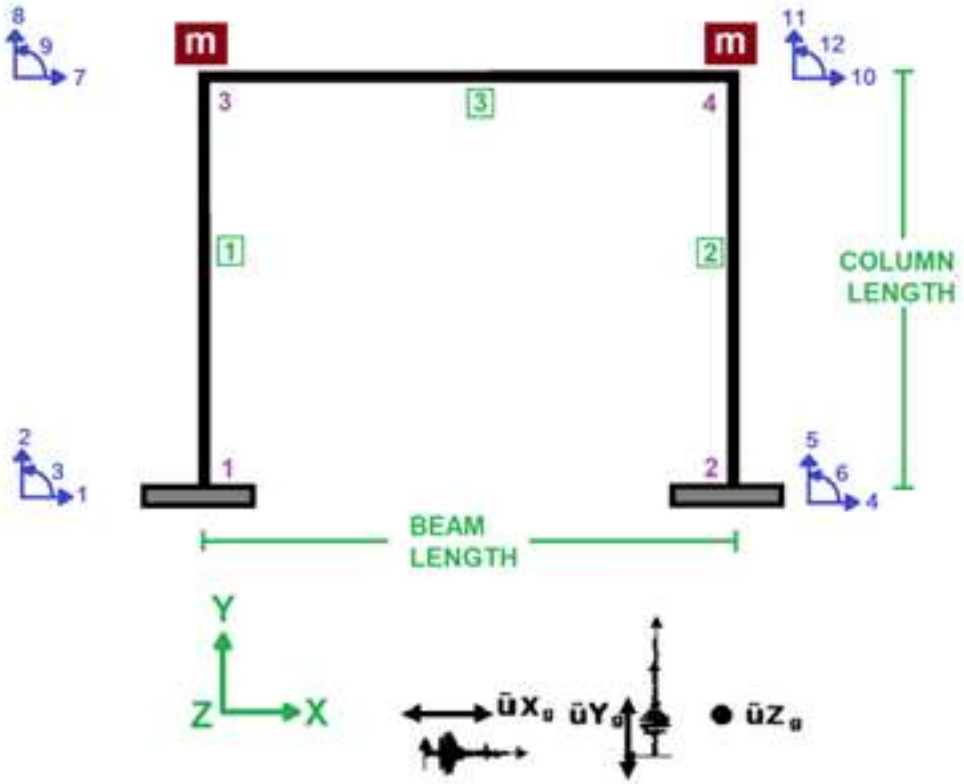
IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL

PROBABILISTIC SEISMIC ASSESSMENT OF RC FRAMES VIA DISTRIBUTED PLASTICITY MODELINGAND MACHINE LEARNING-BASED UNCERTAINTY QUANTIFICATION USING OPENSEES

WRITTEN BY SALAR DELAVAR GHASHGHAEI (QASHQAI)



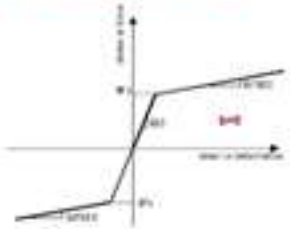
$$Structure\ Ductility\ Damage\ Index = \frac{\Delta_d - \Delta_y}{\Delta_u - \Delta_y}$$

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

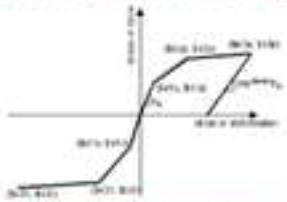
$\Delta_y = Lateral\ Yield\ Displacement\ from\ Pushover\ Analysis$

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

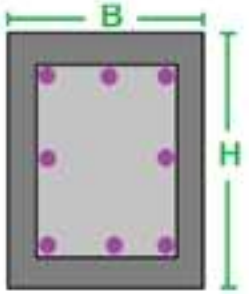
CORE AND COVER CONCRETE REALTION



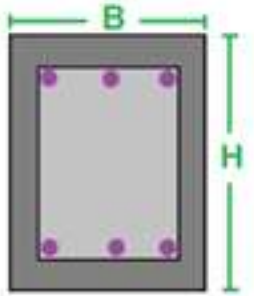
WITHOUT HARDENING AND ULTIMATE STRAIN



WITH HARDENING AND ULTIMATE STRAIN



COLUMN SECTION



BEAM SECTION

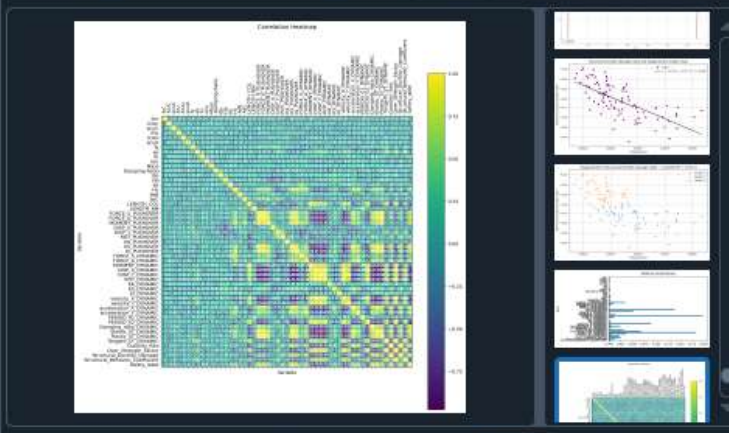
Spyder (Python 3.12)

File Edit Search Source Run Debug Consoles Projects Tools View Help

C:\Users\Dell\Desktop\OPENSEES_FILES\CONCRETE_FRA...XAMPLES\UNCERTAINTY\CONCRETE_FRAME_UNCERTAINTY.py

CONCRETE_FRAME_UNCERTAINTY.py

```
1  ##########################################################################################
2  #            >> IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL <<           #
3  # PROBABILISTIC SEISMIC ASSESSMENT OF RC FRAMES VIA DISTRIBUTED PLASTICITY MODELING      #
4  #        AND MACHINE LEARNING-BASED UNCERTAINTY QUANTIFICATION USING OPENSEES           #
5  #-----------------------------------------------------------------------------------------#
6  #                          DEVELOPED BY SALAR DELAVAR GHASHGHAEI (QASHQAI)              #
7  #                              Email: salar.d.ghashghaei@gmail.com                      #
8  ##########################################################################################
9  """
10 Key Features:
11 -------------
12 1. Probabilistic Nonlinear Frame Modeling:
13    - 2D RC frame with fiber-section nonlinearBeamColumn elements
14    - Corotational geometric transformation for large displacements
15    - Distributed plasticity modeling with 5 integration points
16
17 2. Advanced Material Models:
18    - Concrete:
19      * Confined core (Concrete01): fc' = -27.6 MPa, εc0 = -0.0045
20      * Unconfined cover (Concrete01): fc' = -18 MPa, εc0 = -0.0025
21    - Reinforcement:
22      * Hysteretic steel model with hardening (fy = 400 MPa)
23      * Pinching behavior (pinchX = 0.8, pinchY = 0.5)
24      * Cyclic degradation (θ = 0.1)
25
26 3. Comprehensive Analysis Capabilities:
27    - Static Pushover Analysis:
28      * Displacement-controlled up to 100mm drift
29      * Automated bilinear curve fitting
30      * Ductility ratio and overstrength factor calculation
31    - Nonlinear Time History Analysis:
32      * HHT-α integrator (α=1, γ=1.5, β=0.25)
33      * Rayleigh damping (calibrated to first two modes)
34      * Supports multi-directional excitation (X/Y components)
```



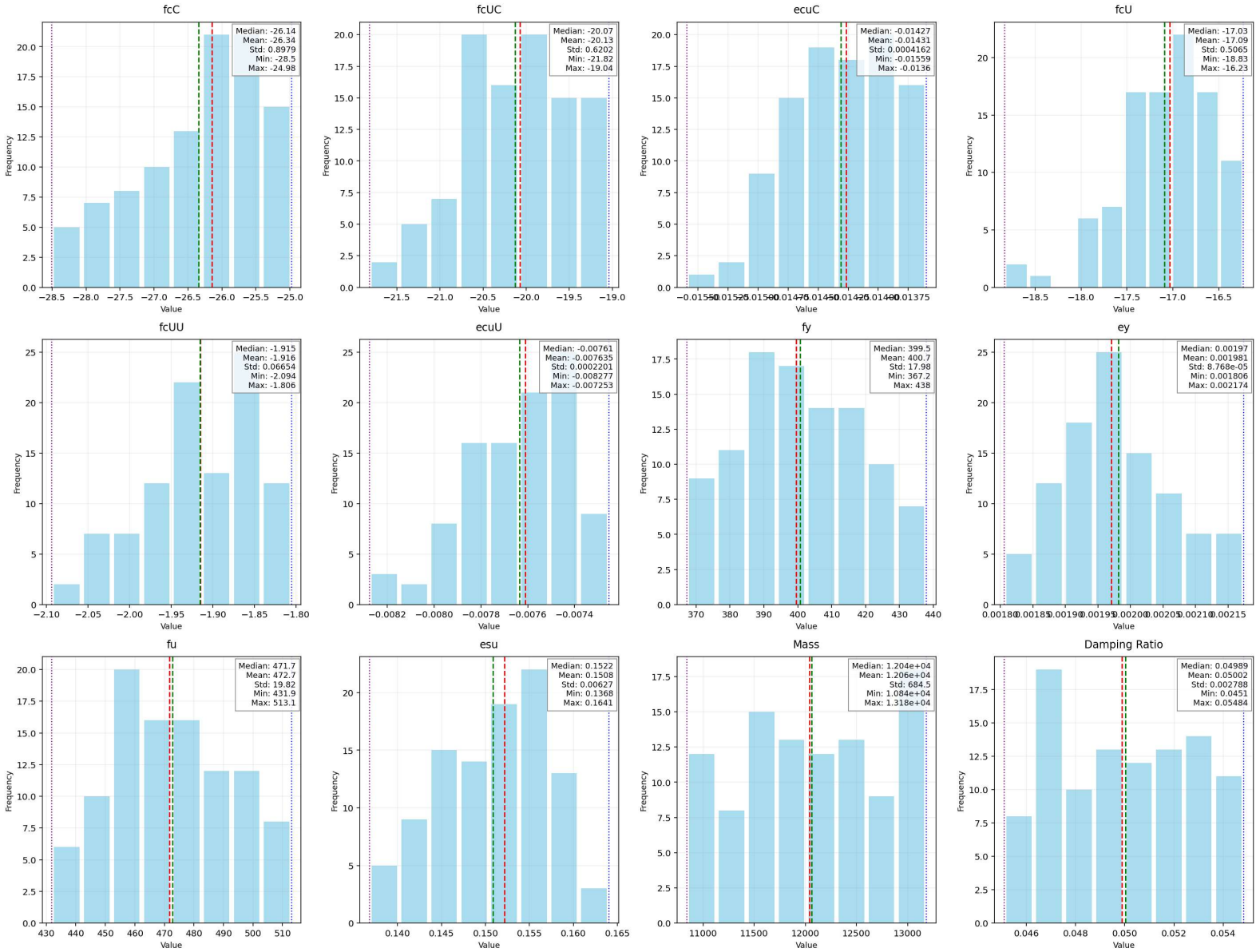
Help Variable Explorer Debugger Plots Files

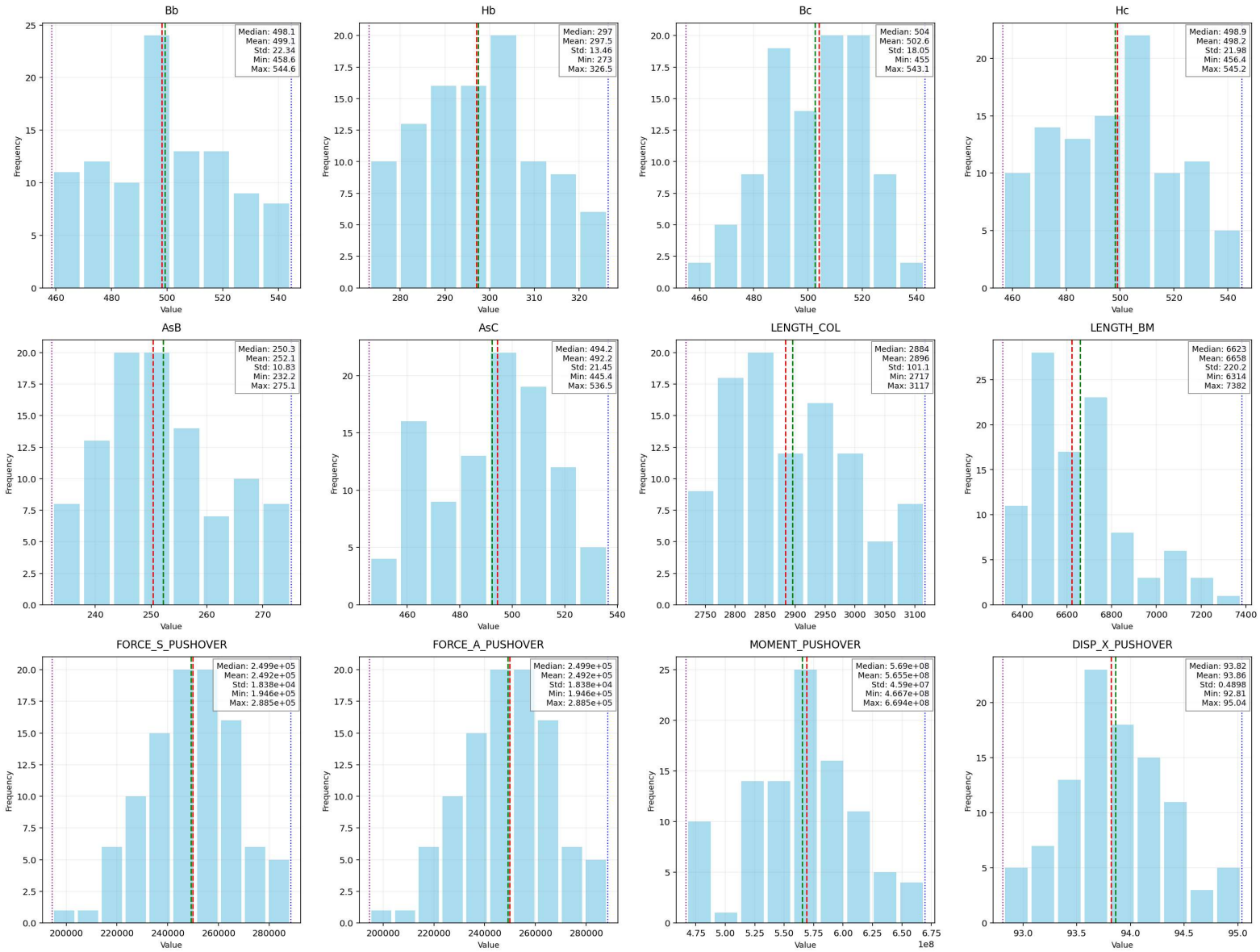
Console 1/A

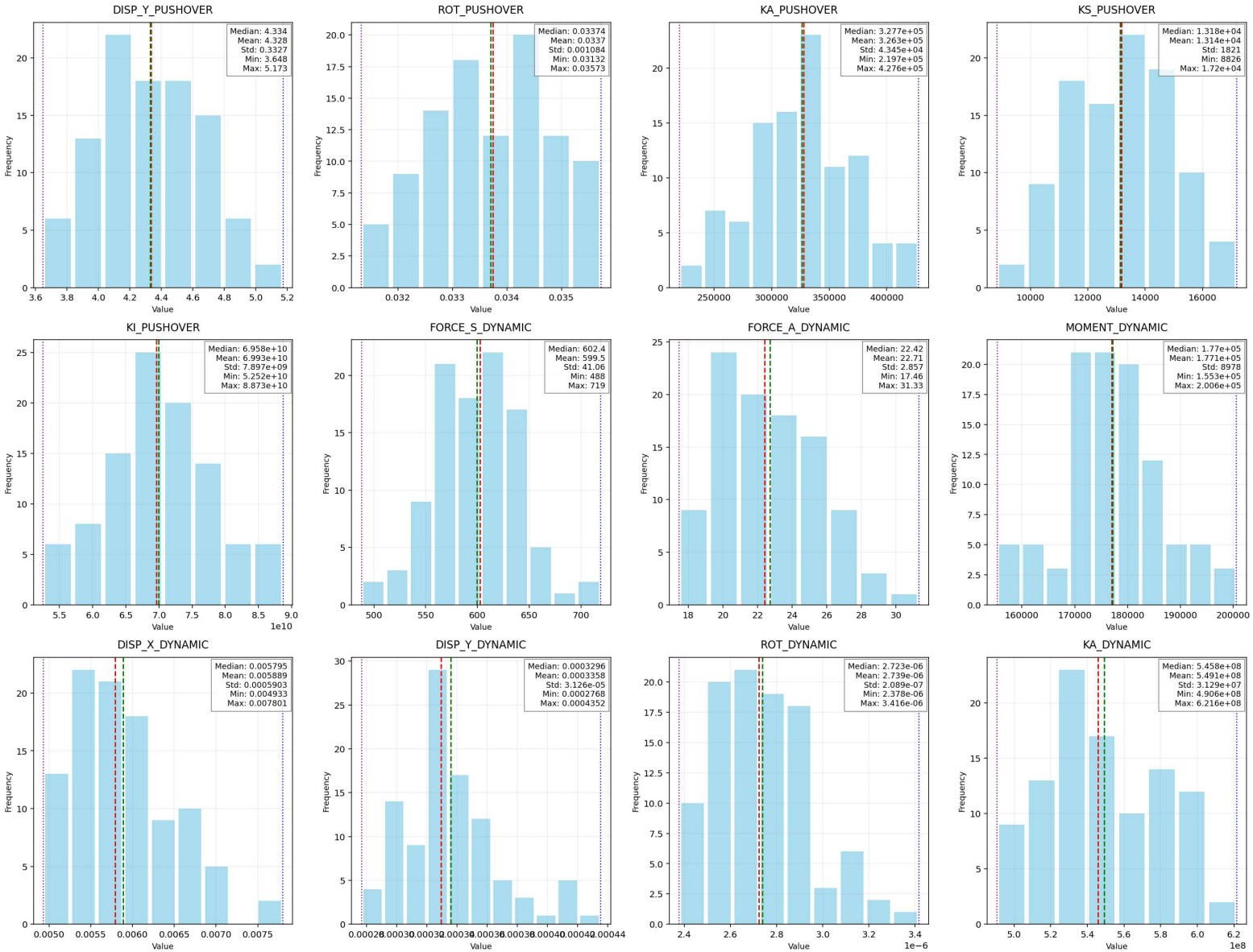
```
errors is correctly specified.
[2] The condition number is large, 2.81e+07. This might
indicate that there are
strong multicollinearity or other numerical problems.
Markov Transition Matrix:
[[0.         0.2        0.6        0.2        0.        ]
 [0.         0.         0.8        0.         0.2       ]
 [0.         0.02564103 0.33333333 0.35897436 0.28205128]
 [0.1        0.06666667 0.33333333 0.3        0.2       ]
 [0.1        0.05       0.5        0.25       0.1       ]]
c:
```

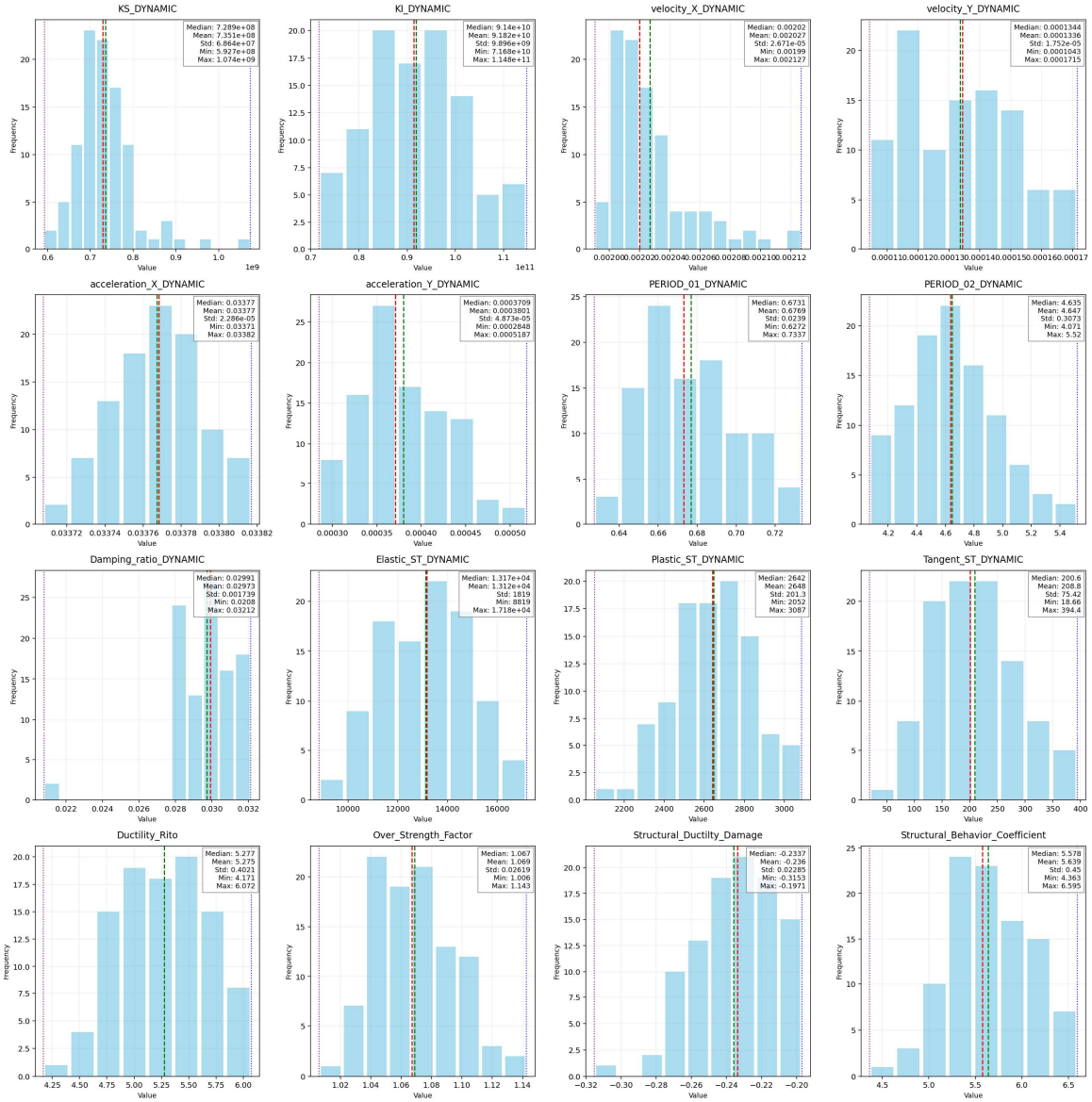
IPython Console History

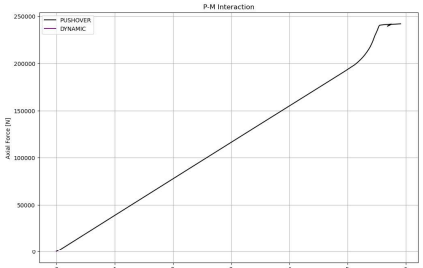
Inline Conda: anaconda3 (Python 3.12.7) LSP: Python Line 1000, Col 47 UTF-8 CRLF RW Mem 50%

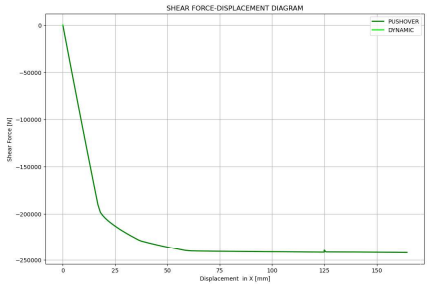

fcC
Median: -26.14
Mean: -26.34
Std: 0.8979
Min: -28.5
Max: -24.98
fcUC
Median: -20.07
Mean: -20.13
Std: 0.6202
Min: -21.82
Max: -19.04
ecuC
Median: -0.01427
Mean: -0.01431
Std: 0.0004162
Min: -0.01559
Max: -0.0136
fcU
Median: -17.03
Mean: -17.09
Std: 0.5065
Min: -18.83
Max: -16.23
fcUU
Median: -1.915
Mean: -1.916
Std: 0.06654
Min: -2.094
Max: -1.806
ecuU
Median: -0.00761
Mean: -0.007635
Std: 0.0002201
Min: -0.008277
Max: -0.007253
fy
Median: 399.5
Mean: 400.7
Std: 17.98
Min: 367.2
Max: 438
ey
Median: 0.00197
Mean: 0.001981
Std: 8.768e-05
Min: 0.001806
Max: 0.002174
fu
Median: 471.7
Mean: 472.7
Std: 19.82
Min: 431.9
Max: 513.1
esu
Median: 0.1522
Mean: 0.1508
Std: 0.00627
Min: 0.1368
Max: 0.1641
Mass
Median: 1.204e+04
Mean: 1.206e+04
Std: 684.5
Min: 1.084e+04
Max: 1.318e+04
Damping Ratio
Median: 0.04989
Mean: 0.05002
Std: 0.002788
Min: 0.0451
Max: 0.05484
Frequency
Value

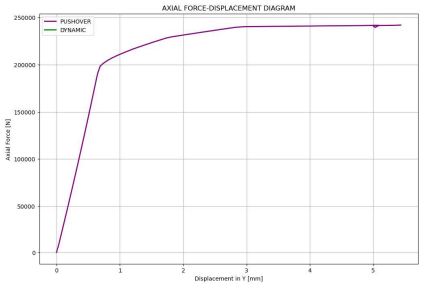

Bb
Median: 498.1
Mean: 499.1
Std: 22.34
Min: 458.6
Max: 544.6
Hb
Median: 297
Mean: 297.5
Std: 13.46
Min: 273
Max: 326.5
Bc
Median: 504
Mean: 502.6
Std: 18.05
Min: 455
Max: 543.1
Hc
Median: 498.9
Mean: 498.2
Std: 21.98
Min: 456.4
Max: 545.2
AsB
Median: 250.3
Mean: 252.1
Std: 10.83
Min: 232.2
Max: 275.1
AsC
Median: 494.2
Mean: 492.2
Std: 21.45
Min: 445.4
Max: 536.5
LENGTH_COL
Median: 2884
Mean: 2896
Std: 101.1
Min: 2717
Max: 3117
LENGTH_BM
Median: 6623
Mean: 6658
Std: 220.2
Min: 6314
Max: 7382
FORCE_S_PUSHOVER
Median: 2.499e+05
Mean: 2.492e+05
Std: 1.838e+04
Min: 1.946e+05
Max: 2.885e+05
FORCE_A_PUSHOVER
Median: 2.499e+05
Mean: 2.492e+05
Std: 1.838e+04
Min: 1.946e+05
Max: 2.885e+05
MOMENT_PUSHOVER
Median: 5.69e+08
Mean: 5.655e+08
Std: 4.59e+07
Min: 4.667e+08
Max: 6.694e+08
1e8
DISP_X_PUSHOVER
Median: 93.82
Mean: 93.86
Std: 0.4898
Min: 92.81
Max: 95.04
Frequency
Value

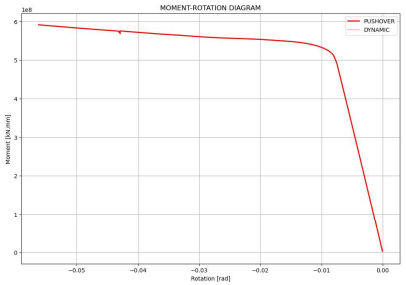

DISP_Y_PUSHOVER
Median: 4.334
Mean: 4.328
Std: 0.3327
Min: 3.648
Max: 5.173
ROT_PUSHOVER
Median: 0.03374
Mean: 0.0337
Std: 0.001084
Min: 0.03132
Max: 0.03573
KA_PUSHOVER
Median: 3.277e+05
Mean: 3.263e+05
Std: 4.345e+04
Min: 2.197e+05
Max: 4.276e+05
KS_PUSHOVER
Median: 1.318e+04
Mean: 1.314e+04
Std: 1821
Min: 8826
Max: 1.72e+04
KI_PUSHOVER
Median: 6.958e+10
Mean: 6.993e+10
Std: 7.897e+09
Min: 5.252e+10
Max: 8.873e+10
1e10
FORCE_S_DYNAMIC
Median: 602.4
Mean: 599.5
Std: 41.06
Min: 488
Max: 719
FORCE_A_DYNAMIC
Median: 22.42
Mean: 22.71
Std: 2.857
Min: 17.46
Max: 31.33
MOMENT_DYNAMIC
Median: 1.77e+05
Mean: 1.771e+05
Std: 8978
Min: 1.553e+05
Max: 2.006e+05
DISP_X_DYNAMIC
Median: 0.005795
Mean: 0.005889
Std: 0.0005903
Min: 0.004933
Max: 0.007801
DISP_Y_DYNAMIC
Median: 0.0003296
Mean: 0.0003358
Std: 3.126e-05
Min: 0.0002768
Max: 0.0004352
ROT_DYNAMIC
Median: 2.723e-06
Mean: 2.739e-06
Std: 2.089e-07
Min: 2.378e-06
Max: 3.416e-06
1e−6
KA_DYNAMIC
Median: 5.458e+08
Mean: 5.491e+08
Std: 3.129e+07
Min: 4.906e+08
Max: 6.216e+08
1e8
Frequency
Value

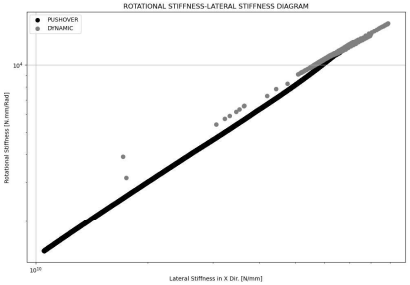

KS_DYNAMIC
Median: 7.289e+08
Mean: 7.351e+08
Std: 6.864e+07
Min: 5.927e+08
Max: 1.074e+09
KI_DYNAMIC
Median: 9.14e+10
Mean: 9.182e+10
Std: 9.896e+09
Min: 7.168e+10
Max: 1.148e+11
velocity_X_DYNAMIC
Median: 0.00202
Mean: 0.002027
Std: 2.671e-05
Min: 0.00199
Max: 0.002127
velocity_Y_DYNAMIC
Median: 0.0001344
Mean: 0.0001336
Std: 1.752e-05
Min: 0.0001043
Max: 0.0001715
acceleration_X_DYNAMIC
Median: 0.03377
Mean: 0.03377
Std: 2.286e-05
Min: 0.03371
Max: 0.03382
acceleration_Y_DYNAMIC
Median: 0.0003709
Mean: 0.0003801
Std: 4.873e-05
Min: 0.0002848
Max: 0.0005187
PERIOD_01_DYNAMIC
Median: 0.6731
Mean: 0.6769
Std: 0.0239
Min: 0.6272
Max: 0.7337
PERIOD_02_DYNAMIC
Median: 4.635
Mean: 4.647
Std: 0.3073
Min: 4.071
Max: 5.52
Damping_ratio_DYNAMIC
Median: 0.02991
Mean: 0.02973
Std: 0.001739
Min: 0.0208
Max: 0.03212
Elastic_ST_DYNAMIC
Median: 1.317e+04
Mean: 1.312e+04
Std: 1819
Min: 8819
Max: 1.718e+04
Plastic_ST_DYNAMIC
Median: 2642
Mean: 2648
Std: 201.3
Min: 2052
Max: 3087
Tangent_ST_DYNAMIC
Median: 200.6
Mean: 208.8
Std: 75.42
Min: 18.66
Max: 394.4
Ductility_Rito
Median: 5.277
Mean: 5.275
Std: 0.4021
Min: 4.171
Max: 6.072
Over_Strength_Factor
Median: 1.067
Mean: 1.069
Std: 0.02619
Min: 1.006
Max: 1.143
Structural_Ductilty_Damage
Median: -0.2337
Mean: -0.236
Std: 0.02285
Min: -0.3153
Max: -0.1971
Structural_Behavior_Coefficient
Median: 5.578
Mean: 5.639
Std: 0.45
Min: 4.363
Max: 6.595
Frequency
Value

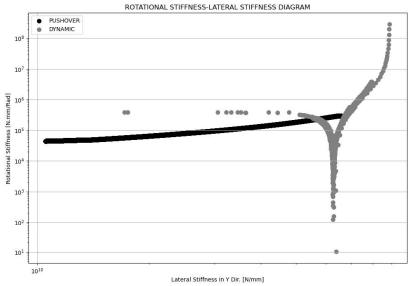

P-M Interaction
PUSHOVER
DYNAMIC
Axial Force [N]
Bending Moment [N.mm]
1e8

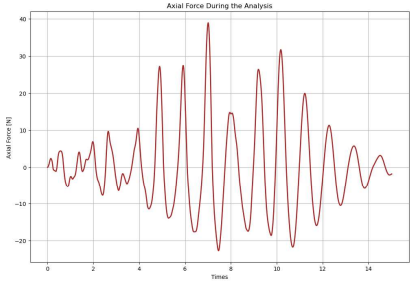

SHEAR FORCE-DISPLACEMENT DIAGRAM
PUSHOVER
DYNAMIC
Shear Force [N]
Displacement in X [mm]

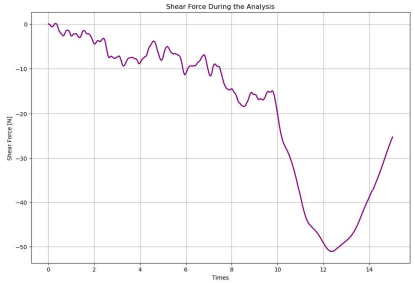

AXIAL FORCE-DISPLACEMENT DIAGRAM
PUSHOVER
DYNAMIC
Axial Force [N]
Displacement in Y [mm]

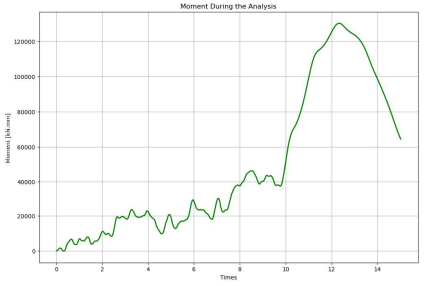

MOMENT-ROTATION DIAGRAM
1e8
PUSHOVER
DYNAMIC
Moment [kN.mm]
Rotation [rad]

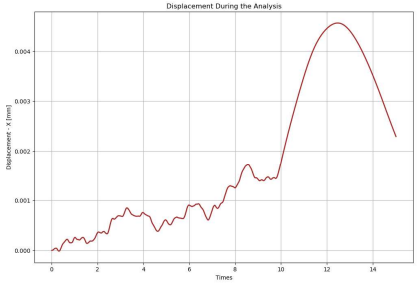

ROTATIONAL STIFFNESS-LATERAL STIFFNESS DIAGRAM
PUSHOVER
DYNAMIC
Rotational Stiffness [N.mm/Rad]
Lateral Stiffness in X Dir. [N/mm]

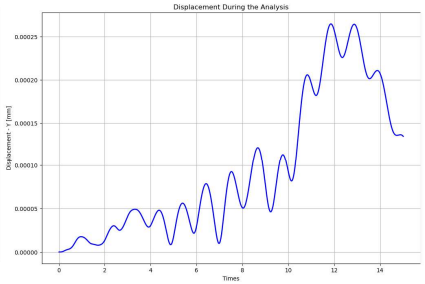

ROTATIONAL STIFFNESS-LATERAL STIFFNESS DIAGRAM
PUSHOVER
DYNAMIC
Rotational Stiffness [N.mm/Rad]
Lateral Stiffness in Y Dir. [N/mm]

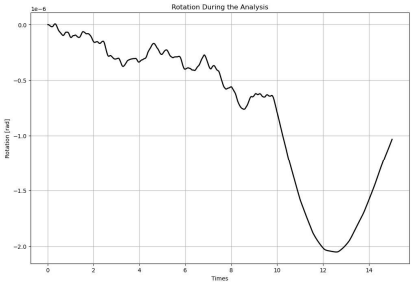

Axial Force During the Analysis
Axial Force [N]
Times

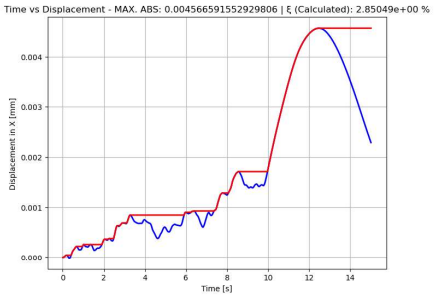

Shear Force During the Analysis
Shear Force [N]
Times

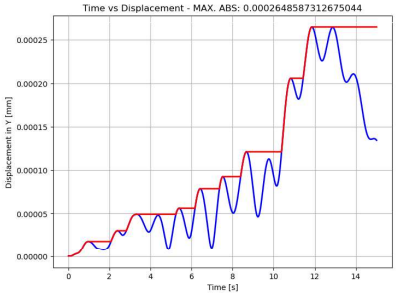

Moment During the Analysis
Moment [kN.mm]
Times

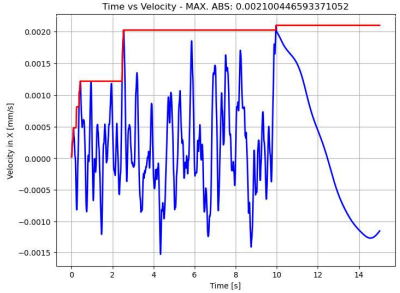

Displacement During the Analysis
Displacement - X [mm]
Times

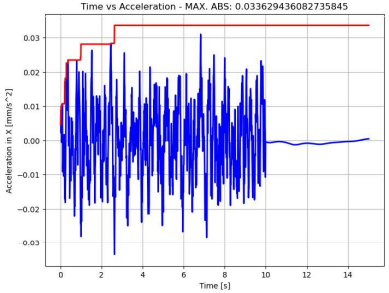

Displacement During the Analysis
Displacement - Y [mm]
Times

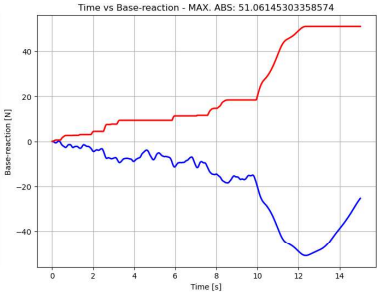

Rotation During the Analysis
1e−6
Rotation [rad]
Times

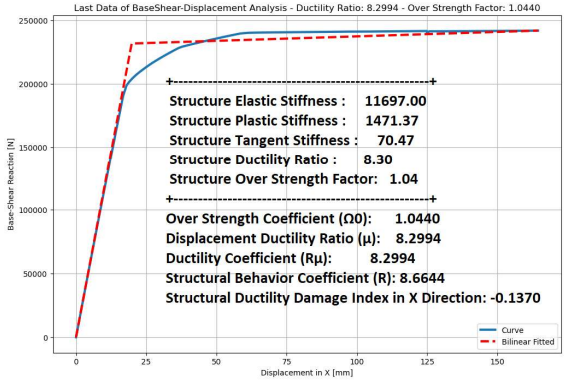

Time vs Displacement - MAX. ABS: 0.004566591552929806 | ξ (Calculated): 2.85049e+00 %
Displacement in X [mm]
Time [s]

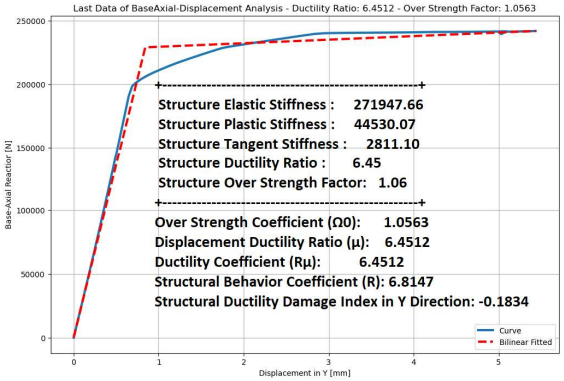

Time vs Displacement - MAX. ABS: 0.0002648587312675044
Displacement in Y [mm]
Time [s]

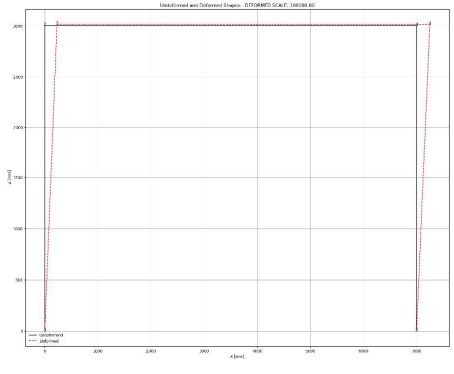

Time vs Velocity - MAX. ABS: 0.002100446593371052
Velocity in X [mm/s]
Time [s]

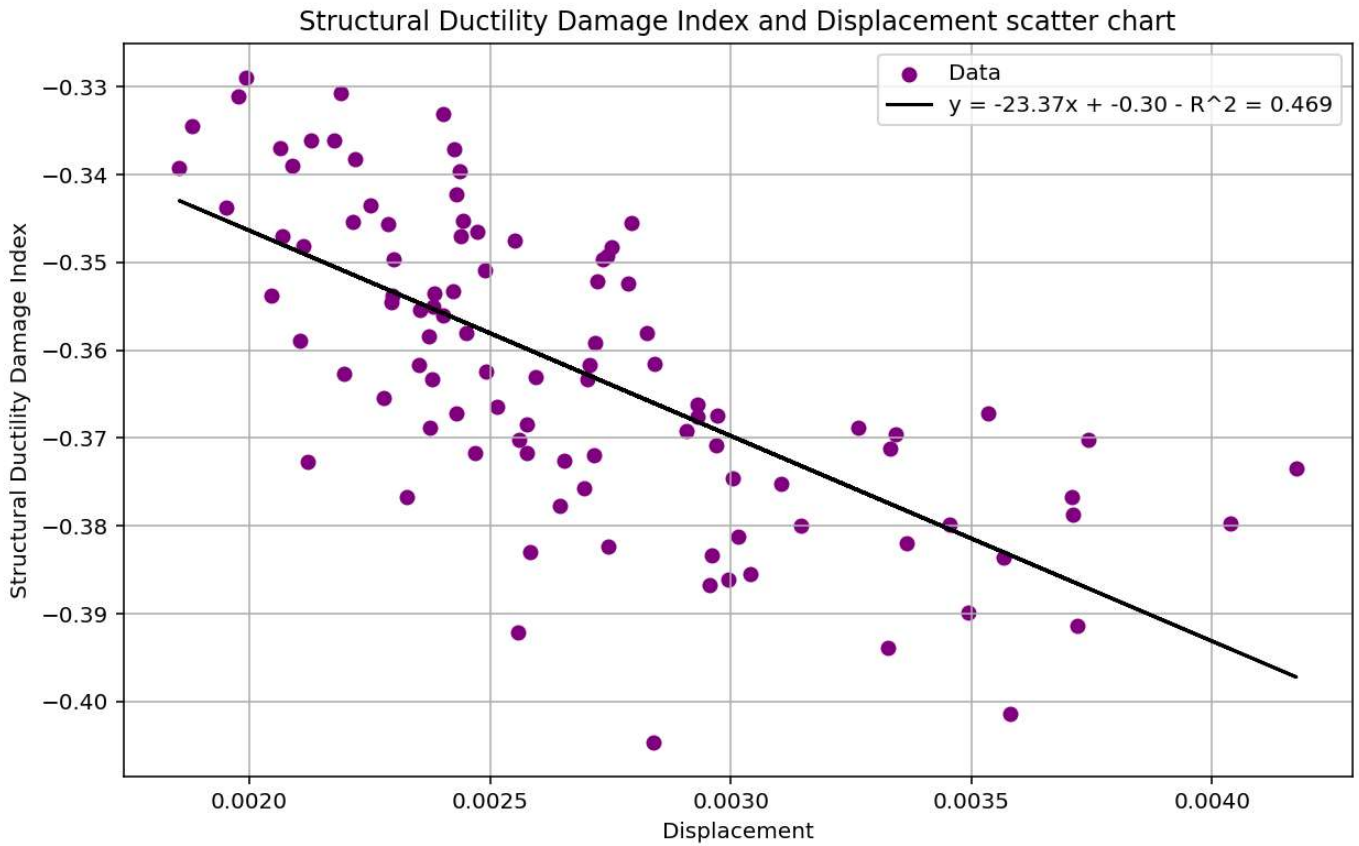

Time vs Acceleration - MAX. ABS: 0.033629436082735845
Acceleration in X [mm/s^2]
Time [s]

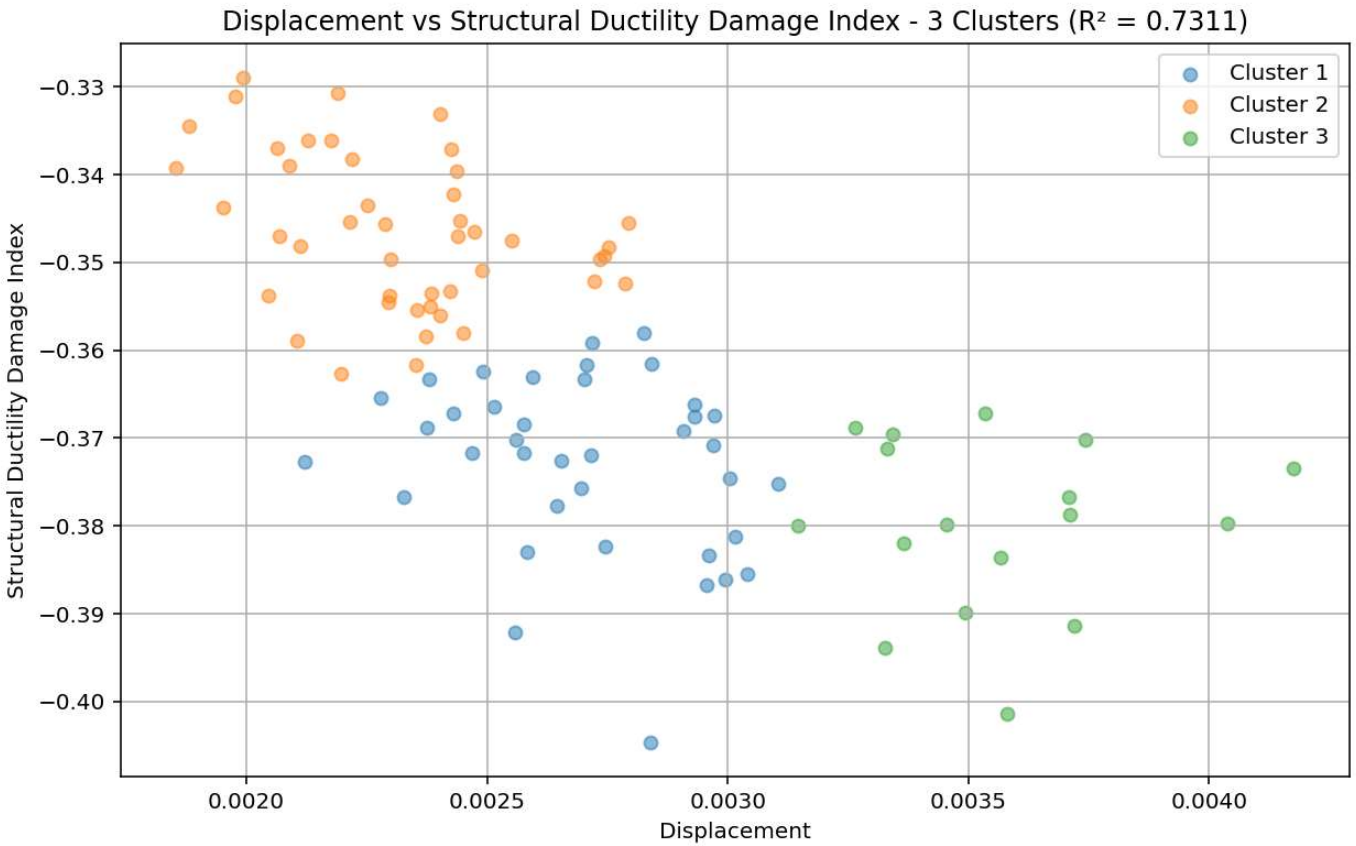

Time vs Base-reaction - MAX. ABS: 51.06145303358574
Base-reaction [N]
Time [s]

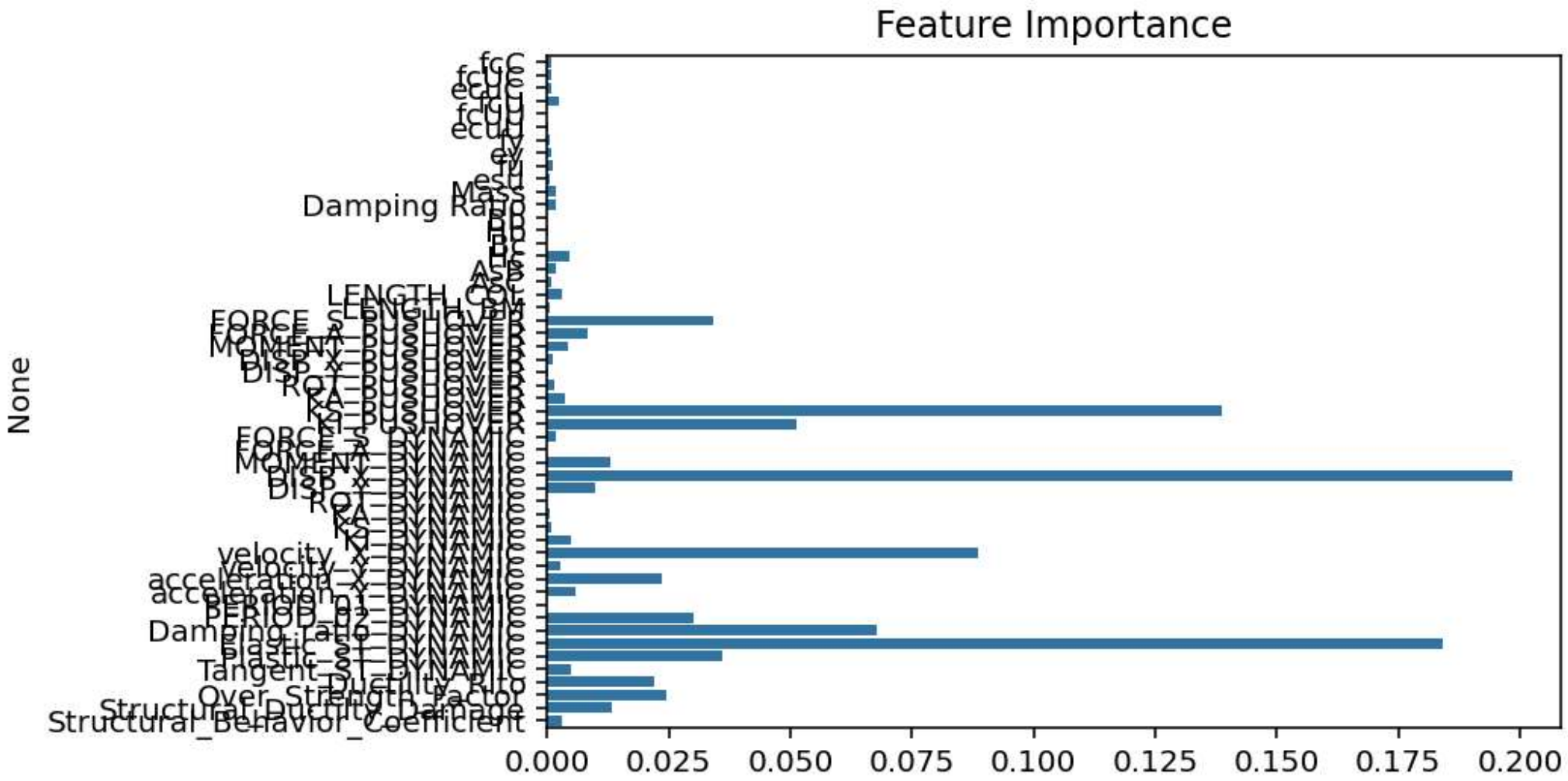

Last Data of BaseShear-Displacement Analysis - Ductility Ratio: 8.2994 - Over Strength Factor: 1.0440
Structure Elastic Stiffness : 11697.00
Structure Plastic Stiffness : 1471.37
Structure Tangent Stiffness : 70.47
Structure Ductility Ratio : 8.30
Structure Over Strength Factor: 1.04
Over Strength Coefficient (Ω0): 1.0440
Displacement Ductility Ratio (μ): 8.2994
Ductility Coefficient (Rμ): 8.2994
Structural Behavior Coefficient (R): 8.6644
Structural Ductility Damage Index in X Direction: -0.1370
Curve
Bilinear Fitted
Base-Shear Reaction [N]
Displacement in X [mm]

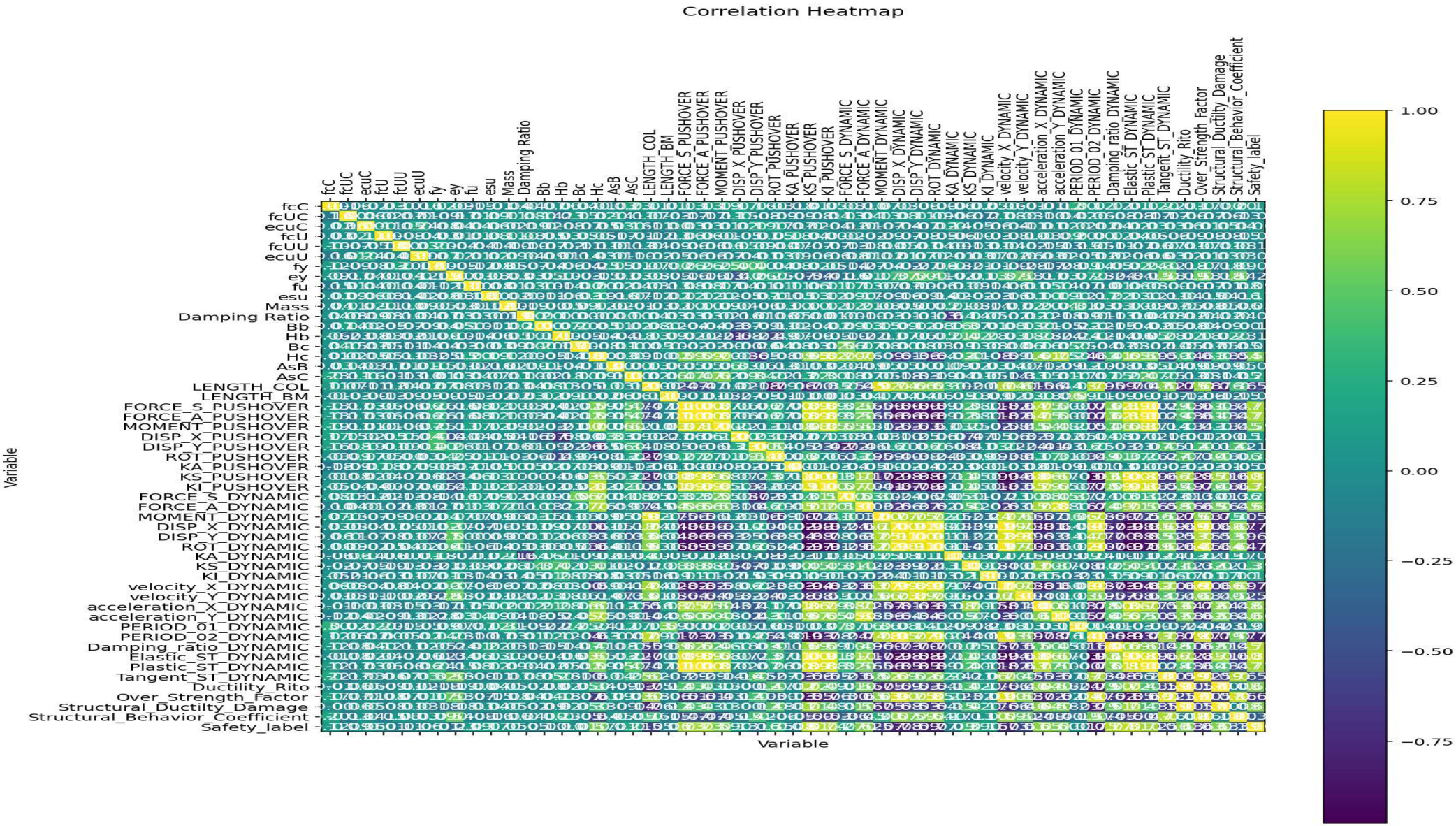

Last Data of BaseAxial-Displacement Analysis - Ductility Ratio: 6.4512 - Over Strength Factor: 1.0563
Structure Elastic Stiffness : 271947.66
Structure Plastic Stiffness : 44530.07
Structure Tangent Stiffness : 2811.10
Structure Ductility Ratio : 6.45
Structure Over Strength Factor: 1.06
Over Strength Coefficient (Ω0): 1.0563
Displacement Ductility Ratio (μ): 6.4512
Ductility Coefficient (Rμ): 6.4512
Structural Behavior Coefficient (R): 6.8147
Structural Ductility Damage Index in Y Direction: -0.1834
Curve
Bilinear Fitted
Base-Axial Reaction [N]
Displacement in Y [mm]




Structural Ductility Damage Index and Displacement scatter chart
Data
y = -23.37x + -0.30 - R^2 = 0.469
Structural Ductility Damage Index
−0.33
−0.34
−0.35
−0.36
−0.37
−0.38
−0.39
−0.40
0.0020
0.0025
0.0030
0.0035
0.0040
Displacement


Displacement vs Structural Ductility Damage Index - 3 Clusters (R² = 0.7311)
Cluster 1
Cluster 2
Cluster 3
Structural Ductility Damage Index
−0.33
−0.34
−0.35
−0.36
−0.37
−0.38
−0.39
−0.40
0.0020
0.0025
0.0030
0.0035
0.0040
Displacement


Feature Importance
None
Damping Ratio
velocity_X
Velocity_X
acceleration_X
Damping_Ratio
Tangent_ST
Over_Strength_Factor
Structural_Behavior_Coefficient
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200

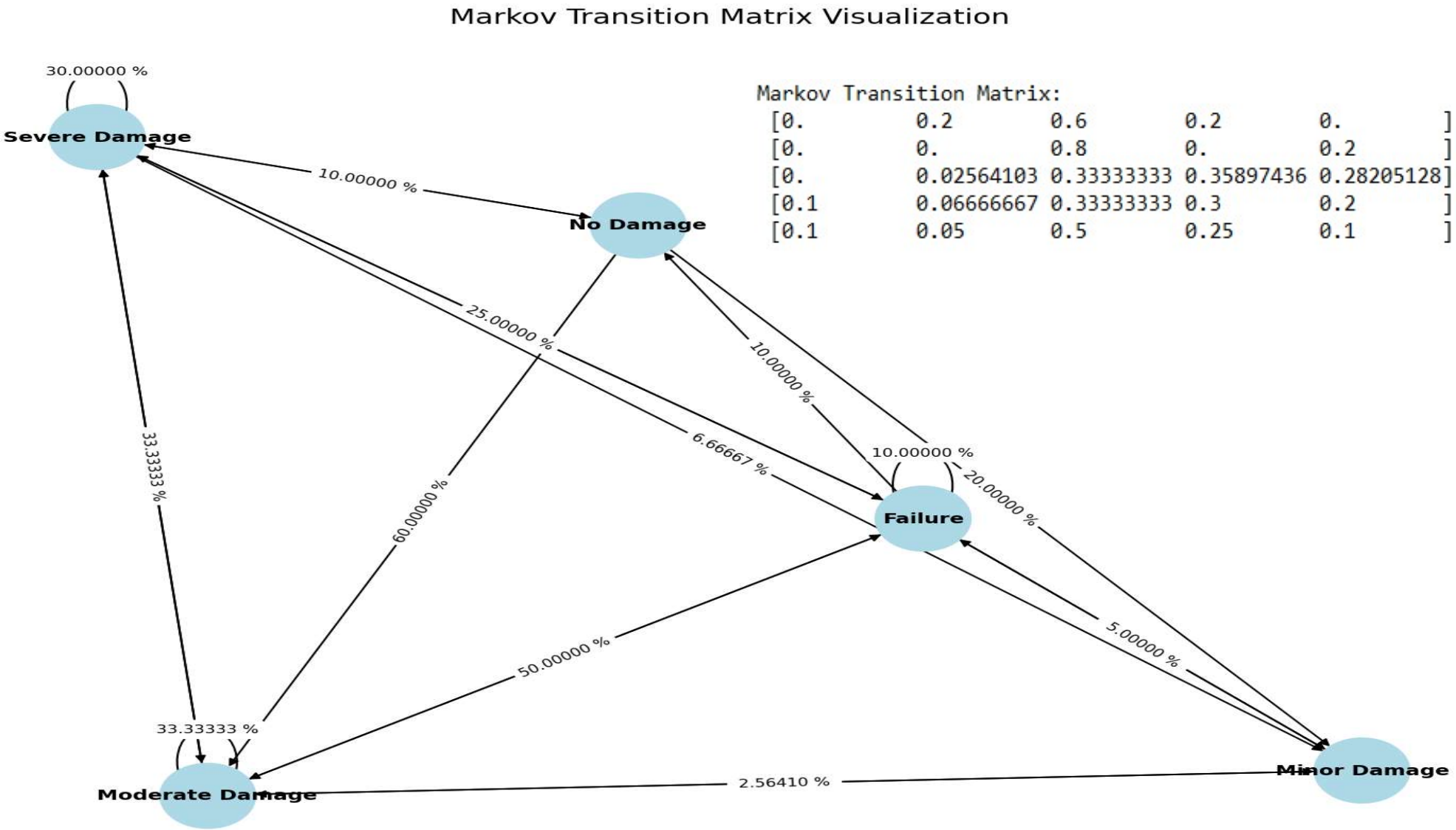

Correlation Heatmap
fcC
fcUC
ecuC
fcU
fcUU
ecuU
fy
ey
fu
esu
Mass
Damping Ratio
Bb
Hb
Bc
Hc
AsB
AsC
LENGTH_COL
LENGTH_BM
FORCE_S_PUSHOVER
FORCE_A_PUSHOVER
MOMENT_PUSHOVER
DISP_X_PUSHOVER
DISP_Y_PUSHOVER
ROT_PUSHOVER
KA_PUSHOVER
KS_PUSHOVER
KI_PUSHOVER
FORCE_S_DYNAMIC
FORCE_A_DYNAMIC
MOMENT_DYNAMIC
DISP_X_DYNAMIC
DISP_Y_DYNAMIC
ROT_DYNAMIC
KA_DYNAMIC
KS_DYNAMIC
KI_DYNAMIC
velocity_X_DYNAMIC
velocity_Y_DYNAMIC
acceleration_X_DYNAMIC
acceleration_Y_DYNAMIC
PERIOD_01_DYNAMIC
PERIOD_02_DYNAMIC
Damping_ratio_DYNAMIC
Elastic_ST_DYNAMIC
Plastic_ST_DYNAMIC
Tangent_ST_DYNAMIC
Ductility_Rito
Over_Strength_Factor
Structural_Ductilty_Damage
Structural_Behavior_Coefficient
Safety_label
Variable
Variable
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75

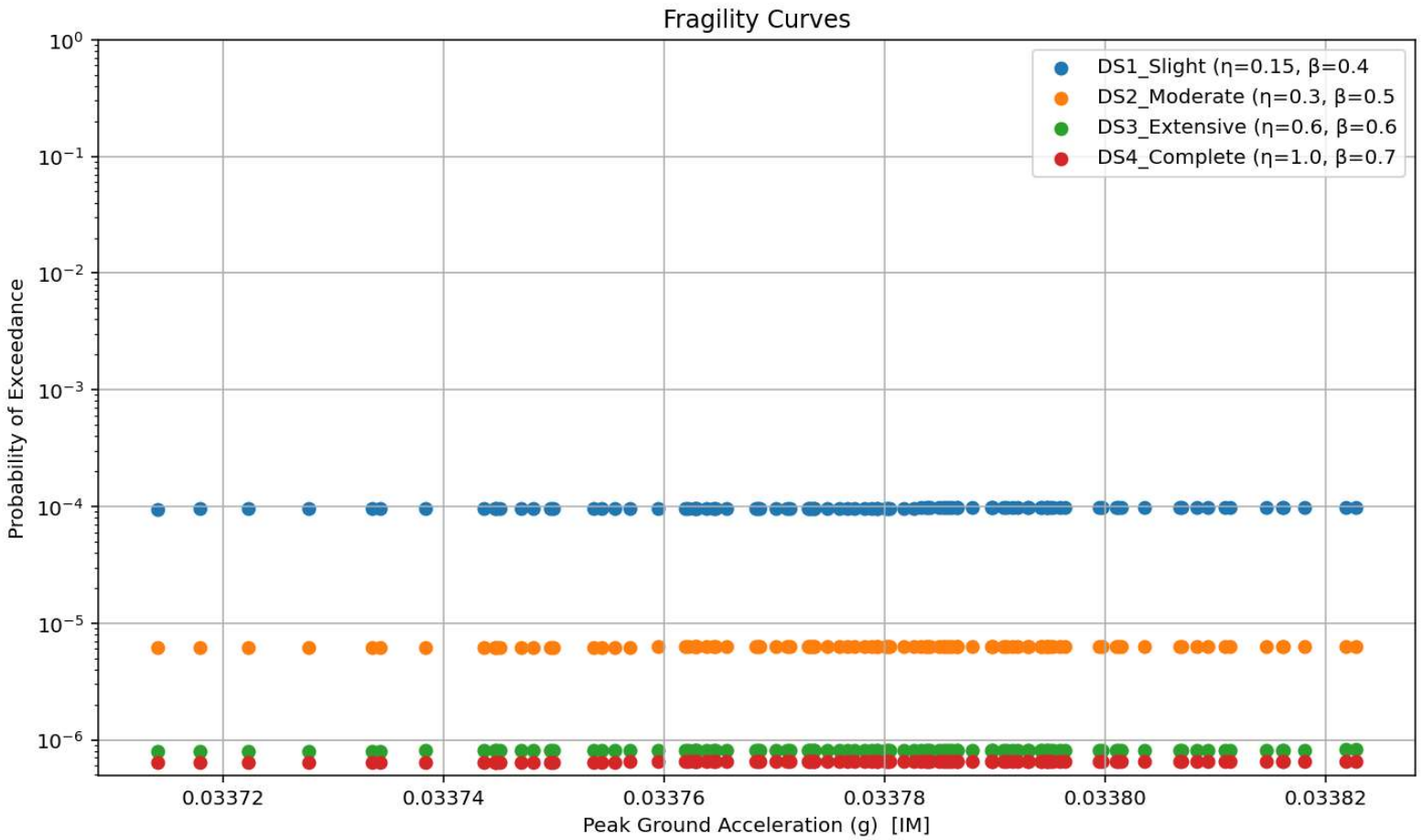
OLS Regression Results

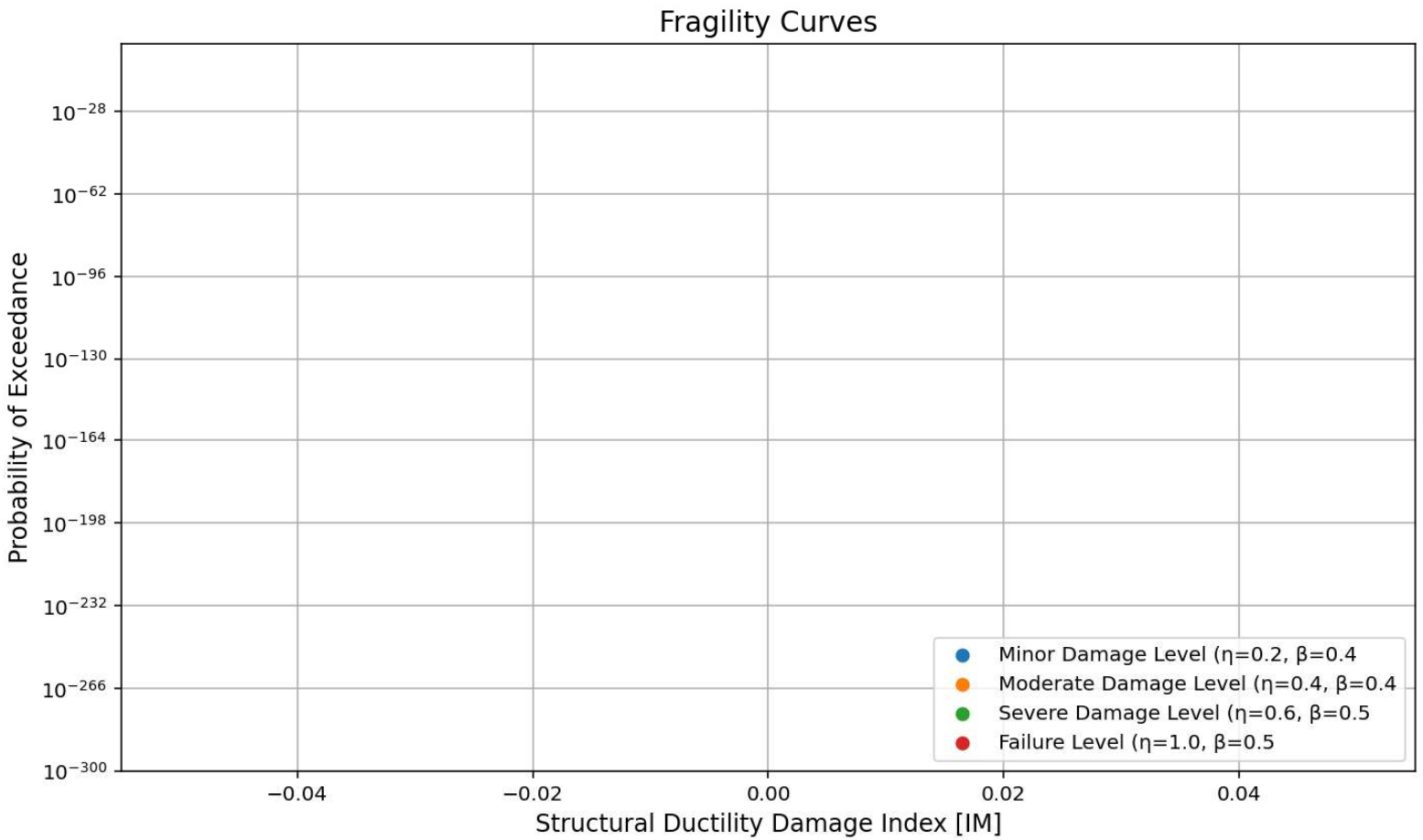
Dep. Variable:	DISP_X_DYNAMIC	R-squared:	0.841
Model:	OLS	Adj. R-squared:	0.833
Method:	Least Squares	F-statistic:	99.53
Date:	Fri, 13 Jun 2025	Prob (F-statistic):	5.51e-36
Time:	20:41:08	Log-Likelihood:	693.58
No. Observations:	100	AIC:	-1375.
Df Residuals:	94	BIC:	-1360.
Df Model:	5		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	0.4448	0.051	8.729	0.000	0.344	0.546
velocity_X_DYNAMIC	5.0684	1.033	4.908	0.000	3.018	7.119
acceleration_X_DYNAMIC	-13.2190	1.494	-8.850	0.000	-16.185	-10.253
FORCE_S_DYNAMIC	1.549e-07	6.05e-07	0.256	0.798	-1.05e-06	1.36e-06
Damping_ratio_DYNAMIC	-0.0058	0.014	-0.405	0.687	-0.034	0.023
Structural_Behavior_Coefficient	-0.0005	7.08e-05	-6.887	0.000	-0.001	-0.000

Omnibus:	3.044	Durbin-Watson:	1.722
Prob(Omnibus):	0.218	Jarque-Bera (JB):	2.650
Skew:	-0.200	Prob(JB):	0.266
Kurtosis:	3.690	Cond. No.	3.85e+07


Markov Transition Matrix Visualization
Markov Transition Matrix:
[0. 0.2 0.6 0.2 0.]
[0. 0. 0.8 0. 0.2]
[0. 0.02564103 0.33333333 0.35897436 0.28205128]
[0.1 0.06666667 0.33333333 0.3 0.2]
[0.1 0.05 0.5 0.25 0.1]
30.00000 %
Severe Damage
10.00000 %
No Damage
25.00000 %
6.66667 %
10.00000 %
10.00000 %
20.00000 %
Failure
33.33333 %
60.00000 %
50.00000 %
5.00000 %
33.33333 %
Moderate Damage
2.56410 %
Minor Damage


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
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.03372
0.03374
0.03376
0.03378
0.03380
0.03382
Peak Ground Acceleration (g) [IM]


Fragility Curves
Probability of Exceedance
10^{-28}
10^{-62}
10^{-96}
10^{-130}
10^{-164}
10^{-198}
10^{-232}
10^{-266}
10^{-300}
−0.04
−0.02
0.00
0.02
0.04
Structural Ductility Damage Index [IM]
Minor Damage Level (η=0.2, β=0.4
Moderate Damage Level (η=0.4, β=0.4
Severe Damage Level (η=0.6, β=0.5
Failure Level (η=1.0, β=0.5