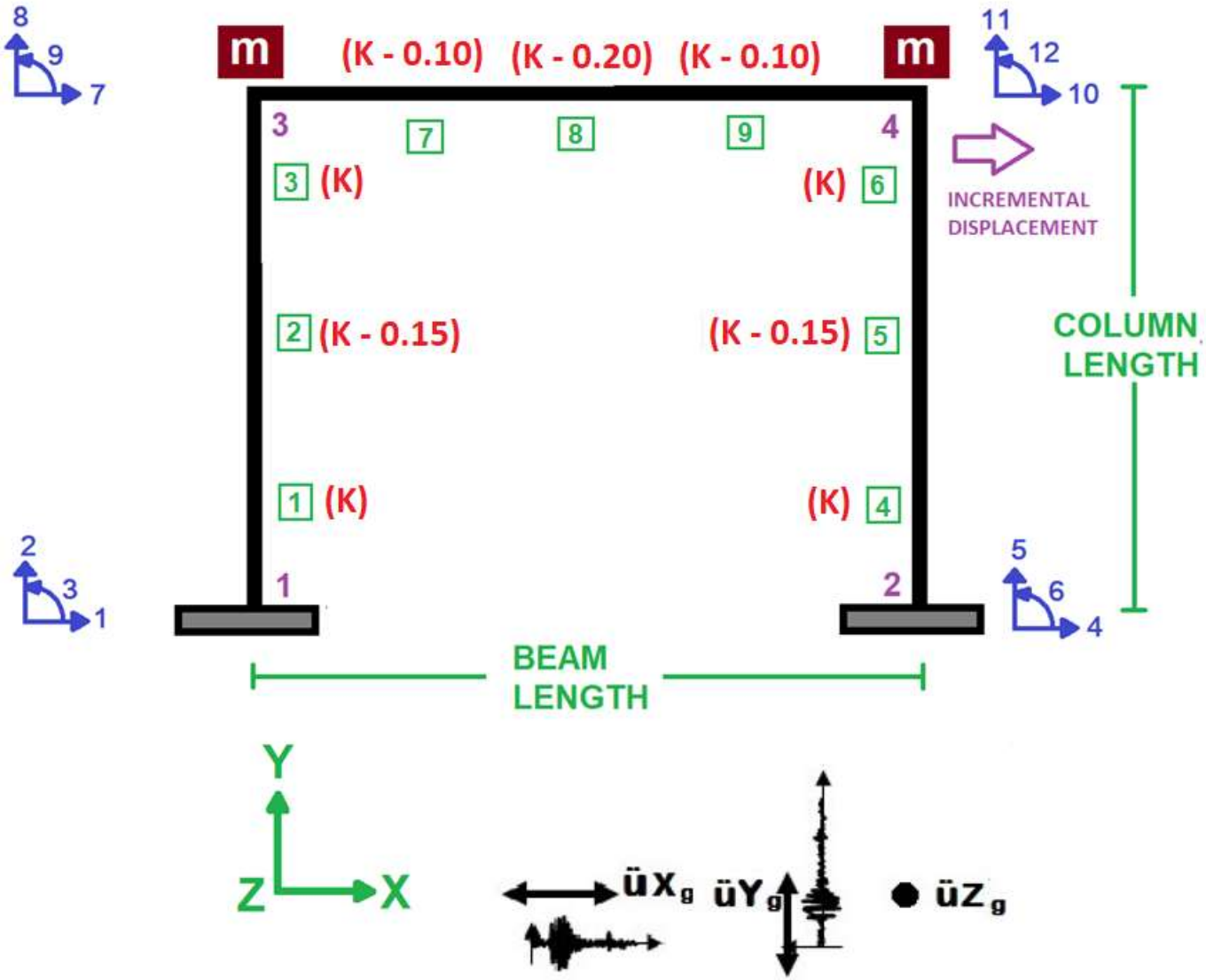
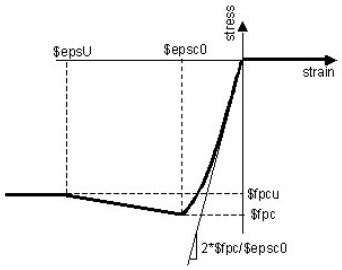
IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL

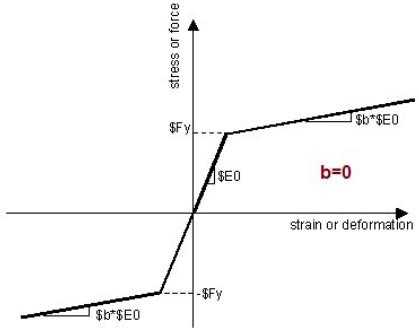
COMPARATIVE STUDY OF ELASTIC AND INELASTIC STRUCTURAL BEHAVIOR THROUGH PUSHOVER DYNAMIC ANALYSIS USING OPENSEES

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)

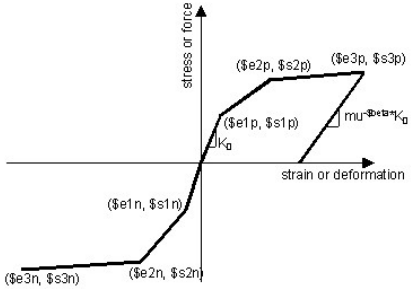

8
9
7
m
(K - 0.10)
(K - 0.20)
(K - 0.10)
m
11
12
10
3
7
8
9
4
3
(K)
(K)
6
INCREMENTAL
DISPLACEMENT
2
(K - 0.15)
(K - 0.15)
5
COLUMN
LENGTH
1
(K)
(K)
4
2
3
1
1
2
5
6
4
BEAM
LENGTH
Y
Z
X
üX g
üY g
üZ g



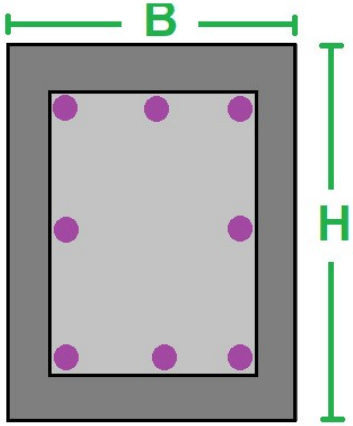
CORE AND COVER CONCRETE RELATION



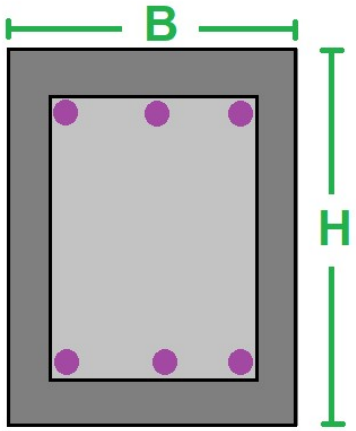
WITHOUT HARDENING AND ULTIMATE STRAIN



WITH HARDENING AND ULTIMATE STRAIN



COLUMN SECTION



BEAM SECTION

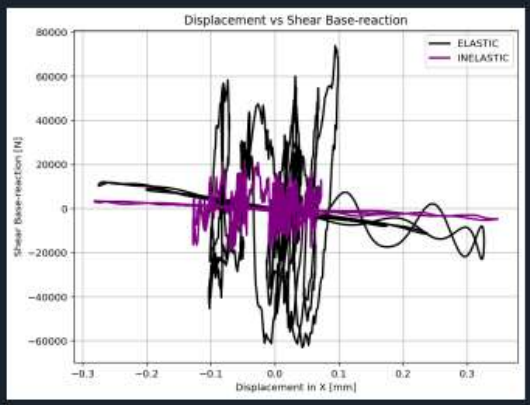
Spyder (Python 3.12)

File Edit Search Source Run Debug Consoles Projects Tools View Help

C:\Users\Dell\Desktop\OPENSEES_FILES\CONCRETE_FRA...INEMENT_NONCONSTANT_ELASTIC_OR_INELASTIC_FRAME.py

CONFINEMENT_NONCON...INELASTIC_FRAME.py

```
#############################################################################################
#                              >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<
#  COMPARATIVE STUDY OF ELASTIC AND INELASTIC STRUCTURAL BEHAVIOR THROUGH PUSHOVER DYNAMIC ANALY
#-------------------------------------------------------------------------------------------
#                                THIS PROGRAM WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)
#                                        EMAIL: salar.d.ghashghaei@gmail.com
#############################################################################################
"""
1. The script performs a comparative study of elastic and inelastic structural behavior using pu
2. It models a 2D reinforced concrete frame with columns (500x500mm) and beams (500x300mm) using
3. Material definitions include confined/unconfined concrete (fc=25MPa) and bilinear steel reinf
4. Two analysis types are implemented: static pushover (displacement-controlled) and dynamic tim
5. Rayleigh damping is calculated based on initial modal periods and target damping ratios (5%).
6. The pushover analysis applies incremental displacements up to 675mm, recording base reactions
7. Dynamic analysis uses Newmark integration with ground motion inputs scaled by 0.01g (El Centr
8. Key outputs include force-displacement curves, moment-rotation relationships, and stiffness d
9. Eigenvalue analysis tracks period elongation due to inelasticity during dynamic events.
10. Damage indices are computed for ductility assessment using bilinear curve fitting.
11. Overstrength factors (Ω), ductility ratios (μ), and R-factors are quantified for seismic per
12. Real-time monitoring of base shear, axial forces, and interstory drifts is implemented.
13. The script includes advanced convergence controls (Newton-Raphson, 1e-6 tolerance).
14. Confinement effects are modeled with variable enhancement ratios (Kc=1.25 for columns).
15. Results are exported to Excel, including displacements, forces, stiffness, and period data.
16. Visualization includes deformed shapes, hysteresis loops, and cumulative response envelopes.
17. Damping ratios are estimated from free vibration decay in dynamic analyses.
18. Both geometric nonlinearities (P-Delta/Corotational) and material nonlinearities are conside
19. The code supports parametric studies by varying steel models (with/without hardening) and el
20. Comprehensive plotting functions enable side-by-side comparison of elastic vs. inelastic res

The script demonstrates professional-grade analysis combining FEMA-356 pushover methods with ASC
"""
import openseespy.opensees as ops
import matplotlib.pyplot as plt
import numpy as np
```



Help | Variable Explorer | Debugger | Plots | Files

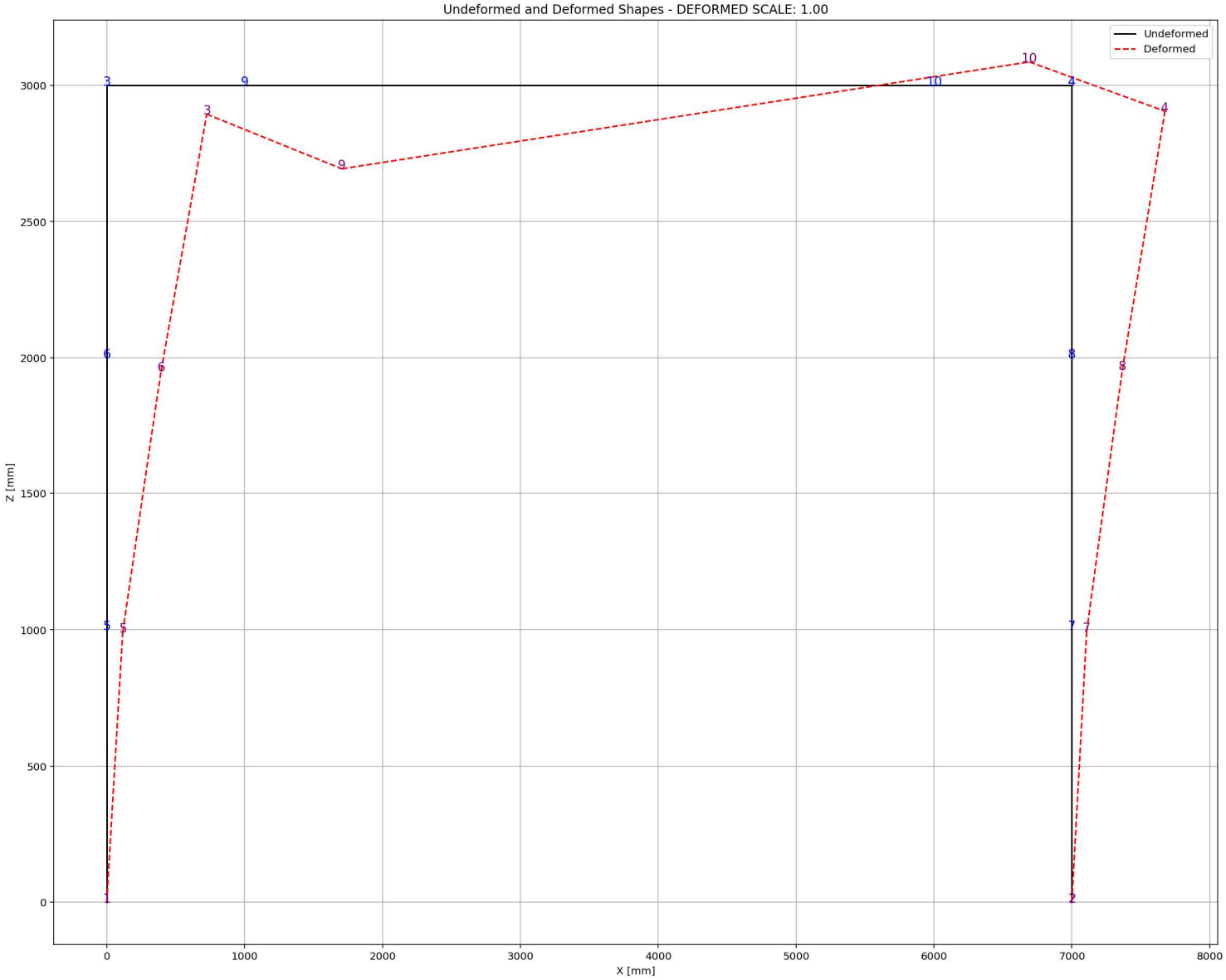
Console 1/A

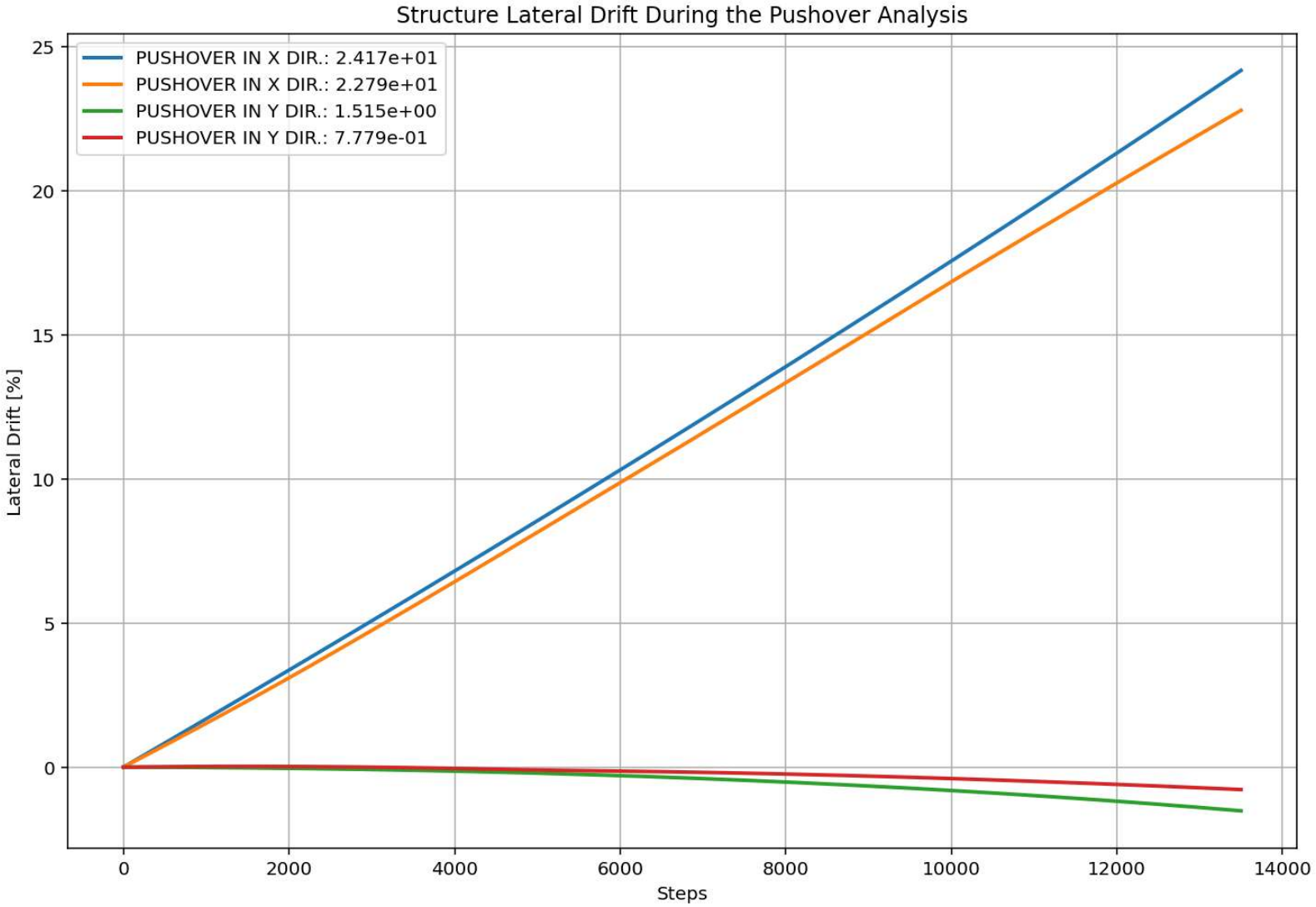
```
Structure Over Strength Factor:   0.93
+-------------------------------------------------+
Over Strength Coefficient (Ω0):      0.9264
Displacement Ductility Ratio (μ):    6.6951
Ductility Coefficient (Rμ):          6.6951
Structural Behavior Coefficient (R): 6.2022
Structural Ductility Damage Index in Y Direction: -0.1750

 Node: 3
    Coordinates  : 0 3000
    Disps: -0.080493 0.0050033 3.61619e-05
    Velocities   : -0.00740551 0.00258162 1.36492e-06
```

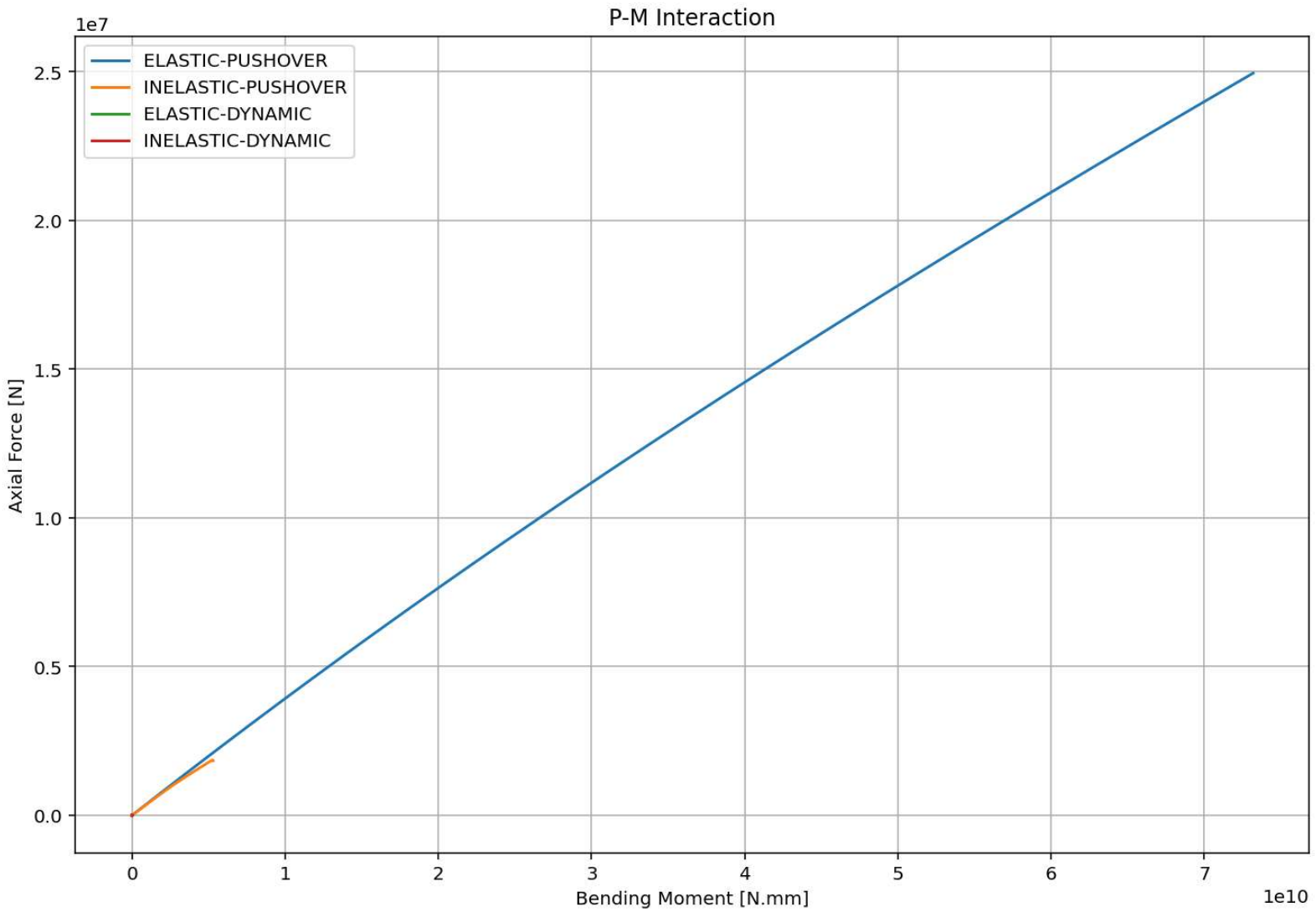
IPython Console | History

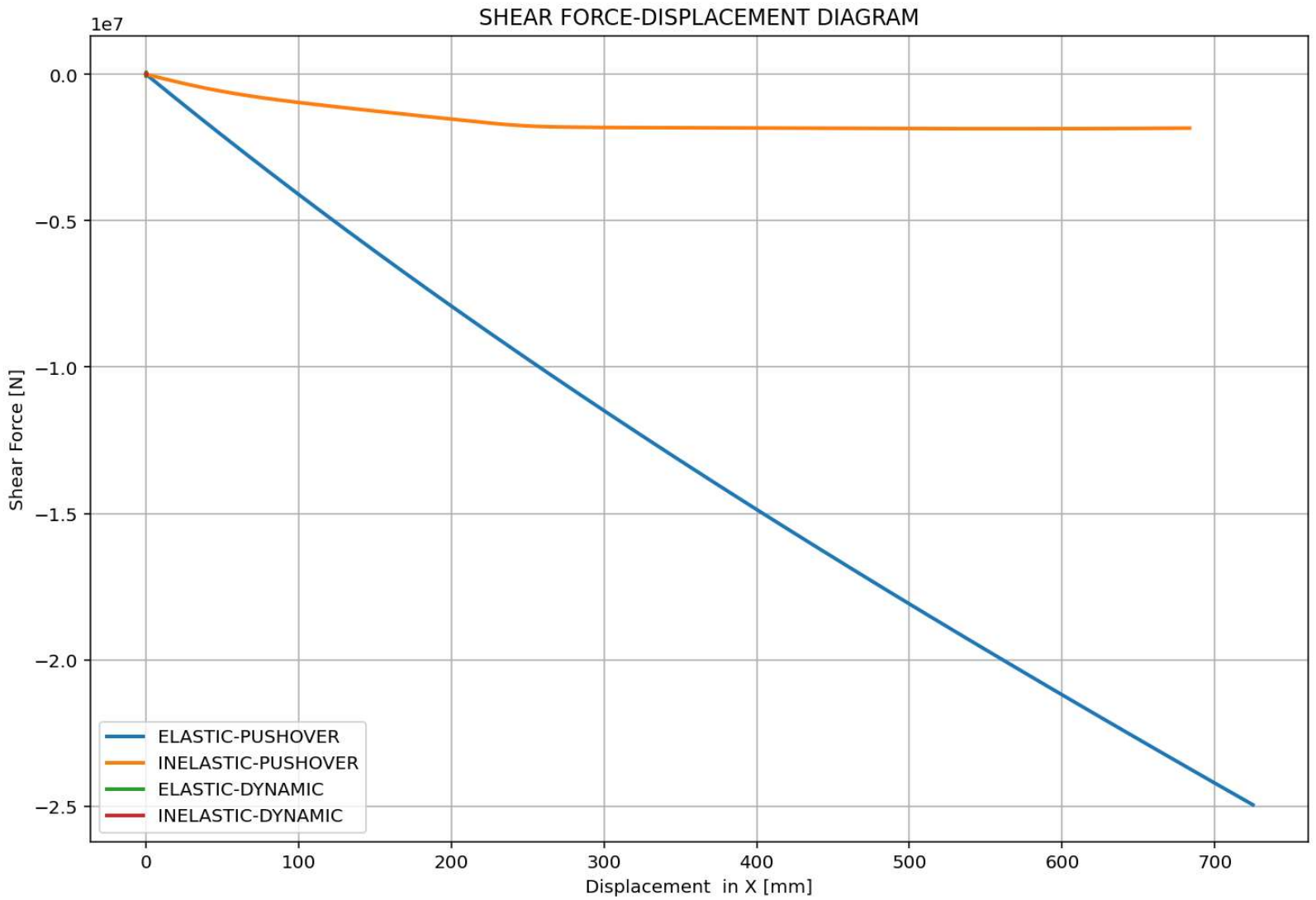
Inline | Conda: anaconda3 (Python 3.12.7) | LSP: Python | Line 8, Col 4 | UTF-8 | CRLF | RW | Mem 37%

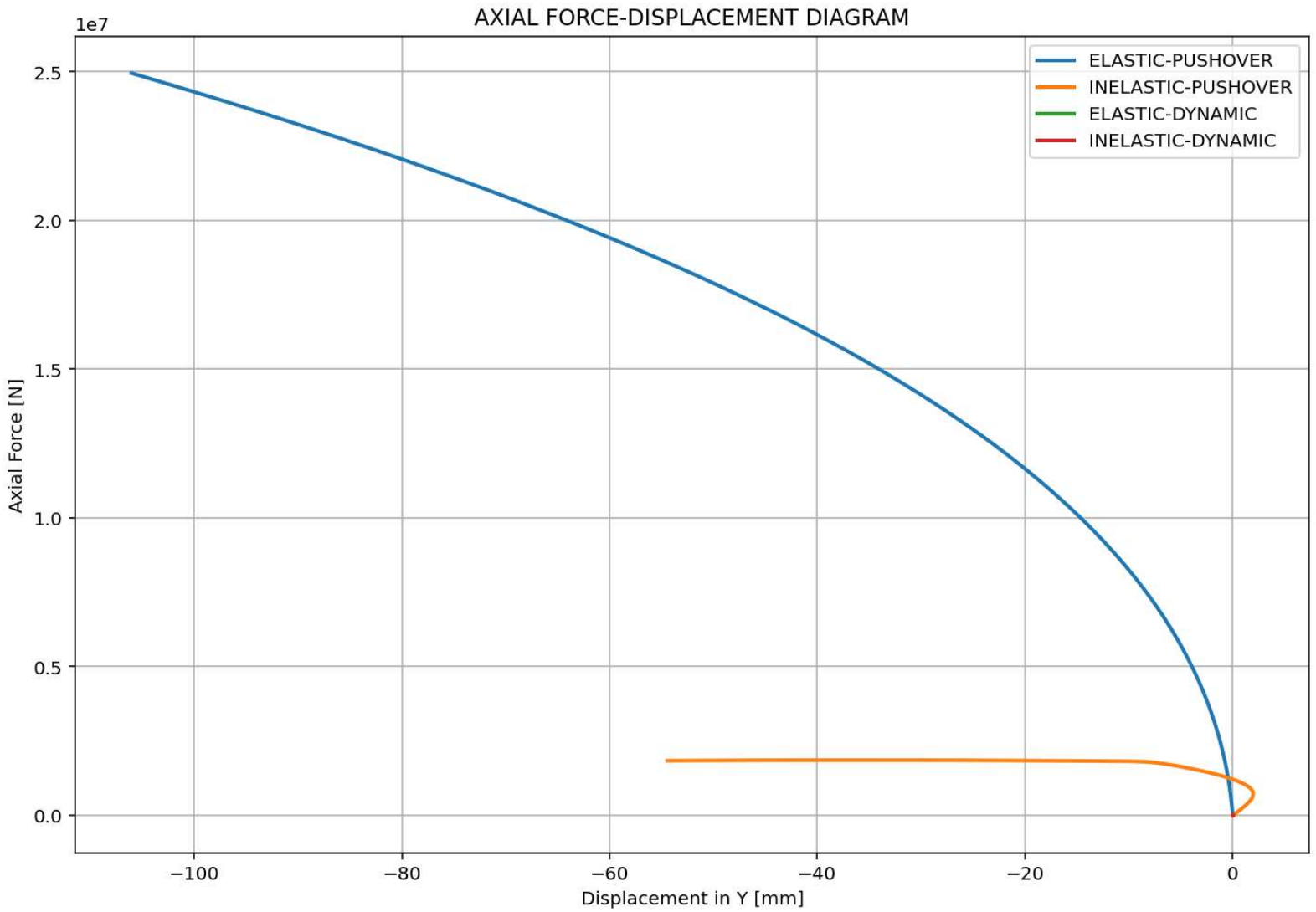
ELASTIC AND INELASTIC STATIC ANALYSIS (PUSHOVER)

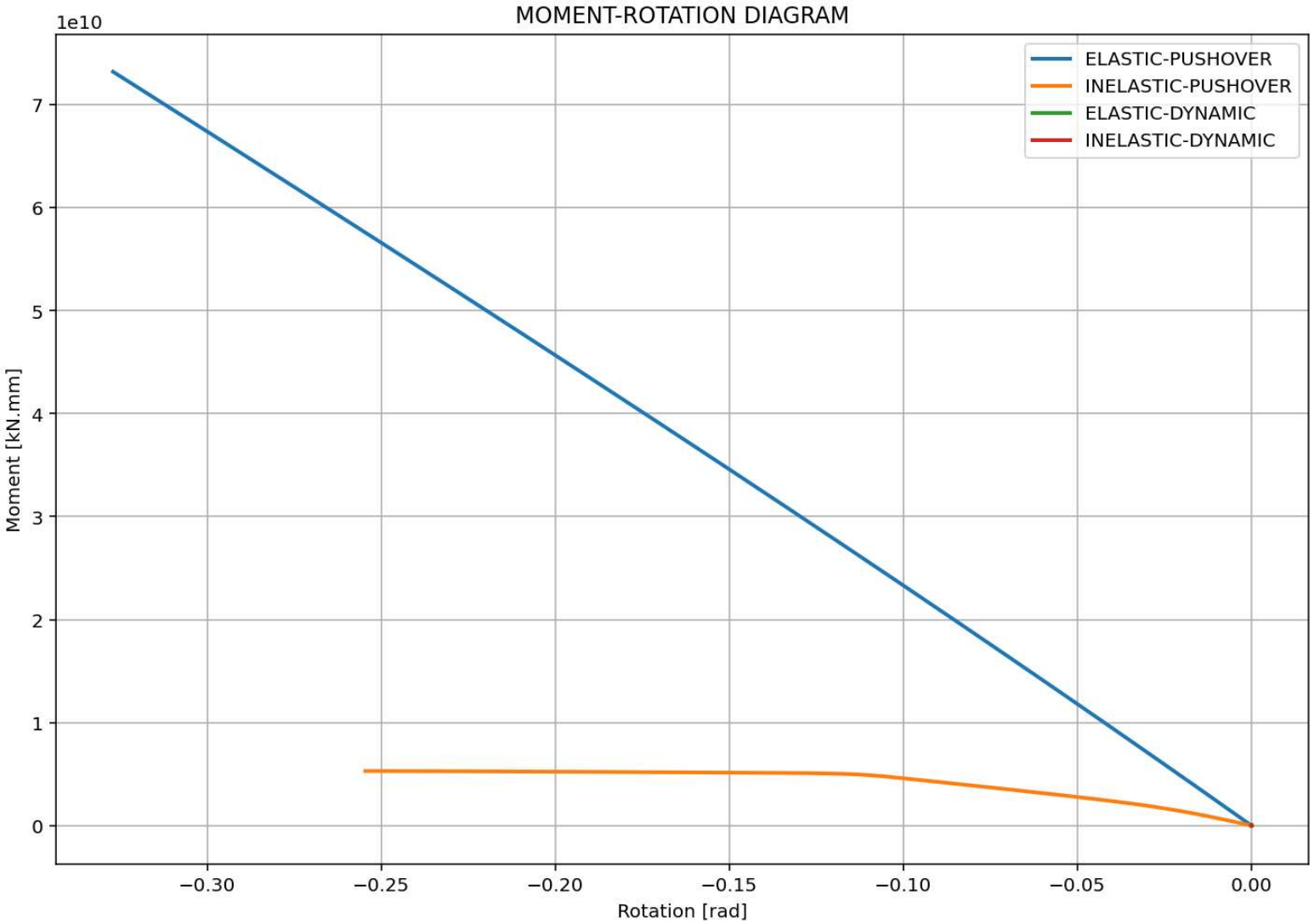

Undeformed and Deformed Shapes - DEFORMED SCALE: 1.00
Undeformed
Deformed
Z [mm]
X [mm]
0
500
1000
1500
2000
2500
3000
0
1000
2000
3000
4000
5000
6000
7000
8000
3
9
10
4
6
8
5
7
1
2

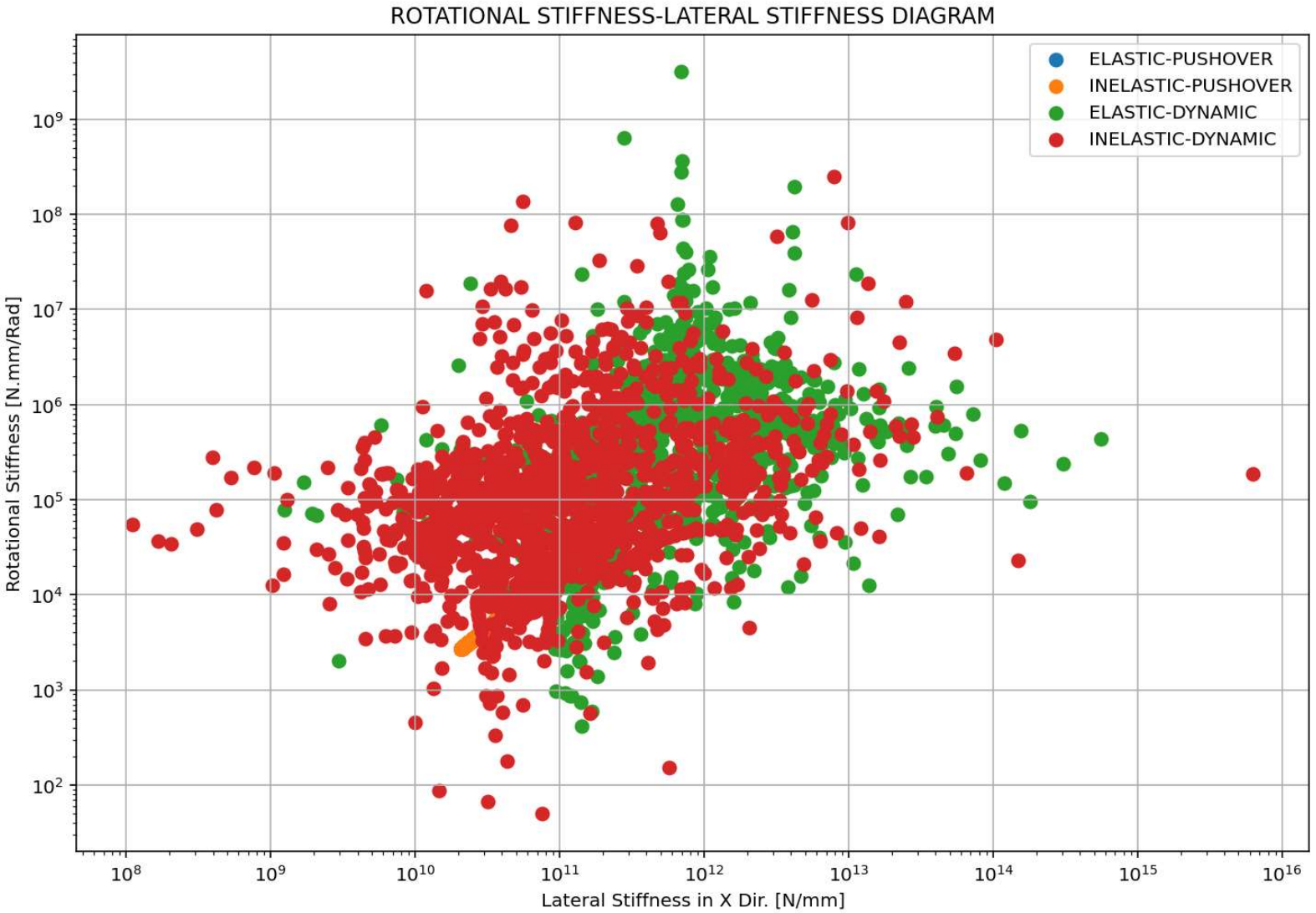

Structure Lateral Drift During the Pushover Analysis
PUSHOVER IN X DIR.: 2.417e+01
PUSHOVER IN X DIR.: 2.279e+01
PUSHOVER IN Y DIR.: 1.515e+00
PUSHOVER IN Y DIR.: 7.779e-01
Lateral Drift [%]
Steps
25
20
15
10
5
0
0
2000
4000
6000
8000
10000
12000
14000

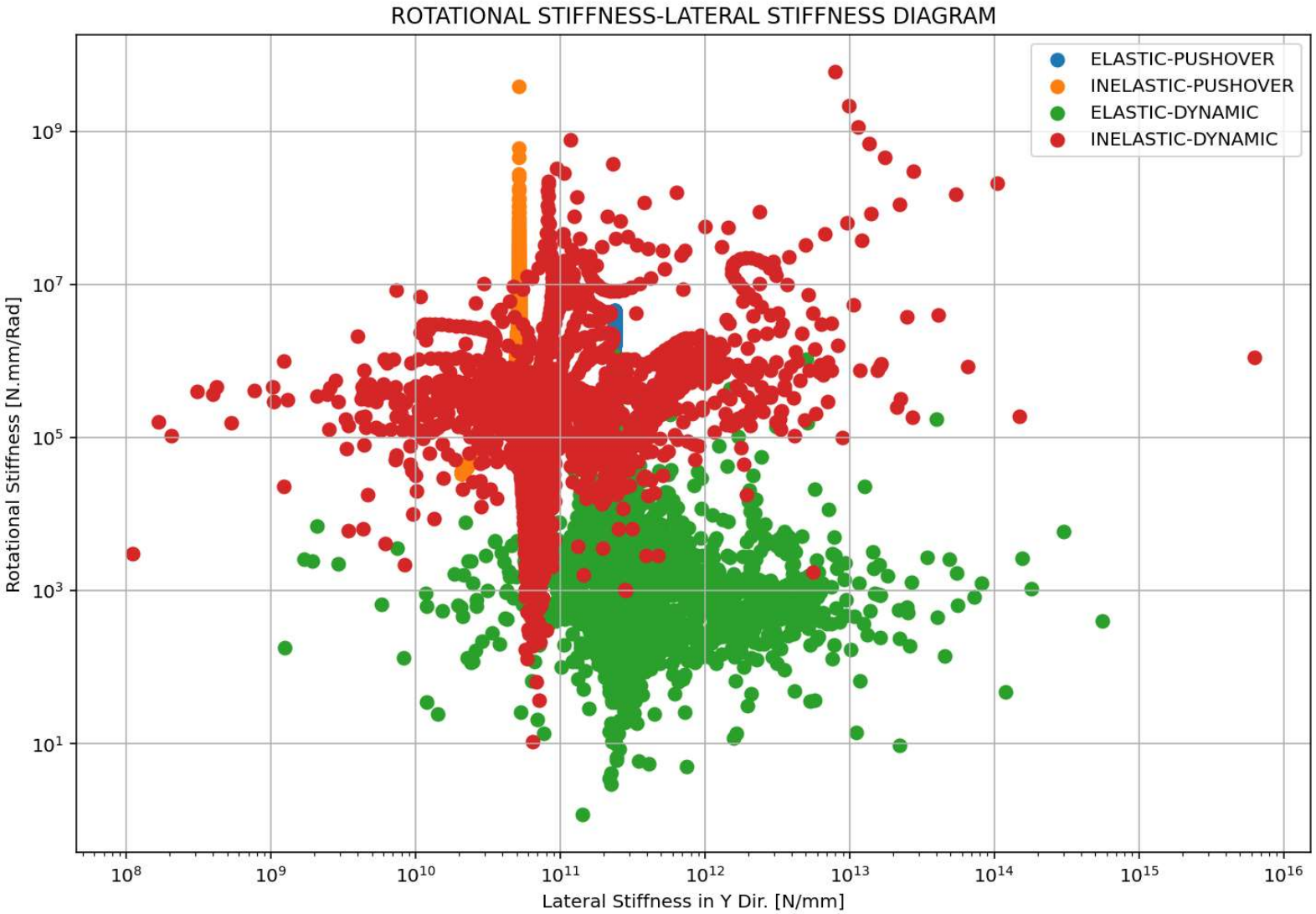

P-M Interaction
1e7
ELASTIC-PUSHOVER
INELASTIC-PUSHOVER
ELASTIC-DYNAMIC
INELASTIC-DYNAMIC
2.5
2.0
1.5
1.0
0.5
0.0
Axial Force [N]
0
1
2
3
4
5
6
7
Bending Moment [N.mm]
1e10

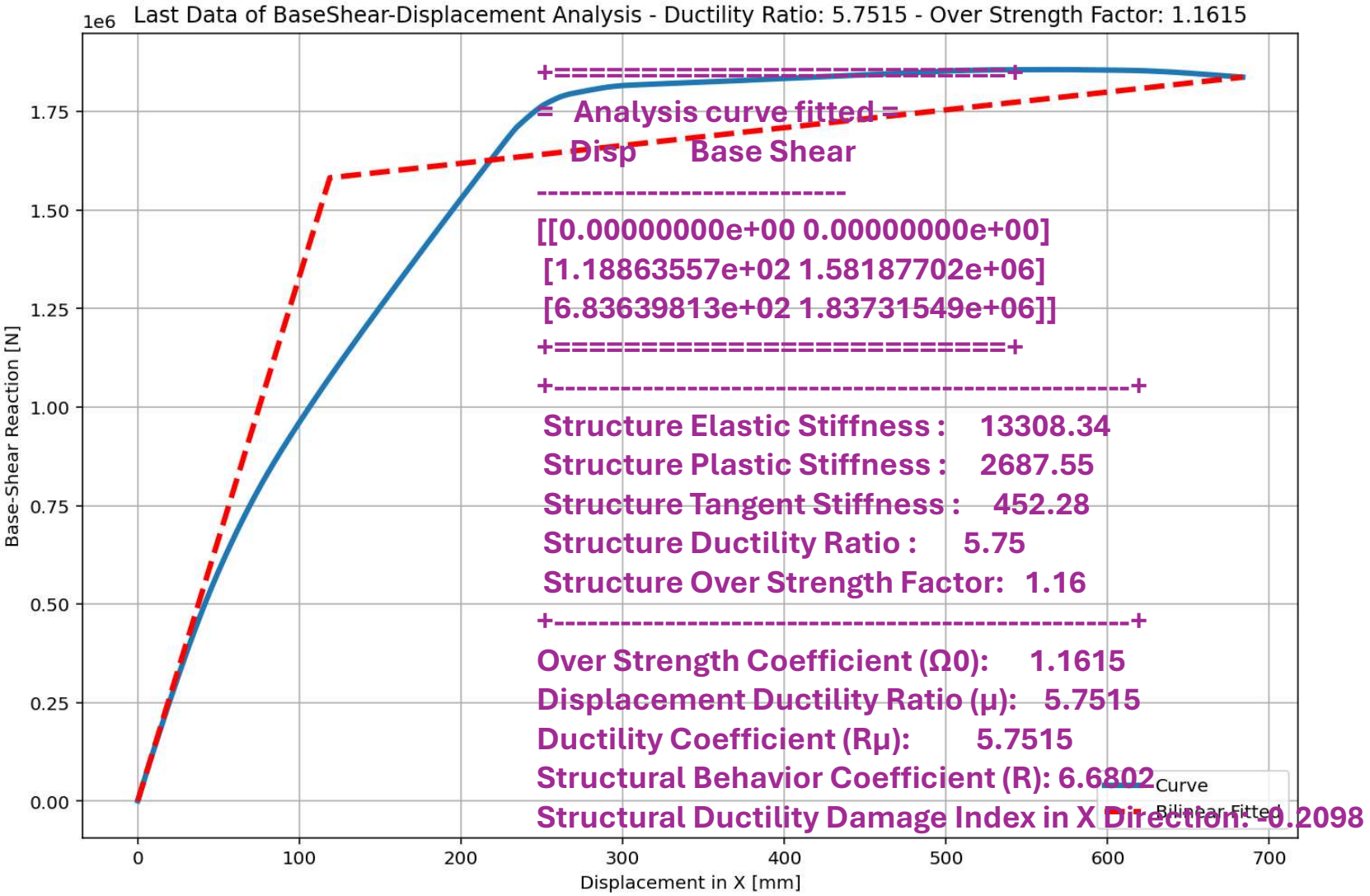

SHEAR FORCE-DISPLACEMENT DIAGRAM
1e7
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
Shear Force [N]
0
100
200
300
400
500
600
700
Displacement in X [mm]
ELASTIC-PUSHOVER
INELASTIC-PUSHOVER
ELASTIC-DYNAMIC
INELASTIC-DYNAMIC


AXIAL FORCE-DISPLACEMENT DIAGRAM
1e7
2.5
2.0
1.5
1.0
0.5
0.0
Axial Force [N]
−100
−80
−60
−40
−20
0
Displacement in Y [mm]
ELASTIC-PUSHOVER
INELASTIC-PUSHOVER
ELASTIC-DYNAMIC
INELASTIC-DYNAMIC

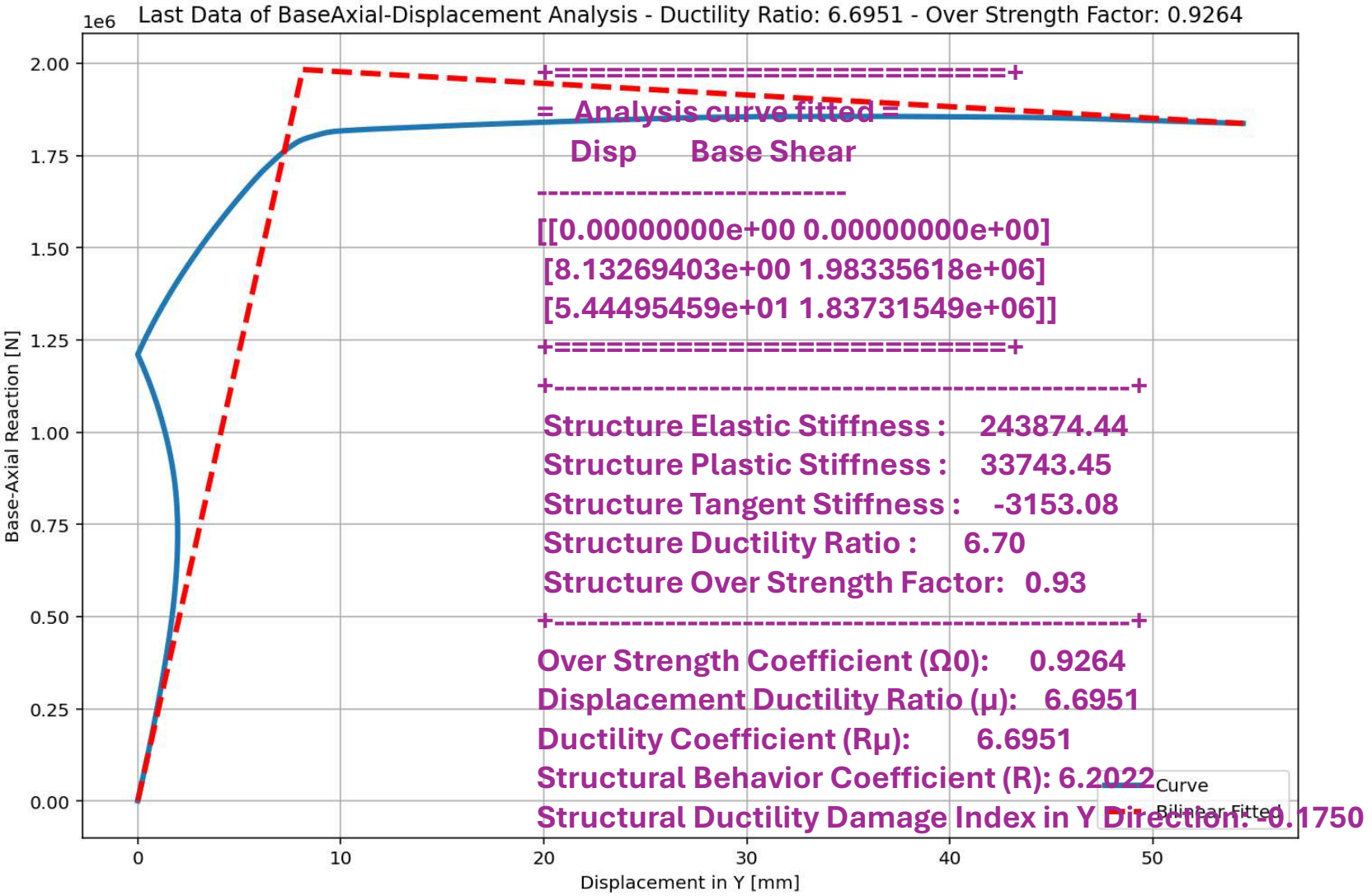

MOMENT-ROTATION DIAGRAM
1e10
ELASTIC-PUSHOVER
INELASTIC-PUSHOVER
ELASTIC-DYNAMIC
INELASTIC-DYNAMIC
Moment [kN.mm]
Rotation [rad]
7
6
5
4
3
2
1
0
−0.30
−0.25
−0.20
−0.15
−0.10
−0.05
0.00


ROTATIONAL STIFFNESS-LATERAL STIFFNESS DIAGRAM
ELASTIC-PUSHOVER
INELASTIC-PUSHOVER
ELASTIC-DYNAMIC
INELASTIC-DYNAMIC
Rotational Stiffness [N.mm/Rad]
Lateral Stiffness in X Dir. [N/mm]
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}


ROTATIONAL STIFFNESS-LATERAL STIFFNESS DIAGRAM
ELASTIC-PUSHOVER
INELASTIC-PUSHOVER
ELASTIC-DYNAMIC
INELASTIC-DYNAMIC
Rotational Stiffness [N.mm/Rad]
Lateral Stiffness in Y Dir. [N/mm]
10^{1}
10^{3}
10^{5}
10^{7}
10^{9}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}

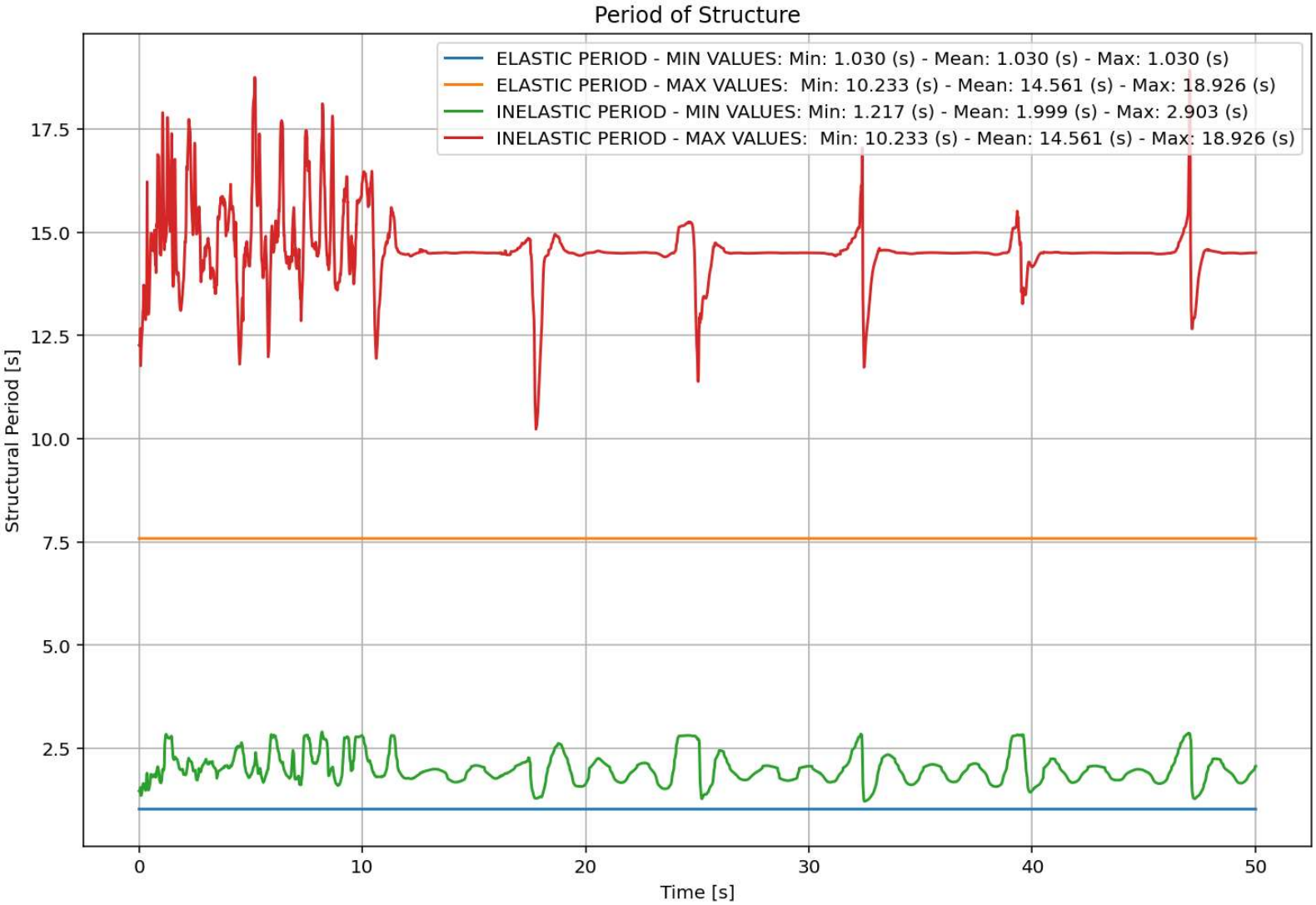

Last Data of BaseShear-Displacement Analysis - Ductility Ratio: 5.7515 - Over Strength Factor: 1.1615
1e6
Base-Shear Reaction [N]
Displacement in X [mm]
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
0
100
200
300
400
500
600
700
+============================+
= Analysis curve fitted =
Disp Base Shear

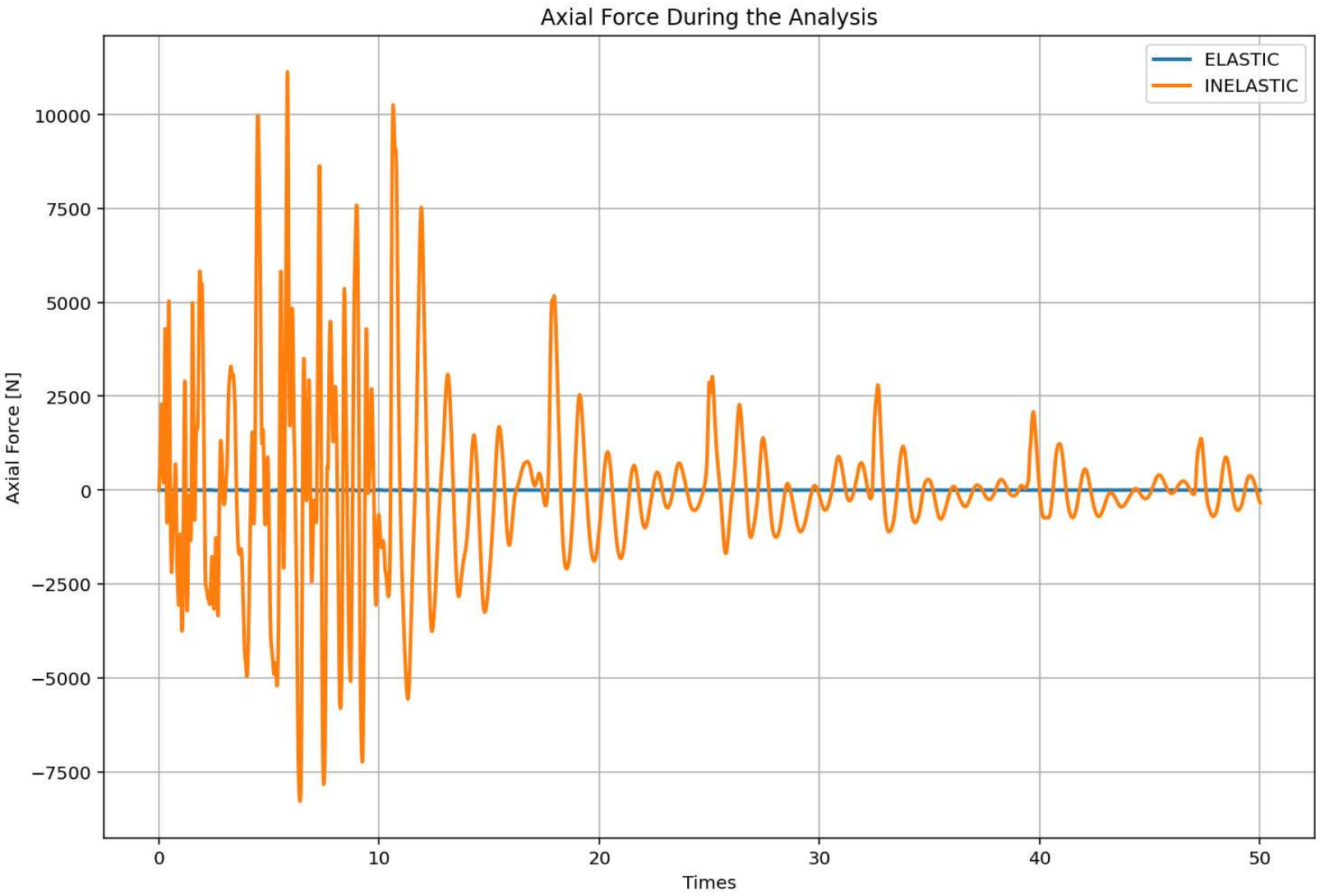
[[0.00000000e+00 0.00000000e+00]
[1.18863557e+02 1.58187702e+06]
[6.83639813e+02 1.83731549e+06]]
+============================+
+--+
Structure Elastic Stiffness : 13308.34
Structure Plastic Stiffness : 2687.55
Structure Tangent Stiffness : 452.28
Structure Ductility Ratio : 5.75
Structure Over Strength Factor: 1.16
+--+
Over Strength Coefficient (Ω0): 1.1615
Displacement Ductility Ratio (μ): 5.7515
Ductility Coefficient (Rμ): 5.7515
Structural Behavior Coefficient (R): 6.6802
Structural Ductility Damage Index in X Direction: -0.2098
Curve
Bilinear Fitted

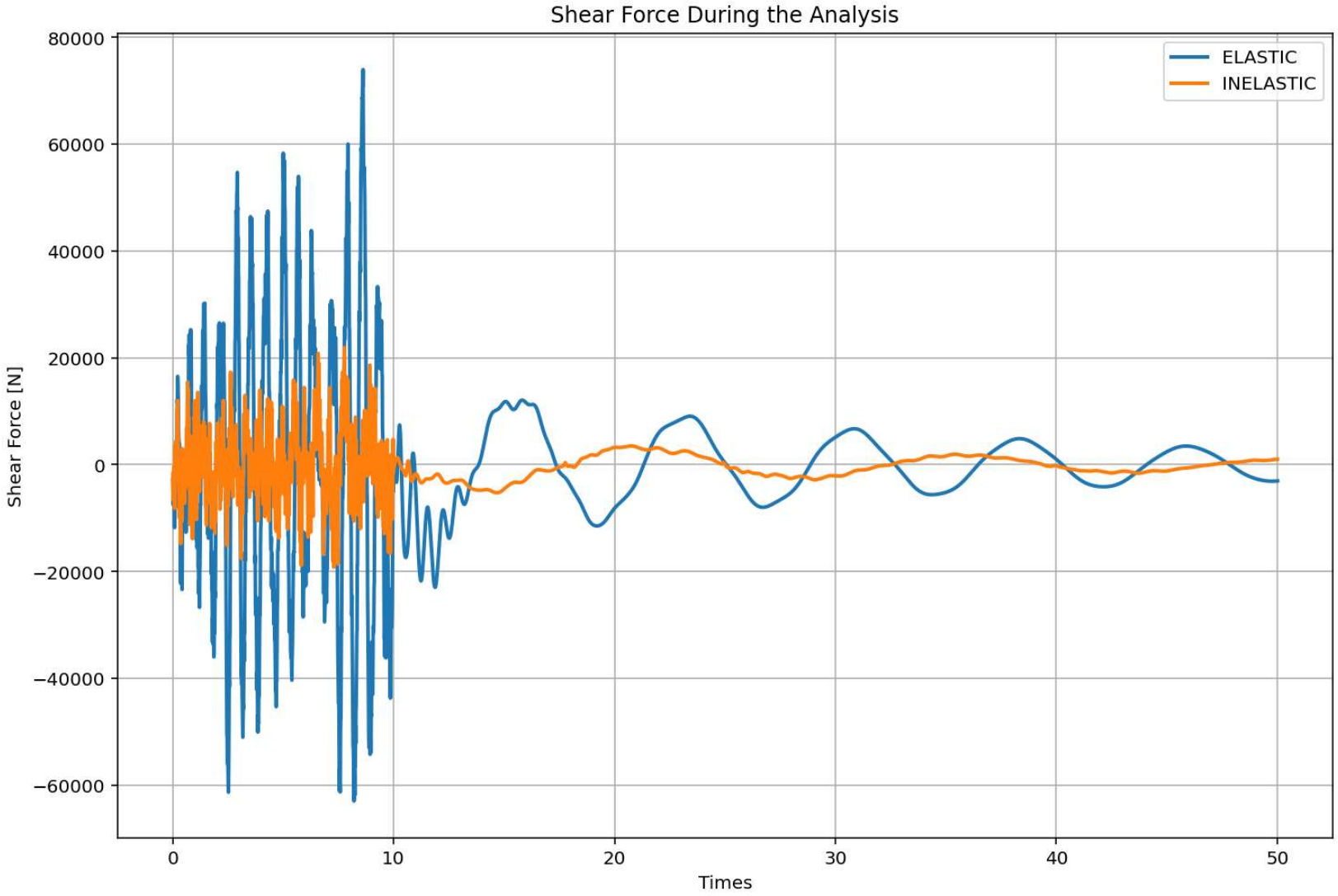

Last Data of BaseAxial-Displacement Analysis - Ductility Ratio: 6.6951 - Over Strength Factor: 0.9264
1e6
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Base-Axial Reaction [N]
0
10
20
30
40
50
Displacement in Y [mm]
+============================+
= Analysis curve fitted =
Disp Base Shear

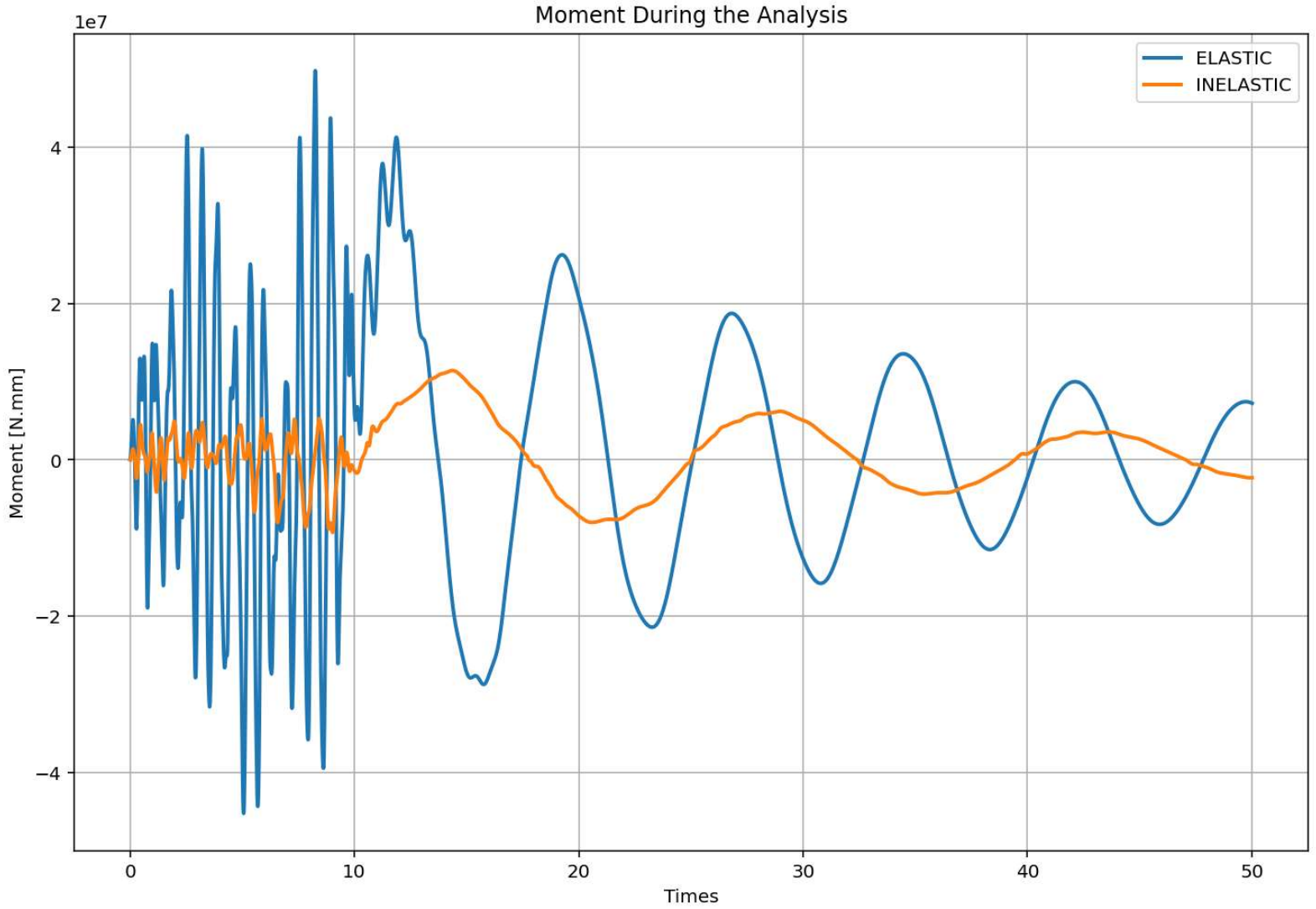
[[0.00000000e+00 0.00000000e+00]
[8.13269403e+00 1.98335618e+06]
[5.44495459e+01 1.83731549e+06]]
+============================+
+--+
Structure Elastic Stiffness : 243874.44
Structure Plastic Stiffness : 33743.45
Structure Tangent Stiffness : -3153.08
Structure Ductility Ratio : 6.70
Structure Over Strength Factor: 0.93
+--+
Over Strength Coefficient (Ω0): 0.9264
Displacement Ductility Ratio (μ): 6.6951
Ductility Coefficient (Rμ): 6.6951
Structural Behavior Coefficient (R): 6.2022
Structural Ductility Damage Index in Y Direction: -0.1750
Curve
Bilinear Fitted

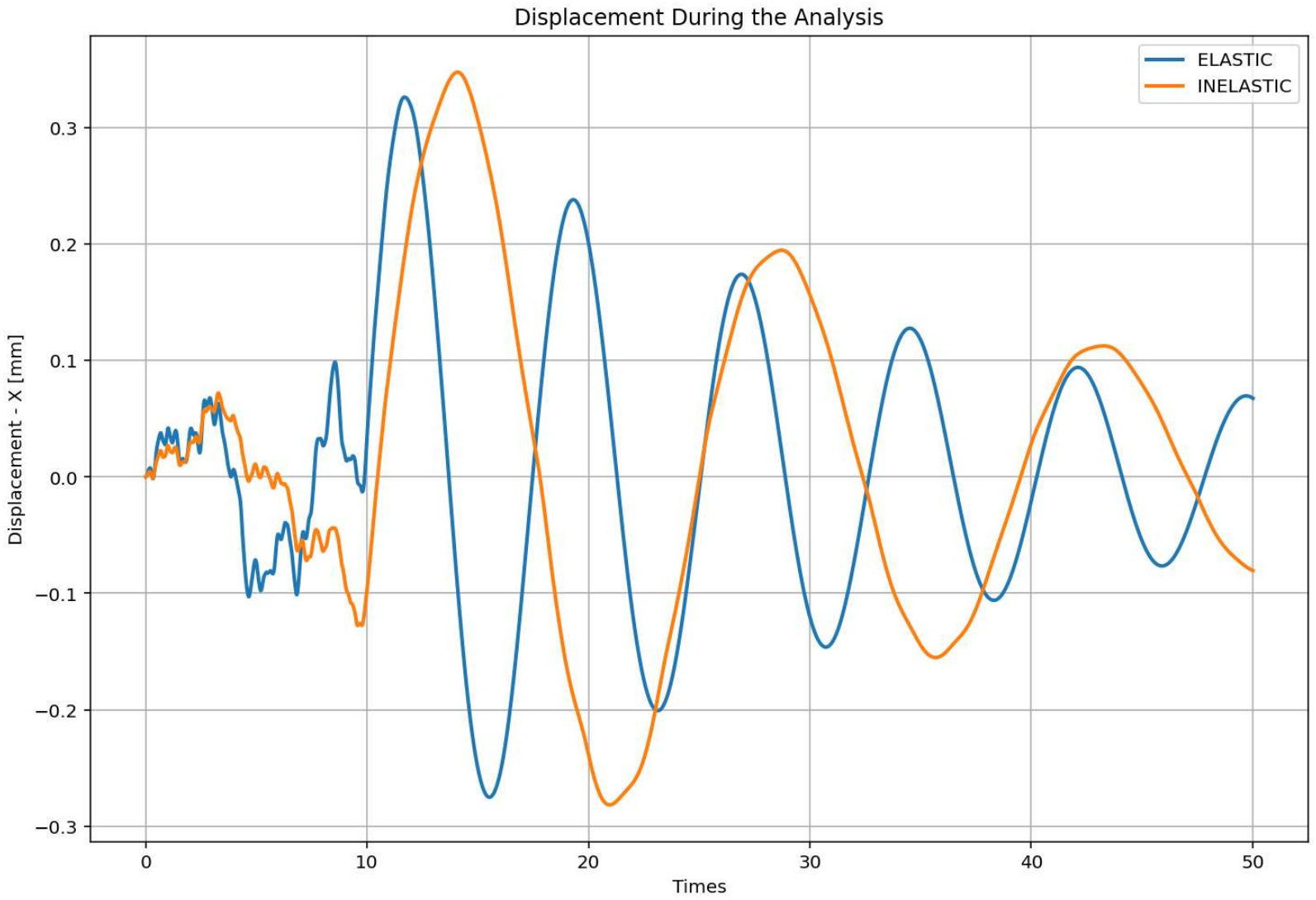
ELASTIC AND INELASTIC DYNAMIC ANALYSIS

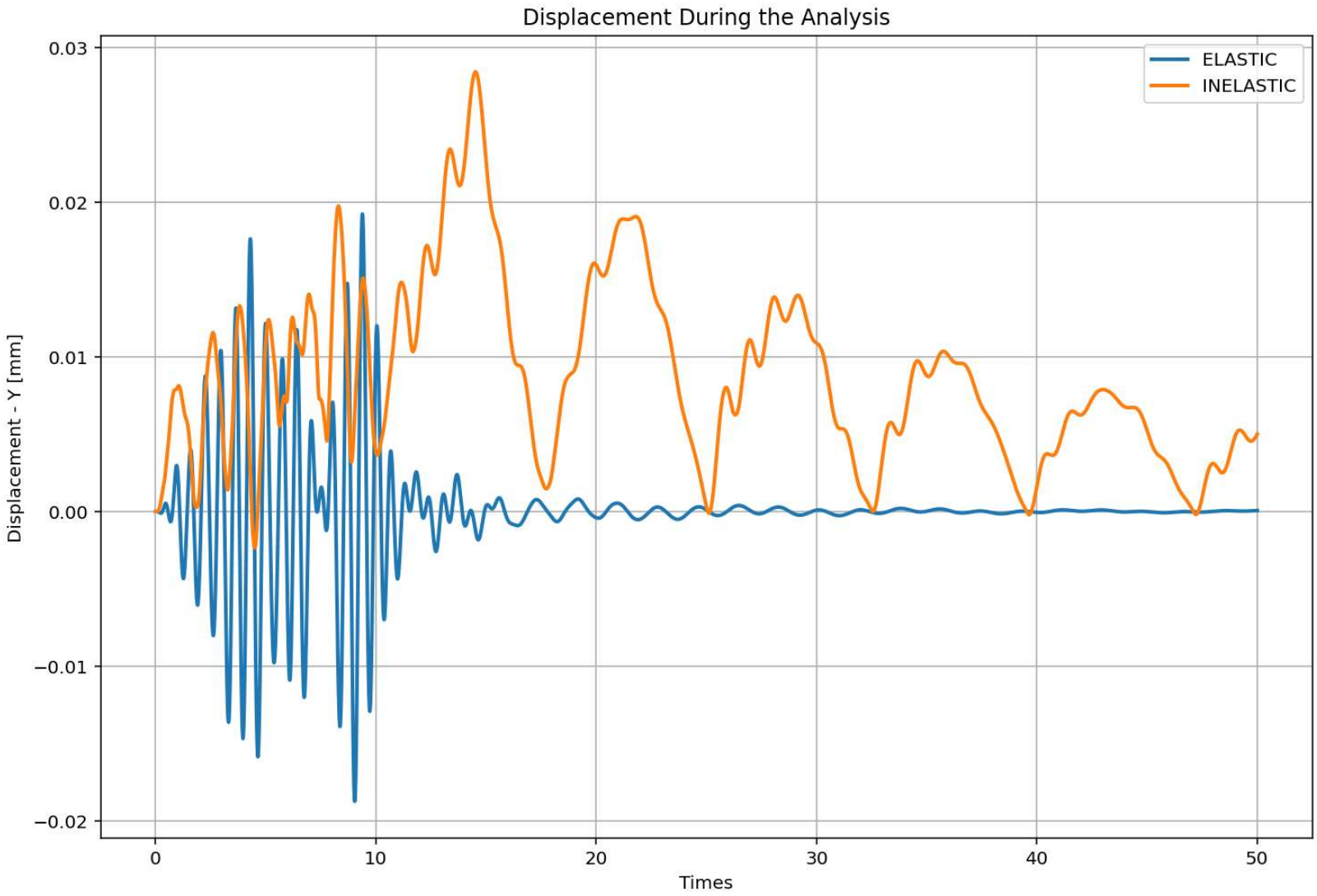

Period of Structure
ELASTIC PERIOD - MIN VALUES: Min: 1.030 (s) - Mean: 1.030 (s) - Max: 1.030 (s)
ELASTIC PERIOD - MAX VALUES: Min: 10.233 (s) - Mean: 14.561 (s) - Max: 18.926 (s)
INELASTIC PERIOD - MIN VALUES: Min: 1.217 (s) - Mean: 1.999 (s) - Max: 2.903 (s)
INELASTIC PERIOD - MAX VALUES: Min: 10.233 (s) - Mean: 14.561 (s) - Max: 18.926 (s)
Structural Period [s]
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0
10
20
30
40
50
Time [s]

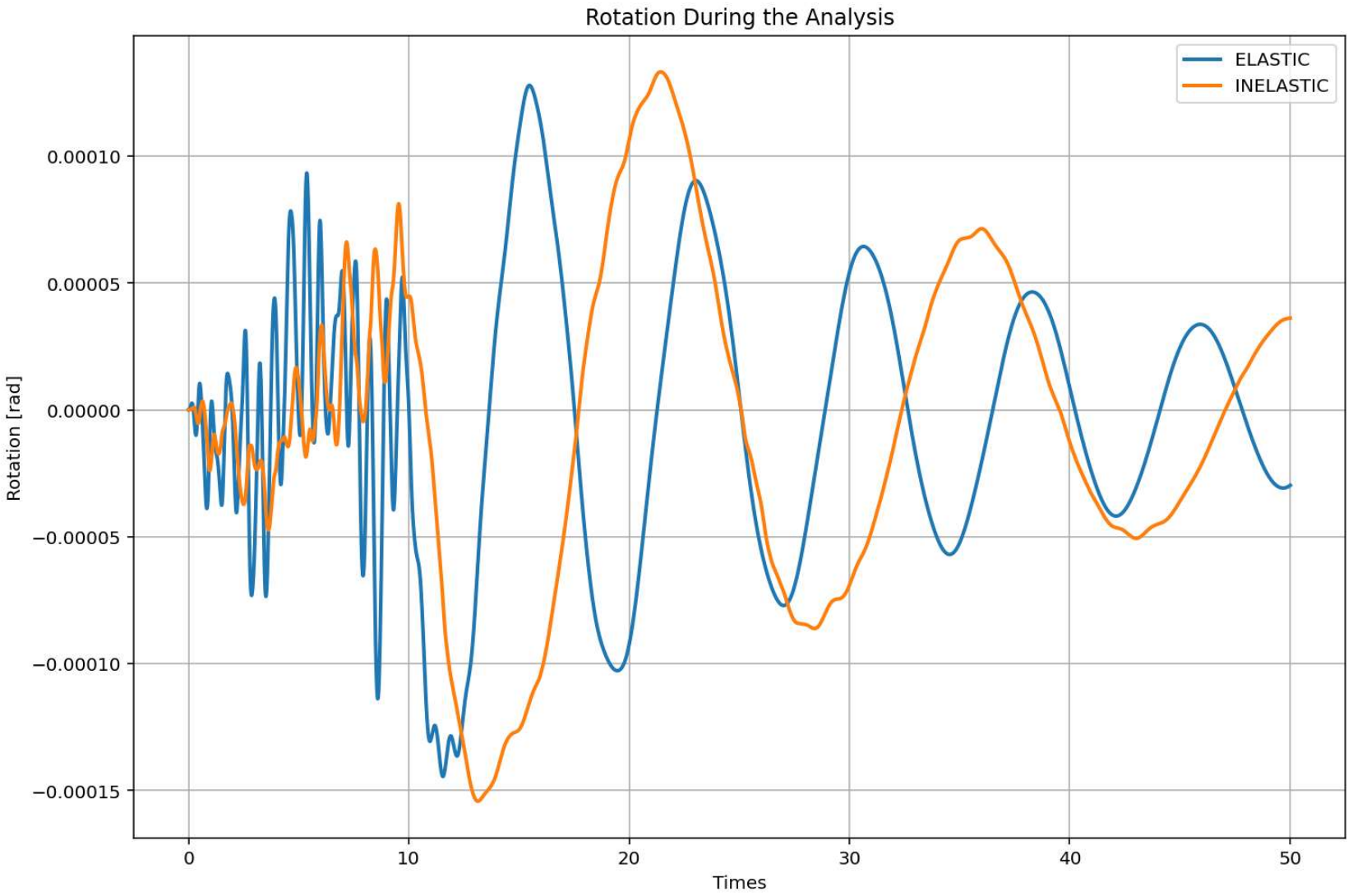

Axial Force During the Analysis
ELASTIC
INELASTIC
Axial Force [N]
10000
7500
5000
2500
0
−2500
−5000
−7500
0
10
20
30
40
50
Times

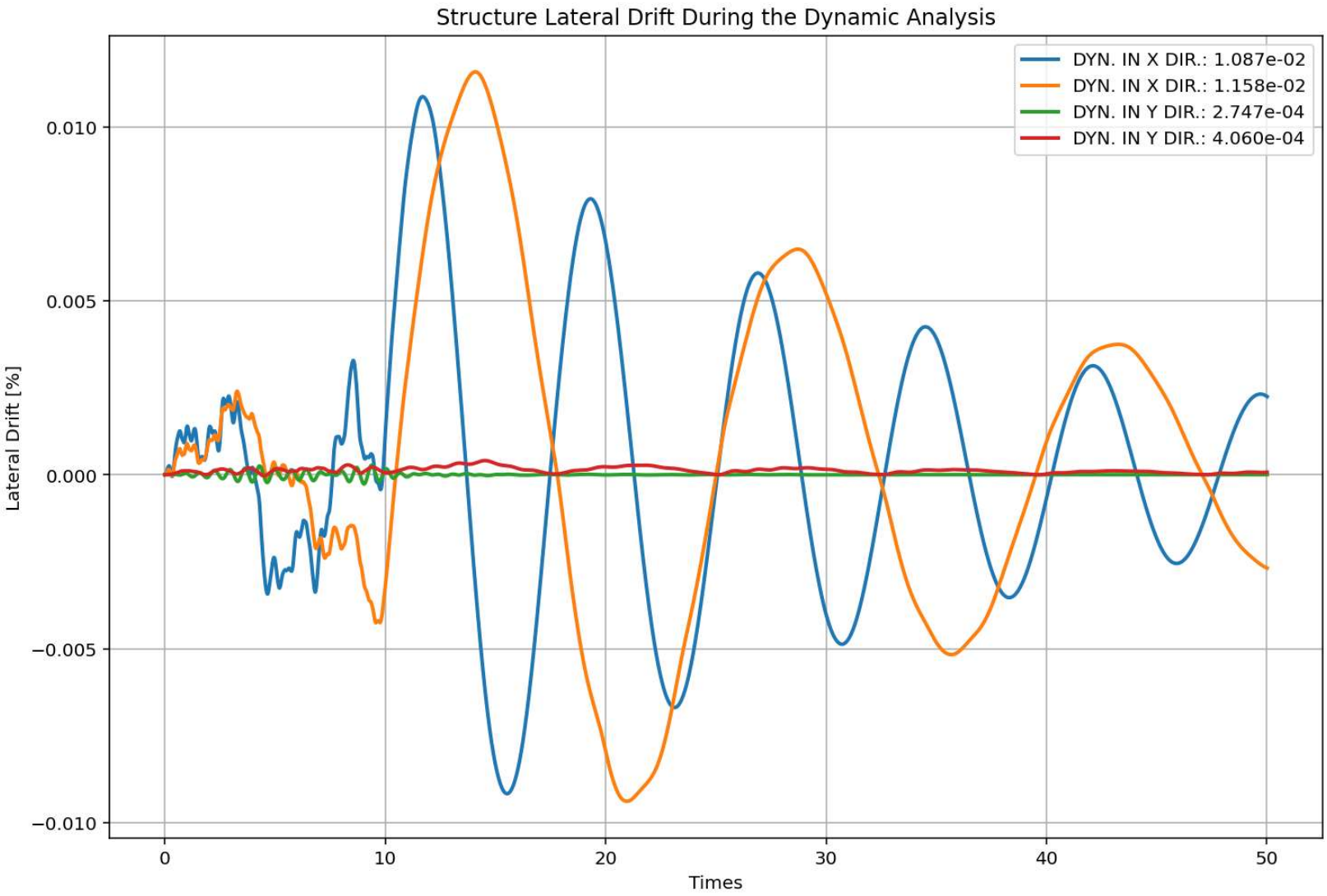

Shear Force During the Analysis
ELASTIC
INELASTIC
Shear Force [N]
80000
60000
40000
20000
0
−20000
−40000
−60000
0
10
20
30
40
50
Times

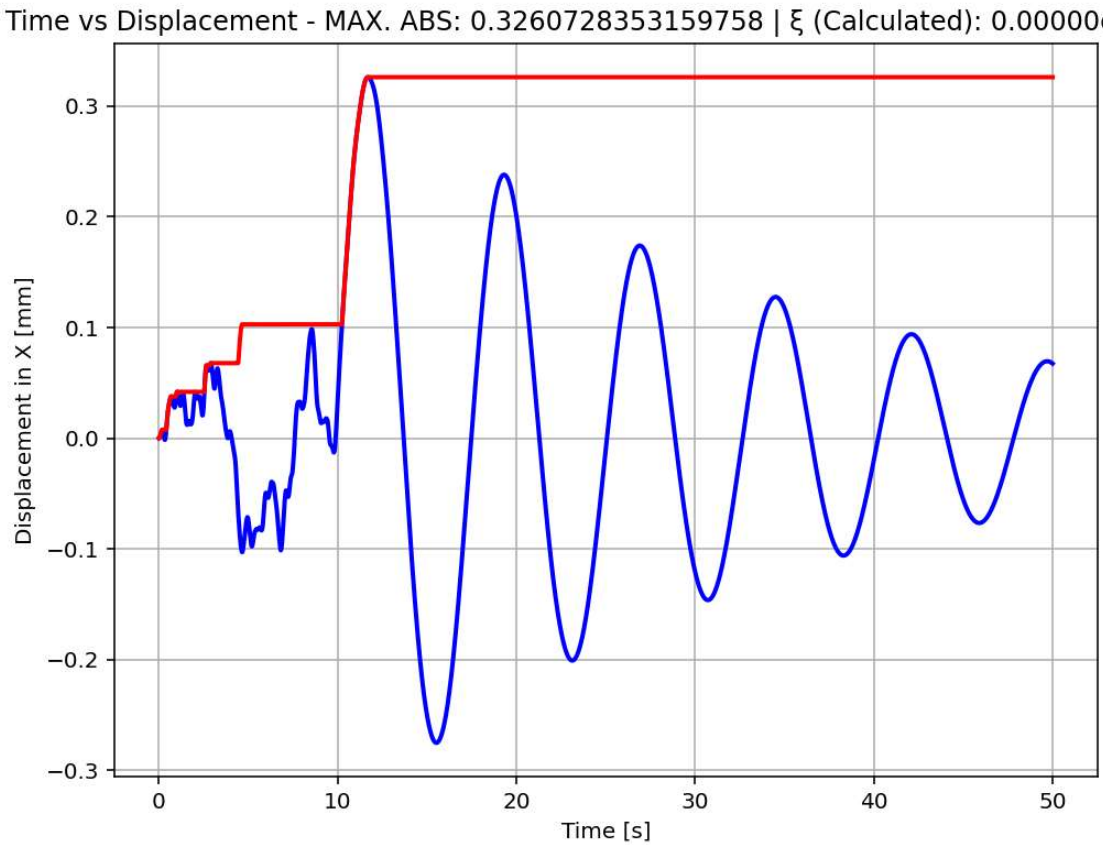

Moment During the Analysis
1e7
ELASTIC
INELASTIC
Moment [N.mm]
4
2
0
−2
−4
0
10
20
30
40
50
Times

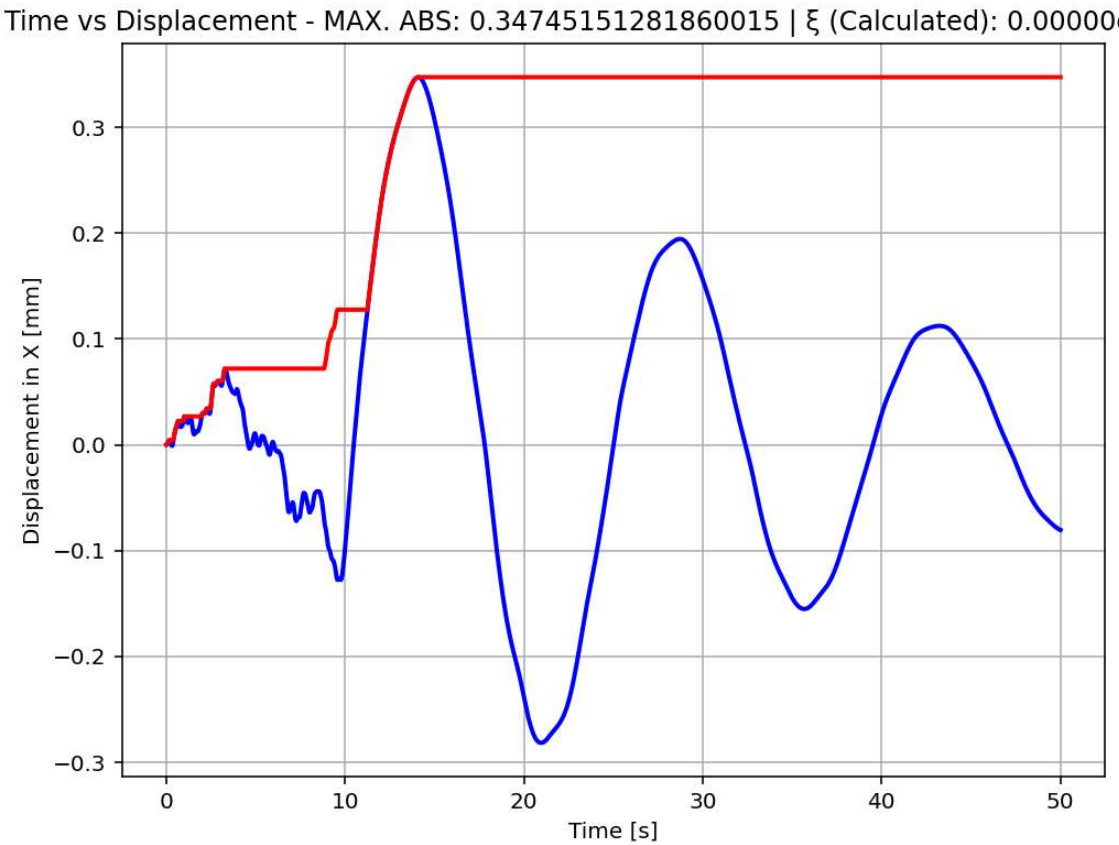

Displacement During the Analysis
ELASTIC
INELASTIC
Displacement - X [mm]
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
10
20
30
40
50
Times

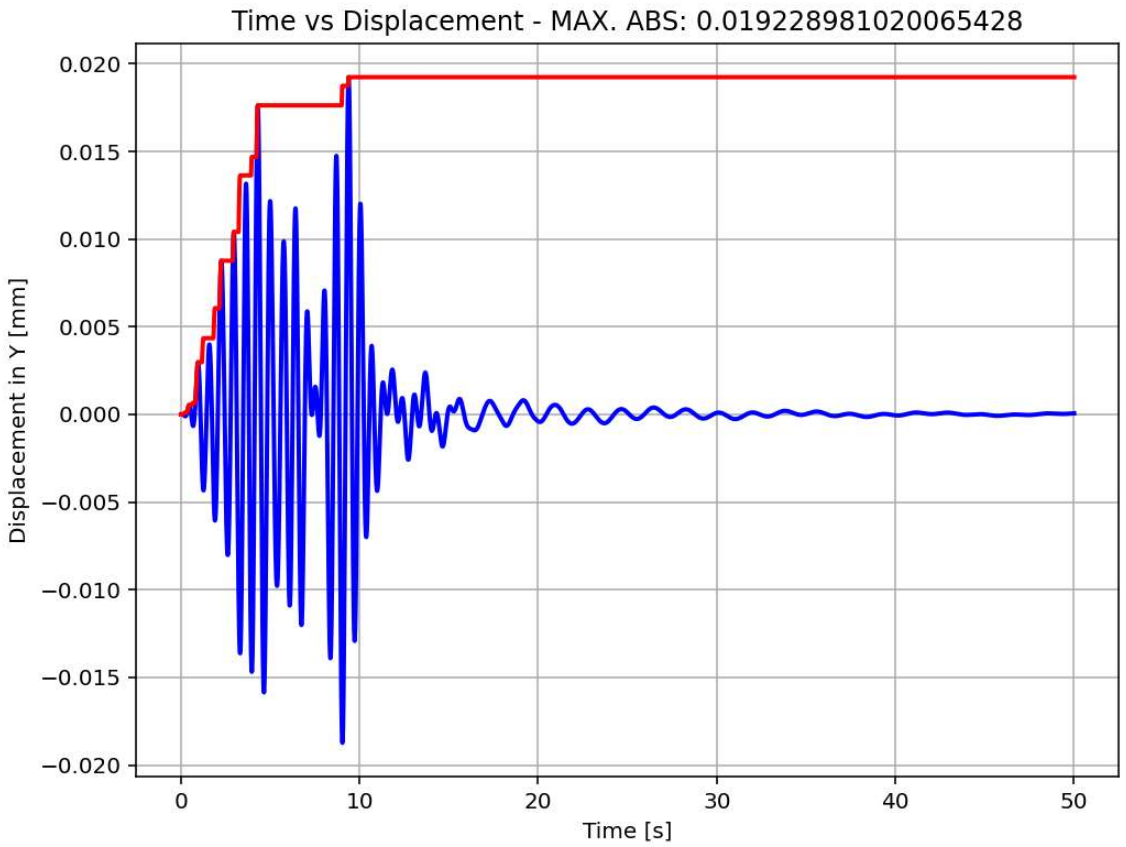

Displacement During the Analysis
ELASTIC
INELASTIC
Displacement - Y [mm]
0.03
0.02
0.01
0.00
−0.01
−0.02
0
10
20
30
40
50
Times

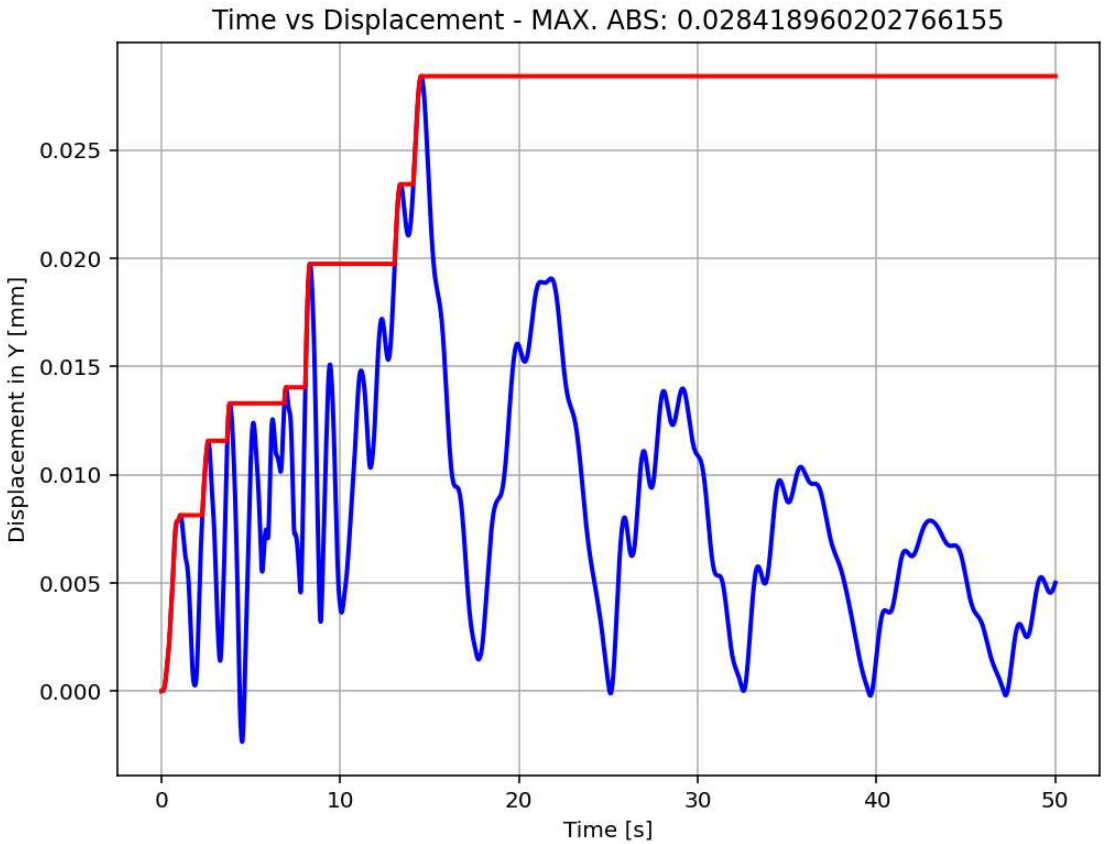

Rotation During the Analysis
ELASTIC
INELASTIC
0.00010
0.00005
0.00000
−0.00005
−0.00010
−0.00015
Rotation [rad]
0
10
20
30
40
50
Times

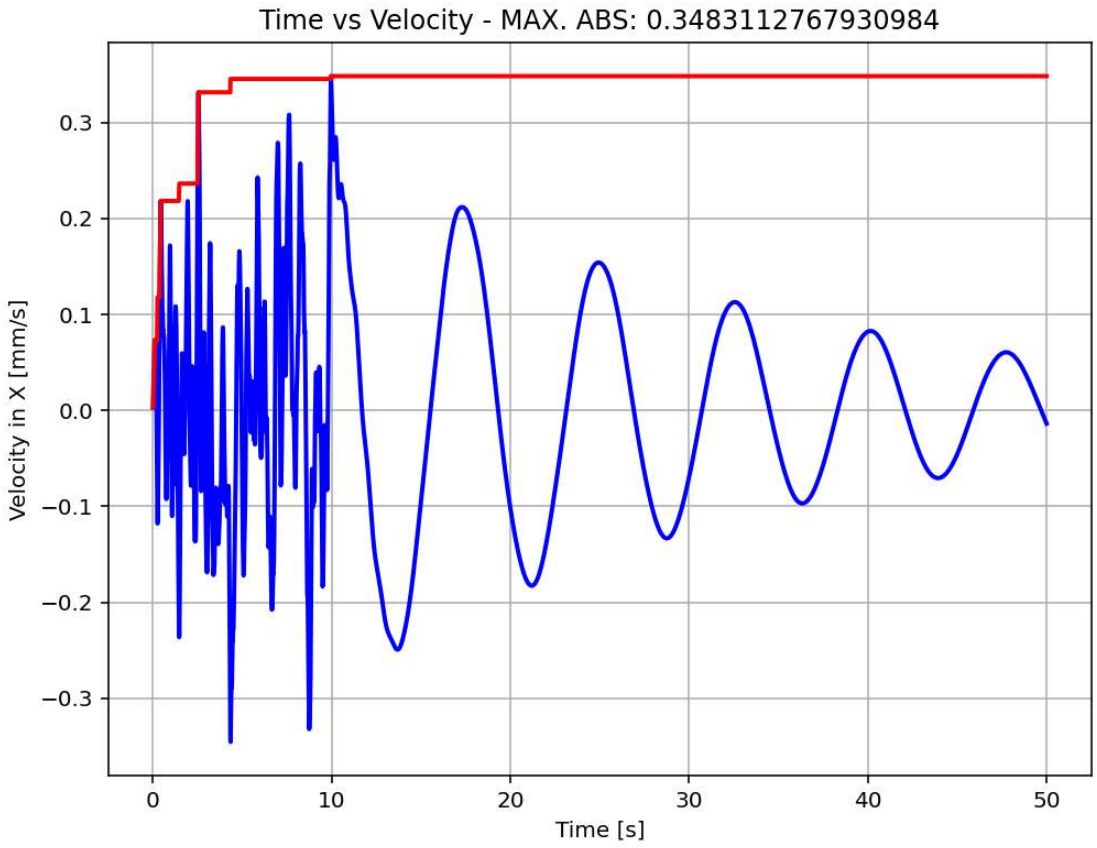

Structure Lateral Drift During the Dynamic Analysis
DYN. IN X DIR.: 1.087e-02
DYN. IN X DIR.: 1.158e-02
DYN. IN Y DIR.: 2.747e-04
DYN. IN Y DIR.: 4.060e-04
Lateral Drift [%]
0.010
0.005
0.000
−0.005
−0.010
0
10
20
30
40
50
Times

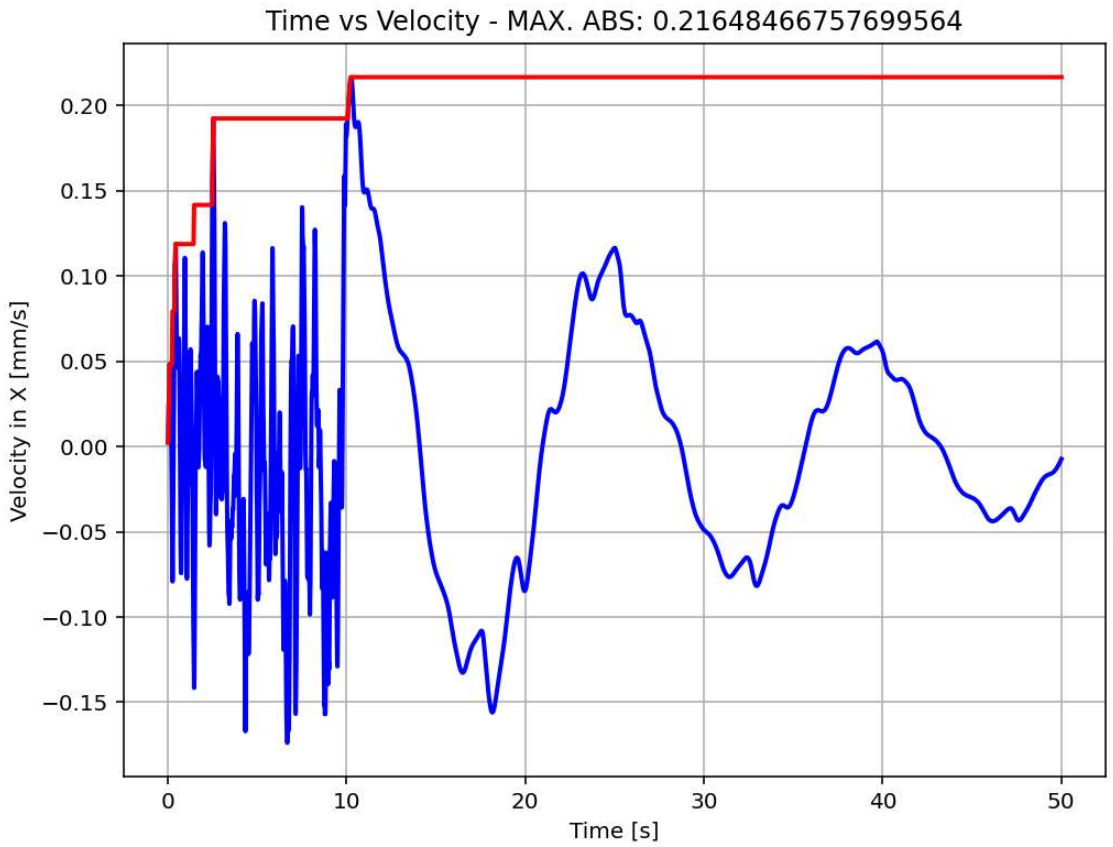

Time vs Displacement - MAX. ABS: 0.3260728353159758 | ξ (Calculated): 0.00000e+00 %
Displacement in X [mm]
Time [s]
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
10
20
30
40
50

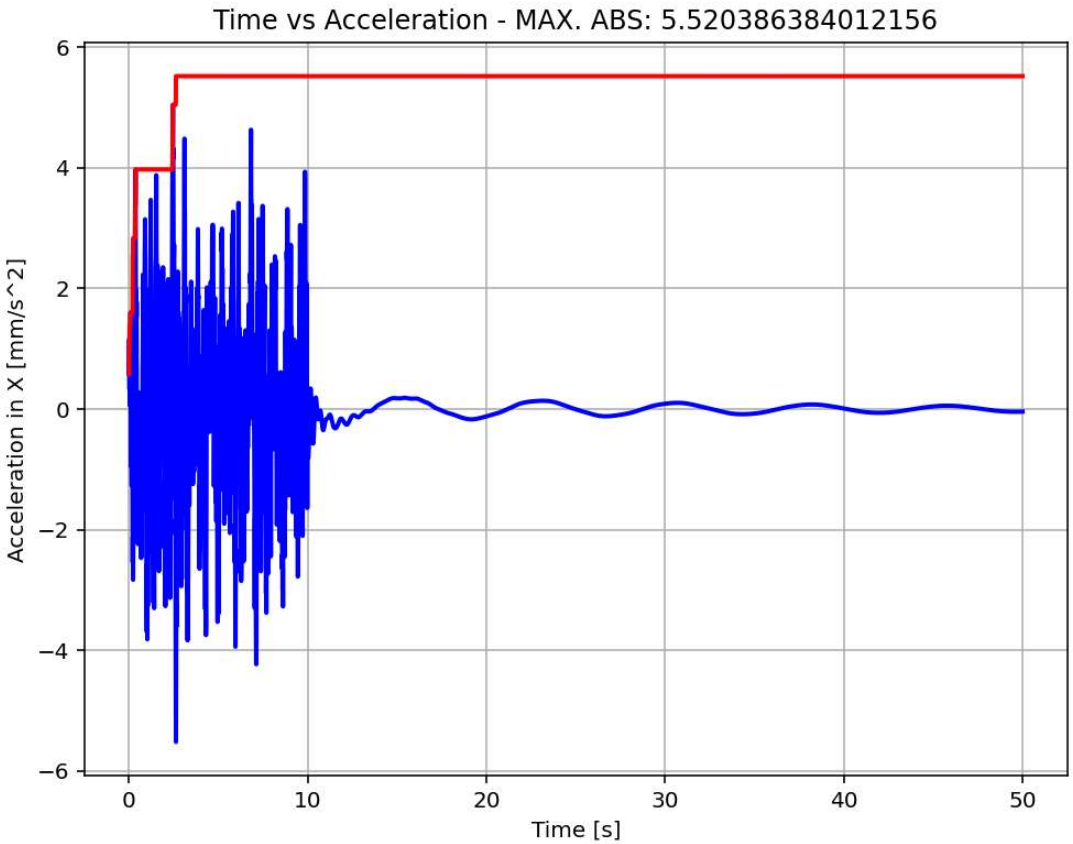

Time vs Displacement - MAX. ABS: 0.34745151281860015 | ξ (Calculated): 0.00000e+00 %
Displacement in X [mm]
Time [s]
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
10
20
30
40
50

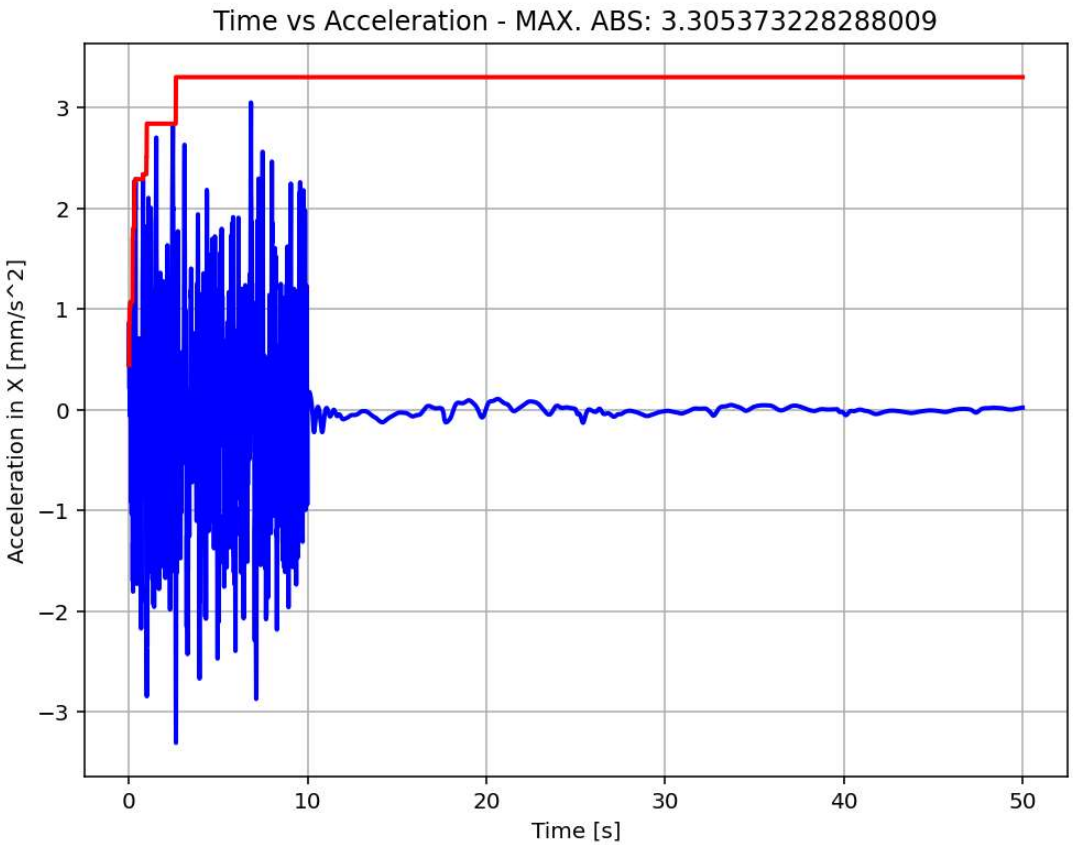

Time vs Displacement - MAX. ABS: 0.019228981020065428
Displacement in Y [mm]
Time [s]
0.020
0.015
0.010
0.005
0.000
−0.005
−0.010
−0.015
−0.020
0
10
20
30
40
50

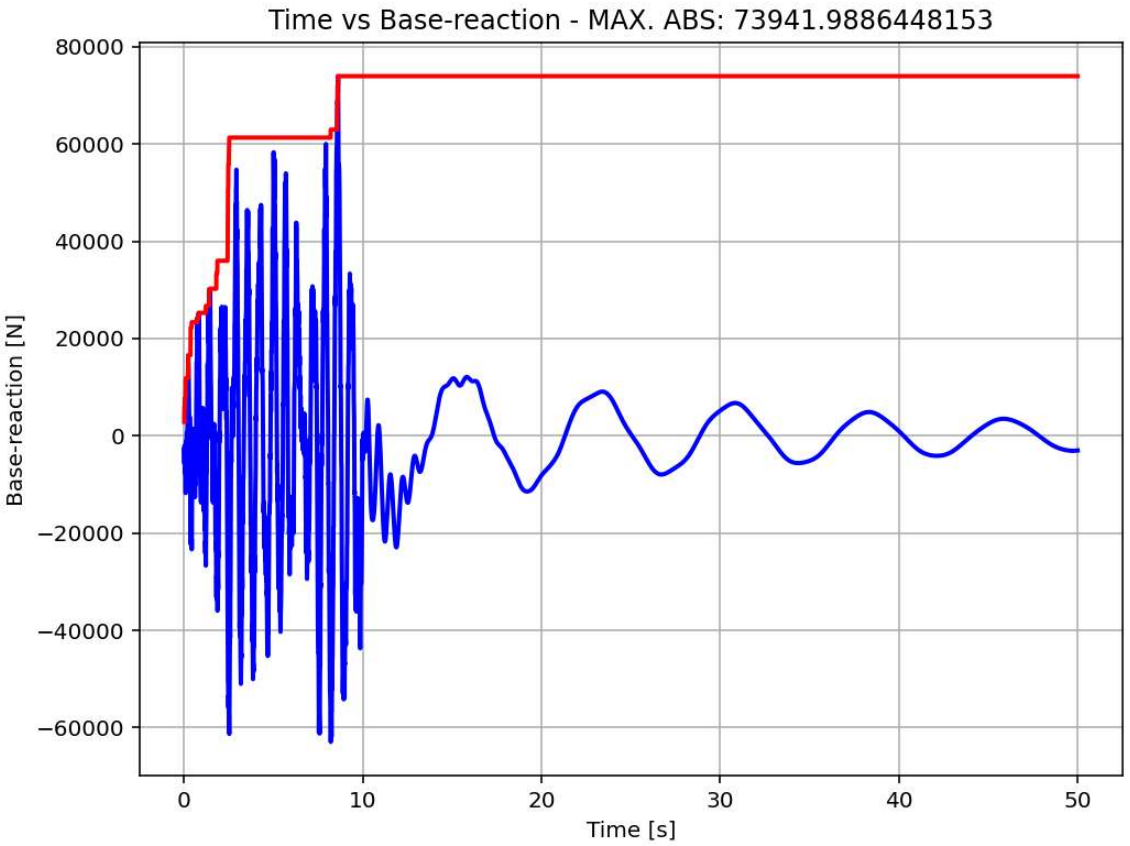

Time vs Displacement - MAX. ABS: 0.028418960202766155
Displacement in Y [mm]
0.025
0.020
0.015
0.010
0.005
0.000
0
10
20
30
40
50
Time [s]

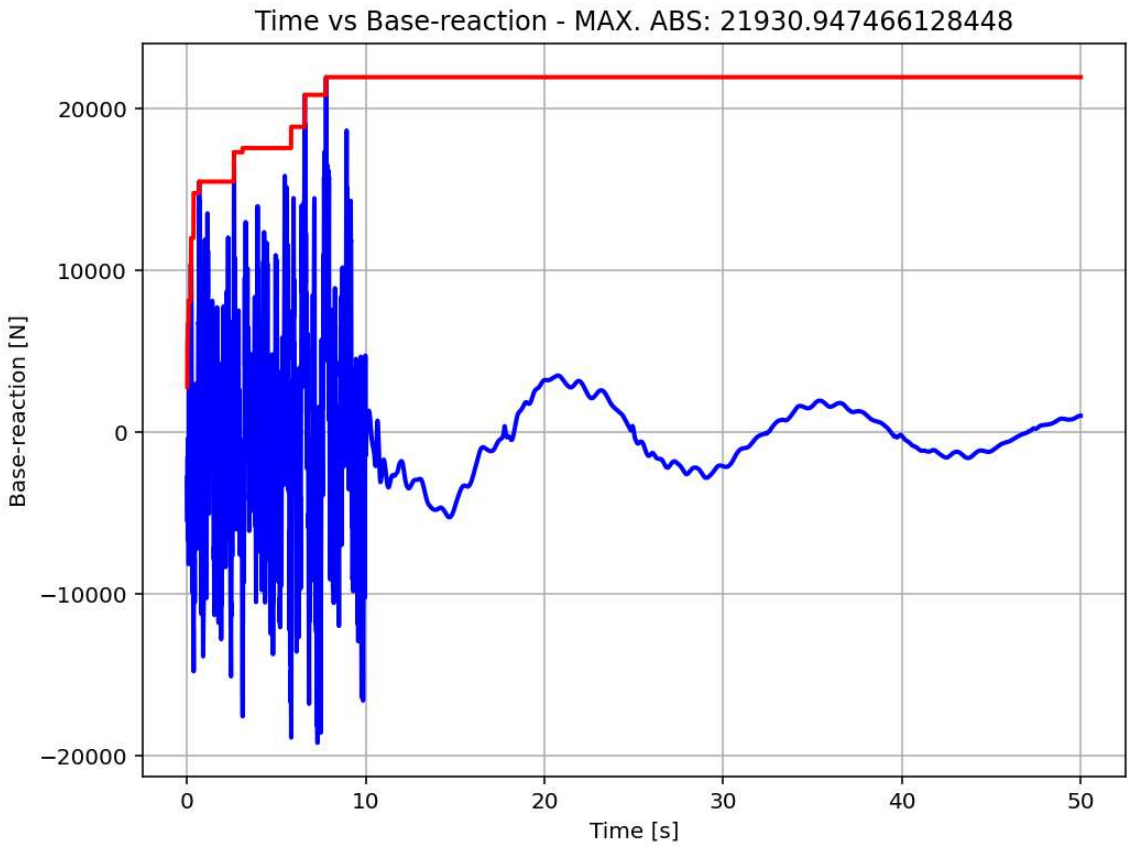

Time vs Velocity - MAX. ABS: 0.3483112767930984
Velocity in X [mm/s]
Time [s]
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
10
20
30
40
50

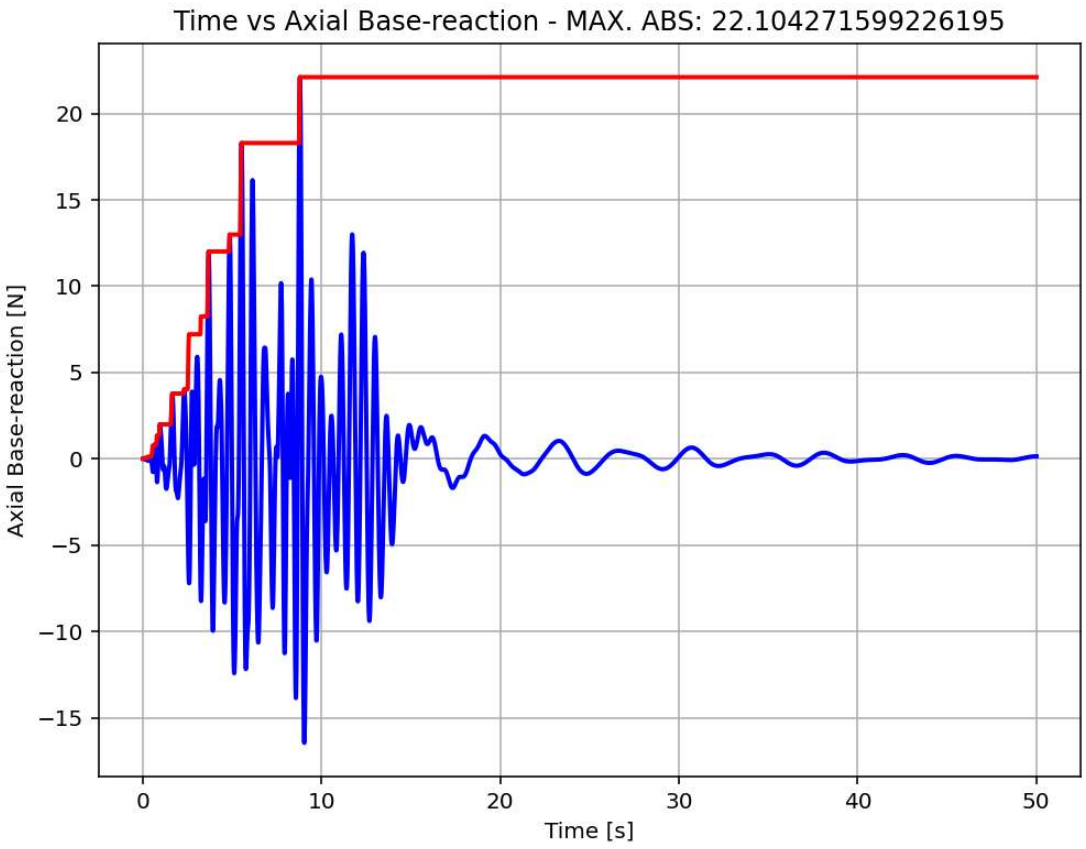

Time vs Velocity - MAX. ABS: 0.21648466757699564
Velocity in X [mm/s]
Time [s]
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
10
20
30
40
50

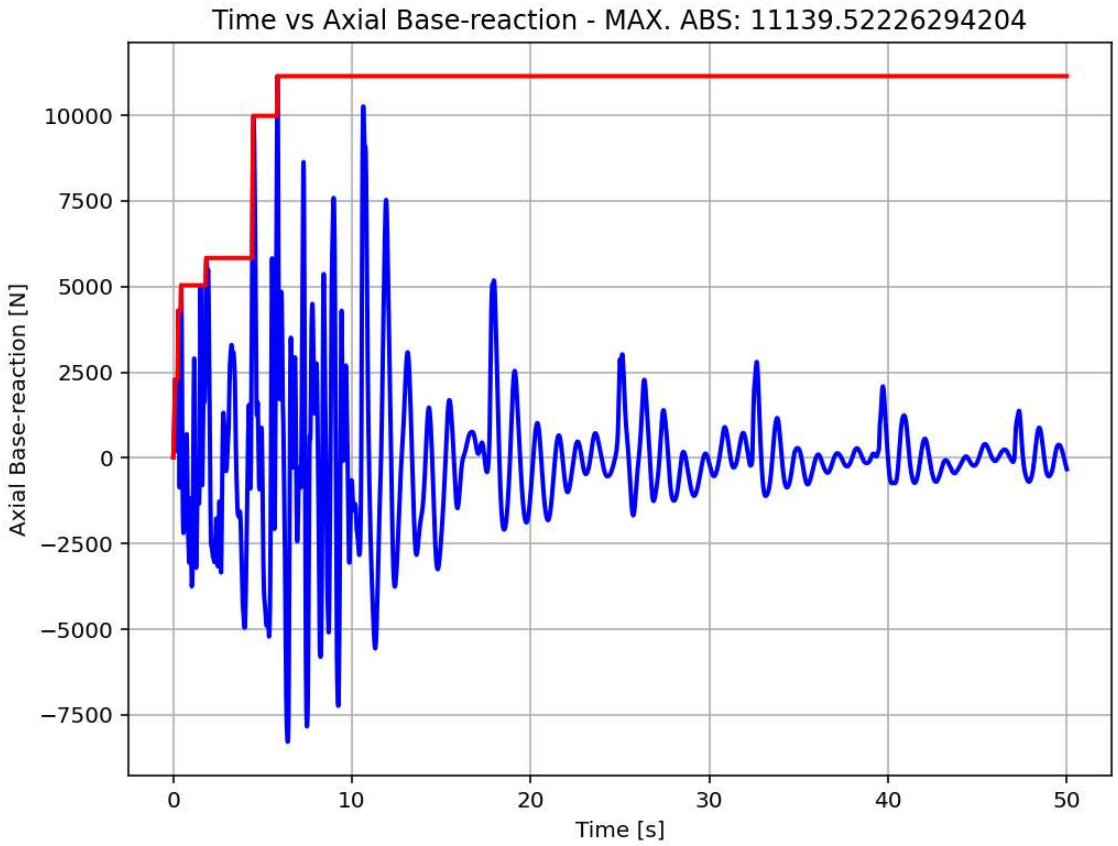

Time vs Acceleration - MAX. ABS: 5.520386384012156
Acceleration in X [mm/s^2]
Time [s]
6
4
2
0
−2
−4
−6
0
10
20
30
40
50

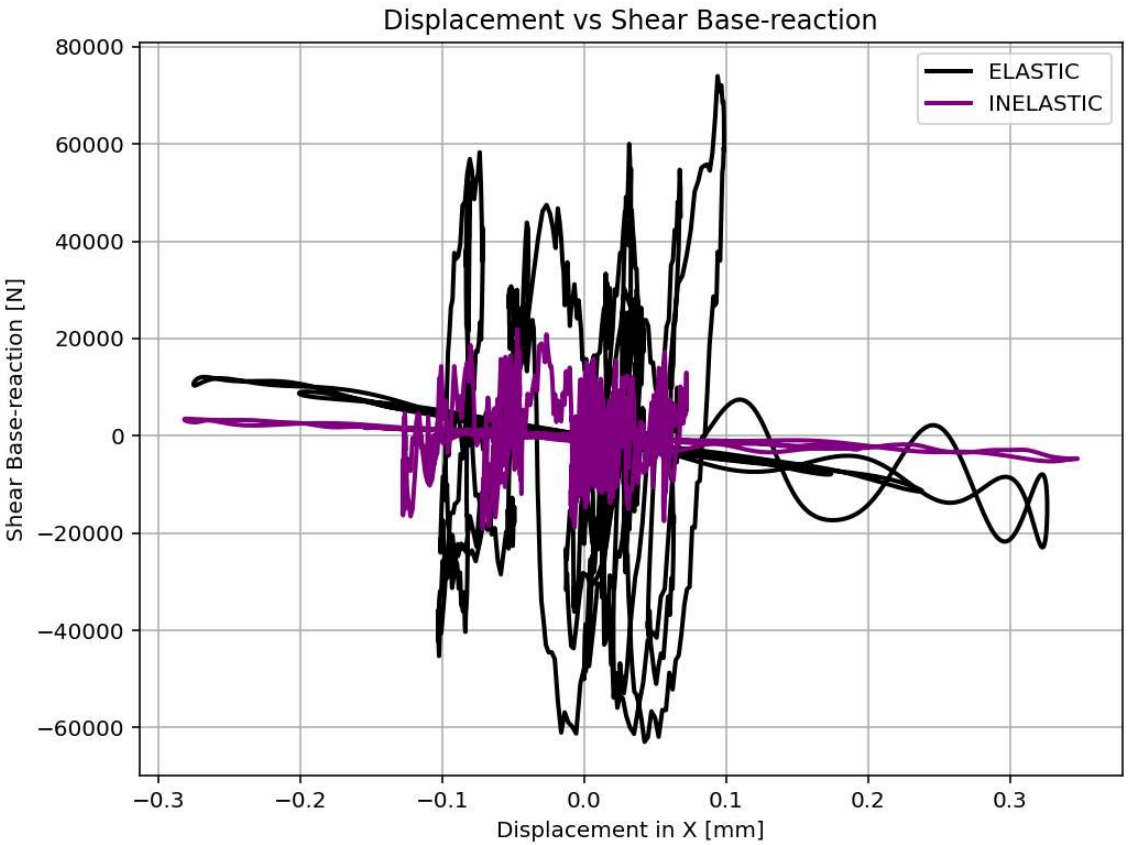

Time vs Acceleration - MAX. ABS: 3.305373228288009
Acceleration in X [mm/s^2]
Time [s]
3
2
1
0
−1
−2
−3
0
10
20
30
40
50

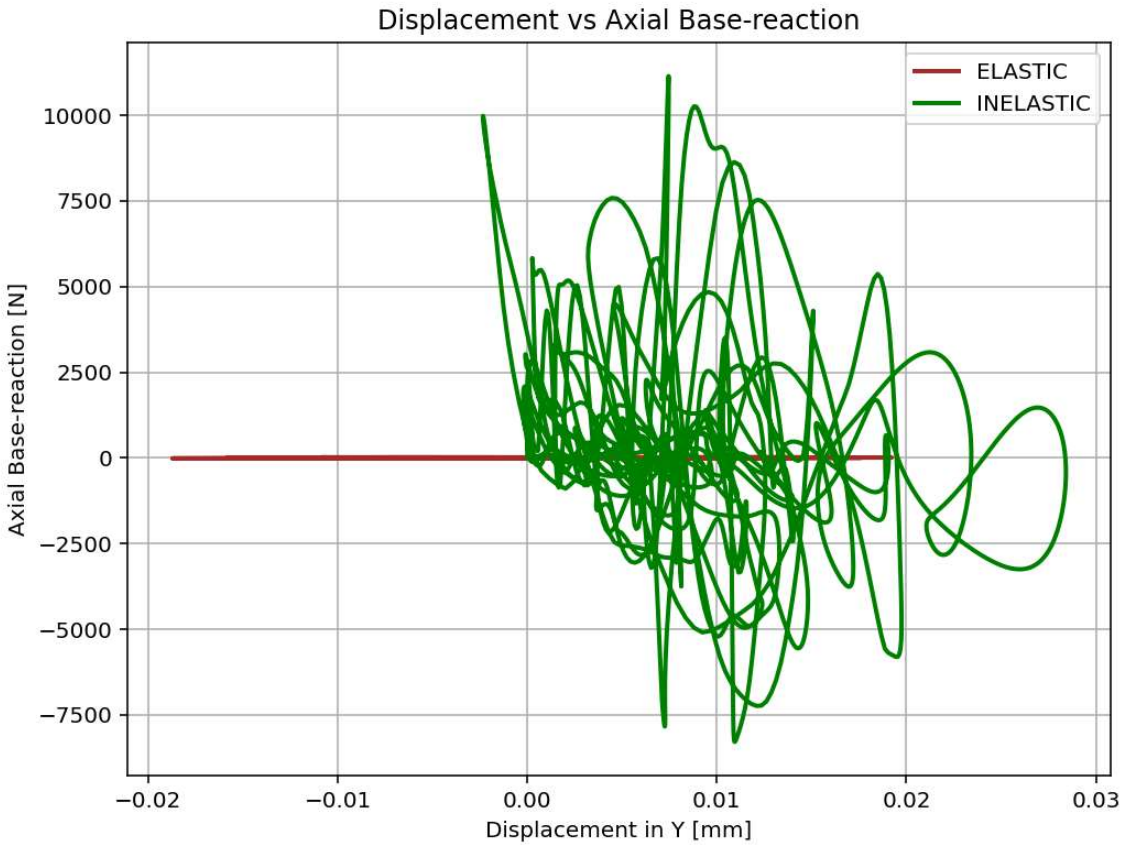

Time vs Base-reaction - MAX. ABS: 73941.9886448153
Base-reaction [N]
Time [s]
80000
60000
40000
20000
0
−20000
−40000
−60000
0
10
20
30
40
50

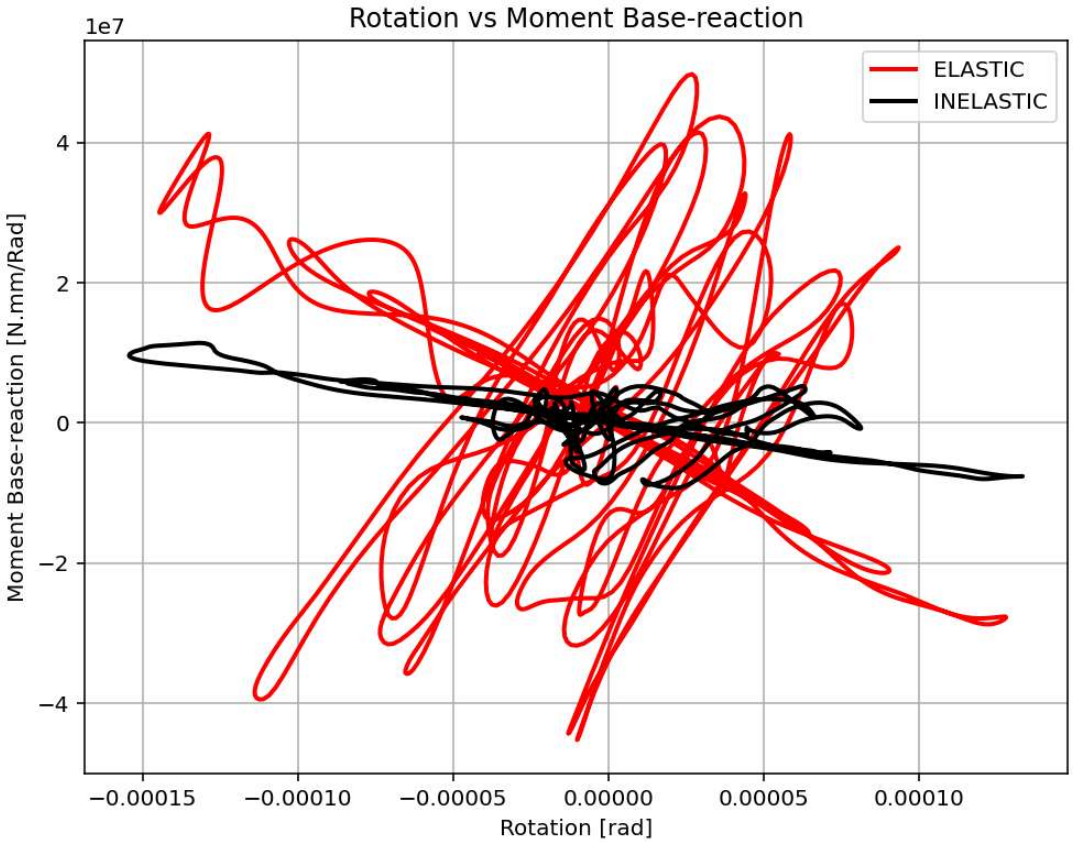

Time vs Base-reaction - MAX. ABS: 21930.947466128448
Base-reaction [N]
Time [s]
20000
10000
0
−10000
−20000
0
10
20
30
40
50


Time vs Axial Base-reaction - MAX. ABS: 22.104271599226195
Axial Base-reaction [N]
Time [s]
20
15
10
5
0
−5
−10
−15
0
10
20
30
40
50


Time vs Axial Base-reaction - MAX. ABS: 11139.52226294204
Axial Base-reaction [N]
10000
7500
5000
2500
0
−2500
−5000
−7500
0
10
20
30
40
50
Time [s]


Displacement vs Shear Base-reaction
ELASTIC
INELASTIC
Shear Base-reaction [N]
Displacement in X [mm]
80000
60000
40000
20000
0
−20000
−40000
−60000
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3


Displacement vs Axial Base-reaction
ELASTIC
INELASTIC
10000
7500
5000
2500
0
−2500
−5000
−7500
Axial Base-reaction [N]
−0.02
−0.01
0.00
0.01
0.02
0.03
Displacement in Y [mm]


Rotation vs Moment Base-reaction
1e7
ELASTIC
INELASTIC
4
2
0
−2
−4
Moment Base-reaction [N.mm/Rad]
−0.00015
−0.00010
−0.00005
0.00000
0.00005
0.00010
Rotation [rad]