Special Elite Engineers Webinar Sequence

An Insider's Perspective

Wednesday, June 17th, 2015

3:00 PM – 4:00 PM EST

Our Elite Engineer of the Month: Vincent Nganga, PE

Copyright Materials

Speaker Information

Vincent Nganga

Senior Bridge Engineer

EDUCATION

- MS, Structural Engineering, Southern Illinois University, Edwardsville
- BS, Civil Engineering, Washington University in St. Louis
- BS, Mathematics, Rockford College, Rockford, Illinois

PAST PROJECTS

- I-270/US 33 Interchange Northwest Freeway Reconstruction, Columbus OH
- Columbus Crossroads design-build project, Columbus OH
- I-5 Everett HOV Design-Build Project, Everett WA

3D FEM Modeling and Seismic Analysis for Evaluating Demand and Capacity of Highway Bridges

Vincent Nganga, PE

Senior Bridge Engineer

June 17th, 2015

1. Introduction

Illustrate the procedure used to perform nonlinear static "pushover" analysis in both the longitudinal and transverse directions.

- **To perform the pushover analysis in the longitudinal direction, the entire bridge is pushed in order to include the frame action of the superstructure and adjacent bents.**
- **To perform the pushover analysis in the transverse direction, a bent may be isolated using the midas Civil "staged construction" feature OR the entire bridge can be pushed.**

2. Model Setup

- Overview of Model
- Foundations Modeling
- Material Modeling
- Column modeling
- Gravity Loads

3. Displacement Demand Analysis

- **Modal Analysis**
- **Response Spectrum Analysis**
- **Displacement Demand**

4. Displacement Capacity Analysis

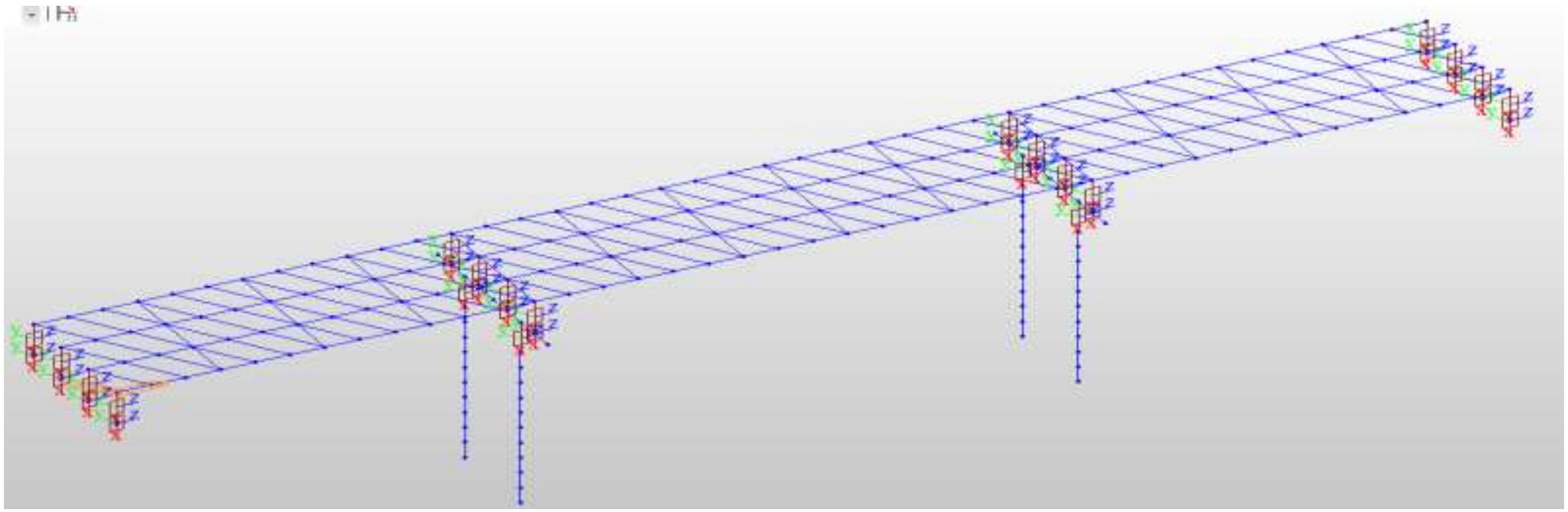
- **Hinge Definitions and Assignments**
- **Pushover Analysis**

5. AASHTO LRFD Code Requirements

- P-Δ Capacity Requirement Check
- Minimum Lateral Strength Check
- Structure Displacement Demand/Capacity Check
- Member Ductility Requirement Check
- Column Shear Demand/Capacity Check
- Balanced Stiffness and Frame Geometry Requirement Check

6. Model Overview

- Three spans 54' , 77' and 54' in length
- Four Prestressed concrete girder lines with 8'-6" spacing
- 8" concrete deck with 34' out-to-out width
- Beams continuous and fixed at the intermediate piers
- Two-5' diameter columns at the intermediate bents on spread footings
- Abutments free in the longitudinal direction and fixed transversely



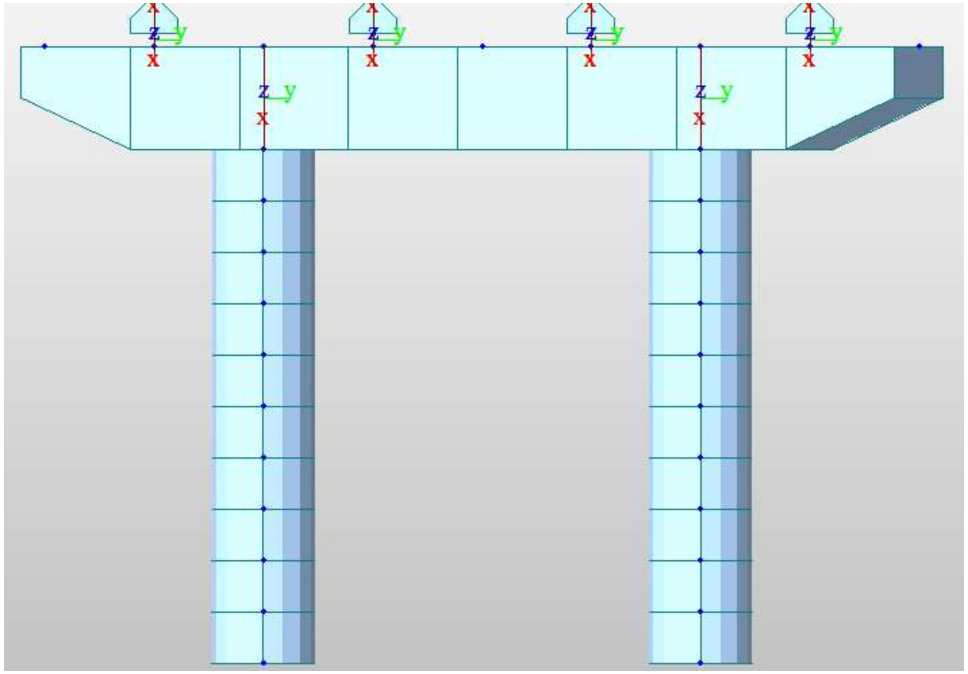
6.1 Foundations Model - Soils

- **The soil parameters used are G = 1,700 ksf and v = 0.35**
- **At the piers, the soil springs could be generated using the method for spread footings**

Degree of Freedom	K_{sur}
Translation along x-axis	$\frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65}+1.2\right]$
Translation along y-axis	$\frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65}+0.4\frac{L}{B}+0.8\right]$
Translation along z-axis	$\frac{GB}{1-v}\left[1.55\left(\frac{L}{B}\right)^{0.75}+0.8\right]$
Rocking about x-axis	$\frac{GB^3}{1-v}\left[0.4\left(\frac{L}{B}\right)+0.1\right]$
Rocking about y-axis	$\frac{GB^3}{1-v}\left[0.47\left(\frac{L}{B}\right)^{2.4}+0.034\right]$
Torsion about z-axis	$GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45}+0.51\right]$

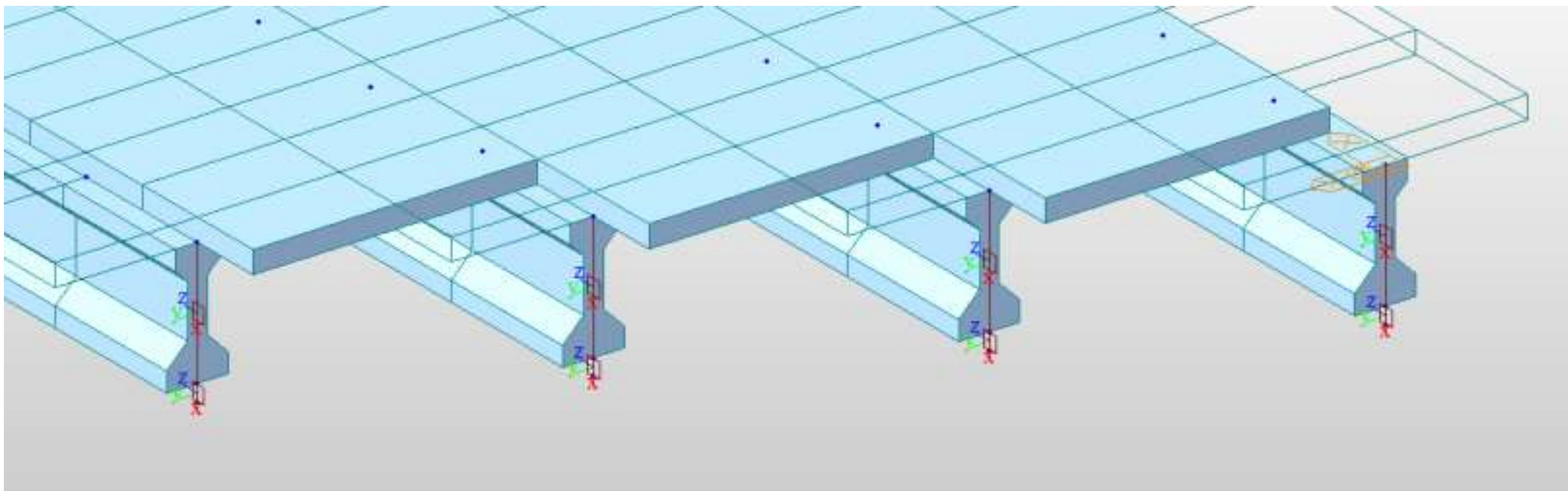
6.2 Foundations Model - Piers

- The springs used in the demand model (response-spectrum model) are the same as the springs used in the capacity model (pushover model)
- Note that it is also acceptable to conservatively use fixed base columns for the capacity model.



6.3 Foundations Model - Abutments

- **AASHTO Guide Specifications for LRFD Seismic Bridge Design require the stiffness of the transverse abutments be modeled.**
- **The girder joint restraint assignments at the abutments are as follows**



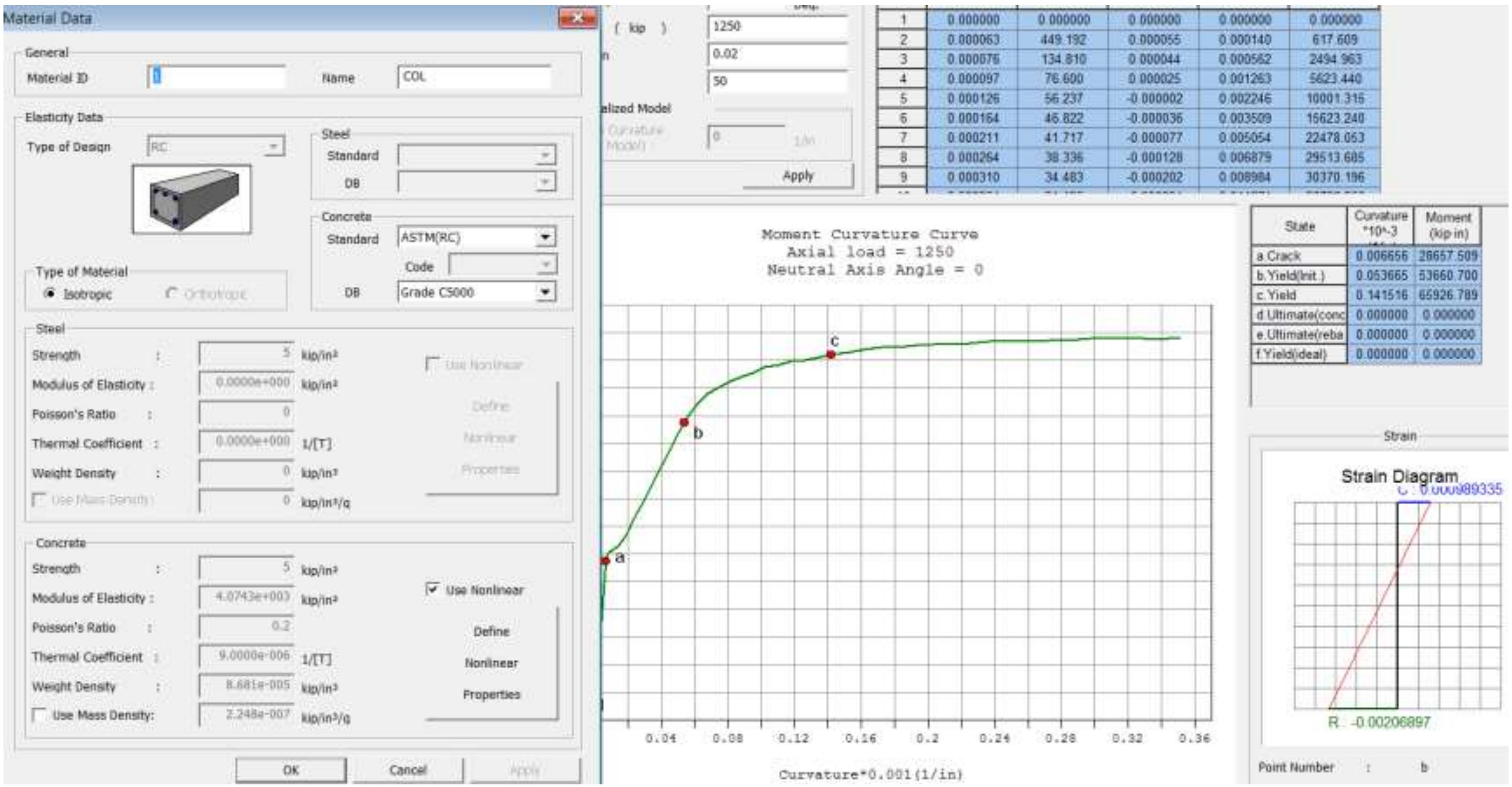
6.3 Material

Material Name	Material Type	Section Property For (Location)	Material Unit Wt. (pcf)	Weight for Modulus of Elasticity (pcf)
Deck - 4000 psi	Concrete	Deck	155	150
Other - 4000 psi	Concrete	CrossBeams & Diaphragms	150	145
Column - 5000 psi	Concrete	Columns	150	145
Girder - 7000 psi	Concrete	Girders	165	155
Rebar - A706 Other	Rebar	Rebar other than Columns	490	-
Column - A706 - Column	Rebar	Column Rebar	490	-

6.4 Column

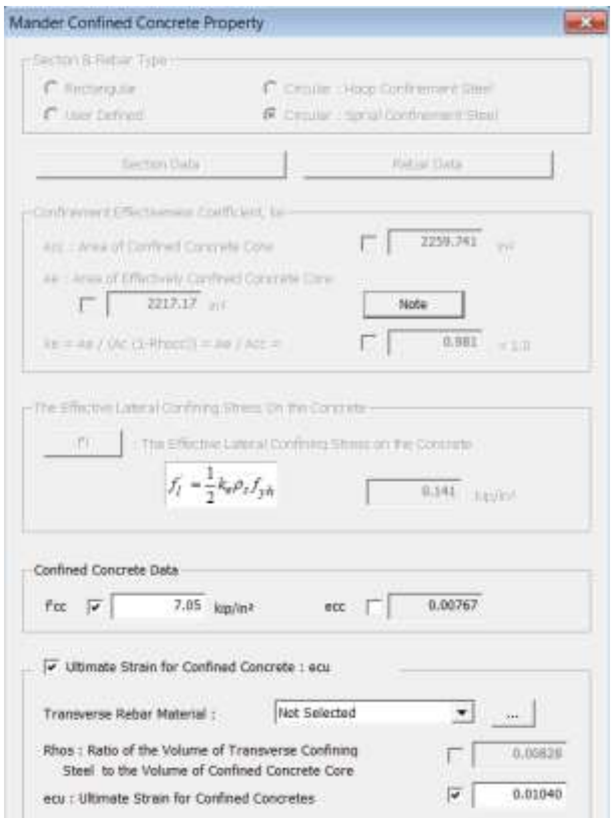
- **There are two columns at each bent.**
- **The columns are five feet in diameter and have (24) #10 bars for longitudinal steel, which amounts to a steel-concrete area ratio of about 1%.**
- **In the hinge zones, the columns have confinement steel consisting of #6 spiral bars with a 3.5 inch pitch.**
- **The column elements have rigid end offsets assigned to them at the footings and cap beams.**
- **Note that the columns are split into ten frame elements.**

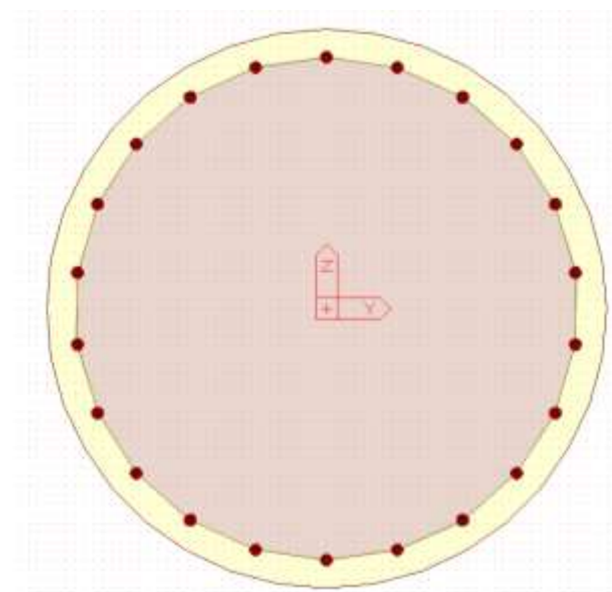
6.4 Column


Material Data
General
Material ID
Name
COL
Elasticity Data
Type of Design
RC
Steel
Standard
DB
Concrete
Standard
ASTM(RC)
Code
DB
Grade C5000
Type of Material
Isotropic
Orthotropic
Steel
Strength
5
kip/in²
Modulus of Elasticity
0.0000e+000
kip/in²
Poisson's Ratio
0
Thermal Coefficient
0.0000e+000
1/[T]
Weight Density
0
kip/in³
Use Mass Density
0
kip/in³/g
Use Nonlinear
Define
Nonlinear
Properties
Concrete
Strength
5
kip/in²
Modulus of Elasticity
4.0743e+003
kip/in²
Poisson's Ratio
0.2
Thermal Coefficient
9.0000e-006
1/[T]
Weight Density
8.681e-005
kip/in³
Use Mass Density:
2.248e-007
kip/in³/g
Use Nonlinear
Define
Nonlinear
Properties
OK
Cancel
Apply
(kip)
1250
0.02
50
Curvature Model
Apply
1 0.000000 0.000000 0.000000 0.000000 0.000000
2 0.000063 449.192 0.000055 0.000140 617.609
3 0.000076 134.810 0.000044 0.000562 2494.963
4 0.000097 76.600 0.000025 0.001263 5623.440
5 0.000126 56.237 -0.000002 0.002246 10001.315
6 0.000164 46.822 -0.000036 0.003509 15623.240
7 0.000211 41.717 -0.000077 0.005054 22478.053
8 0.000264 38.336 -0.000128 0.006879 29513.685
9 0.000310 34.483 -0.000202 0.008984 30370.196
Moment Curvature Curve
Axial load = 1250
Neutral Axis Angle = 0
a
b
c
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
Curvature*0.001(1/in)
State
Curvature *10^-3
Moment (kip in)
a.Crack 0.006656 28657.509
b.Yield(Init.) 0.053665 53660.700
c.Yield 0.141516 65926.789
d.Ultimate(conc 0.000000 0.000000
e.Ultimate(reba 0.000000 0.000000
f.Yield(ideal) 0.000000 0.000000
Strain
Strain Diagram
R : -0.00206897
Point Number
b

midas Civil Section Designer

- The “COLUMN” frame section is defined using a round shape in General Section Designer as shown



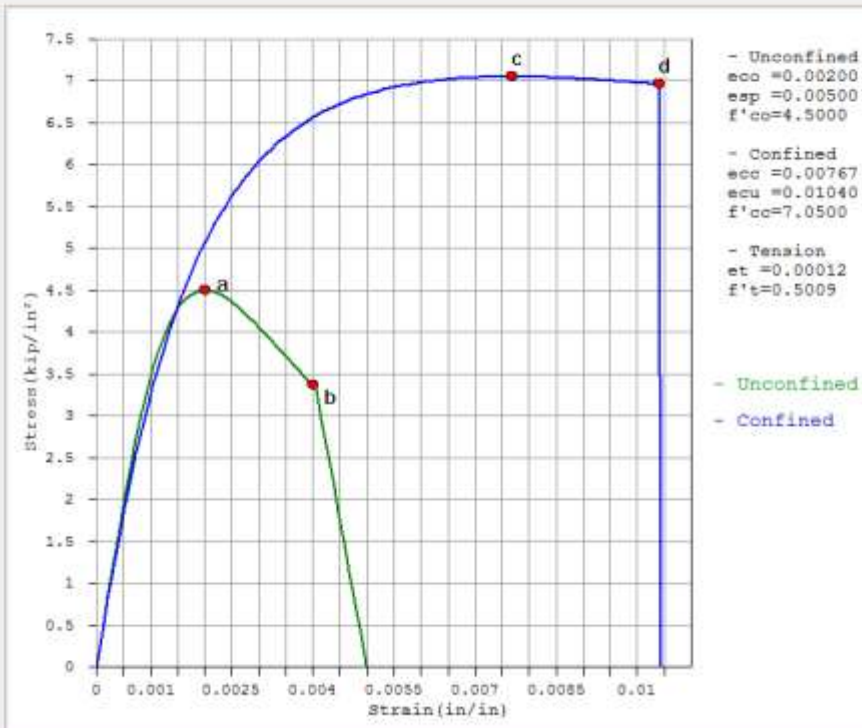


6.4 Column

midas Civil Section Designer

- **Mander confined stress-strain concrete model for the core of the column is shown.**

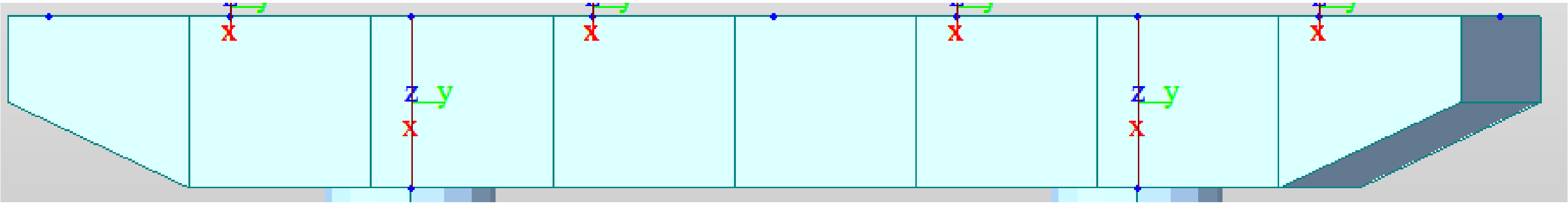
Stress-Strain Curve

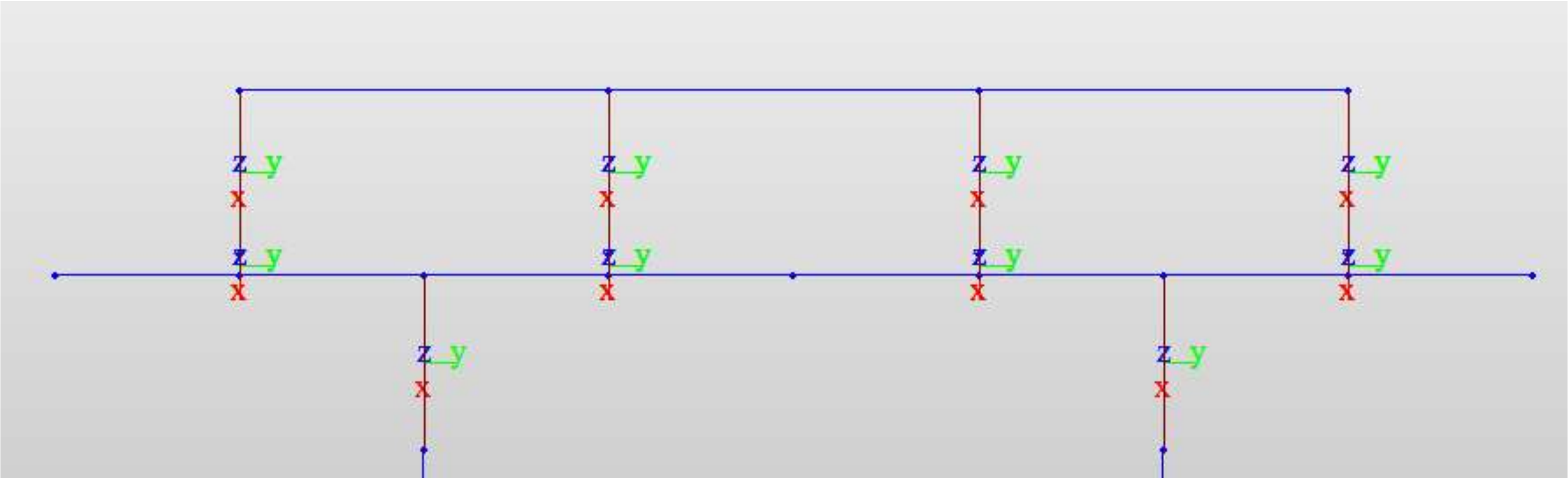


No.	Unconfined		Confined	
	Strain	Stress	Strain	Stress
1	0.00000	0.00000	0.00000	0.00000
2	0.00010	0.41968	0.00010	0.41472
3	0.00021	0.83618	0.00021	0.81431
4	0.00031	1.24535	0.00031	1.19602
5	0.00042	1.64266	0.00042	1.55882
6	0.00052	2.02357	0.00052	1.90242
7	0.00062	2.38384	0.00062	2.22699
8	0.00073	2.71974	0.00073	2.53299
9	0.00083	3.02823	0.00083	2.82103
10	0.00094	3.30709	0.00094	3.09185
11	0.00104	3.55493	0.00104	3.34626
12	0.00114	3.77121	0.00114	3.58509
13	0.00125	3.95613	0.00125	3.80917
14	0.00135	4.11059	0.00135	4.01934
15	0.00146	4.23602	0.00146	4.21641
16	0.00156	4.33425	0.00156	4.40116
17	0.00166	4.40740	0.00166	4.57435
18	0.00177	4.45777	0.00177	4.73669
19	0.00187	4.48772	0.00187	4.88886
20	0.00198	4.49959	0.00198	5.03150
21	0.00200	4.50000	0.00200	5.06313
22	0.00208	4.49564	0.00208	5.16522
23	0.00218	4.47801	0.00218	5.29057
24	0.00229	4.44869	0.00229	5.40811
25	0.00239	4.40951	0.00239	5.51831
26	0.00250	4.36209	0.00250	5.62165
27	0.00260	4.30791	0.00260	5.71857
28	0.00270	4.24826	0.00270	5.80946
29	0.00281	4.18428	0.00281	5.89472

6.5 Pier Cap Beam

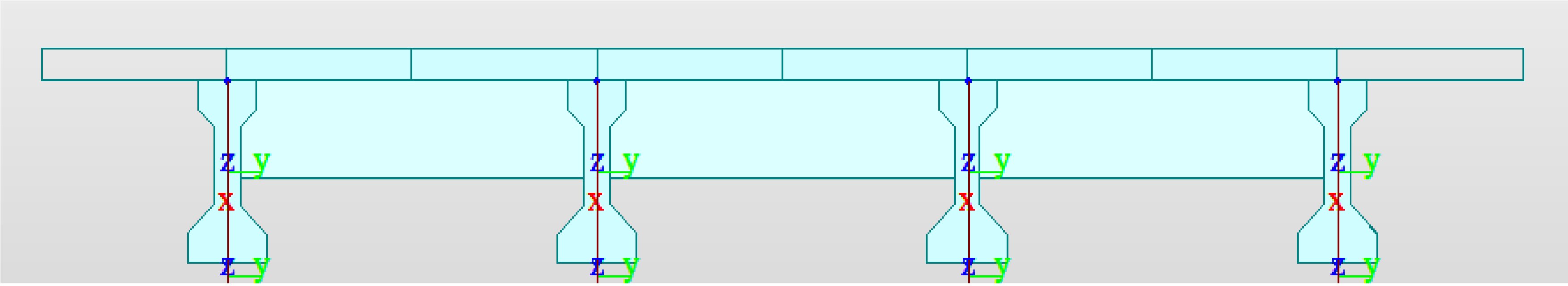
The pier cap beam elements were modeled as frame elements with non-prismatic section properties.





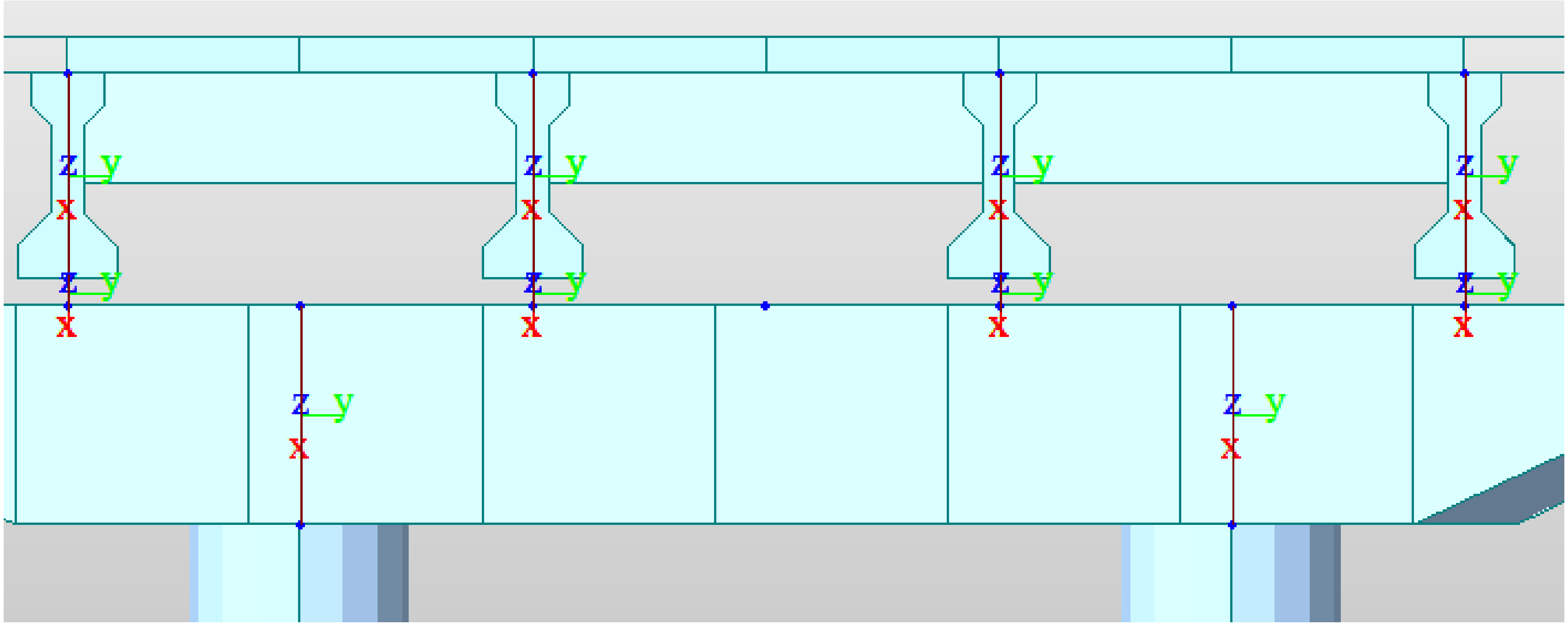
6.6 Superstructure – Deck and Girders

The girders are assigned insertion points such that they connect to the same joints as the deck elements but are below the deck.



6.6 Superstructure – Deck and Girders

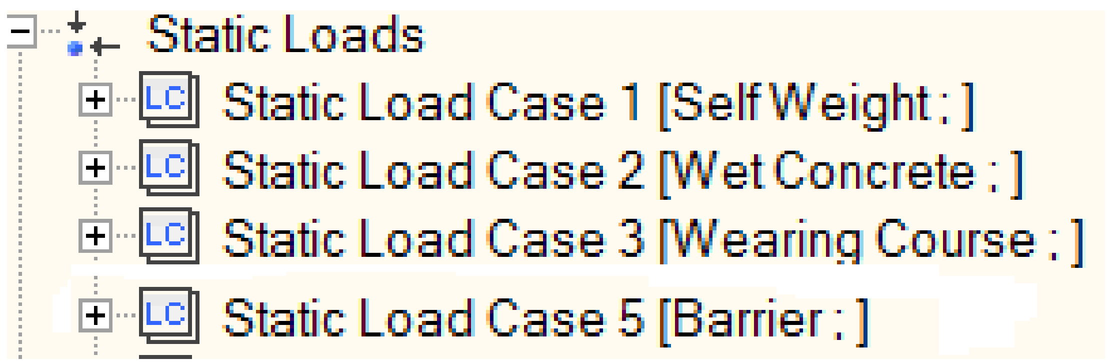
Links connect the girders to the cap beam which models the fixed connection between these elements.



6.7 Gravity Load Patterns

There are three dead load patterns in the model:

- **"DC-Structure", "DC-Barriers", and "DW-Overlay".**
  - **"DC-Structure" case includes the self weight of the structural components.**
  - **"DC-Barriers" case includes the dead load of the barriers, which is applied as line load to the outermost deck elements**
  - **"DW-Overlay" case includes the future overlay loads applied to the deck elements**



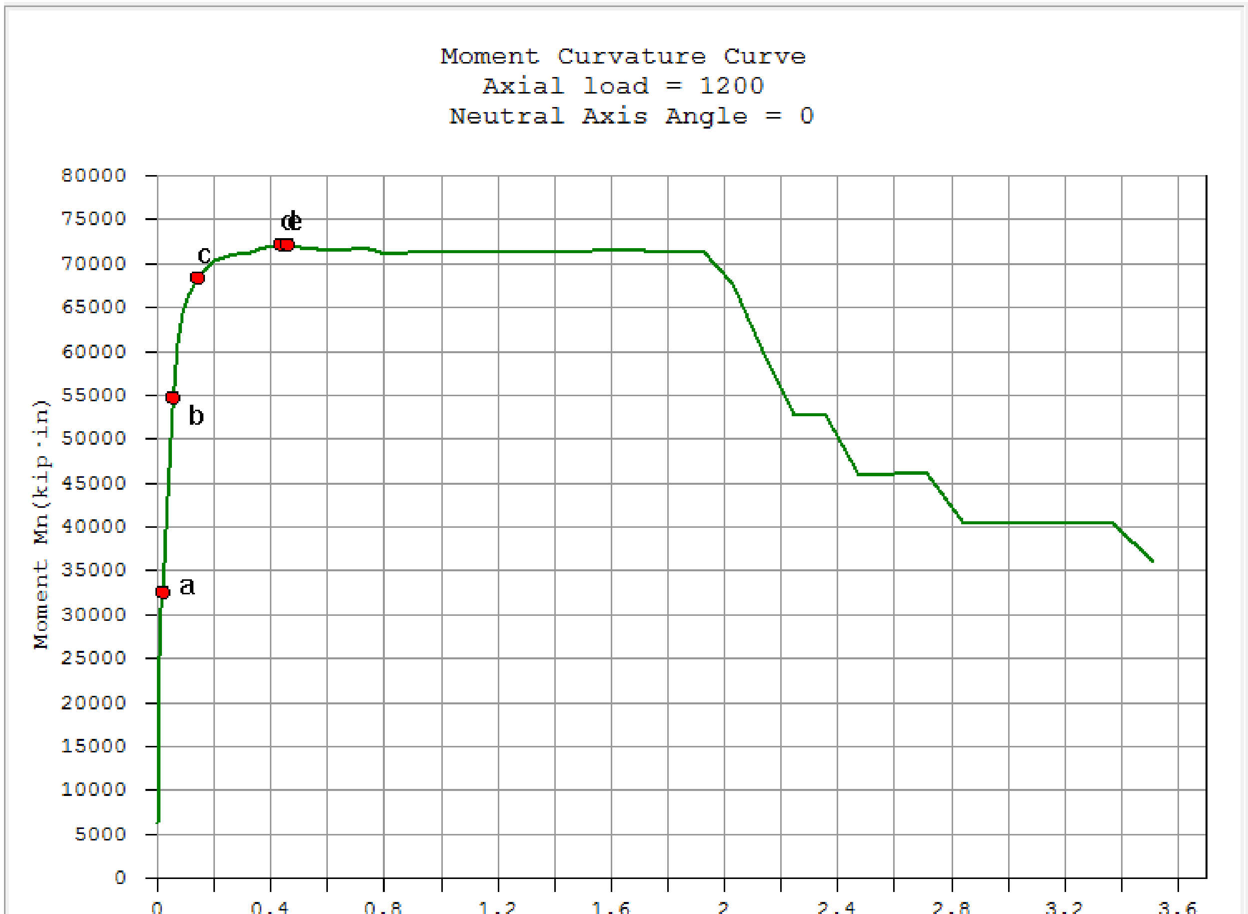
7. Displacement Demand Analysis

Modal Analysis

1. **Mass Source**
   - **All of the dead loads are considered as contributing mass for the modal load case.**
2. **Cracking of Columns**
   - **Section 5.6 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design provides Diagrams that can be used to determine the cracked section properties of the columns**
   - **The column axial dead load at mid-height was calculated in the model to be approximately 1,200 kips without including the effects of the construction staging.**
     - ➢ **For our bridge, the inclusion of staging effects would cause the axial load in the columns to vary by less than ten percent. Such a small change in axial load would not significantly alter the results of this analysis.**

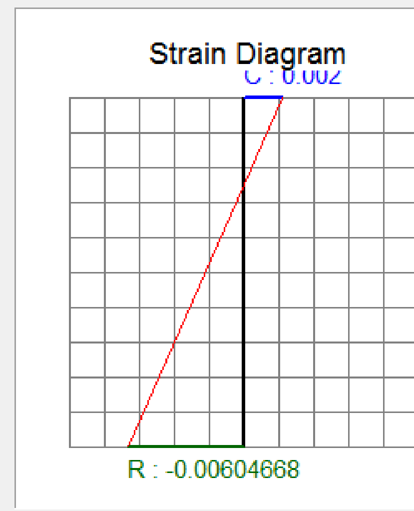
7. Displacement Demand Analysis

Moment Curvature Curve



State	Curvature *10^-3	Moment (kip·in)
a.Crack	0.015719	32322.318
b.Yield(Init.)	0.053586	54678.286
c.Yield	0.141198	68285.502
d.Ultimate(conc	0.434266	72091.352
e.Ultimate(reba	0.454828	72109.051
f.Yield(ideal)	0.000000	0.000000

Strain



7. Displacement Demand Analysis

Property Modifiers

- The previous moment curvature curve we see that concrete strain capacity limits the available plastic curvature.
- The property modifiers are then applied to the column frame elements.
- Note that the torsional constant modifier is 0.2 for columns as required by Section 5.6.5 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design.

7. Displacement Demand Analysis

Verification of Mass Participation

- Section 5.4.3 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design requires a minimum of 90% mass participation in both directions.
- For our bridge, the mass is considered to be the same in both directions even though the end diaphragms are free in the longitudinal direction and restrained in the transverse direction.

8. Response-Spectrum Analysis

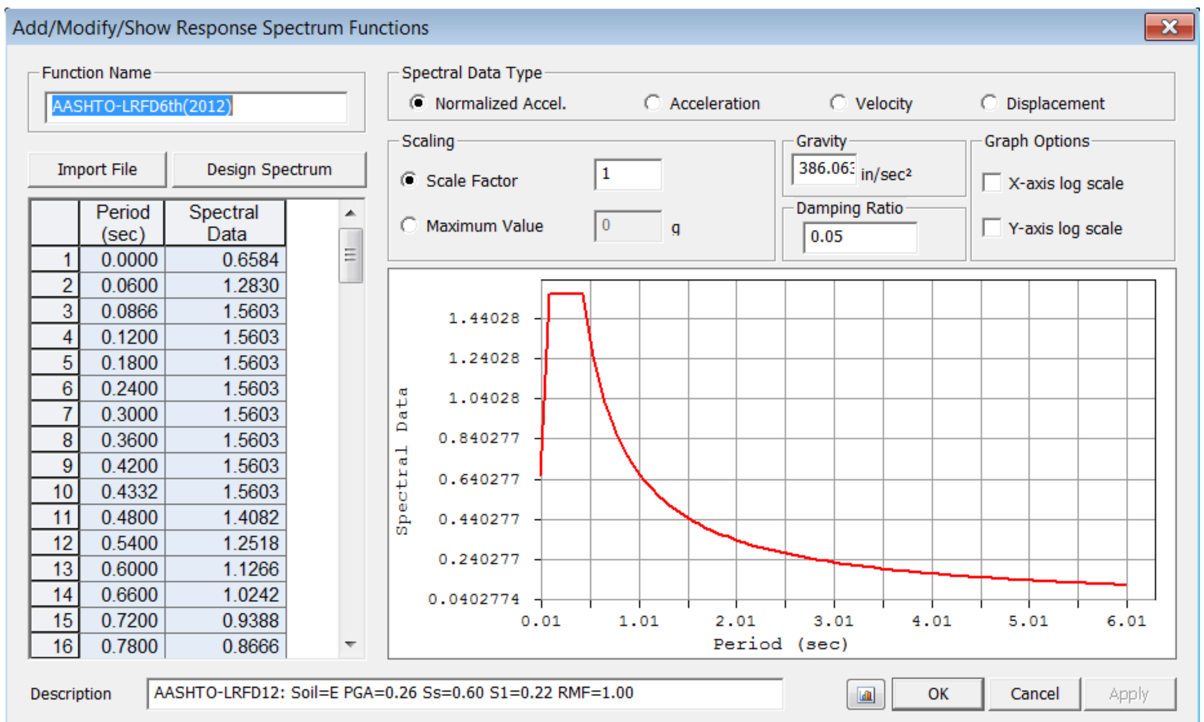
Seismic Hazard

- The bridge is located in Ridgefield, WA. The mapped spectral acceleration coefficients are:
  - ✓ PGA = 0.256 g
  - ✓ Ss = 0.605 g
  - ✓ S1 = 0.217 g
- A site class of E is used and the site coefficients are:
  - ✓ FPGA = 1.422
  - ✓ Fa = 1.489
  - ✓ Fv = 3.129
- Therefore, the response-spectrum was generated using the following parameters:
  - ✓ As = FPGA*PGA = 0.364 g
  - ✓ SDS = Fa*Ss = 0.901 g
  - ✓ SD1 = Fv*S1 = 0.679 g
- Since SD1 is greater than or equal to 0.50, per Table 3.5-1 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design the Seismic Design Category is D.

8. Response-Spectrum Analysis

Response-Spectrum Function

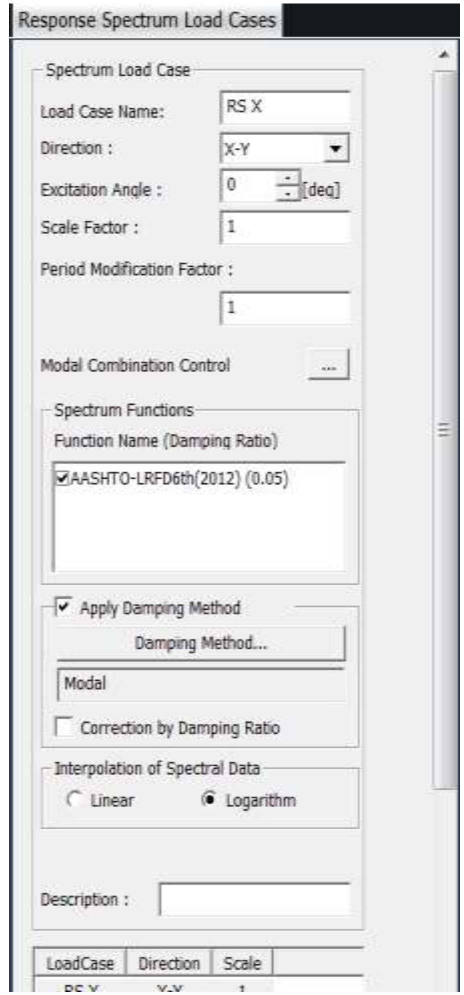
- The spectrum is defined from a file created using the AASHTO Earthquake Ground Motion Parameters tool and also as shown below from midas Civil

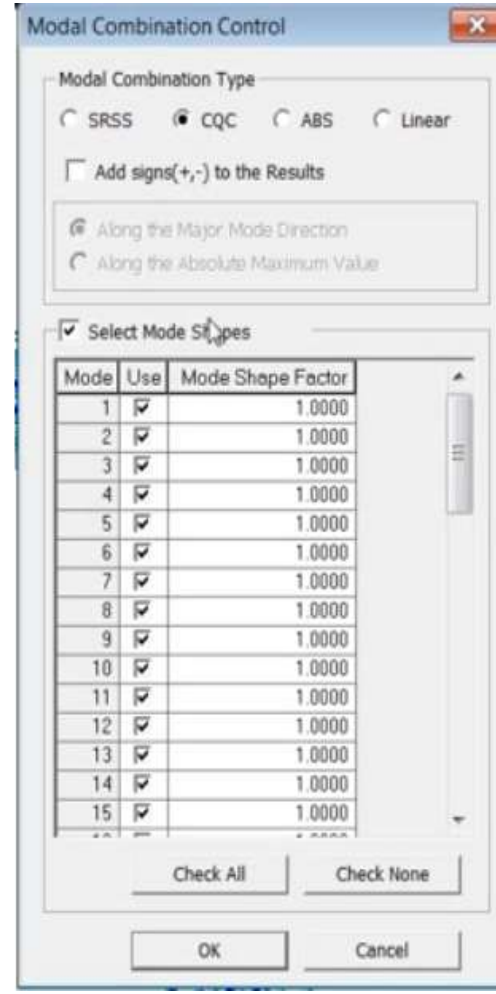


8. Response-Spectrum Analysis

Load Case Setup

- Two response-spectrum analysis cases were setup in midas Civil: one for each orthogonal direction
- Longitudinal Direction – The load case data for the X-direction is as shown

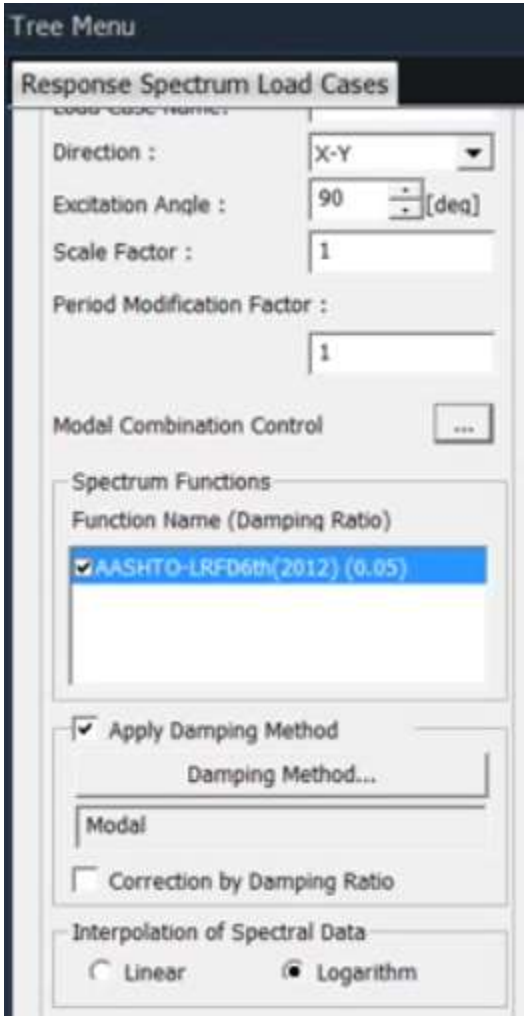




8. Response-Spectrum Analysis

Load Case Setup

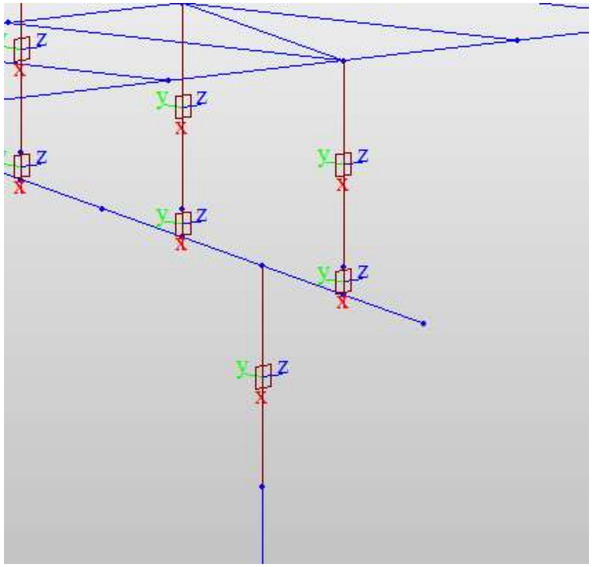
- **Transverse Direction– The load case data for the Y-direction is as shown**



8. Response-Spectrum Analysis

Displacements

- The column displacements were tracked at Joint 229, which is located at the top of a column.
- Longitudinal Direction – The horizontal displacements at the tops of the columns from the RS X analysis case was UX = 7.48 inches and UY = 0.00 inches.

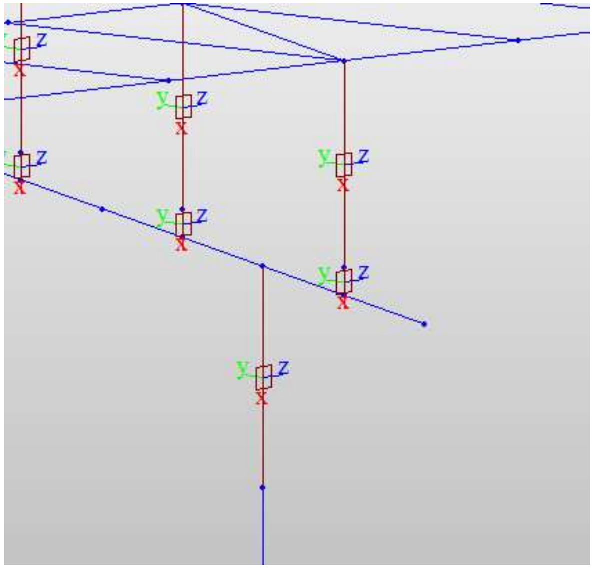


Joint Displacement at Joint 229 for Load Case “RS X”

8. Response-Spectrum Analysis

Displacements

- Transverse Direction – The horizontal displacements at the tops of the columns from the RS Y analysis case were UX = 0.17 inches and UY = 3.55 inches.



Joint Displacement at Joint 229 for Load Case “RS Y”

9. Displacement Demand

Displacement Magnification

- Displacement magnification must be performed in accordance with Section 4.3.3 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design
- Compute Ts and T *:
  - ✓ Ts = SD1 / SDS = 0.679 / 0.901 = 0.754 sec.
  - ✓ T * = 1.25 Ts = 1.25 * 0.754 = 0.942 sec.
- Longitudinal Direction – Computed magnification for the X-direction (Long):
  - ✓ TLong = 0.95 sec.
  - ✓ T* / TLong = 0.942 / 0.95 = 1.00 > 1.0 => Magnification is required
  - ✓ Rd_Long = (1 – 1 / μD)*(T* / T) + 1 / μD = (1 – 1/6)*(1.00)+1/6 = 1.0
  - ✓ (Assume μD =6)

9. Displacement Demand

Displacement Magnification

- **Transverse Direction– Computed magnification for the Y-direction (Trans):**
  - ✓ **TTrans = 0.61 sec.**
  - ✓ **T* / TTrans = 0.942 / 0.61 = 1.54 > 1.0 => Magnification is required**
  - ✓ **Rd_Trans = (1 – 1 / μD)*(T* / T) + 1 / μD = (1 – 1/6)*(1.54)+1/6 = 1.45 (Assume μD =6)**

9. Displacement Demand

Column Displacement Demand

Section 4.4 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design requires that 100% plus 30% of the displacements from each orthogonal seismic load case be combined to determine the displacement demands. The displacements were tracked as Joint 229, which is located at the top of a column.

- **Longitudinal Direction – For the X-direction (100RS X + 30RS Y):**
  - ✓ UX (due to RS X) = 7.48 in.
  - ✓ UX (due to RS Y) = 0.17 in.

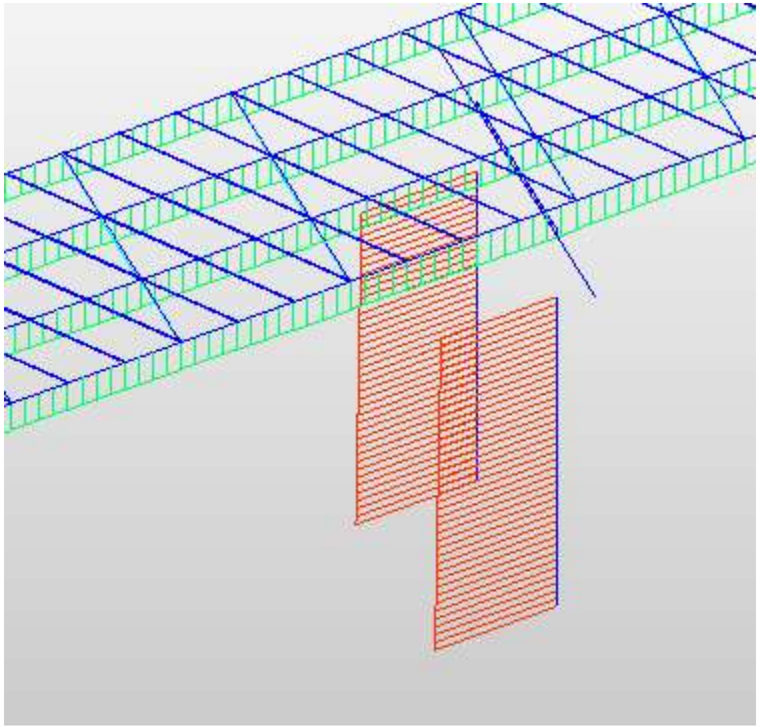
  Δ^{L} D_Long = 1.0 * Rd_Long * 7.48 + 0.3 * Rd_Trans * 0.17
  = 1.0 * 1.00* 7.48 + 0.3 * 1.45 * 0.17 = 7.55 in.
  => This is the displacement demand for the X-Dir
- **Transverse Direction – For the Y-direction (100RS Y + 30RS X):**
  - ✓ UY (due to RS Y) = 3.55 in.
  - ✓ UY (due to RS X) = 0.00 in.

  Δ^{L} D_Trans = 1.0 * Rd_Trans * 3.55 + 0.3 * Rd_Long * 0.00
  = 1.0 * 1.45 * 3.55 + 0.3 * 1.00 * 0.00 = 5.45 in.
  => This is the displacement demand for the Y-Dir

10. Displacement Capacity Analysis

Plastic Hinge Definitions and Assignments

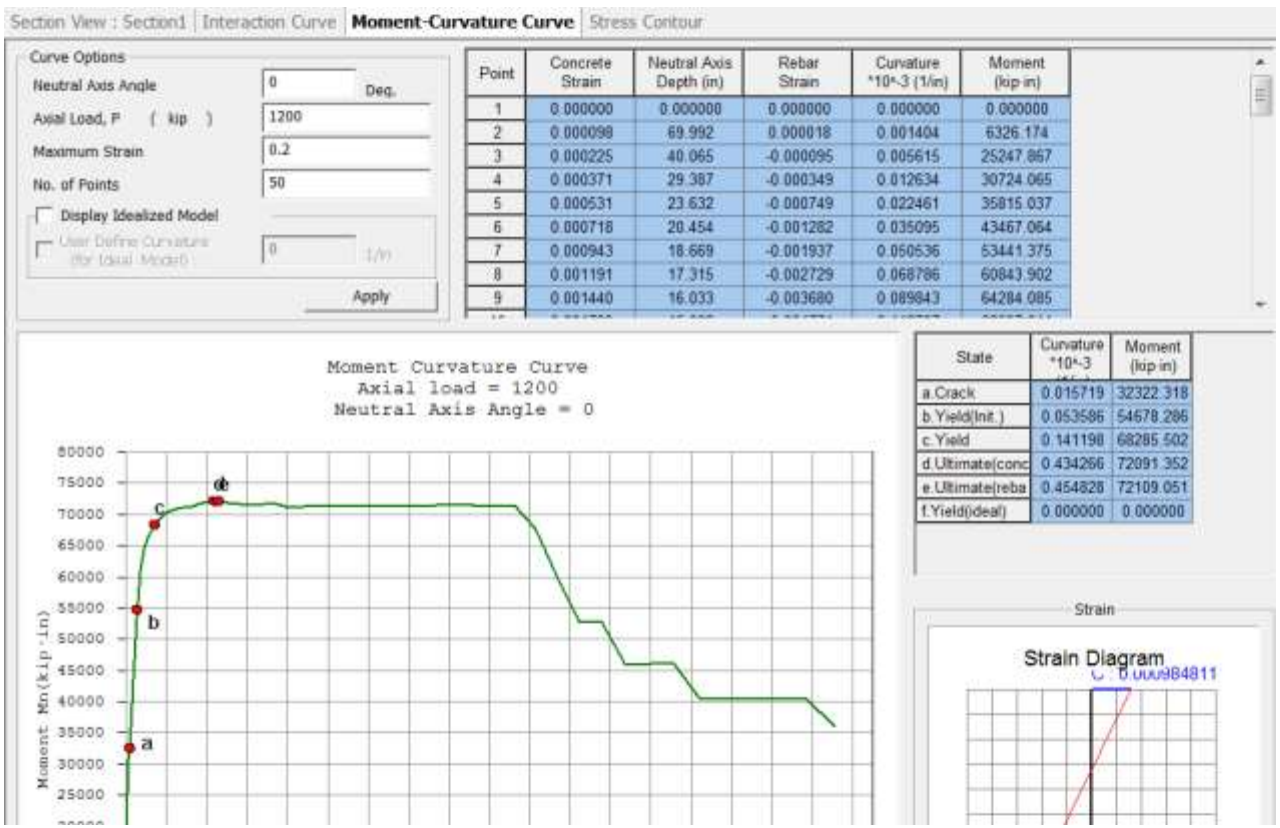
- The tops and bottoms of all columns were found to have enough moment fixity in all directions to cause plastic hinging
- Axial force diagram for the DC+DW load case



10. Displacement Capacity Analysis

Plastic Hinge Definitions and Assignments

- The moment-curvature analysis of the column ***base*** is shown



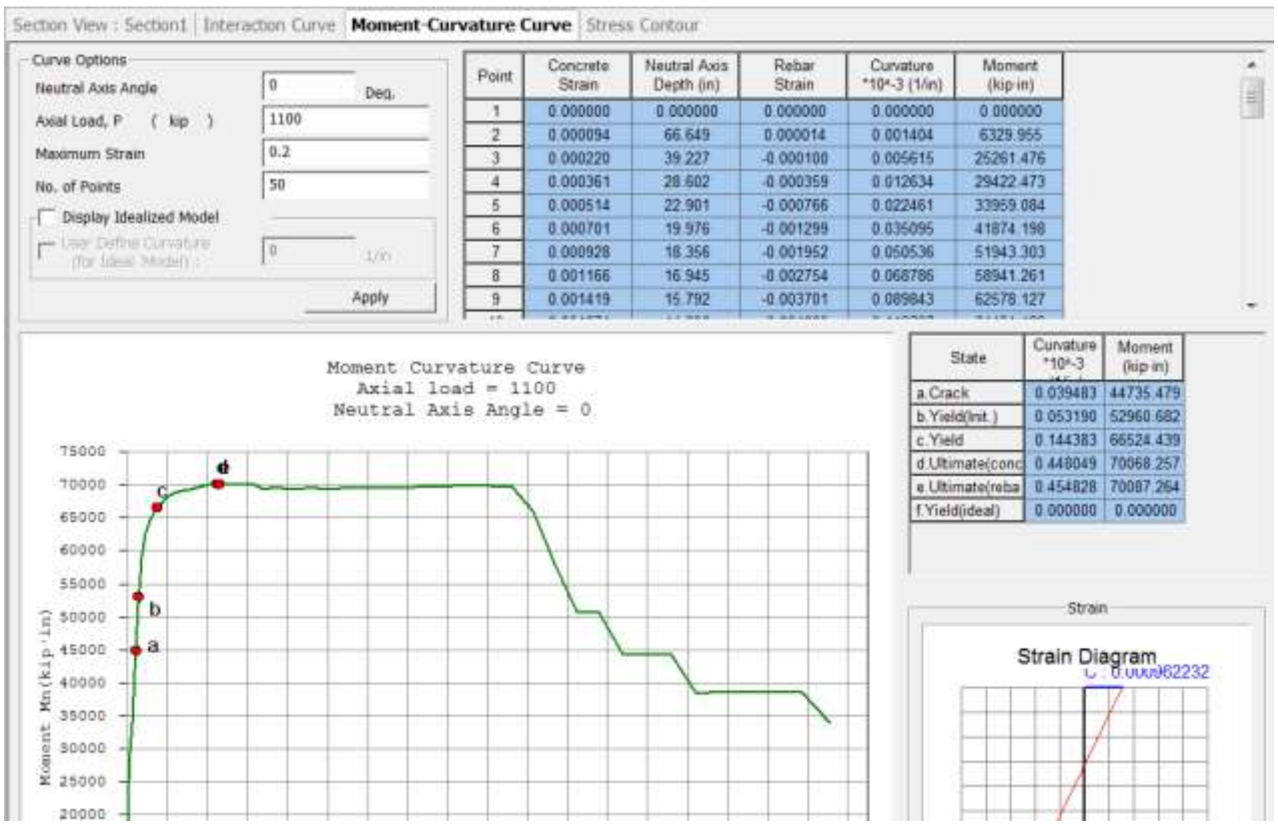
Point	Concrete Strain	Neutral Axis Depth (in)	Rebar Strain	Curvature *10^-3 (1/in)	Moment (kip-in)
1	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.000098	69.992	0.000018	0.001404	6326.174
3	0.000225	40.065	-0.000095	0.005615	25247.867
4	0.000371	29.387	-0.000349	0.012634	30724.065
5	0.000531	23.632	-0.000749	0.022461	35815.037
6	0.000718	20.454	-0.001282	0.035095	43467.064
7	0.000943	18.669	-0.001937	0.050536	53441.375
8	0.001191	17.315	-0.002729	0.068786	60843.902
9	0.001440	16.033	-0.003680	0.089843	64284.085

State	Curvature *10^-3	Moment (kip-in)
a.Crack	0.015719	32322.318
b.Yield(Init.)	0.053586	54678.286
c.Yield	0.141198	68285.502
d.Ultimate(conc	0.434266	72091.352
e.Ultimate(reba	0.454828	72109.051
f.Yield(ideal)	0.000000	0.000000

10. Displacement Capacity Analysis

Plastic Hinge Definitions and Assignments

- The moment-curvature analysis of the column *top* is shown



10. Displacement Capacity Analysis

Plastic Hinge Definitions and Assignments

- **Plastic Hinge Lengths**
  The clear height of the columns is 350 inches; therefore:

  ✓ **L1 = Length from point of maximum moment at *base* of column to inflection point (in.)**
  = 350 x Mp_col_base / (Mp_col_base + Mp_col_top)
  = 350 x 79186 / (79186 + 77920) = 176 in.

  ✓ **L2 = Length from point of maximum moment at *top* of column to inflection point (in.)**
  = 350 – L1 = 350 – 176 = 174 in.

10. Displacement Capacity Analysis

Plastic Hinge Definitions and Assignments

In order to assign the plastic hinges to the column elements, the relative locations of the plastic hinges along the column frame elements were computed.

- **For the bases of the columns:**
  - ✓ **Relative Length = [Footing Offset + (Hinge Length / 2)] / Element Length [30 + (27.0 / 2)] / 146 = 0.30**
- **For the tops of the columns:**
  - ✓ **Relative Length = [Element Length – Capbeam Offset – (Hinge Length / 2)] / Element Length = [146 – 58 – (26.9 / 2)] / 146 = 0.51**

10. Displacement Capacity Analysis

Assign Plastic Hinges

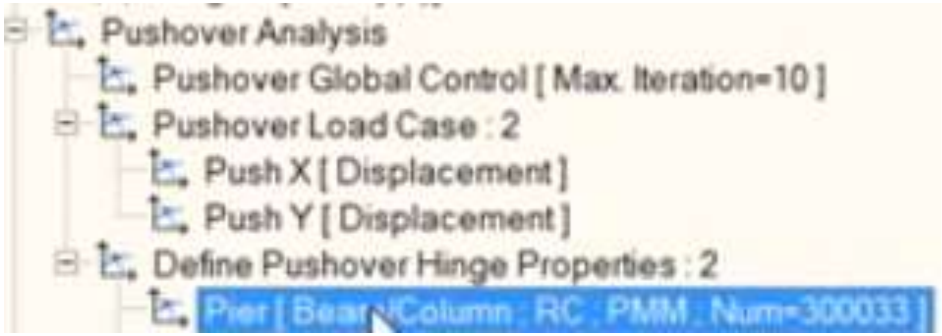
The plastic hinge lengths must be computed at both the tops and bottoms of the columns using the equations in Section 4.11.6 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design.

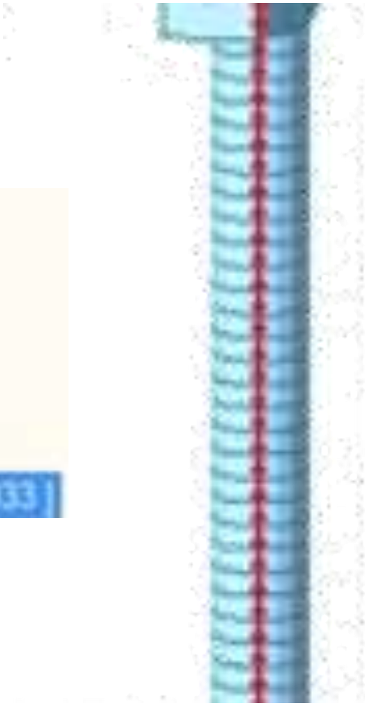
- **The hinge length was computed as follows:**
  $L_p = 0.08L + 0.15 f_{ye} * d_{bl} \geq 0.3 f_{ye} * d_{bl}$
  Where:
  - ✓ L = length of column from point of maximum moment to the point of moment contraflexure (in.)
    - ▪ L1 at the base of the columns (L1Long = L1Trans = 176 in.)
    - ▪ L2 at the top of the columns (L2Long = L2Trans = 174 in.)
  - ✓ fye = expected yield strength of longitudinal column reinforcing steel bars (ksi) = 68 ksi (ASTM A706 bars).
  - ✓ dbl = nominal diameter of longitudinal column reinforcing steel bars (in.) = 1.27 in. (#10 bars)
  - ✓ Lp1 = Plastic hinge length at base of column = 0.08*176 + 0.15*68*1.27 ≥ 0.3*68*1.27 = 27.03 ≥ 25.91 = 27.0 in.
  - ✓ Lp2 = Plastic hinge length at top of column = 0.08*174 + 0.15*68*1.27 ≥ 0.3*68*1.27 = 26.87 ≥ 25.91 = 26.9 in.

10. Displacement Capacity Analysis

Assign Plastic Hinges

The hinges at the columns were assigned as shown

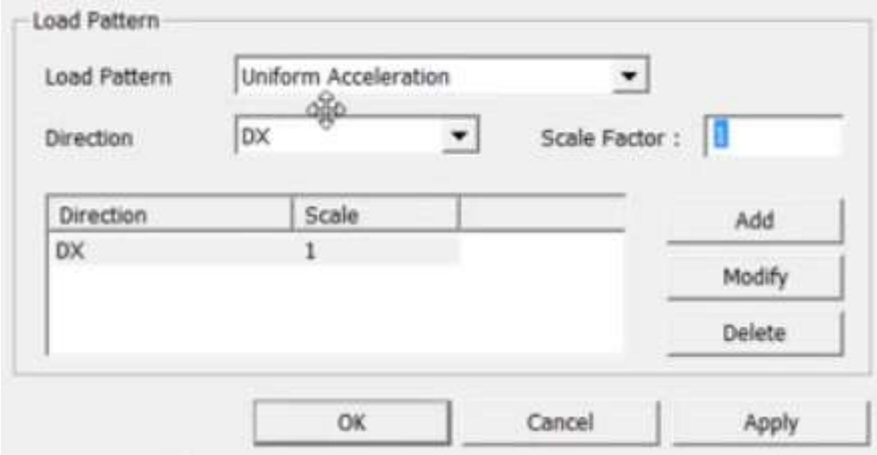




11. Pushover Analysis

Lateral Load Distributions

Longitudinal Direction:
The lateral load distribution used for the pushover analysis in the longitudinal direction is a direct horizontal acceleration on the structure mass. Also, the dead load can be applied as previously defined since the entire structure is present during the pushover analysis.



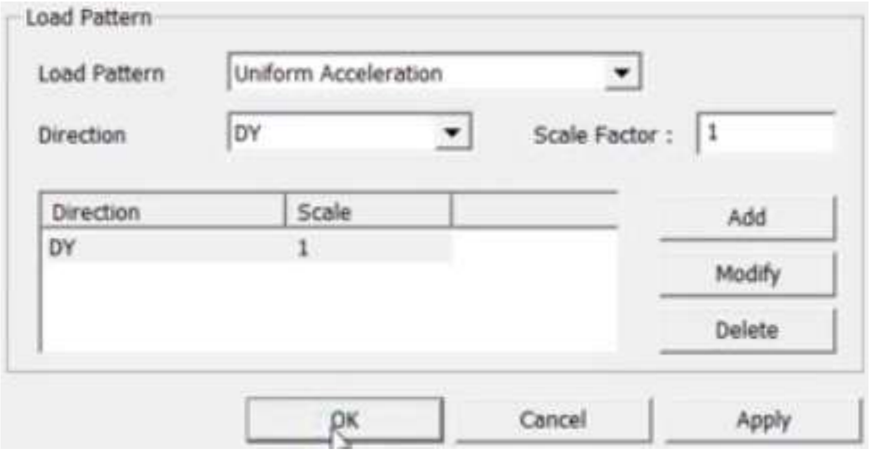
11. Pushover Analysis

Lateral Load Distributions

Transverse Direction:

The lateral load distribution used for the pushover analysis in the transverse direction could be applied as a horizontal load applied at the centroid of the superstructure. This way, the load distribution is used to mimic a direct horizontal acceleration on the superstructure mass.

For our bridge however, the load was applied similar to the Longitudinal direction by changing only the direction.

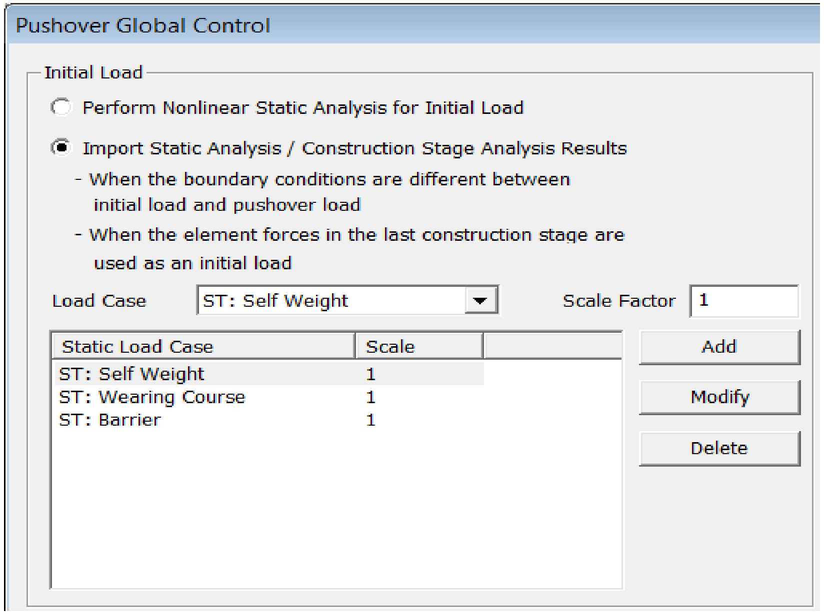


11. Pushover Analysis

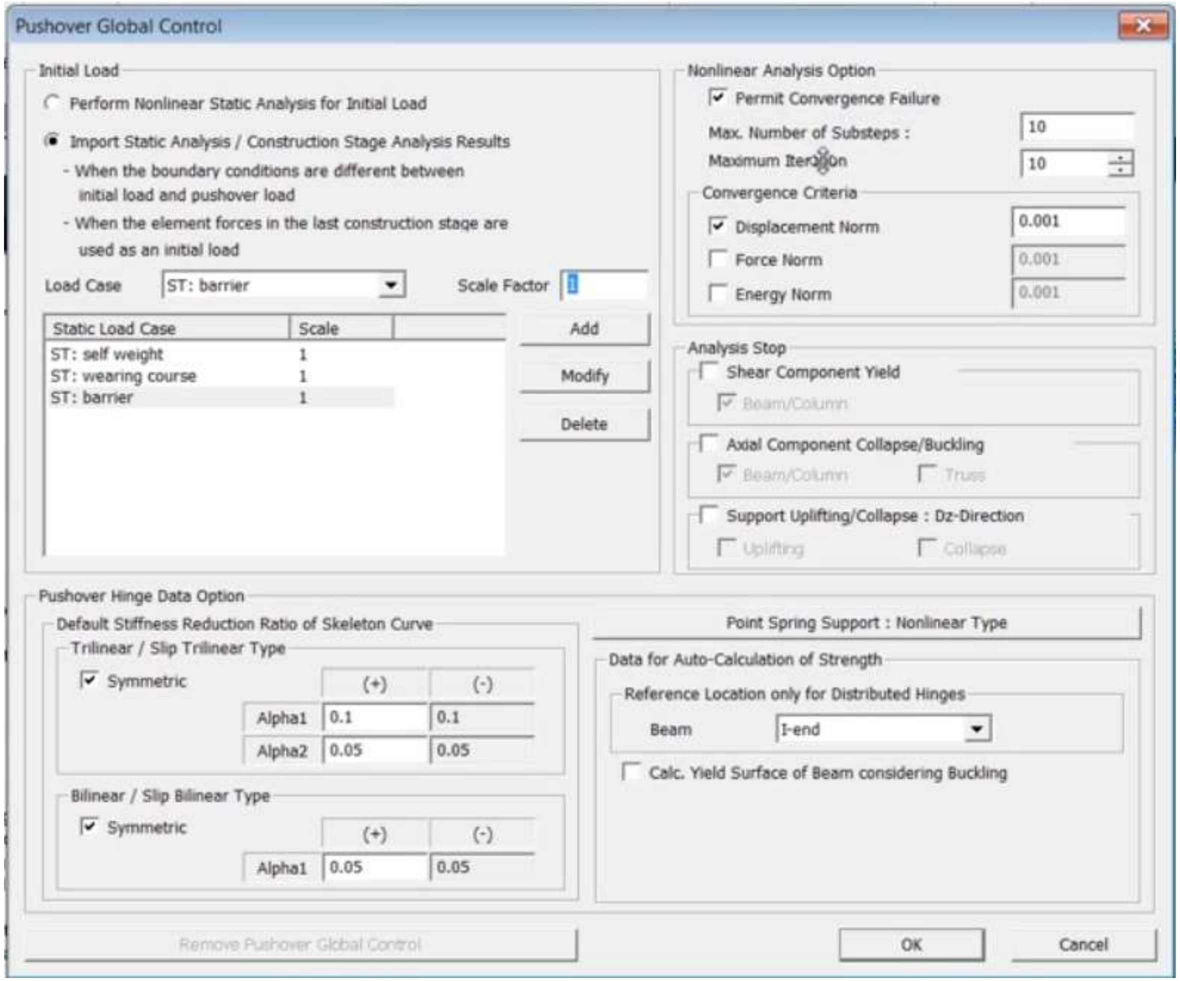
Load Case Setup

The dead load (DC+DW) must be applied prior to performing the pushover analysis. To do so in midas Civil, the initial load is set to "Import Static Analysis/Construction Stage Analysis Results" where the DC + DW were defined.

In this way, the dead load (DC+DW) is applied and the load is run as a nonlinear analysis. By running the load as a nonlinear analysis type, another load case can continue from it with the loads stored in the structure.



Load Case Setup

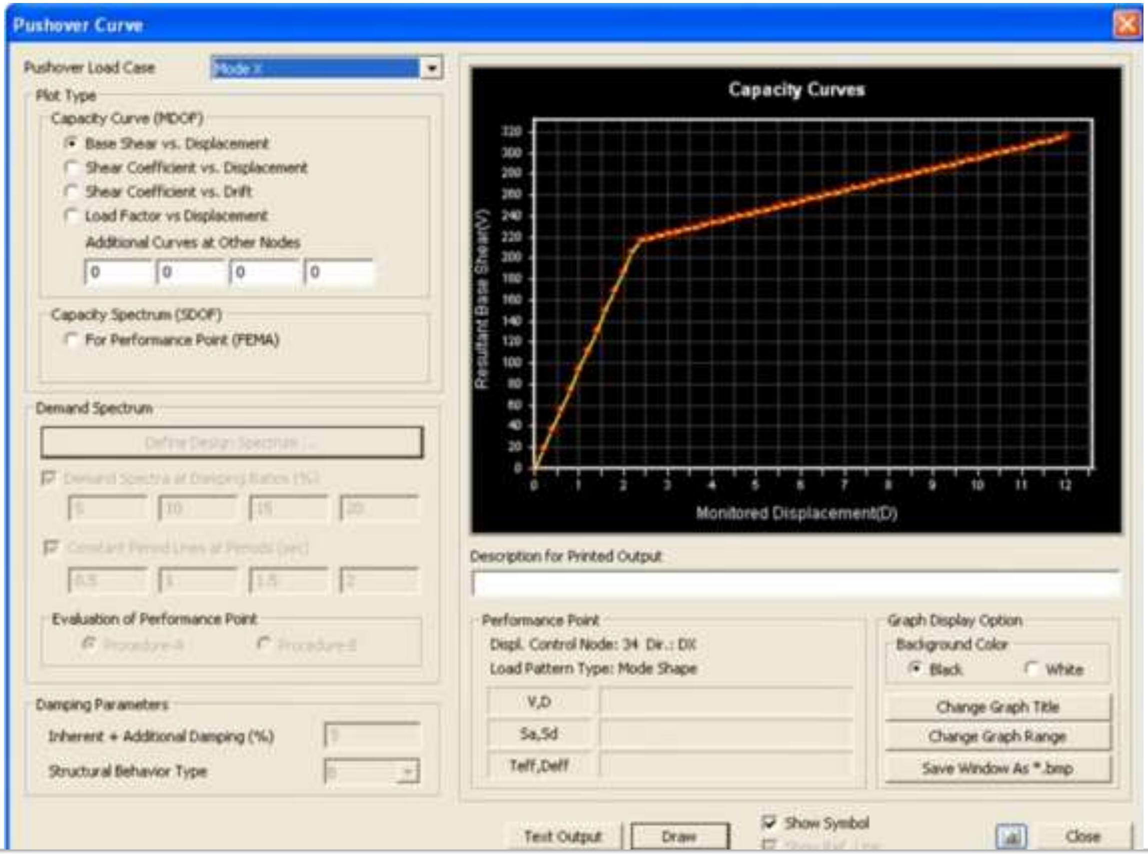


Load Case Results

A new load case is now created called "Mode X", which will actually be the pushover analysis case. The Load Case Data form for the "Mode X" load case is shown.

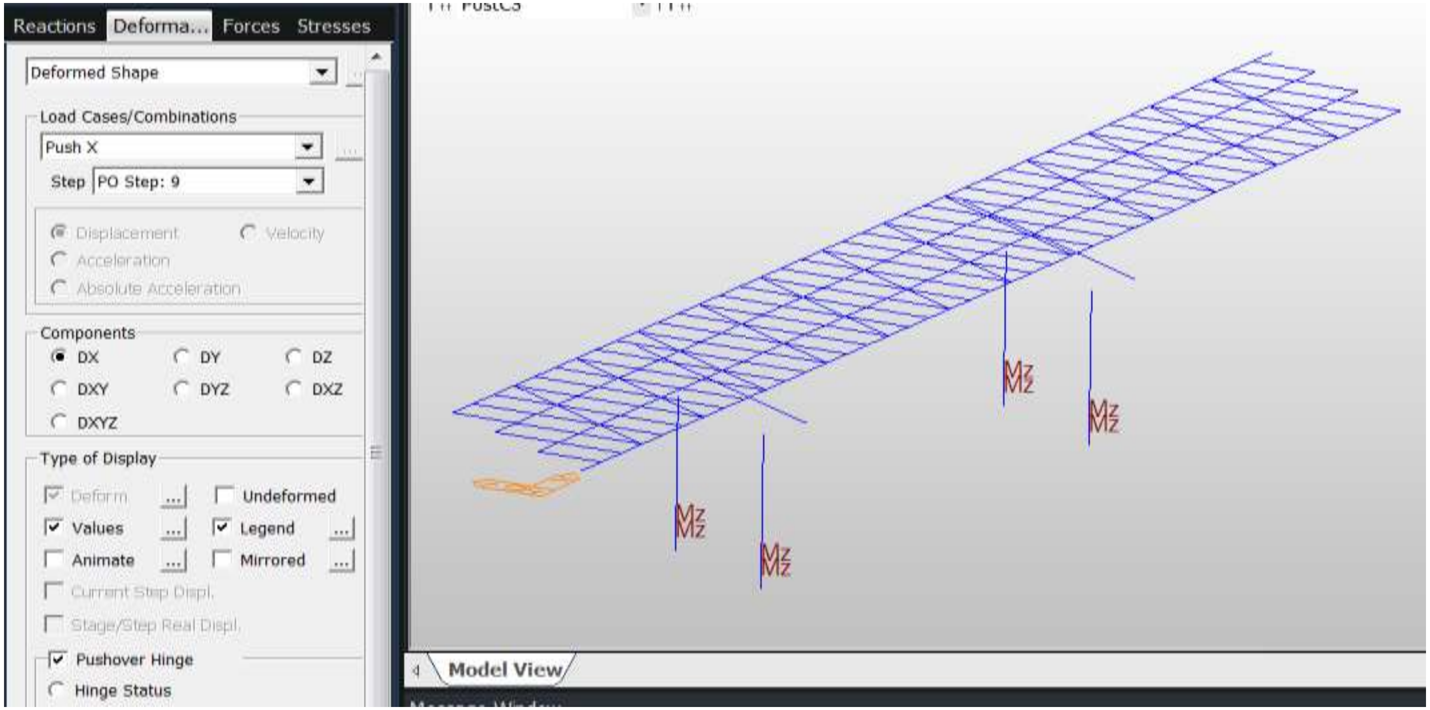
Load Case Results

Longitudinal Direction:
The system pushover curve for the longitudinal direction is shown



Load Case Results

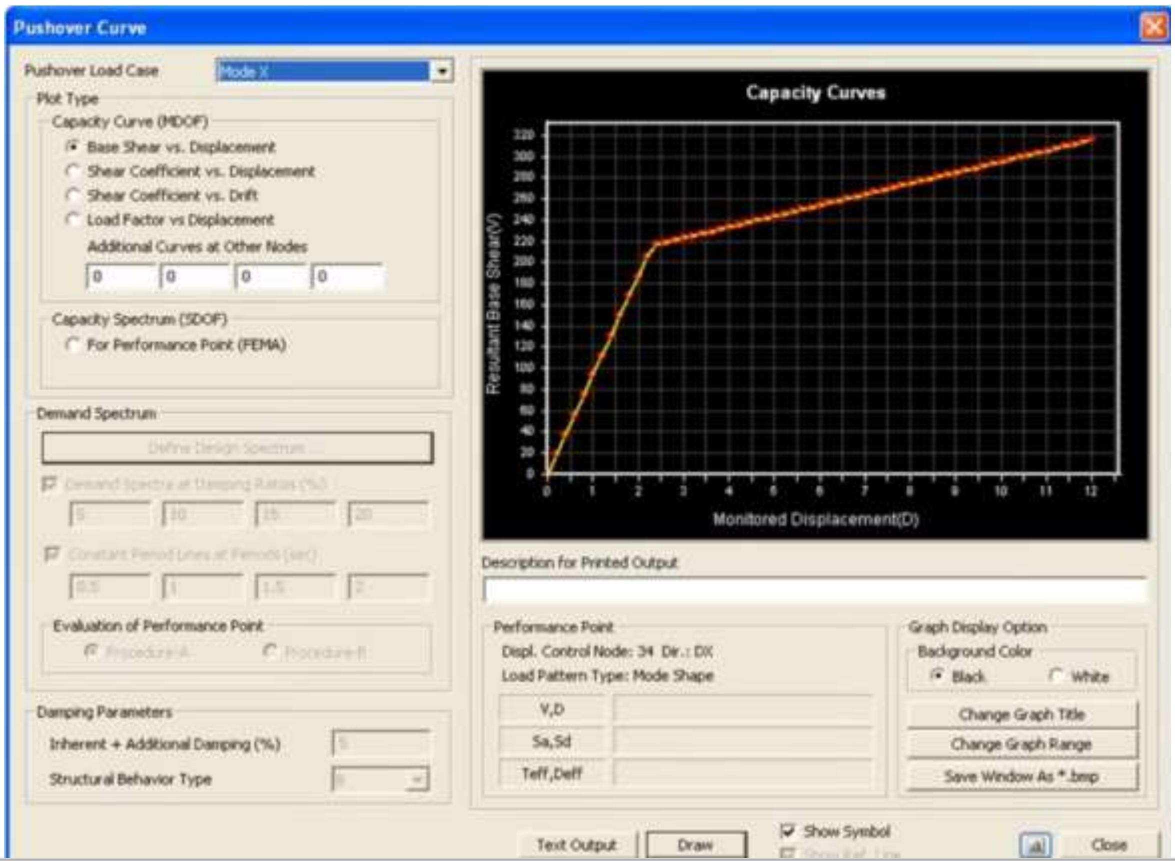
Longitudinal Direction:
The figures show the deformed shape of the structure at displacements for the load case “Push X"



View of Deformed Shape for the Load Case “Push X”

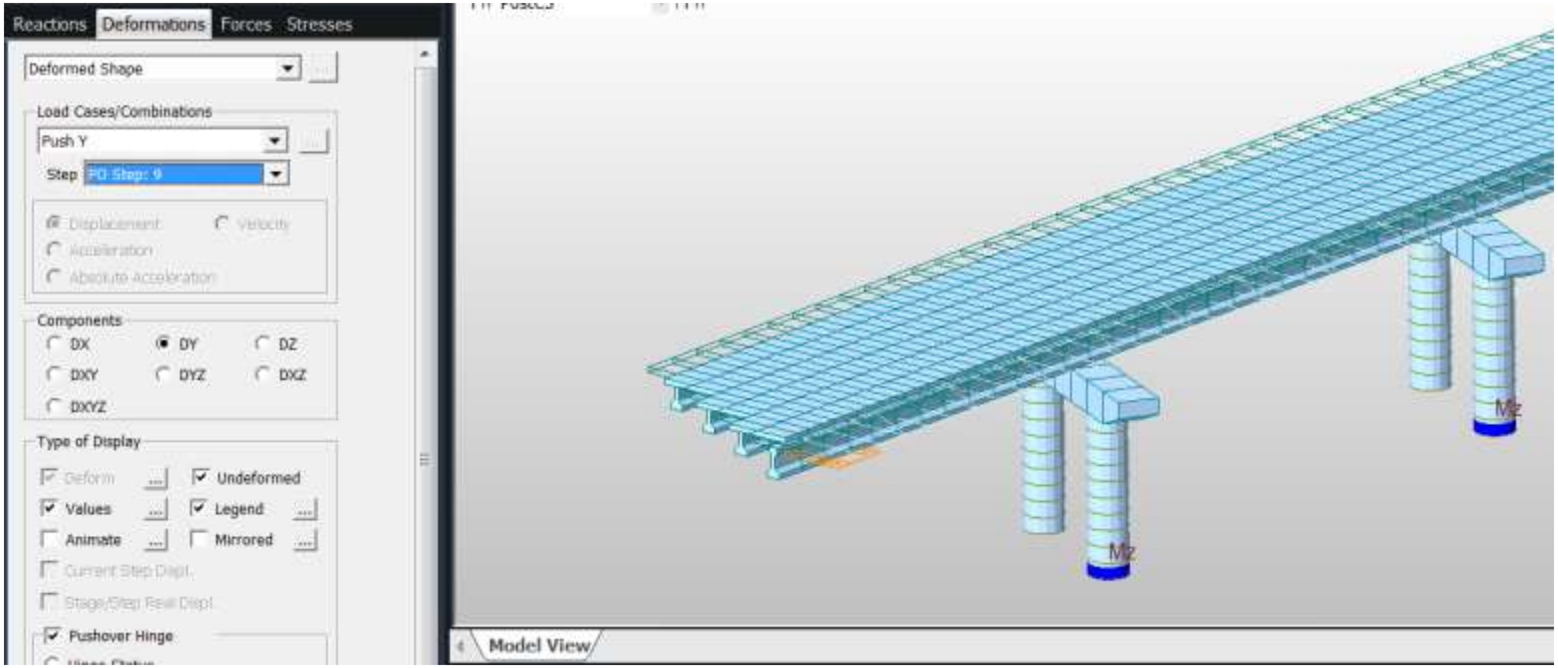
Load Case Results

Transverse Direction:
The system pushover curve for the transverse direction is shown



Load Case Results

Transverse Direction:
The figures show the deformed shape of the structure at various displacements for the load case "Push Y"



View of Deformed Shape for the Load Case "Push Y"

12. Code Requirements

P-Δ Capacity Requirement Check

The requirements of section 4.11.5 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design must be satisfied or a nonlinear time history analysis that includes P-Δ effects must be performed.

The requirement is:

- ✓ **PdlΔr ≤ 0.25 Mp**

Where:

- **Pdl = unfactored dead load on the column (kip) = 1,200 kips**
- **Δr = relative lateral offset between the point of contraflexure and the furthest end of the plastic hinge (in.) = Δ L D / 2 (Assumed since the inflection point is located at approximately mid-height of the column. If the requirements are not met, a more advanced calculation of Δr will be performed)**
- **Mp = idealized plastic moment capacity of reinforced concrete column based upon expected material properties (kip-in.) = 78,560 kip-in.**

12. Code Requirements

P-Δ Capacity Requirement Check

Longitudinal Direction

- ✓ 0.25Mp= 0.25 * 78,560 = 19,640 kip-in.
- ✓ Δr = Δ L D_Long / 2 = 8.76 / 2 = 4.38 in.
- ✓ PdlΔr = 1,200 * 4.38 = 5,256 kip-in. < 0.25Mp = 19,640 kip-in. => Ok

Transverse Direction

- ✓ Δr = Δ L D_Trans / 2 = 6.07 / 2 = 3.04 in.
- ✓ PdlΔr = 1,200 kips * 3.04 = 3,648 kip-in. < 0.25Mp = 19,640 kip-in. => Ok

12. Code Requirements

Minimum Lateral Strength Check

The requirements of Section 8.7.1 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design must be satisfied. The requirement is:

- $Mne \geq 0.1\, Ptrib\, (Hh + 0.5\, Ds) / \Lambda$

  Where;

  - ✓ Mne = nominal moment capacity of the column based upon expected material properties as shown in Figure 8.5-1 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design (kip-in.)
  - ✓ Ptrib = greater of the dead load per column or force associated with the tributary seismic mass collected at the bent (kip)
  - ✓ Hh = the height from the top of the footing to the top of the column or the equivalent column height for a pile extension (in.)
  - ✓ = 34.0 * 12 (Top of footing to top of crossbeam) = 408 in.
  - ✓ Ds = depth of superstructure (in.) = 7.083 * 12 = 85 in.
  - ✓ Λ = fixity factor (See Section 4.8.1 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design) = 2 for fixed top and bottom

12. Code Requirements

Minimum Lateral Strength Check

Determine Mne:

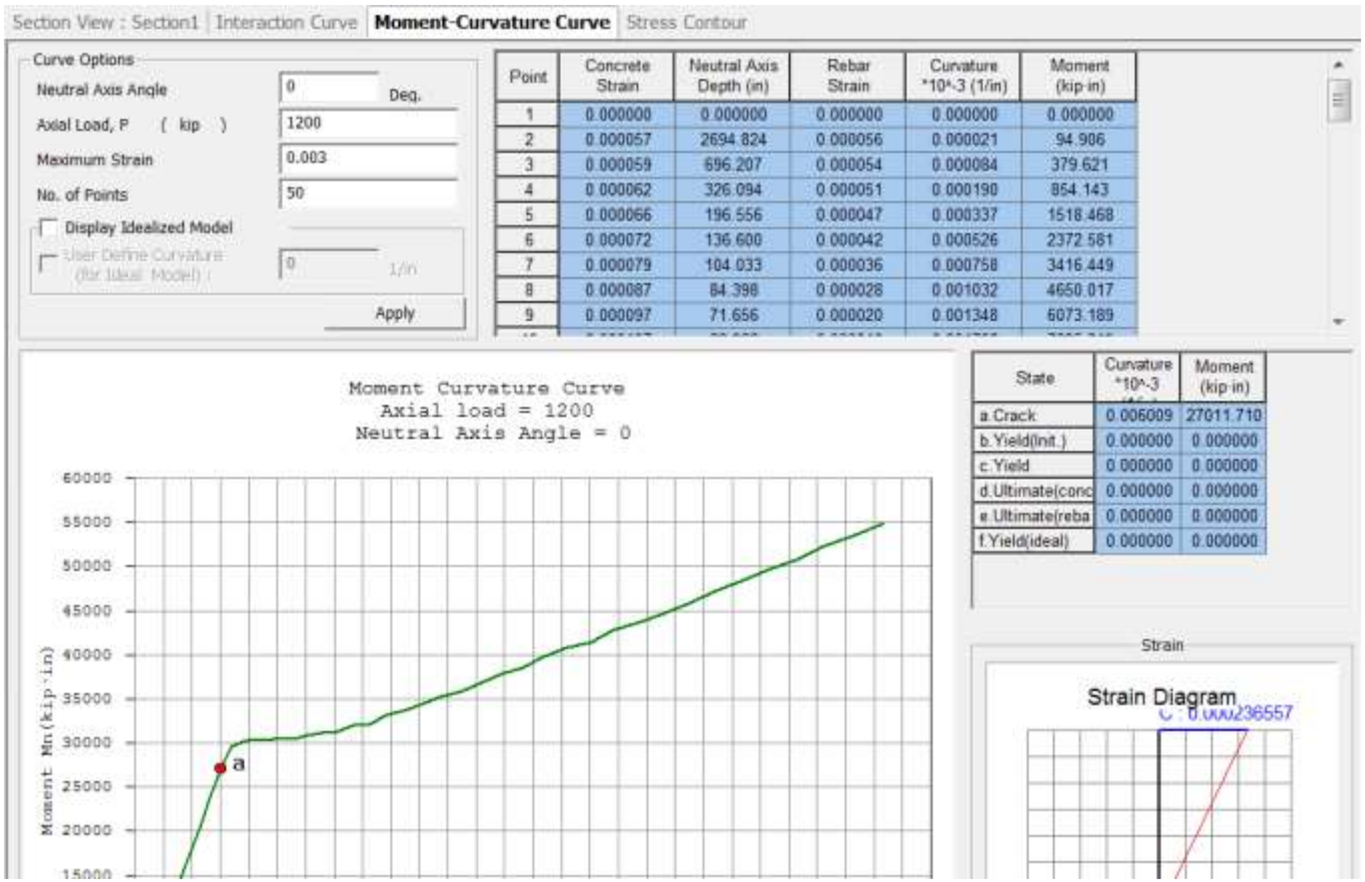
✓ **Mne ≥ 0.1 Ptrib (Hh + 0.5 Ds) / Λ**

- **Section 8.5 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design defines Mne as the expected nominal moment capacity based on the expected concrete and reinforcing steel strengths when the concrete strain reaches a magnitude of 0.003.**
- **General Section Designer in midas Civil is used to determine Mne by performing a moment-curvature analysis and displaying the moment when the concrete reaches a strain of 0.003. The moment-curvature diagram for the column section is shown with values displayed at a concrete strain of 0.003.**

✓ **Mne = 73,482 kip-inches.**

Minimum Lateral Strength Check

Moment-Curvature Curve for Frame Section “COLUMN” at εc = 0.003



12. Code Requirements

Minimum Lateral Strength Check

Determine Ptrib:
Since the abutments were modeled as free in the longitudinal direction, all of the seismic mass is collected at the bents in the longitudinal direction. Therefore, the force associated with the tributary seismic mass collected at the bent is greater than the dead load per column and is computed as follows:

- ✓ **Ptrib = Weight of Structure / # of bents / # of columns per bent = 6,638 / 2 / 2 = 1,660 kips**

Perform Check:

- ✓ **0.1 Ptrib (Hh + 0.5 Ds) / Λ = 0.1 * 1,660 * (408 + 0.5 * 85) / 2**
- ✓ **= 37,392 kip-in. < 73,482 kip-in. = Mne => Ok**

12. Code Requirements

Balanced Stiffness and Frame Geometry Requirement Check

The balanced stiffness and balanced frame geometry requirements of Sections 4.1.2 and 4.1.3 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design must be met.

Other Required Checks

- **Structure Displacement Demand/Capacity Check**
- **Member Ductility Requirement Check**
- **Column Shear Demand/Capacity Check**

13. Acknowledgements

- MIDAS Software
- AASHTO

Thank you!

For any additional inquiries and interest in trying out midas Civil please contact us:

MIDASoft
midasoft@midasuser.com