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Theme: Advanced and cost effective road infrastructure construction, management and maintenance

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SLOVENIAN NATIONAL BUILDING AND CIVIL ENGINEERING INSTITUTE

TRIMM

Monitoring of bridge response to traffic loading

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TRIMM Final Seminar

TOMORROW'S ROAD INFRASTRUCTURE MONITORING & MANAGEMENT

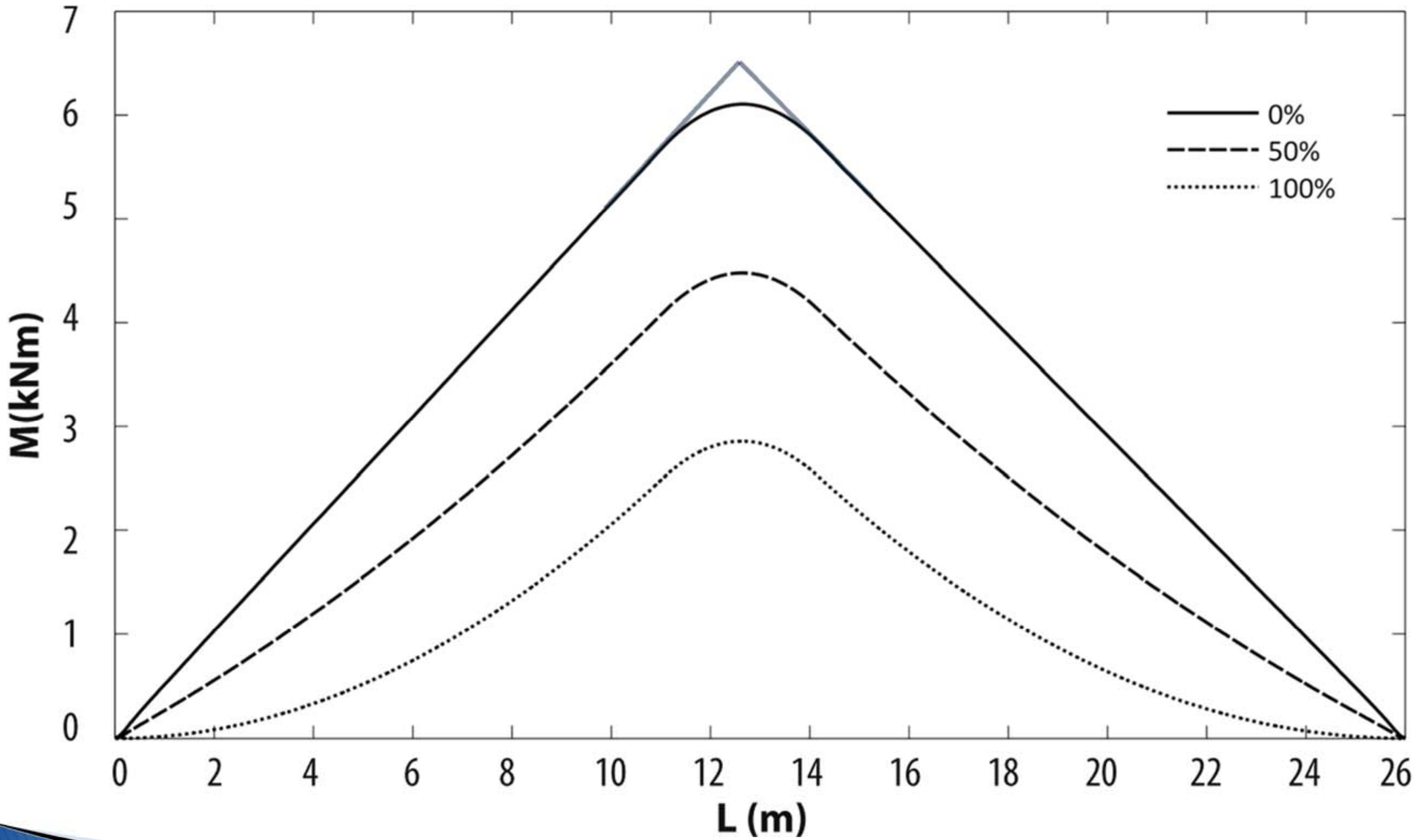
Outline

- Monitoring of joints and bearings
  - Influence lines with bridge WIM systems
  - Modal analysis
- Acoustic Emission - AE

Monitoring of joints and bearings

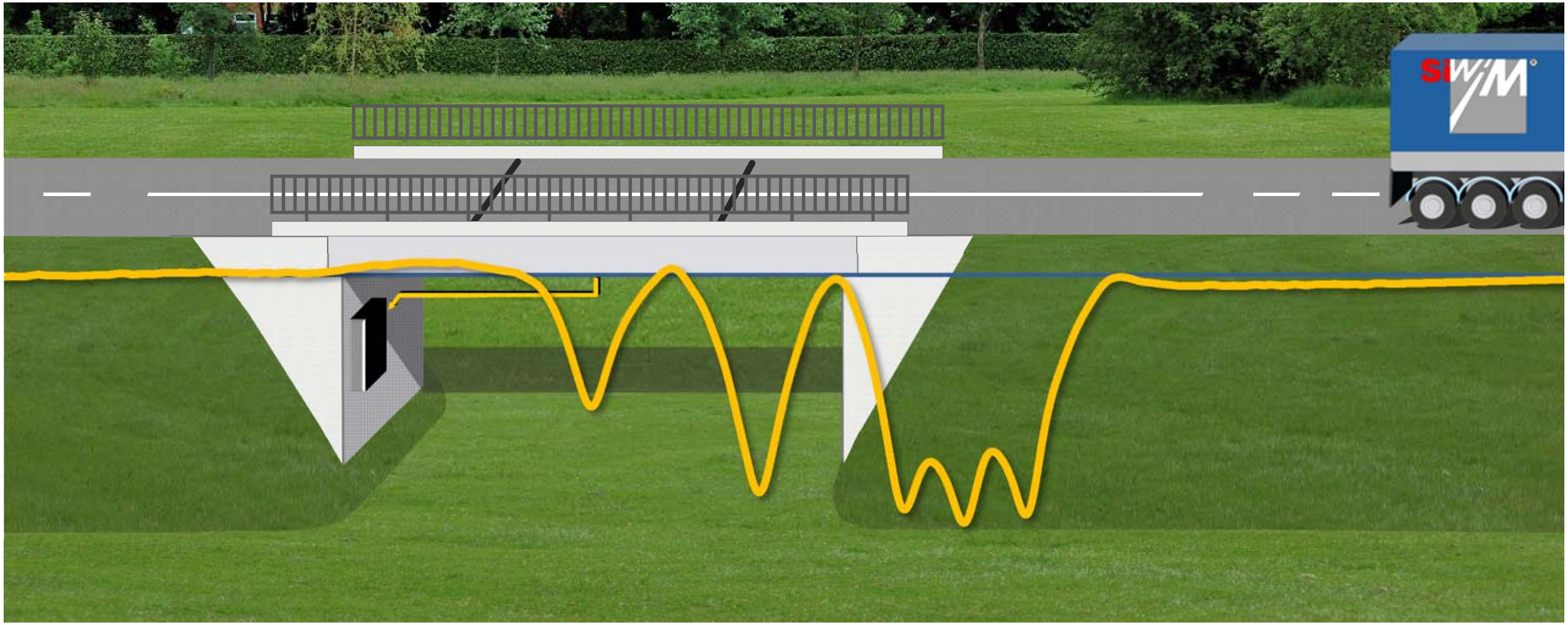
- joints and bearings important but often not properly assessed bridge elements
- structural parameters (IL, LDF and vibration properties) sensitive to stiffness of joints and bearings/boundary conditions
- Ambition:
  - to use them as indicators of EJ&B functionality
  - 2 approaches:
    a. shape of the influence lines based on B-WIM data
    b. modal analysis

Influence lines



Bridge WIM

B-WIM is a measuring system that uses an existing instrumented structure – a bridge or a culvert – to weigh vehicles in motion (at normal highway speed)

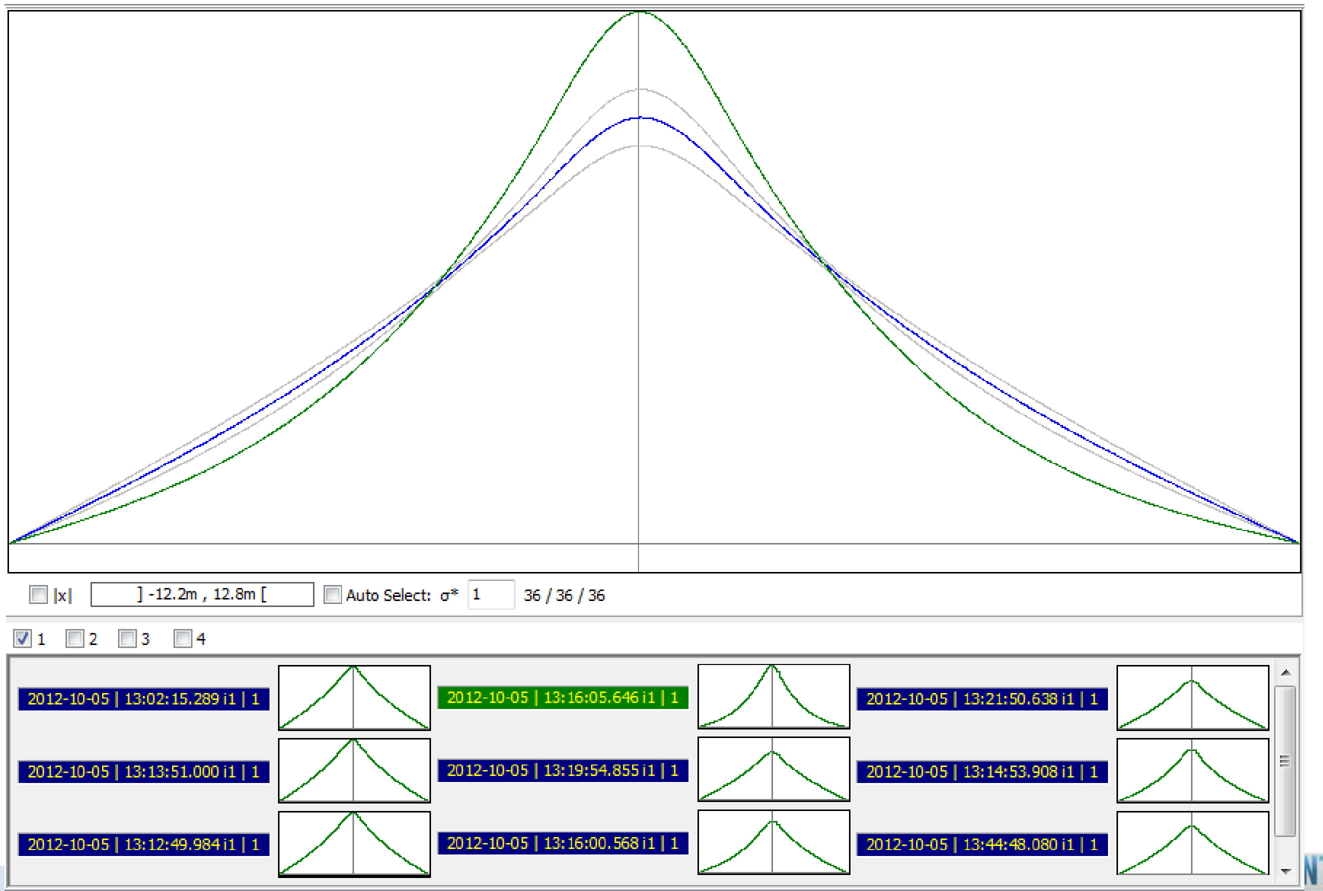


Bridge WIM

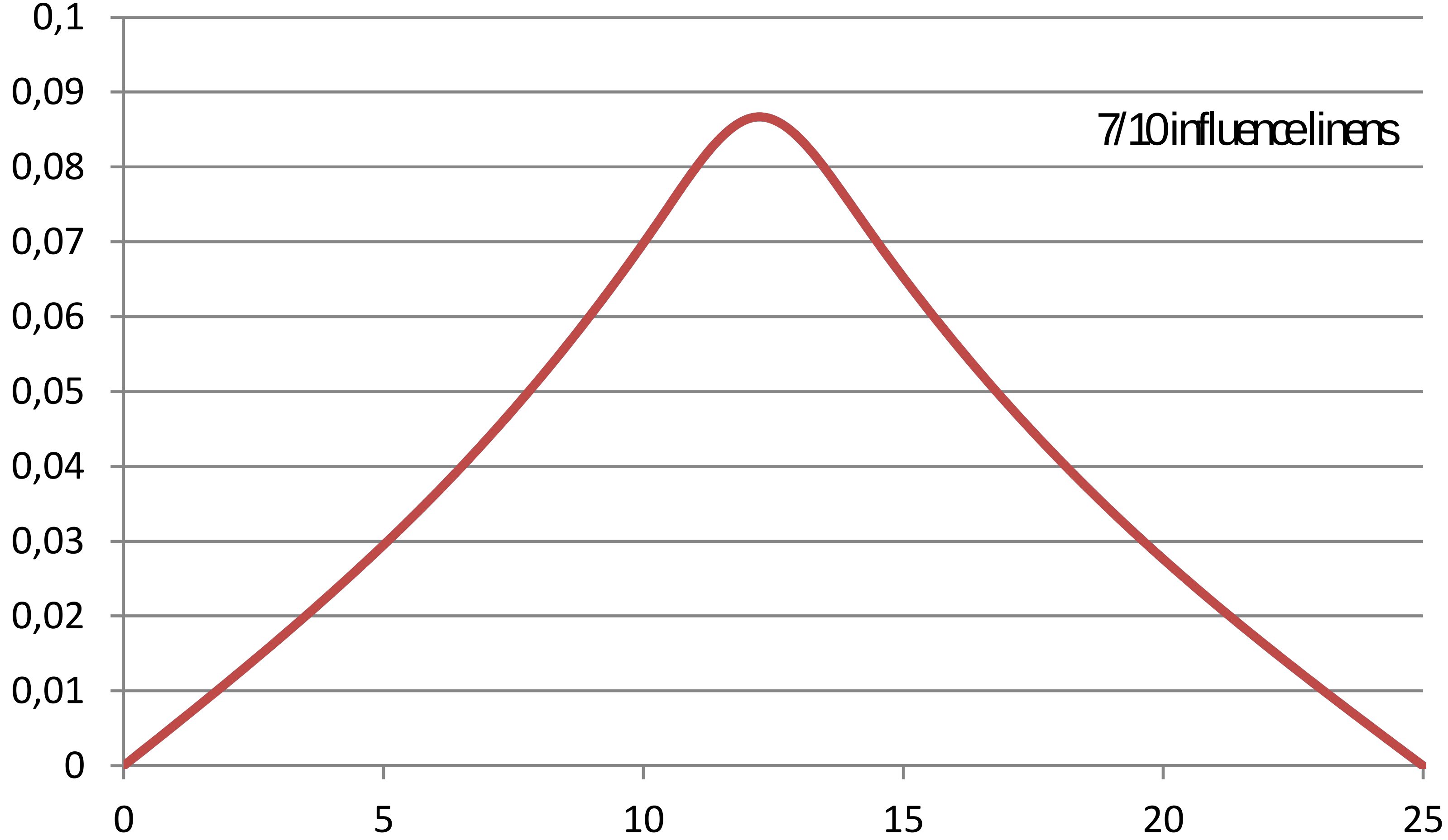
- present since 1980s, successful only in the last decade
- advantages:
  - complete portability, without affecting the accuracy
  - high accuracy
  - ease of installation, *without interrupting the traffic*
  - often bridges cannot be avoided
  - provide additional structural information
- disadvantages:
  - proper bridge is needed
  - less common structures require knowledge about bridges

SiWIM® and influence lines

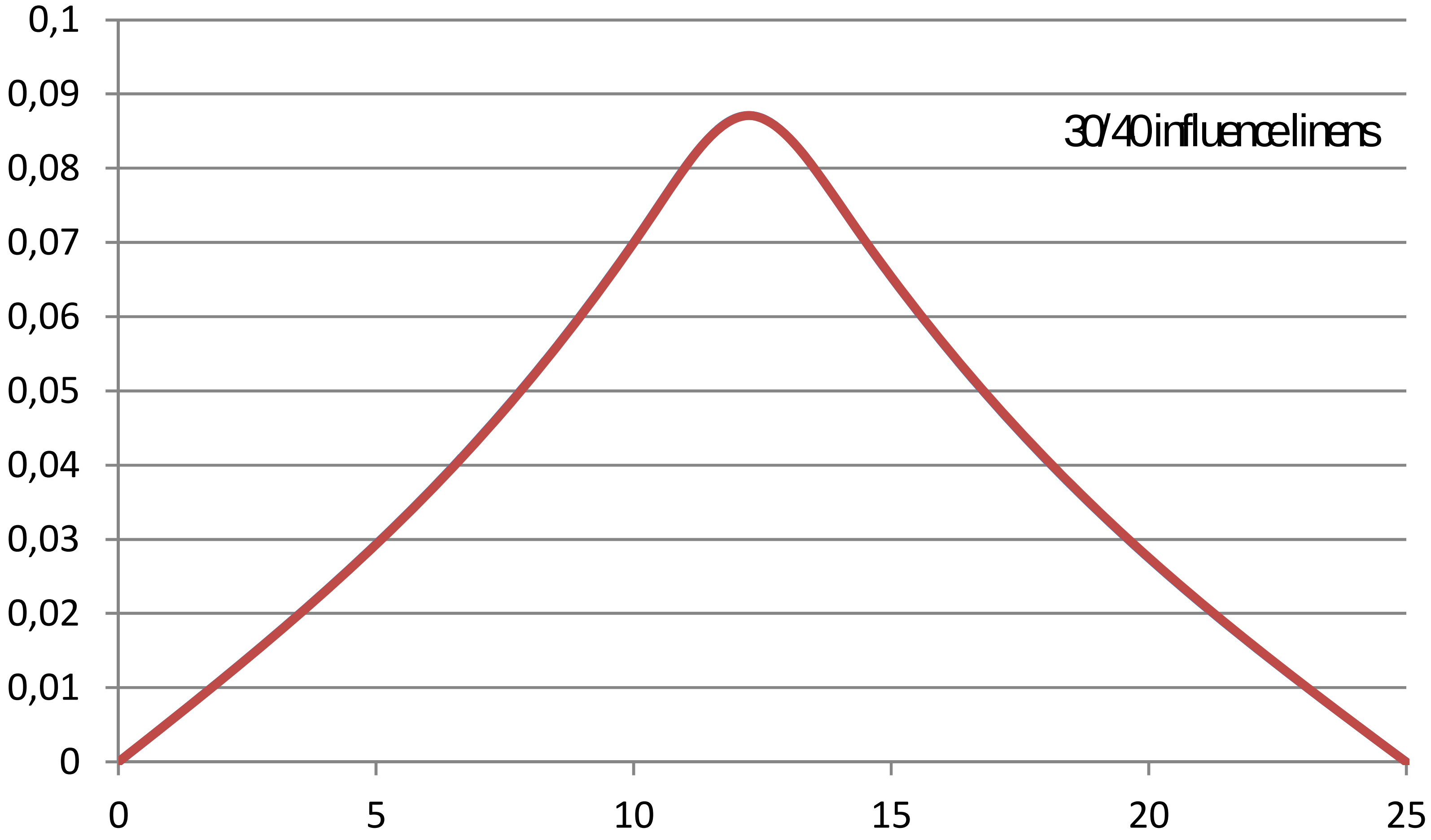
- SiWIM® calculates ILs and LDFs from vehicles passing the bridge
- new IL module
- long-term monitoring of changes



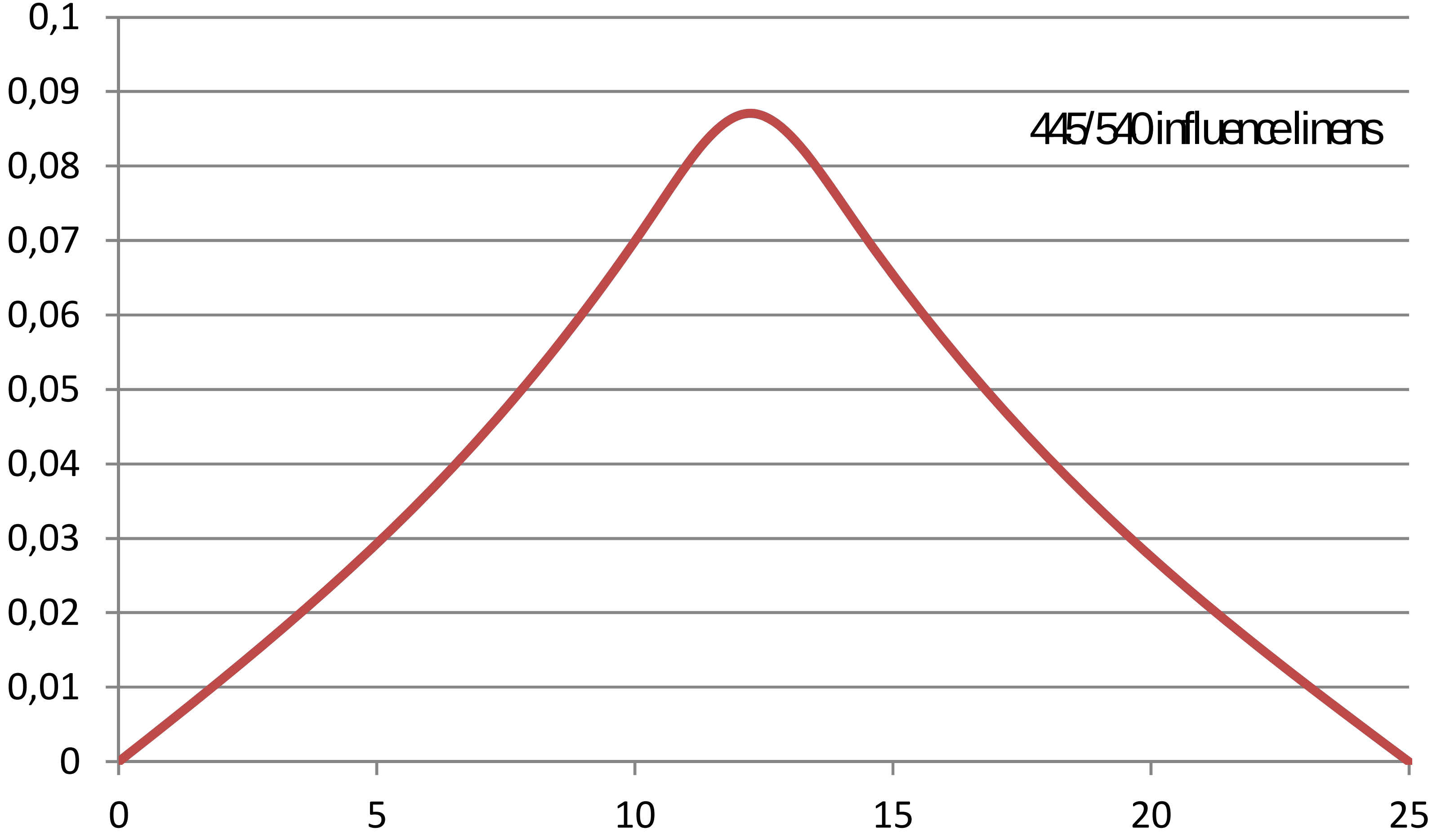
VA0468 influence lines – 10 runs



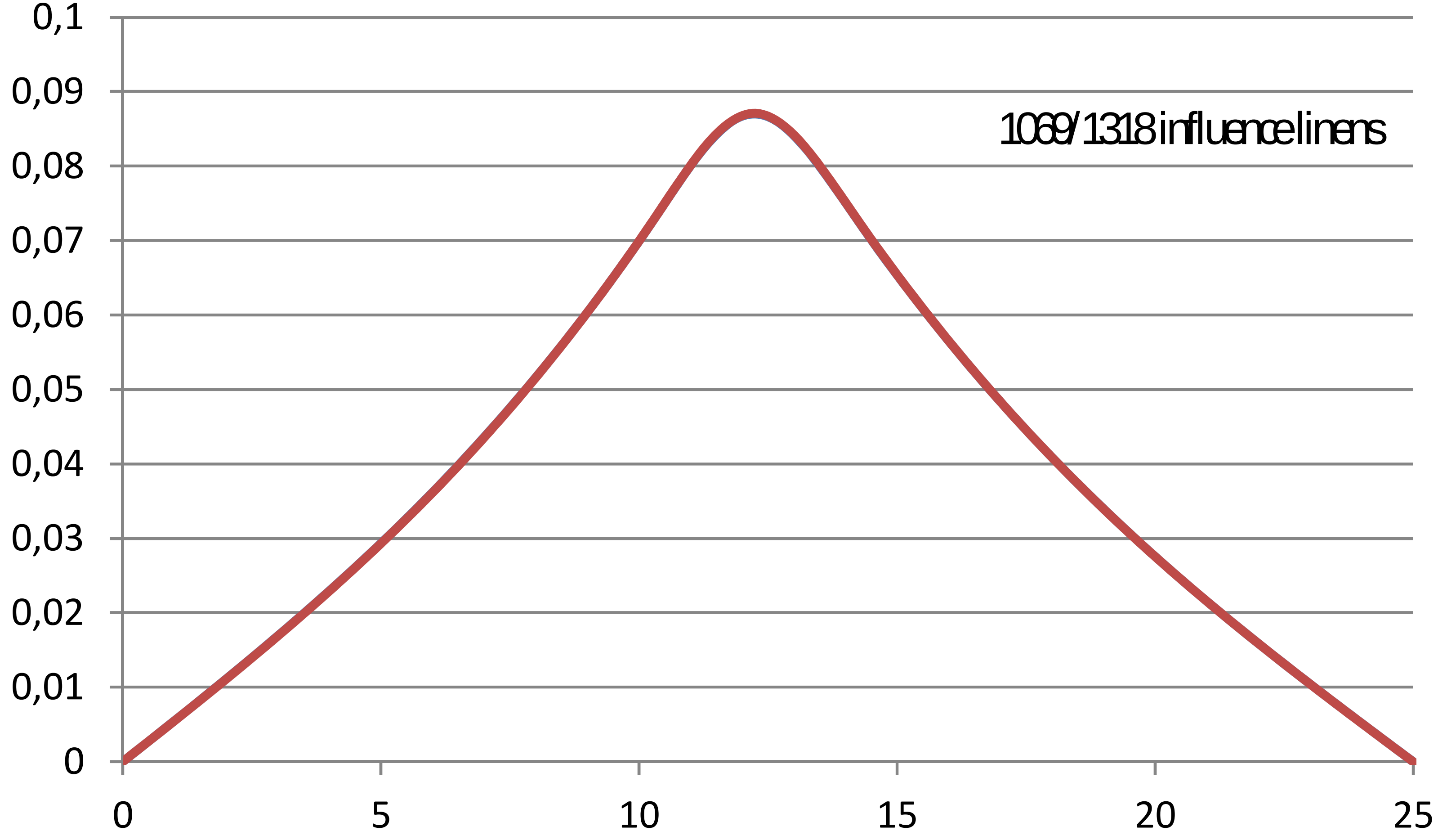
VA0468 influence lines – 1 hour



VA0468 influence lines – 10 hours



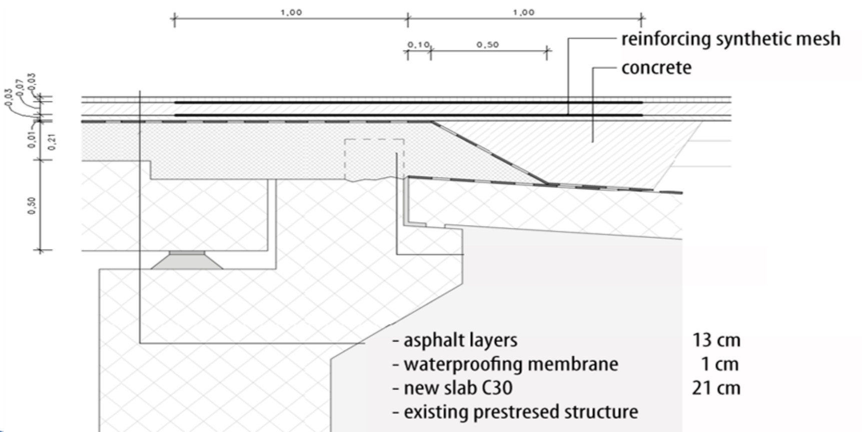
VA0468 influence lines – 34 hours



Bridge VA0468

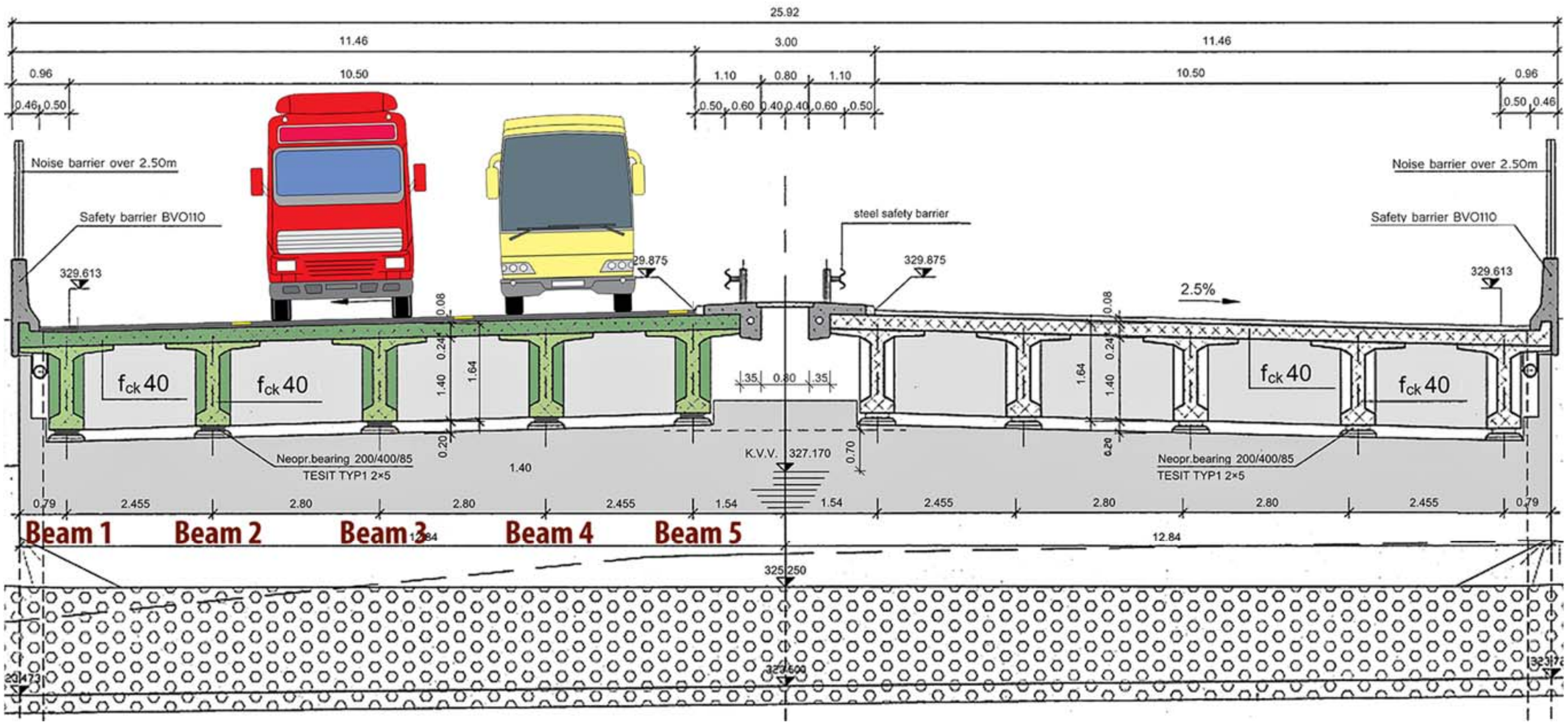
- 25.6 m simply supported span
- 5 beams

Bridge VA0468

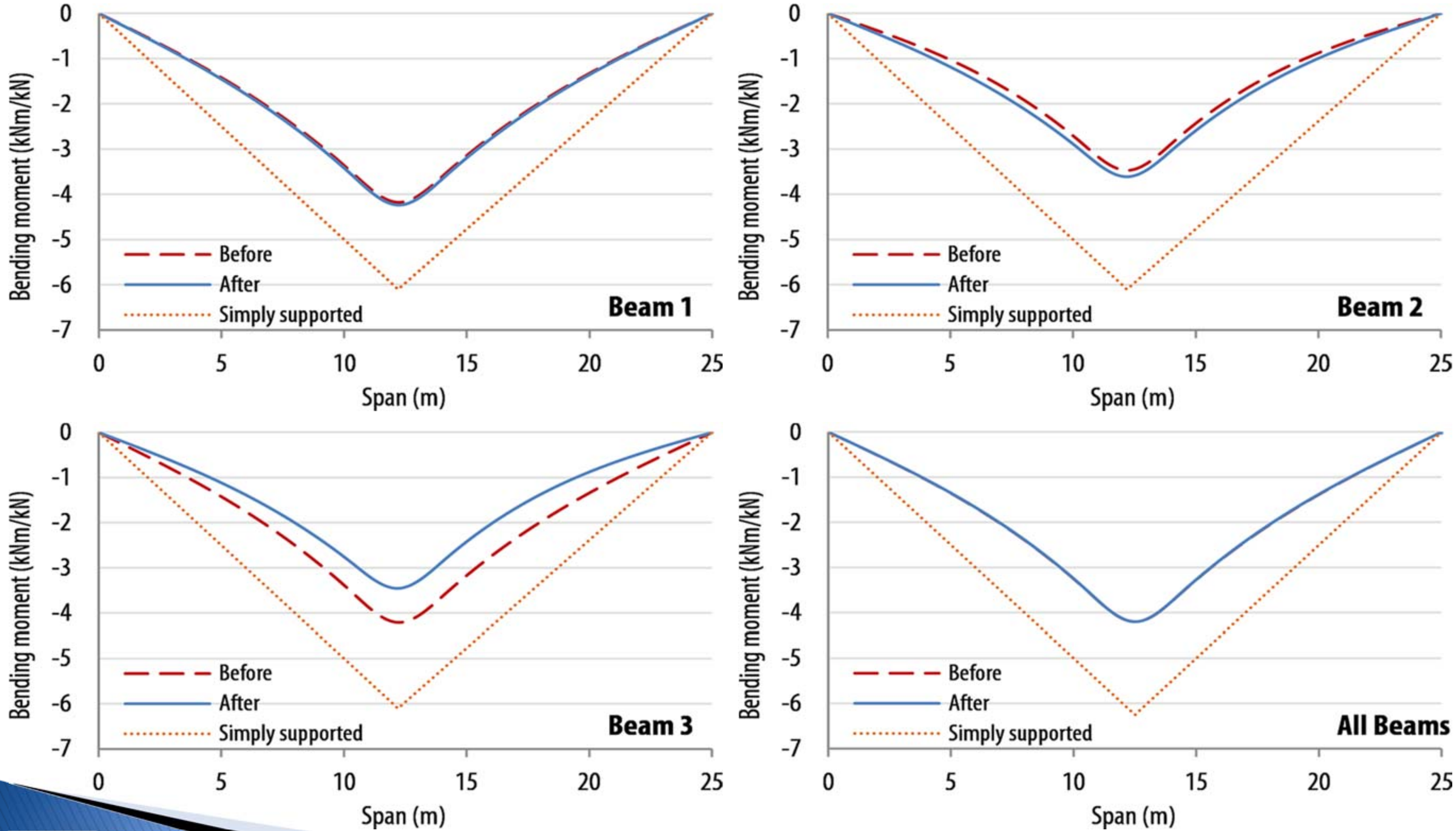


- 25.6 m simply supported span
- 5 beams
- replacement of EJs
- 2 sets of measurements

Bridge VA0468



VA0468 influence lines results



VA0468 influence lines results

Beam	Before Supp L	Before Supp R	After Supp L	After Supp R	Difference Supp L	Difference Supp R	Difference % Supp L	Difference % Supp R
Beam 1	56	58	55	56	-1	-2	98,2%	96,6%
Beam 2	74	81	62	77	-12	-4	83,8%	95,1%
Beam 3	56	57	69	81	13	24	123,2%	142,1%
Beam 4	56	57	57	58	1	1	101,8%	101,8%
Beam 5	55	57	56	57	1	0	101,8%	100,0%
All Beams	56	57	58	57	2	0	103,6%	100,0%

Proposed criteria

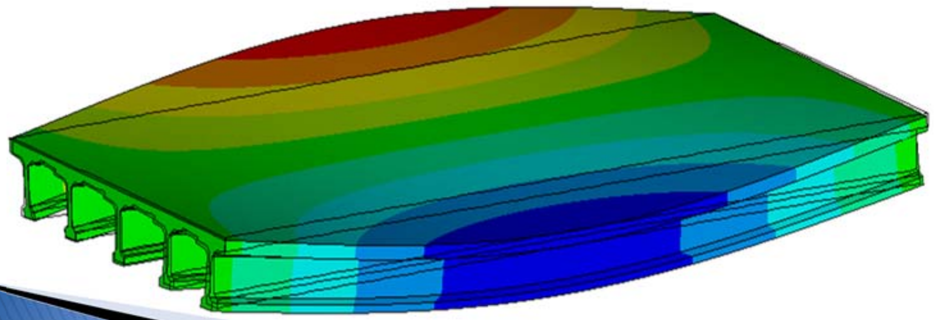
Relative change	Description	Proposed Action
<2%	Difference within the error of the method	No action needed
2% - 10%	Notable change of support constraints	Detailed inspection of the bridge with focus on expansion joints and bearings to identify the reasons
>10%	Considerable change of support constraints	As above plus structural reassessment of the bridge

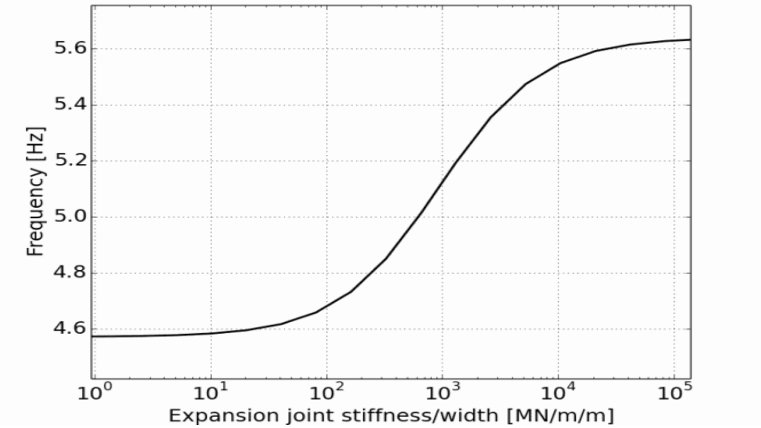
Modal analysis

- Bridge vibration properties: resonant frequencies, mode shapes
- Low hardware requirements to acquire resonant frequencies – 2 sensors sufficient
- Sensitivity evaluated numerically and experimentally
- Numerical examination: change of first resonant frequency

Movement restriction at	Single span bridge	Bridge with 3 spans
Bearings	64 %	11.6 %
Expansion joints	23 %	3.1 %

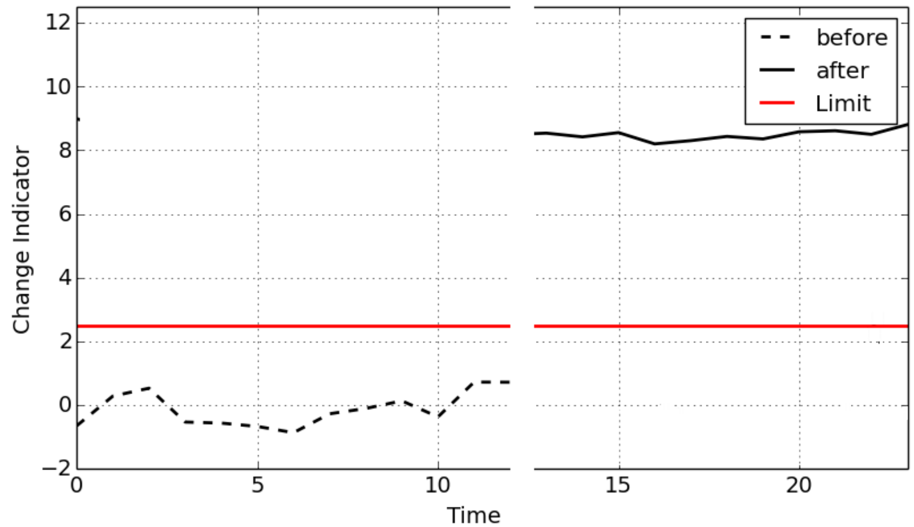
2nd mode shape





Modal analysis

- Proposed indicator: mean of normalized frequency changes
  - Normalized to their standard deviation
- Tests on bridge overpass VA0468
  - Before and after renewal of expansion joint
- Movement restriction can be distinguished from temperature influence or structural defect (opposite sign)



Conclusions on joints & bearings

- both methods:
  - clearly distinguish changes in boundary conditions
  - are cost efficient
- it is difficult/impossible to estimate the nature of damage, but criteria were proposed when to initiate activities – detailed inspection of expansion joints/bearings

TRAFFIC LOADING AND ACOUSTIC EMISSION

Ambitions

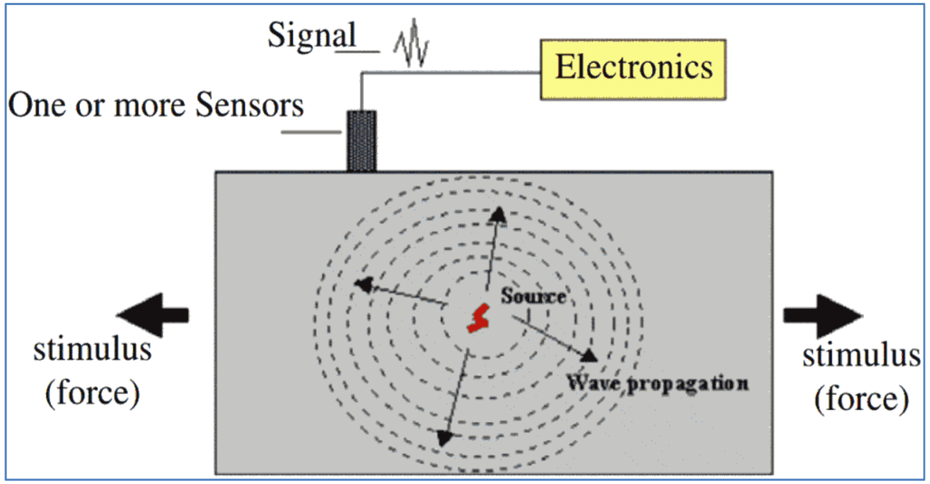
- to apply recommendations of the FP6 ARCHES project and
- **try to combine** bridge weigh-in-motion (**B-WIM**) measurements with Acoustic Emission (**AE**) techniques
- to **correlate** directly the acoustic activities (**progressive damage**) with **real loading** (axle loads) and load effects (strains)
- to assess if combined SiWIM and AE monitoring system can give valuable/useful/worthy information when assessment of bridges is to be performed

Overview

1. AE basics
2. Short info about tests performed
   - Small bridge PT0343
     - Soft load test
     - Proof load test
   - VA0028 highway underpass
     - 2x4 sensors widely spaced
     - 8 sensors in line over half of the span length
     - 8 sensors in a dense 2D array
   - Orthotropic deck viaduct
     - monitoring of cracks on the corner between bucket and crossbeam
3. Conclusions

Acoustic Emission (AE) techniques

- Acoustic Emission (AE) refers to the generation of transient elastic waves produced by a sudden **redistribution of stress in a material** (≅ earthquake)
- Uses signals generated **within** the structure, which are due to
  – crack growth under stress
  – secondary emissions due to e.g. friction of crack interfaces



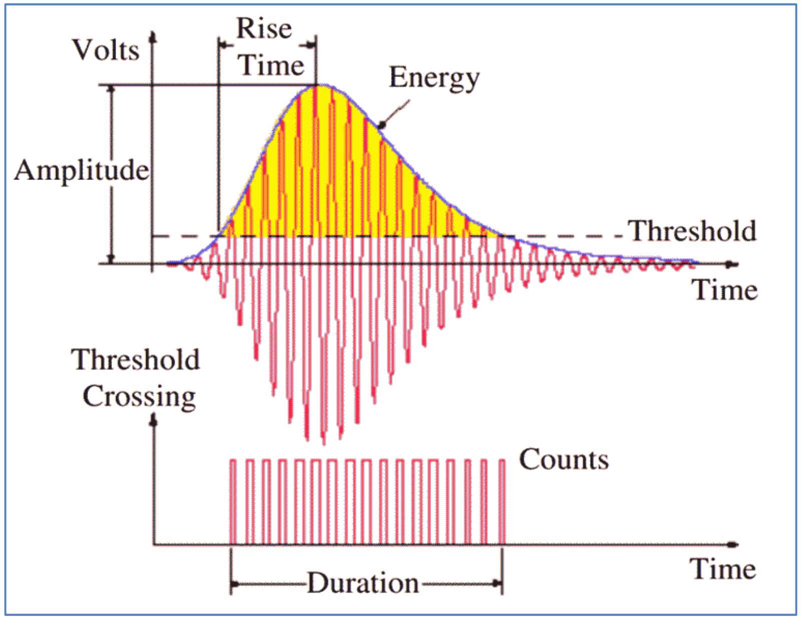
Pros & Contras AE

ADVANTAGES	DISADVANTAGES
Distant events can be detected	The structure has to be loaded
The whole structure can be tested all at once	AE activity depends on microstructure of the material
Measuring equipment is easy to use	Ambient noise can disturb the measurement
Access to the whole structure is not required	Localization is not completely precise
Active cracks can be detected	Demanding interpretation of measurements requiring skilled personnel

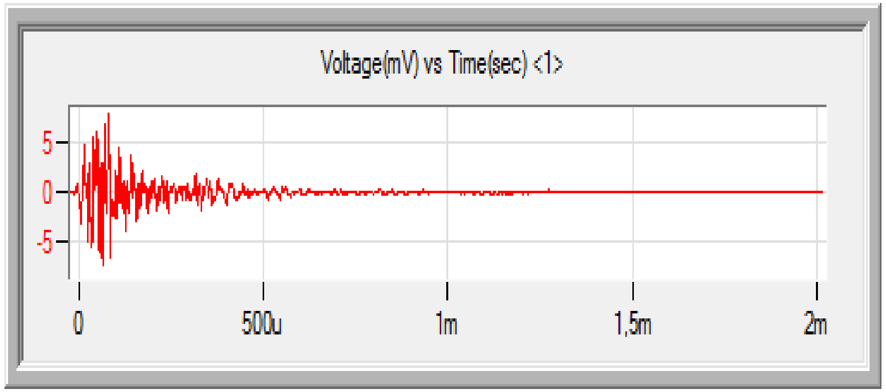
Acquisition of AE data

- AE measuring systems consist of
  - AE sensors
  - pre-amplifier and amplifier
  - A/D converter
  - Computer & software.
- Proper sensor location is fundamental for successful AE based evaluation of the structure; case specific
- Triggering thresholds for each AE channel should be set to eliminate the environment noise.
- AE measuring equipment should be tested under controlled, preferably laboratory conditions

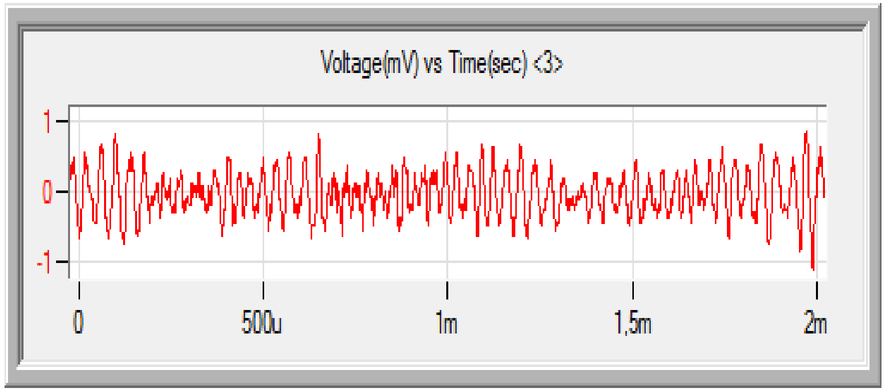
AE signal – basic expressions



Theoretical burst AE signal



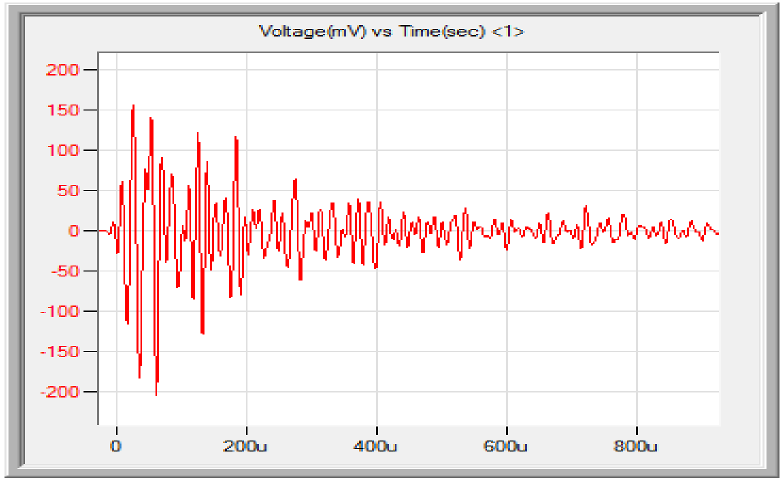
Typical burst AE signal



Typical "continuous" AE signal

Interpretation of AE data

- Demanding interpretation of measurements requires skilled personnel
- AE activity
  - Primary
  - Secondary
- Various interpretation methods
- Combination of different parameters is recommended



Typical burst AE signal

Peak freq. vs. time per channel

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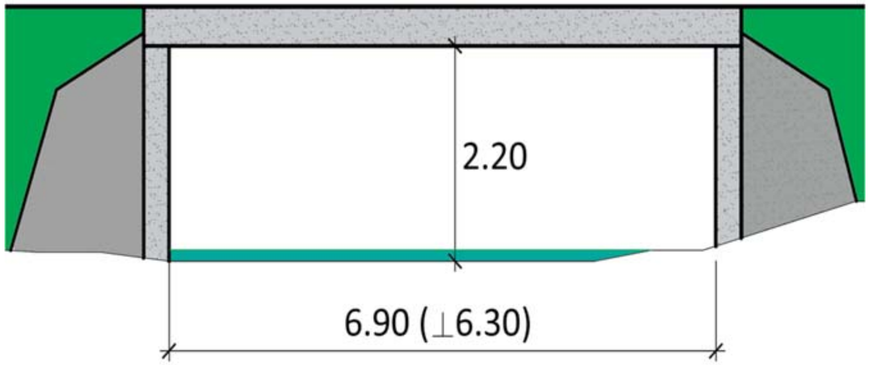
3. Conclusions

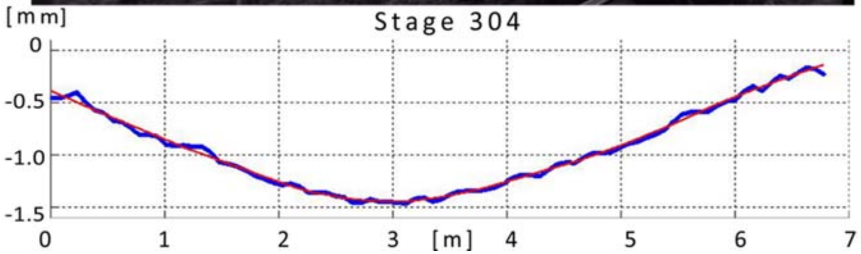
Bridge PT0343

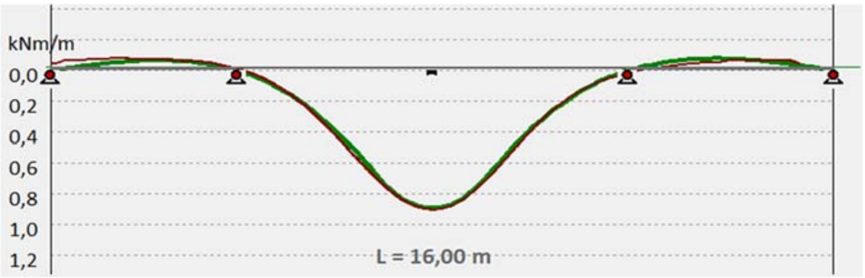
- small bridge
- to be demolished

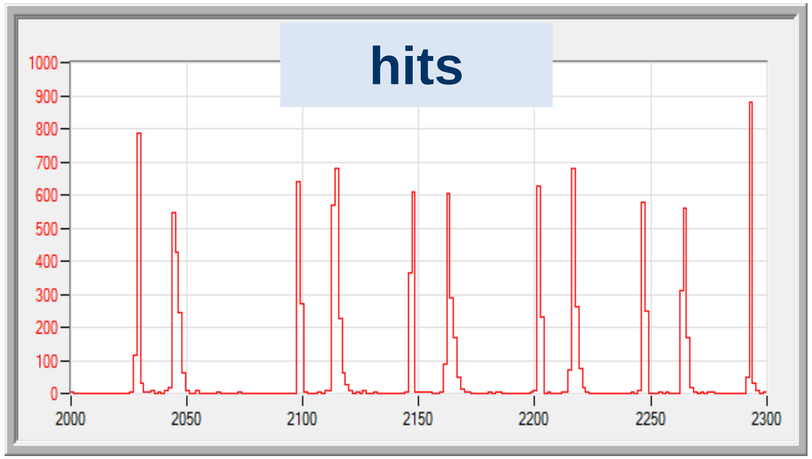


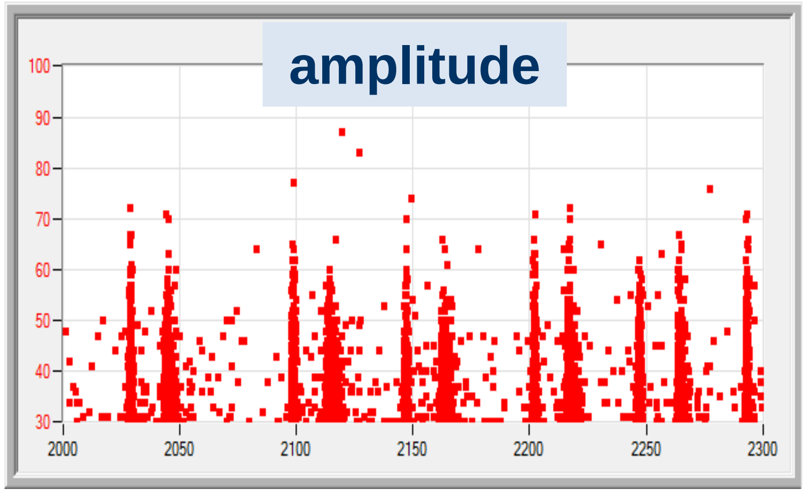
Bridge PT0343 - Soft load testing

Bridge PT0343 - Soft load testing







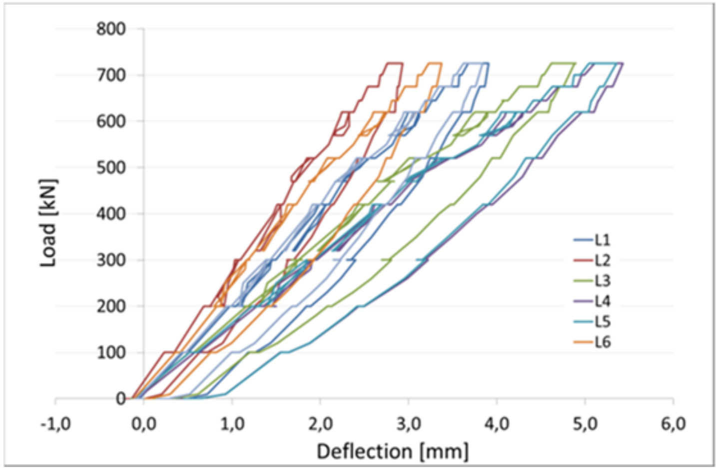


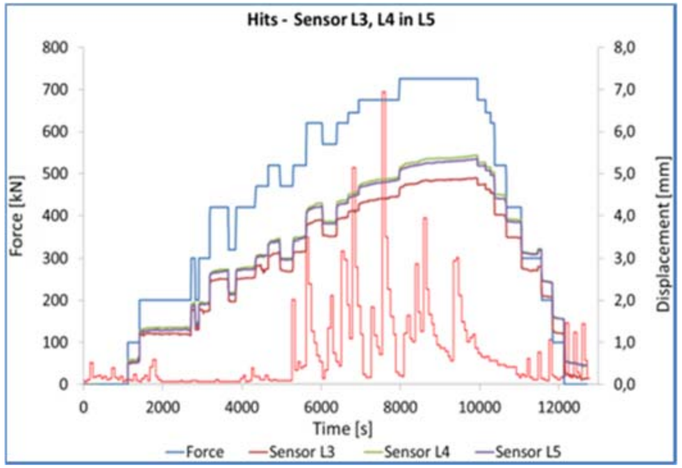
- **Testing the new on-site equipment**
- **AE recordings (number of hits) of individual truck crossings**

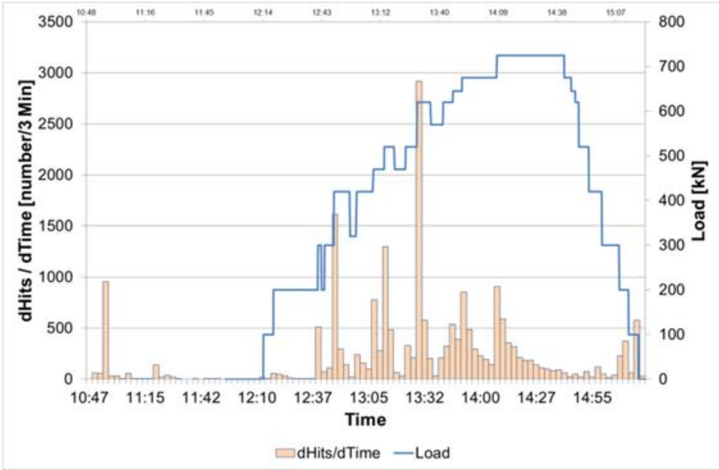
Bridge PT0343 – Proof load testing

- Quasi static loading
- Pre-weighed load, deflection, deformations
- AE: hits, energy, amplitude, …


PT0343 - Proof load test



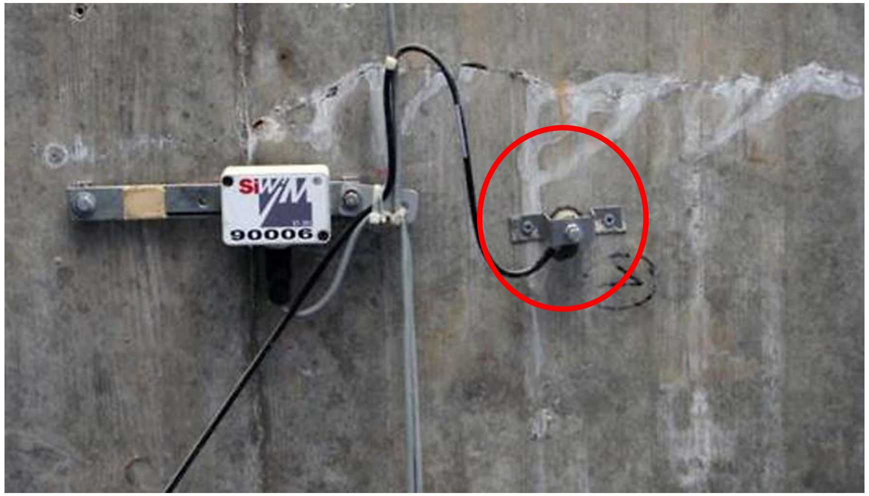




Generally good correlation of AE with loading

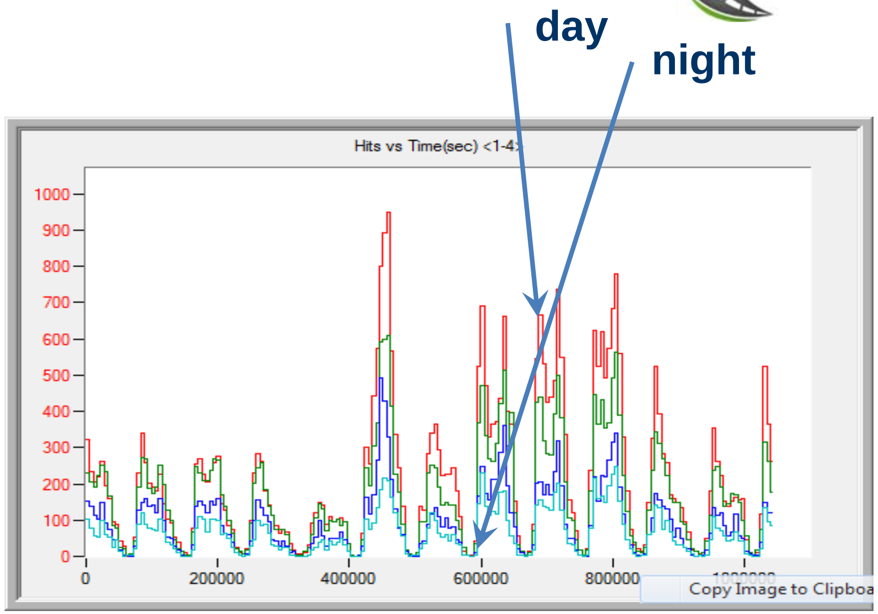
V0028 underpass

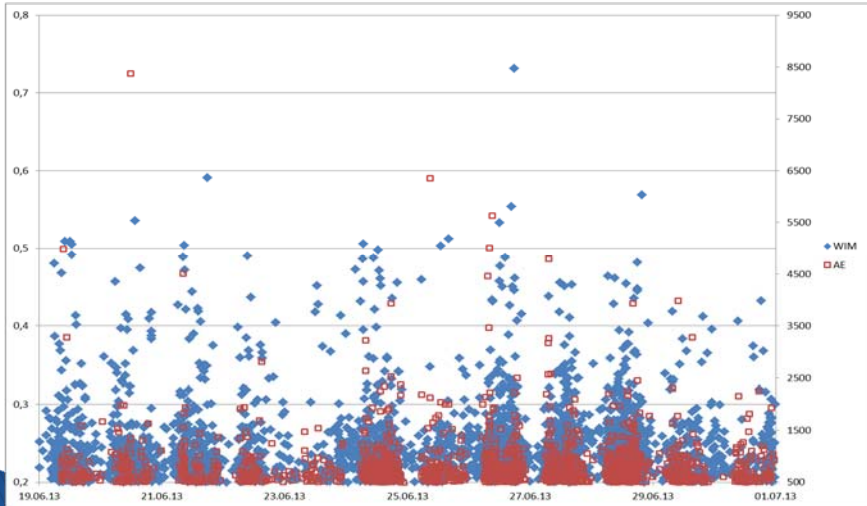
- small underpass (2x), concrete, frame, highway
- continuous SiWIM® & AE monitoring > 1.5 year
- SiWIM®: deformation -> loading
- AE: hits, amplitude, energy,…



TOMORROW'S ROAD INFRASTRUCTURE MONITORING & MANAGEMENT

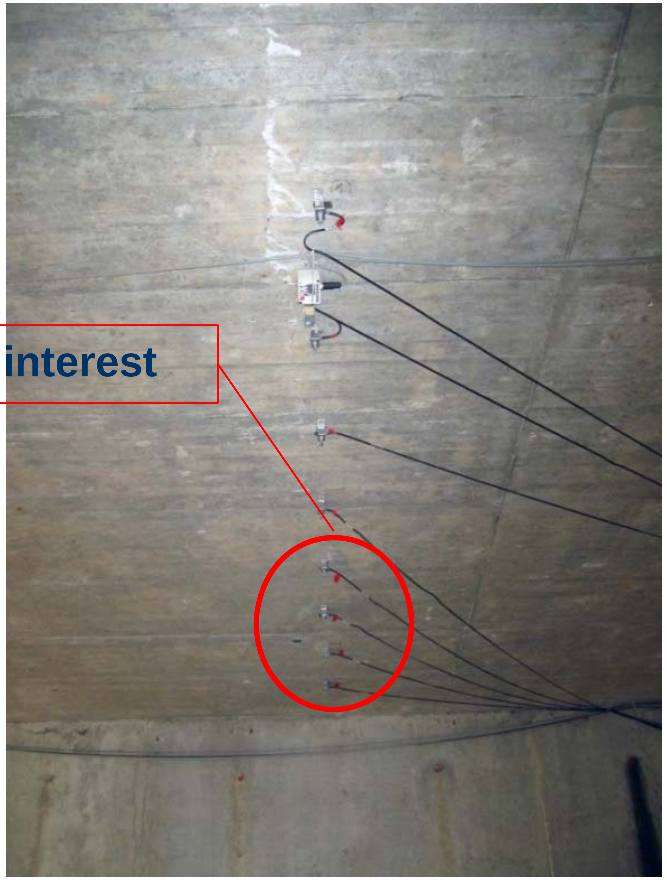
2 x 4 sensors

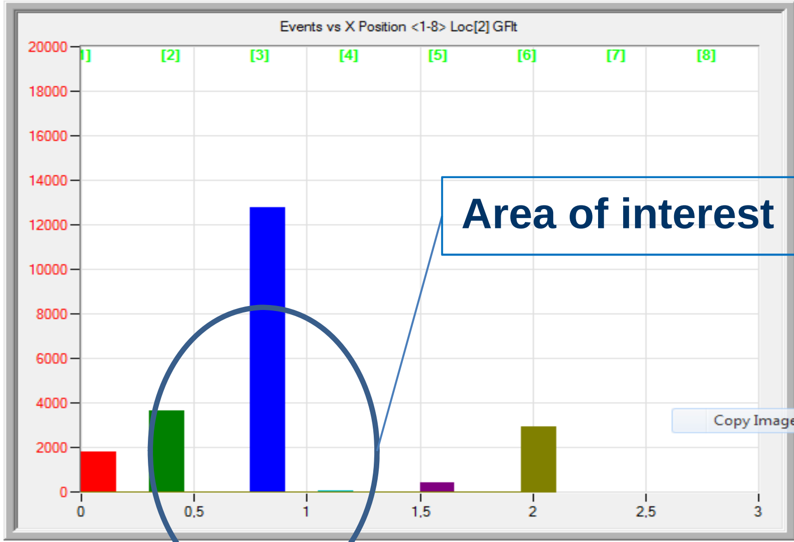


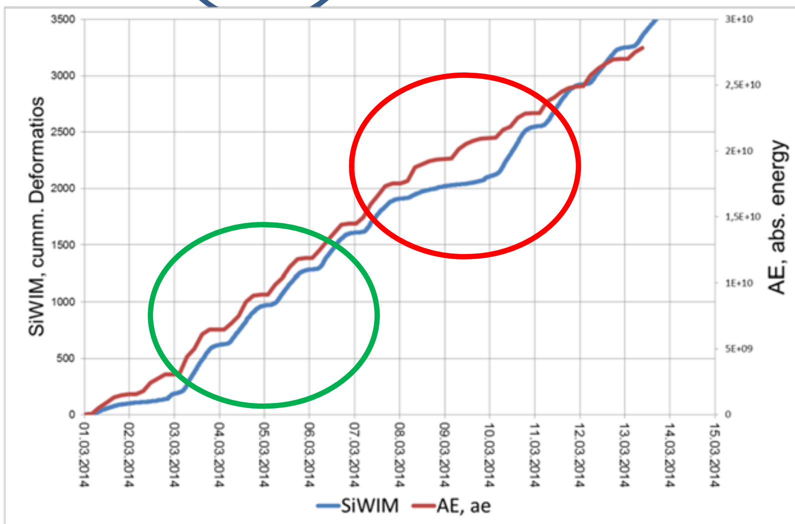


- 13 day recording (example)
- generally good correspondence with traffic load (SiWIM®)

VA0028 - 8 sensors in line (e=40 cm)

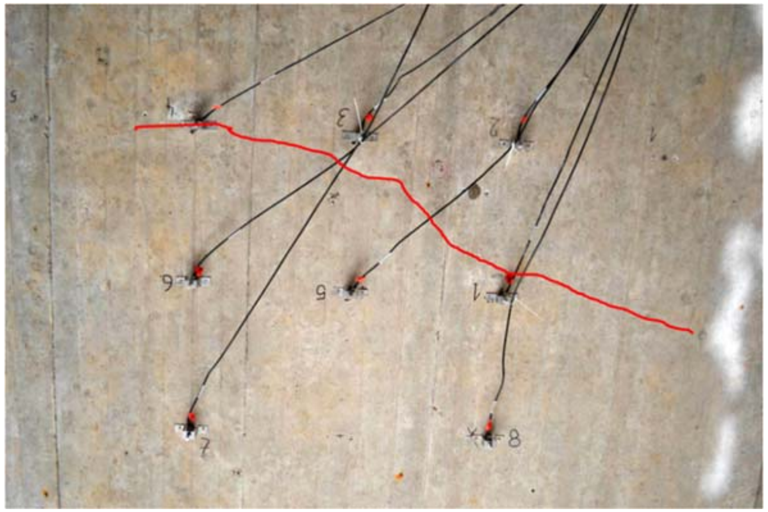


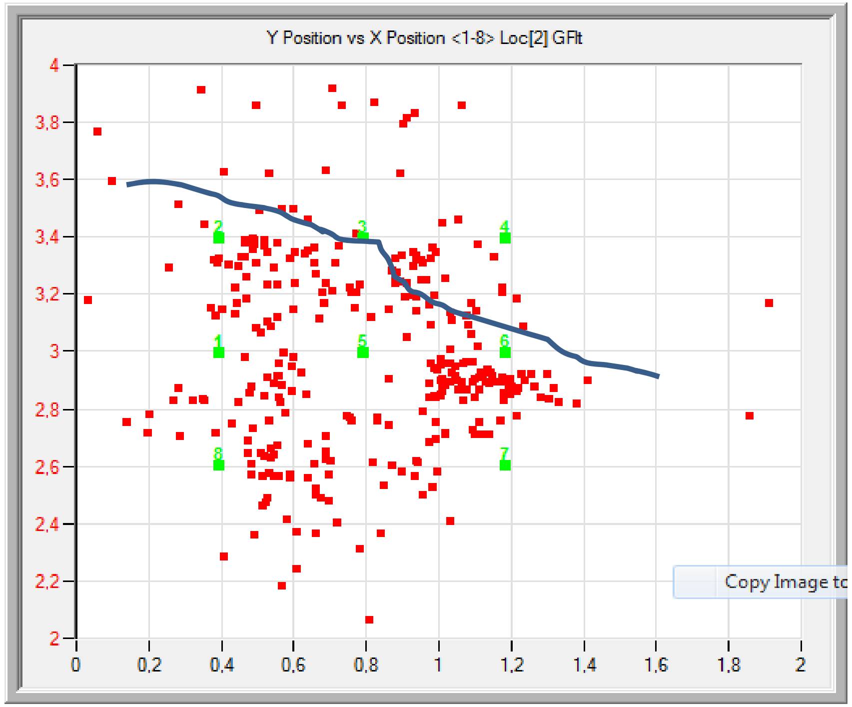


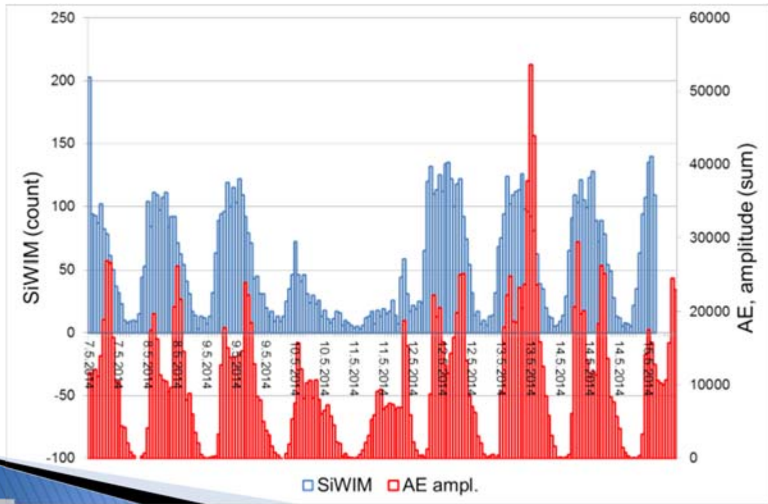


Detection of AE active (damaged?) zones

VA0028 - 8 sensors in a 2D array



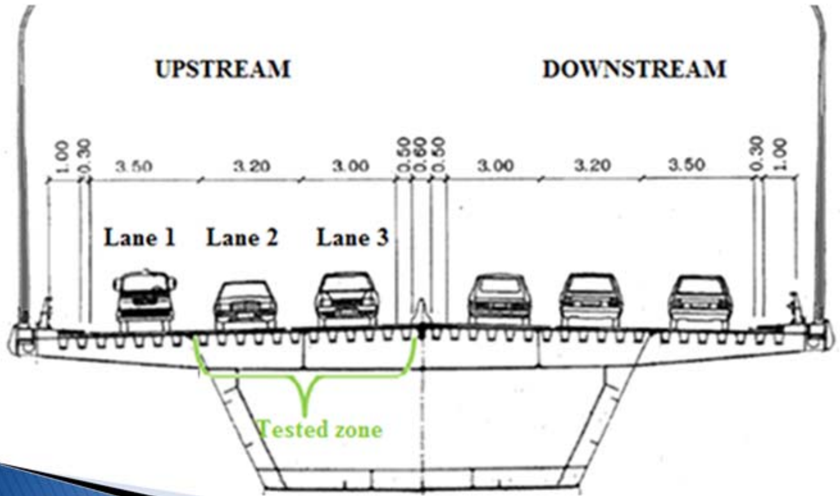


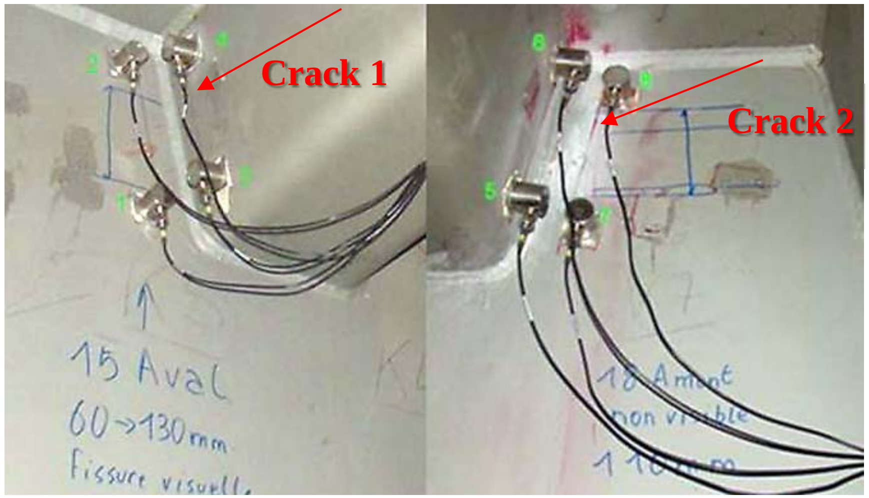


- Excellent correspondence between SiWIM® & AE
- AE active (damaged) zones were located

Cheviré Bridge test

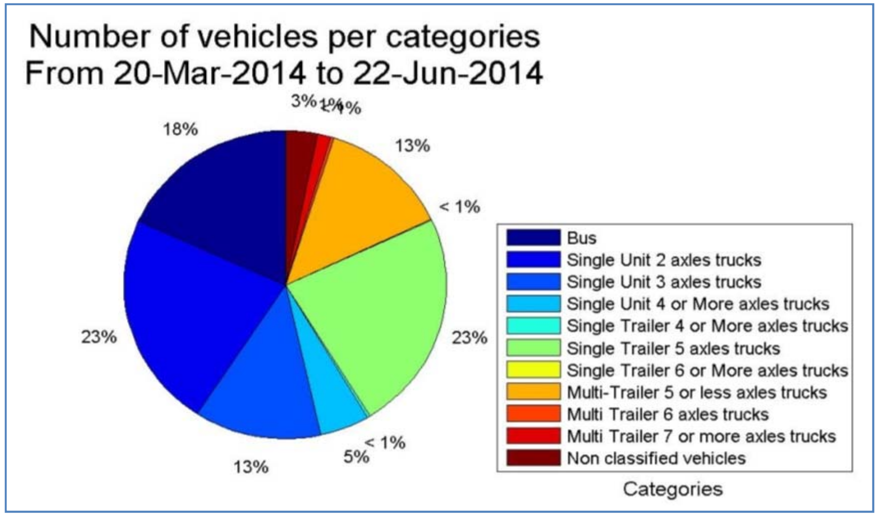
- Nantes, F, “Loire River”
- built in 1986
- 52 m high, 1563 m long, 2×3 lanes
- orthotropic bridge deck
- cracks on the corner between buckets and the crossbeam

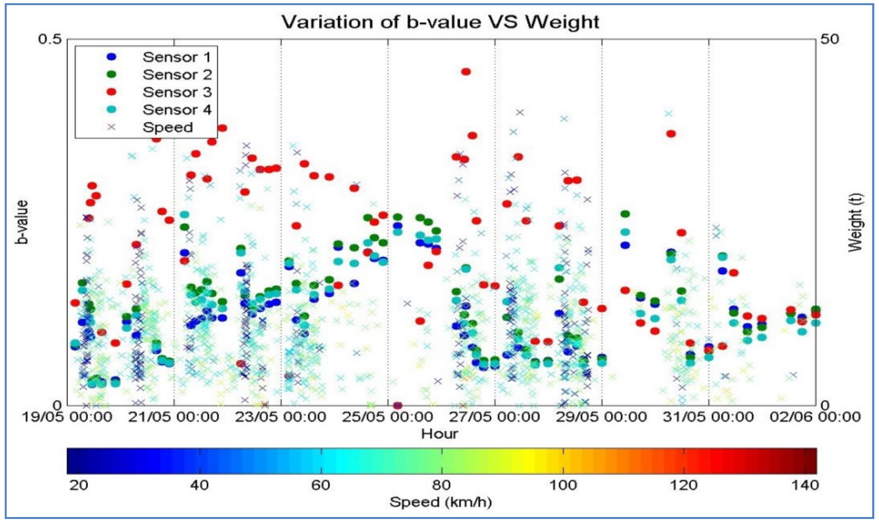




Cheviré Bridge test

- Excellent correlation between WIM analysis output and acoustic parameters
- RA-value and b-value (acoustic emission parameters) seem to be good indicators to study the evolution of a crack
- However, parameters are usually used for concrete and less for steel - reference values for steel are needed





Conclusions

Based on extensive experimental work and the subsequent analyses of data, the following conclusions were made:

- During months-long monitoring periods the two systems, i.e. SiWIM and AE, were successfully simultaneously used for the first time.
- Both systems can monitor the traffic load successfully and deliver comparable results.
- Higher (traffic) loads induce higher AE activities.
- Non-linearity in the response of the structure to high loads was successfully detected by the increased AE activity during a proof load test.
- The change in AE signal characteristics was recorded beyond the point of the linear response of the structure, proving that the source of the AE waves changed too.

Conclusions

- The AE system can successfully be used to detect AE active zones in the structure. These zones could be related to damaged or damage-active zones.
- The damage level could not be evaluated except for the proof load test. It is assumed, based on visual inspection and the load level measured, that the structures tested were in fairly good condition compared to the traffic load applied.
- Using a sufficient number of sensors (which is problem specific) the AE system enables exact determination of source location.
- Traffic is an important factor of acoustic activity. The acoustic emission parameters (RA-value and b-value) seem to be good indicators to study the evolution of a crack in steel. However, these parameters are meant to be used for concrete and less for steel. Reference values for steel (structures) would be needed for more accurate evaluation.

Conclusions

- A combined SiWIM and AE monitoring system can give enhanced information when assessment of bridges is to be performed.
- The assessment of real structures shall involve not only monitoring the progress of any detected defects, but also considering the impact of these defects on the condition of the structure.

Thanks for listening!