LRFD design of steel beams

LRFD Beam Design 1
Lecture 22

Architectural Structures I
ENDS 231
Load and Resistance Factor Design

- loads on structures are
  - not constant
  - can be more influential on failure
  - happen more or less often
  - UNCERTAINTY

\[ \sum \gamma_i R_i \leq \phi R_n \]

- \( \phi \) - resistance factor
- \( \gamma \) - load factors for types of loads (\( R \))
- \( R_n \) – nominal strength
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
Load Combinations

“summation” means AND (combine)

- 1.4(D + F)
- 1.2(D + F + T) + 1.6(L + H) + 0.5(L_r or S or R)
- 1.2D + 1.6(L_r or S or R) + (L or 0.8W)
- 1.2D + 1.6W + L + 0.5(L_r or S or R)
- 1.2D + 1.0E + L + 0.2S
- 0.9D + 1.6W + 1.6H
- 0.9D + 1.0E + 1.6H
Steel Materials

• ASTM A36 – carbon
  – plates, angles
  – $F_y = 36 \text{ ksi}$ & $F_u = 58 \text{ ksi}$

• ASTM A572 – high strength low-alloy
  – some beams
  – $F_y = 60 \text{ ksi}$ & $F_u = 75 \text{ ksi}$

• ASTM A992 – for building framing
  – most beams
  – $F_y = 50 \text{ ksi}$ & $F_u = 65 \text{ ksi}$
Flexure

- limit is in plastic stress range

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

- \( M_u \): 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
- \( A_{\text{tension}} = A_{\text{compression}} \)

\[
M_p = b c^2 f_y = \frac{3}{2} M_y
\]
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

$$M_p = f_y A_1 d = f_y \sum_{n.a} A_i d_i$$
Plastic Hinge Development

\[(a) \ M < M_Y \]

\[(b) \ M = M_Y \]

\[(c) \ M > M_Y \]

\[(d) \ M = M_p \]
Plastic Hinge Examples

- stability can be effected
Plastic Section Modulus

- **shape factor, \( k \)**
  
  \[ k = \frac{M_p}{M_y} \]

  \( \approx 3/2 \) for a rectangle

  \( \approx 1.1 \) for an \( I \)

- **plastic modulus, \( Z \)**

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

\[ \Sigma \gamma_i R_i = V_u \leq \phi_v V_n = 0.9(0.6 F_{yw} A_w) \]

- \( V_u \) - maximum shear
- \( \phi_v \) - resistance factor for shear = 0.9
- \( V_n \) - 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**

\[ \sum \gamma_i R_i = M_u \leq \phi_b M_n \]
Lateral Torsional Buckling

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

\[ C_b = \frac{12.5 M_{\text{max}}}{2.5 M_{\text{max}} + 2 M_A + 4 M_B + 3 M_C} \]

\( C_b = \text{modification factor} \)

\( M_{\text{max}} = |\text{max moment}|, \text{ unbraced segment} \)

\( M_A = |\text{moment}|, 1/4 \text{ point} \)

\( M_B = |\text{moment}|, \text{ center point} \)

\( M_C = |\text{moment}|, 3/4 \text{ point} \)
Beam Design Charts

Beam Design Moments ($\phi_b=0.9$, $C_b=1.0$, $F_y=50$ ksi)

$\phi_b M_{\text{u}, \text{Design Moment}}$ (1 kip-ft increments)

$L_b$, Unbraced Length (0.5 ft increments)
Charts & Deflections

- **beam charts**
  - *solid line* is most economical
  - *dashed* indicates there is another more economical section
  - *self weight* is included in $M_n$

- **deflections**
  - *no factors are applied to the loads*
  - *often governs the design*