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MILANO 2024

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Innovative Hybrid Digital Twin for Structural Health Monitoring

The case study of the Mincio's bridges

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- **Project scope**
- SHM technology
- Data Processing and Analysis Procedures
- Expected Outcome to Benefit A4

PROJECT SCOPE

SHM of bridges involves implementing a systematic approach to continuously monitor their structural integrity and performance over their operational lifetime to ensure:

- safety,
- optimize maintenance strategies,
- extend the lifetime of the structures,
- and evaluate the single bridge and network performance after an extreme event

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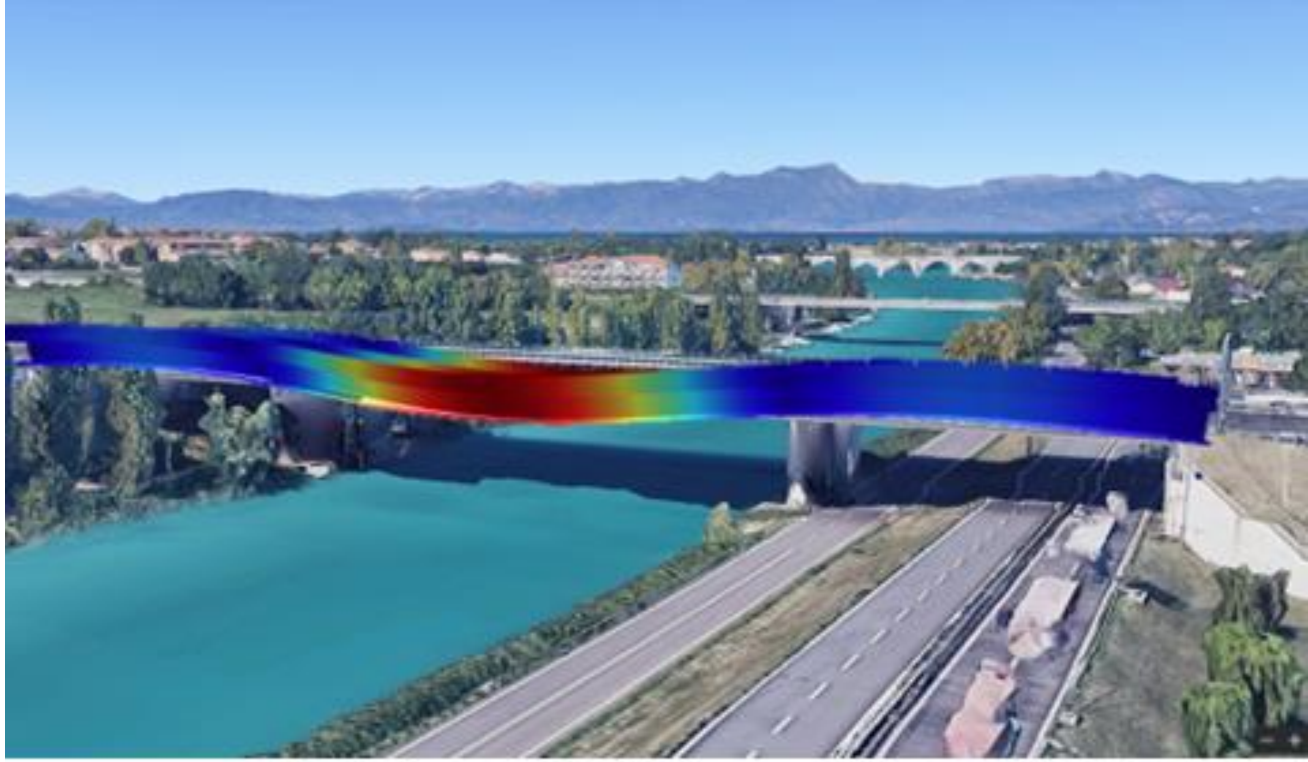

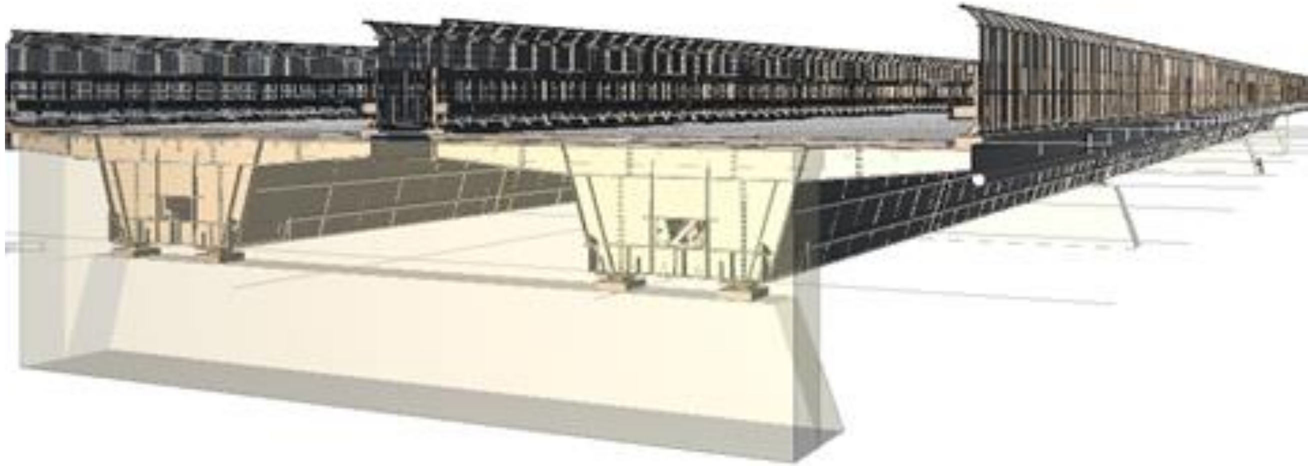

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SHM TECHNOLOGY

Cabled Technology

- ✓ Using triggers and time windows is very limited for highways
- ✓ The system continuously acquires dynamic data to train the AI algorithms
- ✓ Durable IP68;
- ✓ it overcomes the line-of-sight restriction
- ✓ Prevents pocket data loss.

State of the Art Technology

- ✓ Nonlinear finite element (NLFE) software
- ✓ Artificial Intelligence (AI) algorithms integrated with our FEM-GUI and hardware system
- ✓ Extreme Speed combining AI and implicit/explicit solutions, submodelling techniques, multiple CPUs and GPUs,
- ✓ Synchronized, modular, scalable, robust, continuous, and cost-effective

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SHM: SOFTWARE TECHNOLOGY

Artificial Intelligence (AI) and integrated FEM software

1 | **OSP Software**
Genetic algorithms

2 | **Acquisition, Selection, + Signal Processing**
AI algorithms

3 | **Unsupervised Data Driven Structural Identification and Damage Detection**
Frequency and modal identification, and AI algorithms to detect the anomalies and send alerts

4 | **Supervised Model Driven Hybrid Digital Twin (HDT)**
Sensors signals integrated with the FEM.

5 | **Online Dashboard**
Online based dashboard used for decision making

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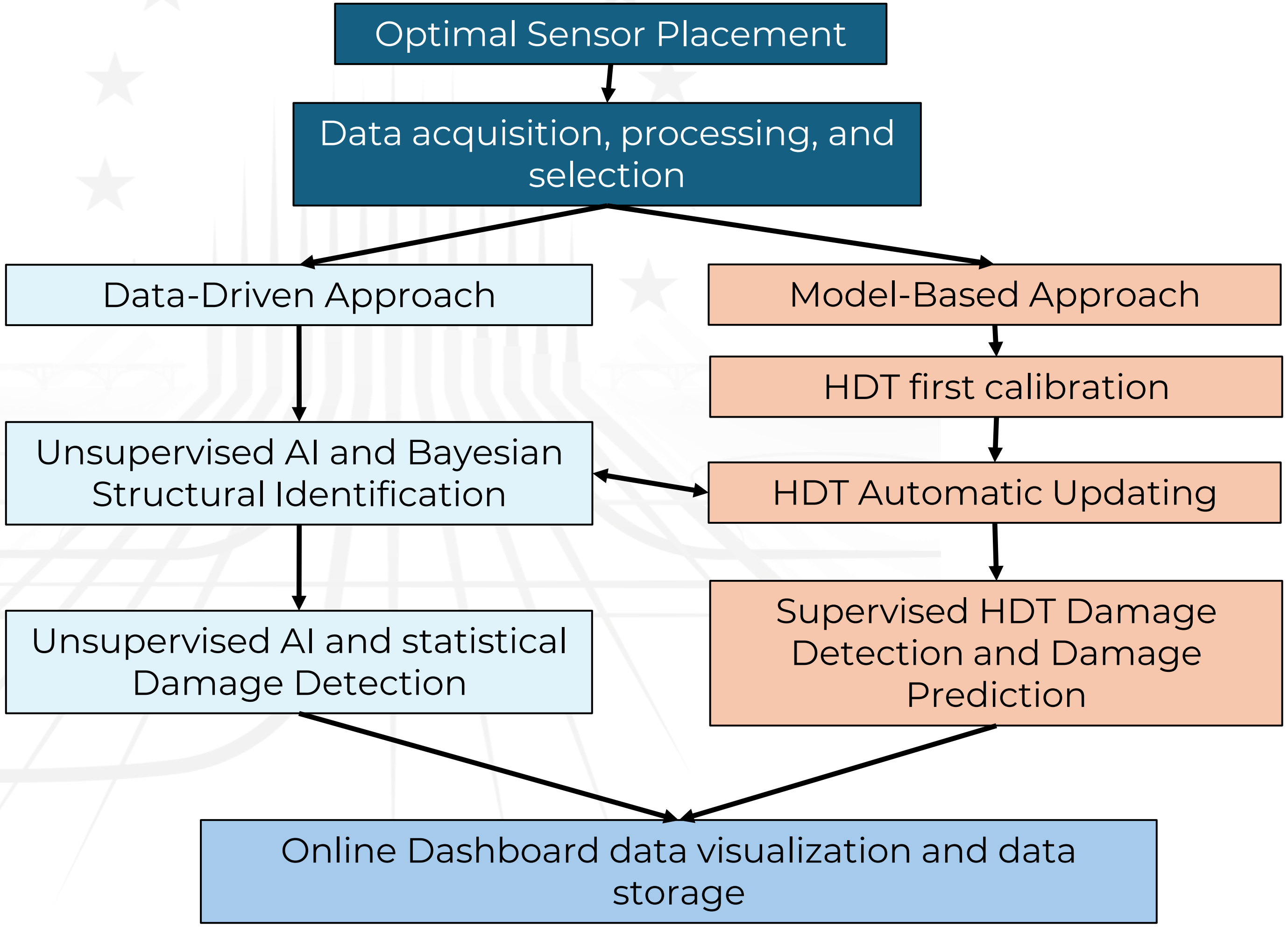
DATA PROCESSING + ANALYSIS PROCEDURES

Mincio's bridges

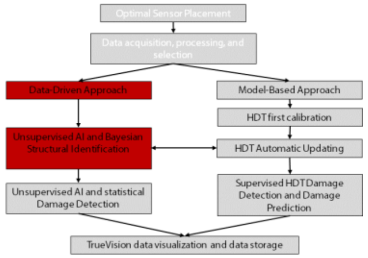
MINCIO's BRIDGE

Two steel bridges 150 meters long. They are on the busiest Italian highway, average of 26.242 heavy vehicles daily.



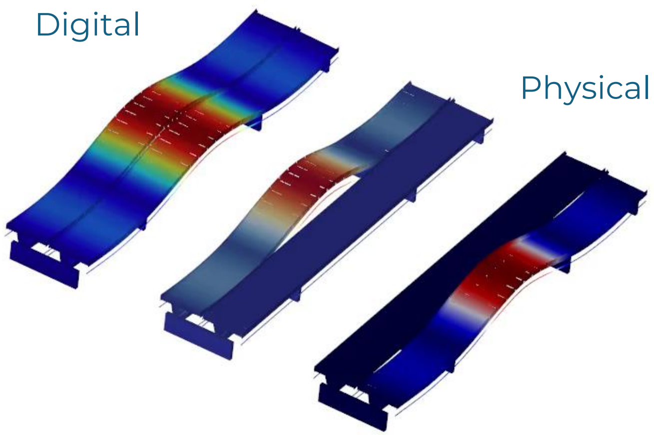
DATA PROCESSING + ANALYSIS PROCEDURES

Data-Driven Approach

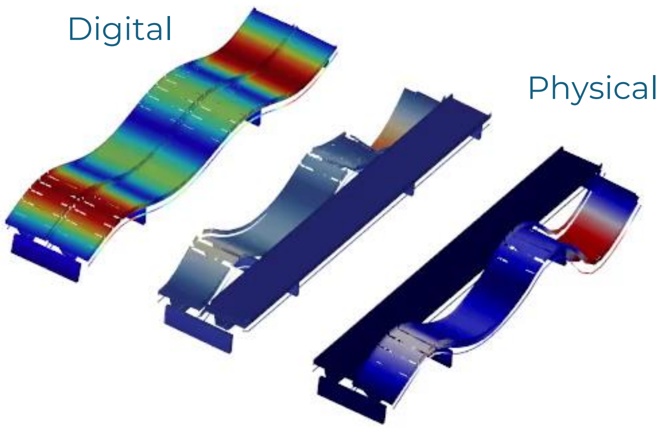


Unsupervised AI and Bayesian Structural Identification

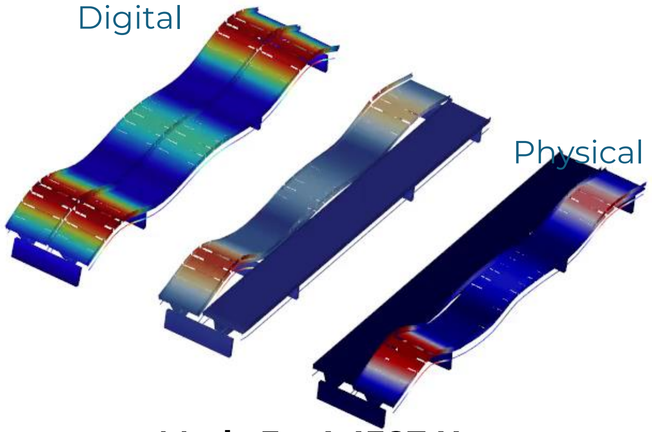
- ✓ A high automation level and an efficient elaboration for digital twins



Mode 1 – 2.0085 Hz



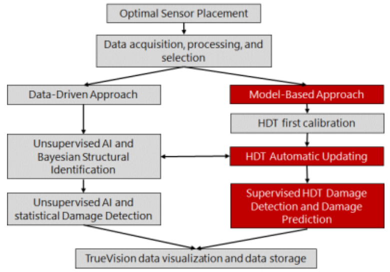
Mode 2 – 4.1294 Hz



Mode 3 – 4.4387 Hz

DATA PROCESSING + ANALYSIS PROCEDURES

Model-Based Approach

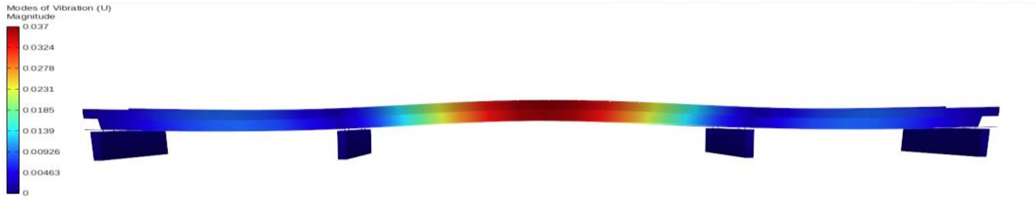


HDT Automatic Updating

- ✓ The correspondence is guaranteed via periodic updating of the numerical model

Supervised HDT Damage Detection + Damage Prediction

- ✓ The AI algorithms learn to classify "healthy" data as regular and "damaged" data as anomalous.



Alarm Check

- ✓ A numerical simulation using the Digital Twin model is run to check the consistency of the alert every time AI-based algorithms flag anomalies.

DATA PROCESSING + ANALYSIS PROCEDURES

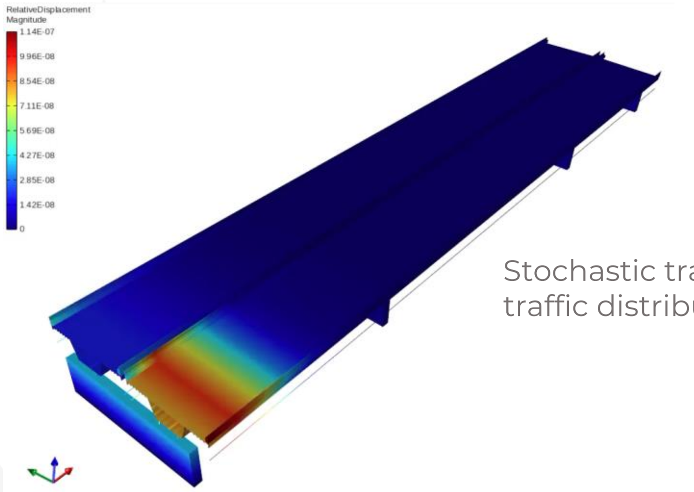
Data vs model based

Data-Based Approach

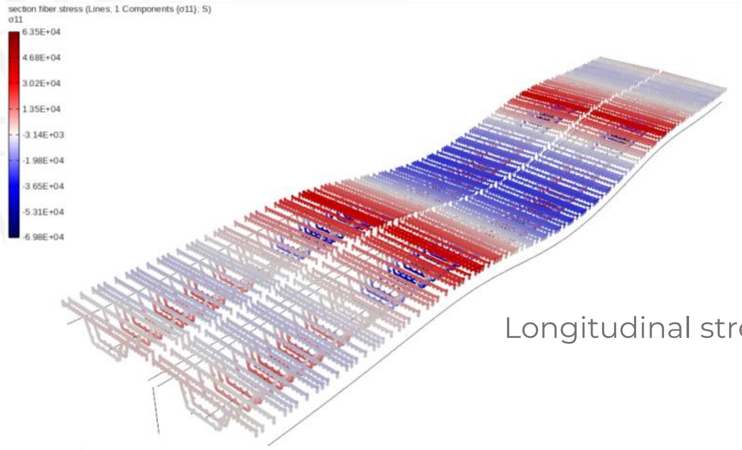
- ✓ Very efficient, automatic, and fast
- ✓ Not accurate during the training phase and for long-term evolutions
- ✓ Not as accurate as HDT in localizing the extent of damage
- ✓ Not accurate for extreme events

Model-Based Approach – HDT

- ✓ **Overcomes all the current limitations** of conventional OMA techniques.
- ✓ Trained with stochastic transient traffic distributions to **assess accurately bridges' present and future performance**
- ✓ Trained for **extreme events**
- ✓ **Very accurate damage prognosis** capability



Stochastic transient traffic distributions



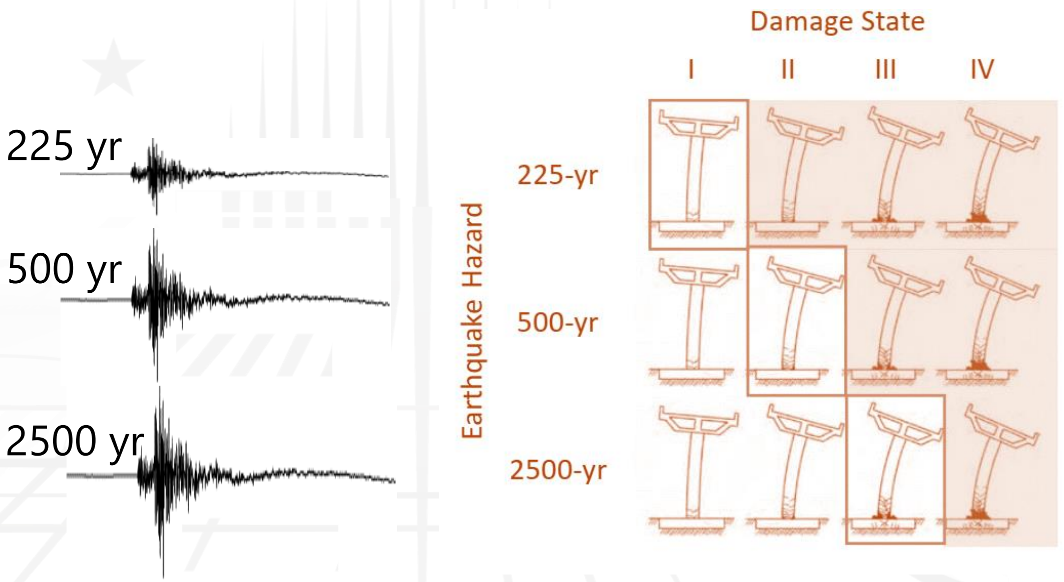
Longitudinal stresses

DATA PROCESSING + ANALYSIS PROCEDURES

Extreme events

AI Training +Analyses

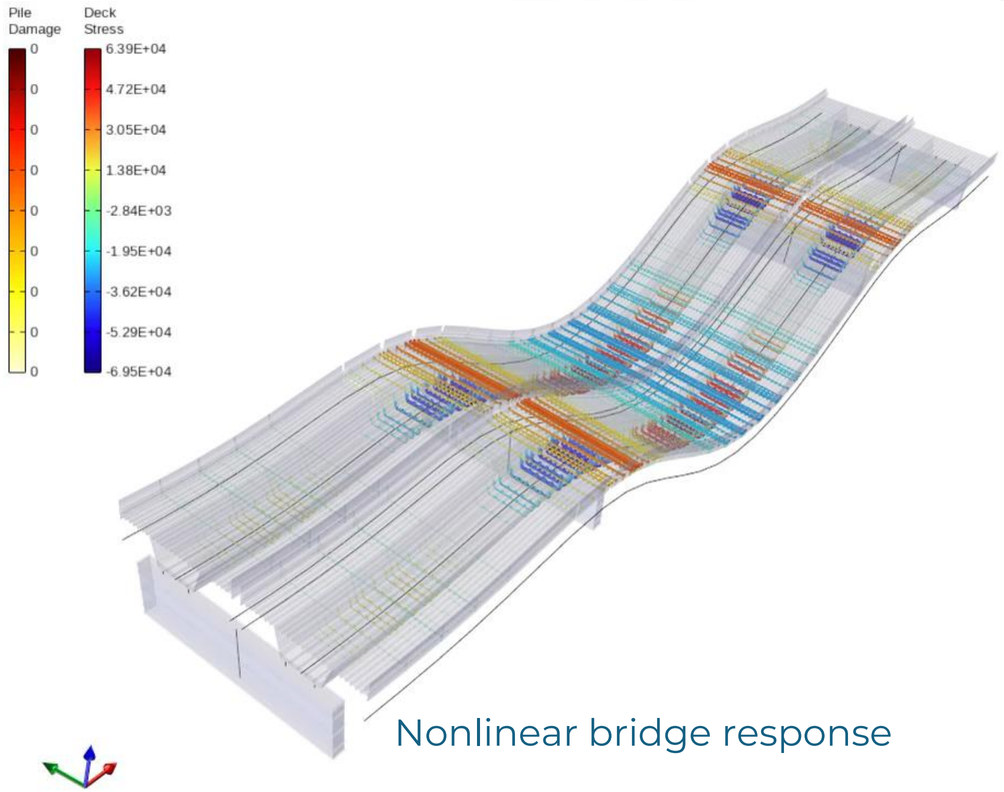
- ✓ Define the site seismic hazard
- ✓ Select sets of accelerograms with different seismic intensities
- ✓ Run several analyses to evaluate the bridge vulnerability and damage scenarios
- ✓ Train the supervised AI to recognize the bridge damage



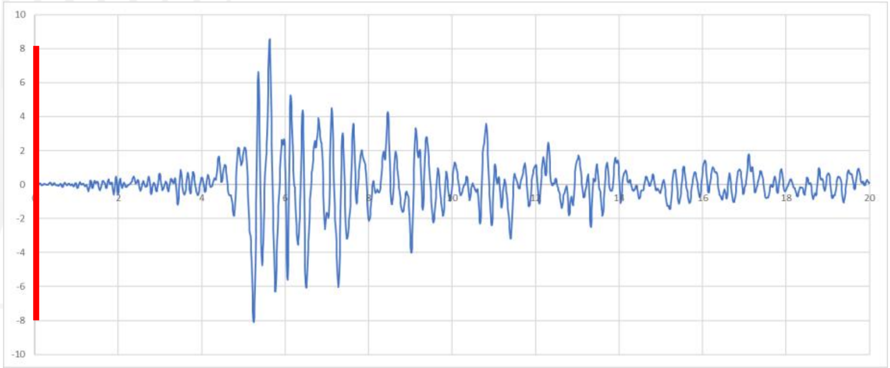
National Cooperative Highway Research Program (NCHRP), Performance-Based Seismic Bridge Design: A Synthesis of Highway Practice, (2013) Report Synthesis 440

DATA PROCESSING + ANALYSIS PROCEDURES

Extreme events



Nonlinear bridge response



Recorded accelerogram after the event

Post event assessment

- ✓ After an event, first evaluate the damage with AI (quick response) and then run the nonlinear analysis with the HDT

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- **Expected Outcome to Benefit A4**

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EXPECTED OUTCOME FOR A4 BRIDGE NETWORK

Detect and Assess any Anomalies, Deformations, Displacements, or Damage

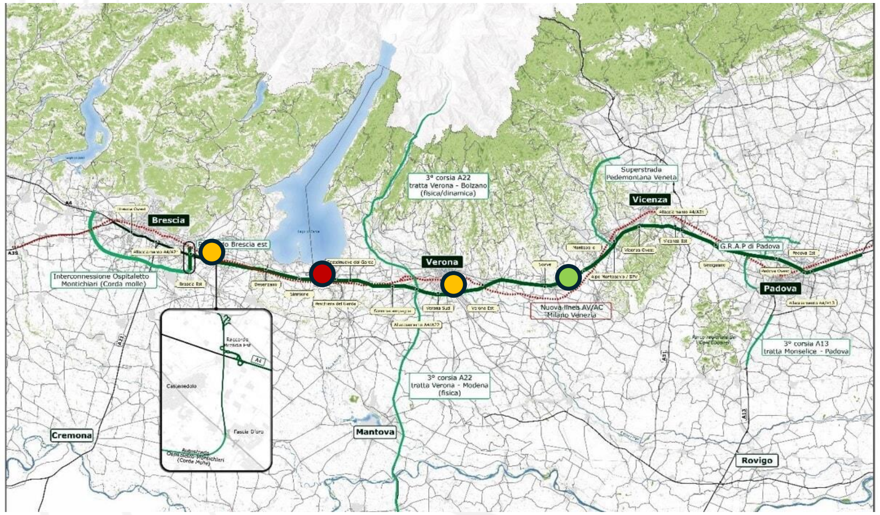
Evaluate the Performance of the Infrastructure/ Structure over Time

Detect the Effects of Extreme Events Such as Earthquakes, Windstorms, or Heavy Loads

Help to Manage Maintenance, Safety, and Emergency at the Urban Scale

Predict the Maintenance Needs Based on Real-time Data and Trends

Time and costs optimization depending on bridges' conditions



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THANK YOU

GRAZIE

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