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We will begin shortly. Please standby.

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.



AISC Live Webinars

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.



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.



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



Course Overview (2)

Strength/Weight + Stiffness/Weight + Competitive \$

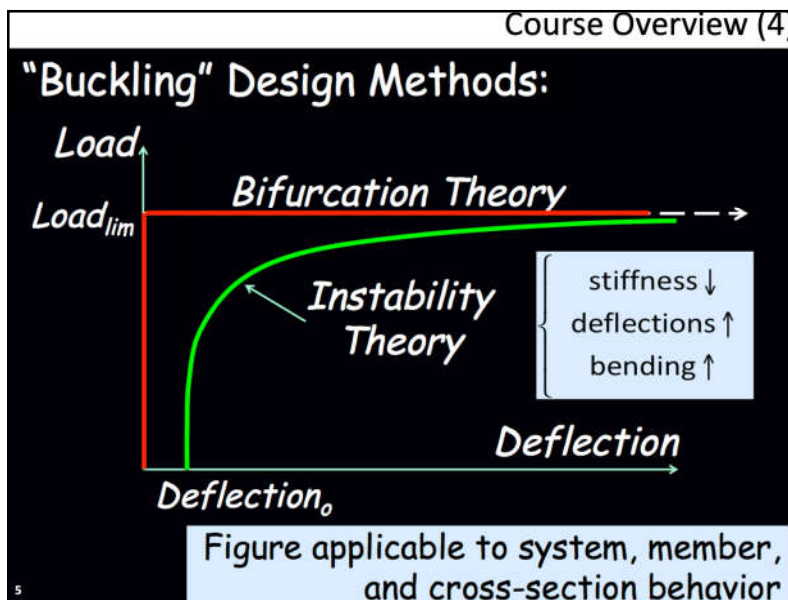
Slender Systems, Members, and Cross-sections

Design for Stability!

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

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

GNIA: same as GNA, but **includes initial imperfections**

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

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

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

Course Introduction

Compression Members – Sessions 1 & 2

Flexural Members – Session 3 & 4

Beam-Columns – Sessions 5 & 6

Systems – Session 7 & 8



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



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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=380184851) Traveler photo submitted by akmhney01 (Mar 2019) accessed September 8, 2020



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Session Overview

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



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Session 3 Review

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



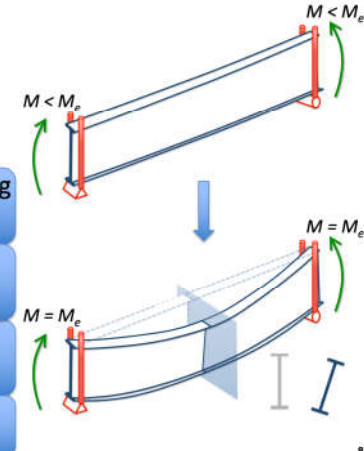
TABLE USER NOTE F1.1 Selection Table for the Application of Chapter F Sections				
Section in Chapter F	Cross Section	Flange Slenderness	Web Slenderness	Limit States
F2		C	C	Y, LTB
F3		NC, S	C	LTB, FLB
F4		C, NC, S	C, NC	CFY, LTB, FLB, TPY
F5		C, NC, S	S	CFY, LTB, FLB, TPY
F6		C, NC, S	N/A	Y, FLB
F7		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



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Lateral Torsional Buckling (LTB)

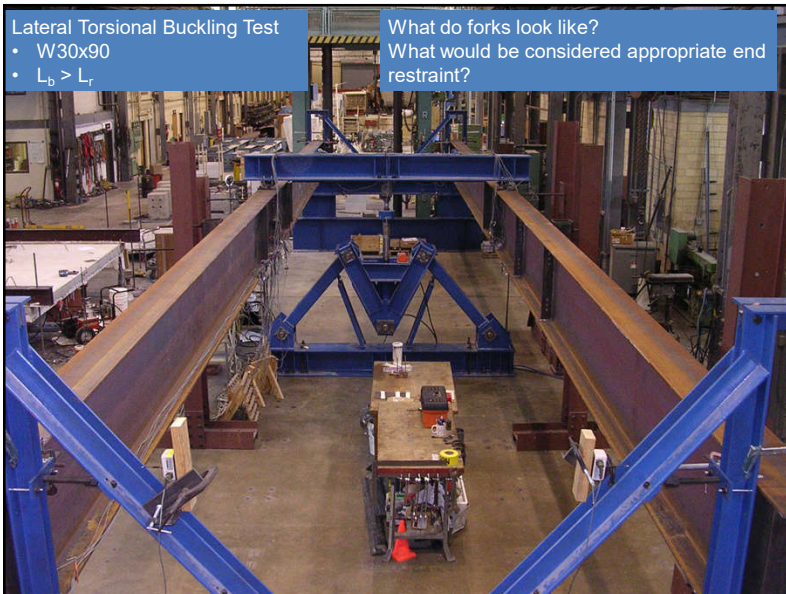
- Bifurcation solution
- Assumptions!
 - prismatic member ($I = \text{constant}$)
 - only major axis bending occurs before buckling
 - linear elastic behavior ($E = \text{constant}$)
 - uniform moment distribution
 - braced at the ends (frictionless)



Lesson 3 Slide 87

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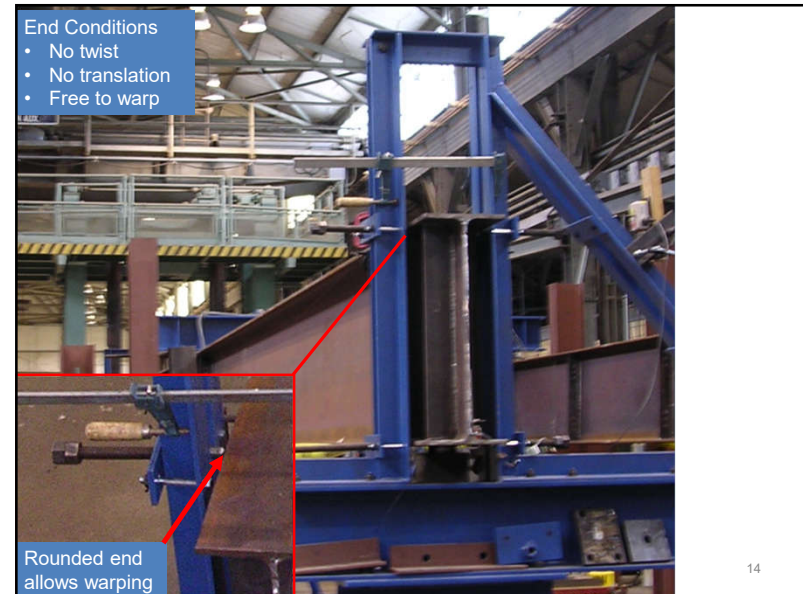
12



Lateral Torsional Buckling Test

- W30x90
- $L_b > L_r$

What do forks look like?
 What would be considered appropriate end restraint?



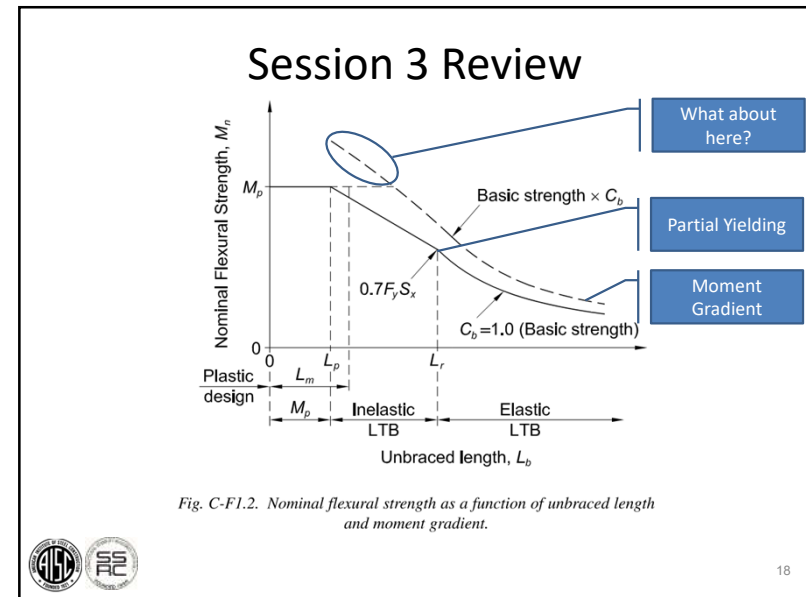
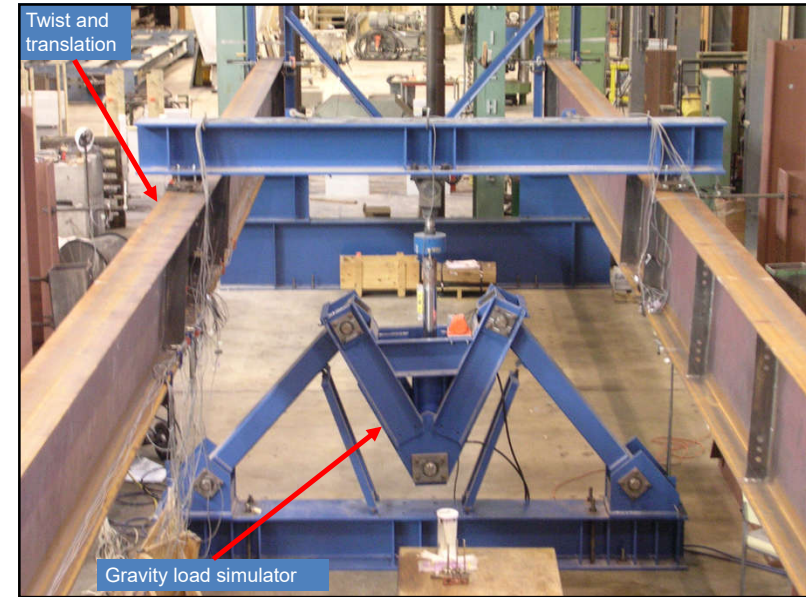
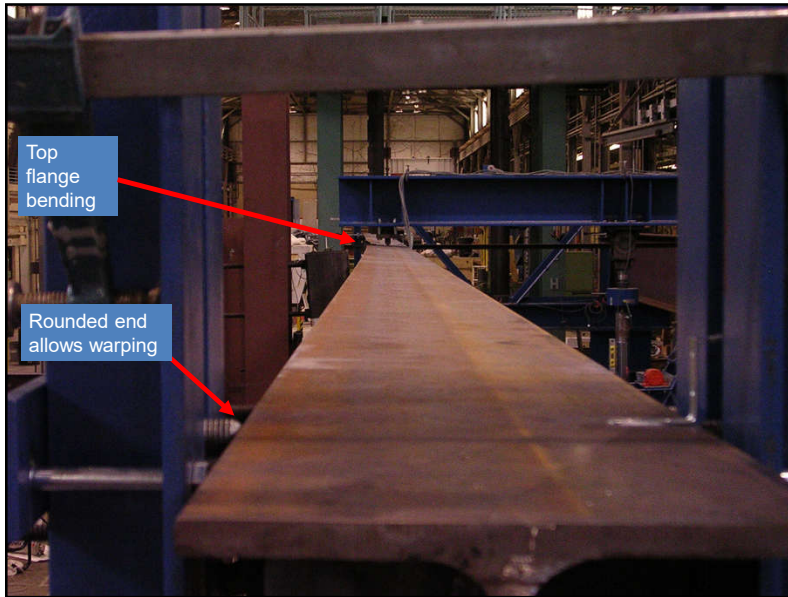
End Conditions

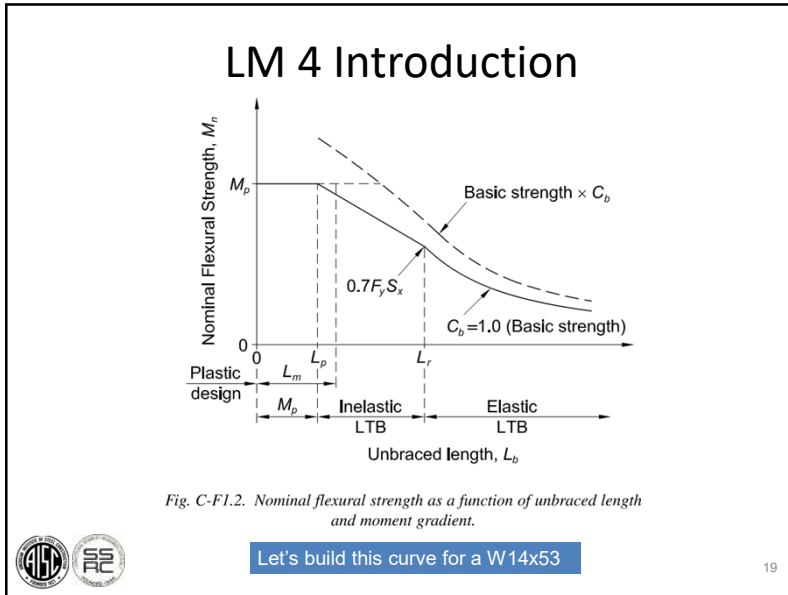
- No twist
- No translation
- Free to warp

Rounded end allows warping

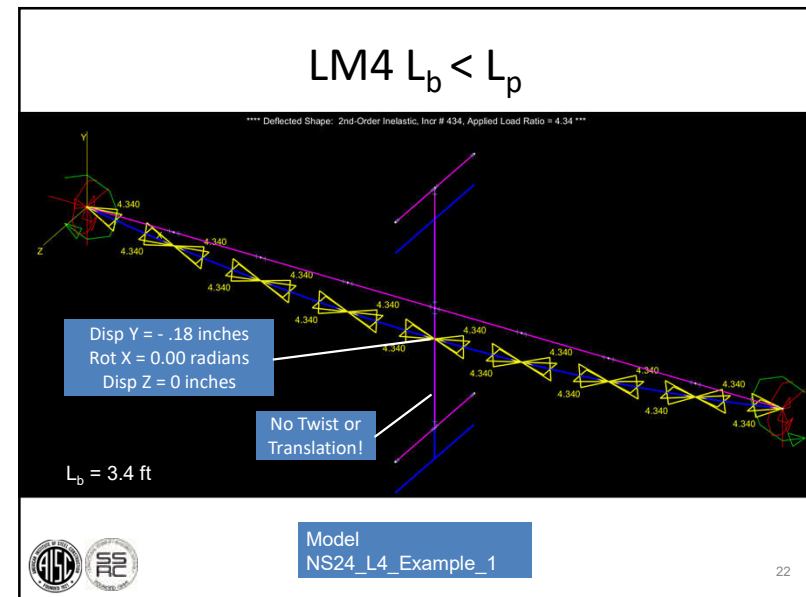
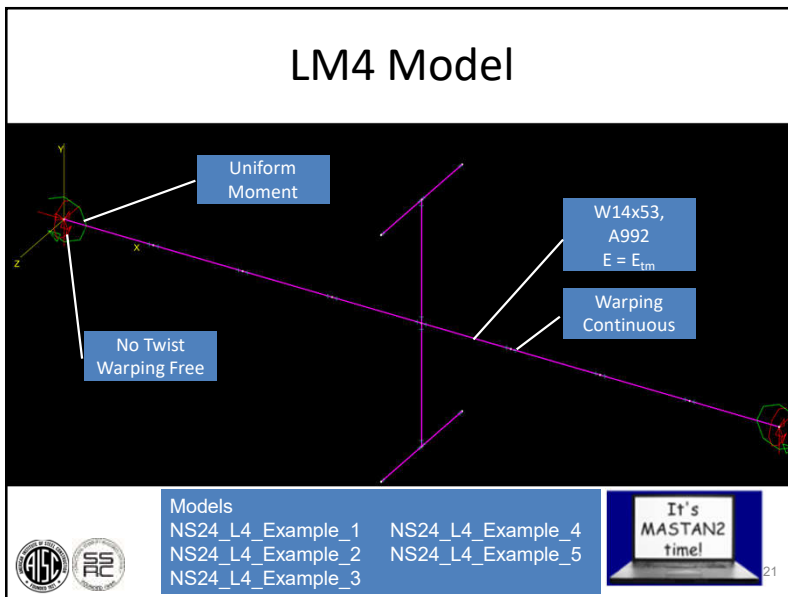
14

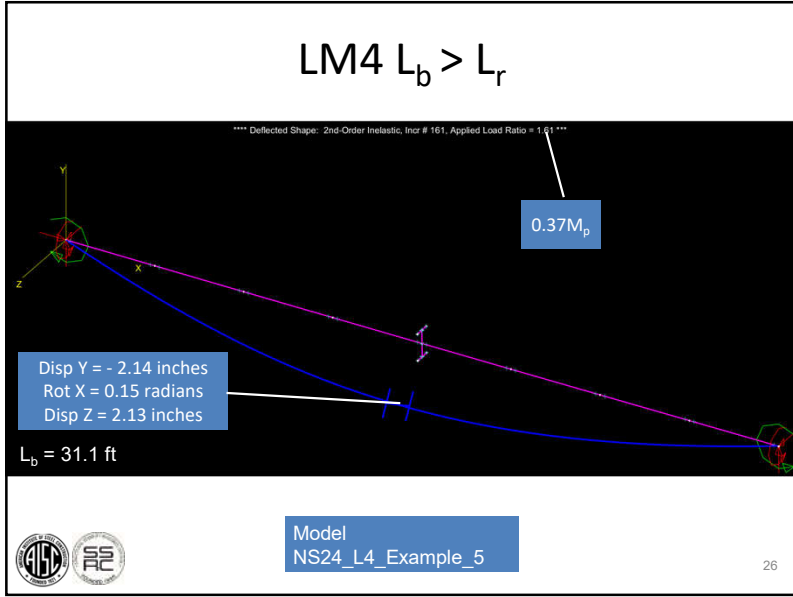
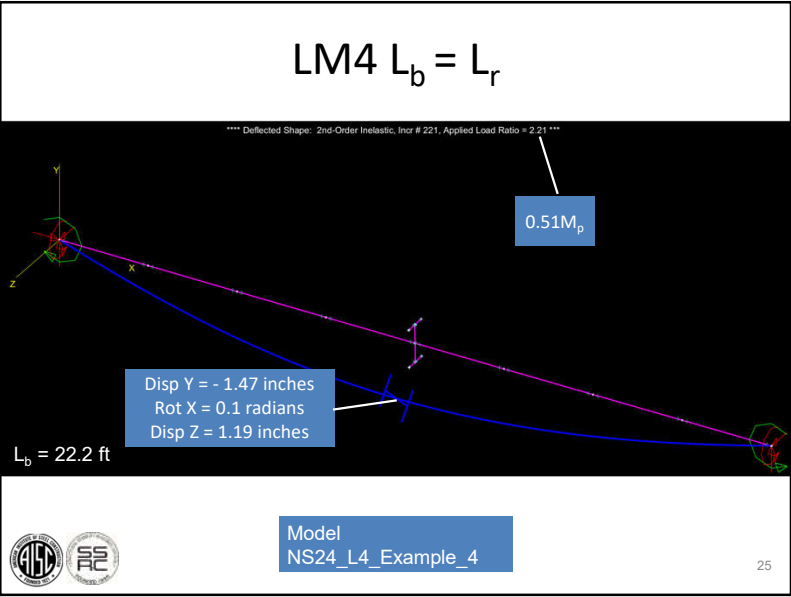
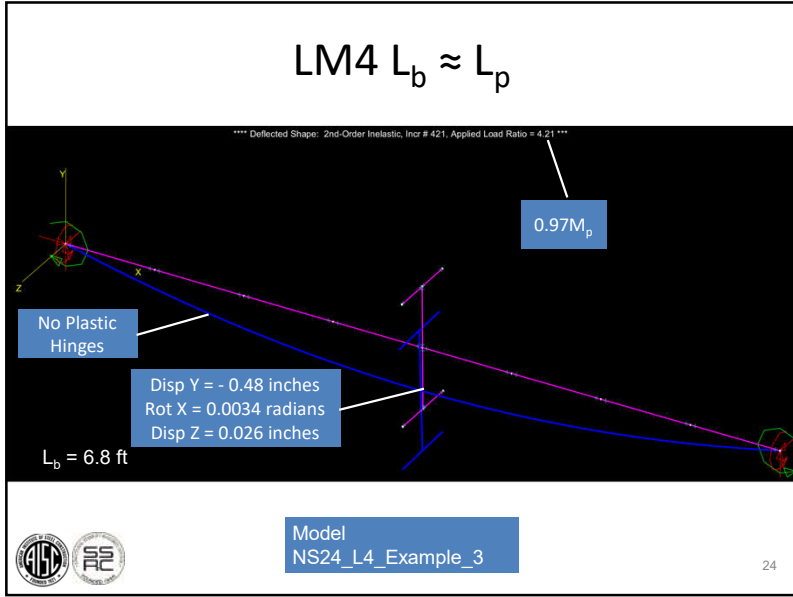
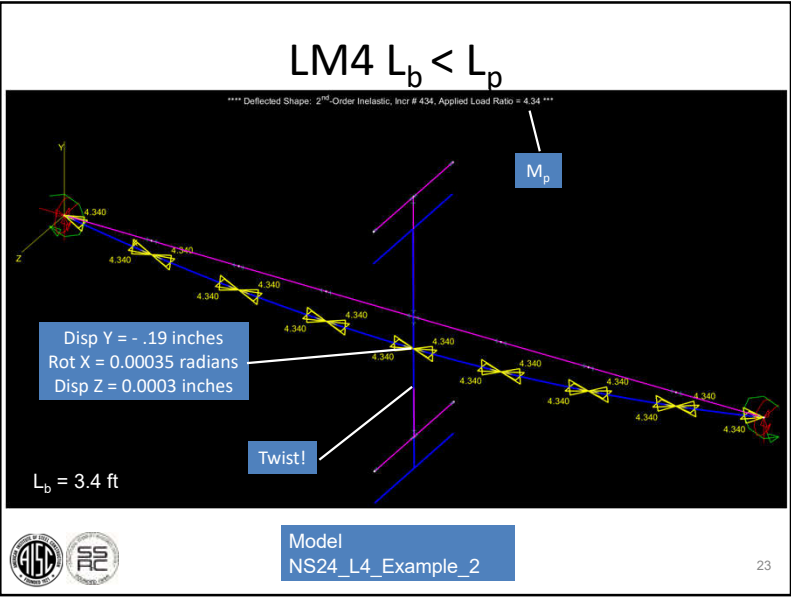


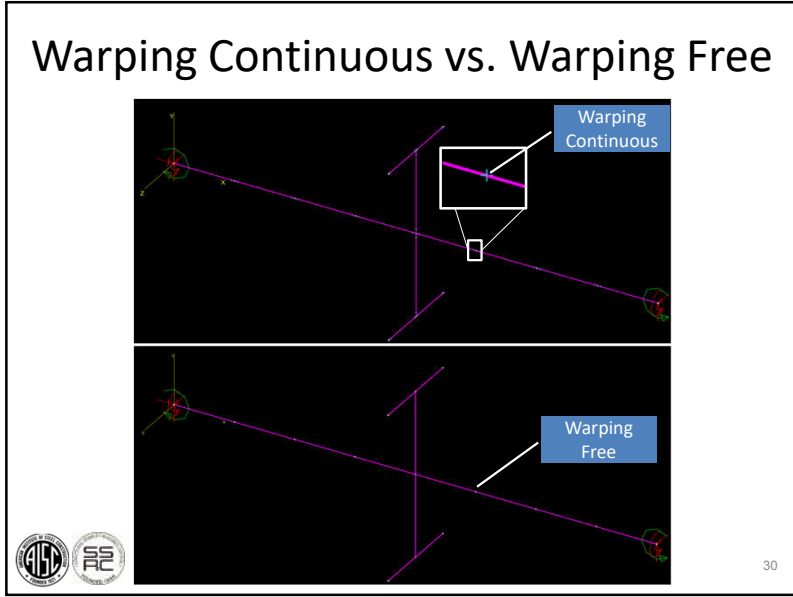
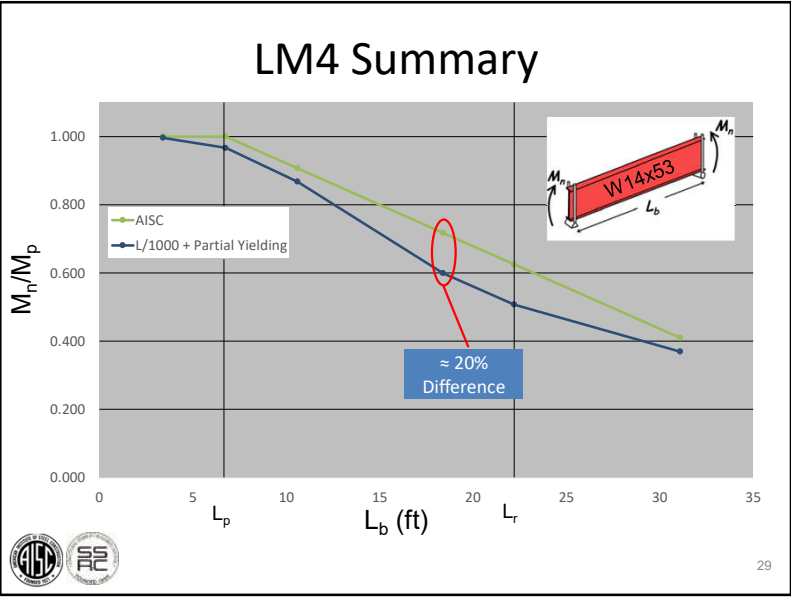
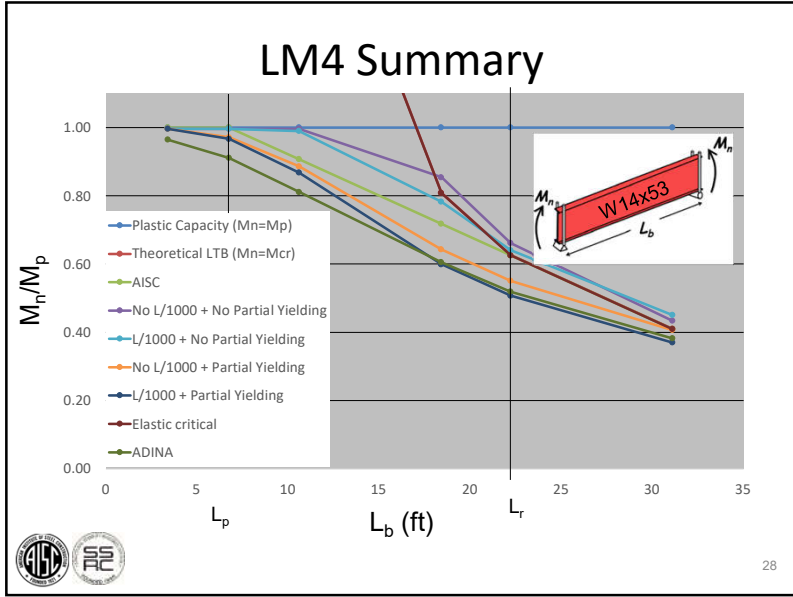
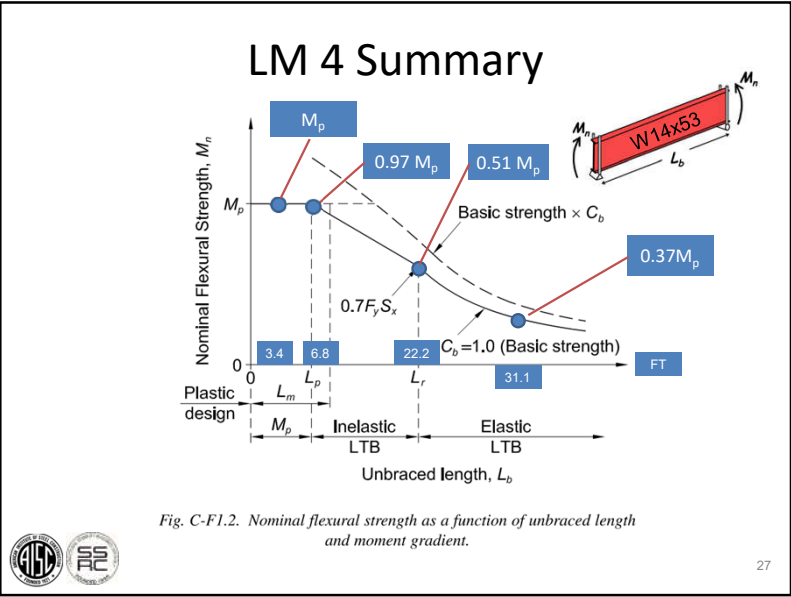




- ### W14x53 Beam Strength Curve
- A992, $E = E_{tm}$
 - Uniform moment
 - Warping continuous
 - No twist and warping free at ends
 - 2nd Order Nonlinear Geometric and Material Analysis
 - $L_b < L_p$, $L_b \approx L_p$, $L_b = L_r$, $L_b > L_r$
- 20

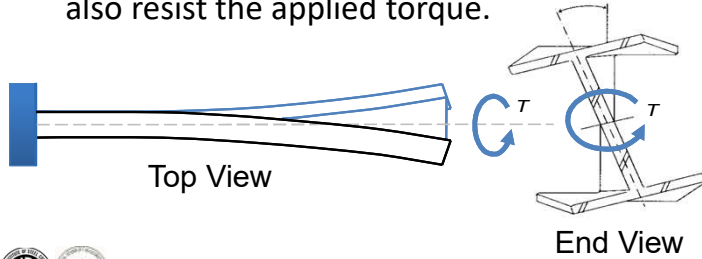






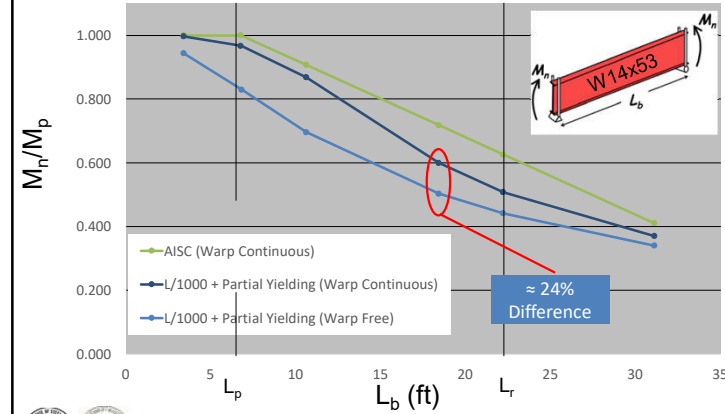
Warping Torsion

- 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.



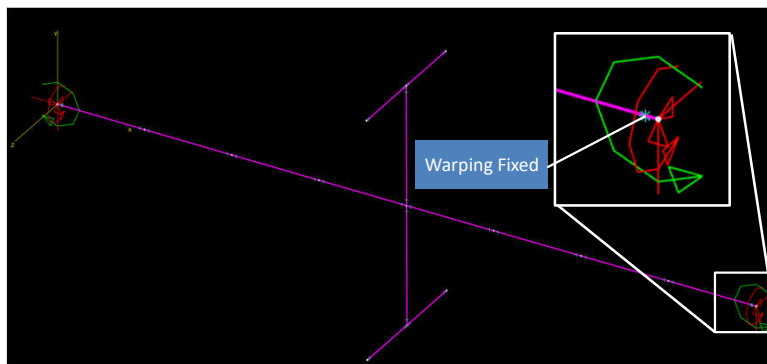
31

LM4 Warping Restraint



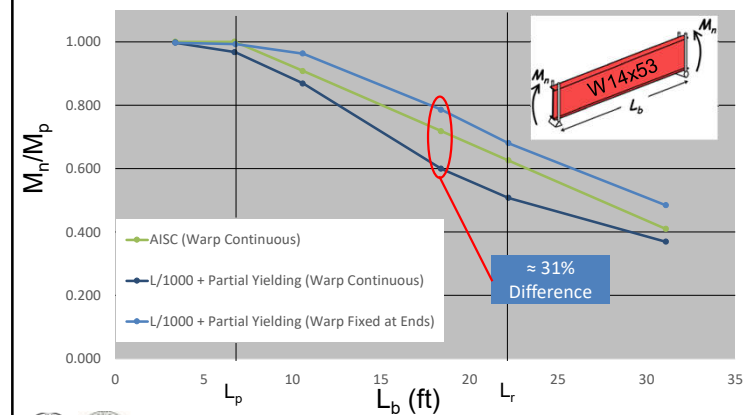
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Warping Continuous and Fixed at Ends



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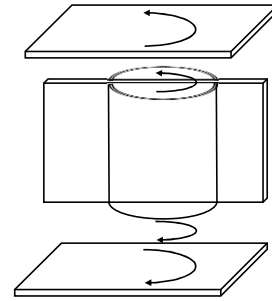
Warping Fixed at Ends



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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

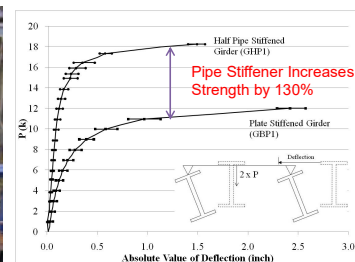
- Ojalvo and Chambers (1977) found 30% to 70% increase in elastic buckling capacity using such devices
- Closed tube offers efficient warping resistance
 - Resistance related to enclosed area
 - $J_{\text{tube}} = 4 \cdot A^2 / (C/t)$
- Has been used in some bridge applications



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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?



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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

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

$K_w L_b$ – 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

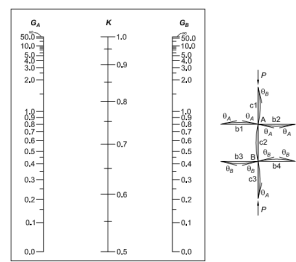


Fig. C-A-7.1. Alignment chart—sidesway inhibited (braced frame)

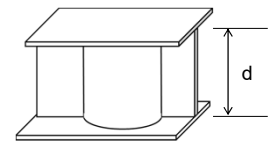
How do we find G?



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 = $GJ_{pipe}/(d/2)$

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



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

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

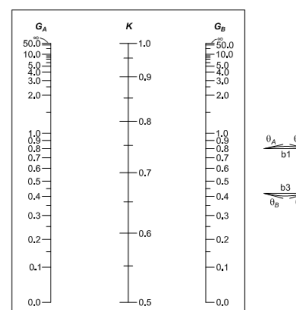


Fig. C-A-7.1. Alignment chart—sidesway inhibited (braced frame)

Are there Other Warping Restraining Conditions?



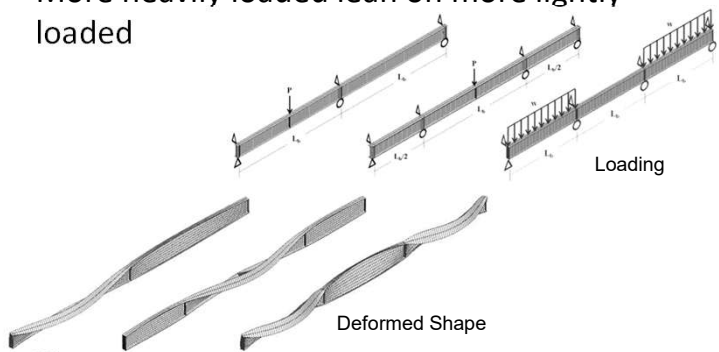
Other end conditions

- *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!



End Conditions – Adjacent Spans

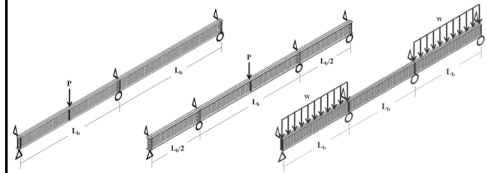
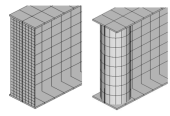
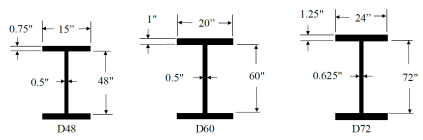
- Adjacent spans offer warping restraint
- More heavily loaded lean on more lightly loaded



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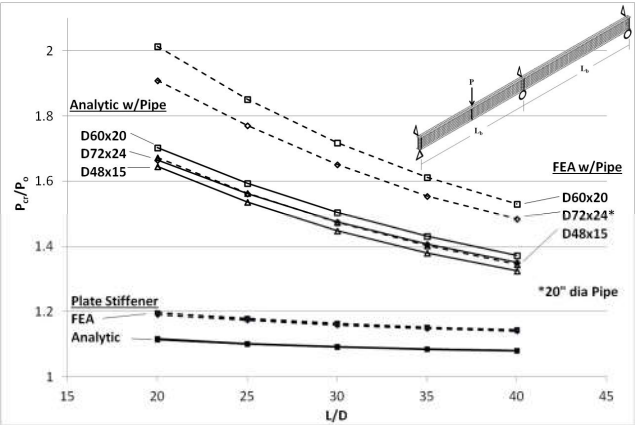
Study Parameters

- Three cross sections
 - Two stiffeners
- Span geometry and load
 - Span to depth
 - 20, 25..., 40



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Study Results – Two Span

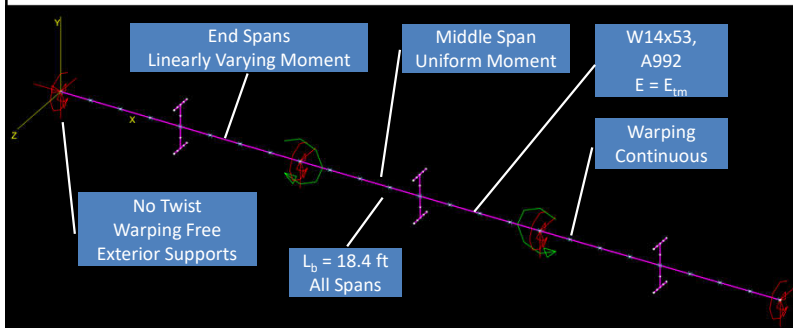


Be sure to account for other factors, such as load height effects, that might mitigate these increases



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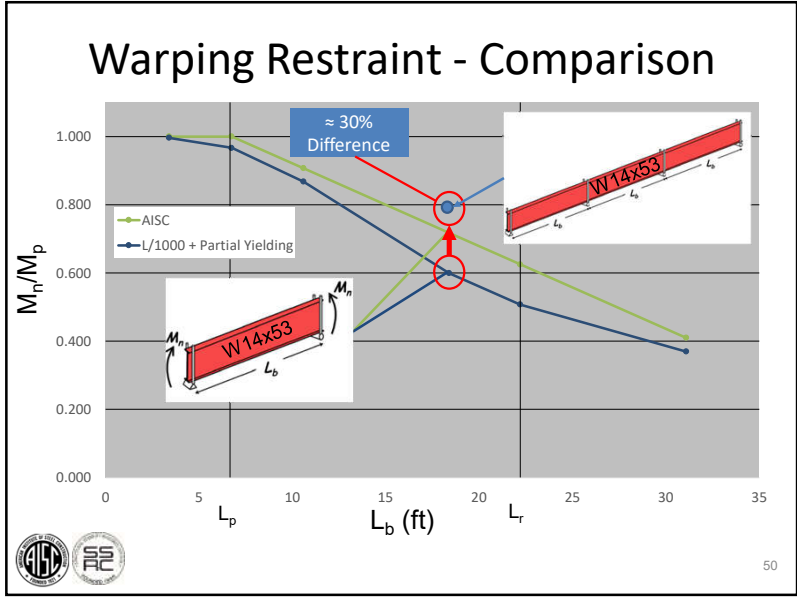
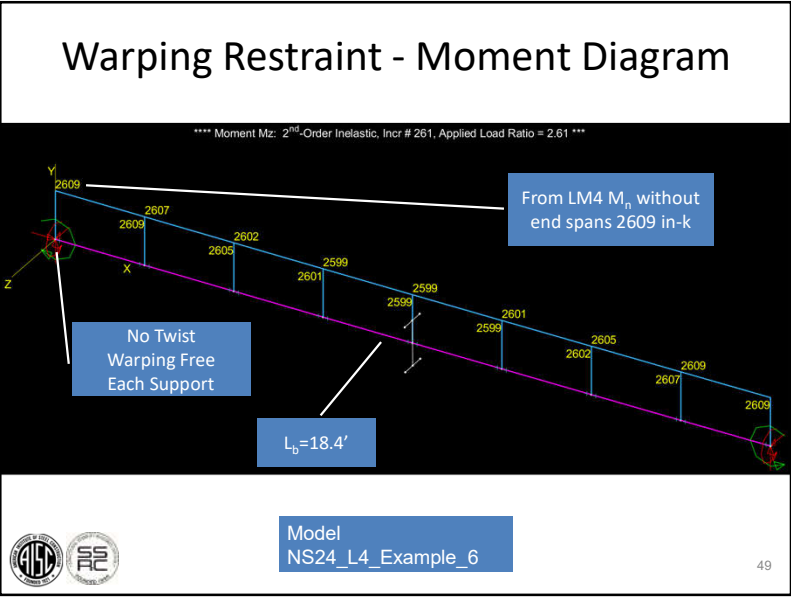
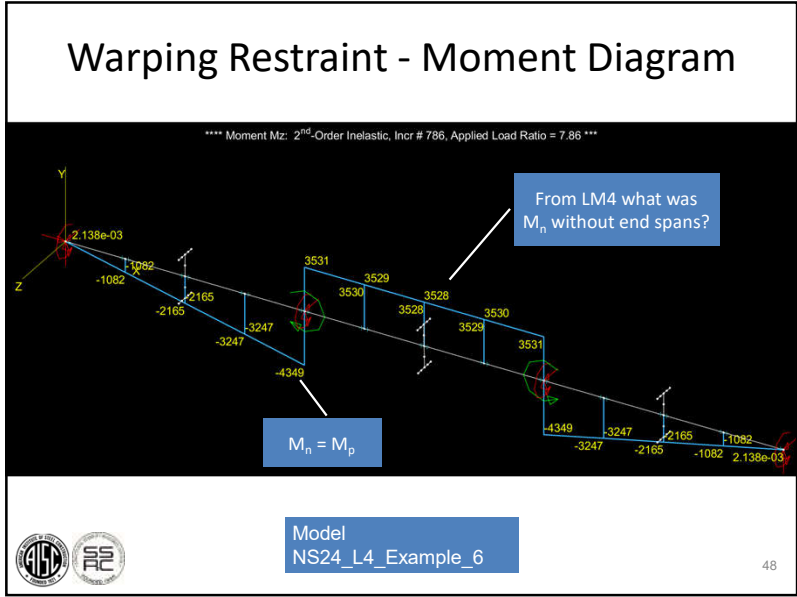
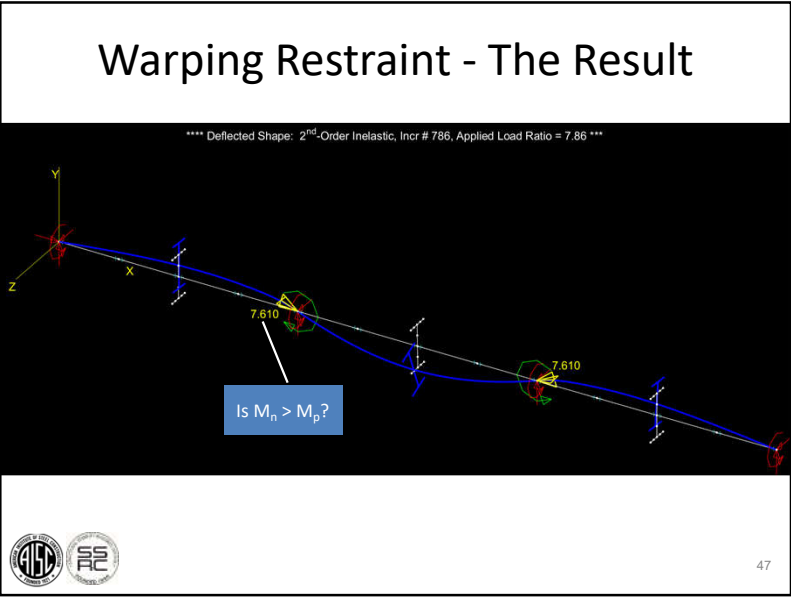
Warping Restraint - The Model



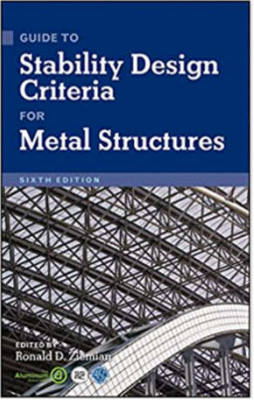
Recall nominal moment was 2,610 in-k with no end spans

Model
NS24_L4_Example_6





Warping Restraint - More Information



Chapter 5

AISC > EDUCATION > CONTINUING EDUCATION > EDUCATION ARCHIVES

Education Archives
The AISC Education Archives contains a collection of recorded webinars, conference proceedings and articles that can be accessed at any time.
THE SEARCH BY PPH CREDIT TO THE COURSES WHERE CONTINUING EDUCATION CREDIT CAN BE EARNED.

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SEARCH
Warping


PDH CREDIT: Select PDH | TYPE: SELECT TYPES | YEAR: Select Year

SEARCH

18 RESULTS FOUND

Course Name	PDH	Date	Author/Speaker	Type
Determining Unbraced Lengths in Continuous Girders Subjected to Warping Restraint	0	Mar 2014	C.E. Quadagno and K.F. Arnett, United States Military Academy, West Point NY	SSBC

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



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Flexural Member Case Study





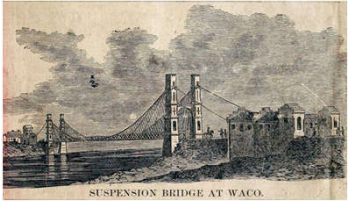
Photo courtesy Trip advisor (https://www.tripadvisor.com/Attraction_Review-g56833-d7931915-Reviews-Waco_Suspension_Bridge-Waco_Texas.html#photos_aggregationid=101&albumid=101&filter=7&ft=380164851) Traveler photo submitted by akmooney01 (Mar 2019) accessed September 8, 2020




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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




SUSPENSION BRIDGE AT WACO.



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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?



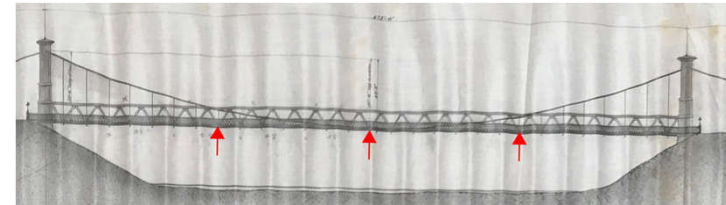
54

Stiffening Truss Shoring



55

Stiffening Truss Carries Construction Load



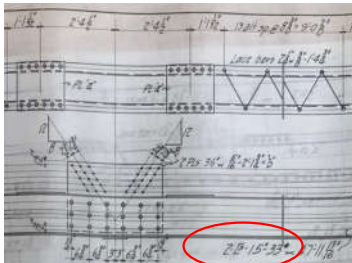
Drawings from The Missouri Valley Bridge & Iron Co. Leavenworth, Kansas



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Top and Bottom Chords

Plan View

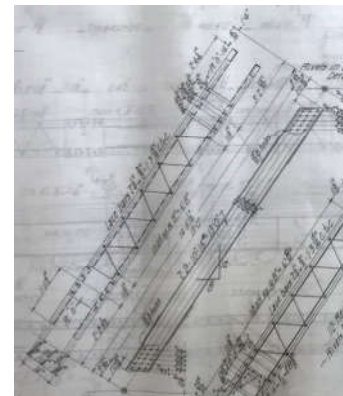


Elevation View



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Web Members



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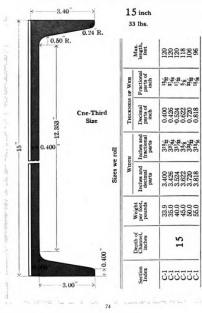
Historic Shape Information

HISTORIC SHAPE REFERENCES

BETHLEHEM	+
CAMBRIDGE	+
CARNegie (LATER YEARS CROSS-POSTED WITH USS)	+
COLUMBIA	+
FLEMING	+
GRAY & GEORGI	+
ILLINOIS (SEE ALSO CARNegie AND USS FOR LATER YEARS)	+
INLAND	+
JONES & LAIDLIN	+
KAISER	+
LACKAWANNA	+
LURENS	+
NATIONAL	+
PASCAY	+
PENNSYLVANIA	+
PITTSBURGH	+
POTTSVILLE	+
REPUBLIC	+
RYERSON	+
ST. PAUL	+
USS (CROSS-POSTED WITH CARNegie)	+

INLAND STEEL COMPANY

Open Heurth Steel Channels



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

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Web to Top Chord Connections

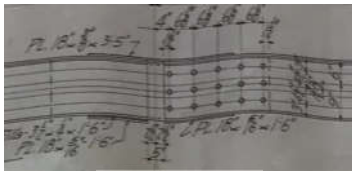


Elevation View



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Top Chord Center Conditions



Elevation View



Plan View

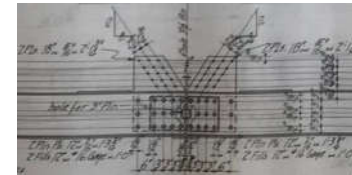


Interior View



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Web to Bottom Chord Center Connection

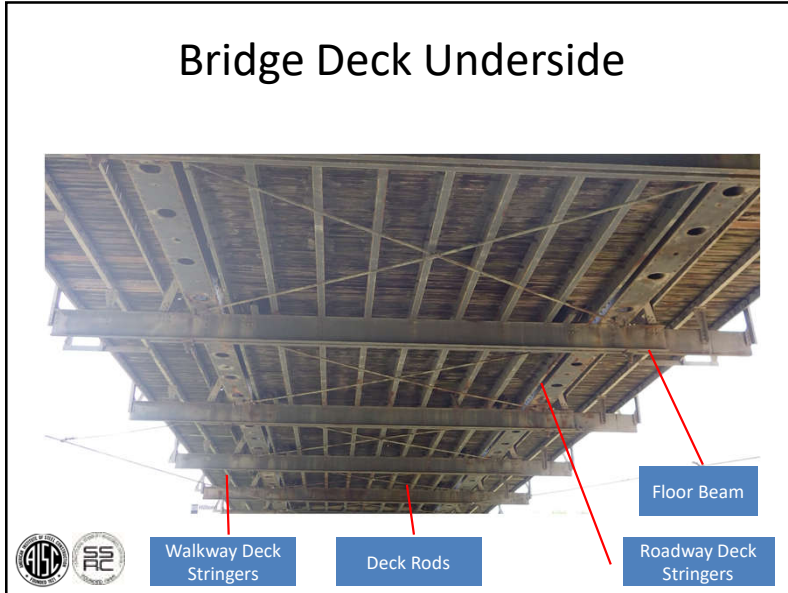


Elevation View



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Bridge Deck Underside



Floor Beam

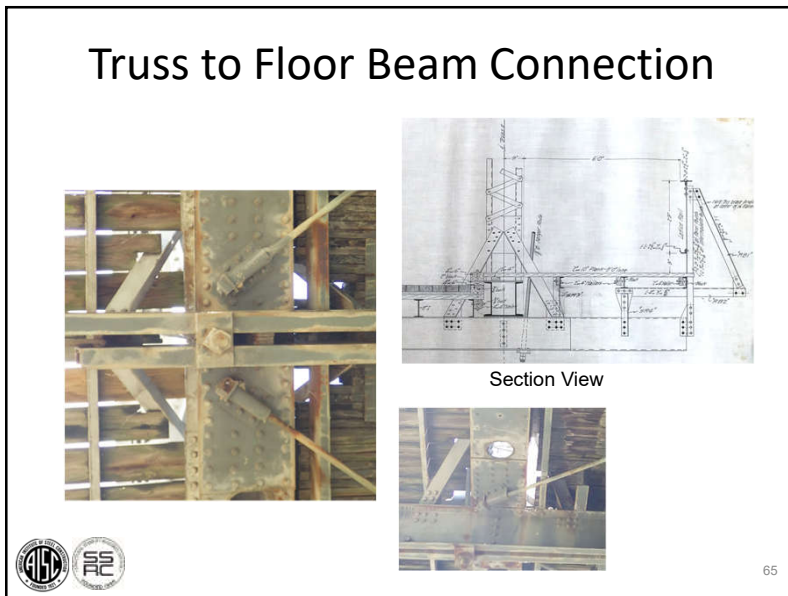


Back to back C15x33 under roadway and a portion of walkway
 C15x33 under most of walkway



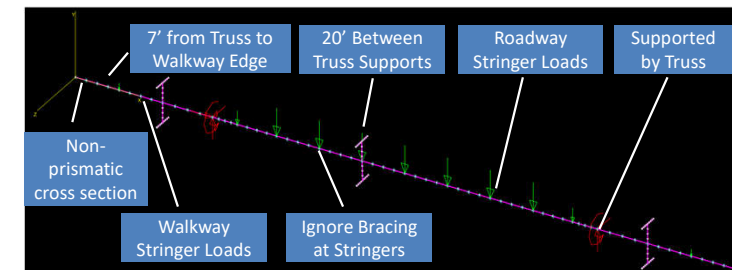
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Truss to Floor Beam Connection



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Floor Beam Model



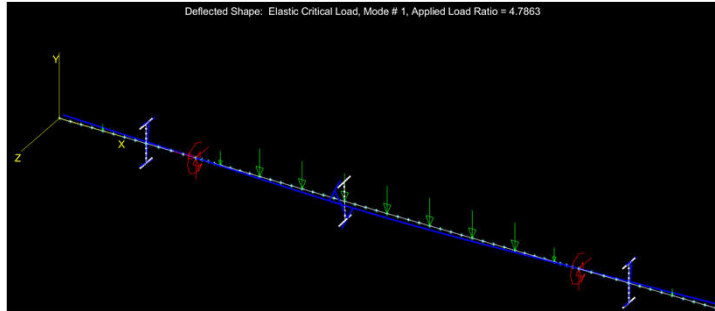
Material is ASTM A7 (1914) with $F_y = 30$ ksi
 Initial imperfection is $L/1000$ sweep

Model
 NS24_L4_Example_7



66

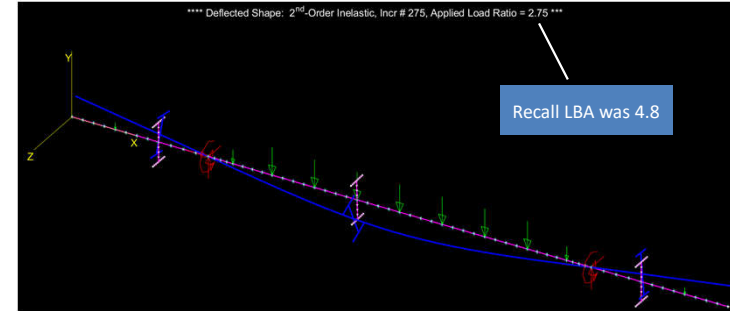
Floor Beam Elastic Critical Load



Model
NS24_L4_Example_7

67

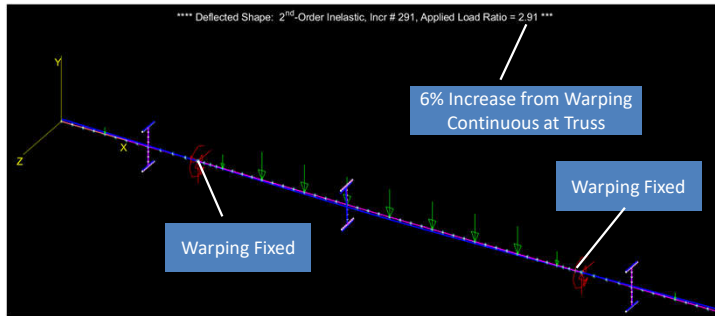
Floor Beam 2nd Order Inelastic Analysis



Model
NS24_L4_Example_7

68

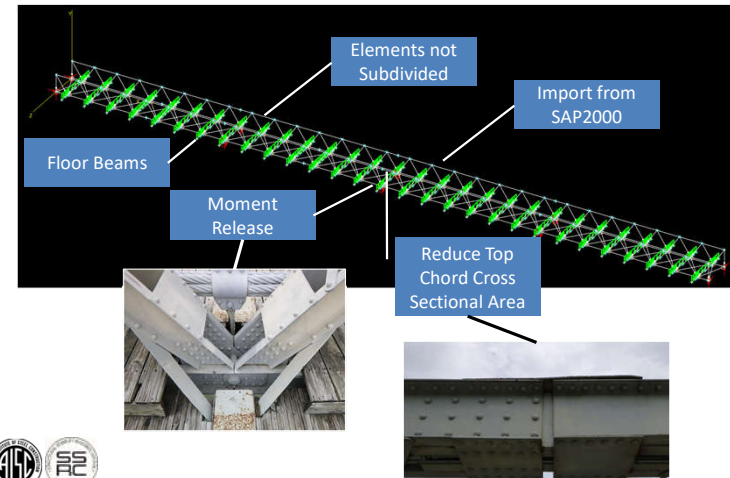
Floor Beam 2nd Order Inelastic Analysis



Model
NS24_L4_Example_7

69

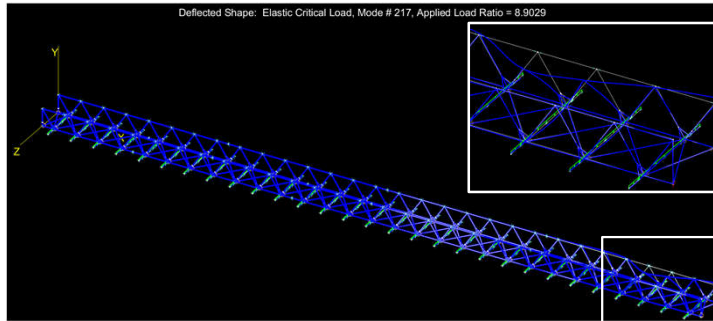
Truss Model



70



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



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 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 and sign in.

The screenshot shows the AISC website's login page. At the top, there is a navigation menu with links for EDUCATION, PUBLICATIONS, STEEL SOLUTIONS CENTER, AWARDS AND COMPETITIONS, and TECHNICAL RESOURCES. Below the menu is a large banner image of a modern building with a glass facade. The AISC logo is prominently displayed in the center of the banner. Below the banner, there is a login form with fields for USERNAME and PASSWORD, a 'Remember Me' checkbox, and a 'LOGIN' button. To the right of the login form, there is a 'DON'T HAVE AN ACCOUNT?' section with a brief description of the MyAISC account and a 'REGISTER NOW' button. At the bottom of the login form, there are links for 'Forgot Username?' and 'Forgot Password?'.

8-Session Registrants

Course Resources

Go to www.aisc.org and sign in.

The screenshot shows the MyAISC user profile page. On the left side, there is a sidebar menu with links for 'IN THIS SECTION', 'Edit Profile', 'My Downloads', 'My Pending Quizzes', 'My Events', 'Order History', 'Course History', and 'Course Resources'. The 'Course Resources' link is circled in red. On the right side, there is a 'MyAISC' profile section with a 'MY PROFILE' subsection containing an 'EDIT PROFILE' button. Below that is a 'MY PURCHASED DOWNLOADS' subsection with a 'VIEW DOWNLOADS' button. At the bottom, there is a 'MY COURSE RESOURCES' subsection with a 'VIEW RESOURCES' button, which is also circled in red. The text below this button reads: 'View online resources for Night School and Live Webinar package registrations.'

8-Session Registrants

Course Resources

The screenshot shows the 'Course Resources' page on the AISC website. The page title is '8-Session Registrants Course Resources'. Below the title, there is a navigation breadcrumb: 'AISC > MY ACCOUNT > COURSE RESOURCES'. The main content area is titled 'Course Resources' and contains a table with the following columns: 'Event', 'Start Date', and 'End Date'. The table lists several courses, including 'Session Overview on Steel', '8-Session Package: Design of Facade Attachments', 'NS 24 8-Session Package: Night School 24 - Fundamentals of Connection Design', 'NS 24 8-Session Package: Night School 24 - Structural Design on Steel', 'NS 24 8-Session Package: Night School 24 - Design of Beam-to-Column Connections', 'NS 24 8-Session Package: Night School 24 - Steel Construction: Mid To Tallness Dist', 'NS 24 8-Session Package: Night School 24 - Connections Design', 'NS 24 8-Session Package: Night School 24 - Classical Methods of Structural Analysis', and '8-Session Package: Seismic Design of Steel - Concrete & Steel Joist'.

8-Session Registrants

Course Resources

Night School 24: Modern Methods for Learning Structural Stability

8-SESSION PACKAGE RESOURCES

Event	Date	Platform	Video	Class	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6 2020 7:00PM EST	OnDemand	Available 10/06/2020 5:00PM EST	Available 10/06/2020 5:00PM EST	Pending
NS24.2 - Compression Members - Practical Considerations	Oct 13 2020 7:00PM EST	OnDemand	Available 10/13/2020 5:00PM EST	Available 10/13/2020 5:00PM EST	Pending
NS24.3 - Behavior of Flexural Members - The Fundamentals	Oct 20 2020 7:00PM EST	OnDemand	Available 10/20/2020 5:00PM EST	Available 10/20/2020 5:00PM EST	Pending
NS24.4 - Flexural Members - Practical Considerations	Oct 27 2020 7:00PM EST	OnDemand	Available 10/27/2020 5:00PM EST	Available 10/27/2020 5:00PM EST	Pending
NS24.5 - Stability of Beam-Columns - The Fundamentals	Nov 3 2020 7:00PM EST	OnDemand	Available 11/03/2020 5:00PM EST	No longer available	Pending
NS24.6 - Stability of Beam-Columns - Practical Considerations	Nov 10 2020 7:00PM EST	OnDemand	Available 11/10/2020 5:00PM EST	No longer available	Pending
NS24.7 - Behavior of Structural Systems - The Fundamentals	Nov 17 2020 7:00PM EST	OnDemand	Available 11/17/2020 5:00PM EST	No longer available	Pending
NS24.8 - Structural Systems - Practical Considerations	Nov 24 2020 7:00PM EST	OnDemand	Available 11/24/2020 5:00PM EST	No longer available	Pending
NS24 - Final Exam	N/A	N/A	Available 12/01/2020 5:00PM EST	No longer available	Pending



