Direct Analysis Method in Robot Structural Analysis Professional

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Firm profile | Souza True & Partners

Structural Consulting Firm Established in 1959

- Waltham, MA
- Single discipline – structural
- Small business – 17 people
- Clients – architects, owners, and
- Primary focus is building design:
  - Health Care
  - Research
  - Academic
  - Commercial
  - Residential
  - Laboratory
  - Museums
  - Historic
  - Parking
  - Commercial
- Typical services:
  - Analysis & Design
  - CA
  - Feasibility
  - Evaluations
  - Peer reviews
  - Expert witnesses

Health Care International Glasgow, Scotland

Reggie Lewis Track and Athletic Center Boston, MA

Cape Cod Hospital Hyannis, MA

Genetics Resource Building, The Jackson Laboratory Bar Harbor, ME

Tubman African American Museum Macon, GA

Firm profile | Involvement with Autodesk

- Consulting with Autodesk last 1.5 years
  - Goal – make RSA more appealing to US market
    - Review features, workflows, etc.
    - Compare to other software
  - Assist with new features
    - Code interpretation and verification – no coding by STP
  - Sample of subjects covered:
    - Direct Analysis Method in Robot Structural Analysis Professional published by Autodesk
    - Wind simulation in RSA
    - And more…

Firm profile | Lin's Involvement with Autodesk

- My involvement
  - Collaborate with RSA team
    - Practicing engineers perspective
    - Workflows
    - Code interpretations – no coding
  - White papers
    - Direct Analysis Method in Robot Structural Analysis Professional published by Autodesk
    - Wind Simulation in Robot Structural Analysis Professional published by Autodesk

Class summary

- This class will review AISC's Direct Analysis Method (DAM) and how it is implemented in Robot Structural Analysis Professional 2015 (RSA). We'll cover the requirements of the DAM, examine it's benefits, and the challenges of applying it in engineering software. We'll explore analysis examples to conduct an in-depth examination of the DAM workflow in RSA. This class will illustrate the benefits of the DAM and the benefits of RSA's unique implementation.

Key learning objectives

At the end of this class, you will be able to:

- Possess a deeper understanding of the DAM and its implementation in design software
- Understand the DAM approach and options in RSA
- Learn how to analyze a structure using the DAM in RSA and review the analysis results
- Learn how to integrate the RSA DAM into a design workflow

AISC stability design

AISC stability design | Why?

- Instability
  - Slight geometric displacements
  - Destabilizing effects amplify demand

- AISC 360-05 and 360-10:
  - Introduction of stability analysis requirements

AISC stability design | Three AISC approaches

- Three approaches in AISC 360-05 and 360-10:
  - Effective Length Method (ELM)
  - First-order Method (FOM)
  - Direct Analysis Method (DAM)
    - AISC's preferred approach in AISC 360-10

AISC stability design | General requirements

- Any analysis that meets the above requirements is permitted
- Stability analysis general requirements:
  - Deformations – shear, axial, bending, etc.
  - 2nd order effects - P-Δ effects and P-δ effects
  - Geometric imperfections
  - Inelasticity
  - Uncertainty in stiffness and strength

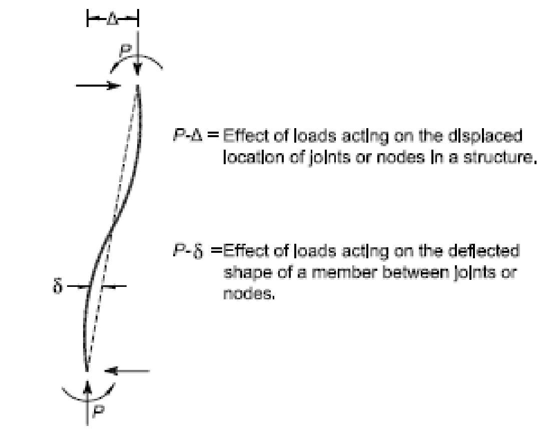


Fig. C-C2.1. P-Δ and P-δ effects in beam-columns.

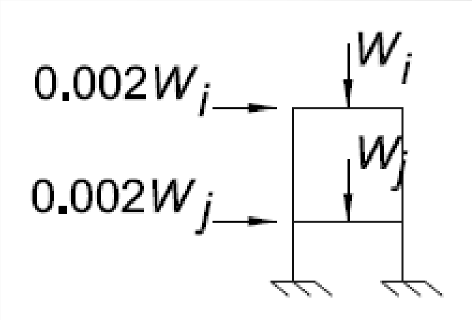
AISC stability design | DAM

- DAM
  - No limitations
  - Stability requirements:
  - 2^{nd} order effects
    - Rigorous or approximate (Appendix 8) second-order analysis.
    - P-δ effects on the <u>overall structure</u> may be ignored if:
      - $\Delta_{2nd\ order} / \Delta_{1st\ order} \leq 1.7$ (both values determined using reduced stiffness and LRFD combos)
      - < 1/3 of the total gravity load is supported by columns that are part of moment-resisting frames

AISC stability design | DAM

- Geometric/initial imperfections
  - Direct modeling – not typically practical
  - Notional loads:

$$N_i = 0.002\alpha Yi$$



where
N*i* = notional load applied at level *i*, (kips)
α = 1.0 (LRFD) or 1.6 (ASD)
Y*i* = total gravity load applied at level *i* (kips)

  - If $\Delta_{2nd\ order} / \Delta_{1st\ order} \leq 1.7$ (reduced stiffnesses and LRFD combos) notional loads need only be applied to gravity load only combinations

AISC stability design | DAM

- Inelasticity and Uncertainty
- Adjustments to stiffness
  - 0.80 applied to all stiffness types (EI and EA)
  - When $\alpha P_r \leq 0.5 P_y$, an additional factor must be applied to flexural stiffness (EI) for all members:

$$\tau_b = 4\left(\alpha P_r/P_y\right)[1 - (\alpha P_r/P_y)]$$

where
α = 1.0 (LRFD) or 1.6 (ASD)
P_r = required axial compression
$P_y = F_y A_g$, the axial yield strength

AISC stability design | DAM

- Inelasticity and Uncertainty (cont.)
  - Alternatively, τb can be set to 1.0 if an additional notional load of $0.001\alpha Yi$ is be **applied to all levels in all load combinations**

AISC stability design | DAM

- Benefits
  - No limitations
  - Simplifies design calculations
    - K = 1.0
    - No B1 or B2 factors
  - Most accurate approach to capture destabilizing effects
    - Effects on demand instead of capacity
- At what cost?
  - Complicates analysis calculations
    - Good software can reduce this dramatically

AISC stability design | Effective Length Method

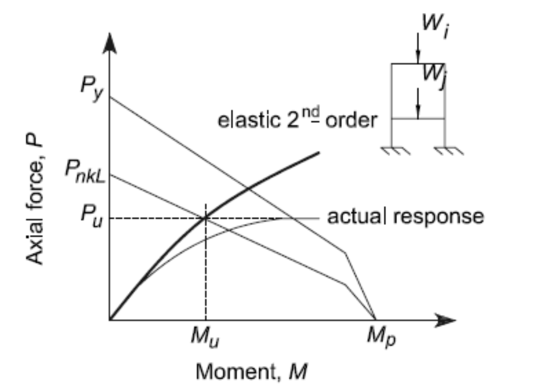
- Effective Length Method (ELM)
  - Limitations:
    - $\Delta_{2nd\ order} / \Delta_{1st\ order} \leq 1.5$ (full stiffness and LRFD combos or 1.6 x ASD combos)
  - Requirements:
    - Second order analysis
    - Notional loads – $N_i = 0.002\alpha Yi$ (gravity load only combos)
    - Stiffness reduction accounted for with K factors
      - Unless $\Delta_{2nd\ order} / \Delta_{1st\ order} \leq 1.1$, then K = 1.0
      - K = 1.0 for non-moment frame members

AISC stability design | First-order Method

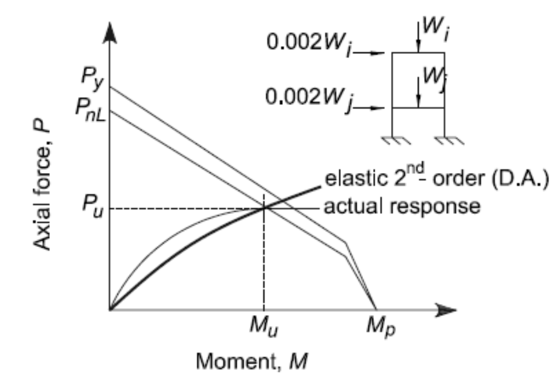
- First-order method (FOM)
  - Limitations:
    - $\Delta_{2nd\ order} / \Delta_{1st\ order} \leq 1.5$ (full stiffness and LRFD combos or 1.6 x ASD combos)
    - $\alpha P_r \leq 0.5\ P_y$
  - Requirements:
    - First-order linear analysis
    - Notional loads – $N_i = 2.1\alpha(\Delta/L) \geq 0.0042\alpha Yi$
      Δ = first-order interstory drift
      L = story height (in)
    - K = 1.0

AISC stability design | Alternate Methods

- Alternate stability methods:
  - Cons
    - **Limitations**
    - K factors (ELM)
    - Less accurate
  - Benefits
    - Simpler analysis (FOM)
    - Familiarity



(a) *Effective length method*



(b) *Direct analysis method*

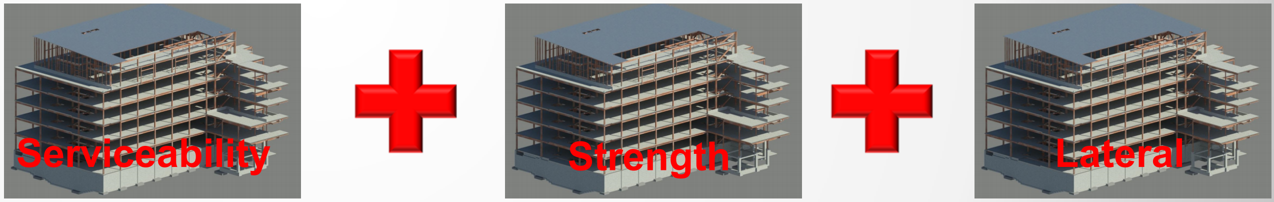
AISC stability design | Software

- Stability design in software
  - Before AISC 360-05, established ELM or FOM workflows
  - Increased computing power
  - Variability in capabilities
    - Second-order analysis common – few can do a true P-δ

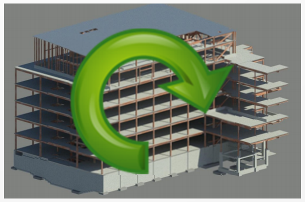
AISC stability design | Software

- What are the challenges?
  - Building complexity
  - Reducing stiffness only for some calculations

Multiple models



Multiple analysis runs



DAM in RSA

DAM in RSA | Approach

- DAM goals in RSA
  - Meet all AISC requirements
  - Easy to implement
  - Customizable
  - Accurate
- Current limitations
  - Phased structures
  - Spectral analysis

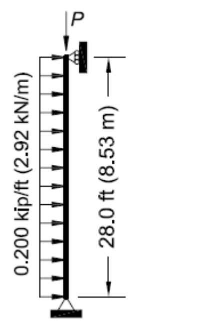
DAM in RSA | AISC requirements

- DAM addresses AISC's requirements:
  - Deformations – flexural shear and axial deformations calculated
  - 2^{nd} order effects – rigorous 2^{nd} order analysis calculates P-Δ and P-δ effects
  - Initial imperfections – generates notional loads
  - Material imperfections – applies stiffness reductions
  - Inelasticity – applies stiffness reductions

DAM in RSA | Implementation

- Easy and customizable
  - Minimal user input required to run basic DAM
  - DAM parameters can be customized
  - Separate DAM analysis model created…but only one project file
    - Toggle between DAM and Main model at any time

DAM in RSA | AISC Benchmarks



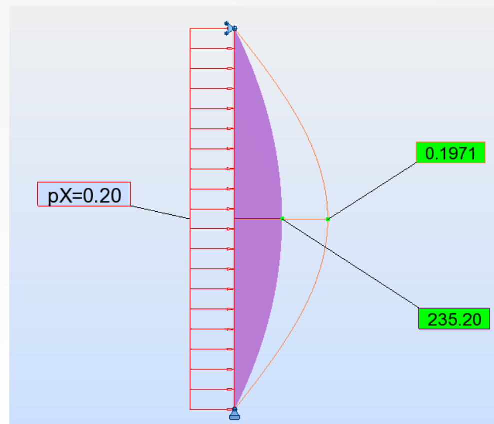
Major axis bending
W14x48 (W360x72)
E=29,000 ksi (200 GPa)

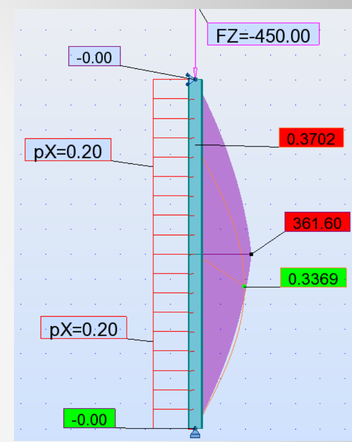
Axial Force, P (kips)	0	150	300	450
M_{mid} (kip-in.)	235 [235]	270 [269]	316 [313]	380 [375]
Δ_{mid} (in.)	0.202 [0.197]	0.230 [0.224]	0.269 [0.261]	0.322 [0.311]

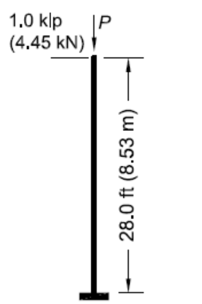
Axial Force, P (kN)	0	667	1334	2001
M_{mid} (kN-m)	26.6 [26.6]	30.5 [30.4]	35.7 [35.4]	43.0 [42.4]
Δ_{mid} (mm)	5.13 [5.02]	5.86 [5.71]	6.84 [6.63]	8.21 [7.91]

Analyses include axial, flexural and shear deformations.
[Values in brackets] exclude shear deformations.

Fig. C-C2.2. Benchmark problem Case 1.







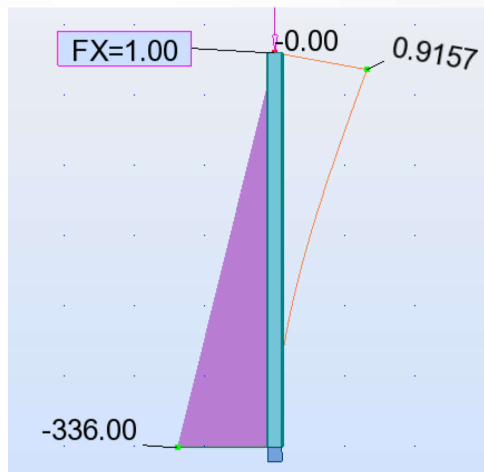
Major axis bending
W14x48 (W360x72)
E=29,000 ksi (200 GPa)

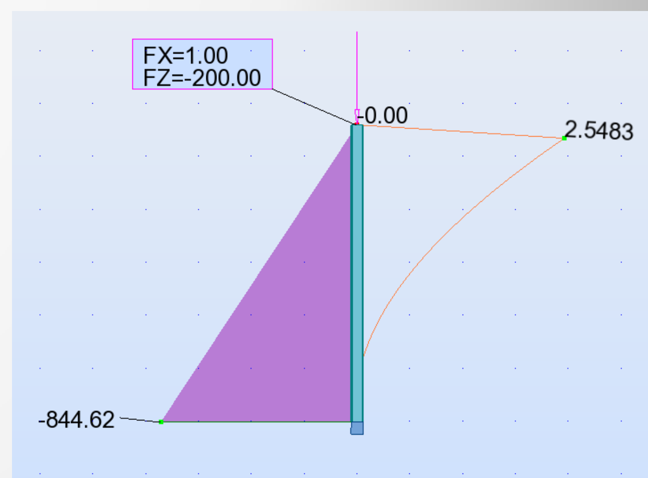
Axial Force, P (kips)	0	100	150	200
M_{base} (kip-in.)	336 [336]	470 [469]	601 [598]	856 [848]
Δ_{tip} (in.)	0.907 [0.901]	1.34 [1.33]	1.77 [1.75]	2.60 [2.56]

Axial Force, P (kN)	0	445	667	890
M_{base} (kN-m)	38.0 [38.0]	53.2 [53.1]	68.1 [67.7]	97.2 [96.2]
Δ_{tip} (mm)	23.1 [22.9]	34.2 [33.9]	45.1 [44.6]	66.6 [65.4]

Analyses include axial, flexural and shear deformations.
[Values in brackets] exclude shear deformations.

Fig. C-C2.3. Benchmark problem Case 2.

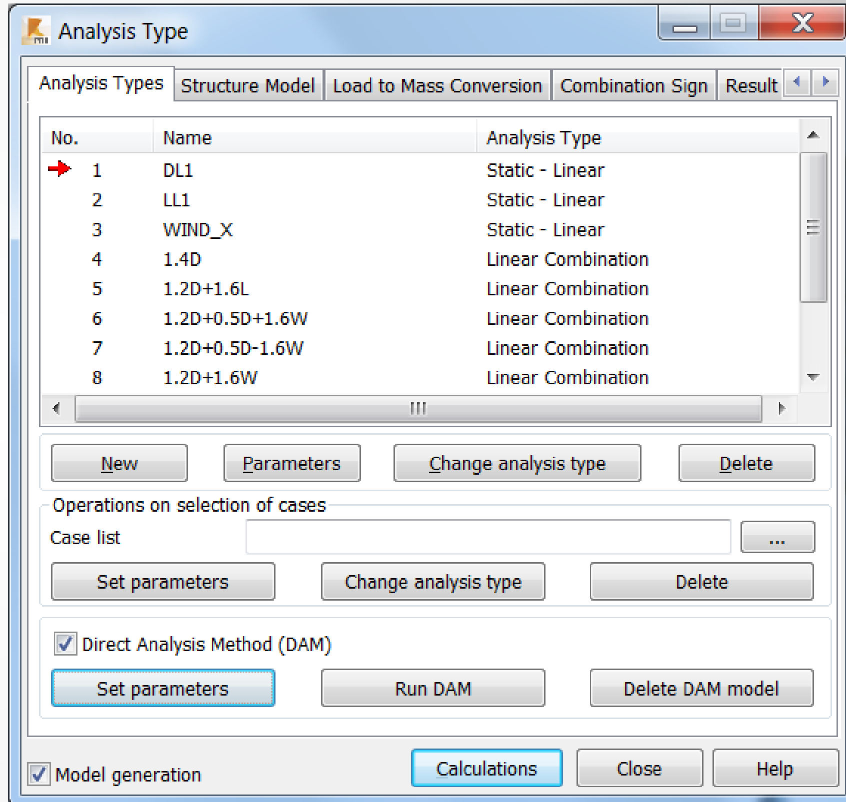




DAM walkthrough

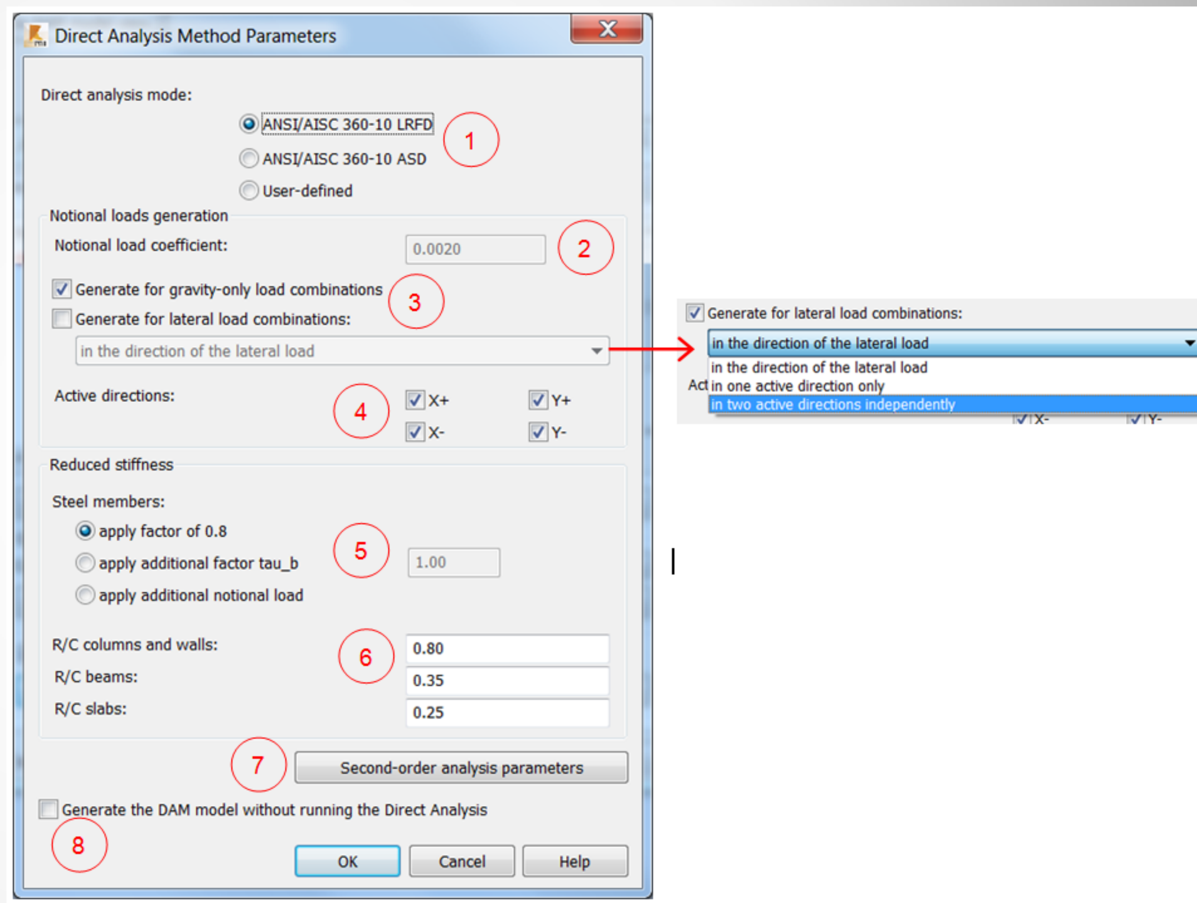
DAM walkthrough | Initialize

- Initializing DAM
  - Text menu or toolbar button
- Analysis Type window:
  - Enable DAM
  - Parameters
  - Run DAM
  - Delete DAM model



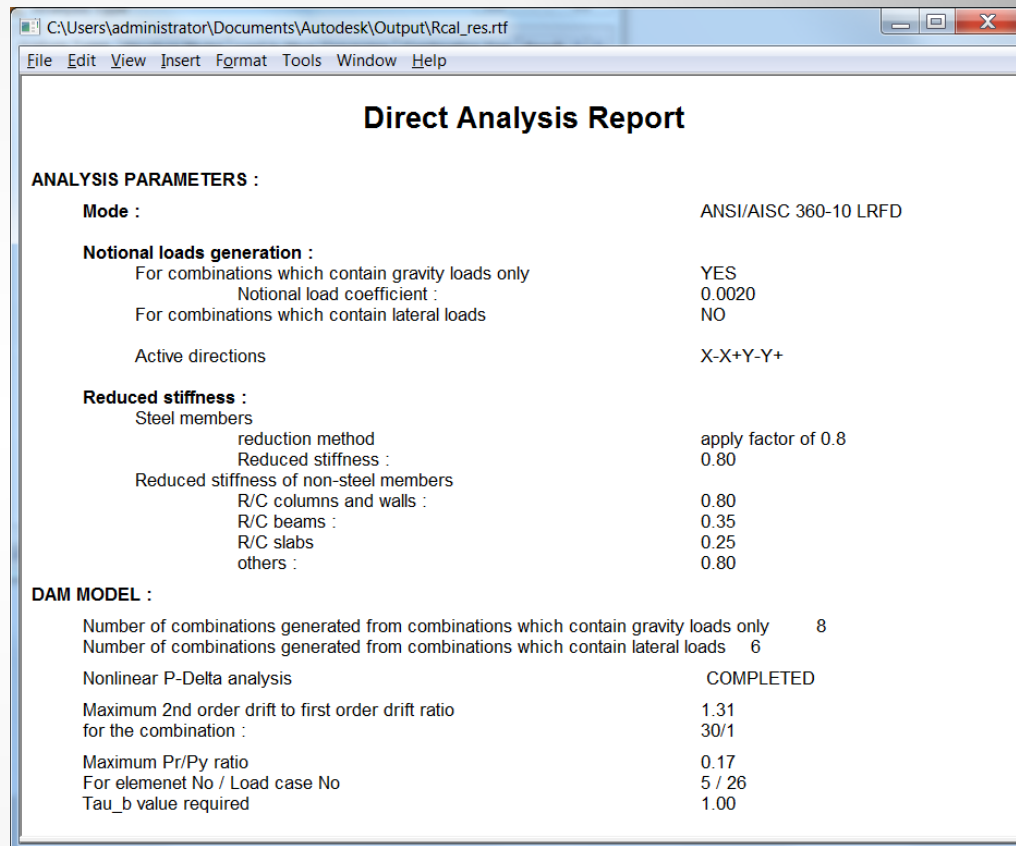
DAM walkthrough | Parameters

- DAM Parameters:
    1. Mode
    2. Notional load coeff.
    3. Notional loads
    4. Active directions
    5. Steel stiffness red.
    6. Reinf. concrete red.
    7. 2^{nd} order analysis
    8. Generate but don't run



DAM walkthrough | DA Report

- DA Report:
  - # combinations: gravity loads only
    and lateral loads
  - Status of the P-Delta analysis
  - Maximum value of $\Delta_{2nd\ order}$ / $\Delta_{1st\ order}$
  - Maximum Pr/Py ratio
  - Maximum τ_b value required



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File Edit View Insert Format Tools Window Help

Direct Analysis Report

ANALYSIS PARAMETERS :

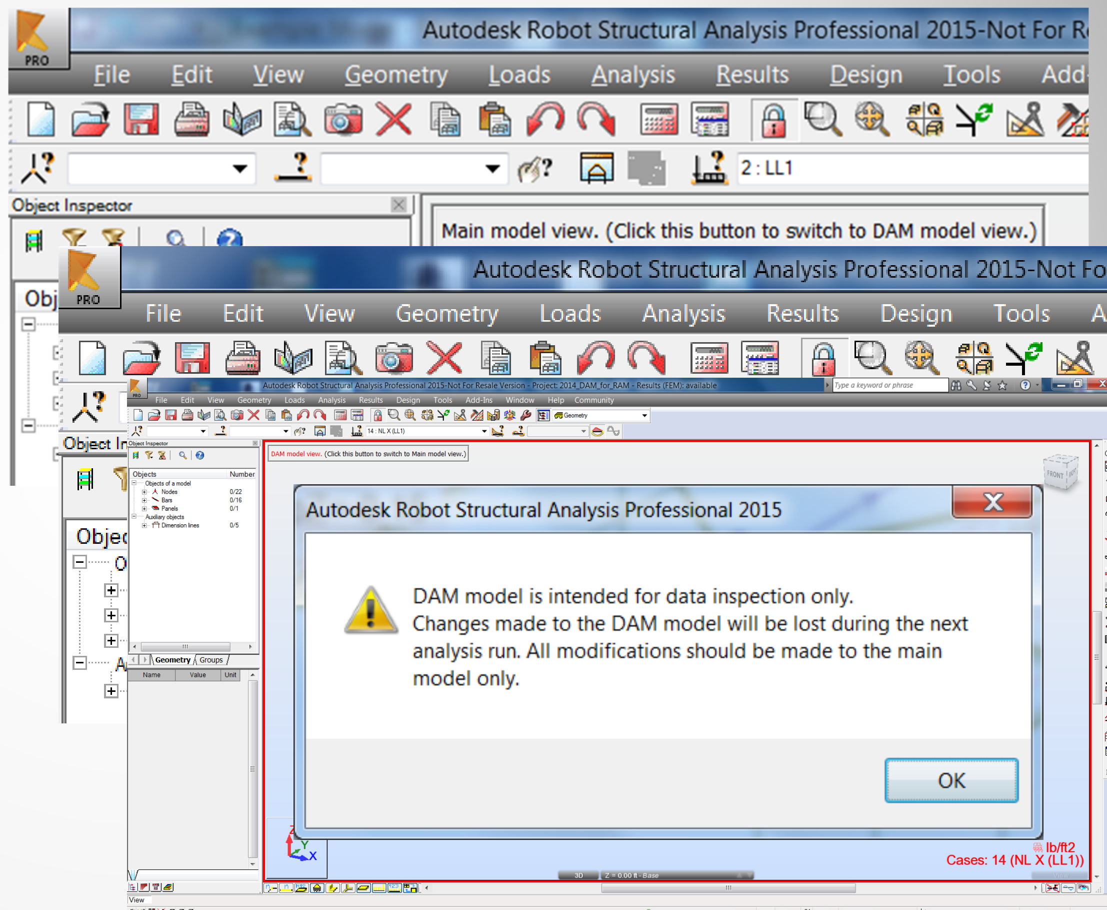
Mode :	ANSI/AISC 360-10 LRFD
Notional loads generation :	
For combinations which contain gravity loads only	YES
Notional load coefficient :	0.0020
For combinations which contain lateral loads	NO
Active directions	X-X+Y-Y+
Reduced stiffness :	
Steel members	
reduction method	apply factor of 0.8
Reduced stiffness :	0.80
Reduced stiffness of non-steel members	
R/C columns and walls :	0.80
R/C beams :	0.35
R/C slabs	0.25
others :	0.80

DAM MODEL :

Number of combinations generated from combinations which contain gravity loads only	8
Number of combinations generated from combinations which contain lateral loads	6
Nonlinear P-Delta analysis	COMPLETED
Maximum 2nd order drift to first order drift ratio	1.31
for the combination :	30/1
Maximum Pr/Py ratio	0.17
For elemenet No / Load case No	5 / 26
Tau_b value required	1.00

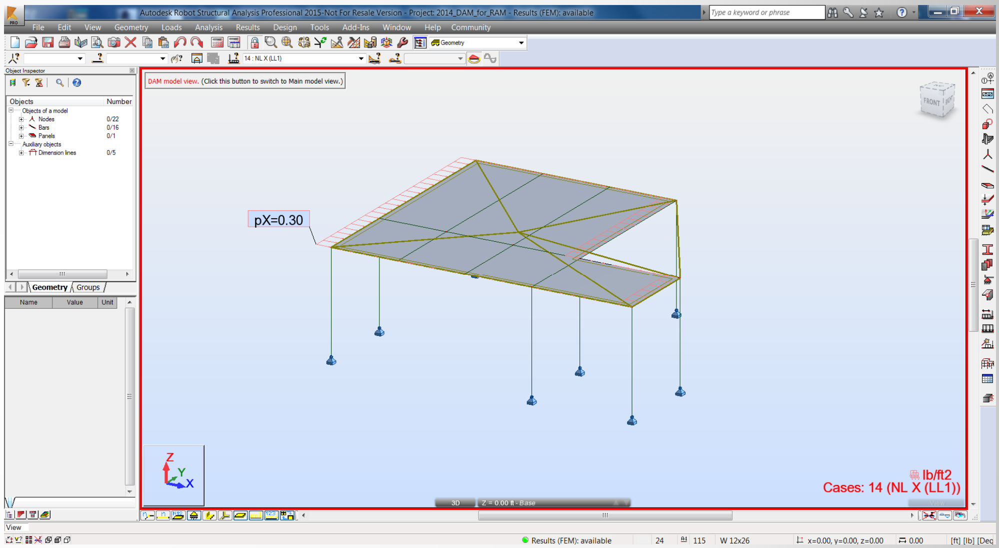
DAM walkthrough | Results review

- Working with DAM model:
  - Switching between DAM and Main model
  - Visual cues – **RED** border
  - Making changes



DAM walkthrough | Example model

- Example model:
  - Simple frame
  - Office building
- Live Demo



DAM in RSA Takeaways

DAM in RSA Takeaways

- Benefits of DAM in RSA
  - Easy to use
    - Visual cues
    - Design checks automatically uses correct combos
  - Very customizable
  - Automates tedious tasks
    - Notional loads
    - Stiffness reductions
    - A model within a model
- Applicable to any steel structure
- Accurate

Session Feedback

- Via the Survey Stations, email or mobile device
- AU 2015 passes given out each day!
- Best to do it right after the session
- Instructors see results in real-time

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