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## Course Description

### Session 5: Planning the Seismic Design March 19, 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.



There's always a solution in steel.

## Seismic Design in Steel: Concepts and Examples

Session 5: Planning the Seismic Design  
March 19, 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

1. Introduction to effective seismic design
2. Seismic design of moment frames
3. Seismic design of braced frames
4. Seismic design of buildings



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## Course outline

### Part II: Application

5. Planning the seismic design
6. Building analysis and diaphragm design
7. Design of the moment frames
8. Design of the braced frames



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There's always a solution in steel.

## Session 5: 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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There's always a solution in steel.

## Given information

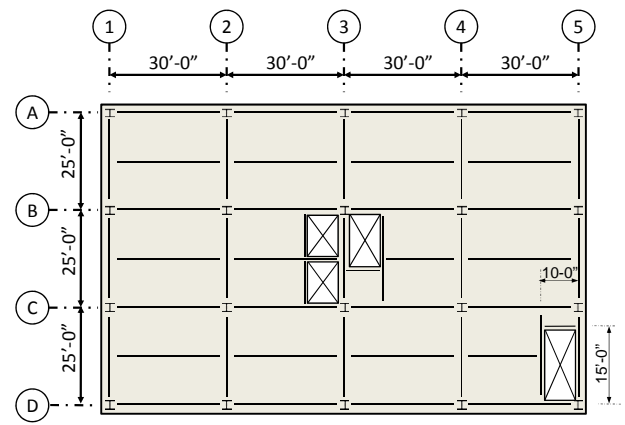


### Given information

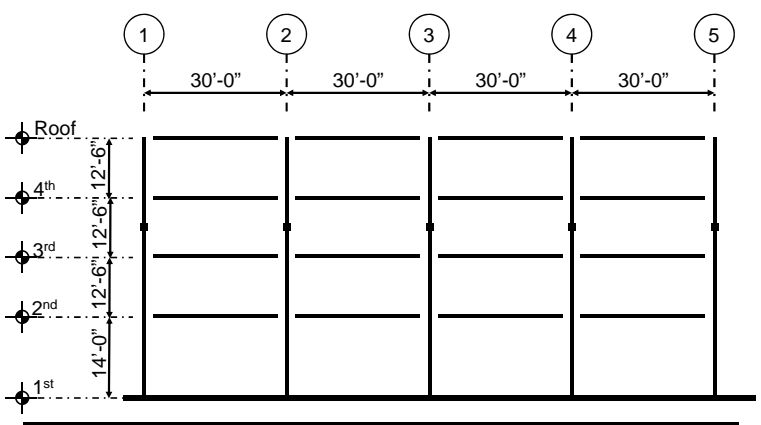
- Design from AISC Seismic Design Manual
- Four-story building
- Special Moment Frame
  - Examples 4.3 and 4.4
- Buckling-restrained Braced Frame
  - Example 5.5
- Diaphragm design similar to Example 8.4.1



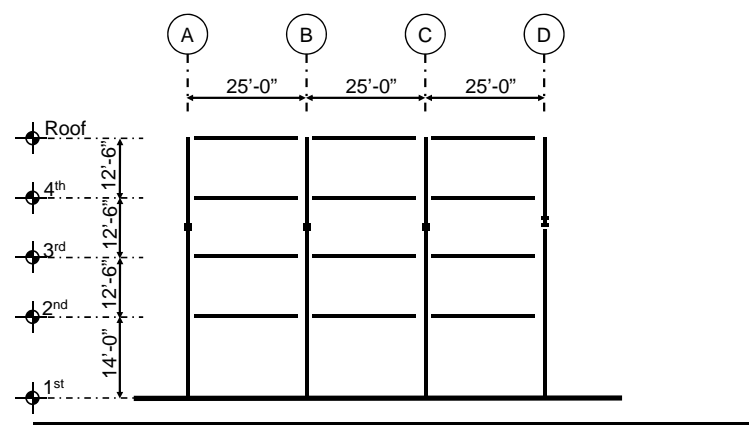
### Plan



### Elevation



### Elevation



## 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	○ AISC 341, 2010
○ ASCE 7, 2010	○ AISC 358, 2010
○ AISC 360, 2010	○ AWS D1.8, 2009
○ ACI 318, 2014	
○ AWS D1.1, 2010	



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

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## Given information

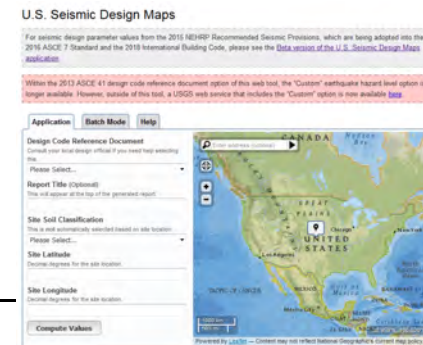
- Loads
  - $D_{floor} = 85$  psf (includes partition allowance)
  - $D_{roof} = 68$  psf (includes partition allowance)
  - $L_{floor} = 50$  psf
    - (reduced; used for all examples regardless of area)
  - $S = 20$  psf
  - Curtain wall  $D$ 
    - $12.5 \times 14$  psf
    - $= 175$  lb/ft along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



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## Determine Seismic Accelerations

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



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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](#).

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](#).

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

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.

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

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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**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.

I or II or III

**Site Latitude**  
 Decimal degrees for the site location.

**Site Longitude**  
 Decimal degrees for the site location.

Compute Values



### 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:  
 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.  
 I or II or III

Site Latitude  
 Decimal degrees for the site location.

Site Longitude  
 Decimal degrees for the site location.

123 Fake Street, EQ, 00000

Quakeville

29 01 27.100 296° W

Compute Values

## Determine Seismic Accelerations

**USGS-Provided Output**

$S_s$	= 1.5 g	$S_{MS}$	= 1.5 g	$S_{ds}$	= 1.0 g
$S_1$	= 0.6 g	$S_{M1}$	= 0.9 g	$S_{d1}$	= 0.6 g

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  $PGA_s$ ,  $T_u$ ,  $C_{ms}$ , and  $C_{m1}$  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.

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## 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

Reduction at higher periods only allowed with GMHA (not USGS maps)

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## System selection

There's always a solution in steel.

## 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, $\Omega_0$	Deflection Amp. Factor, $C_d^b$	Structural System Limitations Including Structural Height, $h_n$ , Limits in ft <sup>c</sup>				
				Seismic Design Category				
				B	C	D <sup>d</sup>	E <sup>d</sup>	F <sup>e</sup>
<b>STEEL SYSTEMS</b>								
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 <sup>d</sup>	35 <sup>d</sup>	NP <sup>e</sup>
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 <sup>d</sup>	NP <sup>e</sup>	NP <sup>e</sup>
Steel ordinary moment frames (OMF)	3 1/2	3	3	NL	NL	NP <sup>e</sup>	NP <sup>e</sup>	NP <sup>e</sup>
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 <sup>e</sup>	NP <sup>e</sup>	NP <sup>e</sup>
Steel systems not specifically detailed for seismic resistance	3	3	3	NL	NL	NP	NP	NP

## Materials

There's always a solution in steel.



## 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

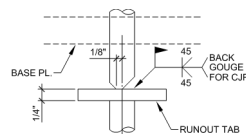
- Typical connections
  - Plate
    - A36
      - $F_y = 36\text{ksi}$
      - $F_u = 58\text{ksi}$
  - Bolts
    - A325X
      - $F_{nv} = 68\text{ksi}$
      - $F_{nt} = 90\text{ksi}$
    - Seismic system
      - Pretensioned
      - Class A faying surface
- Base connections
  - A572 Gr. 50
    - $F_y = 50\text{ksi}$
    - $F_u = 65\text{ksi}$
    - $t > 2"$ 
      - 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

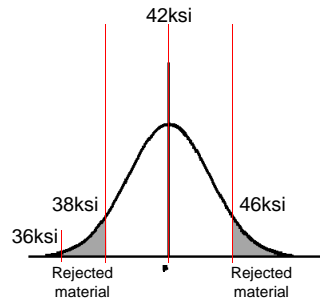
- Welds
  - Matching strength
    - $F_{EXX} = 70\text{ksi}$
  - CVN
    - Seismic system
      - Typical
        - CVN 20ft#@0°F
      - Demand Critical Welds
        - CVN 40ft#@70°F
- Lowest Anticipated Service Temperature
  - Required for modifying CVN testing requirements for cold-weather applications (<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


There's always a solution in steel.



## Quality


- AISC 360 Chapter N
  - Fabrication & Erection QC
  - Inspection QA
    - Task tables
  - NDT
    - Rates
  - Approved fabricators and erectors
    - With AHJ approval, QC only (no 3<sup>rd</sup>-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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There's always a solution in steel.


## Effective seismic weight



## 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
  - $[2*4*30'+4*1'] + [2*3*25'+4*1'] = 398'$


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ASCE 7 §12.7.2
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## Effective seismic weight


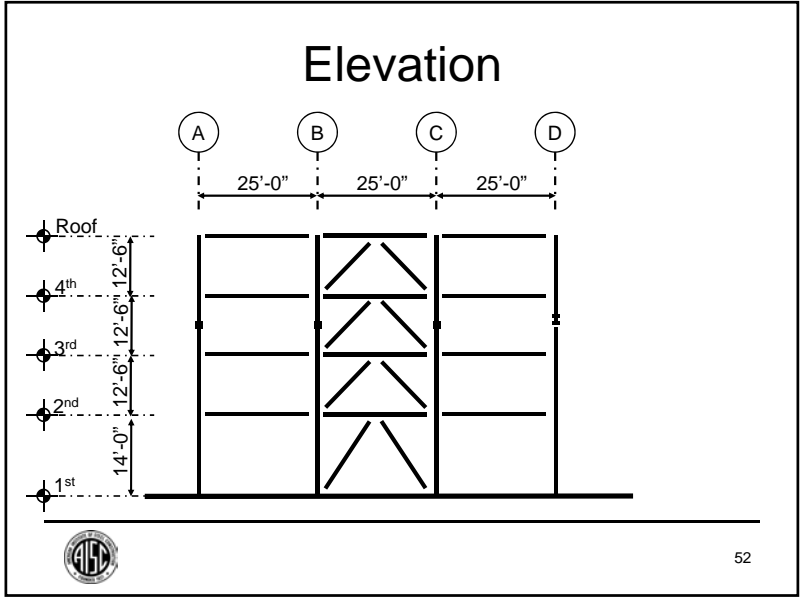
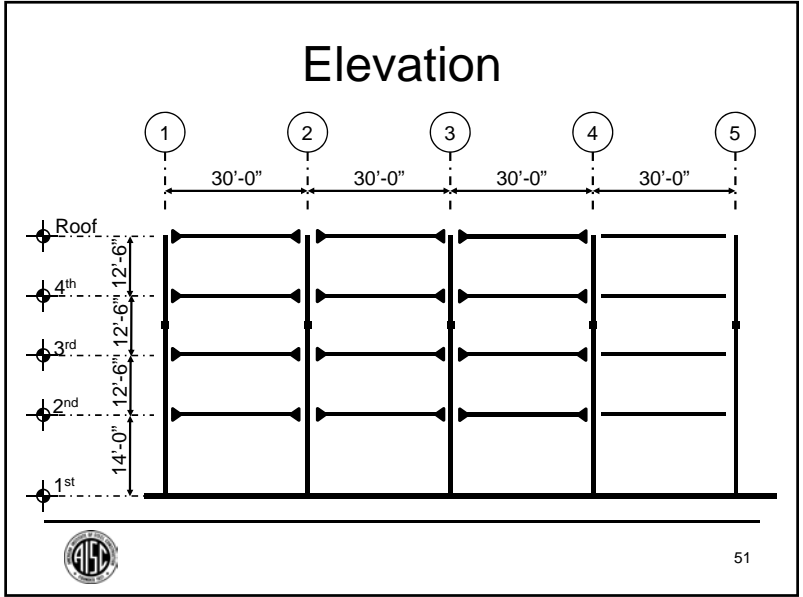
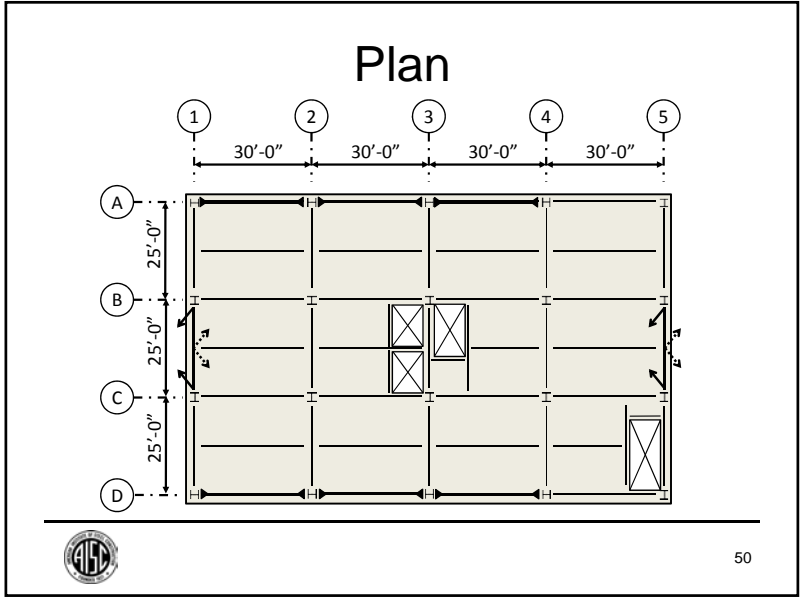
- Floor weight
  - $= 9394\text{sf} * 0.085\text{ksf} + 398' * 0.175\text{klf} = 868\text{K}$
- Roof weight
  - $= 9394\text{sf} * 0.068\text{ksf} + 398' * 0.175\text{klf} = 708\text{K}$
- Total weight:
  - $3 * 868\text{K} + 708\text{K} = 3313\text{K}$

---


ASCE 7 §12.7.2
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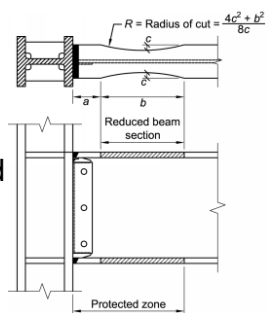
There's always a solution in steel.

## Configuration selection

## 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

There's always a solution in steel.



## 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  $S_{dt} > 0.4$
  - Assume  $T > T_a$ 
    - Based on experience
    - To be confirmed later in design



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## Approximate period

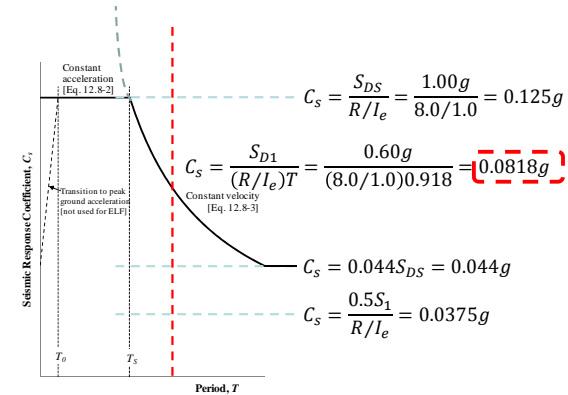
- SMF
  - $T_a = 0.028 * 51.5^{0.8} = 0.656s$
  - Assume  $T > C_u T_a = 1.4 * 0.656s = 0.918s$ 
    - Must be verified after final analysis
- BRBF
  - $T_a = 0.03 * 51.5^{0.75} = 0.577s$
  - Assume  $T > 1.3 T_a$  for  $C_u = 1.4$ 
    - Assume  $T = 1.3 * 0.577s = 0.750s$
    - Must be verified after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



ASCE 7 §12.8.2.1

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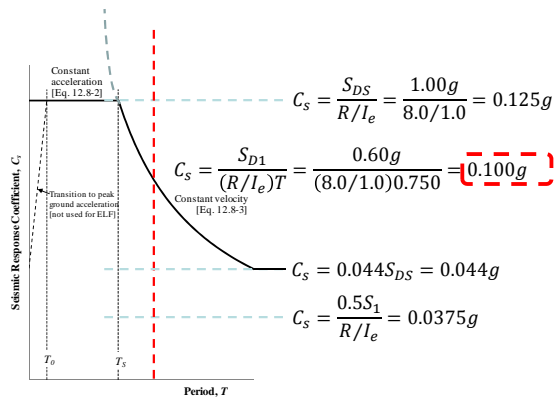
## Base Shear: SMF



ASCE 7 §12.8.1.1

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## Base Shear: BRBF



ASCE 7 §12.8.1.1

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## Base Shear


- SMF
  - $V = 0.0818 * 3313K$
  - $= 271K$
- BRBF
  - $V = 0.100 * 3313K$
  - $= 331K$



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There's always a solution in steel.


## 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 <sup>th</sup>	30.6	29.5	33.8	51.5
3 <sup>rd</sup>	29.0	28.0	32.2	49.1
2 <sup>nd</sup>	26.9	27.5	30.1	48.6

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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
$\Omega_o$ 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
    - $\Delta_{windserv} \leq 0.0025h$
  - 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
        - $V_{wind}/\Delta_{windserv} = (0.7)^{176K}/_{0.0025h} = 49,300K/h$
      - BRBF
        - $C_d V_{seismic}/\Delta = (5)^{331K}/_{0.02h} = 82,800K/h$
      - Ratio
        - $K_{reqEQ}/K_{reqW} = 1.7$



AISC Design Guide 3

66

## Wind vs Seismic

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



AISC Design Guide 3

67

## Determination of Irregularities

There's always a solution in steel.



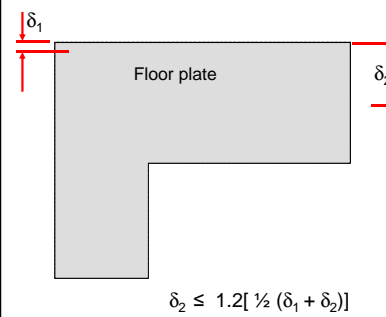
## Irregularities

- 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



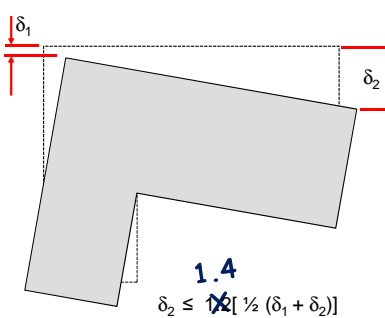
- Basis
  - Buildings with high torsional response are prone to damage
- Addressed by
  - Amplifying torsional moment
  - Restricting torsionally irregular buildings in severe seismic conditions



ASCE 7 Table 12.3-1

70

## Horizontal irregularity: Torsional (extreme)



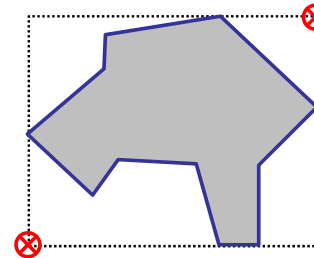
- Basis
  - Buildings with high torsional response are prone to damage
- Addressed by
  - Amplifying torsional moment
  - Restricting torsionally irregular buildings in severe seismic conditions



ASCE 7 Table 12.3-1

71

## Horizontal irregularity: Torsional (complex layout)



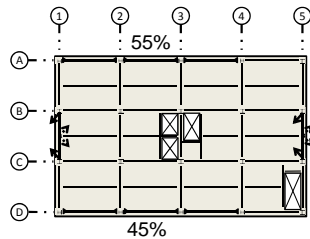
- Draw rectangle around plan
  - Aligned with X & Y analyses
- Pick opposite corners
- Use corner displacements to assess irregularity



ASCE 7 Table 12.3-1

72

### Horizontal irregularity: Torsional



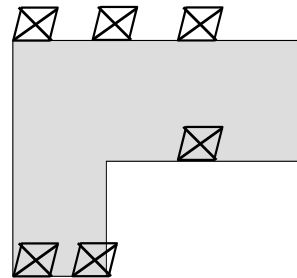
- Considered with accidental torsion
  - $\delta_{max}/\delta_{ave} \leq 55\%/50\% = 1.1$
  - Irregularity does not exist



ASCE 7 Table 12.3-1

73

### Horizontal irregularity: Torsional



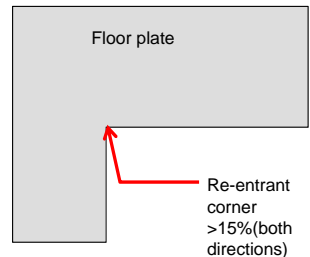
- Control strategies
  - Balance center of rigidity with center of mass
  - Provide resistance at building perimeter
    - Both axes



ASCE 7 Table 12.3-1

74

### Horizontal irregularity: Re-entrant corner



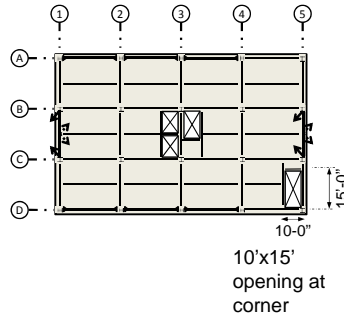
- Basis
  - Notch-like effect amplifies diaphragm forces
- Addressed by
  - Increased diaphragm forces
  - Requiring dynamic analysis for taller buildings



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

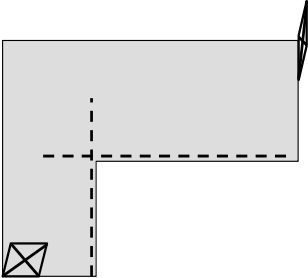


ASCE 7 Table 12.3-1

76




### Horizontal irregularity: Re-entrant corner



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

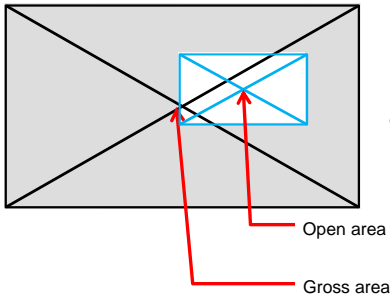
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ASCE 7 Table 12.3-1

77


### Horizontal irregularity: Diaphragm discontinuity



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

Open area  $\leq 0.5$  Gross area

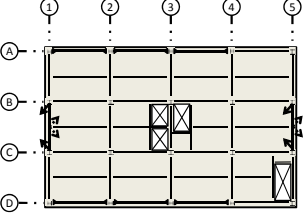
---



ASCE 7 Table 12.3-1

78


### Horizontal irregularity: Diaphragm discontinuity



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

20'x25'  
opening at  
center

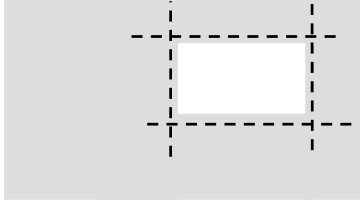
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ASCE 7 Table 12.3-1


79

### Horizontal irregularity: Diaphragm discontinuity



- Control strategies
  - Provide strong ties

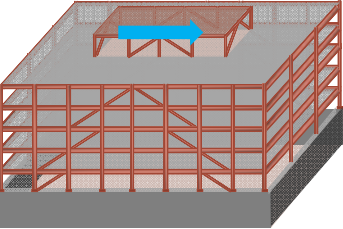
---



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

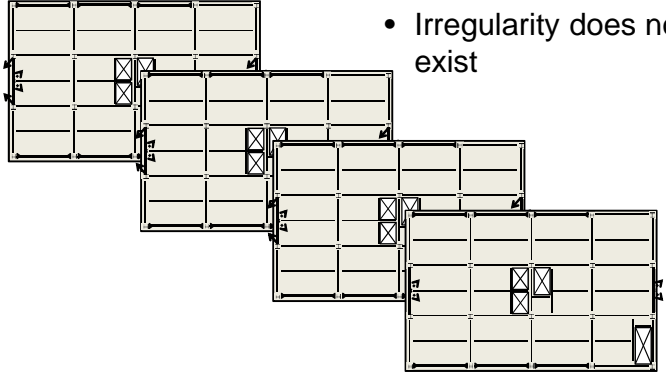
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ASCE 7 Table 12.3-1


81

### Horizontal irregularity: Out-of-plane offset



- Irregularity does not exist

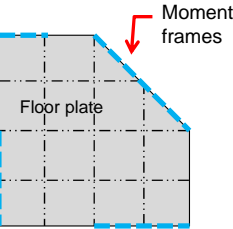
---



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

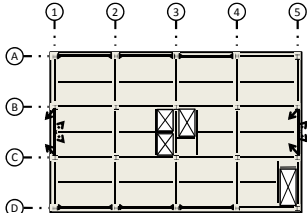
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ASCE 7 Table 12.3-1


83

### Horizontal irregularity: Non-parallel systems



- Irregularity does not exist

---



ASCE 7 Table 12.3-1

84

## Horizontal Irregularities

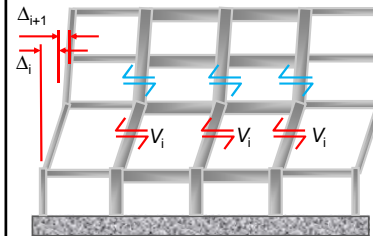
- Torsional *Not present/likely*
- Re-entrant corner *Not present*
- Diaphragm discontinuity *Not present*
- Out-of-plane offset *Not present*
- Non-parallel systems *Not present*



ASCE 7 Table 12.3-1

85

## Vertical irregularity: Soft story



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

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

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

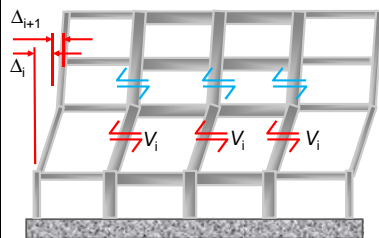


ASCE 7 Table 12.3-2

86

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

## Vertical irregularity: Soft story (extreme)



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

$$K_i \leq 0.6 K_{i+1}$$

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

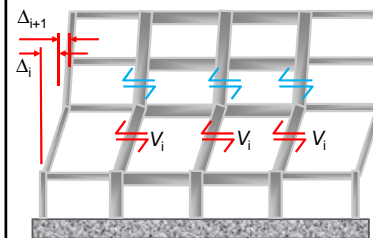


ASCE 7 Table 12.3-2

87

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

## Vertical irregularity: Soft story



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



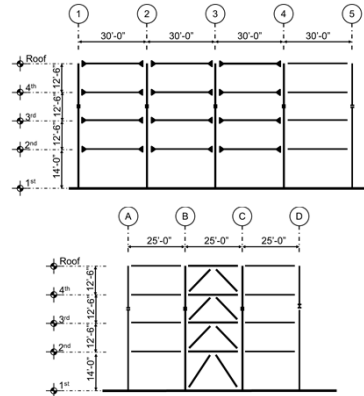
ASCE 7 Table 12.3-2

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

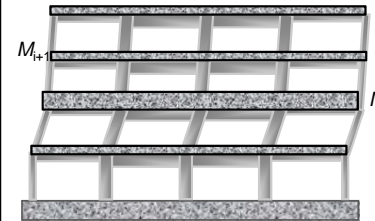
- Proportion members to demand
- Soft-story irregularity not likely
  - Checked after final member selection



89

## Vertical irregularity: Mass

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



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

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

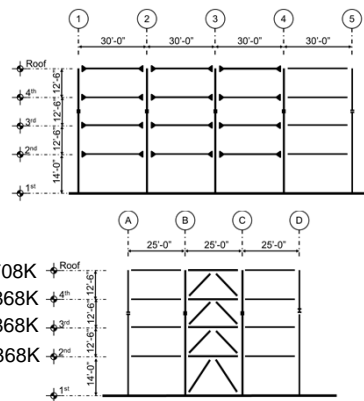


ASCE 7 Table 12.3-2

90

## Vertical irregularity: Mass

- Mass irregularity not present



Roof weight = 708K

Floor weight = 868K

Floor weight = 868K

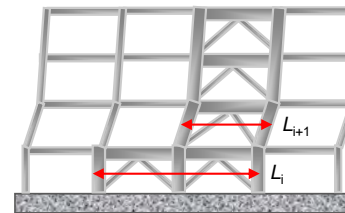
Floor weight = 868K



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



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

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

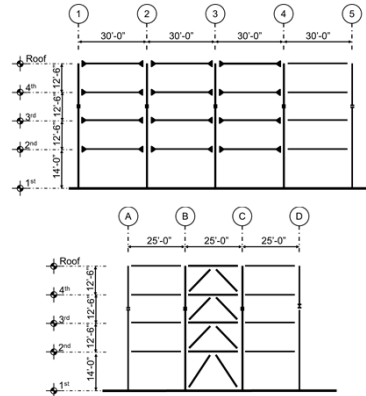


ASCE 7 Table 12.3-2

92

### Vertical irregularity: Geometric

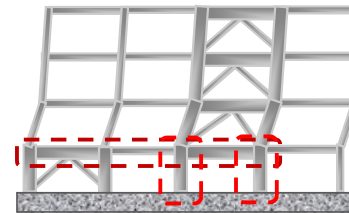
- Geometric irregularity not present



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

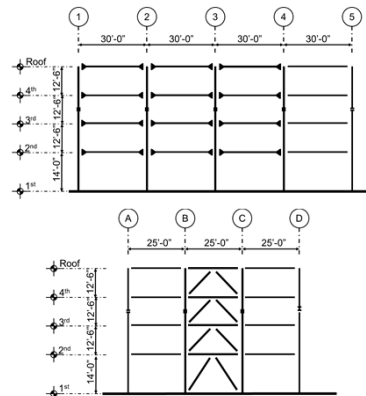


ASCE 7 Table 12.3-2

94

### Vertical irregularity: In-plane offset

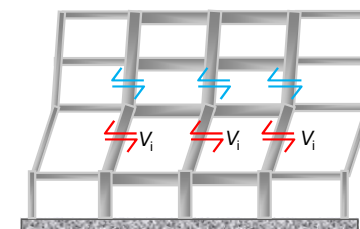
- In-plane offset irregularity not present



95

### Vertical irregularity: Weak story

- 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



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



ASCE 7 Table 12.3-2

96

### Vertical irregularity: Weak story (extreme)

- 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

$\Sigma V_{n_i} \geq 0.8 \Sigma V_{n_{i+1}}$   
~~0.8~~  
 0.65

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

ASCE 7 Table 12.3-2 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  $\rho$
- Determine overstrength factor  $\Omega_o$
- Determine vertical seismic load effect
- Determine live load factor
  - $L < 100\text{psf}$
  - No public assembly
  - $f_1 = 0.5$

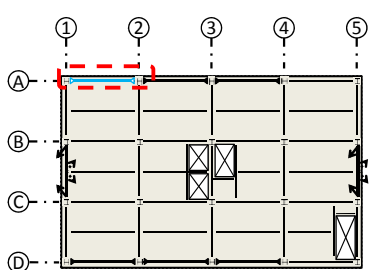
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ASCE 7 §12.4 102

## Redundancy factor $\rho$ SMF

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



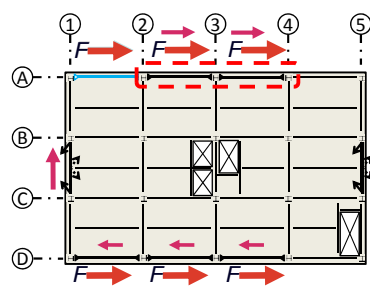

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## Redundancy factor $\rho$ SMF (elastic method)

- With all frames:
  - $F = 1/6 V/\text{frame} (0.167V)$
- 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
  - $2F \sim (2/5)V + 0.385T/75'$ 
    - $= 0.44V$
    - $F = 0.219V/\text{frame}$
    - $\sim 32\%$  increase  $< 33\%$




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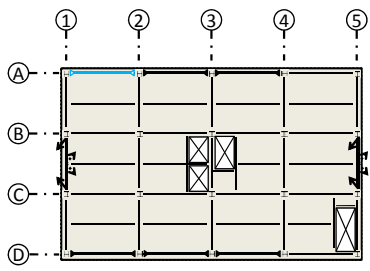



Inelastic methods also permitted for determining strength loss 104

### Redundancy factor $\rho$ SMF (elastic method)

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

$\rho = 1.0$

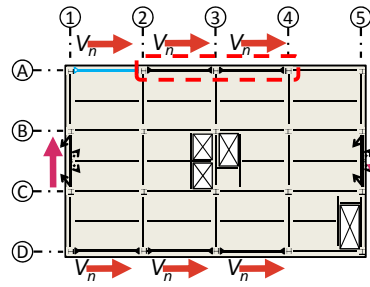




105

### Redundancy factor $\rho$ 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



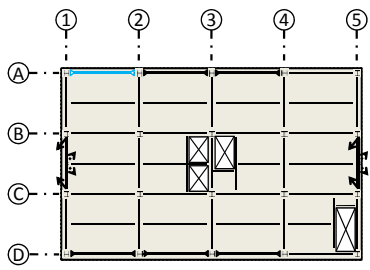

106


### Redundancy factor $\rho$ SMF (inelastic method)

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

$\rho = 1.0$

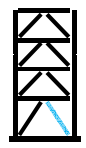
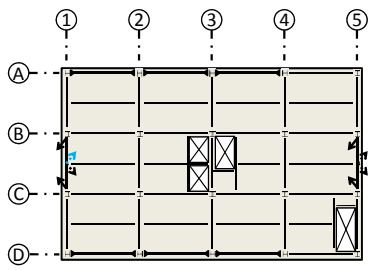
Inelastic methods also permitted for determining strength loss





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### Redundancy factor $\rho$ BRBF

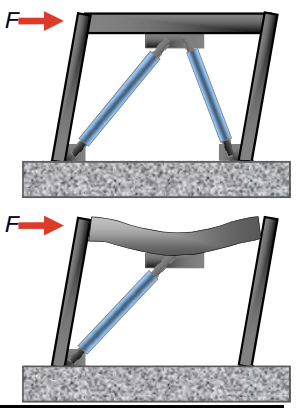
- Braced frame (Table 12.3-3)
  - Evaluate with one brace removed
    - Strength loss < 33%
    - No extreme torsional irregularity






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### Redundancy factor $\rho$ BRBF

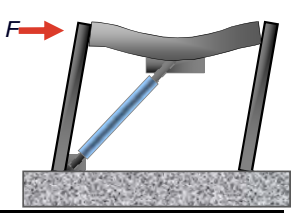
- Original frame
  - $K_1 \sim 2K_F A E \cos^3 \theta / (\frac{1}{2} L_{bay})$
  - $\sim 4K_F A E \cos^3 \theta / L_{bay}$
- With one brace removed
  - $K_2 = 1 / (F_{brace} + F_{beam})$ 
    - $F_{brace} = 2 / K_1$
    - $= L_{bay} / (2K_F A E \cos^3 \theta)$
    - $F_{beam} = \tan^2 \theta L_{bay}^3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





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### Redundancy factor $\rho$ BRBF

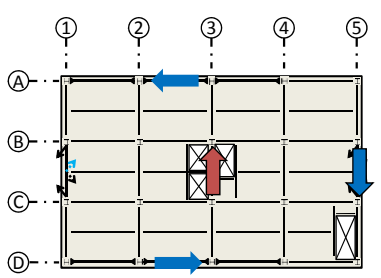
- Much more than 50% loss in stiffness
  - Assume  $K_2 \ll K_1$
- 3 braces remain
  - ~50% effective strength loss in BRBF system
  - SMF resist torsion
    - Assume moment frames as stiff as BRBF





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### Redundancy factor $\rho$ BRBF


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




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### Overstrength factor $\Omega_o$

Seismic Force Resisting System	Resp. Mod. Coeff., $R^a$	Overstrength Factor, $\Omega_o$	Deflection Amp. Factor, $C_d^b$
<b>STEEL SYSTEMS</b>			
Steel special moment frames (SMF)	8	3	5 <sup>1/2</sup>
Steel buckling-restrained braced frames (BRBF)	8	2 <sup>1/2</sup>	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
- $R_u = 1.2D + f_1 L + E_v + \rho E_h$
- $= 1.4D + f_1 L + \rho E_h$
- $R_u = 0.9D - E_v \pm \rho E_h$
- $= 0.7D \pm \rho E_h$



ASCE 7 §12.4.2

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## Basic Load Combinations (BLC)

- Basic Load Combinations
  - $R_u = 1.2D + f_1 L + E_v + \rho E_h$
  - $R_u = 0.9D - E_v \pm \rho E_h$
- 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 ( $\Omega_o$ LC)

- Overstrength Load Combinations
  - $R_u = 1.2D + f_1 L + E_v + \Omega_o E_h$
  - $R_u = 0.9D - E_v \pm \Omega_o E_h$
- 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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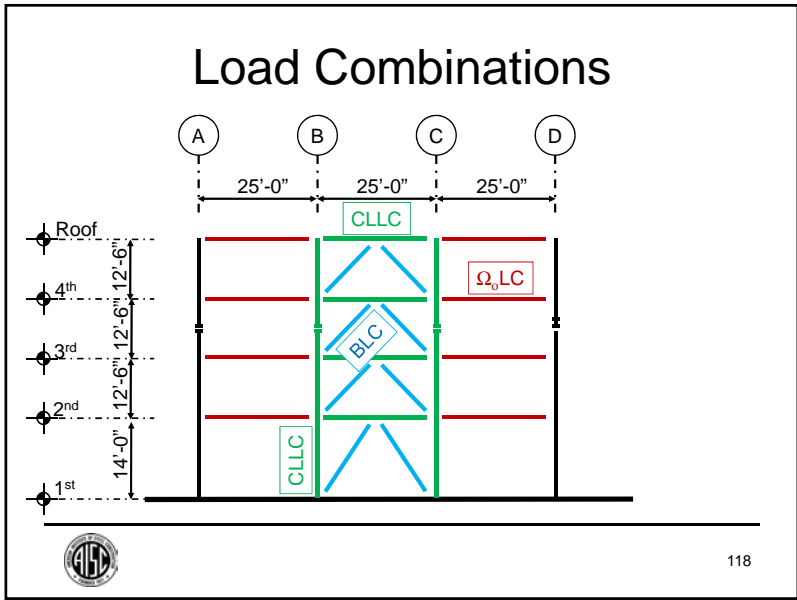
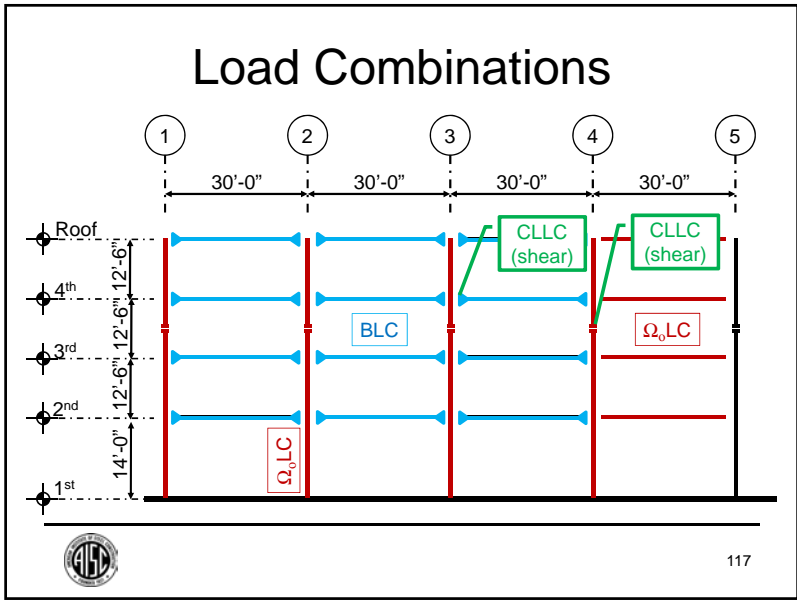
## Capacity-Limited Load Combinations (CLLC)

- Capacity-Limited Load Combinations
  - Related to Overstrength Load Combinations ( $\Omega_o$ LC)
    - Represents actual overstrength
      - Determined by calculation
    - $\Omega_o$ 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 5

*Next:*

## Building analysis and diaphragm design

There's always a solution in steel.



## Question time

There's always a solution in steel.



## Individual Webinar Registrants

### CEU/PDH Certificates

Within 2 business days...

- You will receive an email on how to report attendance from: [registration@aisc.org](mailto: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

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### 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 Registrants

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### CEU/PDH Certificates

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



## 8-Session Registrants

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Access to the quiz: Information for accessing the quiz will be emailed to you by Wednesday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG

Quiz and Attendance records: Posted Tuesday mornings.  
[www.aisc.org/nightschool](http://www.aisc.org/nightschool) - click on Current Course Details.

Reasons for quiz:

- EEU – must take all quizzes and final to receive EEU
- CEUs/PDHS – If you watch a recorded session you must take quiz for CEUs/PDHS.
- REINFORCEMENT – Reinforce what you learned tonight. Get more out of the course.

NOTE: If you attend the live presentation, you do not have to take the quizzes to receive CEUs/PDHS.



## 8-Session Registrants

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**Access to the recording:** Information for accessing the recording will be emailed to you by this Wednesday. The recording will be available for three weeks. For 8-session registrants only. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

**CEUs/PDHS** – If you watch a recorded session you must take AND PASS the quiz for CEUs/PDHS.



### Night School Resources for 8-session package Registrants

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



### Night School Resources for 8-session package Registrants

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VIEW RESOURCES

### Night School Resources for 8-session package Registrants



#### Course Resources

Event	Start Date
NS 13 8-Session Package-Night School 13 - Design of Industrial Buildings	1/30/2017 7:00:00 PM
NS 14 8-Session Package-Night School 14 - Fundamentals of Stability	6/5/2017 7:00:00 PM



## Night School Resources for 8-session package Registrants



Night School 13: Design of Industrial Buildings

### 8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	<a href="#">Handouts</a>	<a href="#">Video</a>	Pass Score 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 02/06/2017 5pm EST	Available 02/06/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 02/13/2017 5pm EST	Available 02/13/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/02/2017 5pm EST	Available 03/02/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/06/2017 5pm EST	Available 03/06/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/13/2017 5pm EST	Available 03/13/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bolt Bracing Design	3/27/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/28/2017 5pm EST	Available 03/28/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 04/03/2017 5pm EST	Available 04/03/2017 5pm EST	Pending
NS13 - Final Exam	4/10/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 04/10/2017 5pm EST	Available 04/10/2017 5pm EST	Pending

## Night School Resources for 8-session package Registrants

- Weekly “quiz and recording” email.
- Weekly updates of the master Quiz and Attendance record found at [www.aisc.org/nightschool](http://www.aisc.org/nightschool). Scroll down to Quiz and Attendance records.
  - Updated on Tuesday mornings.



## Night School Resources for 8-session package Registrants

- Webinar connection information:
  - Found in your registration confirmation/receipt.
  - Reminder email sent out Monday mornings.
- Link to handouts also found here.



# Thank You

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



There's always a solution in steel.