Fundamentals of earthquake engineering for building structures

Session 7: Building Configuration

March 29, 2021 | Rafael Sabelli

Smarter. Stronger. Steel.

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Course Description

Building Configuration
March 29, 2021

This Building Configuration lecture will focus on load path and the role and components of diaphragms. There will be a discussion of foundation issues. Irregularities and their treatment in steel frame design will be covered. The session will present the treatment of 3-dimensional analysis issues as well as of modal-response-spectrum analysis issues. The concept of deformation compatibility will be presented. This lecture will also include a discussion of issues related to fixity and rotation demand.

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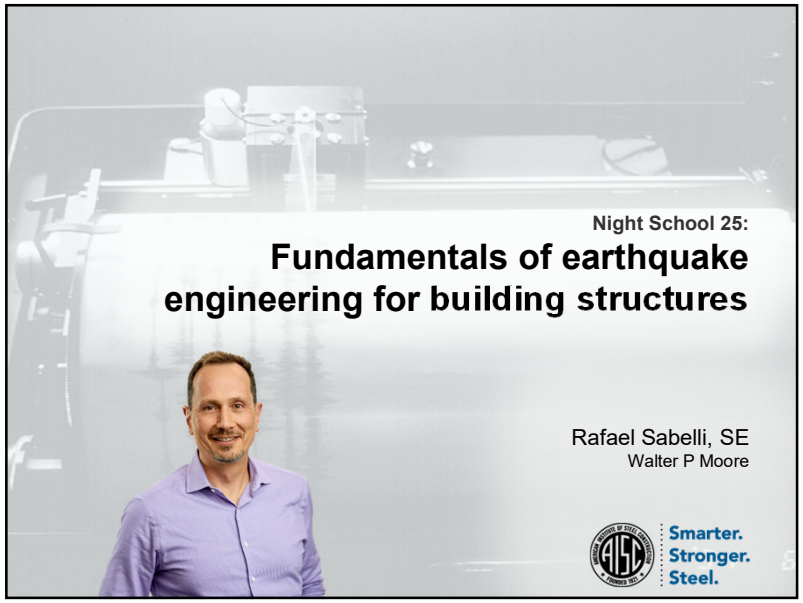
Learning Objectives

- Describe how load path in a building connects point of contact to the point of resistance.
- List potential load path issues in seismic design.
- Describe foundation seismic design for both shallow and deep foundations.
- Explain the role of diaphragms in the load path of buildings.



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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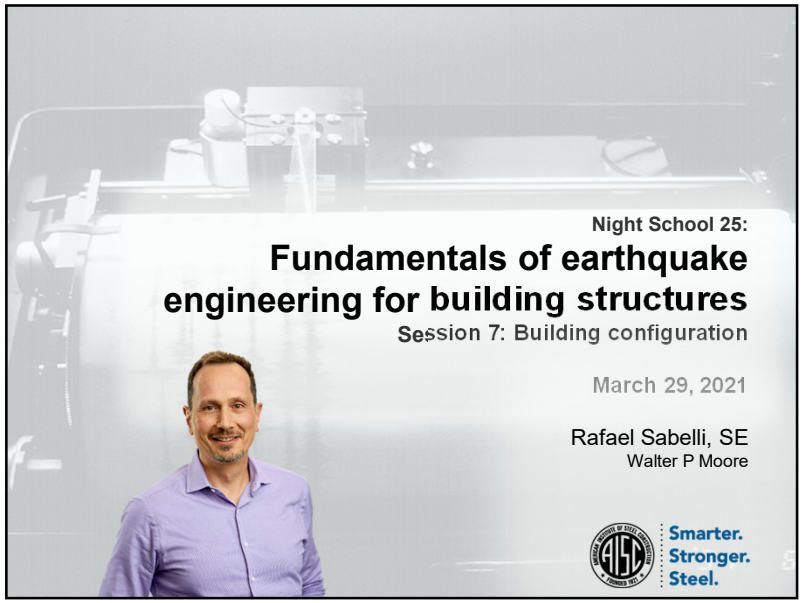

Session topics

- Load path
- Foundations
- Diaphragms
- Collectors
- Deformation compatibility

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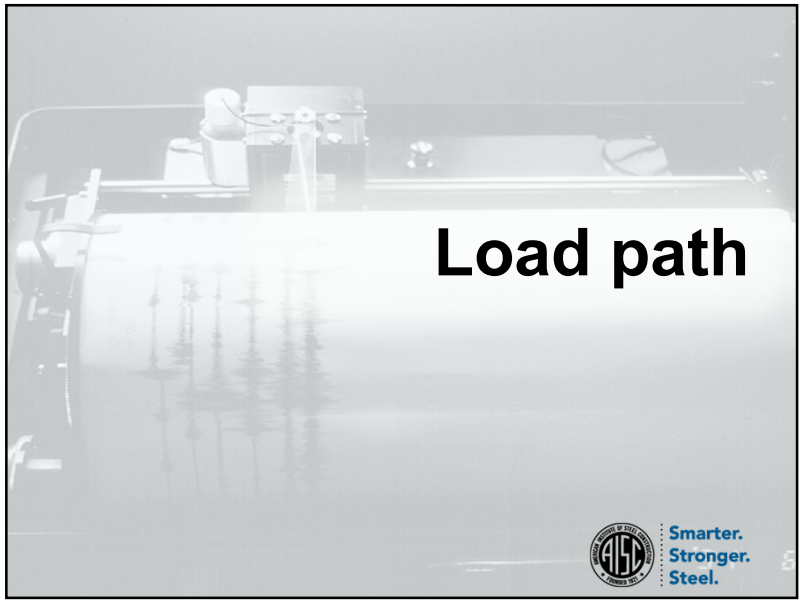
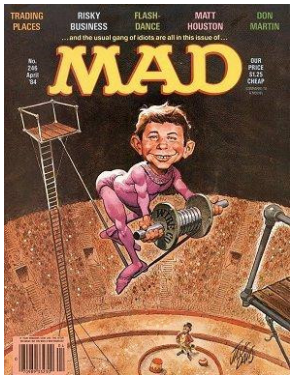


Load path



- Connects “point of application” to “point of resistance”
- In seismic design, every element with mass is considered a point of application
- Foundation is considered point of resistance

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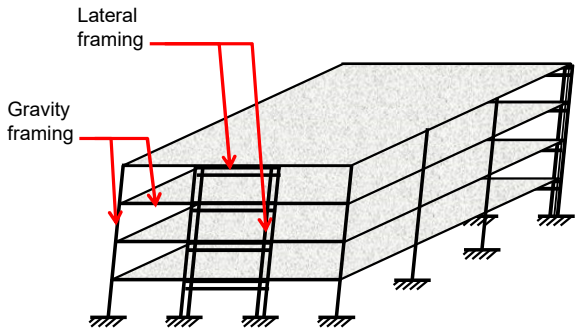
Load path



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Wind vs. seismic loads

- Wind loads
  - External
    - Exposed areas participate
- Seismic loads
  - Inertial
    - All mass participates
- Load path required between mass and foundation

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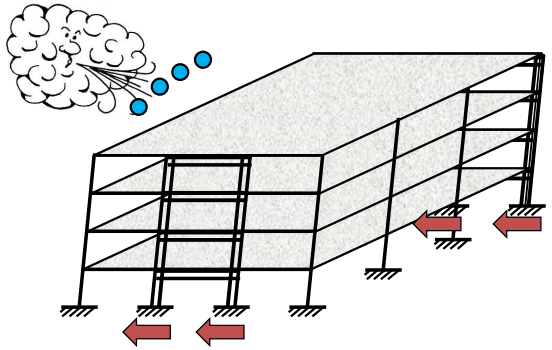
Wind load path



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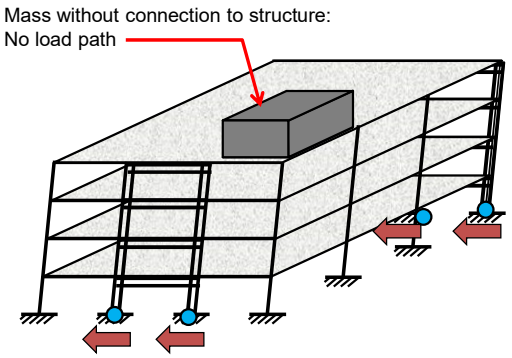
Seismic load path



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Seismic load path

- All masses must have positive connection to seismic-load-resisting system
- Magnitude of connection force due to
  - Ground motion
  - Mass of item
  - Building dynamics (local acceleration)
- Diaphragms contain the majority of typical building mass

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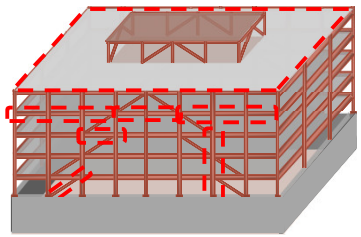
Seismic-load-resisting system



- Vertical frames
  - Beams
  - Columns
  - Braces (if any)
- Diaphragms
  - Deck
  - Chords
  - Collectors
- Foundations

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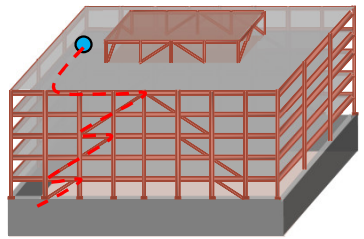
Load path issues

- Continuity
  - Load path must be continuous between mass and foundation



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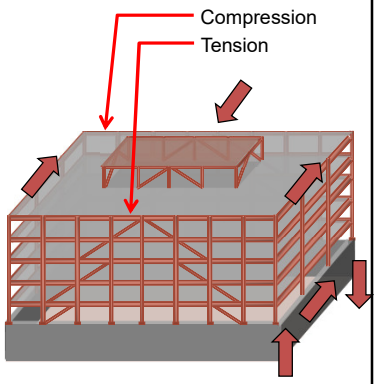
Load path issues

- Eccentricity
  - Horizontal eccentricity between mass and frame causes flexure in diaphragm
  - Vertical eccentricity between mass and foundation causes overturning in frame



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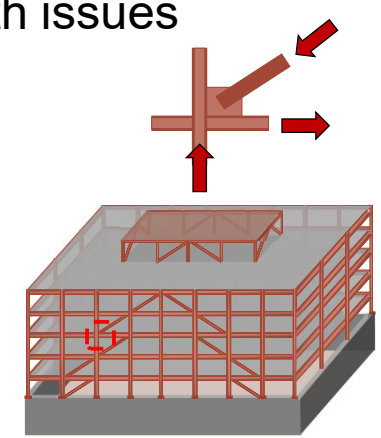
Load path issues

- Change in direction
  - At a change in direction load path there is an additional force
    - Vertical
      - Overturning



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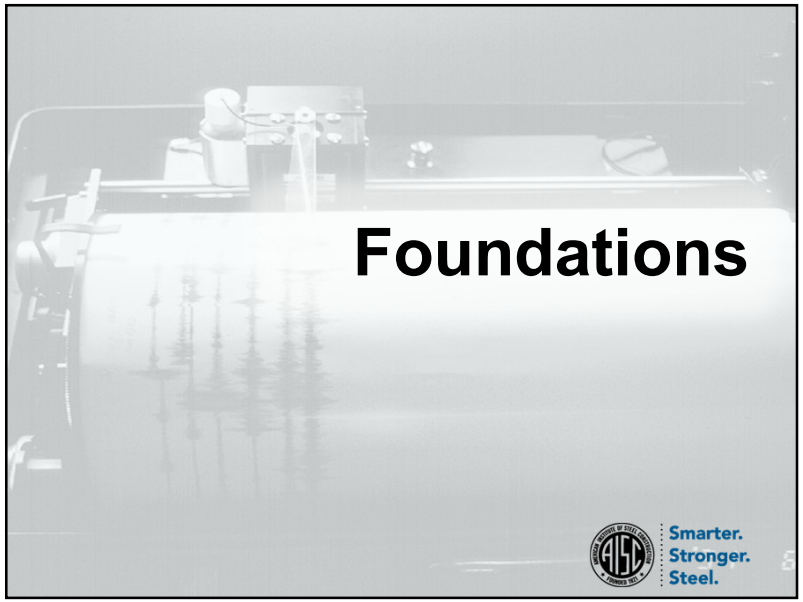

Foundations

- Shallow foundations
  - Support
  - Lateral resistance
  - Stability
- Deep foundations
  - Support
  - Lateral resistance
  - Stability

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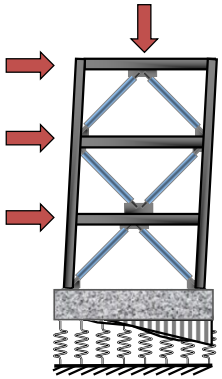
Shallow foundations: support

- Overturning at frames
  - Bearing pressure
    - Short-duration increase in resistance
    - Idealized as triangular
    - Or modeled with soil springs
      - No tension!



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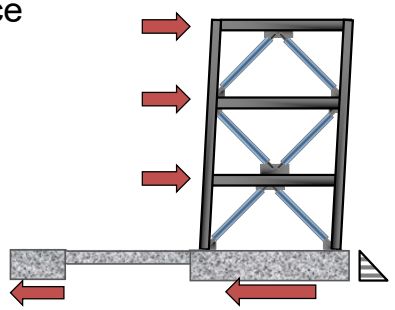
Shallow foundations: lateral resistance

- Lateral resistance
  - "Sliding"
  - Friction
  - Bearing (passive pressure)
  - Engagement of multiple footings



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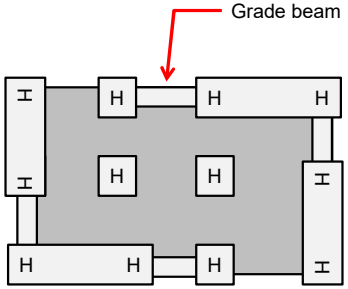
Shallow foundations: lateral resistance

- Lateral resistance
  - "Sliding"
  - Friction
  - Bearing (passive pressure)
  - Engagement of multiple footings
    - Relative lateral movement of footings can be problematic



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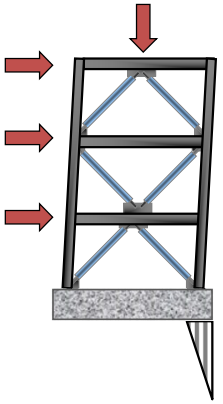
Shallow foundations: stability

- May be governing consideration for foundation
- Nonlinear
  - May be stable under ASD and unstable under LRFD loads
    - Minimum requirement: Evaluate under ASD
    - Design footings for soil capacity (amplified)



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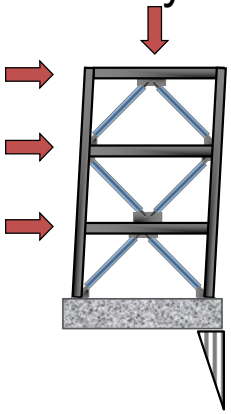
Shallow foundations: stability

- Implications of designing for stability with reduced (1/*R*) loads
  - Rocking may be governing mode
  - System above may have lower ductility demand
  - Displacements may be larger than anticipated



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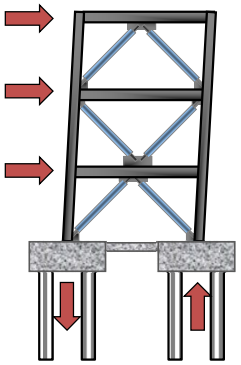
Deep foundations: support

- Overturning at frames
  - Compression
    - End bearing
    - Friction
  - Tension
    - Friction
  - Short-duration increases



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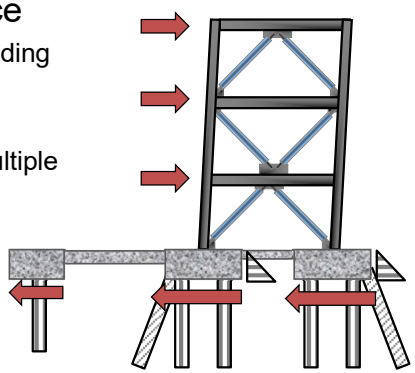
Deep foundations: lateral resistance

- Lateral resistance
  - Pile shear and bending
  - Pile-cap bearing (passive pressure)
  - Engagement of multiple footings
  - Batter piles



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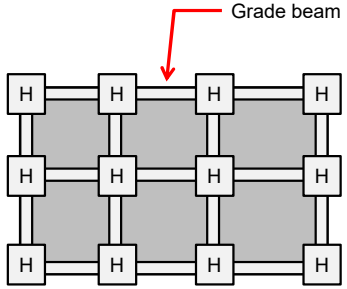
Deep foundations: lateral resistance

- Lateral resistance
  - Pile shear and bending
  - Pile-cap bearing (passive pressure)
  - Engagement of multiple footings
  - Buildings tied together
    - Engage all piles
    - Prevent relative movement



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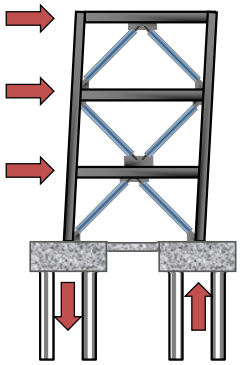
Deep foundations: stability

- Stability
  - Addressed by strength design of piles
  - Upper-bound soil strength difficult to establish
  - Rocking mechanism not applicable



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Diaphragms

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Steel Deck (AKA “Metal Deck”)

Shear load path through steel deck and fasteners.

Steel chords and collectors.

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Deck and Fill

Shear load path through steel deck and fasteners.

Concrete stiffens deck and prevents buckling.

Steel chords and collectors.

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Steel deck with reinforced concrete fill

Shear load path through reinforced concrete and shear studs.
Chords and collectors:
- Steel members, or
- Reinforcement in deck

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Horizontal truss diaphragm

Shear load path through steel diagonals and framing.

Steel chords and collectors.

Deck is for gravity only

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Diaphragms

- Roles of Diaphragms
- Diaphragm Components
- Diaphragm Behavior and Design Principles
- Building Analysis and Diaphragm Forces
- Diaphragm Analysis and Internal Component Forces

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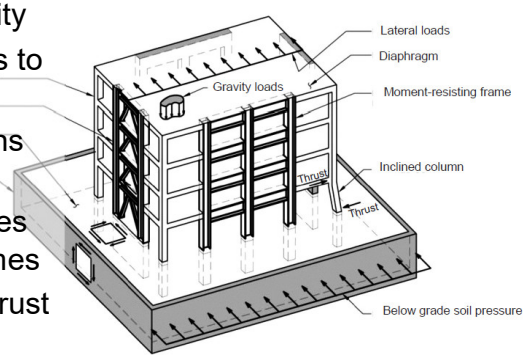
Roles of diaphragms

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



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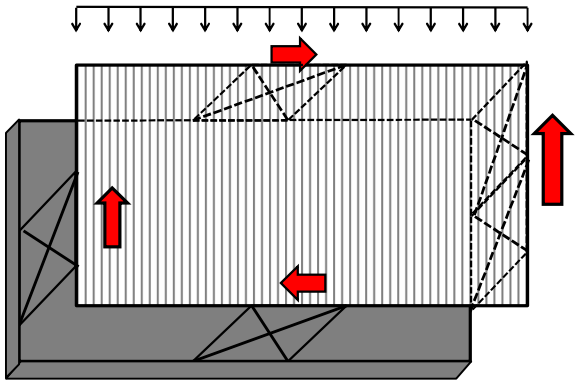
Distribute inertial forces



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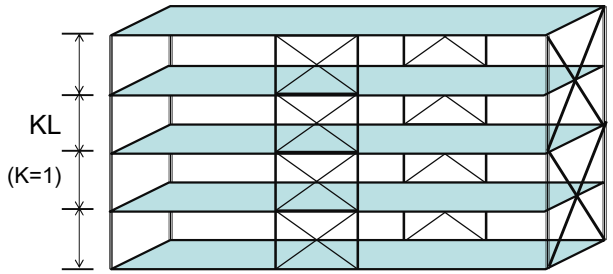
Lateral bracing of columns



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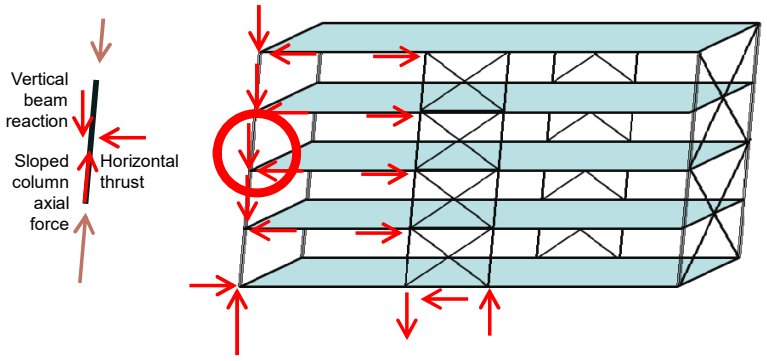
Resist P-Δ thrust



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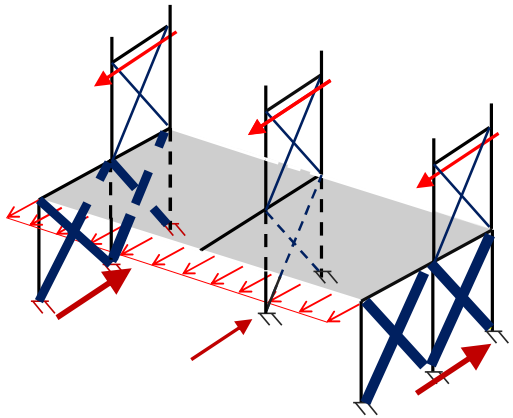
Transfer forces between frames



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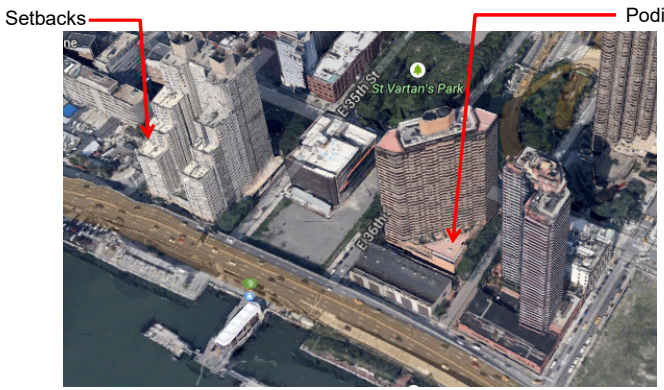
Transfer diaphragms (potential)



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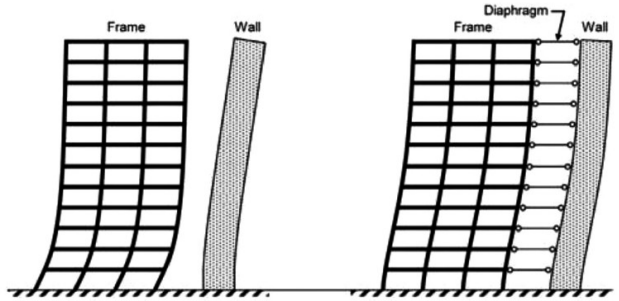
Transfer diaphragms



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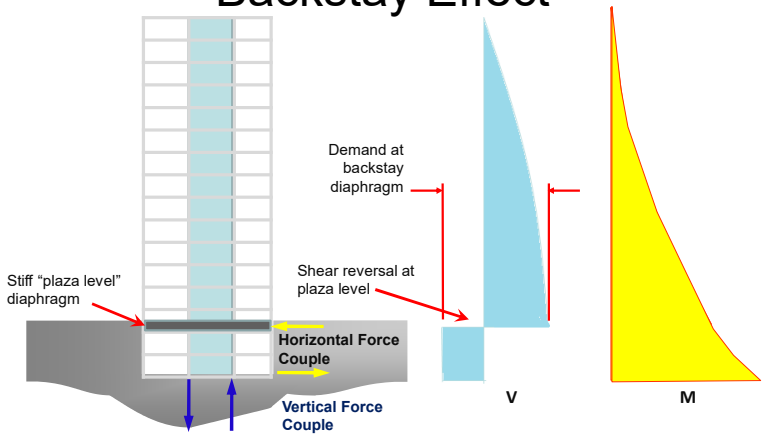
Backstay Effect



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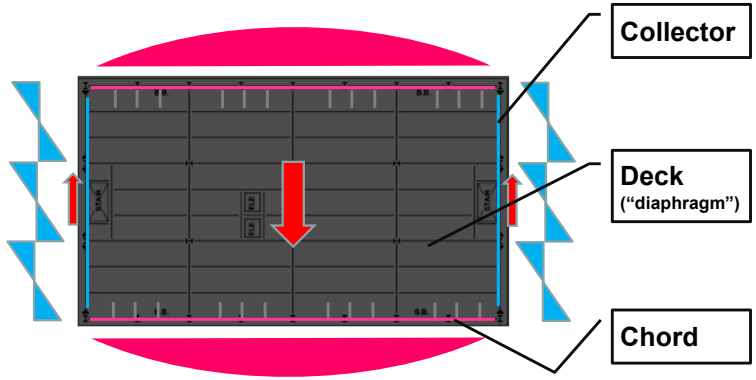
Diaphragm Components



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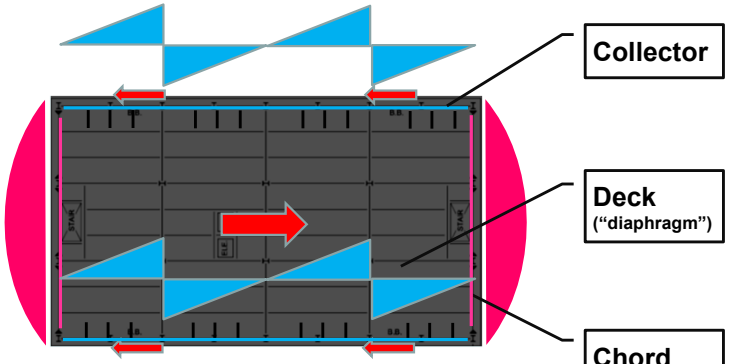
Diaphragm Components



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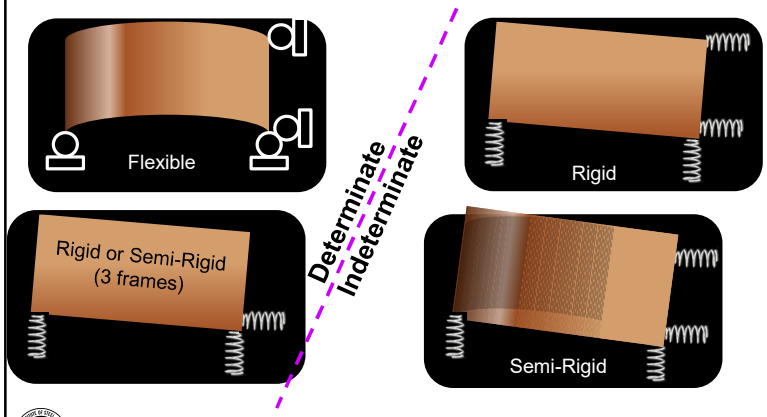
Diaphragm rigidity



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Diaphragm types and analysis

- Determinate
  - Flexible, or
  - 3 lines of resistance
  - ○ Analyze diaphragm
  - ○ Diaphragm reactions load frames
- Indeterminate
  - Rigid, or
  - Semi-rigid
  - ○ Analyze building
    - Relative frame stiffness
    - Diaphragm rigidity
    - Frame location
  - ○ Forces to frames = diaphragm collector forces

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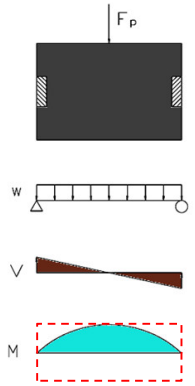
Analysis of Flexible Diaphragms



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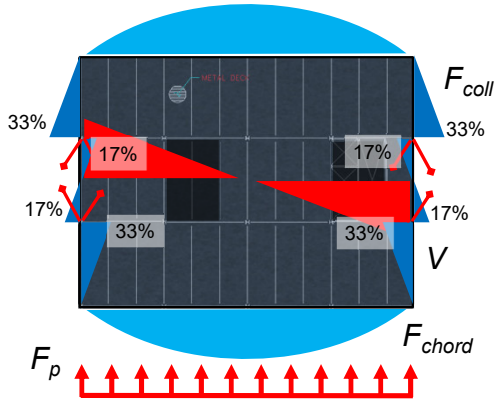
Typical diaphragm analysis



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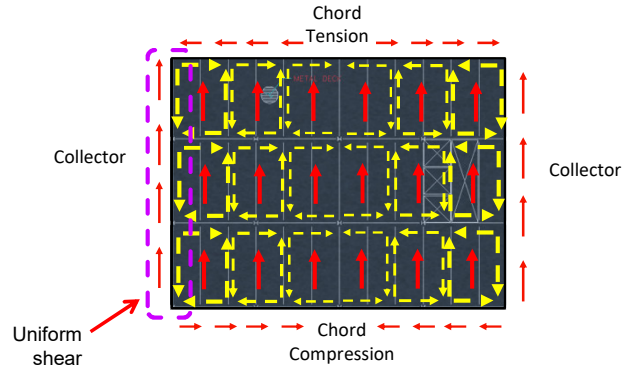
Typical diaphragm analysis



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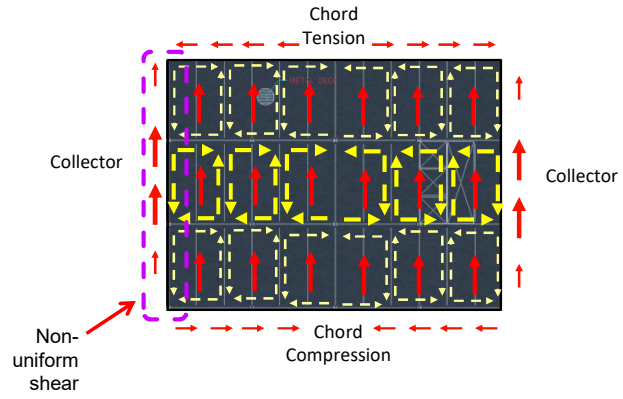
Alternate diaphragm analysis



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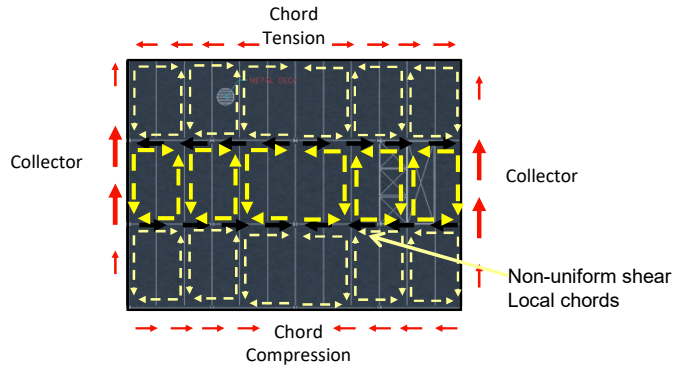
Alternate diaphragm analysis



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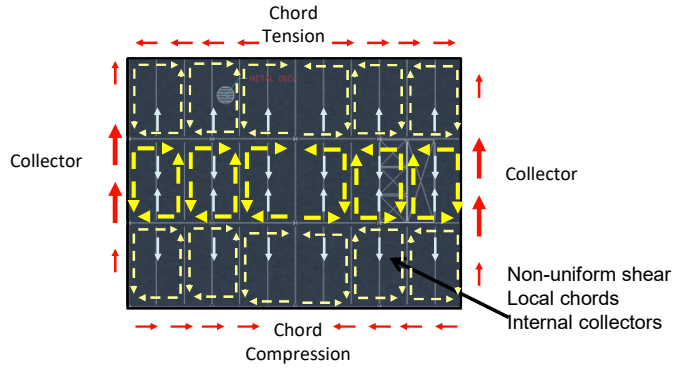
Alternate diaphragm analysis



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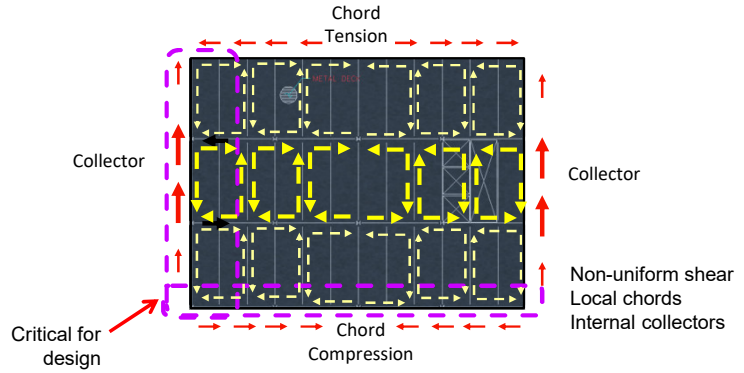
Alternate diaphragm analysis



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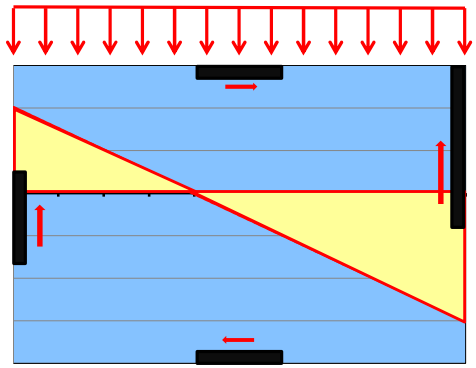
Analysis of Non-flexible Diaphragms



Non-flexible diaphragms activate the perpendicular system to help resist torsion (due to eccentricity between center of mass and center of rigidity)

Shear

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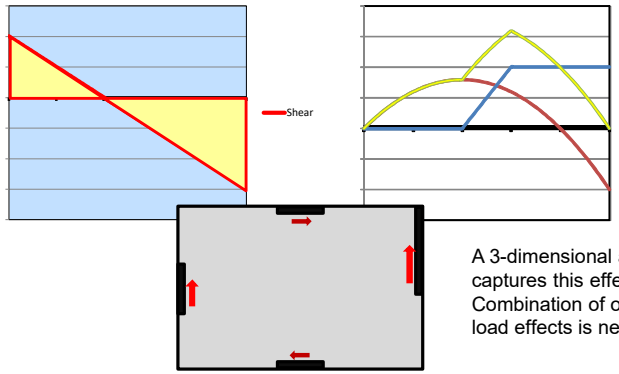
Analysis of Non-flexible Diaphragms



A 3-dimensional analysis captures this effect
Combination of orthogonal load effects is necessary

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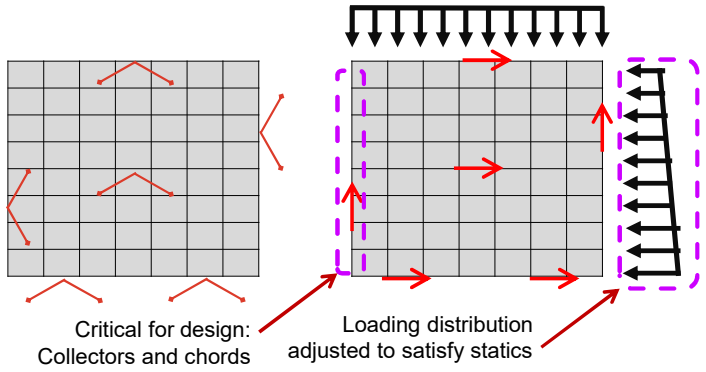
Using the results of 3-D analysis



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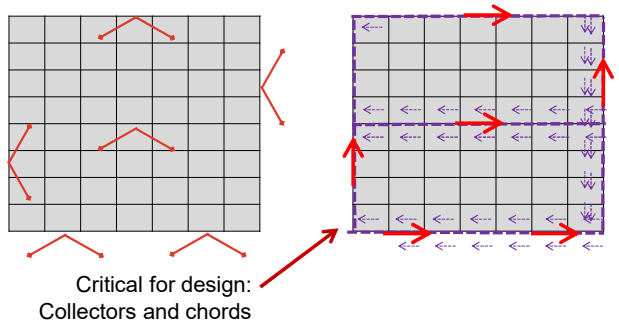
Using the results of 3-D analysis



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Collectors

- Protected element
- Reinforcement in composite deck
- Steel framing

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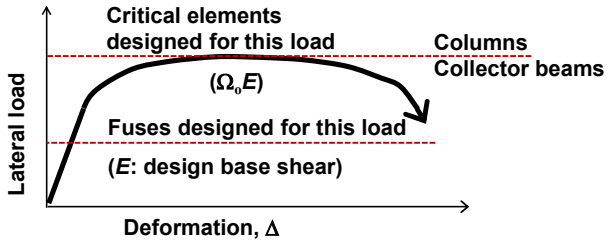
Protected element



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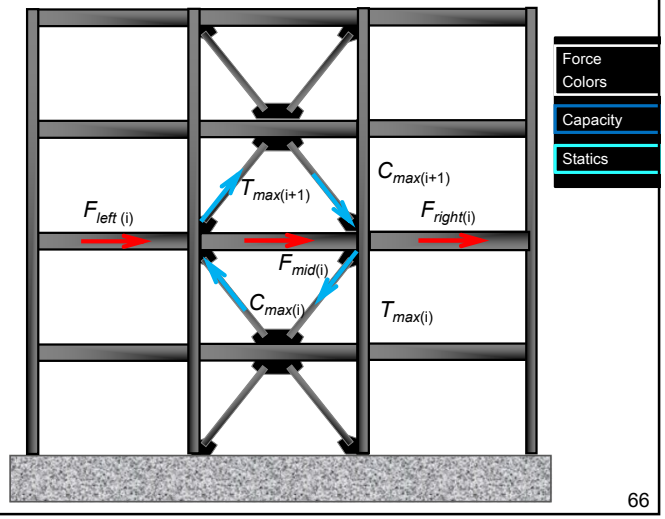
Collector and frame loads: Case 1



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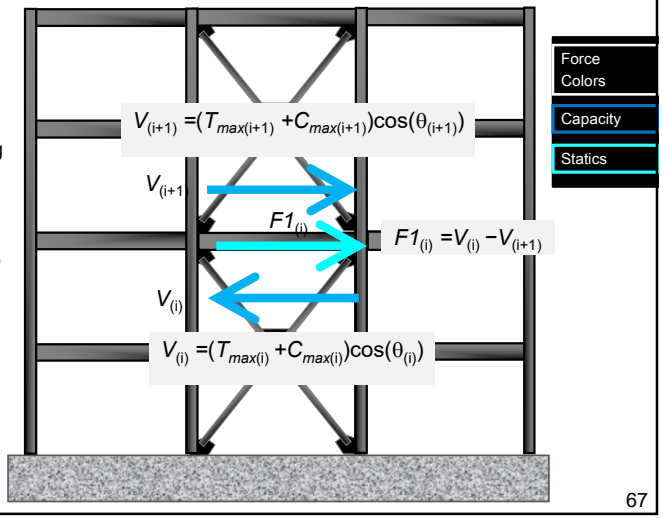
Collector and frame loads: Case 1

Shear entering frame line

$F1_{(i)} = F_{left\ (i)} + F_{mid(i)} + F_{right(i)}$

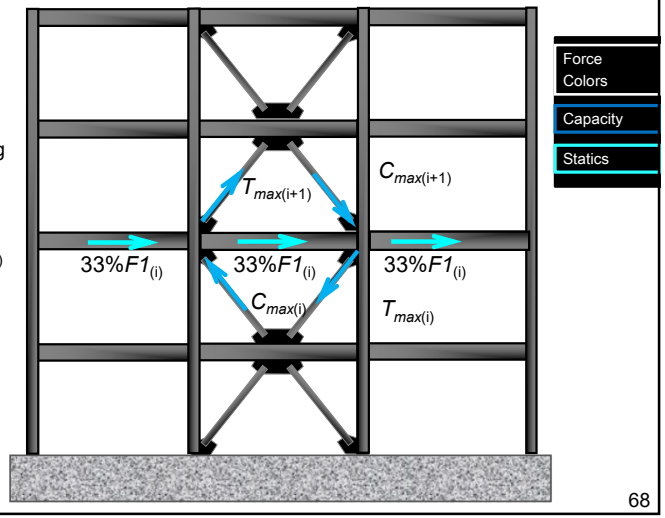


67

Collector and frame loads: Case 1

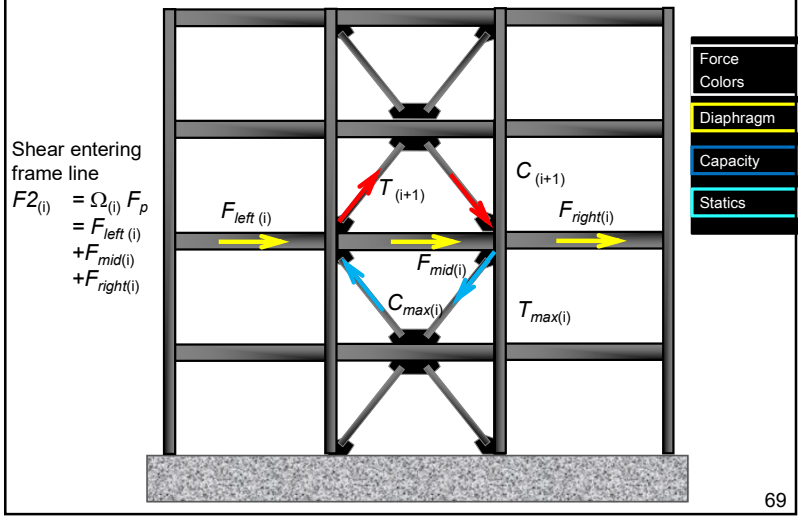
Shear entering frame line

$F1_{(i)} = F_{left\ (i)} + F_{mid(i)} + F_{right(i)}$



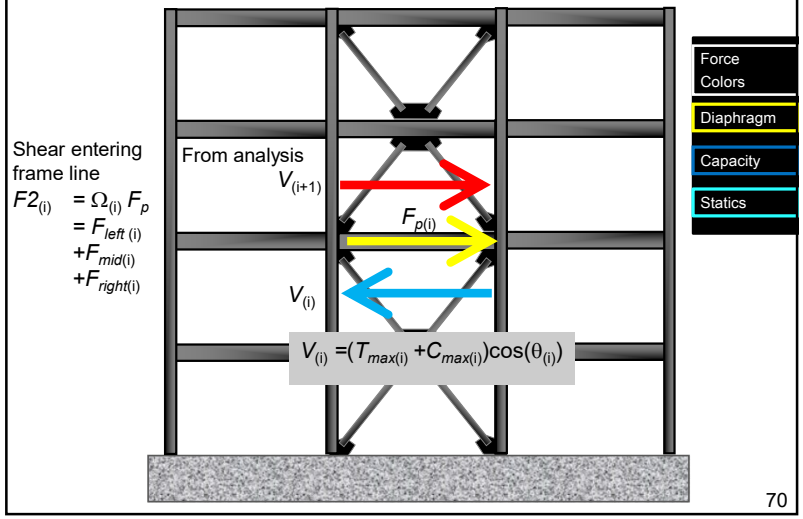
68

Collector and frame loads: Case 2



69

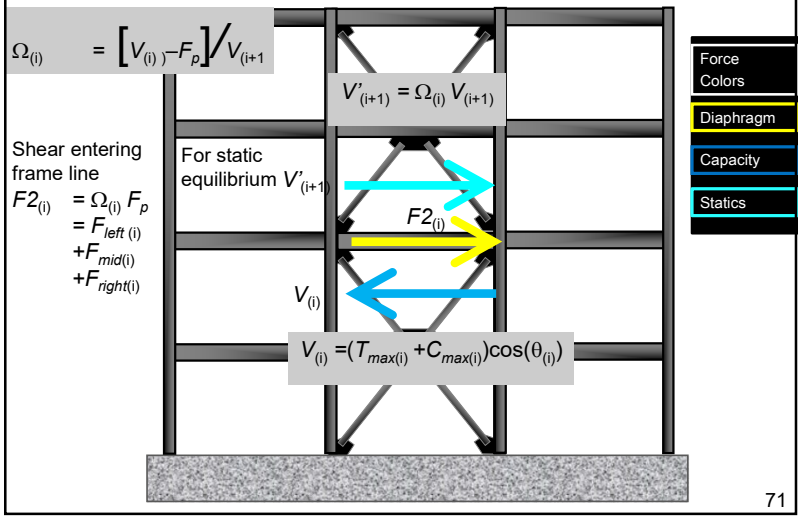
Collector and frame loads: Case 2



70

Collector and frame loads: Case 2

$\Omega_{(i)} = [V_{(i)} - F_p] / V_{(i+1)}$



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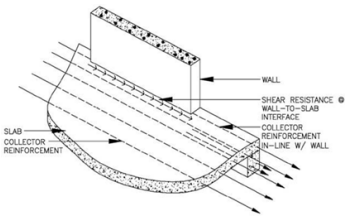
Reinforcement in deck

- Wide section of deck
  - Low stress
  - Stability not critical
- Eccentricity from frame
  - Local chords
- Concentrated shear transfer



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Reinforcement in deck

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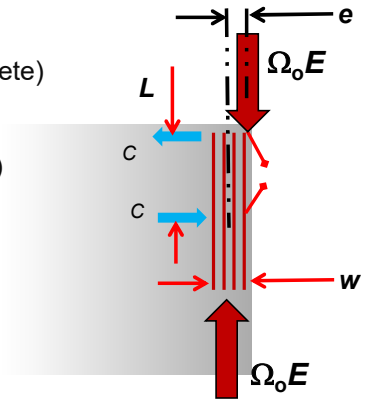
Reinforcement as collector

$\Omega_o E / A = \leq 0.5 f_c'$
(unconfined concrete)

$\Omega_o E / (wt) = \leq 0.5 f_c'$
$w \geq \Omega_o E / (0.5 f_c' t)$

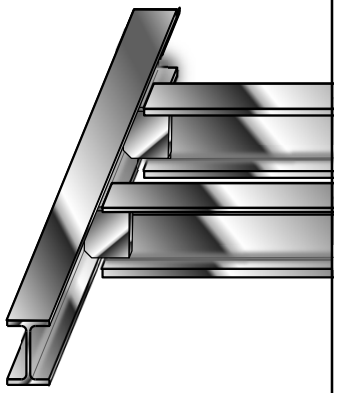
$e = w/2$

Local chord force:
$C = e (\Omega_o E)/L$



Beam-columns

- Compressive strength
  - 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



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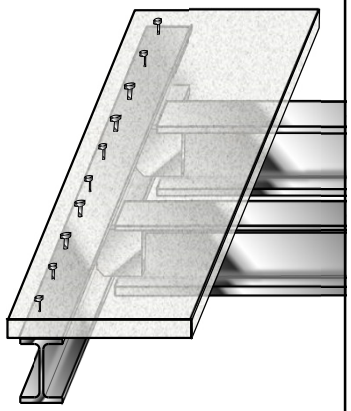
Beam-columns

- 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



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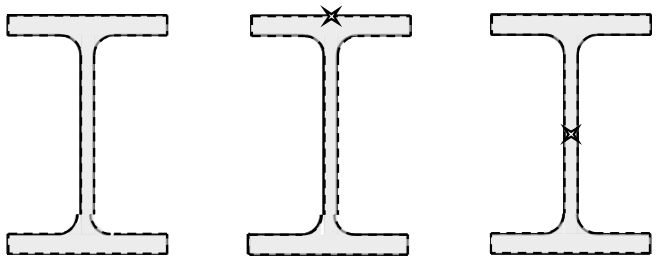
Constrained-axis flexural-torsional buckling



Minor axis flexural buckling (no restraint)

Constrained-axis Flexural-torsional buckling (restraint at top flange)

Torsional buckling (restraint at centroidal axis)

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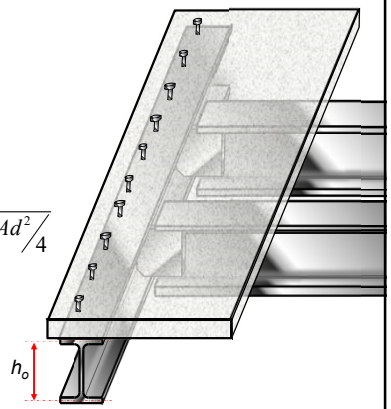
Beam-columns

- Constrained-axis flexural-torsional buckling

$$F_{cr} = 0.9\left[\frac{\pi^2 E I_y \left(h_o^2 + d^2\right)}{4\left(L_{cz}\right)^2} + GJ\right]\frac{1}{I_x + I_y + Ad^2/4}$$



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Beam-columns

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

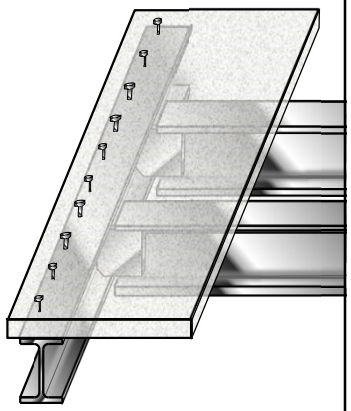

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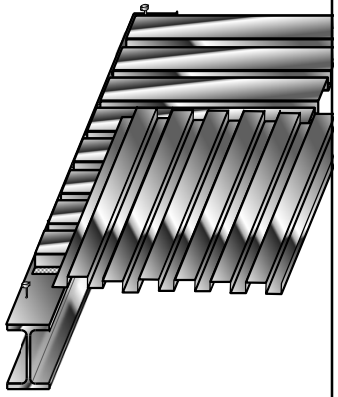
Table 8-1
Summary of Unbraced Lengths and Restraint Conditions for Collector Beams
(Compressive Strength)

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 torsional 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 torsional brace points

Beam-columns

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



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Collector connections

- Gravity
  - Shear forces
- Seismic
  - Axial forces (horizontal)
  - Rotation

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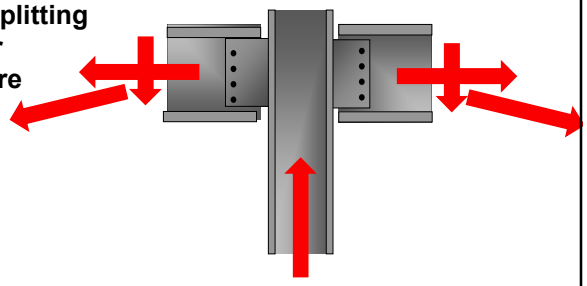
Collector connections

Limit States
Plate Yield & Rupture
Bolt shear
Bearing & Splitting
Block Shear
Weld Rupture



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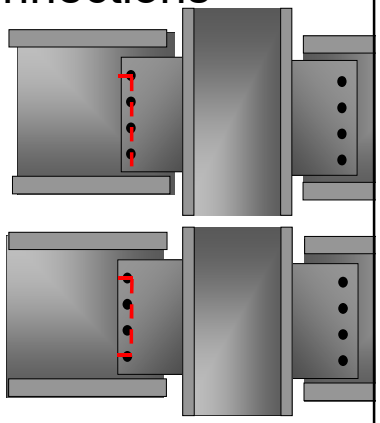
Collector connections

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

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

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



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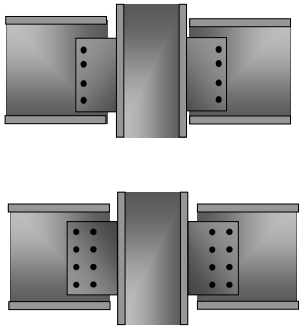
Collector connections



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

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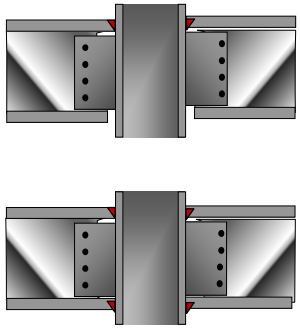
Collector connections



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

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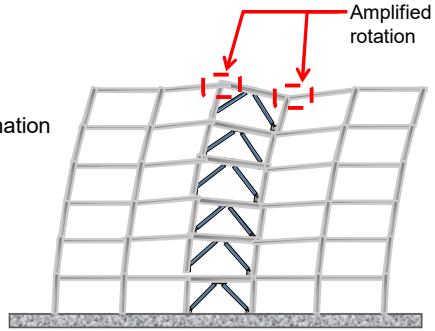
Deformation compatibility

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



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Deformation compatibility

- Necessity
- Connections
- Flexible diaphragms
- Stairs
- Pounding
- Critical conditions

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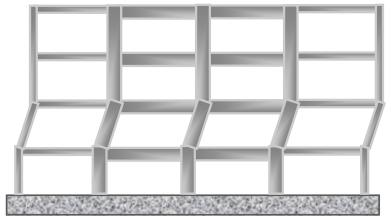
Necessity

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



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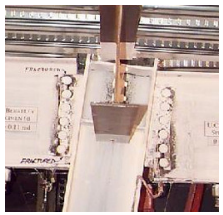
Gravity connections

- 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



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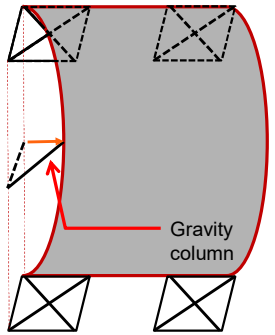
Flexible diaphragms

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



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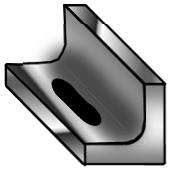
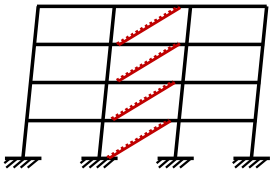
Stairs



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



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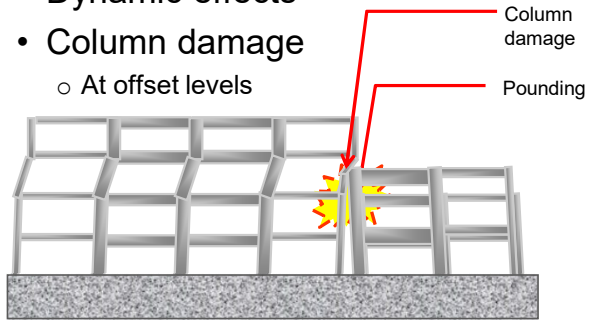
Pounding

- Dynamic effects
- Column damage
  - At offset levels



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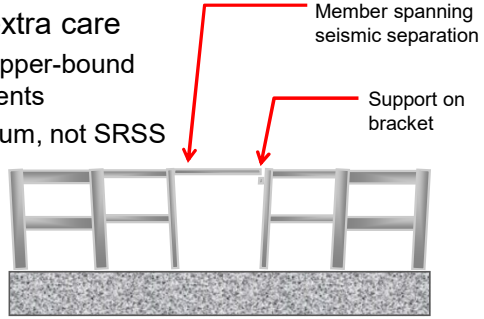
Critical conditions

- 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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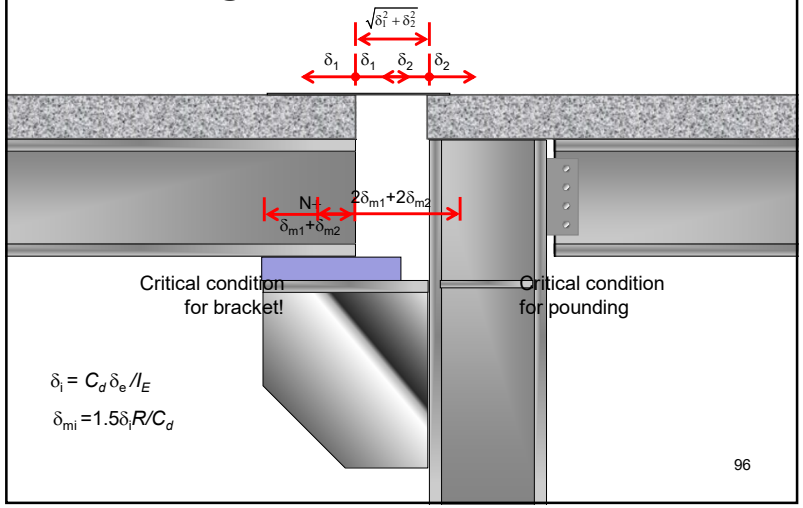
Critical conditions



$\delta_i = C_d \delta_e / I_E$

$\delta_{mi} = 1.5\delta_i R / C_d$

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Summary

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Summary

- Structures require a complete load path to maintain stability
- Foundations and diaphragms are an integral part of the load path
- The entire structure must be capable of deforming along with the seismic load resisting system

Parting thought

How are these issues treated by building codes?

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End of session 7

Next:

Session 8: Building codes

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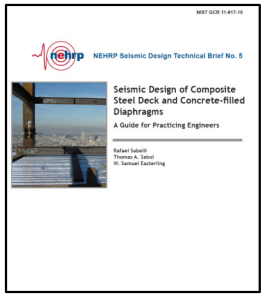
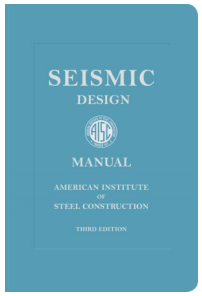
Additional resources





http://www.nehrp.gov/pdf/nistgcr11-917-10.pdf

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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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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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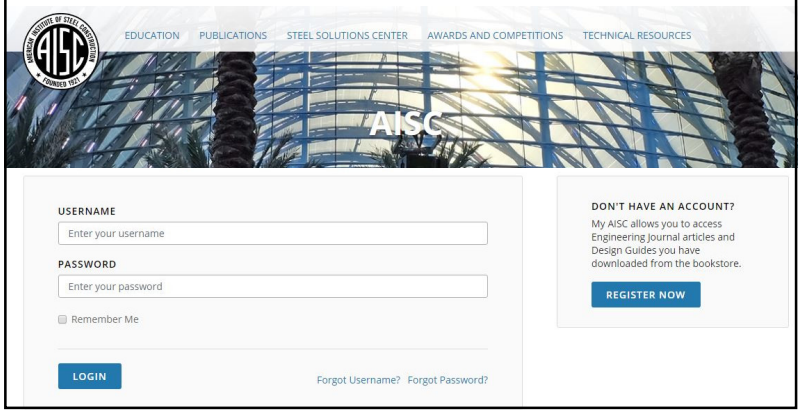
Course Resources

Go to www.aisc.org and sign in.



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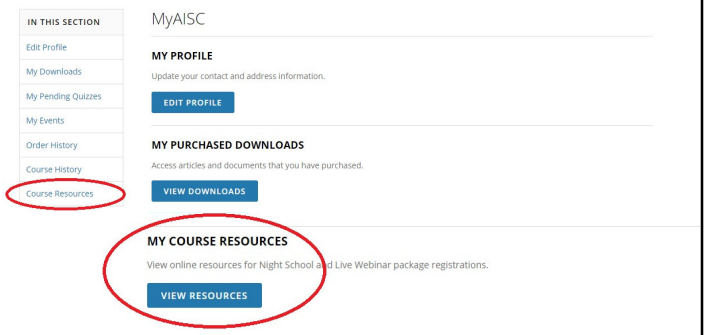
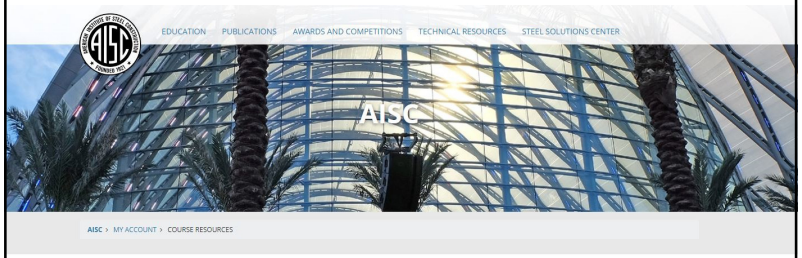


8-Session Registrants

Course Resources

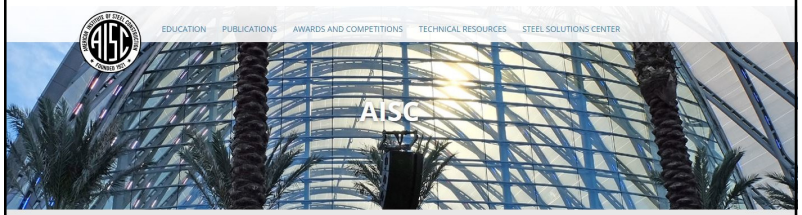


Course Resources

Event	Start Date
Seismic Design in Steel	1/1/1900 12:00:00 AM
4-Session Package-Design of Façade Attachments	5/9/2019 1:30:00 PM
NS 15 8-Session Package-Night School 15 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
NS 16 8-Session Package-Night School 16 - Seismic Design in Steel	2/5/2018 7:00:00 PM
NS 17 4-Session Package-Night School 17: Design of Façade Attachments	7/16/2018 7:00:00 PM
NS 18 8-Session Package-Night School 18: Steel Construction: Mill To Topping Out	10/15/2018 7:00:00 PM
NS 19 8-Session Package-Night School 19: Connection Design	2/4/2019 7:00:00 PM
NS 20 8-Session Package-Night School 20: Classical Methods of Structural Analysis	6/3/2019 7:00:00 PM
8-Session Package-Seismic Design in Steel - Concepts & Examples	7/16/2018 1:30:00 PM

8-Session Registrants

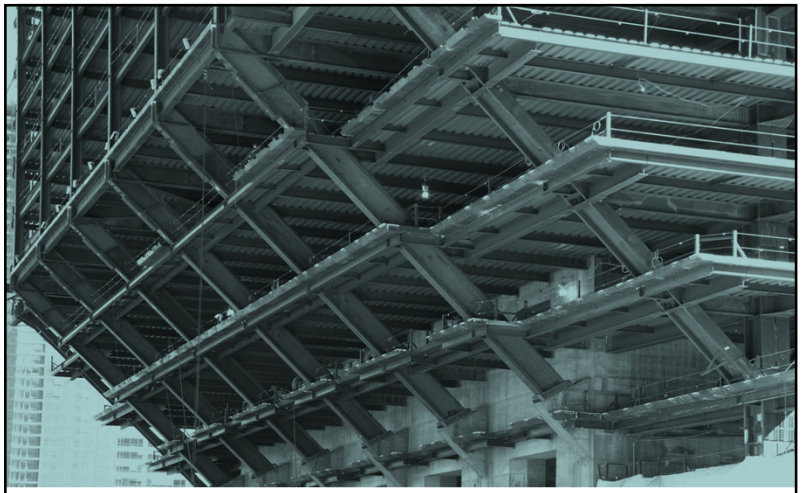
Course Resources



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	



AISC | Thank you.

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