ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Yearly Assessment

SEHM^2 - XXXIV Cycle

PhD. Course in Structural and Environmental Health Monitoring and Management

Bologna

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Automated damage identification applied to structural monitoring dynamic systems

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Advisor: **A. Benedetti**

Co-Advisor: **A. Giorgetti**

Department of Civil, Chemical, Environmental and Material Engineering

OUTLINE

1. Non-Destructive Test on Building Materials;
    - *Timber Elements;*
    - *Masonry Mortars.*

2. Dynamic Investigation and Damage Detection;
    - *Concrete Beam;*
    - *Existing Bridges;*
    - *Lab Structures.*

Non-Destructive Test on Building Materials: Timber Elements (1/2)

Specimens Assessment:

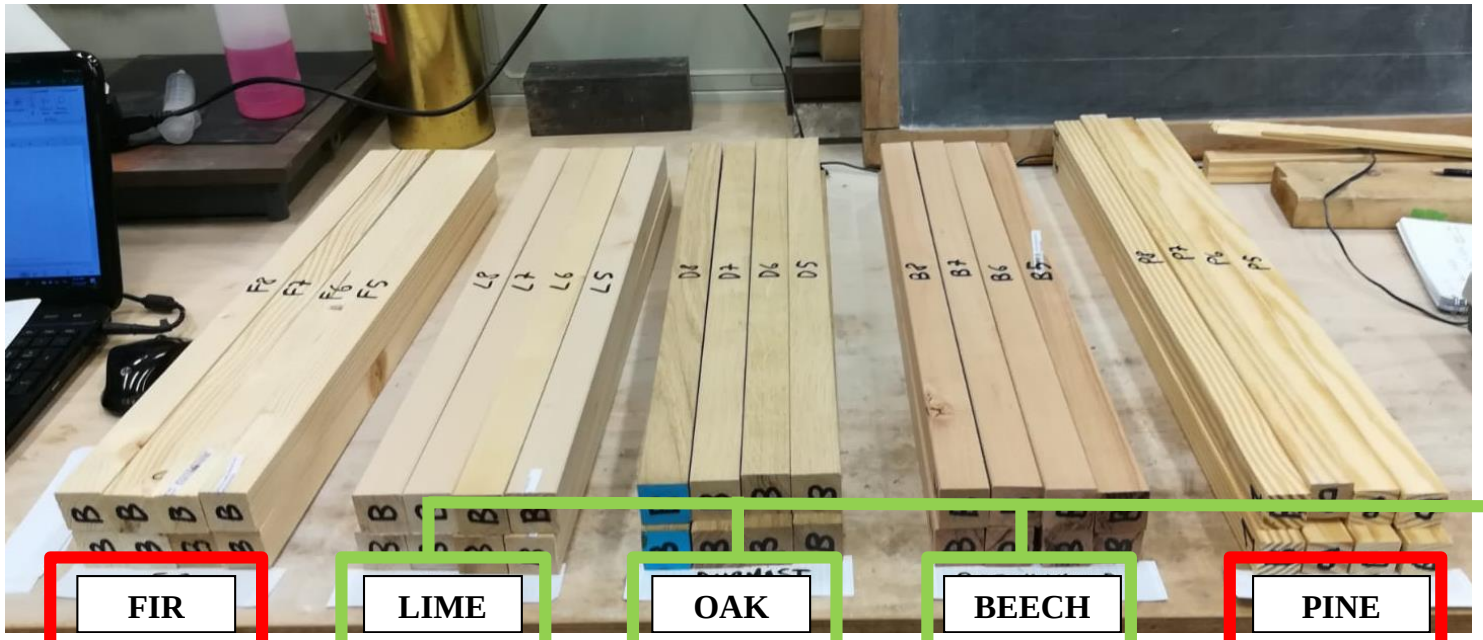
- Moisture Content [%];
- Density Evaluation [ρ].

ND Tests:

- Ultrasonic Test [E_D];
- Helifix Test [ρ, f_m].

Destructive Test:

- 4 Point Bending Test [$f_{m,B}$, E_S].



Softwood

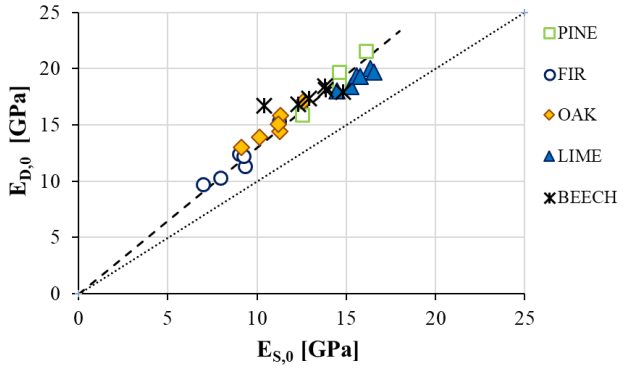
FIR **LIME** **OAK** **BEECH** **PINE**

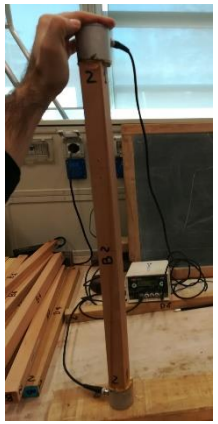
Hardwood

*Benedetti A., Tarozzi M. *"Toward a quantitative evaluation of timber strength through on-site tests"* SEMC 2019, Cape Town, South Africa

Non-Destructive Test on Building Materials: Timber Elements (2/2)

Ultrasonic Test

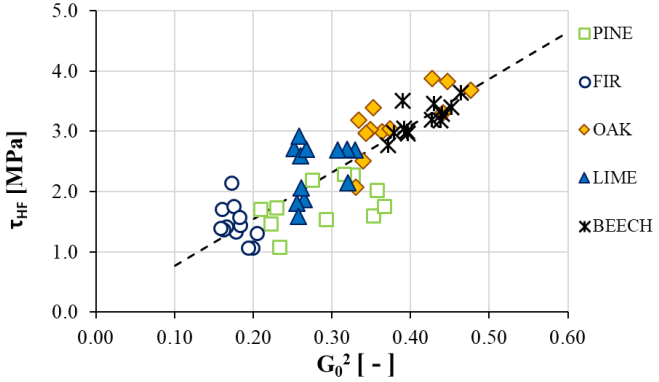




$$y = 1.30x$$
$$R^2 = 0.89$$

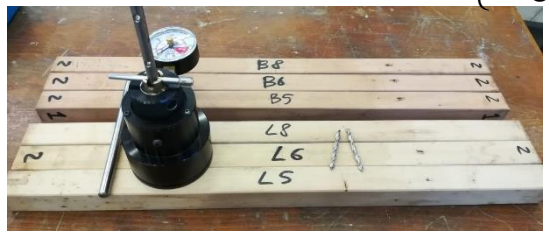
$$V_{us} = \sqrt{\frac{E_D}{\rho_{MC}}}$$

Helifix Test

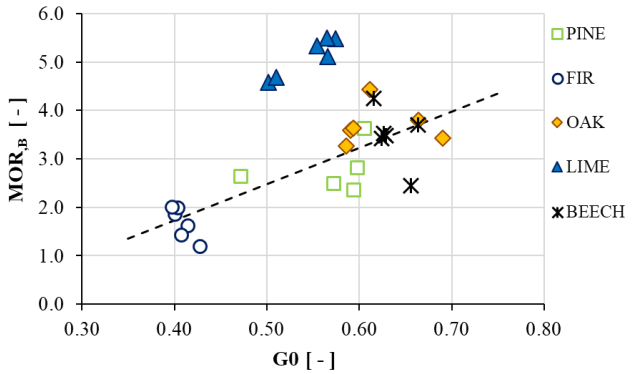


$$y = 7.75x \quad R^2 = 0.72$$

$$F_{ax} = 20 \cdot 10^{-6} \rho_{MC}^2 \, L \, d \cdot \min\left\{1, \frac{L}{6d}\right\}$$



4PBT Test

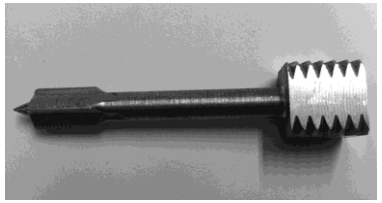


$$y = 7.49x - 1.3$$
$$R^2 = 0.66$$

*Benedetti A., Tarozzi M. *"Toward a quantitative evaluation of timber strength through on-site tests"* SEMC 2019, Cape Town, South Africa

Non-Destructive Test on Building Materials: Masonry Component (Mortar)

TPT



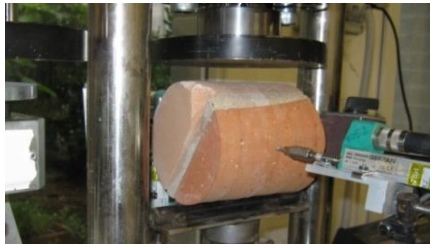
$$f_{mc} = f_0 \cdot \left[\frac{m_v}{2\sqrt{k_E k_G D_e \left(D_e^2 - D_i^2\right)}} \right]^{\frac{2}{\varepsilon+\gamma}}$$

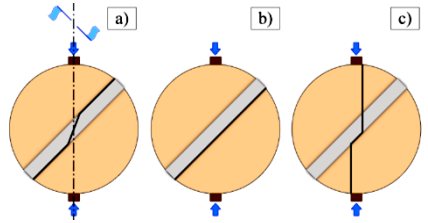
Marastoni et Al.

Helifix Test

$$\tau_0 = \frac{f_c f_t}{f_c + f_t} = f_c \frac{k_t}{1+k_t}$$

Brazilian Test

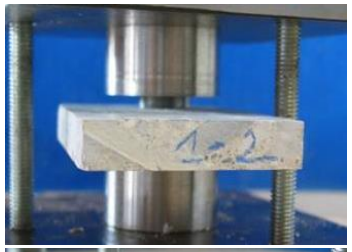




$$f_c = \frac{Q \cdot \cos\alpha}{L \cdot D} \cdot \frac{1-\nu_m^2}{2\nu_m} \cdot \left[\sqrt{1 + \frac{4\tan^2\alpha}{(1-\nu_m)^2}} - 1 \right]$$

Marastoni et Al.

DPT



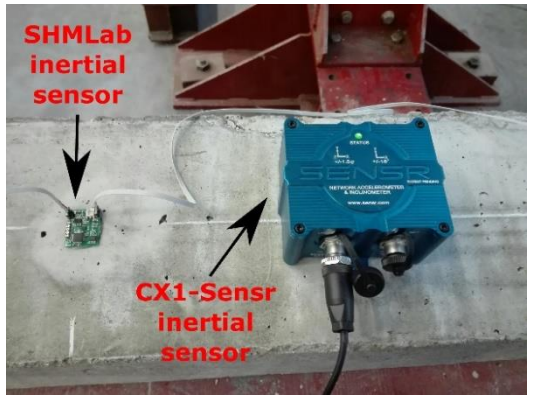
$$f_c = n(1-\mu\eta)\frac{\rho^2(1+k_t)+(1-k_t)}{\rho^2(2+k_t)-k_t}$$

*Benedetti A., Tarozzi M. *"Interpretation formulas for in situ characterization of mortar strength"* Construction Building Materials (Accepted – Under Review)

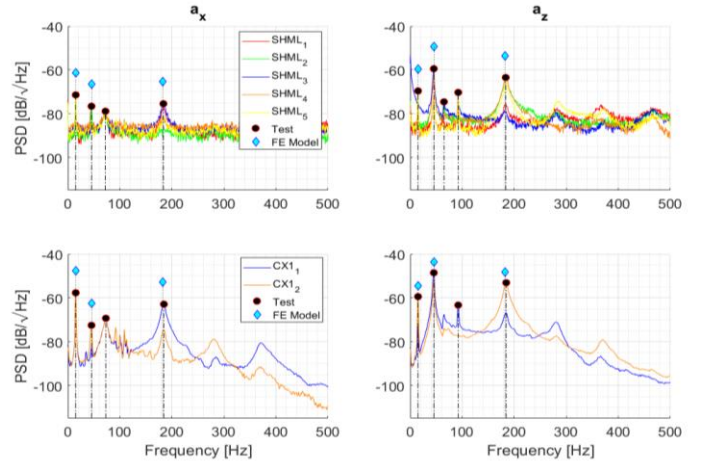
AUTOMATED DAMAGE IDENTIFICATION APPLIED TO STRUCTURAL MONITORING OF DYNAMIC SYSTEMS

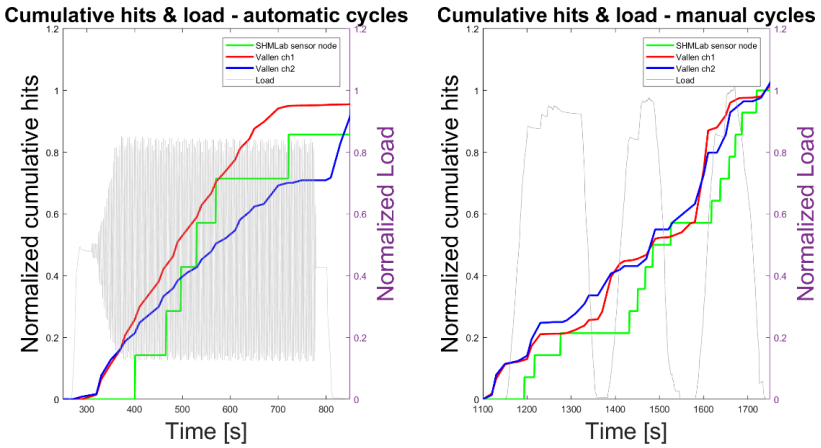
Dynamic Investigation and Damage Detection: Concrete Beam (1/3)

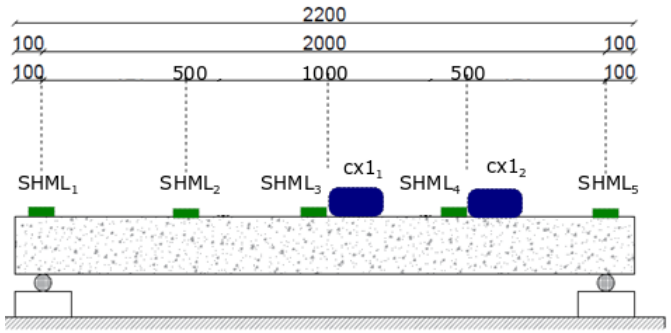
Dynamic Identification & AE Tests on a Concrete Beam

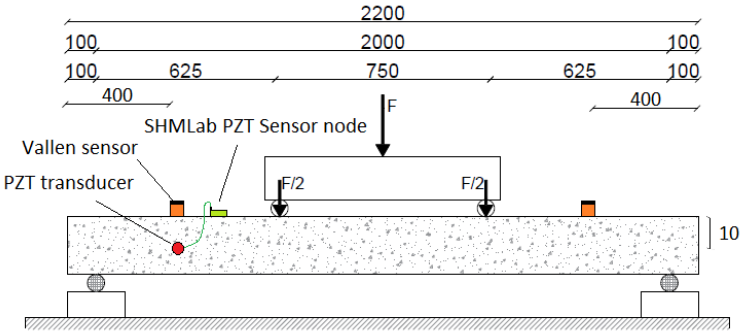


Experimental activity in collaboration with ARCES research Group









*Malatesta M. M., Zonzini F., Bogomolov D., Tarozzi M., Testoni N., Agugliaro G., Mennuti C., Marzani A., De Marchi L., Benedetti A. *"Monitoraggio di una trave di calcestruzzo armato con rete di sensori eterogenea miniaturizzata"* AiPnD 2019 AUTOMATED DAMAGE IDENTIFICATION APPLIED TO STRUCTURAL MONITORING OF DYNAMIC SYSTEMS

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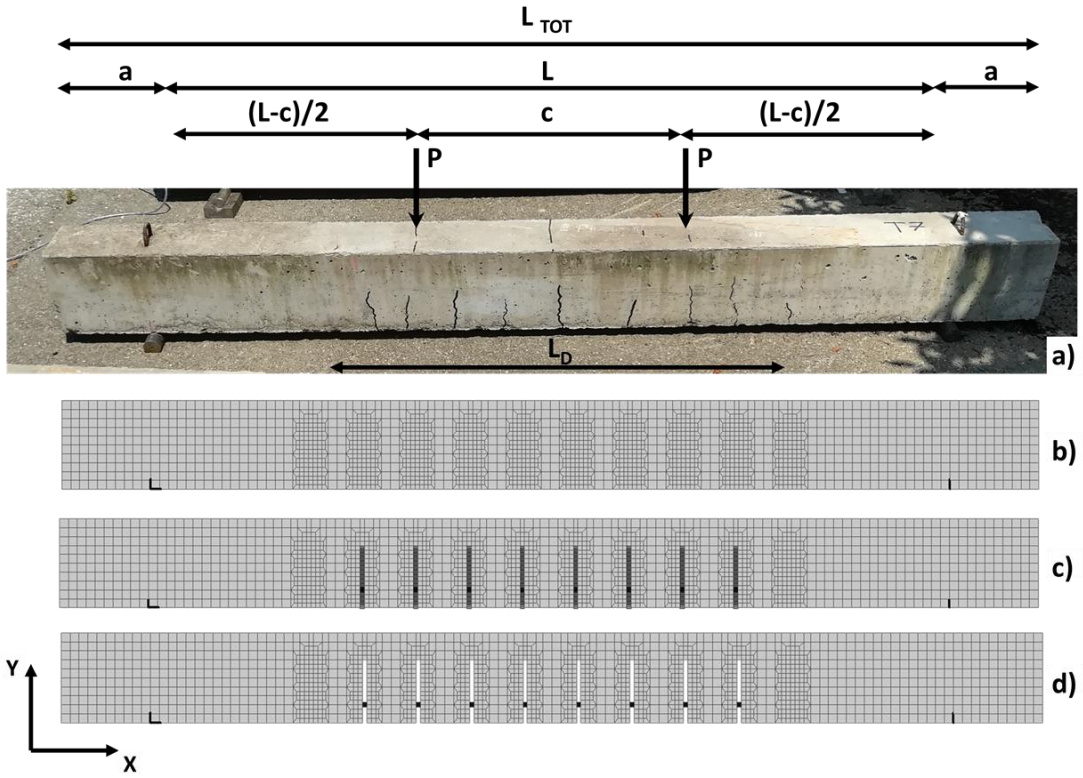
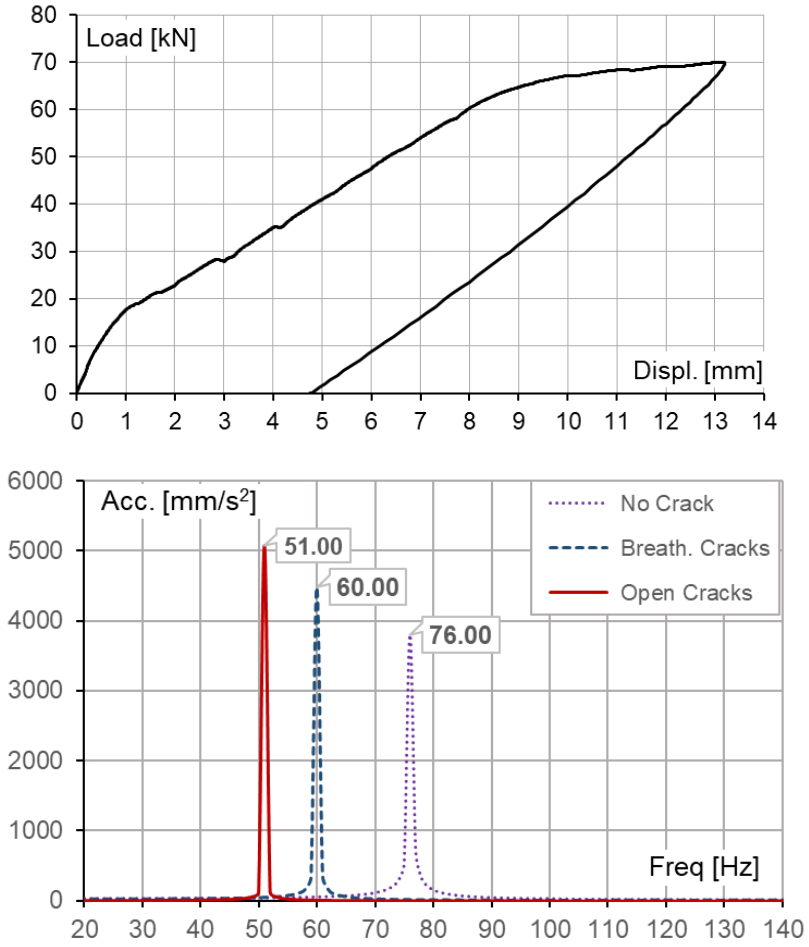
Dynamic Investigation and Damage Detection: Concrete Beam (2/3)

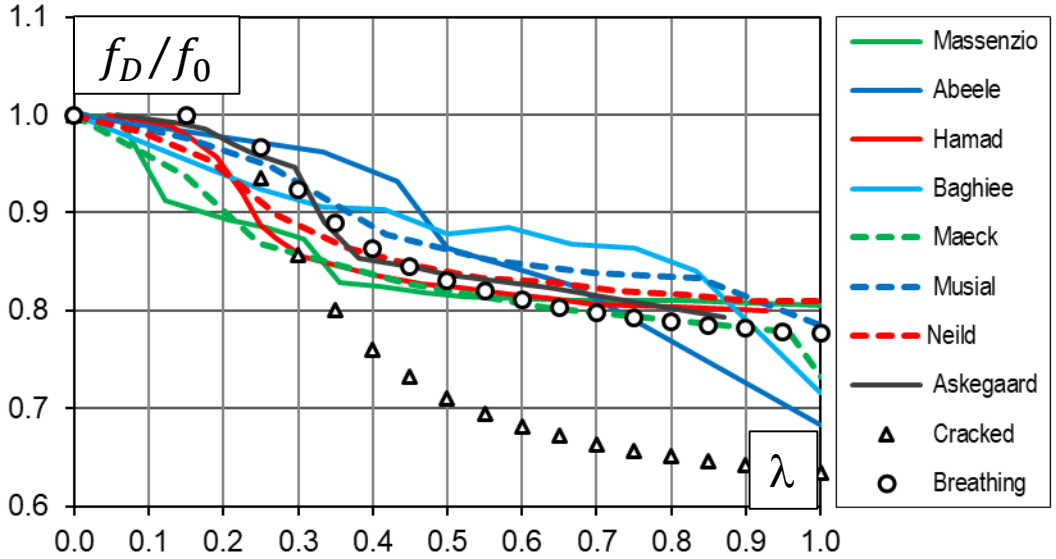
Breathing cracks in damaged concrete beams:





*Benedetti A., Pignagnoli G., Tarozzi M. *"Damage identification of cracked reinforced concrete beams through frequency shift"* Materials and Structures, 2018

Dynamic Investigation and Damage Detection: Concrete Beam (3/3)



$$f_b = \sqrt{\frac{2g}{\delta_c + \delta_o}} = \sqrt{\frac{2 f_c^2 f_o^2}{f_c^2 + f_o^2}}$$

$$\lambda = \frac{M_{\max}}{M_y} = \frac{M_{\max}}{M_{cr}} \cdot \frac{M_{cr}}{M_y} = \frac{\lambda_{cr}}{\alpha}$$

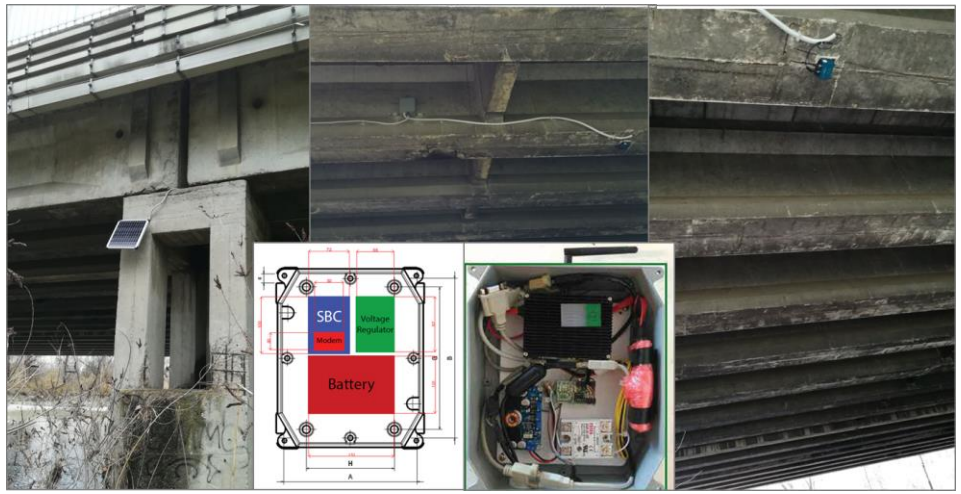
$$k_D(\lambda) = \frac{f_D}{f_0} = 1.025 - \frac{0.25}{1 + 9 \cdot e^{-6.6\lambda}}$$

Crack	Dyn. test	FE model	Err	Equations (2, 12)	Err (%)
Solid	75.60	76.00	0.53	79.00	4.49
Breathing	59.96	60.00	0.06	60.80	1.40
Open	51.21[a]	51.00	0.41	51.90	1.34

*Benedetti A., Pignagnoli G., Tarozzi M. *"Damage identification of cracked reinforced concrete beams through frequency shift"* Materials and Structures, 2018

Dynamic Investigation and Damage Detection: Existing Bridges (1/3)

Bacchelli Bridge:

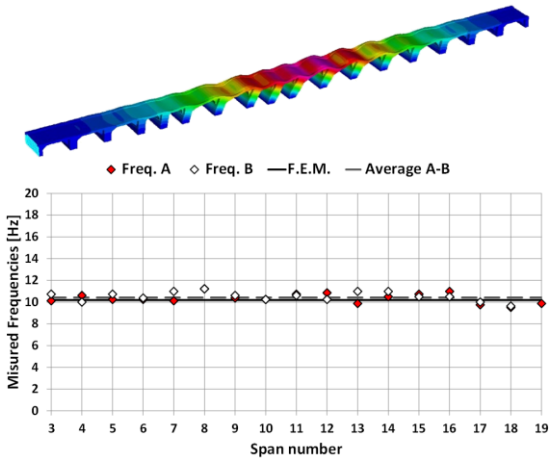


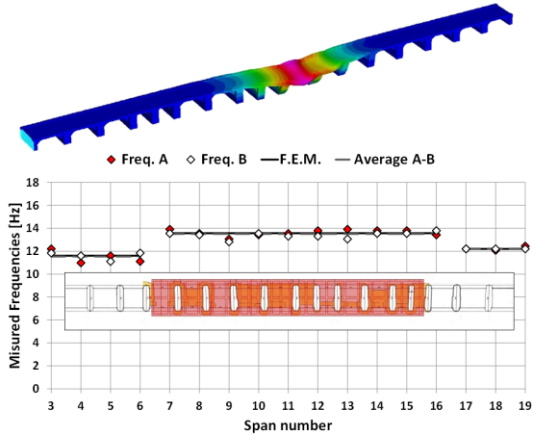
PSD – Algorithm:

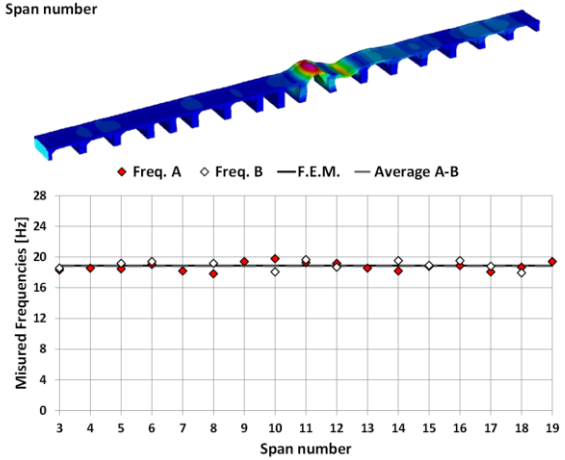
Signal Length:	200 secs
Sampling Frequency:	2000 samples per second
Decimation:	200 samples per second
Detrending:	Removing of linear trend
Lowpass Filtering:	Frequency up to 30 Hz
Hanning Windowing:	8192 samples
Overlap:	50 %
PSD Resolution:	0.02 Hz

Dynamic Investigation and Damage Detection: Existing Bridges (2/3)

Pontelungo Bridge:







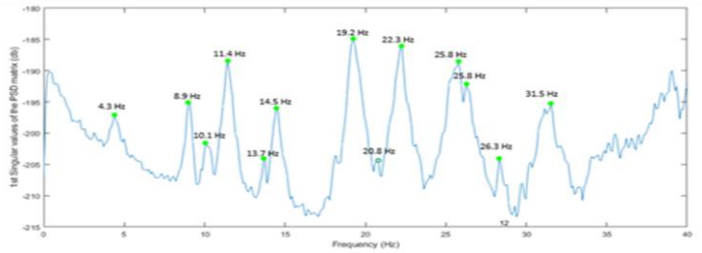
ELEMENTS	MATERIAL	E (MPa)	ρ (Kg/m^3)	ν (–)	k_s (MN/m^3)
Arches, walls, piers	Brick Masonry	5300	1700	0.2	
Fill	Rubble Stones	2600	2200	0.2	
Concrete deck	C 25/30	27460	2400	0.2	
Elastic Sil	Winkler Model	-	-	-	1000

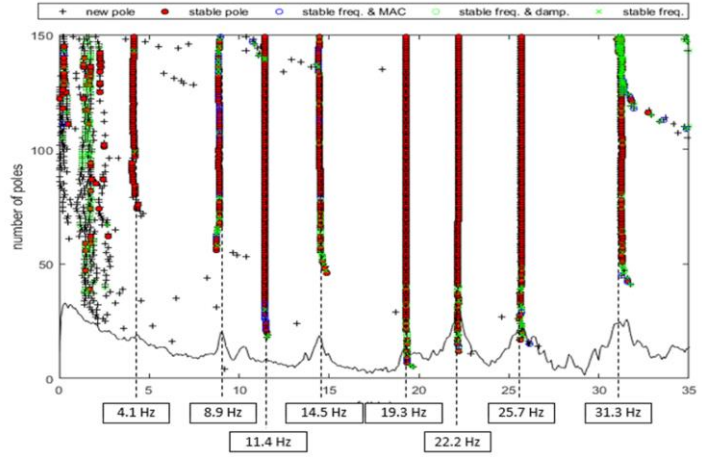
*Benedetti A., Pignagnoli G., Tarozzi M. *"Dynamic investigation and short-monitoring of an historic multi-span masonry arch bridge "* ARCH 2019, Porto, Portugal

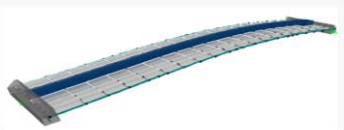
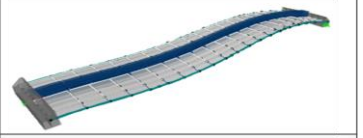
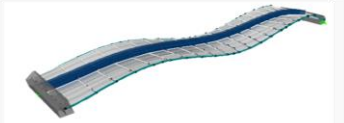
AUTOMATED DAMAGE IDENTIFICATION APPLIED TO STRUCTURAL MONITORING OF DYNAMIC SYSTEMS

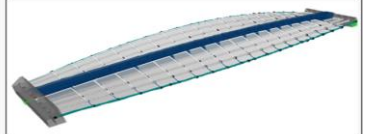
Dynamic Investigation and Damage Detection: Existing Bridges (3/3)

Annibaldi Bridge:



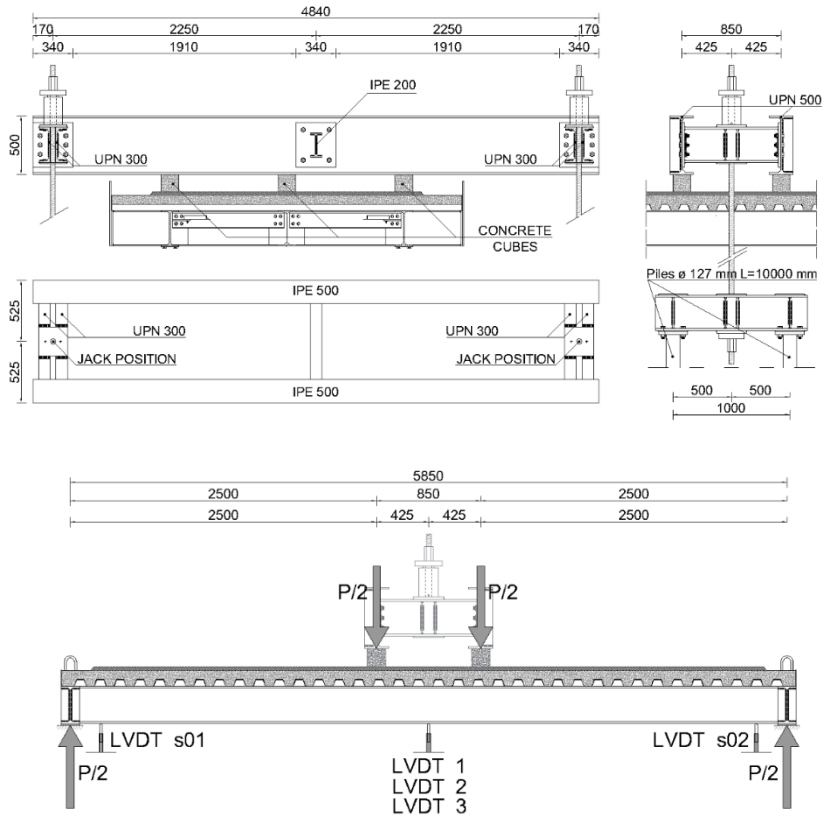


Bending Modes	
1st Bending f_N = 4.10 Hz	
2nd Bending f_N = 11.92 Hz	
3rd Bending f_N = 22.19 Hz	

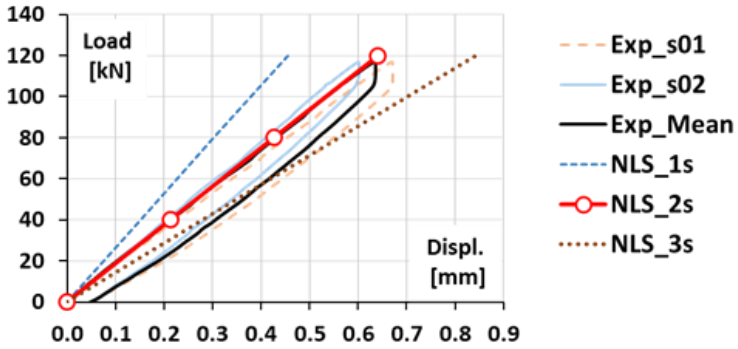
Torsional Modes	
1st Torsional f_N = 8.70 Hz	
2nd Torsional f_N = 15.40 Hz	

Dynamic Investigation and Damage Detection: Lab Structures (1/2)

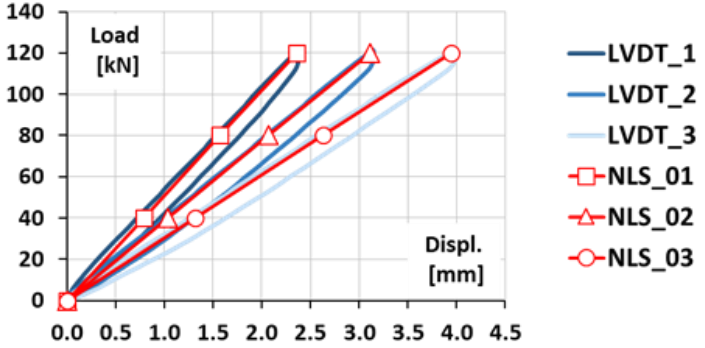
4 Points Bending Test:



Supports sag:



Mid-span sag:



*Tarozzi M., Benedetti A. "*Damage identification using vibration data on a composite Concrete-Steel Bridge*"*

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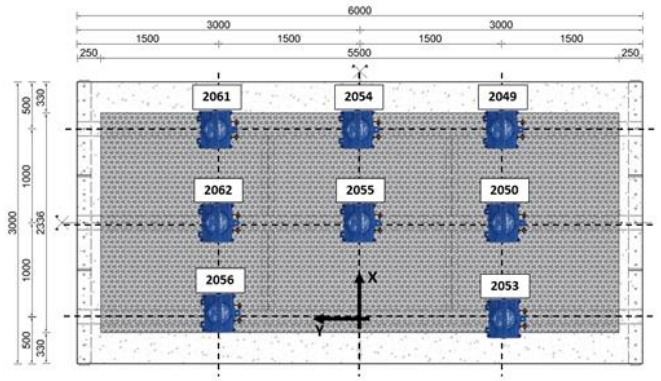
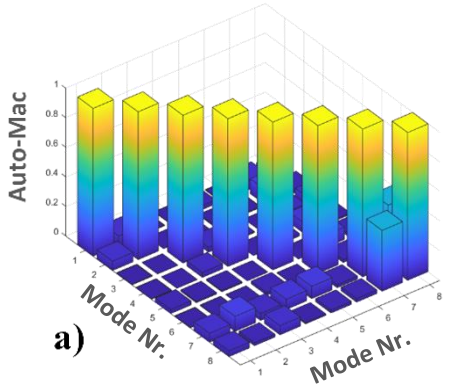
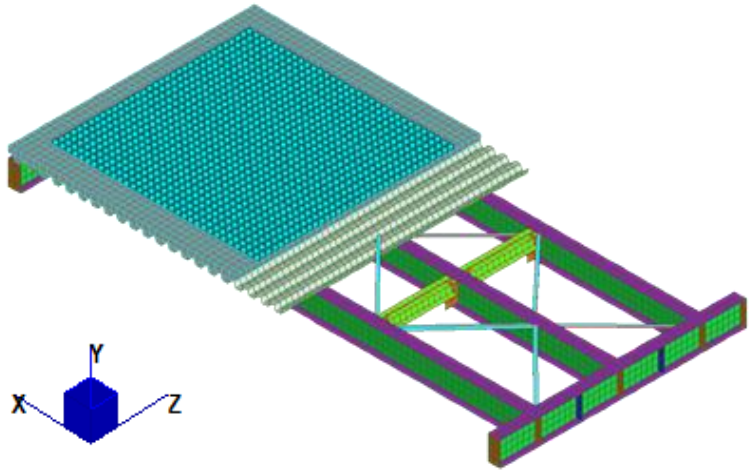
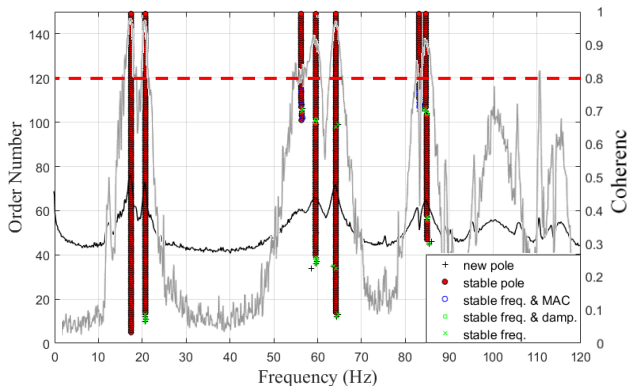
Dynamic Investigation and Damage Detection: Lab Structures (2/2)

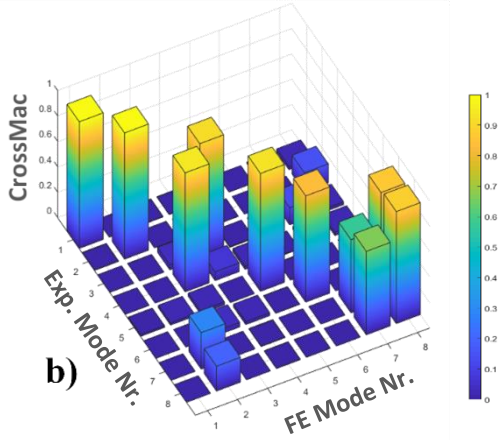
Dynamic Investigation Steel deck:

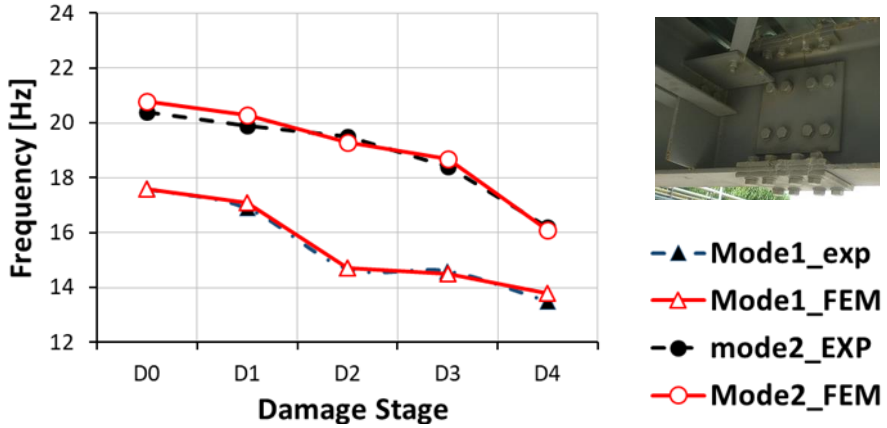






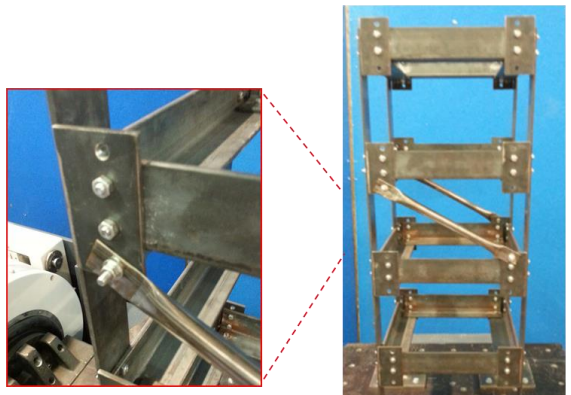




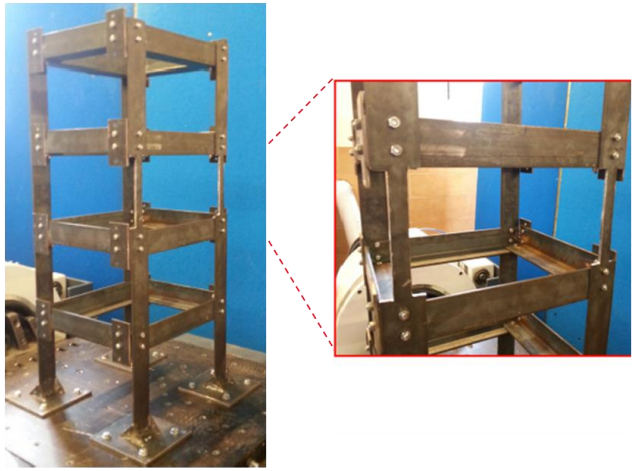


*Tarozzi M., Benedetti A. "*Damage identification using vibration data on a composite Concrete-Steel Bridge"*
AUTOMATED DAMAGE IDENTIFICATION APPLIED TO STRUCTURAL MONITORING OF DYNAMIC SYSTEMS

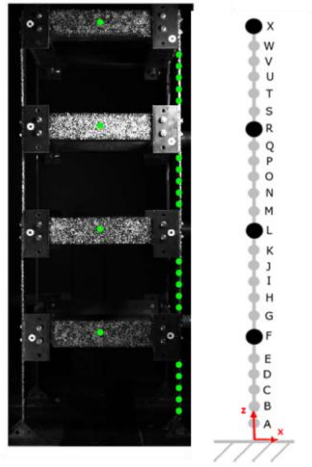
Dynamic Investigation and Damage Detection: Lab Structures (2/2)



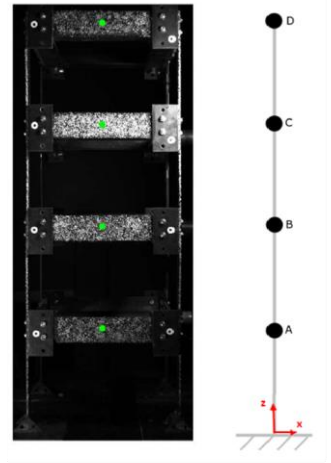
Undamaged scenario



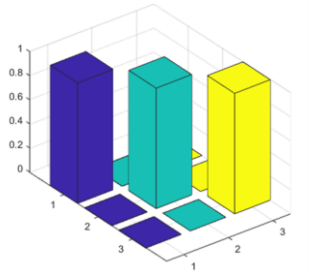
Damaged scenario



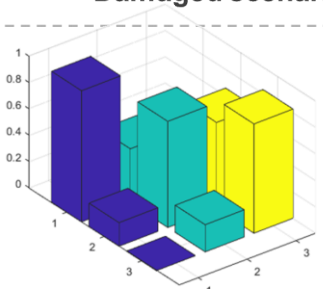
Points of Displacement Measurement



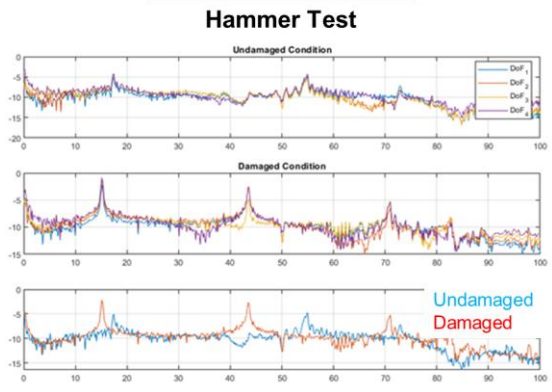
Locations of Accelerometers



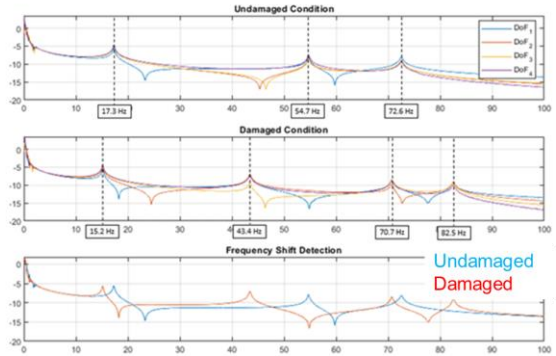
1.000	0.001	0.001
0.001	**1.000**	0.001
0.001	0.001	**1.000**



1.000	0.410	0.150
0.180	**0.810**	0.660
0.001	0.210	**0.830**



Hammer Test



Shaker Test

Future Works

- Deep investigation of the damage of concrete beam (Collaboration with ARCES group), combining Digital Image Correlation, Acoustic Emission, Static and dynamic tests;
- Study of the effect of corrosion on the dynamic properties of a concrete beam;
- Experiemtal campaign on the effect of moisture content on new and old timber members;
- Installation of the new prototype of the monitoring box to the real bridges.
- Study and Implementation of modal parameter tracking algorithms.

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Thank you for your attention

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