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We will begin shortly. Please standby.

Modern Methods for Learning the Basics of Structural Stability: From Behavior to Practice
Session 6: Behavior of Beam-Columns – Practical Considerations
November 17, 2020




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Course Description

Behavior of Beam-Columns – Practical Considerations
November 17, 2020

In this session, the speakers will discuss the results of the learning module on beam-columns and provide some advice for further exploration. They will then present a case study from practice involving beam-columns. They will close out the topic of beam-columns with some final lessons.



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Learning Objectives

- Describe how the five effects that must be considered for stability design (per the AISC *Specification*) are accounted for in design.
- Explain how to construct a beam-column interaction curve using finite element analysis.
- Compare the beam-column interaction curve from analysis with the interaction curve used in the AISC *Specification*.
- List several modeling decisions that need to be made when analyzing a beam-column in a case study from practice.



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

Session 6: Behavior of Beam-Columns – Practical Considerations
November 17, 2020



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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



Course Overview (2)

Strength/Weight + Stiffness/Weight + Competitive \$

Slender Systems, Members, and Cross-sections

Design for Stability!

3

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)

"Buckling" Design Methods:

Load

Load_{lim}

Bifurcation Theory

Instability Theory

stiffness ↓
deflections ↑
bending ↑

Deflection

Deflection₀

Figure applicable to system, member, and cross-section behavior

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Course Overview (5)

Analysis acronyms:

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

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

6



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



Course Learning Module (LM) Schedule

Course Introduction

Compression Members – Sessions 1 (LM1) & 2 (LM2)

Flexural Members – Session 3 (LM5) & 4 (LM4)

Beam-Columns – Sessions 5 (LM7) & 6 (LM8)

Systems – Session 7 (LM9) & 8 (LM9)



Limit States of Flexural Members

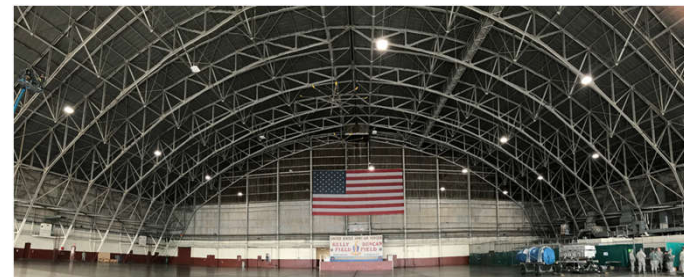
- Full yielding (**today!**)
- Instability
 - Along the member length
 - Lateral torsional buckling (Sessions 3 and 4)
 - Flexural buckling (Sessions 1 and 2)
 - Torsional-flexural buckling (**today!**)
 - At the cross section
 - Local buckling



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Session 6


Beam-Column Member Lab and Case Study



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Session Overview

- Review Session 5
- Perform LM8
- Apply case study from practice



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Session 5 Review

Session 5 Slides 12 - 14

Initial Yield

$$\left| \sigma_{res} + \frac{P}{A} + \frac{M}{S} \right| \leq \sigma_y \Rightarrow \left| \frac{\sigma_{res}}{\sigma_y} + \frac{P}{A\sigma_y} + \frac{M}{S\sigma_y} \right| \leq 1.0$$


Member strength:

$$\frac{P}{P_n} + \frac{8M}{9M_n} \leq 1.0$$

$$\frac{1}{2} \frac{P}{P_n} + \frac{M}{M_n} \leq 1.0$$

Cross section strength (full yield):

$$\frac{P}{P_y} \geq 0.2 \quad \frac{P}{P_y} + \frac{8M}{9M_p} \leq 1.0$$

$$\frac{P}{P_y} < 0.2 \quad \frac{1}{2} \frac{P}{P_y} + \frac{M}{M_p} \leq 1.0$$


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Session 5 in AISC 360-16

- Interaction Equation (Chapter H)
 - Cross section strength
 - Member strength
 - Elastic
 - Inelastic

H1. DOUBLY AND SINGLY SYMMETRIC MEMBERS SUBJECT TO FLEXURE AND AXIAL FORCE

1. Doubly and Singly Symmetric Members Subject to Flexure and Compression

The interaction of flexure and compression in doubly symmetric members and singly symmetric members constrained to bend about a geometric axis (x and/or y) shall be limited by Equations H1-1a and H1-1b.

User Note: Section H2 is permitted to be used in lieu of the provisions of this section.


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

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

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

$$\frac{P}{2P_c} + \left(\frac{M_x}{M_{cx}} + \frac{M_y}{M_{cy}} \right) \leq 1.0 \quad \text{(H1-1b)}$$

Where does stability fit in all this?



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Session 5 in AISC 360-16


C1. GENERAL STABILITY REQUIREMENTS

Stability shall be provided for the structure as a whole and for each of its elements.

Sessions 7 & 8
Sessions 1- 6

- 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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Session 5 in AISC 360-16

- Stability design methods
 - Any rational method of design
 - Direct analysis method (C2)
 - Alternative methods (App. 7)
 - Effective length method
 - First order analysis method

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_1 and P_2)	C2.1(b). Consider second-order effects (P_1 and P_2) ¹⁰	Same as DM (by reference to C2.1)
(3) Consider geometric imperfections. This includes joint position imperfections ¹¹ (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. National loads
	Effect of member imperfections on structure response	Included in the stiffness reduction specified in C2.3
	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 $L_c = L$
	Effect of stiffness reduction on member strength	• 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 slenderness buckling analysis in the member strength check
(5) Consider uncertainty in strength and stiffness. This affects structure response and member strength	Effect of stiffness uncertainty on structure response	Included in the stiffness reduction specified in C2.3
	Effect of stiffness uncertainty on member strength	Included in member strength formulas, with $L_c = L$

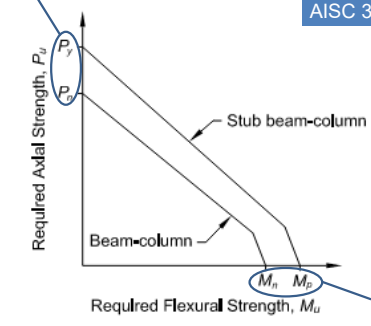
¹⁰In typical building structures, the "joint position imperfections" refers to column-out-of-plumbness.
¹¹Displacement effects may be considered either by a computational P_1 and P_2 analysis or by the approximate method using R_1 and R_2 multipliers specified in Appendix B.



Session 5 in AISC 360-16

Chapter E
Sessions 1 & 2

AISC 360-10



Chapter F
Sessions 3 & 4

Fig. C-H1.3. Interaction curve for stub beam-column and beam-column.

Let's put the AISC curve to the test!



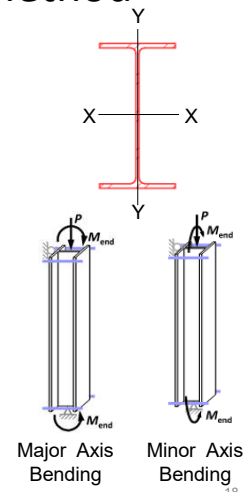
Learning Module 8 Objectives

- Observe the strength limit state behavior of beam-columns, which includes the range of full yielding of the cross-section to elastic/inelastic flexural and lateral torsional buckling.
- Prepare interaction curves that plot member axial strength versus flexural strength.
- Compare results of the AISC interaction equations with results from computational analyses that account for partial yielding (accentuated by the presence of residual stresses) and initial imperfections in geometry.



Learning Module 8 Method

- W14x53, L = 15'
- Two studies
 - AISC strength curve
 - Computational strength
- Axial and major axis (X-axis) bending
- Axial and minor axis (Y-axis) bending



Learning Module 8 AISC Curve

- Given P and M_{end} combinations resulting in AISC interaction values of 1.0
- MASTAN2 GNA to find internal moment (M_{rx} & M_{ry}) and verify AISC interaction values of 1.0
- Plot P/P_y vs M_{endx}/M_{px} and P/P_y vs M_{endy}/M_{py}

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

Demands

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

Initial out-of-straightness and partial yielding accounted for here – do not include in model

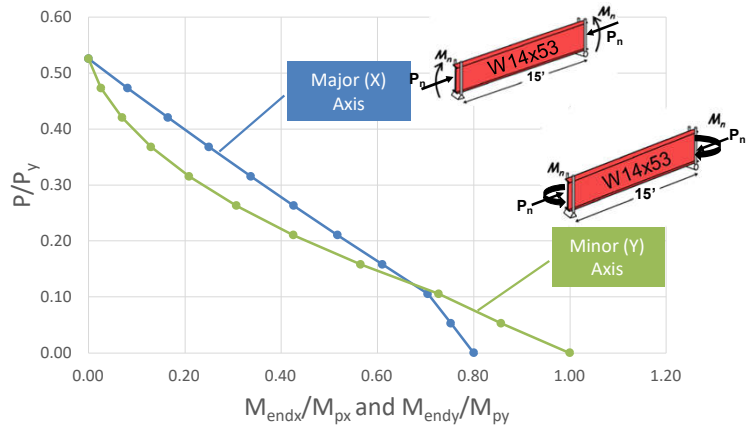
(b) When $\frac{P_r}{P_c} < 0.2$

Capacities

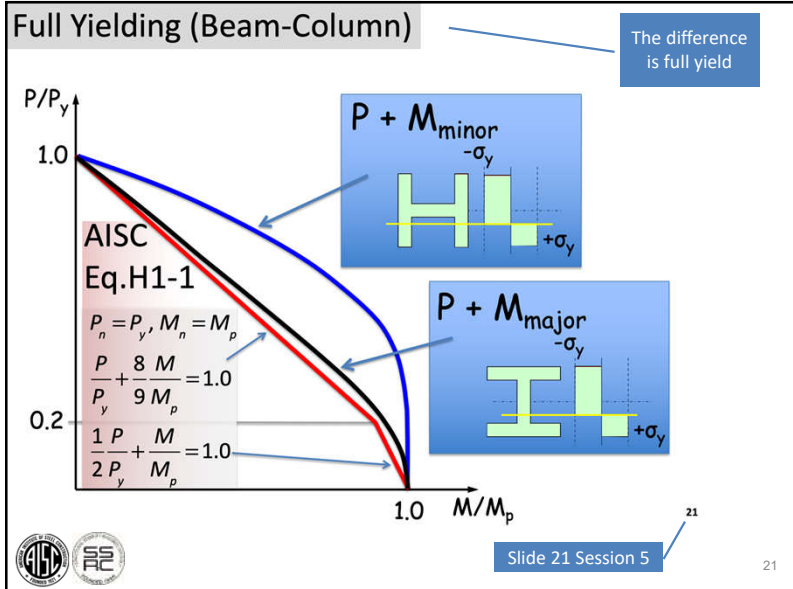
$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1.0 \quad \text{(H1-1b)}$$



LM8 AISC Equation H1-1 Curves

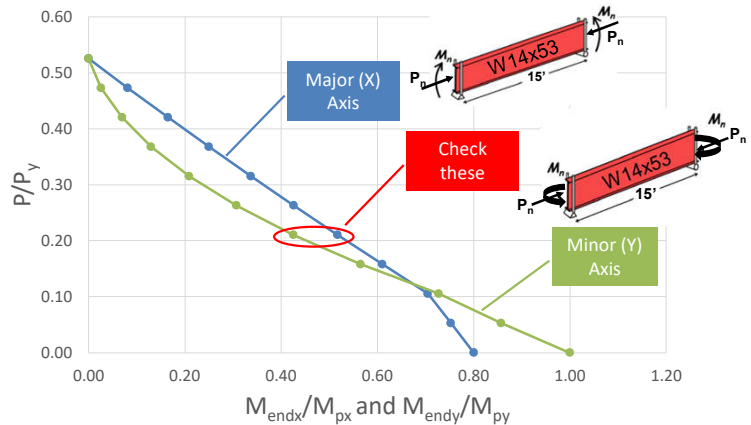


Recall comparison of these curves last session



Slide 21 Session 5

LM8 AISC Equation H1-1 Curves



LM8 AISC Major Axis Model

- No Twist Warping Free
- W14x53, A992
E = E
- No Imperfection GNA
- Axial Load Uniform Moment Major Axis
- Warping Continuous
- $L_b = 15'$
- 3D analysis

It's MASTAN2 time!

Model NS24_L6_Example_1

$P = 164$ k
 $M_{endx} = 2254$ k-in

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LM8 AISC Major Axis

$P = 164$ k; $M_{endx} = 2,254$ k-in

Axial Load Effect Moment Load Effect

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

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

410 k 3485 k-in 0

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

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

Note: ϕ factors are not included

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LM8 AISC Major Axis

$P = 164$ k; $M_{endx} = 2,254$ k-in

Axial Load Effect Moment Load Effect

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

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

(b) When $\frac{P_r}{P_c} < 0.2$ 0.4 0.6 0

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

Note: ϕ factors are not included

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LM8 AISC Minor Axis Model

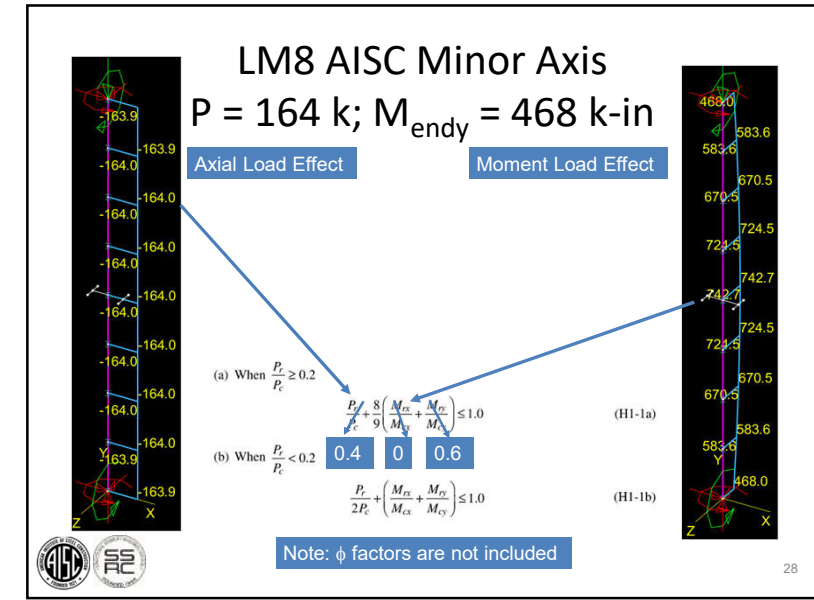
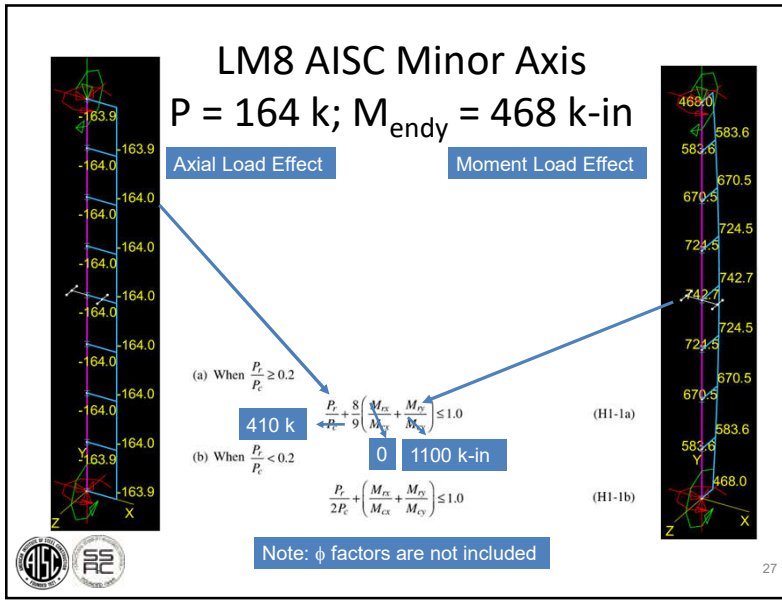
- No Twist Warping Free
- W14x53, A992
E = E
- No Imperfection GNA
- Axial Load Uniform Moment Minor Axis
- Warping Continuous
- $L_b = 15'$
- 3D analysis

It's MASTAN2 time!

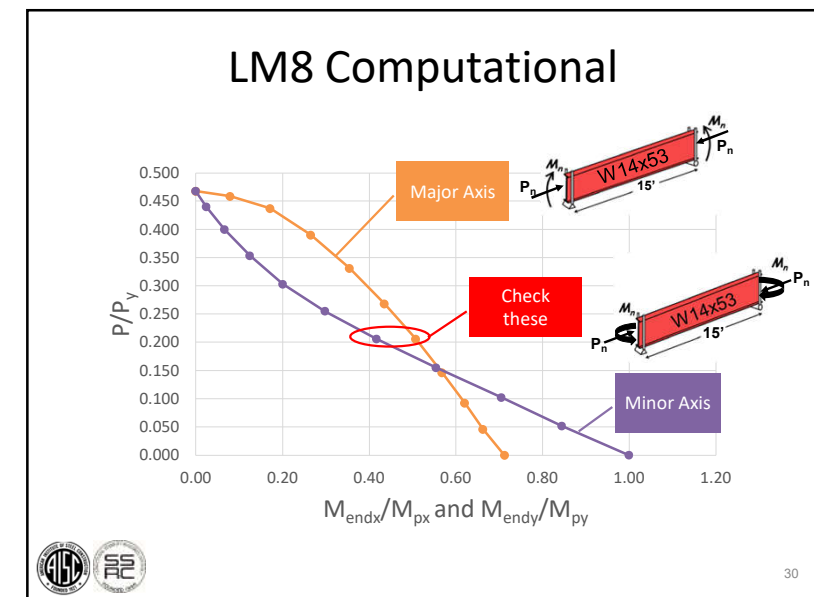
Model NS24_L6_Example_2

$P = 164$ k
 $M_{endy} = 468$ k-in

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- ### LM8 Computational Curves
- Use same P and M_{end} combinations as AISC Curve
 - MASTAN2 to run GMNIA
 - Find ultimate applied load ratio (ALR_{ult})
 - Plot $ALR_{\text{ult}} (P/P_y \text{ vs } M_{\text{endx}}/M_{\text{px}})$
 - Plot $ALR_{\text{ult}} (P/P_y \text{ vs } M_{\text{endy}}/M_{\text{py}})$
- 29



LM8 Comp. Major Axis Model

- No Twist Warping Free
- W14x53, A992
 $E = E_{tm}$
- Imperfection perpendicular to plane of web
GMNIA
- $P = 164 \text{ k}$
 $M_{endx} = 2254 \text{ k-in}$
- Axial Load Uniform Moment Major Axis
- Warping Continuous
- $L_b = 15'$
- 3D analysis
- It's MASTAN2 time!
- Model NS24_L6_Example_3

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Computational Major Axis

$P = 164 \text{ k}; M_{end} = 2,254 \text{ k-in}$

**** Deflected Shape: 2nd-Order Inelastic, Incr # 98, Applied Load Ratio = 0.98 ****

- $P = 0.98 * 164 \text{ k} = 160.7 \text{ k}$
 $P/P_y = 160.7 \text{ k} / 780 \text{ k} = 0.206$
- $M_{endx} = 0.98 * 2,254 \text{ k-in} = 2,209 \text{ k-in}$
 $M_{endx}/M_{px} = 2,209 \text{ k-in} / 4,355 \text{ k-in} = 0.51$

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LM8 Comp. Minor Axis Model

- No Twist Warping Free
- W14x53, A992
 $E = E_{tm}$
- Imperfection perpendicular to plane of web
GMNIA
- $P = 164 \text{ k}$
 $M_{endy} = 468 \text{ k-in}$
- Axial Load Uniform Moment Minor Axis
- Warping Continuous
- $L_b = 15'$
- 3D analysis
- It's MASTAN2 time!
- Model NS24_L6_Example_4

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LM8 Computational Minor Axis

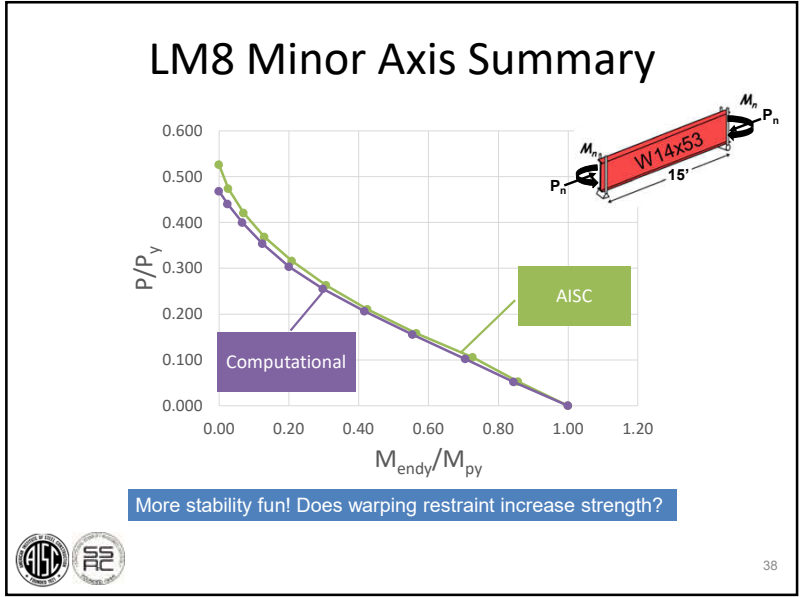
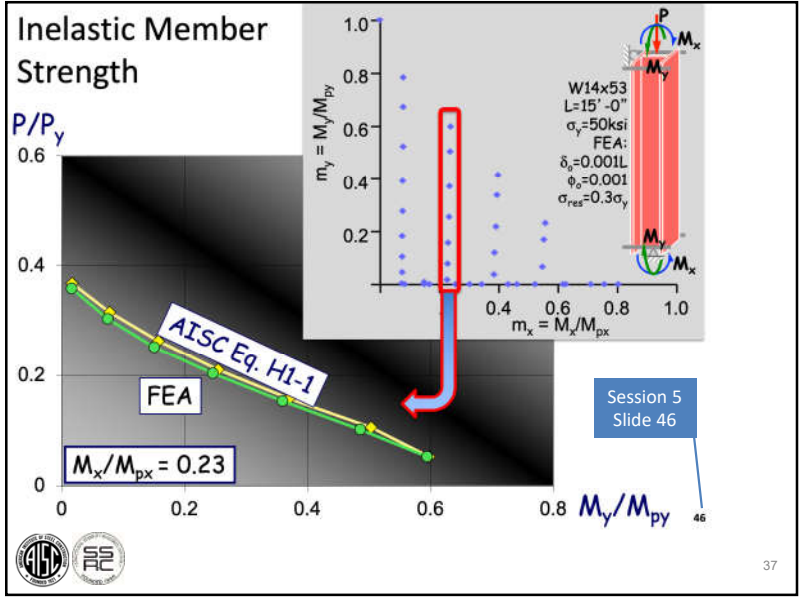
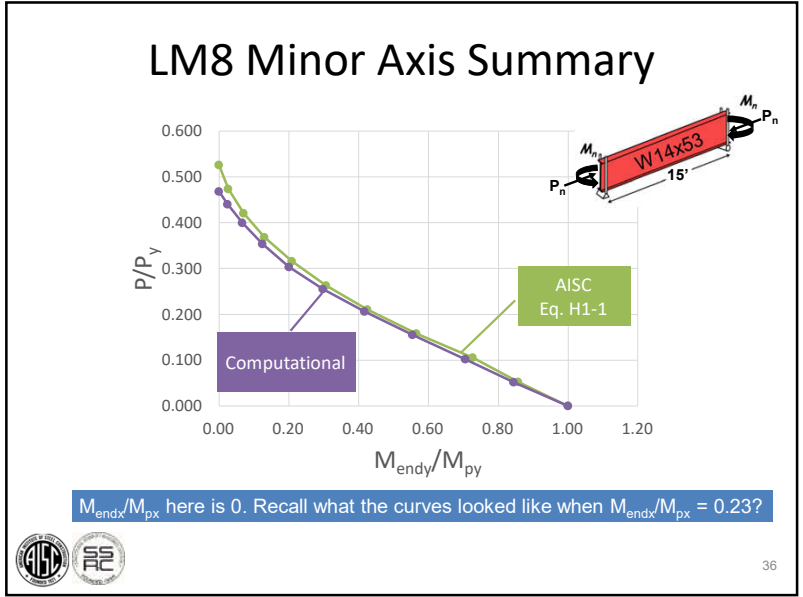
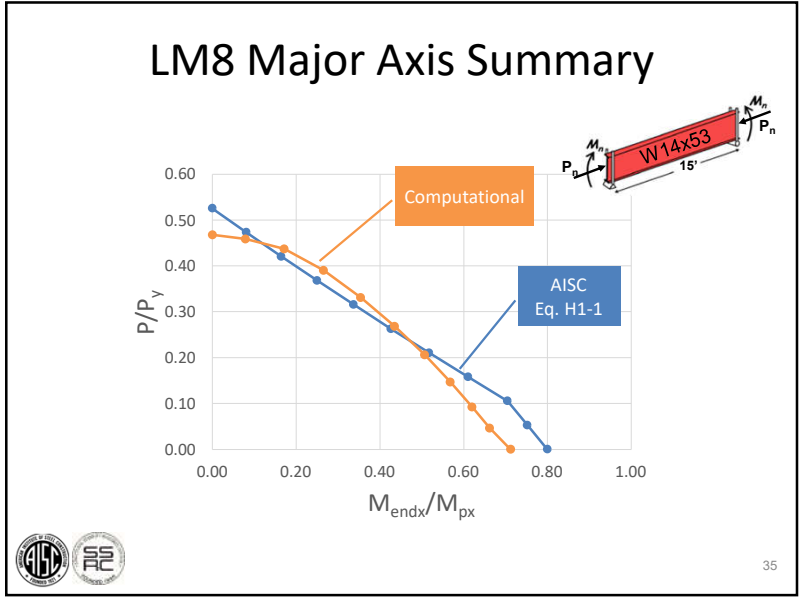
$P = 164 \text{ k}; M_{endy} = 468 \text{ k-in}$

**** Deflected Shape: 2nd-Order Inelastic, Incr # 98, Applied Load Ratio = 0.97562 ****

- $P = 0.98 * 164 \text{ k} = 160.7 \text{ k}$
 $P/P_y = 160.7 \text{ k} / 780 \text{ k} = 0.206$
- $M_{endy} = 0.98 * 468 \text{ k-in} = 459 \text{ k-in}$
 $M_{endy}/M_{py} = 459 / 1,100 \text{ k-in} = 0.42$

Should there be a plastic hinge?

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LM8 More Fun With Computational Analysis!

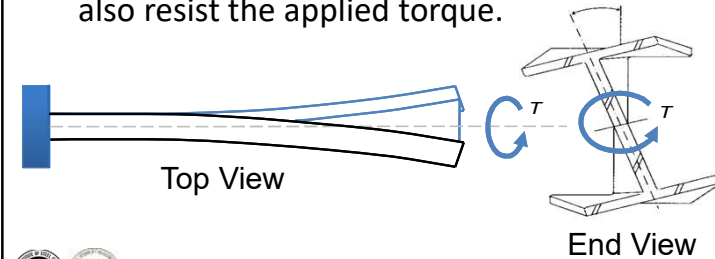
- Repeat computational strength study assuming
 - Warping continuous along length (no change)
 - Warping fixed at ends (change)
- Comment on conservatism of the AISC interaction equation



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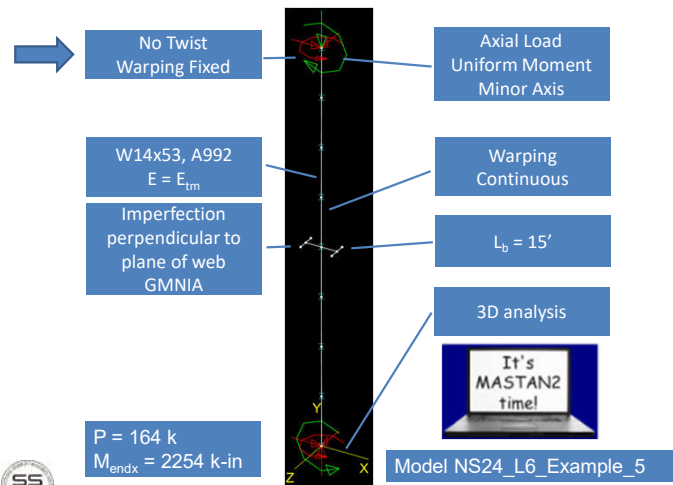
Warping Torsion

- Recall that torque T causing the twist in LTB also causes the flanges to bend in opposite directions. This “cross flange” bending can also resist the applied torque.



40

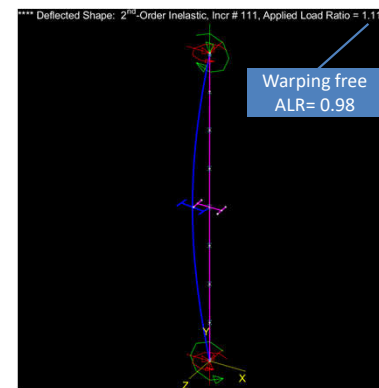
Warping Restraint – Major Axis Model



Recall ALR was 0.98 with warping free end conditions

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LM8 Warping Restraint Computational Major Axis $P = 164 \text{ k}$; $M_{\text{endx}} = 2,254 \text{ k-in}$



$$P = 1.11 \cdot 164 \text{ k} = 182 \text{ k}$$

$$P/P_y = 182 \text{ k} / 780 \text{ k} = 0.23$$

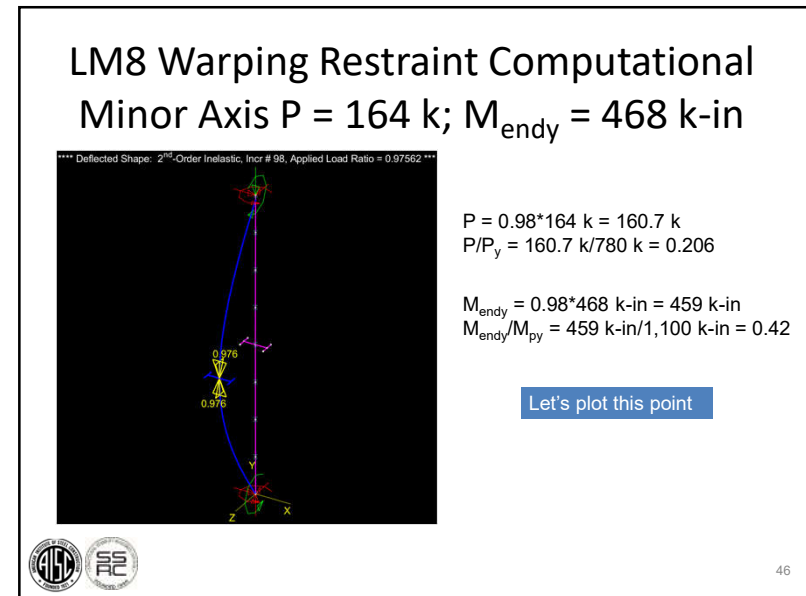
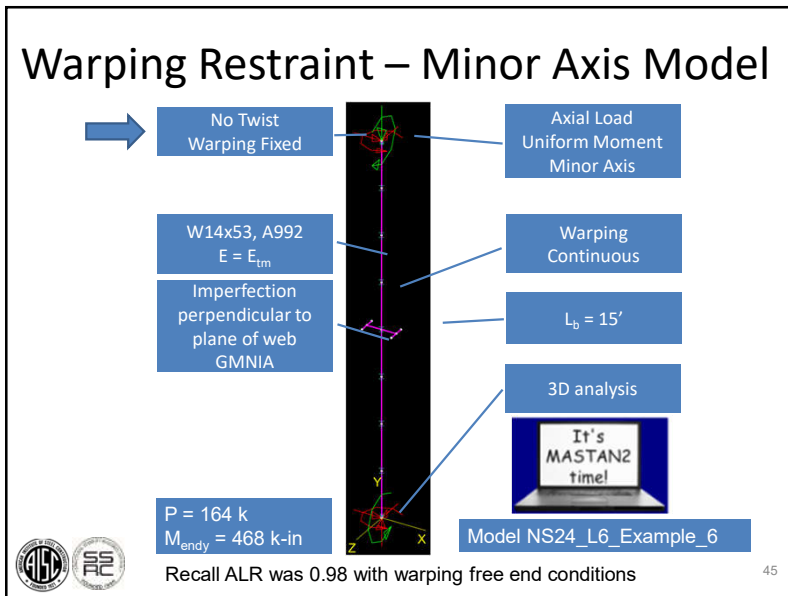
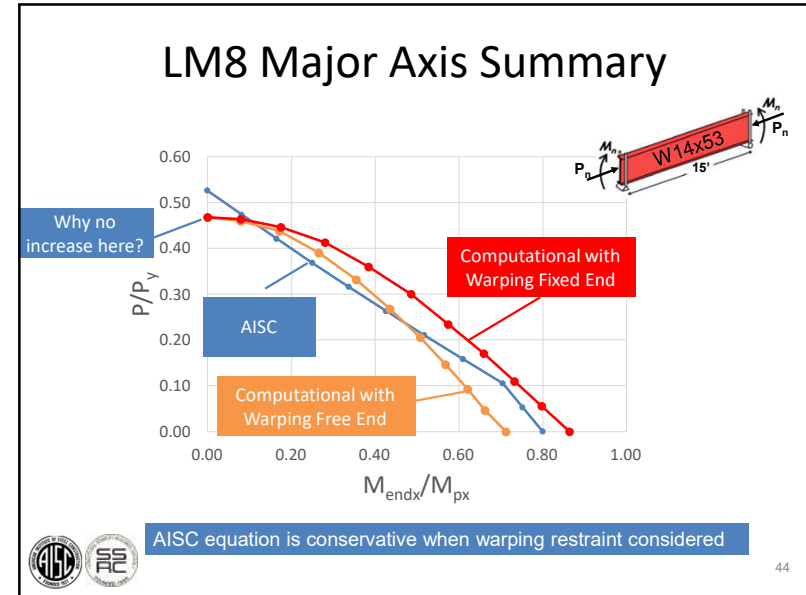
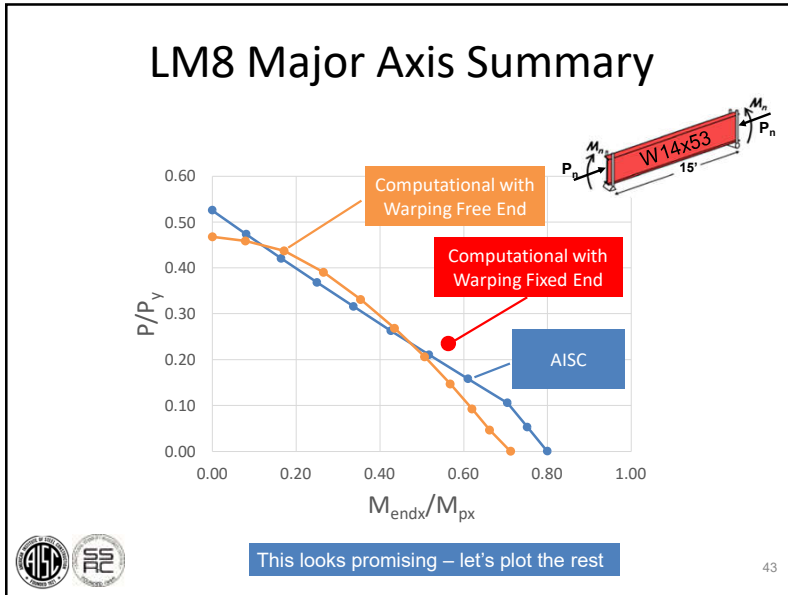
$$M_{\text{endx}} = 1.11 \cdot 2,254 \text{ k-in} = 2,502 \text{ k-in}$$

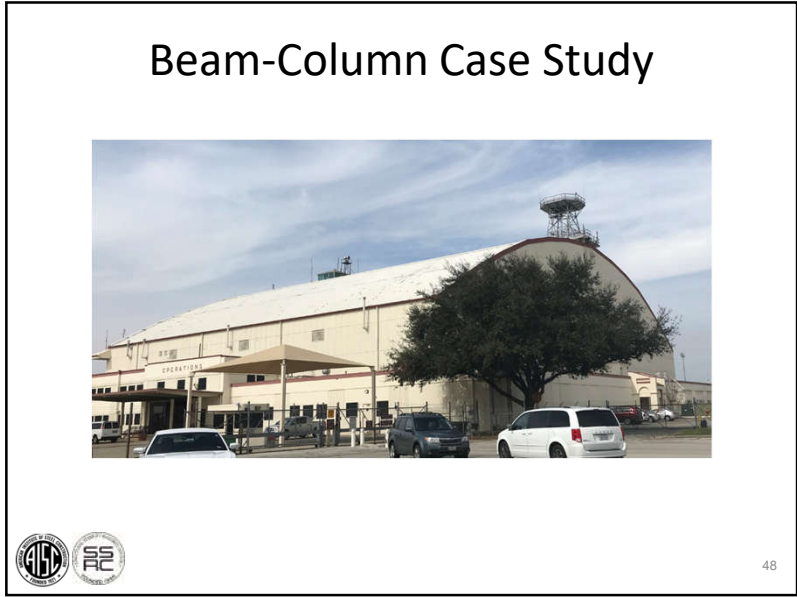
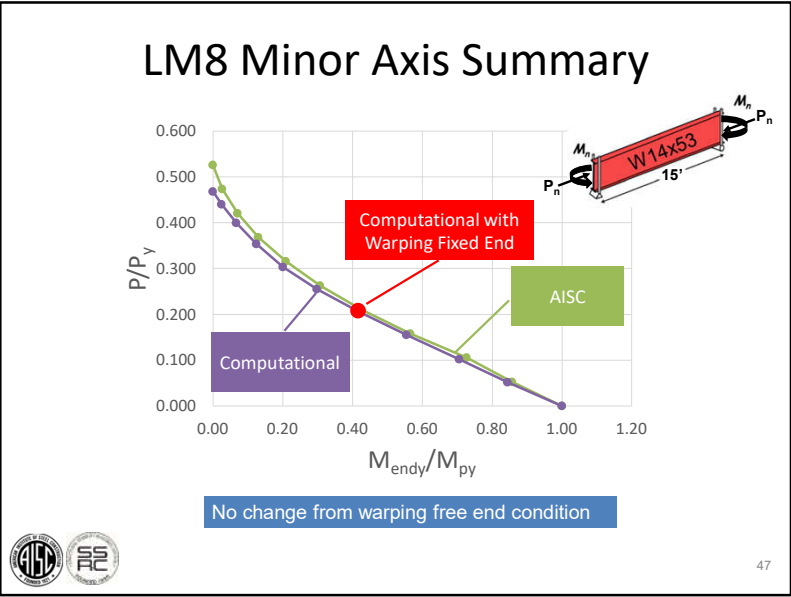
$$M_{\text{endx}}/M_{\text{px}} = 2,502 \text{ k-in} / 4,355 \text{ k-in} = 0.57$$

Let's plot this point



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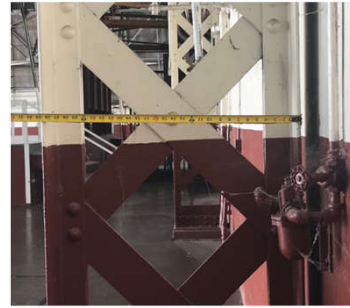
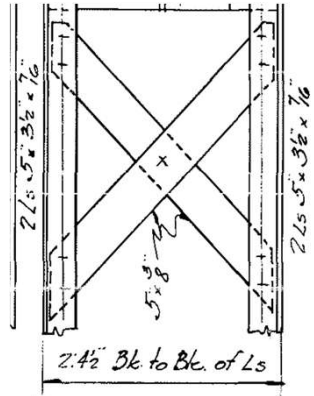
Port San Antonio Hangar

- Fire protection retrofit
 - Wet system
 - Foam system
 - Water risers and laterals to be supported by east wall wind columns
- Structure built in 1940

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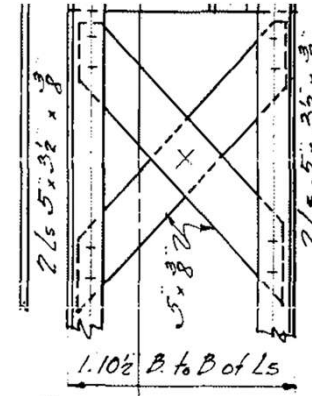


Built-Up Type 1 Column (Biggest)



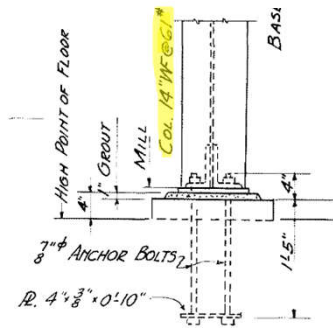
55

Built-Up Type 2 Column (Big)



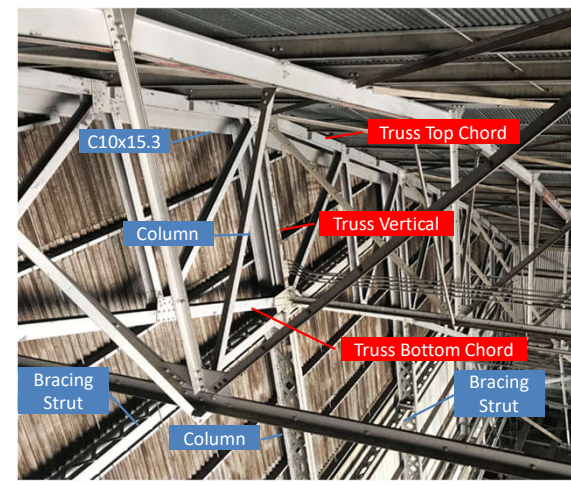
56

Rolled Shape Type 3 Column (Not as Big)



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Column Top



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Column Top

Truss Bottom Chord

DETAIL OF REAR WALL COLS
Scale: 1/2" = 1'-0"

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Column Base

4' x 4' x 12' Concrete Footing

BASE FOR COLS 35, 36, 37, 38, 39 & 40
SCALE: 3/4" = 1'-0"

NOTE: Bottom of all Footings to be 13'-0" below present Grade.

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Bracing Struts

Column

Plan view of column to strut connection

Bracing Strut

Column

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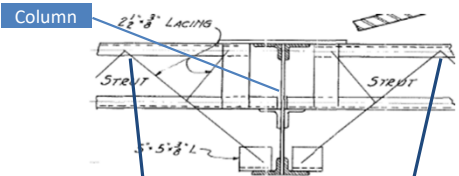
New Piping on East Wall

8" Dia. Risers

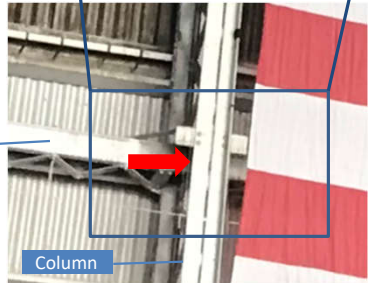
6" Dia. Laterals

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Bracing Strut Restraint on Column



Plan view of column to strut connection



Take 1 – Bracing Strut Restrains X-Disp.

It's MASTAN2 time!

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Column 39 Model- Take 1

Deflected Shape: 2nd-Order Inelastic, Incr # 29, Applied Load Ratio = 0.29

Take	Strut Restraint	ALR
1	X-DISP	0.29

$M_{1st\ Order} = 6,994\ k-in$
 $M_{GMNIA} = 1,549\ k-in$

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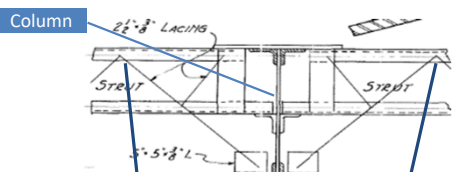
68

Column 39 Model - Take 2

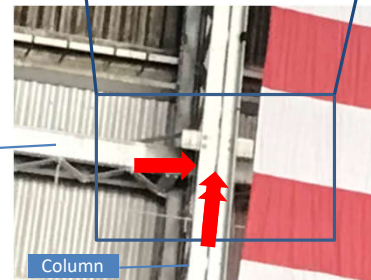
- Warping Free
- Wind Load
- A7
 $E = E_{tm}$
- Imperfection via LBA in X-direction GMNIA
- Self Weight Included
 $P = 5.1\ k\ at\ base$
- Bracing by Struts
X-Disp, Rot-Y
- Warping Continuous
- Warping Fixed

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Bracing Strut Restraint on Column



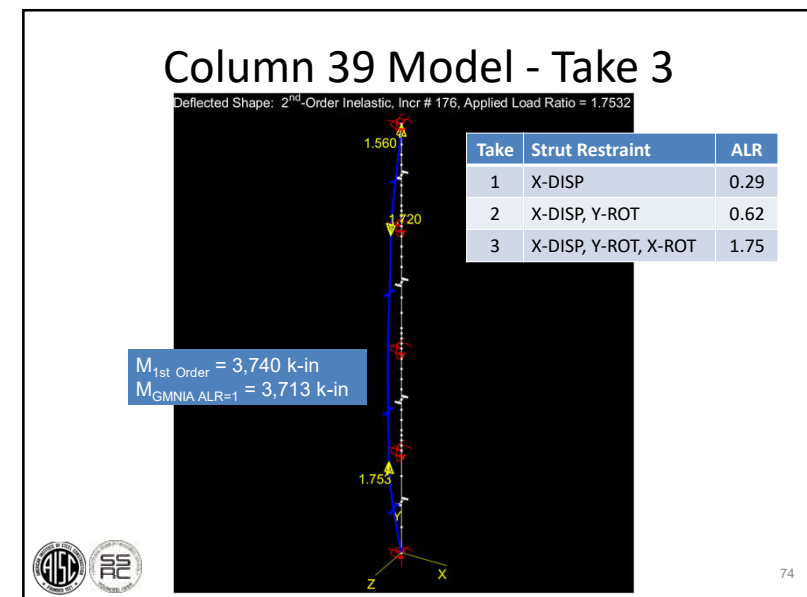
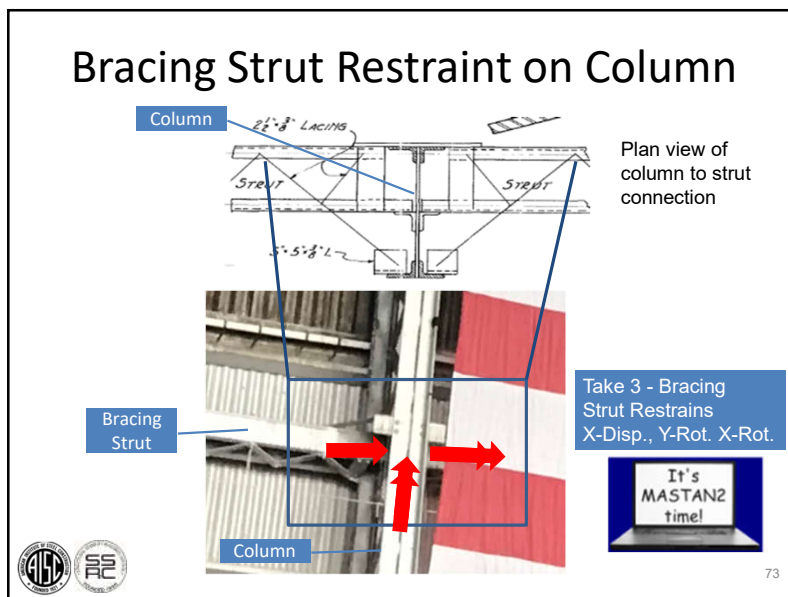
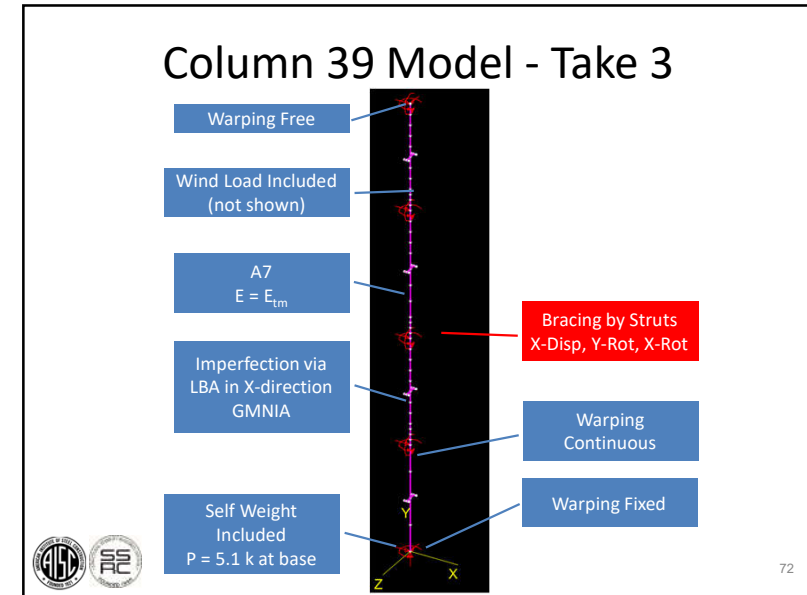
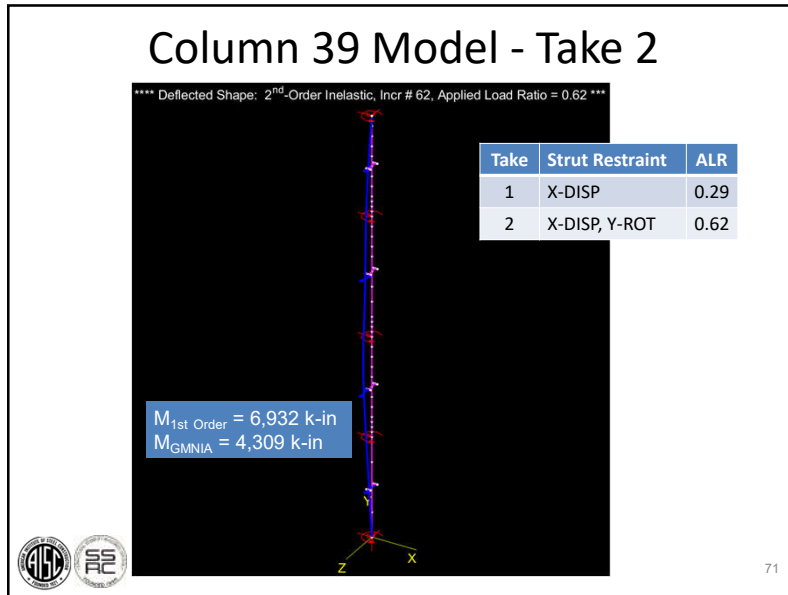
Plan view of column to strut connection

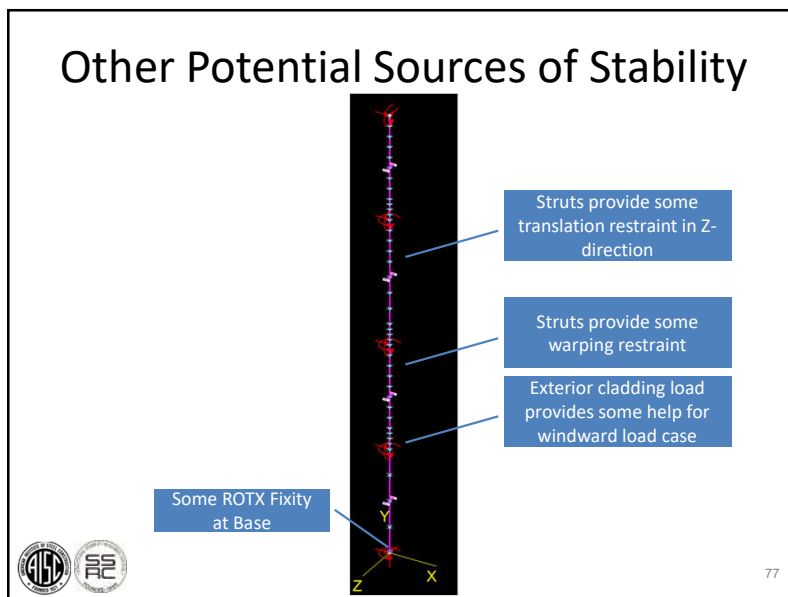
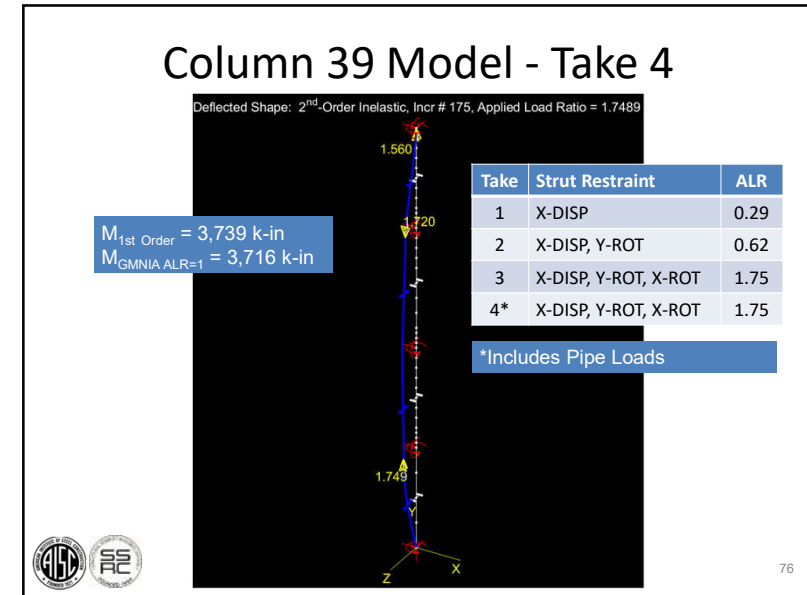
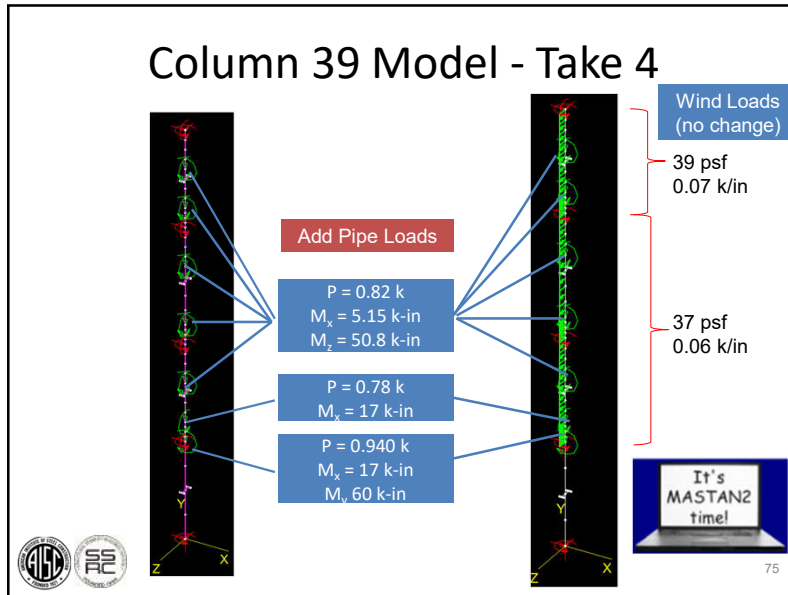


Take 2 - Bracing Strut Restrains X-Disp., Y-Rot.

It's MASTAN2 time!

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- ### Summary
- Understanding behavior is key to knowing how and when to use computational modelling
 - Assess sources of stability model and reasonably apply them
 - Know where your model is conservative and unconservative to assess its relative accuracy
 - Perform thorough existing structure evaluation to assess condition and drawing accuracy – See session 4 slides for documents AISC provides
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AISC | Questions?



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!



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.



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 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.



8-Session Registrants

Course Resources

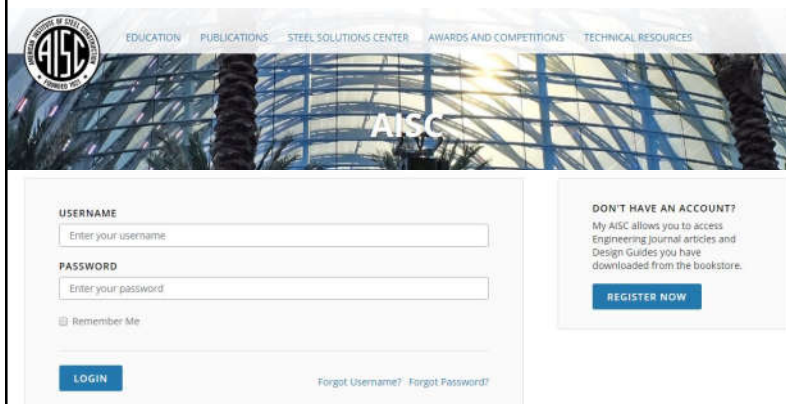
Find all your handouts, quizzes and quiz scores, recording access, and attendance information in one place!



8-Session Registrants

Course Resources

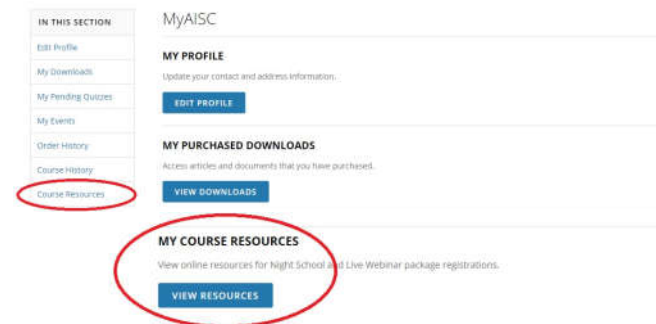
Go to www.aisc.org and sign in.



8-Session Registrants


Course Resources

Go to www.aisc.org and sign in.




8-Session Registrants

Course Resources



EDUCATION PUBLICATIONS AWARDS AND COMPETITIONS TECHNICAL RESOURCES STEEL SOLUTIONS CENTER




AISC > MY ACCOUNT > COURSE RESOURCES

Course Resources


Event	Start Date
Seismic Design of Steel	1/11/2001 12:00:00 AM
8-Session Package-Night School 12: Fundamentals of Connection Design	5/5/2019 3:00:00 PM
NS 20.8-Session Package-Night School 12: Seismic Design of Steel	10/29/2017 7:00:00 PM
NS 27.4-Session Package-Night School 17: Design of Seismic Attachments	1/29/2018 7:00:00 PM
NS 18.8-Session Package-Night School 18: Steel Construction: M4 To Through Out	7/18/2018 7:00:00 PM
NS 18.8-Session Package-Night School 18: Steel Construction: M4 To Through Out	18/15/2018 7:00:00 PM
NS 18.8-Session Package-Night School 18: Connection Design	2/4/2019 7:00:00 PM
NS 20.8-Session Package-Night School 20: Classical Methods of Structural Analysis	6/9/2019 7:00:00 PM
8-Session Package-Night School 20: Classical Methods of Structural Analysis	7/16/2019 8:00:00 PM

8-Session Registrants

Course Resources



EDUCATION PUBLICATIONS AWARDS AND COMPETITIONS TECHNICAL RESOURCES STEEL SOLUTIONS CENTER



AISC > MY ACCOUNT > COURSE RESOURCES > NS24 8-SESSION PACKAGE RESOURCES

Night School 24: Modern Methods for Learning Structural Stability

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Start	End	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6, 2020 7:00PM EDT	Handouts	Video	Available 10/06/2020 5:00PM EDT	Available 10/06/2020 3:00PM EDT	Pending
NS24.2 - Compression Members - Practical Considerations	Oct 13, 2020 7:00PM EDT	Handouts	Video	Available 10/13/2020 5:00PM EDT	Available 10/13/2020 3:00PM EDT	Pending
NS24.3 - Behavior of Flexural Members - The Fundamentals	Oct 20, 2020 7:00PM EDT	Handouts	Video	Available 10/20/2020 5:00PM EDT	Available 10/20/2020 3:00PM EDT	Pending
NS24.4 - Flexural Members - Practical Considerations	Oct 27, 2020 7:00PM EDT	Handouts	Video	Available 10/27/2020 5:00PM EDT	Available 10/27/2020 3:00PM EDT	Pending
NS24.5 - Stability of Beam-Columns - The Fundamentals	Nov 10, 2020 7:00PM EDT	Handouts	Video	Available 11/10/2020 5:00PM EST	No longer available	Pending
NS24.6 - Stability of Beam-Columns - Practical Considerations	Nov 17, 2020 7:00PM EST	Handouts	Video	Available 11/16/2020 5:00PM EST	No longer available	Pending
NS24.7 - Behavior of Structural Systems - The Fundamentals	Dec 1, 2020 7:00PM EST	Handouts	Video	Available 12/01/2020 5:00PM EST	No longer available	Pending
NS24.8 - Structural Systems - Practical Considerations	Dec 8, 2020 7:00PM EST	Handouts	Video	Available 12/08/2020 5:00PM EST	No longer available	Pending
NS24 - Final Exam	N/A				No longer available	



AISC | Thank you.




Smarter. Stronger. Steel.

