Connections

Connection Design Considerations

- joints often critical in design
  - can influence choice of structural system
- types used influenced by:
  - member behavior
  - member geometry
- basic types join by:
  - lapping
  - deforming and interlocking
  - butting

Connectors

- “third-elements”
  - bolts
  - nails
  - welds
  - splice plates
- transfer load at a point, line or surface
  - generally more than a point due to stresses

Connector Rigidity

- pinned joints
  - point type
- rigid joints
  - line and surface types
  - multiple “points” separated by distance resist moment

\[ T = C \quad M = Td = Cd \]
Point Connectors

- connected members in tension cause shear stress
  
  ![Diagram of a bolted connection with shear stress](image)

- connected members in compression cause bearing stress
  
  ![Diagram of a bolted connection with bearing stress](image)

Single Shear

- seen when 2 members are connected
  
  \[
  f_v = \frac{P}{A} = \frac{P}{\pi \frac{d^2}{4}}
  \]

  ![Diagram of a bolted connection with shear stress](image)

Double Shear

- seen when 3 members are connected
  
  \[
  \Sigma F = 0 = -P + 2\left(\frac{P}{2}\right)
  \]

  ![Diagram of a bolted connection in double shear](image)

Bearing Stress

- compression & contact
  
  \[
  f_p = \frac{P}{A_{projected}} = \frac{P}{td}
  \]

  ![Diagram of a bolted connection with bearing stress](image)
Beam Stresses

- shear – horizontal & vertical

Connectors Resisting Beam Shear

- plates with
  - nails
  - rivets
  - bolts

- splices

- $V$ from beam load related to $V_{\text{longitudinal}}$

$$\frac{V_{\text{longitudinal}}}{p} = \frac{VQ}{I}$$

$$nF_{\text{connector}} \geq \frac{VQ_{\text{connected area}}}{I} \cdot p$$

Vertical Connectors

- isolate an area with vertical interfaces

$$nF_{\text{connector}} \geq \frac{VQ_{\text{connected area}}}{I} \cdot p$$
Tension Members

- members with holes have reduced area
- increased tension stress
- $A_e$ is effective net area

$$f_t = \frac{P}{A_e} \left( \text{or} \frac{T}{A_e} \right)$$

Effective Net Area

- likely path to “rip” across
- bolts divide transferred force too

Wood Connectors

- adhesives
  - used in a controlled environment
  - can be used with nails
- mechanical
  - nails
  - bolts
  - lag bolts or lag screws
  - split ring and shear plate connectors
  - timber rivets

Wood Connections

- mechanical
Nails

- tension stress (pullout)
- shear stress
- nails presumed to share load by distance from centroid of nail pattern

Bolts

- bearing stress
  - parallel to grain
  - perpendicular to grain
- shear stress
- tension stress in member
- concerned with end shear rupture

Lag Screws

- tension stress (pullout)
  - avoid parallel to grain
- shear stress

Split Ring Connectors

- bearing stress
  - parallel to grain
  - perpendicular to grain
- shear stress
- tension stress in member
- concerned with end shear rupture
- (like bolts)
Plate Connections

- rigid
  - bolts or nails
  - plate
  - continuous at top & bottom

- shear
  - metal plate with teeth

Miscellaneous Connectors

- beam hangers
- frame anchors
- seats
- etc...

Steel Connections

- needed to:
  - support beams by columns
  - connect truss members
  - splice beams or columns

- transfer load
- subjected to
  - tension or compression
  - shear
  - bending

Bolts

- bolted steel connections
Welds

- welded steel connections

Bolts

- types
  - materials
    - high strength
  - location of threads
    - included
    - excluded
  - friction or bearing
    - always tightened

Bolted Connection Design

- considerations
  - bearing stress
    - yielding
  - shear stress
    - single & double
    - member
    - rupture

Bolted Connection Design

- Unified steel
  - shear:
    \[
    R_a \leq \frac{R_n}{\Omega} \quad R_u \leq \phi_v R_n \\
    \Omega = 2.00 \quad \phi_v = 0.75
    \]
  - bolt strengths
  - bolt types
    - A325-SC, A490-SC
    - A325-N, A490-N
    - A325-X, A490-X

Table T-1: Available Shear Strength of Bolts, kips

- Various bolt strengths and types are listed in the table, indicating their shear and bearing capacities.
Bolted Connection Design

• Unified steel
  – bearing:
    • bolts rarely fail by bearing
    • other part fails first
  – slip critical
    • tightened down
  – holes are 1/16” larger
  – effective hole widths are 1/8” more

Bolted Connection Design

• single shear or tension
  \[ R_u \leq \phi R_n \]
  \[ R_n = F_n A_b \]
  \[ \phi = 0.75 \]
• double shear
  \[ R_n = F_n 2A_b \]
• bolt area
  – threads excluded
  – threads included

Tension Members

• \( A_e = A_n U \)
  – \( A_n \) is actual net area
  – \( U \) is shear lag factor by element type

\[ A_n = A_g - A_{of \ all \ holes} + t \Sigma \frac{S}{4g} \]
Tension Members

- limit states for failure: \( R_u \leq \phi R_n \)
  1. yielding: \( \phi = 0.9 \quad R_n = F_y A_g \)
  2. rupture*: \( \phi = 0.75 \quad R_n = F_u A_e \)

\( A_g \) - gross area
\( A_e \) - effective net area
\( F_u \) = the tensile strength of the steel (ultimate)

Welded Connection Design

- weld terms
  - butt weld
  - fillet weld
  - plug weld
  - throat

- weld materials
  - E60XX
  - E70XX
  \( F_{EXX} = 70 \text{ ksi} \)

Welded Connection Design

- shear failure assumed
- throat
  - \( T = 0.707 \times \text{weld size} \)
- area
  - \( A = T \times \text{length of weld} \)
- weld metal generally stronger than base metal (ex. \( F_y = 50 \text{ ksi} \))
Welded Connection Design

- **minimum**
  - table
- **maximum**
  - material thickness (to ¼”)
  - 1/16” less
- **min. length**
  - 4 x size min.
  - ≥ 1 ½”

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Welded Connection Design

- shear

\[
R_a \leq \frac{R_n}{\Omega} \quad R_s \leq \phi R_n \\
\phi = 0.75
\]

\[
R_n = 0.6F_t \frac{EXX}{Tl} = Sl
\]

- table for \(\phi S\)

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Framed Beam Connections

- **angles**
  - bolted
  - welded

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Framed Beam Connections

- **terms**
  - coping
Framed Beam Connections
• tables for standard bolt holes & spacings
• $n =$ # bolts
• bolt diameter, angle leg thickness
• bearing on beam web

Other Beam Connections
• seated beam
  – unstiffened
  – stiffened
• continuous
  – beam to column
  – beam to beam

Other Connections
• rigid frame knees
• beam splice
• column splice

Beam Connections
• LRFD provisions
  – shear yielding
  – shear rupture
  – block shear rupture
  – tension yielding
  – tension rupture
  – local web buckling
  – lateral torsional buckling
Beam Connections

• LRFD design of connected elements
  – shear yielding \( \phi = 1.00 \quad R_n = 0.60 F_y A_g \)
  – shear rupture \( \phi = 0.75 \quad R_n = 0.60 F_u A_{nv} \)
  – block shear rupture \( \phi = 0.75 \)
  \[ R_n = 0.60 F_u A_{nv} + U_{bs} F_u A_{nt} \leq 0.6 F_y A_{gv} + U_{bs} F_u A_{nt} \]
  where \( U_{bs} \) is 1 for uniform tensile stress

• block shear rupture  • tension rupture

Beam Connections

– tension yielding \( \phi = 0.90 \quad R_n = F_y A_g \)
– tension rupture \( \phi = 0.75 \quad R_n = F_u A_e \)
– flexural yielding \( \phi_b = 0.90 \quad M_n = F_y Z_{(net)} \)
– local web buckling
– lateral torsional buckling

Beam Bearing

• design considerations
  – web crippling
  – base plate bending
  – bearing on concrete, etc.
• load distributed

Figure 5.10  Considerations for bearing in beams with thin webs, as related to web crippling (buckling of the thin web in compression).
Column Base Plates

- **attached by anchor bolts**
  - usually 4
  - 2 if no moment

- **plate level**
  - by shims & grout
  - leveling nuts

- **considers**
  - bearing on steel
  - bending of plate