Digital Integration in Machines and Process Industry

Monitoring of industrial machinery and structures

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Dit - Lab. innovative technologies for safety

Rome, July 7th 2023

Inail, Via IV Novembre 144

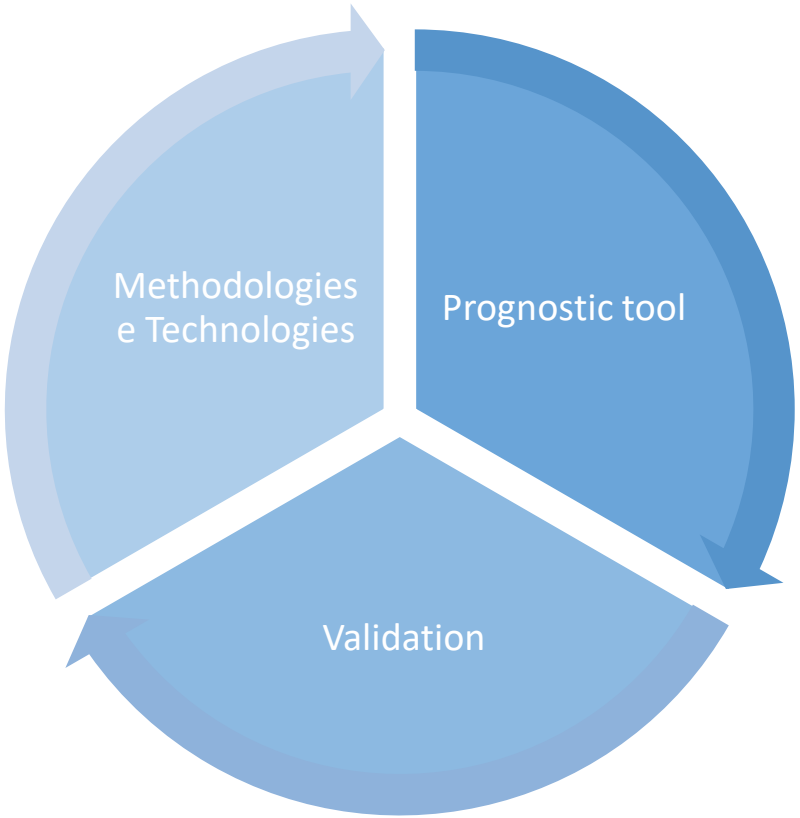
Introduction

Points of interest:

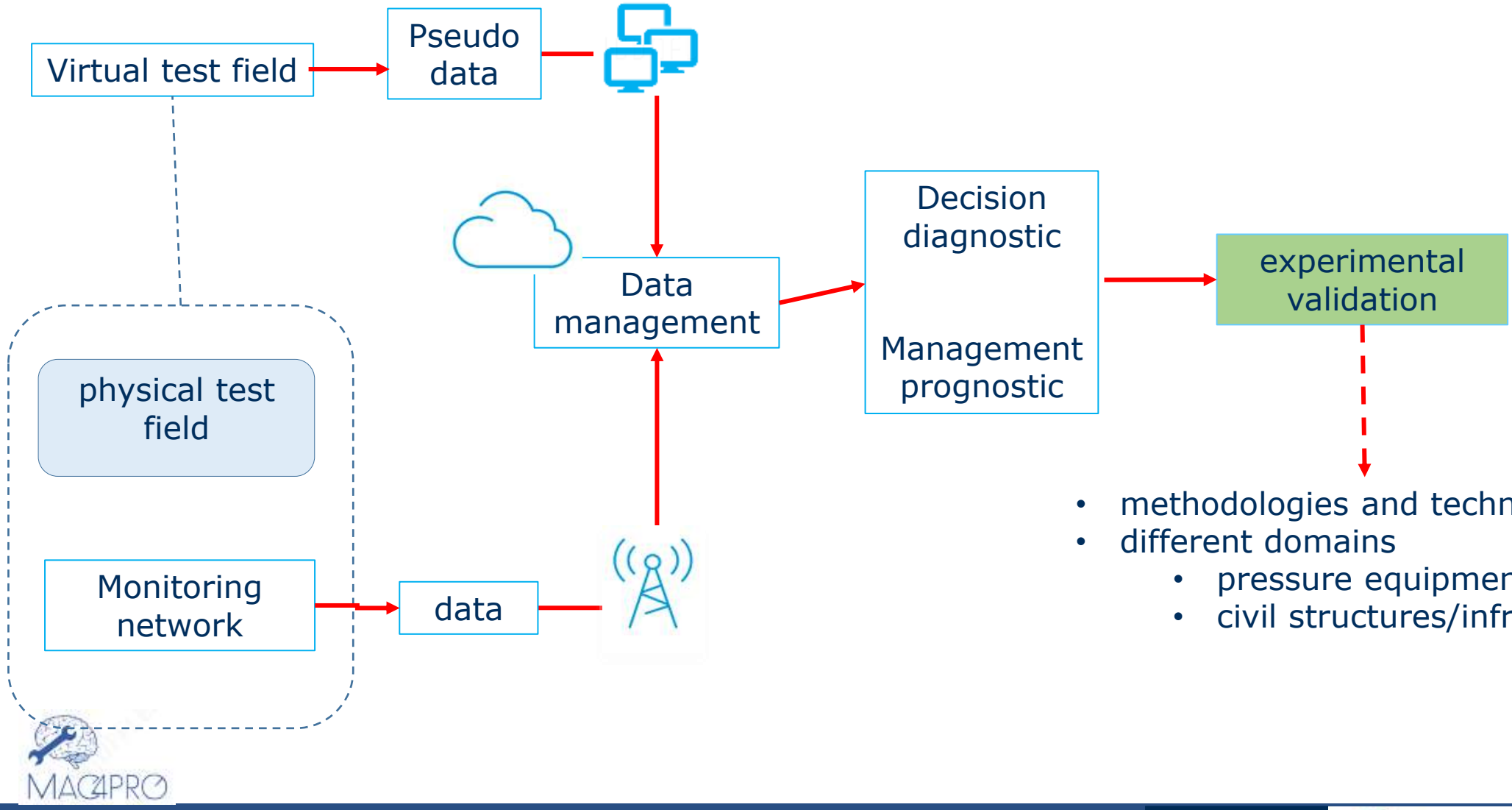
1. Advanced probabilistic models
2. Monitoring network
3. Prognostic approach
4. Validation on representative cases

Goals:

1. Safe and efficient management of pressure equipments and civil infrastructures
2. Eliminate unnecessary or invasive maintenance actions to reduce operating costs

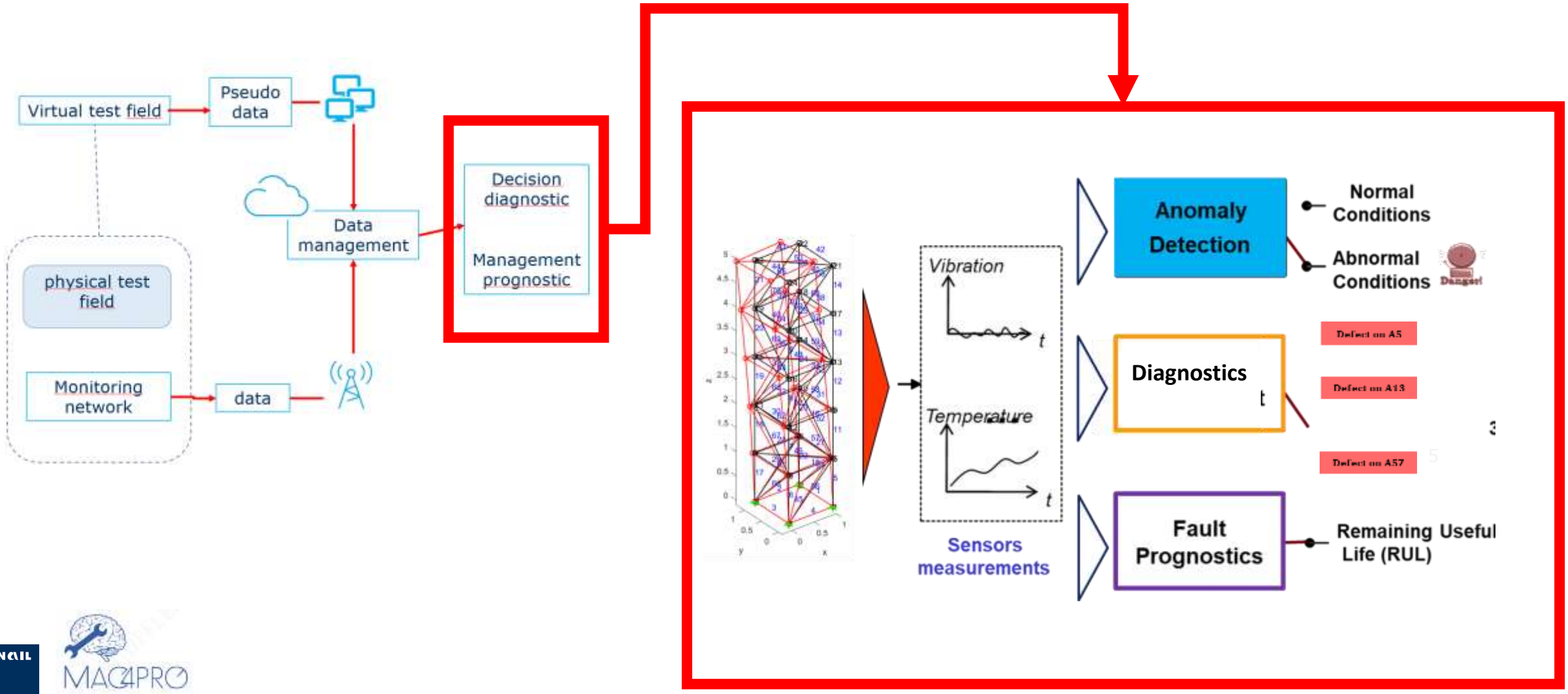


Design scheme



- methodologies and technologies
- different domains
  - pressure equipment
  - civil structures/infrastructures

Design scheme



Methods: Physical test field - Reticular, bridge in reinforced concrete

- Reticular structure

- Bridge

Accelerometer and Acoustic Emission sensors

Methods: prediction of degradation

Equipment history
1. historic monitoring of process parameters
2. Thickness control data

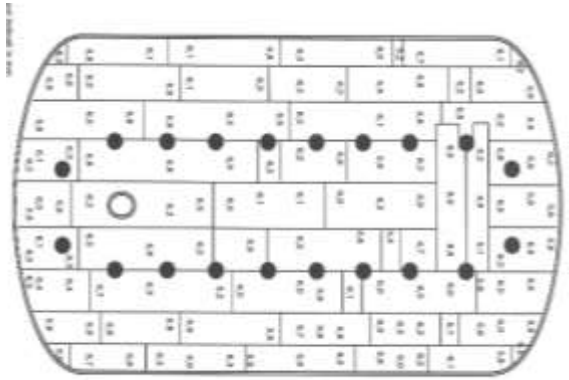
Models
1. Geometry
2. Corrosion law
3. Prognostic Model

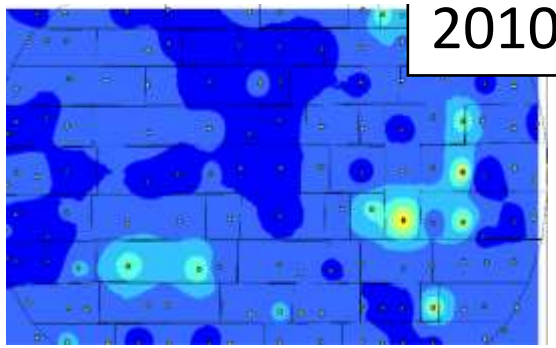
Monitoring systems
1. Sensors (AE)
2. Sensors (MEMS)

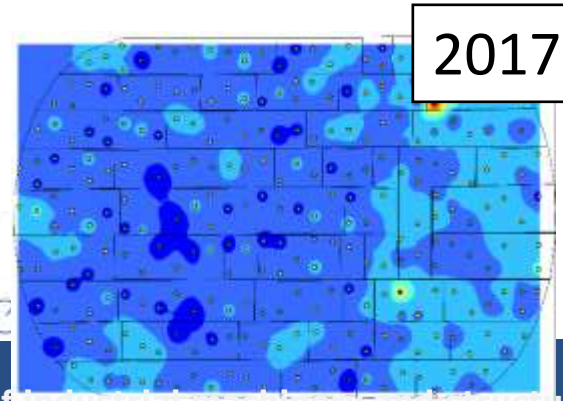
Structure/Infrastructure

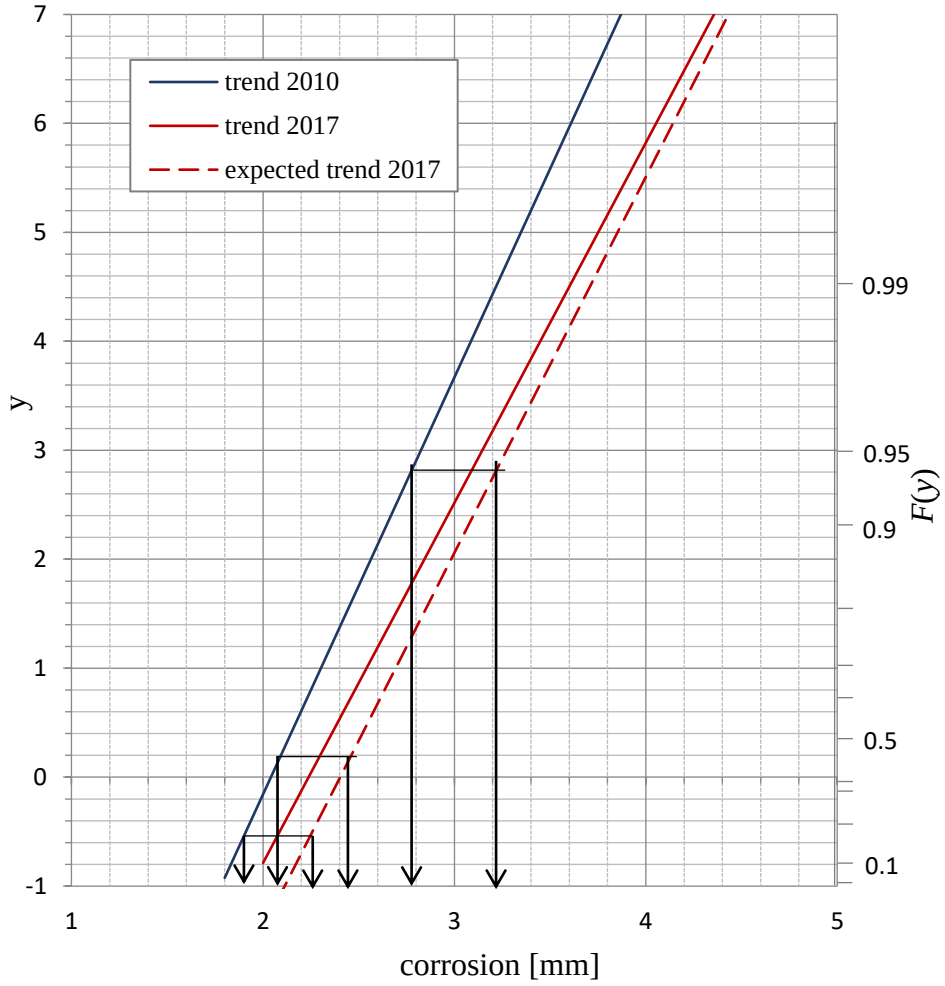
Prognostic
Estimation of residual life time

Methods: prediction of degradation





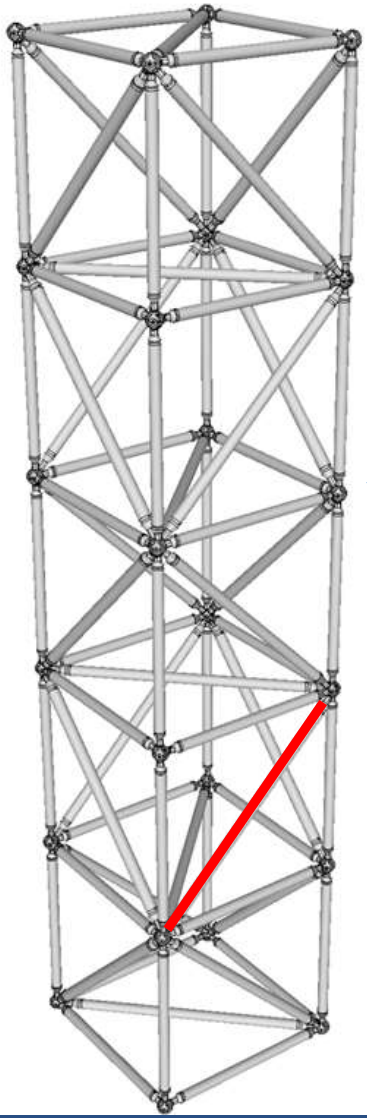


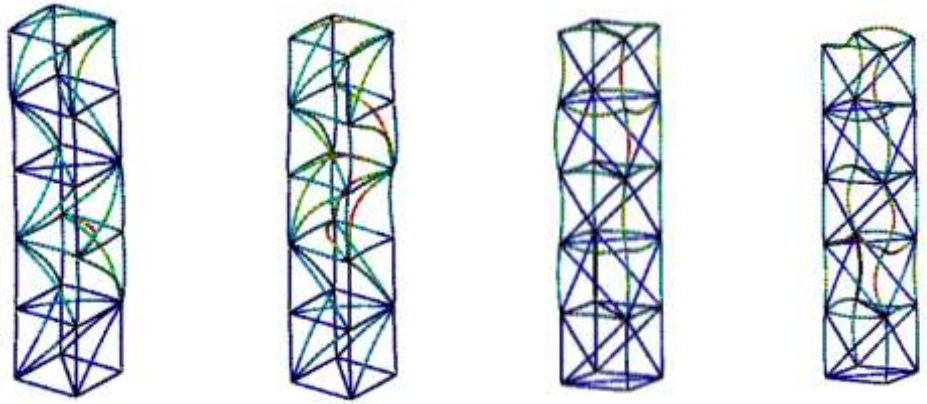


- ✓ Thickness reduction is 2.8 mm with 95% probability and with the same probability it is expected to increase to 3.2 mm in 2017.
- ✓ As of 2017, the real value is 3.15 mm.

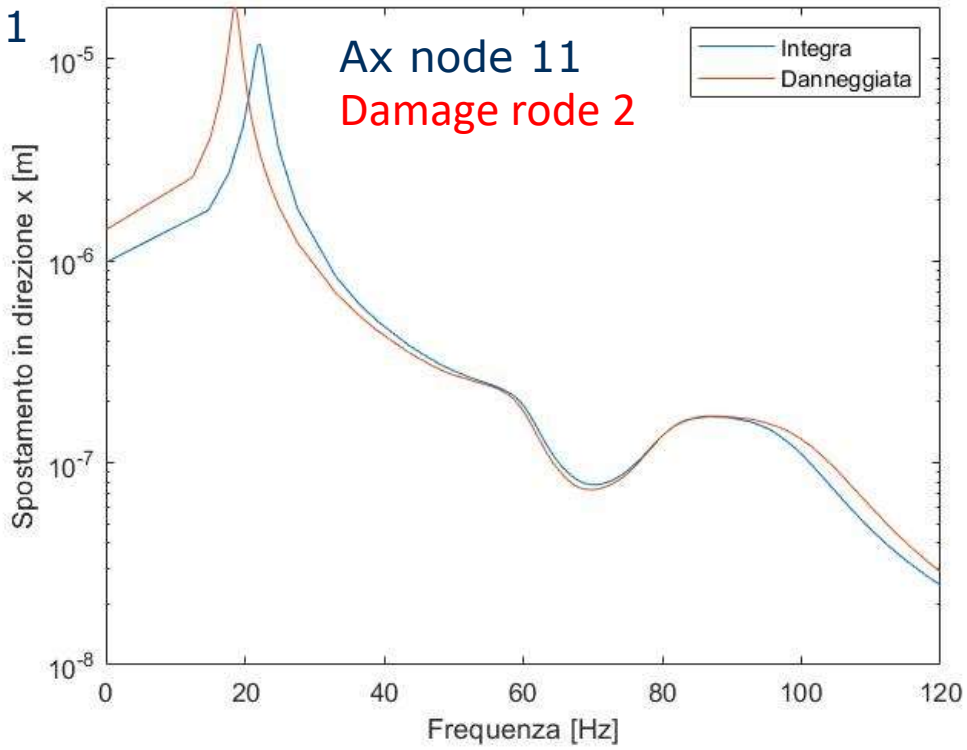
Methods: Advanced structural modeling - Reticular structure

Damaging scenario

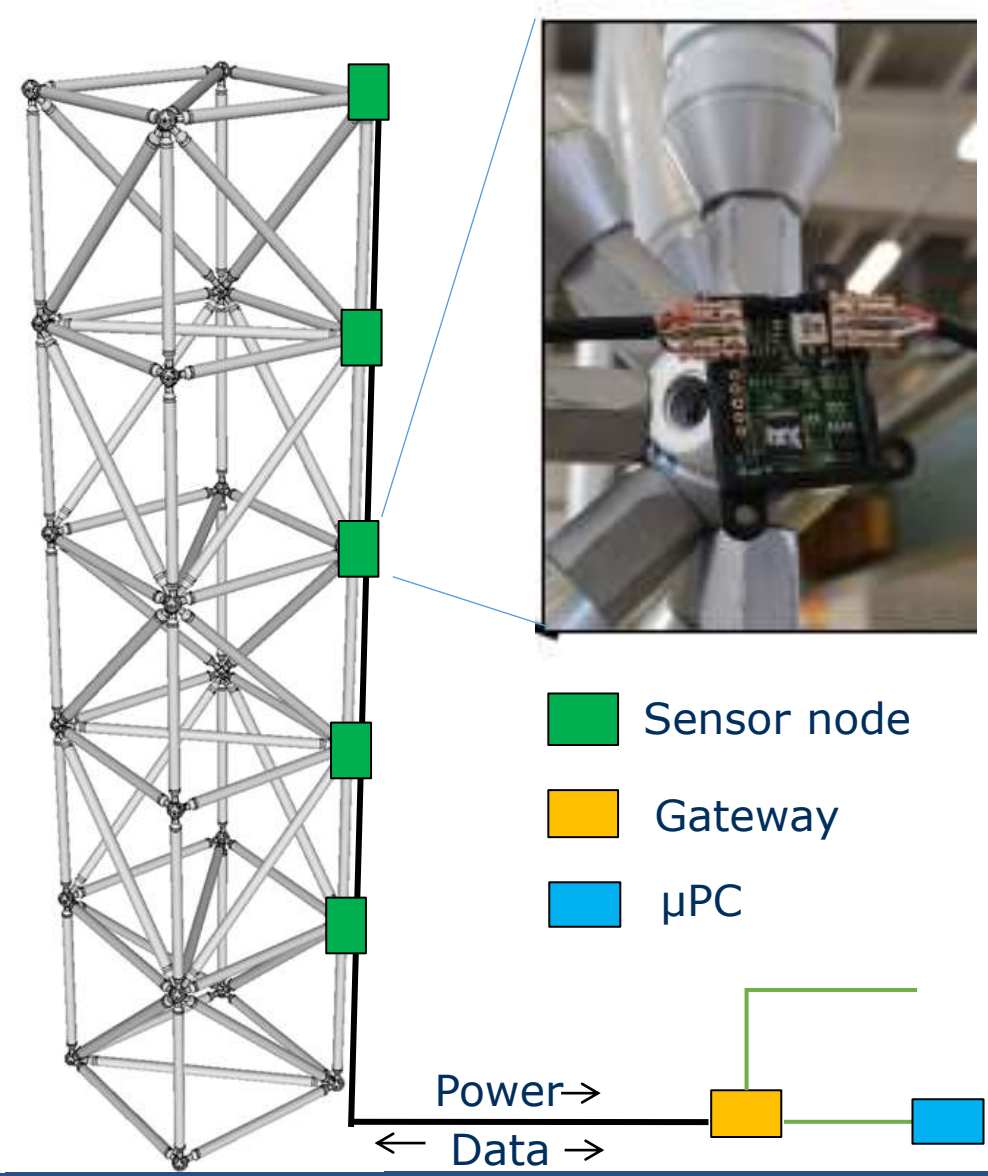




Ax node 11



Methods: sensors network

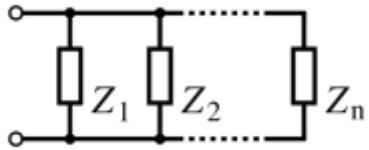


- Local processing
- Compact sensor node
- Significant reduction in cabling, weights, costs and power consumption
- Zero distance between the sensor and the reading electronics
- Use of industrial protocols
- Fully programmable remotely
- Self diagnostics

Methods: pervasive sensors

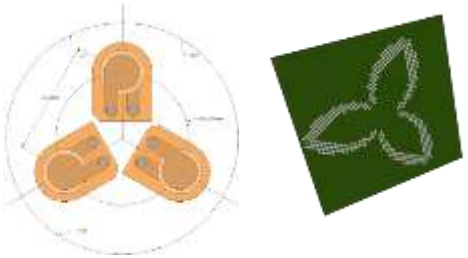
acoustic emissions

Impedance meter

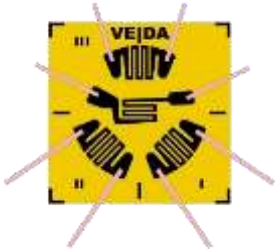


Sensor node

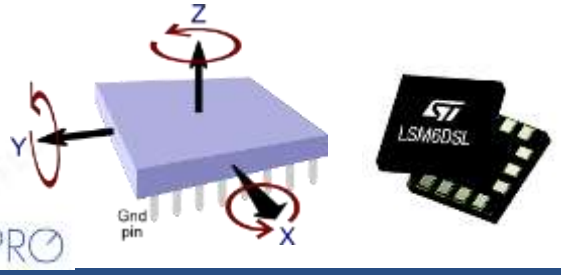
acoustic emissions



strain gauge



vibrations/tilt: IMU



heterogeneous monitoring

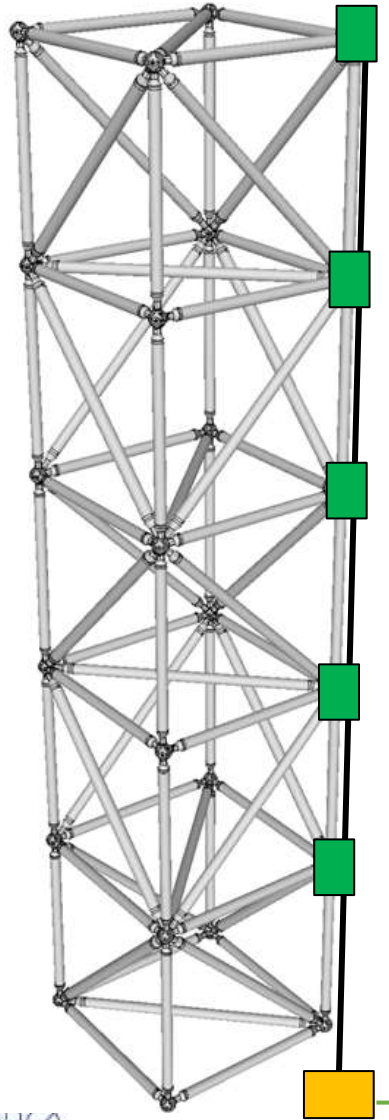
enviromental (temp., humidity, sound)

Methods: data processing and management

WoT platform

- **Extensibility** → Possibility of dynamically adding new sensors or new data processing/display modules.
- **Interoperability** → Transparent management of heterogeneous sensors (accelerometers, piezos, etc) characterized by different data models.
- **Reconfigurability** → Possibility to remotely control the configuration of the sensors and/or to redefine their behaviour.
- **Scalability** → Support for large volumes of data/devices.

Methods: data processing and management



TD

WEB THING
SENSOR 1

TD

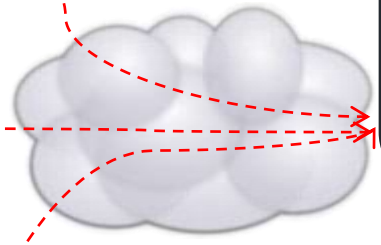
WEB THING
SENSOR 2

•
•
•

TD

WEB THING
STRUCTURE

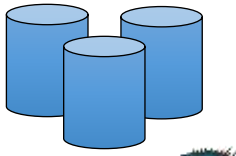
INTERNET NETWORK



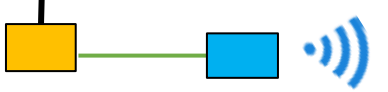
PLUG-IN
DATA
STORAGE

PLUG-IN
DASHBOARD

PLUG-IN
DATA **EXPORT**



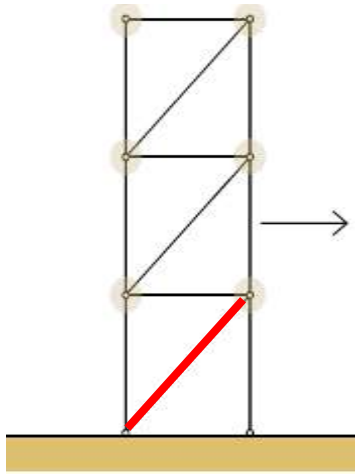
OS5

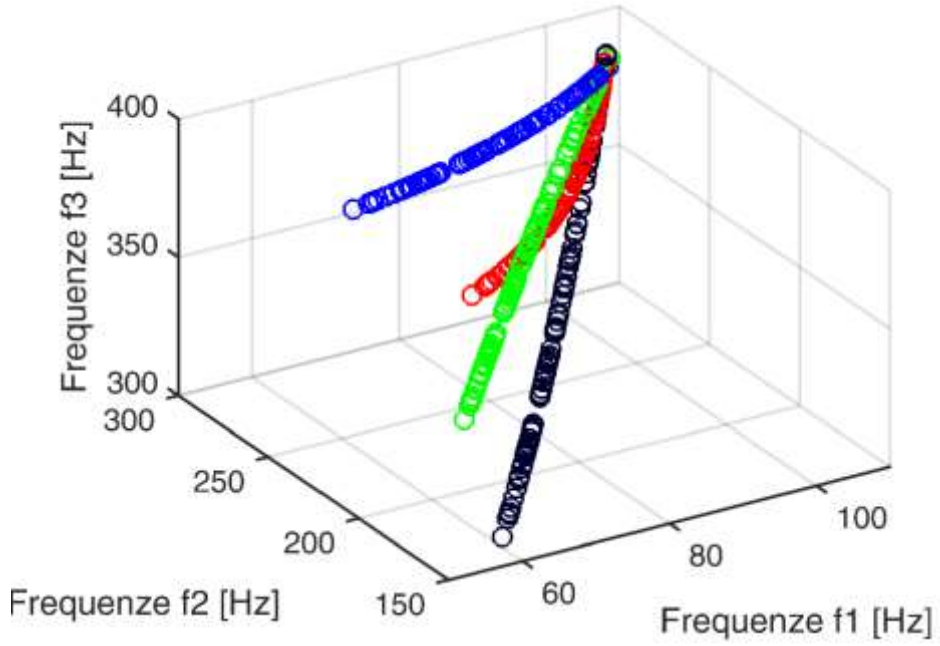


Methods: data processing and management

Prognostic through vibrations:

- Corrosion
- Neural networks



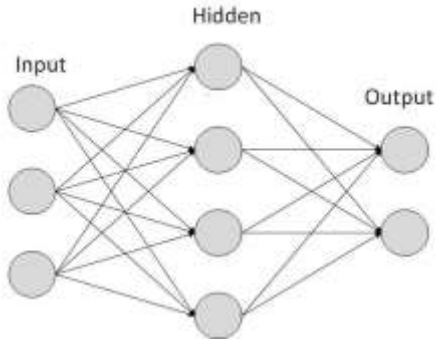


Degradation Model:

$$x(t) = x_0 e^{-\alpha t} + \gamma(t)$$

$x(t)$ = stiffness at time t
x_0 = initial stiffness
α = degradation speed
$\gamma(t)$= noise at time t

$\boldsymbol{f}(t-4)$
$\boldsymbol{f}(t-3)$
...
$\boldsymbol{f}(t)$



$\hat{x}(t+4)$

Methods: fileds of application

Pressure equipment integrity monitoring

Methods: fileds of application

Civil structures/infrastructures integrity monitoring

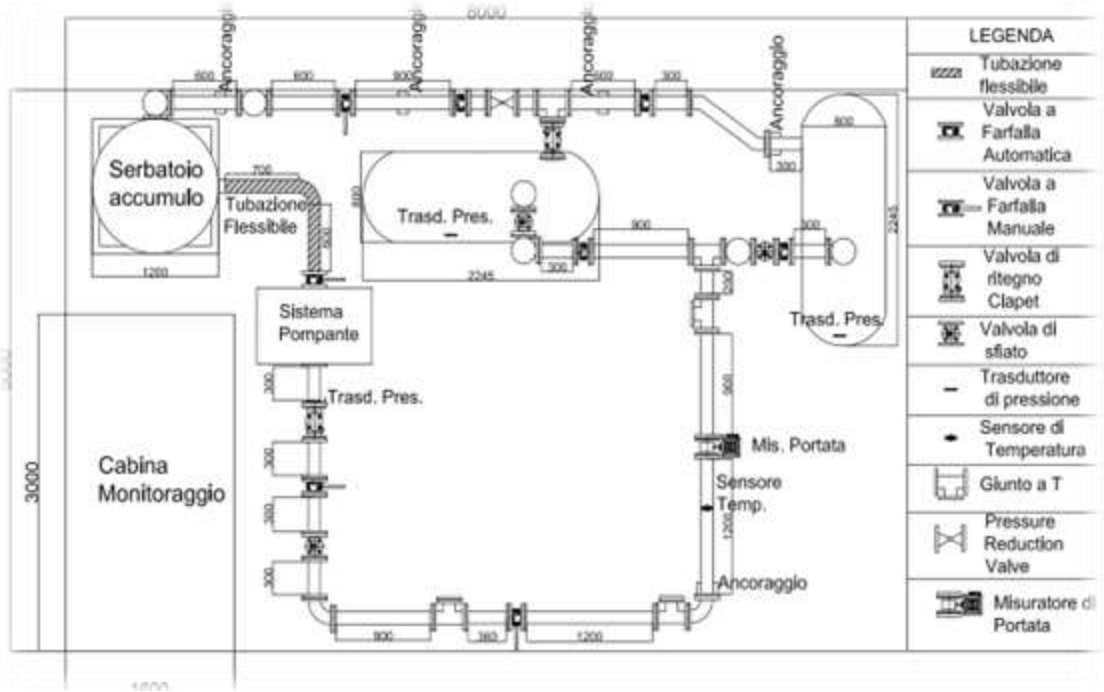
Validation: hydraulic circuit

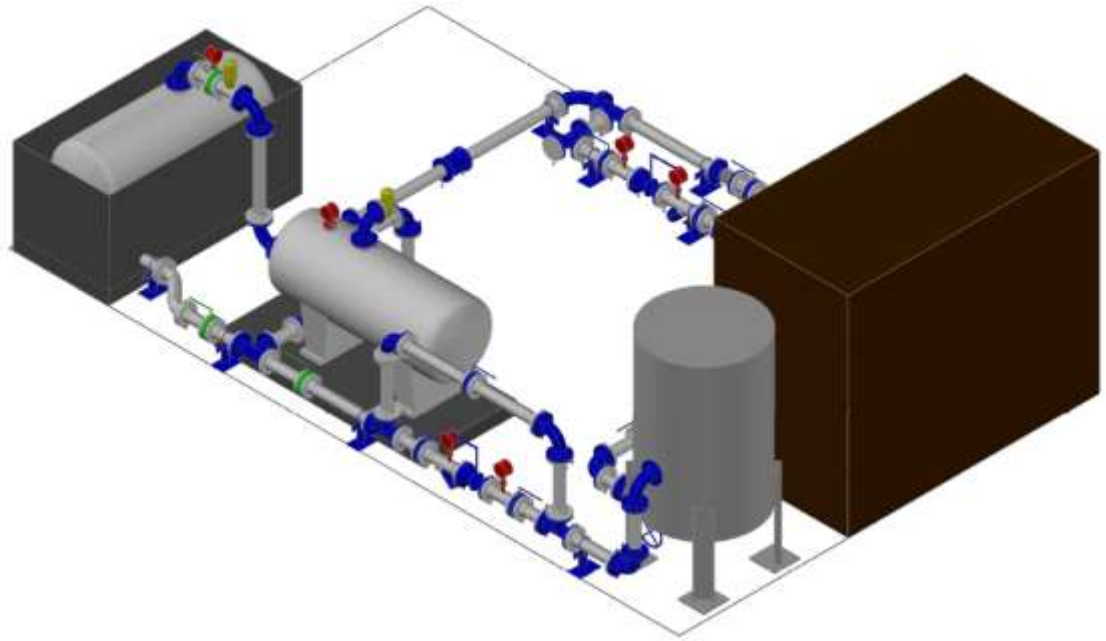
Pressure equipment test scenario

- Leakage vessel and/or pipe
- Pump/turbine cavitation

Hydraulic circuit

- load curve «p»
- «p» in tanks and pumps
- «q» in the pipes
- «T» of water and air
- check closing/opening of valves
- simulate losses

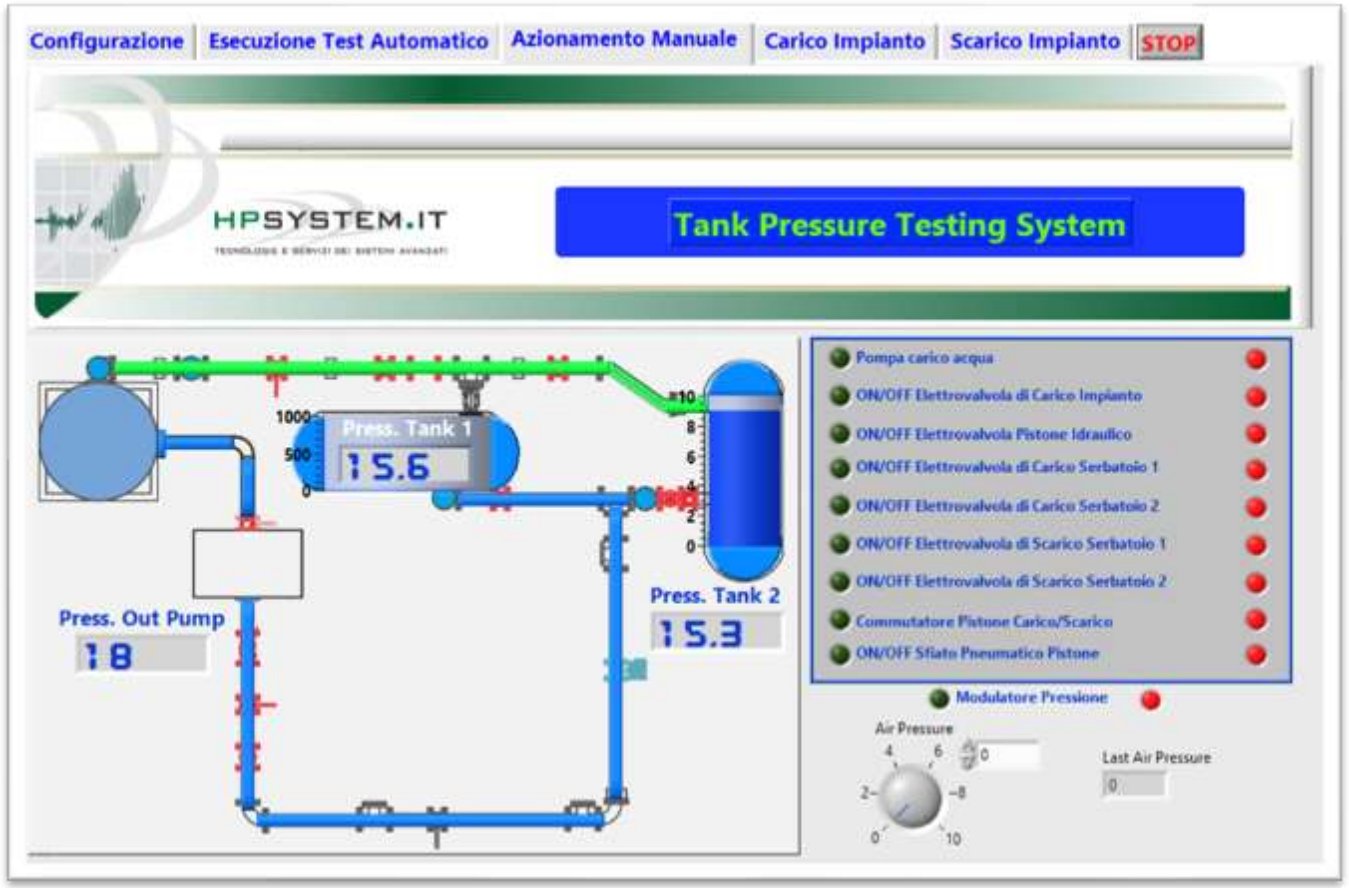




Validation: hydraulic circuit

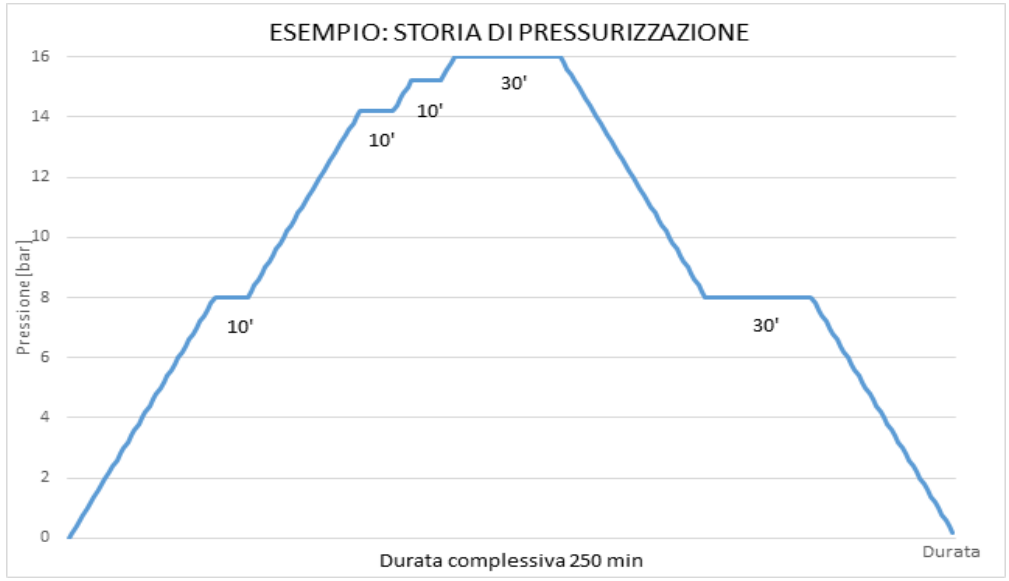
- Pipes DN100
- Storage tank 2000 litres
- 2 steel tanks (1000 litres)
- Distributed SW/HW system for the control of each device
- Two-stage pressurization system

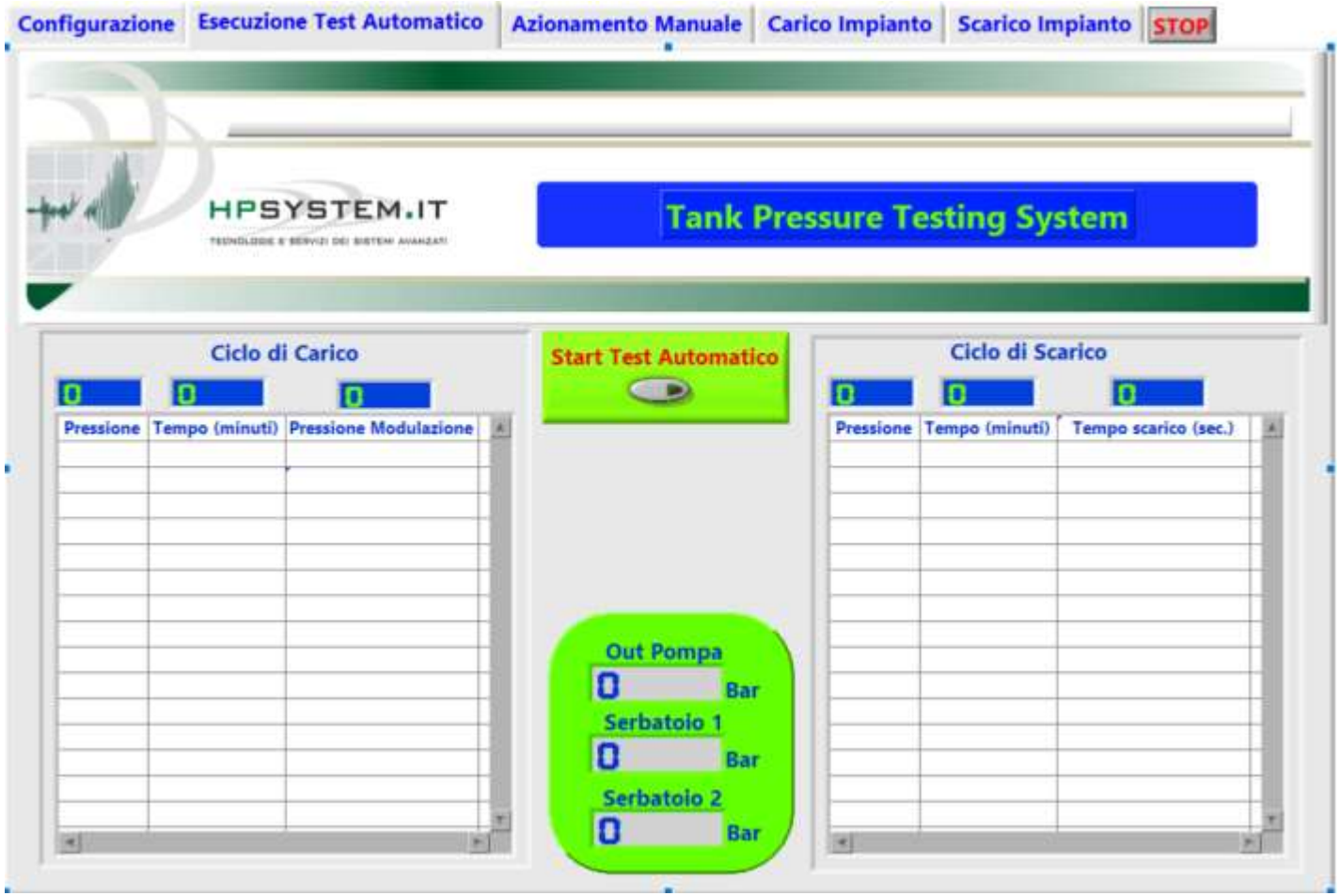
Validation: hydraulic circuit



Validation: hydraulic circuit

Load curve «p»





Validation: hydraulic circuit

Valve for leaks activation

Nozzle of 1 mm

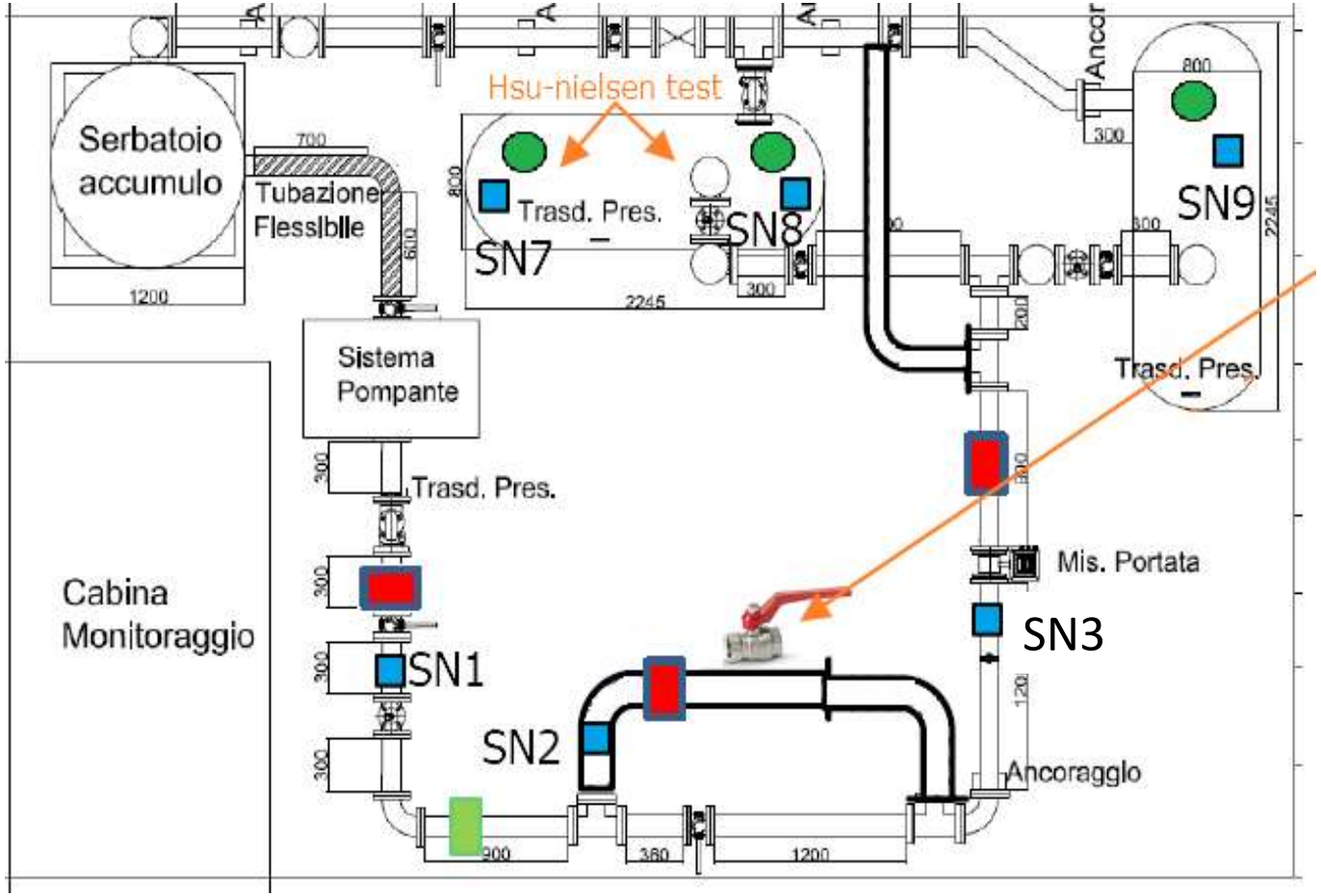
Low frequency AE transducers

High frequency AE transducers

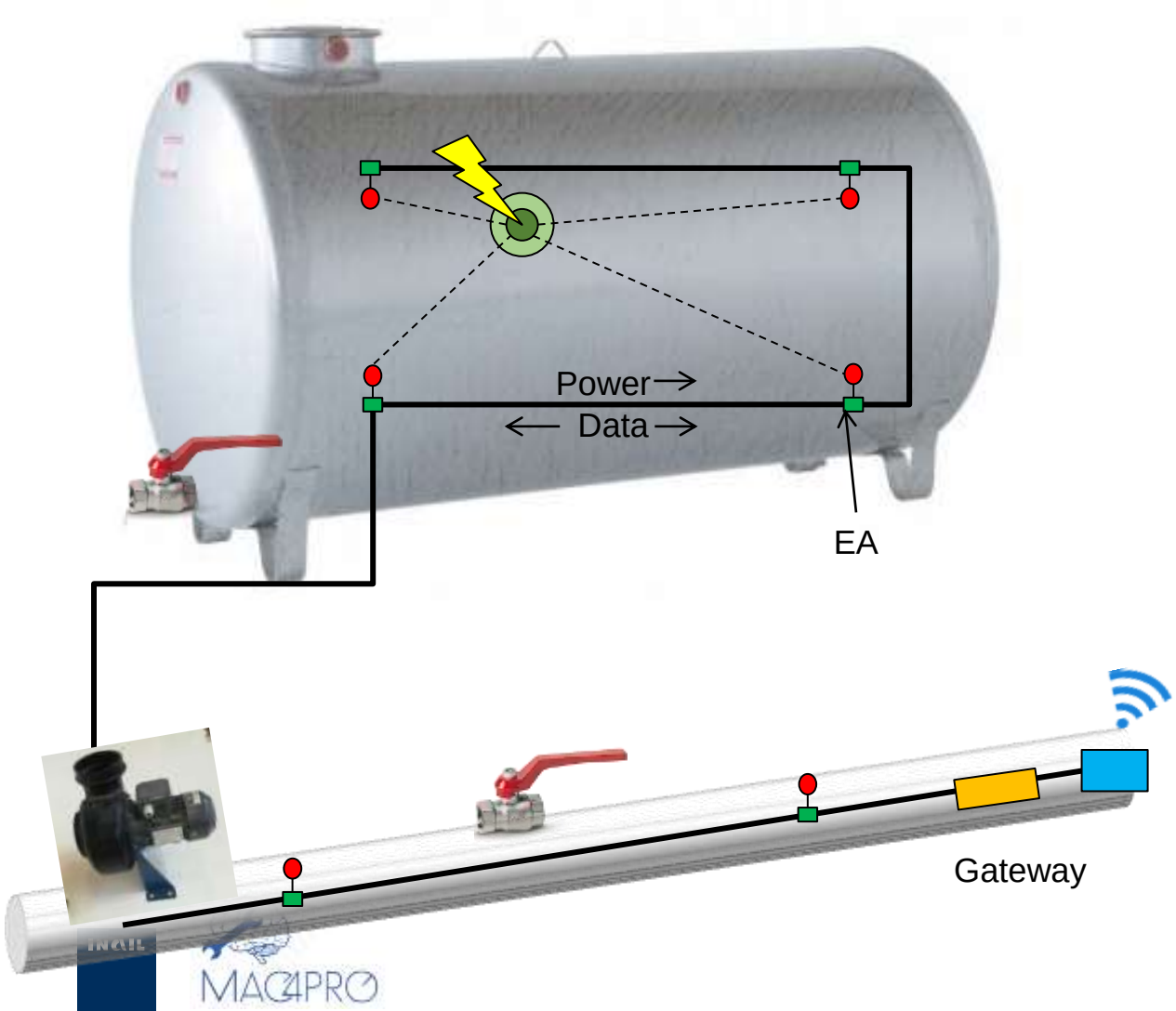
Sensor nodes with accelerometers on board

Vibrodine

Measurement network

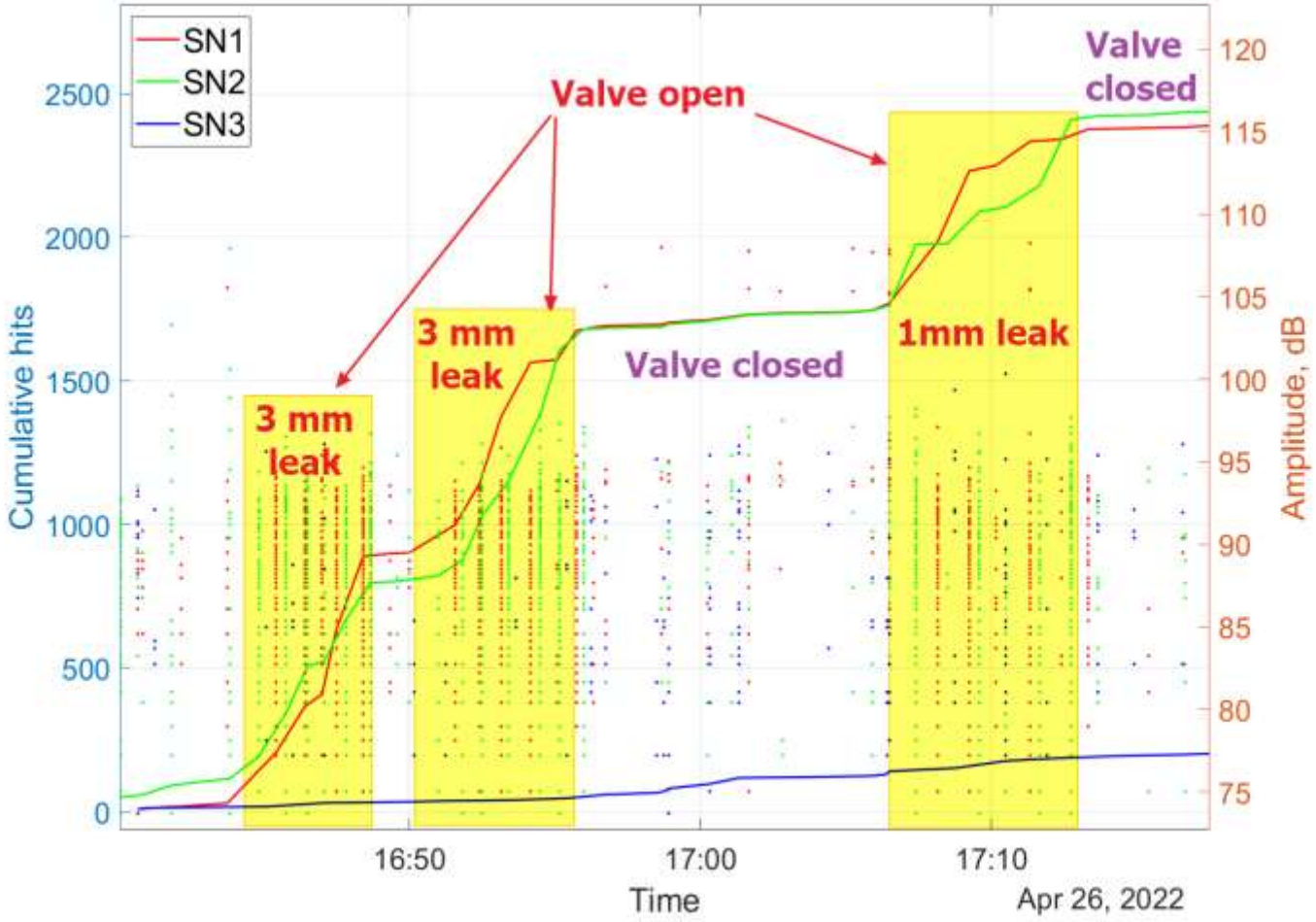


Validation: hydraulic circuit



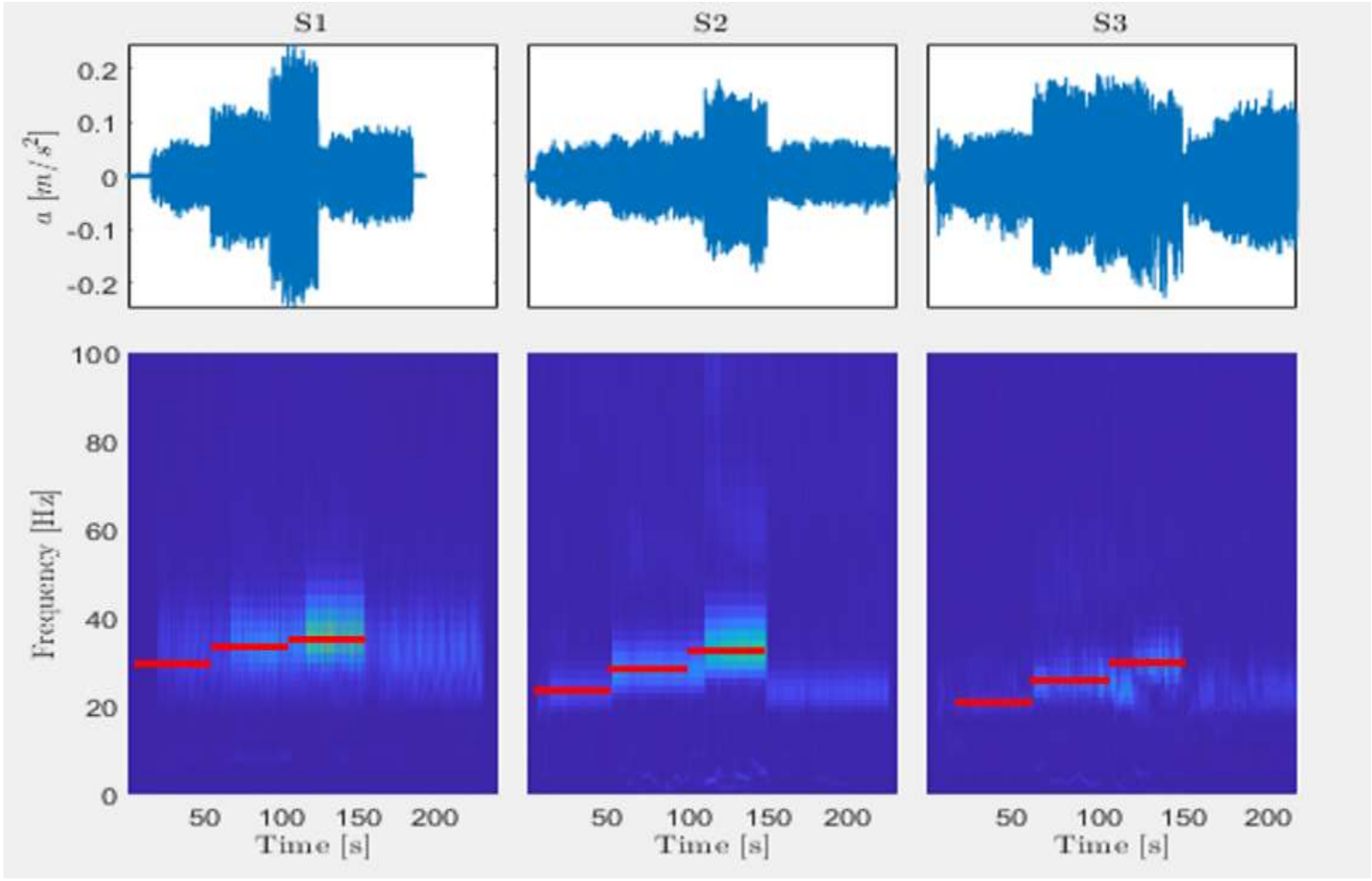
Validation: hydraulic circuit

30 minutes, pressure 5 bar



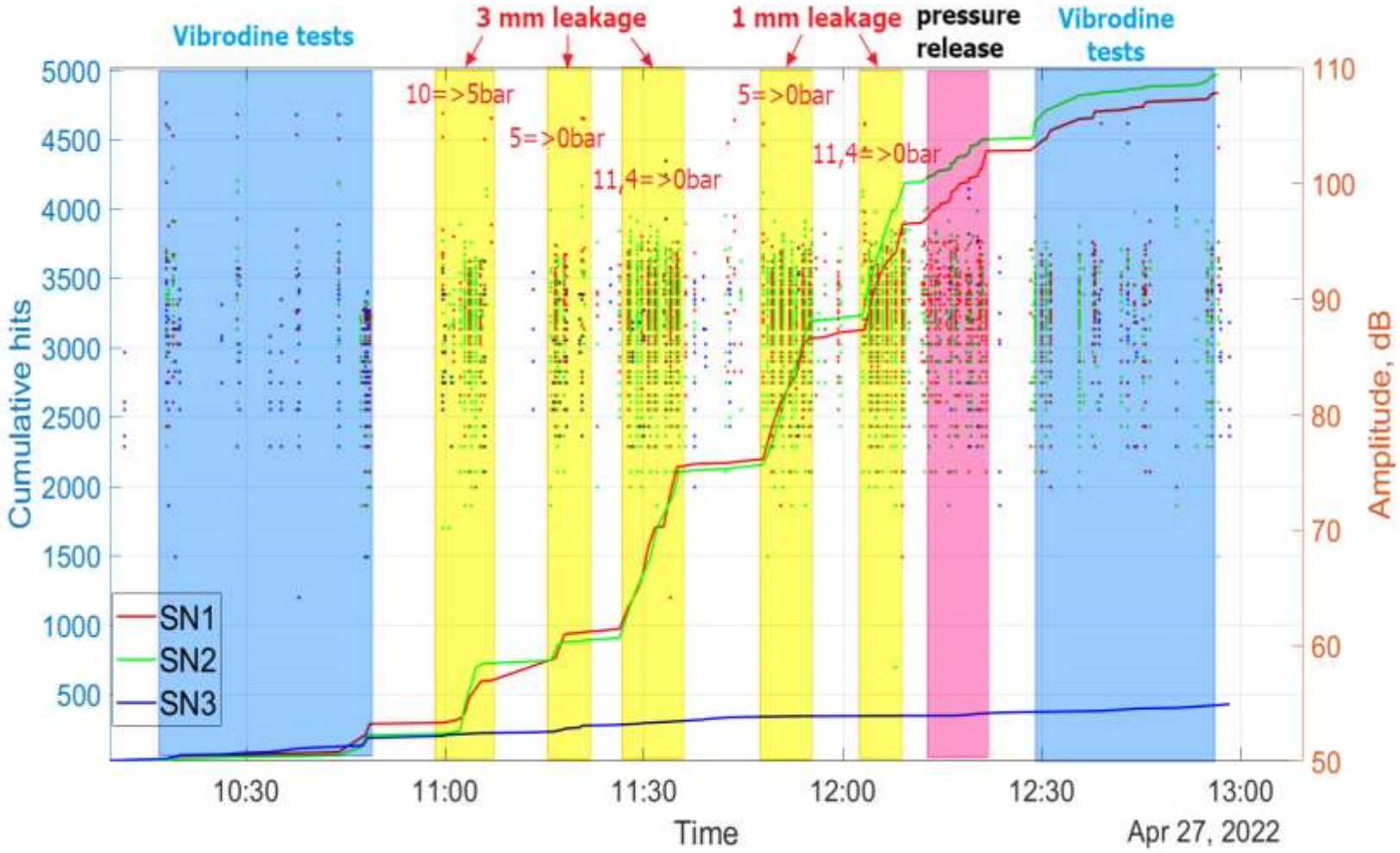
Results: physical test field – hydraulic circuit

150 seconds, pressure 5 bar



Results: physical test field – hydraulic circuit

3 hours of monitoring



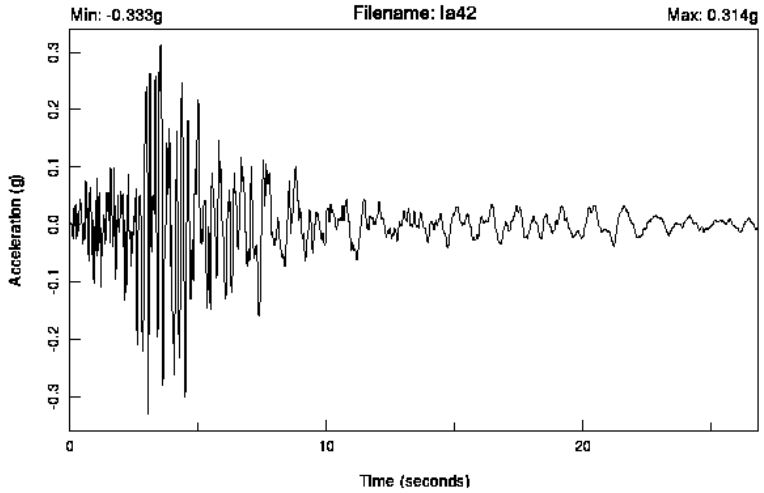
Validation: reinforced concrete frame

Civil structures test scenario

- Seismic action

Frame on vibrating table

- frame in reinforced concrete
- test check
  - motion imprinted on the base
  - frame response
- damage



seismic sequence Amatrice-Norcia-Visso
October 30, 2016
magnitudo of 6.0 (energy)
peak ground acceleration: 0,86 g (Amatrice)

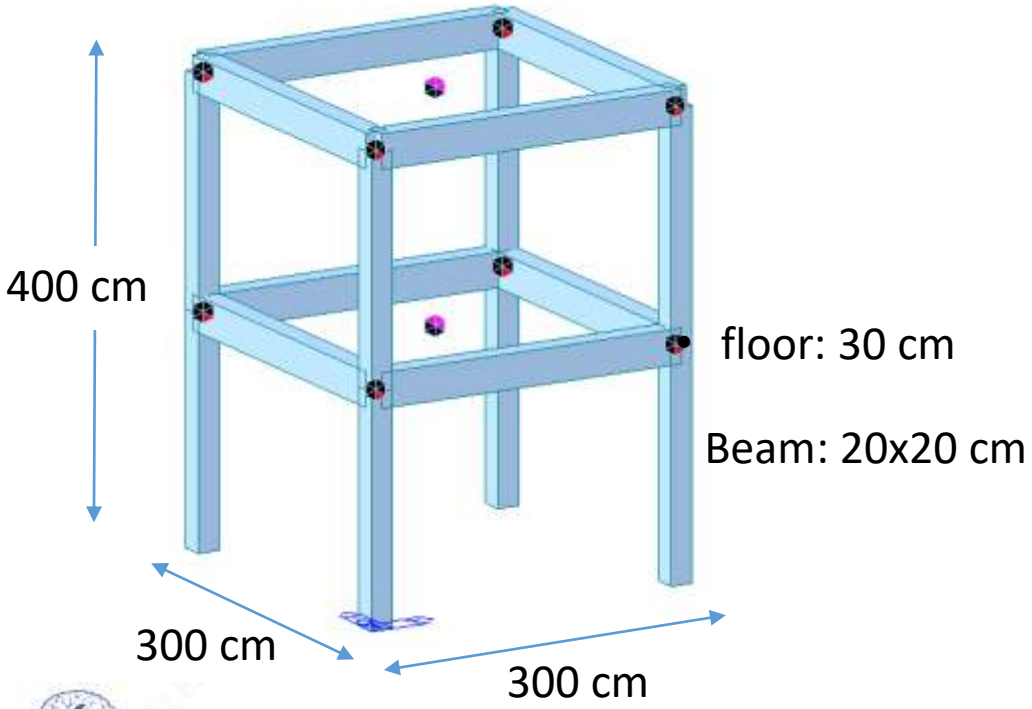
MAC4PRO

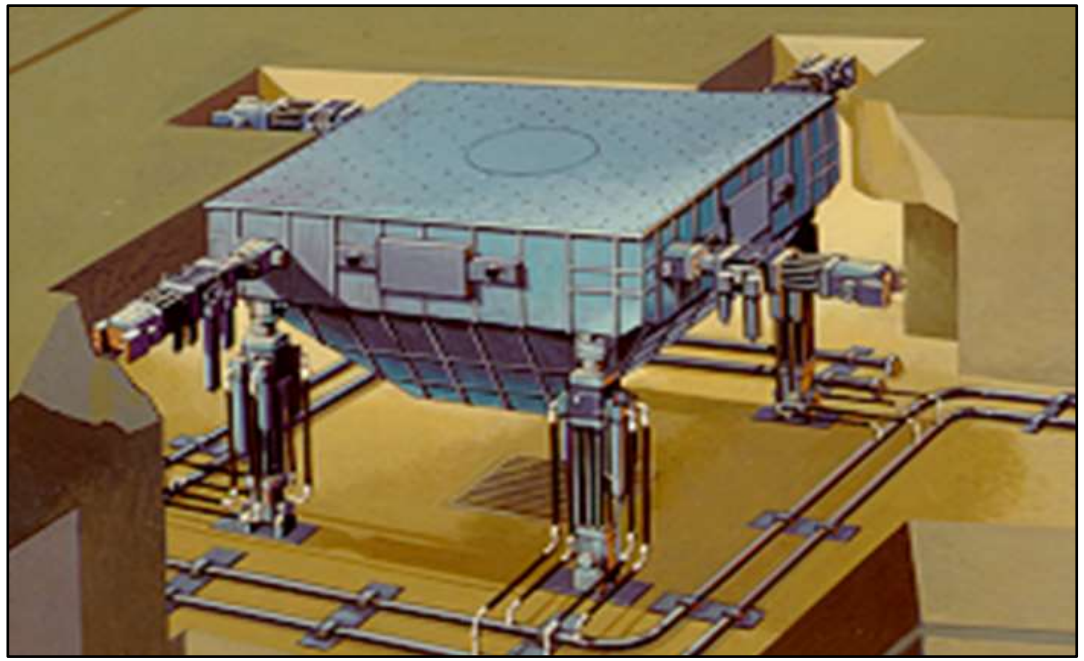
INAIL

INAIL issa INTERNATIONAL SOCIAL SECURITY ASSOCIATION
Section on Machine and System Safety

Validation: reinforced concrete frame

Parameter	System 1
Table size	4 x 4 [m]
Degrees of Freedom	6
Frequency range	0-50 [Hz]
Acceleration	3g peak
Velocity	0.5 m/s (0-peak)
Displacement	0.125 m (0-peak)
Specimen Mass	30 [t]

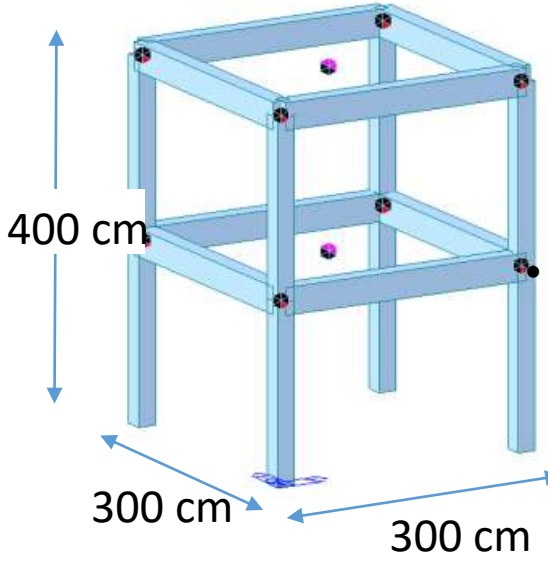




Shaking table in ENEA

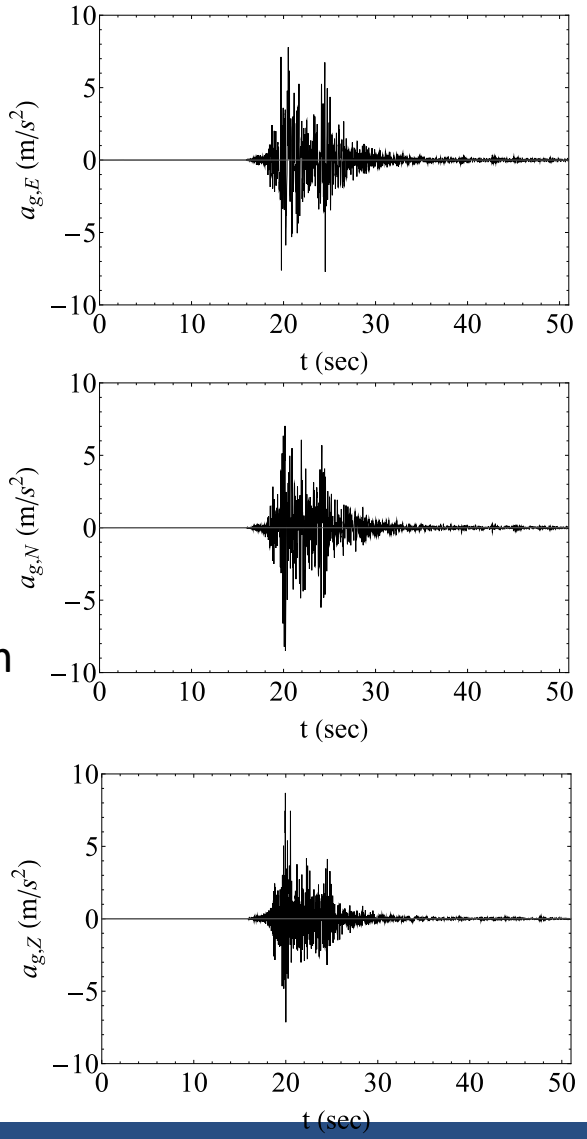
Validation: reinforced concrete frame

earthquake registered from
Savelli station
Norcia – October 30, 2016

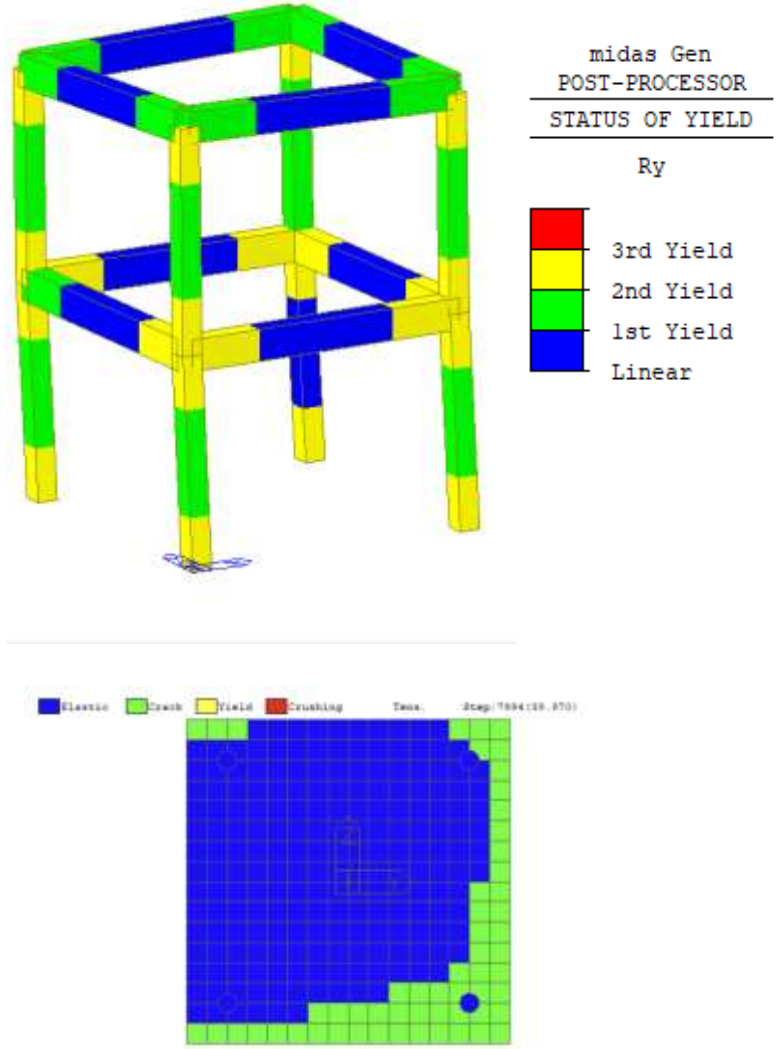


Floor: 30 cm

20x20 cm



Intensity
Peak
Ground
Accelation



Validation: reinforced concrete frame

Validation: reinforced concrete frame

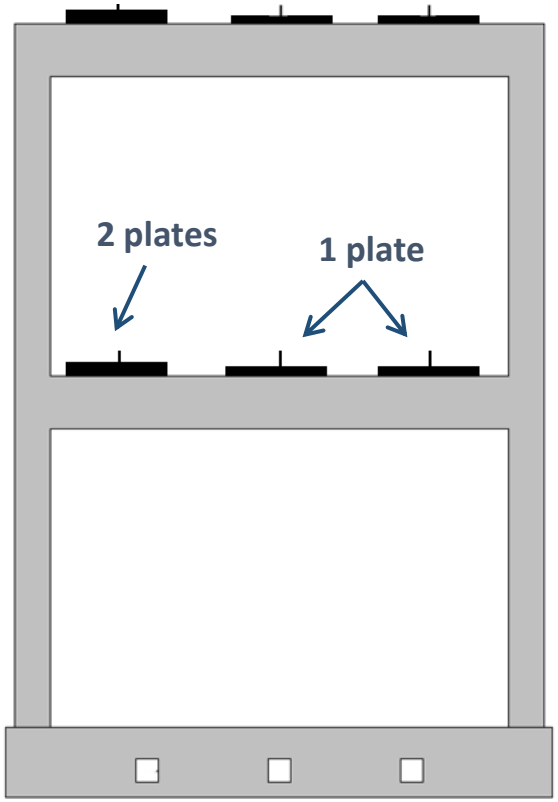
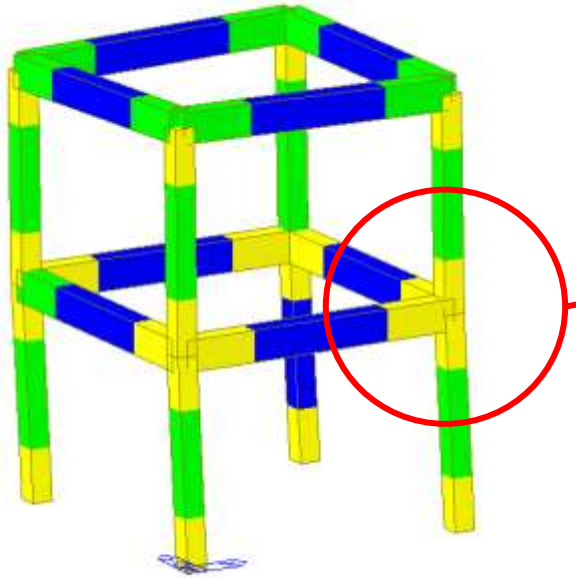
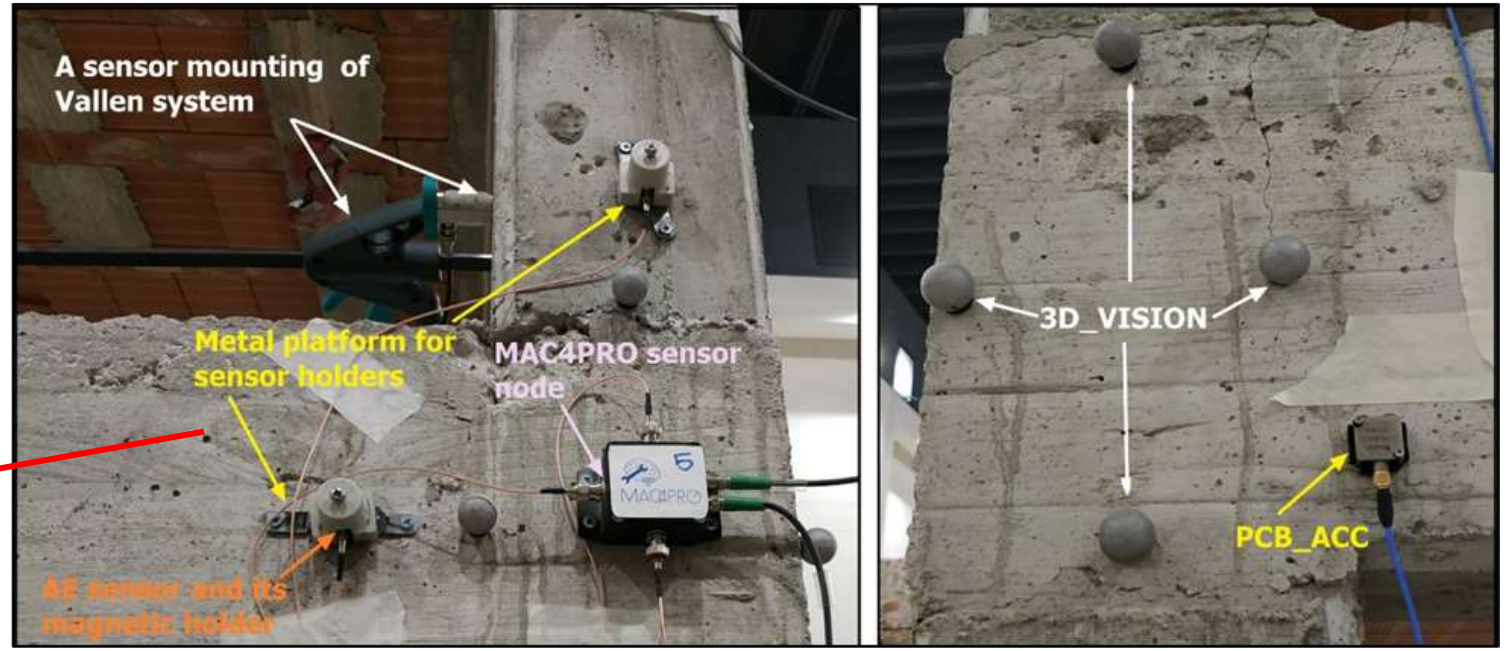


Plate: 100 kg

Validation: reinforced concrete frame

Rete di misura





MAC4PRO Sensors

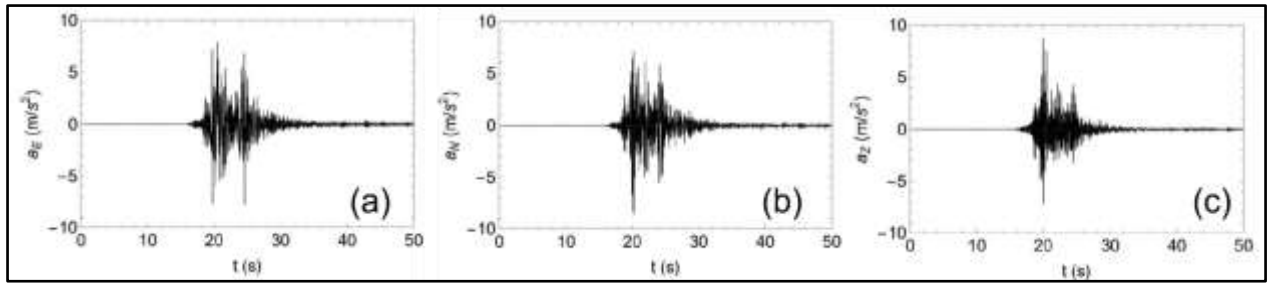
- accelerometers (6)
- Acoustic emission (18)
- gyroscope (9)

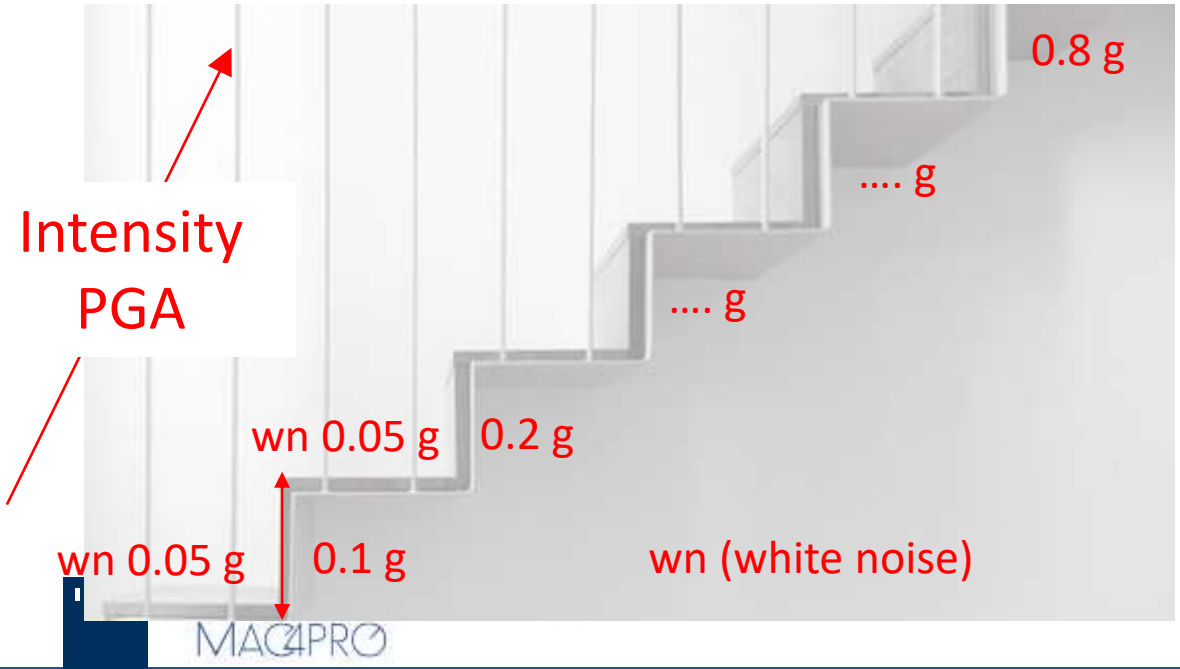
Commercial Sensors

- accelerometers (9)
- AE Vallen (6)
- Optical markers (72)
- Linear Variable Displacement Transducer
- load cells

Results: reinforced concrete frame

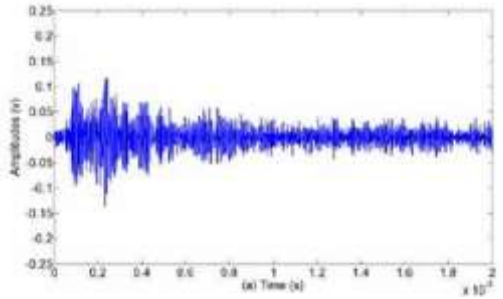
Stazione Savelli, Norcia 30 ottobre 2016 – M = 6.5



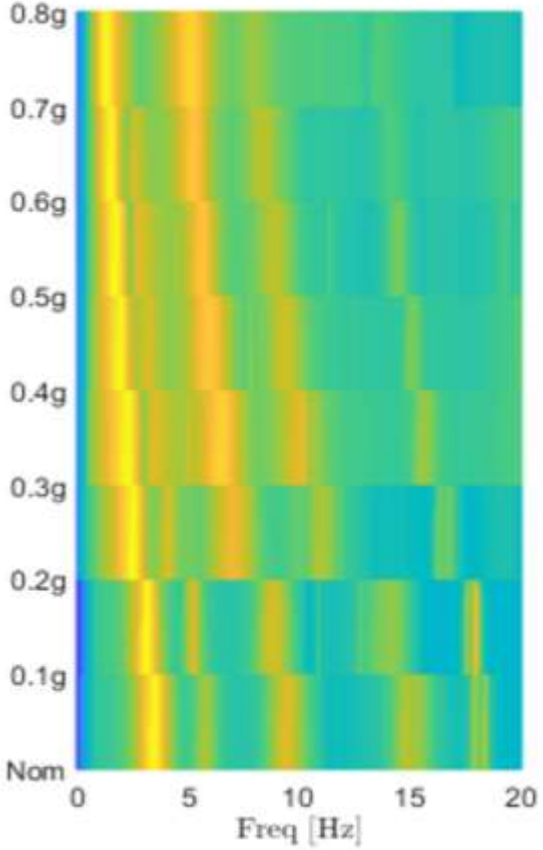


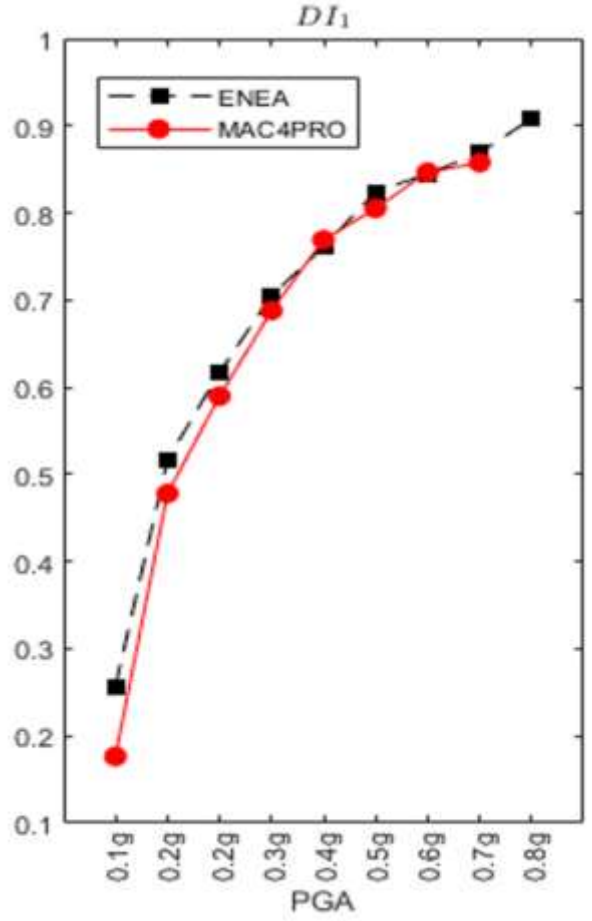
Validation: reinforced concrete frame

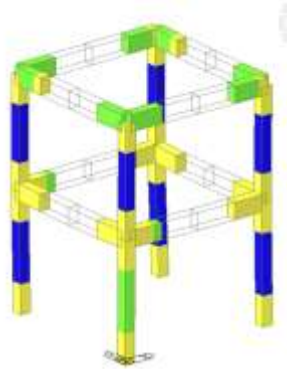
accelerations
wn 0.05 g

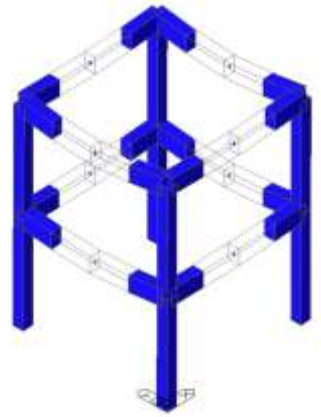


PGA



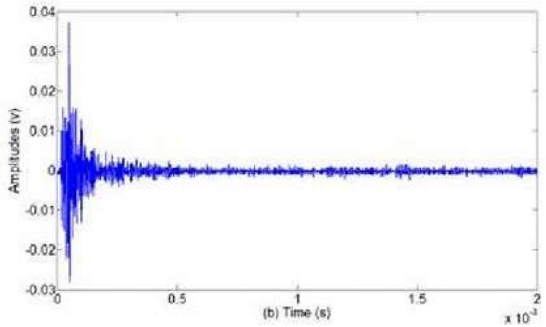


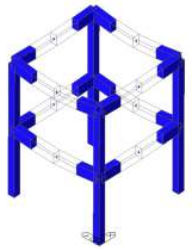


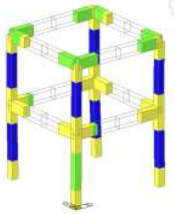


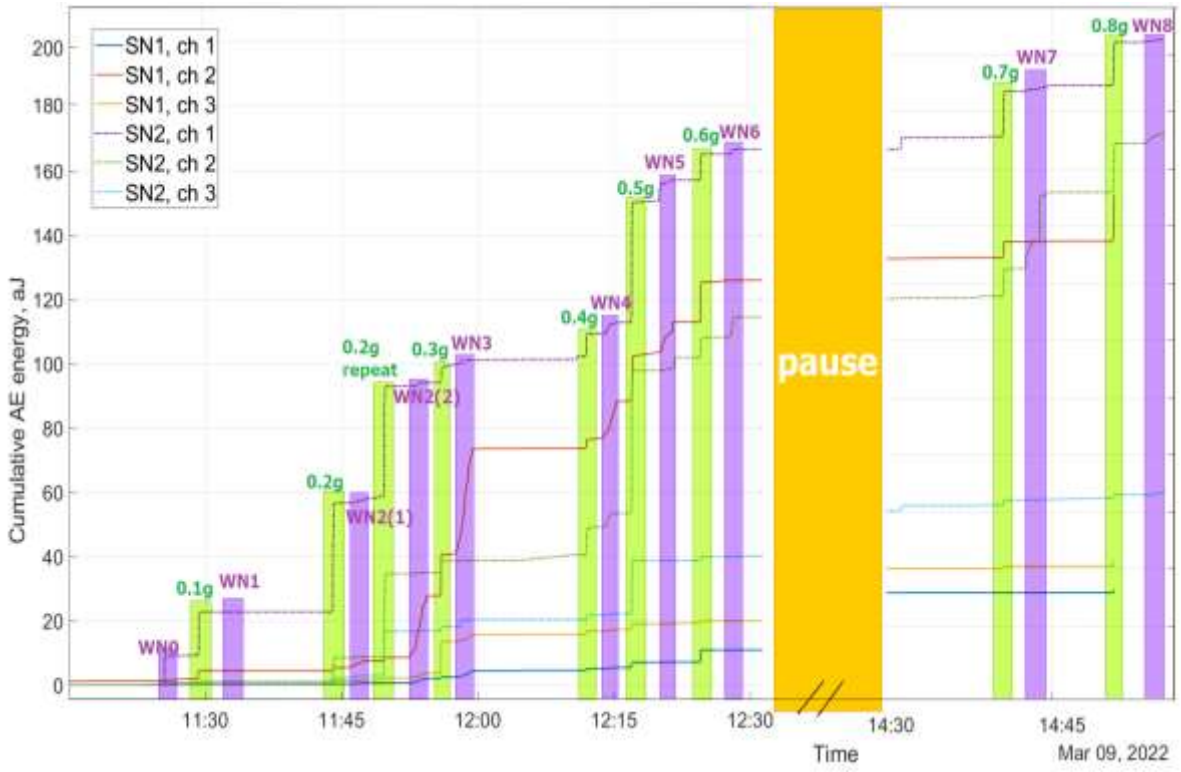
Risultati: telaio in CA

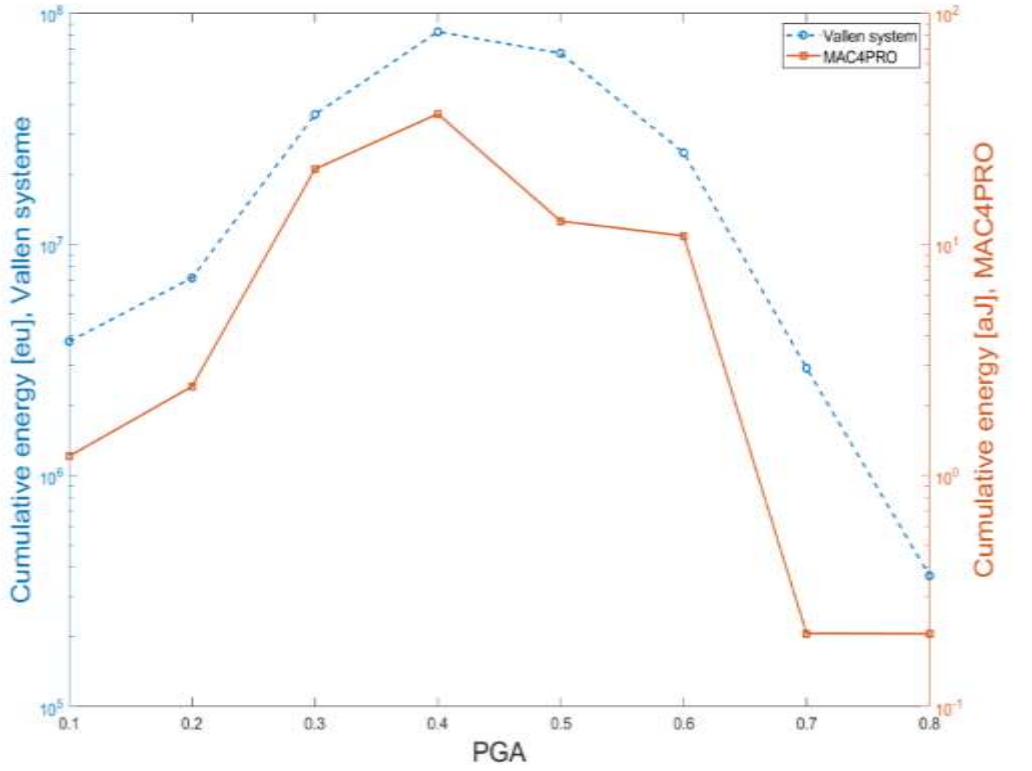
emissioni acustiche



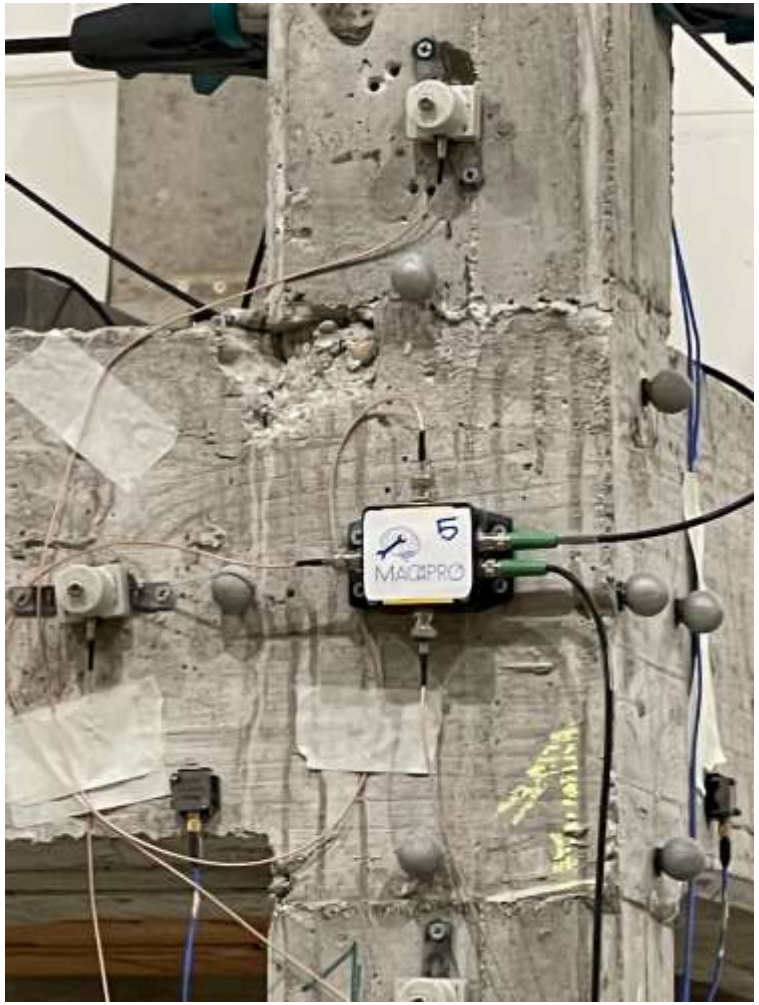


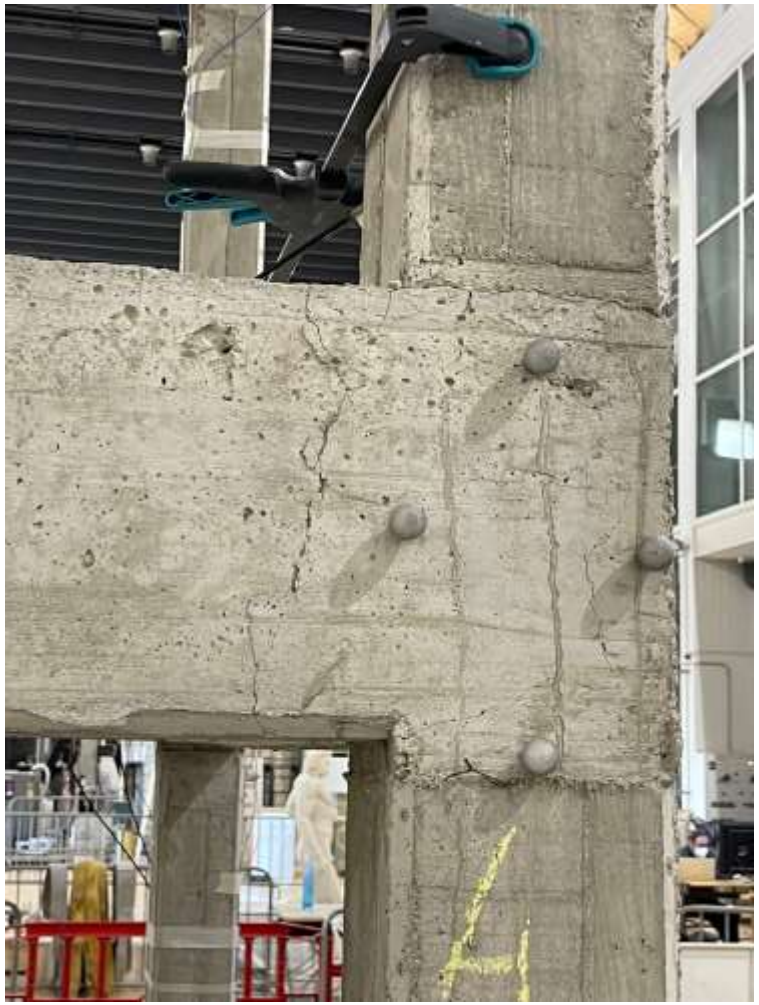


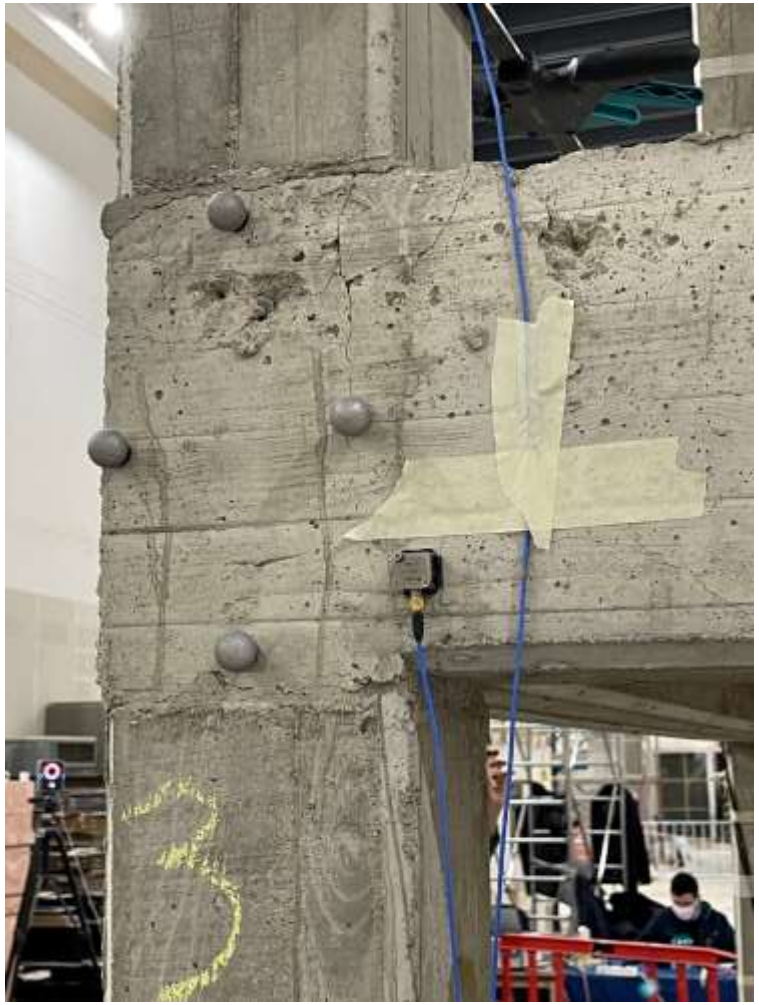




Risultati: telaio in CA







Real case: bridge Volto Santo (Holy Face)

N° spans

4

N° pylons

3

N° decks

4

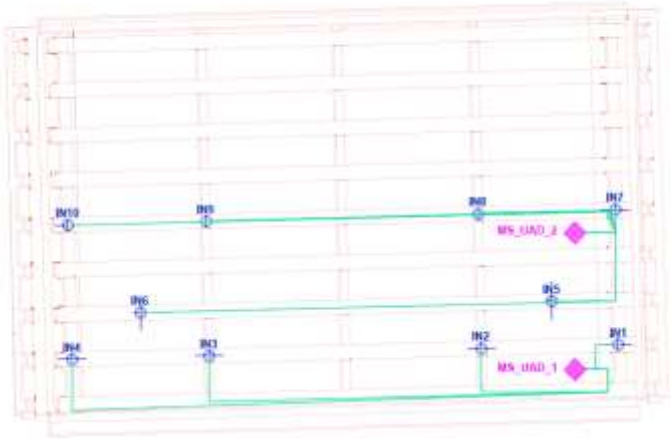
Total lenght

70 m

Real case: Viadotto Volto Santo (Holy Face)

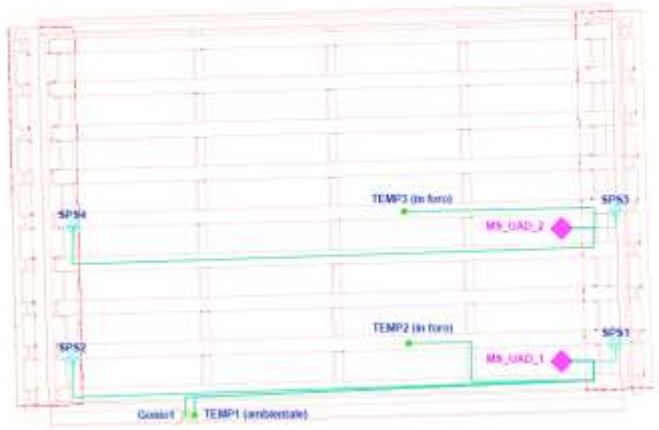
ACCELEROMETRI

LAYOUT INCLINOMETRI

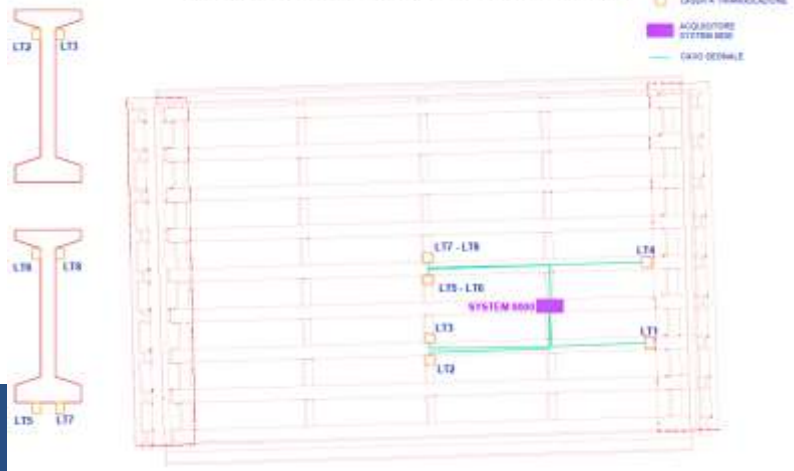


LAYOUT SENSORI LASER A TEMPO DI VOLO

LAYOUT LVDT E AMBIENTALI



LAYOUT SENSORI LASER A TRIANGOLAZIONE



Conclusions

- Tools for monitoring equipment and structures/infrastructures for safety purposes
- Use of different integrated technologies
- Experimental validation in two operational scenarios
- Real case experimentation (viadotto del Volto Santo)
- Contributes to the discussion on methods, installation costs, adaptability and durability of monitoring systems, robustness of damage and prognostic metrics

Thanks for your ... space