Universidade do Porto
Faculdade de Engenharia
FEUP

New trends in dynamic bridge testing The perspective of FEUP

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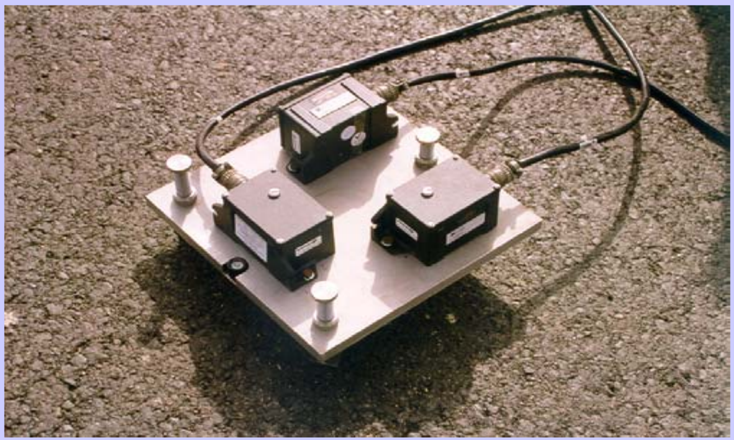
SUMMARY

- Modal identification
- Finite element correlation and updating
- Vibration based damage detection
- Pedestrian induced vibrations
- Traffic induced vibrations
- Cable vibrations
- Structural monitoring
- Control of vibrations

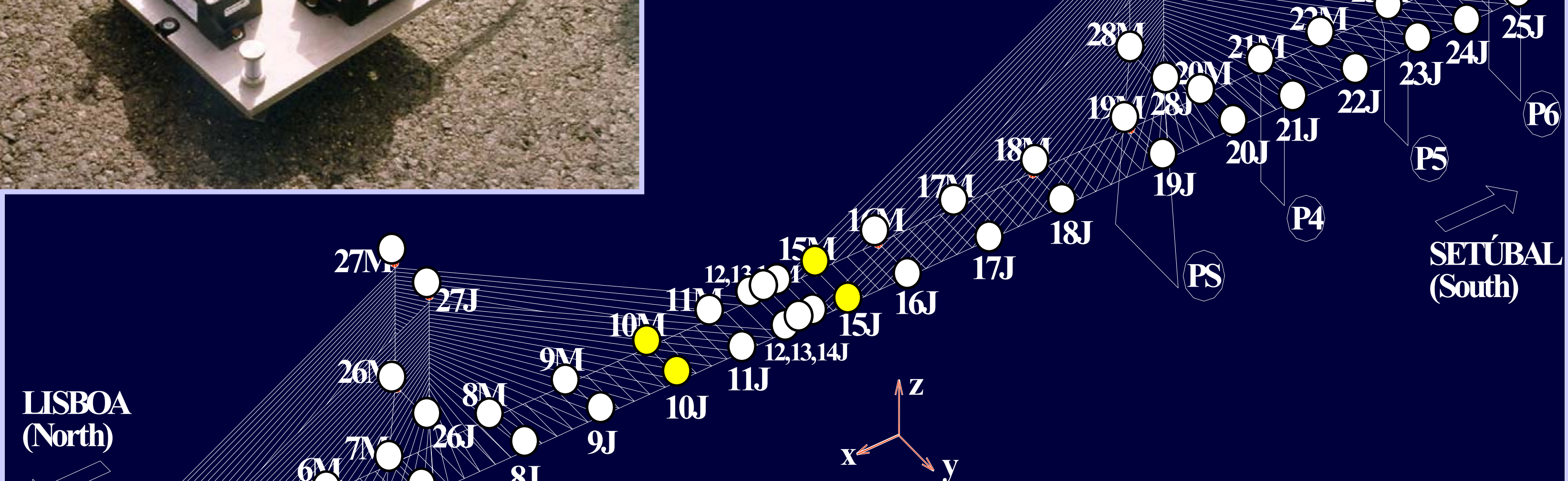
MODAL IDENTIFICATION

Vasco da Gama Bridge

AMBIENT VIBRATION TEST



Vasco da Gama Bridge

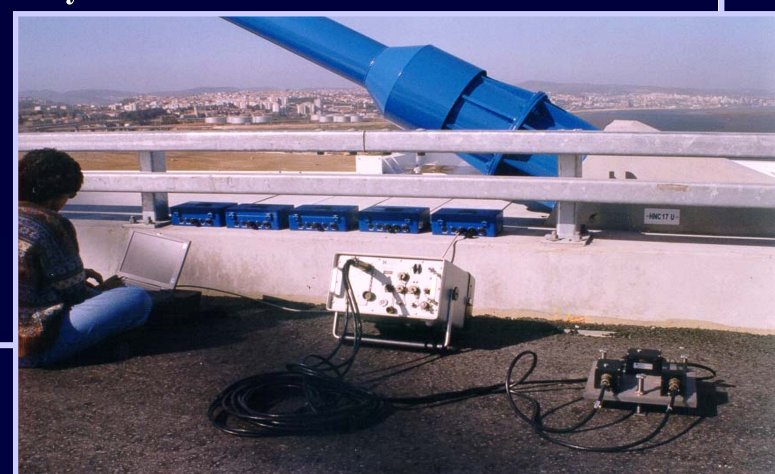


6 triaxial accelerographs

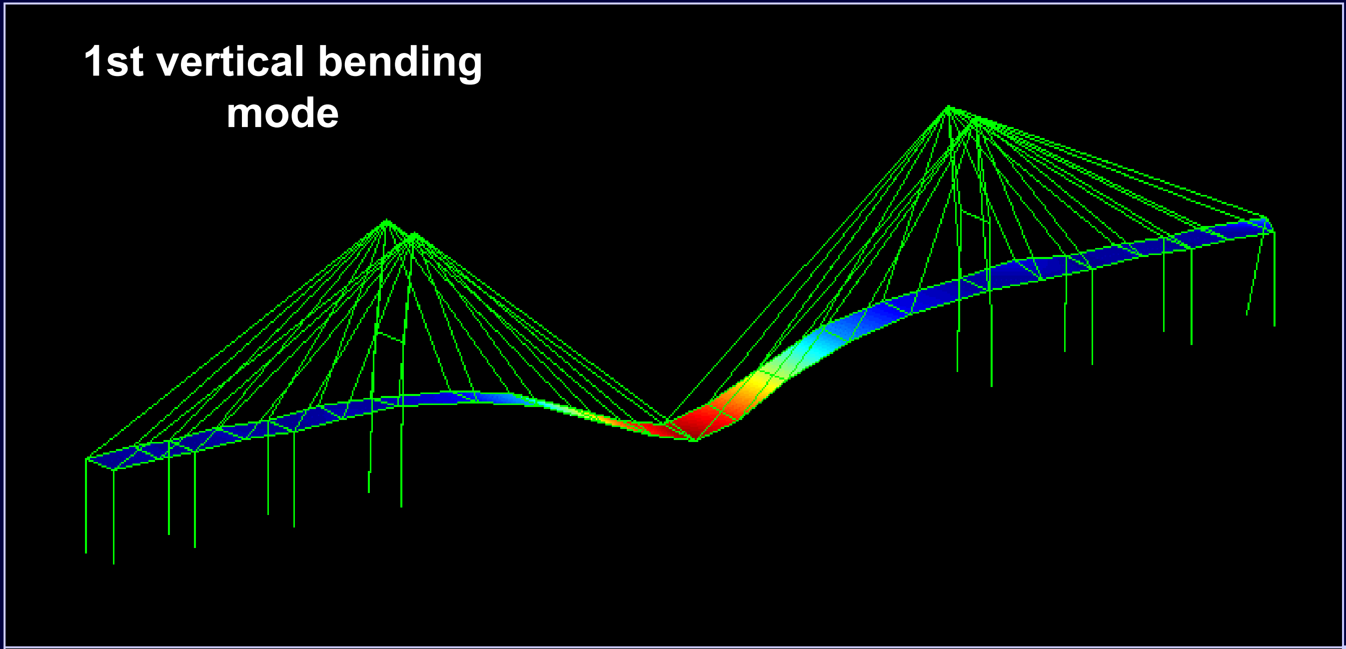
Precision: <1g/2^{16}=0,015mg

Sampling frequency: 50 Hz

Frequency resolution: <0,01Hz



MODAL IDENTIFICATION



Free vibration test

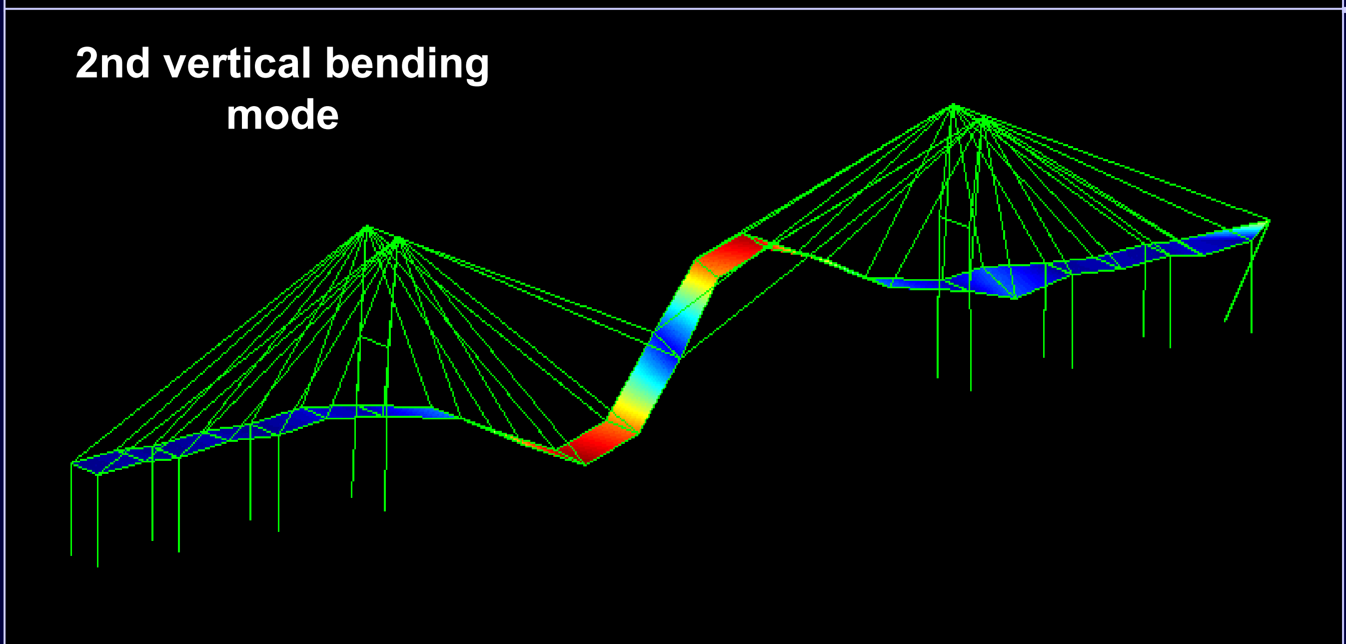
f=0.338 Hz

$\xi = 0{,}16 - 0{,}40$

Stochastic identification

f=0.339 Hz

$\xi = 0{,}41$



Free vibration test

f=0.456 Hz

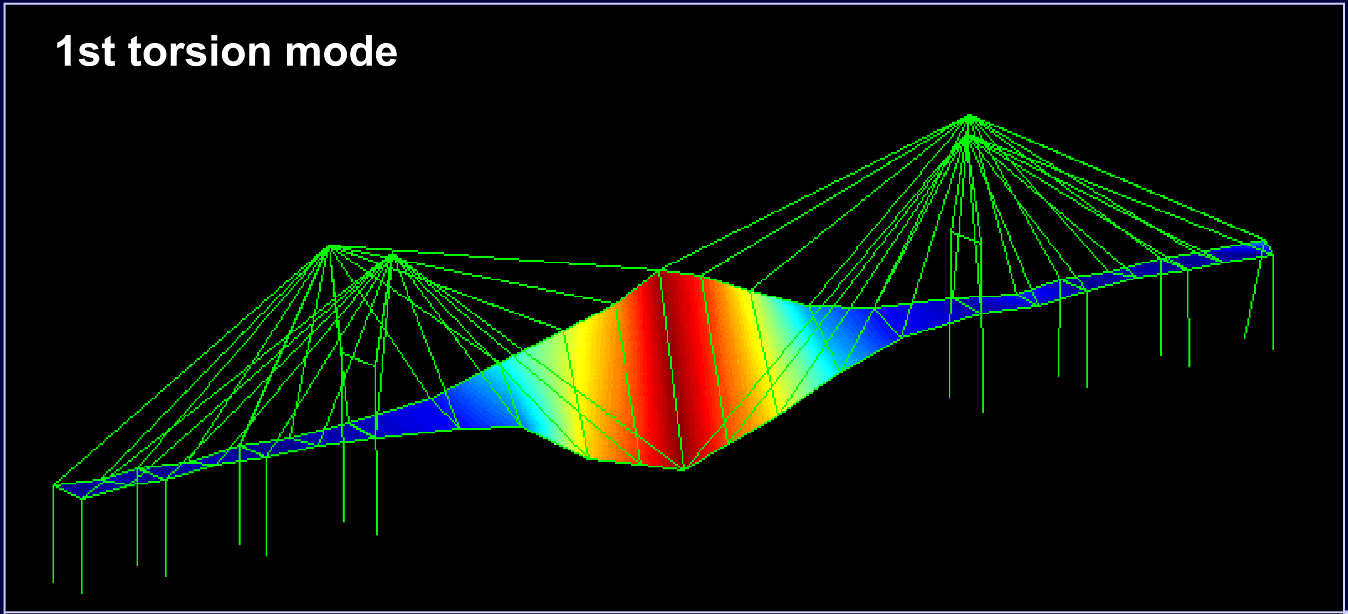
$\xi = 0{,}19 - 0{,}27$

Stochastic identification

f=0.457 Hz

$\xi = 0{,}32$

MODAL IDENTIFICATION



Free vibration test

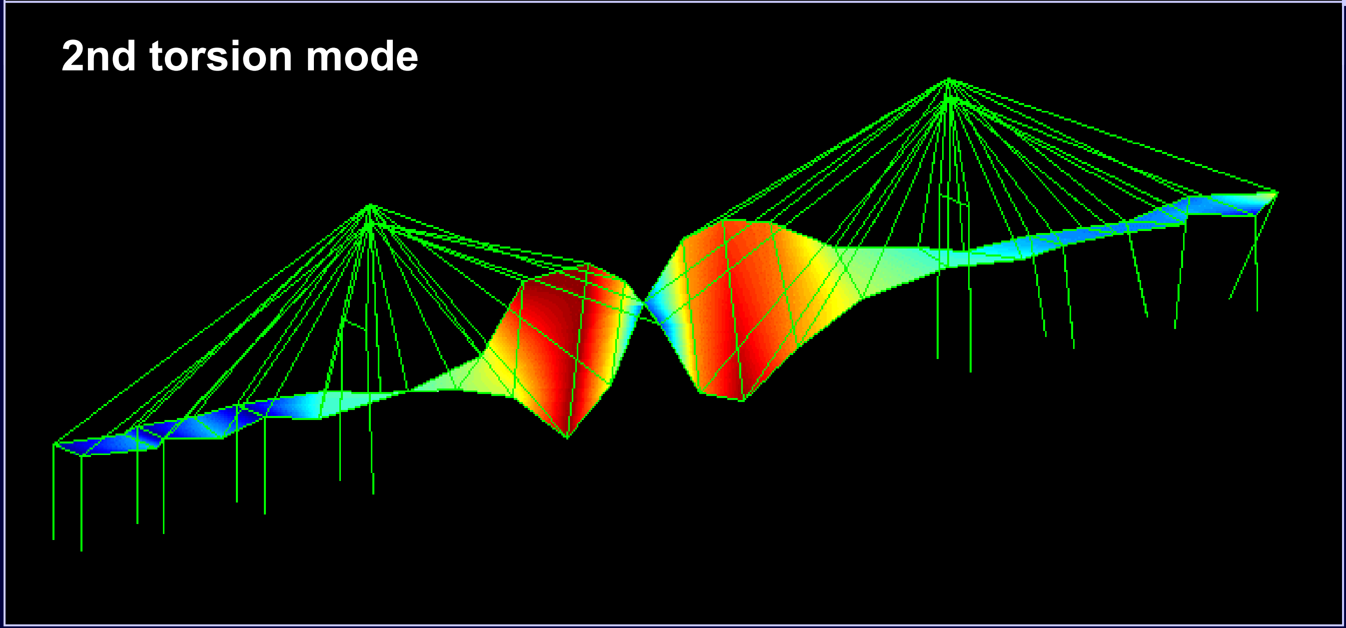
f=0.467 Hz

$\xi = 0,14 - 0,36$

Stochastic identification

f=0.469 Hz

$\xi = 0,34$



Free vibration test

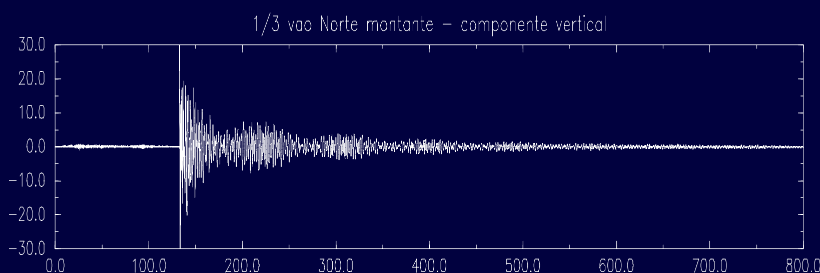
f=0.591 Hz

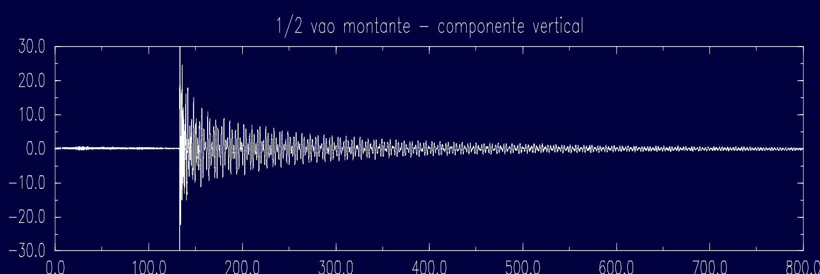
$\xi = 0,30 - 0,39$

Stochastic identification

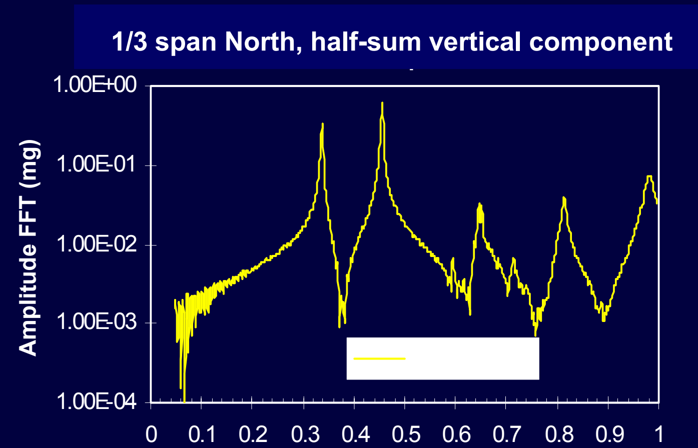
f=0.622 Hz

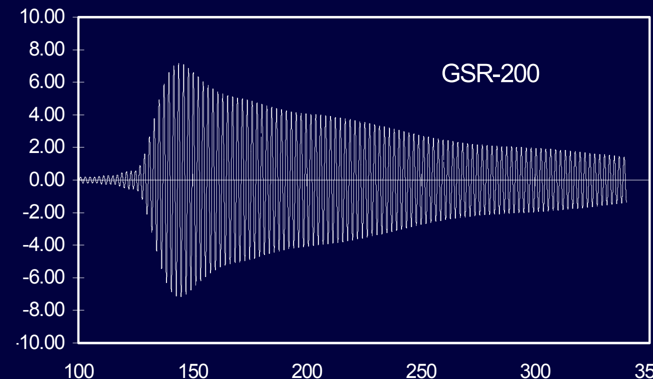
FREE VIBRATION TEST

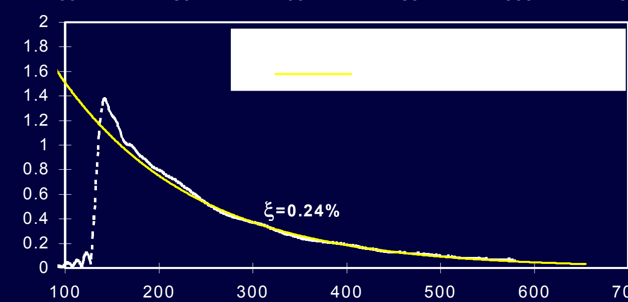




- Identification of modal damping factors





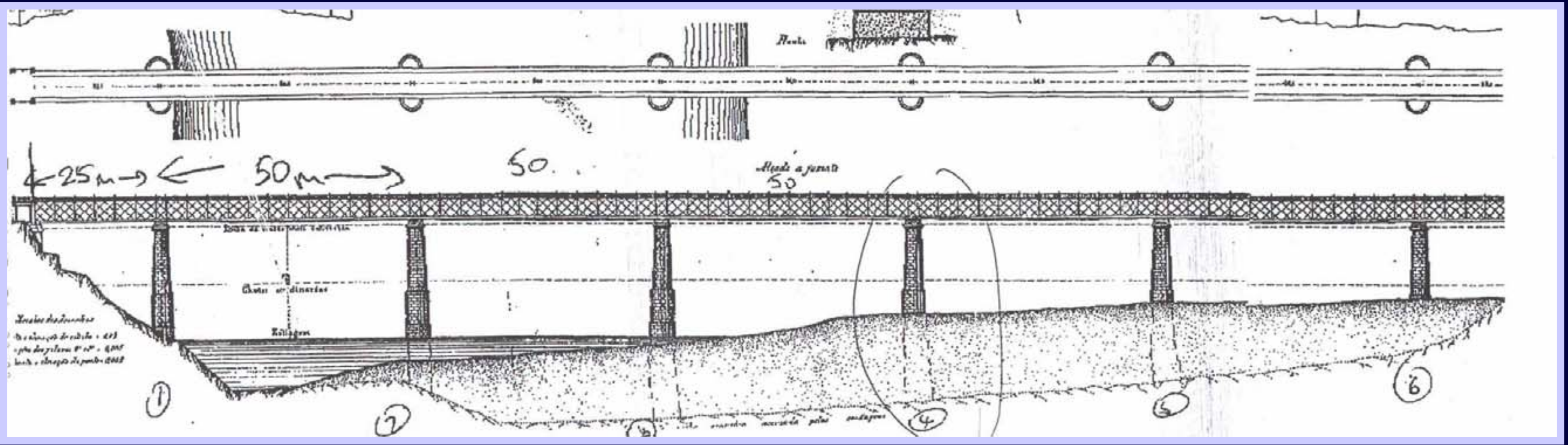


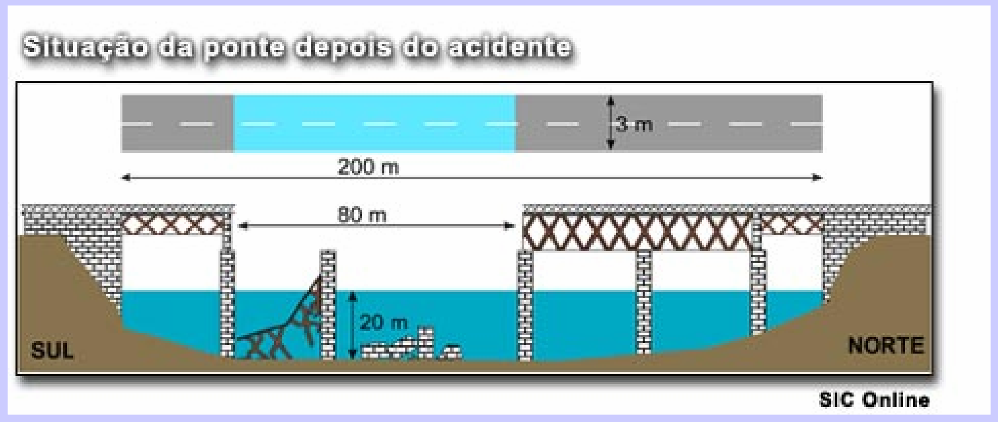
MODAL IDENTIFICATION

Trends for development

- Instrumentation
  - Wireless solution (time synchronization by GPS)
  - Conventional cables solution allowing in-situ modal identification
  - Innovative data acquisition with local digitization and signal conditioning, single cable transmission and remote control from the lab (GSM or Internet)
- Output-only modal identification software
  - Allowing objective and automatic identification

FINITE ELEMENT CORRELATION





7 spans, 6 masonry piers

Steel truss deck

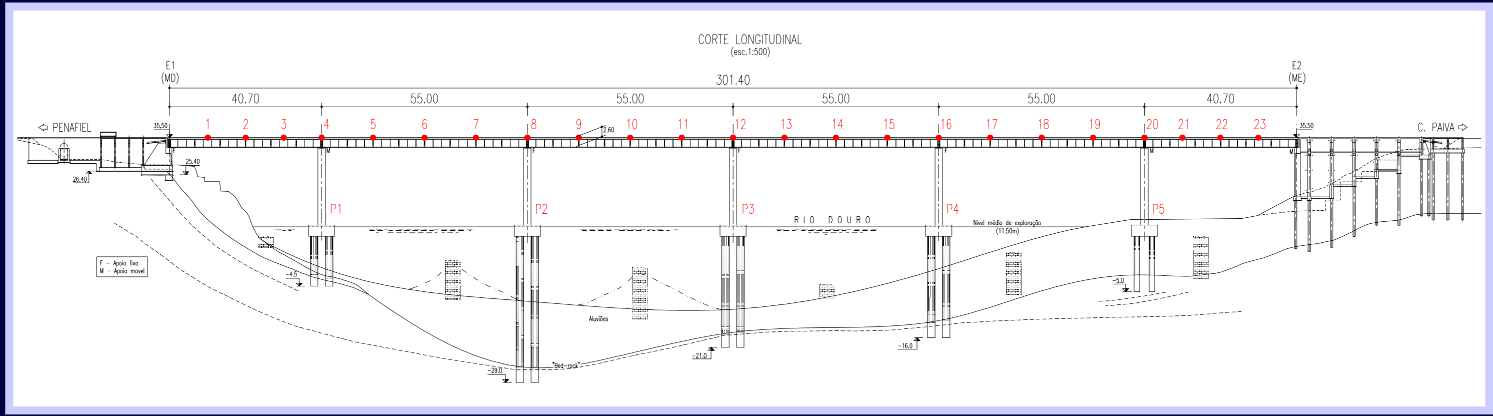
Wood piles

Construction: 1885 (116 y.o.)

The old Hintze Ribeiro Bridge

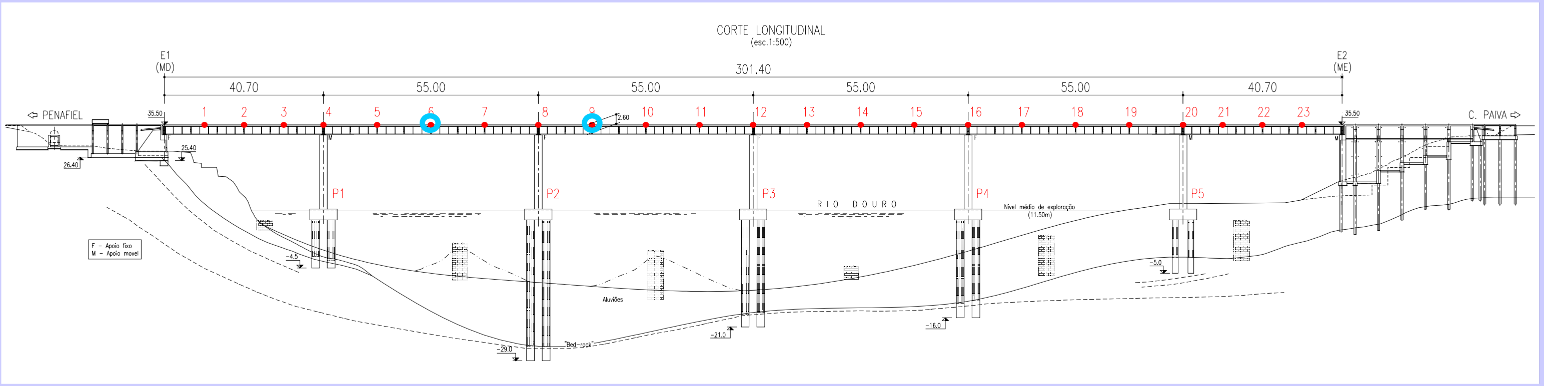
COLAPSE OF HINTZE RIBEIRO BRIDGE

THE NEW HINTZE RIBEIRO BRIDGE



AMBIENT VIBRATION TEST

- Definition of 2 reference stations (6 and 9)
- Measurement at supports, midspan, 1/4th span, top and base of piers

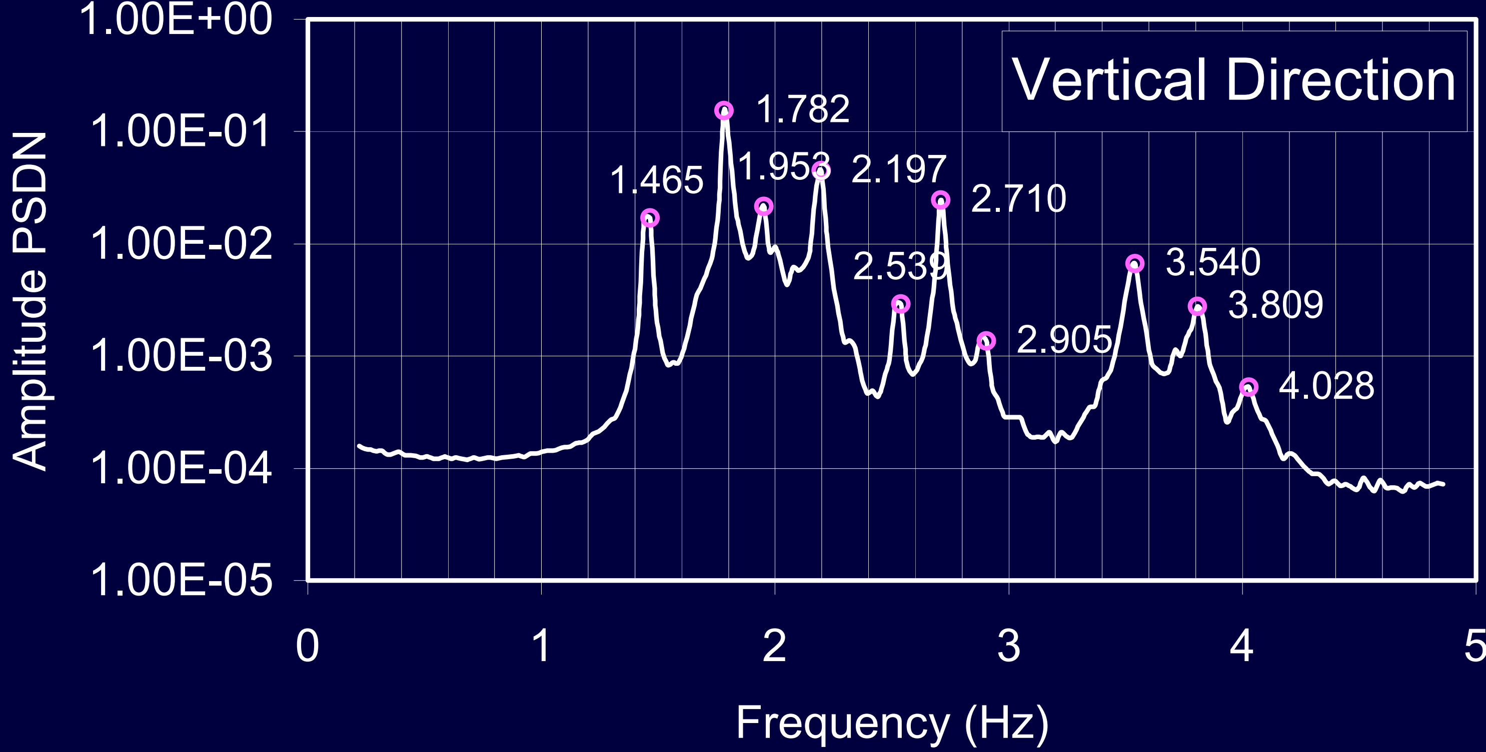


- Measurements along one of the steel I-girders

- 4 seismographs, 18-bit A/D converter
- 1 laptop

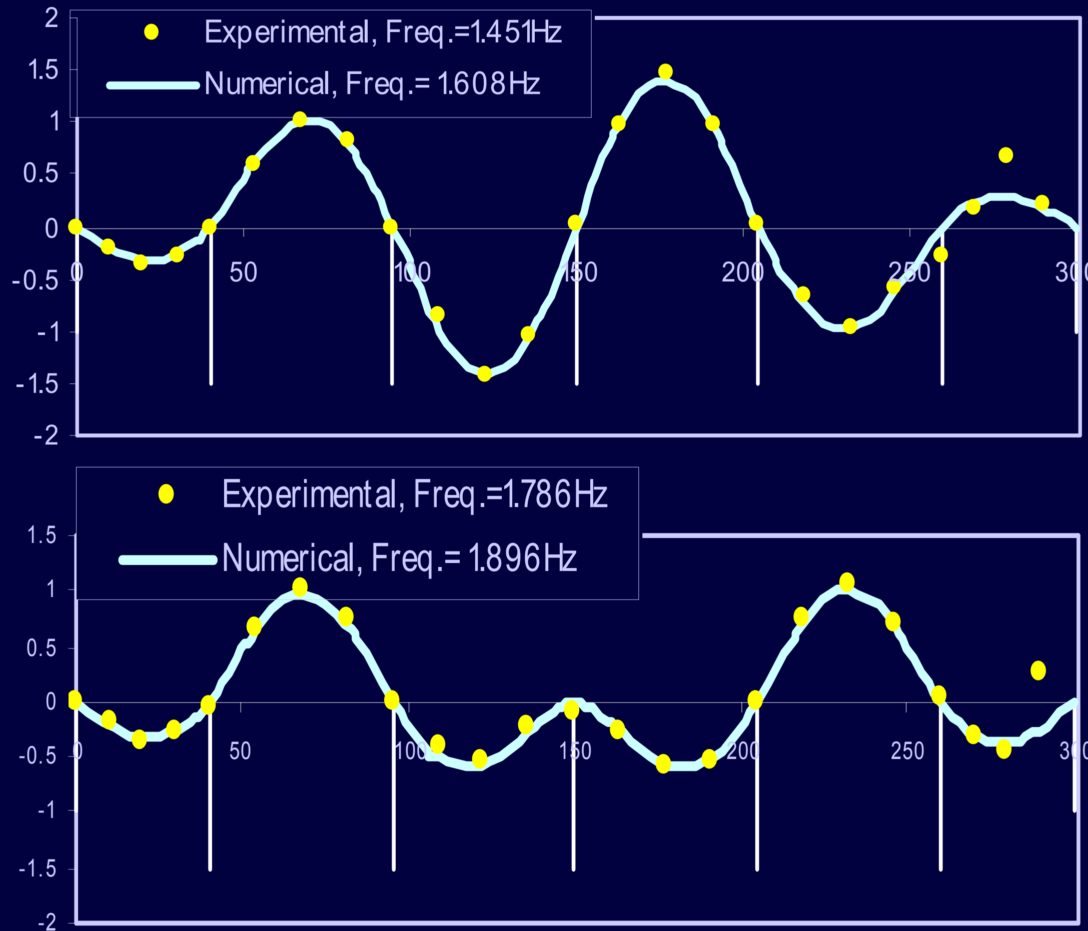
AMBIENT VIBRATION TEST

Average normalized power spectra



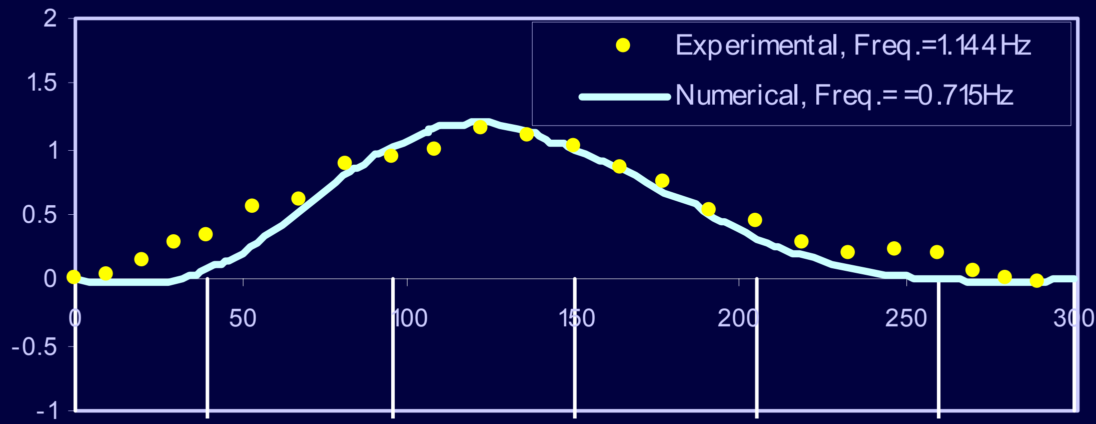
FINITE ELEMENT CORRELATION

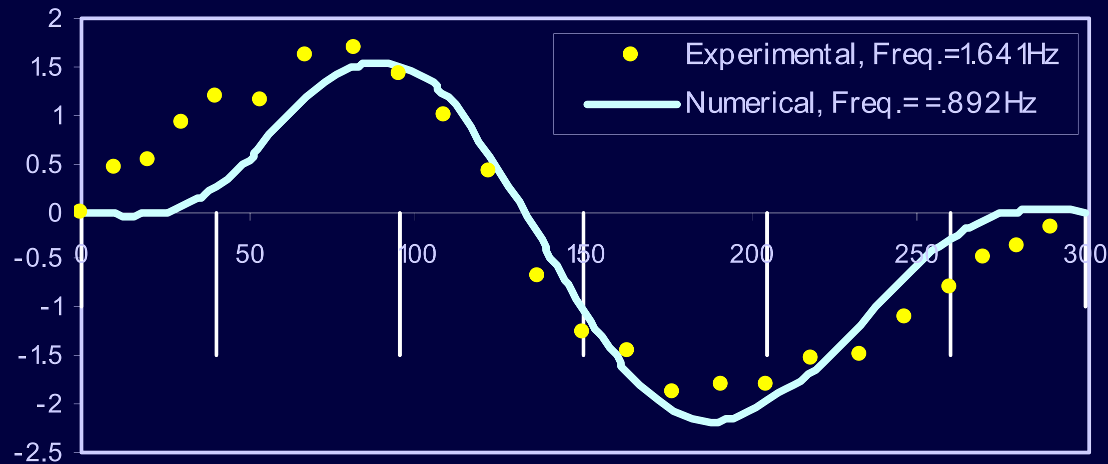
Identified vs calculated modes: vertical component



FINITE ELEMENT CORRELATION

Identified vs calculated modes: lateral component





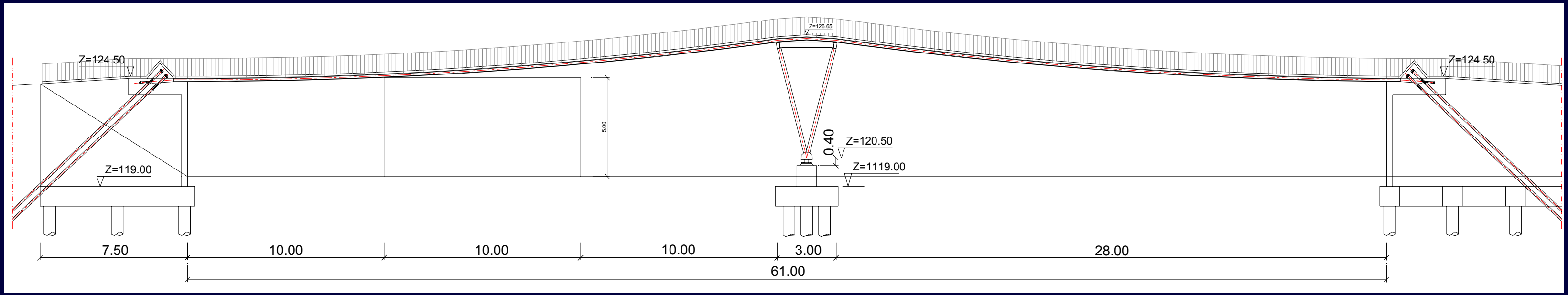
FINITE ELEMENT CORRELATION

Identified vs calculated natural frequencies

Calculated frequency (Hz)	Identified frequency (Hz)	Type of mode (*)
1.608	1.465	1st vertical
1.896	1.782	2nd vertical
2.291	2.710	3rd vertical
2.291	2.890	4th vertical
3.458	3.54	5th vertical

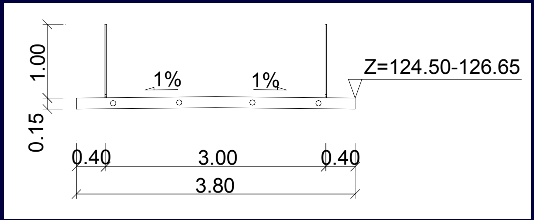
Calculated frequency (Hz)	Identified frequency (Hz)	Type of mode (*)
0.715	1.147	1st lateral
0.892	1.636	2nd lateral
1.180	2.881	3rd lateral

FINITE ELEMENT UPDATING



L_1=30m; L_2=28m

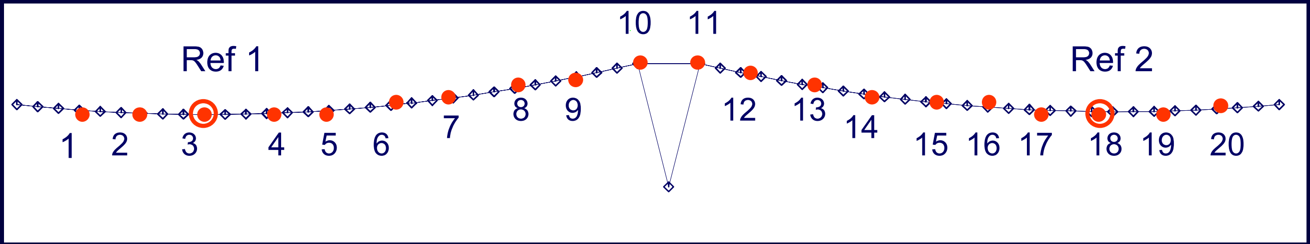
T_0=750kN x 4



Stress-ribbon footbridge

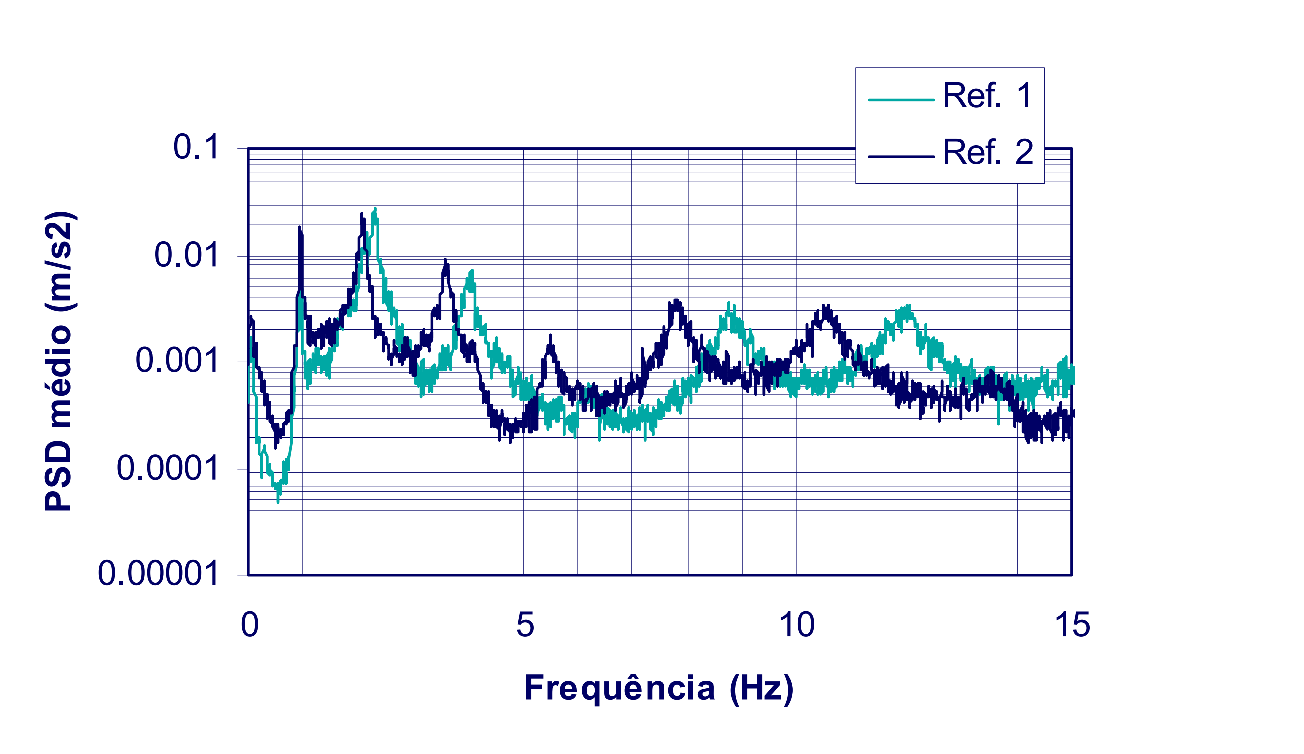
EXPERIMENTAL ASSESSMENT

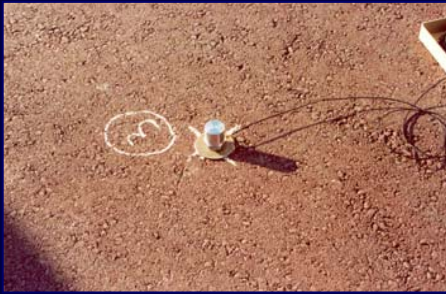
AMBIENT VIBRATION TEST



Moving measurement points

Reference points

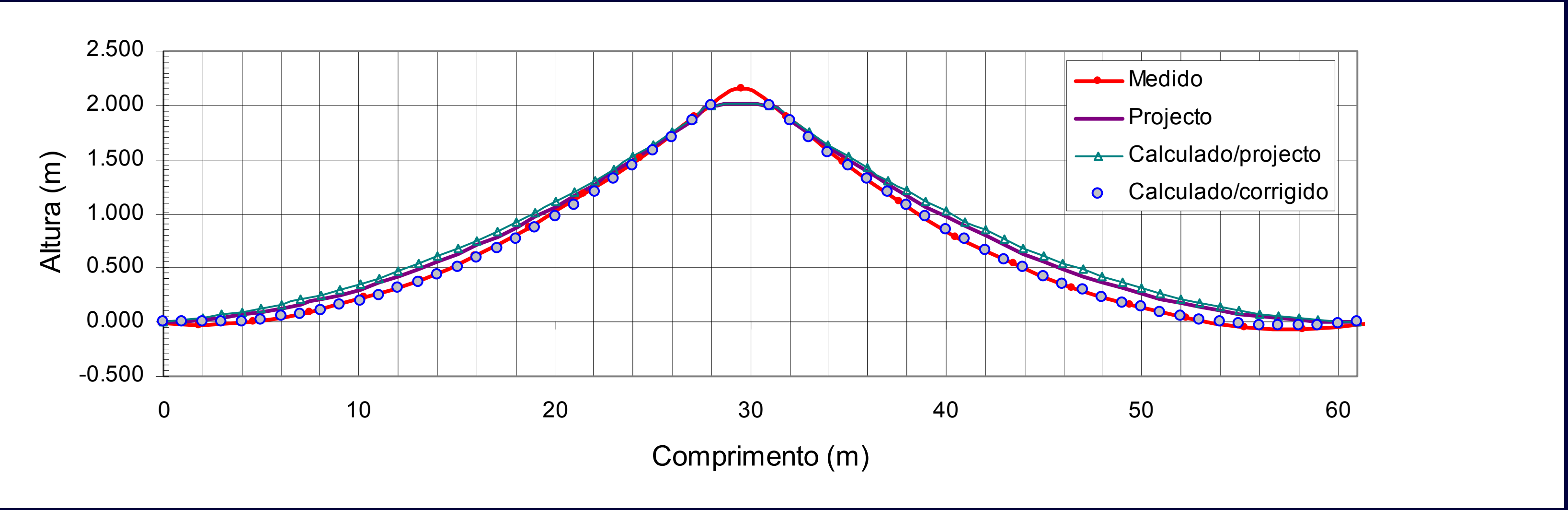




NUMERICAL MODELLING

Model 1

Discretization of the deck in beam finite elements with the geometry corresponding to the design configuration



Model 2

Discretization of the deck in beam finite elements with the geometry corresponding to the measured configuration

NUMERICAL MODELLING

Model 3

Discretization of the deck in truss finite elements with the cables' axial stiffness (neglecting bending stiffness), adjusting the initial cables tension so as to obtain the measured longitudinal profile after progressive application of the loads

Model 4

Discretization of the deck in truss finite elements, with progressive loading and activation of beam elements connecting the nodes of the truss elements

Final model

Consideration of partial rotations between beam elements to simulate the lack of sealing of the joints.
Reduction of the area and inertia of the beam elements to simulate the effects of cracking and lack of adherence between precast and in situ concrete

FINITE ELEMENT UPDATING

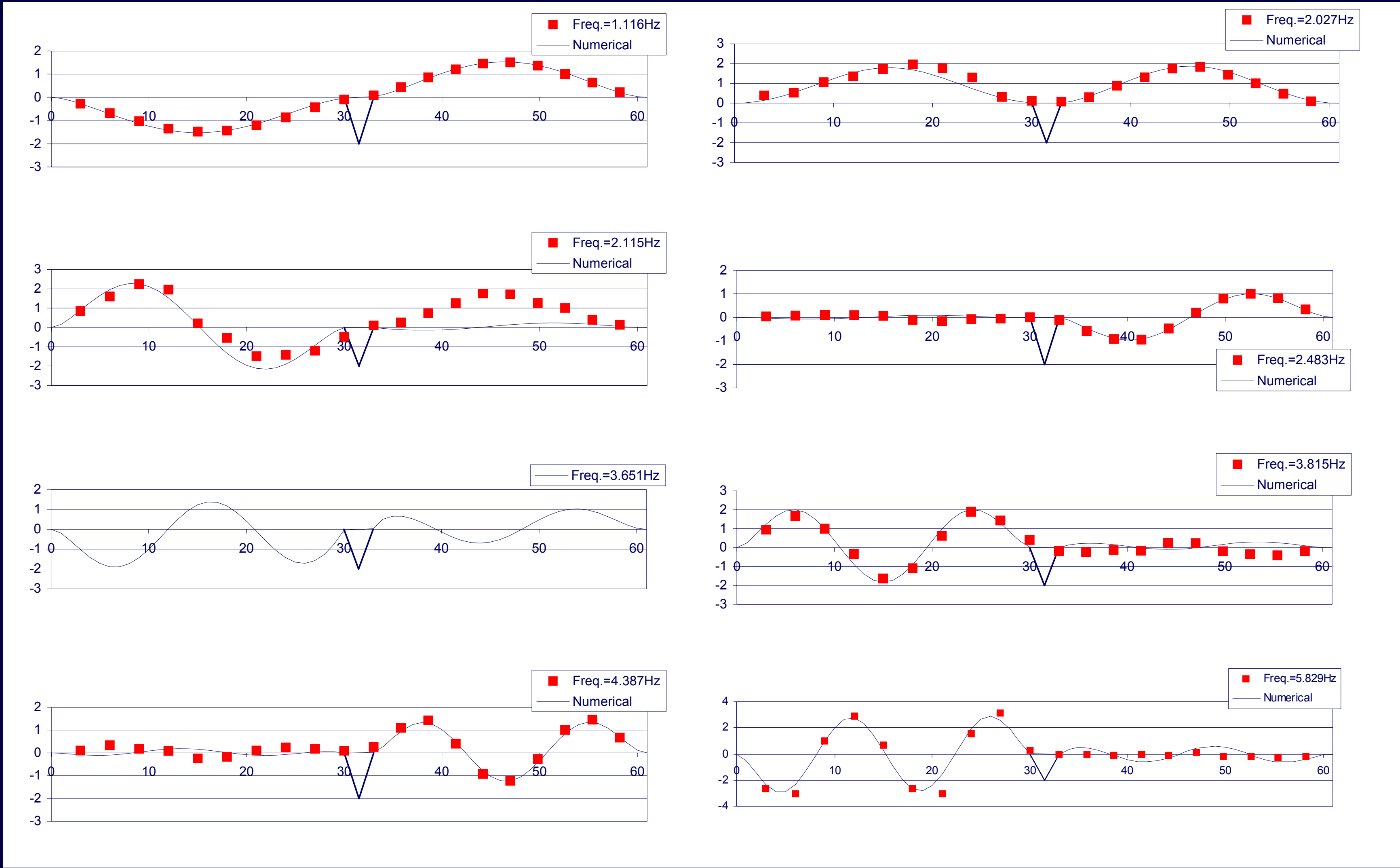
Final model

Discretization of the deck in truss finite elements, with progressive loading and activation of beam elements.
Consideration of partial rotations between beam elements to simulate the lack of sealing of the joints.
Reduction of the area and inertia of the beam elements to simulate the effects of cracking and lack of adherence between precast and in situ concrete.

Modo nº	Freq. medida (Hz)	Modelo 1 Freq. (Hz)	Modelo 2 Freq. (Hz)	Modelo 3 Freq. (Hz)	Modelo 4 Freq. (Hz)	Modelo final Freq. (Hz)
1	1.116	0.849	0.794	0.724	1.096	.980
2	2.027	2.448	2.654	0.937	2.442	2.033
3	2.115	1.902	1.822	1.446	3.813	2.250
4	2.483	2.096	2.002	1.547	3.895	2.550
5	-			2.217	7.496	3.651
6	3.815	3.415	3.401	3.376	7.569	4.115
7	4.387	3.782	3.630	3.034	12.4	4.676

FINITE ELEMENT UPDATING

Identified vs calculated mode shapes

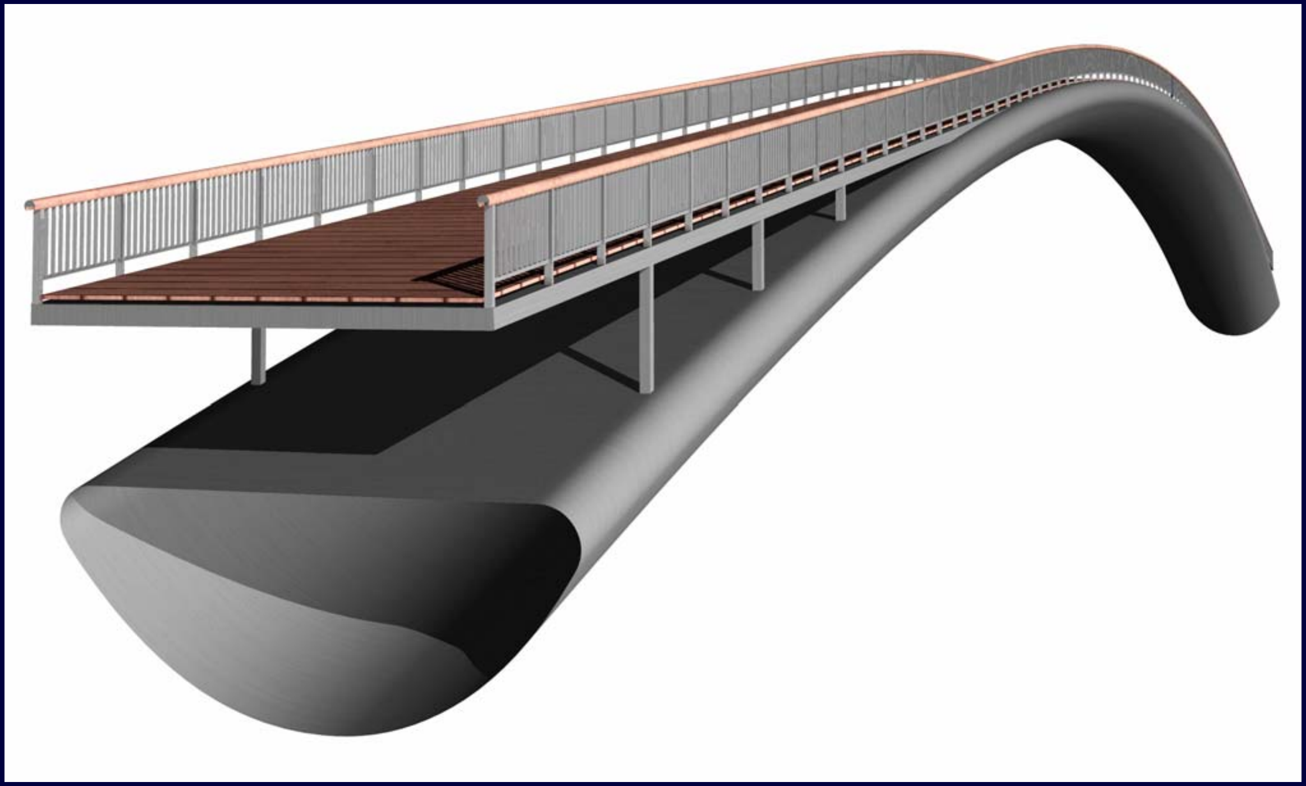


FINITE ELEMENT UPDATING
VIBRATION BASED DAMAGE DETECTION

Trends for development

- Application of automatic procedures for finite element updating and damage detection
- Development of laboratory tests on beams
- Introduction of realistic damage scenarios in an existing bridge

PEDESTRIAN INDUCED VIBRATIONS



Stainless steel
footbridge

TRAFFIC INDUCED VIBRATIONS

SYNPEX Project: Advanced Load Models for Synchronous Pedestrian Excitation and Optimized Design Guidelines for Steel Bridges

Partners: RWTH Aachen, FEUP, CTICM, SBP

Workpackages:

- Requirements, problems and damages
- Pedestrian induced dynamic forces
- Mathematical load models for pedestrian induced forces
- Measurements in existing footbridges
- Numerical simulations
- Development of design guidelines and recommendations
- Control of vibrations

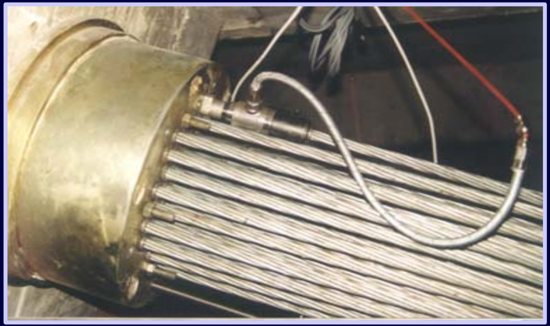
TRAFFIC INDUCED VIBRATIONS

Trends for development

- Measurement of pedestrian forces
- Methods for numerical prediction of maximum levels of vibration
- Design and simulation of control of vibration devices

ROADWAY BRIDGES

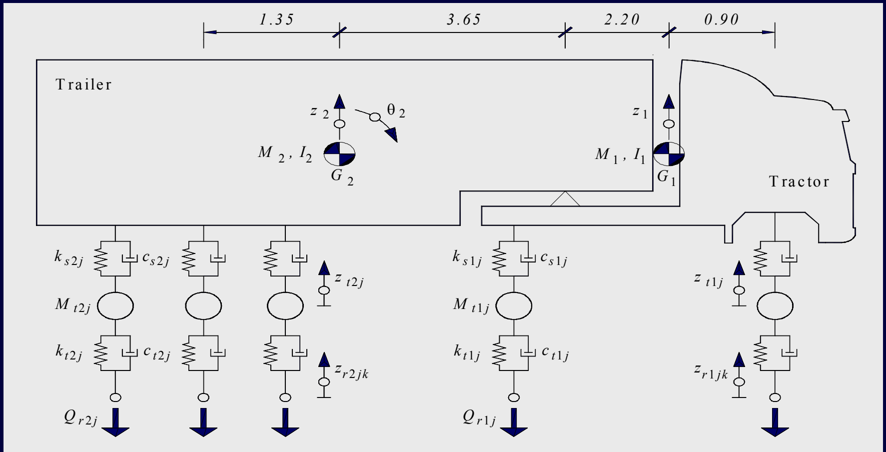
EXPERIMENTAL ASSESSMENT

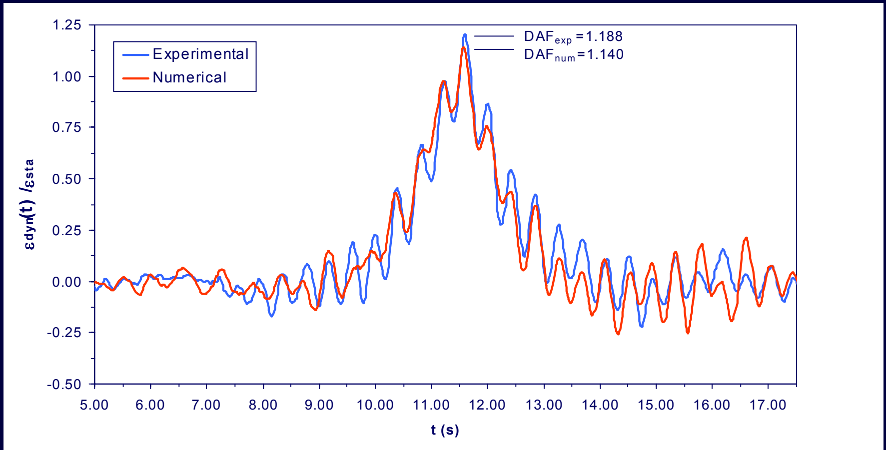


Strain gages Load cells Tests

ROADWAY BRIDGES

NUMERICAL MODELLING AND VALIDATION





Static and dynamic tests

RAILWAY BRIDGES

Trends for development

- Structural integrity assessment of old metalic railway bridges (fatigue assessment)
- High speed railway traffic

  - Dynamic effects in bridges

  - Vibrations in soils

CABLE VIBRATIONS STRUCTURAL MONITORING

Cable vibrations at GUADIANA BRIDGE

CABLE VIBRATIONS STRUCTURAL MONITORING

Damage in stay cables at GUADIANA BRIDGE

CABLE VIBRATIONS STRUCTURAL MONITORING

Cable vibrations in cable-stayed bridges FCT Project

Workpackages:

- Numerical modelling of the dynamic behaviour of a cable-stayed bridge
- Development of a multi-sensorial distributed instrumentation system
- Experimental characterization of the dynamic behaviour of the bridge
- Test and development of force sensors
- Development of video camera for vibration measurements
- Development of monitoring software
- Laboratory tests of physical models of stay cables
- Study of passive and semi-active control solutions

STRUCTURAL MONITORING

Trends for development

- Robust commercial solution
- Innovative solution:
  - multi-sensorial distributed instrumentation system
  - data acquisition with local digitization and signal conditioning
  - single cable transmission
  - remote control from the lab (GSM or Internet)

CONTROL OF VIBRATIONS

Trends for development

- Control of vibrations in footbridges
- Control of vibrations in stay cables
- Design and simulation of:
  - passive
  - active
  - semi-active

  solutions

CONCLUSION

MAIN TOPICS FOR JOINT RESEARCH

- Structural Monitoring and Damage Detection in Bridges
- Analysis and Control of Traffic Induced Vibrations in Bridges