CONGRESO INTERNACIONAL DE LA CONSTRUCCIÓN CON ACERO

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25 Years After the Northridge Earthquake: Reflecting on the Changes to Seismic Design of Steel Structures

by

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Topics to be Covered

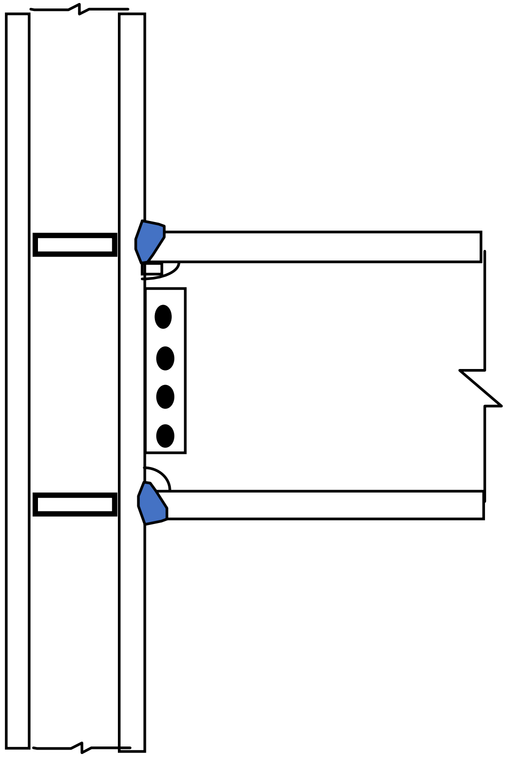
- Seismic Design Codes Prior to 1994 Northridge, California Earthquake
- ANSI/AISC 341-16 – "Seismic Provisions for Structural Steel Buildings"
- Future Directions for Seismic Design in Steel

Codes Before Northridge – 1992 AISC Seismic Provisions (1st Edition)

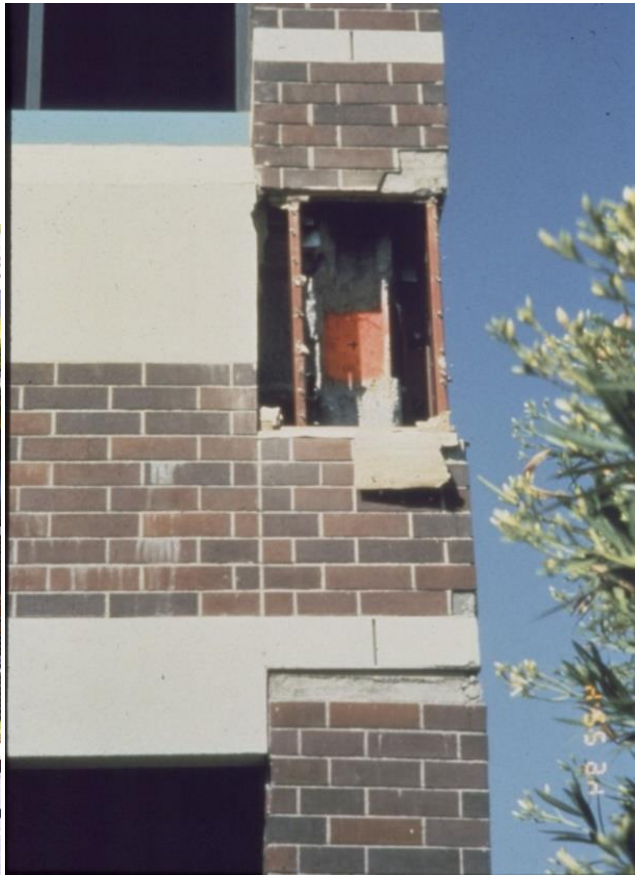
- Total length of 19 pages covered General and Member Requirements, Four Systems (OMF, SMF, CBF and EBF) and Quality Assurance
- Only EBF's were fully developed as capacity based design system (still very similar to present)
- OMF and CBF primarily based on elastic concepts
  - Some requirements for to protect connections and provide ductility in members
- Special Requirements for Column Member and Splice Design
- Required UT of all groove welds

Steel Moment Frames in ’92 AISC Seismic

- 5 pages of provisions
- Defined “Ordinary” and “Special” Moment Frames
- Pre-qualified what came to be known as the “Pre-Northridge” Connection
  - Had become de-facto standard after 1971 UCB Tests
  - Other details penalized with 1.25 factor
- SCWB, Panel Zone, width-thickness and some other checks for SMF’s included



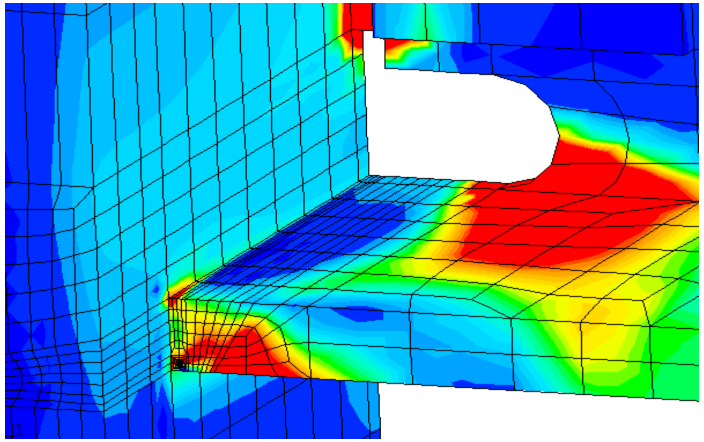
Northridge EQ – January 17,1994



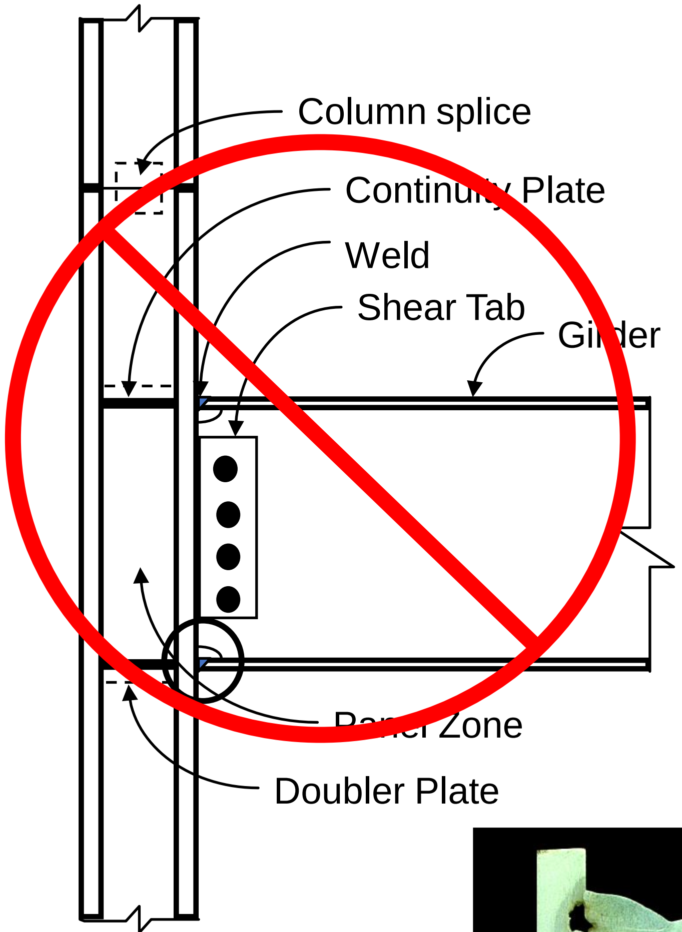
FEMA 350 – FEMA 355

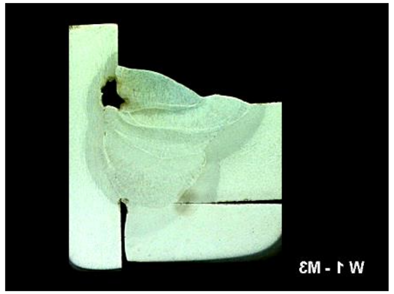
SAC Steel Project – FEMA Funded

- Six year, $10M program of investigations, testing and analysis
  - ➢Materials, Members Connections, Systems
- Led to interim changes to AISC and Codes (1997-2000)
- Guidelines documents led to major changes (2000-present)



Causes of Damage





- Connection geometry
  - ➢Stress concentrations
  - ➢Secondary stress (shear carried by flanges)
  - ➢Tri-axial effects
- Materials issues
  - ➢A36 wasn't
- Welding issues
  - ➢Low toughness materials
  - ➢Lack of control on technique
  - ➢Unreliable inspection procedures
- Caused a reconsideration of ALL steel system design requirements

The "Present" – AISC 341-16

- AISC 341-16 is now included by reference in the 2018 IBC.
- 20 pages of Moment Frame Requirements
  - ➢AISC 341-16 is 430 pages, including Commentary
    - 8 Steel and 12 Composite Systems
  - ➢AISC 358-16 (Pre-qualified connections standard) is another 260 pages
  - ➢AWS D1.8 (Seismic Supplement to D1.1) is another is another 110 pages

SMF's - What's the Same (or Close)?

- Capacity Design of Connections to Develop Mp of beam
  - ➢Now we also want deformation capacity and Ry considered
- Shear Capacity of Connections to develop moment hinges
- Width-thickness requirements for both beams and columns
- Beam lateral support bracing spacing
- Beam-column connection restraint, when braced by beam or not

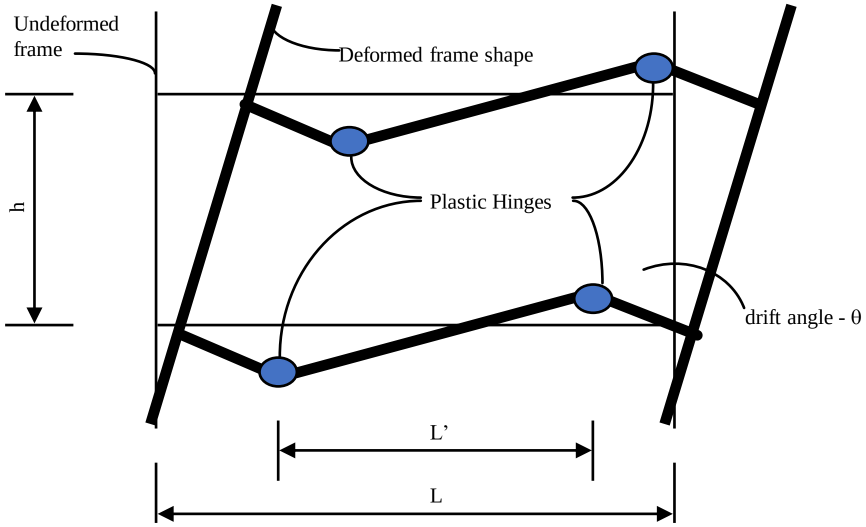
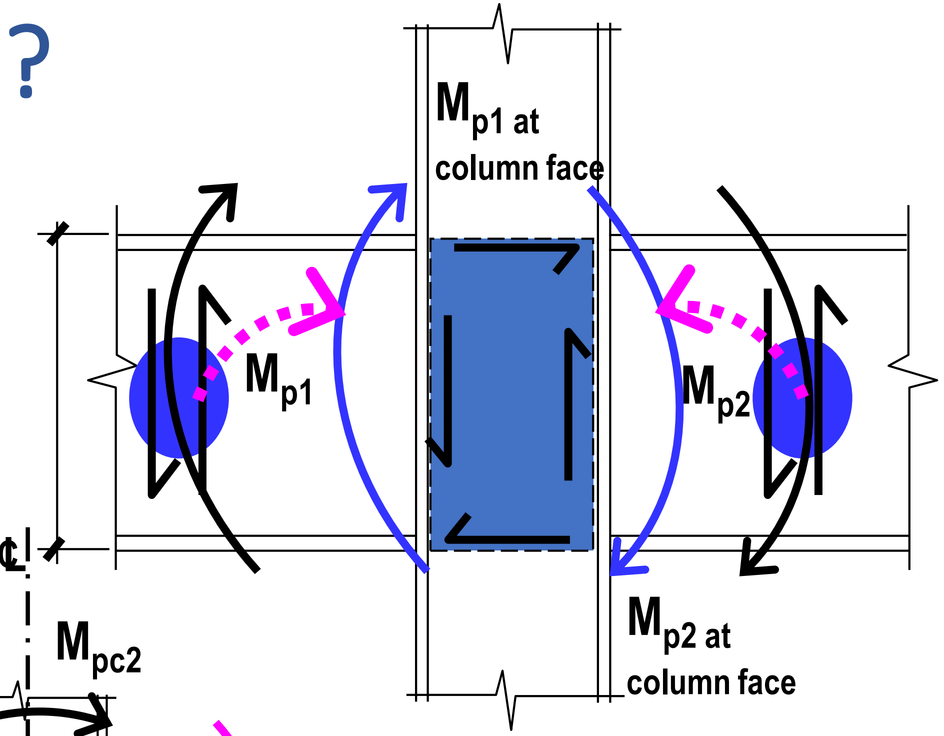


TABLE I-8-1
Limiting Width Thickness Ratios λ_{ps} for Compression Elements

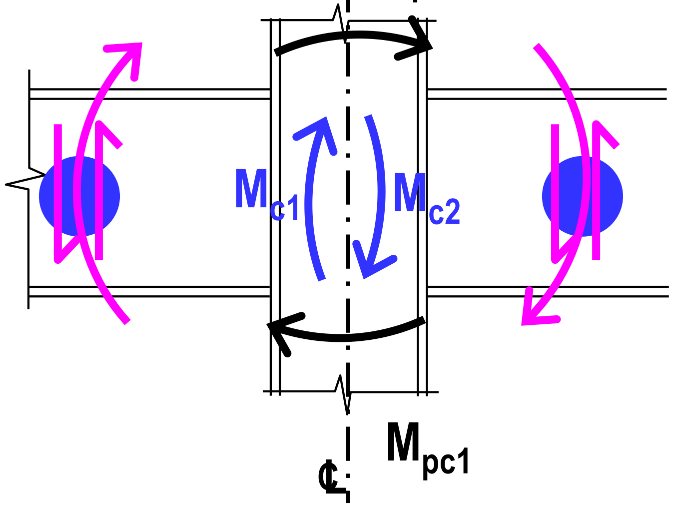
	Description of Element	Width Thickness Ratio	Limiting Width-Thickness Ratios λ_{ps} (seismically compact)
Unstiffened Elements	Flanges of I-shaped rolled, hybrid or welded beams [a], [b], [f], [h]	b/t	$0.30\sqrt{E_s/F_y}$
	Flanges of I-shaped rolled, hybrid or welded columns [a], [c]	b/t	$0.30\sqrt{E_s/F_y}$
	Flanges of channels, angles and I-shaped rolled, hybrid or welded beams and braces [a], [d], [h]	b/t	$0.30\sqrt{E_s/F_y}$
	Flanges of I-shaped rolled, hybrid or welded columns [a], [e]	b/t	$0.38\sqrt{E_s/F_y}$
	Flanges of H-pile sections	b/t	$0.45\sqrt{E_s/F_y}$
	Flat bars[g]	b/t	2.5
	Legs of single angle, legs of double angle members with separators, or flanges of tees [h]	b/t	$0.30\sqrt{E_s/F_y}$
	Webs of tees [h]	d/t	$0.30\sqrt{E_s/F_y}$

SMF's- What's the Same (or Close)?

- Panel Zone Shear Capacity Equation (Krawinkler Equation)
  - ➢ Many other versions considered
- Strong-Column – Weak Beam Concept



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



SMF's - What's Different?

Everything Else!!!!!

Overall Philosophy of AISC 341

- Identify Target Yield Mechanism for Each SLRS
- Designate Deformation-Controlled Elements (Structural Fuse):
  - Design for Reduced Seismic Forces
  - Ductility Design Is Relatively Straightforward (Prescriptive)
- Design Remaining Elements as Force-Controlled:
  - Design for Forces to Remain "Essentially Elastic at Capacity of Fuses"
  - Use Either "Local" or "Global" Approach
  - Capacity Design Requires Good Judgment and Experience

Credit: C. M. Uang

It’s This Simple…

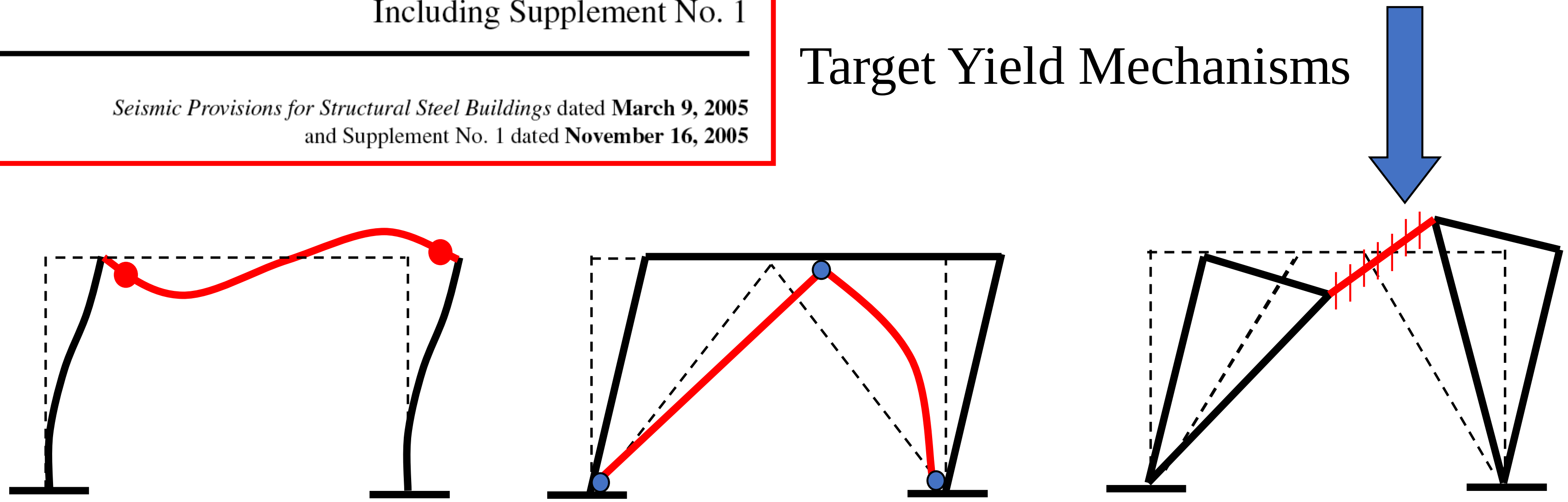
Target Mechanism Plus Ductility Requirements Plus Capacity Design Requirements Equals…

Seismic Provisions for Structural Steel Buildings

Including Supplement No. 1

Seismic Provisions for Structural Steel Buildings dated **March 9, 2005**
and Supplement No. 1 dated **November 16, 2005**

Target Yield Mechanisms



Flexural Yielding | Tensile Yielding/Buckling | Shear Yielding

Major Elements of AISC Seismic Provisions

- Coordinated with ASCE 7 and AWS D1.8
- Incorporate Post-Northridge Findings
    - FEMA/SAC Project Results (FEMA 350 Series) as Well as Other Efforts
- "Unified" Format similar to the Main AISC Specification, with both LRFD and ASD included in one set of provisions
- Format for Various Systems Have Been Standardized
- Design/analysis provisions explicitly follow capacity design approach for ALL systems

Scope Statement / General Requirements

- Intended Primarily for Building Structures
  - Also incorporated for "building like" non-building structures
  - Glossary clarifies that SLRS includes diaphragm chords and collectors, and all elements that resist seismic loads
- For SDC A, B and C, designer has choice
  - Use the Seismic Provisions with appropriate R factor
  - Use AISC LRFD/ASD Provisions with R=3
- Required When Specified by ASCE 7
  - SDC D, E, and F, typically
  - Use ACI 318 for R/C elements in composite systems

General Design Requirements

- SDC, Height Limitations, Design Story Drift per ASCE 7-10
- Defines how to apply Ω_0, E_{mh} and E_{cl} in ASCE 7
- Required Strength either generated by analysis or the system requirements (capacity based design concepts)
- Available Strength per LRFD or ASD

Project Documentation Requirements

- Section to Define Expectations of:
  - Design drawings and specifications
  - Shop Drawings
  - Erection Drawings
- Includes lists of information to be provided such as SLRS designation, connection detailing, welding requirements, protected zones, etc.
- Consistent with FEMA 353 and AWS D1.8 references incorporated in 2010

Material Specifications

- ASTM Specifications for Materials Employed
  - All major structural products incorporated
- Required Strength for Connections or Related Members Based on Expected Yield Strength and Expected Tensile Strength (R_y and R_t)
- Available Strength considers both expected yield and tensile strengths
  - Intent is to help ensure expected inelastic response and ductile failure modes
- Toughness requirements for heavy shapes and thick plates

Newest Material - ASTM 1085 Steel

- New specification for HSS steel with better properties (akin to A992 for wide flange shapes)
  - ➢Single yield stress of 50 ksi
  - ➢Limits on Fy (70 ksi max) and the Fy/Fu ratio
  - ➢Tighter material tolerances added to allow more efficient design based on full wall thickness (rather than 0.93)
  - ➢Ry=1.25 and Rt=1.15

Connections - Bolted Joints

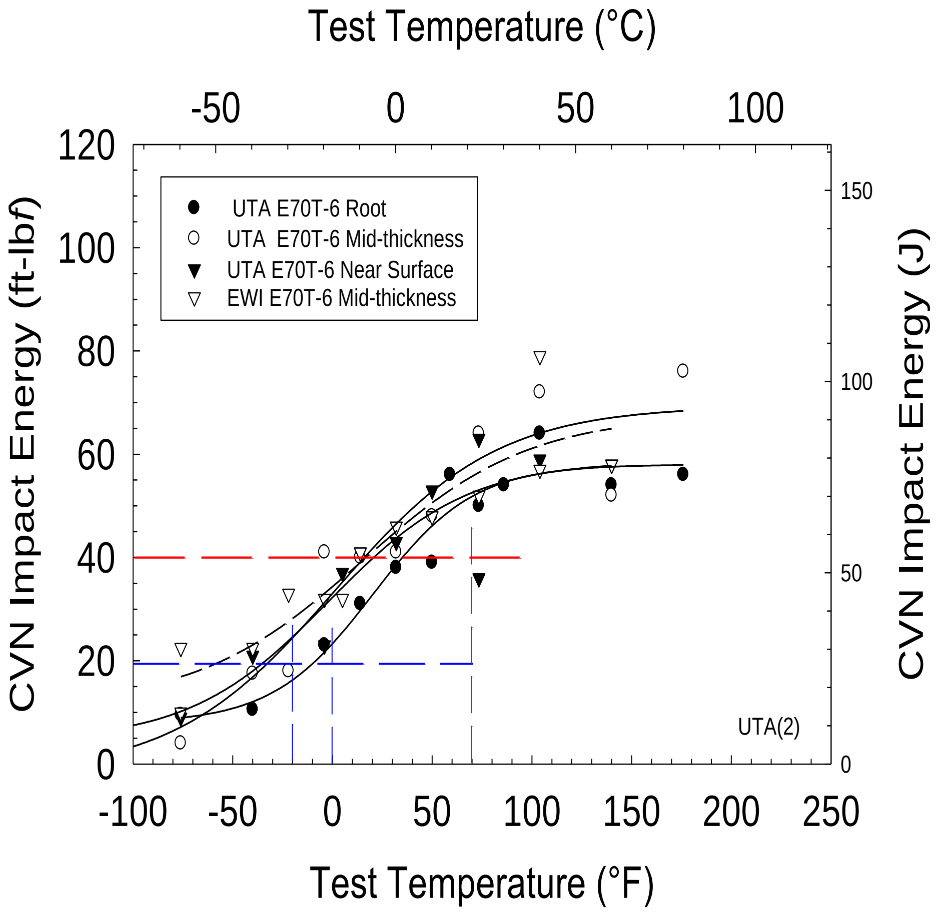
- Fully Tensioned HSB, Class A Slip-Critical, design for bearing strength.
- No sharing of load with welds in a joint or the same force component in a connection.
- Standard holes, or short slots perpendicular to line of force.
  - ➢ Oversized holes in one ply of brace diagonals allowed
  - ➢ Oversized holes also allowed in End Plate connections

Connections - Welded Joints

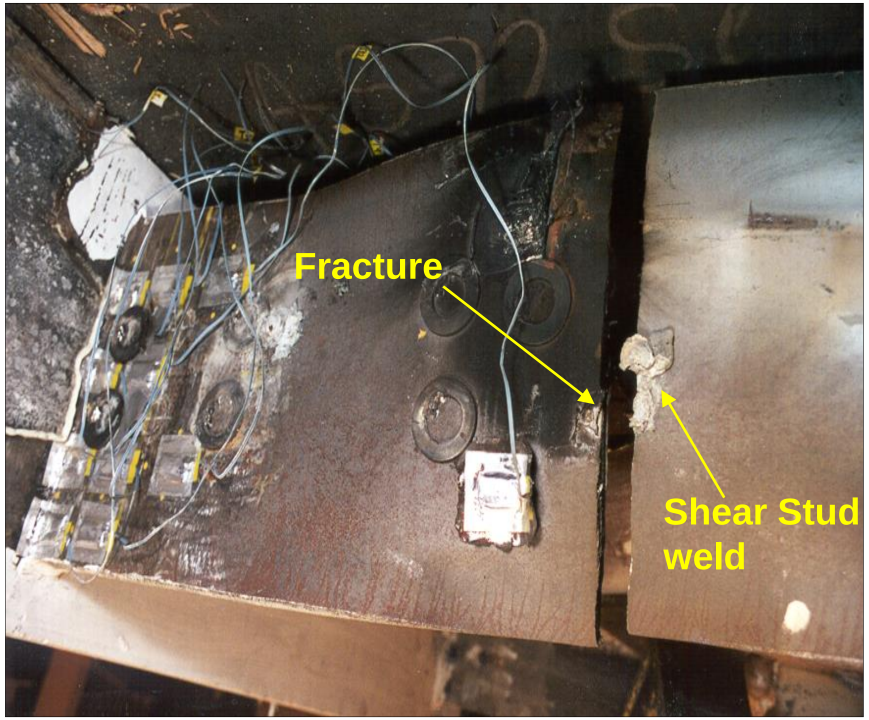
- AWS D1.8 covers welded joint requirements beyond standard AWS D1.1
  - Consistent with FEMA/SAC recommendations
- WPS required / Approved by EOR
- Continuity plate welding and detailing specified

Connections - Welded Joints

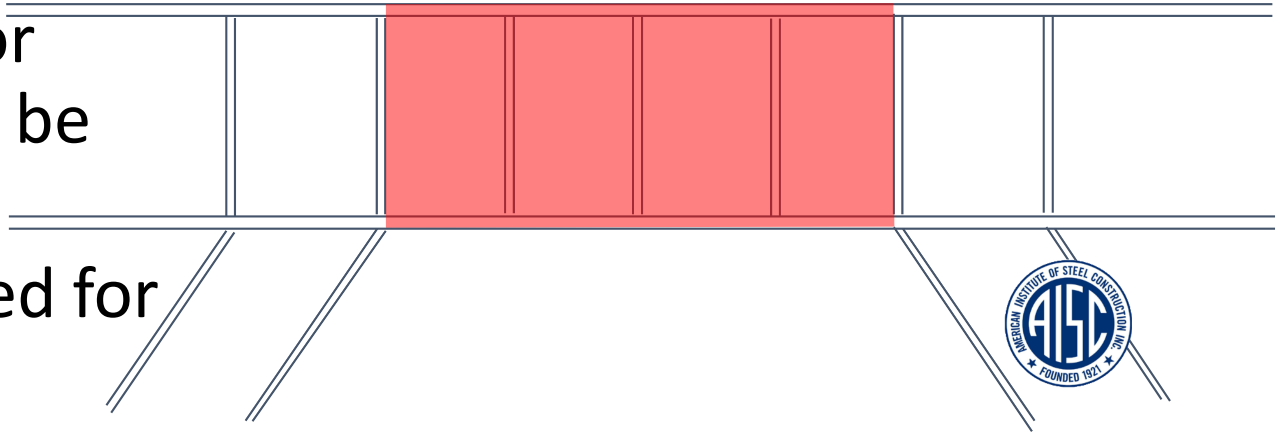
- Filler metal CVN 20 ft.-lbs. @ -0° F for all welds in the seismic load resisting system (SLRS)
- Two level toughness required for designated Demand Critical Welds in SMF, IMF, OMF and EBF defined in AWS D1.8
  - ➢Based on FEMA recommendations
  - ➢Consistent with previous testing
- Locations for DC welds defined in AISC 341 for each system



Welded Joints (continued)



- Defines term "Protected Zone" where special care is required
  - ➢ Eliminates welding and other attachments in plastic hinge zones (shear studs, e.g.). Spot welds acceptable
    - ▪ OK outside hinge zones, but need to verify net section strength
  - ➢ Discontinuities caused by welding or other construction operations must be repaired. Exception for PAFs
  - ➢ Locations of Protected Zones defined for each system

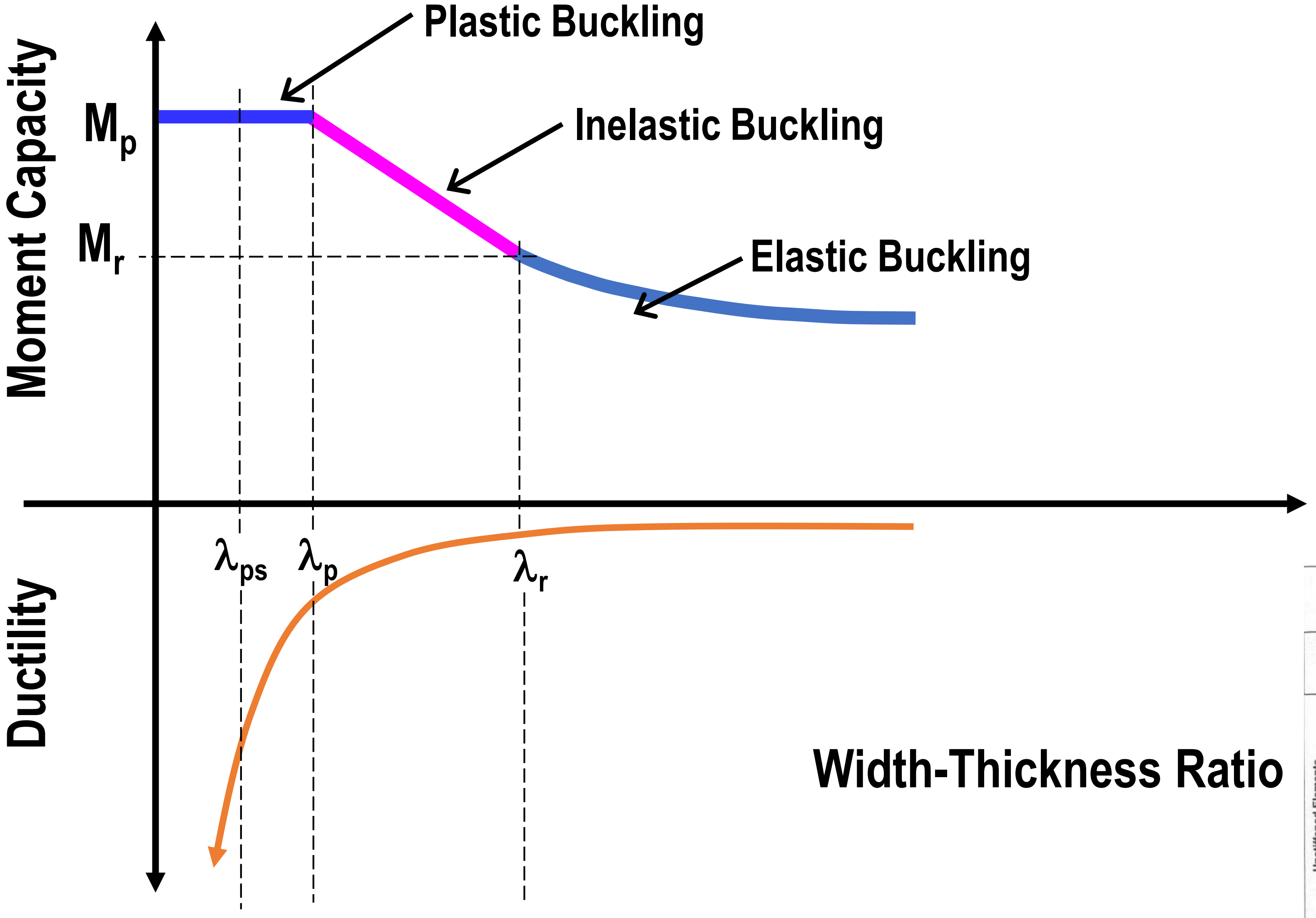


Decking Attachments with PAF's in Protected Zones

- 341-10 Protected Zone Rules Only Allow Spot Welds
  - ➢ Tests at Virginia Tech on Power Actuated Fasteners Showed No Reduction in Rotation Capacity
    - ▪ Multiple full scale tests and patterns
    - ▪ Small scale bend tests as well
  - ➢ Now allow power-actuated fasteners up to 0.18" diameter in flanges.

Members

- Width-thickness ratios often stricter than main specification requirements for special systems
- "Moderately" and "Highly" Ductile (MD and HD)
  - Used for width-thickness and bracing requirements
  - Width-thickness table parallels B4.1 in AISC 360
    - MD like Compact in 360. HD more restrictive to provide more member ductility
    - Composite elements included



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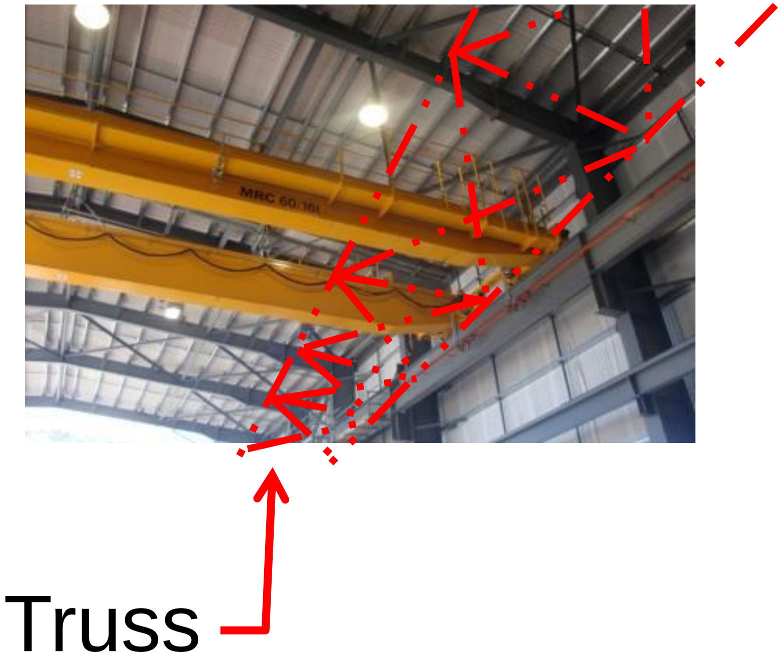
Members – Continued

- Paragraph on diaphragm design
  - Load transfer details required
  - Nominal shear strength defined as concrete above deck, w/o ACI Ch. 22, or test results
- Bracing requirements made uniform for various systems
  - Special requirements at plastic hinges
- Columns with high axial load to be checked for amplified seismic loading
  - ALL lateral system columns checked for Ω_0 level axial forces
  - Requirements for composite columns

Steel bracing used as a diaphragm added in 2016

- 2010 Seismic Provisions did not give explicit requirements for steel members used as truss diaphragm, so added following:
  - "When a truss is used as a diaphragm, all members of the truss and their connections shall be designed for forces calculated using the load combinations of the applicable building code, including overstrength."
  - Exceptions for the following:
    - Design of truss similar to SCBF, or
    - Three dimensional system with ordinary lateral system (OMF or OCBF) and diaphragm designed similar to OCBF



Column Splices/Bases

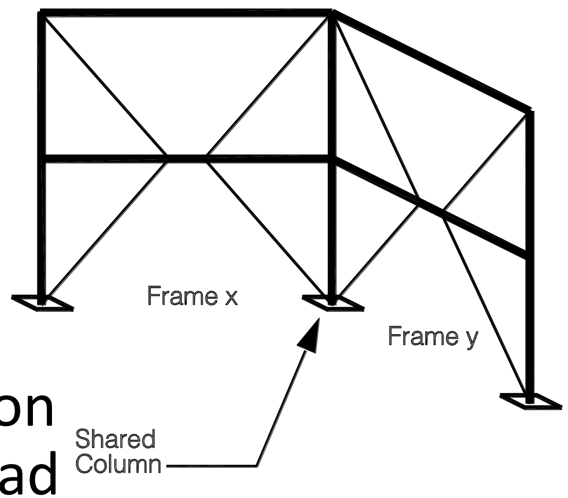
- Beveled transitions in CJP splices and removal of weld tabs (but not backing) require per AWS D1.8
  - Column base weld backing reqt's also defined
- Beveled transitions not required where partial penetration welds are permitted.
- Strength requirement for partial penetration and fillet welded splices of 200% of required strength.
- Requirements for shear strength check of <u>non-frame</u> columns in <u>all</u> systems.
  - Only location in the provisions that refers to elements not part of the SLRS

Members (continued)

- Column base design (continued)
  - General intent to design column base for same forces that the elements connecting to the base are designed for.
    - Axial, shear and flexural strength requirements presented
  - Interaction with concrete elements referred to ACI 318 Appendix D.

Columns participating in orthogonal frames

- Concern about high R factor systems with columns that resist lateral load in both directions
  - Likely will have simultaneous yielding during response, so 100/30 rule may not be adequate
  - Possibly more important for low rise buildings
- New language in 2016:
  - "For columns that are common to intersecting frames, determination of the required axial strength, including the overstrength seismic load or the capacity-limited seismic load, as applicable, shall consider the potential for simultaneous inelasticity from all such frames…."
    - Not required for Ordinary (low R factor) systems or when NLRH analyses are performed
- Similar language for checking SC/WB condition for SMF's.



Deformation Compatibility

- Section highlights need to check non-SLRS members and connections for gravity load effects and deformations at the Design Story Drift as defined in ASCE 7-10
  - ➢User Note added to justify shear tab connections and allow self-limiting inelastic deformations in other connections

Uniform Format for ALL Systems

1. Scope – defines system title
2. Basis of Design – defines expected system response (yielding and protected members etc.)
3. Analysis – defines special analyses for capacity definitions (SCBF, e.g.)
4. System Requirements – stability bracing and other system-wide requirements
5. Members – sets b/t limits, lists protected zones and defines individual member requirements
6. Connections – defines demand critical welds, and connection requirements, including splices

Analysis

- Defines section properties for elastic analyses
  - Elastic sections for steel
  - Cracked sections for concrete and composite elements
- Refers to system chapters for additional (capacity based requirements)
- Refers to ASCE 7, Chapter 16 when nonlinear analyses used

Special Moment Frames (SMF)

- Designs based on cyclic test results to 0.04 radians
  - ➢ Appendix S provides test requirements
    - ▪ For either project specific or "public" tests
  - ➢ Appendix P provides basis for "pre-qualification" of connections
  - ➢ Connections designed in accordance with AISC 358 standard
- Shear connection capacity sufficient to develop force generated by fully plastic beam

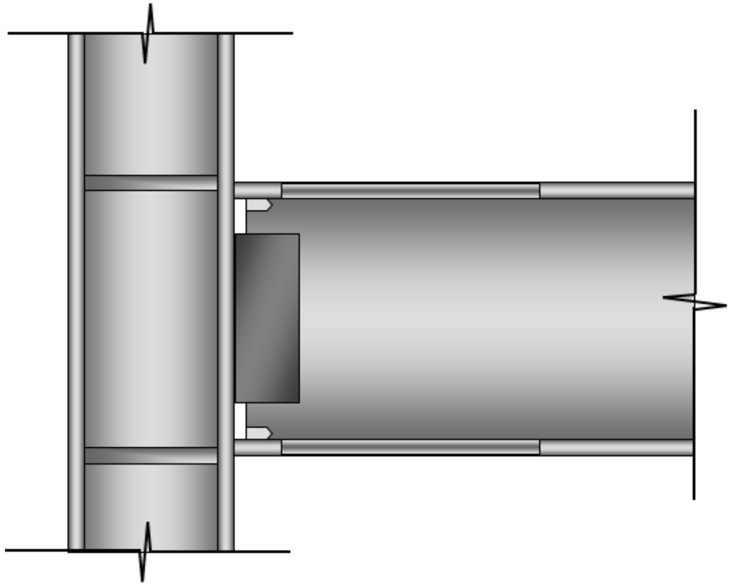
AISC Moment Connection Prequalification Standard – AISC 358

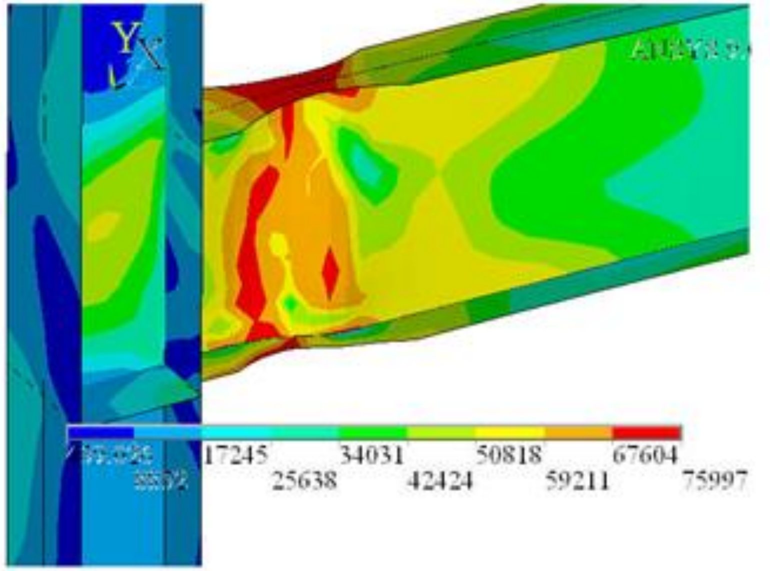
- Official title: “Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications”
  - Developed by separate ANSI standards development committee
- Allows engineers to submit moment frame designs without producing connection test results
  - RBS, End Plate, Bolted Flange Plate, WUF-W, Kaiser Bolted Bracket and ConXTech CONXL connections, included
- Adopted by AISC 341

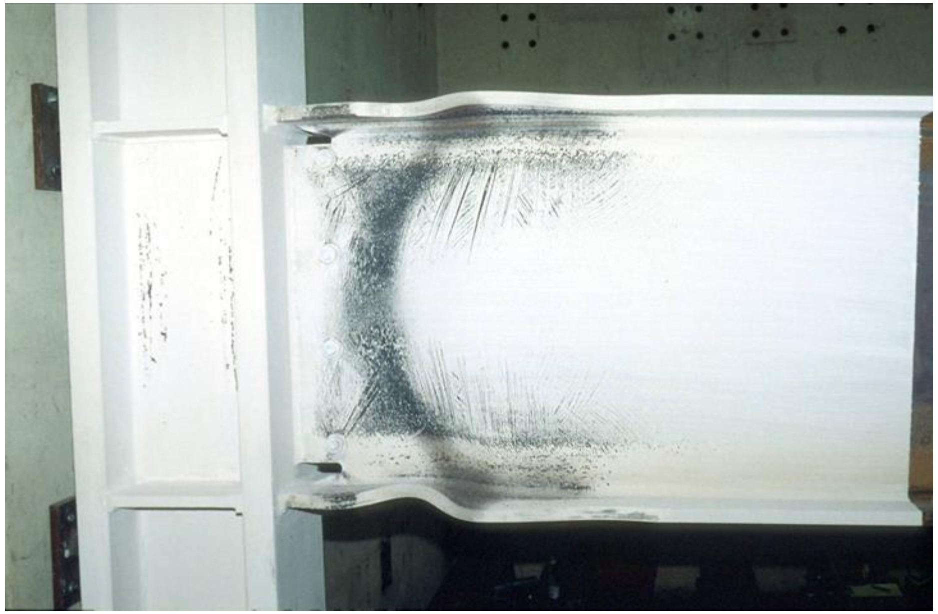
Prequalified Connections

			Column				Beam	
Designation	Type	Domain	W maj	W min	HSS/Box	Biaxial	d	Wt
Bolted End Plate	FR	Public	X				W55	140
Bolted Flange Plate	FR	Public	X		X		W36	150
Reduced Beam Section	FR	Public	X		X		W36	300
Double Tee	FR	Public	X				W24	55
Welded Unreinforced Flange	FR	Public	X		X		W36	150
CONXL	FR	Propr.			X	X	W30	130
Kaiser Bolted Bracket	FR	Propr.	X				W33	130
Sideplate	FR	Propr.	X	X	X	X	W40	302
Simpson Strong Frame	PR	Propr.	X				W16	-
Slotted Web	FR	Propr.	X		X		W36	300

AISC 358 Conformance Demonstration







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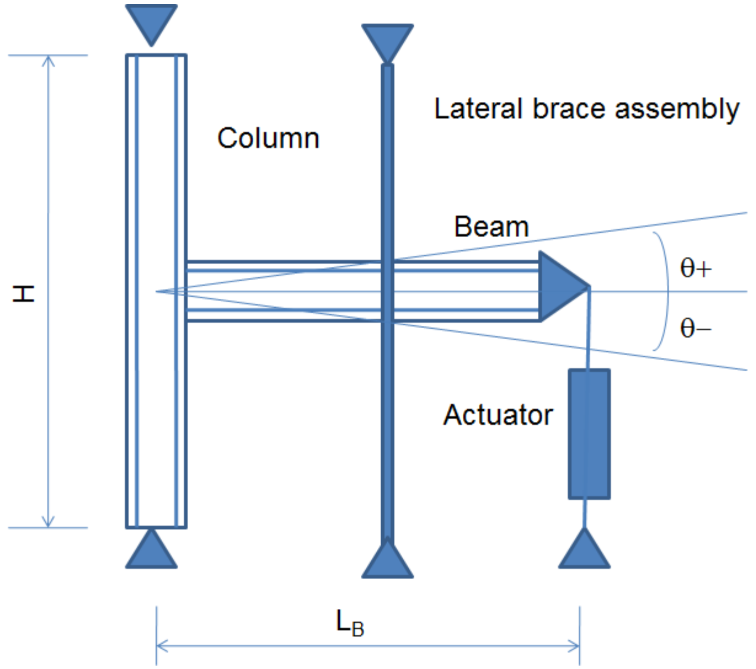
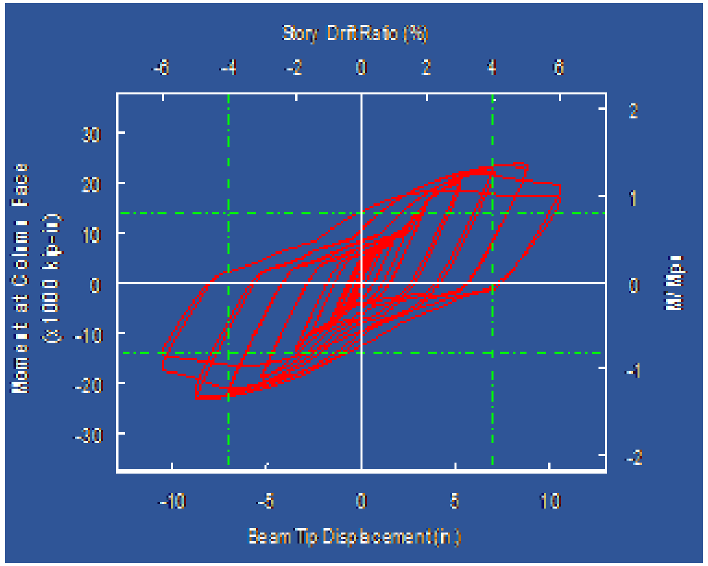
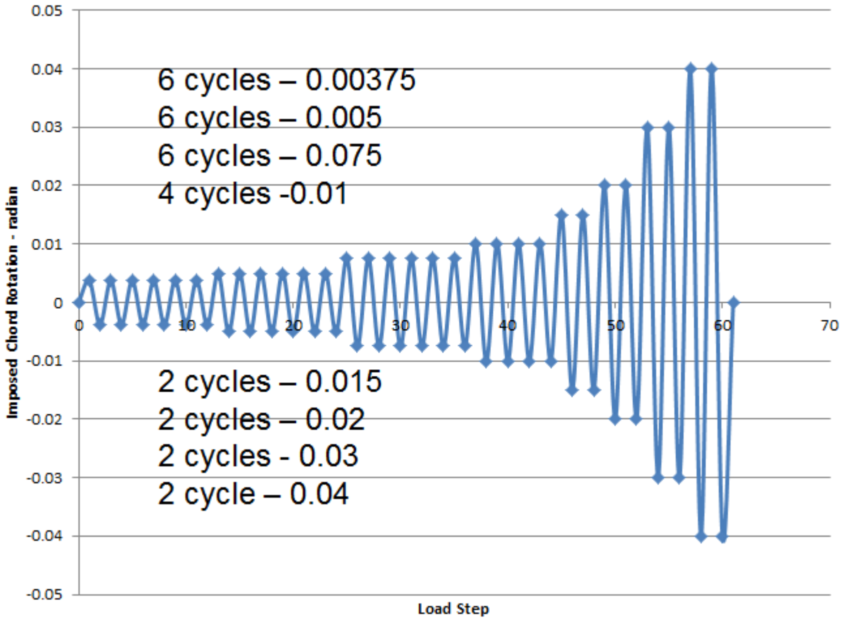
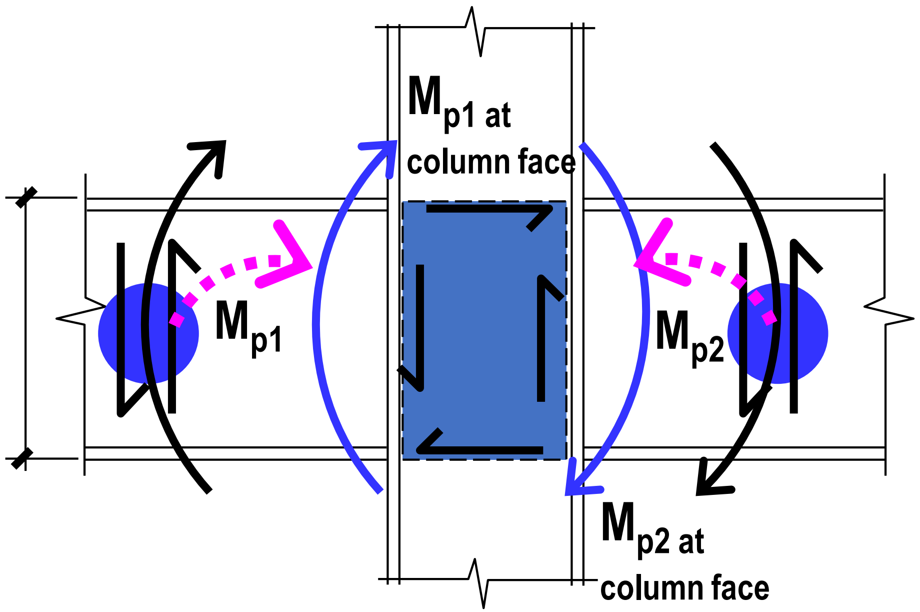






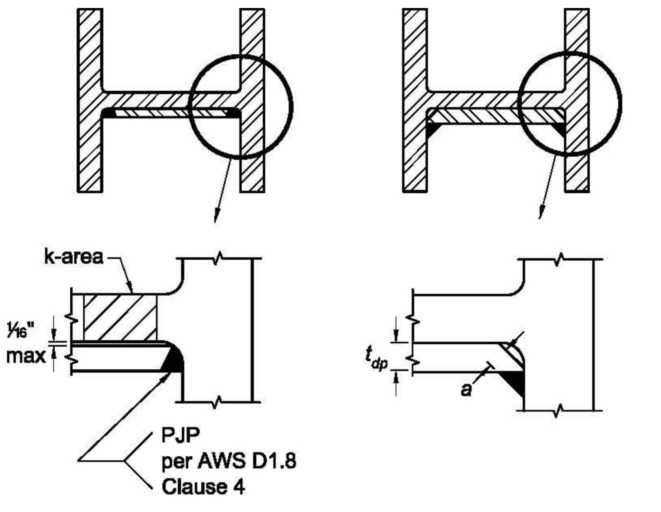
SMF (Continued)

- Panel Zone Design
  - ➢Intended to share yielding with beam
  - ➢Considers some strain hardening of the panel zone to help limit doubler plate thickness



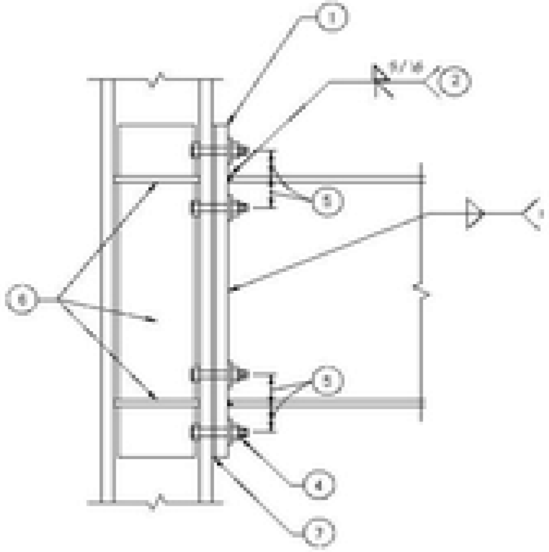
Continuity and doubler plates in SMF

- Continuity plate requirements explicitly refers to the limit states of Section J10 of the Specification (WLY, WLC)
- Doubler plate to column web weld refers to prequalified joint details in AWS D1.8
- Continuity plate minimum thickness of 0.75 tf



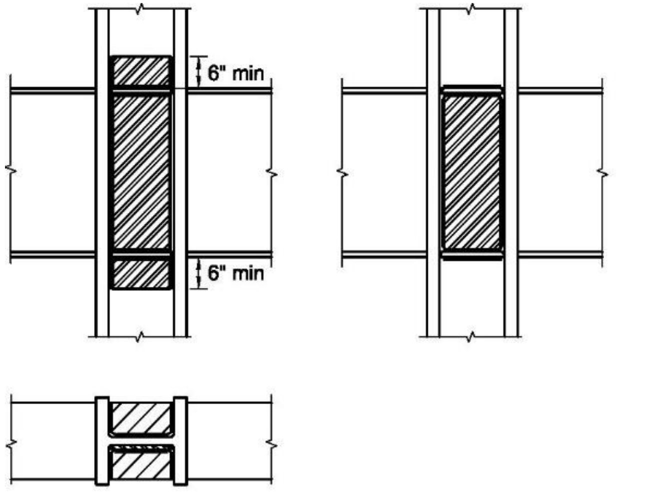
(a) Doubler plate groove welded to column flanges

(b) Doubler plate fillet welded to column flanges



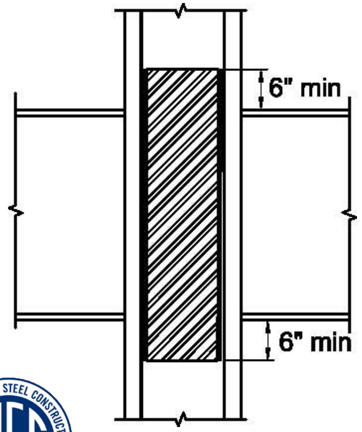
Continuity and Doubler Plates in SMF

- Tricky doubler plate and continuity plate geometry have more options outlined: doublers spaced away from web and doublers extending above and below CPs, e.g.



(a) Doubler plate extended beyond continuity plates

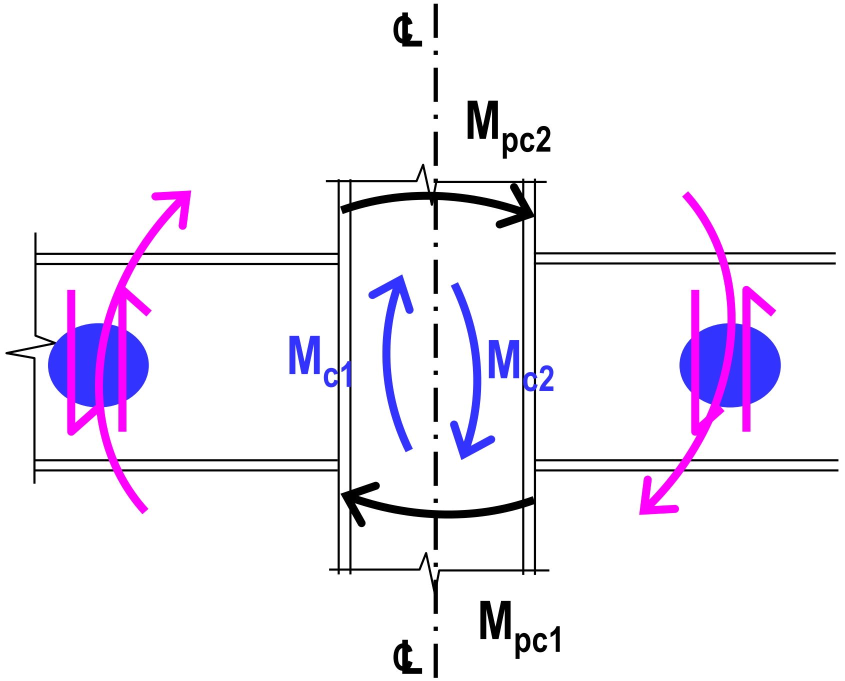
(b) Doubler plate placed between continuity plates



SMF (Continued)

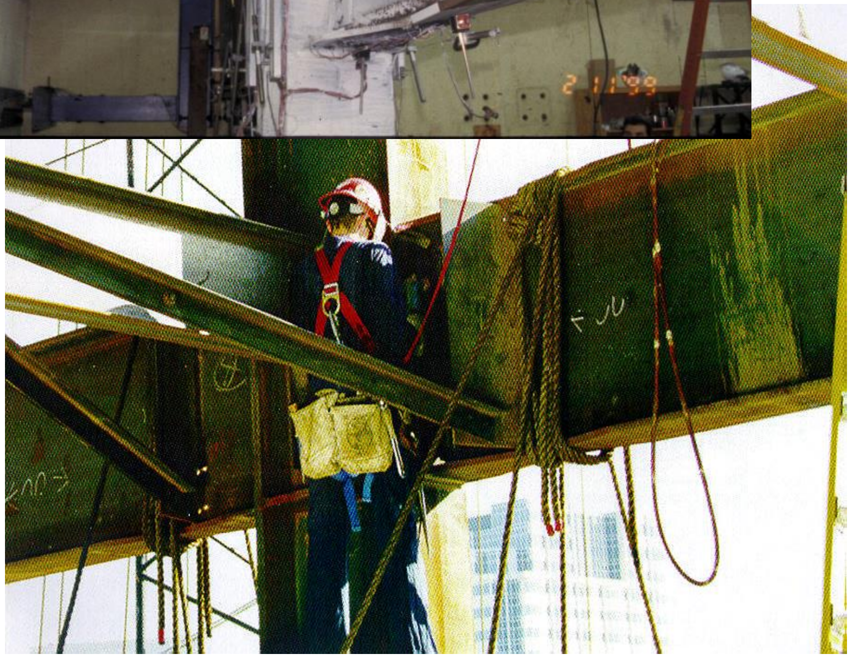
$$\frac{\Sigma M^*_{pc}}{\Sigma M^*_{pb}} \geq 1.0$$

- SCWB Check required for SMF frames
  - ➢Attempting to avoid weak stories
  - ➢Exceptions provided
  - ➢Ω_0 required for axial force reduction



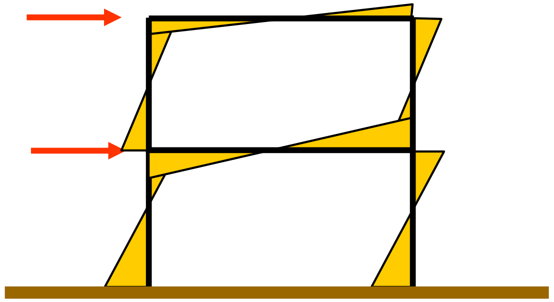
SMF (Continued)

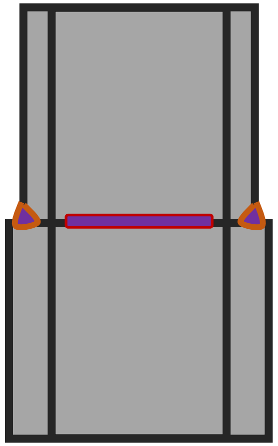
- Lateral Bracing of Beams
  - Nominal bracing required along length for both strength and stiffness based on main spec. equations
  - Bracing at hinges (6%) required as well
    - But, not IN hinge zones!



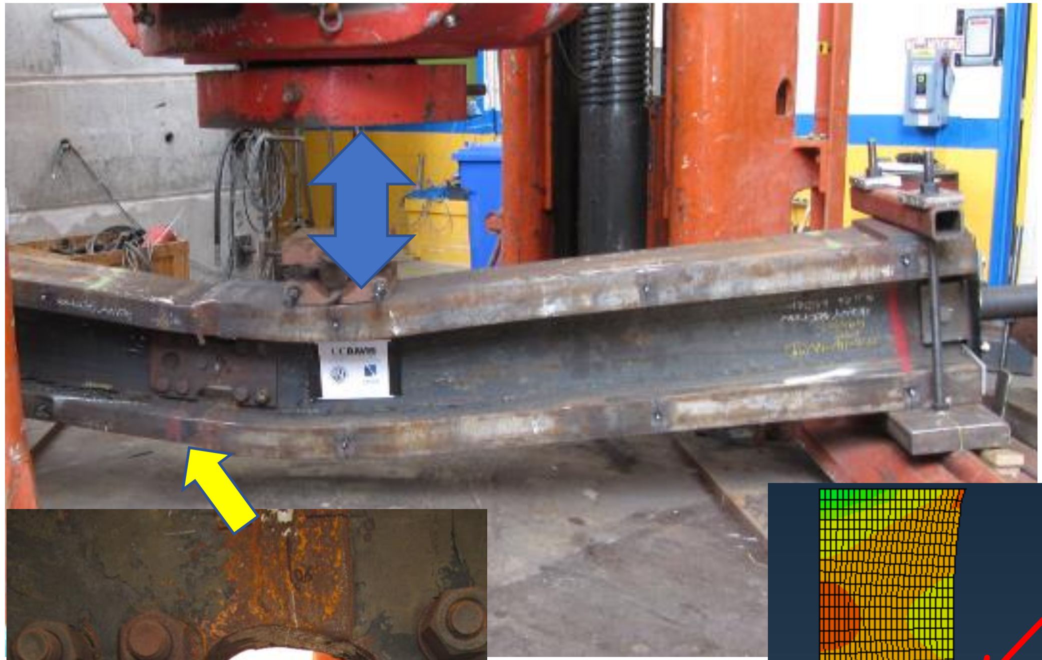
SMF Column Splices/Bases

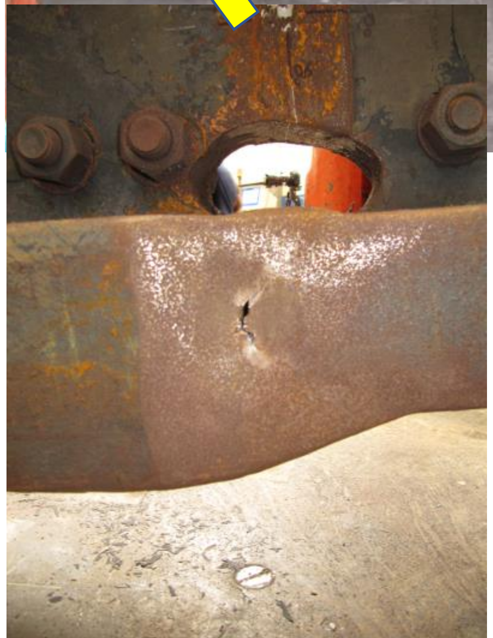
- Column splices pushed to CJP prior to 2016 edition
  - ➢ Challenging for erection

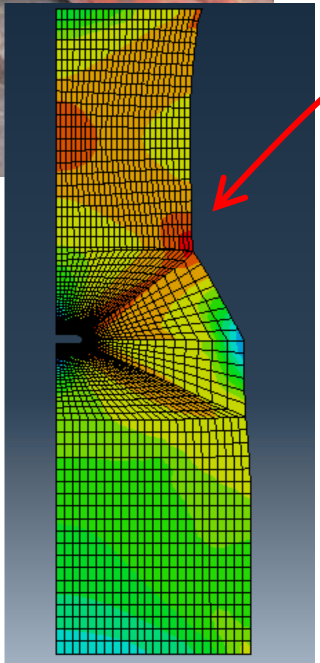


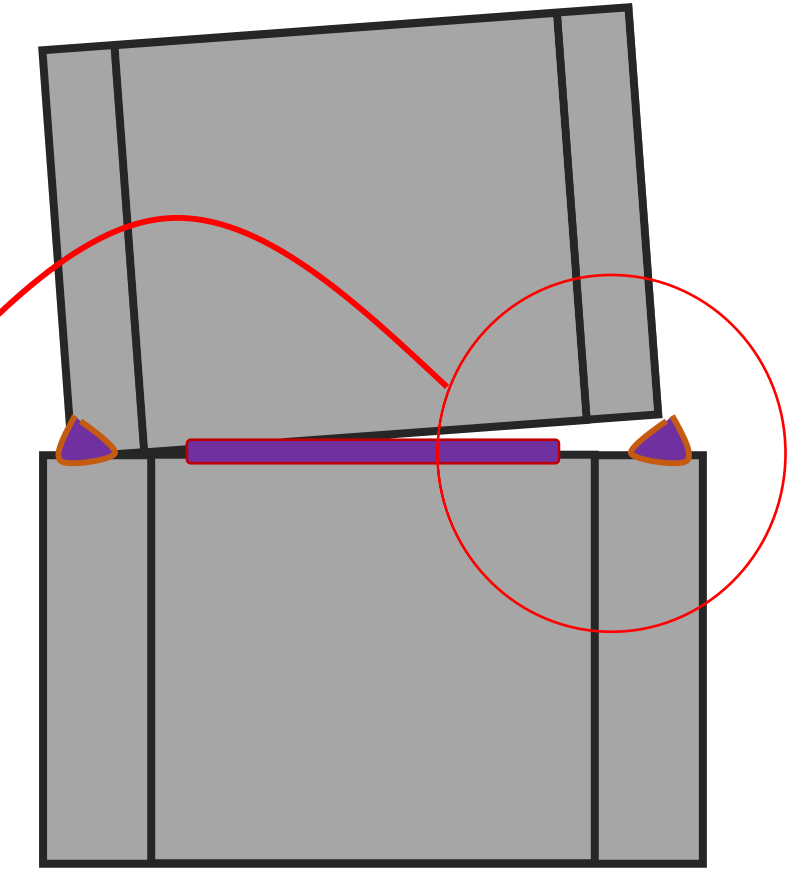


Tests and Analyses on "Heavy" PJP Splice Detail



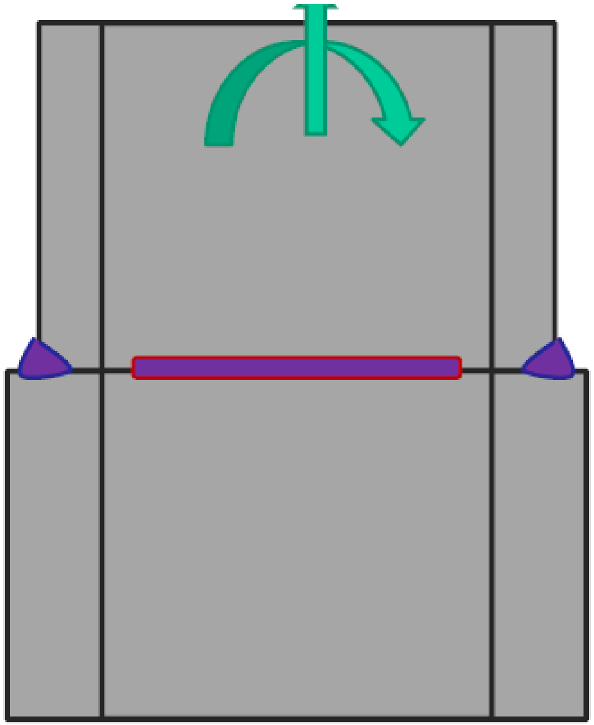






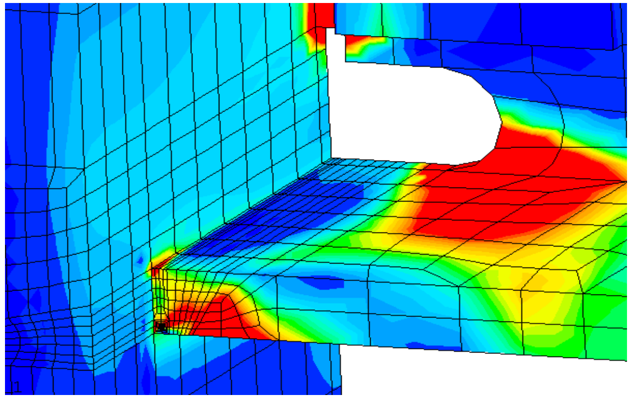
Allowance for PJP welds to be used in SMF column splices

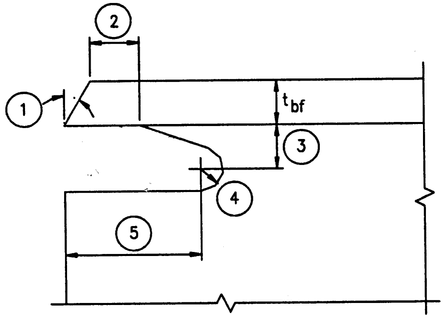
- In 2010, if SMF column splices were welded, they had to be made with CJP welds
- 2016 allows for PJP welds, with the following requirements (among others):
  - Thicker flange at least 5% thicker than thinner one
  - Minimum effective throat of 85% of the smaller flange thickness
  - Tapered transition specified
  - Companion UT requirements developed

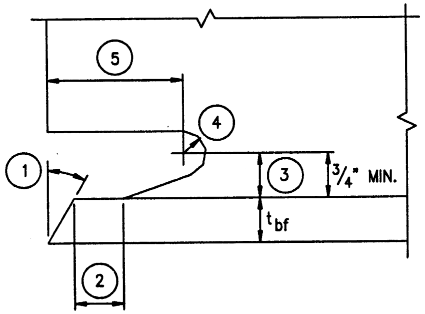


IMF/OMF Requirements

- Intermediate (IMF) provisions similar to SMF
  - Tested capacity to 0.02 radians, beam shear, etc.
  - Other requirements (SCWB, panel zone, b/t, etc.) not as restrictive as SMF.
  - DC welds at splices
- Ordinary (OMF) provisions
  - Allows calculation only, but for strength above 1.1 R_y M_p
  - Specific welding and detailing requirements (access holes, e.g.)

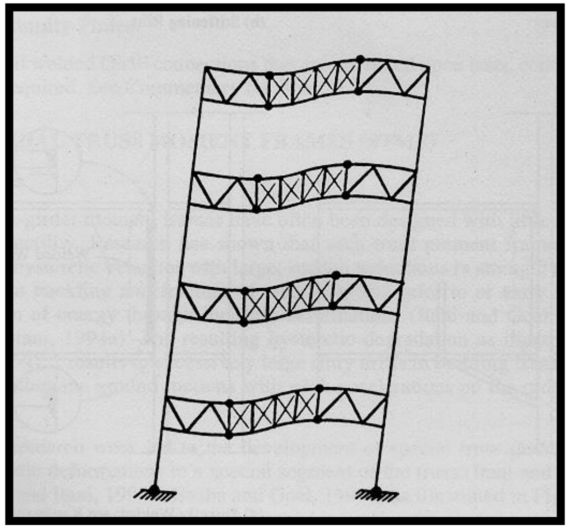


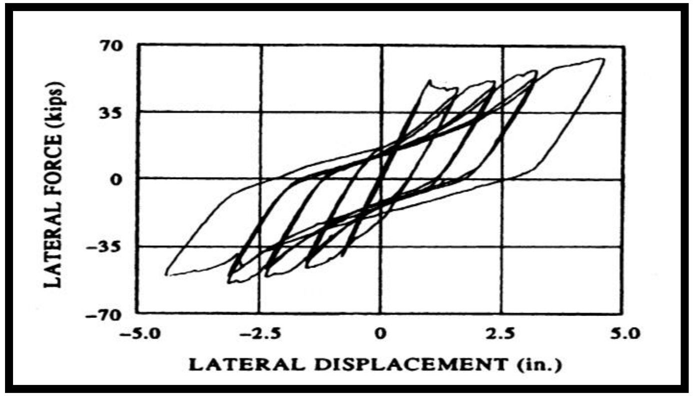




STMF

- Concept Similar to EBF’s
- Ductile Special Segment (SS)
- Other Parts of the Truss Remain Elastic
- Both Cross-braced and Vierendeel configurations
- Span limited to 65 feet
- Depth limited to 6 feet
- DC Welds for Column Splices



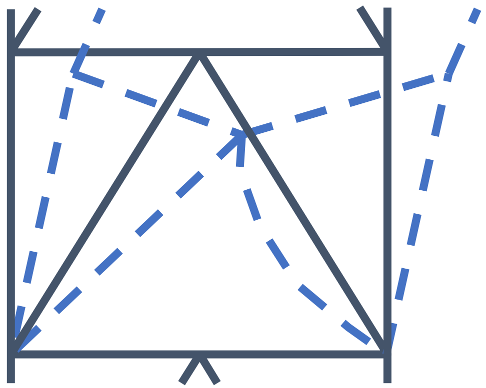


Cantilever Columns

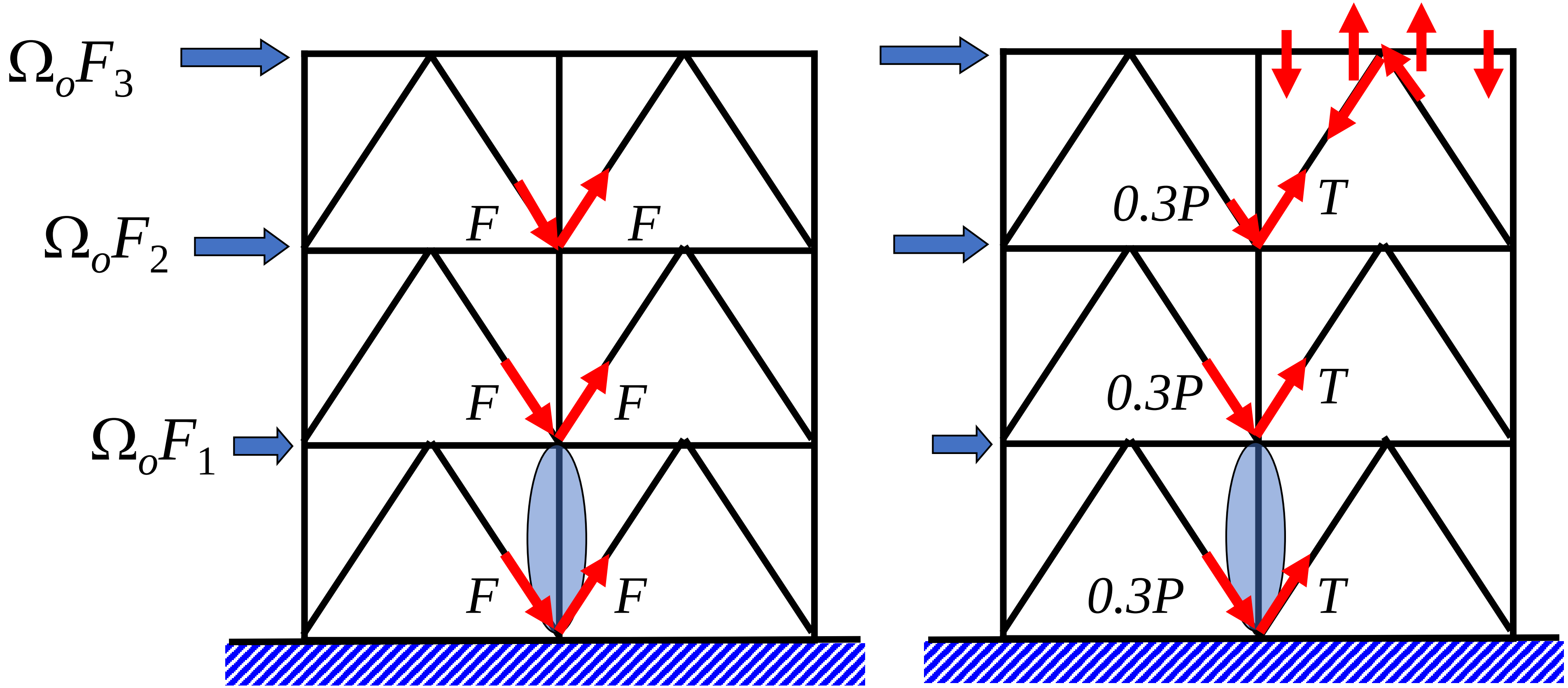
- Two Systems defined to be consistent with ASCE 7 SDC and height limits
- Ordinary System (OCCS)
  - Column axial loads low (15% of available at Ω_0)
  - AISC 360 b/t ratios, no DC welds or protected zones
- Special System (SCCS)
  - HD b/t ratios, stability bracing for MD, protected zone at base, DC welds at base

Special CBF Provisions

- $KL / r < 4 / \sqrt{E/F_y}$ with exception to higher
- Stricter b/t Ratios and Built-up Member Requirements
- Connection Requirements
  - Strength to Develop Tensile Strength
  - Ductility to Allow Buckling in Member or Gusset Plate
- Restrictions on Chevron and K-Bracing
- Stronger Column Splices Required
- Capacity Design Requires two load distributions be checked
- Connection Requirements Increased (EBF and BRBF also), to accommodate drift
- DC welds at column splices and bases. No PJP groove welded splices



SCBF Capacity Design Requirement



T ≈ 0 in Center Column

Uplift in Center Column!

OCBF Provisions

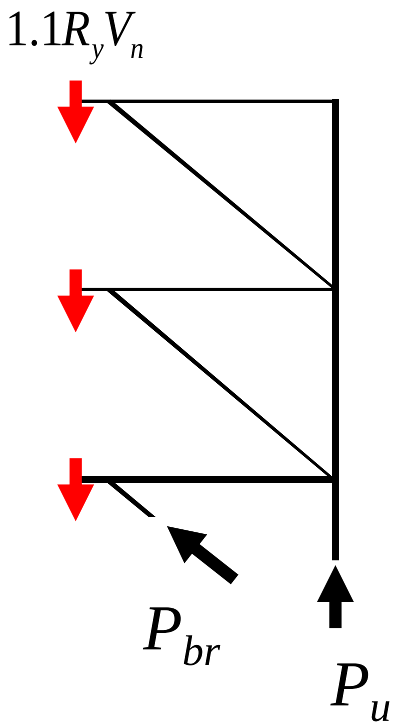
- Limited use in high SDC's
- For V or inverted V, $KL/r < 4.23/\sqrt{E/F_y}$
- Connection strength to develop brace tension capacity or amplified force
- Chevron bracing restrictions
- Tension Only Bracing Systems Allowed for Low and Penthouses
- No K-Bracing & define minor eccentricities (similar for SCBF's)
  - ➢Created issue for multi-tier applications (resulted in 2016 updates)

EBF Provisions

- Inelastic behavior limited to link beams
- Remainder of system (braces and columns) to remain elastic
- Best results for shear link elements, but local demands are higher than SMF's
  - ➢Extensive stiffening requirements
- Built-up Boxes also allowed for links
  - ➢Based on Bruneau research
- Column splice issues similar to SCBF
- Only system that is very similar to 1992!

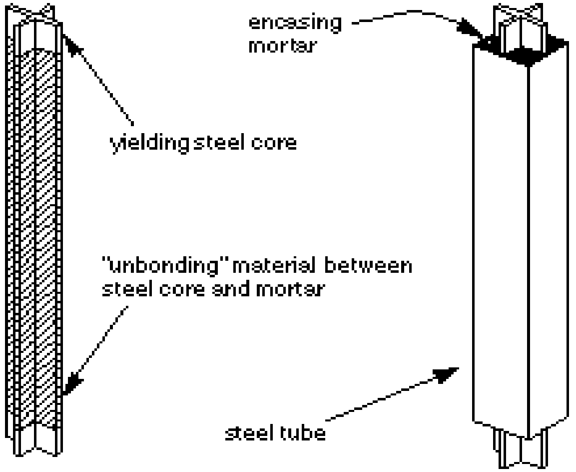
EBF Provisions (Continued)

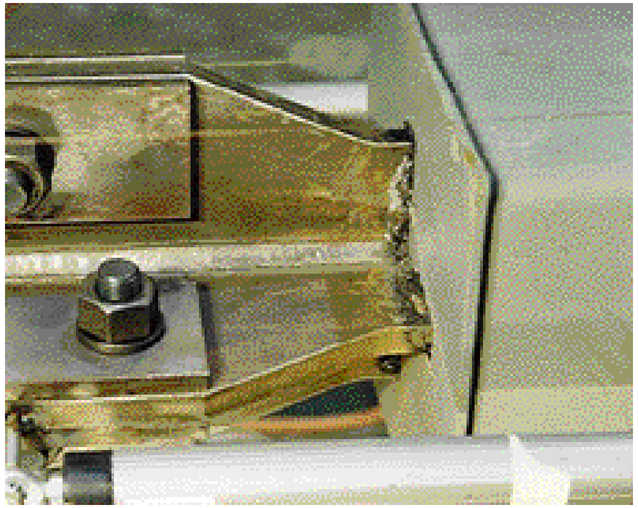
- Link-to-column connections
  - Require testing like SMF
    - Exception allowed
- Beam outside link, braces and columns designed for link capacity, including strain hardening (1.25 & 1.1)
- Lateral bracing requirements similar to SMF
  - 6% at ends of links
  - Elsewhere, strength and stiffness as required in main spec.



BRBF Provisions

- BRBF Frames
  - ➢SCBF development improves braced frame performance, but still limited by brace buckling
- Concept developed in Japan, with many applications
  - ➢Hysteretic behavior similar to elastic - perfectly plastic
- Development of provisions in U.S.
  - ➢Based on use on projects
  - ➢Capacity based approach similar to EBF
  - ➢U.S. practice leads to larger drifts than in Japan
  - ➢Very popular system for low to mid-rise buildings and some high-rise

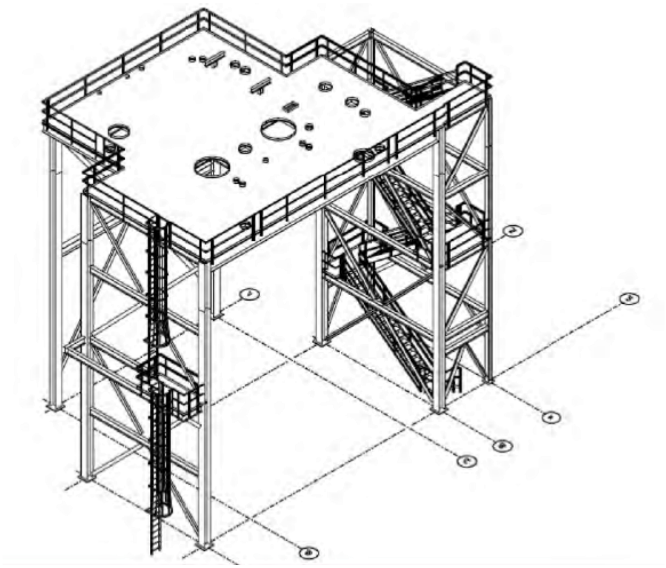




BRBF Provisions (Continued)

- Steel core restrained from buckling
  - Braces tested for twice Design Story Drift
  - Brace strength addresses strain hardening and compression strength increase due to confining system
    - Connections designed for adjusted strength and frame rotation
- Chevron requirements less demanding than SCBF
- Column splices similar to SCBF
- DC welds at column splices and base, and no PJP groove welded splices similar to SCBF

Multi-tiered Braced Frames

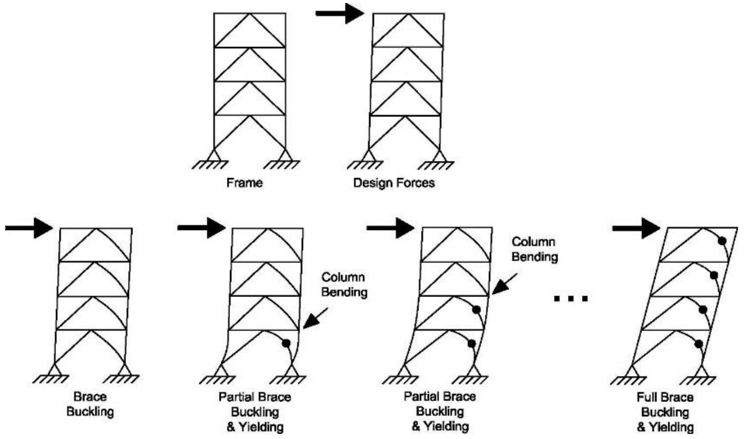


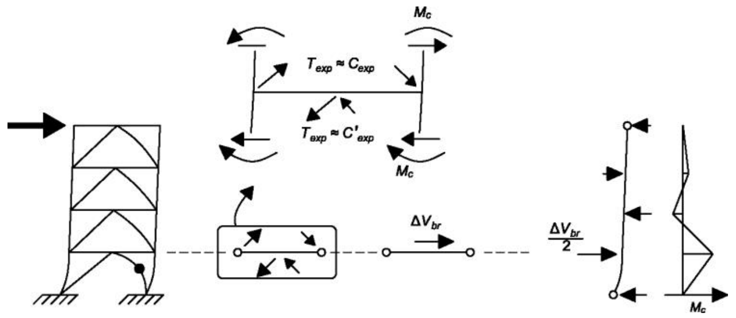
Photos courtesy of Bob Bachman and Larry Fahnestock

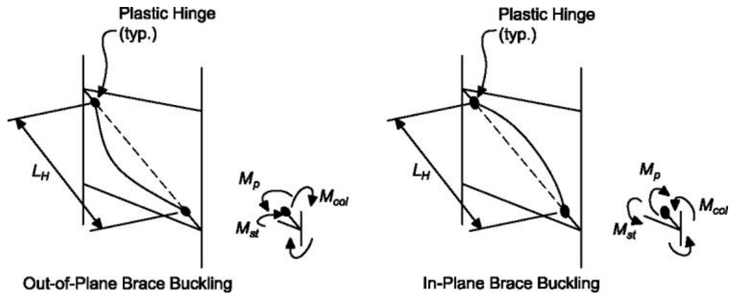
- A braced frame configuration with two or more tiers of bracing between diaphragm levels or out of plane support (called an MTBF) will now be allowed within OCBF, SCBF, and BRBF systems
- Currently considered by some to not be allowed in the 2010 Seismic Provisions because it was considered a K-braced frame

MTBF Concepts/Issues

- Desire is to avoid all deformation in one tier
- Want to force a progression of yielding up the height of the frame
- Need to design shears/moments on columns to allow this to occur
- Strut members are needed to allow frame-like action
- In buckling brace systems (SCBF/OCBF), the effects of hinging moments at ends of braces must be considered



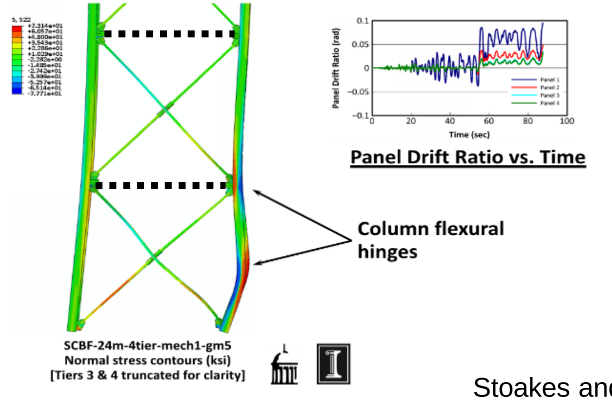




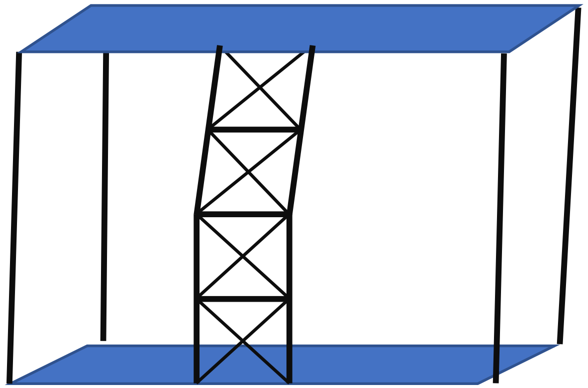
Multi-tiered Braced Frames

- 2016 provisions for MTBF in OCBF, SCBF and BRBF calls for:
  - ➢ Torsional bracing of columns
  - ➢ Horizontal struts at all tier levels
  - ➢ Capacity design of column that accounts for brace yielding and buckling
  - ➢ Mitigation of tendency for inelastic deformation to concentrate in one tier

The column strength limit state varied with frame height and number of tiers under GM5.

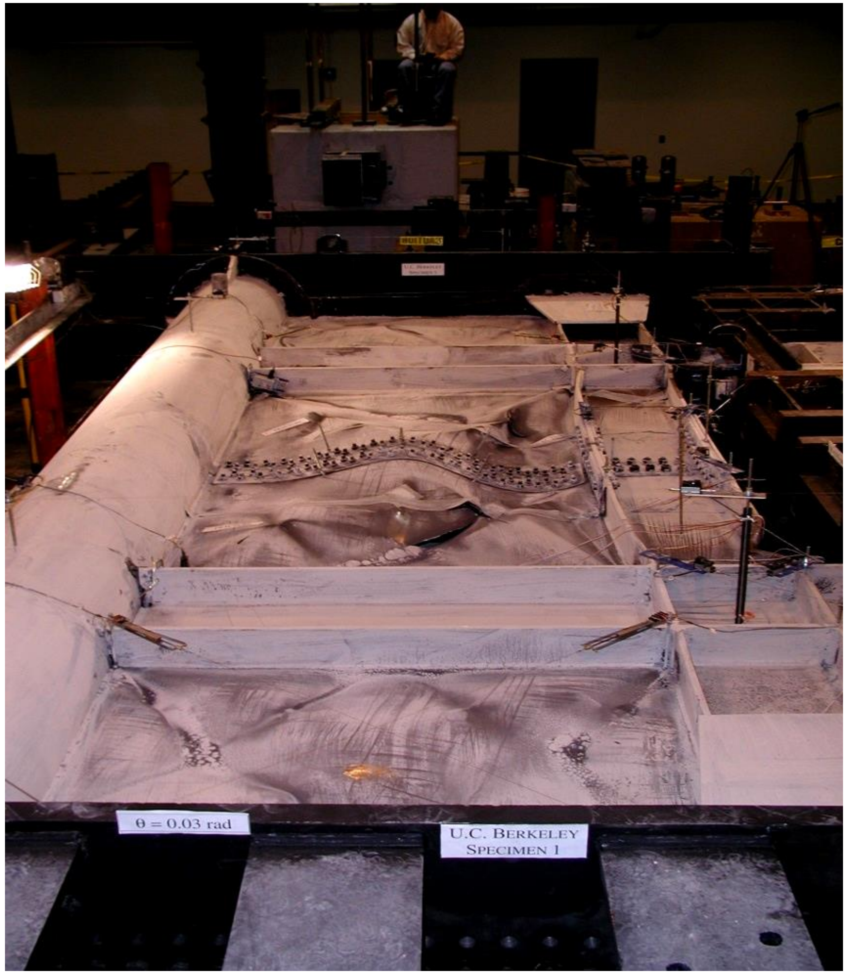


Stoakes and Fahnestock



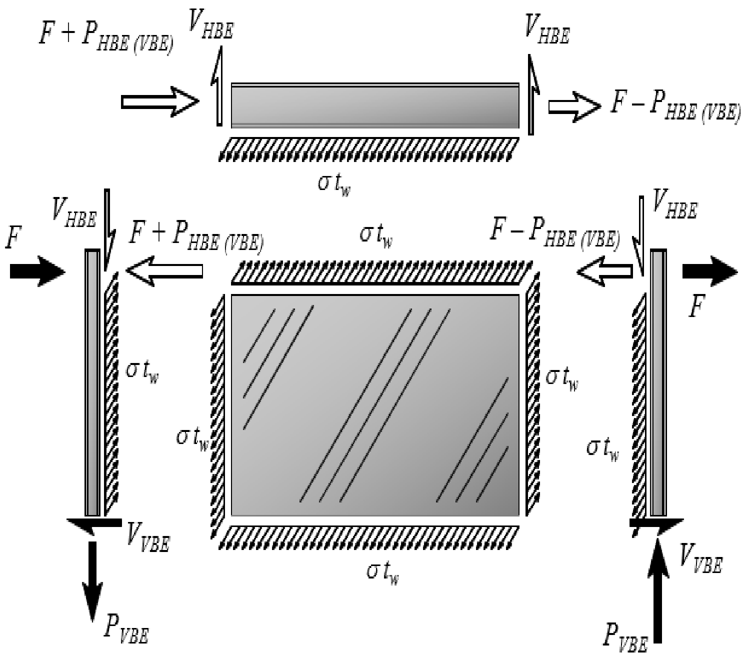
SPSW Provisions

- SPSW like plate girder design approach (tension field theory)
  - ➢ Can generate tremendous strength and stiffness as compared to CBF
- SPSW concept developed in Canada
  - ➢ NBCC Code provisions in place
  - ➢ UC Berkeley research as well
- Panel Shear Capacity Based on Simple Formula with web designed for 100%
  - ➢ Includes panel aspect ratio
  - ➢ L/h between 0.8 and 2.5



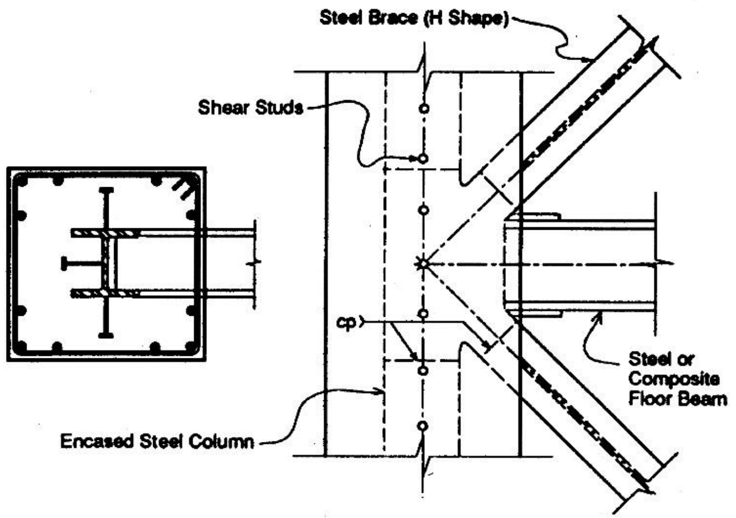
SPSW Provisions (Continued)

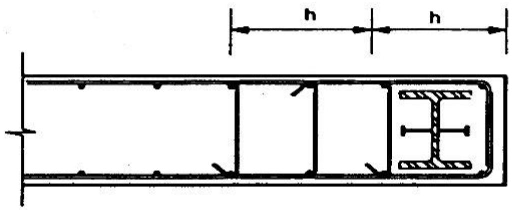
- Panels with Openings to have boundary elements (BE)
- BE's to develop panels. OMF style connections
- Lateral bracing spacing like SMF.
- Vertical BE's also have bending stiffness requirements
- Perforated Webs and corner cut-outs can be used
- Connection rotation requirements, DC welds at column splices and base, and no PJP groove welded splices similar to SCBF

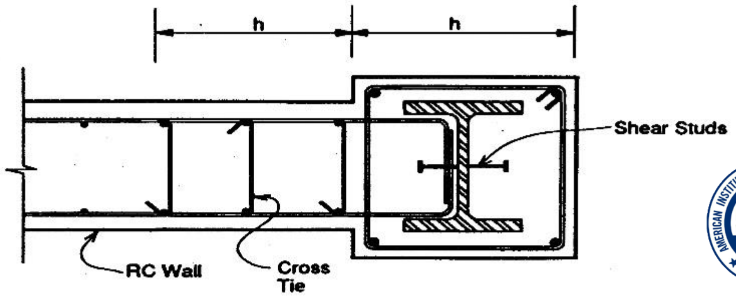


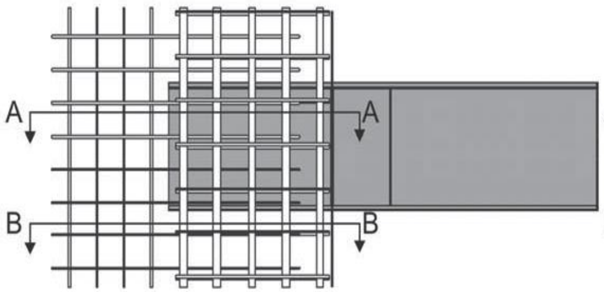
Composite Systems

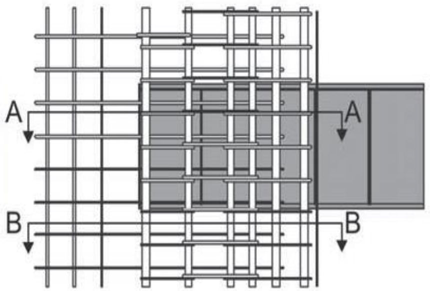
- Chapters G and H - Composite Construction Provisions
  - ➢Identifies Numerous System Options, both frames and walls (12 total)
  - ➢Provides Detailed Requirements for Member and Connection Design
  - ➢Modified to be Consistent with Steel Systems





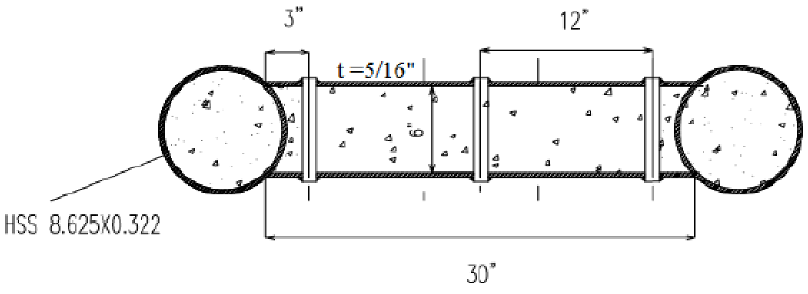


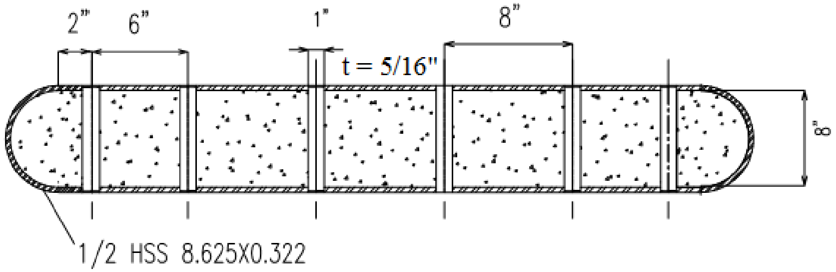




Concrete-filled steel sandwich panel walls

- New type of composite plate shear wall (C-PSW)
- Benefits include
  - Steel can provide confinement of the concrete
  - Steel can act as formwork for accelerated construction
  - Concrete core delays local buckling of steel plate
  - Reinforcing bars are typically not necessary
  - Used on recent high-rise project in Seattle to replace R/C core walls
    - Called "Speed Core" by AISC





Drawings courtesy of Michel Bruneau et al

QC and QA

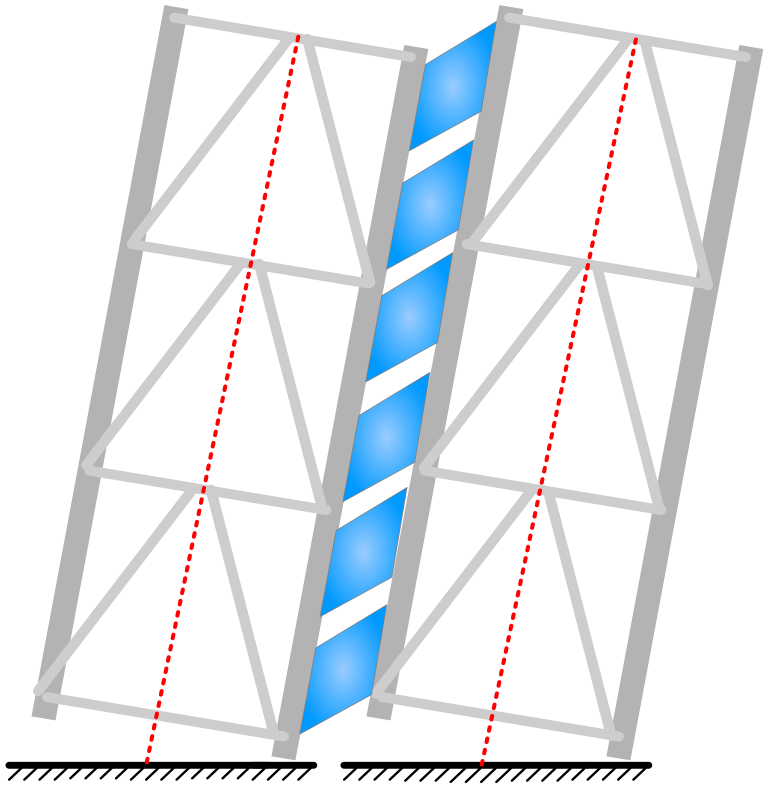
- Detailed requirements replaced general set of provisions in previous editions
- Coordinated with AWS D1.8.
- QA plan required in conjunction with IBC Chapter 17. Covers both QA and QC.
- Documentation requirements listed
- Visual Inspection Points and Frequency Defined
  - For before, during and after welding or bolting by both QA and QC. Shown in tabular format
    - "Observe, Perform and/or Document" vs. Periodic/Continuous
- NDT locations and requirements specified. Both UT and Magnetic Particle incorporated. All results documented.
- Parallel composite construction requirements included

Status and Upcoming Activities

- AISC 341-16 approved by reference in ASCE 7-16, Supplement No. 1
  - To be adopted by 2016 ASCE-7 and IBC 2018. Adopted in California and in other states in 2019 and 2020…
- Work is underway on the 2022 Edition of the Seismic Provisions
- Your comments/suggestions welcome!

What About the Future?

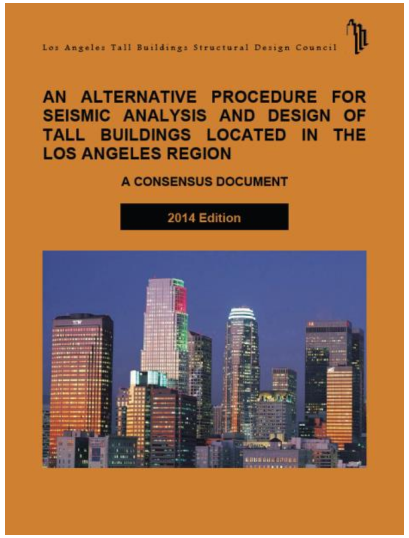
- Where do we go from here?
- What will 2035 look like???



Performance Based Earthquake Engineering is Here

- Provisions for Performance Based Earthquake Engineering (PBEE)
  - ➢LATBSDC Provisions ('14), City of SF, and PEER TBI Guidelines ('10) focus on Tall Buildings
    - Primarily Used for Code Performance Demonstration
    - Two level (Service and Collapse Prevention) design checks required
    - NLRH used for Collapse Prevention
    - Peer Review required
  - ➢ASCE 41 can now be used for (N) Buildings
  - ➢ATC 58 Project provides comprehensive approach to PBEE, but use with caution!

Now Available:
Guidelines for Performance-Based Seismic Design of Tall Buildings



Expanded Use of NLRH Analyses

- Becoming Common for PBEE in Tall Buildings and Major Seismic Retrofits
- Advantages Primarily for More Accurate Estimation of Column Demands
  - Capacity design overly conservative due to higher mode effects
- ASCE 7-16 has Improved Provisions for NLRH
- Typically Used in Conjunction with Peer Review
  - Future Provisions in Development for 2022

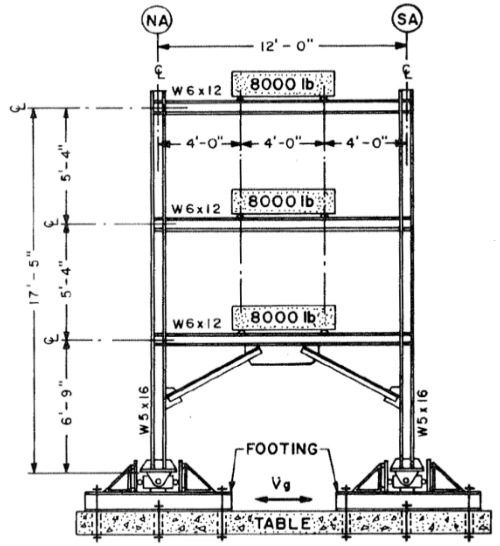
Increased Demand for Higher Performance

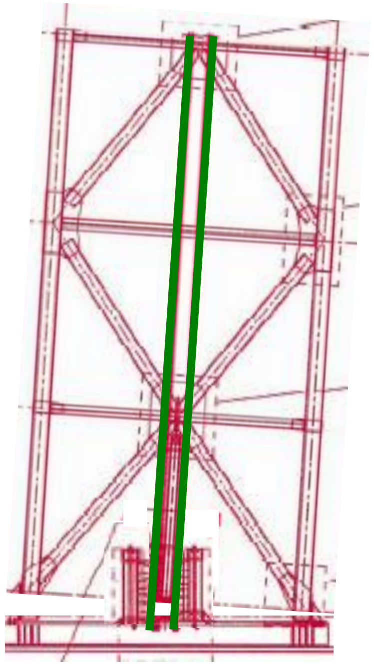
- Owners and Society's Expectations will Continue to Increase
- Prescriptive Code Requirements for Immediate Occupancy Design (I=1.5) are Indirect, at Best
- Considerations Not Addressed in Standards (Yet)
  - Deliberate design to avoid residual drift
  - Design for multiple major earthquakes over building life (replaceable fuses?)
- This may become the basis for Sustainable, Resilient and/or Functional Recovery Design!

What About Rocking?

- More of a question for ASCE 7 than AISC Specifications
  - Can we take advantage of this mechanism to reduce forces/damage to structural system?
- What requirements should there be for design of elements that "control" the rocking (force, deformation, cumulative ductility, etc.)?
- How should we define R for system above rocking base?
- How strict should the detailing requirements be for the rest of the system?
- Impact on adjacent gravity systems is somewhat unique
- Some applications in practice and research is encouraging

Examples of Rocking Systems



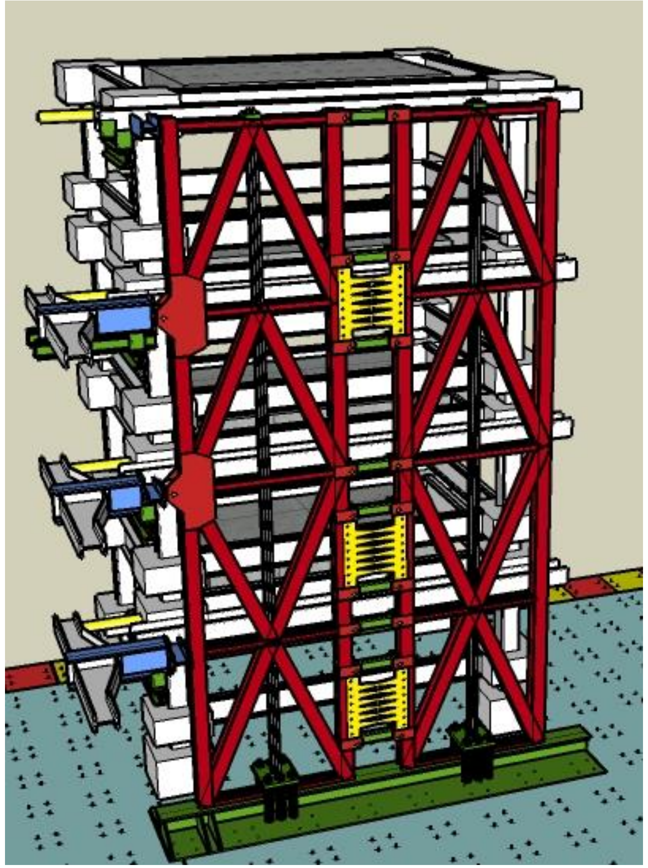


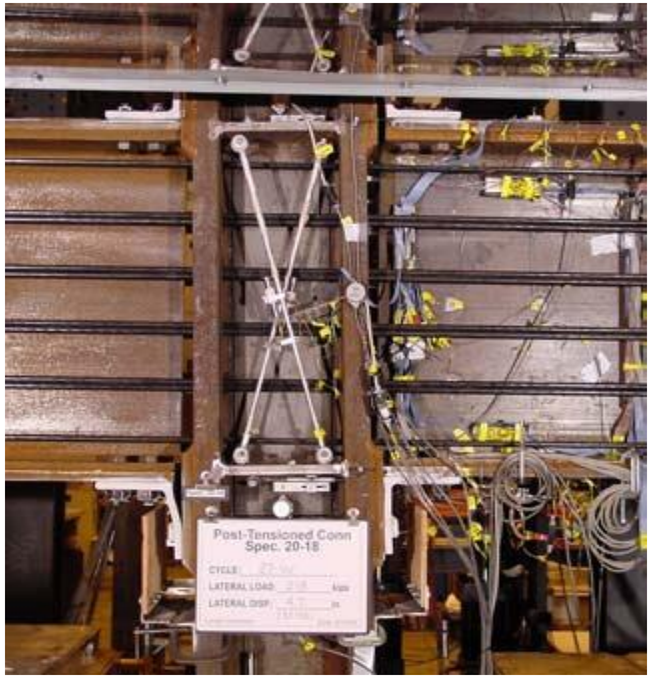
Photos: Clough, et.al. (1977), Tipping, Mar and Associates, and Stanford/UIUC

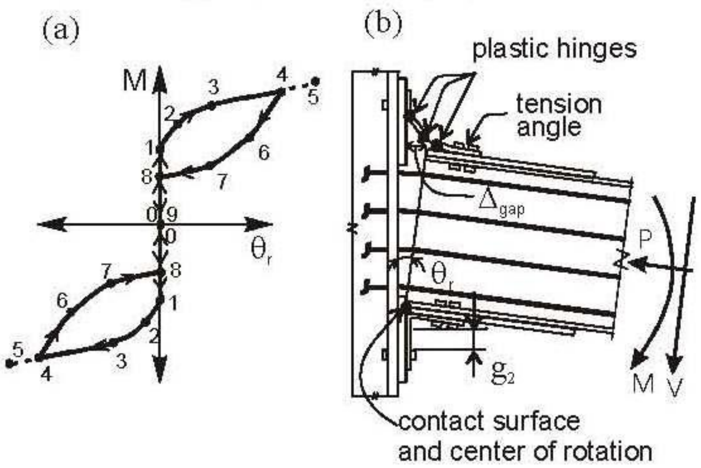
Self-Centering Systems

- Multiple research efforts
  - Lehigh and Stanford/U of Illinois, e.g.
  - Both moment frames and braced frames
- Many existing systems have some limited capacity to self-center, but it is not considered in design
  - Gravity frames with column continuity (AISC splice requirement)
  - But, may not always be present
- Does having some self-centering capacity justify modifying (increasing) R factors?
- Should residual displacements start to enter our criteria for higher performing systems?

Examples of Self-Centering Systems







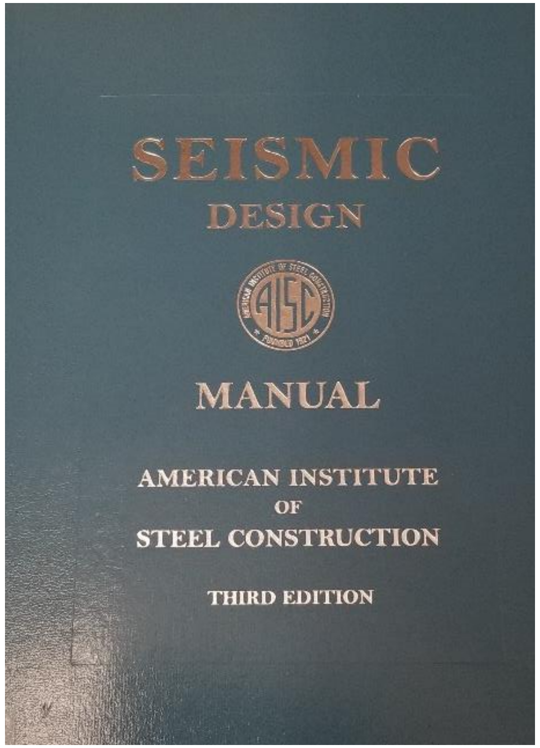
Photos:
UIUC/Stanford
&
Lehigh/Princeton

New Systems – "Mix and Match"?

- Presently, all system definitions require same level of ductility/detailing over height of building in all frames
  - ➢Unlikely that all joints need the same level of ductility
  - ➢May not result in economically optimal structure
- Can we believe our analysis enough that we can use SMF, IMF and/or OMF (or BRBF, SCBF, and/or OCBF) scattered throughout frames?
  - ➢Charney studies suggest this is viable
  - ➢Likely only for NLRH analysis based designs

AISC Documents Related to Seismic Design

- 2016 AISC Seismic Provisions (ANSI/AISC 341)
  - ➢Available via free download.
- 2016 AISC Moment Connection Prequalification Standard (ANSI/AISC 358). Plus supplement
  - ➢Available via free download.
- 2016 AISC Specification for Structural Steel Buildings (ANSI/AISC 360)
  - ➢Available via free download.
- 2018 AISC Seismic Design Manual
  - ➢Available for purchase.



Concluding Comments

- Unified Process for Steel Seismic Provision Development
  - "Single Point of Responsibility" eliminates duplicative effort and minor differences that result in major confusion
  - Allows rapid incorporation of new information
- AISC 2016 Specifications and Seismic Provisions now available for FREE download on AISC website.
  - Companion new edition of AISC Seismic Design Manual available.
- Work is underway on 2022 Provisions
- WE WANT YOUR INPUT AND RECOMMENDATIONS FOR IMPROVEMENTS!

Questions?

CONGRESO INTERNACIONAL DE LA CONSTRUCCIÓN CON ACERO

ICCA INSTITUTO COLOMBIANO DE LA CONSTRUCCIÓN CON ACERO