NDT-CE 2022
ZURICH
SVTI ASIT

August 16-18, 2022

The International Symposium on Nondestructive Testing in Civil Engineering is coming to Zurich, Switzerland.

Application of simulation software for NDT in Civil Engineering

Fabrice, FOUCHER, *Roman FERNANDEZ (EXTENDE)*
Daniel ALGERNON (SVTI)
Vincent DORVAL, Nicolas LEYMARIE, Stéphane LEBERRE (CEA)

SVTI ASIT EXTENDE CIVA

FROM RESEARCH TO INDUSTRY cea tech

Outline

- Introduction to modelling benefits and capabilities

- Applications
  - Sound Field characterization
  - Defect response scenarios
  - Impact of rebars on detectability
  - Parametric studies, sensitivity analysis and POD curves

- Conclusion

NDT in Civil Engineering

- Context:
  - **General aging** of civil engineering infrastructures
  - **Needs efficient and reliable NDT method** to be developed and carried out to assess structural integrity of assets and decide of repairs/replacements
  - NDT needs preliminary tests and investigations to be developed and qualified before implementation

- Benefits of simulation:
  - « **Virtual testing** » to help NDE method **development**:
    - Wide range of testing scenario to converge to a promising solution before implementing physical trials,
    - Gives insights for a better understanding and then mastering of underlying physical phenomena,
    - Less physical mock-ups and less iterations: Save time and money
  - Easy and fast to generate **large amount of data (parametric** variations) needed for sensitivity analysis and NDE process **qualification**

SVTI ASIT EXTENDE CIVA cea tech 0%

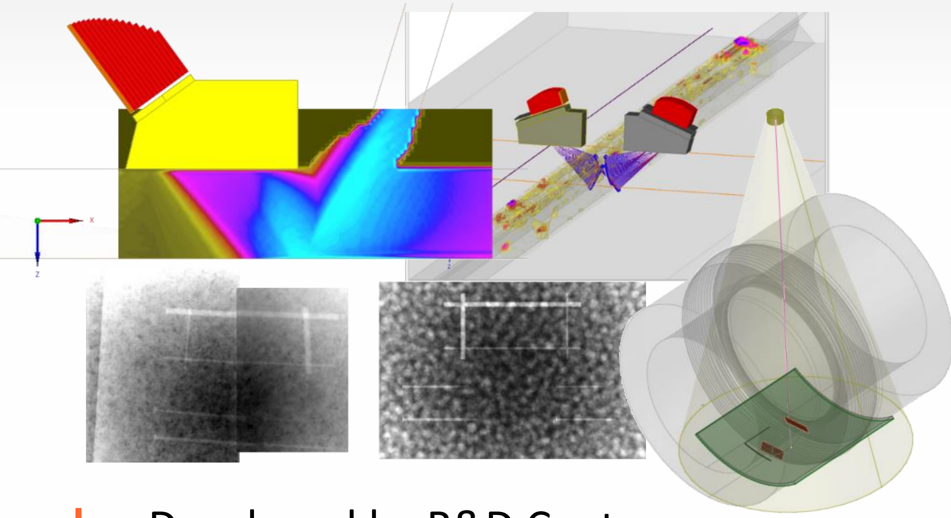
CIVA software in a few words

- Software platform **dedicated** to NDE simulation & analysis

- Multi-technique **Simulation**:
  - **UT: Ultrasounds**
  - **RT-CT: Radiography & Computed Tomography**
  - ET: Eddy Current
  - GWT: Guided Waves
  - SHM-GWT: Structural Health Monitoring by Guided Waves
  - TT : Thermography Testing

- UT Data **Analysis**

CIVA N·D·E 2021



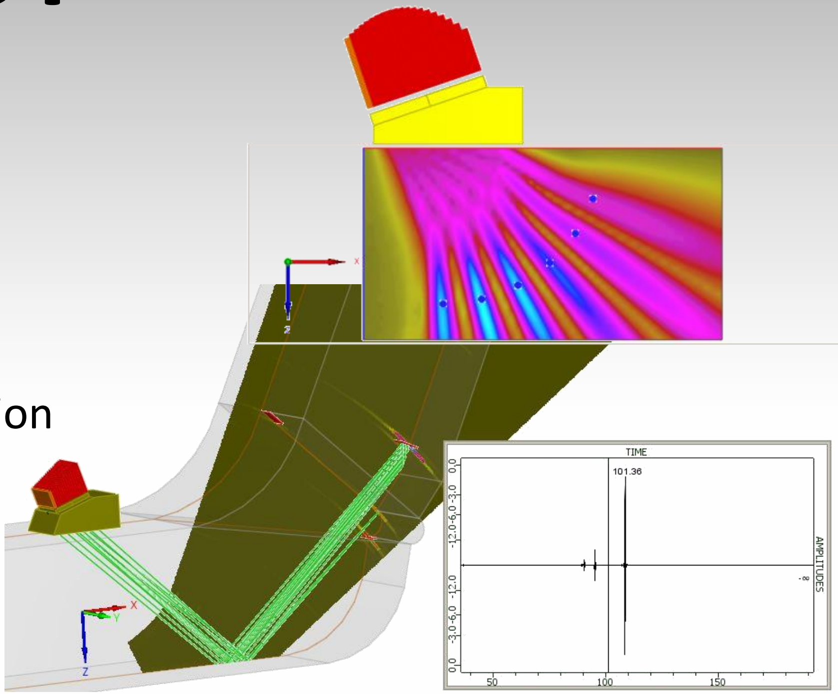
- Developed by R&D Center : **CEA LIST**

- Exclusive Distribution : EXTENDE CIVA

- More than 300 different companies using CIVA worldwide

SVTI ASIT · EXTENDE CIVA · cea tech

CIVA UT

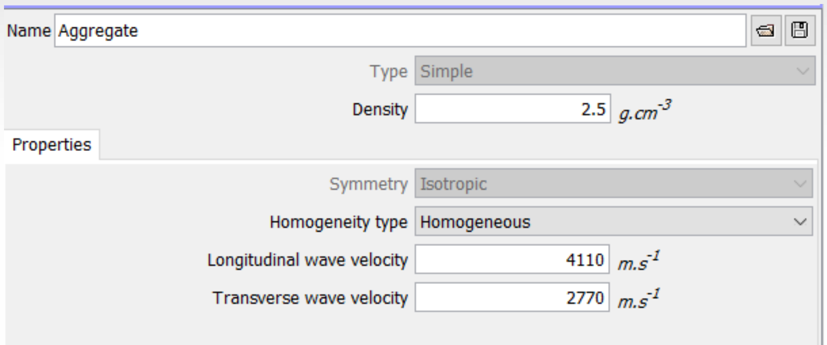


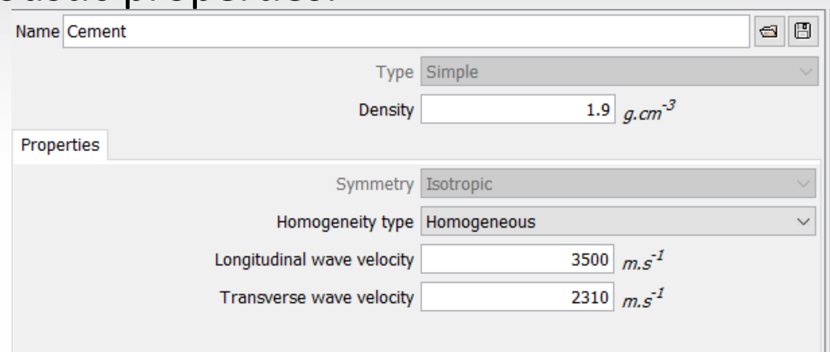
- **CIVA UT includes:**
  - Beam Calculation tool
  - PA settings calculations (delay laws, etc.)
  - Inspection Simulation tool (predict echoes)
  - Sensitivity analysis & POD curves computation

- **Modelling approaches:**
  - Historically based on **fast semi-analytical models** (i.e., “Ray-based” methods: Pencil models, Kirchhoff & GTD beam/flaw interaction models, etc.)
  - Implementing **also FEM solvers**:
    - In house FEM solver is based on high-order spectral Finite Elements showing very good performances compared to traditional generic FEM solvers
    - Also implements **hybrid SA - FEM** approaches (Beam – Beam/Defect interaction) to benefit from advantages of each method

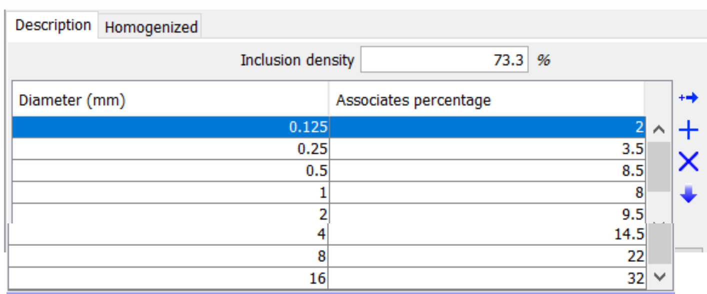
CIVA UT for concrete

- **Current version already includes a homogenized model for concrete:**
  - Description of aggregates and cement acoustic properties:



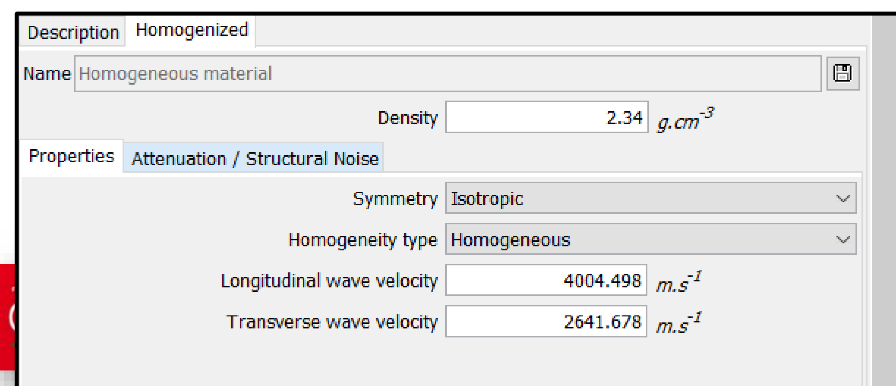


  - Description (table) of aggregates distribution in the concrete block



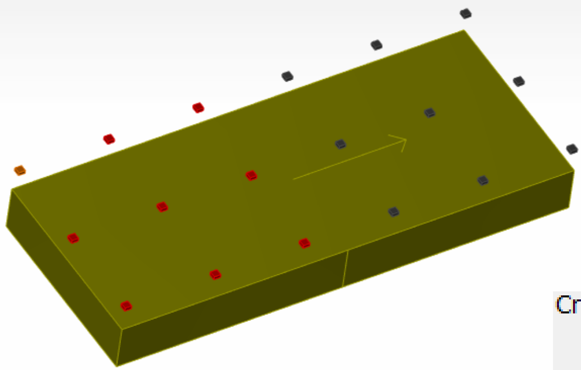
Diameter (mm)	Associates percentage
0.125	2
0.25	3.5
0.5	8.5
1	8
2	9.5
4	14.5
8	22
16	32

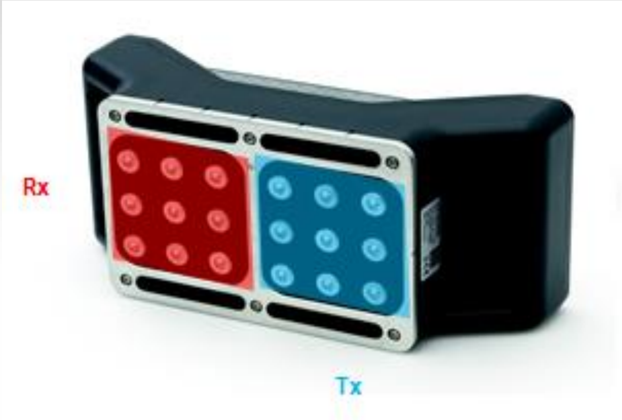
  - **Waterman & Truell** homogenization implemented gives mean acoustic properties and attenuation data (+ possibly structural noise)



CIVA UT for concrete

- Now also includes **dry contact 0° shear wave probes**, reflecting start of the art technique for concrete





Crystal shape

Pattern	Matrix phased array
Solicitation type	Shear vibration (along X)

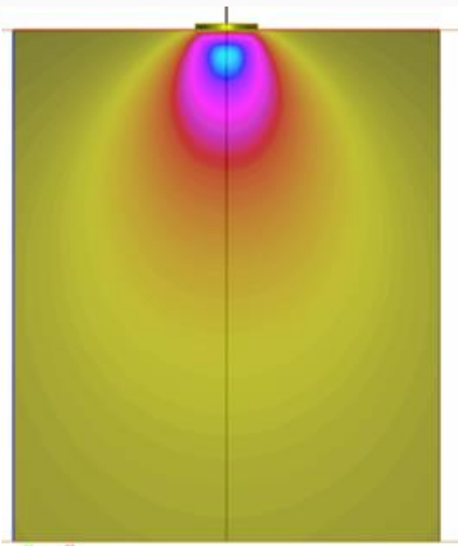
- **FEM solvers for concrete** inspection modelling (non homenized approach) also being implemented (in progress)

See the presentation in this session: "FEM-based simulation tools for ultrasonic concrete inspection" (Dr Dorval, CEA)

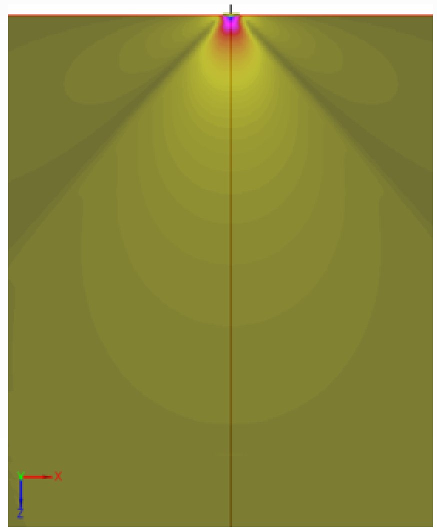
Probe selection and characterization

- Compare **Ultrasound Fields** for different probes :
  performed in the concrete block described before

L waves 0°
Single Element
54kHz

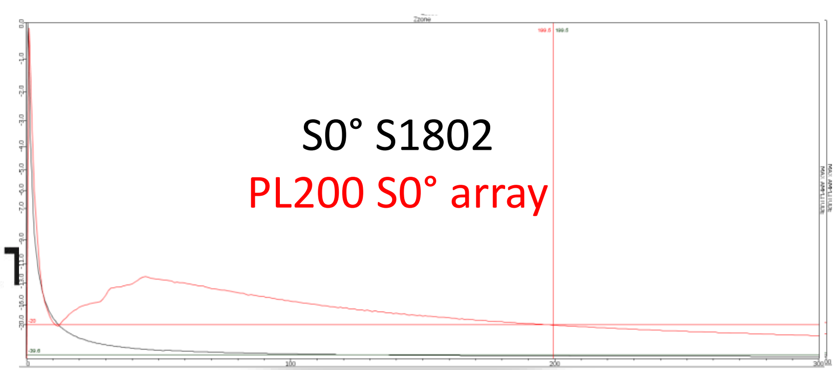


S waves 0°
Single Element S1802
50kHz



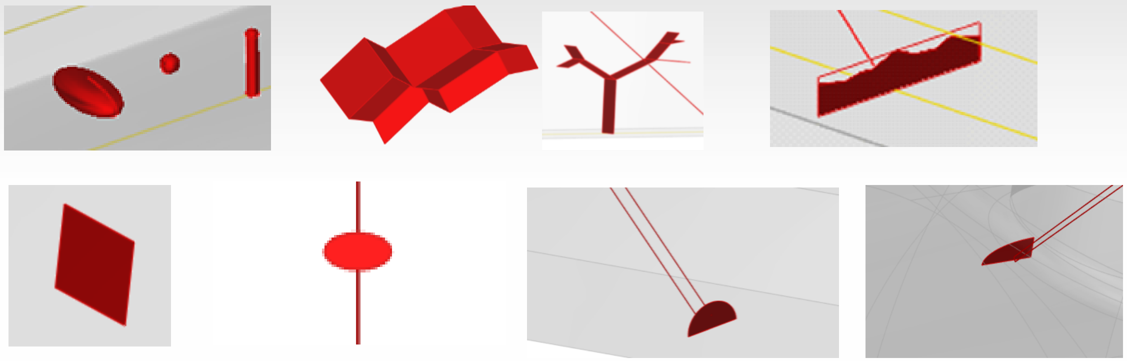
S waves 0°
« PL200 » Array probe
50kHz

- Beam profile extractions :
  (i.e., field amplitude vs depth)

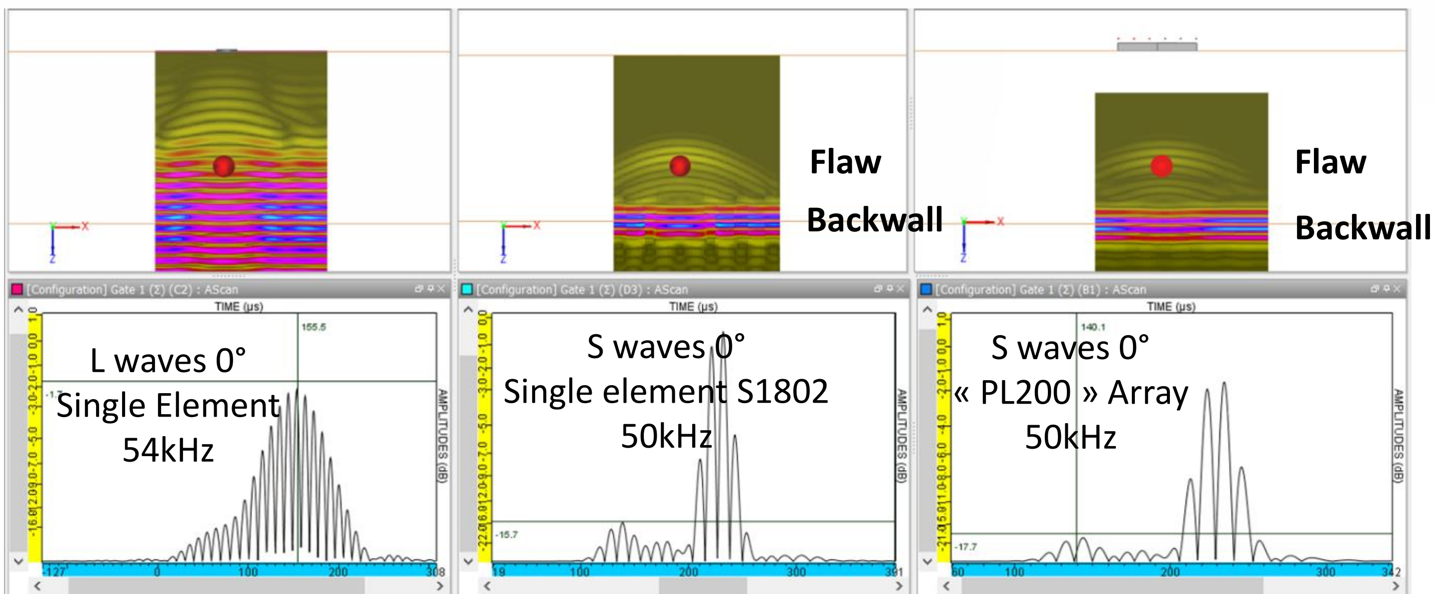


Defect response simulation

- Many damage/defect scenarios can be simulated:
  - Cracks, holes, notches, clusters of voids (« honeycomb »), delaminations, etc.



- Example of signal obtained with a Φ 24 mm void spherical flaw at 200mm depth in the same concrete block (normalized vs backwall acho at 300mm depth) for the 3 probes:



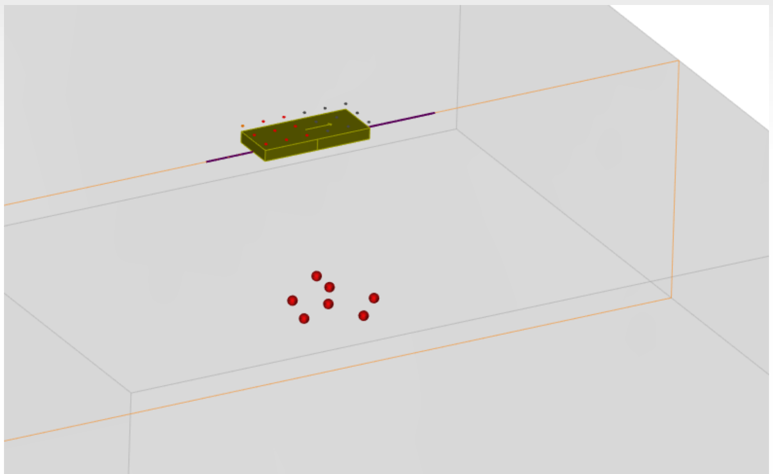
B-Scan views

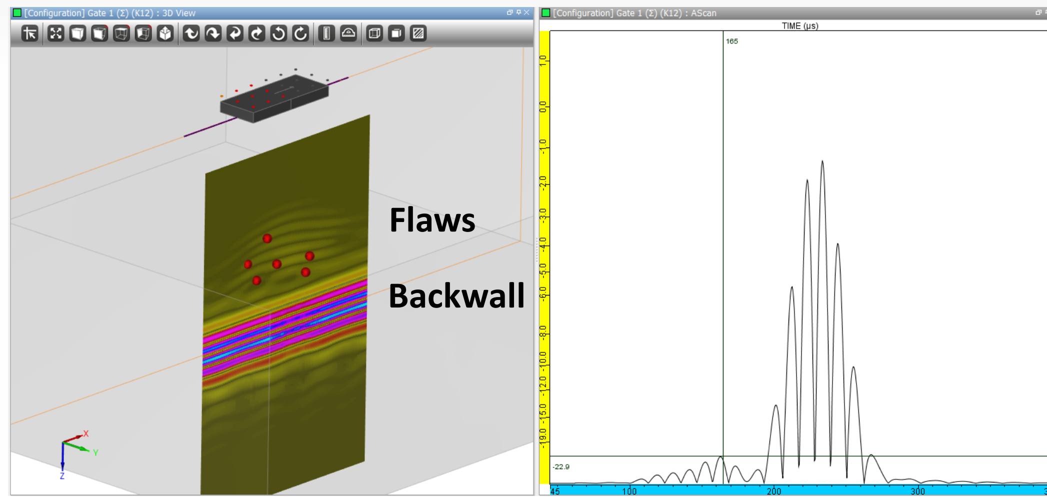
A-Scan views

Defect response simulation

- « Honeycomb » modelled by a set of seven Φ 24 mm void spherical flaws located around 200mm depth :

Just a few minutes to simulate this scan and obtain these B-Scan/A-Scans images





- Knowing noise level versus reference echo (such as backwall echo), you can predict detectability for many defect scenarios

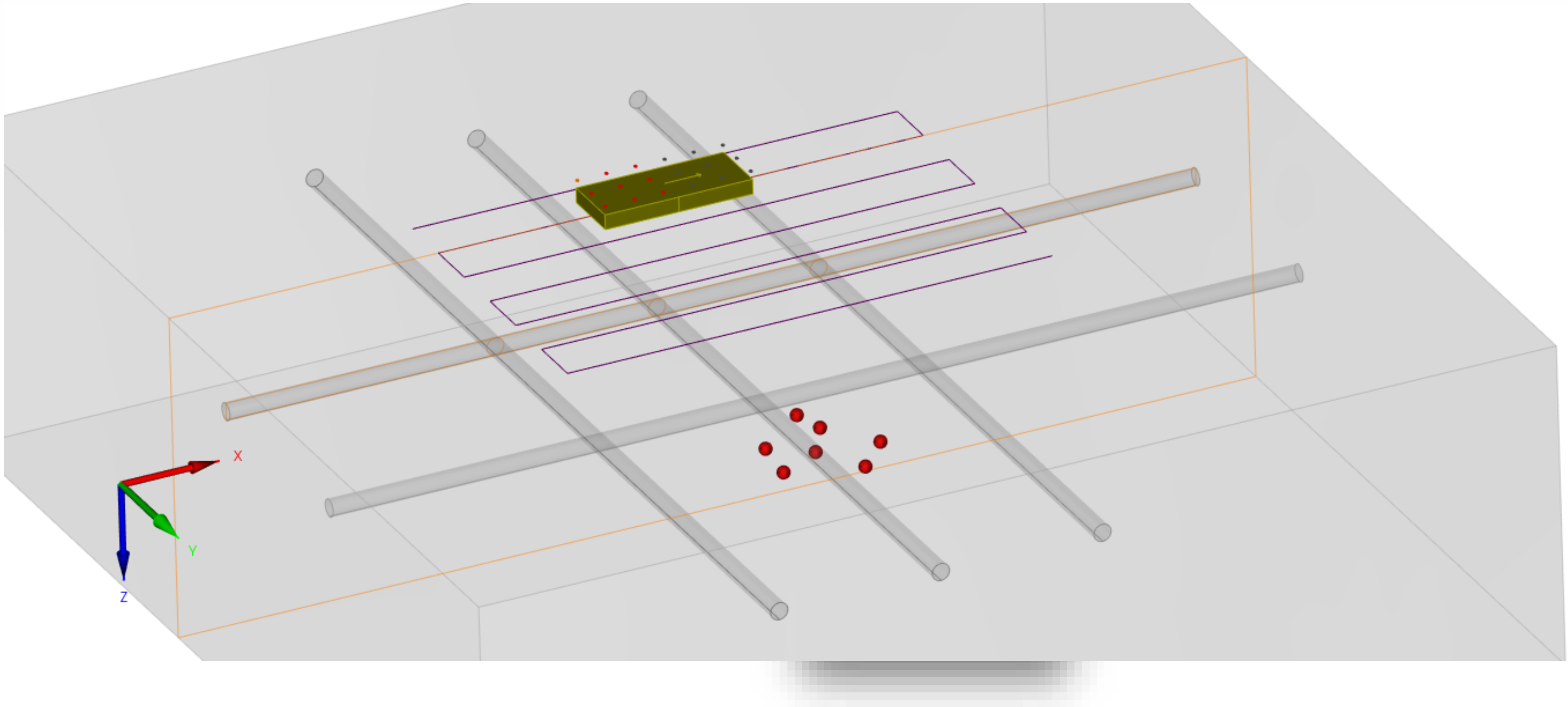
SVTI ASIT   EXTENDE CIVA   cea tech

Impact of rebars on flaw detectability

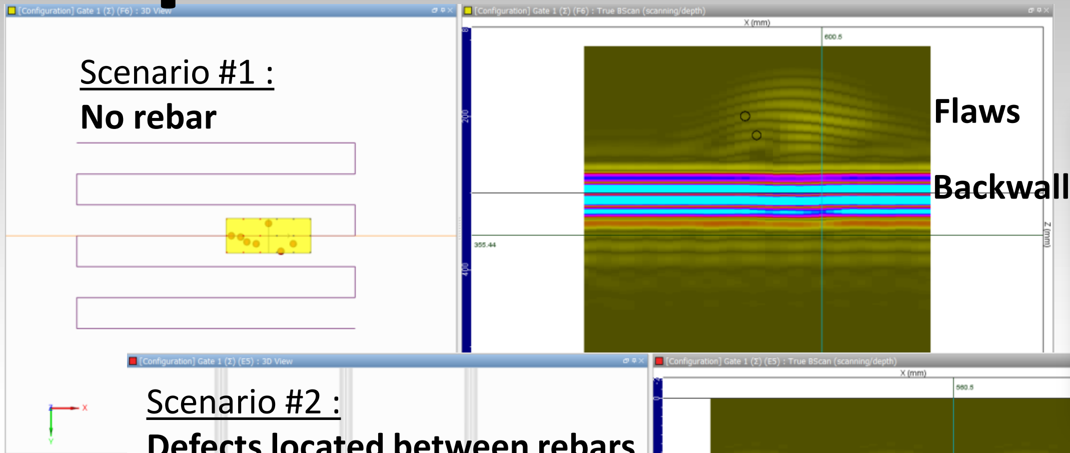
- **Reinforcement steel bars** in concrete parts may interact with the sound beam : Additional echoes, shadowing on flaw echoes, etc.

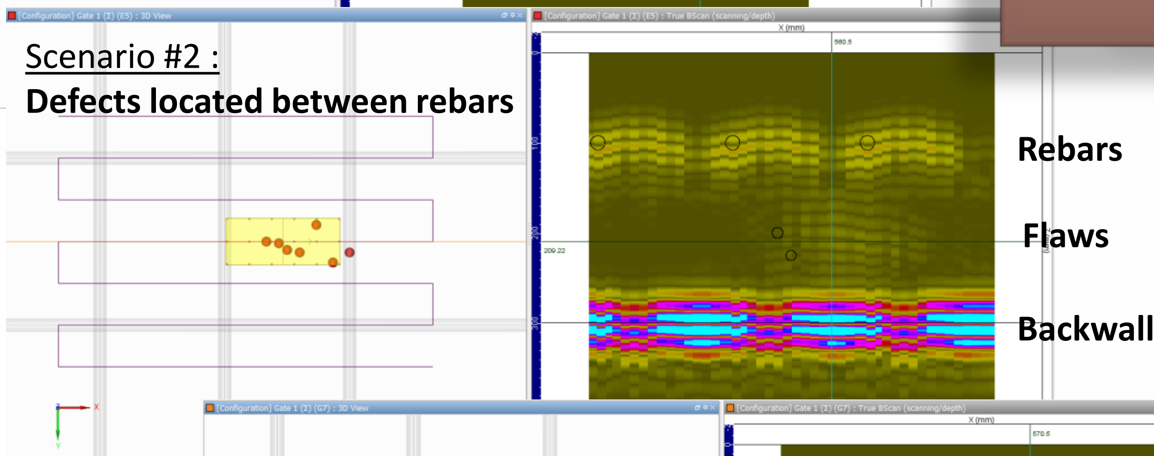
- Modelling helps to **understand** phenomena and to **predict flaw detectability** depending on rebars location, flaw location and sizes, etc.

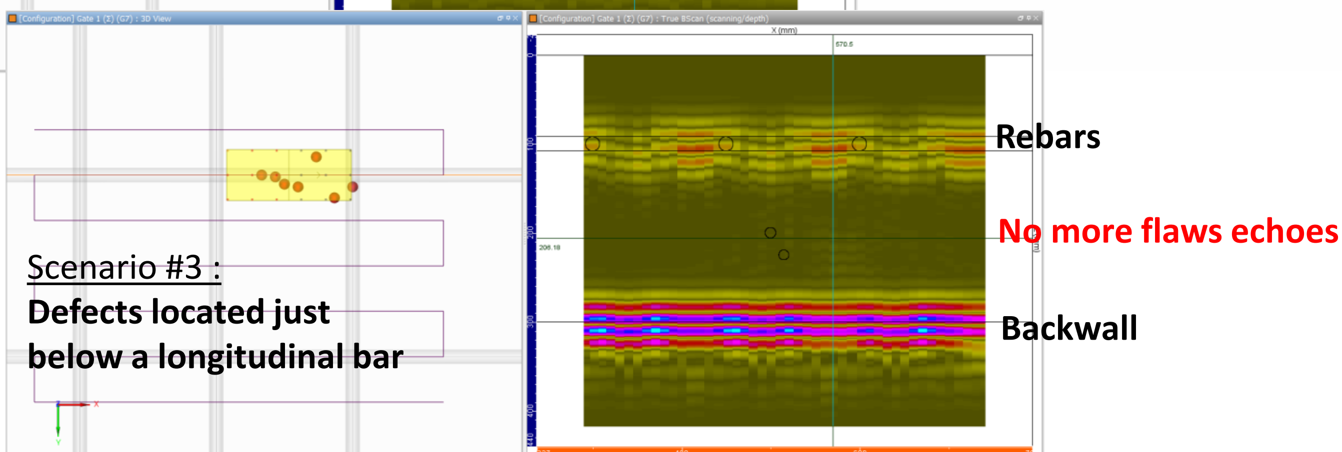
- <u>Illustrative example:</u>
  - Same probe and defect as before with a grid of nine Φ 24 mm steel bars



Impact of rebars on flaw detectability







Modelling help to predict **worst case scenario** and investigate solutions to overcome such situation (reduced scanning step, scanning from another side, etc.)

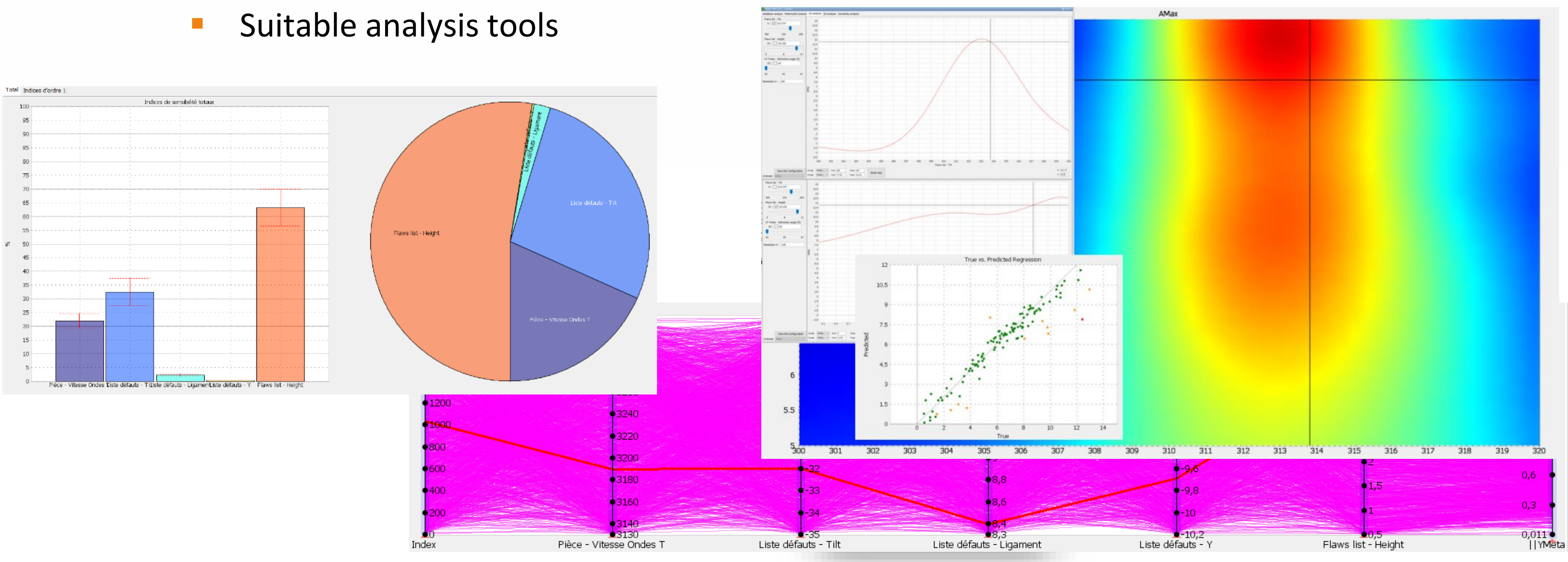
ASIT CIVA

Parametric studies

- **Optimization** or **reliability** analysis studies needs
  a quite large amount of data to provide reliable metrics and statistical analysis

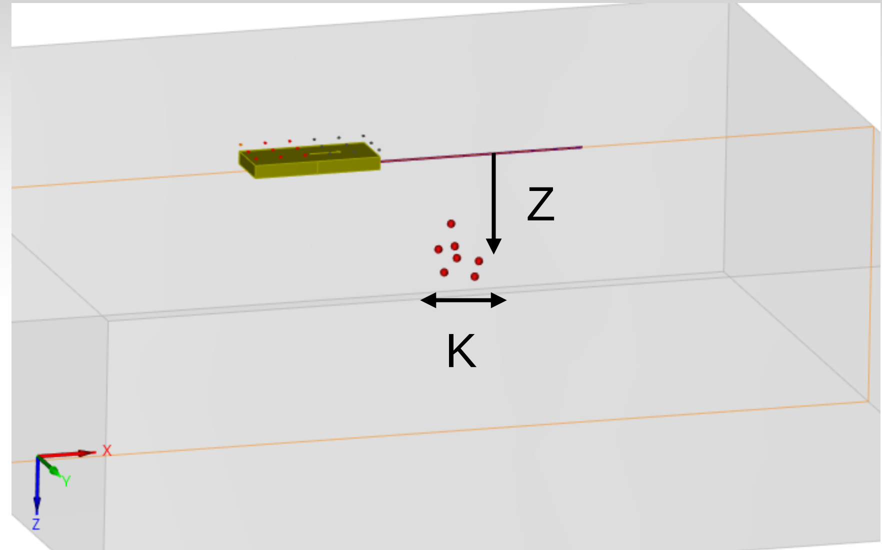
- **Very costly** with a pure experimental approach

- Modelling constitutes an **alternative approach**. CIVA features :
  - Easy **monitoring** of many parameters
  - **Fast** computation times
  - **Metamodels** (surrogate models based on smart interpolators)
  - Suitable analysis tools



Parametric study example

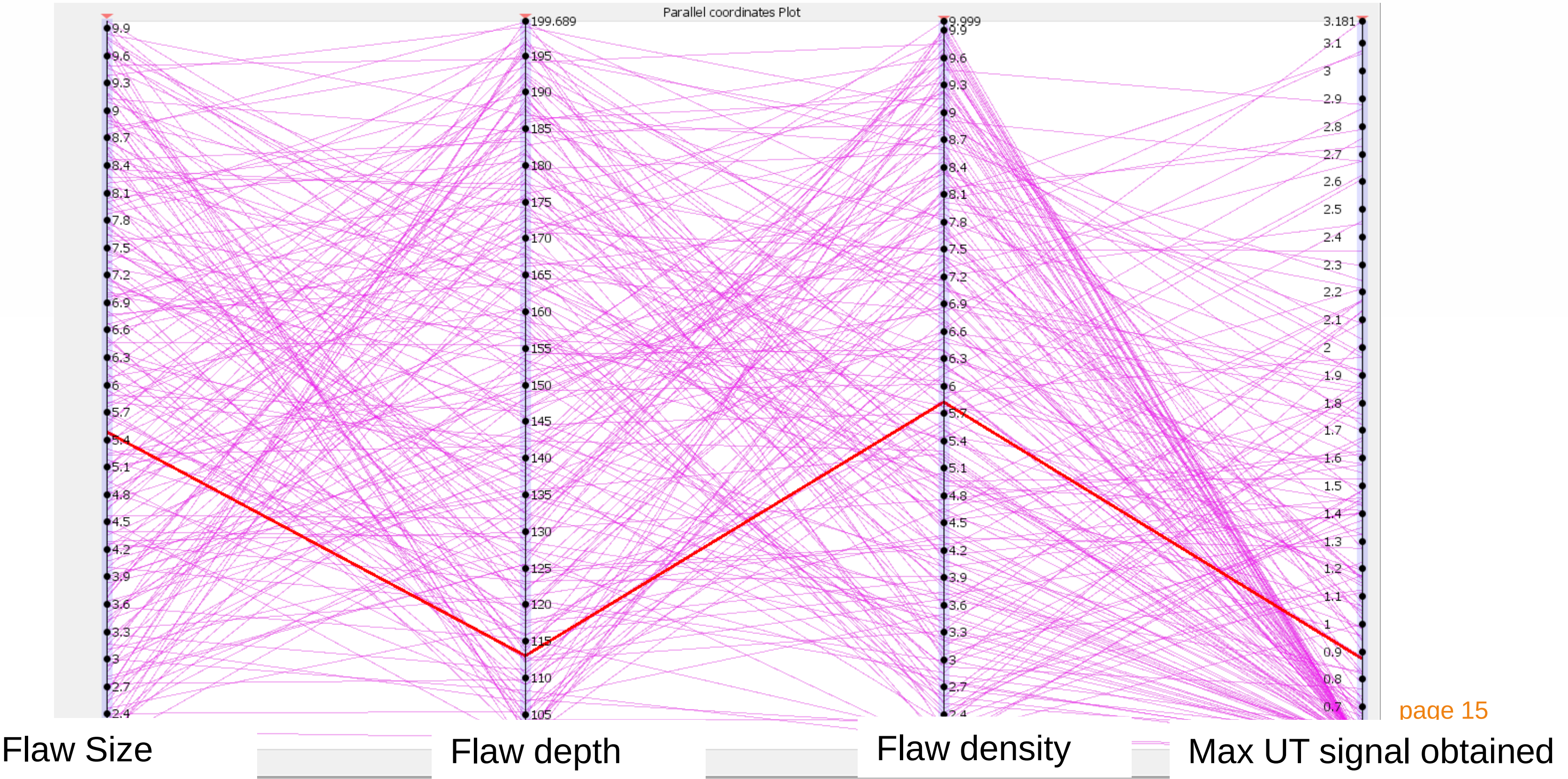
- Design of experiment :
  - 200 simulations
  - 3 variables :
    - Flaw depths « **Z** »
    - Flaw sizes « **Radius** »
    - Void distribution density in the whole honeycomb « **K** »
  - Formulae can be defined to link together flaw properties



Nu...	Category	Tag	Type	Min	Max	Size	Current v...	Dim
1	Variable	RADIUS	LHS	2.0	10.0	200	4.409	☑
2	Formula	RADIUS1	Equation	6.0	7.0	200	4.409	☐
3	Formula	RADIUS2	Equation	6.0	7.0	200	4.409	☐
4	Formula	RADIUS3	Equation	6.0	7.0	200	4.409	☐
5	Formula	RADIUS4	Equation	6.0	7.0	200	4.409	☐
6	Formula	RADIUS5	Equation	6.0	7.0	200	4.409	☐
7	Formula	RADIUS6	Equation	6.0	7.0	200	4.409	☐
8	Variable	Z	LHS	100.0	200.0	200	100.358	☑
9	Formula	Z1	Equation	175.0	275.0	200	125.358	☐
10	Formula	Z2	Equation	120.0	220.0	200	70.358	☐
11	Formula	Z3	Equation	162.0	262.0	200	112.358	☐
12	Formula	Z4	Equation	175.0	275.0	200	125.358	☐
13	Formula	Z5	Equation	154.0	254.0	200	104.358	☐
14	Formula	Z6	Equation	157.0	257.0	200	107.358	☐
15	Variable	K	LHS	2.0	10.0	200	2.024	☑
16	Formula	X	Equation	466.0917...	519.7136...	200	523.807	☐
17	Formula	X1	Equation	493.8073...	527.3210...	200	529.879	☐

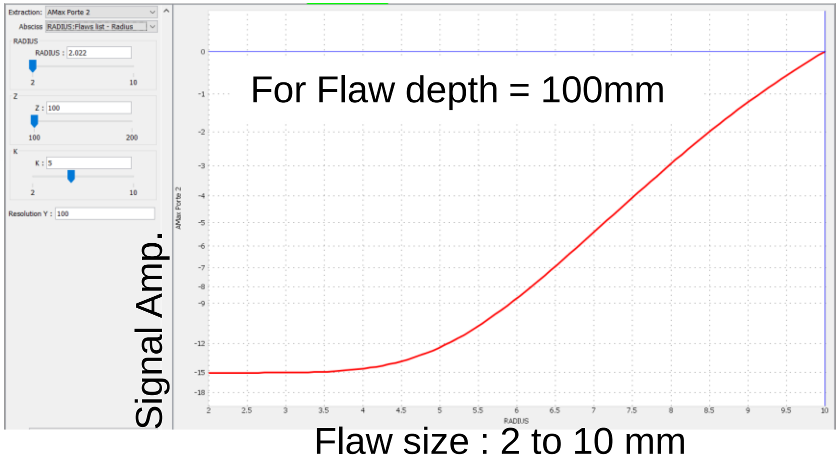
Parametric study example

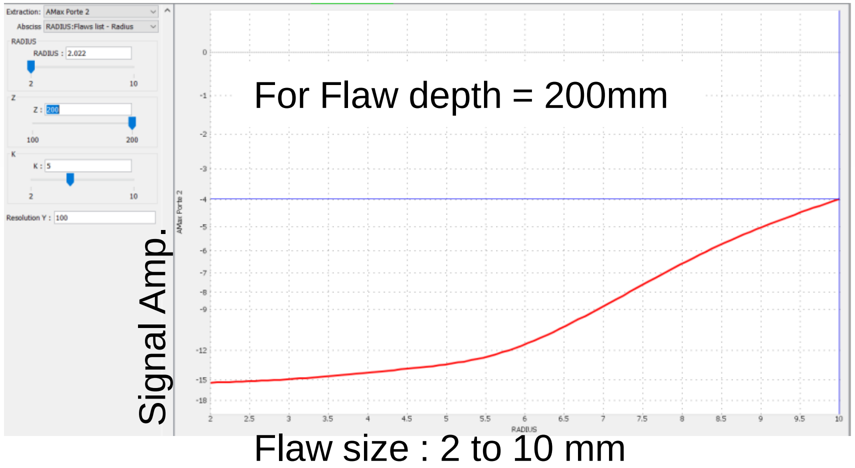
- Different sampling techniques available :
  Regular step, Monte Carlo sampling based on a density function, etc.
  Full factorial or Latin Hypercube Sampling (LHS) for multiparametric scenarios, etc.
- Here, **200 Simulations** with LHS sampling have been performed (in **only 4 hours**)
- Each case can be analysed individually
- Parallel plot view gives at a glance an overview of the simulations performed and the value for a given criterion (for instance max of the UT signal)



Parametric study example

- A metamodel is built from the simulation performed and a parametric analysis can be done from metamodel data:
  - Access to analysis plots built with metamodel data (and not any more only the 200 results « grid »)
  - « Continuous » sampling and exploration of the full range of potential combination of all parameters : **1D plot**
    - Impact of flaw size (between 2mm and 10mm) increase on signal amplitude
      - For defect at 100mm depth : + 15 dB in this case
      - For defect at 200mm depth : + 11 dB in this case

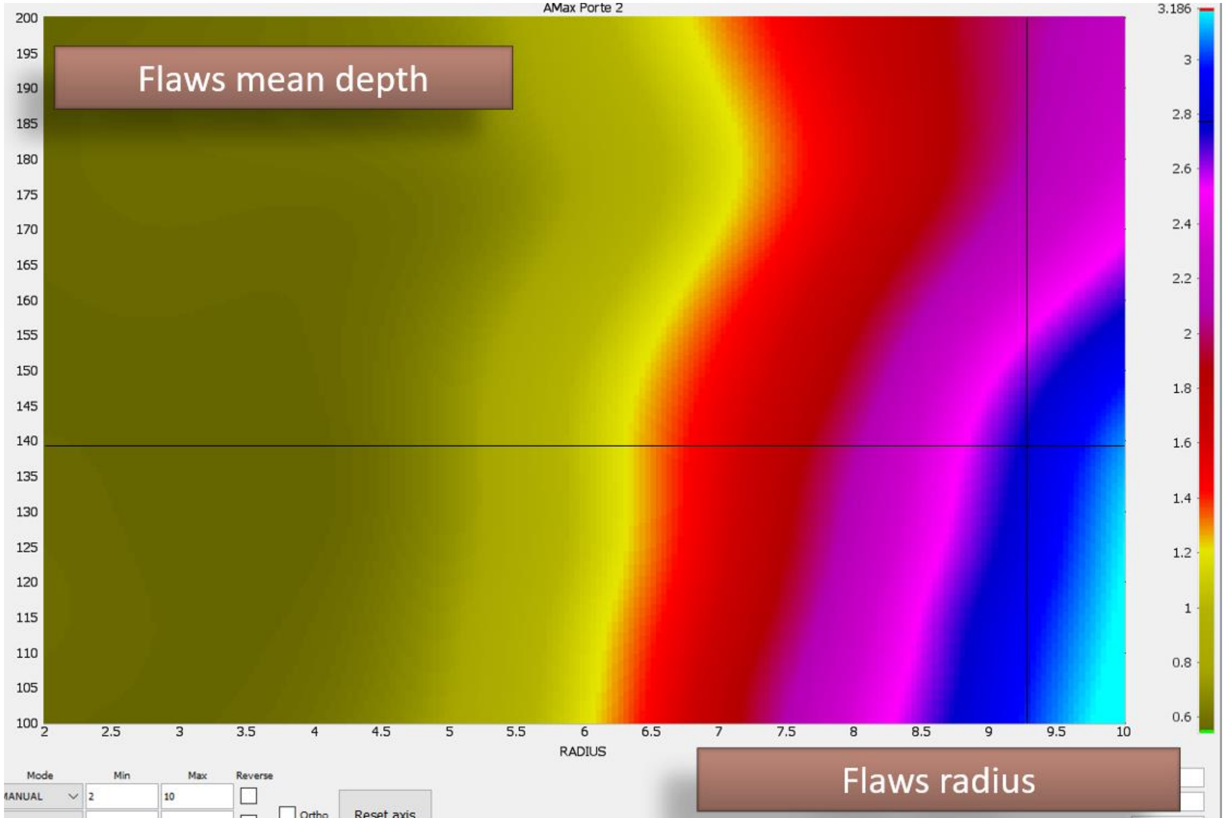




SVTI ASIT EXTENDE CIVA ceatech

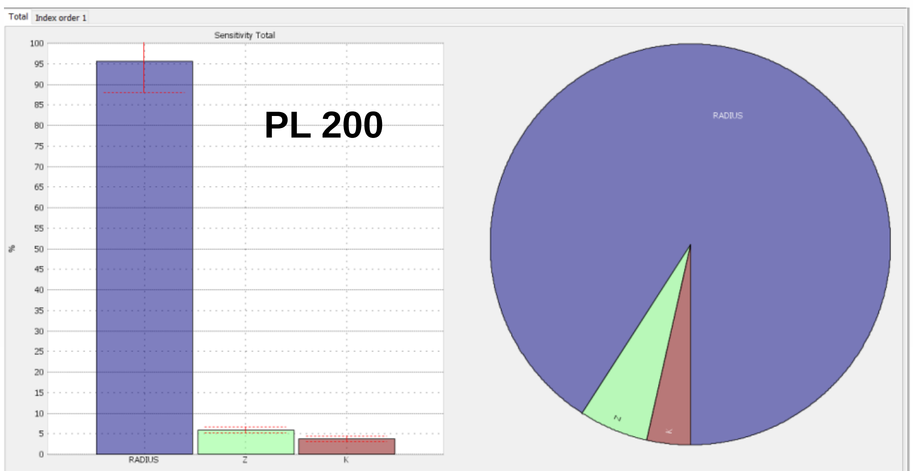
Parametric study example

- A metamodel is built from the simulation performed and a parametric analysis can be done from metamodel data:
  - Access to analysis plots built with metamodel data (and not any more only the 200 results « grid »)
  - « Continuous » sampling and exploration of the full range of potential combination of all parameters : **2D plot**
    - **Joint impact** of flaws depth and radius seen at a glance

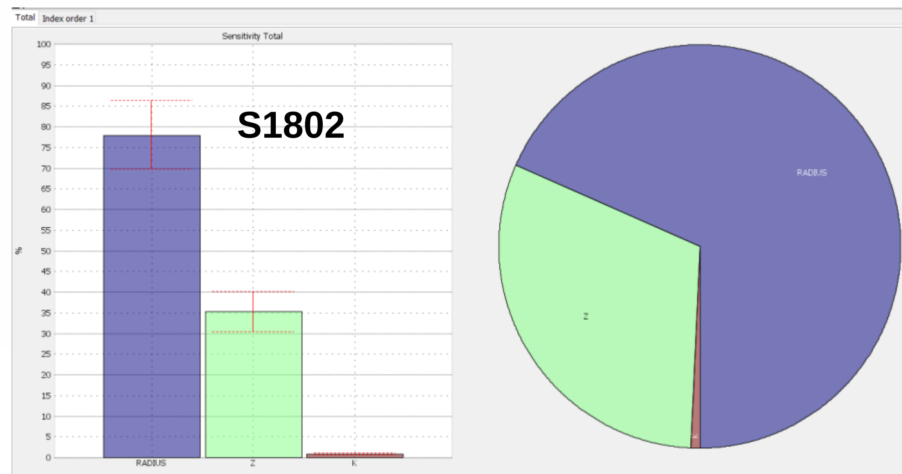


Parametric study example

- Parametric analysis from metamodel data:
  - Sobol indices allows to quantify the influence of parameters on the output signals considering parameters interactions and density functions to account for variable parameters occurence (uniform, gaussian law, etc.)
    - Sobol Indices diagram for the PL200 probe
    - Sobol Indices diagram for the S1802 probe



	RADIUS	Z	K
Sensitivity	95.55	5.86	3.69
Value %	90.92 %	5.57 %	3.51 %
Uncertainty	7.627	0.711	0.670
Uncertainty %	7.982 %	12.136 %	18.177 %

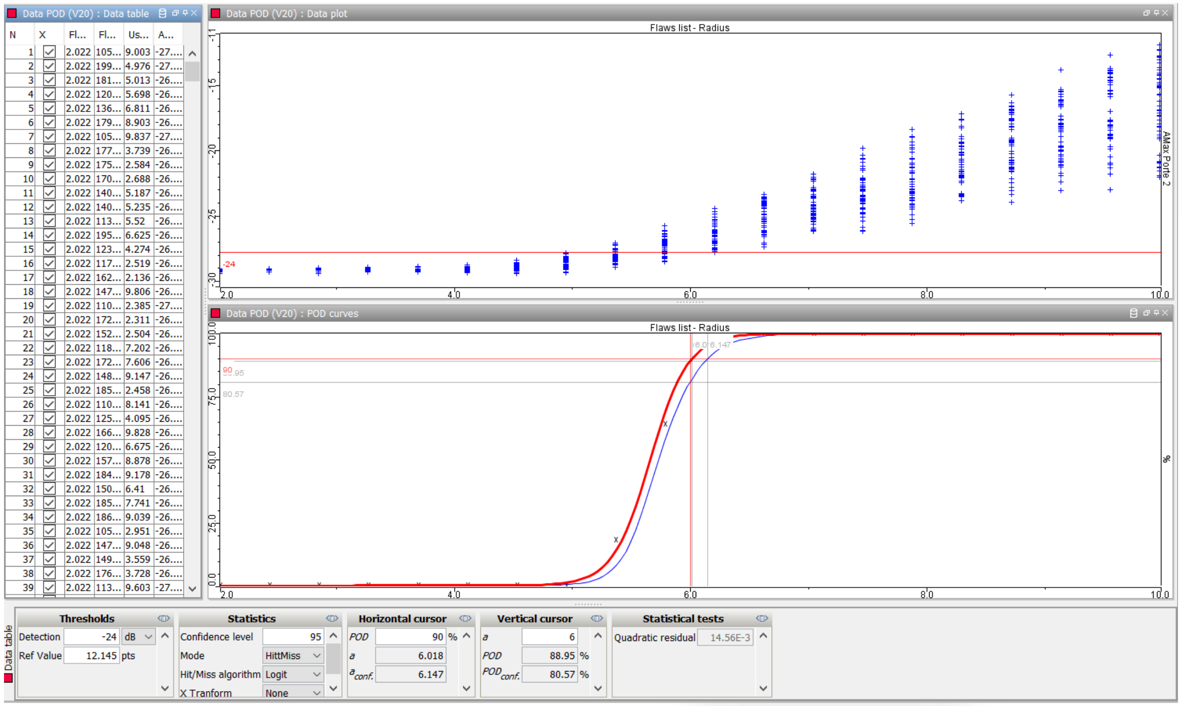


	RADIUS	Z	K
Sensitivity	77.96	35.21	0.82
Value %	68.40 %	30.89 %	0.72 %
Uncertainty	8.355	4.849	0.170
Uncertainty %	10.717 %	13.773 %	20.872 %

Radius is the predominant parameter for signal amplitude.
S1802 is much more sensitive to flaw depth compared to PL 200 (more divergent beam)

Parametric study example

- A POD analysis can be created from the metamodel in a few seconds:
  - Selection of the « characteristic value » for defect size (e.g. radius)
  - Selection of assumed statistical distributions for test variables
  - Data sampling definition (# of defect sizes, # of tests) :
    No limits thanks to metamodel
  - Definition of threshold (for instance here, -24dB vs backwall echo amp.)
  - Selection of suitable POD model (â vs a, Hit/Miss or non parametric)



Conclusion

- Simulation should help NDE procedures development and qualification in civil engineering (virtual testing, help for understanding, parametric studies):
  - Less iterations and more mastering
  - Less physical mock-ups / Less defects in physical mock-ups
  - Save time and money

- CIVA is a well-established software for metallic parts inspection modelling with efficient computation times.
- It now includes more and more capabilities for concrete specimens.
- Several examples have been illustrated here.

- Questions ?

contact@extende.com / www.extende.com

SVTI ASIT EXTENDE CIVA cea tech