Civil engineering R&D on pressure containment vessels

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Sylvie MICHEL-PONNELLE

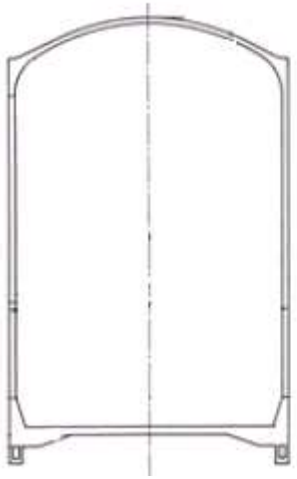
1

Nuclear power stations of EDF

19 Sites – 58 Reactors

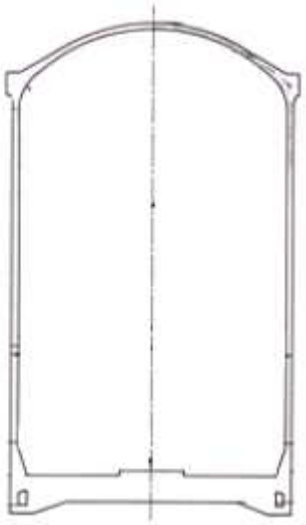
EDF pressure containment designs

900 MWe family : single wall + steel liner



CP0

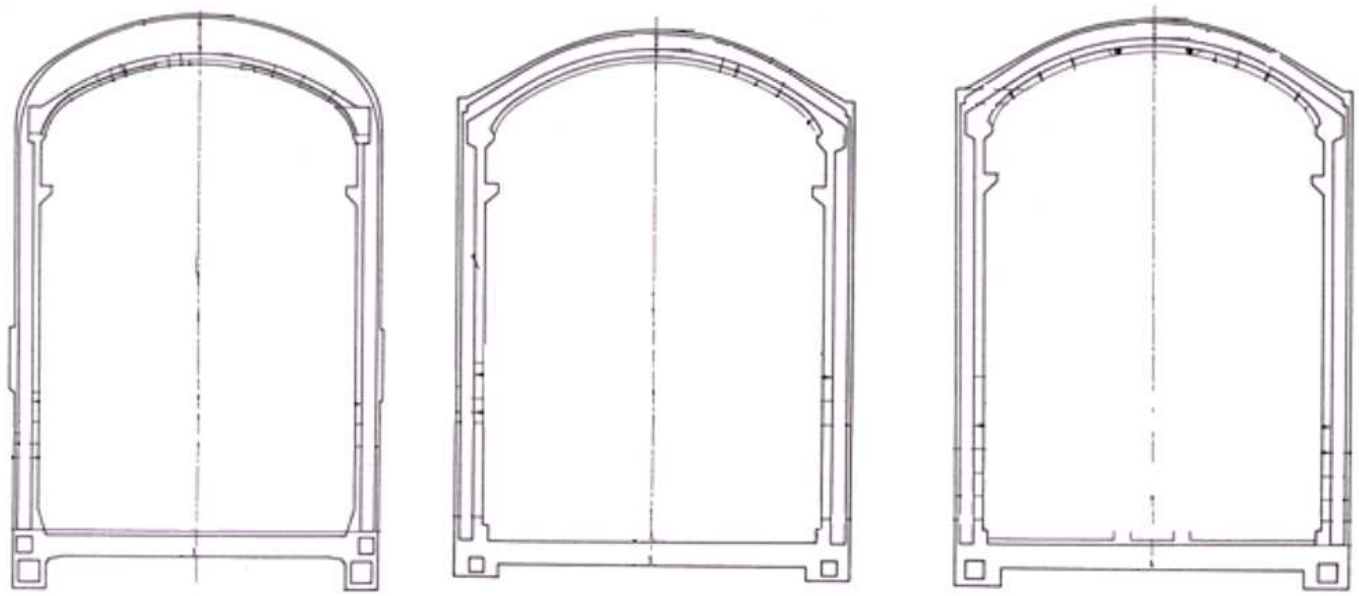
CP0



CP1-CP2

EDF pressure containment designs

1300 MWe family : double wall (w/n liner)



P4 P’4 N4

2

Special features about EDF’s needs in simulation techniques

1. Special features about EDF's needs in simulation techniques

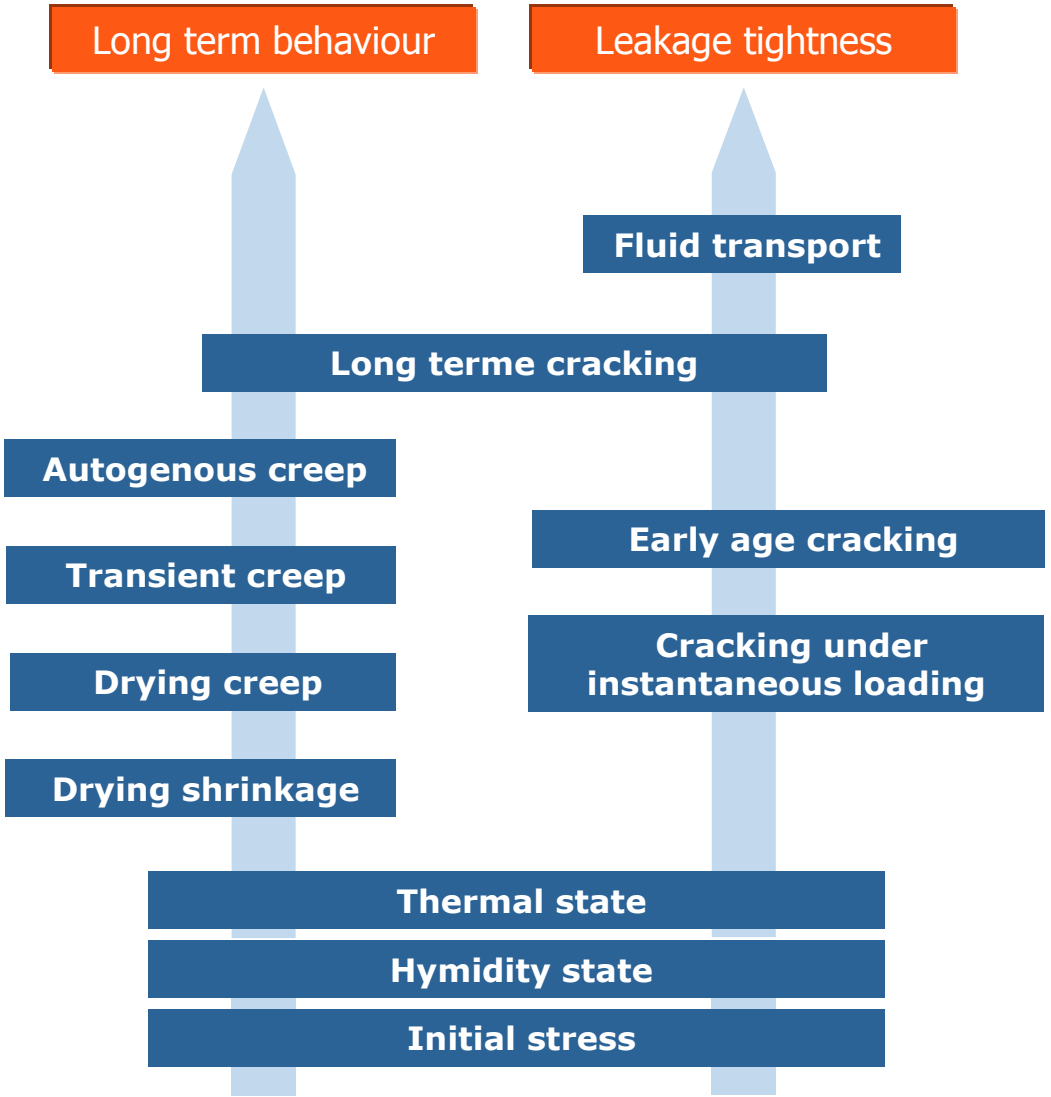
Domains:

- Structural design
- Structural assessment
- Consequences of exceptional loadings
- Forensic engineering

Special features:

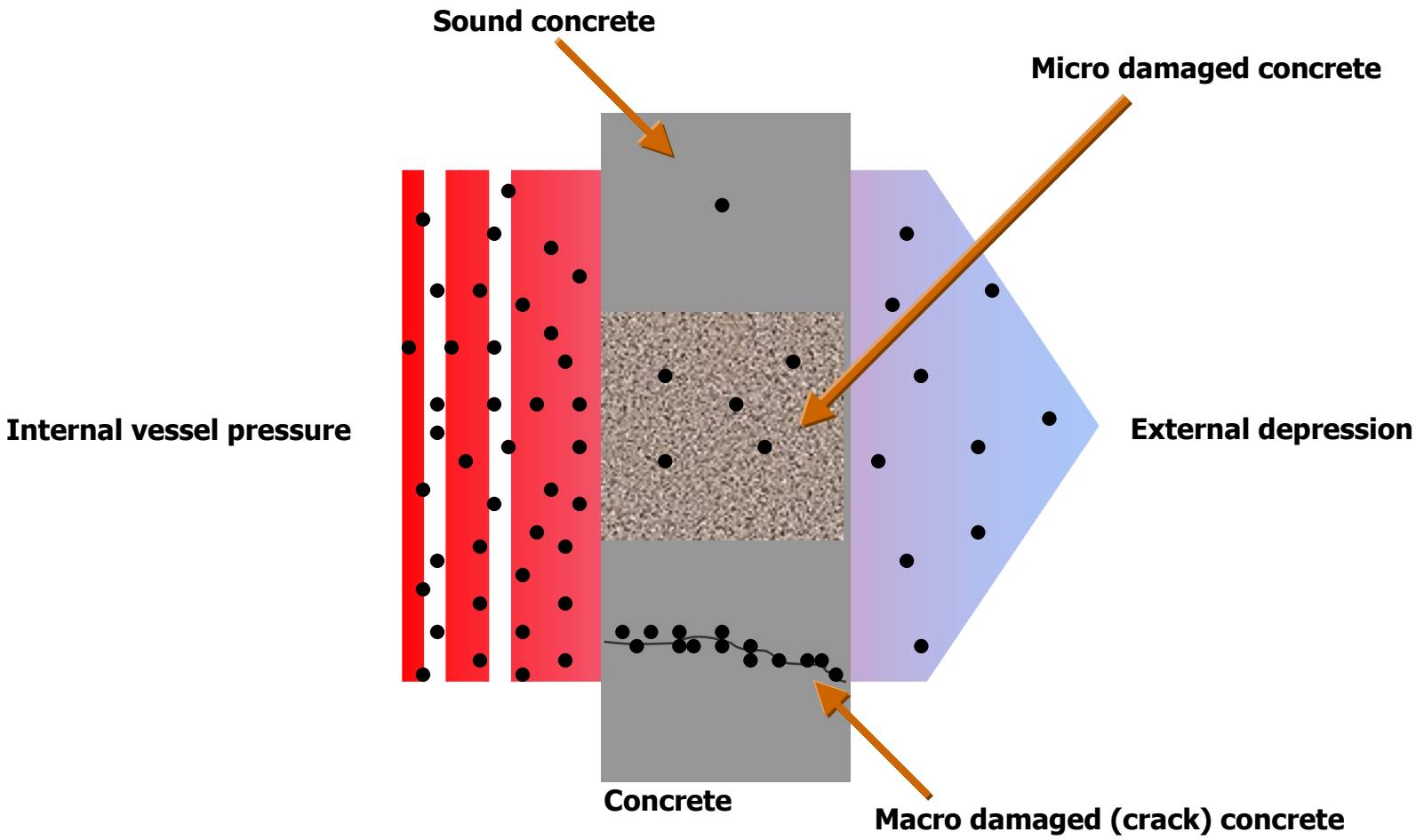
- Some analysis more or less similar to common engineering tasks
- Most analyses specific to nuclear plants
  - Leak tightness
  - Initial state
  - Complex loading (TM, THM)
  - Three dimensional configurations (local effects)
  - Ageing effect

Modelling methodology

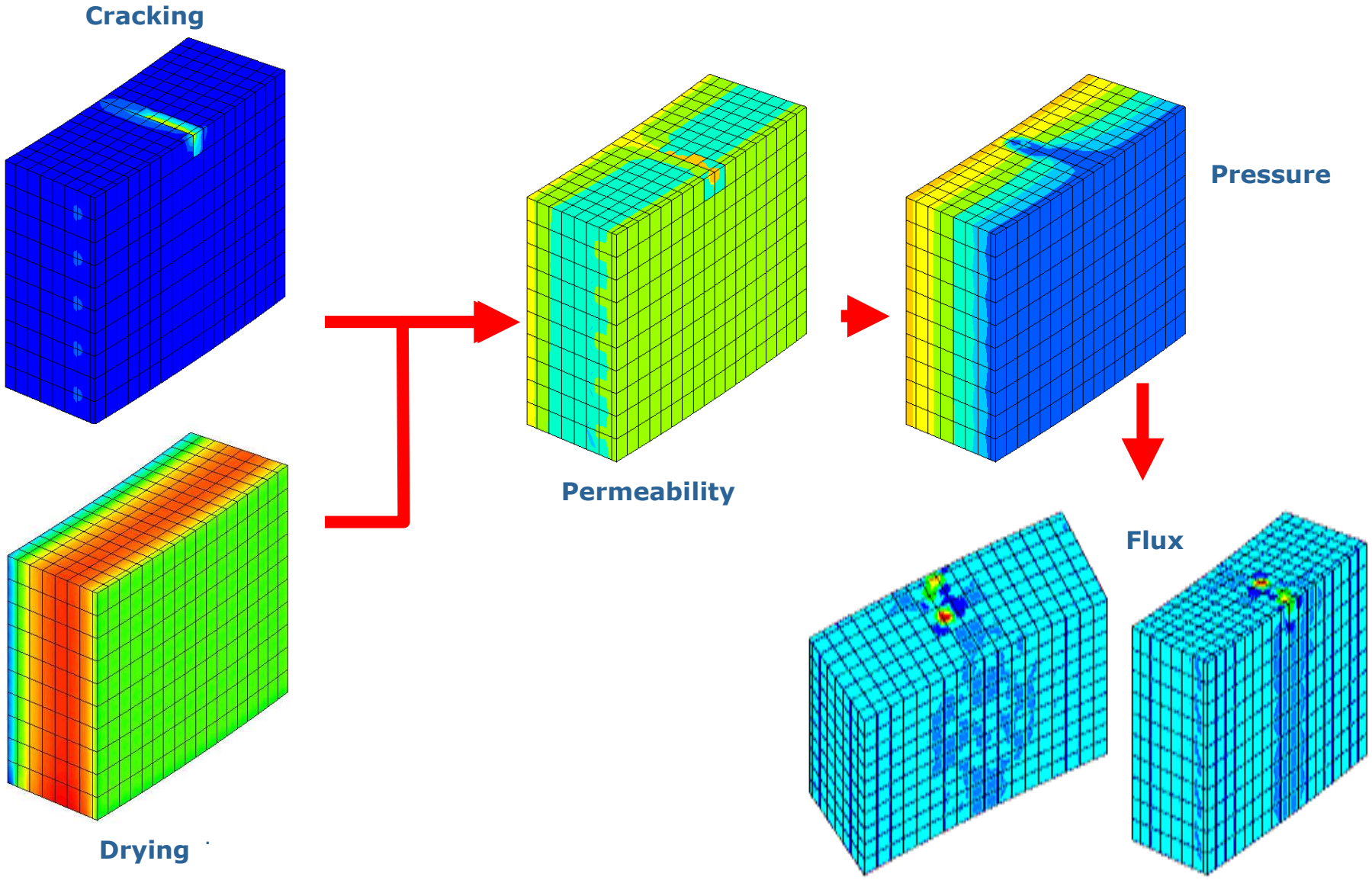


Leakage tightness

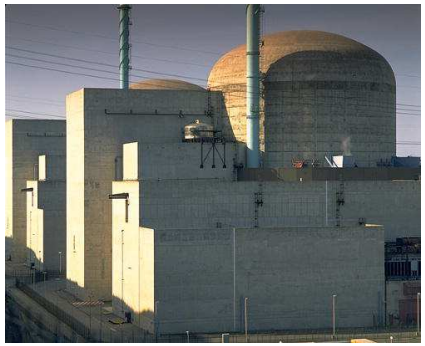
Leakage through concrete



Leakage tightness

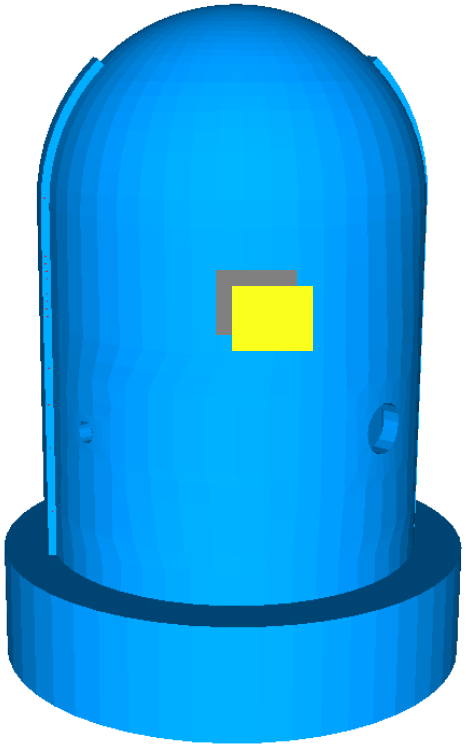


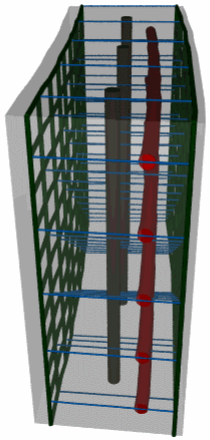
Leakage tightness



Concrete cracking and diffusion

- Concrete cracking
- Thermal analysis
- Concrete drying
- Moisture pressure

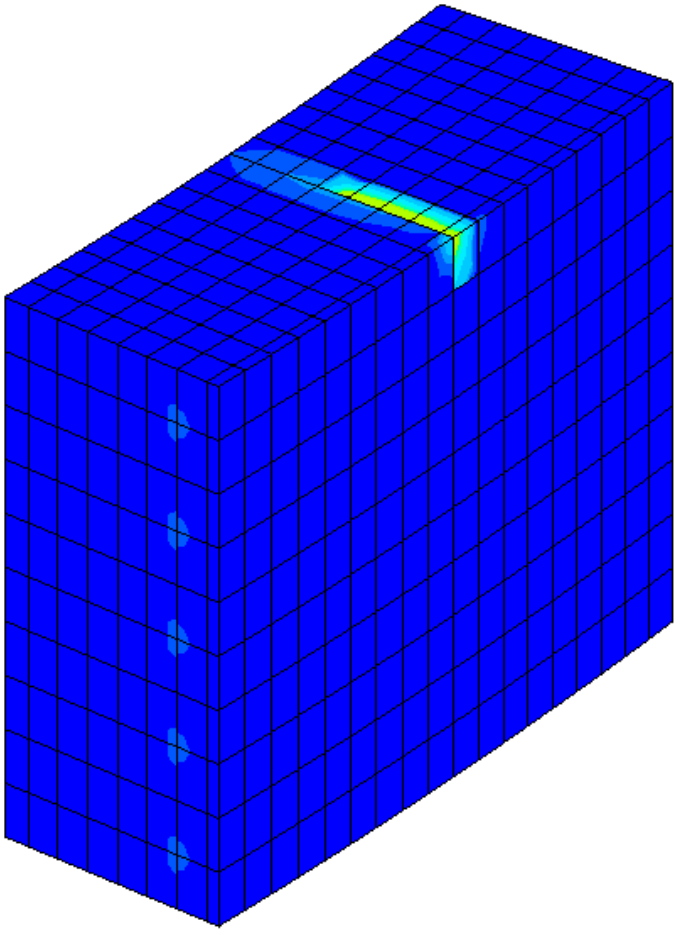


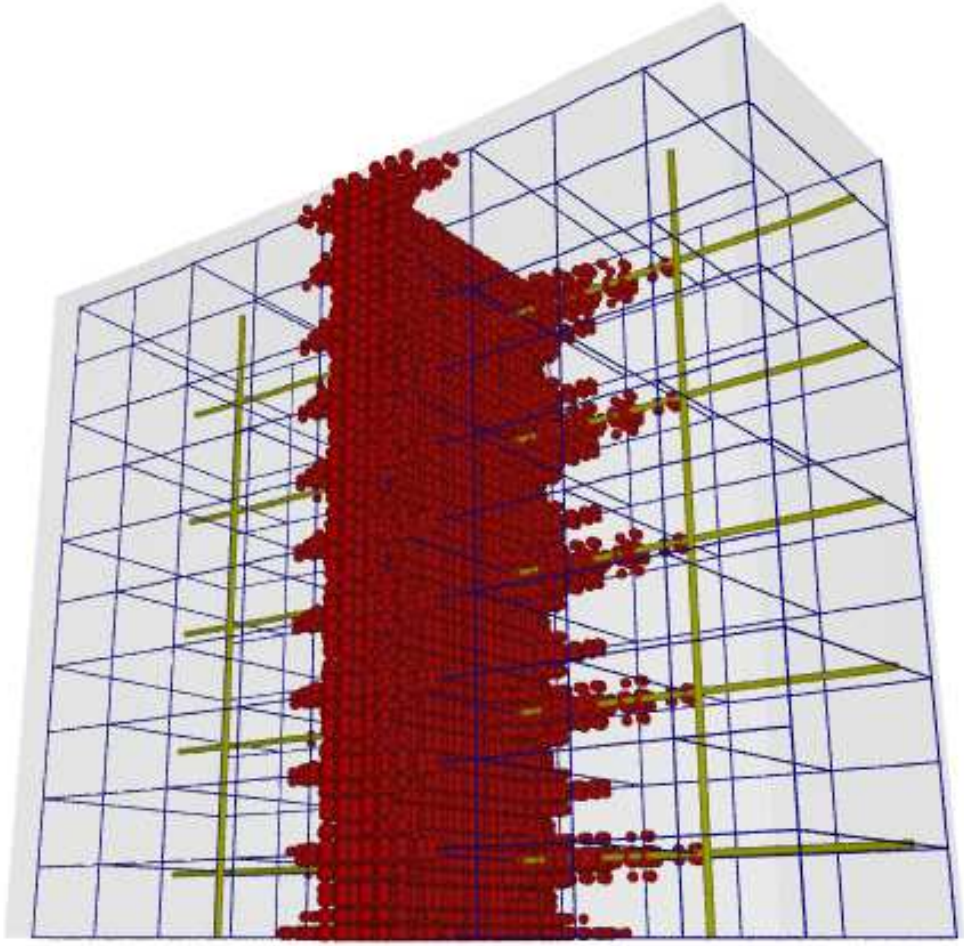


Leakage tightness

Damage index mapping

Crack initiation …..

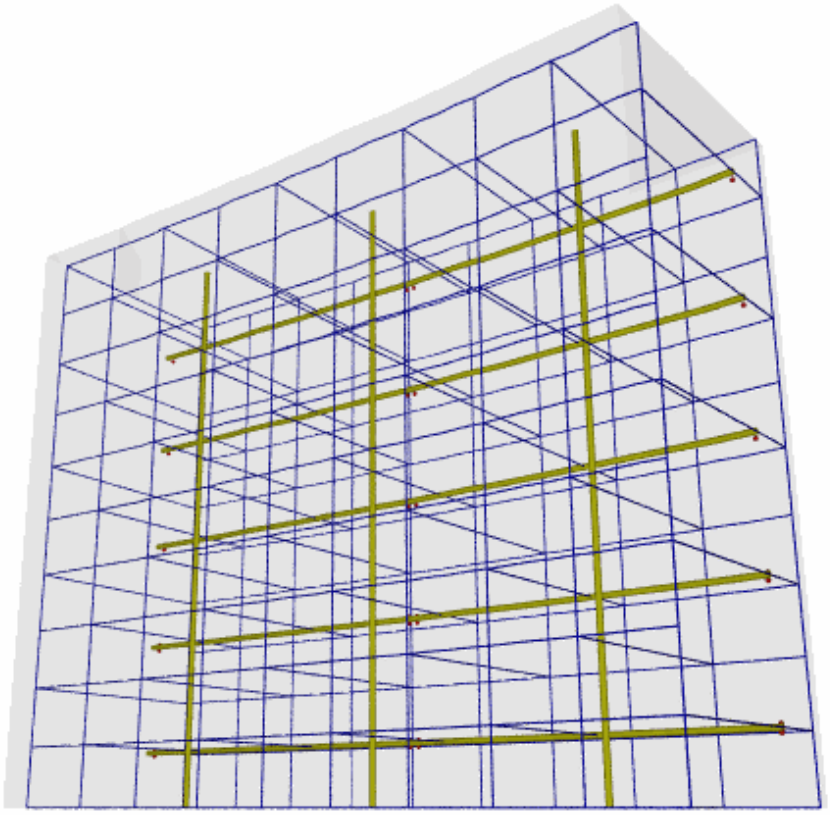




Leakage tightness

Damage index mapping

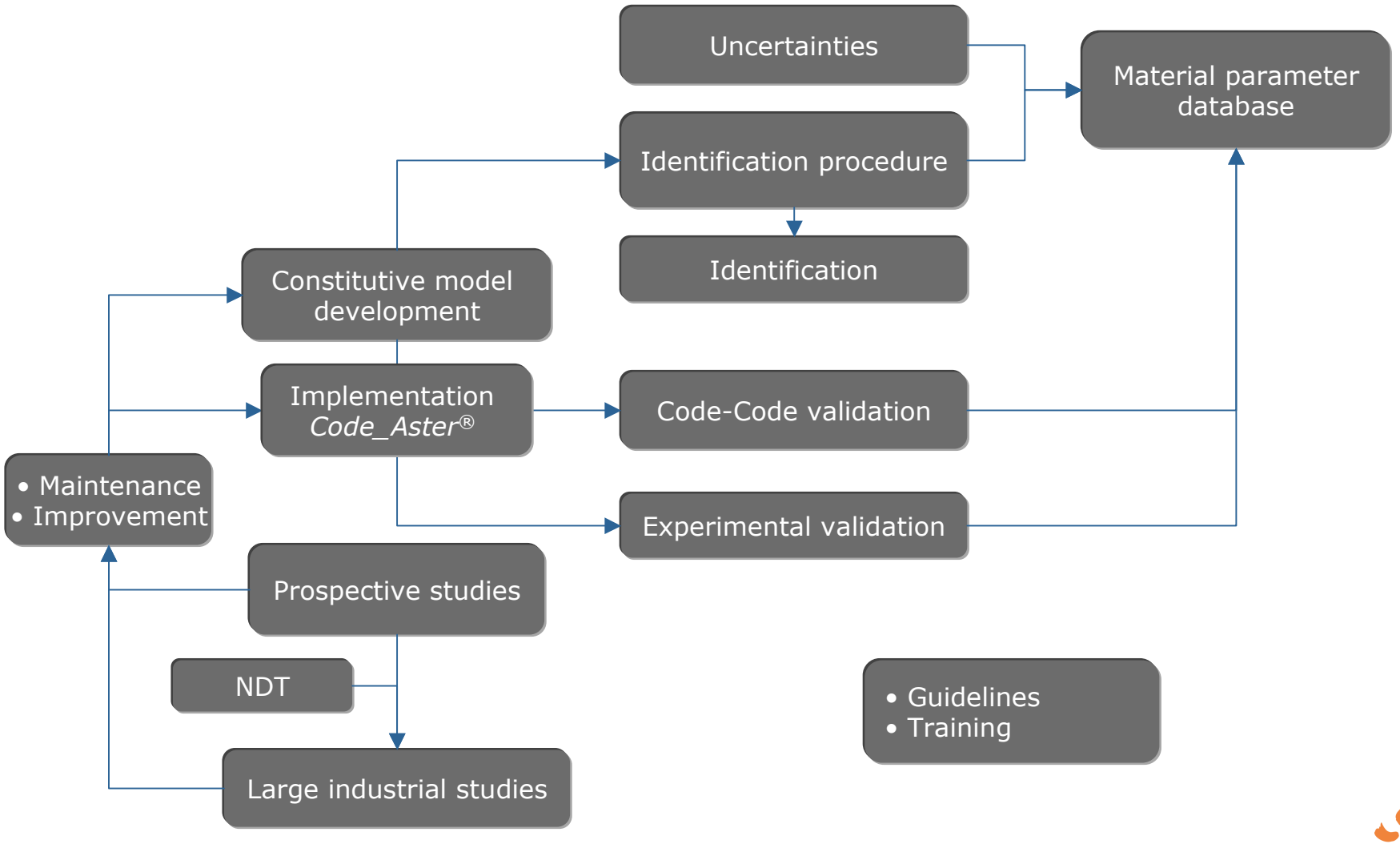
Crack initiation …..



3

R&D in support of engineering division

Activities

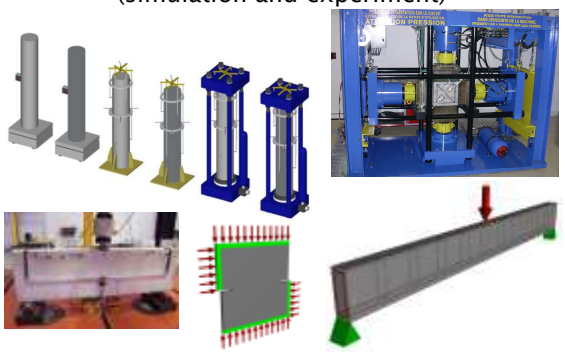

Uncertainties
Material parameter database
Identification procedure
Identification
Constitutive model development
Implementation *Code_Aster*®
Code-Code validation
• Maintenance
• Improvement
Experimental validation
Prospective studies
NDT
• Guidelines
• Training
Large industrial studies

Step by step qualification

Complexity

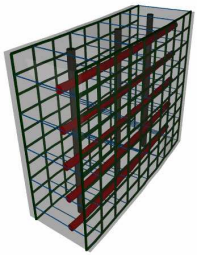
Specimens

TEGG / LCPC / MECA / ECN
(simulation and experiment)



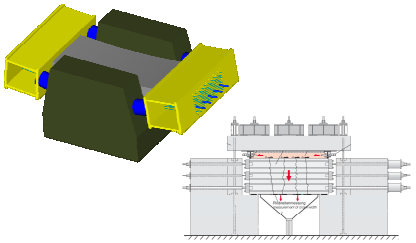
PACE 900/1300/1450

VSR (simulation)



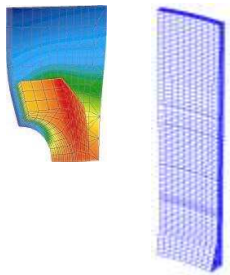
Karlsruhe, PACE 1450 Exp

VSR (experiment)



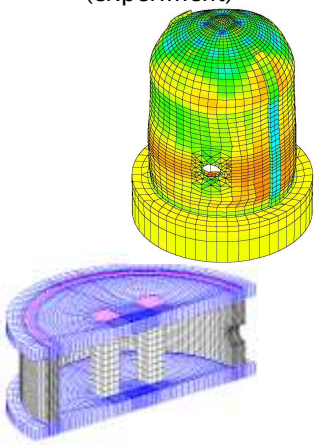
SAS, Gousset

PAGE 1300 / 1450
(simulation)

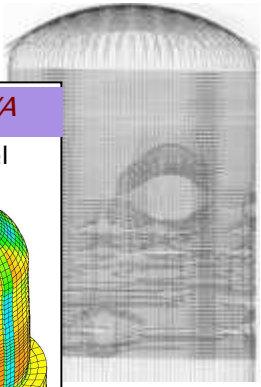


SANDIA 2 / MAEVA

Containment model
(experiment)



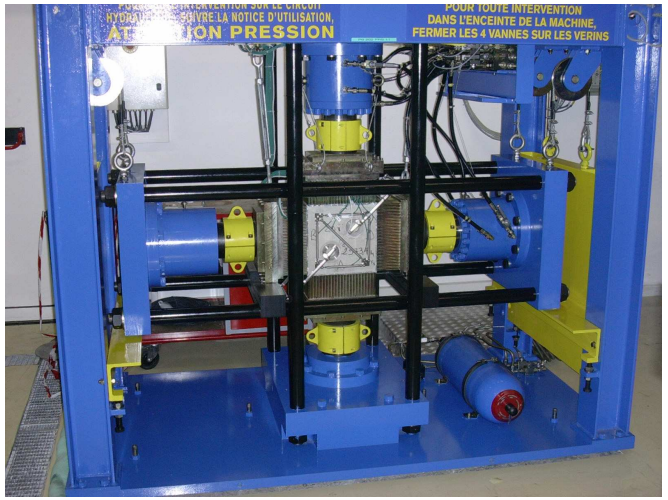
Vessel



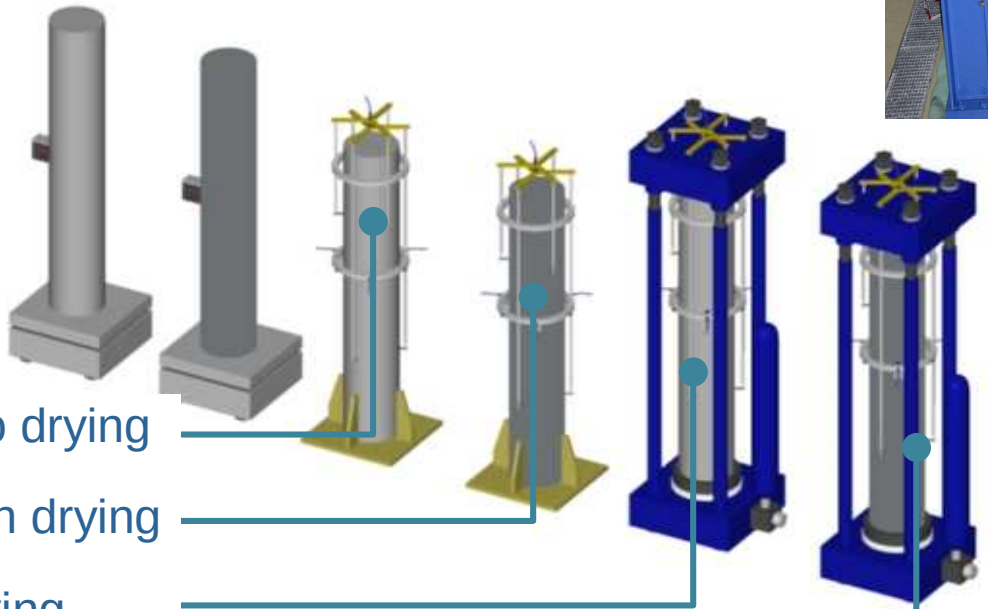
Scale

Long term behaviour

Biaxial loading experiments



Uniaxial loading experiments



Shrinkage w/o drying

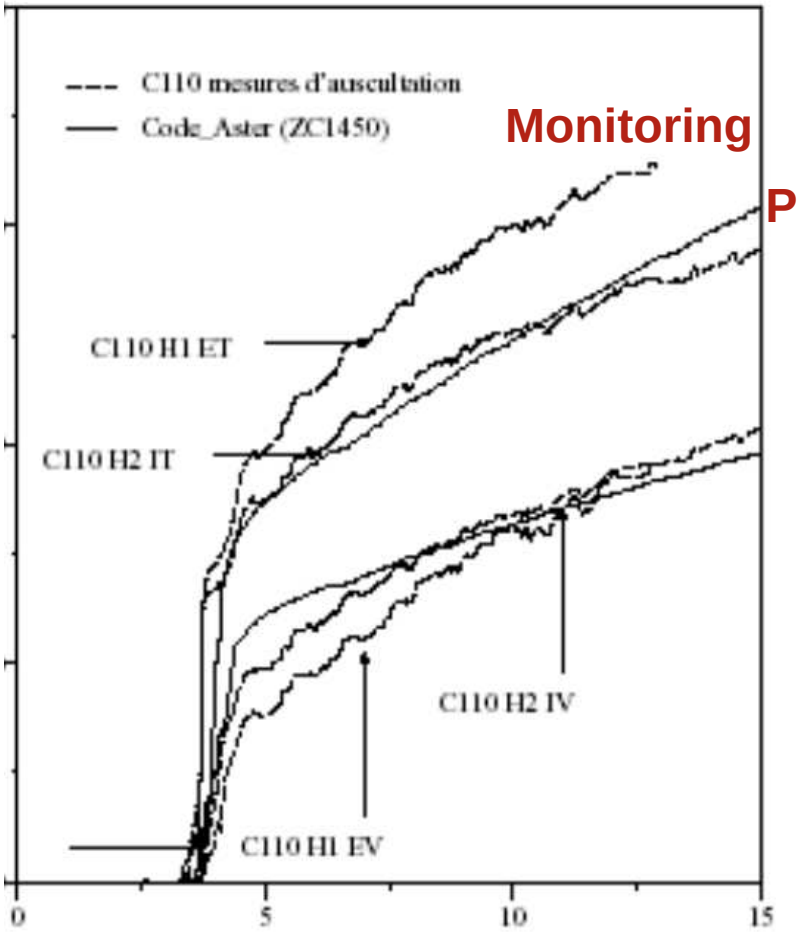
Shrinkage with drying

Creep w/o drying

Creep with drying

Long term behaviour

Prediction and identification



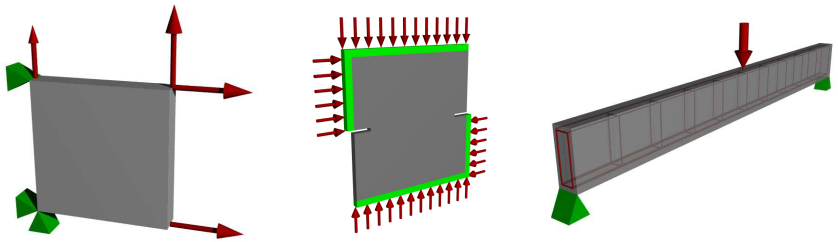
Monitoring

Prediction

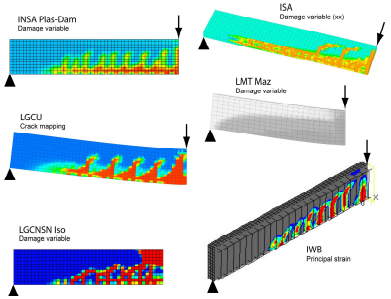
Constitutive model to describe concrete cracking

benchmarking

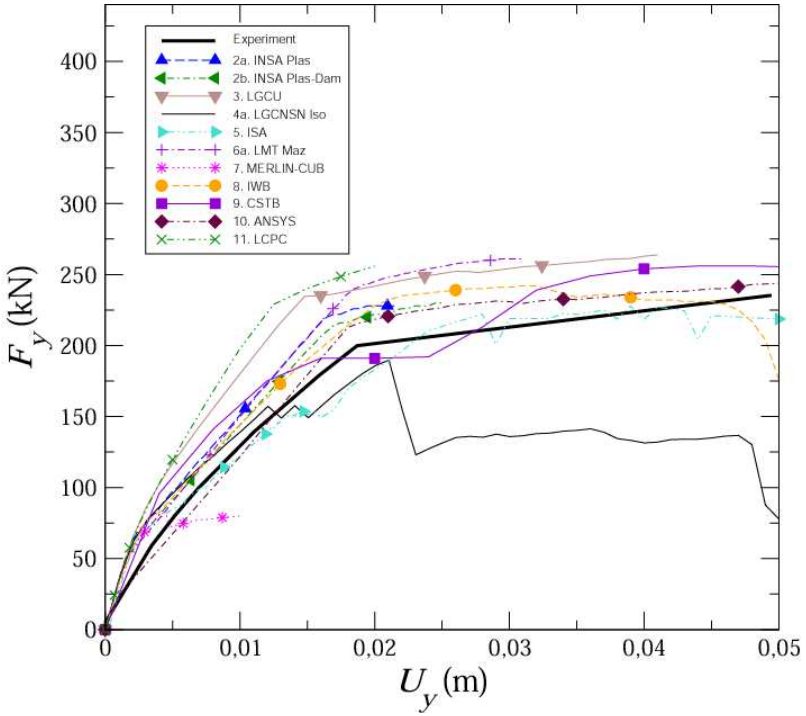
Efficiency of models (reliability and robustness)

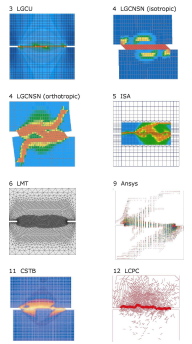


- Concrete cracking
- Rebar yielding



13 teams (international)





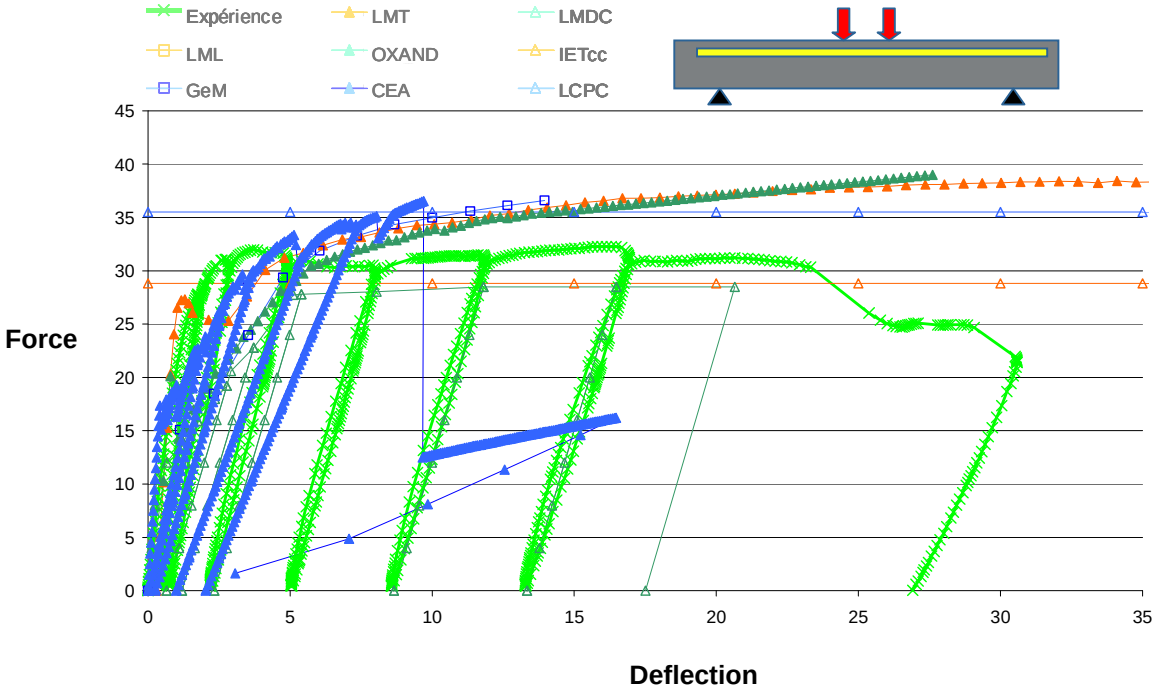
Consequences of corrosion on structures

benchmarking

7 teams (French)

Maximum bearing capacity

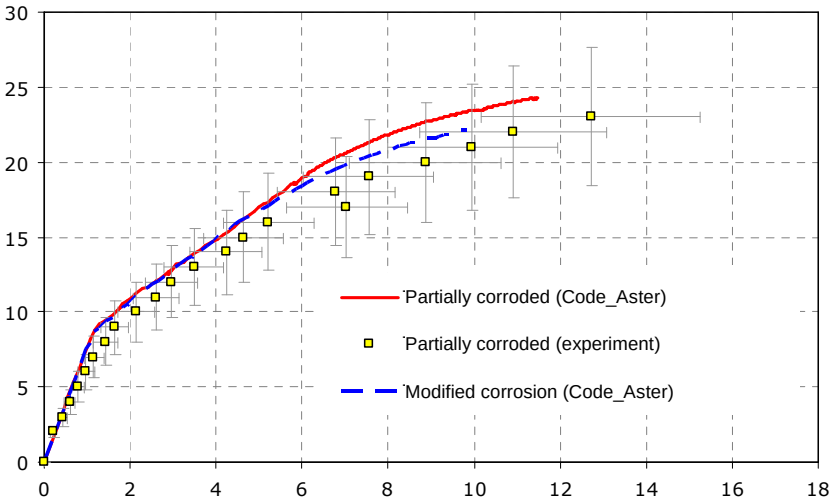
- Concrete cracking
- Rebar corrosion
- Rebar yielding

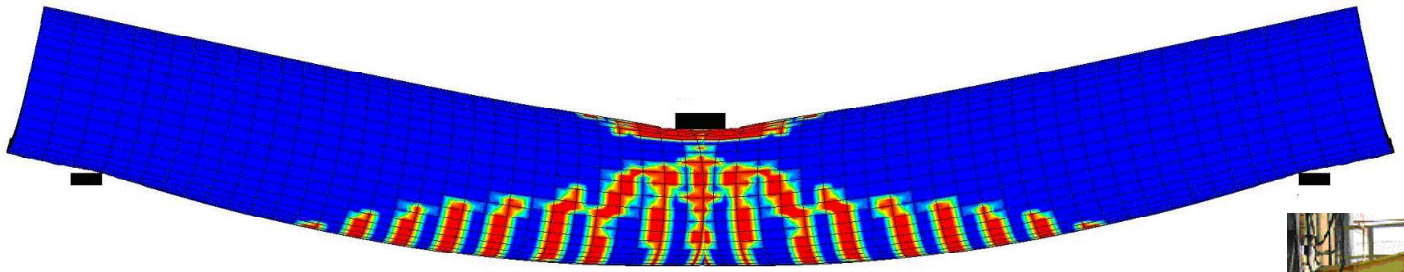


Concrete cylinder pipe with steel liner

Consequences of corrosion on bearing capacity

Force / deflection plot (experiment vs. calculation)





Deflected mesh + damage mapping

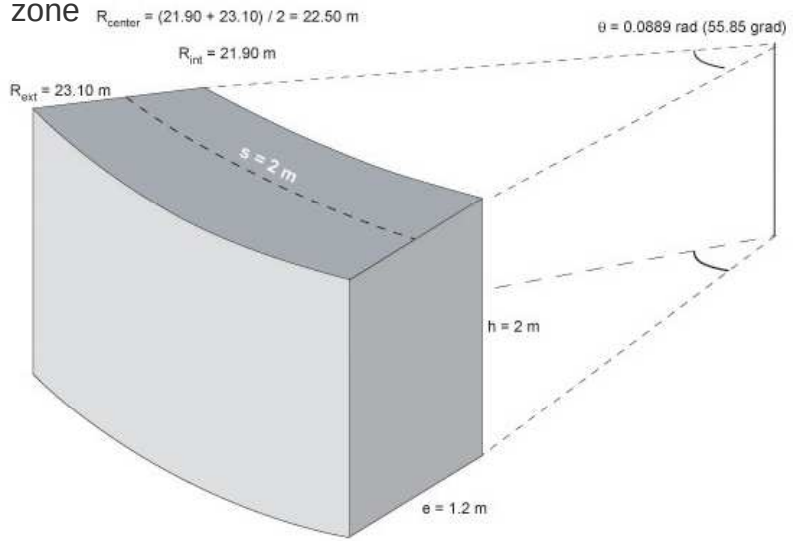
- Concrete cracking
- Reinforcement yielding
- Steel liner corrosion

Testing setup

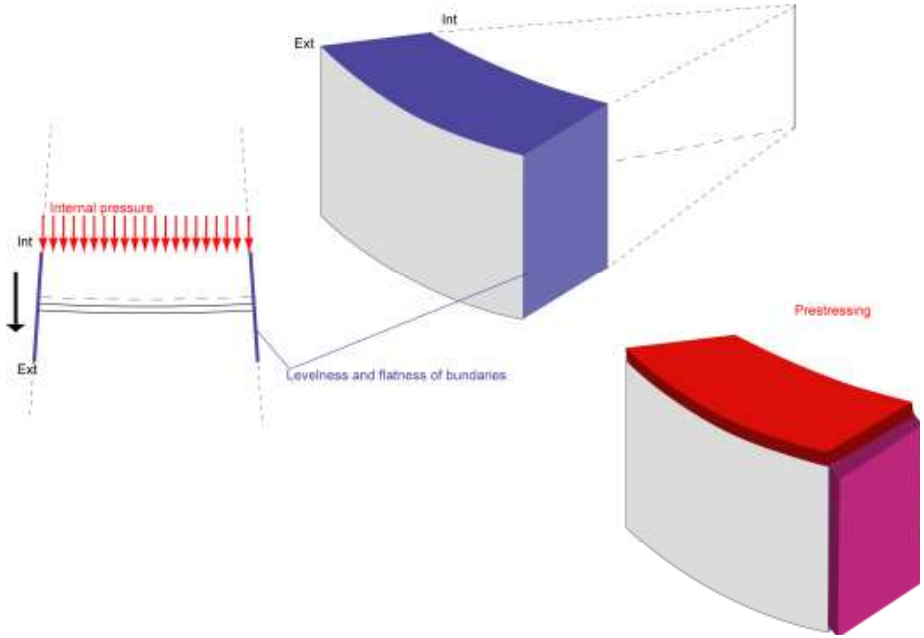
Cracking of a 1300 MWe PCCV (without liner)
PACE 1450 EXP

Characteristics

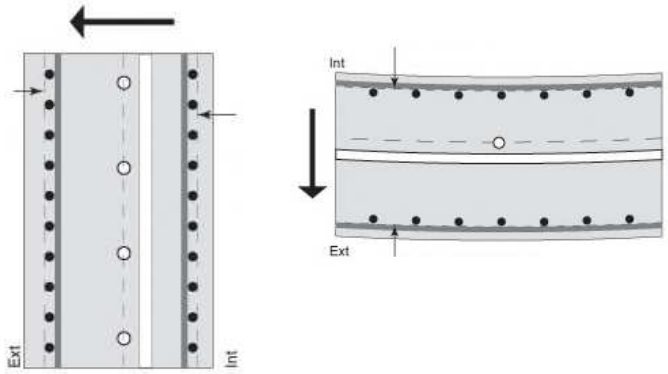
Geometry of observation zone



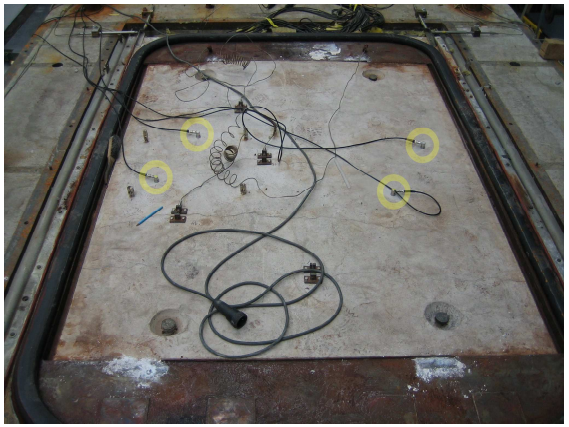
Loading and boundary conditions

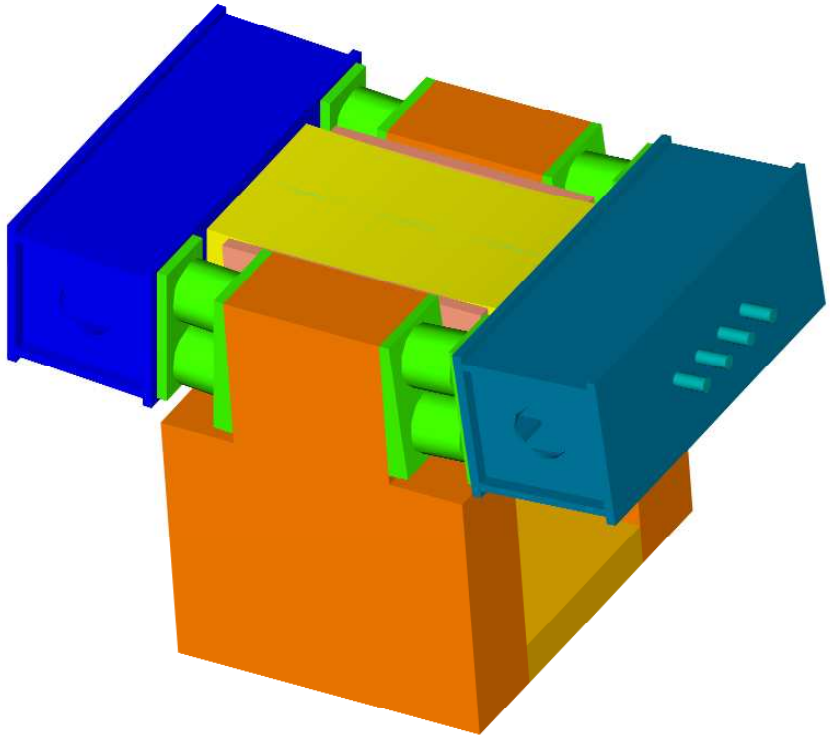


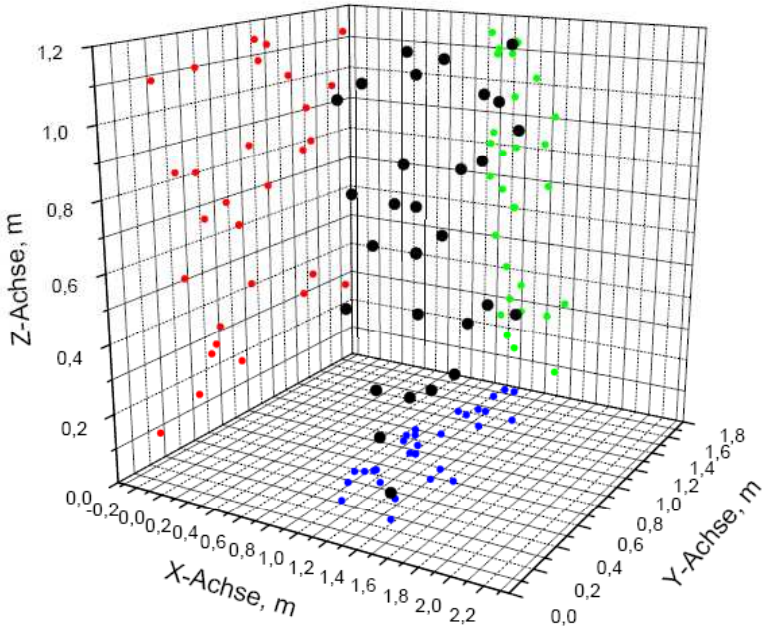
Steel rebars and prestressing

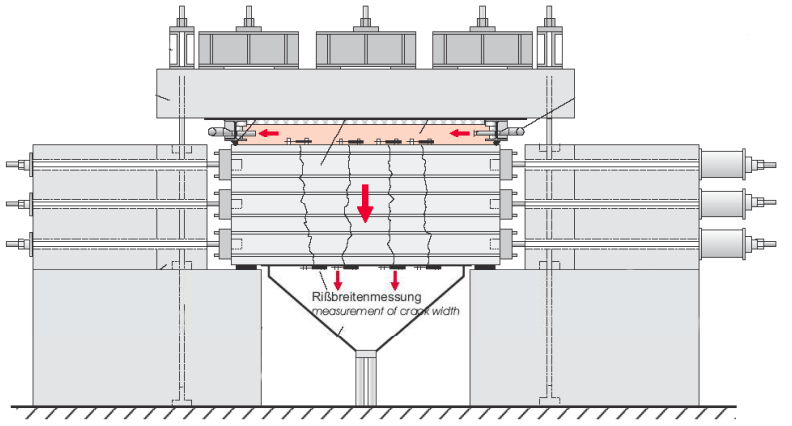


Cracking of a 1300 MWe PCCV (without liner)
PACE 1450 EXP





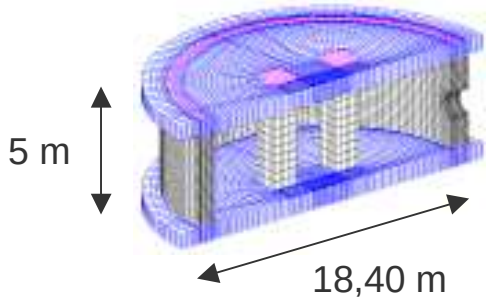




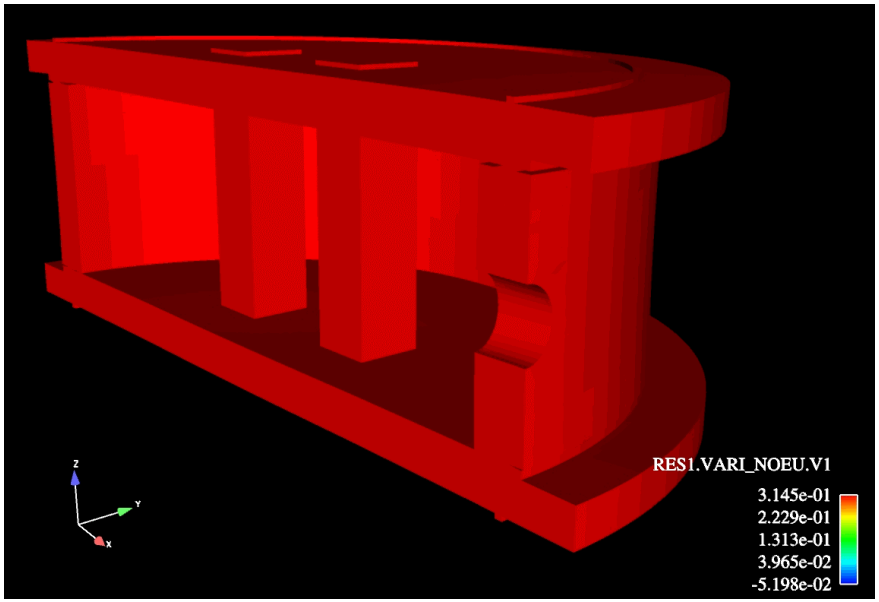
Behaviour of a PCCV model under internal overpressure (MAEVA)

benchmarking

Leakage through reinforced prestressed concrete wall



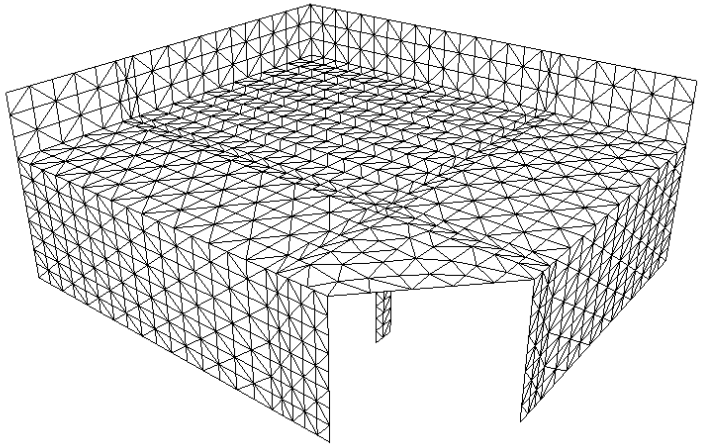
- Prestressing
- Concrete cracking
- Thermal analysis
- Diffusion



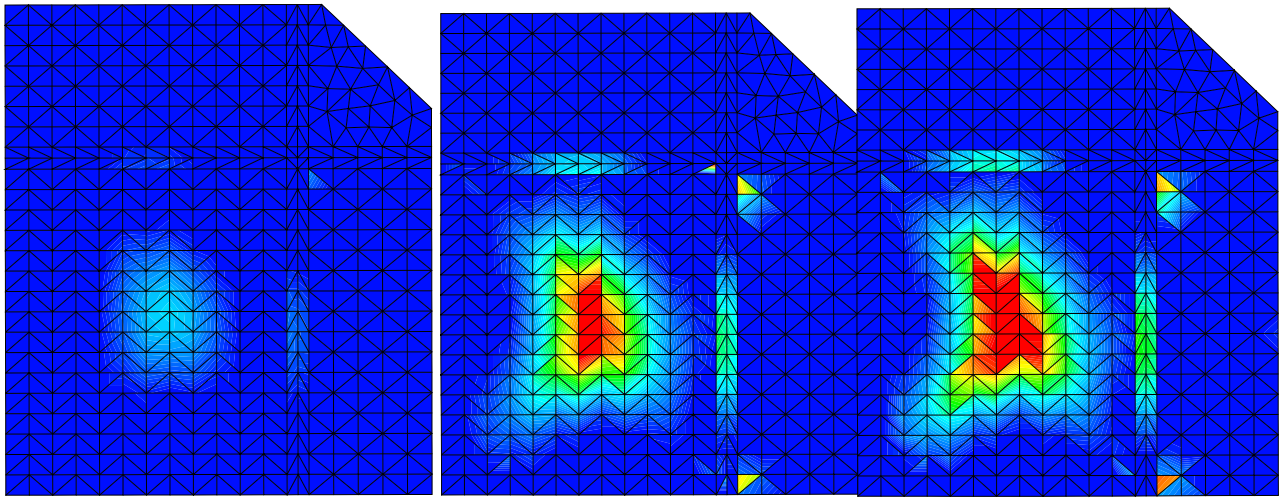
Response of an RC slab under seismic loading

benchmarking

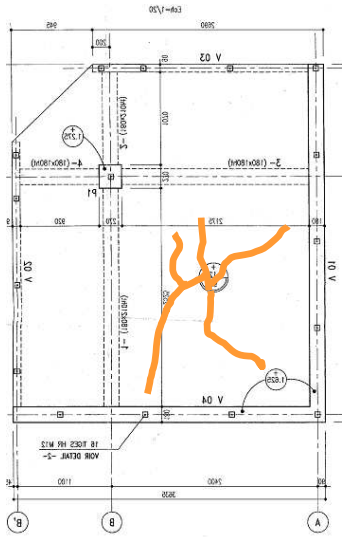
Level of cracking during an earthquake



- Concrete cracking
- Seismic analysis



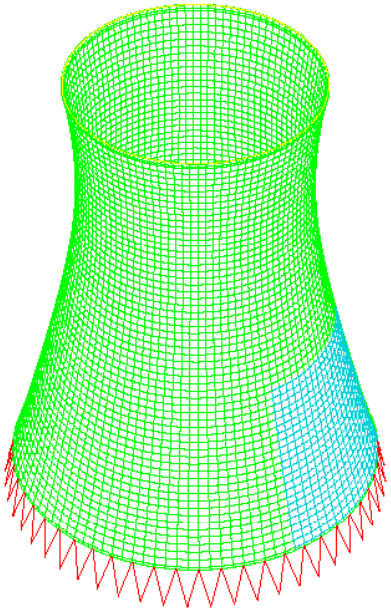
Damage mapping

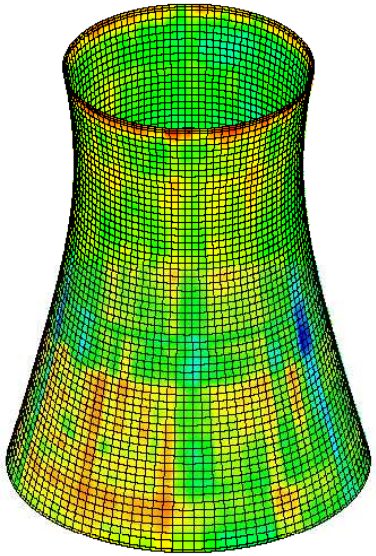


Degradation of cooling towers

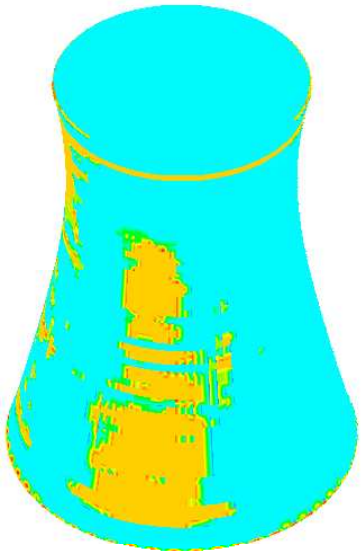
Crack evolution and collapse

- Prestressing
- Cracking
- Initial state





Strain mapping

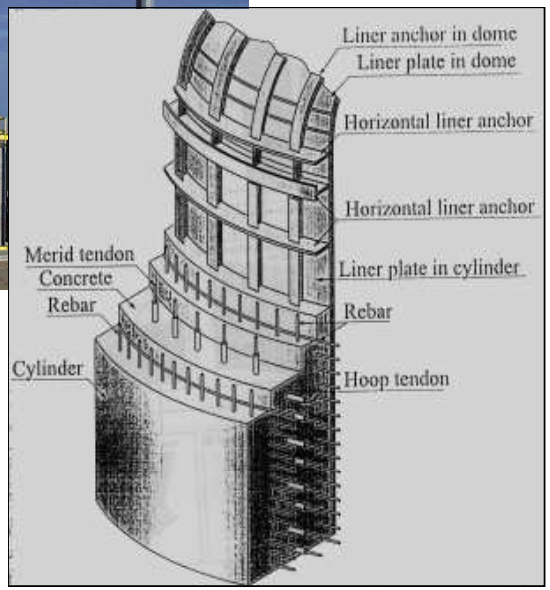


Damage index mapping

(micro damage)

Behaviour of a PCCV model under internal overpressure (SANDIA II)

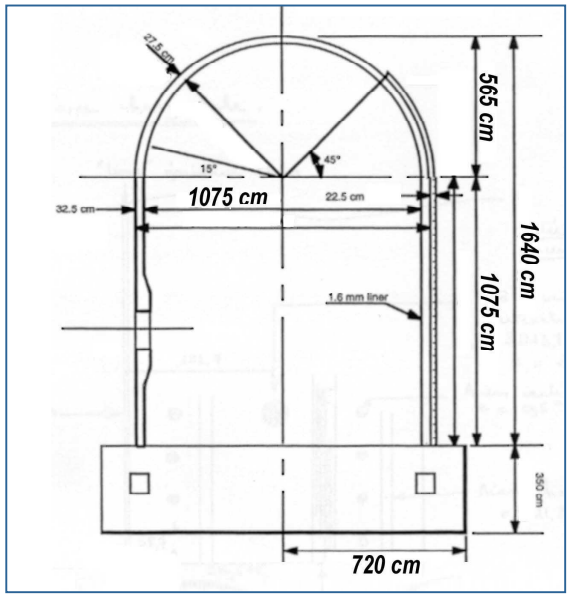
benchmarking



Sandia Labs. USA
NUPEC Japan
NRC USA
OECD

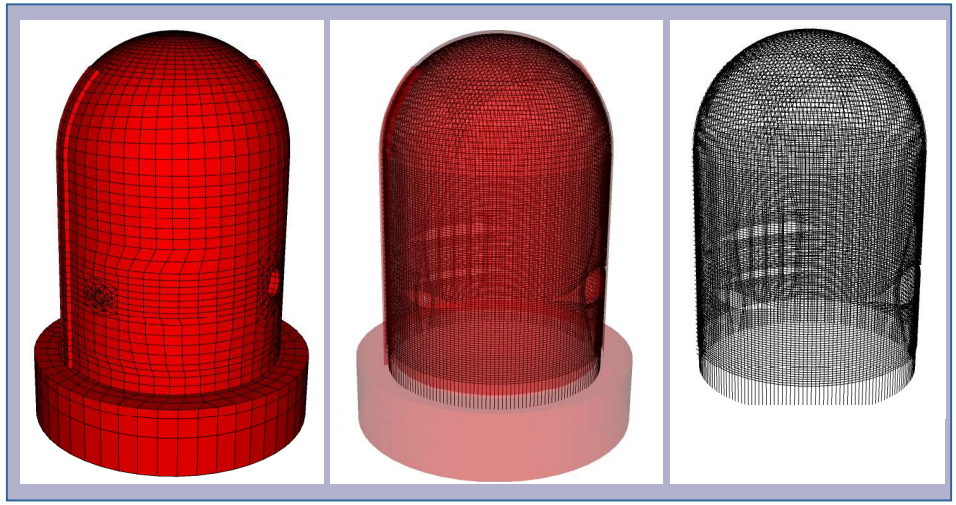
Loss of leakage tightness and collapse

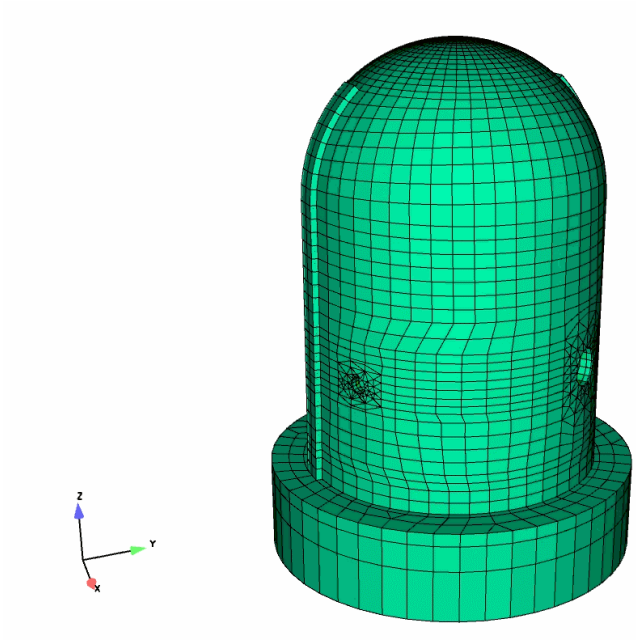
- Prestressing
- Concrete cracking
- Yielding
  (tendons, rebars, liner)



Behaviour of a PCCV model under internal overpressure (SANDIA II)

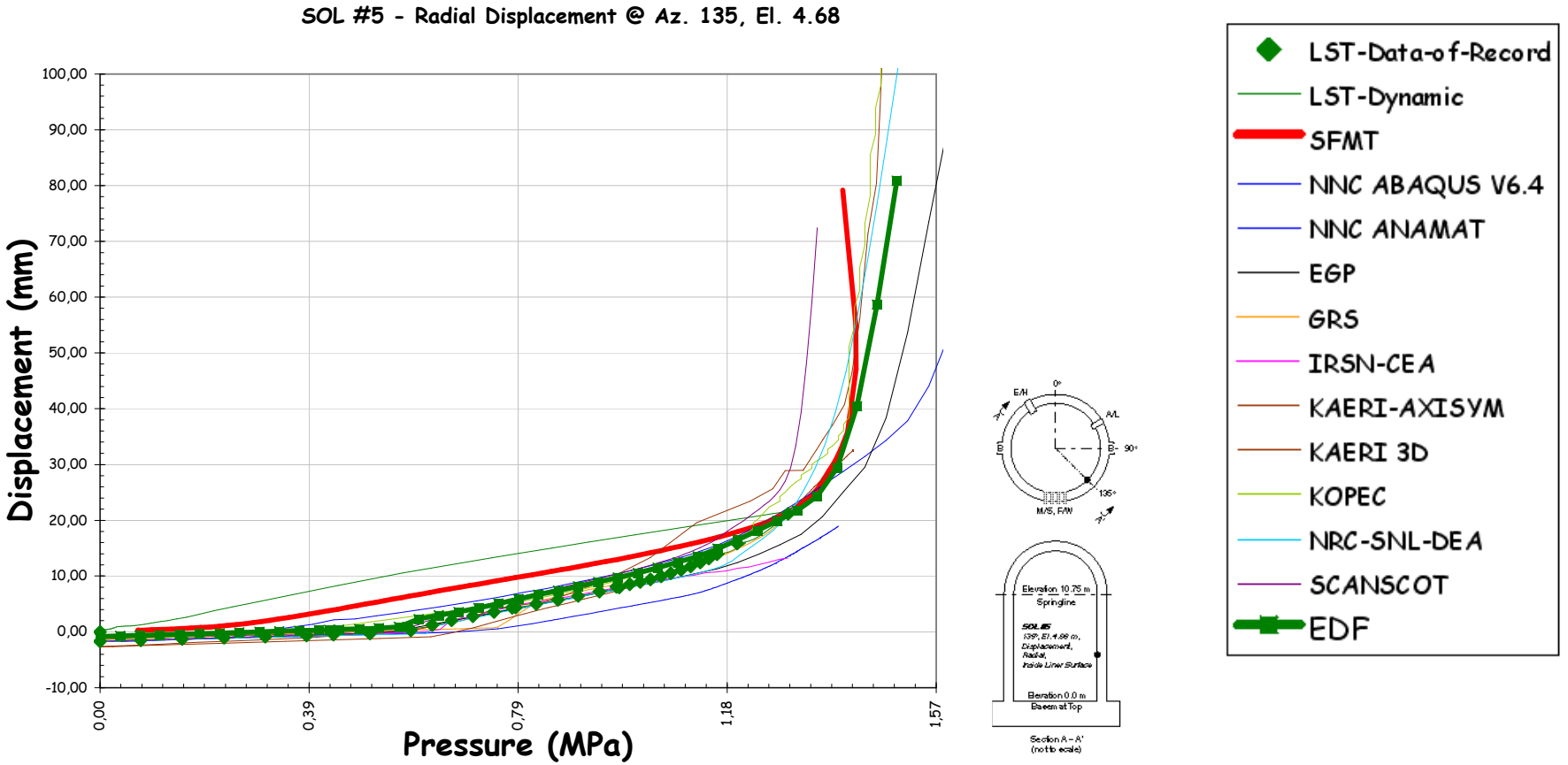
benchmarking





Behaviour of a PCCV model under internal overpressure (SANDIA II)

benchmarking



Conclusion

Features of Code_Aster ® in civil engineering :

Numerical aspects

Finite element

Generally 3D modelling

Implicit algorithm

Physical models

- *Concrete cracking* *Damage mechanics, plasticity, 1D, 2D, 3D, local and global formulation)*
- *Drying and Autogenous creep* *Isotropic and anisotrpic models*
- *Drying and Autogenous shrinkage*
- *Concrete hydration* *Heat generation and hardening*
- *Steel rebar* *Truss and grid representation*
- *Steel rebar corrosion*
- *Steel rebar yielding*
- *Tendon prestressing* *Truss elements (non conincident nodes), with and w/o bonding*
- *Soil mechanics* *Soil-structure insteraction, nonlinear behaviour*

Conclusion (2/3)

« Reliable » and « Robust » tools

+

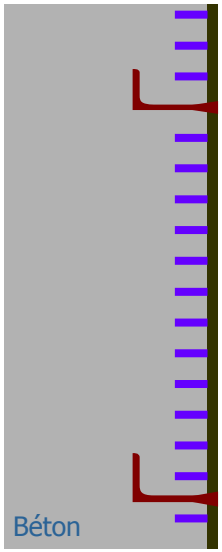
Know how in analysis and expertise

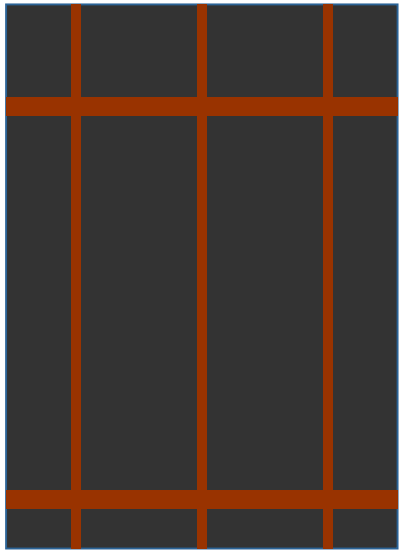
Need for a balanced effort on **« Material – Numerical – Expertise »**

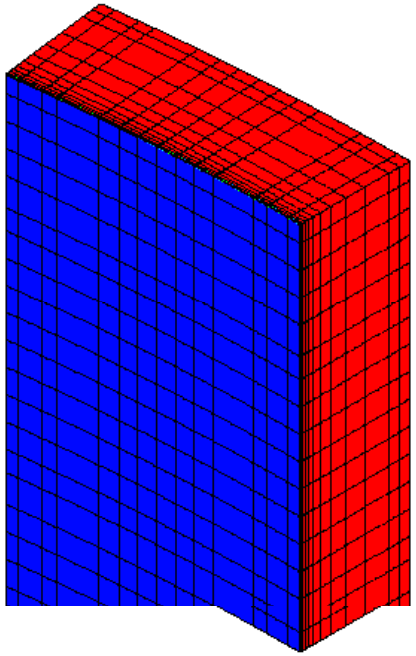
Robust
- *Numerical algorithms*
- *Cost (man power & computation)*

Reliable
- *Representative of physical phenomena*
- *Domain of validity*

Steel concrete interaction







(P9TMELS1)/APRP: Contrainte Szz a t = 1

Prestressing technology