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Experimental Structural Dynamics
Final Presentation – Group 11

M.Sc. Natural Hazards and Risks in Structural Engineering

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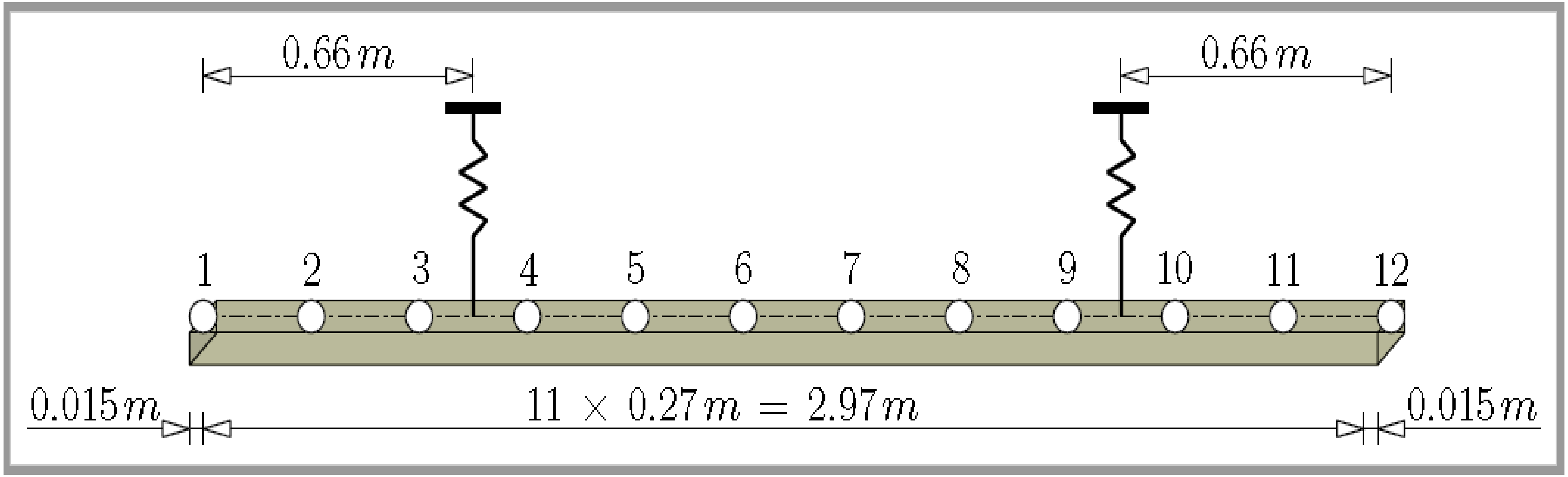
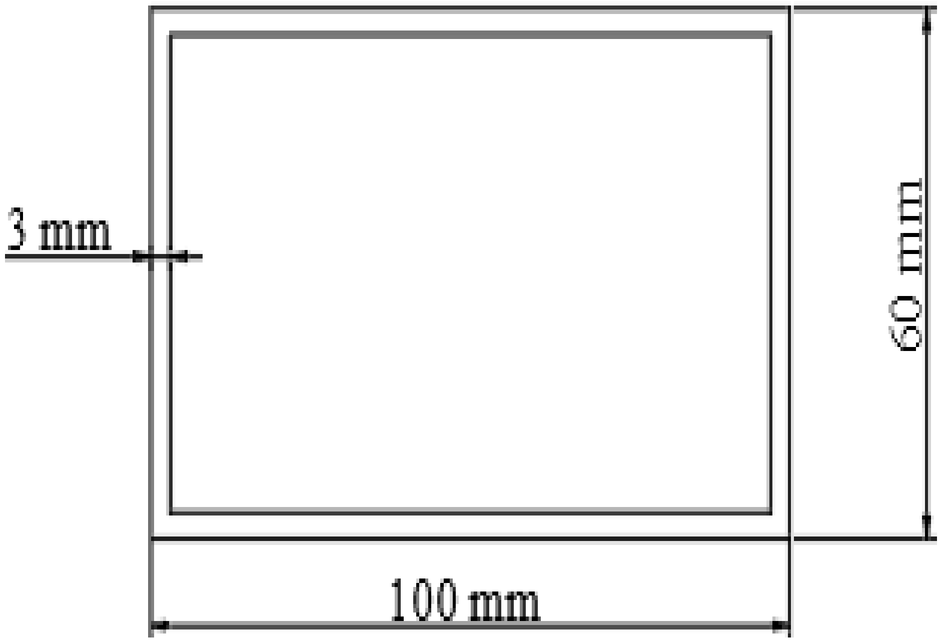
Structural System

Steel Free-free Beam



Cross-section and Material Parameters



Geometric Properties

$A = 100 \times 60 - [(100 - 3 \times 2) \times (60 - 3 \times 2)] = 924\ mm^2$

$I = \{(100 \times 60^3) - [(100 - 3 \times 2) \times (60 - 3 \times 2)^3]\}/12 = 566532\ mm^4$

Material Parameters

Young's modulus: $E = 210$ GPa

Density: $\rho = 7850\ kg/m^3$

Modal Parameters – Analytical Solution

- Natural Frequencies for a Free-free Beam

$$f_k = \frac{1}{2\pi}\left(\frac{\alpha_k}{L}\right)^2\sqrt{\frac{EI}{\rho A}}$$

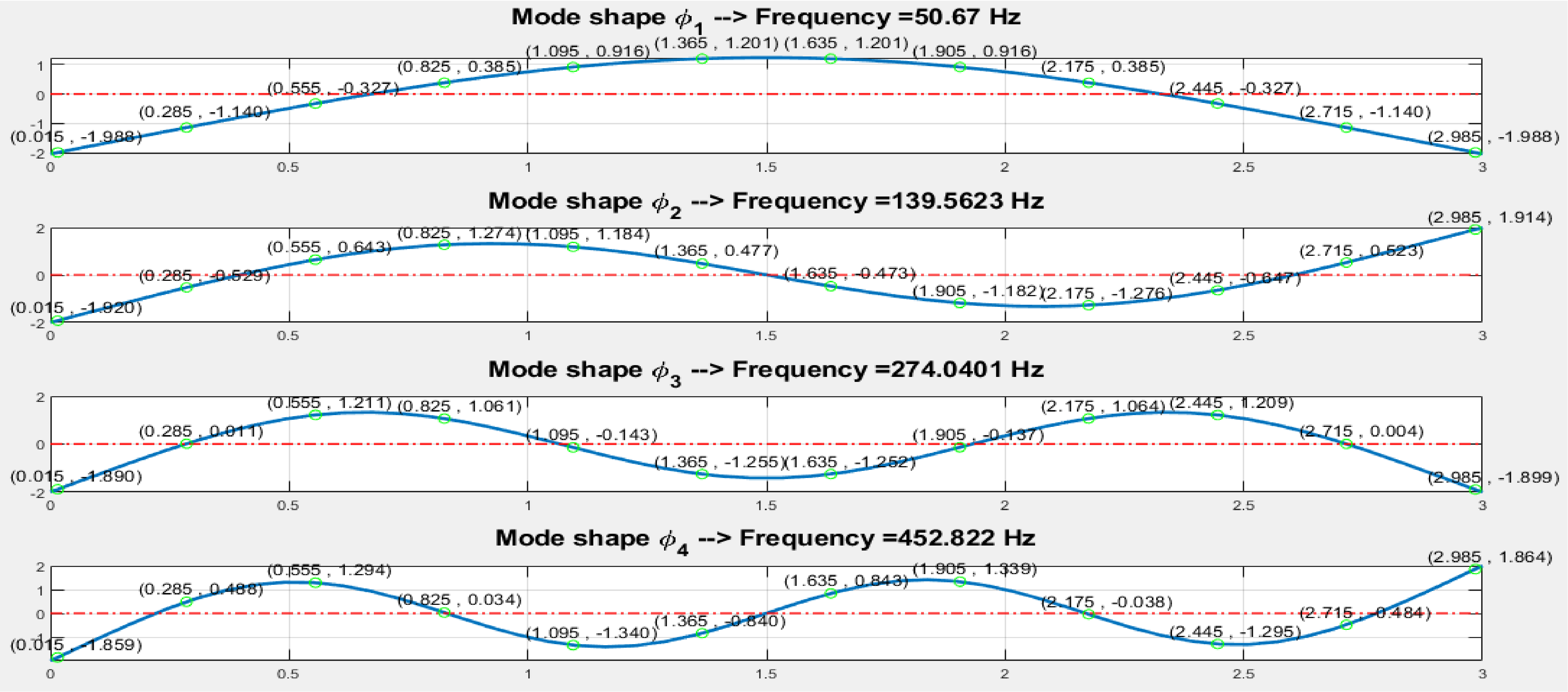
1st mode: $\alpha_1 = 4.73$, 2nd mode: $\alpha_2 = 7.85$, 3rd mode: $\alpha_3 = 11.00$, 4th mode: $\alpha_4 = 14.14$

- Mode Shapes for a Free-free Beam

$$\varphi_k(x) = \sinh\lambda_k x + \sin\lambda_k x - \left(\cosh\lambda_k x + \cos\lambda_k x\right)\frac{\sinh\lambda_k L - \sin\lambda_k L}{\cosh\lambda_k L - \cos\lambda_k L}$$

where $\lambda_k = \alpha_k/L$

Modal Parameters – Analytical Solution



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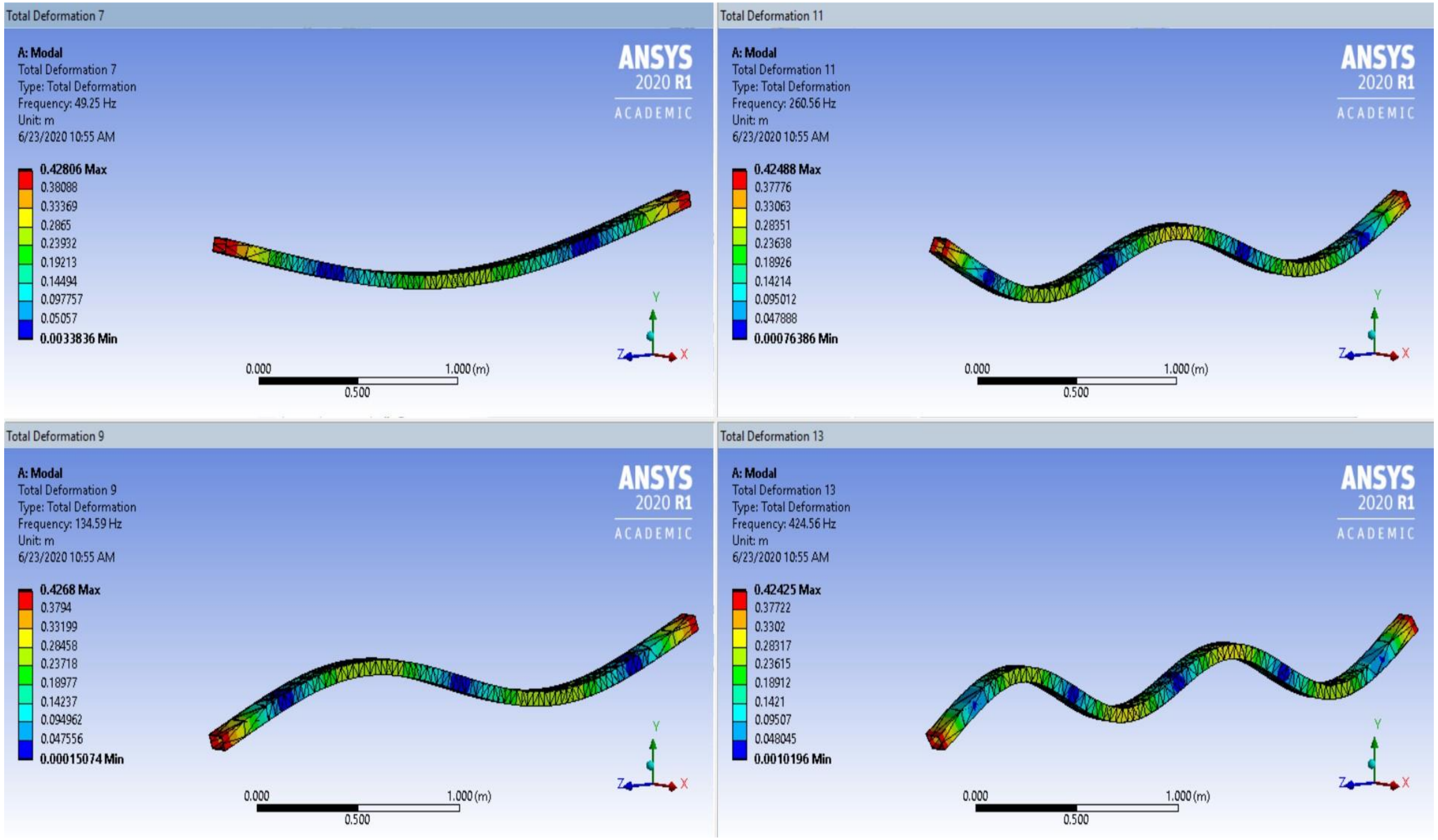
Ansys' Model



Natural Frequencies
f_1 = 49.25 Hz
f_2 = 134.59 Hz
f_3 = 260.56 Hz
f_4 = 424.56 Hz

System's Response – Analytical Solution

- Obtaining a set of decoupled equations for each mode

$$\underbrace{\{\varphi_k\}^T[M]\{\varphi_k\}}_{=1}\ddot{y}_k(t) + \underbrace{\{\varphi_k\}^T[C]\{\varphi_k\}}_{=2\zeta_k\omega_k}\dot{y}_k(t) + \underbrace{\{\varphi_k\}^T[K]\{\varphi_k\}}_{=\omega_k^2}y_k(t) = \underbrace{\{\varphi_k\}^T\{F(t)\}}_{=f_k(t)}$$

- Applying the Central Difference Method

- Superimposing the response components for all considered modes

$$\{\ddot{y}(t)\} = \sum_{k=1}^{n}\{\varphi_k\}\ddot{y}_k(t),\ \{\dot{y}(t)\} = \sum_{k=1}^{n}\{\varphi_k\}\dot{y}_k(t),\ \{y(t)\} = \sum_{k=1}^{n}\{\varphi_k\}y_k(t)$$

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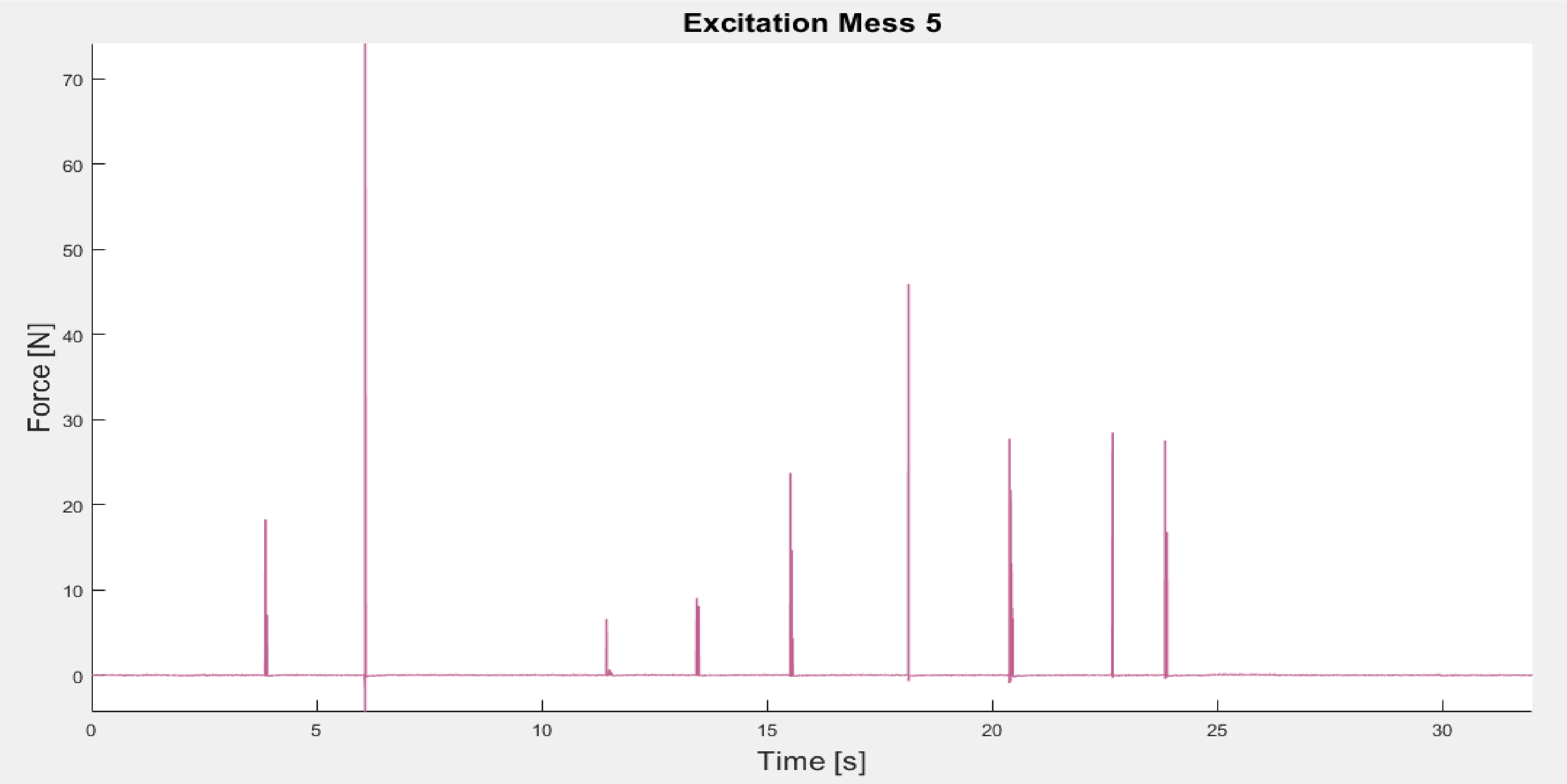
Simulation

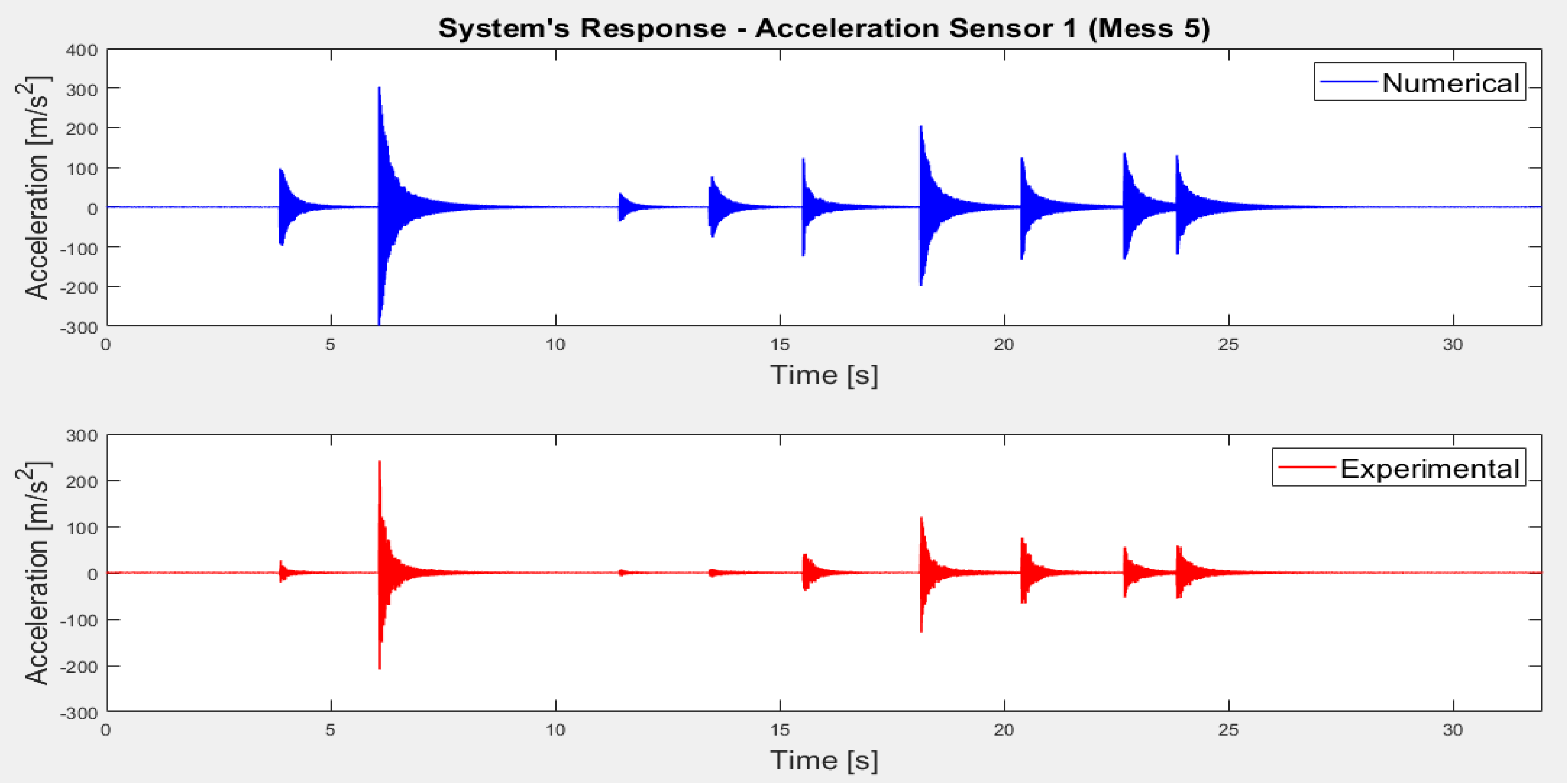
Assumptions:

- Damping ratio: $\zeta = 0.2\%$
- Force applied at the position of sensor 8 ($x = 1.905$m)
- $y_k(0) = 0$ and $\dot{y}_k(0) = 0$

Excitation – Simulation 1



System's Response – Simulation 1



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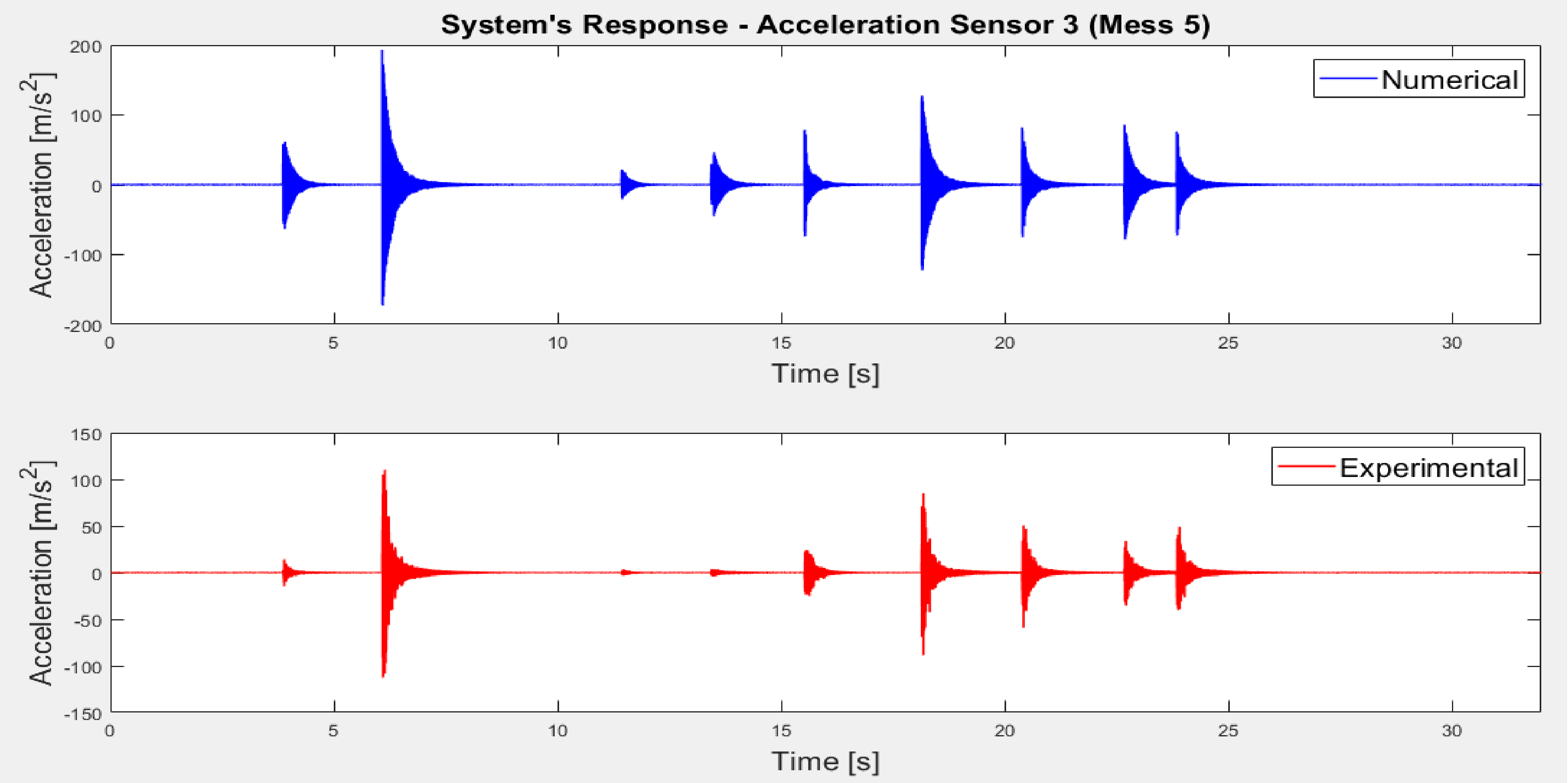
System's Response – Simulation 1



System's Response – Simulation 1

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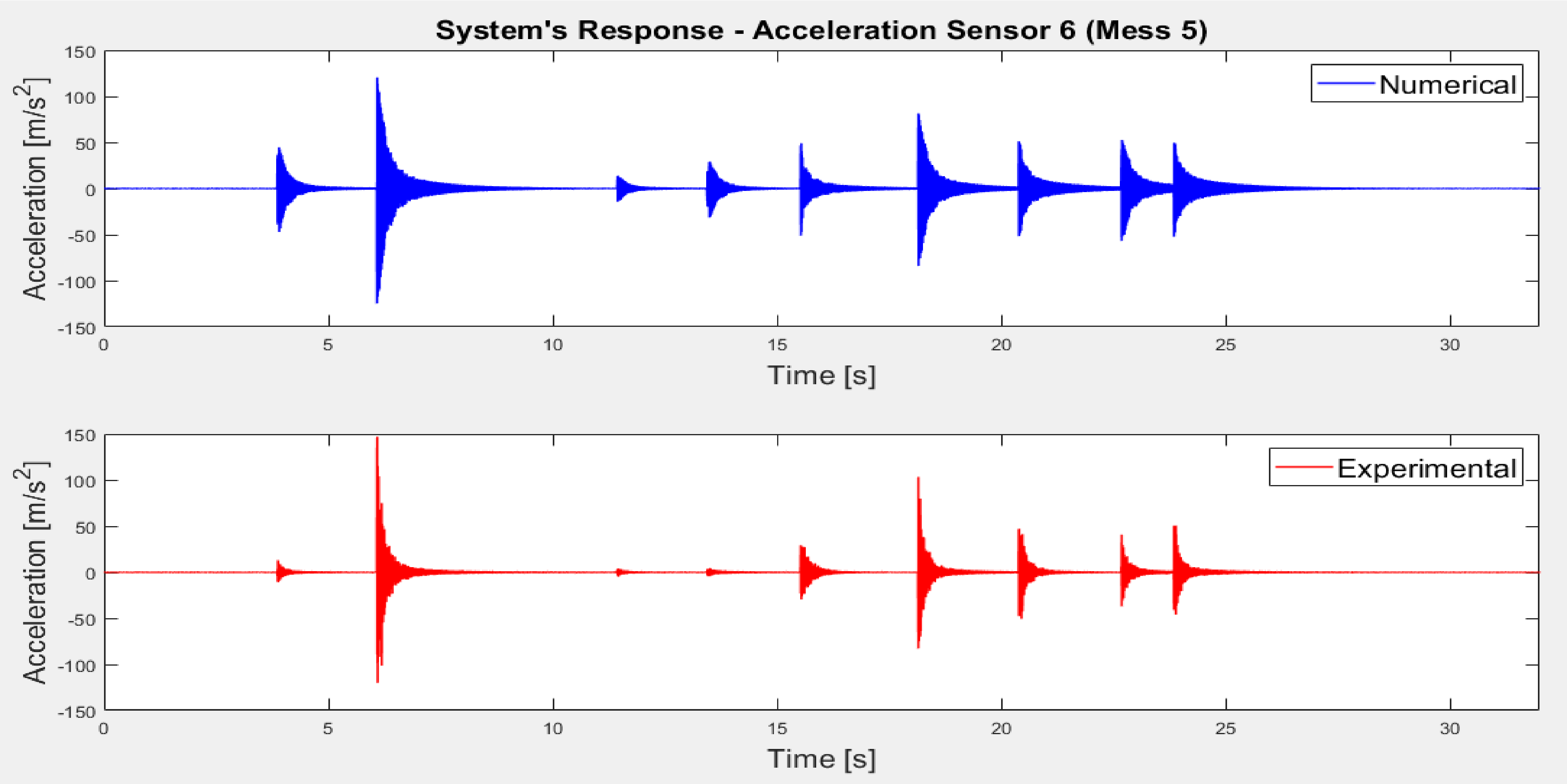
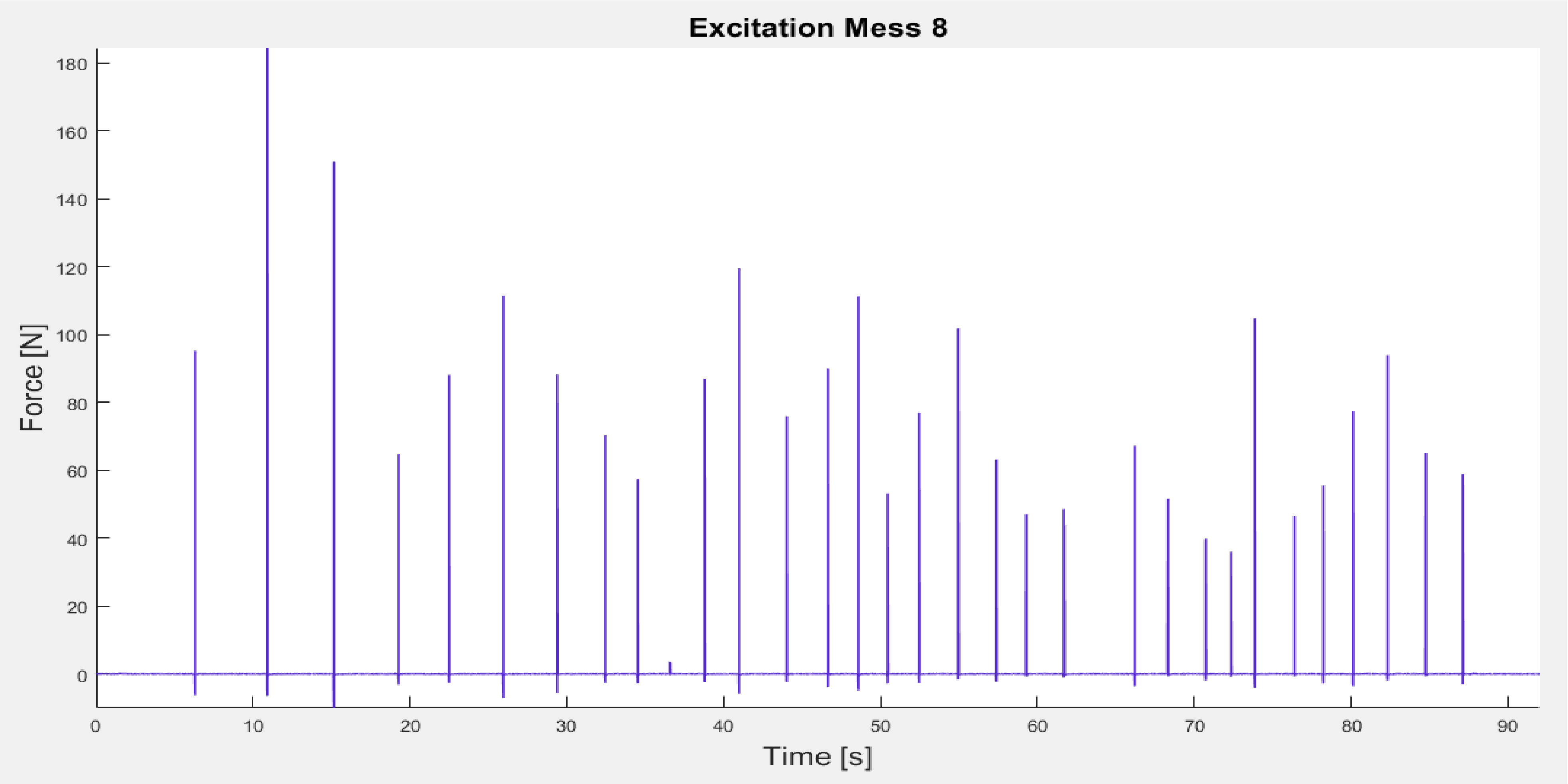
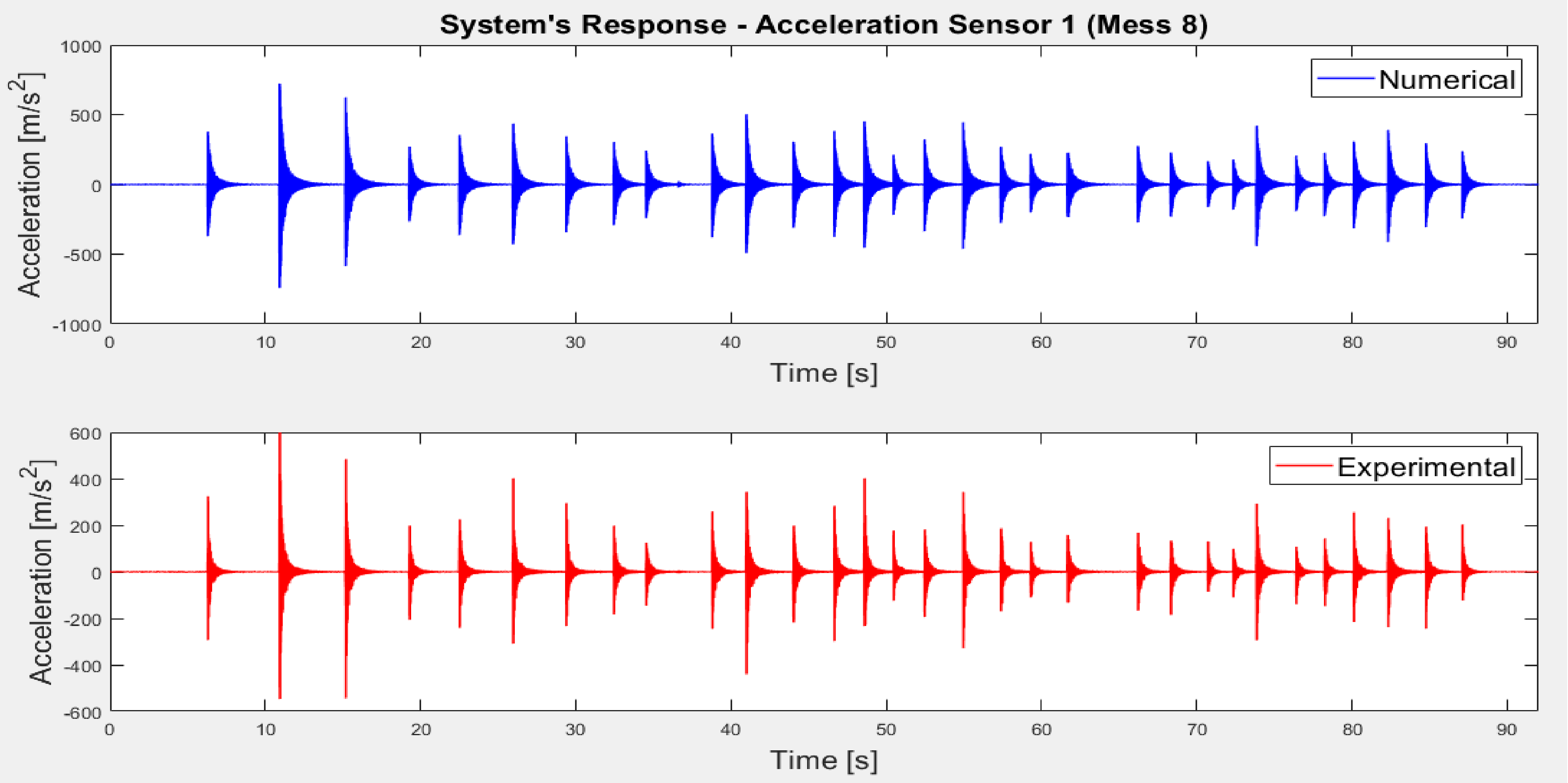


Excitation – Simulation 2



System's Response – Simulation 2



System's Response – Simulation 2

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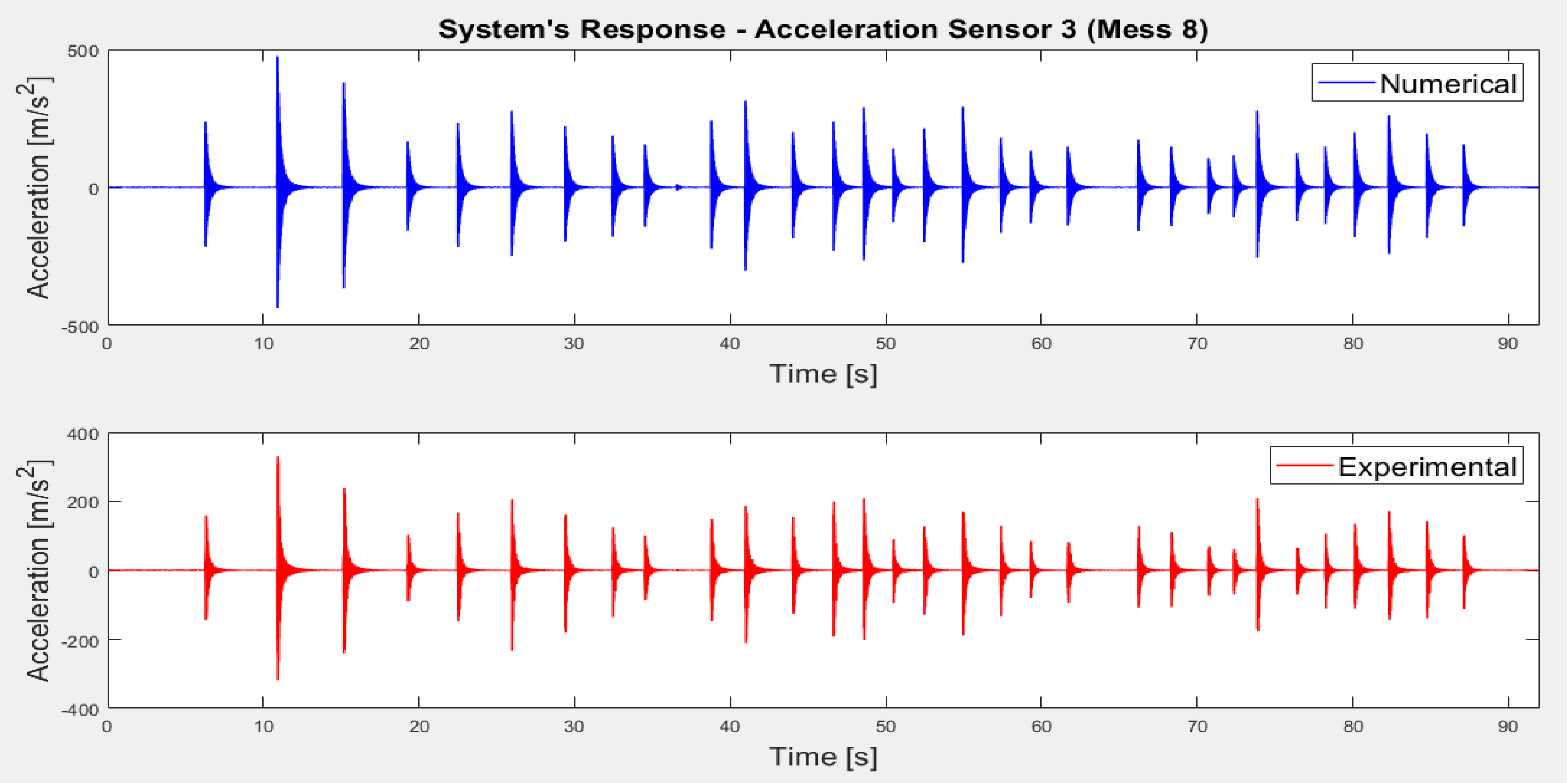

System's Response – Simulation 2

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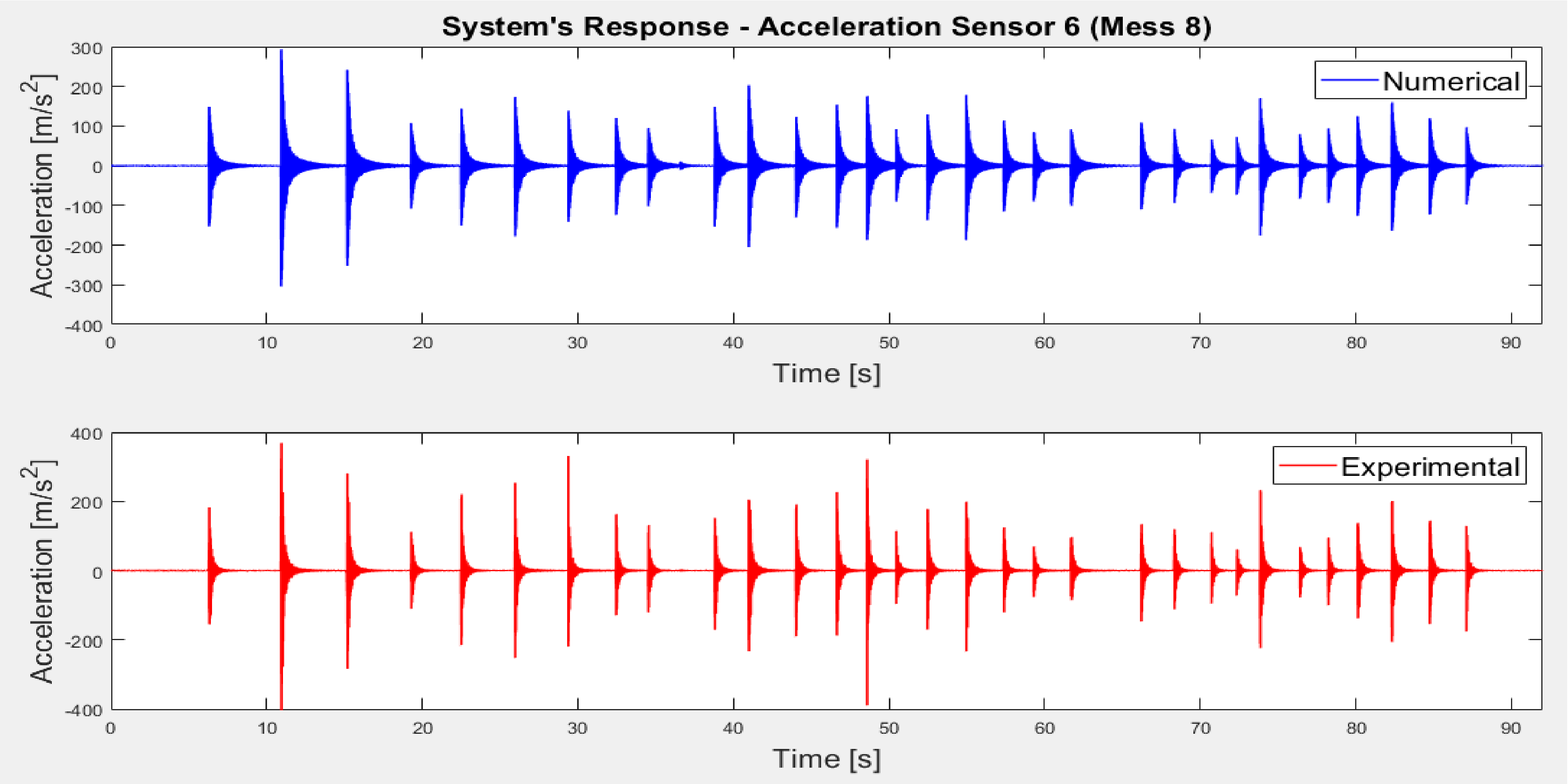

Identification of Modal Parameters with MACEC

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- Modelled the structure with 12 measurement points related to each sensor.
- Used the covariance-driven method.
- Defined number of blocks and system orders:

Parameters	Data 1 (mess 5)	Data 2 (mess 8)	Simulation 1 (mess 5)	Simulation 2 (mess 8)
Number of blocks	50	75	100	100
System orders	2:2:50	2:2:75	2:2:100	2:2:100

Identification of Modal Parameters with MACEC

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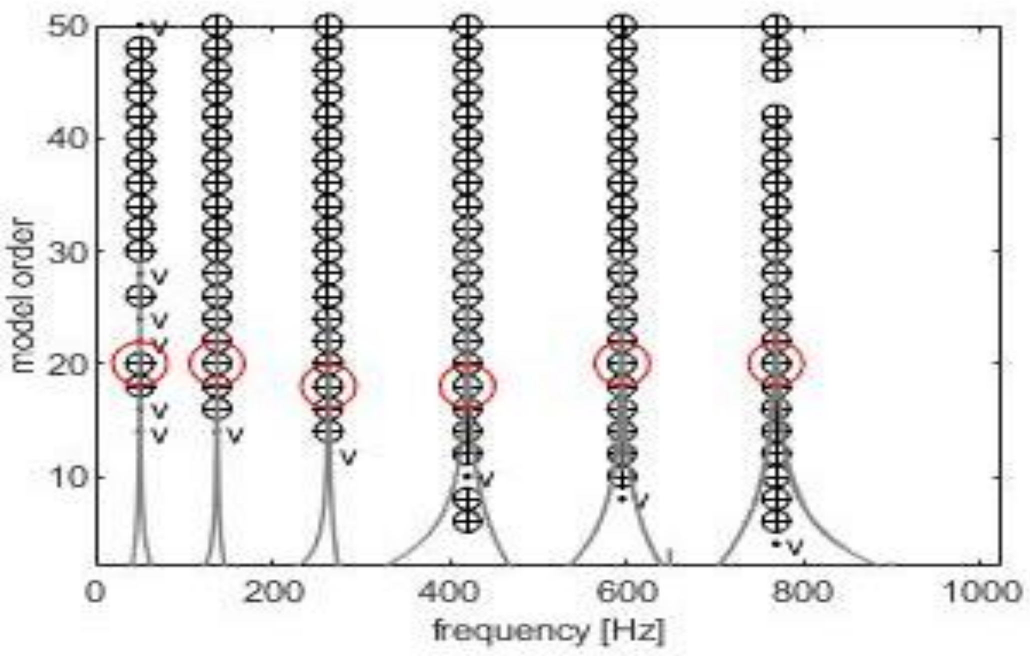
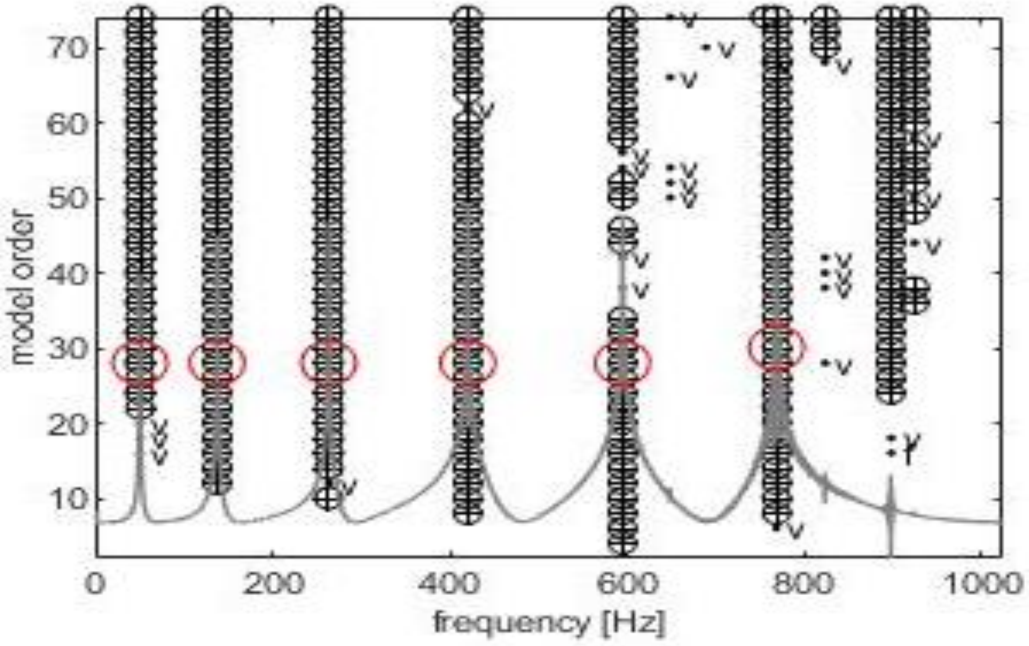
Stabilization Diagrams

Data 1 (mess 5)



Data 2 (mess 8)



Identification of Modal Parameters with MACEC

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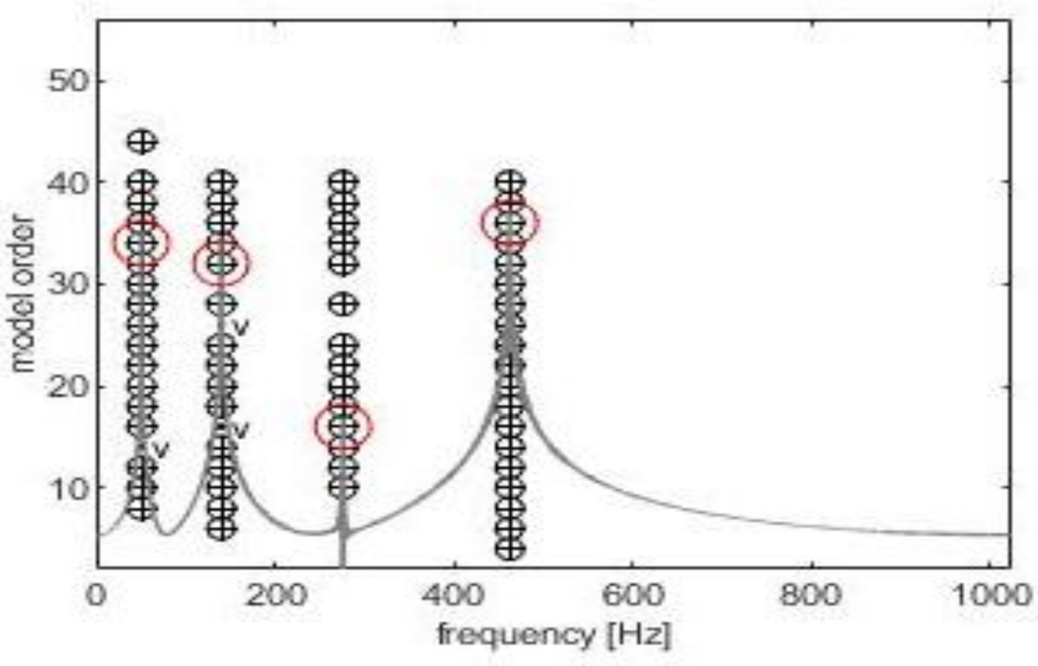
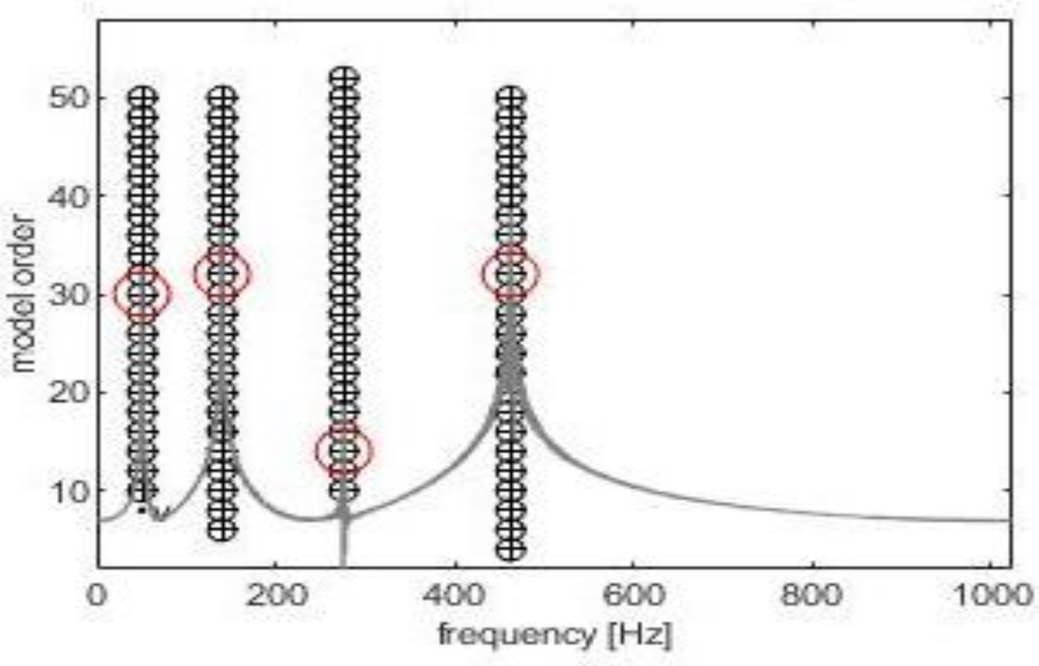
Stabilization Diagrams

Simulation 1 (mess 5)



Simulation 2 (mess 8)



Identification of Modal Parameters with MACEC

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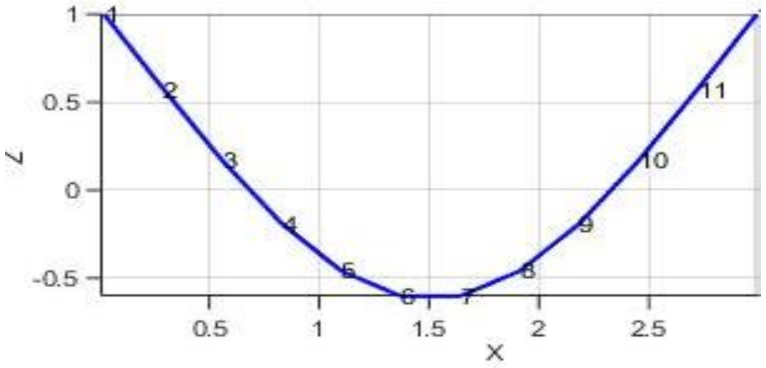
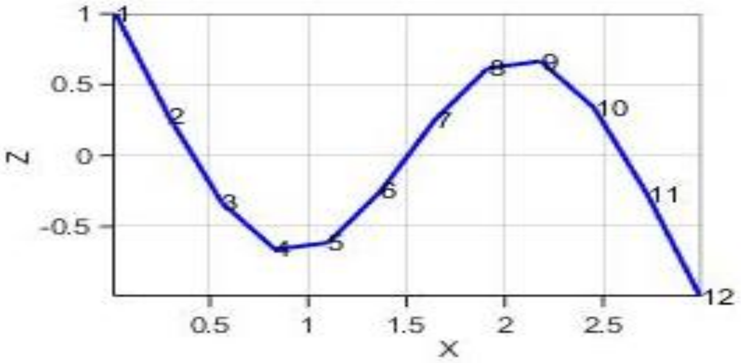
Results of Modal Analysis

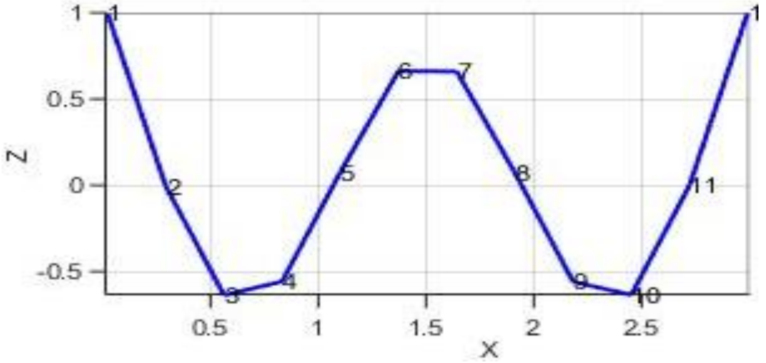
Mode 1



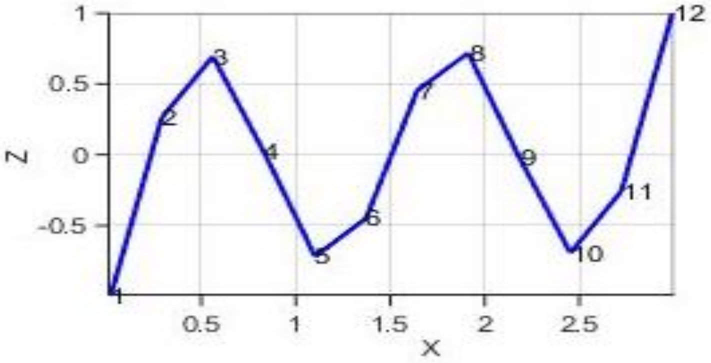
Mode 2



Mode 3



Mode 4



Identification of Modal Parameters with MACEC

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Results of Modal Analysis

Parameter	Data 1 (mess 5)		Data 2 (mess 8)		Simulation 1 (mess 5)		Simulation 2 (mess 8)	
	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
f_1 [Hz]	50.595	0.0064	50.582	0.0048	50.688	0.0260	50.678	0.0058
f_2 [Hz]	137.640	0.0227	137.648	0.0059	139.751	0.0682	139.820	0.0110
f_3 [Hz]	263.587	0.0359	263.597	0.0052	276.073	0.0221	276.086	0.0133
f_4 [Hz]	420.363	0.0358	420.341	0.0027	462.581	0.1072	462.464	0.0068
ζ_1 [%]	0.022	0.0176	0.036	0.0103	0.174	0.0387	0.215	0.0108
ζ_2 [%]	0.059	0.0164	0.036	0.0035	0.262	0.0507	0.202	0.0022
ζ_3 [%]	0.055	0.0058	0.048	0.0023	0.216	0.0269	0.203	0.0048
ζ_4 [%]	0.048	0.0066	0.044	0.0006	0.239	0.0349	0.198	0.0027

Logarithmic Decrement with LABVIEW

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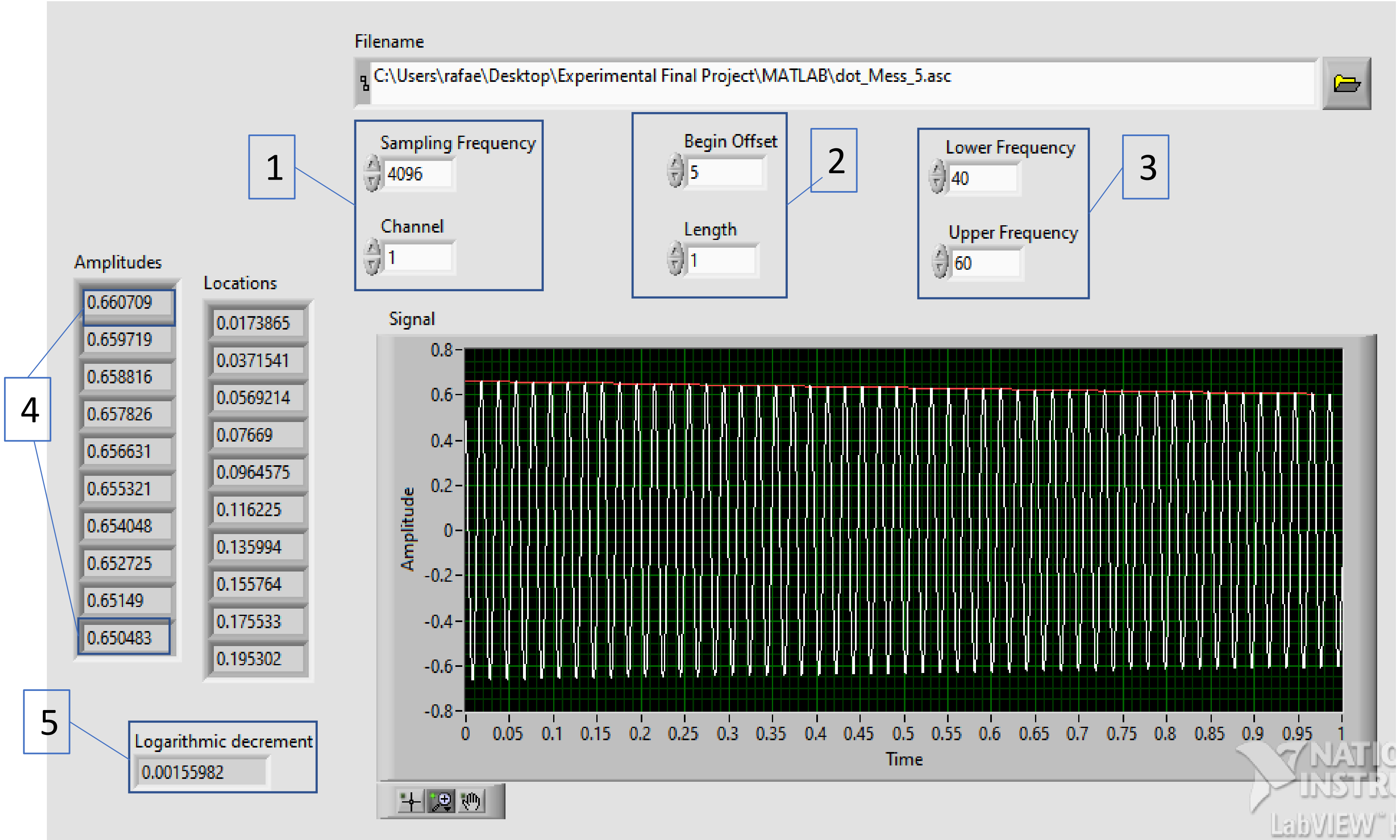

1- Definition of sampling frequency of the signal and choice of channel.

2- Extraction of part of the signal by defining offset and length.

3- Application of bandpass filter to signal in narrow frequency ranges containing the natural frequencies.

4- Choice of first and tenth peaks.

5- Calculation of log. decrement:

$$\Lambda = \frac{1}{n}\frac{x(t_1)}{x(t_1+nT)}$$

Logarithmic Decrement with LABVIEW

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Values of logarithmic decrement

Mode	Frequency Range	Data 1 (mess 5)	Data 2 (mess 8)	Simulation 1 (mess 5)	Simulation 2 (mess 8)
1	40-60	0.001633	0.001656	0.011197	0.011169
2	130-150	0.002691	0.002373	0.010946	0.011334
3	260-280	0.002396	0.002551	0.011098	0.011105
4	420-470	0.003065	0.002727	0.011345	0.011734

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Conclusions and Major Results

- After comparing the natural frequencies obtained from different methods, the results presented a small deviation, giving a good idea of the frequency ranges in which the natural frequencies of the analyzed structure lie.
- The natural frequencies obtained via ANSYS which is based on finite element method is close to the natural frequencies obtained by analyzing experimental data on MACEC tool as shown in the following table.

Parameter	Analytical Solution	ANSYS	MACEC - Data 1 (mess 5)	MACEC - Data 2 (mess 8)	MACEC - Simulation 1 (mess 5)	MACEC - Simulation 2 (mess 8)	Highest Deviation
f_1 [Hz]	50.67	49.25	50.595	50.582	50.688	50.678	2.8 [%]
f_2 [Hz]	139.562	134.59	137.640	137.648	139.751	139.820	3.74 [%]
f_3 [Hz]	274.04	260.56	263.587	263.597	276.073	276.086	5.62 [%]
f_4 [Hz]	452.822	424.56	420.363	420.341	462.581	462.464	7.17 [%]

Conclusions and Major Results

- From the identification of modal parameters on MACEC, it was possible to perceive that the assumed value of damping ratio for the simulation is higher than the modal damping ratios of the real structure. A new calibration of the damping ratio has to be done in order to carry out a new analysis.

- The values obtained on LABVIEW for the logarithmic decrement were consistent with the damping ratios obtained on MACEC. For the provided data, the logarithmic decrement presented a slightly variation for different modes whereas for the simulation, close results were obtained for all the modes as expected for the assumption of a single damping ratio.

References

- Zabel, Volkmar. *Fundamentals of Structural Dynamics*. Institut für Strukturmechanik, Bauhaus-Universität Weimar, 2020.
- Zabel, Volkmar. *Experimental Structural Dynamics*. Institut für Strukturmechanik, Bauhaus-Universität Weimar, 2020.
- Reynders, Edwin, Schevenels, Mattias e Roeck, Guido de. MACEC 3.3 - *A Matlab Toolbox for Experimental and Operational Modal Analysis.* Faculty of Engineering, Department of Civil Engineering, Ku Leuven, 2014.

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THANK YOU FOR YOUR ATTENTION!