DEWESoft® MC2024

Instrumentation and characterization of a two span post-tensioned concrete bridge

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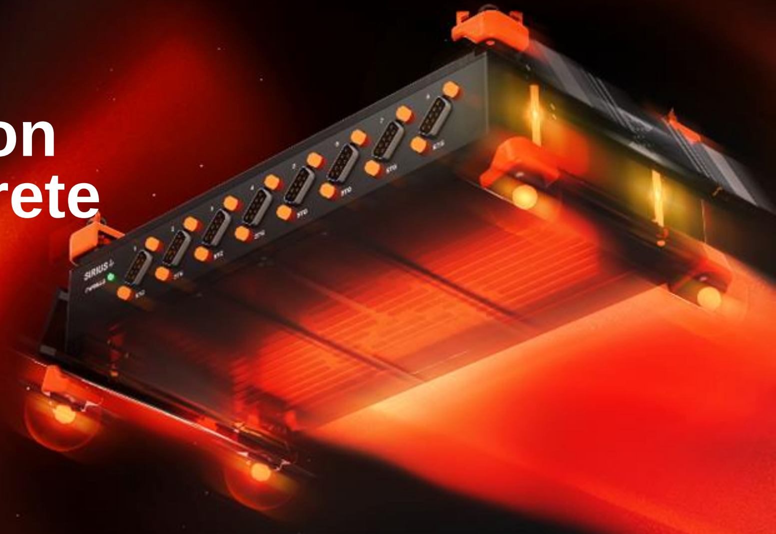
Regional Business Developer, Dewesoft AB.



DEWESoft®
measurement innovation

Agenda

- Why Structural Health Monitoring?
- How to improve engineering decision making?
- The case study
- The three-party project (KTH, StruSoft and Dewesoft)
- FE-model characterization
- Test setup
- Test results and comparison
- Introduction to an advanced application
- Typical Swedish case
- Perspective of the civil engineering industry
- Conclusion

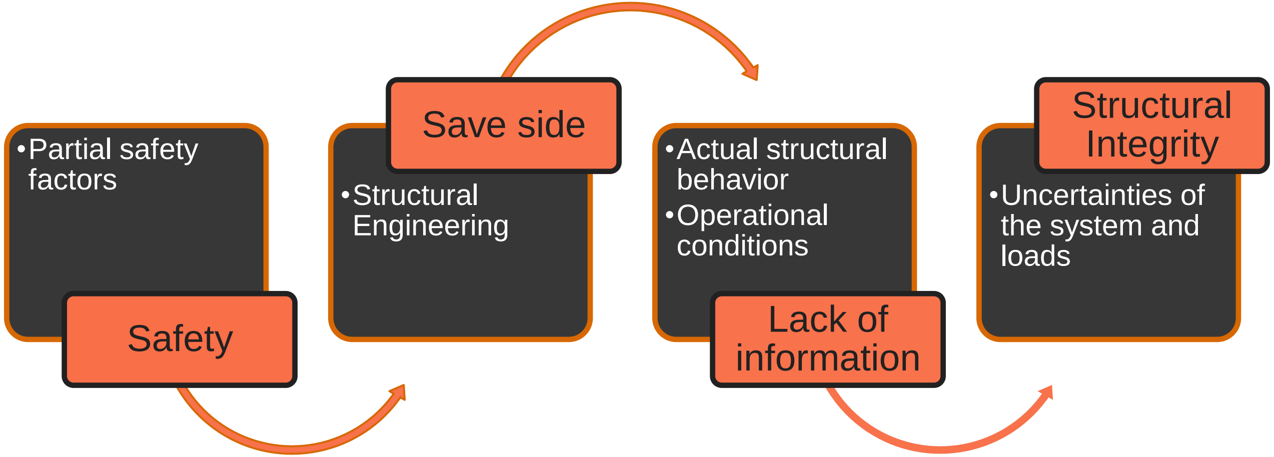
Why Structural Health Monitoring?

- Structural Health Monitoring is essential for wide range of structures such as bridges, pipelines, tunnels, oil rigs, ships, planes, trains and wind farms
- Deterioration, construction errors, quality controls, accidents and **environmental loads** lead to **wear, malfunction or damage**
- Shift from **schedule-driven** maintenance to **conditions-based** maintenance

- Safety Performance
- Early Detection
- Costs Savings and Planning
- Prolonged Service Life
- Performance Assessment

Why monitoring and testing?

Structural assessment is made based on the assumption that you can always come up with a Safe Side approach because of the Lack of Information and Safety



Monitoring Norway

DEWESoft®

Why monitoring and testing?

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ARTBA American Road & Transportation Builders Association

2022 Bridge Report

By Dr. Alison Premo Black, Chief Economist

Highlights:

- 36 percent of U.S. bridges—nearly 224,000 spans—need repair work. 78,800 bridges should be replaced.
- More than 43,500 bridges are rated in poor condition and classified as “structurally deficient.” Motorists cross these structures 167.5 million times a day.
- The number of structurally deficient bridges declined by 1,445 compared to 2020. At current pace, it would take nearly 30 years to repair them all.
- New federal investment under the Infrastructure Investment and Jobs Act will provide additional resources for state highway programs over the next five years, plus two new programs just for bridge repair.
- State-by-state and congressional district details: **artbabridgereport.org**.

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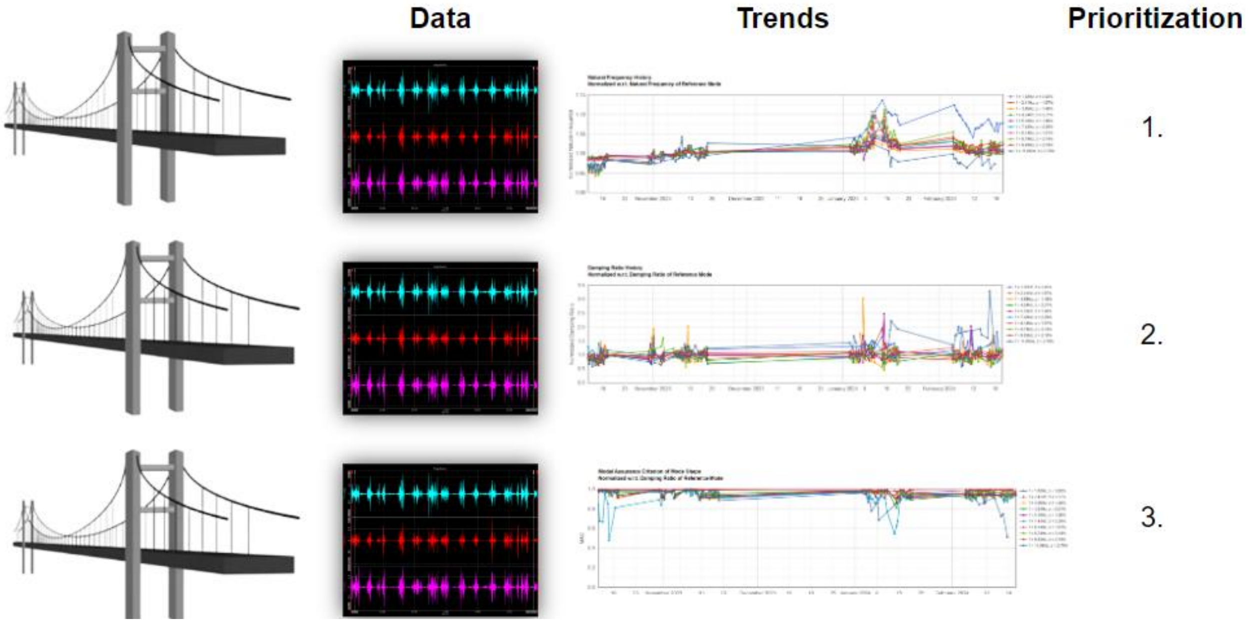

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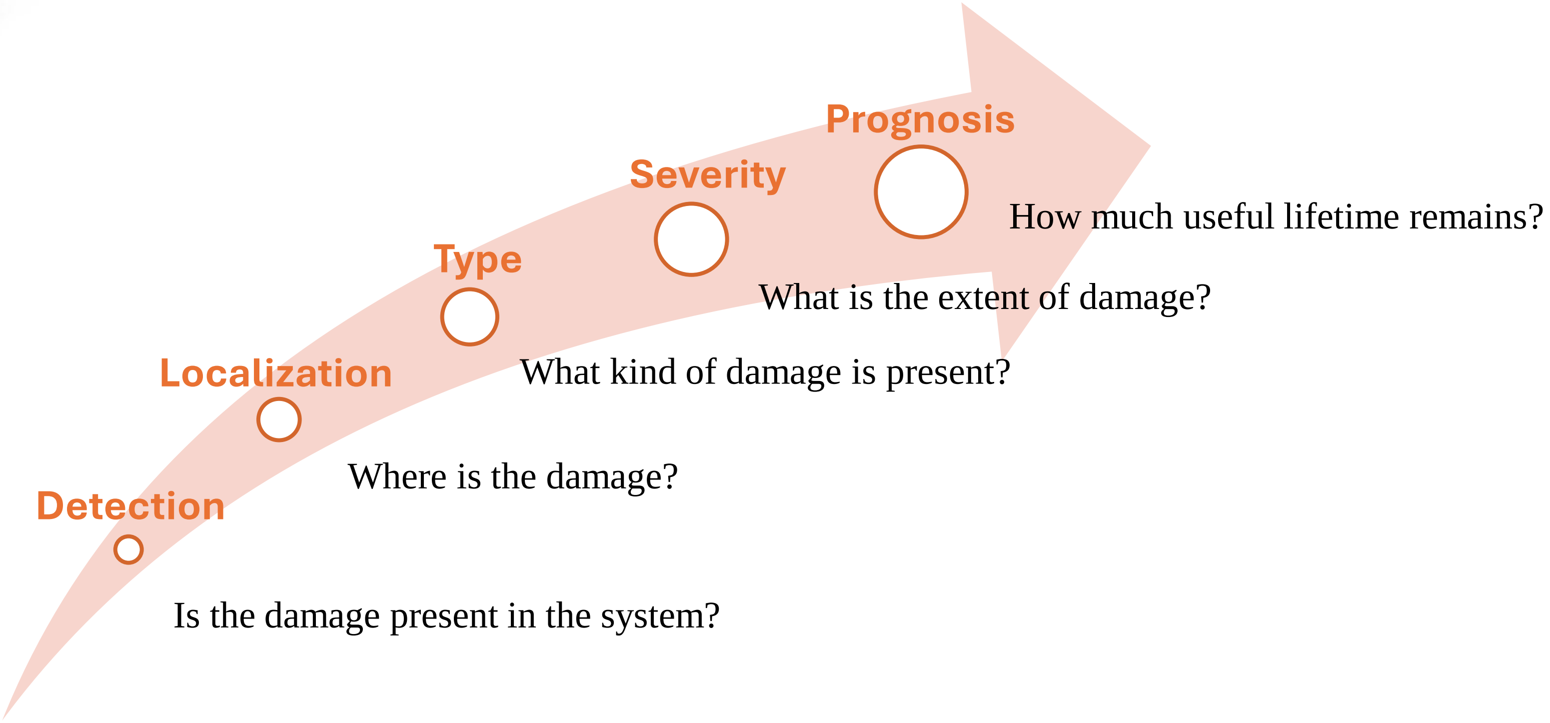

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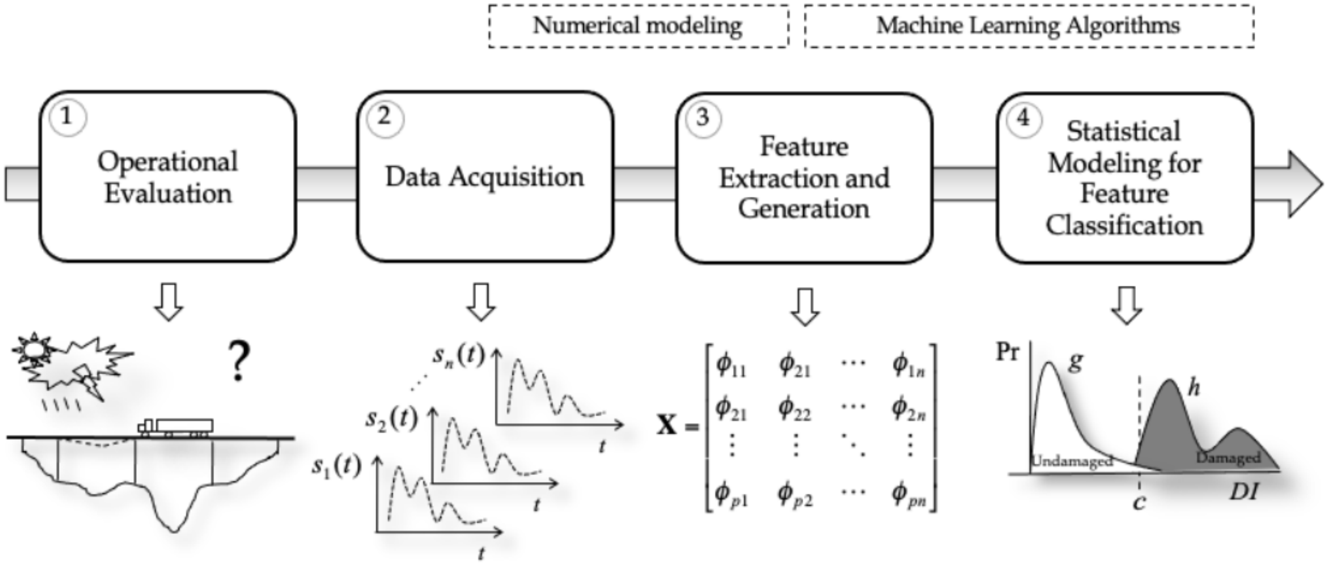
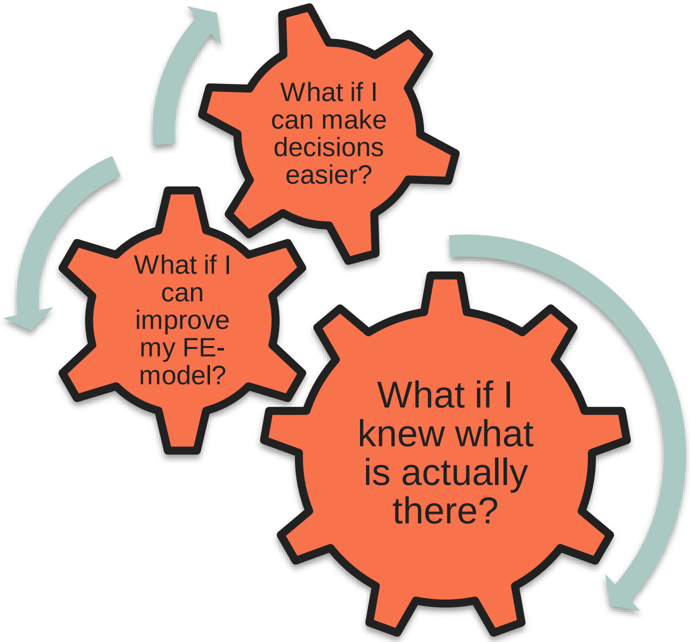
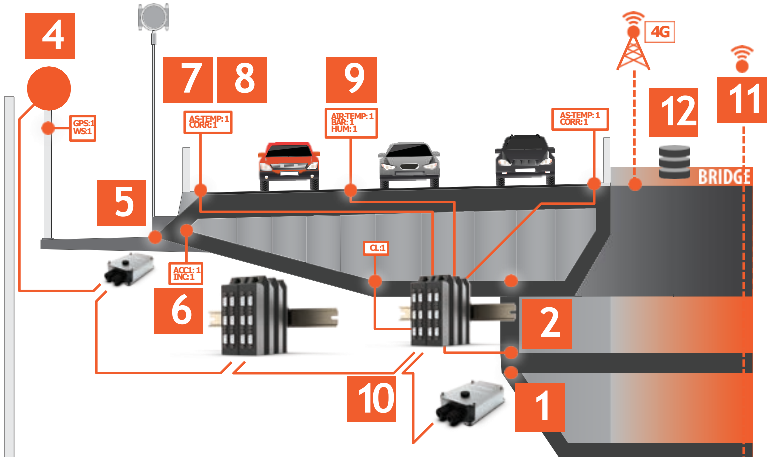


How to improve engineering decision making?

Trafikverket spends 1.3-1.5 Billion SEK per year on bridge operation and maintenance. Our stock go bridges is quite old as many are over 100 years old

- Deterioration of concrete
- Corrosion of reinforcement bars
- Corrosion of steel beams
- Fatigue
- Wear of bearings
- Wear of Expansion Joints
- Loss of prestressing forces
- Support settlements





DAQDEVICES

10- IOLITED:

From single-channel to multi-channel distributed data acquisition devices capable

11- WIRELESS DATA LOGGER: For reading the data from vibrating wire sensors.

12- DATA LOGGER: An embedded data acquisition system and data logger all in one.

INSTRUMENTATION SENSORS

SENSORS

1- ACCELERATION AND INCLINATION MEASUREMENT:
Dewesoft IOLITEdiw-3xMEMS-ACC-INC a Triaxi- al MEMS accelerometer and static inclinometer with EtherCAT interface, 8 g measurement range.

2- DISPLACEMENT MEASUREMENT: Dewesoft IOLIT-Ediw-3xMEMS-ACC a Triaxial MEM

3- STATIC STRAIN MEASUREMENT: Embedment vibrating wire strain gauge designed to be embedded into concrete structures for moni- toring static strain of concrete.

4- ALL IN ONE WEATHER STATION: Weather station providing a measurement of relative humidity, temperature, wind speed & direction, bright- ness, and twilight.

5- DYNAMIC STRAIN GAUGE: Bolt-on dynamic strain gauge designed to be mounted on the structure.

6- IOLITEDIW-3XMEMS-ACC: Triaxial MEMS accelerometer with EtherCAT interface and 8 g measurement range.

7- ASPHALT TEMPERATURE MEASUREMENT

8- CORROSION SENSOR

9- AIR TEMPERATURE AND HUMIDITY MEASUREMENT

Case study

- The KTH campus bridge consists of a post-tensioned concrete continuous two-span bridge The simply supported bridge
- An elastic modulus of 32 GPa
- The spans of the bridge are 34.75 m each
- Support column in the middle of 9 m height.

Case study

The footbridge may experience changes in its dynamic properties due to environmental conditions and it is not clear if the bridge is able to satisfy the design requirements in all the seasons.

Are we designing just for a certain season?
Can we stablish a reference system?
How can we reduce the uncertainties?

The-party project

DEWESoft® measurement innovation

- Measurement knowhow
- Sensor technology
- DAQ

StruSoft

- Engineering conceptual design
- Engineering modelling
- Shell based-model

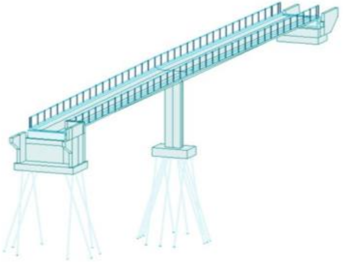
KTH VETENSKAP OCH KONST

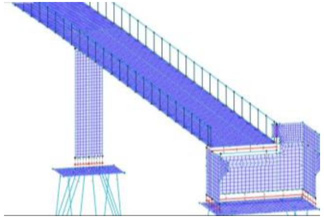
- Research approach
- Research modeling
- Solid based-model

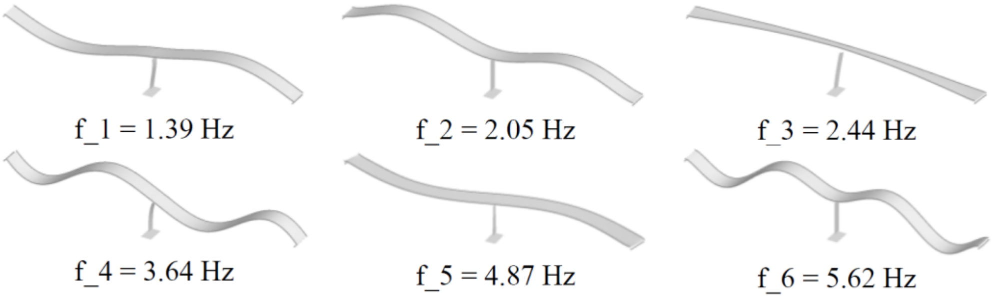
FE-model characterization
Shell Model

Parametric analysis of the natural frequencies of the system as a function of the elastic modulus of the concrete material and the boundary conditions

- Geometry
- Mesh
- Shell element
- Boundary conditions
- Railings







StruSoft

FE-model characterization
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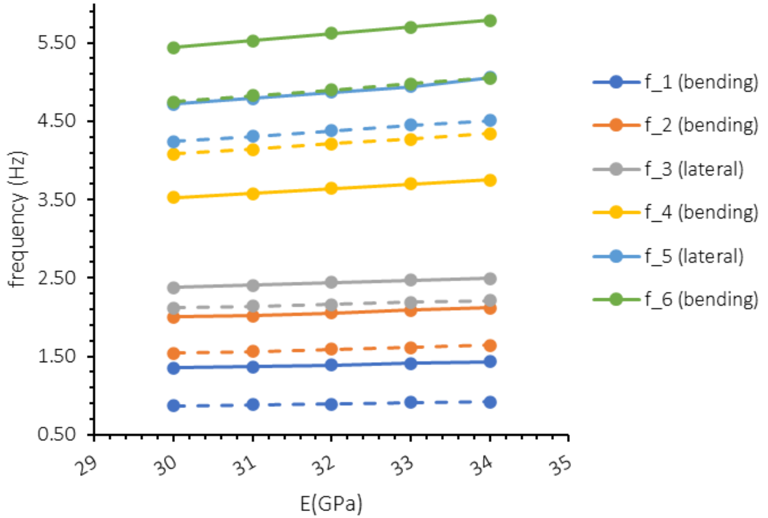
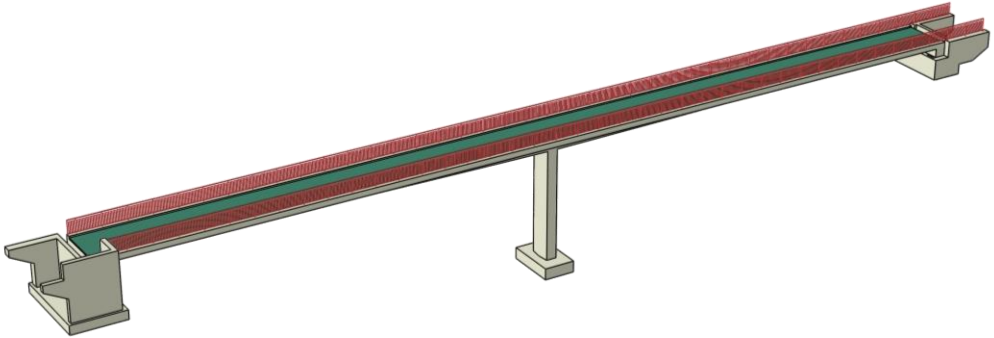
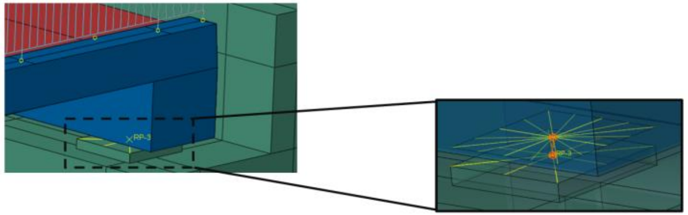


FE-model characterization
Solid Model

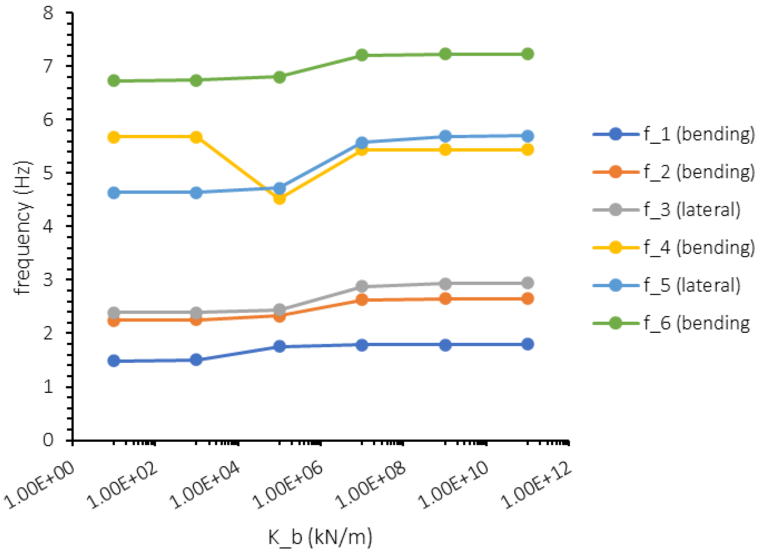
- Geometry
- Mesh
- Shell element
- Railings
- Asphalt layer
- Expansion joint – spring stiffness
- Boundary conditions – spring stiffness
- No soil-structure-interaction





FE-model characterization
Solid Model – Support Bearings

- Parametric analysis of the natural frequencies of the system as a function of the elastic spring stiffness at the support bearings

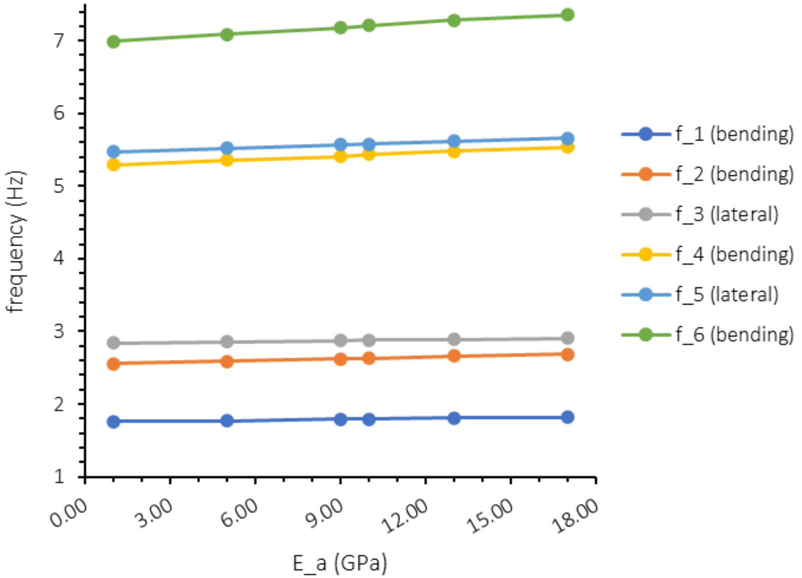


FE-model characterization Solid Model – Asphalt Layer

- Parametric analysis of the natural frequencies of the system as a function of the elastic modulus of the asphalt layer

Analysis of the elastic modulus of the asphalt layer

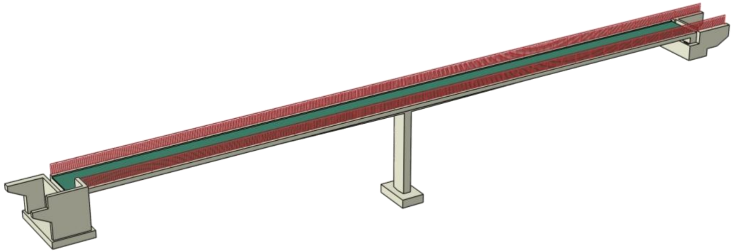
T(◦C)	ν (-)	ρ (kg/m^3)	E (Gpa)
40	0.40	2450	1
0	0.20	2450	17



Negligible changes in the MAC matrix of the system were obtained, indicating non-significant changes in the mode shapes of the system.

FE-model characterization
Solid Model – Expansion Joint

- Parametric analysis of the natural frequencies of the system as a function of the elastic spring stiffness of the expansion joint



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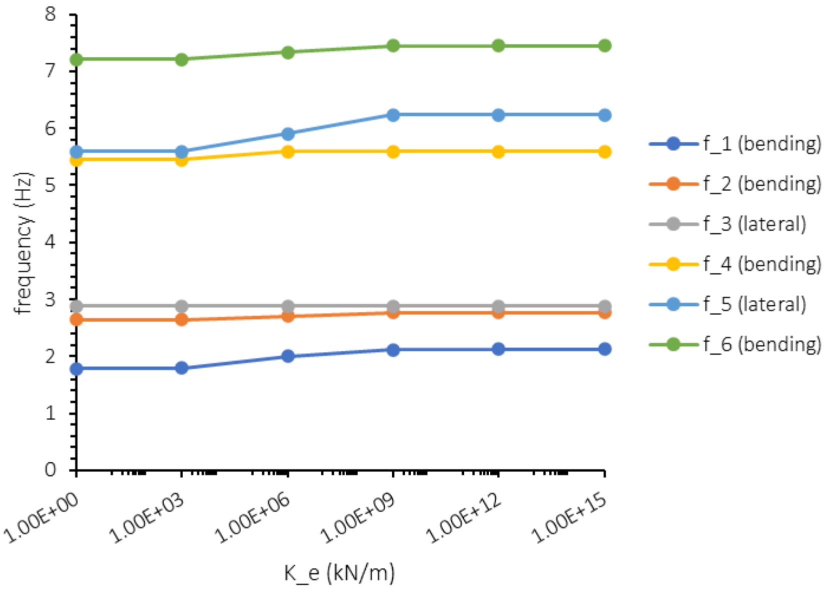
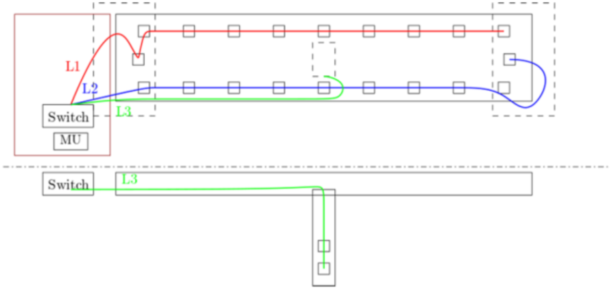


Test setup

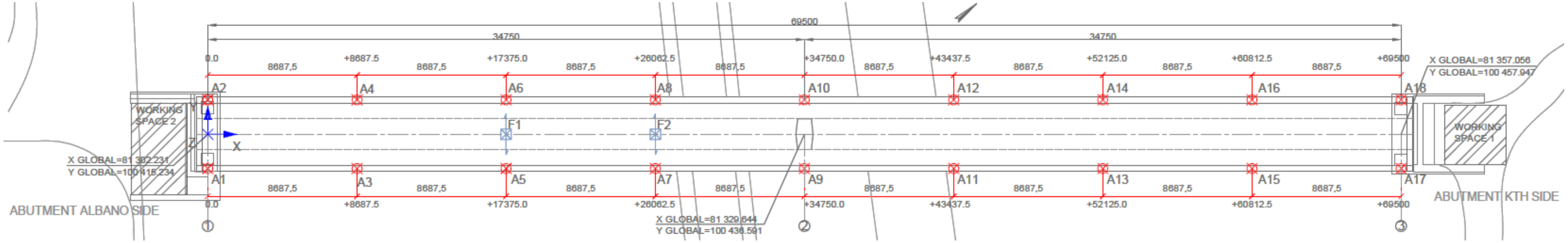
IOLITEiw-3xMEMS-ACC

IOLITEiw-3xMEMS-ACC-T

Dewesoft X
Dewesoft Artemis

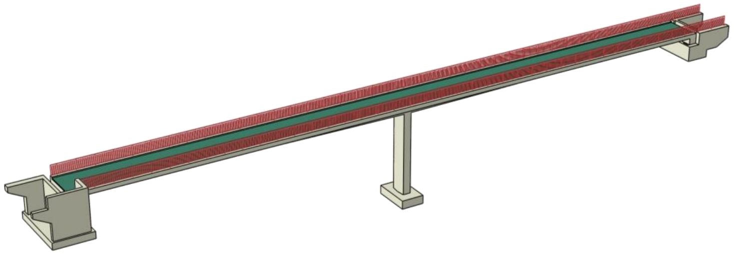


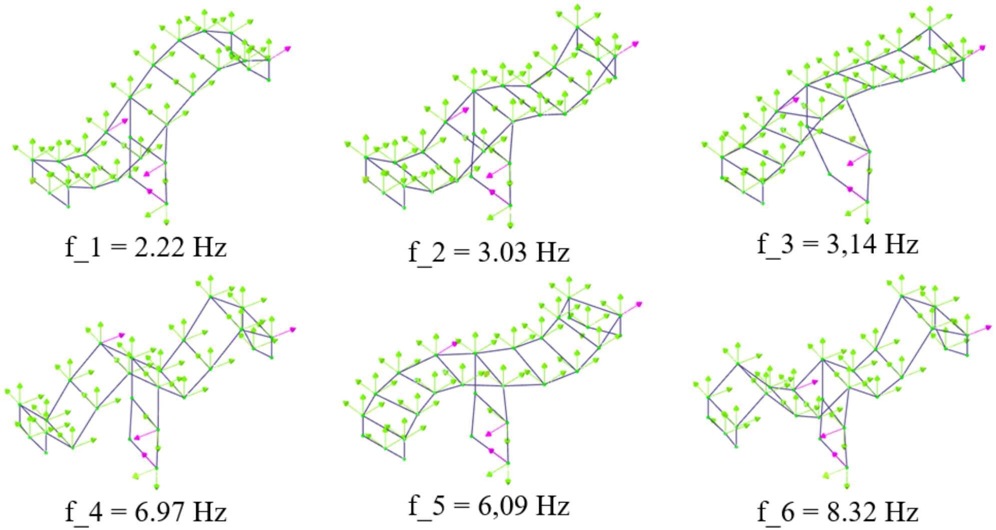
Daisy chain technology



Test results and comparison

- Experimental identified mode shapes in winter weather conditions using Dewesoft Artemis

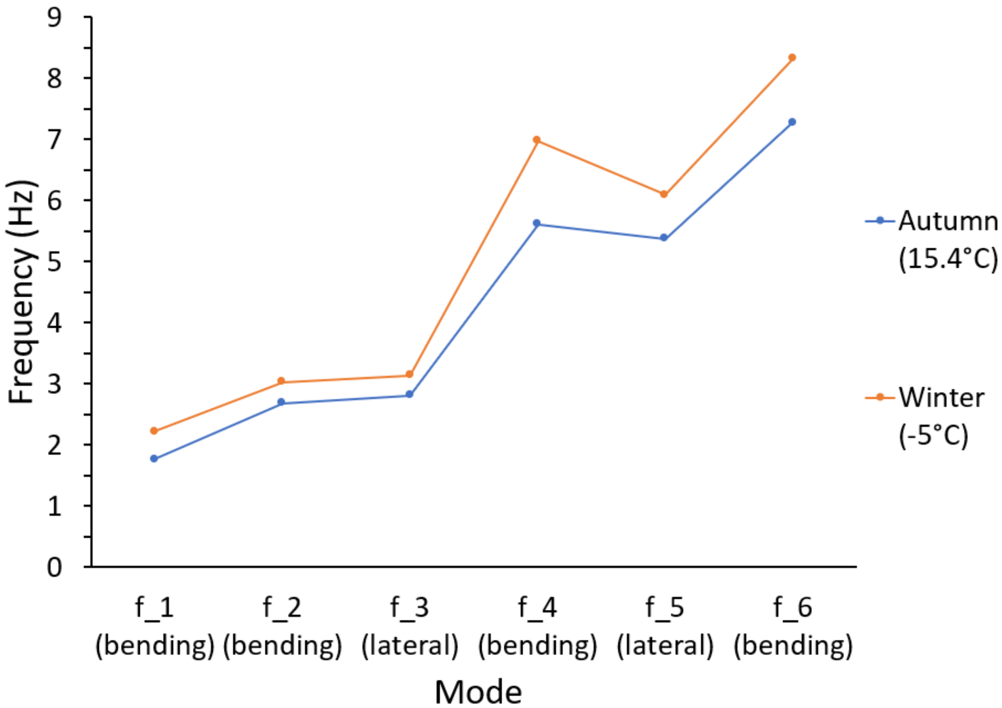




Test results and comparison

- Natural frequencies of the system in autumn and winter weather conditions

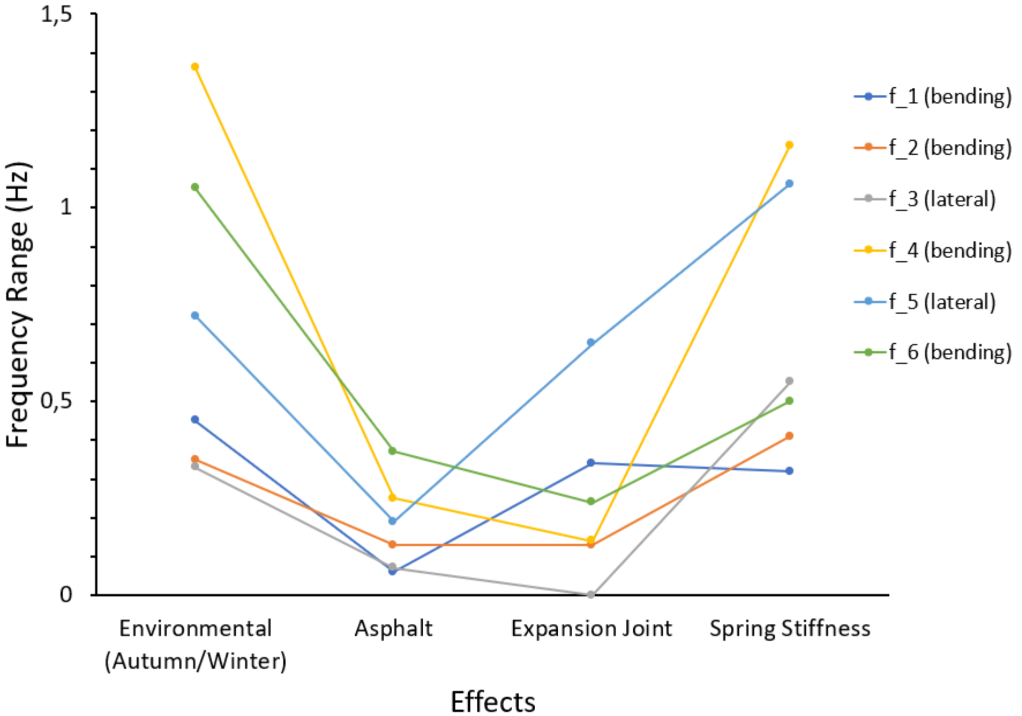
Mode	Autumn (15.4°C)	Winter (-5°C)	Range
	Frequency (Hz)		(Hz)
f_1 (bending)	1,77	2,22	0,45
f_2 (bending)	2,68	3,03	0,35
f_3 (lateral)	2,81	3,14	0,33
f_4 (bending)	5,61	6,97	1,36
f_5 (lateral)	5,37	6,09	0,72
f_6 (bending)	7,27	8,32	1,05



Test results and comparison

- Frequency change due to environmental effects and different modeling aspects

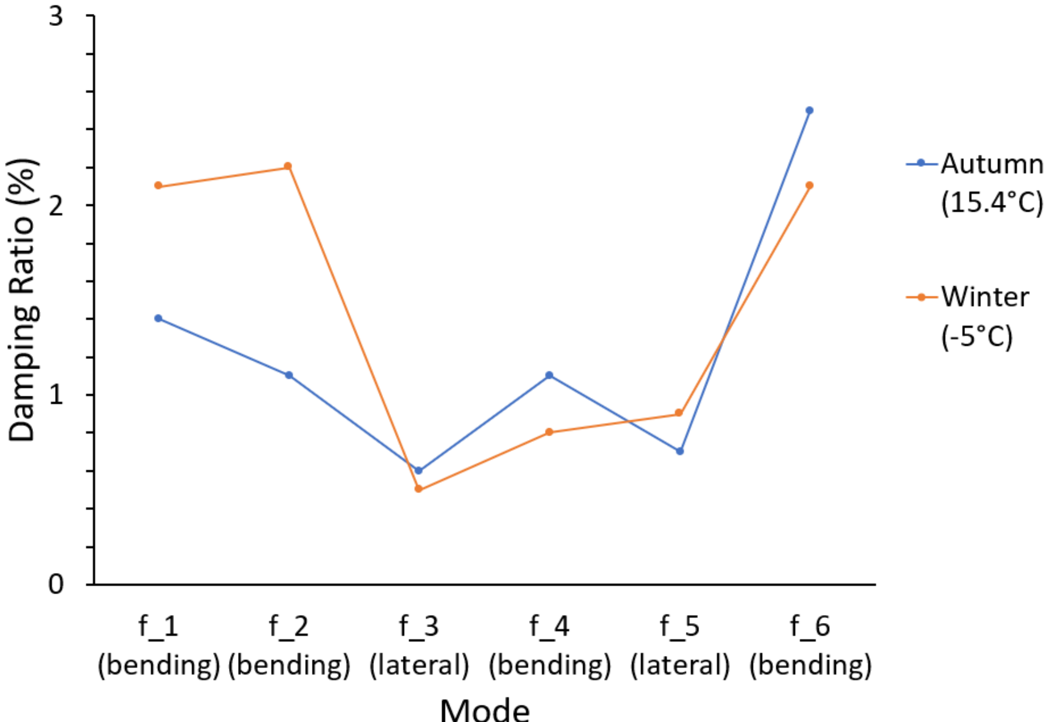
	Range (Hz)			
Mode	Weather	Asphalt	Exapnsion Joint	Spring Stiffness
f_1 (bending)	0,45	0,06	0,34	0,32
f_2 (bending)	0,35	0,13	0,13	0,41
f_3 (lateral)	0,33	0,07	0,00	0,55
f_4 (bending)	1,36	0,25	0,14	1,16
f_5 (lateral)	0,72	0,19	0,65	1,06
f_6 (bending)	1,05	0,37	0,24	0,50



Test results and comparison

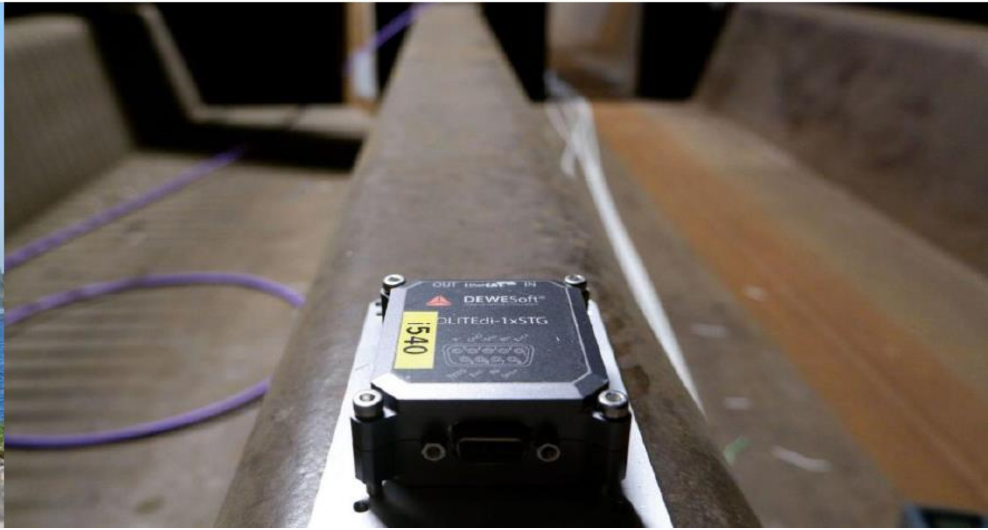
- Damping ratios of the system in autumn and winter weather conditior

Mode	Autumn (15.4°C)	Winter (-5°C)
	Damping (%)	
f_1 (bending)	1,4	2,1
f_2 (bending)	1,1	2,2
f_3 (lateral)	0,6	0,5
f_4 (bending)	1,1	0,8
f_5 (lateral)	0,7	0,9
f_6 (bending)	2,5	2,1



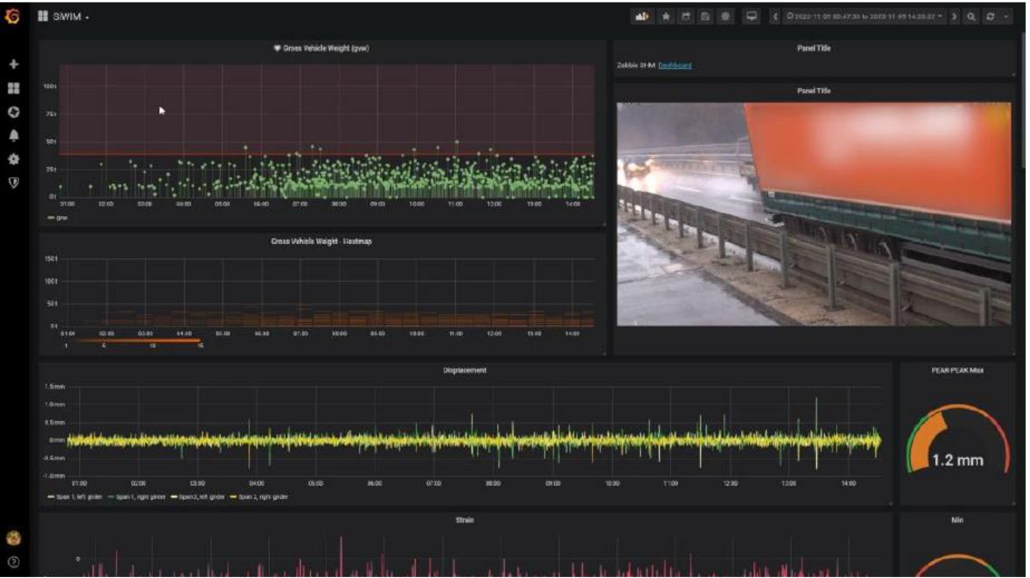
Commercial project: Moerdijk bridge (NL)

- 1 km bridge over the Holland Diep river
- Use:
  - Traffic analysis
  - Bridge analysis
  - Preselection



Unique solution

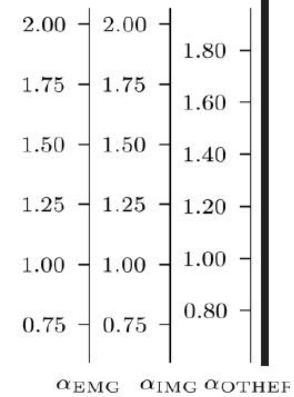
- Live data integrated in a single software solution
  - Traffic (heavy vehicles)
  - Bridge structure behavior
- Advantages for bridge assessment and monitoring

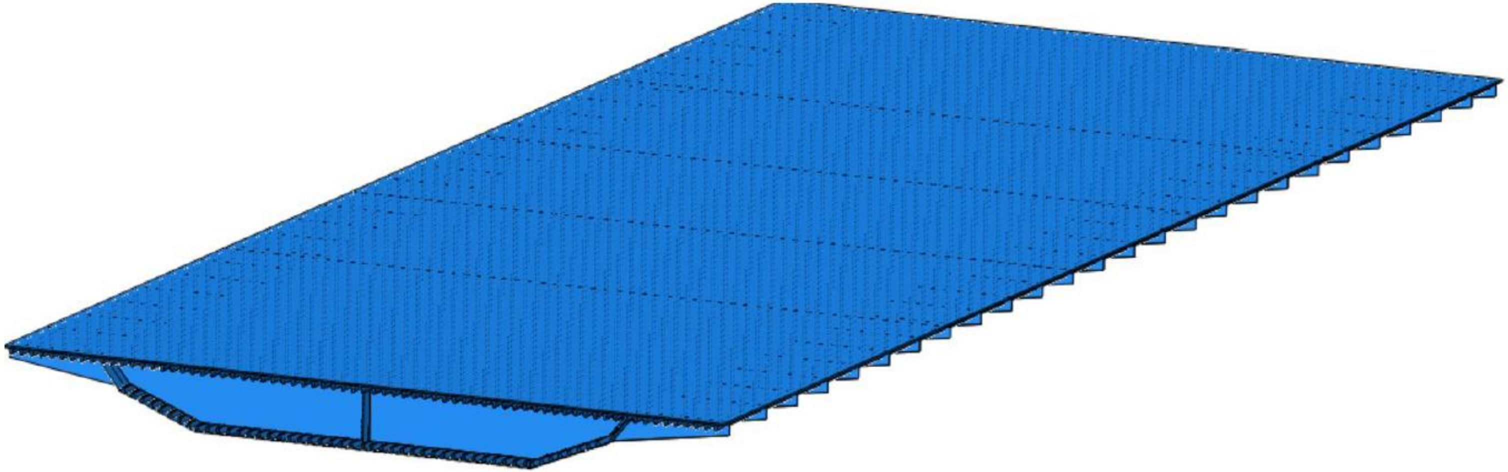


Traffic	Bridge
Gross vehicle weight	Acceleration
Classification	Strain
Axle loads	Displacement
Speed	Girder distribution factor
Axle distances	Dynamic amplification factor
Tyre type	Influence line
ANPR	Actual traffic load
Photo	

Refine the model

FEM parameters

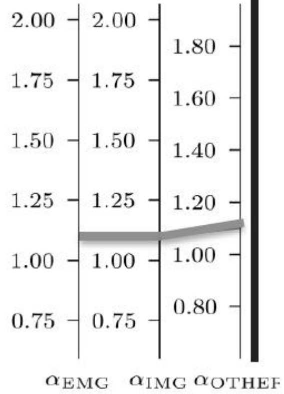


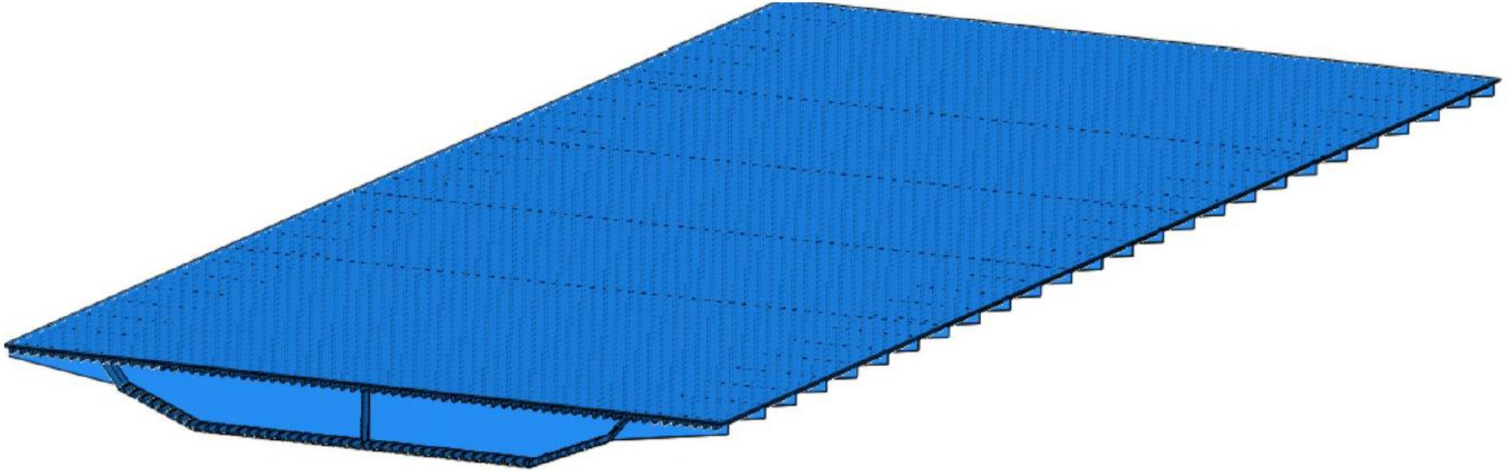


parallel coordinate plot | way of visualizing/analyzing high-dimensional datasets

Refine the model

FEM parameters





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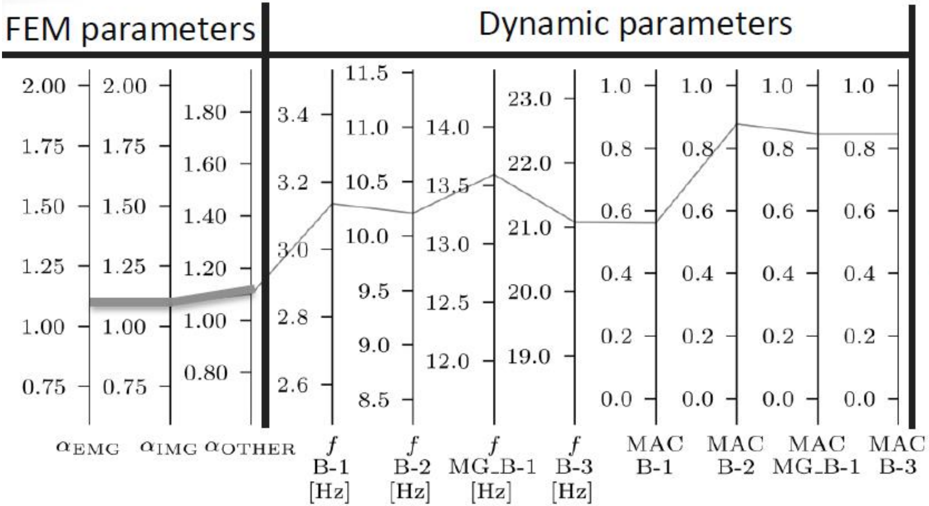
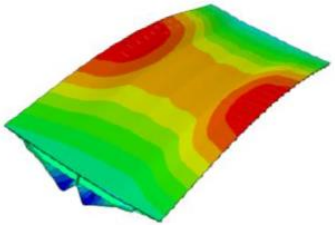
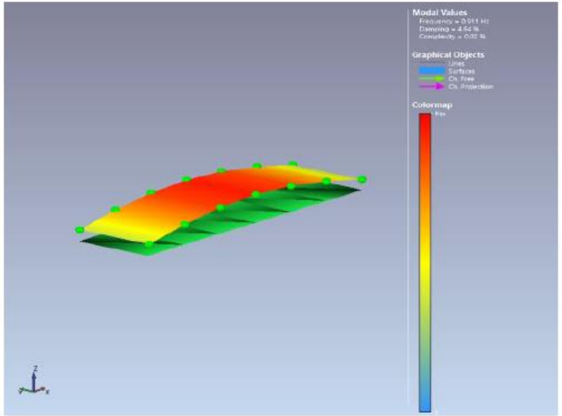


FEM



Monitoring - OMA



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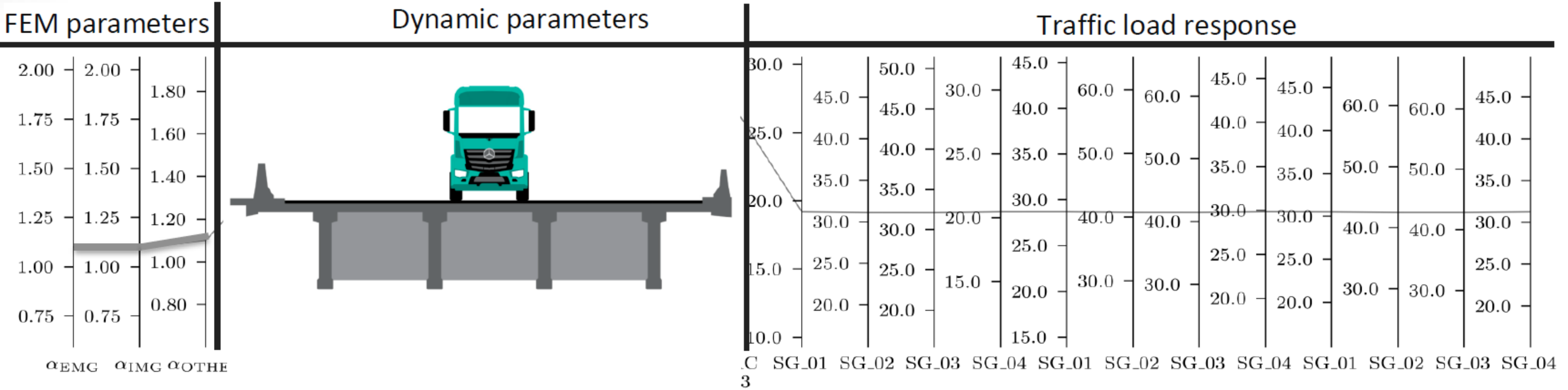

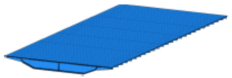

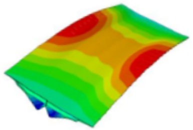

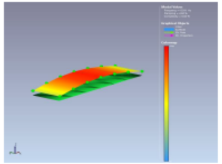

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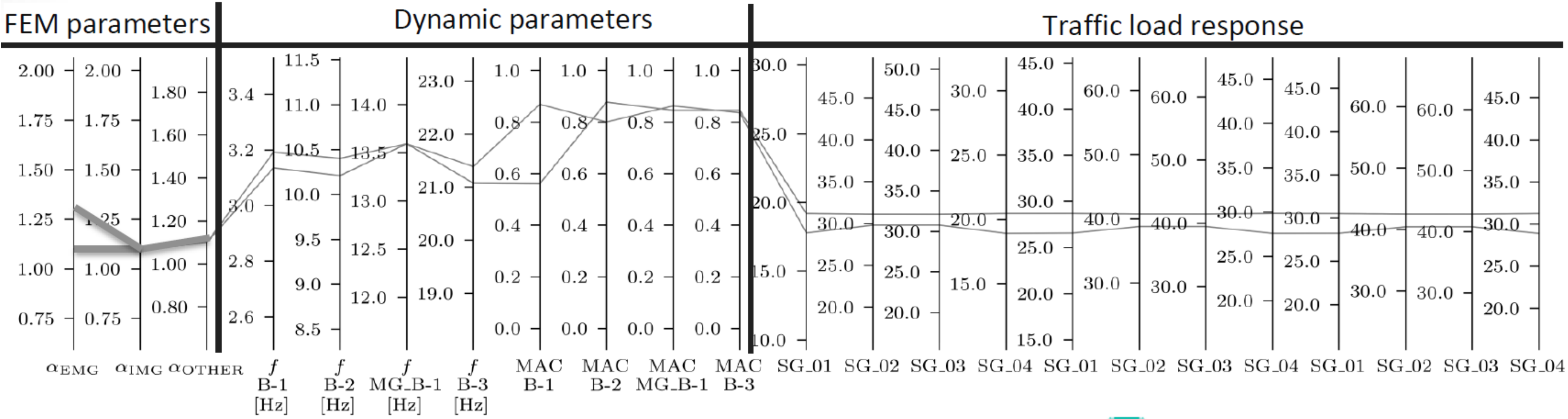

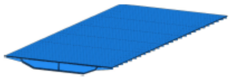

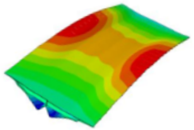

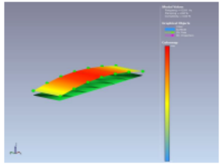

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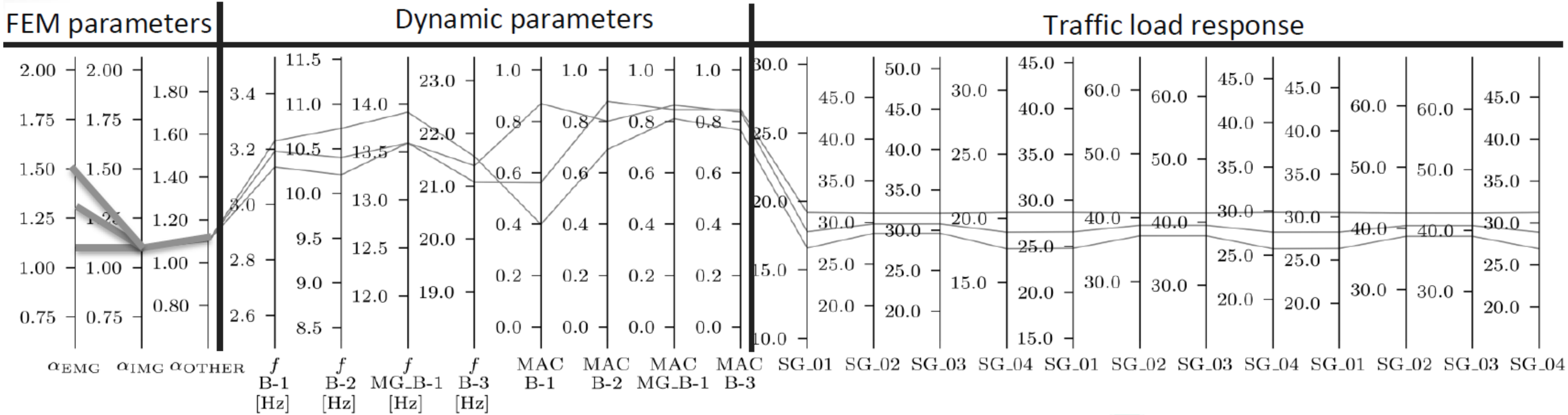
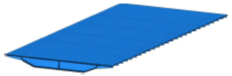
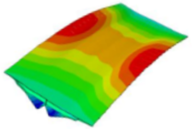
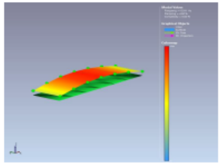
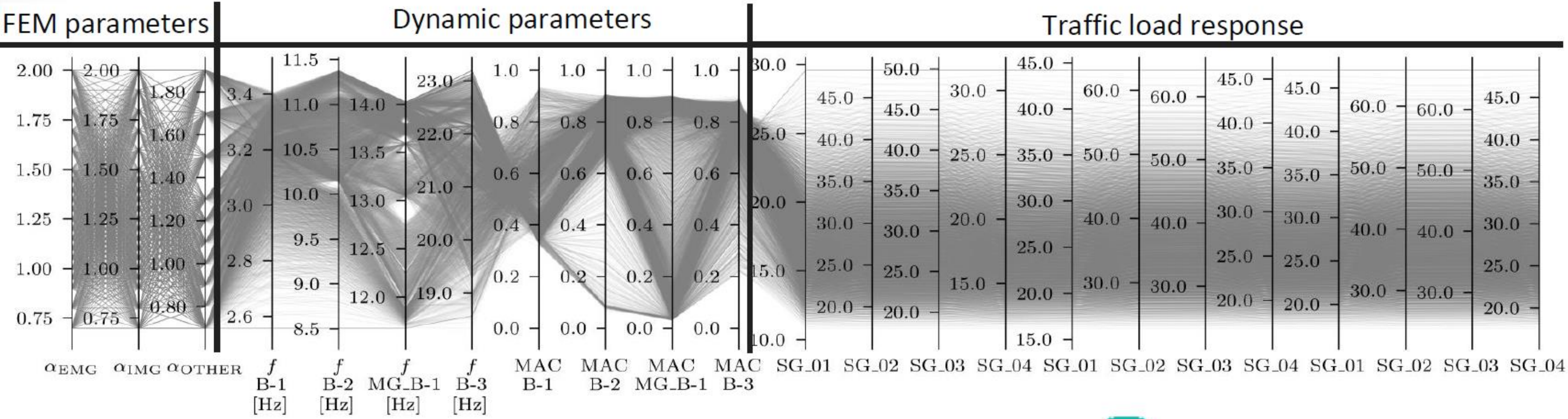


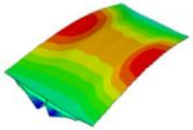


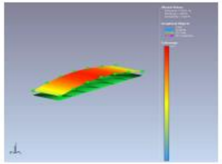




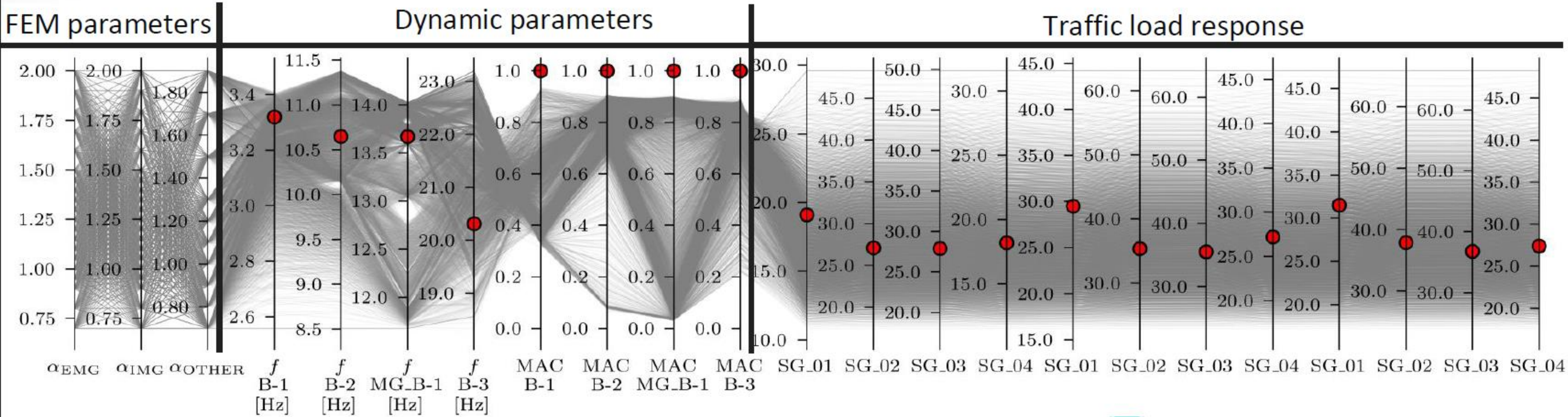
Refine the model

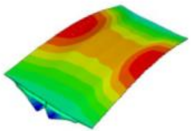


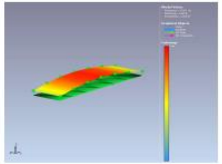




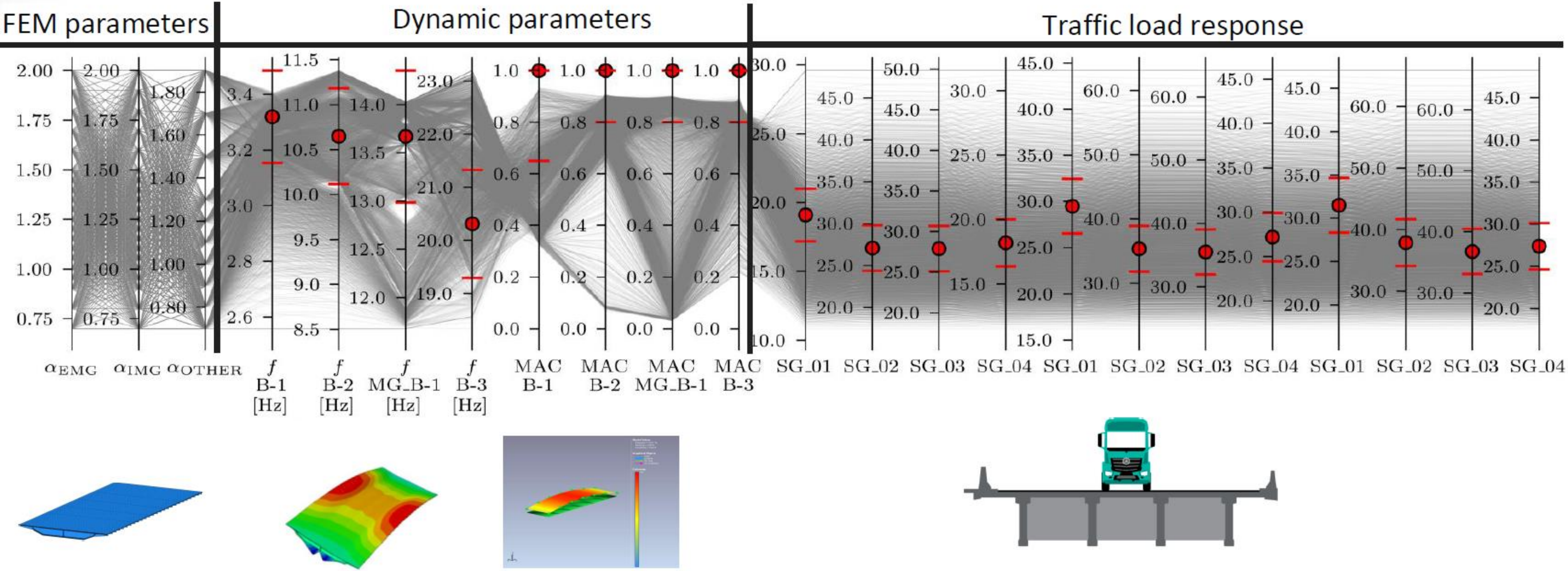
Benchmark measured data



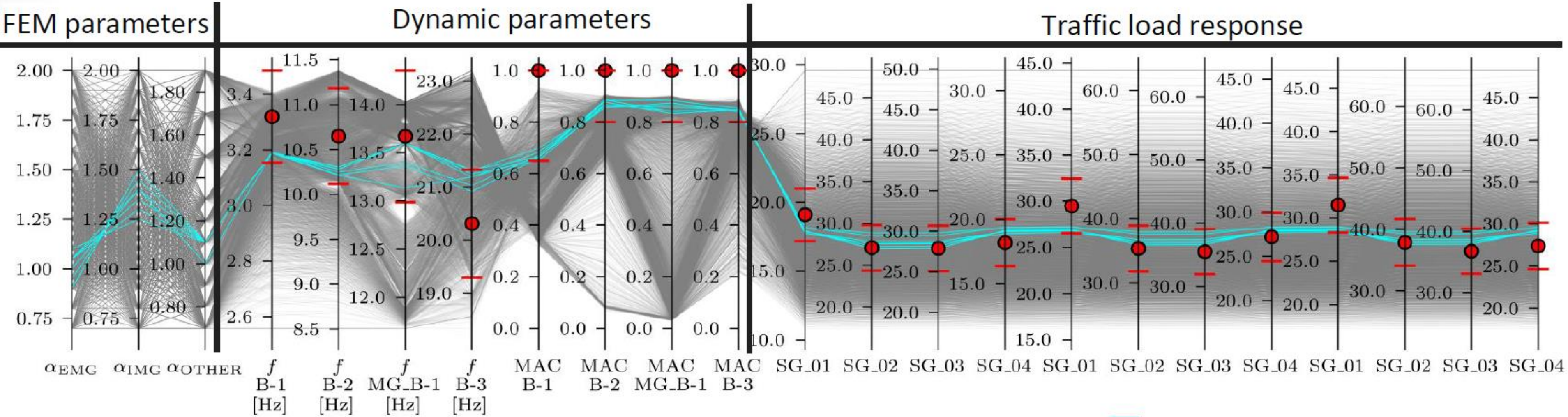


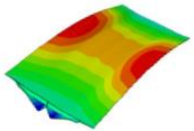


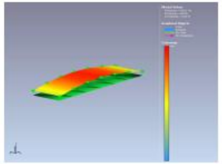
Falsification thresholds



Error Model Domain Falsification



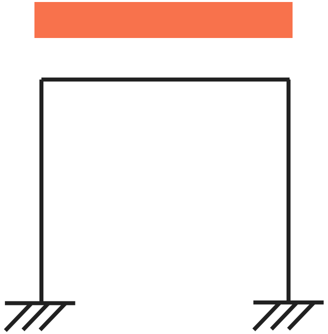


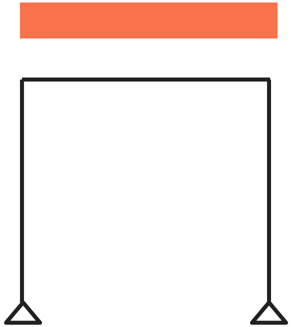


Example – A Portal Frame Bridge

- Most typical bridge in Sweden
- Drawings are old and sometimes it is not possible to determine the detail and hence the boundary conditions

- Different boundary conditions will produce totally different bending moment diagrams under self weight





Can we improve the current engineering decision making process?

Conclusion

The value of this work lies in the shown case studied in which it was demonstrated the significant influence that weather conditions can exert in the dynamic behavior of the system, the uncertainties that can arise upon FE-models both in an engineering and research context

- The problem of unicity of the solution to calibrate the models their corresponding limitations were exposed.

- Monitoring is fundamental not only to evaluate the performance the system but to reduce the uncertainty when modelling the system to improve the current engineering practice.

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Perspective

- Every infrastructural project is unique (boundary conditions).
- We cannot “hang” the bridge.
- We cannot control the testing environment.
- Barely and in the rarest of cases we can actually apply a known input (shaker or hammer test).
- Design life of 100 – 120 years.
- We cannot build another bridge just like that.
- Construction industry is moving forward to have the feedback of verifying the delivered product with respect to the design calculations.
- Detection is already win for us!
- Identifying the limits performance of the “Reference Structure” to help to avoid catastrophes is what every infrastructural owner wants to hear.
- Who takes the responsibility? How about lifes?

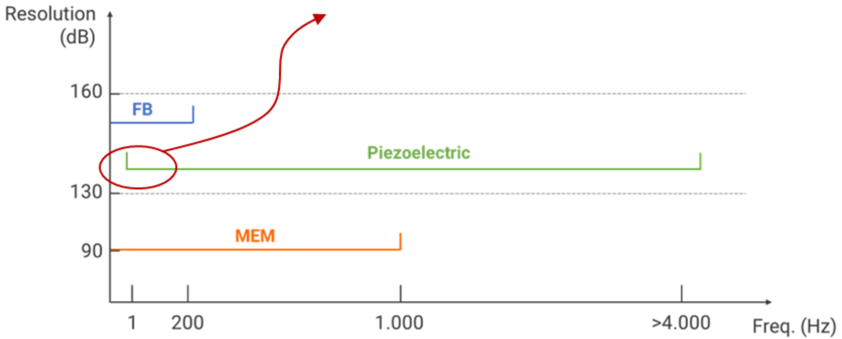
Some Interesting Questions

- What are the life safety and/or economic justifications for monitoring the structure?
- What are the risks associated with the structure?
- How is damage defined for the structural system being monitored?
- What are the operational and environmental conditions under which the structural system of interest operates?
- What are the limitations on acquiring data in the operational environment?
- Which level of knowledge do we need about the structural condition?
- How long do we need to monitor?
- What is the rate of return on investment in SHM?

Thank you

Why monitoring and testing?

Structural assessment is made based on the assumption that you can always come up with a Safe Side approach because of the Lack of Information and Safety



Type	Lower Corner Freq.	Rugged	Signal	Cables	Daisy Chain	Price
Piezoelectric	0,1 Hz (-3dB) ✗	NO ✗	Analog	Per Chanel	NO	High
Force balance	DC (0 Hz) ✓	IP67 ✓	Analog	Per Chanel	NO	High(er)
MEM & DAQ	DC (0 Hz) ✓	IP67 ✓	Digital ✓	Per DAQ ✓	YES ✓	Lower ✓