The monitoring regional guidelines for the management of bridges in the Lombardia region in Italy

Maria Pina Limongelli, Carmelo Gentile, Fabio Biondini, Marco di Prisco, Francesco Ballio, Giacomo Zonno, Paolo Borlenghi, Silvia Bianchi, Luca Capacci, Mattia Anghileri, Giulio Zani, Agnese Scalbi, Katherina Flores Ferreira, Manuel D'Angelo, Gabriele Cazzulani, Lorenzo Benedetti, Claudio Somaschini, Lorenzo Bernardini, Marco Belloli, Ferruccio Resta, Paola Vigo, Aldo Colombo

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Regione Lombardia

Importance of regional transport infrastructure

The performance of transport infrastructures has a relevant impact on the regional development and competitiveness providing:

Economic benefits: regional employment, market size for regional products, touristic flow

Social benefits related to the increased social inclusion of communities

Environmental benefits: quality of the environment through reduced pollution.

The importance of transport infrastructures is also demonstrated by the significant **investments that, in Italy, accounts for a share of about 1.2% of the GDP**.

Transport infrastructure deterioration

The PoliMi-Regione Lombardia project

Collaboration agreement to improve maintenance management of the regional roadway infrastructures.

The goal was to support the regional authority in the **supervision of regional monitoring and maintenance projects.**

Joint activities included in the agreement:

- development of **criteria for the identification of priorities**;
- development of **decision support tools for the management of bridges** in ordinary and in emergency situations due to extreme events, such as floods;
- **development of guidelines** for the classification and monitoring;
- **application to pilot bridges** representative for the region.

The MoRe guidelines for bridge monitoring

The MoRe guidelines for SM put emphasis on:

- **SM is a decision support tool**
- **The design of a SM system is defined and approached as a process**
- **Integrate nine pilots to demonstrate the proposed approach**

Outline of the presentation

- **Existing monitoring guidelines and technical codes** (2000-2021)
- **The MoRe guidelines approach**
- **The MoRe pilot monitoring systems**
  - **Brivio bridge:** dynamic monitoring for emergency management
  - **Mella bridge**: static monitoring and load tests for safety assessment
  - **Isola Dovarese bridge**: static remote and hydraulic monitoring for maintenance management

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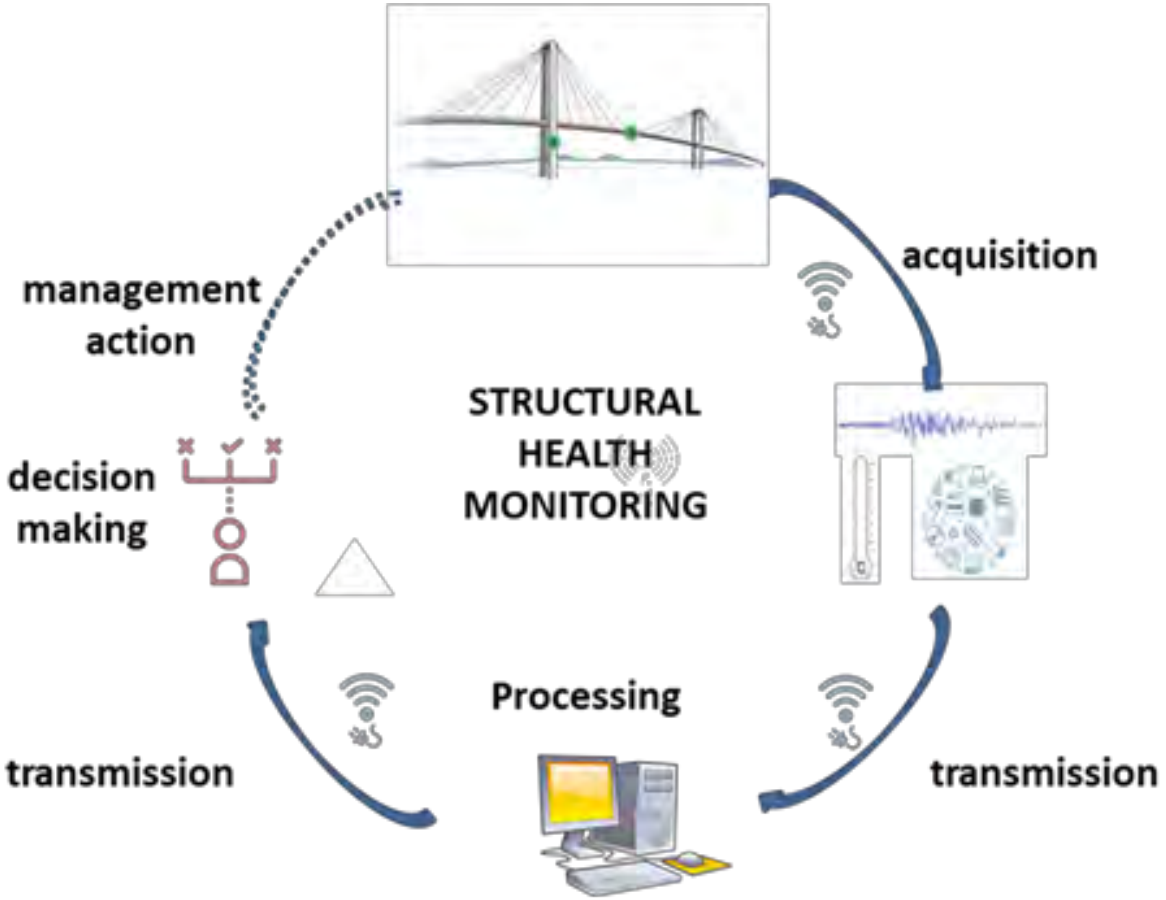
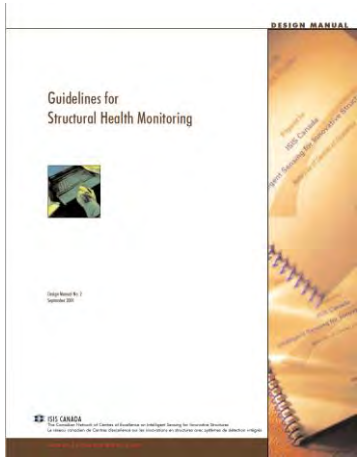
Existing monitoring documents

The monitoring process



Limongelli et al.. (2022). Bridge structural monitoring: the Lombardia regional guidelines. Structure and infrastructure engineering. *Accepted.*

SHM standardization: ISIS 2001

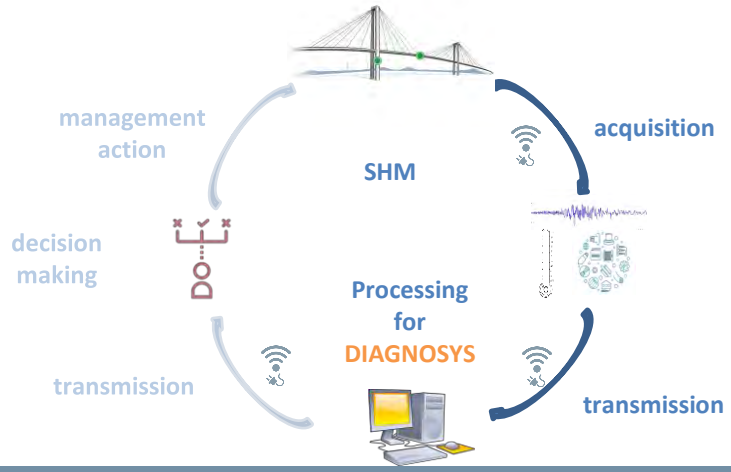


- **The process** (acquisition, transmission, processing, storing)
- **Static/Dynamic Tests**
- **Periodic** monitoring (through static and dynamic tests)
- **Case studies** (bridges, wharf)
- **Annex**: sensors, data acquisition systems, algorithms for VB damage detection

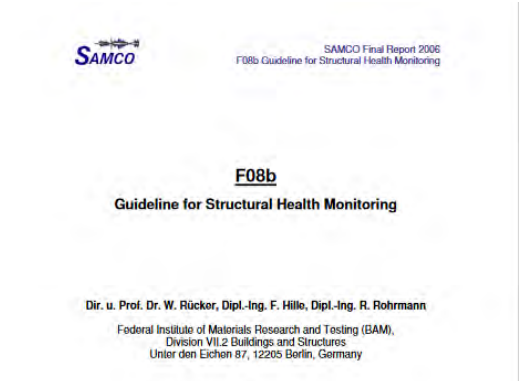
ISIS Canada, 2001

Aim of SHM:

- to **detect damage and validate interventions**
- to reduce the **uncertainty in the demand and capacity** estimation



SHM standardization: SAMCO 2006


SAMCO Final Report 2006
F08b Guideline for Structural Health Monitoring

F08b

Guideline for Structural Health Monitoring

Dir. u. Prof. Dr. W. Rücker, Dipl.-Ing. F. Hille, Dipl.-Ing. R. Rohrmann

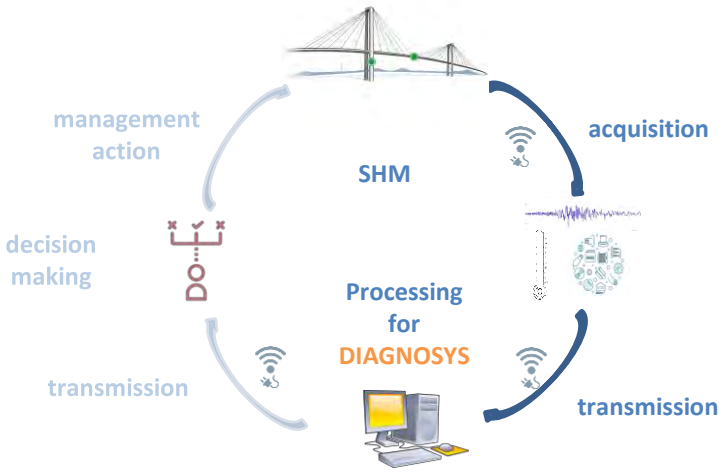
Federal Institute of Materials Research and Testing (BAM),
Division VII.2 Buildings and Structures
Unter den Eichen 87, 12205 Berlin, Germany

SAMCO project (EU), 2006

- **Diagnostic of structures (NDT, SHM, numerical analysis)**
- **Damage identification**
- **Qualification of test personnel**
- **Case studies (bridges)**
- **Annex:** sensor classification, case studies

Aim of SHM:

- to **detect damage and validate interventions**
- to reduce the **uncertainty in the demand and capacity** estimation



SHM standardization: RVS 13.03.2001


MONITORING VON BRÜCKEN UND ANDEREN INGENIEURBAUWERKEN

RVS 13.03.01

MERKBLATT

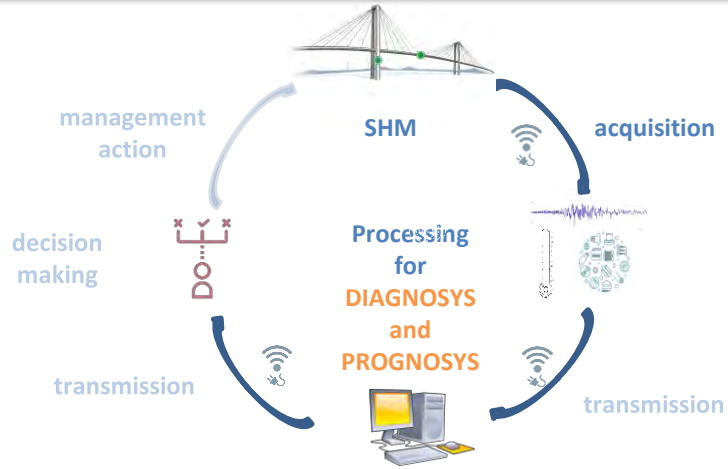
Österreichische Forschungsgesellschaft Straße – Schiene – Verkehr

Austria, 2012

- **Objectives**
- **SHM process**
- **Types of monitoring** (global, local, temporary, permanent)
- **Configuration of a monitoring system** (sensors, DAS, …)
- **Types of measurements (**deformation, frequencies,…)
- **Examples**
- **Qualification of the monitoring staff and maintenance**
- **Inclusion of monitoring in life cycle management**

Aim of SHM:

- Condition assessment
- Life-cycle Management



SHM standardization: GB China 2014


UDC:

GB

NATIONAL STANDARD OF THE
PEOPLE'S REPUBLIC OF CHINA

P GB 50982-2014

Technical code for monitoring
of building and bridge structures

Issued on: October 09, 2014 Implemented on: August 01, 2015

Issued by: Ministry of Housing and Urban-Rural Development of PRC;
General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China.

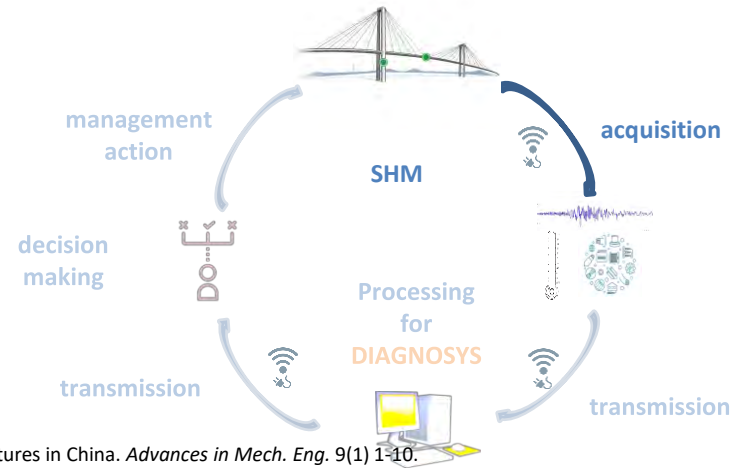
GB, China, 2014

- **Basic requirements of the SHM system** (during/post construction)
- **Methods** (for different type of measurements)
- **Specification for various structural types** (what and where to measure for high-rise, long span spatial, bridge, other)

Annexes: technical requirements of devices, monitoring requirements for different types of bridges

Aim of SHM:

- to **acquire data**
- to check **performance** and **compliance** with design specification



Yang Y., Li Q.S., Yan B.W. (2017) Specifications and applications of the technical code for monitoring of building and bridge structures in China. *Advances in Mech. Eng.* 9(1) 1-10.

SHM standardization: UNI 2016

Norma UNI

UNI/TR 11634:2016

Linee guida per il monitoraggio strutturale

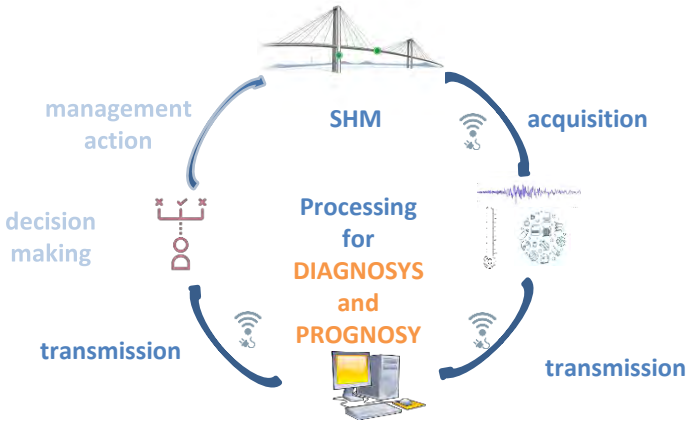
UNI (Italy), 2016

- **Objectives of SHM**
- **SHM process** (objectives, data management, decision making)
- **Technical aspects** (design, installation, maintenance)
- **Data processing, damage identification**
- **SHM for asset management and design**

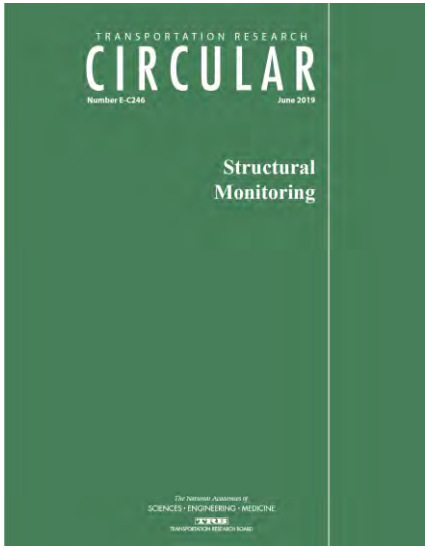
Annexes: model calibration, optimal sensors location, case studies

Aim of SHM:

- **Diagnosys** and **prognosys** (service life extension)
- to reduce the **uncertainty** in the capacity and demand estimation



SHM standardization: TRB 2019

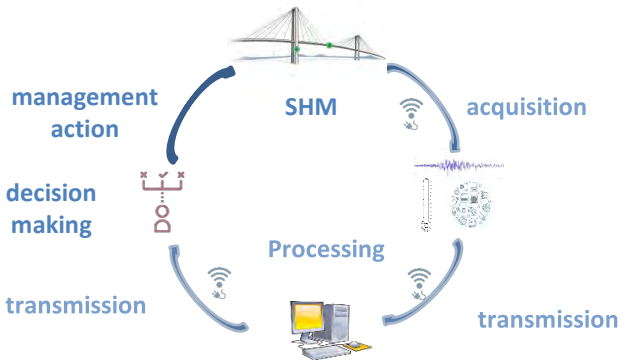


TRB (US), 2019

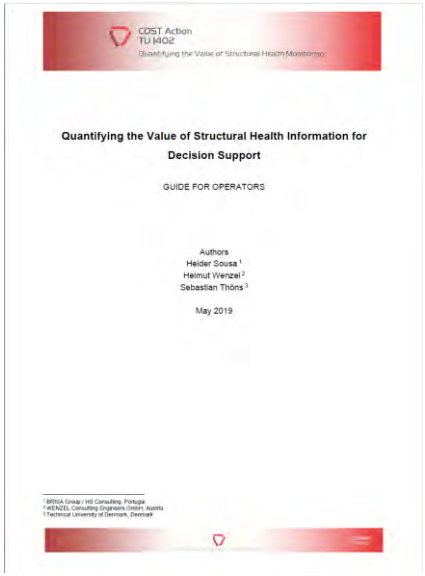
- **Purpose and value of SM (**role for AM**)**
- **When to consider SM (**structural integrity, movements, extreme events, fatigue assessment, tracking tolerances, cable and wire breakage, validate effectiveness of interventions)
- **Types of SM devices (**technology and data management**)**
- **How to implement a SM project** (key objectives of SM and planning)
- **Transforming SM data into knowledge**
- **Ensuring a financial return from a SM project**

Aim of SHM:

- **Assess** structural performance **to inform decisions** within an asset management context
- Provide owners with a **ROI**



SHM standardization: COST TU1402 - 2019


COST Action TU1402

Quantifying the Value of Structural Health Information for Decision Support

GUIDE FOR OPERATORS

Authors
Helder Sousa [1]
Helmut Wenzel [2]
Sebastian Thöns [3]

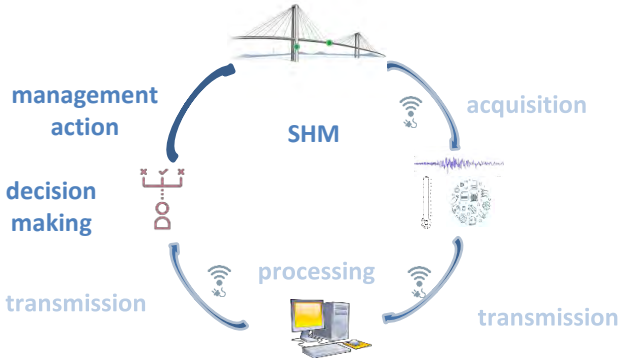
May 2019

COST TU1402, 2019

3 guidelines (scientists, practitioners, owners)

- **Risk-based Informed decision-making**
- **Information modelling**
- **Structural performance modelling**
- **Value of Information analysis**

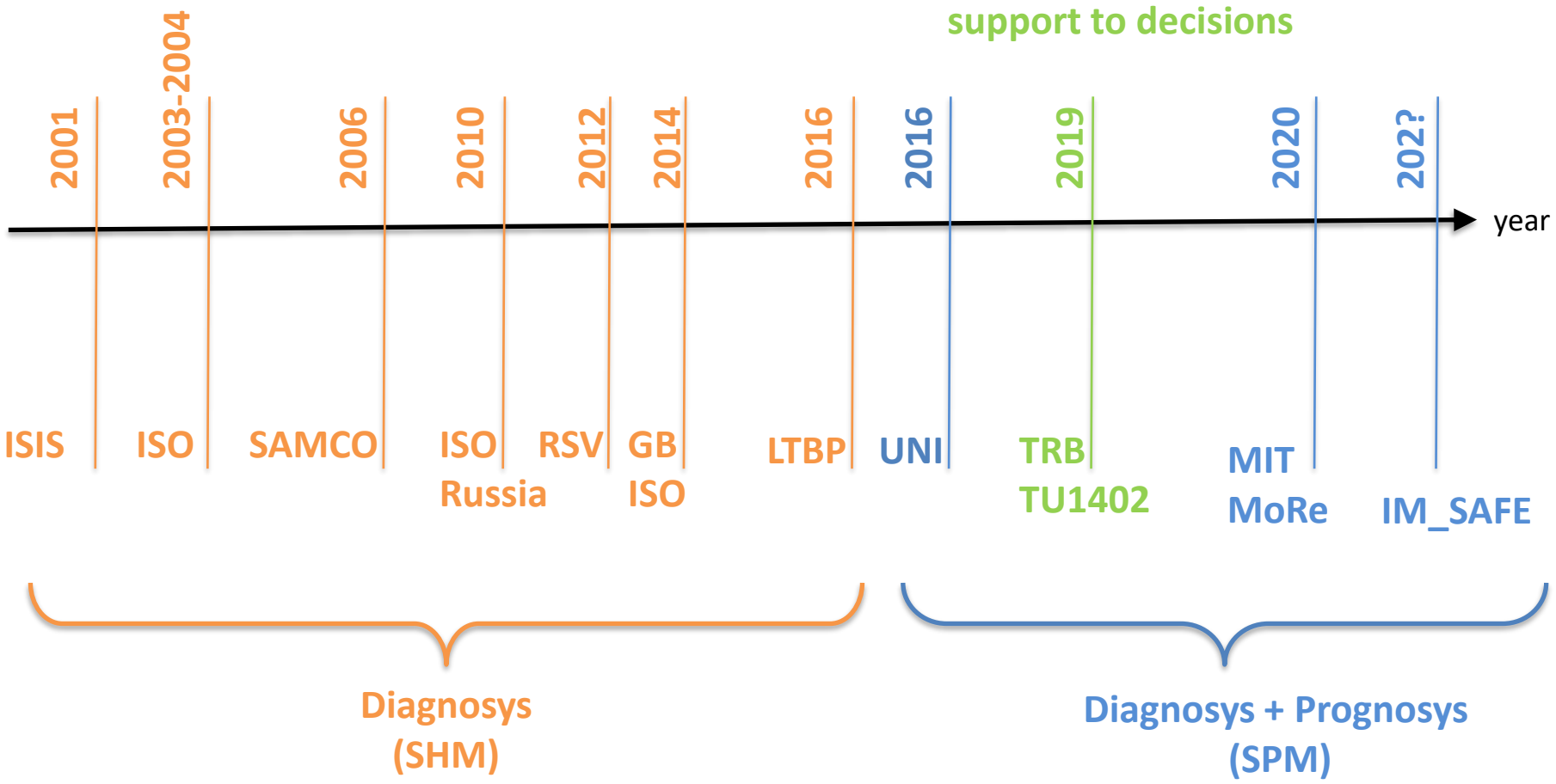
COST Action TU1402: Quantifying the Value of Structural Health Monitoring



Aim of SHM:

- **To support decisions relevant to efficient integrity management**

From SHM to SPM



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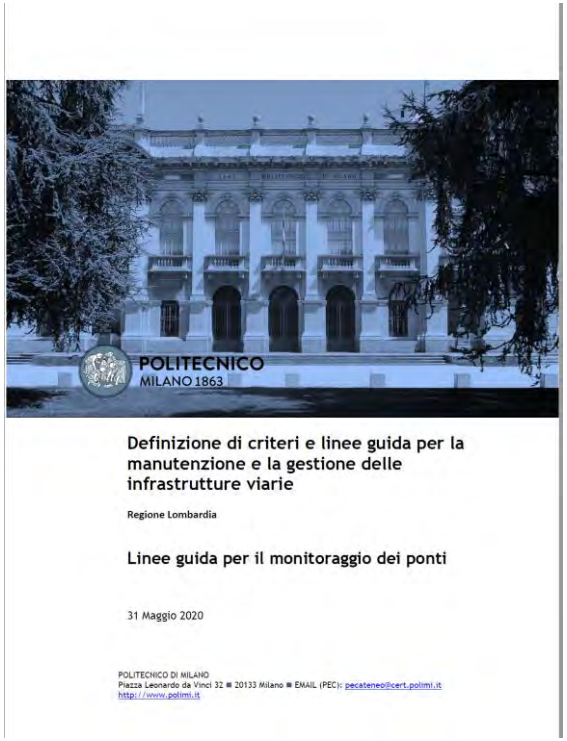
The MoRe guidelines approach

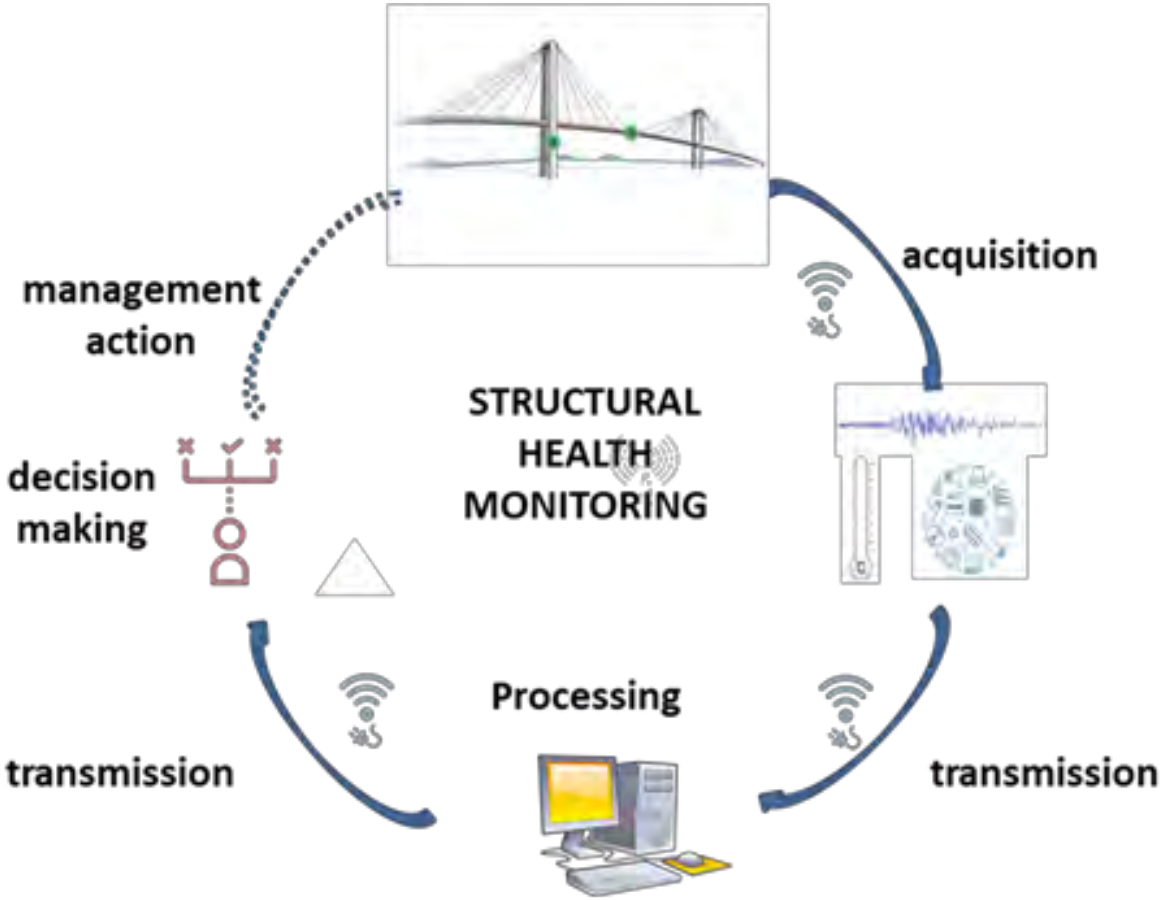
Content of the MoRe guidelines



- **Design of SM as a decision support tool**
- **Monitoring of the system (structure + environment)**
- **Extraction of information from data and threshold selection** (issues and methods)
- **Demonstration through pilots** (on going)

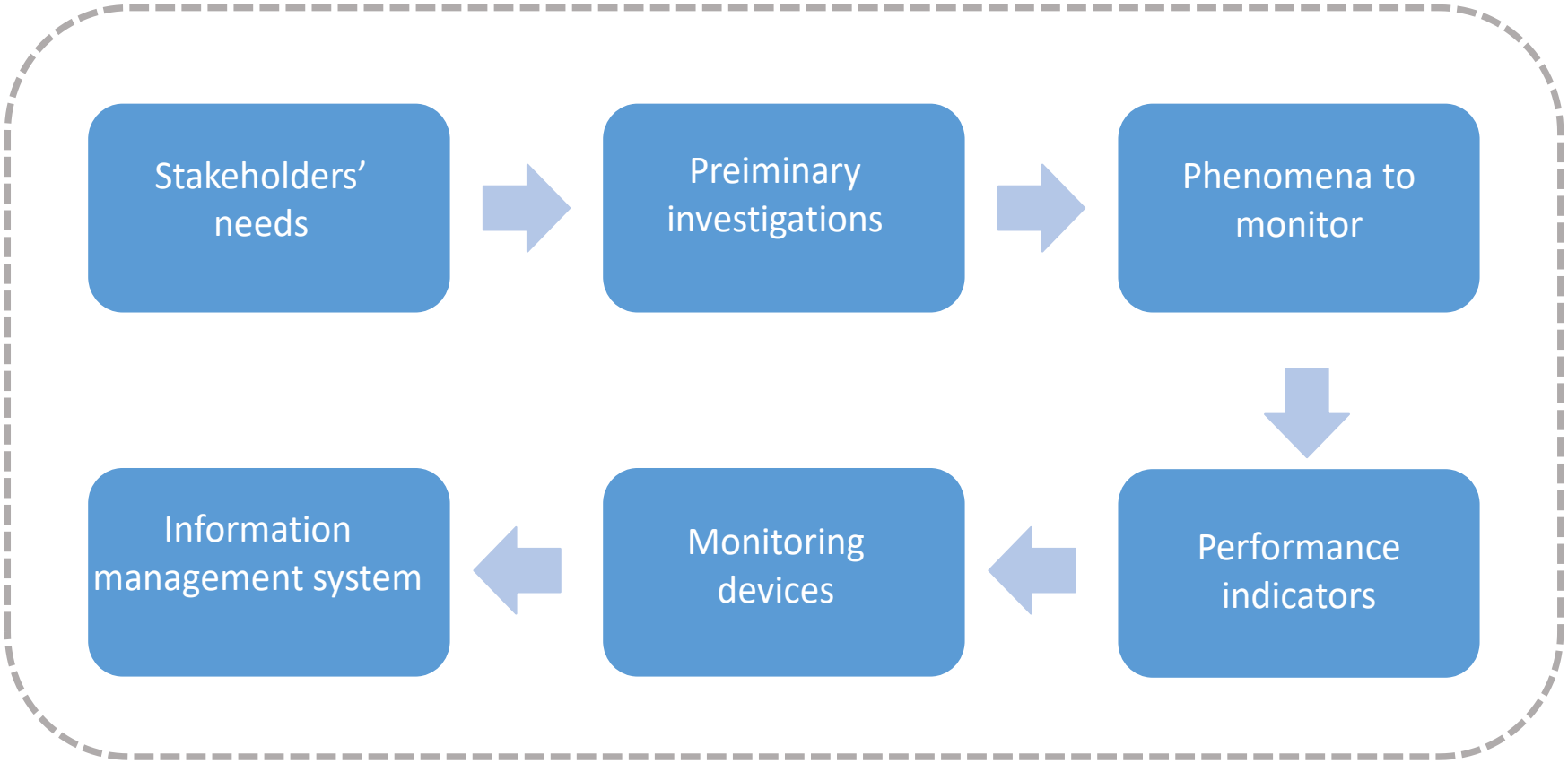
Limongelli et al.. (2022). Bridge structural monitoring: the Lombardia regional guidelines. Structure and infrastructure engineering. *Accepted.*

SM as a decision support tool



Limongelli et al.. (2022). Bridge structural monitoring: the Lombardia regional guidelines. Structure and infrastructure engineering. *Accepted.*

The SM design process



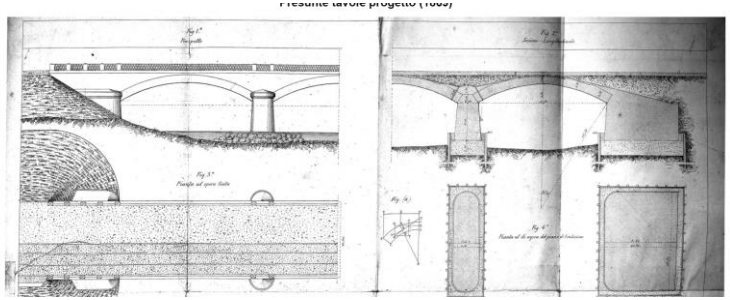
Limongelli et al.. (2022). Bridge structural monitoring: the Lombardia regional guidelines. Structure and infrastructure engineering. *Accepted.*

Stakeholders needs: decision problems

The same monitoring system can support multiple decision problems, the distinction is adopted to highlight the specificities the SM system must present to address each decision problem (e.g. monitoring frequency)

Preliminary investigations

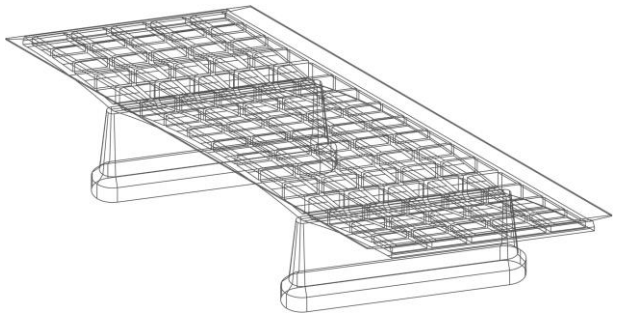
documents collection



surveys

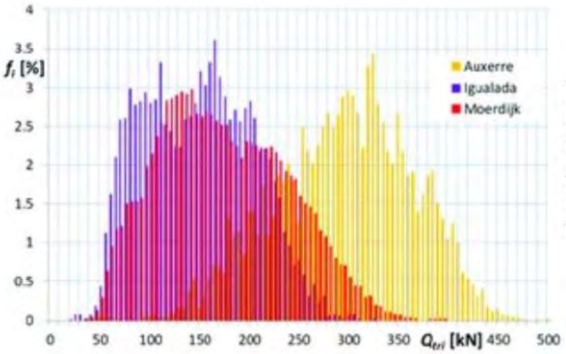
local and/or global tests

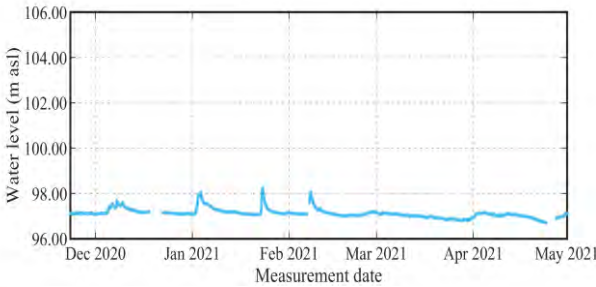
modelling



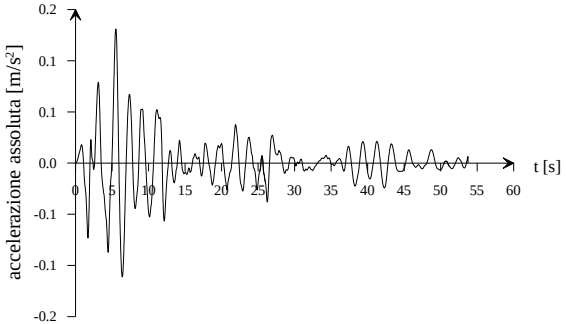
Indicators, measurements, sensing devices

capacity

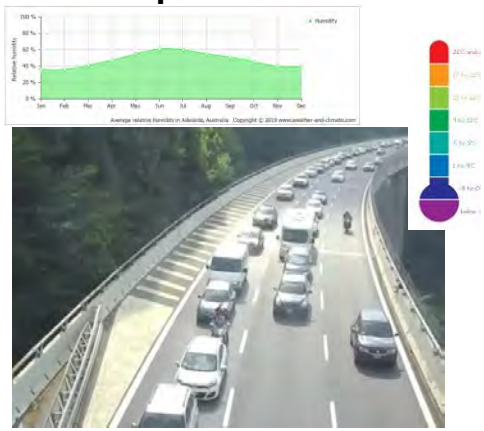




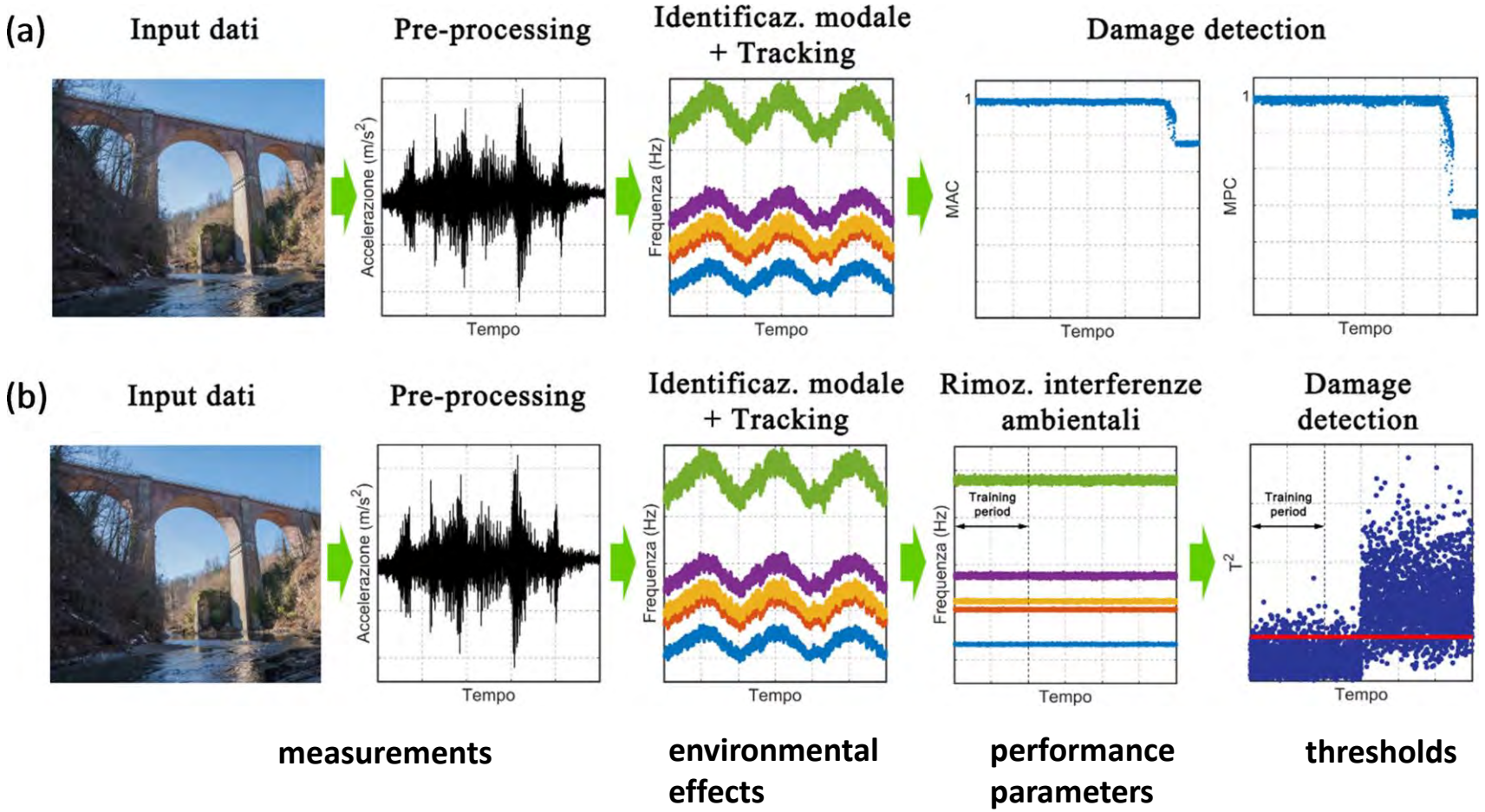
demand



environmental/operational parameters



Processing of data to extract information



measurements | **environmental effects** | **performance parameters** | **thresholds**

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The MoRe pilots

MoRe pilots: location

MoRe pilots: type, decision problem and monitoring system

Management problem	Bridge	Bridge type	Max span	Sensing system
MM S	Mella	R.C. **continuous** multicellular skew bridge	22	Static + hydraulic
MM	Ponte Lambro	Multi-span **simply supported** skewed P.C. girder bridge	20	Static + environmental
MM	Merone	Multi-span **simply supported** P.C. girder bridge with **Gerber saddles**	29	Static
MM S	Isola Dovarese	Multi-span **simply supported** P.C. girder bridge	18	Remote static and hydraulic
MM EM	Brivio	**R.C. tied arch** bridge	44	Dynamic and environmental
EM S	Borgoforte	**Concrete long-span bridge**	64	Dynamic and hydraulic
MM EM S	Candia	Multi-span **masonry arch** bridge	20	Static, environmental and hydraulic
MM EM S	Bressana	**Long-span steel truss** road-rail bridge	77	Dynamic and hydraulic
SA	Baghetto	**Steel-concrete** composite girders with **masonry** piers	18	Dynamic

Goals of the monitoring systems

To **provide information** about:

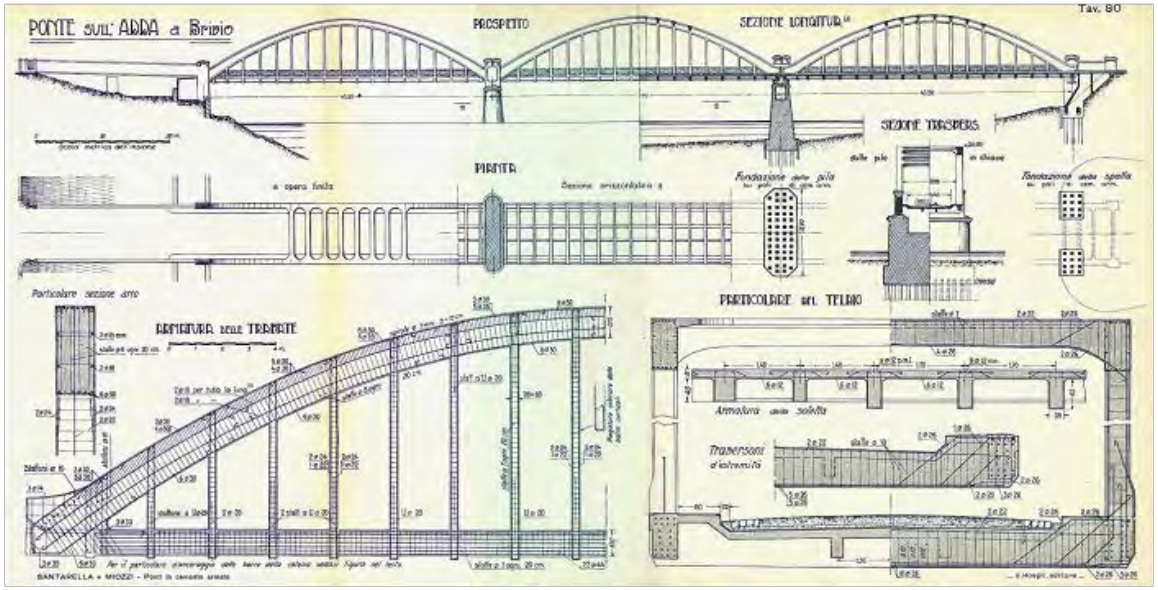
- the development or evolution of deteriorations processes (MM)
- the structural condition after and during sudden and extreme events (EM)
- the structural condition after a repair intervention or a damaging event (SA)
- statistics of the (hydraulic) actions and of the accumulation of debris (S)

This **information will be used to support the management of the bridges** e.g. the planning of maintenance interventions, the selection of optimal emergencyor maintenance management actions, computation of demand.

A selection of the ongoing pilots

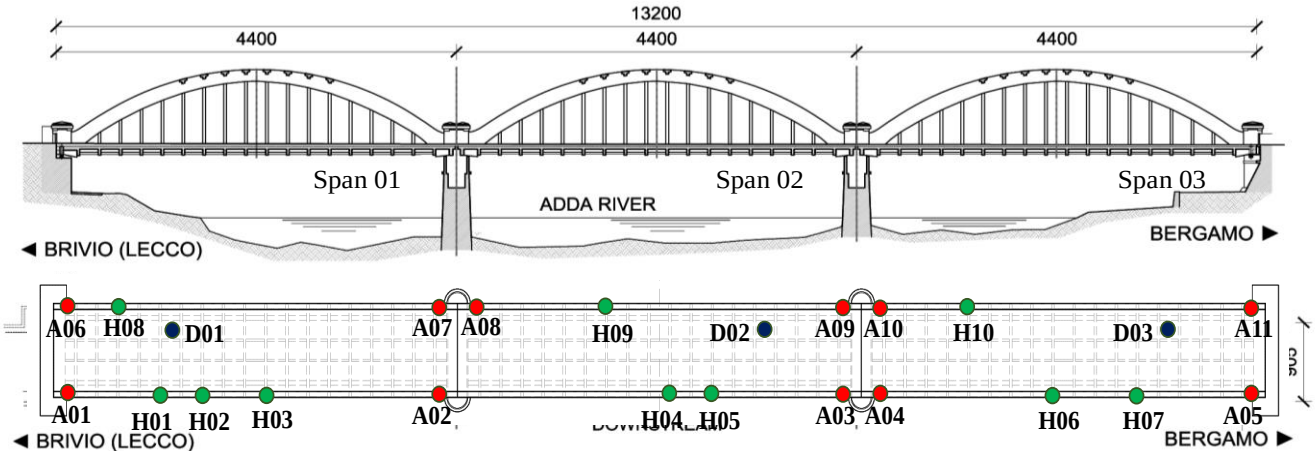
- **Brivio bridge:** dynamic monitoring for emergency management, FE modelling and updating, damage detection
- **Mella bridge**: preliminary investigations, modelling, static monitoring for maintenance management
- **Isola Dovarese bridge**: static remote and hydraulic monitoring for scour emergency and maintenance management

Brivio bridge: dynamic monitoring for scour emergency management



Borlenghi, P., Gentile, C., & Zonno, G. (2021). Monitoring reinforced concrete arch bridges with operational modal analysis. *Eurostruct 2021. Padua, Italy*.

Brivio bridge: materials characterization

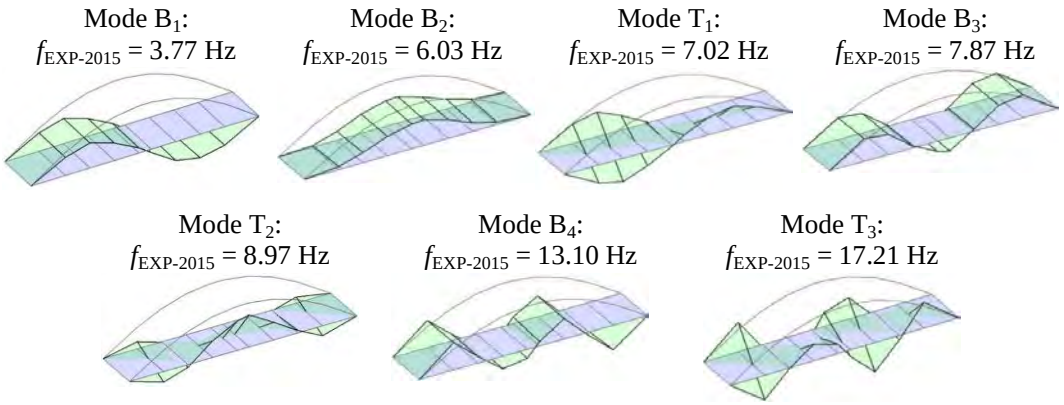


A=Arches
H=Hangers

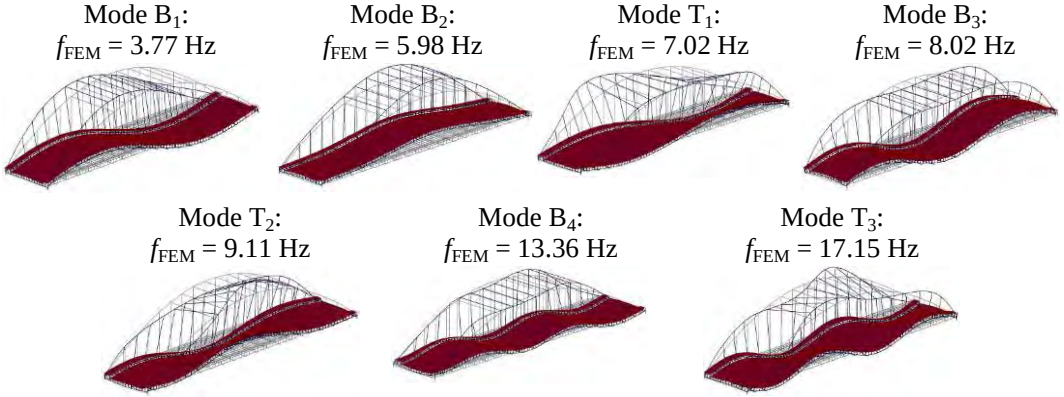
Ultrasonic pulse velocity and compression tests on samples to estimate the compressive strength and the elastic modulus.

Borlenghi, P., Gentile, C., & Zonno, G. (2021). Monitoring reinforced concrete arch bridges with operational modal analysis. *Eurostruct 2021. Padua, Italy*.

Brivio bridge: FE modeling and updating



Span 3 (S3): vibration modes identified during the 2015 AVT



Span 3 (S3): vibration modes of the optimal (updated) model

2014-15.

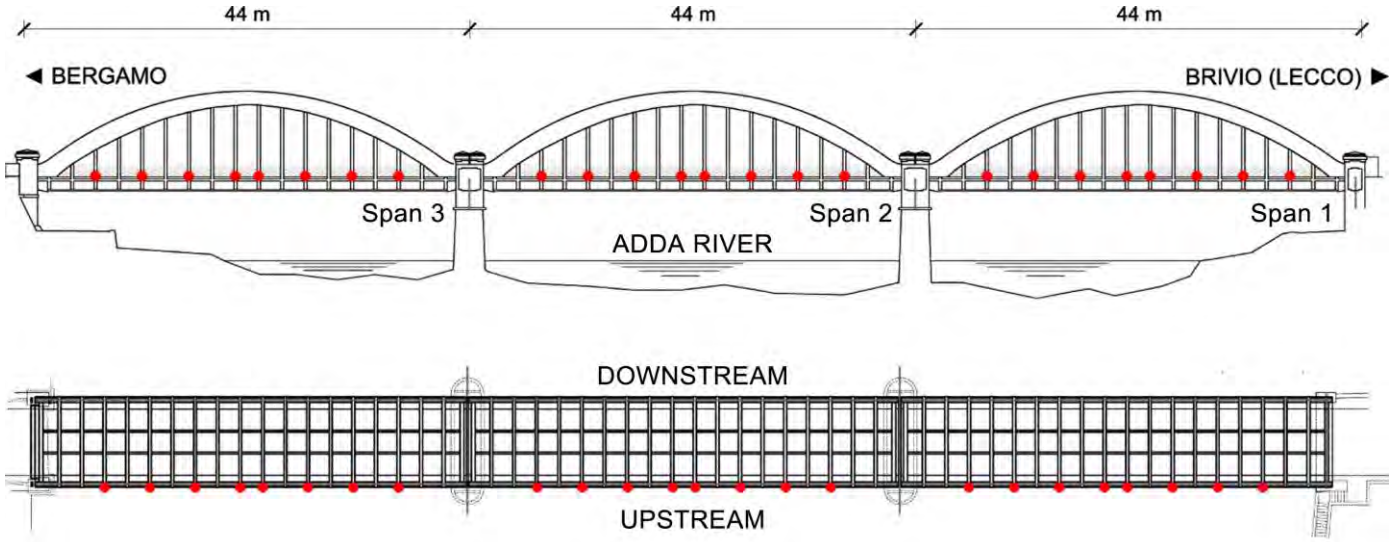
The structural parameters of the optimal models are in good agreement with the available characterization of the materials

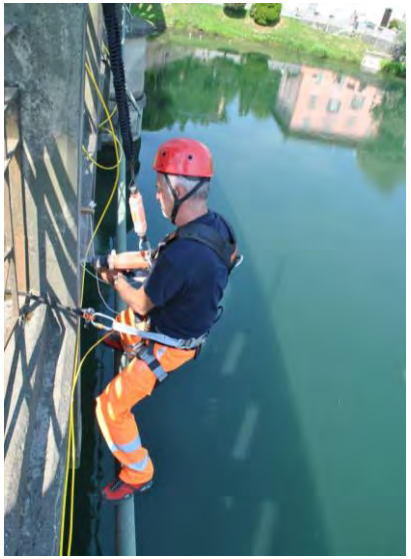
Span 3 (S3)		
$f_{EXP-2015}$ (Hz)	f_{FEM} (Hz)	DF (%)
3.77	3.77	–
6.03	5.98	0.92
7.02	7.02	–
7.87	8.02	−1.79
8.97	9.11	−1.48
13.10	13.36	−1.98
17.21	17.15	0.37

Borlenghi, P., Gentile, C., & Zonno, G. (2021). Monitoring reinforced concrete arch bridges with operational modal analysis. *Eurostruct 2021. Padua, Italy*.

Brivio bridge: dynamic monitoring system

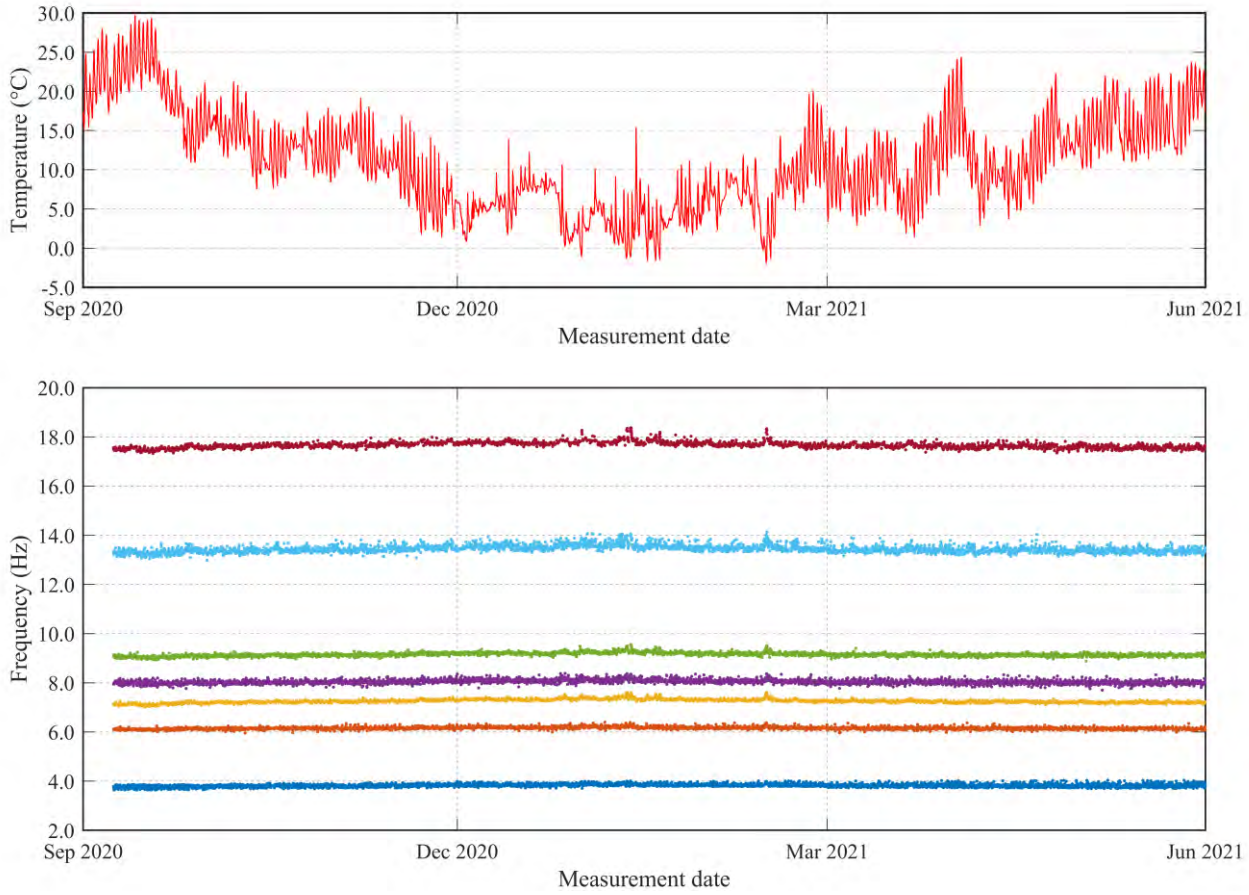
- 8 seismometers and 1 24-bit digitizer per span;
- 1 temperature sensor and 1 UMTS modem for data transfer;
- The structural response is continuously recorded (f_s=100 Hz) and datasets of 3600s (one binary file for each sensor) are created every hour;
- Automated OMA (SSI-Cov)





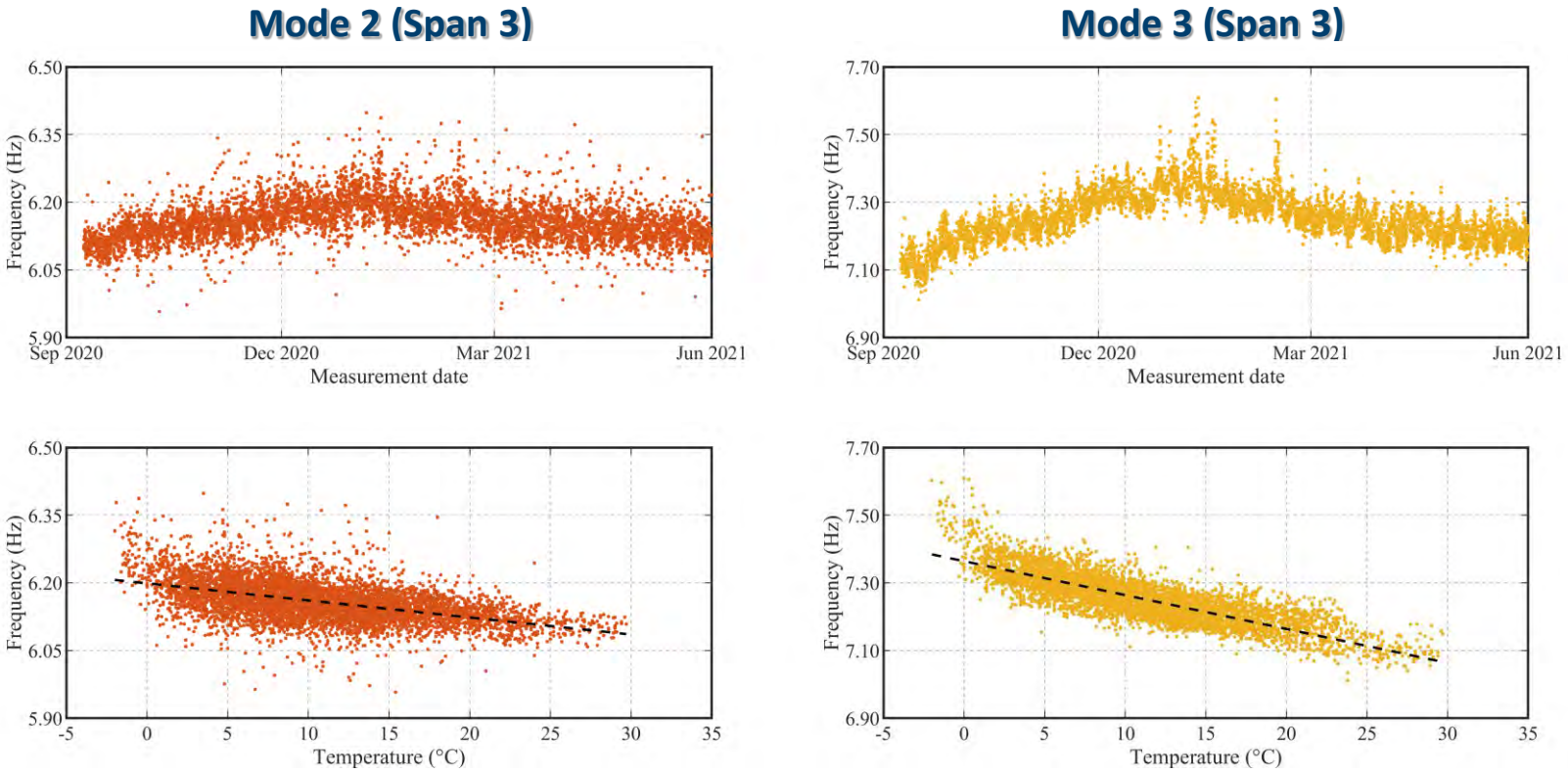
Borlenghi, P., Gentile, C., & Zonno, G. (2021). Monitoring reinforced concrete arch bridges with operational modal analysis. *Eurostruct 2021. Padua, Italy*.

Brivio bridge: effect of temperature on modal frequencies



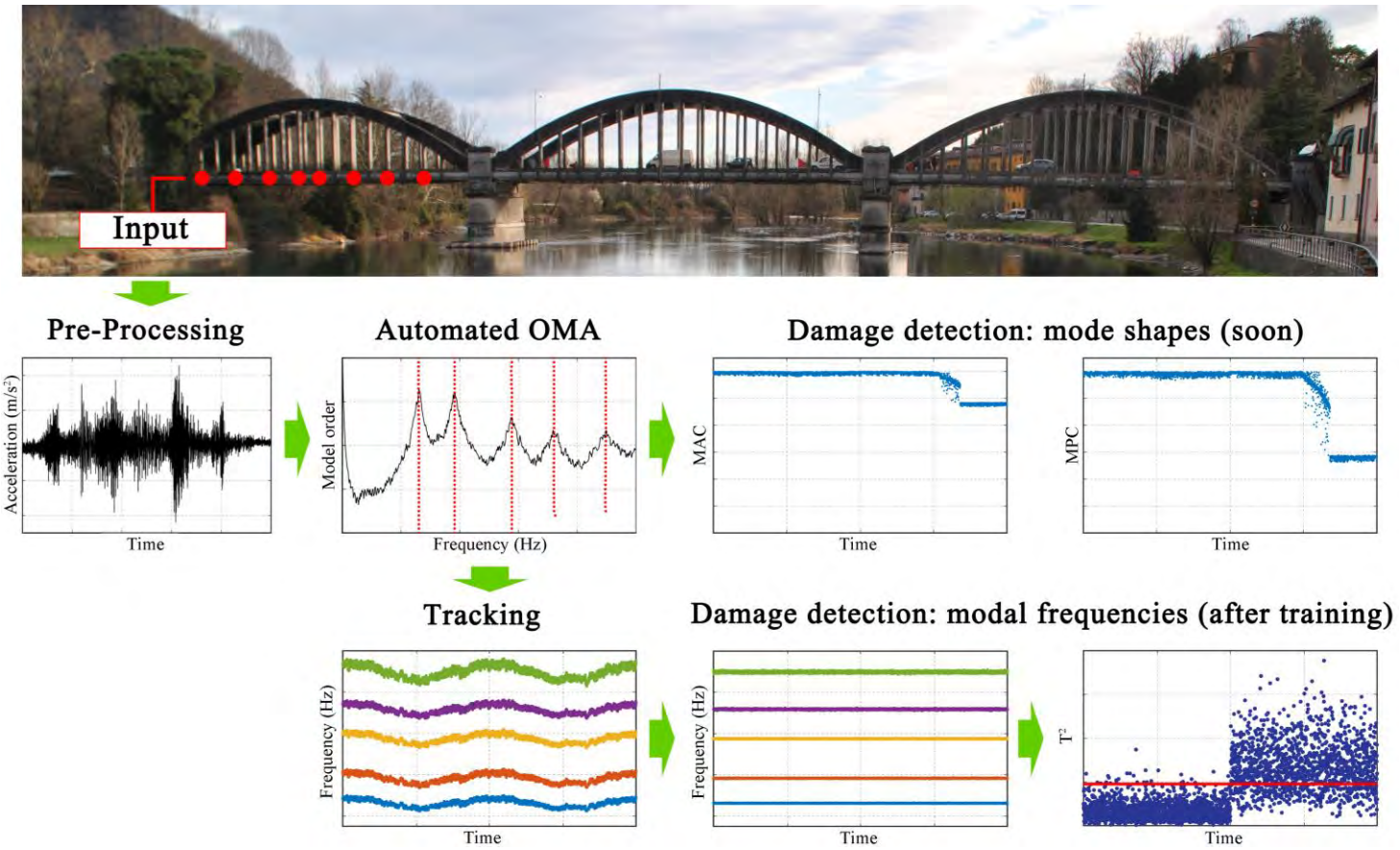
Borlenghi, P., Gentile, C., & Zonno, G. (2021). Monitoring reinforced concrete arch bridges with operational modal analysis. *Eurostruct 2021. Padua, Italy*.

Brivio bridge: temperature effect on modal frequencies



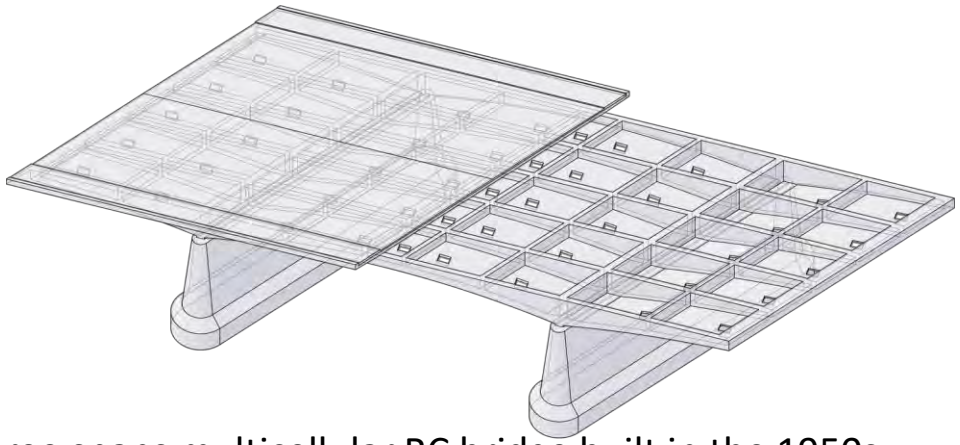
Borlenghi, P., Gentile, C., & Zonno, G. (2021). Monitoring reinforced concrete arch bridges with operational modal analysis. *Eurostruct 2021. Padua, Italy*.

Brivio bridge: damage detection



Borlenghi, P., Gentile, C., & Zonno, G. (2021). Monitoring reinforced concrete arch bridges with operational modal analysis. *Eurostruct 2021. Padua, Italy*.

Mella bridge: static monitoring for maintenance management



Three spans multicellular RC bridge built in the 1950s

Skew deck of width 17.6 m

Total length 42.8 m

3 spans with variable depth (1.4 - 2.8 m): 22 m + 2×10.4 m

Lead sheet bearings

2 piers on deep pile foundations

Zani, G., Scalbi, A., Ferreira, K. F., Somaschini, C., & DiPrisco, M. (2021). Load testing and structural monitoring of a reinforced concrete mid-century bridge. *Eurostruct 2021. Padua, Italy*.

Mella bridge: preliminary investigations

Wide diagnostic campaign

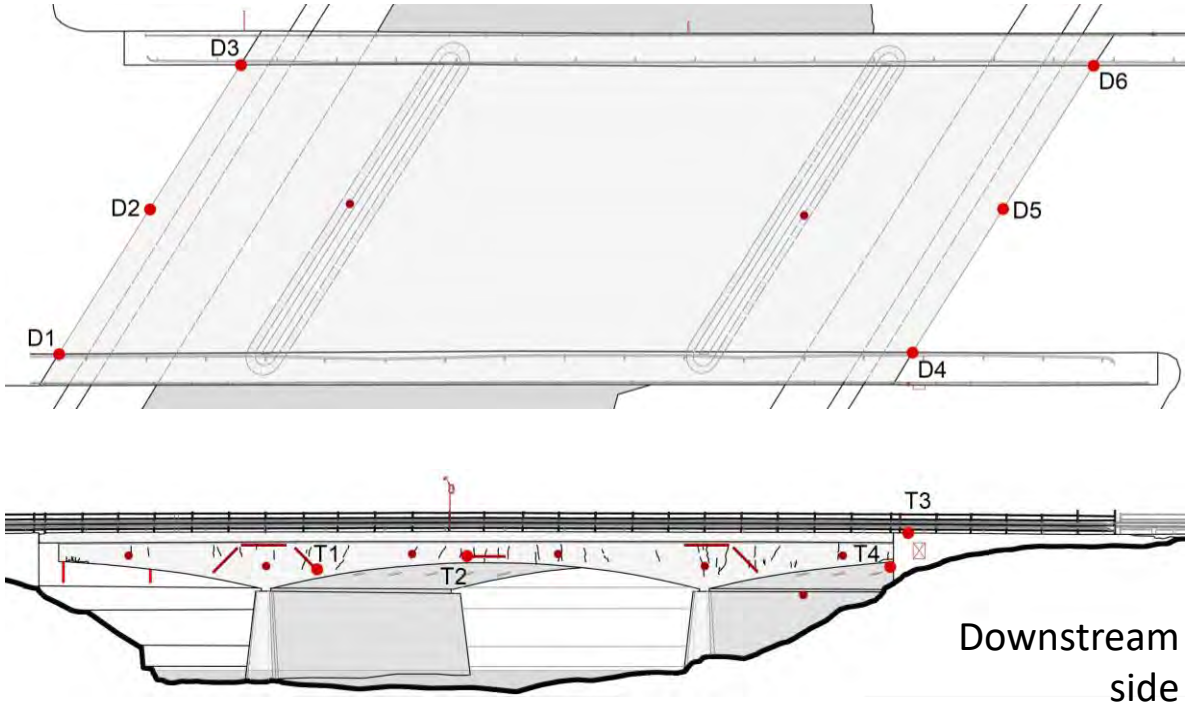
- Laser scanner and photogrammetric survey
- Dynamic characterization (AVT)
- Material characterization (DT and NDT)
  - Concrete coring
  - Carbon tests (right bank pier)
  - Radar scans (piers and deck)
  - Direct sonic pulse velocity tests (SPV, piers)
  - Indirect ultra-sonic pulse velocity tests (deck)
  - Rebound hammer tests
  - Measurement of exposed rebars

Zani, G., Scalbi, A., Ferreira, K. F., Somaschini, C., & DiPrisco, M. (2021). Load testing and structural monitoring of a reinforced concrete mid-century bridge. *Eurostruct 2021. Padua, Italy*.

Mella bridge: static monitoring system

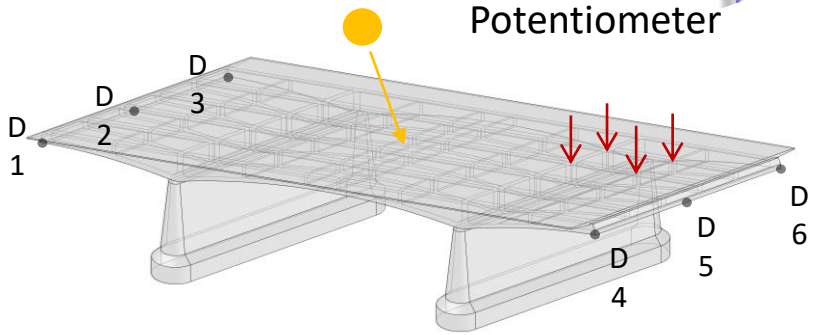
Measurements: displacement and rotations, crack opening, water , temperature, flow rate

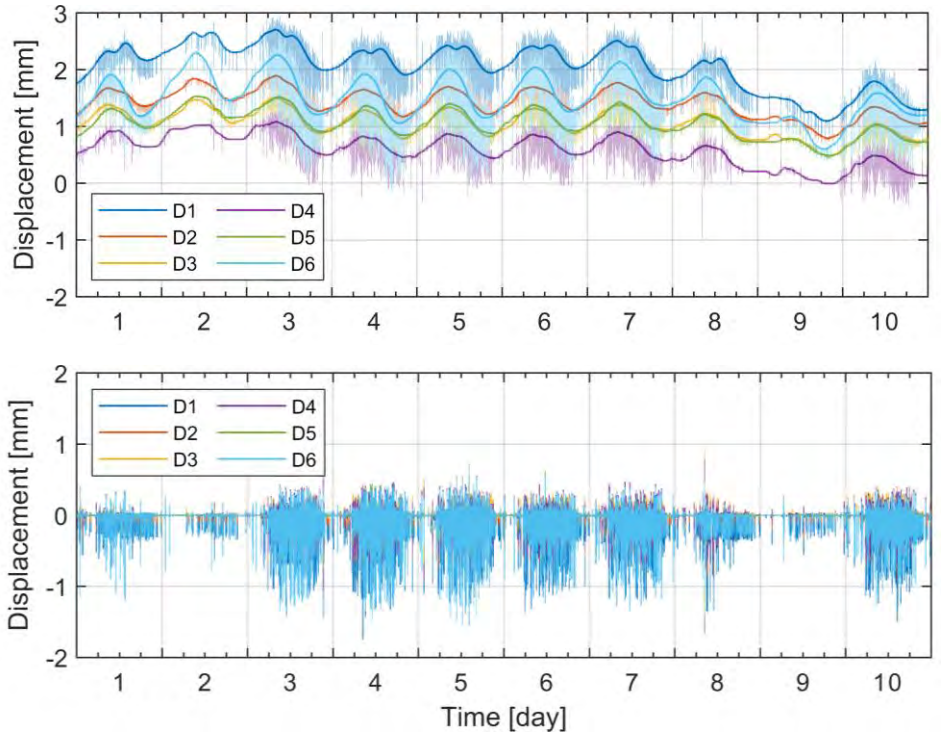
- 8 biaxial MEMS tiltmeters on the deck and at the top of the piers
- 12 electrical wire deformometers (D)
- 4 surface temperature sensors (T)
- 1 hydrometer ,1 digital camera
- 1 weather station



Zani, G., Scalbi, A., Ferreira, K. F., Somaschini, C., & DiPrisco, M. (2021). Load testing and structural monitoring of a reinforced concrete mid-century bridge. *Eurostruct 2021. Padua, Italy*.

Mella bridge: static monitoring system





Vertical displacements affected by traffic and temperature ($\Delta T=1°\div26.5°$ at the deck top and $\Delta T=5°\div9.5°$ at bottom).

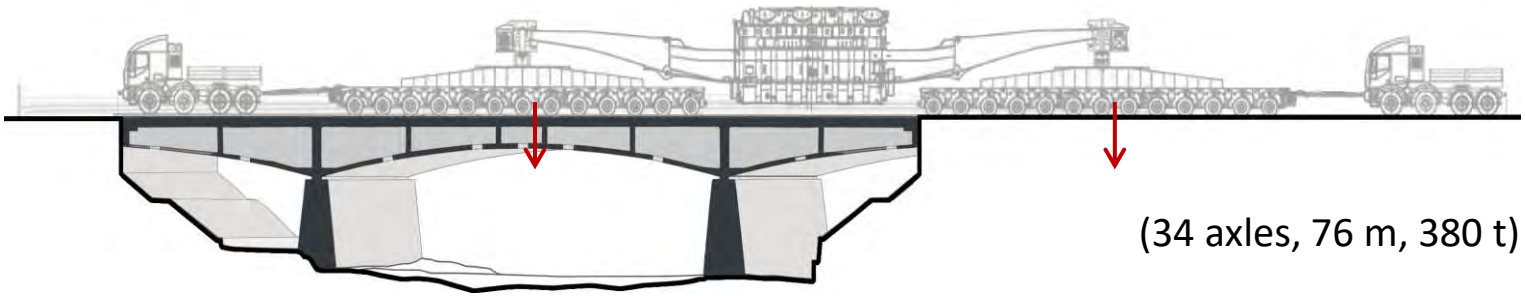
Removing the temperature effect, the vertical displacements due to traffic range between +1 and -2 mm

Zani, G., Scalbi, A., Ferreira, K. F., Somaschini, C., & DiPrisco, M. (2021). Load testing and structural monitoring of a reinforced concrete mid-century bridge. *Eurostruct 2021. Padua, Italy*.

Mella bridge: static load test

The monitoring system recorded the passage of a heavy goods vehicle transporting a massive transformer.

Two load configurations were measured

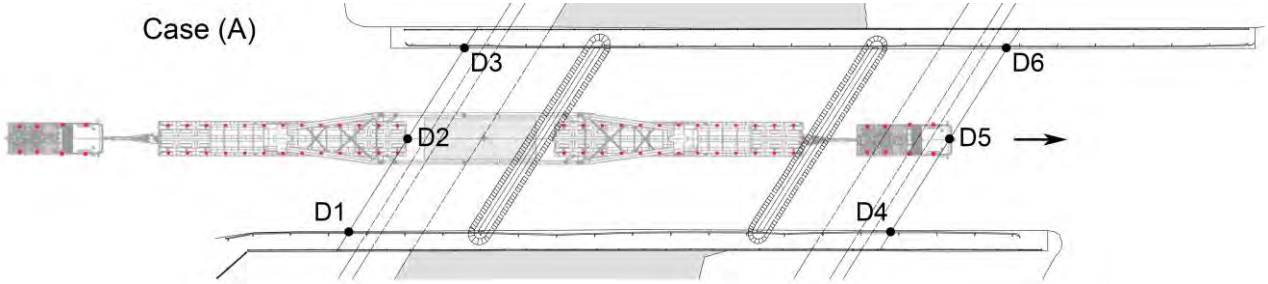


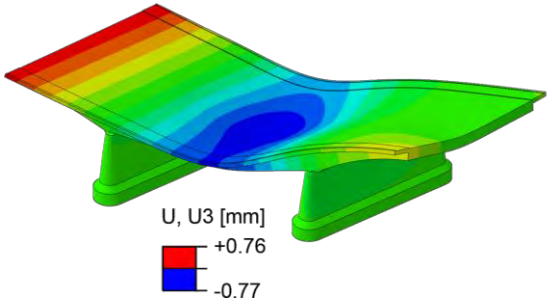
(34 axles, 76 m, 380 t)

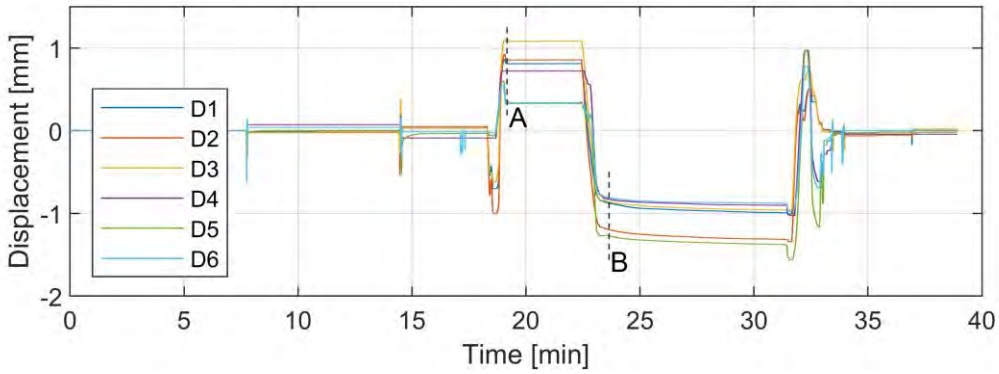
Zani, G., Scalbi, A., Ferreira, K. F., Somaschini, C., & DiPrisco, M. (2021). Load testing and structural monitoring of a reinforced concrete mid-century bridge. *Eurostruct 2021. Padua, Italy*.

Mella bridge: model calibration

1st combination: max load on the central span





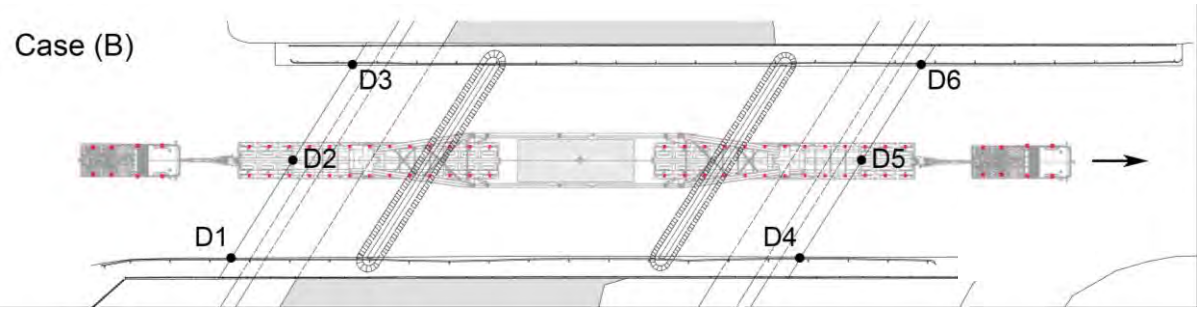


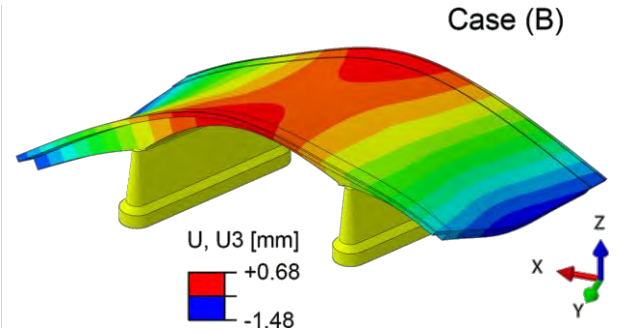
Under the HGV load, the vertical displacements range between +1 and -2 mm

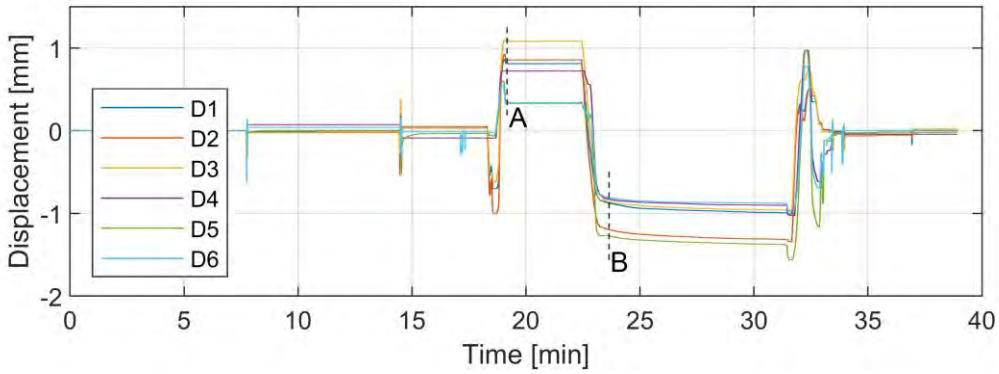
Zani, G., Scalbi, A., Ferreira, K. F., Somaschini, C., & DiPrisco, M. (2021). Load testing and structural monitoring of a reinforced concrete mid-century bridge. *Eurostruct 2021. Padua, Italy*.

Mella bridge: model calibration

2nd combination: max load on the lateral spans







Under the HGV load, the vertical displacements range between +1 and -2 mm

Zani, G., Scalbi, A., Ferreira, K. F., Somaschini, C., & DiPrisco, M. (2021). Load testing and structural monitoring of a reinforced concrete mid-century bridge. *Eurostruct 2021. Padua, Italy*.

Isola Dovarese bridge: remote and hydraulic monitoring for maintenance management

Year of construction: 1969

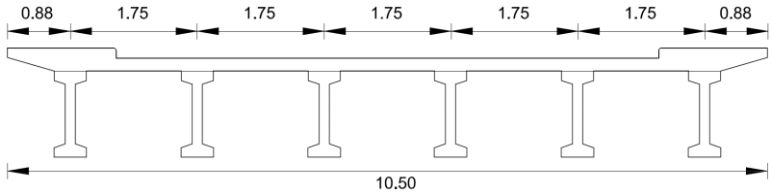
Total length: 107,00 m

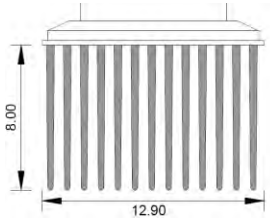
Number of Spans: 7

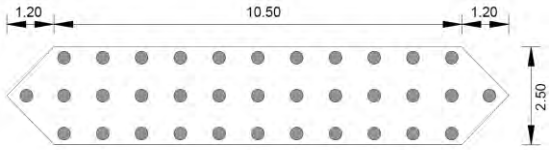
Spans: 7 simply supported (8,40÷18,00 m)

Deck width: 10,50 m

Foundation: Piles







Bianchi, S., Biondini, F., D'Angelo, M., Ballio, F., Anghileri, M., Rosati, G., & Cazzulani, G. (2021). Satellite-based Structural and Hydraulic Monitoring of a 50-year-old Bridge over the Oglio River. Eurostruct 2021. Padua, Italy.

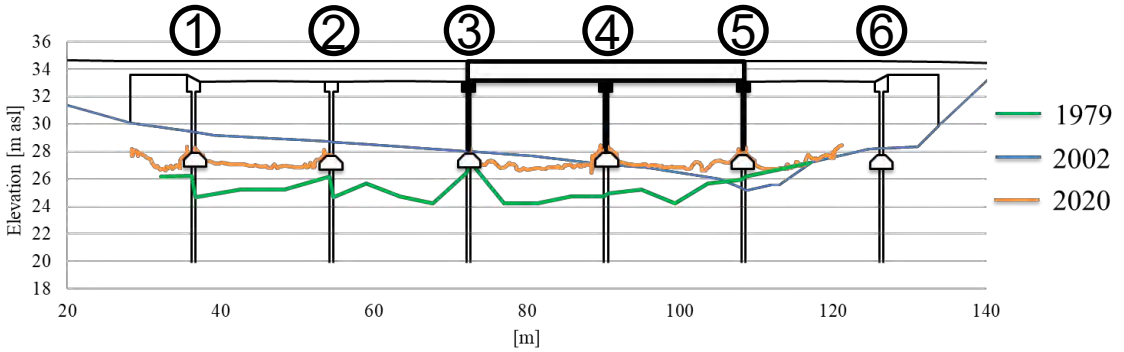
Isola Dovarese bridge: preliminary investigations

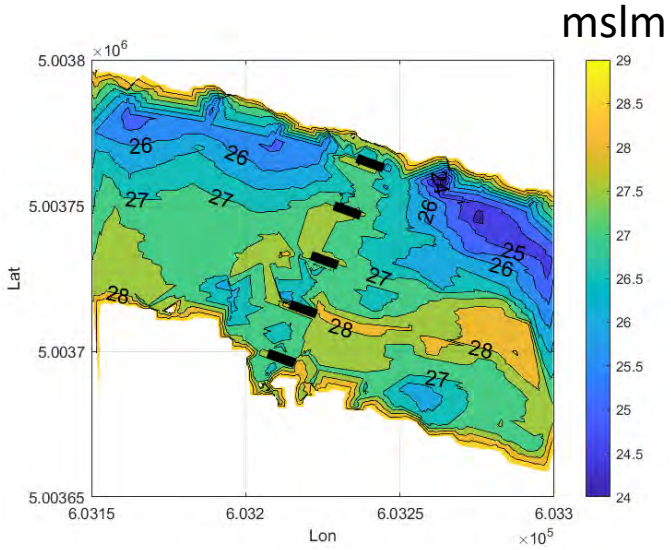
2018: DESTRUCTIVE AND NON DESTRUCTIVE TESTS

2019: PASSIVATION OF PIERS REINFORCING BARS

Bianchi, S., Biondini, F., D'Angelo, M., Ballio, F., Anghileri, M., Rosati, G., & Cazzulani, G. (2021). Satellite-based Structural and Hydraulic Monitoring of a 50-year-old Bridge over the Oglio River. Eurostruct 2021. Padua, Italy.

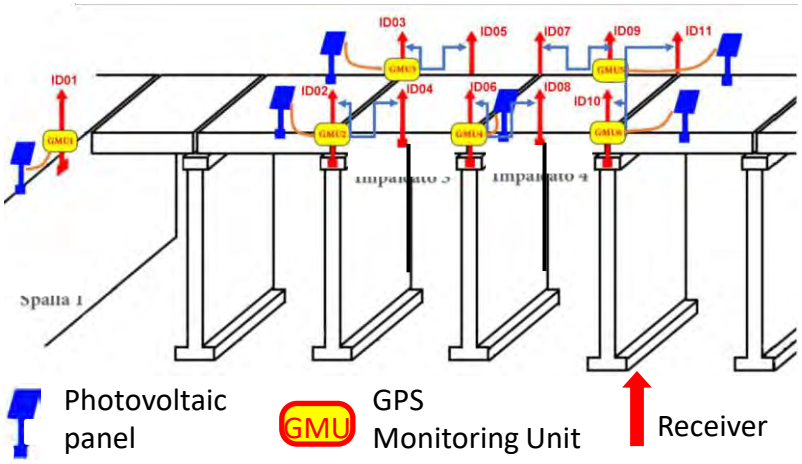
Isola Dovarese bridge: hydraulic monitoring

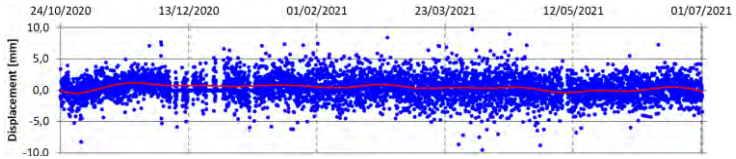




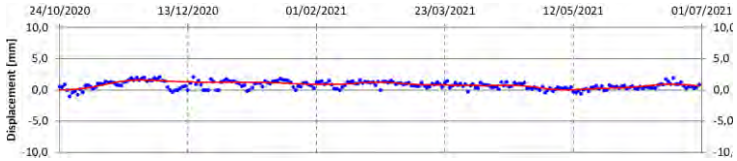
Bianchi, S., Biondini, F., D'Angelo, M., Ballio, F., Anghileri, M., Rosati, G., & Cazzulani, G. (2021). Satellite-based Structural and Hydraulic Monitoring of a 50-year-old Bridge over the Oglio River. Eurostruct 2021. Padua, Italy.

Isola Dovarese bridge: GPS-based monitoring





1-hour time interval



24-hour time interval

Bianchi, S., Biondini, F., D'Angelo, M., Ballio, F., Anghileri, M., Rosati, G., & Cazzulani, G. (2021). Satellite-based Structural and Hydraulic Monitoring of a 50-year-old Bridge over the Oglio River. Eurostruct 2021. Padua, Italy.

Conclusions

The MoRe Guidelines if the Lombardia region in Italy have a **twofold objective**:

- to support allocation of resources on behalf of the authority of regional transport
- to guide professionals in the design of monitoring systems

A **design conceptual workflow** is proposed stemming from the decision problem to tackle is proposed

The approach is demonstrated in **nine pilots.**

Data processing is ongoing

Future development

Currently the **second phase of the project** is being discussed.

Planned developments include:

- the use of the data to **develop digital tools** for decision support across lifecycle (e.g., digital twins);
- the development of procedures to identify the **optimal information** to support decisions for different bridge typologies, and
- the implementation of techniques for **data fusion** to benefit from the several types of installed monitoring systems
- The use of data to develop and validate **deterioration models** to support maintenance planning

Research team

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Dept. of Mechanics

Marco Belloli, Ferruccio Resta, Gabriele Cazzulani, Lorenzo Benedetti, Claudio Somaschini, Lorenzo Bernardini.

Paola Vigo, Aldo Colombo

Questions?