Bauhaus-Universität Weimar

Metsovo Bridge

Experimental structural dynamics and Structural monitoring

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1. Objective

The objective of this project has been to compare the dynamic response of the Metsovo bridge between a numerical model that has been developed in SAP2000 software and the data obtained from an experimental scale test, where the data has been processed using MATLAB Toolbox MACEC.

Figure 1: Metsovo Bridge (Costas et al. 2020)

2. Metsovo Bridge

The bridge is located at the Egnatia motorway in Thessaloniki city (Greece). It is composed in its superstructure with 4 span of prestressed concrete and columns with RC.

In order to obtain the dynamic properties of the system and subsequently the soil-structure interaction, a model corresponding to a scale of 1:100 is developed during the construction stage. The created model is not made as concrete, it is generated as steel given the difficulties for its creation using concrete.

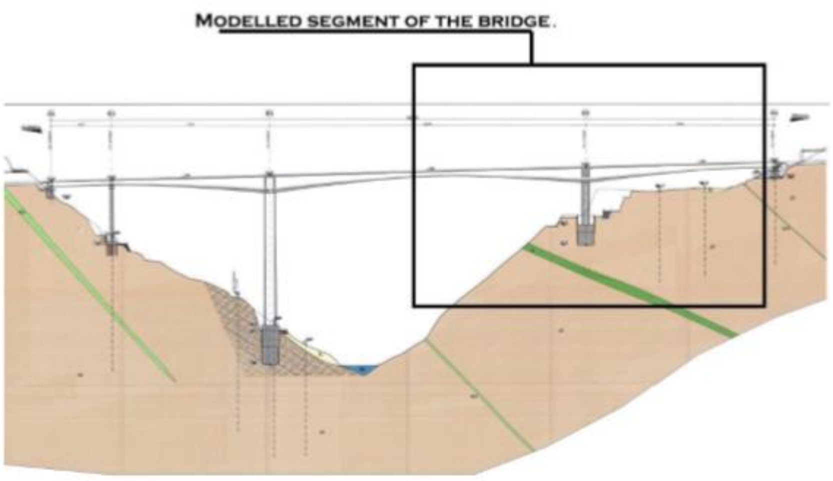


Figure 2: Modelled segment of the bridge

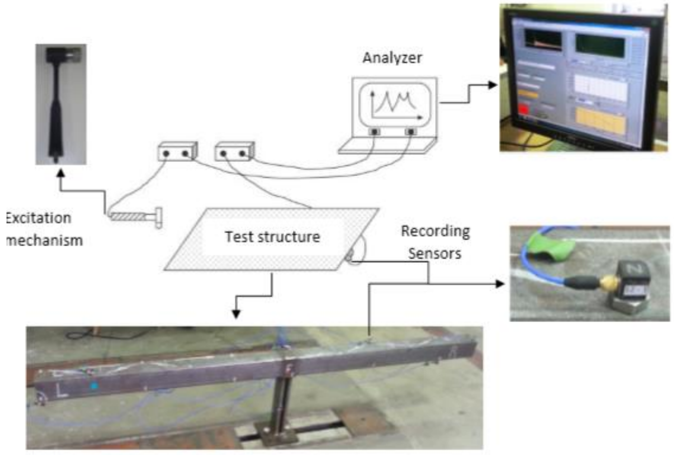


Figure 3: Test set up

3. Numerical model

A numerical model is developed in **SAP2000.20** software. The dimensions used are the same as those developed by the university of Aristotle and Bauhaus.

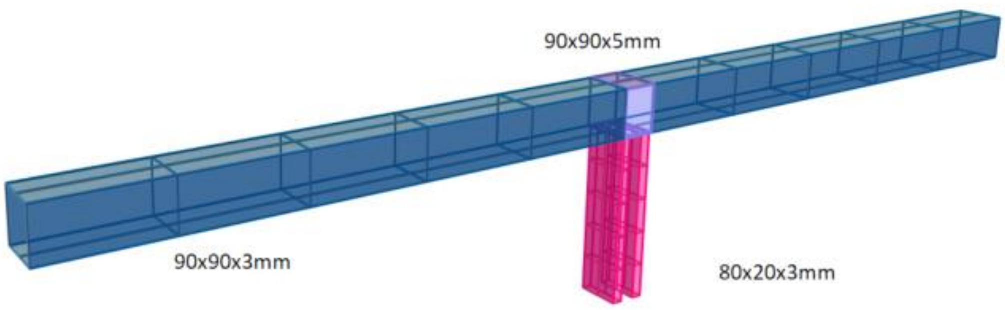


Figure 4: Numerical model for Metsovo bridge

[SAP2000 software allows the element to be modeled as frames, however, as it is of interest to find the rotations and torsion of the elements, the model is carried out with shell elements.]

Table 1: Dimensions of the Metsovo bride model

Item	Longitude	Section
Central Part of Deck	6.500cm	100x100x5mm
Deck Length	2.165cm	90x90x3mm
2 Piers	31.000cm	80x20x3mm

Due to the problems generated in the connection of the joints of the 90x90x3 and 100x100x5 sections, a modification is made using instead of the 100x100 section a 90x90 section but using a thickness of 5 to add rigidity.

3. Numerical model

A numerical model is developed in **SAP2000.20** software.

[A mesh was made using as a reference the joints where the sensors are located in the modeled system to subsequently facilitate their visualization and allow an effective comparison of the results in the future.]

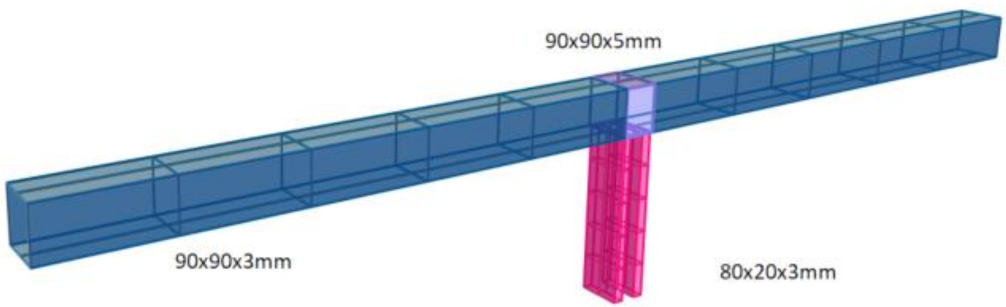


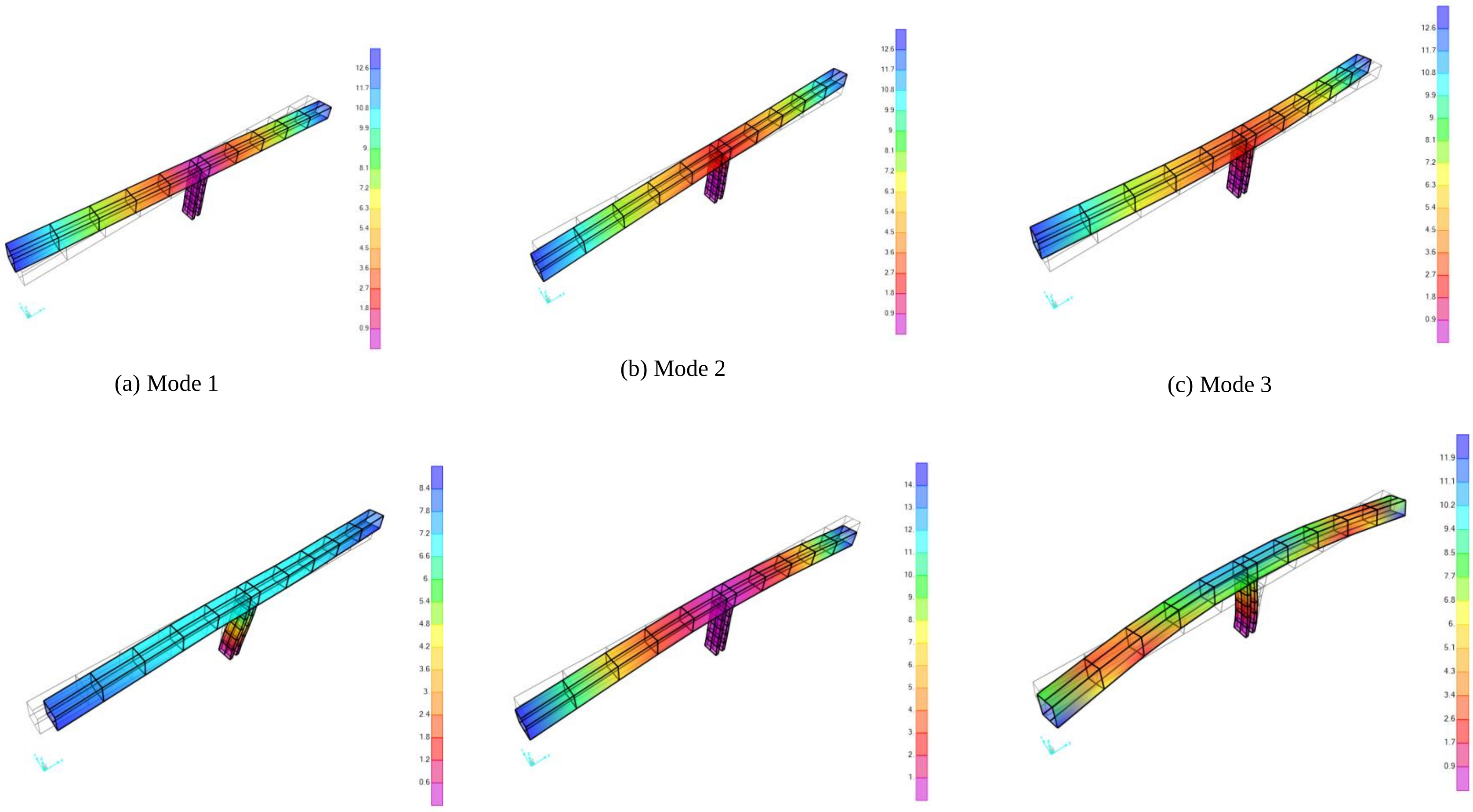
Figure 5: Numerical model for Metsovo bridge

Table 2: Mechanical properties: A992fy50

Item	Value [kN,m,C]
Material Grade	Grade 50
Weight per unit Volume	76.973
Modulus of Elasticity, E	1.999E+08
Poisson, U	0.3
Minimum Yield Stress, Fy	344737.9
Minimum Tensile Stress, Fu	448159.3

The type of steel used is A992Fy50 and its mechanical properties are specified in table 2.

3. Numerical model



(a) Mode 1 (b) Mode 2 (c) Mode 3

(d) Mode 4 (e) Mode 5 (f) Mode 6

Figure 6: Mode shape for first 6 modes

3. Numerical model

For the configuration shown in figure 6, the first five modes with their respective periods and frequencies are presented in table 3.

Table 3: Modal period and Frequencies for the first 5 modes

Mode	Period [s]	Frequency [Cyc/s]
1	0.056	17.821
2	0.029	34.381
3	0.013	75.206
4	0.012	81.052
5	0.011	90.278

3. Numerical model

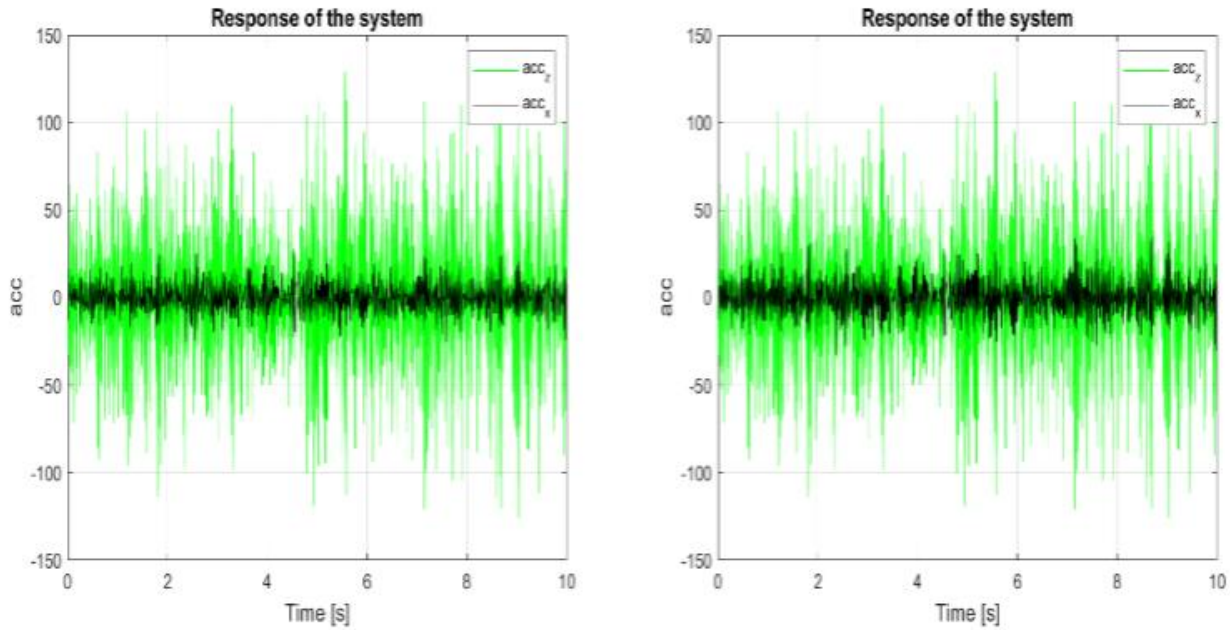


Figure 7: Response of the structure, at the top (Right) and bottom (Left)

The response expressed in accelerations was obtained for the nodes where the sensors were placed. An example is shown below, for the sensor placed on the on the right-hand side of the beam at the top and bottom as shown in figure 8.

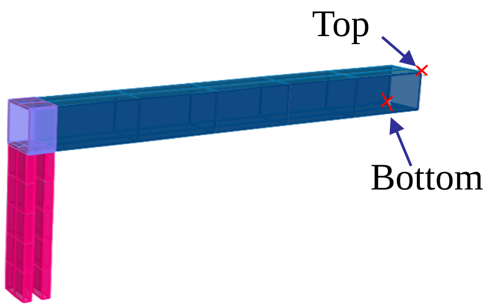


Figure 8: Location sketch of the structure responses obtained

4. Test description

4.1 Excitation mechanism

The excitation mechanism is a hammer used at different points of the structure (The hammer tip has a force transducer, with a load cell that can log the time history of the loading to the analyzer).

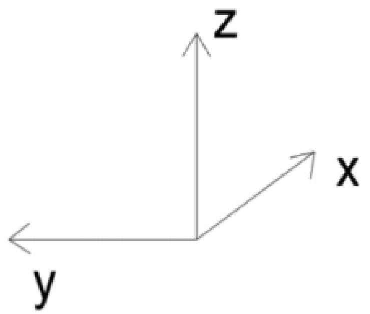
4.2 Recording sensors

The accelerometers that have been used in the experiment are Eight triaxle(Model 356A16 by PCB Piezotronics Inc). These accelerometers are fixed on the system by means of magnetic force.

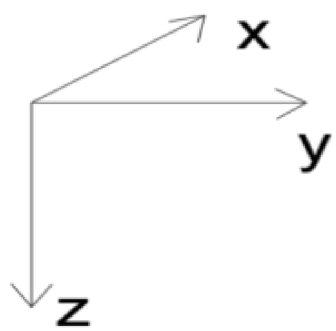
4.3 Test structure and sensor arrangement

The accelerometers that have been used in the experiment are Eight triaxle(Model 356A16 by PCB Piezotronics Inc). These accelerometers are fixed on the system by means of magnetic force.

It is important to note that the sensors have been placed at the top and bottom of the bridge model and therefore the direction of the axes is modified.



(a) At the Top



(b) At the bottom

Figure 9: Axes for the sensors at the top and bottom of the bridge model

4. Test description

4.3 Test structure and sensor arrangement

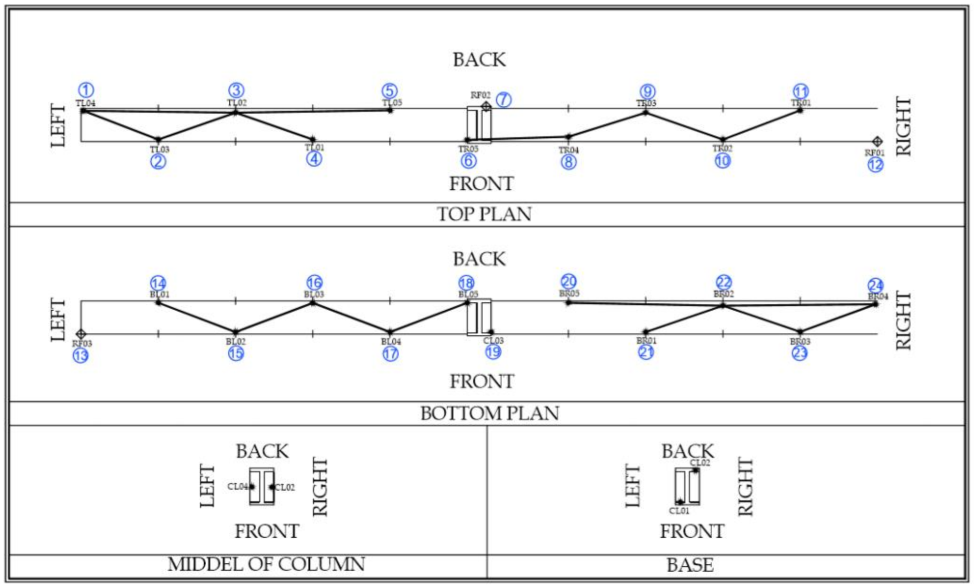


Figure 10: Sensor arrangement

Table 4: Experiment setup circle

Configuration	Sensor							
01	RF01	RF02	RF03	TR01	BR01	TL01	BL01	CL01
02	RF01	RF02	RF03	TR02	BR02	TL02	BL02	CL02
03	RF01	RF02	RF03	TR03	BR03	TL03	BL03	CL03
04	RF01	RF02	RF03	TR04	BR04	TL04	BL04	CL04
05	RF01	RF02	RF03	TR05	BR05	TL05	BL05	CL05

Figure 10 shows the sensor arrangement and the identification number used in this report to facilitate the manipulation of information.

The first two index in the sensor label stands for:

RF- Reference sensors

TR- Movable sensors on the Top Right part of the beam

BR- Movable sensors on the Bottom Right part of the beam

TL- Movable sensors on the Top Left part of the beam

BL- Movable sensors on the Bottom left part of the beam

CL- Movable sensors on the Column

4. Test description

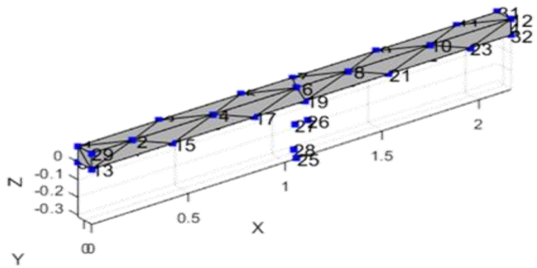
4.4 Analyzer

In each cycle the excitation force and the recorded acceleration time history in real time are logged in to the analyzer. Table 5 shows the available data, the configuration of the sensors, the recorded duration and the location where the excitation is carried out for each of the tests

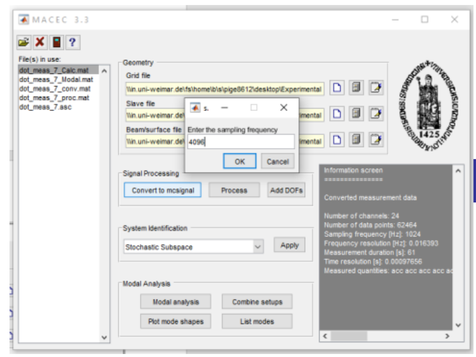
Table 5: Configuration data

Name Data	Configuration	Duration $[s]$	Excitation location
$meas\_1$	01	61	Left end
$meas\_2$	01	61	Left end
$meas\_3$	02	71	Right end
$meas\_4$	02	60	Left end
$meas\_5$	03	60	Left end
$meas\_6$	03	60	Right end
$meas\_7$	04	61	Left end
$meas\_8$	04	60	Right end
$meas\_9$	05	60	Left end
$meas\_10$	05	60	Right end
$meas\_12$	03	16	Left end
$meas\_13$	03	10	Left end
$meas\_14$	03	20	Left end

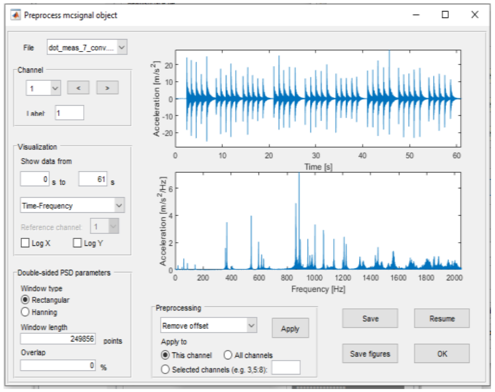
5. MACEC: A matlab toolbox for experimental and operational modal analysis



(a) Grid file, Slave file, Surface file

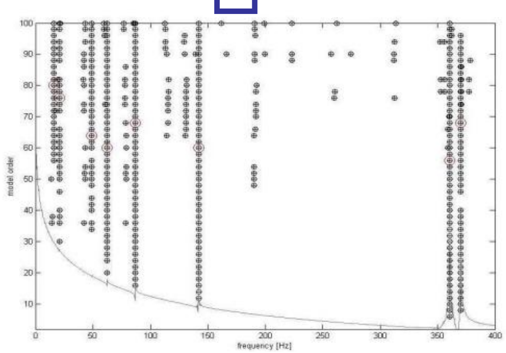


(b) Convert to mcsignal format

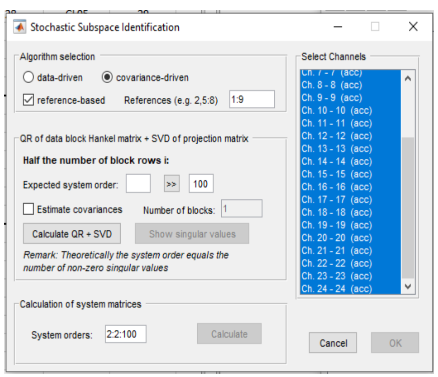


(c) Signal processing

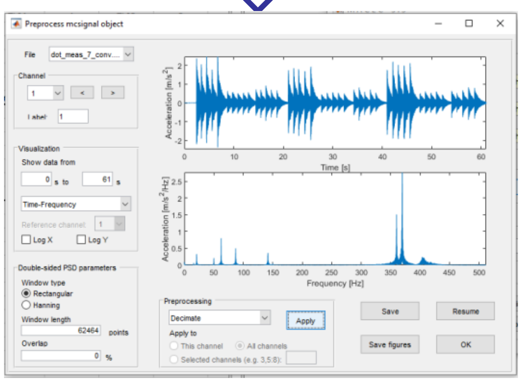
(g) Modes combination



(f) Modal analysis: Stabilization diagrams



(f) Stochastic Subspace identification



(d) Preprocessing: Decimate, Remove offset and delete chanels

Figure 11: Methodology diagram in MACEC

5. MACEC: A matlab toolbox for experimental and operational modal analysis

The frequencies and damping ratio after the combination are presented below

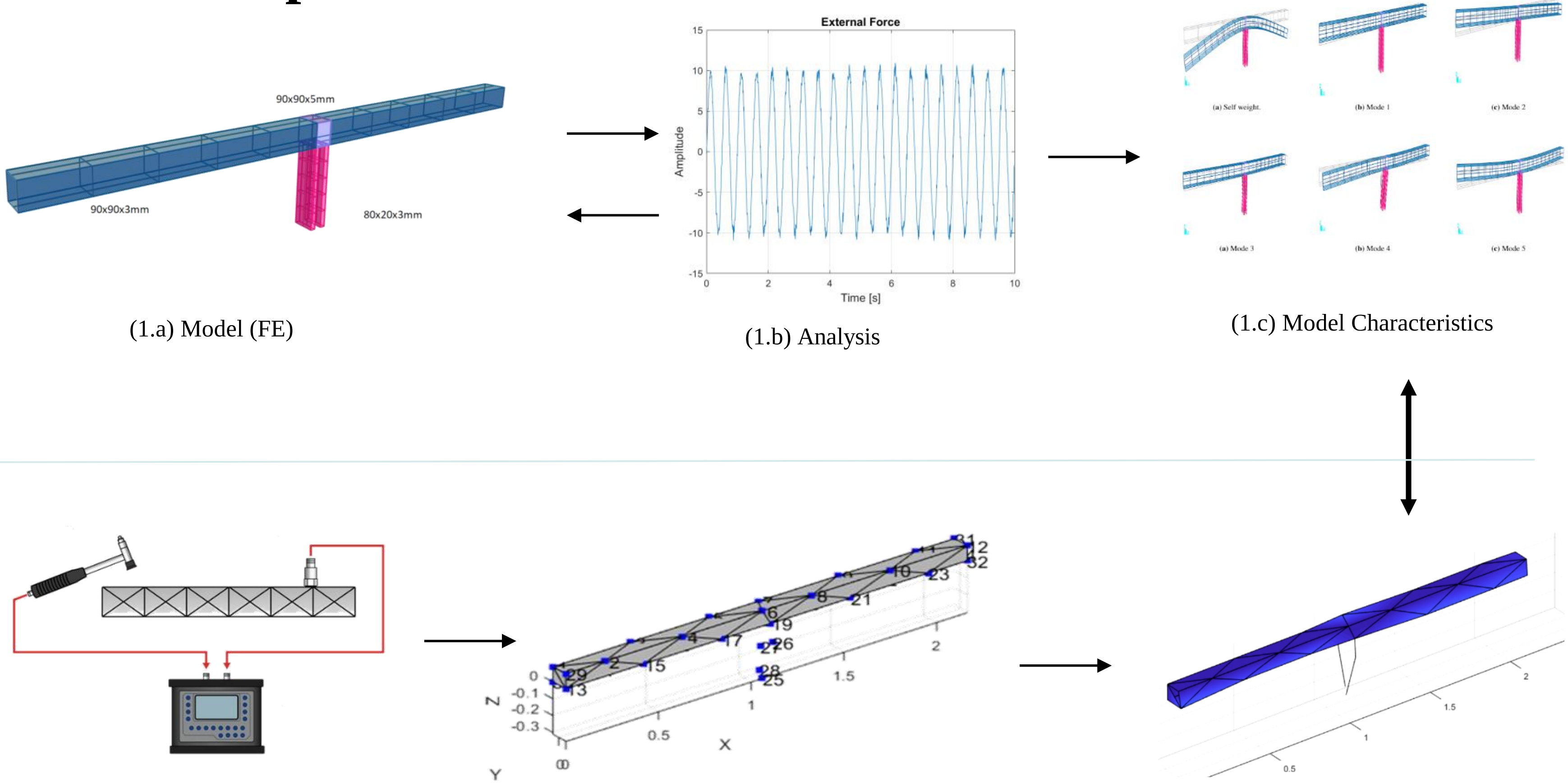
Table 6: Frequencies and damping ratios

Mode	Frequencies [Hz]	Damping ratios [%]
1	15.722	0.136
2	20.793	0.312
3	49.062	0.313
4	62.389	0.120
5	87.340	0.146
6	142.265	0.125
7	371.064	0.044
8	405.644	0.574
9	546.440	0.168
10	598.906	0.040

6. Result comparison

Simulation- FEM

Experiment-EMA



(1.a) Model (FE)

(1.b) Analysis

(1.c) Model Characteristics

(2.a) System

(2.b) Structural identification

(2.c) Model Characteristics

Figure 12: EMA vs FEM comparison process

FEM- Finite element methods

EMA- Experimental Modal Analysis

6. Result comparison

The comparison between the frequencies obtained with the finite element model (FEM) are higher than those obtained experimentally in the first modes. For the analyzed structure, a bridge, the low frequencies are more relevant, the first mode has a 12% change and the second 40%.

Table 7: Frequency comparison with EMA and FEM

Mode	Frequencies EMA [Hz]	Frequencies FEM [Hz]	[%]
1	15.722	17.822	12
2	20.793	34.381	40
3	49.062	75.206	35
4	62.389	81.052	23
5	87.340	90.277	3
6	142.265	194.322	27
7	371.064	362.405	-2
8	405.064	377.050	-8
9	546.440	489.870	-12
10	598.906	525.900	-14

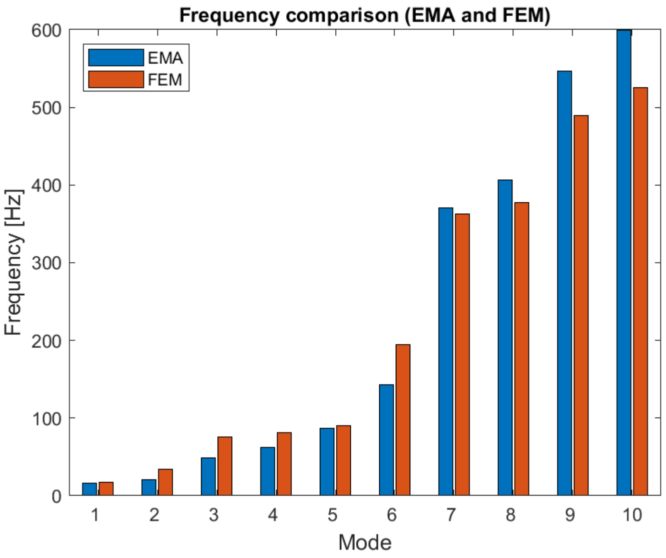


Figure 13: Frequency comparison with EMA and FEM

Remark: Some uncertainties in the configuration of the sensors in the development of the experiment do not allow a valid comparison of the mode shapes.

6. Result comparison

In order to improve the mathematical model used and to reduce the difference in the frequencies obtained, the material properties are adjusted.

Table 8: Mechanical properties: S235

Item	Value [kN,m,C]
Material Grade	S235
Weight per unit Volume	76.973
Modulus of Elasticity, E	2.100E+08
Poisson, U	0.3
Minimum Yield Stress, Fy	235000
Minimum Tensile Stress, Fu	360000

Table 9: Frequency comparison with EMA and FEM

Mode	Frequencies EMA [Hz]	Frequencies FEM [Hz]	[%]
1	15.722	16.788	6
2	20.793	31.518	34
3	49.062	74.431	34
4	62.239	75.419	17
5	87.340	88.144	1
6	142.265	181.770	22
7	371.064	364.591	-2
8	405.644	386.034	-5
9	546.440	417.480	-31
10	598.906	486.822	-23

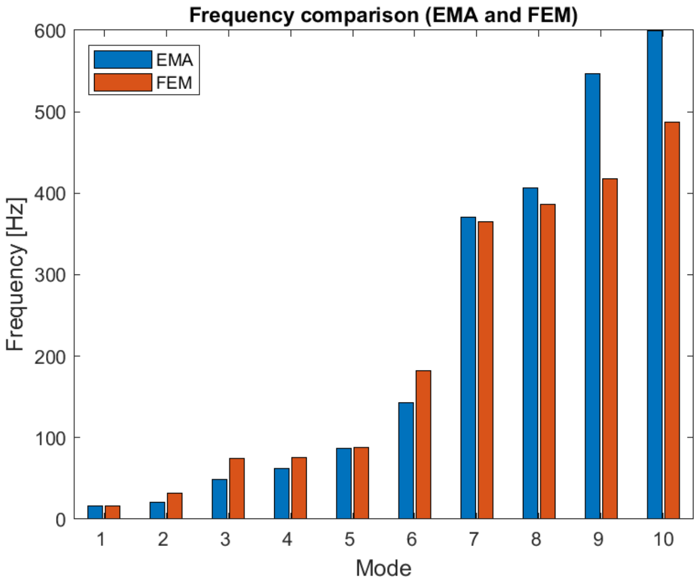


Figure 14: Frequency comparison with EMA and FEM

6. Result comparison

In the first identified modes, the dynamic response of the system is very similar. The following figure shows the difference for the first 6 modes. Furthermore, the identified mode shapes are the same for EMA and FEM.

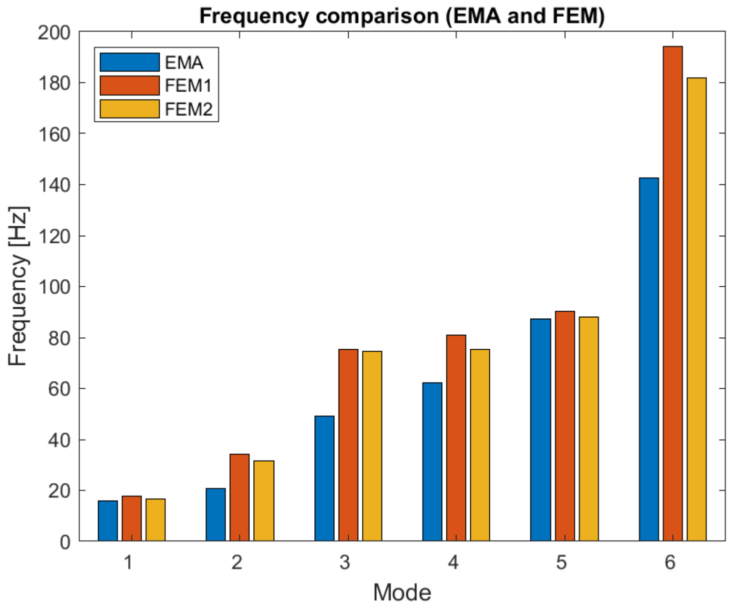
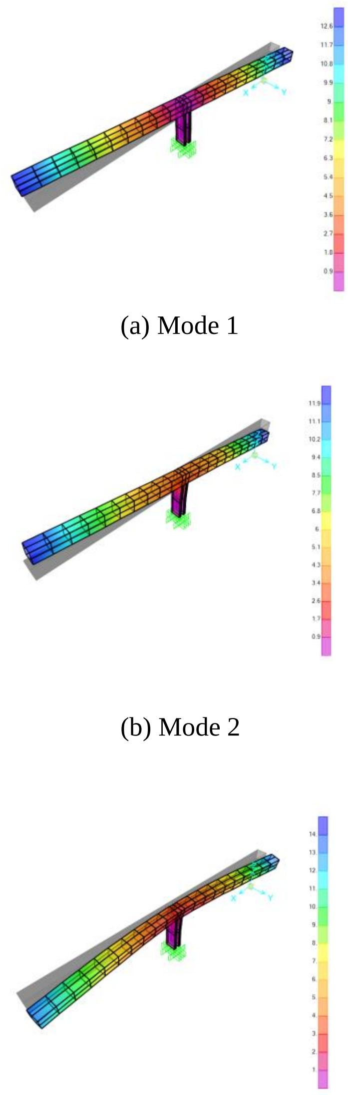


Figure 15: Frequency comparison with EMA and FEM



(a) Mode 1

(b) Mode 2

(c) Mode 3

Figure 16: Mode shape for first 3 modes

6. Result comparison

FRF: Contains the dynamic characteristics of the structure: mass, stiffness, damping, obtained due the excitation force.

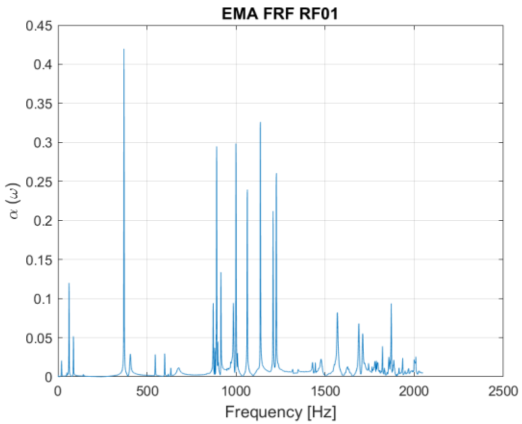


Figure 17: FRF at the RF01 Sensor of EMA

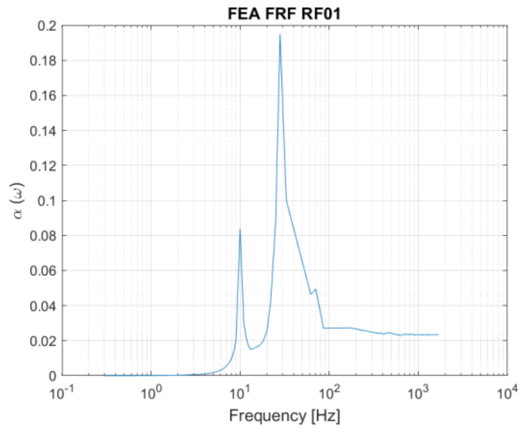


Figure 18: FRF at the RF01 Sensor of FMA

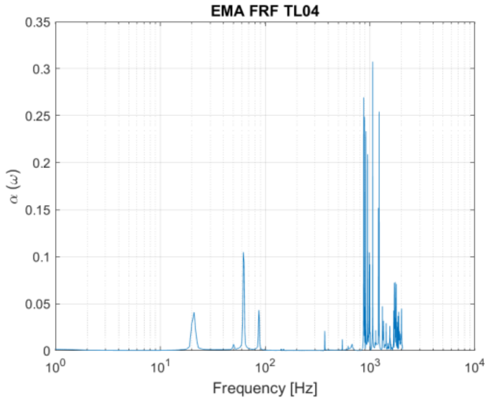


Figure 19: FRF at the TL04 Sensor of EMA

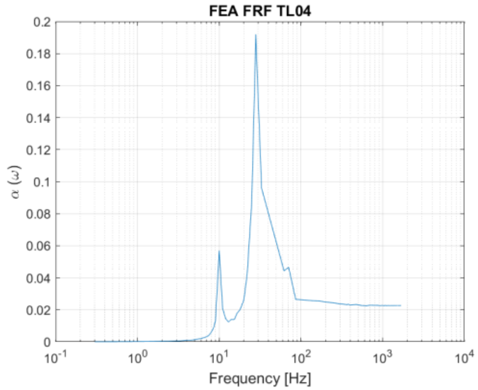
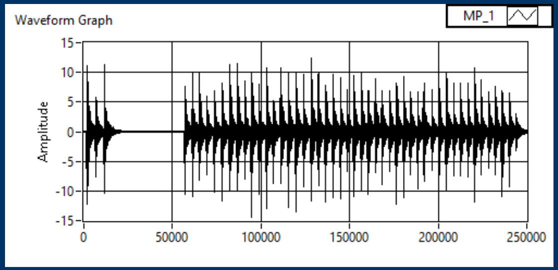


Figure 20: FRF at the TL04 Sensor of FMA



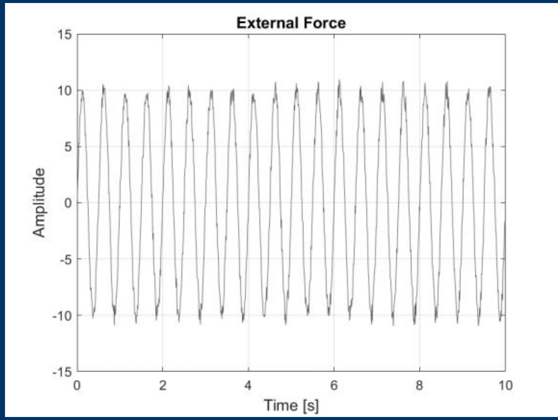


Figure 21: Response function

In the EMA graphs can be observed a greater range of frequencies while the FEA graphs show only the first frequencies.

6. Result comparison

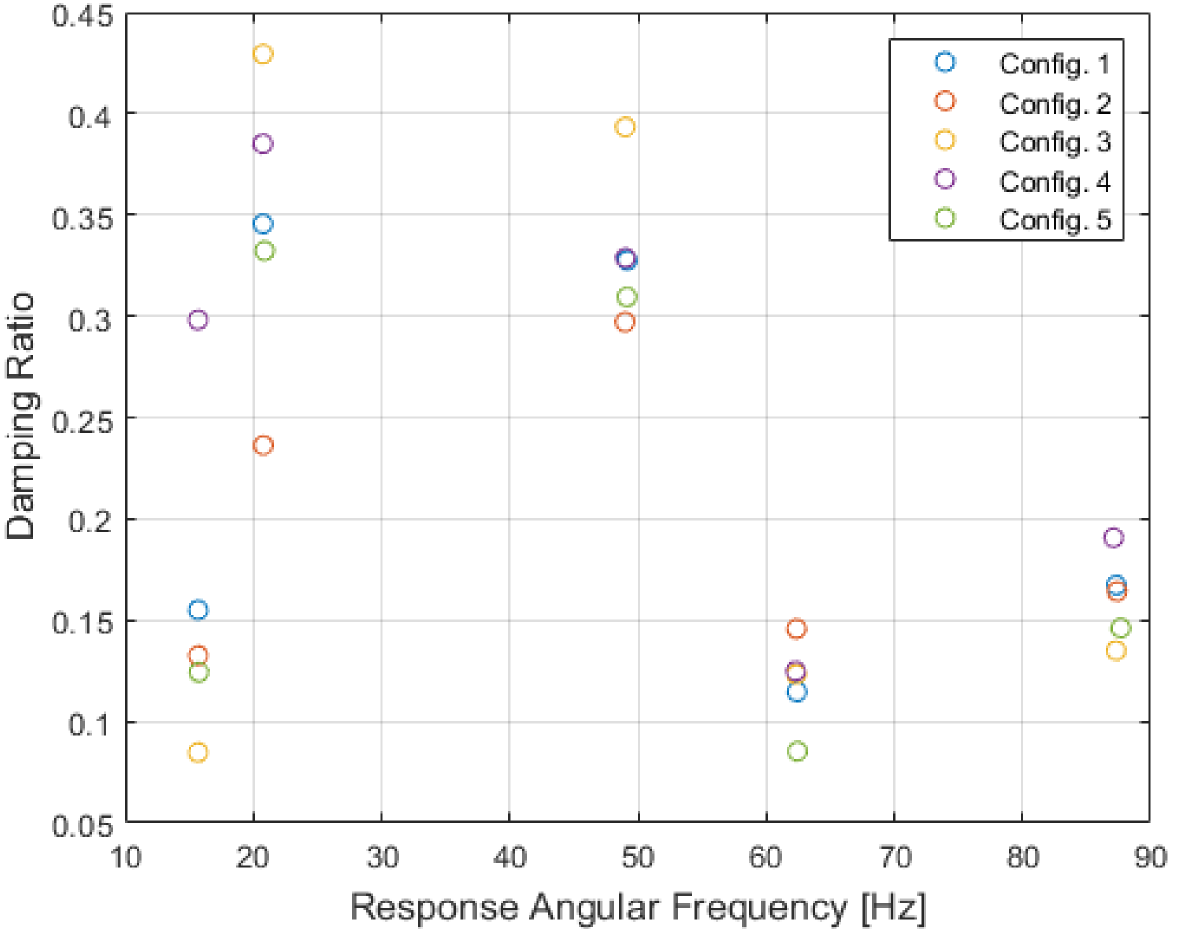


Figure 21: Frequencies obtained according to the different configuration of the placed Sensors.

7. Conclusions

- In order to improve the mathematical model used and to reduce the difference in the frequencies obtained, the material properties are adjusted.
- The difficulty of simulating the bridge section at scale for experimental modal analysis makes it necessary to use different materials that may lead to a differentiation in the dynamic response obtained.
- When comparing the results obtained by both approach (FEM and EMA) in terms of frequency, it is observed how the resulting in FEM are higher, this may be due to the difficulty of accurately simulating the scale model adjusting the dimensions and sections. Nevertheless, the experimental model may have a contribution by having errors in data processing. Still, the overall results are close, and the mode shapes show the same behavior.

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References

Costas, Argyris, Papadimitriou Costas, Panetsos Panagiotis, y Tsopelas Panos. 2020. «Bayesian Model-Updating Using Features of Modal Data: Application to the Metsovo Bridge», junio, 25.

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Thank you for your attention!