DE LA RECHERCHE À L'INDUSTRIE

EXPERIMENTAL STUDY FOR THE VALIDATION OF CIVA PREDICTIONS IN TOFD INSPECTIONS

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EXPERIMENTAL VALIDATION OF CIVA UT PREDICTIONS
TOFD INSPECTION

Long term validation work undertaken for 3 years by the CEA-LIST with EXTENDE

- **Pulse echo inspections**
  - monoelement and phased array probes
  - reference reflectors (Side Drilled Holes and Flat Bottom Holes)
  - corner echoes from notches
  - echoes from the specimen geometry…

- **TOFD inspections** with monoelement probes
  - Side Drilled Holes
  - now, notch edge diffraction echoes

- Results are made available on the **EXTENDE web site**

Main steps of the process of experimental validation of CIVA UT

- Define and perform experiments
- Describe accuratly in CIVA the experimental inspection : determine the appropriate input parameter values
  and perform the CIVA computations
- Compare and interpret measured and simulated results

Outline

- Information about experiments and simulation procedures
- Examples of comparisons and considerations about CIVA input parameters and approximations of the models

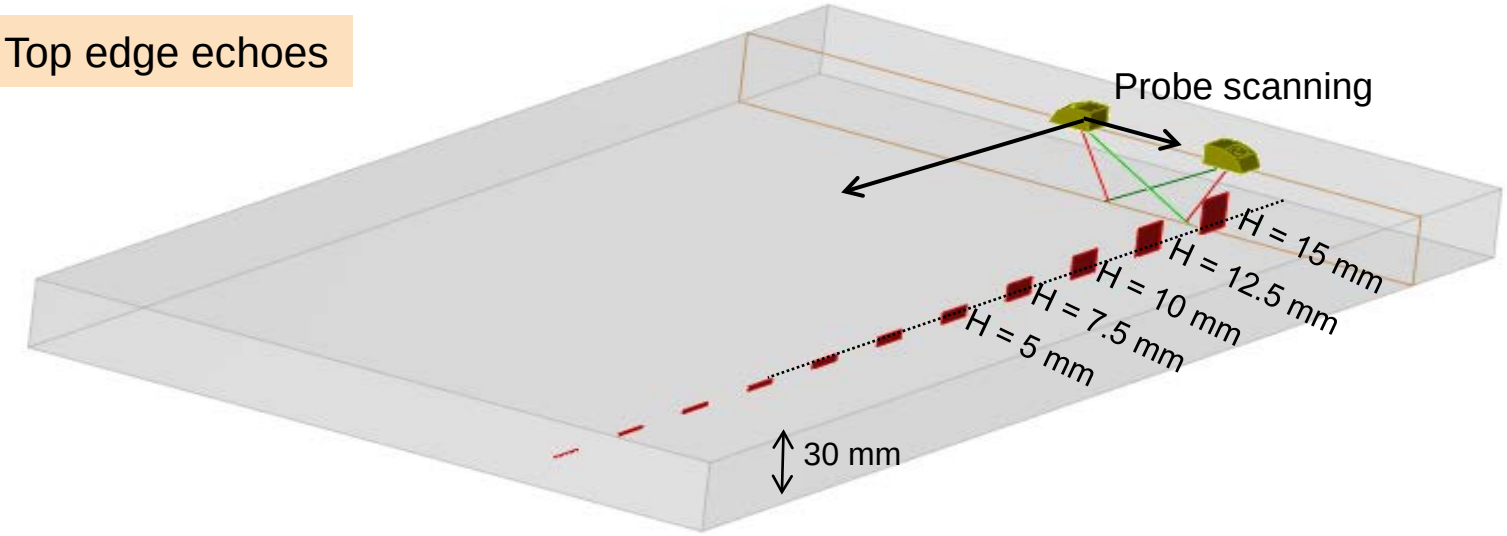
For details on new models implemented in CIVA11, see presentation by Steve Mahaut later in this session

EXPERIMENTS AND SIMULATION PROCEDURE

DESCRIPTION OF THE EXPERIMENTS

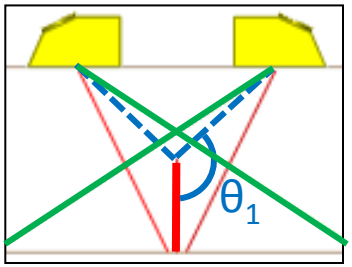
Measure of the **echoes coming from top and bottom edge** of artificial notches of different heights

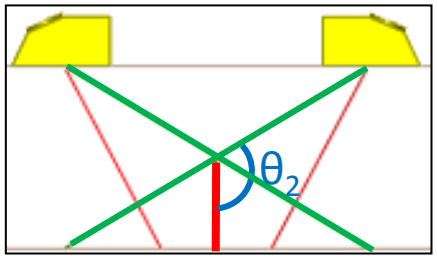
Top edge echoes

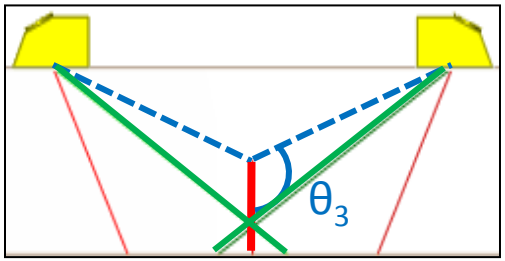


Several inspections with various PCSs:

- **various incident angles** on the notch edge
- **various positions of the edge** in the probe incident beams





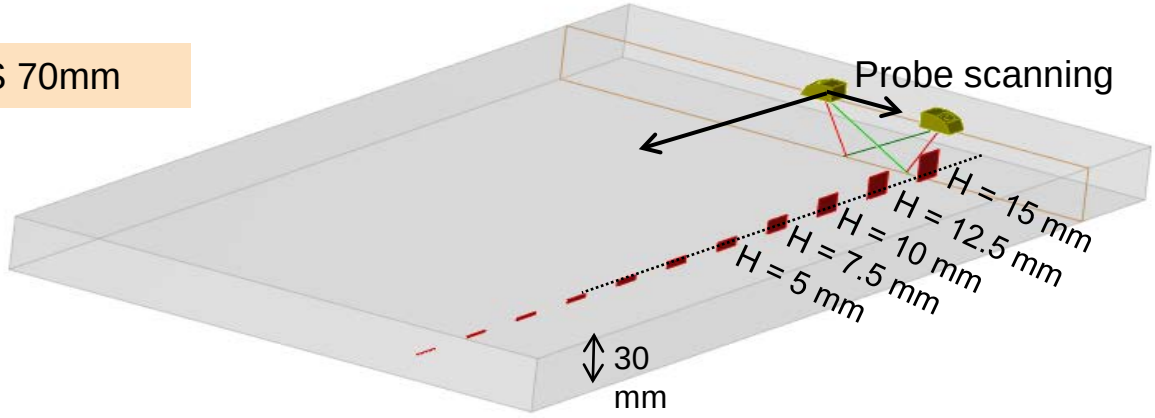


EXPERIMENTS, REPRODUCIBILITY

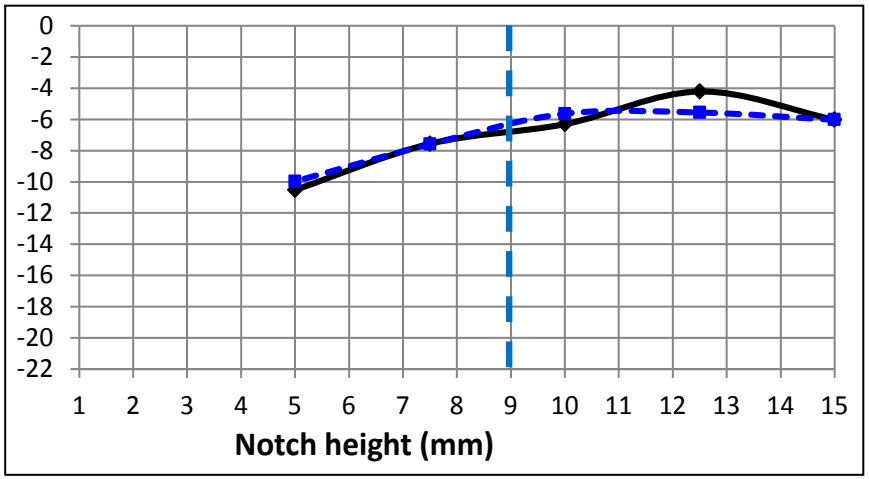
Contact Ø6.35mm, 5MHz, L60°

PCS 70mm

___ measure n°1
- - - measure n°2

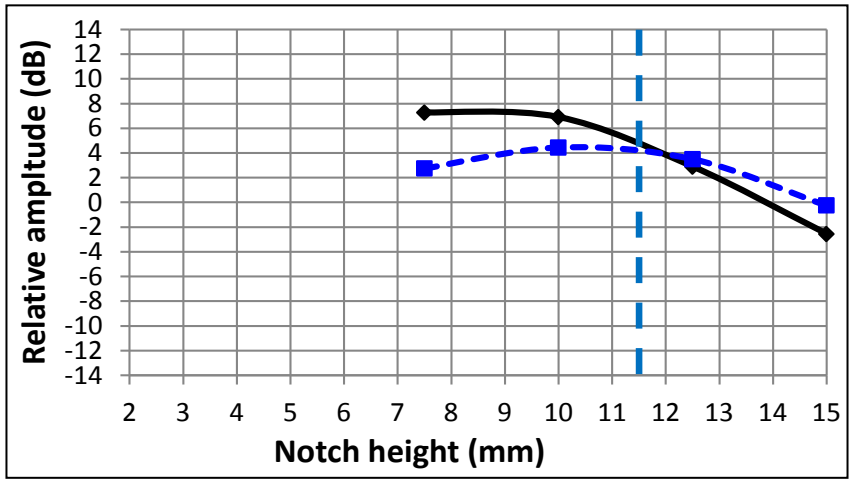


Top edge



Reproducibility: ok (discreapnacies < 2 dB)

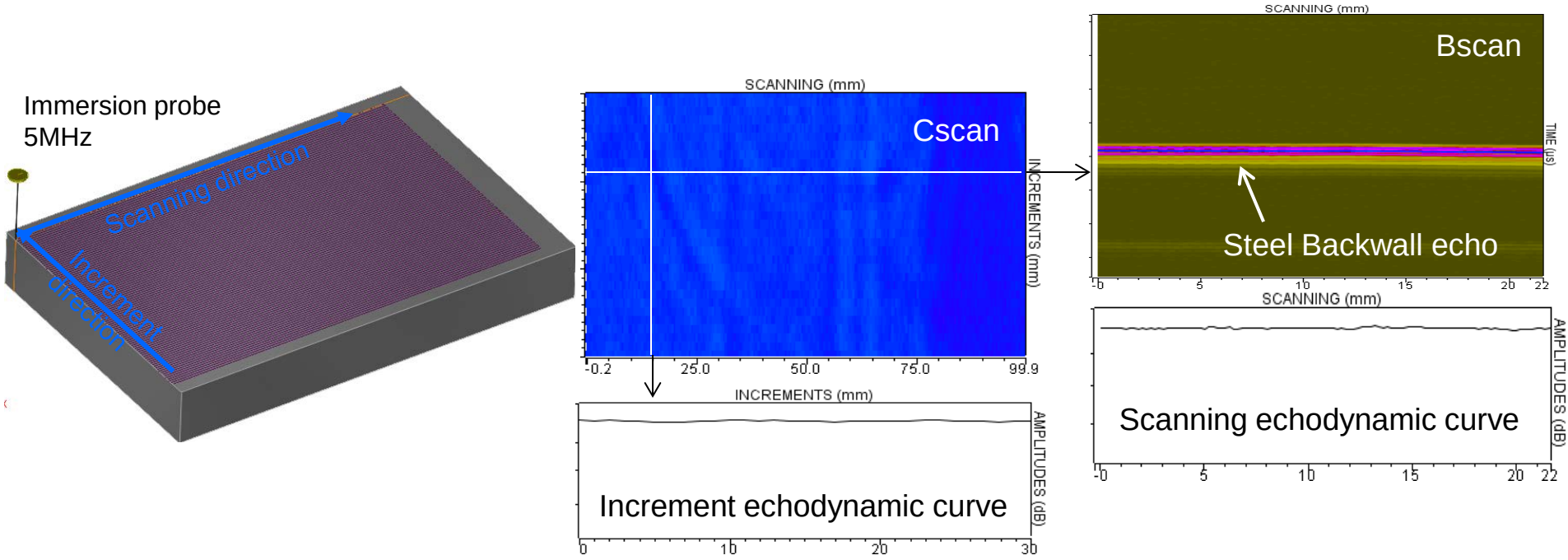
Bottom edge



Reproducibility: not ok => all the bottom edge diffraction echo measurements are going to be performed again

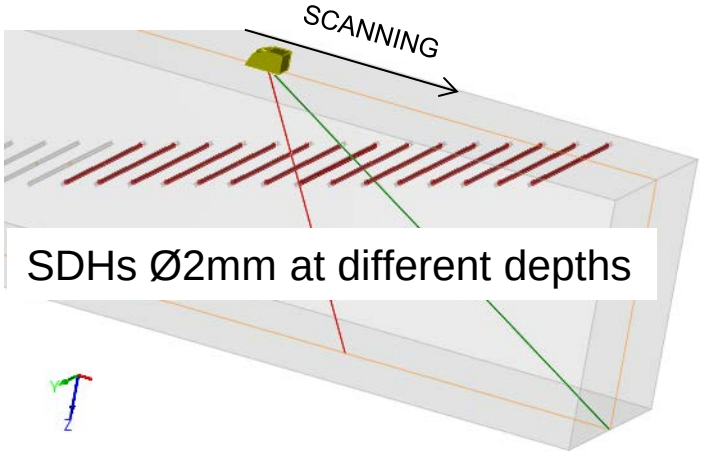
- Specimen parameters in CIVA
  - Isotropic et homogeneous (ferritic steel)
  - L waves attenuation ignored
  - Velocities : time measurement between successive backwall echoes
    - V_L : using a $L_{0°}$ probe at 5MHz
    - V_T : using a contact $T_{0°}$ probe at 5MHz

Material Homogeneity: L0° Cscan, variations of the backwall echo amplitude < 0.5 dB

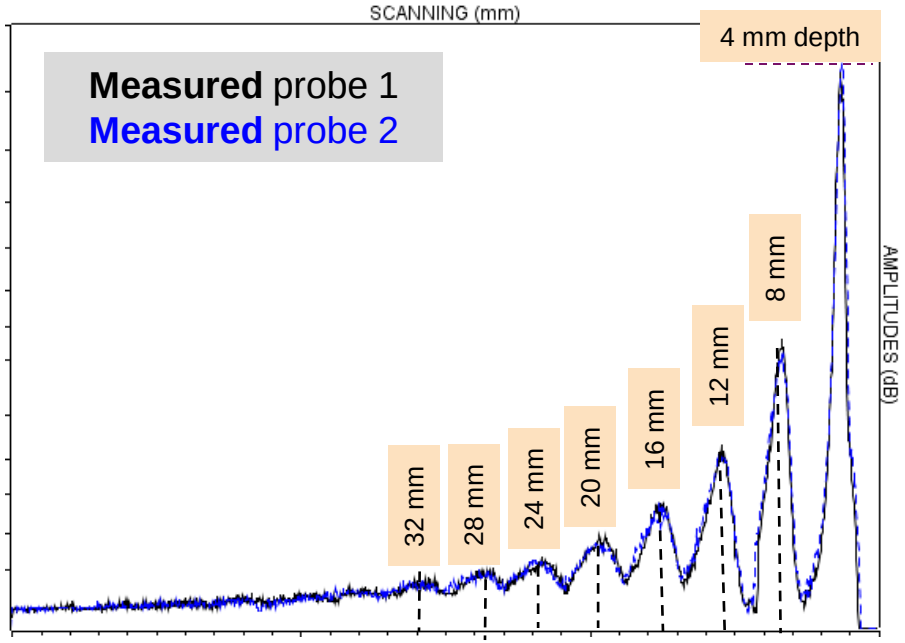


- Contact probes currently used for TOFD inspections (Ø6.35mm, 5MHz, L45° and L60°)
- Experimental check of their resemblance

Contact probes Ø6.35mm, 5MHz, L60°



Echodynamic curves



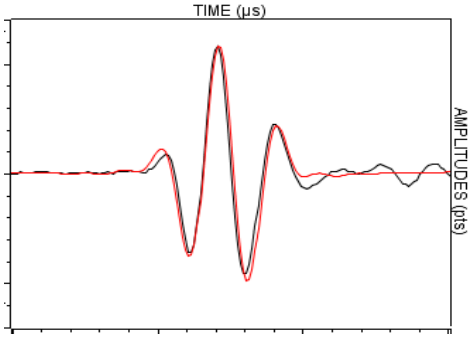
The measured SDH responses of the 2 probes are very close:
- amplitude discrepancy < 1dB
- same L refraction angle

- **Diameter and shape**: manufacturer information
- **L waves refraction angle in the specimen**: SDH calibration (pulse echo)
- **Wedge parameters**: measurement
  - L and T wave velocities with L0° and T0° probes
  - Wedge height and length with a sliding caliper
  - Index point using the calibration block n°1

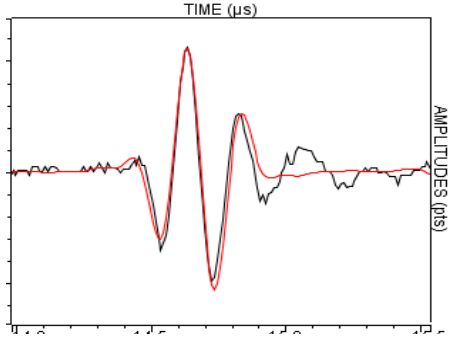
- **Determination of the probe input signal (**centre frequency, phase, bandwidth): adjusted by matching the shapes of the measured and simulated Ascans of SDH specular L direct echoes (pulse echo mode)

Contact Ø6.35mm, 5MHz, L60° __ Measured __ CIVA

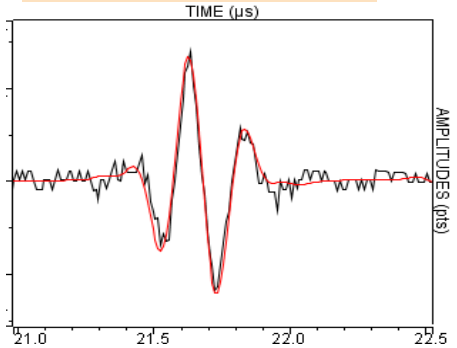
SDHØ2mm at 4mm depth



at 16mm depth

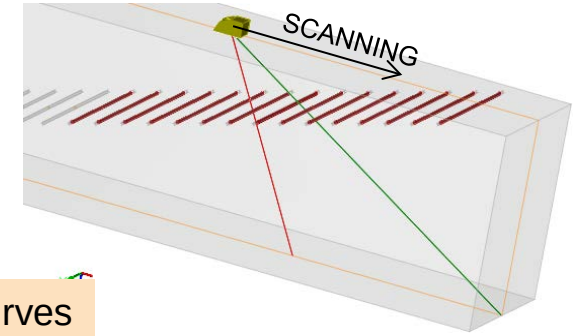


at 28mm depth



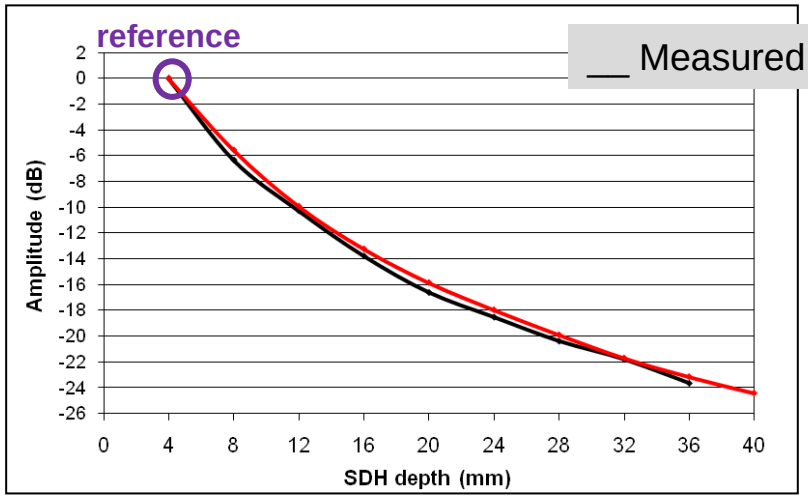
CIVA input signal parameters well ajusted by matching the experimental and CIVA Ascans

To check the previous probe parameters:
comparison of the experimental and simulated inspection of the SDHs Ø2mm at different depths in pulse echo mode



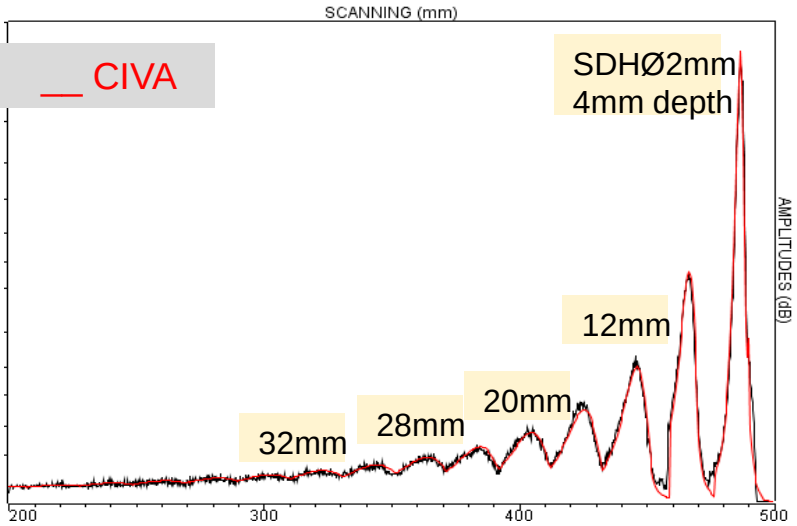
Contact Ø6.35mm, 5MHz, L60°

Amplitude/SDH depth



Scanning echodynamic curves

__ Measured __ CIVA



Measured and simulated SDH responses of each probe are very close:

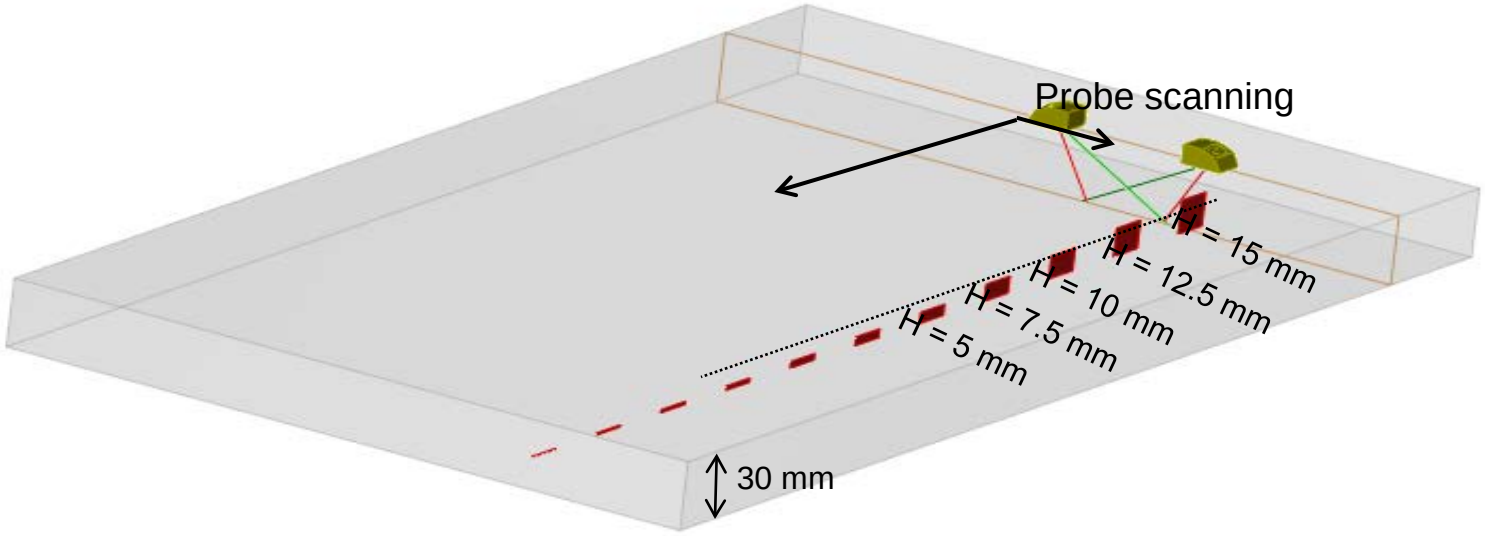
- same amplitude decrease with the SDH depth
- same L refraction angle

⇒ validation of the CIVA input parameters of the probes

Same validation made for the L45° probes

NOTCHES (1/2)
ECHOES STUDIED
MODELS OF INTERACTION

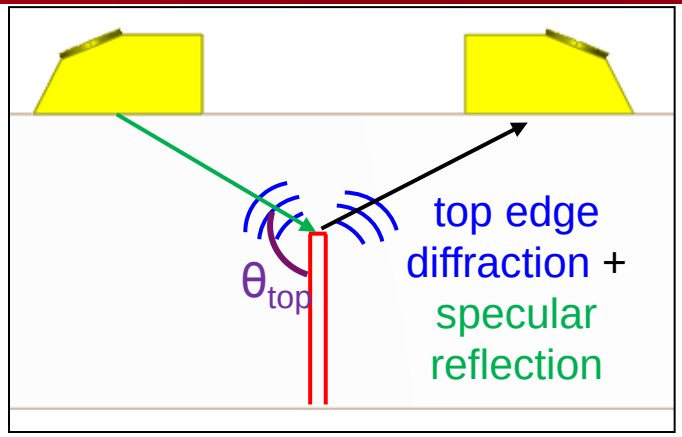
- Manufacturer information: artificial notches, aperture of 0,2mmm
- **Longitudinal echoes coming from the top edges** of the notches
- **GTD** (Geometrical Theory of Diffraction)
  => **not possible to take into account the notch aperture**



SIMULATION PROCEDURE

NOTCHES (2/2)
ECHOES STUDIED
MODELS OF INTERACTION

- **Neccessity to take into account the notch aperture** (additionnal specular echo from the top edge)

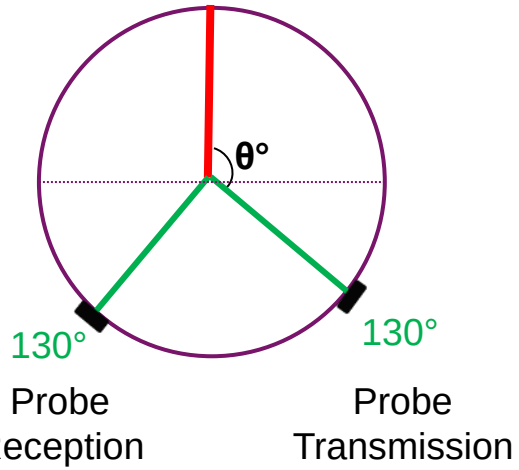


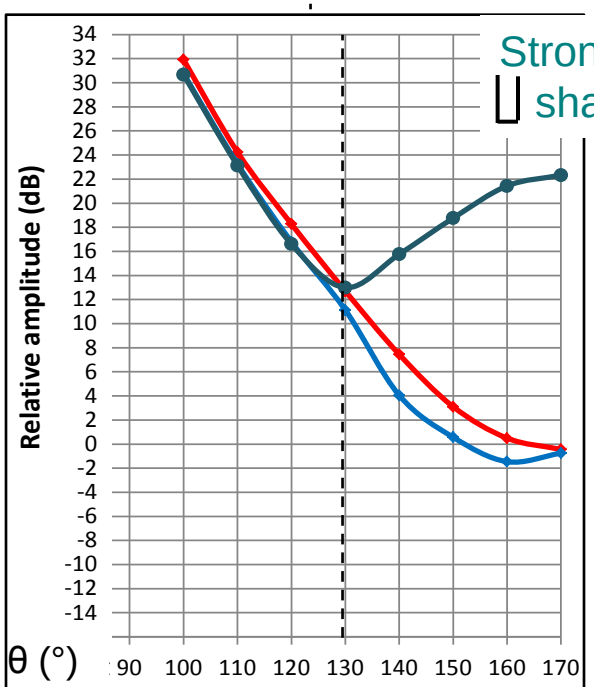
- Simulation with the coupling code of **CIVA-ATHENA-2D**

Ravenscroft configuration

Top edge diffraction

Contact Ø10mm, 5MHz, L0°





Strong increase : ⊔ shape of the notch

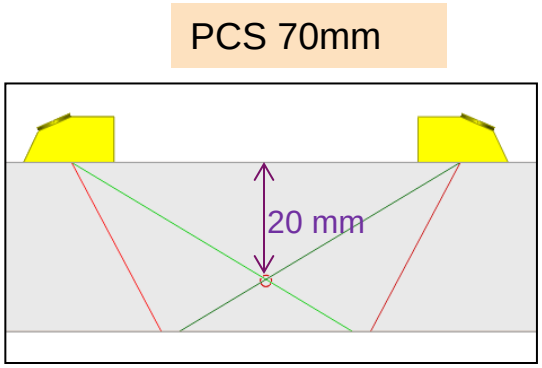
__ CIVA-2D
quasi null notch aperture

__ CIVA-ATHENA-2D
quasi null notch aperture

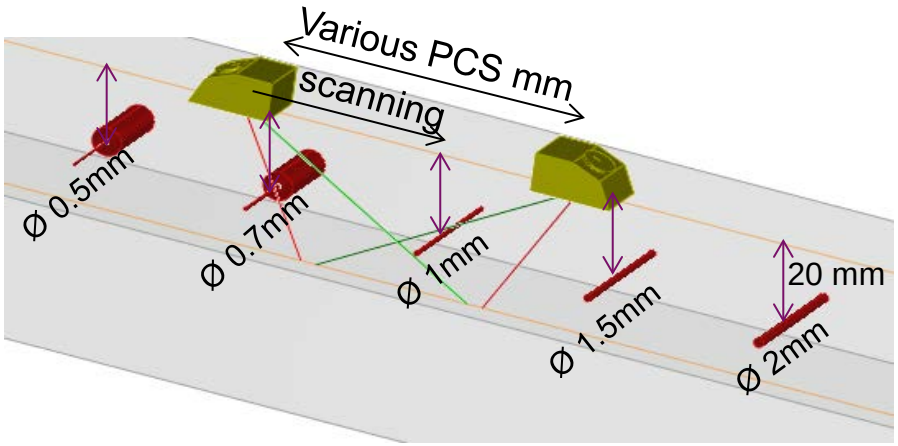
__ CIVA-ATHENA-2D
notch aperture 0.2mm

F. A. Ravenscroft, K. Newton and C. B. Scruby, "Diffraction of Ultrasound by Cracks: comparison of Experiment with Theory", *Ultrasonics,* Vol 29, pp 29-37, January 1991.

Reference for the amplitude comparisons:
TOFD, L direct echo of a SDH Ø2mm at 20mm depth, PCS 70mm



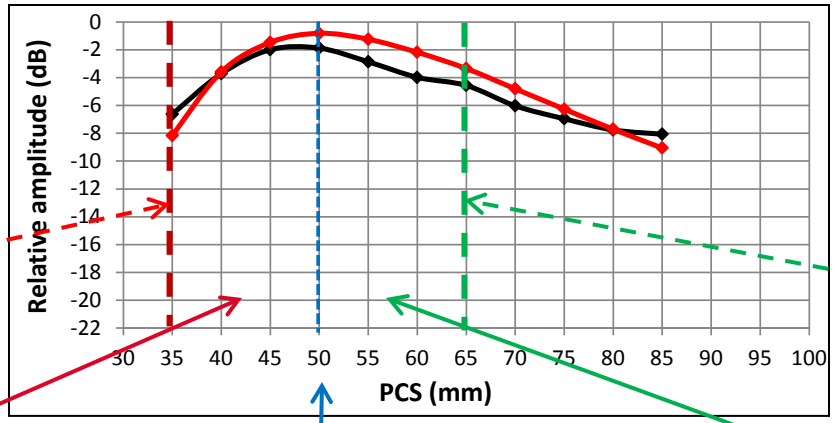
The amplitude of this reference simulated with CIVA (SOV model) is reliable (experimental validation study, L direct echoes of SDHs responses obtained for TOFD inspection, ICNDE 2012)



EXPERIMENTAL VALIDATION AND DISCUSSION

TOP EDGE DIFFRACTION
MOCK-UP AND COMPARISON CURVES

Example of amplitude / PCS curve



__ Measured
__ CIVA

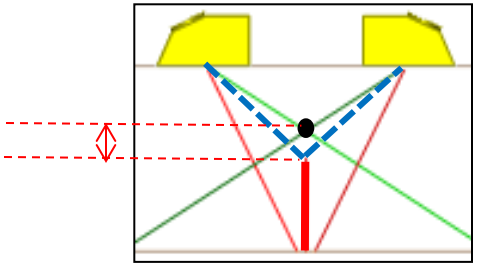
crossing point above top edge, Δ = 4 mm

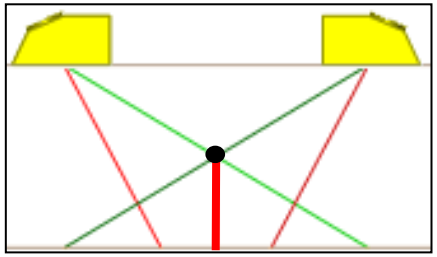
crossing point below top edge, Δ = 4 mm

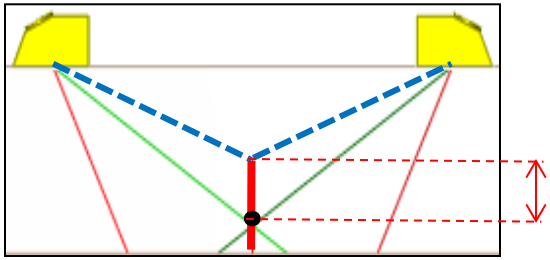
L axis crossing point **above** top edge

L axis crossing point **close to** the top edge

L axis crossing point **below** top edge







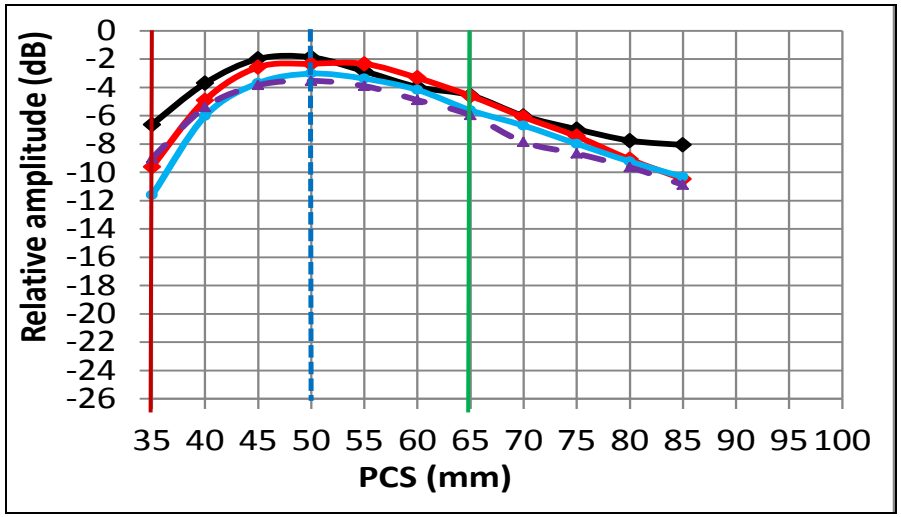
TOP EDGE DIFFRACTION
AMPLITUDE COMPARISON RESULTS, L60°

Contact Ø6.35mm, 5MHz, L60°

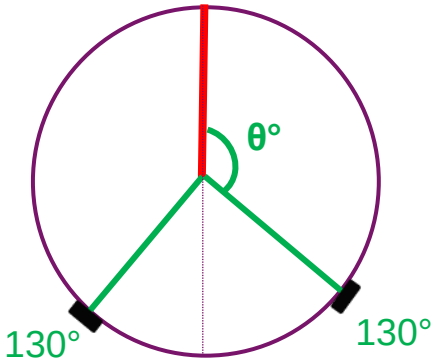
Reference: TOFD, L direct echo
SDH Ø2mm at 20mm depth, PCS 70mm

Amplitude/PCS curves

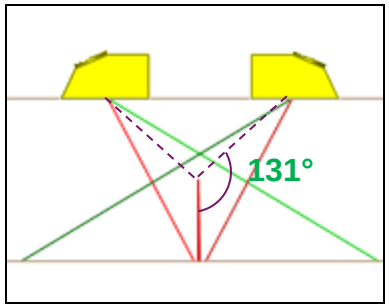
Notch height 15mm



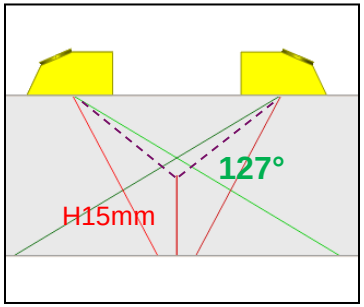
Measured
CIVA
CIVA-ATHENA 2D, notch aperture quasi nul
CIVA-ATHENA 2D, notch aperture 0.2mm



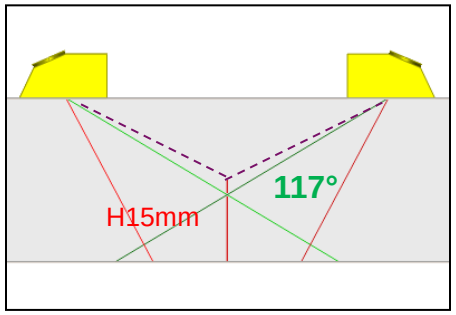
PCS 35mm



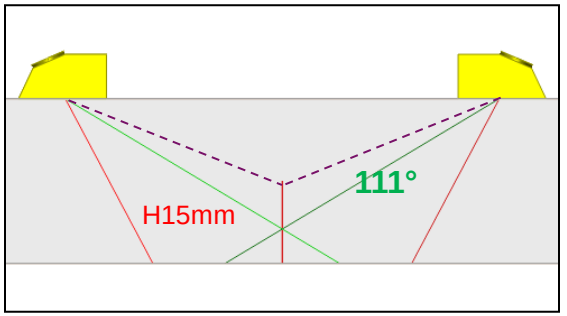
PCS 40mm



PCS60mm



PCS80mm



Almost no effect of the notch aperture as expected (theta<130°)
Good agreement between measure and CIVA predictions

TOP EDGE DIFFRACTION
AMPLITUDE COMPARISON RESULTS, L60°

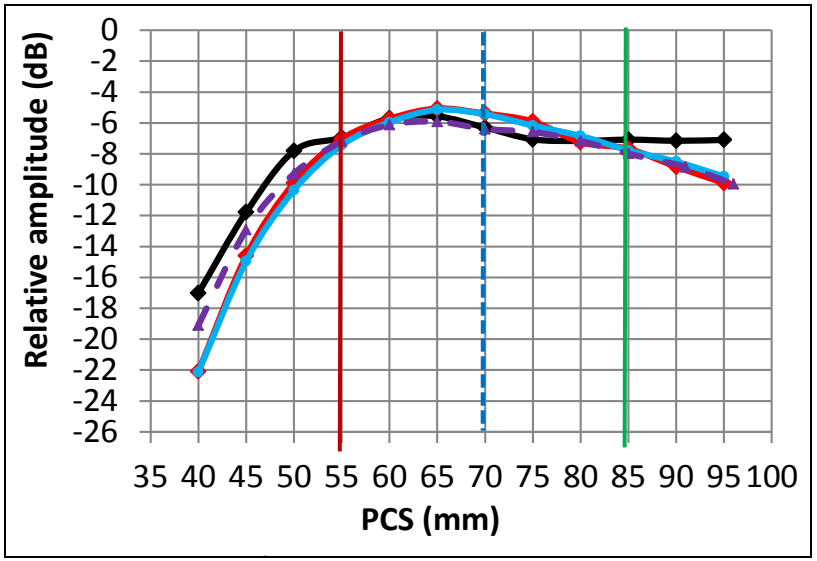
Contact Ø6.35mm, 5MHz, L60°

Reference: TOFD, L direct echo
SDH Ø2mm at 20mm depth, PCS 70mm

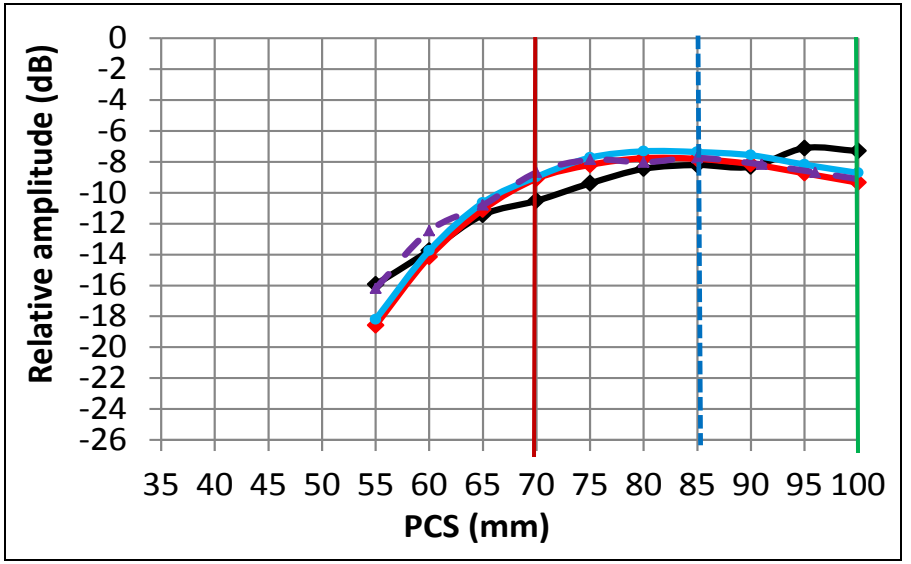
Measured
CIVA
CIVA-ATHENA 2D, notch aperture quasi nul
CIVA-ATHENA 2D, notch aperture 0.2mm

Amplitude/PCS curves

Notch height 10mm



Notch height 5mm



Again:
No effect of the notch aperture as expected according to Ravenscroft results
Good agreement between measure and CIVA predictions remains

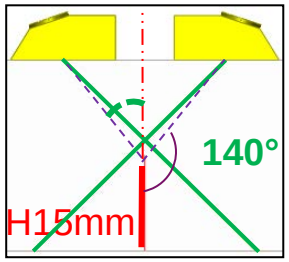
TOP EDGE DIFFRACTION
AMPLITUDE COMPARISON RESULTS, L45°

Contact Ø6.35mm, 5MHz, L45°

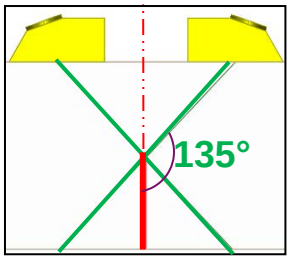
Notch height 15mm

Reference: TOFD, L direct echo
SDH Ø2mm at 20mm depth, PCS 40mm

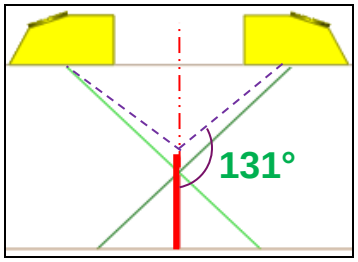
PCS 25mm



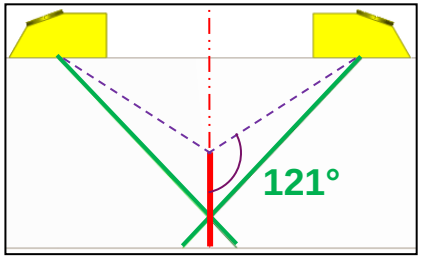
PCS 30mm

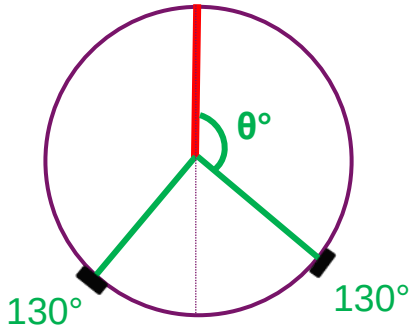


PCS 35mm



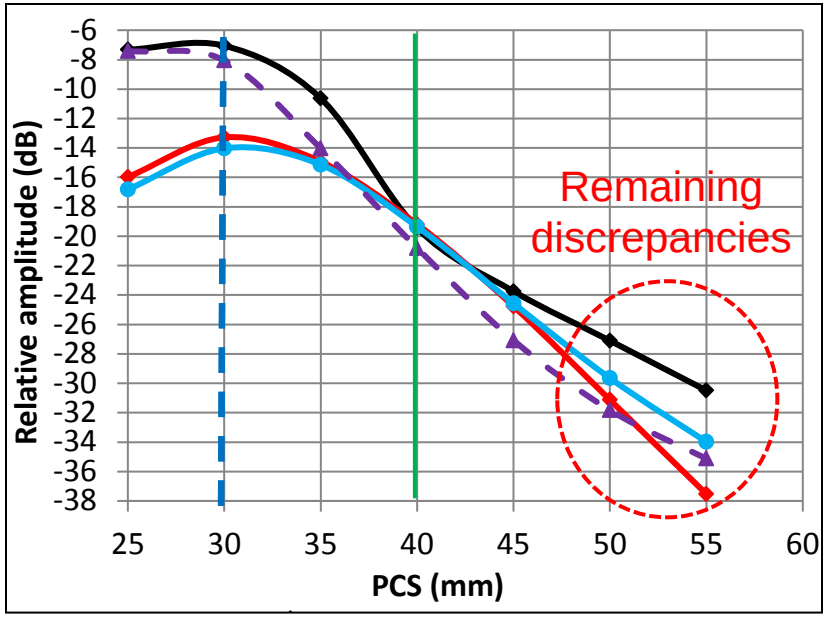
PCS 50mm





Amplitude/PCS curves

___ Measured
___ CIVA
___ CIVA-ATHENA 2D, notch aperture quasi nul
- - - CIVA-ATHENA 2D, notch aperture 0.2mm



Effect of the notch aperture on the L diffraction echo of the top edge for incident angles > 130°

TOP EDGE DIFFRACTION
AMPLITUDE COMPARISON RESULTS, L45°

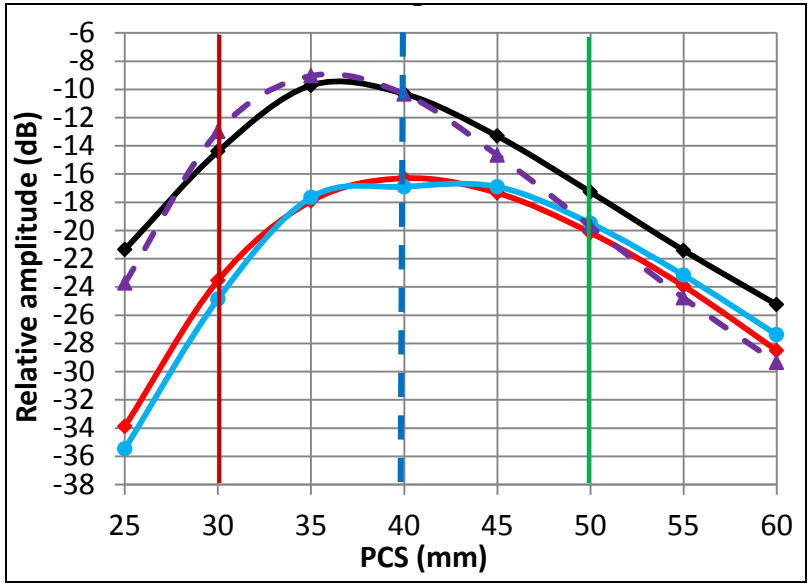
Contact Ø6.35mm, 5MHz, L45°

Reference: TOFD, L direct echo
SDH Ø2mm at 20mm depth, PCS 40mm

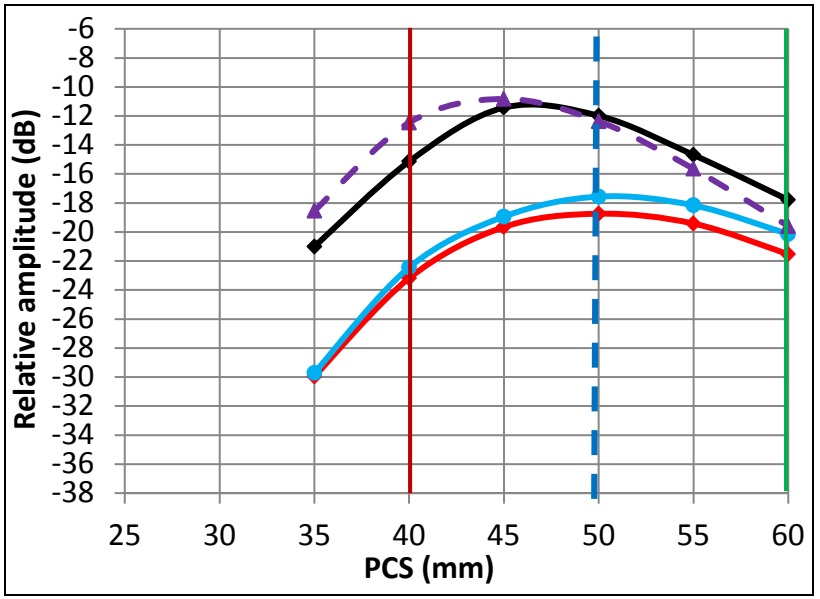
Amplitude/PCS curves

Measured
CIVA
CIVA-ATHENA 2D, notch aperture quasi nul
CIVA-ATHENA 2D, notch aperture 0.2mm

Notch height 10mm



Notch height 5mm



When taken into account the notch aperture effect, a good agreement for the amplitudes (and Ascans) between measure and CIVA-ATHENA 2D predictions

TOP EDGE DIFFRACTION
REMAINING DISCREPANCIES, L45°

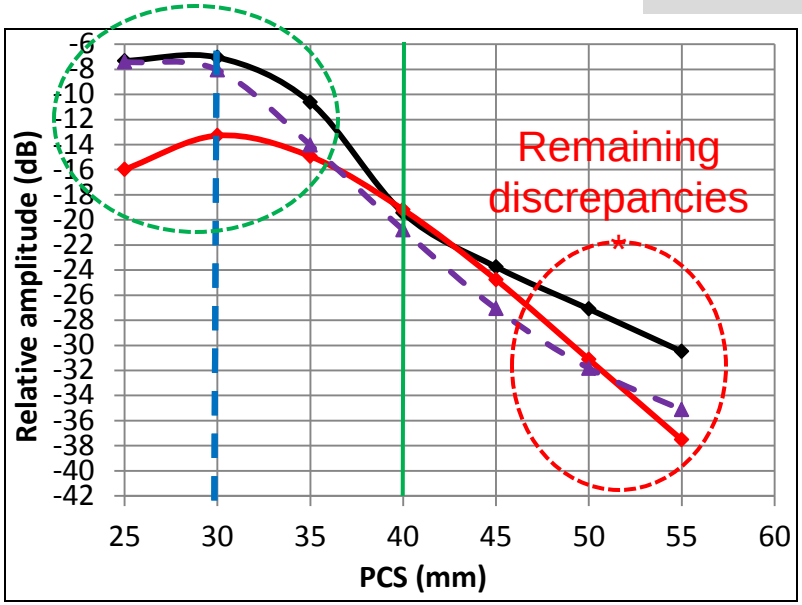
Discrepancies observed at the largest PCS:
may be due to approximation of the field made in CIVA for the echo computation

Contact Ø6.35mm, 5MHz, L45°

Notch height 15mm

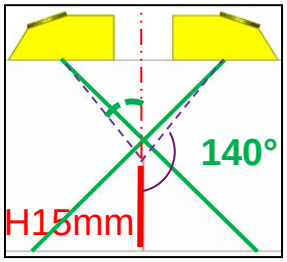
Reference: TOFD, L direct echo
SDH Ø2mm at 20mm depth, PCS 40mm

Amplitude/PCS curves

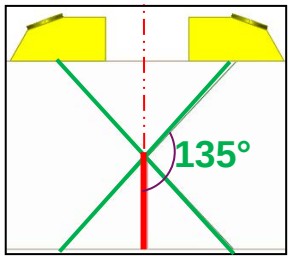


__ Measured
__ CIVA
- - - CIVA-ATHENA 2D
(notch aperture 0.2mm)

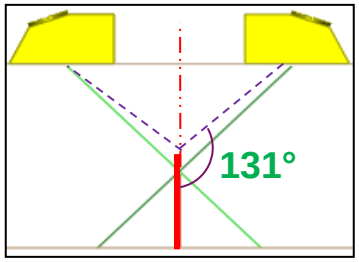
PCS 25mm



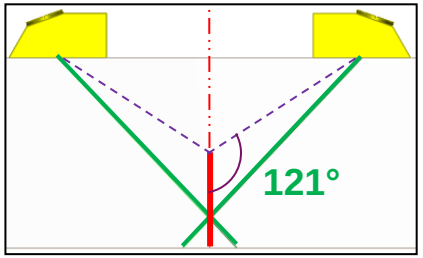
PCS 30mm



PCS 35mm



PCS 50mm



CONCLUSION

- **Results of an experimental validation study** aiming at quantifying the reliability of CIVA UT predictions in the case of TOFD inspections were presented.

- **Experimental and simulation procedures** were described

- In the **case of artificial notches** and for some values of the incident angle: **necessity to take into account the notch aperture** for top edge echo computation

- **Good agreement** in the studied cases
  - with GTD model of CIVA where notch aperture has no effect (**case of real cracks**)
  - with coupling code of CIVA-ATHENA-2D where notch aperture has effect

- **Some discrepancies** (top edge not the zone of interest) : simplification of the field for echo computation

- **Work in progress**:
  - 3D numerical models (FEM, BEM)
  - real description of the incident beam for echo response

The complete results of this study are available on the EXTENDE website

THANK YOU FOR YOUR ATTENTION !

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