# INCREASING RESILIENCE AND ROBUSTNESS OF CRITICAL INFRASTRUCTURES TO HAZARDS USING ARTIFICIAL INTELLIGENCE AND STRUCTURAL MONITORING

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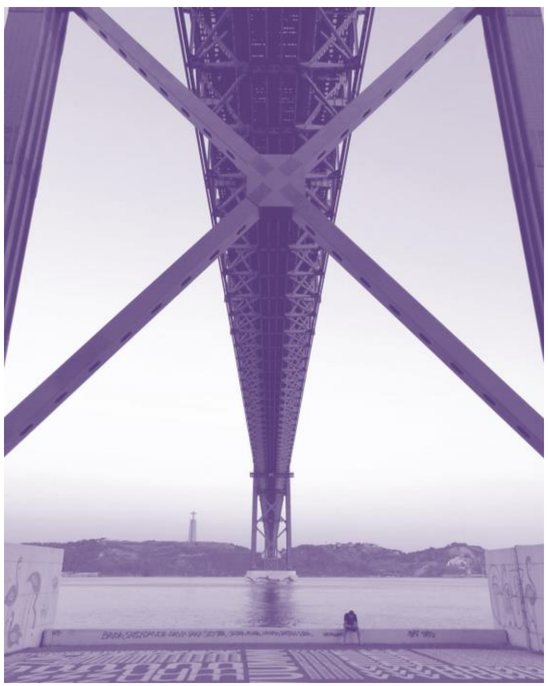
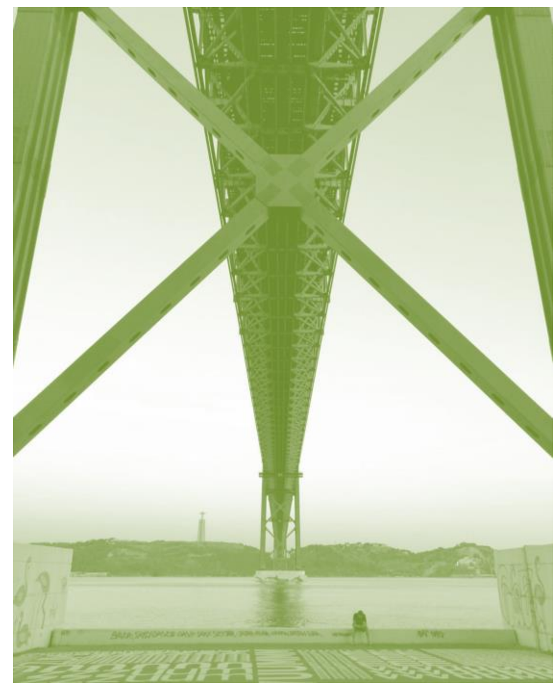




- Timeline and activities
- Structural Health Monitoring
- Case study
- Topics reviewed
- Expected work

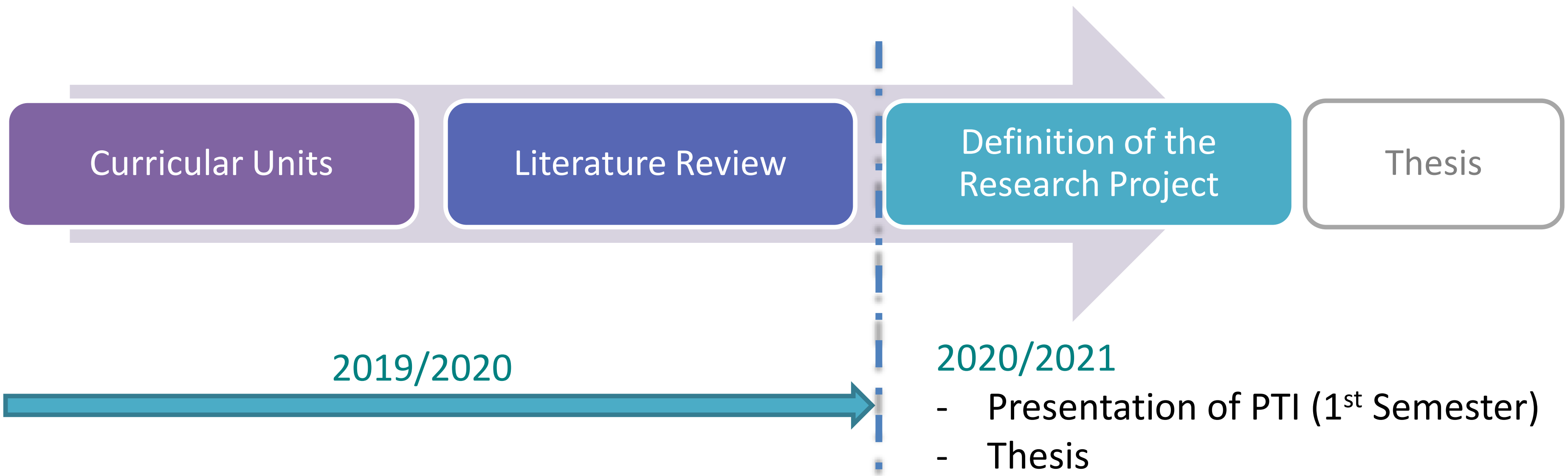
# TIMELINE AND ACTIVITIES

Curricular units completed:

- Multivariate Data Analysis / FEUP
- Analysis, Identification and Control of Dynamic Systems / FEUP
- Instrumentation and Monitoring of Structures / FEUP
- Uncertainty Modelling and Risk Analysis / FEUP
- Reliability and Risk Analysis / UMINHO

On going:

Research Seminar in Structures / FEUP



# STRUCTURAL HEALTH MONITORING

- Provide, through different technologies and algorithms, **information** about the behavior of existing and new structures.

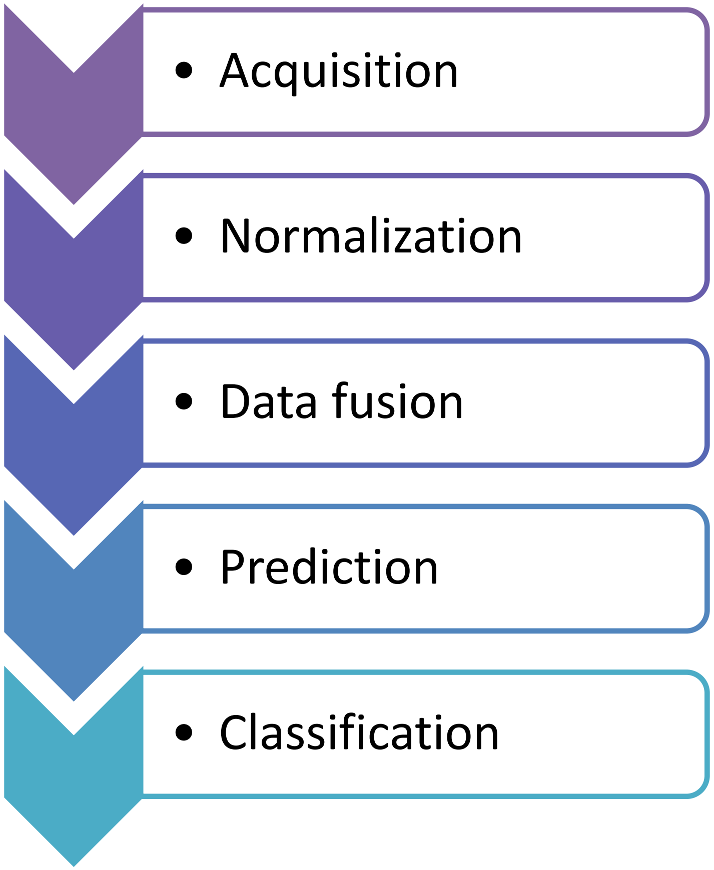
- Identify **changes/damages** in the structural systems.

- Can be collected ***in situ***.

- Widely accepted as a useful aid to **risk analysis and integrity management** of structures.

- Its value is **not quantified and is hardly communicated** to the owners or managers of the analyzed structures.

- Gathered data can represent **a "big data" problem** due to the quantity, complexity and diversity.




*Same conceptual steps of "big data" processing

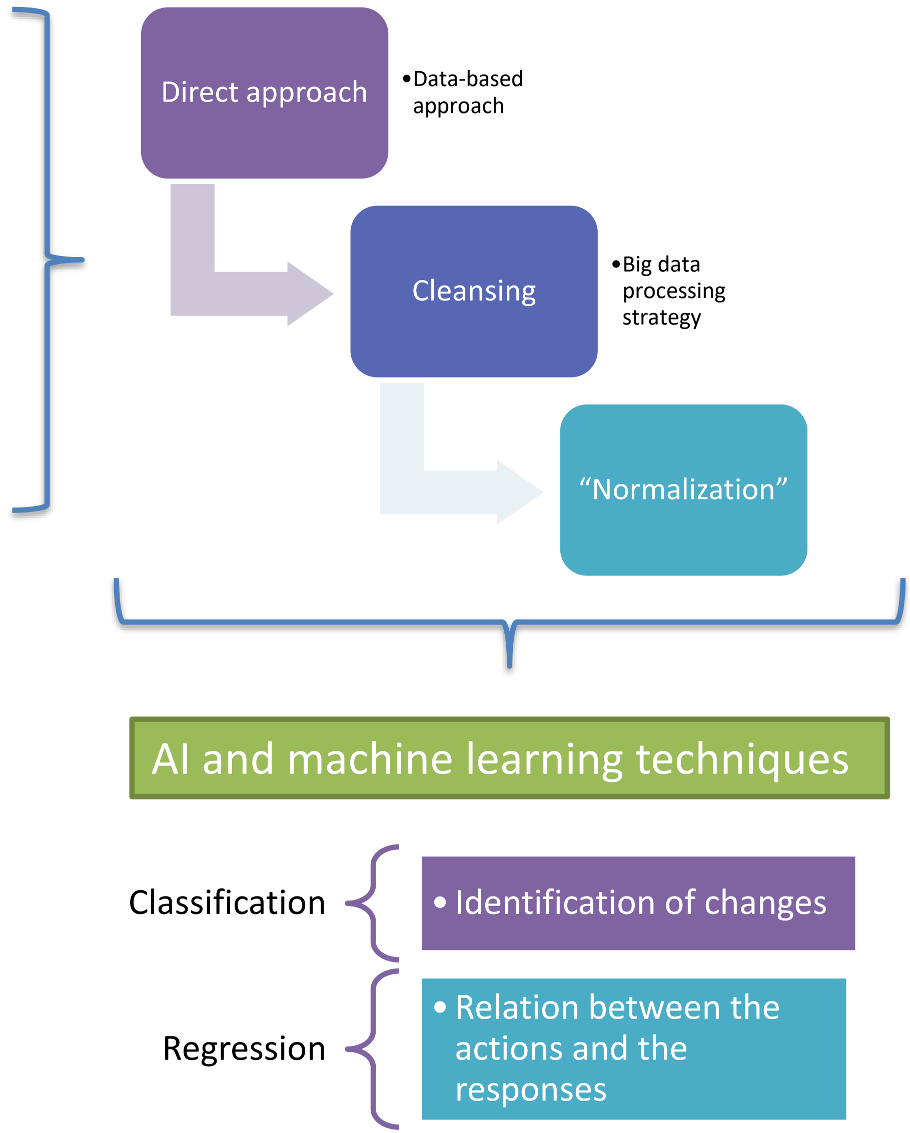
# STRUCTURAL HEALTH MONITORING METHODS

- Generally the SHM methods follows a **data-driven approach** (inverse; incorporated on the numerical models)

- Data obtained could contain important **incidence of false alerts**, that difficult the following process

- Is **difficult to find sensitive and robust** damage indicators.

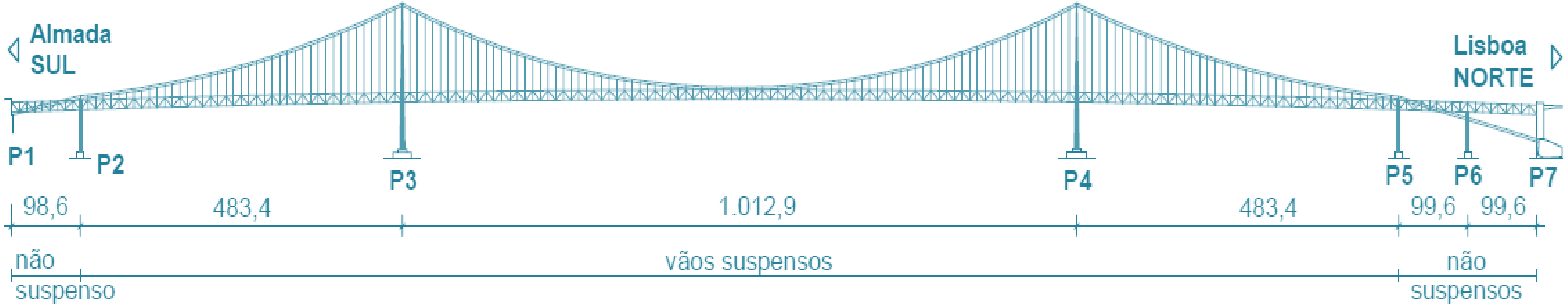
- The outputs are obtained through **deterministic methods**, based on upper and lower thresholds, not properly accurate for decision making



# CASE STUDY: Ponte 25 de Abril

The suspension bridge over the Tagus River in Lisbon is a structure with a total length of **2,277 m** between anchorages, including the **suspended central span with 1,013 m**, two suspended side spans with 483 m and, also three backstay spans with about 99 m each.

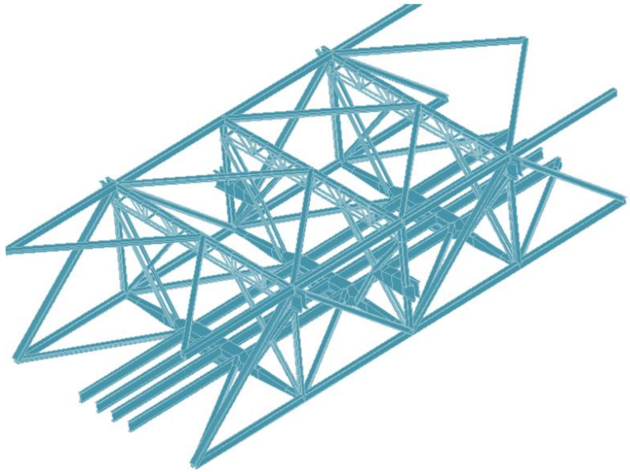
It was opened to the traffic in **1966** with a **4 lanes roadway deck**, located at the level of the upper chord of the stiffening truss. In **1999**, the bridge had construction works to **add a 2 lines railway deck**, at the level of the lower chord of the stiffening truss, and to widen the **roadway deck to 6 lanes**.

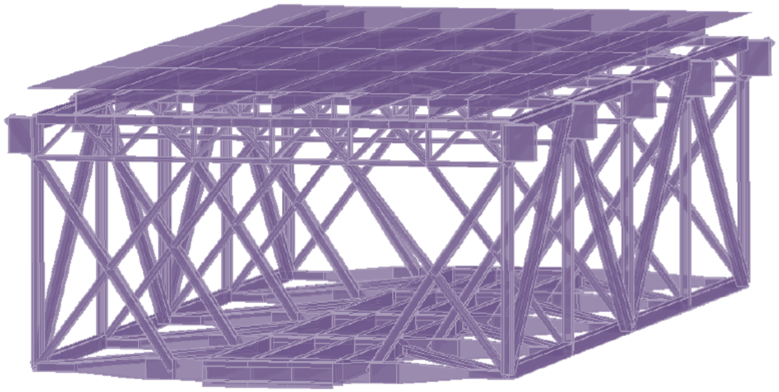


# FEM Model

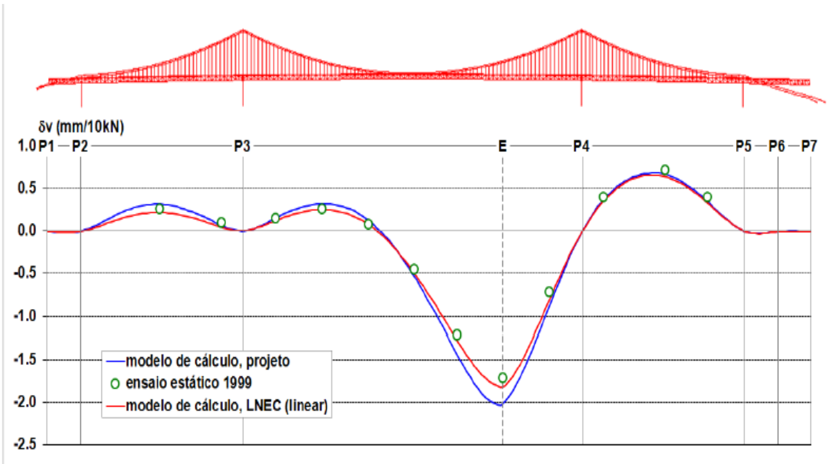
In **2012,** LNEC developed a **model** for structural analysis of the bridge, recognizing the importance that it has for the interpretation of the data that is continuously being observed with the structural monitoring system.

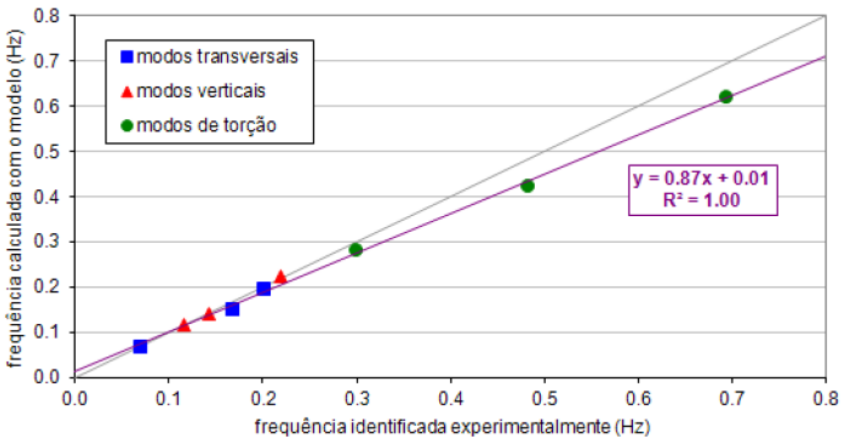
Calibration of the model was made through the comparison of static and dynamic tests performed





# Comparison of results obtained in experimental tests




## Static Test:

Performed after adding the railway and widening the roadway, considering **concentrated loads and distributed loads** materialized by locomotives and ballast wagons.

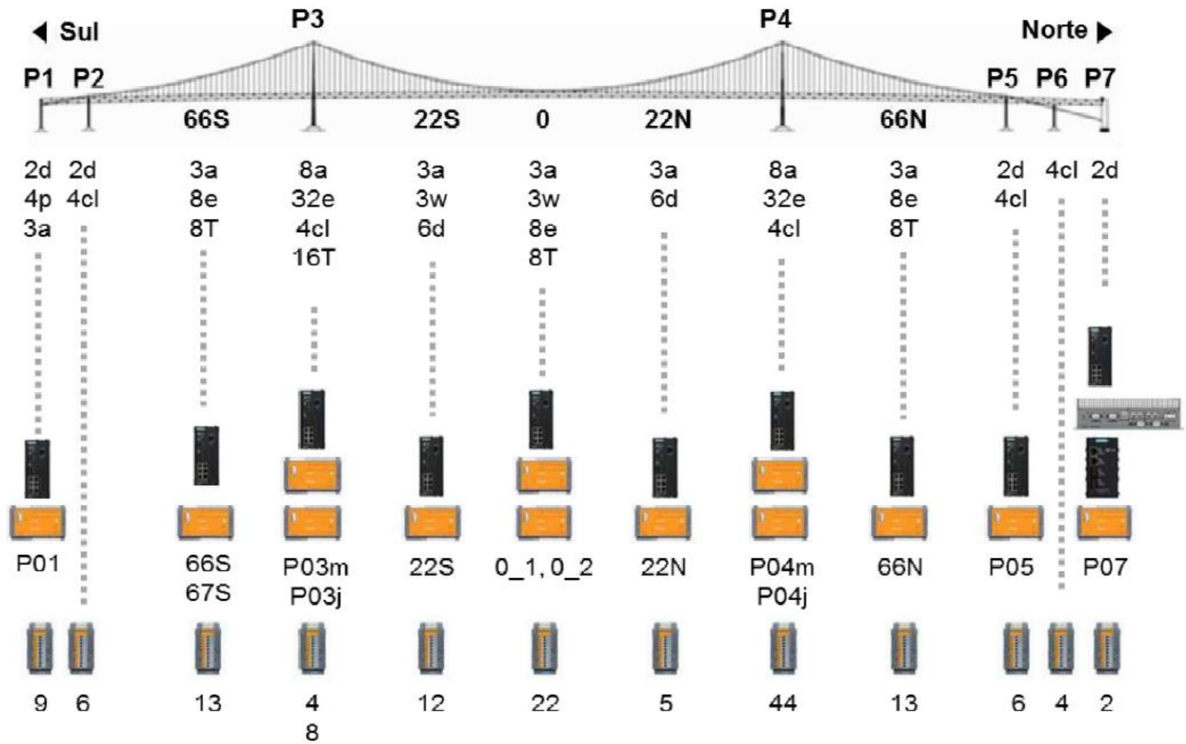
## Dynamic Test:

Measured the acceleration response of the structure to traffic and wind action. **Seismographs with servo-type accelerometers** were installed in seven sections of the deck, the registers were analyzed with **stochastic modal identification**, that allow to identify the global vibration modes of the structure.

The observed values were then compared with the values obtained with the model, in order to validate it.

# Monitoring system

The monitoring system proposed for the 25 de Abril's Bridge follows the program of (Silveira, 2013) with updates of (Santos,2015). It considers **210 sensors*** located in strategic sections of the bridge according its structural behaviour.

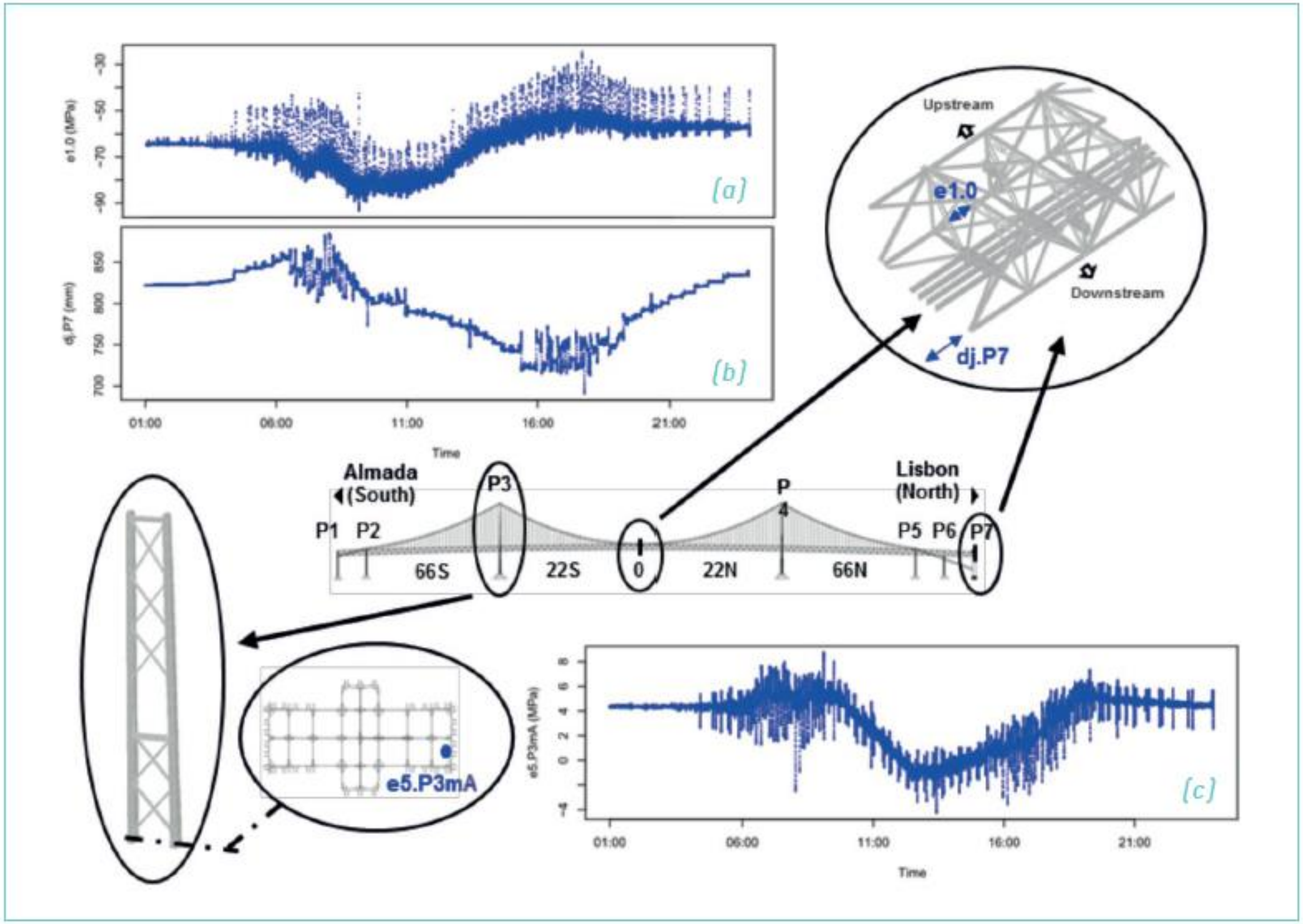



d - deslocamento longitudinal (transdutores magnetoestrictivos)
cl - rotação (clinómetros eléctricos de gravidade)
a - aceleração (acelerómetros uniaxiais servo)
e – tensão 1D (pontes de extensómetros de resistência eléctrica com leitura em uma direção)

T - temperatura (termómetros NPC)
w - velocidade e rumo do vento (anemómetros de ultra-sons)
p - pesagem dos eixos de comboios (palmilhas com sensores de F.O.)

* (understood as the acquired measurements and not as the physical instrument)

500 lectures per second/378 million of lectures per hour are transferred daily to the server and automatically filtered, the results are temporal series that then are going to be correlated and analysed with the structural behaviour of the bridge or possible anomalies

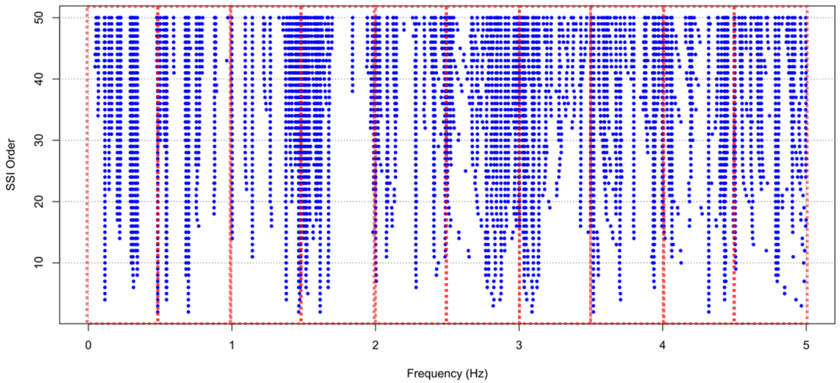


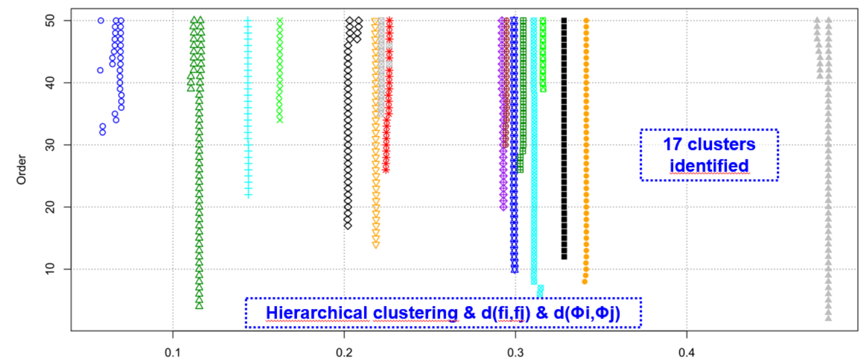

a) Tension on the rigid beam, b) displacement in a joint, c) tension in the base of the column

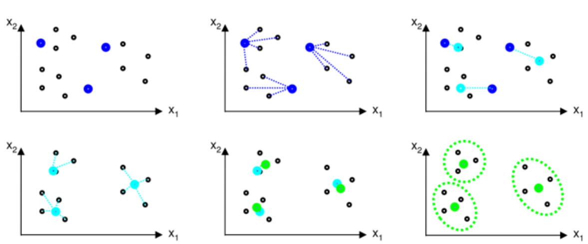
# Operational Modal Analysis

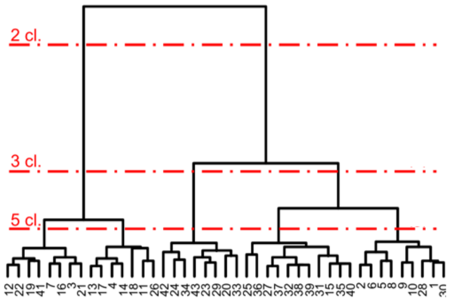
Strategy capable to overcome the challenges identified in the experimental modal analysis: comparison of new data with baseline of modal information and demands of human technical inputs, through:

Time-domain method: the SSI-COV → Clustering pattern recognition → Applied in frequency windows, for modal estimation → Applied in time windows, for modal tracking





# Damage scenarios identified in the bridge

Imposition of actions + Imposition of displacements + Degradation

Stiffness loss on most demanded structural elements → Stiffness loss on metallic elements

| Observed loads in the bridge | Seismic action and damage scenarios | Imposition of damage scenarios and accidental actions |
|---|---|---|
| • Vehicle loads<br>• Train loads<br>• Traffic<br>• Wind<br>• Temperature | • Earthquake<br>• Erosion<br>• Fatigue<br>• Corrosion | • Car accidents<br>• Train accidents<br>• Navy accidents<br>• Fire |

## Online early damage detection

Is a continuous on-line early-damage detection strategy without the need to specify prior data references in which a target structural system must be assumed undamaged and unchanged through multi-layer perceptron neural network and k-mean clustering algorithms.

## Multivariate statistical analysis for damage detection

Is a novel data-driven strategy to detect early damage under environmental effects, based on static monitoring and on multivariate statistical methods.

## OMA strategies

Operational Modal Analysis, consists in the obtention, continuously and in real time, of frequencies, mode shapes and damping ratios, which are directly dependent on the stiffness, mass and damping properties that at the same time are directly influenced by damage occurrences.

*Machine learning, Neural Networks, Auto-regression techniques, PCA, Wavelets, Clustering*

Topics reviewed

Topics reviewed

## LCM framework

Life Cycle Management framework covers the prediction of the time-variant structural performance and the future interventions scheduling, including inspections, monitoring, maintenance and/or repairs actions, with a multi objective optimisation approach of the bridge and by extension the road network

## Structural damage identification

Through structural response (e.g. to traffic loads) analysis with physical meaning (e.g. bending) in frequency and time domain analysis. By comparing the bending stiffness values identified from the vehicle-collected data for the bridge under the undamaged and damaged states that are monitored regularly by the test vehicle, the bridge damage location and severity can be identified.

## Time dependent risk assessment based on Cumulative-Time Failure Probability

The cumulative-time probability of failure must be used to assess risk. With this approach, after estimating the occurrence probabilities and consequences associated with the failure scenarios, the time-dependent risks are assessed.

*Probabilistic analysis, Structural response models, Robust damage indicators, Simplified Models based on instrumentation, Traffic loads, Transportation networks*

# EXPECTED WORK

## Limitations found in current SHM methods

TO BE ADRESSED

- **Real-time identification** without important incidence of **false alerts** is challenging.
- **SHM** is not generally defined for life-cycle management or post-hazard / post-damage decision making, but **only for damage identification**.
- ***Sensor placement*** *is* ***empirical****, does not consider damage scenarios or limit states in a quantitative and systematic manner.*

## Limitations found in the current data analysis

TO BE ADRESSED

- **Robust and sensitive** damage indicators are **needed**.
- **Deterministic** damage indicators are often used instead of **probabilistic or risk-based indicators**
- The **risk associated** with damage scenarios is generally **not considered** for defining the best damage identification strategies.
- *The appropriate learning of* ***relations*** *between actions and responses or between responses for all the ranges of actions* ***is still challenging.***

# Data and Strategies to be explored and expected to be used

- **Structural responses** with physical meaning in the time and frequency domain:
  - **Time domain**: stress, displacement, force, rotation, strain, curvatures
  - **Frequency domain**: frequencies, damping, mode shapes, modal energy, modal curvatures
- Deep **neural networks** for modelling structural responses
- **Probabilistic SHM output data analysis**, either including simplified models or based on data only
- System risk assessment accounting **multi hazard interactions.**