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**Night School**

Thank you for joining our live webinar today.  
We will begin shortly. Please standby.

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

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



  **Smarter.  
Stronger.  
Steel.**

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  **Smarter.  
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## AISC Live Webinars

### 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.



## AISC Live Webinars

### 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.



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

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



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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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Stronger.  
Steel.



## Course Overview (2)

Strength/  
Weight

Stiffness/  
Weight

Competitive  
\$

Slender Systems, Members, and Cross-sections

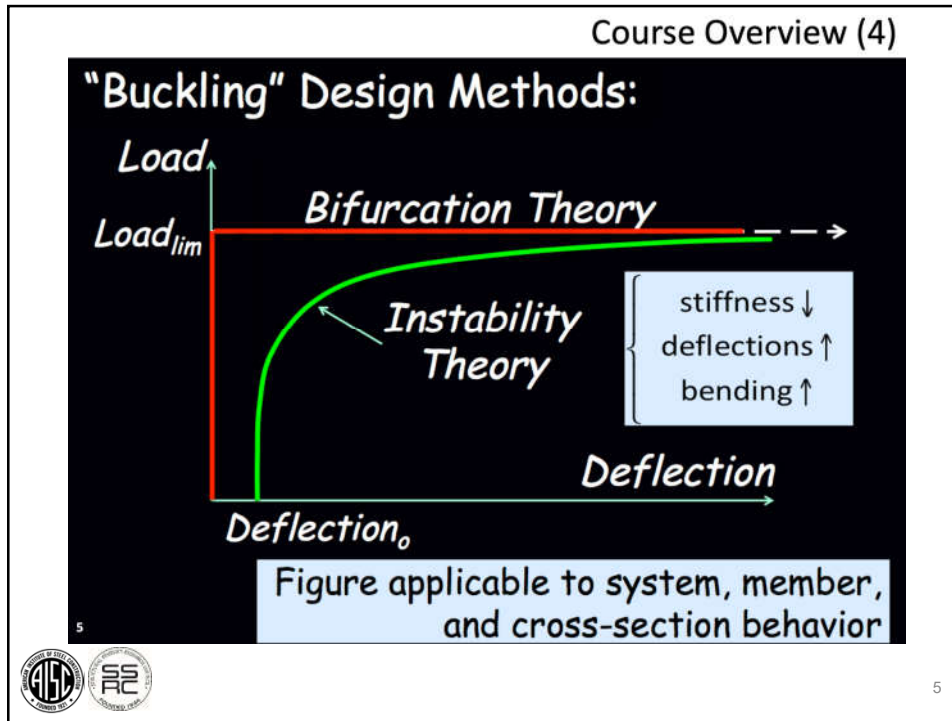
Design for Stability!

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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 (5)

Analysis acronyms:

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

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

**GNA:** geometric nonlinear analysis; **2<sup>nd</sup>-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; **1<sup>st</sup>-order inelastic analysis**; assumes equilibrium on the undeformed shape and accounts for yielding, with no initial imperfections

**GMNIA:** geometric and material nonlinear analysis; **2<sup>nd</sup>-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

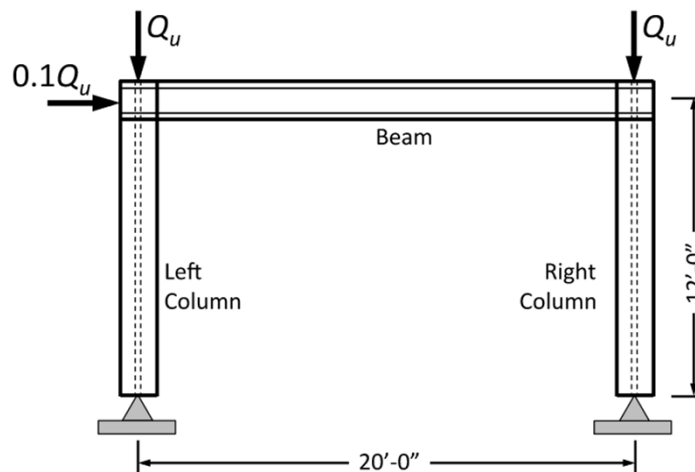
Systems – Session 7 & 8



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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 ( $P-\Delta$  and  $P-\delta$ )
  - 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

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 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)
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(3) Consider geometric imperfections <i>This includes joint-position imperfections<sup>I</sup> (which affect structure response) and member imperfections (which affect structure response and member strength)</i>	Effect of system imperfections on structure response Effect of member imperfections on structure response Effect of member imperfections on member strength	Same as DM, second option only (by reference to C2.2b)  All these effects are considered by using $L_c = KL$ from a side-sway 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 side-sway buckling analysis in the member strength check
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(5) Consider uncertainty in strength and stiffness <i>This affects structure response and member strength</i>	Effect of stiffness/strength uncertainty on structure response Effect of stiffness/strength uncertainty on member strength	Included in the stiffness reduction specified in C2.3 Included in member strength formulas, with $L_c = L$

Basic Requirements must be considered, but to what degree is based on Engineer's judgement

Note that stiffness reduction and member strength formulas account for multiple requirements

Big 5

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# Session 7 in AISC 360-16 Direct Analysis Method

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<sup>H</sup> In typical building structures, the "joint-position imperfections" refers to column out-of-plumbness.  
<sup>I</sup> Second-order effects may be considered either by a computational P-Δ and P-δ analysis or by the approximate method (using B<sub>1</sub> and B<sub>2</sub> multipliers) specified in Appendix 8.

Deflected Shape: 2<sup>10</sup>-Order Elastic, Incr # 20, Applied Load Ratio = 1



Accomplished via Computational Analysis (GNA)

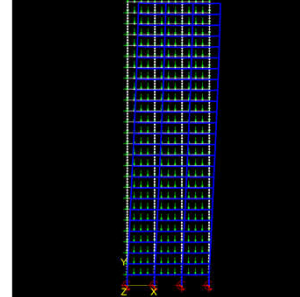
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Deflected Shape: 2<sup>10</sup>-Order Elastic, Incr # 20, Applied Load Ratio = 1



$$N_i = 0.002\alpha Y_i \quad (C2-1)$$

where  
 $\alpha = 1.0$  (LRFD);  $\alpha = 1.6$  (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)



## Session 7 in AISC 360-16 Direct Analysis Method

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<sup>H</sup> Second-order effects may be considered either by a computational P- $\Delta$  and P- $\delta$  analysis or by the approximate method (using  $\delta_1$  and  $\delta_2$  multipliers) specified in Appendix 8.

- 0.8 factor applied to all stiffnesses contributing to structure stability



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- 0.8 factor applied to all stiffnesses contributing to structure stability
- Additional  $\tau_b$  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  $\tau_b$



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# Session 7 in AISC 360-16 Direct Analysis Method

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H In typical building structures, the "joint-position imperfections" refers to column out-of-plumbness.  
I Second-order effects may be considered either by a computational P-Δ and P-δ analysis or by the approximate method using  $\delta_2$  and  $\delta_1$  multipliers specified in Appendix B.

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

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

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

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

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

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

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

where

$A_g$  = gross cross-sectional area of member, in.<sup>2</sup> (mm<sup>2</sup>)  
 $E$  = modulus of elasticity of steel = 29,000 ksi (200 000 MPa)

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



## 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  $\frac{P_r}{P_c} \geq 0.2$

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

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

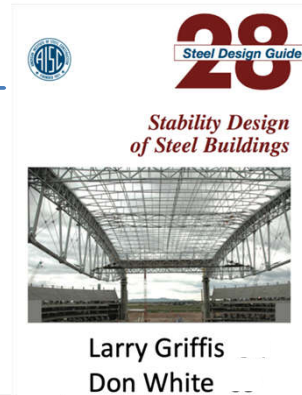
$$\frac{P_r}{2P_c} + \left( \frac{M_{rx} + M_{ry}}{M_{cx} + M_{cy}} \right) \leq 1.0 \quad (H1-1b)$$

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



## 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)



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

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



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## Learning Module 9 Objectives

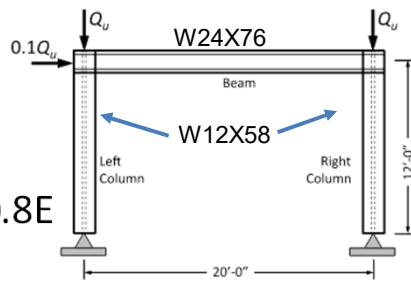
- Apply the Direct Analysis Method to assess structural system adequacy
- Use rigorous second-order analysis to determine beam-column required strength
- Use notional loads to simulate initial imperfections and stiffness reduction due to partial yielding
- Use interaction equations to check member adequacy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



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## Learning Module 9 Method

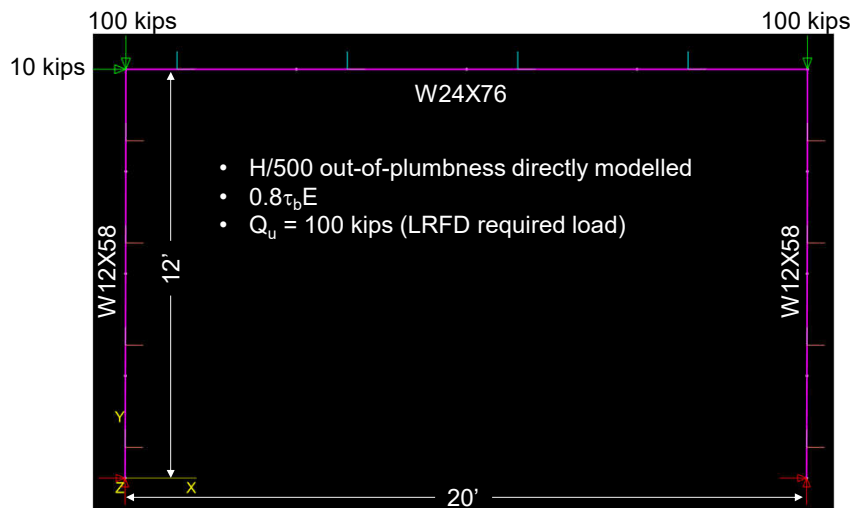
- A992 STEEL
- Beam  $L_b = L_c = 0$
- Stiffness reduction of  $0.8E$
- Three studies
  - Case 1: H/500 out-of-plumbness &  $\tau_b$
  - Case 2: Use Case 1 to find  $Q_u$  for DCR = 1.0
  - Case 3: Use notional loads instead of out-of-plumbness and  $\tau_b$



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  $\phi$  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  $\phi$  factors are included



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

## Stability Sensitive Structural Systems

- Indicators include:
  - B<sub>1</sub> and B<sub>2</sub> factors
  - Elastic/Inelastic critical buckling load factors  $\lambda_{cr}$  and mode shapes
  - Natural periods and mode shapes

$$B_2 = \frac{1}{1 - \frac{\alpha P_{story}}{P_{e story}}} \quad P_{e story} = R_M \frac{HL}{\Delta H}$$

• Eurocode uses ratio  $\lambda_{cr}$  (think LBA) between the the critical buckling loading and applied loading :

- $\lambda_{cr} < 3$ , must employ rigorous 2<sup>nd</sup>-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 ( $B_2 < 1.1$ )

Recall this slide from Session 7

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## Case 1

### Elastic Critical Load to Estimate B<sub>2</sub>

Deflected Shape: Elastic Critical Load, Mode # 1, Applied Load Ratio = 2.8697

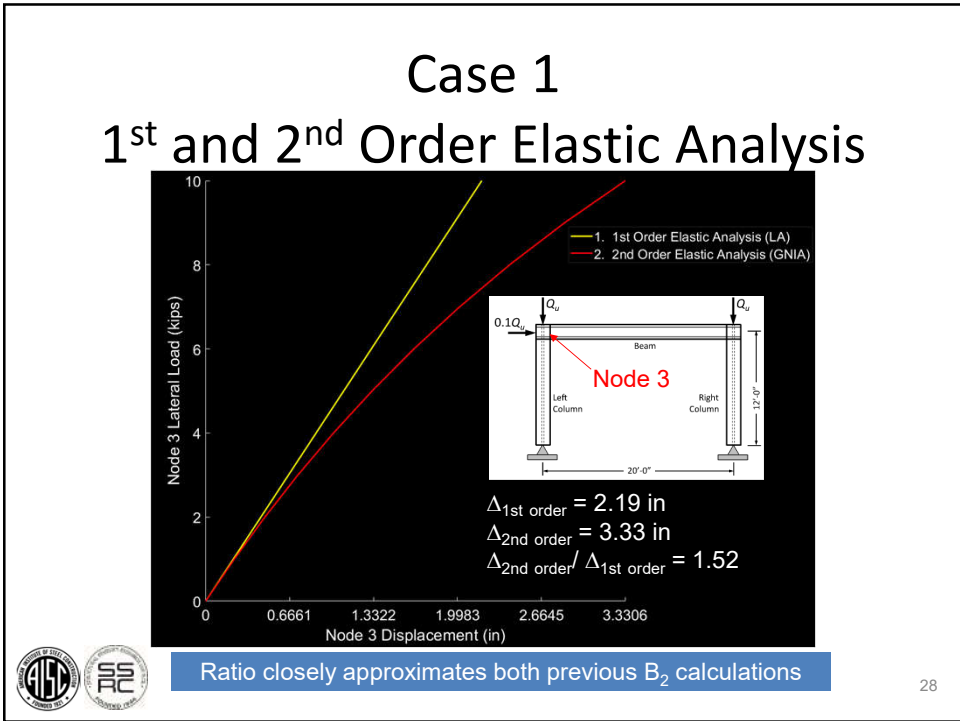
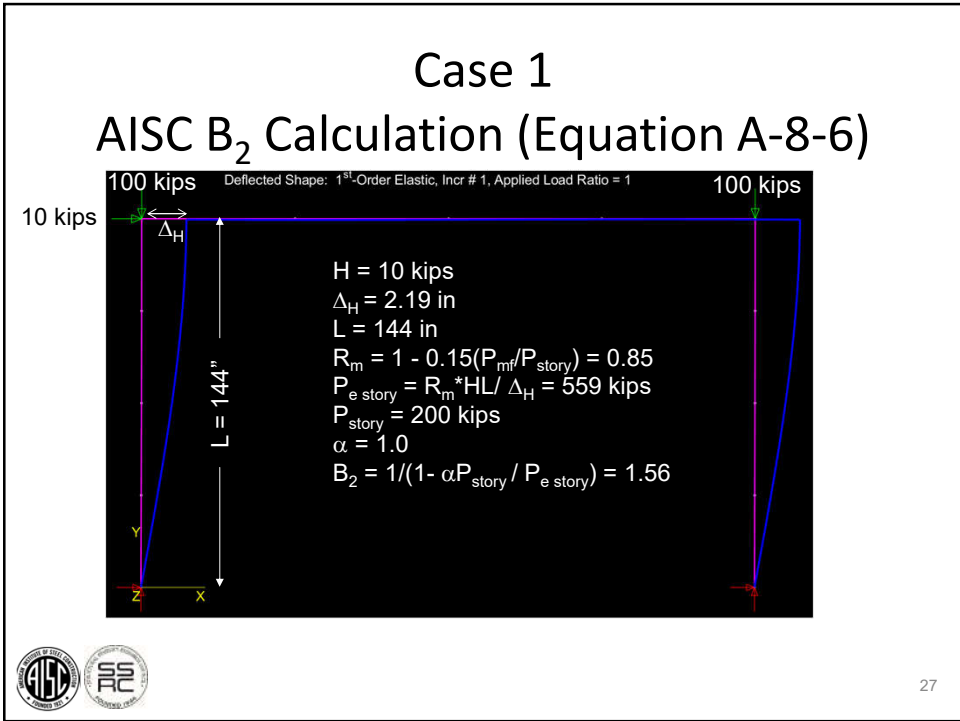
$\lambda_{cr} = 2.87$  (less than 3)  
 Use  $\lambda_{cr}$  to estimate B<sub>2</sub>  
 $B_2 \approx 1/(1 - 1/\lambda_{cr}) = 1.53$

Note: P<sub>e story</sub> = 2 x 100 kips x 2.87 = 574 kips

System is sensitive to 2<sup>nd</sup> order effects

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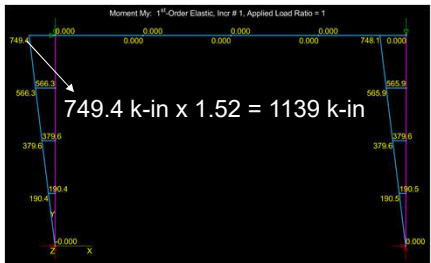




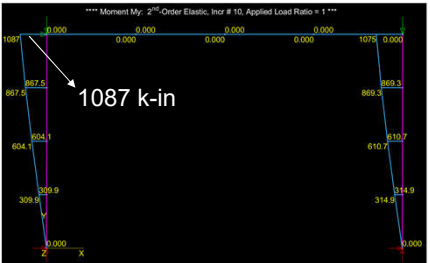
## Case 1

### 1<sup>st</sup> and 2<sup>nd</sup> Order Elastic Analysis



**1<sup>st</sup> Order Elastic Analysis (LA)**



**2<sup>nd</sup> Order Elastic Analysis (GNA)**



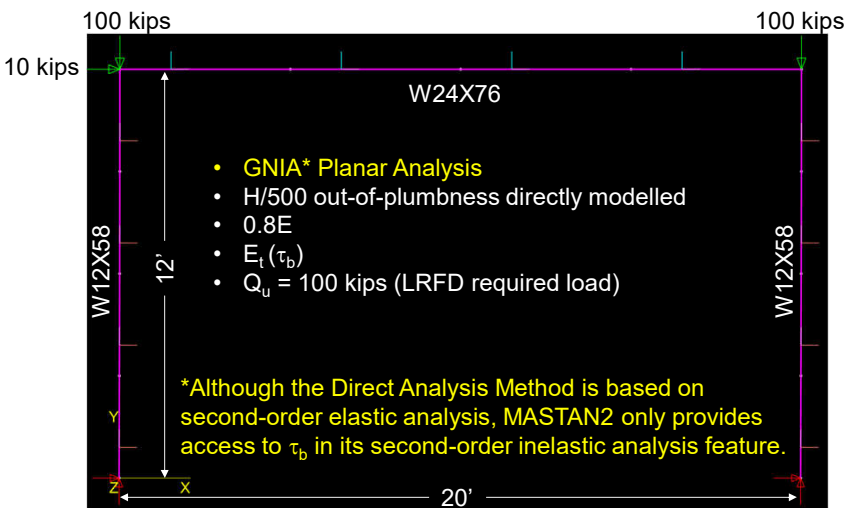
Using the 2<sup>nd</sup> to 1<sup>st</sup> order drift ratio as moment amplifier gives a conservative estimate within 5% of the 2<sup>nd</sup> order moment

System is sensitive to 2<sup>nd</sup> order effects



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## Learning Module 9 Case 1 Model



- GNIA\* Planar Analysis**
- H/500 out-of-plumbness directly modelled
- 0.8E
- $E_t(\tau_b)$
- $Q_u = 100$  kips (LRFD required load)

\*Although the Direct Analysis Method is based on second-order elastic analysis, MASTAN2 only provides access to  $\tau_b$  in its second-order inelastic analysis feature.



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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 $\tau_b$ via MASTAN2
Stiffness reductions due to inelasticity on member strength	$P_c$
Uncertainty on structure	0.8E via MASTAN2
Uncertainty on member	$P_c$

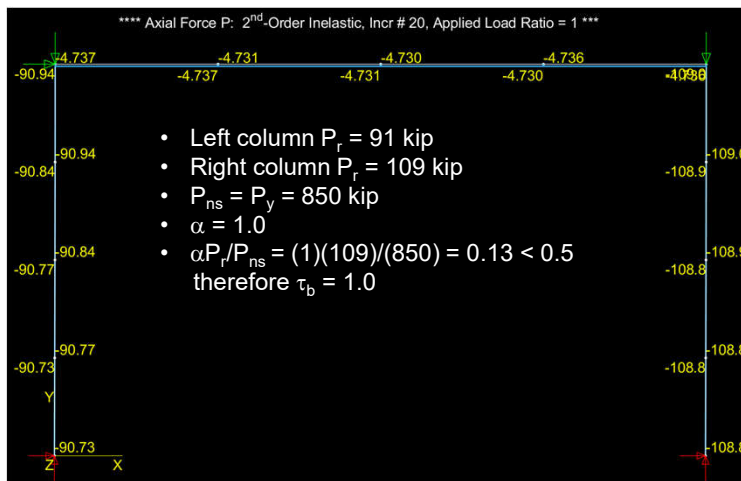


Model NS24\_L8\_Example\_1



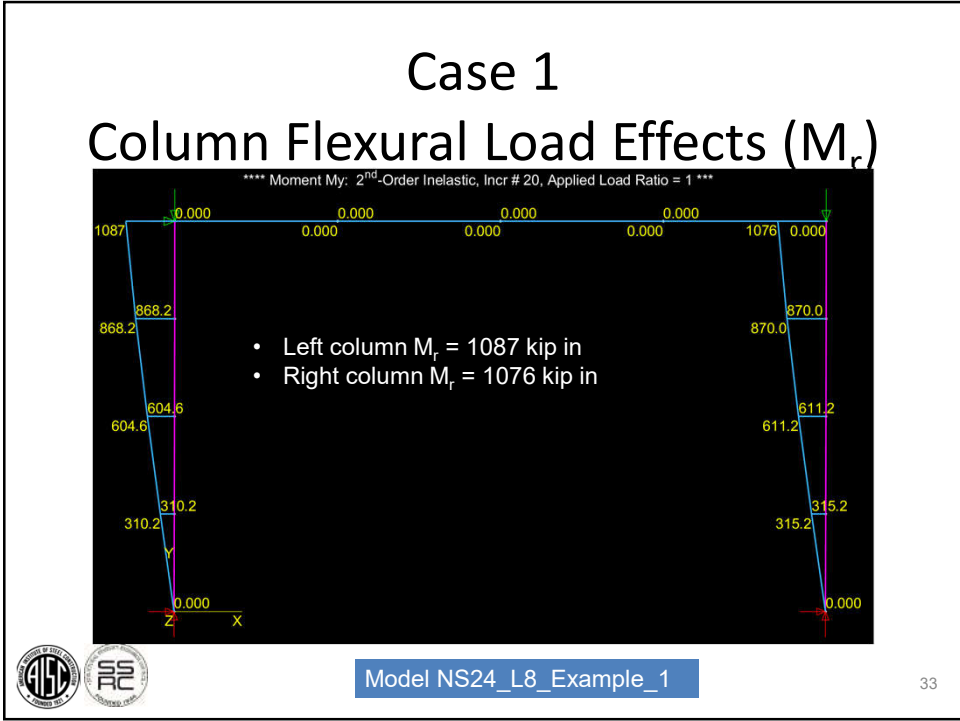
31

## Case 1 Axial Load Effects ( $P_r$ )

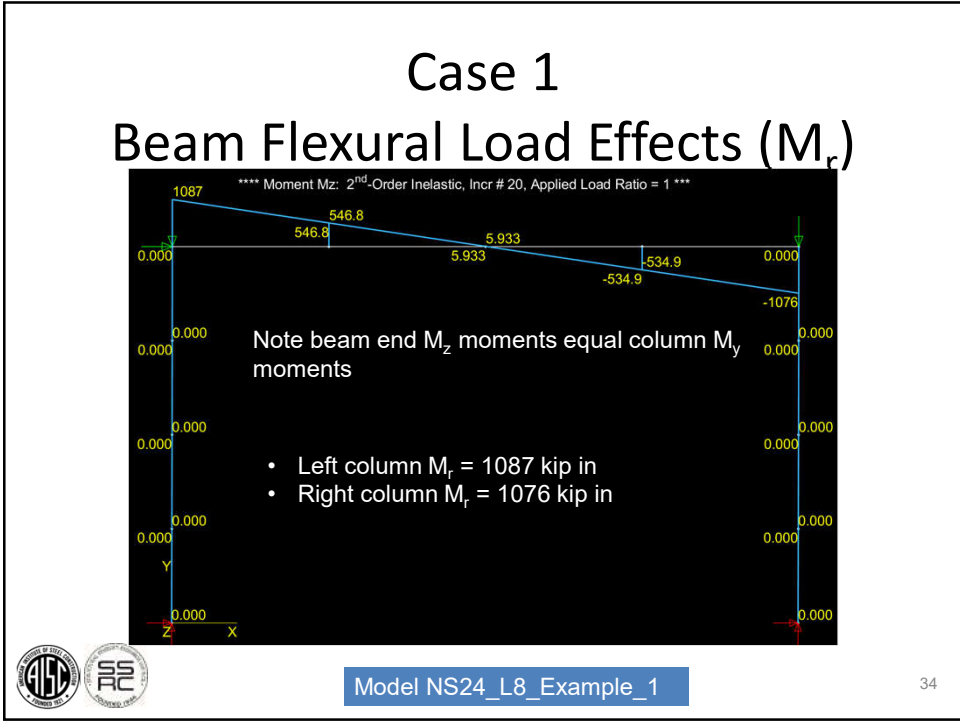


Model NS24\_L8\_Example\_1

32



33



34



## Case 1 Interaction Values W12x58 Left Column

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

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

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

91 kips  $\frac{P_r}{P_c} = 0.15$

603 kips  $\frac{P_r}{P_c} < 0.2$

91 kips  $\frac{P_r}{P_c} < 0.2$

1087 kip-in  $\frac{P_r}{P_c} < 0.2$

1206 kips  $\frac{P_r}{P_c} < 0.2$

1464 kip-in  $\frac{P_r}{P_c} < 0.2$

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



35

## Case 1 Interaction Values W12x58 Right Column

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

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

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

109 kips  $\frac{P_r}{P_c} = 0.18$

603 kips  $\frac{P_r}{P_c} < 0.2$

109 kips  $\frac{P_r}{P_c} < 0.2$

1076 kip-in  $\frac{P_r}{P_c} < 0.2$

1206 kips  $\frac{P_r}{P_c} < 0.2$

1464 kip-in  $\frac{P_r}{P_c} < 0.2$

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



36

## Case 1 Interaction Values W24x76 Beam

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

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

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

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

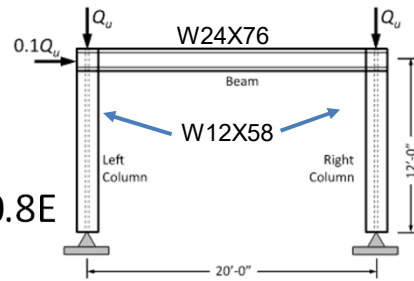
4.7 kips  $\frac{P_r}{P_c}$  0.005  
 1008 kips  $2P_c$  4.2 kips  $\frac{M_{rx}}{M_{cx}}$  1087 kip-in  $\frac{M_{ry}}{M_{cy}}$  0.12  
 2016 kips  $2P_c$  9000 kip-in



37

## 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 &  $\tau_b$
  - Case 2: Use Case 1 to find  $Q_u$  for DCR = 1.0
  - Case 3: Use notional loads instead of out-of-plumbness and  $\tau_b$



LRFD Methodology

38

## Learning Module 9 Case 2 Take 1 Model

$Q_u = 120$  kips

$0.1 Q_u = 12$  kips

$Q_u = 120$  kips

W24X76

- GNIA Planar Analysis
- H/500 out-of-straightness directly modelled
- 0.8E
- $E_t(\tau_b)$
- Take 1:  $Q_u = 100 * 1/0.83 = 120$  kips

W12X58

12'

20'

39

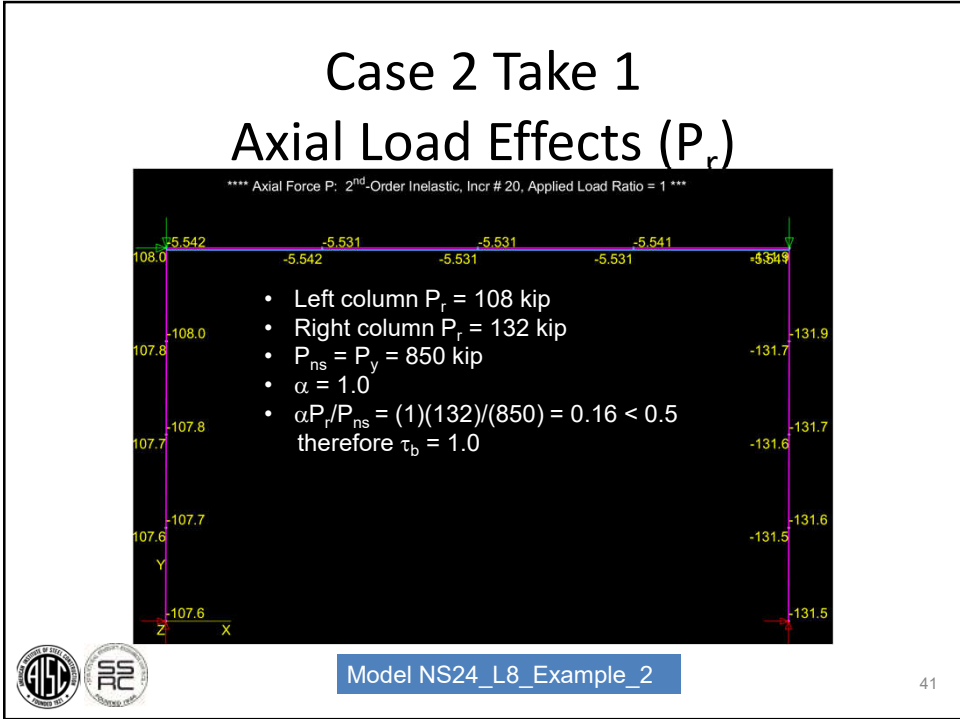
## Learning Module 9 Case 2

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 $\tau_b$ via MASTAN2
Stiffness reductions due to inelasticity on member strength	$P_c$
Uncertainty on structure	0.8E via MASTAN2
Uncertainty on member	$P_c$

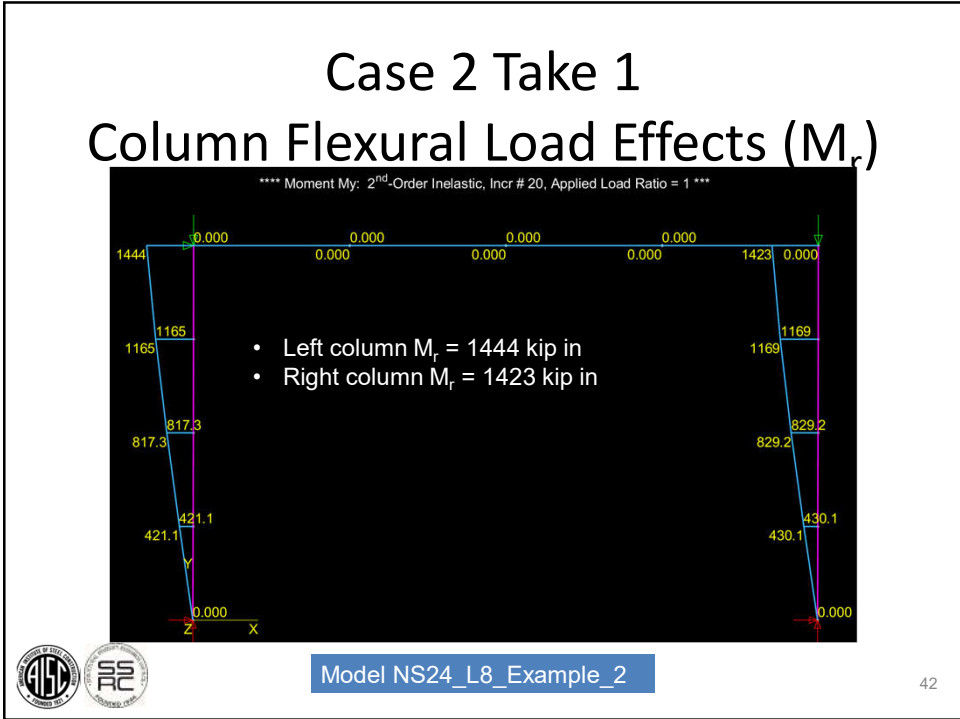
Model NS24\_L8\_Example\_2

40





41



42



## Case 2 Take 1 Interaction Values W12x58 Right Column


132 kips  
When  $\frac{P_r^*}{P_c} \geq 0.2$  0.22  
603 kips

132 kips 1423 kip-in  
 $\frac{P_r^*}{P_c} + \frac{8}{9} \left( \frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0$  1.08 CASE 2 TAKE 1  
603 kips 1464 kip-in  $Q_u = 120$  kips (H1-1a)

109 kips  
When  $\frac{P_r^*}{P_c} < 0.2$  0.18  
603 kips

109 kips 1076 kip-in  
 $\frac{P_r^*}{2P_c} + \left( \frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0$  0.83 CASE 1  
1206 kips 1464 kip-in  $Q_u = 100$  kips (H1-1b)

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



43

## Learning Module 9 Case 2 Take 2 Model

$Q_u = 114$  kips  $Q_u = 114$  kips

$0.1Q_u = 11.4$  kips

W24X76


- GNIA Planar Analysis
- H/500 out-of-plumbess directly modelled
- 0.8E
- $E_t(\tau_b)$
- Take 2:  $Q_u = 114$  kips

12'

20'

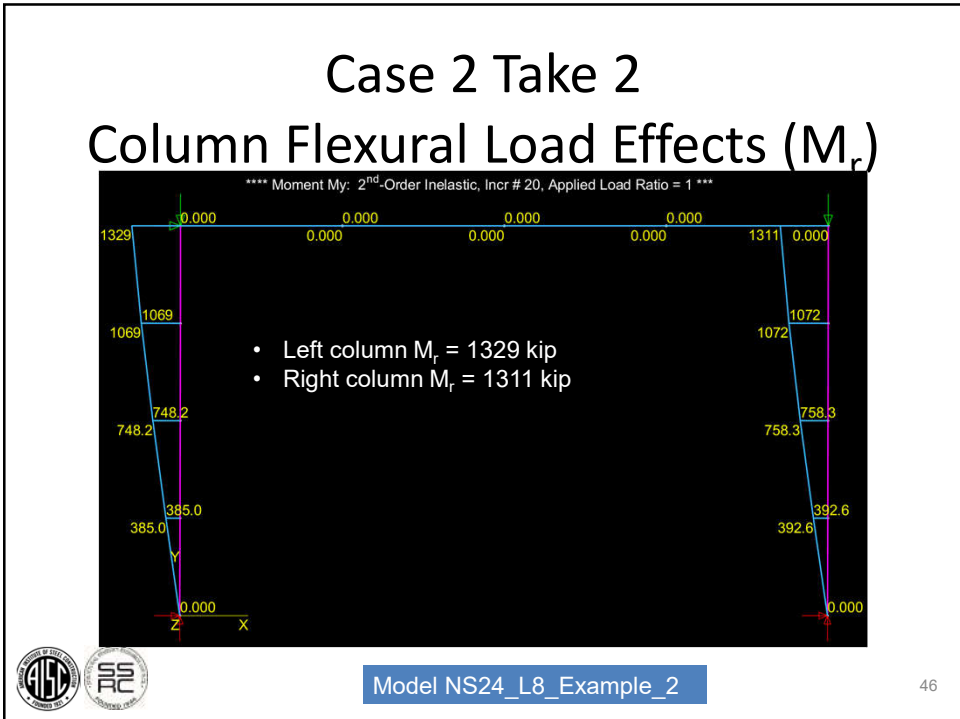
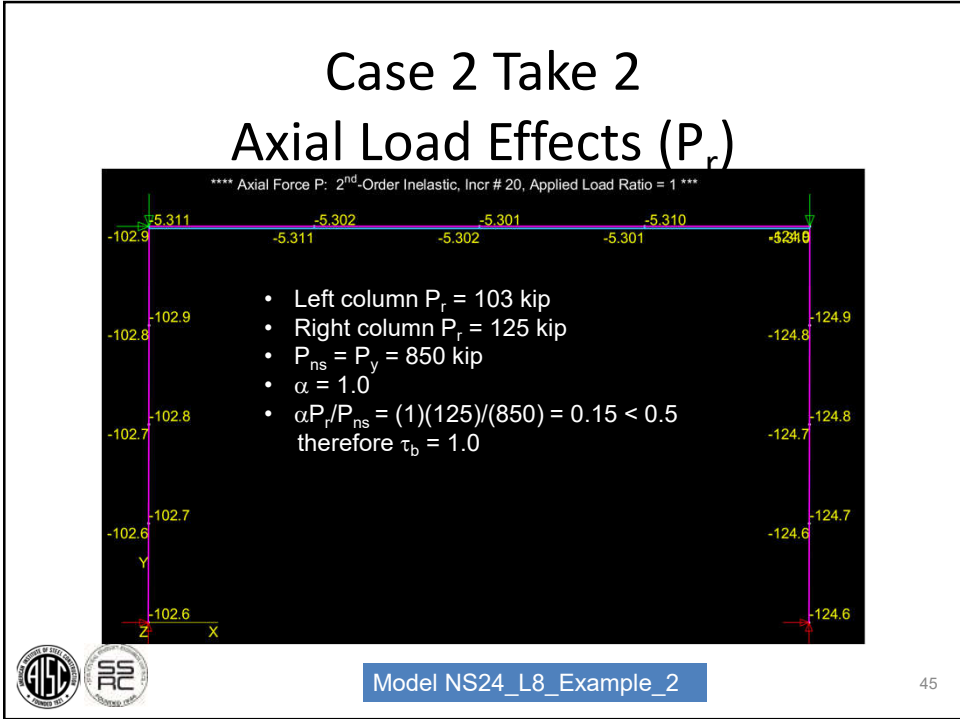
W12X58 W12X58

Model NS24\_L8\_Example\_2



44





## Case 2 Take 2 Interaction Values W12x58 Right Column

125 kips  
When  $\frac{P_r}{P_c} \geq 0.2$  0.21

$$\frac{P_r}{P_c} + \frac{8}{9} \left( \frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0 \quad 1.00 \quad Q_u = 114 \text{ kips (H1-1a)}$$

603 kips      125 kips      1311 kip-in      CASE 2 TAKE 2

132 kips  
When  $\frac{P_r}{P_c} \geq 0.2$  0.22

$$\frac{P_r}{P_c} + \frac{8}{9} \left( \frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0 \quad 1.08 \quad Q_u = 120 \text{ kips (H1-1a)}$$

603 kips      132 kips      1423 kip-in      CASE 2 TAKE 1

109 kips  
When  $\frac{P_r}{P_c} < 0.2$  0.18

$$\frac{P_r}{2P_c} + \left( \frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0 \quad 0.83 \quad Q_u = 100 \text{ kips (H1-1b)}$$

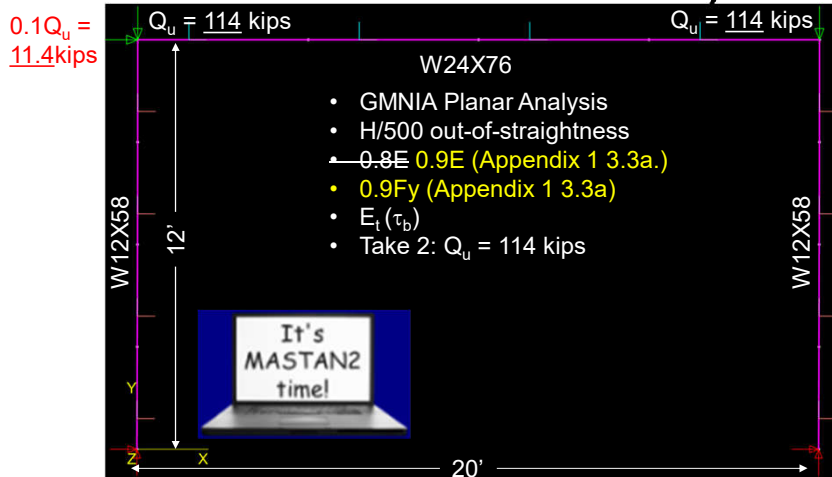
603 kips      109 kips      1076 kip-in      CASE 1

1206 kips      1464 kip-in



47

## Case 2 Take 2 2<sup>nd</sup> Order Inelastic Analysis



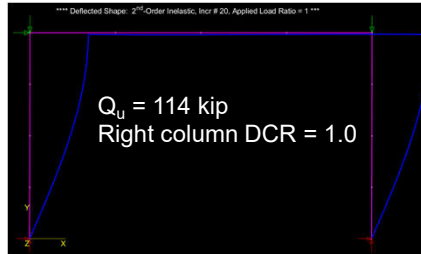
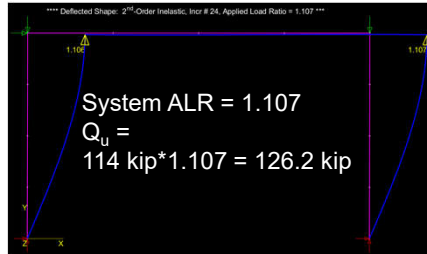
Model NS24\_L8\_Example\_3

48

## Case 2 Take 2 Inelastic Analysis vs Direct Analysis Method

Direct Analysis Method-GMNA  
(Appendix 1.3)

Direct Analysis Method-GNIA  
(Chapter C)

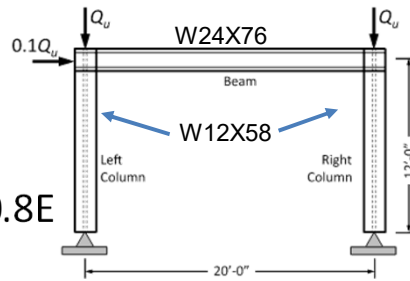


Model NS24\_L8\_Example\_3

49

## 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 &  $\tau_b$
  - Case 2: Use Case 1 to find  $Q_u$  for DCR = 1.0
  - Case 3: Use notional loads instead of out-of-plumbness and  $\tau_b$



LRFD Methodology

50

## Learning Module 9 Case 3 Model

- GNIA Planar Analysis
- $H/500$  out-of-plumbness directly modelled
- $0.002 * 200 \text{ kips} = 0.4 \text{ kip notional load for out-of-plumbness}$
- $0.8E$
- $E_x (\tau_b)^*$
- $Q_u = 100 \text{ kips}$

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

51

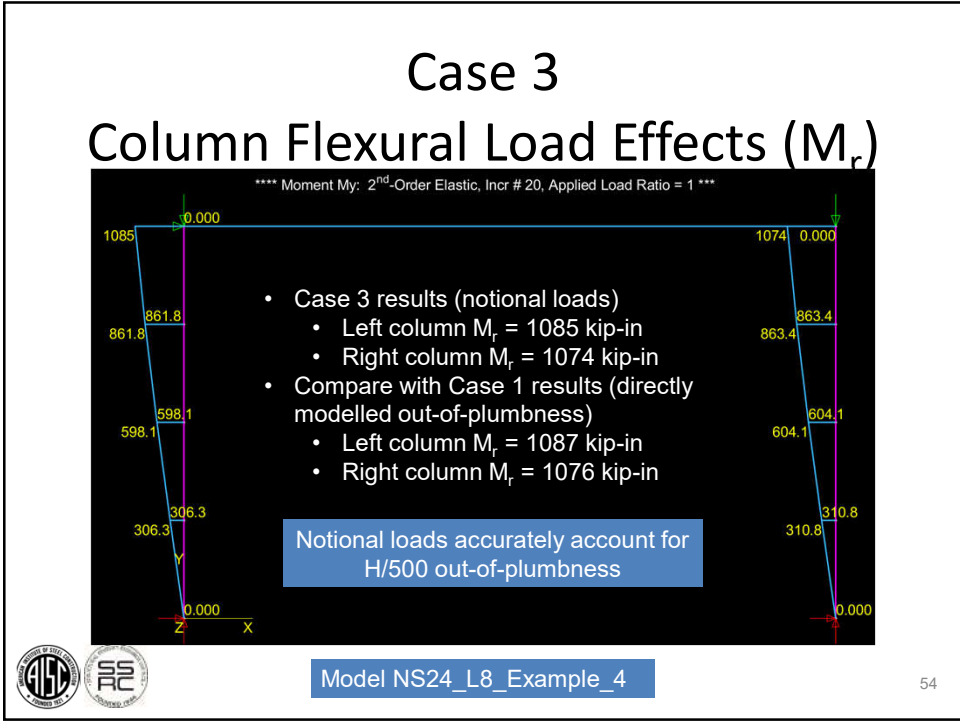
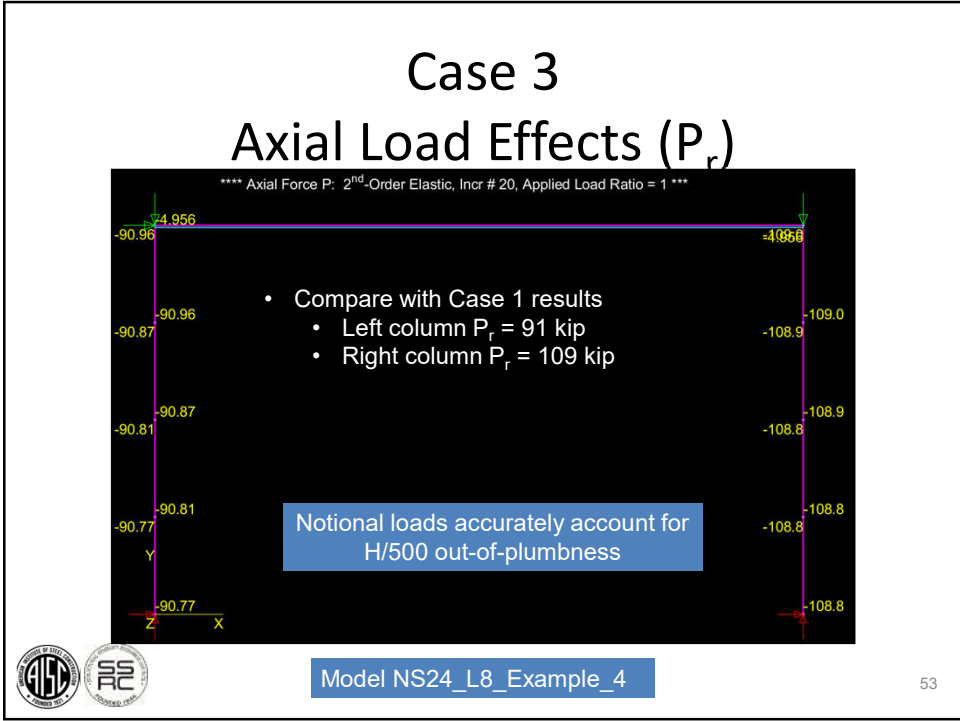
## Learning Module 9 Case 3

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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## 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 heeeeeeeeeeeeeere's Ronny!



55



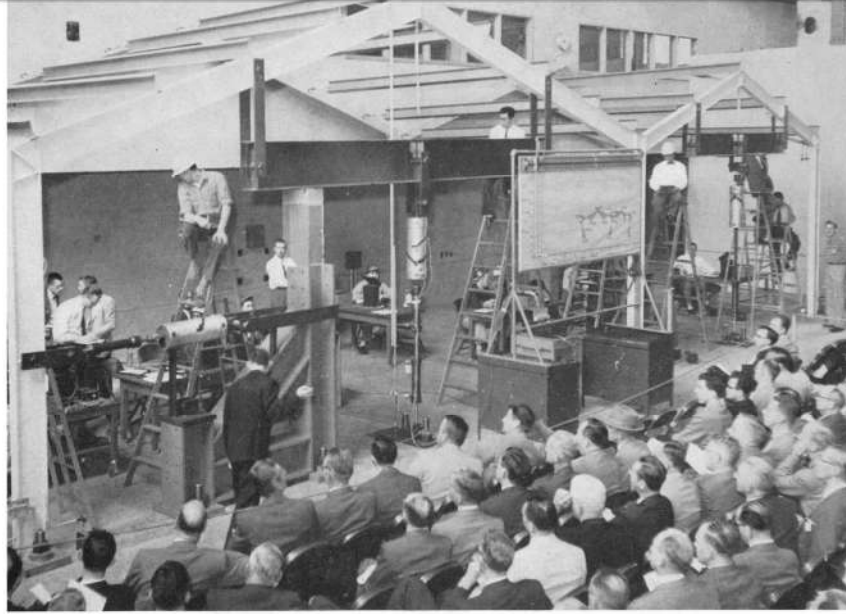
Design and analysis, perfect together...

**LOOKING TO THE FUTURE BY  
STARTING WITH THE PAST...**

56

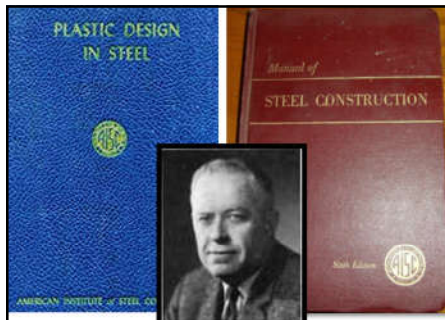


### Thoughts on future of advanced analysis in design...



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

57

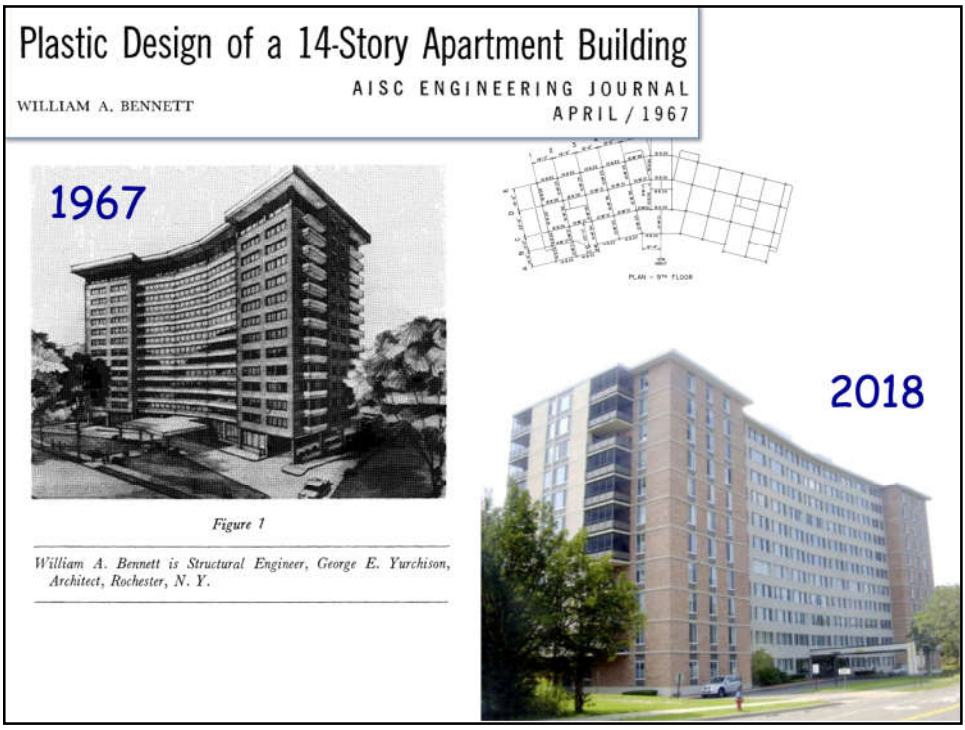


## AISC, 6<sup>th</sup> Edition PART 2

### 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



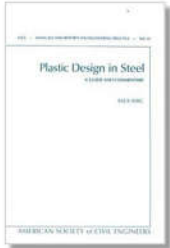
Plastic Design of a 14-Story Apartment Building  
WILLIAM A. BENNETT  
AISC ENGINEERING JOURNAL  
APRIL / 1967

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

- ✓ More rational method
- ✓ Significant economies gained
- ✓ Included P- $\Delta$  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

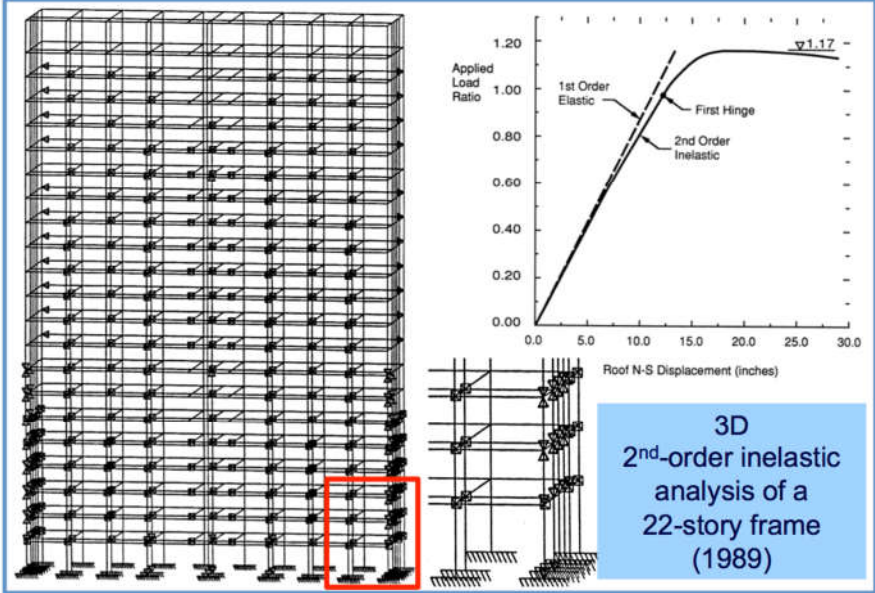


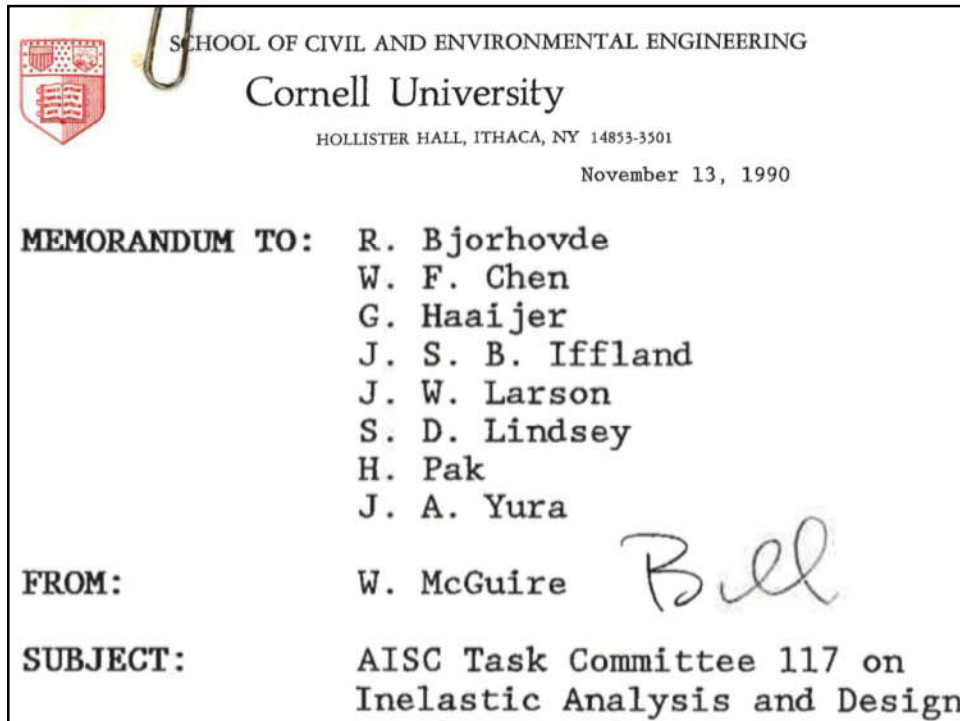
### Computer programs - lots of further research...

1970's

- Computing hardware
- Graphical user interfaces
- Geometric nonlinear:
  - 2<sup>nd</sup>-order effects ( $P-\Delta$ ,  $P-\delta$ )
- Material nonlinear:
  - Plastic hinge vs. zone

1990's






Computer programs -  
lots of further research...

1970's

- Computing hardware
- Graphical user interfaces
- Geometric nonlinear:
  - 2<sup>nd</sup>-order effects ( $P-\Delta$ ,  $P-\delta$ )
- Material nonlinear:
  - Plastic hinge vs. zone

1990's

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



66

AS 4100 - 1990  
Australian Standard™

Steel structures

APPENDIX D  
ADVANCED STRUCTURAL ANALYSIS  
(Normative)

Building Code of Australia  
primary referenced Standard

ABCB  
Australian Building Codes Board

STANDARDS AUSTRALIA

Wow!

67

Editors: D.W. White  
and W.F. Chen  
SSRC, 1993

Editors: A. Surovek  
ASCE, 2010

PLASTIC HINGE  
BASED METHODS FOR  
ADVANCED ANALYSIS  
AND DESIGN OF  
STEEL FRAMES

AN ASSESSMENT OF THE  
STATE-OF-THE-ART

ADVANCED ANALYSIS  
IN STEEL FRAME  
DESIGN

Guidelines for Direct Second-Order  
Elastic Analysis

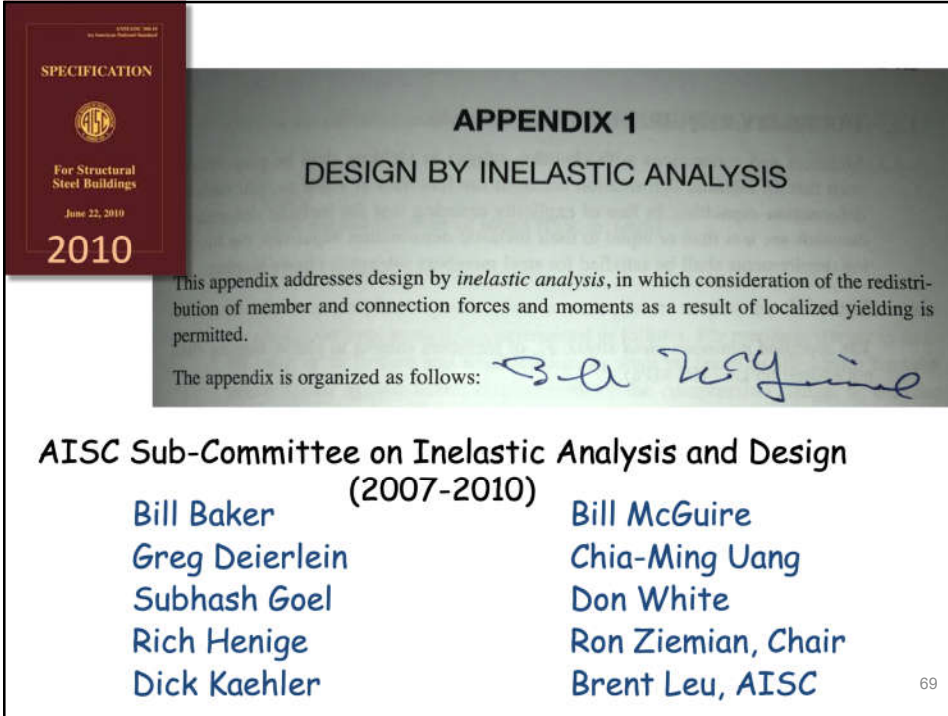
Edited by  
Andrea E. Surovek

ASCE

SEI  
STRUCTURAL ENGINEERING  
INSTITUTE

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**SPECIFICATION**  
For Structural Steel Buildings  
June 22, 2010  
**2010**

**APPENDIX 1**  
**DESIGN BY INELASTIC ANALYSIS**

This appendix addresses design by *inelastic analysis*, in which consideration of the redistribution of member and connection forces and moments as a result of localized yielding is permitted.

The appendix is organized as follows: *See 2010*

**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



## Inelastic analysis and seismic design, perfect together...

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## Inelastic analysis and seismic design, perfect together...

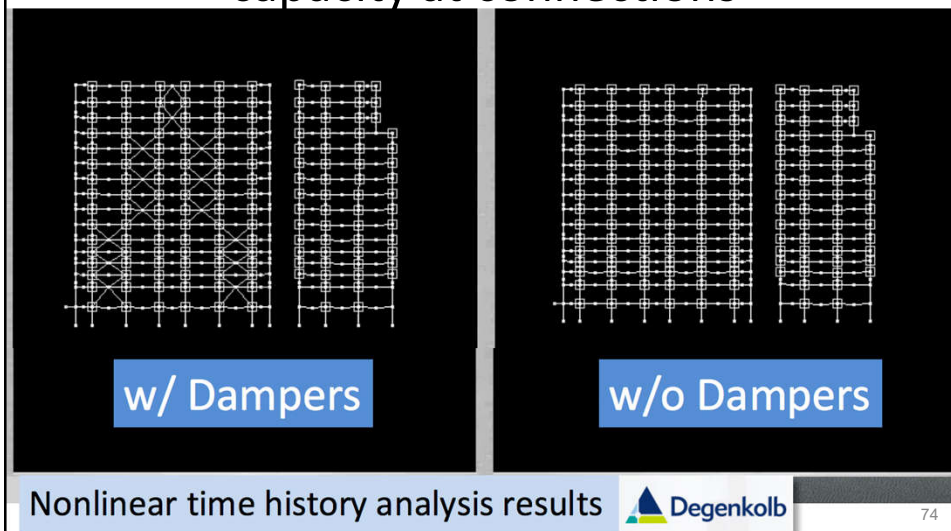
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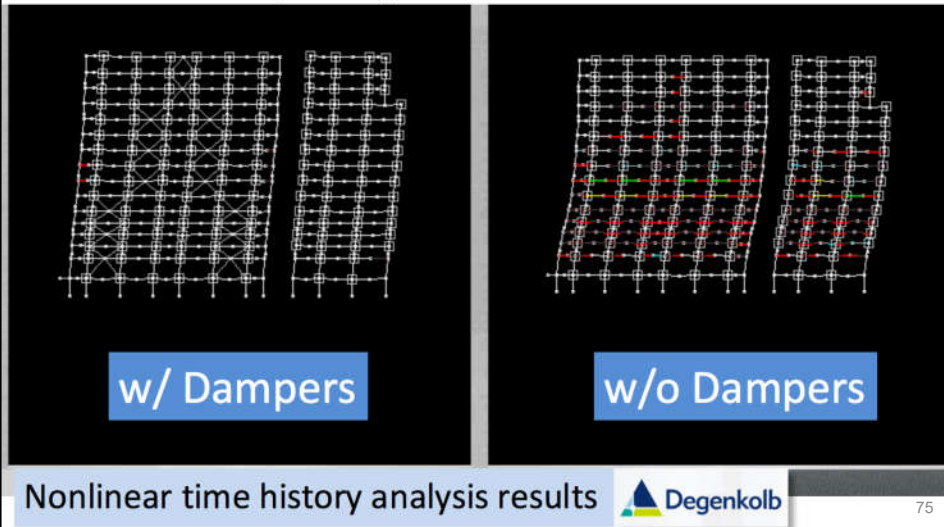
## Caltrans District 4 Office Building retrofitted with viscous dampers (Oakland, CA)



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



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



## 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

## Future of Advanced Analysis in Design

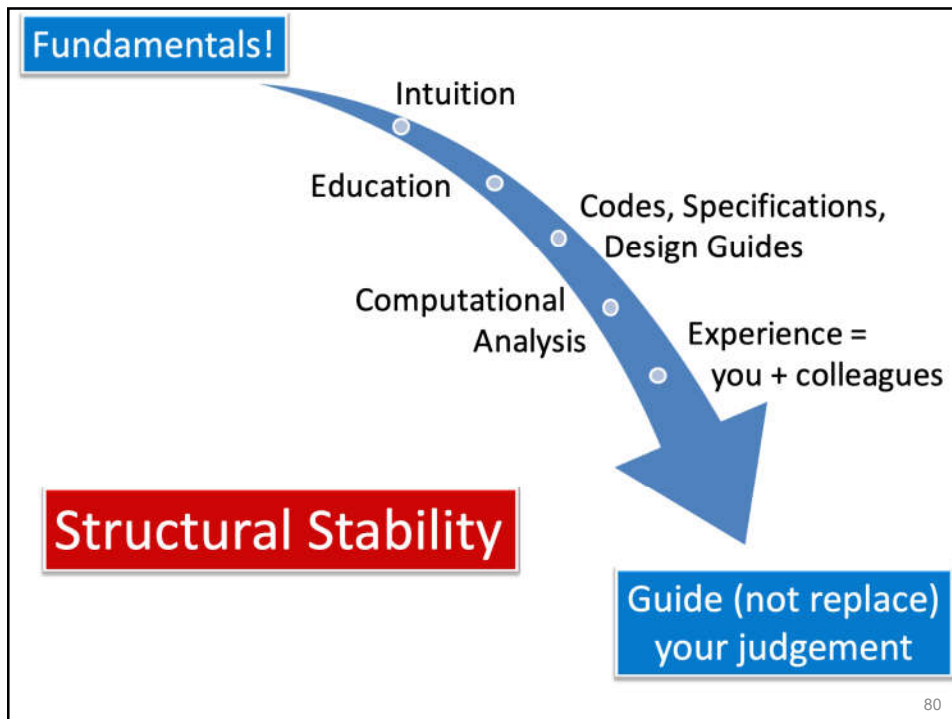
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- Virtual reality, artificial intelligence, and big data? <sup>77</sup>

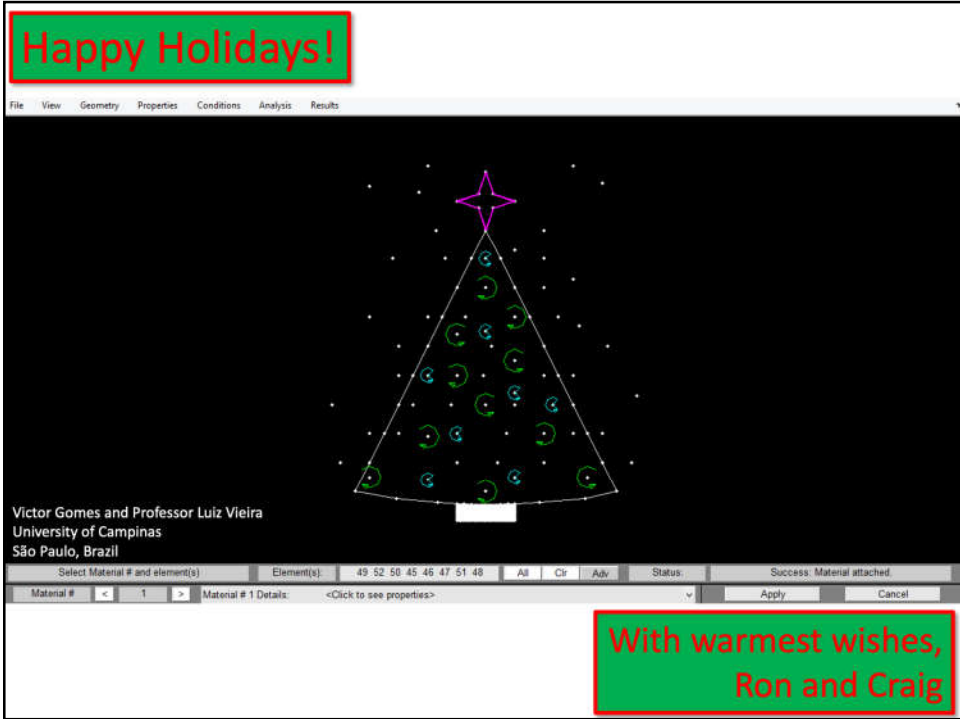
## Future of Advanced Analysis in Design

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- Virtual reality, artificial intelligence, and big data? <sup>79</sup>





## Single-Session Registrants

### CEU / PDH Certificates

- You will receive an email on how to report attendance from:  
[registration@aisc.org](mailto: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!



Smarter.  
Stronger.  
Steel.

## 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.



Smarter.  
Stronger.  
Steel.

## 8-Session Registrants

### CEU / PDH Certificates

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



## 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 [night school@aisc.org](mailto:night school@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.



## 8-Session Registrants

### Course Resources

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



## 8-Session Registrants

### Course Resources

Go to [www.aisc.org](http://www.aisc.org) and sign in.



## 8-Session Registrants

### Course Resources

Go to [www.aisc.org](http://www.aisc.org) and sign in.

The screenshot shows the MyAISC user interface. On the left, a sidebar menu lists various options, with 'Course Resources' circled in red. The main content area is divided into sections: 'MY PROFILE' with an 'EDIT PROFILE' button, 'MY PURCHASED DOWNLOADS' with a 'VIEW DOWNLOADS' button, and 'MY COURSE RESOURCES' with a 'VIEW RESOURCES' button. The 'MY COURSE RESOURCES' section is also circled in red.

## 8-Session Registrants

### Course Resources

The screenshot shows the AISC website's Course Resources page. At the top, there is a navigation menu with links for EDUCATION, PUBLICATIONS, AWARDS AND COMPETITIONS, TECHNICAL RESOURCES, and STEEL SOLUTIONS CENTER. Below the menu is a large image of a modern building with a glass facade and palm trees, with the AISC logo overlaid. The page title is 'AISC > MY ACCOUNT > COURSE RESOURCES'. Below the title, the 'Course Resources' section contains a table of events.

Event	Start Date
8-Session Design in Steel	1/2/1990 12:00:00 AM
8-Session Package-Design of Facade Attachments	5/9/2019 1:30:00 PM
05_15 8-Session Package-Night School 15 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
05_16 8-Session Package-Night School 16 - Seismic Design in Steel	2/5/2018 7:00:00 PM
05_17 8-Session Package-Night School 17 - Design of Facade Attachments	7/18/2018 7:00:00 PM
05_18 8-Session Package-Night School 18 - Steel Construction: Mill To Topping Out	10/15/2018 7:00:00 PM
05_19 8-Session Package-Night School 19 - Connection Design	2/4/2019 7:00:00 PM
05_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 - Concrete & Braced	7/18/2018 1:30:00 PM



## 8-Session Registrants

### Course Resources

Event	Date	Handouts	Videos	Quiz	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6 2020 7:00PM EDT	<a href="#">Handouts</a>	Available 10/06/2020 5:00PM EDT	Available 10/08/2020 5:00PM EDT	Pending
NS24.2 - Compression Members - Practical Considerations	Oct 13 2020 7:00PM EDT	<a href="#">Handouts</a>	Available 10/13/2020 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	<a href="#">Handouts</a>	Available 10/20/2020 5:00PM EDT	Available 10/22/2020 5:00PM EDT	Pending
NS24.4 - Flexural Members - Practical Considerations	Oct 27 2020 7:00PM EDT	<a href="#">Handouts</a>	Available 10/28/2020 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	<a href="#">Handouts</a>	Available 11/10/2020 5:00PM EST	No longer available	Pending
NS24.6 - Stability of Beam-Columns - Practical Consideration	Nov 17 2020 7:00PM EST	<a href="#">Handouts</a>	Available 11/17/2020 5:00PM EST	No longer available	Pending
NS24.7 - Behavior of Structural Systems - The Fundamentals	Dec 1 2020 7:00PM EST	<a href="#">Handouts</a>	Available 12/03/2020 5:00PM EST	No longer available	Pending
NS24.8 - Structural Systems - Practical Considerations	Dec 8 2020 7:00PM EST	<a href="#">Handouts</a>	Available 12/10/2020 5:00PM EST	No longer available	Pending
NS24 - Final Exam	N/A			No longer available	

**AISC** | Thank you.

**Smarter.  
Stronger.  
Steel.**

