ICOLD
INTERNATIONAL
COMMISSION ON
LARGE DAMS

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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

*2D Seismic analysis of Pine Flat concrete gravity dam including mass of foundation*

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# 2D - FE Model

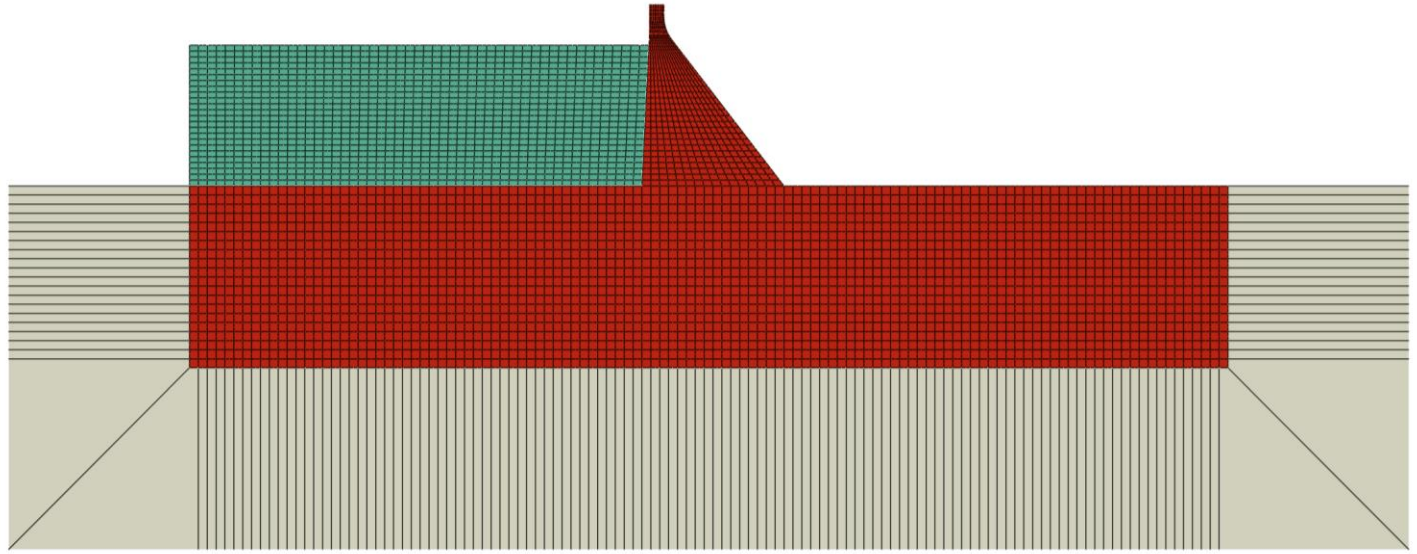


Plain strain elements (CPE8R)

Acoustic elements (AC2D8)

Infinte elements (CINPE5R)

Merged dam body and foundation



Fluid Structure Interaction

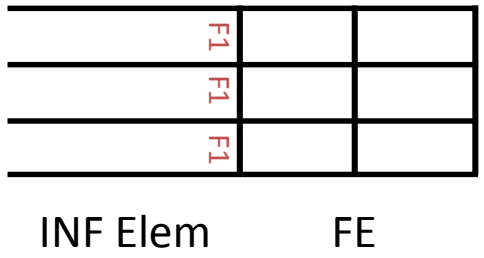
Tie constraint at U/S face of dam and bottom of reservoir

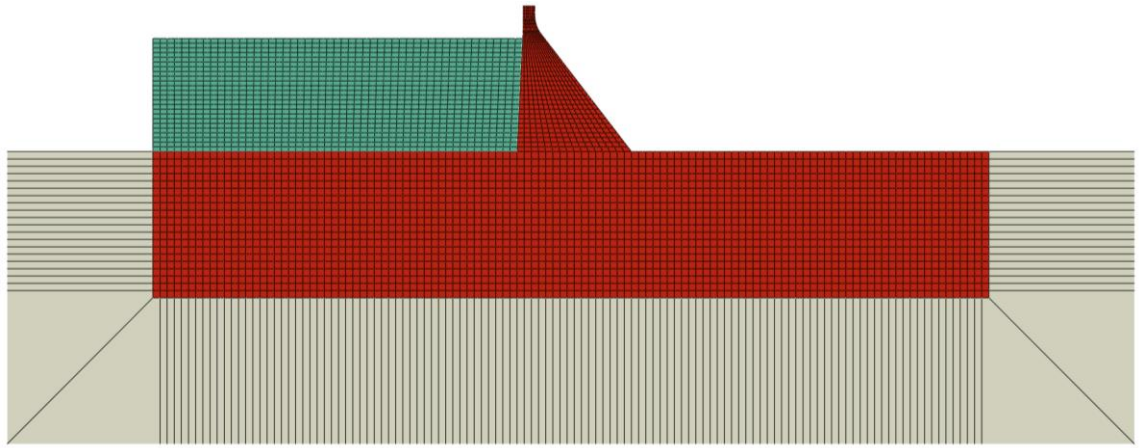
Total reflection at reservoir bottom

# Infinite (INF) Elements in Abaqus



- available in 2D (plain strain and plain stress) and 3D
- used in problems where the surrounding medium (rock foundation) is larger than the area of interest
- linear elastic behavior in static load cases, additionally isotropic material in dynamic analyses
- stiffness of elements are provided in static solid continuum analyses
- in dynamic analyses infinite elements add a quiet boundary to FE model (Lysmer and Kuhlemeyer)
- same material parameters as FE



# Modal Analysis

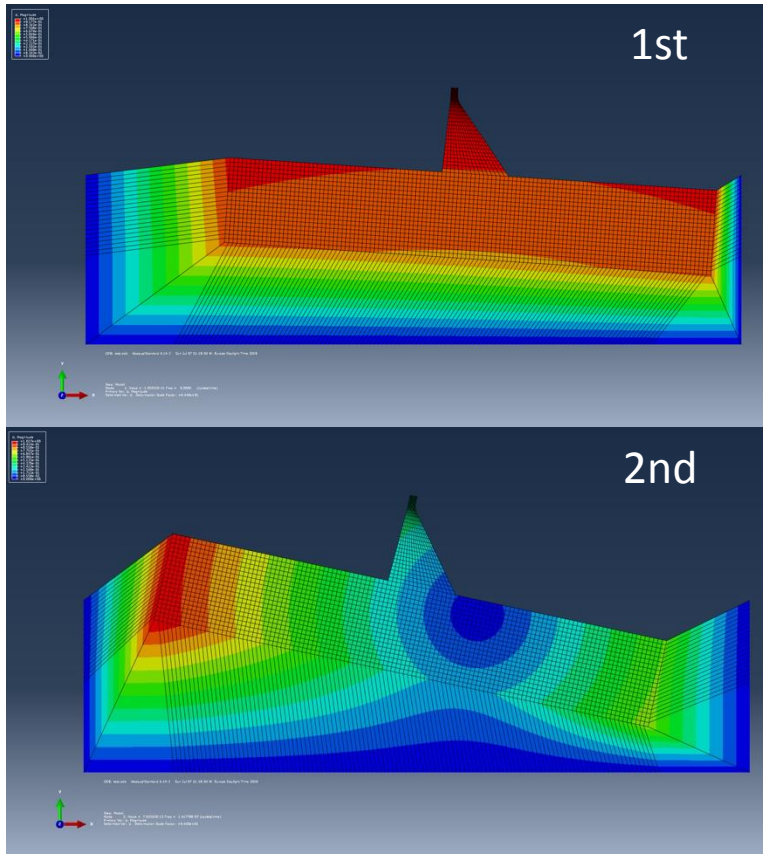
Application of boundary conditions

- displacement DOF closed at outer boundaries of infinite elements
- infinite elements don't contribute to modal solution
- first three natural frequencies = 0 Hz

Improvement

- -> no INF elements in modal analyses,
- displacement closed at outer boundaries of FE rock domain in perpendicular l to the surfaces
- displacement closed at outer boundaries of FE rock domain in vertical and horizontal direction –> **final model**

load case: empty reservoir

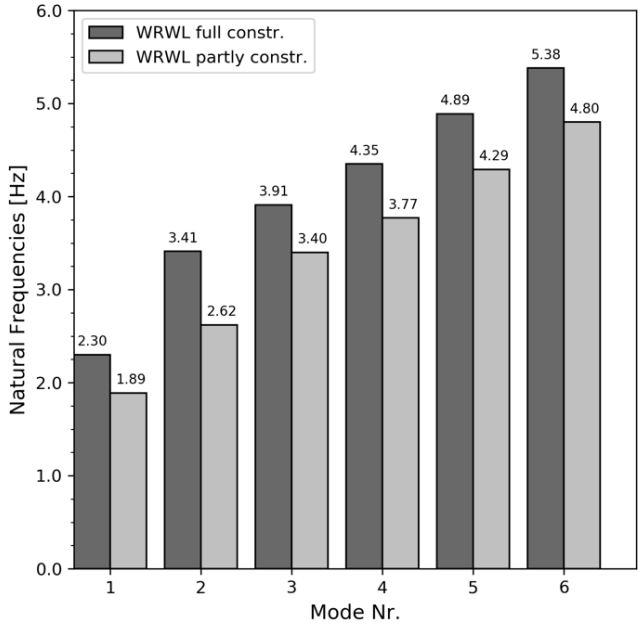


# Modal Analysis



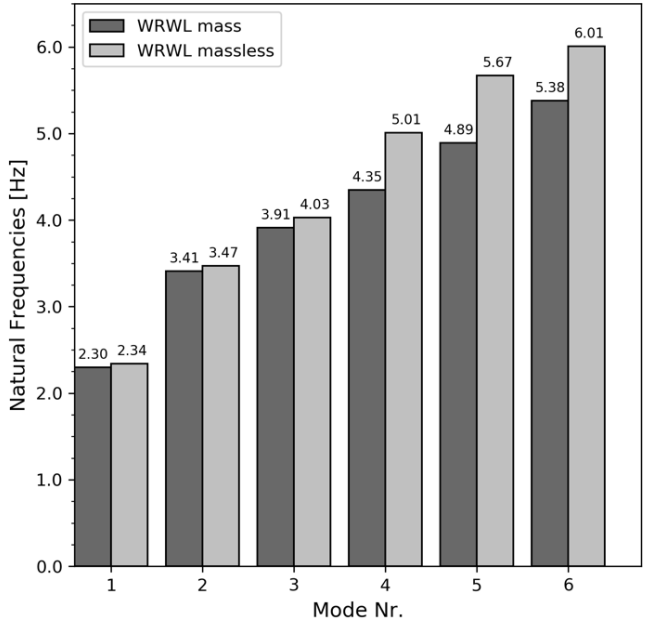
Application of boundary conditions – without INF elements

- displacement DOF closed perpendicular at outer boundaries of finite elements
- natural frequencies lower as in final model




Massless foundation

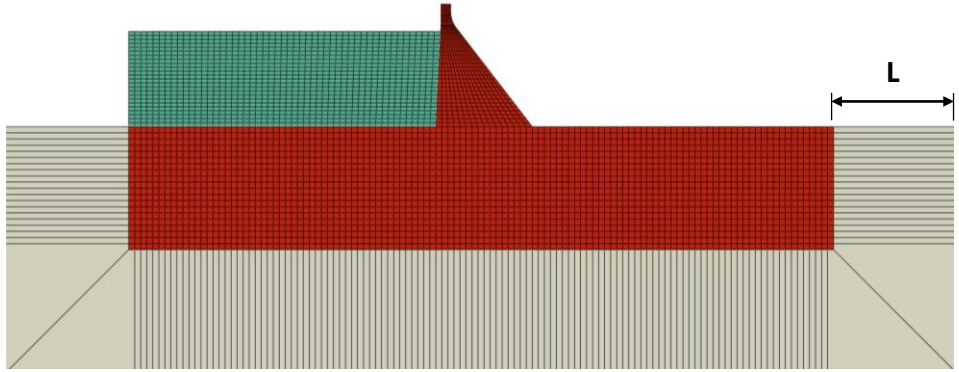
- first three natural frequencies good agreement with model in which mass foundation is considered

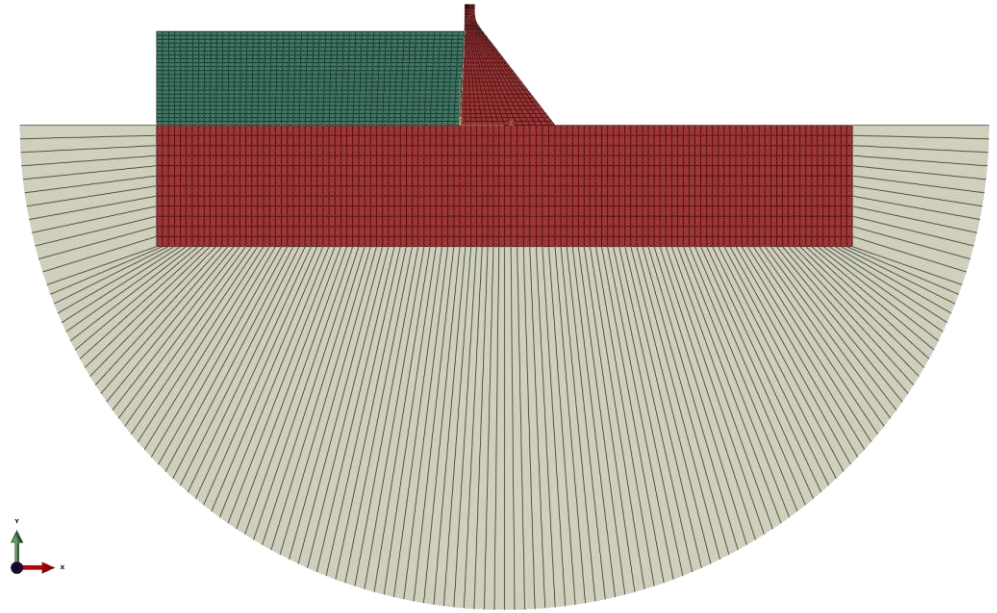


# Case D-1 - Variation Shape of INF Element layer



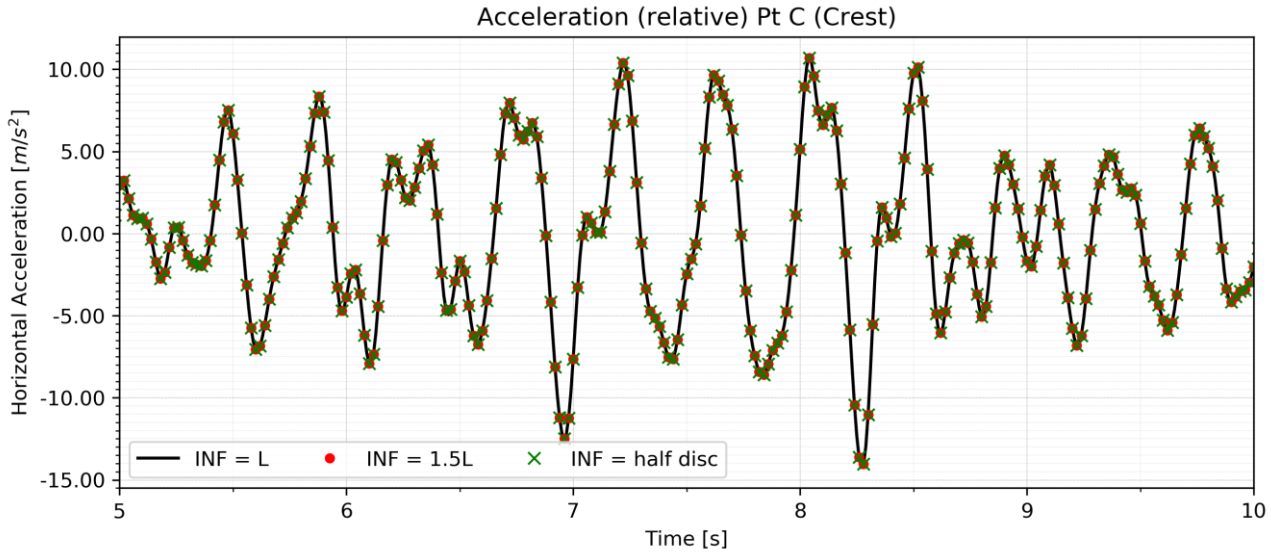
- const. thickness INF layer: L = 122 m (= height of FE part)
- const. thickness of INF layer: 1.5*L
- INF layer half disc: $L_{min}$ = 122 m

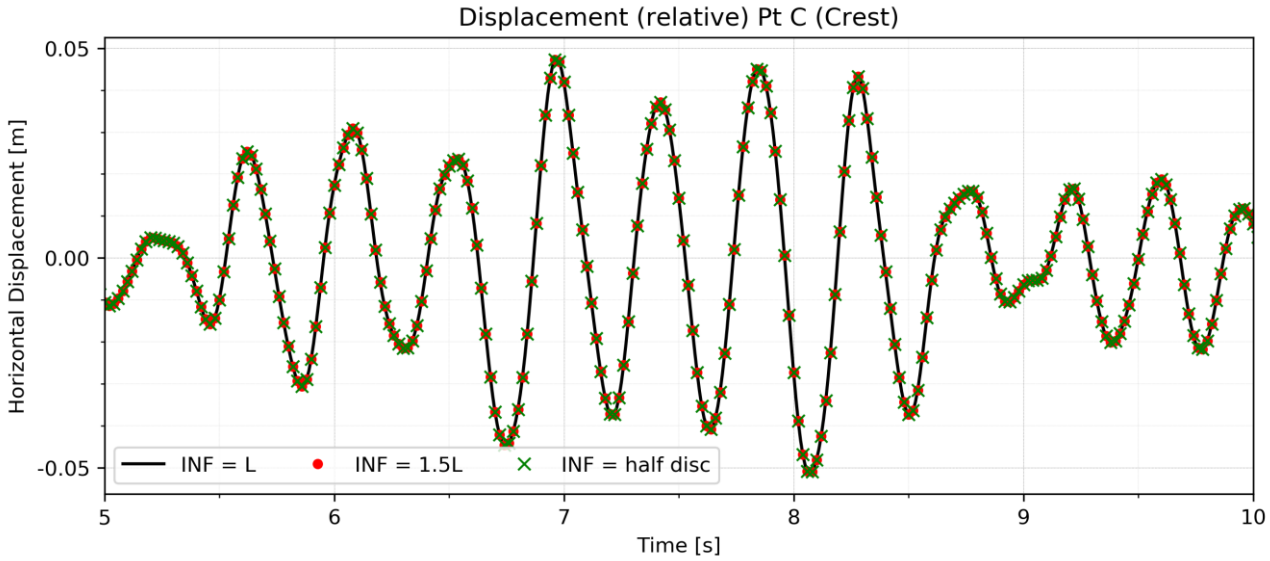


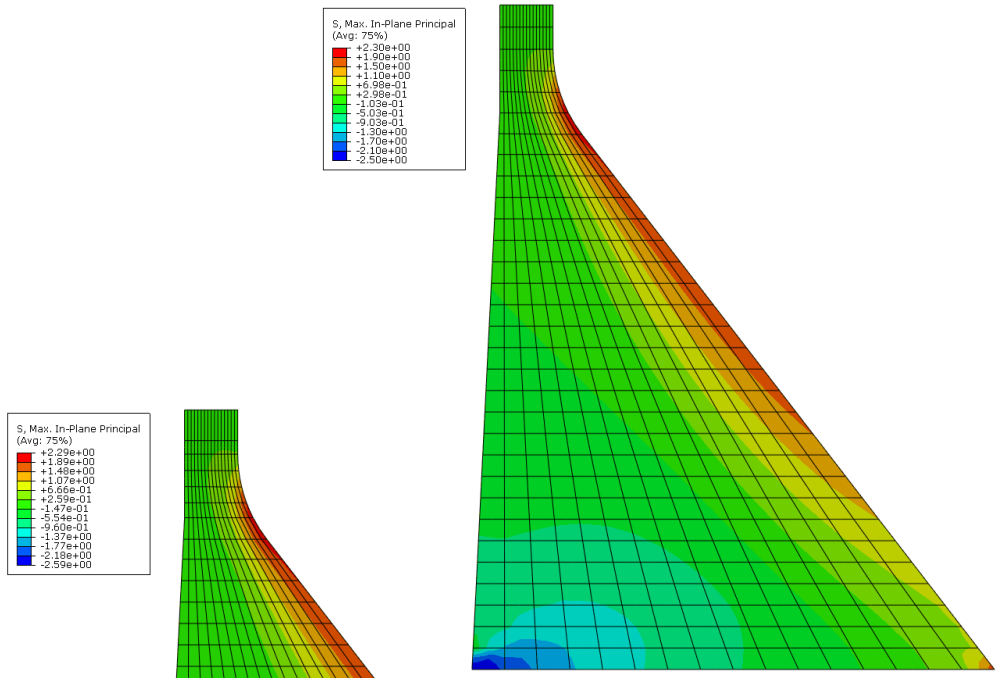



# Case D-1 - Variation Shape of INF Element layer

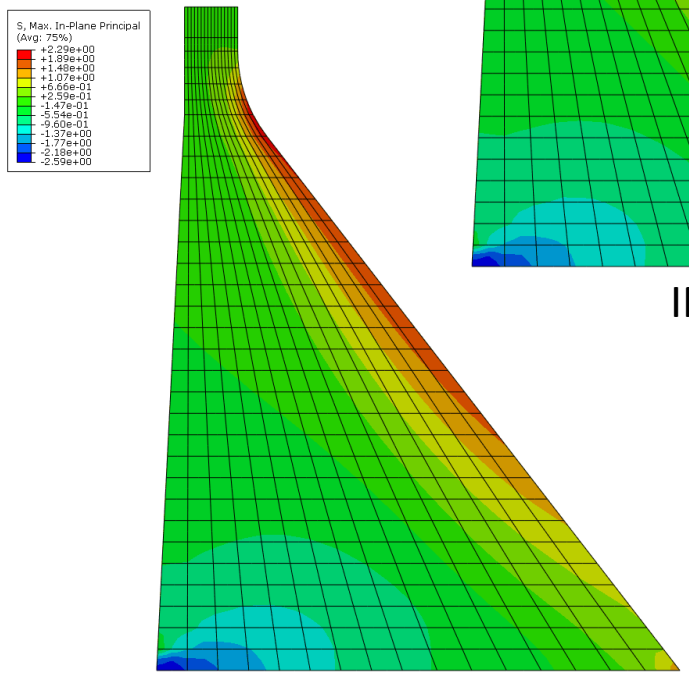





INF = 1.5L



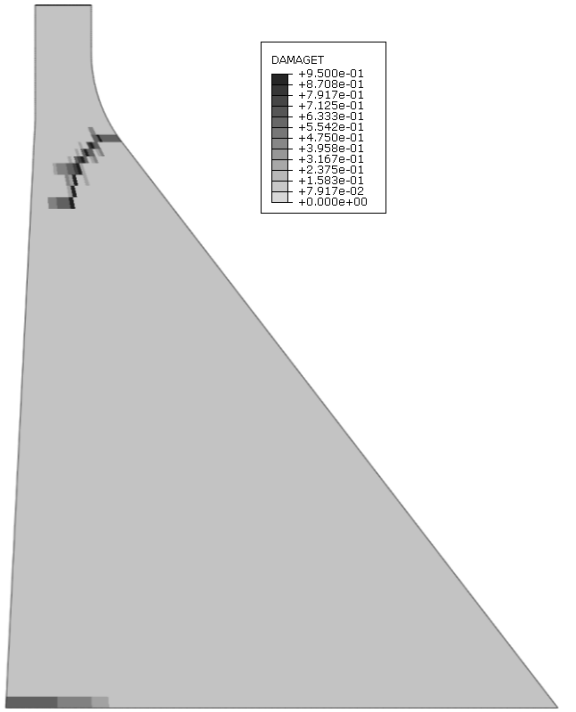

INF = half disc

# CASE E-1, TAFT record

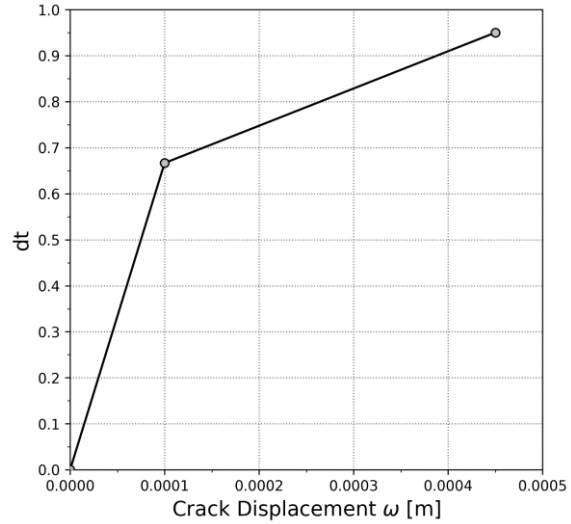
Concrete Damaged Plasticity material model

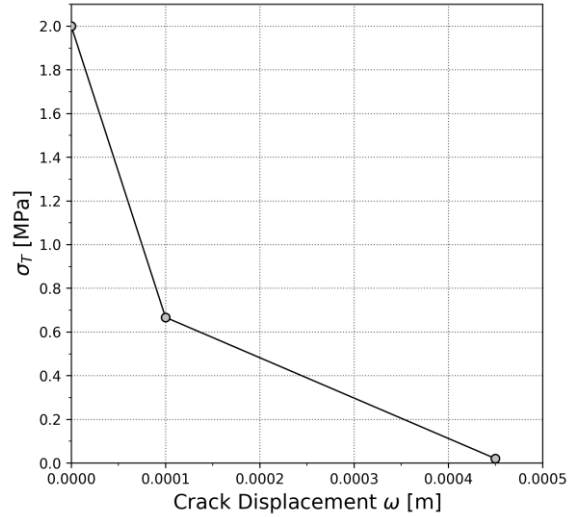
- compressive behavior acc. to EC 2
- linear-elastic behavior up to yield strength in tension
- bi-linear tension softening (Hillerborg 1988)
- tensile damage $d_{t,max} = 0.95$

- Damaged length of base joint = 18m (~19%)
- Damage Index cross section ~1.5%




t = 54.15 sec



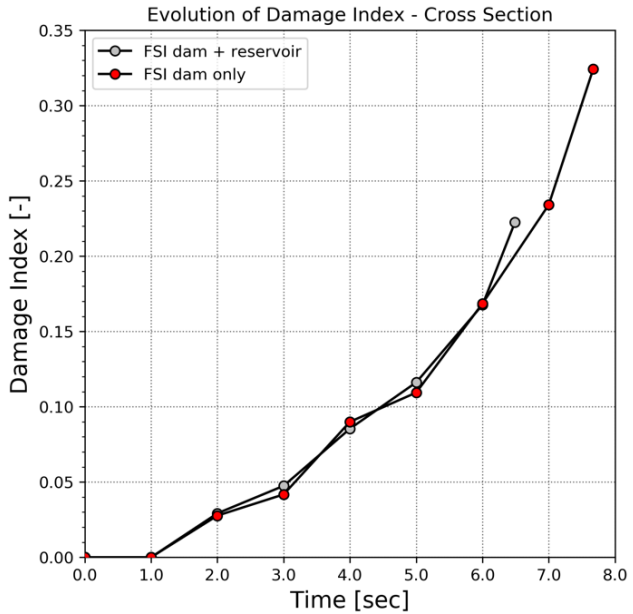



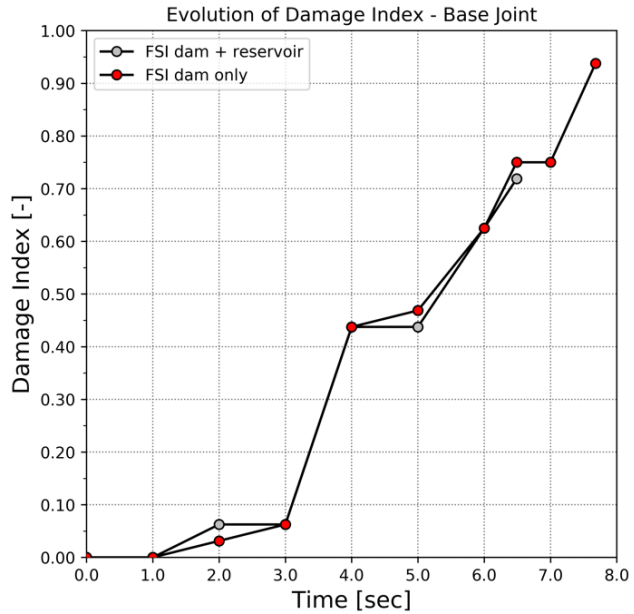
# CASE E-2, ETAF

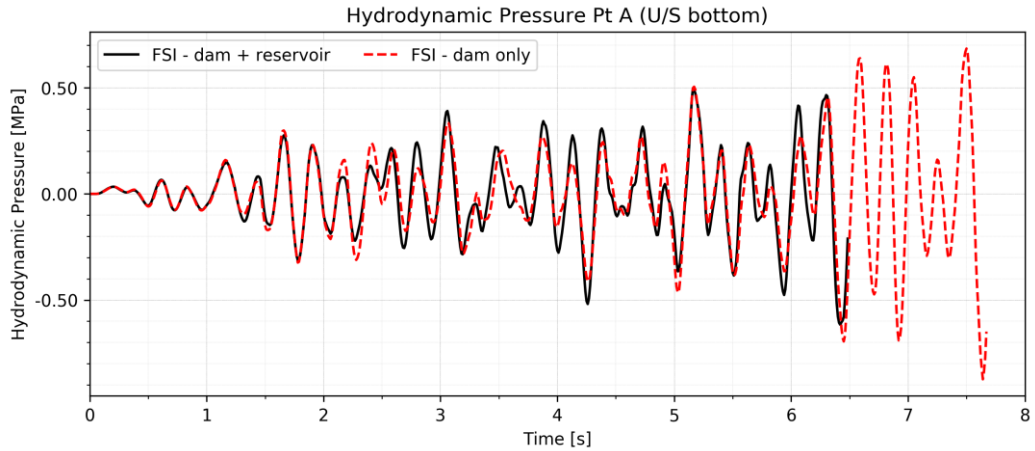
Concrete Damaged Plasticity material model

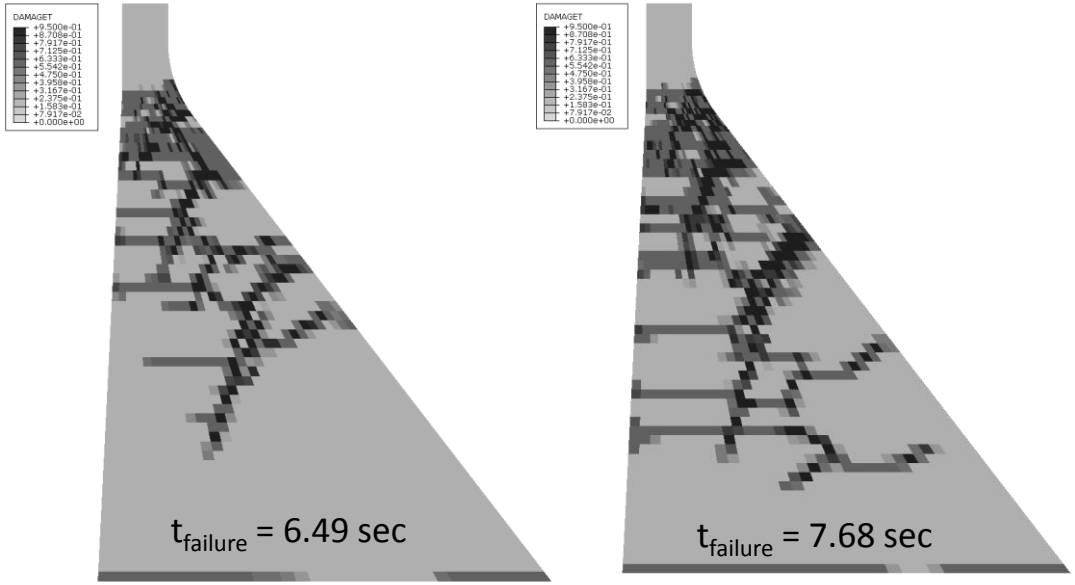
variation of surfaces at which FSI is considered

- FSI at U/S face dam + reservoir bottom
- FSI only at U/S face dam




FSI U/S dam + reservoir

FSI U/S dam only

# Conclusion



Lessons learned

- First three natural frequencies show good agreement massless and mass applied foundation block
- No difference in results if thickness and shape of infinite element layer is varied (at least for these case study where only horizontal acceleration is applied)
- Concrete Damaged Plasticity non-linear concrete material model
  - No major damage for TAFT record (Case E-1)
  - Influence of FSI surfaces on response of dam

Future Studies

- Include structural non-linearity, non bonding contact at dam-foundation interface and/or lift joints
- different assumptions for hardening and softening curves (linear, bi-linear exponential) non-linear material model
- 3D model of Pine Flat including block joints at monolith boundaries

# Discussion

Luenersee gravity dam, Voralberg (Austria)