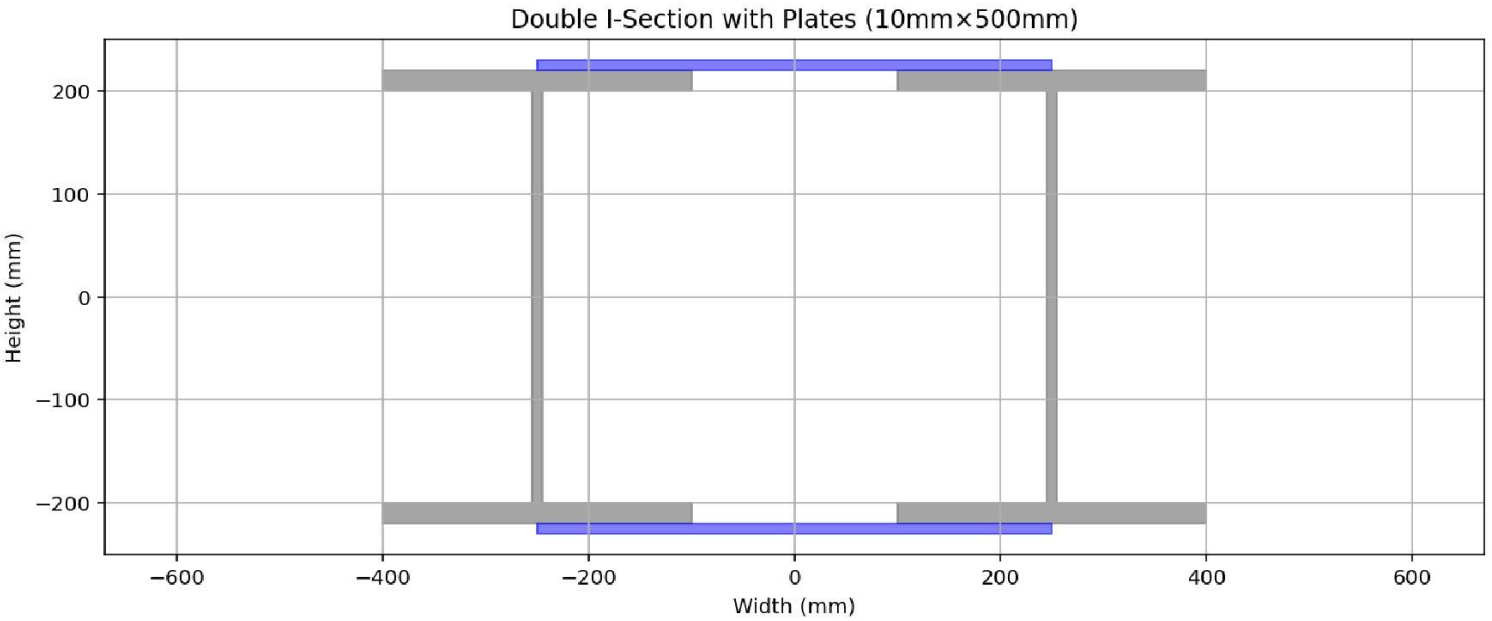
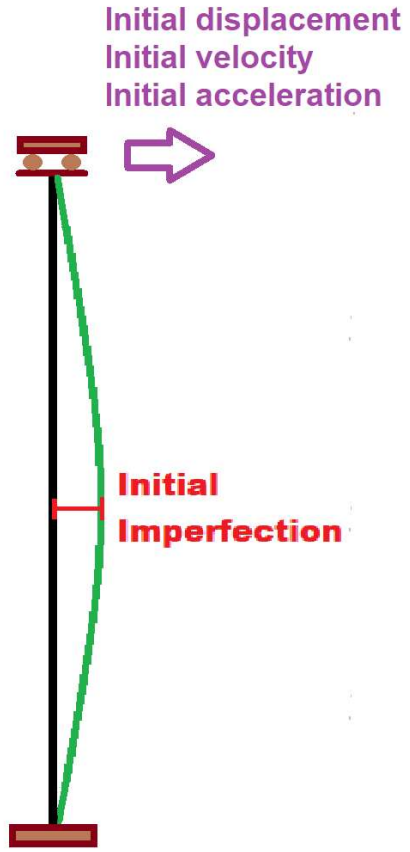
>> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<

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

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)

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





Spyder (Python 3.12)

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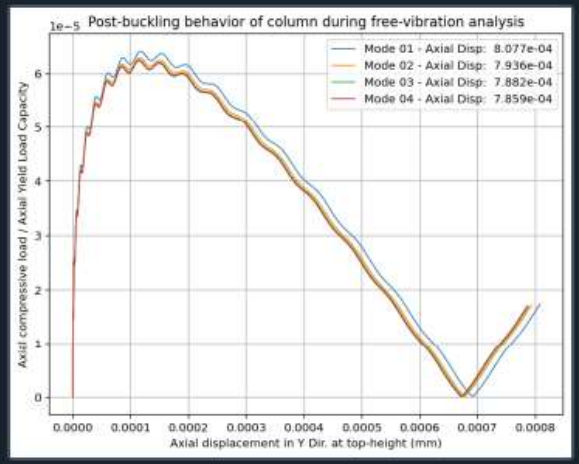
C:\Users\Dell\Desktop\OPENSEES_FILES\MULTI-MODE-P...MN_SEMI-RIGID_NONLINEAR_FREE_VIBRATION_LATERAL.py

MULTI-MODE-POST_BU...BRATION_LATERAL.py

```
1  ##########################################################################################################
2  #                    >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<
3  #    INVESTIGATION OF FREE-VIBRATION ANALYSIS WITH LATERAL DISPLACEMENT OF MULTI-MODE POST-BUCKLING
4  #  PHENOMENA STEEL COLUMNS USING OPENSEES CONSIDERING THE GEOMETRIC AND MATERIAL PROPERTIES NONLINEARI
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 I
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 TOP-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
```



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

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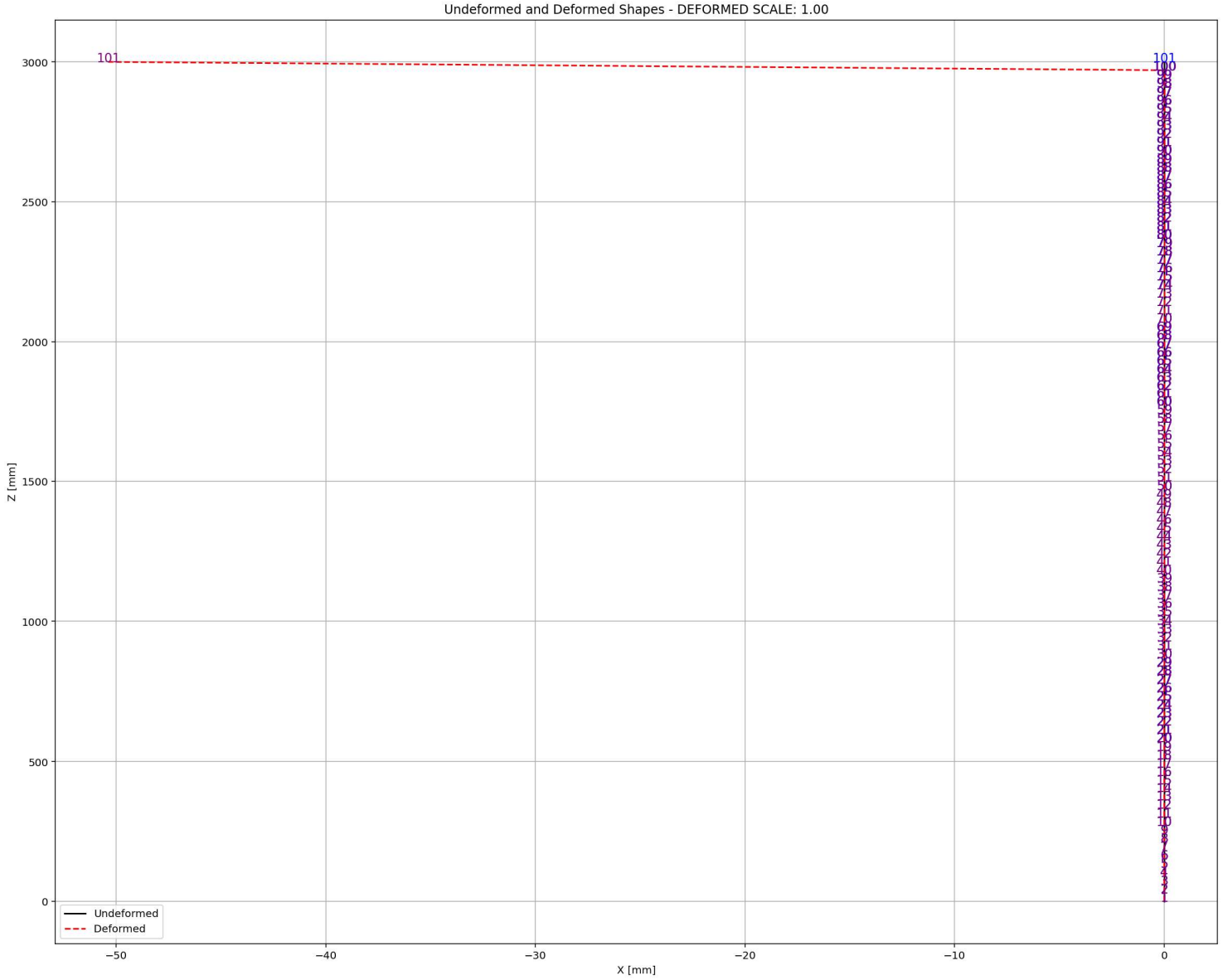
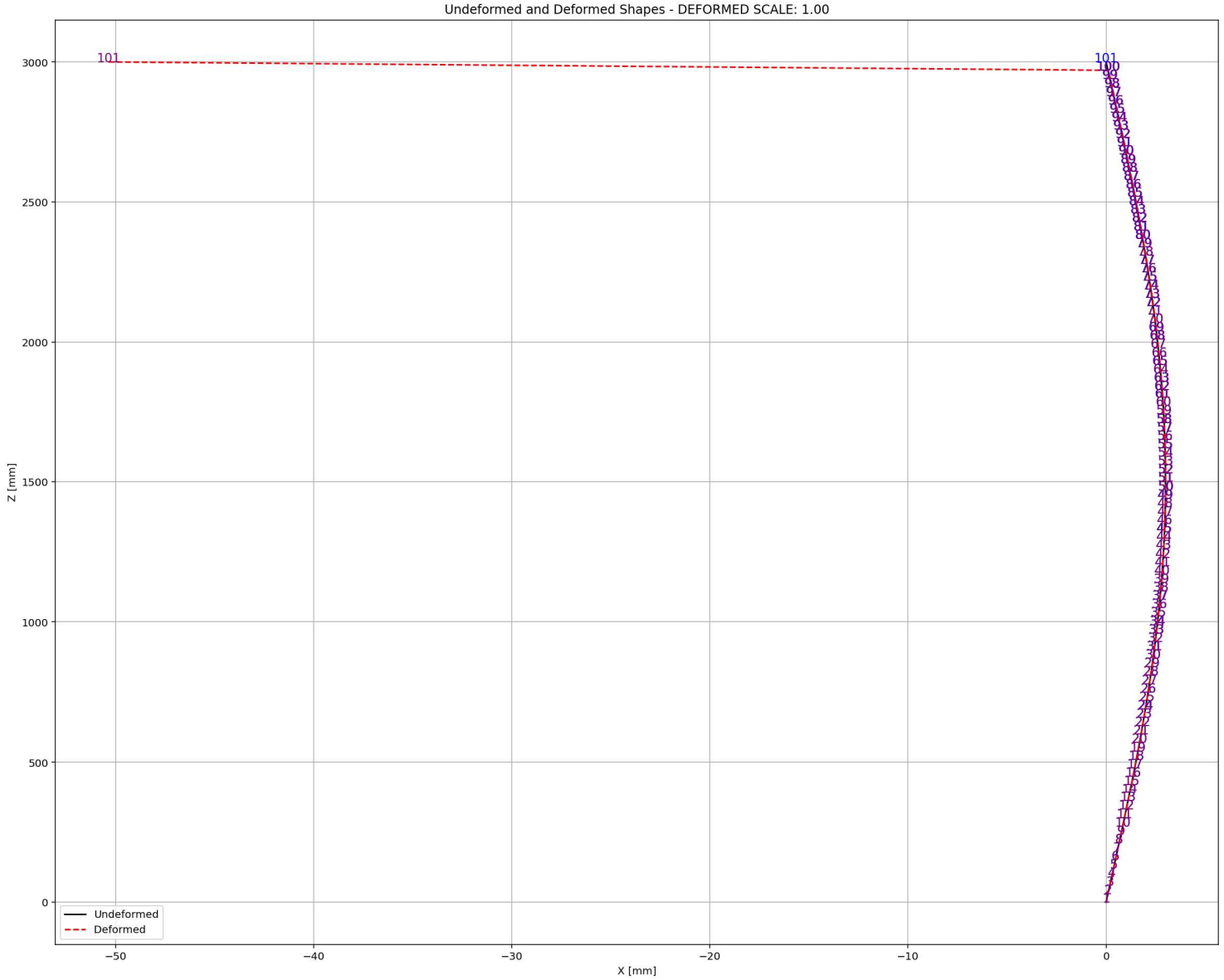
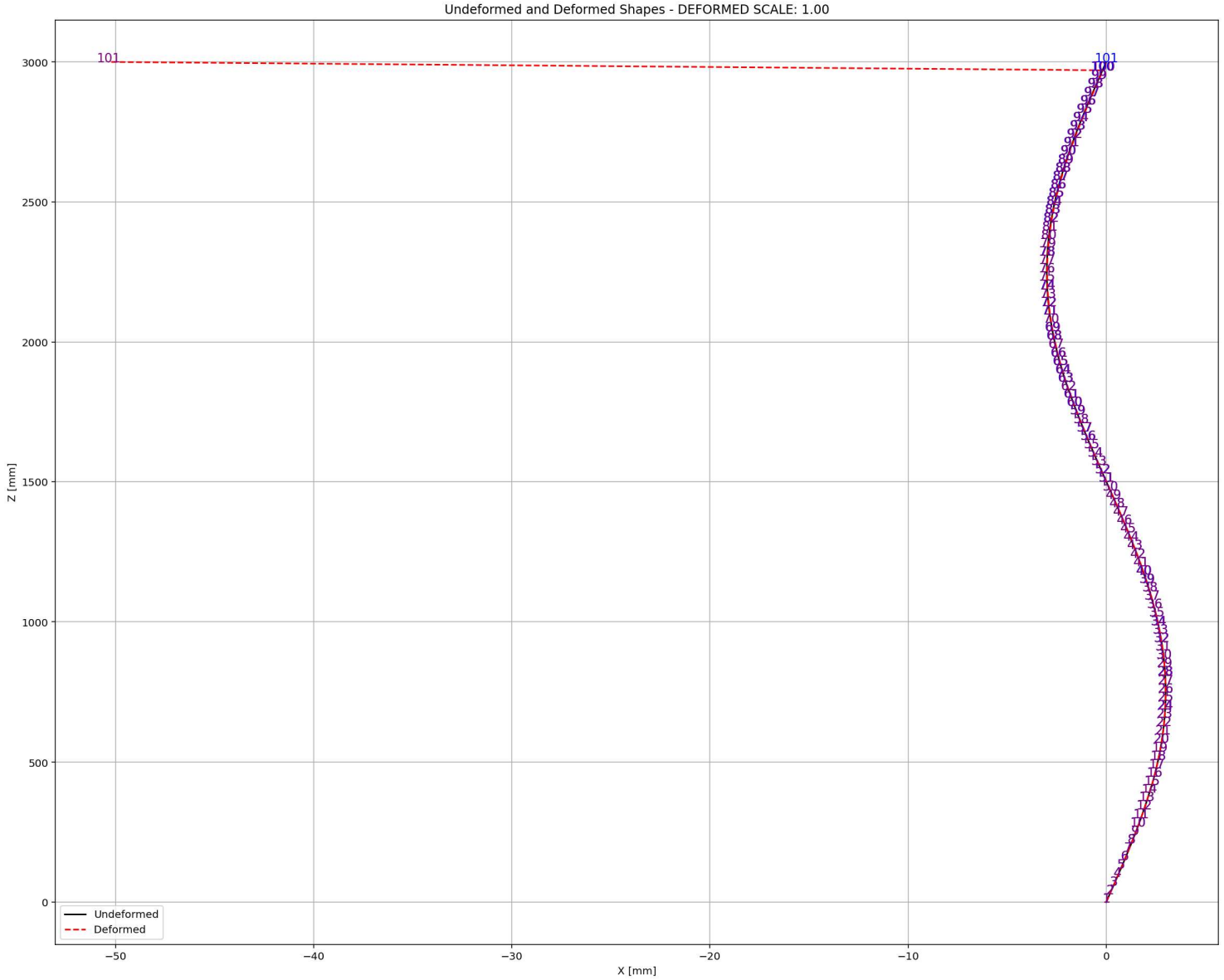
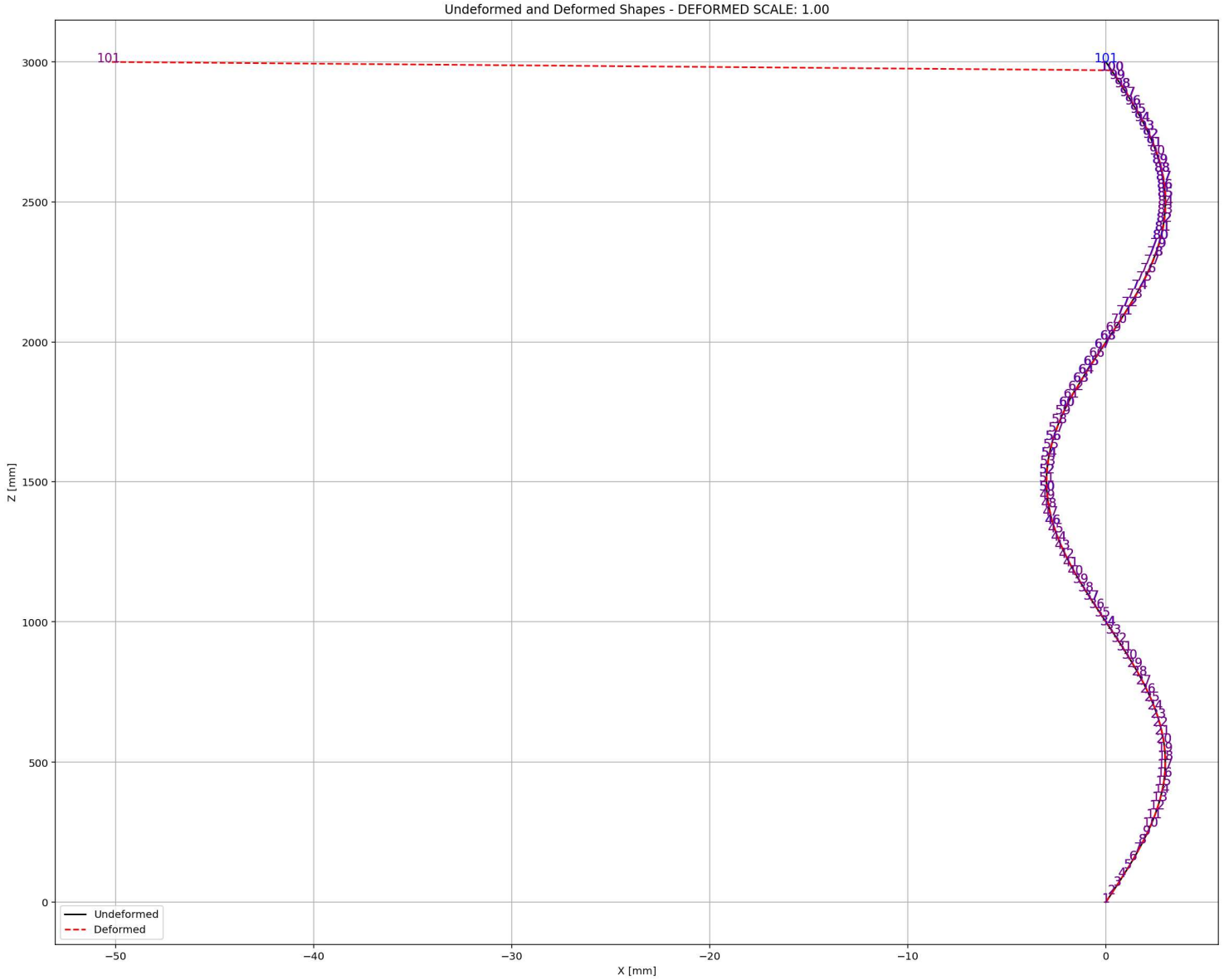
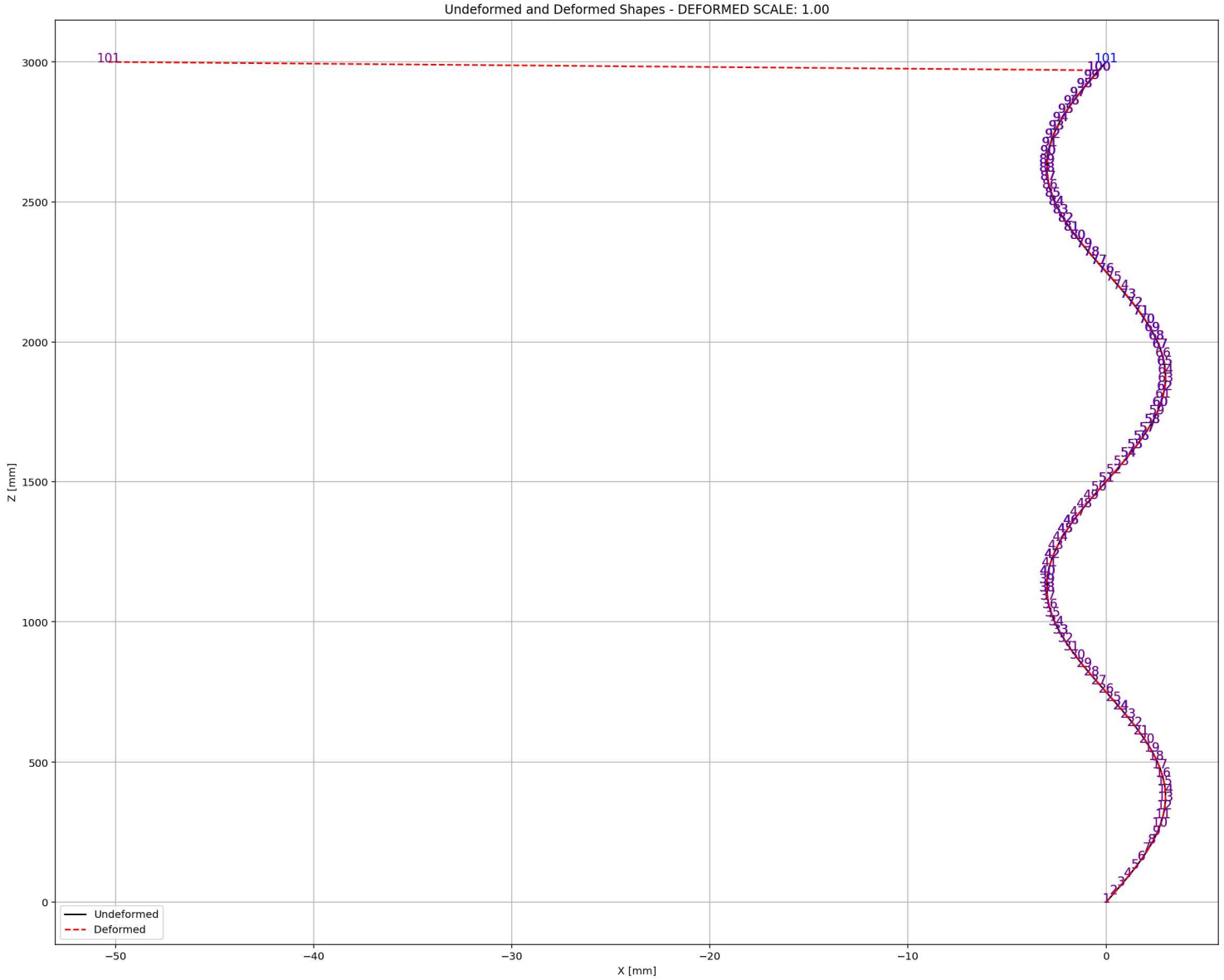
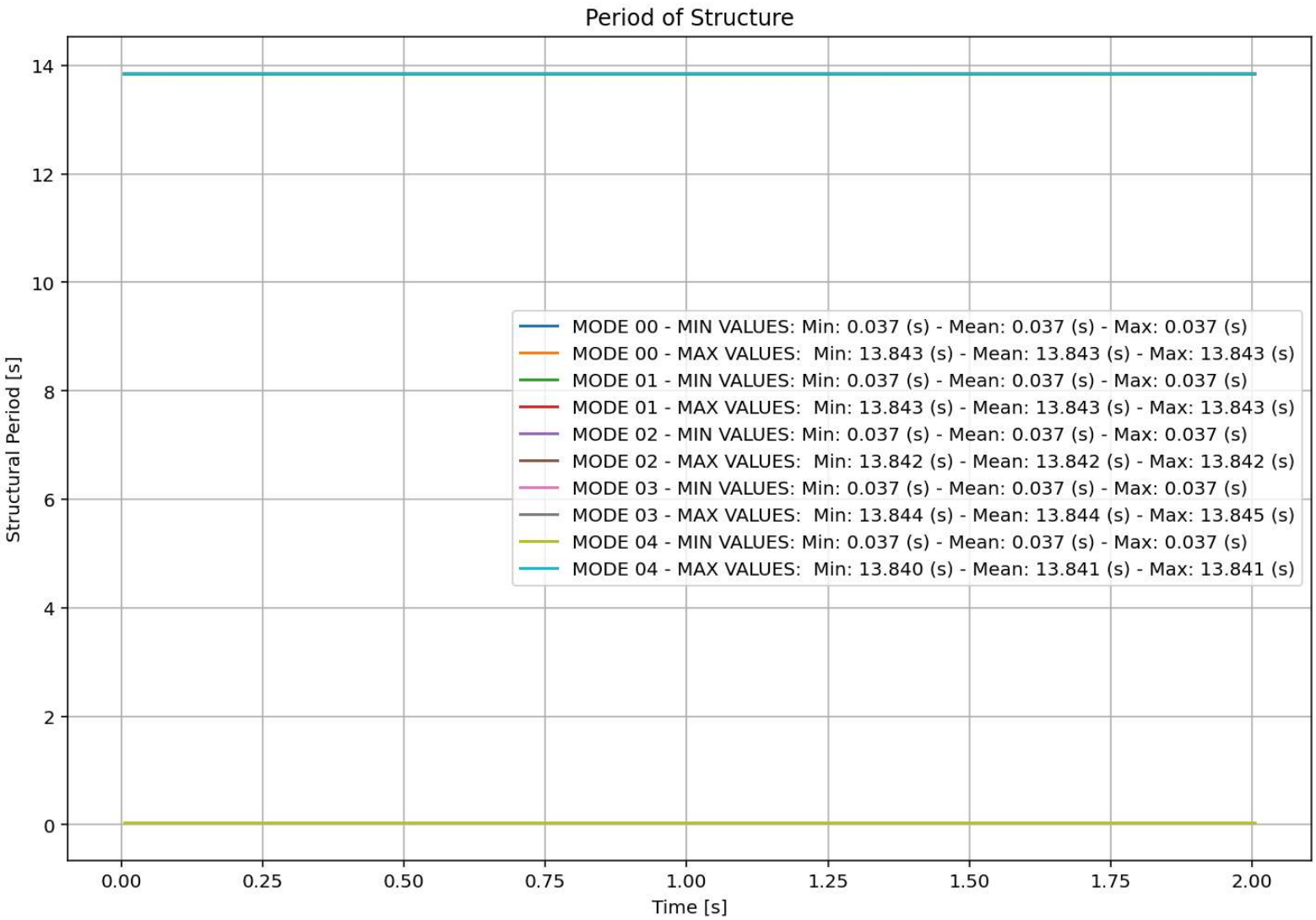

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Z [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−50
−40
−30
−20
−10
0
101
101
Undeformed
Deformed

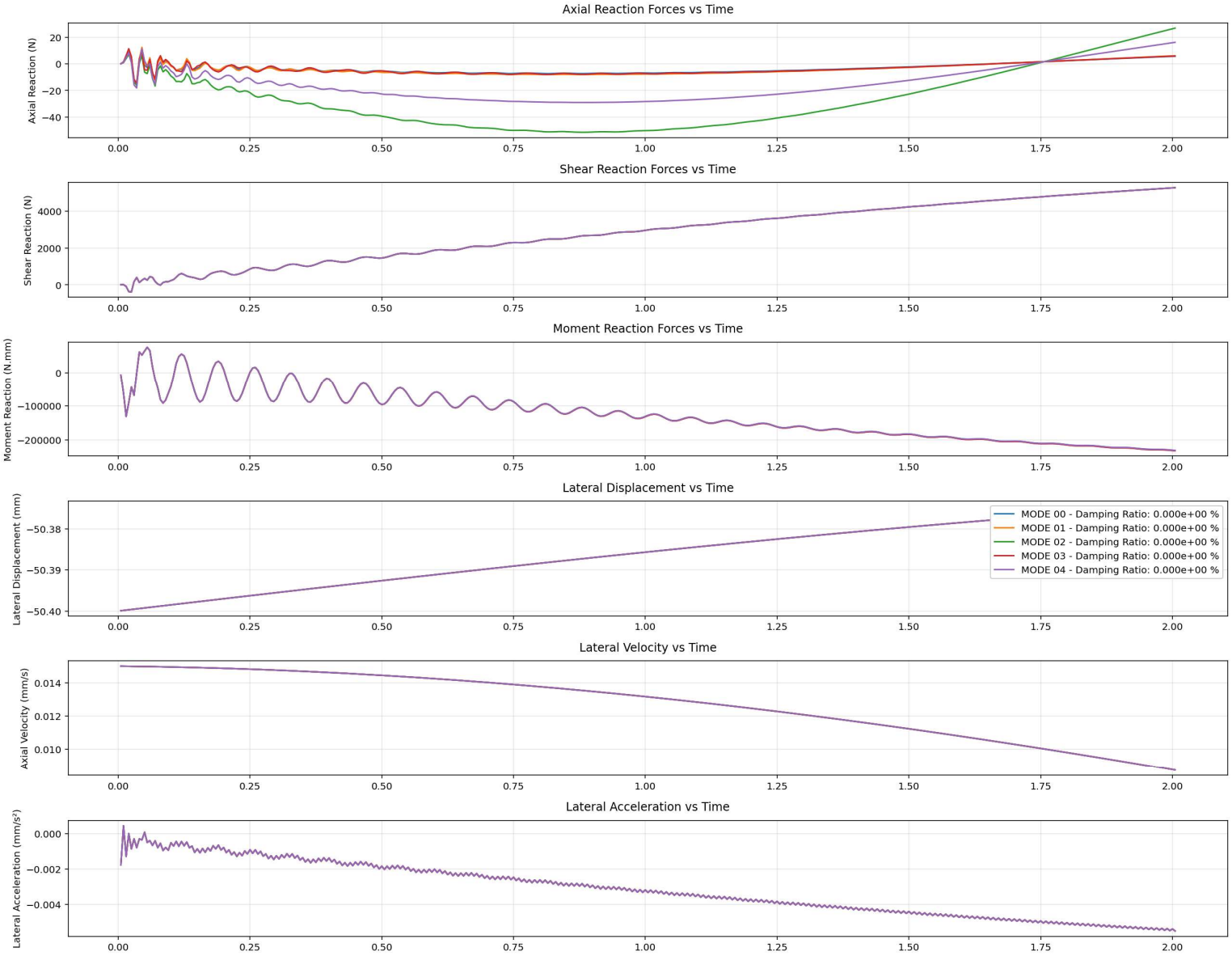

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Z [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−50
−40
−30
−20
−10
0
101
101
Undeformed
Deformed

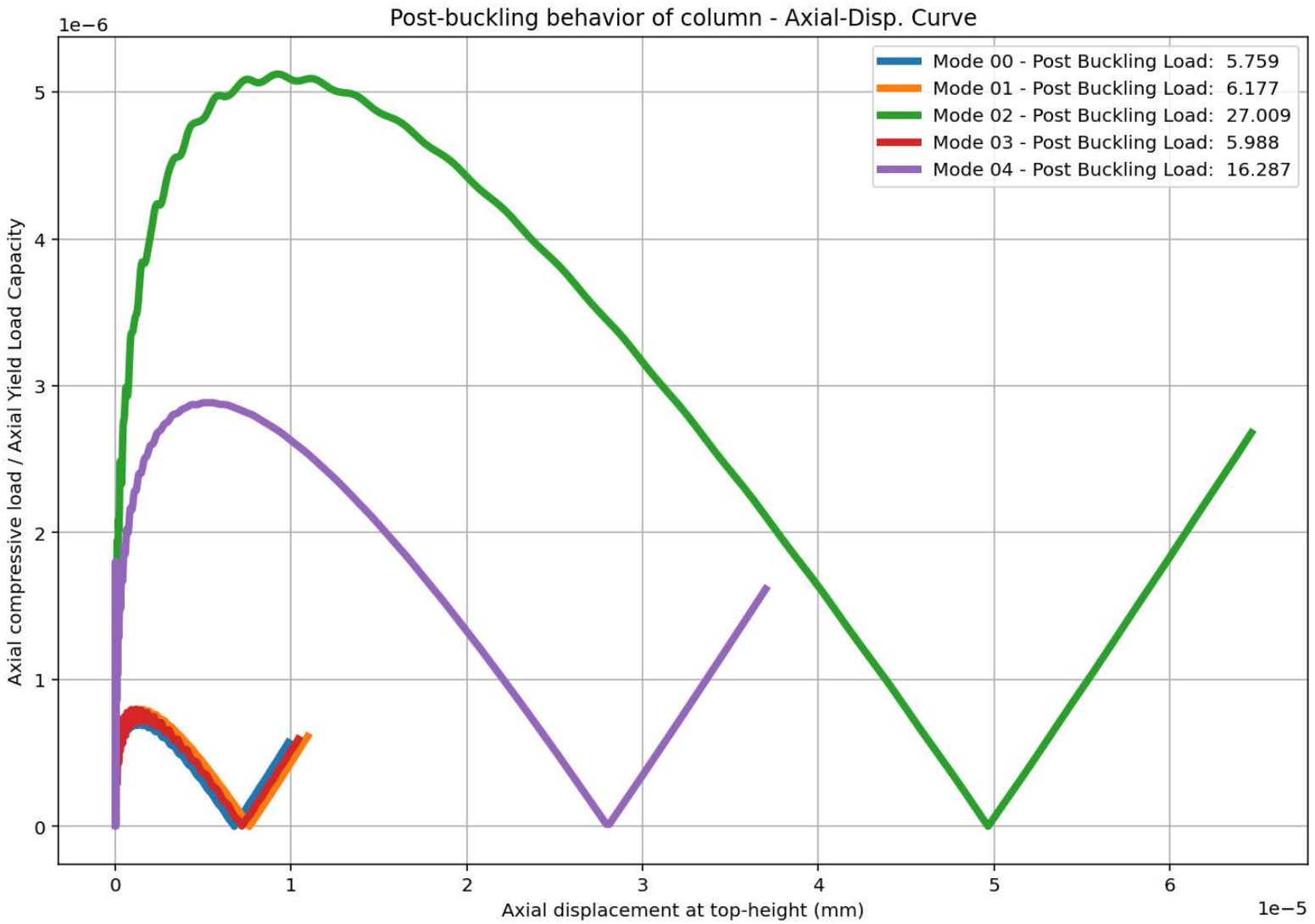

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Z [mm]
X [mm]
Undeformed
Deformed
3000
2500
2000
1500
1000
500
0
−50
−40
−30
−20
−10
0
101

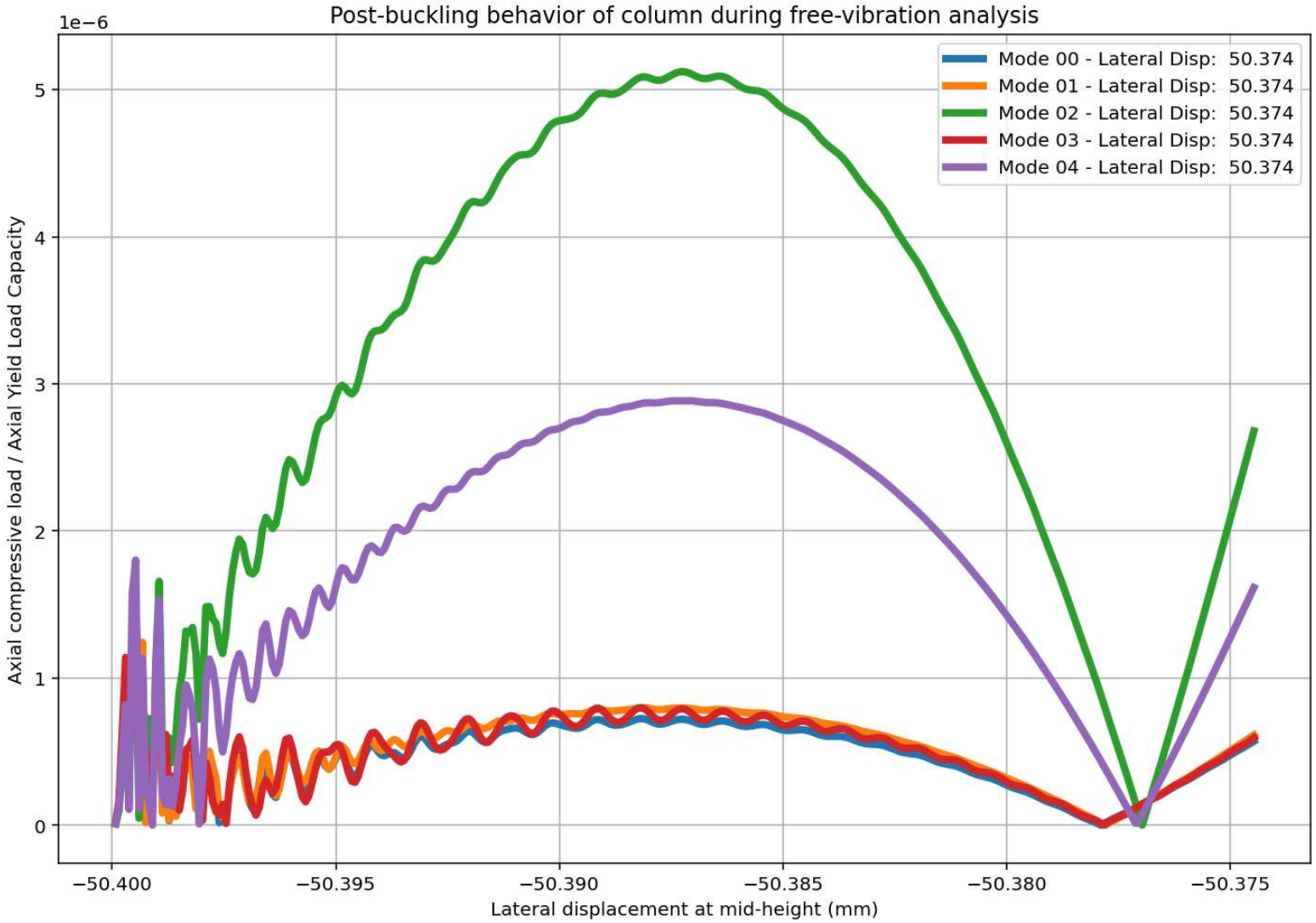

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Z [mm]
X [mm]
Undeformed
Deformed
3000
2500
2000
1500
1000
500
0
−50
−40
−30
−20
−10
0
101
101

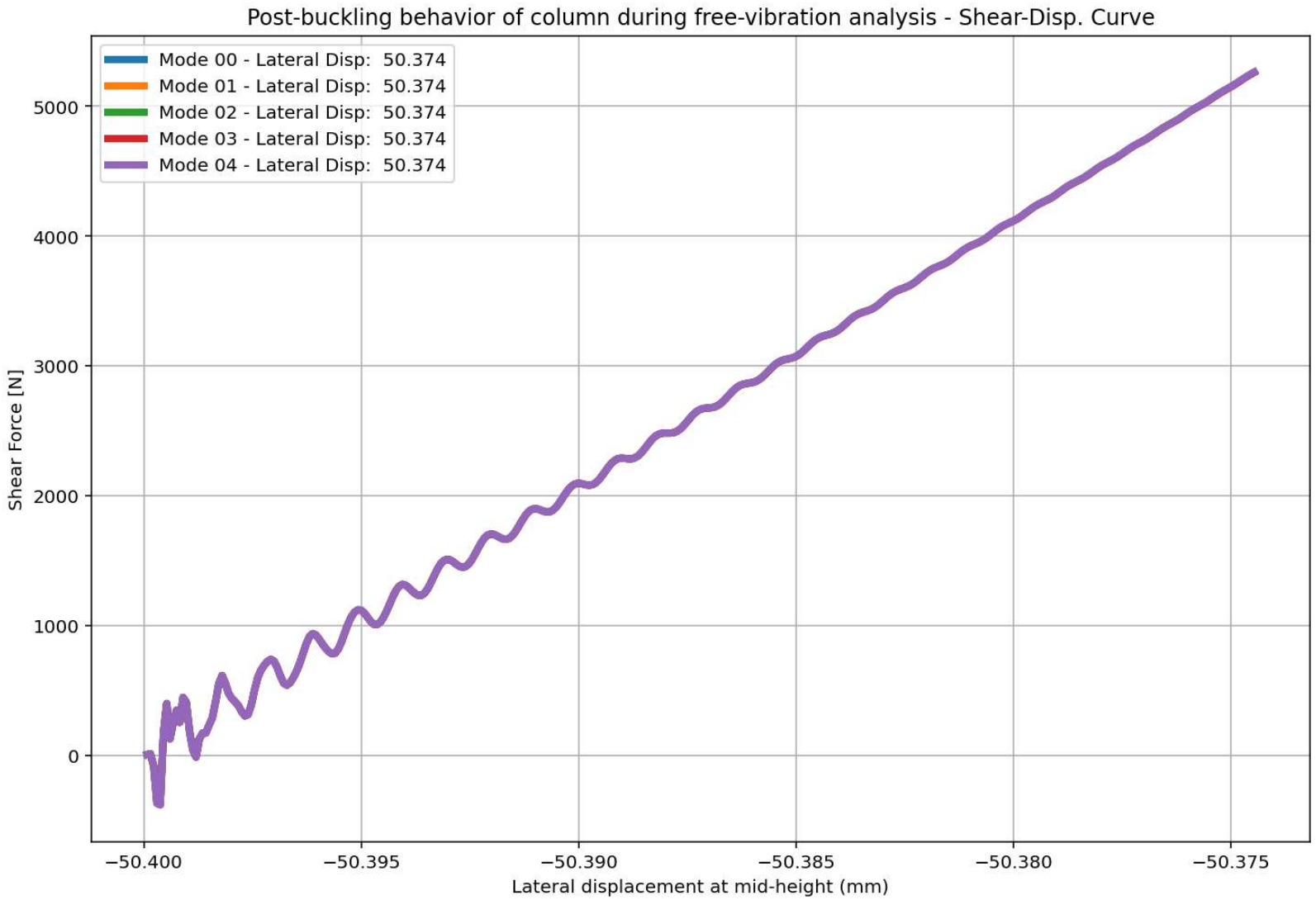

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Z [mm]
X [mm]
Undeformed
Deformed
3000
2500
2000
1500
1000
500
0
−50
−40
−30
−20
−10
0
101

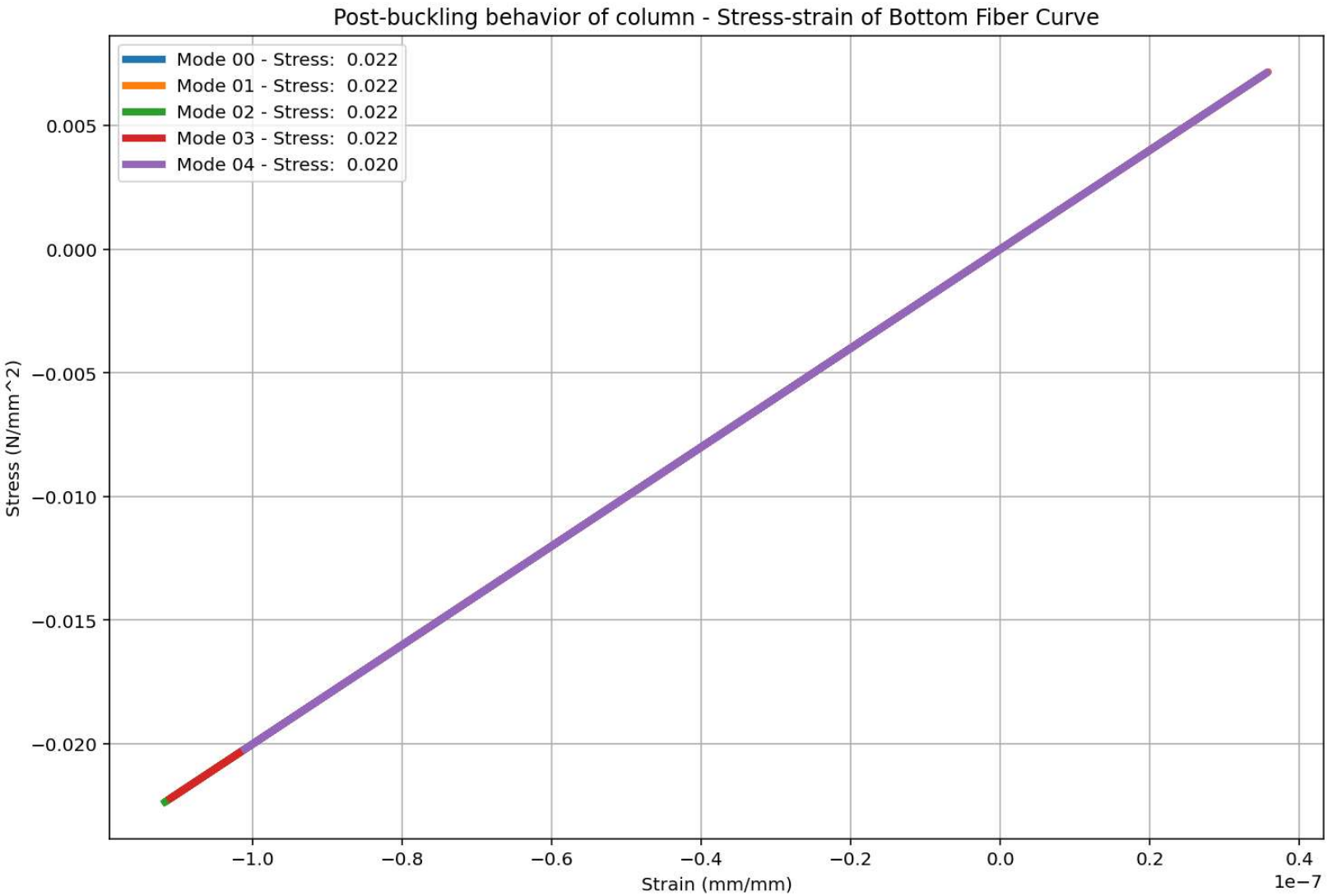

Period of Structure
Structural Period [s]
Time [s]
0
2
4
6
8
10
12
14
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
MODE 00 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 00 - MAX VALUES: Min: 13.843 (s) - Mean: 13.843 (s) - Max: 13.843 (s)
MODE 01 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 01 - MAX VALUES: Min: 13.843 (s) - Mean: 13.843 (s) - Max: 13.843 (s)
MODE 02 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 02 - MAX VALUES: Min: 13.842 (s) - Mean: 13.842 (s) - Max: 13.842 (s)
MODE 03 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 03 - MAX VALUES: Min: 13.844 (s) - Mean: 13.844 (s) - Max: 13.845 (s)
MODE 04 - MIN VALUES: Min: 0.037 (s) - Mean: 0.037 (s) - Max: 0.037 (s)
MODE 04 - MAX VALUES: Min: 13.840 (s) - Mean: 13.841 (s) - Max: 13.841 (s)

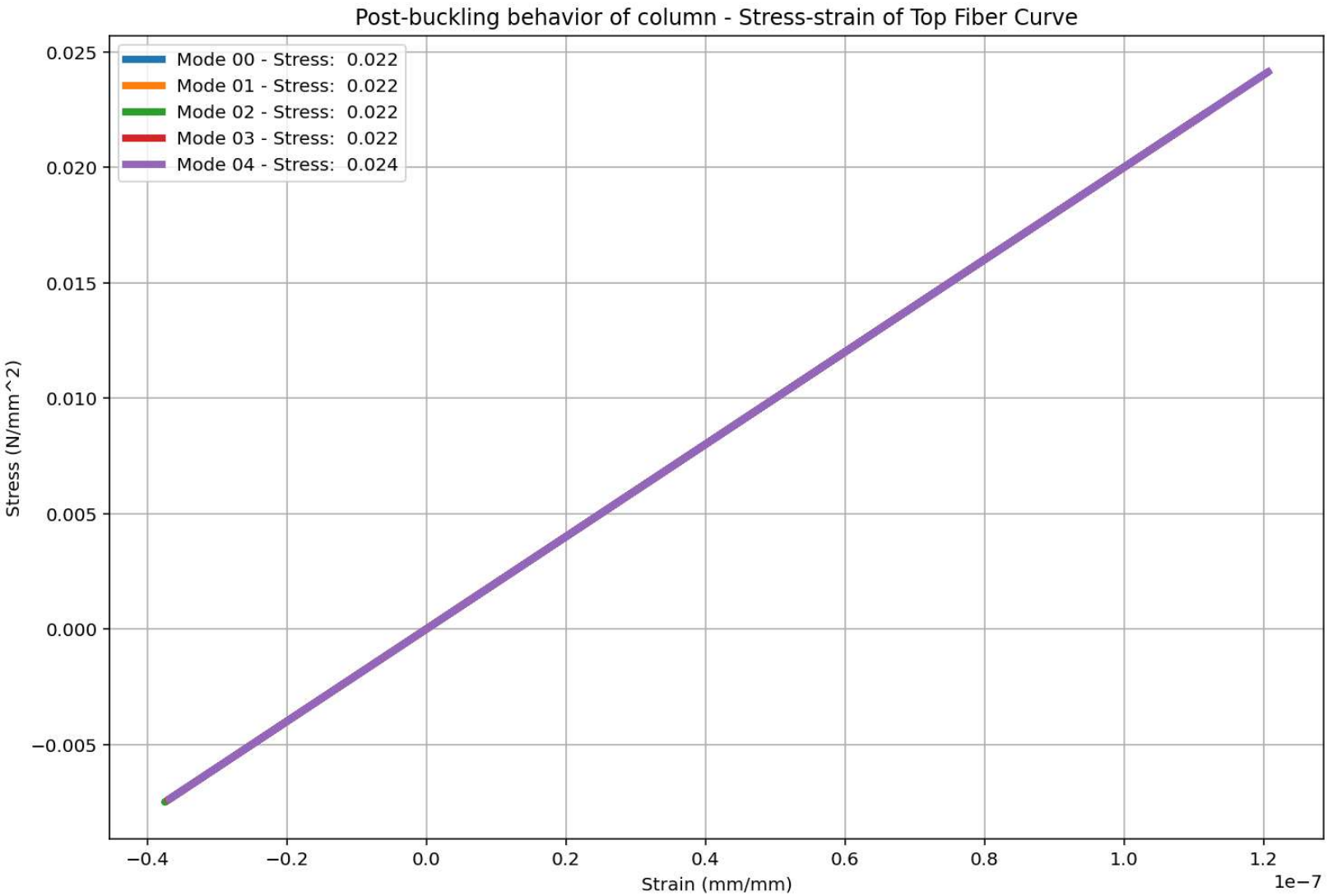

Axial Reaction Forces vs Time
Axial Reaction (N)
Shear Reaction Forces vs Time
Shear Reaction (N)
Moment Reaction Forces vs Time
Moment Reaction (N.mm)
Lateral Displacement vs Time
Lateral Displacement (mm)
MODE 00 - Damping Ratio: 0.000e+00 %
MODE 01 - Damping Ratio: 0.000e+00 %
MODE 02 - Damping Ratio: 0.000e+00 %
MODE 03 - Damping Ratio: 0.000e+00 %
MODE 04 - Damping Ratio: 0.000e+00 %
Lateral Velocity vs Time
Axial Velocity (mm/s)
Lateral Acceleration vs Time
Lateral Acceleration (mm/s²)

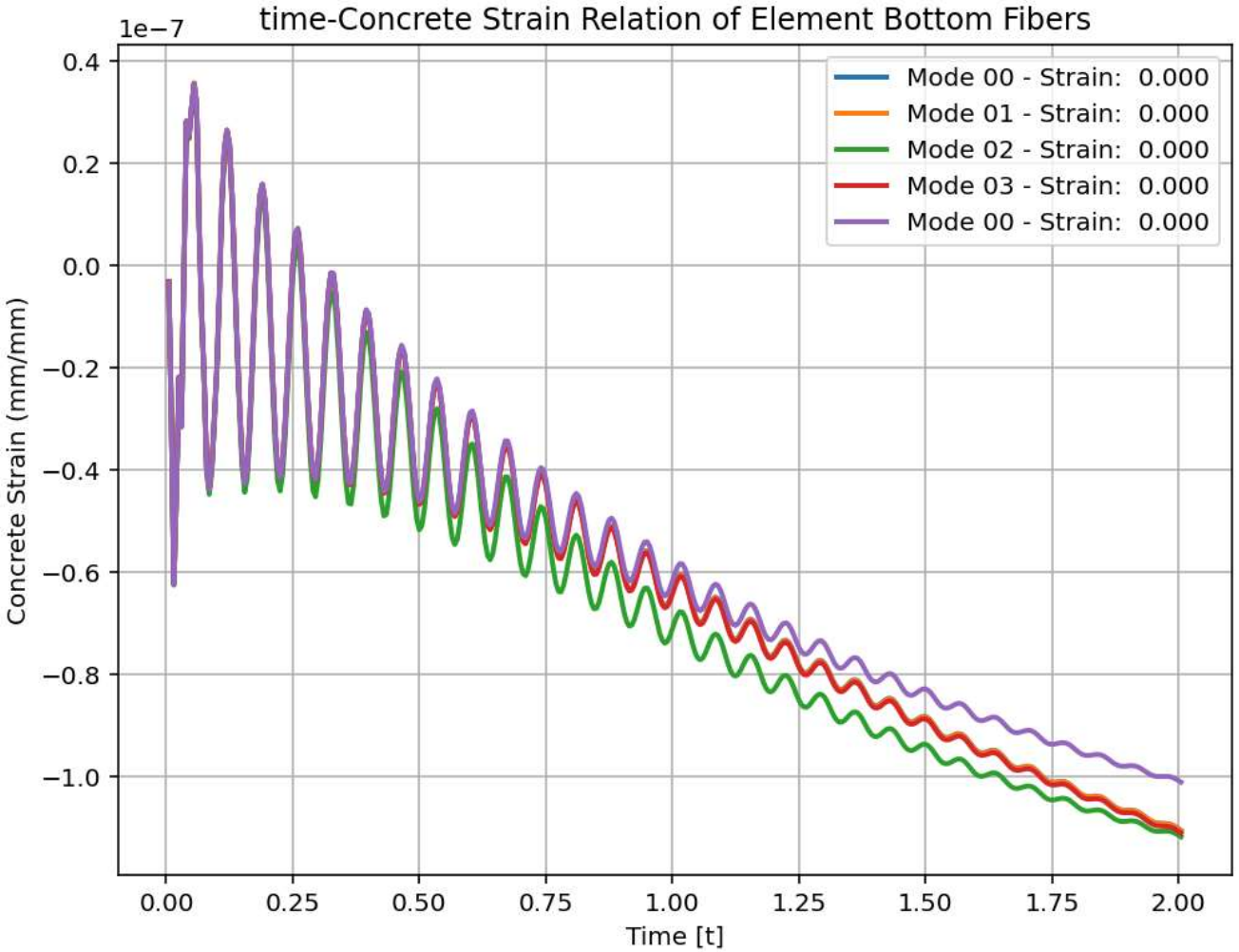

Post-buckling behavior of column - Axial-Disp. Curve
1e−6
Axial compressive load / Axial Yield Load Capacity
Axial displacement at top-height (mm)
1e−5
Mode 00 - Post Buckling Load: 5.759
Mode 01 - Post Buckling Load: 6.177
Mode 02 - Post Buckling Load: 27.009
Mode 03 - Post Buckling Load: 5.988
Mode 04 - Post Buckling Load: 16.287

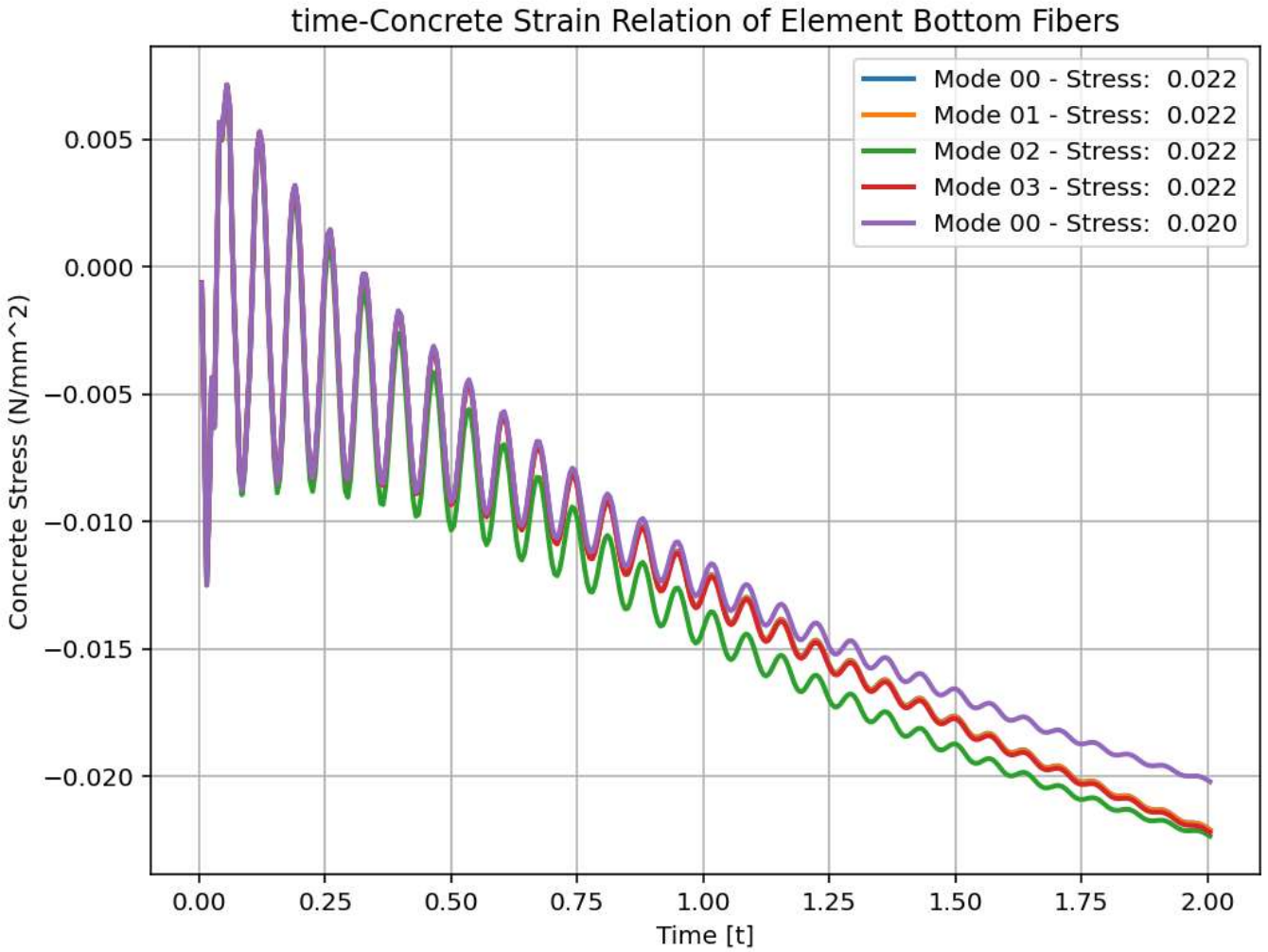

Post-buckling behavior of column during free-vibration analysis
1e−6
Axial compressive load / Axial Yield Load Capacity
Lateral displacement at mid-height (mm)
Mode 00 - Lateral Disp: 50.374
Mode 01 - Lateral Disp: 50.374
Mode 02 - Lateral Disp: 50.374
Mode 03 - Lateral Disp: 50.374
Mode 04 - Lateral Disp: 50.374
0
1
2
3
4
5
−50.400
−50.395
−50.390
−50.385
−50.380
−50.375

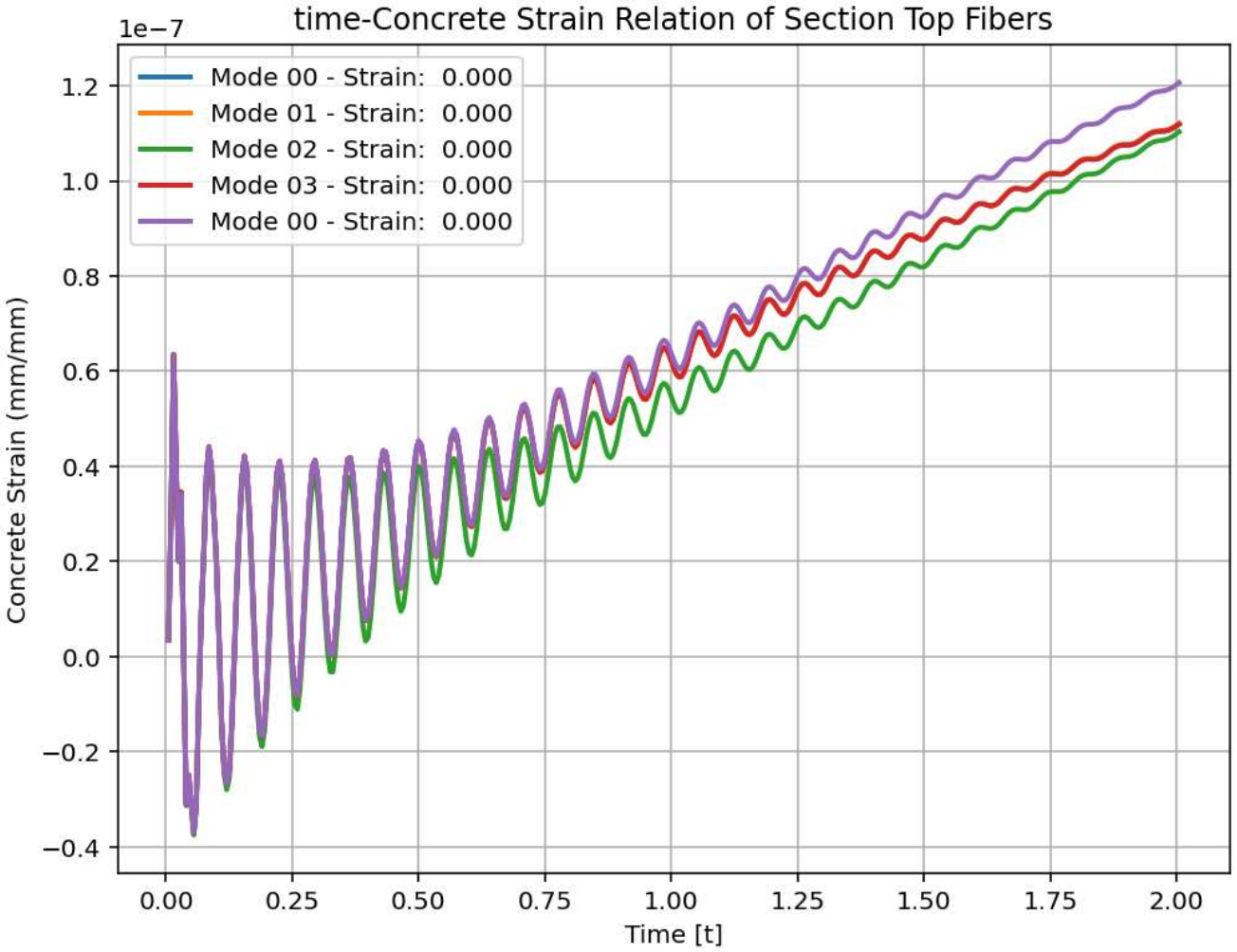

Post-buckling behavior of column during free-vibration analysis - Shear-Disp. Curve
Mode 00 - Lateral Disp: 50.374
Mode 01 - Lateral Disp: 50.374
Mode 02 - Lateral Disp: 50.374
Mode 03 - Lateral Disp: 50.374
Mode 04 - Lateral Disp: 50.374
Shear Force [N]
5000
4000
3000
2000
1000
0
−50.400
−50.395
−50.390
−50.385
−50.380
−50.375
Lateral displacement at mid-height (mm)

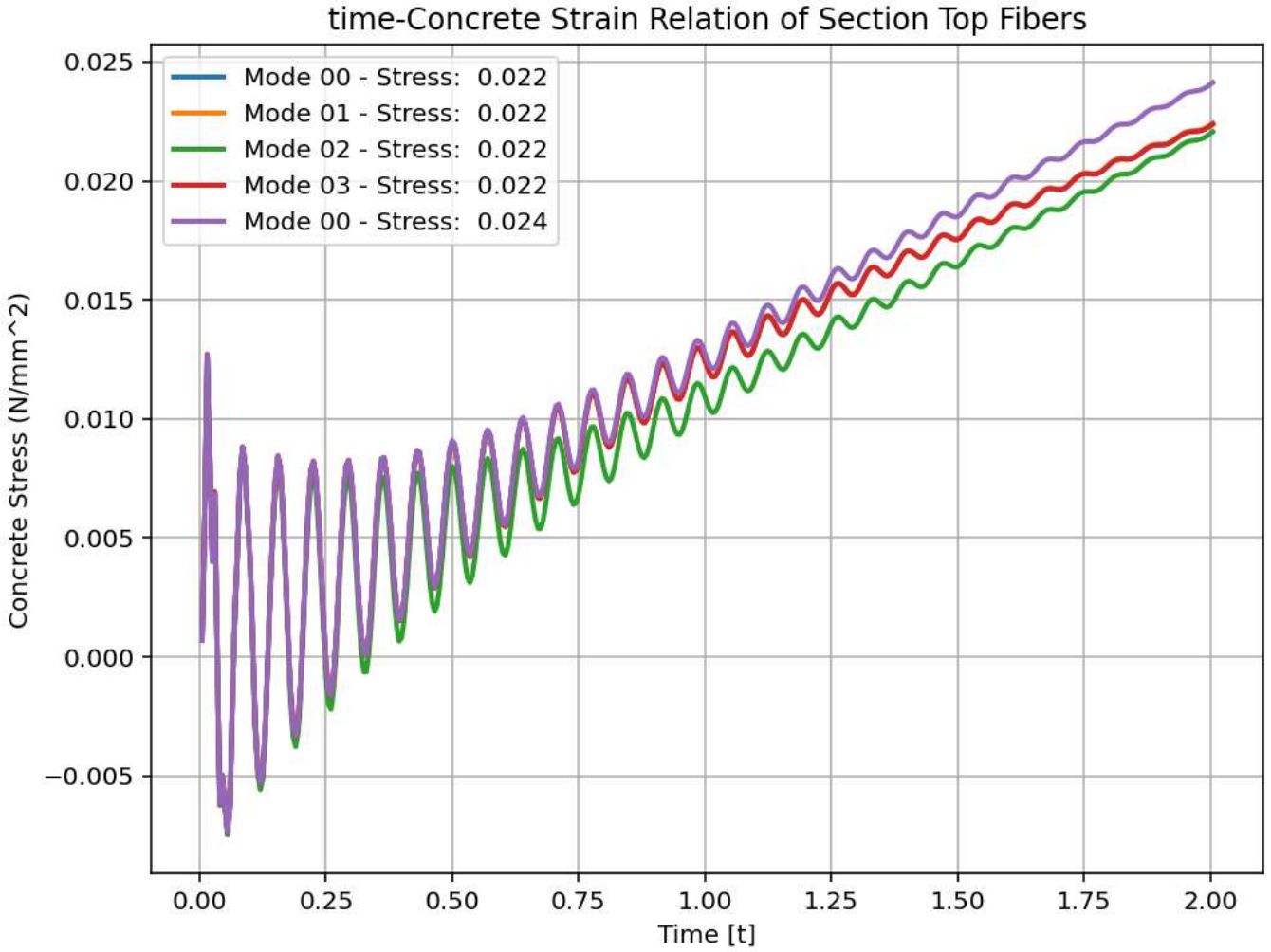

Post-buckling behavior of column - Stress-strain of Bottom Fiber Curve
Mode 00 - Stress: 0.022
Mode 01 - Stress: 0.022
Mode 02 - Stress: 0.022
Mode 03 - Stress: 0.022
Mode 04 - Stress: 0.020
0.005
0.000
−0.005
−0.010
−0.015
−0.020
Stress (N/mm^2)
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
1e−7
Strain (mm/mm)

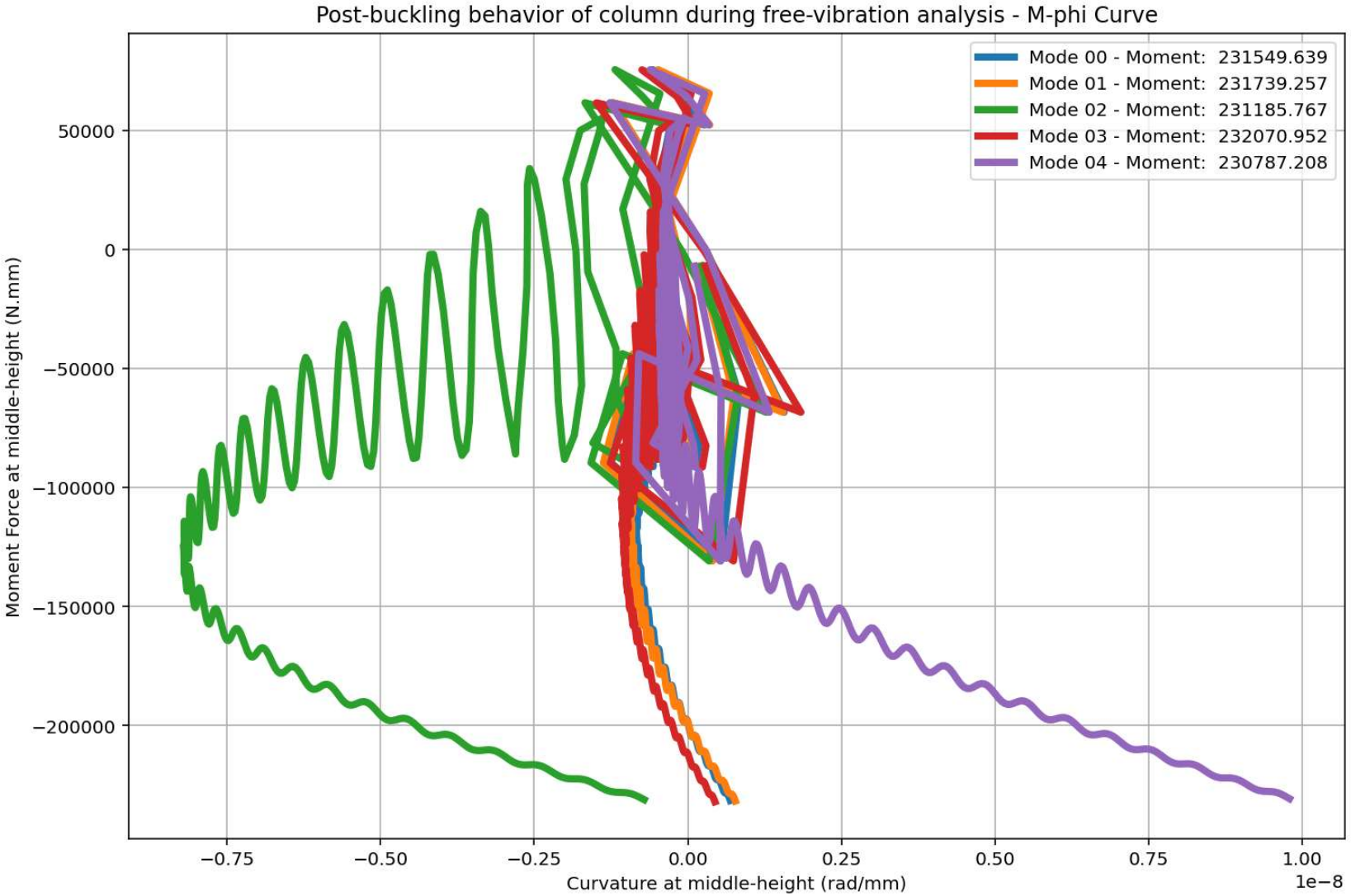

Post-buckling behavior of column - Stress-strain of Top Fiber Curve
Mode 00 - Stress: 0.022
Mode 01 - Stress: 0.022
Mode 02 - Stress: 0.022
Mode 03 - Stress: 0.022
Mode 04 - Stress: 0.024
Stress (N/mm^2)
0.025
0.020
0.015
0.010
0.005
0.000
−0.005
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Strain (mm/mm)
1e−7

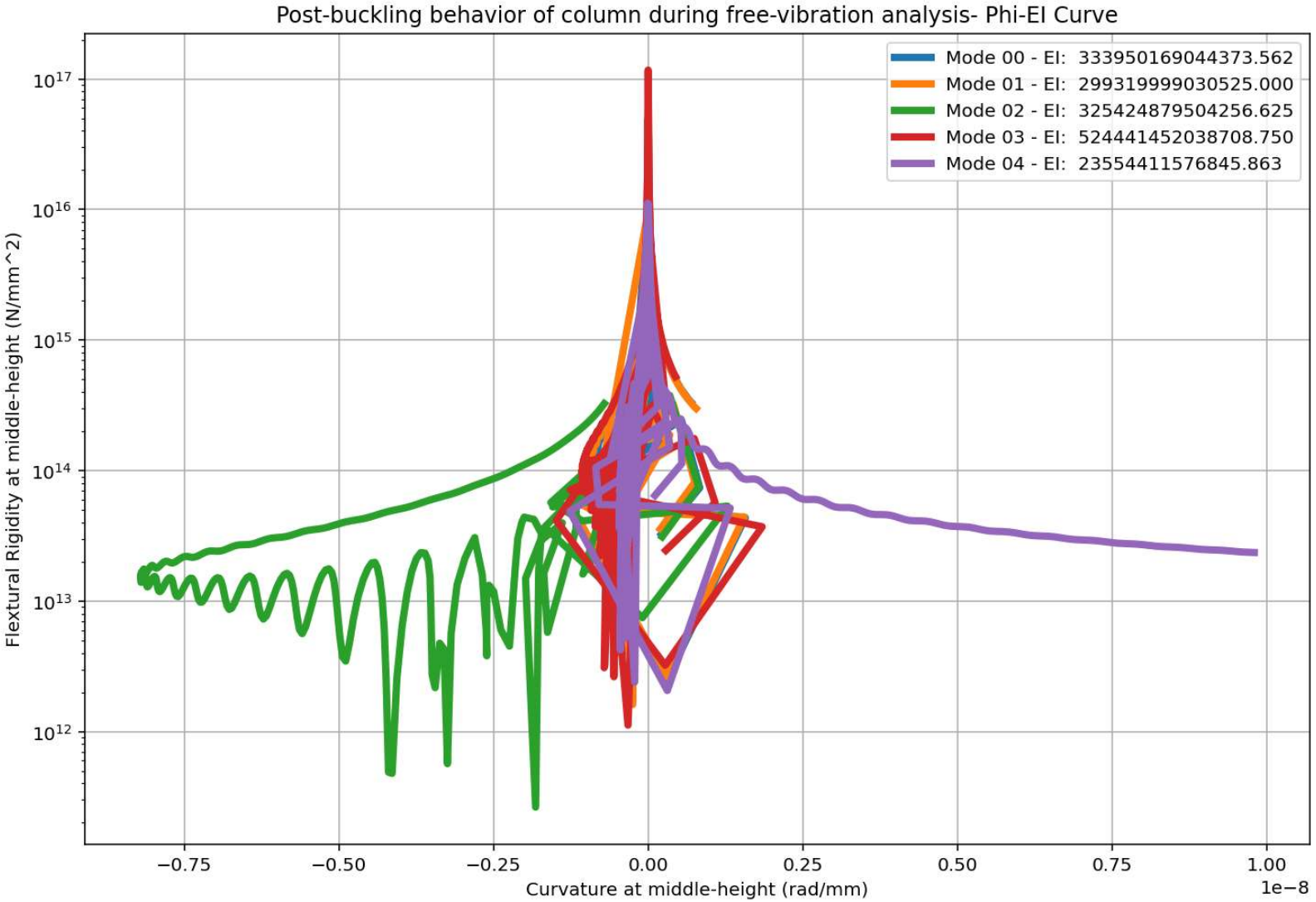

time-Concrete Strain Relation of Element Bottom Fibers
1e−7
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
Concrete Strain (mm/mm)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time [t]
Mode 00 - Strain: 0.000
Mode 01 - Strain: 0.000
Mode 02 - Strain: 0.000
Mode 03 - Strain: 0.000
Mode 00 - Strain: 0.000

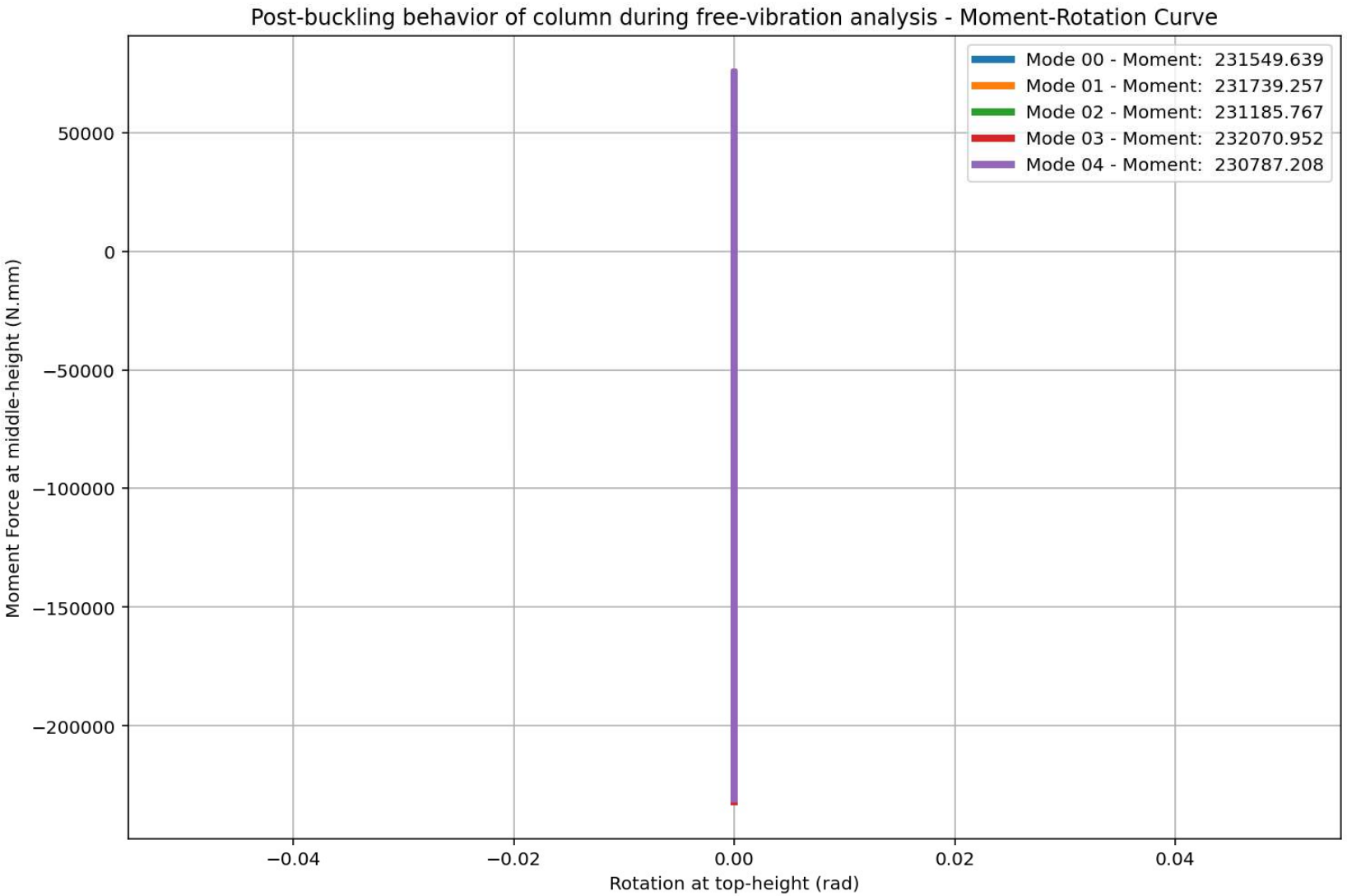

time-Concrete Strain Relation of Element Bottom Fibers
Mode 00 - Stress: 0.022
Mode 01 - Stress: 0.022
Mode 02 - Stress: 0.022
Mode 03 - Stress: 0.022
Mode 00 - Stress: 0.020
Concrete Stress (N/mm^2)
0.005
0.000
−0.005
−0.010
−0.015
−0.020
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time [t]

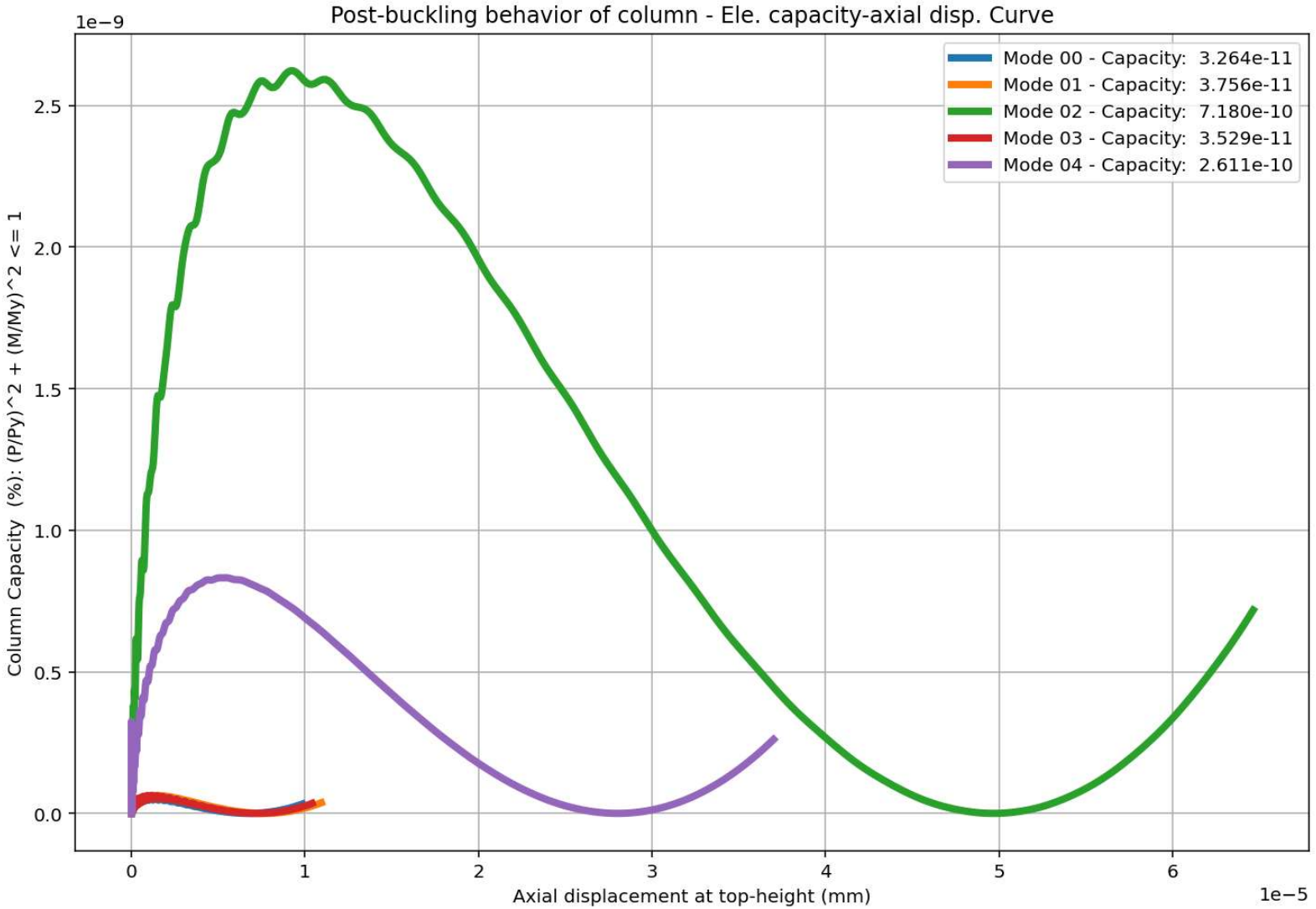

time-Concrete Strain Relation of Section Top Fibers
1e−7
Mode 00 - Strain: 0.000
Mode 01 - Strain: 0.000
Mode 02 - Strain: 0.000
Mode 03 - Strain: 0.000
Mode 00 - Strain: 0.000
Concrete Strain (mm/mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time [t]


time-Concrete Strain Relation of Section Top Fibers
Mode 00 - Stress: 0.022
Mode 01 - Stress: 0.022
Mode 02 - Stress: 0.022
Mode 03 - Stress: 0.022
Mode 00 - Stress: 0.024
Concrete Stress (N/mm^2)
0.025
0.020
0.015
0.010
0.005
0.000
−0.005
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
Mode 00 - Moment: 231549.639
Mode 01 - Moment: 231739.257
Mode 02 - Moment: 231185.767
Mode 03 - Moment: 232070.952
Mode 04 - Moment: 230787.208
Moment Force at middle-height (N.mm)
50000
0
−50000
−100000
−150000
−200000
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
1e−8
Curvature at middle-height (rad/mm)


Post-buckling behavior of column during free-vibration analysis- Phi-EI Curve
Mode 00 - EI: 333950169044373.562
Mode 01 - EI: 299319999030525.000
Mode 02 - EI: 325424879504256.625
Mode 03 - EI: 524441452038708.750
Mode 04 - EI: 23554411576845.863
Flextural Rigidity at middle-height (N/mm^2)
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
1e−8
Curvature at middle-height (rad/mm)


Post-buckling behavior of column during free-vibration analysis - Moment-Rotation Curve
Mode 00 - Moment: 231549.639
Mode 01 - Moment: 231739.257
Mode 02 - Moment: 231185.767
Mode 03 - Moment: 232070.952
Mode 04 - Moment: 230787.208
50000
0
−50000
−100000
−150000
−200000
Moment Force at middle-height (N.mm)
−0.04
−0.02
0.00
0.02
0.04
Rotation at top-height (rad)


Post-buckling behavior of column - Ele. capacity-axial disp. Curve
1e−9
Column Capacity (%): (P/Py)^2 + (M/My)^2 <= 1
Axial displacement at top-height (mm)
1e−5
Mode 00 - Capacity: 3.264e-11
Mode 01 - Capacity: 3.756e-11
Mode 02 - Capacity: 7.180e-10
Mode 03 - Capacity: 3.529e-11
Mode 04 - Capacity: 2.611e-10
0.0
0.5
1.0
1.5
2.0
2.5
0
1
2
3
4
5
6