2016 Elite Engineers Webinar Series

Session 1

Pushover Analysis of a Torsionally Eccentric Cellular Abutment

Date 11/03/2016

3 PM – 4 PM Eastern Time

Today's Presenter:

Jon Emenheiser, PE

Copyright Materials

CONTINUING EDUCATION

Presentation Outline

- Project Overview
- Superstructure Analysis
- Substructure Analysis
    - Substructure Model
    - Elastic Analysis
    - Inelastic Analysis
- Pushover Analysis in Midas Civil 3D
    - Elastic Model
    - General Section Designer
    - Pushover Analysis
- Result Comparisons
- Shear Design of Column and Element Detailing

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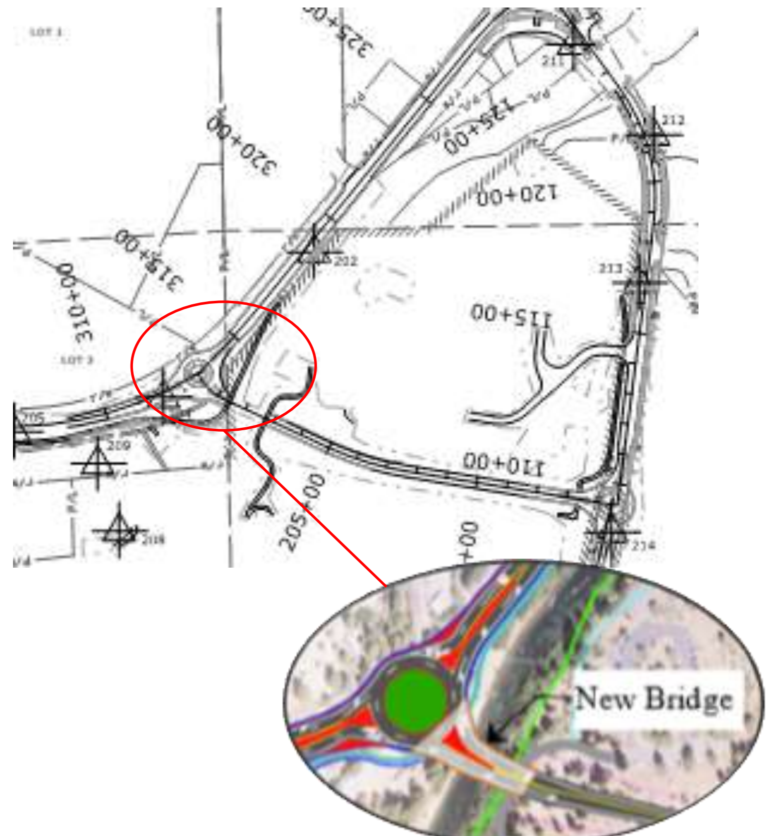
Presentation Overview

- Presentation Objectives
  - Develop understanding of:
    - Modeling Techniques
    - Inelastic Analysis
    - Midas General Section Designer
    - Midas Civil 3D Pushover Analysis
- Limitations of Presentation
  - Presentation will not:
    - Discuss foundation bearing and sliding capacity
    - Explain all theory behind topics
    - Provide all steps required to use software
    - Provide algorithms used for calculations

Project Overview

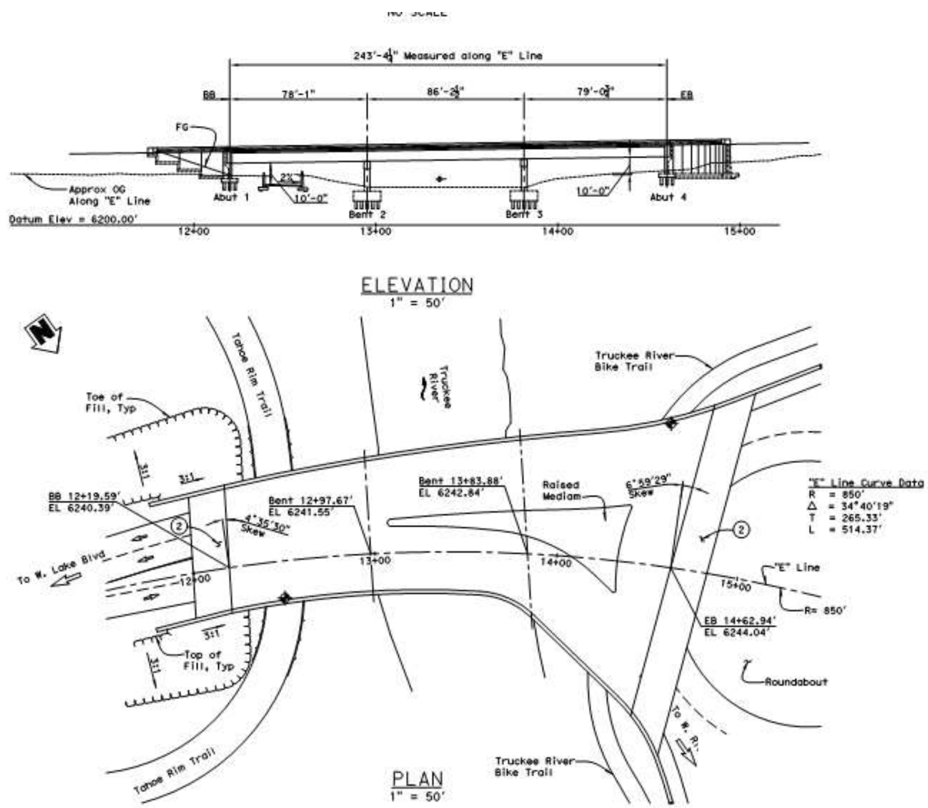
Project Overview

- Led by Central Federal Lands
- Funded by Federal Lands Access Program
- Project Location
  - Tahoe National Forest
  - Placer County, CA
  - Tahoe City, CA



Project Overview

- Structure Selection
  - Original Structure
    - Three Spans
    - Deep Foundations
    - Complicated Geometry
  - Revised Design
    - Single Main Span
    - Shallow Foundations
    - Square Geometry



Project Overview

- Truckee River Bridge
- Bridge Description
  - 119’-0” Simple Span Decked Bulb Tee Girder
  - 14’-0” Cellular Abutments
    - Retaining wall toward Embankment
    - Columns toward River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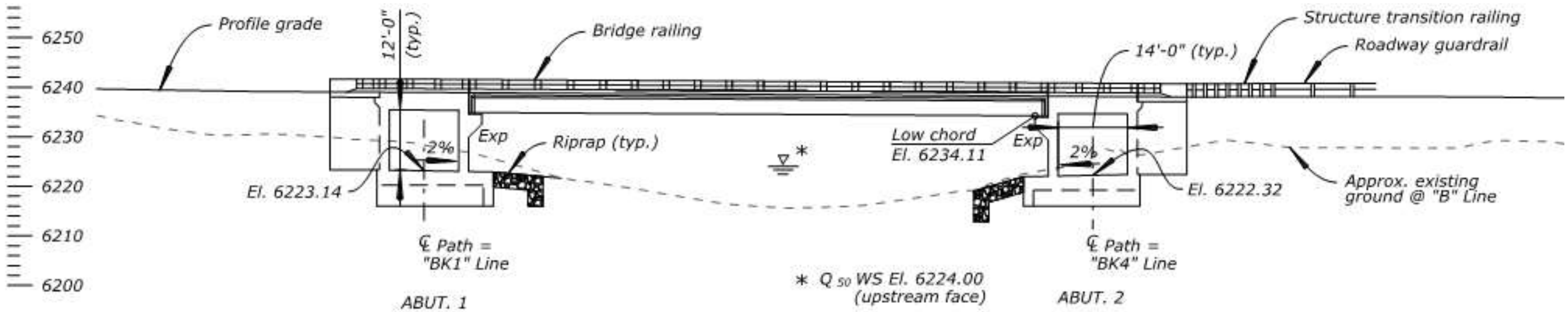
Project Overview

- Bridge Elevation



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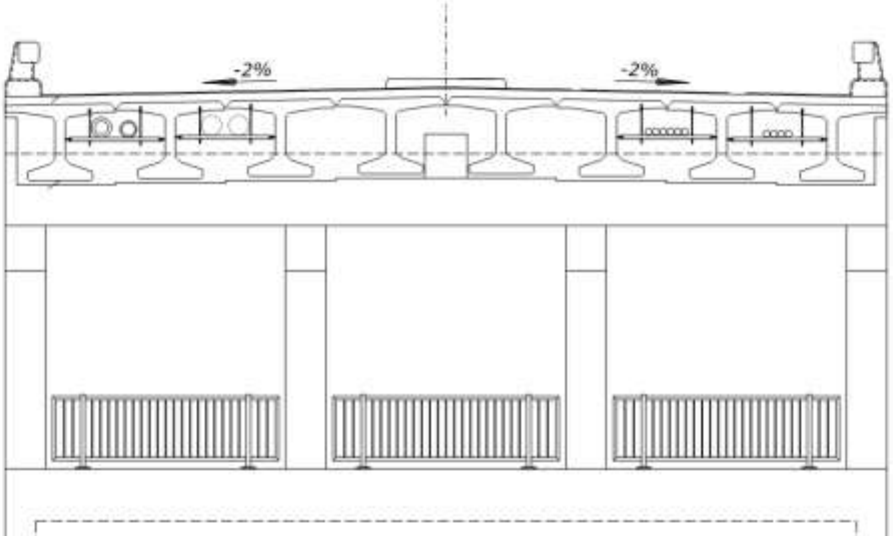
Superstructure Analysis

Superstructure Analysis

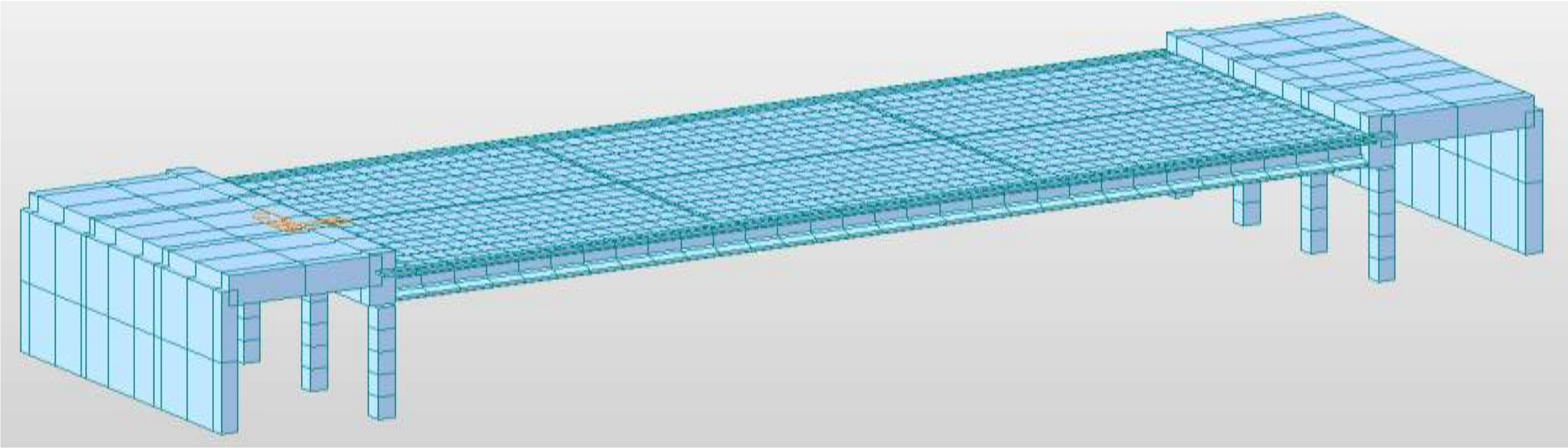
- Superstructure
  - AASHTO LRFD 2012 6th Edition with Caltrans Amendments
  - Decked Bulb Tee Girders – UDOT Typical Section
  - Level Bearing Seats
  - Steel Reinforced Elastomeric Bearing Pads
  - CIP Concrete Topping
  - CIP Diaphragms
  - CIP Barriers



Typical Section

Superstructure Analysis

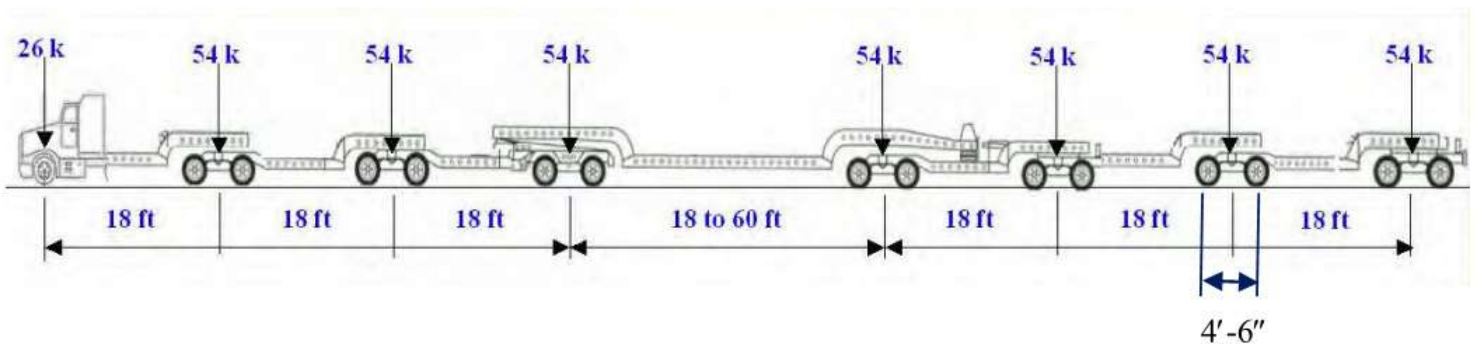
- Midas Civil 3D Superstructure Wizard
  - Not used for primary design
  - Used to verify distribution factors were conservative



Superstructure Model with Abutments

Superstructure Analysis

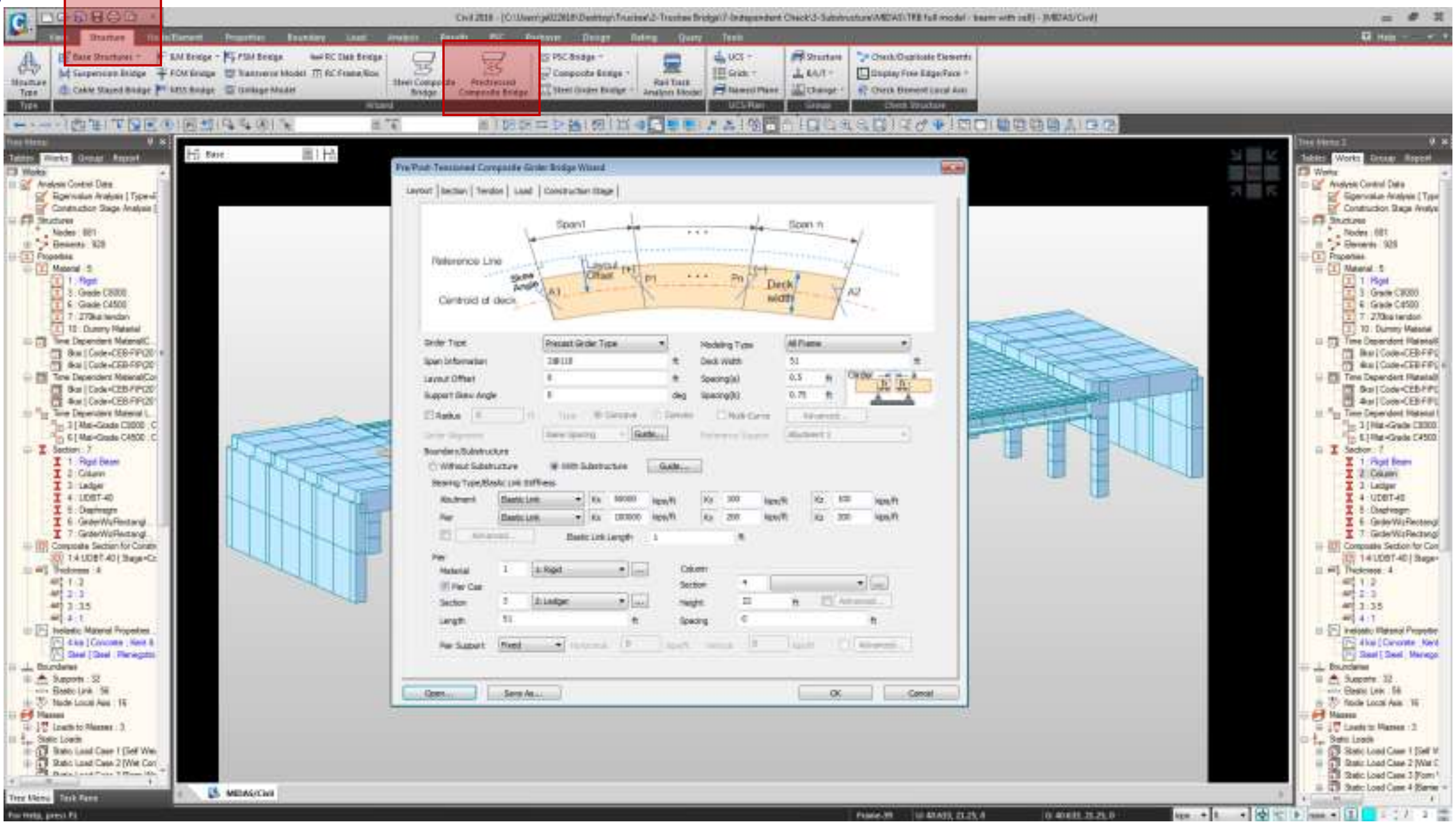
- For Interior Moment with 2 trucks
  - AASHTO Equations g=0.52
  - CONSPAN Grillage g=0.46
  - Midas Grillage g=0.41



Caltrans P15 Permit Truck

Superstructure Analysis

- Midas Civil 3D Superstructure Wizard

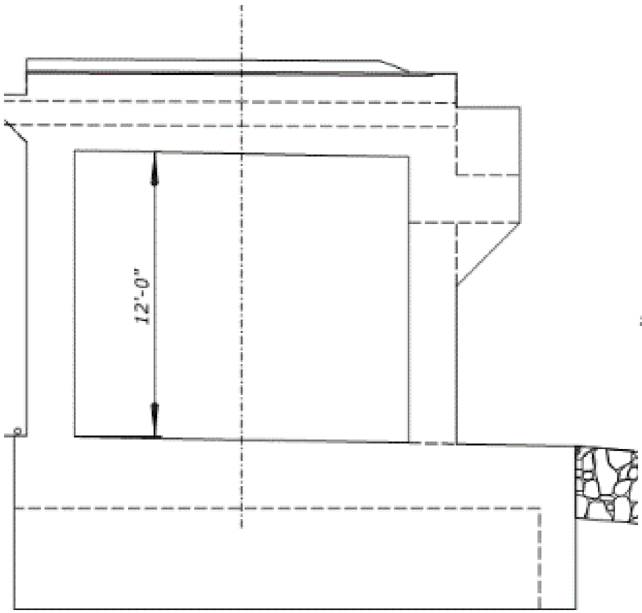


Substructure Analysis

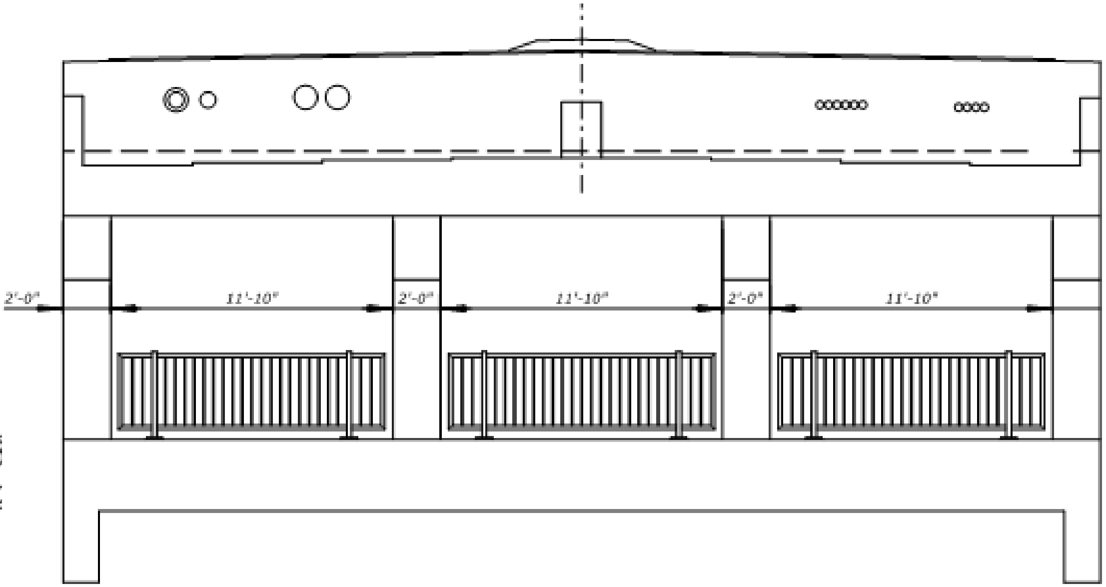
Substructure Analysis

- Design Codes
  - AASHTO LRFD 2012 6th Edition with Caltrans Amendments
  - AASHTO LRFD 2011 Guide Specifications for Seismic Design of Highway Bridges
  - Caltrans Seismic Design Criteria 2013 v.1.7
- Substructure Overview
  - Spread Footing with Toe Walls
  - Columns with Corbel for Girder Supports
  - Retaining Wall as Backwall
  - Solid Top Slab with Utility Voids

Substructure Analysis



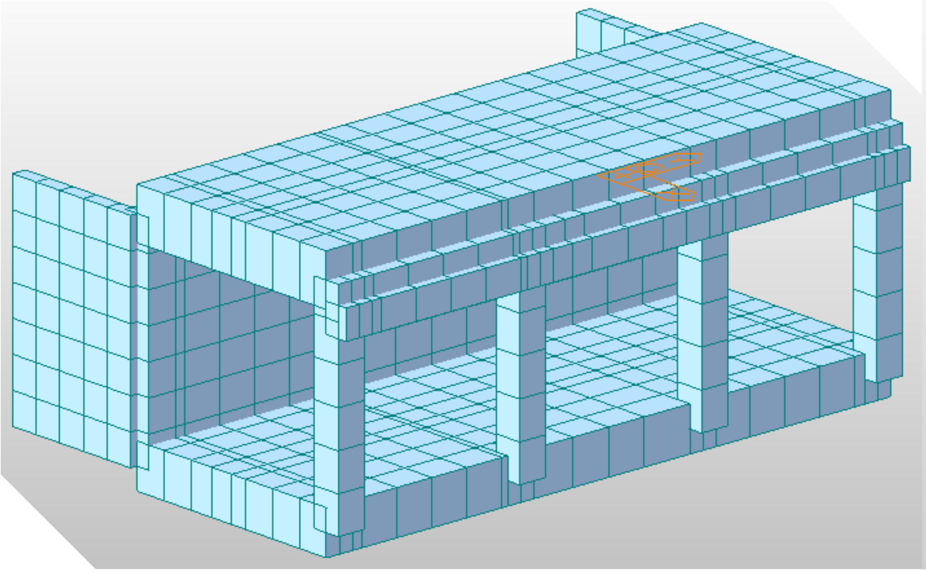
Side Elevation



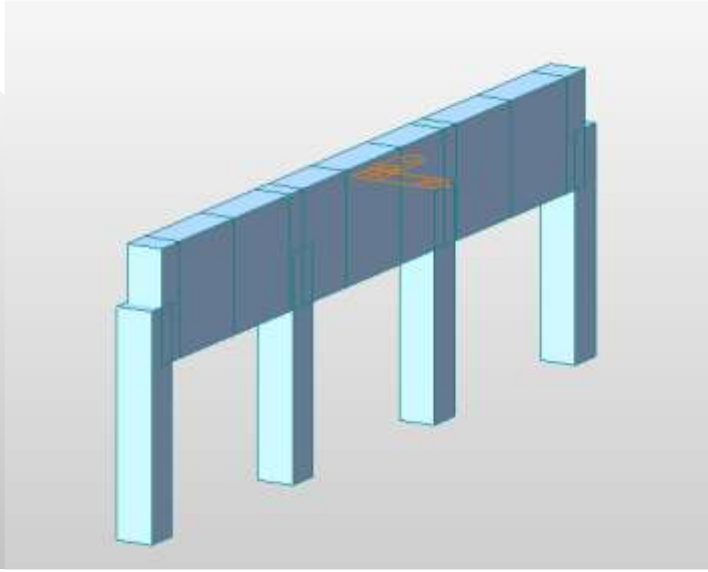
Front Elevation

Substructure Analysis

- Substructure Model
  - Solid Element Model in CSiBridge
  - Plate Element Model in Midas Civil 3D
  - Beam Element Model was used for Corbel Design



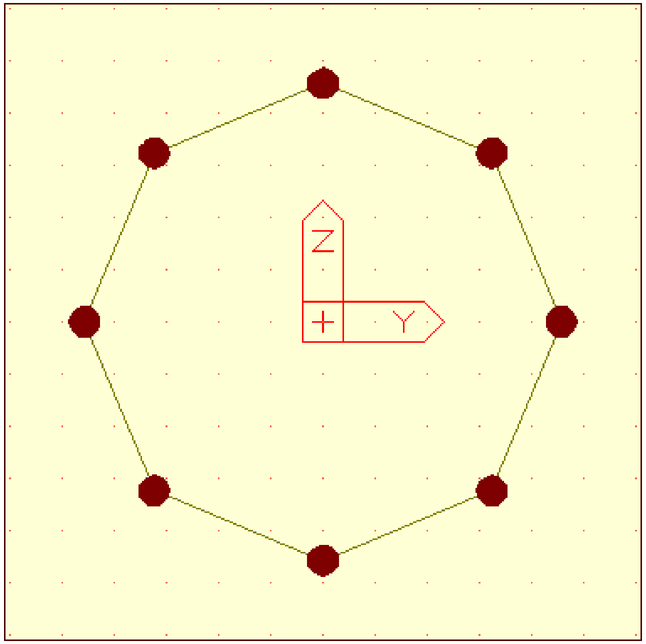
Cellular Abutment Model



Idealized Corbel Beam Model

Substructure Analysis

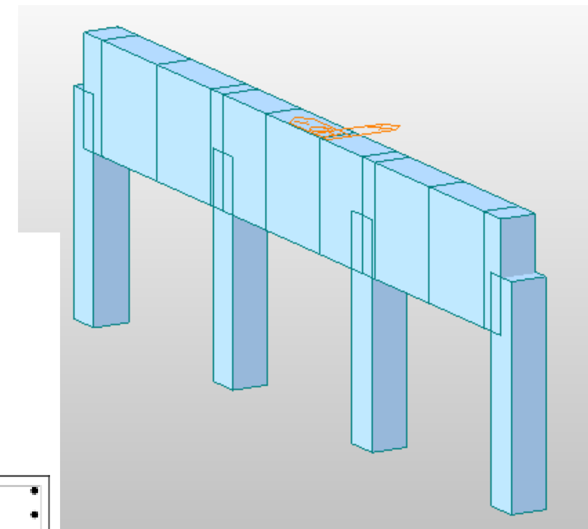
- Elastic Properties of Column
  - Used for Initial Design
  - Nominal Material Properties
  - No Confined Concrete
  - Rectangular Section

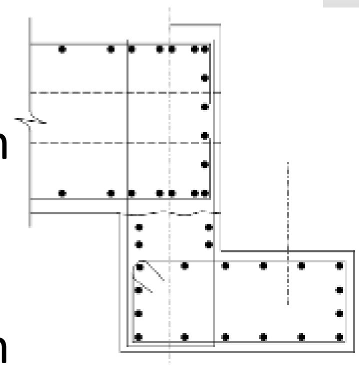


Column Section with Nominal Material Properties

Substructure Analysis

- Element Design
  - Bottom Slab, Back Wall, Top Slab
    - Plate Analysis
    - Design Forces per 1 ft Strip
    - Reinforced Concrete Design
  - Corbel Beam
    - Stiffness considerations
    - Designed as idealized beam
    - TxDOT Design Example based on AASHTO 2010 –
      - AASHTO 5.13.2.4
  - Columns
    - Designed to Remain elastic during Design Event





Texas Department of Transportation

BRIDGE DIVISION

County: Any Hwy: Any Design: BRG Date: 6/2010

Inverted Tee Bent Cap Design Example

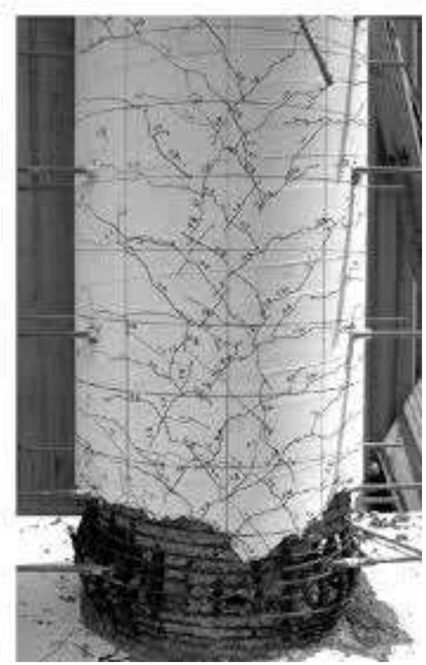
Design example is in accordance with the AASHTO LRFD Bridge Design Specifications, 5th Ed. (2010) as prescribed by TxDOT Bridge Design Manual - LRFD (May 2009).

Substructure Analysis

- Inelastic Analysis
  - Determine design value for base shear to ensure ductile plastic hinging in column

Column Shear Failure

http://www.arch.virginia.edu/~km6e/tti/tti-summary/full/mex-city-shear-col-noted.jpeg

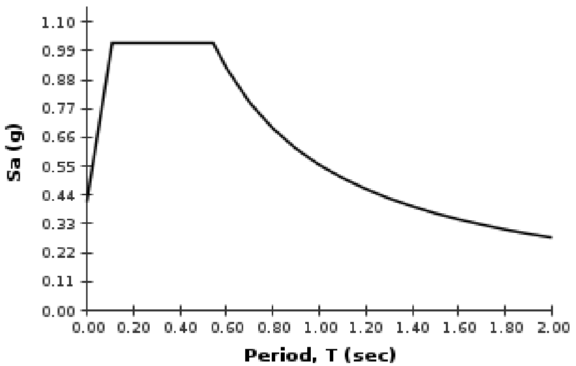


Column Plastic Hinge

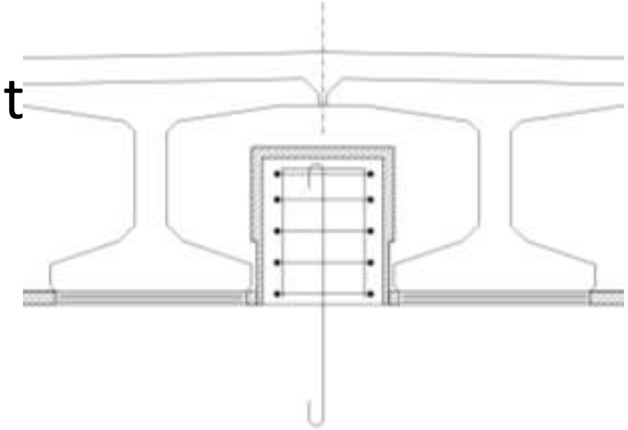
http://www.dot.ca.gov/hq/esc/earthquake_engineering/damage_report/1_Visual_Catalog_of_RC_Bridge_Damage.pdf

Substructure Analysis

- Seismic Design
  - PGA 0.44G – T=0
  - Site Class D
  - Seismic Design Category D
  - Isolated Shear Key
  - Shear Key for ¼ Superstructure Weight
  - Minimum Seat Width
  - Considered Deflection for Utilities



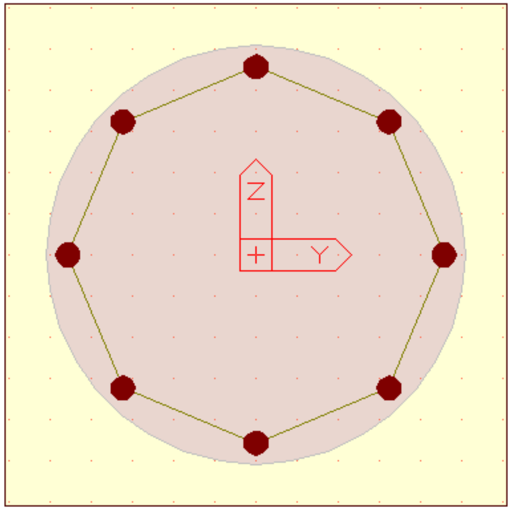
Design Response Spectrum (USGS)



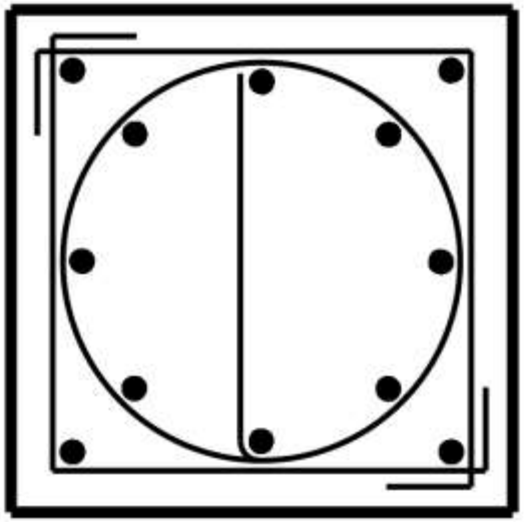
Shear Key Detail

Substructure Analysis

- Inelastic Section Properties
  - Expected Material Properties
    - 1.3 x $f`_c$ (5.85 ksi)
    - 1.13 x f_y (68 ksi)
  - Concrete Confined Inside Spirals



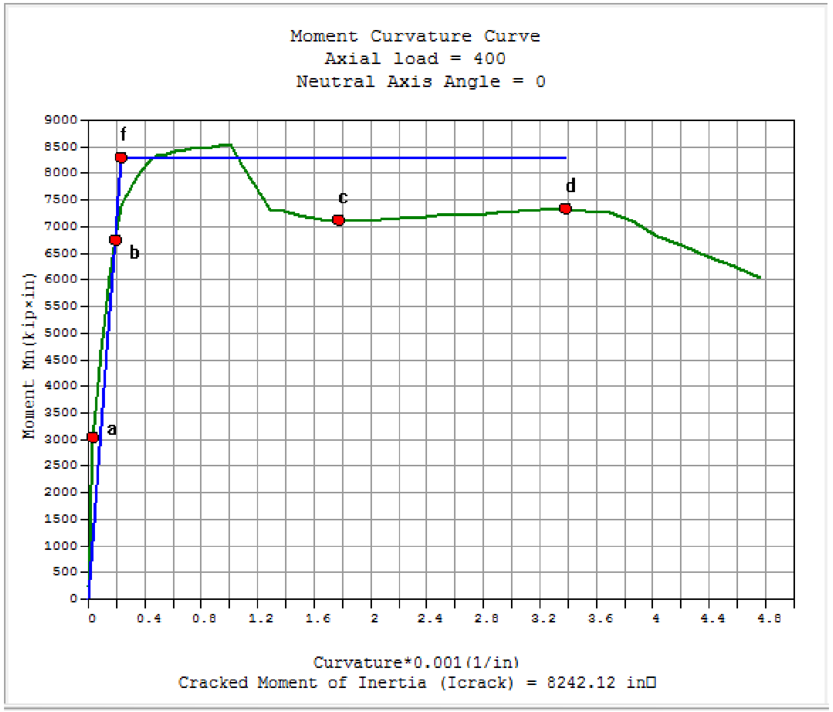
Column Section with Expected Material Properties



Column Section

Substructure Analysis

- Moment Curvature Analysis
  - Determine Curvature of Section at increasing Moments



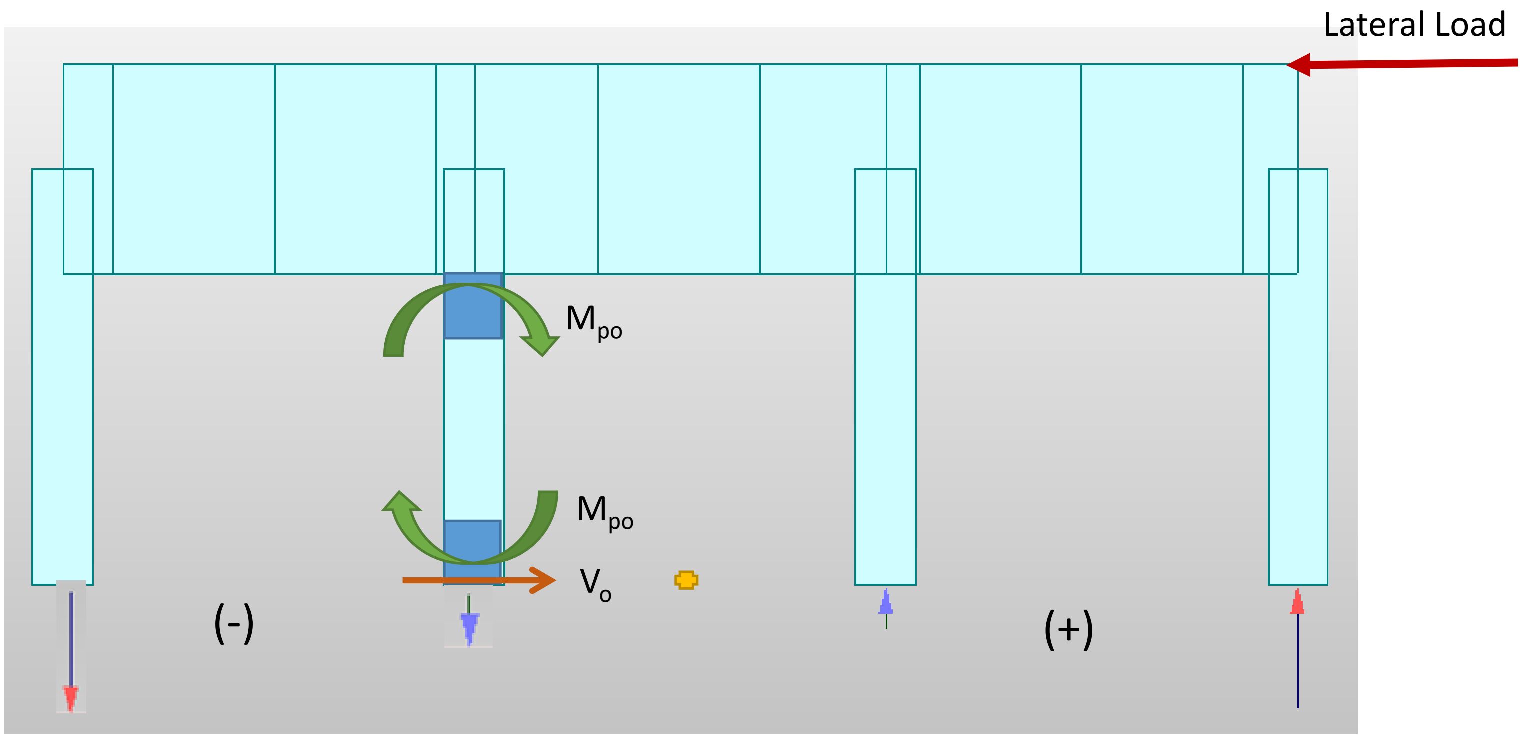
State	Curvature *10^-3 (1/in)	Moment (kip×in)
a.Crack	0.030227	3007.628
b.Yield(Init.)	0.186939	6717.772
c.Yield	1.767234	7098.877
d.Ultimate(conc)	3.384659	7325.386
e.Ultimate(rebar)	-	-
f.Yield(ideal)	0.230062	8267.406

Substructure Analysis

- Pushover Analysis
  - Moment Curvature Analysis
  - Determine Overstrength Moments
    - M_{po}=1.2 x M_p Caltrans SDC - Section 4.3
  - Calculate Shear with only Service Axial Force (Dead Load)
    - $V_o=(M_{po\text{-}top}+M_{po\text{-}bot})/h$
  - Sum Base Shears
  - Apply Total Shear as Lateral Force
  - Recalculate Axial Forces Include Overturning
  - Iterate until Lateral Force and Total Shear Converge

Substructure Analysis

- Pushover Analysis



Substructure Analysis

- Pushover Analysis

Abutment Pushover

<u>Transverse Pushover</u>

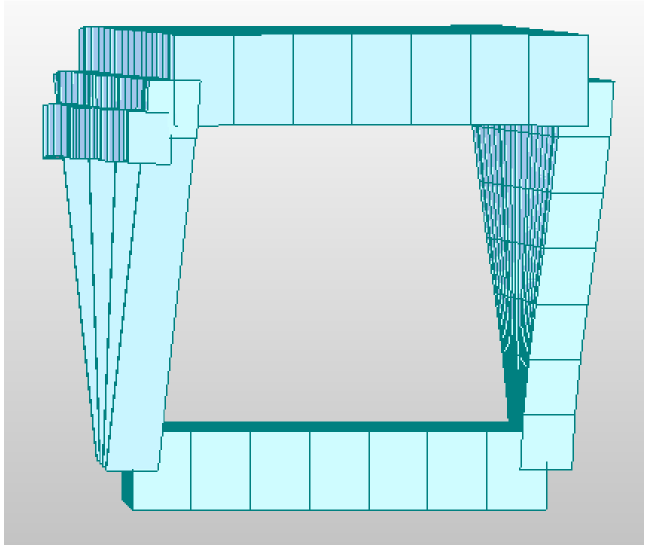
Cap beam assumed to be rigid for pushover analysis

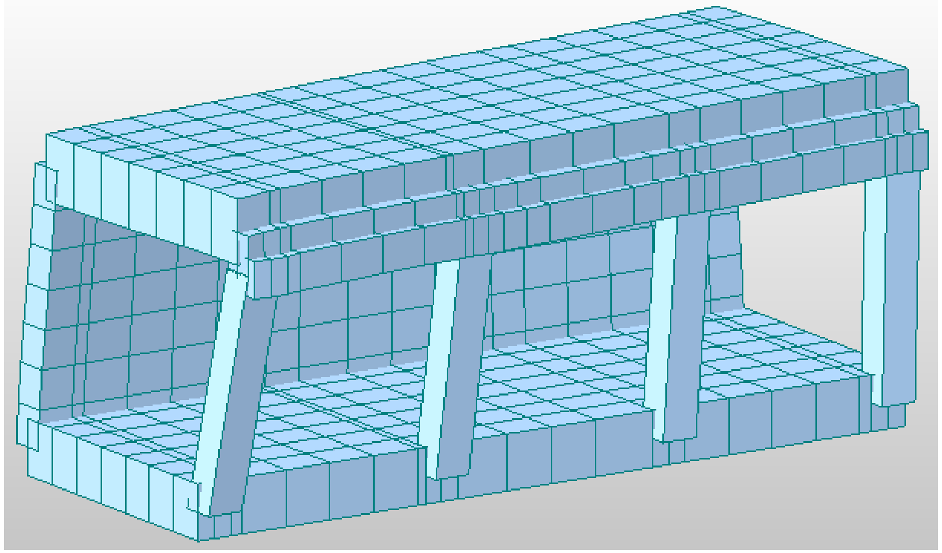
Column Height	14.2	ft
Column Spacing	15.25	ft (between exterior columns)
Lp (in)	23.01	
Plastic Hinge L	1.92	ft
P_top	270	kips (DL from bridge + DL of cap beam)
Column Weight	8.5	kips

	Trial 0						Trial 1					
Column	P_ot	P_top	P_bott	Mo_top	Mo_bott	Vo	P_ot	P_top	P_bott	Mo_top	Mo_bott	Vo
	kips	kips	kips	k-ft	k-ft	kips	kips	kips	kips	k-ft	k-ft	kips
1	0.00	250	259	630.2	634.5	89.07	-99.52	170	179	588.9	593.5	83.27
2	0.00	250	259	630.2	634.5	89.07	-33.17	237	245	623.5	627.8	88.12
3	0.00	250	259	630.2	634.5	89.07	33.17	303	312	657.1	661.1	92.83
4	0.00	250	259	630.2	634.5	89.07	99.52	370	378	688.4	692.4	97.24
				Total		356.261				Total		361.46
										converge =		1.439%

Substructure Analysis

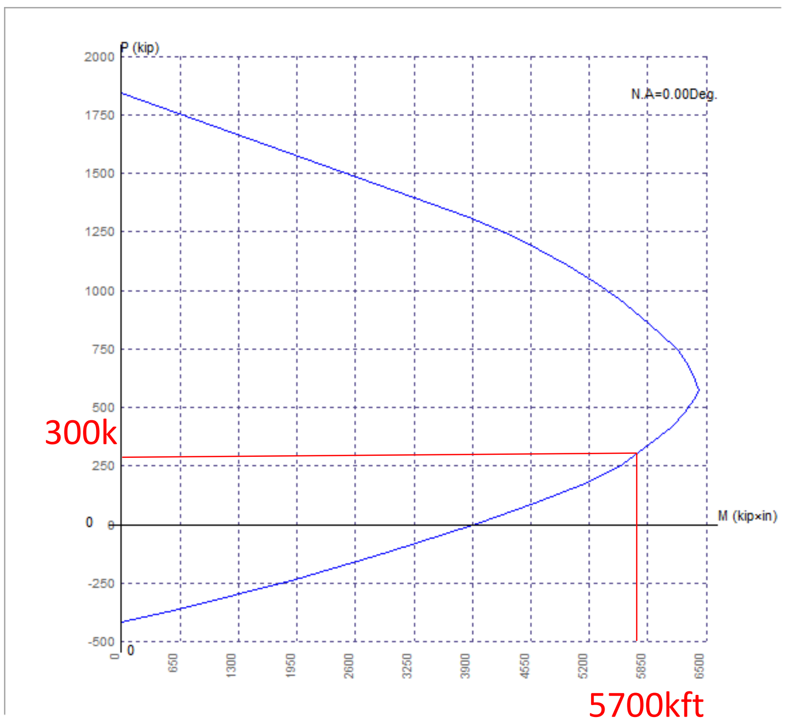
- Torsional Eccentricity
  - Bending about both Column Axes
  - Restraint from Back Wall

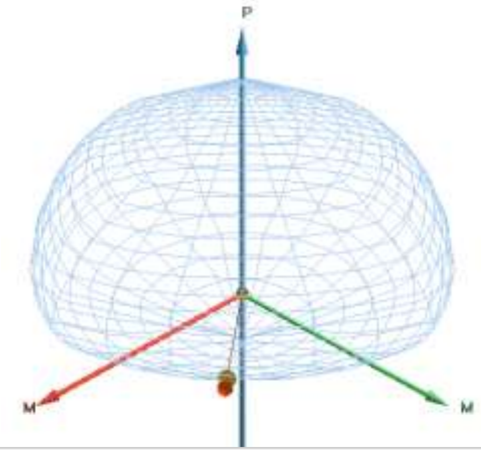


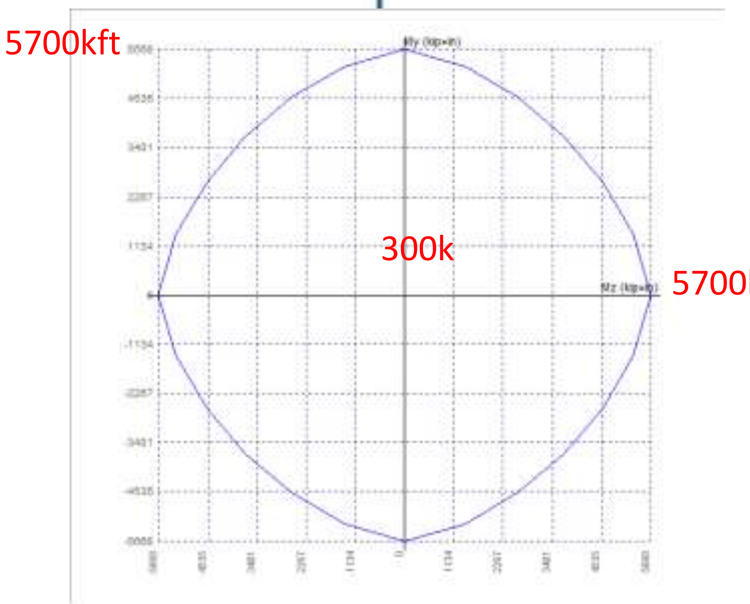


Substructure Analysis

- Torsional Eccentricity
  - Column Interaction







Pushover Analysis in Midas Civil 3D

Pushover Analysis in Midas Civil 3D

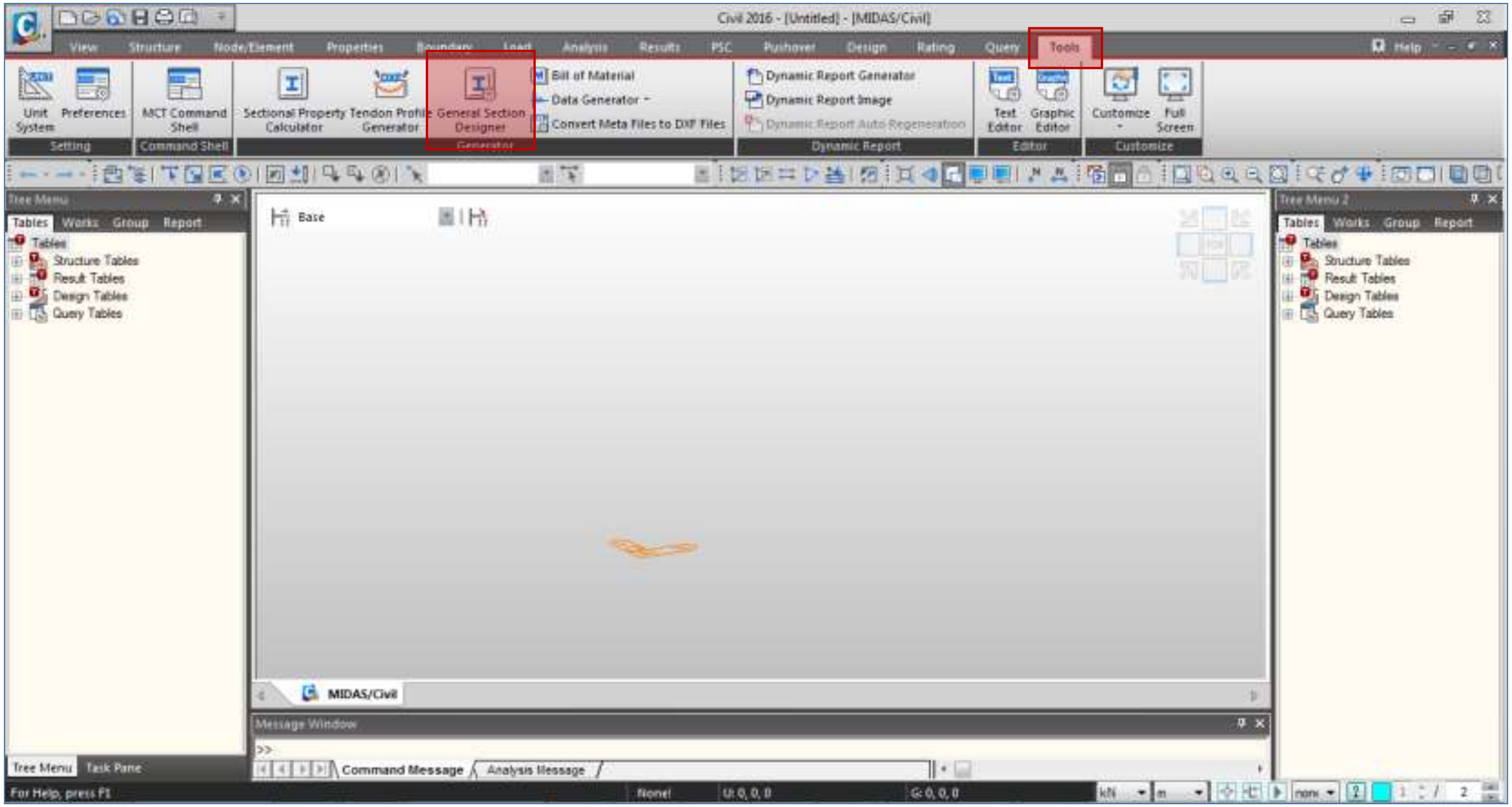
- General Procedure
  - Create Elastic Model in Midas Civil 3D (Midas)
  - General Section Designer (GSD)
    - Inelastic Section Properties
    - Moment Curvature Analysis
  - Pushover Analysis
    - Define Hinge and Assign Plastic Hinge
    - Perform Analysis

Pushover Analysis in Midas Civil 3D

- Elastic Model
  - Elements must be similar to those used in GSD
    - Used to calculate initial elastic properties in pushover analysis
  - Items to verify
    - Material Properties
    - Section Properties
    - Reinforcement Steel Layout
  - Alternatively, Properties can be entered in GSD and Linked to Midas

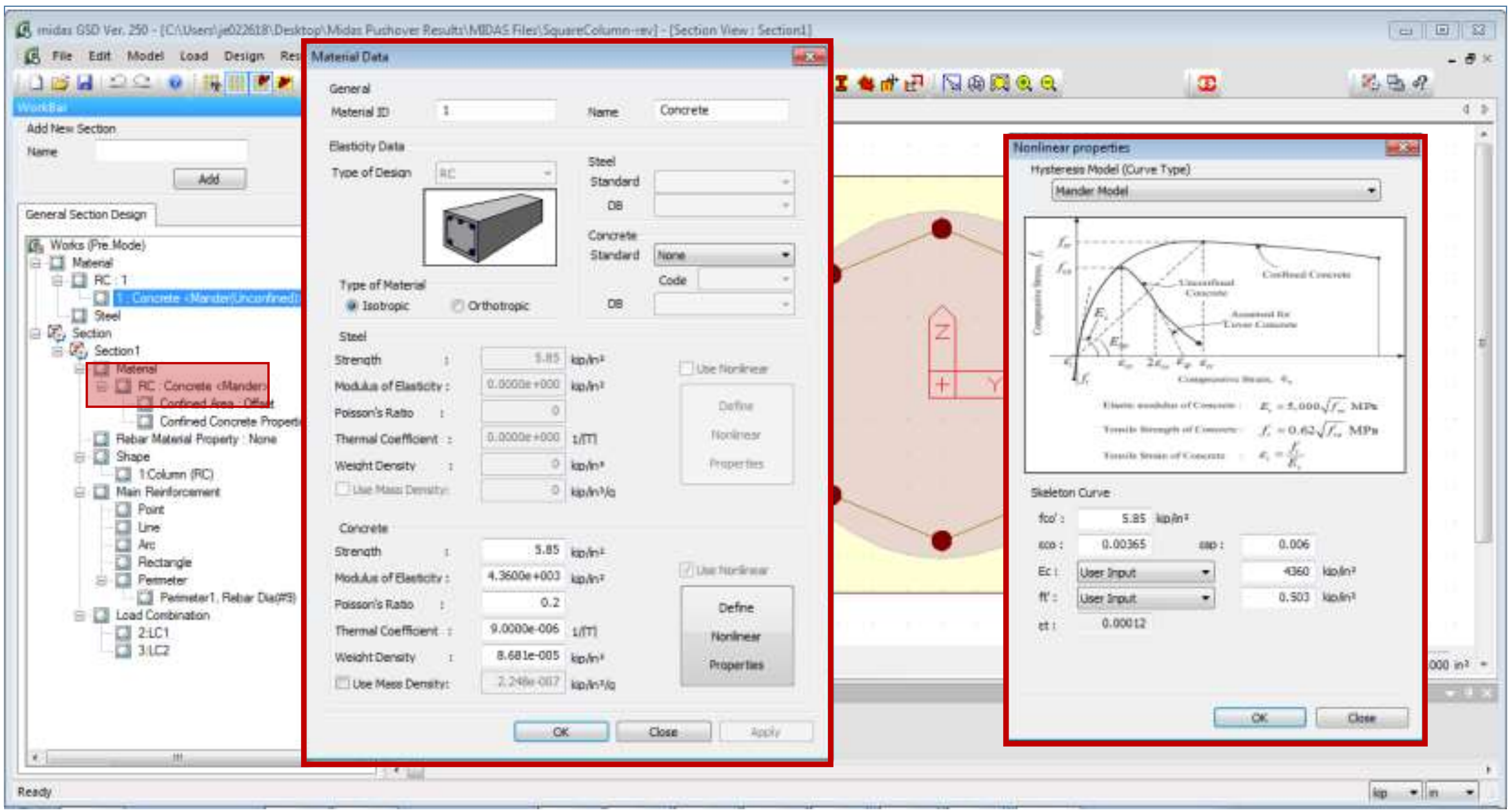
Pushover Analysis in Midas Civil 3D

- General Section Designer



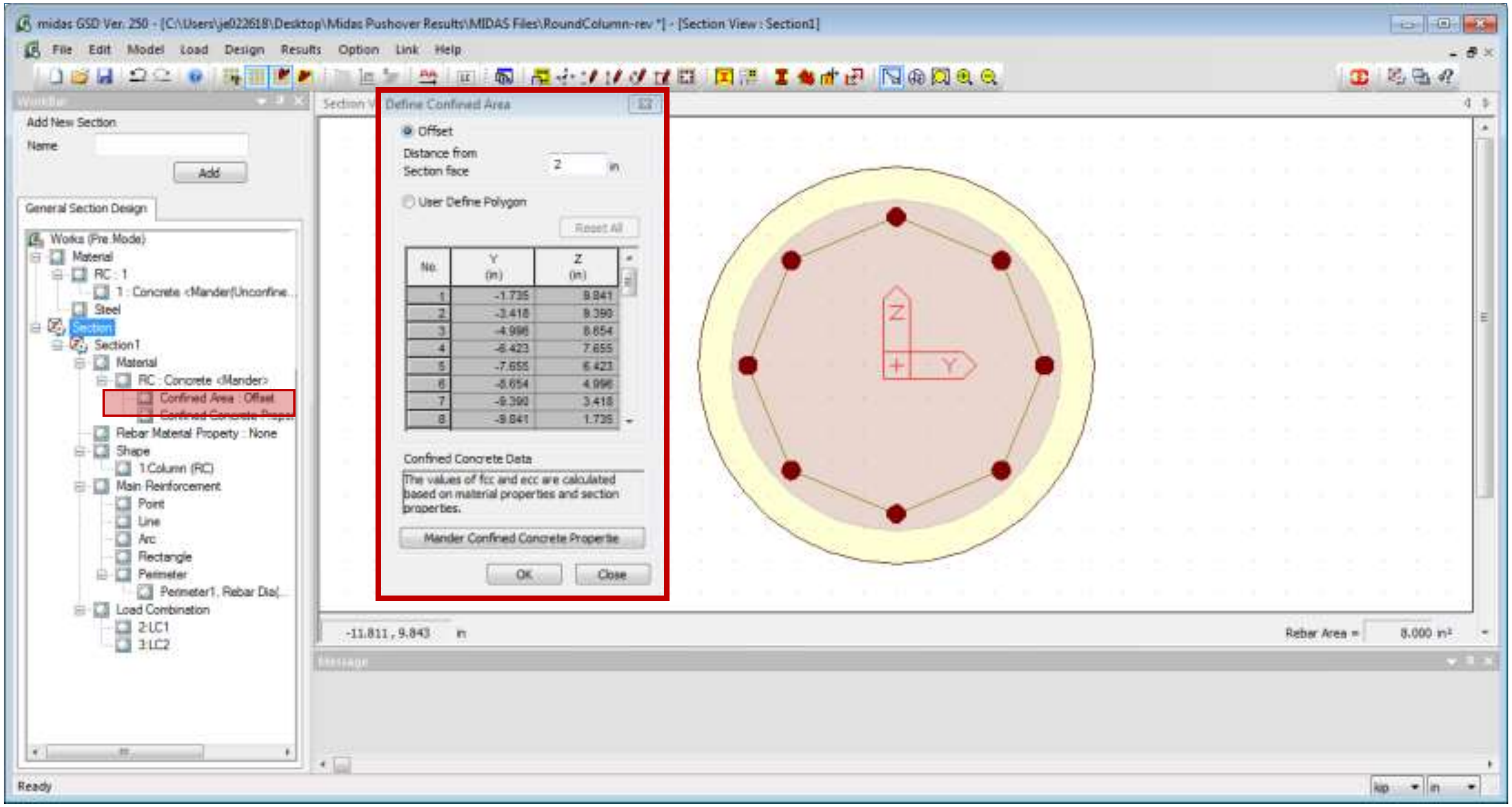
Pushover Analysis in Midas Civil 3D

- GSD – Material - Unconfined Concrete



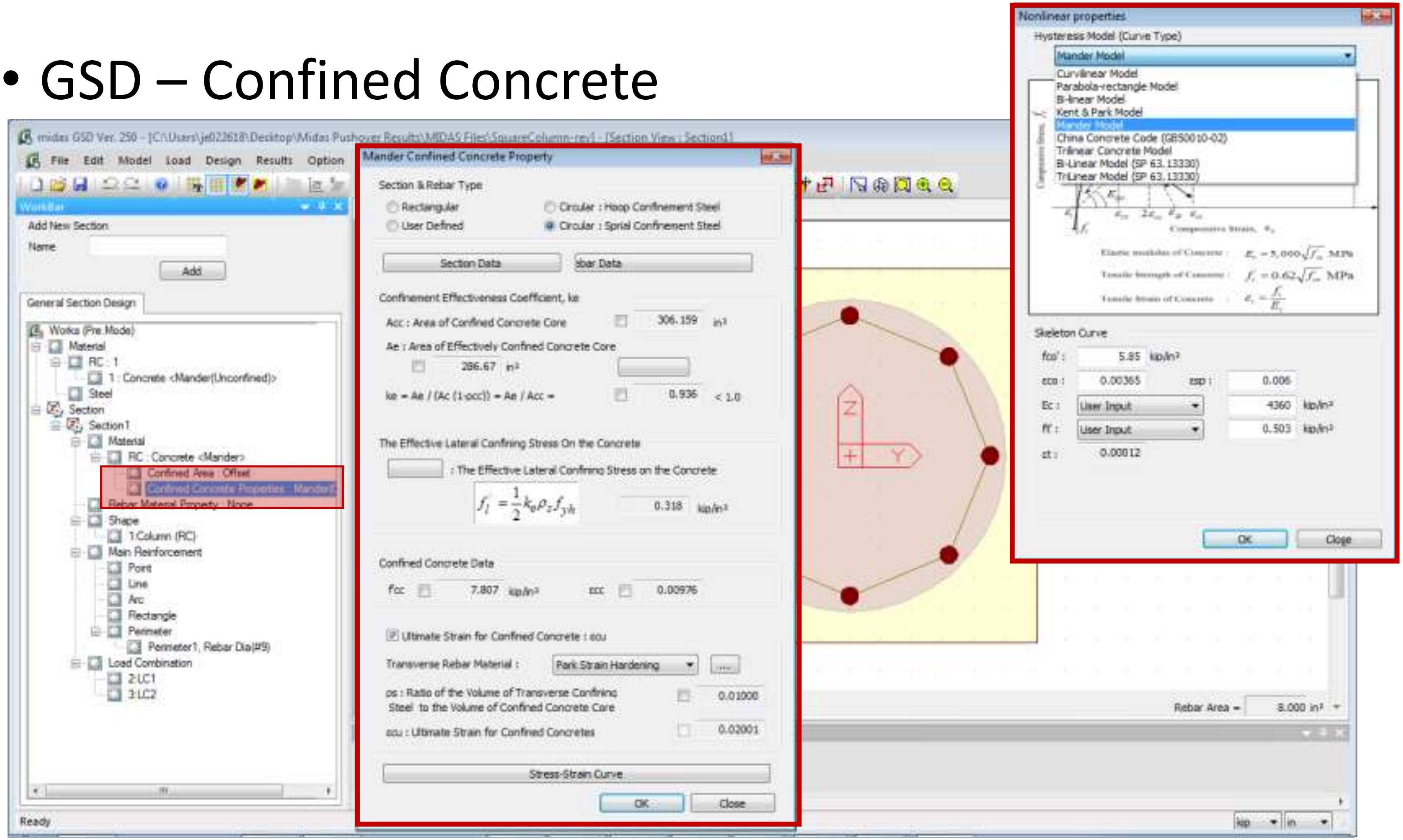
Pushover Analysis in Midas Civil 3D

- GSD – Confined Area



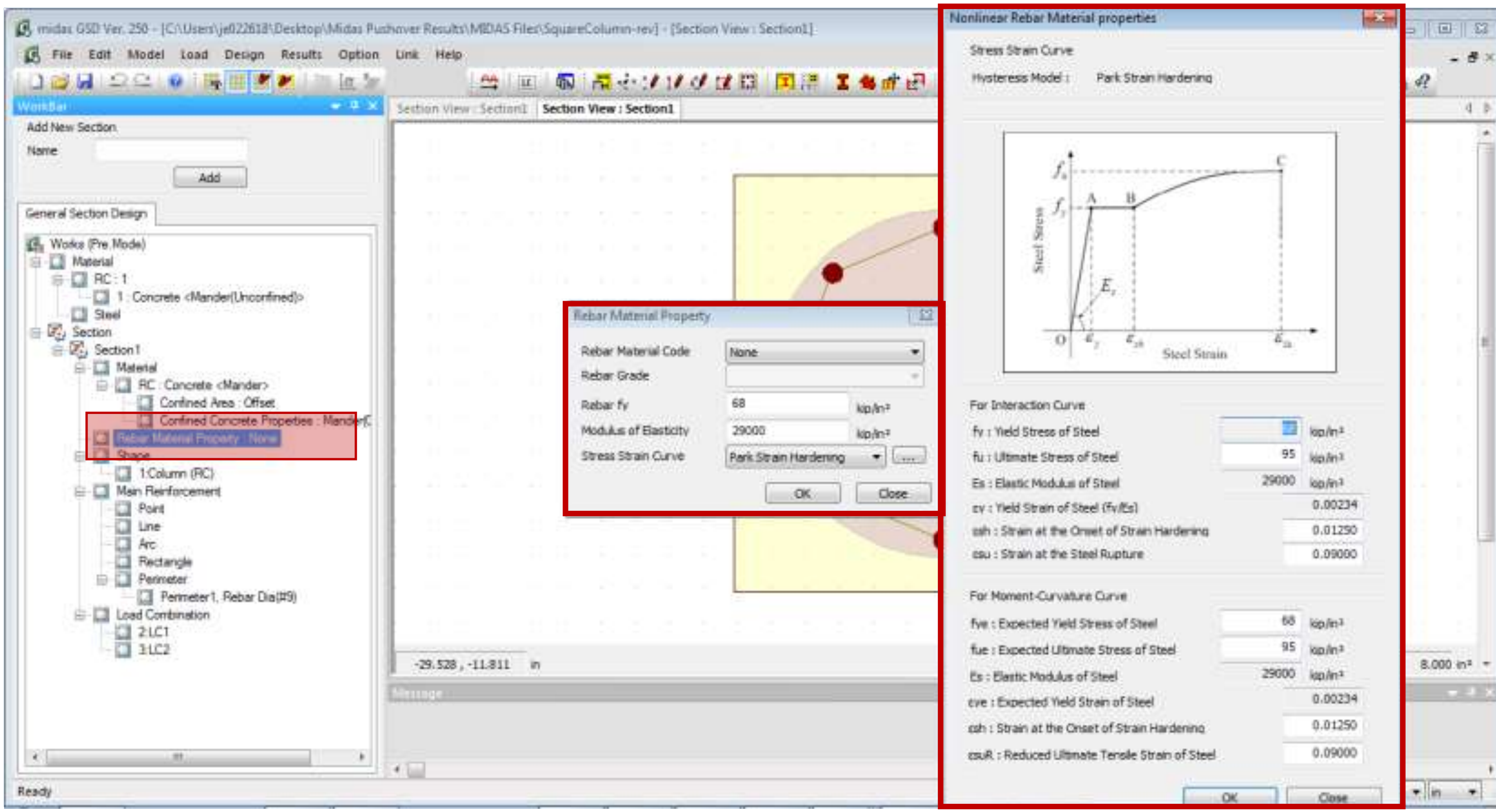
Pushover Analysis in Midas Civil 3D

- GSD – Confined Concrete



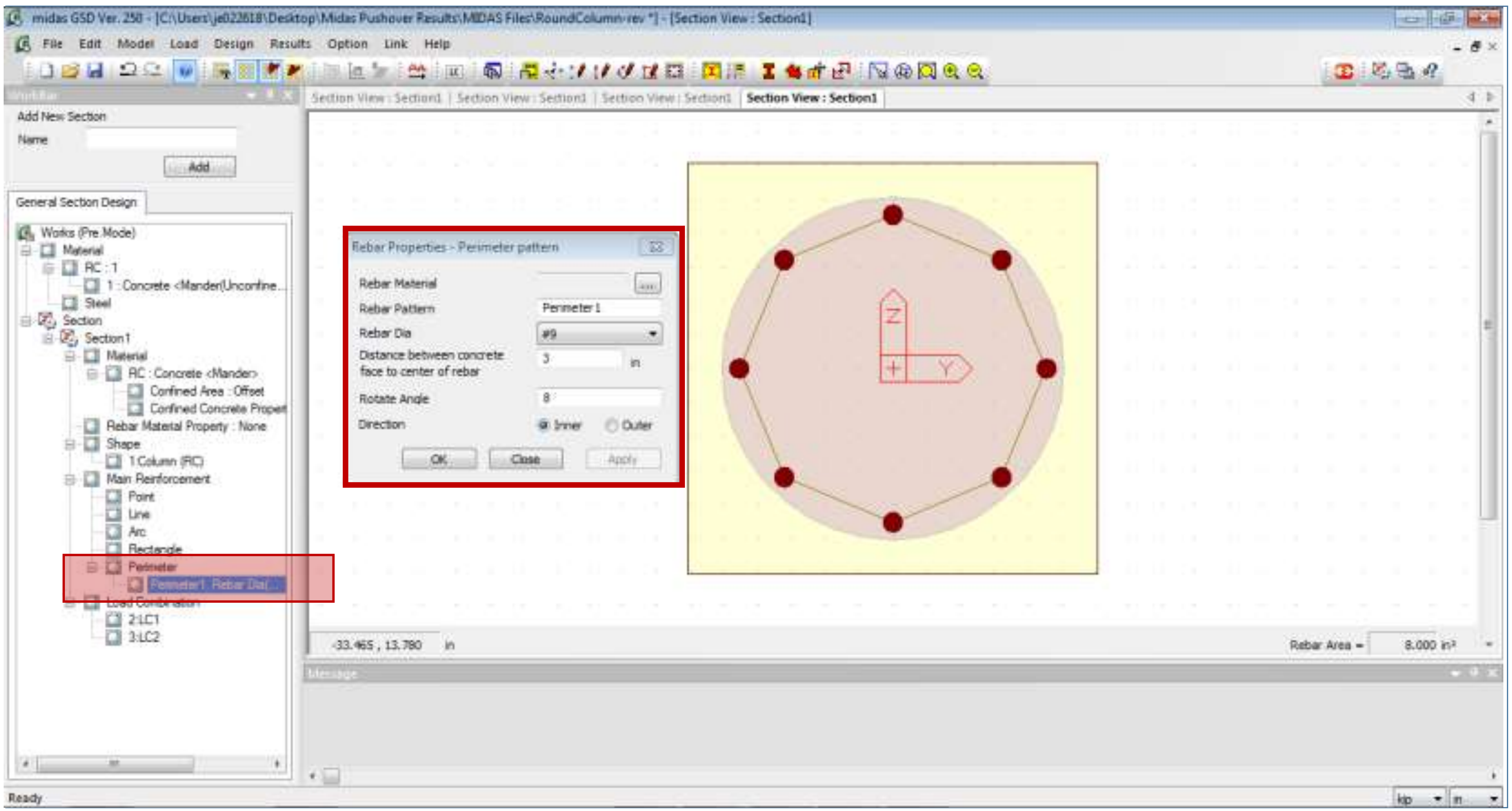
Pushover Analysis in Midas Civil 3D

- GSD – Steel Properties



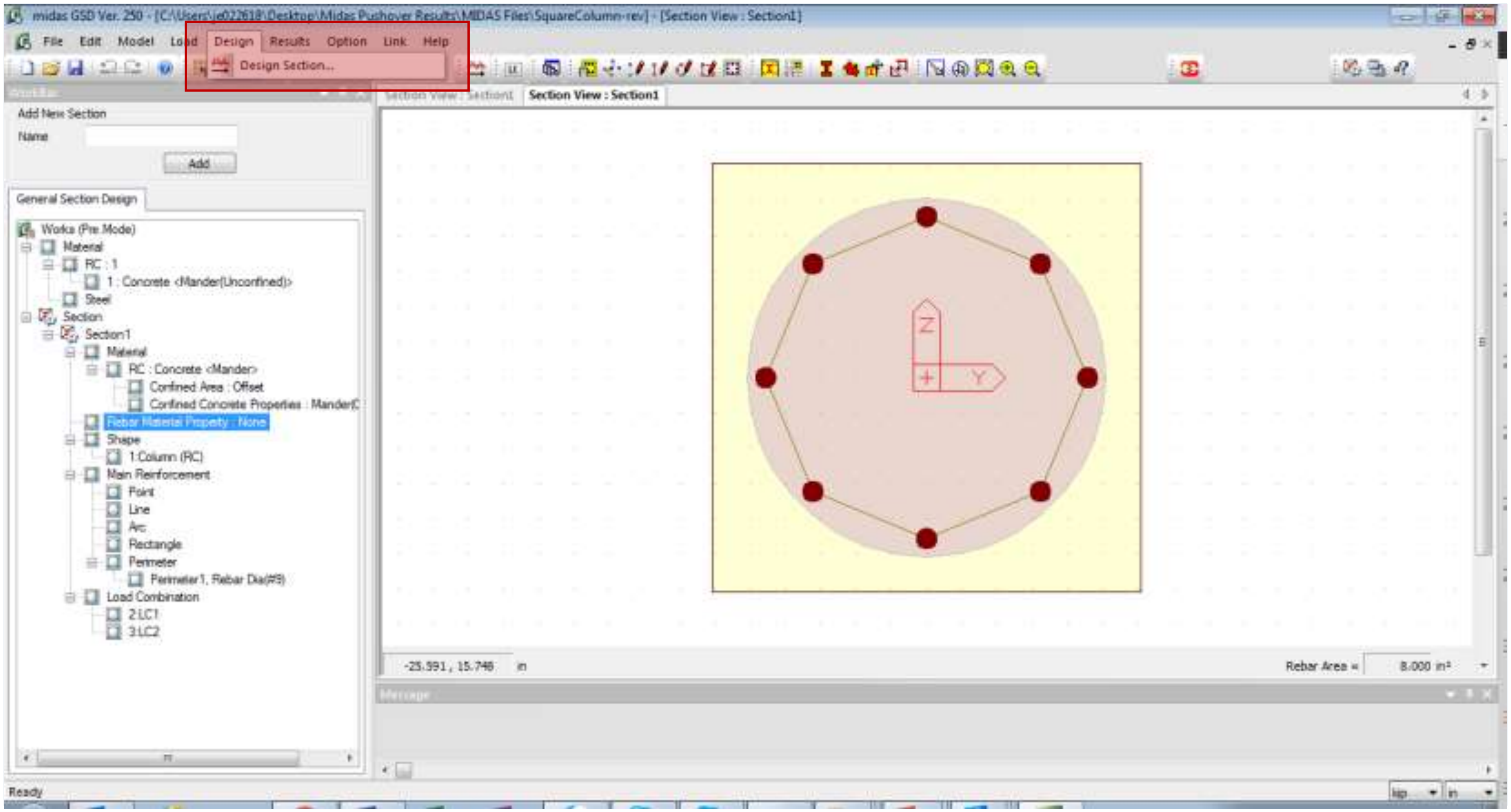
Pushover Analysis in Midas Civil 3D

- GSD – Steel Pattern



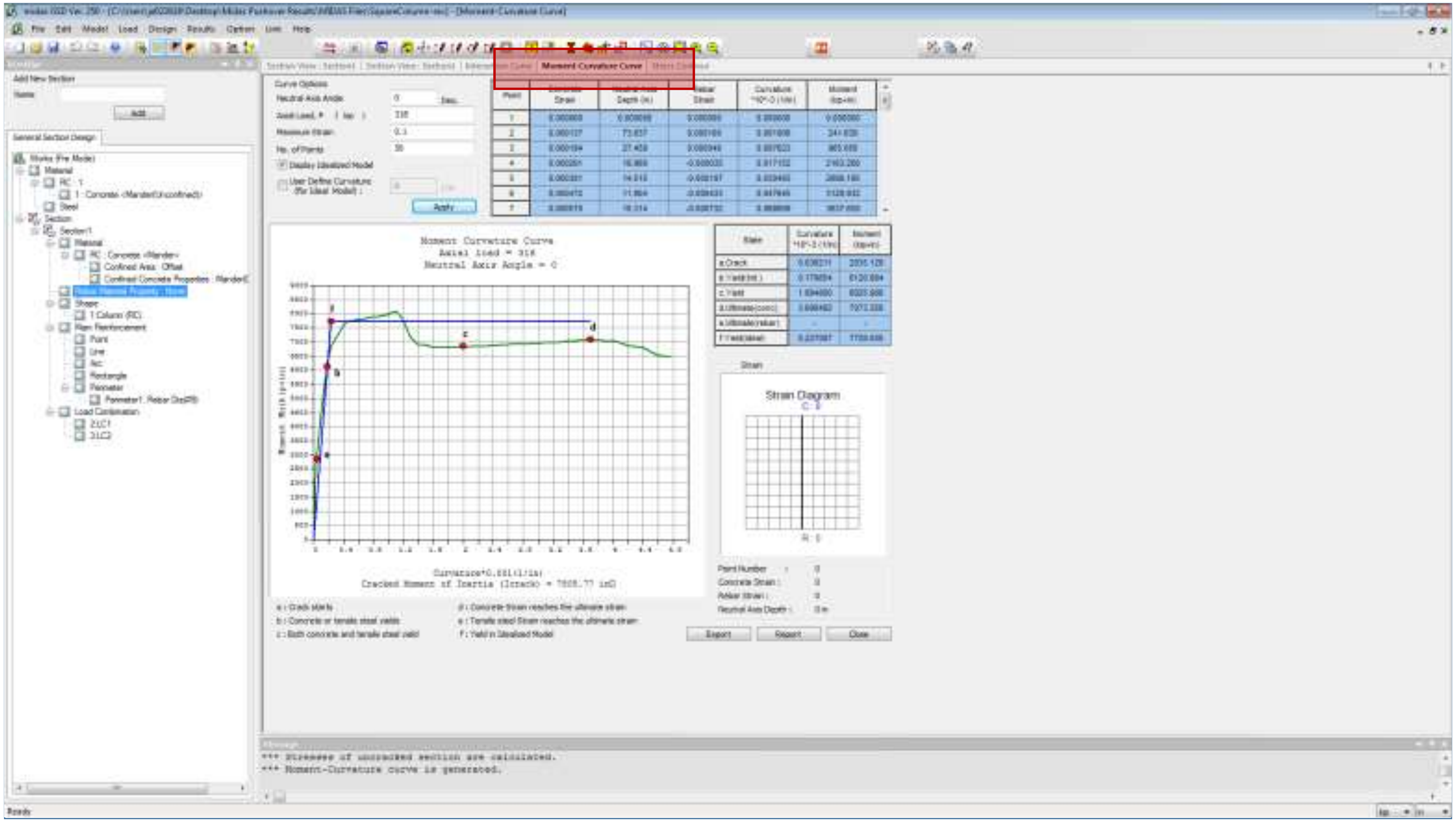
Pushover Analysis in Midas Civil 3D

- GSD – Run Analysis



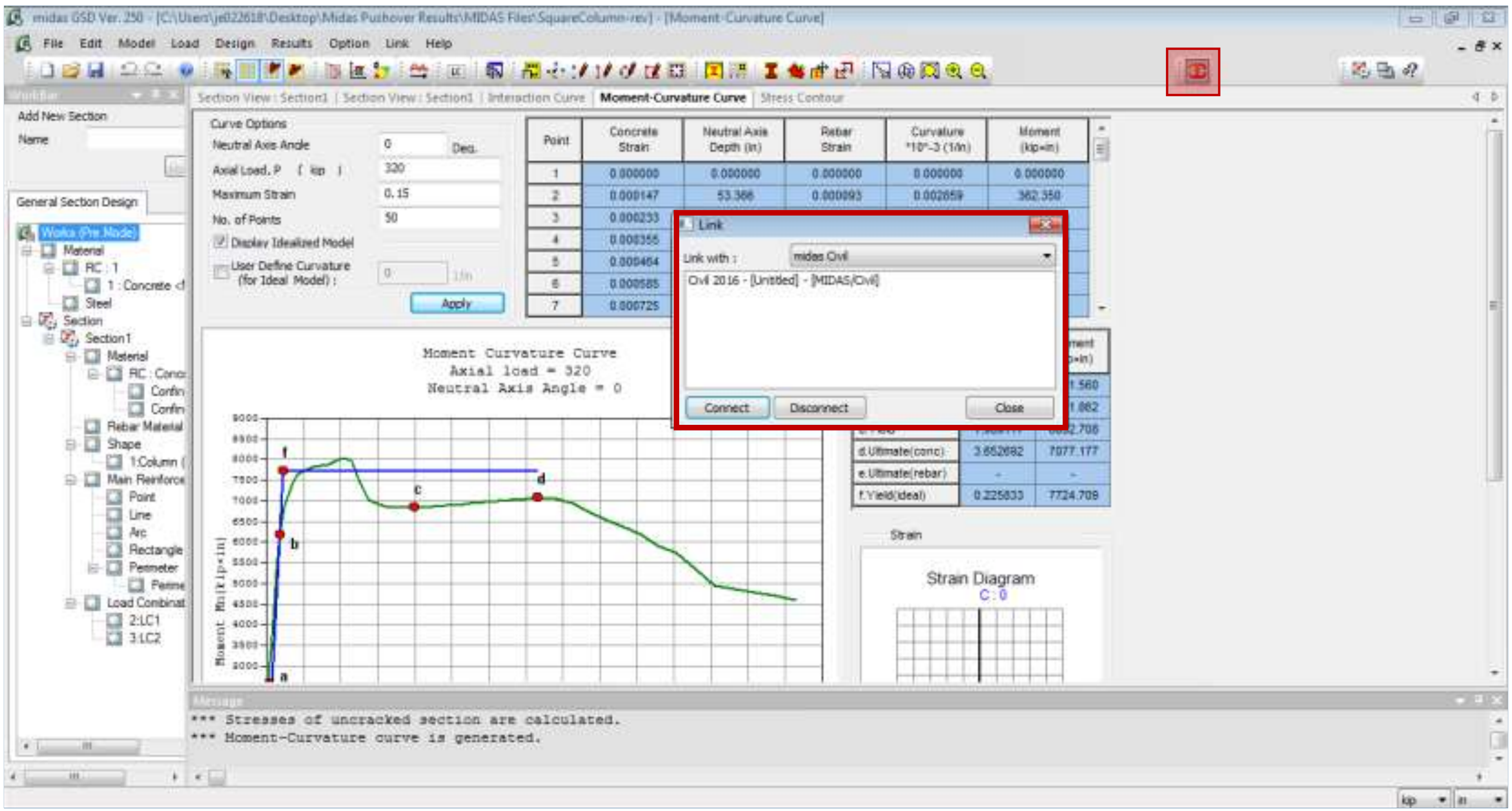
Pushover Analysis in Midas Civil 3D

- GSD – Moment Curvature



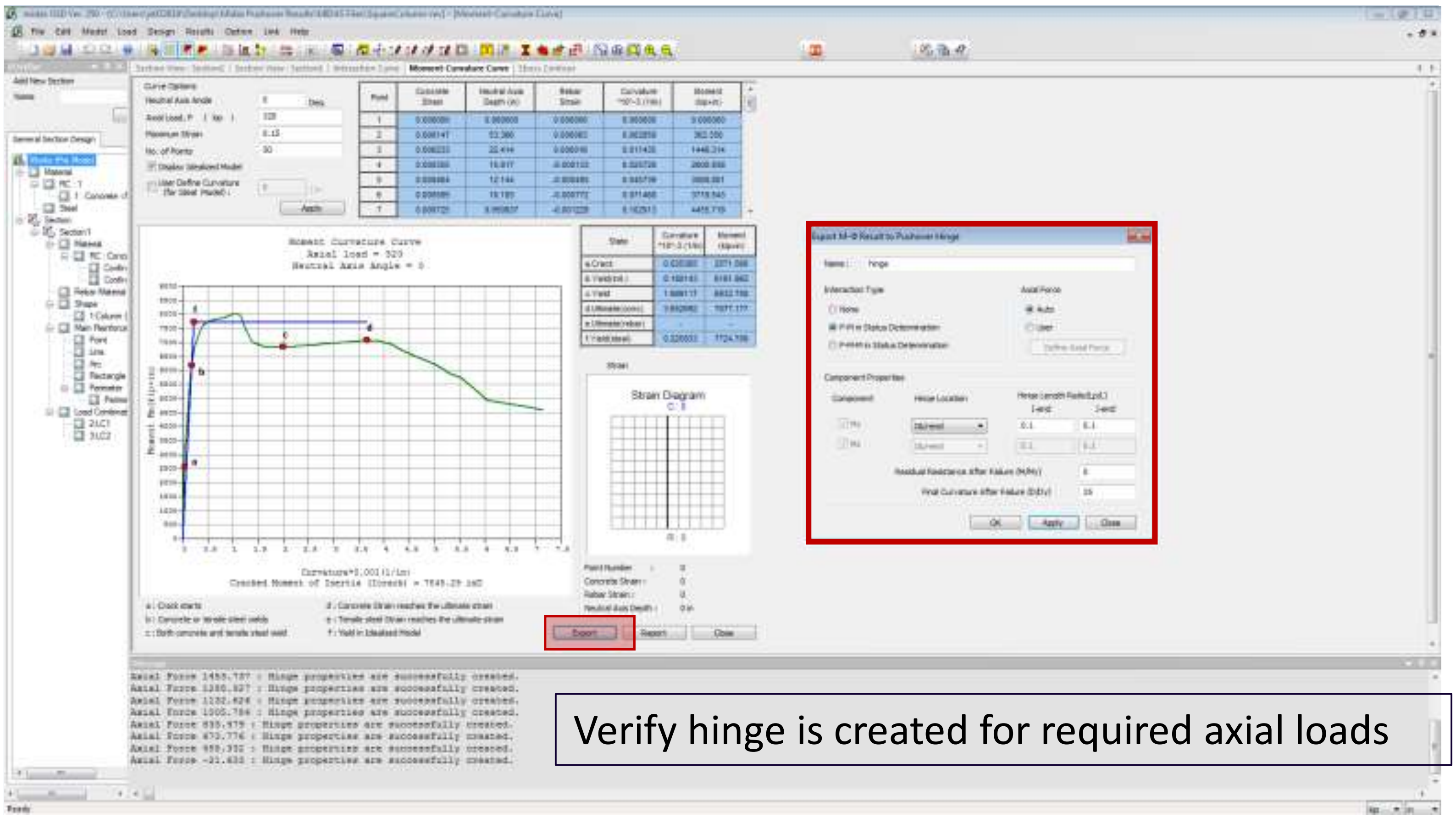
Pushover Analysis in Midas Civil 3D

- GSD – Link to Midas Civil



Pushover Analysis in Midas Civil 3D

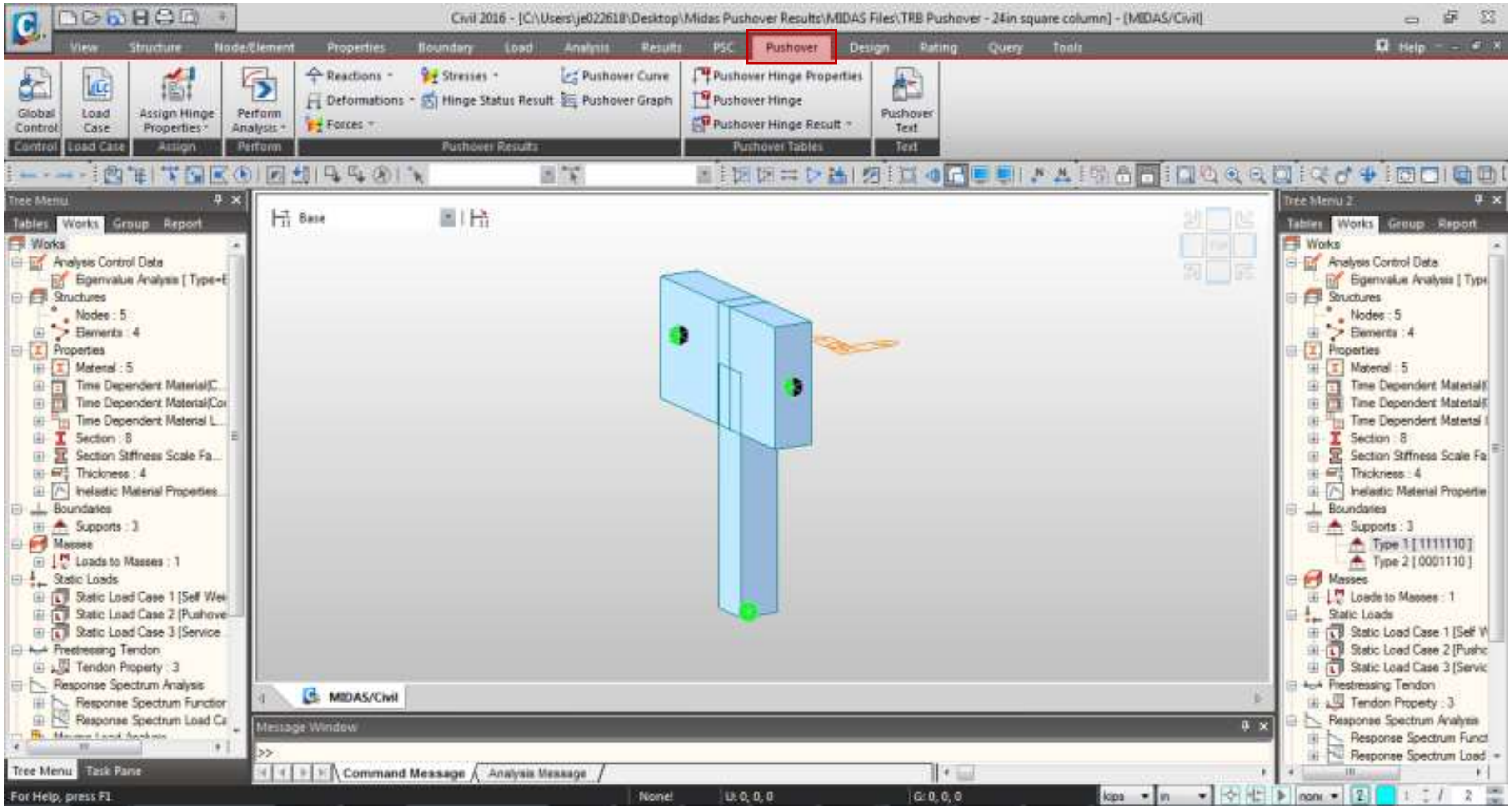
- GSD – Export Hinge



Verify hinge is created for required axial loads

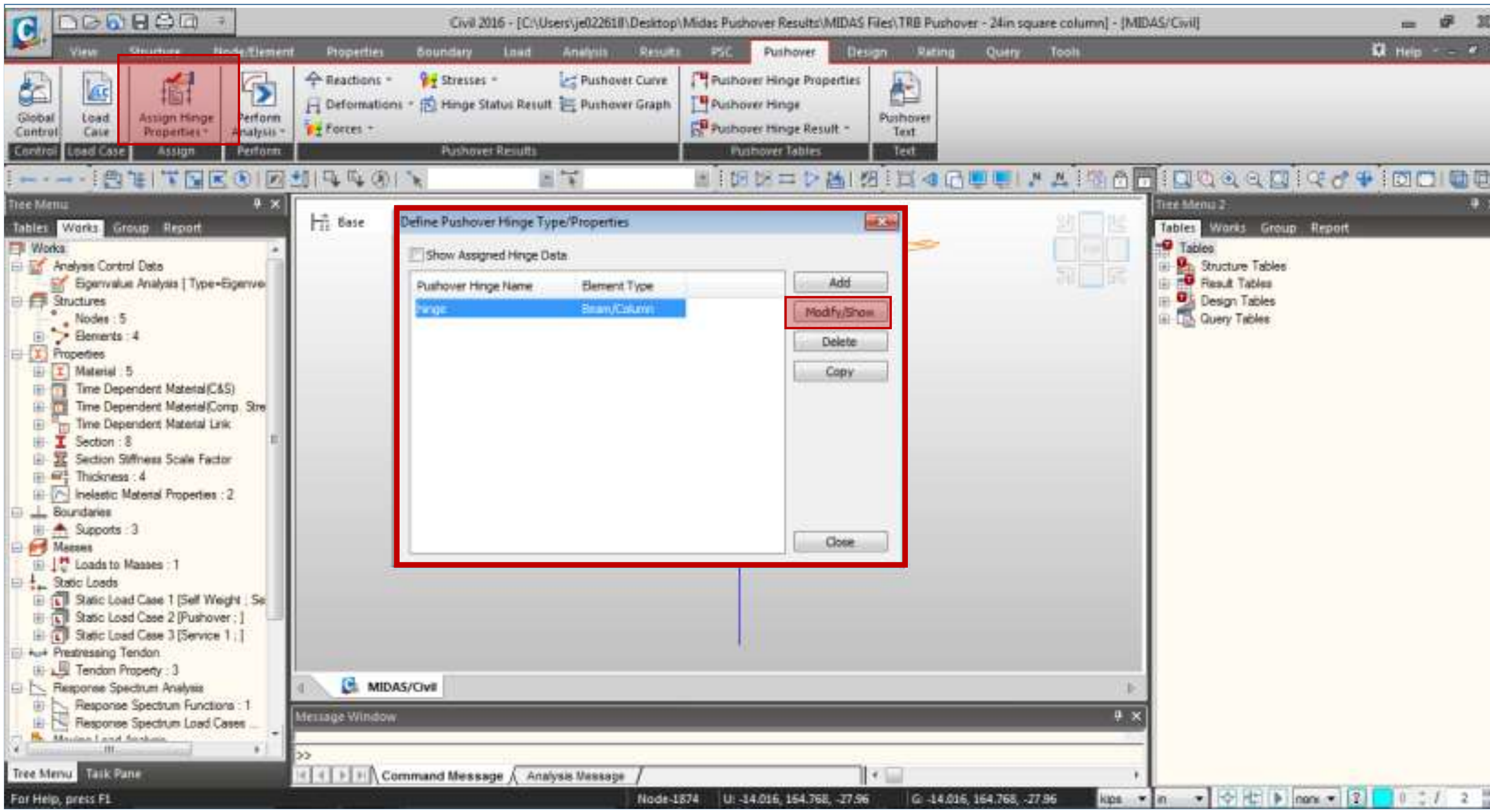
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis



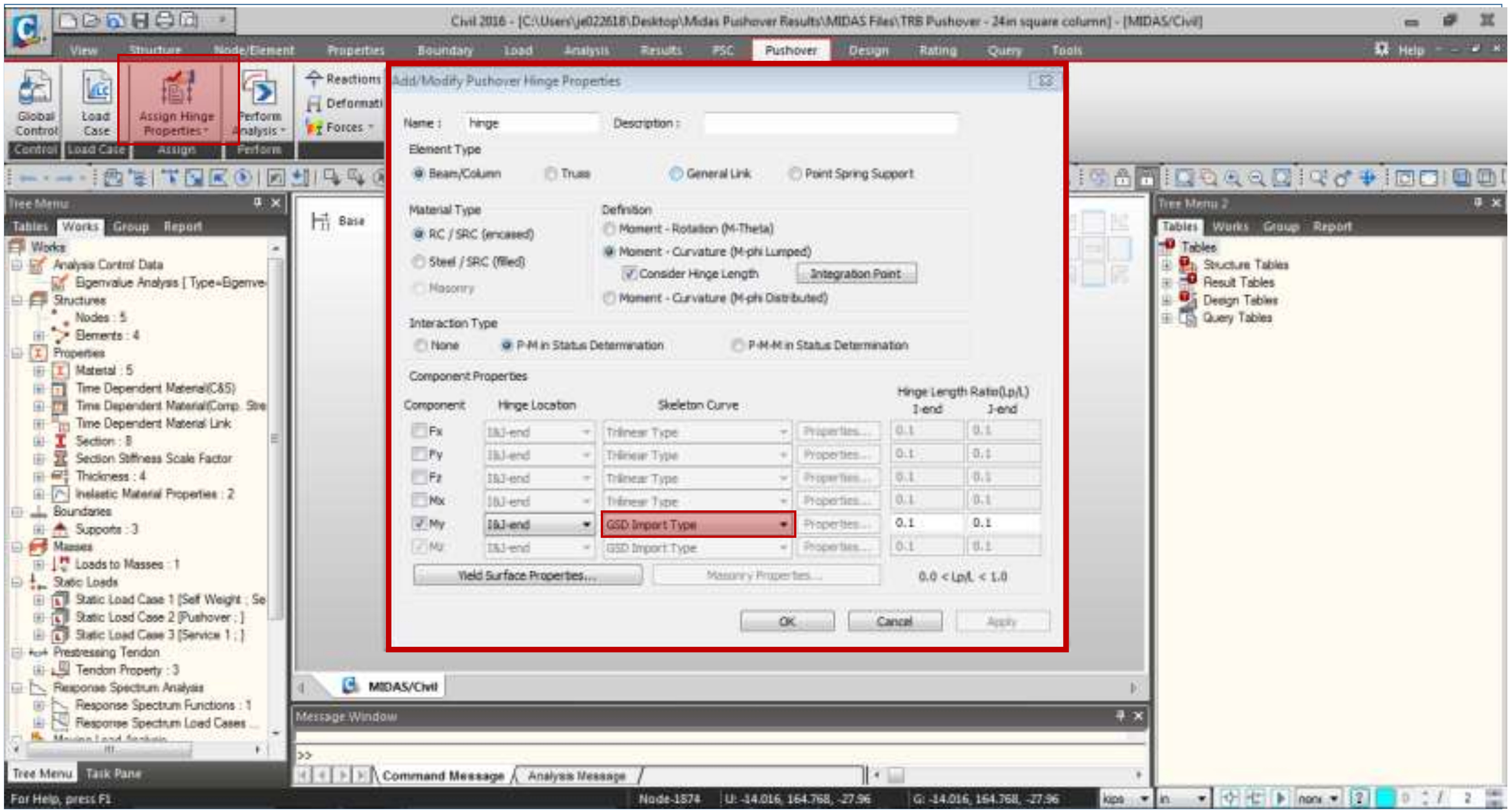
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Define Hinge



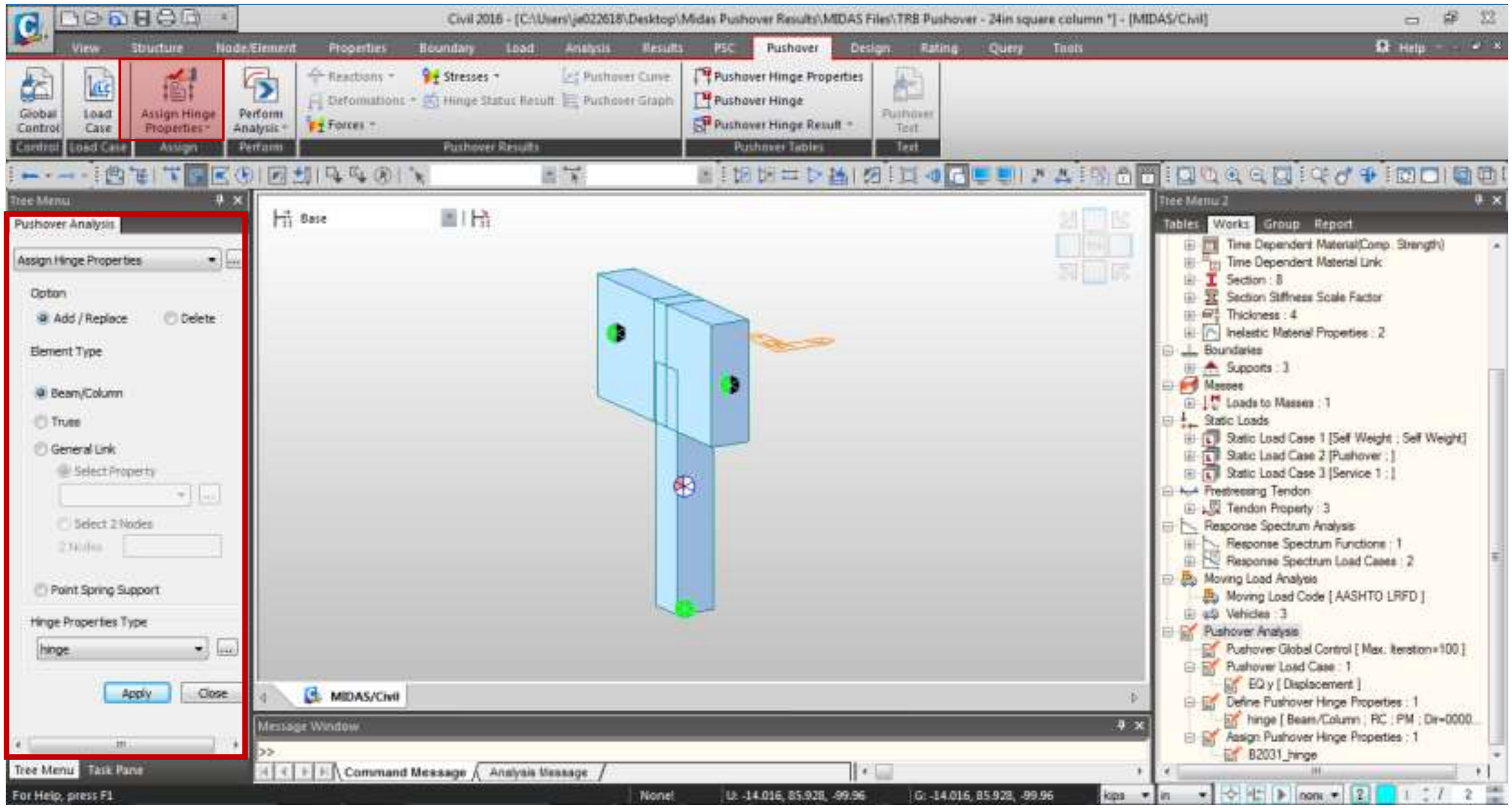
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Define Hinge



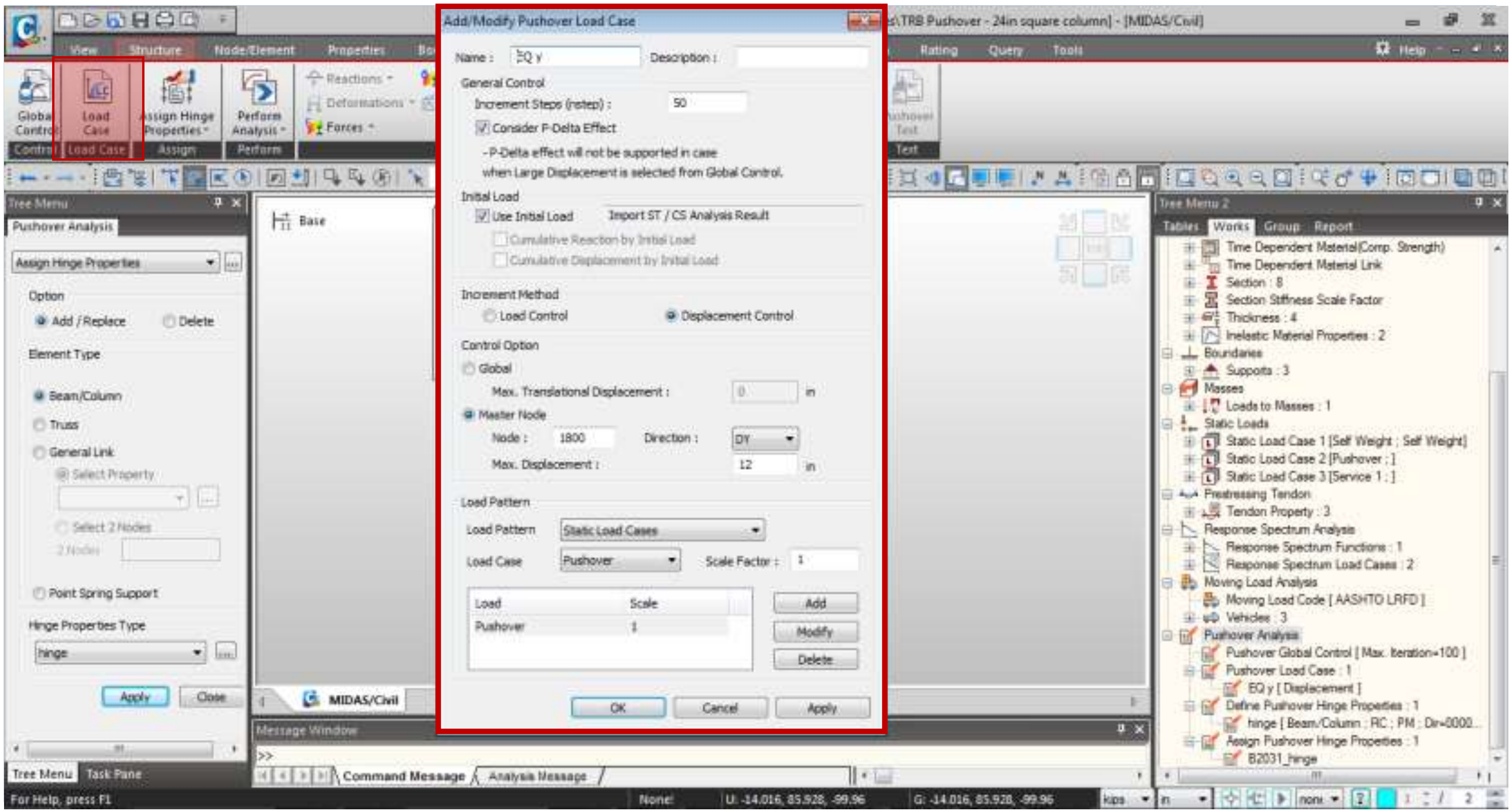
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Assign Hinge



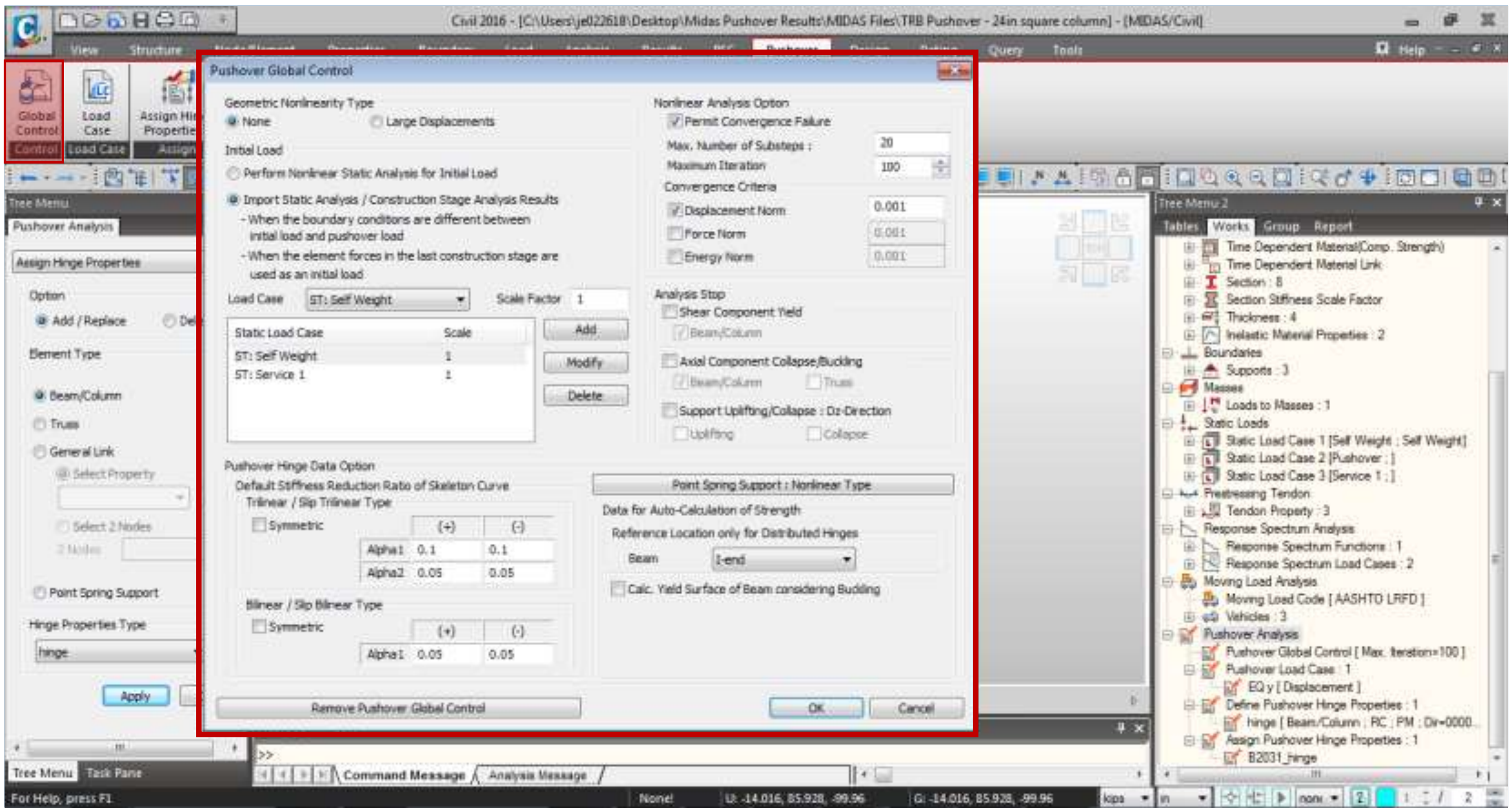
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Load Case



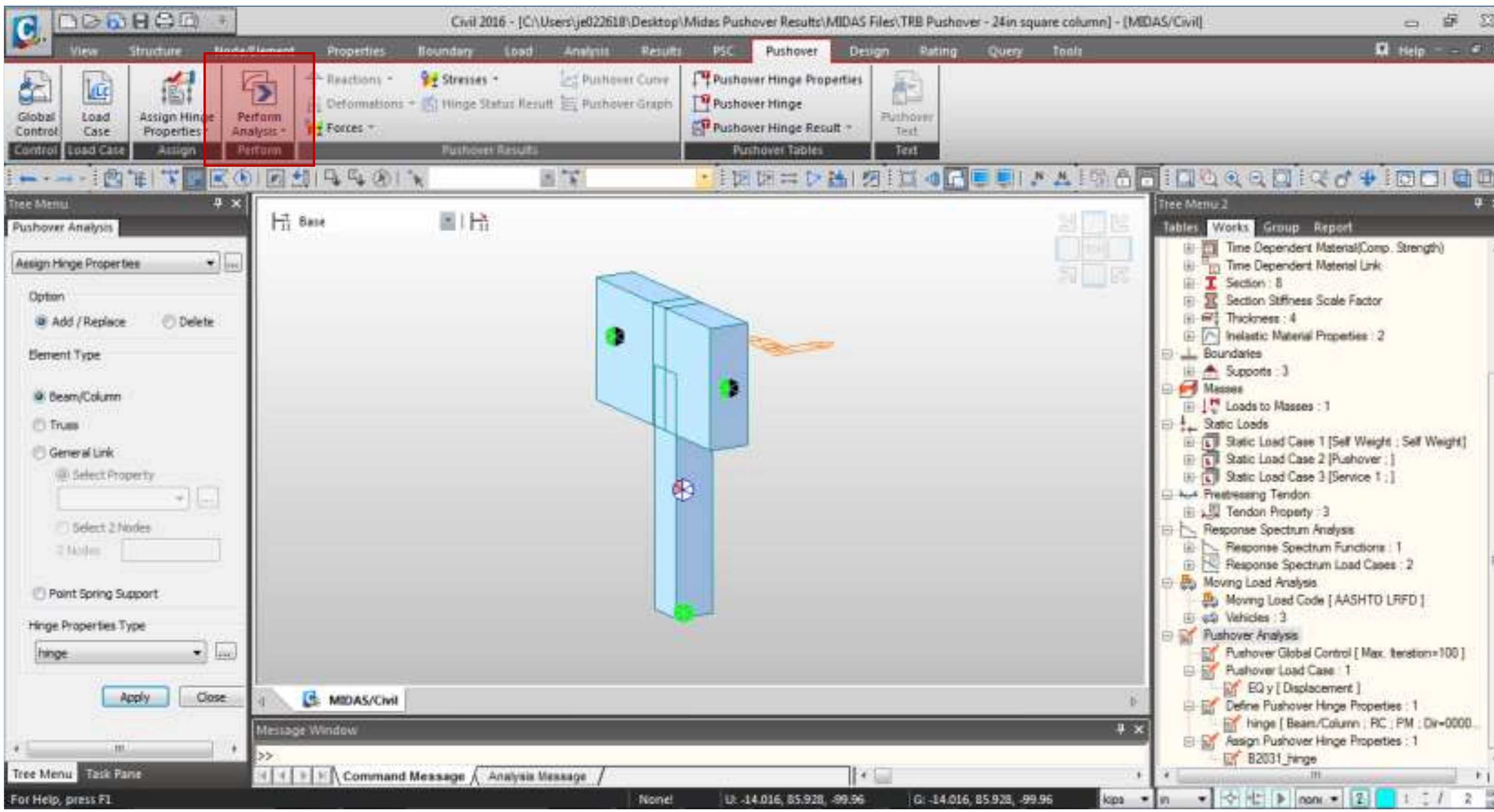
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Global Control Options



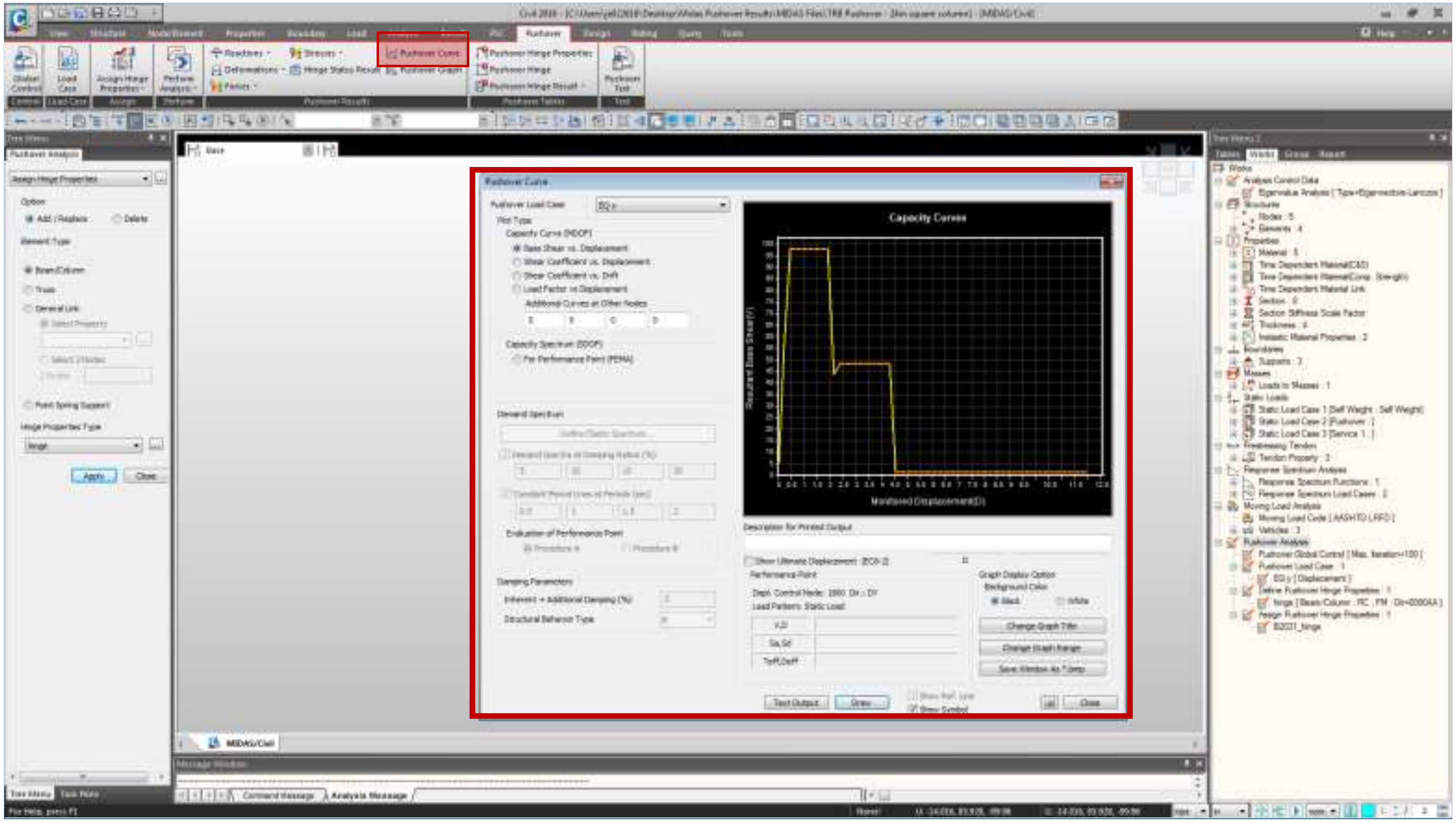
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Perform Analysis



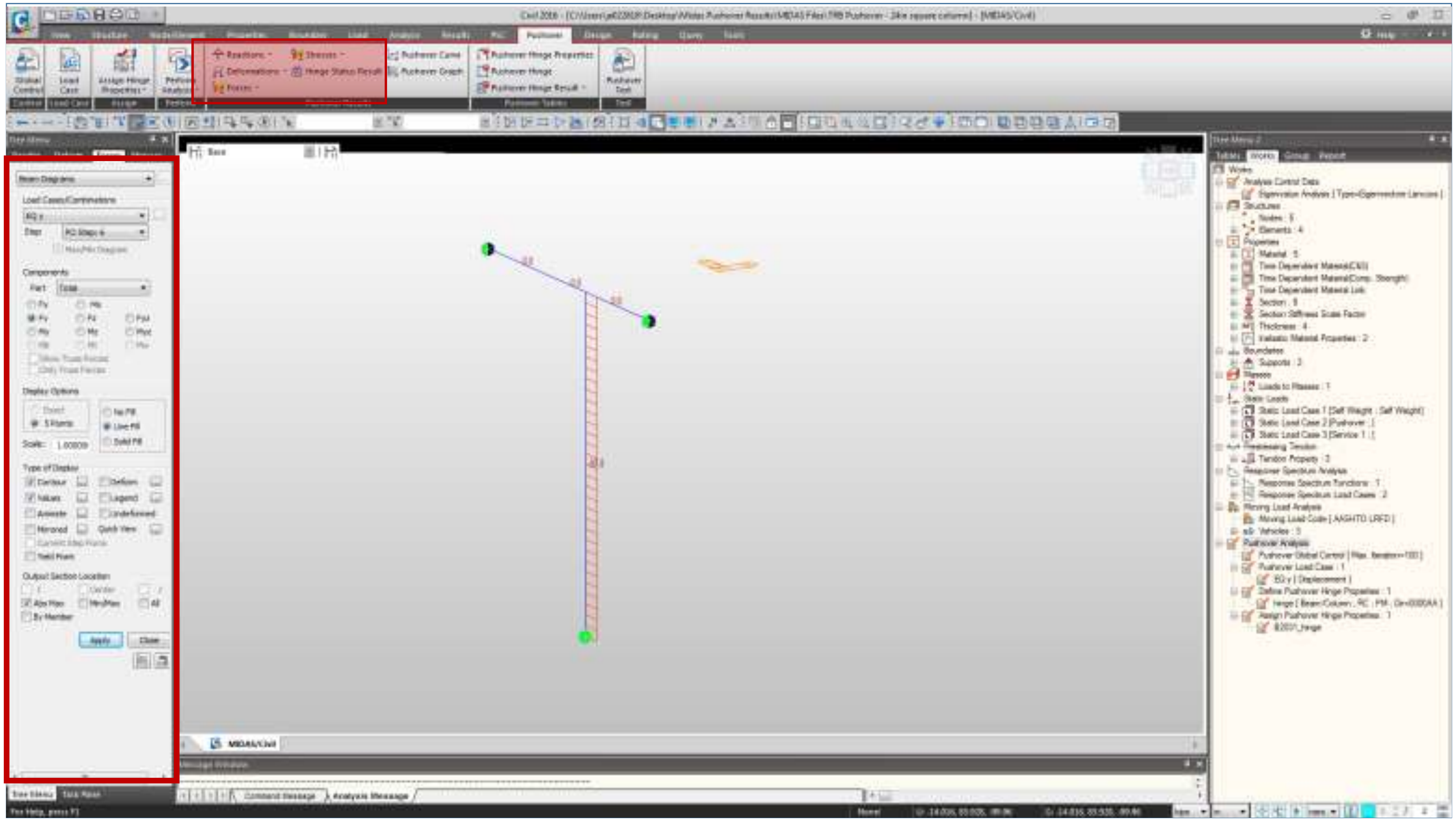
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Results – Pushover



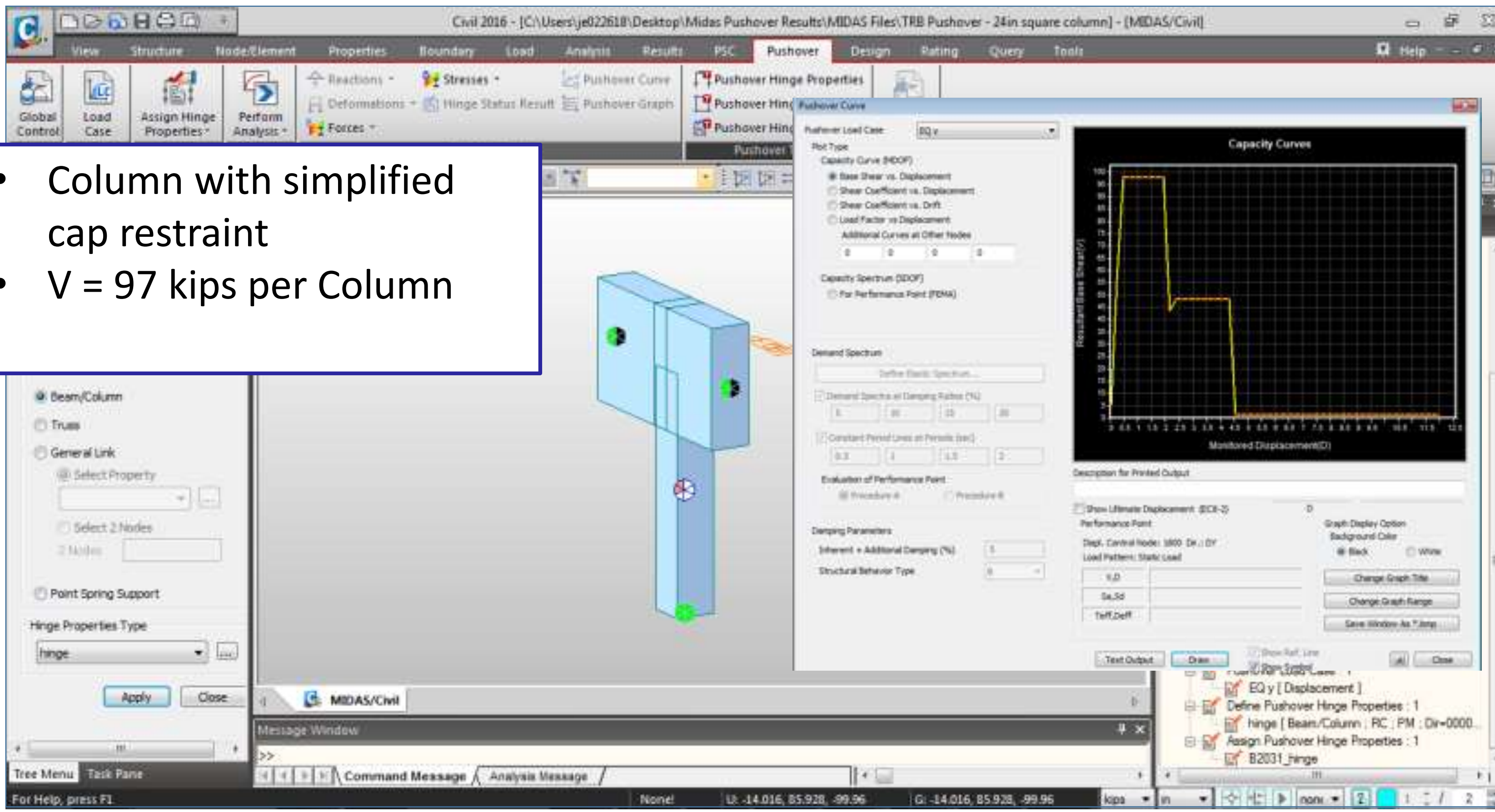
Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Results – Force Effects



Pushover Analysis in Midas Civil 3D

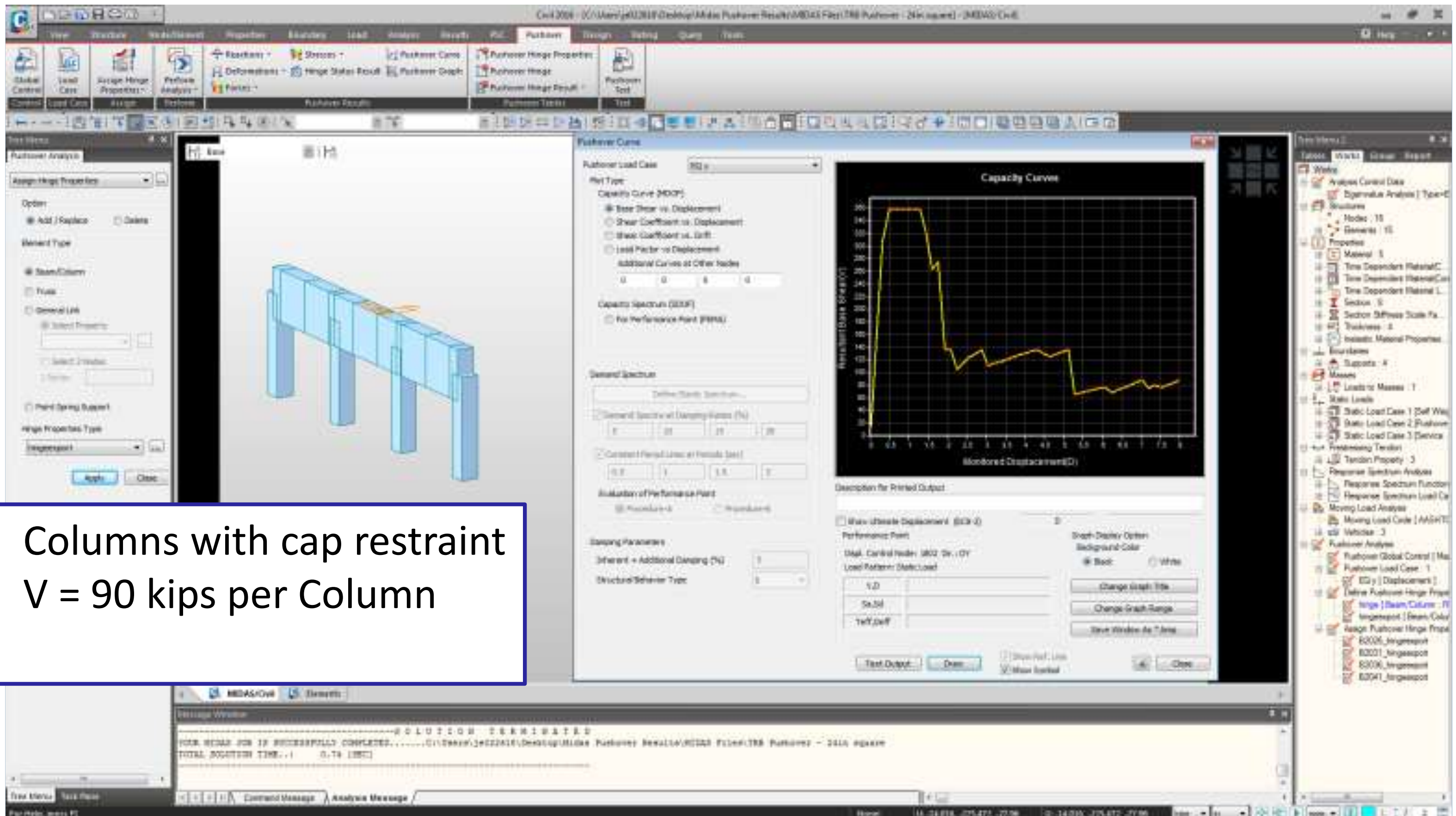
- Midas - Pushover Analysis – Single Column



- Column with simplified cap restraint
- V = 97 kips per Column

Pushover Analysis in Midas Civil 3D

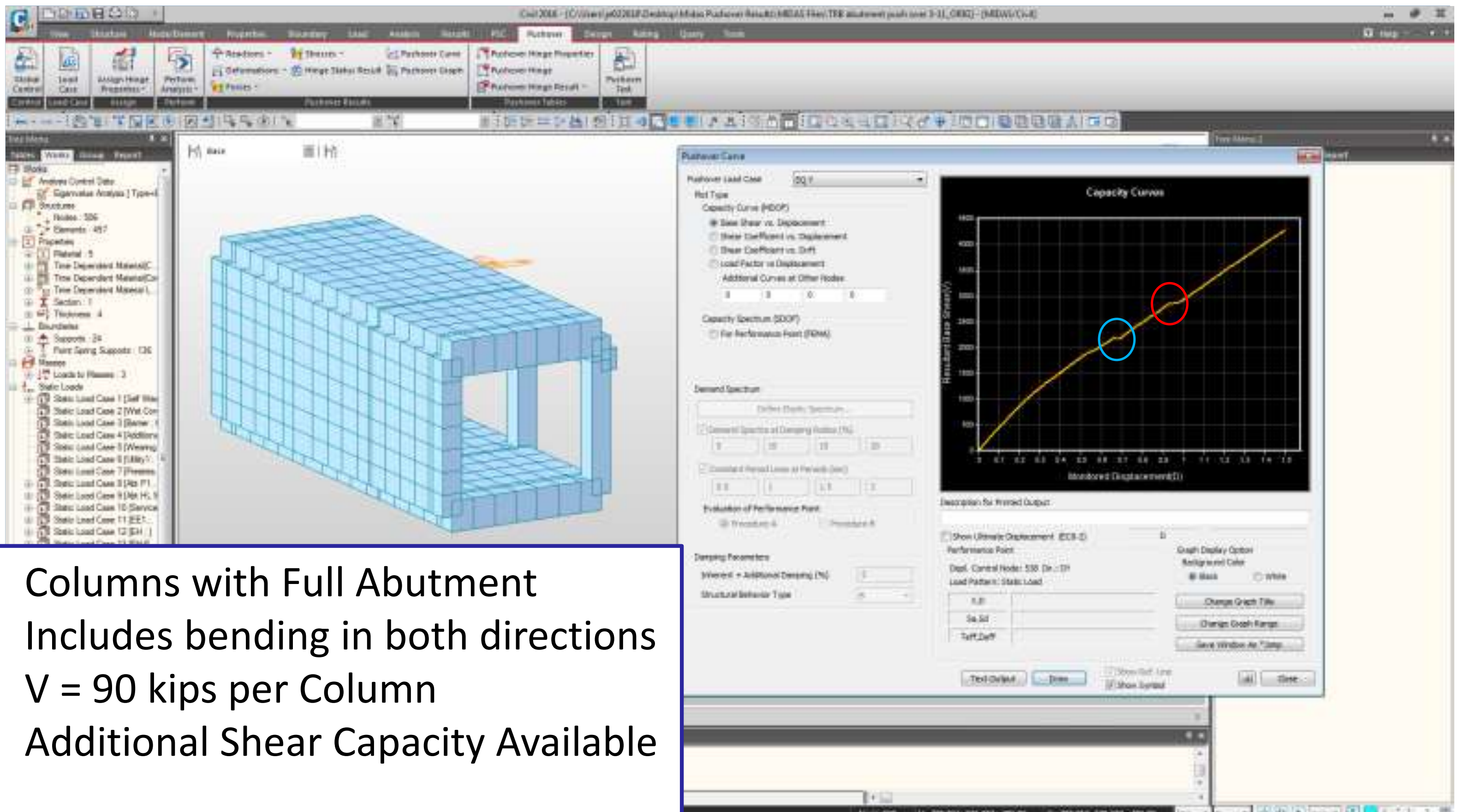
- Midas - Pushover Analysis – Frame



- Columns with cap restraint
- V = 90 kips per Column

Pushover Analysis in Midas Civil 3D

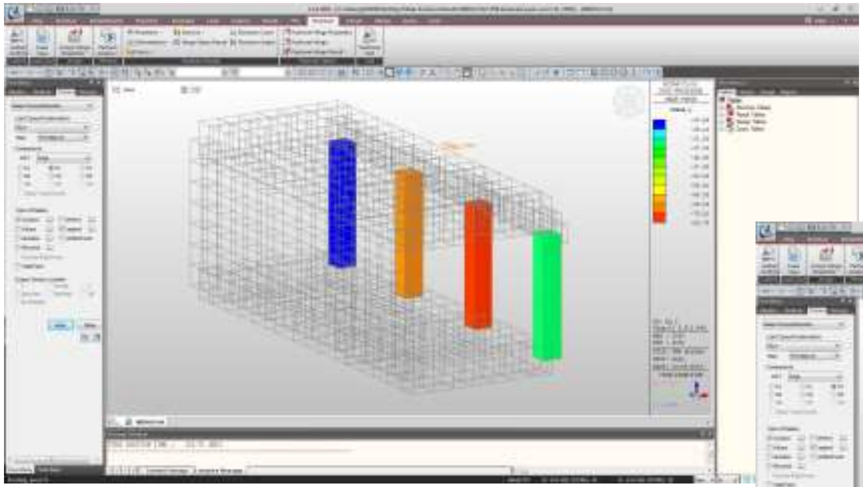
- Midas - Pushover Analysis – Full Plate Model



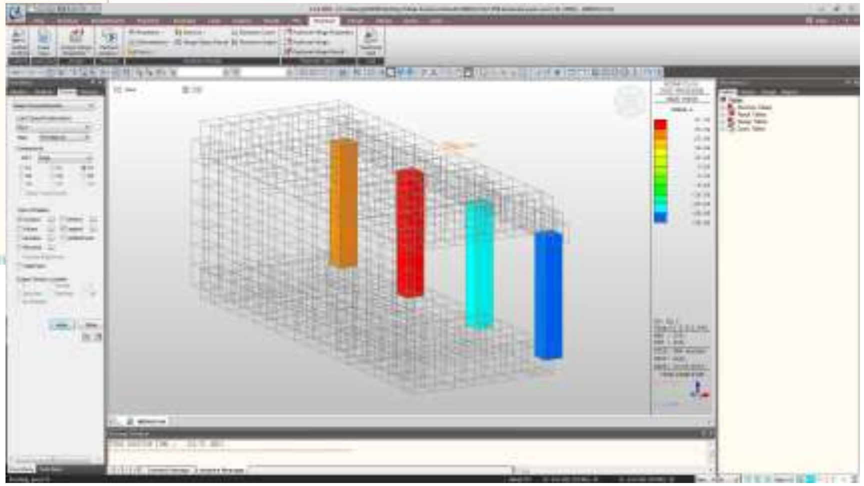
- Columns with Full Abutment
- Includes bending in both directions
- V = 90 kips per Column
- Additional Shear Capacity Available

Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Full Plate Model



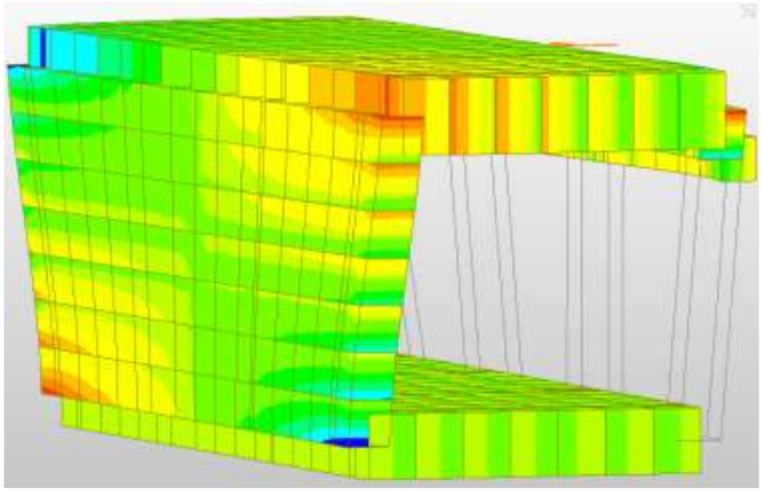
Transverse Shear

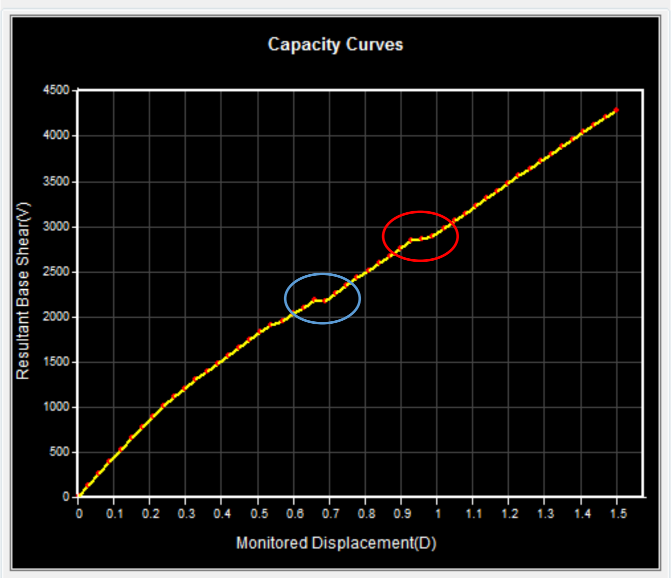


Longitudinal Shear

Pushover Analysis in Midas Civil 3D

- Midas - Pushover Analysis – Full Plate Model
  - Column Loses Shear Capacity at Step 33
  - Continues to Load backwall
  - Element model is required for Backwall Hinging



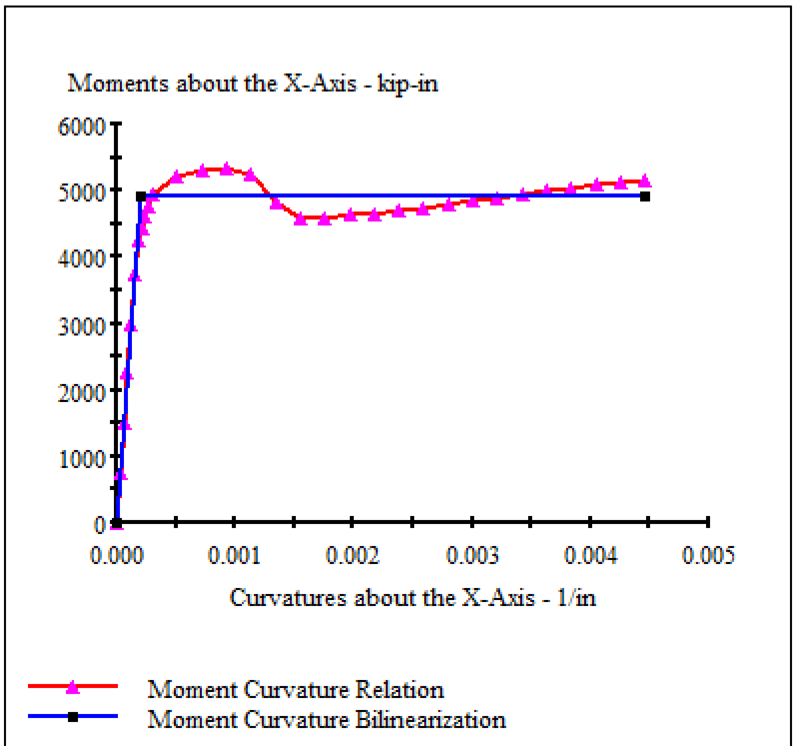


Result Comparison

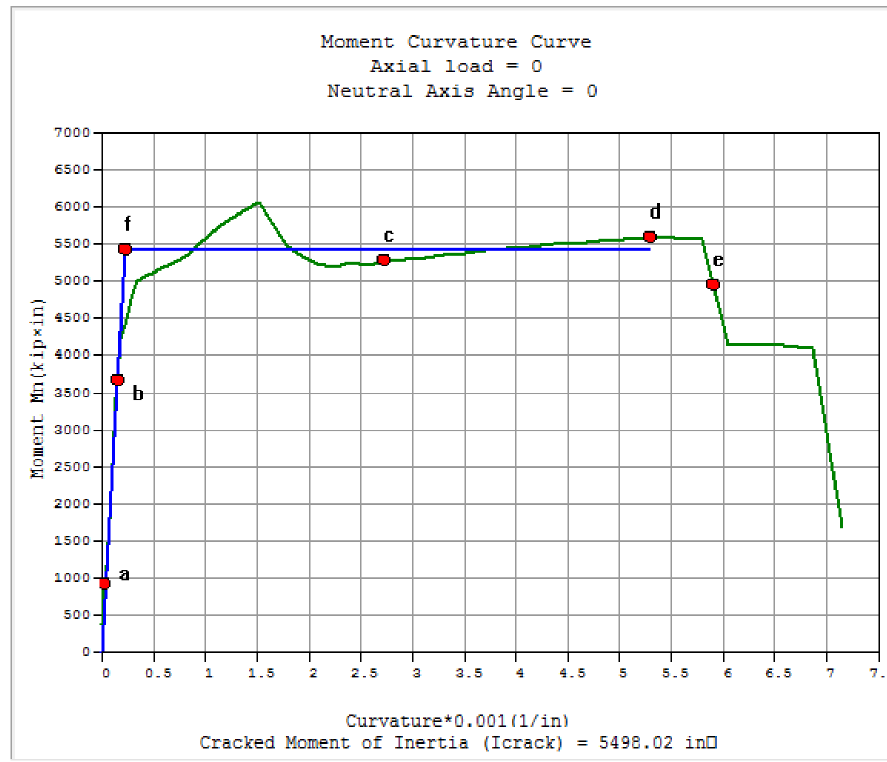
MIDAS ch2m:

Result Comparison

- Moment Curvature



Xtract Moment Curvature

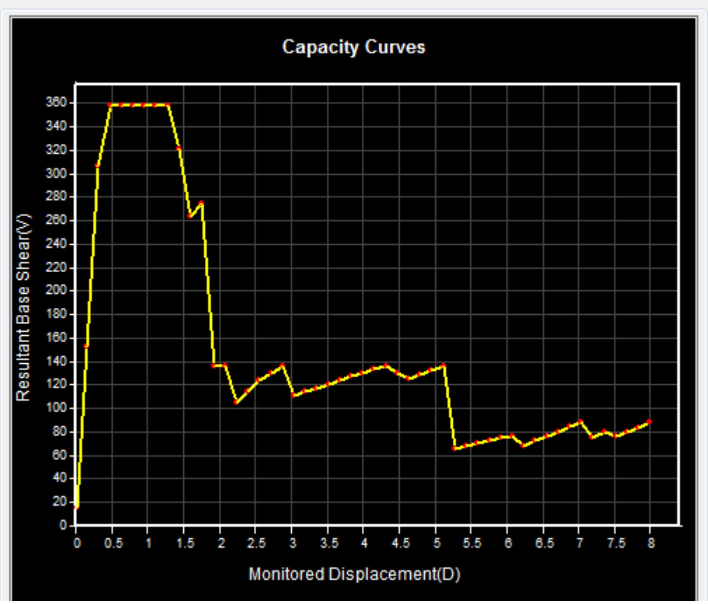


Midas GSD Moment Curvature

Result Comparison

- Pushover Analysis
  - Both methods resulted in nearly V=90k per column
  - Slight Variations from Interaction with Model Elements

Trial 1					
P_ot	P_top	P_bott	Mo_top	Mo_bott	Vo
kips	kips	kips	k-ft	k-ft	kips
-99.52	170	179	588.9	593.5	83.27
-33.17	237	245	623.5	627.8	88.12
33.17	303	312	657.1	661.1	92.83
99.52	370	378	688.4	692.4	97.24
			Total		361.46



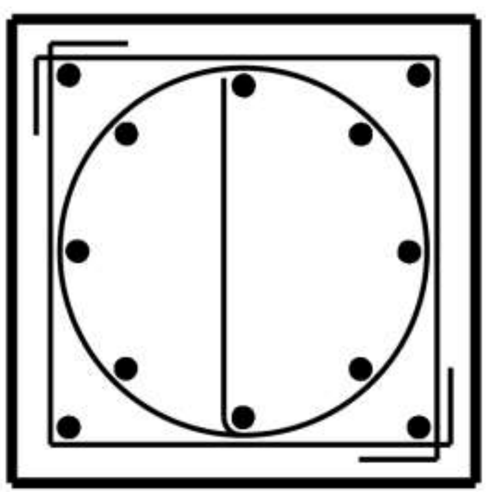
Result Comparison

- Reasons for differences
  - Steel Model
    - Xtract – Bilinear with Strain Hardening
    - GSD – Kent and Park with Strain Hardening
    - Results vary by 25% without strain hardening
  - Variations in calculations

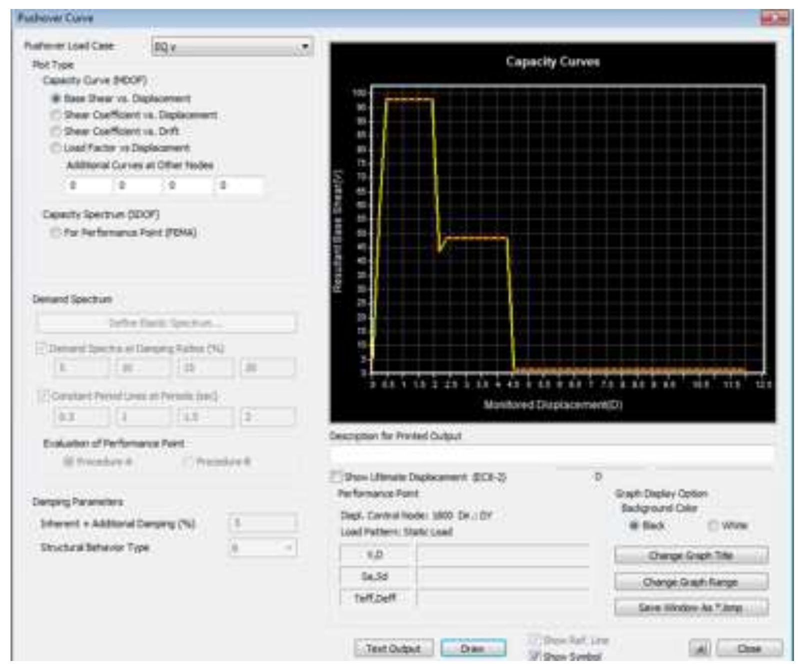
Shear Design and Element Detailing

Shear Design

- Followed AASHTO LRFD Guide Spec – Section 8.6
  - Concrete Strength (Vc)
  - Rebar Strength considering spirals only (Vs)

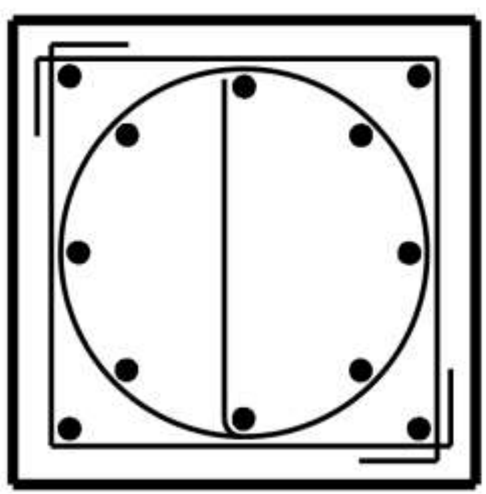


Column Detailing - Section

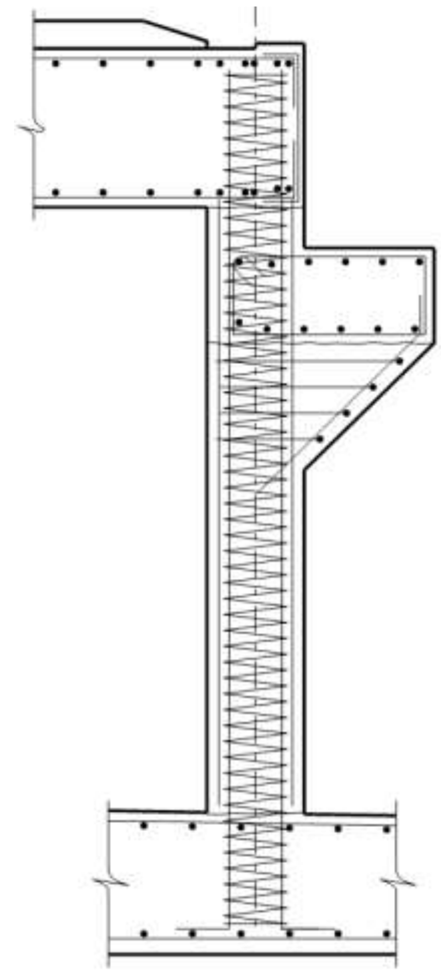


Element Detailing

- Columns
  - Caltrans SDC – Section 8
    - Longitudinal Embedment – 8.2
  - AASHTO LRFD Guide Spec – Section 8.8
    - Spiral terminations – 8.8.7



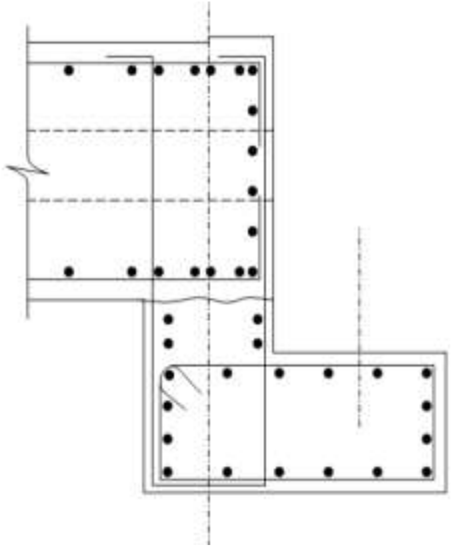
Column Detailing - Section



Column Detailing

Element Detailing

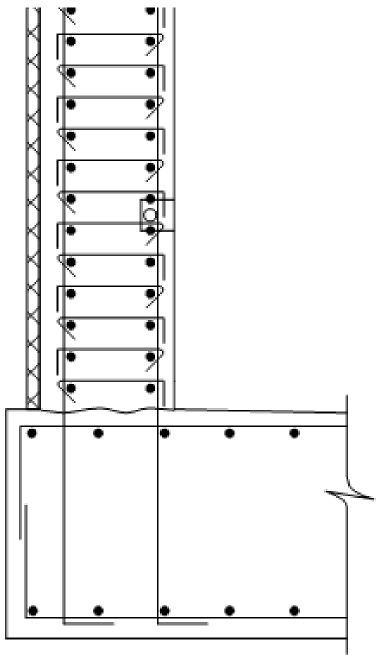
- Corbel Beam
  - AASHTO LRFD Guide Spec – Section 8.13
    - Determine Level of Detailing
    - Principal Stress Checks for SDC D
    - Calculated Based on Column Moments



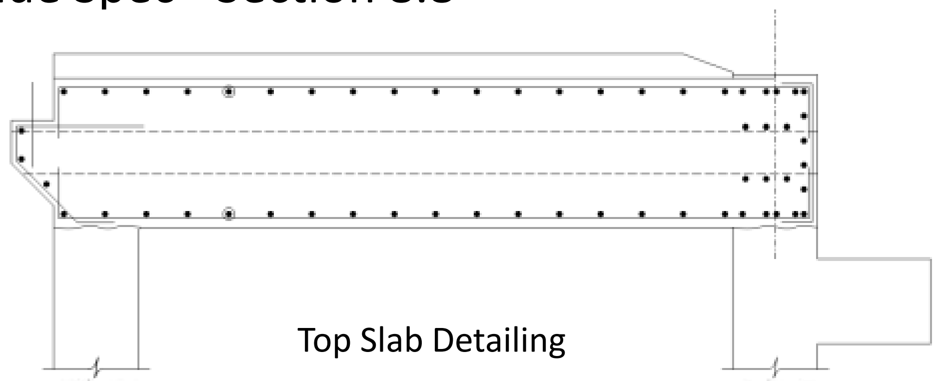
Corbel Detailing

Element Detailing

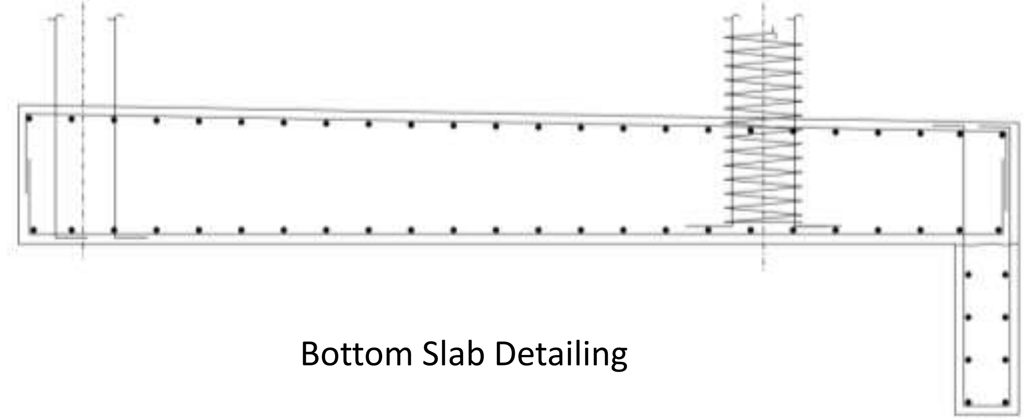
- Slabs
  - Caltrans SDC – Section 8
  - AASHTO LRFD Guide Spec - Section 8.8



Back Wall Detailing



Top Slab Detailing



Bottom Slab Detailing

Summary

- Elastic Analysis
- Inelastic Analysis
- Midas Civil 3D Pushover Analysis
- Result Checking
- Shear Design

Acknowledgements

- Midasoft
- Central Federal Lands
- CH2M
- Design Workshop
- LEAP – CONSPAN
- CSiBridge
- TxDOT
- XTRACT

References

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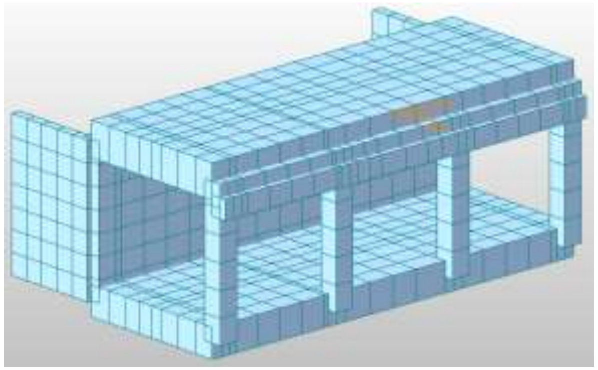
Questions



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