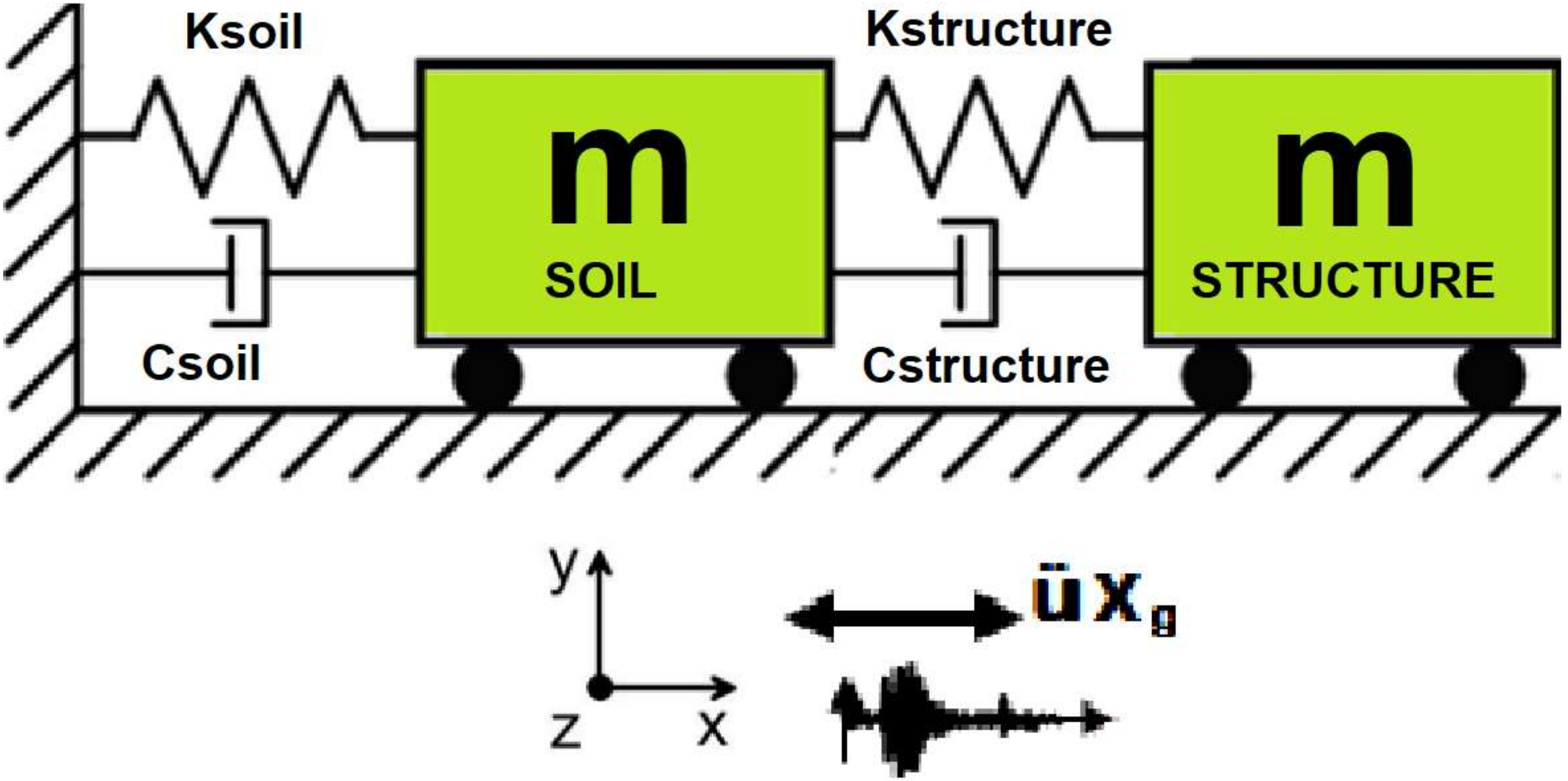
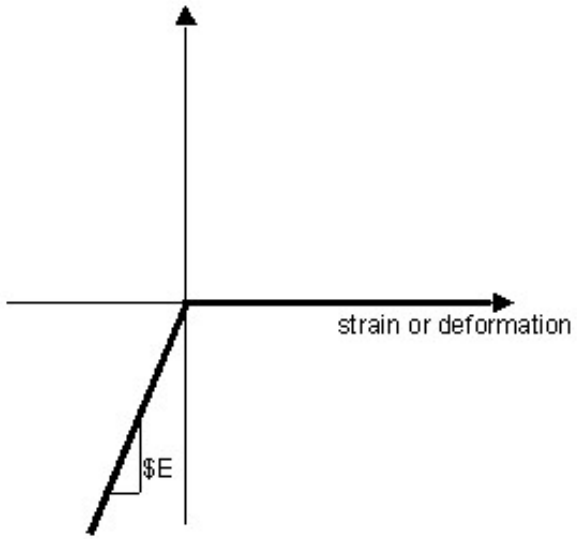
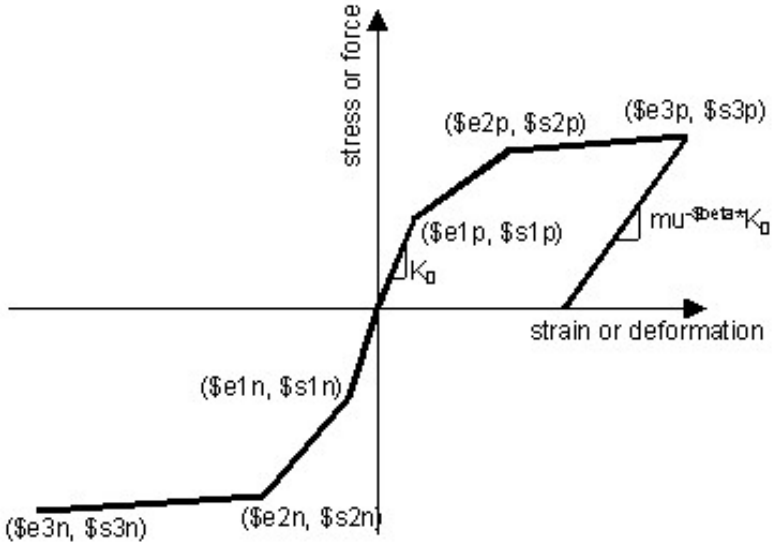
>> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<

NONLINEAR DYNAMIC ANALYSIS OF A TWO-DOF SOIL–STRUCTURE SYSTEM UNDER 20 GROUND MOTIONS WITH RESPONSE SPECTRA AND DUCTILITY DAMAGE INDEX CALCULATION IN OPENSEES

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)

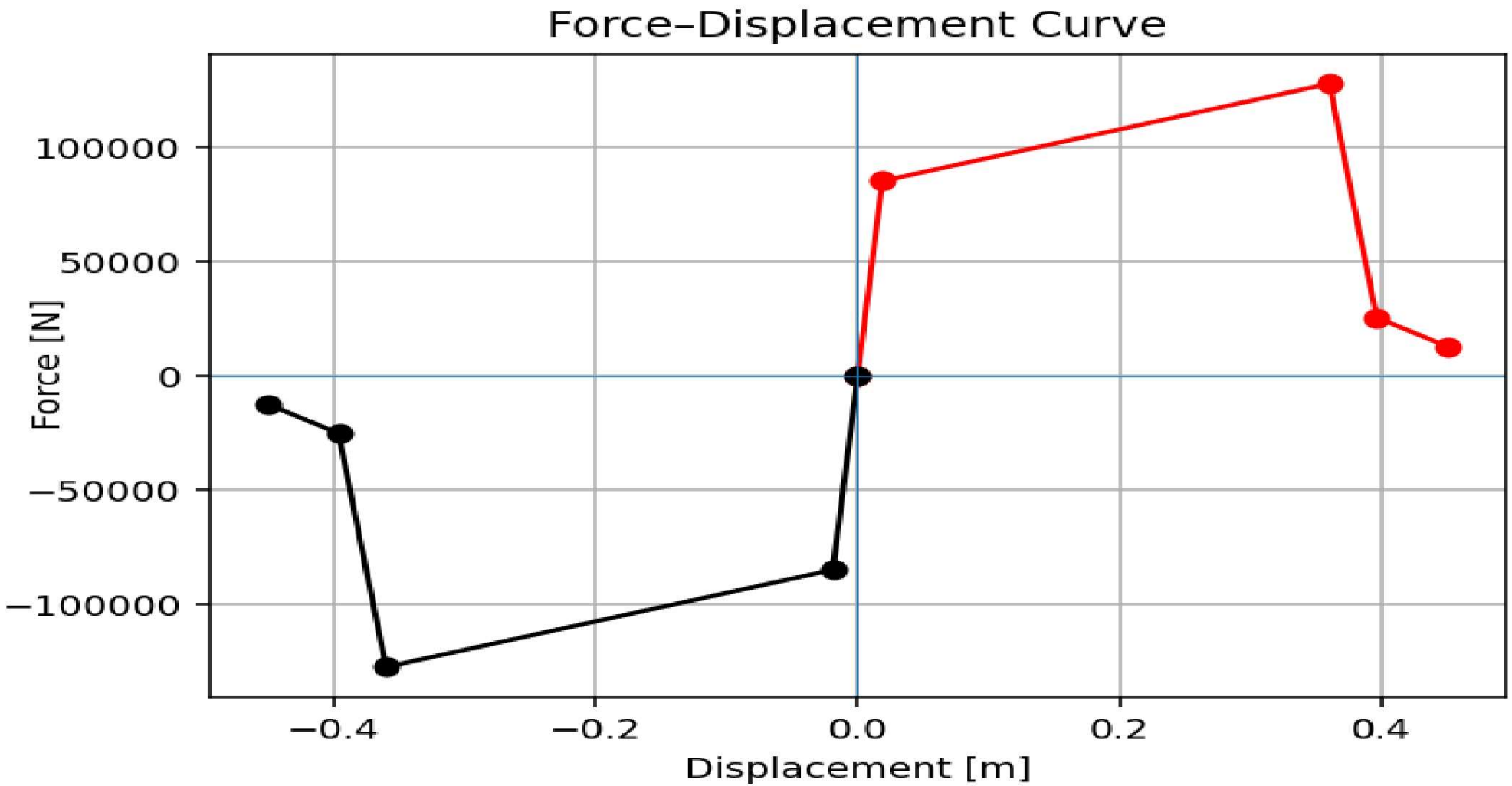

Ksoil
Kstructure
m
SOIL
m
STRUCTURE
Csoil
Cstructure
y
z
x
ü x g





SOIL STIFFNESS

STRUCTURE STIFFNESS


Force–Displacement Curve
100000
50000
0
−50000
−100000
Force [N]
−0.4
−0.2
0.0
0.2
0.4
Displacement [m]

$$Structural\ Ductility\ Damage\ Index = \frac{\Delta_d - \Delta_y}{\Delta_u - \Delta_y}$$

$$\Delta_d = Lateral\ Displaement\ from\ Dynamic\ Analysis$$

$$\Delta_y = Lateral\ Yield\ Displaement\ from\ Pushover\ Analysis$$

$$\Delta_u = Lateral\ Ultimate\ Displaement\ from\ Pushover\ Analysis$$

Spyder (Python 3.12)

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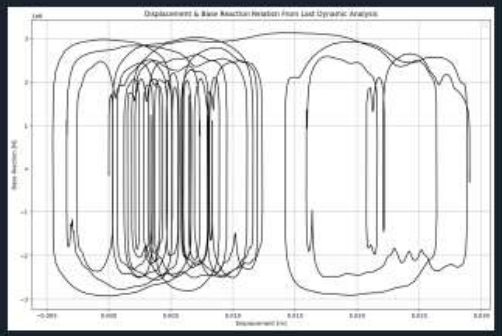
...rs\Dell\Desktop\OPENSEES_FILES\MDOF_RESPONSE_SPECTRUM_SEISMIC

C:\Users\Dell\Desktop\OPENSEES_FILES\MDOF_RESPONS...OIL_&_INELASTIC_RESPONSE_SPECTRUM_SEISMIC_SDOF.py

SOIL__INELASTIC_R...UM_SEISMIC_SDOF.py | FRAGILITY_CURVE_FUN.py

```
1  ##########################################################################################################
2  #                    >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<                    #
3  #       NONLINEAR DYNAMIC ANALYSIS OF A TWO-DOF SOIL-STRUCTURE SYSTEM UNDER 20 GROUND MOTIONS WITH       #
4  #                RESPONSE SPECTRA AND DUCTILITY DAMAGE INDEX CALCULATION IN OPENSEES                     #
5  #--------------------------------------------------------------------------------------------------------#
6  #                           THIS PROGRAM WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)                   #
7  #                                  EMAIL: salar.d.ghashghaei@gmail.com                                   #
8  ##########################################################################################################
9
10 """
11 This code implements a comprehensive nonlinear dynamic analysis framework for
12 performance-based earthquake engineering assessment of multi-degree-of-freedom
13 (MDOF) systems. The methodology combines traditional nonlinear time-history
14 analysis with modern probabilistic and machine learning techniques for advanced
15 structural performance evaluation.
16
17 KEY ENGINEERING OBJECTIVES:
18 1. Comparative assessment of hysteretic models for seismic response prediction
19 2. Probabilistic seismic demand analysis using multiple ground motions
20 3. Development of fragility curves for performance-based earthquake engineering
21 4. Integration of data science methods for structural reliability assessment
22
23 ANALYTICAL FEATURES:
24 - Nonlinear material behavior with pinching and degradation
25 - Response spectrum analysis across period range
26 - Real-time structural health monitoring metrics
27 - Statistical characterization of seismic demands
28 - Machine learning-based damage prediction
29 ---------------------------------
30 Model setup:
31  - SDOF properties: mass (m), initial stiffness (k), yield displacement (Dy), ultimate displacement (Du), visc
32  - Hysteresis models: HYSTERETICSM (pinching, stiffness degradation, strength decay).
33  - Damping: Rayleigh (or equivalent viscous) damping specified by target damping ratio xi for the fundamental
34
```

18 %



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

Spyder (Python 3.12)

File Edit Search Source Run Debug Consoles Projects Tools View Help

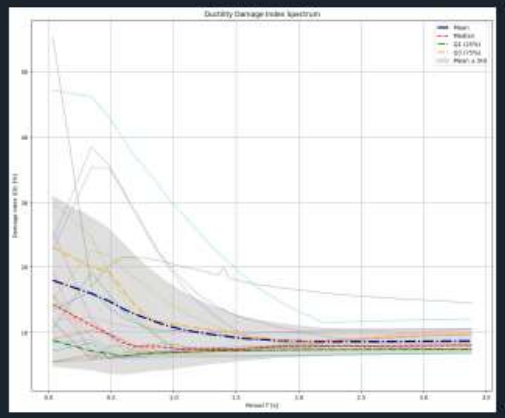
...rs\Dell\Desktop\OPENSEES_FILES\MDOF_RESPONSE_SPECTRUM_SEISMIC

C:\Users\Dell\Desktop\OPENSEES_FILES\SDOF_RESPONSE_SPECTRUM_SEISMIC\FRAGILITY_CURVE_FUN.py

SOIL__INELASTIC_R...UM_SEISMIC_SDOF.py | FRAGILITY_CURVE_FUN.py

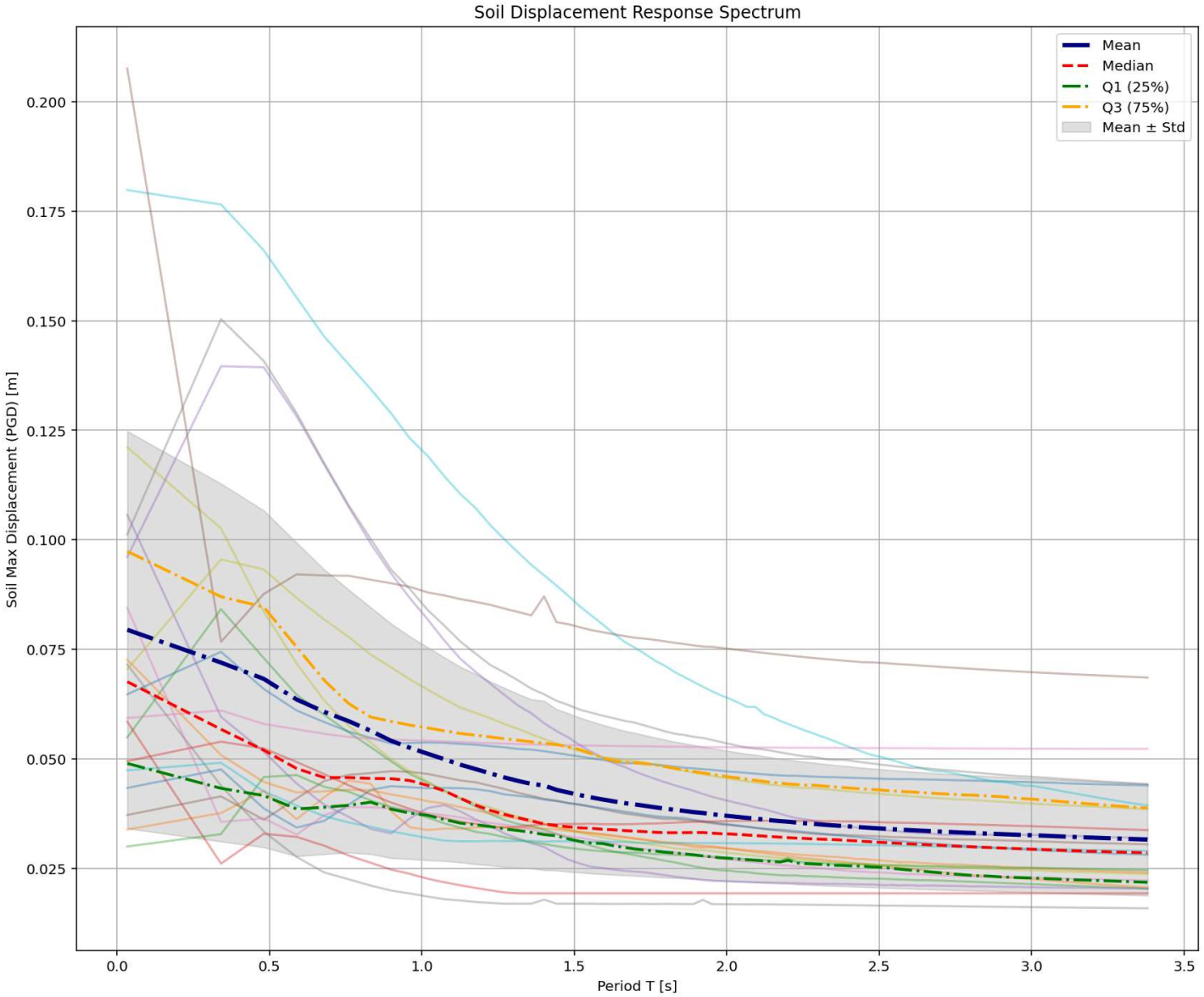
```python
def FRAGILITY_CURVE(im_values, damage_states, X_LABEL, SEMILOGY=True, PLOT_KIND=True):
    # THIS FUNCTION WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)
    from scipy.stats import norm
    import numpy as np
    import matplotlib.pyplot as plt

    # Fragility curves
    plt.figure(1, figsize=(12, 8))
    # Calculate and plot fragility curves for each damage state
    for damage_state, (median, beta) in damage_states.items():
        # Calculate log-normal probabilities
        ln_im = np.log(im_values)
        ln_median = np.log(median)
        probabilities = norm.cdf((ln_im - ln_median) / beta)
        if PLOT_KIND == False:
            plt.scatter(im_values, probabilities, marker='o', label=f'{damage_state} (η={median}, θ={beta}')
        if PLOT_KIND == True:
            plt.plot(im_values, probabilities, lw=2, label=f'{damage_state} (η={median}, θ={beta})')
    plt.xlabel(X_LABEL)
    plt.ylabel('Probability of Exceedance')
    plt.title('Fragility Curves')
    plt.legend()
    if PLOT_KIND == True:
        plt.semilogy()
    plt.ylim(0, 1.0)
    plt.grid(True)
    plt.tight_layout()
    plt.show()
```

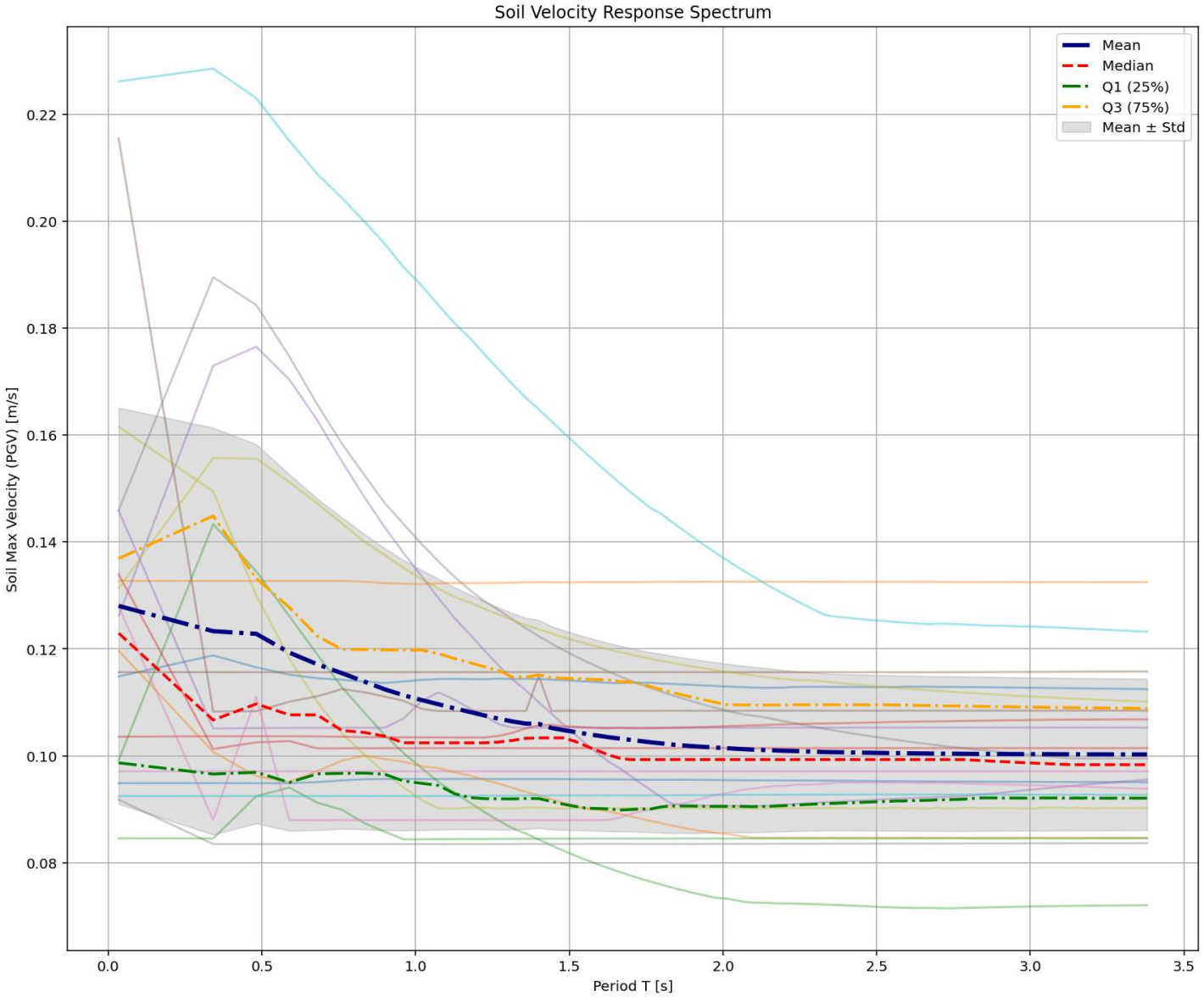
18 %

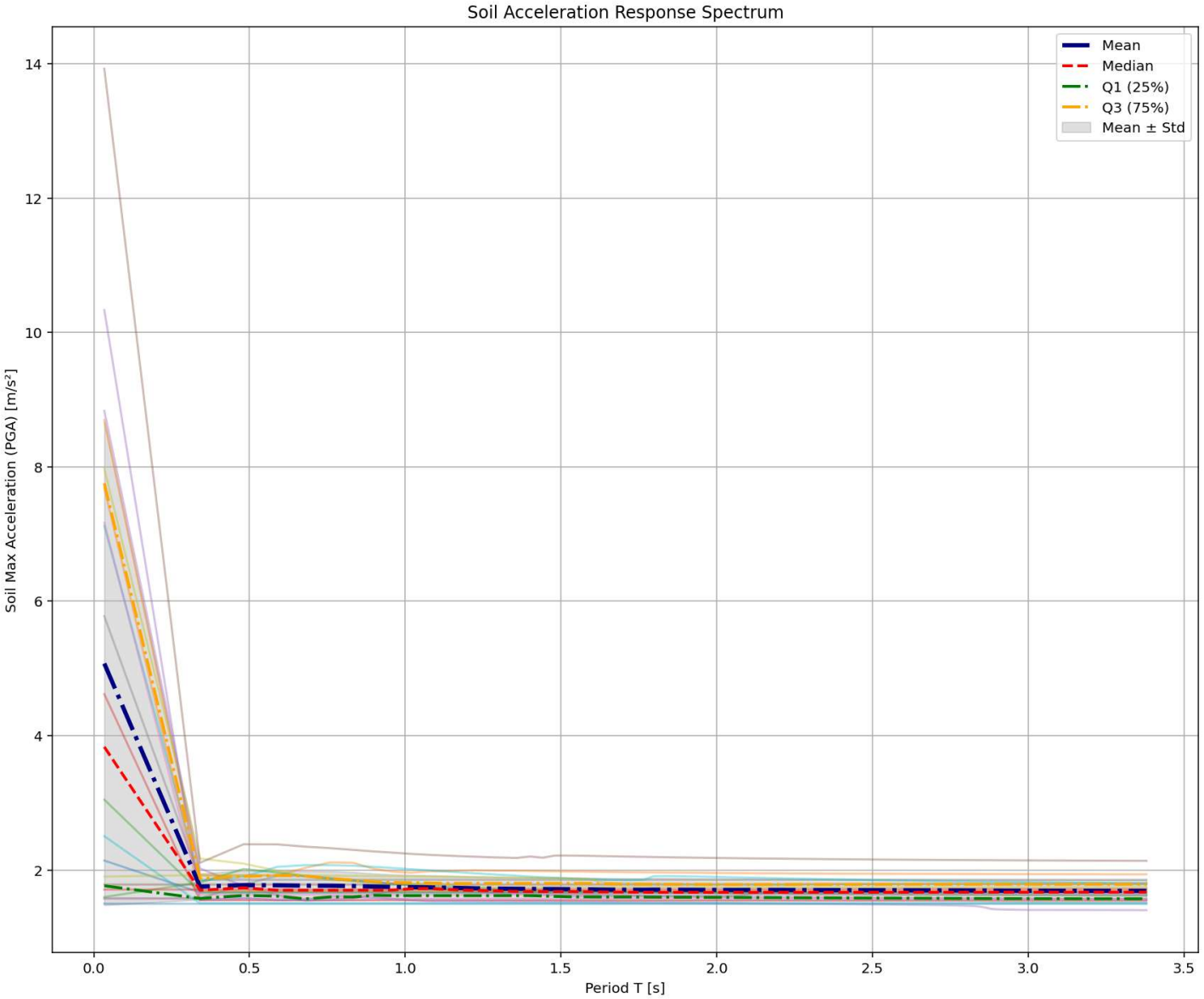


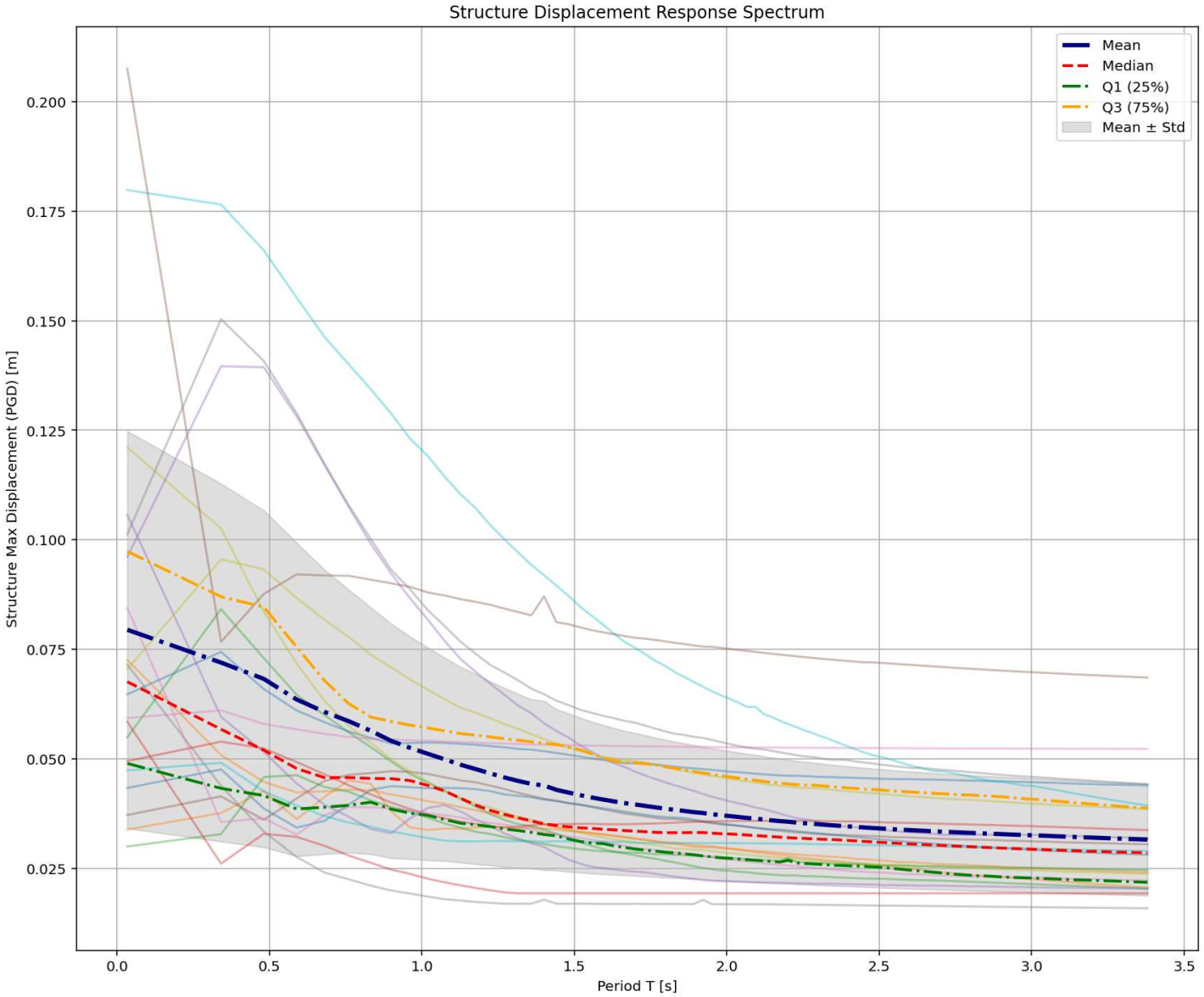
IPython Console | Files | Help | Variable Explorer | Debugger | Plots | History

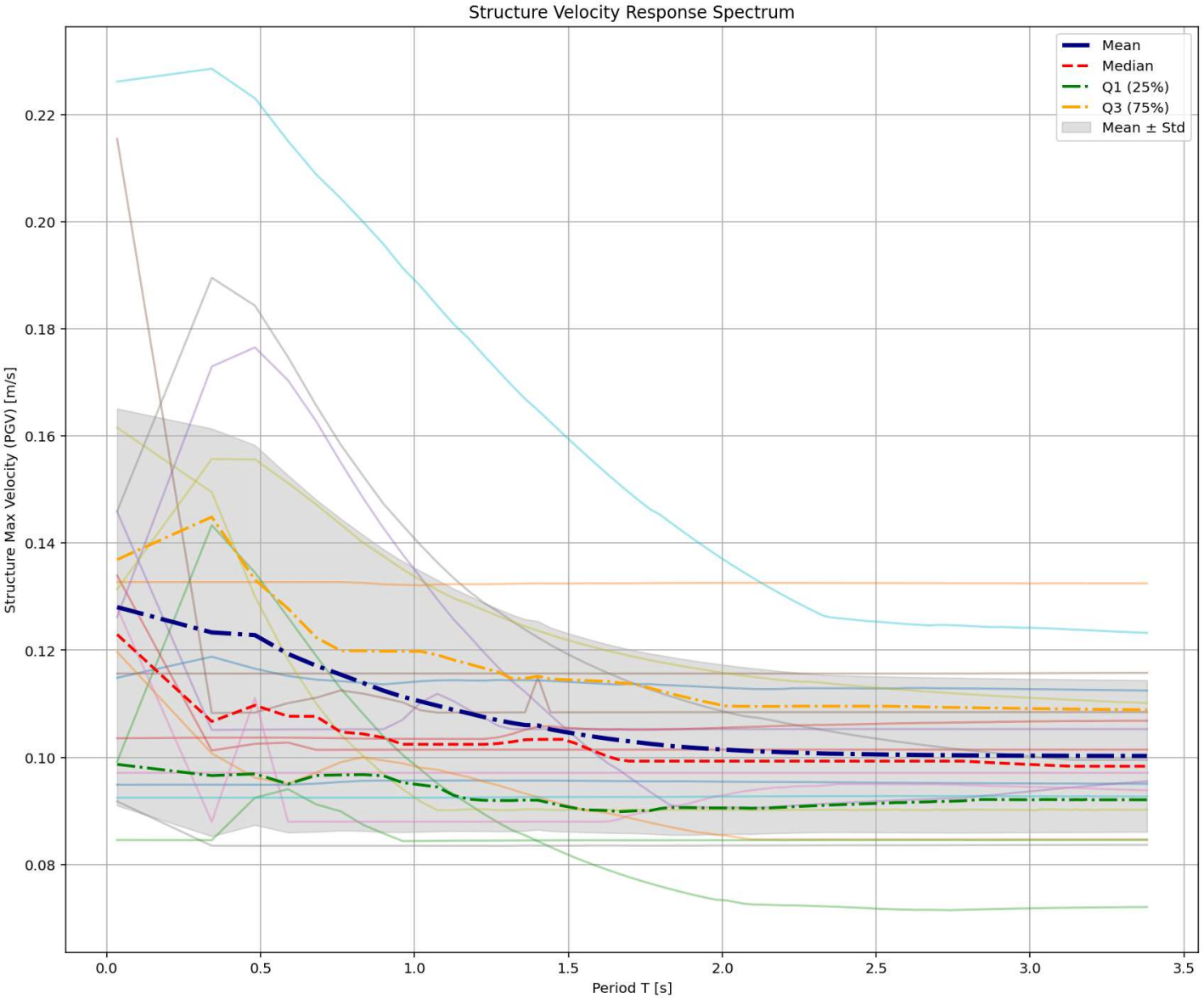
Inline Conda: anaconda3 (Python 3.12.7) LSP: Python Line 1, Col 1 UTF-8 CRLF RW Mem 47%

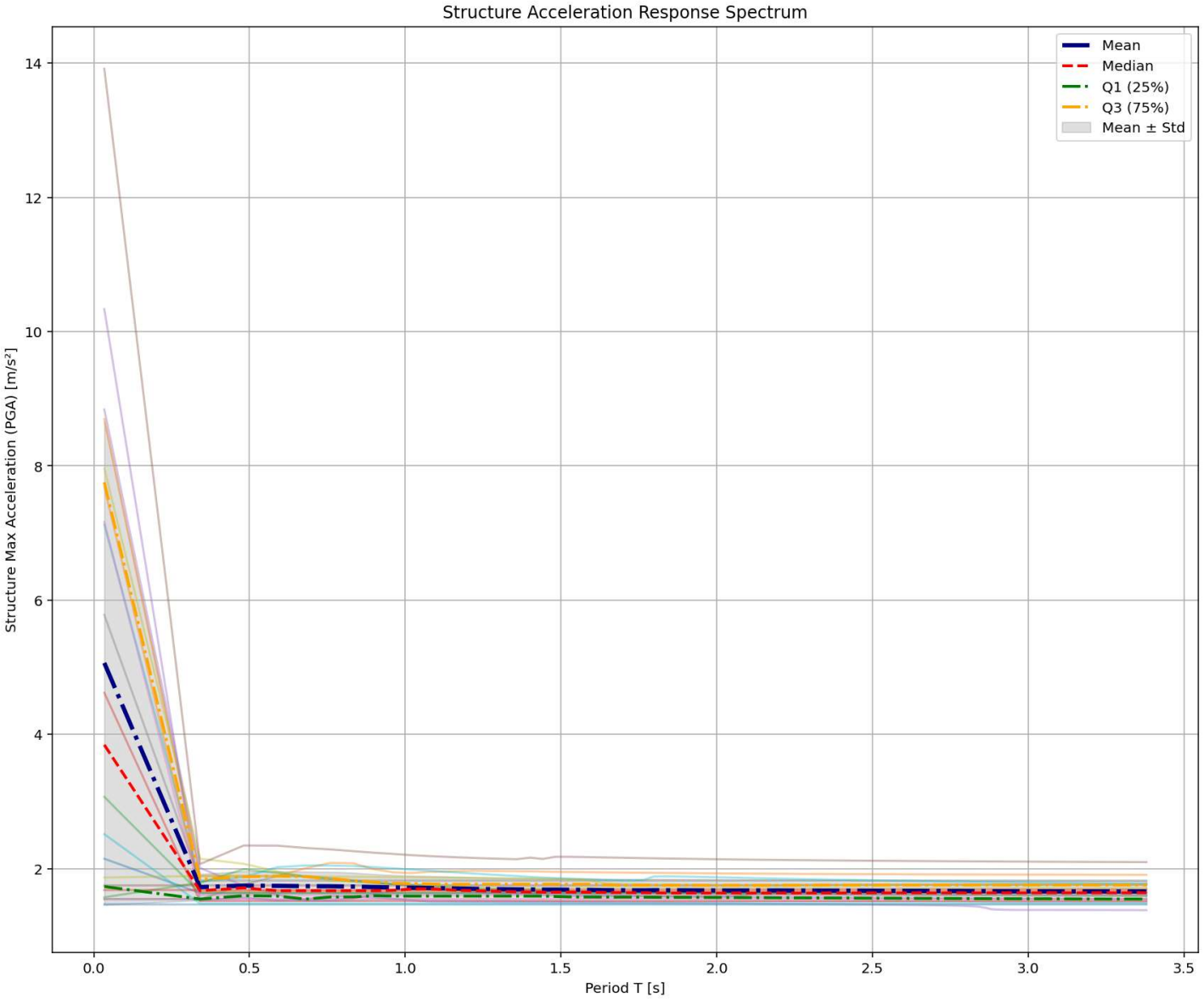

Soil Displacement Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Soil Max Displacement (PGD) [m]
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Period T [s]

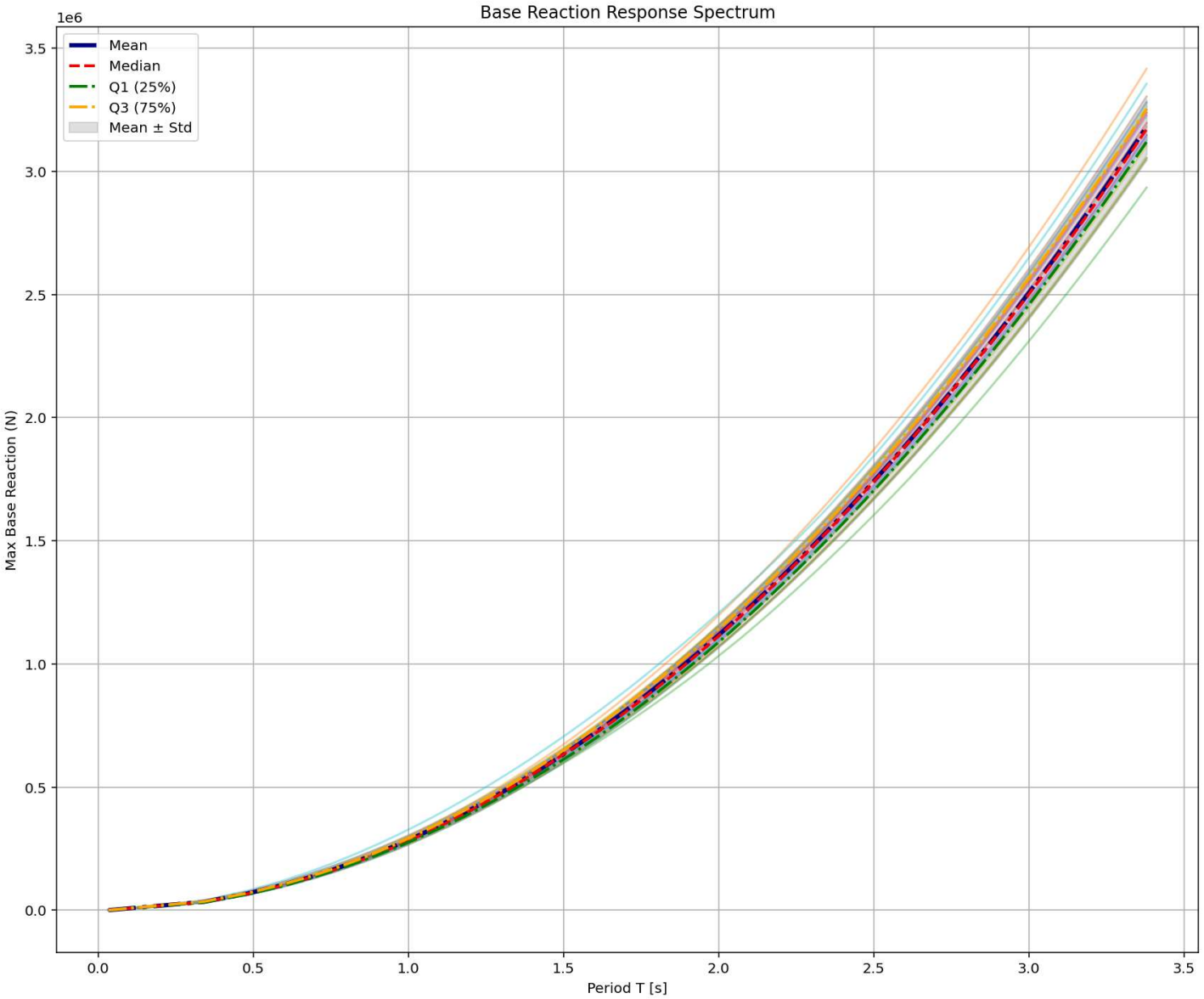

Soil Velocity Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Soil Max Velocity (PGV) [m/s]
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Period T [s]

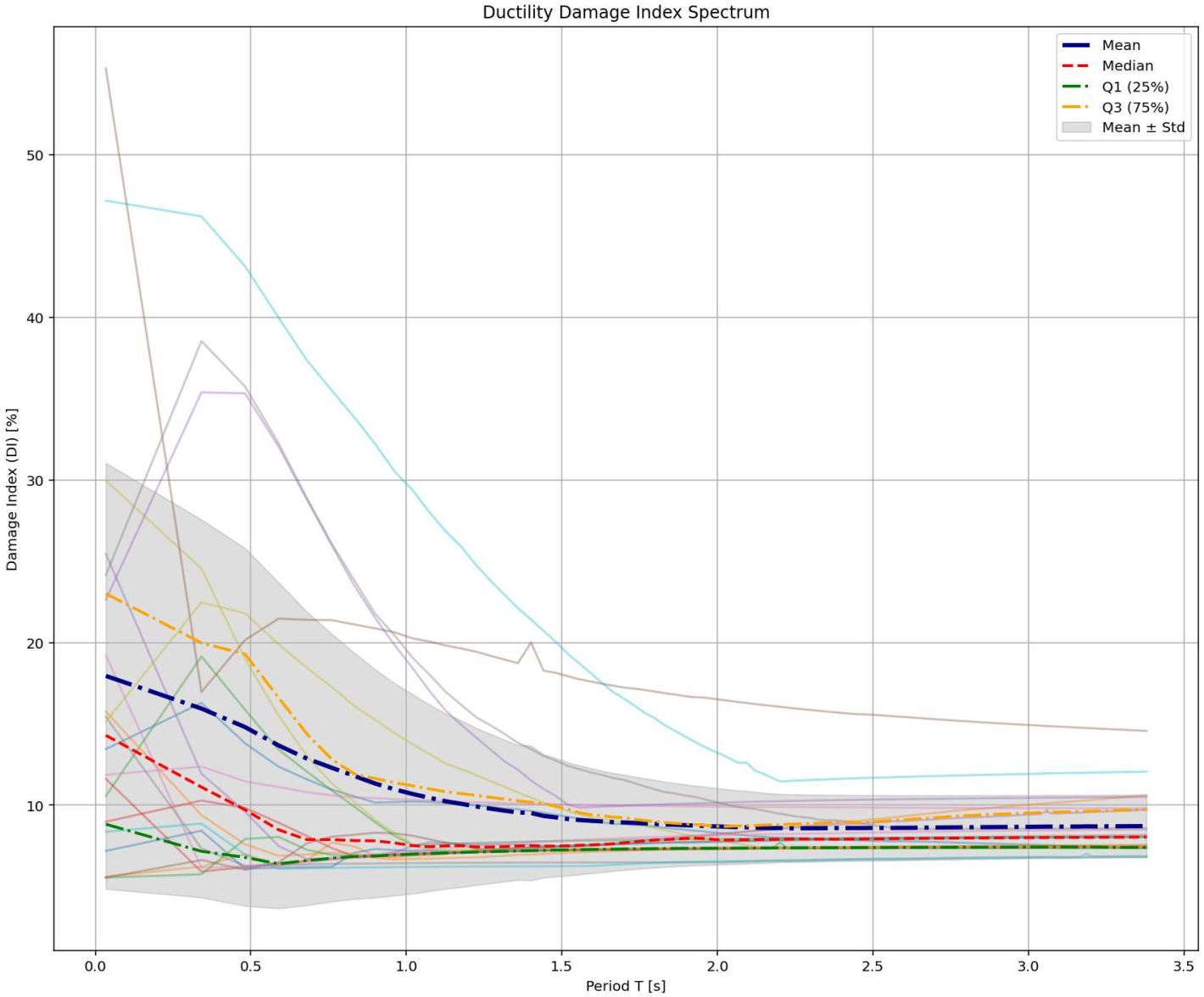

Soil Acceleration Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Soil Max Acceleration (PGA) [m/s²]
Period T [s]
2
4
6
8
10
12
14
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

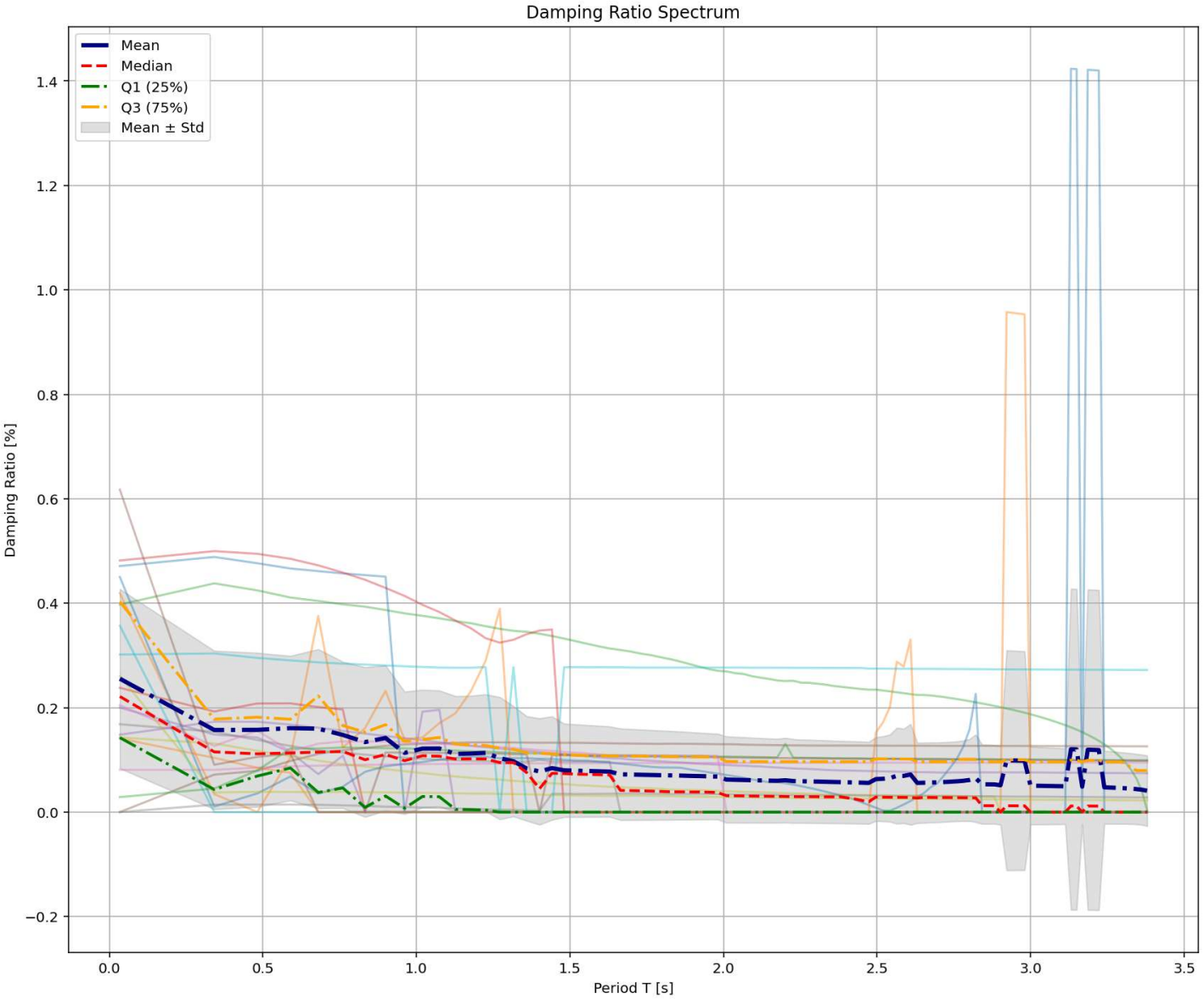

Structure Displacement Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Structure Max Displacement (PGD) [m]
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Period T [s]

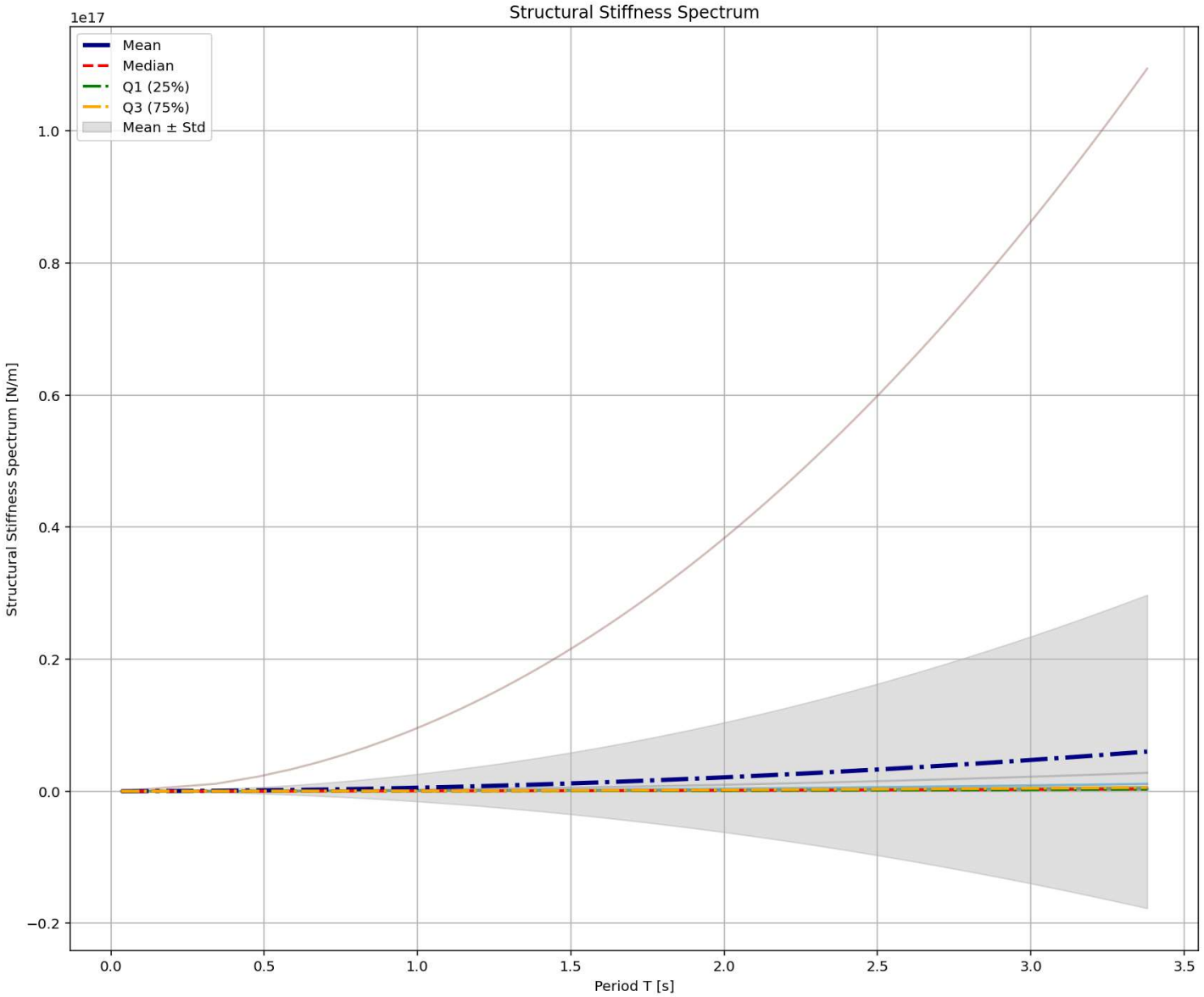

Structure Velocity Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Structure Max Velocity (PGV) [m/s]
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Period T [s]

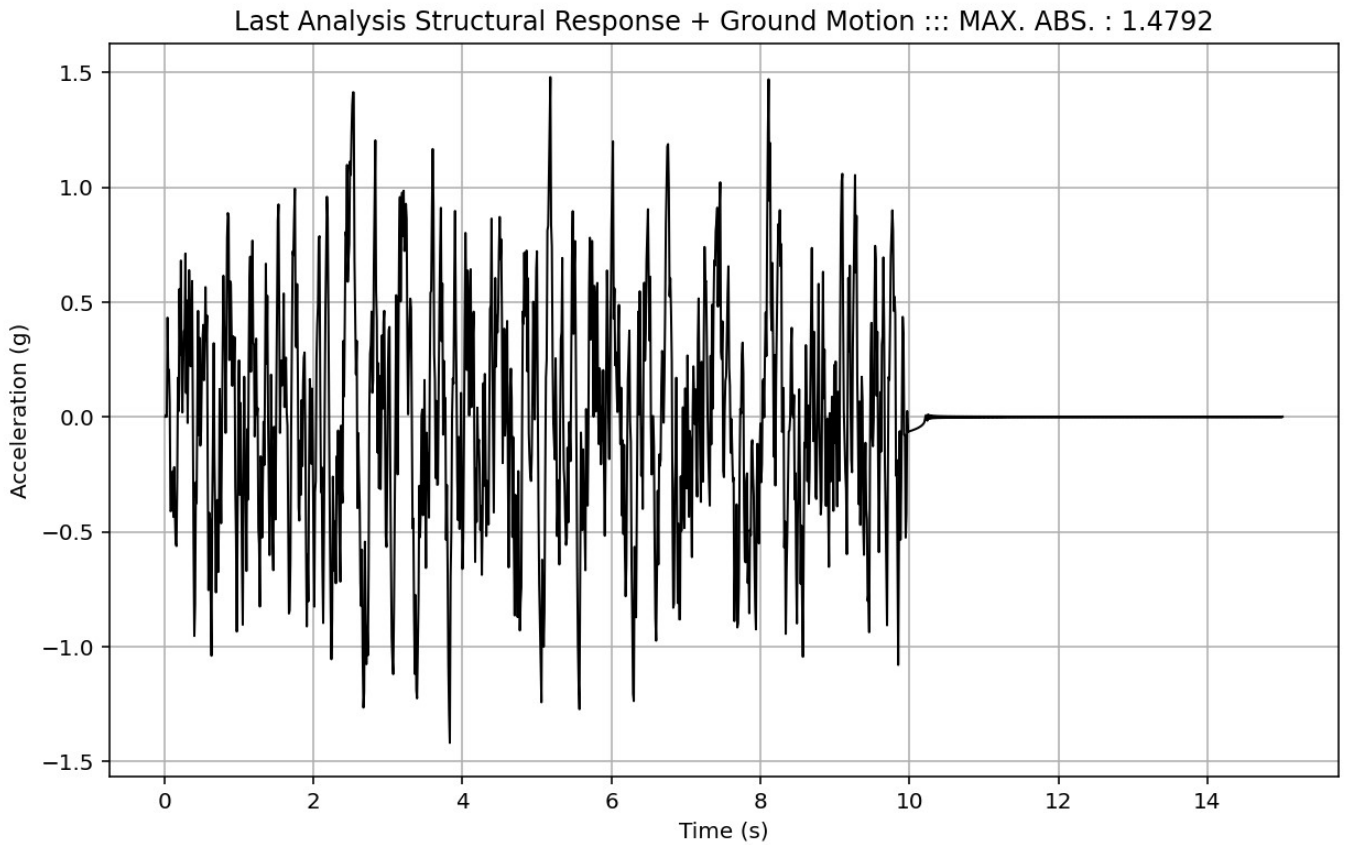

Structure Acceleration Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Structure Max Acceleration (PGA) [m/s²]
Period T [s]
14
12
10
8
6
4
2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

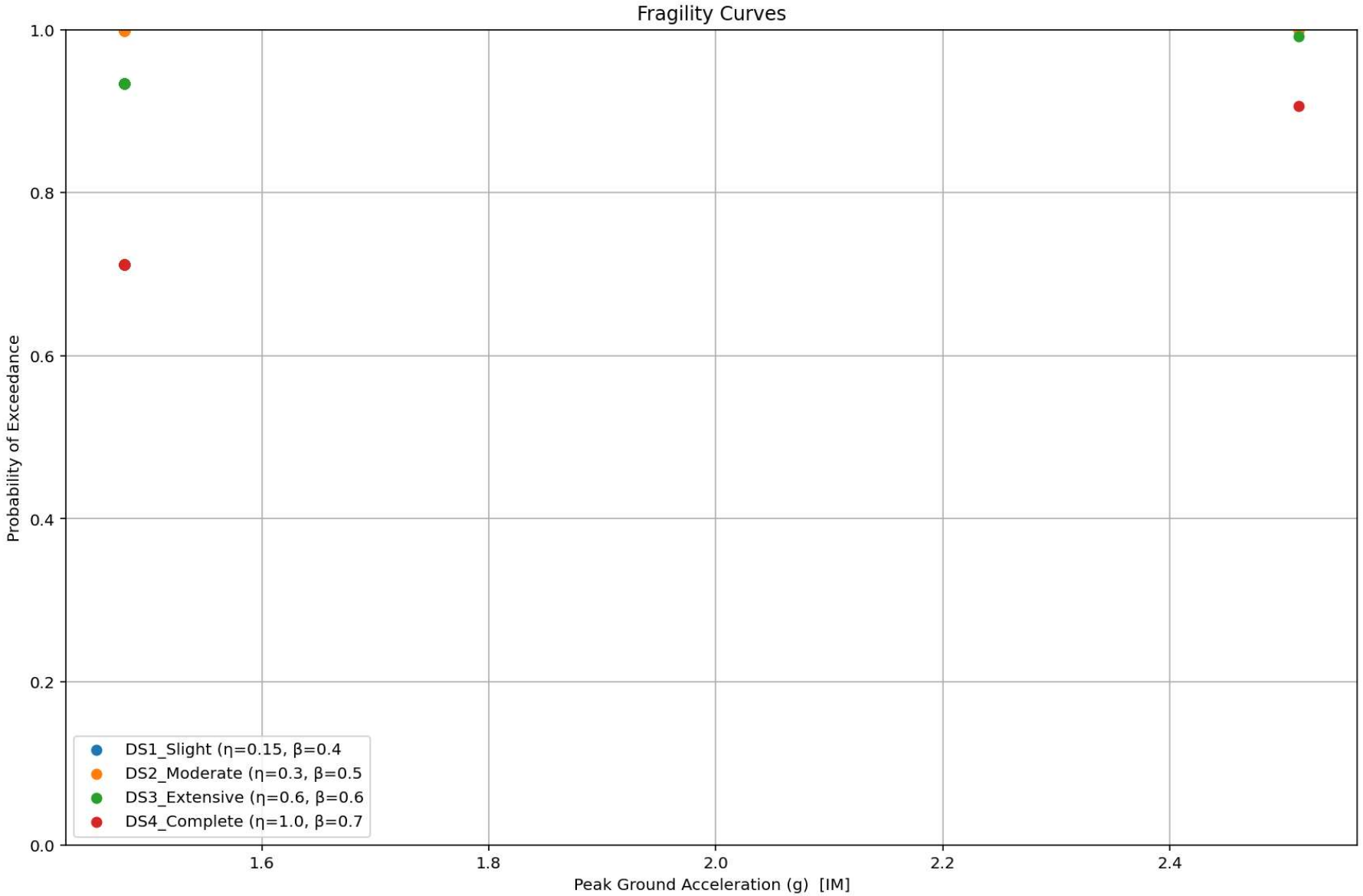

Base Reaction Response Spectrum
1e6
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Max Base Reaction (N)
Period T [s]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

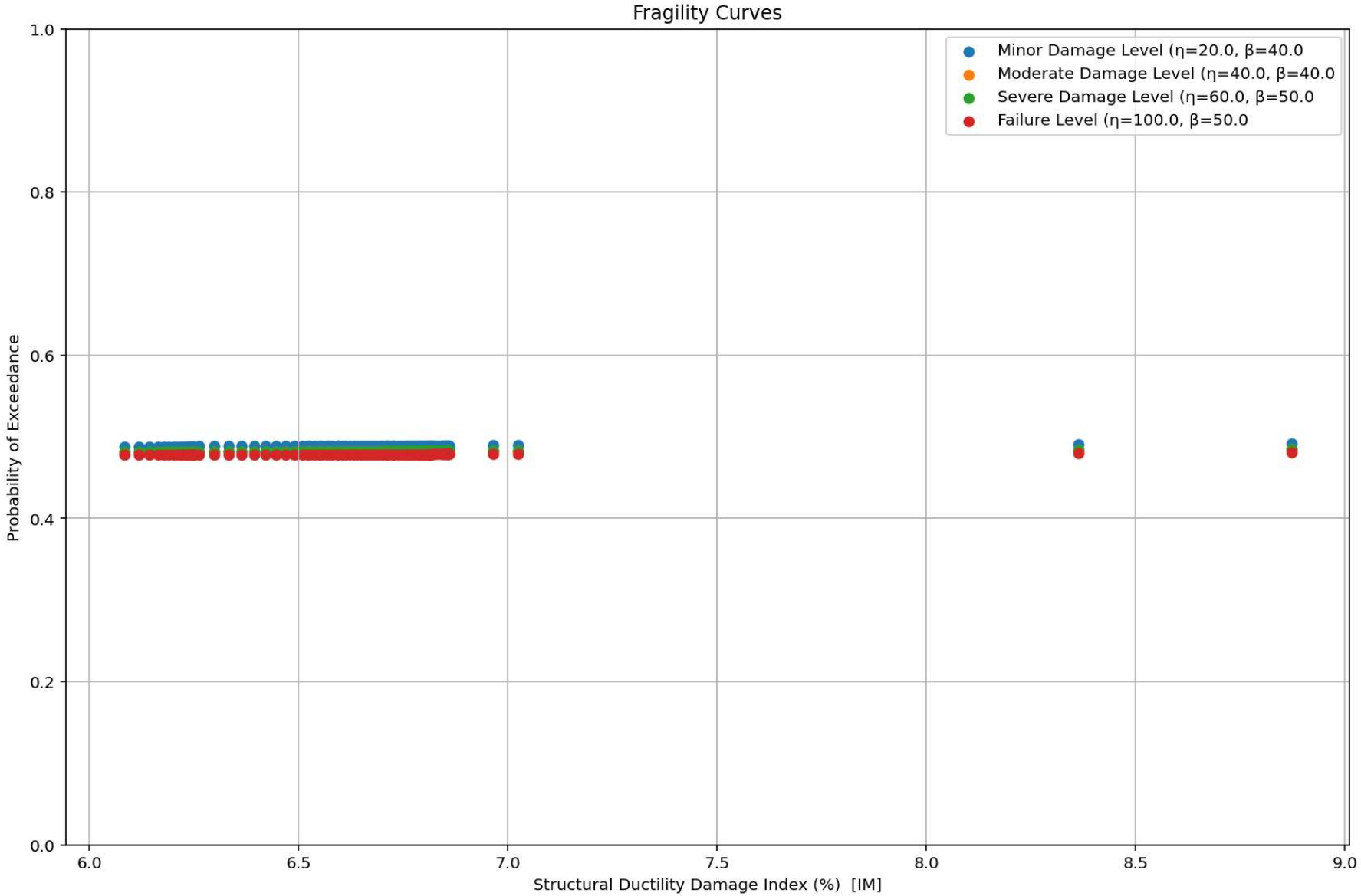

Ductility Damage Index Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Damage Index (DI) [%]
Period T [s]
10
20
30
40
50
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

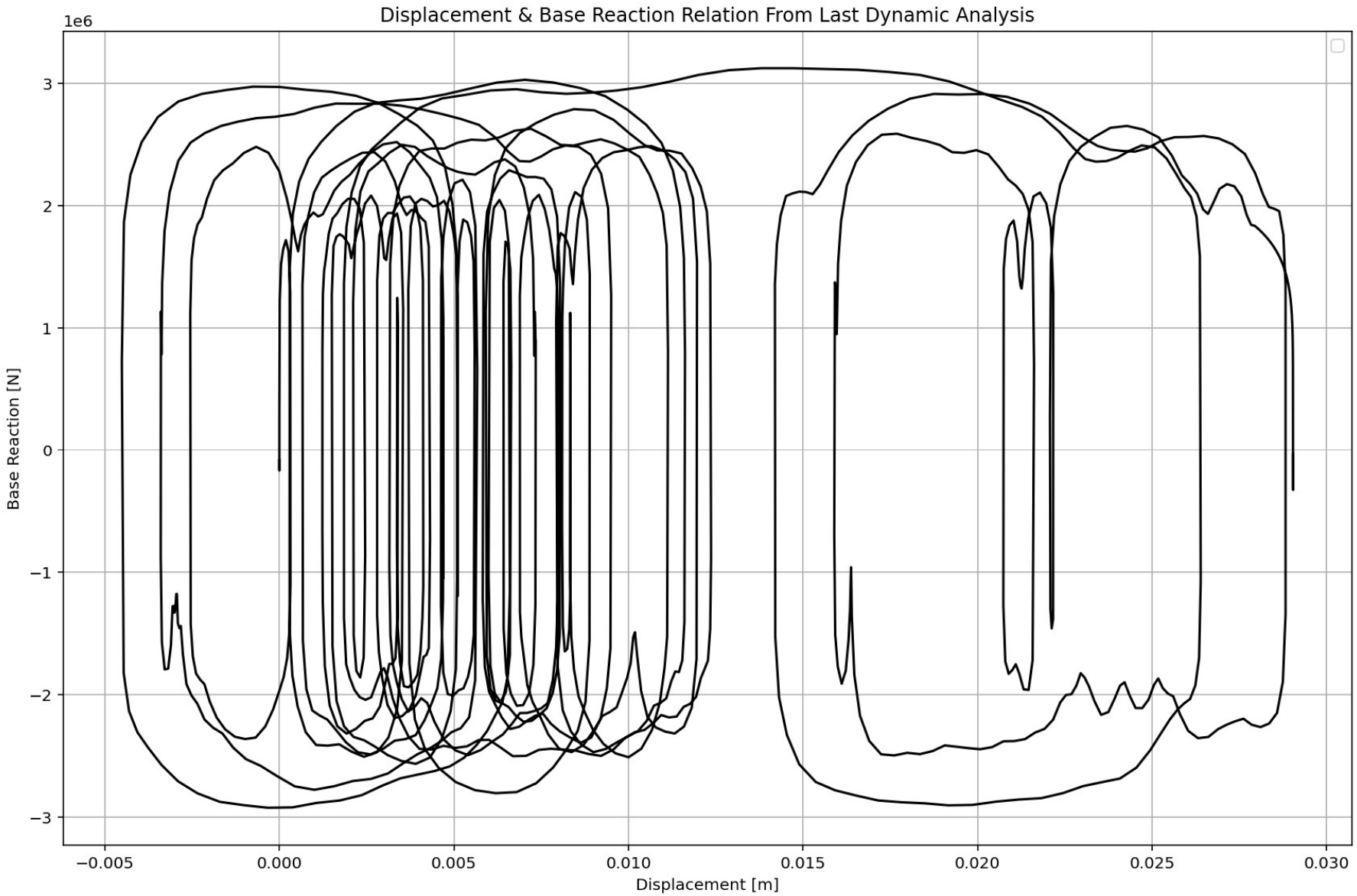

Damping Ratio Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Damping Ratio [%]
Period T [s]
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

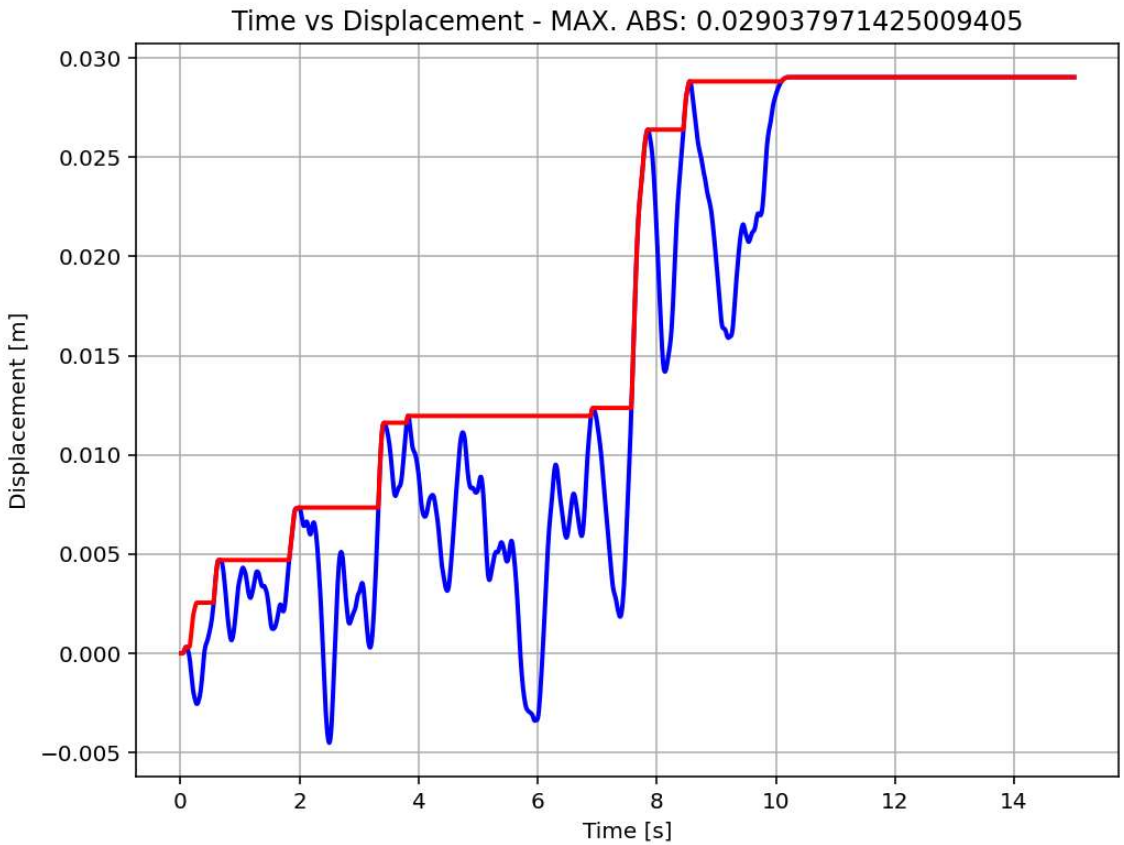

Structural Stiffness Spectrum
1e17
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
Structural Stiffness Spectrum [N/m]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Period T [s]

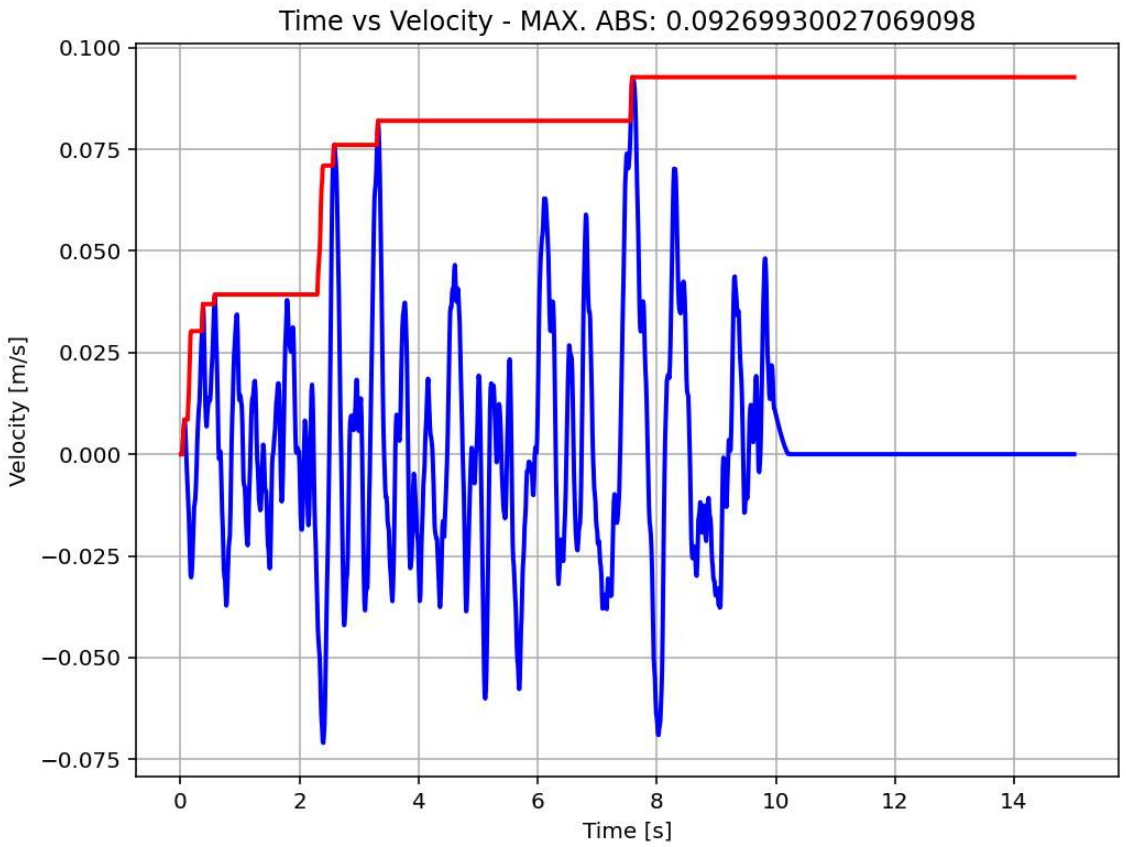

Last Analysis Structural Response + Ground Motion ::: MAX. ABS. : 1.4792
Acceleration (g)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
2
4
6
8
10
12
14
Time (s)

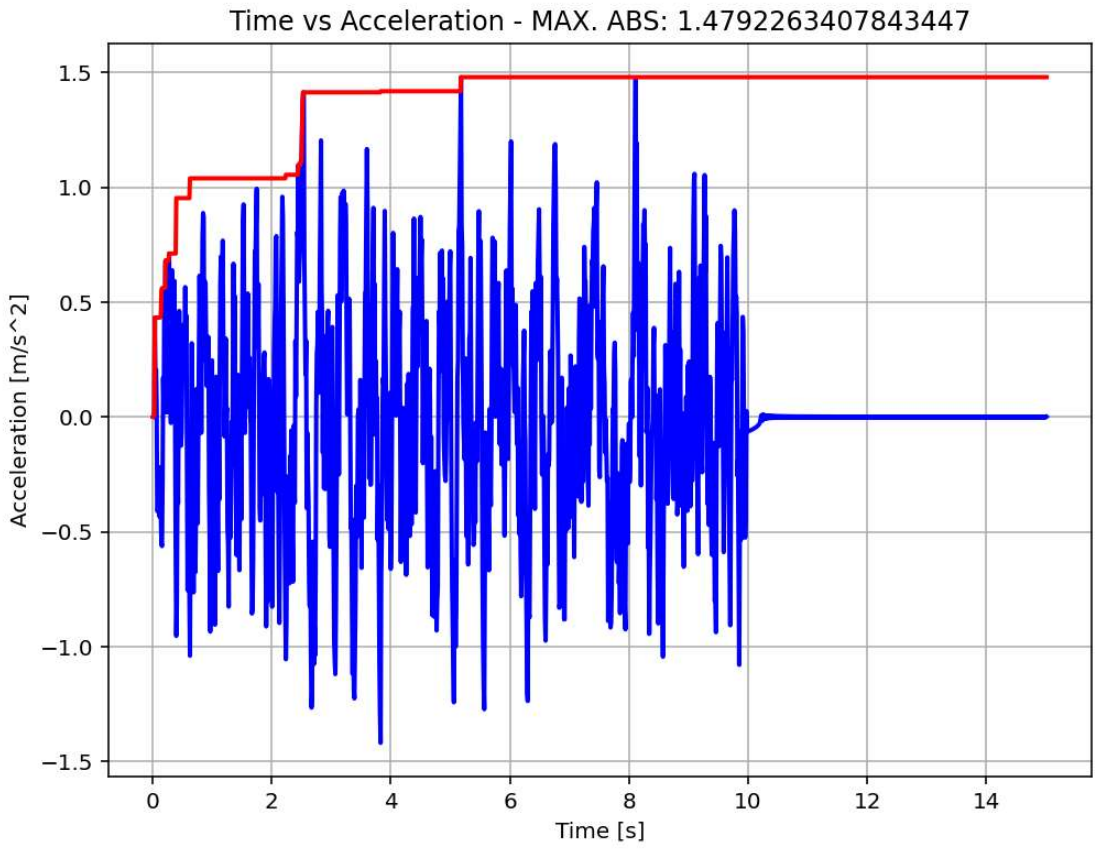

Fragility Curves
Probability of Exceedance
Peak Ground Acceleration (g) [IM]
1.0
0.8
0.6
0.4
0.2
0.0
1.6
1.8
2.0
2.2
2.4
DS1_Slight (η=0.15, β=0.4
DS2_Moderate (η=0.3, β=0.5
DS3_Extensive (η=0.6, β=0.6
DS4_Complete (η=1.0, β=0.7

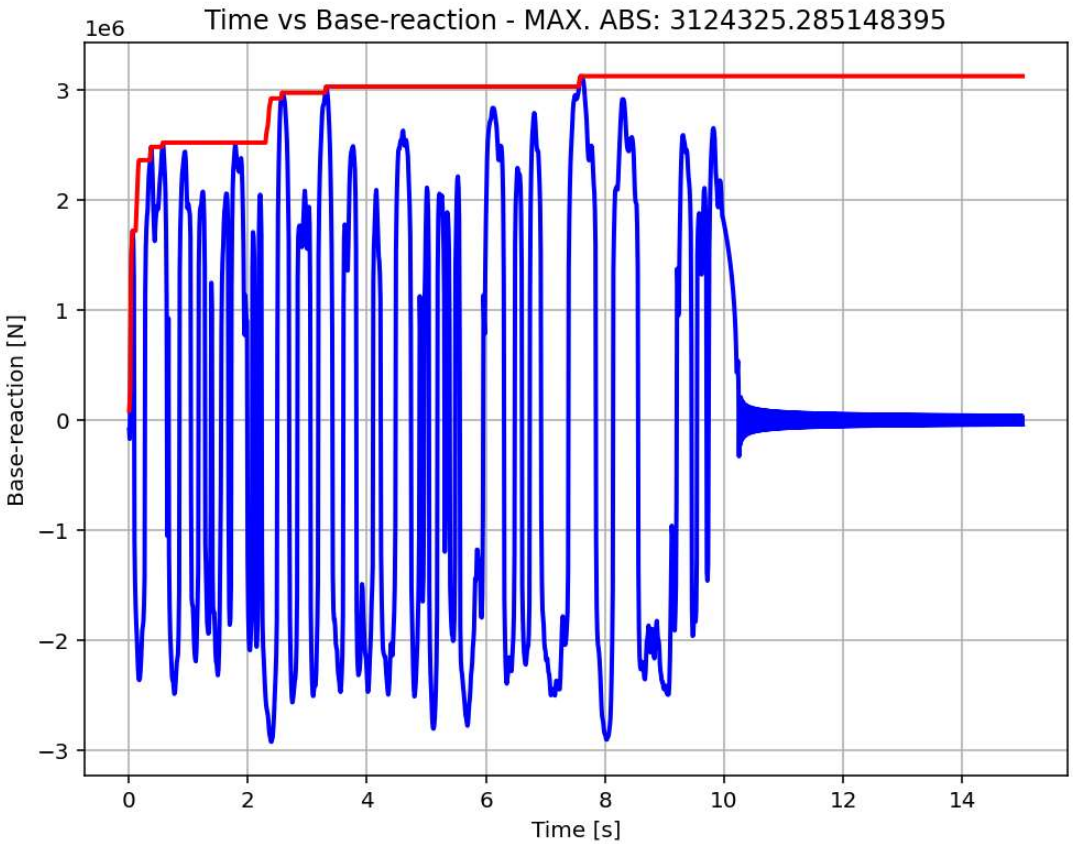

Fragility Curves
Minor Damage Level (η=20.0, β=40.0
Moderate Damage Level (η=40.0, β=40.0
Severe Damage Level (η=60.0, β=50.0
Failure Level (η=100.0, β=50.0
Probability of Exceedance
1.0
0.8
0.6
0.4
0.2
0.0
6.0
6.5
7.0
7.5
8.0
8.5
9.0
Structural Ductility Damage Index (%) [IM]

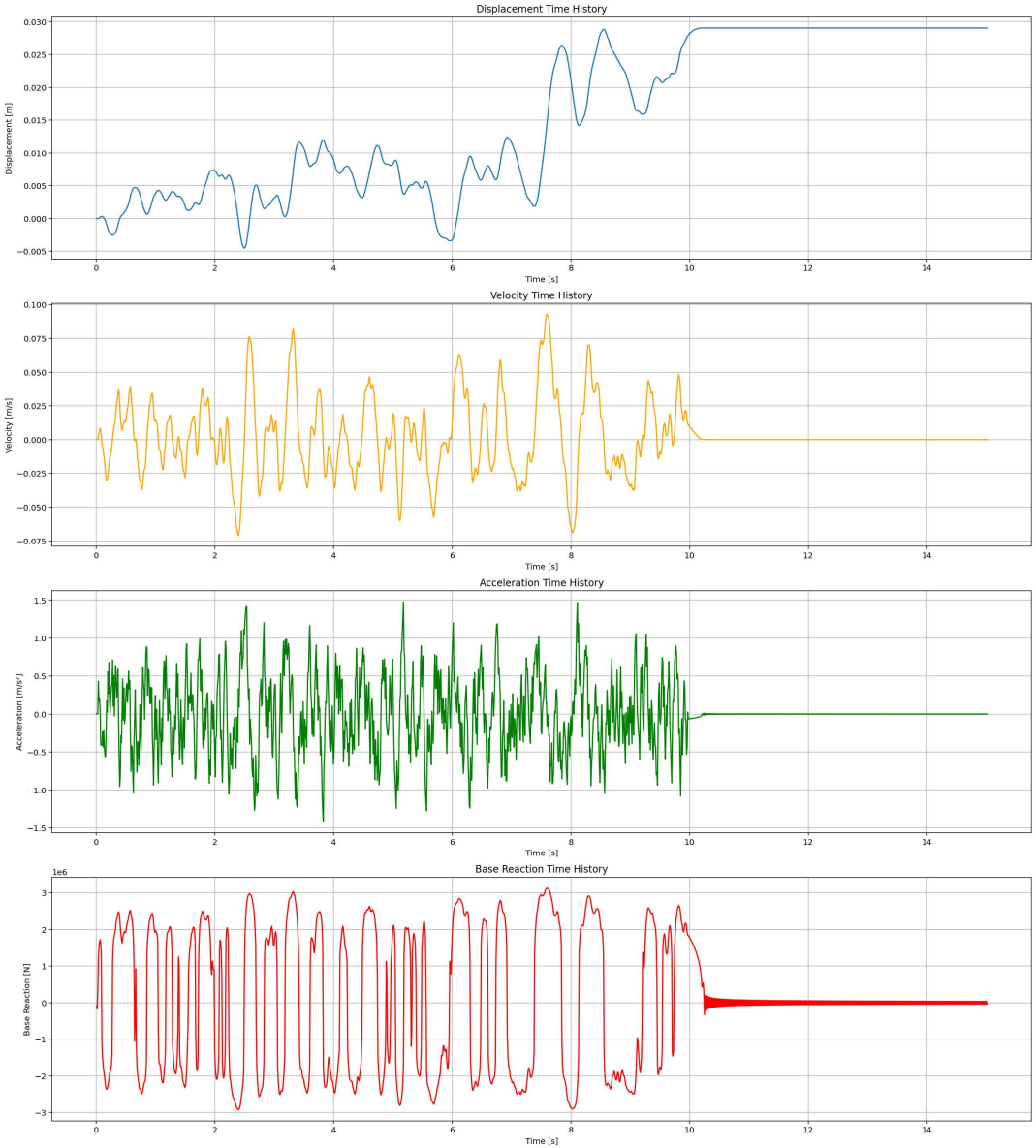

Displacement & Base Reaction Relation From Last Dynamic Analysis
1e6
3
2
1
0
−1
−2
−3
Base Reaction [N]
−0.005
0.000
0.005
0.010
0.015
0.020
0.025
0.030
Displacement [m]

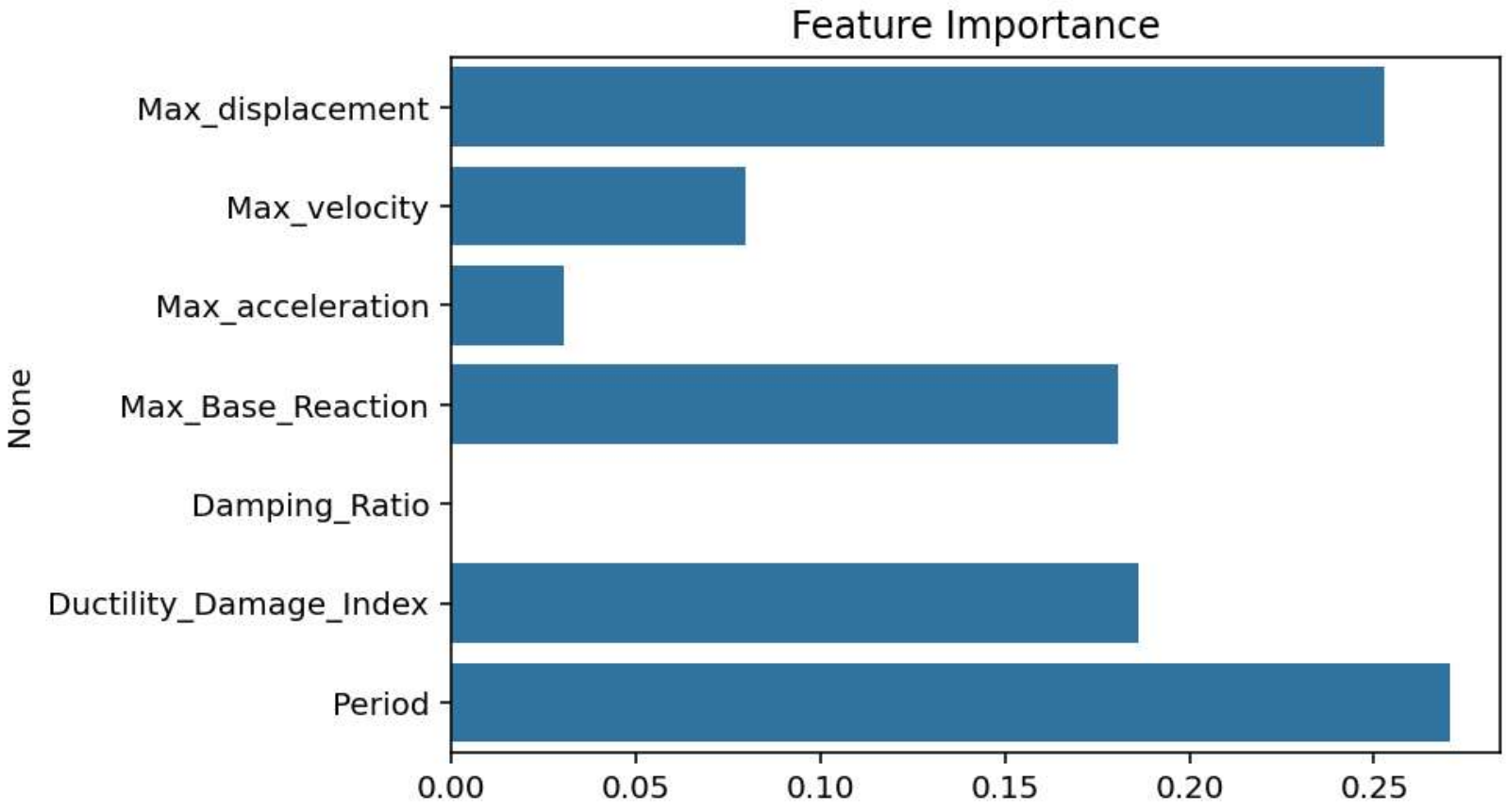

Time vs Displacement - MAX. ABS: 0.029037971425009405
Displacement [m]
0.030
0.025
0.020
0.015
0.010
0.005
0.000
−0.005
0
2
4
6
8
10
12
14
Time [s]

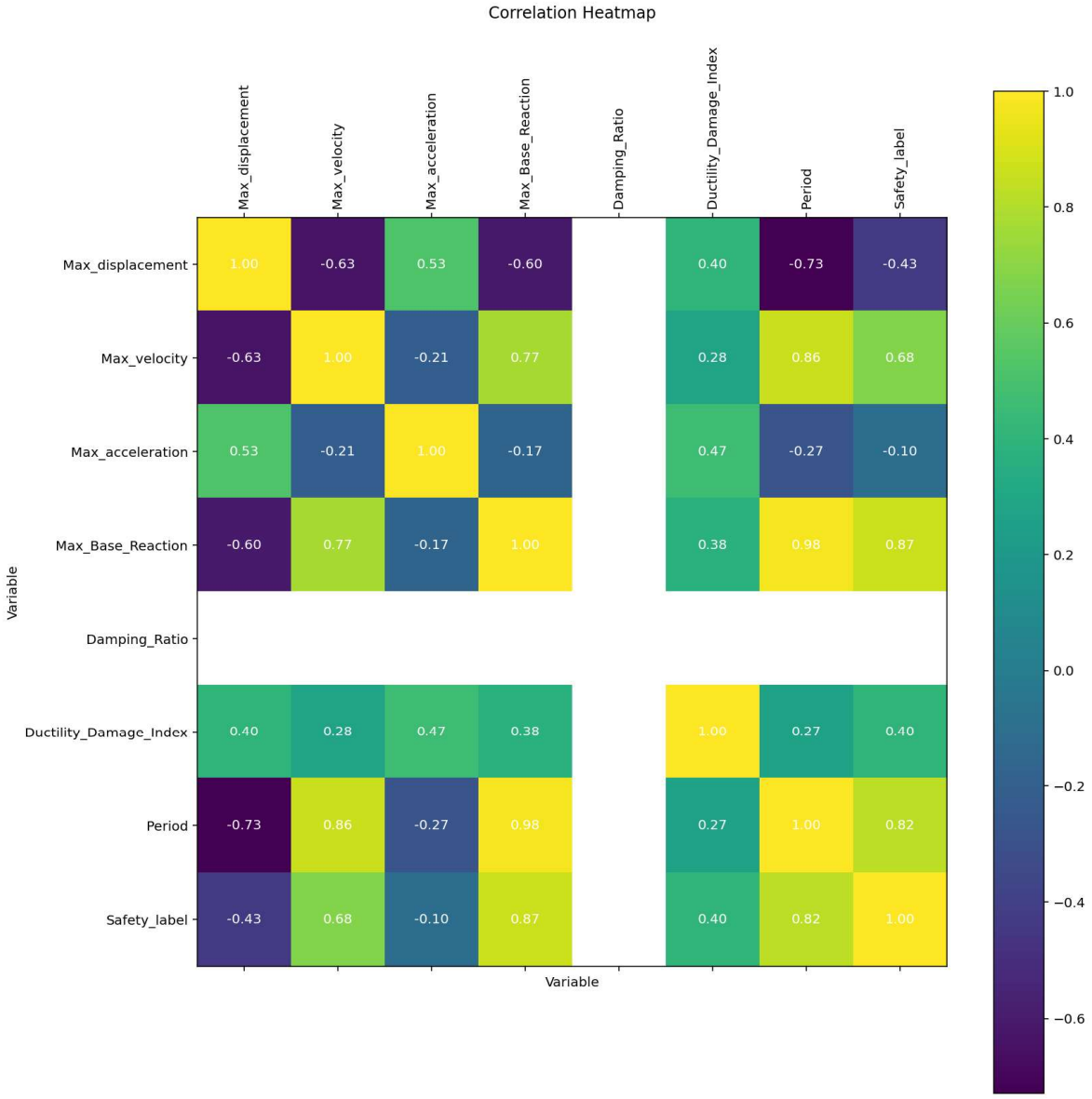

Time vs Velocity - MAX. ABS: 0.09269930027069098
Velocity [m/s]
Time [s]
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
0
2
4
6
8
10
12
14


Time vs Acceleration - MAX. ABS: 1.4792263407843447
Acceleration [m/s^2]
Time [s]
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
2
4
6
8
10
12
14


Time vs Base-reaction - MAX. ABS: 3124325.285148395
1e6
3
2
1
0
−1
−2
−3
Base-reaction [N]
0
2
4
6
8
10
12
14
Time [s]


Displacement Time History
Displacement [m]
Time [s]
Velocity Time History
Velocity [m/s]
Time [s]
Acceleration Time History
Acceleration [m/s²]
Time [s]
Base Reaction Time History
1e6
Base Reaction [N]
Time [s]


Feature Importance
Max_displacement
Max_velocity
Max_acceleration
Max_Base_Reaction
Damping_Ratio
Ductility_Damage_Index
Period
None
0.00
0.05
0.10
0.15
0.20
0.25


Correlation Heatmap
Max_displacement
Max_velocity
Max_acceleration
Max_Base_Reaction
Damping_Ratio
Ductility_Damage_Index
Period
Safety_label
Variable
Variable
1.00 -0.63 0.53 -0.60 0.40 -0.73 -0.43
-0.63 1.00 -0.21 0.77 0.28 0.86 0.68
0.53 -0.21 1.00 -0.17 0.47 -0.27 -0.10
-0.60 0.77 -0.17 1.00 0.38 0.98 0.87
0.40 0.28 0.47 0.38 1.00 0.27 0.40
-0.73 0.86 -0.27 0.98 0.27 1.00 0.82
-0.43 0.68 -0.10 0.87 0.40 0.82 1.00
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6