CE591 Fall 2013
Lecture 26: Moment Connections

- Explain basic design procedure for moment (FR) connections
- Explain considerations for connections in moment-resisting frames for seismic demands
- Describe problems observed with the “pre-Northridge” connection and detailing
- Describe some of the requirements for the “WUF-B” connection developed after Northridge
- Describe some other connections, including current AISC prequalified connections
Welded Moment Connections

- Develop moment (typically $M_{pbeam}$) at joint
- Prefer compact sections
- Specify Complete Joint Penetration Weld (CJP) with “matching” weld
Basic Design Assumptions

- Bending Moment – tension and compression in flanges
- Shear – web connection
  - Eccentricity may be ignored [AISC 12-3]

Column may require horizontal stiffeners “Continuity Plates”
Moment Connections (Seismic)

- Adequate strength and stiffness for FR connection
- + Considerations / detailing for ductile behavior (moment frame)
\[ V = \frac{S_{DSI} I}{R} W \]

- Special Moment Frame \( \rightarrow 8 \)
- Ordinary Moment Frame \( \rightarrow 3.5 \)

Note: \( R=3 \)
Not specifically detailed for seismic resistance
\[ V = \frac{S_{DSI}}{R} \cdot W \]

Special Moment Frame \( \rightarrow 8 \)
Ordinary Moment Frame \( \rightarrow 3.5 \)

\underline{R = 3}
Design according to AISC Specifications
(no special detailing required)

\underline{R > 3}
Must follow detailing requirements in AISC Seismic Provisions

Note: R=3
Not specifically detailed for seismic resistance
**Strong Column – Weak Beam Concept**

AISC Seismic Provisions 2010, Section E3

\[
\frac{\Sigma M^*_{pc}}{\Sigma M^*_{pb}} \geq 1.0
\]

Includes reduction for axial force in column

Includes factors to increase based on expected yield stress, etc.
# Expected Strength Factor, $R_y$

AISC Seismic Provisions 2010, Table A3.1

<table>
<thead>
<tr>
<th>Hot-rolled Shapes</th>
<th>$R_y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A36</td>
<td>1.5</td>
</tr>
<tr>
<td>A992</td>
<td>1.1</td>
</tr>
</tbody>
</table>

\[
\frac{F_y}{F_y} - \text{expected} \quad \frac{F_y}{F_y} - \text{nominal}
\]
## TABLE A3.1
*RY* and *Rt* Values for Steel and Steel Reinforcement Materials

<table>
<thead>
<tr>
<th>Application</th>
<th><em>Ry</em></th>
<th><em>Rt</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-rolled structural shapes and bars:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• ASTM A36/A36M</td>
<td>1.5</td>
<td>1.2</td>
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<tr>
<td>• ASTM A1043/1043M Gr. 36 (250)</td>
<td>1.3</td>
<td>1.1</td>
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<tr>
<td>• ASTM A572/572M Gr. 50 (345) or 55 (380),</td>
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<td>1.1</td>
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<tr>
<td></td>
<td>• ASTM A913/A913M Gr. 50 (345), 60 (415), or 65 (450),</td>
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<tr>
<td></td>
<td></td>
<td>• ASTM A588/A588M, ASTM A992/A992M</td>
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<tr>
<td>• ASTM A1043/A1043M Gr. 50 (345)</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>• ASTM A529 Gr. 50 (345)</td>
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<td>1.2</td>
</tr>
<tr>
<td>• ASTM A529 Gr. 55 (380)</td>
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<td>1.2</td>
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<tr>
<td>Hollow structural sections (HSS):</td>
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<td>• ASTM A500/A500M (Gr. B or C), ASTM A501</td>
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<td>1.3</td>
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<tr>
<td>Pipe:</td>
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<tr>
<td>• ASTM A53/A53M</td>
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<tr>
<td>Plates, Strips and Sheets:</td>
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</tr>
<tr>
<td>• ASTM A36/A36M</td>
<td>1.3</td>
<td>1.2</td>
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<td>1.1</td>
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<td>• A1011/A1011M HSLAS Gr. 55 (380)</td>
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<td>1.1</td>
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<tr>
<td>• ASTM A572/A572M Gr. 42 (290)</td>
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<td>1.0</td>
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<tr>
<td>• ASTM A572/A572M Gr. 50 (345), Gr. 55 (380), ASTM A588/A588M</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>• ASTM 1043/1043M Gr. 50 (345)</td>
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<td>1.1</td>
</tr>
<tr>
<td>Steel Reinforcement:</td>
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<td></td>
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<tr>
<td>• ASTM A615, ASTM A706</td>
<td>1.25</td>
<td>1.25</td>
</tr>
</tbody>
</table>
Special Moment Frames (SMF)

- Expected to withstand significant inelastic deformations
- Must have story drift rotation capacity of 0.04 radians
- Flexural strength must be at least $0.8 \, M_{pbeam}$ at 0.04 radians
- Must have qualifying cyclic test results or be “Prequalified”

Ordinary Moment Frames (OMF)

- Expected to withstand limited inelastic deformations
- Must develop moment in connection of $1.1R_y M_{pbeam}$ or max $M_u$
- Detailing requirements
- FR or PR allowed

*(Intermediate Moment Frames (IMF) are “in between”)*
A992 Specification (1997)

- More scrap-based production of steel (recycling)
- No upper limit on strength for A36, A572
- “Strong Column – Weak Beam” therefore less reliable, “matching” weld metal less reliable

A992 → similar to Gr. 50, but with upper limit on $F_y$ of 65 ksi, minimum $F_u$ of 65 ksi, and

\[
\frac{F_y}{F_u} \leq 0.85
\]

- Recommended for steel moment frames
- Now, preferred material specification for W-shapes
Recommended b/t ratios
AISC Seismic Provisions Table D1.1

Flanges in I-shaped Beams
For “Highly Ductile”

\[ \frac{b_f}{2t_f} \leq 0.3 \sqrt{\frac{E}{F_y}} \]

Webs in Flexural Compression in SMF (zero axial load)
For “Highly Ductile”

\[ \frac{h}{t_w} \leq 2.45 \sqrt{\frac{E}{F_y}} \]
Required Shear Strength, $V_u$

$1.2D + 0.5L + 0.2S \text{ (for example)} + V_p$ resulting from $1.1R_yF_yZ$

For directly-welded flange moment connection, hinge location typ. $\sim \frac{d_b}{2}$ from column face

Distance between plastic hinges
Northridge Earthquake

- January 17, 1994
- Brittle fractures of welded moment connections
- Included sites with only “moderate” shaking

SAC Joint Venture (SAC Steel Project)
- SAC = SEAOC, ATC, CUREE
- Studies of connection performance, metallurgy, steel framing systems, etc.
- “Prequalified” connections and other recommendations (FEMA-350 series)
Pre-Northridge Connection

- CJP Weld
- Column
- Beam
- Backing Bar
- Panel Zone
- Shear Tab
- Weld Access Hole
- Continuity Plate
Pre-Northridge Detail to “Prequalified” WUF-B

- WUF-B $\rightarrow$ Welded Unreinforced Flange, Bolted Web
- Detailing requirements, specified originally by FEMA-350
- More stringent inspection requirements
- Initially prequalified for Ordinary Moment Frames only; now, some WUF-B details are required for welded OMF (AISC Seismic Provisions 2010)
Welds

Pre-Northridge
Low notch toughness

Downhand field weld results in defects, “crack initiators”

WUF-B
Specified notch toughness
e.g. 20 ft-lbs @ 0°F
Weld Access Holes

Pre-Northridge
Strain concentrations at
toes of weld access holes

WUF-B
Recommended geometries
for weld access holes
(+ shall be ground smooth)
Improved Weld Access Hole

Examples of requirements

Notes:
1. Bevel as required for selected groove weld.
2. Larger of \( t_{bf} \) or \( \frac{1}{2} \) in. (13 mm) (plus \( \frac{1}{2} t_{bf} \), or minus \( \frac{1}{4} t_{bf} \))
3. \( \frac{3}{4} t_{bf} \) to \( t_{bf} \), \( \frac{3}{4} \) in. (19 mm) minimum (\( \pm \frac{1}{4} \) in.) (\( \pm 6 \) mm)
4. \( \frac{3}{8} \) in. (10 mm) minimum radius (plus not limited, minus 0)
5. \( 3 t_{bf} \) (\( \pm \frac{1}{2} \) in.) (\( \pm 13 \) mm)

Tolerances shall not accumulate to the extent that the angle of the access hole cut to the flange surface exceeds 25\(^\circ\).
Backing Bar

Pre-Northridge
Typically left in place
“Crack initiator”

WUF-B
Bar removed, weld back-gouged, reinforcing fillet weld added
Bottom flange back-up bar tack welded into place.

Typical: 3/8” root 30-degree bevel on beam flange
Typical Pre-Northridge Bottom Flange Weld
Weld tabs and runoff regions removed; ground smooth

Back-up bar removed; root visually inspected, defects removed; small reinforcing fillet weld placed at bottom of groove weld

Improved POST-Northridge Bottom Flange Weld
Beam

Pre-Northridge
A572 Gr. 50 typically

Very DEEP sections

WUF-B (original requirements from FEMA350)
A992 recommended
W36 and shallower beams only
+ minimum span to depth ratio, L/d = 7

THICK flanges

1” thick flange, maximum
Tri-Axial Stress State

- Distortion Energy
  - (Timoshenko Goodier p. 248)

\[
\frac{1 + \nu}{6E} \left[ (\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 \right] + \frac{1}{2G} \left[ \tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2 \right]
\]

- In a pure tri-axial stress state, we do not have strain due to distortion (slip/shear), but we have volumetric strain
- So, theoretically, we can never be on the yield envelope, but we can get enough strain to FRACTURE
Panel Zone & Continuity Plates

Pre-Northridge
May have weak panel zones

local kinking

Some connections w/o continuity plates failed

WUF-B
Recommend shear yield in panel zone at same time as yield in beam, Or all yield in beam

New recommendations for continuity plates
An experiment (cover-plated connection) where the panel zone is the primary yielding element.
Very weak panel zone; localized “kinks” cause strain concentrations, ultimately leading to fracture in vicinity of beam flange groove welds.
Same specimen as previous slide. Connection failed at moment well below $M_n$. 
- Moment connection details -- “prequalified connections”
- Recommended design procedures, limits of usage (e.g., OMF only, W36 beams and shallower, flange thickness limits, web connection, etc.)
- Not a standard; but still a valuable reference
WUF-B
### TABLE 2.1. Prequalified Moment Connections

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Chapter</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced beam section (RBS)</td>
<td>5</td>
<td>SMF, IMF</td>
</tr>
<tr>
<td>Bolted unstiffened extended end plate (BUEEP)</td>
<td>6</td>
<td>SMF, IMF</td>
</tr>
<tr>
<td>Bolted stiffened extended end plate (BSEEP)</td>
<td>6</td>
<td>SMF, IMF</td>
</tr>
<tr>
<td>Bolted flange plate (BFP)</td>
<td>7</td>
<td>SMF, IMF</td>
</tr>
<tr>
<td>Welded unreinforced flange-welded web (WUF-W)</td>
<td>8</td>
<td>SMF, IMF</td>
</tr>
<tr>
<td>Kaiser bolted bracket (KBB)</td>
<td>9</td>
<td>SMF, IMF</td>
</tr>
<tr>
<td>ConXtech ConXL moment connection (ConXL)</td>
<td>10</td>
<td>SMF, IMF</td>
</tr>
</tbody>
</table>
Reduced Beam Section (RBS)

Also called “Dogbone” connection; less costly, simpler than reinforced connections.

Forces hinge formation to occur within reduced section.

Now one of the most commonly used connections.
Connection at $\theta \approx 0.04$ radian.....
Reduced Beam Section (RBS) Moment Connection

**Groove or Fillet**
required strength per 358-2.4.4b

**Continuity Plates**
may be required per 358-2.4.4
If provided, design per 360-J10 and 358-2.4.4a

**Corner Clip: straight or curved** (341-7.5)
\[ C_w \geq k_{det} + 1\frac{1}{2}'' \]
\[ k_1 \leq C_f \leq k_1 + 1\frac{1}{2}'' \]
radius if curved \( \geq 1\frac{1}{2}'' \)

**Parameter Limits**
358-5.8
\[ 0.5b_{bf} \leq a \leq 0.75b_{bf} \]
\[ 0.65d_b \leq b \leq 0.85d_b \]
\[ 0.1b_{bf} \leq c \leq 0.25b_{bf} \]

**Beam Web Connection Limitations**
\[ V_{web} = 2M_{pr}/L' + V_{gravity} \]
CJP between access holes; place \( \leq 3/4'' \) behind CJP

**Column Splice**
Demand-critical CJP or fillet per 341-9.9 (SMF) or 341-10.9 (IMF)
Column Splice
Demand-critical CJP or fillet per 341-9.9 (SMF) or 341-10.9 (IMF)
Locate fillet-welded splice per 341-8.4a: min. 4 ft above TOS (or 1\(\frac{1}{2}\) clear height above TOS if clear height < 8 ft.)

Doubler Plate
If required per 360-J10 SMF: detailed per 341-9.3c
Weld to column flange is CJP or fillet weld to develop full strength of plate.

Panel Zone (358-5.4(1))
Available shear strength per 360-J10.6
SMF: required shear strength per 341-9.3a; min. thickness per 341-9.3b
IMF: no additional requirements beyond 360

Column Limitations (358-5.3.2)
\(d_v \leq W_{36}\)
Beam connected to column flange
SMF: Seismically compact per 341, Table I-8-1
IMF: Compact per 360 Table B4.1
Column strength per 341-8.3
Lateral bracing per 341-9.7 (SMF) or 10.7 (IMF)

Beam Web Connection
Limitations
\(V_{wabs} = 2M_{pf}L' + V_{gravity}\)
CJP between access holes; plate \(\geq 3/8\)" can be used as CJP backing

Shear Plate (if provided)
Allowed for IMF or as CJP backing for SMF when \(t_{sp} \geq 3/4\)" (358-5.6)
(use for temporary erection support bolt holes are allowed in beam web)

Steel Backing (358-3.3.2)
when used, backing must be removed and the root pass must be backgouged and back-welded with a reinforcing fillet.

Beam Limitations
\(F_y \leq 50 \text{ ksi} \) (341-6.1)
\(d_v \leq W_{36}\)
\(t_{pf} \leq 13/4\)" (358-5.3.1)
SMF: seismically compact per 341, Table I-8-1
IMF: compact per 360, Table B4.1
weight \(\leq 300 \text{ lb/ft}\)
clear-span to depth ratio
\(\geq 7\) for SMF
\(\geq 5\) for IMF

Lateral Bracing per 341-9.8
(SMF) and 10.8 (IMF)
Max. spacing:
SMF: \(L_y = 0.086r_yE/F_y\)
IMF: \(L_y = 0.17r_yE/F_y\)
If the exception in 358-5.3.1(7) is not met, first brace must be \(\leq d_v/2\) from protected zone for SMF (358-5.3.1). All braces must meet provisions of 360 Appendix 6 Eqs. A-6-7 and A-6-8 with \(M_x = R_yF_yZ_{xx}\)

341 refers to ANSI/AISC 341-05, Seismic Provisions for Structural Steel Buildings
358 refers to ANSI/AISC 358-05, Perqualified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications
360 refers to ANSI/AISC 360-05, Specification for Structural Steel Buildings
Bolted Unstiffened and Stiffened Extended End-Plate Moment Connections

(a) Four-Bolt Unstiffened, 4E
(b) Four-Bolt Stiffened, 4ES
(c) Eight-Bolt Stiffened, 8ES
End-Plate Connections

a) Strong plate connection

b) Weak plate connection

Sumner, et al., 2000
End-Plate Connections

Sumner, et al., 2000
End plate and column flange bending strengths are determined using yield line analysis.
Bolted Flange Plate (BFP)

Fig. 7.1. Bolted flange plate moment connection.
Welded Unreinforced Flange – Welded Web (WUF-W)

Fig. 8.1. WUF-W moment connection.
Section 8.6
Beam Web-to-Column Connection Limitations

Shear tab thickness equal at least to that of beam web; overlap with weld access holes as specified.

Notes

- $a = \frac{3}{4}$ in. (6 mm) minimum, $\frac{1}{2}$ in. (12 mm) maximum
- $b = 1$ in. (25 mm) minimum
- $c = 30^\circ (\pm 10^\circ)$
- $d = 2$ in. (50 mm) minimum
- $e = \frac{1}{2}$ in. (12 mm) minimum distance, 1 in. (25 mm) maximum distance from end of fillet weld to edge of access hole

Fig. 8.3. Details at top and bottom of single-plate shear connection.
Experimental Evaluation of Kaiser Bolted Bracket Steel Moment-Resisting Connections
Scott M. Adan and William Gibb
AISC Engineering Journal 2009

http://www.steelcastconnections.com/
ConXtech ConXL moment connection

- Collar flange assembly
- Concrete fill
- Collar corner assembly
- Moment beams on any or all faces
- Square steel HSS or built-up column
“This innovative connection system enables beams to be simply lowered and locked onto square columns in the field, resulting in a dimensionally accurate structural chassis. The system is often referred to as a full-scale erector set.”

http://www.conxtech.com/conx-system/

http://dcm-designs.com/steel-prefabricated-moment-frame/
Connections in process of prequalification

- Double Tee
- Simpson Strong Frame
- SENSE TSC
- Side Plate
- SOM Pin Fuse Joint
Double Tee

Photo courtesy of Jim Swanson
Univ. of Cincinnati

http://www.aisc.org/uploadedcontent/2012NASCCSessions/N11/
Simpson Strong Frame (Yield Link)

http://www.aisc.org/uploadedcontent/2012NASCCSessions/N11/
SENSE TSC

Shear studs for composite floor (not shown)

Shop-welded coupler for top re-bars

Composite floor (solid, or ribbed)

TSC beam segment

Field-bolted beam splice

Shop-welded beam stub

Mechanical shear key

http://www.aisc.org/uploadedcontent/2012NASCCSessions/N11/
SidePlate

http://www.aisc.org/uploadedcontent/2012NASCCSessions/N11/
SOM Pin Fuse Joint

http://www.som.com/content.cfm/pin_fuse_joint