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



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Combined AE and B-WIM based monitoring of bridges

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TOMORROW'S ROAD INFRASTRUCTURE MONITORING & MANAGEMENT

FP7 TRIMM TG 3.2 ambitions

TG3.2 Traffic loading and acoustic monitoring

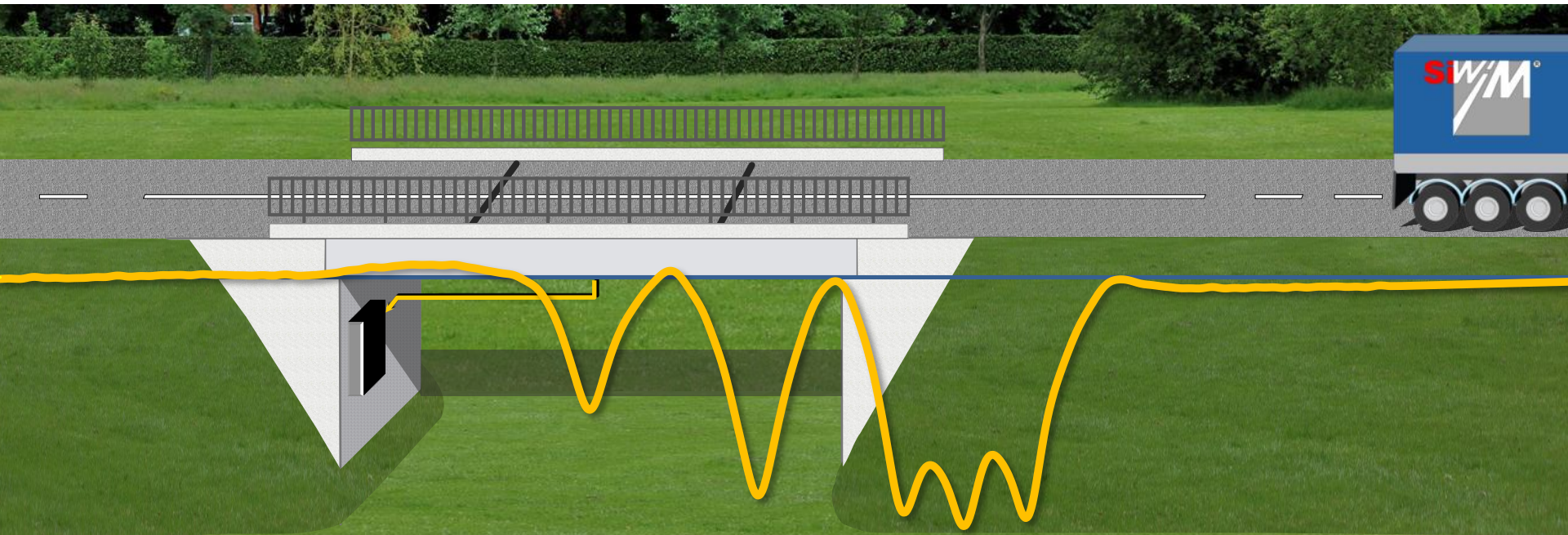
- to apply recommendations of the FP6 ARCHES project and
- **try to combine** bridge weigh-in-motion (**B-WIM**) measurements with Acoustic Emission (**AE**) techniques,
- to **correlate** directly the acoustic activities (**progressive damage**) with **real loading** (axle loads) and load effects (strains).
- 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. WIM basics
2. AE basics
3. Short info about tests performed
 - Small bridge PT0343
 - Soft load
 - Proof load
 - 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
4. Conclusions

Bridge WIM (B-WIM) basics

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



B-WIM history

Three periods:

1. 1979-1994: B-WIM system in US and AU (on culverts)
2. 1994-2000: EU research projects COST 323 and WAVE resulted in substantial progress and SiWIM prototype
3. After 2000:
 - **SiWIM**® commercialisation
 - constant improvements
 - developments in Slovenia, Ireland, Japan, Korea
 - currently FP7 BRIDGEMON project:
 - further improvements in accuracy
 - railway B-WIM
 - extensive use of B-WIM for bridge assessment

B-WIM today

- **SiWIM®** used on >1000 sites in 16 countries
- main advantages:
 - accuracy, including GVW (Gross Vehicle Weight), SA (Single Axle) and AG (Axle Groups) determination
 - connectivity, cameras etc.
 - easy and fast installation
 - **portability**
 - **free-of-axle detector (FAD) installation** (does not need to close the traffic)
 - **bridge assessment**
- **limitations:**
 - need for a bridge
 - some bridges not appropriate

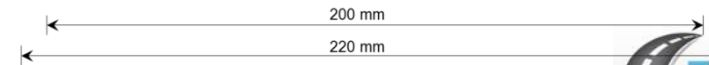
B-WIM Calibration



With pre-weighed vehicles



With vehicles from traffic flow



Bridge load testing

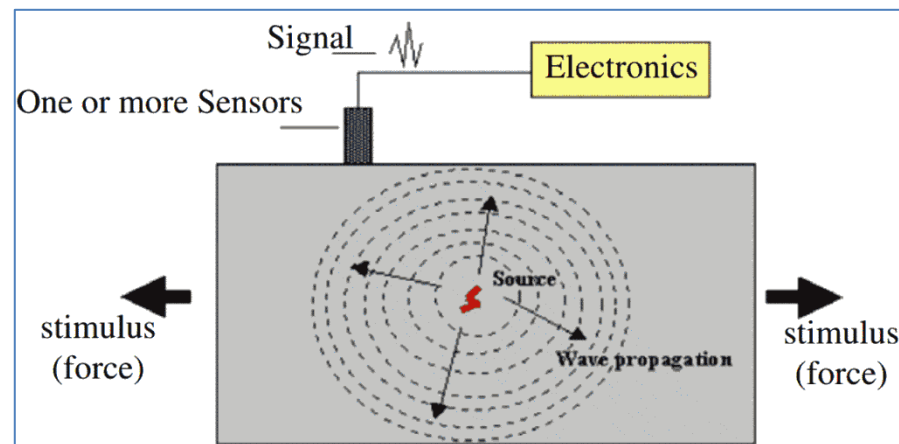
- **Proof load testing**
 - high loads
 - road closer needed

- **Soft load testing (B-WIM)**
 - traffic load
 - no traffic closure needed



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** (\cong 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



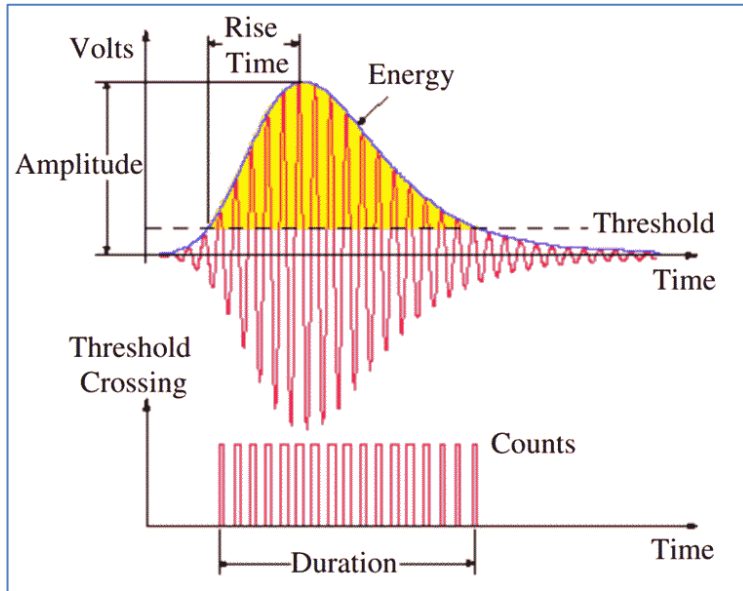
Pros & Contrasts AE

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

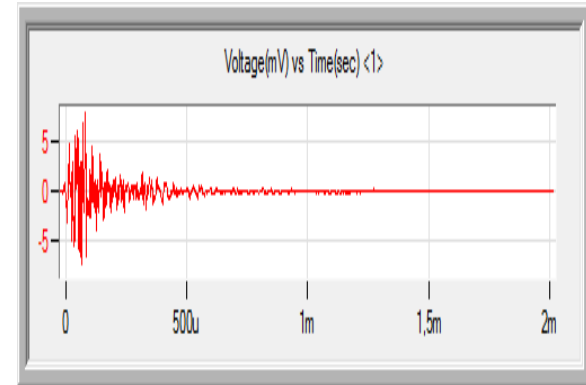
Acquisition of AE data

- 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

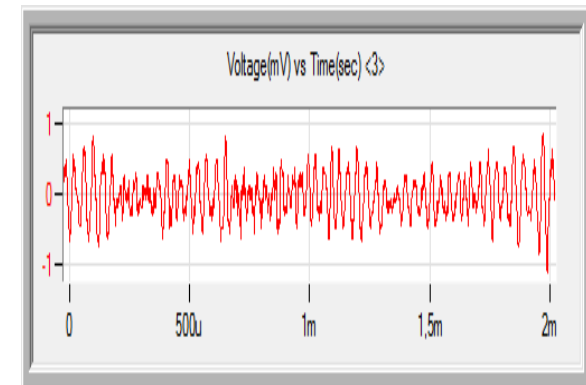
AE signal – basic expressions



Theoretical burst AE signal



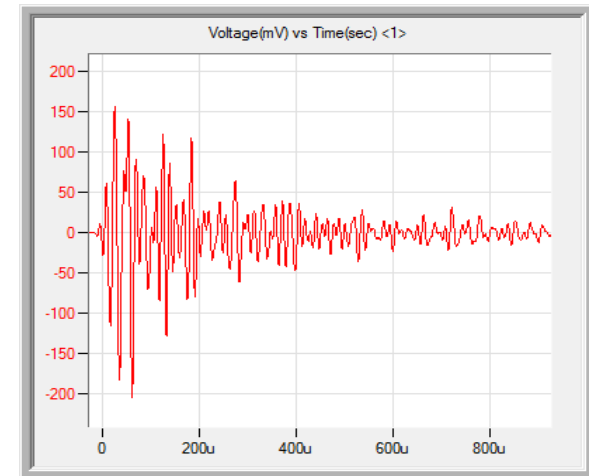
Typical burst AE signal



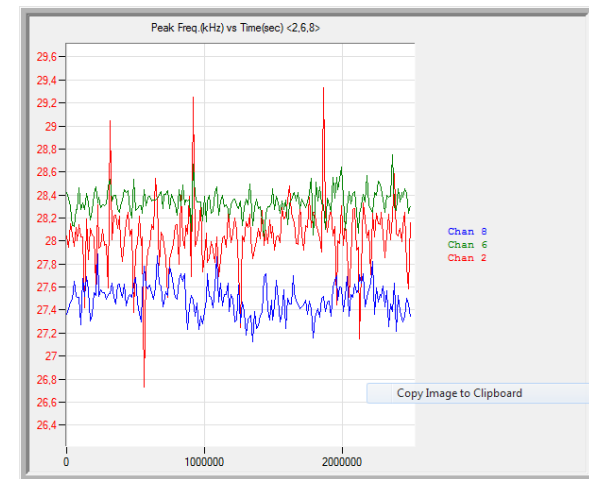
Typical “continuous” AE signal

Interpretation of AE data

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



Typical burst AE signal

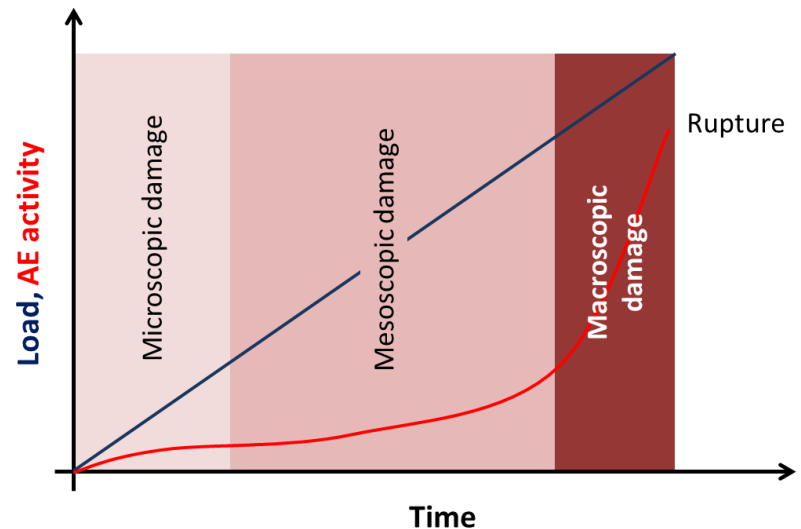


Peak freq. vs. time per channel

Interpretation of AE data

Primary AE activity

- Crack formation induced AE is defined as primary AE activity. When load increases, the failure processes and thus AE activity increase exponentially.
- These phenomena can be successfully used, in combination with proof-load testing, to abort the loading process before a substantial damage is induced on the tested bridge.



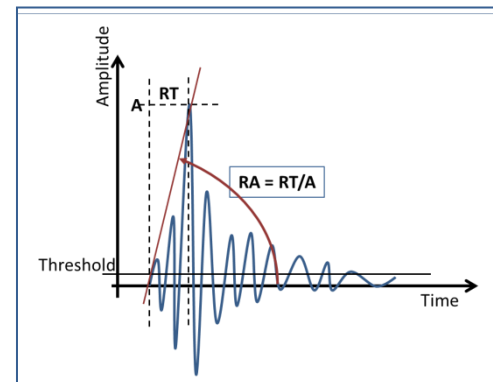
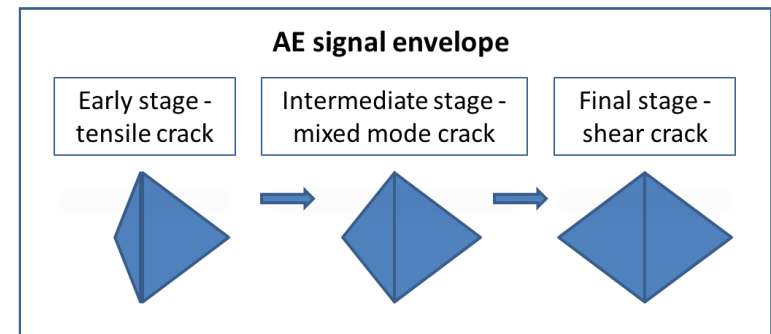
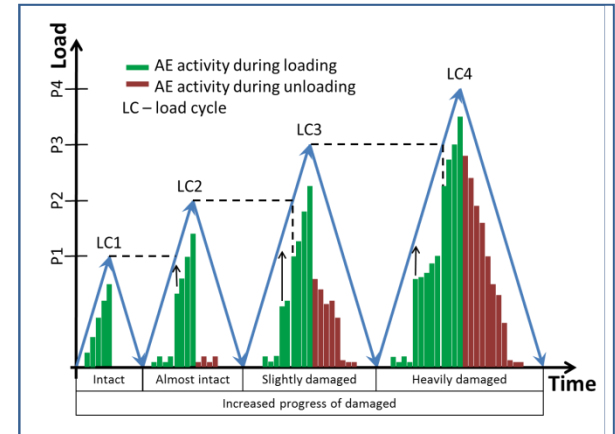
Interpretation of AE data

Secondary AE activity

- Comes from existing cracks

Interpretation

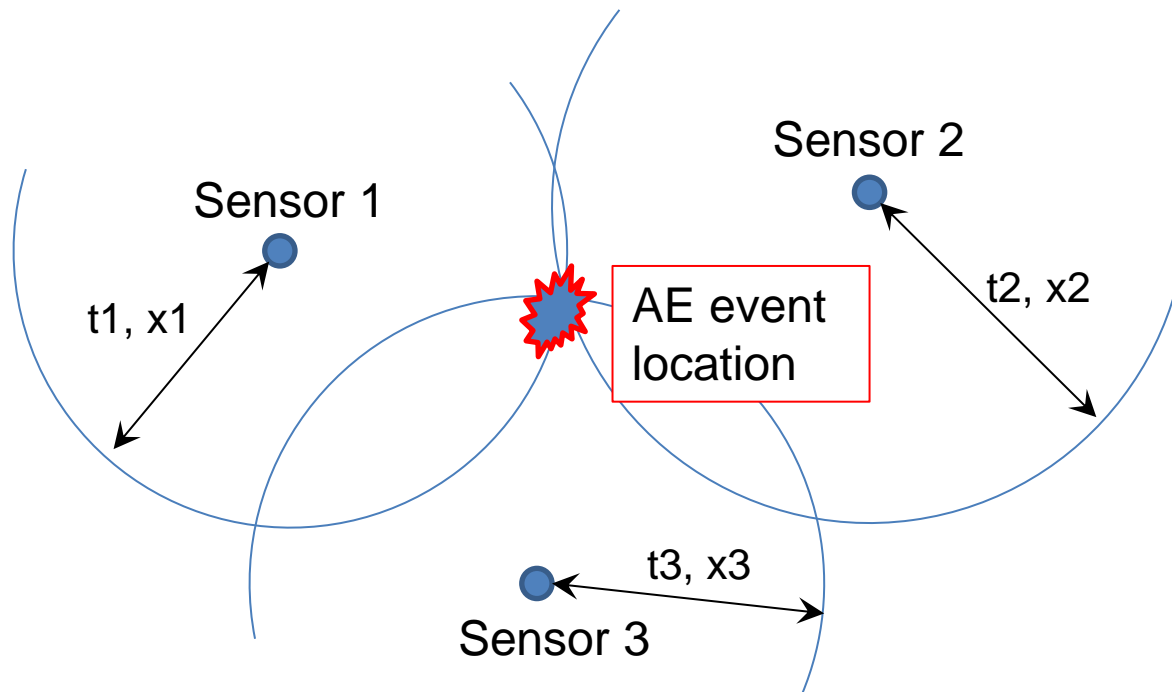
- Kaiser Effect, Load Ratio, Calm Ratio, RTRI Ratio
- AE waveforms characteristics based evaluation, RA, frequency distribution
- b-value Analysis



Interpretation of AE data

AE event location determination

- An AE measuring system can be used to determine the location of the AE event



Overview

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2. AE basics

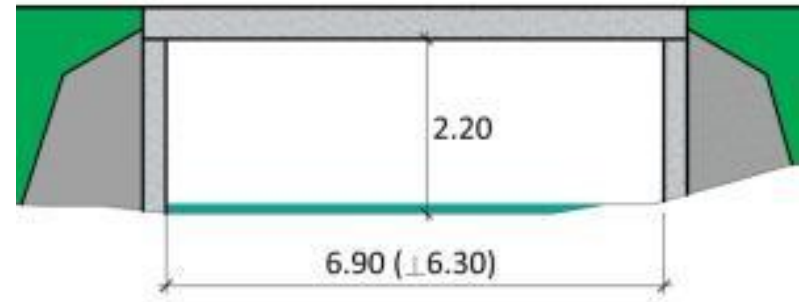
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4. Conclusions

Bridge PT0343

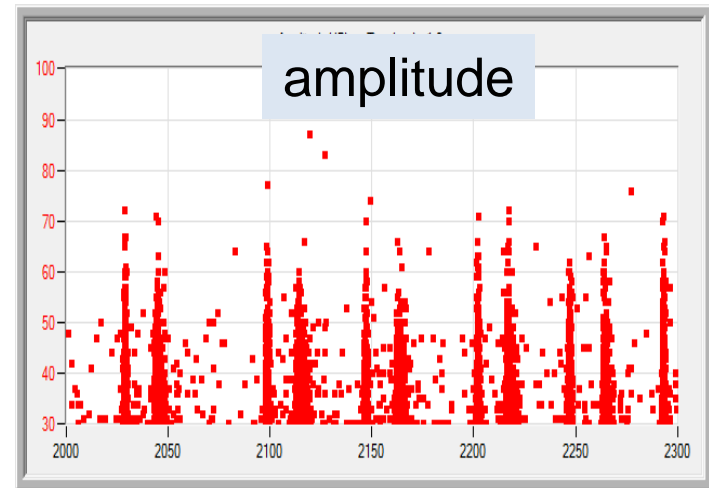
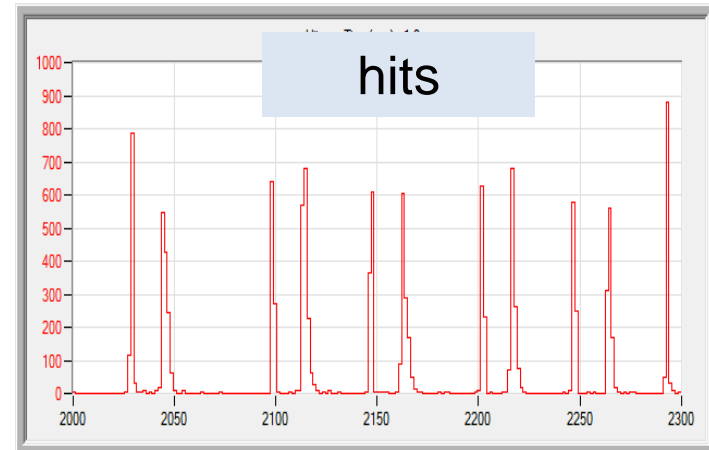
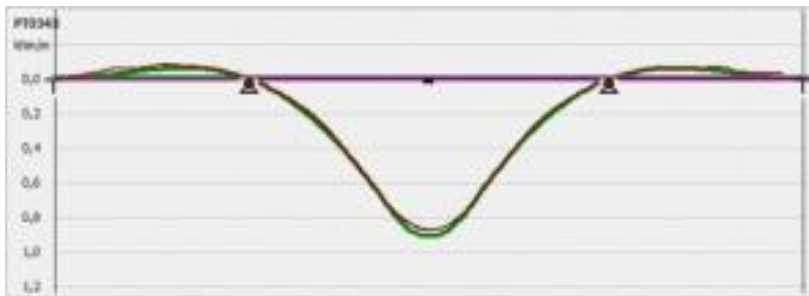
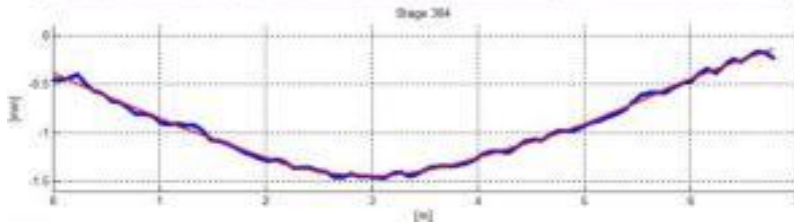
- Small bridge
- To be demolished



Bridge PT0343 - Soft load testing



Bridge PT0343 - Soft load testing



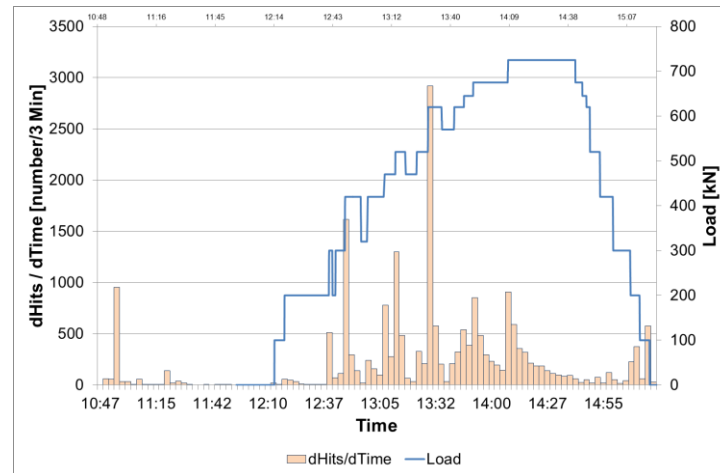
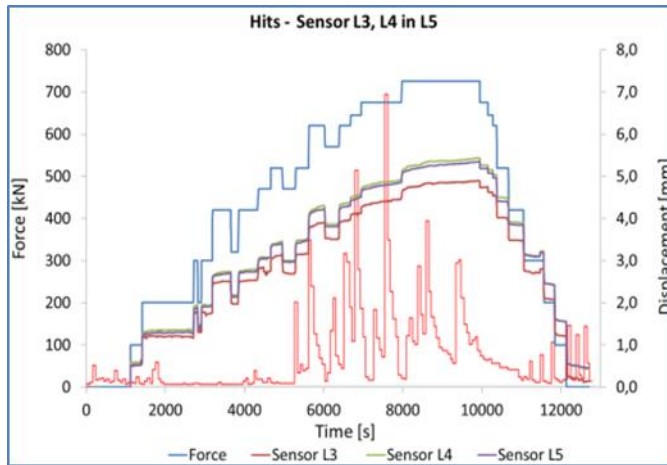
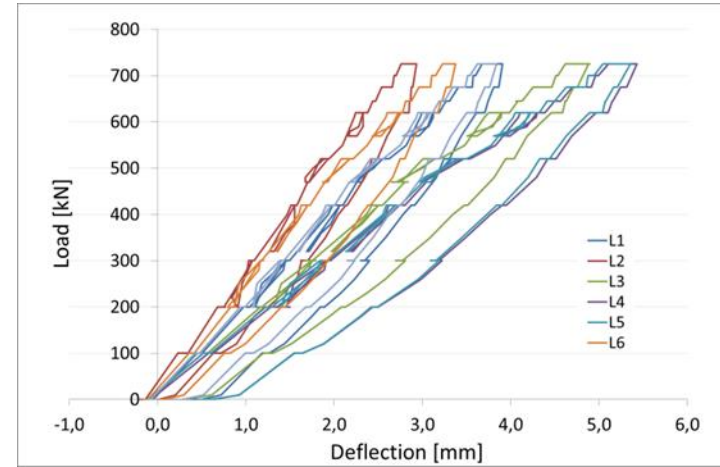
- Testing the new on-site equipment
- AE recordings (number of hits) of individual truck crossings

Bridge PT0343 – Proof load testing

- Quasi static loading
- Pre-weighted load, deflection, deformations
- AE: hits, energy, amplitude, ...



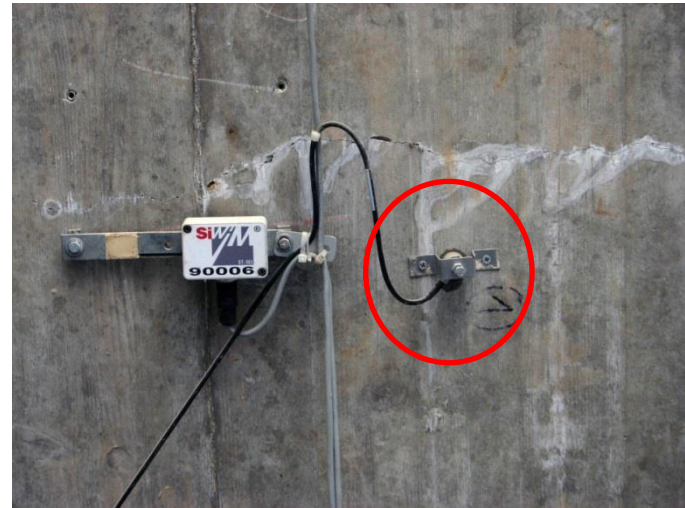
PT0343 - Proof load



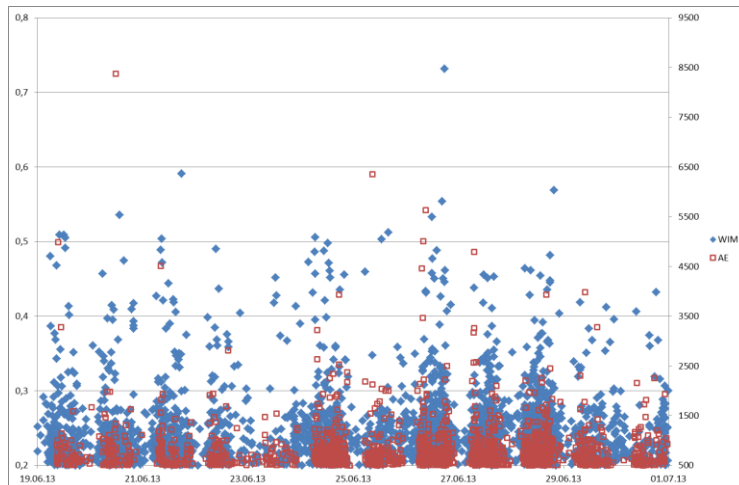
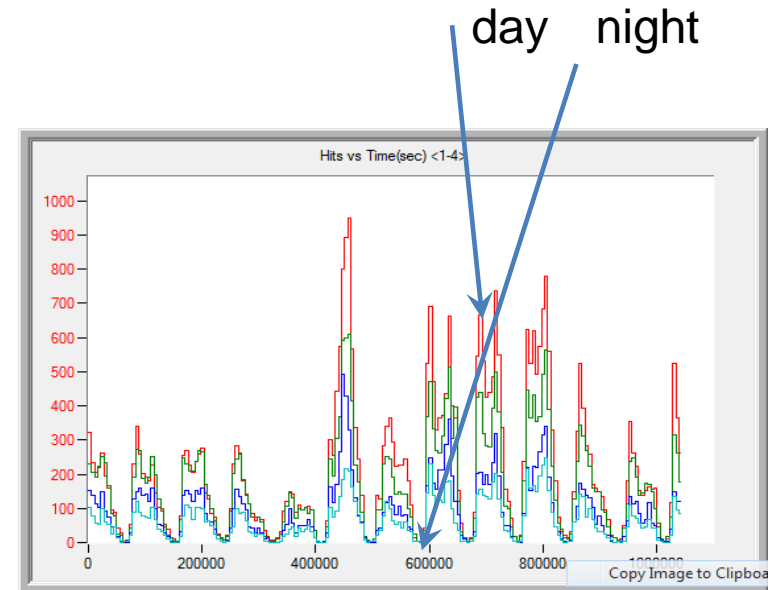
Generally good correspondence of AE with load

VA0028 highway underpass – traffic load

- Small underpass (2x), concrete, frame, highway
- Continuous WIM & AE monitoring > 1.5 year
- SiWIM: deformation -> load
- AE: hits, amplitude, energy,...

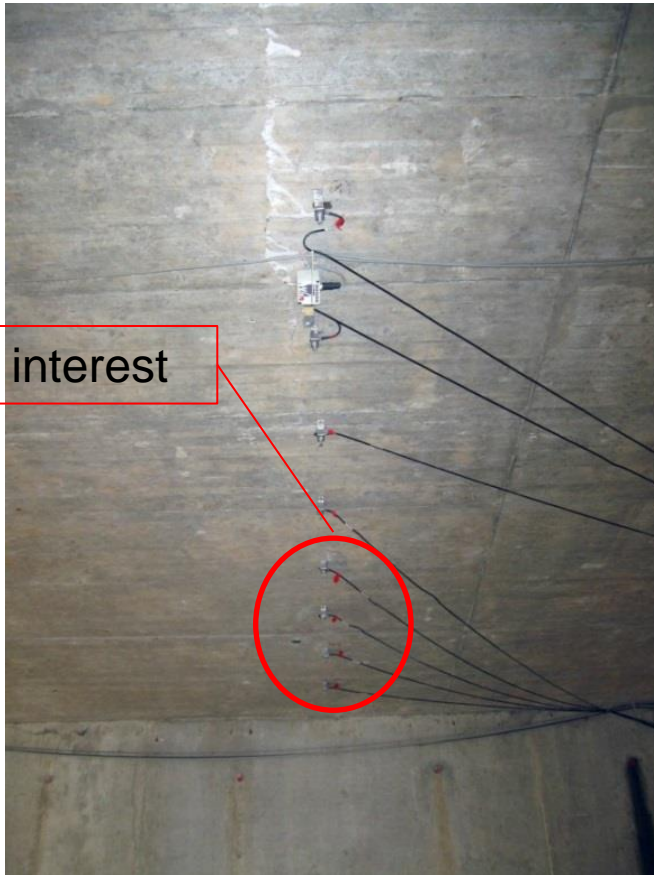


2 x 4 sensors

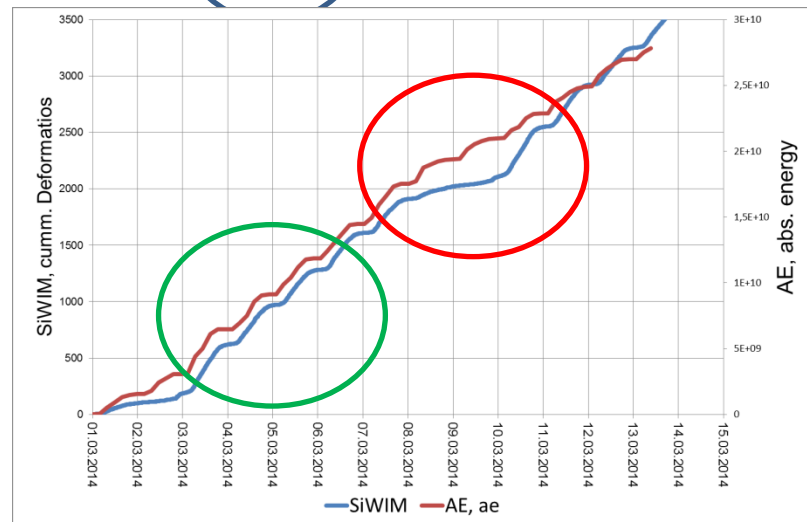
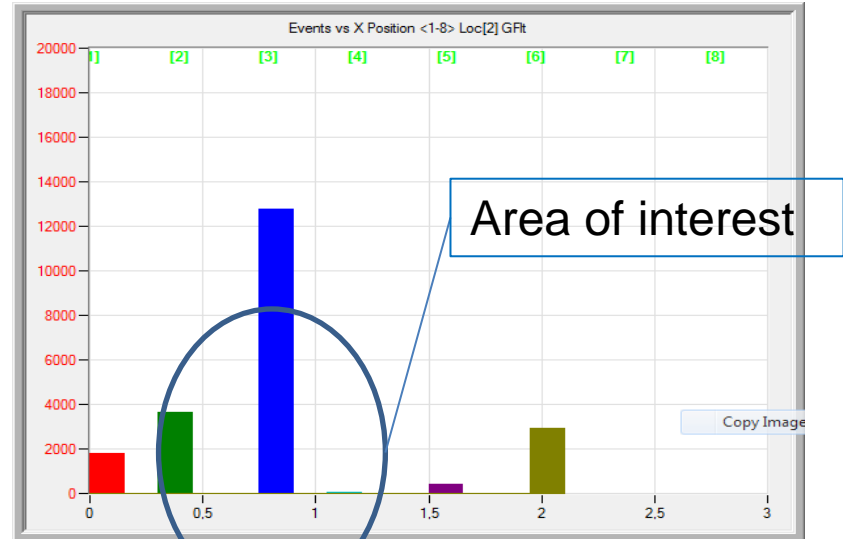


- 13 day recording (example)
- Generally good correspondence with traffic load (SiWIM)

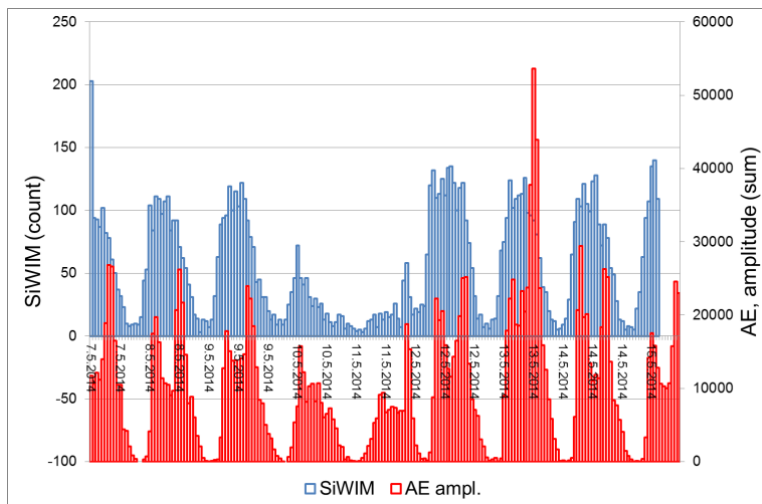
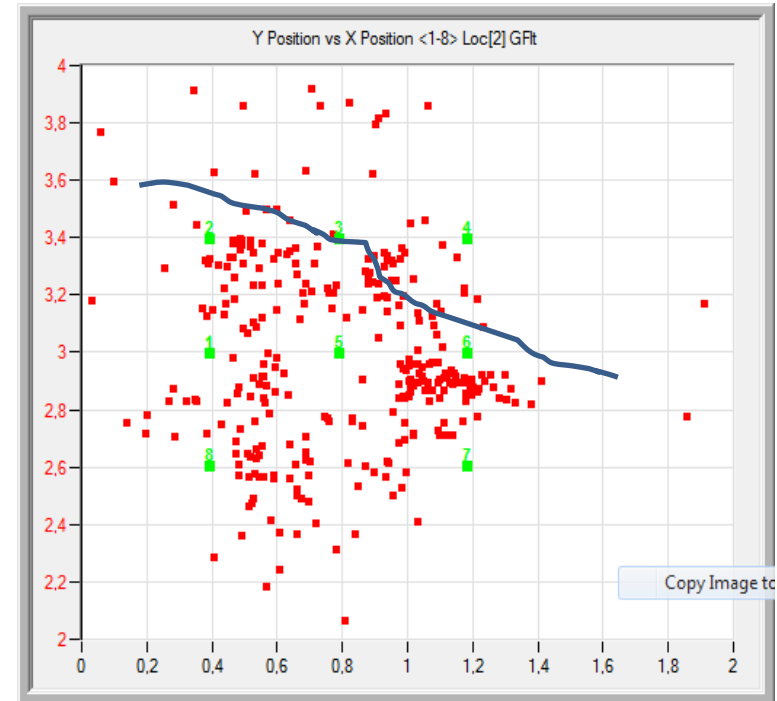
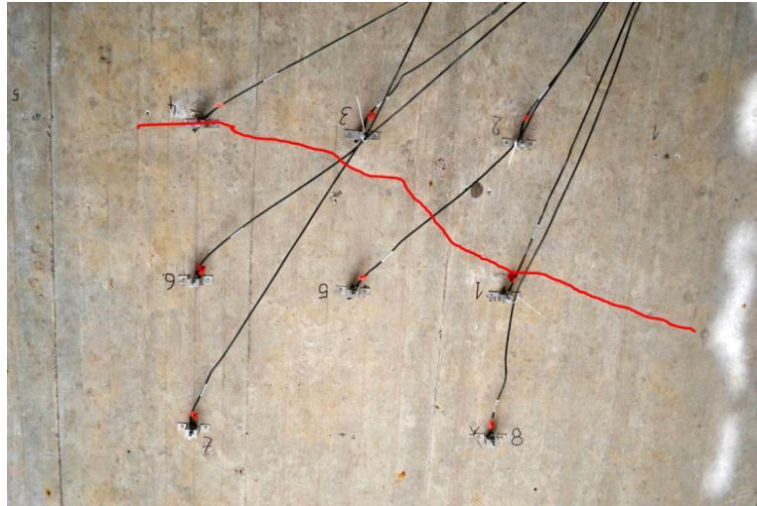
VA0028 - 8 sensors in line (e=40 cm)



Detection of AE active (damaged?) zones



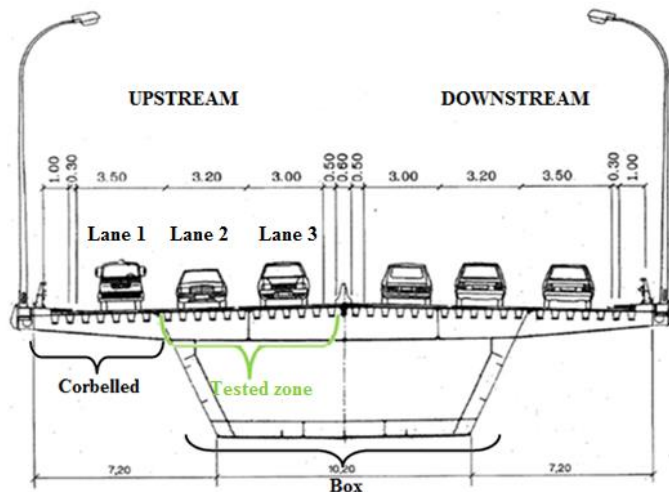
VA0028 - 8 sensors in a 2D array



- Excellent correspondence between Si-WIM & AE
- AE active (damaged) zones were located

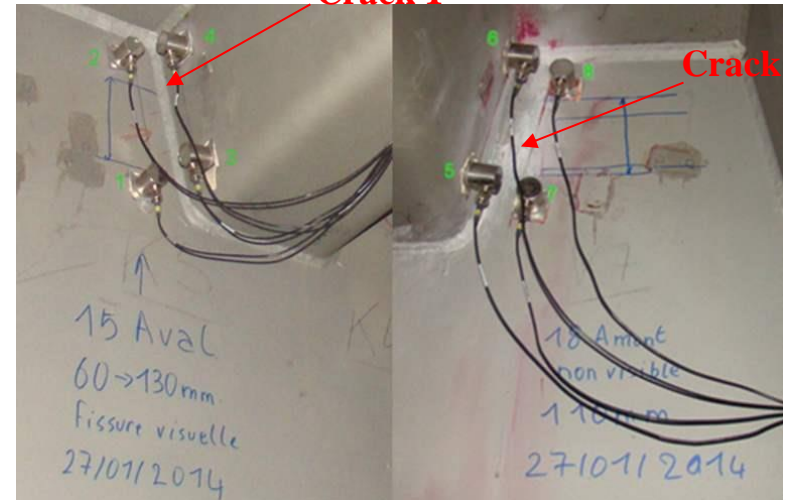
Cheviré Bridge test

- Nantes, F, “Loire River”
- built in 1986
- 52 m high and 1563 m long, 2x3 lanes
- orthotropic bridge deck
- Cracks on the corner between buckets and the crossbeam



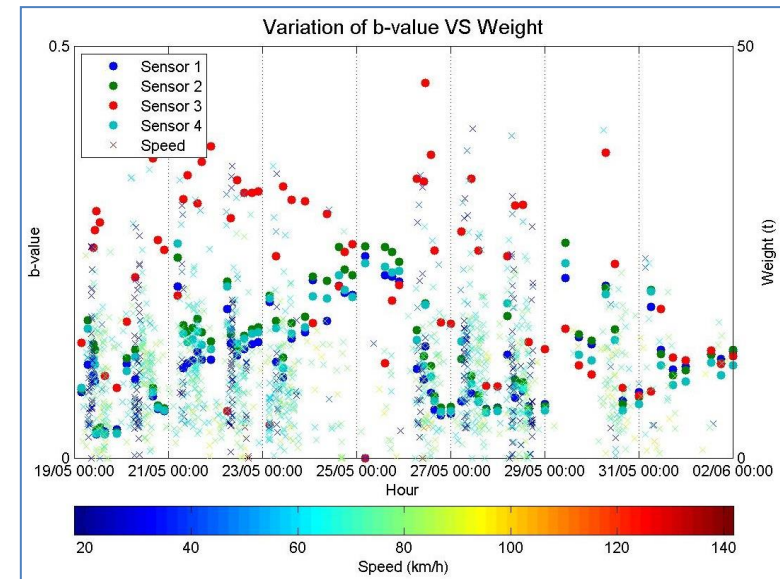
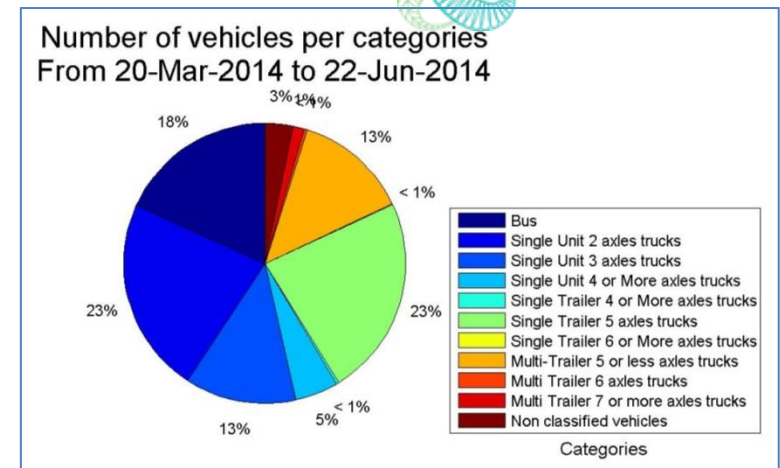
Crack 1

Crack 2



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!

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