



TRIMM is supported by funding from the 7th Framework Programme Call: IST-2011.3.2-2
Theme: Advanced and cost effective road
infrastructure construction, management
and maintenance

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INSTITUTE



Monitoring of bridge response to traffic loading

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TRIMM Seminar



TOMORROW'S ROAD INFRASTRUCTURE MONITORING & MANAGEMENT

Outline



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

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Monitoring of joints and bearings

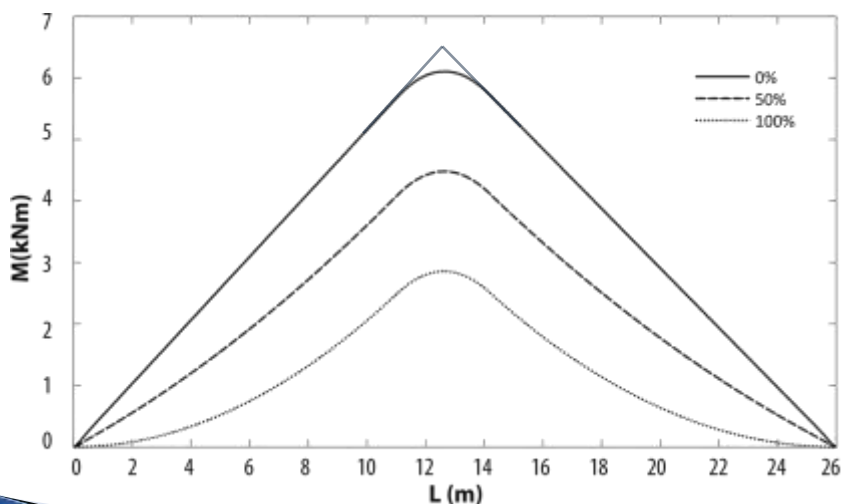


- joints and bearings important yet often not properly addressed bridge elements
- structural parameters (IL, LDF and vibration properties) sensitive to changes in boundary conditions – stiffness of joints and bearings
- ambition:
 - to use them as indicators of EJ&B functionality
 - 2 approaches:
 -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

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Influence lines



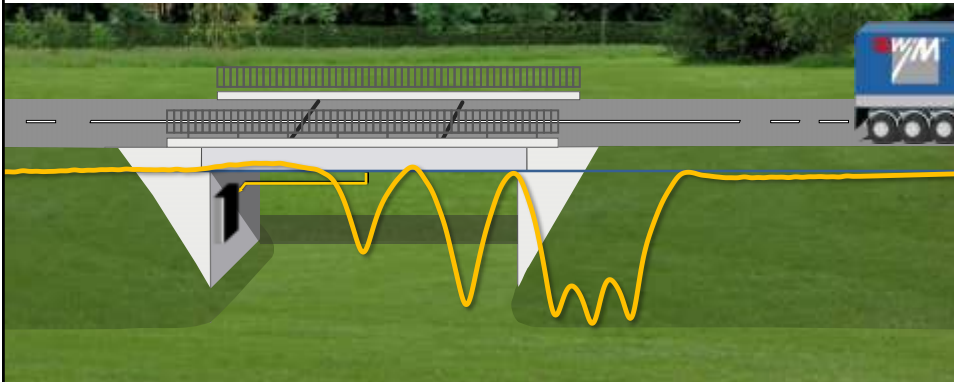
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Bridge weigh-in-motion



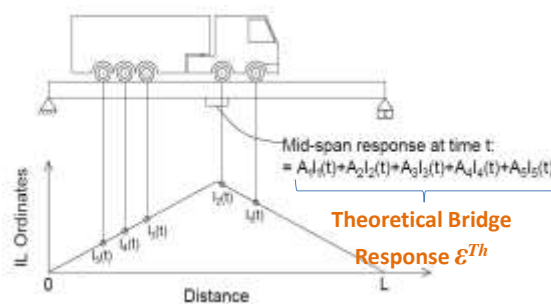
B-WIM is a measuring system that uses an existing instrumented structure – **a bridge or a culvert** – to weigh vehicles in motion (at normal highway speed)



Bridge weigh-in-motion theory



The idea is to solve for the axle weights which provide the closest match between the theoretical (ε^{Th}) and the measured (ε^{Me}) strain.



$$\sum (\varepsilon^{Th} - \varepsilon^{Me})^2$$

Minimise this error function

Bridge weigh-in-motion



- present since 1980s
- successful only in the last decade
- advantages:
 - complete portability, without affecting the accuracy
 - high accuracy
 - easy to install, *without interrupting the traffic*
 - provides additional structural information
- disadvantages:
 - proper bridge is needed
 - less common structures require knowledge about bridges

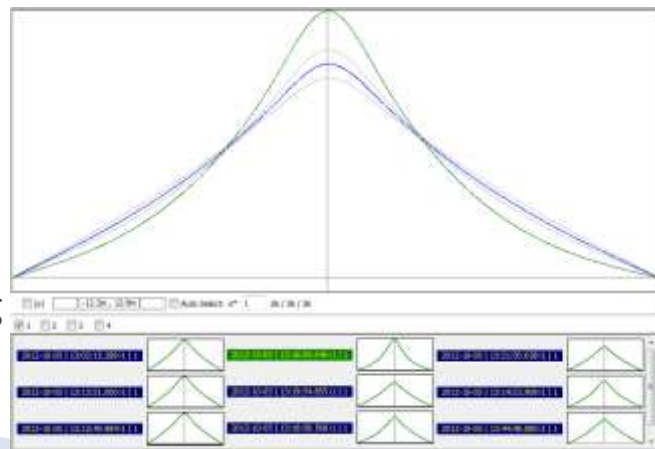
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SiWIM[®] and influence lines

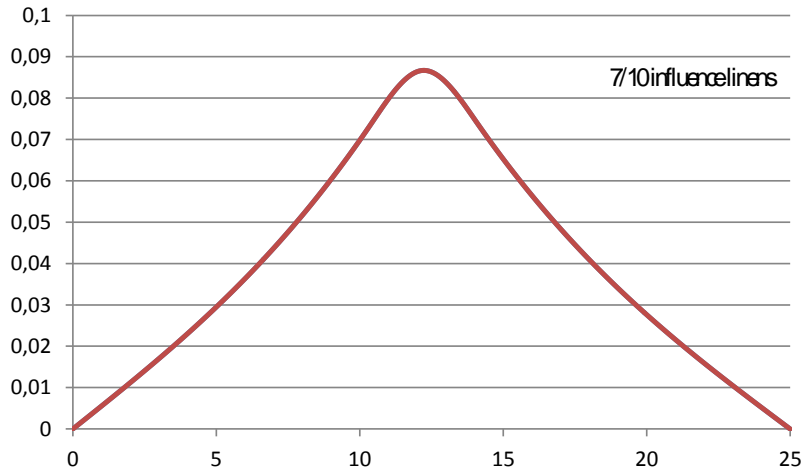


- SiWIM[®] calculates ILs and LDFs from vehicles passing the bridge
- **new IL module**
- long-term monitoring of changes



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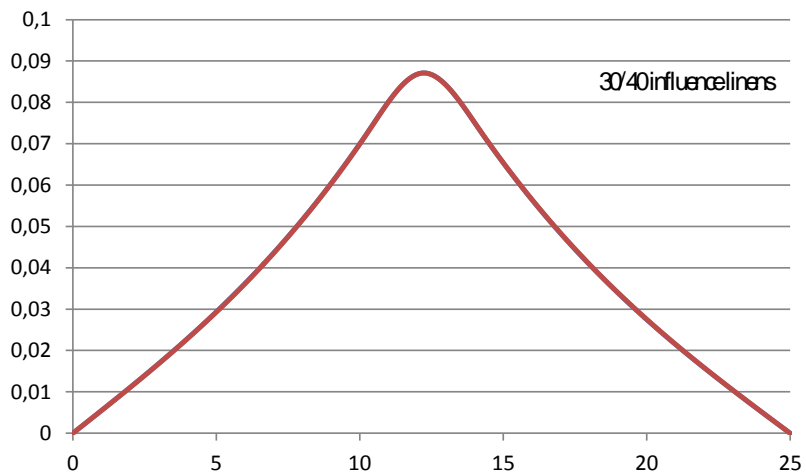
VA0468 influence lines – 10 runs



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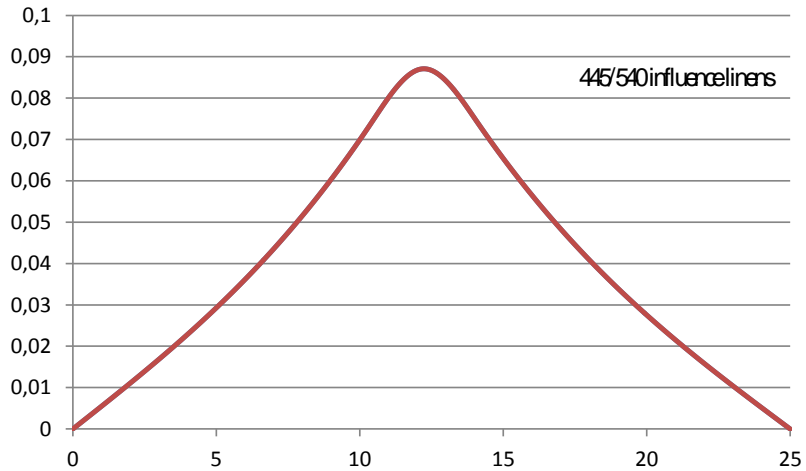
VA0468 influence lines – 1 hour



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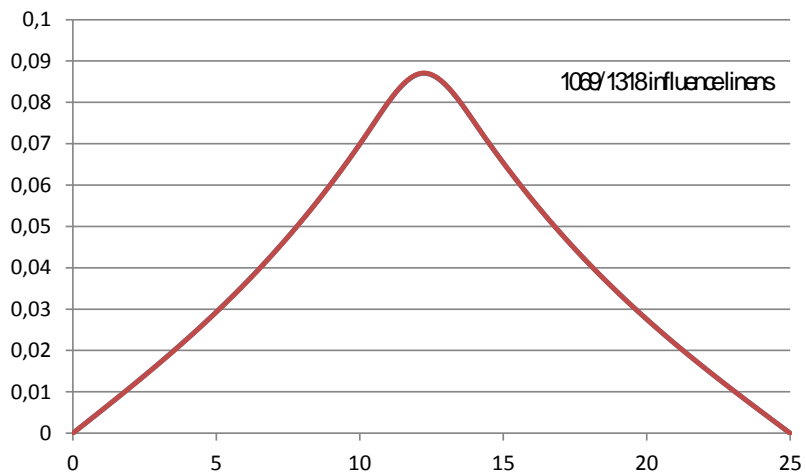
VA0468 influence lines – 10 hours



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VA0468 influence lines – 34 hours



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Bridge VA0468



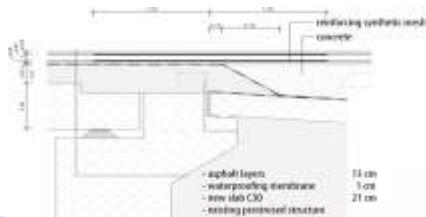
- 25.6 m simply supported span
- 5 beams

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Bridge VA0468



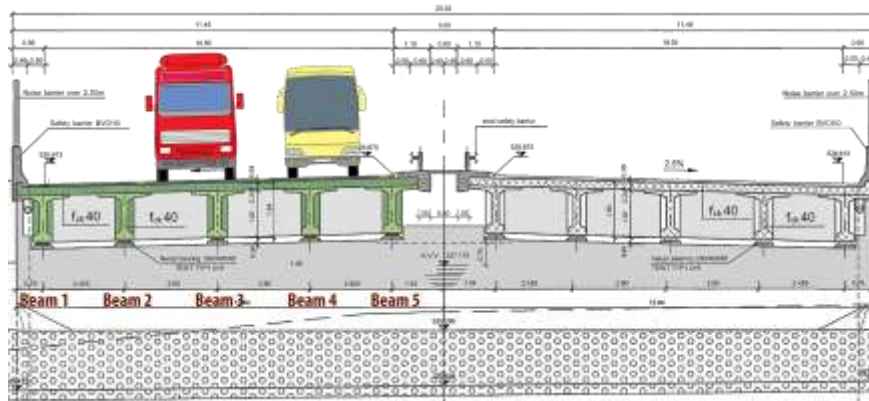
- 25.6 m simply supported span
- 5 beams
- replacement of EJs
- 2 sets of measurements

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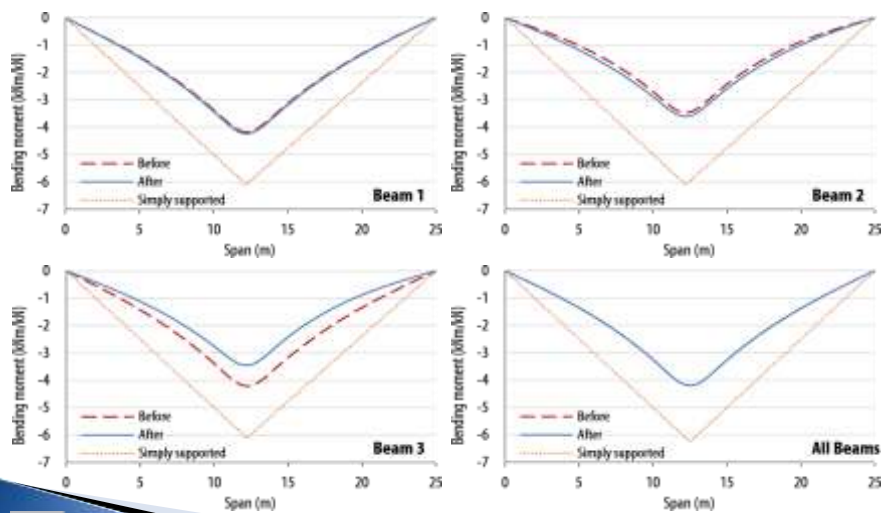
Bridge VA0468



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VA0468 influence lines results



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VA0468 influence lines results



Beam	Before		After		Difference		Difference %	
	Supp L	Supp R	Supp L	Supp R	Supp L	Supp R	Supp L	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

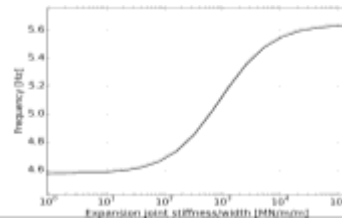
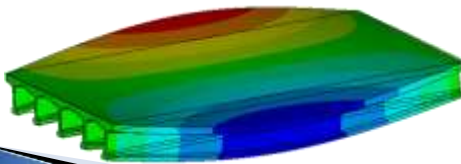
Modal analysis



- 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



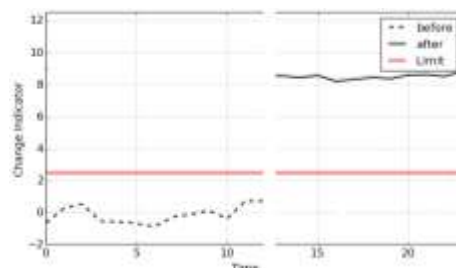
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Modal analysis



- 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)



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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

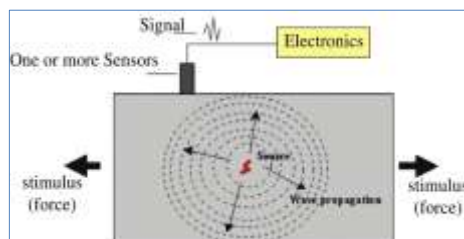


- to apply recommendations of the FP6 ARCHES project and
- **try to combine** bridge weigh-in-motion (**B-WIM**) measurements with Acoustic Emission (**AE**) techniques
- to **correlate** directly the acoustic activities (**progressive damage**) with **real loading** (axle loads) and load effects (strains)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

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)
- Measures signals generated **within** the structure, due to:
 - crack growth under stress
 - secondary emissions due to e.g. friction of crack interfaces



Acoustic Emission (AE) techniques



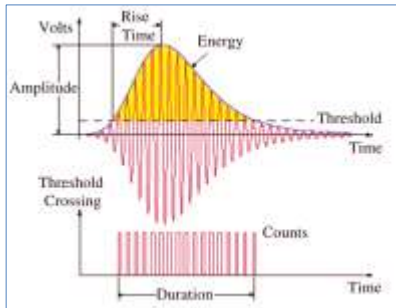
ADVANTAGES	DISADVANTAGES
Distant events can be detected	The structure has to be loaded
The whole structure can be tested at once	AE activity depends on microstructure of the material
Equipment is easy to use	Ambient noise can disturb the measurement
Access to the whole structure is not required	Localization is not absolutely precise
Active cracks can be detected	Interpretation of measurements requires skilled personnel

Acquisition of AE data

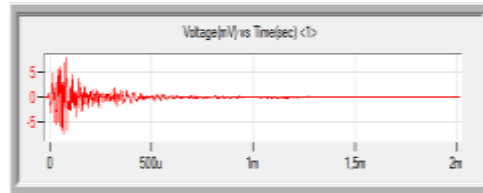


- AE measuring systems consist of
 - AE sensors
 - pre-amplifier and amplifier
 - A/D converter
 - computer & software
- proper sensor location is fundamental for successful AE based evaluation of the structure; case specific
- triggering thresholds for each AE channel should be set to eliminate the environment noise

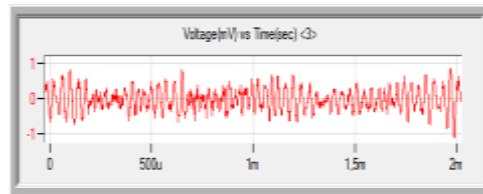
AE signal – basic expressions



Theoretical burst AE signal



Typical burst AE signal

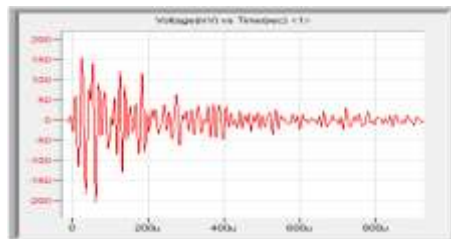


Typical "continuous" AE signal

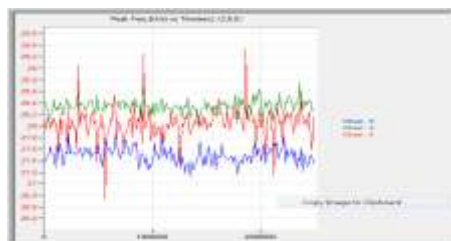
Interpretation of AE data



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



Typical burst AE signal

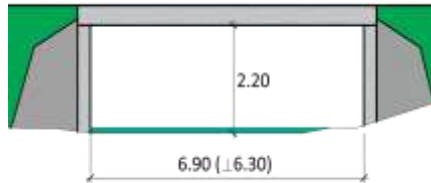


Peak freq. vs. time per channel

Bridge PT0343



- small bridge
- to be demolished
- load testing:
 - soft with SiWIM®
 - proof



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Bridge PT0343 - Soft load testing

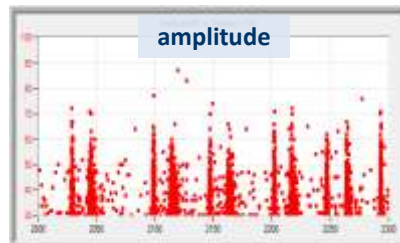
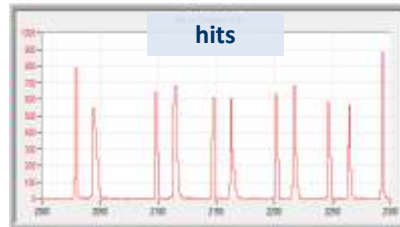


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Bridge PT0343 - Soft load testing



- AE recordings (number of hits) of individual truck crossings

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Bridge PT0343 – Proof load testing



- increasing static loading
- measured deflection, deformations
- AE: hits, energy, amplitude, ...

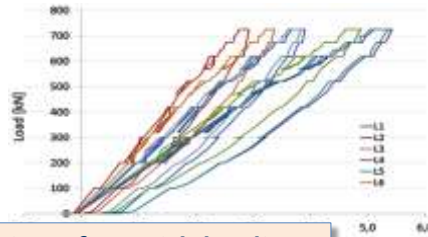


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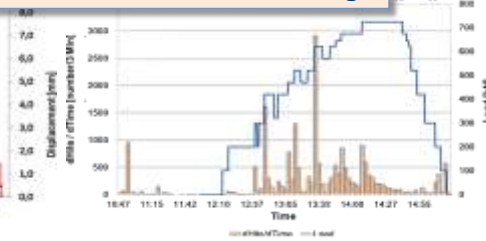
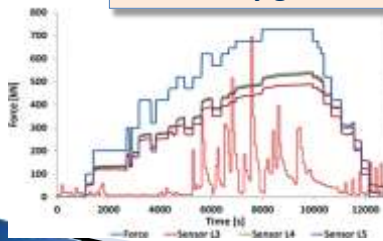
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Bridge PT0343 – Proof load testing



Generally good correlation of AE with loading



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V0028 underpass



- small underpass, concrete, frame, highway
- continuous SiWIM® & AE monitoring > 1.5 year
- SiWIM®: deformation -> loading
- AE: hits, amplitude, energy,...

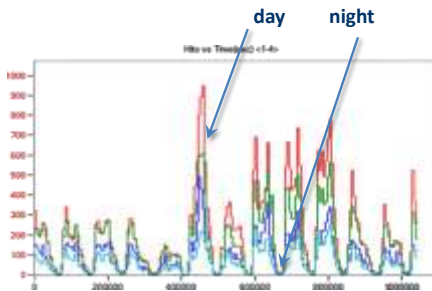
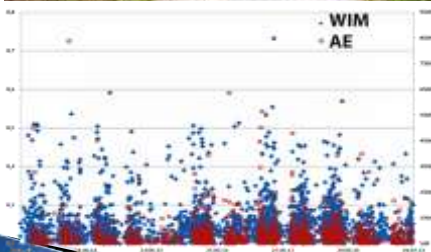


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2 x 4 sensors



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

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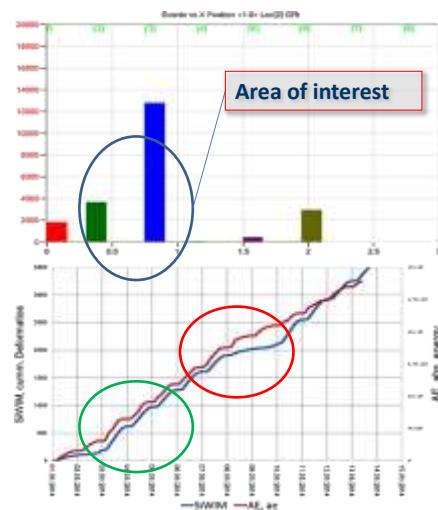
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VA0028 - 8 sensors in line (e=40 cm)



Area of interest

Detection of AE active (damaged?) zones

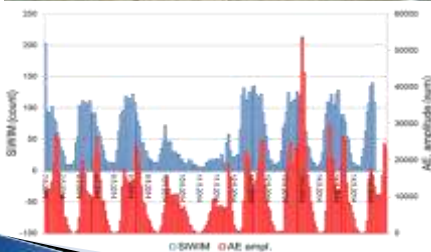
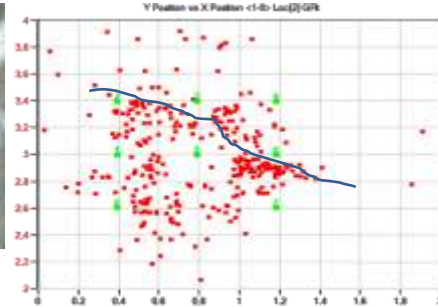
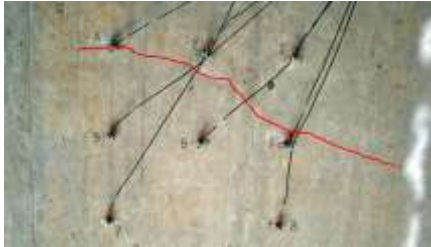


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VA0028 - 8 sensors in a 2D array



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

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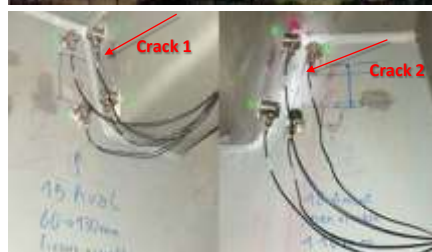
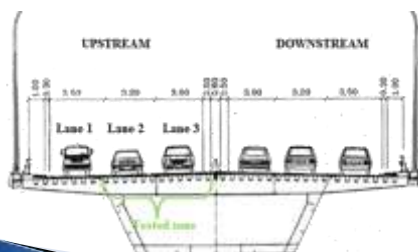
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Cheviré Bridge test



- 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



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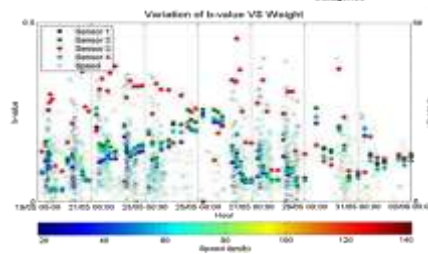
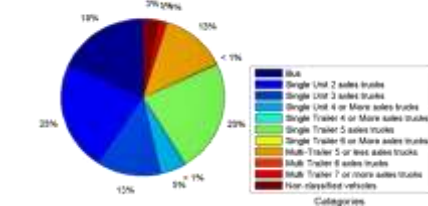
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Cheviré Bridge test



- 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

Number of vehicles per categories
From 20-Mar-2014 to 22-Jun-2014



Conclusions



- A combined SiWIM and AE monitoring system can give enhanced information when assessment of bridges is to be performed.
- Both systems monitored the traffic loads and delivered matching results – higher loads induce higher AE activities.
- Non-linearity in the structural response to loads was detected by the increased AE activity during a proof load test.
- The AE system can be used to detect AE active zones in the structure related to damaged or damage-active zones.

Conclusions



- The damage level could not be evaluated except for the proof load test. Structures tested were in condition which were too good compared to the traffic load applied.
- Sufficient number of AE sensors (which is problem-specific) allows to determine the location of the source.
- The AE parameters (RA-value and b-value) seem to be good indicators to study the evolution of a crack in steel. However, reference values for steel (structures) would be needed for more accurate evaluation.

Thanks for listening!

