Experimental Structural Dynamics & Structural Monitoring

Group -1 Castle Tower

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Natural Hazards and Risks In Structural Engineering

Bauhaus Universität Weimar

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Motivation

Civic Tower at Montelupone, Italy

- Experienced the damages during April 6th, 2009 L'Aquila Earthquake.

Main Goals of the Dynamic Analysis:

1. Determination of the modal properties.
2. Verification of the numerical modal.
3. Implementation of the retrofitting techniques.

Figure 1: Civic Tower, Italy[2]

Case Study

Schloss Weimar is selected as Case Study.

- It is located in Weimar, Thuringia.
- Home of dukes of Saxe-Weimar and Eisenach.
- Schloss Weimar experienced damages as a result of fire.

Figure 2: Schloss Weimar[1]

Methodology

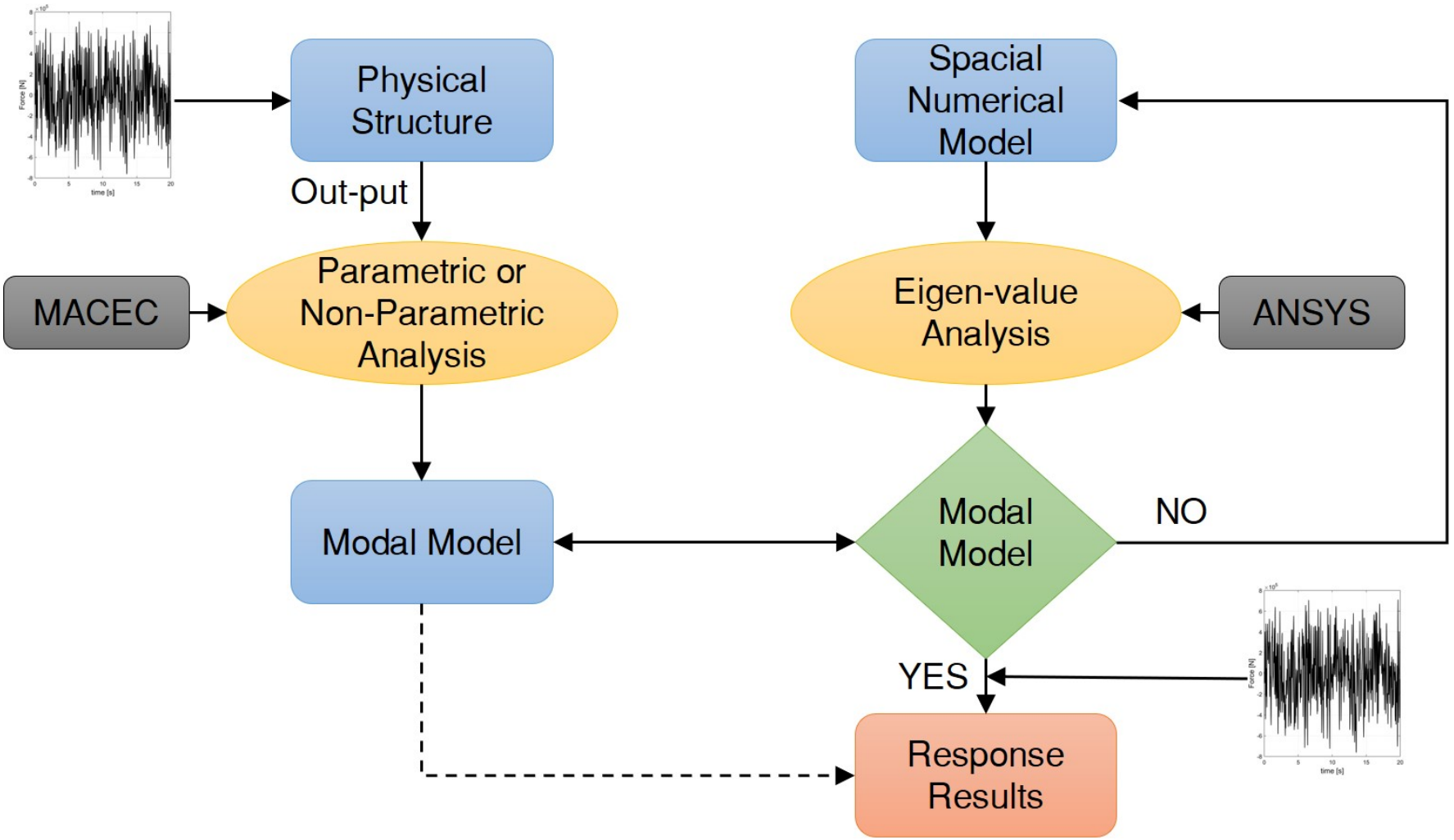

Figure 3: Flow Chart of Methodology

Numerical Modelling

- 3D Finite Element model is developed using ANSYS Software.
- Composed of two main geometries
  1. Geometry 1 (Masonry)
  2. Geometry 2 (Timber)

Table 1: Material Properties of Model

Property	Masonry (Geo-1)	Timber (Geo-2)
Density (Kg/m^3)	2100	7850
Young's Modulus (Mpa)	2781	9200
Poisson's Ratio	0.15	0.25
Bulk Modulus (Mpa)	1367	6133
Shear Modulus (Mpa)	1248	3680
Modal Damping(%)	10	10

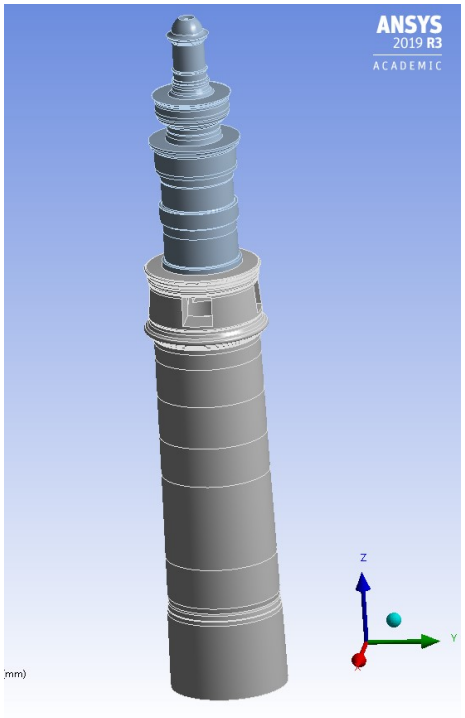

Figure 4: Model Geometry

Mode Shapes and Frequencies

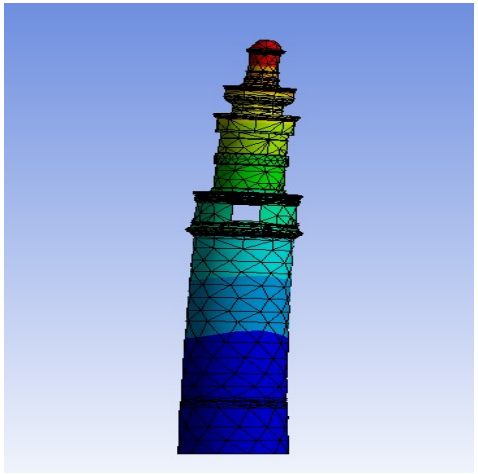

Figure 5: Mode 1 (Bending 0.67 Hz)

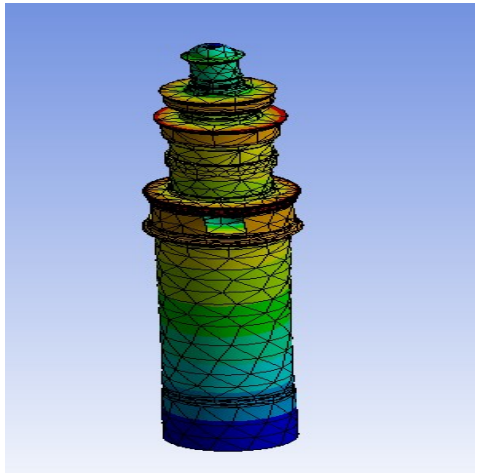

Figure 7: Mode 5 (Torsional 4.47 Hz)

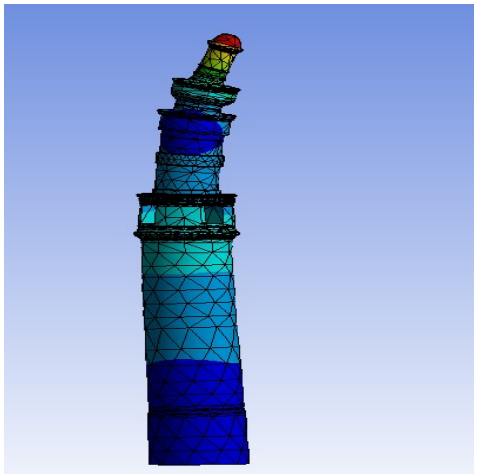

Figure 6: Mode 3 (Bending 2.52 Hz)

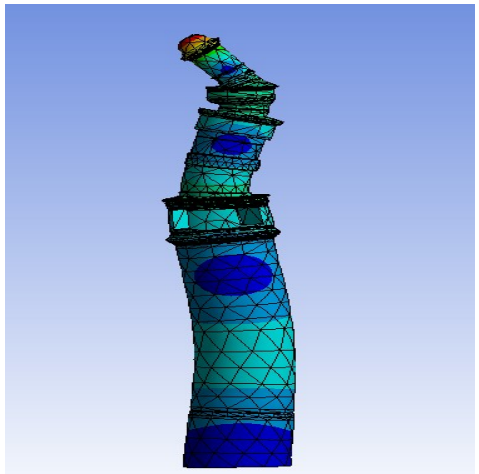

Figure 8: Mode 10 (Bending 7.68 Hz)

Generation of Random Force Signal

- Random Force Signal is generated using LabView program
- Five random random signal type:
  1. Sine
  2. DC
  3. Sawtooth
  4. Square
  5. Sawtooth
- Provision of Low Pass Filter (Cut off frequency10Hz)

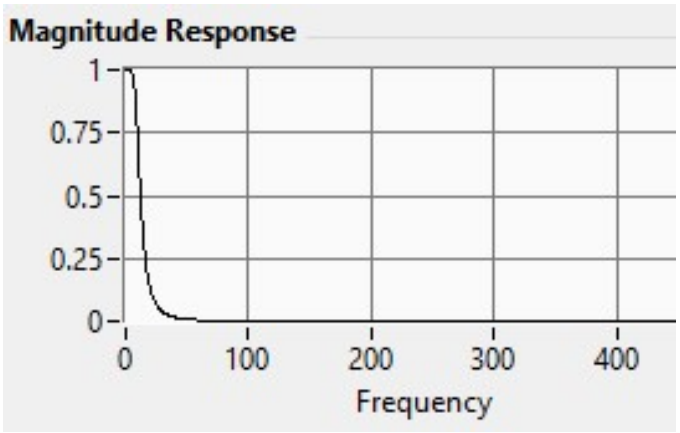

Figure 9: Low Pass Filter

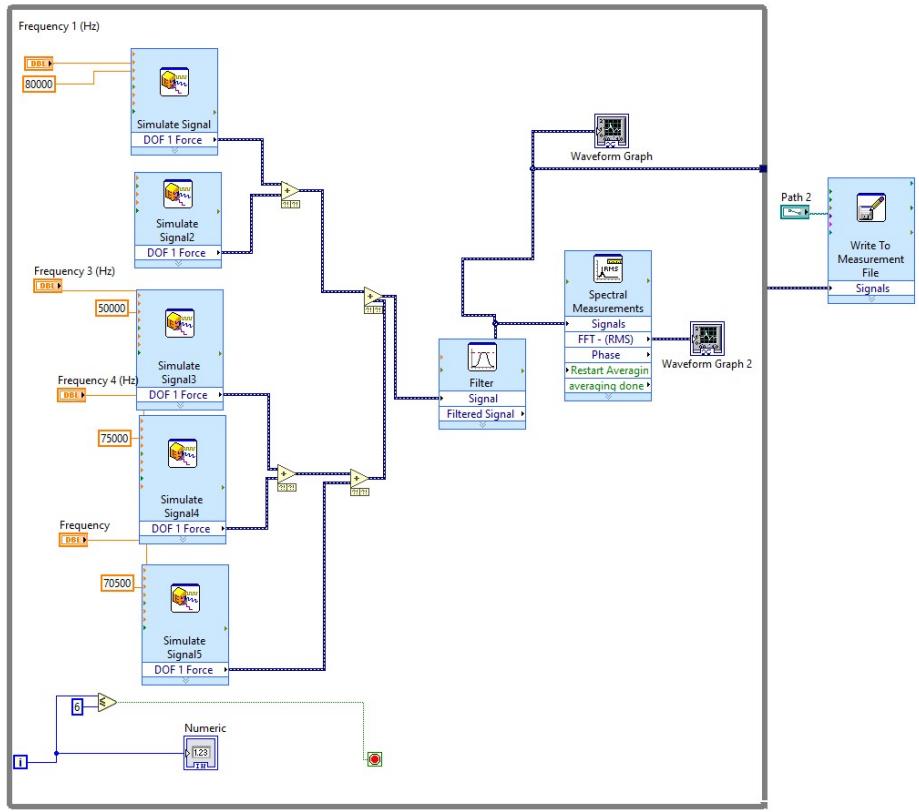

Figure 10: Layout of Random Force Generation

Force Input

- FP_1 represent the location of Applied Force.
- TP_1-5 represent the locations where the Response of the Structure is recorded.

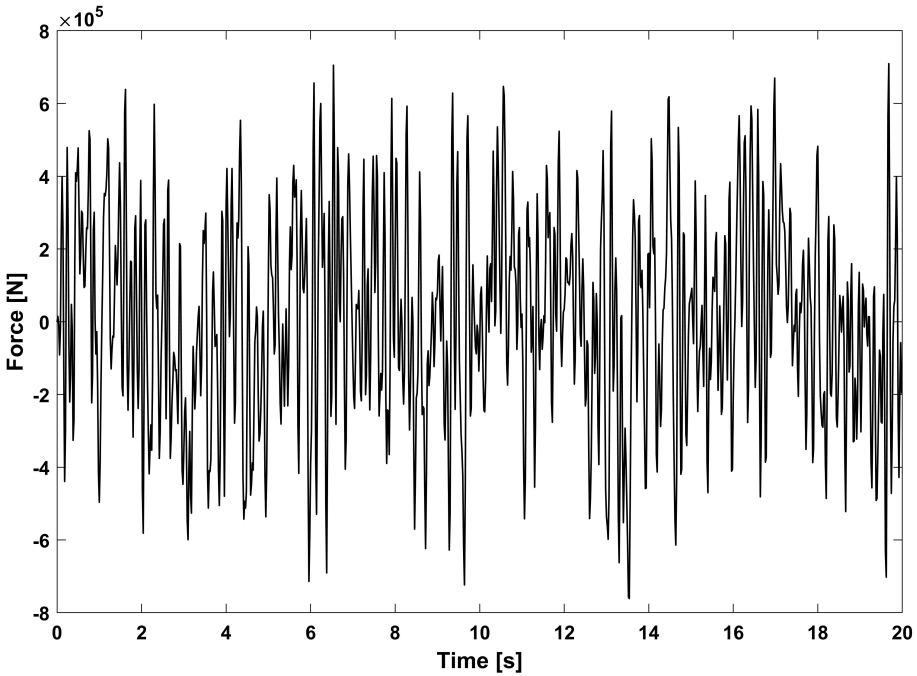

Figure 11: Applied Excitation Force

Figure 12: Location of Force & Response

Response of Model

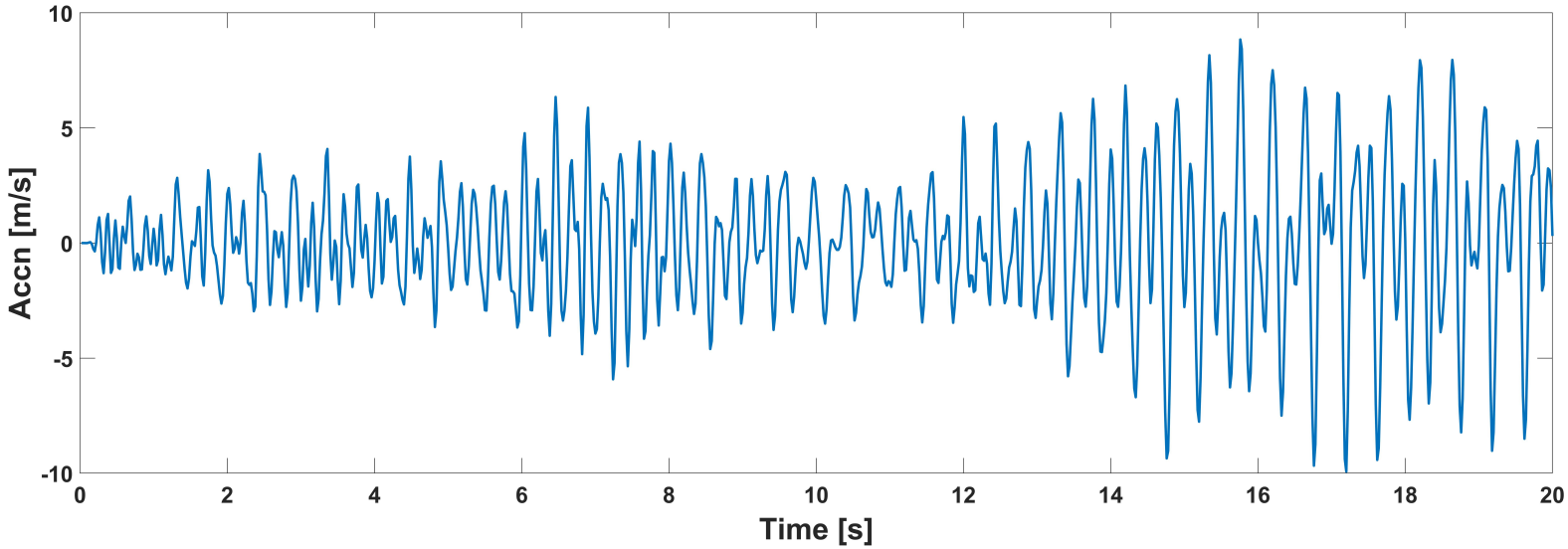

Figure 13: Response at TP_1

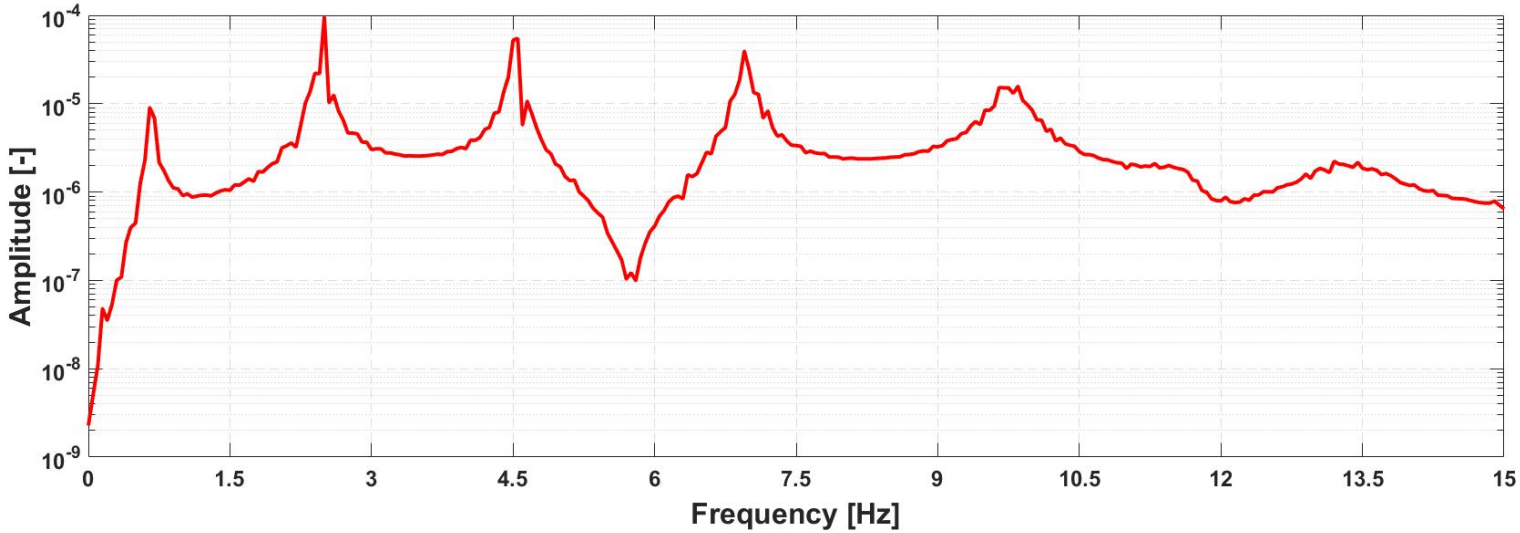

Figure 14: FRF of Model

Measurements Setup

- Total nine setups with five measurements per setup.
- Two reference measurements.
- Data collected at sample rate of 512 Hz and total time of 600 sec per measurement.

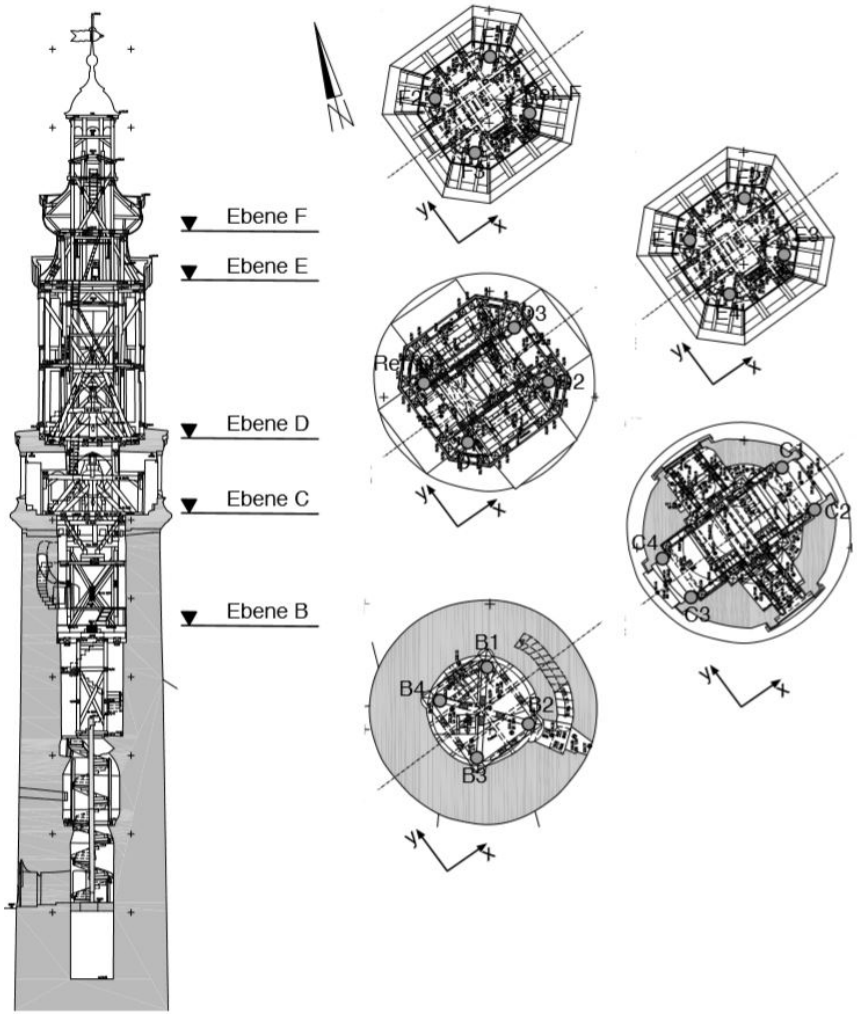

Figure 15: Measurement Setup

MACEC

- It is a MATLAB toolbox which is extensively used for the Operational and Experimental modal analysis of the structures.

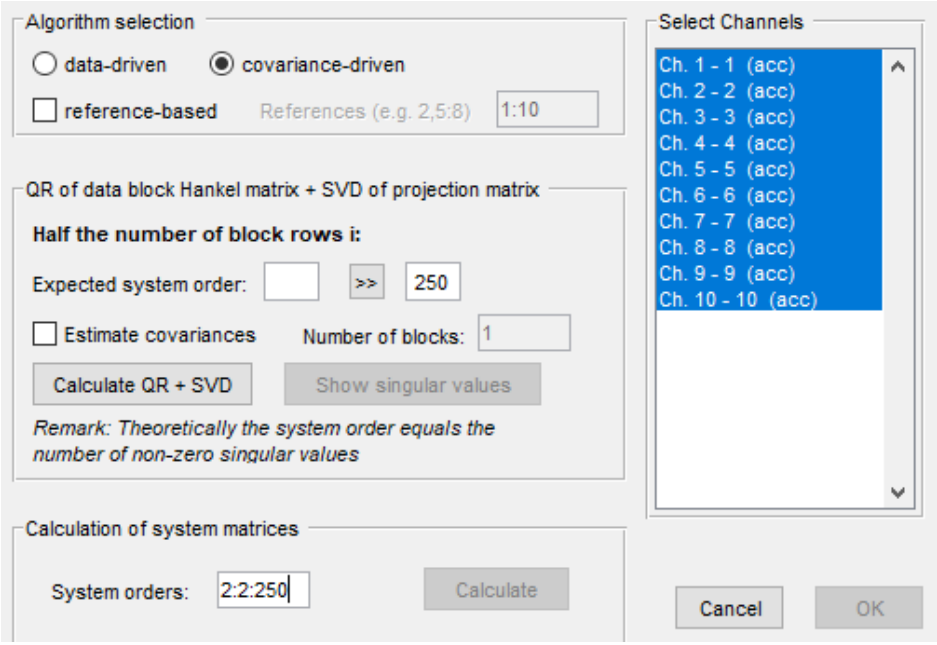

Figure 16: System Order

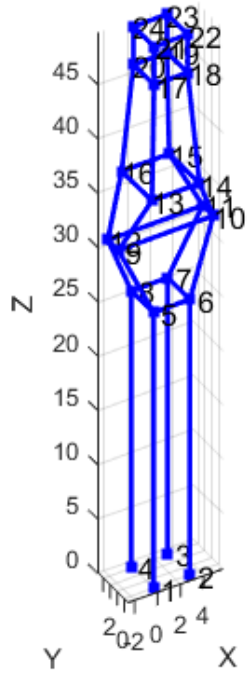

Figure 17: Measurements Points

Identified Modes

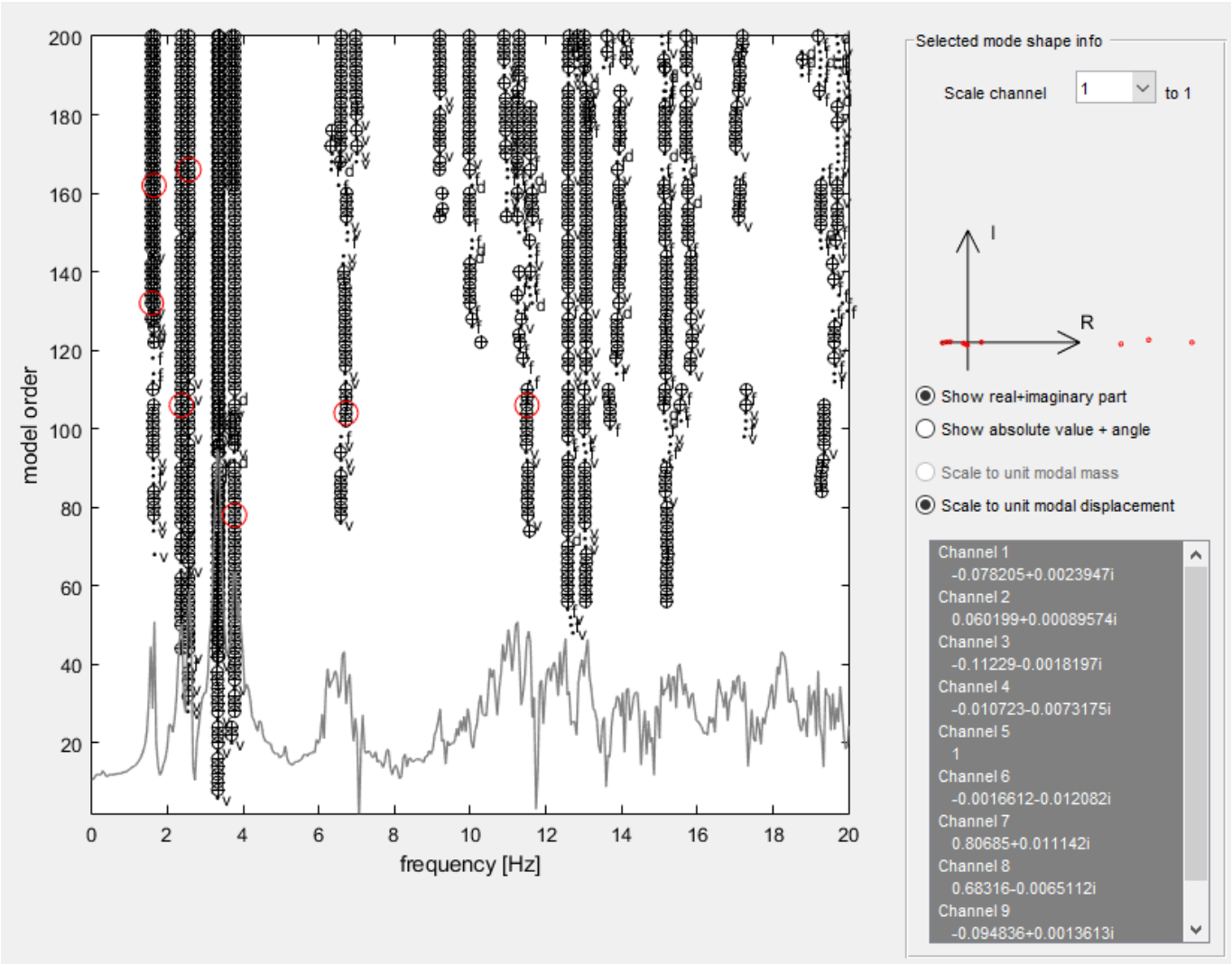

Figure 18: Stabilization Plot

Mode Shapes

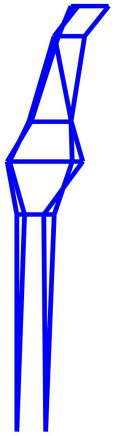

Figure 19: Mode 1 (f=1.6 Hz, D=1.72 %)

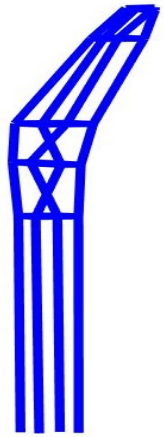

Figure 20: Mode 5 (f=3.3 Hz, D=1.72 %)

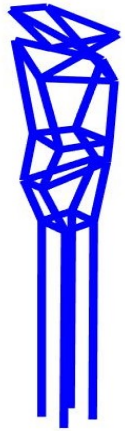

Figure 21: Mode 8 (f=6.8 Hz, D=1.72 %)

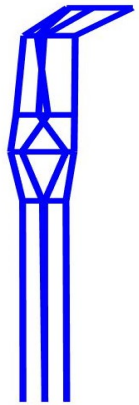

Figure 22: Mode 9 (f=10.05 Hz, D=1.72 %)

Calibration of Model

Table 2: Material Properties of Calibrated Model

Property	Masonry (Geo-1)	Timber (Geo-2)
Density (Kg/m^3)	1500	800
Young's Modulus (Mpa)	2781	2000
Poisson's Ratio	0.15	0.25
Bulk Modulus (Mpa)	1367	1333
Shear Modulus (Mpa)	1248	800
Modal Damping(%)	5	5

Calibrated Modes

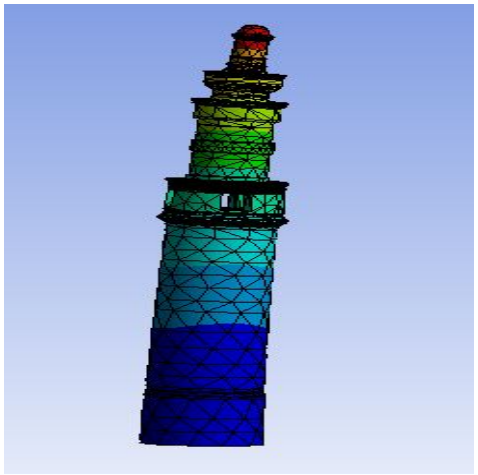

Figure 23: Mode 1 (Bending 1.36 Hz)

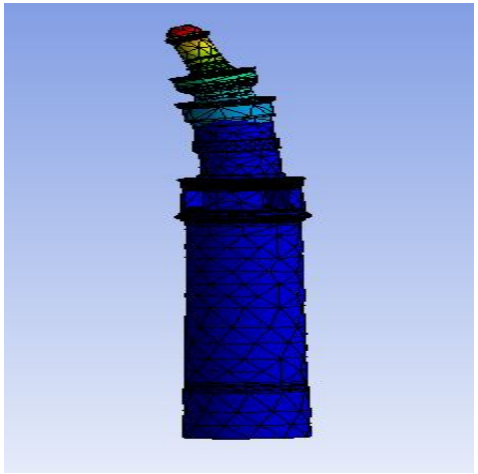

Figure 24: Mode 3 (Bending 3.38 Hz)

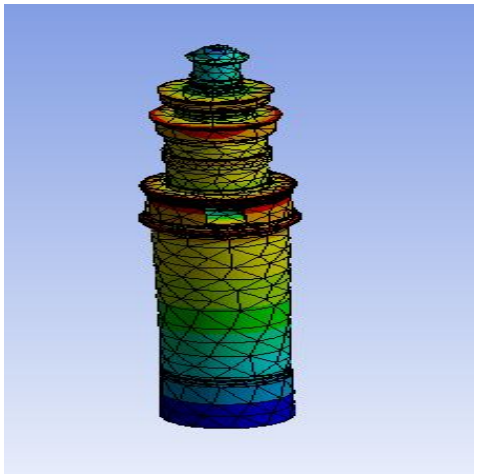

Figure 25: Mode 5 (Torsional 6.48 Hz)

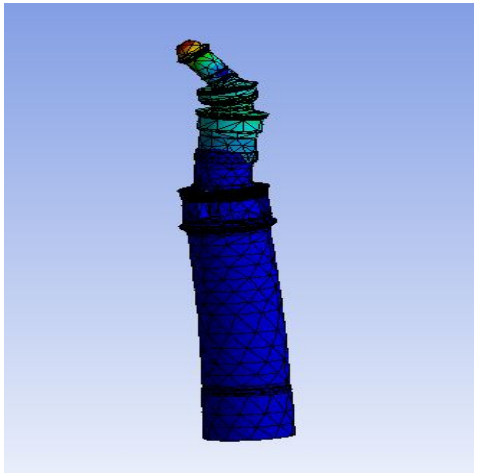

Figure 26: Mode 10 (Bending 4.45 Hz)

Comparison of Modal Parameters

Table 3: Comparison of Modal Parameters

Modes	Frequency (Hz)			Difference (%)	Identified Damping (%)
	Initial Model	Identified Model	Calibrated Model		
1	0.672	1.581	1.340	15.24	1.71
2	2.520	3.440	3.404	1.05	2.35
3	4.470	6.797	6.490	4.52	2.25
4	7.680	10.050	9.457	5.90	1.66

Conclusions

- The contribtuing mode shapes are bending, torsional and axial modes.
- The inital (assumed) numerical model have frequency ranges from 0.672 to 7.68 Hz.
- The identified modes in the operational modal analysis have frequency ranges from 1.58 to 10.05Hz with damping ratios of 1.7 – 2.3 %.
- The results indicate that the initial numerical model is softer than the actual structure.
- The numercal model properties (mass, stiffness and damping) are modified keeping geometry constant and final modal frequencies range from 1.34 to 9.5 Hz.
- The difference in modal parameters is mainly attributed to the complexity of the geometry.
- The modified numerical model can be used for monitoring, evaluation, rehabilitation of the existing structure.

References

[1] Stadtschloss Weimar. Library Catalog: www.klassik-stiftung.de.

[2] Gian Paolo Cimellaro, S Piantà, and A De Stefano. Output-only modal identification of ancient l'aquila city hall and civic tower. *Journal of structural engineering*, 138(4):481–491, 2012.

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Thank you for your attention !