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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).

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Learning Objectives

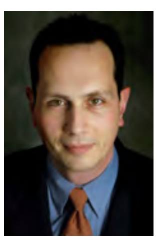
- List requirements to determine base shear.
- List horizontal irregularities that must be considered in the building design.
- List vertical irregularities that must be considered in the building design.
- Describe factors that affect load combinations including the redundancy factor and overstrength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

structural STEEL

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Course objectives

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

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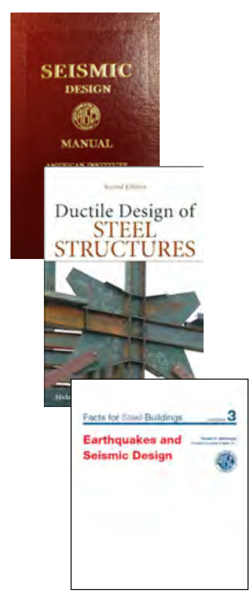
Resources



- 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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Session 5: Planning the seismic design

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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
  - o Examples 4.3 and 4.4
- Buckling-restrained Braced Frame
  - o Example 5.5
- Diaphragm design similar to Example 8.4.1

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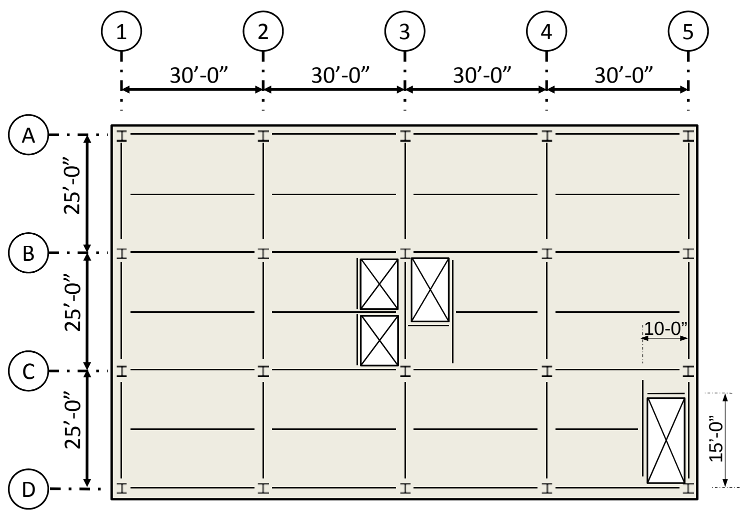
Plan



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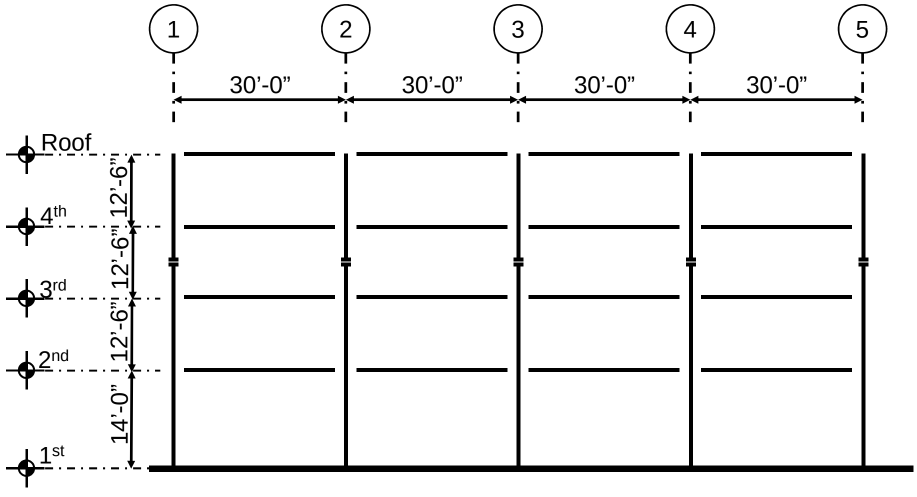
Elevation



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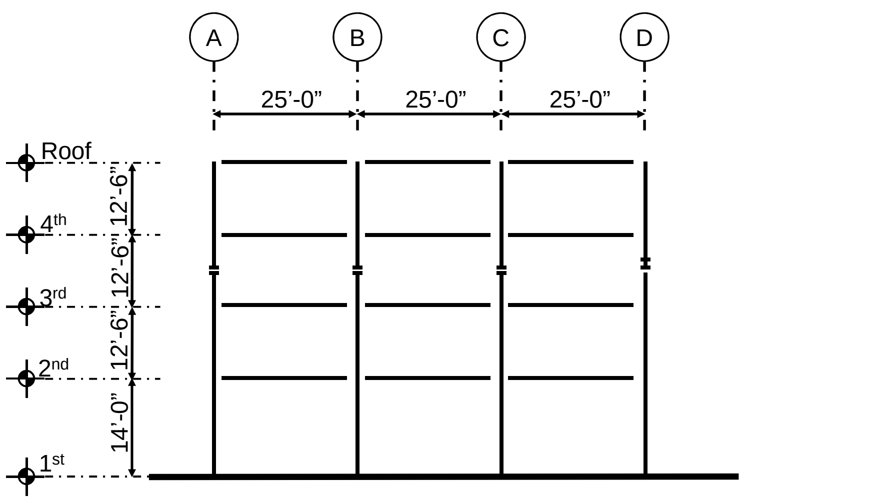
Elevation



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Given information

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

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Given information

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

ASCE 7 16, AISC 341 16
also discussed

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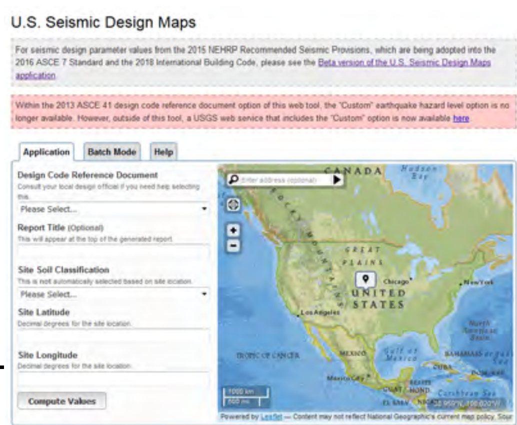
Given information

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

Determine Seismic Accelerations

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



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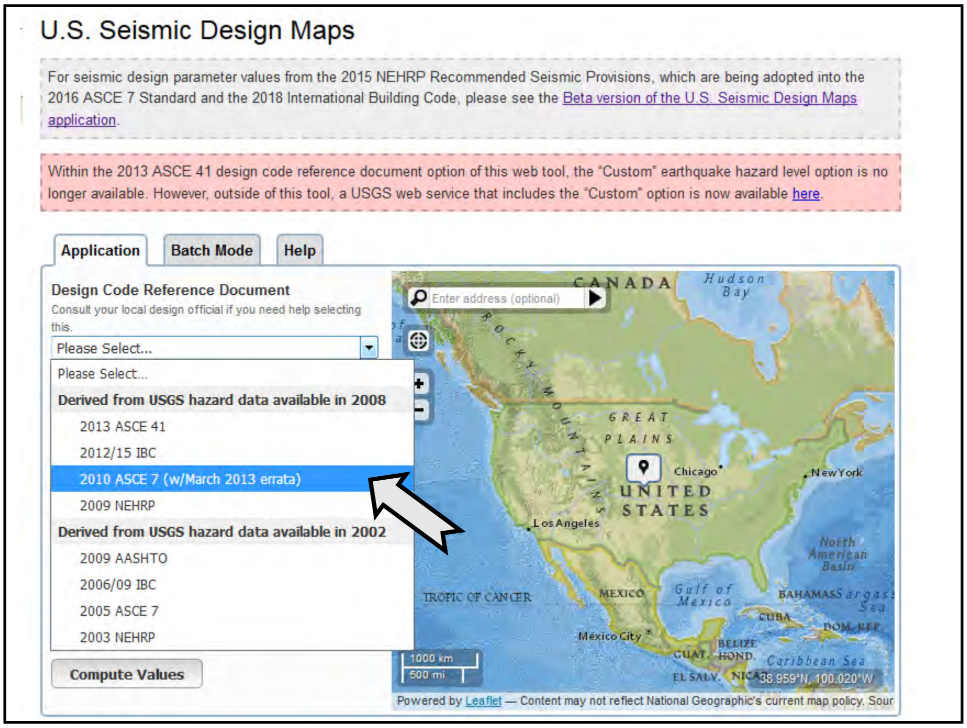
U.S. Seismic Design Maps
For seismic design parameter values from the 2015 NEHRP Recommended Seismic Provisions, which are being adopted into the 2016 ASCE 7 Standard and the 2018 International Building Code, please see the Beta version of the U.S. Seismic Design Maps application.
Within the 2013 ASCE 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
Enter address (optional)
CANADA
Hudson Bay
GREAT PLAINS
UNITED STATES
Chicago
New York
Los Angeles
North American Basin
TROPIC OF CANCER
MEXICO
Gulf of Mexico
BAHAMAS
CUBA
México City
BELIZE
Caribbean Sea
1000 km
500 mi
38.959°N, 100.020°W
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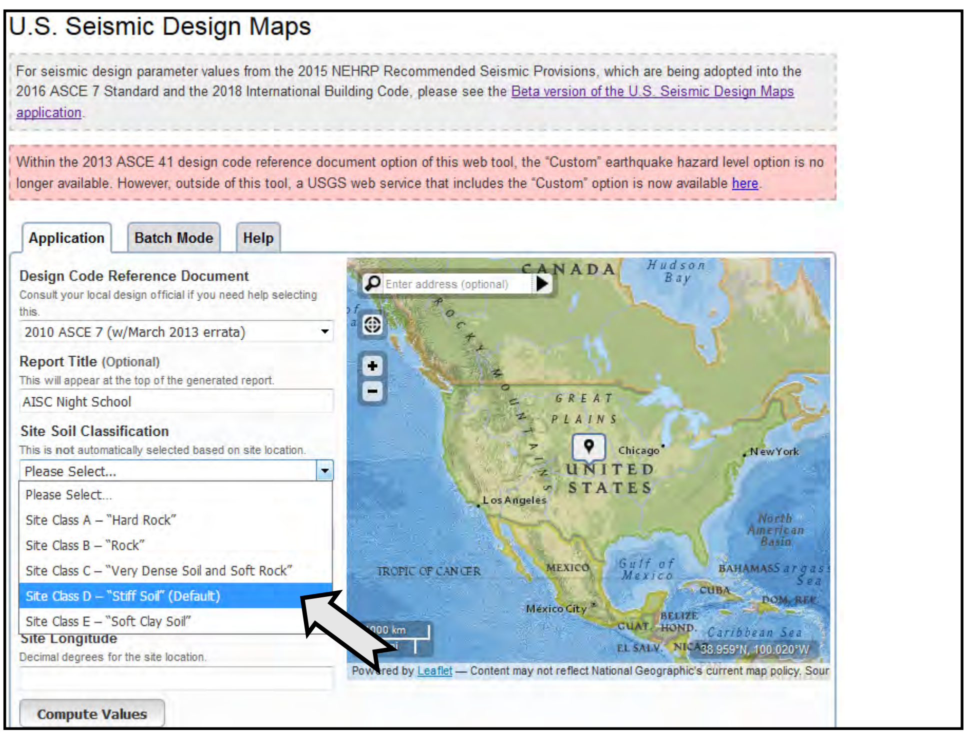
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Application
Batch Mode
Help
Design Code Reference Document
Consult your local design official if you need help selecting this.
2010 ASCE 7 (w/March 2013 errata)
Report Title (Optional)
This will appear at the top of the generated report.
AISC Night 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
Enter address (optional)
CANADA
Hudson Bay
GREAT PLAINS
UNITED STATES
Chicago
New York
Los Angeles
North American Basin
TROPIC OF CANCER
MEXICO
Gulf of Mexico
BAHAMAS
CUBA
México City
BELIZE
Caribbean Sea
38.959°N, 100.020°W
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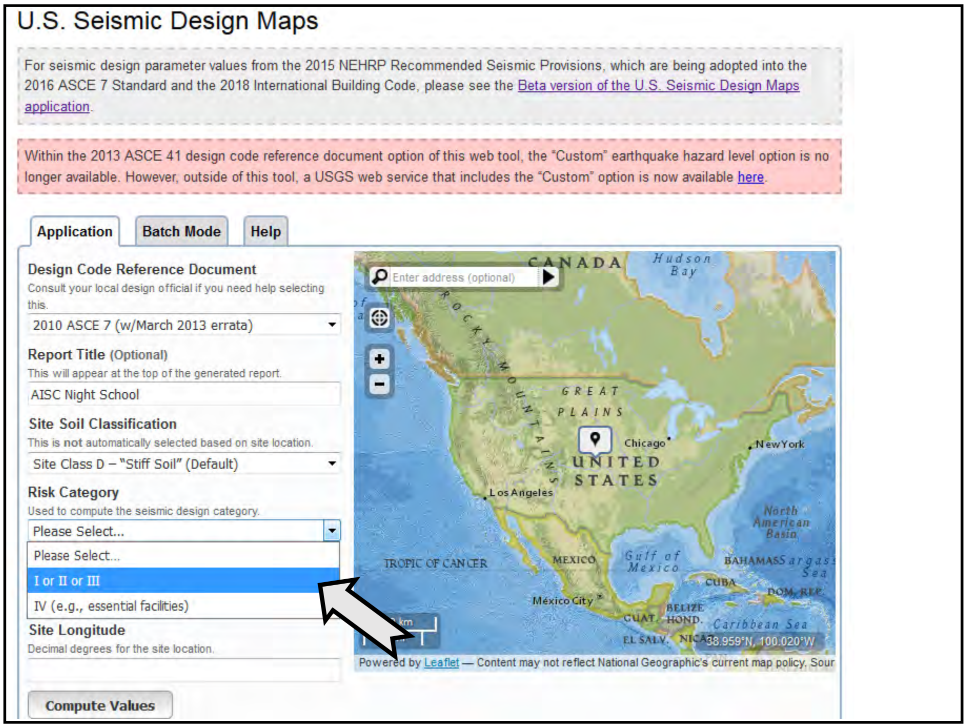

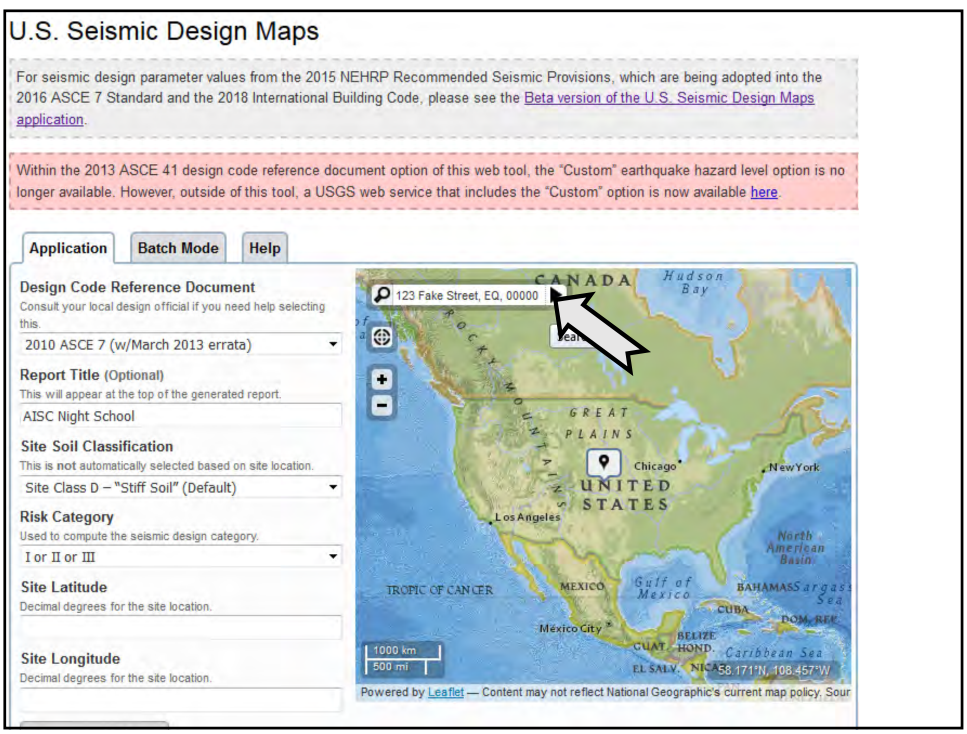

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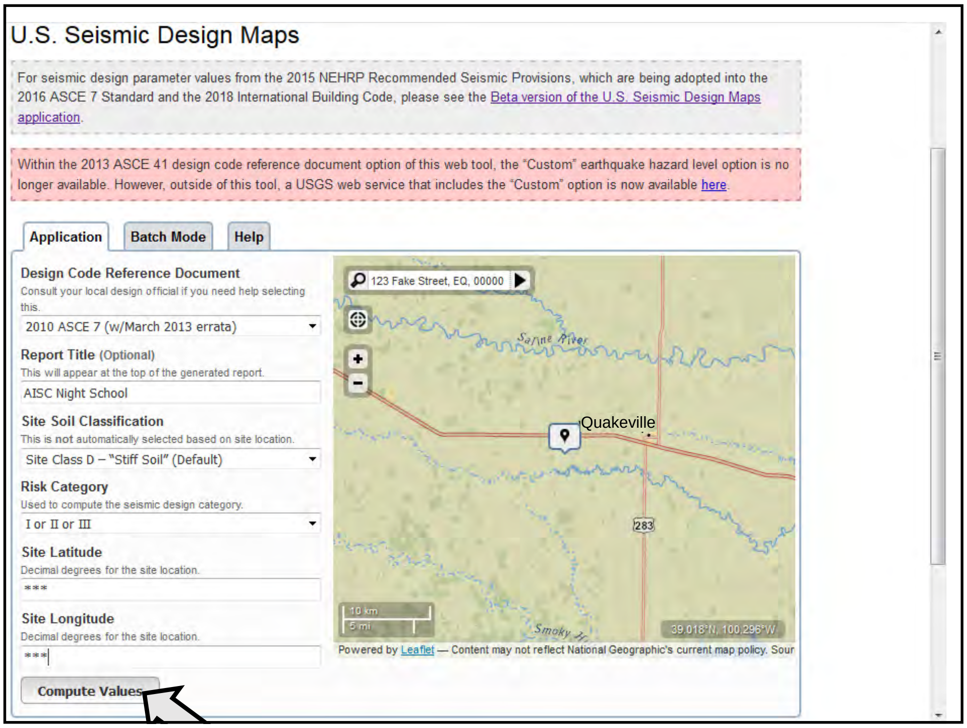
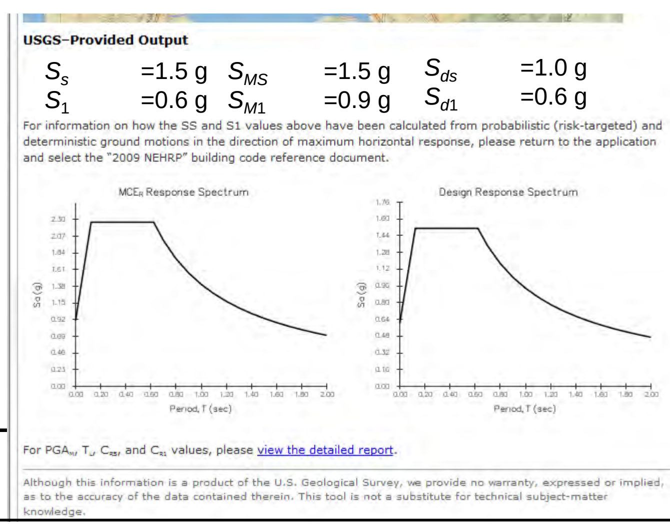


Determine Seismic Accelerations



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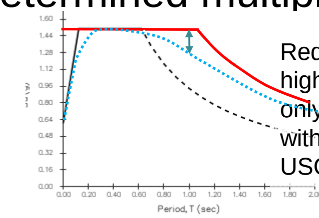
Determine Seismic Accelerations

- 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

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Seismic Design Category (SDC)

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

	Risk Category	
Value of S_{DS}	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

	Risk Category	
Value of S_{D1}	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
  - o S_{ds} =1.0 g > 0.5 g
    - SDC D (or greater)
  - o S_{d1} = 0.6g > 0.2 g
    - SDC D (or greater)
  - o S_1 = 0.6g < 0.75 g
    - **<u>Not</u>** SDC E

	Risk Category	
Value of S_{DS}	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

	Risk Category	
Value of S_{D1}	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_0	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
  - o Beams
    - ASTM A992
      - o F_y = 50ksi
      - o F_u = 65ksi
      - o R_y = 1.1
    - t_f >1½"
      - o CVN 20ft#@70ºF
        - AISC 341 §A3.3
  - o Columns
    - ASTM A992
      - o F_y = 50ksi
      - o F_u = 65ksi
      - o R_y = 1.1
    - t_f >1½"
      - o CVN 20ft#@70ºF
        - AISC 341 §A3.3
    - A913 Gr. 65 & 70 (2016) allowed for BRBF and SMF columns
      - o AISC 341 §A3.1

Steel Design

- Typical connections
  - o Plate
    - A36
      - o F_y = 36ksi
      - o F_u = 58ksi
  - o Bolts
    - A325X
      - o F_{nv} = 68ksi
      - o F_{nt} = 90ksi
    - Seismic system
      - o Pretensioned
      - o Class A faying surface
- Base connections
  - o A572 Gr. 50
    - F_y = 50ksi
    - F_u = 65ksi
    - t>2"
      - o CVN 20ft#@70ºF
        - AISC 341 A3.3
  - o F1554 Grade 55
    - F_y = 55ksi
    - F_u = 75ksi
    - Supplement S1

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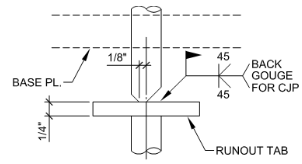
Steel Design

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



Steel Design

- Welds
  - o Matching strength
    - F_{EXX} = 70ksi
  - o CVN
    - Seismic system
      - o Typical
        - CVN 20ft#@0ºF
      - o Demand Critical Welds
        - CVN 40ft#@70ºF

- Lowest Anticipated Service Temperature
  - o Required for modifying CVN testing requirements for cold-weather applications (<50ºF)
  - o All steel within climate-controlled space in this project

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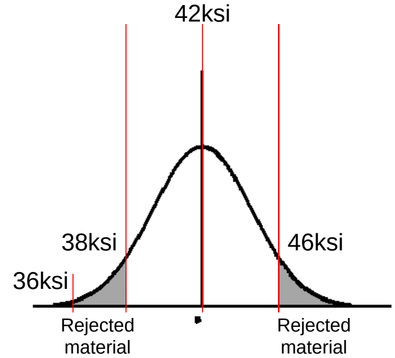
Steel Design

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



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Steel Design

- BRB connections
  - o Gusset plates
    - A572 Gr. 50
      - o $F_y =$ 50ksi
      - o $F_u =$ 65ksi
  - o Bolts at BRB-to-gusset connections
    - A490X
      - o $F_{nv} =$ 84ksi
      - o $F_{nt} =$ 113ksi
- Materials match tested specimens by manufacturer
  - o To be confirmed after manufacturer selection
  - o 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
  - o Fabrication & Erection QC
  - o Inspection QA
    - Task tables
  - o NDT
    - Rates
  - o Approved fabricators and erectors
    - With AHJ approval, QC only (no 3rd-party QA)
- AISC 341 Chapter J
  - o Additional requirements for QA/QC
  - o Demand Critical Welds
- AISC 358 §5.7
  - o 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
  - o (<5%)
- Snow load need not be considered
  - o (<30PSF)
- Plan area
  - o [4*30'+2*1'][3*25'+2*1']=9394sf
- Perimeter
  - o [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
  - o =9394sf*0.085ksf+398'*0.175klf = 868K
- Roof weight
  - o =9394sf*0.068ksf+398'*0.175klf = 708K
- Total weight:
  - o 3*868K+708K = 3313K

ASCE 7 §12.7.2

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Configuration selection

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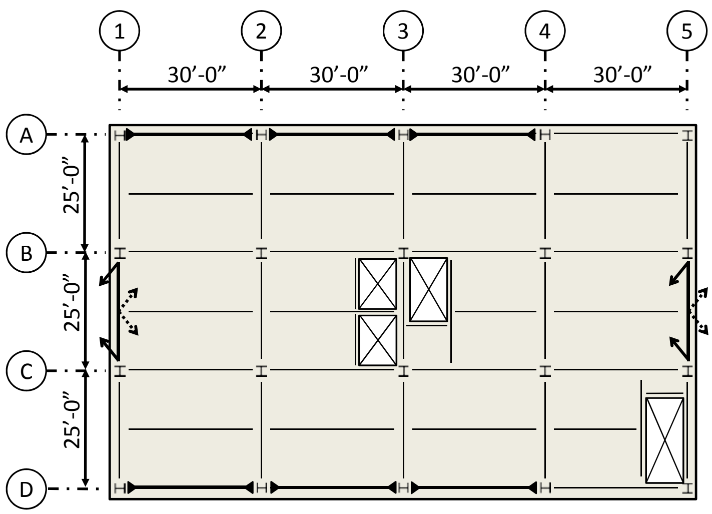
Plan



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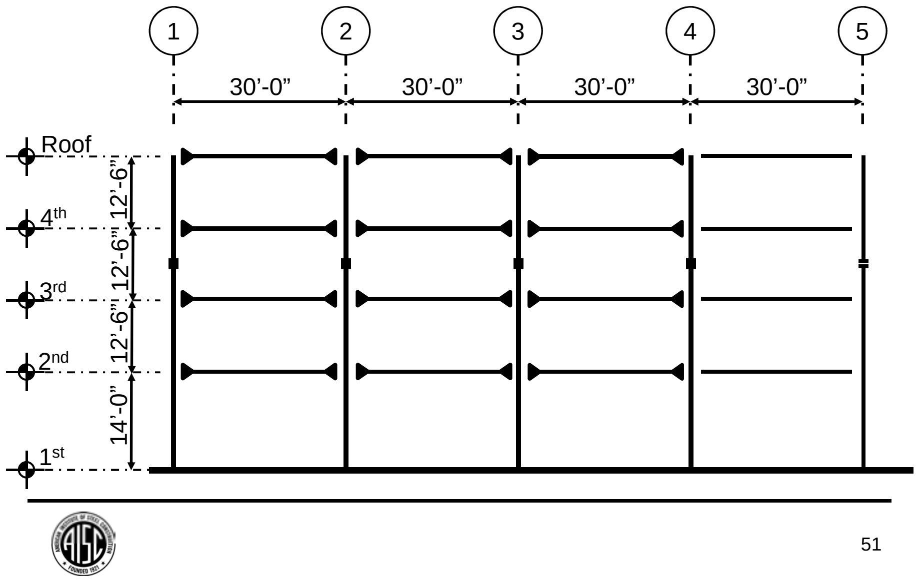
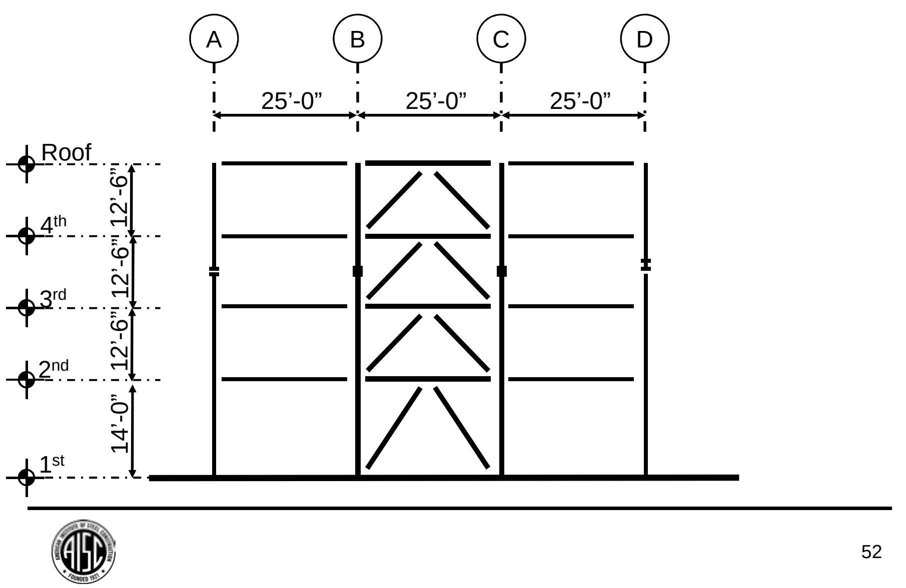
Elevation



Elevation



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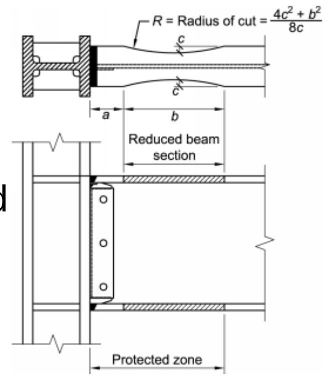
SMF: Reduced beam section

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



AISC 358 §5.3

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BRBF

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

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Base-shear determination

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Approximate period

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

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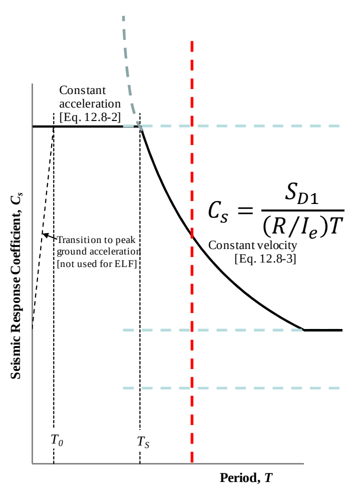
Approximate period

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

Base Shear: SMF



$$C_s = \frac{S_{DS}}{R/I_e} = \frac{1.00g}{8.0/1.0} = 0.125g$$

$$C_s = \frac{S_{D1}}{(R/I_e)T} = \frac{0.60g}{(8.0/1.0)0.918} = \boxed{0.0818g}$$

$$C_s = 0.044S_{DS} = 0.044g$$

$$C_s = \frac{0.5S_1}{R/I_e} = 0.0375g$$

ASCE 7 §12.8.1.1

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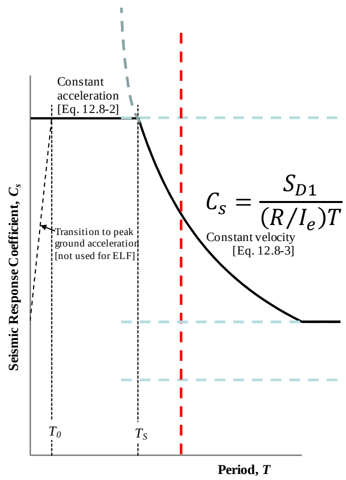
Base Shear: BRBF



$$C_s = \frac{S_{DS}}{R/I_e} = \frac{1.00g}{8.0/1.0} = 0.125g$$

$$C_s = \frac{S_{D1}}{(R/I_e)T} = \frac{0.60g}{(8.0/1.0)0.750} = \boxed{0.100g}$$

$$C_s = 0.044S_{DS} = 0.044g$$

$$C_s = \frac{0.5S_1}{R/I_e} = 0.0375g$$

ASCE 7 §12.8.1.1

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Base Shear

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

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There's always a solution in steel.

Wind vs seismic comparison

structural STEEL

Wind vs. seismic comparison

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

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Wind Load

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

	Figure 27.4-8 - Case I			
	X-direction		Y-direction	
Level	*p* (psf)	*F* (k)	*p* (psf)	*F* (k)
Roof	31.9	15.3	35.0	26.7
4th	30.6	29.5	33.8	51.5
3rd	29.0	28.0	32.2	49.1
2nd	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

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Wind vs Seismic

- Wind serviceability
  - o 10-year wind
    - 0.7 times 50-year wind pressures
      - o Note that ASCE 7-16 no longer uses 50-year wind
  - o H/400 deflection limit
    - $\Delta_{windserv} \leq 0.0025h$
  - o 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

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Wind vs Seismic

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

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Wind vs Seismic

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

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There's always a solution in steel.

Determination of Irregularities

structural
STEEL

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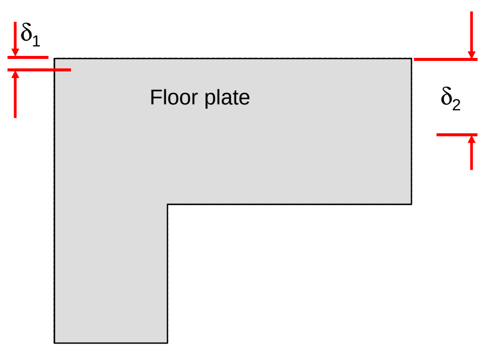
Irregularities

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

Horizontal irregularity: Torsional



$\delta_2 \leq 1.2[\,½\,(\delta_1 + \delta_2)]$

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

ASCE 7 Table 12.3-1

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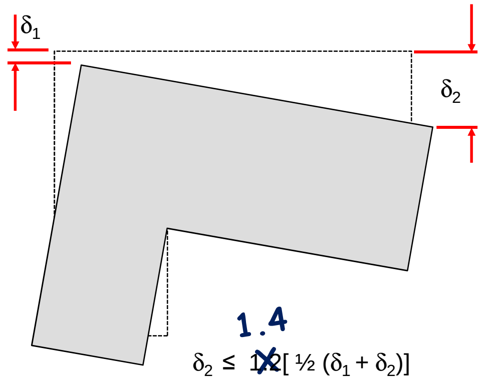
Horizontal irregularity: Torsional (extreme)



1.4

$\delta_2 \le \cancel{1.2}[\,½\,(\delta_1 + \delta_2)]$

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

ASCE 7 Table 12.3-1

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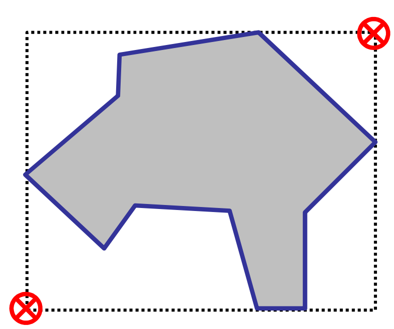
Horizontal irregularity: Torsional (complex layout)



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

ASCE 7 Table 12.3-1

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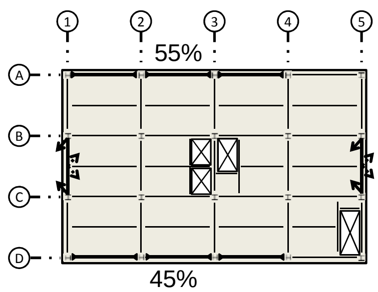
Horizontal irregularity: Torsional



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

ASCE 7 Table 12.3-1

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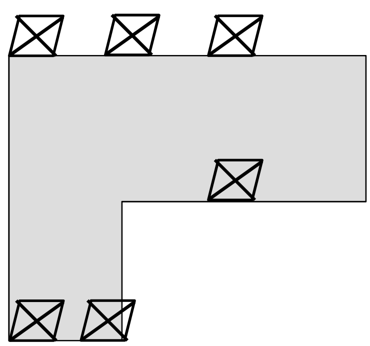
Horizontal irregularity: Torsional



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

ASCE 7 Table 12.3-1

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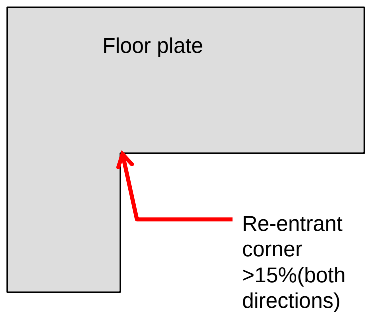
Horizontal irregularity: Re-entrant corner



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

ASCE 7 Table 12.3-1

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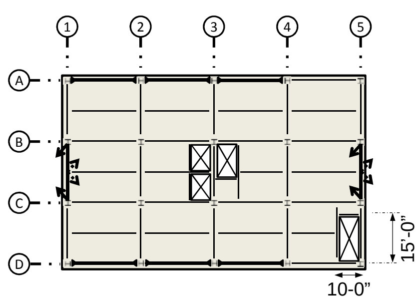
Horizontal irregularity: Re-entrant corner



10'x15' opening at corner

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

ASCE 7 Table 12.3-1

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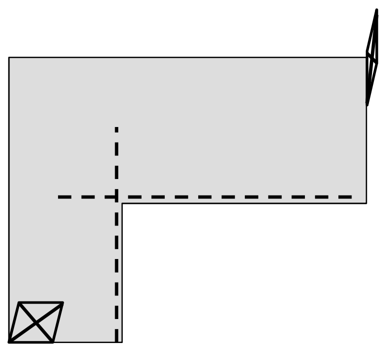
Horizontal irregularity: Re-entrant corner



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

ASCE 7 Table 12.3-1

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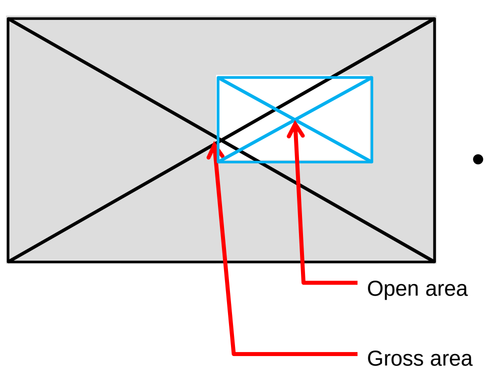
Horizontal irregularity: Diaphragm discontinuity



Open area ≤ 0.5 Gross area

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

ASCE 7 Table 12.3-1

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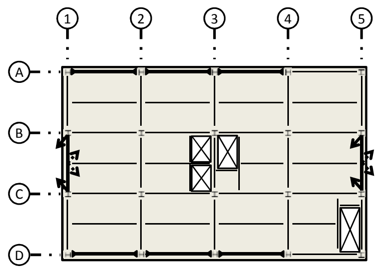
Horizontal irregularity: Diaphragm discontinuity



20'x25' opening at center

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

ASCE 7 Table 12.3-1

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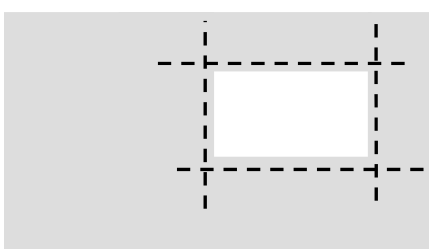
Horizontal irregularity: Diaphragm discontinuity



- Control strategies
  - o Provide strong ties

ASCE 7 Table 12.3-1

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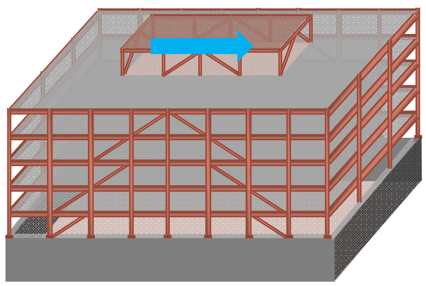
Horizontal irregularity: Out-of-plane offset



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

ASCE 7 Table 12.3-1

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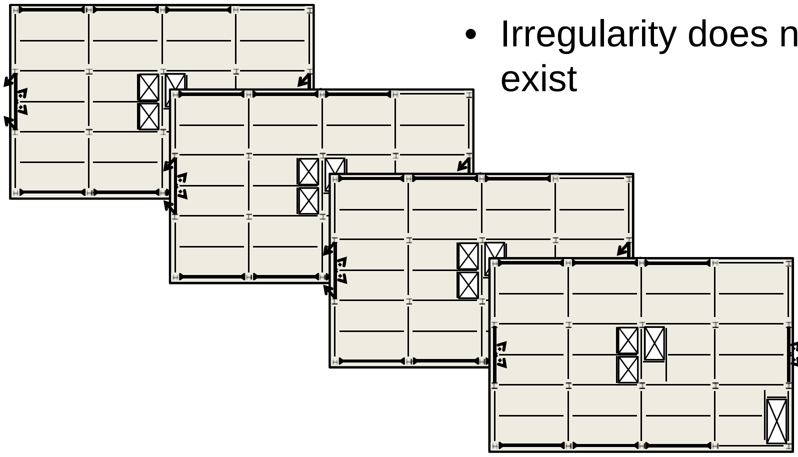
Horizontal irregularity: Out-of-plane offset



- Irregularity does not exist

ASCE 7 Table 12.3-1

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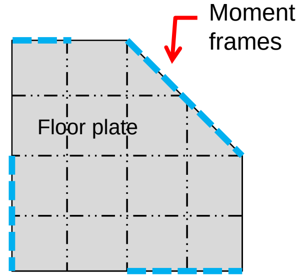
Horizontal irregularity: Non-parallel systems



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

ASCE 7 Table 12.3-1

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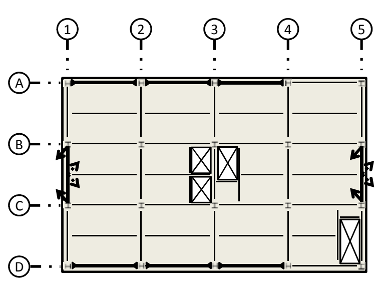
Horizontal irregularity: Non-parallel systems



- Irregularity does not exist

ASCE 7 Table 12.3-1

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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

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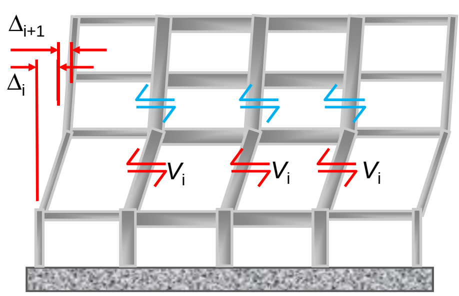
Vertical irregularity: Soft story

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



$K_i = \Sigma\, V_i / \Delta_i$

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

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

ASCE 7 Table 12.3-2

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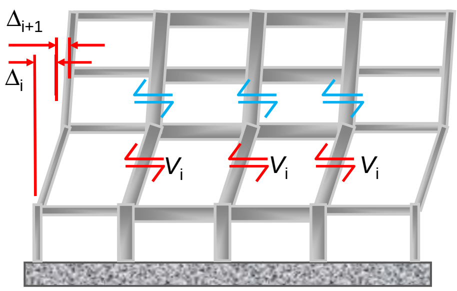
Vertical irregularity: Soft story (extreme)



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

$K_i = \Sigma\, V_i / \Delta_i$

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

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

ASCE 7 Table 12.3-2

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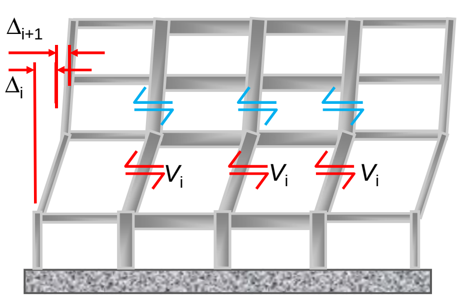
Vertical irregularity: Soft story



$K_i = \Sigma\, V_i / \Delta_i$

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

ASCE 7 Table 12.3-2

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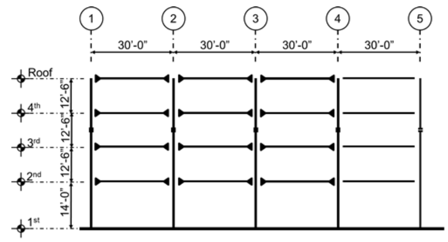
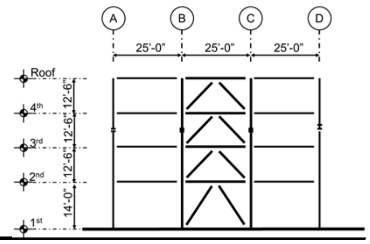
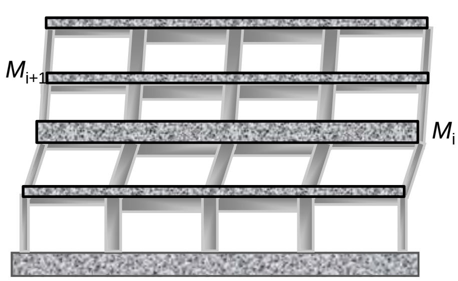
Vertical irregularity: Soft story

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





Vertical irregularity: Mass



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

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

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

ASCE 7 Table 12.3-2

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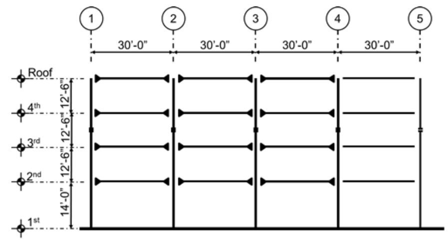
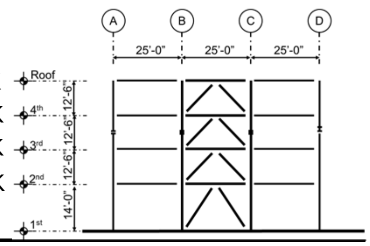
Vertical irregularity: Mass

- Mass irregularity not present



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



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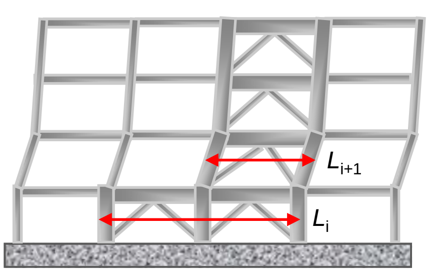
Vertical irregularity: Geometric



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

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

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

ASCE 7 Table 12.3-2

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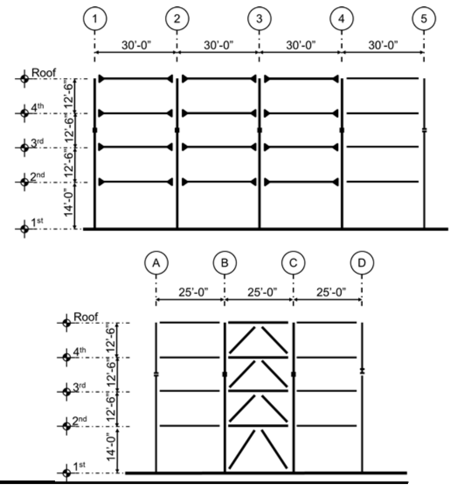
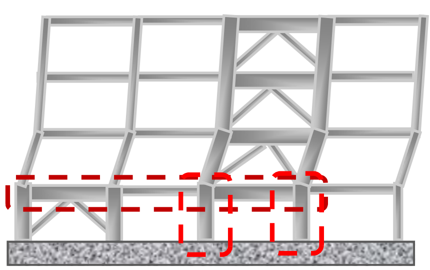
Vertical irregularity: Geometric

- Geometric irregularity not present



Vertical irregularity: In-plane offset



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

ASCE 7 Table 12.3-2

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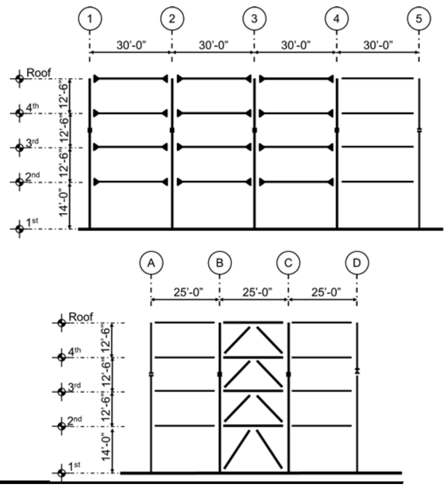
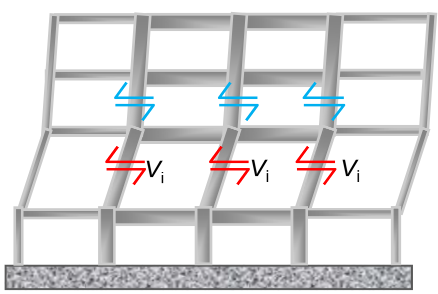
Vertical irregularity: In-plane offset

- In-plane offset irregularity not present



Vertical irregularity: Weak story



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

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

ASCE 7 Table 12.3-2

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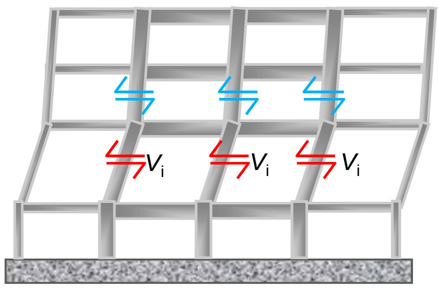
Vertical irregularity: Weak story (extreme)



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

0.65

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

ASCE 7 Table 12.3-2

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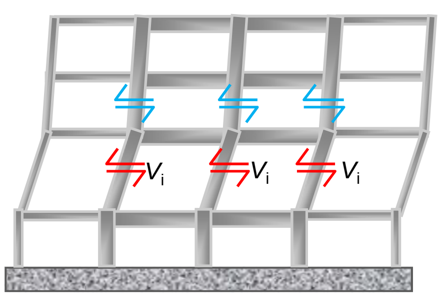
Vertical irregularity: Weak story



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

ASCE 7 Table 12.3-2

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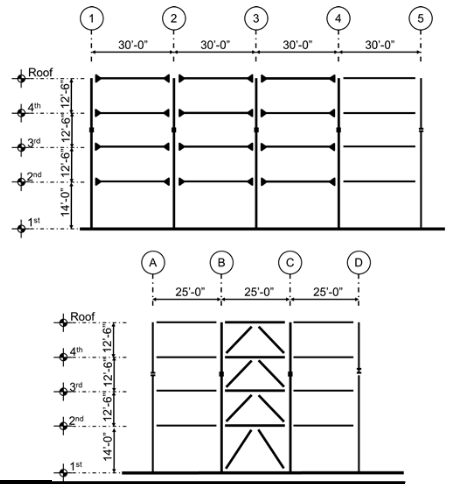
Vertical irregularity: Weak story

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



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Vertical Irregularities

- Soft story *Not present/likely*
- Mass *Not present*
- Geometric *Not present*
- In-plane offset *Not present*
- Weak story *Not present/likely*

ASCE 7 Table 12.3-2

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There's always a solution in steel.

Load combinations

structural STEEL

Load Combinations

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

ASCE 7 §12.4

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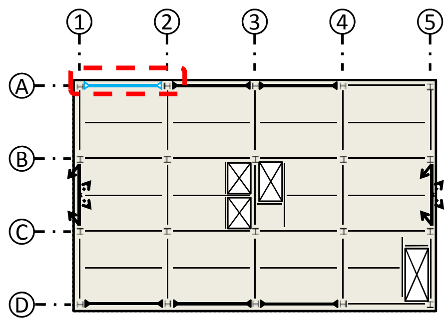
Redundancy factor ρ
SMF

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



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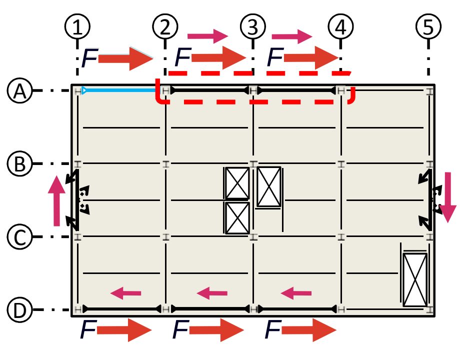
Redundancy factor ρ
SMF (elastic method)

- With all frames:
  - o F=1/6V/frame (0.167V)



- With one frame removed
  - o $T=Ve$
    - e= [3 (37.5')−2 (37.5')]/5 =7.5'
  - o Assume $^{75}/_{(120+75)}$=38.5% T resisted by moment frames
  - o $2F$~ ($^{2}/_{5}V$+0.385T/75') = 0.44V
    - F=0.219V/frame
    - ~32% increase<33%

Inelastic methods also permitted for determining strength loss

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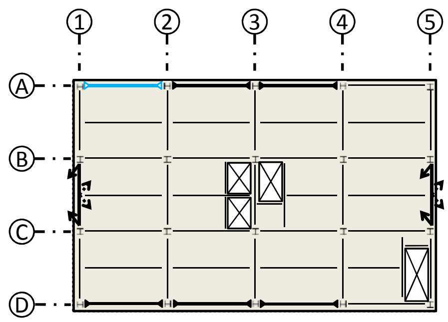
Redundancy factor ρ SMF (elastic method)

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



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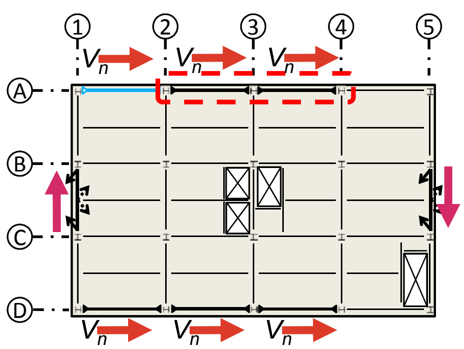
Redundancy factor ρ SMF (inelastic method)

- With all frames:
  - o $V = 6V_n$



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

Inelastic methods also permitted for determining strength loss

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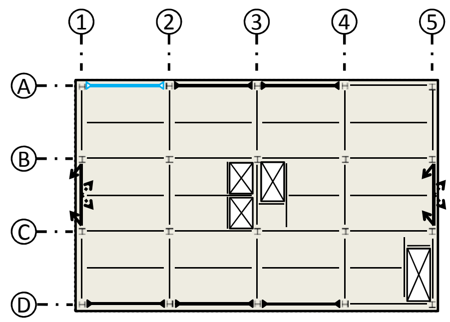
Redundancy factor ρ SMF (inelastic method)

- Lines A & D
  - o $\Delta_D = 3F/3K_{Frame}$
  - o $\Delta_A \geq 2F/2K_{Frame} = \Delta_D$
- Lines 1 & 5
  - o Assume $K_1 = K_5 = K_D$
  - o $\Delta_1 = \Delta_5 = 0.313F/K_D = 0.104\Delta_D$
  - o $\theta_{plan} = 0.104\Delta_D/(½*120')$
- $\Delta_{ave} \geq \Delta_D$
- $\Delta_{max} = \Delta_D + 75'\theta_{plan}$
  - o $\Delta_{max}/\Delta_{ave} \leq 1+0.104(75'/60') = 1.13 < 1.4$ OK



ρ = 1.0

Inelastic methods also permitted for determining strength loss

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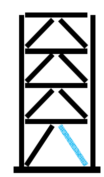
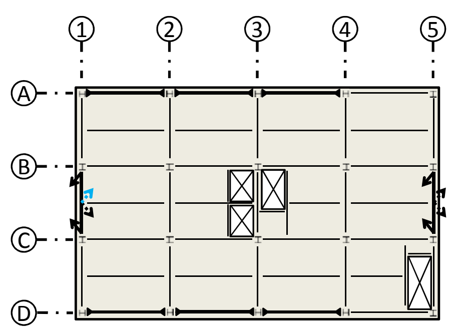
Redundancy factor ρ BRBF

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





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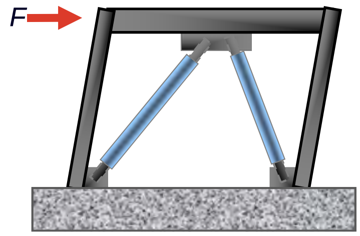
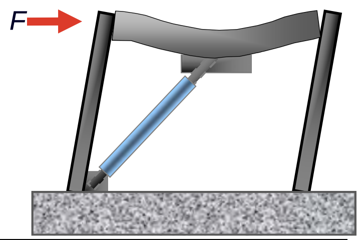
Redundancy factor ρ BRBF

- Original frame
  - o $K_1 \sim 2K_F AE\cos^3\theta/(½L_{bay})$
    $\sim 4K_F AE\cos^3\theta/L_{bay}$
- With one brace removed
  - o $K_2 = 1/(F_{brace} + F_{beam})$
    - $F_{brace} = 2/K_1$
      $= L_{bay}/(2K_F AE\cos^3\theta)$
    - $F_{beam} = \tan^2\theta L_{bay}^3/48EI$
    - $F_{beam} = L_{bay}h^2/12EI$





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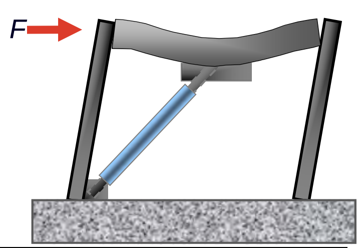
Redundancy factor ρ BRBF

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



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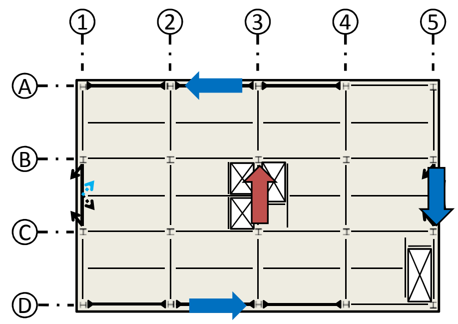
Redundancy factor ρ BRBF

- Line 5
  - o Δ_5=V/K
  - o e=60'
  - o T=Ve
- Lines A & D
  - o V_{frame}=T/75'=0.8V
  - o Δ_{AD}=0.8V/K
  - o θ_{plan}= 2Δ_{AD}/75'
- Line 1
  - o Δ_1 =Δ_5 + θ_{plan} 120'
    = 3.56V/K
  - o $\Delta_{max}/\Delta_{ave}$=3.56/0.8
    = 4.45>>1.4 **ρ = 1.3**



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Overstrength factor Ω_o

Seismic Force Resisting System	Resp. Mod. Coeff., R[a]	Over-strength Factor, Ω_0	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

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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

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Basic Load Combinations (BLC)

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

ASCE 7 §12.4.2

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Overstrength Load Combinations (Ω_oLC)

- 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_oLC)
    - Represents actual overstrength
      - Determined by calculation
    - Ω_oLC 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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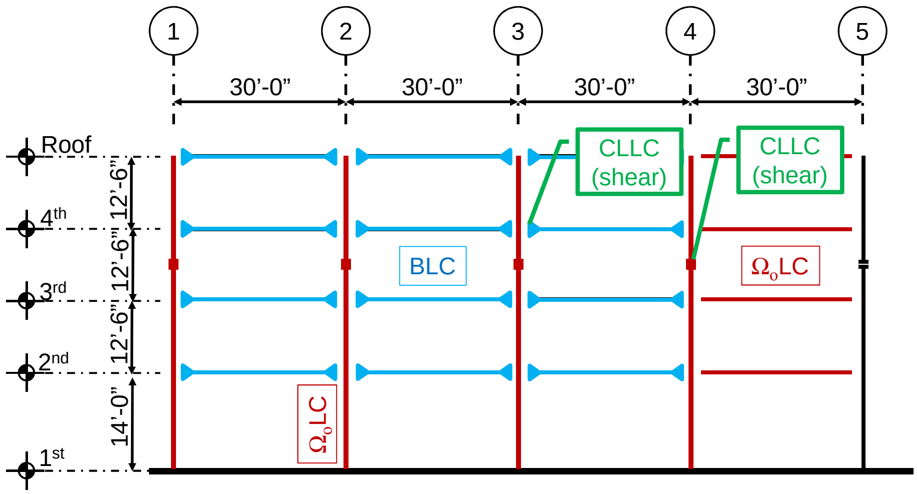
Load Combinations



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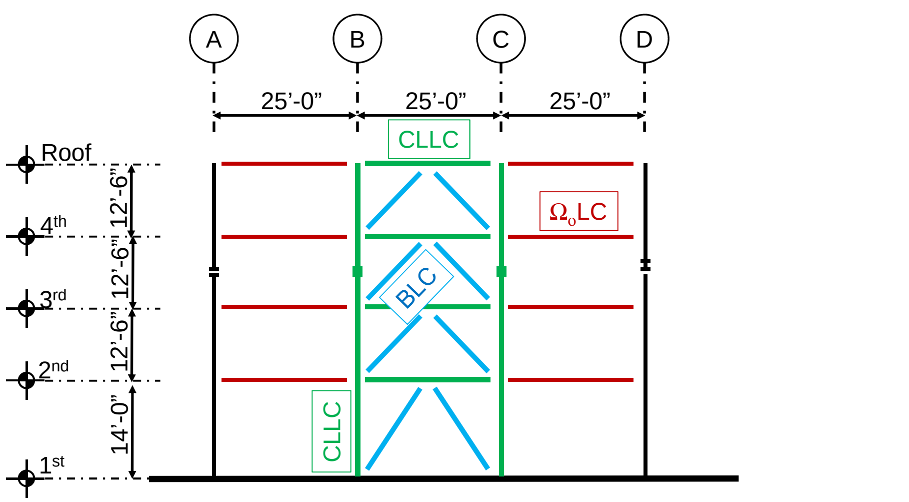
Load Combinations



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Load Combinations

- Drift
  - o $1.0D + 0.5L + E_h$
    - 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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There's always a solution in steel.

Summary

structural
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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There's always a solution in steel.

End of session 5

Next:

Building analysis and diaphragm design

structural STEEL

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There's always a solution in steel.

Question time

structural STEEL

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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

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•EEU – must take all quizzes and final to receive EEU
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•REINFORCEMENT – Reinforce what you learned tonight. Get more out of the course.

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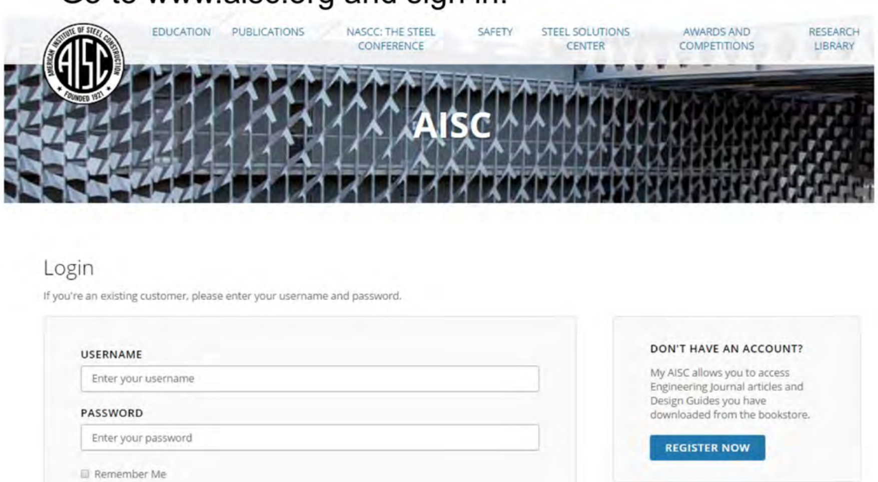

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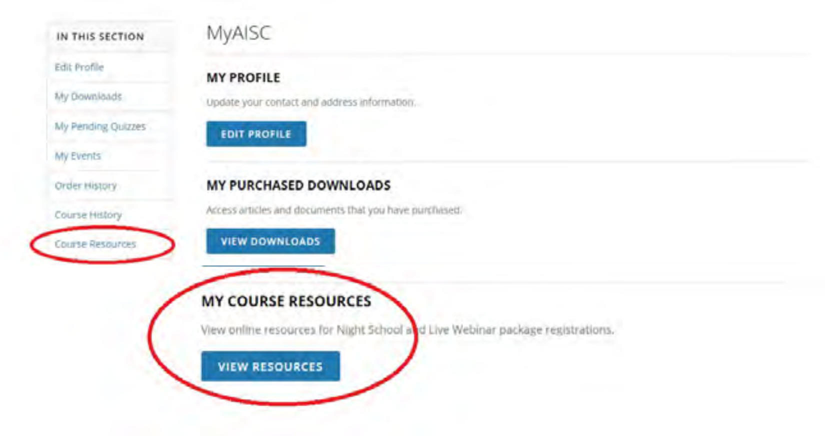

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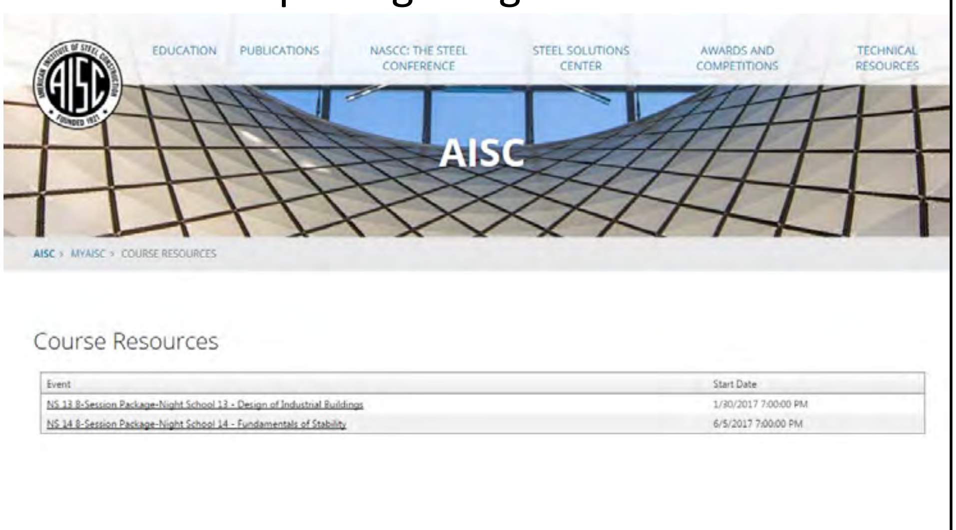

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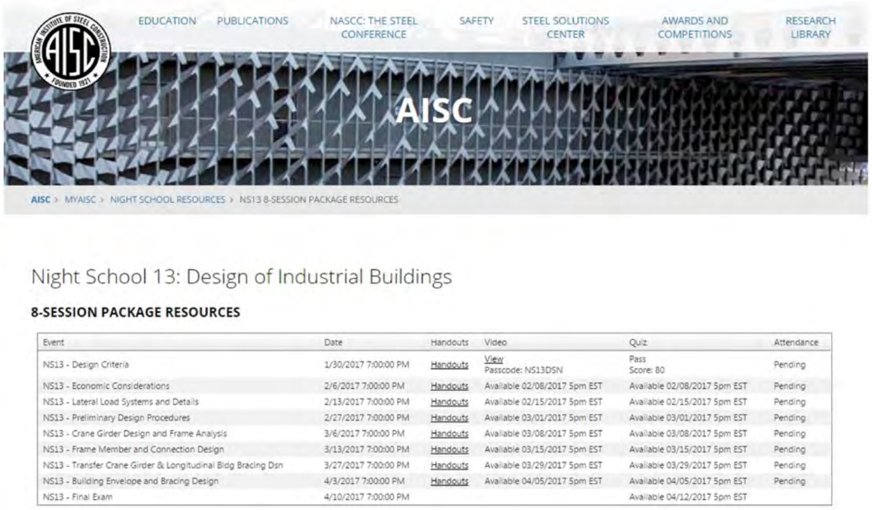
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Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	Handouts	View Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	Handouts	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	Handouts	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	Handouts	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	Handouts	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	Handouts	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dsn	3/27/2017 7:00:00 PM	Handouts	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	Handouts	Available 04/05/2017 5pm EST	Available 04/05/2017 5pm EST	Pending
NS13 - Final Exam	4/10/2017 7:00:00 PM			Available 04/12/2017 5pm EST	

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

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- Link to handouts also found here.

There's always a solution in steel.

Thank You

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

structural STEEL

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