software and solutions
for structural engineers

THE DIRECT ANALYSIS METHOD MADE SIMPLE

Matthew Newton – President
Jason Ericksen, SE – Technical Manager

CSC Inc

Before We Start

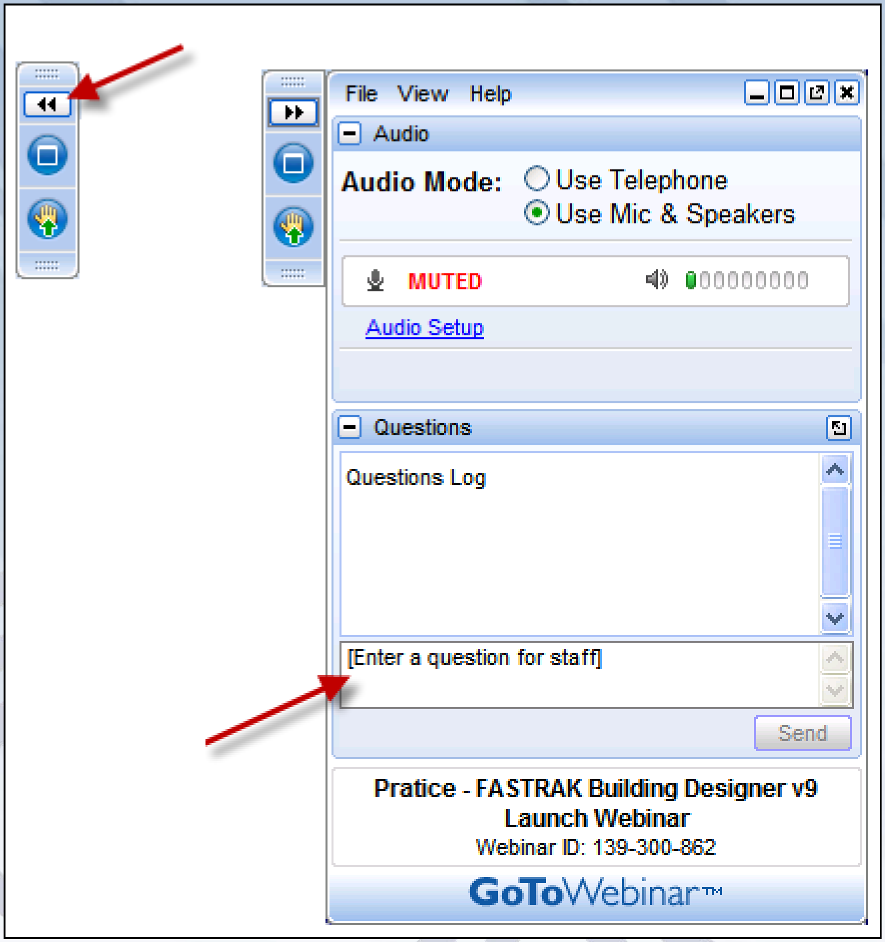
- Maximize Screen
- Screen saver
  - Black screen

Before We Start

- Posing Questions
- Listen to Audio:
  - Use speakers

  or

  - Use telephone



CSC ▶ Fastrak™

- Certificate administration
  - This Webinar provides 1.0 PDH (0.1 CEU)
  - Provide details at the end
- Shared Q&A
  - Distributed following the event
- Free Composite Beam Software for each attendee
  - Provide details at the end
- Website
  http://www.cscworld.com/fastrak/us/
- Contact
  Matthew.newton@cscworld.com
  Tel: 877 710 2053

software and solutions
for structural engineers

THE DIRECT ANALYSIS METHOD MADE SIMPLE

Matthew Newton – President
Jason Ericksen, SE – Technical Manager

CSC Inc

Corporate Info

- Established in 1975
- Structural Engineering Software
- Successful, Focussed Business
- 6,000 customers
- 60+ employees
- Lead Products
  - TEDDS
    - Hand Calculations in MS Word
  - FASTRAK Building Designer…

Worldwide Customers

- Whitby Bird & Partners
- Hyder Consulting
- Beca
- P & T GROUP Architects & Engineers
- BONACCI GROUP
- White Young Green
- URS
- Halcrow
- ATKINS
- BAA
- BHPSTEEL
- Scott Wilson
- Buro Happold
- Waterman Group
- JE JACOBS
- FOSTER WHEELER
- BECHTEL
- Mott MacDonald
- FABER MAUNSELL
- BOUYGUES CONSTRUCTION
- Mouchel
- corus
- PB
- ARUP
- SKM
- BLACK & VEATCH
- KAJIMA
- GHD
- SKIDMORE, OWINGS & MERRILL LLP
- MEINHARDT

Corporate Information

- Global
  - CSC offices in UK, Malaysia, Singapore, Australia and USA
  - Partner network
  - US support office in Chicago
- Reputation for quality
- Technical presentations common
  - Chief Engineer presents regularly
  - Jason Ericksen (former-AISC) contributes to AISC technical committees

THE DIRECT ANALYSIS METHOD MADE SIMPLE

Matthew Newton – President
Jason Ericksen, SE – Technical Manager

CSC Inc

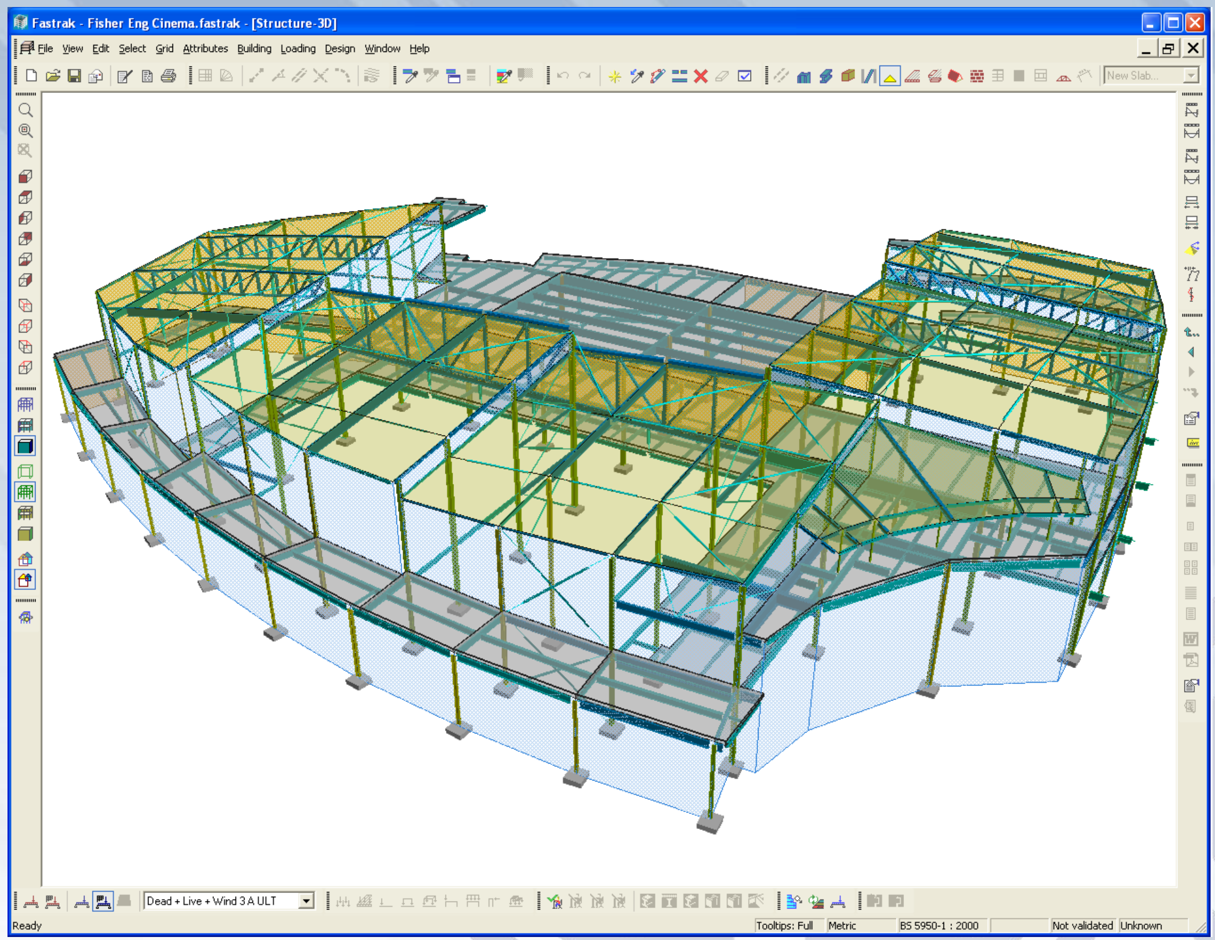
software and solutions for structural engineers

www.cscworld.com

Why are we here today?

- AISC has made significant changes
- Initial imperfections, inelasticity, 2^{nd} Order Analysis
- Direct Analysis Method (DAM)

Why are we here today?



Model courtesy of Fisher Engineering

What does the DAM mean to you?

- Straight-forward Analysis and Design
- Improved Results
- Less potential for error
- K=1.0

2005 AISC Specification

- Brings ASD and LRFD together
  - Same nominal strength, R_n
  - Little change to LRFD
  - ASD reformatted substantially
  - No significant change to limit states

2005 AISC Specification

- Updates Stability Design Requirements
  - New requirements for analysis
  - Recognizes current analysis options
  - Addresses shortcomings of previous methods (K = ?)
  - Provides straight-forward methods

Seminar Topics

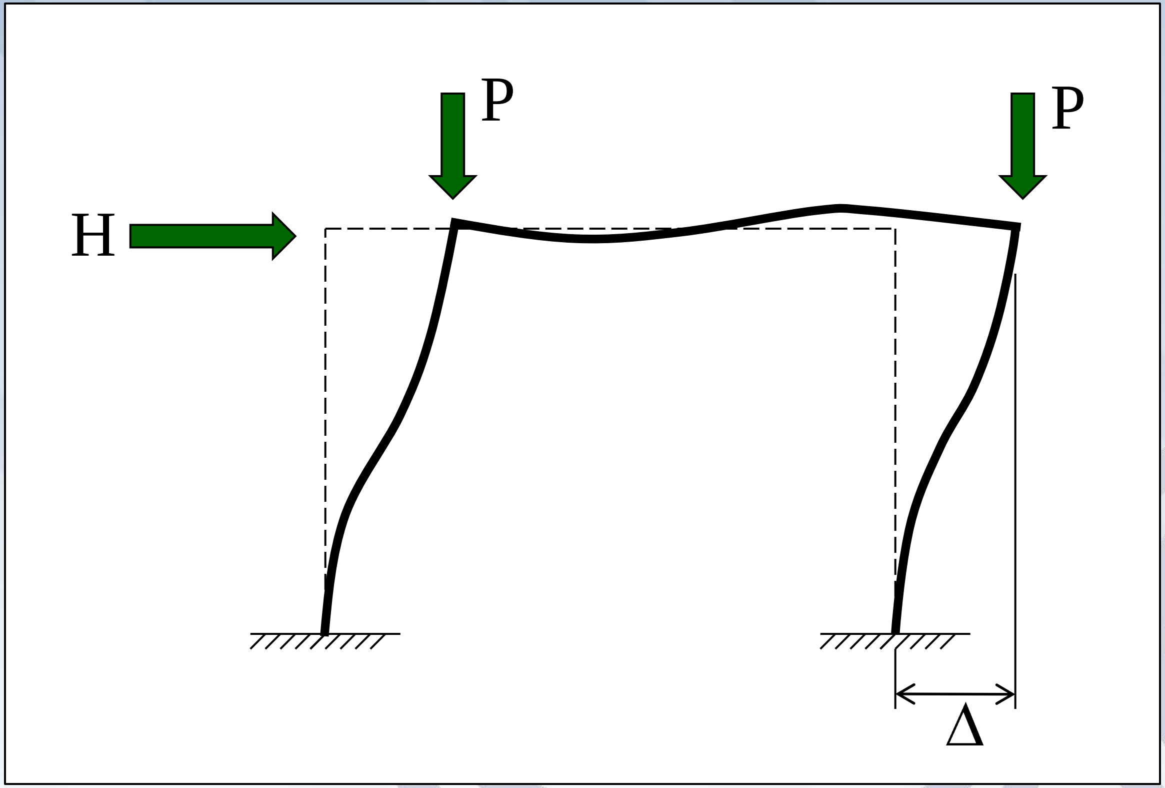
- Real world effects in steel buildings
- Previous methods
- 2005 AISC Requirements
- Stability Analysis and Design with Modern Software
- DAM using FASTRAK Building Designer

Real World Effects

- P- Delta Effects
- Initial Geometric Imperfections
- Reduced member stiffness due to inelasticity

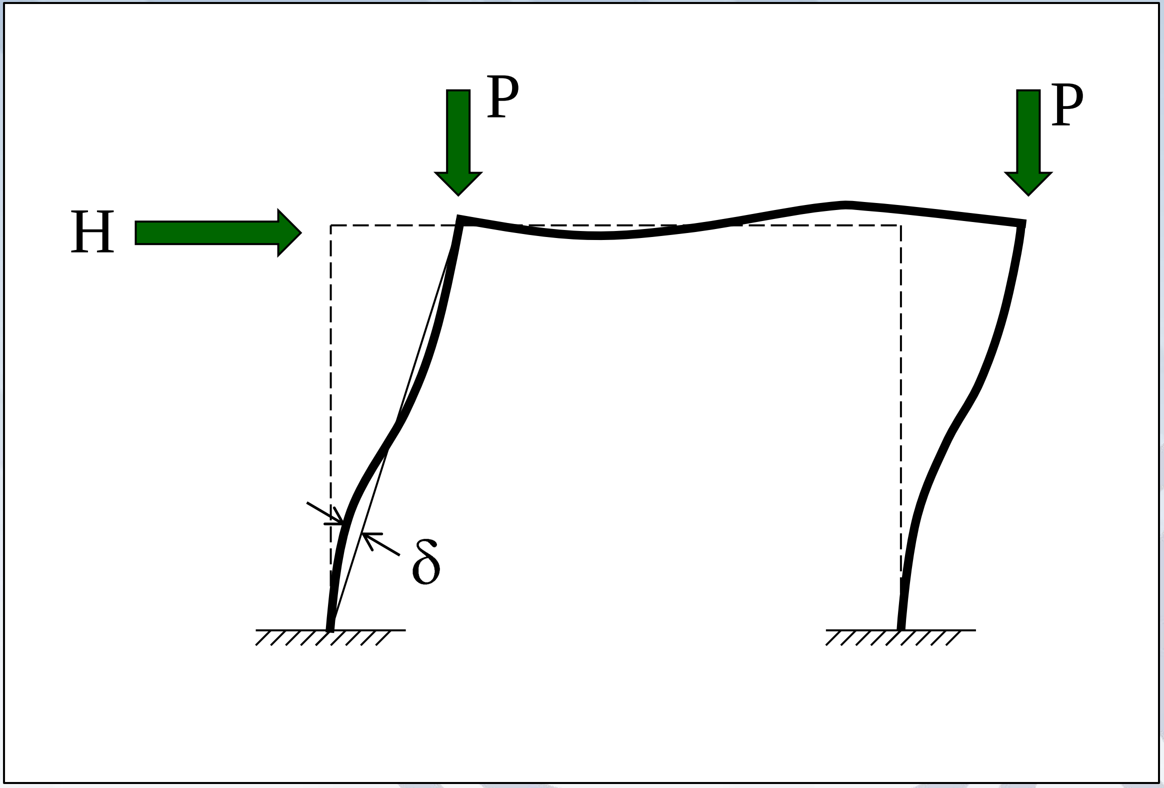
Real World Effects

- P- Delta Effects
  - P-Δ (Structure Effect)



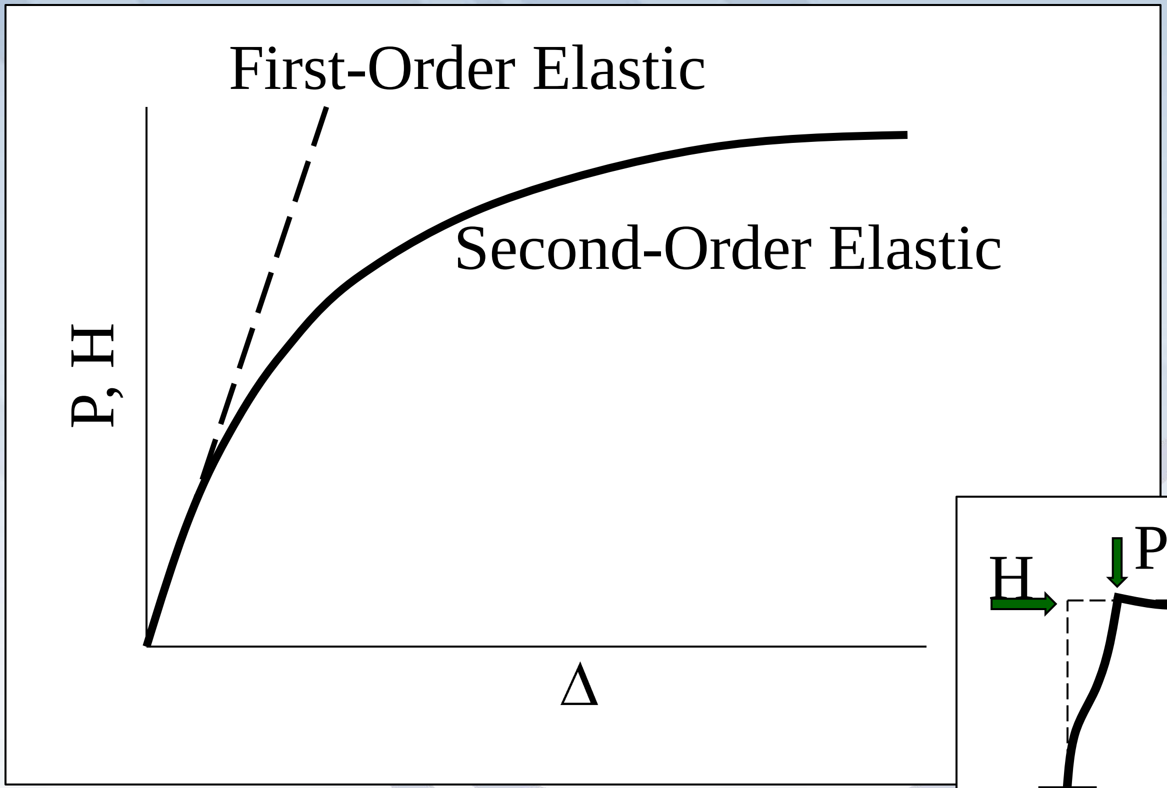
Real World Effects

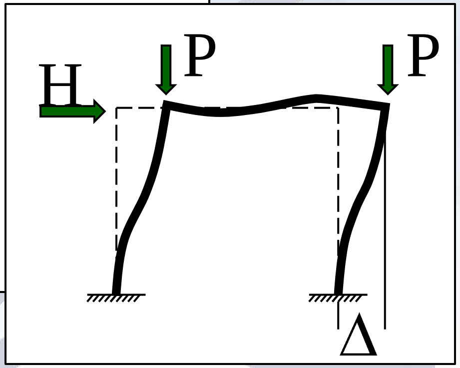
- P- Delta Effects
  - P-δ (Member Effect)



Real World Effects

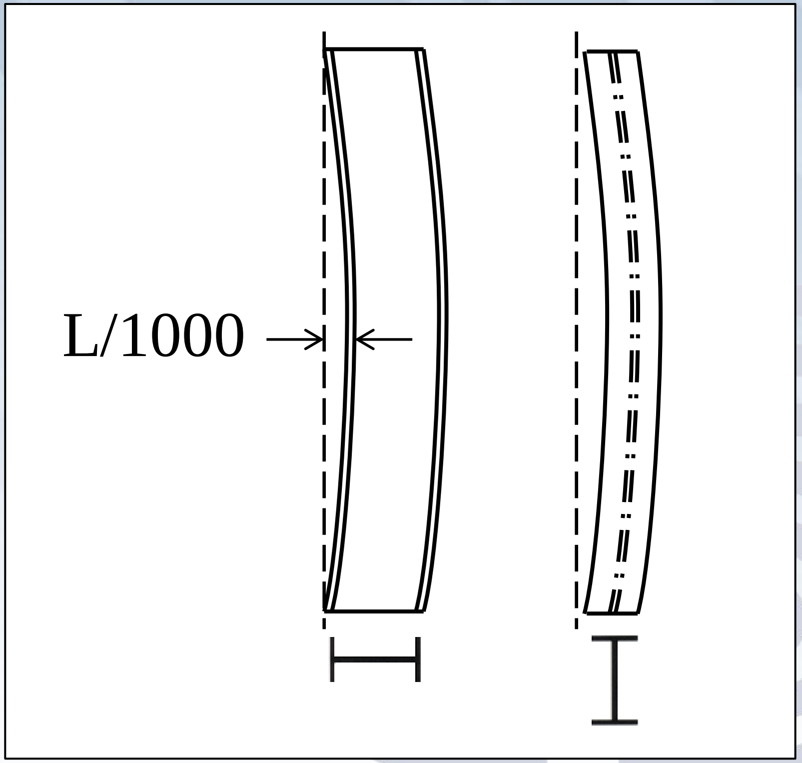
- P- Delta Effects
  - Nonlinear Response





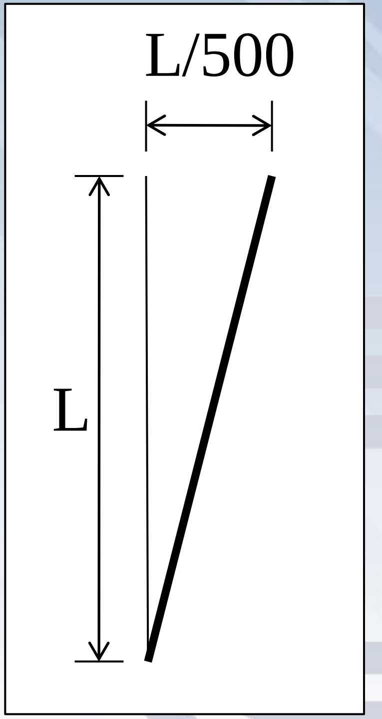
Real World Effects

- Initial Geometric Imperfections
  - Out-of-straightness
  - Tolerance from ASTM A6



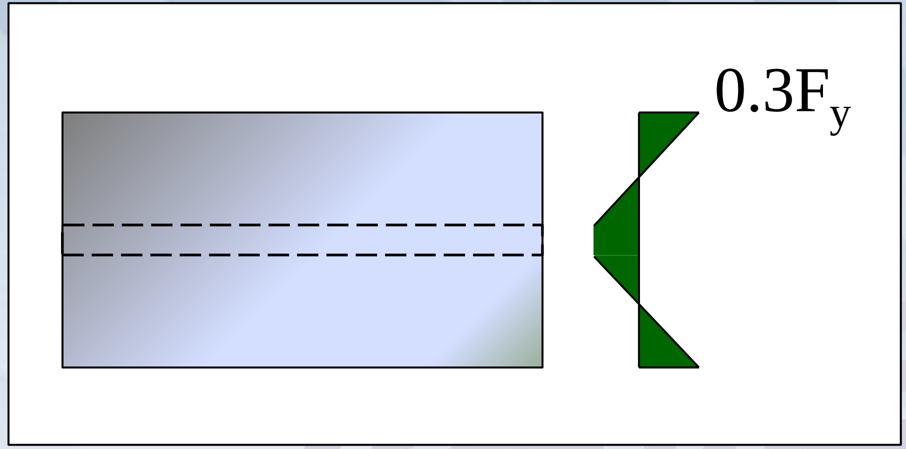
Real World Effects

- Initial Geometric Imperfections
  - Out-of-plumbness
    - AISC Code of Standard Practice



Real World Effects

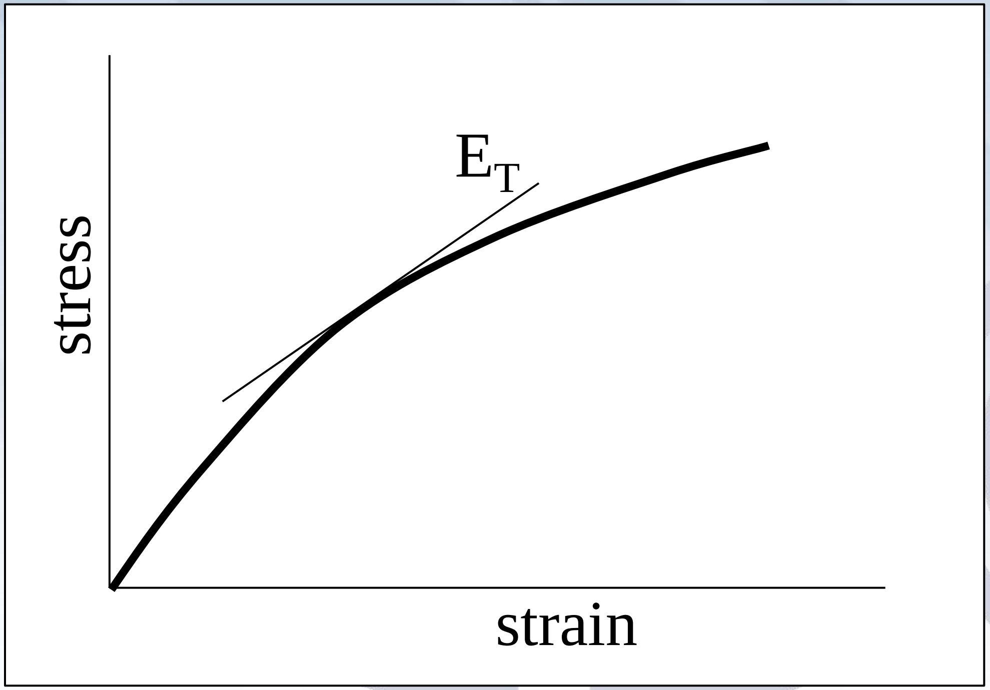
- Reduced member stiffness due to inelasticity
  - Residual Stresses from rolling process



  - 'Early' yielding when applied loads results in 0.7 F_y

Real World Effects

- Reduced member stiffness due to inelasticity
  - Overall stiffness of the section is reduced (tangent modulus)



Seminar Topics

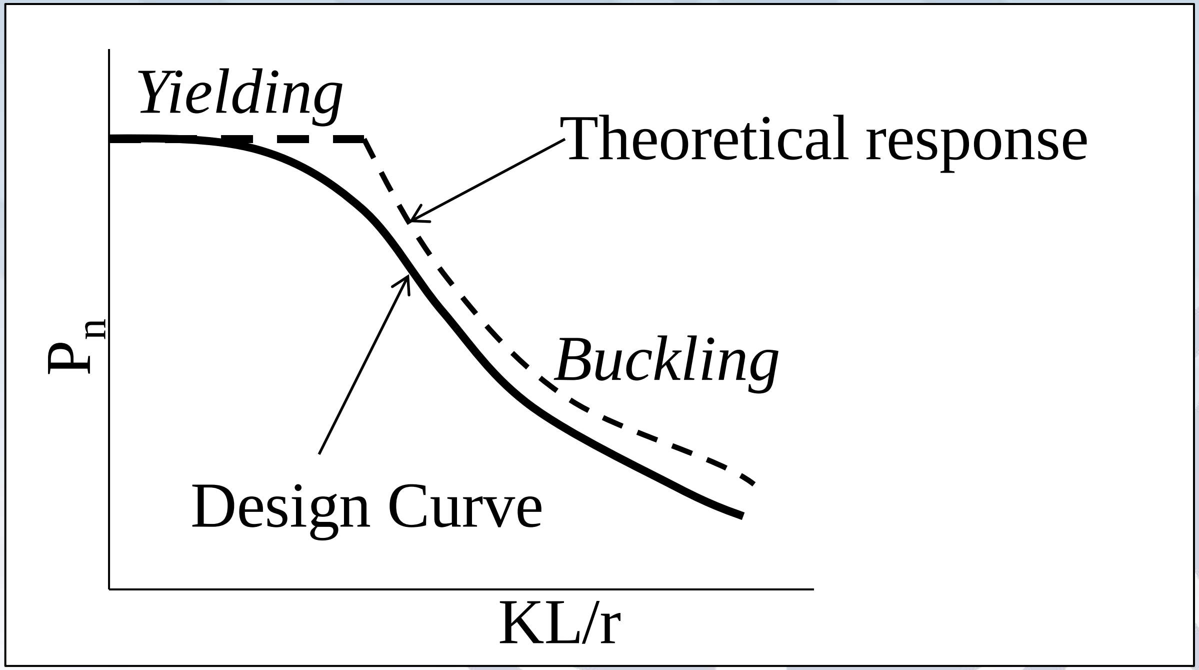
- Real world effects in steel buildings
- Previous methods
- 2005 AISC Requirements
- Stability Analysis and Design with Modern Software
- Example using Fastrak Building Designer

Before 2005

- Analysis Requirements (Demand)
  - 2^{nd} Order Analysis was required!
    - B_1, B_2 method been in Specification since 1^{st} LRFD in 1986
    - Required in 1989 ASD
  - Effect of initial imperfections not considered
  - Effect of inelasticity not considered

Before 2005

- Design Requirements (Capacity)
  - Accounts for inelasticity
  - Accounts for initial imperfections



Before 2005

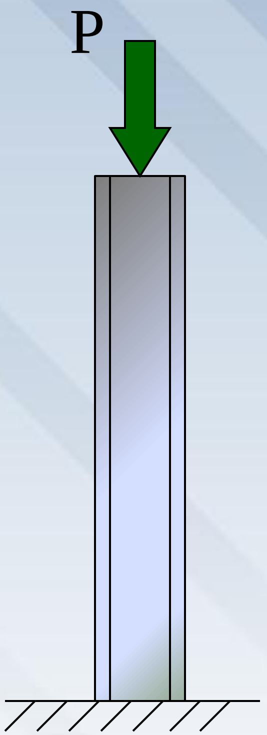
- Design Requirements (Capacity)
  - Effective Length Factor, K
    - Used to compensate for neglecting effects in the analysis
    - Relates the analysis and design method to ‘actual’ buckling behavior

Before 2005

- Does K compensate?
  - Likely will give adequate columns size
  - Underestimates moments in surrounding members/elements
  - Underestimates displacements at strength level, including effect on stability

Before 2005

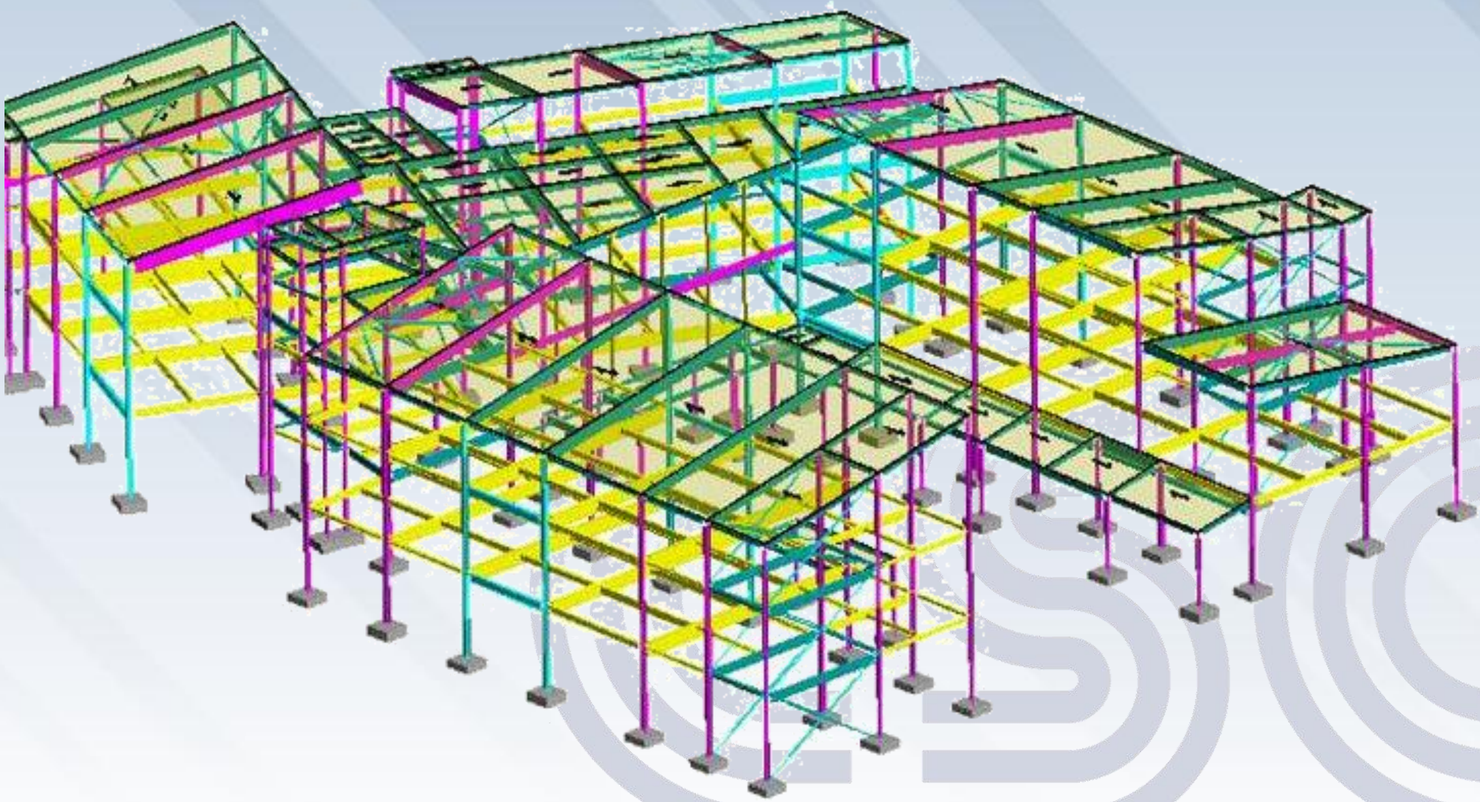
- Does K compensate? – Example



  - Even with 2nd Order analysis, base moment = 0 k*ft
  - K = 2.1 compensates for column design
  - Base plate (or other supporting elements) will have understated moments

Before 2005

- Modern Buildings: Stability Analysis more critical



Before 2005

- Modern Buildings: Stability Analysis more critical
  - Higher Strength Steel
  - More complex geometry
  - Less often have substantial walls
  - Less redundancy
  - Longer spans
  - Frames are working harder!

Before 2005

- Other problems with K
  - Tedious to calculate
  - Difficult to calculate correctly
    - Alignment charts based on 9 assumptions that are rarely met in real structures
    - Behavior is purely elastic
    - Rotations at opposite ends of restraining beams are equal producing reverse curvature
    - All columns buckle at the same time
      - Leaning columns violates this assumption

Before 2005

- Other problems with K
  - Can be overly conservative
  - If not all effects are considered, can be unconservative

Seminar Topics

- Real world effects in steel buildings
- Previous methods
- 2005 AISC Requirements
- Stability Analysis and Design with Modern Software
- DAM using FASTRAK Building Designer

What does the 2005 AISC Specification/DAM mean to you?

- **K=1.0**
- Straight-forward Analysis and Design
  - Real world effects accounted for
- When combined with modern software
  - Improved Results
  - Less potential for error

2005 AISC Specification

- AISC 360-05 (2005 Specification) Chapter C
  - C1. Stability Design Requirements
  - C2. Calculation of Required Strength

2005 AISC Specification

- C1.1 Stability Design Requirements
  - Any method that considers the influence of the following on the stability of the structure and its elements is permitted.
    - Second-order effects (P-Δ and P-δ)
    - Flexural, shear and axial deformations
    - Geometric imperfections
    - Member stiffness reduction due to inelastic behavior (inelasticity)

2005 AISC Specification

- Second-Order effects
  - Any analysis that considers both P-Δ and P-δ is allowed
    - Direct (rigorous) analysis
    - Amplified first-order analysis (B_1,B_2 method)
- Flexural, Axial and Shear deformation
  - Included in most analysis software
- Geometric imperfections and inelasticity
  - Any rational method or those presented in C2.

2005 AISC Specification

- What is really NEW?
  - Second-Order analysis
    - Not new, but more specific
  - Initial out-of-plumbness
  - Inelastic behavior (including Residual stress)
    - Only the influence on the stability of the structure

2005 AISC Specification

- C2.2 Design Requirements
  - Second-order analysis (C2.2a)
    - **Limited application**
    - Effective Length Method (uses K>1.0)
  - First-order analysis (C2.2b)
    - **Limited application**
    - Simplest approach
  - Direct Analysis Method (Appendix 7)
    - **Applies to all buildings**
    - Preferred method

Design Methods

- Design by Second-Order Analysis: Effective Length Method
  - Applies when $\Delta_{2nd\text{-}order}/\Delta_{1st\text{-}order} \leq 1.5$
  - Notional Loads, $N_i = 0.002Y_i$ (gravity load combinations)
  - Second-Order Analysis
    - Nominal Geometry
    - Nominal Stiffness
  - K from a sidesway buckling analysis
    - $\Delta_{2nd\text{-}order}/\Delta_{1st\text{-}order} \leq 1.1$ then K=1.0

Design Methods

- Design by First-Order Analysis
  - Applies when $\Delta_{2nd\text{-}order}/\Delta_{1st\text{-}order} \leq 1.5$ and $\alpha P_r \leq 0.5P_y$ for all lateral members
  - Notional Loads
    - $N_i = 2.1(\Delta_{1st\text{-}order}/L)Y_i \geq 0.0042Y_i$
  - First-Order Analysis on Nominal Geometry using Nominal Stiffness
  - Apply B_1 to total member moments
  - Use K=1.0

Design Methods

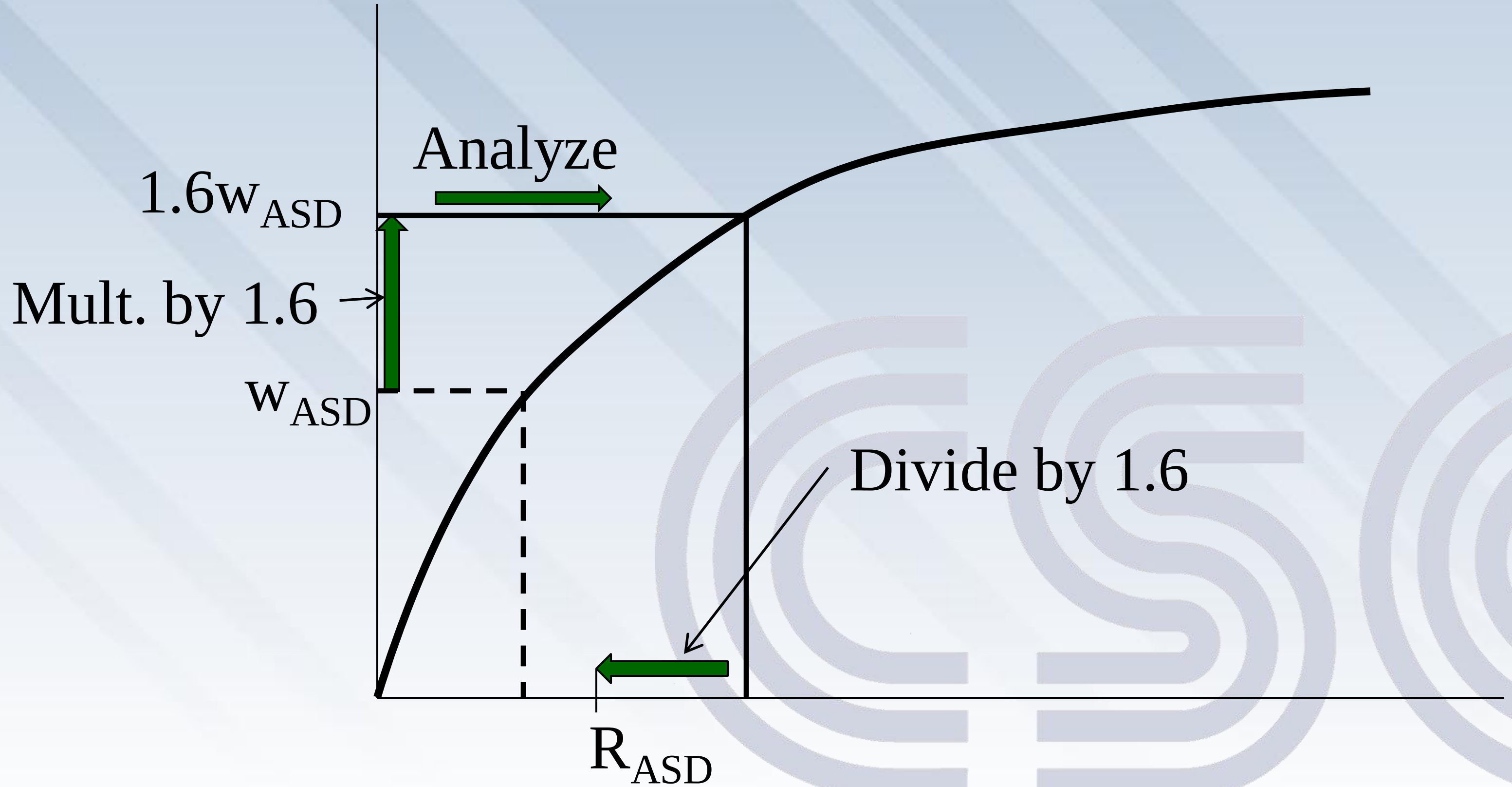
- Direct Analysis Method
  - **Applies to all structures**
  - Required when $\Delta_{2nd\text{-}order}/\Delta_{1st\text{-}order} > 1.5$
  - K = 1.0
  - Applies to all lateral systems or combination of systems w/o distinction
  - Most accurate determination of internal forces when combined with rigorous second-order analysis

Direct Analysis Method

- Second Order Analysis
  - Consider both P-Δ and P-δ
    - Any general second-order analysis
    - Amplified first-order analysis (B_1,B_2 method)
  - ASD
    - Carried out under 1.6 times ASD load combination
    - Results divided by 1.6 to obtain required strengths

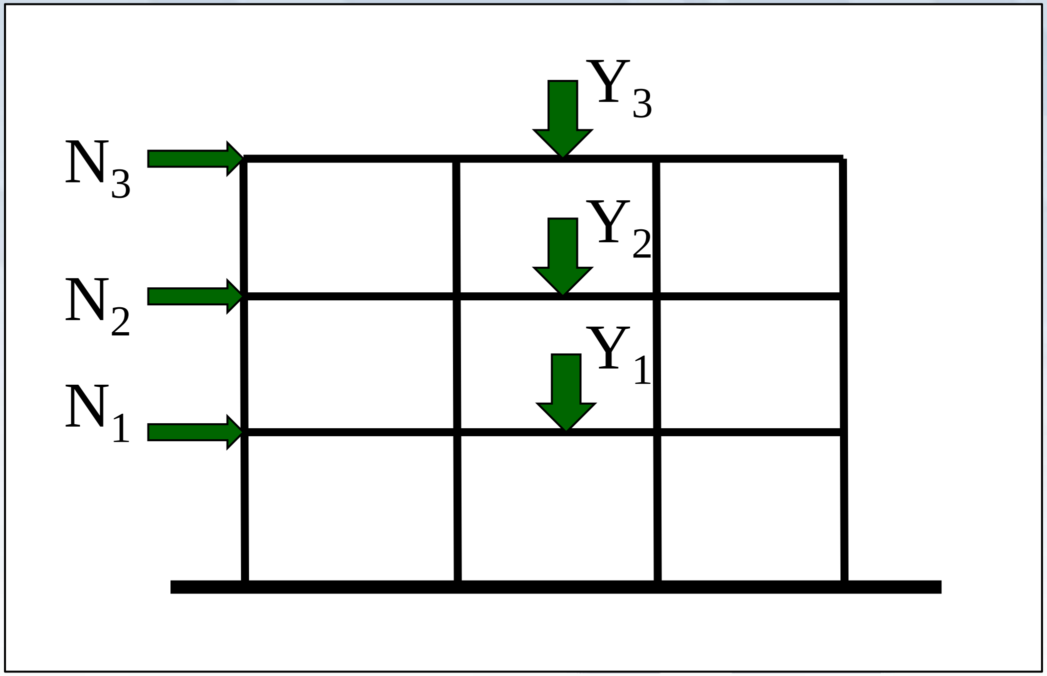
Direct Analysis Method

- Second Order Analysis - ASD



Direct Analysis Method

- Initial imperfections
  - Notional Loads at each level
  - $N_i = 0.002Y_i$
  - Y_i = total gravity load on a level



Direct Analysis Method

- Initial imperfections
  - Notional Loads at each level
  - $N_i = 0.002Y_i$
  - Y_i = total gravity load on a level
  - Correlates to maximum initial out-of-plumbness allowed for columns in COSP of 1/500
    - Smaller value can be used if out-of-plumbness is known

Direct Analysis Method

- Notional Loads
  - Applied to all load combinations
  - If $\Delta_{2nd\text{-}order}/\Delta_{1st\text{-}order}$ < 1.5 they can be treated as a minimum (gravity load combos only)

Direct Analysis Method

- Stiffness Reductions (Inelasticity)
  - Axial Stiffness
    - $EA^* = 0.8\ EA$
  - Flexural Stiffness
    - $EI^* = 0.8\tau_b EI$
    - $\tau_b \leq 1.0$
  - Ultimately this allows for K=1.0

Direct Analysis Method

- Stiffness Reductions
  - τ_b depends on the axial stress
    - for $\alpha P_r \le 0.5P_y$
      - $\tau_b = 1.0$
    - for $\alpha P_r > 0.5P_y$
      - $\tau_b = 4(\alpha P_r/P_y*(1-\alpha P_r/P_y))$
      - $\alpha = 1.0$ (LRFD), $\alpha = 1.6$ (ASD)
  - $\tau_b = 1.0$ may be used for all members provided an additive notional load of $0.001Y_i$ is applied

Direct Analysis Method

- Member design
  - Design all individual members using the provisions in Chapters E, F, G, H and I
  - **K=1.0** For compression design

Direct Analysis Method

- Procedure Summary
  - Model the structure (no change)
  - Apply Notional Loads
  - Perform second-order analysis on nominal geometry with reduced stiffness
  - Design all members for resulting forces
  - Design compression members with **K=1.0**

2005 AISC Specification

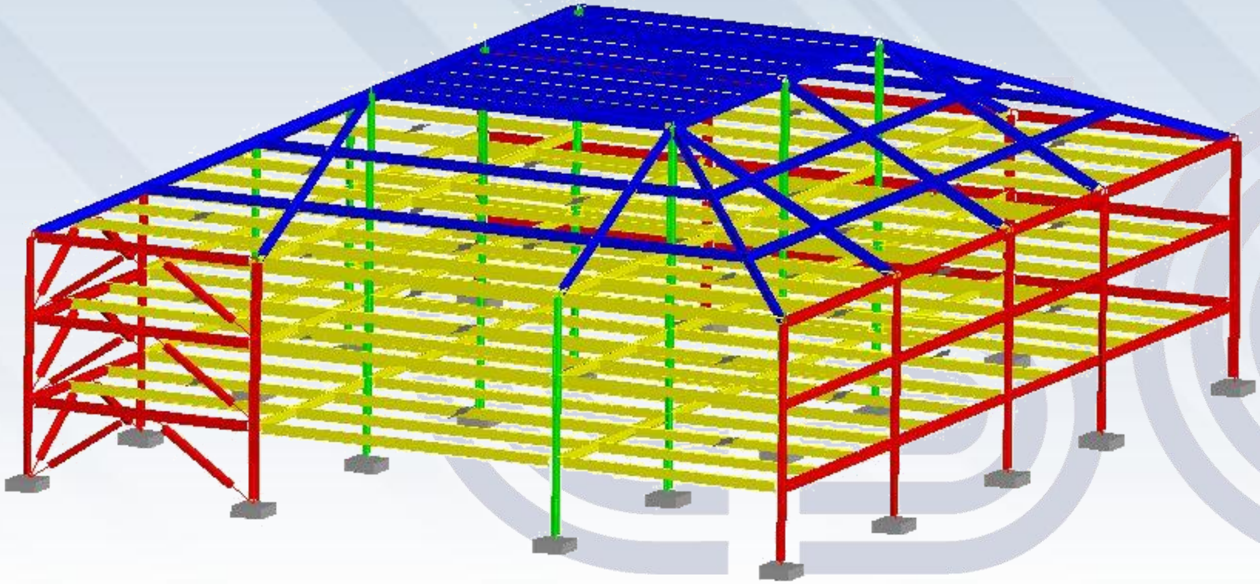
- AISC has clarified requirements for stability analysis and design
- DAM applies to all buildings
- DAM is most general and accurate approach
- When combined with modern software and structural analysis the DAM is straight-forward and eliminates problems with previous methods

Seminar Topics

- Real world effects in steel buildings
- Previous methods
- 2005 AISC Requirements
- Stability Analysis and Design with Modern Software
- DAM using FASTRAK Building Designer

Modern Software

- Buildings have changed over the years
  - Frame is working harder (less redundancy)
  - Less substantial permanent walls
  - Architecture creates irregular lateral framing (differing systems)



Modern Software

- Sophisticated structural analysis tools are readily available
  - Rigorous second-order analysis is practical in the average engineering office
  - Hand methods (such as B_1, B_2 method) can be replaced with more accurate analyses

Modern Software

- Stability analysis is more critical in modern buildings
- Rigorous Second-Order analysis is practical
- DAM was developed in recognition of these issues
  - requirements easily automated

Modern Software

- Second-Order Analysis
  - General second-order analysis that considers both P-Δ and P-δ effects
  - Amplified first-order analysis (B_1, B_2)

Modern Software

- Limitations of Amplified First-Order Analysis (AISC Commentary)
  - AISC does not recommend when $\Delta_{2nd\text{-}order}/\Delta_{1st\text{-}order} > 1.2$
  - Difficult to distribute moments where several members join
  - Complex geometry cause difficulties
    - Sloping beams and columns
    - Floor levels not readily identifiable

Modern Software

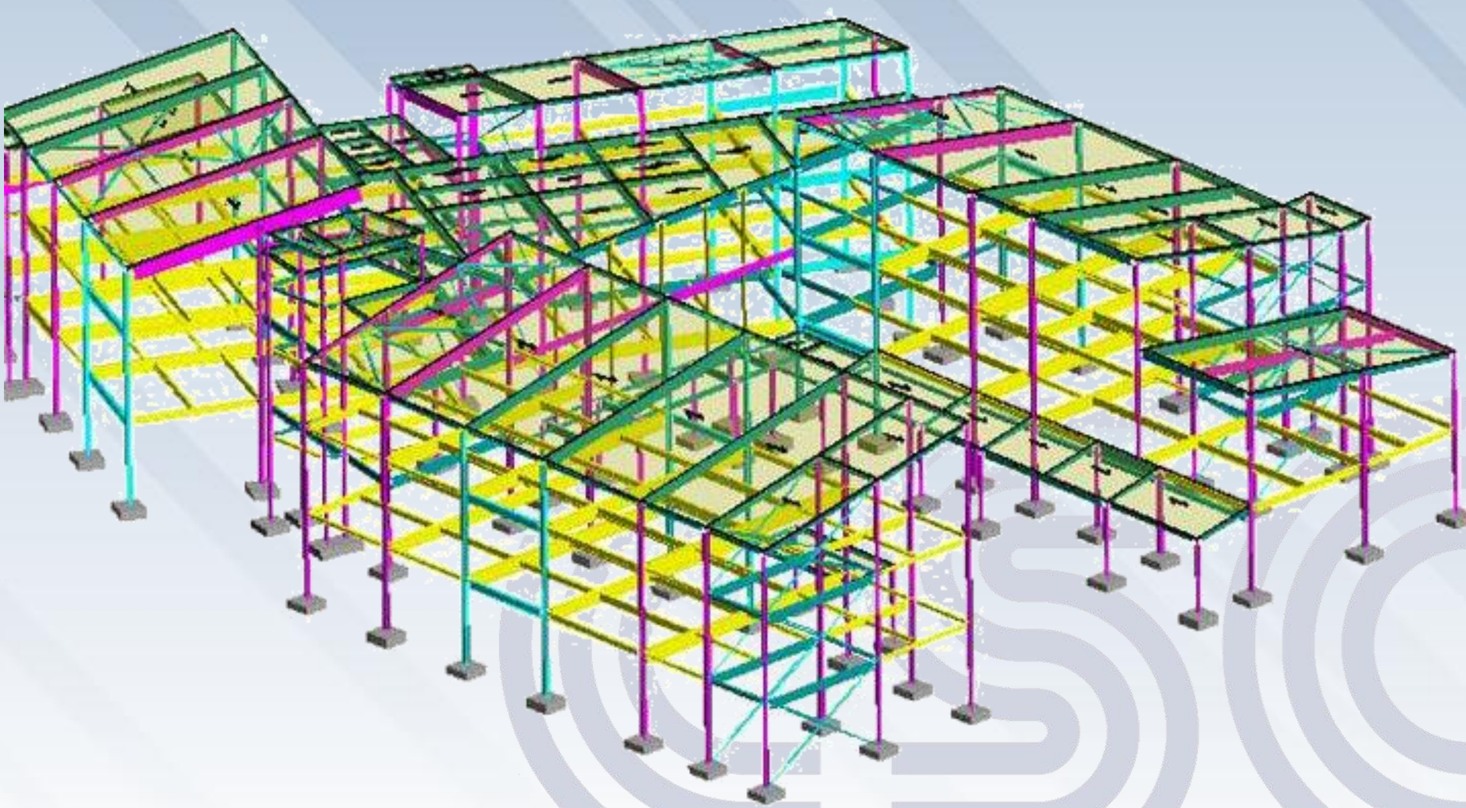
- Limitations of Amplified First-Order Analysis
  - Have to separate translation and no-translation moments
  - Engineering judgment often required (can't be automated!)
    - Distribution of moments where B_2 factors vary at a joint

Modern Software

- General Second-Order Analysis
  - Free of limitations of amplified first-order method
  - More accurate determination of internal forces and strength level deformations
    - Complex geometry
    - irregular lateral framing
  - Structure Analyzed for Load Combinations
    - ASD with a 1.6 factor
  - Stable model required

Modern Software

- Representative Project
  - B_1 = ?; B_2 = ?



Seminar Topics

- Real world effects in steel buildings
- Previous methods
- 2005 AISC Requirements
- Stability Analysis and Design with Modern Software
- DAM using FASTRAK Building Designer

FASTRAK Building Designer

- Fastrak Building Designer is design modeling software focusing on the analysis and design of structural steel buildings
- Example implementation of Stability and Analysis requirements

FASTRAK Building Designer

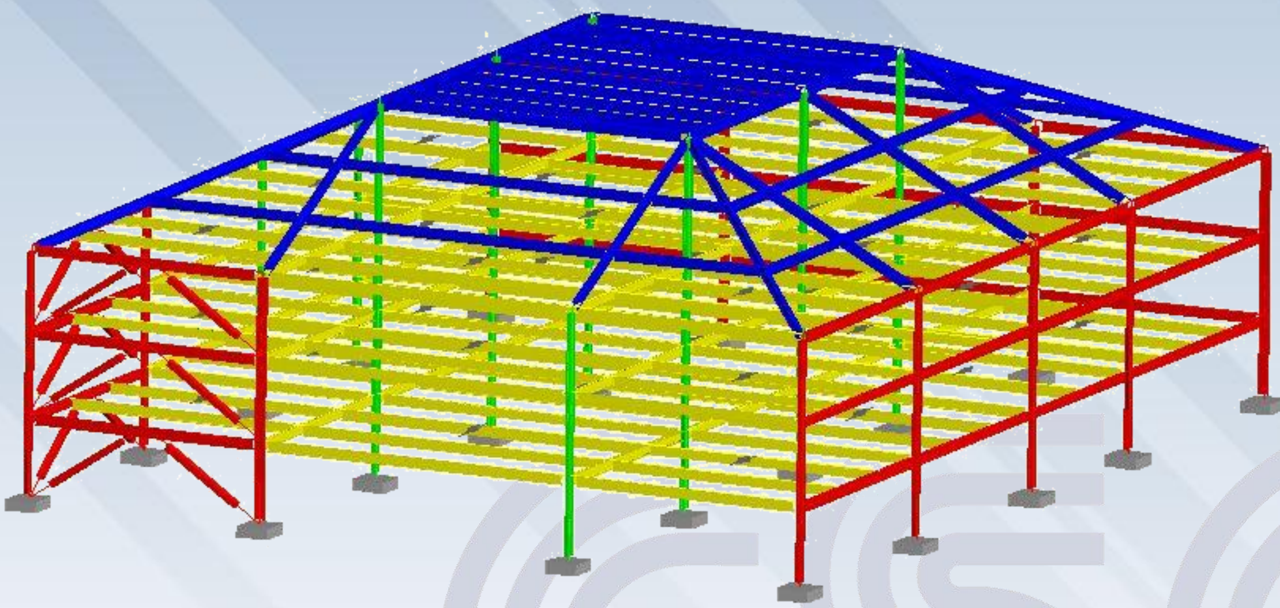
- Stability Analysis and Design in Fastrak
  - Direct Analysis Method Applied
  - Rigorous Second-Order Analysis Performed
  - Member stiffness reductions applied automatically (τ_b = 1.0)
  - Notional Loads applied automatically
    - $N_i = 0.003Y_i$

FASTRAK Building Designer

AISC Requirements	FASTRAK
Flexural, shear, and axial deformations	✓
All component and connection deformation	✓
Second-order effects (both P-Δ and P-δ)	✓
Geometric imperfections	✓
Member stiffness reductions due to inelasticity	✓

FASTRAK Building Designer

EXAMPLE IMPLEMENTATION



CSC Fastrak™

FASTRAK Building Designer

- When using FASTRAK, how does all this affect your design practice?
  - Very little!
  - FASTRAK does all the work
    - A Rigorous Second-Order analysis performed automatically
    - Initial out-of-plumbness considered automatically with notional loads
    - Inelastic behavior considered automatically with stiffness reductions (and notional loads)

FASTRAK Building Designer

- When using FASTRAK, how does all this affect your design practice?
  - Understanding is key
    - AISC Requirements
    - Details of DAM implementation
    - Effects of second-order analysis on modeling and results
  - Tools provided to help create stable analysis model

FASTRAK Building Designer

- When using FASTRAK, how does all this affect your design practice?
  - More accurate results and more efficient designs on a wider range of building structures
  - No need to assess whether the building is suitable for DAM
  - K=1.0

2010 AISC

- The next AISC specification comes out in 2010
- DAM will be default method in body of code
- CSC will summarize the changes to Stability Analysis and the Direct Analysis Method in an upcoming webinar

Contact Info

- Jason Ericksen – Technical Manager
- **jason.ericksen@cscworld.com**
- Contact me for
  - Link to download State of the Industry paper on Stability Analysis from CSC
  - Questions on today's material

CSC Fastrak™

- Q&A
- Certificates within 1-week
- Free Composite Beam Software
  - http://www.cscworld.com/fastrak/us/composite_download.html
- Direct Analysis Paper
- Survey
- Website
  http://www.cscworld.com/fastrak/us/
- Contact
  Matthew.newton@cscworld.com
  Tel: 877 710 2053