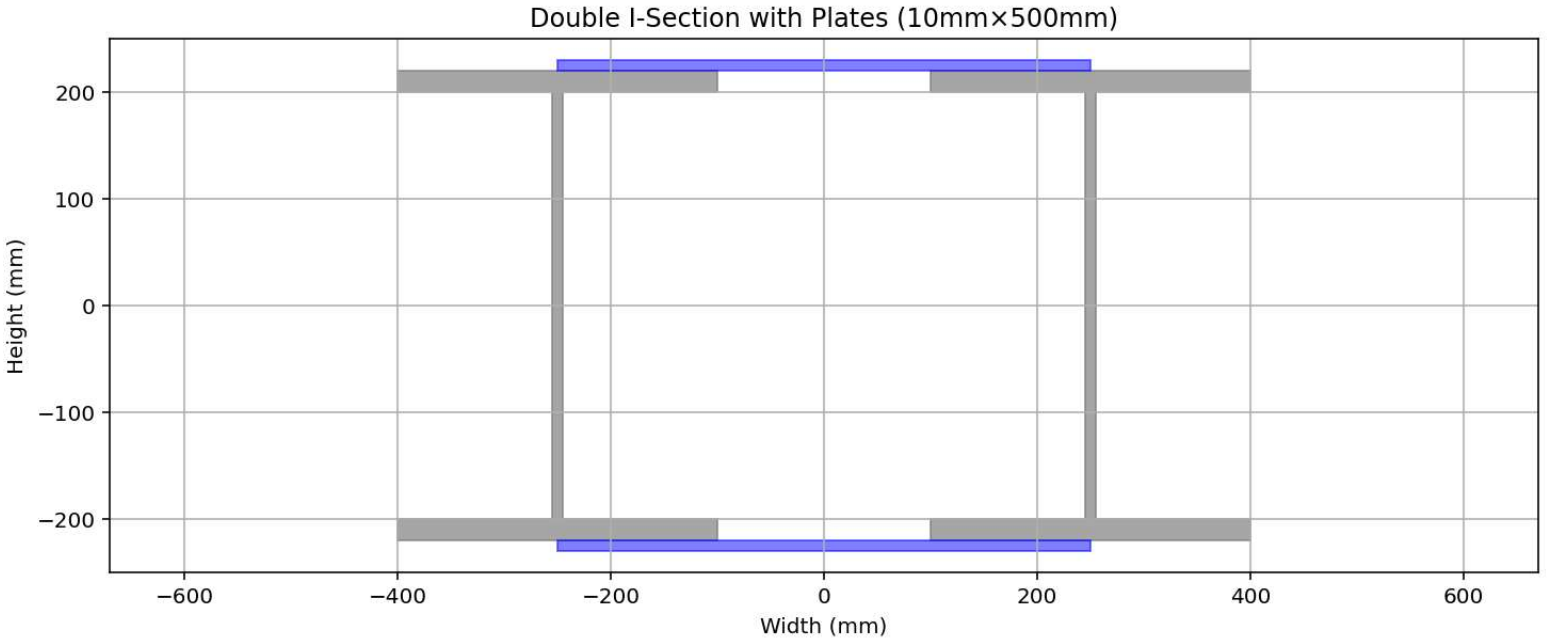
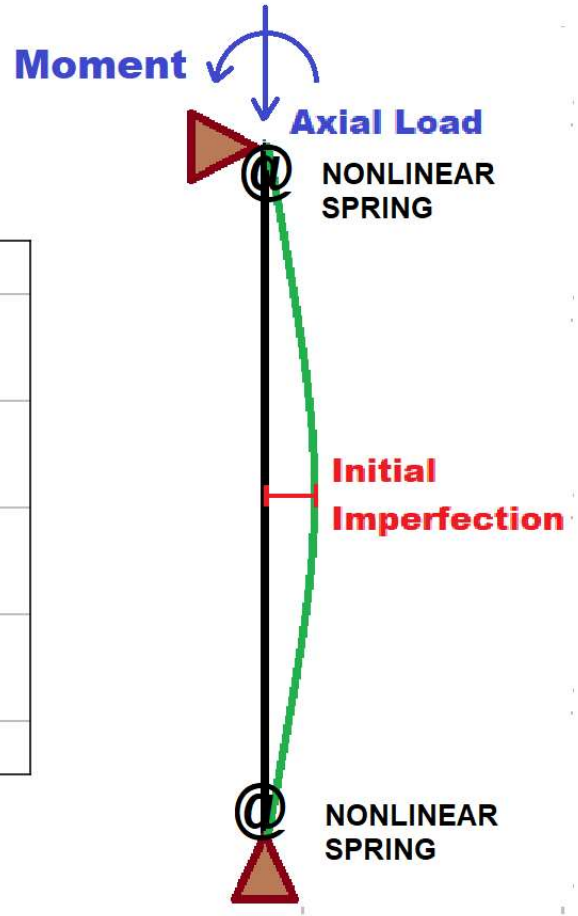
>> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<

INVESTIGATION 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)

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





Spyder (Python 3.12)

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

MULTI-MODE-POST_BU...LINEAR_CAPACITY.py | STEEL_FIBER_SECTION.py

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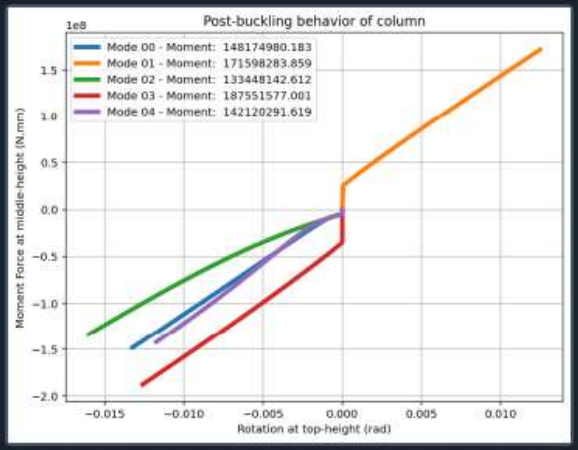
1  ##########################################################################################################
2  #                    >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<
3  #    INVESTIGATION OF MULTI-MODE POST-BUCKLING PHENOMENA IN WITH AND WITHOUT SEMI-RIGID STEEL COLUMNS
4  #          USING OPENSEES CONSIDERING THE GEOMETRIC AND MATERIAL PROPERTIES NONLINEARITY
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 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_HYSTERETIC_FORCE_DISP_FUN as S03
34 import time as TI
```



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

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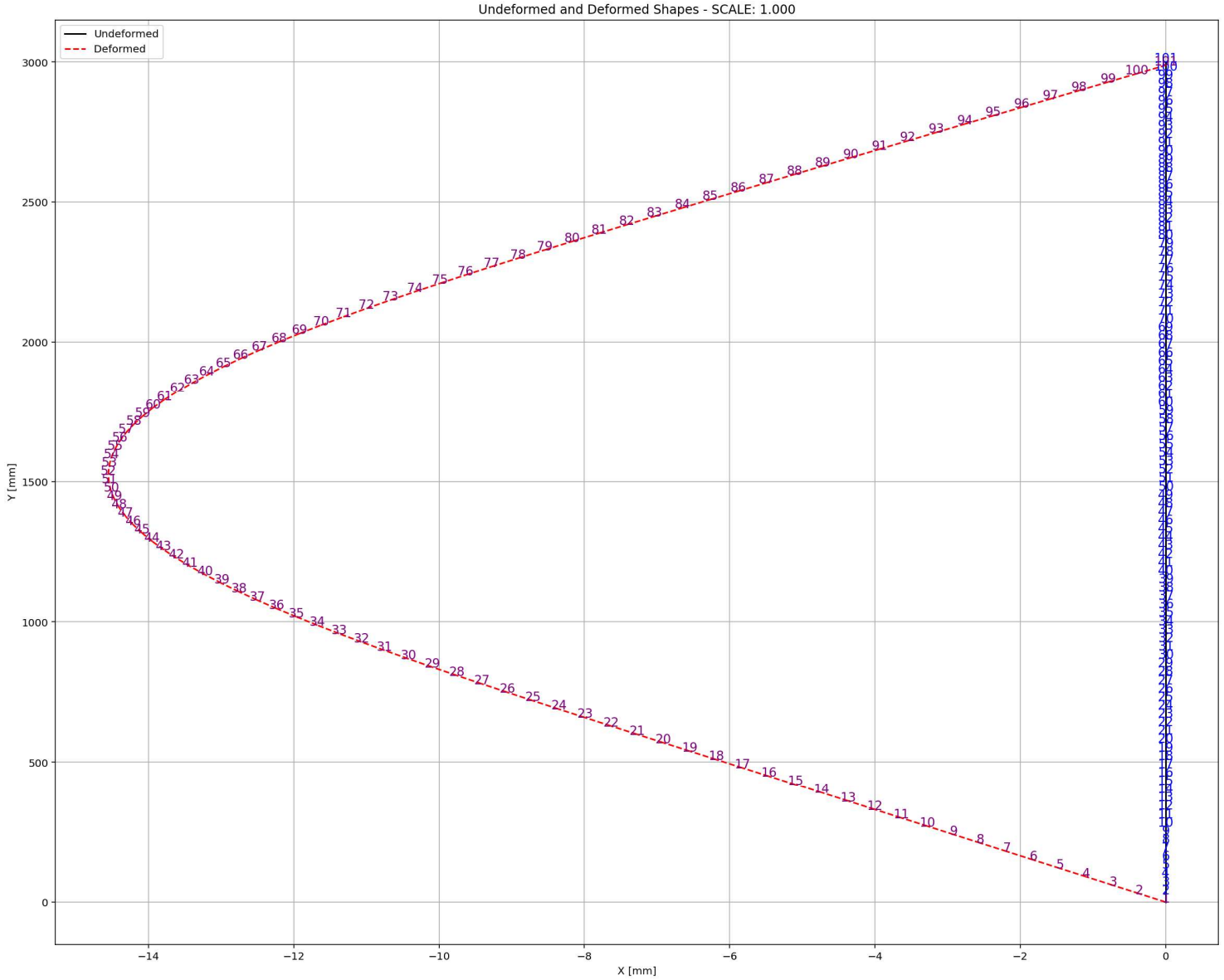
Undeformed and Deformed Shapes - SCALE: 1.000
Undeformed
Deformed
Y [mm]
X [mm]
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2000
1500
1000
500
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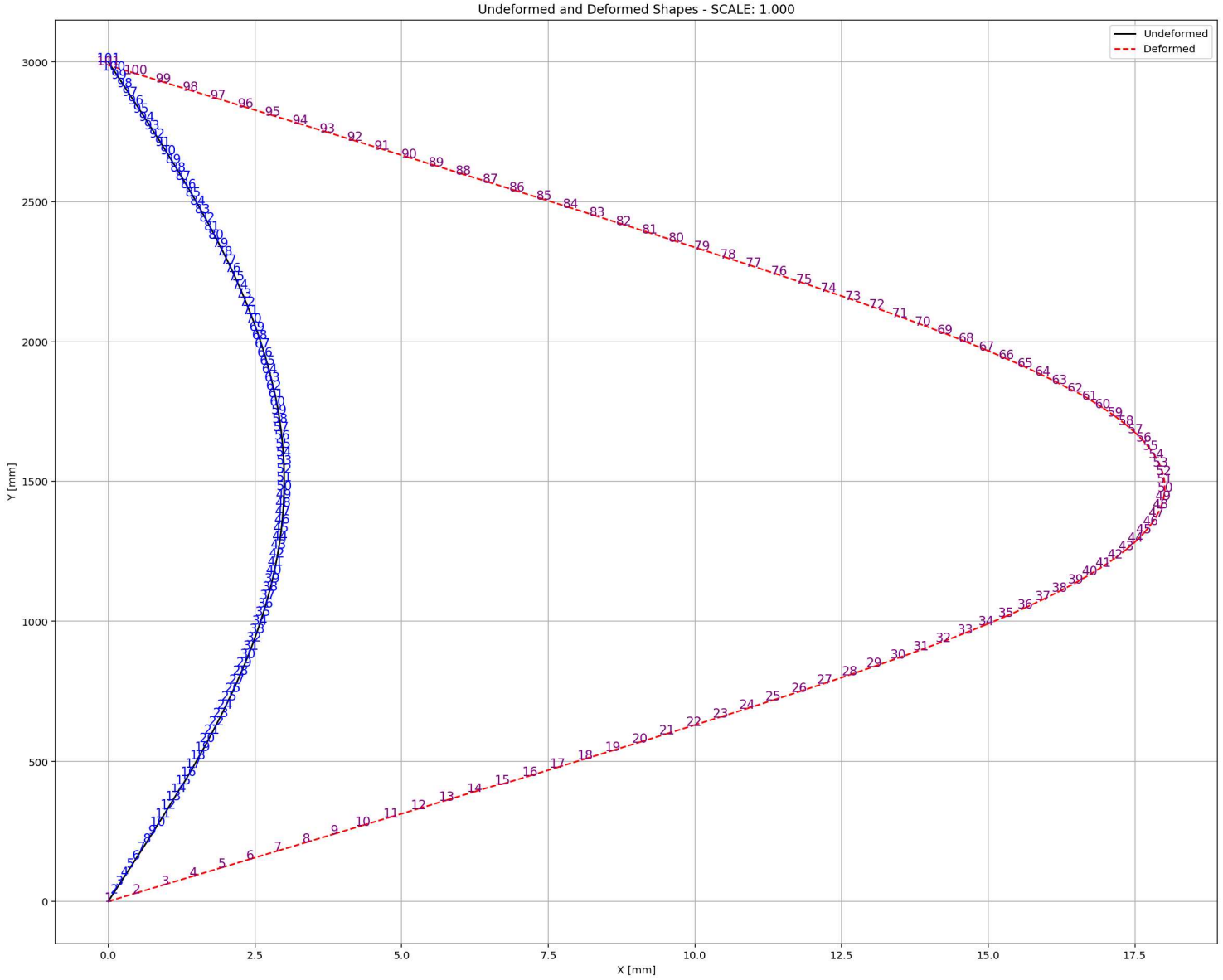
−10
−8
−6
−4
−2
0


Undeformed and Deformed Shapes - SCALE: 1.000
Undeformed
Deformed
Y [mm]
X [mm]
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2500
3000
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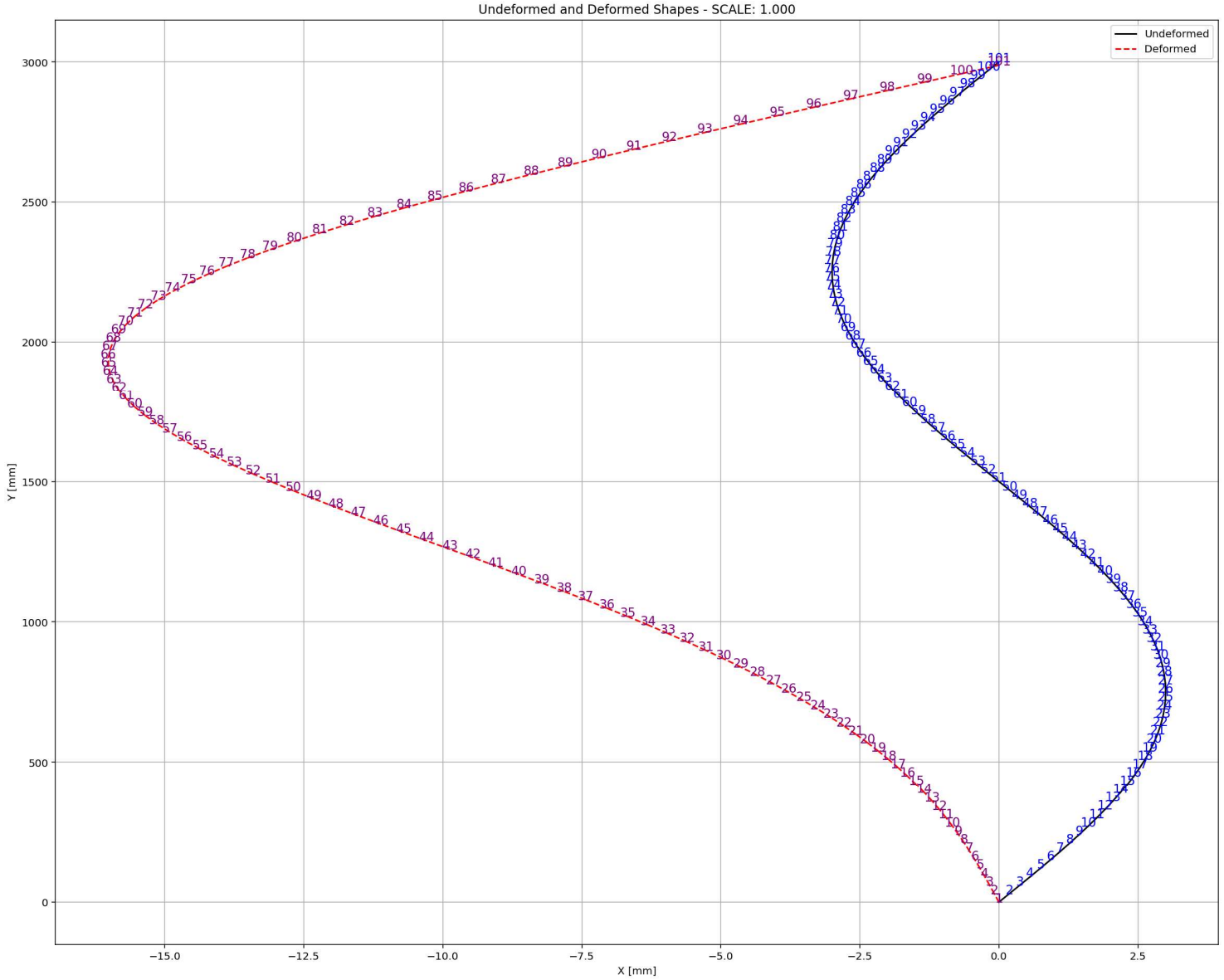
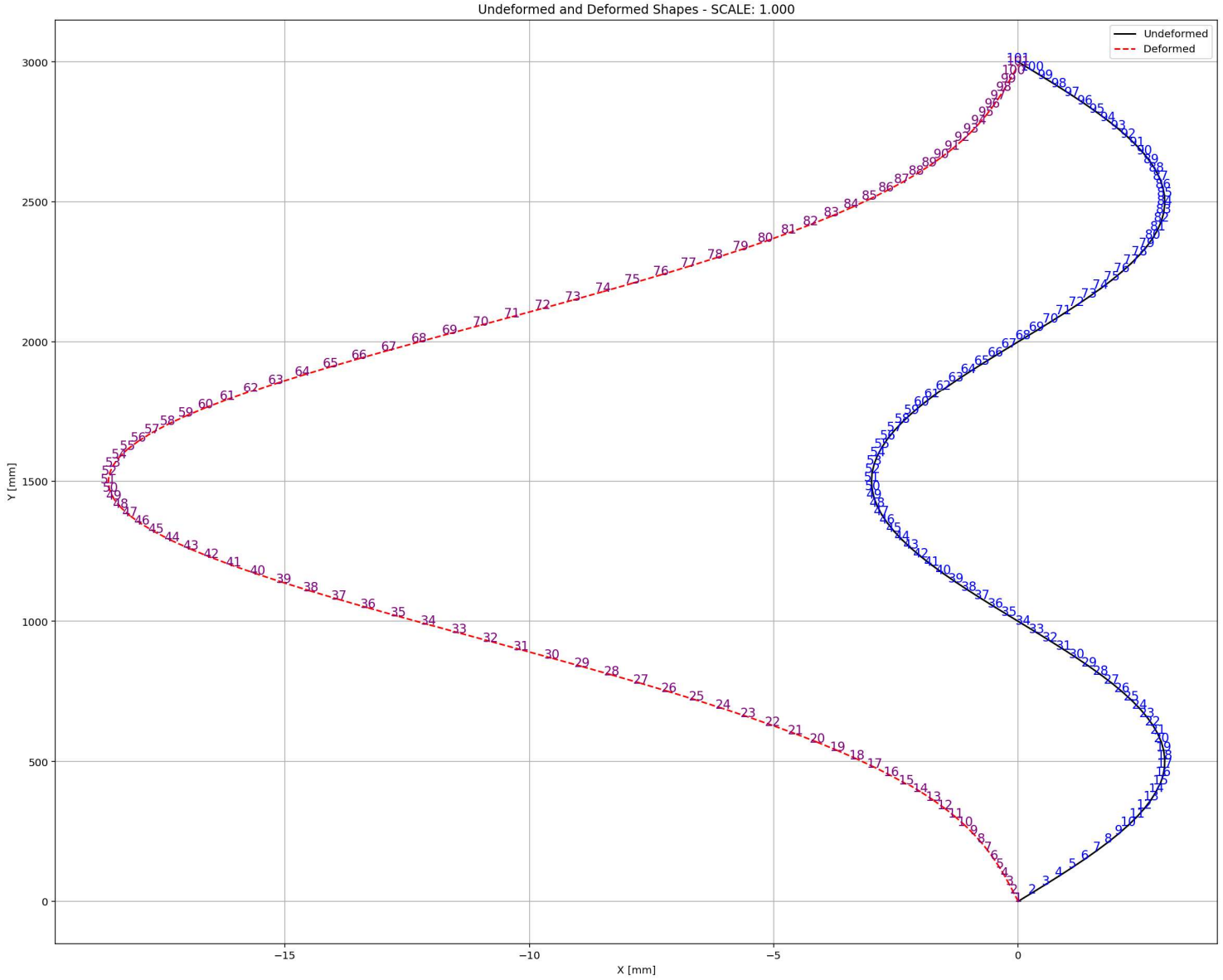
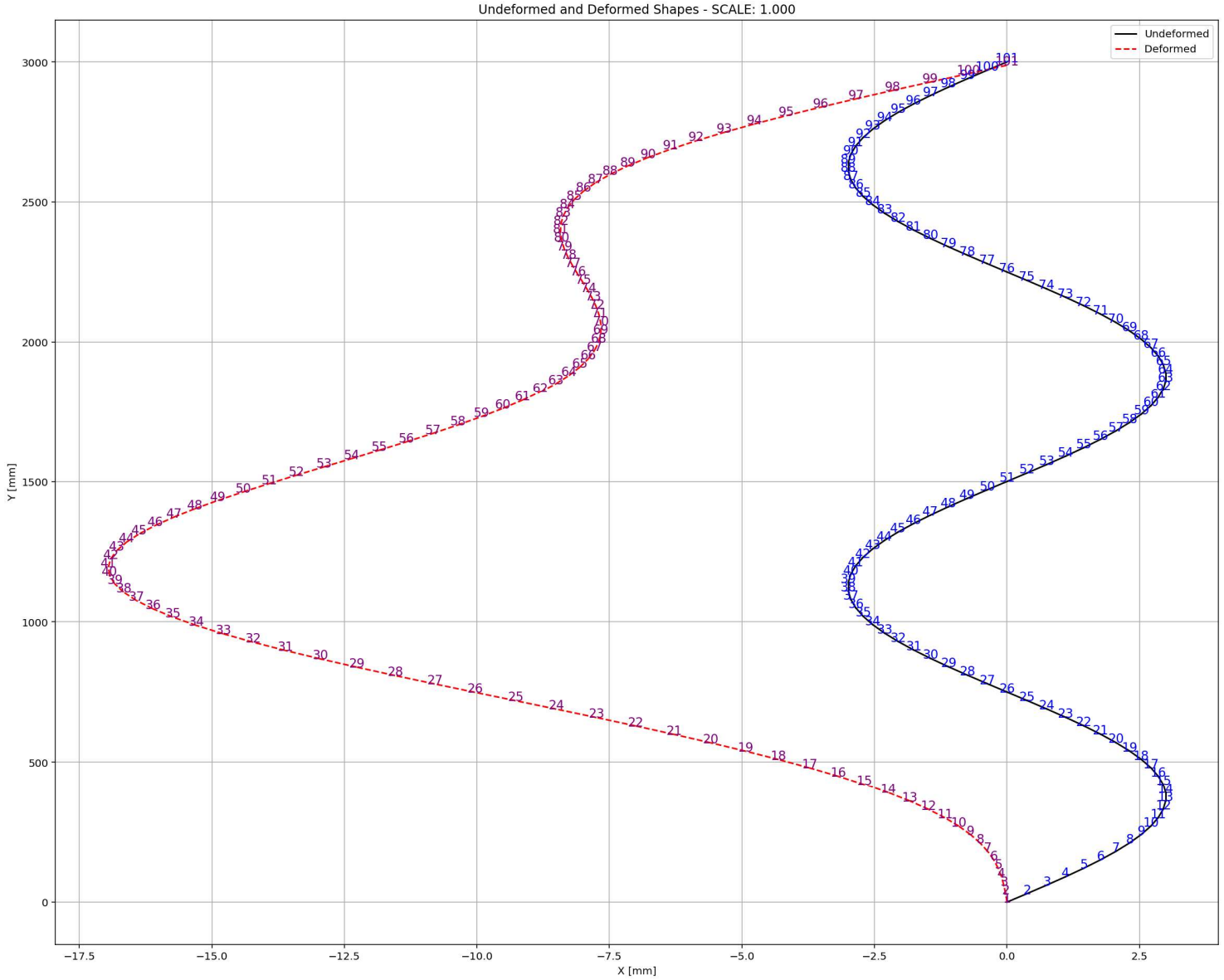
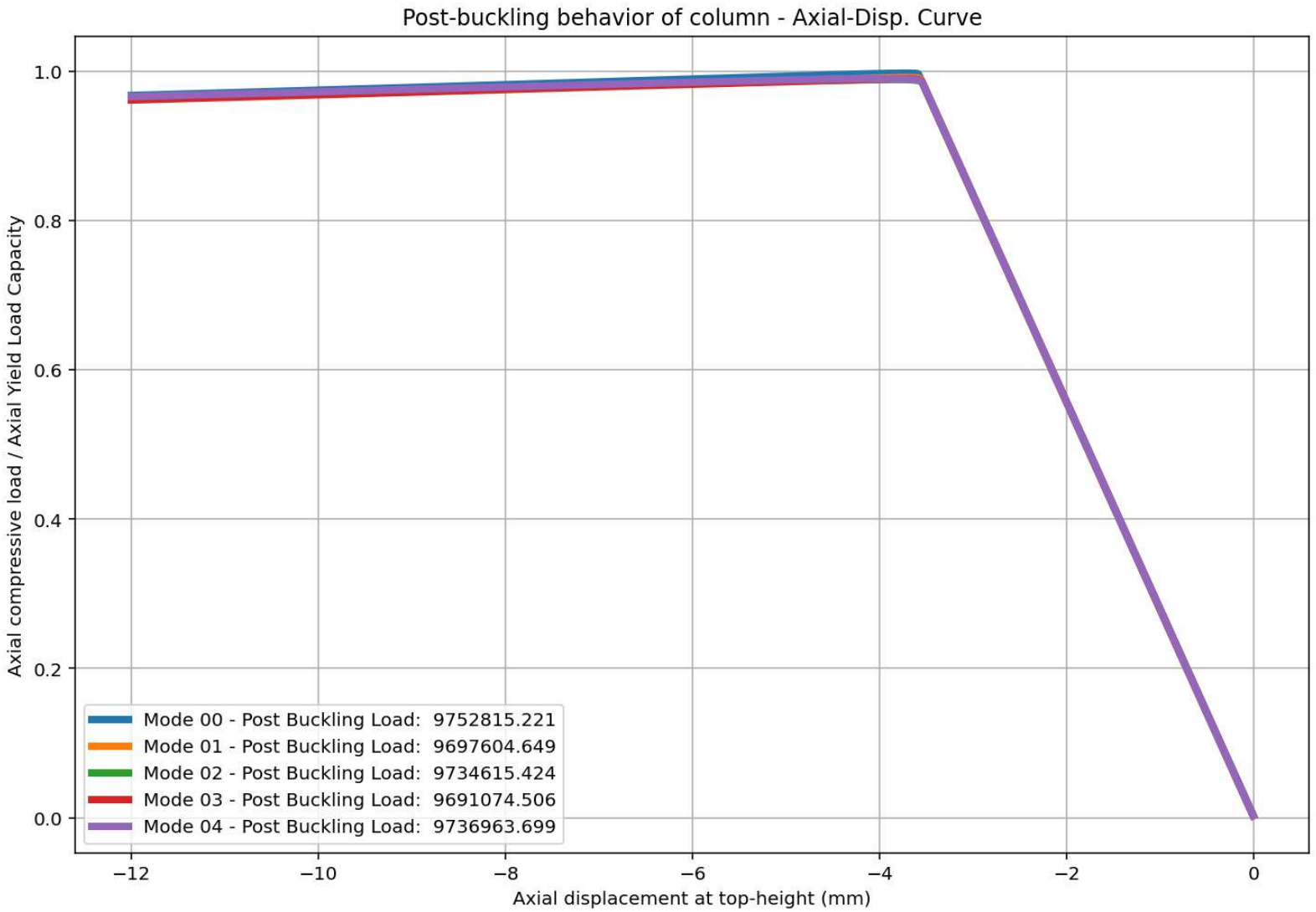
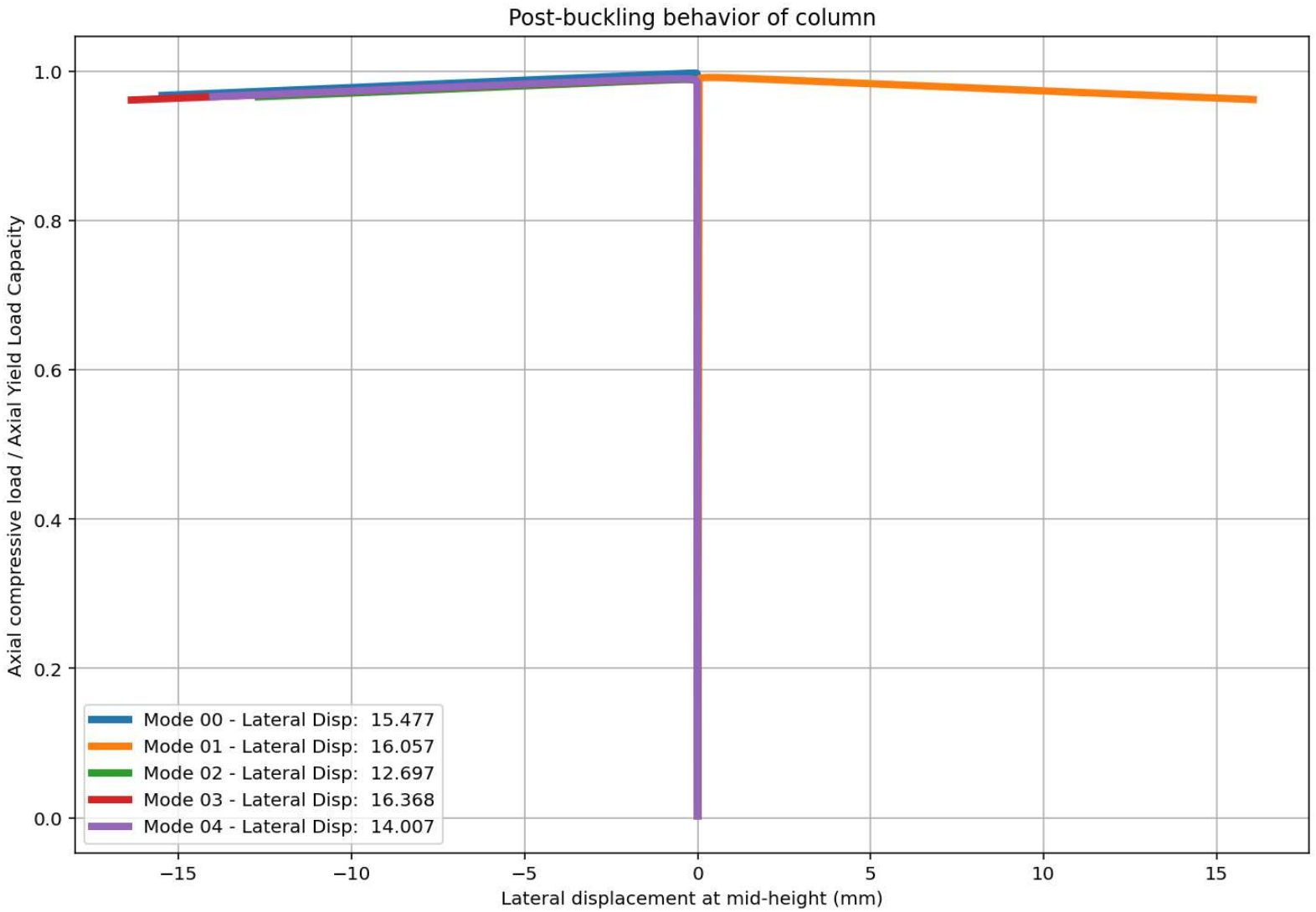
5.0
7.5
10.0
12.5
15.0
17.5

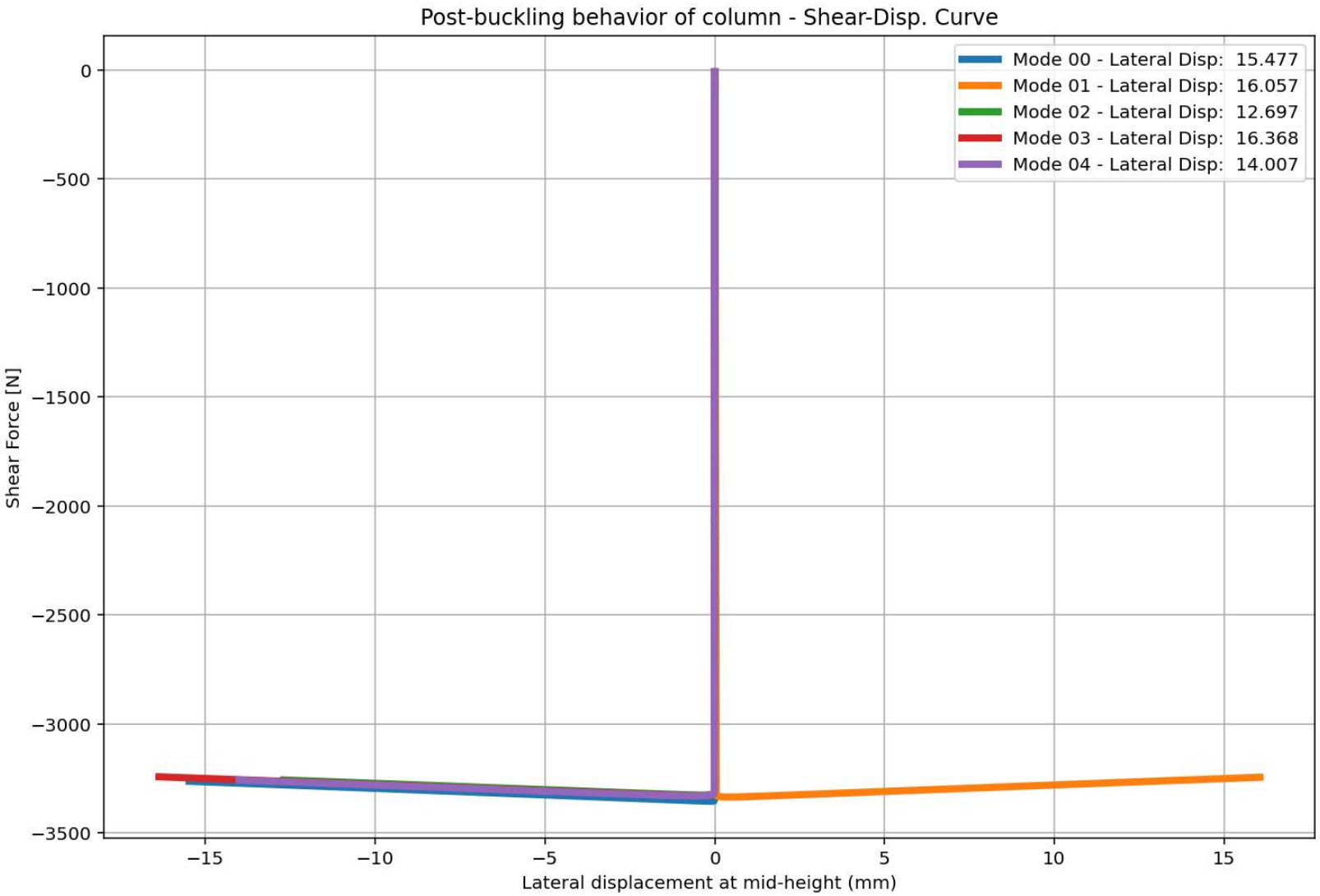

Undeformed and Deformed Shapes - SCALE: 1.000
Undeformed
Deformed
Y [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−15.0
−12.5
−10.0
−7.5
−5.0
−2.5
0.0
2.5

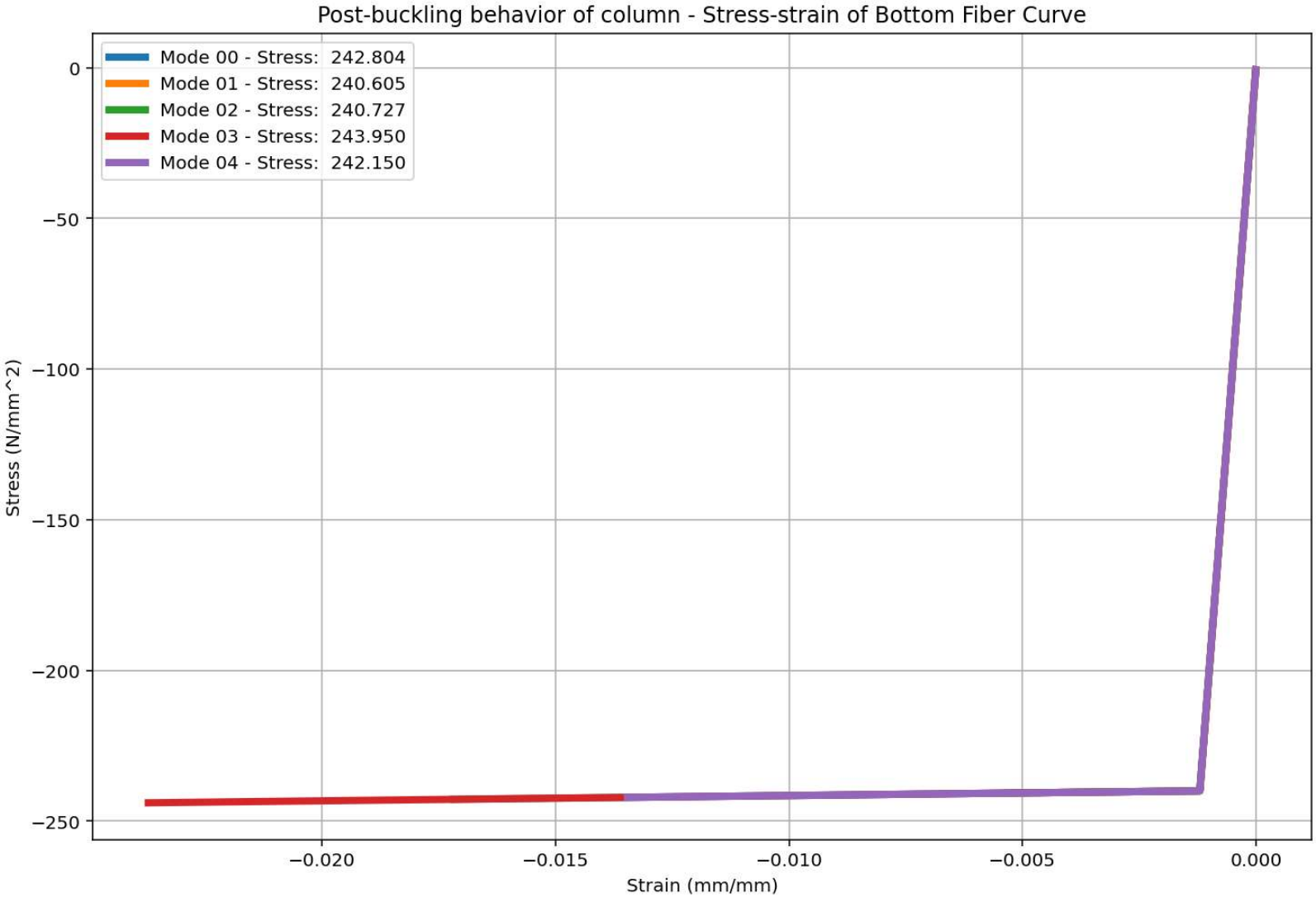

Undeformed and Deformed Shapes - SCALE: 1.000
Undeformed
Deformed
Y [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−15
−10
−5
0

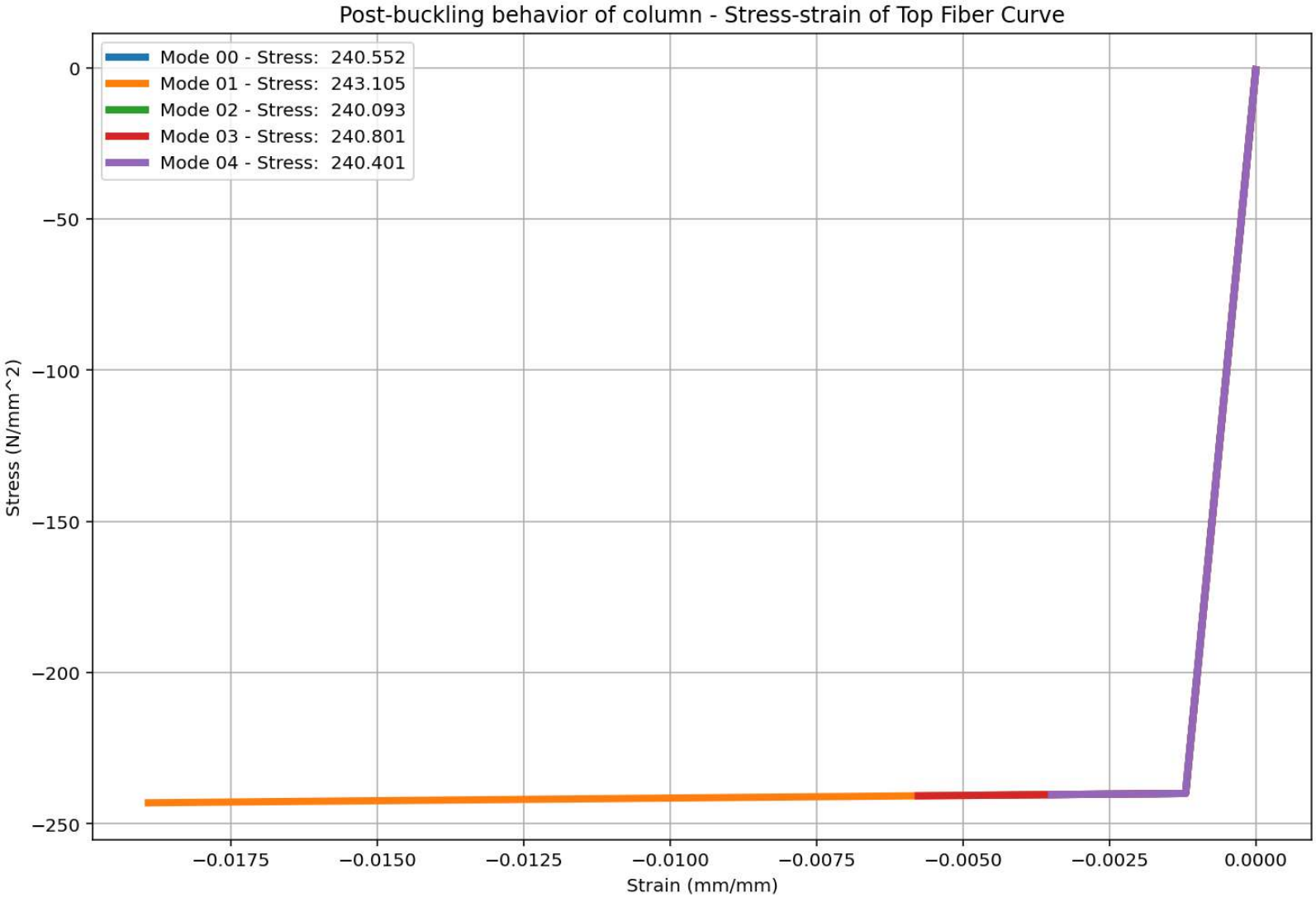

Undeformed and Deformed Shapes - SCALE: 1.000
Undeformed
Deformed
Y [mm]
X [mm]
3000
2500
2000
1500
1000
500
0
−17.5
−15.0
−12.5
−10.0
−7.5
−5.0
−2.5
0.0
2.5

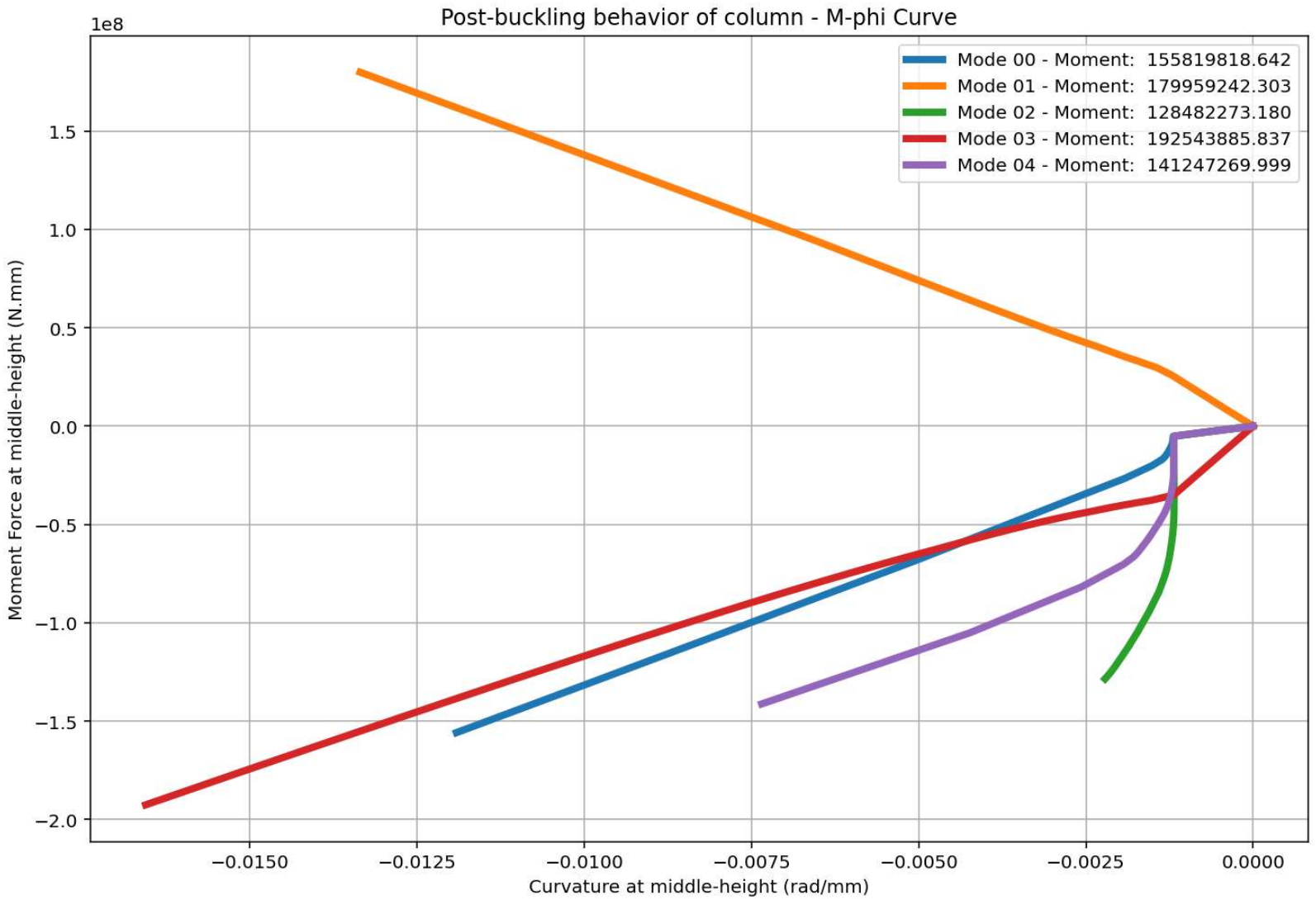

Post-buckling behavior of column - Axial-Disp. Curve
Axial compressive load / Axial Yield Load Capacity
1.0
0.8
0.6
0.4
0.2
0.0
−12
−10
−8
−6
−4
−2
0
Axial displacement at top-height (mm)
Mode 00 - Post Buckling Load: 9752815.221
Mode 01 - Post Buckling Load: 9697604.649
Mode 02 - Post Buckling Load: 9734615.424
Mode 03 - Post Buckling Load: 9691074.506
Mode 04 - Post Buckling Load: 9736963.699

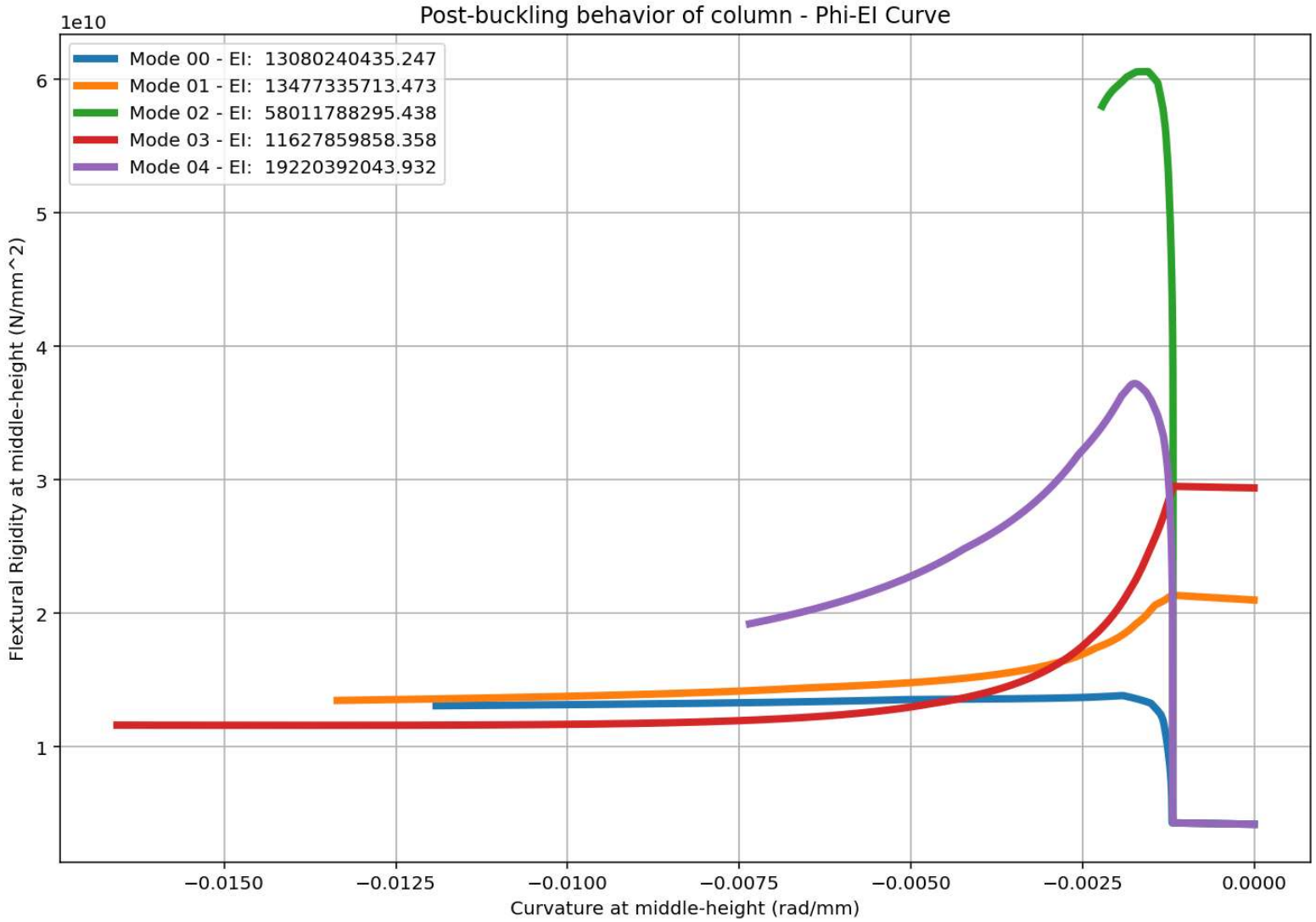

Post-buckling behavior of column
Axial compressive load / Axial Yield Load Capacity
Lateral displacement at mid-height (mm)
1.0
0.8
0.6
0.4
0.2
0.0
−15
−10
−5
0
5
10
15
Mode 00 - Lateral Disp: 15.477
Mode 01 - Lateral Disp: 16.057
Mode 02 - Lateral Disp: 12.697
Mode 03 - Lateral Disp: 16.368
Mode 04 - Lateral Disp: 14.007

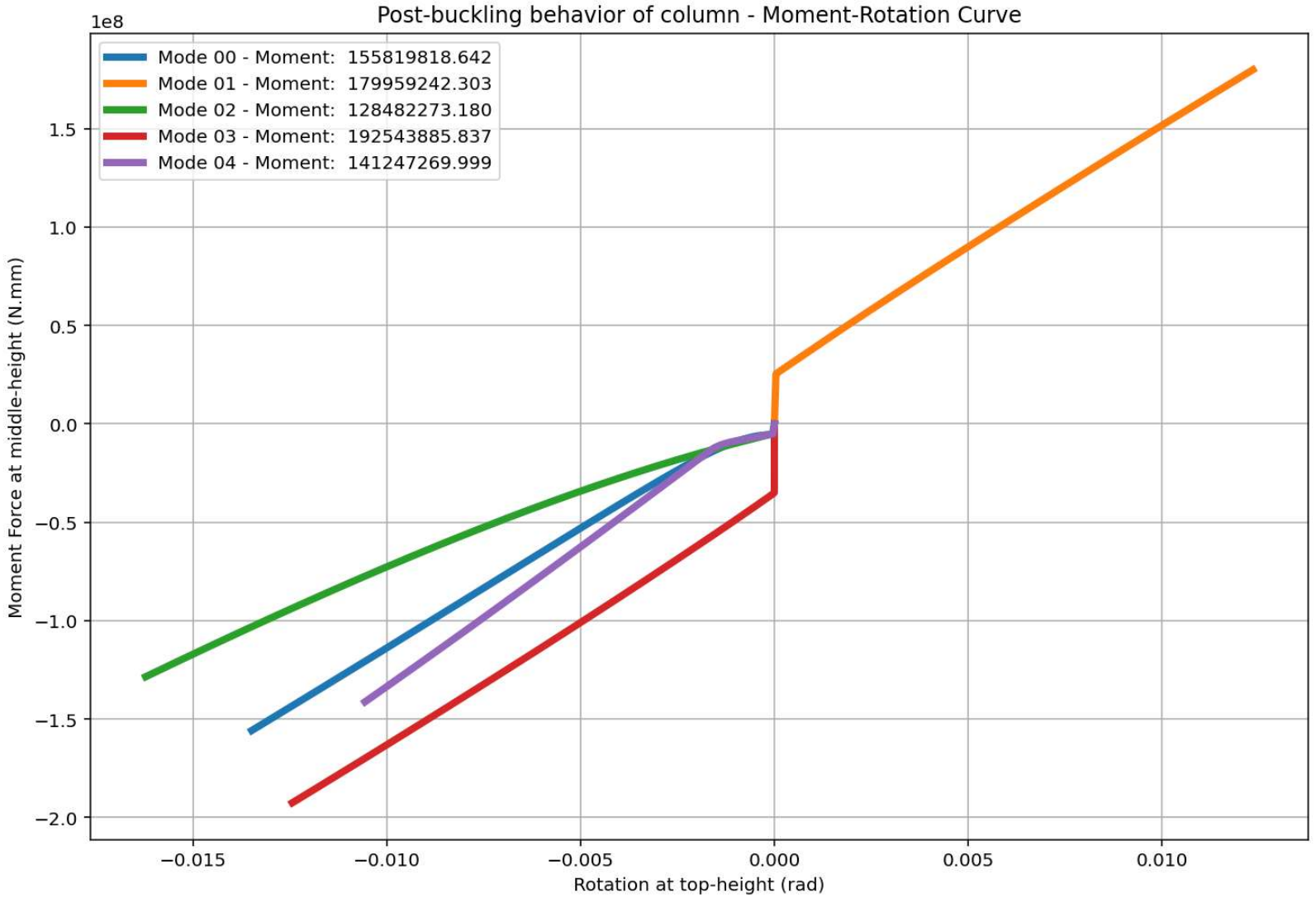

Post-buckling behavior of column - Shear-Disp. Curve
Mode 00 - Lateral Disp: 15.477
Mode 01 - Lateral Disp: 16.057
Mode 02 - Lateral Disp: 12.697
Mode 03 - Lateral Disp: 16.368
Mode 04 - Lateral Disp: 14.007
Shear Force [N]
0
−500
−1000
−1500
−2000
−2500
−3000
−3500
−15
−10
−5
0
5
10
15
Lateral displacement at mid-height (mm)

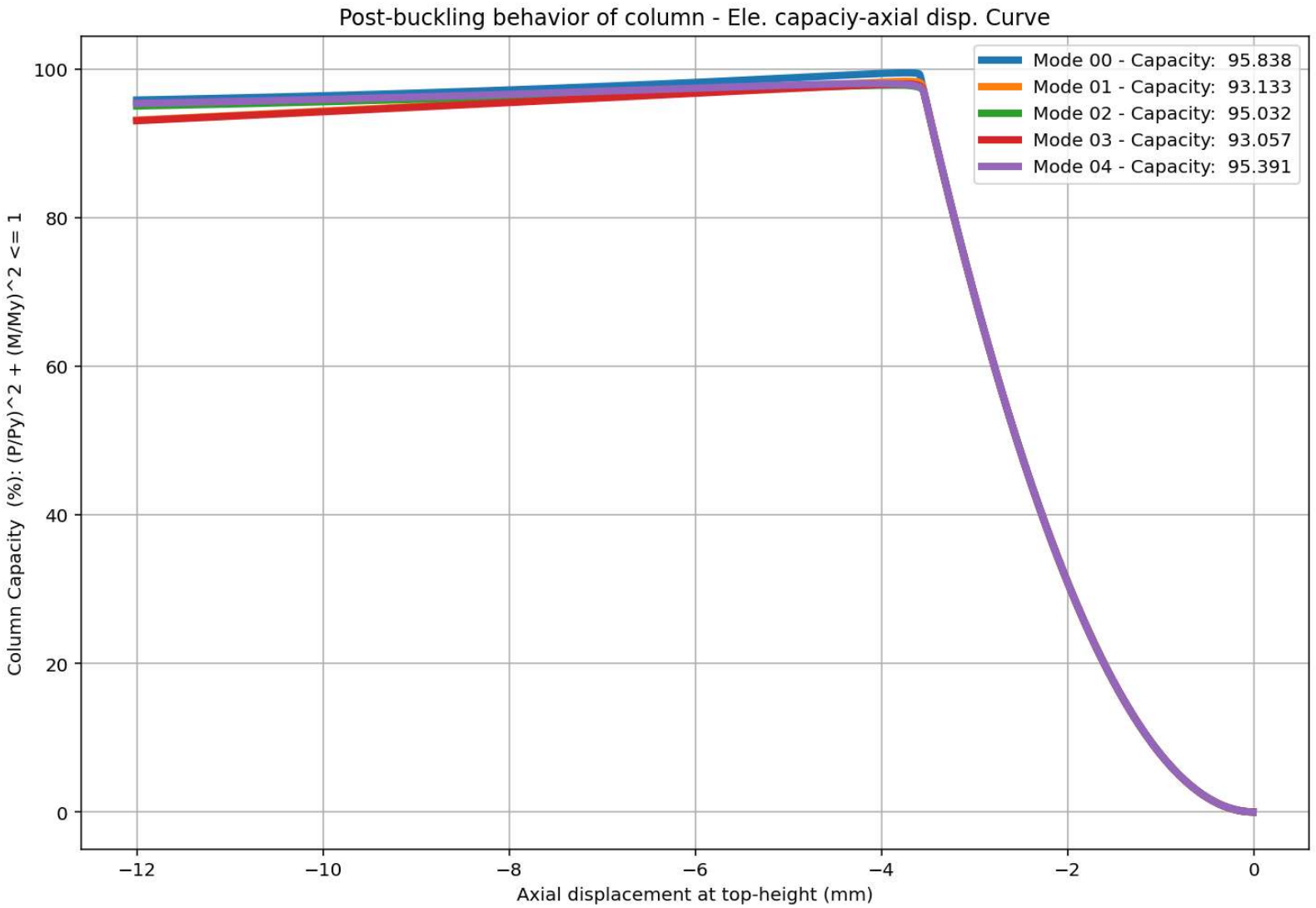

Post-buckling behavior of column - Stress-strain of Bottom Fiber Curve
Mode 00 - Stress: 242.804
Mode 01 - Stress: 240.605
Mode 02 - Stress: 240.727
Mode 03 - Stress: 243.950
Mode 04 - Stress: 242.150
0
−50
−100
−150
−200
−250
Stress (N/mm^2)
−0.020
−0.015
−0.010
−0.005
0.000
Strain (mm/mm)

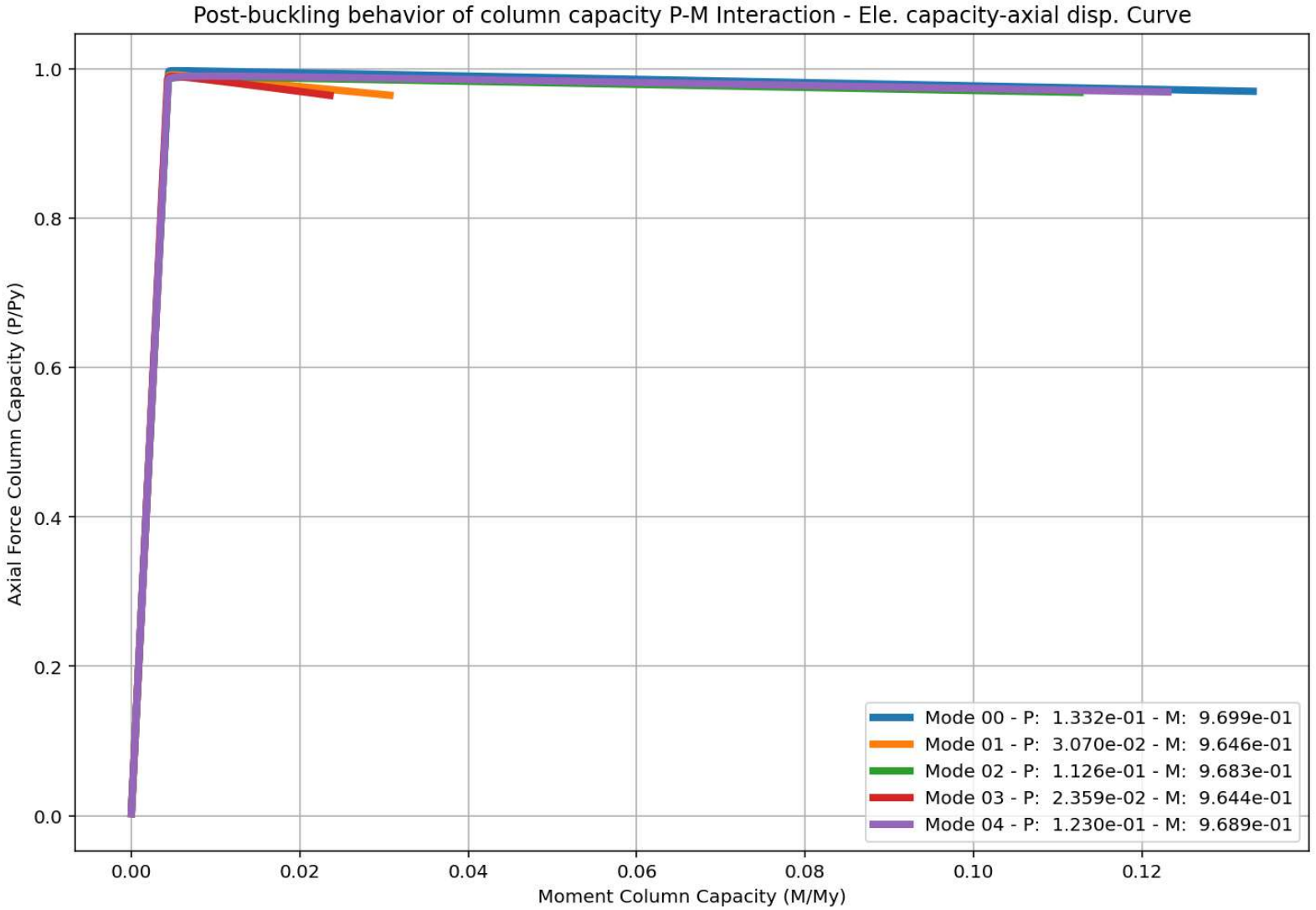

Post-buckling behavior of column - Stress-strain of Top Fiber Curve
Mode 00 - Stress: 240.552
Mode 01 - Stress: 243.105
Mode 02 - Stress: 240.093
Mode 03 - Stress: 240.801
Mode 04 - Stress: 240.401
0
−50
−100
−150
−200
−250
Stress (N/mm^2)
−0.0175
−0.0150
−0.0125
−0.0100
−0.0075
−0.0050
−0.0025
0.0000
Strain (mm/mm)


Post-buckling behavior of column - M-phi Curve
1e8
Mode 00 - Moment: 155819818.642
Mode 01 - Moment: 179959242.303
Mode 02 - Moment: 128482273.180
Mode 03 - Moment: 192543885.837
Mode 04 - Moment: 141247269.999
Moment Force at middle-height (N.mm)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−0.0150
−0.0125
−0.0100
−0.0075
−0.0050
−0.0025
0.0000
Curvature at middle-height (rad/mm)


Post-buckling behavior of column - Phi-EI Curve
1e10
Mode 00 - EI: 13080240435.247
Mode 01 - EI: 13477335713.473
Mode 02 - EI: 58011788295.438
Mode 03 - EI: 11627859858.358
Mode 04 - EI: 19220392043.932
Flextural Rigidity at middle-height (N/mm^2)
Curvature at middle-height (rad/mm)
6
5
4
3
2
1
−0.0150
−0.0125
−0.0100
−0.0075
−0.0050
−0.0025
0.0000


Post-buckling behavior of column - Moment-Rotation Curve
1e8
Mode 00 - Moment: 155819818.642
Mode 01 - Moment: 179959242.303
Mode 02 - Moment: 128482273.180
Mode 03 - Moment: 192543885.837
Mode 04 - Moment: 141247269.999
Moment Force at middle-height (N.mm)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−0.015
−0.010
−0.005
0.000
0.005
0.010
Rotation at top-height (rad)


Post-buckling behavior of column - Ele. capaciy-axial disp. Curve
Mode 00 - Capacity: 95.838
Mode 01 - Capacity: 93.133
Mode 02 - Capacity: 95.032
Mode 03 - Capacity: 93.057
Mode 04 - Capacity: 95.391
Column Capacity (%): (P/Py)^2 + (M/My)^2 <= 1
100
80
60
40
20
0
−12
−10
−8
−6
−4
−2
0
Axial displacement at top-height (mm)


Post-buckling behavior of column capacity P-M Interaction - Ele. capacity-axial disp. Curve
Axial Force Column Capacity (P/Py)
Moment Column Capacity (M/My)
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Mode 00 - P: 1.332e-01 - M: 9.699e-01
Mode 01 - P: 3.070e-02 - M: 9.646e-01
Mode 02 - P: 1.126e-01 - M: 9.683e-01
Mode 03 - P: 2.359e-02 - M: 9.644e-01
Mode 04 - P: 1.230e-01 - M: 9.689e-01