 (Figures 10.60 and 10.61)

An 18' tall 6×8 Southern pine column supports a roof load (dead load plus a 7-day live load) equal to 16 kips. The weak axis of buckling is braced at a point 9'6" from the bottom support. Determine the adequacy of the column.

$$F_c = 975 \text{ psi}, E = 1.6 \times 10^6 \text{ psi}$$



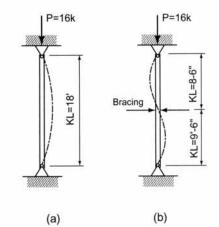


Figure 10.61 (a) Strong axis. (b) Weak axis.

## Example 4 (pg 381)

Example Problem 10.20:

Design of Wood Columns(Figure 10.66)

A 22'-tall glu-lam column is required to support a roof load (including snow) of 40 kips. Assuming  $8^{3}/_{4}$ " in one dimension (to match the beam width above), determine the minimum column size if the top and bottom are pin supported.

Select from the following sizes:

$$8^{3}/_{4}$$
" × 9" ( $A = 78.75 \text{ in.}^{2}$ )

$$8^{3/4}$$
"  $\times$  10<sup>1</sup>/<sub>2</sub>" ( $A = 91.88 \text{ in.}^{2}$ )

$$8^{3/4}$$
" × 12" ( $A = 105.00 \text{ in.}^{2}$ )

