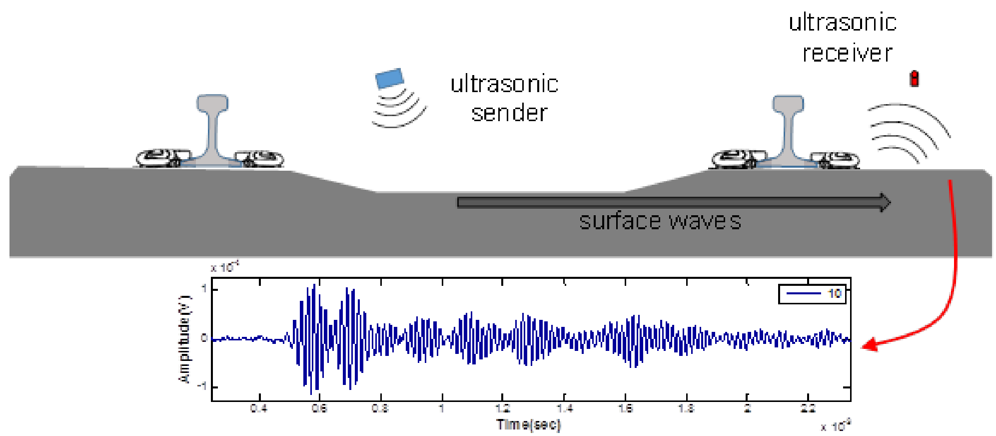
William W. Hay Railroad Engineering Seminar

"Non-destructive in-place condition assessment technologies for deterioration in railroad ties"

John Popovics
Associate Professor
University of Illinois
at Urbana-Champaign



Date: Friday, February 27, 2015 Time: Seminar Begins 12:20

Location: Newmark Lab, Yeh Center, Room 2311
University of Illinois at Urbana-Champaign

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NON-DESTRUCTIVE IN-PLACE CONDITION ASSESSMENT TECHNOLOGIES FOR DETERIORATION IN RAILROAD TIES

John S. Popovics

The University of Illinois at Urbana-Champaign

RailTEC Hay Seminar

February 27, 2015

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Presentation outline

1) Objective, motivation, review of previous work
2) Development of data analysis/evaluation schemes
3) Improvement of ultrasonic testing set-up
4) Experimental results
5) Future Work

Motivation

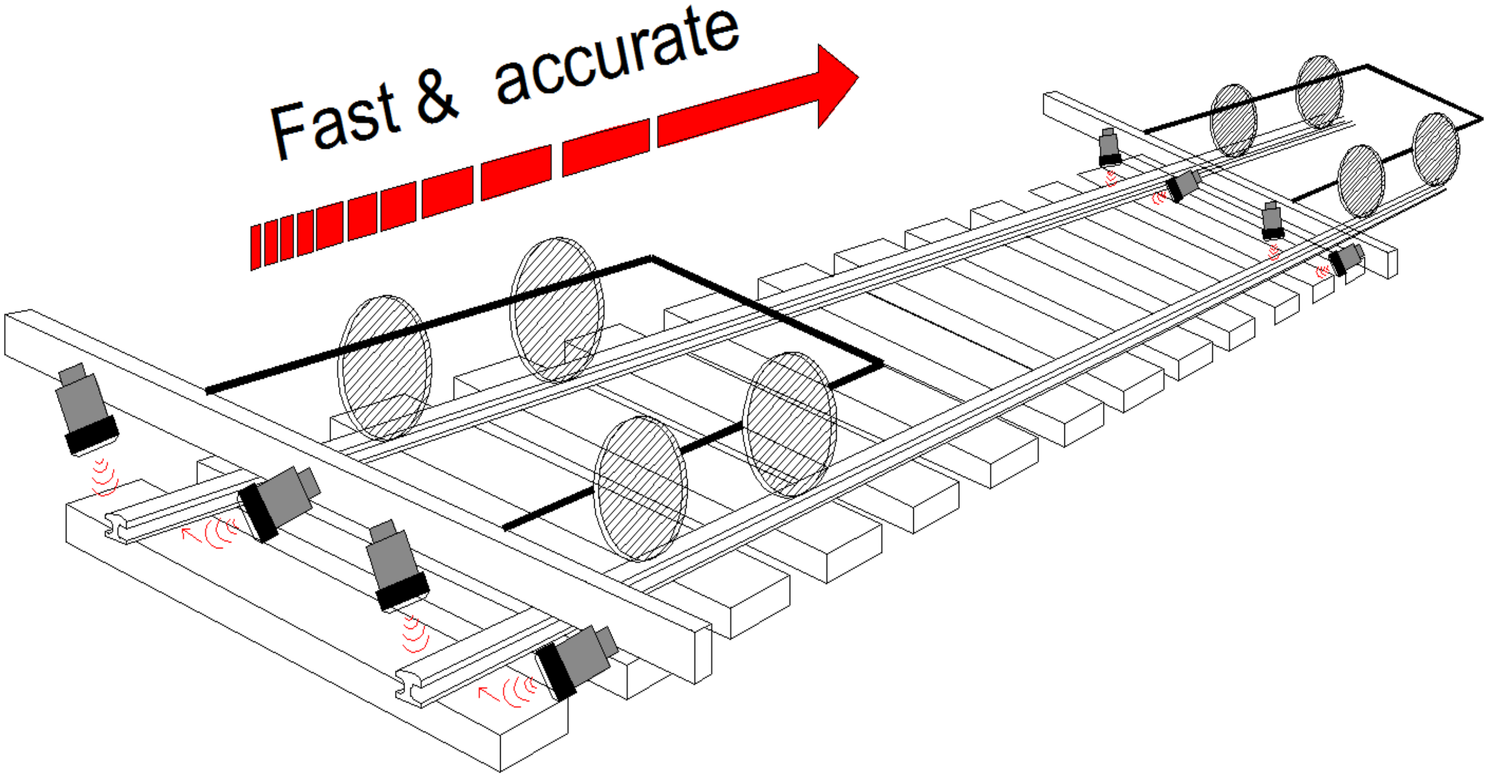
Concrete and timber crossties are important components in the rail bed structure:

* Distribute wheel loads (Support)
* Maintain track geometry (Stability)
* Electrically isolate rails (Isolation)

Material integrity of ties especially important for high speed rail structures

<J.R. Edwards>

Vision for ultrasonic evaluation of rail ties



Concept of implementation for performing cost effective inspection: one-sided, air-coupled ultrasound techniques carried out from a *moving platform*

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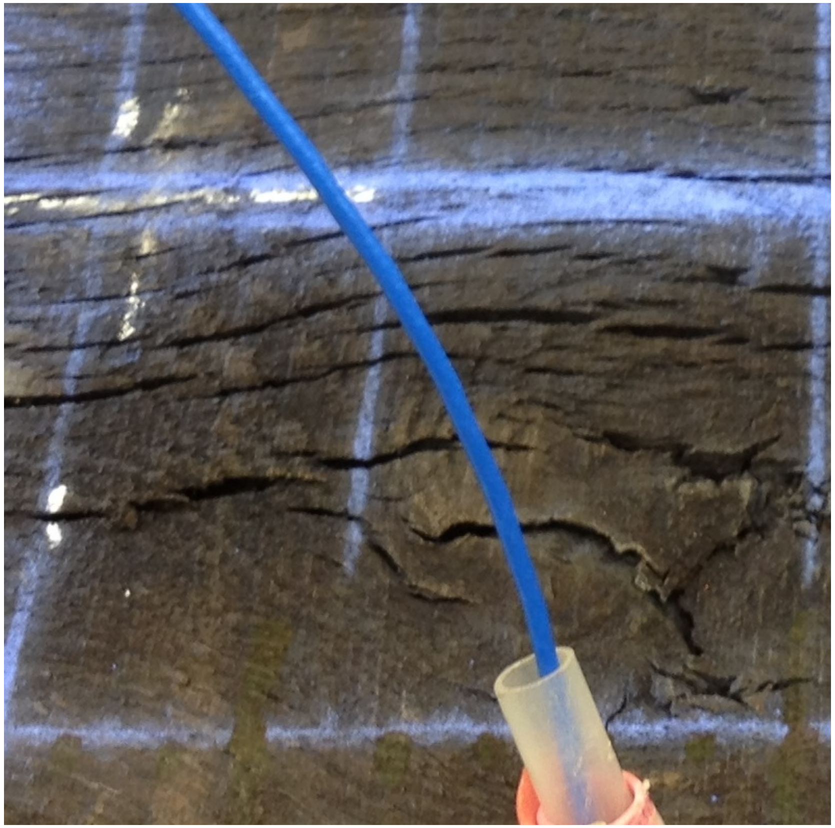
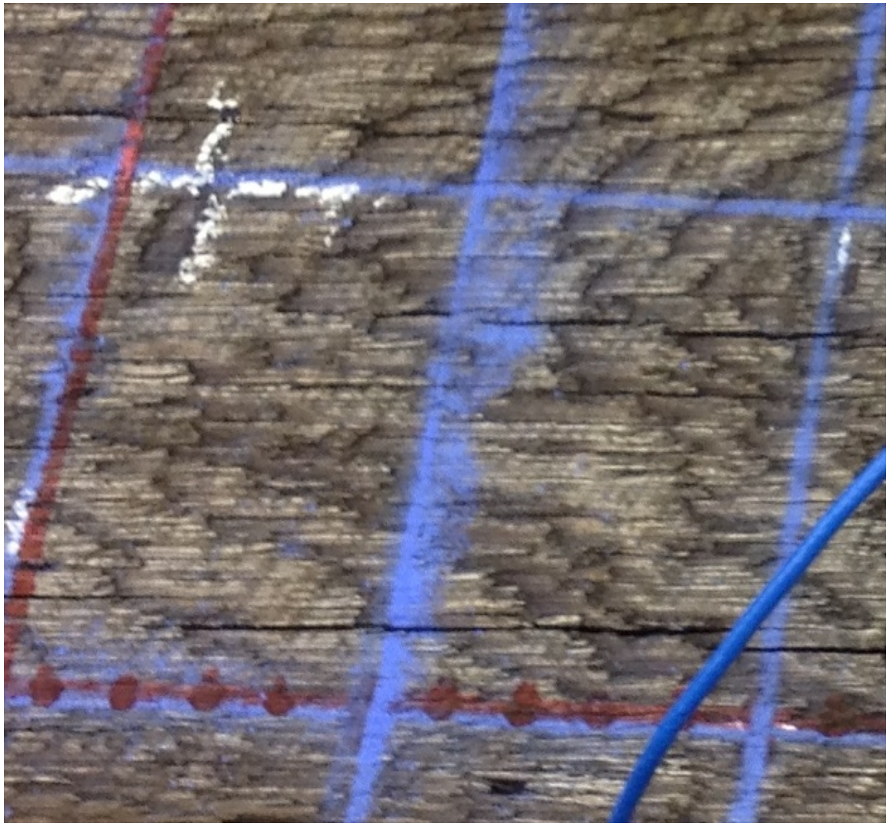
Timber rail ties have long been used in rail structures in the US. Structural deficiency arises from natural degradation mechanisms

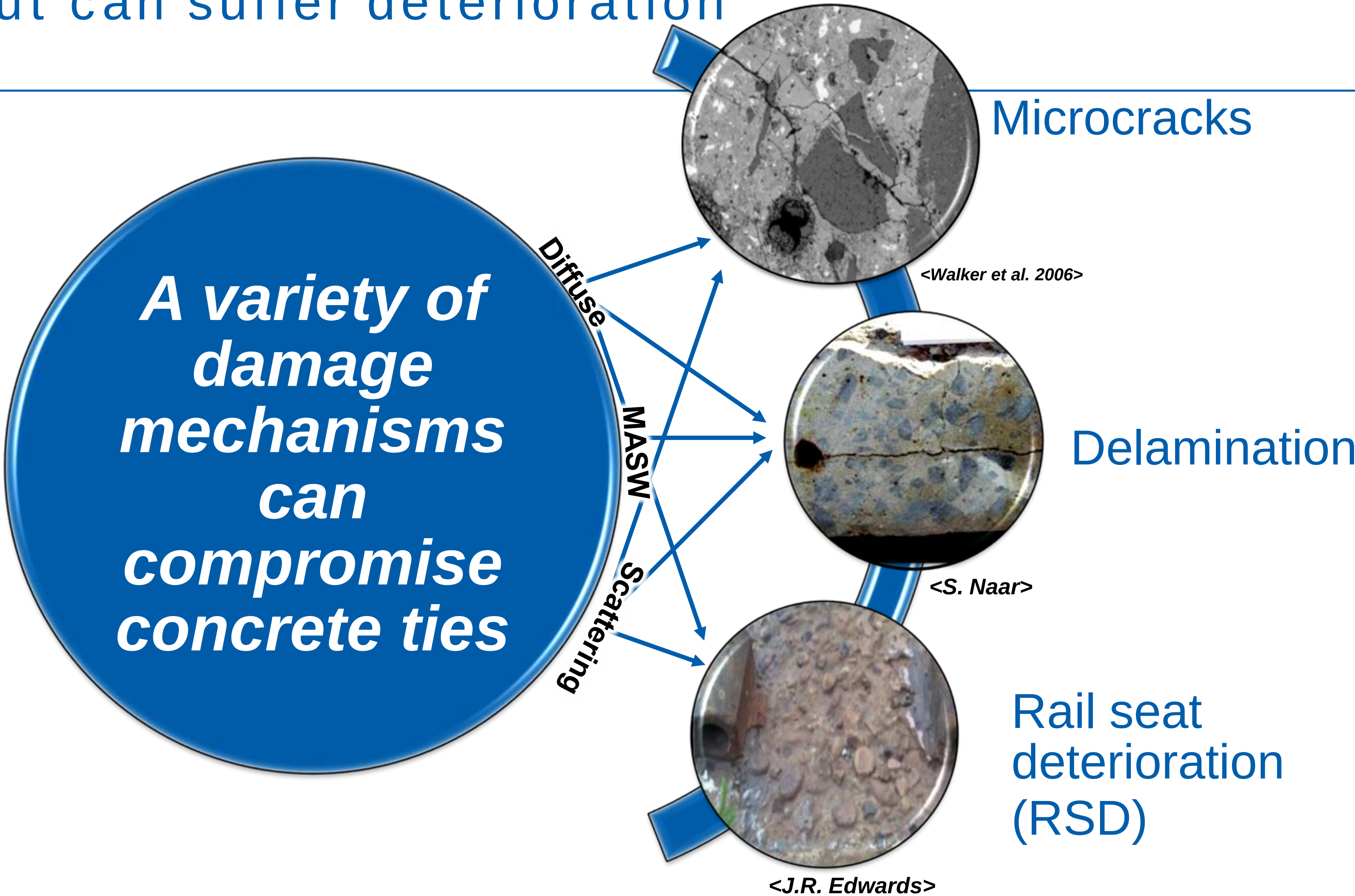


Deteriorated wood



Sound wood

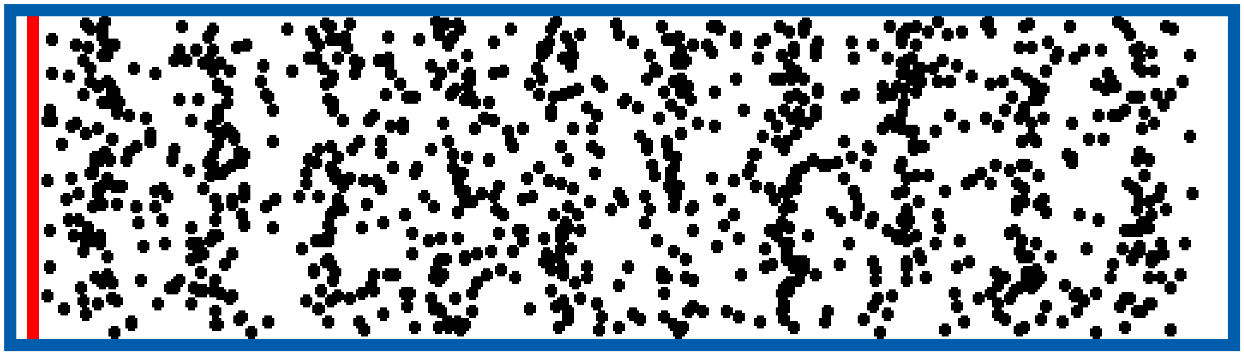
Concrete rail ties are becoming more prevalent, but can suffer deterioration



Mechanical body waves in solids: P-waves

also: Longitudinal (L-) Waves, Compression Waves

Excitation



<T. Voigt >

Direction of Travel

Direction of Particle Motion

Wave Velocity:

$$v_P = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}$$

Governing Parameters

Young's Modulus E

Poisson's Ratio ν

Density ρ

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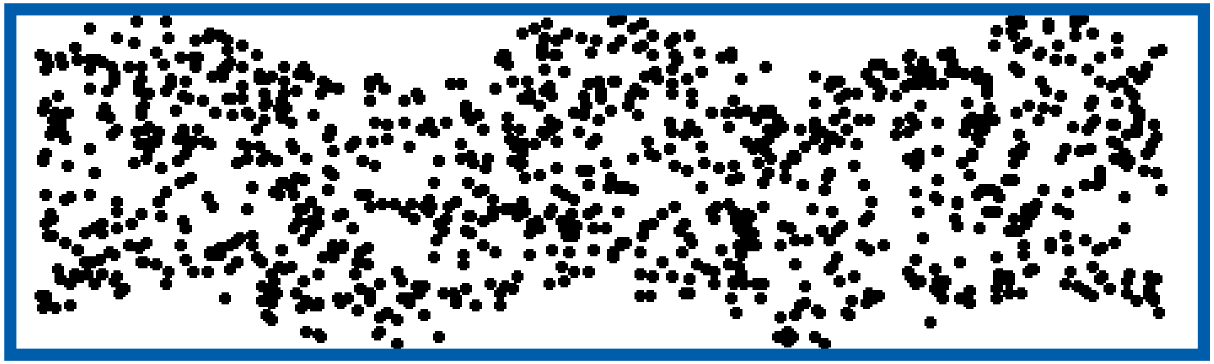
Mechanical body waves in solids: S-waves

also: Transverse (T-) Waves, Shear Waves

Excitation



<T. Voigt >

Direction of Travel

Direction of Particle Motion

Wave Velocity in solids:

$$v_S = \sqrt{\frac{G}{\rho}}$$

Governing Parameters

Shear Modulus G

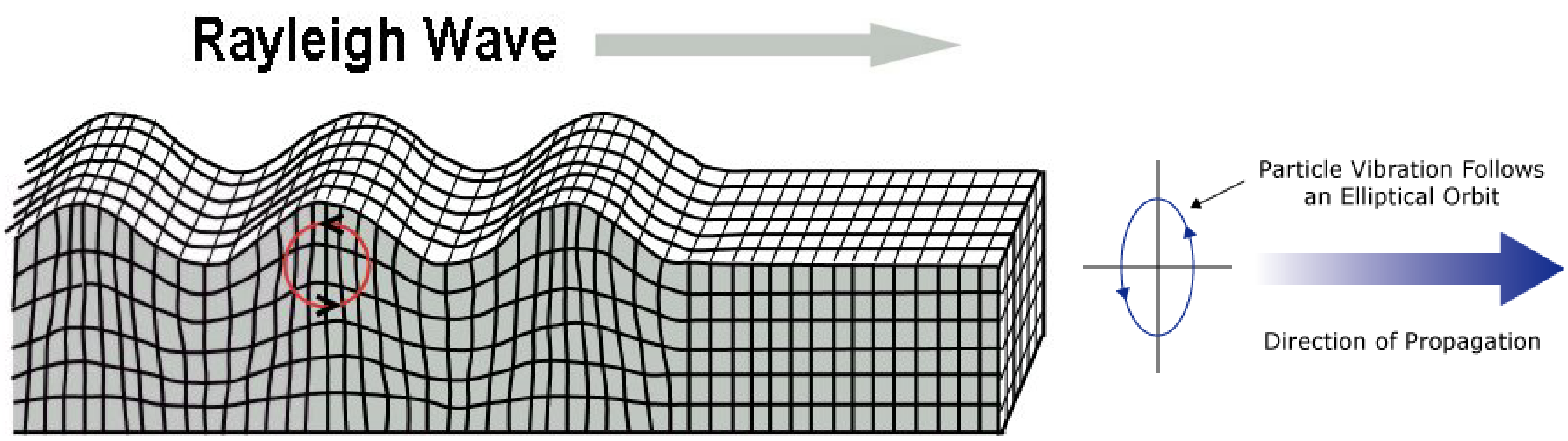
Density ρ

no propagation in liquids or gases !

$V_P > V_S$ in all known solids

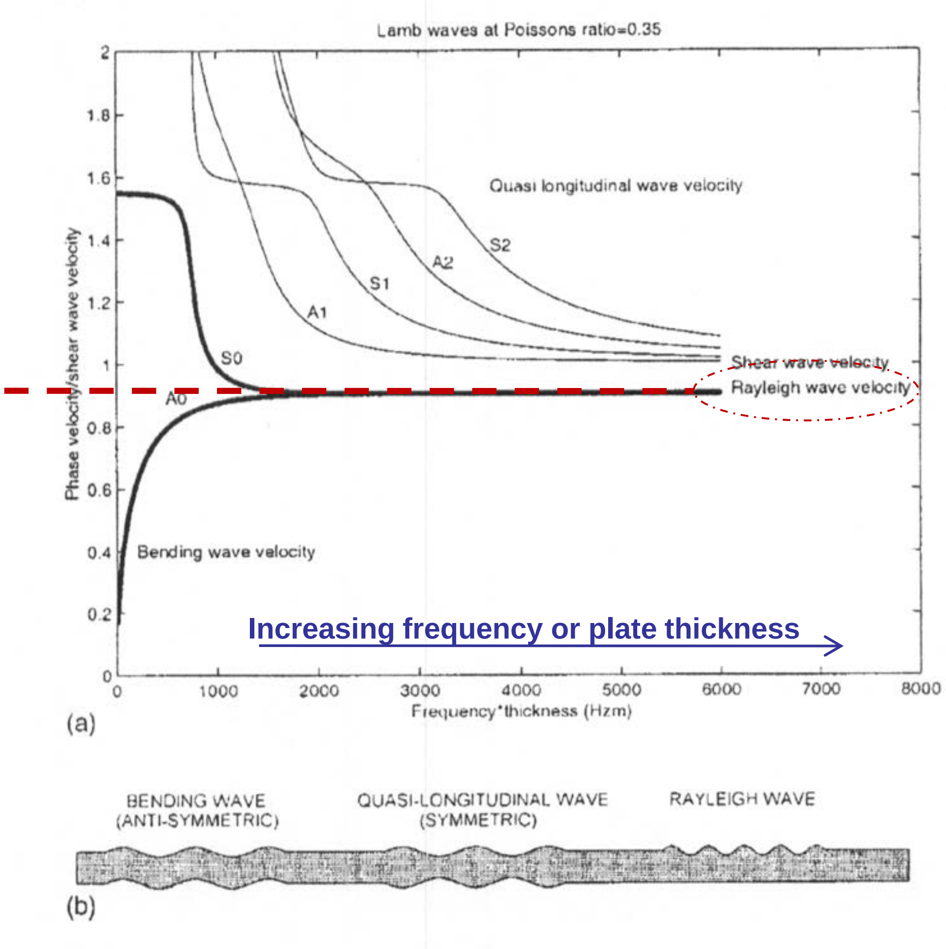
Guided waves: Surface waves

Rayleigh surface wave travels along free surface but do not propagate far into the body of the material. Rayleigh waves travel slightly slower than shear waves, and show coupled longitudinal and shear motion



<www.lamit.ro/earthquake-early-warning-system.htm>

Guided waves: Lamb waves in plates



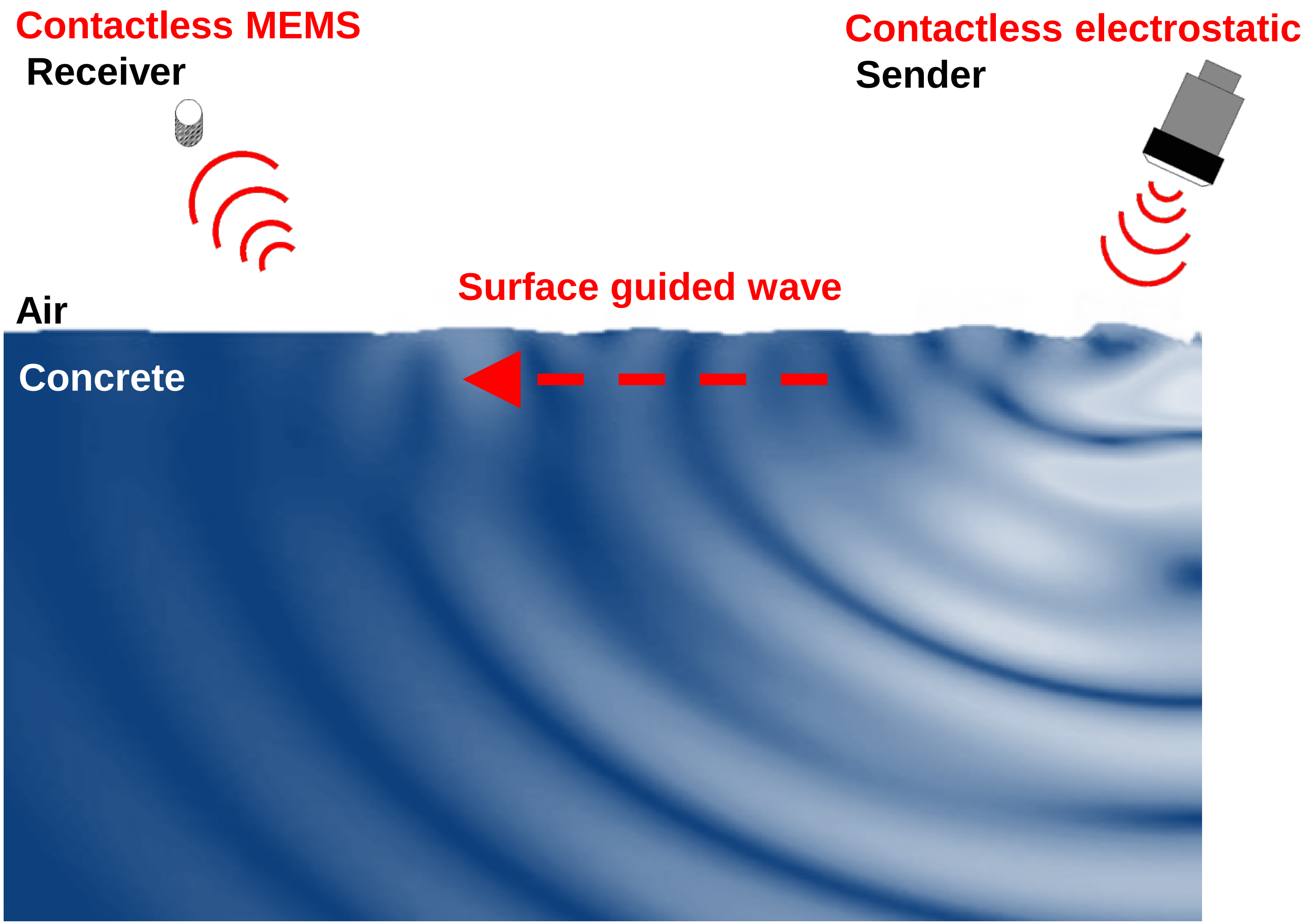
<N. Ryden>

Lamb wave are <u>set up</u> in large plates

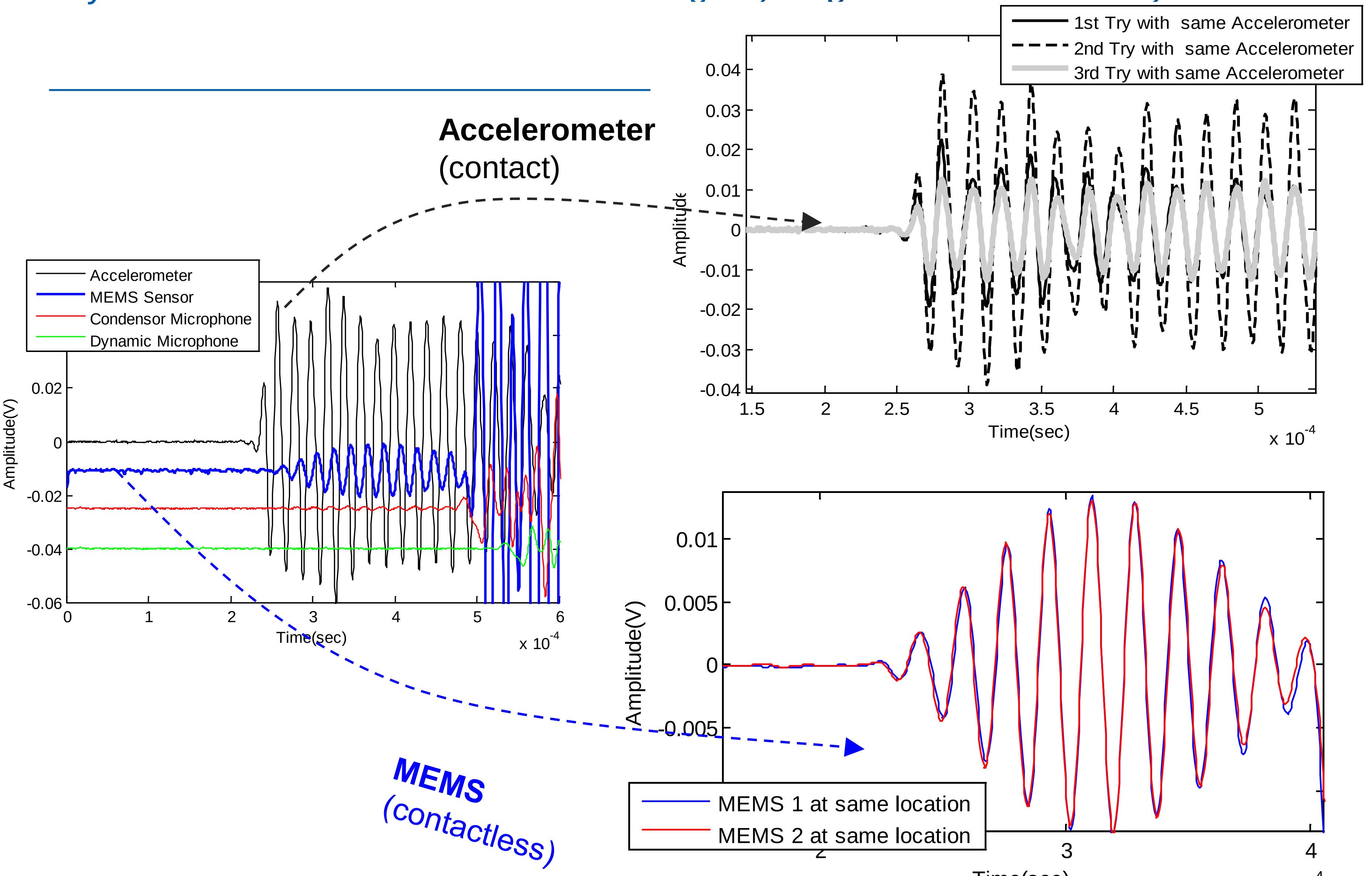
Multiple (infinite) modes of propagation, with varying motion character and propagation velocity

Can be visualized as a propagating resonance

Fully contactless ultrasonic technique

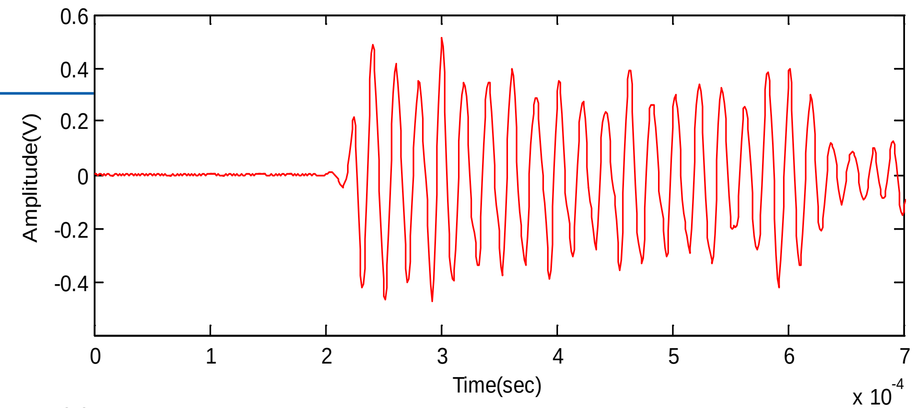


Key feature of contactless sensing: *1) Signal consistency*

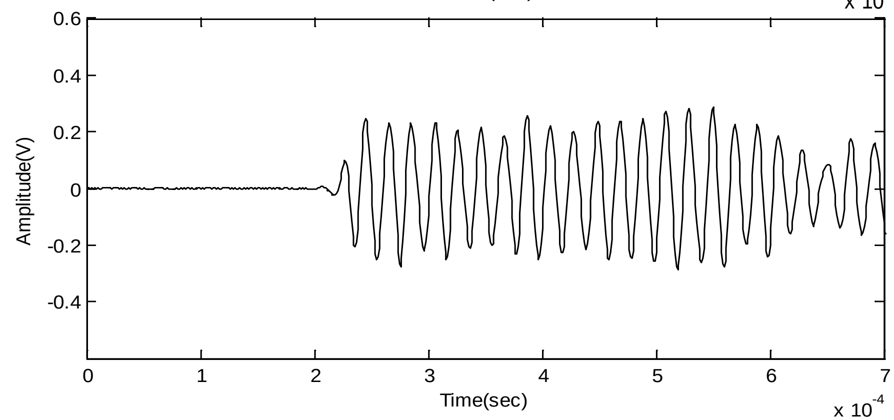


Key feature of contactless sensing: *2) Application to rough surfaces*

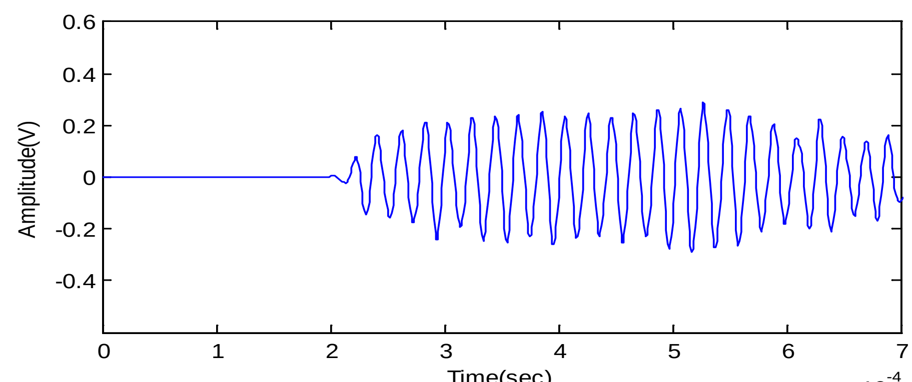
Smooth



Medium

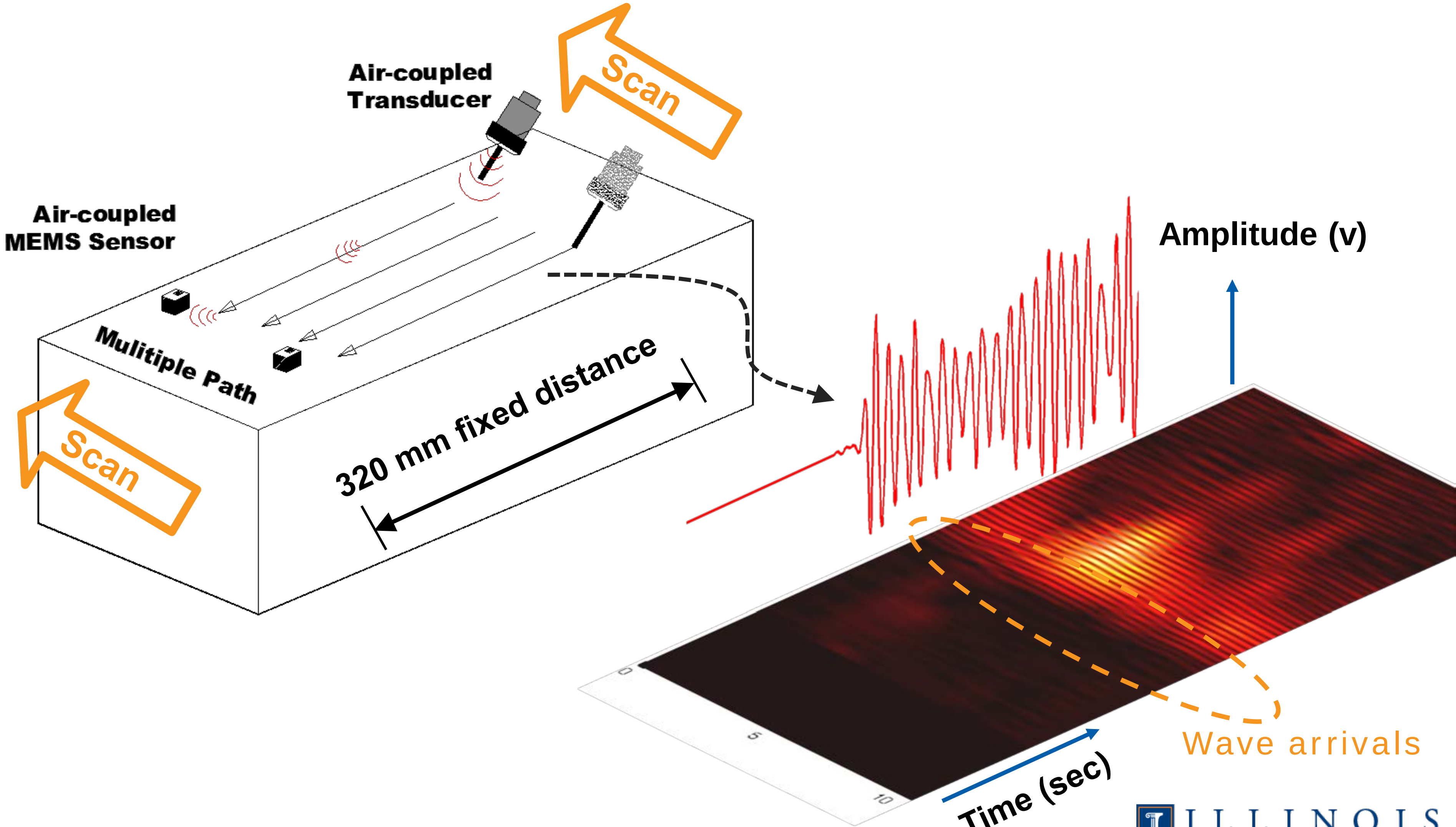


Extremely Rough



Development of data analysis/evaluation schemes

Ultrasonic surface wave data scans reveal that signal velocity and attenuation indicate presence of distributed damage



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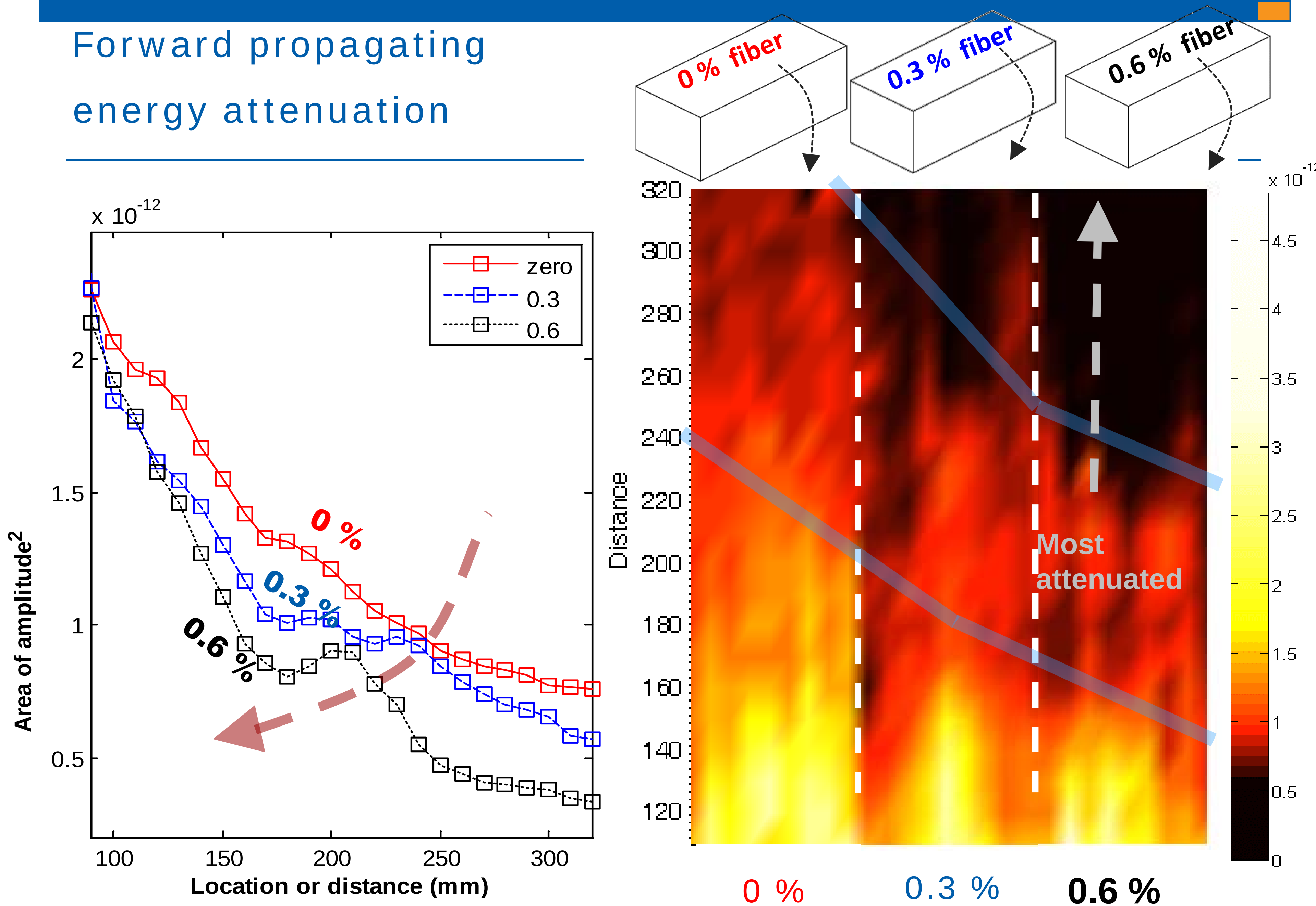
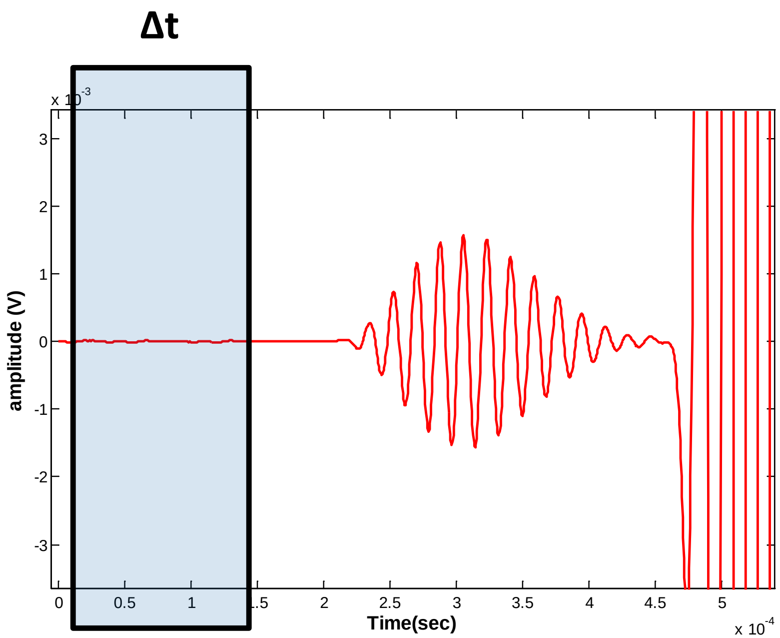
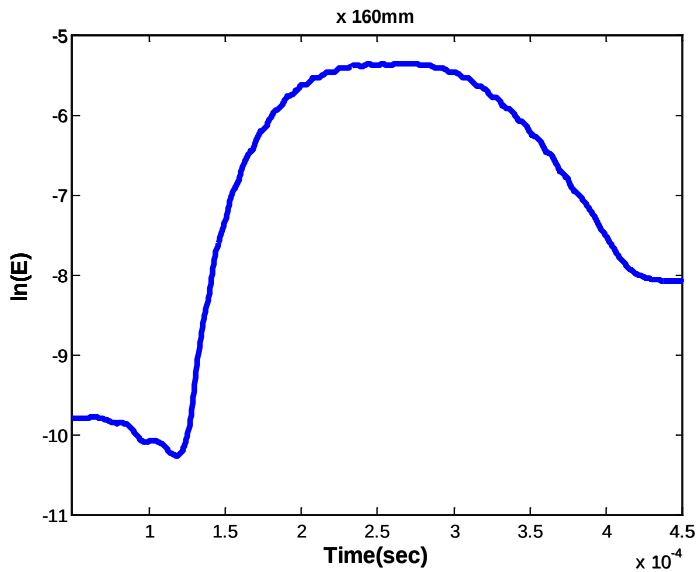
Forward propagating energy attenuation



Characterization of forward propagating signal energy through short-time-interval computation





A short-time-interval average signal a window width equal to the duration of the excitation pulse, of the square of the filtered signal was then constructed (Weaver & Sachse, 1995).

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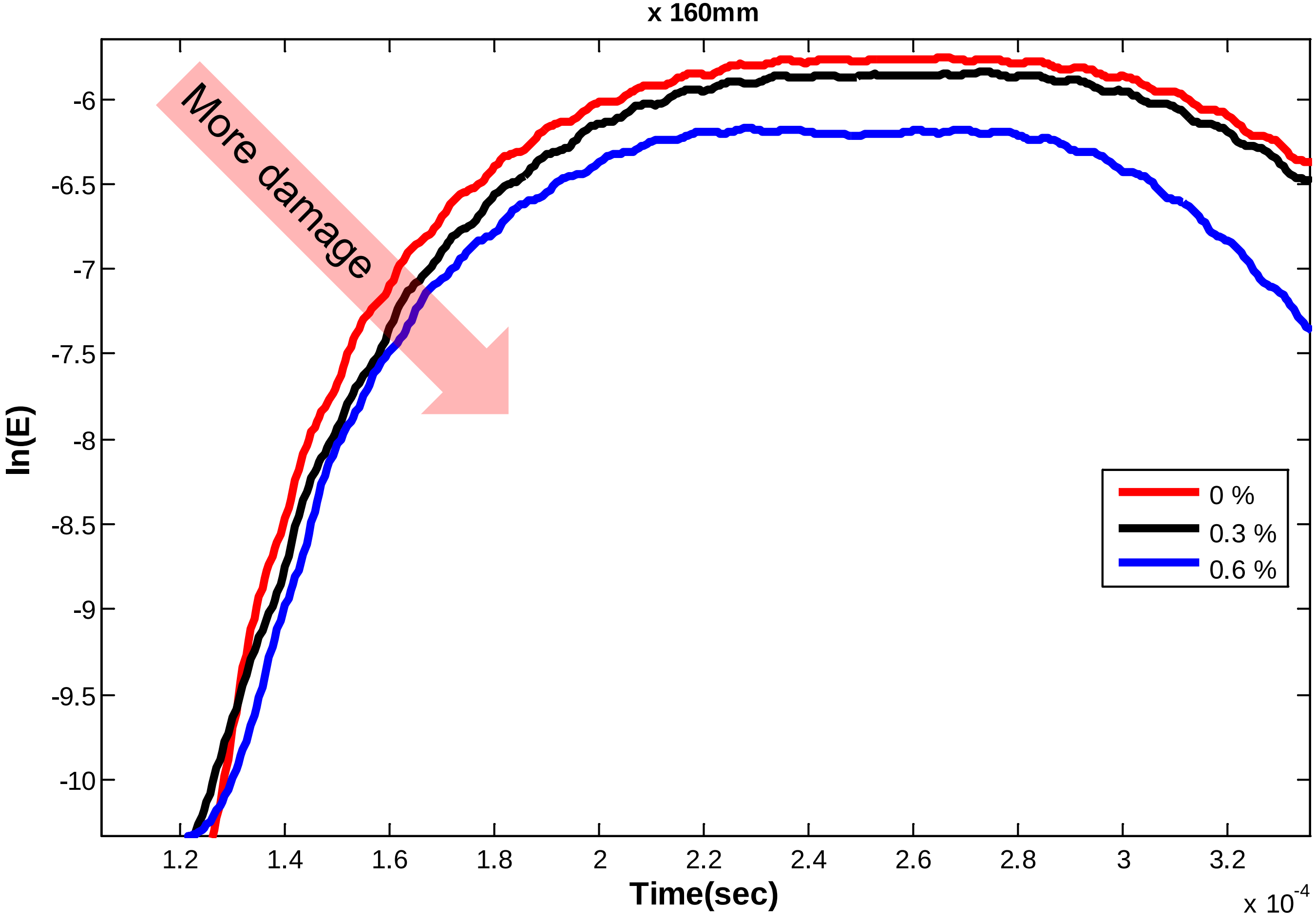
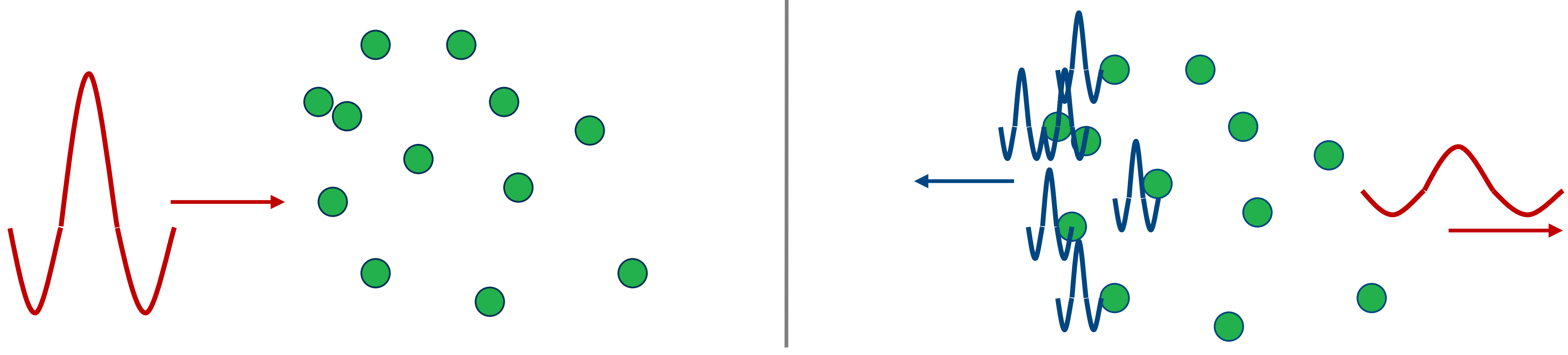
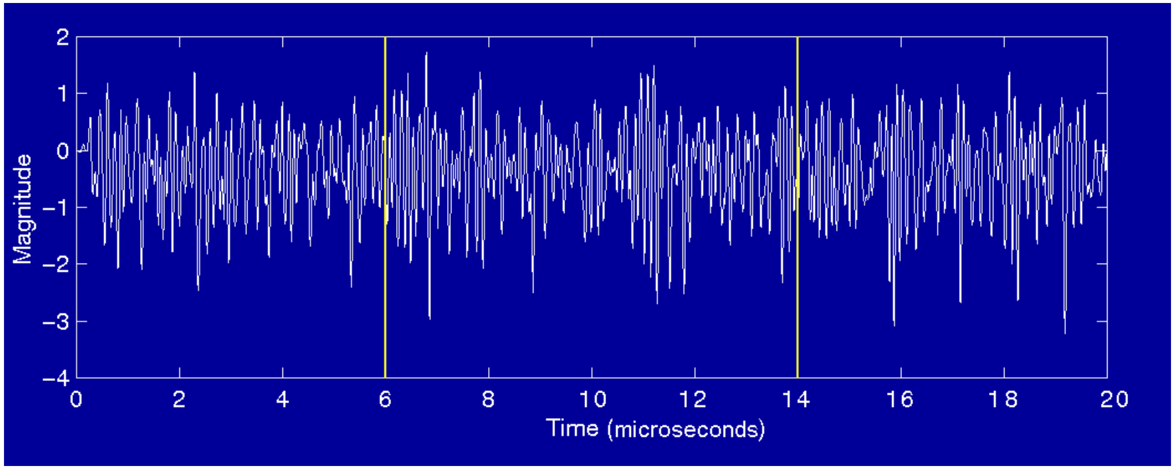
Shifting of energy envelope indicates energy dissipation from wave scattering



Wave scattering

The reflection of ultrasonic energy away from the original direction of propagation; caused by reflection, refraction and mode conversion from internal inclusions. Causes signal loss, signal dispersion and scattering “noise”





Detected back-scattered signal

<Oelze 2007>

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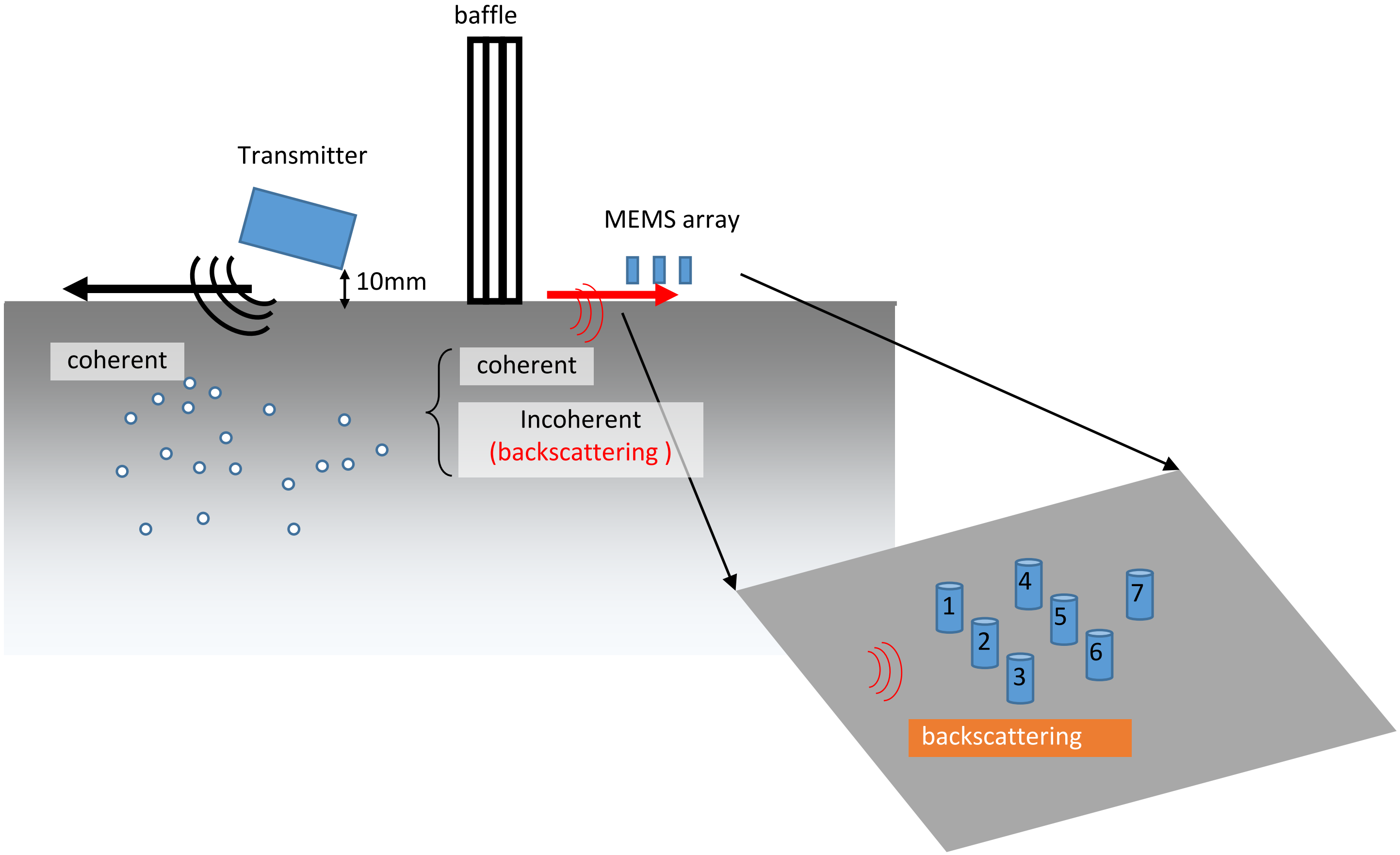
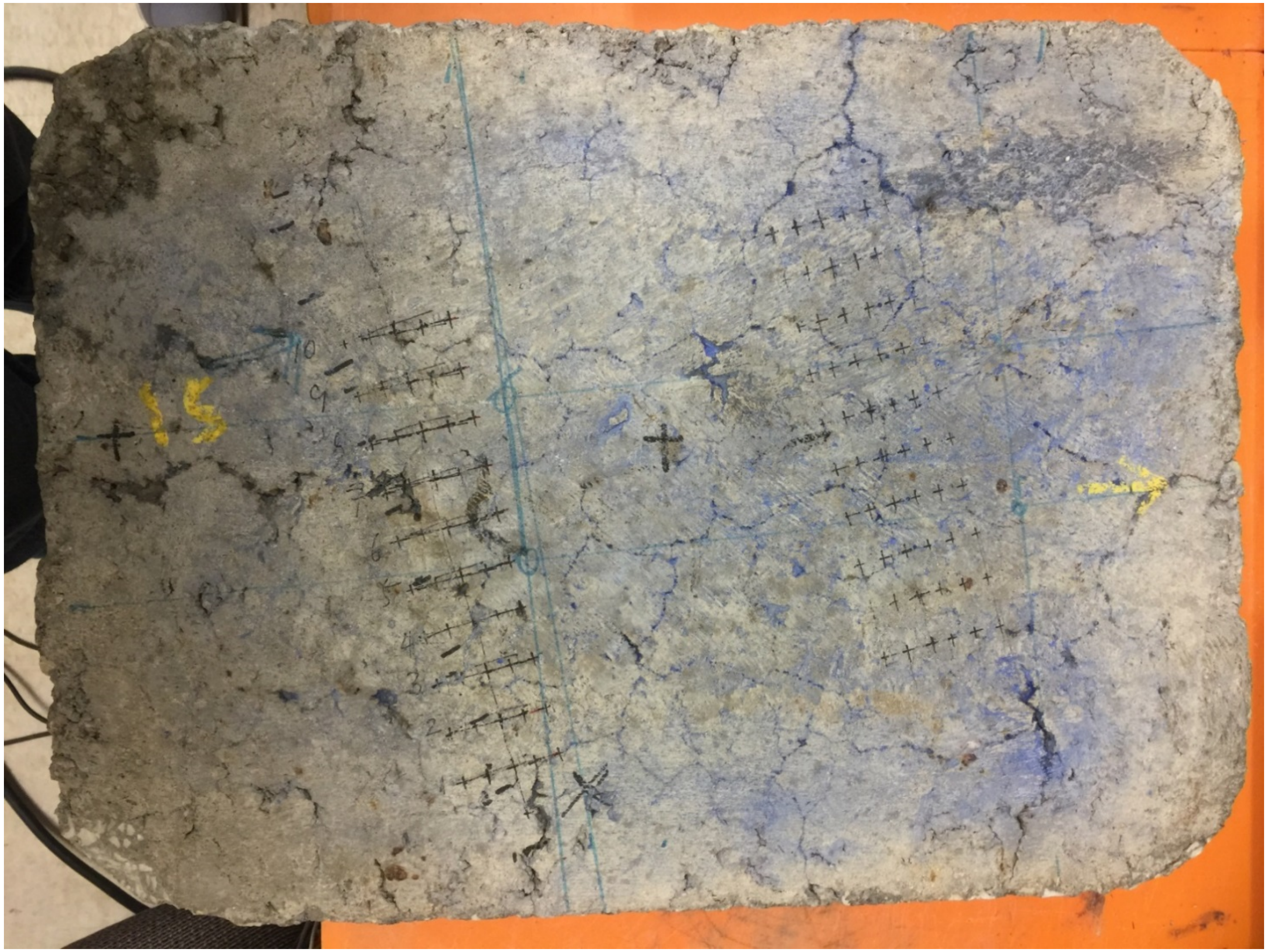
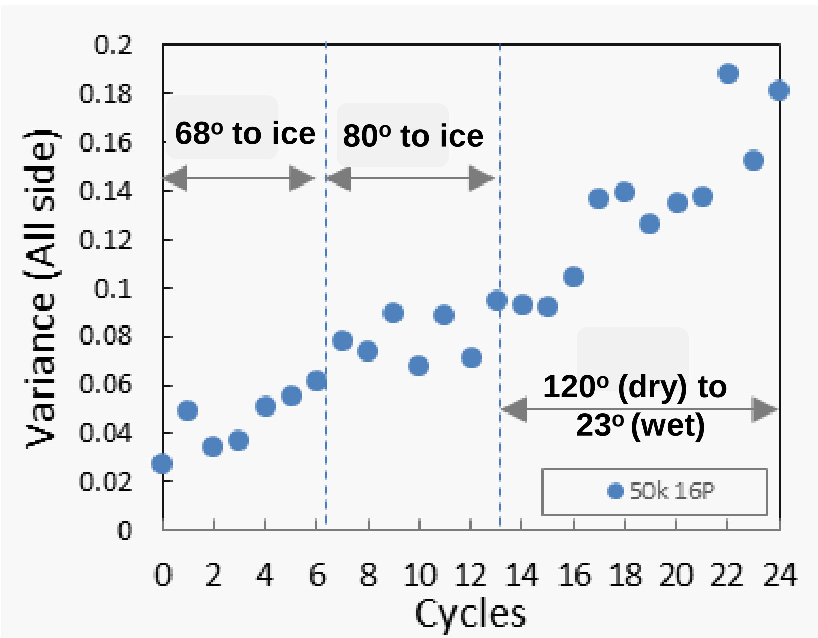
Can we make use of ultrasonic backscatter measurements to characterize distributed damage in concrete using surface waves?



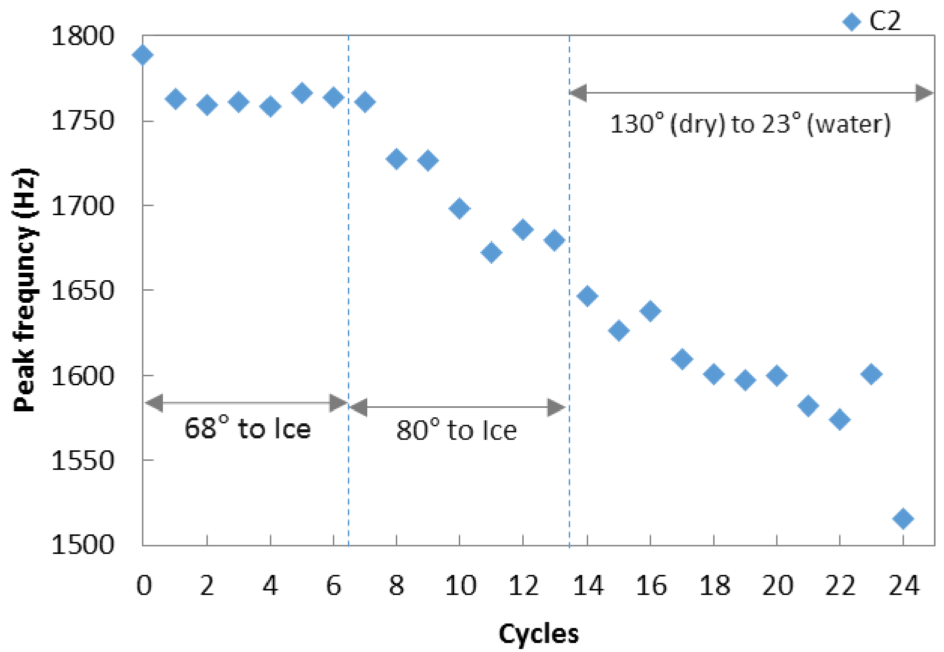
Concrete samples subjected to sets of repeated hot-cold and wet-dry cycles to impart distributed damage



Ultrasonic backscatter and resonant frequency data for concrete samples subjected to many damage cycles



UT Backscattering variance



Standard resonance frequency

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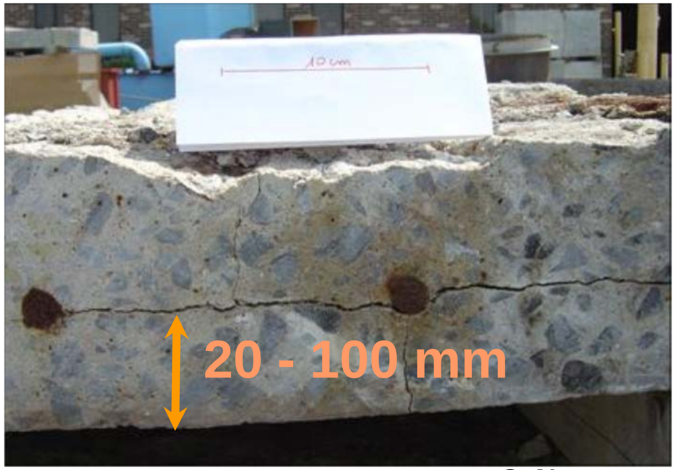
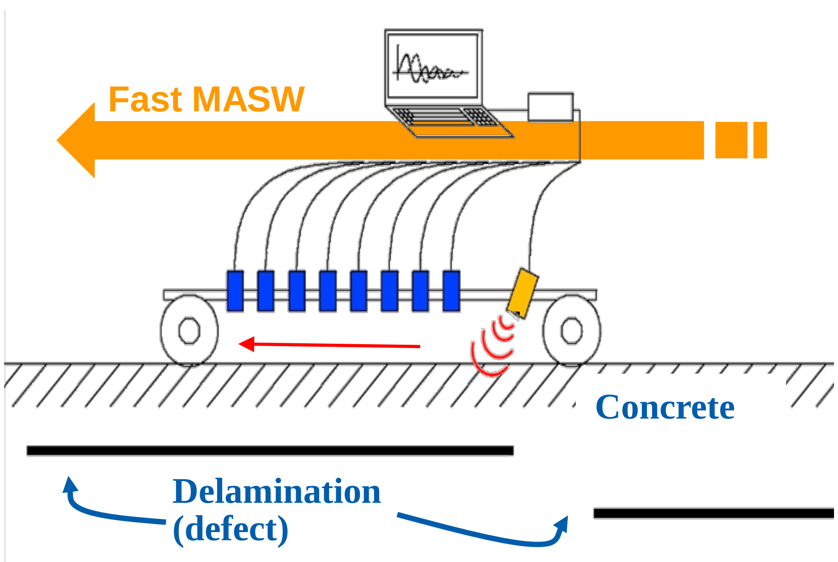
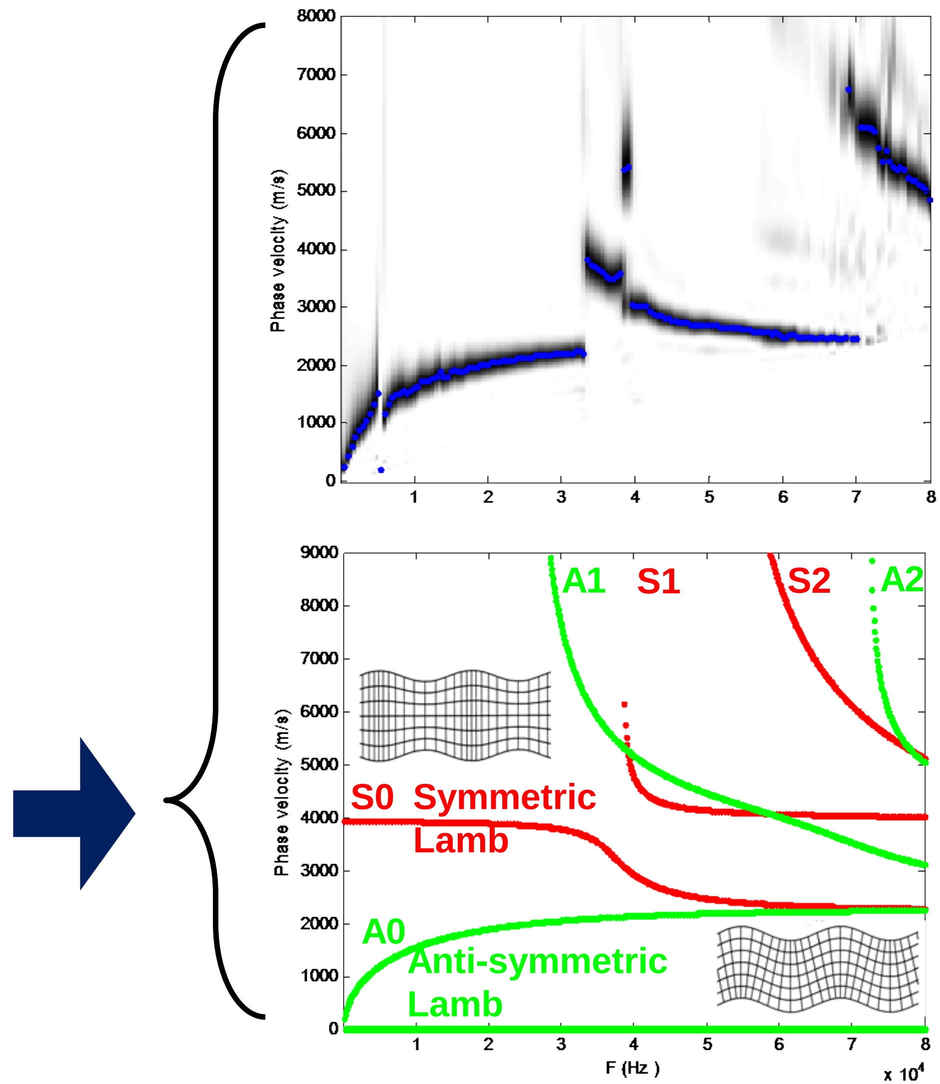
Air-coupled ultrasonic approach to detect delamination in concrete ties using Lamb waves



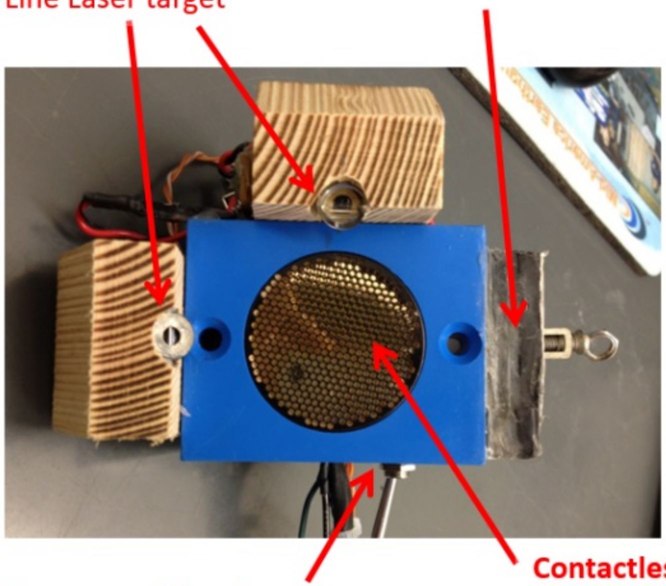
<S. Naar>





Improvement of ultrasonic testing set-up

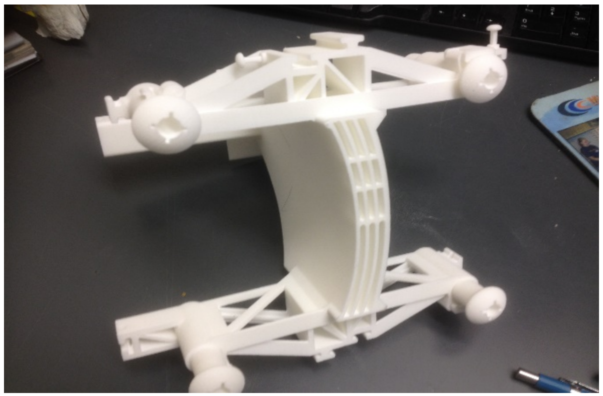
Improved ultrasonic pulse control enables empowered test schemes and data analysis approaches

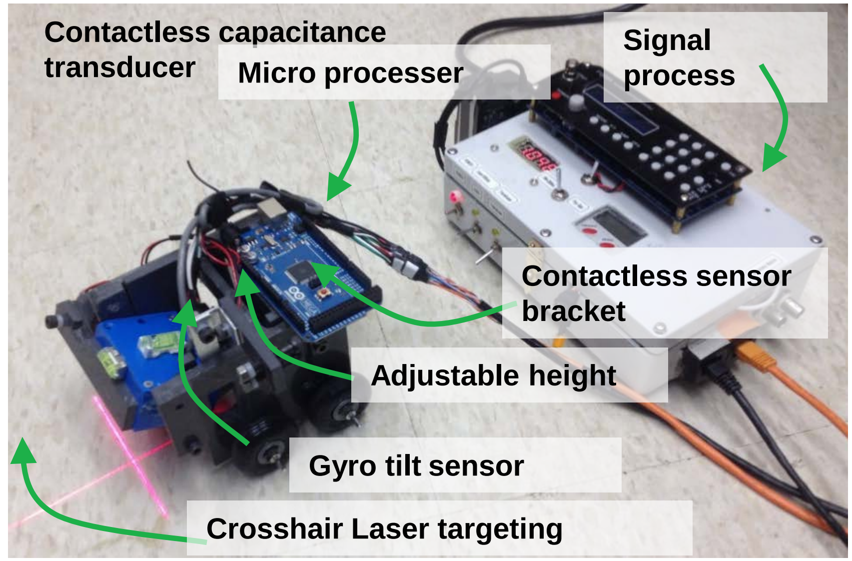


We have improved output amplitude, voltage biasing control, signal to noise ratio and frequency and bandwidth control of input signal for the transmitting transducer

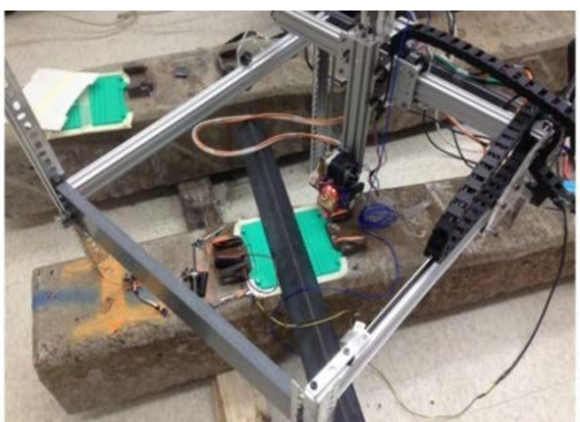
- **Center frequency control between 10-90 kHz**
- **Improved pulse duration and shape control: chirp and tone burst signals now possible**

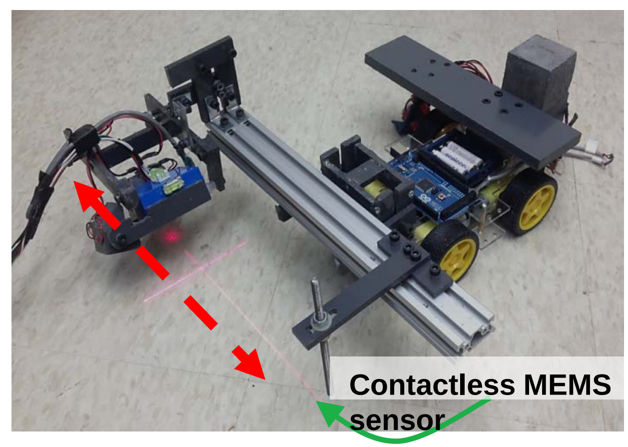
Ultrasonic hardware developments





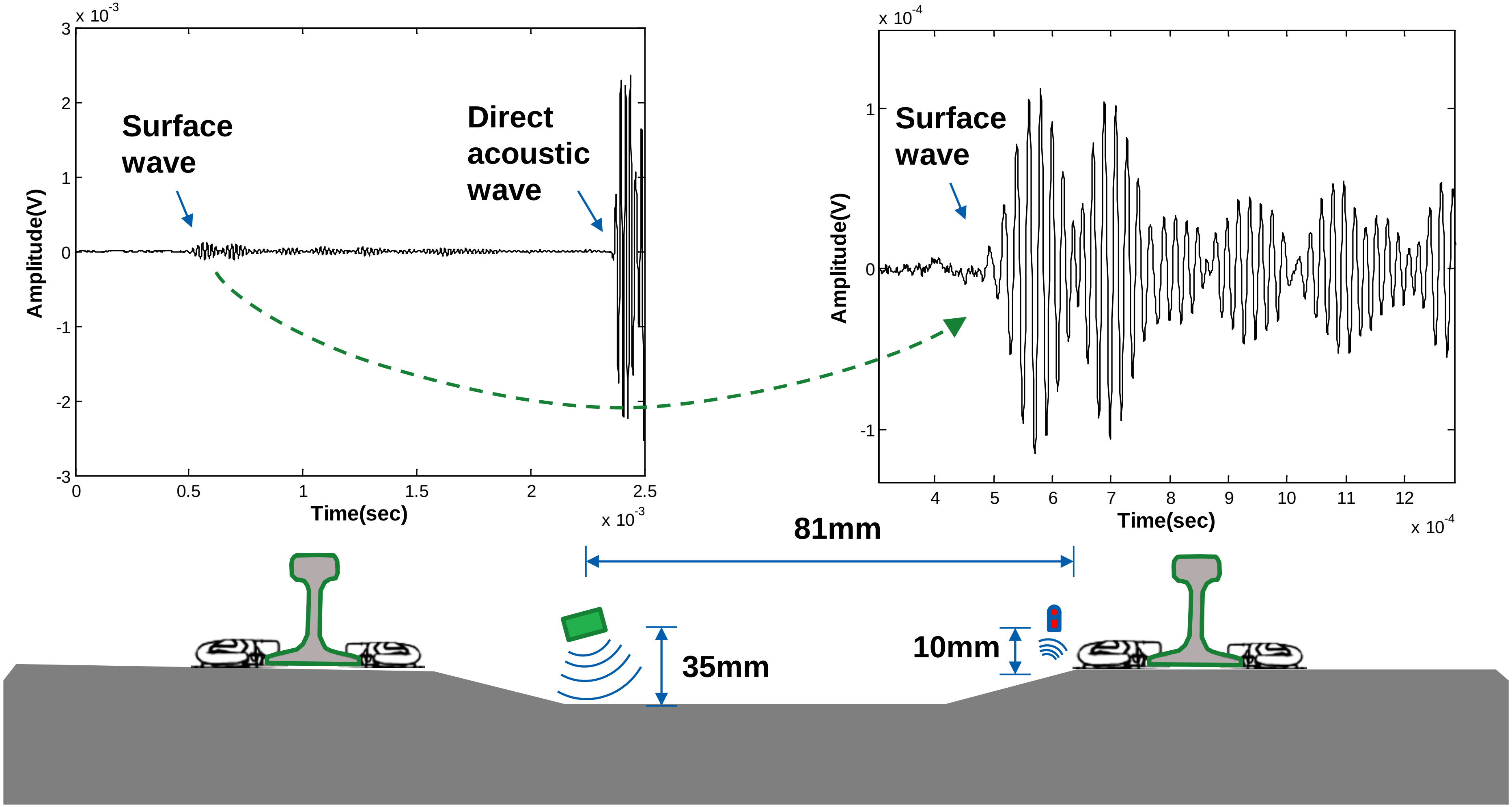
Improved sensor design



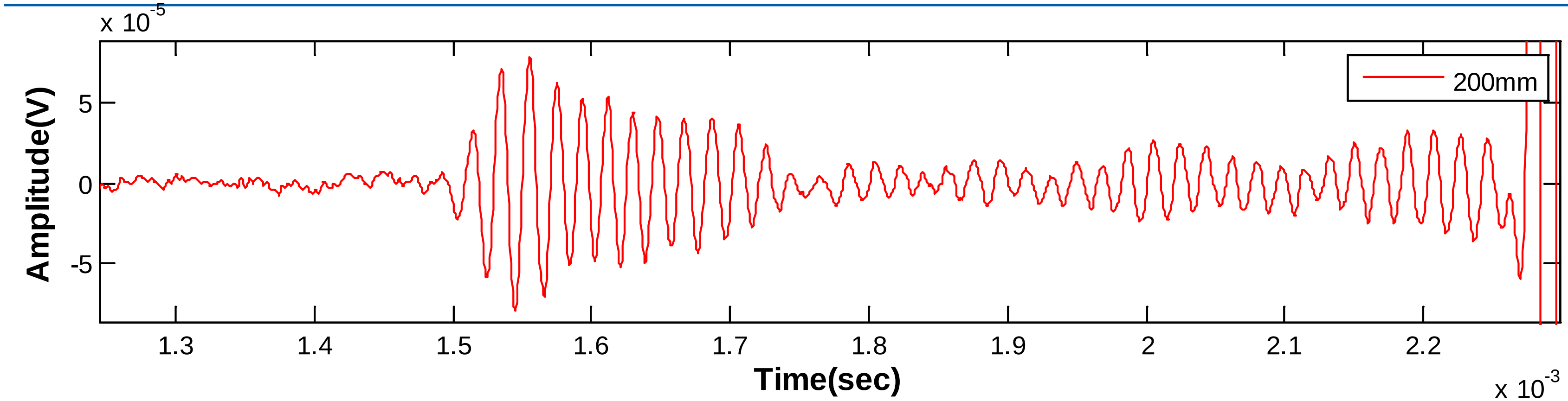


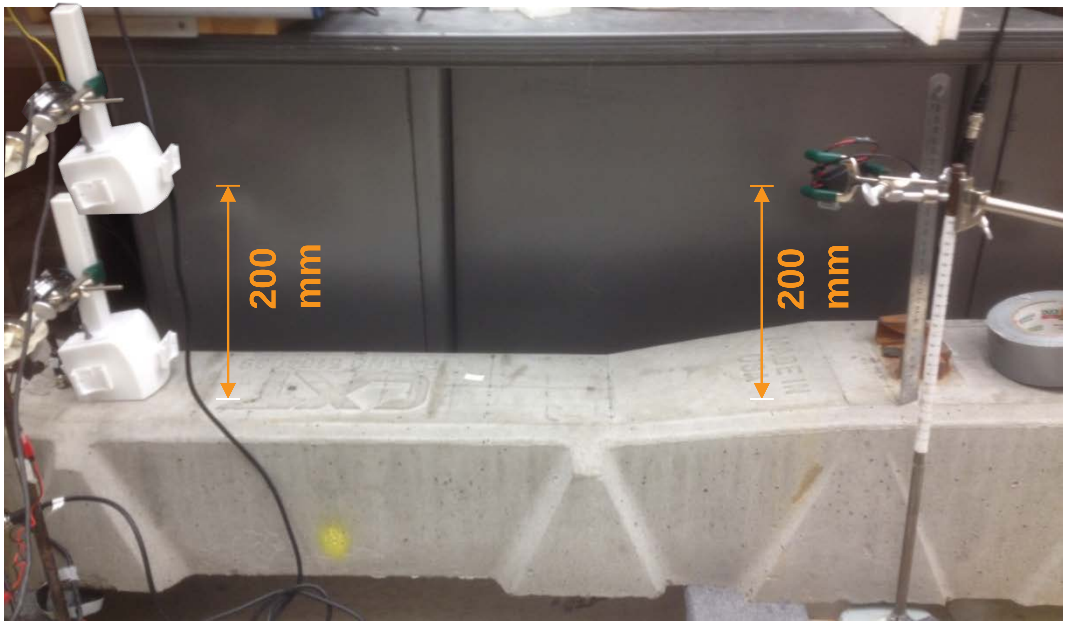
Scanning systems

Increased offset distance between sensors and rail tie is critical for practical application: at least 20 cm (8 inch) offset needed



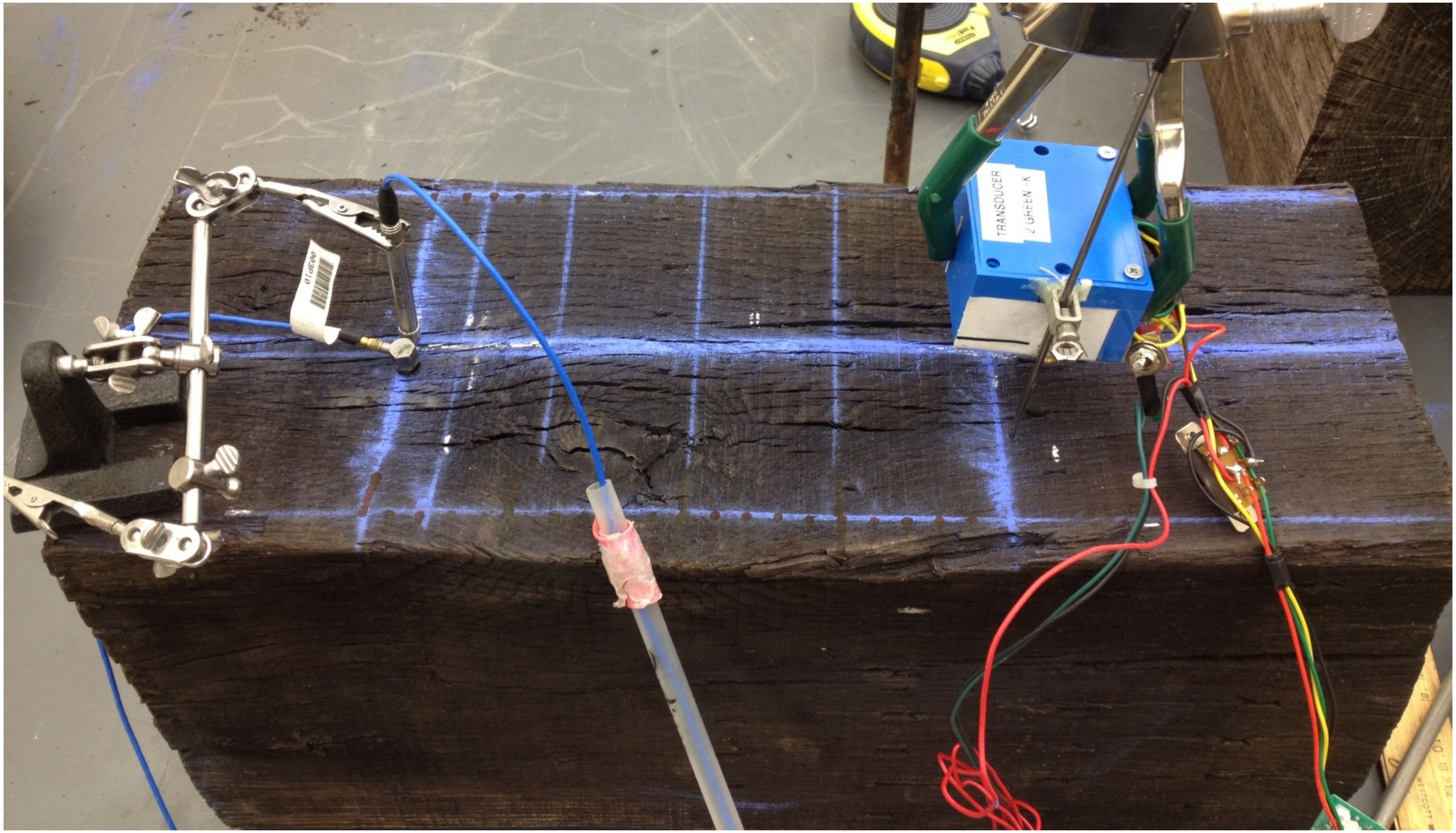
Increased transmitter and receiver offsets yield good surface wave signal. However large lateral spacing may require modification of signal analysis schemes



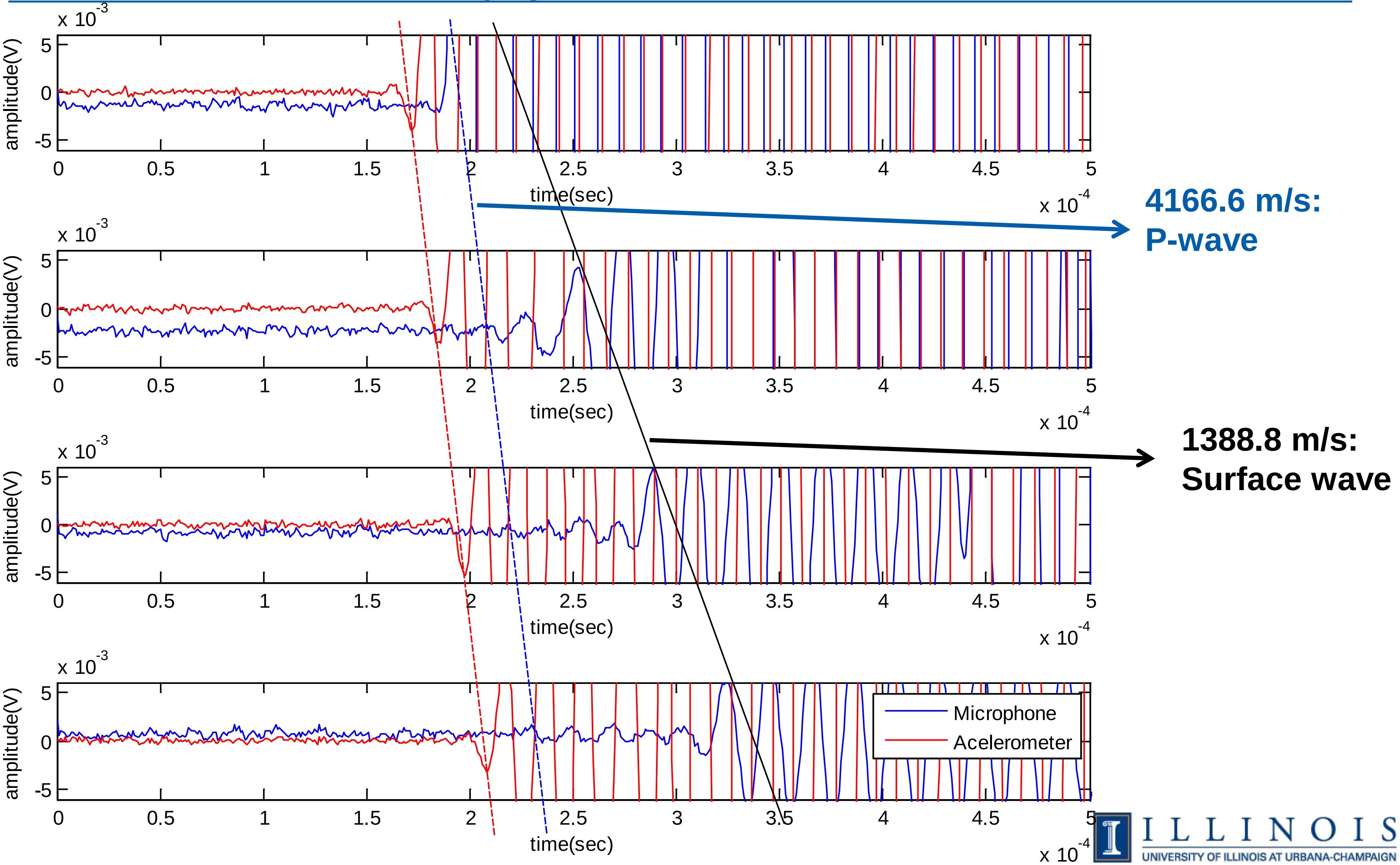


Experimental Results

Optimal (for concrete) air-coupled configuration applied to samples from timber ties. Contact sensor used for comparison



Ultrasonic signals from sound timber across varying distance. 100 times averaging used. Both P-waves and surface waves readily generated in timber.



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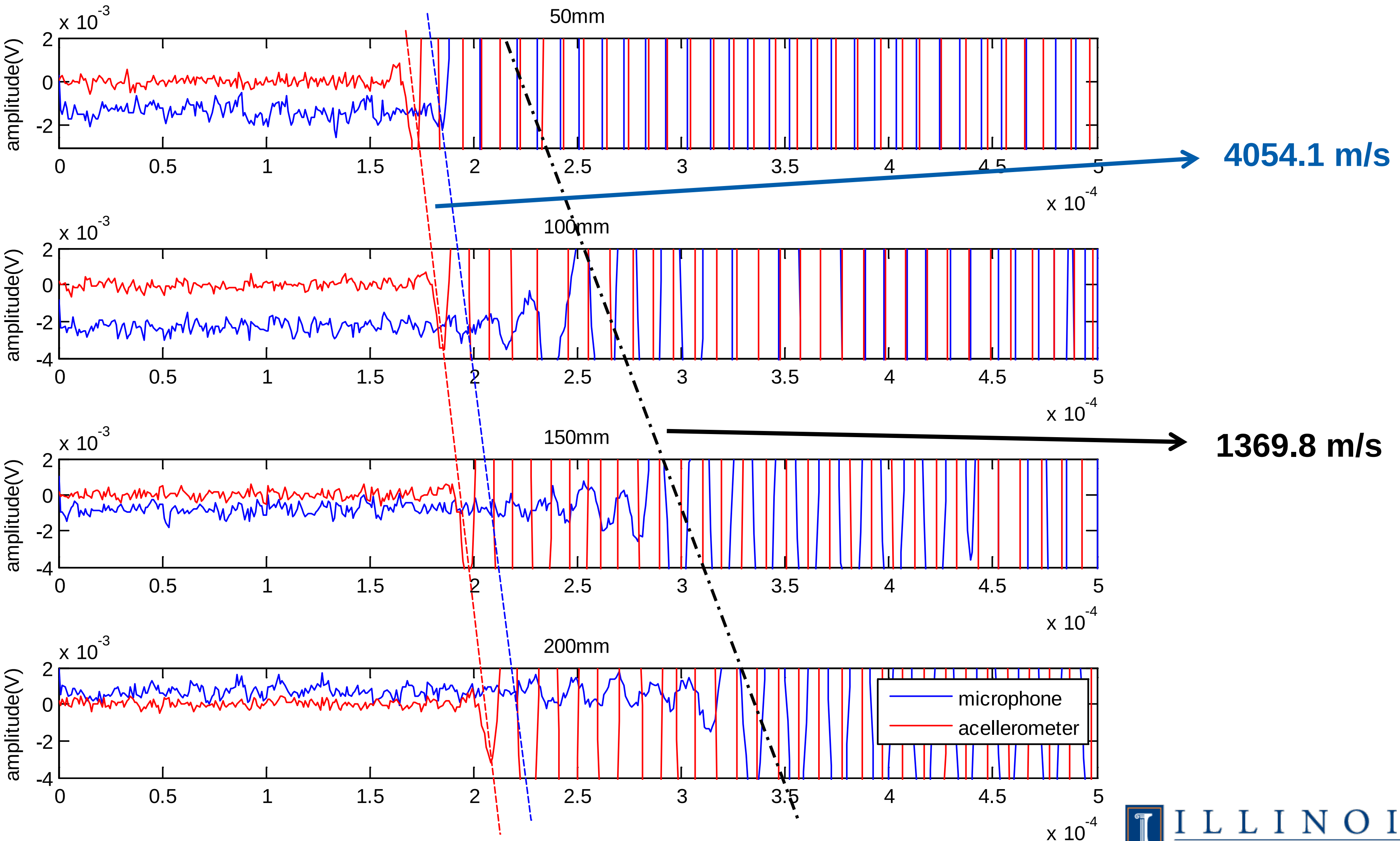
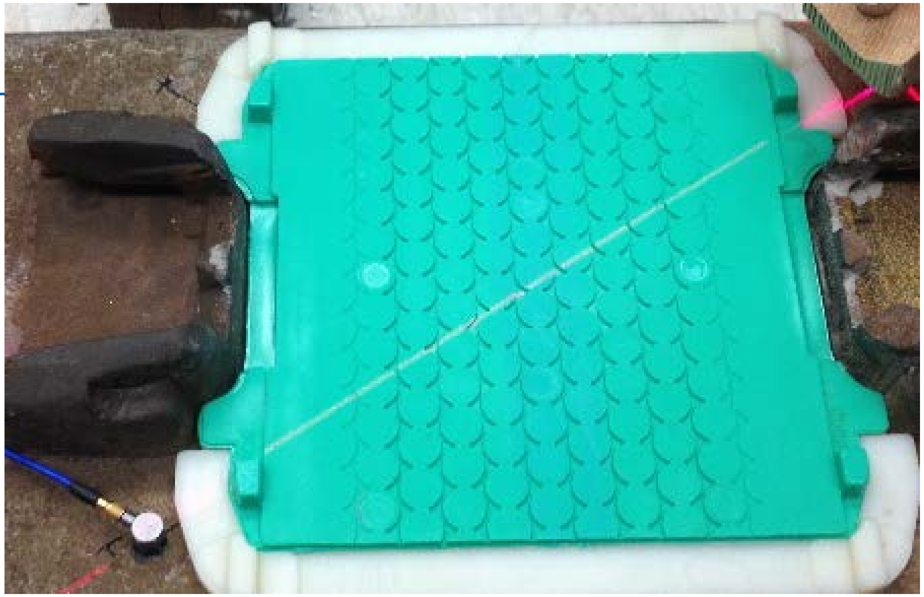
Ultrasonic signals from deteriorated timber across varying distance. 100 times averaging used. Both P-waves and surface waves show distinction of material quality.



Detection of rail seat damage (RSD) in concrete ties

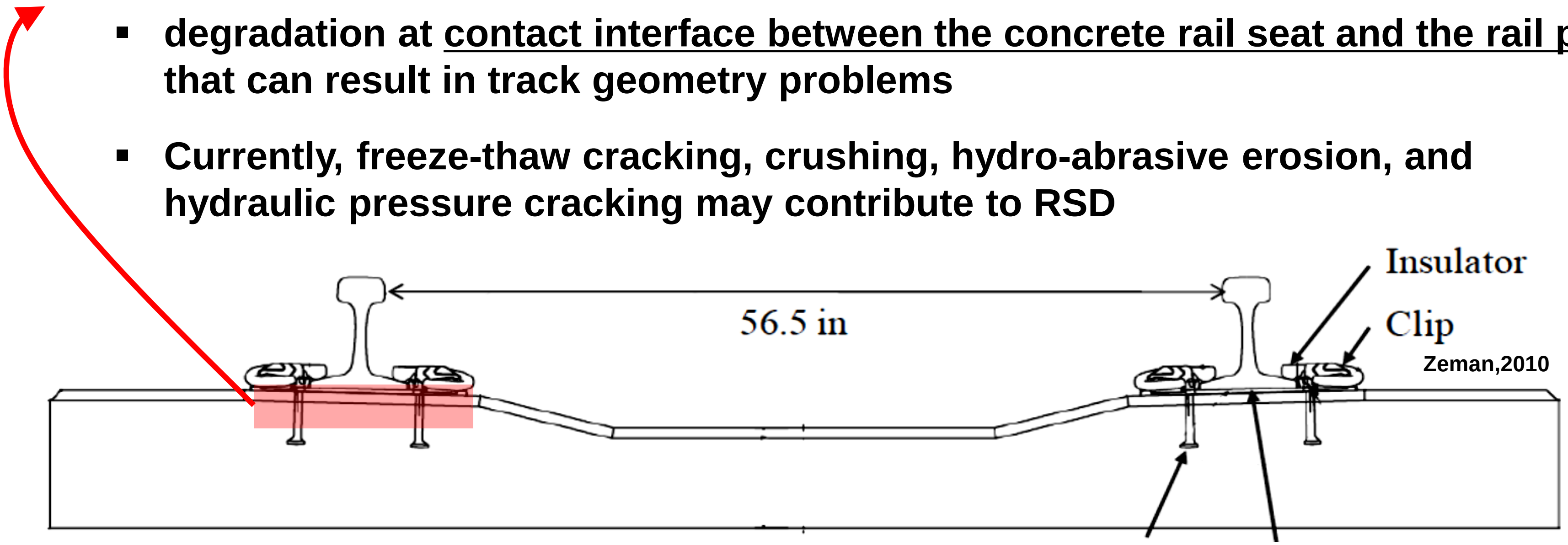
The goal is to develop understanding of inter-relation between damage and surface wave behavior

Rail seat deterioration (RSD)



Zeman,2010

- **degradation at <u>contact interface between the concrete rail seat and the rail pad</u> that can result in track geometry problems**
- **Currently, freeze-thaw cracking, crushing, hydro-abrasive erosion, and hydraulic pressure cracking may contribute to RSD**



Zeman,2010

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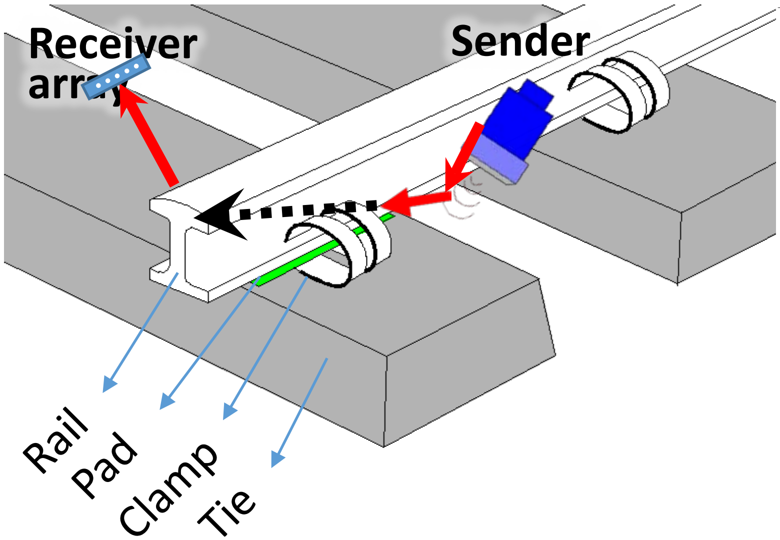
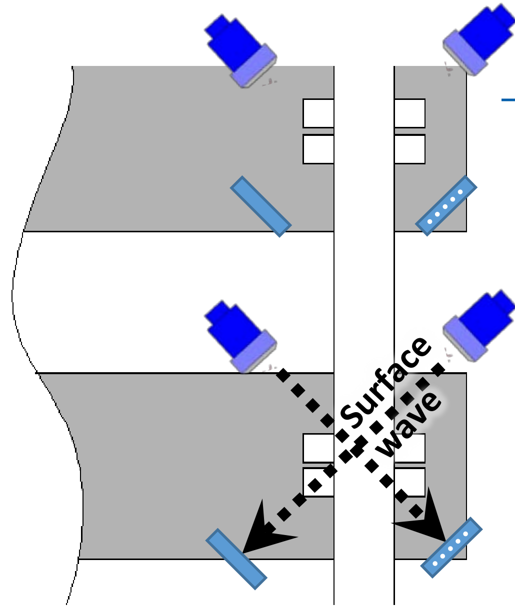
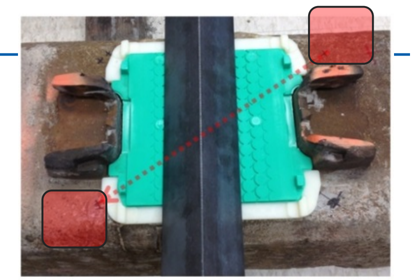
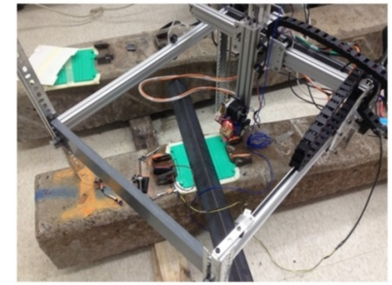
Preliminary RSD testing configuration: small offset









R1 : no damage

R2 : moderate RSD

R3 : serious RSD

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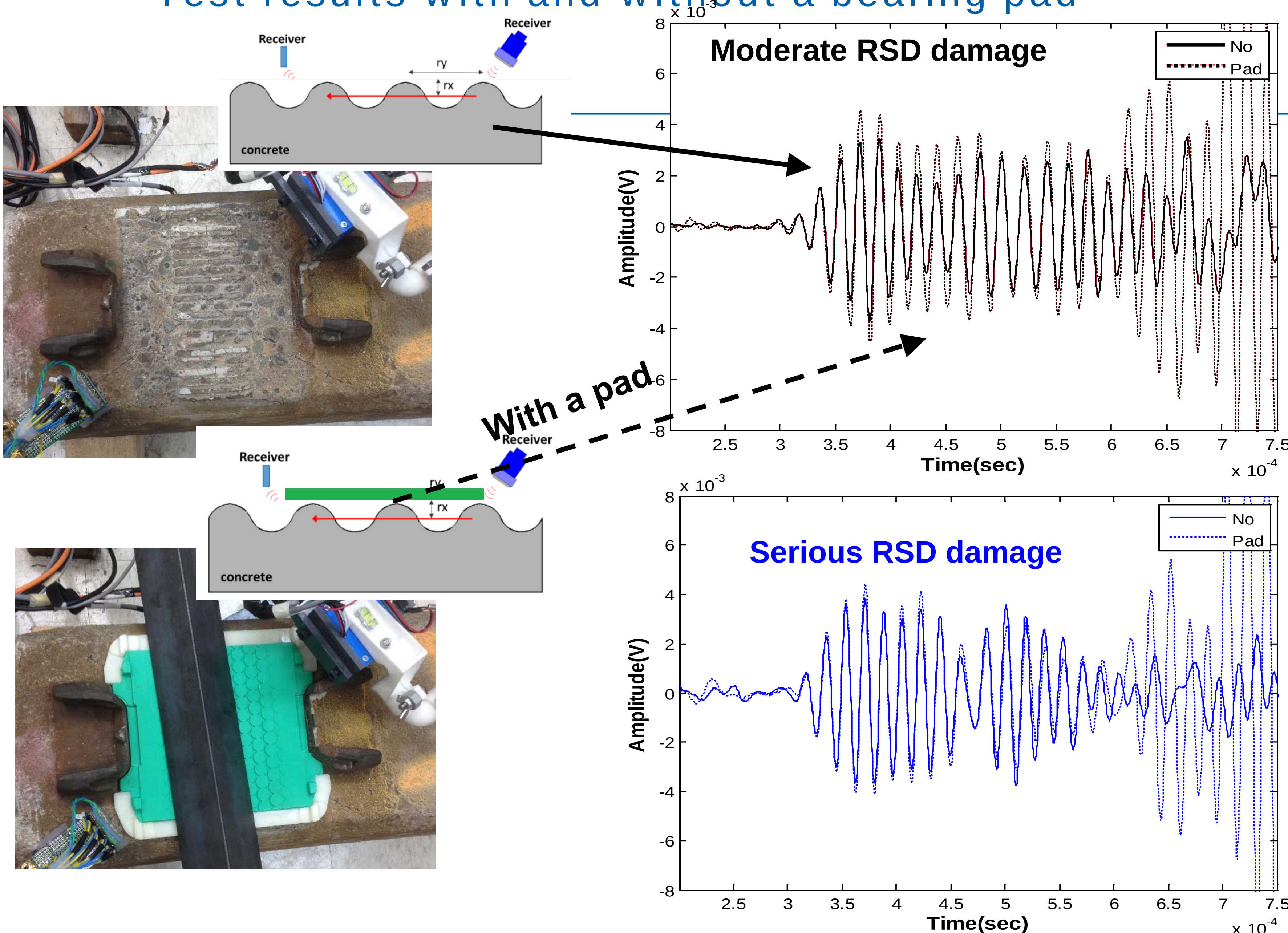
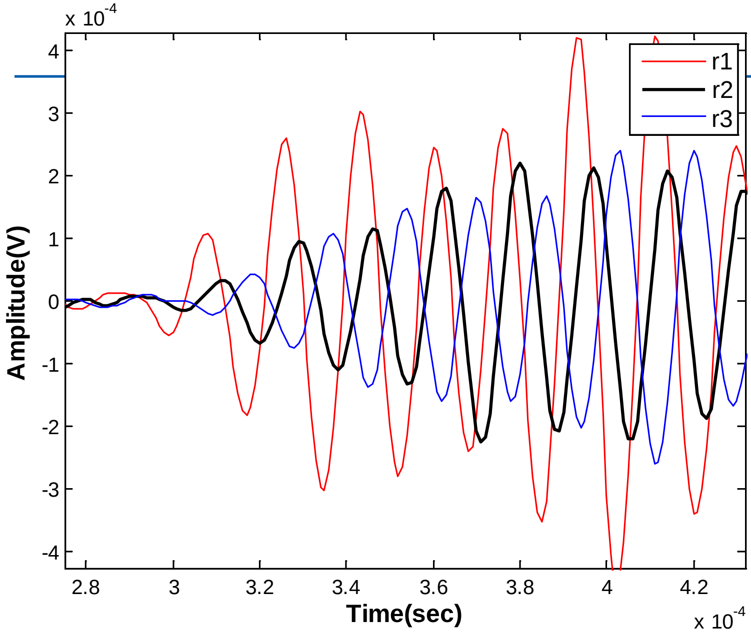
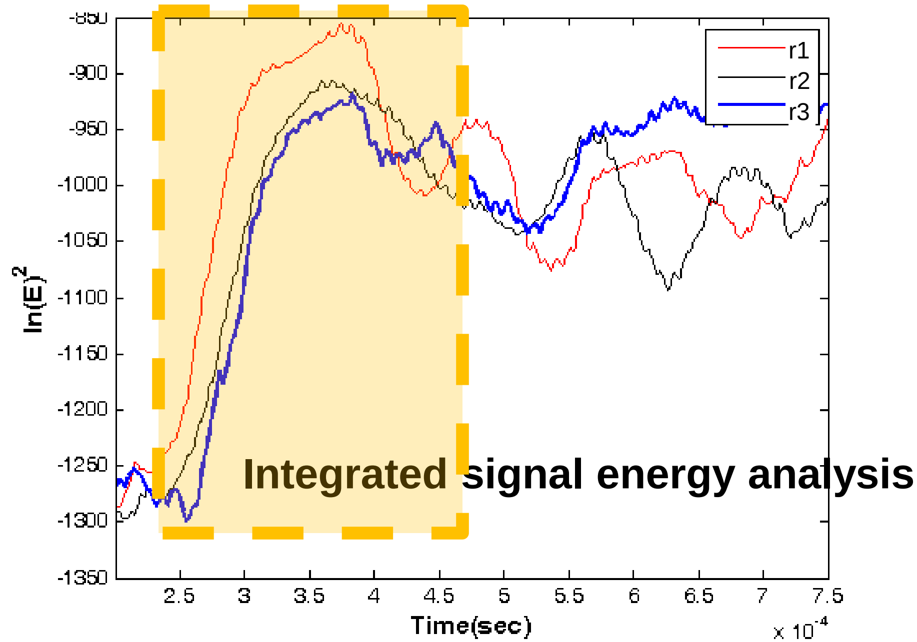
Test results with and without a bearing pad



Are individual signal data reliable?



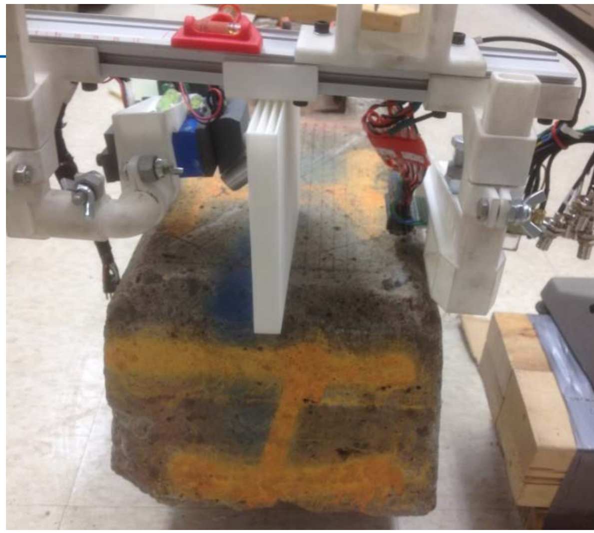


R1

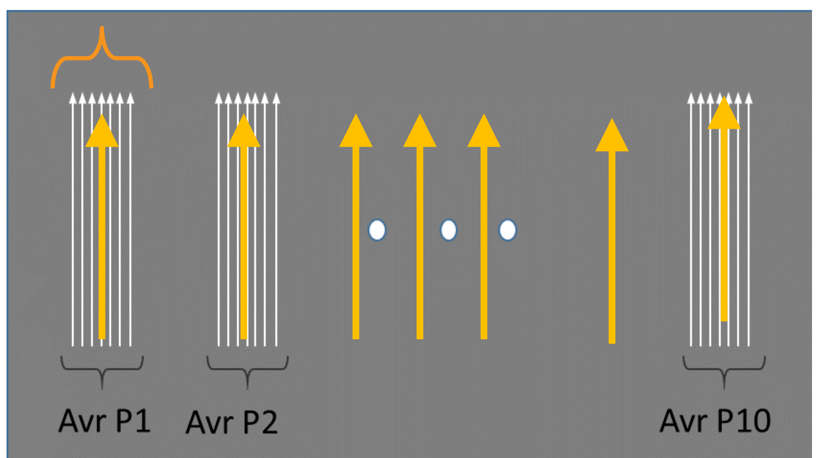
R2

R3

Spatially averaged signals from multi-sensor array



Array averaged = Group = position, p1, p2….



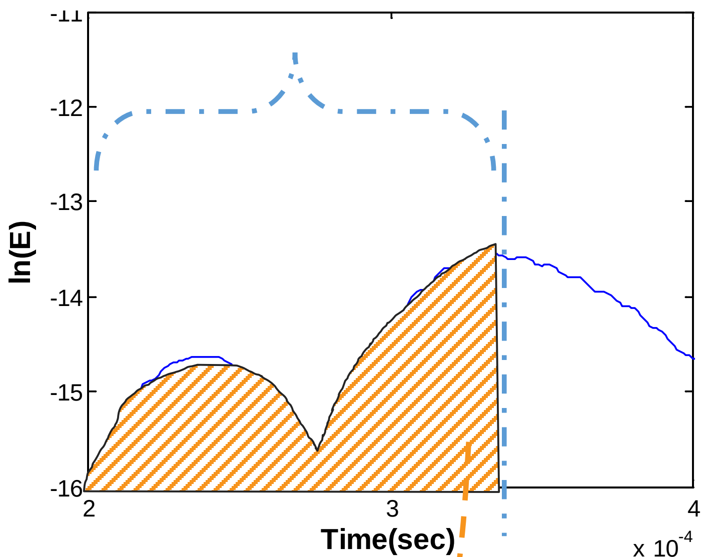
Statistical analysis for inhomogeneous material

$$S_{avr}(t) = \frac{1}{N_{path}} \sum_{y=1}^{N_{path}} T_{avr\_y}(t)$$

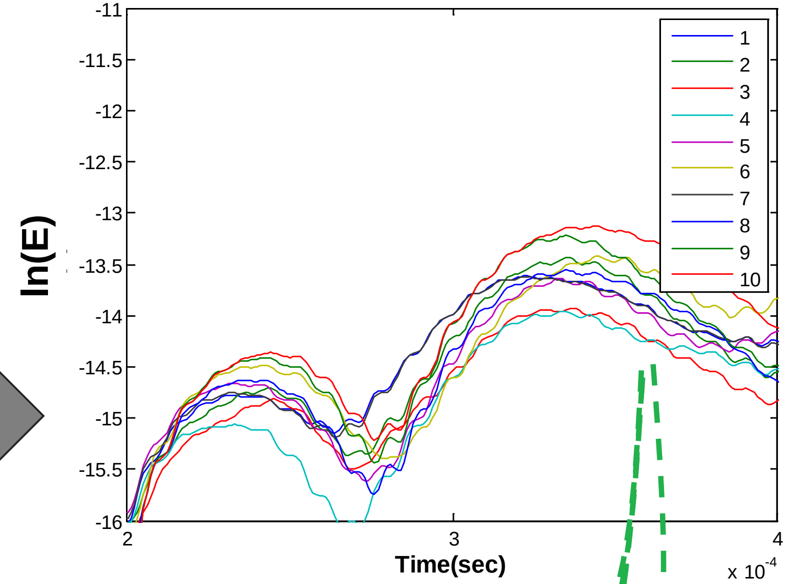
In total seventy signal of each damage region

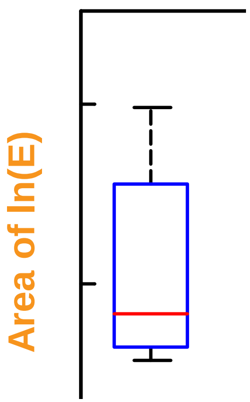
Quantification and statistical interpretation

averaged data on position-1 has 7 signals

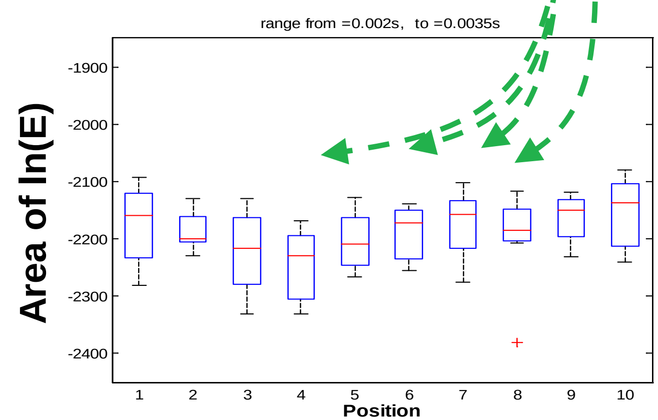


10 different positions

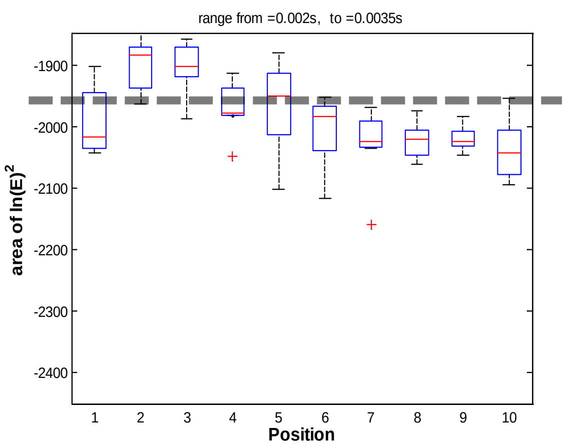


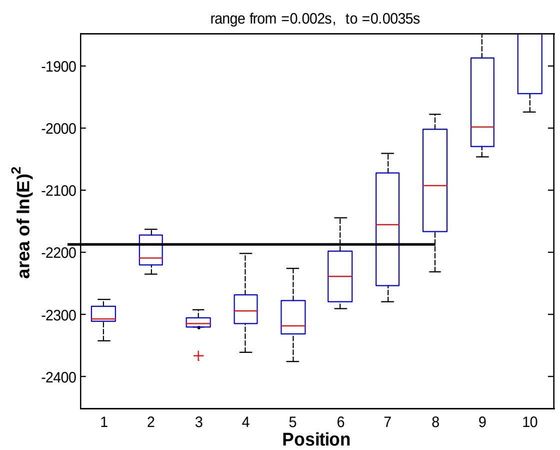


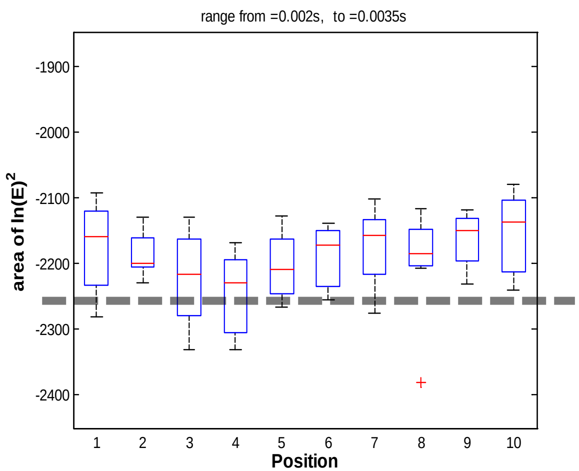
So, a Box plot has <u>seven</u> array signals



Statistical interpretation of test data shows distinction only of most severe RSD damage







R1

R2

R3

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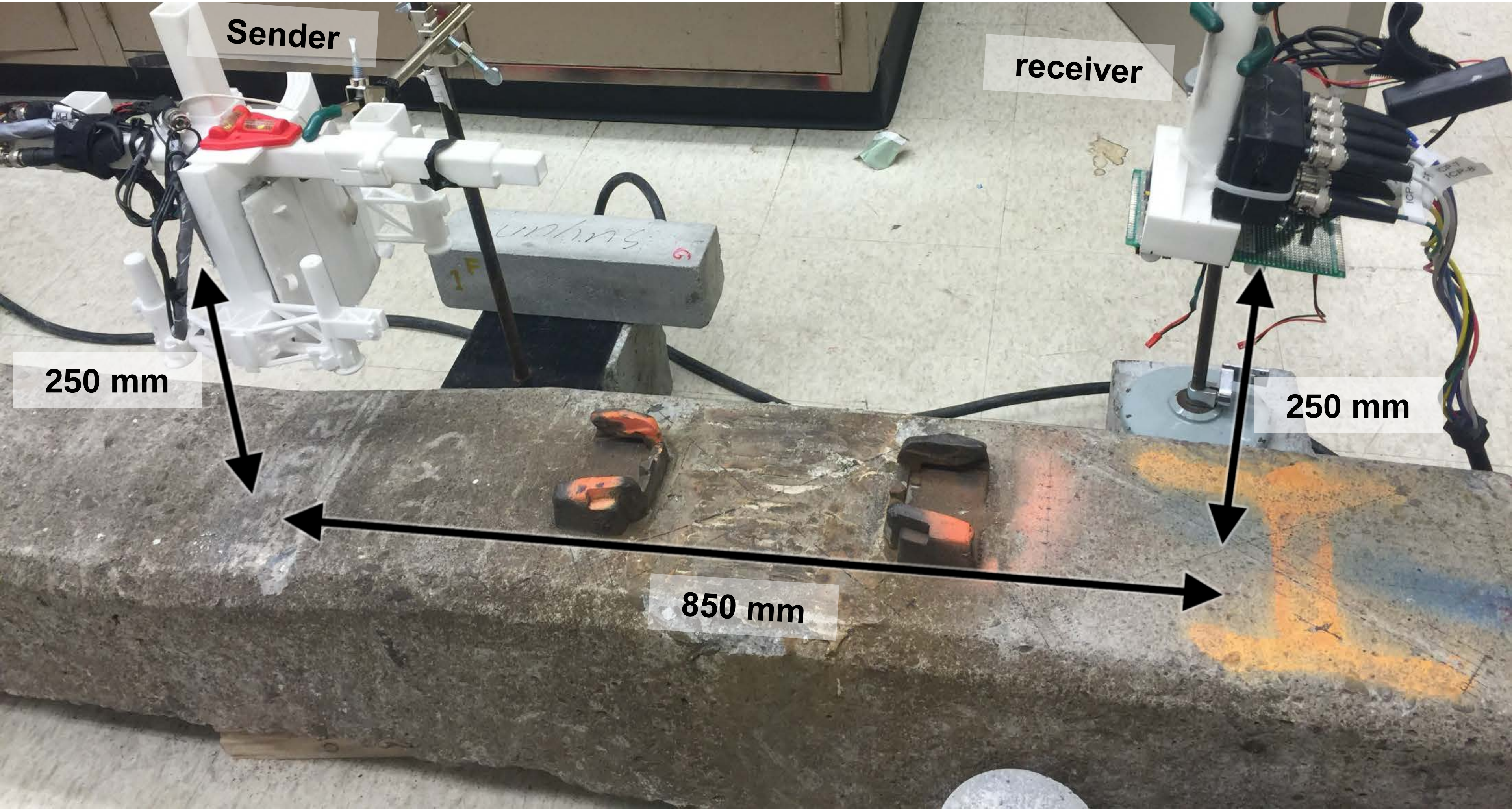
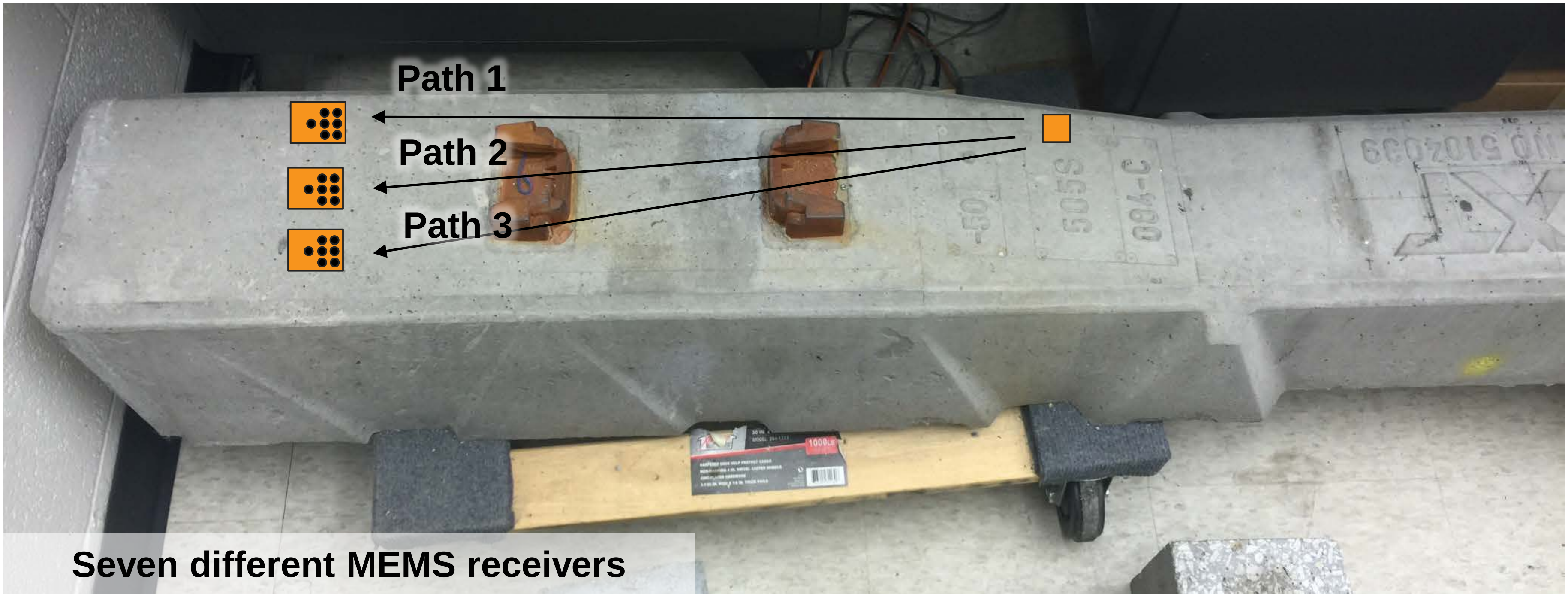
Follow on RSD testing configuration: large offset

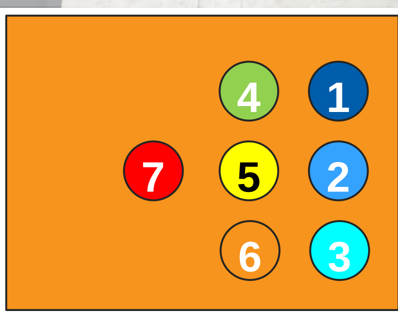
Testing configuration



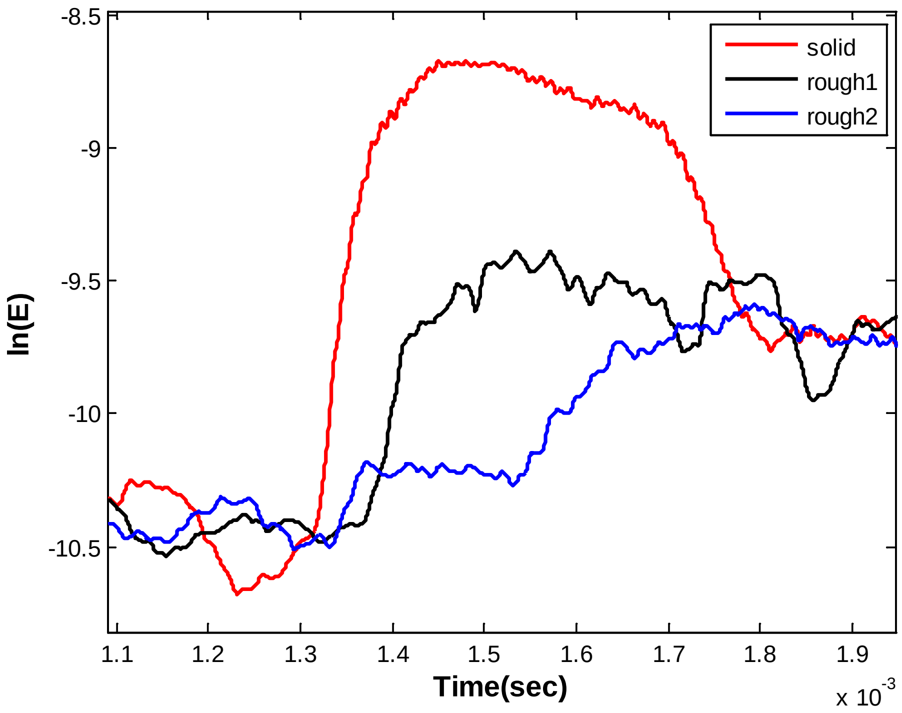
Ultrasonic ray paths and sensor configuration



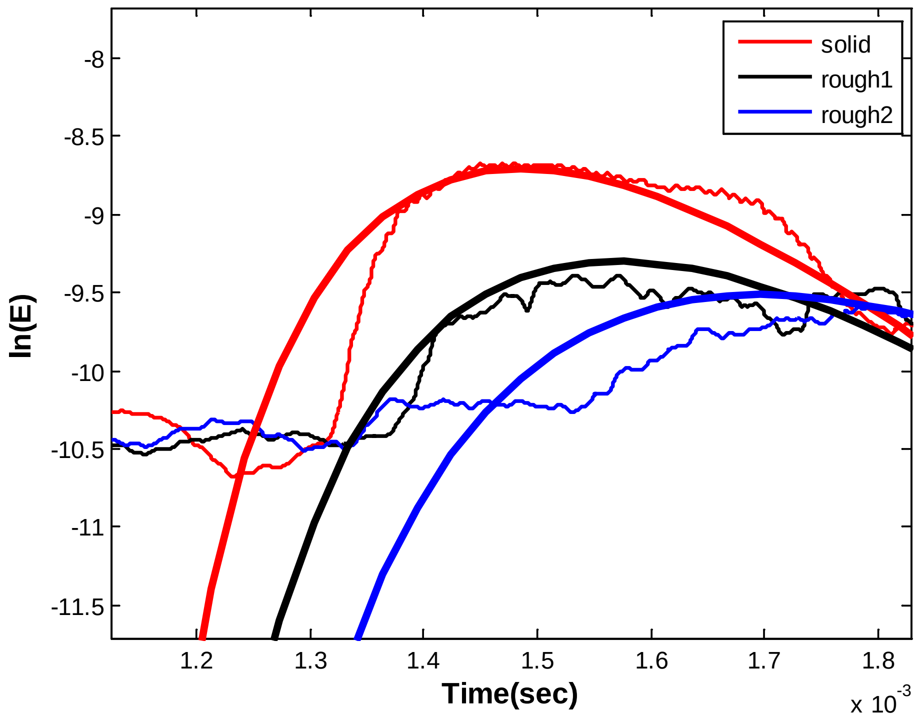
Seven different MEMS receivers



Energy envelope data collected along path 1 shows clear distinction between damage extent levels



Raw energy envelope data



Envelope data with diffusion fits

Future work

Optimize data analysis/evaluation schemes

- **Develop schemes to target tie regions rather than specific defects, providing overall tie heath index**

Test prototype development and evaluation

- **Incorporate hardware in moving test platform**
- **Evaluate on in-place ties**

Acknowledgments

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