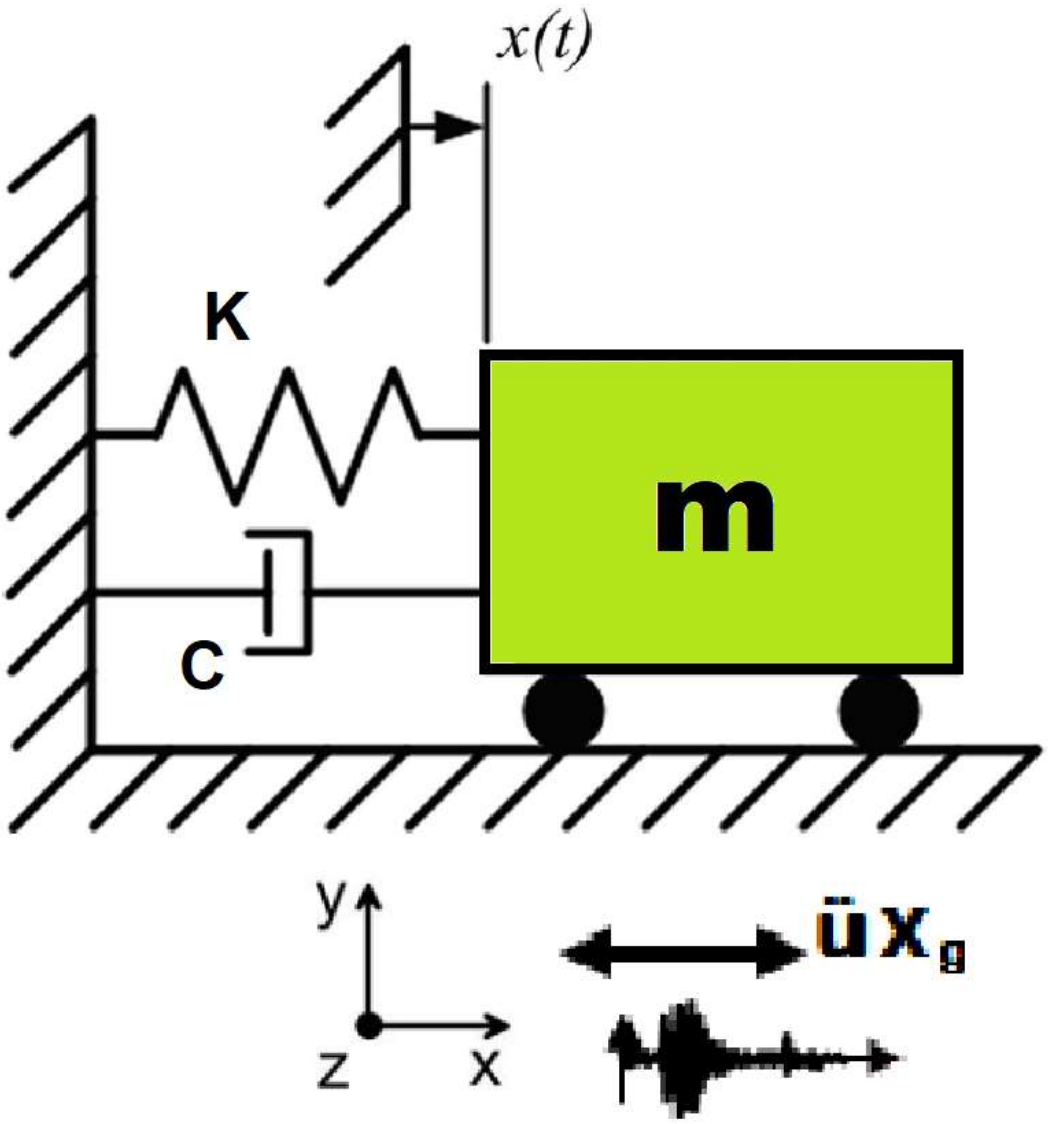
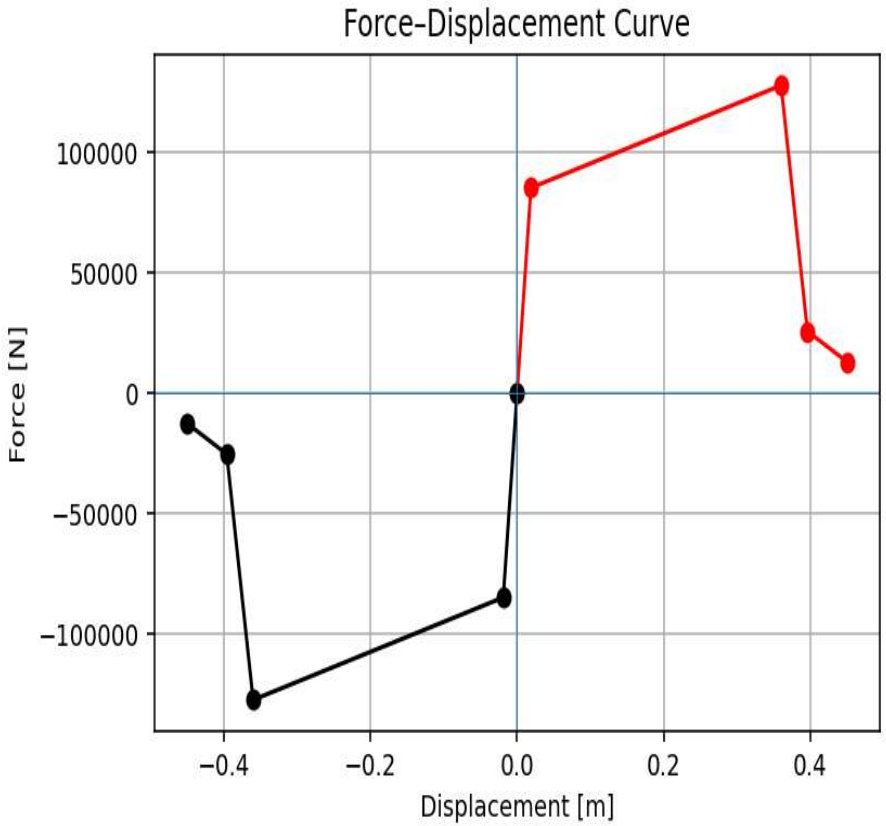
>> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<

FRAGILITY ANALYSIS BASED ON ACCELERATION AND STRUCTURAL DUCTILITY DAMAGE INDEX WITH INCREMENTAL DYNAMIC ANALYSIS (IDA) OF A SINGLE-DEGREE-OF-FREEDOM (SDOF) SYSTEM UTILIZING 100 GROUND MOTIONS IN OPENSEES

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)


x(t)
K
m
C
y
z
x
ü x g


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

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

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

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

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

Spyder (Python 3.12)

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C:\Users\Dell\Desktop\OPENSEES_FILES\SDOF_INCREME...STIC_SDOF_INCREMENTAL_DYNAMIC_ANALYSIS_SEISMIC.py

INELASTIC_SDOF_INC...NALYSIS_SEISMIC.py | FRAGILITY_CURVE_FUN.py

```
##################################################################################################################
#                  >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<                              #
#          FRAGILITY ANALYSIS BASED ON ACCELERATION AND STRUCTURAL DUCTILITY DAMAGE INDEX WITH                    #
#             INCREMENTAL DYNAMIC ANALYSIS (IDA) OF A SINGLE-DEGREE-OF-FREEDOM (SDOF) SYSTEM                     #
#                              UTILIZING 100 GROUND MOTIONS IN OPENSEES                                          #
#-----------------------------------------------------------------------------------------------------------------#
# This program performs Incremental Dynamic Analysis (IDA) on a Single-Degree-of-Freedom (SDOF) system           #
# subjected to 100 seismic ground motions. The analysis evaluates the structural response under varying          #
# levels of seismic intensity.                                                                                    #
# The framework is designed to support researchers and engineers in assessing the probabilistic seismic         #
# performance of structures, with a focus on understanding the impact of uncertainty on structural              #
# response and design.                                                                                            #
#-----------------------------------------------------------------------------------------------------------------#
# Key Features:                                                                                                   #
# - Simulation of SDOF system using OpenSees.                                                                     #
# - Incremental scaling of ground motions for IDA.                                                                #
# - Probabilistic fragility assessment based on predefined damage states.                                         #
# - Visualization of structural response and fragility curves.                                                    #
# - Export of results for further analysis.                                                                       #
#-----------------------------------------------------------------------------------------------------------------#
#                          THIS PROGRAM WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)                             #
#                                    EMAIL: salar.d.ghashghaei@gmail.com                                          #
##################################################################################################################


"""
This code implements a comprehensive nonlinear dynamic incemental analysis framework for
performance-based earthquake engineering assessment of single-degree-of-freedom
(SDOF) systems. The methodology combines traditional nonlinear time-history
analysis with modern probabilistic and machine learning techniques for advanced
structural performance evaluation.

KEY ENGINEERING OBJECTIVES:
1. Comparative assessment of hysteretic models for seismic response prediction
2. Probabilistic seismic demand analysis using multiple ground motions
```

Console 1/A

```
STEP 44 DONE
PERIOD: 1.601157
STEP 45 DONE
PERIOD: 1.601157
STEP 46 DONE
PERIOD: 1.601157
STEP 47 DONE
PERIOD: 1.601157
STEP 48 DONE
PERIOD: 1.601157
STEP 49 DONE
PERIOD: 1.601157
STEP 50 DONE

 SEISMIC 91 DONE

PERIOD: 1.601157
STEP 1 DONE
PERIOD: 1.601157
STEP 2 DONE
PERIOD: 1.601157
STEP 3 DONE
PERIOD: 1.601157
STEP 4 DONE
PERIOD: 1.601157
STEP 5 DONE
PERIOD: 1.601157
STEP 6 DONE
PERIOD: 1.601157
STEP 7 DONE
PERIOD: 1.601157
STEP 8 DONE
PERIOD: 1.601157
STEP 9 DONE
```

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Spyder (Python 3.12)

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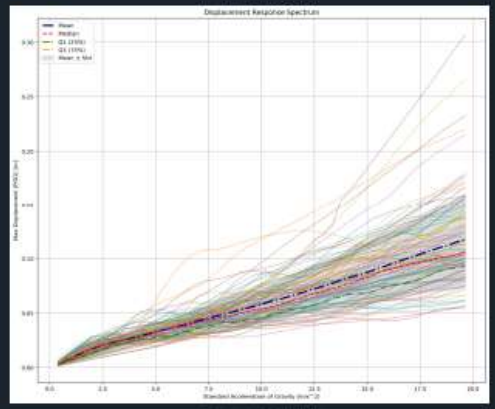
C:\Users\Dell\Desktop\OPENSEES_FILES\SDOF_INCREME...L_DYNAMIC_ANALYSIS_SEISMIC\FRAGILITY_CURVE_FUN.py

INELASTIC_SDOF_INC...NALYSIS_SEISMIC.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()
```



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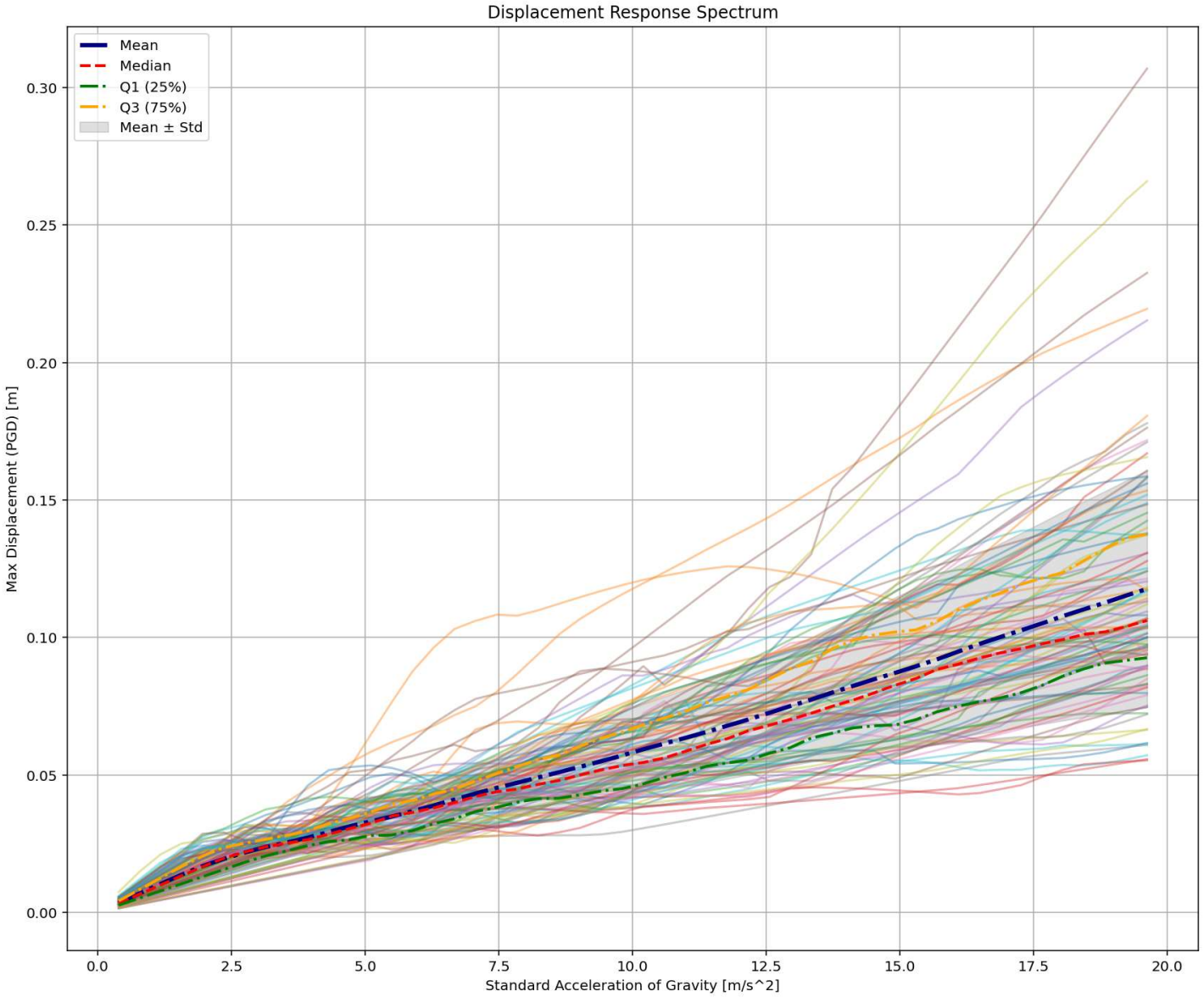
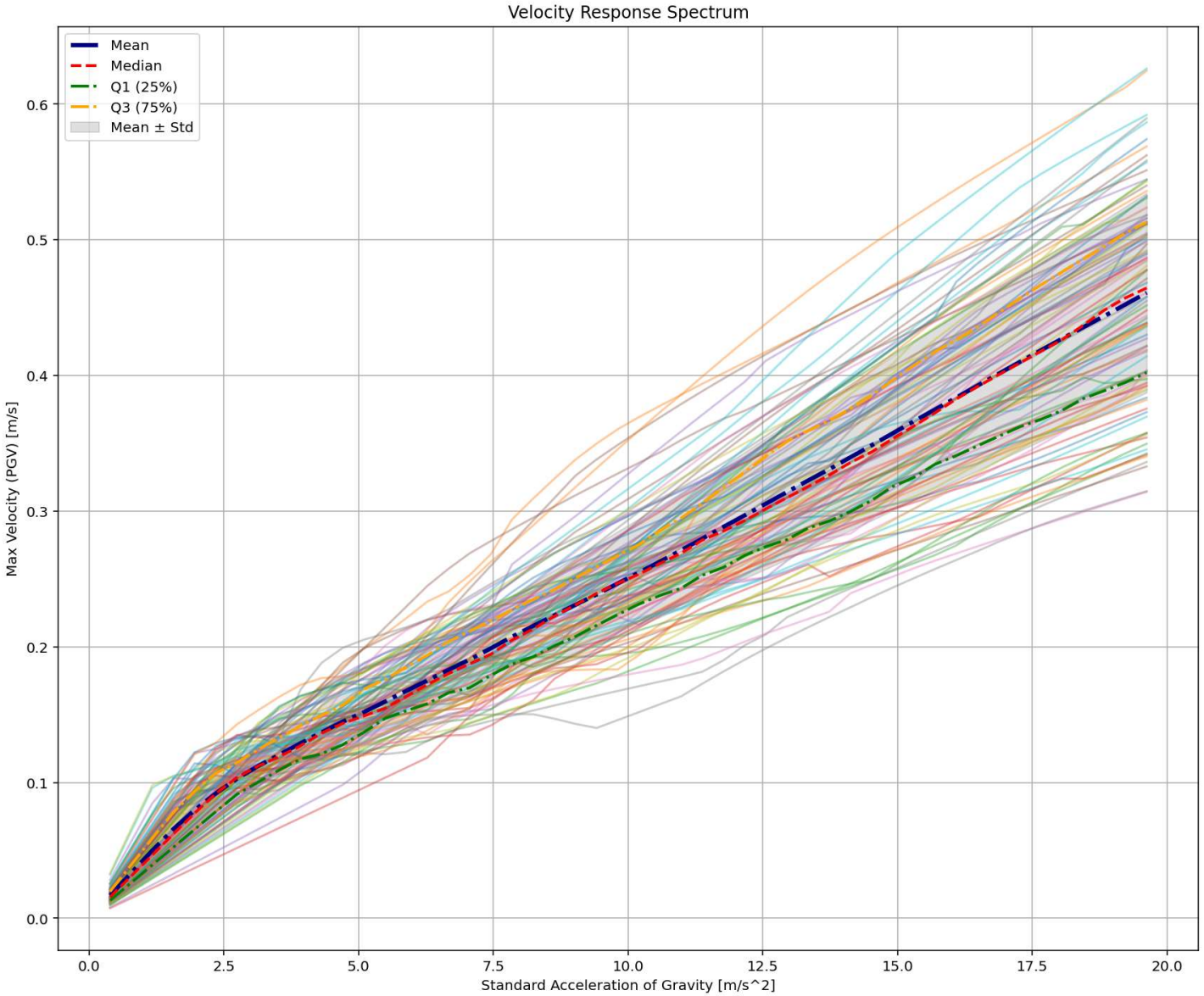
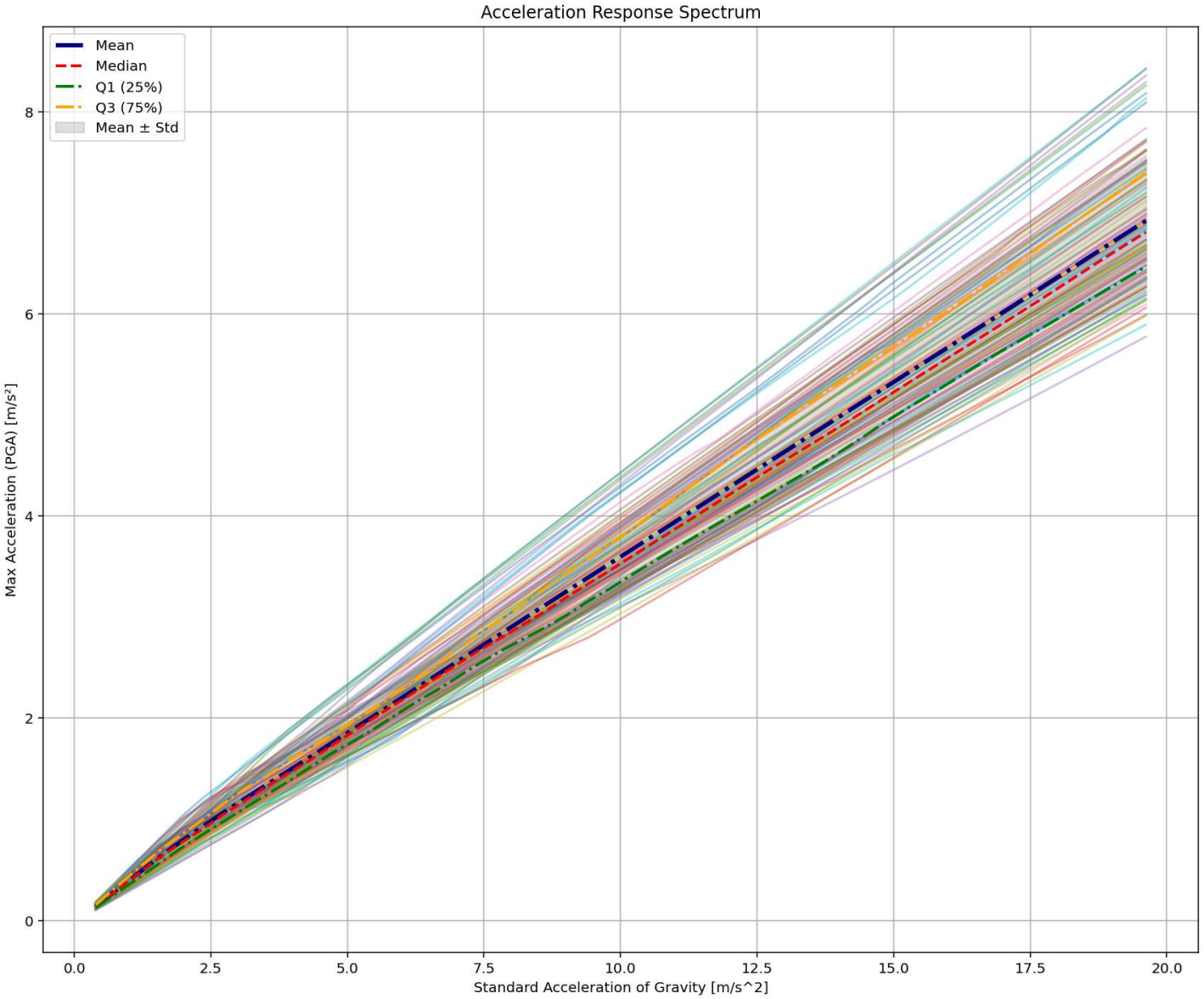
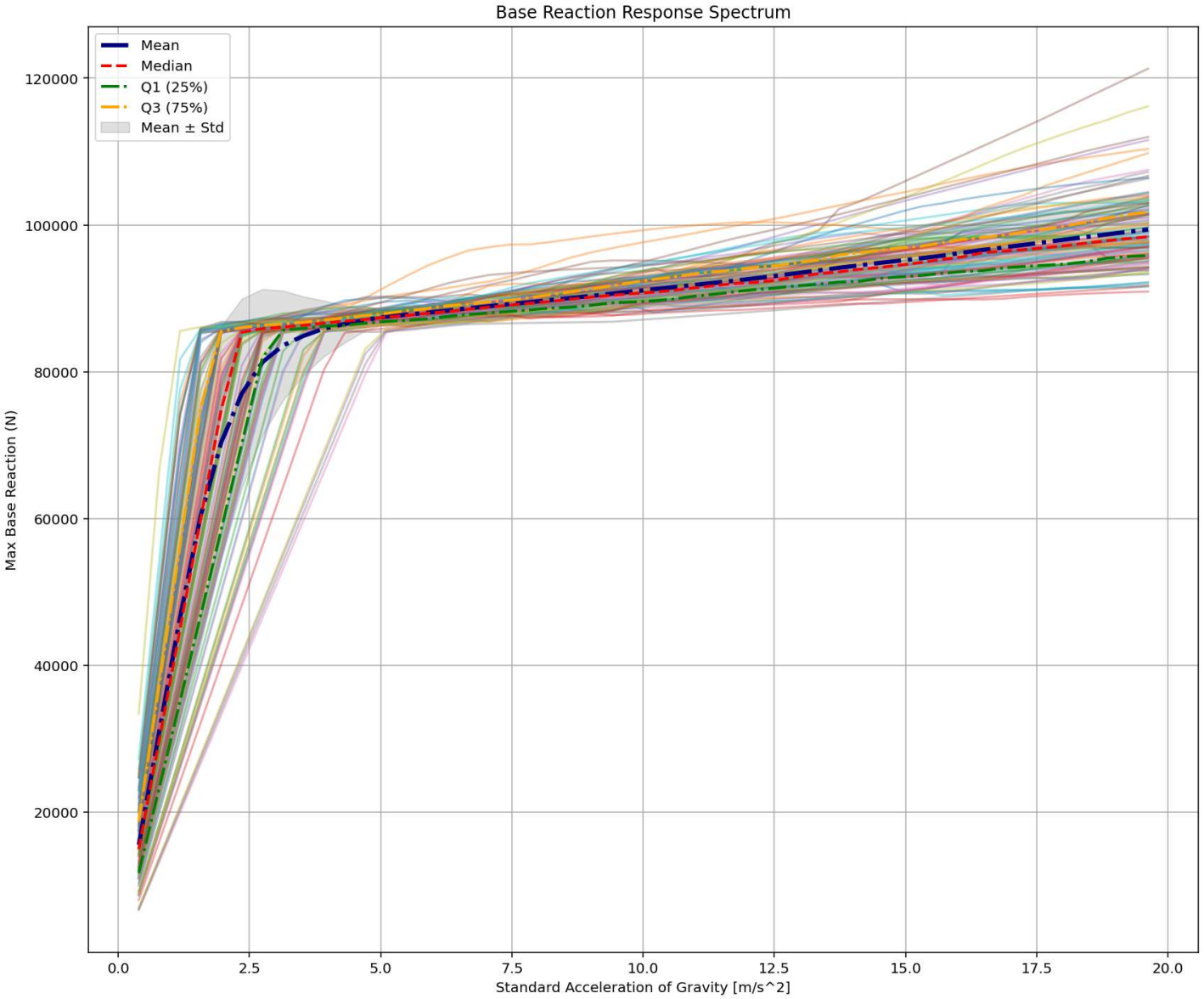
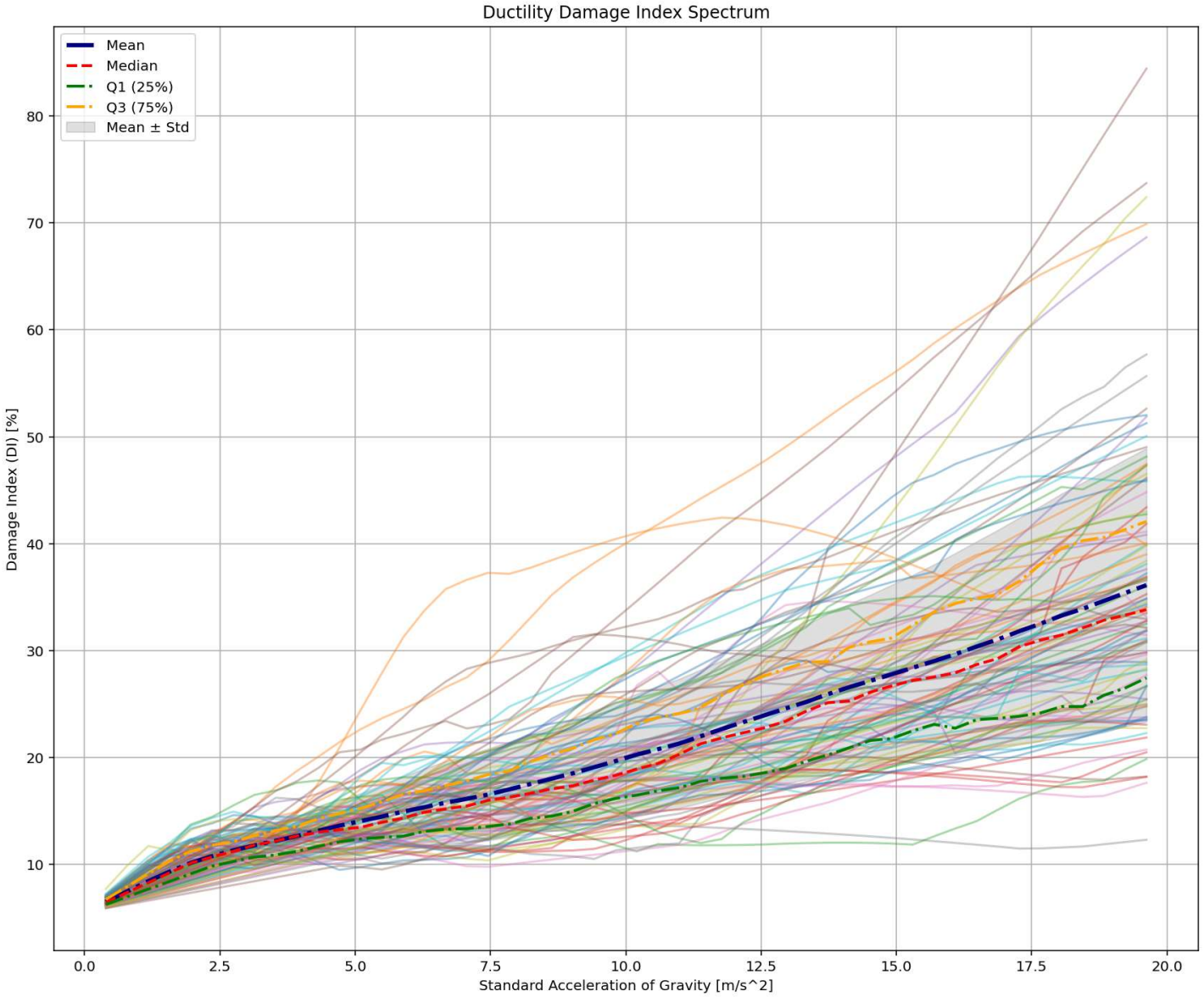
Inline Conda: anaconda3 (Python 3.12.7) LSP: Python Line 2, Col 20 UTF-8 CRLF RW Mem 44%

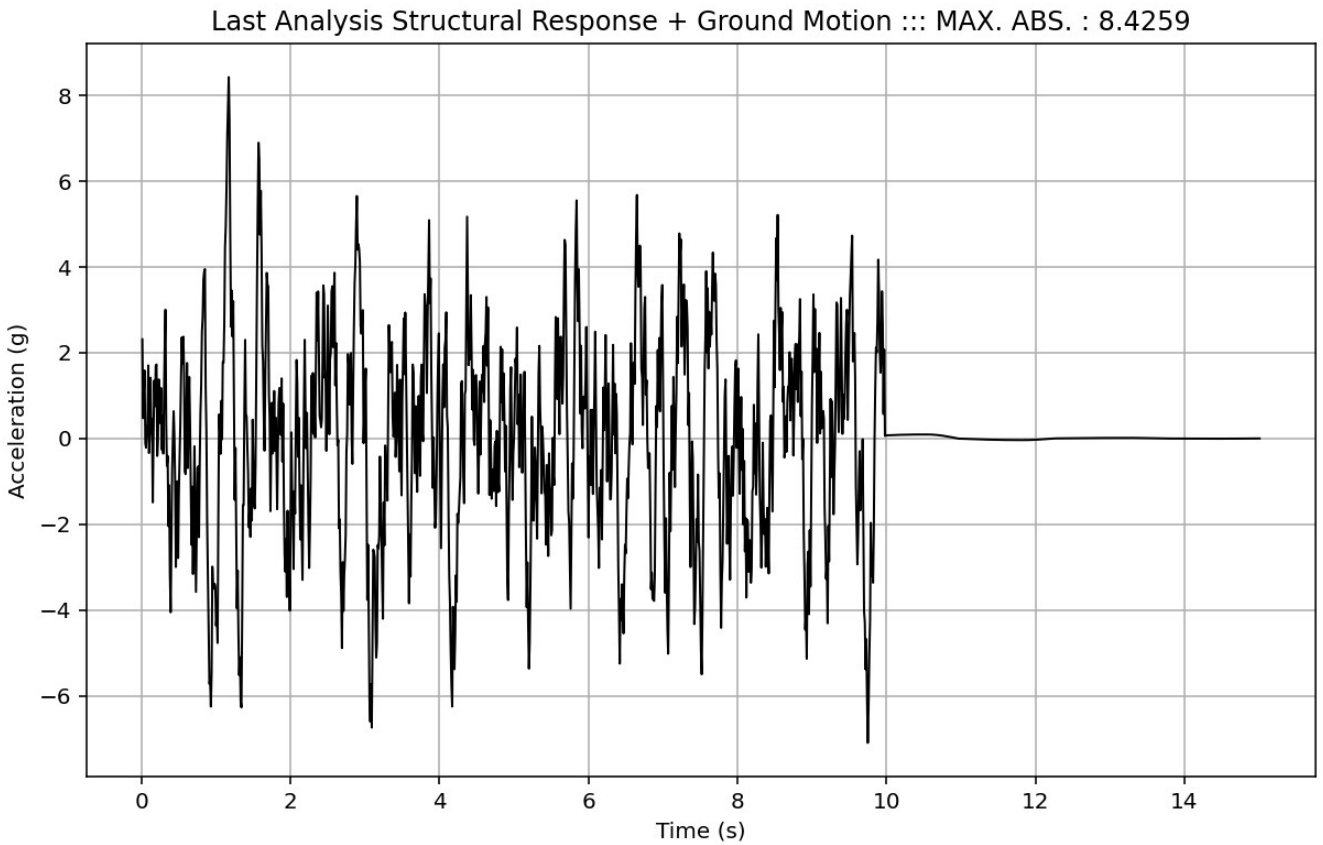

Displacement Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Max Displacement (PGD) [m]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Standard Acceleration of Gravity [m/s^2]

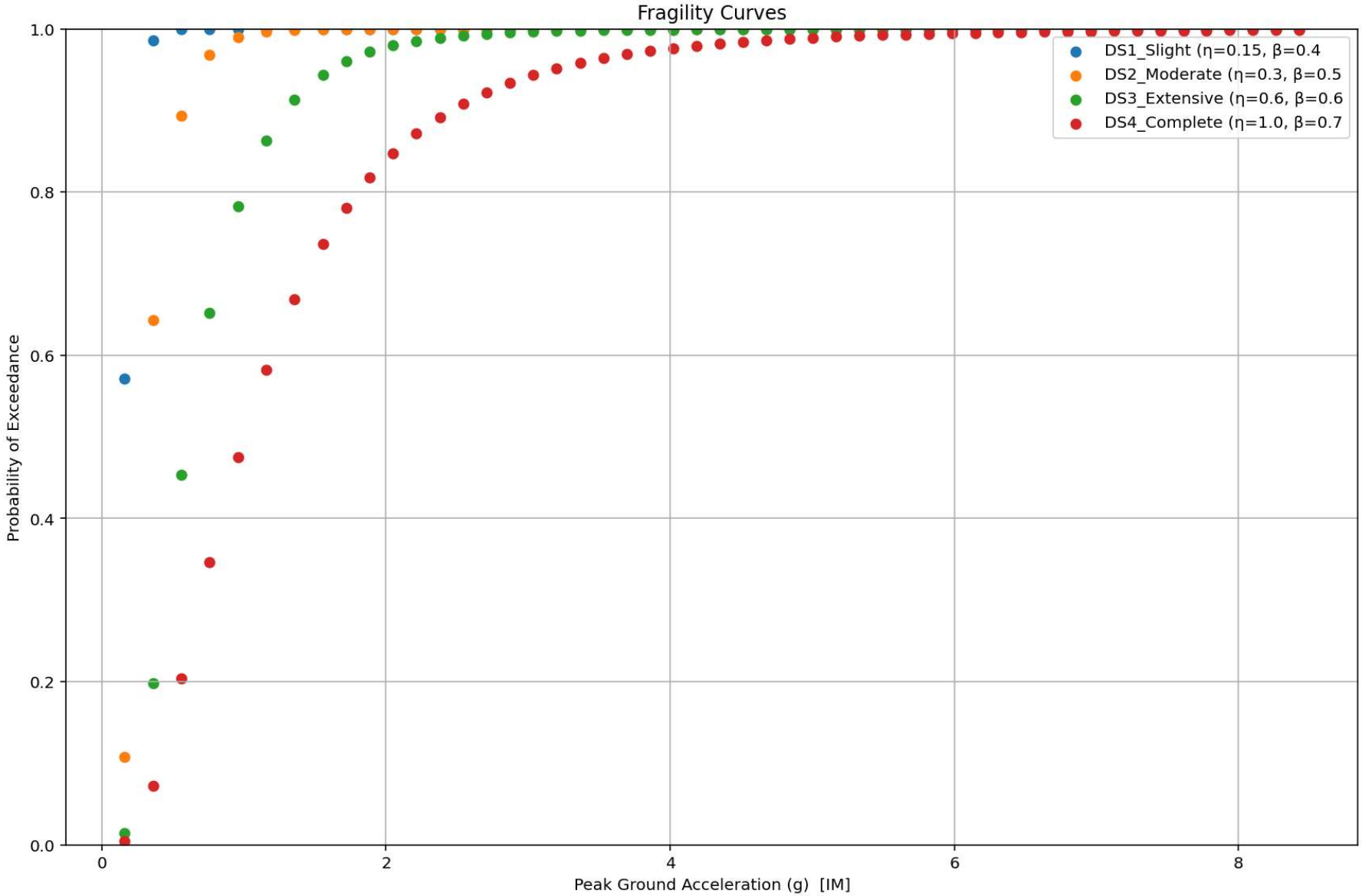

Velocity Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Max Velocity (PGV) [m/s]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Standard Acceleration of Gravity [m/s^2]

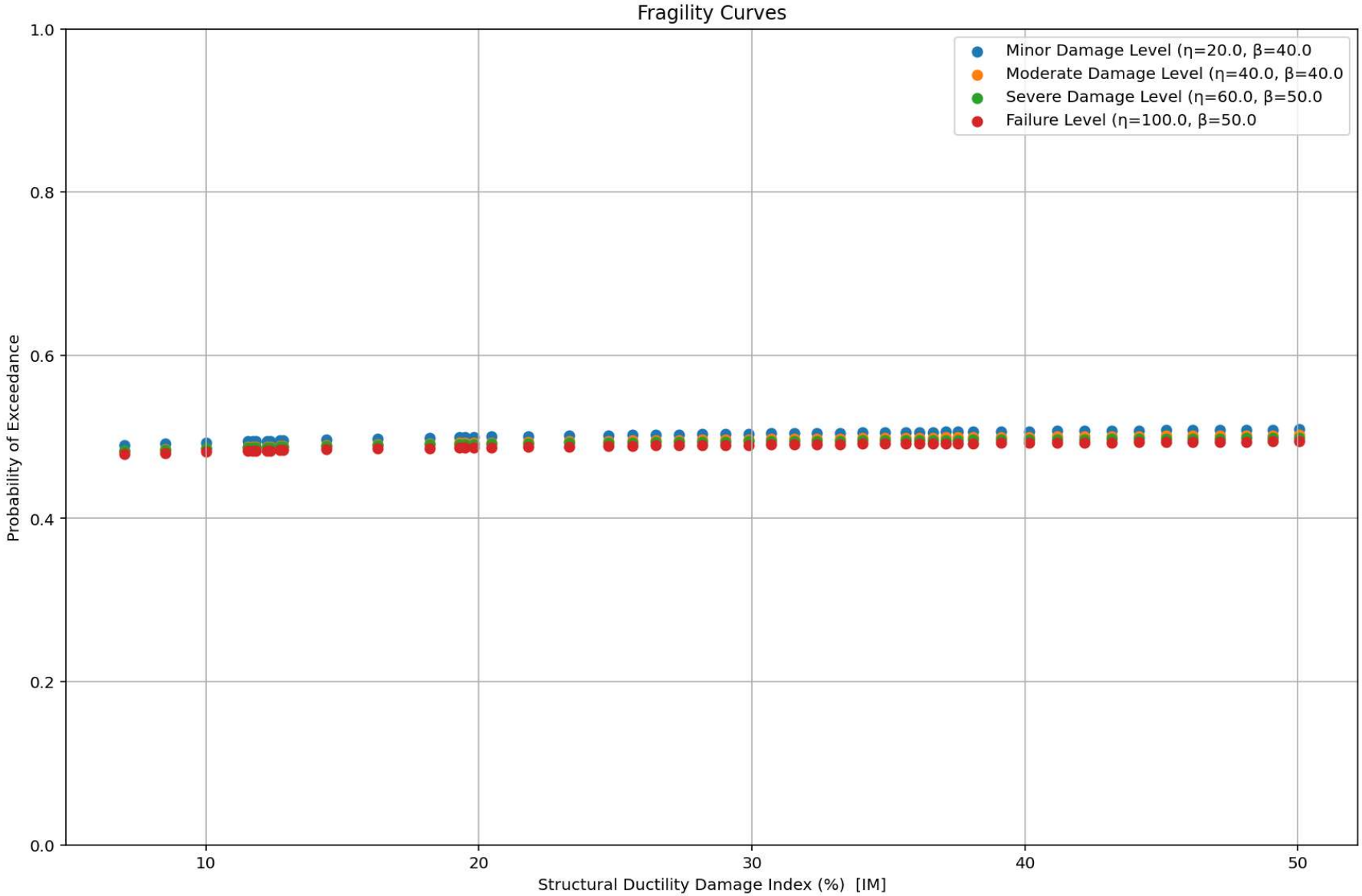

Acceleration Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Max Acceleration (PGA) [m/s²]
0
2
4
6
8
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Standard Acceleration of Gravity [m/s^2]

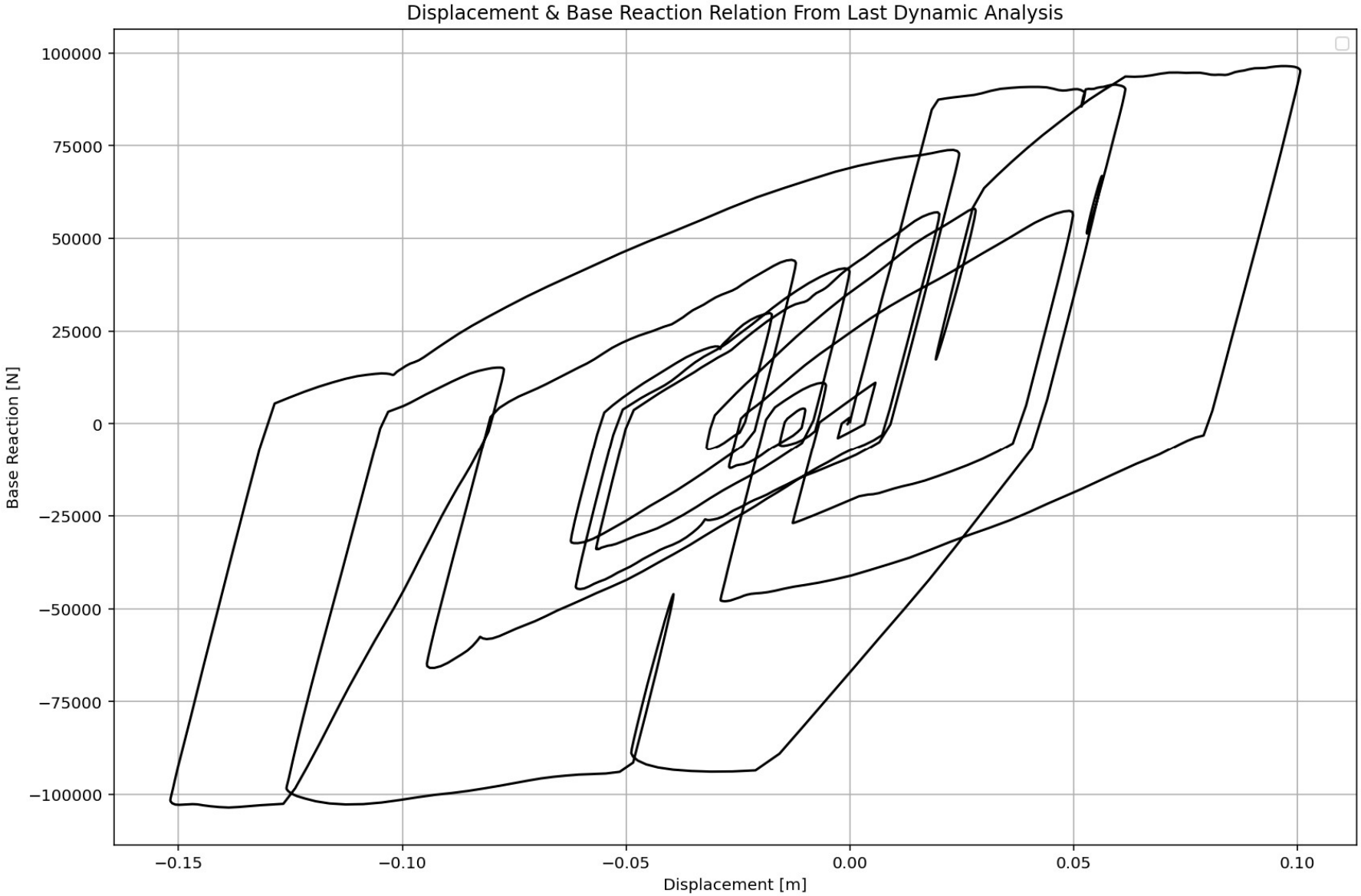

Base Reaction Response Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
120000
100000
80000
60000
40000
20000
Max Base Reaction (N)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Standard Acceleration of Gravity [m/s^2]

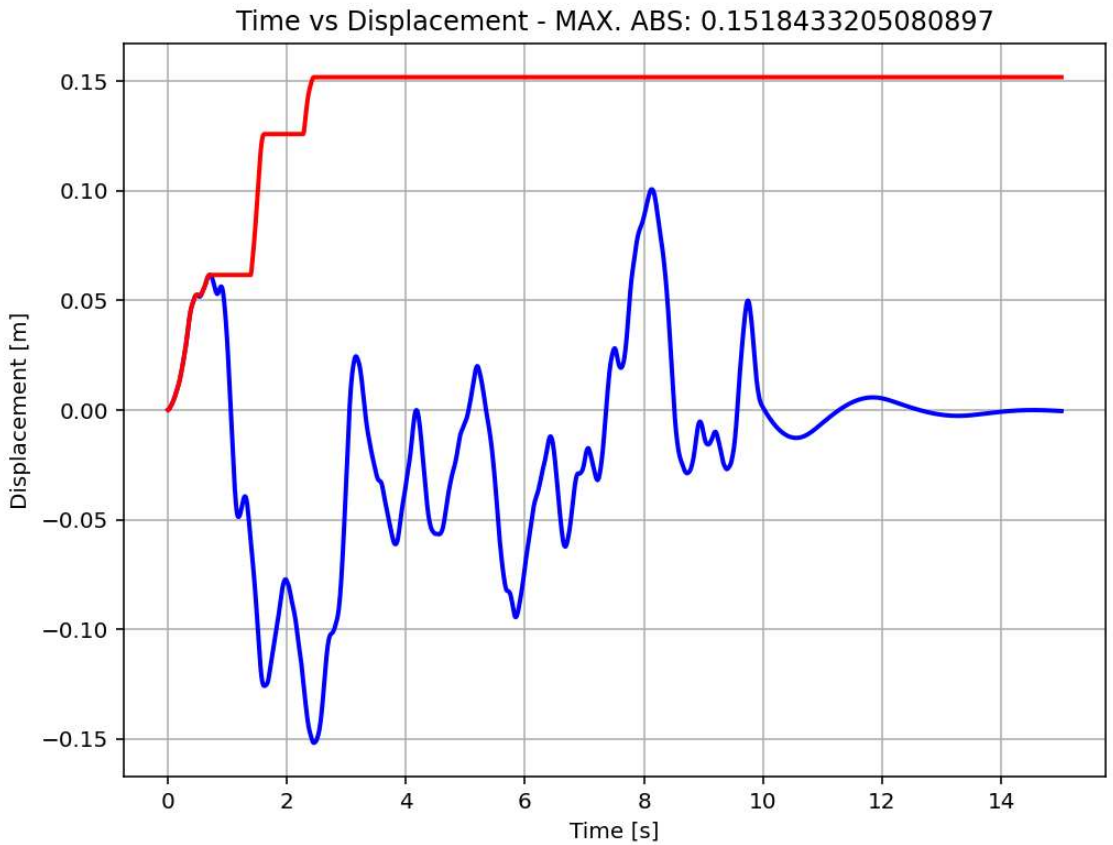

Ductility Damage Index Spectrum
Mean
Median
Q1 (25%)
Q3 (75%)
Mean ± Std
Damage Index (DI) [%]
Standard Acceleration of Gravity [m/s^2]
10
20
30
40
50
60
70
80
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0

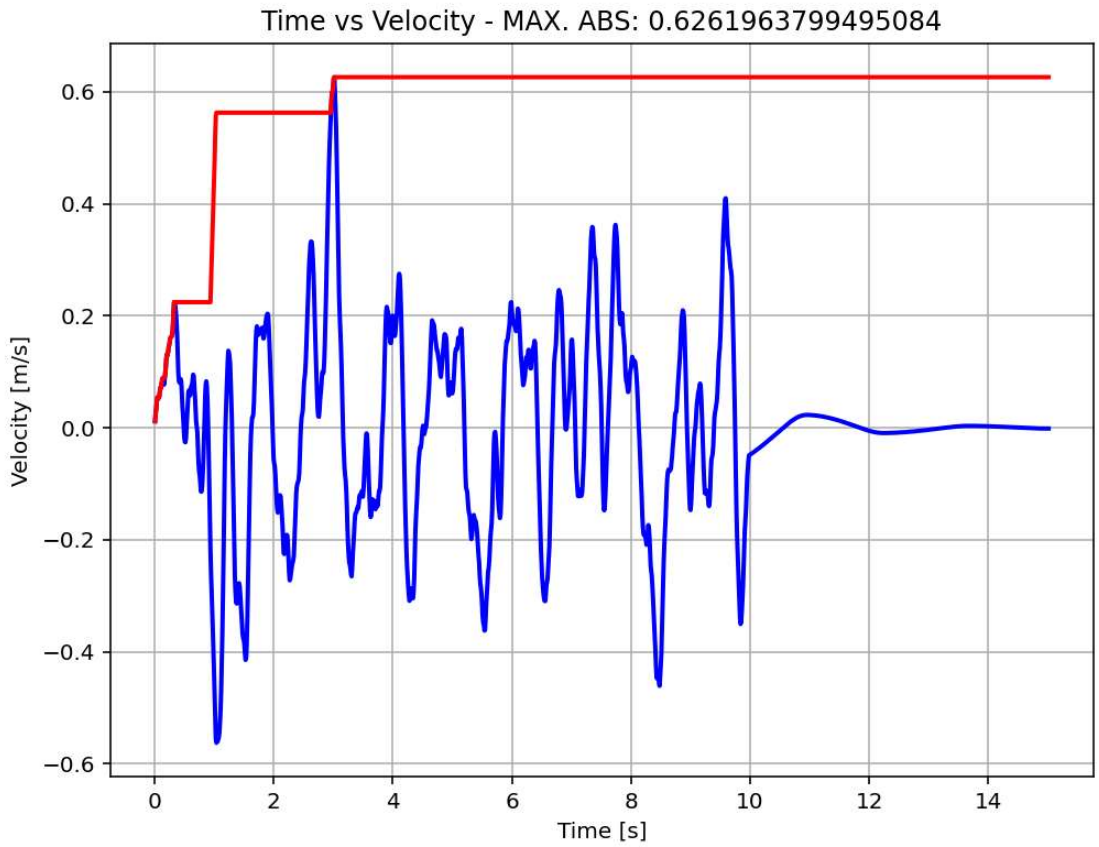

Last Analysis Structural Response + Ground Motion ::: MAX. ABS. : 8.4259
Acceleration (g)
8
6
4
2
0
−2
−4
−6
0
2
4
6
8
10
12
14
Time (s)

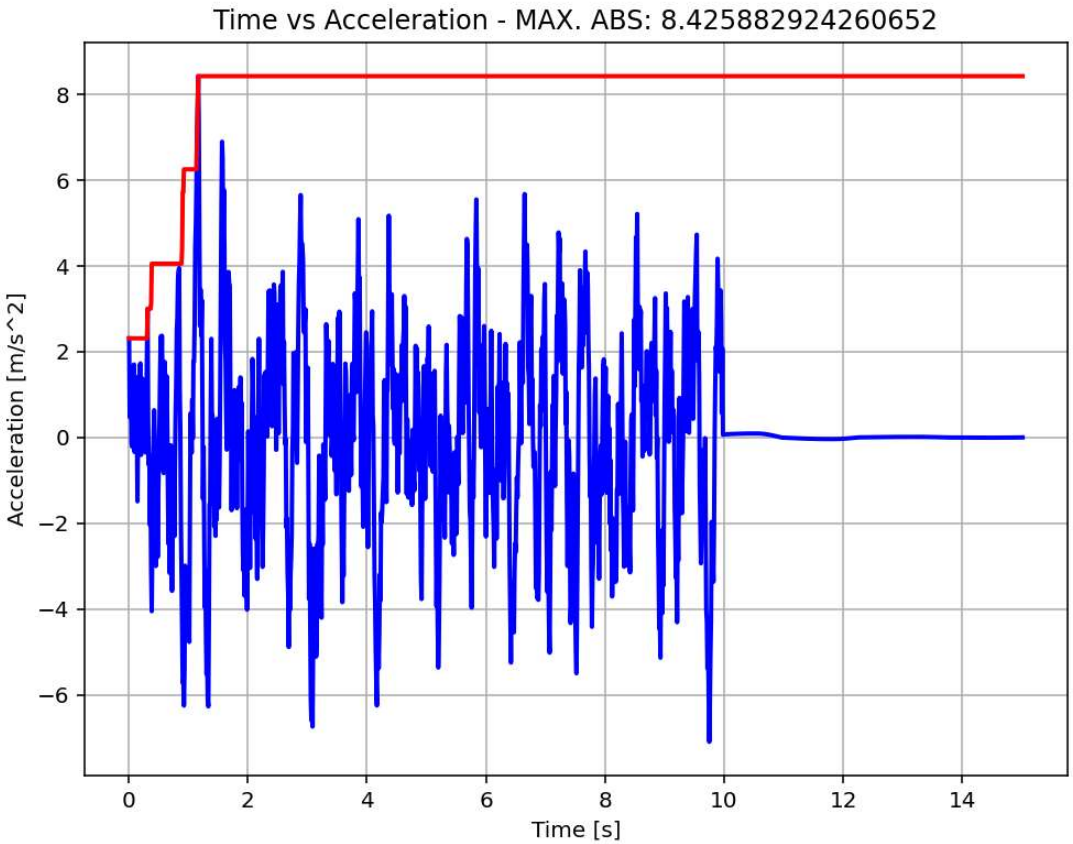

Fragility Curves
DS1_Slight (η=0.15, β=0.4
DS2_Moderate (η=0.3, β=0.5
DS3_Extensive (η=0.6, β=0.6
DS4_Complete (η=1.0, β=0.7
Probability of Exceedance
Peak Ground Acceleration (g) [IM]
0.0
0.2
0.4
0.6
0.8
1.0
0
2
4
6
8

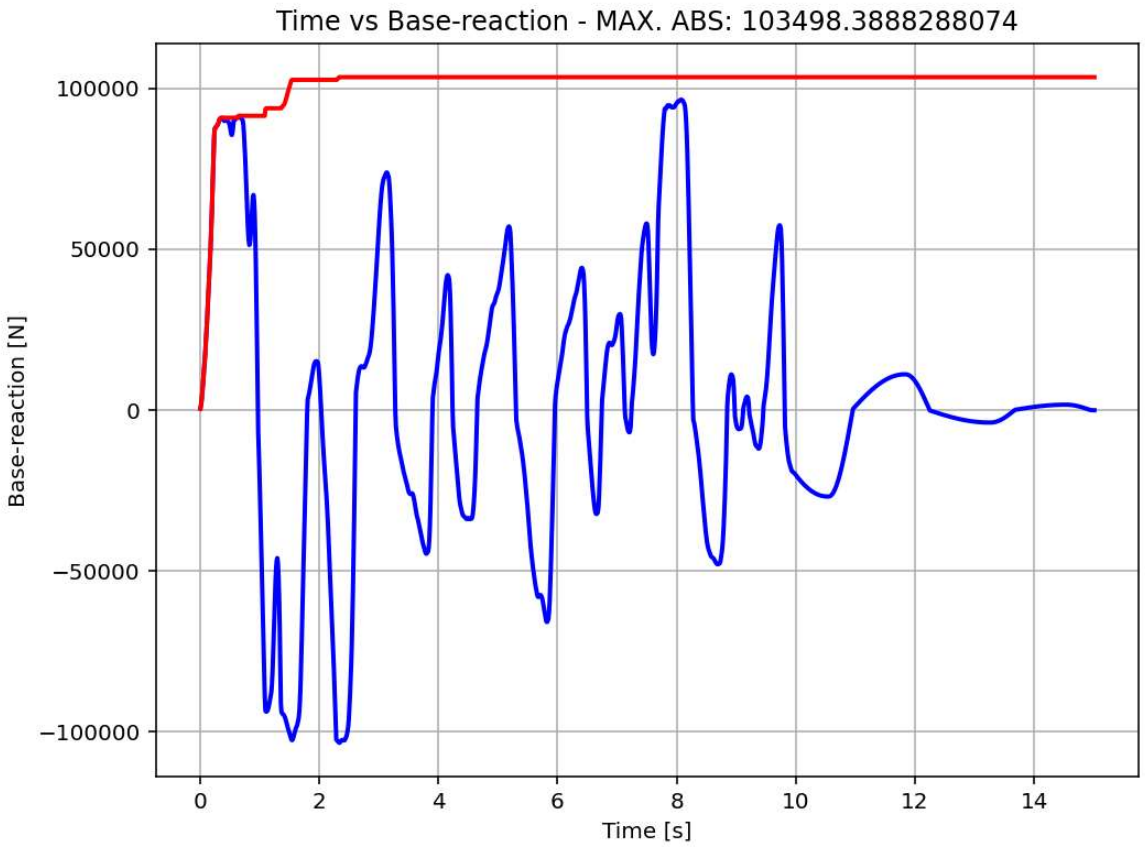

Fragility Curves
Minor Damage Level (η=20.0, β=40.0
Moderate Damage Level (η=40.0, β=40.0
Severe Damage Level (η=60.0, β=50.0
Failure Level (η=100.0, β=50.0
Probability of Exceedance
1.0
0.8
0.6
0.4
0.2
0.0
10
20
30
40
50
Structural Ductility Damage Index (%) [IM]

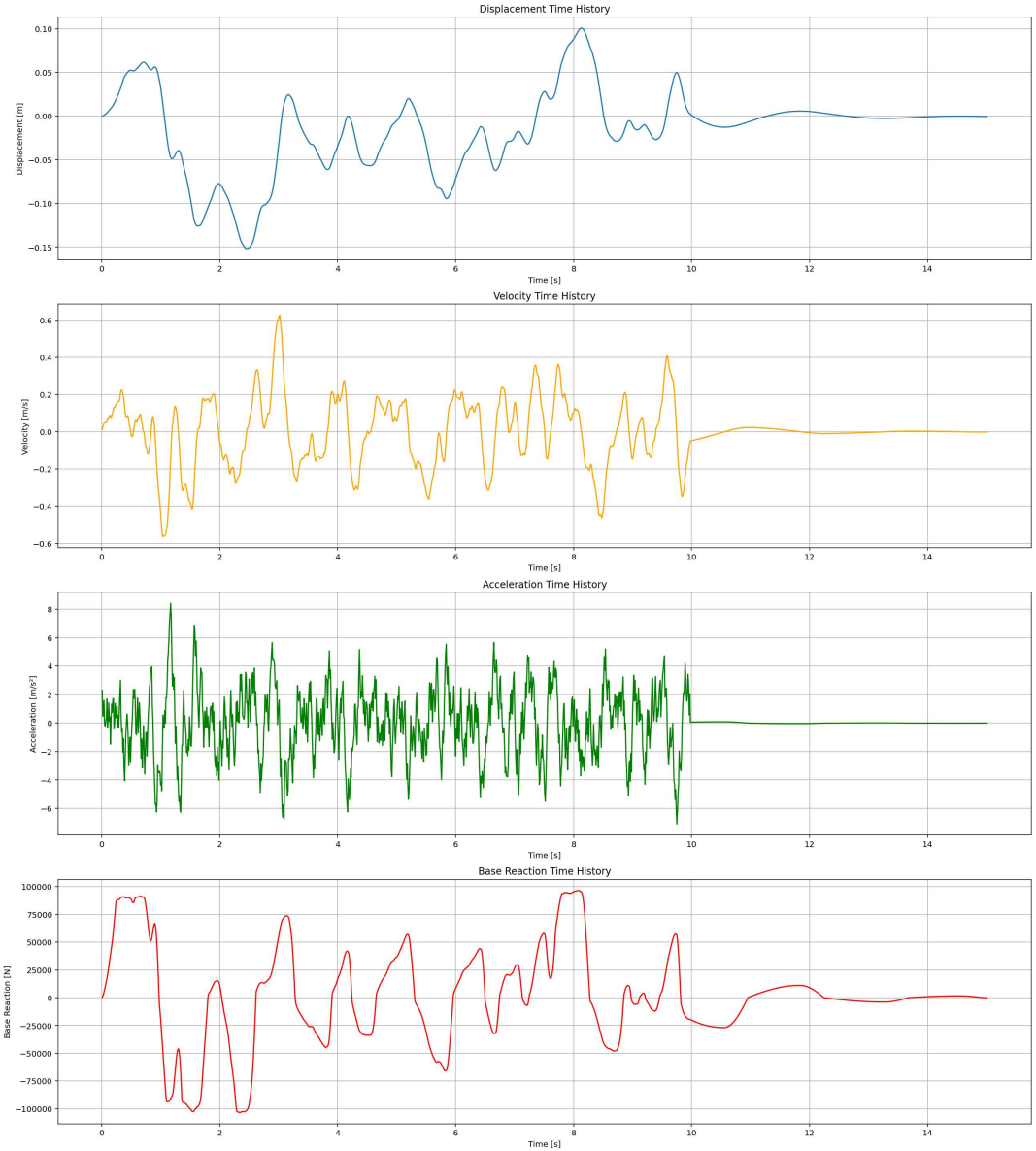

Displacement & Base Reaction Relation From Last Dynamic Analysis
Base Reaction [N]
Displacement [m]
100000
75000
50000
25000
0
−25000
−50000
−75000
−100000
−0.15
−0.10
−0.05
0.00
0.05
0.10

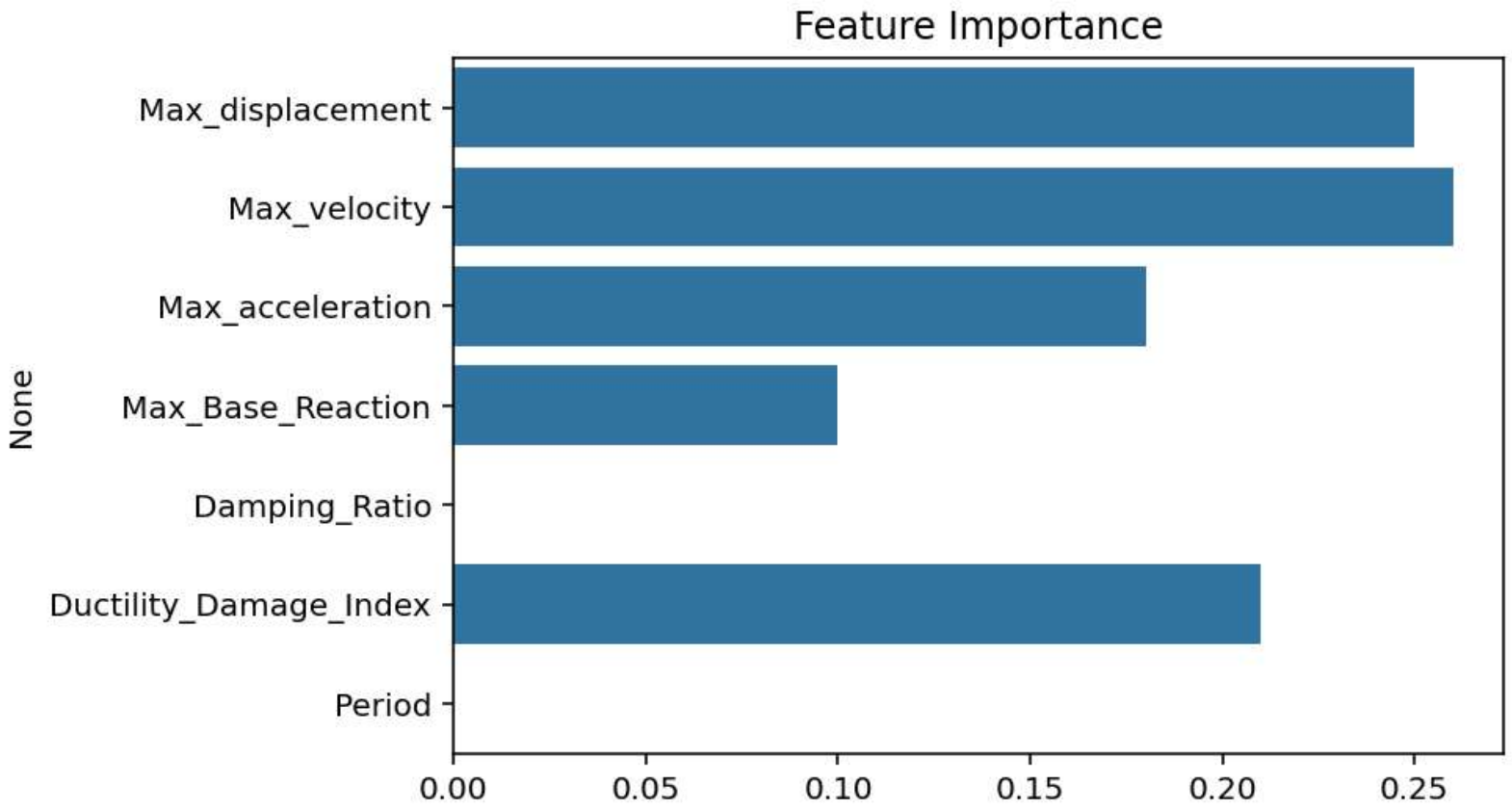

Time vs Displacement - MAX. ABS: 0.1518433205080897
Displacement [m]
Time [s]
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
2
4
6
8
10
12
14

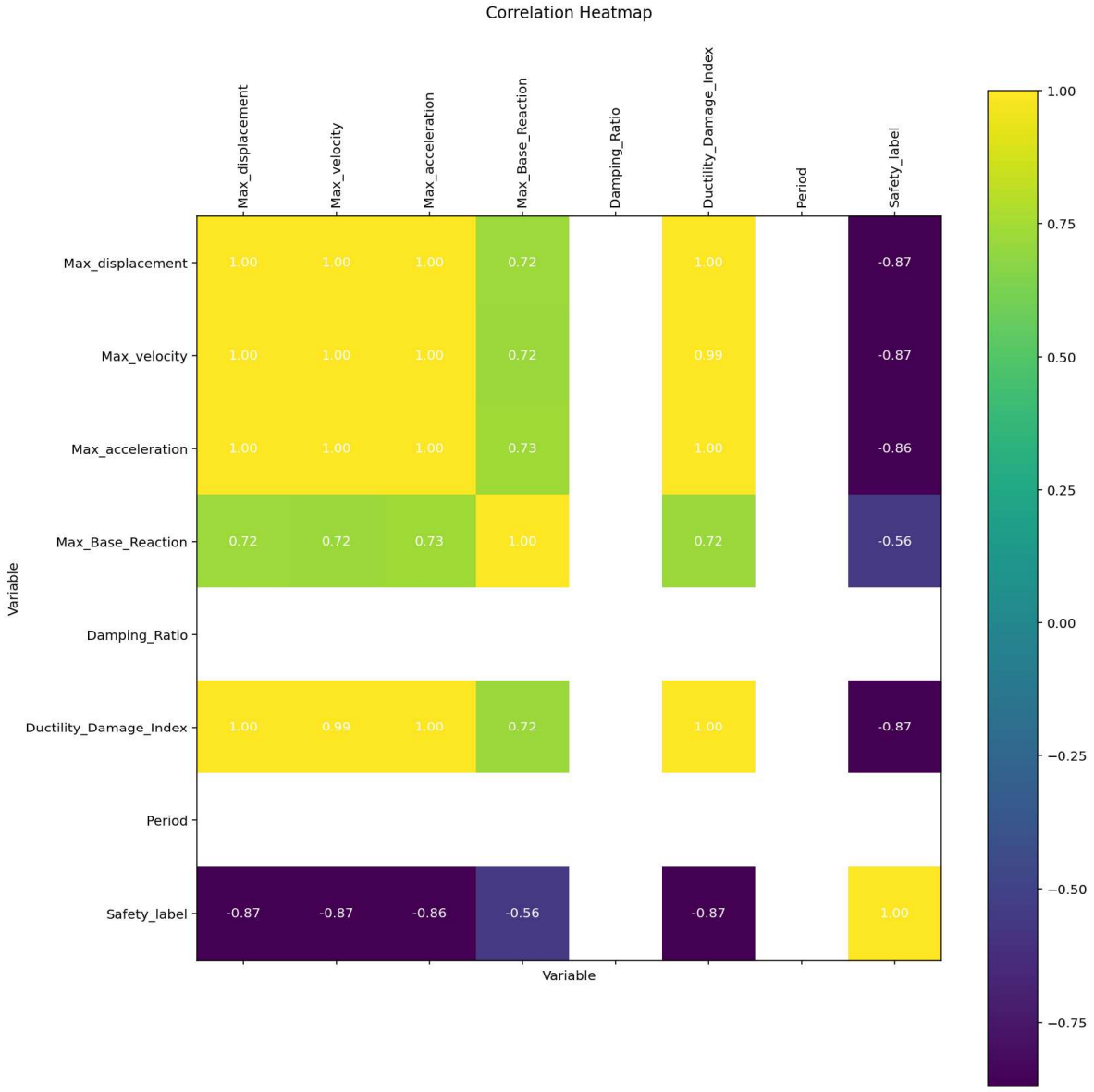

Time vs Velocity - MAX. ABS: 0.6261963799495084
Velocity [m/s]
Time [s]
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
2
4
6
8
10
12
14


Time vs Acceleration - MAX. ABS: 8.425882924260652
Acceleration [m/s^2]
Time [s]
8
6
4
2
0
−2
−4
−6
0
2
4
6
8
10
12
14


Time vs Base-reaction - MAX. ABS: 103498.3888288074
Base-reaction [N]
100000
50000
0
−50000
−100000
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
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
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
1.00 1.00 1.00 0.72 1.00 -0.87
1.00 1.00 1.00 0.72 0.99 -0.87
1.00 1.00 1.00 0.73 1.00 -0.86
0.72 0.72 0.73 1.00 0.72 -0.56
1.00 0.99 1.00 0.72 1.00 -0.87
-0.87 -0.87 -0.86 -0.56 -0.87 1.00