Données, SHM et analyse statistique

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Rennes

1ère Journée nationale SHM-France

15 mars 2018

Outline

Context: Structural Health Monitoring

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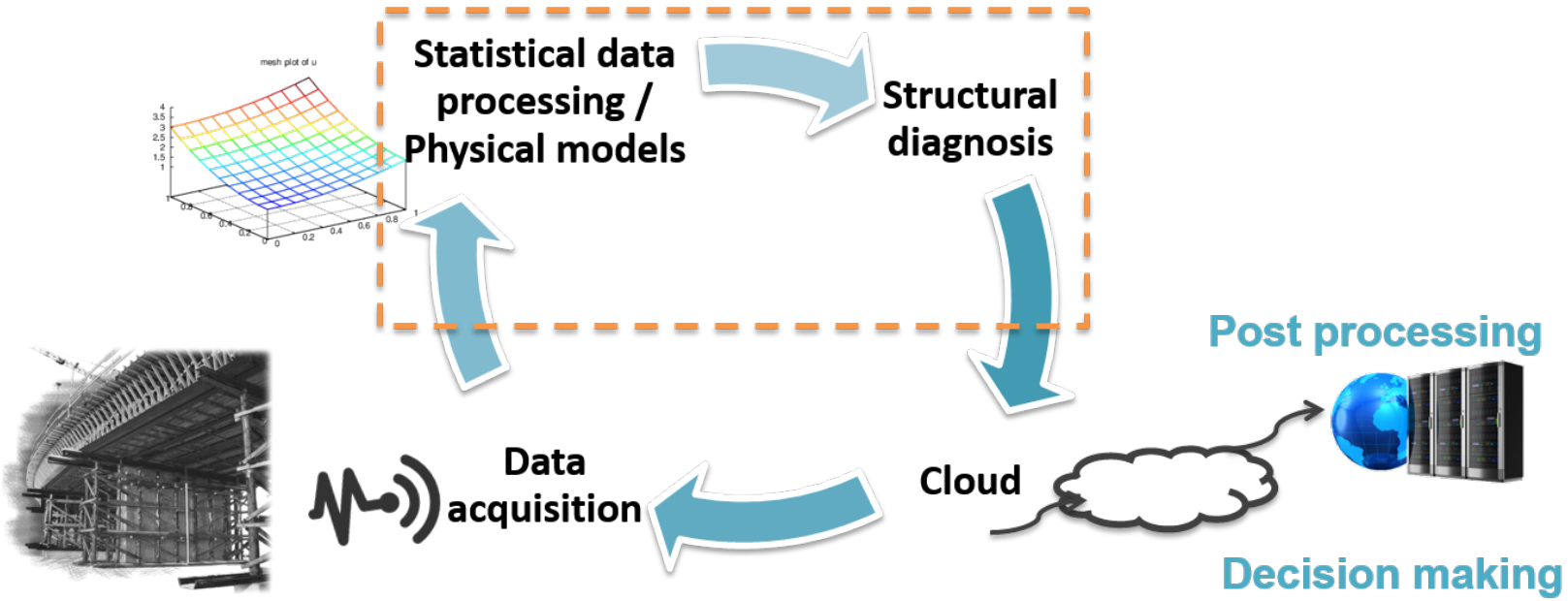
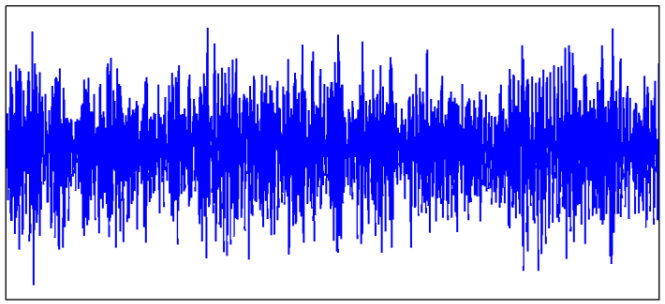


Context: Structural Health Monitoring

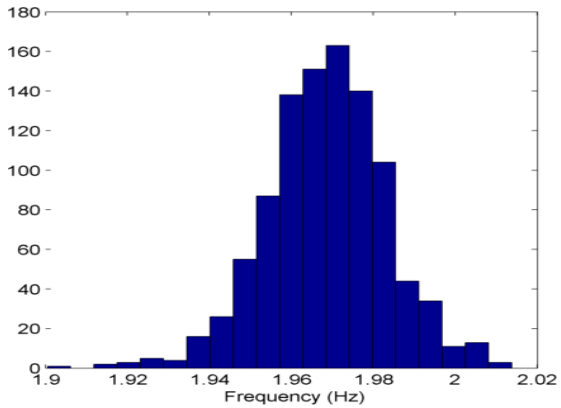
Physical parameter θ



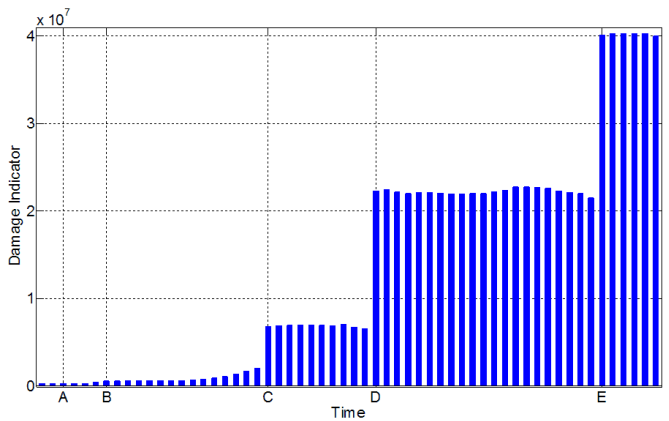
Vibration measurements

System identification

Change detection



Estimate $\hat{\theta}$



Statistical tests

Outline

Subspace methods

From automatic control

- Stochastic framework under ambient excitation with or without known inputs
- Parameter-free – no optimisation – no iteration

Identification algorithm

- Data $\Rightarrow$ SVD $\Rightarrow$ Least Squares $\Rightarrow$ Eigenvalues
- Identification of modal parameters
  - Natural frequencies
  - Damping ratios
  - Mode shapes

$$\begin{aligned} \mathcal{M}\ddot{z} + \mathcal{C}\dot{z} + \mathcal{K}z &= \nu \\ y &= L\ddot{z} + w \end{aligned}$$

$$\begin{aligned} x_{k+1} &= Ax_k + v_k \\ y_k &= Cx_k + w_k \end{aligned}$$

Uncertainty quantification

Why?

- Assess quality of estimates
- Establish confidence bounds
- Comparison of modal parameters (e.g. for monitoring) would be meaningless without uncertainty bounds

Variance due to...

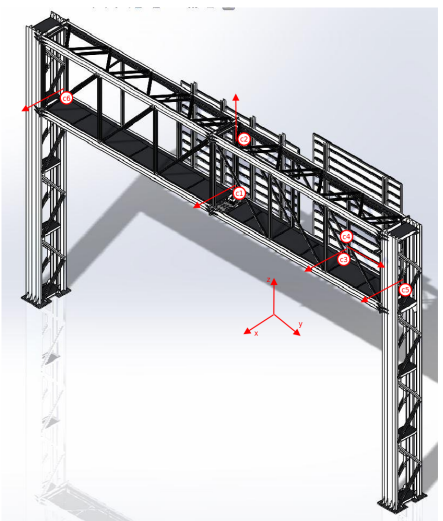
- Unknown system inputs – ambient excitation
- Measurement noise
- Finite data length

Fast and memory efficient implementation for uncertainty quantification

M. Döhler and L. Mevel. Efficient multi-order uncertainty computation for stochastic subspace identification. Mechanical Systems and Signal Processing, 38(2):346-366, 2013.

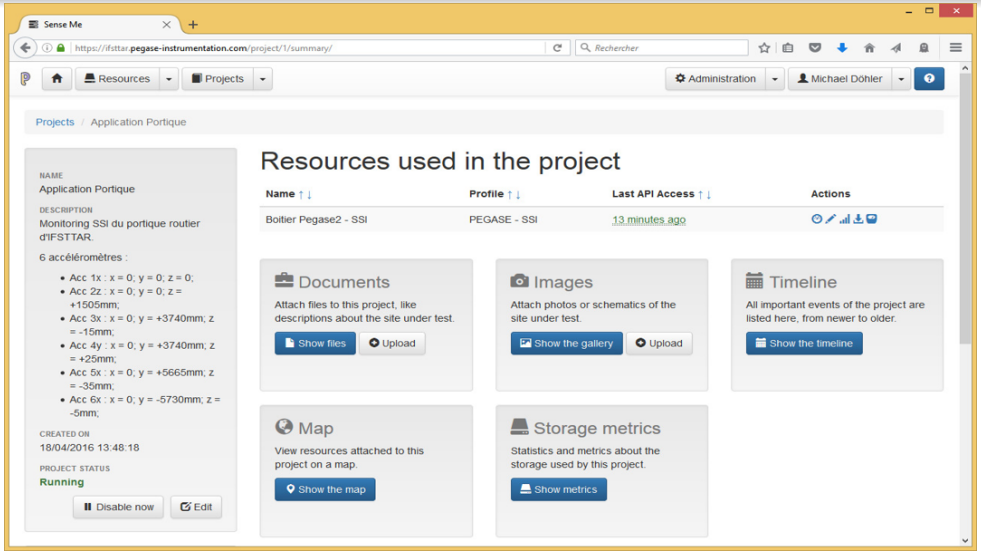
Ifsttar gantry

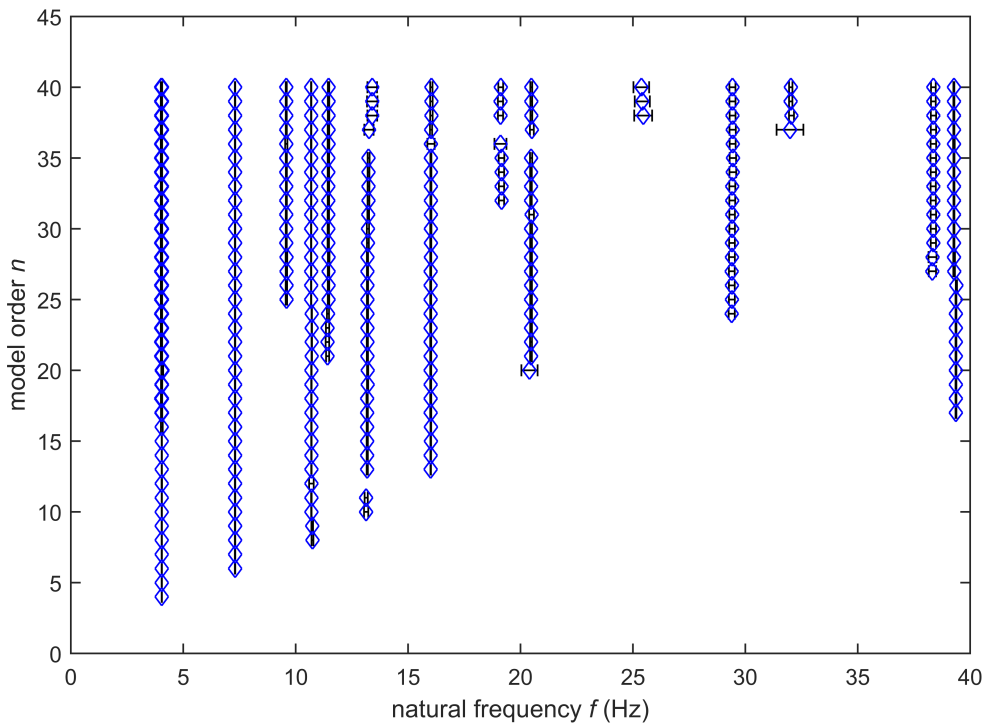
- Vibration monitoring using PEGASE2 platform
- Embedded modal analysis and uncertainty quantification
- Cloud application for remote monitoring

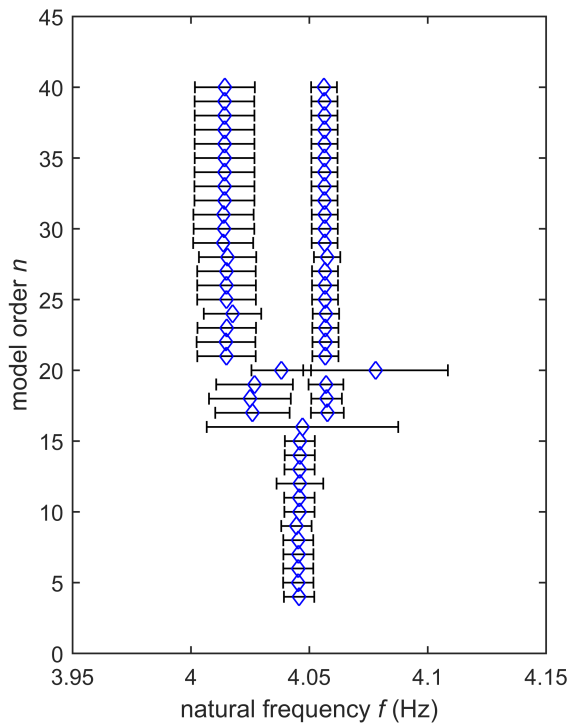


FUI SIPRIS, with VINCI ADVITAM, in collaboration with LISIS

Ifsttar gantry

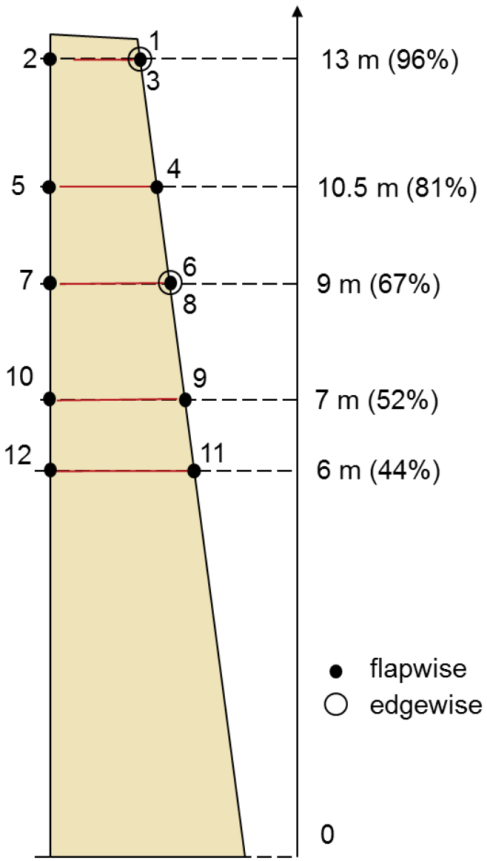


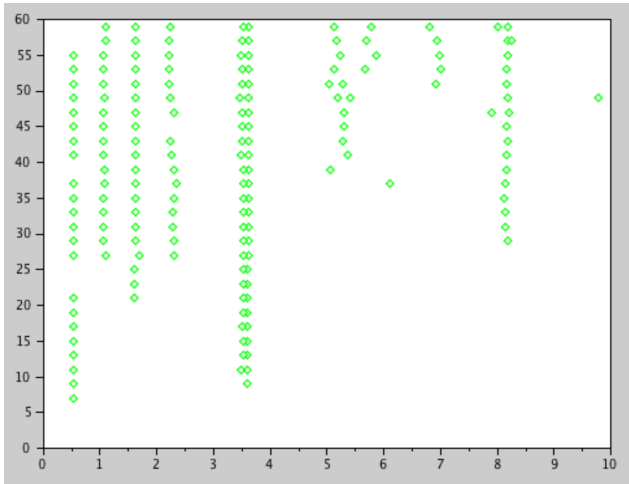




Wind turbine: Vestas V27, with Brüel & Kjær

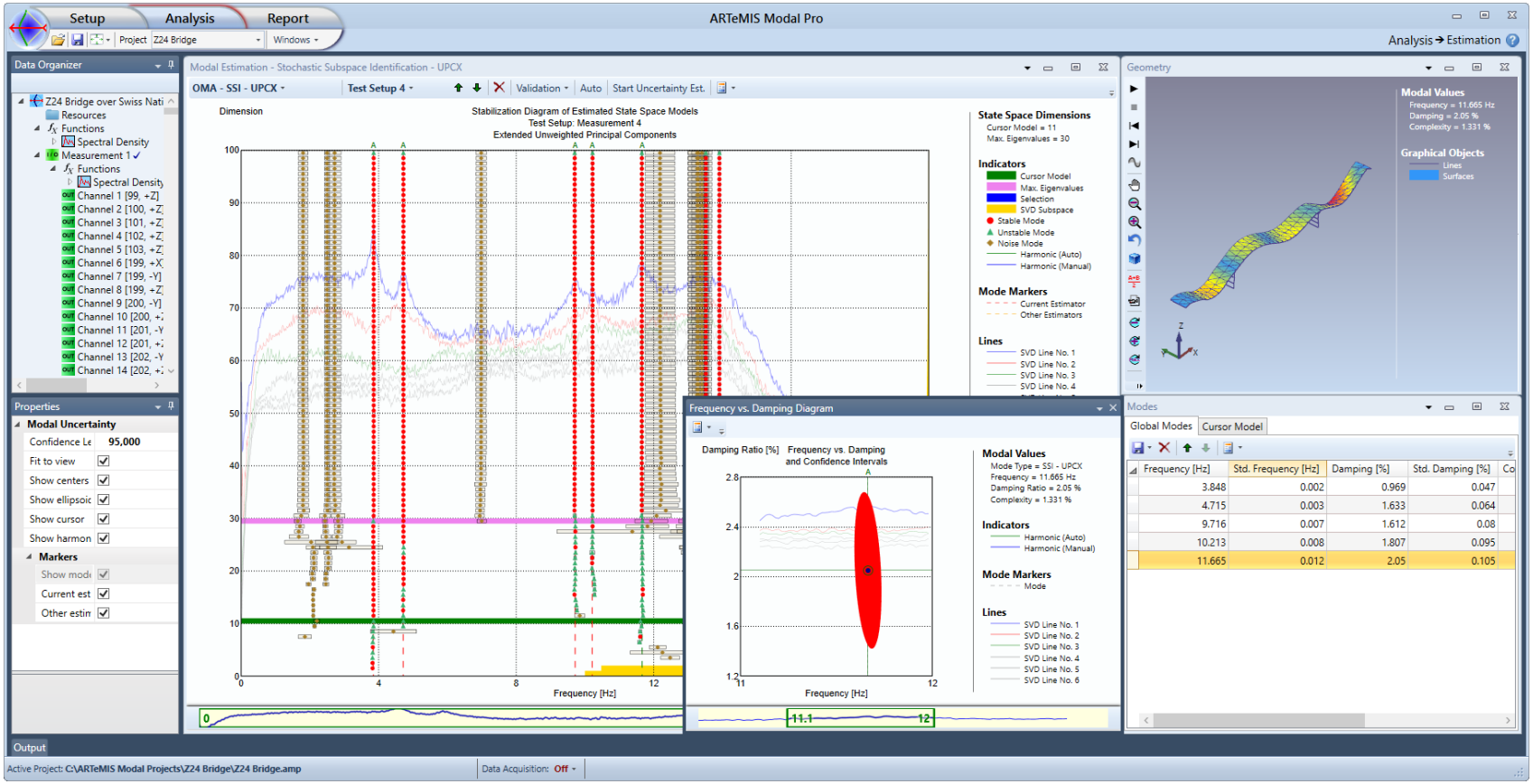
- Modal analysis of wind turbine in operation
- Take into account the periodic dynamics





Also on wind turbine with CEA-tech in Pays de Loire region

Transfer to commercial software ARTeMIS



Structural Vibration Solutions A/S, Denmark

Outline

Structural health monitoring

Context

- Change detection in vibration measurements
- Damage diagnosis for civil or mechanical structures

Damage diagnosis

1. **Detection:** is structure damaged?
2. **Localization:** where is the damage?
3. **Quantification:** what is the damage extent?
4. **Remaining life prediction**

How?

“Compare” vibration data from reference and current state

How?

Statistical distance measures

- Use data from healthy state to set up a reference
- Compare new dataset to reference in statistical tests
- Exceeding threshold: alarm

- **Detection:** data-driven – no FE model required
- **Localization, quantification:** use also FE model

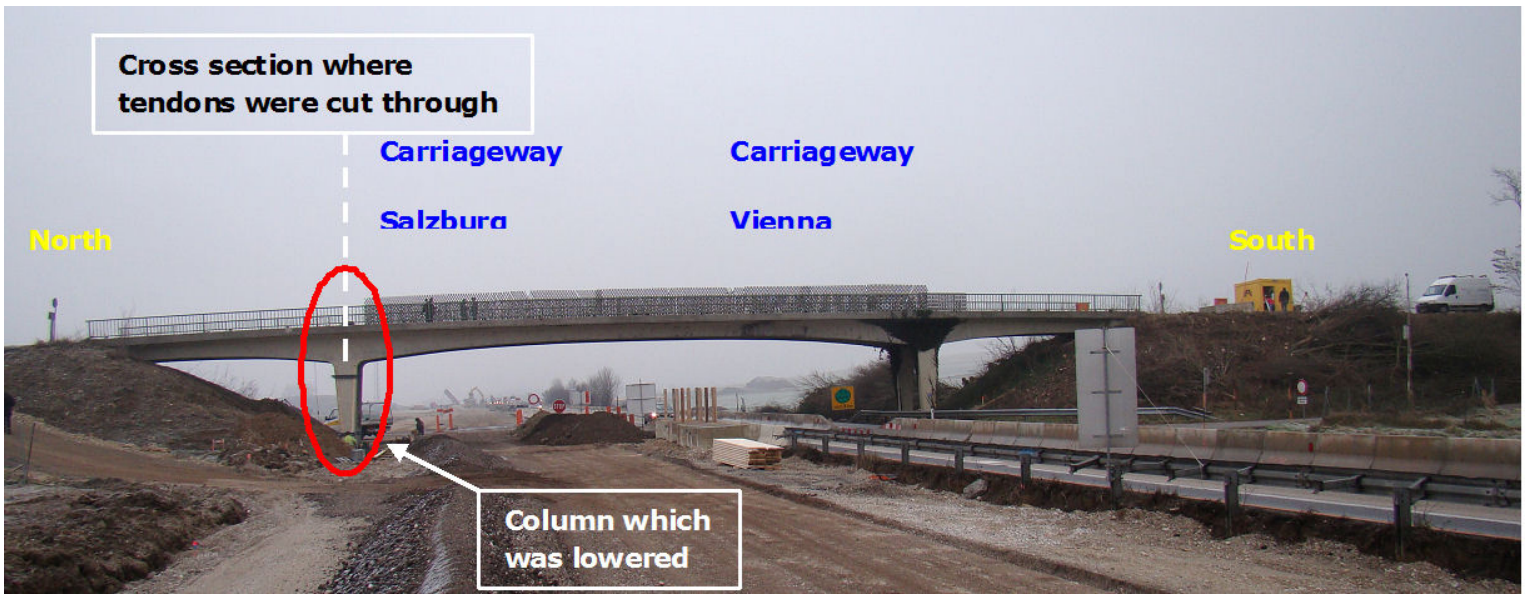
M. Döhler, L. Mevel, and F. Hille. Subspace-based damage detection under changes in the ambient excitation statistics. *Mechanical Systems and Signal Processing*, 45(1):207-224, 2014.

M. Döhler, L. Mevel, Q. Zhang. Fault detection, isolation and quantification from Gaussian residuals with application to structural damage diagnosis. *Annual Reviews in Control*, 42:244-256, 2016.

S101 Bridge - collaboration with BAM, Berlin

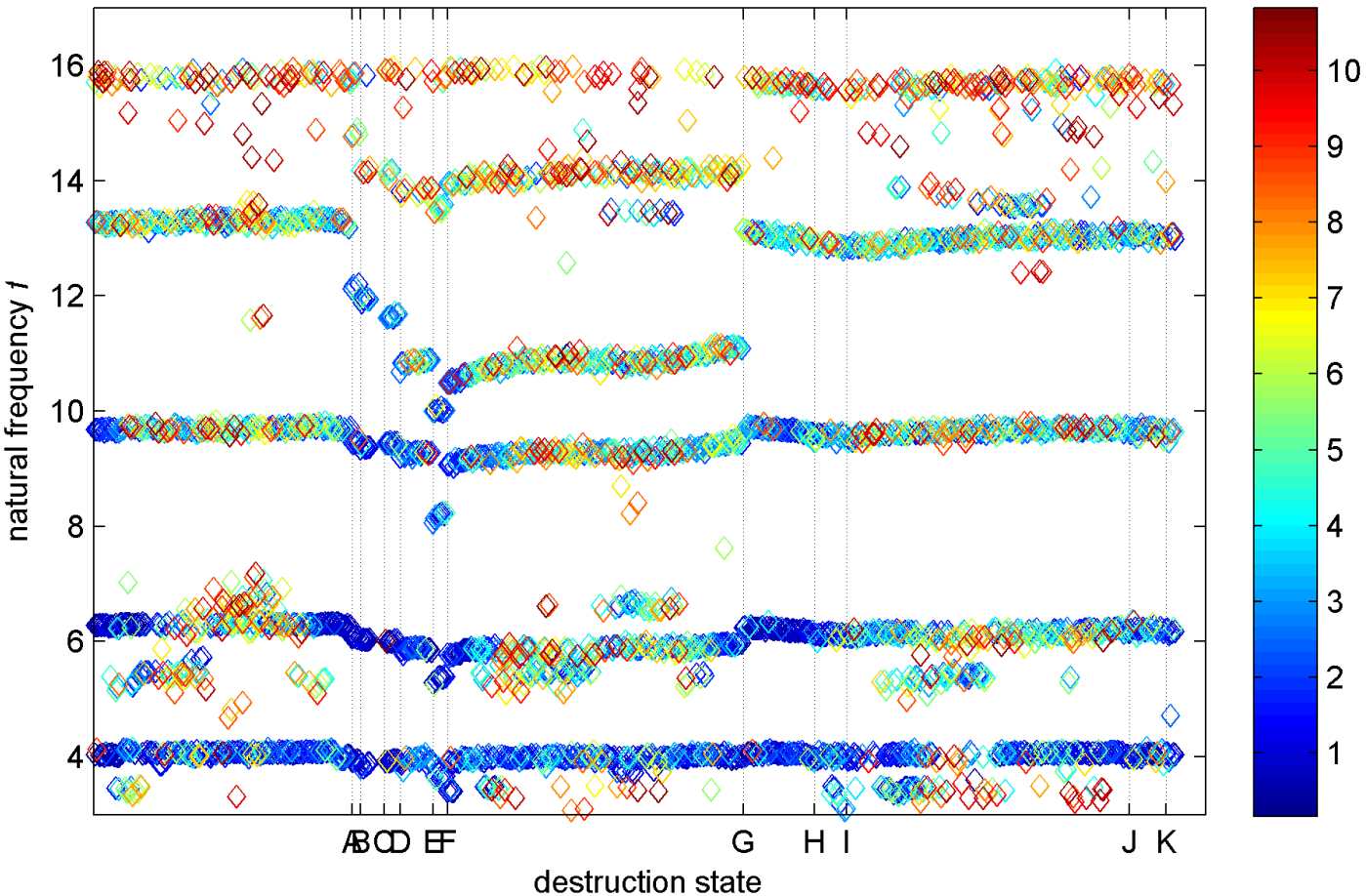
Damage detection on S101 Bridge

- In FP7 IRIS: Large scale progressive damage test as benchmark for damage identification
- 4 days of measurements with different damage actions
  - Lowering a column in 3 steps
  - Cutting the prestressing cables

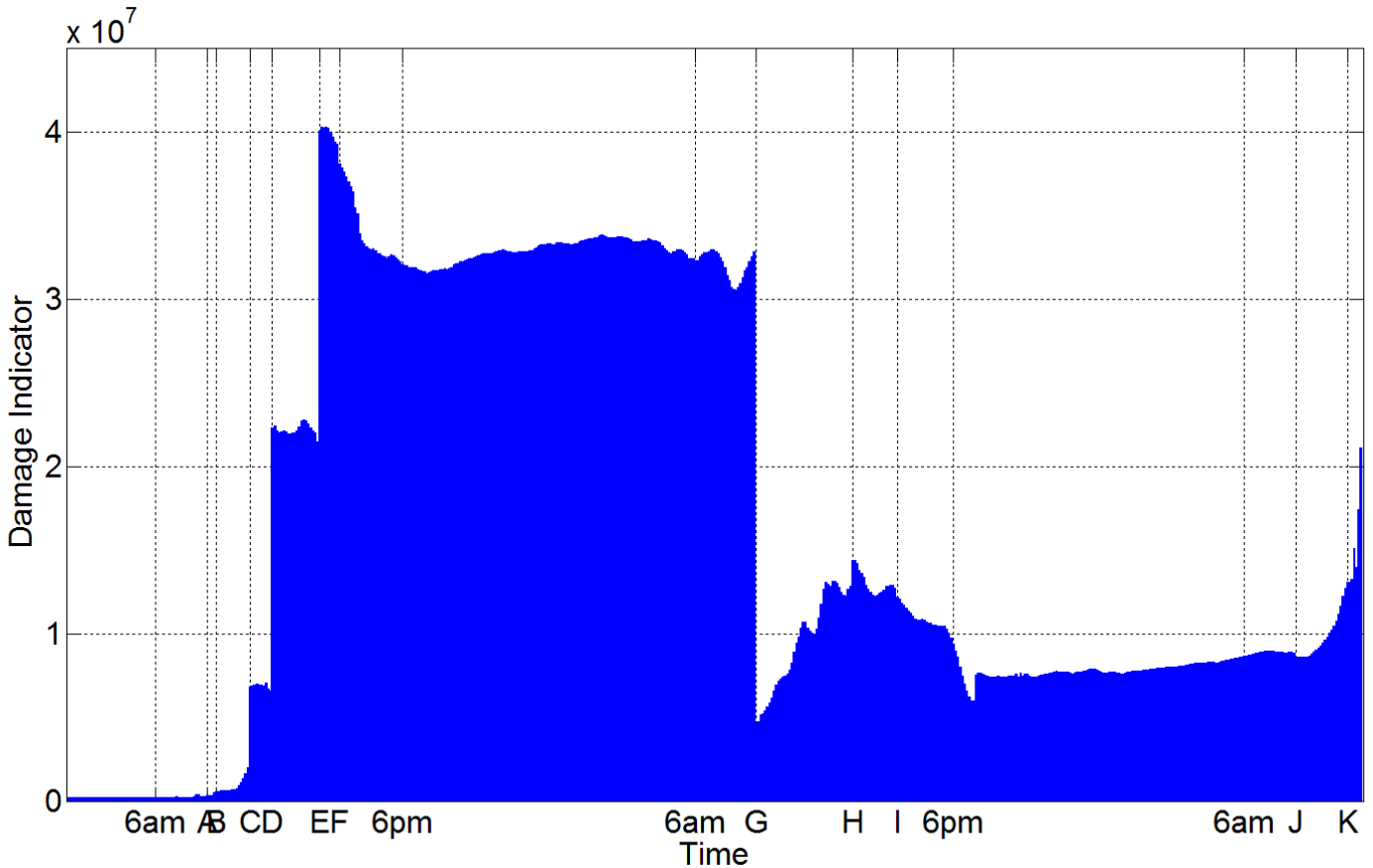


Döhler, Hille, Mevel & Rücker (2014), Structural health monitoring with statistical methods during progressive damage test of S101 Bridge. *Engineering Structures*, 69: 183-193.

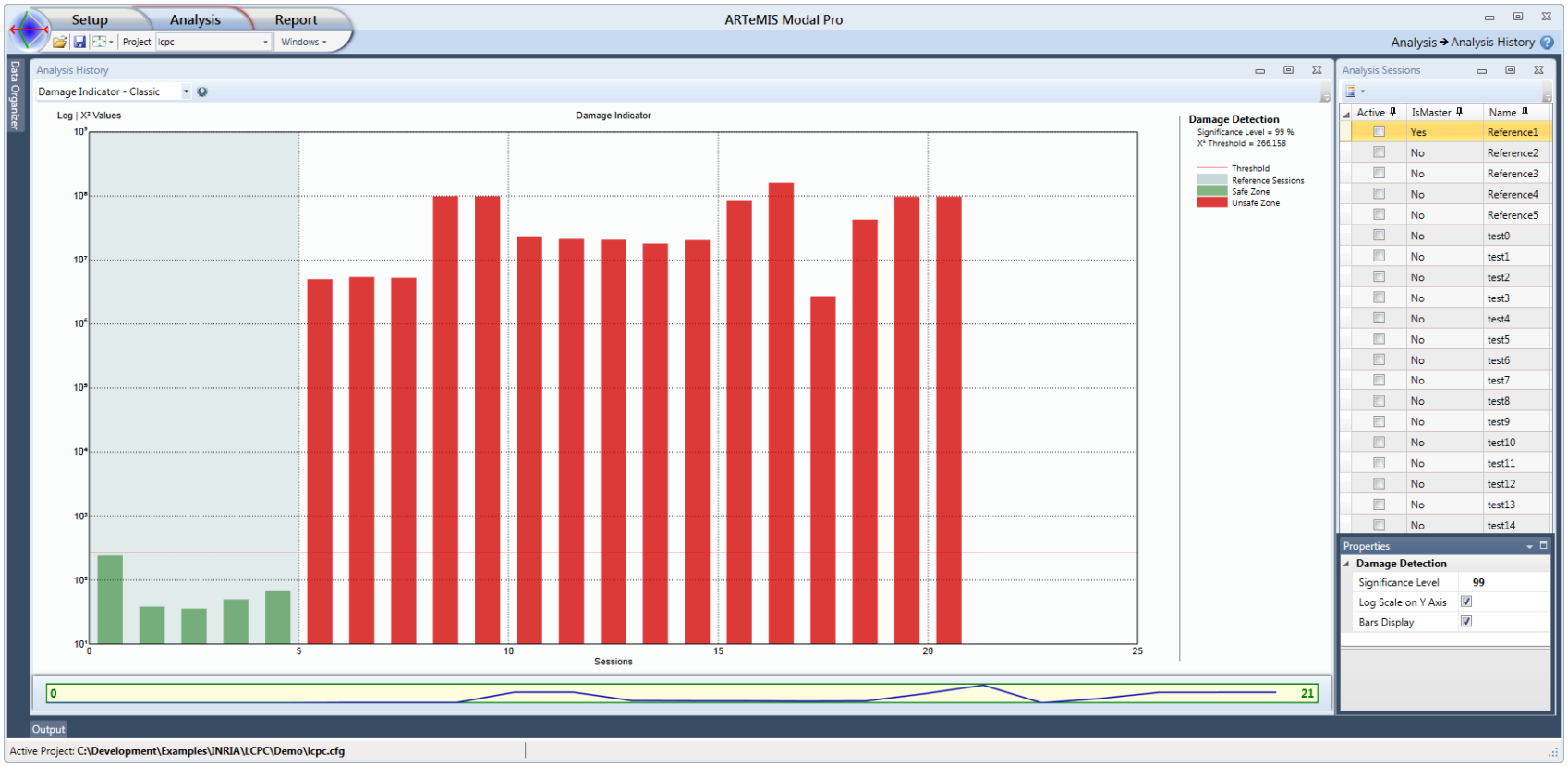
S101 Bridge


16
14
12
10
8
6
4
natural frequency f
A B C D E F G H I J K
destruction state
10
9
8
7
6
5
4
3
2
1

S101 Bridge

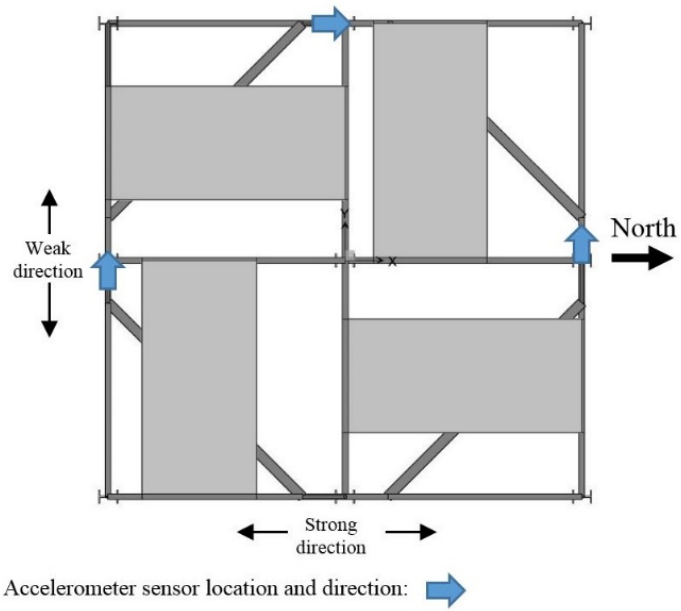

x 10^7
Damage Indicator
0
1
2
3
4
6am
A
B
CD
EF
6pm
6am
G
H
I
6pm
6am
J
K
Time

Transfer to commercial software ARTeMIS

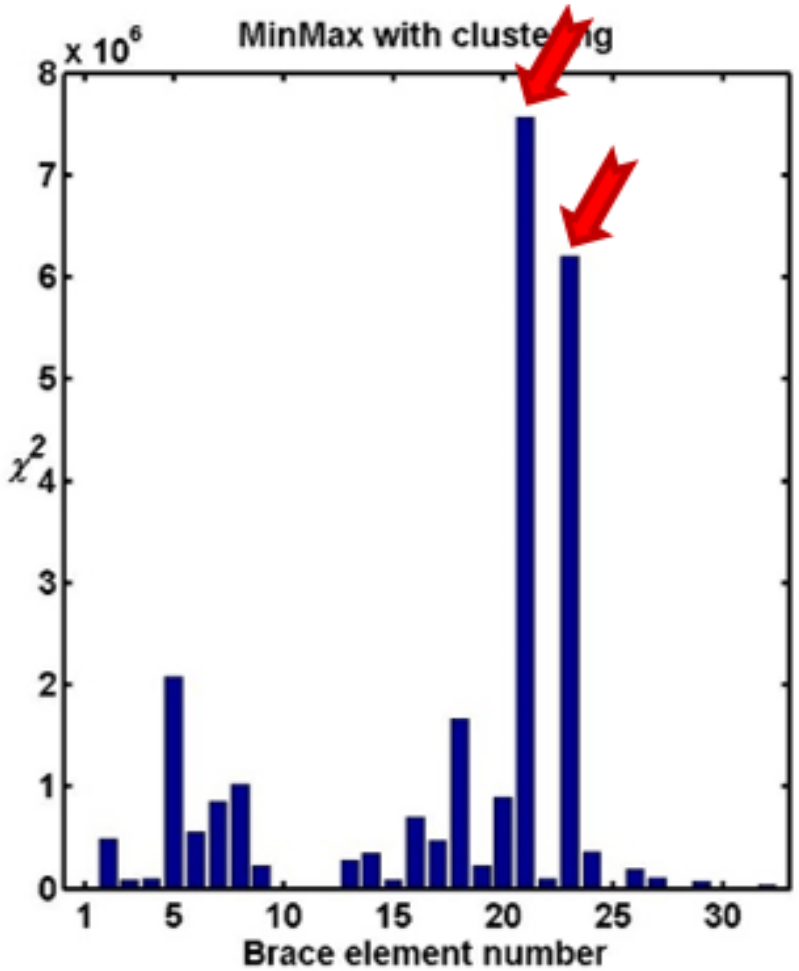


Yellow Frame: damage localization

- University of British Columbia, Vancouver
- 12 accelerometers, ambient excitation
- Damage introduced by removing braces



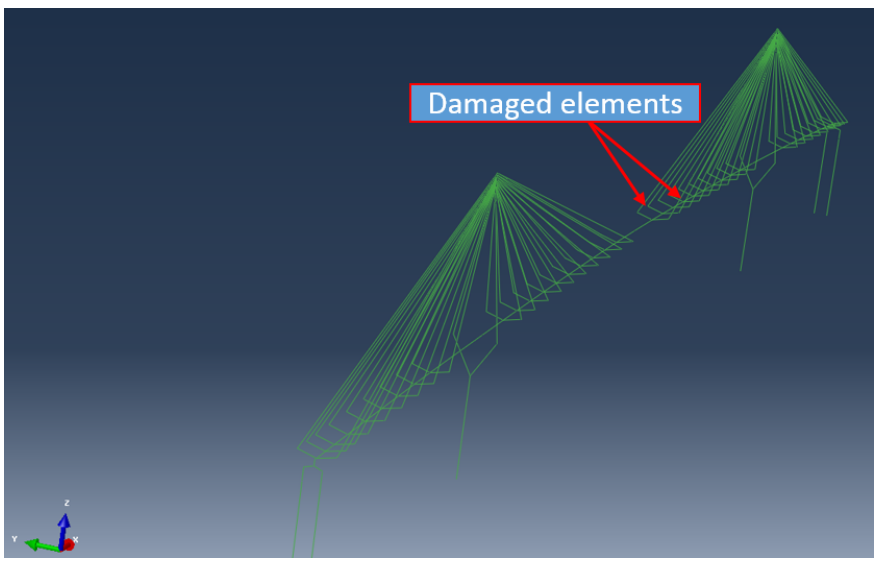
Yellow Frame: damage localization



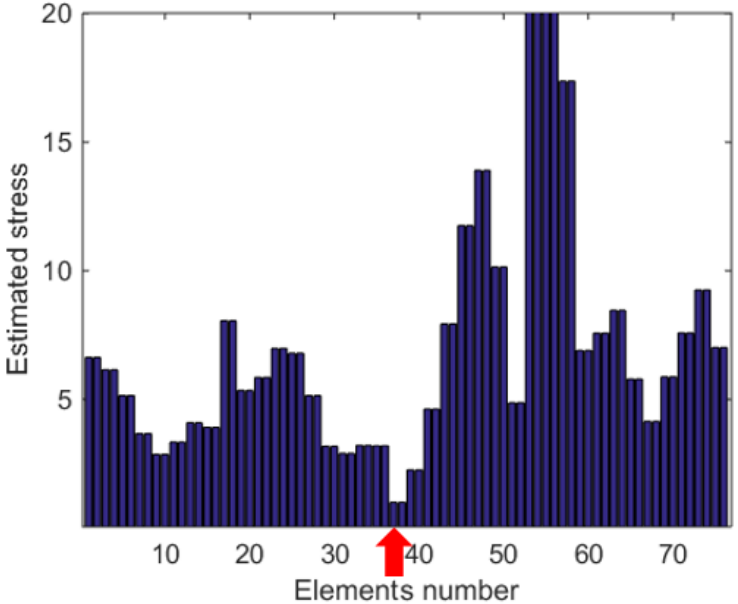
Allahdadian, Döhler, Ventura & Mevel (2017), Damage localization of a real structure using the statistical subspace damage localization method. *International Workshop of Structural Health Monitoring*.

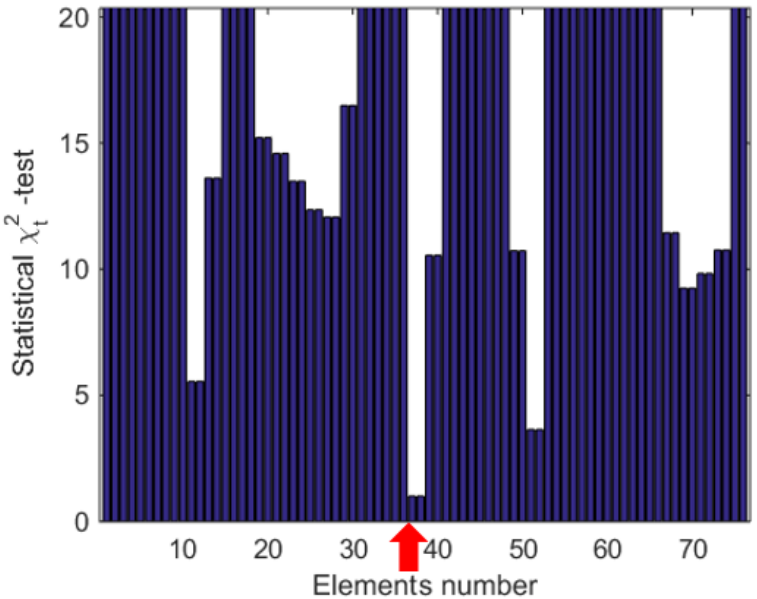
Ongoing: Saint-Nazaire Bridge mockup

- GeM, University of Nantes
- 10 accelerometers, white noise excitation
- Damage introduced by removing 2 cable rods

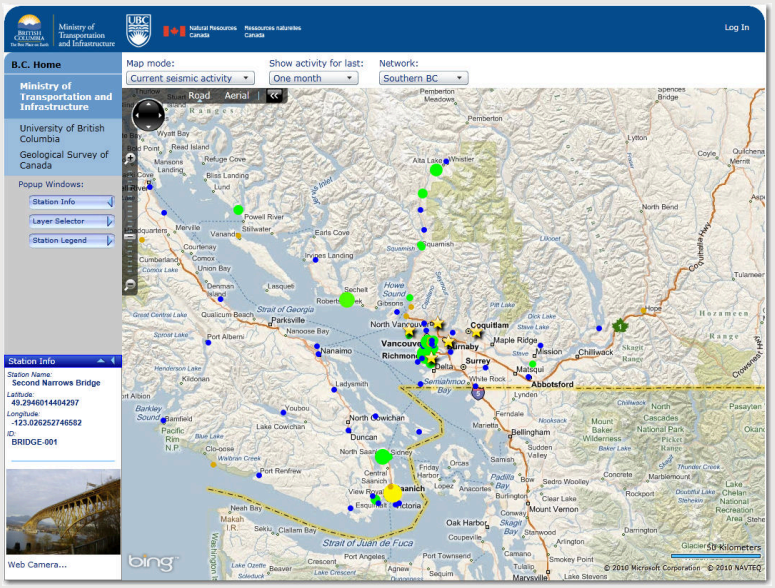


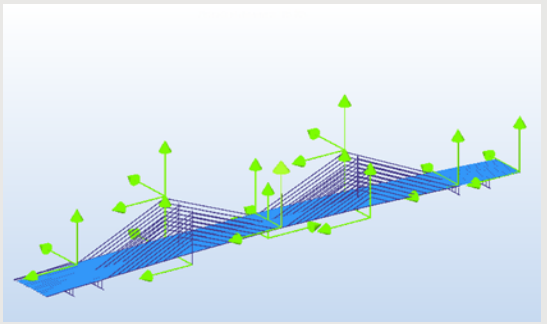
Ongoing: Saint-Nazaire Bridge mockup

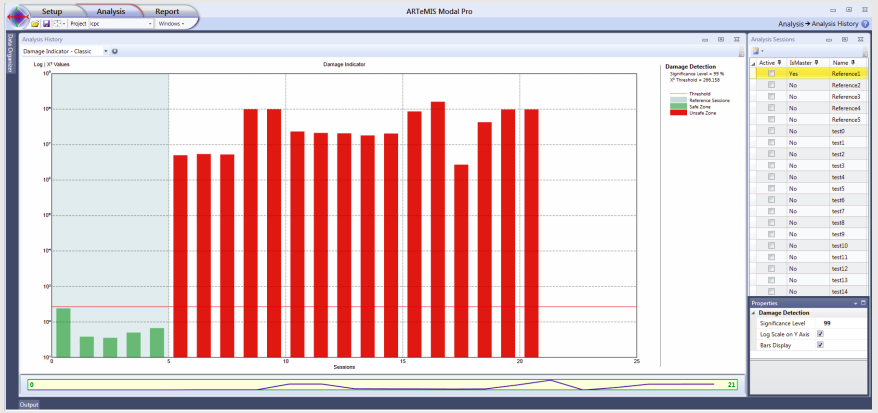


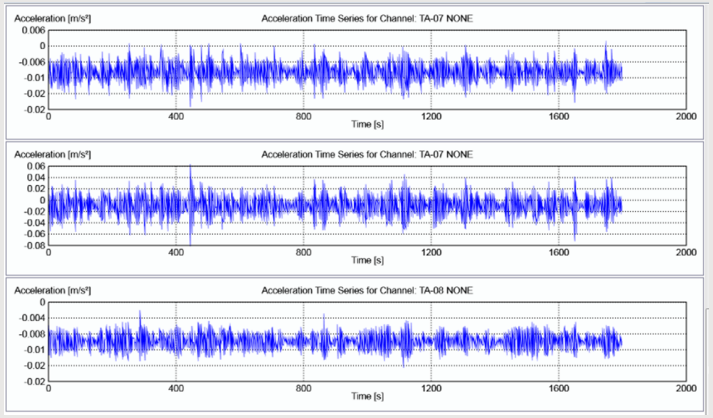


Structural Health Monitoring: SIMS, CA

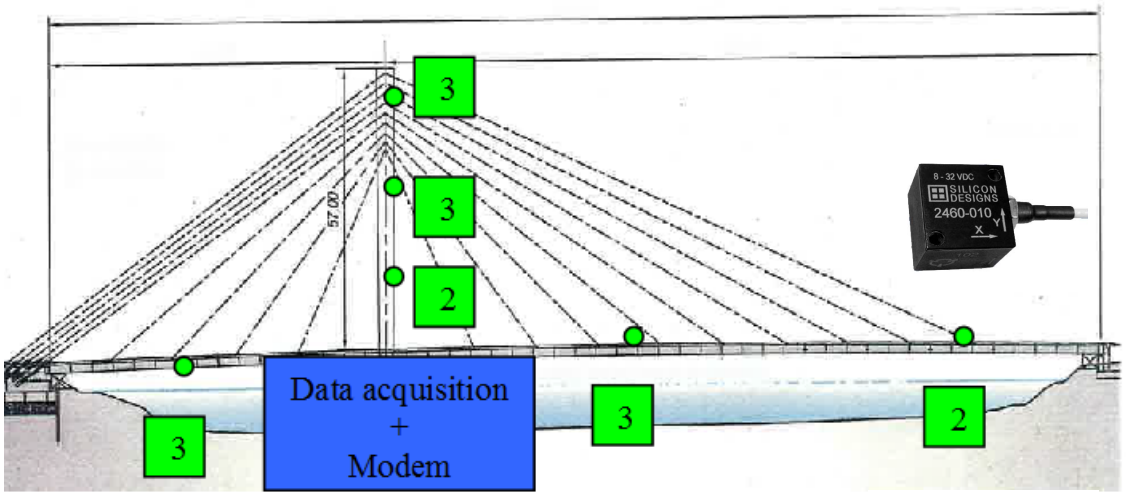








Inria
INVENTEURS DU MONDE NUMÉRIQUE

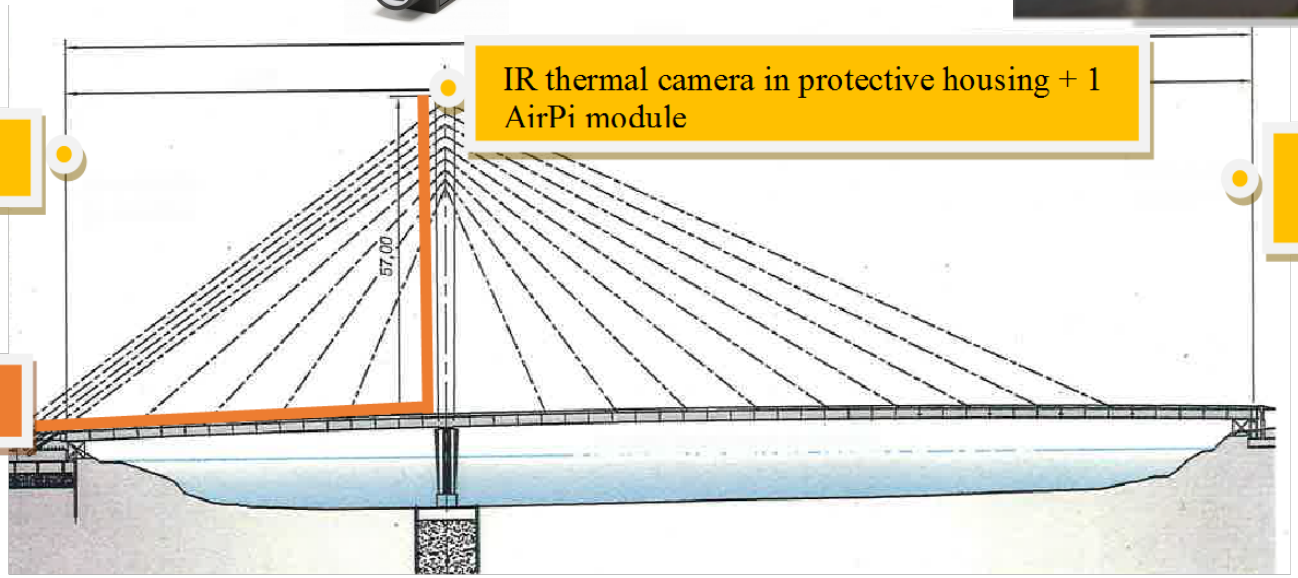


AirPi module

IR thermal camera in protective housing + 1 AirPi module

Weather station
Vaisala WXT 520

IP Network



Outline

Conclusion

Statistical methods for vibration analysis of civil structures

1. Modal analysis with uncertainty quantification
2. Damage detection, localization, quantification

- Strong theoretical background, perform well under noise
- Fast and memory efficient implementation
- Validated on case studies in the lab and in the field
- Available for PEGASE2 and in commercial software

Current and future focus

Coupling data with physical modelling for precise damage assessment

- Multi sensors : fiber optic, morphosense, imaging, etc
- Localization, quantification of damages
- Temperature nuisance
- Marine growth
- Scour
- ...