Seismic Design of New Structural Steel Buildings

using the International Building Code

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Introduction

- The SEAOC Blue Book and the UBC have used in Earthquake Engineering Design Caribbean, this is replaced with the IBC using NEHRP provisions .
- In the Caribbean while loading requirements are followed the code prescribed detailing is generally not.
- Therefore many buildings will not behave in the manner expected during the design earthquake.

Introduction

Earthquake Failures

Focus of Presentation

1. IBC Code – Seismic Design Criteria
2. AISC Seismic Provisions
3. Pre-Qualified Connections – FEMA 350
4. Quality Assurance in IBC

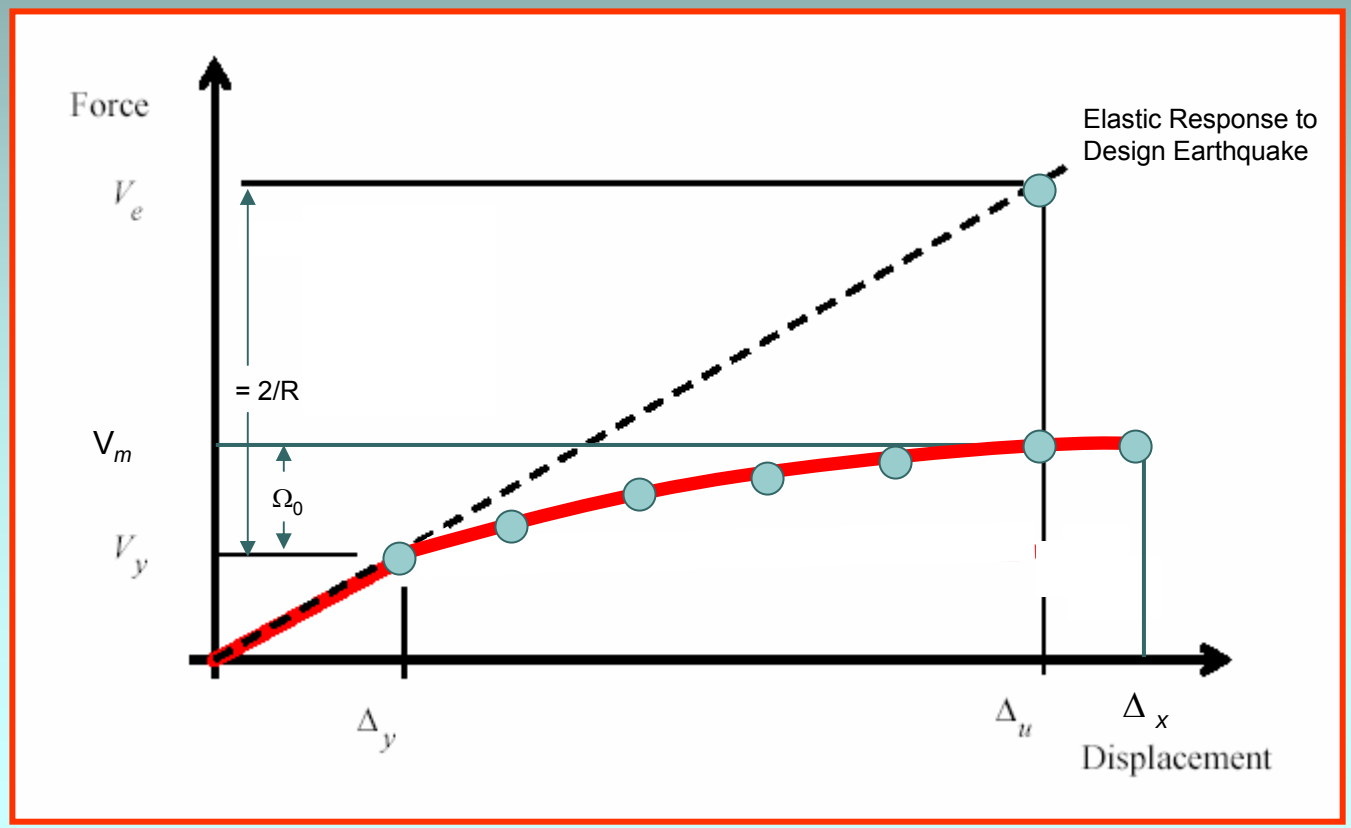
1. IBC CODE
Seismic Design

IBC CODE Design Criteria

- Actual earthquake forces in a building can be significantly higher than the design loads.
- UBC and IBC have prescriptive provisions used to allow inelastic behavior and prevent collapse.

Earthquake-resistant Design

Design Philosophy



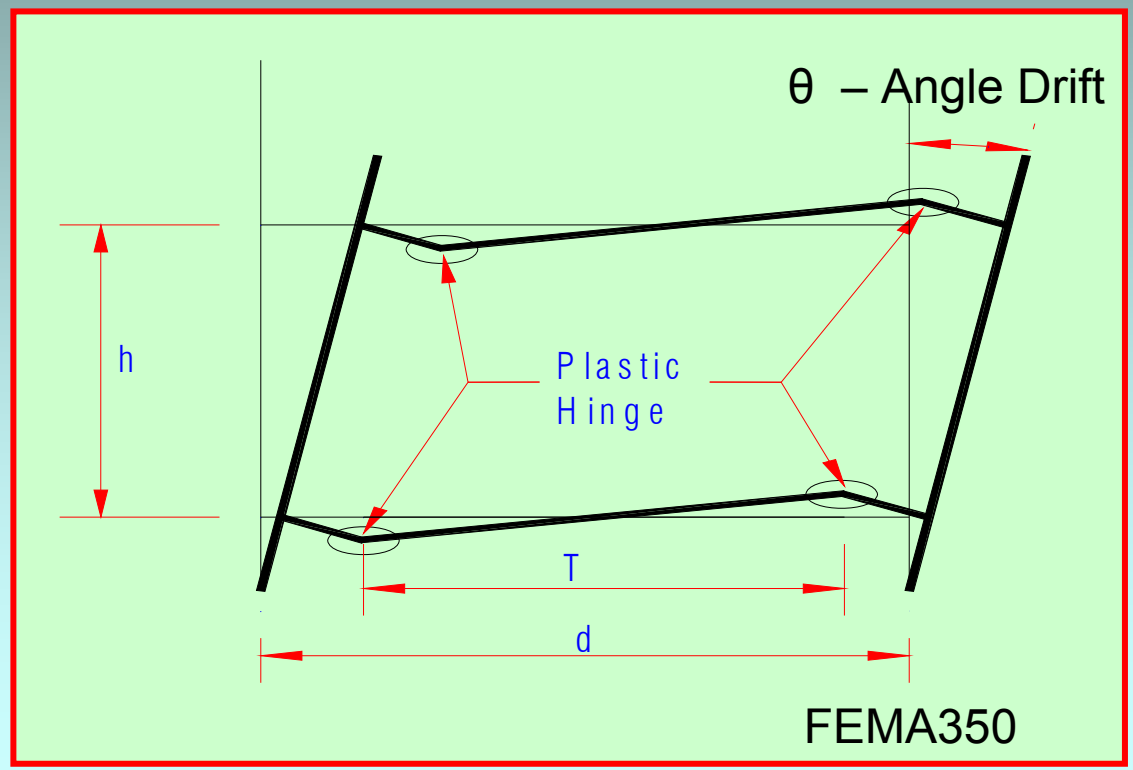
1.IBC code

DESIGN CRITERIA –(Collapse Prevention)

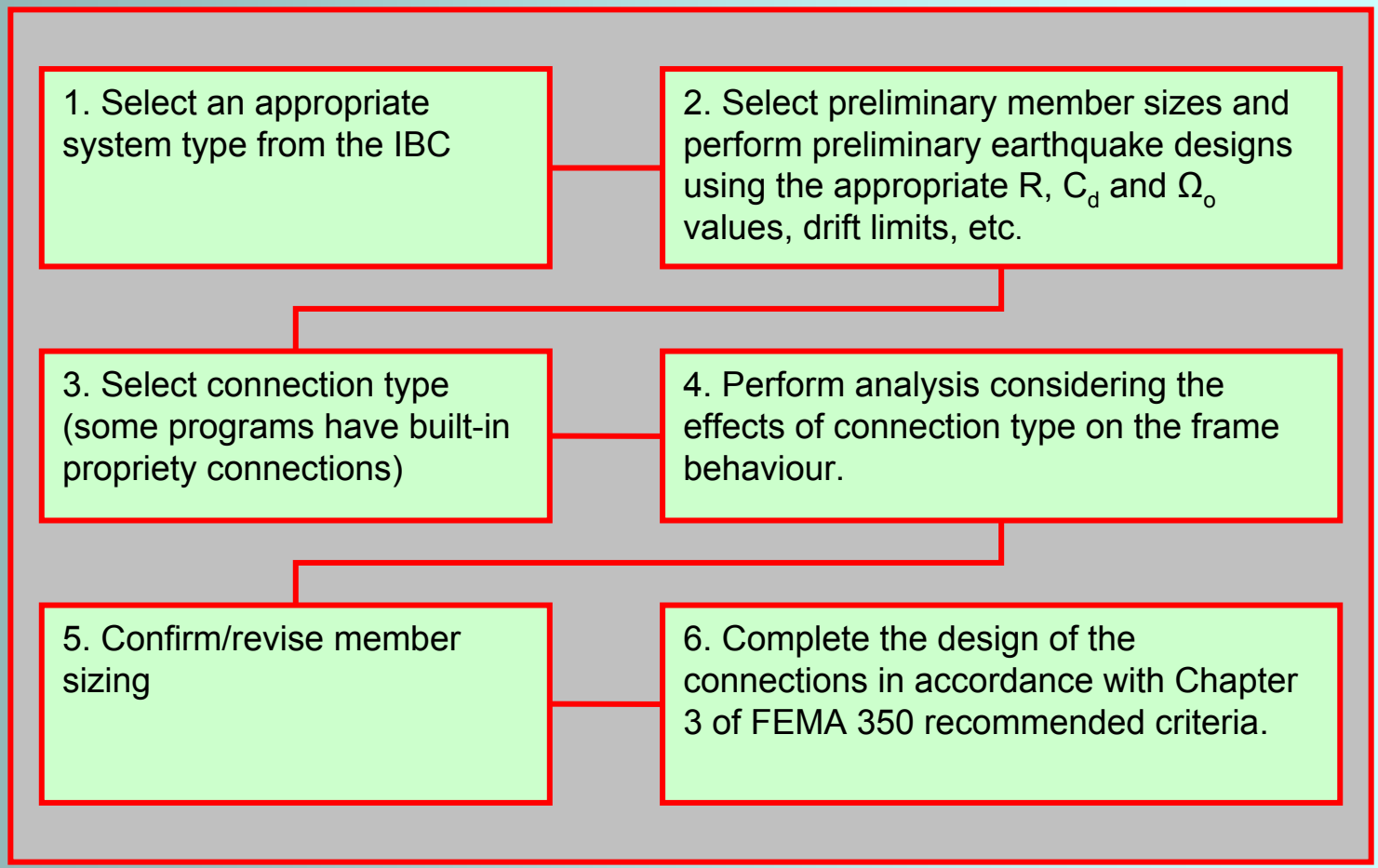
- IBC encourages the use of building configurations, systems, materials and details capable of ductile behaviour
- For earthquake design it is assumed that linear elastic analysis was done but the frame will experience inelastic behaviour
- The IBC therefore uses a prescriptive rather than an analytical approach

1.IBC code

DESIGN CRITERIA –(Collapse Prevention)



1.IBC Code
(DESIGN APPROACH)



1.IBC Code (Steel seismic force resisting systems)

IBC2000 BASIC SEISMIC FORCE RESISTING SYSTEM	Detailing Ref. Sec.	R	Ω_o	C_d	SYSTEM LIMITATIONS AND BUILDING HEIGHT LIMITATIONS BY SEISMIC DESIGN CATEGORY A&B	C	D	E	F	2003 IBC R	2003 IBC Ω_o
Building Frame System											
Steel eccentrically braced frames, moment-resisting connections at columns away from links (EBF)	15 [8]	8	2	4	NL (NL)	NL (NL)	160 (160)	160 (160	160 (160)	8.0	2.0
Steel EBF, non-moment-resisting connections at columns away from links	Note 9(15)	7	2	4	NL (NL)	NL (NL)	160 (160)	160 (160)	160 (160)	7.0	2.0
Special Steel Concentric Braced Frames (SCBF)	Note 9(15)	6	2	5	NL (NL)	NL (NL)	160 (160)	160 (160)	160 (100)	6.0	2.0
Ordinary Steel Concentric Braced Frames (OCBF)	Note 9(15)	5	2	4.5	NL	NL	160 (35)	100 (35)	100 (NP)	5.0	2.0
Buckling Restrained Braced Frames (BRBF)										8.0	2.5
Special Steel Plate Shear Walls										8.0	2.5

1. IBC Code (Steel seismic force resisting systems (Cont'd))

IBC2000 BASIC SEISMIC FORCE RESISTING SYSTEM	Detailing Ref. Sec.	R	Ω_o	C_d	SYSTEM LIMITATIONS AND BUILDING HEIGHT LIMITATIONS BY SEISMIC DESIGN CATEGORY A&B	C	D	E	F	2003 IBC R	2003 IBC Ω_o
Moment-resisting Frame systems											
Special Steel Moment Frames (SMF)	Note 9(9)	8	3	5.5	NL (NL)	NL (NL)	NL (NL)	NL (NL)	NL (NL)	8.0	3.0
Special steel truss moment frames (STMF)	Note 9(12)	7	3	5.5	NL	NL	160 (160)	100 (100)	NP (NP)	7.0	3.0
Intermediate steel moment frames (IMF)	Note 9(10)	6	3	5	NL (NL)	NL (NL)	165 (35)	100 (NP)	NP (NP)	4.5	3.0
Ordinary steel moment frames	Note 9(11)	4	3	3.5	NL (NL)	NL (NL)	35 (NP)	NP (NP)	NP (NP)	3.5	3.0

1.IBC Code
Building System Changes

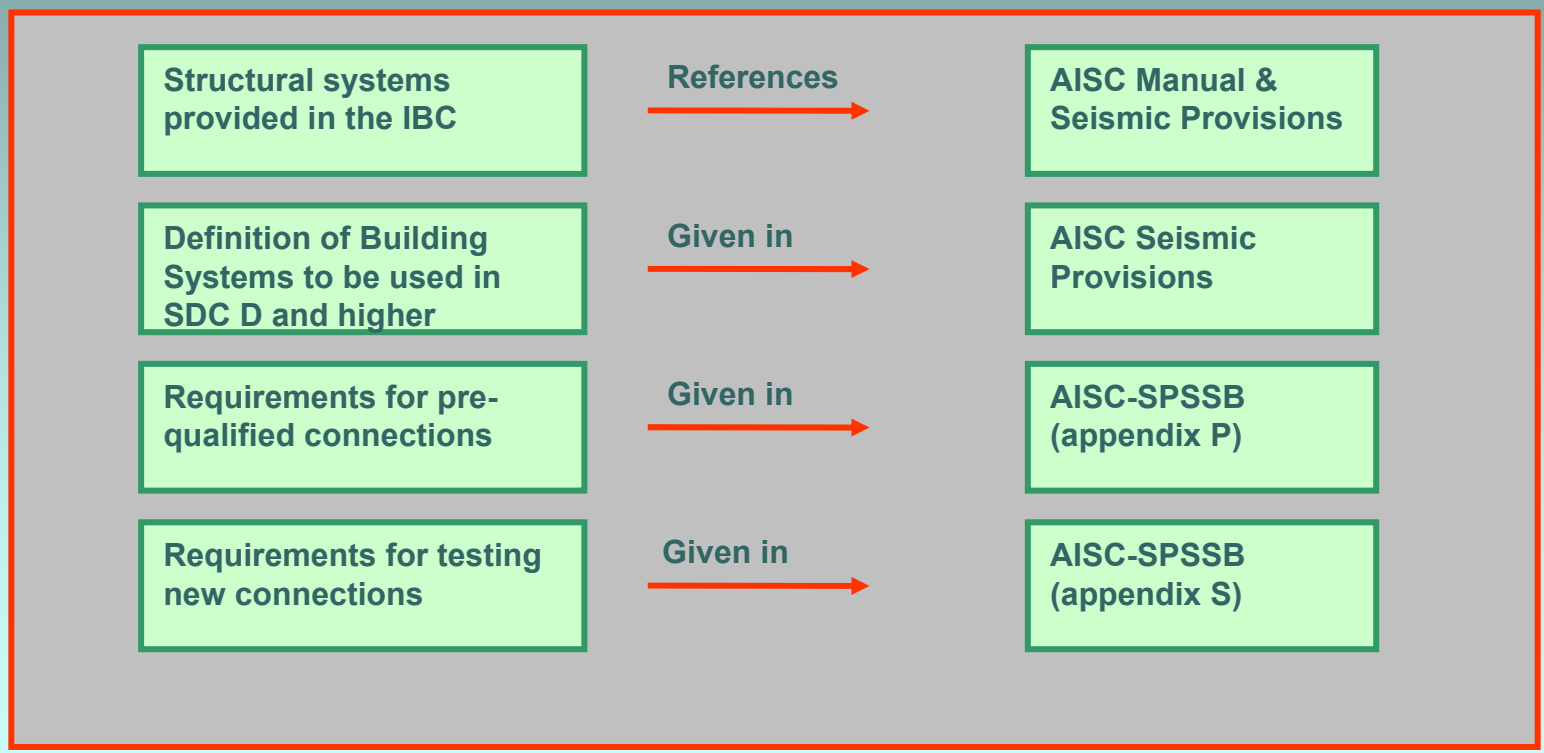
- AISC seismic provisions must correspond to the IBC and UBC codes that they are referenced in.

Example of Steel IMF in SDC D

	IBC 2000	IBC 2003
Height of building	165 ft	35 ft
C_d Deflection modification factor	5.0	4.0
R value	6.0	4.5

1.IBC Code (Con't)

AISC Seismic Provisions



2. AISC SEISMIC PROVISIONS FOR STRUCTURAL STEEL BUILDINGS 2002

(SPSSB)

2.AISC-SEISMIC PROVISIONS

Contents of AISC-SPSSB

- PART 1 – Structural Steel Buildings
  Appendix P – Pre-qualification of Connections
  Appendix S – Qualifying Cyclic tests for New Connections
  Appendix X – Welding Procedure for Toughness Verification Tests

- PART II – Composite Steel and R.C Building
- PART III – Allowable Stress Design
- COMMENTARY

2. AISC-SPSSB (Cont'd)

Part 1 – General requirements

- System overstrength factor Ω_0.
- Material overstrength factor R_y for ASTM material types.
- P-Δ effects check is defined using storey drift parameter Ψ. When Ψ is greater than 1.0 a P-Δ analysis is required.
- b/t limiting ratios for flanges in compression.
- Charpy V-Notch toughness requirements for thick plates and welds such as beam flange to column.

2. AISC-SPSSB (Cont'd)
Part 1 – General requirements

- Connection requirements such as:
  1. All bolts to be pre-tensioned.
  2. No sharing of forces between bolts and welds on the same faying surface.
- Column Strength e.g.: If $P_u/(\Phi Pn)$ is greater than 0.4, axial strength must be checked using Ω_0.
- t_w/h ratios checks for column web buckling.

2. AISC-SPSSB (Cont'd)

Part 1 – General requirements

- Column Splices to be located min. 4ft away from beam-col. Connection.
- Column Splices are subject to net tensile stresses must use Ω_0 in load combination.

2. AISC-SPSSB (Cont'd)
SMF – Requirements.

- Connections must be able to rotate thru 0.04 rads and sustain 80% of M_p at that level of drift.

- Shear strength from 1.2D + 0.5L + shear forces from appl. of moments $\{2[1.1R_y F_y Z/T]\}$.

- Panel zone shear strength and minimum thickness requirements.

2. AISC-SPSSB (Cont'd)
SMF – Requirement (Cont'd)

- Beam and column limitations e.g.: protected regions of the beam
- Strong column-weak beam applies
- Restraint requirements for columns and beams in compression - Do not usually apply with concrete floors.

2. AISC-SPSSB (Cont'd)

IMF - Requirements

- In SDC D, (Zone 3) Building heights are limited to 35 ft. No limits to use in SDC A,B and C but IMF must not be used in SDC E.
- Connections used in IMFs are the same for SMFs. AISC Seismic Provisions 2005 however will have IMF connections.
- Connection must rotate thru 0.02 rads and sustain 80% M_p at that level of drift.

2. AISC-SPSSB (Cont'd)
IMF – Requirements (Cont'd)

- Connection shear strength from load case 1.2D + 0.5L plus shear strength from appl. of moments. $\{2[1.1R_yF_y\ Z\ /T]\}$.
- Panel zone has no special requirements
- No strong column-weak beam requirements.

2. AISC-SPSSB (Cont'd)
OMF - Requirements

- Connections must rotate thru 0.01 rads drift.
- IBC 2003 has height limits of 60ft with roof dead loads less than 15 psf in SDC D but OMF are not permitted in SDC E & F. They are permitted without limitations in SDC A,B and C.
- Connection strength in flexure must develop M_u not less than $[1.1 \times R_y \times M_p]$ which is inelastic behaviour.
- No special requirement for panel zones.

2. AISC-SPSSB (Cont'd)
OMF– Requirements (Cont'd)

- Continuity plates if needed must be as thick as beam flange or connection plate.
- No strong column-weak beam requirements
- No restraint for beam or connections needed
- The use of design procedures for pre-qualified connections is permitted for any shape

3. Pre-Qualified Connections

3. Pre-Qualified Connections

- AISC seismic provisions require SMFs, IMFs and EBFs to have either connections that have already been pre-qualified as per appendix P or new connections tested accordance with appendix S
- Neither IBC nor AISC-SPSSB references any source for pre-qualified connections
- In FEMA350/355D there are configurations and design procedures for pre-qualified connections
- Most of the connections referred in App. P were tested under the SAC joint venture

3. Pre-Qualified Connections
SAC joint venture

- The SAC joint venture was commissioned by FEMA after the Northridge 1994 earthquake to study the failures of steel moment frames.
- Phase II of the SAC study included extensive full scale testing of beam-column assemblies and connections
- These studies resulted in a set of FEMA publications of Recommended Criteria

3. Pre-Qualified Connections
SAC joint venture

- FEMA 350 – Recommended Seismic Design Criteria for New Steel Moment- Frame Buildings.
- FEMA 351 – Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings.
- FEMA 352 – Recommended Post-Earthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings.

3. Pre-Qualified Connections

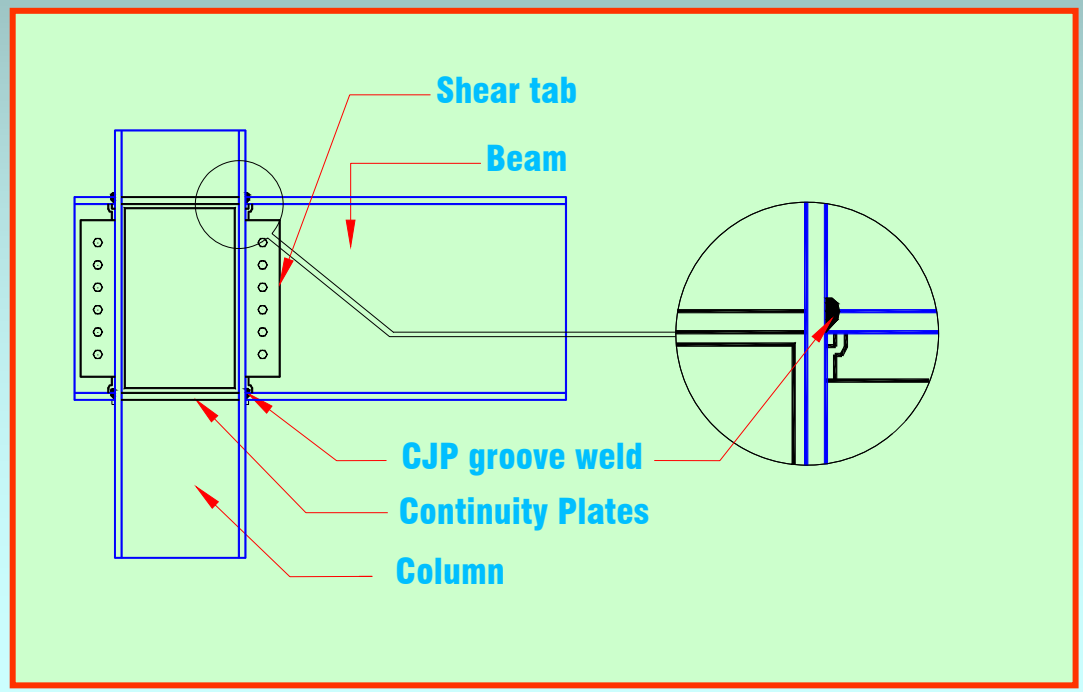
SAC joint venture (Cont'd)

- FEMA 353 – Recommended Specifications & Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications.
- FEMA 355D – State of the Art Report on Connection Performance.

3. Pre-Qualified Connections

Pre-Northridge Connection

- This was the only pre-qualified connection referenced by UBC to be used in regions of high seismiscity. Discontinued in1994



3. Pre-Qualified Connections

FEMA 350

Common connections in FEMA 350 for seismic applications:

- Reduced Beam Section
- Bolted Unstiffened End Plate
- Bolted Stiffened End Plate
- Bolted Flange Plate

3. Pre-Qualified Connections (Cont'd)

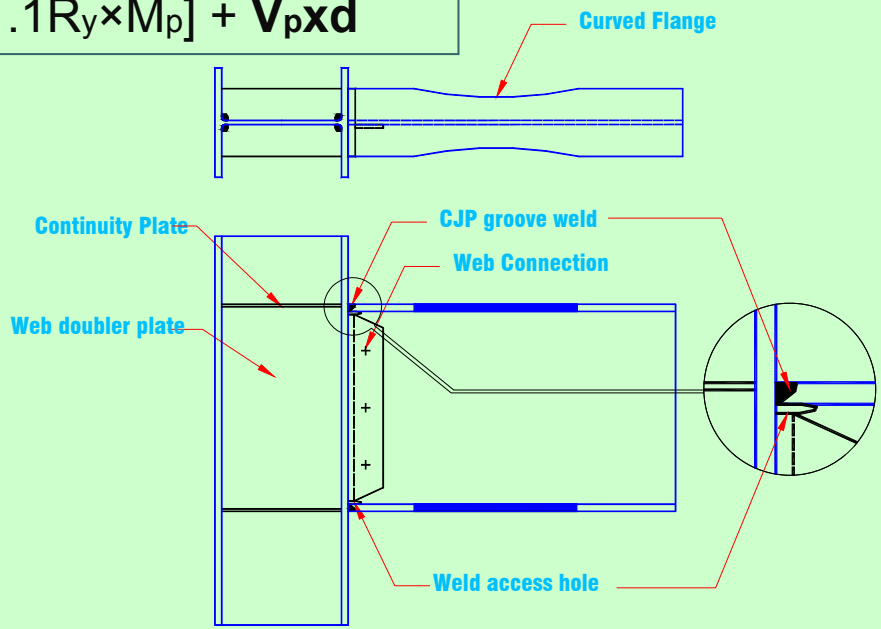
Reduced Beam Section (RBS)

- This is AISC favoured connection is a fully restrained connection. It has a circular cut in the flanges of the beam.
- The top and bottom of the beam flanges are welded to the column flange with complete penetration groove weld.

3. Pre-Qualified Connections

RBS Connection

Design Moment is
$[1.1R_y \times M_p] + \mathbf{V_p x d}$



3. Pre-Qualified Connections (Cont'd)

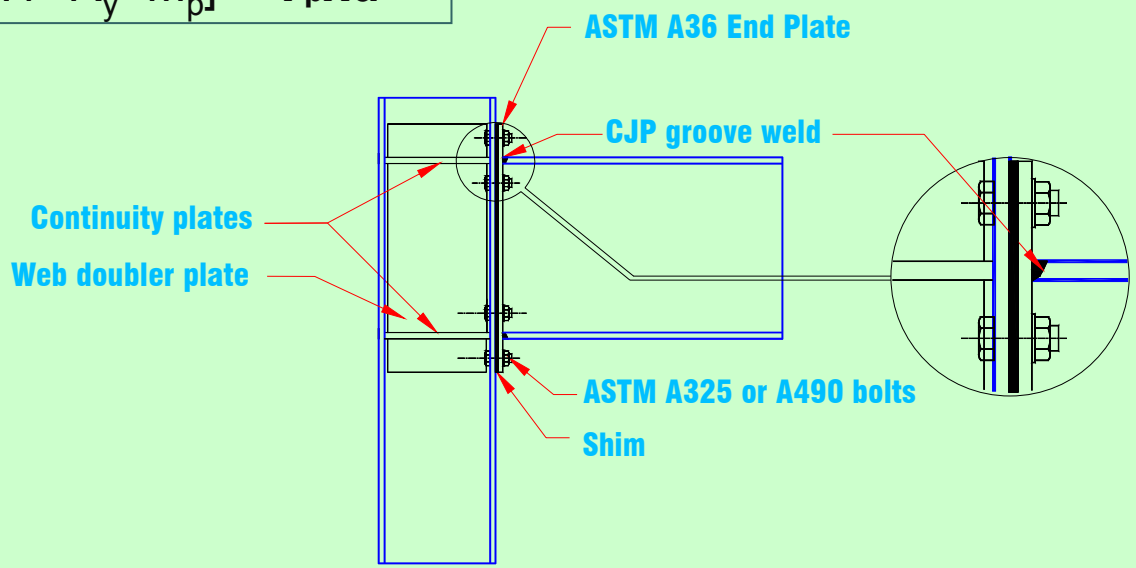
Bolted Unstiffened End Plate connection

- Flanges are welded with CJP welds.
- The end plates are bolted to column flange with pre-tensioned bolts.

3. Pre-Qualified Connections

(Drawing of bolted connection with welded end plate).

Design Moment is
$[1.1 \times R_y \times M_p] + \mathbf{V_p x d}$



3. Pre-Qualified Connections (Cont'd)

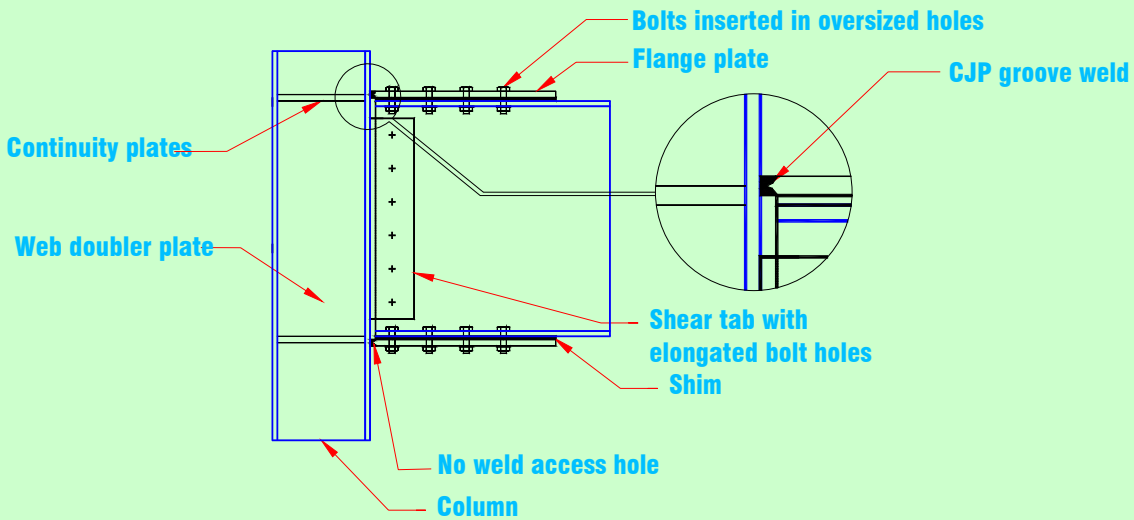
Bolted flange plate connection

- Flange plate is bolted to the beam flange and the web of beam is bolted to a shear tab.
- The bolt holes in the flange plate are specified to be oversized. Bolt holes in the shear tab specified to be elongated.

3. Pre-Qualified Connections

(Drawing of bolted flange plate connection).

Design Moment is
$[1.1R_y \times M_p] + V_p xd$



3. Pre-Qualified Connections (Cont'd)

Column weak axis connections

- No tested connections into the weak axis of the column have been accepted by AISC or FEMA.
- A section on cruciform columns will be introduced in AISC seismic provisions 2005.

4. Quality Assurance in IBC

4. Quality Assurance in IBC

- Chapter 17 in IBC deals with Testing and Inspections.
- Requires that testing agencies meet the requirements of the building officials.
- Requires that copies of tests and inspection records be filed with the B.O.
- Special Inspectors are required to inspect during critical activities during construction.

4. Quality Assurance in IBC

The Special Inspector- Steel Elements

- Not required where work is done on the premises registered and approved fabricator. Periodic monitoring required.
- Installation of high strength bolts to be periodically inspected.
- All CJP and PJP welds that are in tension and part of the seismic resisting system must be tested using non-destructive methods.

4. Quality Assurance in IBC
The Special Inspector- Steel Elements

- Not required to continuously inspect welding by qualified welders for single pass fillet welds, deck and stud welding.
- For pre-tensioned bolts the S.I. must observe pre-installation testing and calibration of torque wrenches and tension calibrators.
- Slip critical connections require continuous monitoring.

Conclusion

- Steel structures must be designed so that life safety and collapse prevention requirements are met
- Detailing is critical in collapse prevention
- Quality assurance need to begin at the design stage with a QA procedure prepared by the Engineer.
- Apart from the Engineer the role of the Special Inspector is critical in QA.

Conclusion

THE END