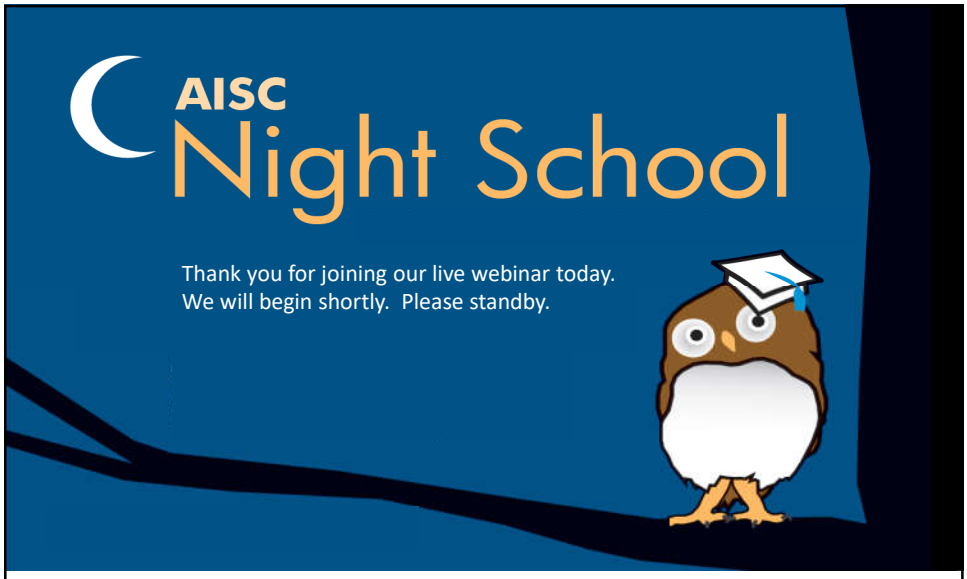

Modern Methods for Learning the Basics of Structural Stability: From Behavior to Practice

Session 4: Behavior of Flexural Members – Practical Considerations

October 27, 2020

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Course Description

Behavior of Flexural Members – Practical Considerations
October 27, 2020

In this session, the speakers will discuss and explore the results of the learning module on flexural members and provide some advice for further study. They will then present a case study from practice involving instability of flexural members. The session will conclude with some final lessons and thoughts on flexural members.

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Learning Objectives

- Identify each region of the beam strength curve and explain the associated behavior for each.
- Compare the beam strength curve produced by structural analysis to what is codified in the AISC *Specification*.
- Describe the concept of warping torsion restraint for wide flange beams and explain how it affects flexural strength.
- Identify one beam end detail that can provide warping restraint.

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

Session 4: Behavior of Compression Members – Practical Considerations
October 27, 2020

Ronald D. Ziemian, PE, PhD
Professor
Bucknell University

Craig Quadrato, PE, PhD
Senior Associate
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 – Sessions 1 & 2
- Flexural Members – Sessions 3 & 4
- Beam-Columns – Session 5 & 6
- Systems – Sessions 7 & 8

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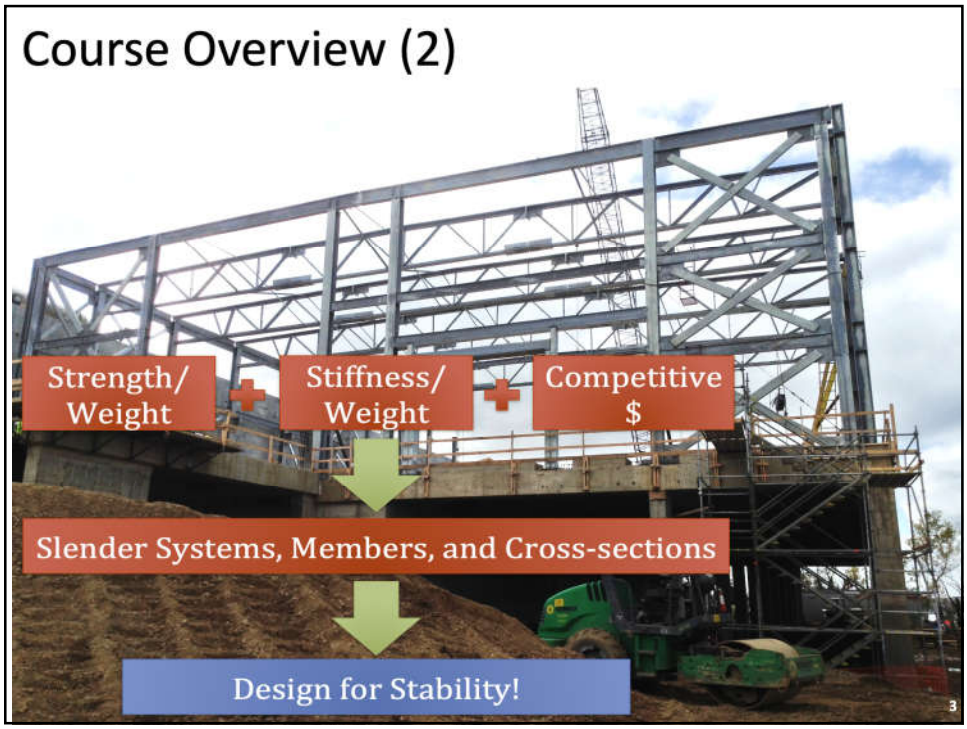
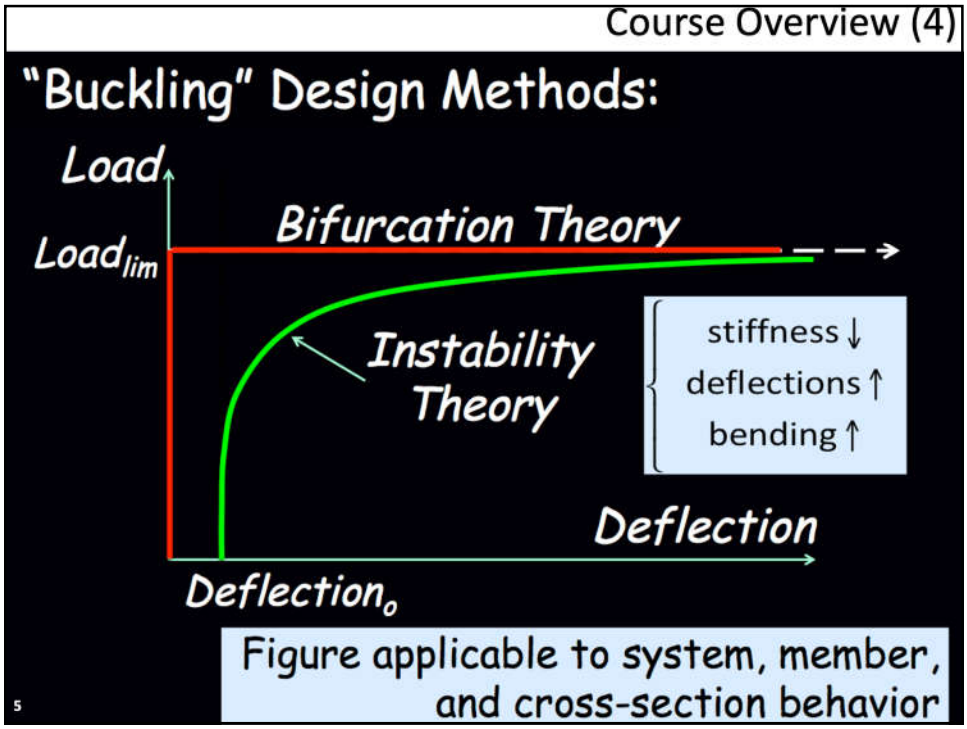


Course Overview (3)

- 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

4



Course Overview (5)

Analysis acronyms:

LBA: linear bucking 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

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Limit States of Flexural Members

- Full yielding (today!)
- Instability
  - Along the member length (today!)
    - Lateral torsional buckling
      - elastic
      - inelastic
  - At the cross section
    - local buckling

8

8

Session 4

Flexural Member Lab and Case Study

Photo courtesy Trip advisor (https://www.tripadvisor.com/Attraction_Review-g56833-d7931915-Reviews-Waco_Suspension_Bridge-Waco_Texas.html#photos;aggregationId=101&albumid=101&filter=7&ff=380164851 Traveler photo submitted by akmohney01 (Mar 2019) accessed September 8, 2020

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Session Overview

- Review Session 3
- Perform LM4
- Apply case study from practice

10

Session 3 Review

- Investigated basic LTB equation
- Investigated assumptions
  - Initial imperfection
  - Partial yielding
  - Moment gradient
  - Brace points
- Built beam curve

TABLE USER NOTE F1.1
Selection Table for the Application of Chapter F Sections

Section in Chapter F	Cross Section	Flange Slenderness	Web Slenderness	Limit States
F2		C	C	Y, LTB
F3		NC, S	C	LTB, FLB
F4		C, NC, S	C, NC	CFY, LTB, FLB, TFY
F5		C, NC, S	S	CFY, LTB, FLB, TFY
F6		C, NC, S	N/A	Y, FLB
F7		C, NC, S	C, NC, S	Y, FLB, WLB, LTB
F8		N/A	N/A	Y, LB
F9		C, NC, S	N/A	Y, LTB, FLB, WLB
F10		N/A	N/A	Y, LTB, LLB
F11		N/A	N/A	Y, LTB
F12	Unsymmetrical shapes, other than single angles	N/A	N/A	All limit states

Y = yielding, CFY = compression flange yielding, LTB = lateral-torsional buckling, FLB = flange local buckling, WLB = web local buckling, TFY = tension flange yielding, LLB = leg local buckling, LB = local buckling, C = compact, NC = noncompact, S = slender, N/A = not applicable

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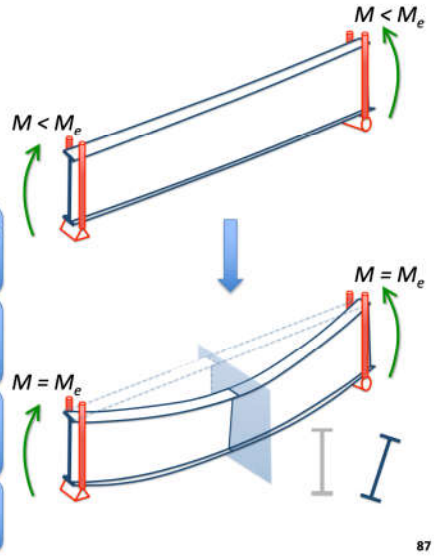
Lateral Torsional Buckling (LTB)

- Bifurcation solution
- Assumptions!
  - prismatic member (I = constant)
  - only major axis bending occurs before buckling — Undone
  - linear elastic behavior (E = constant) — Undone
  - uniform moment distribution — Undone
  - braced at the ends (frictionless) — Undone



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Lesson 3 Slide 87

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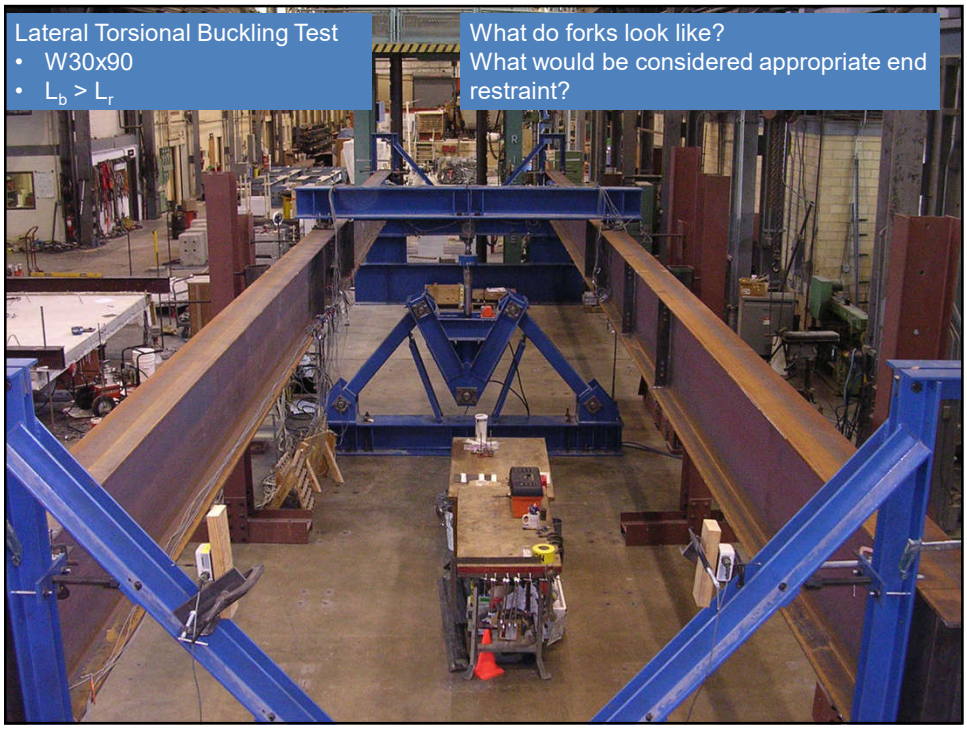

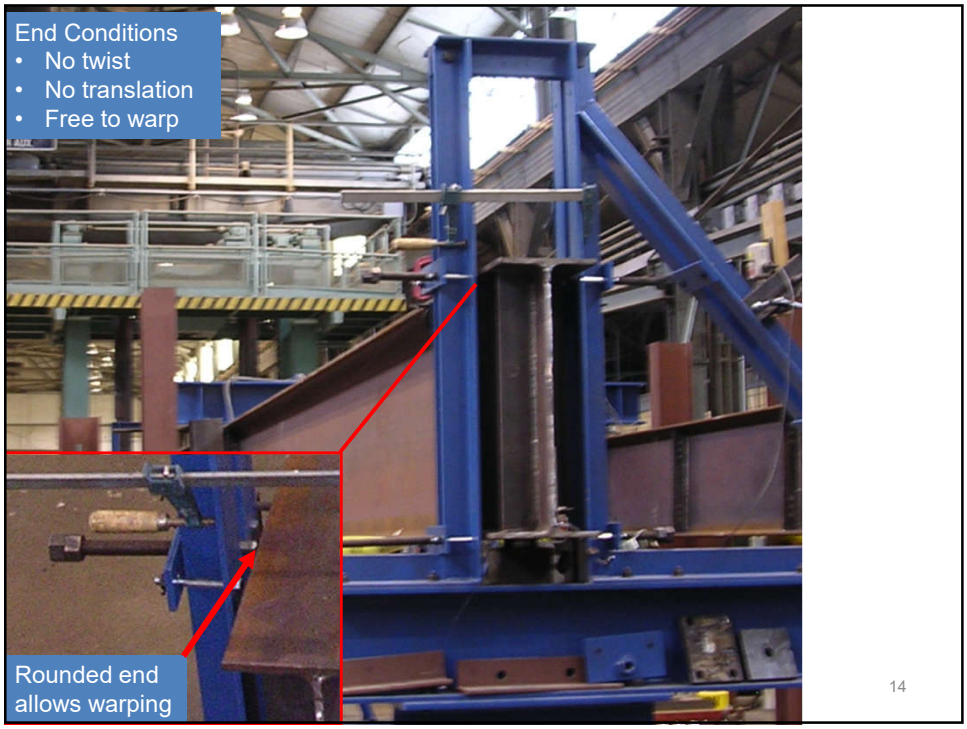

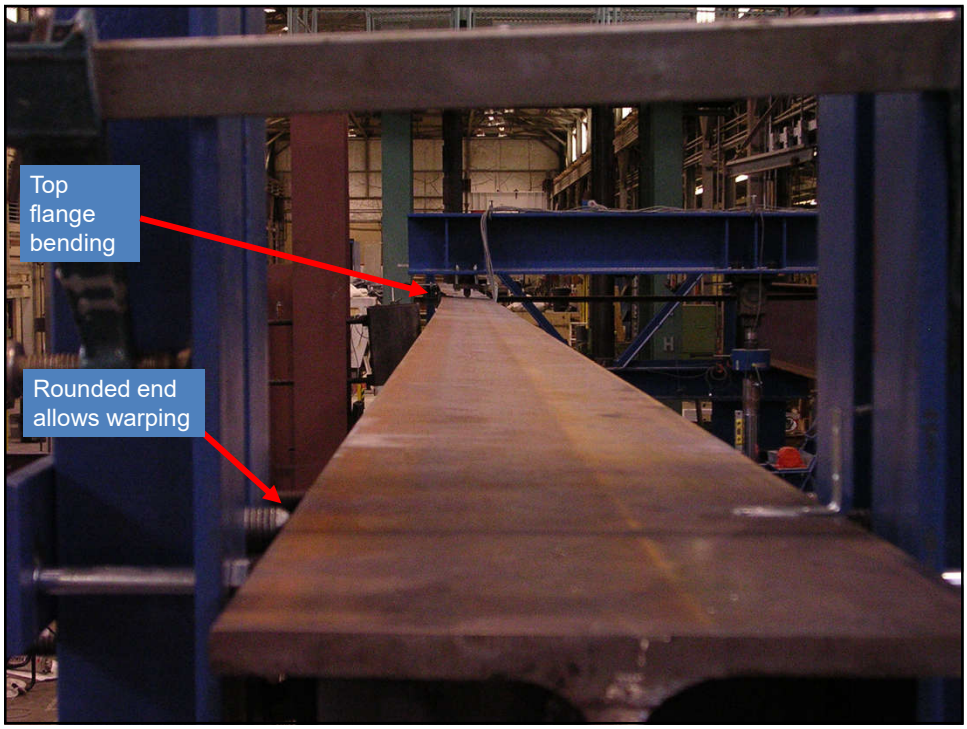

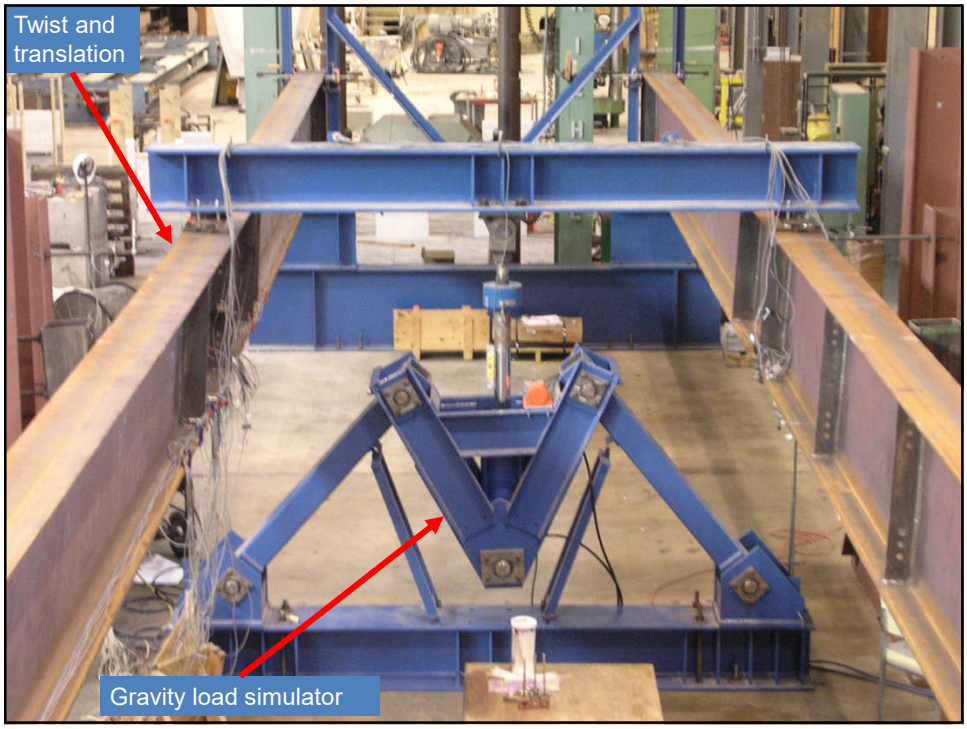

Session 3 Review

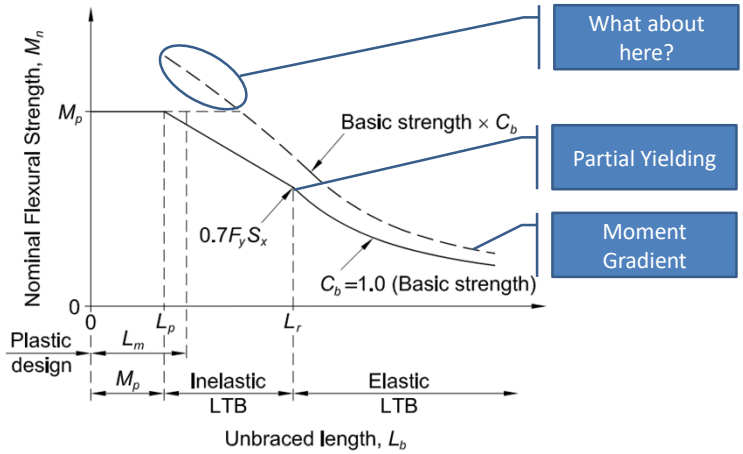

Fig. C-F1.2. Nominal flexural strength as a function of unbraced length and moment gradient.

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LM 4 Introduction

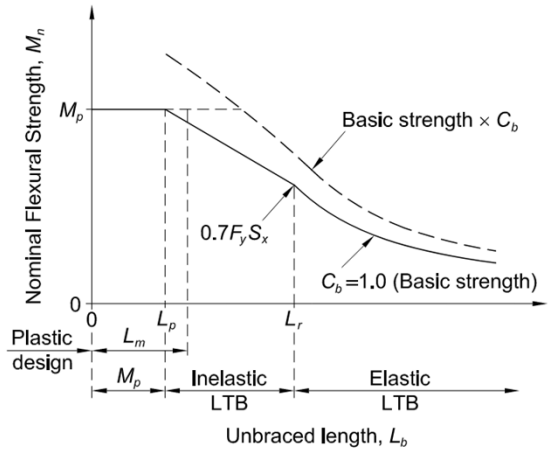

Fig. C-F1.2. Nominal flexural strength as a function of unbraced length and moment gradient.

Let's build this curve for a W14x53

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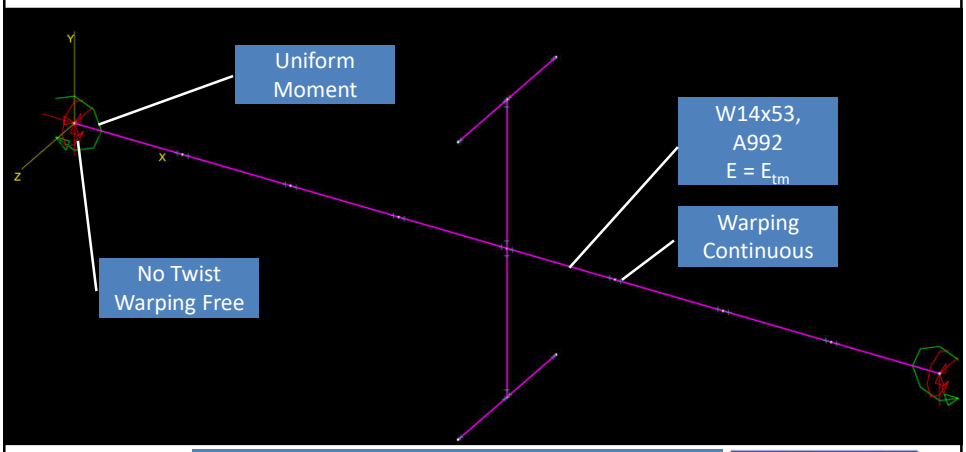
W14x53 Beam Strength Curve

- A992, $E = E_{tm}$
- Uniform moment
- Warping continuous
- No twist and warping free at ends
- 2nd Order Nonlinear Geometric and Material Analysis
- $L_b < L_p$, $L_b \approx L_p$, $L_b = L_r$, $L_b > L_r$

20

LM4 Model



Models
NS24_L4_Example_1
NS24_L4_Example_2
NS24_L4_Example_3
NS24_L4_Example_4
NS24_L4_Example_5

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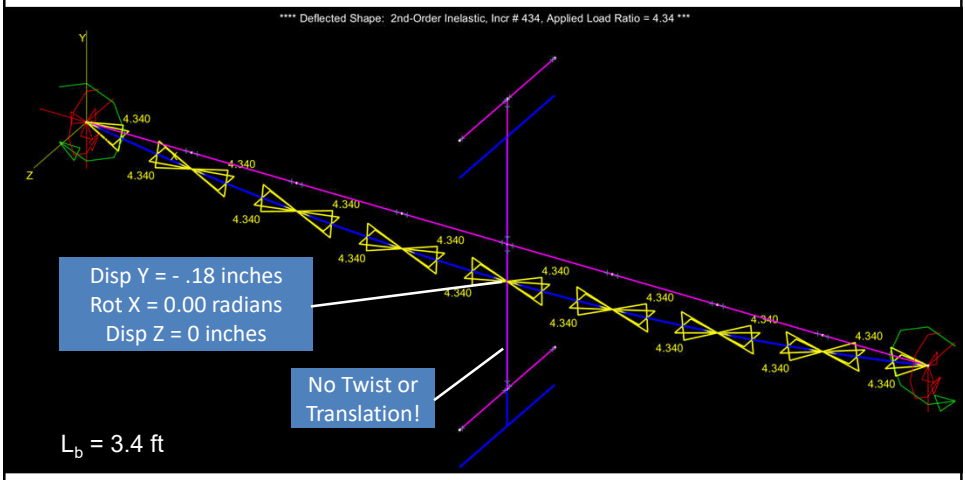
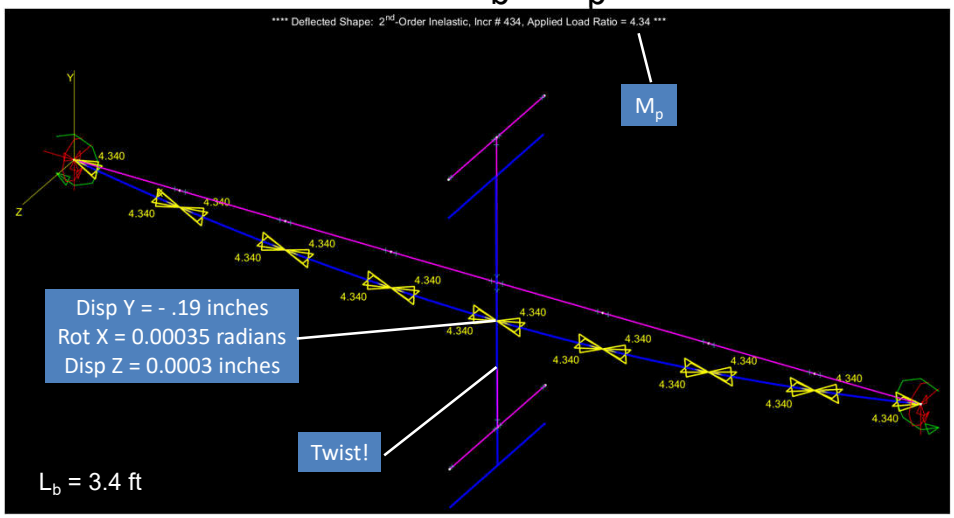
LM4 $L_b < L_p$



Model
NS24_L4_Example_1

22

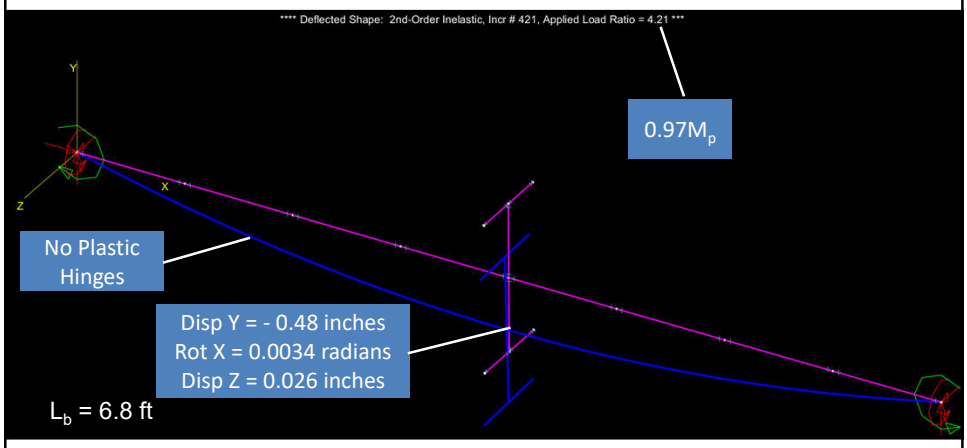
LM4 $L_b < L_p$



Model
NS24_L4_Example_2

23

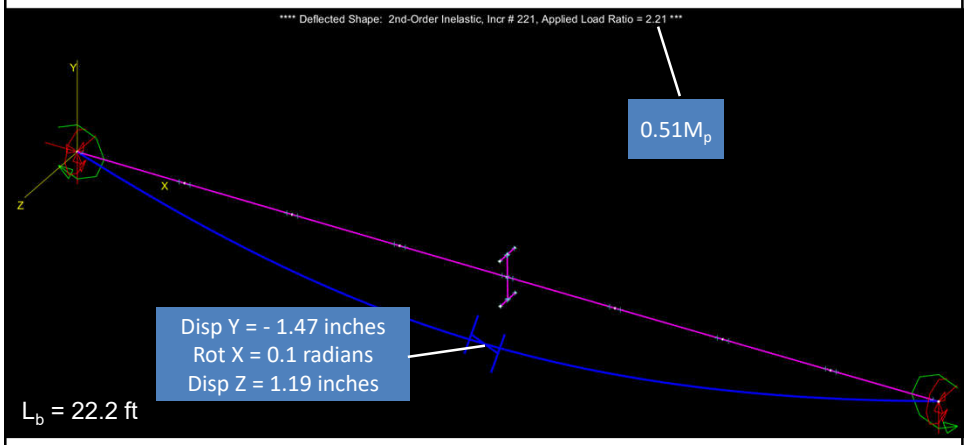
LM4 $L_b \approx L_p$



Model
NS24_L4_Example_3

24

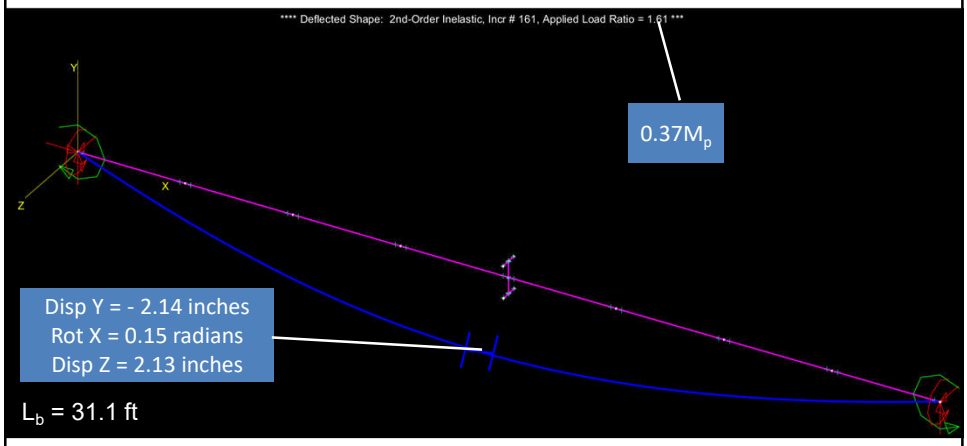
LM4 $L_b = L_r$



Model
NS24_L4_Example_4

25

LM4 $L_b > L_r$



Model
NS24_L4_Example_5

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LM 4 Summary

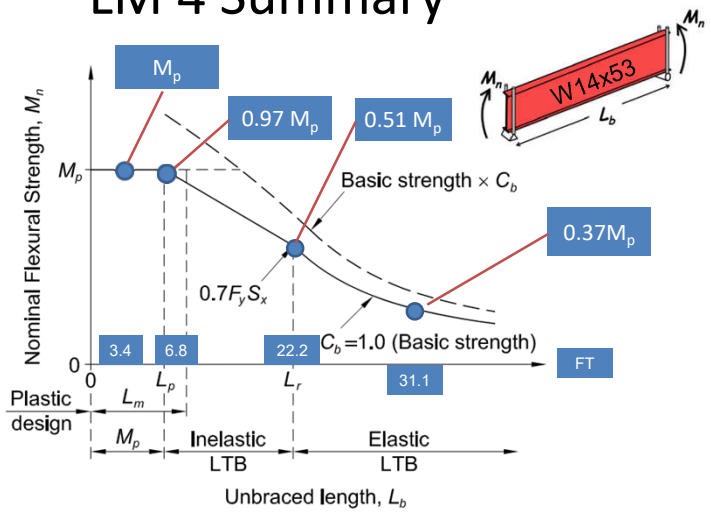

Fig. C-F1.2. Nominal flexural strength as a function of unbraced length and moment gradient.

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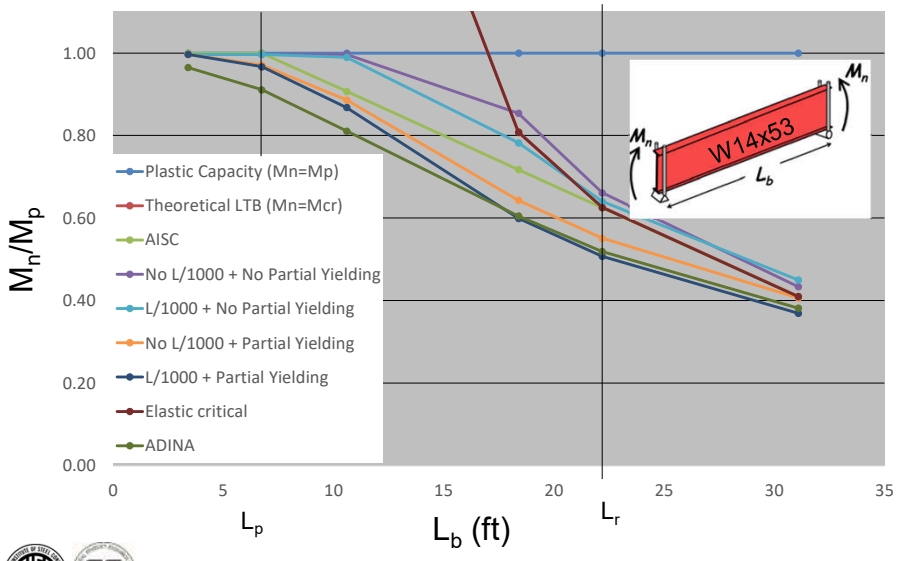
LM4 Summary



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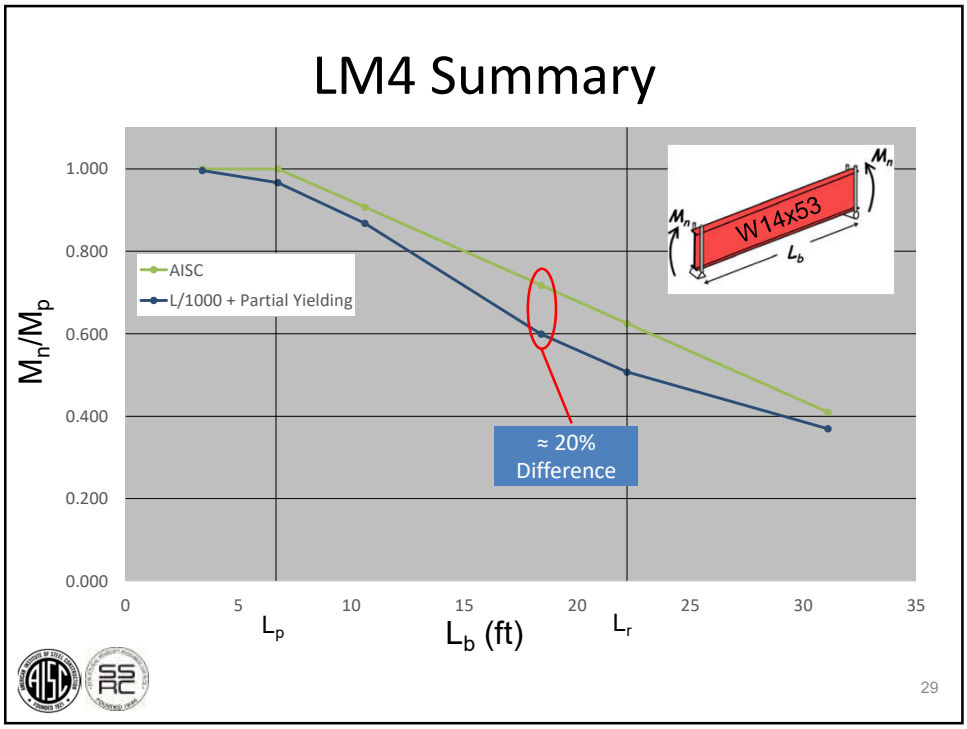
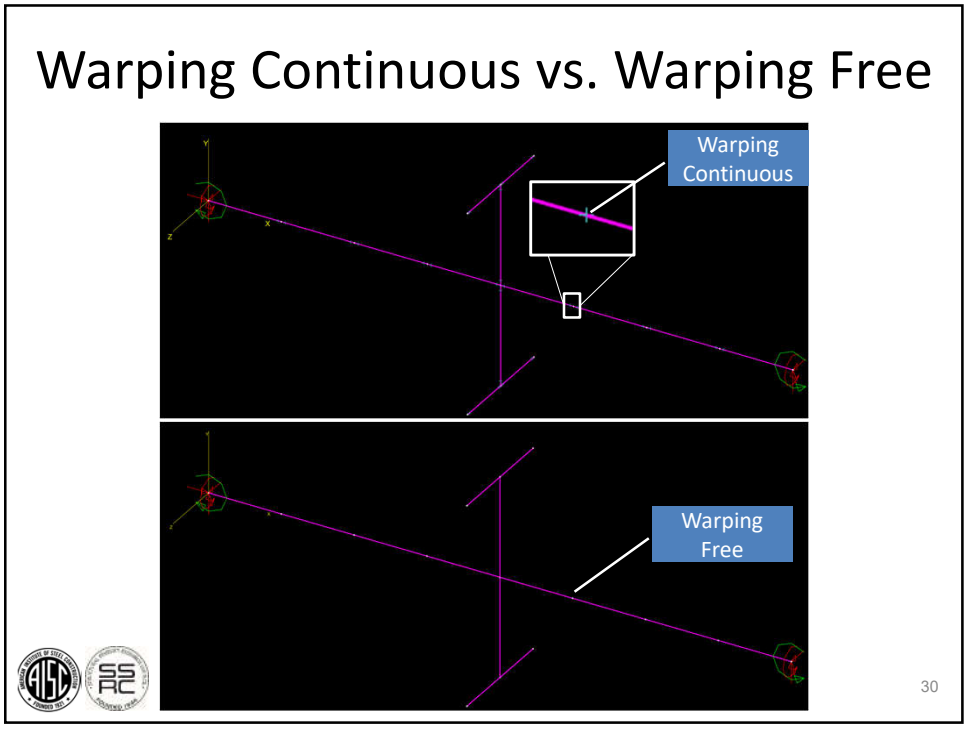
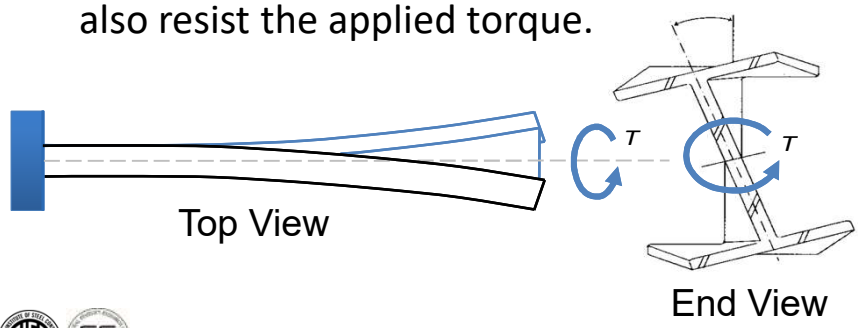




Warping Torsion

- 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.



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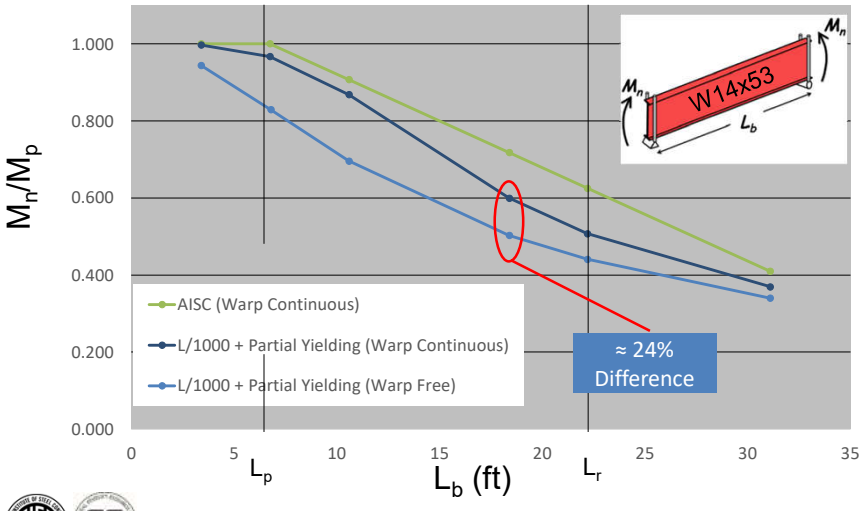
LM4 Warping Restraint



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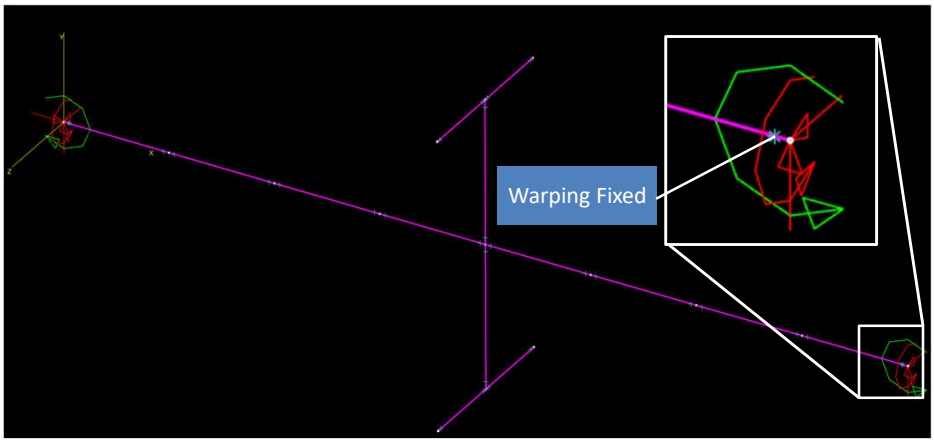
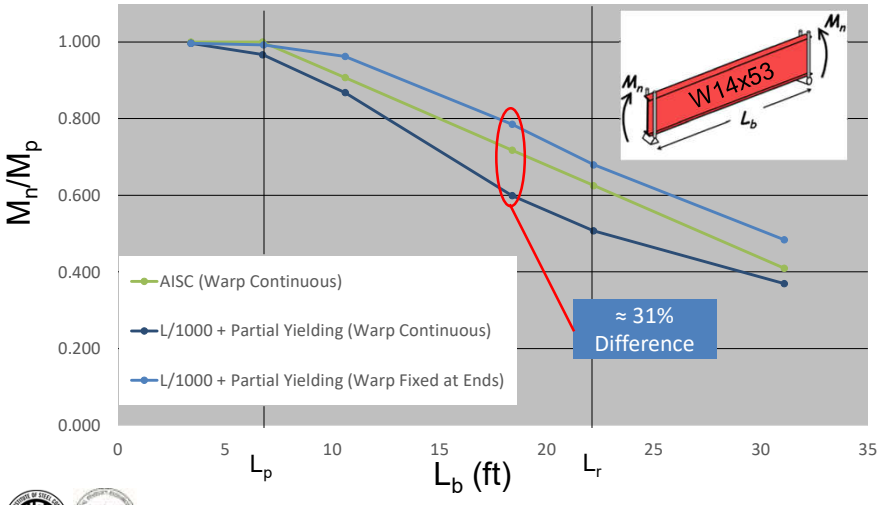
Warping Continuous and Fixed at Ends



33

Warping Fixed at Ends



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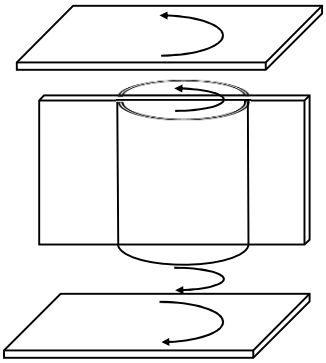
Warping Restraint Impact on LTB

- Warping restraint causes one flange to restrain the other
- Stiffens girder against lateral torsional buckling
- Changes AISC assumed "free to warp" end condition



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Tube Shape Warping Restraint

- Ojalvo and Chambers (1977) found 30% to 70% increase in elastic buckling capacity using such devices
- Closed tube offers efficient warping resistance
  - Resistance related to enclosed area
  - $J_{tube} = 4*A^2/(C/t)$
- Has been used in some bridge applications

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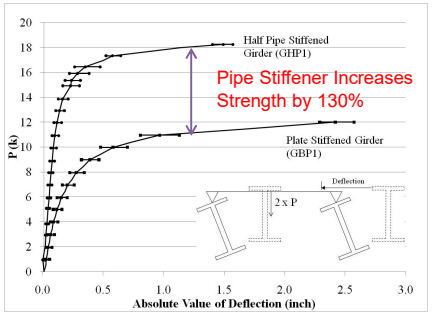
End Conditions – Warping Restraint

- Full scale test at University of Texas at Austin
- W30x90



How do we predict the increase in elastic buckling strength?

37

End Conditions – Warping Restraint

- Increases the effectiveness of warping torsion Component
- Impacts the torsional boundary condition
- Modify L_b with torsional effective length Factor, K_w

$$M_e = \frac{\pi}{L_b}\sqrt{EI_yGJ + \left(\frac{\pi E}{K_w L_b}\right)^2 I_y C_w}$$

K_wL_b – Similar to column effective lengths

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End Conditions – Warping Restraint

- K_w Calculated much like K for sidesway inhibited columns
- Use alignment chart

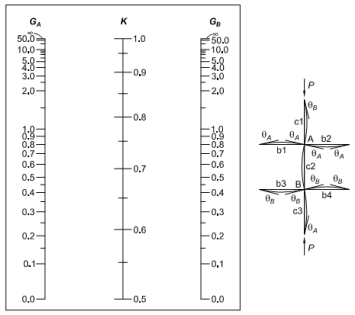


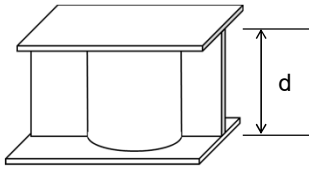
Fig. C-A-7.1. Alignment chart—sidesway inhibited (braced frame).

How do we find G?

End Conditions – Warping Restraint

- G is ratio of supported member stiffness to supporting member stiffness
- Compression flange stiffness in strong plane = EI_{fl}/L_b
- Pipe torsional stiffness = $GJ_{pipe}/(d/2)$

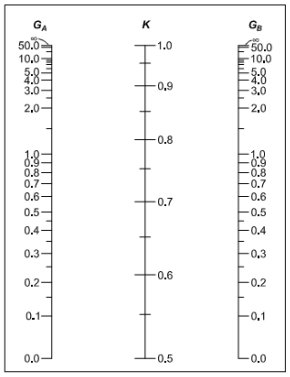
$$G = \frac{\left(EI / L_b\right)_{fl}}{GJ_{pipe} / \left(d / 2\right)}$$



End Conditions – Warping Restraint

- Enter chart with G for each end of unbraced segment
- G's may be different
- G = 50 if no warping restraint

$$G = \frac{\left(EI / L_b\right)_{fl}}{GJ_{pipe} / \left(d / 2\right)}$$



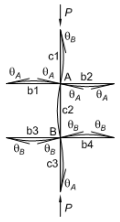


Fig. C-A-7.1. Alignment chart—sidesway inhibited (braced frame).

Are there Other Warping Restraining Conditions?

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Other end conditions

- *Distortion and Warping at Beam Supports* by Yong-Lin Pi and Nicholas Trahair (ASCE Journal of Structural Engineering Paper No. 21787)
- Covers many other end conditions
- Don't assume fixed torsional support!

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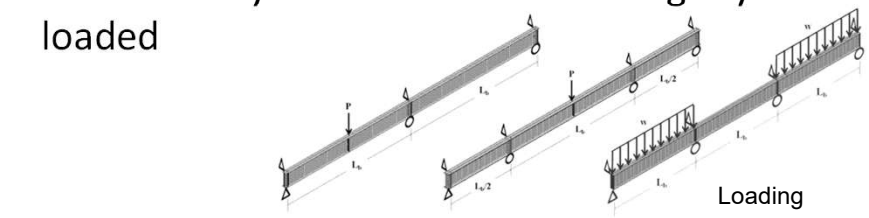
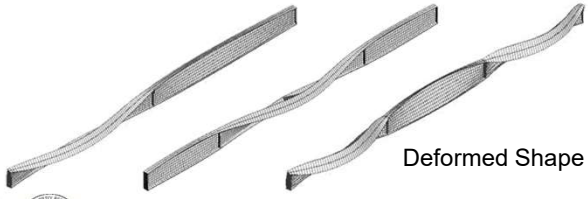
End Conditions – Adjacent Spans

- Adjacent spans offer warping restraint
- More heavily loaded lean on more lightly loaded





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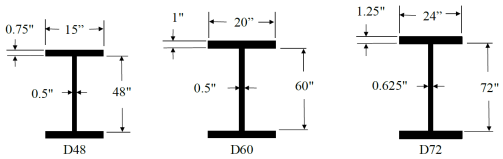
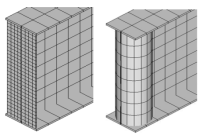
Study Parameters

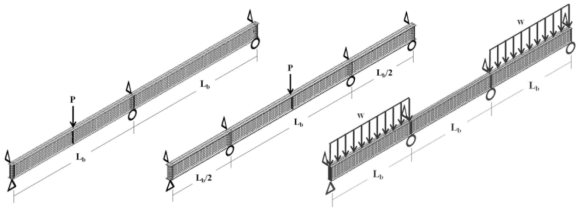
- Three cross sections



- Two stiffeners



- Span geometry and load



- Span to depth
  - 20, 25…, 40

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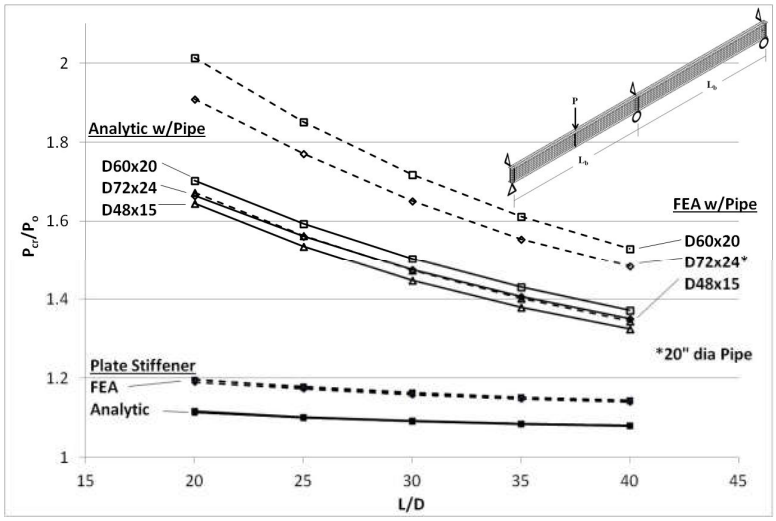
Study Results – Two Span



Be sure to account for other factors, such as load height effects, that might mitigate these increases

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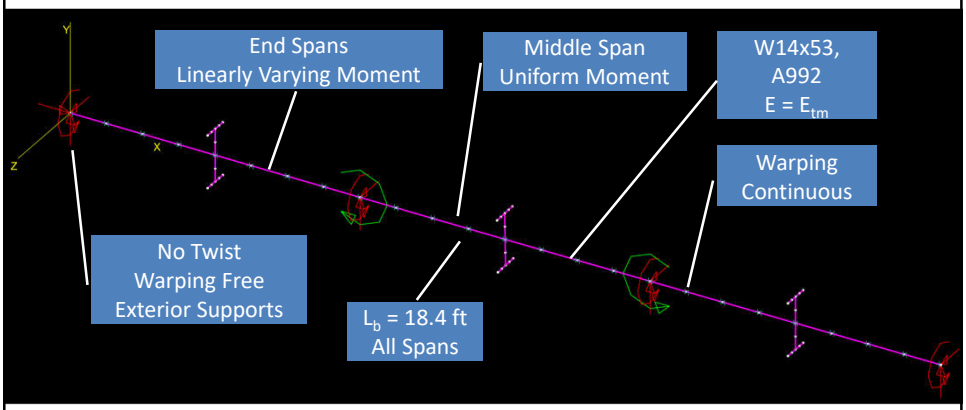
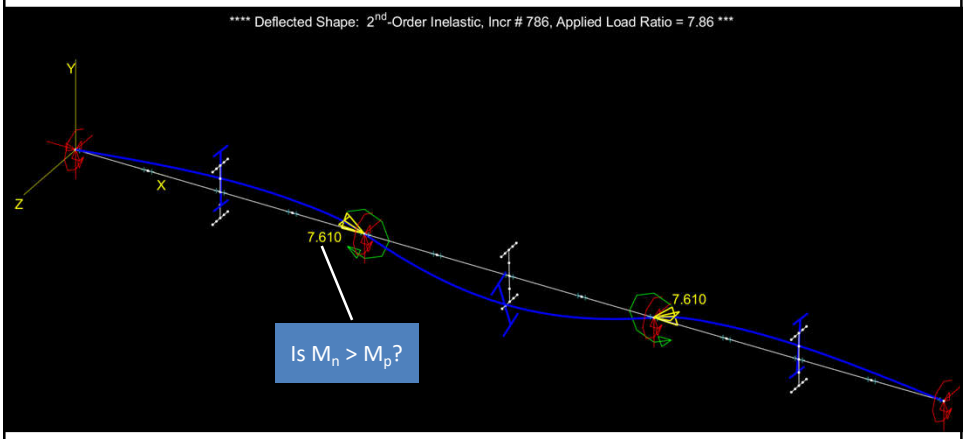
Warping Restraint - The Model



Recall nominal moment was 2,610 in-k with no end spans

Model
NS24_L4_Example_6

Warping Restraint - The Result



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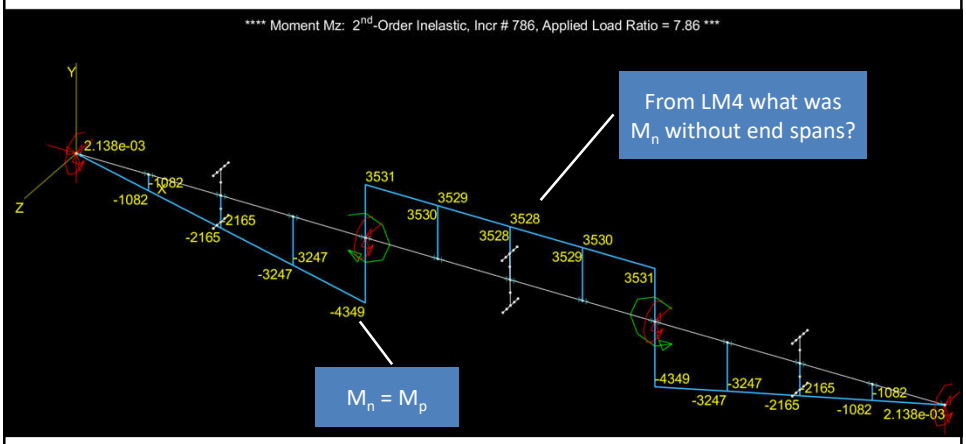
Warping Restraint - Moment Diagram



Model
NS24_L4_Example_6

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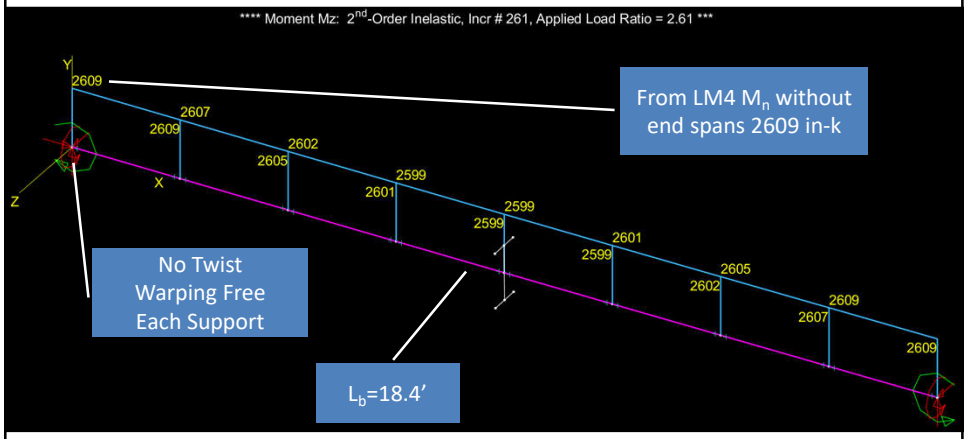
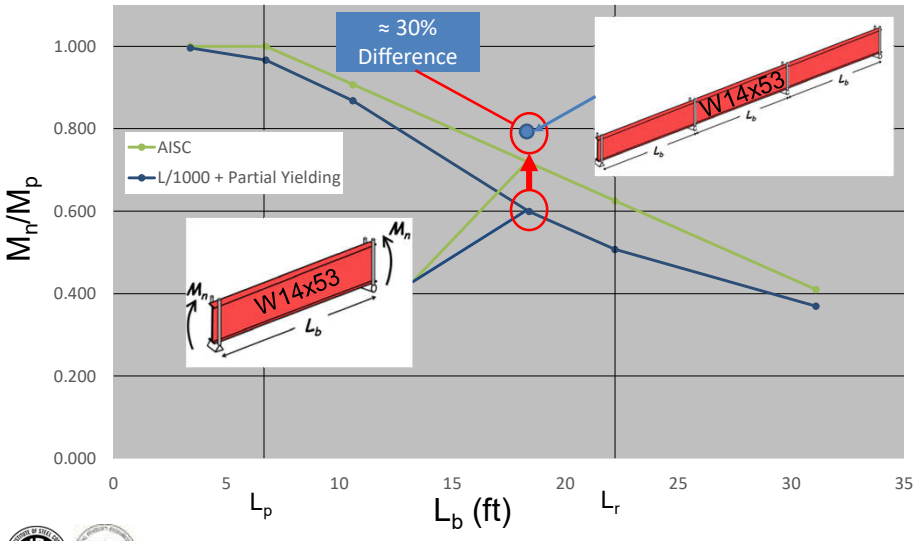
Warping Restraint - Moment Diagram

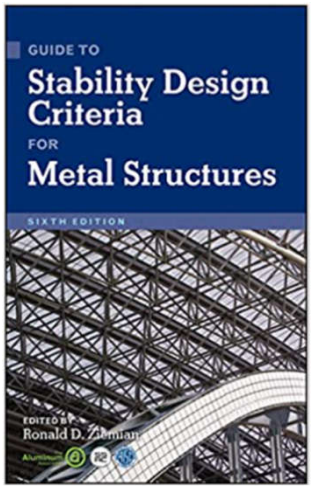


Model
NS24_L4_Example_6

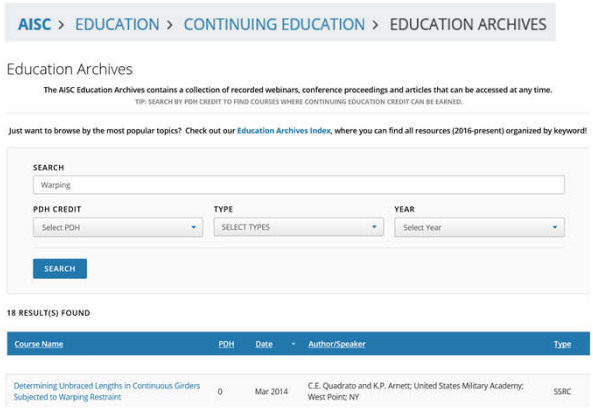
Warping Restraint - Comparison



Warping Restraint - More Information



Chapter 5



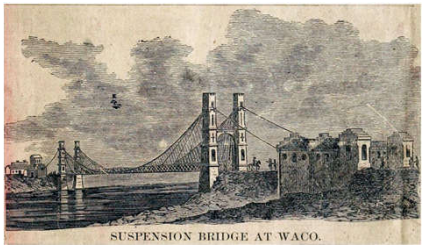
https://www.aisc.org/education/continuingeducation/education-archives/

Flexural Member Case Study

Photo courtesy Trip advisor (https://www.tripadvisor.com/Attraction_Review-g56833-d7931915-Reviews-Waco_Suspension_Bridge-Waco_Texas.html#photos;aggregationId=101&albumid=101&filter=7&ff=380164851 Traveler photo submitted by akmohney01 (Mar 2019) accessed September 8, 2020

Waco Suspension Bridge

- Suspension bridge
- Metal stiffening truss
- Main Span 475 ft
- Roadway width 18 ft



- Built John A. Roebling Sons in 1870
- Stiffening trusses added in rebuild of 1914
- Read more at historicbridges.org

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Waco Suspension Bridge Retrofit

- Replace suspension cables
- Wood roadway deck to be replaced with 3-inch thick concrete
- Paint bridge
- Can floor beams support the construction loads?

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Stiffening Truss Shoring

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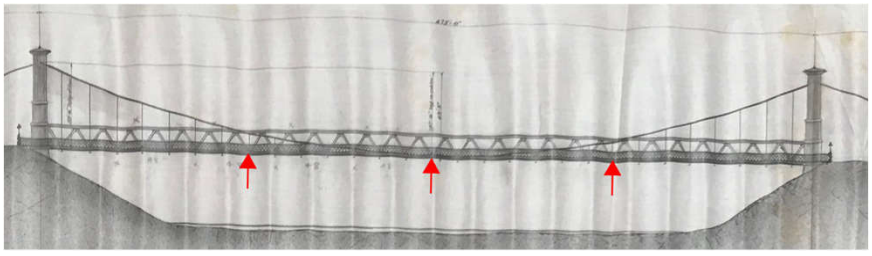
Stiffening Truss Carries Construction Load



Drawings from The Missouri Valley Bridge & Iron Co. Leavenworth, Kansas

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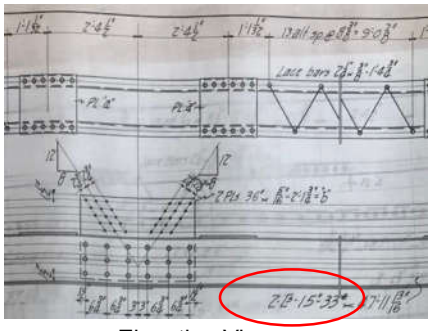
Top and Bottom Chords

Plan View



Elevation View

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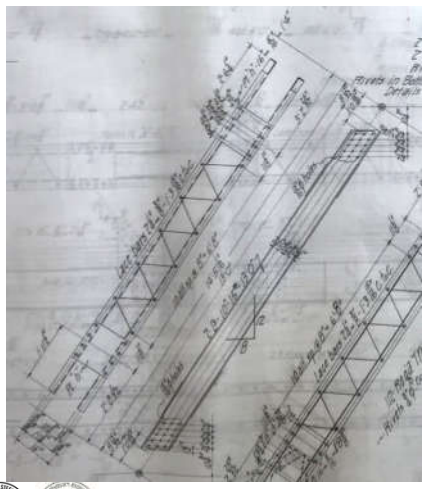
Web Members



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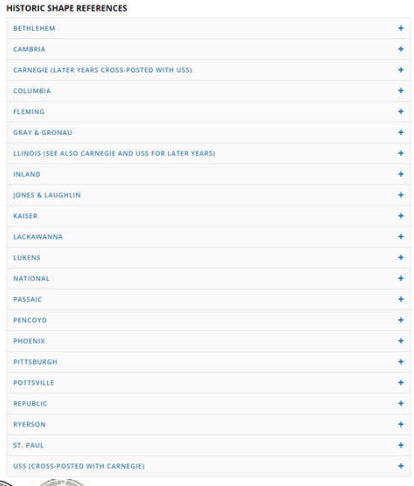
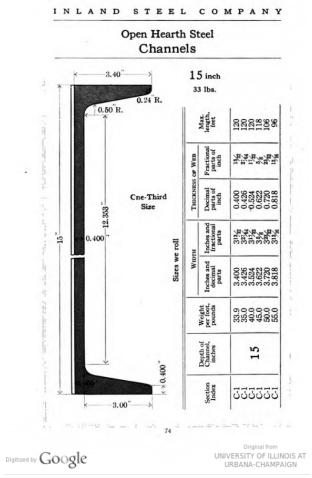
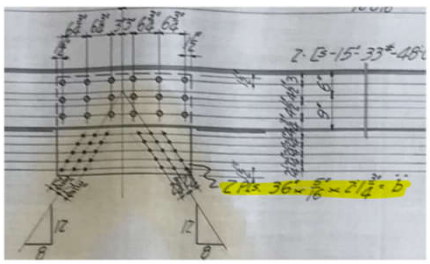
Historic Shape Information





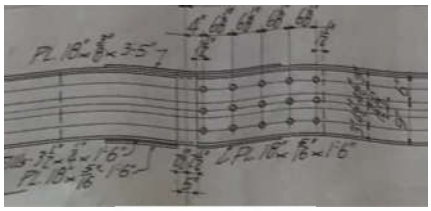
https://www.aisc.org/publications/historic-shape-references/

Web to Top Chord Connections

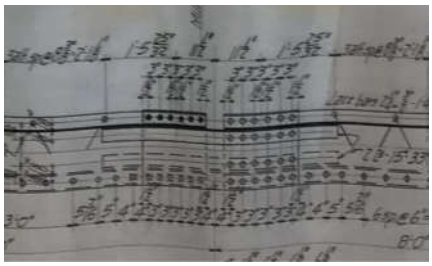


Elevation View

Top Chord Center Conditions



Elevation View



Plan View

Interior View

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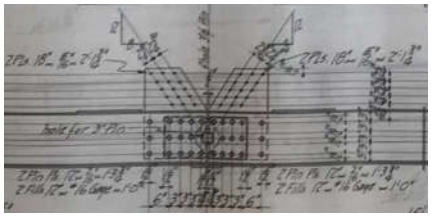
Web to Bottom Chord Center Connection



Elevation View

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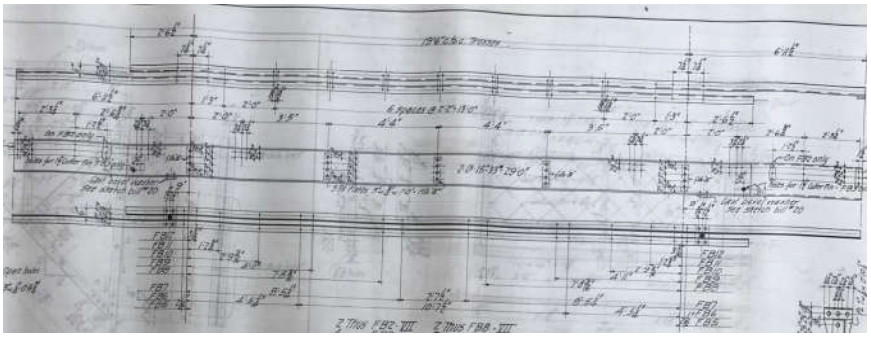
Bridge Deck Underside

Floor Beam



Back to back C15x33 under roadway and a portion of walkway
C15x33 under most of walkway

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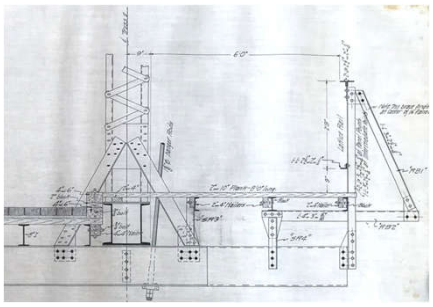
Truss to Floor Beam Connection



Section View

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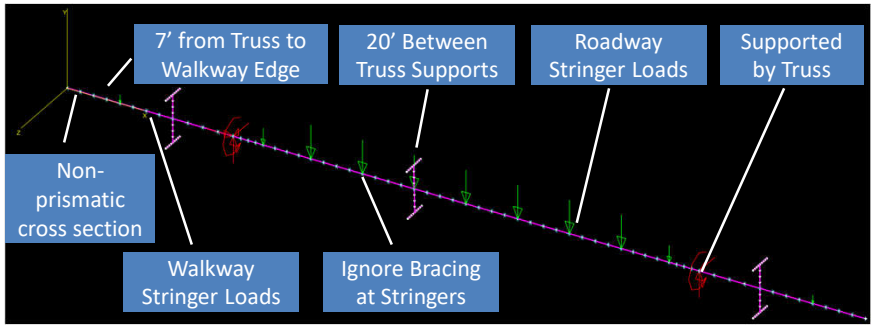
Floor Beam Model



Material is ASTM A7 (1914) with F_y = 30 ksi
Initial imperfection is L/1000 sweep

Model
NS24_L4_Example_7

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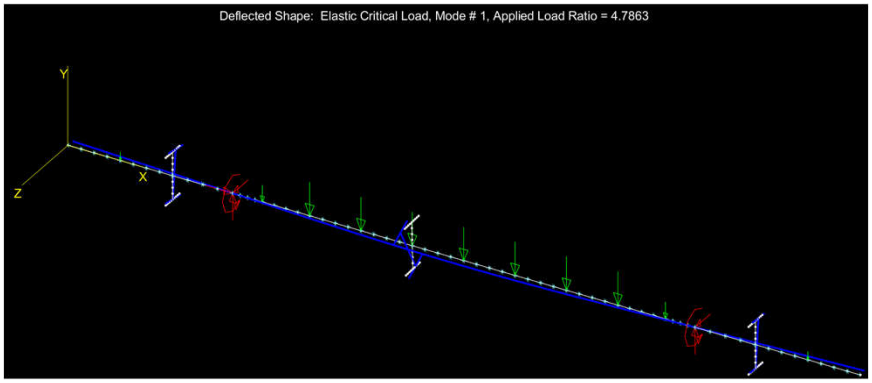
Floor Beam Elastic Critical Load



Model
NS24_L4_Example_7

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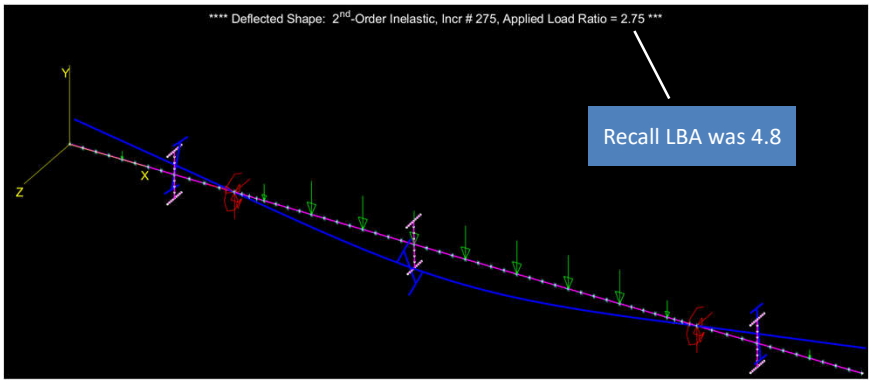
Floor Beam 2nd Order Inelastic Analysis



Model
NS24_L4_Example_7

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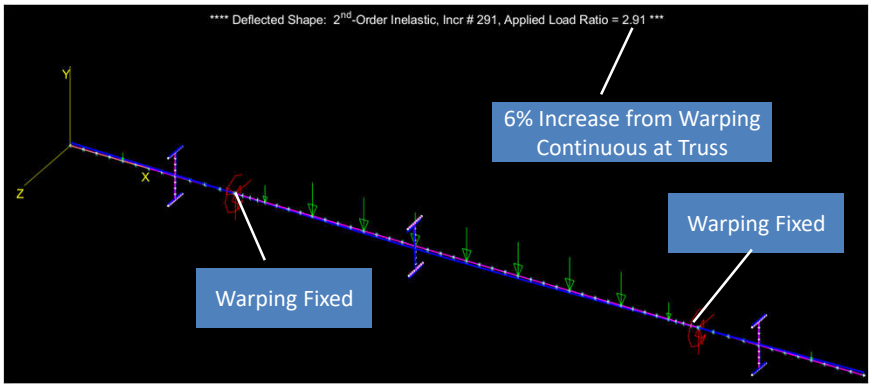
Floor Beam 2nd Order Inelastic Analysis



Model
NS24_L4_Example_7

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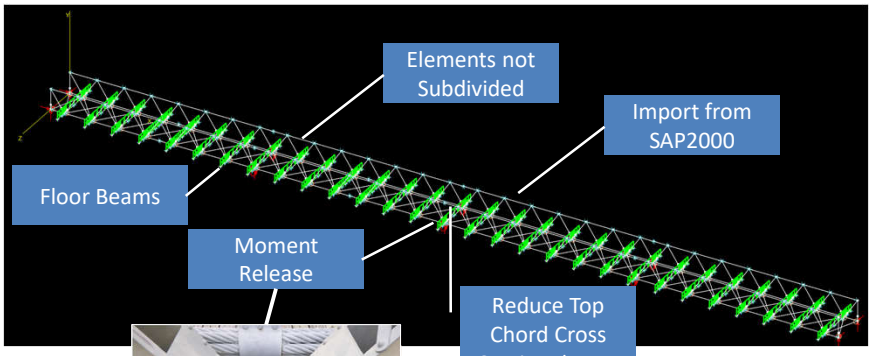
Truss Model



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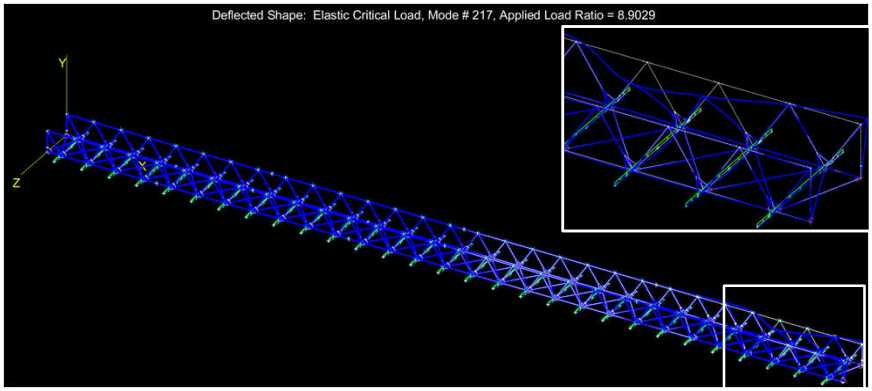
Truss Lateral Torsional Buckling



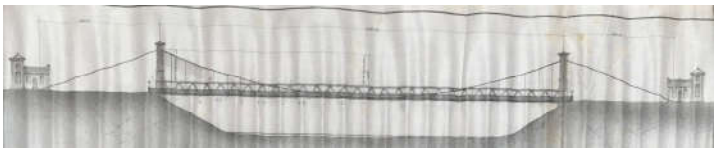
Compare with SAP2000 Applied Load Ratio of 9.3

71

Summary

- Another great mathematical solution
- Remember what they say about assumptions
- Understanding behavior is key to knowing how and when to use computational modelling
- Bracing is key to efficiency

72



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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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Attendance and PDH Certificates

- You have two options to receive credit for a given session.
  - Option 1: Watch the live session. Credit for live attendance will be displayed on the Course Resources table within two days of the session.
  - Option 2: Watch the recording and pass the associated quiz.

Videos and Quizzes

- For each session, find access within two business days after the live air date. (An email will be sent from nightschool@aisc.org.)
- Reasons for quiz:
  - EEU – You must take all quizzes and the final exam to receive EEU.
  - PDHs – If you watch a recorded session, you must pass quiz for PDHs.
  - Reinforce what you learn in the lectures and get more out of the course!

Distribution of Certificates

All certificates will be issued after the course is completed. Only the registrant will receive a certificate for the course.

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Course Resources

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

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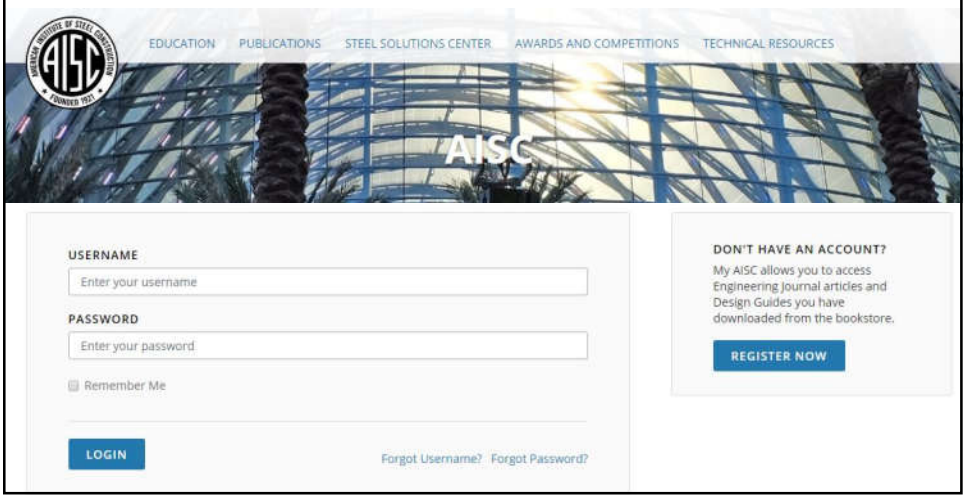
Course Resources

Go to www.aisc.org and sign in.



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Course Resources

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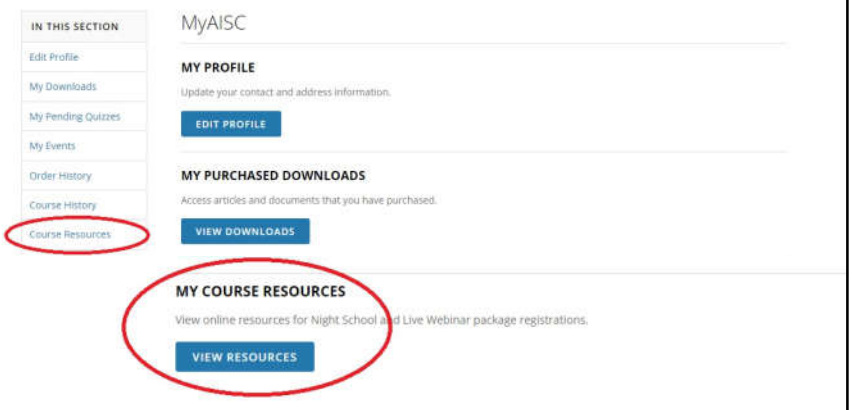

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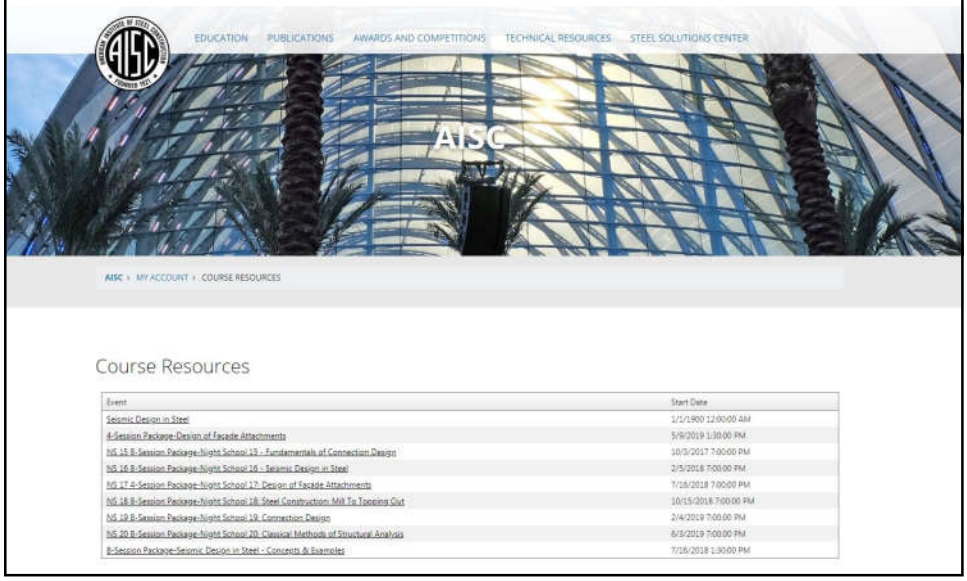
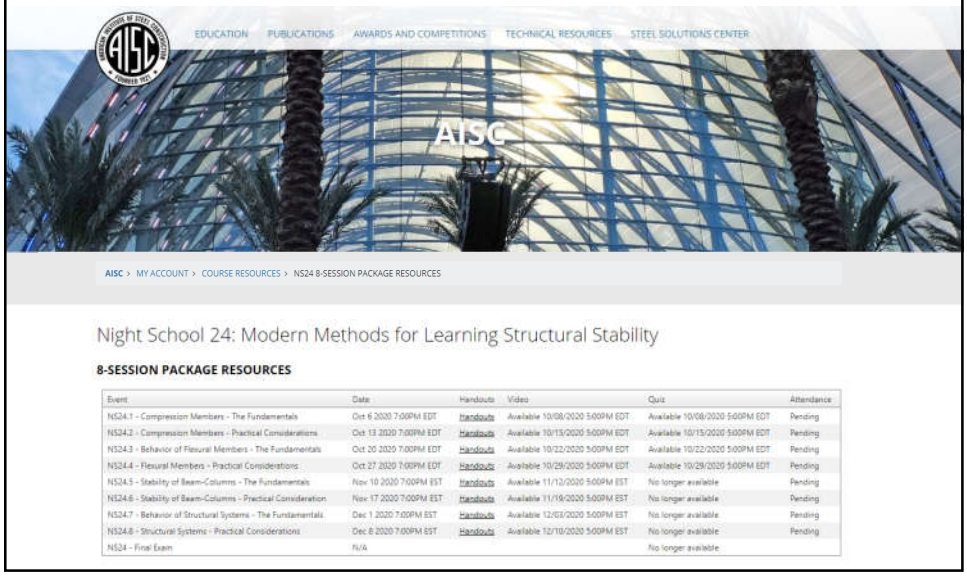
Course Resources



8-Session Registrants

Course Resources



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