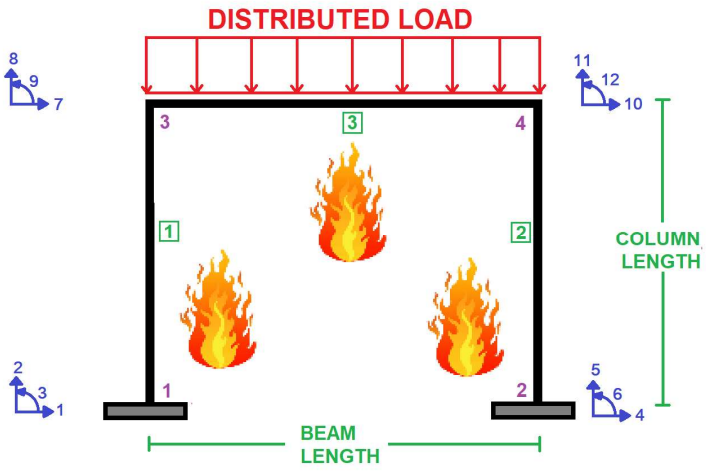
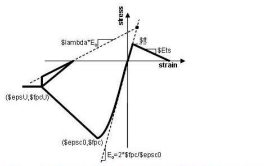
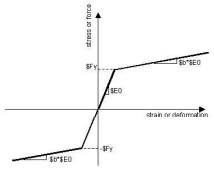
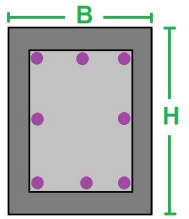




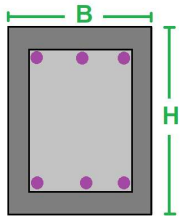
Concrete02 Thermal Material - Linear Tension Softening



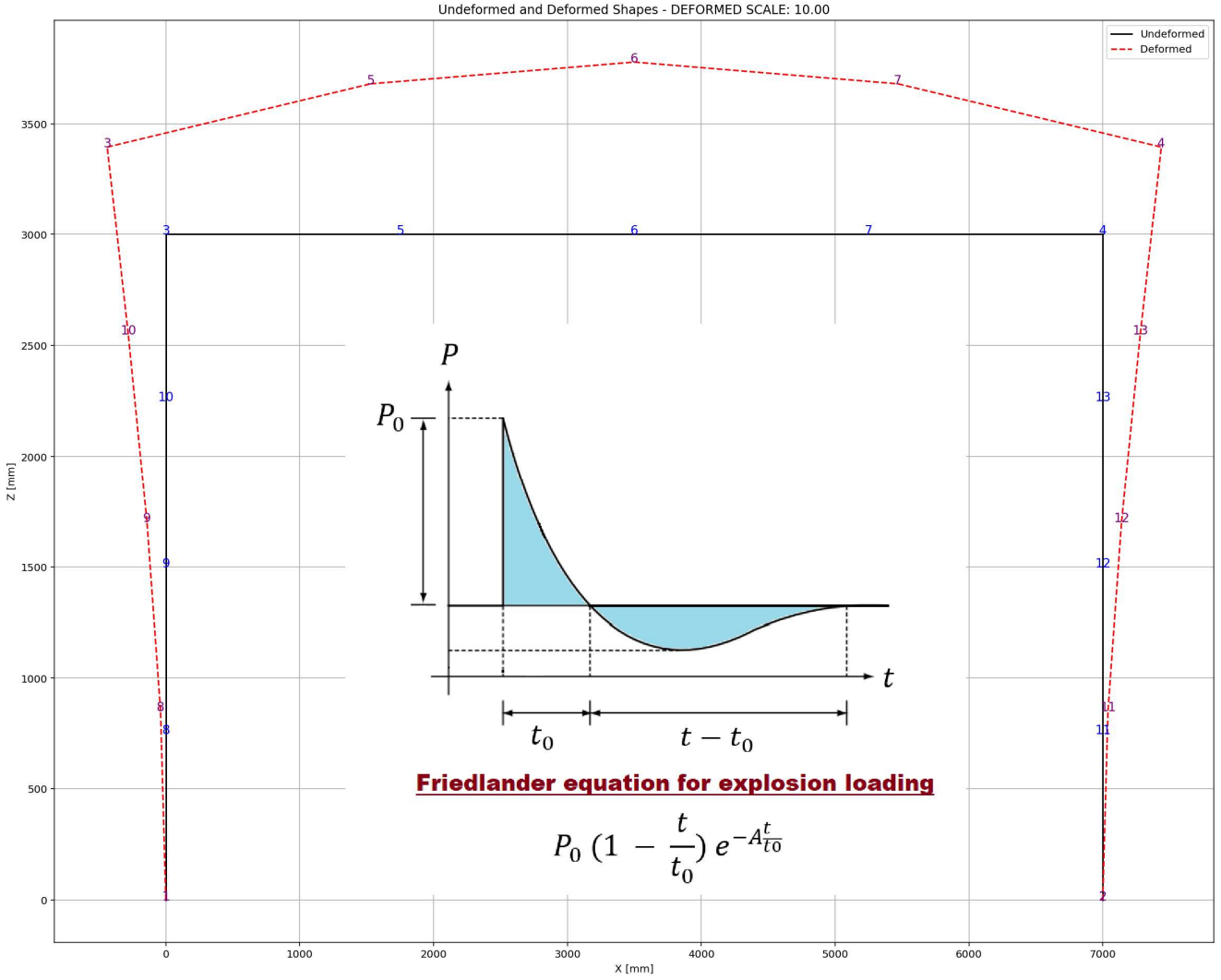
Steel01 Thermal Material



COLUMN SECTION



BEAM SECTION



Friedlander equation for explosion loading

$$P_0 \left(1 - \frac{t}{t_0}\right) e^{-A\frac{t}{t_0}}$$

IN THE NAME OF ALLAH

SEQUENTIAL EXPLOSION IMPACT AND THERMAL LOAD ANALYSIS OF A CONCRETE FRAME USING OPENSEES. THERMAL LOAD APPLIED THERMAL LOAD ON ALL ELEMENTS

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)

Spyder (Python 3.12)

File Edit Search Source Run Debug Consoles Projects Tools View Help

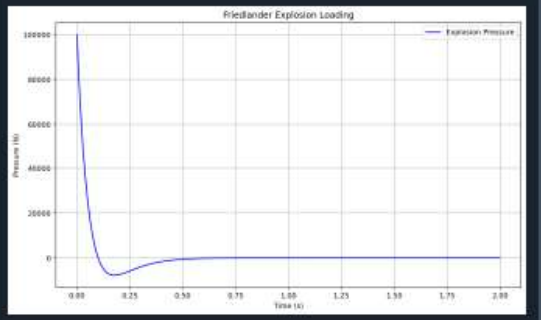
...PACT_LOAD-THERMAL_LOAD\EXPLOSION_IMPACT_LOAD-THERMAL_LOAD

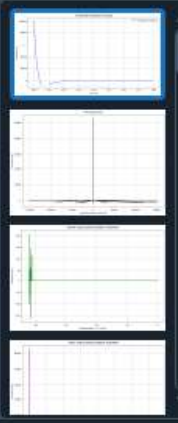
C:\Users\Dell\Desktop\OPENSEES_FILES\CONCRETE_FRA...CRETE_FRAME_EXPLOSION_IMPACT_LOAD-THERMAL_LOAD.py

CONCRETE_FRAME_EXP...AD-THERMAL_LOAD.py

```
##########################################################################################################
#                          >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<
#              SEQUENTIAL EXPLOSION IMPACT AND THERMAL LOAD ANALYSIS OF A CONCRETE FRAME USING OPENSEES
#                                  THERMAL LOAD APPLIED THERMAL LOAD ON ALL ELEMENTS
#---------------------------------------------------------------------------------------------------------
#                                THIS PROGRAM WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)
#                                        EMAIL: salar.d.ghashghaei@gmail.com
##########################################################################################################

"""
Explosion Impact and Thermo-Mechanical Analysis of Reinforced Concrete Frames Using OpenSees

This computational framework performs coupled nonlinear analyses of 2D RC frames subjected to:
- Transient explosion loading (Friedlander wave equation)
- Steady-state thermal gradients
- Distributed mechanical loads

Key Analysis Components:

[1] Material Modeling:
   - Concrete02Thermal material for temperature-dependent concrete behavior (Eurocode 2 compliant)
   - Steel01Thermal for reinforcing steel with thermal effects
   - Distinct confined/unconfined concrete material models
   - Fiber section discretization for nonlinear section response

[2] Structural Configuration:
   - Multi-element 2D frame with refined mesh (quarter-point nodes)
   - Corotational geometric transformation for large displacements
   - Lobatto integration for accurate section response
   - Fixed base boundary conditions

[3] Loading Protocols:
   - Dynamic explosion loading via Friedlander equation (P0, t0, A parameters)
   - Thermal gradients across section depth (beam/column specific)
```

23 %





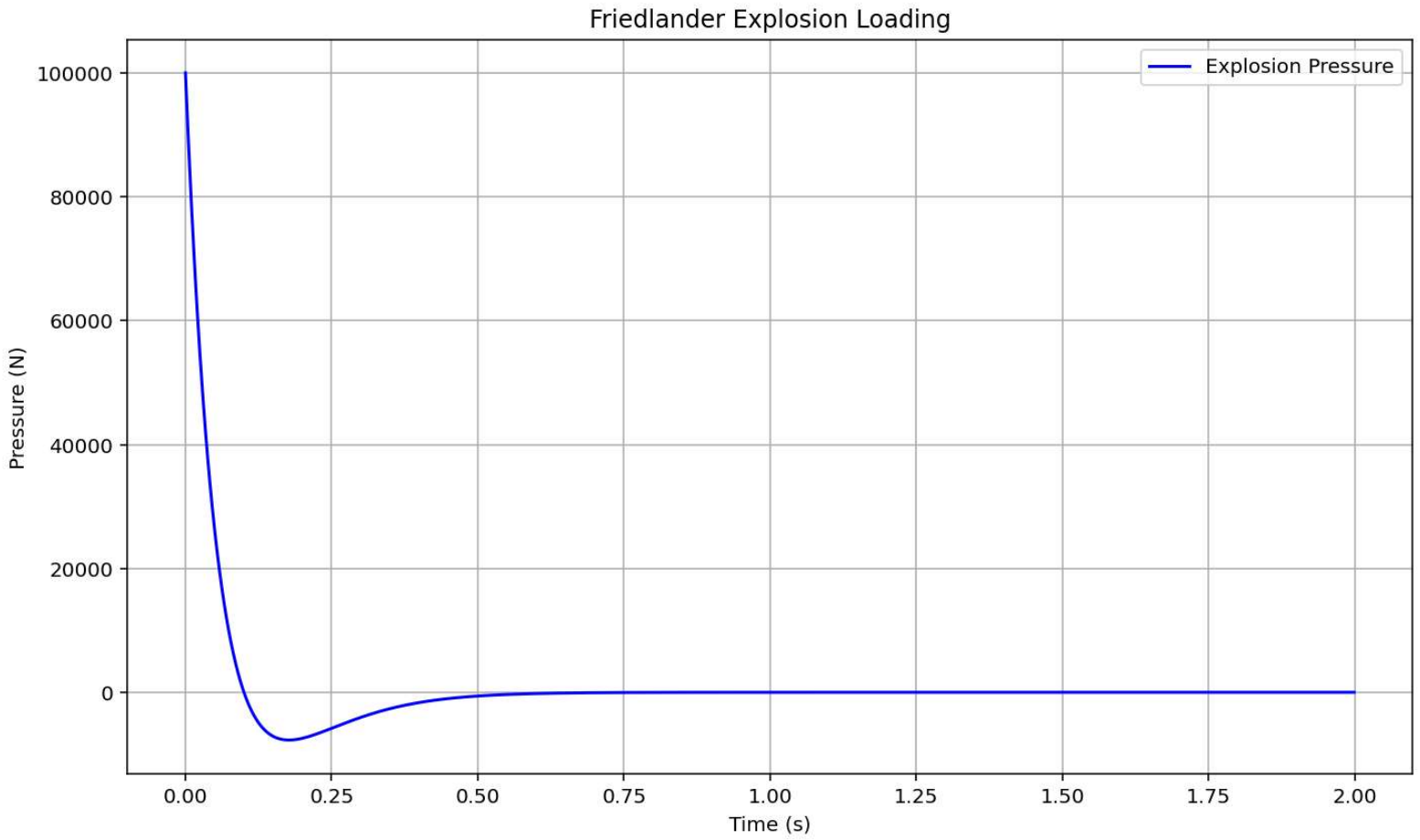
Help | Variable Explorer | Debugger | Plots | Files

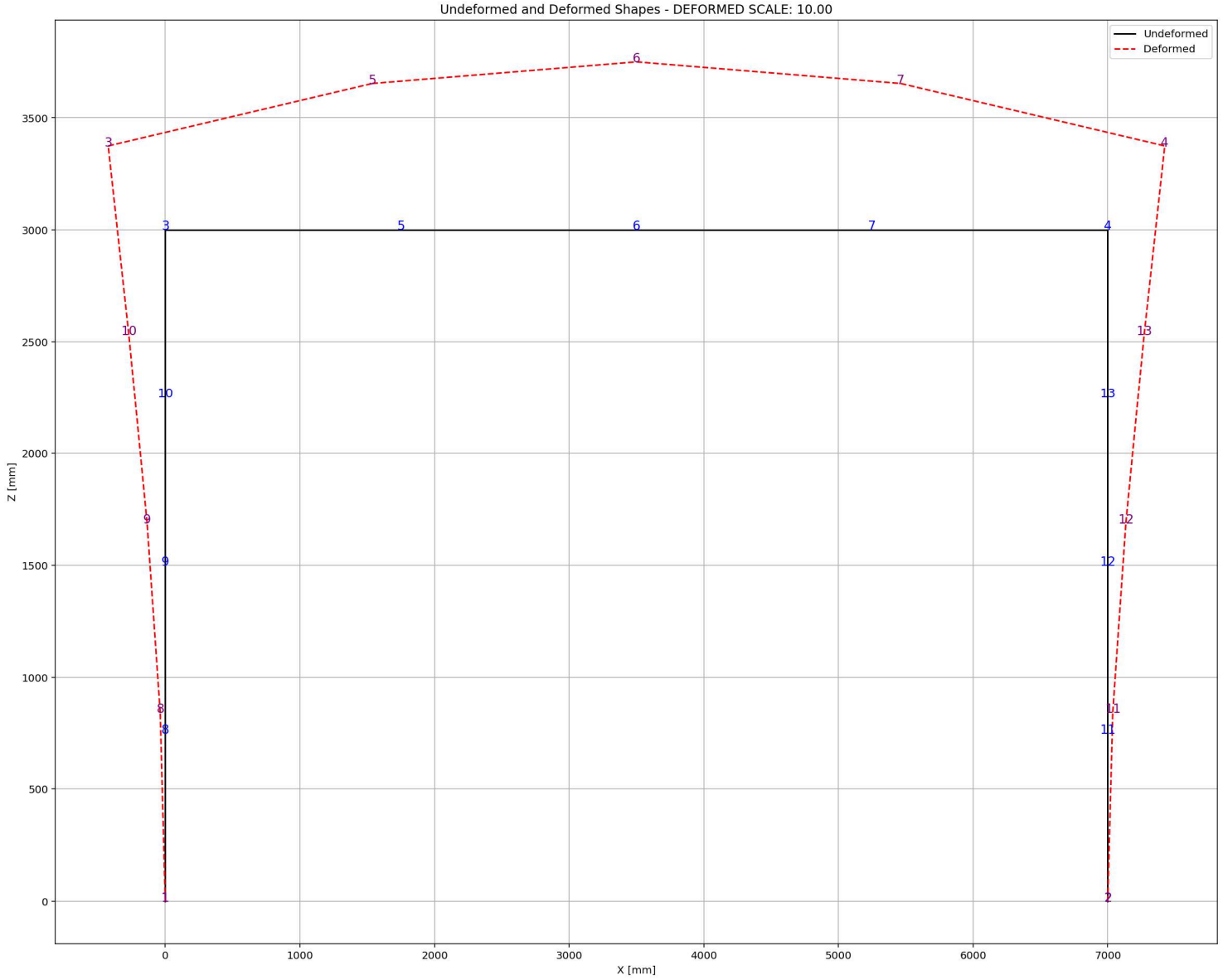
Console 1/A

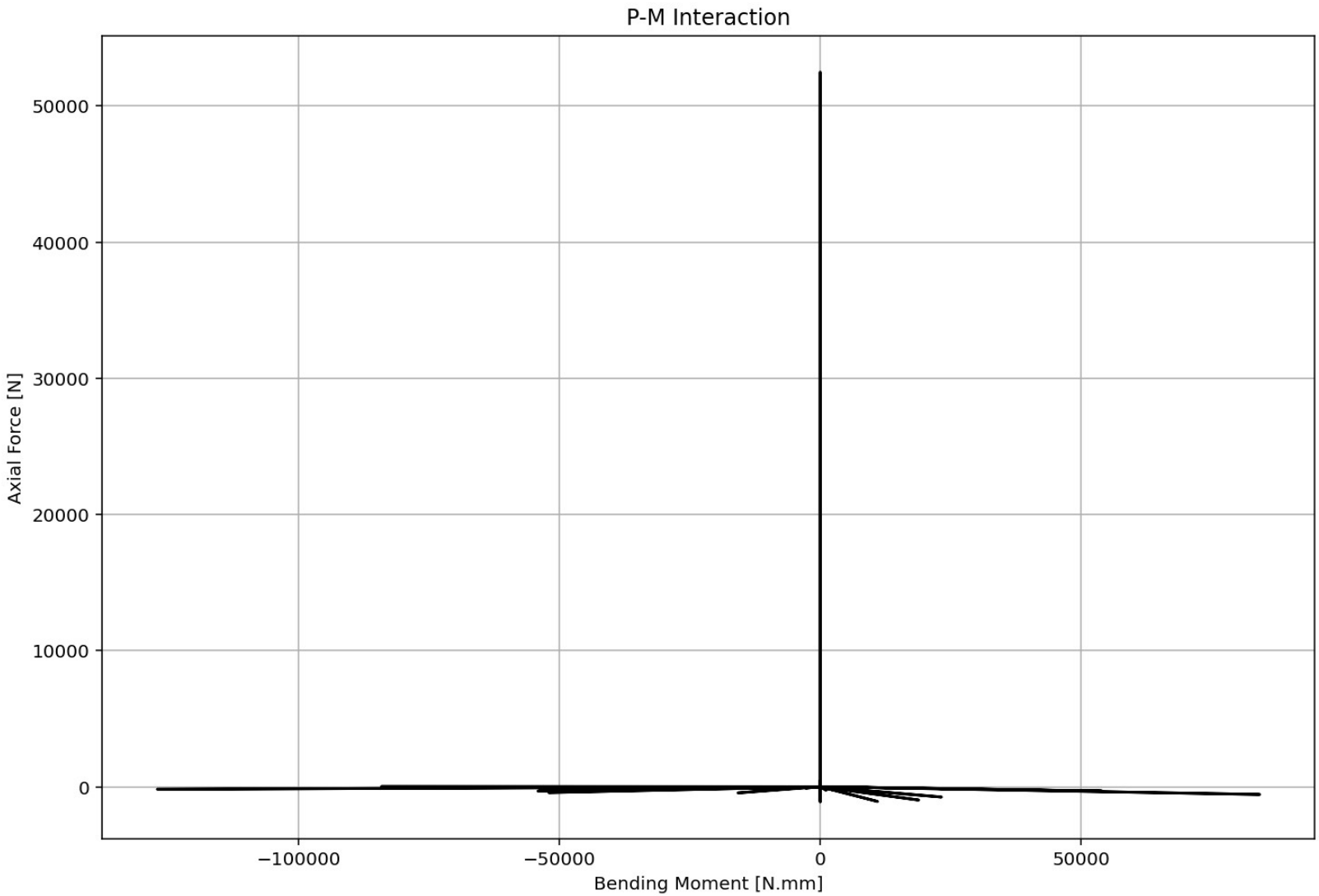
```
FiberSection2dThermal, tag: 10
    Section code: 2 1
    Number of Fibers: 106
    Centroid: 1.78611e-16

FiberSection2dThermal, tag: 10
    Section code: 2 1
    Number of Fibers: 106
    Centroid: 1.78611e-16

In [2]:
```

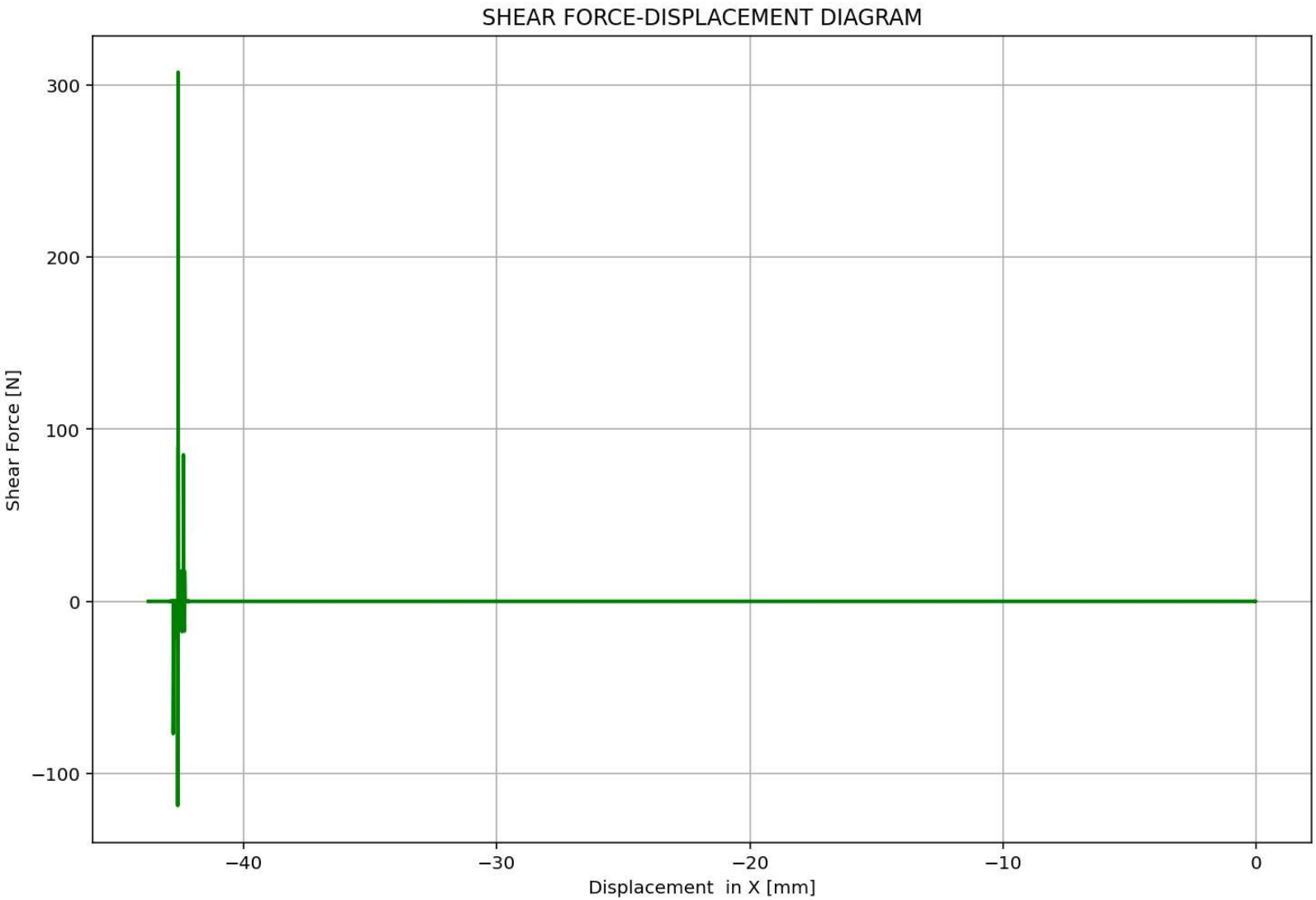
IPython Console | History

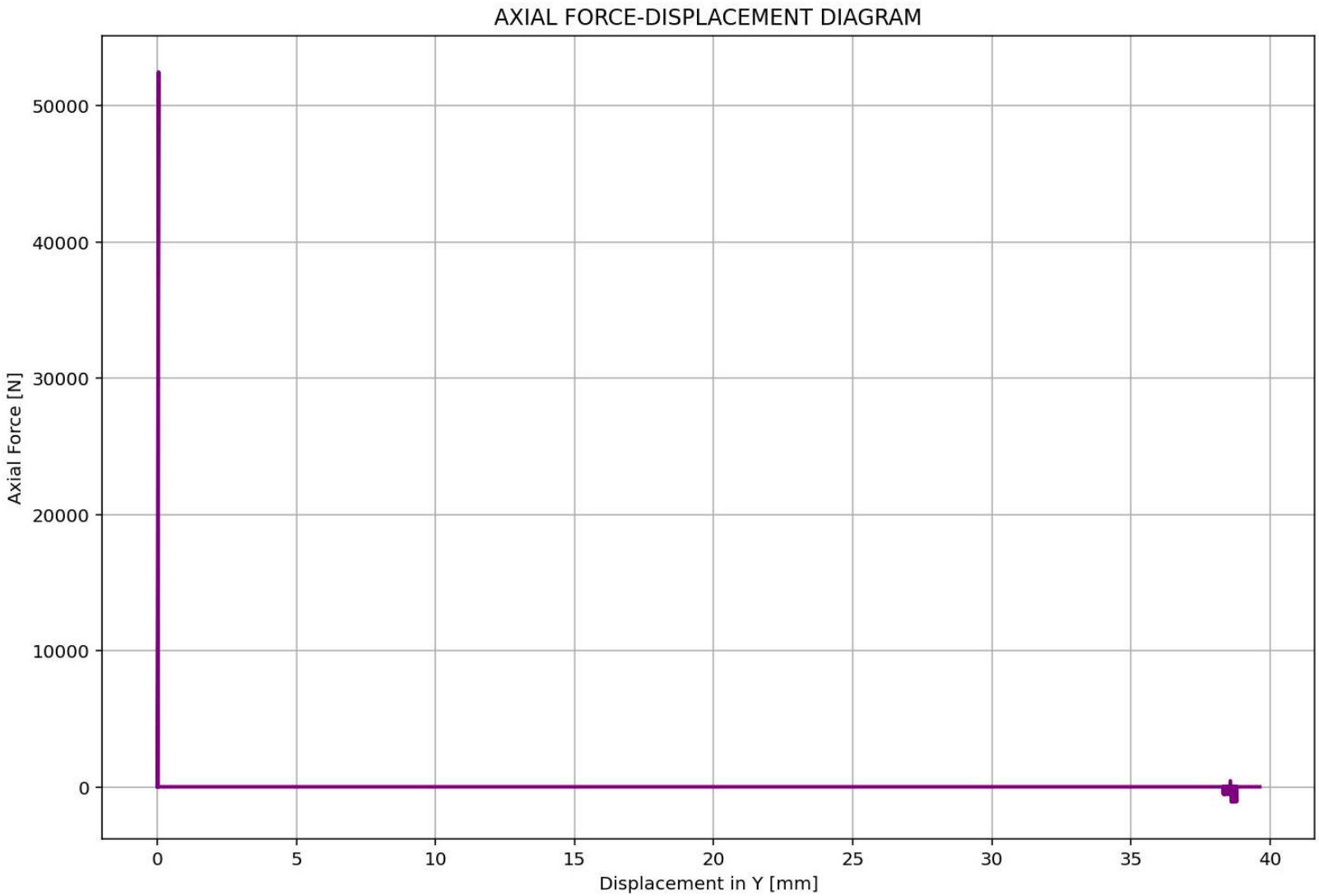
Inline Conda: anaconda3 (Python 3.12.7) LSP: Python Line 138, Col 25 UTF-8 CRLF RW Mem 42%

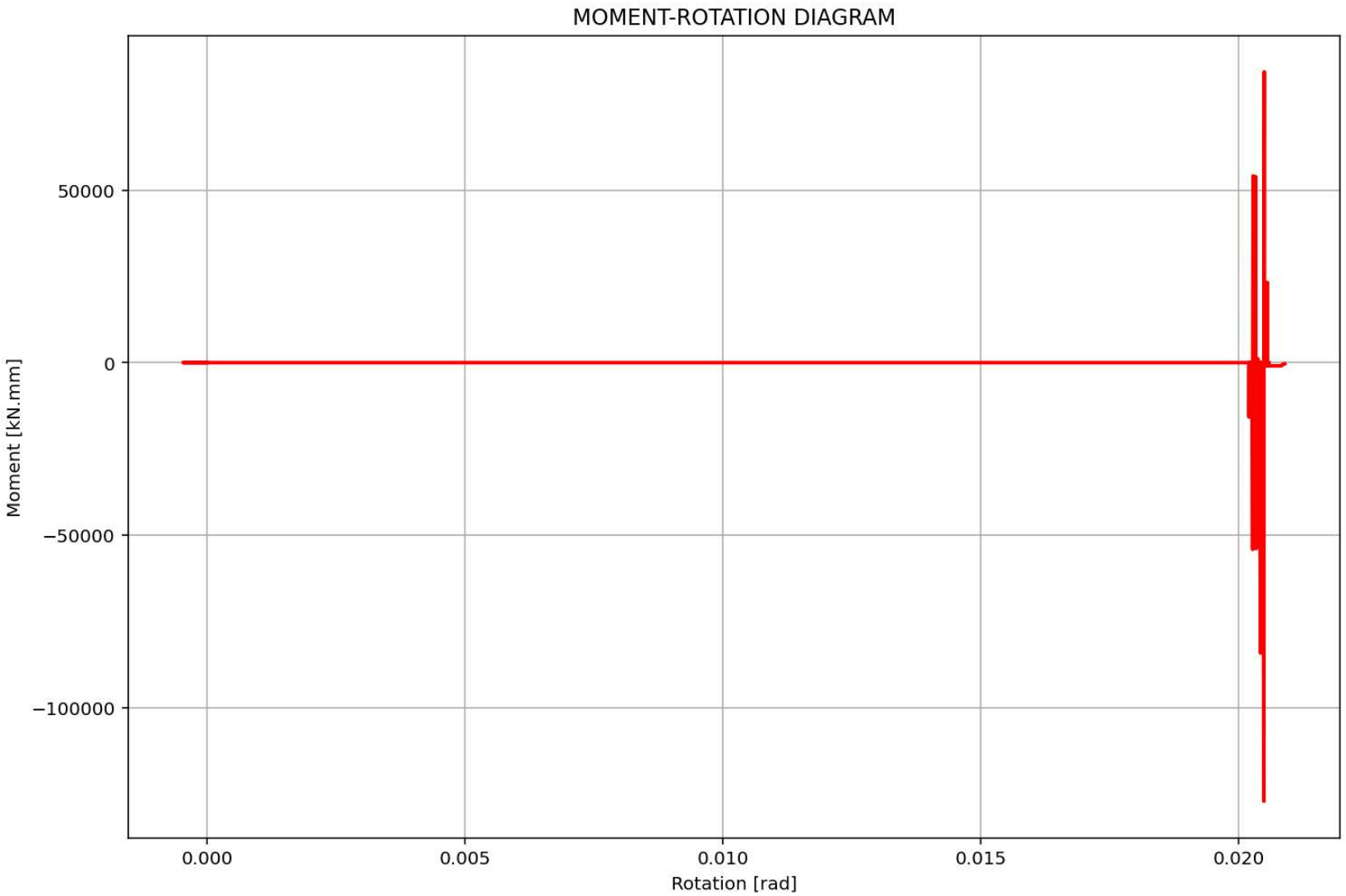

Friedlander Explosion Loading
Explosion Pressure
Pressure (N)
100000
80000
60000
40000
20000
0
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time (s)

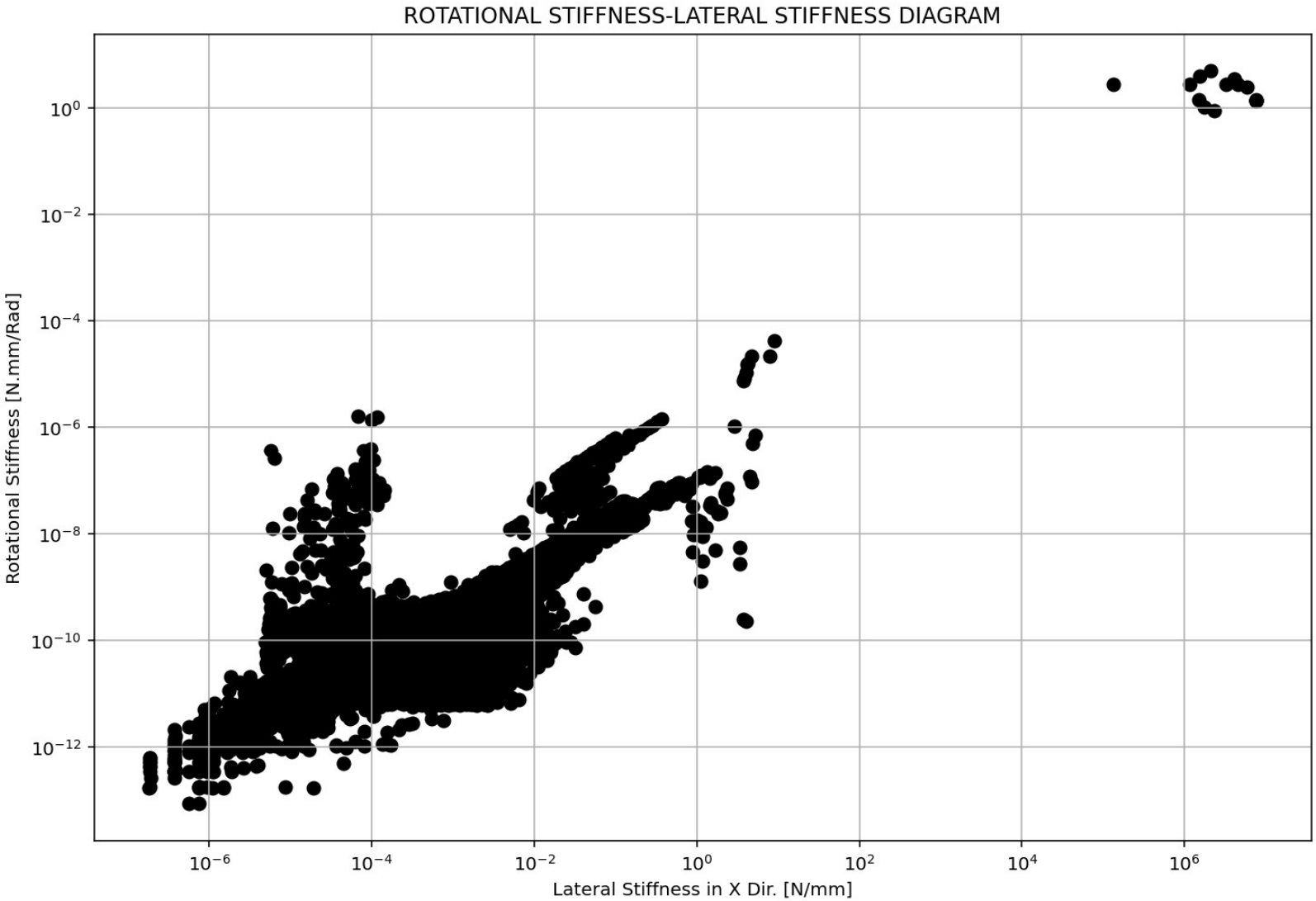

Undeformed and Deformed Shapes - DEFORMED SCALE: 10.00
Undeformed
Deformed
Z [mm]
X [mm]
0
500
1000
1500
2000
2500
3000
3500
0
1000
2000
3000
4000
5000
6000
7000
1
2
3
4
5
6
7
8
9
10
11
12
13

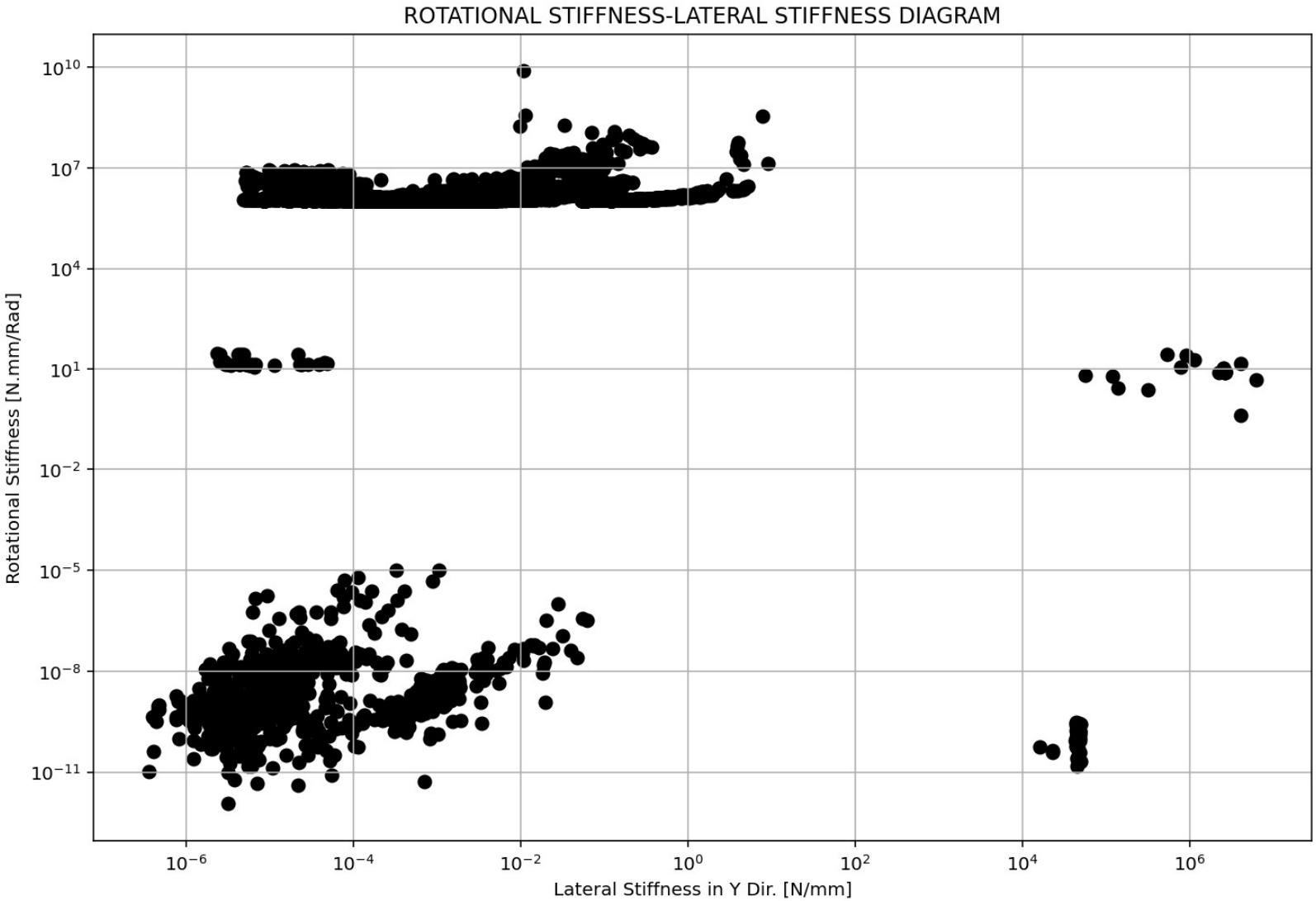

P-M Interaction
50000
40000
30000
20000
10000
0
Axial Force [N]
−100000
−50000
0
50000
Bending Moment [N.mm]

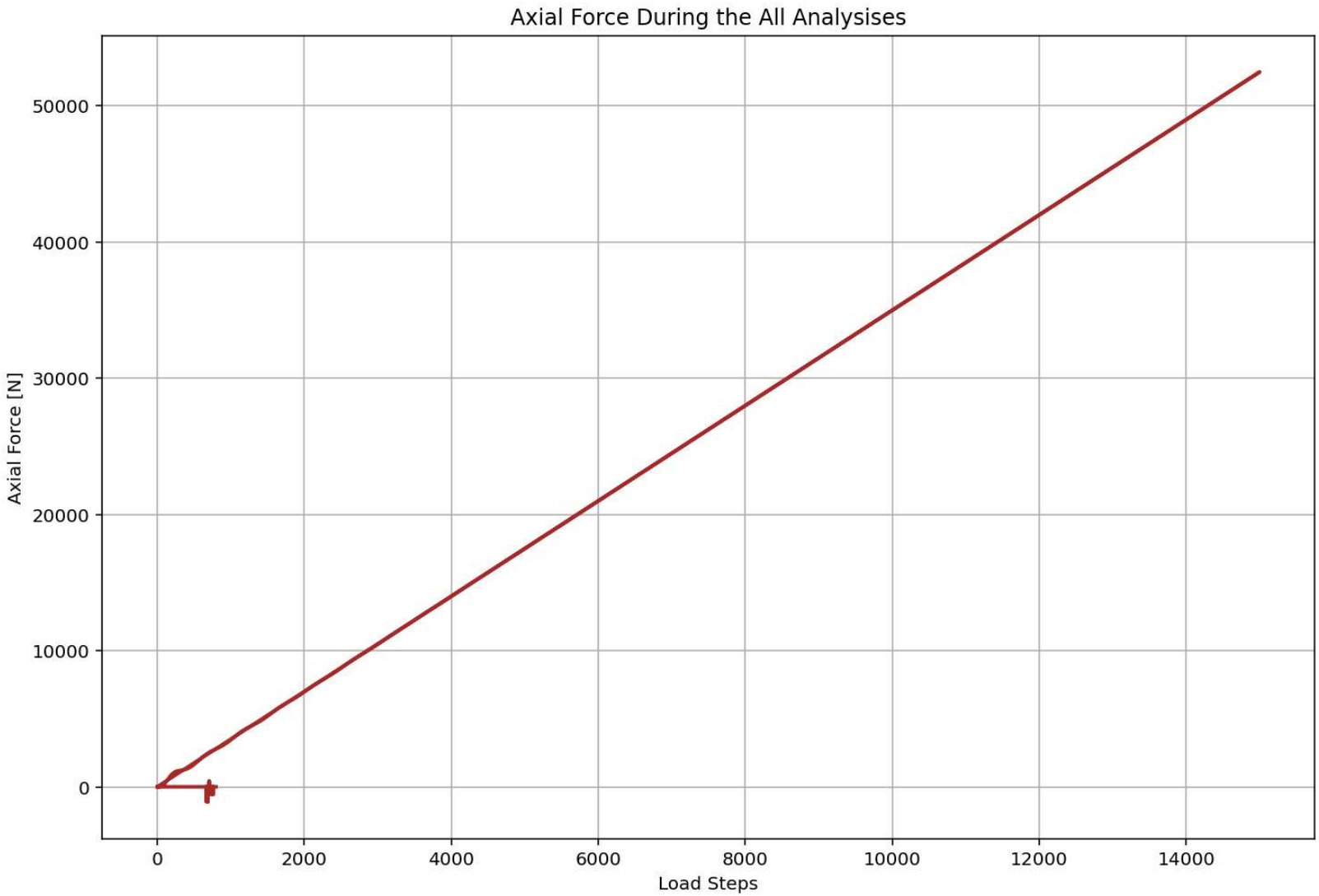

SHEAR FORCE-DISPLACEMENT DIAGRAM
300
200
100
0
−100
Shear Force [N]
−40
−30
−20
−10
0
Displacement in X [mm]

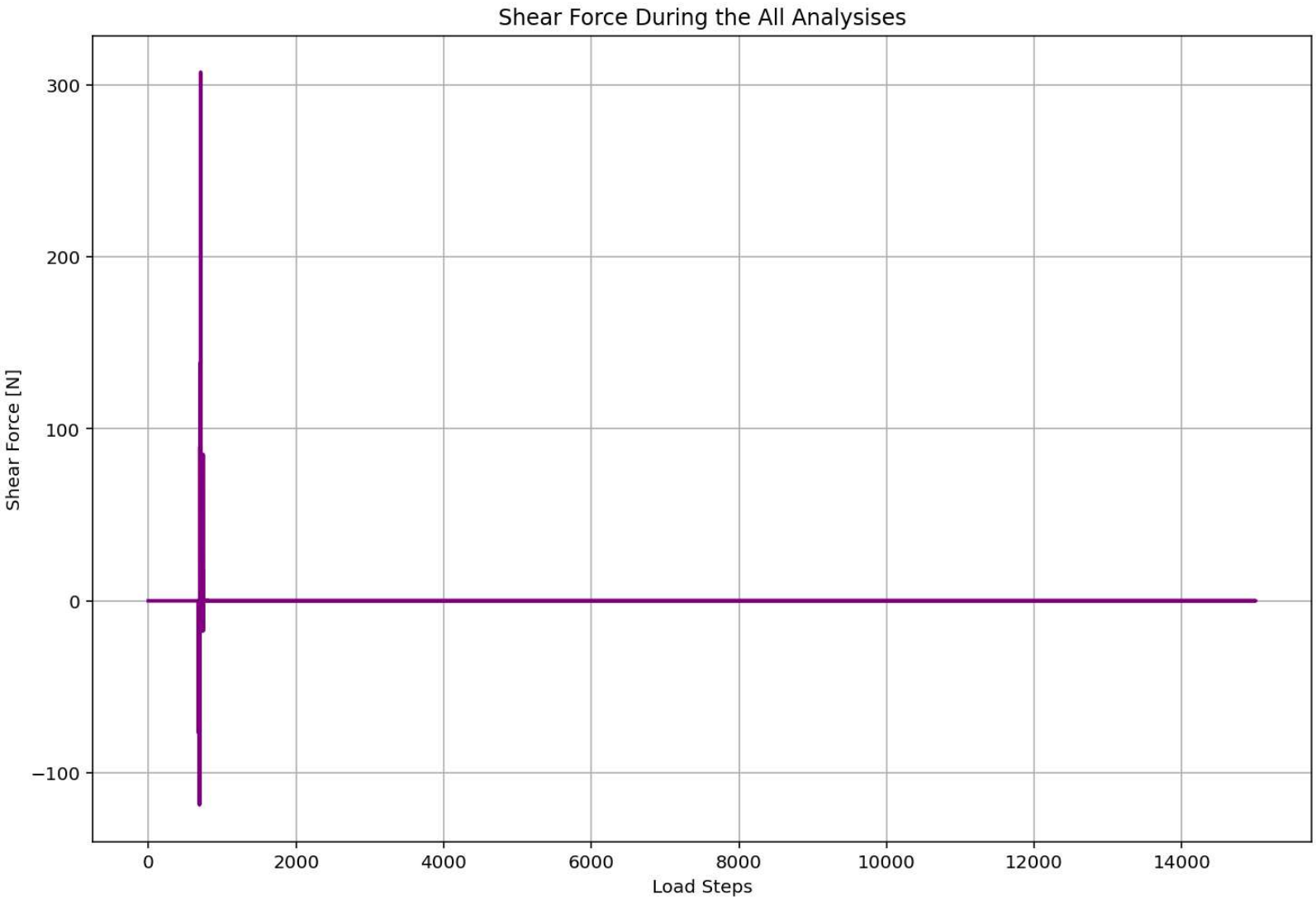

AXIAL FORCE-DISPLACEMENT DIAGRAM
Axial Force [N]
50000
40000
30000
20000
10000
0
0
5
10
15
20
25
30
35
40
Displacement in Y [mm]

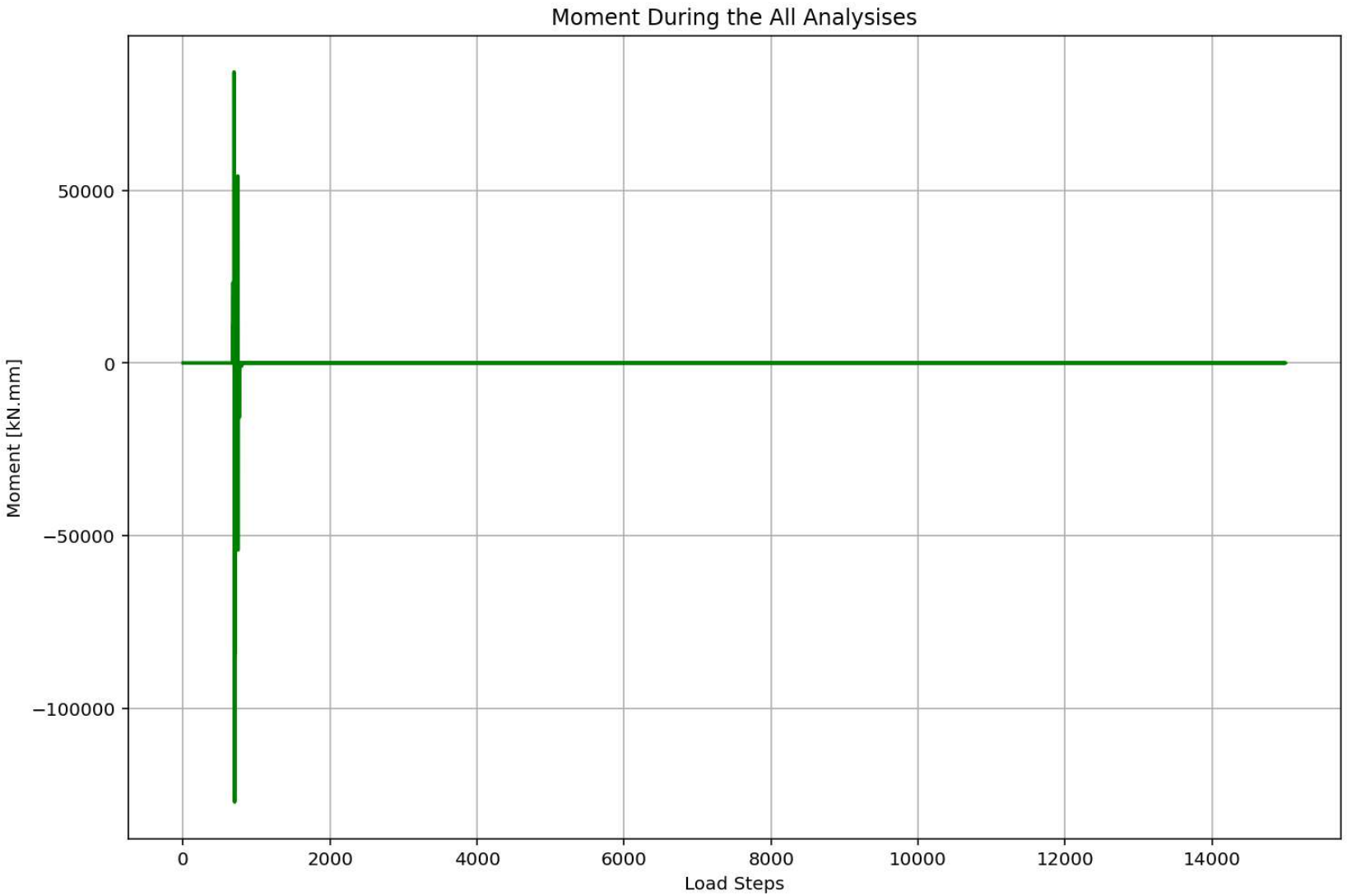

MOMENT-ROTATION DIAGRAM
50000
0
−50000
−100000
Moment [kN.mm]
0.000
0.005
0.010
0.015
0.020
Rotation [rad]

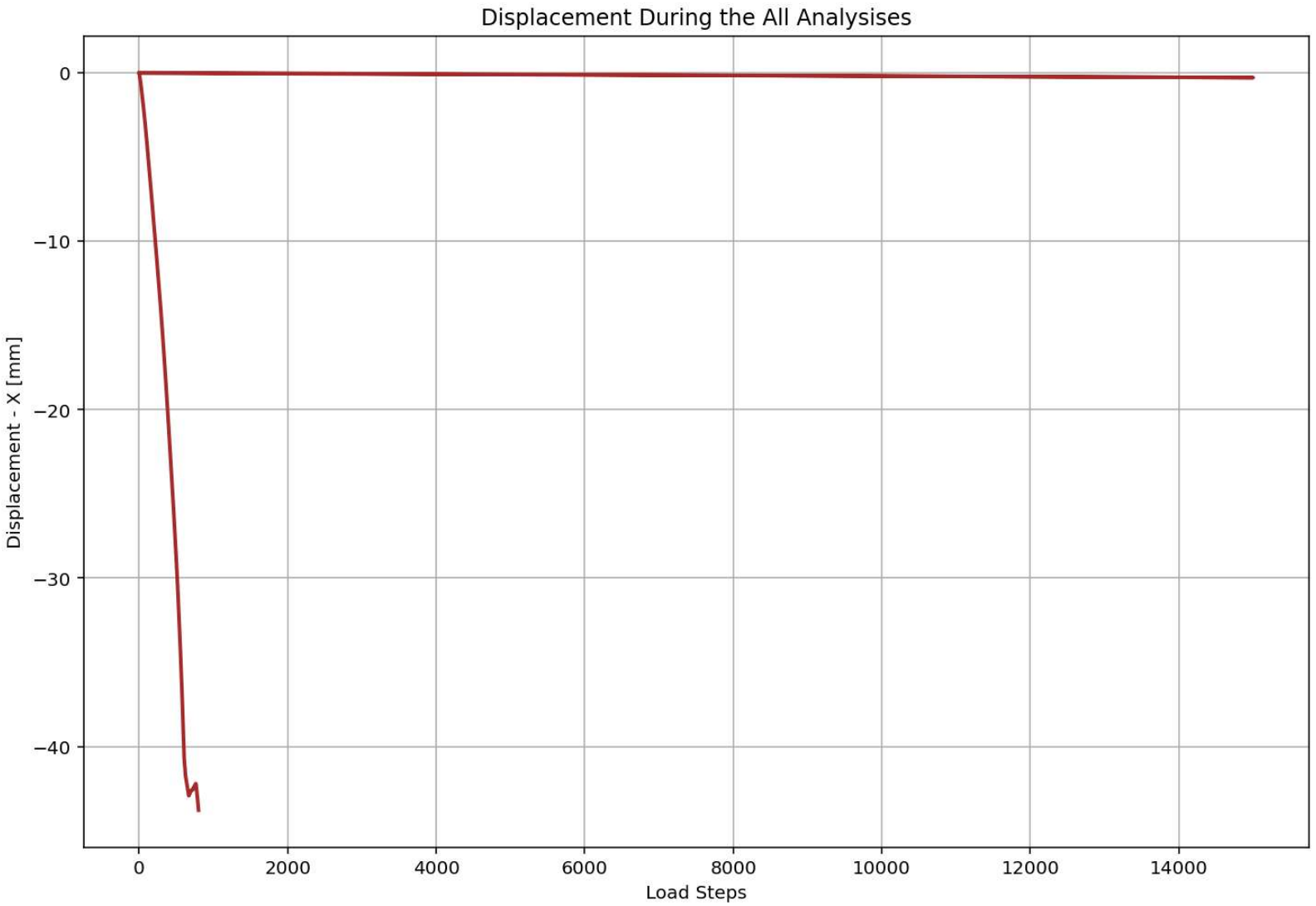

ROTATIONAL STIFFNESS-LATERAL STIFFNESS DIAGRAM
Rotational Stiffness [N.mm/Rad]
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
Lateral Stiffness in X Dir. [N/mm]

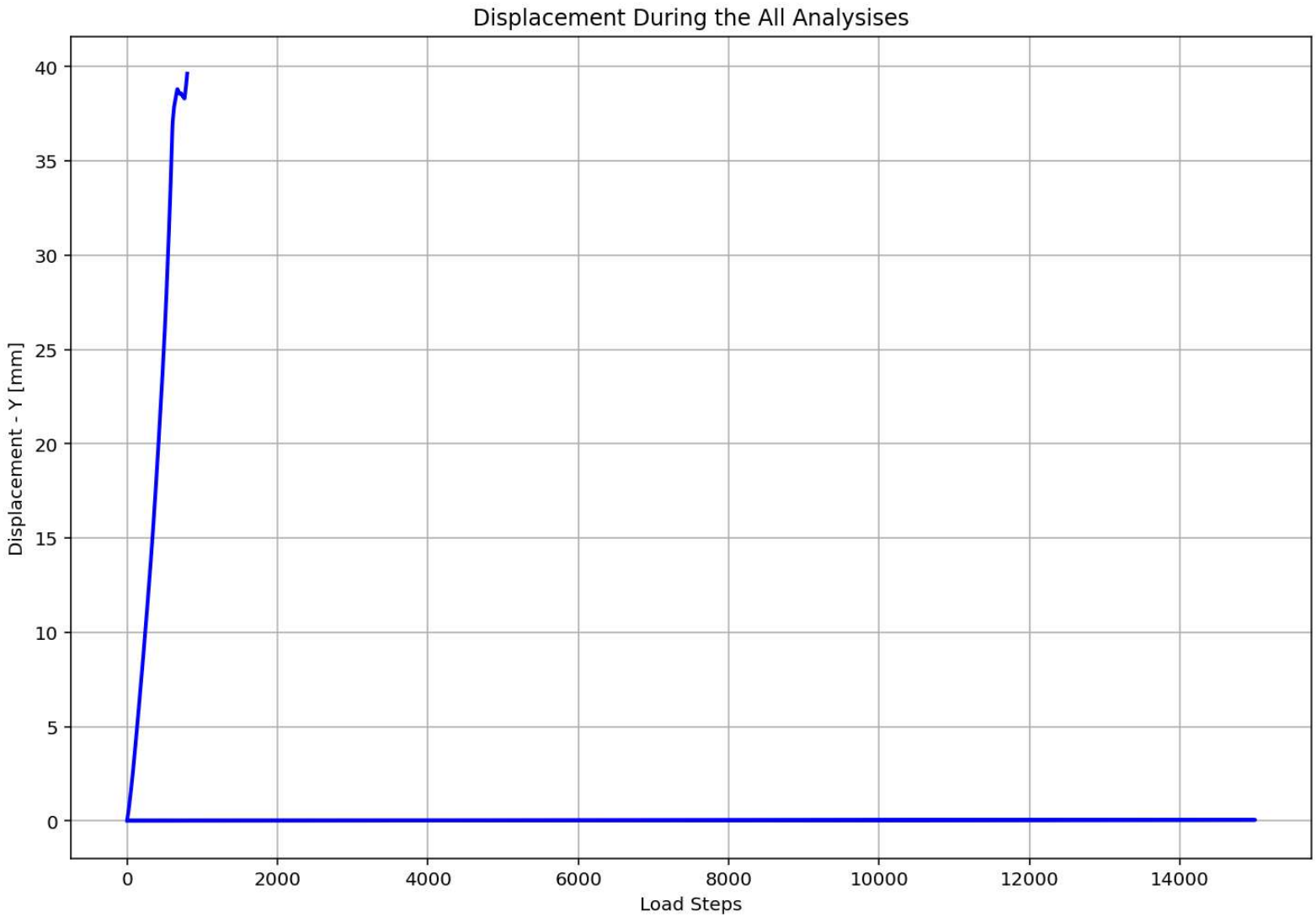

ROTATIONAL STIFFNESS-LATERAL STIFFNESS DIAGRAM
Rotational Stiffness [N.mm/Rad]
10^{10}
10^{7}
10^{4}
10^{1}
10^{-2}
10^{-5}
10^{-8}
10^{-11}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
Lateral Stiffness in Y Dir. [N/mm]

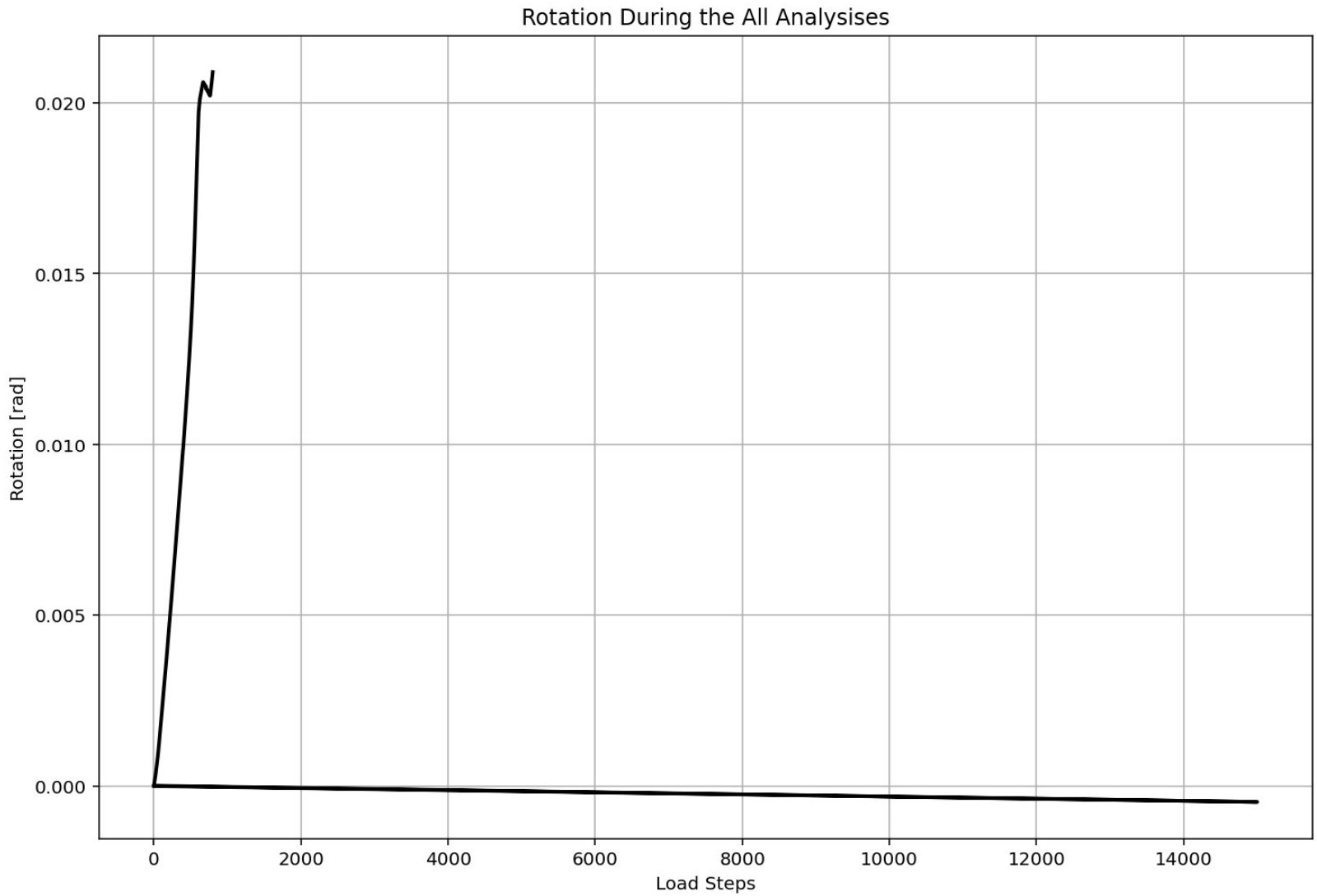

Axial Force During the All Analysises
Axial Force [N]
50000
40000
30000
20000
10000
0
0
2000
4000
6000
8000
10000
12000
14000
Load Steps


Shear Force During the All Analysises
Shear Force [N]
300
200
100
0
−100
0
2000
4000
6000
8000
10000
12000
14000
Load Steps

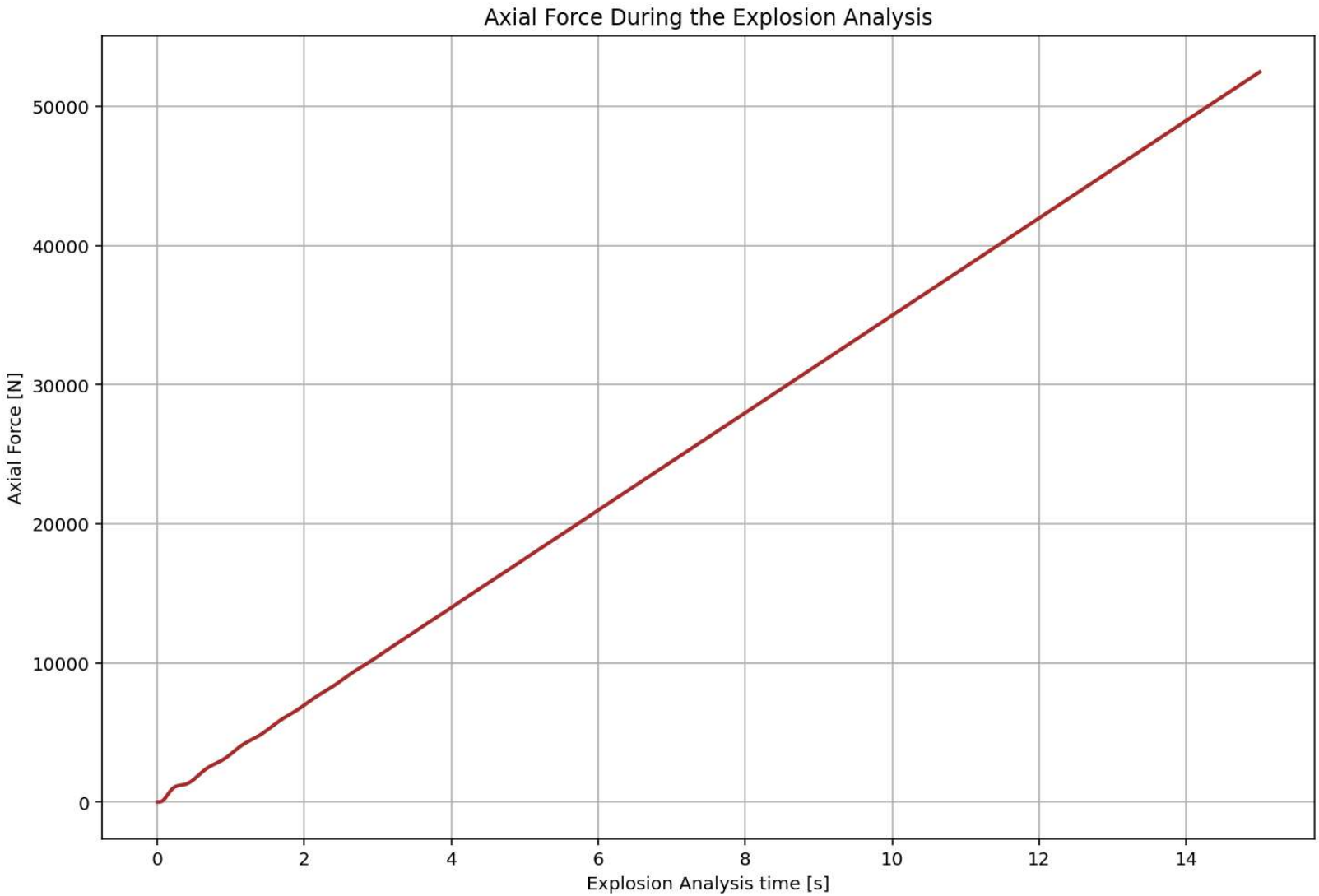

Moment During the All Analysises
Moment [kN.mm]
50000
0
−50000
−100000
0
2000
4000
6000
8000
10000
12000
14000
Load Steps

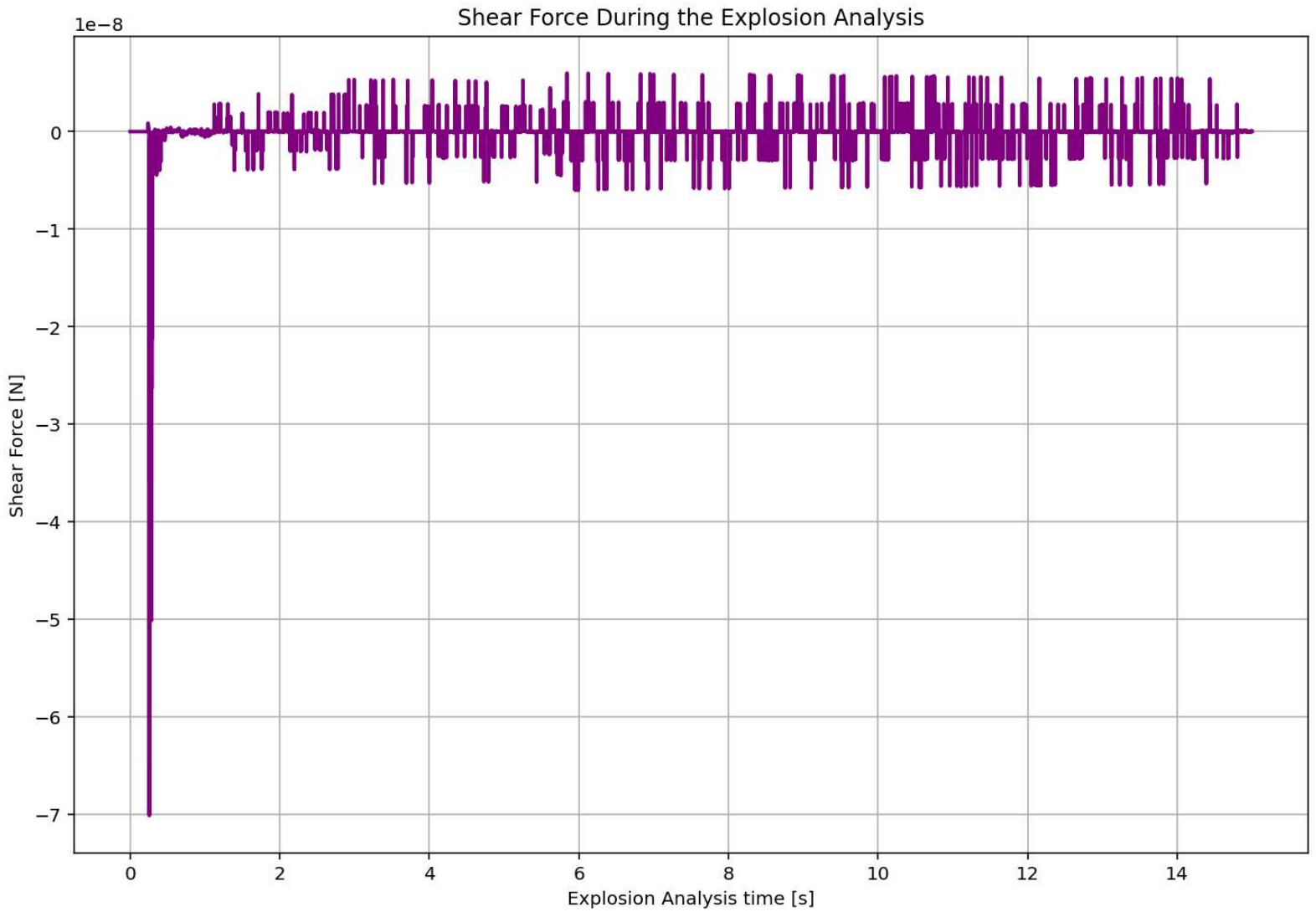

Displacement During the All Analysises
0
−10
−20
−30
−40
Displacement - X [mm]
0
2000
4000
6000
8000
10000
12000
14000
Load Steps

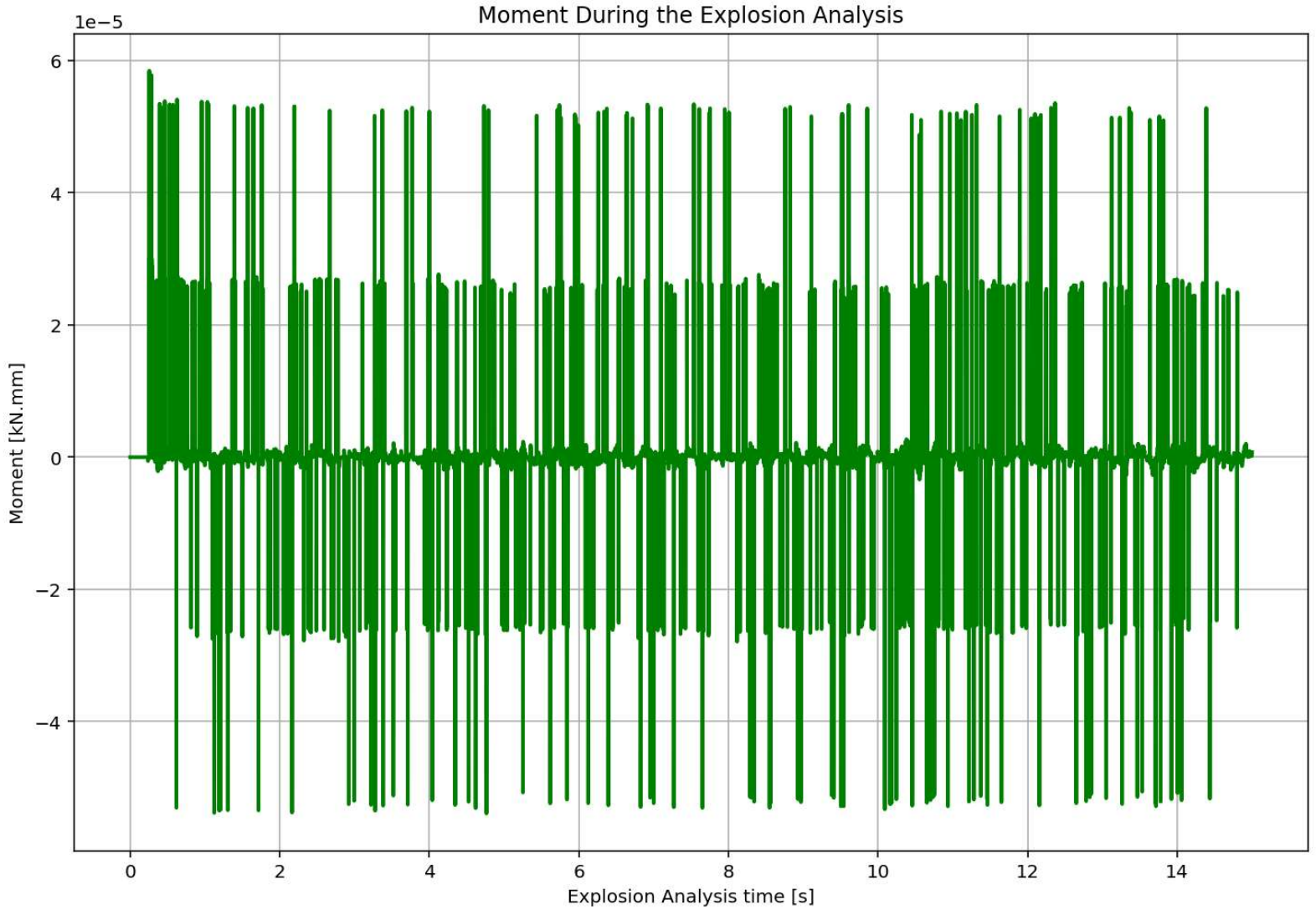

Displacement During the All Analysises
Displacement - Y [mm]
40
35
30
25
20
15
10
5
0
0
2000
4000
6000
8000
10000
12000
14000
Load Steps

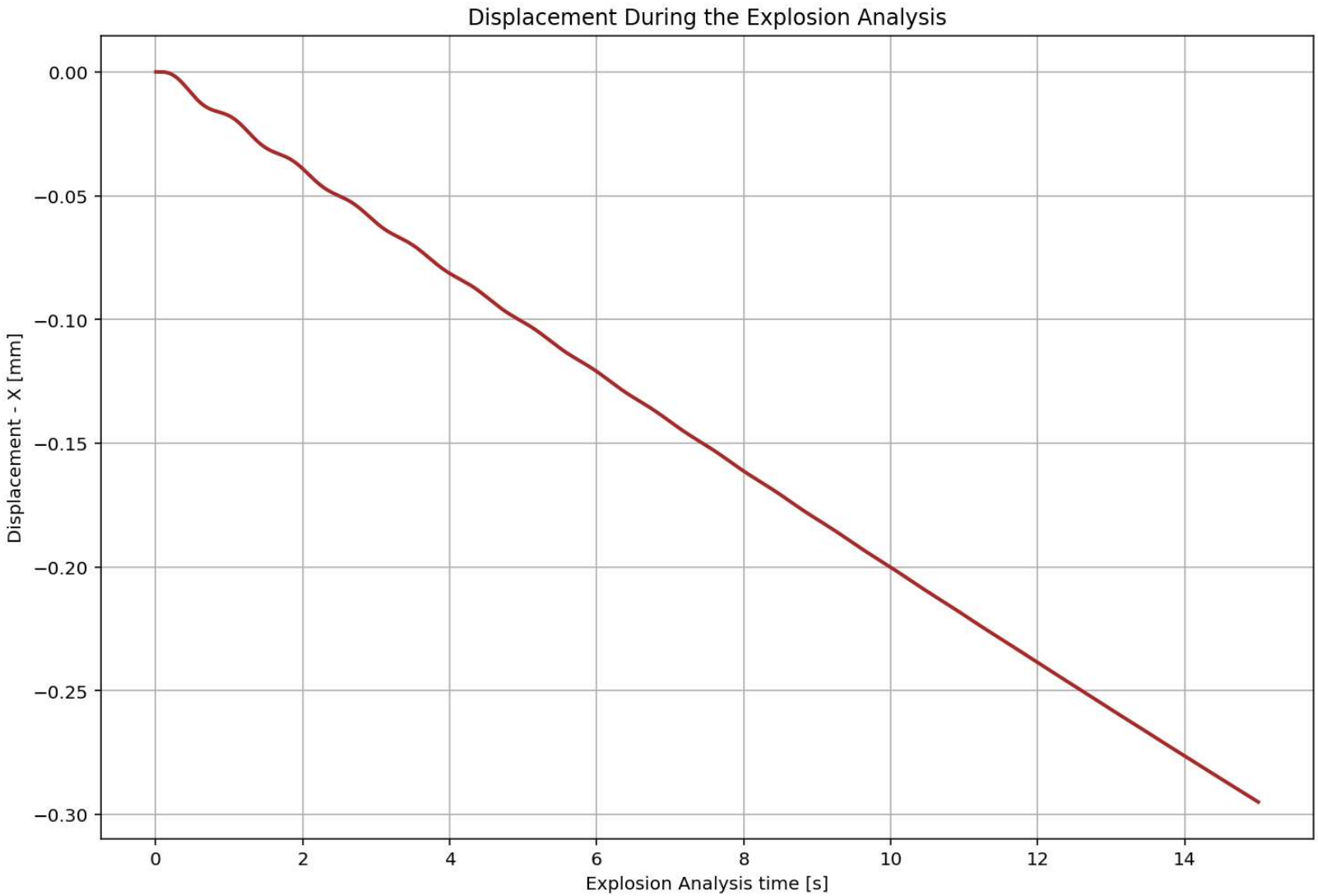

Rotation During the All Analysises
Rotation [rad]
0.020
0.015
0.010
0.005
0.000
0
2000
4000
6000
8000
10000
12000
14000
Load Steps

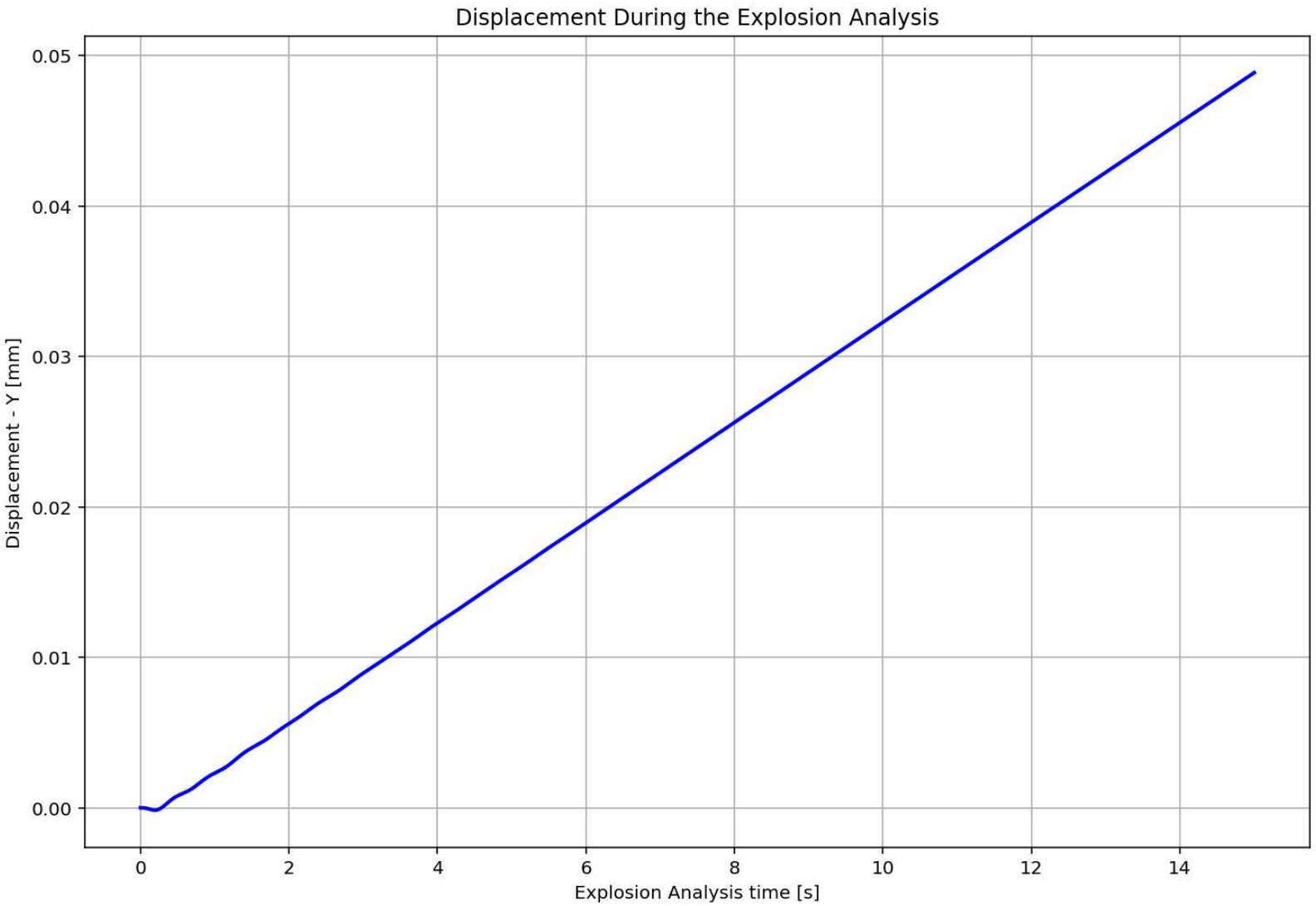
EXPLOSION IMPACT ANALYSIS RESULTS

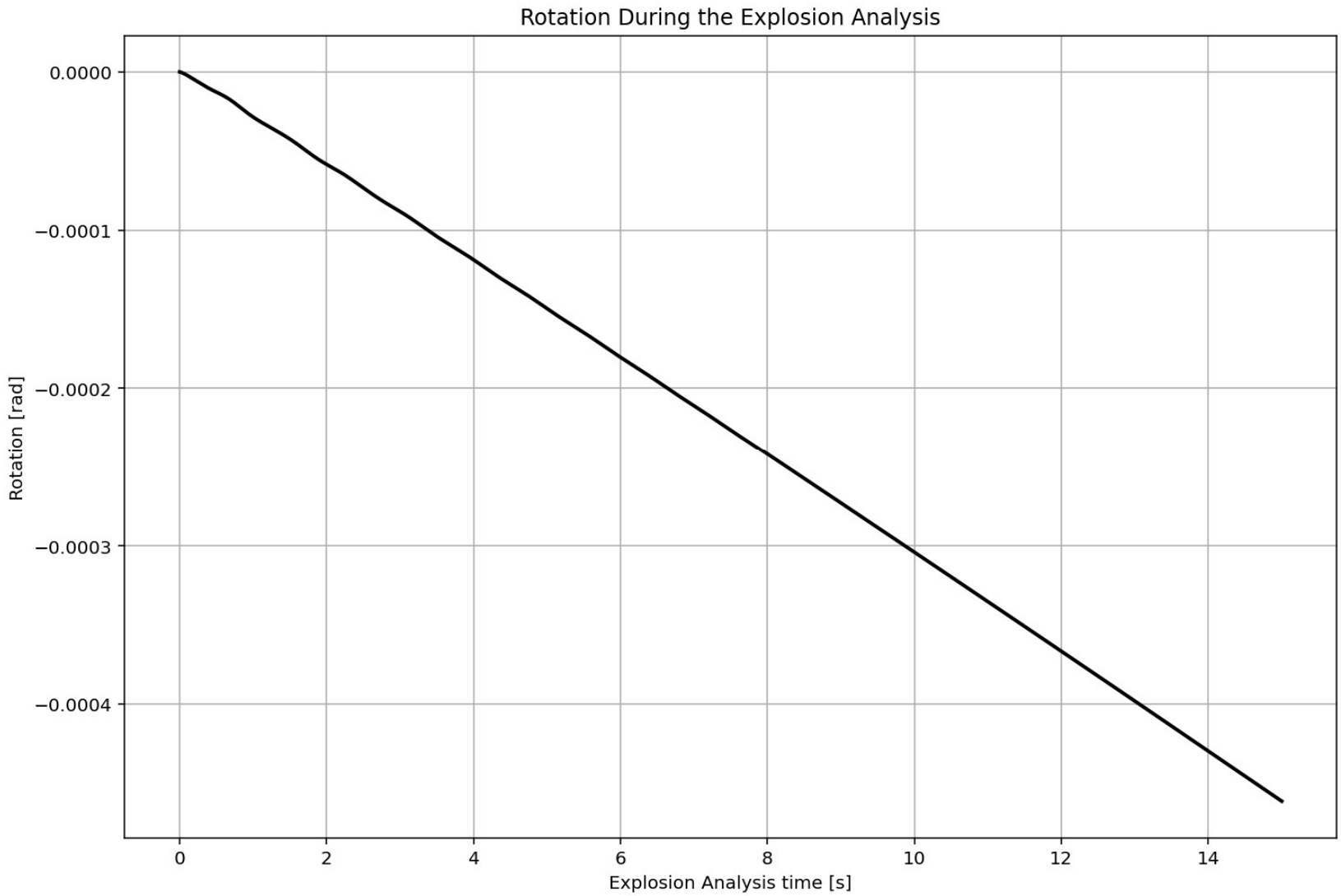

Axial Force During the Explosion Analysis
Axial Force [N]
50000
40000
30000
20000
10000
0
0
2
4
6
8
10
12
14
Explosion Analysis time [s]


Shear Force During the Explosion Analysis
1e−8
0
−1
−2
−3
−4
−5
−6
−7
Shear Force [N]
0
2
4
6
8
10
12
14
Explosion Analysis time [s]

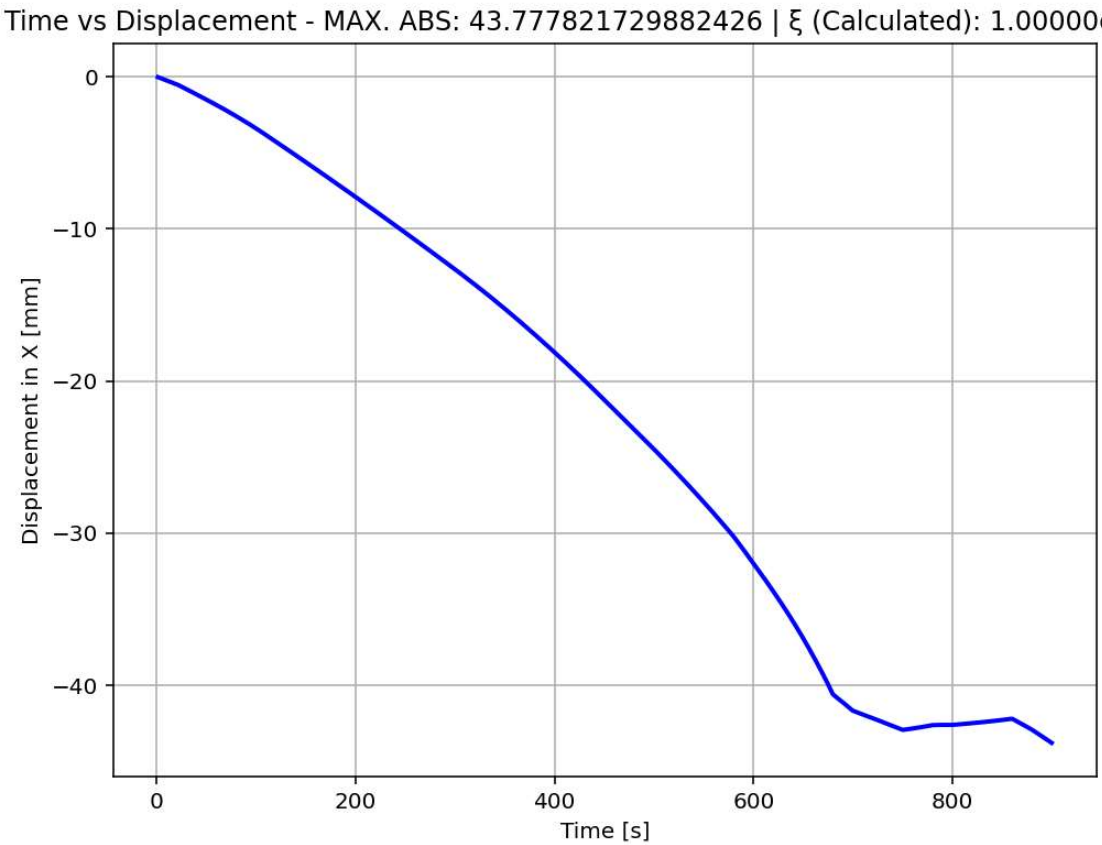

Moment During the Explosion Analysis
1e−5
6
4
2
0
−2
−4
Moment [kN.mm]
0
2
4
6
8
10
12
14
Explosion Analysis time [s]

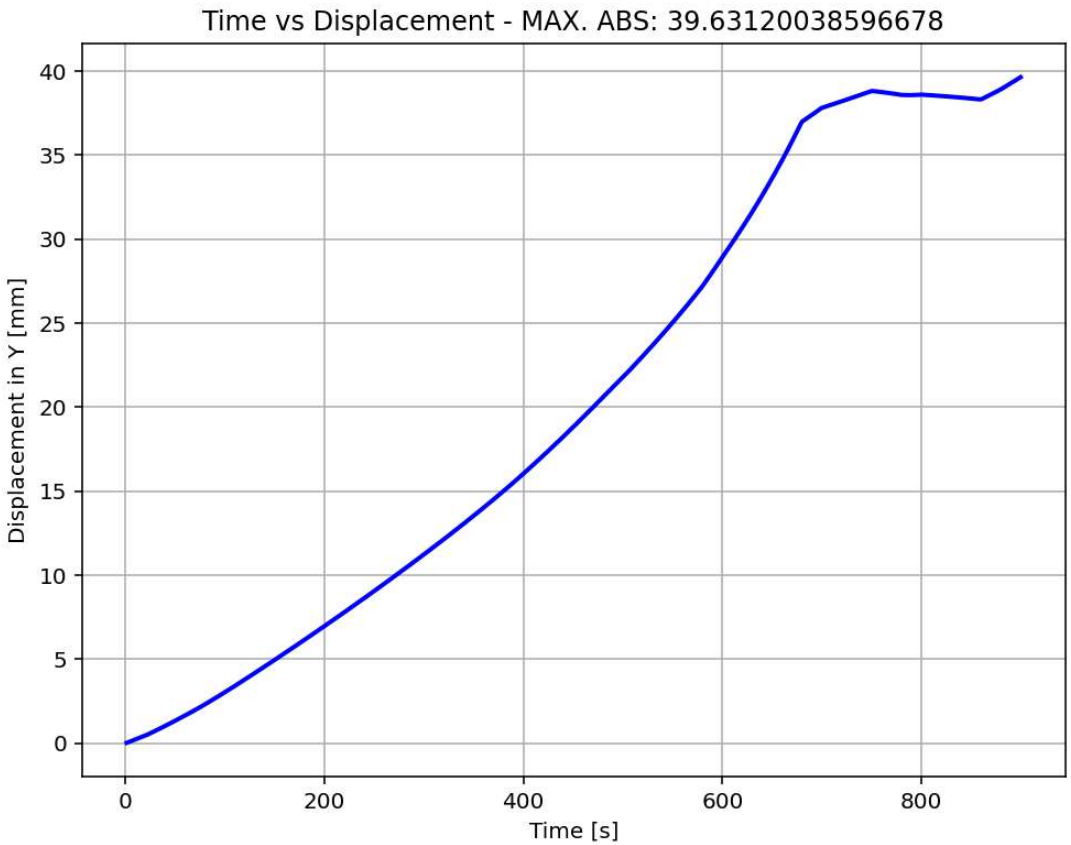

Displacement During the Explosion Analysis
Displacement - X [mm]
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
0
2
4
6
8
10
12
14
Explosion Analysis time [s]

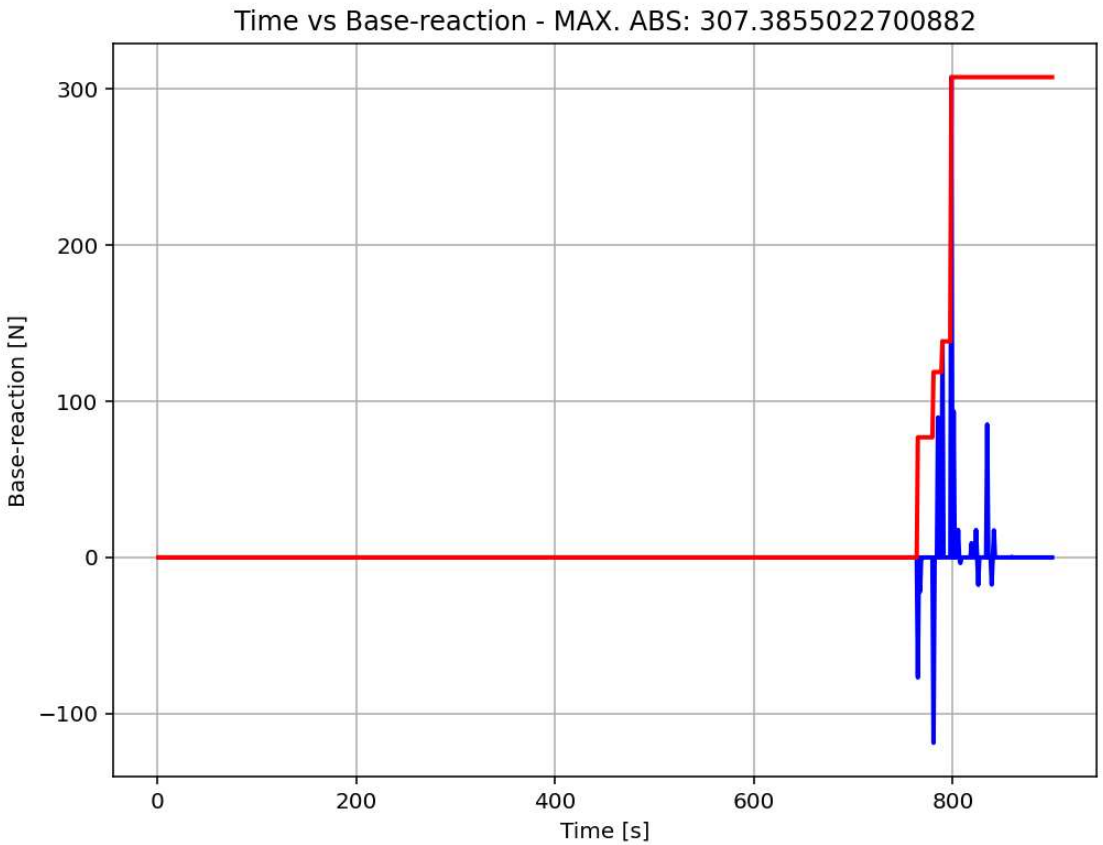

Displacement During the Explosion Analysis
Displacement - Y [mm]
0.05
0.04
0.03
0.02
0.01
0.00
0
2
4
6
8
10
12
14
Explosion Analysis time [s]

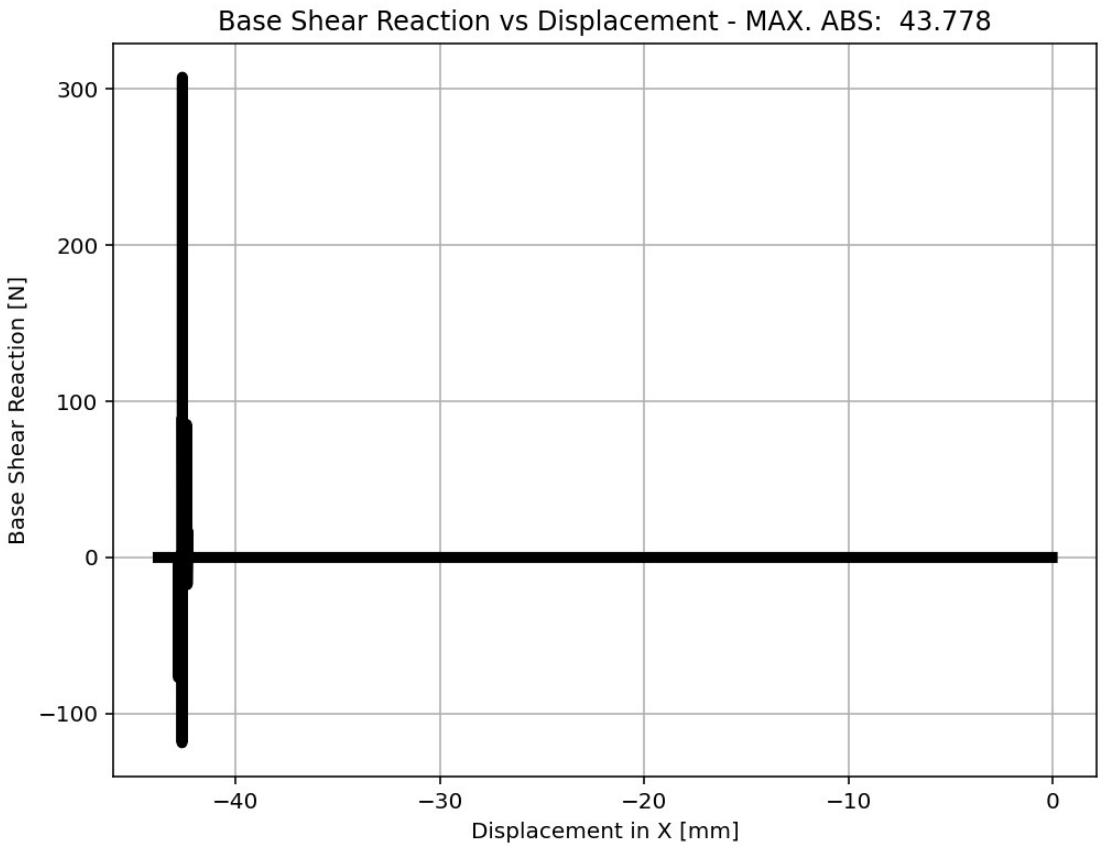

Rotation During the Explosion Analysis
0.0000
−0.0001
−0.0002
−0.0003
−0.0004
Rotation [rad]
0
2
4
6
8
10
12
14
Explosion Analysis time [s]

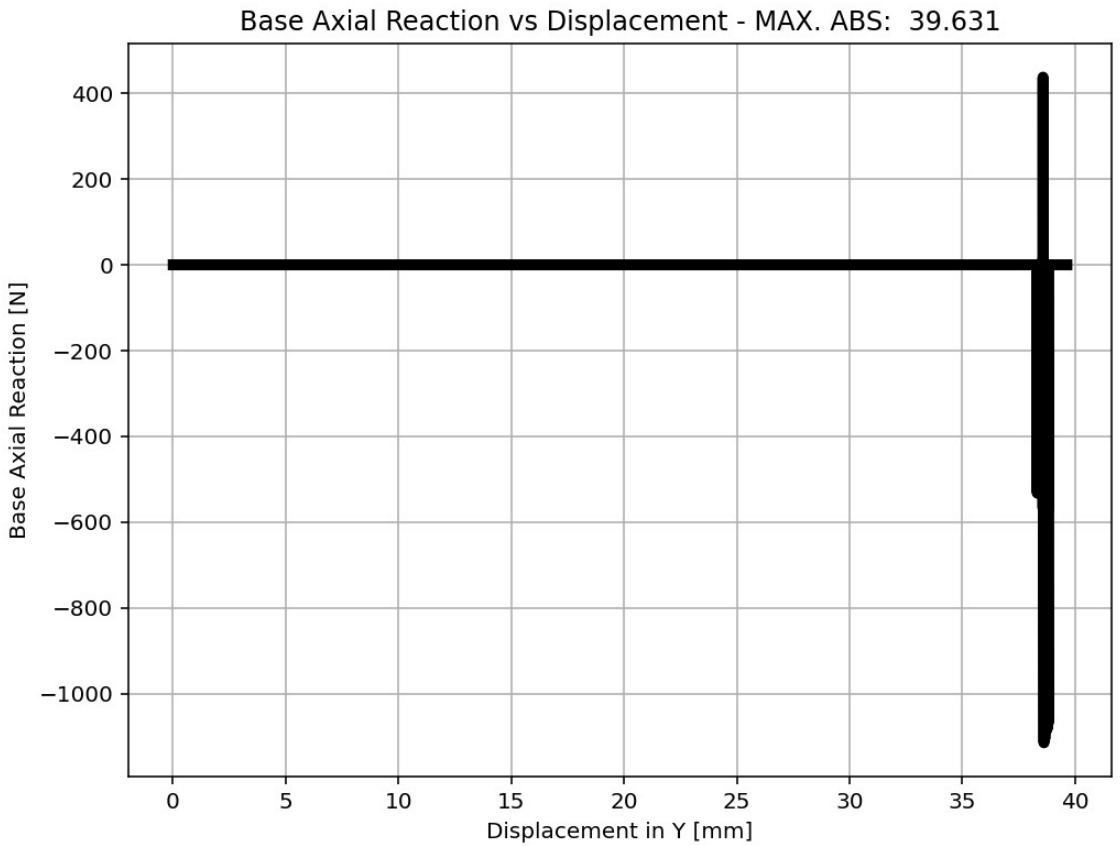
THERMAL
ANALYSIS RESULTS

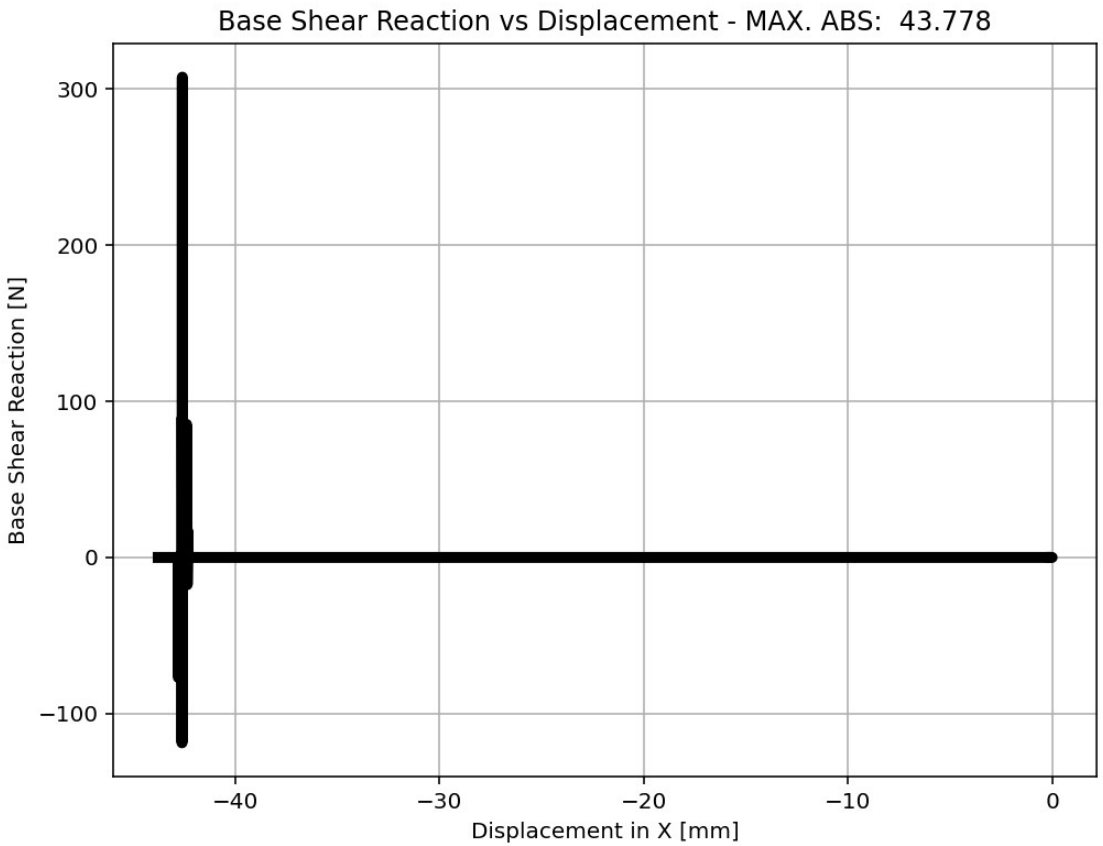

Time vs Displacement - MAX. ABS: 43.777821729882426 | ξ (Calculated): 1.00000e+02 %
Displacement in X [mm]
0
−10
−20
−30
−40
0
200
400
600
800
Time [s]

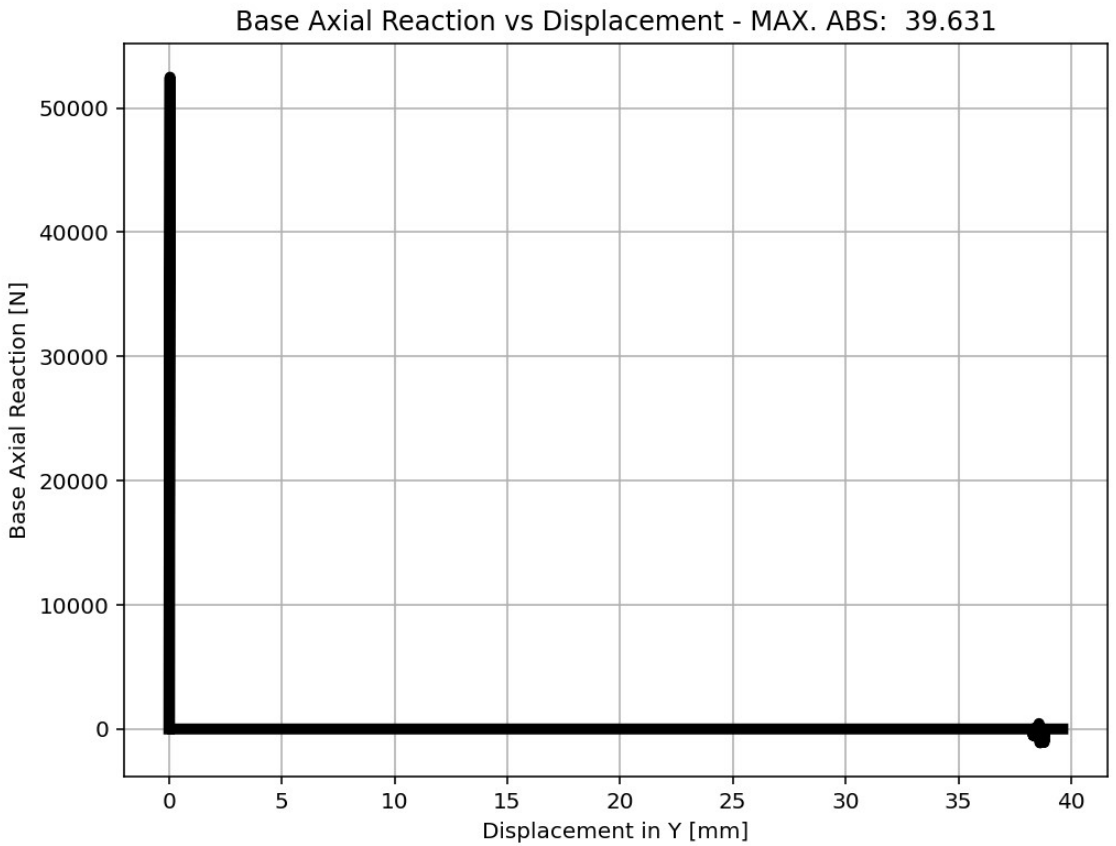

Time vs Displacement - MAX. ABS: 39.63120038596678
Displacement in Y [mm]
Time [s]
0
5
10
15
20
25
30
35
40
0
200
400
600
800

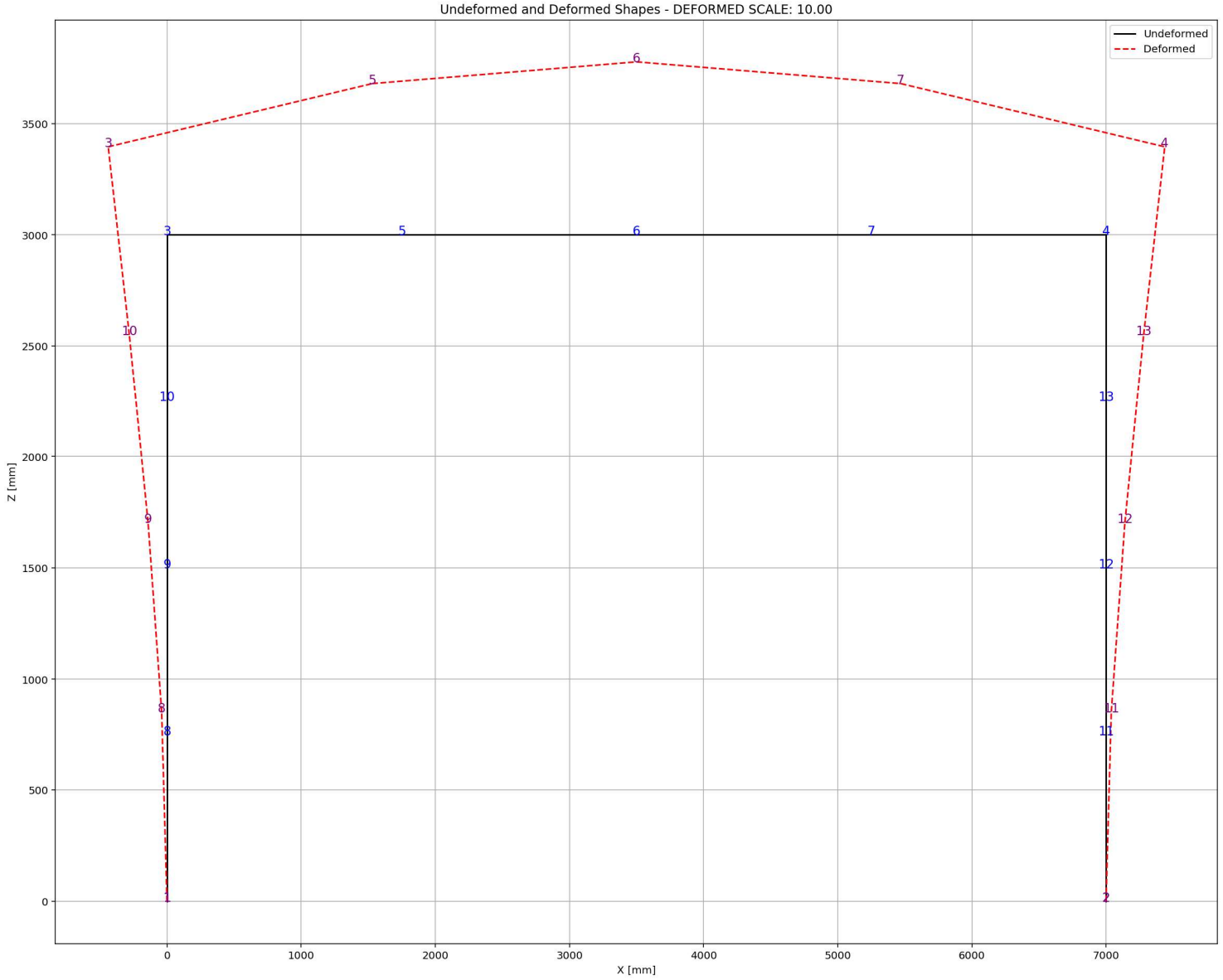

Time vs Base-reaction - MAX. ABS: 307.3855022700882
Base-reaction [N]
300
200
100
0
−100
0
200
400
600
800
Time [s]


Base Shear Reaction vs Displacement - MAX. ABS: 43.778
Base Shear Reaction [N]
300
200
100
0
−100
−40
−30
−20
−10
0
Displacement in X [mm]


Base Axial Reaction vs Displacement - MAX. ABS: 39.631
Base Axial Reaction [N]
400
200
0
−200
−400
−600
−800
−1000
0
5
10
15
20
25
30
35
40
Displacement in Y [mm]


Base Shear Reaction vs Displacement - MAX. ABS: 43.778
Base Shear Reaction [N]
300
200
100
0
−100
−40
−30
−20
−10
0
Displacement in X [mm]


Base Axial Reaction vs Displacement - MAX. ABS: 39.631
Base Axial Reaction [N]
50000
40000
30000
20000
10000
0
0
5
10
15
20
25
30
35
40
Displacement in Y [mm]


Undeformed and Deformed Shapes - DEFORMED SCALE: 10.00
Undeformed
Deformed
Z [mm]
X [mm]
0
500
1000
1500
2000
2500
3000
3500
0
1000
2000
3000
4000
5000
6000
7000