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SIMULATION OF NDT INSPECTIONS IN 3D ELASTIC WAVEGUIDES INVOLVING ARBITRARY DEFECTS

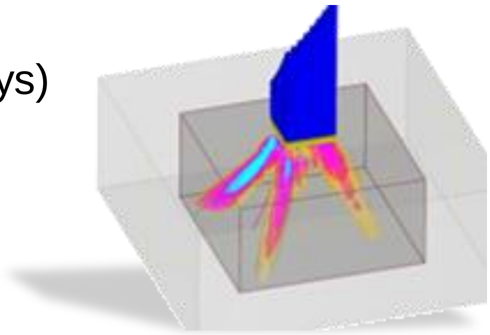
WCNDT 2016 | Jezzine Karim

- *Context: CIVA GWT*
- *Hybrid SAFE-FE modelling*
- *Numerical validations on circular cylinders*
- *Application to square rods / rail inspections*
- *Conclusions & Perspectives*

CIVA: NDT SIMULATION SOFTWARE

WHY USING SIMULATION IN NDT?

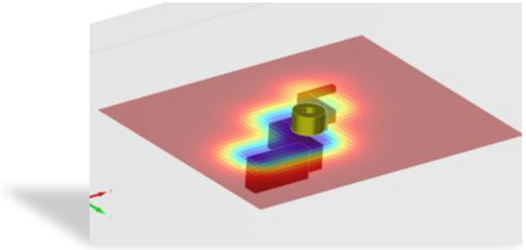
- Design of new methods and probes (e.g. phased arrays)
- Qualification of methods, performance demonstration
- Interpretation of complex results, diagnosis
- « Virtual testing » in product design phases
- Training



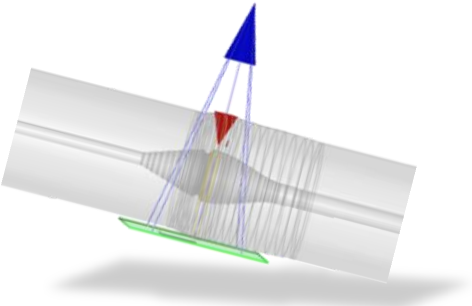
UT : Transmitted beam computation

CIVA: SIMULATION FOR NDT

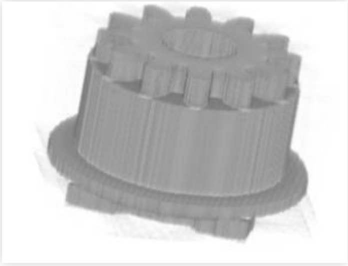
- Multi-technique platform: UT, ET, RT-CT… Guided Waves (since 2012)
- Experimental validation within international benchmarks



ET : 2D map of a complex defect



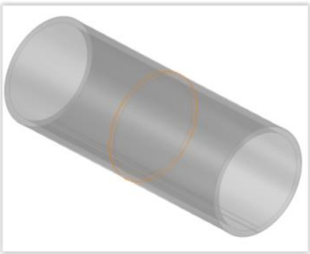
RT : weld inspection

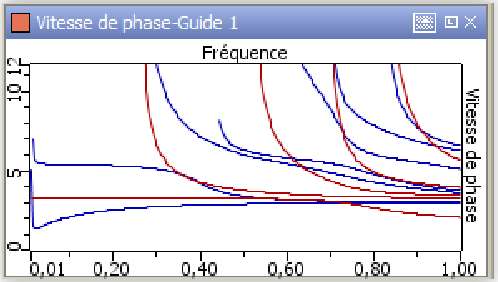


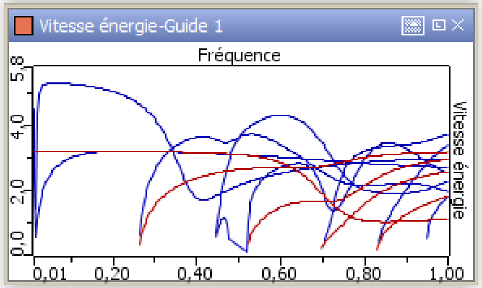
CT : tomographic reconstruction of complex parts

PRESENTATION OF CIVA GWT (1/2)

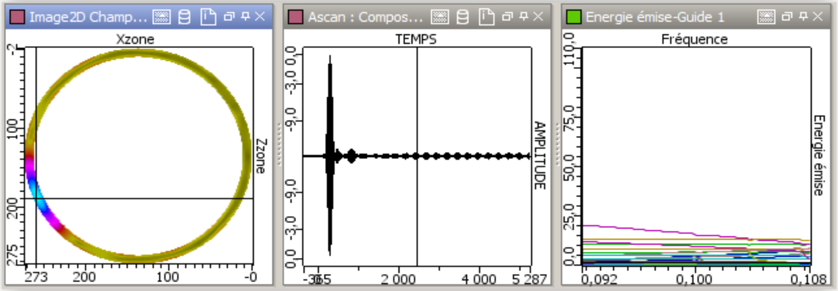
1) Knowledge of modes propagating in a waveguide *(modes computation)*



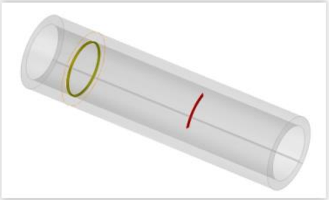


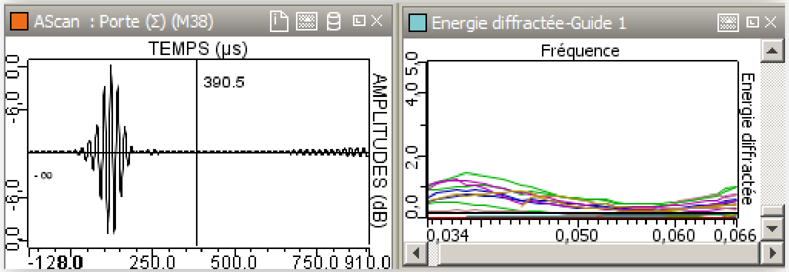


2) Knowledge of the beam emitted by an ultrasonic transducer *(beam computation)*



3) Knowledge of the response of a defect *(inspection simulation)*





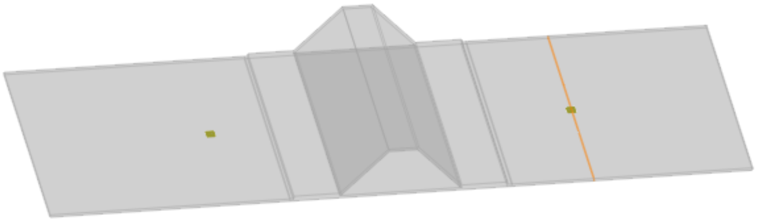
PRESENTATION OF CIVA GWT (2/2)

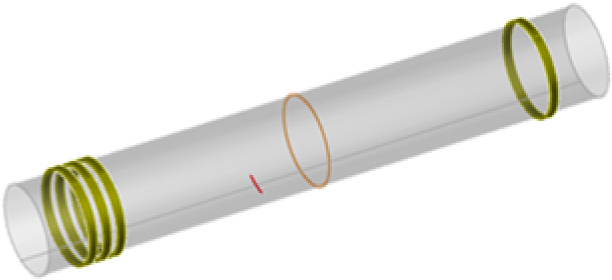
SPECIMENS

- Plates (with weld, groove or CAD defined junction) *[2D computation: Lamb/SH wave]*
- Pipes/cylinders *[2D and 3D computation]*
- Arbitrary CAD defined waveguide cross-section (eg. Rail) *[3D computation]*

MATERIALS

- Isotropic solid (anisotropic in development version)
- Inner fluid in pipes
- Attenuation law: linear with frequency



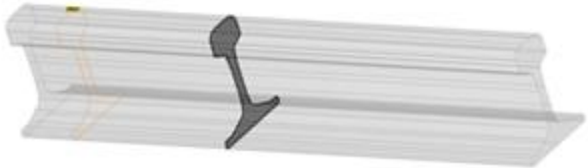


TRANSDUCERS

- Contact with or without wedge
- Encircling/encircled probes (phased arrays)
- EMATs
- Different type of solicitations
- Pulse-echo/pitch-catch configurations

FLAWS

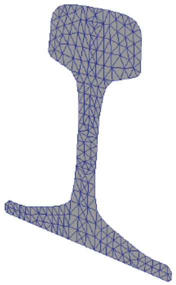
- Cracks, FBH, spherical,…
- CAD defined



MODELLING APPROACH: MODE COMPUTATION

Mode computation with the Semi-Analytical Finite Element method

(discretization of the guide section with finite elements)

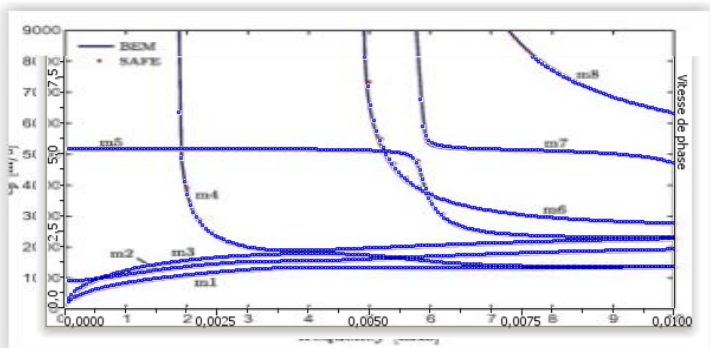


CIVA mesh
169 elements P2
1188 dof

$$(\mathbf{K}_1 - j\beta\mathbf{K}_2 + \beta^2\mathbf{K}_3)\mathbf{d} - \omega^2\mathbf{M}\mathbf{d} = 0$$

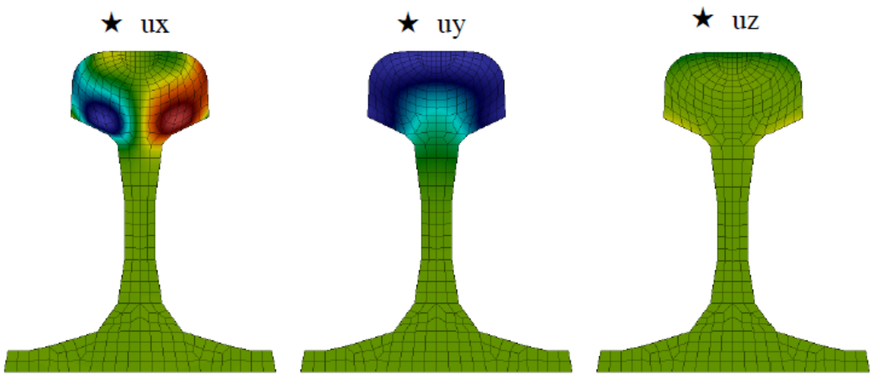
- Eigenvalues: wavenumbers
- Eigenvectors: modal displacement

Phase velocity



Frequency

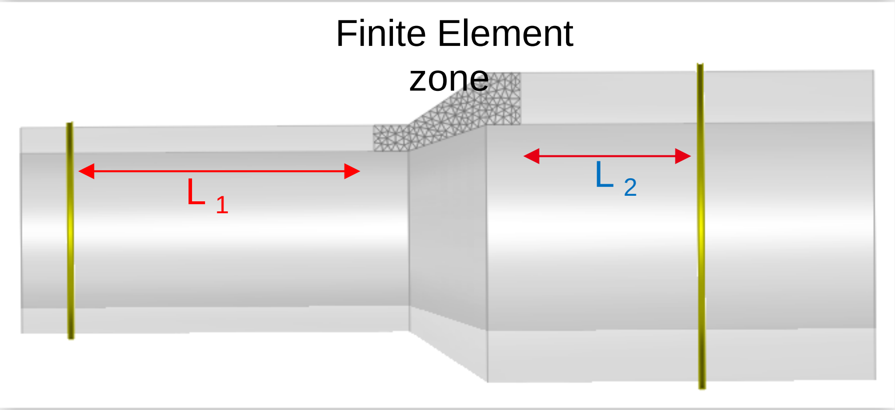
- CIVA
- *Mazzotti et al. (2013)*
  (1496 elements P1, 2505 dof)

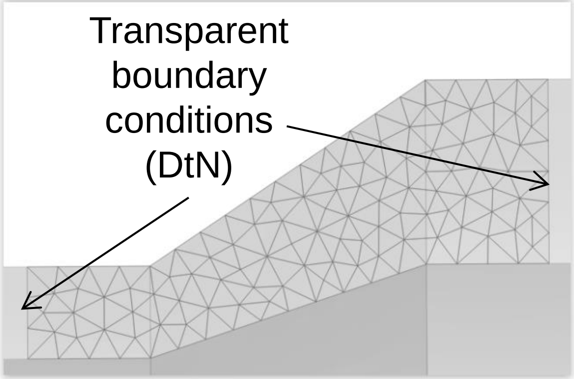


Modal displacements

HYBRID MODAL/FE MODELLING

Use of **modal decomposition** in regular parts of waveguides and **Finite Elements** in perturbation zones (V. Baronian PhD thesis, 2009)





$$s(\omega) = -j\omega \sum_{n\in\mathbb{N}} \sum_{m\in\mathbb{N}} A_m^e(\omega) e^{-j\beta_m(\omega)L_1} \; S_{nm}(\omega) \, A_n^r(\omega) \, e^{-j\beta_n(\omega)L_2}$$

Modal amplitudes (emission) ~Green function

Modal diffraction matrix

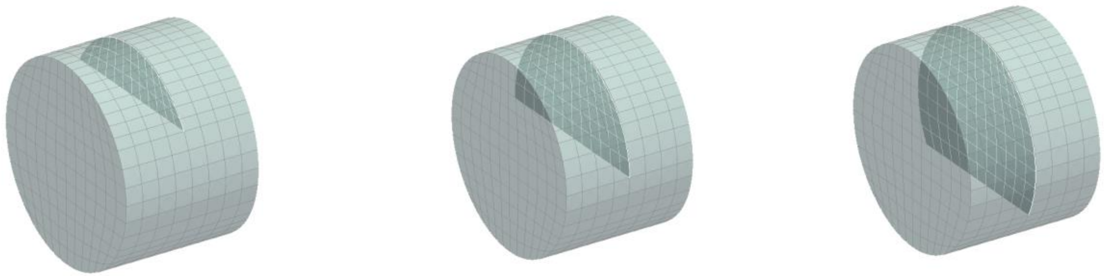
Modal sensitivity of Receiver

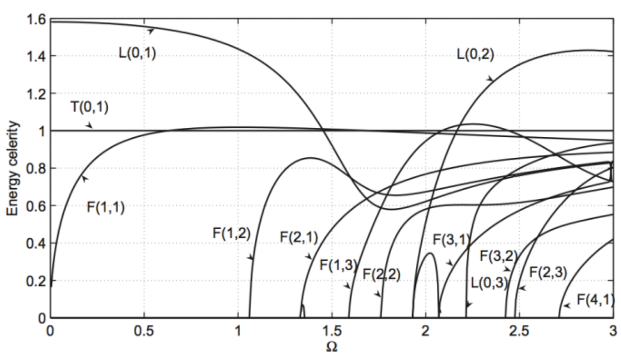
Use of Inverse Fast Fourier Transform to obtain signals in the time domain

- Context: CIVA GWT
- Hybrid SAFE-FE modelling
- Numerical validations on circular cylinders
- Application to square rod / rail inspections
- Conclusions & Perspectives

CRACKS OF DIFFERENT DEPTHS IN CIRCULAR CYLINDERS

F. Benmeddour, F. Treyssède, L. Laguerre, **Numerical modeling of guided wave interaction with non-axisymmetric cracks in elastic cylinders (2011)**





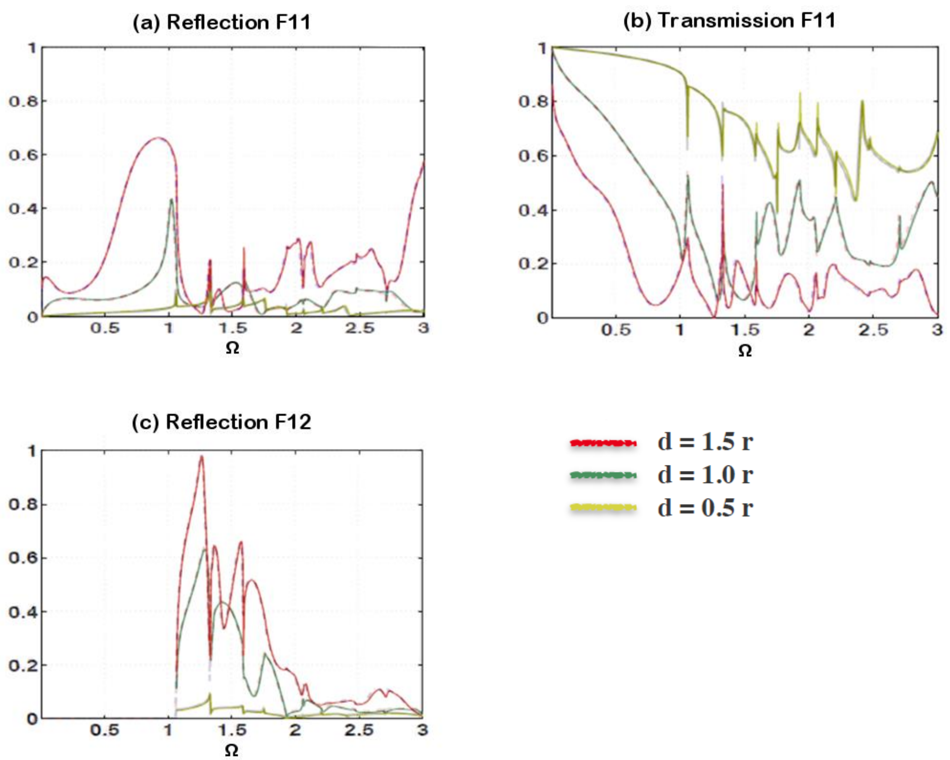
Materials properties:

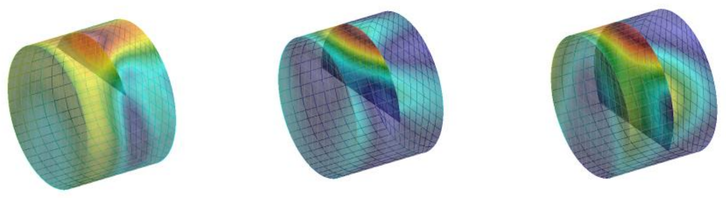
- radius r = 10 mm
- Poisson coefficient ν = 0.25
- density ρ = 7800 kg/m3
- Young modulus E = 2e11 Pa
- dimensionless frequency is $\Omega = \omega\ (r/cL)$

CRACKS OF DIFFERENT DEPTHS IN CIRCULAR CYLINDERS

Power Reflection/Transmission for the F11 (flexural) incident mode:

Excellent agreement with *Benmeddour et al.* results





d= 0.5r *d= r* *d= 1.5r*

- Sharp variations at cut-off frequencies
- Very little reflection for the smallest crack

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- ***Application to square rods / rail inspections***
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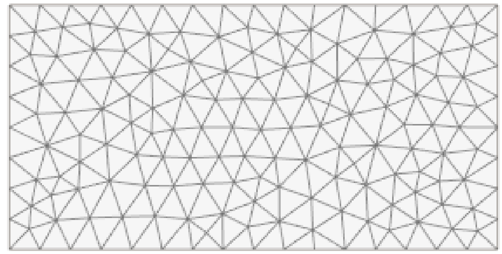
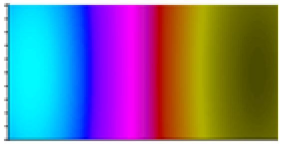
SIMULATION OF RECTANGULAR RODS INSPECTIONS (1/2)

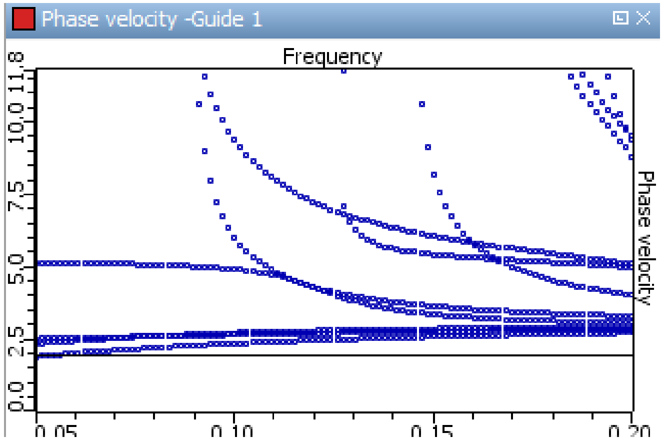
Steel rectangular rod (10 x 20 mm)

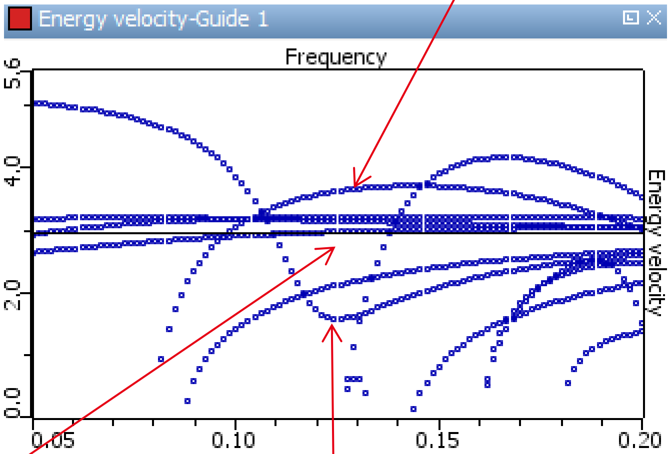




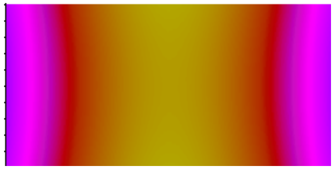
Axial displacement
(flexural mode)

Dispersion curves (50 kHz to 200 kHz)





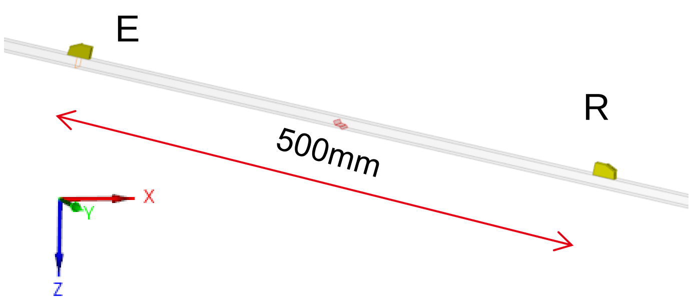
Axial displacement
(torsional mode)

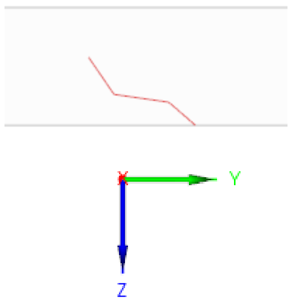


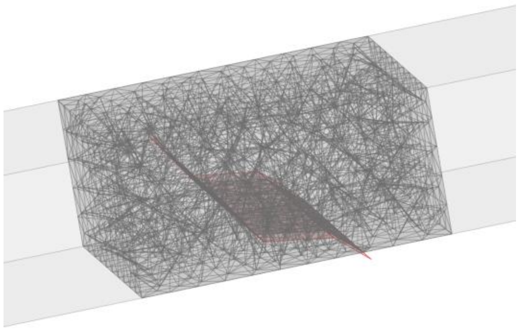
Axial displacement
(extensional mode)

SIMULATION OF RECTANGULAR RODS INSPECTIONS (2/2)

Multi-faceted flaw

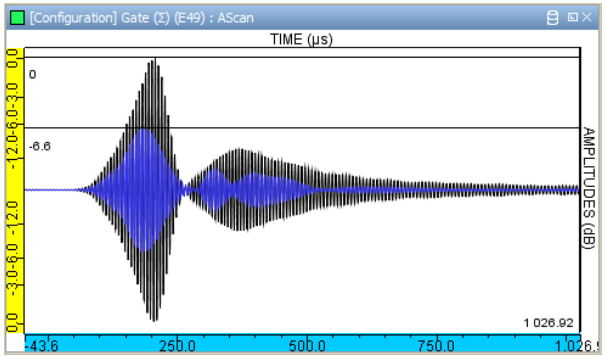






~5100 nodes

- f_{exc} ~160kHz
- bw ~ 10%



Safe rod

Cracked rod

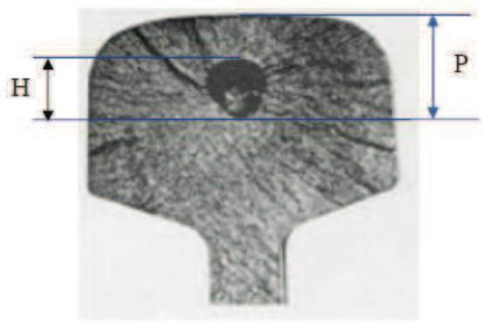
SIMULATION OF RAIL INSPECTIONS

Natural candidate for GW inspection

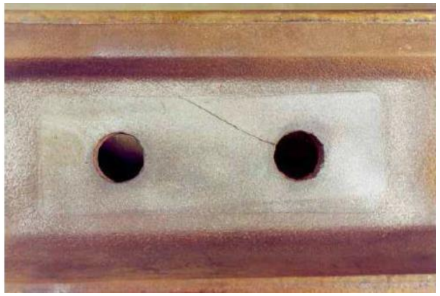
(a large length of rails can be inspected from a single position)

Typical defects

- shelling (head)
- transverse cracks (head)
- longitudinal cracks (head or web)
- corrosion
- defective welds



Transverse crack in head

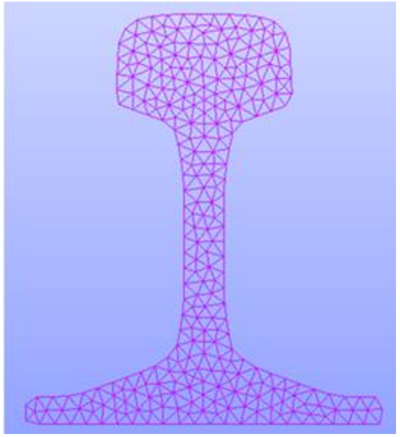


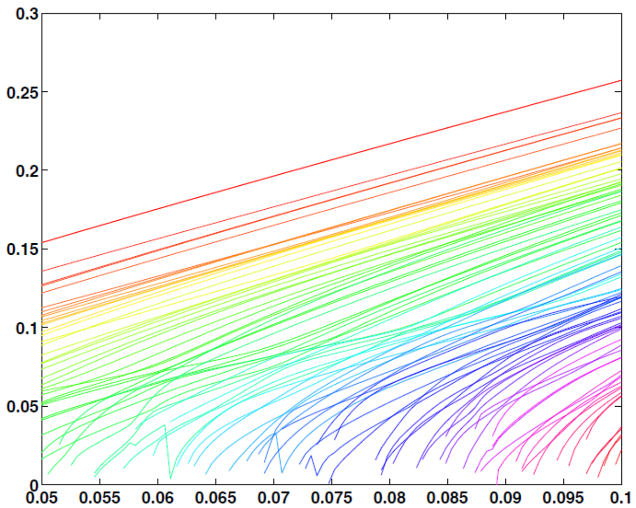
Bolt hole crack (web)

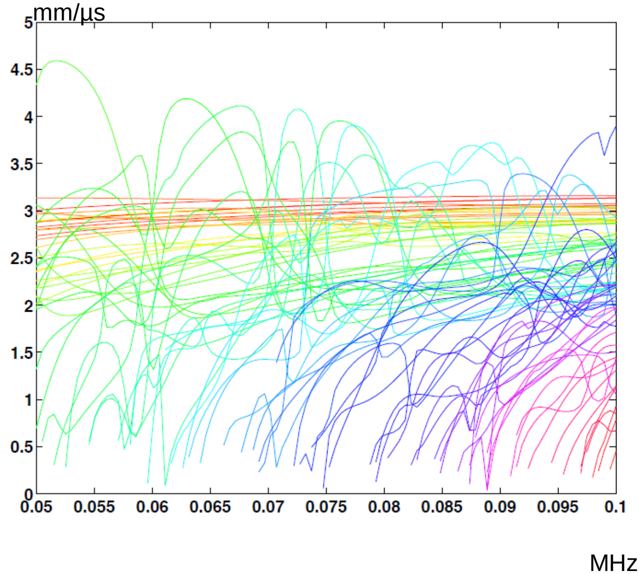
Frequency range : ~20-80kHz

CRACK DETECTION IN THE RAIL HEAD (1/2)

Computation of dispersion curves

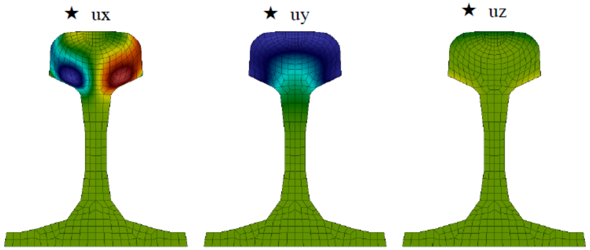






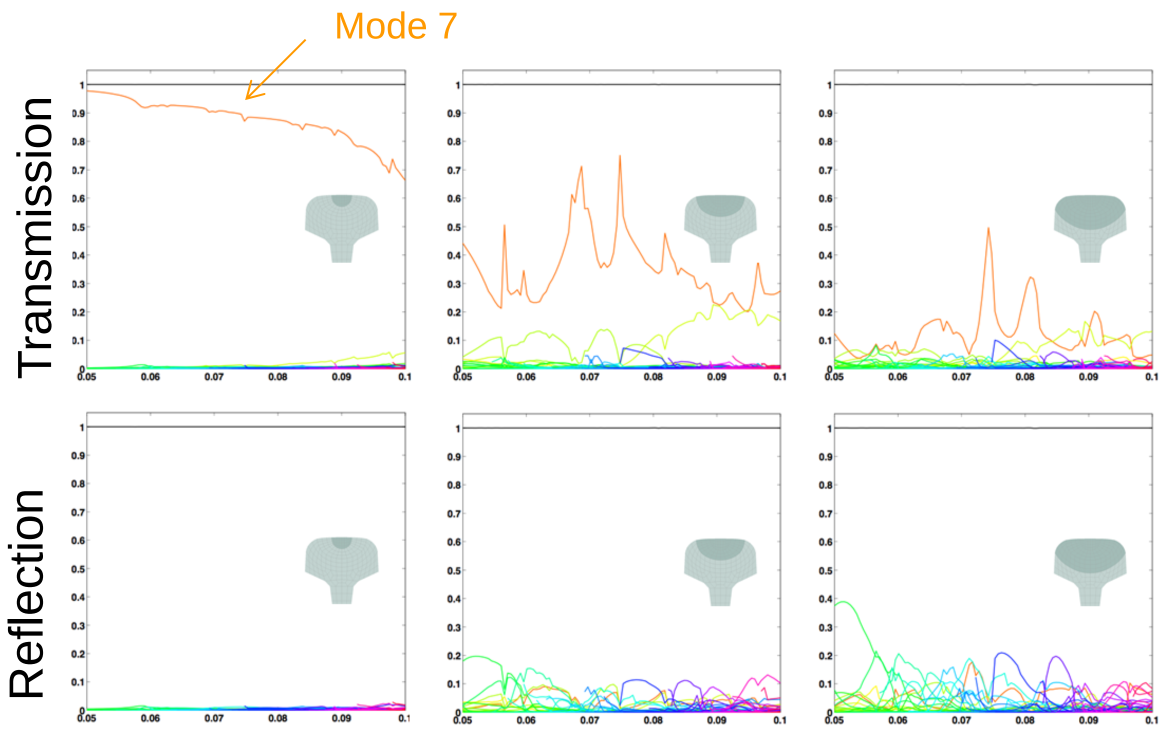
Selection of a mode whose energy is confined in the rail head

7th mode (at 70 KHz)



CRACK DETECTION IN THE RAIL HEAD (2/2)

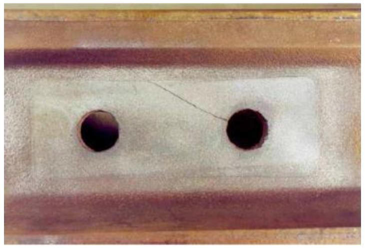
Reflection and transmission of mode 7 for different crack sizes



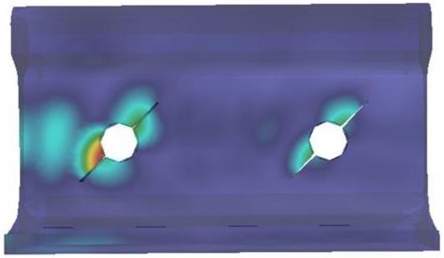
- detection of smallest crack difficult at such low frequencies
- various modes are reflected/transmitted depending on the frequency

DETECTION OF BOLT HOLE CRACK (1/3)

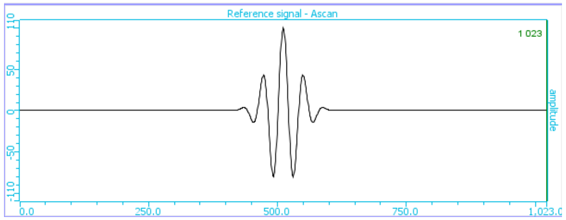
Used to connect the ends of two rails



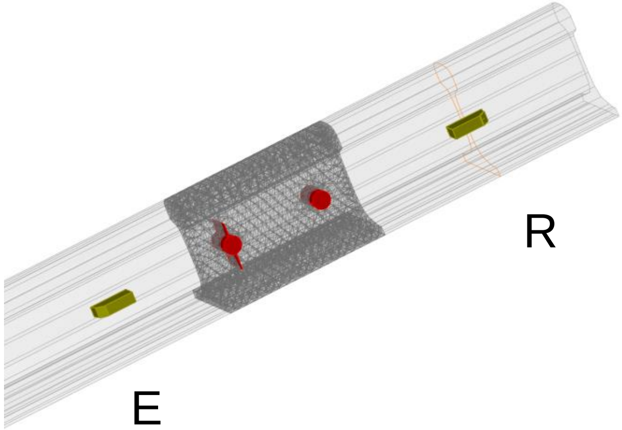
May be subject to fatigue cracking



Simulation in transmit mode

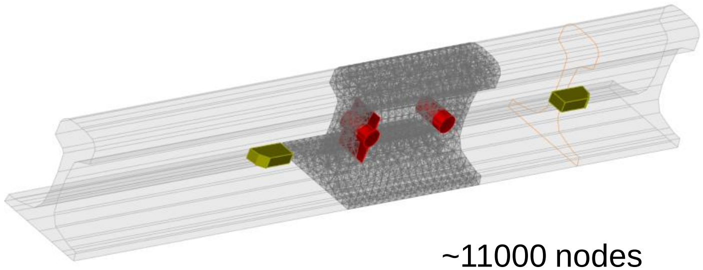


f_c~= 25 kHz

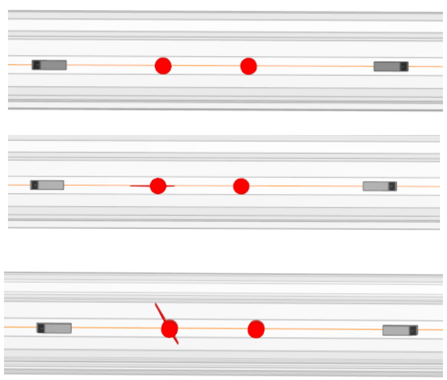


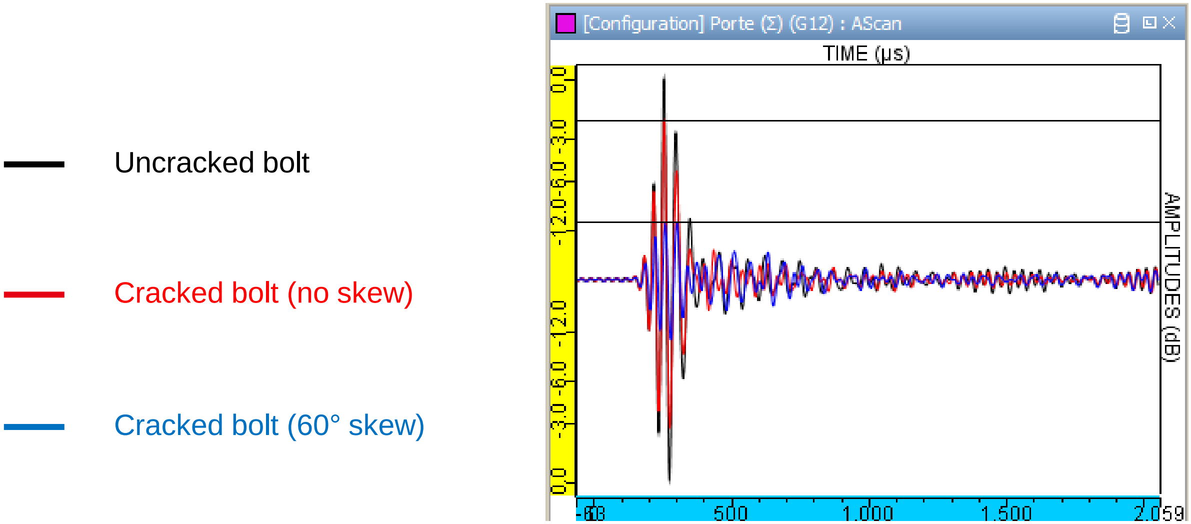
DETECTION OF BOLT HOLE CRACK (2/3)

- 15 existing modes at 25kHz
- wedge transducer (incidence 45°)
- fc ~25kHz, 50% bw



~11000 nodes

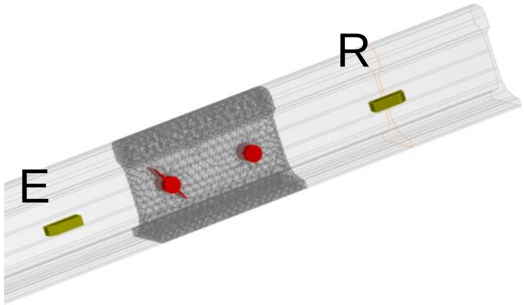


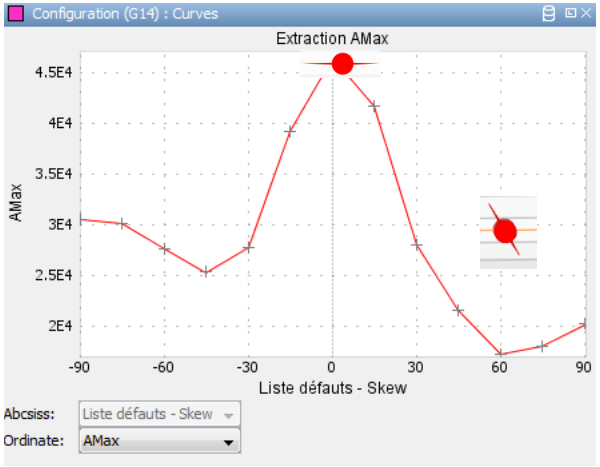


Computation time ~20' on a Intel Xeon 2.4 GHz desktop

DETECTION OF BOLT HOLE CRACK (3/3)

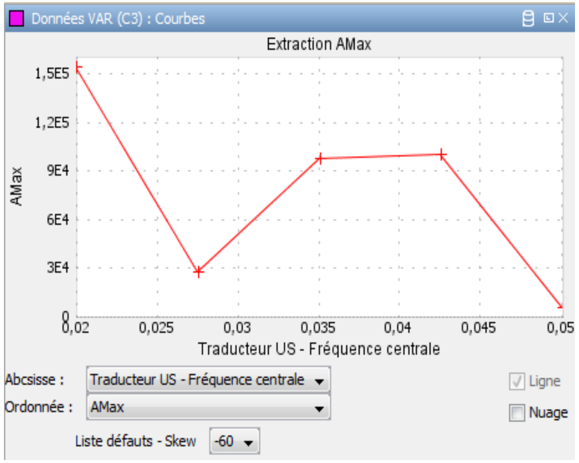
Influence of crack skew angle





Max amplitude as a function of crack skew angle

Influence of probe center frequency



Max amplitude as a function of probe center frequency

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CONCLUSIONS AND PERSPECTIVES

- The use of simulation is now well-established in NDE applications. Efficient tools exist for the major NDE techniques (UT, ET, RT, …)

- For guided waves: FE/modal hybrid models have been developed and implemented in the GW module of CIVA platform

- Work in progress
  - Simulation of SHM configurations (network of sensors)
  - Account of leaky modes
  - Post-processing of signals

- Contact and demonstration for CIVA: visit EXTENDE stand

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