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Course Description

Session L1: Planning the Seismic Design

September 10, 2018

This live webinar addresses design steps including system selection, configuration selection, base-shear determination, including wind vs seismic comparison and determination of irregularities. The session will also examine load combinations, including determination of redundancy and identifying load combination extents (i.e., which elements get Omegified).



Learning Objectives

- List requirements to determine base shear.
- List horizontal irregularities that must be considered in the building design.
- List vertical irregularities that must be considered in the building design.
- Describe factors that affect load combinations including the redundancy factor and overstrength factor.



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Seismic Design in Steel: Concepts and Examples

Session L1: Planning the Seismic Design
September 10, 2018



Rafael Sabelli, SE



Course objectives

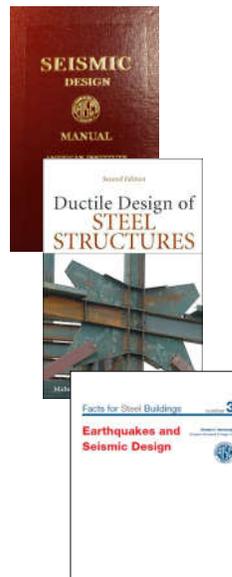
- Understand the principles of seismic design of steel structures.
- Understand the application of those principles to two common systems:
 - Special Moment Frames
 - Buckling-Restrained Braced Frames.
- Understand the application of design requirements for those systems.



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Resources

- *AISC Seismic Design Manual*
- *Ductile Design of Steel Structures*, Bruneau, Uang, and Sabelli, McGraw Hill.
- *Earthquakes and Seismic Design*, Facts for Steel Buildings #3. Ronald O. Hamburger, AISC.
- Other publications suggested in each session



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Other resources

- AISC Solutions Center
 - 866.ASK.AISC (866-275-2472)
 - Solutions@AISC.org
- AISC Night School
 - Nightschool@AISC.org



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Course outline

Part I: Concepts

- R1. Introduction to effective seismic design
- R2. Seismic design of moment frames
- R3. Seismic design of braced frames
- R4. Seismic design of buildings



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Course outline

Part II: Application

- L1. Planning the seismic design
- L2. Building analysis and diaphragm design
- L3. Design of the moment frames
- L4. Design of the braced frames



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Session L1: Planning the seismic design



Session topics

- System selection
- Effective seismic weight
- Configuration selection
- Base-shear determination
- Wind vs seismic comparison
- Determination of Irregularities
- Load combinations



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Given information

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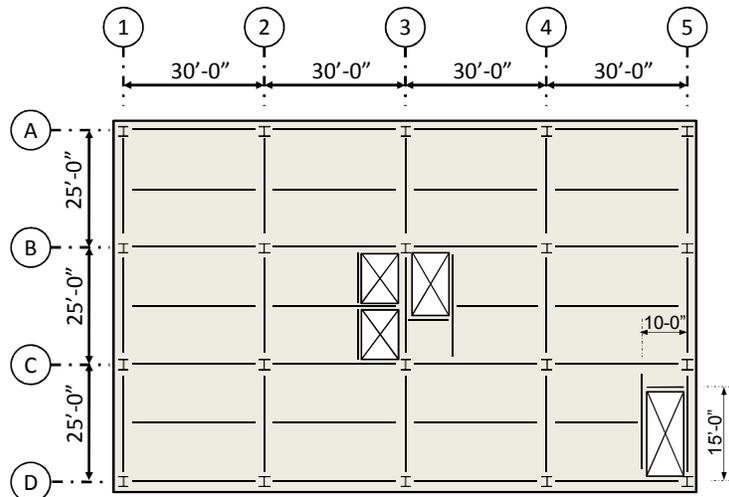
Given information

- Design from AISC Seismic Design Manual
- Four-story building
- Special Moment Frame
 - Examples 4.3 and 4.4
- Buckling-restrained Braced Frame
 - Example 5.5
- Diaphragm design similar to Example 8.4.1

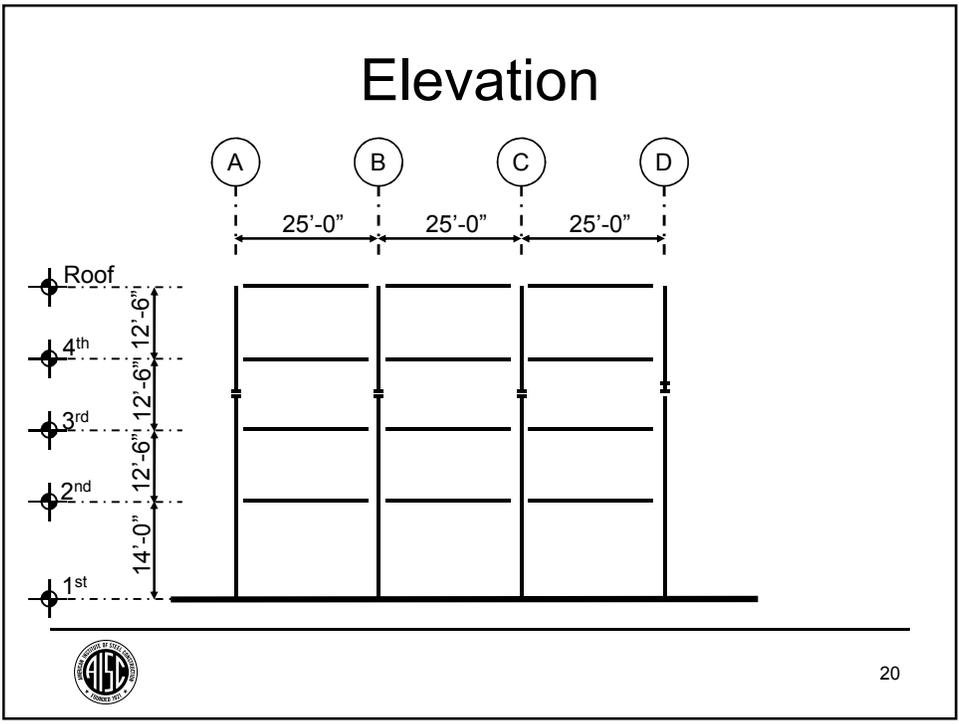
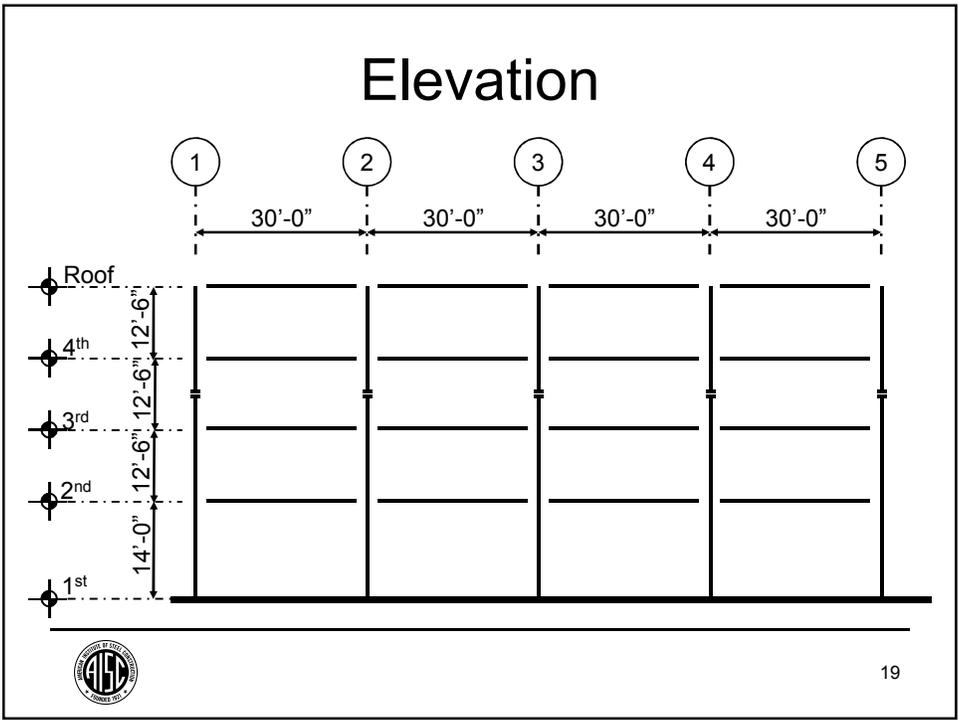


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Plan



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Given information

- Address:
 - 123 Fake Street, Quakeville, EQ, USA
- Soil Type D
- Office building
 - Occupancy/Risk Category II
 - $I_e = 1.0$
 - $\Delta_{all} = 0.025h$
 - $\Delta_{all} = 0.02h$ used to limit cladding drift demands



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Given information

- Codes:
 - IBC 2015
 - ASCE 7, 2010
 - AISC 360, 2010
 - ACI 318, 2014
 - AWS D1.1, 2010
 - AISC 341, 2010
 - AISC 358, 2010
 - AWS D1.8, 2009



ASCE 7 **16**, AISC 341 **16**
also discussed

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Given information

- Loads
 - D_{floor} = 85 psf (includes partition allowance)
 - D_{roof} = 68 psf (includes partition allowance)
 - L_{floor} = 50 psf
 - (reduced; used for all examples regardless of area)
 - S = 20 psf
 - Curtain wall D
 - 12.5'*14psf
 - =175 lb/ft along building perimeter at every level



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Determine Seismic Accelerations

- <https://earthquake.usgs.gov/designmaps/us/application.php>

U.S. Seismic Design Maps

For seismic design parameter values from the 2015 IBC/ASCE Recommended Seismic Provisions, which are being adopted into the 2018 ASCE 7 Standard and the 2018 International Building Code, please see the [Data version of the U.S. Seismic Design Maps application](#).

Within the 2013 ASCE 41 design code reference document option of this web tool, the "Custom" earthquake hazard level option is no longer available. However, outside of this tool, a USGS web service that includes the "Custom" option is now available [here](#).



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U.S. Seismic Design Maps

For seismic design parameter values from the 2015 NEHRP Recommended Seismic Provisions, which are being adopted into the 2016 ASCE 7 Standard and the 2018 International Building Code, please see the [Beta version of the U.S. Seismic Design Maps application](#).

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Application Batch Mode Help

Design Code Reference Document
Consult your local design official if you need help selecting this.

Please Select...
Please Select...
Derived from USGS hazard data available in 2008
2013 ASCE 41
2012/15 IBC
2010 ASCE 7 (w/March 2013 errata)
2009 NEHRP
Derived from USGS hazard data available in 2002
2009 AASHTO
2006/09 IBC
2005 ASCE 7
2003 NEHRP

Compute Values



U.S. Seismic Design Maps

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Application Batch Mode Help

Design Code Reference Document
Consult your local design official if you need help selecting this.

2010 ASCE 7 (w/March 2013 errata)

Report Title (Optional)
This will appear at the top of the generated report.
AISC Night School

Site Soil Classification
This is not automatically selected based on site location.

Please Select...
Please Select...
Site Class A - "Hard Rock"
Site Class B - "Rock"
Site Class C - "Very Dense Soil and Soft Rock"
Site Class D - "Stiff Soil" (Default)
Site Class E - "Soft Clay Soil"

Site Longitude
Decimal degrees for the site location.

Compute Values



U.S. Seismic Design Maps

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Application **Batch Mode** **Help**

Design Code Reference Document
 Consult your local design official if you need help selecting this.
 2010 ASCE 7 (w/March 2013 errata)

Report Title (Optional)
 This will appear at the top of the generated report.
 AISC Night School

Site Soil Classification
 This is not automatically selected based on site location.
 Site Class D - "Stiff Soil" (Default)

Risk Category
 Used to compute the seismic design category.
 Please Select...
 Please Select...
I or II or III
 IV (e.g., essential facilities)

Site Longitude
 Decimal degrees for the site location.

Compute Values

U.S. Seismic Design Maps

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Report Title (Optional)
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 AISC Night School

Site Soil Classification
 This is not automatically selected based on site location.
 Site Class D - "Stiff Soil" (Default)

Risk Category
 Used to compute the seismic design category.
 I or II or III

Site Latitude
 Decimal degrees for the site location.

Site Longitude
 Decimal degrees for the site location.



U.S. Seismic Design Maps

For seismic design parameter values from the 2015 NEHRP Recommended Seismic Provisions, which are being adopted into the 2016 ASCE 7 Standard and the 2018 International Building Code, please see the [Beta version of the U.S. Seismic Design Maps application](#).

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AISC Night School

Site Soil Classification
This is not automatically selected based on site location.
Site Class D - "Stiff Soil" (Default)

Risk Category
Used to compute the seismic design category.
I or II or III

Site Latitude
Decimal degrees for the site location.

Site Longitude
Decimal degrees for the site location.

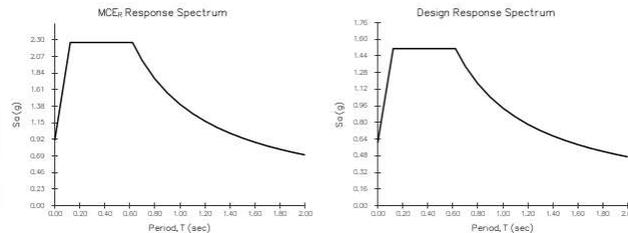
Compute Values

Determine Seismic Accelerations

USGS-Provided Output

$$\begin{array}{llll}
 S_s & = 1.5 \text{ g} & S_{MS} & = 1.5 \text{ g} & S_{ds} & = 1.0 \text{ g} \\
 S_1 & = 0.6 \text{ g} & S_{M1} & = 0.9 \text{ g} & S_{d1} & = 0.6 \text{ g}
 \end{array}$$

For information on how the S_s and S_1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.



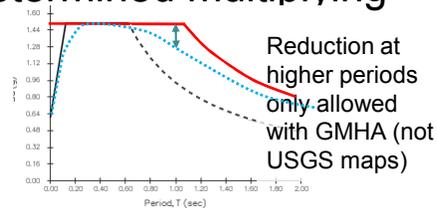
For PGA_{uv} , T_u , C_{2x} , and C_{2y} values, please [view the detailed report](#).

Although this information is a product of the U.S. Geological Survey, we provide no warranty, expressed or implied, as to the accuracy of the data contained therein. This tool is not a substitute for technical subject-matter knowledge.



Determine Seismic Accelerations

- **ASCE 7-16** Section 11.4.8(3) requires that a ground motion hazard analysis be performed for structures on Site Class D with S_1 greater than or equal to 0.2, or that the base shear be determined multiplying EQ12.8-3 by 1.5



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System selection

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Seismic Design Category (SDC)

- ASCE 7 §11.6
- Based on
 - Risk category
 - Site seismicity
 - Including soil effects
 - Check for
 - 0.2 sec response
 - 1.0 sec response
 - $S_1 \geq 0.75$
 - SDC E: RC I, II, III
 - SDC F: RC IV

Value of S_{DS}	Risk Category	
	I or II or III	IV
$S_{DS} < 0.167$	A	A
$0.167 \leq S_{DS} < 0.33$	B	C
$0.33 \leq S_{DS} < 0.50$	C	D
$0.50 \leq S_{DS}$	D	D

Value of S_{D1}	Risk Category	
	I or II or III	IV
$S_{D1} < 0.067$	A	A
$0.067 \leq S_{D1} < 0.133$	B	C
$0.133 \leq S_{D1} < 0.20$	C	D
$0.20 \leq S_{D1}$	D	D



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Seismic Design Category

- ASCE 7 §11.6
- 3 tests; highest SDC of the three
 - $S_{ds} = 1.0 \text{ g} > 0.5 \text{ g}$
 - SDC D (or greater)
 - $S_{d1} = 0.6 \text{ g} > 0.2 \text{ g}$
 - SDC D (or greater)
 - $S_1 = 0.6 \text{ g} < 0.75 \text{ g}$
 - **Not** SDC E

Value of S_{DS}	Risk Category	
	I or II or III	IV
$S_{DS} < 0.167$	A	A
$0.167 \leq S_{DS} < 0.33$	B	C
$0.33 \leq S_{DS} < 0.50$	C	D
$0.50 \leq S_{DS}$	D	D

Value of S_{D1}	Risk Category	
	I or II or III	IV
$S_{D1} < 0.067$	A	A
$0.067 \leq S_{D1} < 0.133$	B	C
$0.133 \leq S_{D1} < 0.20$	C	D
$0.20 \leq S_{D1}$	D	D



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ASCE 7 Table 12.2-1 Seismic Force Resisting System	Resp. Mod. Coeff., R^a	Over-strength Factor, Ω_o	Deflection Amp. Factor, C_d^b	Structural System Limitations Including Structural Height, h_n , Limits in ft ^c				
				Seismic Design Category				
				B	C	D ^d	E ^d	F ^e
STEEL SYSTEMS				Up to 240' for regular buildings				
Steel eccentrically braced frames (EBF)	8	2	4	NL	NL	160	160	100
Steel special concentrically braced frames (SCBF)	6	2	5	NL	NL	160	160	100
Steel ordinary concentrically braced frames (OCBF)	3 ^{1/4}	2	3 ^{1/4}	NL	NL	35 ^g	35 ^g	NP ^g
Steel buckling-restrained braced frames (BRBF)	8	2 ^{1/2}	5	NL	NL	160	160	100
Steel special plate shear walls (SPSW)	7	2	6	NL	NL	160	160	100
Steel special moment frames (SMF)	8	3	5 ^{1/2}	NL	NL	NL	NL	NL
Steel special truss moment frames (STMF)	7	3	5 ^{1/2}	NL	NL	160	100	NP
Steel intermediate moment frames (IMF)	4 ^{1/2}	3	4	NL	NL	35 ^h	NP ^h	NP ^h
Steel ordinary moment frames (OMF)	3 ^{1/2}	3	3	NL	NL	NP ⁱ	NP ⁱ	NP ⁱ
Steel special cantilever column systems (SCCS)	2 ^{1/2}	1 ^{1/4}	2 ^{1/2}	35	35	35	35	35
Steel ordinary cantilever column systems (OCCS)	1 ^{1/4}	1 ^{1/4}	1 ^{1/4}	35	35	NP ⁱ	NP ⁱ	NP ⁱ
Steel systems not specifically detailed for seismic resistance	3	3	3	NL	NL	NP	NP	NP

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Materials





Steel Design

- Members

- Beams

- ASTM A992
 - $F_y = 50\text{ksi}$
 - $F_u = 65\text{ksi}$
 - $R_y = 1.1$
- $t_f > 1\frac{1}{2}"$
 - CVN 20ft#@70°F
 - AISC 341 §A3.3

- Columns

- ASTM A992
 - $F_y = 50\text{ksi}$
 - $F_u = 65\text{ksi}$
 - $R_y = 1.1$
- $t_f > 1\frac{1}{2}"$
 - CVN 20ft#@70°F
 - AISC 341 §A3.3
- A913 Gr. 65 & 70 (2016) allowed for BRBF and SMF columns
 - AISC 341 §A3.1



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Steel Design

- Typical connections

- Plate

- A36
 - $F_y = 36\text{ksi}$
 - $F_u = 58\text{ksi}$

- Bolts

- A325X
 - $F_{nv} = 68\text{ksi}$
 - $F_{nt} = 90\text{ksi}$
- Seismic system
 - Pretensioned
 - Class A faying surface

- Base connections

- A572 Gr. 50

- $F_y = 50\text{ksi}$
- $F_u = 65\text{ksi}$
- $t > 2"$
 - CVN 20ft#@70°F
 - AISC 341 A3.3

- F1554 Grade 55

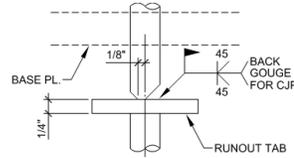
- $F_y = 55\text{ksi}$
- $F_u = 75\text{ksi}$
- Supplement S1



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Steel Design

- Anchor rods
 - F1554 Grade 55
 - Supplement S1
 - Provides weldable material
 - Grade 36 always weldable
 - Grade 105 never weldable
 - Anchor-rod damage or misalignment
 - Solutions in Design Guide 1



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Steel Design

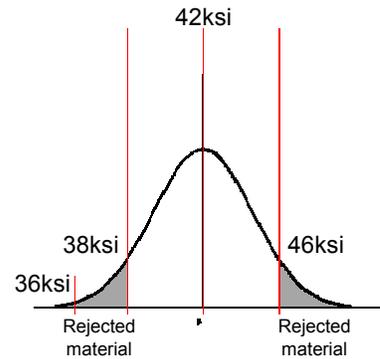
- Welds
 - Matching strength
 - $F_{EXX} = 70\text{ksi}$
 - CVN
 - Seismic system
 - Typical
 - CVN 20ft#@0°F
 - Demand Critical Welds
 - CVN 40ft#@70°F
- Lowest Anticipated Service Temperature
 - Required for modifying CVN testing requirements for cold-weather applications (<50°F)
 - All steel within climate-controlled space in this project



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Steel Design

- BRB cores
 - A36 with limited yield range
 - $F_y \geq 38\text{ksi}$
 - $F_y \leq 46\text{ksi}$
 - $F_{ye} = 42\text{ksi}$



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Steel Design

- BRB connections
 - Gusset plates
 - A572 Gr. 50
 - $F_y = 50\text{ksi}$
 - $F_u = 65\text{ksi}$
 - Bolts at BRB-to-gusset connections
 - A490X
 - $F_{nv} = 84\text{ksi}$
 - $F_{nt} = 113\text{ksi}$
- Materials match tested specimens by manufacturer
 - To be confirmed after manufacturer selection
 - Manufacturers may assist in connection design or review connection design to confirm adequacy



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Concrete

- Floors and roof
 - 2" steel deck
 - 3.25" light-weight topping
 - 4000psi
 - #3@12" each way
- Foundations
 - Normal-weight concrete
 - 4000psi



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Quality

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Quality

- AISC 360 Chapter N
 - Fabrication & Erection QC
 - Inspection QA
 - Task tables
 - NDT
 - Rates
 - Approved fabricators and erectors
 - With AHJ approval, QC only (no 3rd-party QA)
- AISC 341 Chapter J
 - Additional requirements for QA/QC
 - Demand Critical Welds
- AISC 358 §5.7
 - Special requirements at RBS cut
- AWS D1.1 §6
- AWS D1.8 §7



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Effective seismic weight

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Effective seismic weight

- No significant storage
 - (<5%)
- Snow load need not be considered
 - (<30PSF)
- Plan area
 - $[4*30'+2*1'] [3*25'+2*1'] = 9394\text{sf}$
- Perimeter
 - $[2*4*30'+4*1'] + [2*3*25'+4*1'] = 398'$



ASCE 7 §12.7.2

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Effective seismic weight

- Floor weight
 - $= 9394\text{sf} * 0.085\text{ksf} + 398' * 0.175\text{klf} = 868\text{K}$
- Roof weight
 - $= 9394\text{sf} * 0.068\text{ksf} + 398' * 0.175\text{klf} = 708\text{K}$
- Total weight:
 - $3 * 868\text{K} + 708\text{K} = 3313\text{K}$



ASCE 7 §12.7.2

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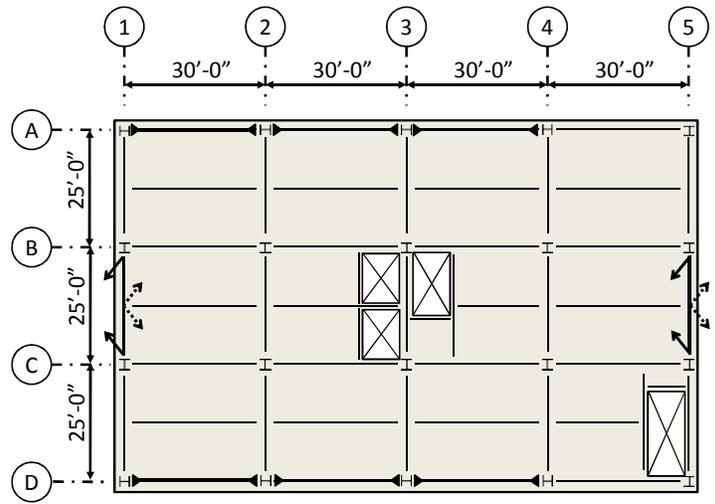


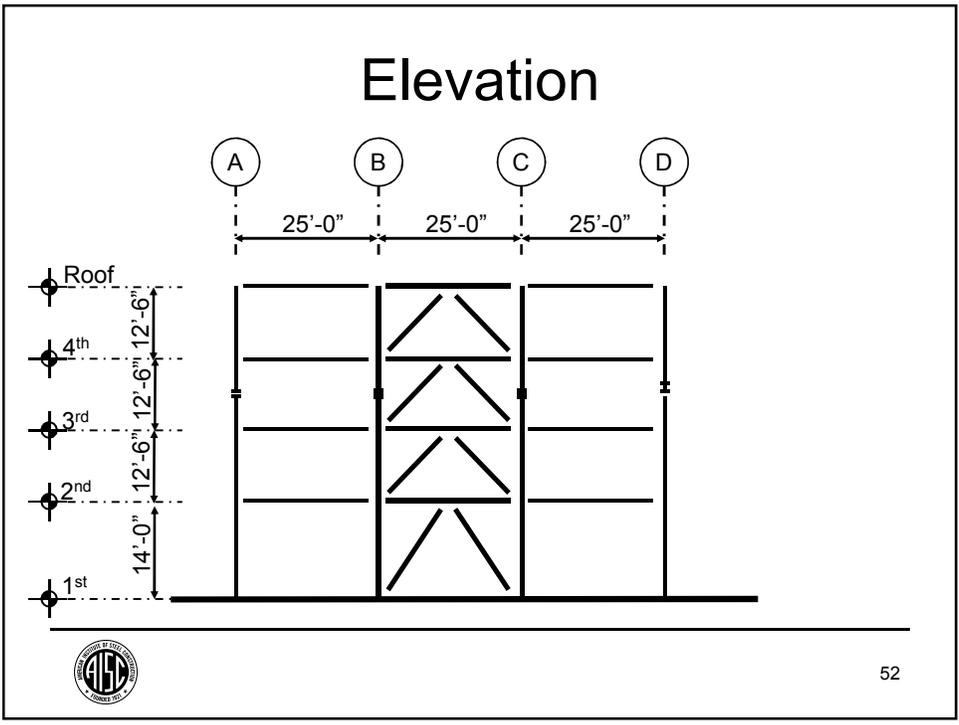
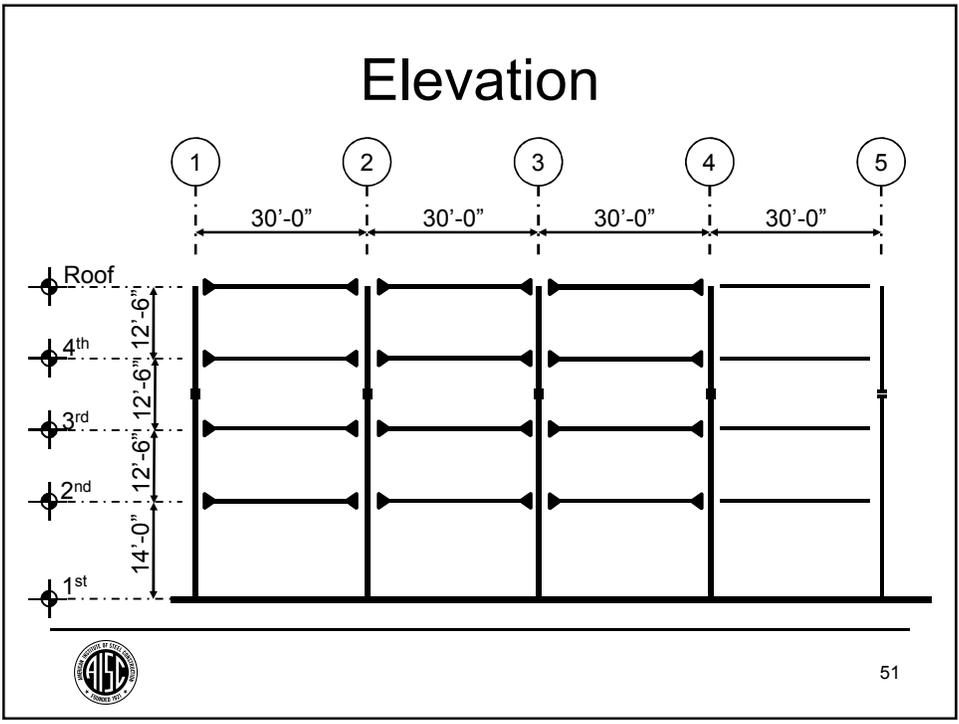
There's always a solution in steel.

Configuration selection



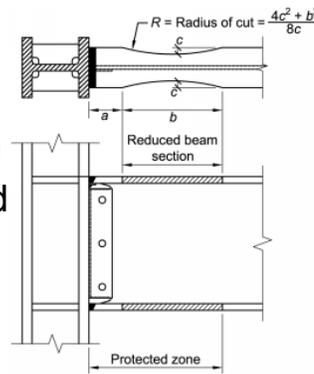
Plan





SMF: Reduced beam section

- Beam intentionally weakened to create controlled yielding
- Connection at face of column stronger than reduced section
- Capacity design ensures good performance
- Reduction in stiffness
- Potential reduction in stability



AISC 358 §5.3

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BRBF

- Investigate availability
 - Core Brace
 - Nippon Steel
 - Others?
- Braces up to 1000 kips readily available
- Braces ~1.4 as stiff as work-point-to-work-point
 - Chevron configuration
 - 30' Bay (consult manufacturer for 25' bay)



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Base-shear determination



Approximate period

- ASCE 7 §12.8.2.1
 - Approximate period T_a based on height
 - $H=51.5'$
- “Real” (model) period may be used
 - Limited by $C_u T_a$ (for strength, not for drift)
 - $C_u = 1.4$ for $S_{d1} > 0.4$
 - Assume $T > T_a$
 - Based on experience
 - To be confirmed later in design



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Approximate period

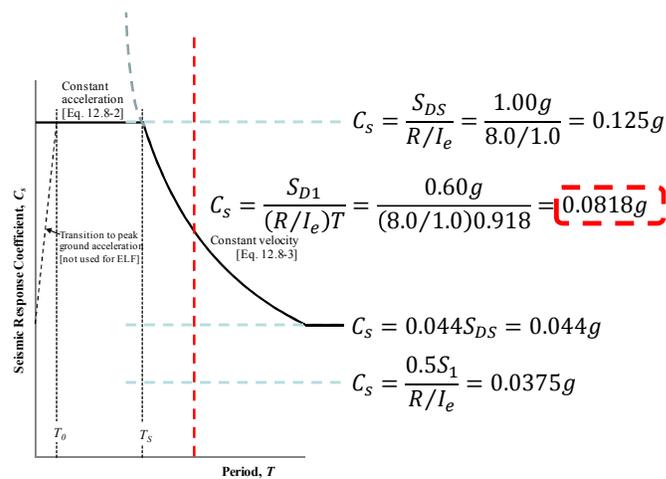
- SMF
 - $T_a = 0.028 * 51.5^{0.8} = 0.656s$
 - Assume $T > C_u T_a = 1.4 * 0.656s = 0.918s$
 - Must be verified after final analysis
- BRBF
 - $T_a = 0.03 * 51.5^{0.75} = 0.577s$
 - Assume $T > 1.3 T_a$ for $C_u = 1.4$
 - Assume $T = 1.3 * 0.577s = 0.750s$
 - Must be verified after final analysis



ASCE 7 §12.8.2.1

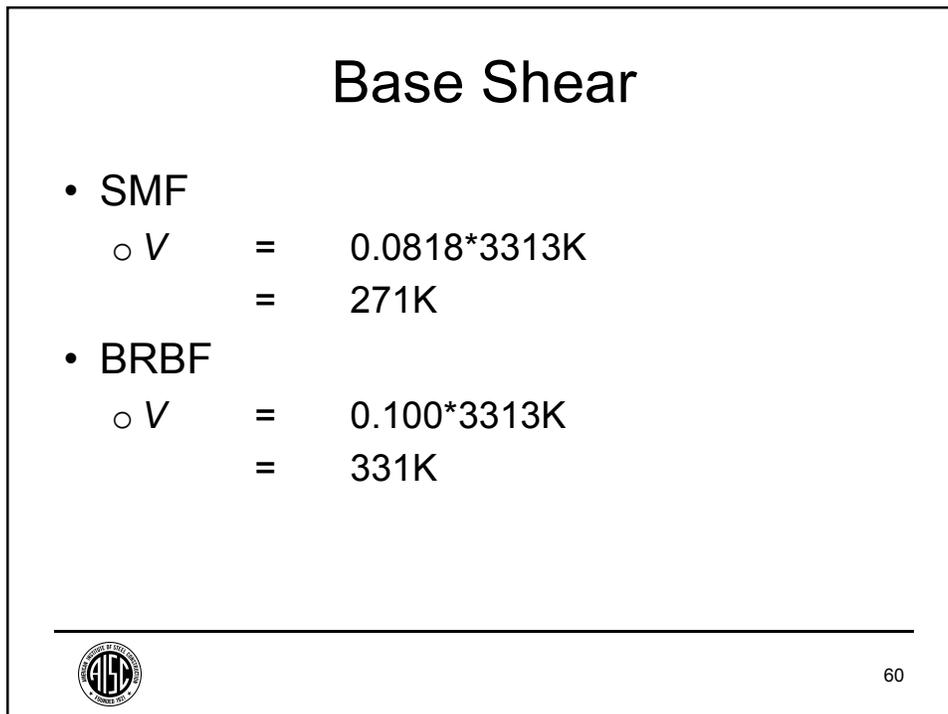
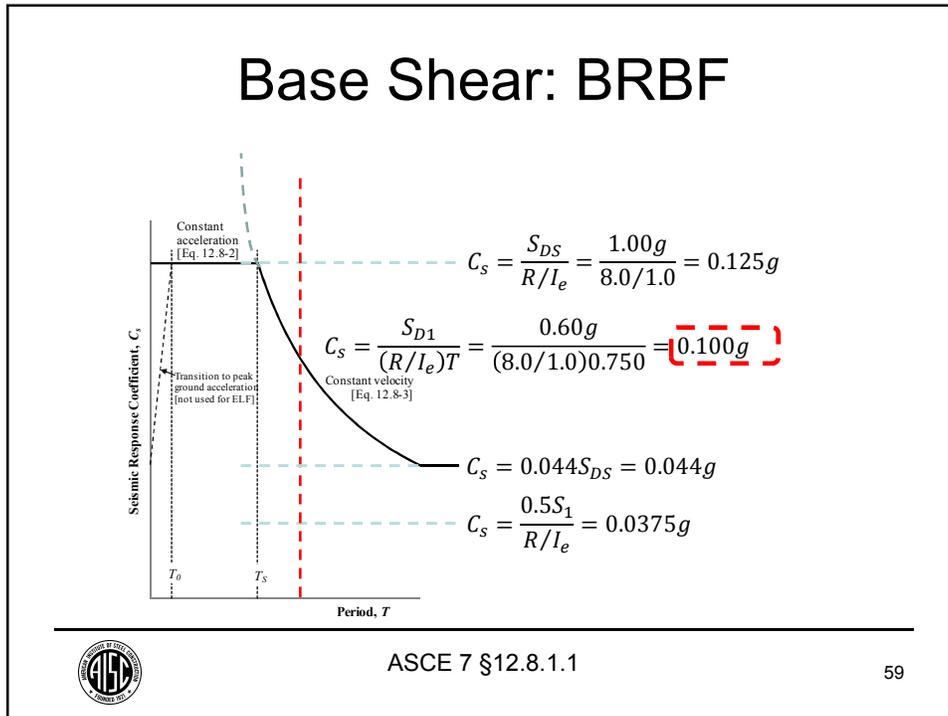
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Base Shear: SMF



ASCE 7 §12.8.1.1

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Wind vs seismic comparison



Wind vs. seismic comparison

- Effective design
 - Select members for governing load effect
 - Check adequacy for other load effects
 - Reduce design work
- Comparison
 - Strength requirements
 - Stiffness requirements
 - Wind serviceability
 - Seismic drift control



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Wind Load

- Basic Wind Speed
 - 115 MPH
- Wind Exposure Category B
- Topographic factor
 - $K_{zt} = 1.0$
- Risk Category II

Level	Figure 27.4-8 - Case I			
	X-direction		Y-direction	
	<i>p</i> (psf)	<i>F</i> (k)	<i>p</i> (psf)	<i>F</i> (k)
Roof	31.9	15.3	35.0	26.7
4 th	30.6	29.5	33.8	51.5
3 rd	29.0	28.0	32.2	49.1
2 nd	26.9	27.5	30.1	48.6



ASCE 7 Chapter 27

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Wind vs Seismic

	Moment Frames		Braced Frames	
	Wind	Seismic	Wind	Seismic
Base Shear (k)	100	271	176	331
Overturning (ft-k)	3,065	10,487	5,365	12,704
Ω_o Overturning (ft-k)		31,461		31,761

- Seismic controls the main lateral system
- Components and cladding may be governed by wind



If wind controls base shear
check story shear at every level

64



Wind vs Seismic

- Wind serviceability
 - 10-year wind
 - 0.7 times 50-year wind pressures
 - Note that **ASCE 7-16** no longer uses 50-year wind
 - H/400 deflection limit
 - $\Delta_{\text{wind serv}} \leq 0.0025h$
 - Compare combined base shear & drift limit
 - Seismic force distribution causes more drift
 - Seismic drift base shear may be lower than design base shear, especially for SMF



AISC Design Guide 3

65

Wind vs Seismic

- Wind serviceability
 - Very rough stiffness requirements
 - North-south
 - Wind
 - $V_{\text{wind}} / \Delta_{\text{wind serv}} = (0.7)^{176} K / 0.0025h = 49,300 K/h$
 - BRBF
 - $C_d V_{\text{seismic}} / \Delta = (5)^{331} K / 0.02h = 82,800 K/h$
 - Ratio
 - $K_{\text{reqEQ}} / K_{\text{reqW}} = 1.7$



AISC Design Guide 3

66



Wind vs Seismic

- Wind serviceability
 - Very rough stiffness requirements
 - East-West
 - Wind
 - $V_{wind} / \Delta_{wind\text{serv}} = (0.7)^{100} K / 0.0025h = 28,000K/h$
 - SMF
 - Base shear for drift may be lower
 - $C_d V_{seismic} / \Delta = (5.5)^{271} K / 0.02h = 74,500K/h$
 - Ratio
 - $K_{reqEQ} / K_{reqW} = 2.7$
 - Check wind drift after final seismic design



AISC Design Guide 3

67

There's always a solution in steel.

Determination of Irregularities



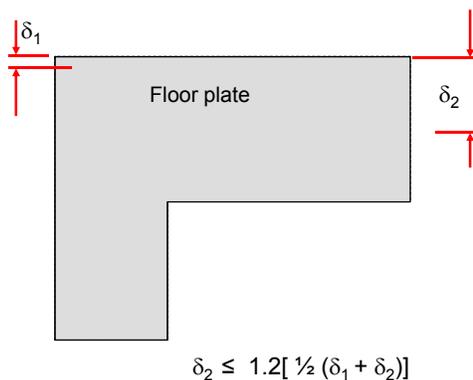
Irregularities

- May limit analysis options
 - Equivalent Lateral Force (ELF) method not permitted for some irregular buildings
- May be result of building layout
 - Check for irregularities at beginning
- May emerge later in design
 - Double check prior to finalizing design



69

Horizontal irregularity: Torsional



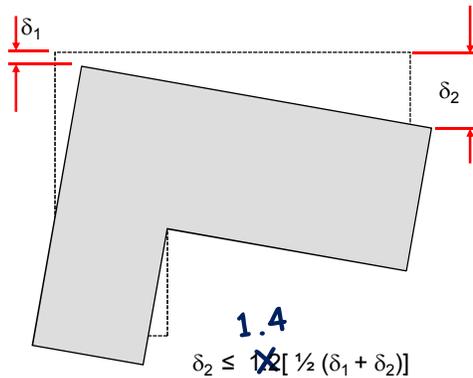
- Basis
 - Buildings with high torsional response are prone to damage
- Addressed by
 - Amplifying torsional moment
 - Restricting torsionally irregular buildings in severe seismic conditions



ASCE 7 Table 12.3-1

70

Horizontal irregularity: Torsional (extreme)



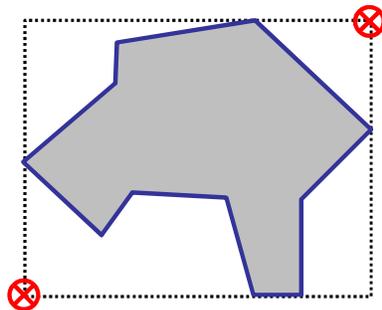
- Basis
 - Buildings with high torsional response are prone to damage
- Addressed by
 - Amplifying torsional moment
 - Restricting torsionally irregular buildings in severe seismic conditions



ASCE 7 Table 12.3-1

71

Horizontal irregularity: Torsional (complex layout)



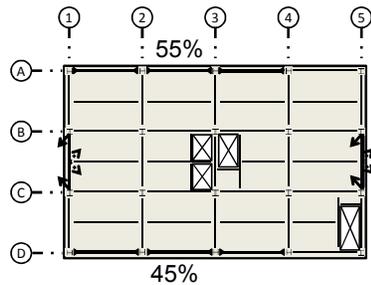
- Draw rectangle around plan
 - Aligned with X & Y analyses
- Pick opposite corners
- Use corner displacements to assess irregularity



ASCE 7 Table 12.3-1

72

Horizontal irregularity: Torsional



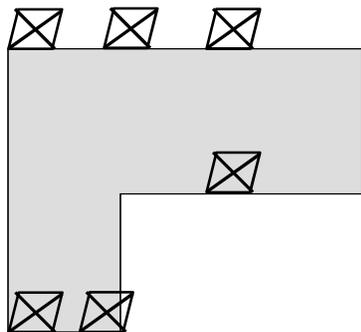
- Considered with accidental torsion
 - $\delta_{\max}/\delta_{\text{ave}} \leq 55\%/50\% = 1.1$
 - Irregularity does not exist



ASCE 7 Table 12.3-1

73

Horizontal irregularity: Torsional



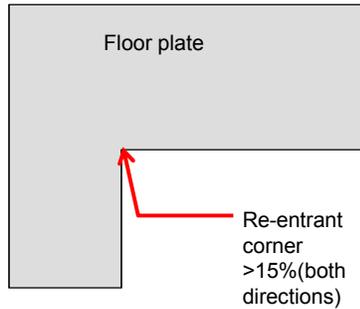
- Control strategies
 - Balance center of rigidity with center of mass
 - Provide resistance at building perimeter
 - Both axes



ASCE 7 Table 12.3-1

74

Horizontal irregularity: Re-entrant corner



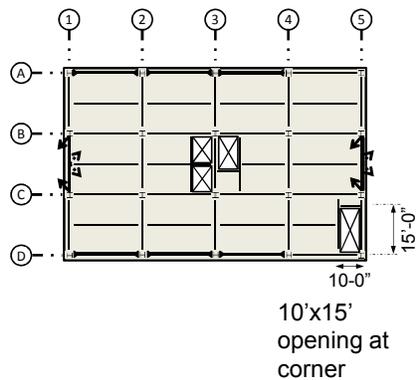
- Basis
 - Notch-like effect amplifies diaphragm forces
- Addressed by
 - Increased diaphragm forces
 - Requiring dynamic analysis for taller buildings



ASCE 7 Table 12.3-1

75

Horizontal irregularity: Re-entrant corner



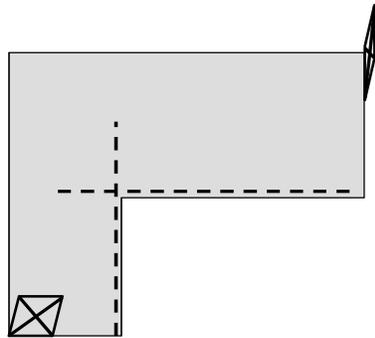
- $10' < 15\%(122') = 18.3'$
 - OK
- $15' > 15\%(77') = 11.6'$
- Irregularity does not exist



ASCE 7 Table 12.3-1

76

Horizontal irregularity: Re-entrant corner



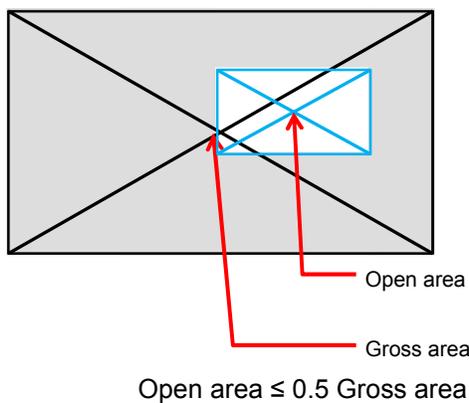
- Control strategies
 - Provide strong ties at re-entrant corners
 - Provide proportional lateral resistance in wings



ASCE 7 Table 12.3-1

77

Horizontal irregularity: Diaphragm discontinuity



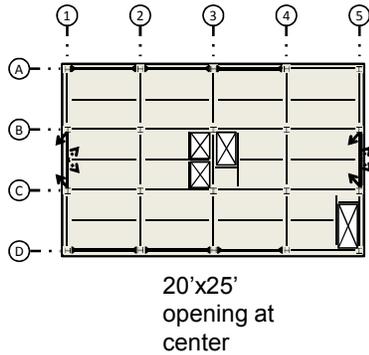
- Basis
 - Notch-like effect amplifies diaphragm forces
- Addressed by
 - Increased diaphragm forces
 - Requiring dynamic analysis for taller buildings



ASCE 7 Table 12.3-1

78

Horizontal irregularity: Diaphragm discontinuity



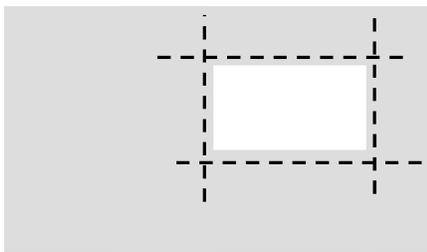
- Opening
 - 20'x25'=500SF
- Plan area = 9394SF
 - Irregularity does not exist



ASCE 7 Table 12.3-1

79

Horizontal irregularity: Diaphragm discontinuity



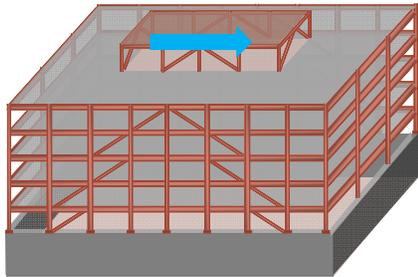
- Control strategies
 - Provide strong ties



ASCE 7 Table 12.3-1

80

Horizontal irregularity: Out-of-plane offset



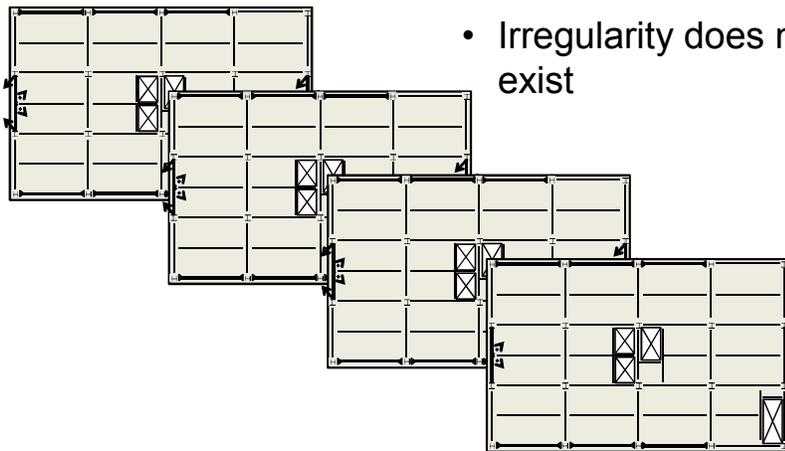
- Basis
 - Continuity of load path sometimes neglected
- Addressed by
 - Following load path
 - Increased diaphragm forces



ASCE 7 Table 12.3-1

81

Horizontal irregularity: Out-of-plane offset



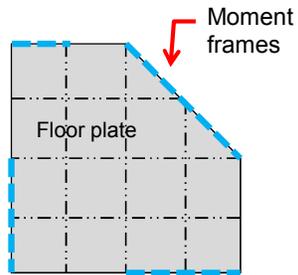
- Irregularity does not exist



ASCE 7 Table 12.3-1

82

Horizontal irregularity: Non-parallel systems



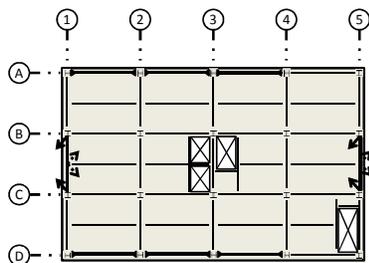
- Basis
 - Analysis in principal building axes insufficient
- Addressed by
 - Using Square-root-of-the-sum-of-the-squares (SRSS) of orthogonal analysis forces



ASCE 7 Table 12.3-1

83

Horizontal irregularity: Non-parallel systems



- Irregularity does not exist



ASCE 7 Table 12.3-1

84

Horizontal Irregularities

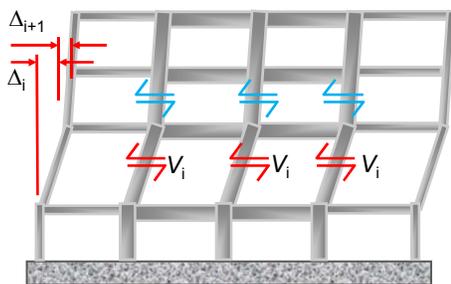
- Torsional *Not present/likely*
- Re-entrant corner *Not present*
- Diaphragm discontinuity *Not present*
- Out-of-plane offset *Not present*
- Non-parallel systems *Not present*



ASCE 7 Table 12.3-1

85

Vertical irregularity: Soft story



$$K_i = \sum V_i / \Delta_i$$

$$K_i \leq 0.7 K_{i+1}$$

$$K_i \leq 0.8 (K_{i+1} + K_{i+2} + K_{i+3})/3$$

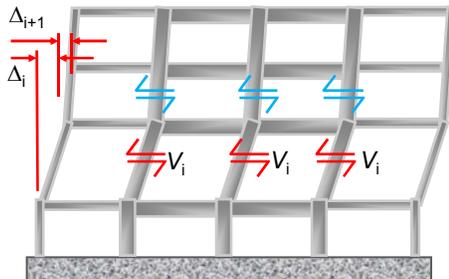
- Basis
 - Static analysis may miss dynamic effect
- Addressed by
 - Requiring dynamic (modal) analysis for certain buildings
 - Engineers should consider strengthening the weak story instead



ASCE 7 Table 12.3-2

86

Vertical irregularity: Soft story (extreme)



$$K_i = \sum V_i / \Delta_i \quad K_i \leq 0.6 K_{i+1}$$

$$K_i \leq 0.7 (K_{i+1} + K_{i+2} + K_{i+3})/3$$

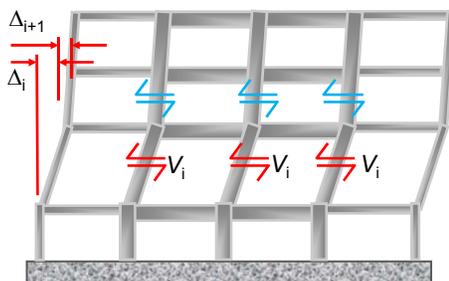


ASCE 7 Table 12.3-2

87

- Basis
 - Static analysis may miss dynamic effect
- Addressed by
 - Requiring dynamic (modal) analysis for certain buildings

Vertical irregularity: Soft story



$$K_i = \sum V_i / \Delta_i$$



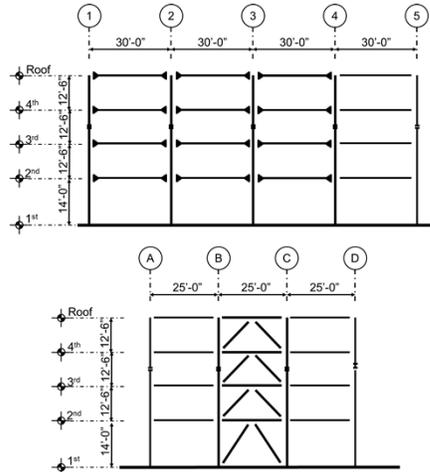
ASCE 7 Table 12.3-2

88

- Story stiffness
 - $\sum V_i / \Delta_i$, right?
 - ELF
 - Corresponds to given loading pattern
 - Overturning affects stiffness
 - MRSA
 - Corresponds to MRSA shears and MRSA displacements
 - Story stiffness varies with analysis type

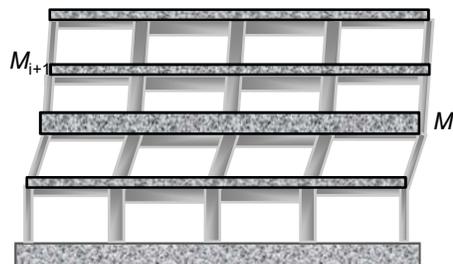
Vertical irregularity: Soft story

- Proportion members to demand
- Soft-story irregularity not likely
 - Checked after final member selection



89

Vertical irregularity: Mass



$$M_i \geq 1.5 M_{i+1}$$

$$M_i \geq 1.5 M_{i-1}$$

- Basis
 - Static analysis may miss dynamic effect
- Addressed by
 - Requiring dynamic (modal) analysis for certain buildings

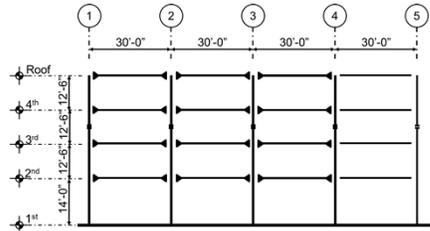


ASCE 7 Table 12.3-2

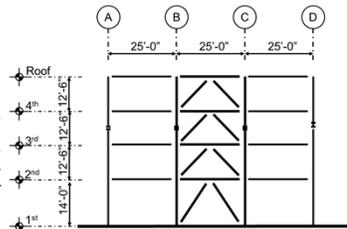
90

Vertical irregularity: Mass

- Mass irregularity not present



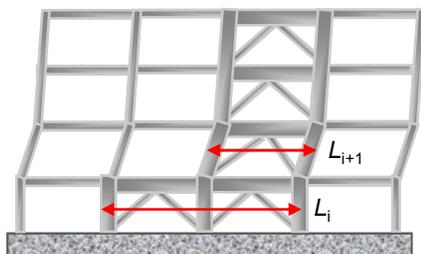
Roof weight = 708K
Floor weight = 868K
Floor weight = 868K
Floor weight = 868K



91

Vertical irregularity: Geometric

- Basis
 - Change in dimension may correspond to change in stiffness
 - Static analysis may miss dynamic effect
- Addressed by
 - Requiring dynamic (modal) analysis for certain buildings



$$L_i \geq 1.3 L_{i+1}$$

$$L_i \geq 1.3 L_{i-1}$$

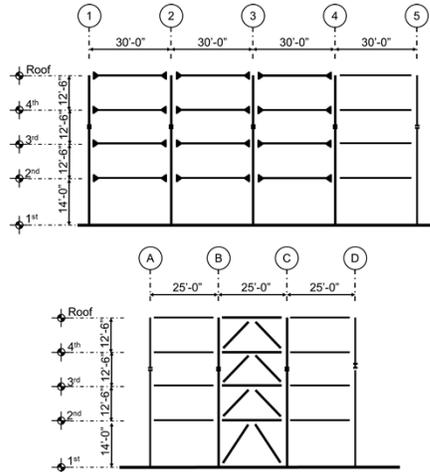


ASCE 7 Table 12.3-2

92

Vertical irregularity: Geometric

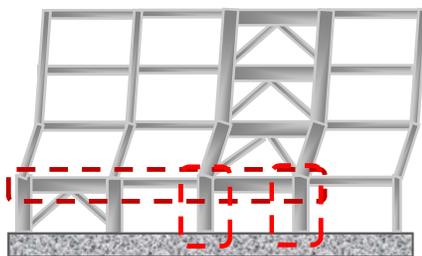
- Geometric irregularity not present



93

Vertical irregularity: In-plane offset

- Basis
 - Overturning forces occur below discontinuous frame
- Addressed by
 - Requiring amplified overturning forces in supporting members
 - Requiring amplified diaphragm shear forces

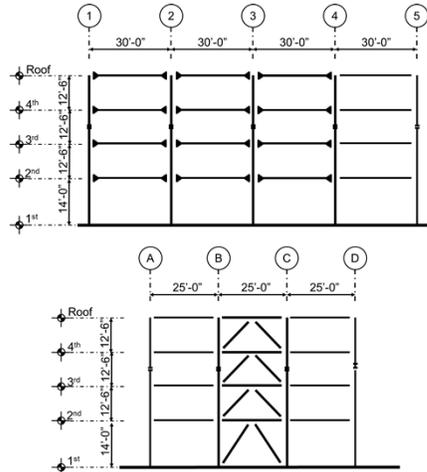


ASCE 7 Table 12.3-2

94

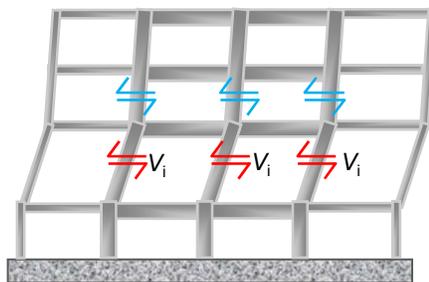
Vertical irregularity: In-plane offset

- In-plane offset irregularity not present



95

Vertical irregularity: Weak story



$$\sum V_{n_i} \geq 0.8 \sum V_{n_{i+1}}$$

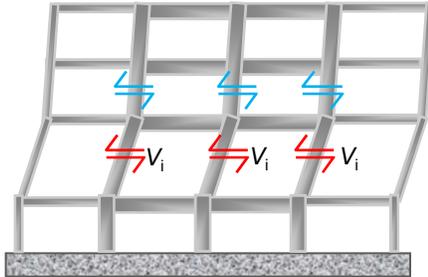
- Basis
 - Change in strength may correspond to change in stiffness
 - Elastic methods may miss concentration of damage
- Addressed by
 - Requiring dynamic analysis
 - Prohibiting certain uses



ASCE 7 Table 12.3-2

96

Vertical irregularity: Weak story (extreme)



$$\Sigma V_{n_i} \geq 0.8 \Sigma V_{n_{i+1}}$$

~~0.8~~
0.65

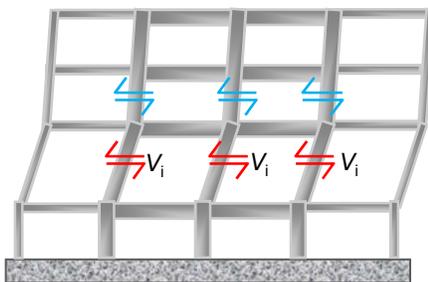
- Basis
 - Change in strength may correspond to change in stiffness
 - Elastic methods may miss concentration of damage
- Addressed by
 - Requiring dynamic analysis
 - Prohibiting certain uses



ASCE 7 Table 12.3-2

97

Vertical irregularity: Weak story



- Story strength
 - Braced Frames
 - Brace strength
 - $\Sigma V_n = \Sigma R_n \cos(\theta)$
 - Moment Frames
 - Beam strength
 - $\Sigma V_n = \Sigma V_c$
 - Portal frame (Session 2)
 - $V_c = \Sigma [M_{pr}(L/L_h)/h]$



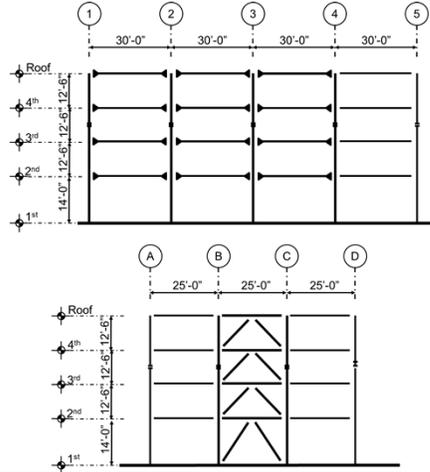
ASCE 7 Table 12.3-2

98



Vertical irregularity: Weak story

- Proportion members to demand
- Weak-story irregularity not likely
 - Checked after final member selection



99

Vertical Irregularities

- | | |
|-------------------|---------------------------|
| • Soft story | <i>Not present/likely</i> |
| • Mass | <i>Not present</i> |
| • Geometric | <i>Not present</i> |
| • In-plane offset | <i>Not present</i> |
| • Weak story | <i>Not present/likely</i> |



ASCE 7 Table 12.3-2

100

There's always a solution in steel.

Load combinations



Load Combinations

- Determine redundancy factor ρ
- Determine overstrength factor Ω_o
- Determine vertical seismic load effect
- Determine live load factor
 - $L < 100$ psf
 - No public assembly
 - $f_1 = 0.5$

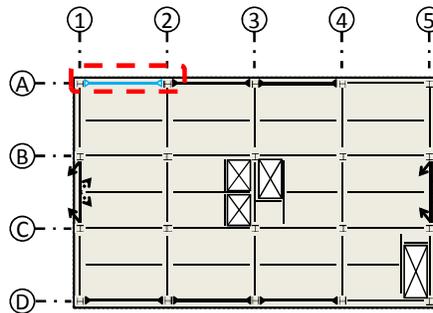


ASCE 7 §12.4

102

Redundancy factor ρ SMF

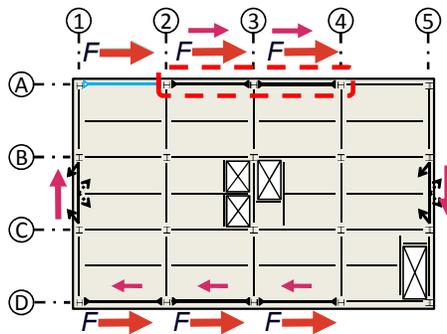
- Moment frame
(Table 12.3-3)
 - Evaluate with one beam removed
 - Strength loss <33%
 - No extreme torsional irregularity



103

Redundancy factor ρ SMF (elastic method)

- With all frames:
 - $F = 1/6V/\text{frame}$ ($0.167V$)
- With one frame removed
 - $T = Ve$
 - $e = [3(37.5') - 2(37.5')]/5 = 7.5'$
 - Assume $75/(120+75) = 38.5\%$
 T resisted by moment frames
 - $2F \sim (2/5V + 0.385T/75')$
 $= 0.44V$
 - $F = 0.219V/\text{frame}$
 - $\sim 32\%$ increase <33%

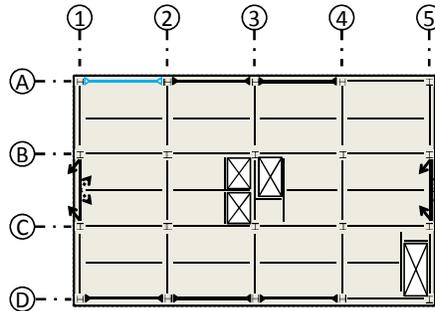


Inelastic methods also permitted
for determining strength loss

104

Redundancy factor ρ SMF (elastic method)

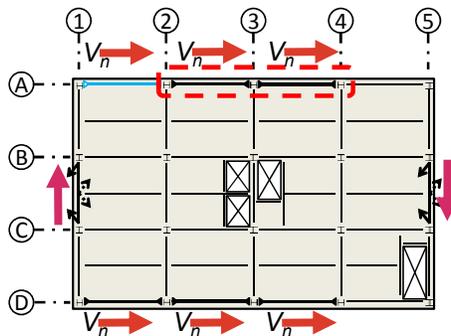
- Line D
 - $\Delta_D = 0.562V/3K$
 $= 0.187V/K$
 - Line A
 - $\Delta_A = 0.439V/2K$
 $= 0.219V/K$
 - $\Delta_{ave} = 0.203V/K$
 - $\Delta_{max}/\Delta_{ave} = 0.219/0.203$
 $= 1.08 < 1.4$ OK
- $\rho = 1.0$



105

Redundancy factor ρ SMF (inelastic method)

- With all frames:
 - $V = 6V_n$
- With one frame removed
 - $V = 5V_n$
 - 17% strength loss
 - $T = Ve$
 - $e = 7.5'$
 - T resisted by braced frames
 - $Ve/120' = 0.0625V$
 $= 0.313V_n$
 - BRBF OK

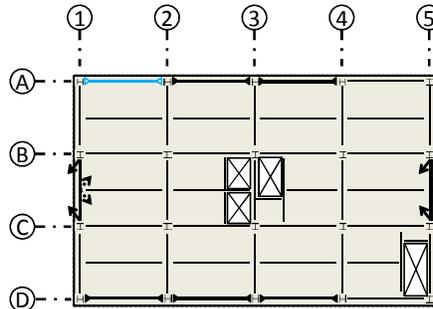


Inelastic methods also permitted
for determining strength loss

106

Redundancy factor ρ SMF (inelastic method)

- Lines A & D
 - $\Delta_D = 3F/3K_{Frame}$
 - $\Delta_A \geq 2F/2K_{Frame} = \Delta_D$
- Lines 1 & 5
 - Assume $K_1 = K_5 = K_D$
 - $\Delta_1 = \Delta_5 = 0.313F/K_D = 0.104\Delta_D$
 - $\theta_{plan} = 0.104\Delta_D / (\frac{1}{2} * 120')$
- $\Delta_{ave} \geq \Delta_D$
- $\Delta_{max} = \Delta_D + 75' \theta_{plan}$
 - $\Delta_{max} / \Delta_{ave} \leq 1 + 0.104(75'/60')$
 $= 1.13 < 1.4$ OK



$\rho = 1.0$

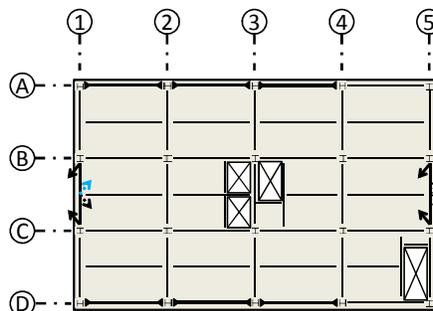
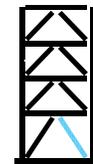


Inelastic methods also permitted
for determining strength loss

107

Redundancy factor ρ BRBF

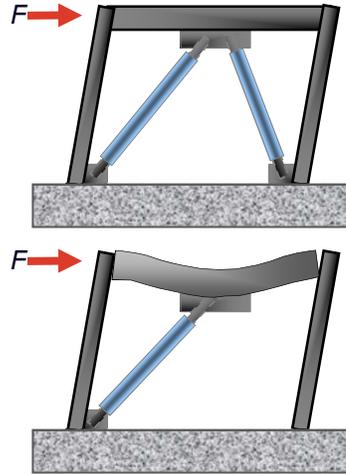
- Braced frame
(Table 12.3-3)
 - Evaluate with one
brace removed
 - Strength loss < 33%
 - No extreme
torsional irregularity



108

Redundancy factor ρ BRBF

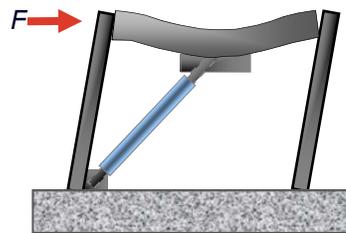
- Original frame
 - $K_1 \sim 2K_F A E \cos^3 \theta / (\frac{1}{2} L_{bay})$
 $\sim 4K_F A E \cos^3 \theta / L_{bay}$
- With one brace removed
 - $K_2 = 1 / (F_{brace} + F_{beam})$
 - $F_{brace} = 2 / K_1$
 $= L_{bay} / (2K_F A E \cos^3 \theta)$
 - $F_{beam} = \tan^2 \theta L_{bay}^3 / 48EI$
 - $F_{beam} = L_{bay} h^2 / 12EI$



109

Redundancy factor ρ BRBF

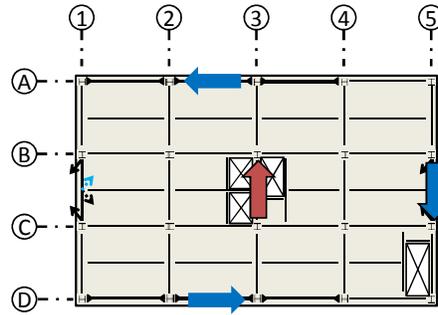
- Much more than 50% loss in stiffness
 - Assume $K_2 \ll K_1$
- 3 braces remain
 - ~50% effective strength loss in BRBF system
 - SMF resist torsion
 - Assume moment frames as stiff as BRBF



110

Redundancy factor ρ BRBF

- Line 5
 - $\Delta_5 = V/K$
 - $e = 60'$
 - $T = Ve$
- Lines A & D
 - $V_{frame} = T/75' = 0.8V$
 - $\Delta_{AD} = 0.8V/K$
 - $\theta_{plan} = 2\Delta_{AD}/75'$
- Line 1
 - $\Delta_1 = \Delta_5 + \theta_{plan} 120'$
 $= 3.56V/K$
 - $\Delta_{max}/\Delta_{ave} = 3.56/0.8$
 $= 4.45 >> 1.4 \quad \rho = 1.3$



111

Overstrength factor Ω_o

Seismic Force Resisting System	Resp. Mod. Coeff., R^a	Overstrength Factor, Ω_o	Deflection Amp. Factor, C_d^b
STEEL SYSTEMS			
Steel special moment frames (SMF)	8	3	5 ^{1/2}
Steel buckling-restrained braced frames (BRBF)	8	2 ^{1/2}	5



ASCE 7 Table 12.2-1

112



Vertical seismic load effect

- $E_v = 0.2 S_{ds} D$
- $= 0.2 * 1.0 * D = 0.2D$
- Combine with D
- $R_u = 1.2D + f_1L + E_v + \rho E_h$
- $= 1.4D + f_1L + \rho E_h$
- $R_u = 0.9D - E_v \pm \rho E_h$
- $= 0.7D \pm \rho E_h$



ASCE 7 §12.4.2

113

Basic Load Combinations (BLC)

- Basic Load Combinations
 - $R_u = 1.2D + f_1L + E_v + \rho E_h$
 - $R_u = 0.9D - E_v \pm \rho E_h$
- SMF
 - $R_u = 1.4D + 0.5L + 1.0E_h$ combo M-BLC-1
 - $R_u = 0.7D \pm 1.0E_h$ combo M-BLC-2
- BRBF
 - $R_u = 1.4D + 0.5L + 1.3E_h$ combo B-BLC-1
 - $R_u = 0.7D \pm 1.3E_h$ combo B-BLC-2



ASCE 7 §12.4.2

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Overstrength Load Combinations (Ω_o LC)

- Overstrength Load Combinations
 - $R_u = 1.2D + f_1L + E_v + \Omega_o E_h$
 - $R_u = 0.9D - E_v \pm \Omega_o E_h$
- SMF
 - $R_u = 1.4D + 0.5L + 3.0E_h$ combo M-OLC-1
 - $R_u = 0.7D \pm 3.0E_h$ combo M-OLC-2
- BRBF
 - $R_u = 1.4D + 0.5L + 2.5E_h$ combo B-OLC-1
 - $R_u = 0.7D \pm 2.5E_h$ combo B-OLC-2



ASCE 7 §12.4.3

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Capacity-Limited Load Combinations (CLLC)

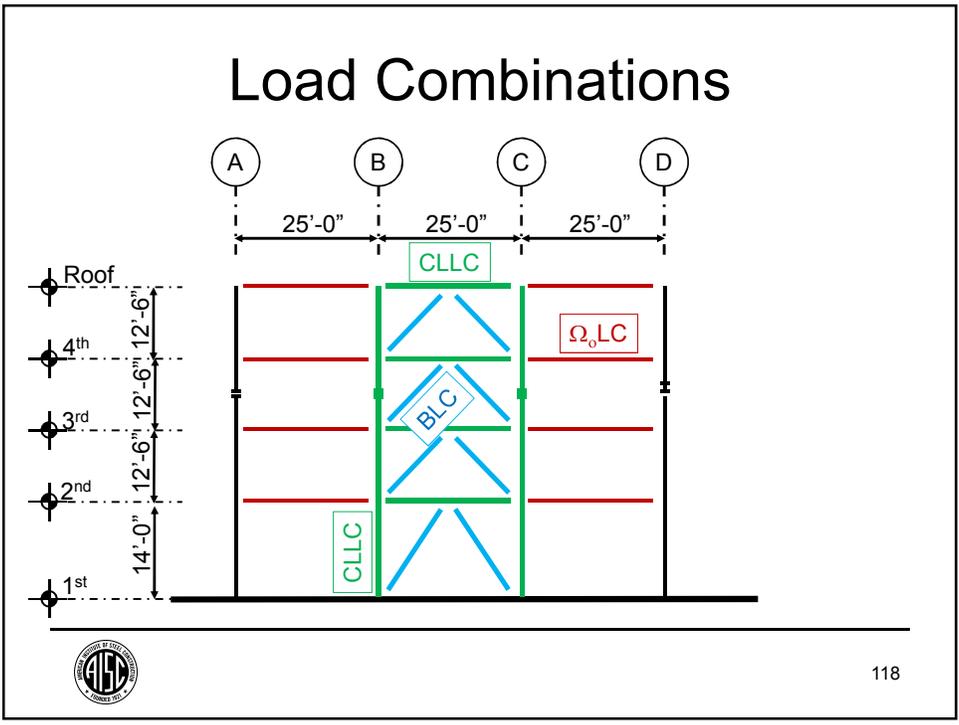
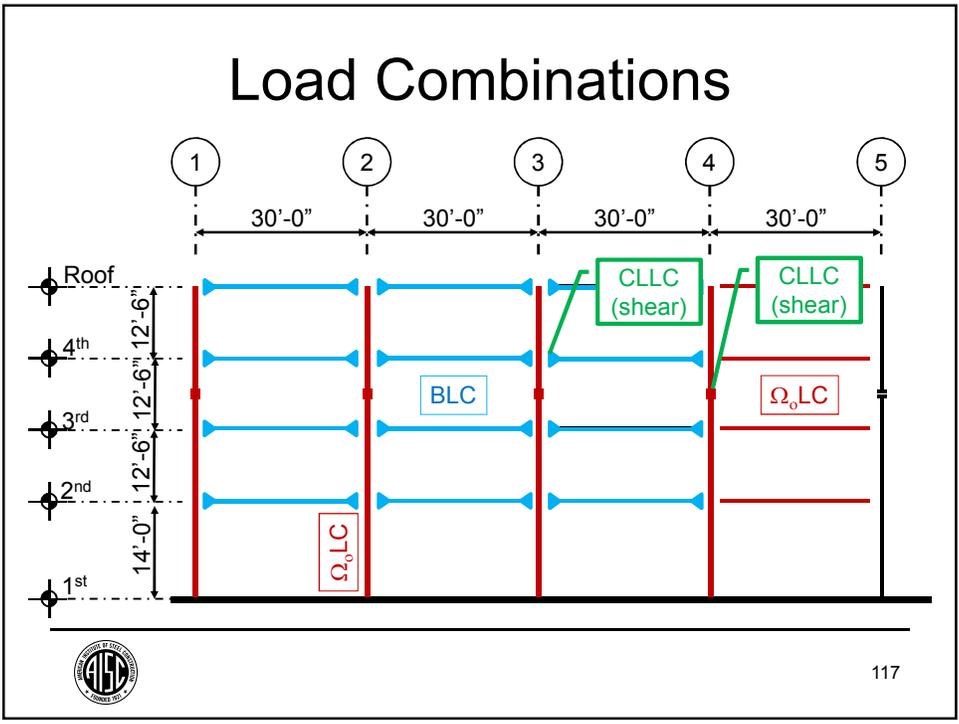
- Capacity-Limited Load Combinations
 - Related to Overstrength Load Combinations (Ω_o LC)
 - Represents actual overstrength
 - Determined by calculation
 - Ω_o LC need never be taken as greater than CLLC (E_{cl})
 - CLLC (E_{cl}) Required for certain elements of certain systems
 - Shear in SMF beams and column splices
 - BRBF beams & columns, and brace connections
- SMF & BRBF
 - $R_u = 1.4D + 0.5L + E_{cl}$ combo CLLC-1
 - $R_u = 0.7D \pm E_{cl}$ combo CLLC-2



ASCE 7 **2016** §12.4.3

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Load Combinations

- Drift
 - $1.0D + 0.5L + E_h$
 - Base shear based on model period (not limited by $C_u T_a$)
 - $P\Delta$ based on $1.0D+0.5L$



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Summary

There's always a solution in steel.



Summary

- Building presented
- Seismic accelerations obtained
- Seismic Design Category D Determined
- SMF & BRBF selected
- Base shear determined
- Load combinations set up
- Wind load determined to be secondary to seismic for main lateral systems



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End of Session L1

Next:
**Building analysis and
diaphragm design**

There's always a solution in steel.



There's always a solution in steel.

Question time



Individual Webinar Registrants CEU/PDH Certificates

Within 2 business days...

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!



Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days...

- New reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.



8-Session Package Registrants

CEU/PDH Certificates

One certificate will be issued at the conclusion of
all 8 sessions.



8-Session Package Registrants

Videos and Quizzes

Videos

- For Sessions R1 – R4, access has been available since July 16.
- For Sessions L1 – L4, find access to recordings within two days after the live air date. (An email will be sent from webinars@aisc.org.)
- All recordings are available through October 22.

Quizzes

- For Sessions R1 – R4, access has been available since July 16. Quizzes are due on October 22.
- For Sessions L1 – L4, find access to quizzes within two days after the live air date. (An email will be sent from webinars@aisc.org.) Quizzes are due three weeks after each live session.
- A final exam will also be given. It will be available October 5 and due October 22.
- Quiz scores are displayed in the Course Resources table.



8-Session Package Registrants

Videos and Quizzes

Attendance and PDH Certificates

- For Sessions R1 – R4, you must pass the quiz to receive credit for the session.
- For Sessions L1 – L4, you have two options to receive credit for the session.
 - Option 1: Watch the session live. Credit for live attendance will be displayed in the Course Resources table within two days of the session.
 - Option 2: Watch the recording and pass the quiz.

EEU Certificates – Certificate of Completion

- In addition to PDH certificates earned for each individual session, an EEU (Equivalent Education Unit) certificate of completion will be issued for participants who complete the full course. Participants must pass at least 7 of 8 quizzes and the final exam to earn the EEU.

Distribution of Certificates

- All certificates (PDH and EEU) will be issued after the final session. Only the registrant will receive certificates for the course.



8-Session Package Registrants Course Resources

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!



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Course Resources

Event	Start Date
Test Course	1/1/1900 12:00:00 AM
15.14.8-Session Package-Night School 15 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
15.14.8-Session Package-Night School 14 - Seismic Design in Steel	2/9/2018 7:00:00 PM
15.17.4-Session Package-Night School 17- Design of Facade Attachments	7/16/2018 7:00:00 PM
8-Session Package-Seismic Design in Steel - Concepts & Examples	7/18/2018 1:30:00 PM



8-Session Package Registrants Course Resources



Seismic Design in Steel

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
R1: Introduction To Effective Seismic Design	N/A	Handouts	Video Pascode: 18NCR51	Pass Score: 100	N/A
R2: Seismic Design Concepts - Moment Frames	N/A	Handouts	Video Pascode: 18D21218	Pass Score: 100	N/A
R3: Seismic Design Concepts - Braced Frames	N/A	Handouts	Video Pascode: 3810305	Pass Score: 100	N/A
R4: Seismic Design Concepts - Design	N/A	Handouts	Video Pascode: N/A	Pass Score: 100	N/A
L1: Application - Planning the Seismic Design	Sep 10 2018 1:30PM EDT	Handouts	Available 09/12/2018 5:00PM EDT	Available 09/12/2018 5:00PM EDT	Pending
L2: Application - Building Analysis/Diaphragms	Sep 17 2018 1:30PM EDT	Handouts	Available 09/18/2018 5:00PM EDT	Available 09/18/2018 5:00PM EDT	Pending
L3: Application - Moment Frames	Sep 24 2018 1:30PM EDT	Handouts	Available 09/26/2018 5:00PM EDT	Available 09/26/2018 5:00PM EDT	Pending
L4: Design of the Braced Frames	Oct 1 2018 1:30PM EDT	Handouts	Available 10/03/2018 5:00PM EDT	Available 10/03/2018 5:00PM EDT	Pending
Seismic Design in Steel - Final Exam	Oct 3 2018 12:00AM EDT			Available 10/03/2018 5:00PM EDT	

There's always a solution in steel.

Thank You

Please give us your feedback!
Survey at conclusion of webinar.



