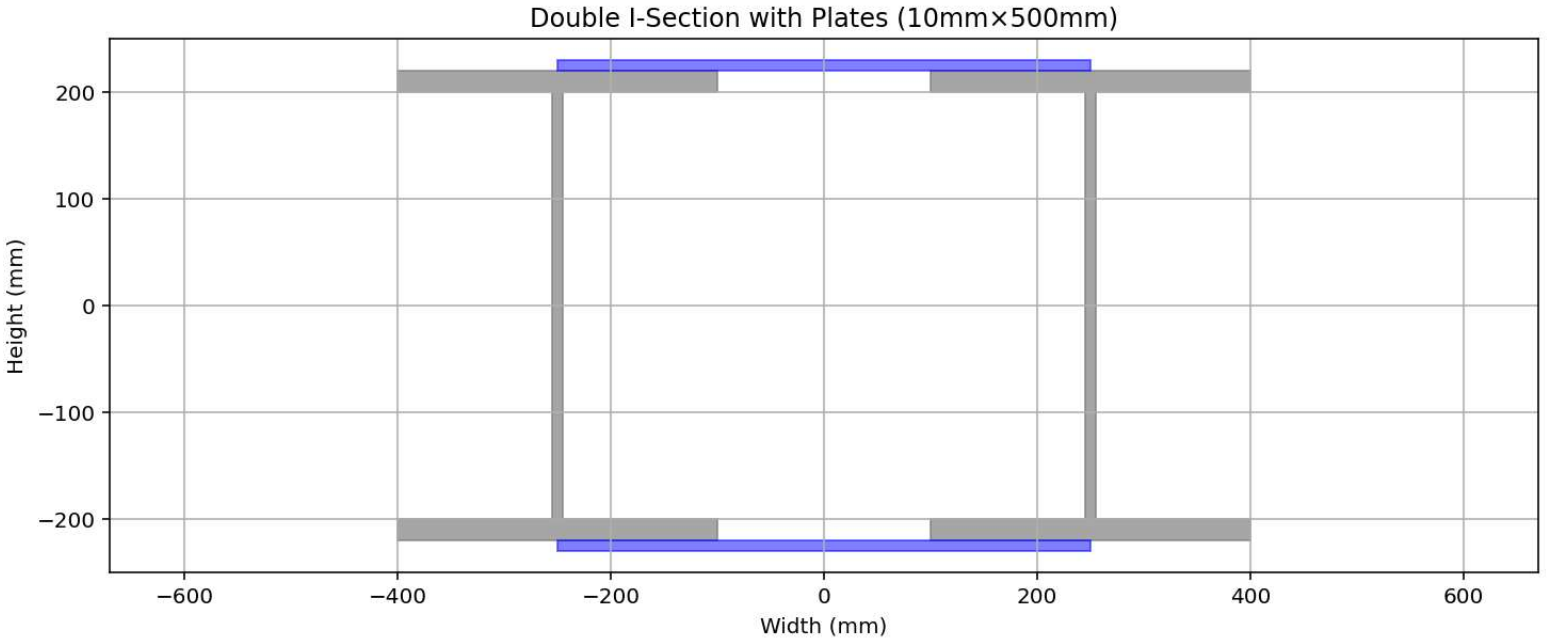
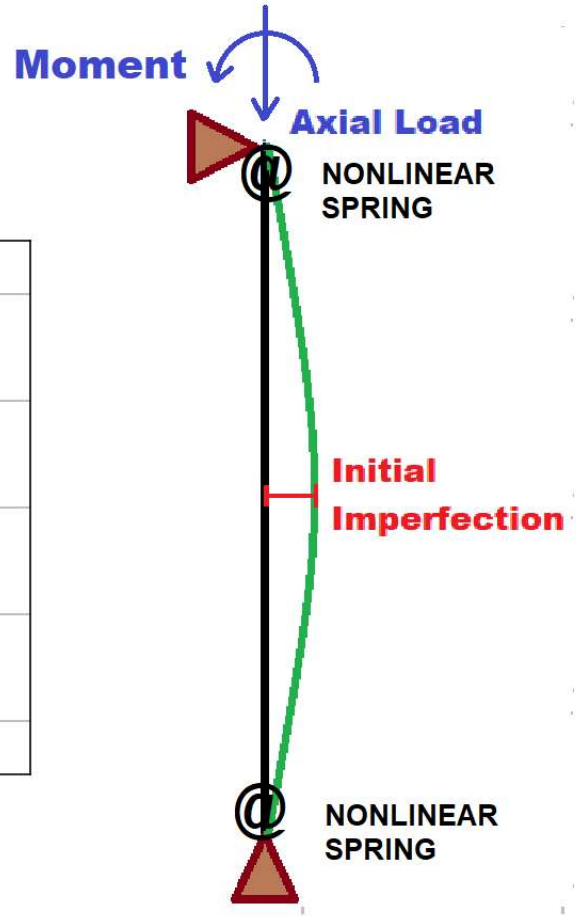
>> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<

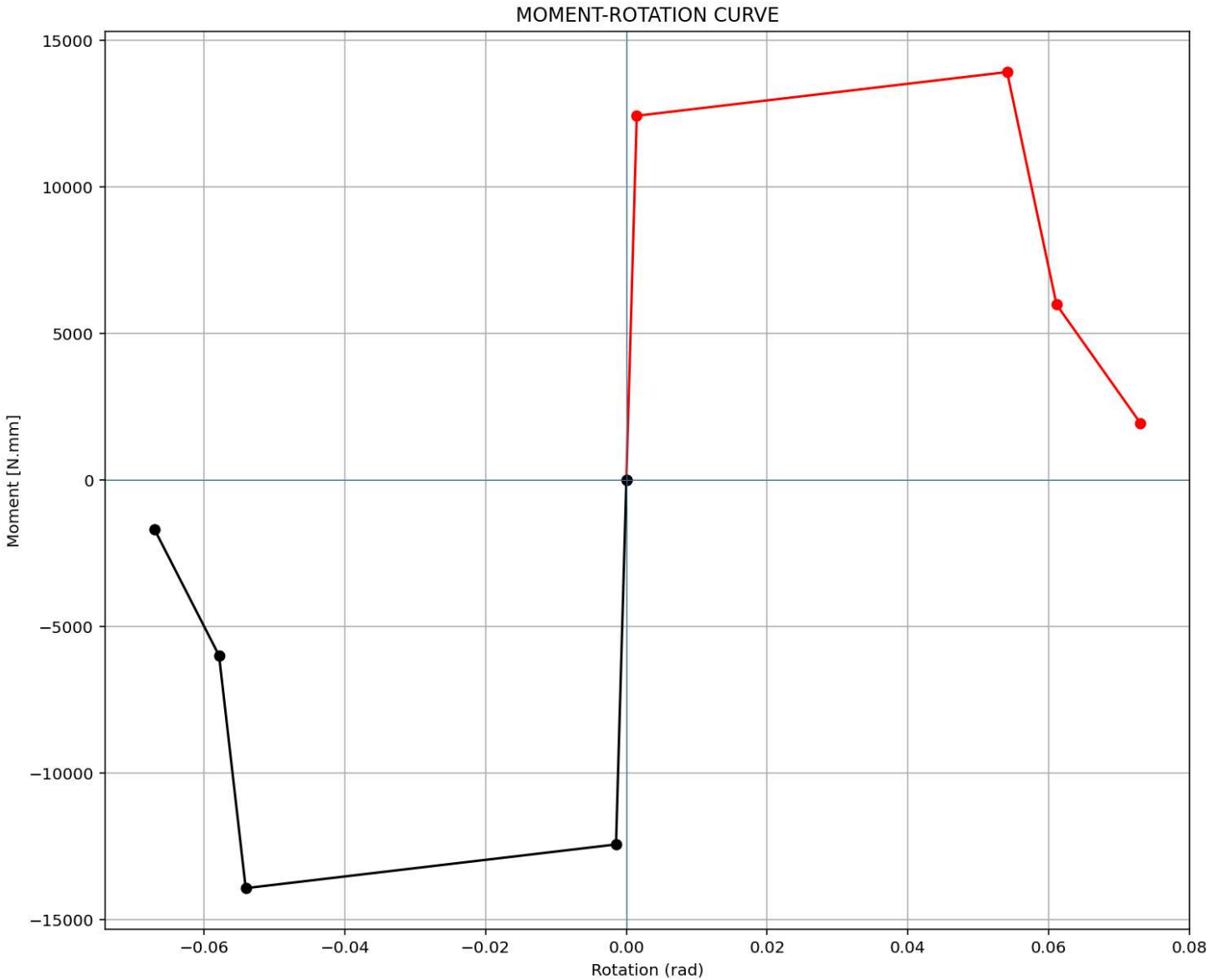
INVESTIGATION OF FREE-VIBRATION ANALYSIS WITH AXIAL DISPLACEMENT OF MULTI-MODE POST-BUCKLING PHENOMENA IN SEMI-RIGID STEEL COLUMNS USING OPENSEES CONSIDERING THE GEOMETRIC AND MATERIAL PROPERTIES NONLINEARITY

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)

$$(\frac{P}{P_y})^2 + (\frac{M}{M_y})^2 \leq 1$$






MOMENT-ROTATION CURVE
15000
10000
5000
0
−5000
−10000
−15000
Moment [N.mm]
−0.06
−0.04
−0.02
0.00
0.02
0.04
0.06
0.08
Rotation (rad)

Spyder (Python 3.12)

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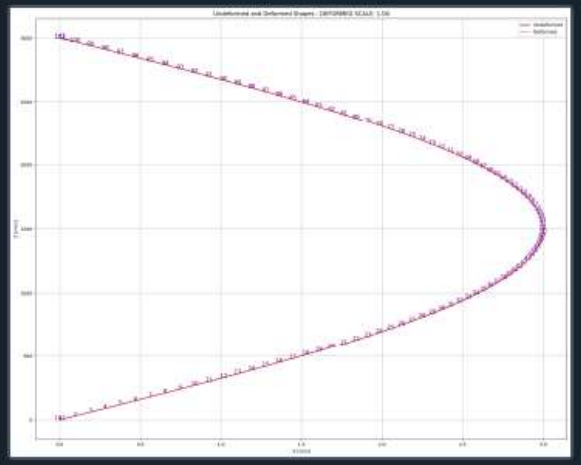
C:\Users\Dell\Desktop\OPENSEES_FILES\MULTI-MODE-P...ING_STEEL_COLUMN_SEMI-RIGID_NONLINEAR_FV_AXIAL.py

MULTI-MODE-POST_BU...LINEAR_FV_AXIAL.py

```
1  ##########################################################################################################
2  #                    >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<
3  # INVESTIGATION OF FREE-VIBRATION ANALYSIS  WITH AXIAL DISPLACEMENT OF MULTI-MODE POST-BUCKLING PHENOMI
4  #IN SEMI-RIGID STEEL COLUMNS USING OPENSEES CONSIDERING THE GEOMETRIC AND MATERIAL PROPERTIES NONLINEAI
5  #----------------------------------------------------------------------------------------------------
6  # IT MODELS A 2D INELASTIC BEAM-COLUMN WITH AN INITIAL IMPERFECTION (FOUR DIFFRENET SHAPES)
7  #  AND APPLIES AN AXIAL COMPRESSIVE LOAD TO ANALYZE LARGE DISPLACEMENTS.
8  # 1. MODEL SETUP: A COLUMN OF LENGTH L IS DEFINED WITH N ELEMENTS, INCORPORATING A SMALL INITIAL
9  # IMPERFECTION (HALF-SINE WAVE).
10 # 2. NODES & BOUNDARY CONDITIONS: NODES ARE CREATED, WITH THE BOTTOM FIXED IN X, Y AND THE TOP FIXED II
11 # X BUT FREE IN Y AND ROTATION.
12 # 3. ELEMENT DEFINITION: THE COLUMN IS MODELED USING ELASTIC BEAM-COLUMN ELEMENTS WITH COROTATIONAL
13 # TRANSFORMATION FOR GEOMETRIC NONLINEARITY.
14 # 4. LOAD APPLICATION: A STATIC AXIAL FORCE P IS APPLIED AT THE TOP NODE.
15 # 5. ANALYSIS SETUP: A DISPLACEMENTCONTROL INTEGRATOR IS USED TO INCREMENTALLY PUSH THE COLUMN DOWNWARI
16 # 6. NONLINEAR SOLVER: THE NEWTON METHOD IS USED WITH A NORMDISPINCR TEST FOR CONVERGENCE.
17 # 7. ANALYSIS EXECUTION: THE LOOP PERFORMS INCREMENTAL LOADING STEPS, RECORDING AXIAL DISPLACEMENT,
18 # LATERAL DISPLACEMENT, AND AXIAL FORCE.
19 # 8. BUCKLING BEHAVIOR CAPTURE: LATERAL DISPLACEMENTS AT THE MID-HEIGHT NODE INDICATE POST-BUCKLING
20 # DEFORMATION.
21 # 9. RESULTS EXTRACTION: REACTION FORCES AT THE BASE NODE PROVIDE THE AXIAL COMPRESSIVE LOAD.
22 # 10. PLOTTING: THE SCRIPT VISUALIZES AXIAL FORCE VS. LATERAL DISPLACEMENT, SHOWING THE POST-BUCKLING
23 # RESPONSE OF THE COLUMN.
24 #----------------------------------------------------------------------------------------------------
25 #                         THIS PROGRAM WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)
26 #                                  EMAIL: salar.d.ghashghaei@gmail.com
27 ##########################################################################################################
28 import openseespy.opensees as ops
29 import numpy as np
30 import matplotlib.pyplot as plt
31 import STEEL_FIBER_SECTION as S01
32 import ANALYSIS_FUNCTION as S02
33 import OPENSEEES_HYSTERETICSM_FORCE_DISP_FUN as S03
34 import RAYLEIGH DAMPING FUN as S04
```

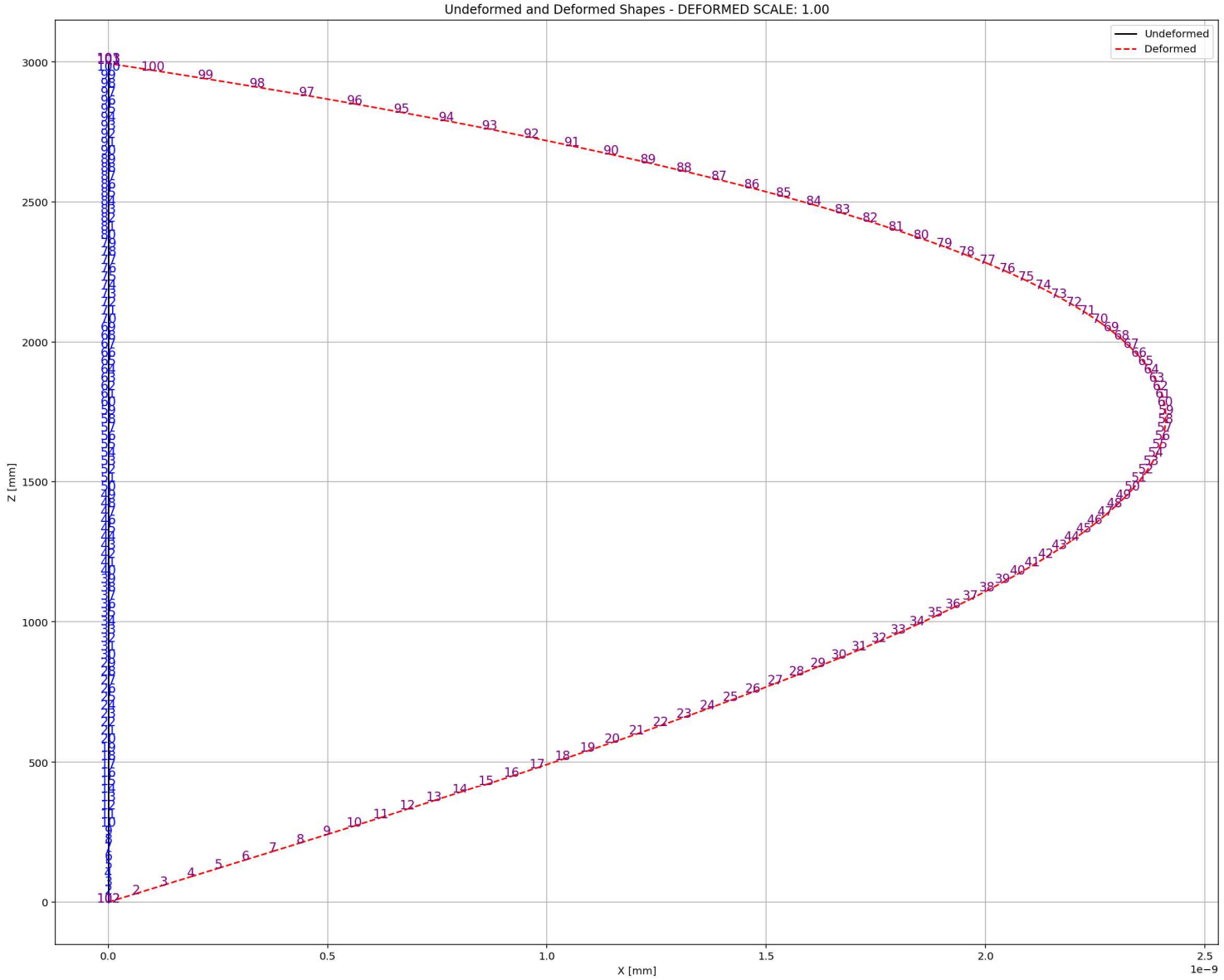
..._BUCKLING_STEEL_COLUMN_SEMI-RIGID_NONLINEAR_FREE_VIBRATION

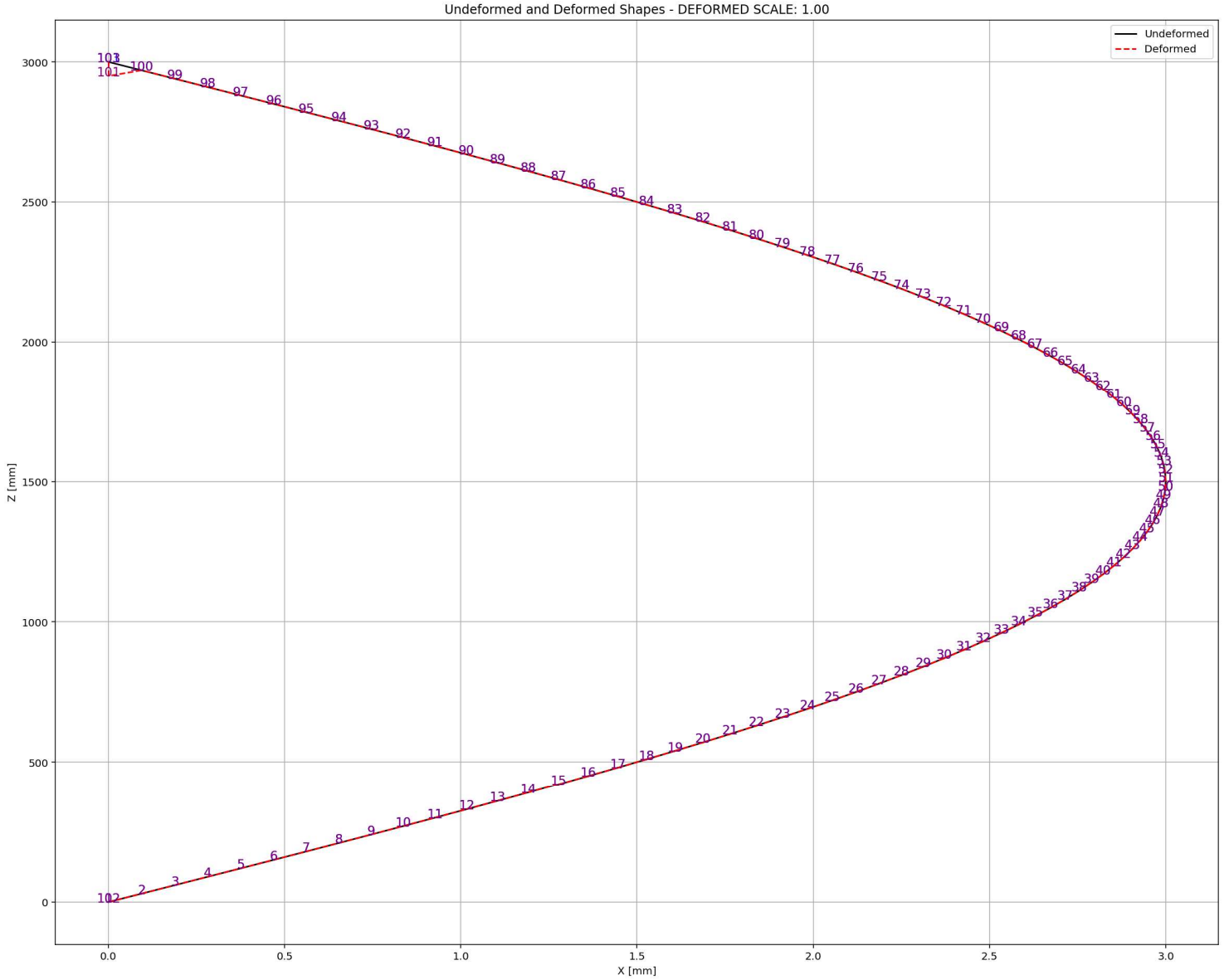
16 %

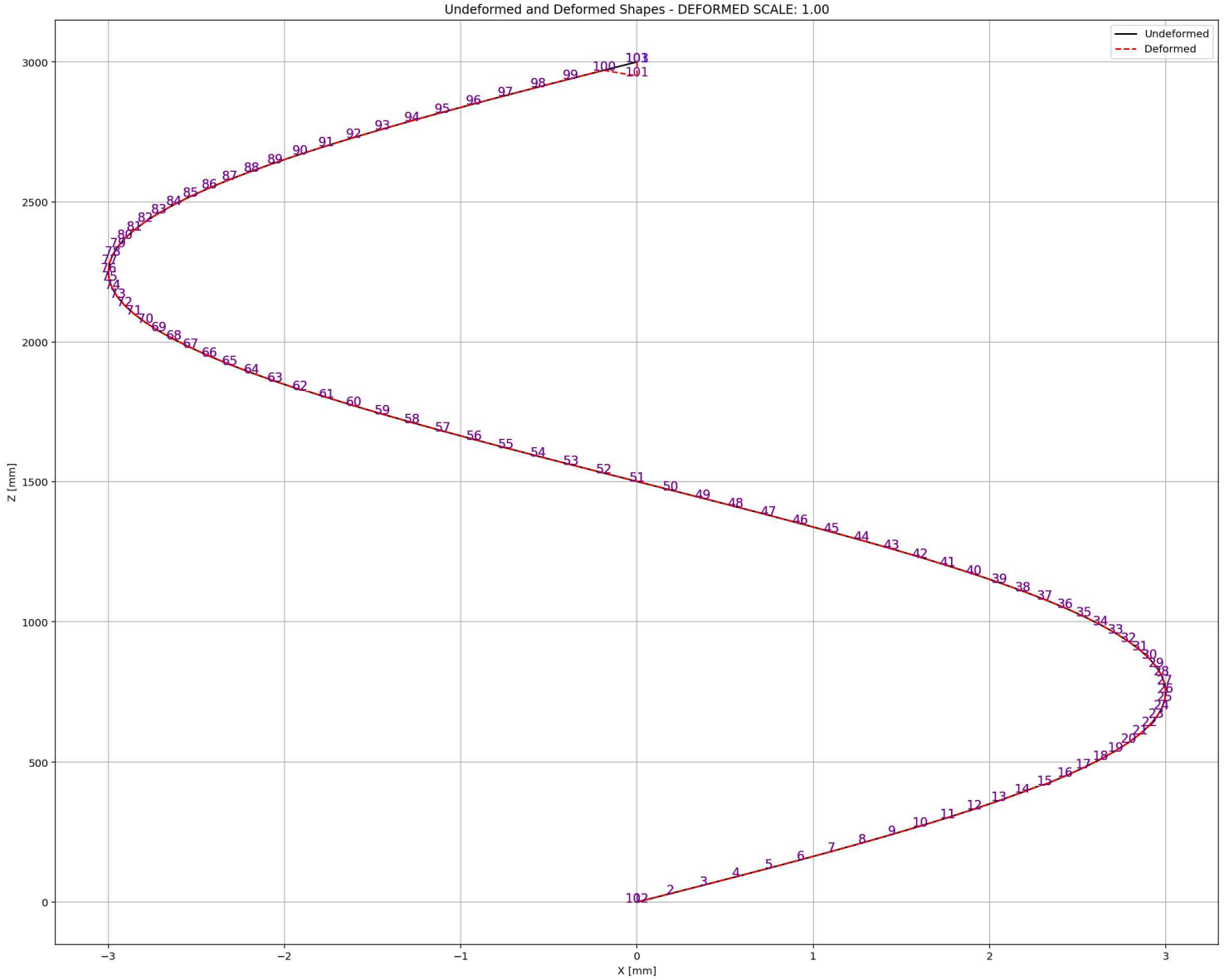


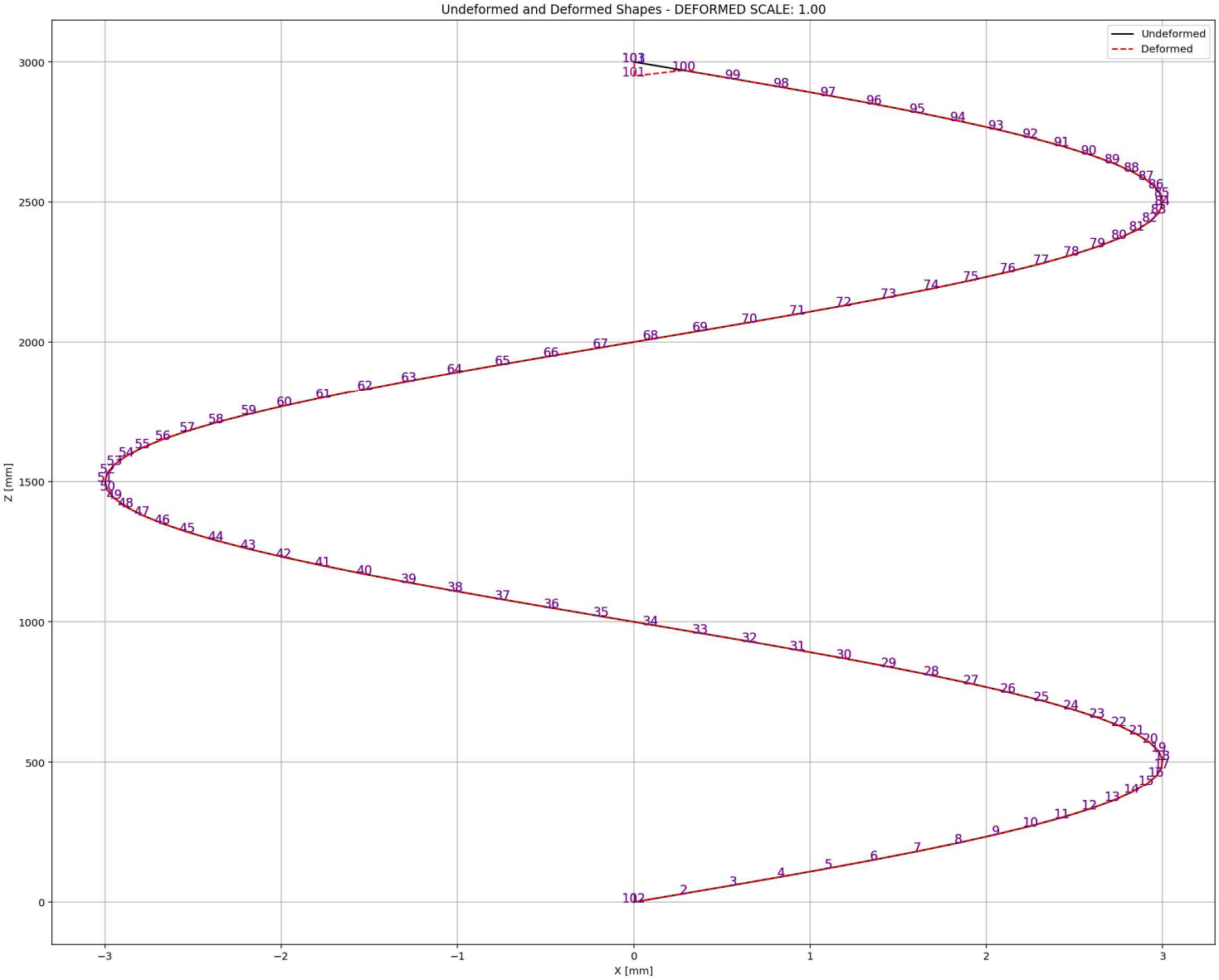
IPython Console | Files | Help | Variable Explorer | Debugger | Plots | History

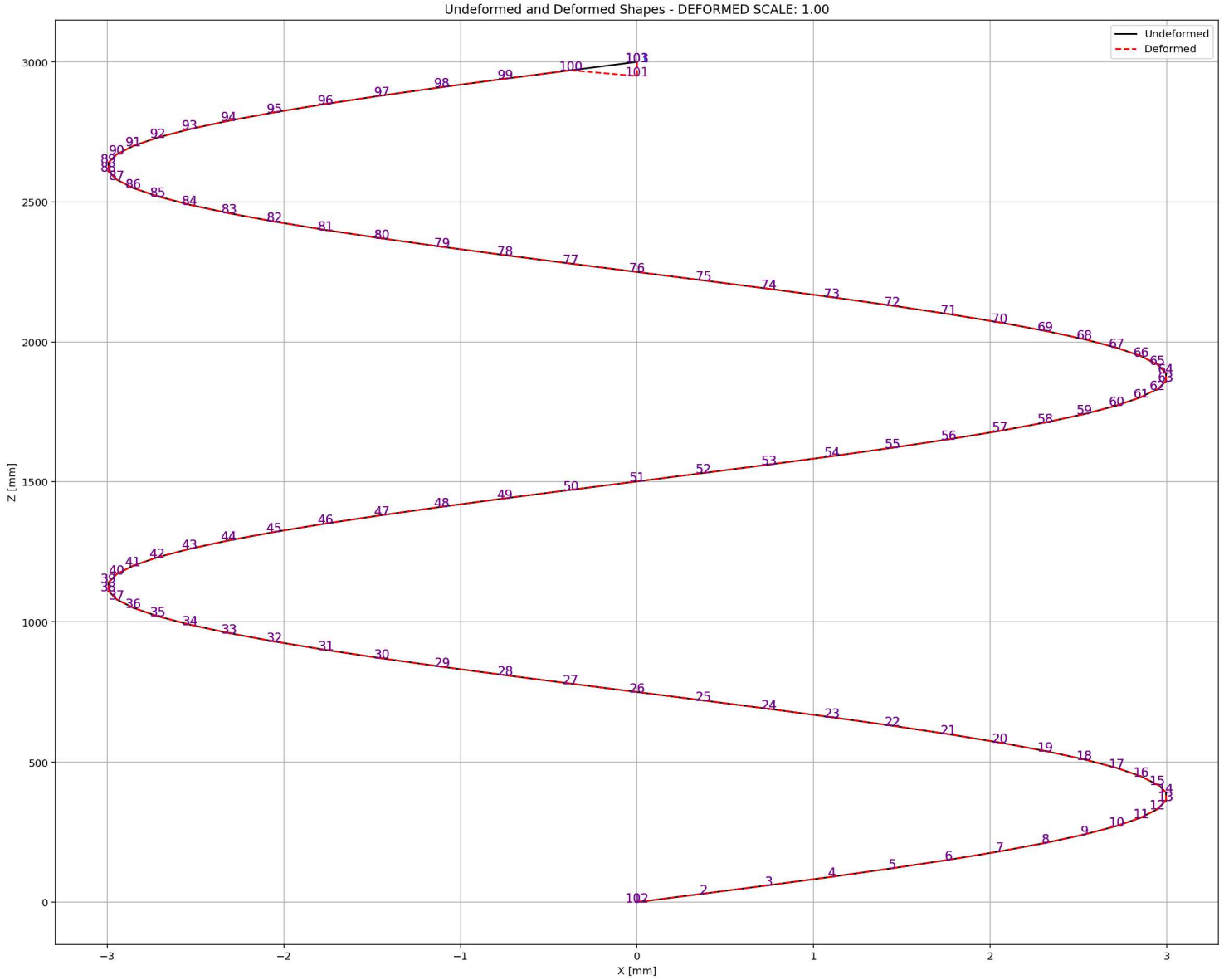
Inline | Conda: anaconda3 (Python 3.12.7) | LSP: Python | Line 10, Col 23 | UTF-8 | CRLF | RW | Mem 46%

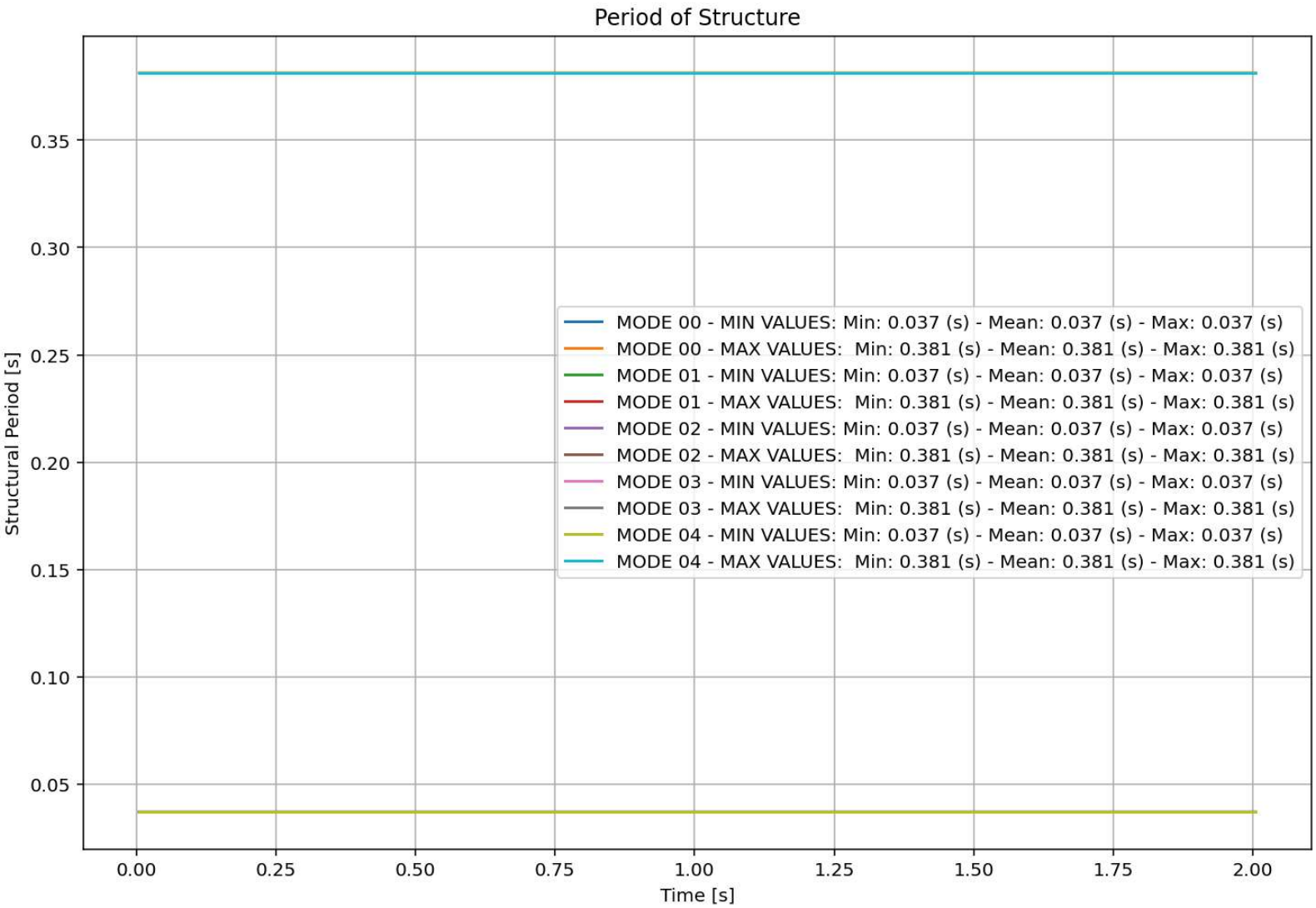

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Undeformed
Deformed
Z [mm]
X [mm]
1e−9
0
500
1000
1500
2000
2500
3000
0.0
0.5
1.0
1.5
2.0
2.5

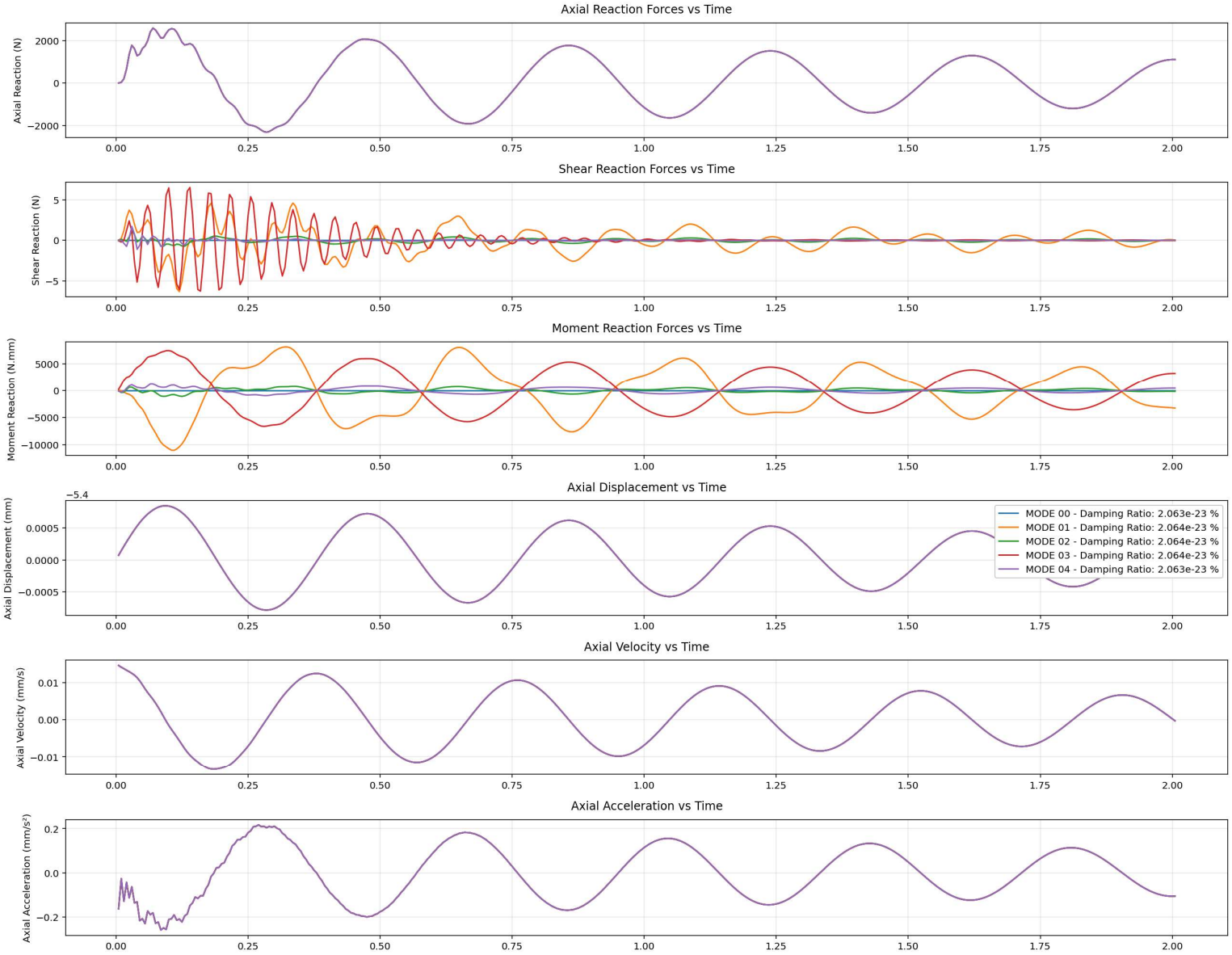

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Undeformed
Deformed
Z [mm]
X [mm]
0
500
1000
1500
2000
2500
3000
0.0
0.5
1.0
1.5
2.0
2.5
3.0

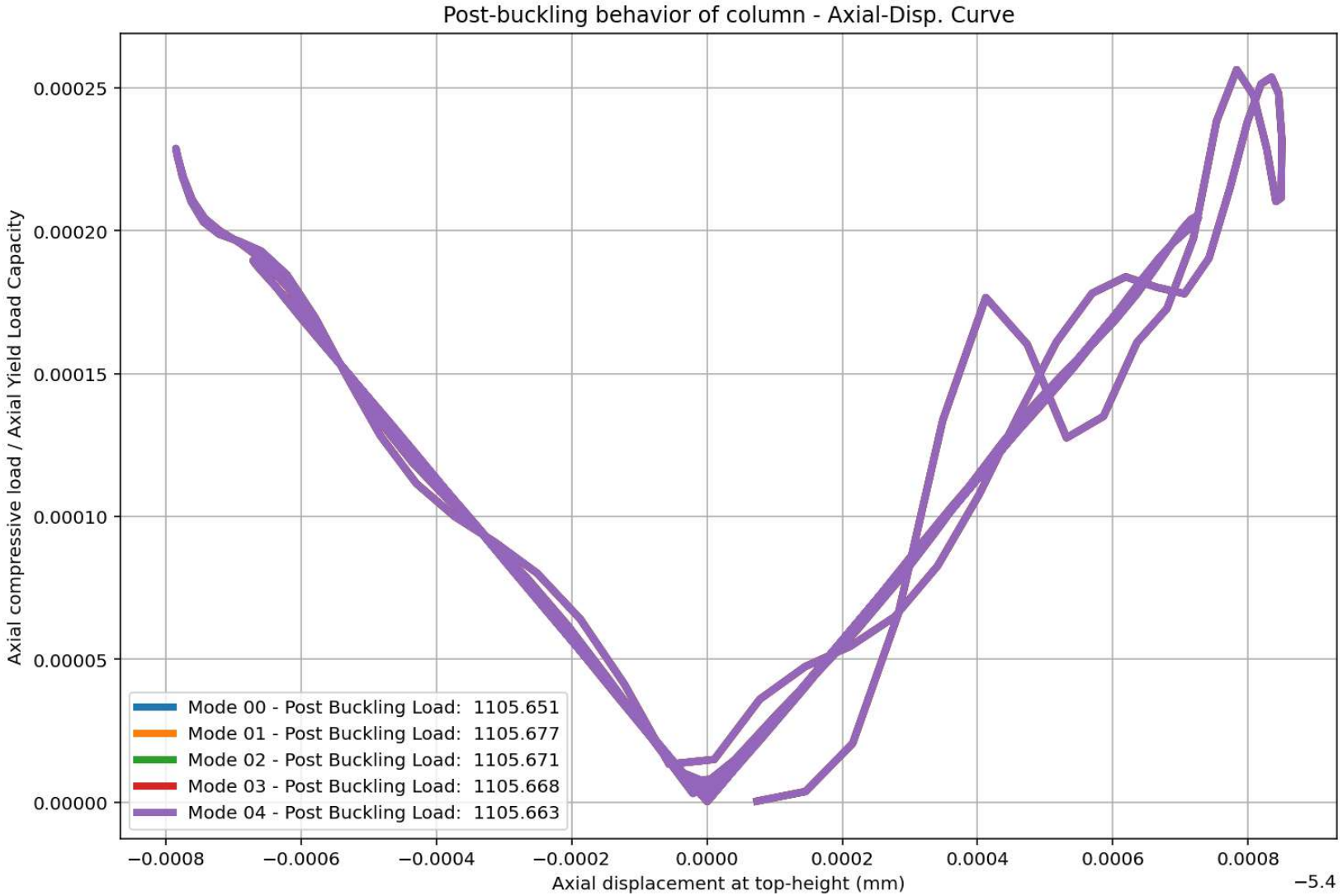

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Undeformed
Deformed
Z [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−3
−2
−1
0
1
2
3

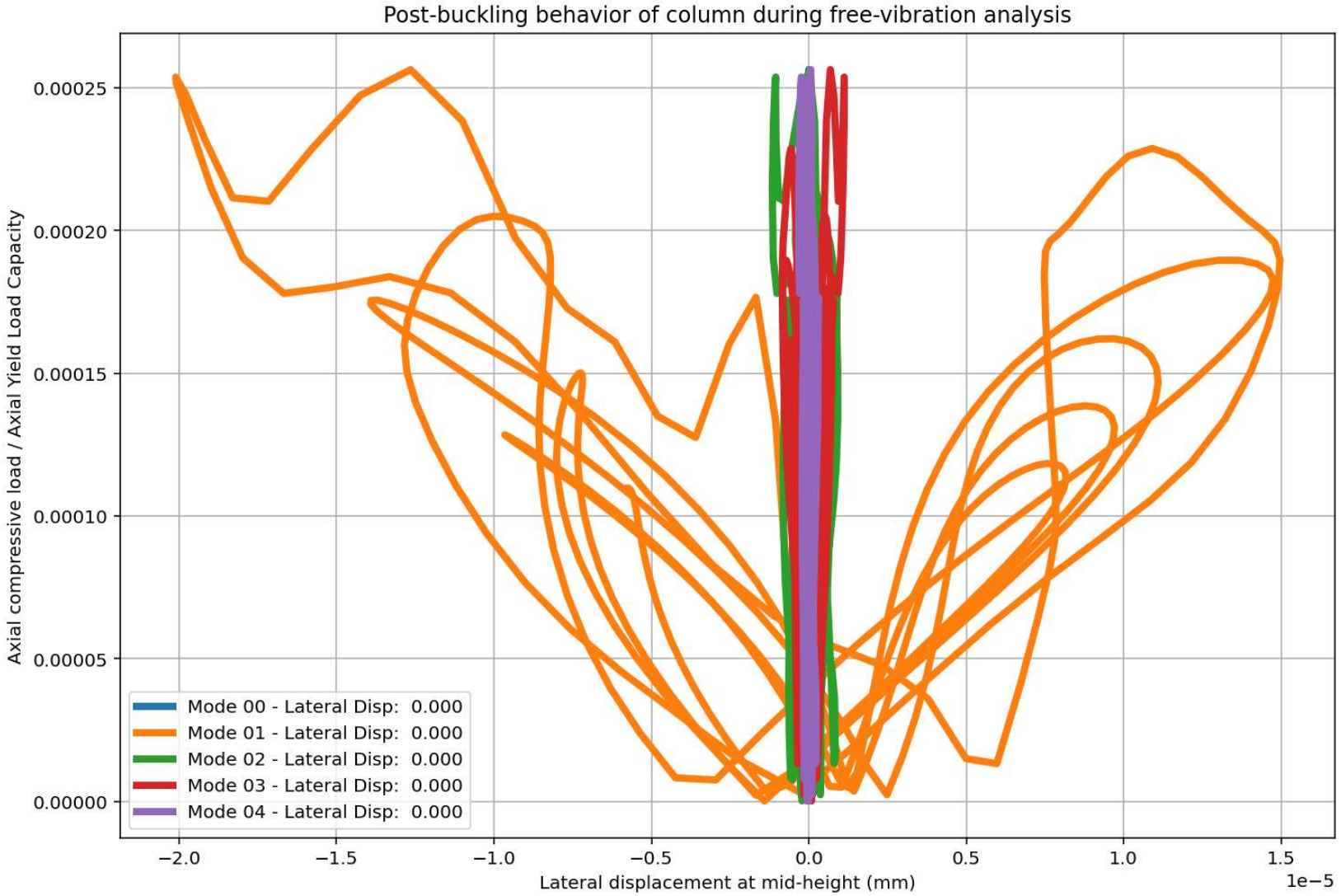

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Undeformed
Deformed
Z [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−3
−2
−1
0
1
2
3

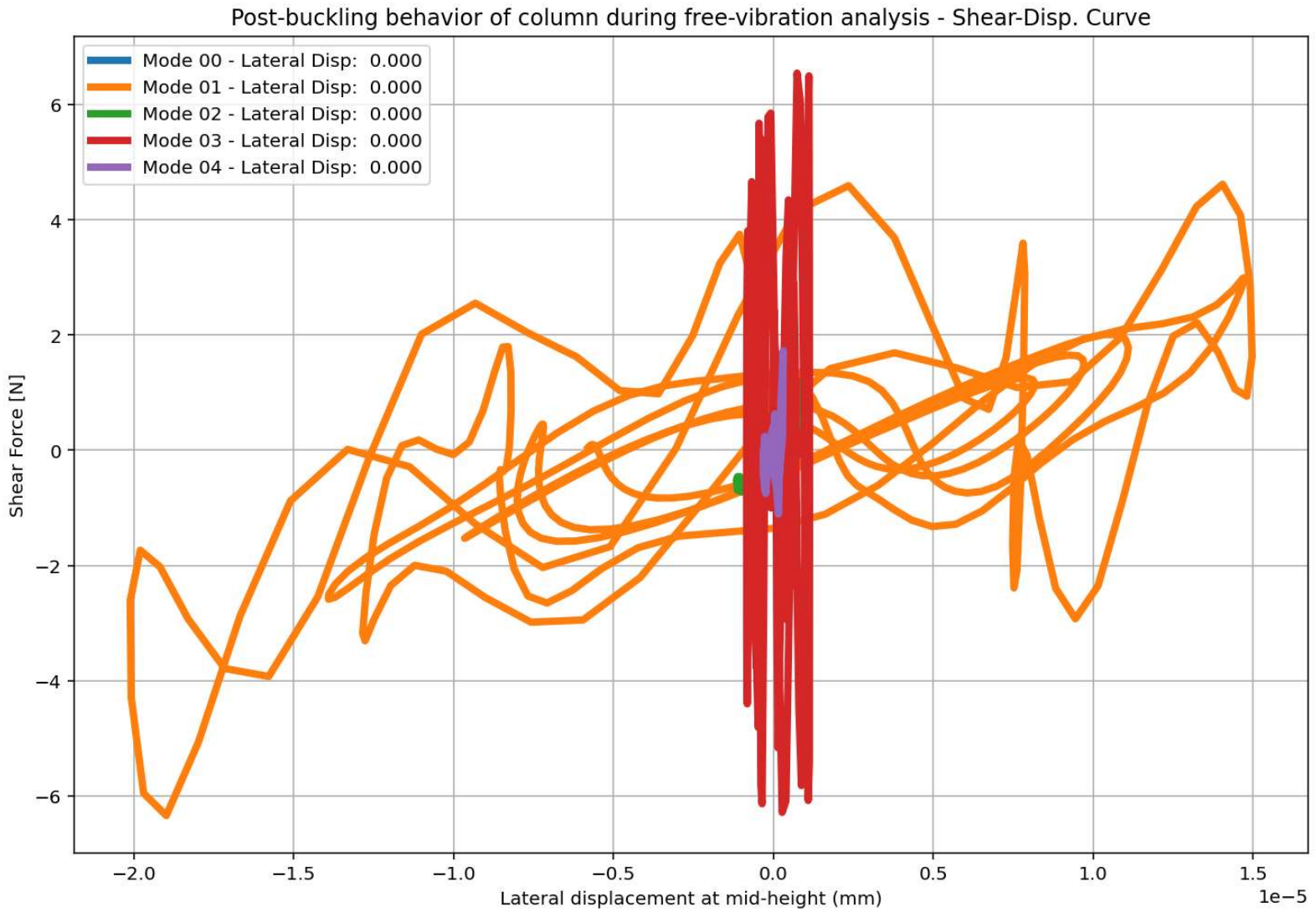

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Undeformed
Deformed
Z [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−3
−2
−1
0
1
2
3

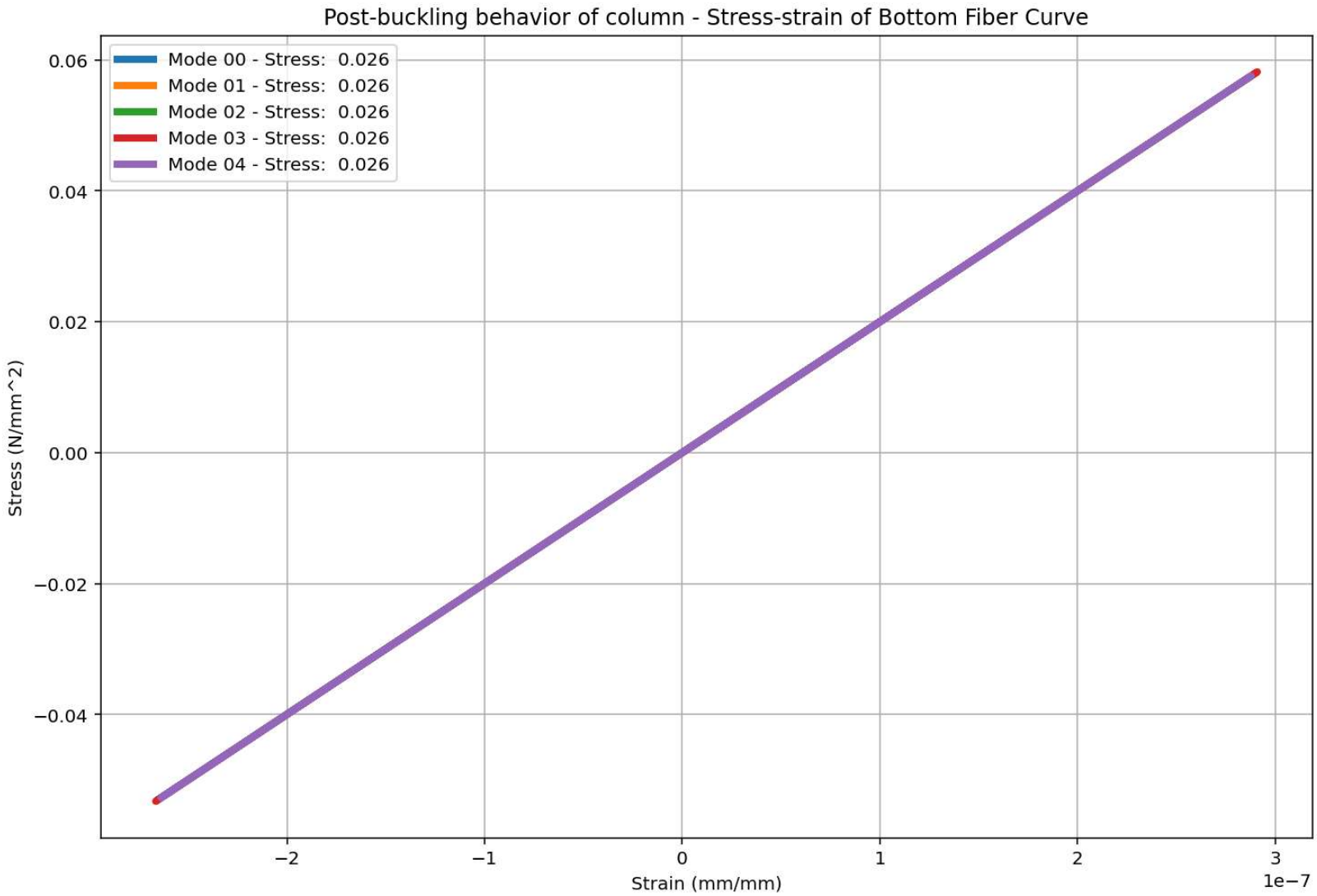

Period of Structure
Structural Period [s]
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time [s]
MODE 00 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 00 - MAX VALUES: Min: 0.381 (s) - Mean: 0.381 (s) - Max: 0.381 (s)
MODE 01 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 01 - MAX VALUES: Min: 0.381 (s) - Mean: 0.381 (s) - Max: 0.381 (s)
MODE 02 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 02 - MAX VALUES: Min: 0.381 (s) - Mean: 0.381 (s) - Max: 0.381 (s)
MODE 03 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 03 - MAX VALUES: Min: 0.381 (s) - Mean: 0.381 (s) - Max: 0.381 (s)
MODE 04 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 04 - MAX VALUES: Min: 0.381 (s) - Mean: 0.381 (s) - Max: 0.381 (s)

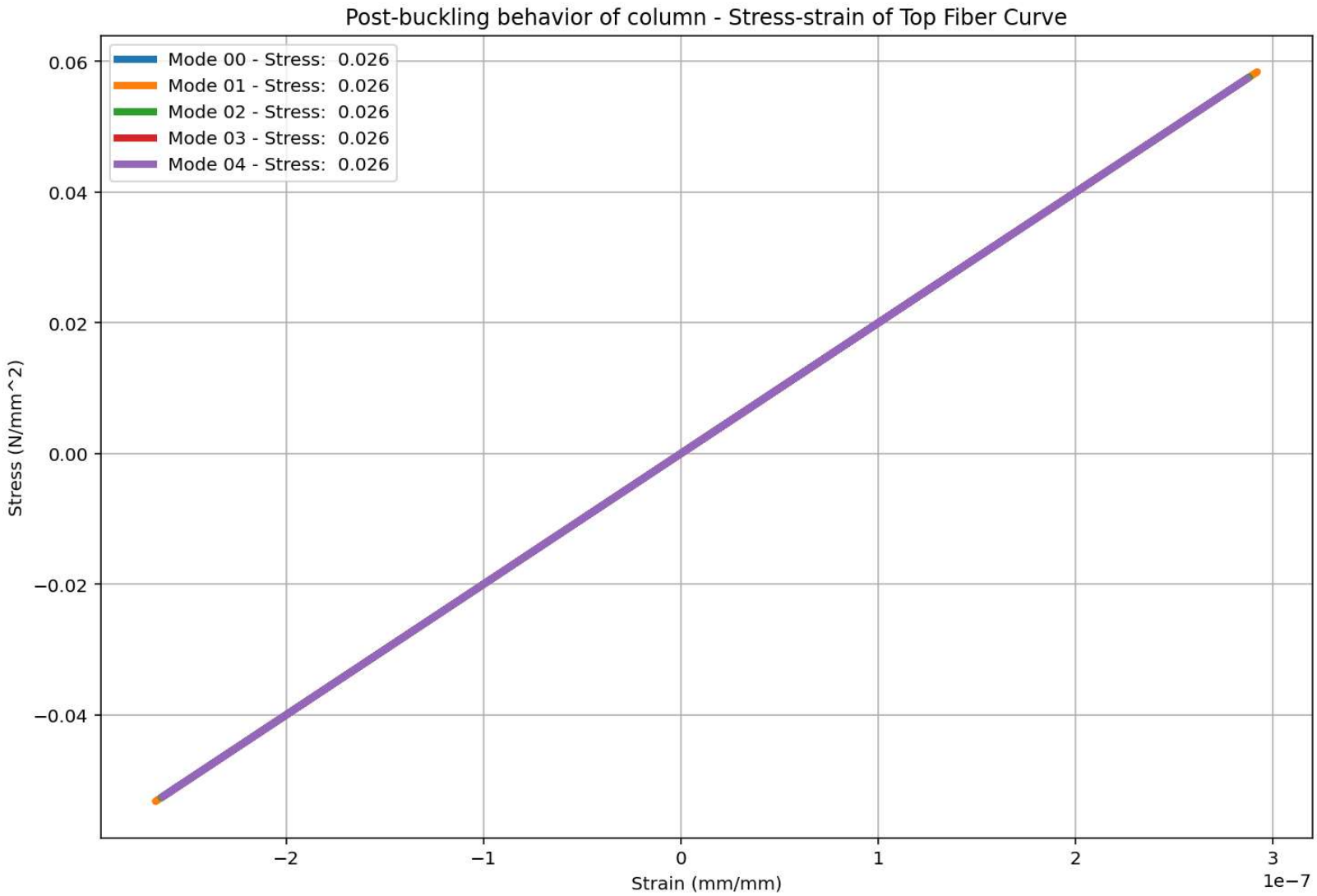

Axial Reaction Forces vs Time
Axial Reaction (N)
Shear Reaction Forces vs Time
Shear Reaction (N)
Moment Reaction Forces vs Time
Moment Reaction (N.mm)
Axial Displacement vs Time
−5.4
Axial Displacement (mm)
MODE 00 - Damping Ratio: 2.063e-23 %
MODE 01 - Damping Ratio: 2.064e-23 %
MODE 02 - Damping Ratio: 2.064e-23 %
MODE 03 - Damping Ratio: 2.064e-23 %
MODE 04 - Damping Ratio: 2.063e-23 %
Axial Velocity vs Time
Axial Velocity (mm/s)
Axial Acceleration vs Time
Axial Acceleration (mm/s²)

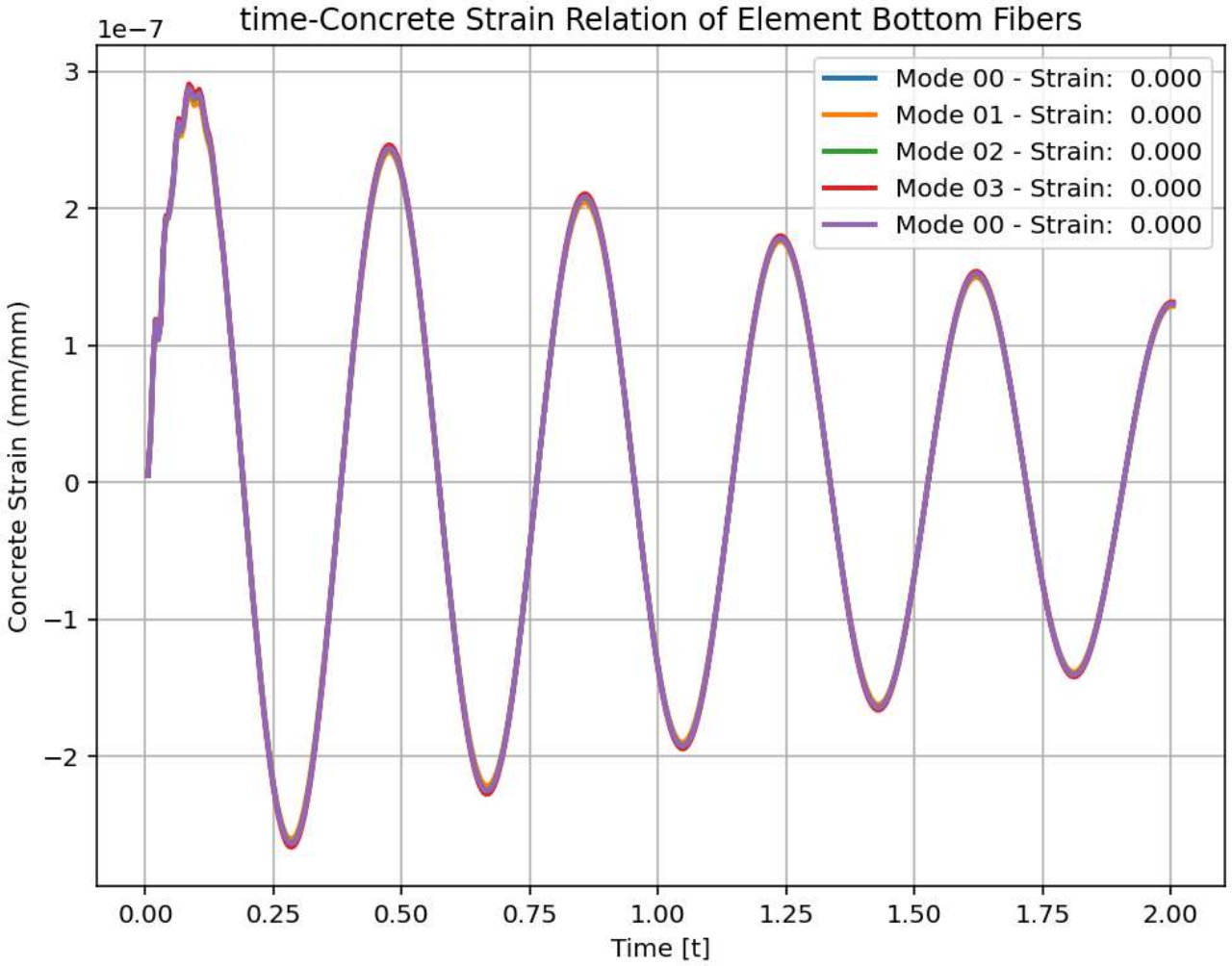

Post-buckling behavior of column - Axial-Disp. Curve
Axial compressive load / Axial Yield Load Capacity
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
−0.0008
−0.0006
−0.0004
−0.0002
0.0000
0.0002
0.0004
0.0006
0.0008
Axial displacement at top-height (mm)
−5.4
Mode 00 - Post Buckling Load: 1105.651
Mode 01 - Post Buckling Load: 1105.677
Mode 02 - Post Buckling Load: 1105.671
Mode 03 - Post Buckling Load: 1105.668
Mode 04 - Post Buckling Load: 1105.663

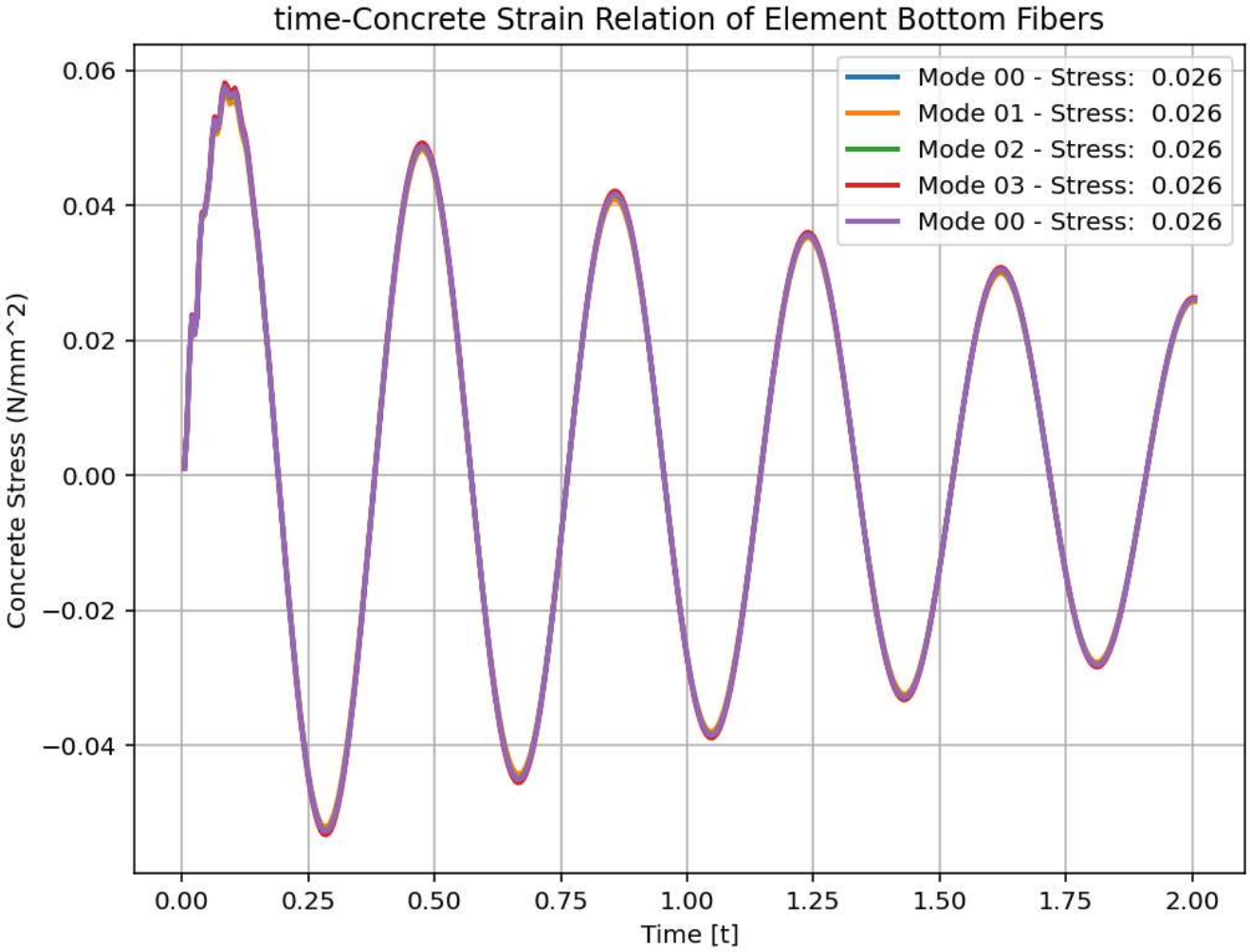

Post-buckling behavior of column during free-vibration analysis
Axial compressive load / Axial Yield Load Capacity
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
1e−5
Lateral displacement at mid-height (mm)
Mode 00 - Lateral Disp: 0.000
Mode 01 - Lateral Disp: 0.000
Mode 02 - Lateral Disp: 0.000
Mode 03 - Lateral Disp: 0.000
Mode 04 - Lateral Disp: 0.000

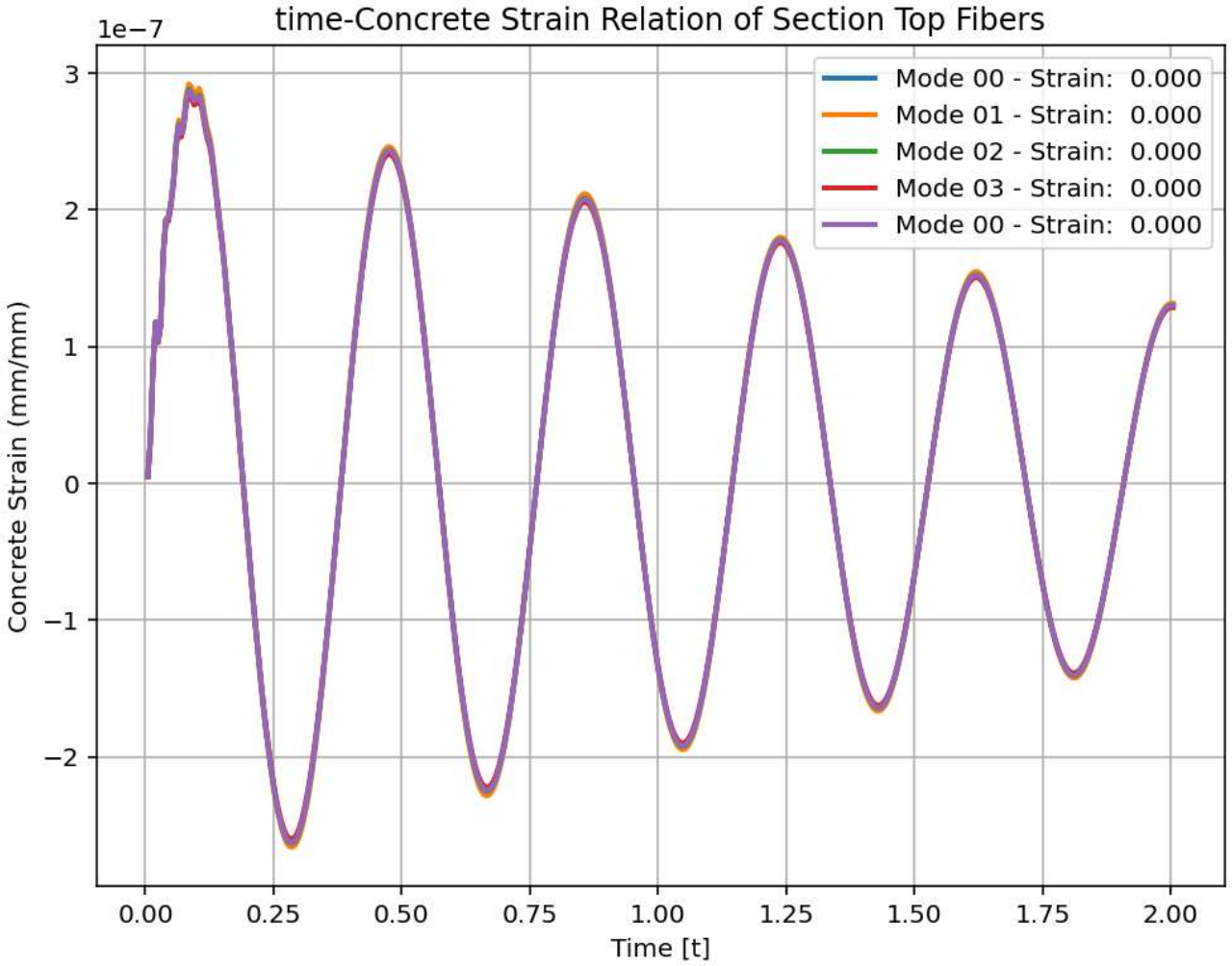

Post-buckling behavior of column during free-vibration analysis - Shear-Disp. Curve
Mode 00 - Lateral Disp: 0.000
Mode 01 - Lateral Disp: 0.000
Mode 02 - Lateral Disp: 0.000
Mode 03 - Lateral Disp: 0.000
Mode 04 - Lateral Disp: 0.000
Shear Force [N]
6
4
2
0
−2
−4
−6
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Lateral displacement at mid-height (mm)
1e−5

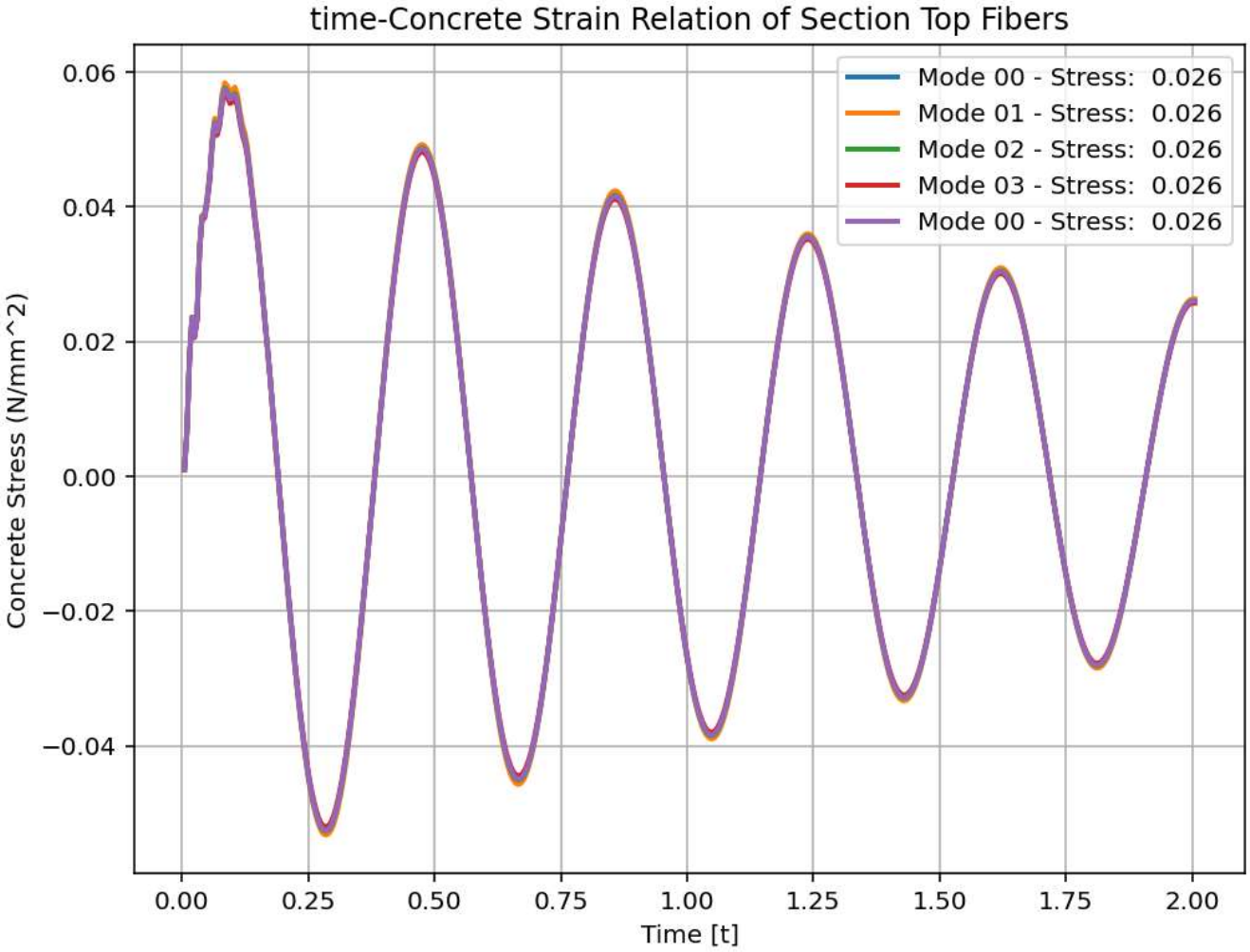

Post-buckling behavior of column - Stress-strain of Bottom Fiber Curve
Mode 00 - Stress: 0.026
Mode 01 - Stress: 0.026
Mode 02 - Stress: 0.026
Mode 03 - Stress: 0.026
Mode 04 - Stress: 0.026
0.06
0.04
0.02
0.00
−0.02
−0.04
Stress (N/mm^2)
−2
−1
0
1
2
3
1e−7
Strain (mm/mm)

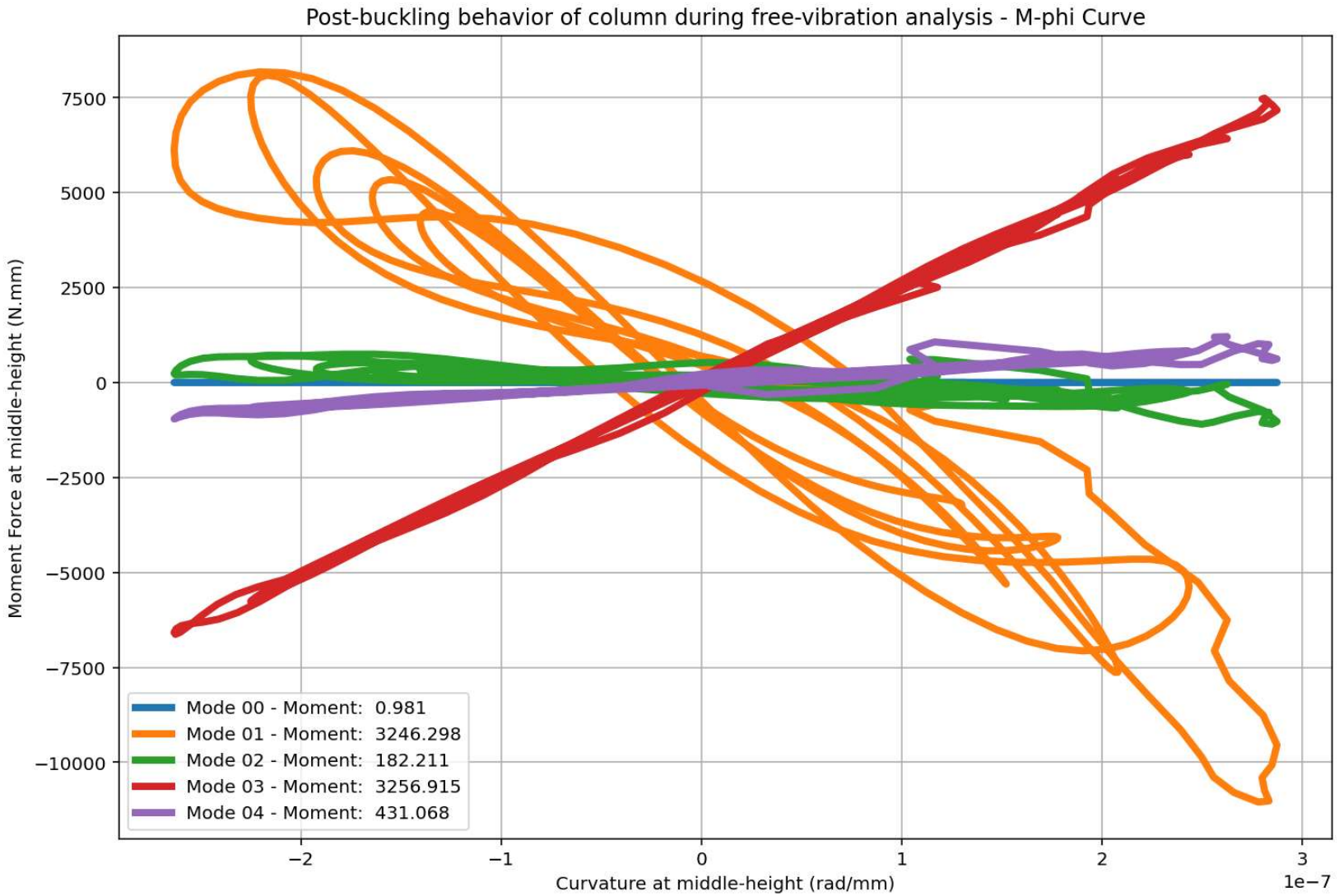

Post-buckling behavior of column - Stress-strain of Top Fiber Curve
Mode 00 - Stress: 0.026
Mode 01 - Stress: 0.026
Mode 02 - Stress: 0.026
Mode 03 - Stress: 0.026
Mode 04 - Stress: 0.026
0.06
0.04
0.02
0.00
−0.02
−0.04
Stress (N/mm^2)
−2
−1
0
1
2
3
1e−7
Strain (mm/mm)

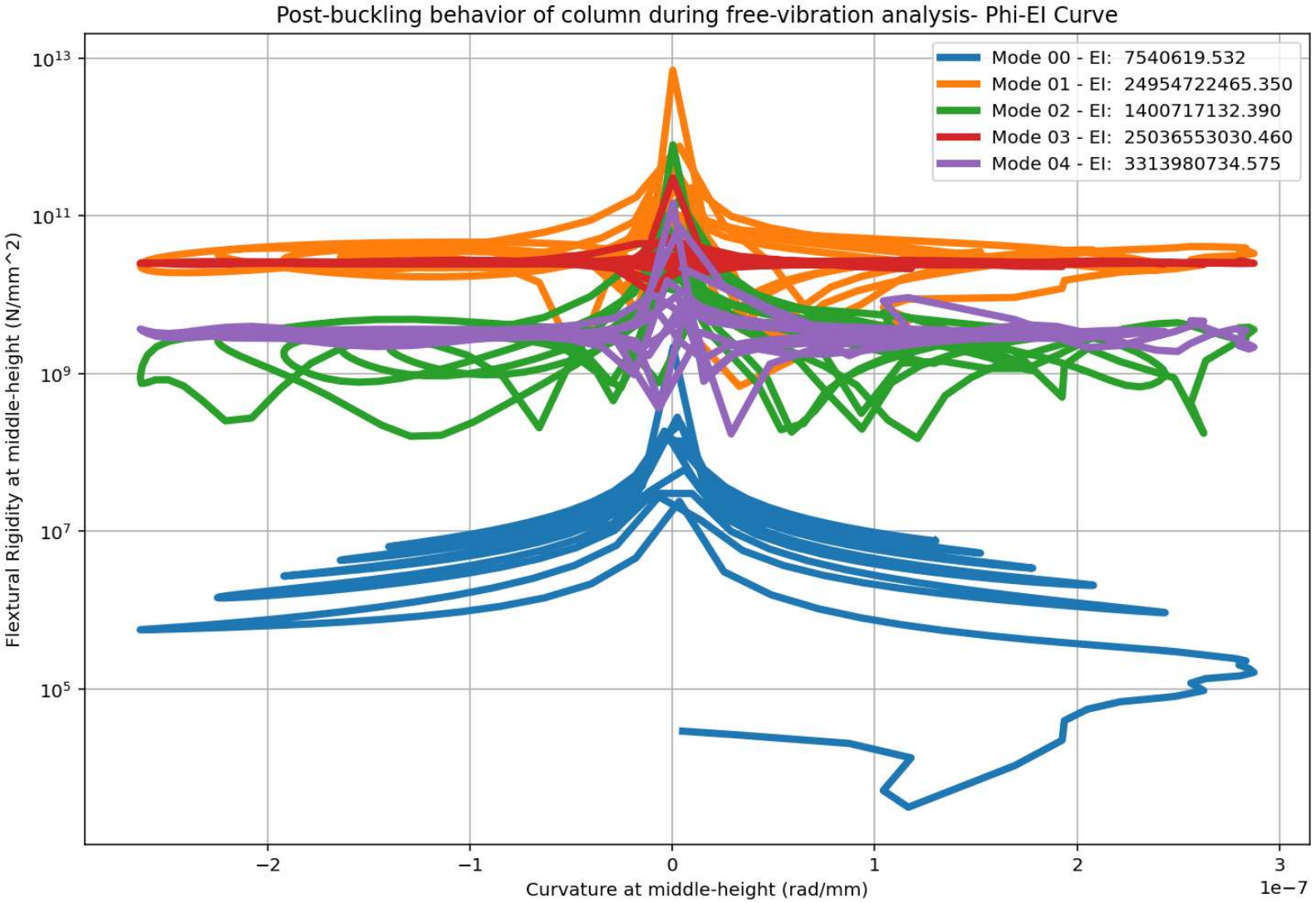

time-Concrete Strain Relation of Element Bottom Fibers
1e−7
Concrete Strain (mm/mm)
Time [t]
Mode 00 - Strain: 0.000
Mode 01 - Strain: 0.000
Mode 02 - Strain: 0.000
Mode 03 - Strain: 0.000
Mode 00 - Strain: 0.000
3
2
1
0
−1
−2
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

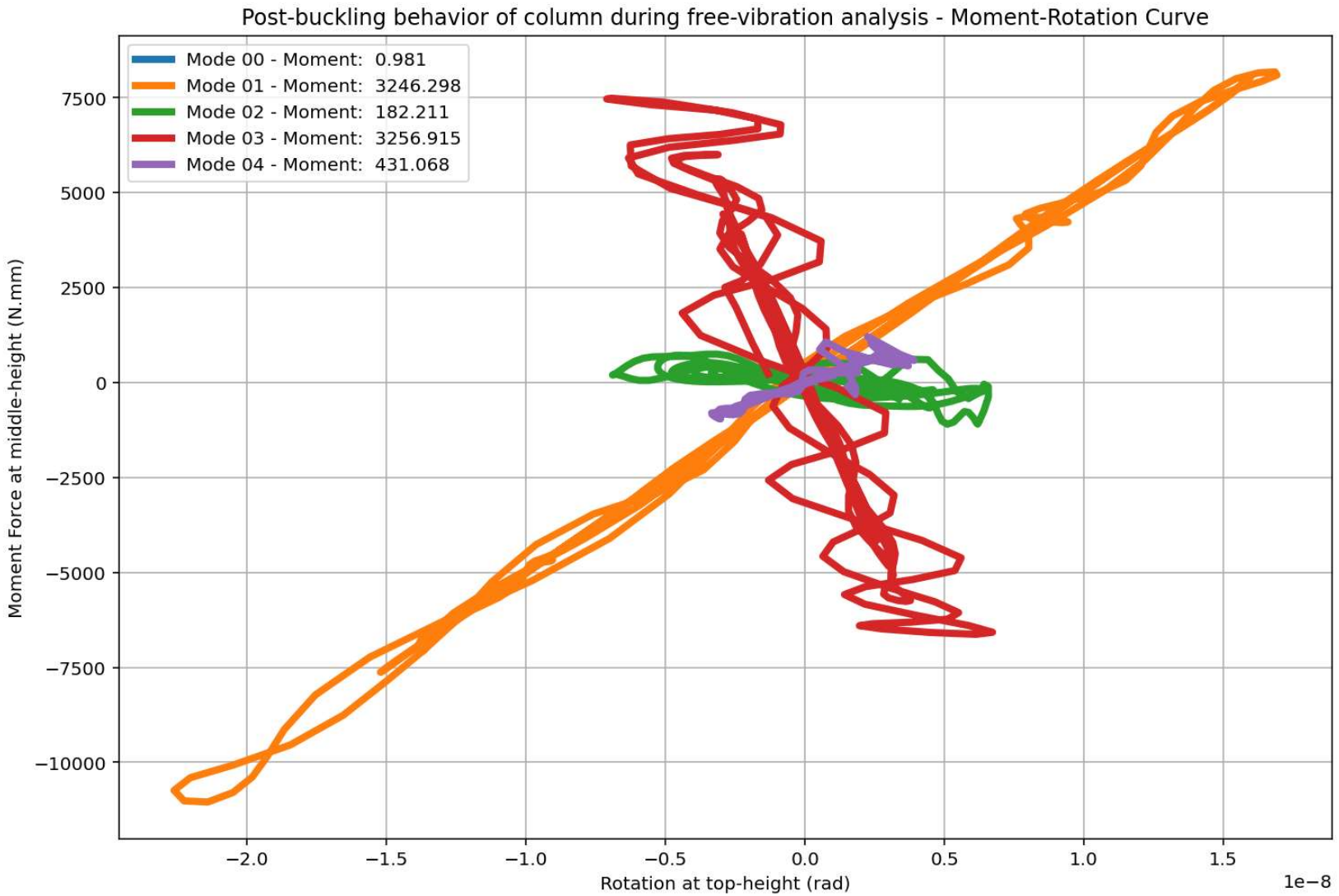

time-Concrete Strain Relation of Element Bottom Fibers
Mode 00 - Stress: 0.026
Mode 01 - Stress: 0.026
Mode 02 - Stress: 0.026
Mode 03 - Stress: 0.026
Mode 00 - Stress: 0.026
Concrete Stress (N/mm^2)
0.06
0.04
0.02
0.00
−0.02
−0.04
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time [t]

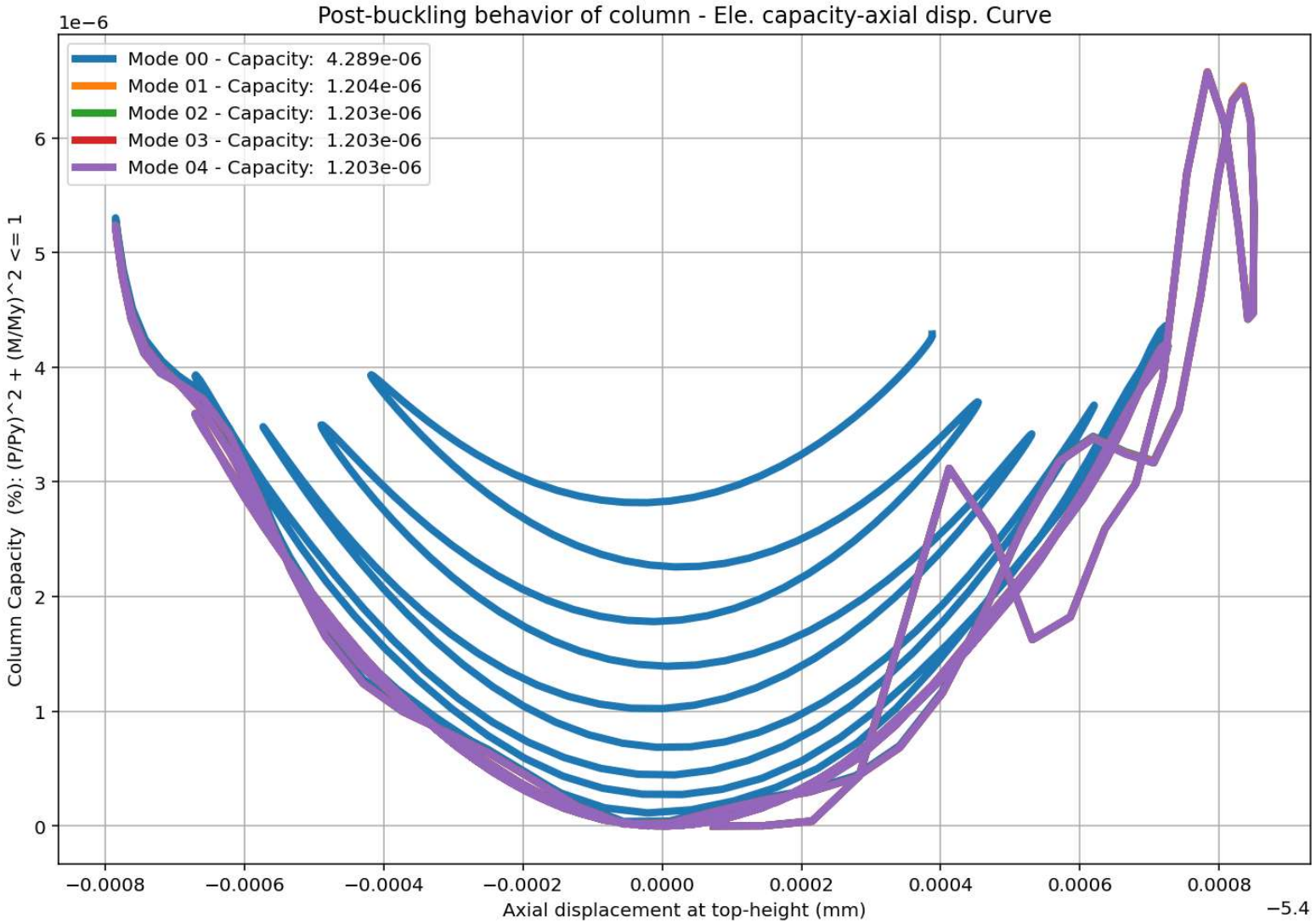

time-Concrete Strain Relation of Section Top Fibers
1e−7
Concrete Strain (mm/mm)
Time [t]
Mode 00 - Strain: 0.000
Mode 01 - Strain: 0.000
Mode 02 - Strain: 0.000
Mode 03 - Strain: 0.000
Mode 00 - Strain: 0.000
3
2
1
0
−1
−2
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00


time-Concrete Strain Relation of Section Top Fibers
Mode 00 - Stress: 0.026
Mode 01 - Stress: 0.026
Mode 02 - Stress: 0.026
Mode 03 - Stress: 0.026
Mode 00 - Stress: 0.026
Concrete Stress (N/mm^2)
0.06
0.04
0.02
0.00
−0.02
−0.04
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time [t]


Post-buckling behavior of column during free-vibration analysis - M-phi Curve
Moment Force at middle-height (N.mm)
Curvature at middle-height (rad/mm)
1e−7
7500
5000
2500
0
−2500
−5000
−7500
−10000
−2
−1
0
1
2
3
Mode 00 - Moment: 0.981
Mode 01 - Moment: 3246.298
Mode 02 - Moment: 182.211
Mode 03 - Moment: 3256.915
Mode 04 - Moment: 431.068


Post-buckling behavior of column during free-vibration analysis- Phi-EI Curve
Mode 00 - EI: 7540619.532
Mode 01 - EI: 24954722465.350
Mode 02 - EI: 1400717132.390
Mode 03 - EI: 25036553030.460
Mode 04 - EI: 3313980734.575
Flextural Rigidity at middle-height (N/mm^2)
10^{13}
10^{11}
10^{9}
10^{7}
10^{5}
−2
−1
0
1
2
3
1e−7
Curvature at middle-height (rad/mm)


Post-buckling behavior of column during free-vibration analysis - Moment-Rotation Curve
Mode 00 - Moment: 0.981
Mode 01 - Moment: 3246.298
Mode 02 - Moment: 182.211
Mode 03 - Moment: 3256.915
Mode 04 - Moment: 431.068
Moment Force at middle-height (N.mm)
7500
5000
2500
0
−2500
−5000
−7500
−10000
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Rotation at top-height (rad)
1e−8


Post-buckling behavior of column - Ele. capacity-axial disp. Curve
1e−6
Mode 00 - Capacity: 4.289e-06
Mode 01 - Capacity: 1.204e-06
Mode 02 - Capacity: 1.203e-06
Mode 03 - Capacity: 1.203e-06
Mode 04 - Capacity: 1.203e-06
Column Capacity (%): (P/Py)^2 + (M/My)^2 <= 1
0
1
2
3
4
5
6
−0.0008
−0.0006
−0.0004
−0.0002
0.0000
0.0002
0.0004
0.0006
0.0008
Axial displacement at top-height (mm)
−5.4