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Fundamentals of earthquake engineering for building structures

Session 8: Building Codes

April 19, 2021 | Rafael Sabelli

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Course Description

Building Codes

April 19, 2021

This session includes a presentation of the formal relationship of codes in the U.S. for building design. The basic concepts employed in code-seismic design, such as seismic design category, maximum considered earthquake, importance factor, etc. will be explained. The lecture will also explain of general analysis and design requirements. There will be a discussion of detailed systems (designed using the AISC *Seismic Provisions*) and non-detailed systems (designed using only the AISC *Specification*). The treatment of wind-vs.-seismic comparison issues for building design will be covered. The session will end with a discussion of future directions in earthquake engineering.

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Learning Objectives

- Understand the codes used in the U.S. for building design.
- List the underlying concepts of ASCE 7.
- List building irregularities that must be considered in seismic design.
- Compare wind-based design vs seismic-based design.

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Fundamentals of earthquake engineering for building structures

Rafael Sabelli, SE
Walter P Moore

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Course outline

1. Seismology and earthquake effects
2. Dynamics and response
3. Building dynamics and response
4. Steel behavior
5. System ductility and seismic design
6. Steel systems
7. Building configuration
8. **Building codes**

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Fundamentals of earthquake engineering for building structures

Session 8: Building Codes
April 19, 2021

Rafael Sabelli, SE
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Session topics

- System of codes
- ASCE 7
- Wind vs. seismic
- Future directions
- Course review

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System of codes

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System of codes

- Local or state code
  - Adopts (or copies from)
- Model code (International Building Code = IBC)
  - Addresses
    - Occupancies
    - Plan review
    - Inspection
  - Adopts
- ASCE 7

System of codes

- ASCE 7
  - Addresses
    - Loads
    - Analysis
    - System limits
  - Adopts
    - AISC 360
      - Specification
    - AISC 341
      - Seismic Provisions
    - ACI 318

System of codes

- AISC 360
  - Addresses
    - Materials
    - Strength of members and connections
    - Analysis
  - Adopts
    - AWS D1.1
      - Structural welding code
    - (AISC 341)

System of codes

- AISC 341
  - Addresses
    - Proportioning
    - Detailing
    - Materials
    - Analysis
  - Adopts
    - AISC 358
      - Prequalified moment connections
    - AWS D1.8
      - Seismic welding supplement

There's always a solution in steel.

ASCE 7

structural STEEL

ASCE 7

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ASCE 7

- Underlying concepts
- Fundamental requirements
- Methodology
  - Seismic Design Category
  - Seismic systems
  - Irregularities
  - Analysis methodology
  - Diaphragms

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ASCE 7: Underlying concepts

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Underlying concepts

- Earthquake demand
  - Risk-targeted Maximum Considered Earthquake (MCE_r)
    - Return period 500-2500 years
    - Given the MCE_r, there should be no more than 10% chance of collapse.
    - MCE_r selected such that typical (new) building designed per ASCE 7 for MCE_r accelerations no more than 1% chance of (earthquake induced) collapse in 50-year period

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Underlying concepts

- Earthquake demand
  - Risk-targeted Maximum Considered Earthquake (MCE_r)
    - Adjusted for local soil conditions
    - Multiplied by 2/3 and divided by R/I_e for design

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Underlying concepts

- Earthquake demand
  - Multiplied by 2/3
    - 2/3 factor should be understood as multiplying R by 1.5
  - Response reduction factor R
    - Represents ductility (R_μ)
    - Also overstrength ("R_o")
  - I_e >1 represents lower permitted ductility demand for higher Risk Category structures

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Underlying concepts

- Risk Category
  - Occupancy
    - Number of people at risk
    - Importance for post-earthquake response and recovery
  - Danger to the public
    - Number of people at risk
  - Importance factors
  - Drift limits

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Risk Categories

Examples

Risk Category I: Shed

Risk Category II: House

Risk Category III: School

Risk Category IV: Hospital

Risk Category IV: Hazardous facility

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Underlying concepts

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life.	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	
Buildings and other structures designated as essential facilities.	
Buildings and other structures, the failure of which could pose a substantial hazard to the community.	
Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	

[a]Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Ri if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 t release of the substances is commensurate with the risk associated with that Risk Category.

Risk Category from Table 1.5-1	Seismic Importance Factor, I_e
I	1.00
II	1.00
III	1.25
IV	1.50

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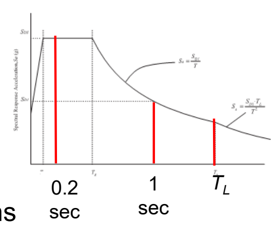
Underlying concepts

- Response spectrum
  - Generalized spectrum
  - Constructed from spectral acceleration at
    - 0.2 sec. period
    - 1.0 sec. period
    - "T_L"
  - Values mapped by USGS
    - Based on stiff soil/rock
    - Adjusted for other conditions



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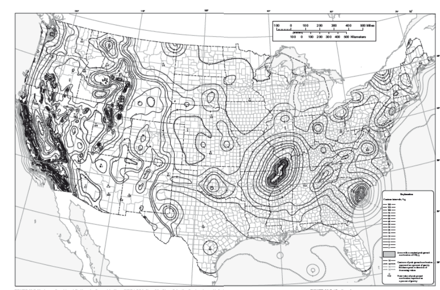
Underlying concepts

- USGS maps
  - Printed maps in ASCE 7
    - Separate maps for
      - Peak Ground Acceleration (PGA)
      - 0.2 sec.
      - 1.0 sec.
      - T_L



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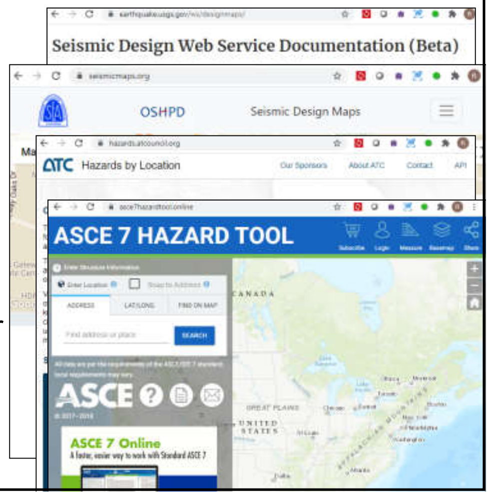
Underlying concepts

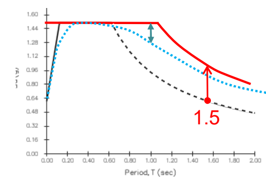
- USGS maps
  - Web applications
    - Same data
    - Read using latitude and longitude
    - Processed for soil type, etc.



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 (Ground Motion Hazard Analysis); not with USGS maps



USGS Mapped values underestimate accelerations for Site Class D with S_1 greater than or equal to 0.2 for some periods

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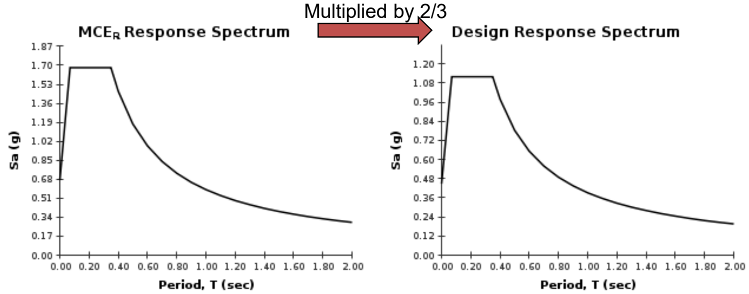
Underlying concepts

- Response spectrum



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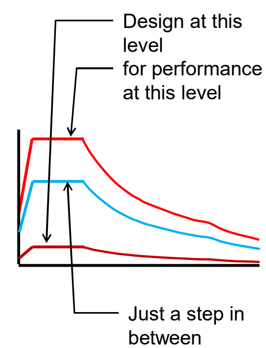
Underlying concepts

- Response spectrum
  - MCE$_r$ Response Spectrum
    - Performance tied to this level
      - ≤10% chance of collapse
  - "Design Response Spectrum"
    - 2/3 MCE$_r$ Response Spectrum
    - No performance defined
    - No design for "Design Response Spectrum"
  - Reduced Response Spectrum
    - 1/*R* * Design Response Spectrum
    - Design at this level



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Fundamental Requirements

- Strength
  - The seismic-load-resisting system must have sufficient strength to limit ductility demands
    - Reduced spectrum used $\dfrac{2/3\, MCE_r}{R/I_e}$
    - System-specific reduction factor *R* implies level of acceptable ductility

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Fundamental Requirements

R factor	Systems
8	Special Moment Frames Eccentrically Braced Frames Buckling-Restrained braced Frames
7	Steel Plate Shear Walls Special Truss Moment Frame
6	Special Concentrically Braced Frames
4.5	Intermediate Moment Frames
3.5	Ordinary Moment Frames
3.25	Ordinary Concentrically Braced Frames
3	Non-detailed braced frames and moment frames
2.5	Special Cantilevered Columns
1.25	Ordinary Cantilevered Columns

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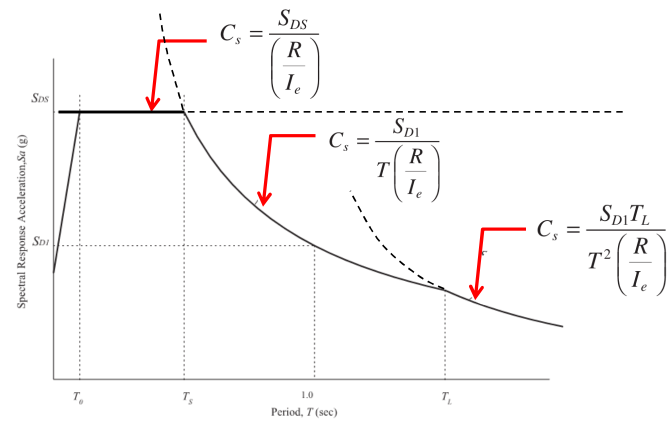
ASCE 7 Base Shear



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Fundamental Requirements

- Strength
  - Period-dependent range
    - $T > T_s$
    - Over-estimate of period results in lower required strength
    - Code imposes maximum period to be used for strength check
      - $T \le C_u T_a$

Design Spectral Response Acceleration Parameter at 1 s, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

$T_a = C_t h_n^{\,x}$

System	C_t	X
SMF	0.028	0.8
EBF & BRBF	0.03	0.75
Other	0.02	0.75

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Fundamental Requirements

- Stiffness
  - The seismic-load-resisting system must have sufficient stiffness to control drift
    - Reduced spectrum used $\frac{{}^{2}/_{3}\,MCE_r}{{}^{R}/_{I_e}}$
    - Amplified by system specific factor C_d
    - Corrected by I_e $\quad {}^{2}/_{3}\,MCE_r \frac{C_d}{R}$

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Fundamental Requirements

- Stiffness
  - C_d/R
    - Theoretically $C_d/R = 1.0$
      - "Equal displacement rule"
    - $C_d/R < 1.0$
      - Reflects traditional design practice
      - Corresponds to drift limits in code
      - Variation in not well supported

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Fundamental Requirements

C_d/R	Systems
0.5	Eccentrically Braced Frames
0.625	Buckling-Restrained braced Frames
0.688	Special Moment Frames
0.786	Special Truss Moment Frame
0.833	Special Concentrically Braced Frames
0.857	Steel Plate Shear Walls Ordinary Moment Frames
0.889	Intermediate Moment Frames
1	Ordinary Concentrically Braced Frames Non-detailed braced frames and moment frames Special Cantilevered Columns Ordinary Cantilevered Columns

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Fundamental Requirements

Mapped MCE$_r$ values	Adjusted for soil type	Multiplied by 2/3	Reduced for strength design	Amplified for drift check
Hazard level		SDC determined at this level	Strength checked at this level	Drift checked at this level
S_S (0.2 sec)	$S_{MS} = F_a S_S$	$S_{DS} = 2/3 S_{MS}$	$V = W^* S_{DS} / [R/I_e]$	$\delta = W^* S_{DS} ^*(C_d/R)/K$
S_{M1} (1.0 sec)	$S_{M1} = F_V S_S$	$S_{D1} = 2/3 S_{M1}$	$V = W^* S_{D1} / (T^*[R/I_e])$	$\delta = W^* S_{D1} ^*(C_d/R)/KT$

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Fundamental Requirements

- Proportioning
  - Critical elements required to be designed for amplified load
    - $E_m = \Omega_o E$
      - Represents system overstrength
      - $1 \le \Omega_o \le 3$
  - Collectors
  - Elements supporting discontinuous frames
  - Other triggers for this in AISC 341

$$\Omega_o \frac{2/3\, MCE_r}{R/I_e}$$

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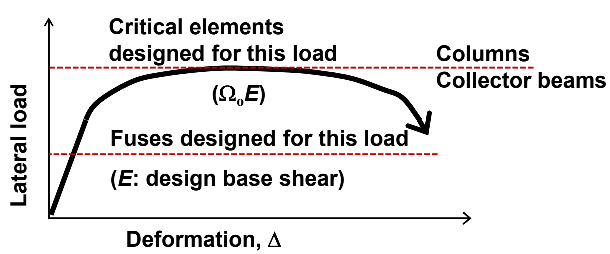
Protected element



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Fundamental Requirements

- Integrity
  - The seismic-load-resisting system must have sufficient integrity to prevent separation of elements and components
    - Tie or anchorage forces are required for all components
    - Deformability is required to accommodate seismic displacements

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Fundamental Requirements

- Stability
- The seismic-load-resisting system must have sufficient strength and stiffness to ensure that second order effects are not too significant
  - A second order check is performed
  - The permissible level of second-order effect can be increased for systems with extra capacity

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} \qquad \theta_{max} = \frac{0.5}{\beta C_d} \leq 0.25$$

where β is the ratio of shear demand to shear capacity

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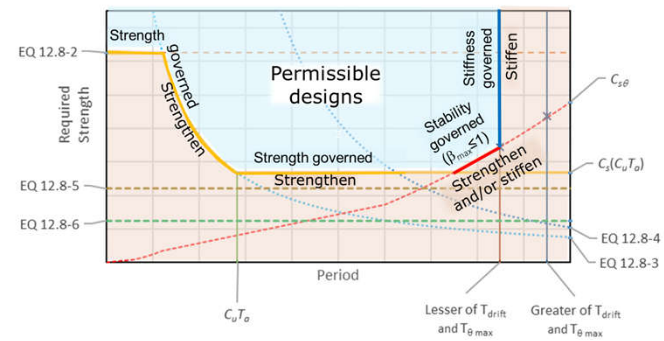
Design Space



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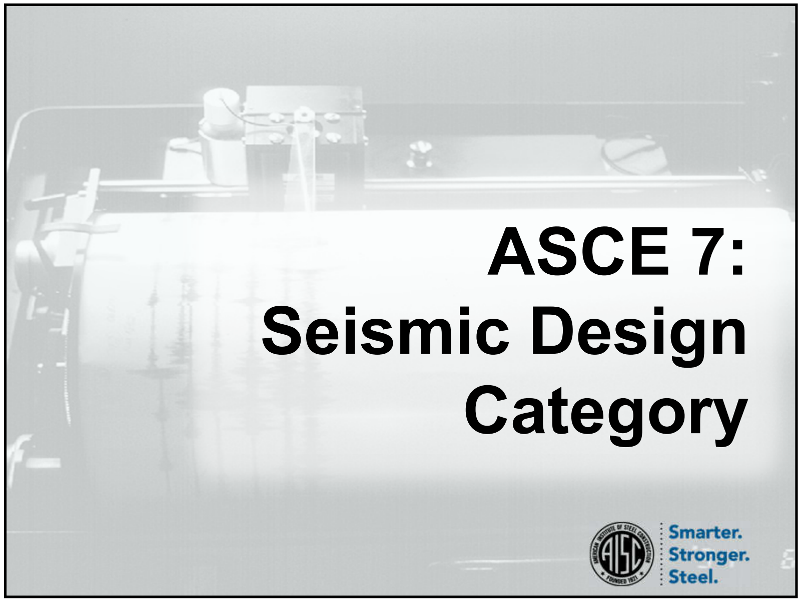

ASCE 7: Seismic Design Category

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Seismic Design Category (SDC)

- Based on
  - Risk category
  - Site seismicity
    - Including soil effects
    - Check for both
      - 0.2 sec response
      - 1.0 sec response
- Affects
  - Permissible systems
  - System height limits
  - Design requirements
  - Analysis requirements
  - Irregularity penalties

	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

- Seismic Design Categories (SDC)
  - SDC A
    - No seismic design
    - Basic system integrity requirements of ASCE 7 (Section 1.4) deemed sufficient
  - SDC B
    - Limits on cantilever-column systems

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Seismic Design Category

- Seismic Design Categories (SDC)
  - SDC C
    - (SDC B requirements)
    - Amplified collector forces
    - Geotechnical investigation required
    - Consideration of bi-directional ground motion for non-parallel systems
    - Special foundation-design requirements

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Seismic Design Category

- Seismic Design Categories (SDC)
  - SDC D
    - (SDC C requirements)
    - Additional geotechnical investigation items required
    - Restriction on system types
    - Lower system height limits
    - Certain irregularities not permitted
    - Certain irregularity penalties

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Seismic Design Category

- Seismic Design Categories (SDC)
  - SDC D
    - Consideration of structural redundancy
    - Vertical seismic forces on cantilevers
    - Special design of columns shared by intersecting frames (corner columns)
    - Limitations on analysis type
    - Consideration of deformation compatibility
    - Additional foundation-design requirements

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Seismic Design Category

- Seismic Design Categories (SDC)
  - SDC E and F
    - (SDC D requirements)
    - Not permitted on active fault rupture location
    - Certain irregularities not permitted

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Seismic Force Resisting System	Resp. Mod. Coeff., R^a	Over-strength Factor, Ω_o	Deflection Amp. Factor, C_d^b	Structural System Limitations Including Structural Height, h_n, Limits in ft[c] — Seismic Design Category				
				B	C	D[d]	E[d]	F[e]
STEEL SYSTEMS								
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)	3¼	2	3¼	NL	NL	35[g]	35[g]	NP[g]
Steel buckling-restrained braced frames (BRBF)	8	2½	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	5½	NL	NL	NL	NL	NL
Steel special truss moment frames (STMF)	7	3	5½	NL	NL	160	100	NP
Steel intermediate moment frames (IMF)	4½	3	4	NL	NL	35[h]	NP[h]	NP[h]
Steel ordinary moment frames (OMF)	3½	3	3	NL	NL	NP[i]	NP[i]	NP[i]
Steel special cantilever column systems (SCCS)	2½	1¼	2½	35	35	35	35	35
Steel ordinary cantilever column systems (OCCS)	1¼	1¼	1¼	35	35	NP[i]	NP[i]	NP[i]
Steel systems not specifically detailed for seismic resistance	3	3	3	NL	NL	NP	NP	NP

Irregularities

- Horizontal (plan)
  - Torsional
  - Re-entrant corner
  - Diaphragm discontinuity
  - Out-of-plane offset
  - Non-parallel systems
- Vertical (elevation)
  - Soft story
  - Mass
  - Geometric
  - In-plane offset
  - Weak story

Basis
Addressed by
(other penalties/consequences)
Control strategies

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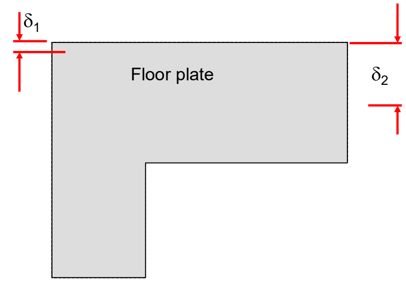
Horizontal irregularity: Torsional



$\delta_2 \leq 1.2[\frac{1}{2}(\delta_1 + \delta_2)]$

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

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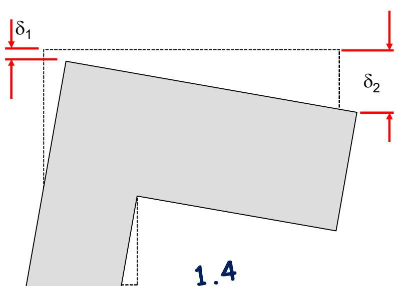
Horizontal irregularity: Torsional (extreme)



$\delta_2 \leq$ ~~1.2~~ 1.4 $[\frac{1}{2}(\delta_1 + \delta_2)]$

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

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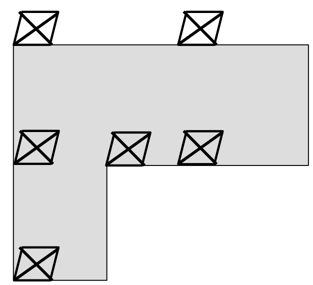
Horizontal irregularity: Torsional



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

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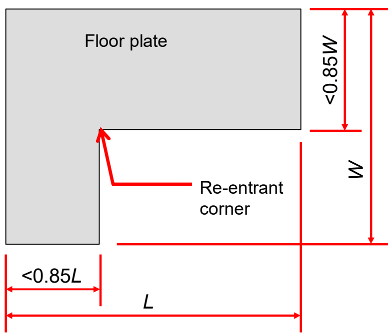
Horizontal irregularity: Re-entrant corner



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

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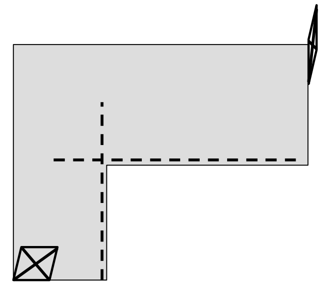
Horizontal irregularity: Re-entrant corner



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

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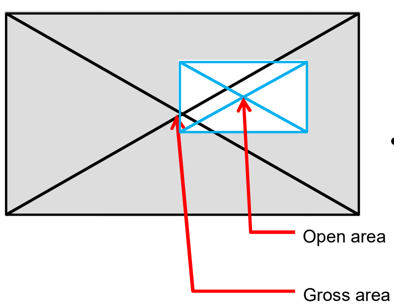
Horizontal irregularity: Diaphragm discontinuity



Open area ≤ 0.5 Gross area

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

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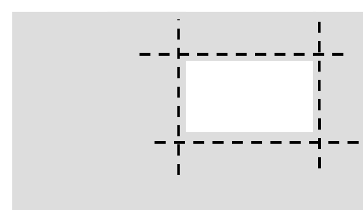
Horizontal irregularity: Diaphragm discontinuity



- Control strategies
  - Provide strong ties

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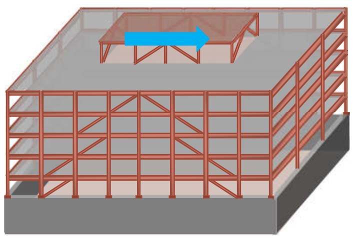
Horizontal irregularity: Out-of-plane offset



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

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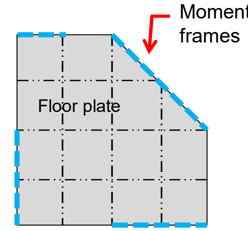
Horizontal irregularity: Non-parallel systems



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

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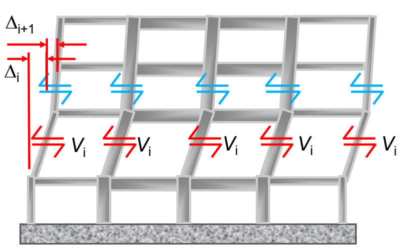
Vertical irregularity: Soft story



- Basis
  - Static analysis may miss higher shears at soft stories
- Addressed by
  - Requiring dynamic (modal) analysis for certain buildings

$K_i = \Sigma V_i / \Delta_i$ $K_i \leq 0.7\, K_{i+1}$

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

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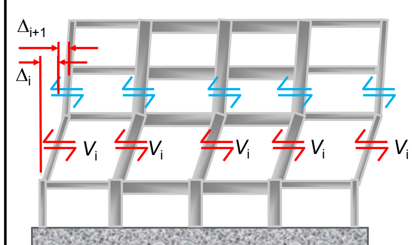
Vertical irregularity: Soft story (extreme)



- Basis
  - Static analysis may miss higher shears at soft stories
- Addressed by
  - Requiring dynamic (modal) analysis for certain buildings

$K_i = \Sigma V_i / \Delta_i$ $K_i \leq \mathbf{0.6}\, K_{i+1}$

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

Extreme soft stories are prohibited in SDC E and F

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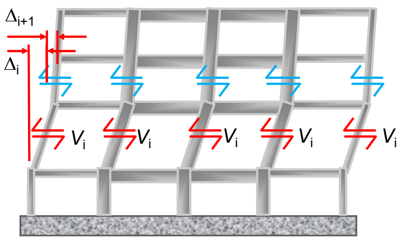
Vertical irregularity: Soft story



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

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

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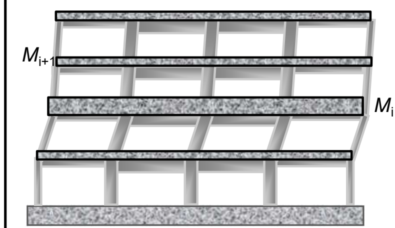
Vertical irregularity: Mass



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

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

- Basis
  - ELF based on first mode; may not be accurate
- Addressed by
  - Requiring dynamic (modal) analysis for certain buildings

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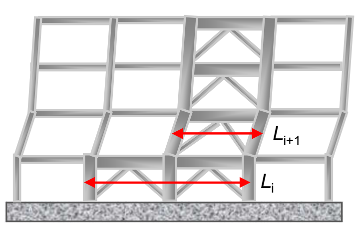
Vertical irregularity: Geometric



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

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

- 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

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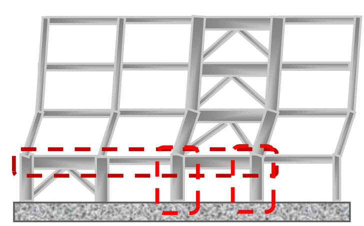
Vertical irregularity: In-plane offset



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

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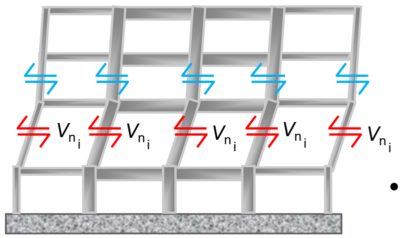
Vertical irregularity: Weak story



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

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

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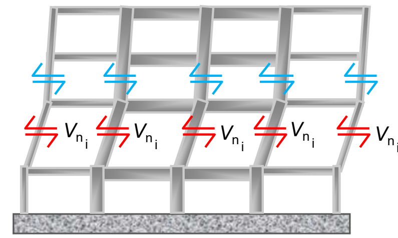
Vertical irregularity: Weak story (extreme)



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

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

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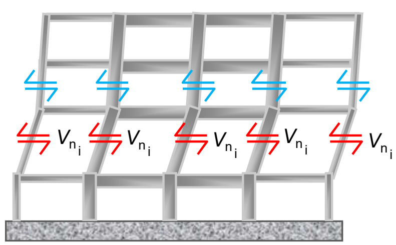
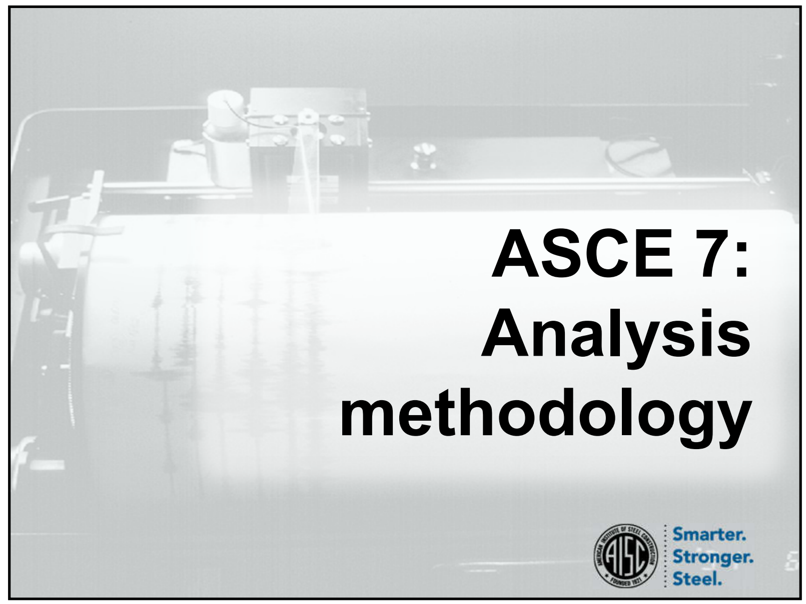
Vertical irregularity: Weak story



- Story strength
  - Braced Frames
    - Brace strength
      - $\Sigma V_n = \Sigma R_n \cos(\theta)$
  - Moment Frames
    - Column shear based on beam strength
      - $\Sigma V_n = \Sigma V_c$
        - Portal frame (Session 6)
        - $V_c = \Sigma[M_{pr}(L/L_h)/h]$

75



Analysis methods

- Equivalent Lateral Force (ELF)
- Modal Response Spectrum Analysis (MRSA)
- Response History Analysis (RHA)

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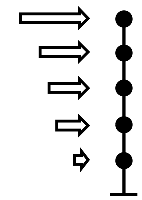
Analysis methods

- Equivalent Lateral Force (ELF)
  - Base shear applied in pattern similar to inverted triangle
    - Captures story shear
    - Captures overturning
    - Supplemental diaphragm forces capture forces at lower stories



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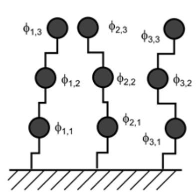
Analysis methods

- Modal Response Spectrum Analysis (MRSA)
  - Base shear scaled to **100%** of ELF base shear
    - Assumed benefit to supposedly more accurate analysis
      - Not borne out in reliability comparisons
    - Tends to exhibit far less overturning



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Analysis methods

- Response History Analysis (RHA)
  - Linear
    - Ground motion histories based on to MCE_r hazard
    - Scaled to match response value for range near fundamental period (T to $1.5T$)
    - Adjusted same as other methods
      - Soil factors
      - 2/3
      - R/I_e
      - C_d/I_e

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Analysis methods

- Response History Analysis (RHA)
  - Nonlinear
    - Ground motion histories based on to MCE_r hazard
    - Scaled to match response value for range near fundamental period (*T* to 1.5*T*)
    - Adjusted by
      - Soil factors

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Analysis methods

- Response History Analysis (RHA)
  - Nonlinear
    - Elements divided
      - “Deformation-controlled”
        - Nonlinear modeling
        - Deformation limits based on
          - » Testing
          - » Other sources (ASCE 41)
      - “Force-controlled”

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Analysis methods

- Response History Analysis (RHA)
  - Nonlinear
    - Elements divided
      - “Force-controlled”
        - Linear modeling
        - Strength per design standard
          - » AISC 360
          - » ACI 318
          - » etc.

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Analysis methods

- Response History Analysis (RHA)
  - Nonlinear
    - Statistics
      - 11+ ground motion pairs
        - Use mean values
        - Factors applied based on element criticality

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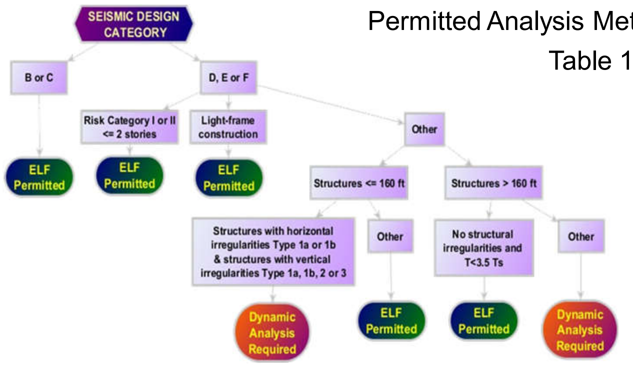
Analysis Methods



Permitted Analysis Methods
Table 12.6-1

85

Analysis methods

- ELF or MRSA or RHA
  - Seismic Design Category B or C
  - Seismic Design Category D, E, or F
    - Light Frame
    - Risk Category I or II buildings ≤ 2 stories
    - Buildings ≤ 160ft
      - Without:
        - Horizontal irregularities 1a or 1b (torsional)
        - Vertical irregularities 1a, 1b, 2, or 3 (soft story, weight, vertical geometric)

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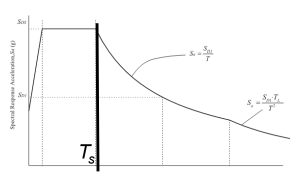
Analysis methods

- ELF or MRSA or RHA
  - Seismic Design Category D, E, or F
    - Buildings > 160ft
      - Without any irregularities, and
      - $T < 3.5T_s$
        - $T_s = S_{D1}/S_{Ds}$



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Analysis methods

- MRSA or RHA (ELF not allowed)
  - Seismic Design Category D, E, or F
    - Buildings ≤ 160ft
      - With:
        - Horizontal irregularities 1a or 1b (torsional), or
        - Vertical irregularities 1a, 1b, 2, or 3 (soft story, weight, vertical geometric)
    - Buildings > 160ft
      - With any irregularity, or
      - $T > 3.5T_s$

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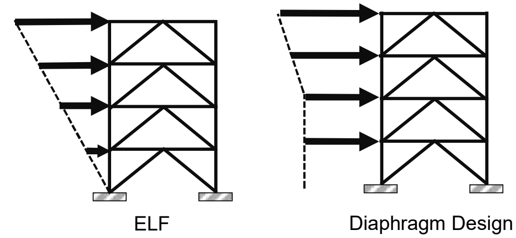
Diaphragm forces

- Vertical force distribution insufficient



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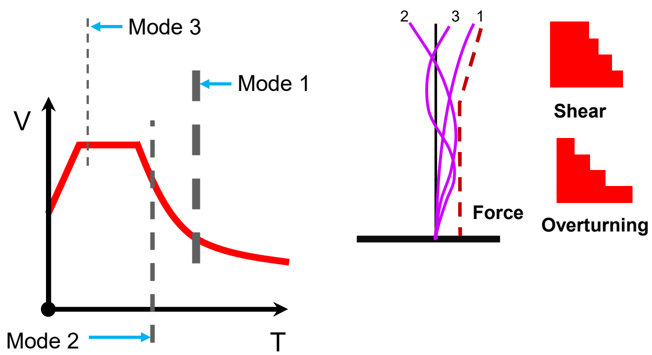
Modal Response



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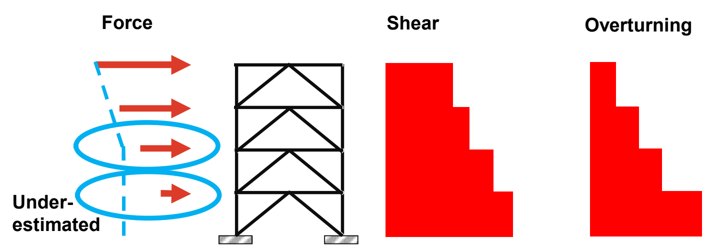
ELF vertical distribution



$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

ASCE 7
Eq. 12.8-12

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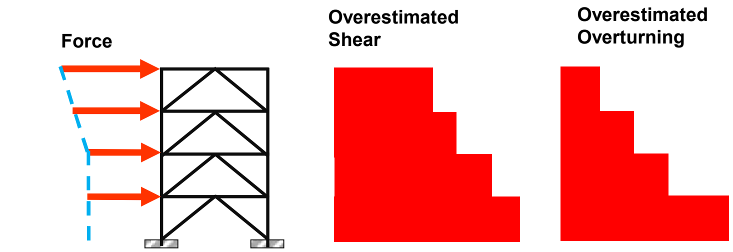
Diaphragm force coefficients



$F_{pi} \leq 0.4 S_{DS} I w_{px}$

$$F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} w_{px}$$

ASCE 7
Eq. 12.10-1

$F_{pi} \geq 0.2 S_{DS} I w_{px}$

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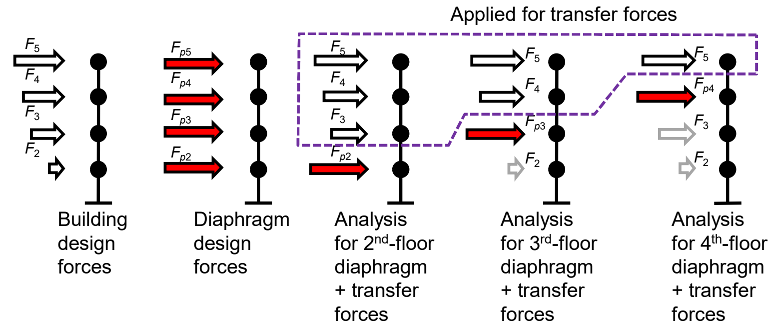
Combining diaphragm and transfer forces



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Wind vs. Seismic

- Compare for:
  - Vertical elements
    - Shear
    - Overturning
      - Often amplified or governed by capacity design
  - Cladding
  - Components

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Wind vs. Seismic

- Comparison
  - 2005
    - LRFD: 1.6 *W* vs. 1.0 *E*
    - ASD: 1.0 *W* vs. 0.7 *E*
    - LRFD somewhat more likely to be wind-controlled
  - 2010, 2016
    - LRFD: 1.0 *W* vs. 1.0 *E*
    - ASD: 0.6 *W* vs. 0.7 *E*

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Wind vs. Seismic

- Vertical elements
  - Compare
    - Base shear
    - Story shear
    - Overturning moment
  - No matter which governs, always check
    - Wind drift (serviceability check)
    - Seismic drift
    - ASCE 7 seismic stability

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Wind vs. Seismic

Base shear comparison is not enough!

Wind

Story forces based on area
Moderate increase with height

Seismic

Story forces based on mass & elevation
Large increase with height
Large overturning
Amplified for column design
and anchorage (AISC 341)

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Future directions

- Performance-based design
  - Nonlinear analysis to address:
    - Ductility demands
    - System response
    - Other parameters (repair cost, downtime, etc.)
  - Less dependence on defined systems
  - Special attention required to address unknowns
    - Earthquake characteristics
    - Material variability (especially soil)
    - Statistical methods to condense data
    - Dealing with some analyzed failures

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Future directions

- Damage-tolerant approach
  - Fuse-type design
    - Damage concentrated in highly ductile elements
  - Self-centering systems
  - Isolation
- Design for multiple hazards
  - Tsunami loading

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Summary

- Design in the US is governed by a system of codes, each with its scope
- ASCE 7 is the principal code for
  - Loads
  - Analysis requirements
  - System limitations
- Performance based design promises freedom from some constraints

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Course review

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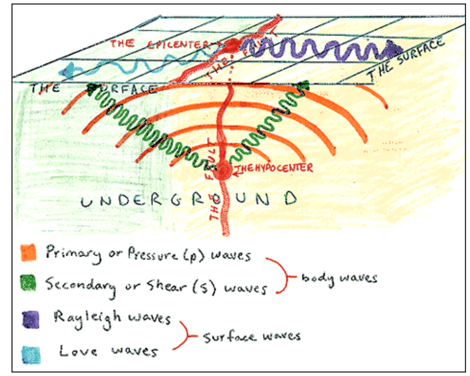
Seismic waves



eGFI teacher resources

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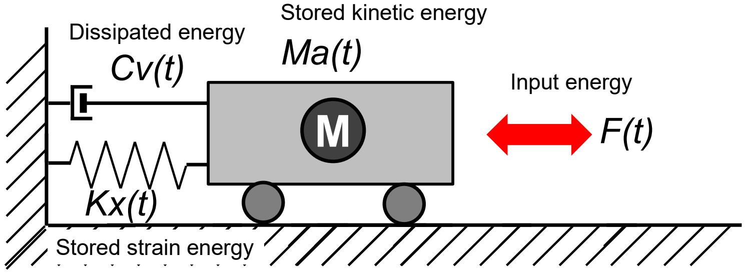
Forces



$$Ma(t)+Cv(t)+Kx(t) = -F(t)$$

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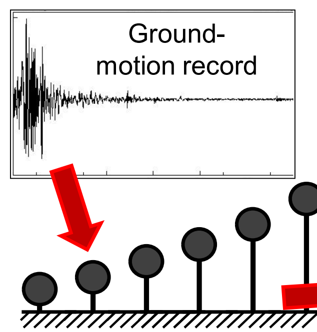
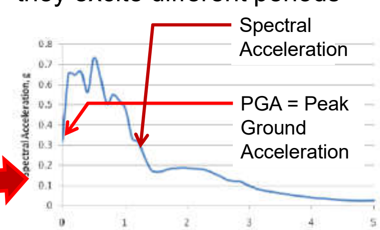
Seismic response spectrum



Earthquake spectra can be characterized by how much they excite different periods



Response spectrum (acceleration)

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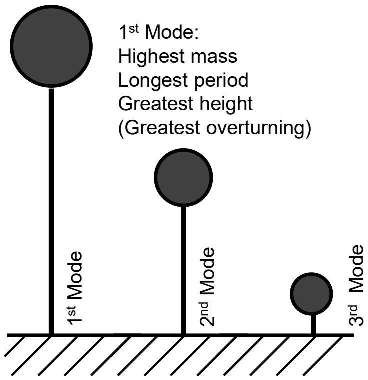
Independent modes



Each mode has:

- Modal mass
- Modal stiffness
- Modal period
- Modal shape (not represented)

Each mode can be represented by single degree-of-freedom [SDOF] model

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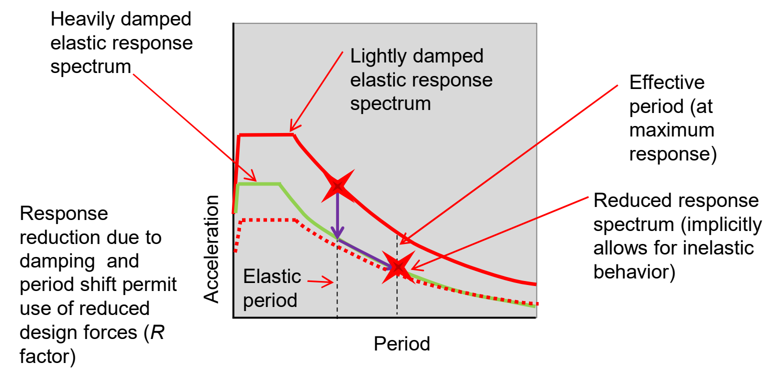
Reduced response



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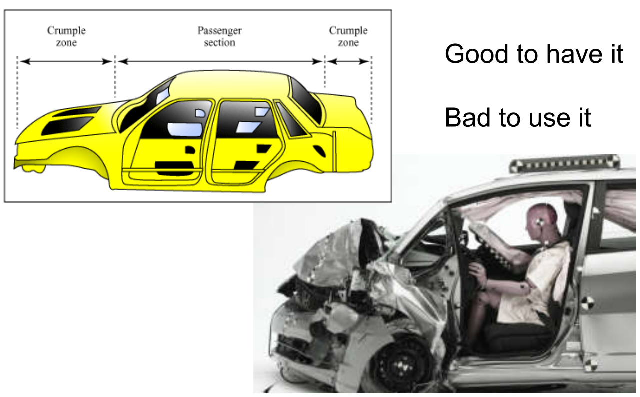
System ductility



Good to have it

Bad to use it

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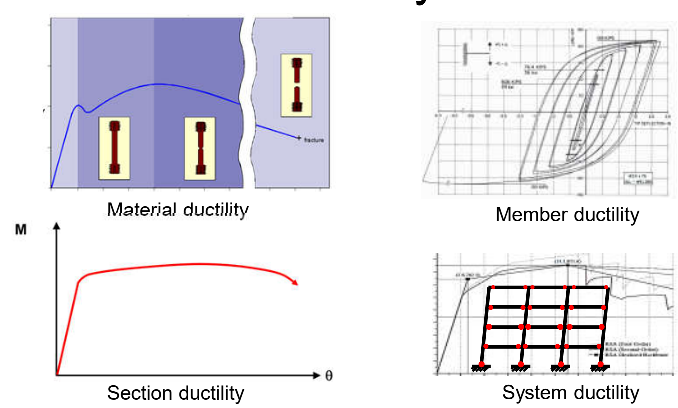
Ductility



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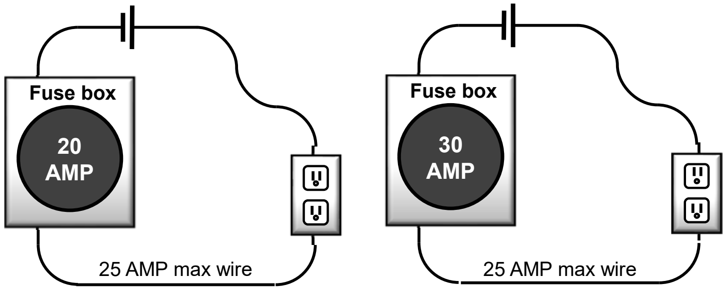
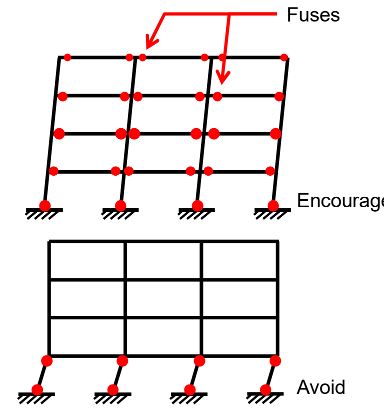
Capacity design (system): Fuse concept



System quality is not only due to strength;
Proportioning is key to good behavior

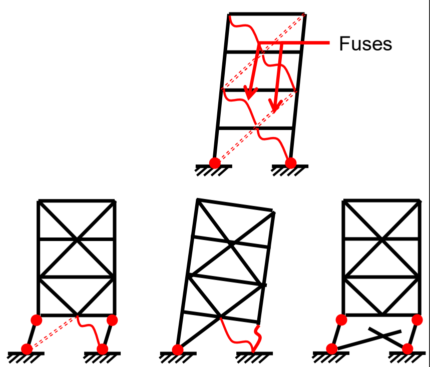
Moment frames

- Encourage
  - Flexural hinging in beams
- Avoid
  - Flexural hinging in columns
    - (occurs at base)
  - Connection failure
  - Excessive column panel-zone yielding



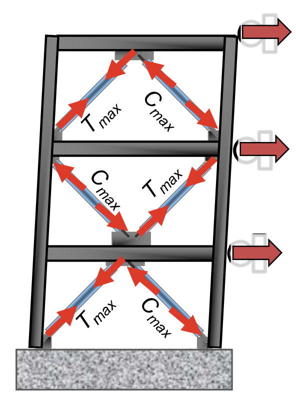
Concentrically braced frames

- Encourage
  - Yielding of braces
  - Buckling of braces
- Avoid
  - Flexural hinging in columns (story mechanisms)
  - Buckling of beams or columns
  - Connection failure



Plastic mechanism analysis

- Apply fuse capacity as load on other members
  - Fuse = total load on brace connections
  - Combine with gravity for
    - Beams
    - Columns



End of session 8

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Parting thought

The ductility of steel (and the methods that translate that into system ductility) provide the means to design safe, reliable structures for seismic loads.

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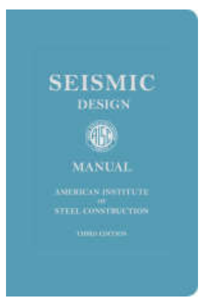
Additional resources



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Question time

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Single-Session Registrants

CEU / PDH Certificates

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

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8-Session Registrants

CEU / PDH Certificates

One certificate will be issued at the conclusion of the course.

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8-Session Registrants

CEU / PDH Certificates

One certificate will be issued at the conclusion of the course.

Quiz 8 issued: April 21, 2021
Final Exam issued: April 26, 2021
Quiz 8 and Final Exam due: May 17, 2021

PDH Certificates and EEU Certificates of Completion will sent by:
May 21, 2021

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8-Session Registrants

Attendance and PDH Certificates

- You have two options to receive credit for a given session.
  - Option 1: Watch the live session. Credit for live attendance will be displayed on the Course Resources table within two days of the session.
  - Option 2: Watch the recording and pass the associated quiz.

Videos and Quizzes

- For each session, find access within two business days after the live air date. (An email will be sent from nightschool@aisc.org.)
- Reasons for quiz:
  - EEU – You must take all quizzes and the final exam to receive EEU.
  - PDHs – If you watch a recorded session, you must pass quiz for PDHs.
  - Reinforce what you learn in the lectures and get more out of the course!

Distribution of Certificates

All certificates will be issued after the course is completed. Only the registrant will receive a certificate for the course.

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Course Resources

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

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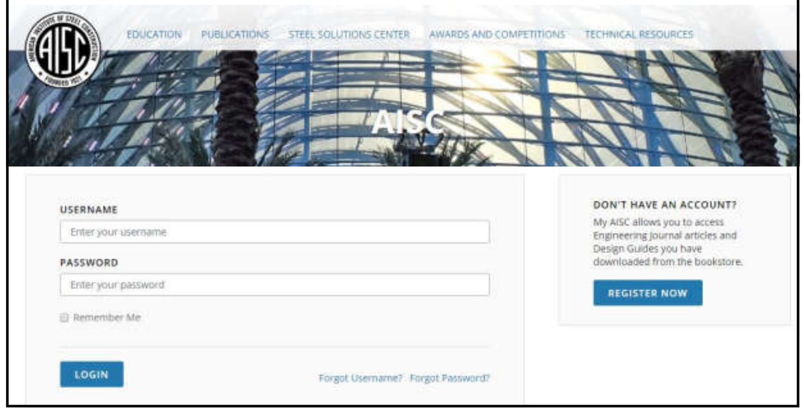
Course Resources

Go to www.aisc.org and sign in.



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Course Resources

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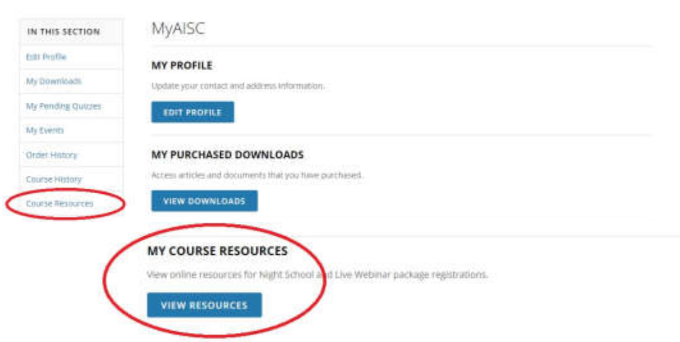

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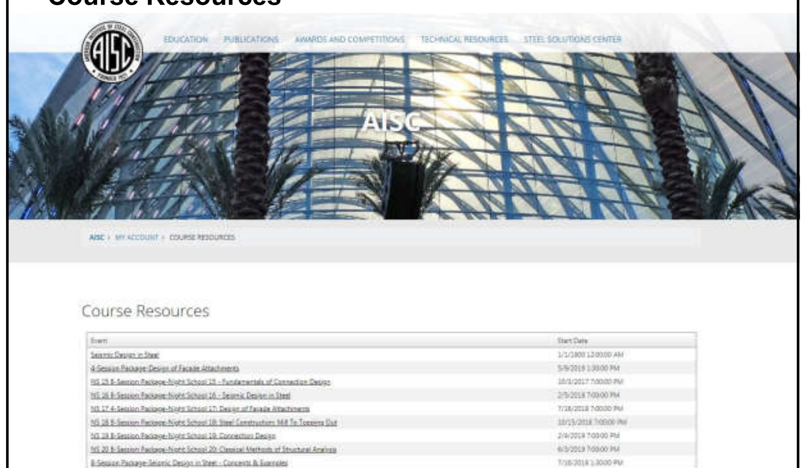
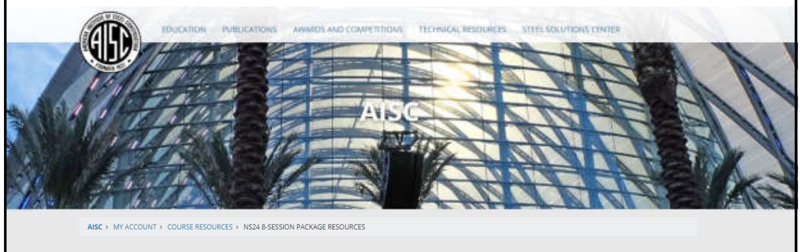
Course Resources



8-Session Registrants

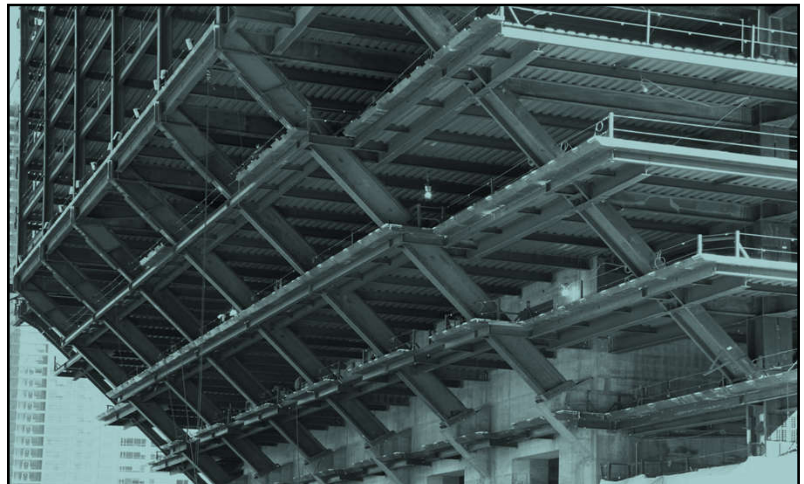
Course Resources



Night School 24: Modern Methods for Learning Structural Stability

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6 2020 7:00PM EDT	Handouts	Available 10/08/2020 5:00PM EDT	Available 10/08/2020 5:00PM EDT	Pending
NS24.2 - Compression Members - Practical Considerations	Oct 13 2020 7:00PM EDT	Handouts	Available 10/15/2020 5:00PM EDT	Available 10/15/2020 5:00PM EDT	Pending
NS24.3 - Behavior of Flexural Members - The Fundamentals	Oct 20 2020 7:00PM EDT	Handouts	Available 10/22/2020 5:00PM EDT	Available 10/22/2020 5:00PM EDT	Pending
NS24.4 - Flexural Members - Practical Considerations	Oct 27 2020 7:00PM EDT	Handouts	Available 10/29/2020 5:00PM EDT	Available 10/29/2020 5:00PM EDT	Pending
NS24.5 - Stability of Beam-Columns - The Fundamentals	Nov 10 2020 7:00PM EST	Handouts	Available 11/12/2020 5:00PM EST	No longer available	Pending
NS24.6 - Stability of Beam-Columns - Practical Consideration	Nov 17 2020 7:00PM EST	Handouts	Available 11/19/2020 5:00PM EST	No longer available	Pending
NS24.7 - Behavior of Structural Systems - The Fundamentals	Dec 1 2020 7:00PM EST	Handouts	Available 12/03/2020 5:00PM EST	No longer available	Pending
NS24.8 - Structural Systems - Practical Considerations	Dec 8 2020 7:00PM EST	Handouts	Available 12/10/2020 5:00PM EST	No longer available	Pending
NS24 - Final Exam	N/A			No longer available	



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AISC | Thank you.