Latest and Current Activities in Structural Health Monitoring (SHM) and Structural Control (SC)

Structural Engineering Research Laboratory

Swiss Federal Laboratories for Materials Testing and Research
(EMPA)

SAMCO – Workshop / 26 – 27. January 04 / Wien

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Main Research Fields

- Our Vision: Improvement of Safety and Sustainability of Engineering Structures

- Structural Health Monitoring
- Adaptive Structures
- Application of Composite Materials in Construction

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Research Projects in these Fields

- Structural Health Monitoring (SHM)

- EU/FP 6 “Sustainable Bridges”
- Damage Identification on a Prestressed Concrete Bridge (Hergiswil)
- Damage Identification of Prestressed Concrete Girders and Cables of the Cantine-Bridge
- System Diagnostics with Curvature Measurements using Fibre Optical Sensors
- Non Destructive Inspection of Stay Cables
- Non Destructive Testing of Cable Anchor Heads using “Guided Waves”
- Influence of Fungal Decay on Elastic Wave Propagation in Wood
- Magnetic and Diamagnetic Levitation for Inertial Sensing Systems and High Precision Instrumentation

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Research Projects in these Fields

- Adaptive Structures

- Semi-Active Damping of Cable Vibrations

- Application of Composite Materials in Construction
- Poststrengthening with Composite Materials of Cantine-Bridge Girders

- Testing Platform „Smart Bridge“

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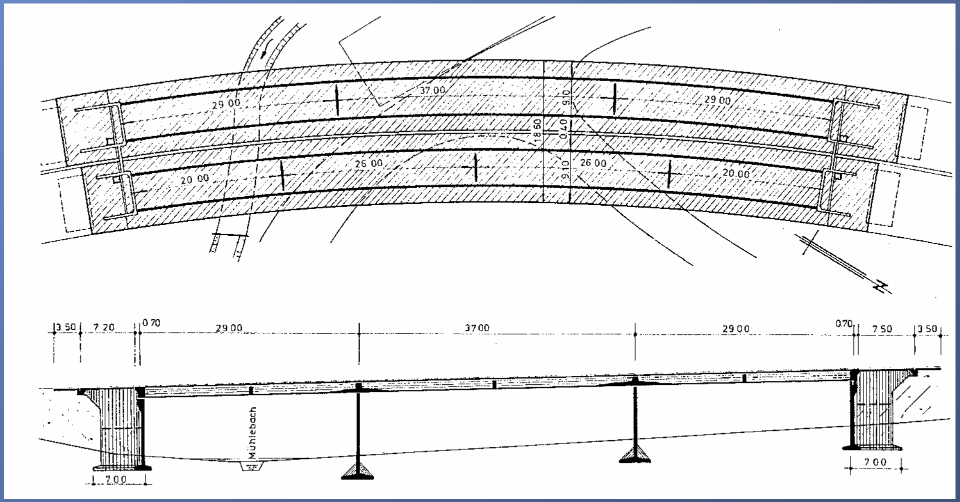
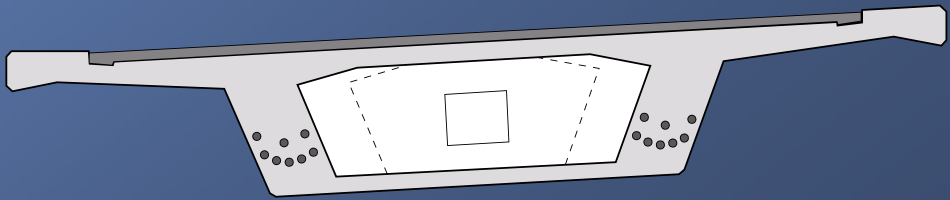
Damage Identification - Romeo Bridge (Hergiswil)

- Long term monitoring of bridge “Romeo”
- 2 damage szenarios
- for 2nd damage szenario 3 damage identification levels are investigated





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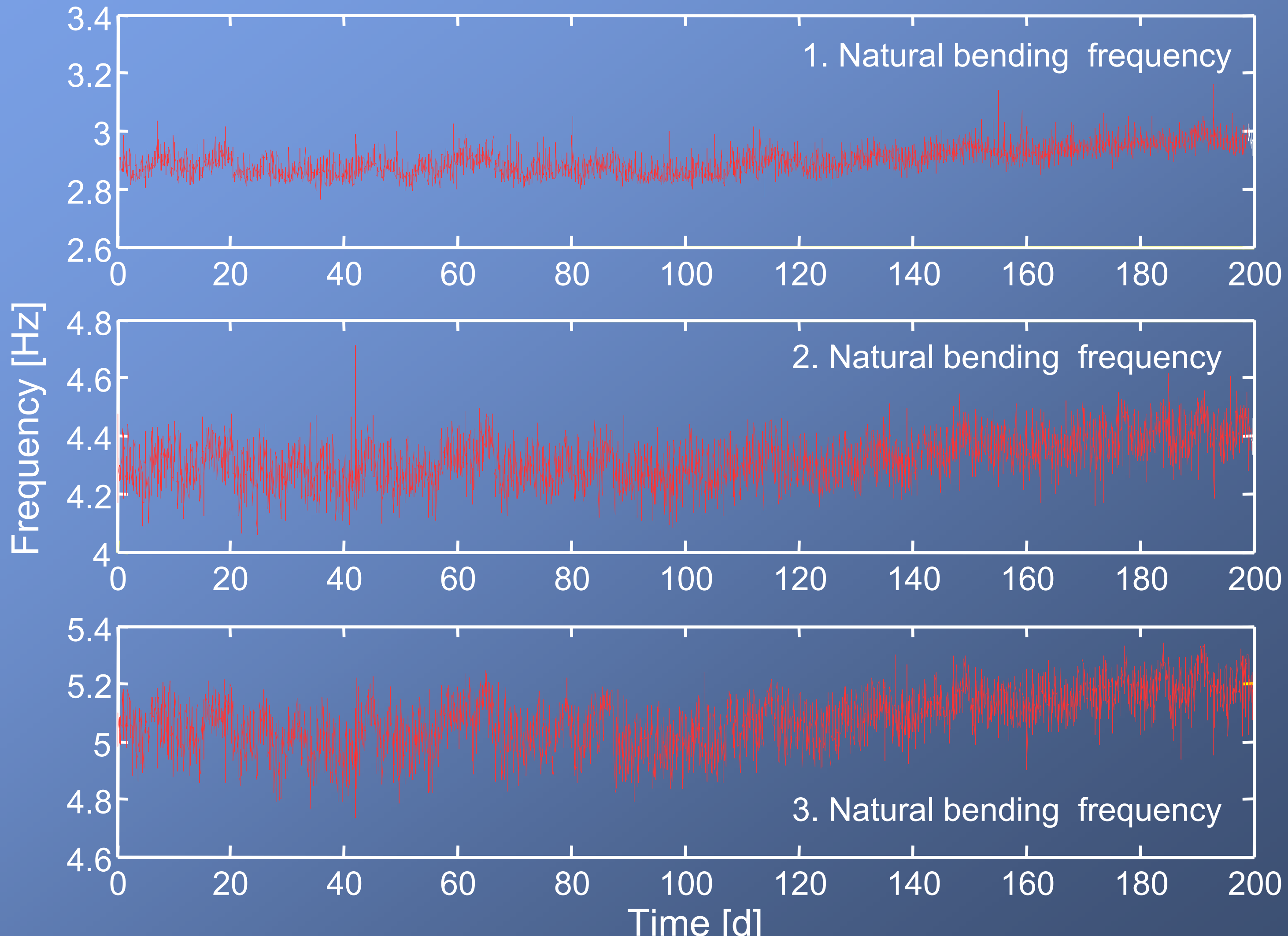
Behavior of first 3 natural bending frequencies

Monitoring period 200 d – May/December



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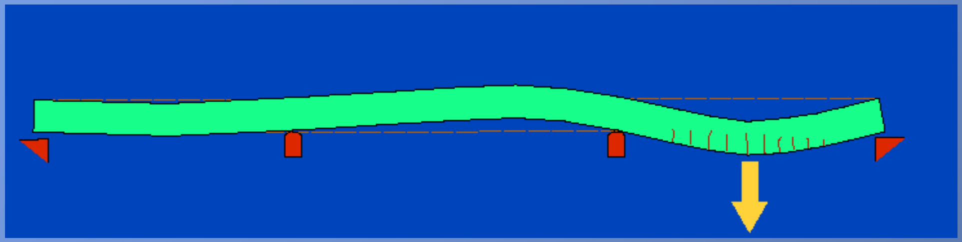
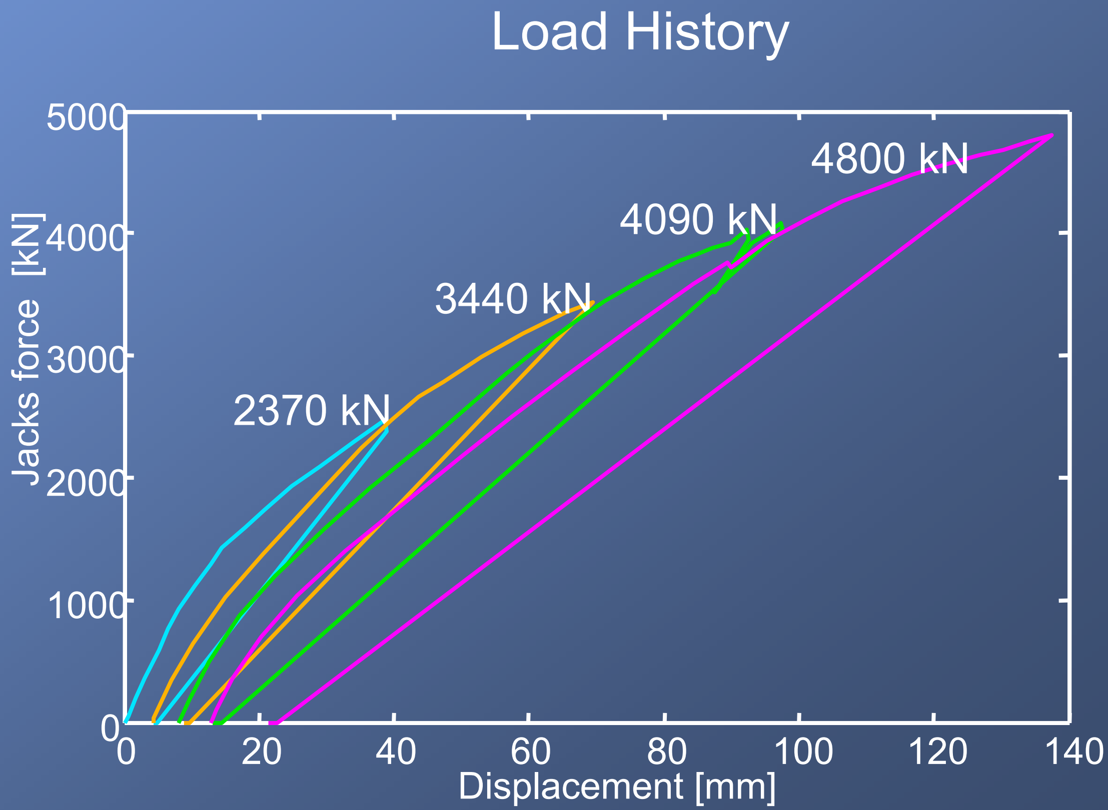
Damage Szenario 2 (Tests 5-9)





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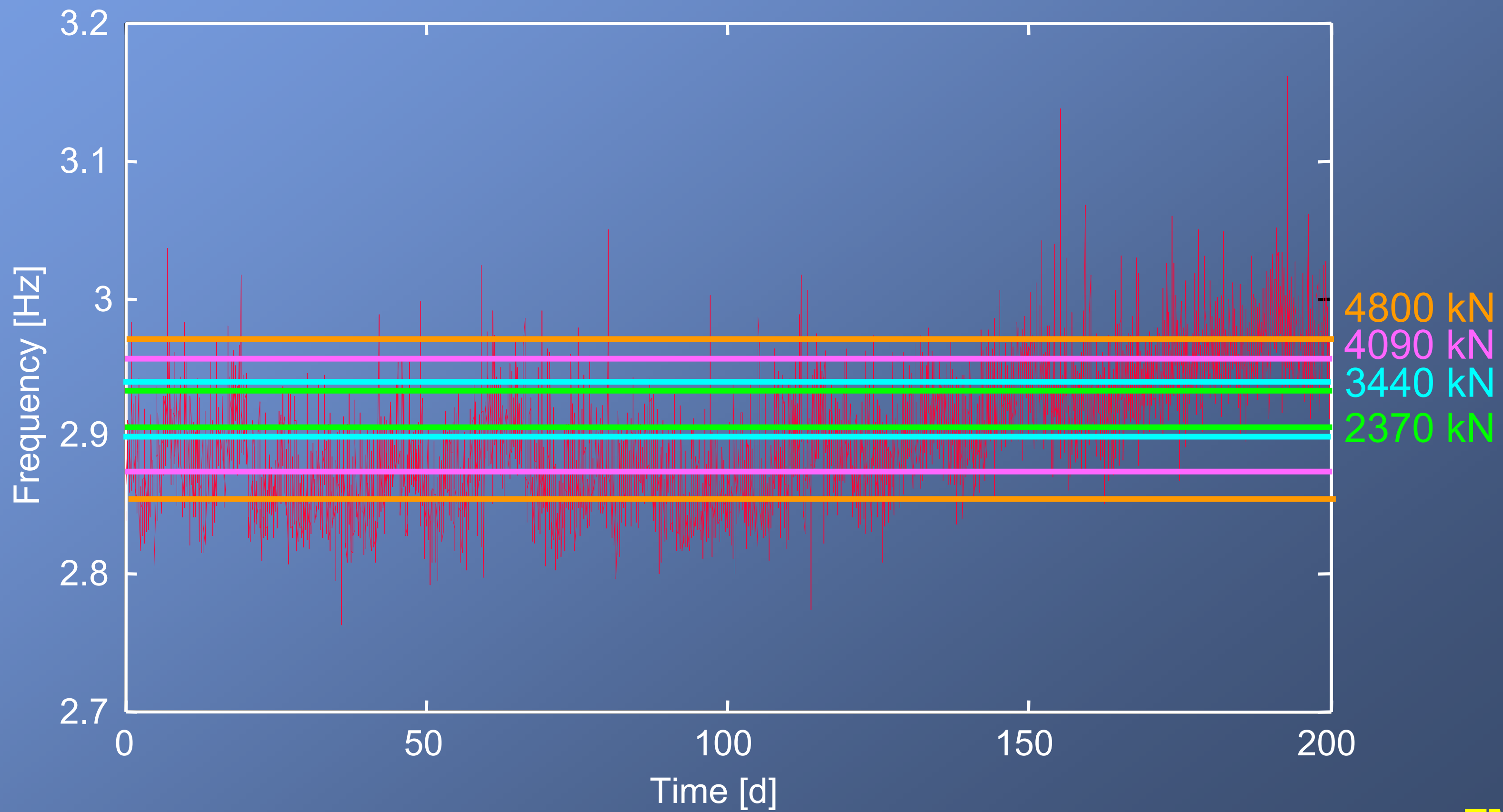
Main results

- Changing of natural frequencies and MAC-values are small

Changes of the first natural bending frequency caused by damage and temperature fluctuations (red)



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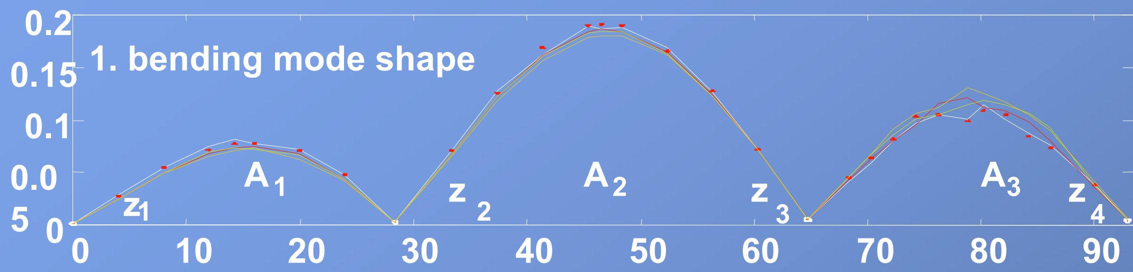
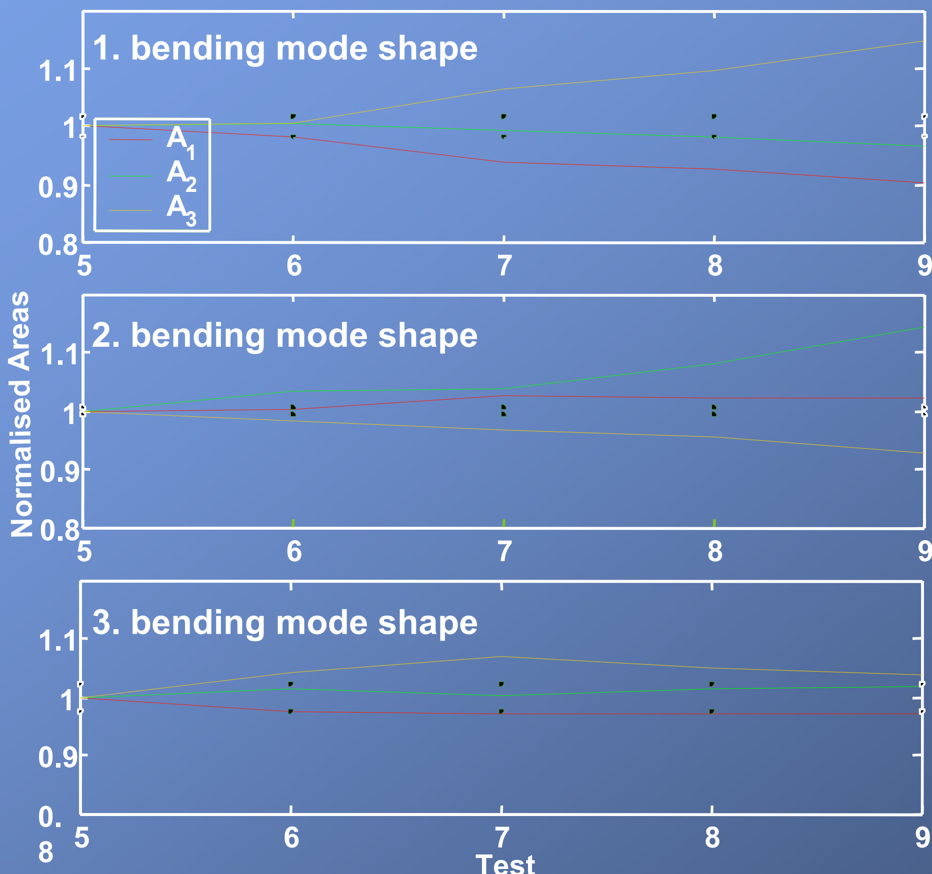
Changing of mode shape area index





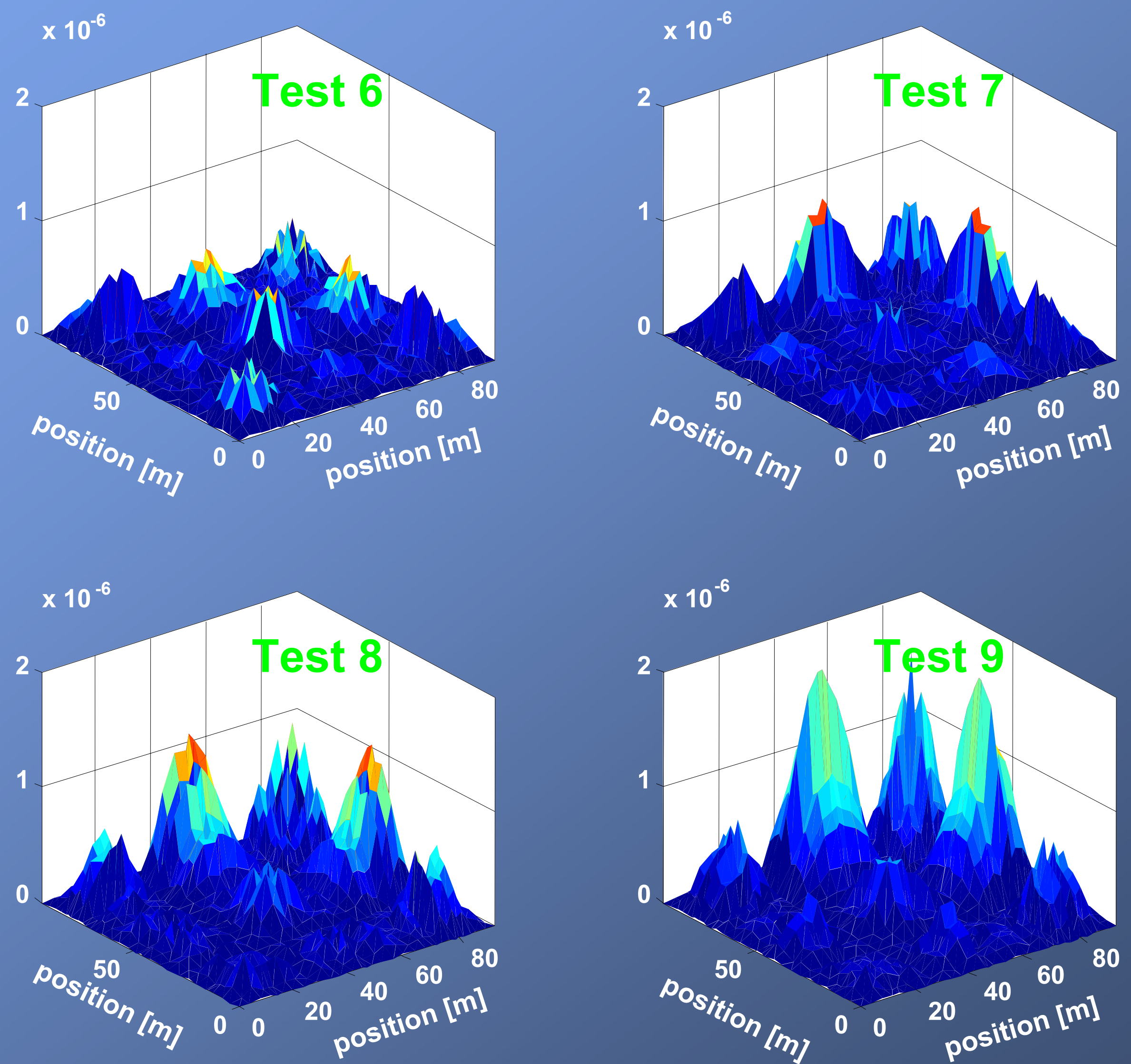
Area part

$$\int_0^L |\phi(x)| dx = \sum_{i=1}^{n} \int_{z_{i-1}}^{z_i} |\phi(x)| dx = \sum_{i=1}^{n} A_i(\phi)$$

Normalisation

$$\sum_{i=1}^{n} \frac{\int_{z_{i-1}}^{z_i} |\phi(x) dx|}{\int_0^L |\phi(x) dx|} = \sum_{i=1}^{n} \overline{A}_i(\phi) = 1$$

Changing of the flexibility matrix



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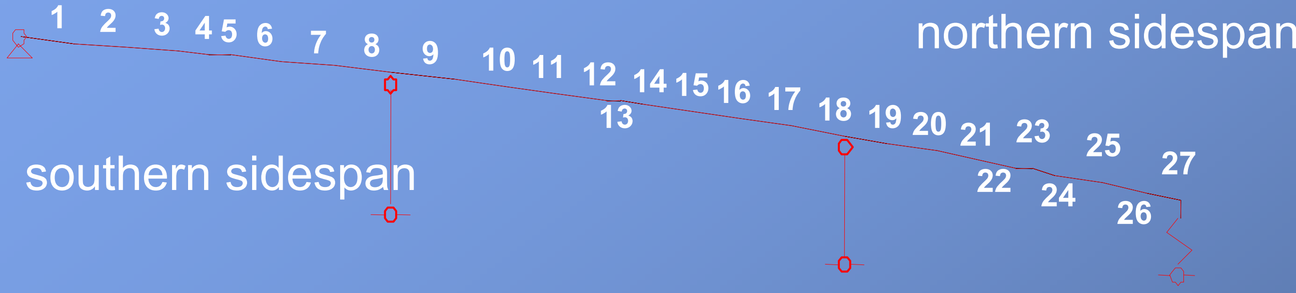
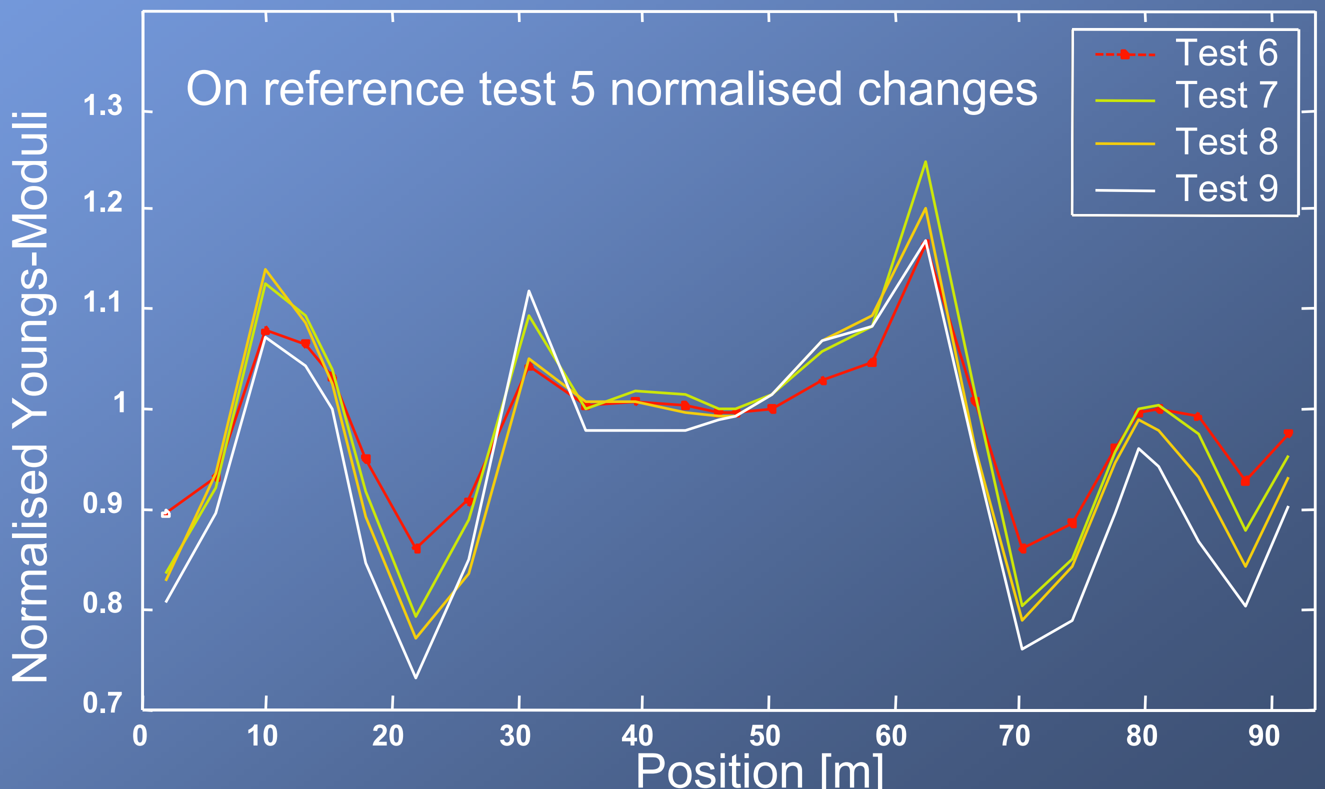
FE-Model Updating





Failure of FE-updating: if number of unknown parameters>number of used modal parameters

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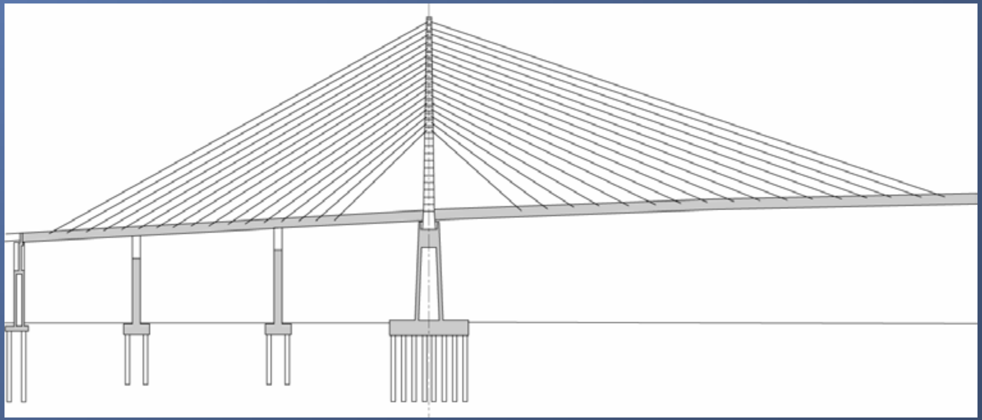
Flaw Localization in Large Diameter Steel Cables

- No government regulations about inspection intervals
- Main problems: fatigue and corrosion
- Ideal situation: identify and repair defective stays **before** the end of their operative life!



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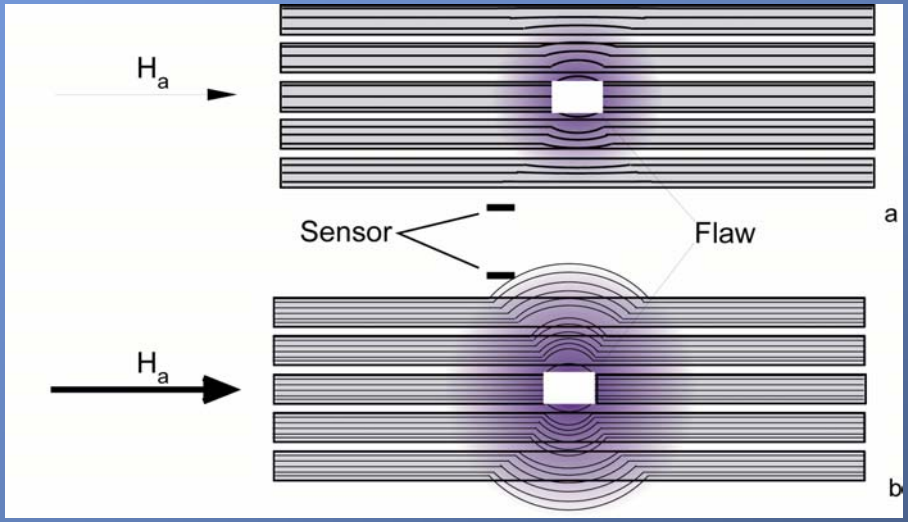
Magnetic Flux Leakage-based NDE

- Presence of a flaw (air inclusion) introduces a local discontinuity of the magnetic properties of the cable



- Under suitable condition the flaw induces a deformation of the magnetic field that is detectable on the surface of the cable

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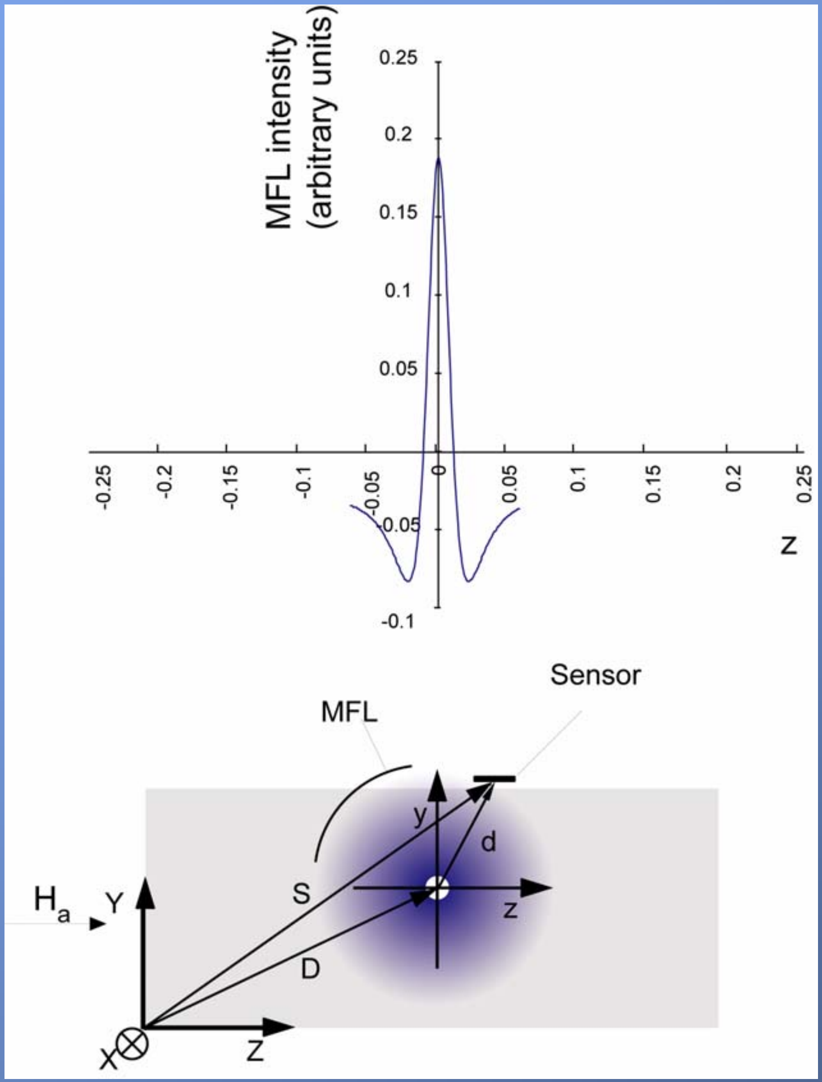
Dipole approximation in 2D

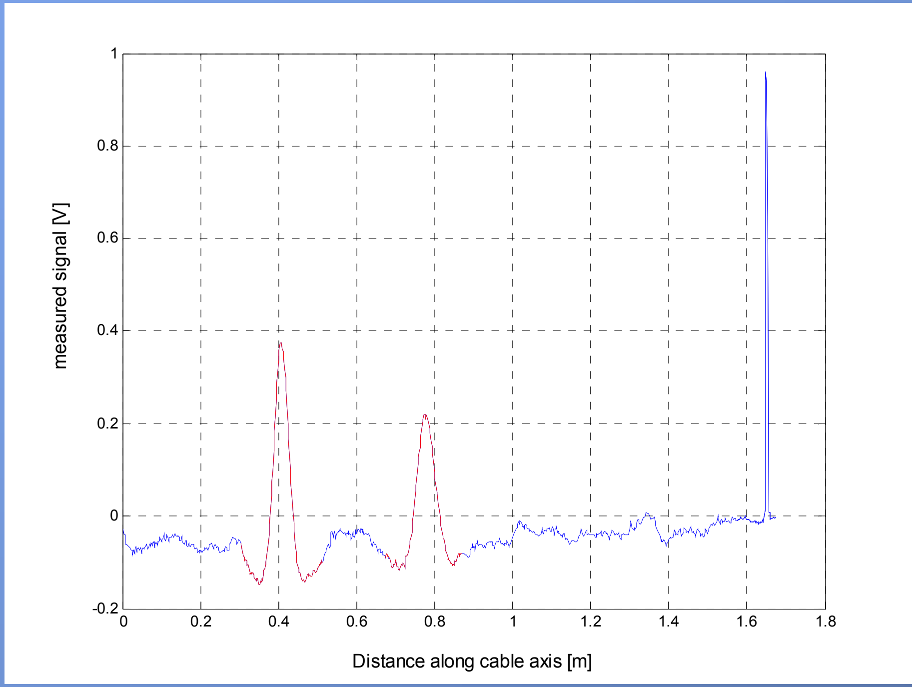


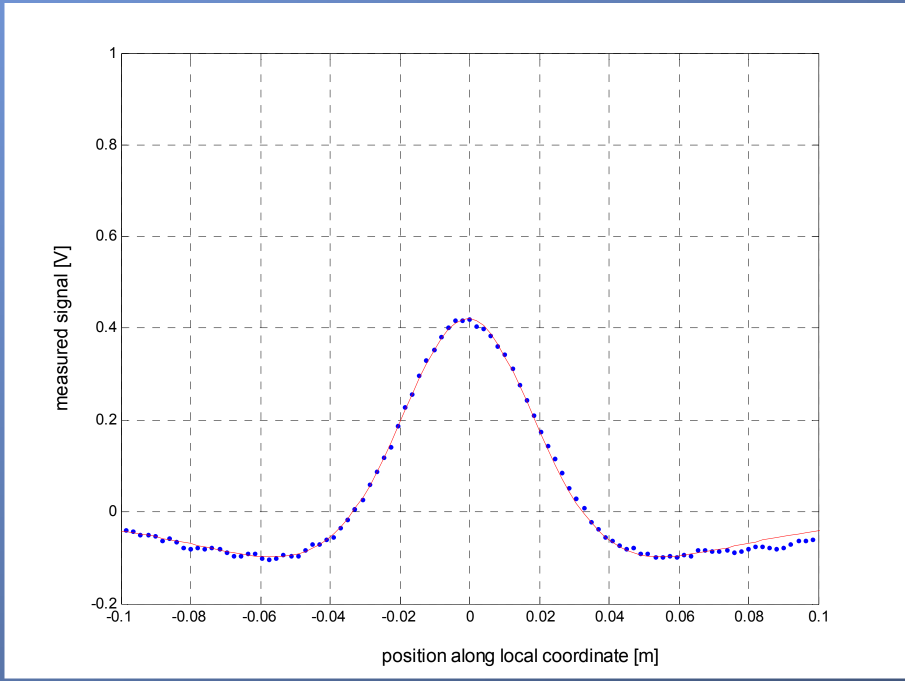
$$H_y = \frac{m_{eff}}{(d_z^{\,2} + d_y^{\,2})^2} 2d_z d_y - 2H_a a^2 \frac{2d_z d_y}{(d_z^{\,2} + d_y^{\,2})^2}$$

with

$$m_{eff} = \frac{2\mu_m}{\mu_m + \mu_i} \left[1 - \left(\frac{\mu_m - \mu_i}{\mu_m + \mu i} \right)^2 \left(\frac{a}{2d_y} \right) \right]^{-1} \frac{\mu_m - \mu_i}{\mu_m + \mu_i} H_a a^2$$

Automatic recognition of a flaw

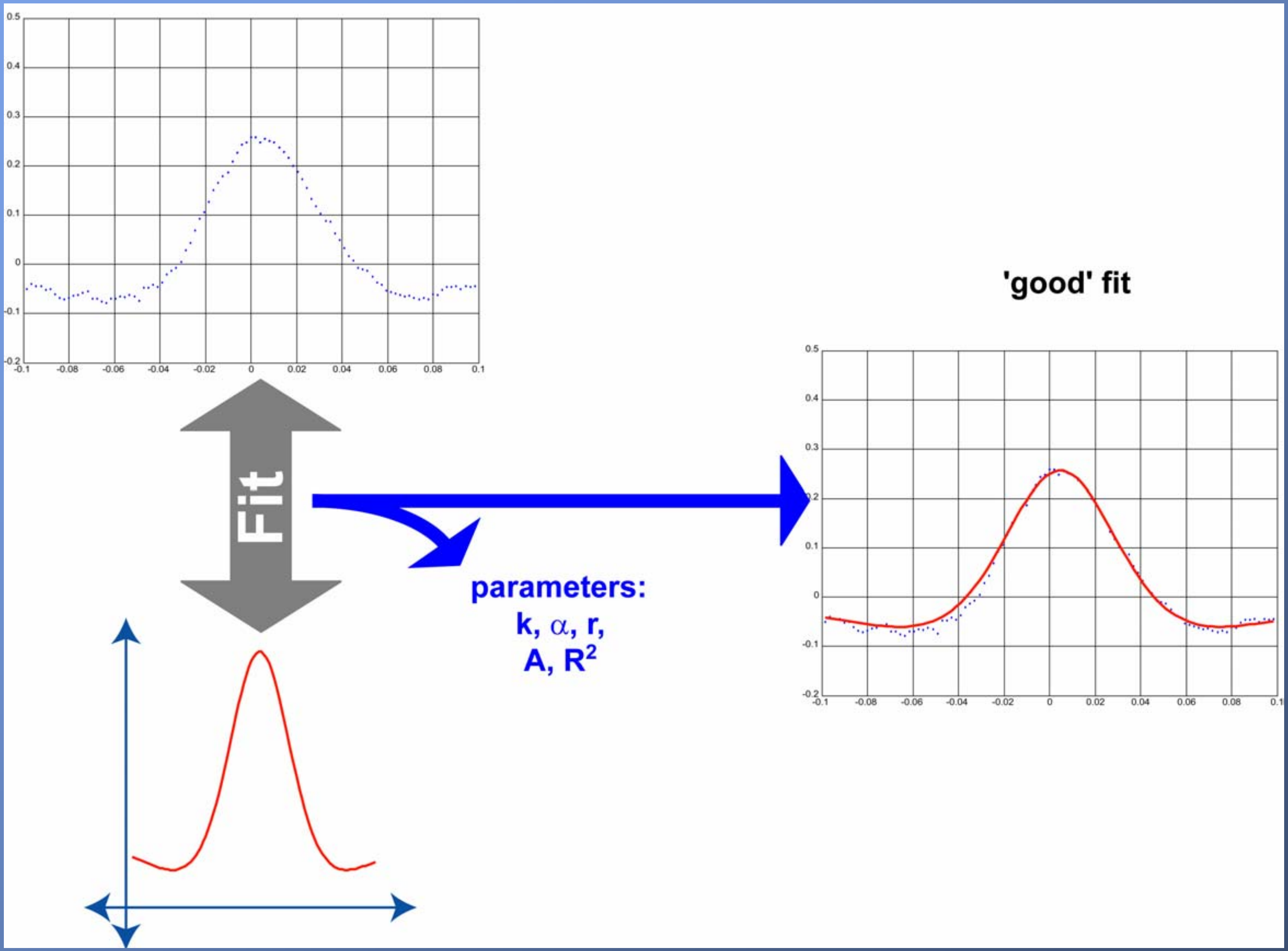




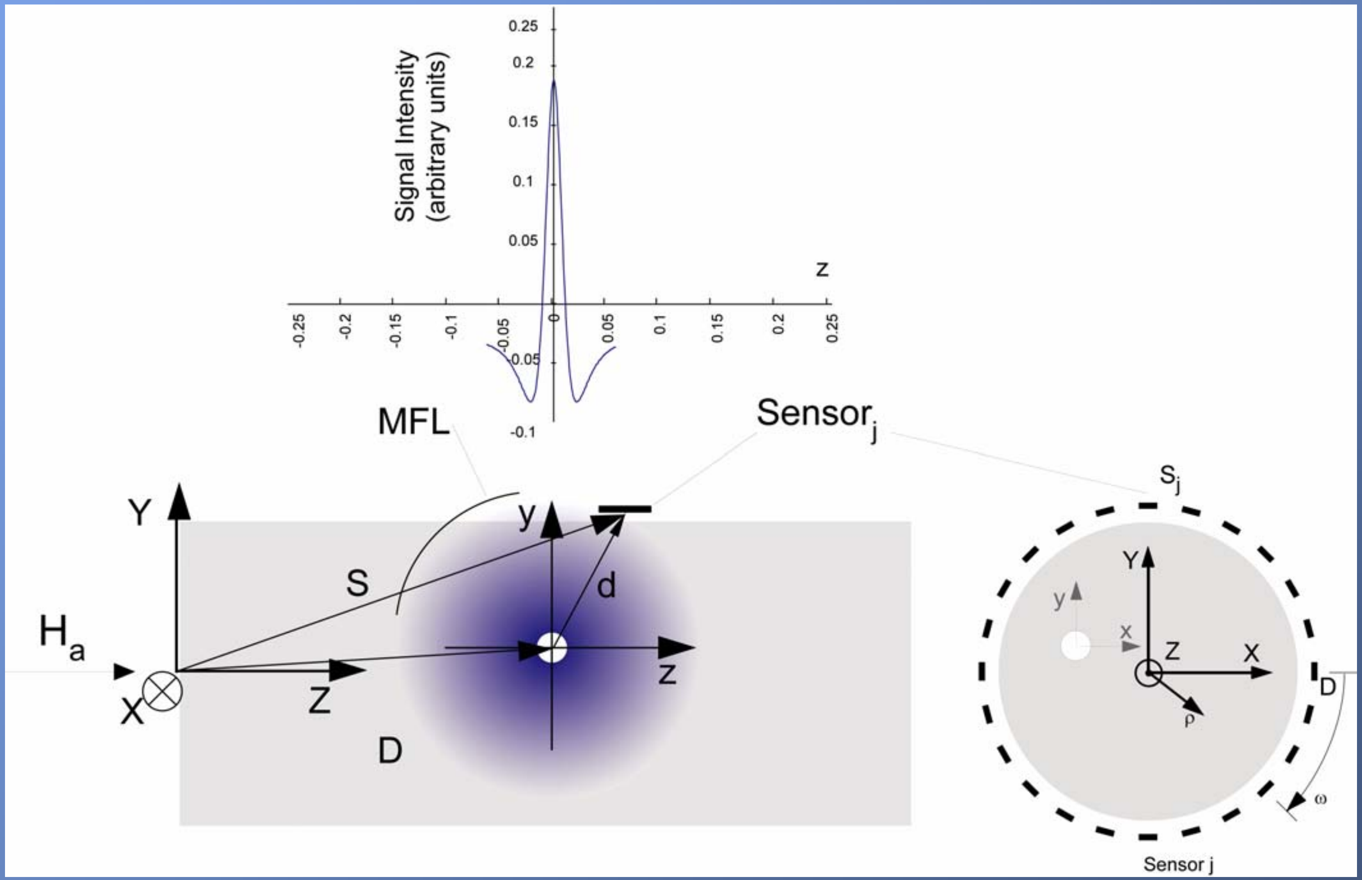
Threshold is not a sufficient criterion:

Additional: conformity of the measured data to the expected signal

Fit quality parameters



Fitting the dipole approximation function to the measured signal



$$U \propto \frac{\partial}{\partial_z}\begin{vmatrix} H_x \\ H_y \\ H_z \end{vmatrix} = k\frac{\partial}{\partial_z}\left(\begin{vmatrix} 0 \\ 0 \\ H_a \end{vmatrix} + \frac{\mu_m - \mu_i}{2\mu_m + \mu_i} H_a a^3 \begin{vmatrix} 3d_x d_z / d^5 \\ 3d_y d_z / d^5 \\ \left(3d_z{}^2 - d^2\right)/ d^5 \end{vmatrix}\right)$$

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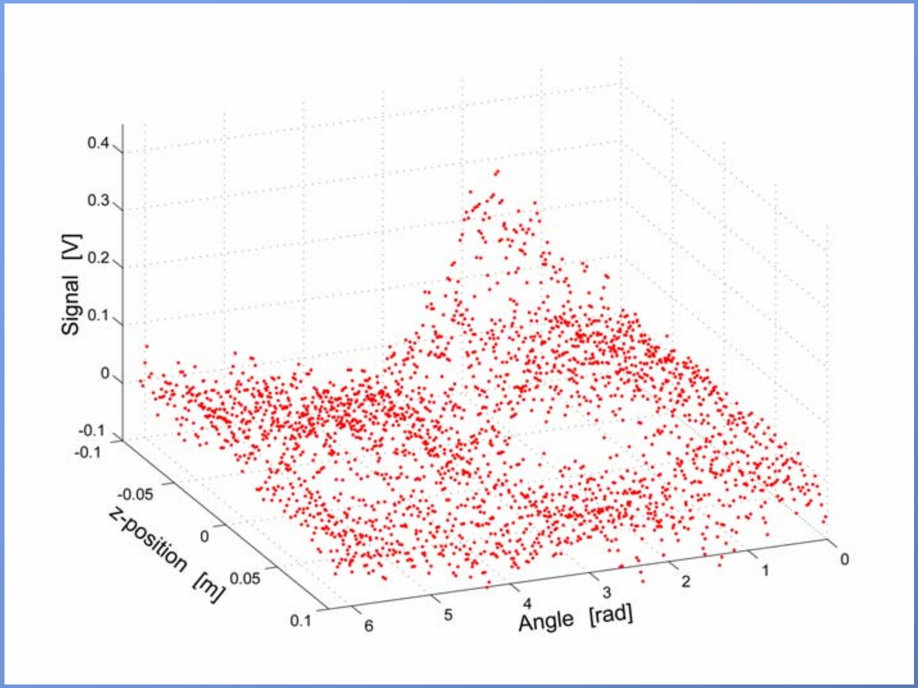
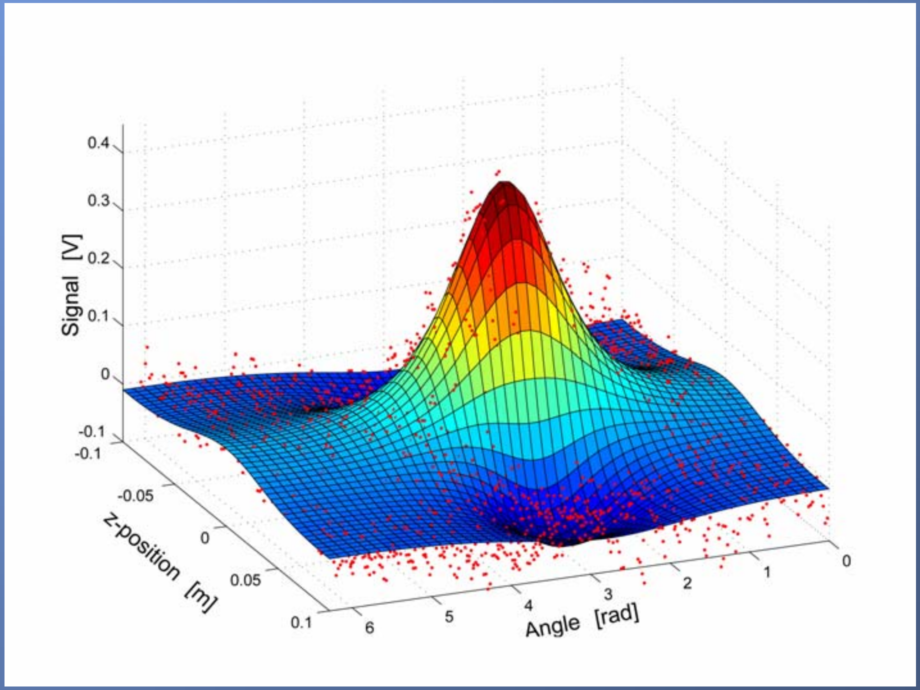
Measured data and fit function



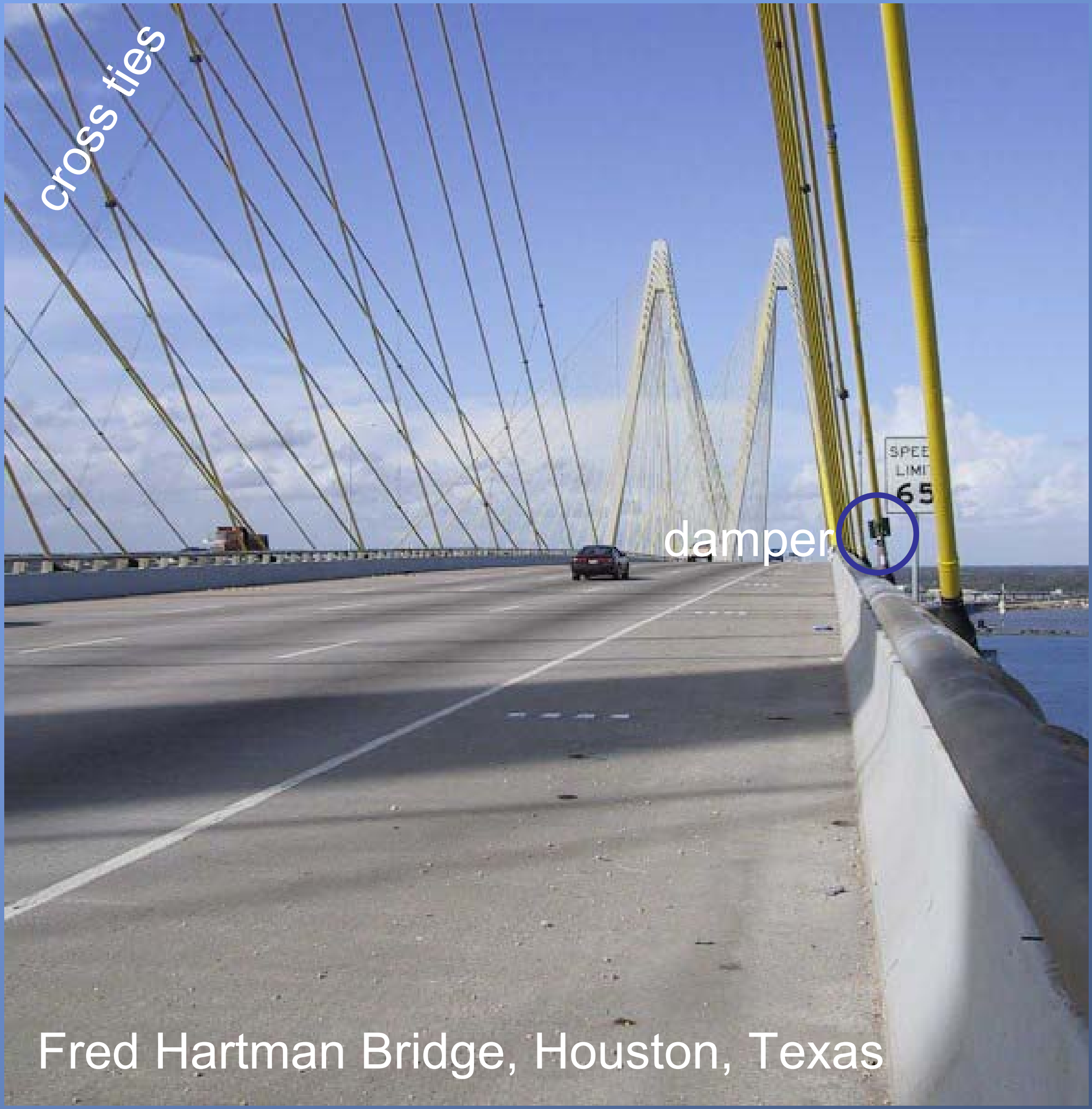


r_{act} = 26.6mm → r_{calc} = 27mm

α_{act} = 300° → α_{calc} = 301.3°

k_{calc} = -0.14

Controlled Damping Applying Rheological Materials



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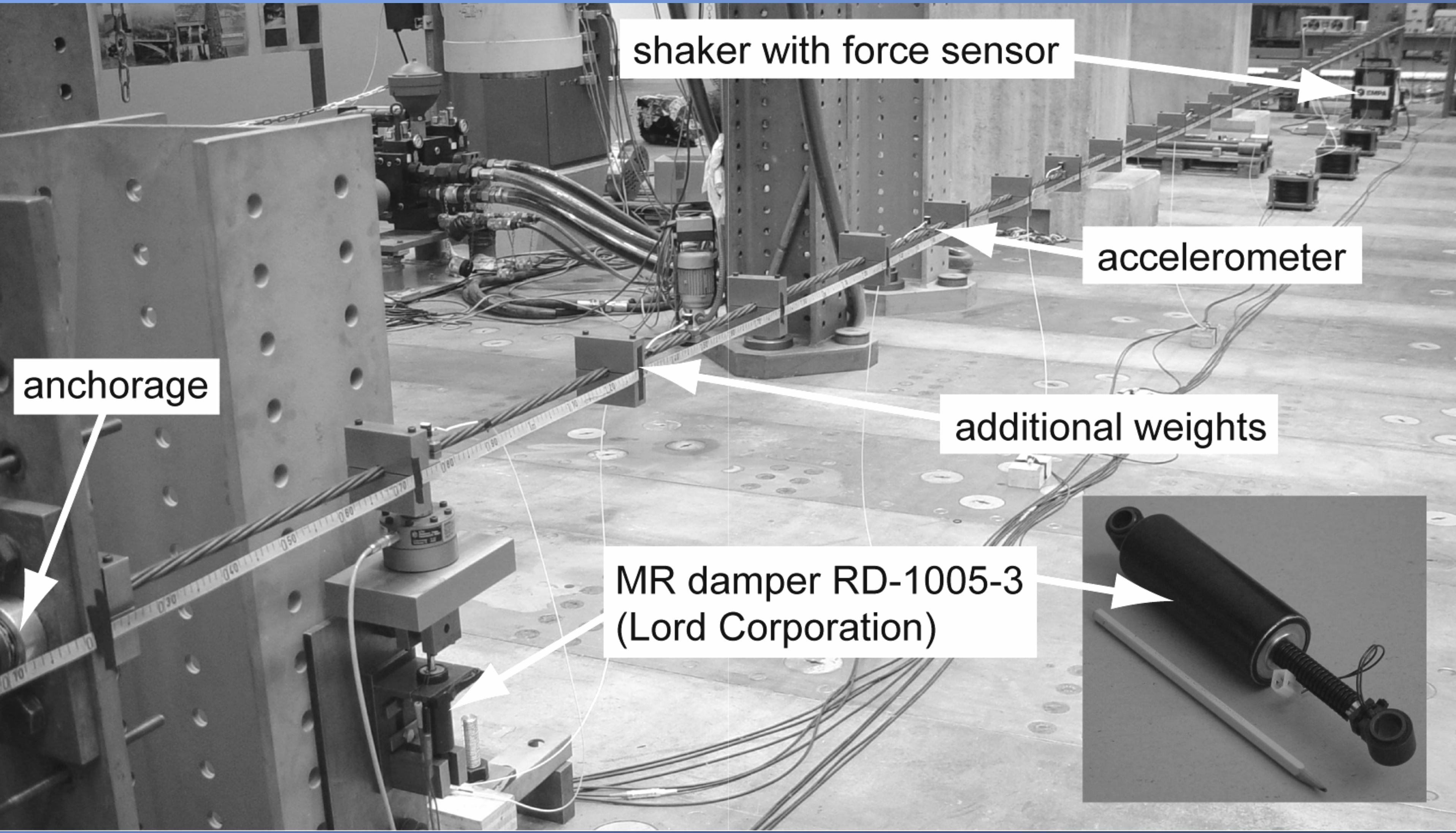
Test Cable with Controlled MR Damper



Main Steps

- Modelling of the connected system damper-cable (Matlab/Simulink)

⇩

- Identification of model parameters by measuring the static and dynamic behavior of the damper and the cable. Model-based controller design

⇩

- Optimization of controller parameters by simulation of the closed loop system

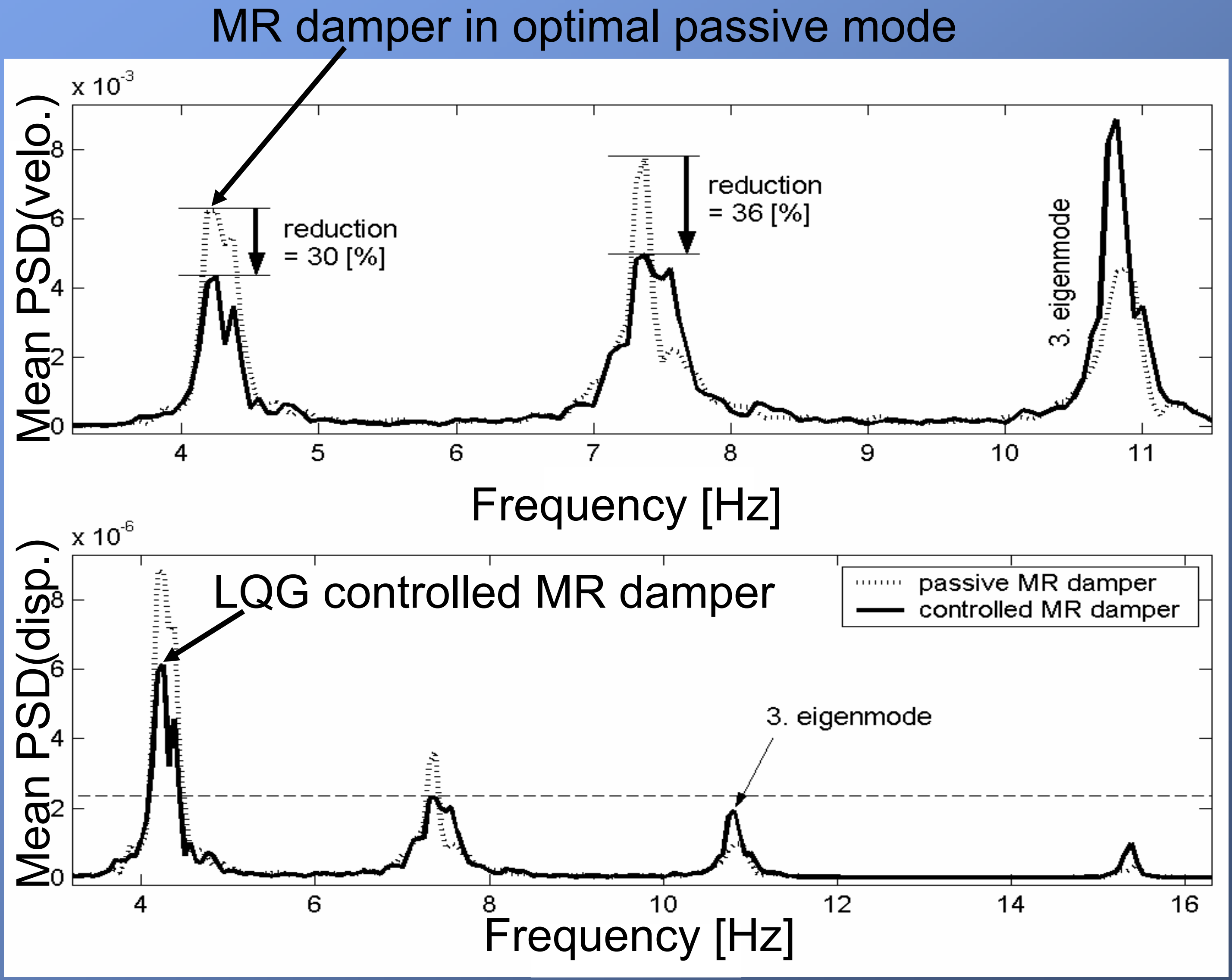
⇩

- Implementation of the control algorithm at the test setup computer

⇩

- Verification of controller performance at the real system damper-cable

Additional Damping



Smart Cable-Stayed Bridge

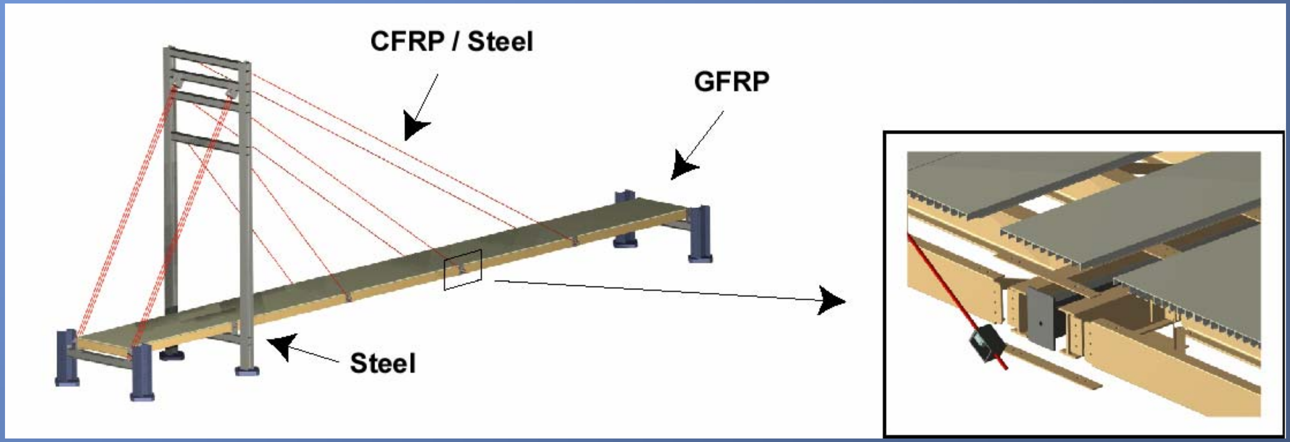
- Different projects of our research group and from external partners are integrated:
  - Structural vibrations (passive, semi-active, active vibration mitigation, health monitoring)
  - Integrated, distributed sensing (fiberoptic sensor, piezoelectric fiber sensors)
  - New structural materials (glass- and carbon-fiber reinforced polymers)

- Closing the gap between complex real-world applications and simplified laboratory experiments
- Training of students in modal analysis and dynamic measurements

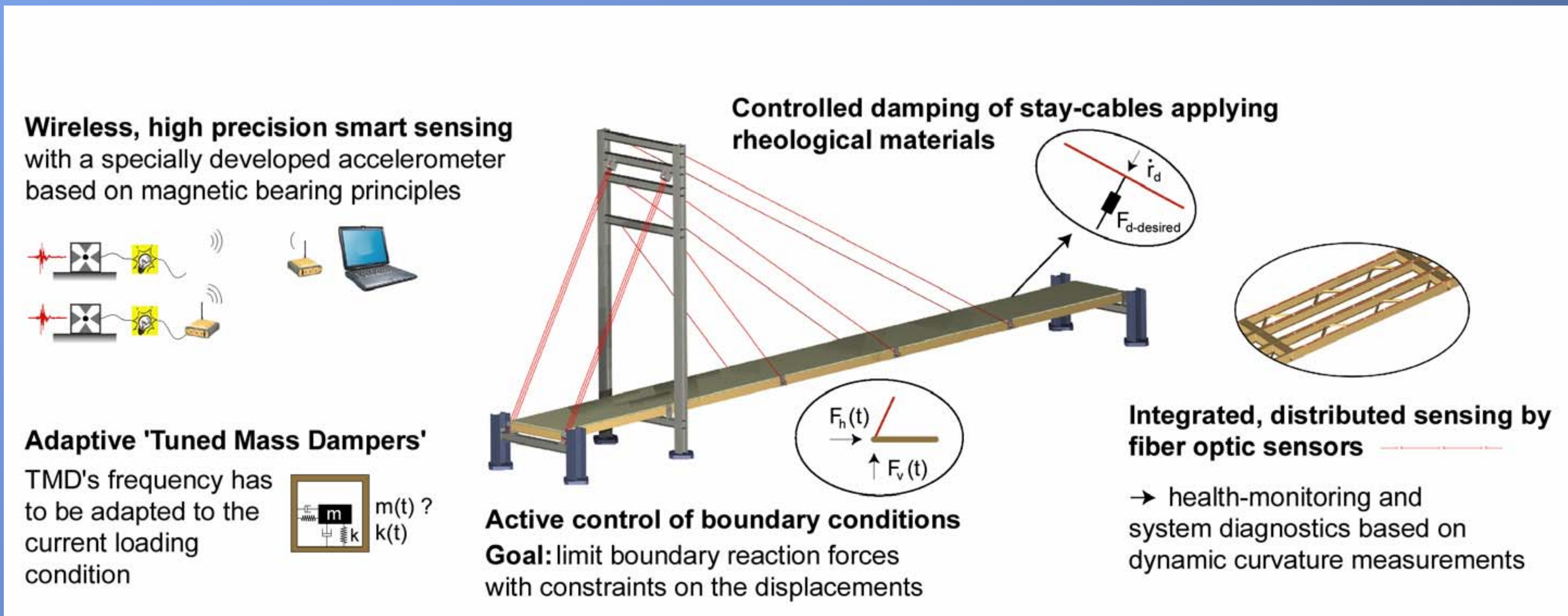
Guidelines

- Cable stayed bridge
- Pedestrian-bridge
- Glass-FRP bridge deck
- Modular system
- Dimensions 20.0 m x 2.0 m x 7.5 m

→ light and slender structure susceptible to vibrations



Subprojects



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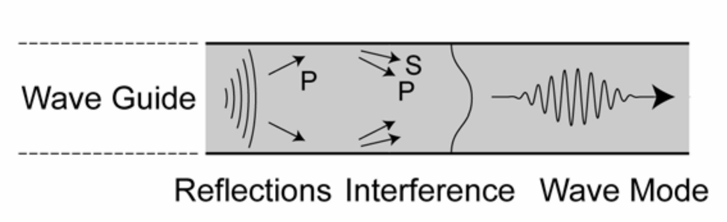
Guided Waves in Cables

Goal: Damage detection in the anchor heads

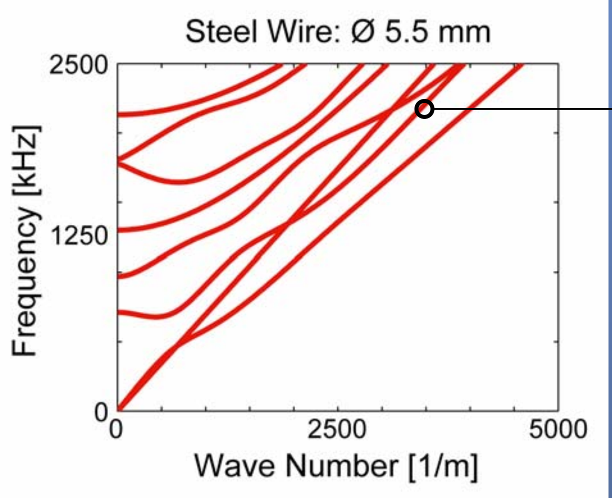
principle of „Guided Waves“

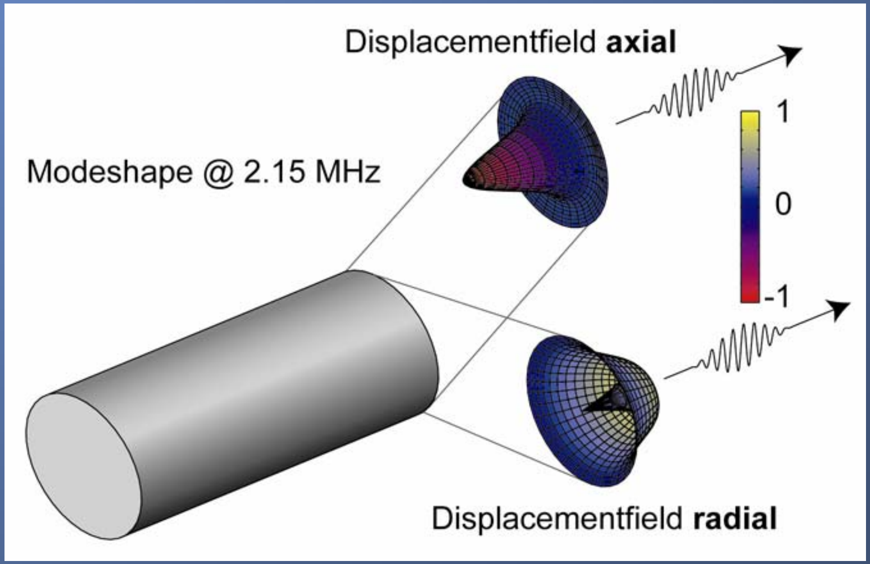


criteria for mode-choice

- min. surface deformations
  $\Rightarrow$ min. energy lost and min. interaction with border

Dispersion: ($\lambda = f(\omega)$)

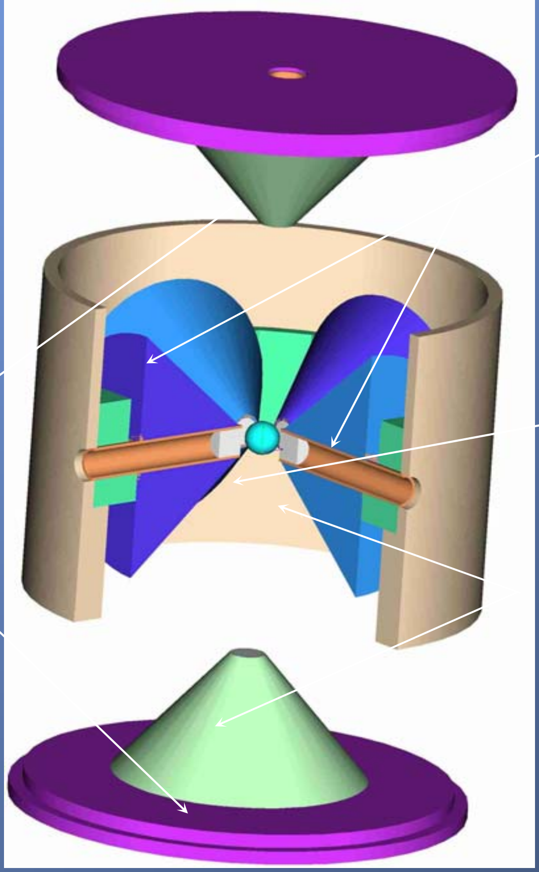




Magnetic Levitation for Inertial Sensing Systems

Goal: Development of a contact-less inertial sensor based on the magnetic levitation of an inertial mass

•Sensor will be
-robust
-very sensitive
-low cost



horizontal pair of

ferromagnetic inertial

vertical pair of

high precision position

Six electromagnets are diametrically disposed in pairs along three orthogonal axis

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Structural Engineering Research Laboratory

- within SAMCO
- Guidelines for structural control

- Proposals for the new call of FP 6
- Nonlinear system identification by using ridgelets
- Adaptive control of structural vibrations
- Adaptive structures: shape memory alloys (SMA) as actuators
- Non Destructive Testing of Cable Anchor Heads using “Guided Waves”
- Magnetic and Diamagnetic Levitation for Inertial Sensing Systems and High Precision Instrumentation
- As general research platform: “Smart Bridge”

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