Steel Construction
• standard rolled shapes
• open web joists
• plate girders
• decking

Steel
• cast iron – wrought iron - steel
• cables
• columns
• beams
• trusses
• frames

Steel Construction
• welding
• bolts

Steel Construction
• welding
• bolts
Steel Construction

- fire proofing
  - cementicious spray
  - encasement in gypsum
  - intumescent – expands with heat
  - sprinkler system

Steel Materials

- high strength to weight ratio
- ductile
- beam size often limited by deflection
- column size limited by slenderness

Steel Beams

- types
  - manufactured shapes
  - castellated

Steel Beams

- types
  - wide flange
Steel Beams

- types
  - open web joists (manufactured trusses)

Steel Beams

- types (more)
  - plate girder
  - decking

Steel Beams

- lateral stability - bracing
- local buckling - stiffen
Local Buckling

- steel I beams
- flange
  - buckle in direction of smaller radius of gyration
- web
  - force
  - “crippling”

Shear in Web

- panels in plate girders or webs with large shear
- buckling in compression direction
- add stiffeners

Steel Beams

- end conditions
  - a) away from connection - full section effective
  - b) high shear – only web effective
Steel Beams

• end conditions
  
  • c) bolt holes – less material
  
  • d) local web buckling

Steel Beams

• bearing
  
  – provide adequate area
  – prevent local yield of flange and web

Steel Beams

• connections
  
  – welds
  – bolts

Steel Design – Open Web Joists

• SJI: www.steeljoist.com
• Vulcraft: www.vulcraft.com
  
  – K Series (Standard)
    • 8-30" deep, spans 8-50 ft
  
  – LH Series (Long span)
    • 18-48" deep, spans 25-96 ft
  
  – DLH (Deep Long Spans)
    • 52-72" deep, spans 89-144 ft
  
  – SLH (Long spans with high strength steel)
    • pitched top chord
    • 80-120" deep, spans 111-240 ft
Steel Design – Open Web Joists

Steel Beam Design

- American Institute of Steel Construction
  - steel grades
    - ASTM A36 – carbon
      - plates, angles
      - $F_y = 36$ ksi & $F_u = 58$ ksi
    - ASTM A572 – high strength low-alloy
      - some beams
      - $F_y = 60$ ksi & $F_u = 75$ ksi
    - ASTM A992 – for building framing
      - most beams
      - $F_y = 50$ ksi & $F_u = 65$ ksi
Unified Steel Design

- ASD
  \[ R_a \leq \frac{R_n}{\Omega} \]
  - bending (braced) \( \Omega = 1.67 \)
  - bending (unbraced) \( \Omega = 1.67 \)
  - shear \( \Omega = 1.5 \) or \( 1.67 \)
  - shear (bolts & welds) \( \Omega = 2.00 \)
  - shear (welds) \( \Omega = 2.00 \)

* flanges in compression can buckle

LRFD Steel Beam Design

- limit state is yielding all across section
- outside elastic range
- load factors & resistance factors

Load Types

- \( D = \) dead load
- \( L = \) live load
- \( L_r = \) live roof load
- \( W = \) wind load
- \( S = \) snow load
- \( E = \) earthquake load
- \( R = \) rainwater load or ice water load
- \( T = \) effect of material & temperature

![Graph](image_url)
LRFD Load Combinations

- 1.4D
- 1.2D + 1.6L + 0.5(L_r or S or R)
- 1.2D + 1.6(L_r or S or R) + (L or 0.5W)
- 1.2D + 1.0W + L + 0.5(L_r or S or R)
- 1.2D + 1.0E + L + 0.2S
- 0.9D + 1.0W
- 0.9D + 1.0E
  - F has same factor as D in 1-5 and 7
  - H adds with 1.6 and resists with 0.9 (permanent)

Pure Flexure

\[ \sum \gamma_i R_i = M_u \leq \phi_b M_n = 0.9 F_y Z \]

- \(M_u\) - maximum moment
- \(\phi_b\) - resistance factor for bending = 0.9
- \(M_n\) - nominal moment (ultimate capacity)
- \(F_y\) - yield strength of the steel
- \(Z\) - plastic section modulus*

Internal Moments - at yield

- material hasn’t failed

\[
M_y = \frac{I}{c} f_y = \frac{bh^2}{6} f_y
\]

\[
= \frac{b(2c)^2}{6} f_y = \frac{2bc^2}{3} f_y
\]

Internal Moments - ALL at yield

- all parts reach yield
- plastic hinge forms
- ultimate moment
- \(A_{\text{tension}} = A_{\text{compression}}\)

\[
M_p = bc^2 f_y = \frac{3}{2} M_y
\]
n.a. of Section at Plastic Hinge

- cannot guarantee at centroid
- \( f_y A_1 = f_y A_2 \)
- moment found from yield stress times moment area

\[
M_p = f_y A_1 d = f_y \sum_i A_i d_i
\]

Plastic Hinge Development

Plastic Hinge Examples

- stability can be effected

Plastic Section Modulus

- shape factor, \( k \)

\[
k = \frac{M_p}{M_y} = \frac{Z}{S}
\]

- plastic modulus, \( Z \)

\[
Z = \frac{M_p}{f_y}
\]
Shear

\[ \Sigma \gamma_i R_i = V_u \leq \phi_v V_n = 1.0(0.6F_{yw}A_w) \]

- \( V_u \): maximum shear
- \( \phi_v \): resistance factor for shear = 1.0
- \( V_n \): nominal shear
- \( F_{yw} \): yield strength of the steel in the web
- \( A_w \): area of the web = \( t_w d \)

Flexure Design

- limit states for beam failure
  1. yielding
  2. lateral-torsional buckling
  3. flange local buckling
  4. web local buckling
- minimum \( M_n \) governs

\[ \Sigma \gamma_i R_i = M_u \leq \phi_b M_n \]

Compact Sections

- plastic moment can form before any buckling
- criteria

\[ - \frac{b_f}{2t_f} \leq 0.38 \left( \frac{E}{F_y} \right) \]

\[ - \text{ and } \frac{h_c}{t_w} \leq 3.76 \left( \frac{E}{F_y} \right) \]

Lateral Torsional Buckling

\[ M_n = C_b \left[ \text{moment based on lateral buckling} \right] \leq M_p \]

\[ C_b = \frac{12.5M_{\text{max}}}{2.5M_{\text{max}} + 3M_A + 4M_B + 3M_C} \]

- \( C_b \): modification factor
- \( M_{\text{max}} \): \( |\text{max moment}| \), unbraced segment
- \( M_A \): \( |\text{moment}| \), 1/4 point
- \( M_B \): \( |\text{moment}| \), center point
- \( M_C \): \( |\text{moment}| \), 3/4 point
**Beam Design Charts**

<table>
<thead>
<tr>
<th>W Shapes</th>
<th>Available Moment vs. Unbraced Length</th>
</tr>
</thead>
</table>

- Table 3-10 (continued)

**Deflection Limits**

- based on service condition
- no “impairment” to serviceability
- avoid ponding
- L/360 due to live load for beams & girders supporting plaster (service)

**Steel Arches and Frames**

- solid sections
- or open web

**Steel Shell and Cable Structures**

- [Link](http://nisee.berkeley.edu/godden)
Approximate Depths

Unified Column Design

- limit states for failure

\[ P_a \leq \frac{P_n}{\Omega} \]
\[ \phi_c = 0.90 \]
\[ P_n = F_{cr}A_g \]
\[ P_u \leq \phi_c P_n \]

1. yielding \[ \frac{KL}{r} \leq 4.71 \left( \frac{E}{F_y} \right) \text{ or } F_e \leq 0.44F_y \]

2. buckling \[ \frac{KL}{r} > 4.71 \left( \frac{E}{F_y} \right) \text{ or } F_e < 0.44F_y \]

\( F_e \) – elastic buckling stress (Euler)

Procedure for Analysis

1. calculate KL/r
   - biggest of KL/r with respect to x axes and y axis

2. find \( F_{cr} \) from appropriate equation
   - tables are available

3. compute \( P_n = F_{cr}A_g \)
   - or find \( f_c = P_n/A \) or \( P_u/A \)

4. is \( P_a \leq \frac{P_n}{\Omega} \) or \( P_u \leq \phi_c P_n \)?
   - yes: ok
   - no: insufficient capacity and no good
**Procedure for Design**

1. **guess a size (pick a section)**
2. **calculate KL/r**
   - biggest of KL/r with respect to x axes and y axis
3. **find** $F_{cr}$ **from appropriate equations**
   - or find a table
4. **compute** $P_n = F_{cr}A_g$
   - or find $f_c = P_a/A$ or $P_u/A$

**Procedure for Design (cont’d)**

5. **is $P_a \leq P_n/\Omega$ or $P_u \leq \phi P_n$?**
   - yes: ok
   - no: pick a bigger section and go back to step 2.
6. **check design efficiency**
   - percentage of stress $= \frac{P_r}{P_c} \cdot 100\%$
   - if between 90-100%: good
   - if < 90%: pick a smaller section and go back to step 2.

---

**Column Tables**

<table>
<thead>
<tr>
<th>$F_y = 50$ ksi</th>
<th>(continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available Strength in Axial Compression, kips</strong></td>
<td>W Shapes</td>
</tr>
<tr>
<td></td>
<td>W12x</td>
</tr>
<tr>
<td>W10</td>
<td>( P_{f1/\Omega} )</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td><strong>ASD</strong></td>
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<tr>
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<td>--------</td>
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<td>0</td>
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<td>756</td>
</tr>
<tr>
<td>11</td>
<td>739</td>
</tr>
</tbody>
</table>

**Beam-Column Design**

- **moment magnification ($P-\Delta$)**
  
  \[
  M_u = B_1 M_{\text{max-factorized}} \quad B_1 = \frac{C_m}{1 - (P_u/P_{c1})}
  \]

  \(C_m\) – modification factor for end conditions

  \(= 0.6 - 0.4(M_s/M_2)\) or

  \(0.85\) restrained, \(1.00\) unrestrained

  \(P_{c1}\) – Euler buckling strength
  \(P_{c1} = \frac{\pi^2 EA}{(Kl/r)^2}\)
Beam-Column Design

- LRFD (Unified) Steel
  - for \( \frac{P_r}{P_c} \geq 0.2 \):
    \[
    \frac{P_u}{\phi_c P_n} + \frac{8}{9} \left( \frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) \leq 1.0
    \]
  - for \( \frac{P_r}{P_c} < 0.2 \):
    \[
    \frac{P_u}{2\phi_c P_n} + \frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \leq 1.0
    \]

\( P_r \) is required, \( P_c \) is capacity

\( \phi_c \) - resistance factor for compression = 0.9
\( \phi_b \) - resistance factor for bending = 0.9

Construction Supervision

- proper grade material
  - high strength bolts
- quality welds
- proper bolted conditions (ex. sc)
- fabrication and erection of steel frame connection details