




AISC
Night School

**Basic Steel Design -- Session 6:
Stability Analysis and Design I**

Louis F. Geschwindner




Smarter.
Stronger.
Steel.



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Session Description

22.6 Stability Analysis and Design I March 10, 2020

Part I of this 2-session lecture on Stability Analysis and Design will review the five stability requirements to be considered in design. The session will review required strength and available strength. The session will then discuss 2nd order analysis and demonstrate how methods to calculate 2nd order effects by hand. This will include presenting the development of the B1-B2 method discussed in the AISC Specification, Appendix 8 – Approximate Second-Order Analysis.





Learning Objectives:

- List the five stability requirements that must be considered in the design of structural steel buildings per the AISC Specification.
- Describe how geometric imperfections affect the stability of a structure.
- List the methods used to calculate 2nd order effects by hand.
- Describe the approximate second-order analysis method included in the AISC Specification, Appendix 8.



Basic Steel Design: A review of the principles of steel design according to ANSI/AISC 360-16

Night School 22

Lesson 6

Stability Analysis and Design I



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Stability Analysis and Design I

- Stability analysis and design introduction
 - Design requirements
 - Structural analysis
 - Stability considerations
 - Geometric imperfections
 - Second-order analysis
 - Approximate second-order analysis



6.9

Design Requirements

- The design of members and connections shall be consistent with the intended behavior and the assumptions made in the structural analysis.
- The loads and load combinations shall be as stipulated by the applicable building code.



6.10

Design Requirements

- The required strength of structural members and connections shall be determined by structural analysis for the appropriate load combinations.
- Design by elastic or inelastic analysis is permitted.

Elastic analysis is the most common approach in practice.



6.11

Structural Analysis

- Process used to determine how a structure responds to specific loads or actions.
- Results are measured by establishing the magnitude of forces and deformations throughout the structure.



6.12

Structural Analysis

- A mathematical model is used to predict behavior of a real structure based on:
 - Engineering mechanics theory
 - Laboratory research
 - Model and field experimentation
 - Experience
 - Engineering judgment
- In the end, the results must satisfy equilibrium



6.13

Structural Analysis

1. Determinate vs. indeterminate analysis
2. Linear vs. nonlinear analysis
3. Small vs. large displacement theory
4. First-order vs. second-order analysis

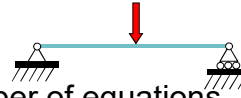


6.14

1. Structural Analysis

- **Determinate Analysis**

- Number of unknowns = number of equations
 - Equations of equilibrium plus condition equations
- Forces and moments independent of member properties



- **Indeterminate Analysis**

- Number of unknowns > number of equations
 - Equilibrium plus condition equations
 - Additional equations are needed
- Forces and moments are dependent on relative member properties



6.15

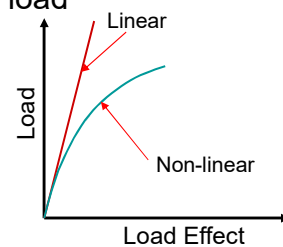
2. Structural Analysis

- **Linear Analysis**

- Effects of load proportional to load
- Elastic material
- **Superposition applicable**

- **Non-linear Analysis**

- Effects of load not proportional to load
- Geometric nonlinearities
- Elastic-plastic material
- Inelastic material
- **Superposition not valid**



6.16

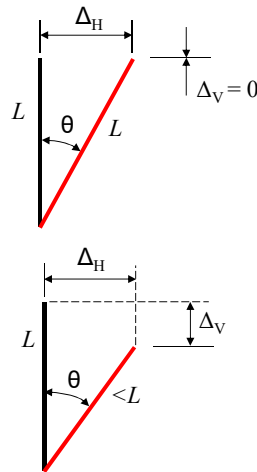
3. Structural Analysis

- Small deflection theory

$$\sin \theta = \tan \theta = \theta$$

- Large deflection theory

$$\sin \theta \neq \tan \theta \neq \theta$$



6.17

4. Structural Analysis

- First-order
 - Equilibrium formulated about the structures undeformed geometry
 - Analysis of beam-columns ignores the impact of axial load on moment
- Second-order
 - Equilibrium formulated about the structures final displaced geometry
 - Analysis of beam-columns includes the impact of axial load on moment



6.18

Structural Engineering

- What is structural engineering really?

“The art of modeling materials that we do not wholly understand, into shapes that we cannot precisely analyze, so as to withstand forces we cannot really assess, in such a way that the community at large has no reason to suspect the extent of our ignorance!”

A. R. Dykes, IStructE

“Is the exact analysis of an approximate model good enough to qualify as an approximate analysis of the exact structure?”

M. Sozen



6.19

Design for Stability

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**.”



6.20

Design for Stability

C1. General Stability Requirements

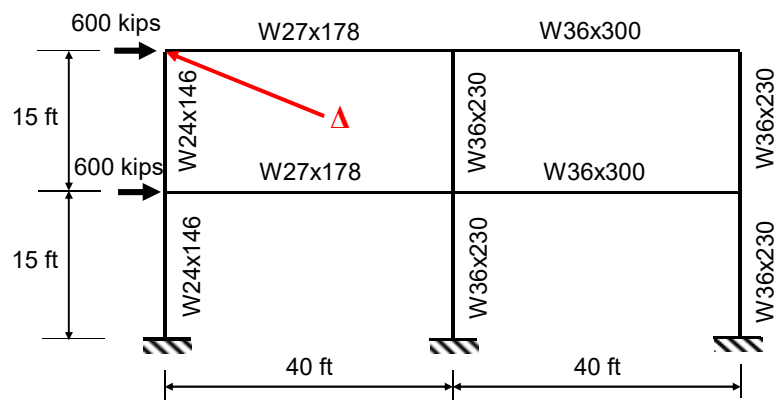
- a) Flexural, shear and axial member deformations and all other component and connection deformations that contribute to displacements of the structure
- b) Second-order effects (including $P-\Delta$ and $P-\delta$ effects)
- c) Geometric imperfections
- d) Stiffness reductions due to inelasticity...
- e) Uncertainty in ... strength and stiffness

Any rational method of design for stability that considers all of the listed effects is permitted.



6.21

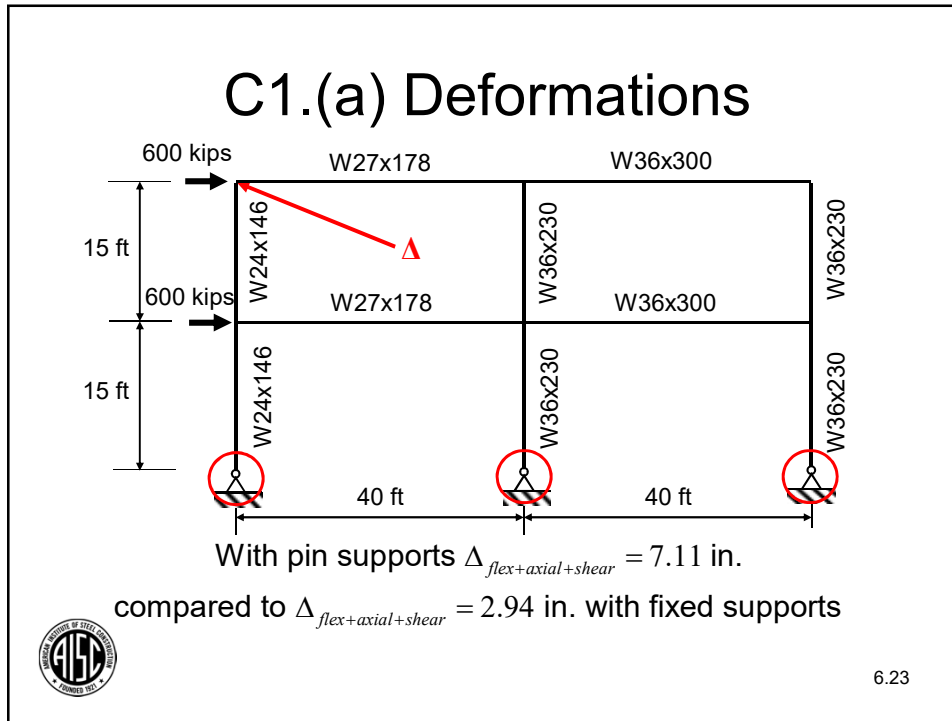
C1.(a) Deformations



$$\Delta_{flex+axial+shear} = 2.94 \text{ in.}, \Delta_{flex+axial} = 2.42 \text{ in.}, \Delta_{flex} = 2.24 \text{ in.}$$

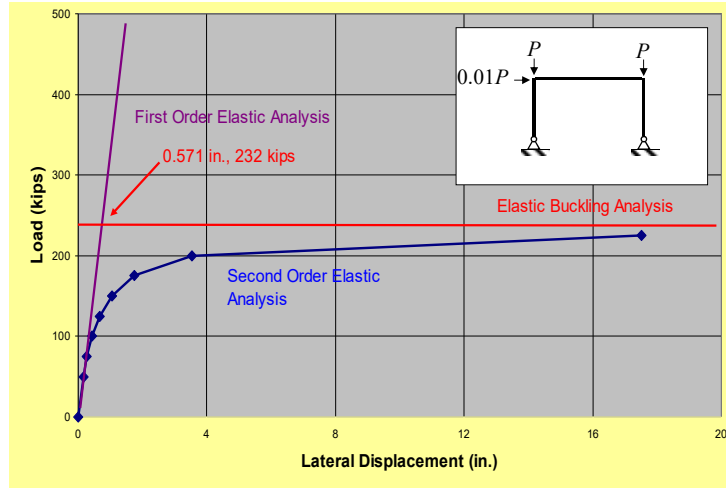


6.22



- ### C1.(b) Second-order Effects
- Second-order analysis changes:
 - Moments in beams and columns
 - Shears and axial forces in beams and columns
 - Forces on connections and foundations
 - Second-order moments may have a different distribution than first-order moments
 - Superposition does not apply
- 6.24

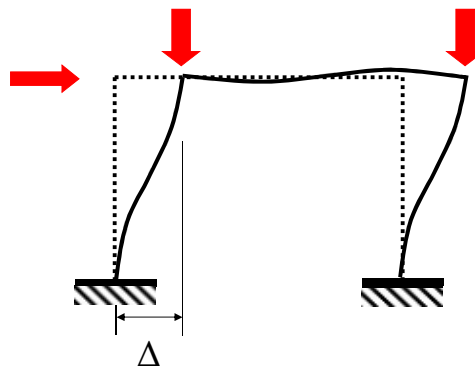
C1.(b) Second-order Effects



6.25

C1.(b) Second-order Effects

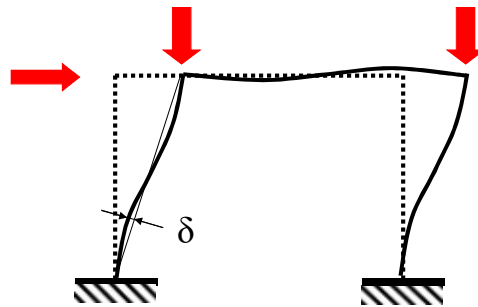
- $P-\Delta$ effects (sway effect) (structure effect)



6.26

C1.(b) Second-order Effects

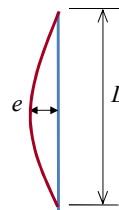
- $P-\delta$ effects (member effect)



6.27

C1.(c) Geometric Imperfections

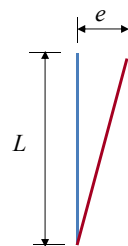
- Out-Of-Straightness



ASTM A6
Tolerance:

$$e = L/1000$$

- Out-Of-Plumbness



AISC Code of Standard
Practice
Tolerance:

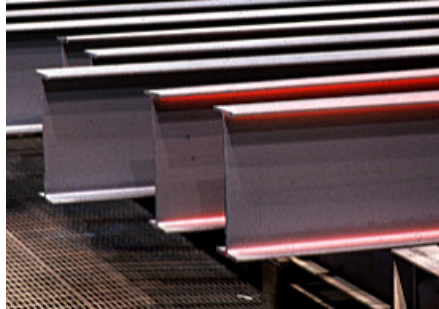
$$e = L/500$$



6.28

C1.(d) Stiffness Reduction

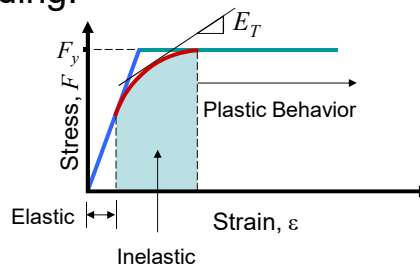
- Effects of Inelasticity
 - Cooling during the production process produces residual stresses



6.29

C1.(d) Stiffness Reduction

- Effects of Inelasticity
 - Stress-strain relationship no longer linear.
 - Use the Tangent Modulus of Elasticity at level of loading.



$$\tau_b = \frac{E_T}{E}$$



6.30

C1.(d) Stiffness Reduction

- Depends on the level of axial stress in the member given by ratio of required strength to maximum strength:

$$\text{when } \alpha P_r / P_{ns} \leq 0.5; \quad \tau_b = 1.0 \quad (\text{C2-2a})$$

$$\text{when } \alpha P_r / P_{ns} > 0.5; \quad \tau_b = 4 \left[\frac{\alpha P_r}{P_{ns}} \left(1 - \frac{\alpha P_r}{P_{ns}} \right) \right] \quad (\text{C2-2b})$$

$$P_{ns} = F_y A_g \quad \text{or} \quad P_{ns} = F_y A_e$$

$$\alpha = 1.0 \text{ (LRFD)} \quad \alpha = 1.6 \text{ (ASD)}$$



6.31

C1.(e) Uncertainty

- Included in available strength determination
 - Resistance factor, ϕ
 - Safety factor, Ω
- Included in stiffness reduction factor, τ_b



6.32

Design for Stability

- 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.
 - Direct Analysis Method (Chapter C, Sections C2 and C3)
 - Effective Length Method (Appendix 7.2)
 - First-order Analysis Method (Appendix 7.3)
 - Any other method that gives the correct answers



6.33

Design for Stability

- Calculation of Required Strengths
 - Each method has different requirements for how the 5 considerations are to be included.
 - In this lesson we will look in more detail at geometric imperfections and second-order effects.
 - The other considerations are either automatically addressed by the strength equations or are specific to an analysis method and will be discussed in the next lesson.



6.34

Design for Stability

- One of the second-order analysis requirements is that we must carry out the analysis for LRFD or 1.6ASD load combinations
 - This is to insure that all analysis is done at the ultimate load level.
 - We will see that carrying out the analysis at the ultimate load level can have a significant impact.
 - This is where the $\alpha = 1.0$ for LRFD and 1.6 for ASD comes from.

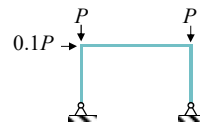
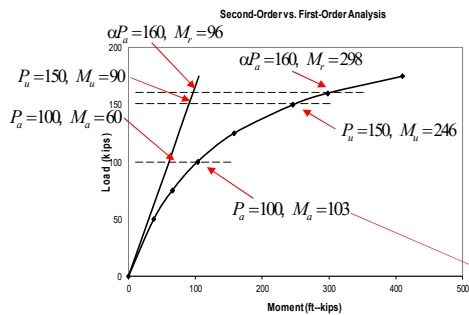


6.35

Design for Stability

- Analysis for LRFD or 1.6ASD load combinations

$P_L = 75$ kips, $P_D = 25$ kips



Use α to be sure that the analysis captures the nonlinear aspects at the ultimate strength.

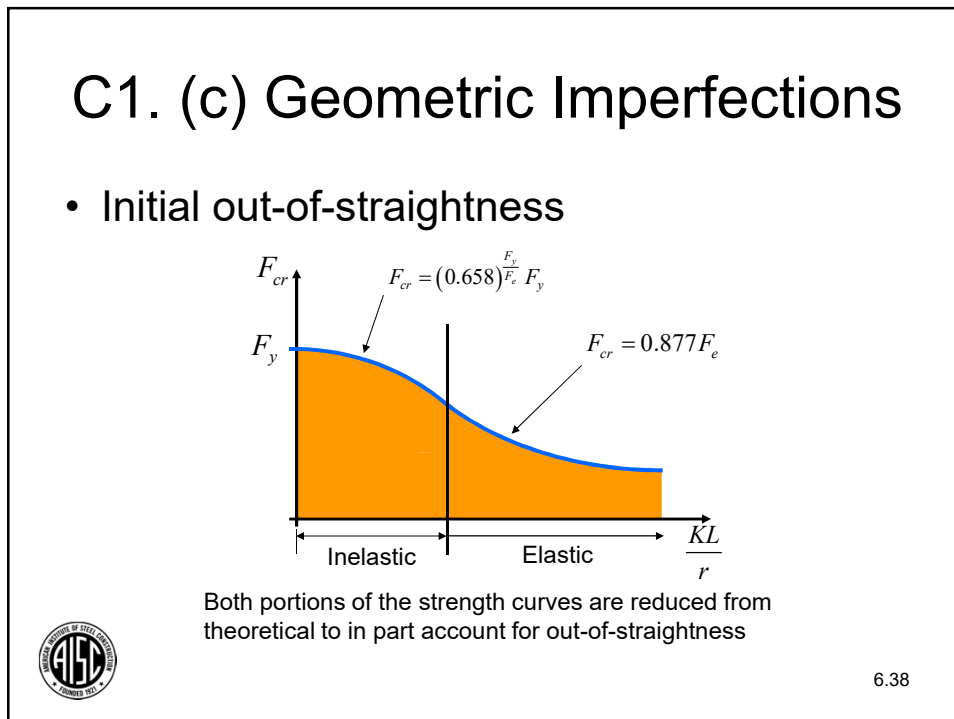
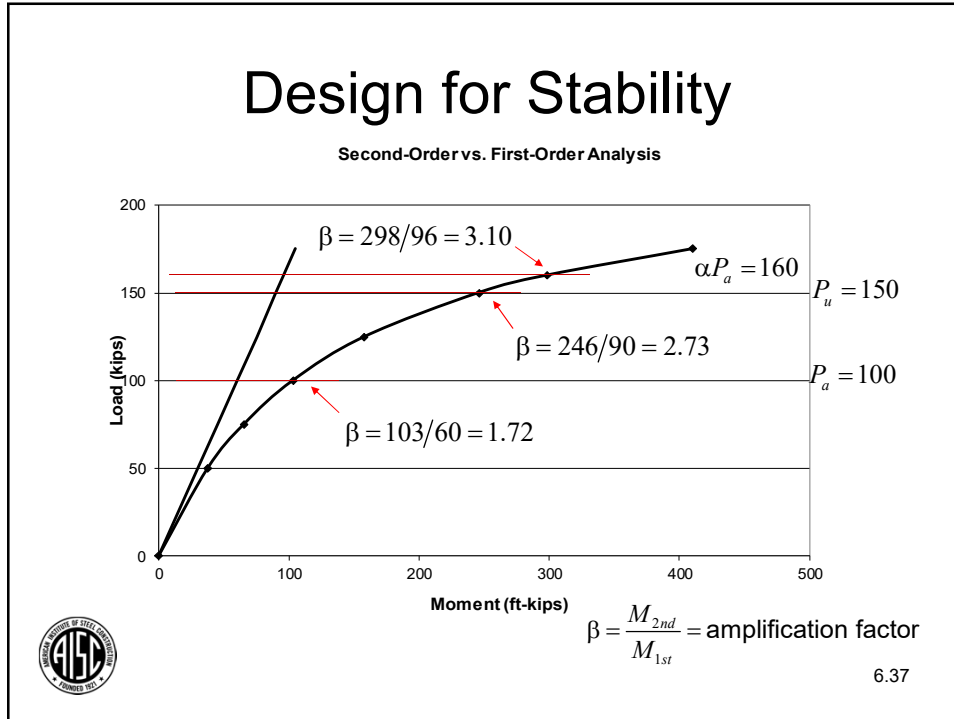
For design by ASD

$$P_r = 160/1.6 = 100 \text{ kips}$$

$$M_r = 298/1.6 = 186 \text{ ft-kips}$$



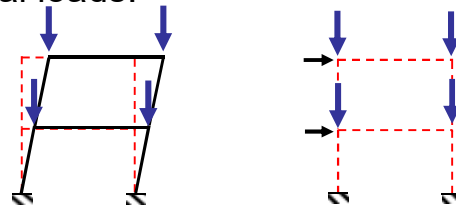
6.36



C1. (c) Geometric Imperfections

- Initial out-of-plumbness

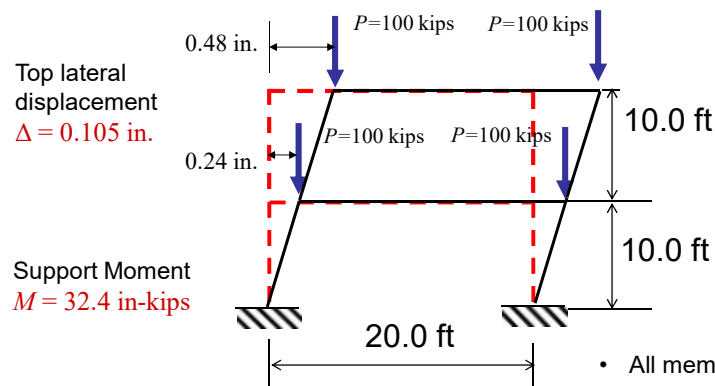
The effect of initial imperfections on the stability of the structure shall be taken into account either by direct modeling of imperfections in the analysis or by applying notional loads.



6.39

C1. (c) Geometric Imperfections

Direct Modeling



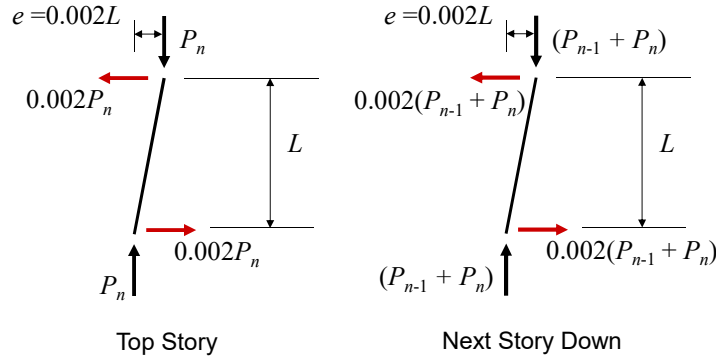
- All members W8x24
- First-Order Analysis
- Imperfection = $H/500$



6.40

C1. (c) Geometric Imperfections

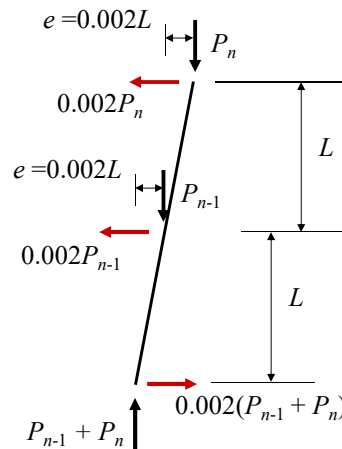
- What external forces would keep the out-of-plumb structure in equilibrium?



6.41

C1. (c) Geometric Imperfections

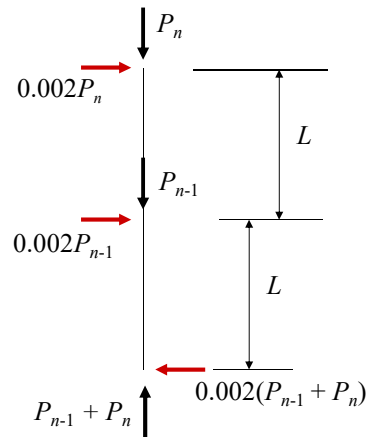
- To keep the structure in equilibrium, with the levels combined.
- These forces then represent the impact of the out-of-plumbness on the structure



6.42

C1. (c) Geometric Imperfections

- Turn those forces around and apply them as loads on the plumb structure.
- These are referred to as notional loads.



6.43

C1. (c) Geometric Imperfections

- Notional Loads
 Apply notional loads, N_i , where

$$N_i = 0.002\alpha Y_i$$

Y_i = the total gravity load on that story

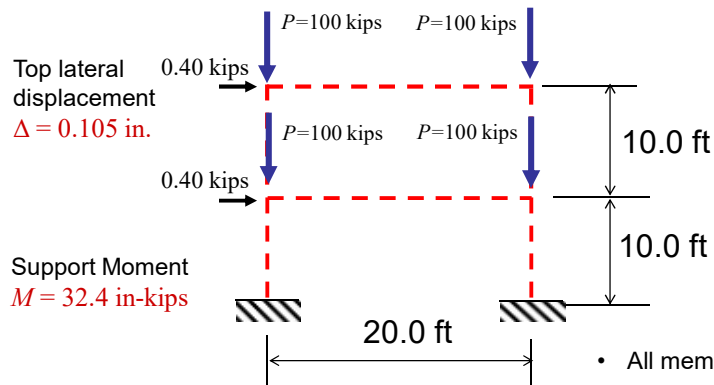
Applies to tiered buildings and accounts for an initial out-of-plumbness at the maximum of 1/500 as defined in the COSP. If a lesser out-of-plumbness is known, N_i can be reduced.



6.44

C1. (c) Geometric Imperfections

- Notional Loads = $0.002(1.0)(100 + 100) = 0.40$ kips



- All members W8x24
- First-Order Analysis
- Imperfection = $H/500$

6.45



C1. (b) Second-Order Analysis

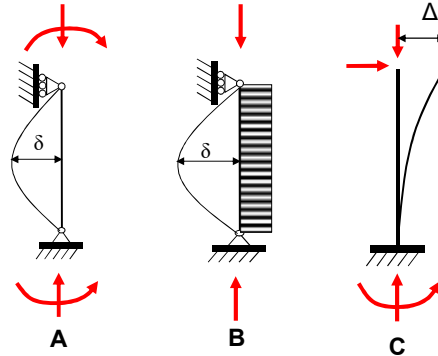
- The second-order analysis should include the member effects, $P-\delta$, and structure (sway) effects, $P-\Delta$.
- Any method that gives the correct answer is permitted, including “rigorous” methods or approximate methods.



6.46

C1. (b) Second-Order Analysis

- In Lesson 1 we looked at 3 examples and illustrated an approximate step-by-step second-order analysis



6.47

C1. (b) Second-Order Analysis

- It was clear that the moments, when considering second-order effects, are larger than those when only first-order effects are considered.
- Second-order moments are also distributed differently.
- These differences can be significant when comparing required strength to available strength.



6.48

C1. (b) Second-Order Analysis

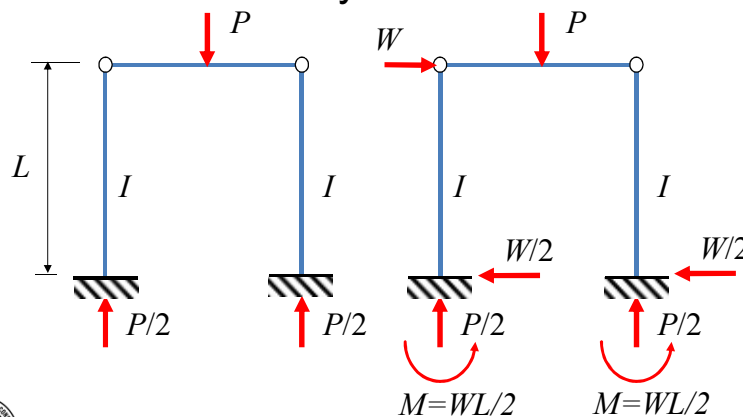
- Now look at what we might expect from the results of a rigorous second-order analysis.
- Compare the results of the second-order analysis with those of a first-order analysis for:
 - Gravity load only
 - Gravity plus lateral



6.49

Symmetric Portal Frame

- First-Order Analysis



6.50

Symmetric Portal Frame

- Second-Order Analysis

No Change
Results change

6.51

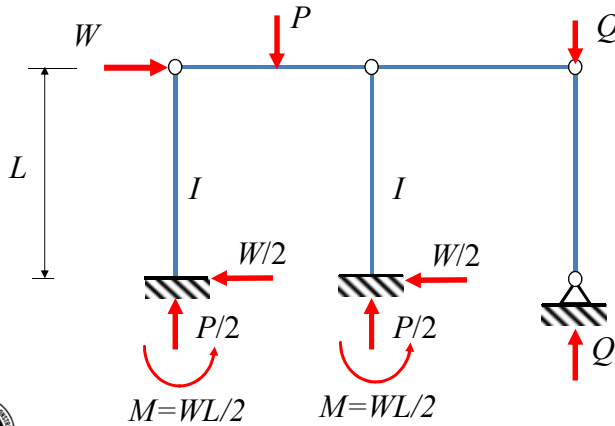
Symmetric Frame with Gravity Only Column

First-Order Analysis

6.52

Gravity Only Column and Lateral Load

First-Order Analysis



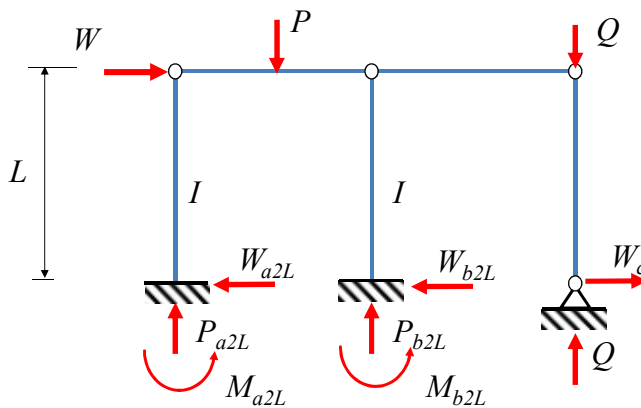
Gravity only column has **no influence** under a first-order analysis



6.53

Gravity Only Column and Lateral Load

Second-Order Analysis

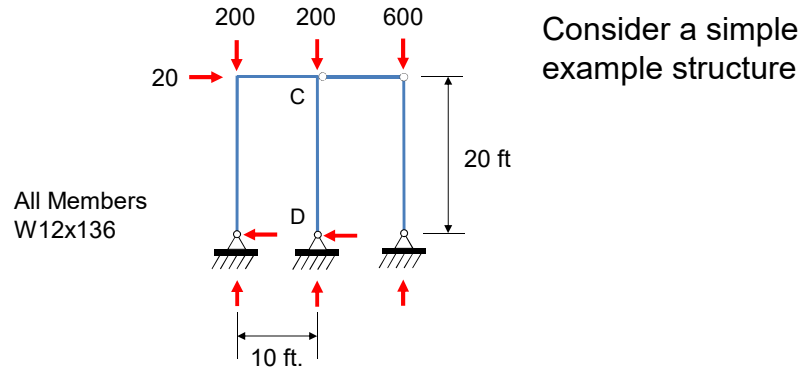


Gravity only column **has influence** under a second-order analysis



6.54

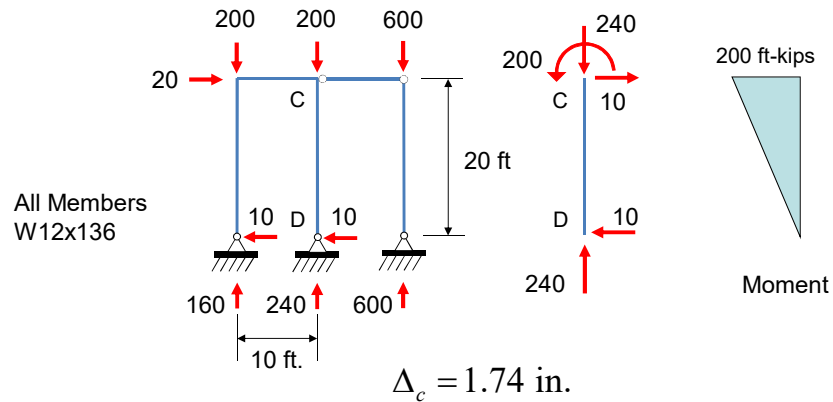
Rigorous Second-Order Analysis



6.55

Rigorous Second-Order Analysis

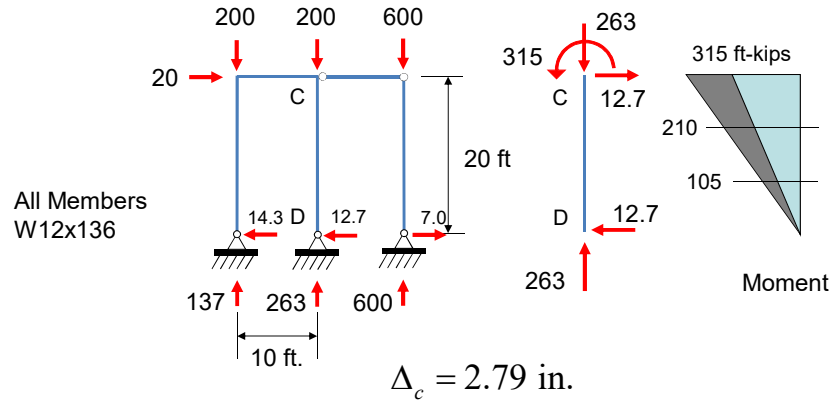
First-Order Analysis



6.56

Rigorous Second-Order Analysis

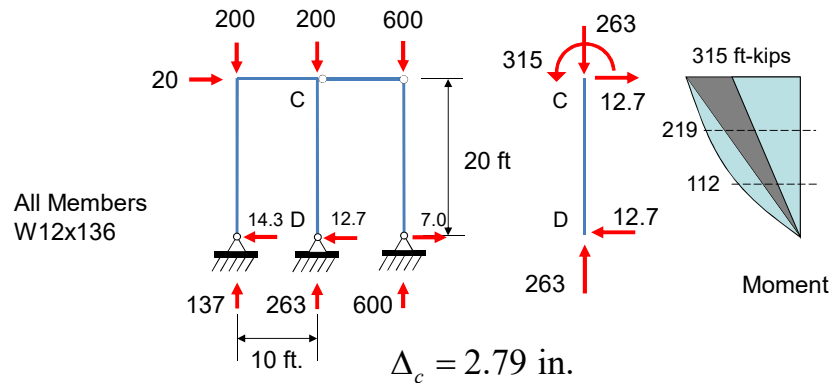
Second-Order Analysis



6.57

Rigorous Second-Order Analysis

Second-Order Analysis



6.58

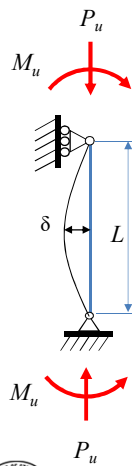
Second-Order Analysis by Amplified First-Order Analysis

- The Goal:
 Develop a relationship between the first-order moment and the second-order moment that will permit a simple amplification of the results of a first-order analysis to determine the results of a second-order analysis



6.59

Second-Order Analysis by Amplified First-Order Analysis



Write the equilibrium equation at mid-height

$$M_{2nd} = M_u + P_u \delta$$

Define the amplification factor

$$AF(M_u) = M_{2nd} = M_u + P_u \delta$$

Solve for AF

$$AF = \frac{M_u + P_u \delta}{M_u}$$



6.60

Second-Order Analysis by Amplified First-Order Analysis

- Add to the denominator and simplify

$$(P_u \delta - P_u \delta)$$

$$AF = \frac{M_u + P_u \delta}{M_u + (P_u \delta - P_u \delta)} = \frac{1}{1 - \frac{P_u \delta}{M_u + P_u \delta}}$$



6.61

Second-Order Analysis by Amplified First-Order Analysis

- Simplifying Assumptions

$$\frac{\delta}{M_u + P_u \delta} \approx \frac{\delta}{M_u}$$

$$\frac{M_u}{\delta} = \frac{8EI}{L^2} \approx \frac{\pi^2 EI}{L^2} = P_e$$

- Substituting into the equation for AF



6.62

Second-Order Analysis by Amplified First-Order Analysis

- The amplification factor for the “**member effect**” when there is uniform moment is thus:

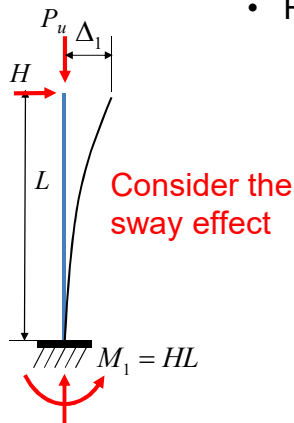
$$AF = \frac{1}{1 - \frac{P_u}{P_e}}$$



6.63

Second-Order Analysis by Amplified First-Order Analysis

- For a first-order analysis



$$M_1 = HL$$

$$\Delta_1 = \frac{HL^3}{3EI}$$



6.64

Second-Order Analysis by Amplified First-Order Analysis

• For second-order analysis assume these two models are equal

$$\Delta_2 = \frac{\left(H + \frac{P_u \Delta_2}{L}\right) L^3}{3EI}$$

$$= \frac{HL^3}{3EI} \left(1 + \frac{P_u \Delta_2}{HL}\right)$$

$$\Delta_2 = \Delta_1 + \frac{P_u \Delta_1 \Delta_2}{HL}$$

6.65

Second-Order Analysis by Amplified First-Order Analysis

• Solve for Δ_2

$$\Delta_1 = \left(1 - \frac{P_u \Delta_1}{HL}\right) \Delta_2$$

• Thus,

$$\Delta_2 = \frac{\Delta_1}{\left(1 - \frac{P_u \Delta_1}{HL}\right)} = (AF) \Delta_1$$

• So for the “sway effect”

$$AF = \frac{1}{1 - \frac{P_u \Delta_1}{HL}}$$

6.66

Second-Order Analysis by Amplified First-Order Analysis

- Amplification for **member effect**

$$AF = \frac{1}{1 - \frac{P_u}{P_e}}$$

- Amplification for **sway effect**

$$AF = \frac{1}{1 - \frac{P_u \Delta_1}{HL}}$$



6.67

Approximate Second-order Analysis

- Second-Order Analysis by Amplified First-Order Elastic Analysis

Any second-order analysis method that considers both $P-\Delta$ and $P-\delta$ effects may be used.

The Approximate Second-Order Analysis Method defined in Appendix 8 is an accepted method for second-order elastic analysis of braced, moment, and combined framing systems. This is essentially what we have just developed.



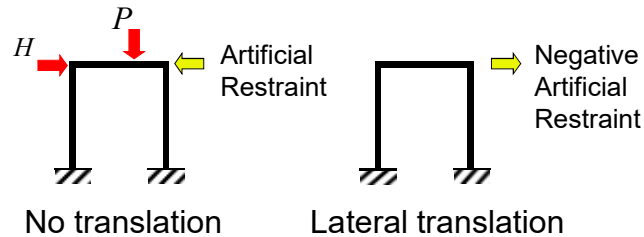
6.68

Approximate Second-order Analysis

- Required second-order flexural and axial strength

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

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



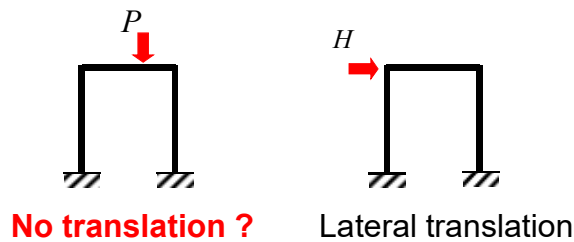
6.69

Approximate Second-order Analysis

- Common design office approximation

M_{nt} = gravity load moments

M_{lt} = lateral load moments



6.70

Approximate Second-order Analysis

- App.8.2.1. Multiplier B_1 for P - δ effects

$$B_1 = \frac{C_m}{\left(1 - \frac{\alpha P_r}{P_{e1}}\right)} \geq 1.0 \quad (\text{A-8-3})$$

for members not loaded transversely

$$C_m = 0.6 - 0.4(M_1/M_2) \quad (\text{A-8-4})$$

$$\alpha = 1.0 \quad (\text{LRFD}) \quad \alpha = 1.6 \quad (\text{ASD})$$



6.71

Approximate Second-order Analysis

- App.8.2.1. Multiplier B_1 for P - δ effects

P_{e1} is the elastic critical buckling strength in the plane of bending for the column as if it were in a braced frame.

$$K = 1.0 \quad P_{e1} = \frac{\pi^2 EI^*}{L_{c1}^2} \quad (\text{A-8-5})$$

EI^* = the flexural rigidity required to be used in the analysis



6.72

Approximate Second-order Analysis

- App.8.2.2. Multiplier B_2 for P - Δ effects

$$B_2 = \frac{1}{1 - \frac{\alpha P_{story}}{P_{e story}}} \geq 1.0 \quad (\text{A-8-6})$$

$P_{e story}$ = elastic critical buckling strength in plane of bending
 determined for a sidesway buckling analysis

P_{story} = total vertical load supported by all columns in story

$$\alpha = 1.0 \quad (\text{LRFD}) \quad \alpha = 1.6 \quad (\text{ASD})$$



6.73

Approximate Second-order Analysis

- App.8.2.2. Multiplier B_2 for P - Δ effects

$$P_{e story} = R_M \frac{HL}{\Delta_H} \quad (\text{A-8-7})$$

Δ_H = first-order translation of the story

H = story shear force producing Δ_H

L = story height



6.74

Approximate Second-order Analysis

- App.8.2.2. Multiplier B_2 for $P-\Delta$ effects

$$R_M = 1 - 0.15 \left(\frac{P_{mf}}{P_{story}} \right) \quad (\text{A-8-8})$$

R_M = coefficient to account for influence of $P-\delta$ on $P-\Delta$

P_{mf} = total vertical load in columns that are part of moment frames

P_{story} = total vertical load supported by all columns in story



6.75

Approximate Second-order Analysis

- App.8.2.2. Multiplier B_2 for $P-\Delta$ effects

$$R_M = 1 - 0.15 \left(\frac{P_{mf}}{P_{story}} \right) \quad (\text{A-8-8})$$

- For braced frames

$$R_M = 1.0$$

- For moment frames with no gravity only columns

$$R_M = 0.85 \quad (\text{conservative to use in all cases})$$



6.76

Approximate Second-order Analysis

- Application (LRFD)

H

6.77

Approximate Second-order Analysis

- No translation

H

6.78

Approximate Second-order Analysis

- Translation

18.75 kips
 $L = 20 \text{ ft}$
 $H_{lt} = 18.75 \text{ kips}$
 $P_{lt} = 0 \text{ kips}$
 $Q_{lt} = 0 \text{ kips}$
 $M_{lt} = 375 \text{ ft-k}$
 $W14x132$
 $I_x = 1530 \text{ in.}^4$

6.79

Approximate Second-order Analysis

- Summary of first-order analysis:

$$M_{nt} = 125 \text{ ft-kips}$$

$$M_{lt} = 375 \text{ ft-kips}$$

$$P_{nt} = 500 \text{ kips}$$

$$P_{lt} = 0 \text{ kips}$$

$$M_u = M_{nt} + M_{lt} = 125 + 375 = 500 \text{ ft-kips}$$

$$P_u = P_{nt} + P_{lt} = 0 + 500 = 500 \text{ kips}$$

6.80

Approximate Second-order Analysis

- Member Amplification

$$B_1 = \frac{C_m}{1 - \frac{\alpha P_r}{P_{e1}}} \geq 1$$

$$C_m = 1.0 \text{ (transverse load)}$$

$$\alpha P_r = \alpha (P_{nt} + P_{lt}) = 1.0(500 + 0) = 500 \text{ kips}$$

$$P_{e1} = \frac{\pi^2 EI^*}{(L_{c1})^2} = \frac{\pi^2 (29,000)(1530)}{(20(12))^2} = 7,600 \text{ kips}$$



6.81

Approximate Second-order Analysis

- Member Amplification

$$B_1 = \frac{C_m}{1 - \frac{\alpha P_r}{P_{e1}}} = \frac{1.0}{1 - \frac{500}{7,600}} = 1.07 \geq 1.0$$



6.82

Approximate Second-order Analysis

- Sway Amplification

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

$$\alpha P_{story} = \alpha(P + Q) = 1.0(500 + 500) = 1,000 \text{ kips}$$

$$\Delta_H = \frac{HL^3}{3EI^*} = \frac{1.0(20)^3(1,728)}{3(29,000)(1530)} = 0.104 \text{ in.}$$



6.83

Approximate Second-order Analysis

- Sway Amplification

$$R_M = 1 - 0.15 \left(\frac{P_{mf}}{P_{story}} \right) = 1 - 0.15 \left(\frac{500}{1000} \right) = 0.925$$

$$P_{e story} = R_m \frac{HL}{\Delta_H} = 0.925 \frac{1.0(20)(12)}{0.104} = 2,130 \text{ kips}$$

$$B_2 = \frac{1}{1 - \frac{\alpha P_{story}}{P_{e story}}} = \frac{1}{1 - \frac{1,000}{2,130}} = 1.88 \geq 1.0$$

The influence of $P-\delta$ on $P-\Delta$ resulted in an increase in B_2 from 1.76 to 1.88, about 7%.



6.84

Approximate Second-order Analysis

- Second-order results

This $B_2 = 1.88$ amplification is more than is normally acceptable. There are limits on what methods can be used because of that.

$$M_r = B_1 M_{nt} + B_2 M_{lt}$$

$$= 1.07(125) + 1.88(375) = 839 \text{ ft-kips}$$

$$P_r = P_{nt} + B_2 P_{lt}$$

$$= 500 + 1.88(0) = 500 \text{ kips}$$



6.85

Approximate Second-order Analysis

- If there had been no load on the gravity only column

$$R_M = 1 - 0.15 \left(\frac{P_{mf}}{P_{story}} \right) = 1 - 0.15 \left(\frac{500}{500} \right) = 0.85$$

$$P_{e \text{ story}} = R_m \frac{HL}{\Delta_H} = 0.85 \frac{1.0(20(12))}{0.104} = 1,960 \text{ kips}$$

$$B_2 = \frac{1}{1 - \frac{\alpha P_{story}}{P_{e \text{ story}}}} = \frac{1}{1 - \frac{500}{1,960}} = 1.34 \geq 1$$

The influence of $P-\delta$ on $P-\Delta$ resulted in an increase in B_2 from 1.28 to 1.34, about 5%.



6.86

Example 1 (LRFD)

Determine the 2nd-order forces and moments for a 12.5 ft W14x120 beam-column in a moment frame when the results of a 1st-order elastic analysis yields:

$$P_{nt} = 408 \text{ kips}$$

$$P_{lt} = 98 \text{ kips}$$

$$M_{ntA} = 47.3 \text{ ft-kips}$$

$$M_{ntB} = 94.5 \text{ ft-kips}$$

$$M_{ltA} = 77.5 \text{ ft-kips}$$

$$M_{ltB} = 155 \text{ ft-kips}$$

$$\text{Load Case} = 1.2D + 0.5L + 1.0W$$



6.87

Example 1 (LRFD)

Determine the member effect amplification:

No translation, M_{nt}

$$C_m = 0.6 - 0.4(M_1/M_2)$$

$$C_m = 0.6 - 0.4(47.3/94.5) = 0.4$$



6.88

Example 1 (LRFD)

$$P_{e1} = \frac{\pi^2 EI^*}{L_{c1}^2}$$

$$P_{e1} = \frac{\pi^2 (29,000)(1,380)}{(1.0(12.5)(12))^2} = 17,600 \text{ kips}$$



6.89

Example 1 (LRFD)

$$B_1 = \frac{C_m}{1 - \frac{\alpha P_r}{P_{e1}}} \geq 1.0$$

$$B_1 = \frac{0.4}{1 - \frac{(408 + 98)}{17,600}} = 0.41 \not\geq 1.0 \therefore B_1 = 1.0$$



6.90

Example 1 (LRFD)

Determine the translation amplification factors

Translation, M_{lt} ,

Assume the frame deflection under a service wind load will be limited, in the final design, to

$$\Delta_H = L/400$$



6.91

Example 1 (LRFD)

For the entire frame at this story

$H = 150$ kips (service load to cause drift limit)

$P_{story} = 2,450$ kips (total LRFD gravity load)

thus,

if all load is on moment frame columns, $R_M = 0.85$,

$$P_{e\ story} = R_M \frac{HL}{\Delta_H} = 0.85(150)(400) = 51,000 \text{ kips}$$

This is a measure of the frame lateral buckling strength



6.92

Example 1 (LRFD)

- Sway amplification factor

$$B_2 = \frac{1}{1 - \frac{\alpha P_{story}}{P_{e story}}} \geq 1.0$$

$$B_2 = \frac{1}{1 - \frac{1.0(2,450)}{51,000}} = 1.05$$



6.93

Example 1 (LRFD)

Second-order force

$$P_r = P_{nt} + B_2 P_{lt}$$

$$P_u = (408) + 1.05(98) = 511 \text{ kips}$$

Second-order moment

$$M_r = B_1 M_{nt} + B_2 M_{lt}$$

$$M_u = 1.0(94.5) + 1.05(155) = 257 \text{ ft-kips}$$



6.94

Example 1 (ASD)

Determine the 2nd-order forces and moments for a 12.5 ft W14x120 beam-column in a moment frame when the results of a 1st-order elastic analysis yields:

$$P_{nt} = 378 \text{ kips}$$

$$P_{lt} = 46 \text{ kips}$$

$$M_{ntA} = 43.9 \text{ ft-kips}$$

$$M_{ntB} = 87.8 \text{ ft-kips}$$

$$M_{ltA} = 36.0 \text{ ft-kips}$$

$$M_{ltB} = 72.0 \text{ ft-kips}$$

$$\text{Load Case} = D + 0.75L + 0.75(0.6W)$$



6.95

Example 1 (ASD)

Determine the amplification factors for the no translation, M_{nt} , member effect;

$$C_m = 0.6 - 0.4(M_1/M_2)$$

$$C_m = 0.6 - 0.4(43.9/87.8) = 0.4$$



6.96

Example 1 (ASD)

$$P_{e1} = \frac{\pi^2 EI}{(L_{c1})^2}$$

$$P_{e1} = \frac{\pi^2 (29,000)(1,380)}{(1.0(12.5)(12))^2} = 17,600 \text{ kips}$$



6.97

Example 1 (ASD)

$$B_1 = \frac{C_m}{1 - \frac{\alpha P_r}{P_{e1}}} \geq 1.0$$

$$B_1 = \frac{0.4}{1 - \frac{1.6(378 + 46)}{17,600}} = 0.42 \not\geq 1.0 \therefore B_1 = 1.0$$



6.98

Example 1 (ASD)

Determine the amplification factors for translation, M_{lt} , the sway effect;

Assume the frame deflection under a service wind load will be limited, in the final design, to

$$\Delta_H = L/400$$



6.99

Example 1 (ASD)

For the entire frame at this story

$H = 150$ kips (service load to cause drift limit)

$P_{story} = 2,270$ kips (total ASD gravity load)

thus,

if all load is on moment frame columns, $R_M = 0.85$,

$$P_{e\ story} = R_M \frac{HL}{\Delta_H} = 0.85(150)(400) = 51,000 \text{ kips}$$

This is a measure of the frame lateral buckling strength



6.100

Example 1 (ASD)

- Sway amplification factor

$$B_2 = \frac{1}{1 - \frac{\alpha P_{story}}{P_{e story}}} \geq 1.0$$

$$= \frac{1}{1 - \frac{1.6(2,270)}{51,000}} = 1.08$$



6.101

Example 1 (ASD)

Second-order force

$$P_r = P_{nt} + B_2 P_{lt}$$

$$P_a = (378) + 1.08(46.0) = 428 \text{ kips}$$

Second-order moment

$$M_r = B_1 M_{nt} + B_2 M_{lt}$$

$$M_a = 1.0(87.8) + 1.08(72.0) = 166 \text{ ft-kips}$$



6.102

Second-Order Analysis for the Design Office

- Exact solutions
 - Limited to fairly simple problems/elements.
- Rigorous Analysis
 - Many methods implemented in the wide variety of software packages available.
- Amplified 1st-Order Analysis (Appendix 8)
 - Equally acceptable and advantageous in some applications.



6.103

Summary

- Looked at the basic requirements for design and analysis.
- Considered the impact of the general stability requirements.
- Investigated two approaches to account for geometric imperfections.
- Addressed rigorous approaches for second-order analysis.
- Derived an approximate second-order analysis approach.
- Recommended approaches for the design office.



6.104

Lesson 7

- The next lesson will discuss the effective length method of design.
- It will also address the direct analysis method of design
- We will continue to work with Chapter C and will also look at Appendix 7.



6.105

Lesson 7

- The next lesson will discuss the effective length method of design.
- It will also address the direct analysis method of design
- You might want to look at the paper:

Carter, C. and Geschwindner, L., "A Comparison of Frame Stability Analysis Methods in ANSI/AISC 360-05," AISC Engineering Journal, 3rd Quarter, 2008, Vol. 45, No. 3, pp.159-170.



6.106



Thank You

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Chicago, IL 60601



6.107

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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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8-Session Registrants

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Reasons for quiz

- EEU – You must take all quizzes and the final exam to receive EEU.
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- REINFORCEMENT – Reinforce what you learn tonight. Get more out of the course.



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