



AISC
Night School

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

Modern Methods for Learning the Basics of Structural Stability: From Behavior to Practice
Session 7: Behavior of Structural Systems – The Fundamentals
December 1, 2020



  **Smarter. Stronger. Steel.**

AISC Live Webinars

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Please type any questions or comments through the chat feature in the left portion of your screen.

  **Smarter. Stronger. Steel.**



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Course Description

Behavior of Structural Systems – The Fundamentals
December 1, 2020

This lecture will begin with a review of basic concepts related to the stability of structural systems. With an eye toward design, the difference between a bifurcation or critical load analysis and the loss in stiffness due to second-order effects and material yielding, as the maximum resistance of physical structures is approached, will be emphasized. The lecture will then provide an overview of the direct analysis and effective length methods. The speakers will conclude by introducing the fourth learning module.



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Learning Objectives

- Describe how the story lateral stiffness is related to $P-\Delta$ effects.
- Identify indicators for assessing whether a structure is a stability-sensitive system.
- Compare and contrast the direct analysis method and the effective length method.
- Explain the modeling considerations for direct analysis by advanced elastic analysis and inelastic methods, and the repercussions for determining member capacity.



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

Session 7: Behavior of Systems – The Fundamentals
December 1, 2020



Ronald D. Ziemian, PE, PhD
Professor
Bucknell University



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



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Steel.

Course Overview

- Topics
 - Compression Members (Weeks 1 & 2)
 - Flexural Members (Weeks 3 & 4)
 - Beam-Columns (Weeks 5 & 6)
 - Systems (Weeks 7 & 8)
- “Active” learning! Weekly virtual lab experiences...
- Case studies from the real world...

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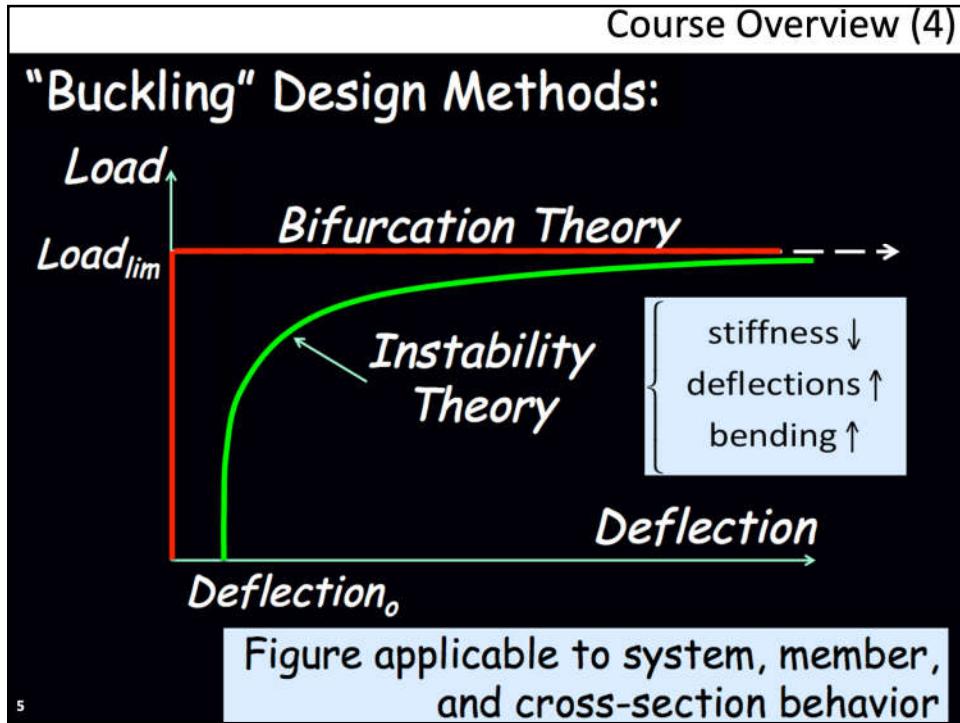


Course Overview (2)



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



Course Overview (5)

Analysis acronyms:

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

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

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

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

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

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

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

Course Introduction

Compression Members

Flexural Members

Beam-Columns

Systems



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“Buckling” Design Methods:

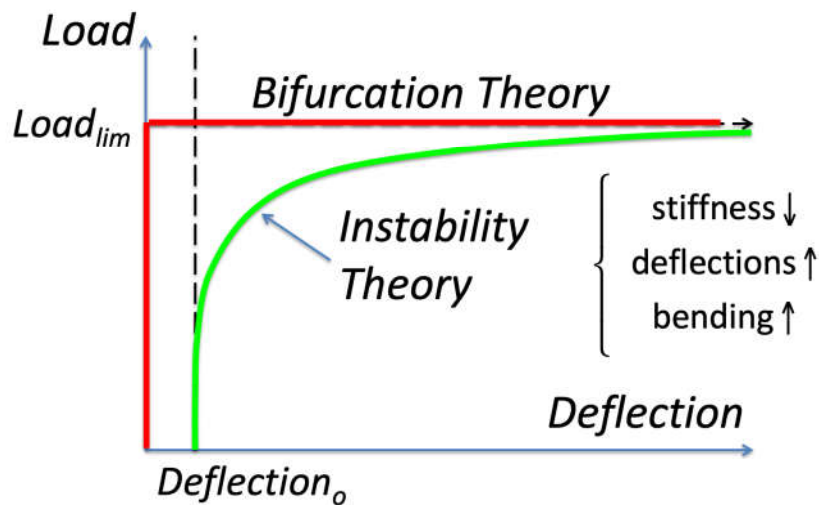
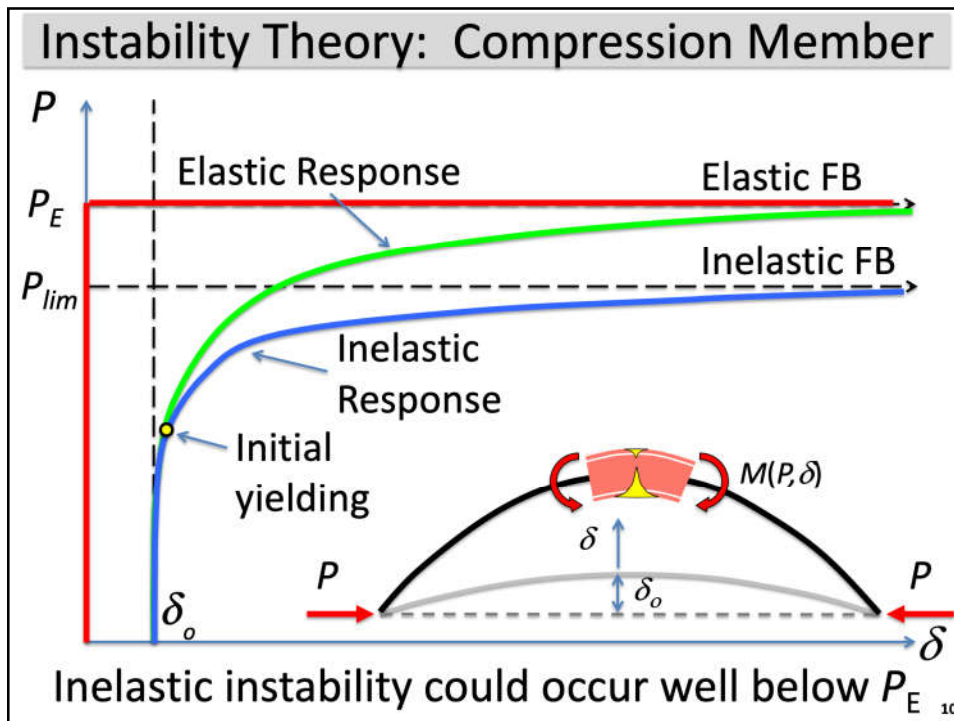
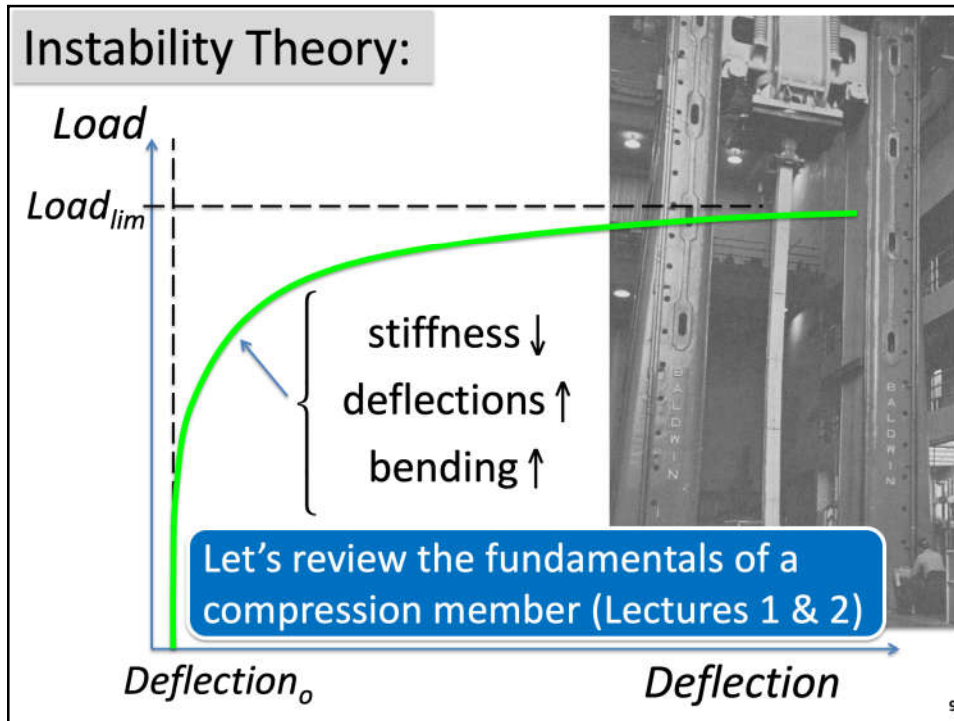
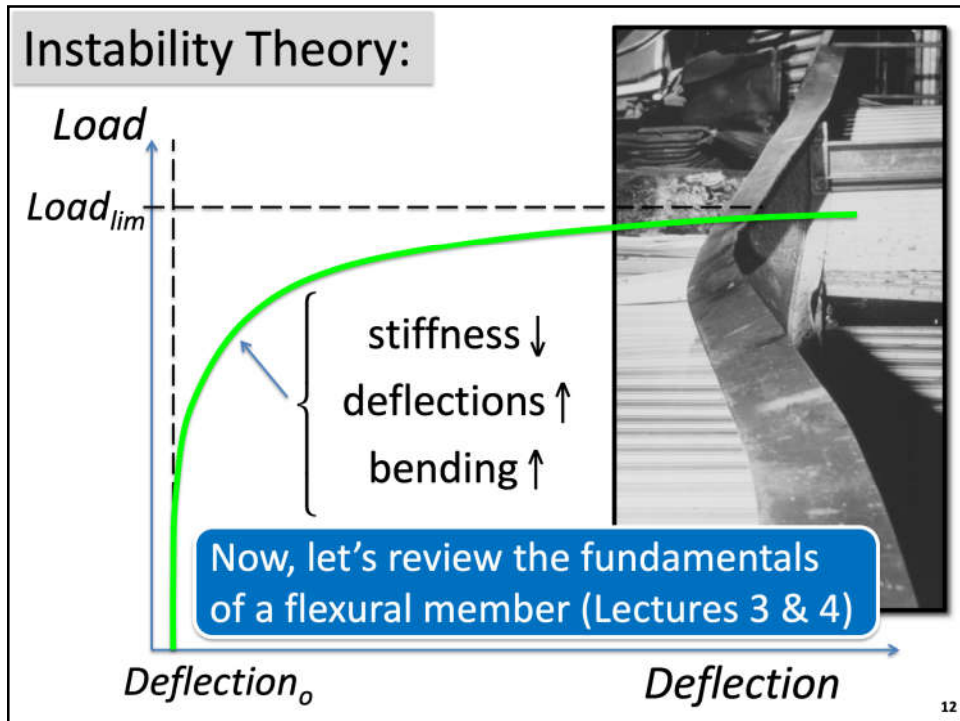
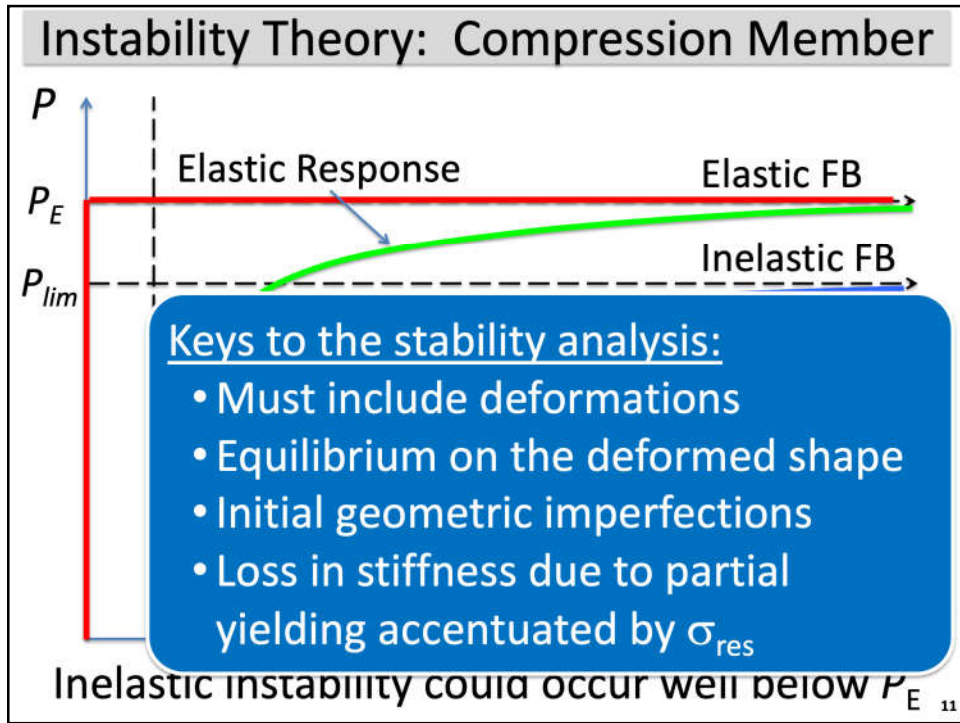


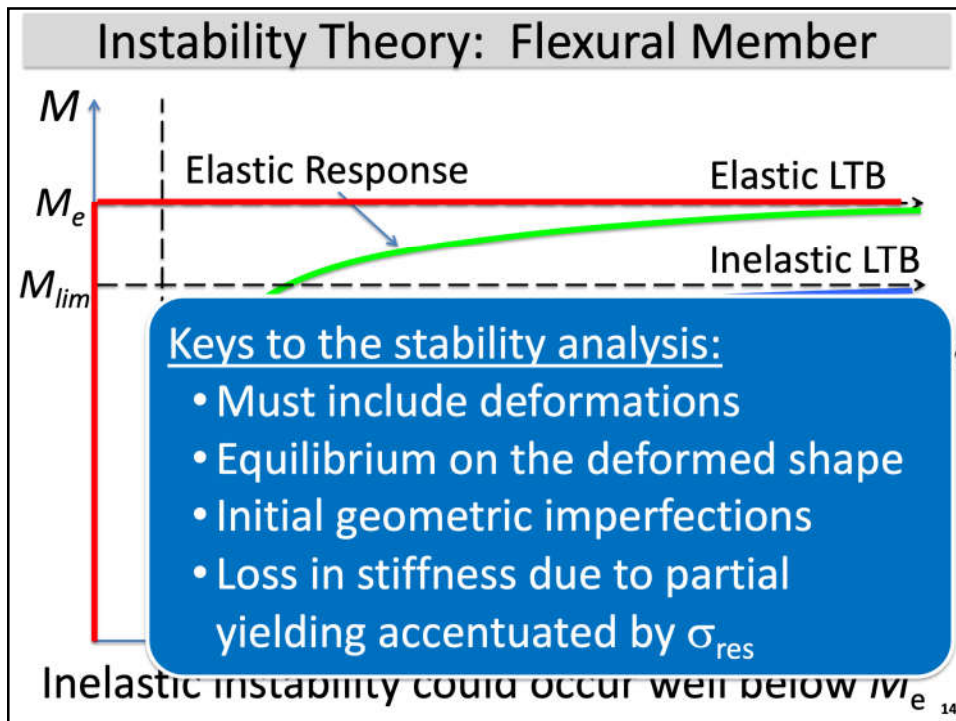
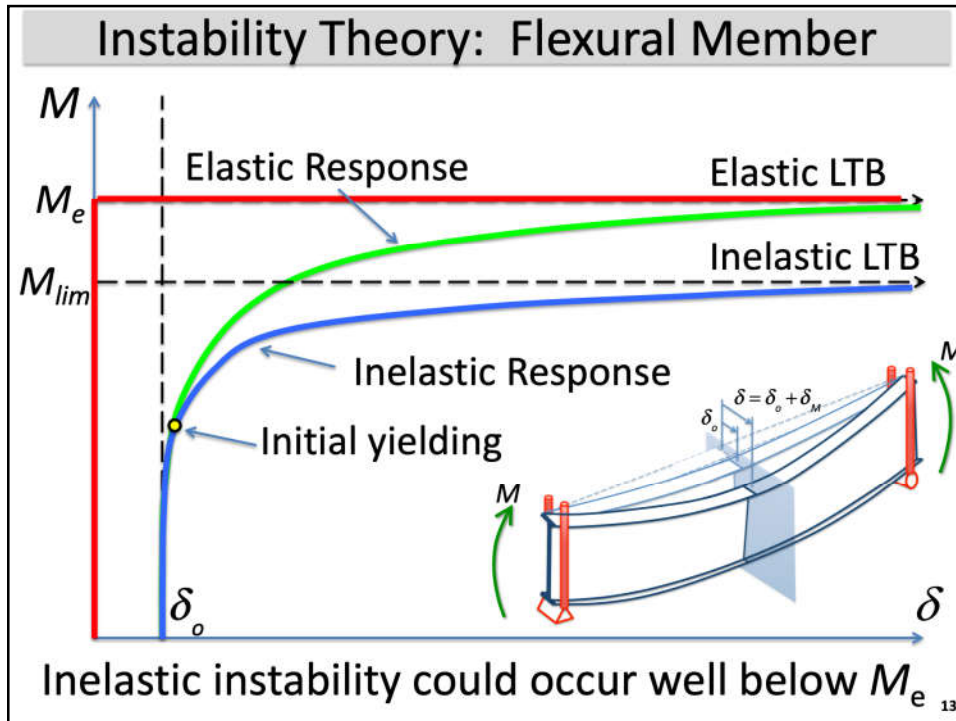
Figure applicable to system, member,
and cross-section behavior

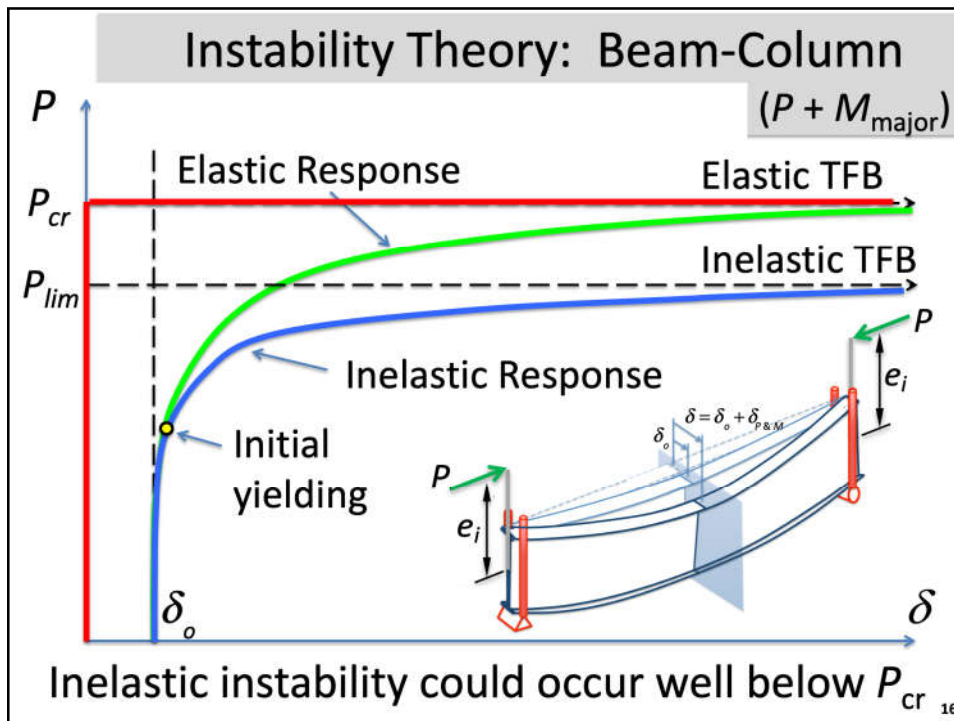
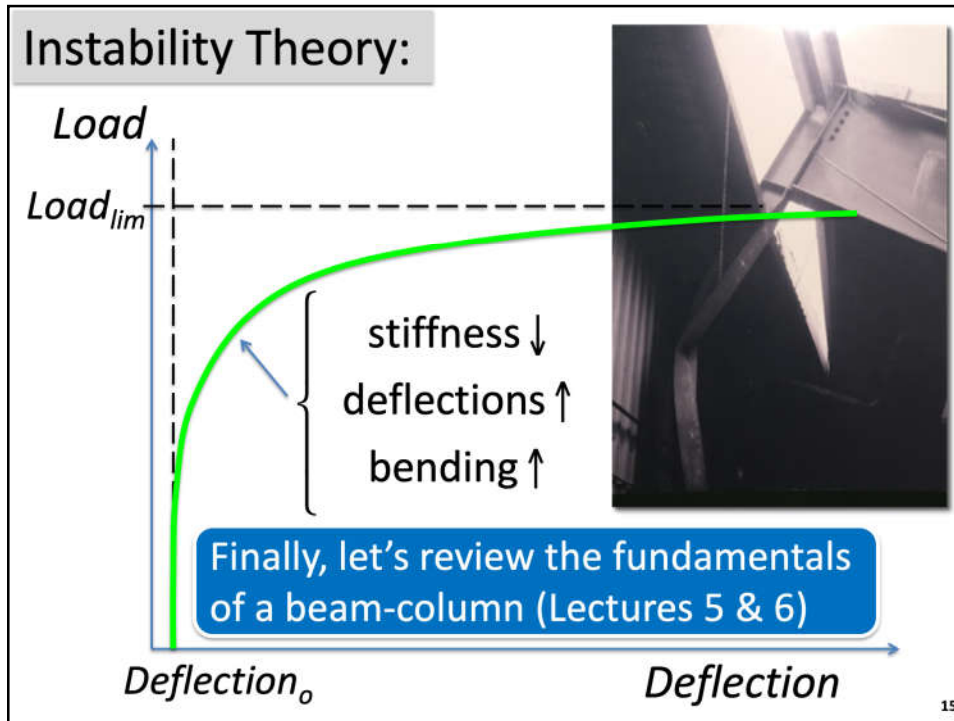
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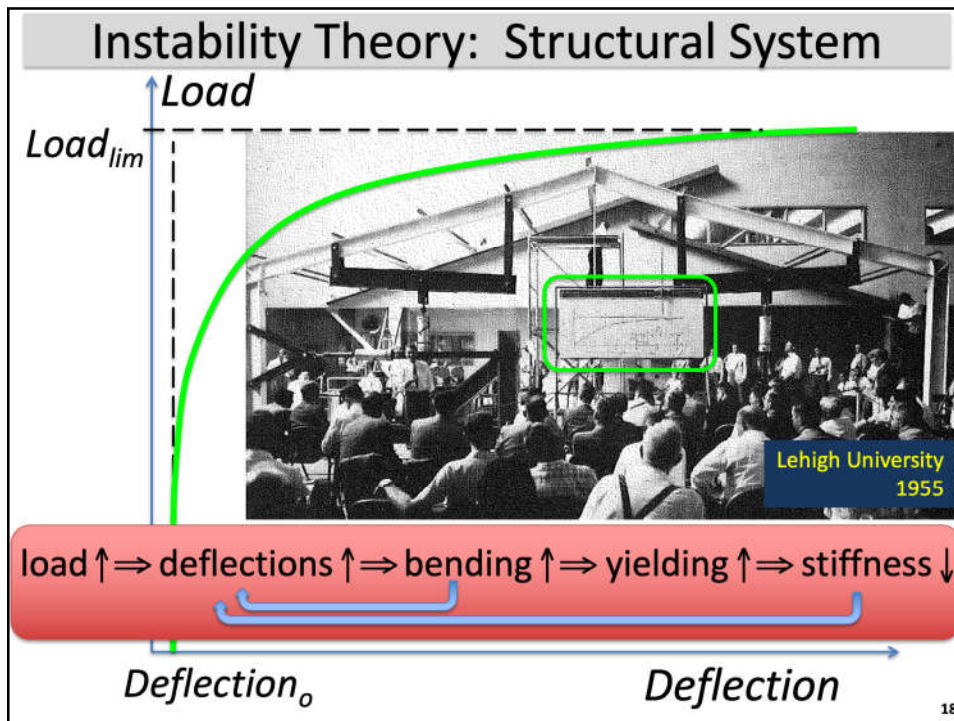
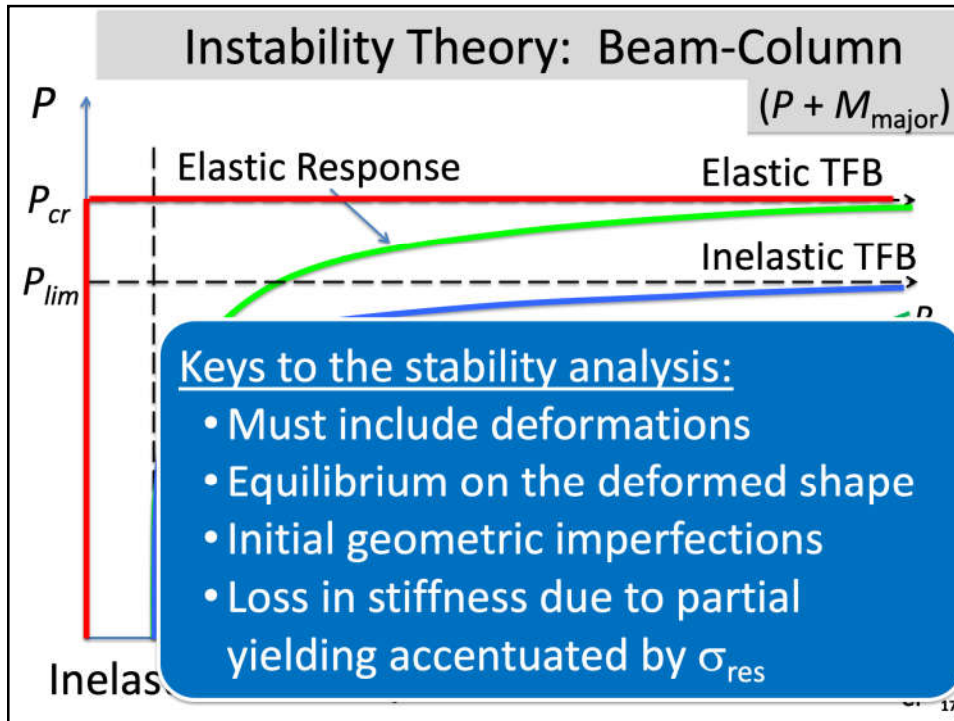












Instability Theory: Structural System

Beams		Columns		
Levels		Levels	Exterior Columns	Interior Columns
1	W21x48	1-3	W8x67	W8x35
2	W21x55	3-5	W12x87	W12x79
3	W21x55	5-7	W14x109	W14x109
4	W21x55	7-9	W14x132	W14x132
5	W21x55	9-11	W14x145	W14x159
6	W24x62	11-13	W14x176	W14x211
7	W24x62	13-15	W14x211	W14x233
8	W24x68	15-17	W14x233	W14x283
9	W24x68	17-19	W14x257	W14x311
10	W24x68	19-21	W14x283	W14x342
11	W24x76	21-23	W14x311	W14x370
12	W24x76	23-25	W14x342	W14x398
13	W24x84	25-27	W14x370	W14x426
14	W24x84			
15	W24x84			
16	W24x84			
17	W27x84			
18	W27x84			
19	W27x84			
20	W27x84			
21	W27x84			
22	W27x84			
23	W27x94			
24	W27x94			
25	W27x94			
26	W27x94			

Nominal Loads:
 Roof Load: Live @ 30 psf
 Dead @ 40 psf
 Floor Load: Live @ 75 psf
 Dead @ 50 psf
 Wall Load: 18 kips/story
 Wind Load: 20 psf

Frame Spacing = 30 ft

Load Combination Investigated:
 1.2 Dead + 0.5 Live + 1.3 Wind

Fy = 36 ksi
 E = 29000 ksi

Analysis Model	Total CPU Time (seconds)
A	722
B	1785
C	2123
D	1652
E	195
F	620
G	968
H	1847
I	1645

GMNIA (RZ, 1989)

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Instability Theory: Structural System

MASTAN2: /Users/ziemian/Documents/AISC Night School/NS24/MSA2 Files New/NS24_L7_Example_1.mat [14:07]

File View Geometry Properties Conditions Analysis Results

Mode # 1, Applied Load Ratio = 8.2868

LBA

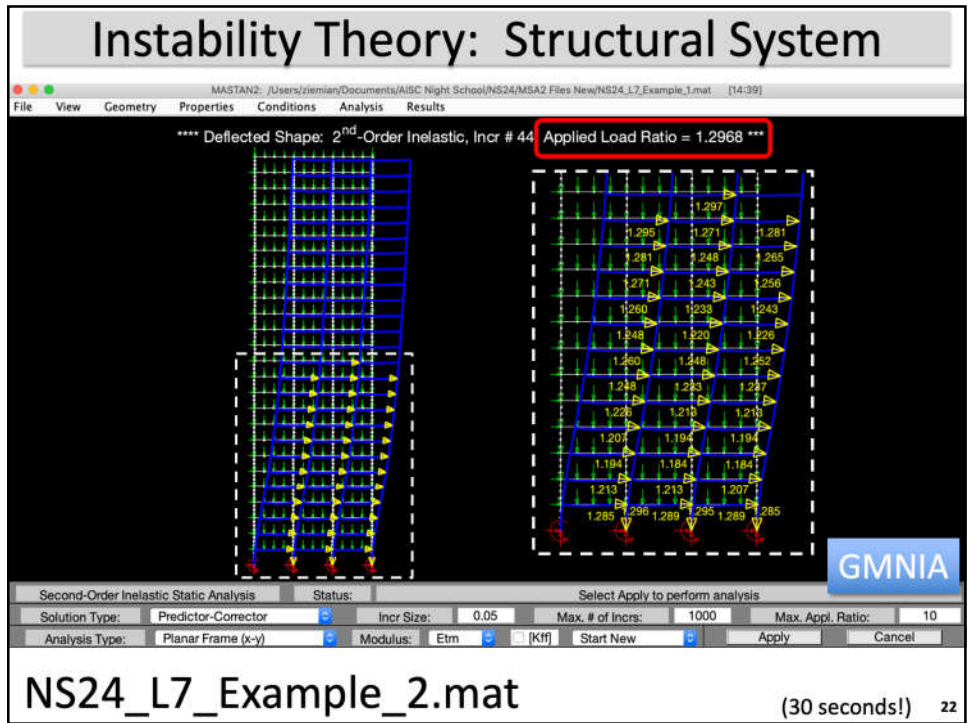
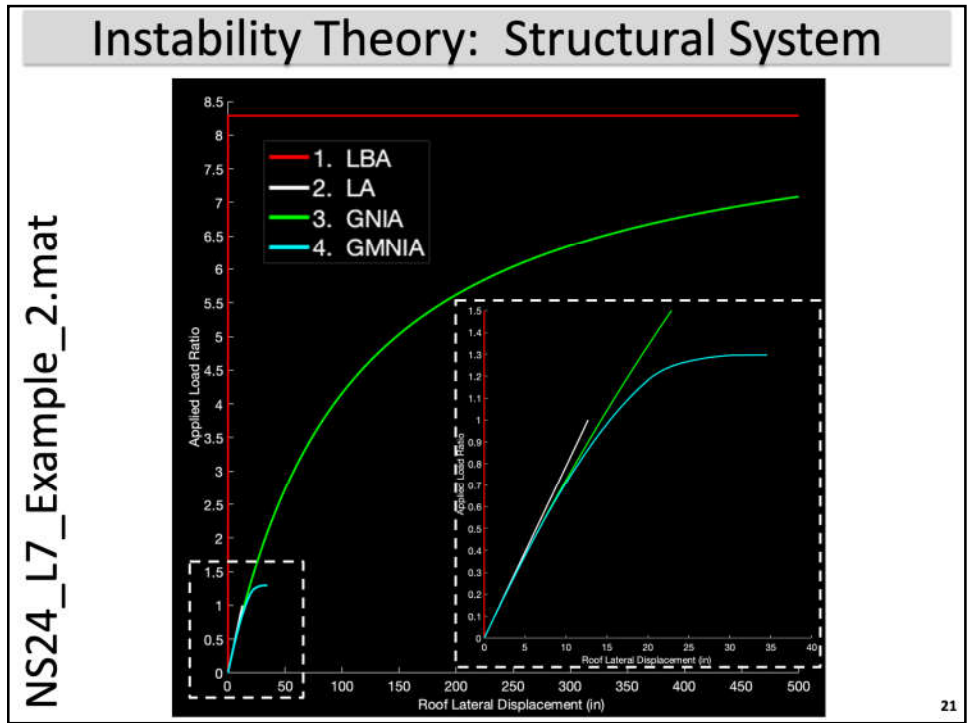
Elastic Critical Load Analysis Status: Select Apply to perform an eigenvalue analysis

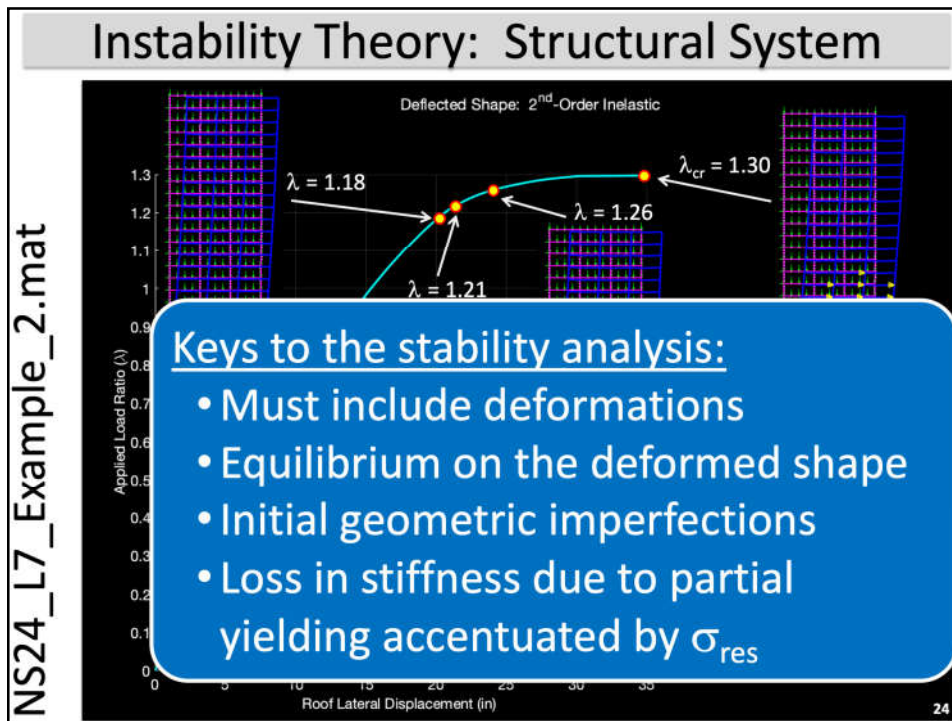
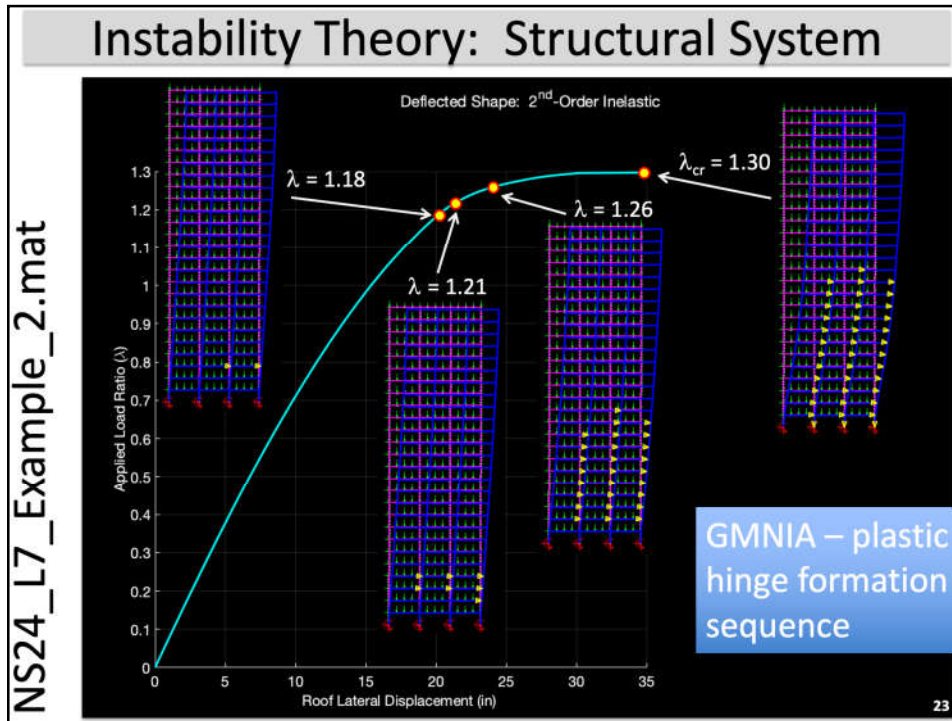
Analysis Type: Planar Frame (x-y) Max. # of Modes: < 1 > Apply Cancel

NS24_L7_Example_1.mat

20







Systems...

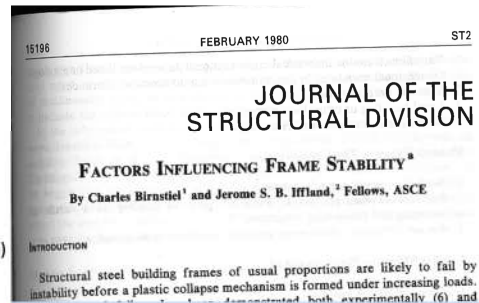
DESIGNING FOR STRUCTURAL STABILITY

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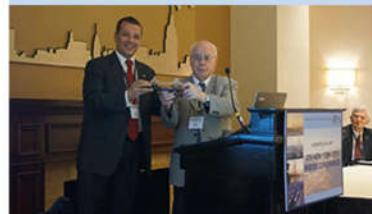
Factors influencing frame stability

Birstiel and Iffland, 1980

- Geometric effects
 - Axial force on bending stiffness
 - Relative joint displacement
 - Length changes due to axial strain & bowing
 - Initial crookedness of members (manufacturing)
 - Initial out-of-plumb of systems (erection)
 - Finite joint size and panel zone deformations
- Material effects
 - Nonlinear stress-strain relationship
 - Residual stresses (manufacturing and fabrication)
 - Spread of yielding as member forces increase
 - Variations in cross section dimensions
 - Shearing deformations
 - Local buckling
 - Out-of-plane movement of frames and members
 - Connection flexibility
 - Strain Hardening
 - Contributions of slab to strength and stiffness
- Load effects
 - Proportional vs. Non-proportional loading
 - Variable repeated loading
 - Dynamic effects



Bridge Engineering Association recognizes
Dr. Charles Birstiel with a
Lifetime Achievement Award (2018)



John
Fisher

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Factors influencing frame stability

Birnstiel and Iffland, 1980

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Factors influencing frame stability

Birnstiel and Iffland, 1980

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Factors influencing frame stability

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Birnstiel and Iffland, 1980

In the spirit of transparency...
AISC 2005-2016

CHAPTER C
DESIGN FOR STABILITY

This chapter addresses requirements for the design of structures for *stability*. The *direct analysis method* is presented herein; alternative methods are presented in Appendix 7.

The chapter is organized as follows:

- C1. General Stability Requirements
- C2. Calculation of Required Strengths
- C3. Calculation of Available Strengths

C1. GENERAL STABILITY REQUIREMENTS

Stability shall be provided for the structure as a whole and for each of its elements. The effects of all of the following on the stability of the structure and its elements shall be considered: (1) flexural, shear and axial member deformations, and all other deformations that contribute to displacements of the structure; (2) *second-order effects* (both *P-Δ* and *P-δ* effects); (3) geometric imperfections; (4) *stiffness* reductions due to inelasticity; and (5) uncertainty in stiffness and strength. All *load-dependent* effects shall be calculated at a level of loading corresponding to *LRFD load combinations* or 1.6 times *ASD load combinations*.

Any rational method of design for stability that considers all of the listed effects is permitted; this includes the methods identified in Sections C1.1 and C1.2.

Factors influencing frame stability

- Out-of-plane movement of frames and members
- Connection flexibility
- Strain Hardening
- Contributions of slab to strength
- Load effects
 - Proportional vs. Non-proportional loading
 - Variable repeated loading
 - Dynamic effects

AISC Chapter C's "Big 5":

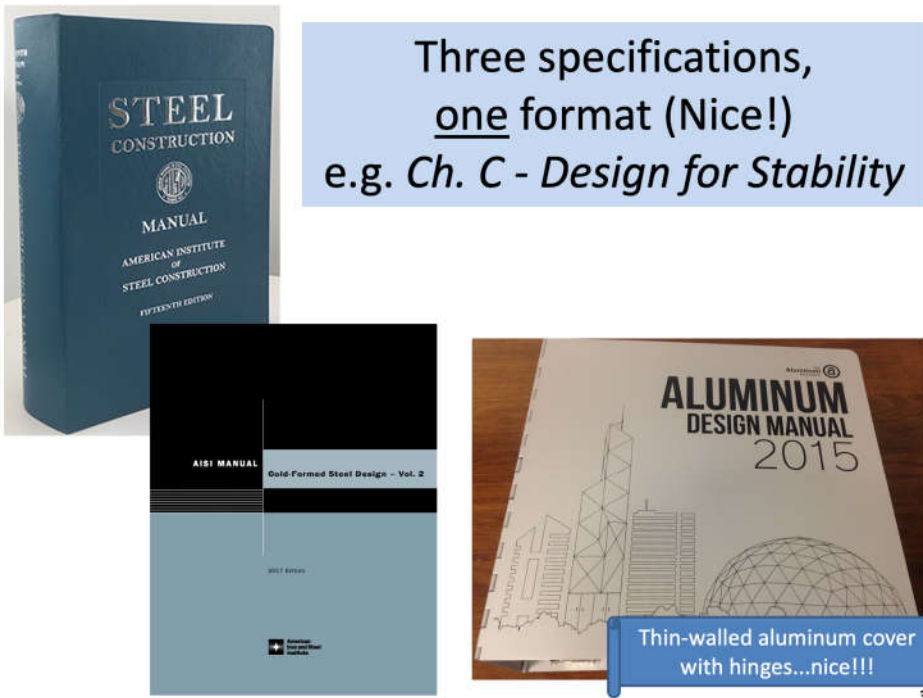
- ✓ Must include pertinent deformations
- ✓ Equilibrium on the deformed shape
- ✓ Initial geometric imperfections
- ✓ Loss in stiffness due to partial yielding accentuated by σ_{res}
- ✓ Potential for variation

C1. GENERAL STABILITY REQUIREMENTS

Stability shall be provided for the structure as a whole and for each of its elements. The effects of all of the following on the stability of the structure and its elements shall be considered: (1) flexural, shear and axial member deformations, and all other deformations that contribute to displacements of the structure; (2) *second-order effects* (both *P-Δ* and *P-δ* effects); (3) geometric imperfections; (4) *stiffness* reductions due to inelasticity; and (5) uncertainty in stiffness and strength. All *load-dependent* effects shall be calculated at a level of loading corresponding to *LRFD load combinations* or 1.6 times *ASD load combinations*.

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Three specifications,
one format (Nice!)
e.g. *Ch. C - Design for Stability*

Thin-walled aluminum cover
with hinges...nice!!!

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Basis for Design of Systems

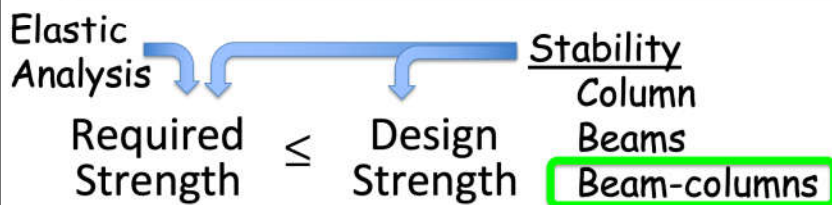
- Elastic Analysis (AISC Spec., Chs. A-K, Apps. 6-8)
 - Allows for no force redistribution due to yielding
 - Strength (stability) of system is indirectly assessed by assessing strength of its components
 - In other words, strength of system is assured by ensuring adequate strength of its components
- Inelastic Analysis (AISC Spec., Appendix 1)
 - Force redistribution due to yielding is accounted for in the analysis
 - System strength (stability) can be assessed directly by the analysis

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Basis for Design of Systems

- Elastic Analysis (AISC Spec., Chs. A-K, Apps. 6-8)
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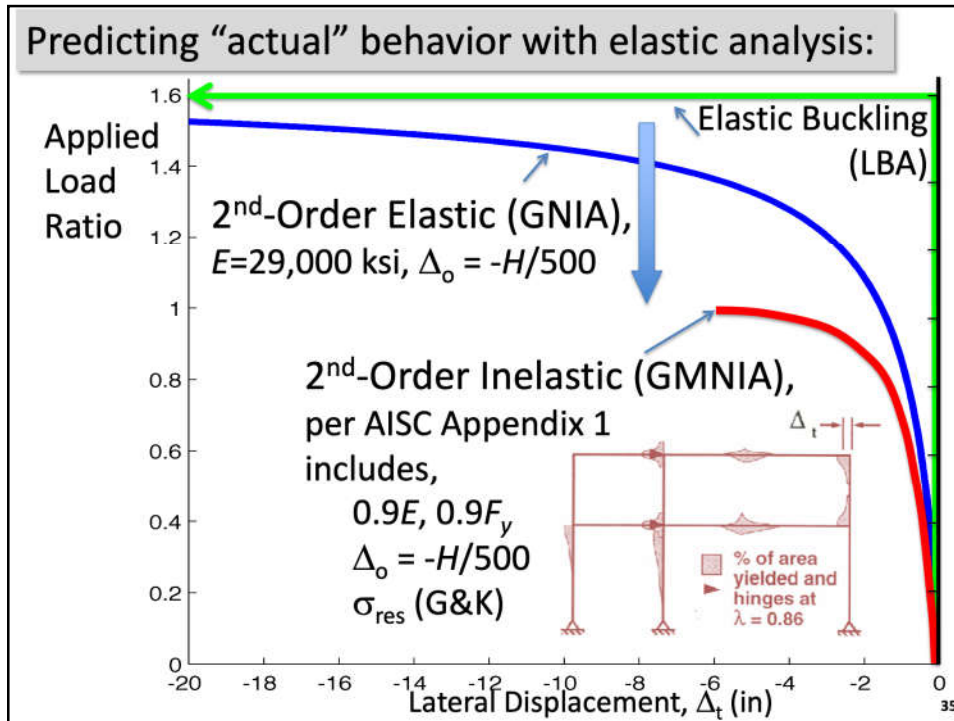
33

Basis for Design of Systems

- Elastic Analysis (AISC Spec., Chs. A-K, Apps. 1,6-8)
 - Allows for no force redistribution due to yielding
 - Strength (stability) of system is indirectly assessed by assessing strength of its components
 - In other words, strength of system is assured by ensuring adequate strength of its components
- Inelastic Analysis (AISC Spec., Appendix 1.3)
 - Force redistribution due to yielding is accounted for in the analysis
 - System strength (stability) can be assessed directly by the analysis – GMNIA!

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General Stability Design Methods:

Analysis for load effects:

- Reality: Equilibrium on deformed shape

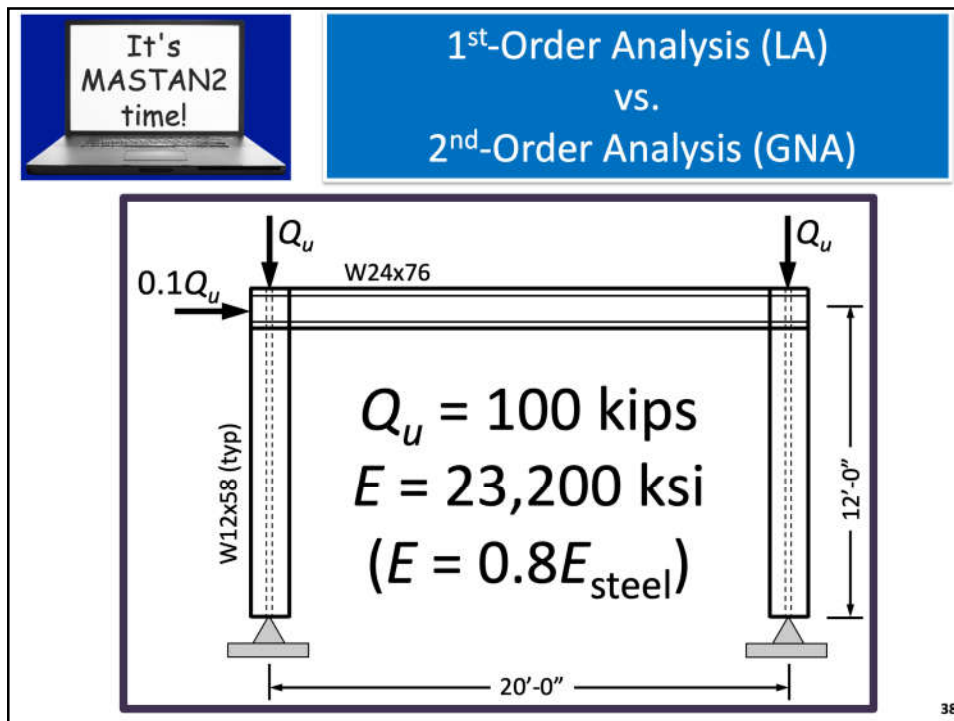
$R_u \leq \phi R_n$

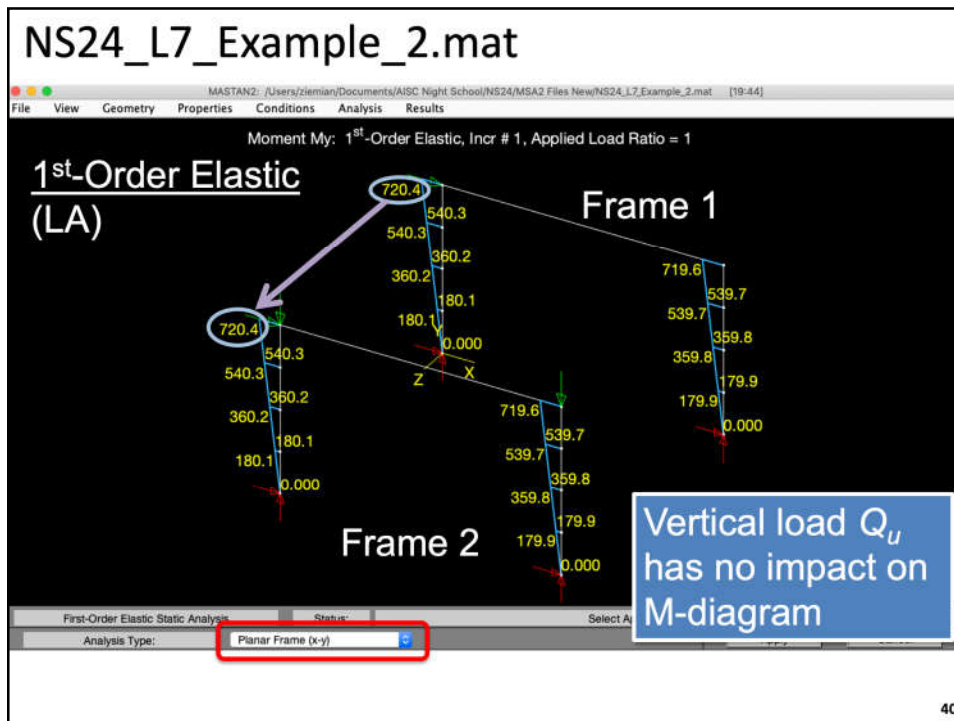
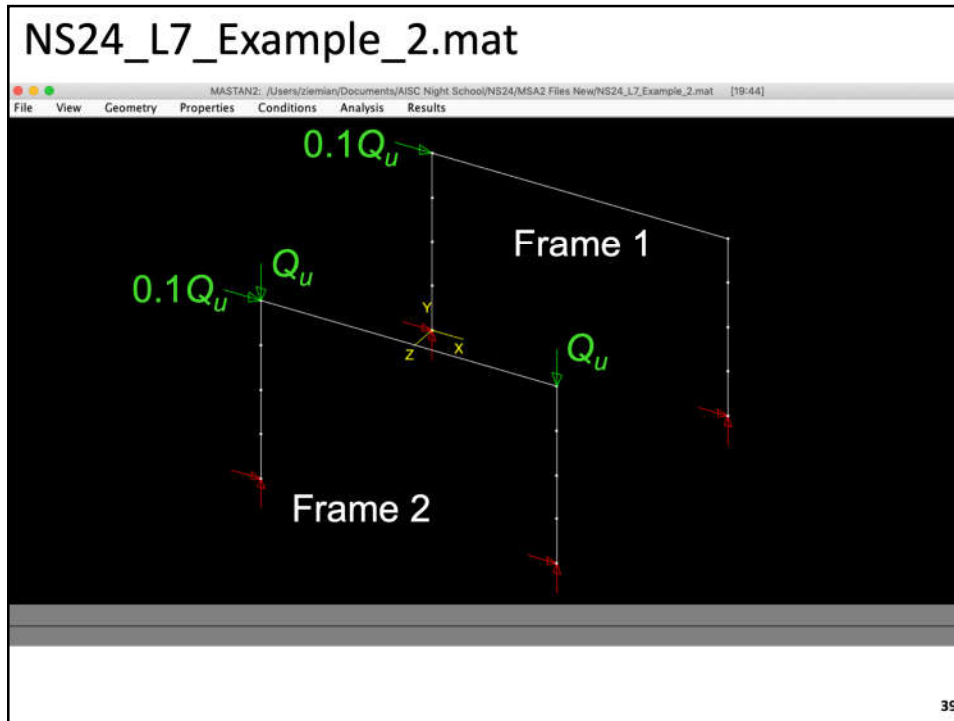
- Effective length method
- Direct analysis method

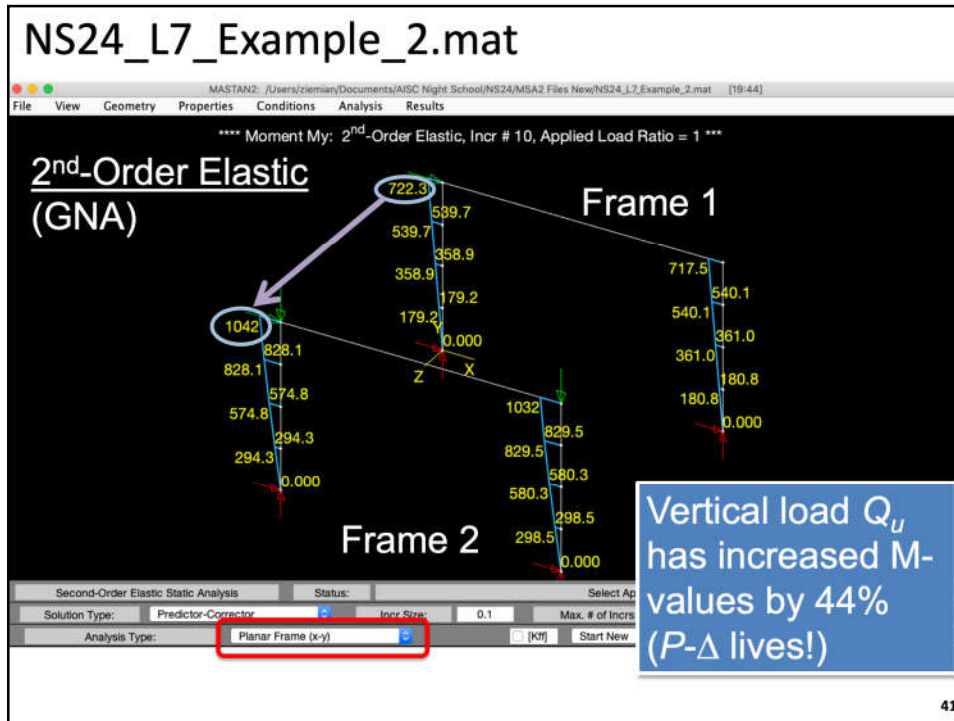
NOTE! Both methods require consideration of 2nd-order effects

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Including Second-Order Effects

- Analysis options for :
 - Rigorous computational analysis (**recommended!**)
 - loads applied incrementally/iteratively
 - geometric stiffness matrix
 - updating geometry after each increment of loading
 - B_1 and B_2 amplification factors
 - $M = B_1 M_{nt} + B_2 M_{lt}$
- Approximate indicators of their significance
 - $P\delta$ provided by B_1
 - $P\Delta$ provided by B_2



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P-Δ (1)

Second-order Effects:
P-Δ

Lateral displacement due to:

Story Shear

Frame Bending

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P-Δ (2)

$$\frac{1}{1 - \frac{P}{P_E}} \Rightarrow \frac{1}{1 - \frac{\sum P}{\sum P_E}}$$

Factor to account for P-Δ at each story

$$B_2 = \frac{1}{1 - \frac{P_{\text{story}}}{P_{e, \text{story}}}}$$

$$P_{\text{story}} = \sum_{i=1}^3 P_i$$

$$P_{e, \text{story}} = ?$$

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Simple example relating story buckling load to story shear stiffness:

Rigid Beam
Story buckling load: $P_{e,story}$

of cols

$$P_{e,story} = \sum_{i=1} P_{e,i}$$

$$P_{e,story} = 2 \times \frac{\pi^2 EI}{(2.0L)^2} = \frac{\pi^2}{2} \left(\frac{EI}{L^3} \right) L$$

Rigid Beam
Story shear stiffness: $k = V/\Delta$

$$\Delta = \frac{(V/2)L^3}{3EI}$$

$$\frac{V}{\Delta} = 6 \frac{EI}{L^3}$$

$$P_{e,story} = \frac{\pi^2}{2} \left(\frac{1}{6} \frac{V}{\Delta} \right) L$$

$$P_{e,story} = 0.82 \frac{V}{\Delta} L$$

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AISC factor to account for $P-\Delta$ at each story

$P-\Delta$ (4)

$$B_2 = \frac{1}{1 - \frac{P_{story}}{P_{e,story}}}$$

with:

$$P_{story} = \sum_{i=1}^3 P_i \quad \text{and} \quad P_{e,story} = R_M \frac{\sum V_i}{\Delta_{\Sigma V_i}} L$$

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Stability Sensitive Structural Systems

- Indicators include:

- B_1 and B_2 factors
- Elastic/Inelastic critical buckling load factors λ_{cr} and mode shapes
- Natural periods and mode shapes

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

- Eurocode uses ratio λ_{cr} (think LBA) between the the critical buckling loading and applied loading :

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

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$$B_A = \frac{1}{1 - \frac{3gT^2}{8\pi^2 H}}$$

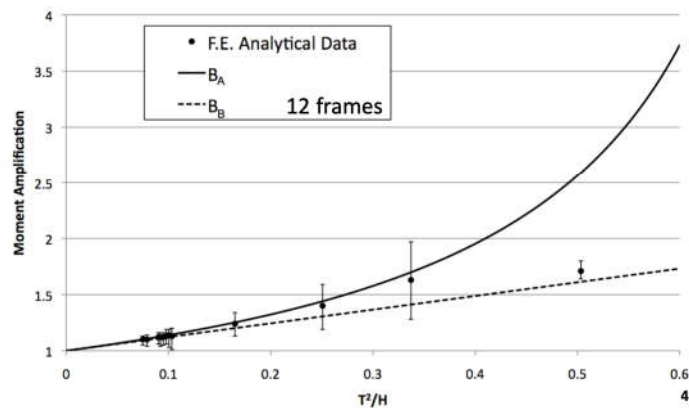
$$B_B = 1 + \frac{3gT^2}{8\pi^2 H}$$



*Proceedings of the
 Annual Stability Conference
 Structural Stability Research Council
 Pittsburgh, Pennsylvania, May 10-14, 2011*

The Natural Period as an Indicator of Second-Order Effects

D.E. Statler¹, R.D. Ziemian², L.E Robertson³



Note: Most important to also plot the mode shape

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Stability Sensitive Structural Systems

- Indicators include:
 - B_1 and B_2 factors
 - Elastic/Inelastic critical buckling load factors λ_{cr} and mode shapes
 - Natural periods and mode shapes

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

- Eurocode uses ratio λ_{cr} (think LBA) between the the critical buckling loading and applied loading :



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

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AISC's Stability Provisions!

“Any rational method of design for stability... is permitted” with AISC code provisions for

- ✓ Effective length K-factor method (staple of profession since 1960)
- ✓ Direct analysis method (now becoming staple of the profession)

- Out-of-plane movement of trusses and members
- Connection flexibility
- Strain Hardening
- Contributions of slab to strength and stiffness
- Load effects
 - Proportional vs. Non-proportional loading
 - Variable repeated loading
 - Dynamic effects

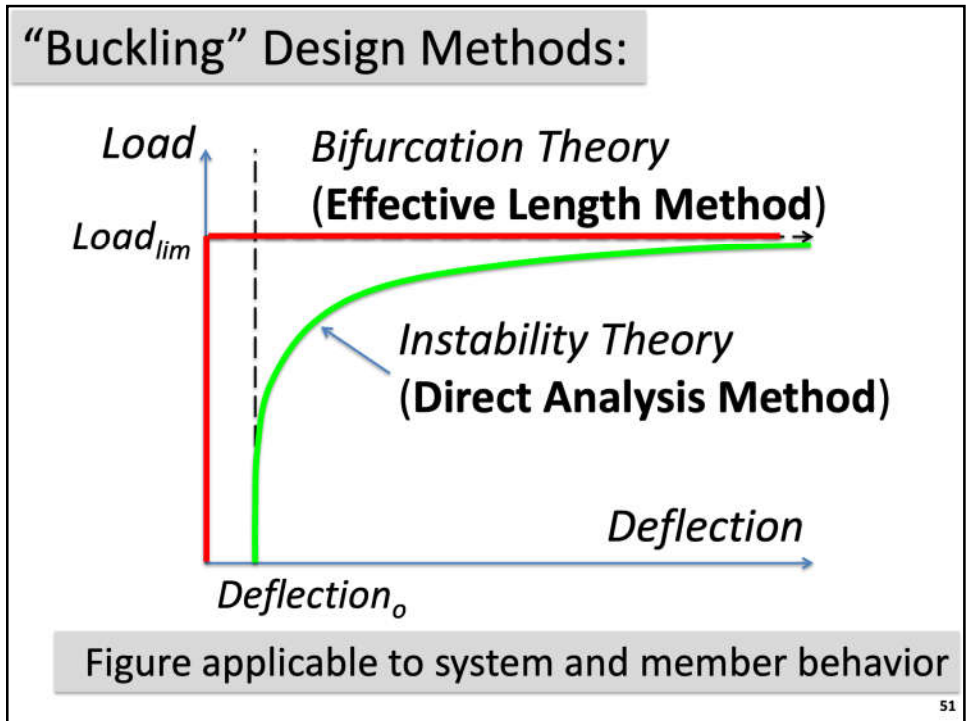
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Any rational method of design for stability that considers all of the listed effects is permitted; this includes the methods identified in Sections C1.1 and C1.2.

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Effective Column Length—Tier Buildings

T. R. HIGGINS

SUMMARY

The trend in modern tier building construction away from heavy masonry exterior walls and substantial tight connections...

New lighter systems warrant $K > 1$
 ...no worries, nomographs to assist...designers will gain experience and develop a feel for the problem as they have for other design rules in the past...

Engineering Journal
American Institute of Steel Construction

1964
 Vol. 1
 pp. 12-15

K-factors first appearing in 1961 AISC Specification

for the problem as they have developed a feel for the design of structural members under the more familiar rules of the past.

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Effective Length Method

Analysis for load effects:

- Equilibrium on deformed shape

$$R_u \leq \phi R_n$$

Based on bifurcation theory (binary buckling)

- Effective lengths account for all effects known to impact system and member instability
- Given the correct effective length of all compression members, this method has been proven acceptable (55+ years of use!)

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Effective Length Method

2nd-order elastic analysis

For $\frac{P}{P_n} \geq 0.2$, $\frac{P}{P_n} + \frac{8M}{9M_n} \leq 1.0$

P_n based on effective length
 $L_c = KL$, with $K \geq 1$:
 comparing KL/r to $4.71\sqrt{E/\sigma_y}$

$\sigma_{cr} = 0.658 \frac{\sigma_y}{\sigma_e} \sigma_y$
 or
 $\sigma_{cr} = 0.877 \sigma_e$

Effects on system stability:

- flexural, shear, axial deformations
- second-order effects
- geometric imperfections
- stiffness reductions due to inelasticity

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Effective Length Method

- Does the K-factor really account for those system stability effects?
 - Indirectly, through its conservatism...
- Common methods for computing *K*-factors
 - Alignment charts or modifications based on undoing inherent assumptions
 - be very careful!
 - Buckling or critical load analyses (eigenvalue)
 - $KL = \pi\sqrt{EI/P}$
 - be very careful!
- How confident are you in your *K*-factors???

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Effective Length Method

- Does the K-factor really account for those system stability effects?
 - Indirectly, through its conservatism...
- Common methods for computing *K*-factors
 - Alignment charts or modifications based on undoing inherent assumptions
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Effective Length Method

- Does the K-factor really account for those system stability effects?
 - Indirectly, through its conservatism...
- Common methods for computing K-factors
 - Alignment charts or modifications based on undoing inherent assumptions
 - be very careful!
 - Buckling or critical load analyses (eigenvalue)
 - $KL = \pi\sqrt{EI/P}$
 - be very careful!
- How confident are you in your K-factors???

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Effective Length Method

- Resources for improving odds of computing accurate K's
 - ASCE Task Committee on Effective Length (1997), *Effective Length and Notional Load Approaches for Assessing Frame Stability: Implications for American Steel Design*, American Society of Civil Engineers. [Ed. Jerry Hajjar]
 - Ziemian, R.D. (ed.) (2010), *Guide to Stability Design Criteria for Metal Structures*, 6th Ed., John Wiley & Sons, Inc.



$$KL/r \rightarrow P_n = \#$$

$$\lambda L/r \rightarrow \phi_n = ??$$

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“General” Direct Analysis Method

Analysis for load effects:

- Equilibrium on deformed shape

$$R_u \leq \phi R_n$$

Based on instability theory
stiffness ↓
deflections ↑
bending moments ↑

- By directly modeling effects known to impact system, member, and cross-section instability, simplifications are granted in computing design resistance
- Design process will not permit system, member, and cross-section instabilities

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General Direct Analysis Method

Primary effects:

- All pertinent deformations
 - Equilibrium on the deformed shape ($P-\delta$ and $P-\Delta$)
 - Initial imperfections (system and component)
 - Yielding accentuated by residual stresses
 - F/M redistribution from relative stiffness changes
- By directly modeling effects known to impact system, member, and cross-section instability, simplifications are granted in computing design resistance
 - Design process will not permit system, member, and cross-section instabilities

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AISC's Direct Analysis Method

Analysis for load effects:

- Equilibrium on deformed shape

$$R_u \leq \phi R_n$$

Based on instability theory (approaching buckling) stiffness ↓
 deflections ↑
 bending ↑

- By directly modeling effects known to impact system, member, ~~and cross-section~~ instability, simplifications are granted in computing design resistance
- Design process will not permit system, member, ~~and cross-section~~ instabilities

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AISC's Direct Analysis Method (2005-16)

Elastic Analysis for load effects:

- **Effects modeled:**
 - All pertinent deformations
 - Equilibrium on deformed shape ($P-\delta$ and $P-\Delta$)
 - Initial system imperfections (out-of-plumb)
 - Yielding accentuated by residual stresses (0.8τ)
- By directly modeling effects known to impact system, member, ~~and cross-section~~ **simplifications are granted** resistance
- Design process will not permit ~~cross-section~~ instabilities

Simplification granted:

- Flexural compressive strength P_n is based on unbraced length ($L_c=L$)

DM 62



Direct Analysis Method

2nd-order “elastic” analysis

For $\frac{P}{P_n} \geq 0.2$, $\frac{P}{P_n} + \frac{8M}{9M_n} \leq 1.0$

P_n based on effective length L_c , with $L_c = L$

Effects on system stability:

- flexural, shear, axial deformations
- second-order effects
- geometric imperfections
- stiffness reductions due to inelasticity

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Direct Analysis Method (2)

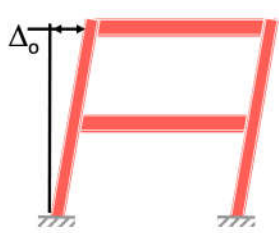
2nd-order “elastic” analysis

For $\frac{P}{P_n} \geq 0.2$, $\frac{P}{P_n} + \frac{8M}{9M_n} \leq 1.0$

Effects on system stability:

- geometric imperfections

1. Member out-of-straightness accounted for in column curve
2. Frame out-of-plumb



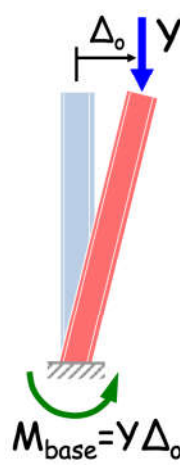
Direct Modeling: distort computational model to include maximum amount considered in design (e.g. AISC Code of Standard Practice, $\Delta_o \leq H/500$)

Notional Loads: represent effect of imperfection by equivalent lateral load of $N_i = 0.002Y_i$ for level i

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Direct Modeling:



$M_{base} = Y\Delta_o$

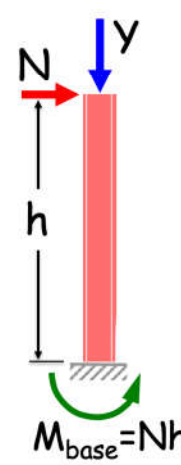
Wait! Where did that equivalent notional load come from?

Require equivalent base moments:

$M_{base} = Y\Delta_o = Nh$
or $N = Y\Delta_o/h$
with $\Delta_o = h/500$
 $N = Y(h/500)/h$

$N = 0.002Y$

Notional Load:



$M_{base} = Nh$

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Direct Analysis Method (3)

2nd-order "elastic" analysis

For $\frac{P}{P_n} \geq 0.2$, $\frac{P}{P_n} + \frac{8M}{9M_n} \leq 1.0$

Loss in stiffness due to partial yielding accentuated by presence of residual stresses

$(EI)_{analysis} = 0.8\tau(EI)$

Think back to compression slides...

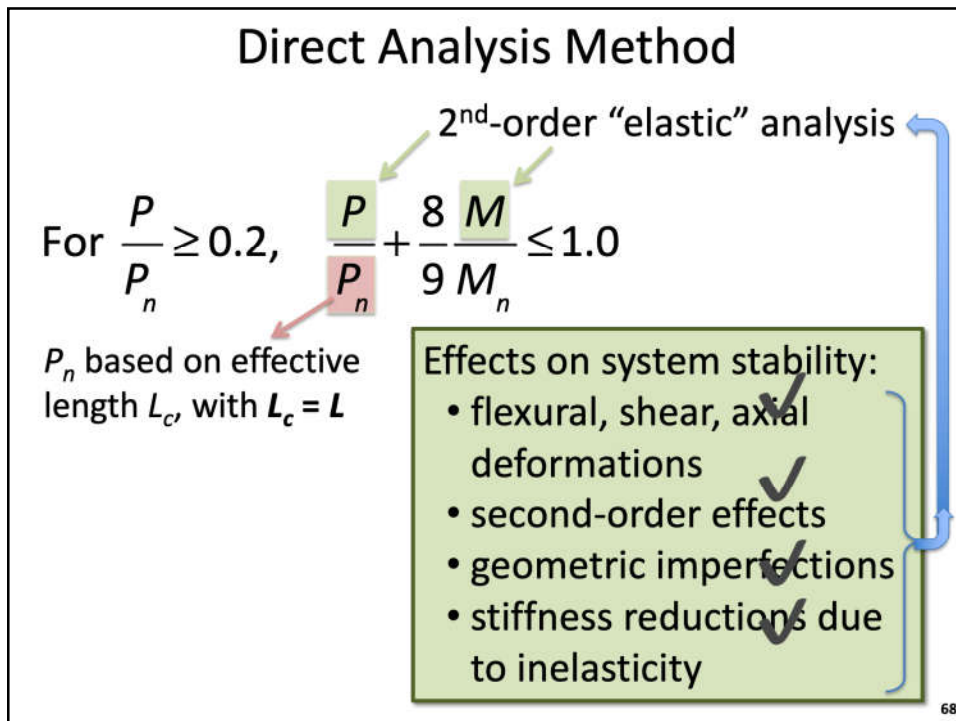
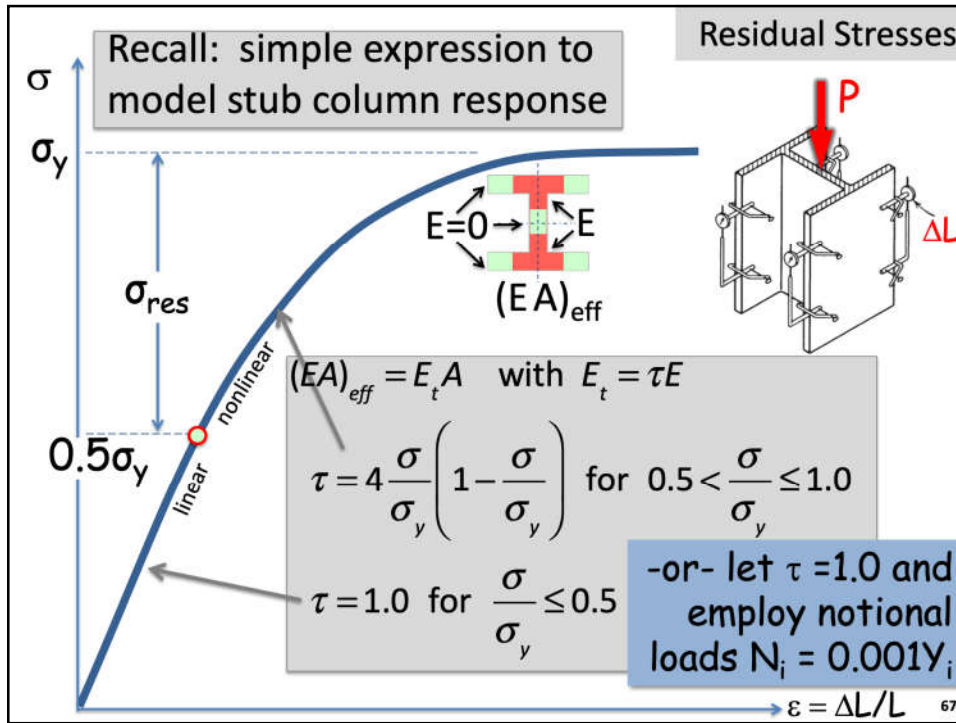
Effects on system stability:

- stiffness reductions due to inelasticity

From extensive studies calibrating DM to advanced FEA results (0.8 is applied to all stiffness contributing to system stability)

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AISC's Direct Analysis Method (2016) ←

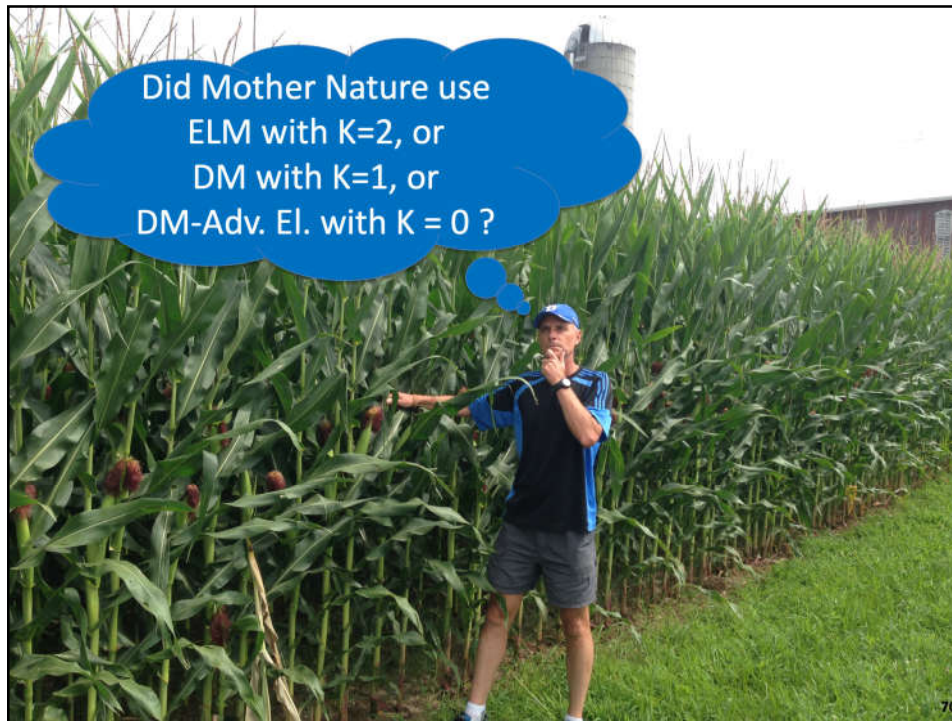
Elastic Analysis for load effects: ←

- **Effects modeled:**
 - All pertinent deformations
 - Equilibrium on deformed shape ($P-\delta$ and $P-\Delta$)
 - Initial system imperfections (out-of-plumb)
 - Initial member imperfections (out-of-straight)
 - Yielding accentuated by residual stresses (0.8τ)
- By directly modeling effects known to impact system, member, and cross-section, **simplifications are granted** in resistance

Simplification granted:

- Compressive strength P_n taken as cross-section axial strength P_{ns}

DM-Adv. Elastic 69



AISC Interaction Equation

The big tradeoff!

$$\frac{P_u}{\phi P_n} + \frac{8 M_u}{9 \phi M_n} \leq 1.0$$

M_u increasing
 ELM
 DM ($\Delta_o, 0.8\tau$)
 DM-Adv. El. ($\Delta_o, 0.8\tau, \delta_o$)

P_n increasing
 ELM ($L_c=KL, K>1$)
 DM ($L_c=L$)
 Adv. El. ($P_n=A_e F_y$)

Methods often give very similar designs

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AISC's Direct Analysis Method (2010-16)

Inelastic Analysis for load effects: Based on instability

- Eq. **Effects modeled:**
 - All pertinent deformations
 - Equilibrium on deformed shape ($P-\delta$ and $P-\Delta$)
 - Initial system and member imperfections
 - Yielding and residual stresses (directly modeled)
 - Redistribution of stresses (F/M's) resulting from changes in relative stiffness distributions
- By directly modeling effects known to impact system, member, and cross-section instability, simplifications are granted in computation
- | | |
|-------------------|---|
| DM-Adv. Inelastic | <ul style="list-style-type: none"> Specification design equations waived Go beyond first-plastic hinge! |
|-------------------|---|

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Additional thoughts...

- Automated modeling and analysis is not the objective, more opportunities for better engineering is the aim
- Goal is to improve design process by providing a more detailed, and hopefully more “realistic” understanding of structural behavior...
- Real question is *where does an engineer have the most knowledge and confidence for a given design situation?*

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Additional thoughts...

- Automated modeling and analysis is not the objective, more opportunities for better engineering is the aim
- Goal is to improve design process by providing a more detailed, and hopefully more “realistic” understanding of structural behavior...
- Real question is *where does an engineer have the most knowledge and confidence for a given design situation?*

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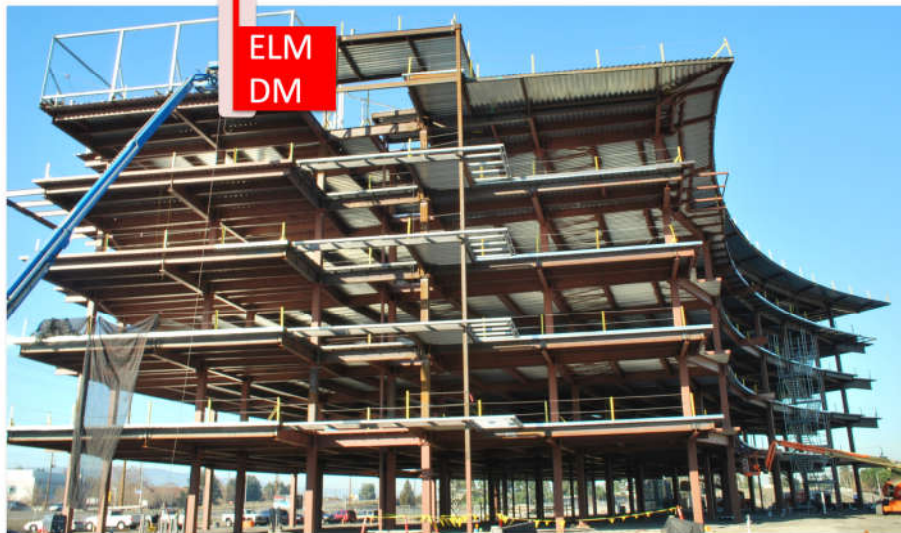


Additional thoughts on DM...

- Automated modeling and analysis is not the objective, more opportunities for better engineering is the aim
- Goal is to improve design process by providing a more detailed, and hopefully more “realistic” understanding of structural behavior...
- Real question is *where does an engineer have the most knowledge and confidence for a given design situation?*



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More ← Prescriptive specification equations → Less
Less ← Given Design Situation → More
Directly modeling effects impact stability

DM-Adv. Elastic

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Pedestrian Bridges
Walter P. Moore and Associates, Inc.

Ensure adequate strength of top compression chord and that bracing is adequate

Modeled:
 ✓ "Member" imperfections
 ✓ System Imperfection

Larry Griffis

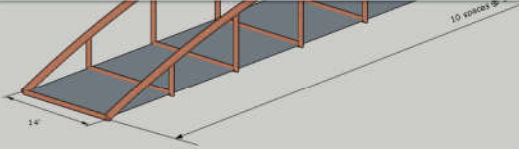
78



Pedestrian Bridges

Design by Advanced Elastic Analysis (AISC App 1.2):

- Initial system imperfections (out-of-plumb)
- Initial member imperfections (out-of-straightness)
- Yielding accentuated by presence of residual stresses approximated by reducing member stiffness by 0.8τ
- Rigorous 2nd-order elastic analysis (GNIA)
- Only need to confirm cross-section strengths ($P_n = P_{ns}$)



Modeled:

- ✓ "Member" imperfections
- ✓ System Imperfection

Larry Griffis

WALTER P. MOORE


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More ← Prescriptive specification equations → Less
 Less ← Given Design Situation → More
 Directly modeling effects impacting stability → More

DM-Inelastic

Excuse me, will you please comment on those ladder columns

Sure, they were designed using AISC's Appendix 1.3



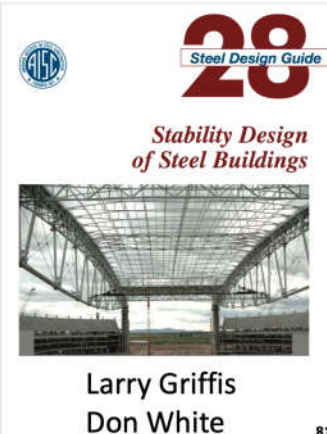
LeMessurier

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More ← Prescriptive specification equations → Less
Less ← Directly modeling effects impacting stability → More

AISC's Direct Analysis Method
provides a wide range of
design opportunities...

- ✓ Elastic Analysis (Ch. C)
- ✓ Design by Advanced Elastic Analysis (App. 1.2)
- ✓ Design by Advanced Inelastic Analysis (App. 1.3)



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Summary – Systems

- Fundamentals of Stability
 - Compression (Lectures 1 & 2)
 - Flexural (Lectures 3 & 4)
 - Combined compression and flexure (Lectures 5 & 6)
 - Systems (**today!** and Lecture 8)
- Factors impacting system stability
 - flexural, shear, axial deformations
 - second-order effects (equilibrium on deformed shape!)
 - rigorous analysis vs. amplification factors B_1 and B_2
 - geometric imperfections
 - stiffness reductions due to inelasticity

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Summary – Systems (cont.)

- Basis for Design of Systems
 - Elastic Analysis (AISC Spec., Chs. A-K, Apps. 1,6-8)
 - strength of system is assured by ensuring adequate strength of its components
 - Inelastic Analysis (AISC Spec., Appendix 1)
 - System strength (stability) can be assessed directly by the analysis
- AISC Methods (lots of options!)
 - Effective Length Method (LBA and GNA)
 - Direct Analysis Method
 - 3 methods based on elastic analysis (GNIA and LA)
 - 1 method on inelastic analysis (GMNIA)

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Summary – Systems (cont.)

- Finally, if you still do not have confidence that your structural system is stable, then you can always...



Your virtual laboratory assignment...

- Rerun examples presented in this lecture
- Complete a portion of Learning Module 9

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Thank You!

Hope you enjoyed this lecture!



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- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!



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- Password: Same as AISC website password.



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 - Option 2: Watch the recording and pass the associated quiz.

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- 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!

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Event	Start Date
Seismic Design in Steel	1/2/1900 12:00:00 AM
4-Session Package-Design of Facade Attachments	3/9/2019 1:00:00 PM
NS 15 8-Session Package-Night School 15 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
NS 16 8-Session Package-Night School 16 - Seismic Design in Steel	2/5/2018 7:00:00 PM
NS 17 8-Session Package-Night School 17- Design of Facade Attachments	7/18/2018 7:00:00 PM
NS 18 8-Session Package-Night School 18- Steel Construction: Mill Top Topping Out	10/15/2018 7:00:00 PM
NS 19 8-Session Package-Night School 19- Connection Design	2/4/2019 7:00:00 PM
NS 20 8-Session Package-Night School 20- Classical Methods of Structural Analysis	8/9/2019 7:00:00 PM
8-Session Package-Seismic Design in Steel - Concepts & Examples	7/16/2018 1:30:00 PM

8-Session Registrants

Course Resources

Night School 24: Modern Methods for Learning Structural Stability

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6 2020 7:00PM EDT	Handouts	Available 10/06/2020 5:00PM EDT	Available 10/06/2020 5:00PM EDT	Pending
NS24.2 - Compression Members - Practical Considerations	Oct 13 2020 7:00PM EDT	Handouts	Available 10/13/2020 5:00PM EDT	Available 10/13/2020 5:00PM EDT	Pending
NS24.3 - Behavior of Flexural Members - The Fundamentals	Oct 20 2020 7:00PM EDT	Handouts	Available 10/22/2020 5:00PM EDT	Available 10/22/2020 5:00PM EDT	Pending
NS24.4 - Flexural Members - Practical Considerations	Oct 27 2020 7:00PM EDT	Handouts	Available 10/29/2020 5:00PM EDT	Available 10/29/2020 5:00PM EDT	Pending
NS24.5 - Stability of Beam-Columns - The Fundamentals	Nov 10 2020 7:00PM EST	Handouts	Available 11/12/2020 5:00PM EST	No longer available	Pending
NS24.6 - Stability of Beam-Columns - Practical Consideration	Nov 17 2020 7:00PM EST	Handouts	Available 11/19/2020 5:00PM EST	No longer available	Pending
NS24.7 - Behavior of Structural Systems - The Fundamentals	Dec 1 2020 7:00PM EST	Handouts	Available 12/03/2020 5:00PM EST	No longer available	Pending
NS24.8 - Structural Systems - Practical Considerations	Dec 8 2020 7:00PM EST	Handouts	Available 12/10/2020 5:00PM EST	No longer available	Pending
NS24 - Final Exam	N/A			No longer available	





AISC | Thank you.



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