Validation of CIVA ultrasonic simulation in canonical configurations

Raphaële RAILLON[1], Gwénaël TOULLELAN[1], Michel DARMON[1], Pierre CALMON[1], Sébastien LONNE[1]
[1]CEA-LIST, Gif-sur-Yvette
{raphaele.raillon; gwenael.toullelan; michel.darmon; pierre.calmon}@cea.fr
[2]EXTENDE, 86 rue de Paris, 91400 Orsay, France
sebastien.lonne@extende.com

April 2012

The CIVA-UT modules allow calculating the echoes from postulated defects during a postulated NDT inspection

The calculations apply propagation and scattering models based on semi-analytical kernels and numerical integration.

Over the years:

- a large amount of experimental comparisons have been carried out using CIVA in the framework of studies dedicated to different industrial applications, either at CEA or by CIVA users
- in parallel CEA has participated to various international modeling benchmarks in particular organized by WFNDEC (World Federation of NDE Centers)
- to go further a long-term validation work is being done at CEA in order to precisely quantify the level of reliability of the predictions, and accurately define the domain of applicability of the models.

CIVA10, validation procedure

Example of results for 2 experimental validation studies:

1. Specular direct echoes of Side drilled holes
   SDH = reference reflector for all the calibration of the probes used for the validation
   SOV model

2. First validation study : SV45° corner echoes of back-wall breaking notches
   Back-wall breaking notches simulate back-wall breaking cracks
   SV45° corner echoes: usually used for the detection of these cracks
   KIRCHHOFF model

Conclusion and perspectives

CIVA10, validation procedure

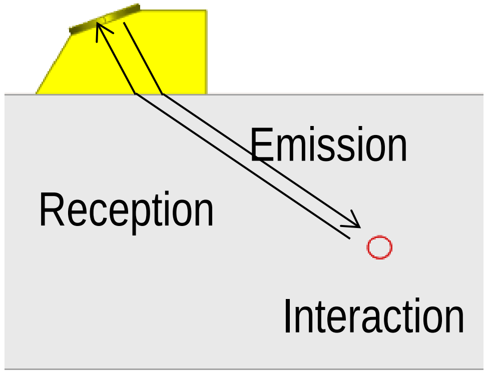
Example of results for 2 experimental validation studies:

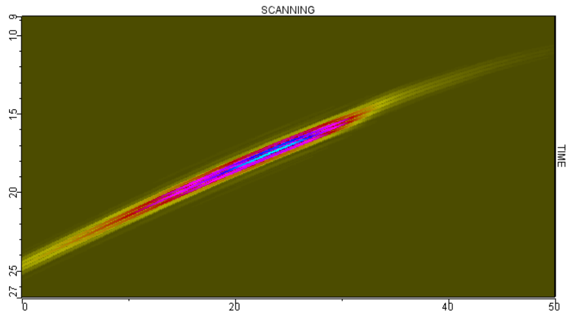
1. Specular direct echoes of Side drilled holes
   SOV model

2. SV45° corner echoes of back-wall breaking notches, planar specimen
   KIRCHHOFF model

Conclusion and perspectives

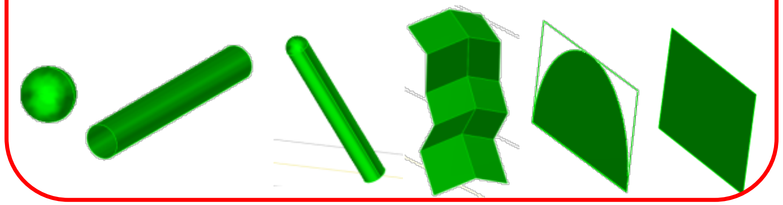
The models are based on a combination of the emission field, the reception field and beam/flaw interaction coefficients



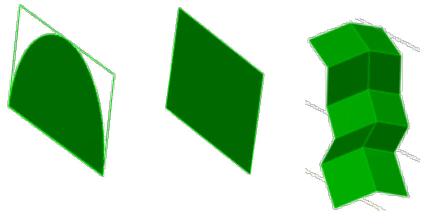


Depending on the defect shape and nature and the kind of interaction, several models are implemented in CIVA Defect Response module to simulate wave/defect interactions

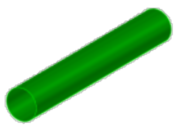
Kirchhoff
Voids, cracks (specular reflection)



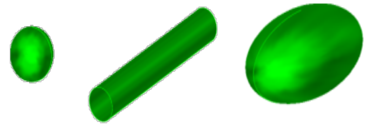
GTD
Cracks (diffraction)



SOV
Side drilled holes



Modified Born
Solid inclusions



Important to evaluate the level of reliability of the CIVA predictions

Long-term validation work is being done at CEA in order to precisely quantify the level of reliability of the predictions and accurately define the domain of applicability of the models of the CIVA-UT code by experiments

Process of experimental validation, three main steps:

1) Define and perform experiments

- First scope of validation: very classical “canonical” configurations
  - direct echoes of reference reflectors
  - SV, P and mixed corner echoes of back-wall breaking notches
  - specular echoes from the specimen geometry (backwall and surface)
  - homogeneous isotropic planar specimens
  - NDE "conventional" 2MHz and 5MHz planar contact or immersion probes
  - pulse-echo mode
- Parameters under investigation chosen by physical considerations

2) Perform the corresponding computations with CIVA

- Civa10.0
- Input parameters: listed and checked (avoid erroneous inputs)
- Check of the coherence between the output of the code and the experimental data

3) Interpret the results of comparisons between experiment and simulation

- Physical quantity considered: echo amplitude

- Comparison results analyse
  - Good agreement: information about the domain of applicability and accuracy of the CIVA predictions.
  - Discrepancies: possible origins
    - experimental uncertainties (+/-2dB)
    - simulation uncertainties (numerical noise)
    - inaccuracy on the definition of essential inputs
    - bugs (abnormal behavior of the code)
    - possible error on the reference reflector amplitude (that introduces a constant gap in the comparisons results)
    - inaccuracy of the models

In our study, discrepancies above 2dB observed => inaccuracy of the models

CIVA10, validation procedure

Example of results for 2 experimental validation studies:

1. Specular direct echoes of Side drilled holes
    - SOV model

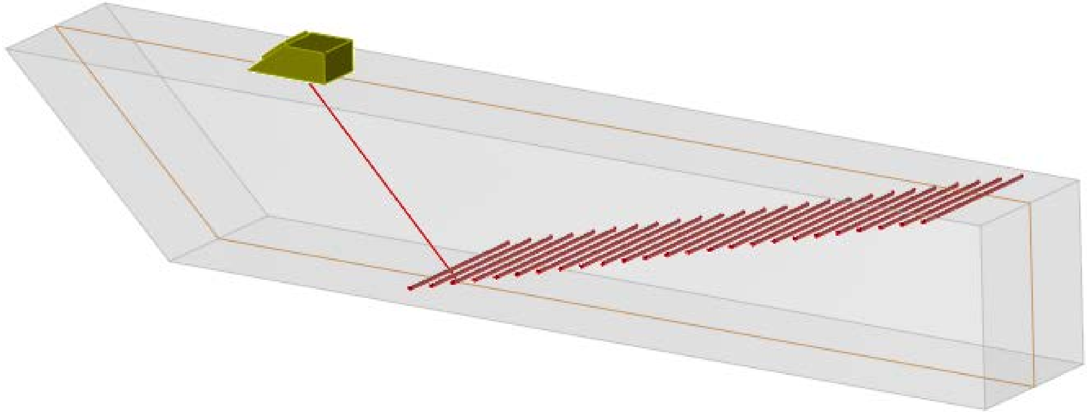
2. SV45° corner echoes of back-wall breaking notches, planar specimen
    - KIRCHHOFF model

Conclusion and perspectives

Side Drilled Holes (SDHs)

SDH Ø2mm at different depths

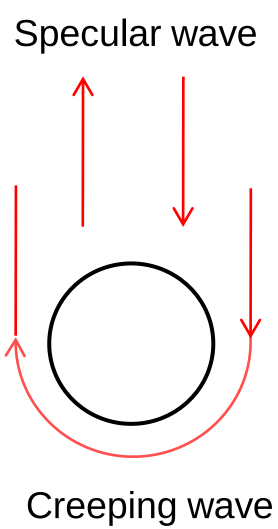
SDH calibration mock-up



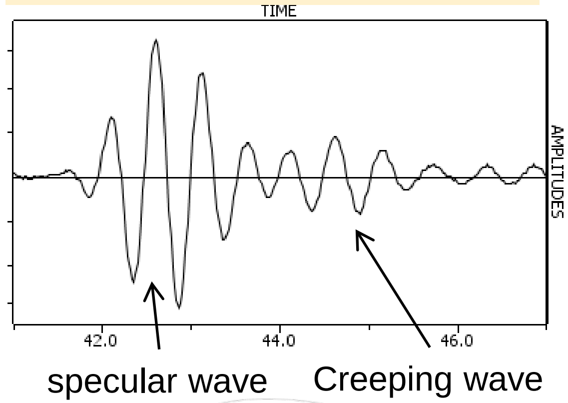
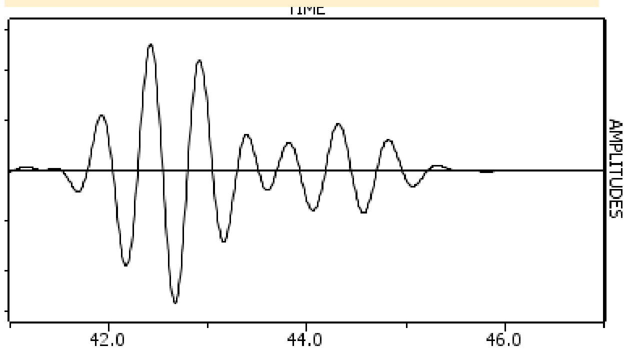
SOV model

Exact model for a plane incident wave based on a separation of variables

Only applicable for simple geometries: sphere, infinite cylinder



SDHØ2mm at 36mm depth, normalized Ascans
Contact rectangular (20mmx22mm) planar probe 2MHZ

Measure	CIVA
	

Gaps in dB between the measured and the CIVA10.0 simulated maximal amplitudes
Immersion probe

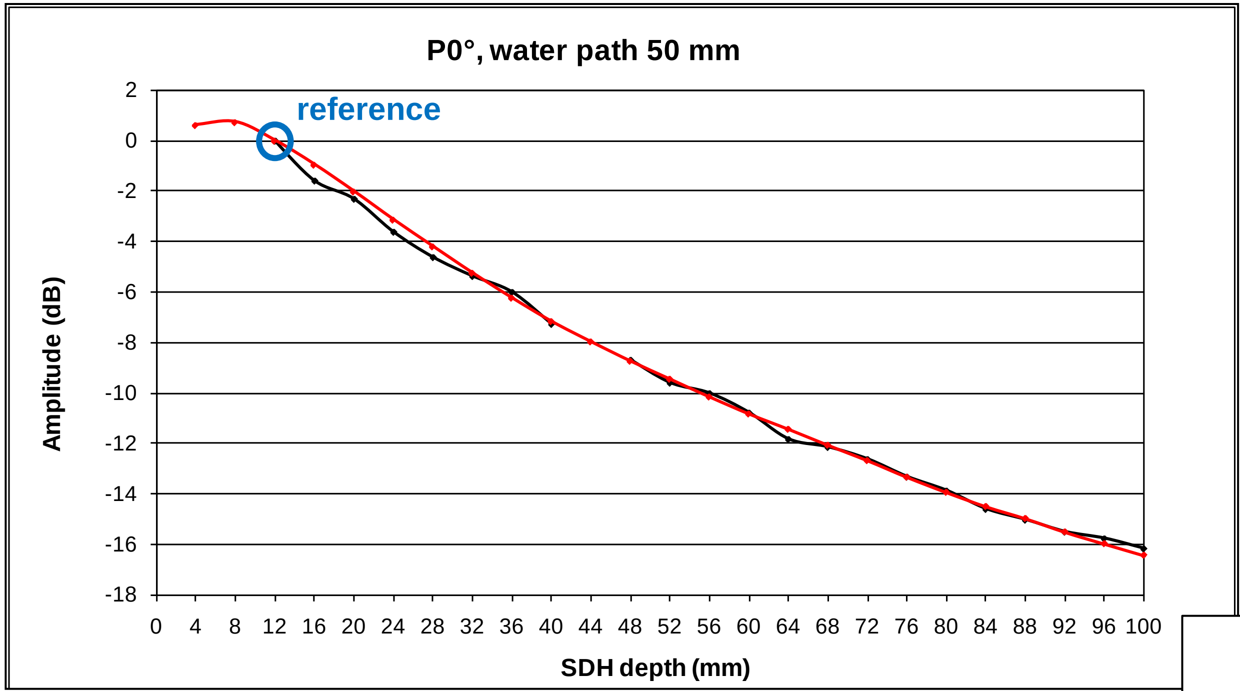
Reference mode	P0°			
Reference depth (mm)	12			
Water path (mm)	50			
Probe dimension (mm)	12.7			
fc (MHz)	2.25			
SDH depth \ Mode	**P0°**	**P45°**	**P60°**	**SV45°**
4		-0,7		1,2
8		0,0	-1,1	0,6
12	**0,0**	0,3	-0,1	0,7
16	-0,6	0,2	0,4	0,4
20	-0,3	0,4	-0,2	0,6
24	-0,5	0,6	-0,2	0,8
28	-0,4	0,5	0,0	0,9
32	-0,1	0,6	-0,3	1,0
36	0,2	0,3	-0,2	1,0
40	-0,1	0,6	-0,4	1,2
44		0,6	-0,1	1,3
48	0,1	1,0	0,4	1,8
52	-0,1	0,7	0,3	1,1
56	0,2	0,6	0,2	1,0
60	0,1	0,7	0,5	0,8

General very good agreement

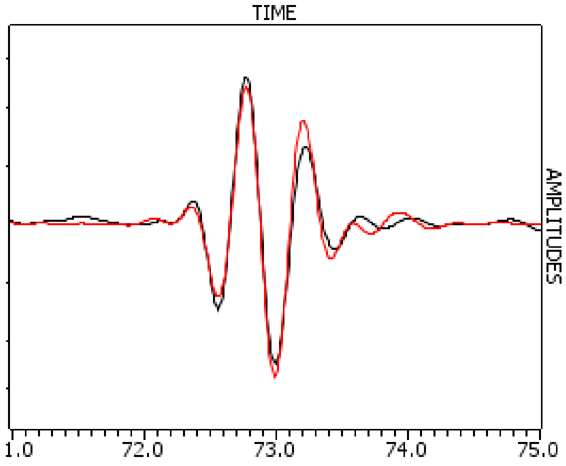
Side Drilled Holes (SDHs)

SDH Ø2mm at different depths, comparison results

Immersion probe Ø12.7mm, 2.25MHz, P0°, water path 50mm
Reference: SDHØ2mm at 12mm depth

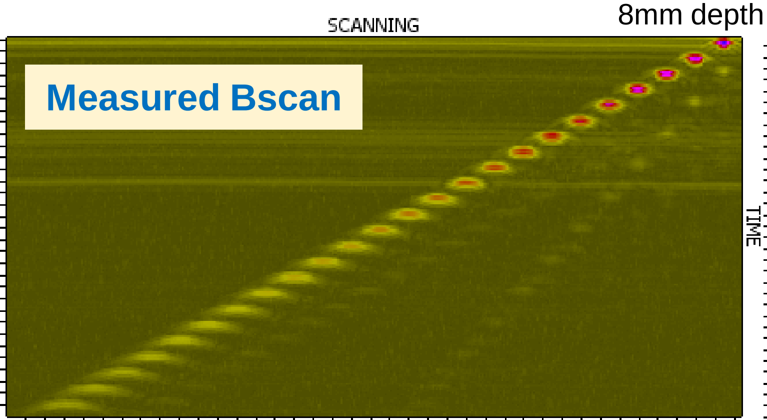


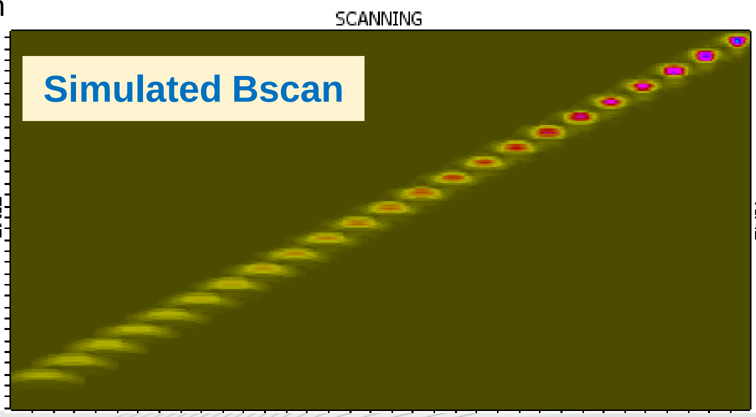
SDHØ2mm
12mm depth
(Input signal adjustment)

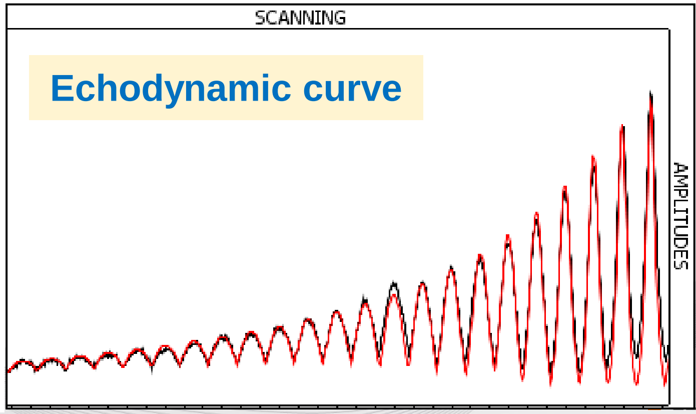


Measured
Simulated CIVA10

SDHØ2mm
8mm depth

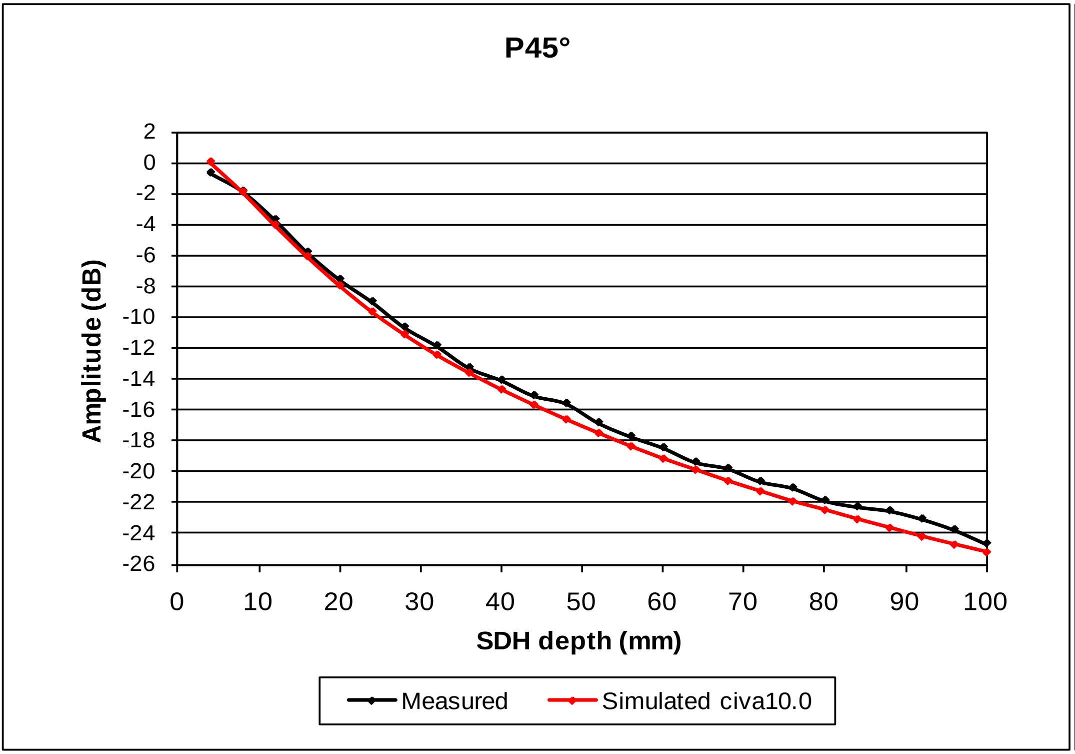




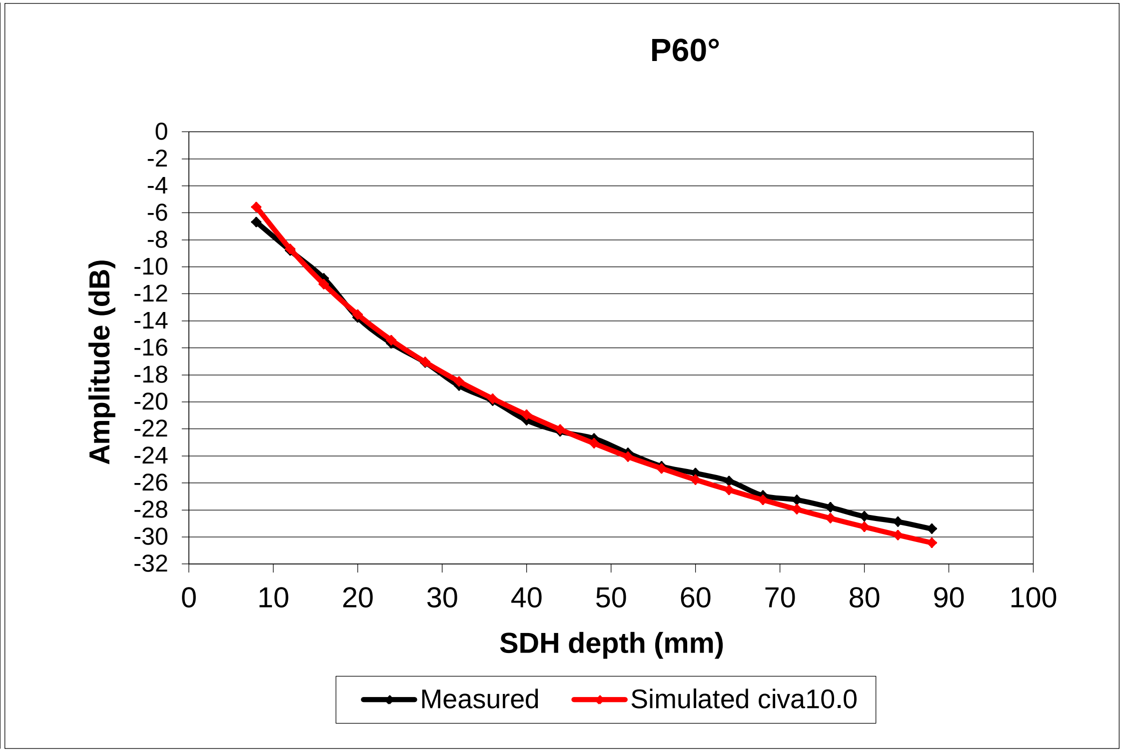


SDH Ø2mm at different depths, comparison results

Immersion probe Ø12.7mm, 2.25MHz, P45°,
Reference: SDHØ2mm at 12mm depth, P0°



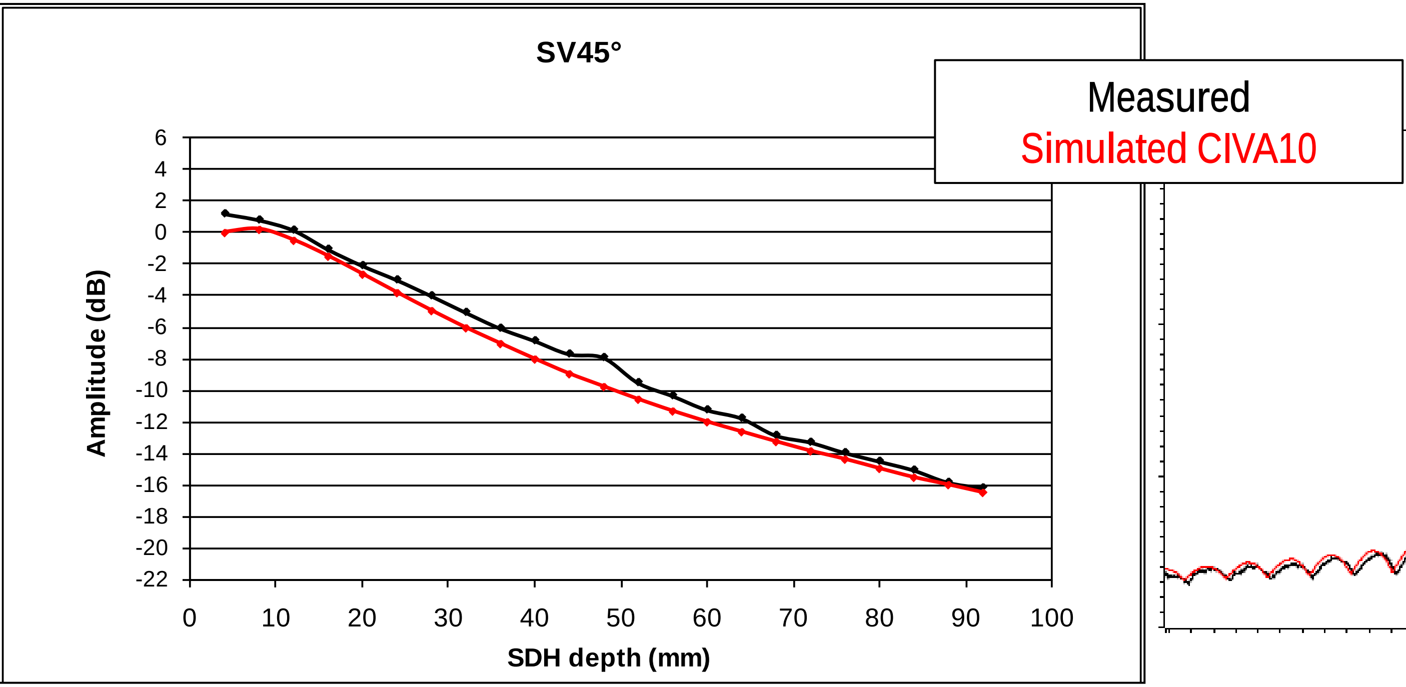
Immersion probe Ø12.7mm, 2.25MHz, P60°,
Reference: SDHØ2mm at 12mm depth, P0°



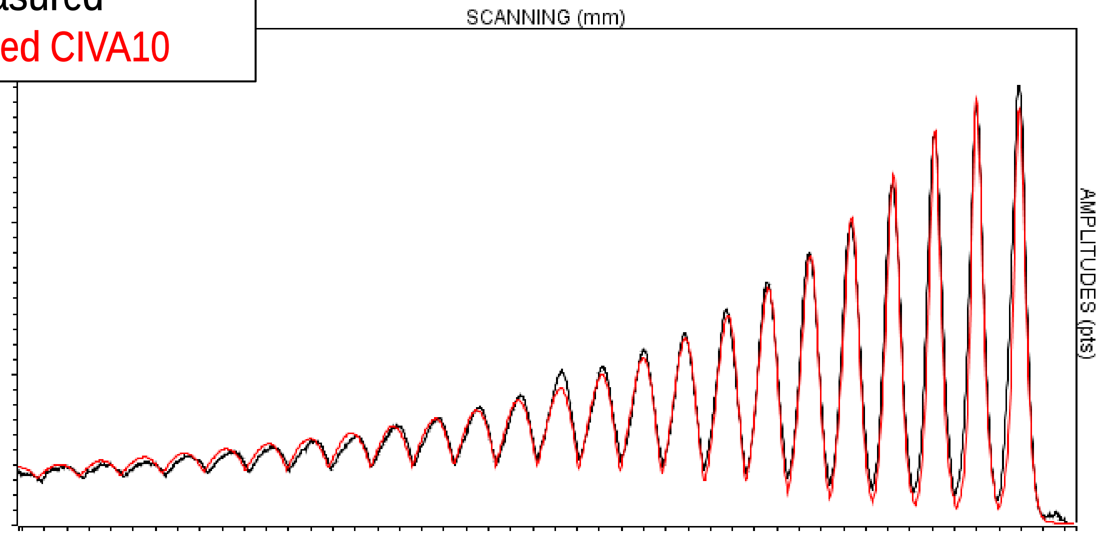
SDH Ø2mm at different depths, comparison results

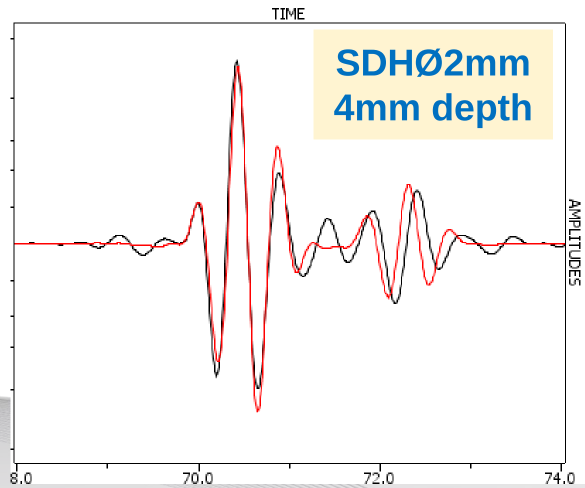
Immersion probe Ø12.7mm, 2.25MHz, SV45°, water path 50mm

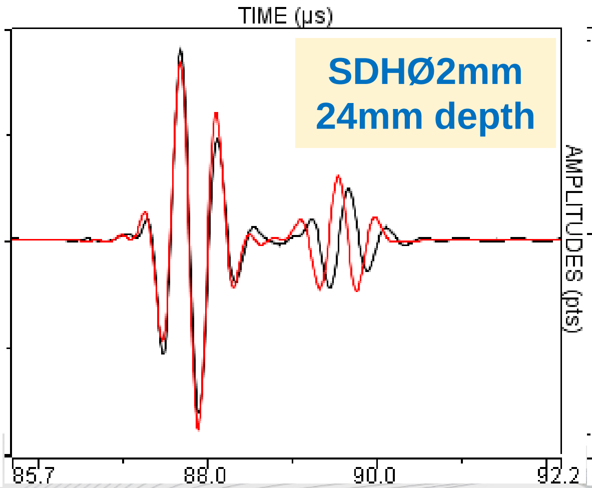
Reference: SDHØ2mm at 12mm depth, P0°

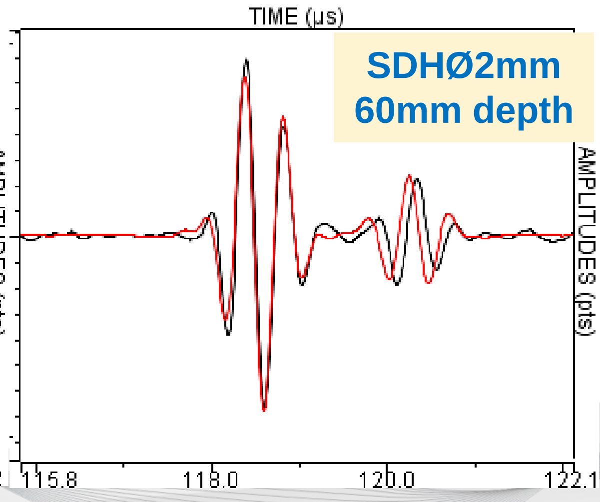


Echodynamic curve









SDH Ø2mm at different depths , comparison results

Gaps in dB between the measured and the CIVA10.0 simulated maximal amplitudes

Contact probe

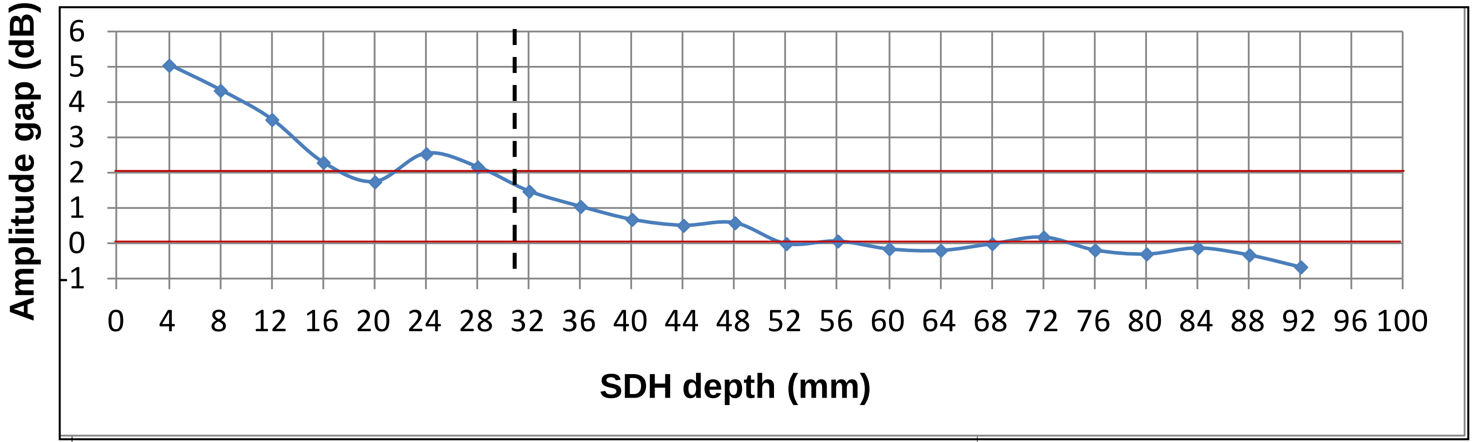
Ref. depth (mm)	8	8	4	20	52	32	4	4	36
Probe dim. (mm)	6,35	12,7	12,7	12,7	22x20	22x20	6,35	6,35	12,7
fc (MHz)	2,25	2,25	2,25	2,25	2,00	2,00	5	5	5
SDH depth / Mode	SV45°	P45°	P60°	SV45°	SV45°	SV60°	P45°	P60°	SV45°
4	1,2	1,3	0,0	3,7	5,1	3,5	0,0	0,0	2,1
8	0,0	0,0	-0,3	2,6	4,3	2,3	-0,4	-0,8	1,8
12	-0,3	-0,6	-0,4	1,4	3,5	1,2	-0,4	-0,3	1,3
16	0,6	-0,7	-0,4	0,6	2,3	0,2	0,0	-0,5	1,2
20	0,9	-0,9	-0,3	0,0	1,7	0,1	-0,4	-0,7	1,1
24	1,5	-0,7	0,1	-0,1	2,5	0,2	-0,2	-0,5	0,4
28	1,1	-0,6	0,4	-0,4	2,2	0,2	-0,6	-0,5	0,2
32	-1,8	-0,6	0,5	0,0	1,5	0,0	pb exp	-0,1	-0,8
36	0,5	-0,7	0,6	0,1	1,1	-0,2	-0,5	-0,5	0,0
40	-0,1	-0,6	0,5	0,3	0,7	-0,1	-0,1		-0,6
44	0,5	-0,6	0,3	0,3	0,5	-0,3	-0,2		-0,1
48	0,2	-0,6	0,7	0,3	0,6	-0,2	-0,1		-0,2
52	-1,4	-0,2	1,3	0,2	0,0	-0,3	-0,9		0,0
56	-1,0	-0,5	1,0	0,2	0,1	0,0	0,1		-0,3
60	-1,1	-0,7	1,0	0,1	-0,1	0,2	-0,4		-0,2
64					-0,2				
68					0,0				
72					0,2				
76					-0,2				
80					-0,3				
84					-0,1				
88					-0,3				
92					-0,7				

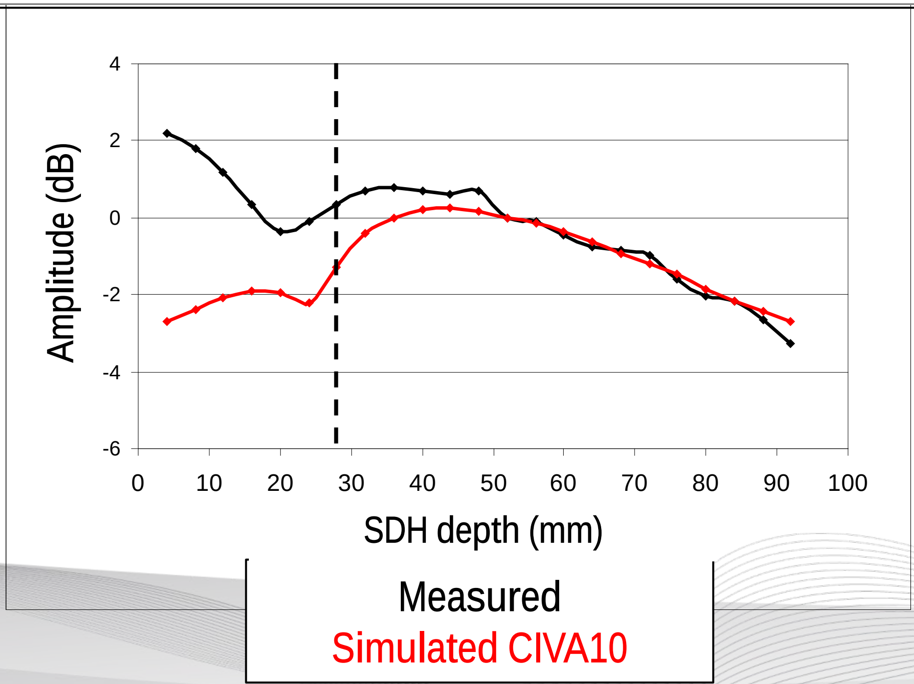
General very good agreement

Discrepancies (1/3)

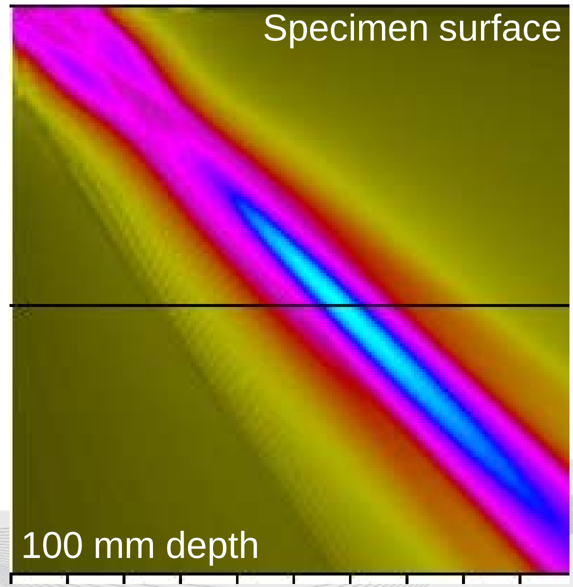
- SDH at the smallest depths (approximation of the radiated field for the interaction computation)

Contact probe, 20mmx22mm, 2.25MHz, SV45° mode





CIVA simulated beam in the specimen



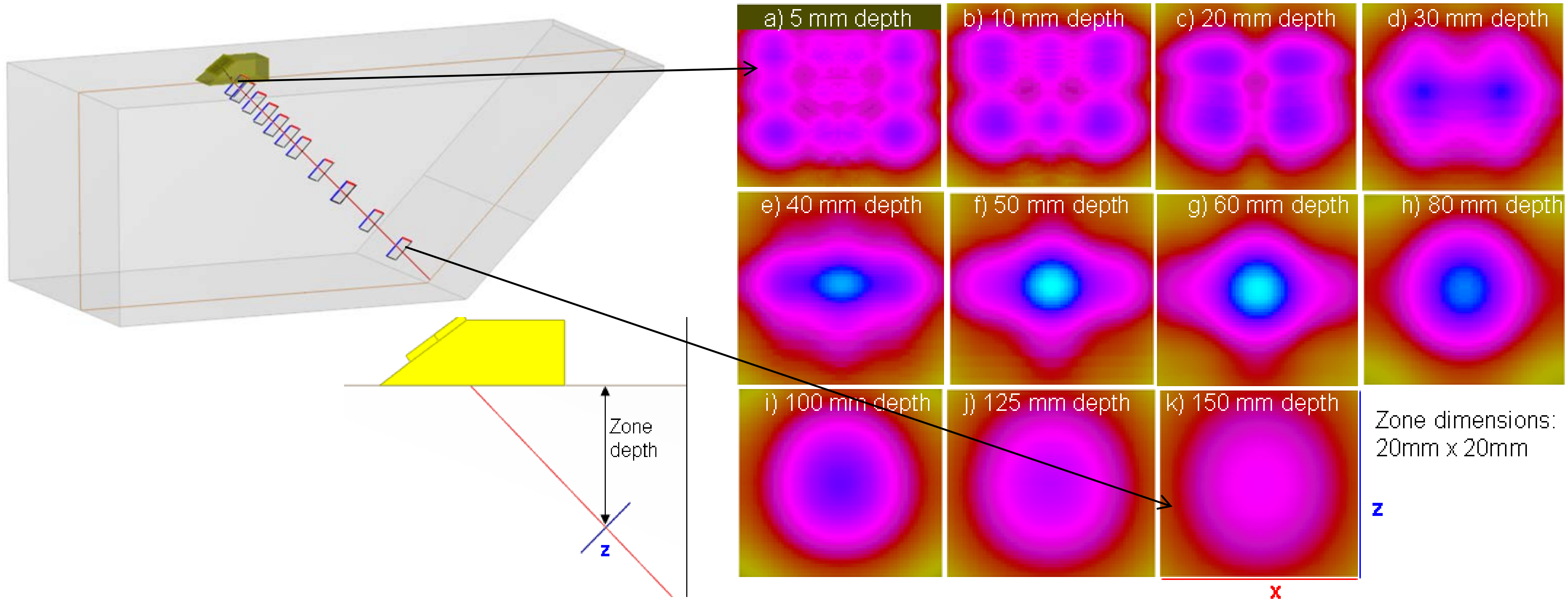
Side Drilled Holes (SDHs)

SDH Ø2mm at different depths, cases of discrepancy

Discrepancies (2/3)

- SDH at the smallest depths : strong amplitude variations in the near field not well taken into account for the defect interaction computation

Contact probe 20mmx22mm, 2MHz, SV45°
CIVA beam computation (displacement module)

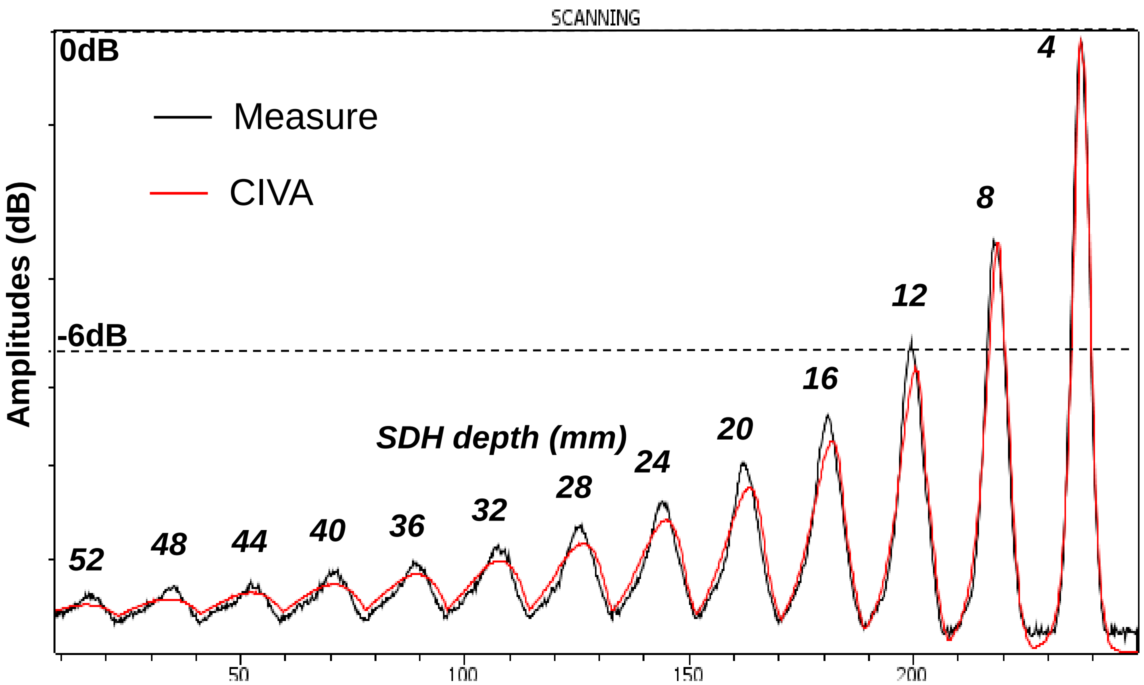


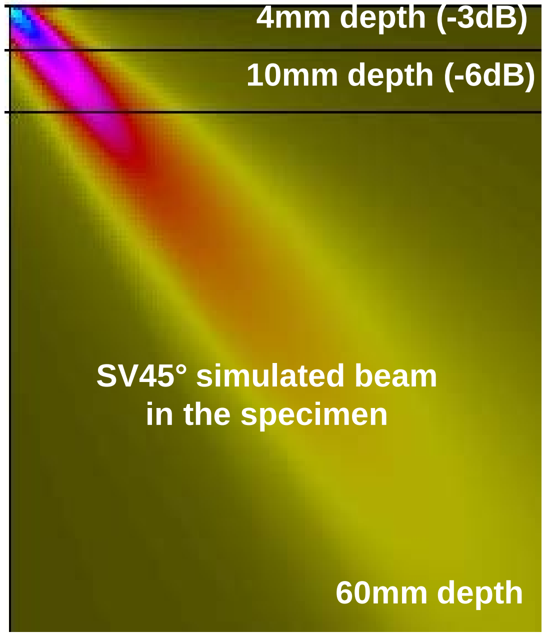
Discrepancies (3/3)

- Small discrepancies for the SDHs in field area of low amplitude

Probe dimension (mm)	6,35
fc (MHz)	2,25
	SV45°
4	1,0
8	0,9
12	1,4
16	1,8
20	1,8
24	2,1
28	2,1
32	2,1
36	2,1
40	2,3
44	2,2
48	2,4
52	2,4
56	
60	

Immersion probe, Ø6.35mm, 2.25MHz, water path 20mm, SV45°
echo-dynamic curves and refracted beam





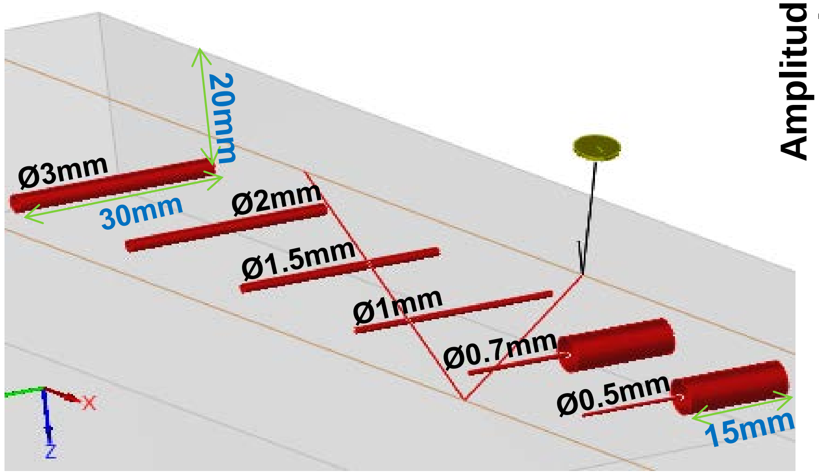
Small differences observed between simulation and measure both in amplitude and echodynamic curves shapes for deep SDHs

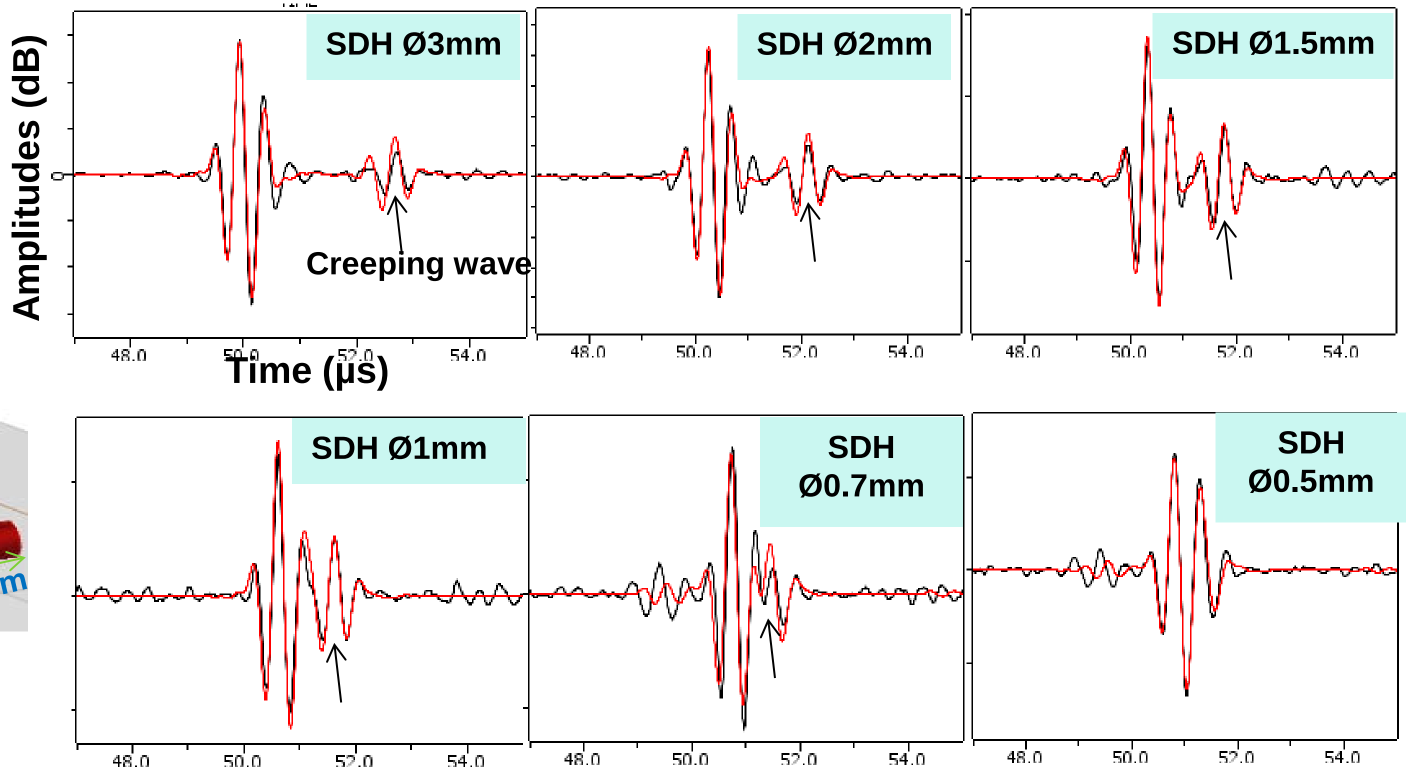
The interpretation of these discrepancies observed in far field is still under study

SDHs of different diameters at the same depth , comparison results

Immersion probe, Ø6.35 mm, 2.25MHz, water path 25 mm, SV45°

Normalized Ascans





Measured
Simulated Civa10

Very good prediction for the complex waveforms and the amplitudes ratio for the two waves (specular and creeping)

CIVA10, validation procedure

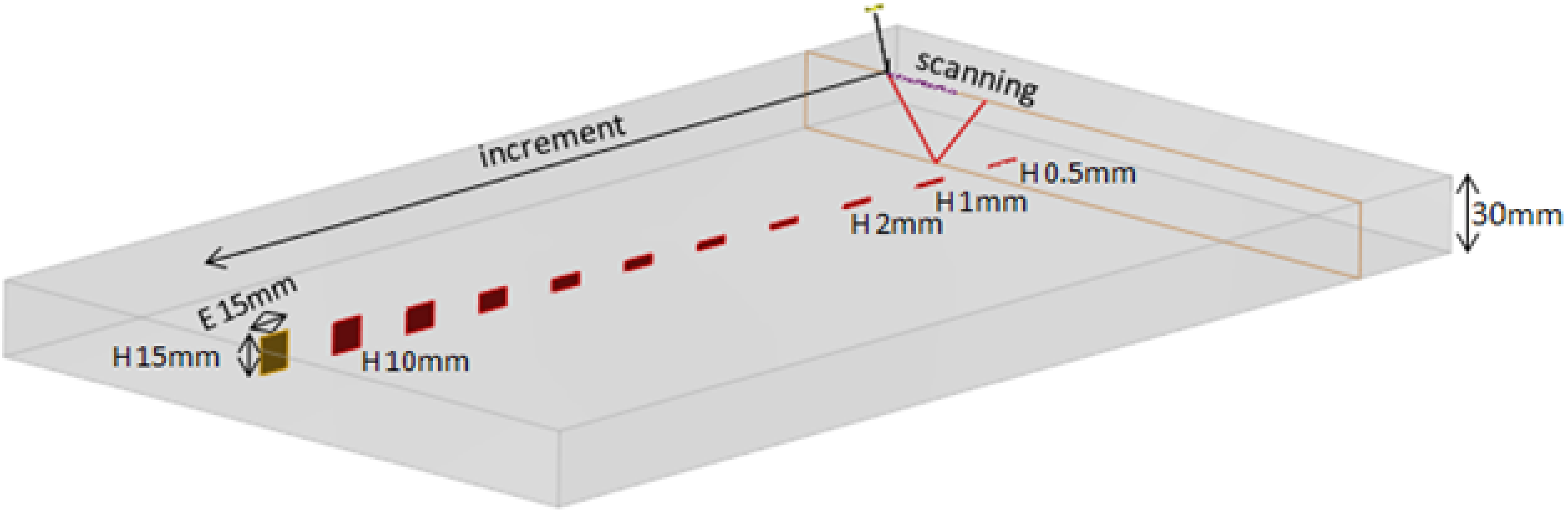
Example of results for 2 experimental validation studies:

1. Specular direct echoes of Side drilled holes
   SOV model

2. SV45° corner echoes of back-wall breaking notches, planar specimen
   KIRCHHOFF model

Conclusion and perspectives

Mock-up: various notch heights varying from 0.5 mm to 15 mm



Inspection with 3 probes: SV45° inspections

2MHz aperture Ø6.35mm

2MHz aperture Ø12.7mm

5 MHz aperture Ø6.35mm

Parameters under investigation: chosen by physical considerations

"notch height": corner echoes = specular echoes / known small defect limitation of the Kirchhoff model used in CIVA

"divergence of the probe" : imprecise field prediction in very far field and possible creeping wave contribution

"notch orientation" or "notch extension": not considered

Immersion planar probe, Ø6.35mm, 5MHz:

- very good agreement for all notches (0.5mm to 15mm height).

Immersion planar probe , Ø6.35mm, 2.25 MHz:

- very good agreement for the highest notches (15mm to 4mm height)
- but strong deviations for the smallest ones (up to 8dB for the 0.5mm notch)

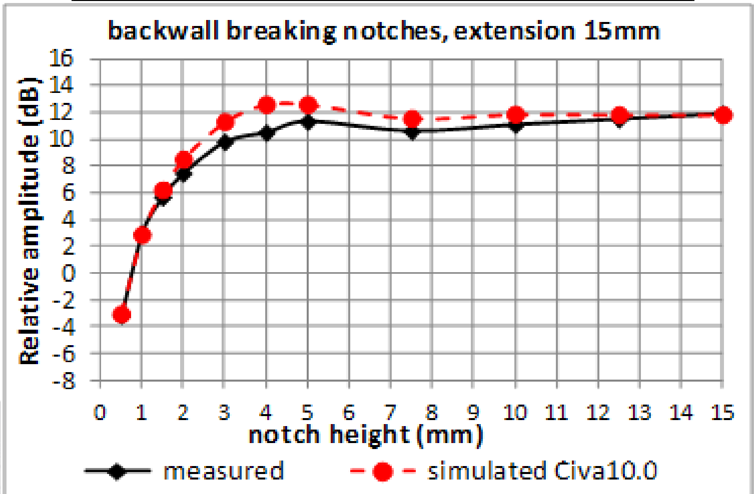
Immersion planar probe, Ø12.7mm, 2.25MHz:

Aim: separate the effects of both the centre frequency and the beam divergence

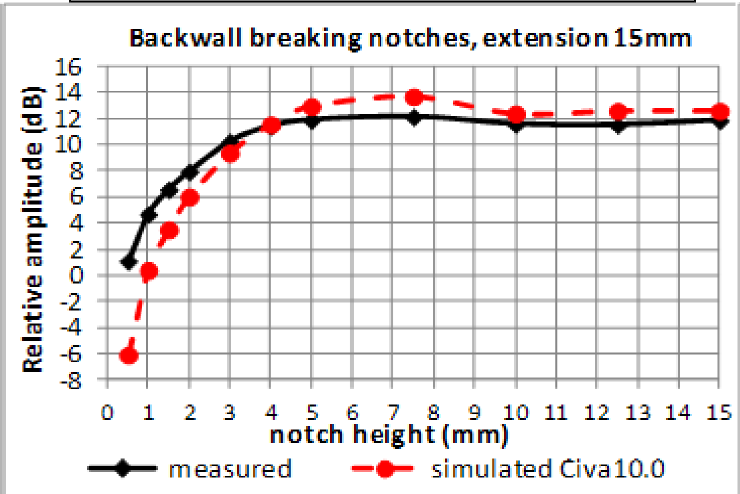
- good agreement for the highest notches is kept
- Compared to Ø6.35mm:significant decrease of the discrepancies on the smallest notches (about 4dB for the 0.5mm notch)

Immersion probes, SV45°, corner echoes of backwall breaking notches
Relative amplitudes

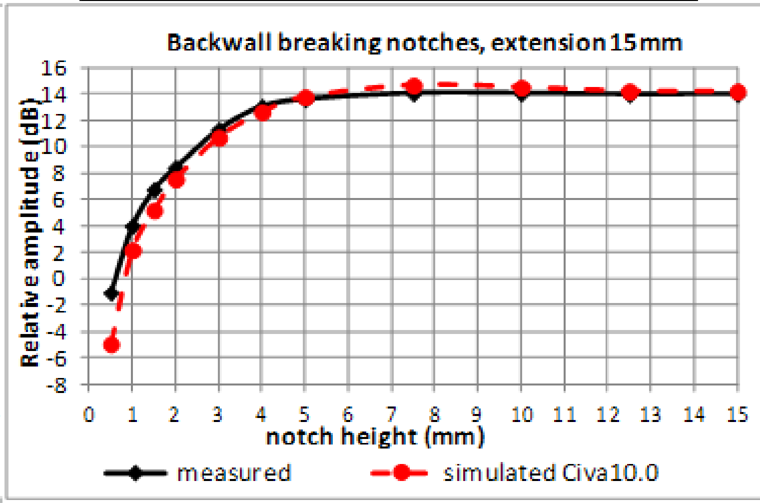
Immersion probe Ø6.35mm, 5MHz



Immersion probe Ø6.35mm, 2.25MHz



Immersion probe Ø12.7mm, 2.25MHz



The previous results and the results not shown here show the reliability of CIVA predictions of SV45° corner echoes inspections.

- In most cases, the observed errors between simulation and measure are below the experimental uncertainties (around +/- 2dB))

- Nevertheless discrepancies are observed
    - on very small notches (0.5mm height notably) inspected at low frequency relatively to the notch height (Ø6.35mm and Ø12.7mm, 2MHz probes)

or/and

- in the case of examination with divergent probes (Ø6.35mm, 2MHz probe).

The strongest errors are obtained when these two limitations are combined.

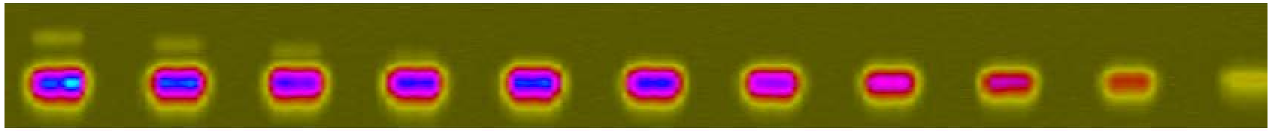
SV45° corner echoes of back-wall breaking notches

Comparison results

Immersion planar probe, Ø6.35mm, 5MHz

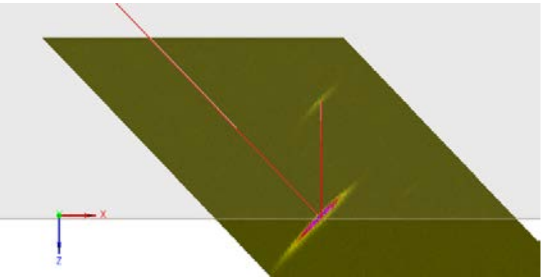
Measured Cscan

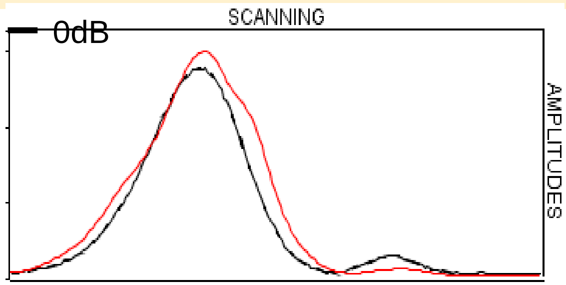
H=15mm H=4mm H=0.5mm

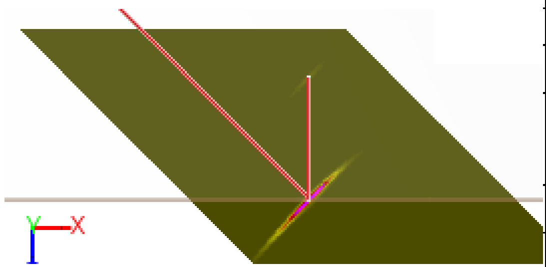


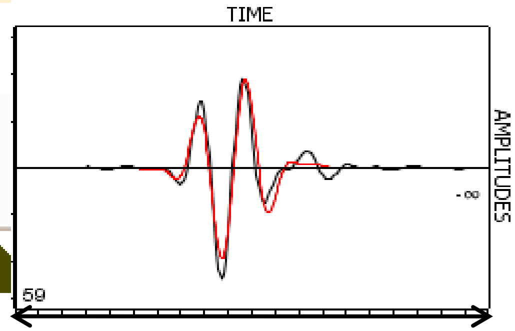
Measured SV true Bscan | **Echodynamic curves** | **CIVA SV true Bscan** | **Ascans**

Notch 15mm height

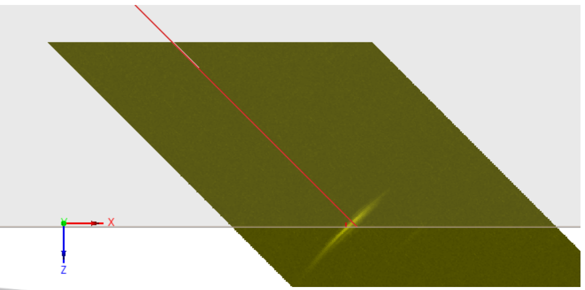


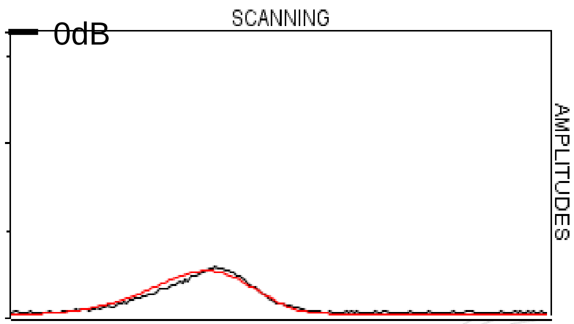


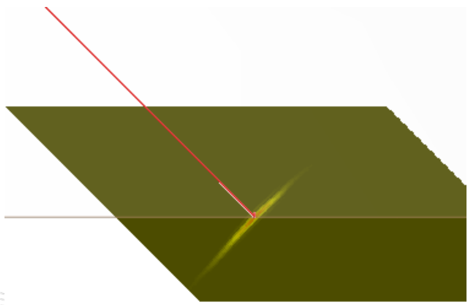


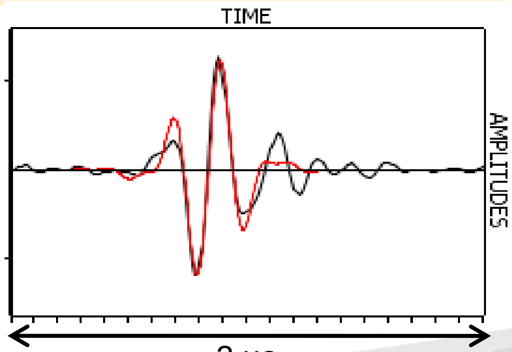


Notch 0.5mm height









Measured

Simulated Civa10

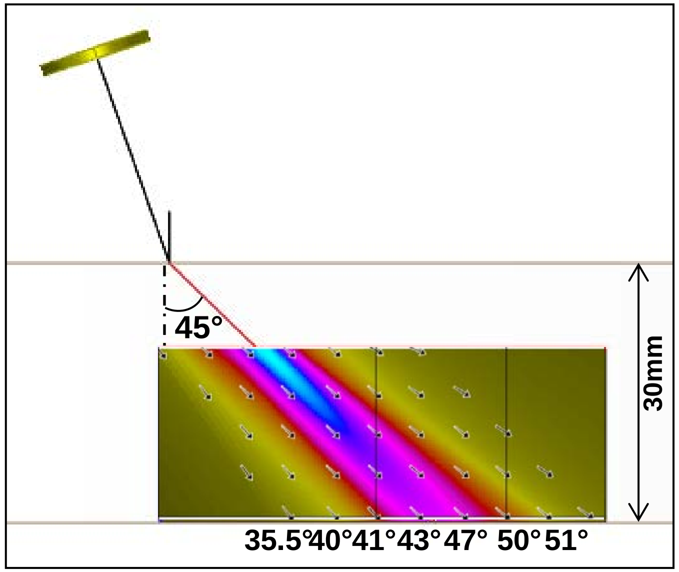
SV45° corner echoes of back-wall breaking notches

Comparison results, cases of discrepancies

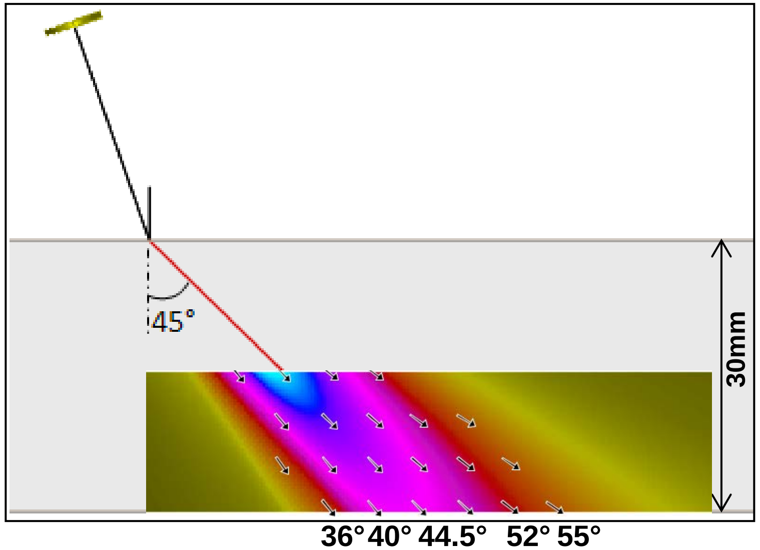
Discrepancies:

- Small notch sizes: limitations of the Kirchhoff approximation which is a high frequency approximation valid for large *ka* (*k* wave number, *a* characteristic dimension of the flaw)
- Probe divergence: imprecise field description in very far field and possible creeping wave contribution

Immersion probe Ø12.7mm 2.25MHz, SV45°

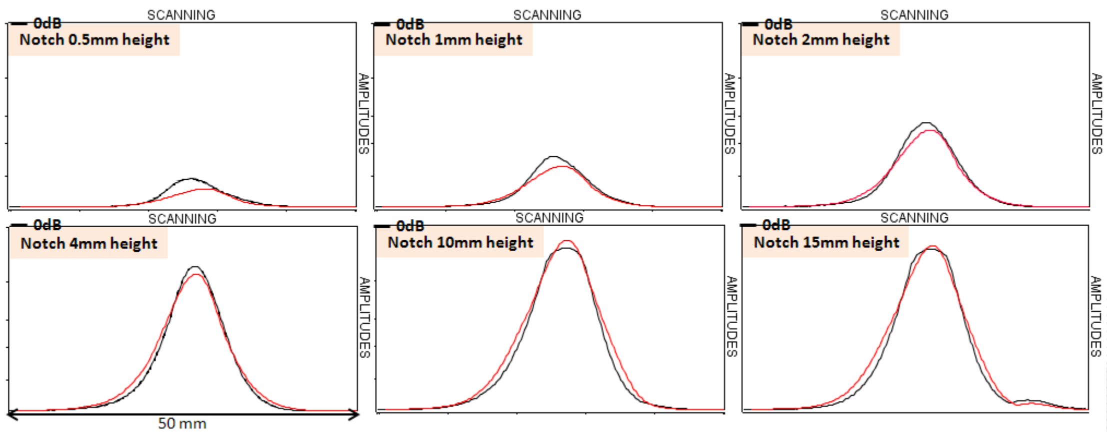


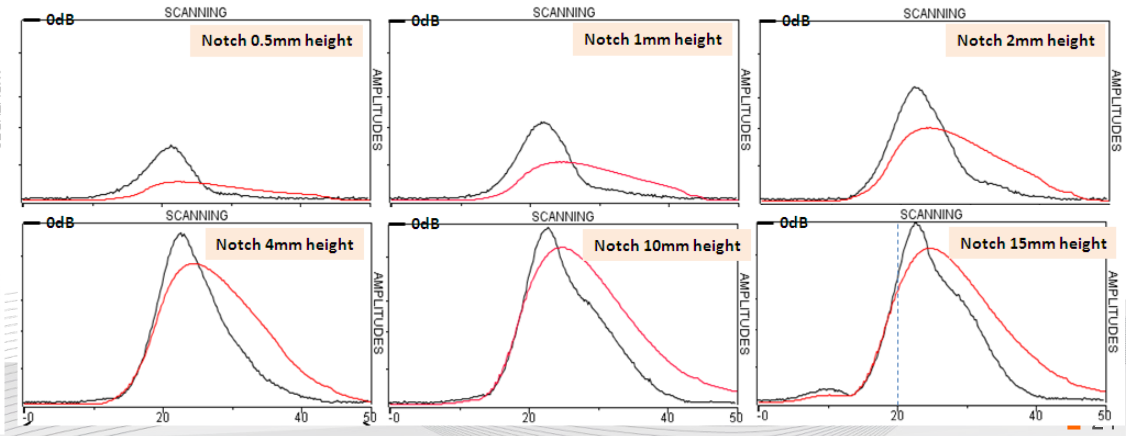
Immersion probe Ø6.35mm 2.25MHz, SV45°



Measured

Simulated Civa10





CIVA10, validation procedure

Example of results for 2 experimental validation studies:

1. Specular direct echoes of Side drilled holes
   SOV model

2. SV45° corner echoes of back-wall breaking notches, planar specimen
   KIRCHHOFF model

Conclusion and perspectives

Results of a validation study aiming at quantifying the reliability of CIVA UT predictions on canonical cases were presented.

Selection of cases concerning

- SDH reflectors
- SV45° corner echoes of back-wall breaking notches at 2MHz and 5Mhz.

These results show that the CIVA predictions are very reliable in most cases and indicate also cases of discrepancies.

Work is in progress at CEA LIST in order to improve the models in these cases.

Other CIVA validation studies are in progress.

The validation data are made available on the web site of EXTENDE

(distributor of CIVA)

EXTENDE CIVA

NON-DESTRUCTIVE-EVALUATION

Home News Resources CIVA Validation Training Consulting R&D About us

English

- **SIDE DRILLED HOLES**
- **SIDE DRILLED HOLES AT DIFFERENT DEPTHS**

In this part we consider echoes from Ø2mm Side Drilled Holes (SDH) at different depths with different probes:

- Mono-element Immersion probes
- Mono-element Contact probes
- Phased-Array Contact probes

The results show a very good agreement. It can be noticed that Civa generally underestimates the amplitude of the echoes in the very near field (less than 4dB discrepancy).

Back to the UT Module Validation menu
Back to the Validation menu

- **SIDE DRILLED HOLES AT DIFFERENT DEPTHS AND IMMERSION PROBES**

Global overview:

IMMERSION PROBES	2.0MHz Ø19mm	2.25MHz Ø12.7mm	2.25MHz Ø6.35mm	2.4MHz Ø20mm	4.5MHz Ø12.7mm	4.7MHz Ø6.35mm
P0°	Done	Done	Done	Done		
P45°				Done		Done
P60°				Done		Done
SV45°			Done	Done	Done	Done
SV50°					Done	Done
SV55°					Done	Done
SV60°				Done	Done	

SEARCH

CIVA NDE 10

CIVA DISTRIBUTION

- InsightKK
- Jaewoo
- Matrix U/E
- NDTS

PARTNERS

cea

GROUPE CEDRAT

cea list

énergie atomique • énergies alternatives