AISC Night School

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Modern Methods for Learning the Basics of Structural Stability: From Behavior to Practice

Session 8: Behavior of Structural Systems – Practical Considerations

December 8, 2020

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Course Description

Behavior of Structural Systems – Practical Considerations
December 8, 2020

In this session, the speakers will review the general design for stability requirements provided in the AISC *Specification*. They will discuss the results of the learning module on systems, developing each of the three case studies for a portal frame. They will close out the course with some discussion of how the industry has evolved in its treatment of stability and what the future holds.

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Learning Objectives

- Explain how the AISC requirements for stability design are met by the direct analysis method.
- List the analysis methods that are provided in the AISC *Specification* to address stability design.
- Compare the results of an analysis that accounts system geometric imperfections through direct modeling to one that uses notional loads.
- Describe the concept of inelastic design and explain why it may be used more frequently in the future.

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Modern Methods for Learning The Basics of Structural Stability: From Behavior to Practice

Session 8: Behavior of Systems – Practical Considerations
December 8, 2020

Ronald D. Ziemian, PE, PhD
Professor
Bucknell University

Craig Quadrato, PE, PhD
Associate Principal
Wiss, Janney, Elstner Associates, Inc.

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Modern Methods for Learning The Basics of Structural Stability: From Behavior to Practice

Course Introduction

Compression Members

Flexural Members

Beam-Columns

Systems

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Course Overview (2)

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Course Overview (3)

- Focus of the course is on fundamentals!
- Better understanding of behavior will result in improved design
- Key Definitions
  - **Stability:** Under load, component returns to current state after applying a small disturbance such as a deflection
  - **Bifurcation (critical load):** Theoretical point at which loading a component results in an instantaneous change from current state to significant deflection – two options: not buckled or buckled
  - **Instability:** Loading a component results in a realistic transition from small deflection to significant deflection – buckling preceded by deflection

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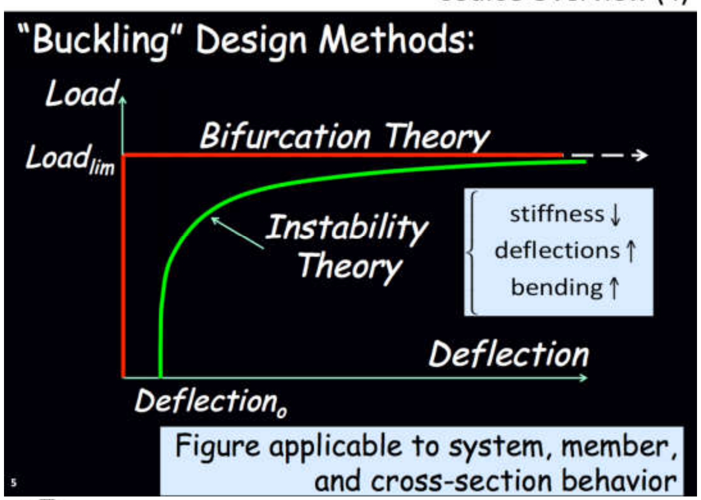
Course Overview (4)



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Course Overview (5)

Analysis acronyms:

LBA: linear bucking analysis; elastic critical load analysis; elastic eigenvalue analysis; assumes bifurcation theory

LA: linear analysis; 1st-order elastic analysis; assumes equilibrium on the undeformed shape and linear elastic material, with no initial imperfections.

GNA: geometric nonlinear analysis; 2nd-order elastic analysis; assumes equilibrium on the deformed shape and linear elastic material, with no initial imperfections

GNIA: same as GNA, but includes initial imperfections

MNA: material nonlinear analysis; 1st-order inelastic analysis; assumes equilibrium on the undeformed shape and accounts for yielding, with no initial imperfections

GMNIA: geometric and material nonlinear analysis; 2nd-order inelastic analysis; assumes equilibrium on the deformed shape, accounts for yielding, and includes initial imperfections

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Modern Methods for Learning The Basics of Structural Stability: From Behavior to Practice

Course Introduction

Compression Members – Sessions 1 & 2

Flexural Members – Session 3 & 4

Beam-Columns – Sessions 5 & 6

Systems – Session 7 & 8

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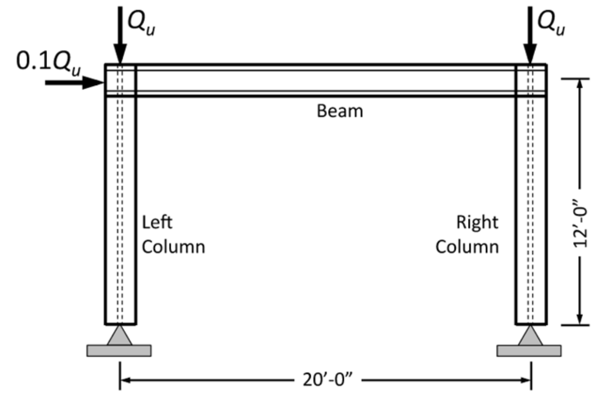
Session 8

System Behavior Lab



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Session Overview

- Review Direct Analysis Method
- Perform LM9
- Looking to the Future by Starting with the Past with Ron

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Session 7 in AISC 360-16 General Stability Requirements (C1)

- Member stability must account for:
  - Axial, flexural, shear, torsional, connection deformations
  - Second order effects (P-Δ and P-δ)
  - Geometric imperfection
  - Stiffness reductions due to inelasticity
  - Uncertainty in system, member, and connection strength and stiffness

Session 5 Slide 82 & Chapter C

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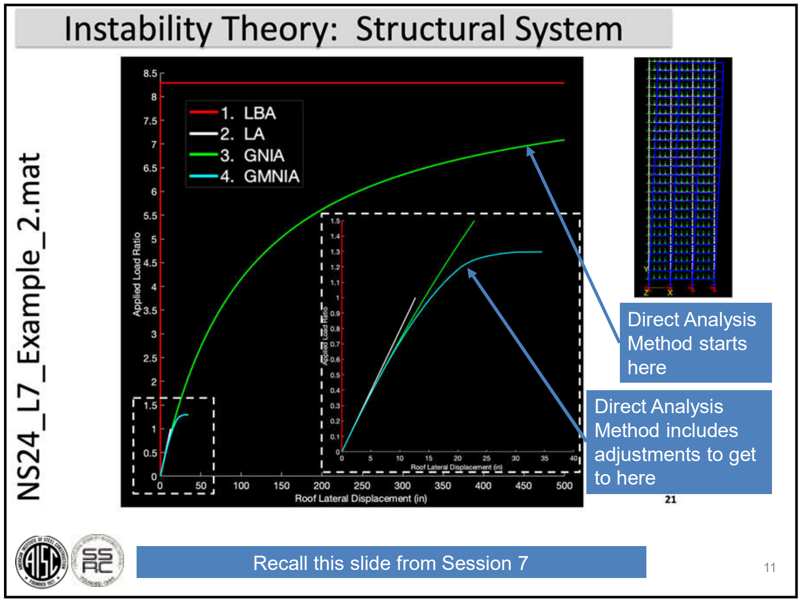
Instability Theory: Structural System
NS24_L7_Example_2.mat
1. LBA
2. LA
3. GNIA
4. GMNIA
Applied Load Ratio
Roof Lateral Displacement (in)
Direct Analysis Method starts here
Direct Analysis Method includes adjustments to get to here
Recall this slide from Session 7
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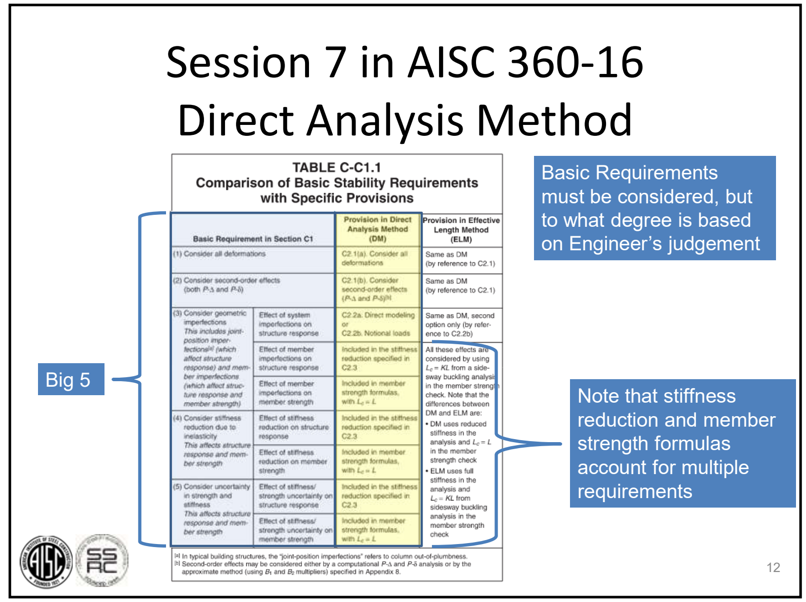
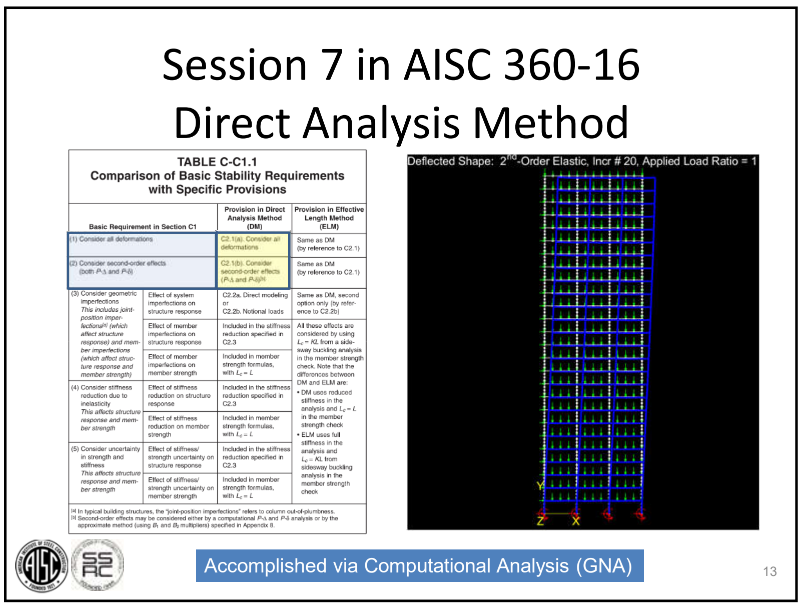

Session 7 in AISC 360-16
Direct Analysis Method
TABLE C-C1.1
Comparison of Basic Stability Requirements with Specific Provisions
Basic Requirements must be considered, but to what degree is based on Engineer's judgement
Big 5
Note that stiffness reduction and member strength formulas account for multiple requirements
12


Session 7 in AISC 360-16
Direct Analysis Method
TABLE C-C1.1
Comparison of Basic Stability Requirements with Specific Provisions
Accomplished via Computational Analysis (GNA)
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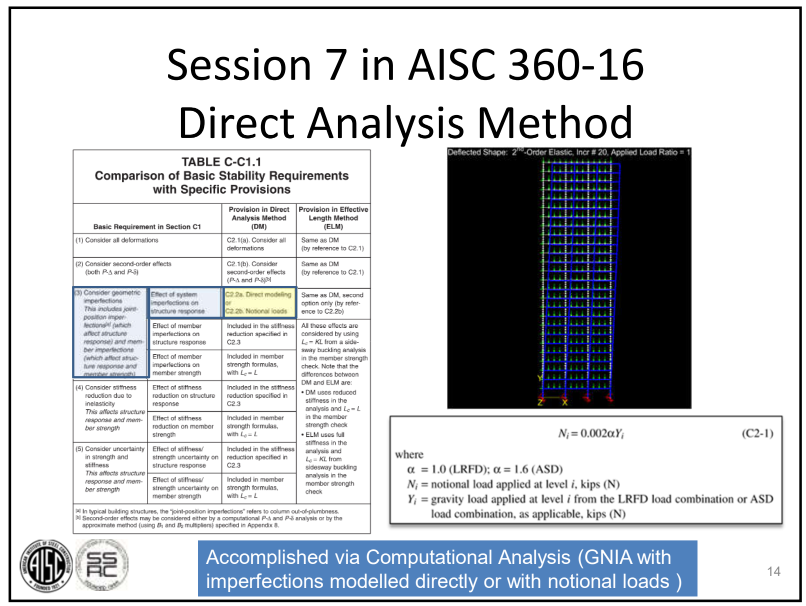
Session 7 in AISC 360-16
Direct Analysis Method
TABLE C-C1.1
Comparison of Basic Stability Requirements with Specific Provisions
N_i = 0.002αY_i (C2-1)
where
α = 1.0 (LRFD); α = 1.6 (ASD)
N_i = notional load applied at level i, kips (N)
Y_i = gravity load applied at level i from the LRFD load combination or ASD load combination, as applicable, kips (N)
Accomplished via Computational Analysis (GNIA with imperfections modelled directly or with notional loads)
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Session 7 in AISC 360-16
Direct Analysis Method

TABLE C-C1.1
Comparison of Basic Stability Requirements with Specific Provisions

Basic Requirement in Section C1		Provision in Direct Analysis Method (DM)	Provision in Effective Length Method (ELM)
(1) Consider all deformations		C2.1(a). Consider all deformations	Same as DM (by reference to C2.1)
(2) Consider second-order effects (both P-Δ and P-δ)		C2.1(b). Consider second-order effects (P-Δ and P-δ)[b]	Same as DM (by reference to C2.1)
(3) Consider geometric imperfections *This includes joint-position imperfections[a] (which affect structure response) and member imperfections (which affect structure response and member strength)*	Effect of system imperfections on structure response	C2.2a. Direct modeling or C2.2b. Notional loads	Same as DM, second option only (by reference to C2.2b)
	Effect of member imperfections on structure response	Included in the stiffness reduction specified in C2.3	All these effects are considered by using $L_c = KL$ from a sidesway buckling analysis in the member strength check. Note that the differences between DM and ELM are: • DM uses reduced stiffness in the analysis and $L_c = L$ in the member strength check • ELM uses full stiffness in the analysis and $L_c = KL$ from sidesway buckling analysis in the member strength check
	Effect of member imperfections on member strength	Included in member strength formulas, with $L_c = L$	
(4) Consider stiffness reduction due to inelasticity *This affects structure response and member strength*	Effect of stiffness reduction on structure response	Included in the stiffness reduction specified in C2.3	
	Effect of stiffness reduction on member strength	Included in member strength formulas, with $L_c = L$	
(5) Consider uncertainty in strength and stiffness *This affects structure response and member strength*	Effect of stiffness/strength uncertainty on structure response	Included in the stiffness reduction specified in C2.3	
	Effect of stiffness/strength uncertainty on member strength	Included in member strength formulas, with $L_c = L$	

[a] In typical building structures, the "joint-position imperfections" refers to column out-of-plumbness.
[b] Second-order effects may be considered either by a computational P-Δ and P-δ analysis or by the approximate method (using B_1 and B_2 multipliers) specified in Appendix 8.

- 0.8 factor applied to all stiffnesses contributing to structure stability

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Session 7 in AISC 360-16
Direct Analysis Method

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	Effect of stiffness/strength uncertainty on member strength	Included in member strength formulas, with $L_c = L$	

[a] In typical building structures, the "joint-position imperfections" refers to column out-of-plumbness.
[b] Second-order effects may be considered either by a computational P-Δ and P-δ analysis or by the approximate method (using B_1 and B_2 multipliers) specified in Appendix 8.

- 0.8 factor applied to all stiffnesses contributing to structure stability
- Additional τ_b on flexural stiffness of members whose flexural stiffness contribute to stability if $\alpha P_r/P_{ns} > 0.5$
- If $\alpha P_r/P_{ns} > 0.5$ additional $0.001\alpha Y_i$ may be used in lieu of τ_b

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Session 7 in AISC 360-16
Direct Analysis Method

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	Effect of stiffness reduction on member strength	Included in member strength formulas, with $L_c = L$	
(5) Consider uncertainty in strength and stiffness *This affects structure response and member strength*	Effect of stiffness/strength uncertainty on structure response	Included in the stiffness reduction specified in C2.3	
	Effect of stiffness/strength uncertainty on member strength	Included in member strength formulas, with $L_c = L$	

[a] In typical building structures, the "joint-position imperfections" refers to column out-of-plumbness.
[b] Second-order effects may be considered either by a computational P-Δ and P-δ analysis or by the approximate method (using B_1 and B_2 multipliers) specified in Appendix 8.

The nominal compressive strength, P_n, shall be determined based on the limit state of flexural buckling:

$$P_n = F_{cr} A_g \quad \text{(E3-1)}$$

The critical stress, F_{cr}, is determined as follows:

(a) When $\frac{L_c}{r} \le 4.71\sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} \le 2.25$)

$$F_{cr} = \left(0.658^{\frac{F_y}{F_e}}\right) F_y \quad \text{(E3-2)}$$

(b) When $\frac{L_c}{r} > 4.71\sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} > 2.25$)

$$F_{cr} = 0.877 F_e \quad \text{(E3-3)}$$

where

A_g = gross cross-sectional area of member, in.² (mm²)
E = modulus of elasticity of steel = 29,000 ksi (200 000 MPa)

E3 shown, see E4 for torsional and flexural-torsional buckling

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Direct Analysis Method

- Stiffness reductions account for the following on structural response
  - Axial, flexural, shear, torsional, connection deformations
  - Second order effects (P-Δ and P-δ)
  - Geometric imperfection
  - Inelasticity
  - Uncertainty

(a) When $\frac{P_r}{P_c} \ge 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \le 1.0 \quad \text{(H1-1a)}$$

(b) When $\frac{P_r}{P_c} < 0.2$

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \le 1.0 \quad \text{(H1-1b)}$$

- Member strength formulas account for the following on member strength
  - Member imperfections (Axial Only)
  - Inelasticity
  - Uncertainty

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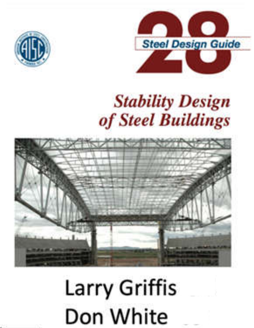
Session 7 in AISC 360-16

- Other Stability Design Methods
  - Effective length (Appendix 7)
  - First-order analysis (Appendix 7)
  - Advanced analysis (Appendix 1)
    - Elastic
    - Inelastic
- Alternative analysis method: Approximate second-order analysis (Appendix 8)

$$M_r = B_1 M_{nt} + B_2 M_{lt} \quad \text{(A-8-1)}$$

$$P_r = P_{nt} + B_2 P_{lt} \quad \text{(A-8-2)}$$



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Learning Module 9 Objectives

- Apply the Direct Analysis Method to assess structural system adequacy
- Use rigorous second-order analysis to determine beam-column required strength
- Use notional loads to simulate initial imperfections and stiffness reduction due to partial yielding
- Use interaction equations to check member adequacy
- Use drift ratios as indicator of system sensitivity to second-order effects

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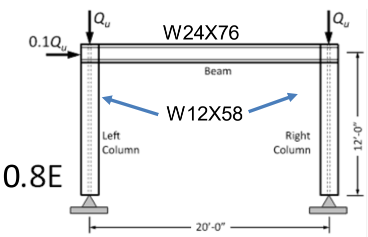
Learning Module 9 Method

- A992 STEEL
- Beam $L_b = L_c = 0$
- Stiffness reduction of 0.8E
- Three studies
  - Case 1: H/500 out-of-plumbness & τ_b
  - Case 2: Use Case 1 to find Q_u for DCR = 1.0
  - Case 3: Use notional loads instead of out-of-plumbness and τ_b



LRFD Methodology

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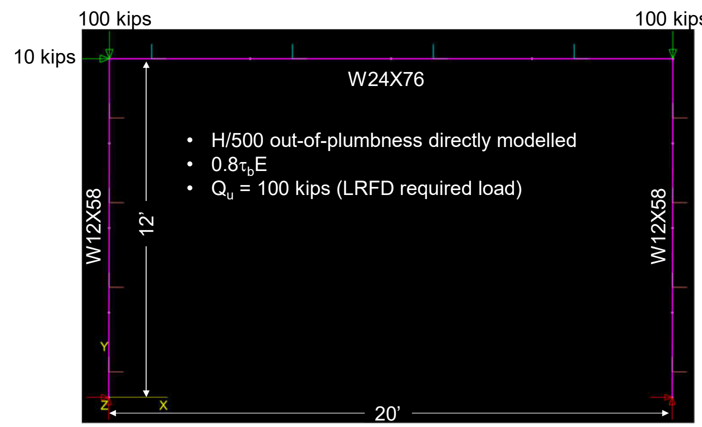
Learning Module 9 Case 1 Model



Use Direct Analysis Method

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Learning Module 9 Member Capacities (P_c and M_c)

- W12x58 Left Column
  - $P_c = \phi P_n$ = 603 kips
  - $M_c = \phi M_{ny}$ = 1464 kip-in
- W12x58 Right Column
  - $P_c = \phi P_n$ = 603 kips
  - $M_c = \phi M_{ny}$ = 1464 kip-in

Note in this study ϕ factors are included

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Learning Module 9 Member Capacities (P_c and M_c)

- W24x76 Beam
- $P_c = \phi P_n$ = 1008 kips
- $M_c = \phi M_p$ = 9000 kip-in

Note in this study ϕ factors are included

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First, let's check how sensitive this system is to 2nd order effects using the Direct Analysis Method

Stability Sensitive Structural Systems

$$B_2 = \frac{1}{1-\frac{\alpha P_{story}}{P_{e\,story}}} \qquad P_{e\,story} = R_M \frac{HL}{\Delta_H}$$

- Indicators include:
  - B_1 and B_2 factors
  - Elastic/Inelastic critical buckling load factors λ_{cr} and mode shapes
  - Natural periods and mode shapes
- Eurocode uses ratio λ_{cr} (think LBA) between the the critical buckling loading and applied loading :

  - $\lambda_{cr} < 3$, must employ rigorous 2nd-order analysis ($B_2 > 1.5$)
  - $3 \leq \lambda_{cr} < 10$, approximate methods acceptable
  - $\lambda_{cr} \geq 10$, no need to consider P-Δ effects ($B_2 < 1.1$)

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Recall this slide from Session 7

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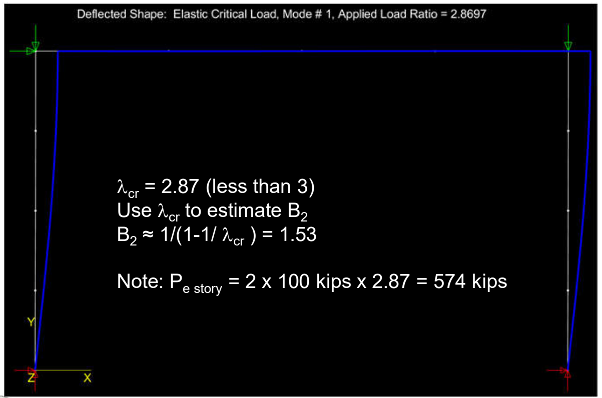
Case 1
Elastic Critical Load to Estimate B_2



System is sensitive to 2nd order effects

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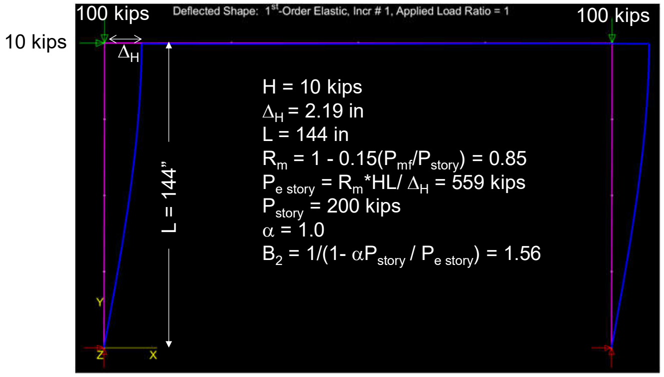
Case 1
AISC B_2 Calculation (Equation A-8-6)



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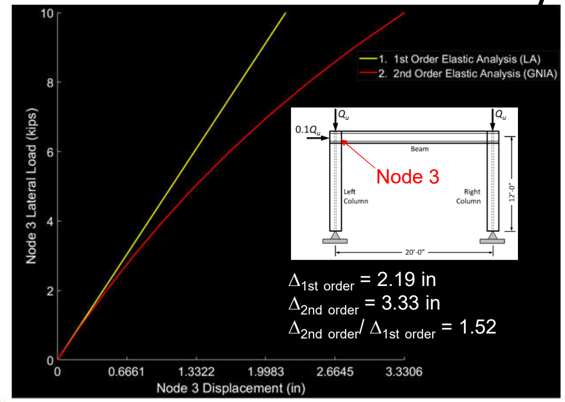
Case 1
1st and 2nd Order Elastic Analysis



Ratio closely approximates both previous B_2 calculations

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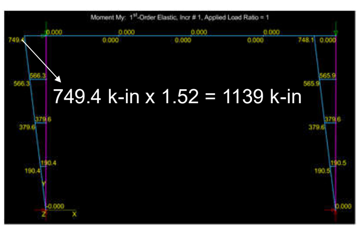
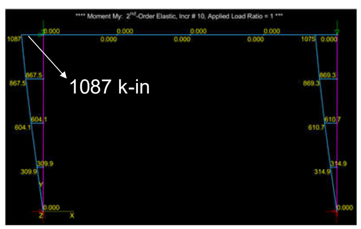
Case 1
1st and 2nd Order Elastic Analysis

1st Order Elastic Analysis (LA)



2nd Order Elastic Analysis (GNA)



Using the 2nd to 1st order drift ratio as moment amplifier gives a conservative estimate within 5% of the 2nd order moment

System is sensitive to 2nd order effects

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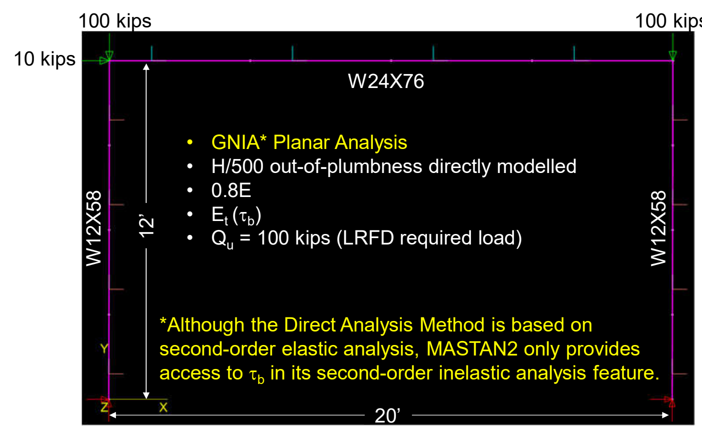
Learning Module 9 Case 1 Model



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Learning Module 9 Case 1

General Stability Requirement	How Accomplished
Deformations	GNIA via MASTAN2
Second order effects	GNIA via MASTAN2
System imperfections on structure	Directly modelled (H/500)
Member imperfections on structure	0.8E via MASTAN2
Member imperfections on member strength	P_c
Stiffness reductions due to inelasticity on structure	0.8E and τ_b via MASTAN2
Stiffness reductions due to inelasticity on member strength	P_c
Uncertainty on structure	0.8E via MASTAN2
Uncertainty on member	P_c

Model NS24_L8_Example_1

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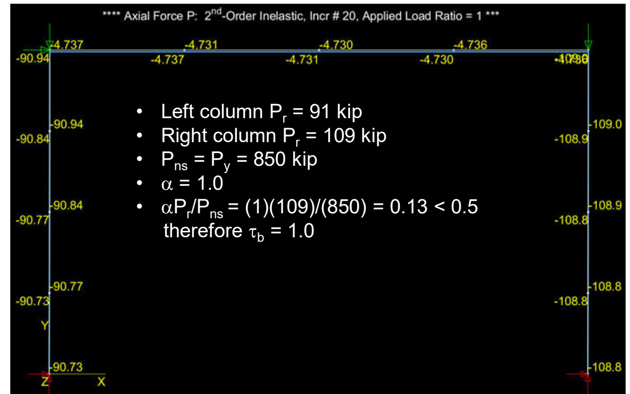
Case 1 Axial Load Effects (P_r)



Model NS24_L8_Example_1

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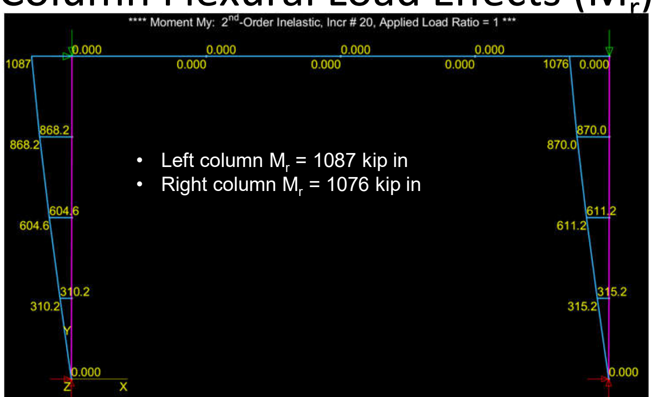
Case 1
Column Flexural Load Effects (M_r)



Model NS24_L8_Example_1

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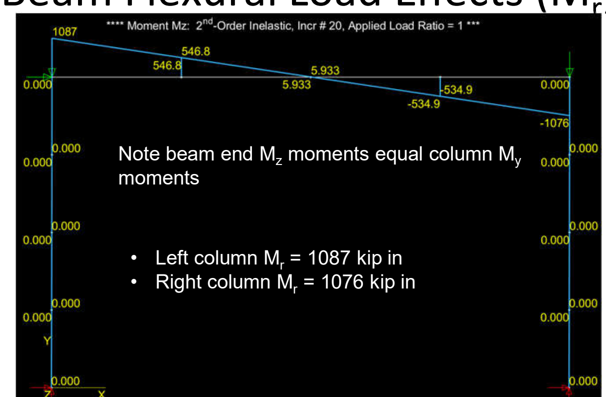
Case 1
Beam Flexural Load Effects (M_r)



Model NS24_L8_Example_1

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Case 1 Interaction Values W12x58 Left Column

(a) When $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \qquad \text{(H1-1a)}$$

(b) When $\frac{P_r}{P_c} < 0.2$ 0.15 (P_r = 91 kips, P_c = 603 kips)

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \quad 0.82 \qquad \text{(H1-1b)}$$

91 kips, 1206 kips, 1087 kip-in, 1464 kip-in

Case 1 Interaction Values W12x58 Right Column

(a) When $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \qquad \text{(H1-1a)}$$

(b) When $\frac{P_r}{P_c} < 0.2$ 0.18 (P_r = 109 kips, P_c = 603 kips)

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \quad 0.83 \qquad \text{(H1-1b)}$$

109 kips, 1206 kips, 1076 kip-in, 1464 kip-in

Case 1 Interaction Values W24x76 Beam

(a) When $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \qquad \text{(H1-1a)}$$

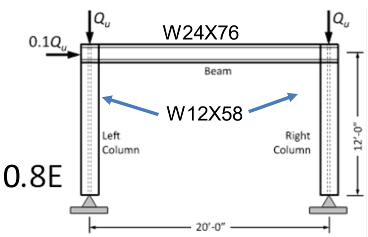
(b) When $\frac{P_r}{P_c} < 0.2$ 0.005 (P_r = 4.7 kips, P_c = 1008 kips)

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \quad 0.12 \qquad \text{(H1-1b)}$$

4.2 kips, 2016 kips, 1087 kip-in, 9000 kip-in

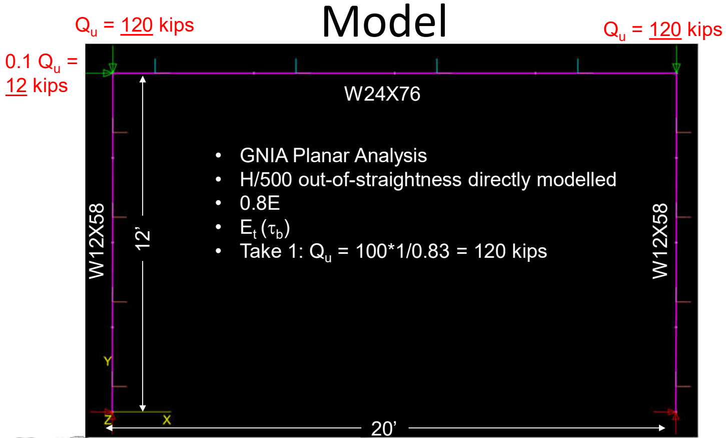
Learning Module 9 Method

- A992 STEEL
- Beam L_b = L_c = 0
- Stiffness reduction of 0.8E
- Three studies
  - Case 1: H/500 out-of-plumbness & τ_b
  - Case 2: Use Case 1 to find Q_u for DCR = 1.0
  - Case 3: Use notional loads instead of out-of-plumbness and τ_b



LRFD Methodology

Learning Module 9 Case 2 Take 1 Model

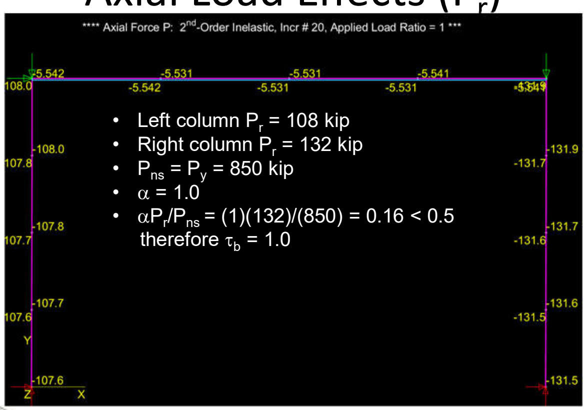


Learning Module 9 Case 2

General Stability Requirement	How Accomplished
Deformations	GNIA via MASTAN2
Second order effects	GNIA via MASTAN2
System imperfections on structure	Directly modelled (H/500)
Member imperfections on structure	0.8E via MASTAN2
Member imperfections on member strength	P_c
Stiffness reductions due to inelasticity on structure	0.8E and τ_b via MASTAN2
Stiffness reductions due to inelasticity on member strength	P_c
Uncertainty on structure	0.8E via MASTAN2
Uncertainty on member	P_c

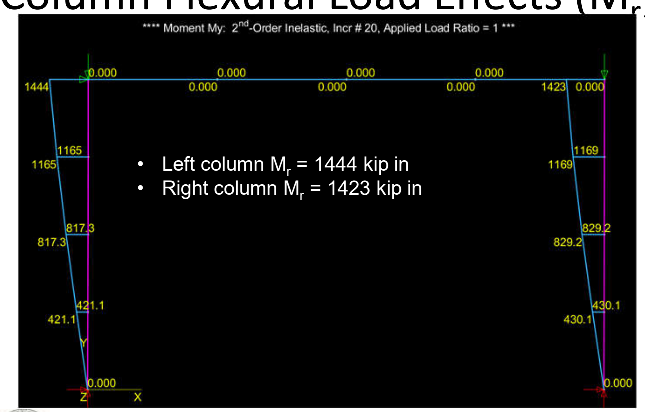
Model NS24_L8_Example_2

Case 2 Take 1 Axial Load Effects (P_r)



Model NS24_L8_Example_2

Case 2 Take 1 Column Flexural Load Effects (M_r)



Model NS24_L8_Example_2

Case 2 Take 1 Interaction Values W12x58 Right Column

When $\frac{P_r}{P_c} \ge 0.2$ 0.22 (132 kips / 603 kips)

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \le 1.0 \quad 1.08 \qquad \text{(H1-1a)}$$

132 kips / 603 kips; 1423 kip-in / 1464 kip-in

CASE 2 TAKE 1 Q_u = 120 kips

When $\frac{P_r}{P_c} < 0.2$ 0.18 (109 kips / 603 kips)

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \le 1.0 \quad 0.83 \qquad \text{(H1-1b)}$$

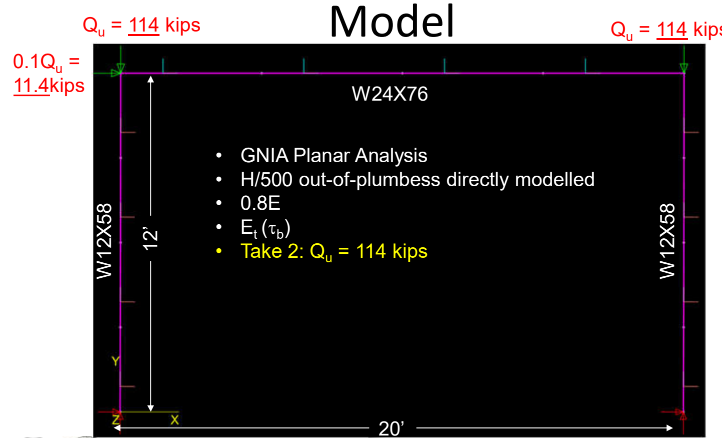
109 kips / 1206 kips; 1076 kip-in / 1464 kip-in

CASE 1 Q_u = 100 kips

Try about 2/3 of the way between two for Q_u = 114 kips

43

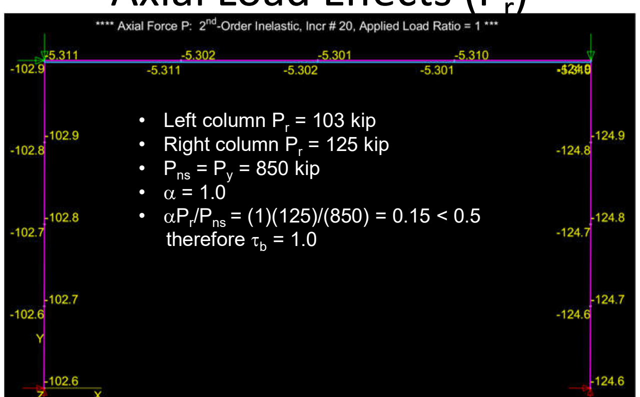
Learning Module 9 Case 2 Take 2 Model



Model NS24_L8_Example_2

44

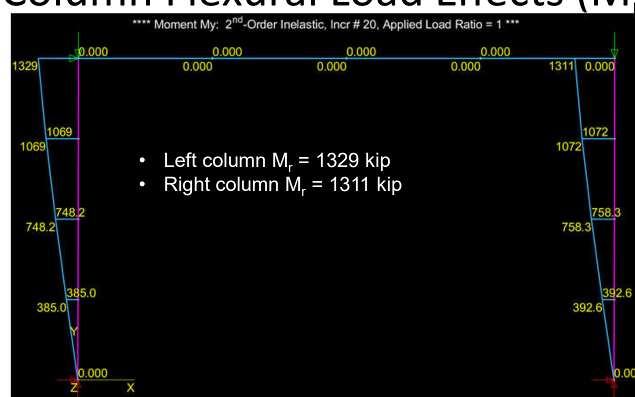
Case 2 Take 2 Axial Load Effects (P_r)



Model NS24_L8_Example_2

45

Case 2 Take 2 Column Flexural Load Effects (M_r)



Model NS24_L8_Example_2

46

Case 2 Take 2 Interaction Values W12x58 Right Column

When $\frac{P_r}{P_c} \geq 0.2$: 125 kips / 603 kips = 0.21

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \quad \text{(H1-1a)}$$

125 kips / 603 kips; 1311 kip-in / 1464 kip-in → 1.00 — CASE 2 TAKE 2, Q_u = 114 kips

When $\frac{P_r}{P_c} \geq 0.2$: 132 kips / 603 kips = 0.22

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \quad \text{(H1-1a)}$$

132 kips / 603 kips; 1423 kip-in / 1464 kip-in → 1.08 — CASE 2 TAKE 1, Q_u = 120 kips

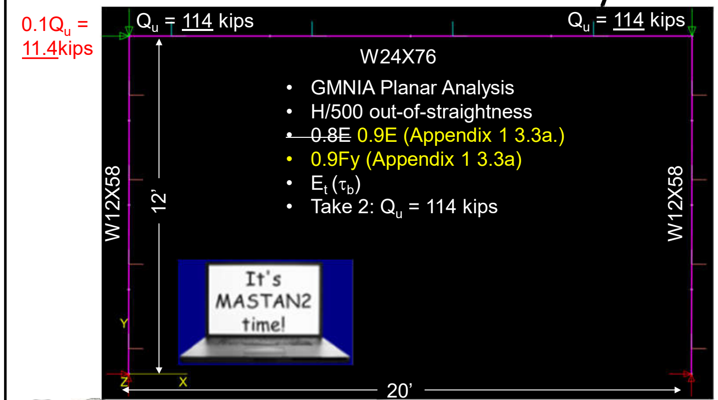
When $\frac{P_r}{P_c} < 0.2$: 109 kips / 603 kips = 0.18

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \quad \text{(H1-1b)}$$

109 kips / 1206 kips; 1076 kip-in / 1464 kip-in → 0.83 — CASE 1, Q_u = 100 kips

47

Case 2 Take 2 2nd Order Inelastic Analysis



Model NS24_L8_Example_3

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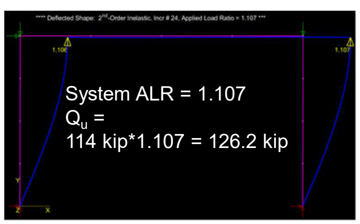
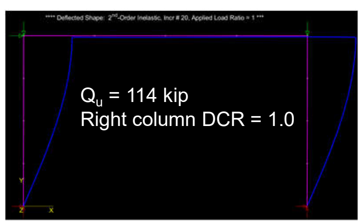
Case 2 Take 2 Inelastic Analysis vs Direct Analysis Method

Direct Analysis Method-GMNIA (Appendix 1.3)



Direct Analysis Method-GNIA (Chapter C)



Model NS24_L8_Example_3

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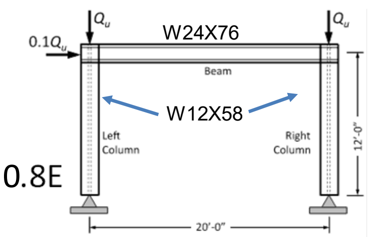
Learning Module 9 Method

- A992 STEEL
- Beam $L_b = L_c = 0$
- Stiffness reduction of 0.8E
- Three studies
  - Case 1: H/500 out-of-plumbness & τ_b
  - Case 2: Use Case 1 to find Q_u for DCR = 1.0
  - Case 3: Use notional loads instead of out-of-plumbness and τ_b



LRFD Methodology

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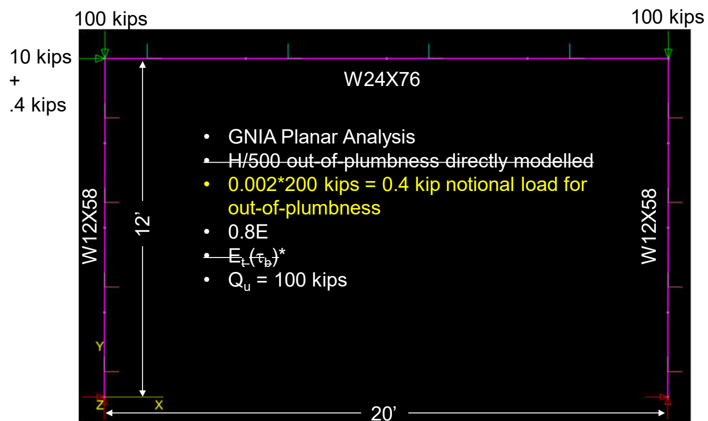
Learning Module 9 Case 3 Model



*Recall $\alpha P_r/P_{ns}$<0.5 so τ_b = 1.0 and no additional notional load required

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Learning Module 9 Case 3

General Stability Requirement	How Accomplished
Deformations	GNIA via MASTAN2
Second order effects	GNIA via MASTAN2
System imperfections on structure	Notional Load ($0.002\Sigma Q_u$)
Member imperfections on structure	0.8E via MASTAN2
Member imperfections on member strength	P_c
Stiffness reductions due to inelasticity on structure	0.8E via MASTAN2
Stiffness reductions due to inelasticity on member strength	P_c
Uncertainty on structure	0.8E via MASTAN2
Uncertainty on member	P_c

Model NS24_L8_Example_4

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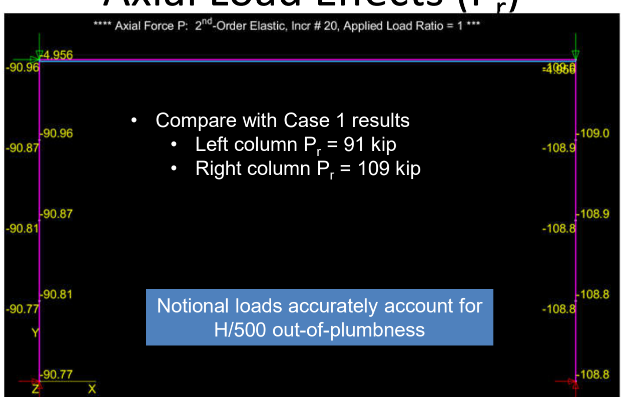
Case 3
Axial Load Effects (P_r)



Model NS24_L8_Example_4

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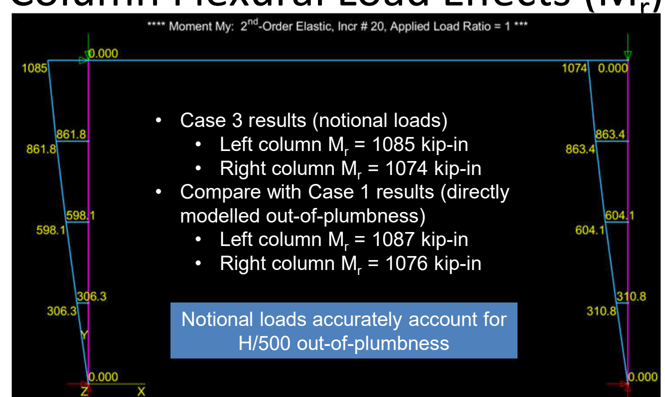
Case 3
Column Flexural Load Effects (M_r)



Model NS24_L8_Example_4

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Summary

- General stability requirements "the BIG 5" must be considered
- The Direct Analysis Method in Chapter C is based on a second order elastic analysis and is one way to account for general stability requirements
- There are 4 other AISC stability design methods in Appendices 1 and 7 that can be used to account for the general stability requirements

And now heeeeeeeeeeeeeeere's Ronny!

55

Design and analysis, perfect together…

LOOKING TO THE FUTURE BY STARTING WITH THE PAST…

56

Thoughts on future of advanced analysis in design…

Fifty-foot Two-span Continuous Gabled Frame Test at Lehigh University

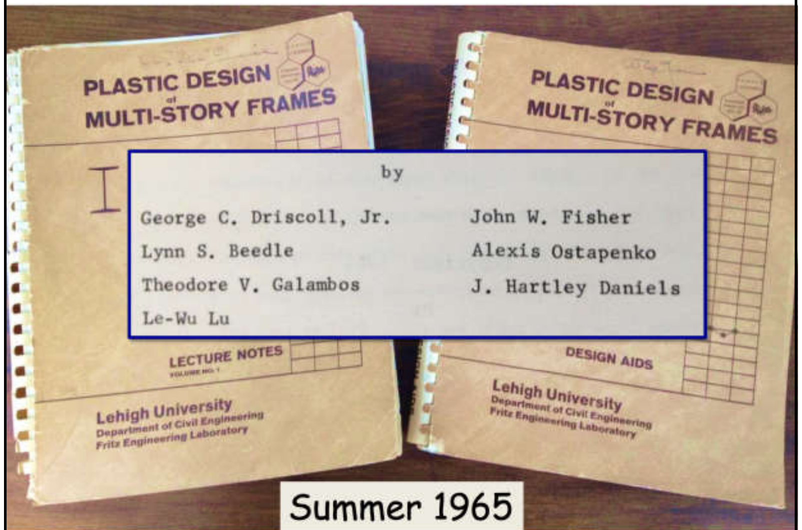
57

AISC, 6th Edition
PART 2

SECTION 2.1 SCOPE (ADOPTED NOVEMBER 30, 1961)

Subject to the limitations contained herein, simple or continuous beams, one and two-story rigid frames classified as Type 1 construction in Sect. 1.2 and similar portions of structures rigidly constructed so as to be continuous over at least one interior support,* may be proportioned on the basis of plastic design, i.e., of their maximum strength. This strength, as determined by rational analysis, shall not be less than that required to support 1.70 times the given live load and dead load for simple and continuous beams. For continuous frames it shall not be less than 1.85 times the given live load and dead load, nor 1.40 times these loads acting in conjunction with 1.40 times any specified wind or earthquake forces.

58



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Plastic Design of a 14-Story Apartment Building

WILLIAM A. BENNETT

AISC ENGINEERING JOURNAL
APRIL / 1967

Figure 1

William A. Bennett is Structural Engineer, George E. Yurchison, Architect, Rochester, N. Y.

Plastic Design of a 14-Story Apartment Building

WILLIAM A. BENNETT

AISC ENGINEERING JOURNAL
APRIL / 1967

Bennett indicates…Better understanding of stability and strength limit state behavior resulted in a better design

- ✓ More rational method
- ✓ Significant economies gained
- ✓ Included P-Δ effects
- ✓ Track limit state behavior
- ✓ More flexibility in design process

61

"It is expected that further research will produce computer programs which can provide solutions for extremely complex frames and include more secondary effects, as well as proportional and nonproportional loading of frames."

Plastic Design in Steel - Guide and Commentary
ASCE, 1971

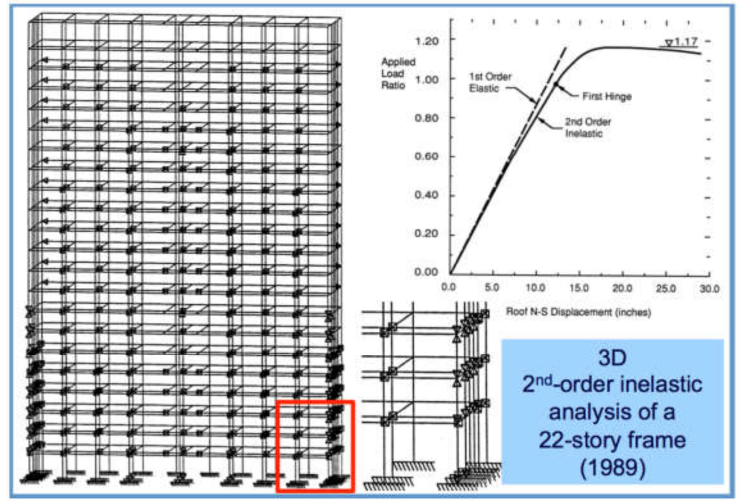
62

Computer programs – lots of further research…

1970's → 1990's

- Computing hardware
- Graphical user interfaces
- Geometric nonlinear:
  - 2^{nd}-order effects (P-Δ , P-δ)
- Material nonlinear:
  - Plastic hinge vs. zone

63



3D 2^{nd}-order inelastic analysis of a 22-story frame (1989)

64

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
Cornell University
HOLLISTER HALL, ITHACA, NY 14853-3501

November 13, 1990

MEMORANDUM TO: R. Bjorhovde
W. F. Chen
G. Haaijer
J. S. B. Iffland
J. W. Larson
S. D. Lindsey
H. Pak
J. A. Yura

FROM: W. McGuire Bill

SUBJECT: AISC Task Committee 117 on Inelastic Analysis and Design

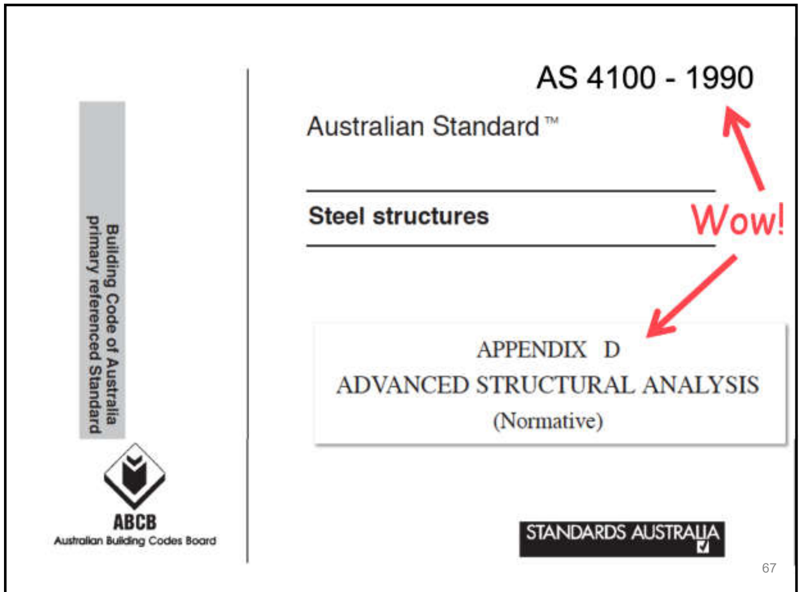
Computer programs – lots of further research…

1970's → 1990's

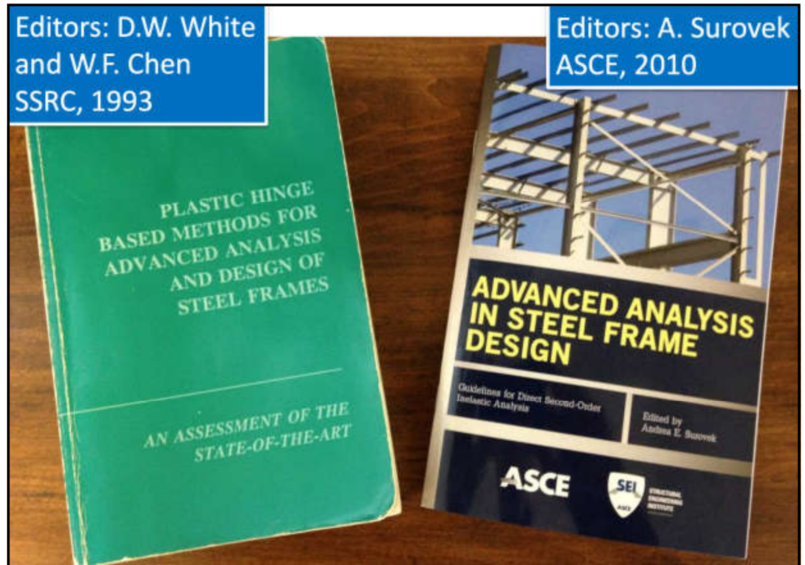
- Computing hardware
- Graphical user interfaces
- Geometric nonlinear:
  - 2^{nd}-order effects (P-Δ , P-δ)
- Material nonlinear:
  - Plastic hinge vs. zone

U.S. steel design profession slow to adopt limit states design philosophy (LRFD)

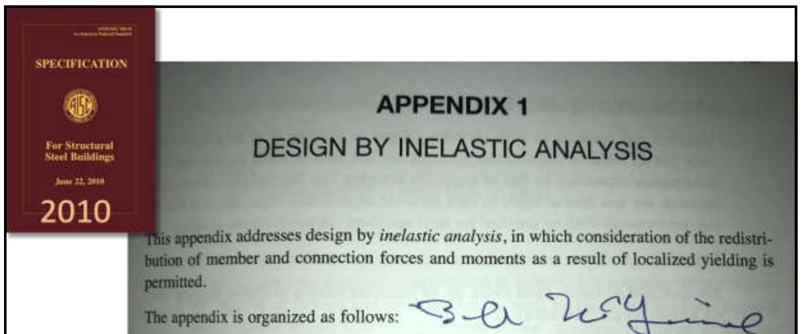
66



67



68



AISC Sub-Committee on Inelastic Analysis and Design (2007-2010)

Bill Baker	Bill McGuire
Greg Deierlein	Chia-Ming Uang
Subhash Goel	Don White
Rich Henige	Ron Ziemian, Chair
Dick Kaehler	Brent Leu, AISC

69

Inelastic analysis and seismic design, perfect together…

- Over the years, the use of pushover analyses has become quite common, especially for structures in high seismic areas
- Today, the use of full nonlinear, or at least material nonlinear, time history analyses are now sometimes being employed
- With this in mind, AISC has recently formed an ad hoc TG on Seismic Analysis (John Hooper – Chair)
  - Direct Analysis Method dovetail with seismic
  - AISC 341 may include a new Appendix 1 - Design Verification Using Nonlinear Response History Analysis

70

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71

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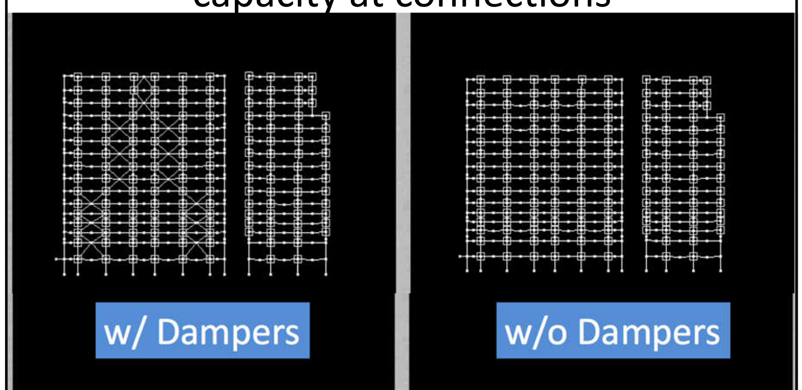
72

Caltrans District 4 Office Building retrofitted with viscous dampers (Oakland, CA)

73

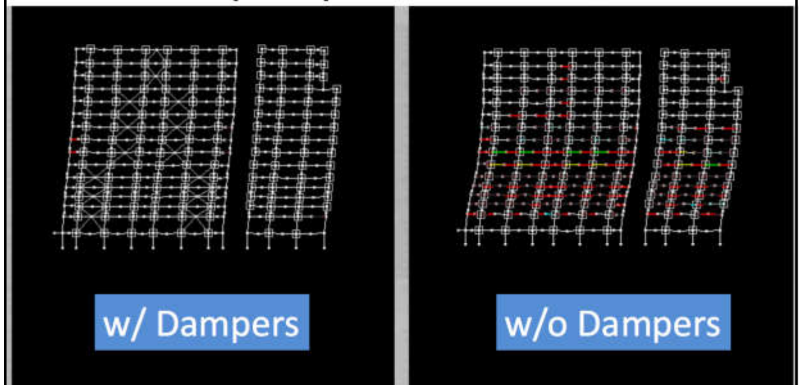
Caltrans District 4 Office Building – assess rotational deformation demand-to-capacity at connections



Nonlinear time history analysis results Degenkolb

74

Caltrans District 4 Office Building – assess rotational deformation demand-to-capacity at connections



Nonlinear time history analysis results

Degenkolb

75

Future of Advanced Analysis in Design

- **Focus will shift to better modeling the load effects…Dynamic loading due to Earth, Wind, & Fire**
- Future speeds of computer hardware/software will permit amazingly sophisticated nonlinear time history analyses…yeah!
- But…if we could suddenly increase the speed of our computers by 1,000x, would the SE profession?
  a) Use existing analysis capabilities, but quadruple the number of load cases currently being investigated
  b) Continue to investigate the same number of load cases, but perform much more sophisticated analyses of many of them
- Virtual reality, artificial intelligence, and big data?

76

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78

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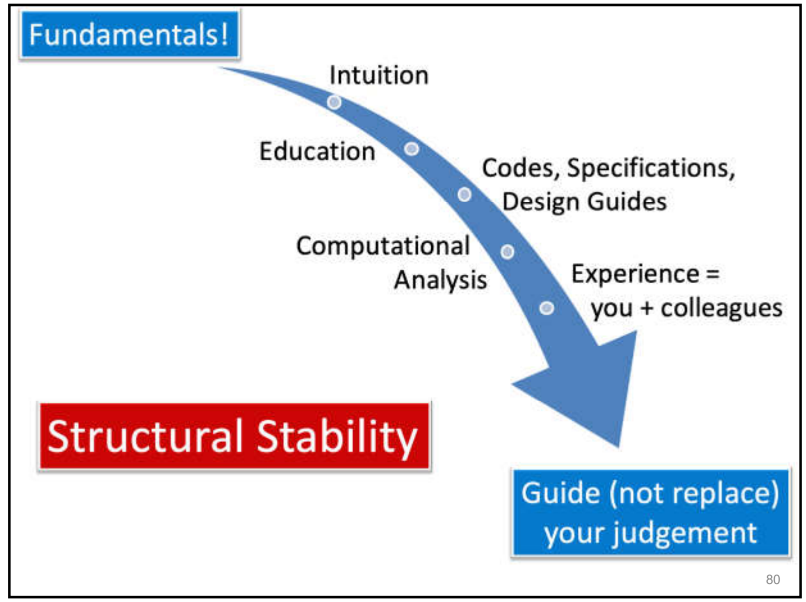
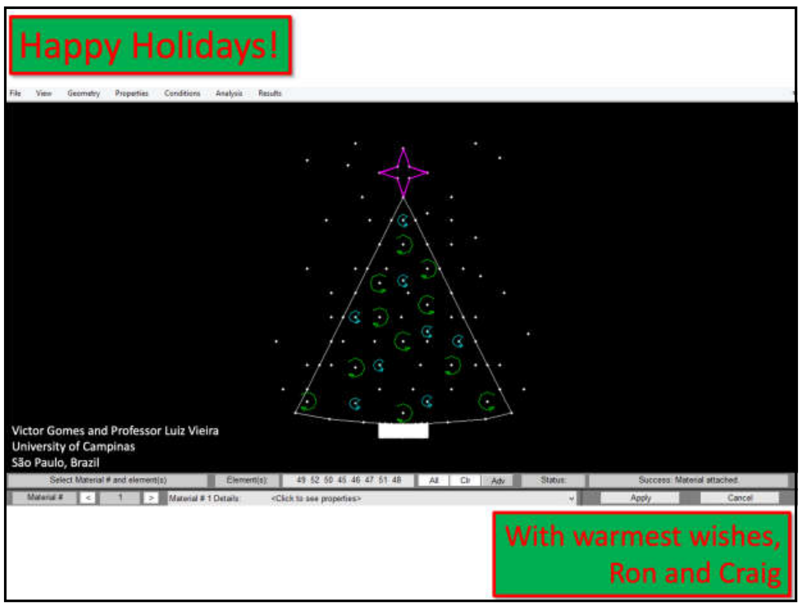
79





Thank You!

Hope you enjoyed this lecture!

Smarter.
Stronger.
Steel.

Single-Session Registrants

CEU / PDH Certificates

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

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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

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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8-Session Registrants

Course Resources

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

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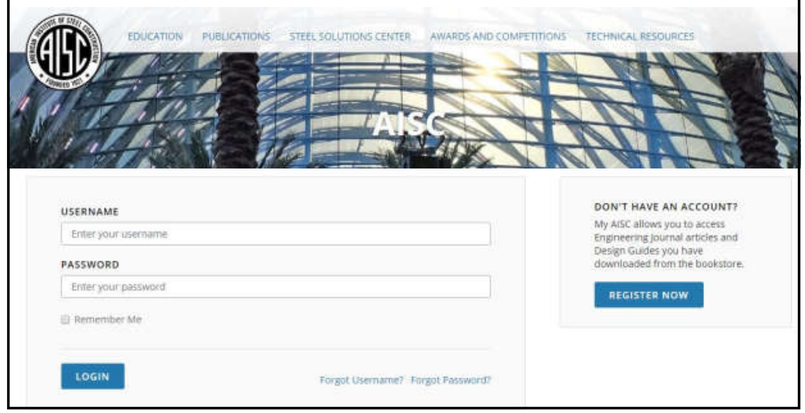
8-Session Registrants

Course Resources

Go to www.aisc.org and sign in.



8-Session Registrants

Course Resources

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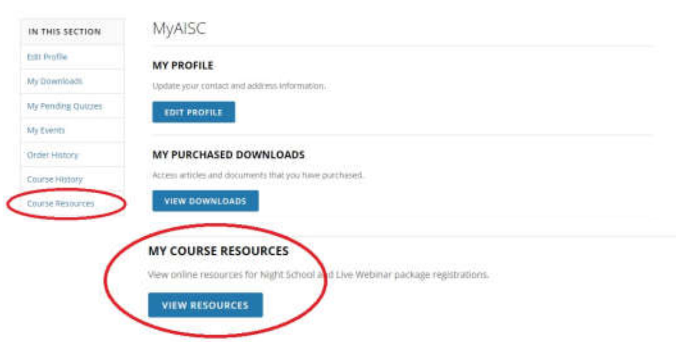
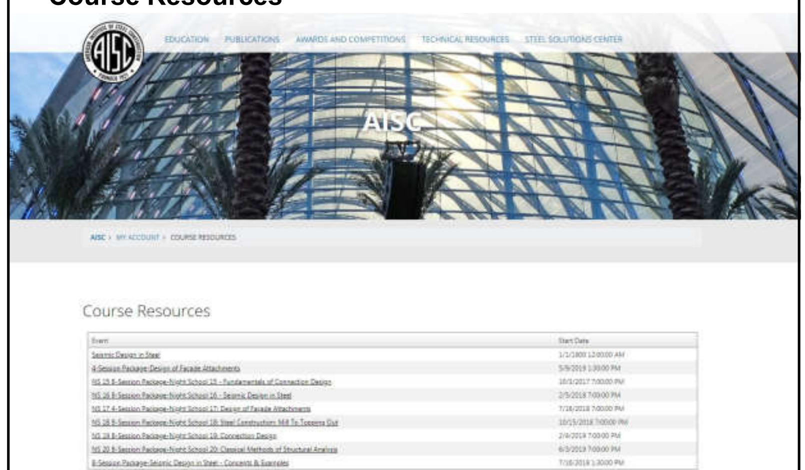


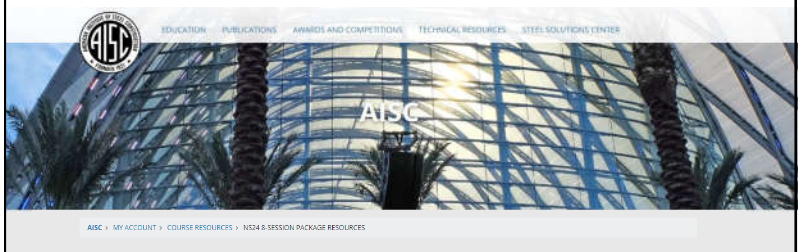
8-Session Registrants

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	

AISC | Thank you.

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