ICOLD
INTERNATIONAL
COMMISSION ON
LARGE DAMS

ICOLD-BW 2019
9th-11th September
MILANO
Numerical analysis of dams

ICOLD COMMITTEE ON COMPUTATIONAL ASPECTS OF ANALYSIS AND DESIGN OF DAMS

15th INTERNATIONAL BENCHMARK WORKSHOP ON NUMERICAL ANALYSIS OF DAMS

Theme A - Formulation

SEISMIC ANALYSIS OF PINE FLAT CONCRETE DAM

9 September 2019, Milan, Italy

Consequences of concrete nonlinear behavior on the seismic dam response

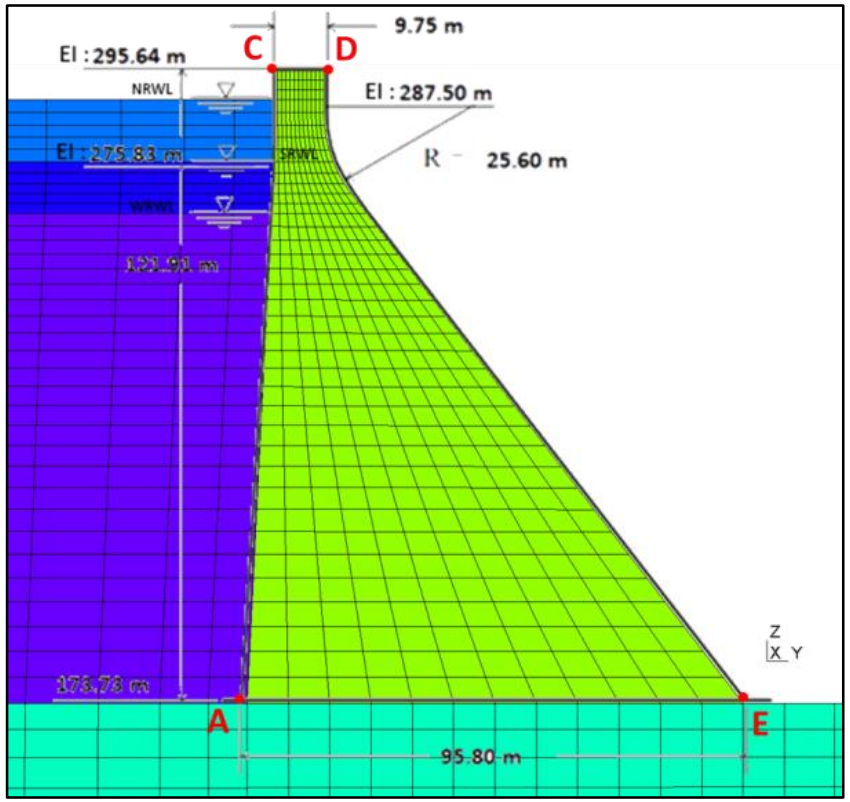
Paul PETON, Thibaud THENINT

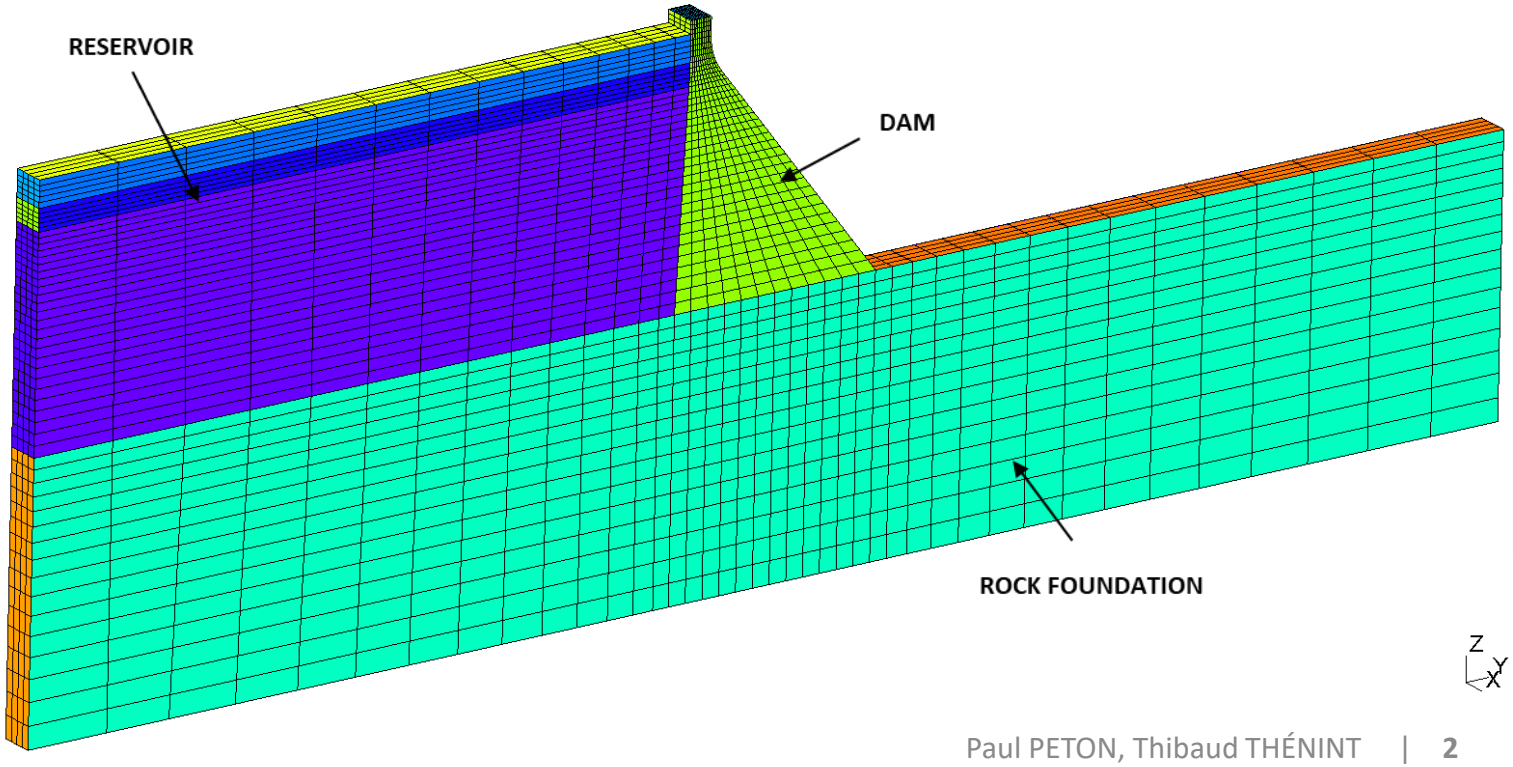
sixense
Necs

MESH & MODELLING PRINCIPLES

- Tri-dimensional finite elements model:

Linear hexahedrons elements	DOFs
~ 1800 (Dam) ~ 2500 (Rock) ~ 2000 (Reservoir)	~ 30 000





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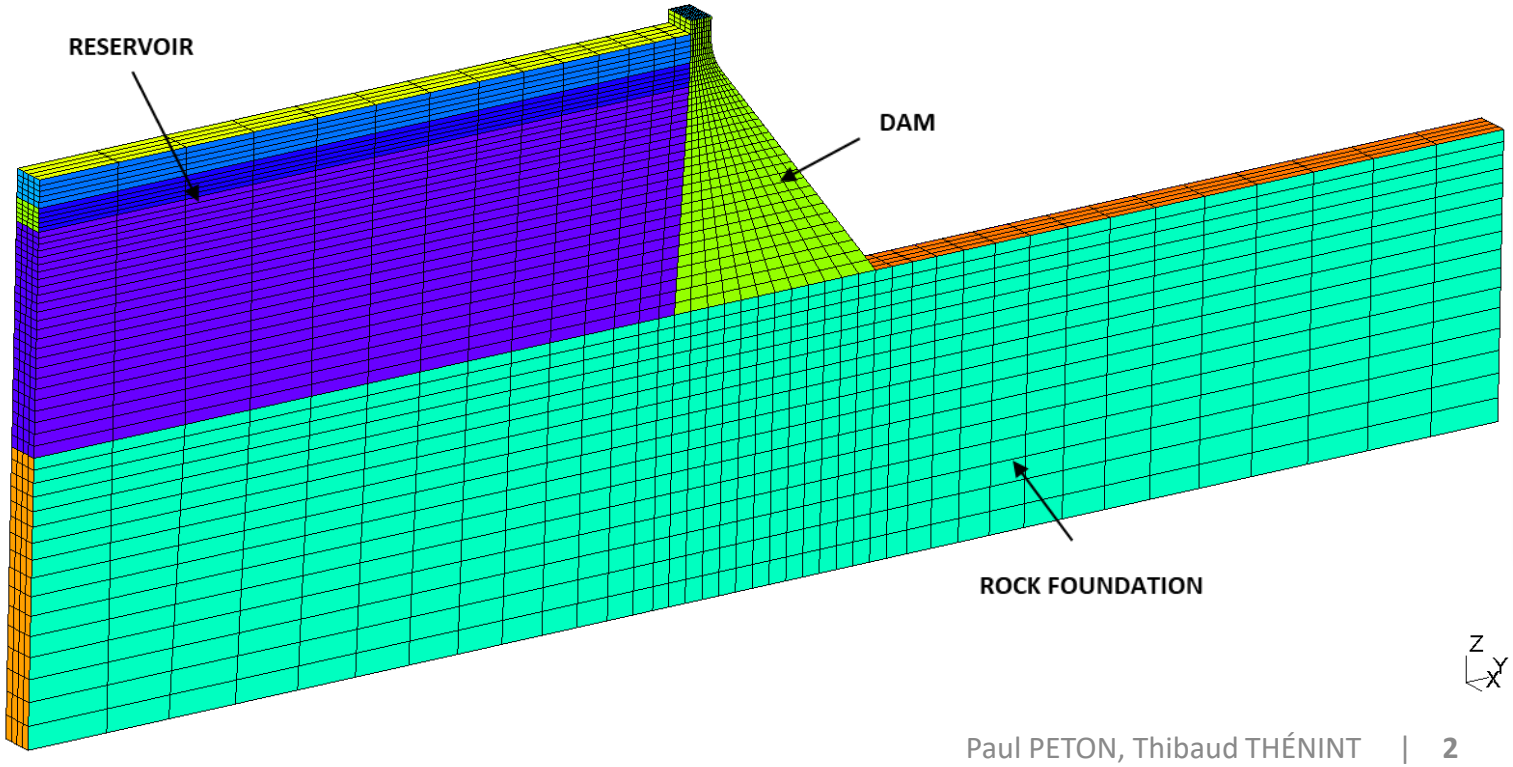

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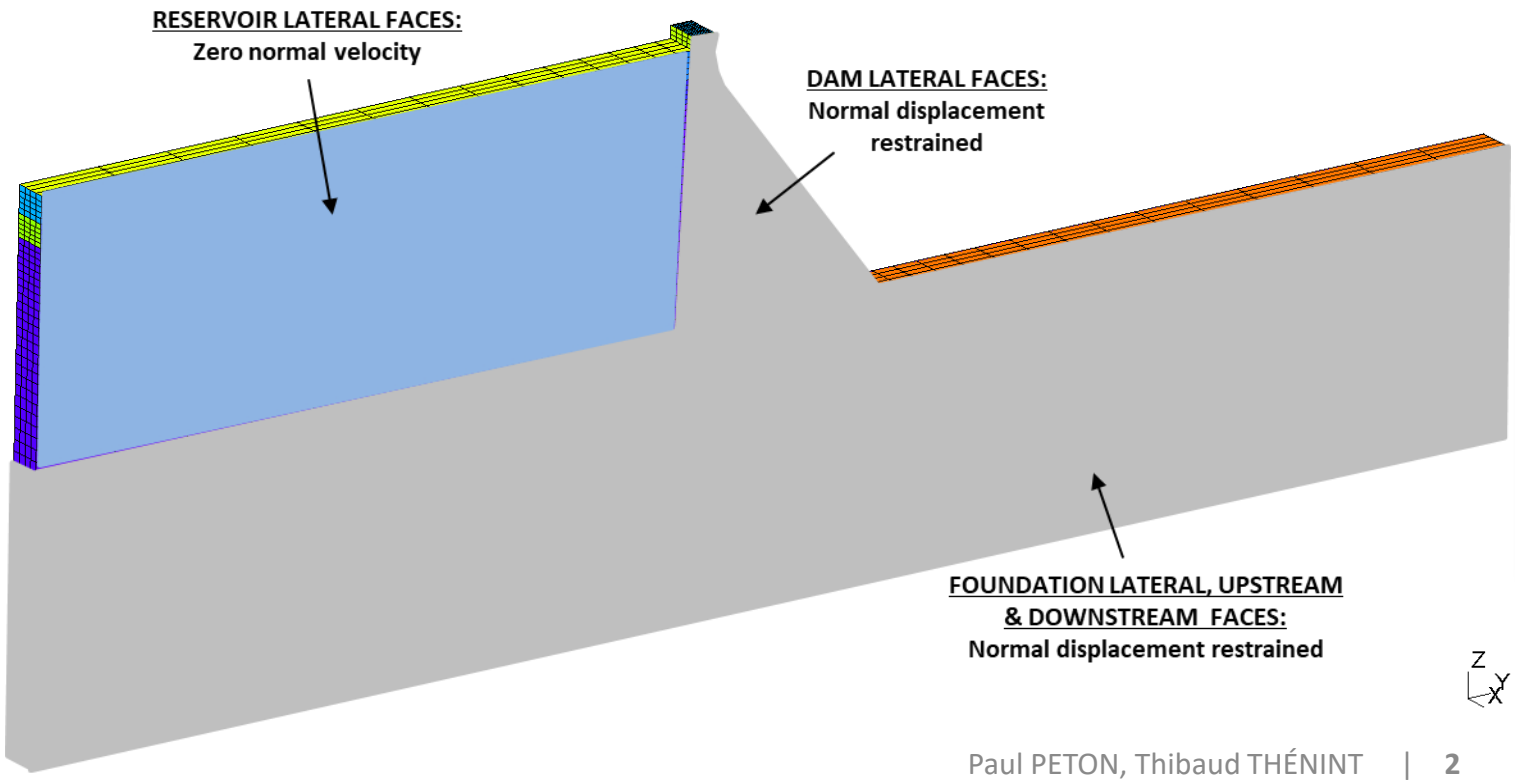

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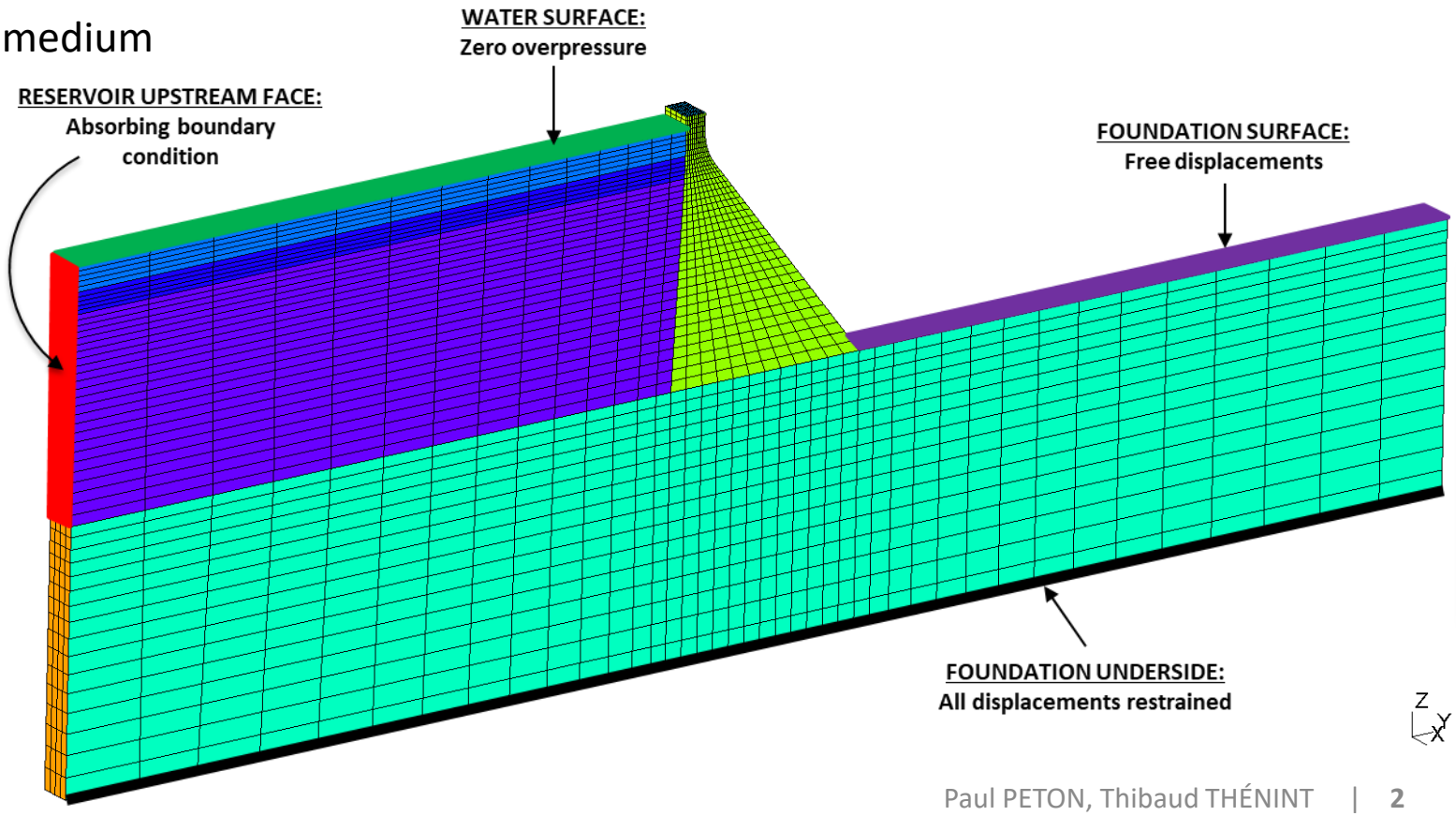

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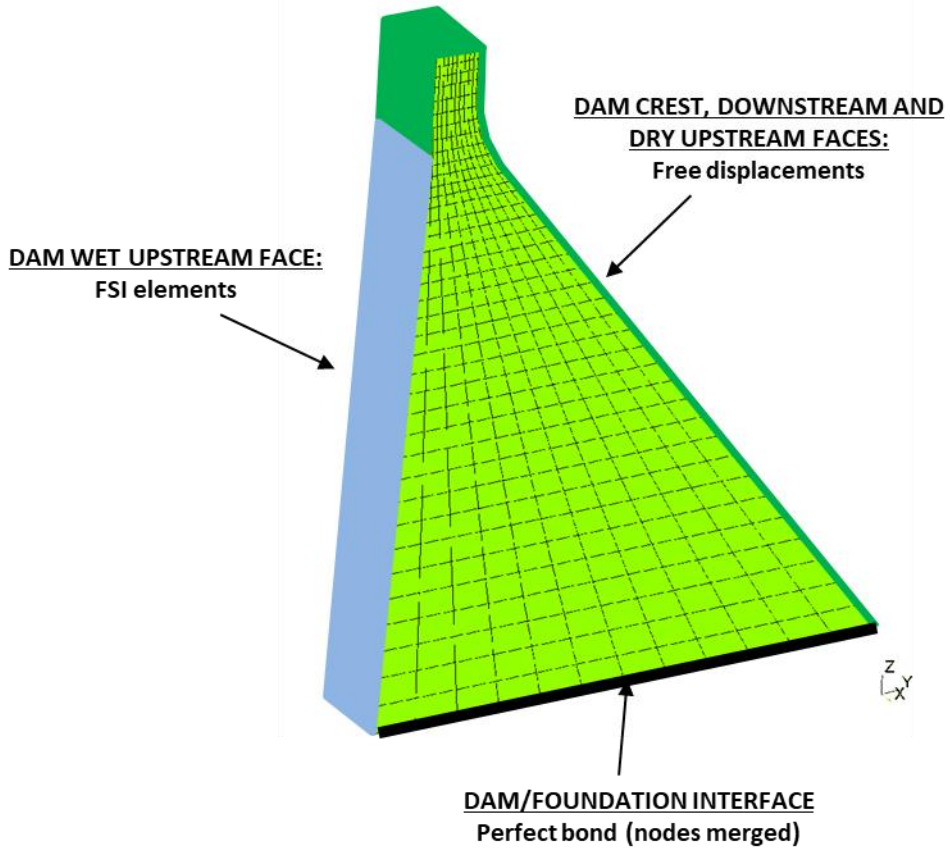

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- Dam interfaces:

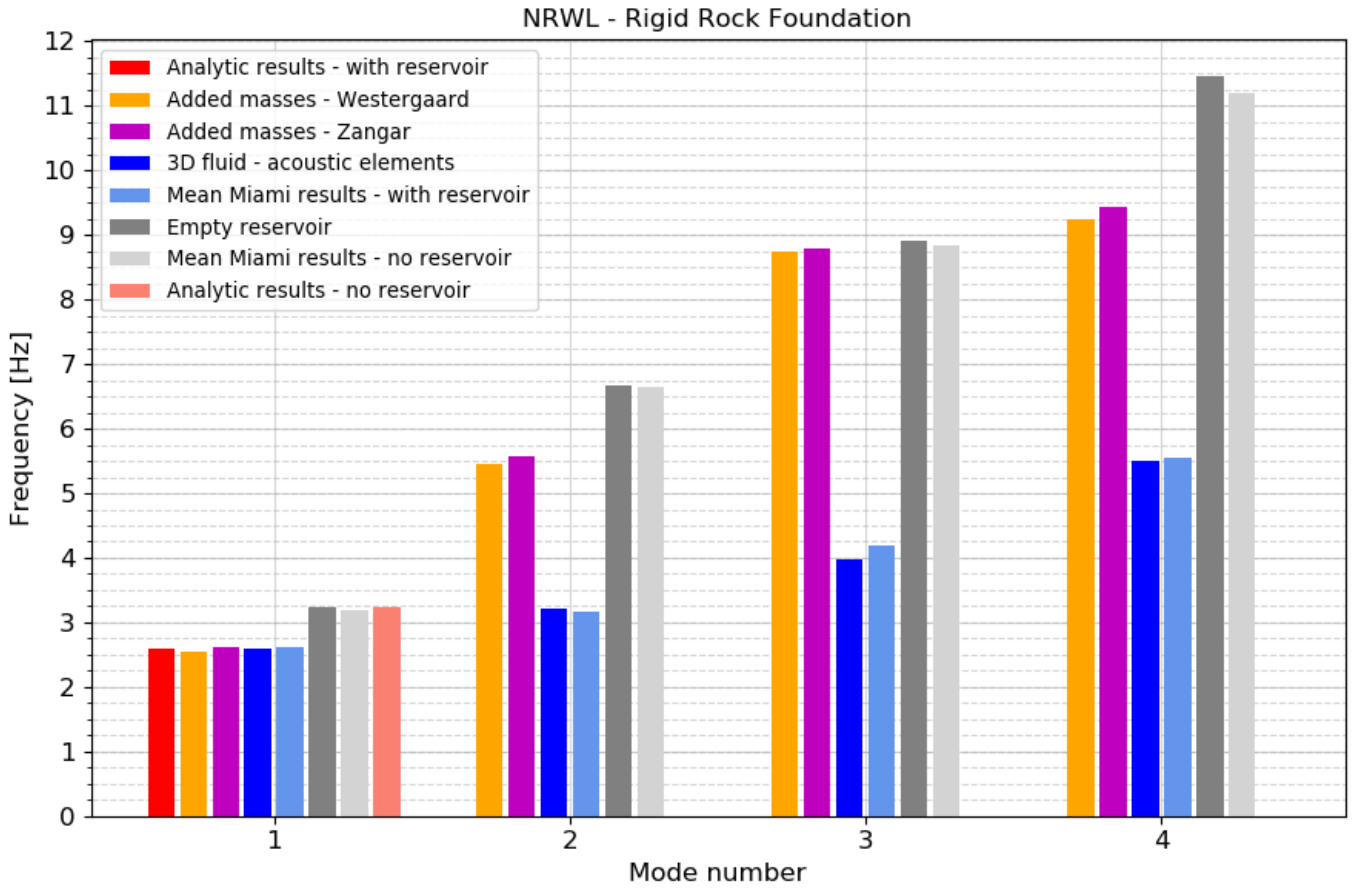
- Modelling and computation software's : SALOME, code_aster

Model Validation - Modal Analyses

- Rigid foundation hypothesis
- Normal reservoir water level
- Comparison of different modal analyses:
  - Analytic results
  - 2 added mass approachs
  - Miami results

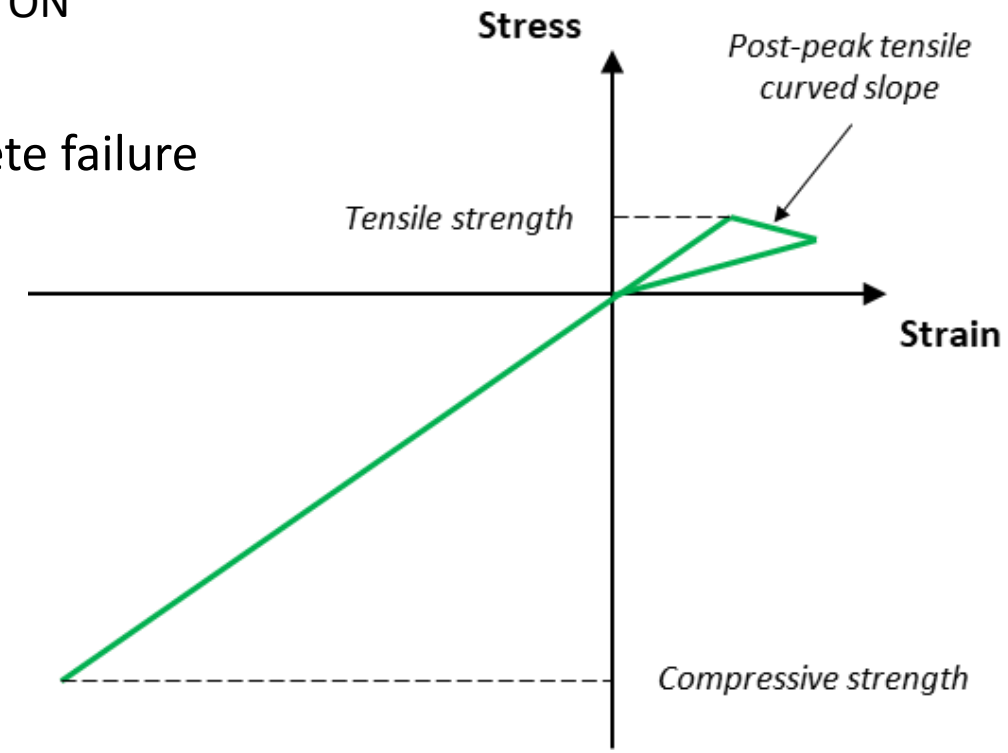
→ 1st frequency : all model are consistent

→ Higher frequencies FSI model match with previous Miami results



Seismic linear and nonlinear analyses

- Frame: Test Cases E & F.
- Dam material constitutive law: *Code_Aster*® ENDO_ISOT_BETON
- Fragile-elastic behavior which describe only tensile concrete failure
- Concrete compressive state must remains moderate
- Loss of rigidity measured by an evolving scalar:
  - 0: Healty material
  - 1: completely damaged



Seismic linear and nonlinear analyses

- Implicit numerical transient analyses
  - Massless foundation
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  - Relative displacement is computed
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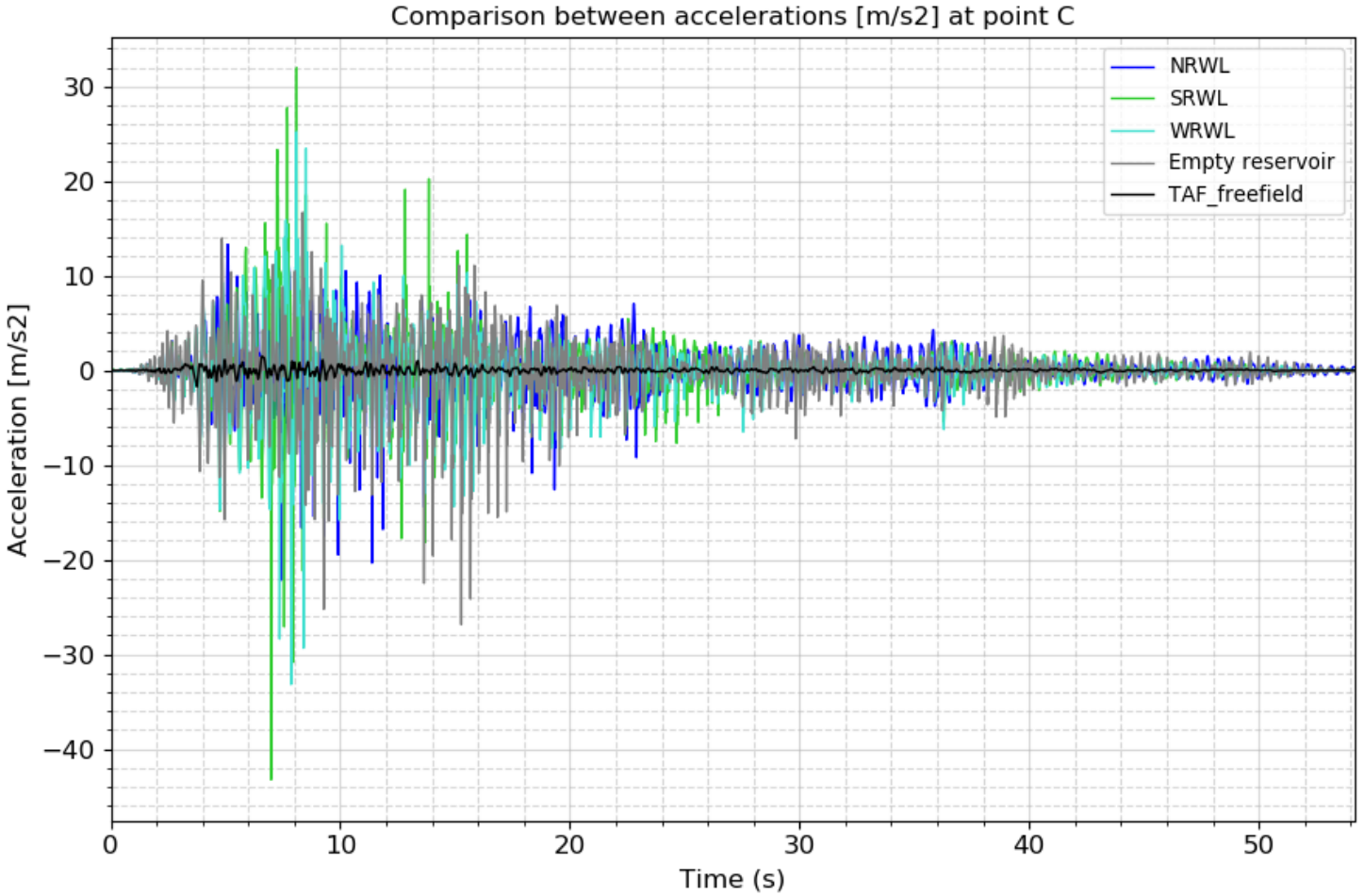
  - **Crest accelerations (N.L. models)**



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  - **Comparative table**

Maximum values	NRWL		SRWL		WRWL		Empty reservoir	
	L.	NL.	L.	NL.	L.	NL.	L.	NL.
Max. crest acceleration (m/s²)	17.6	22.1	25.9	43.2	20.0	33.2	22.3	26.9
Crest amplification : $\frac{A_{Crest}}{A_{max,load}}$	**10.1**	**12.7**	**14.9**	**24.8**	**11.5**	**19.1**	**12.8**	**15.5**
Max. crest displacement (mm)	64	55	108	104	84	120	41	42
Heel Hydrodynamic pressure (kPa)	242	186	369	252	285	289	-	-

Seismic linear and nonlinear analyses

- Implicit numerical transient analyses
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- Results:
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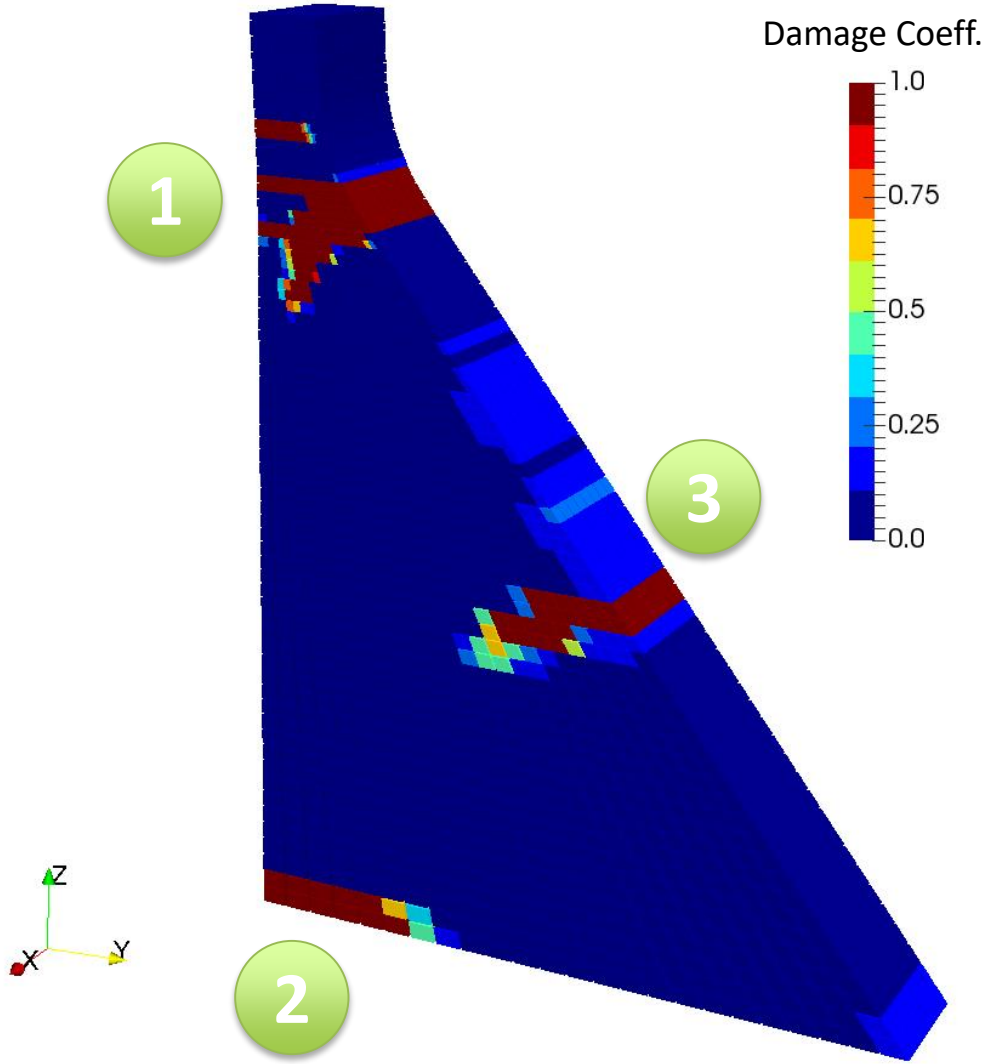
  - **Concrete damaged indicator (SRWL)**



Conclusions & Perspectives

- Intermediate water levels could have more consequences on the dam both for L. & N.L.
- Nonlinear analyses:
  - give coherent results (displacements, damage)
  - describe tensile stiffness loss
- Simple geometrical problem raises a lot of computational and modelling problematics
  - Foundation & reservoir modelling
  - Seismic loading
  - Boundaries conditions

- To go further:
  - More complex behaviors could be considered
  - Determination of the “modal behavior” after the seismic loading
  - Consider another seismic loading, planes waves associated with absorbing boundaries conditions

Thanks **Merci**

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