Note: Revisions have been made to Slides 104 and 106 of this handout.

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Course Description

Session 4: Seismic Design of Buildings

March 12, 2018

This session presents the formal relationship of codes in the US and explains the basic concepts employed in code- seismic design, such as seismic design category, maximum considered earthquake, importance factor, etc. General analysis, design requirements and detailed systems (designed using the AISC Seismic Provisions) and non-detailed systems (designed using only the AISC Specification) will be discussed. The session will also review treatment of wind-vs.-seismic comparison issues, diaphragms and deformation compatibility.

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Learning Objectives

- Describe the relationship of local, model and steel codes employed in seismic design.
- Describe the steps per ASCE 7 in which earthquake demand is determined.
- Describe the response modification factor, R, and how and why it differs depending on the seismic force resisting system.
- List the irregularities, both horizontal and vertical, that must be considered in the seismic design of a building.

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Seismic Design in Steel: Concepts and Examples

Session 4: Seismic Design of Buildings

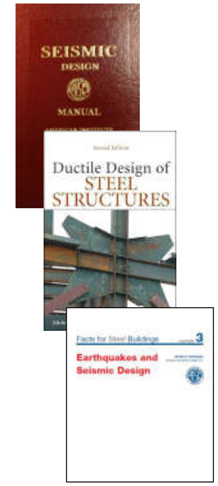
March 12, 2018

Rafael Sabelli, SE

Course objectives

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

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

Other resources

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

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**

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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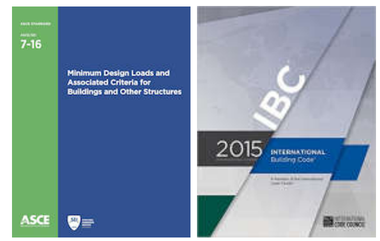
Session 4: Seismic design of buildings



structural STEEL

Session topics

- System of codes
- ASCE 7
- Diaphragms
- Deformation compatibility
- Wind vs. seismic

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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
  - ASCE 7 & IBC Adopt
    - 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

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ASCE 7

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

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ASCE 7:
Underlying concepts

structural STEEL

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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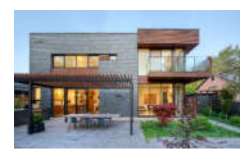
Risk Categories

Risk Category I: Shed

Examples



Risk Category II: House

Risk Category III: School (assembly)

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

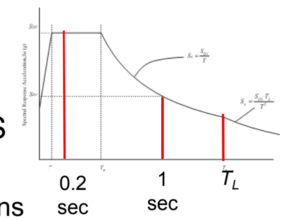
Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. 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.	III
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.	IV

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

Risk Category from Table 1.5-1	Table 12.12-1 Allowable Story Drift, Δ_a	Seismic Importance Factor, I_e
I	0.020h	1.00
II	0.020h	1.00
III	0.015h	1.25
IV	0.010h	1.50

Underlying concepts

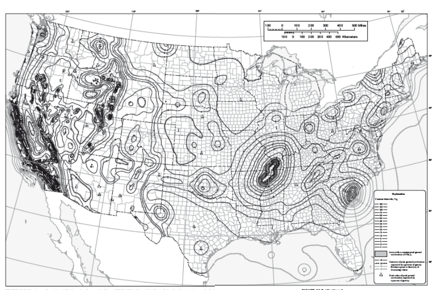
- Response spectrum
  - Generalized spectrum
  - Constructed from spectral acceleration at
    - 0.2 sec. period
    - 1.0 sec. period
    - "T_L"
  - Values mapped by USGS
    - Based on stiff soil/rock
    - Adjusted for other conditions



ASCE 7 §11.4.5

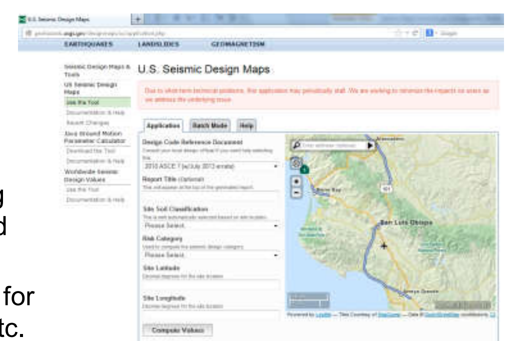
Underlying concepts

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



Underlying concepts

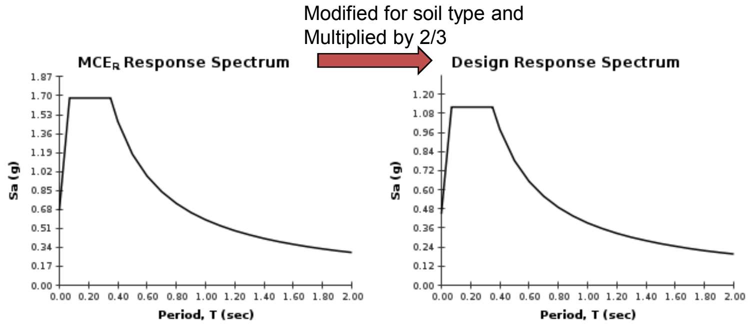
- USGS maps
  - Web application
    - Same data
    - Read using latitude and longitude
    - Processed for soil type, etc.



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

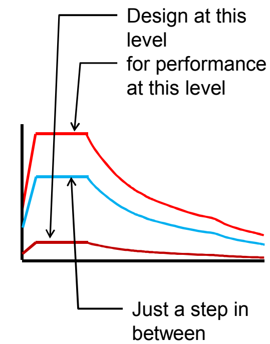
Underlying concepts

- Response spectrum



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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ASCE 7:
Fundamental Requirements

structural STEEL

Fundamental Requirements

- Strength
  - The seismic-load-resisting system must have sufficient strength to limit ductility demands
    - Reduced spectrum used $\frac{{}^{2}/_{3}\, MCE_r}{{}^{R}/_{I_e}}$
      - ⅔ factor is the same as increasing *R* factor 50%
        - *R* originally targeted life safety (475-year return period)
        - 1.5*R* targets collapse prevention (2475-year)
    - System-specific *R* factor implies level of ductility

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

ASCE 7 Table 12.2-1

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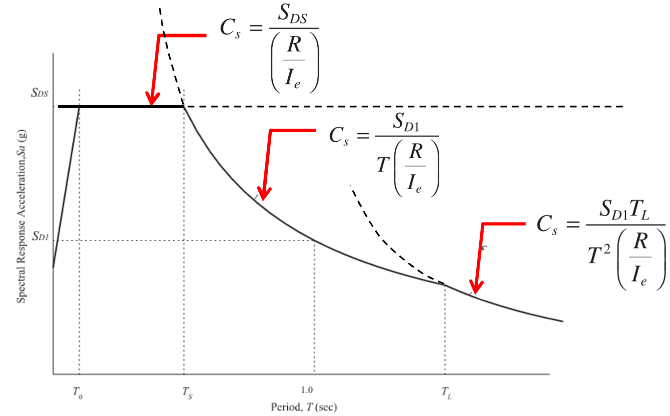
ASCE 7 Base Shear



ASCE 7 §12.8.1

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Fundamental Requirements

- Strength
  - Determine structural period
    - Using approximate methods
      - Approximate period formulae in ASCE 7 §12.8.2.1
      - Based on measured response
        - Includes effects of cladding, partitions, etc.

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

System	C_t	x
Moment Frames	0.028	0.8
EBF & BRBF	0.03	0.75
Other	0.02	0.75

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Fundamental Requirements

- Strength
  - Determine structural period
    - Using building model
      - Period from model
      - Over-estimate of period results in lower required strength
      - Code imposes maximum period to be used for strength k
        - $T \le C_u T_a$

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

ASCE 7 §12.8.2

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Fundamental Requirements

- Stiffness
  - The seismic-load-resisting system must have sufficient stiffness to control drift
    - Reduce damage
    - Prevent instability
    - Reduced spectrum used

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

    - Amplified by system specific factor C_d
    - Corrected by I_e

$$2/3\, MCE_r \frac{C_d}{R}$$

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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

ASCE 7 Table 12.2-1

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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
      - $2 \leq \Omega_o \leq 3$
  - 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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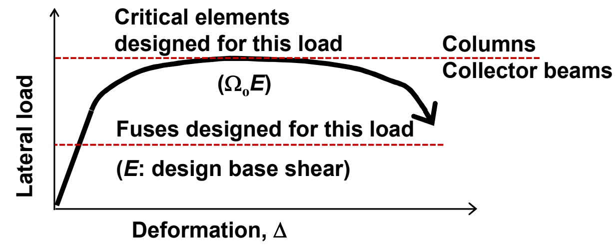
Protected element



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Fundamental Requirements

- Integrity
  - The seismic-load-resisting system must have sufficient integrity to prevent separation 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 limit second order effects
  - A second order check is performed
  - The permissible level can be increased for systems with extra capacity (overstrength)

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

Where β is the ratio of shear demand to shear capacity

ASCE 7 §12.8.7

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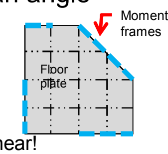
Fundamental Requirements

- Redundancy
  - Factor ρ = 1.0
    - Systems with multiple elements well distributed
  - Factor ρ = 1.3
    - Systems with few elements, poor distribution, or with high torsion
  - Tests
    - Prescriptive check: 2 or more perimeter frames
    - Analysis: remove one member
      - Check torsion and strength

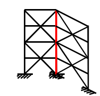
ASCE 7 §12.3.4

Fundamental Requirements

- Direction of loading
  - Seismic ground motions are 3-dimensional
  - Strong accelerations can happen at any plan angle
    - Worst case for skewed frames determined
      - Application of load aligned with frame
      - 100%+30% of results from principal axes
      - SRSS of results from principal axes
      - Orthogonal combination creates 141% of base shear!



  - Intersecting frames have columns affected by each direction of loading
    - Requirements vary by system



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ASCE 7:
Seismic Design Category

structural STEEL

Seismic Design Category (SDC)

- ASCE 7 §11.6
- Based on
  - Risk category
  - Site seismicity
    - Including soil effects
    - Check for
      - 0.2 sec response
      - 1.0 sec response
      - S_1≥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
$0.167 \le S_{DS} < 0.33$	B	C
$0.33 \le S_{DS} < 0.50$	C	D
$0.50 \le S_{DS}$	D	D

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

Seismic Design Category (SDC)

- Affects
  - Permissible systems
  - System height limits
  - Design requirements
  - Analysis requirements
  - Irregularity penalties

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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
    - Restrictions on certain non-steel systems

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Seismic Design Category

- Seismic Design Categories (SDC)
  - SDC C
    - All SDC B requirements
    - More restrictions on non-steel systems
    - Amplified collector forces
    - Geotechnical investigation required
    - Consideration of bi-directional ground motion
    - Special foundation-design requirements

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Seismic Design Category

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

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Seismic Design Category

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

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ASCE 7: Seismic systems

structural STEEL

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

R=3 vs R>3

- R=3
  - AISC 360
    - Design
    - QA/QC
    - Analysis
  - ASCE 7
    - Limits
    - Analysis
    - Overstrength, irregularity, & redundancy
      - By SDC
- R>3 (and cantilever systems)
  - All R=3 requirements
  - AISC 341
    - General requirements
      - Columns
      - Connections
    - System requirements
      - Design/proportioning
      - Detailing
    - QA/QC

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ASCE 7:
Irregularities

structural STEEL

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

Irregularities presented in detail in Session 5

ASCE 7 Table 12.3-1 ASCE 7 Table 12.3-2

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ASCE 7:
Analysis methodology

structural STEEL

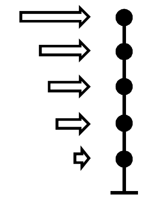
Analysis methods

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

ASCE 7 Table 12.6-1

Analysis methods

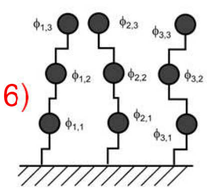
- Equivalent Lateral Force (ELF)
  - Base shear applied in pattern similar to inverted triangle
    - Captures story shear
    - Captures overturning
    - Supplemental diaphragm forces capture forces at lower stories



ASCE 7 §12.8

Analysis methods

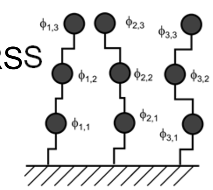
- Modal Response Spectrum Analysis (MRSA)
  - Base shear scaled to 85% ELF base shear (100% in ASCE 7-16)
    - Assumed benefit to supposedly more accurate analysis
      - Not borne out in reliability comparisons
    - Tends to exhibit far less overturning



ASCE 7 §12.9

Analysis methods

- Modal Response Spectrum Analysis (MRSA)
  - Modes are combined using SRSS
    - Signs are lost
    - Static consistency is lost
    - Quantities of interest (e.g., drift) must be tracked mode by mode and combined
      - Difference between maxima is not meaningful



ASCE 7 §12.9

Analysis methods

- Response History Analysis (RHA)
  - Linear analysis
    - Ground motion histories based on 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

ASCE 7 §16

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Analysis methods

- Response History Analysis (RHA)
  - Nonlinear analysis
    - Ground motion histories based on MCE_r hazard
    - Scaled to match response value for range near fundamental period (T to $1.5T$)
    - Adjusted by
      - Soil factors
    - Response
      - Need to establish element nonlinear deformation limits
      - Reduce drift for comparison with code limits

ASCE 7 §16

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Analysis methods

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

ASCE 7 §16

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Analysis methods

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

ASCE 7 §16

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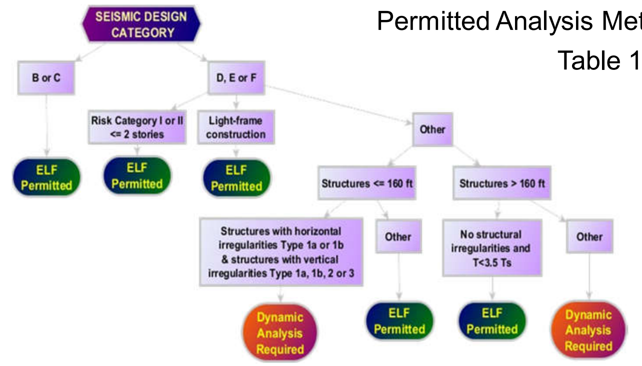
Analysis methods

- Response History Analysis (RHA)
  - ○ Nonlinear analysis
    - Statistics
      - ○ 3-6 ground-motion pairs
        - Use maximum values
      - ○ 7+ ground-motion pairs
        - Use mean values
      - ○ 11 ground-motion pairs required in ASCE 7 16, except
        - » 7 for seismic isolation
        - » 7 for engineered damped systems

ASCE 7 §16

Analysis Methods

Permitted Analysis Methods
Table 12.6-1

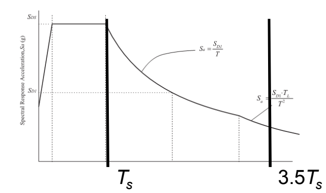


Analysis methods

- ELF or MRSA or RHA
  - ○ Seismic Design Category B or C
    - No restrictions
  - ○ 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)

Analysis methods

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



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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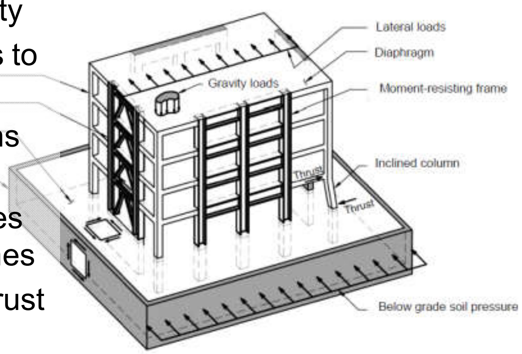
There's always a solution in steel.

ASCE 7: Diaphragms

structural STEEL

Roles of diaphragms

- Support gravity
- Deliver forces to frames
- Brace columns for stability
- Transfer forces between frames
- Resist P-Δ thrust



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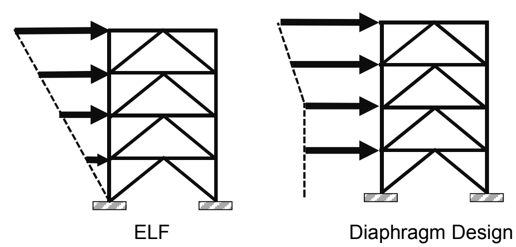
Diaphragm forces

- Vertical force distribution insufficient



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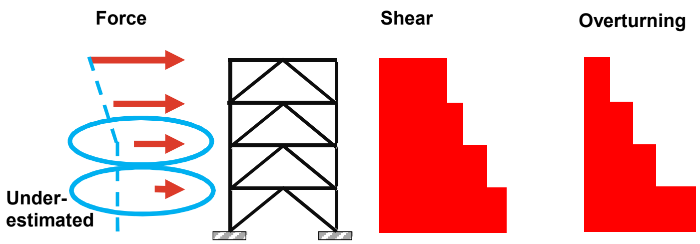
ELF vertical distribution



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

ASCE 7
Eq. 12.8-12

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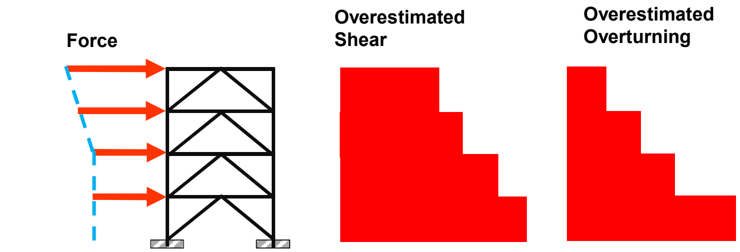
Diaphragm force coefficients



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

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

ASCE 7
Eq. 12.10-1

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

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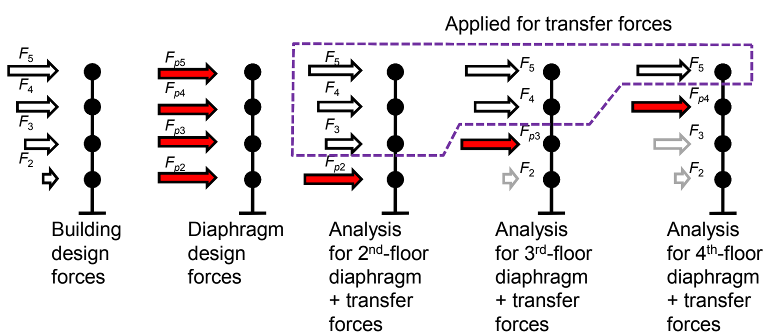
Combining diaphragm and transfer forces



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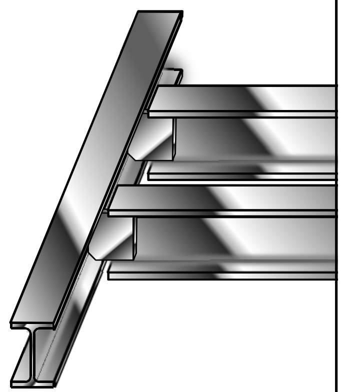
There's always a solution in steel.

Collectors

structural STEEL

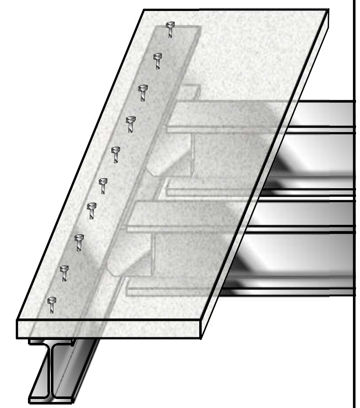
Beam-columns

- Compressive strength
  - $\Omega_o E_h$ (ASCE 7 §12.10.2)
  - Wide-flange with discreet lateral and torsional bracing
    - Major axis flexural buckling
    - Minor-axis flexural buckling
    - Torsional buckling
      - Higher strength than minor-axis FB for same unbraced length

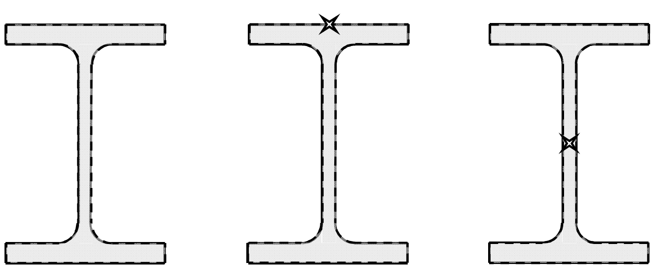


Beam-columns

- Compressive strength
  - Wide-flange with continuous lateral bracing
    - Major axis flexural buckling
    - Constrained-axis flexural-torsional buckling
      - Strength between minor-axis FB and torsional buckling



Constrained-axis flexural-torsional buckling

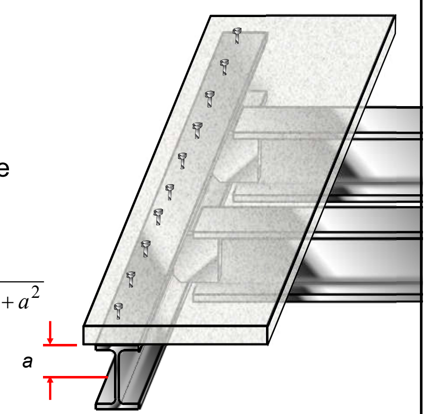


Minor axis flexural buckling (no restraint) | Constrained-axis Flexural-torsional buckling (restraint at top flange) | Torsional buckling (restraint at centroidal axis)

Beam-columns

- Constrained-axis flexural-torsional buckling
  - Use 0.9 P_E to calculate F_{cr}

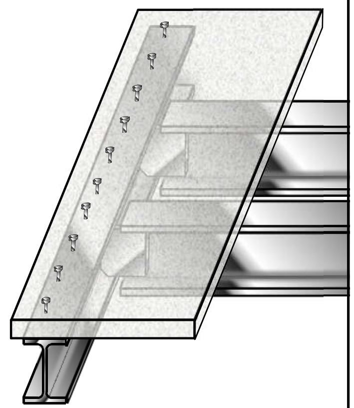
$$P_e = \left[\frac{\pi^2 E\left(C_w + I_y a^2\right)}{(K_z L)^2} + GJ\right]\frac{1}{r_x^2 + r_y^2 + a^2}$$



AISC Seismic Design Manual §8.3

Beam-columns

- Compressive strength
  - Wide-flange with continuous torsional bracing
    - Major axis flexural buckling
    - Required torsional stiffness
      - Slab stiffness
      - Web stiffness



AISC Seismic Design Manual **Table 8-1**

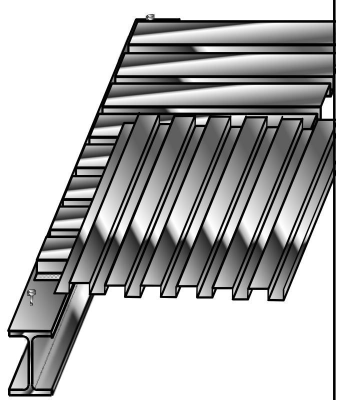
Summary of Unbraced Lengths and Restraint Conditions for Collector Beams

(Compressive Strength)

Condition		Major Axis Flexural Buckling Length	Minor Axis Flexural Buckling Length	Constrained-Axis Flexural-Torsional Buckling Length	Torsional Buckling Length
Steel deck	Ribs parallel to beam	Full length	Between lateral brace points	≤	Between torsiona brace points
	Ribs perpendicular to beam	Full length	Not applicable (continuously braced) ≤	Between torsional brace points	Not applicable
Composite deck or slab		Full length	Not applicable (continuously braced) ≤	Between torsional brace points[1]	Not applicable[1]
Horizontal diagonal bracing		Full length	Between lateral brace points	≤	Between torsiona brace points

Beam-columns

- Flexural strength
  - Composite deck
    - Composite strength
  - Steel deck only
    - Lateral bracing with flutes perpendicular
    - Unbraced with flutes parallel



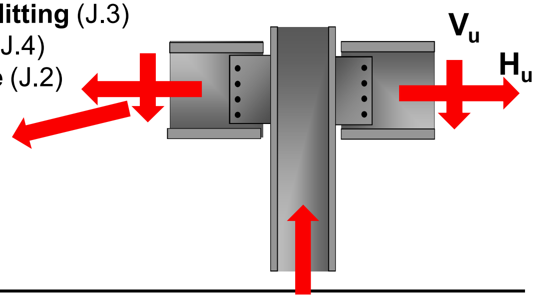
Collector connections

- Gravity
  - Shear forces
- Seismic
  - Axial forces (horizontal)
    - $\Omega_o E_h$
  - Rotation
    - Gravity
    - Lateral drift

Collector connections

Limit States

- **Plate Yield & Rupture** (J.4)
- **Bolt shear** (J.3)
- **Bearing & Splitting** (J.3)
- **Block Shear** (J.4)
- **Weld Rupture** (J.2)



AISC 360 Chapter J

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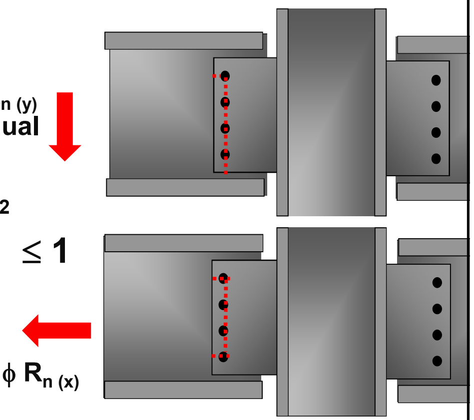
Collector connections

$\phi R_{n\,(y)}$ from Manual

$$\left(\frac{H_u}{\phi R_{n\,(x)}}\right)^2 + \left(\frac{V_u}{\phi R_{n\,(y)}}\right)^2 \leq 1$$

$\phi R_{n\,(x)}$



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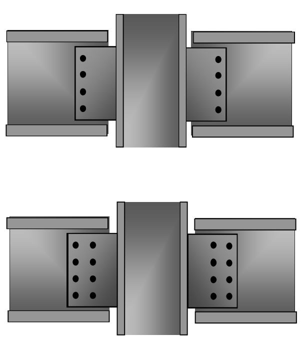
Collector connections



- Rotation
  - Single-plate connection
    - Follow Manual rules
      - Plate thickness
      - Bolt size
      - Spacing
  - Double column of bolts
    - Extended plate method
    - Proportioning rules

AISC Manual Part 10

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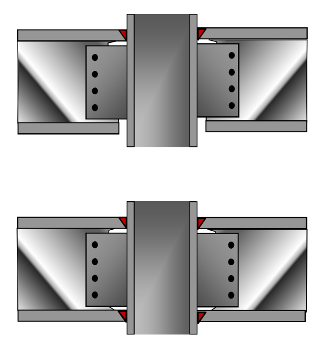
Collector connections



- Rotation
  - Welded top flange
    - Introduces some eccentricity
  - Moment connection
    - Attracts moments
    - May have ductility demands
    - Detail for ductility
      - OMF connection in braced frames

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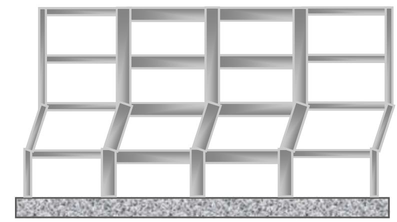
There's always a solution in steel.

Deformation Compatibility

structural STEEL

Necessity

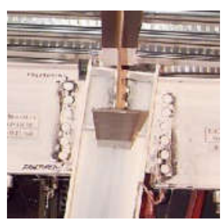
- Inelastic response
  - Large drifts
    - Lateral system
    - Gravity system
- Performance goal
  - Prevent collapse
    - Global
    - Local



ASCE 7 §12.12.5

Gravity connections

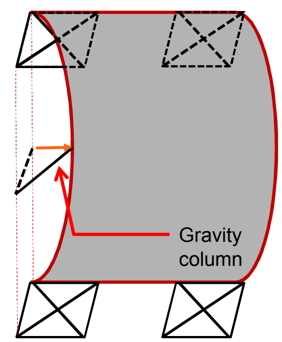
- Connection rotation angle ~ drift angle
- Simple connections in the *Manual* provide inelastic rotation capacity
  - 3% (minimum) for design range
  - Seismic drift assumed to be accommodated
  - No additional justification required



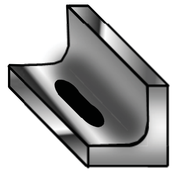
AISC Manual Part 10

Flexible diaphragms

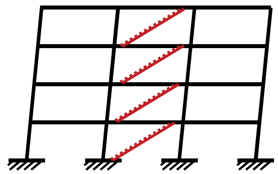
- Diaphragm deformation adds to story drift
- Columns and connections at diaphragm mid-span
  - Increased rotations
  - Increased P-Δ



Stairs

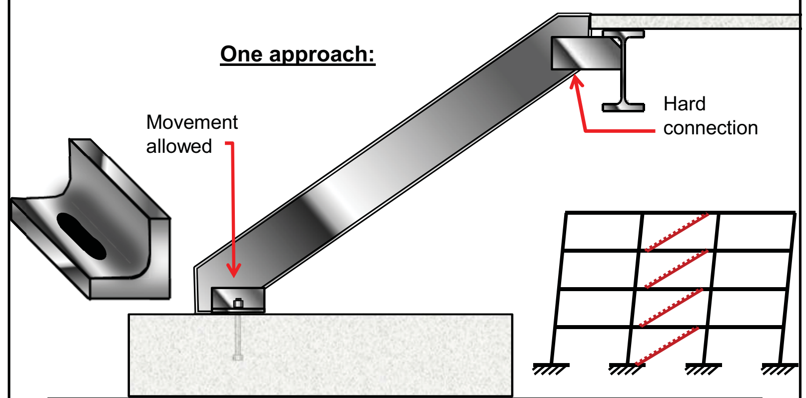


- Act as braces
  - Stiff
- Not ductile
- Continued function necessary
  - I_p=1.5
- Detail to allow movement
  - Maintain gravity support



ASCE 7 §13.1.3

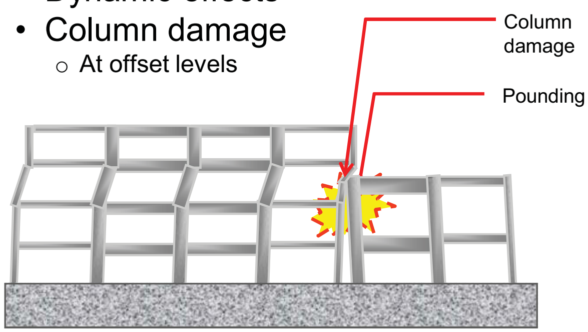
Stairs



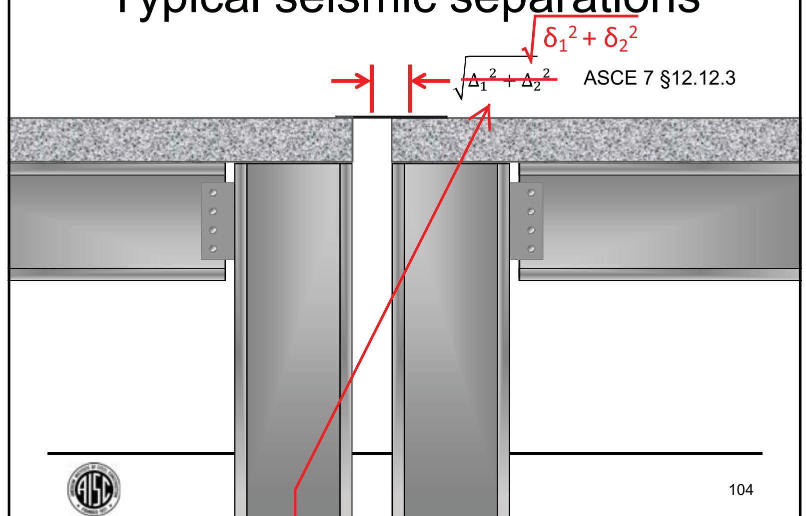
ASCE 7 §12.12.5

Pounding

- Dynamic effects
- Column damage
  - At offset levels



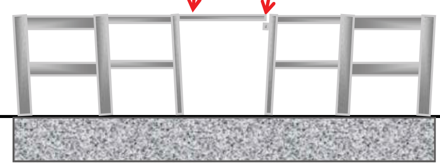
Typical seismic separations



Revision from original to match ASCE 7 notation, clarifying displacement (not story drift) should be used here. (As stated during the lecture.)

Critical support conditions

- High consequence
  - Loss of gravity support
  - Loss of egress
- Treat with extra care
  - Estimate upper-bound displacements
  - Absolute sum, not SRSS



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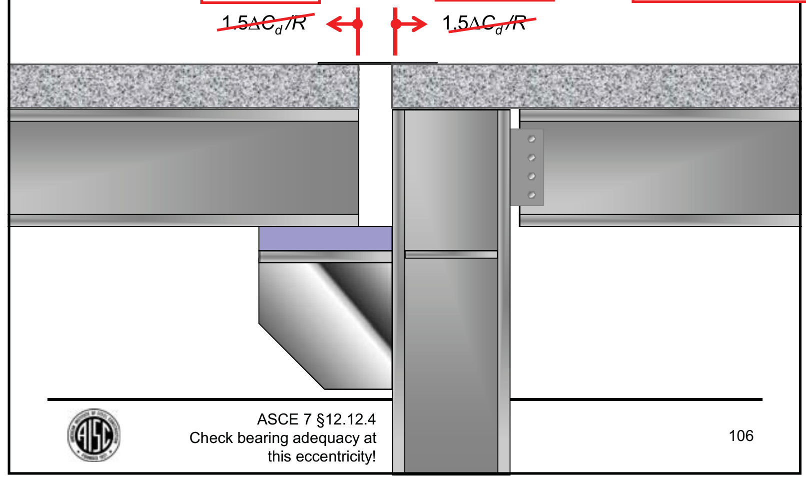
Critical support conditions



ASCE 7 §12.12.4
Check bearing adequacy at this eccentricity!

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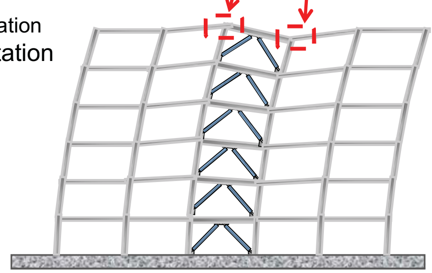
Deformation compatibility

- Shear distortion adjacent to tall frames
  - Due to
    - Lateral drift
    - Column axial deformation
  - May result in large rotation demands



ASCE 7 §12.12.5

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There's always a solution in steel.

Wind vs. seismic

structural STEEL

Wind vs. seismic

- Efficient design
  - Design for governing case
    - Member selection
  - Check for other cases
    - Simplified checks, where possible
- In many cases different loads govern for different portions
  - e.g., light cladding typically wind-governed

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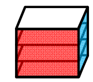
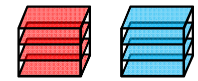
Wind vs. seismic



- Wind
  - Area contributes
  - ~uniform distribution
    - Moderate M_{ot}/V
  - No proportioning requirements
  - Serviceability
  - Strength



- Seismic
  - Mass contributes
    - System dependent
  - Top-heavy distribution
    - High M_{ot}/V
  - Proportioning requirements
    - $\Omega_o M_{ot}$
  - Drift
  - Strength
  - Stability

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Wind vs. seismic

- Compare base shear
  - If wind governs base shear, compare
    - Story shears
    - Overturning moments
      - Including Ω_o, where applicable
  - If seismic governs
    - Compare required seismic and wind stiffness
- Always check
  - Permitted lateral systems
  - Wind serviceability
  - Wind on light cladding, roof screens
  - Seismic on heavy cladding, mechanical units interior components
  - Seismic stability

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Summary

There's always a solution in steel.

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

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There's always a solution in steel.

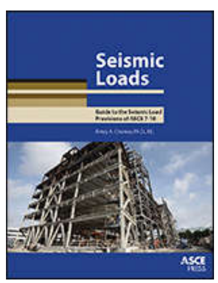
End of session 4

Next:

Planning the seismic design

structural STEEL

Additional resources



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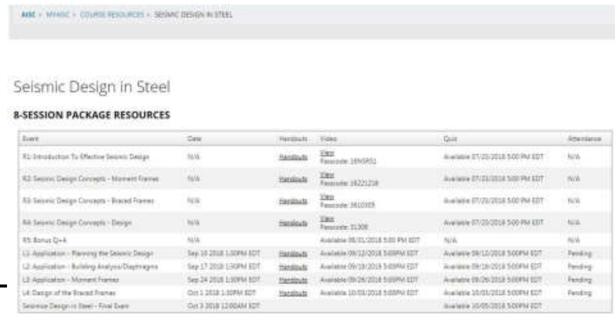
There's always a solution in steel.

Question time

structural STEEL

8-Session Package Registrants
Course Resources

1. Log on to your AISC account and go to Course Resources.
   https://www.aisc.org/myaisc/course-resources/
2. Locate your course.
3. Access handouts, videos, quizzes, quiz scores and attendance records.



AISC > MYAISC > COURSE RESOURCES > SEISMIC DESIGN IN STEEL

Seismic Design in Steel

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
R1: Introduction To Effective Seismic Design	N/A	Handouts	View Passcode: [illegible]	Available 07/23/2018 5:00 PM EDT	N/A
R2: Seismic Design Concepts - Moment Frames	N/A	Handouts	View Passcode: [illegible]	Available 07/23/2018 5:00 PM EDT	N/A
R3: Seismic Design Concepts - Braced Frames	N/A	Handouts	View Passcode: [illegible]	Available 07/23/2018 5:00 PM EDT	N/A
R4: Seismic Design Concepts - Design	N/A	Handouts	View Passcode: [illegible]	Available 07/23/2018 5:00 PM EDT	N/A
R5: Bonus Q+A	N/A		Available 08/31/2018 5:00 PM EDT	N/A	N/A
L1: Application - Planning the Seismic Design	Sep 10 2018 1:30PM EDT	Handouts	Available 09/12/2018 5:00PM EDT	Available 09/12/2018 5:00PM EDT	Pending
L2: Application - Building Analysis/Diaphragms	Sep 17 2018 1:30PM EDT	Handouts	Available 09/19/2018 5:00PM EDT	Available 09/19/2018 5:00PM EDT	Pending
L3: Application - Moment Frames	Sep 24 2018 1:30PM EDT	Handouts	Available 09/26/2018 5:00PM EDT	Available 09/26/2018 5:00PM EDT	Pending
L4: Design of the Braced Frames	Oct 1 2018 1:30PM EDT	Handouts	Available 10/03/2018 5:00PM EDT	Available 10/03/2018 5:00PM EDT	Pending
Seismic Design in Steel - Final Exam	Oct 3 2018 12:00AM EDT			Available 10/05/2018 5:00PM EDT	

8-Session Package Registrants
Videos and Quizzes

Videos
- For Sessions R1 – R4, find access to recordings starting July 16. Recording access expires on October 22.
- Bonus Q&A Session R5 will be available starting August 31.
- For Sessions L1 – L4, find access to recordings within two days after the live air date. Recording access expires three weeks after the live session.

Quizzes
- For Sessions R1 – R4, find access to quizzes starting July 23. Quizzes are due on October 22.
- For Sessions L1 – L4, find access to quizzes within two days after the live air date. Quizzes are due three weeks after the live session.
- A final exam will also be given.
- Quiz scores are displayed in the Course Resources table.

8-Session Package Registrants
Course Credit

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

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

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