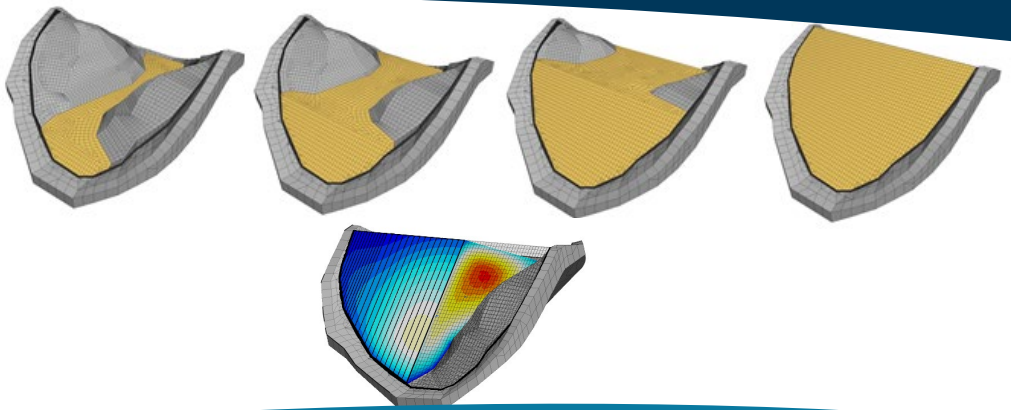
Verification of the mitigation measures for preventing the concrete face failure of a 210m CFRD



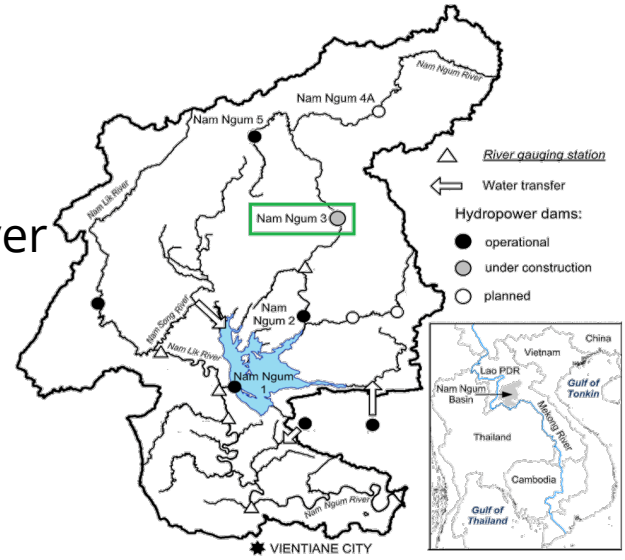
Frédéric ANDRIAN.
Jean-Rémi LHERBIER
Mohamed MONKACHI

FIFTH INTERNATIONAL ITASCA SYMPOSIUM 2020 VIENNA, AUSTRIA

ARTELIA

Nam Ngum 3 dam

DAM DESCRIPTION

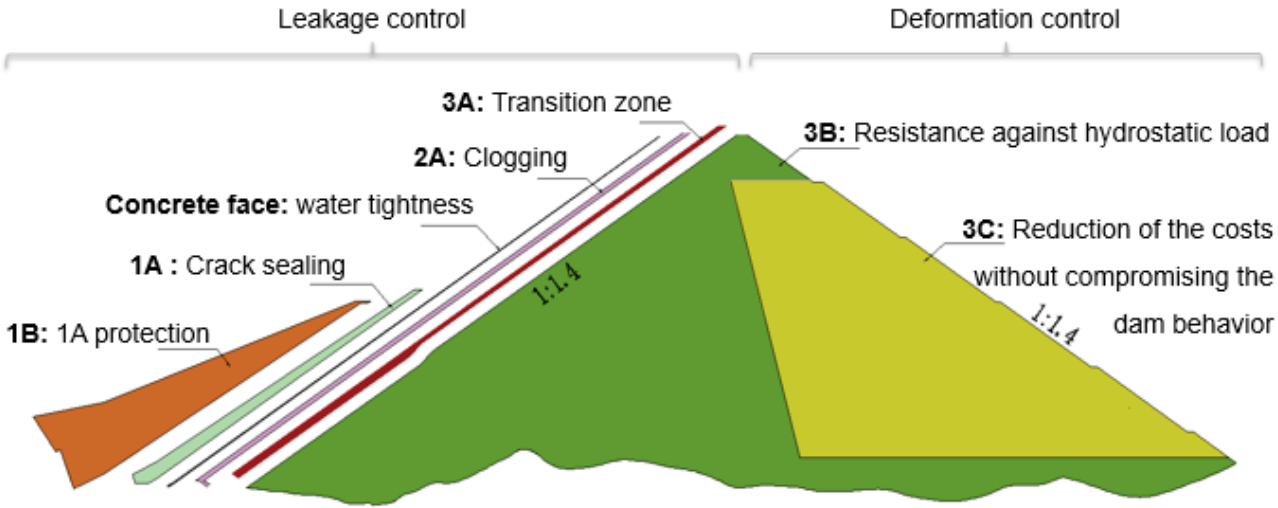


- 480 MW HPP Scheme in Laos – Nam Ngum river
  - ARTELIA Owner's Engineer for EDL
- 210 m high, 520 m crest length
  - Upstream slope 1.4 H / 1 V
  - Downstream slope 1.5 H / 1V (including berms)
- Foundation: sandstones and conglomerates

ARTELIA
Passion & Solutions

Nam Ngum 3 dam

DAM ZONING



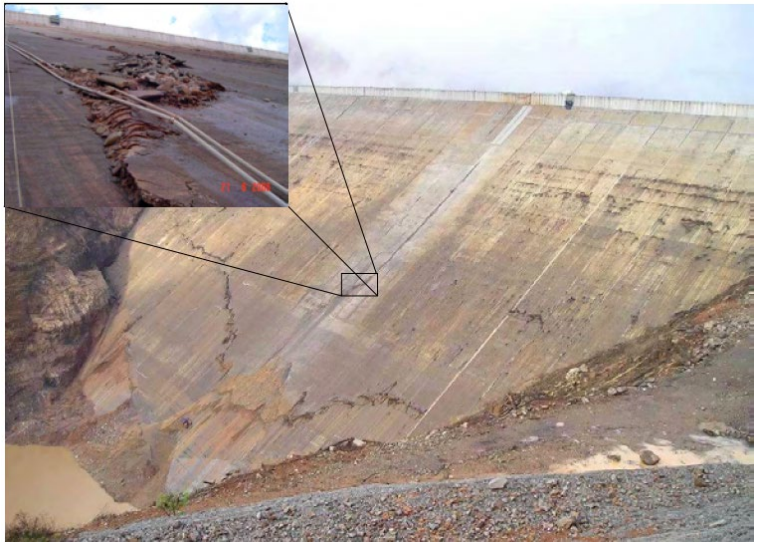
- 3B fresh gneiss (70%), 3C moderately weathered gneiss (90%)
- Maximum particle size: 800mm (~lift thickness)

ARTELIA
Passion & Solutions

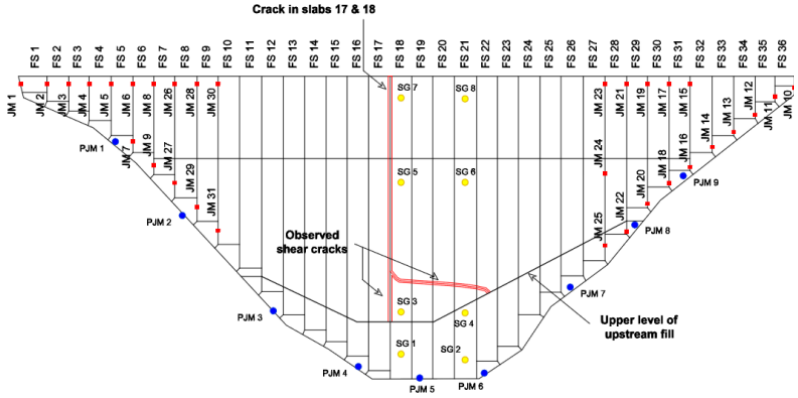
Nam Ngum 3 dam

FAILURE FEEDBACK ON HIGH CFRDs

Campos Novos (202m -Brazil)



Mohale (145m -Lesotho)



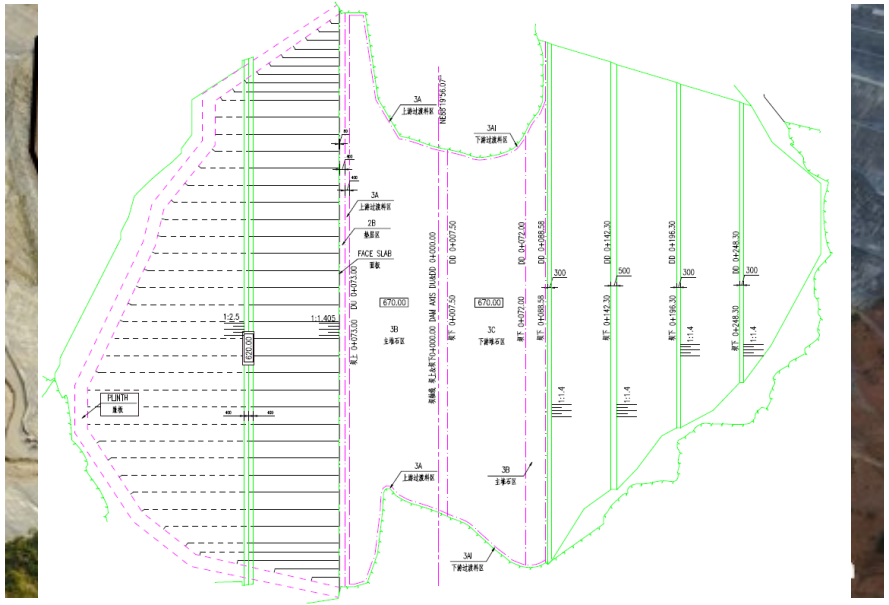
- Concrete face under prescribed displacement

ARTELIA
Passion & Solutions

Nam Ngum 3 dam

A VERY PECULIAR VALLEY SHAPE

- Concrete face constructed slightly upstream the narrowest part of the valley
  - Probably for rockfill volume saving
- High stiffness contrast between the side and the central part of rockfill
  - Behavior at the impounding?



Cross section at El. 670

Concrete face footprint

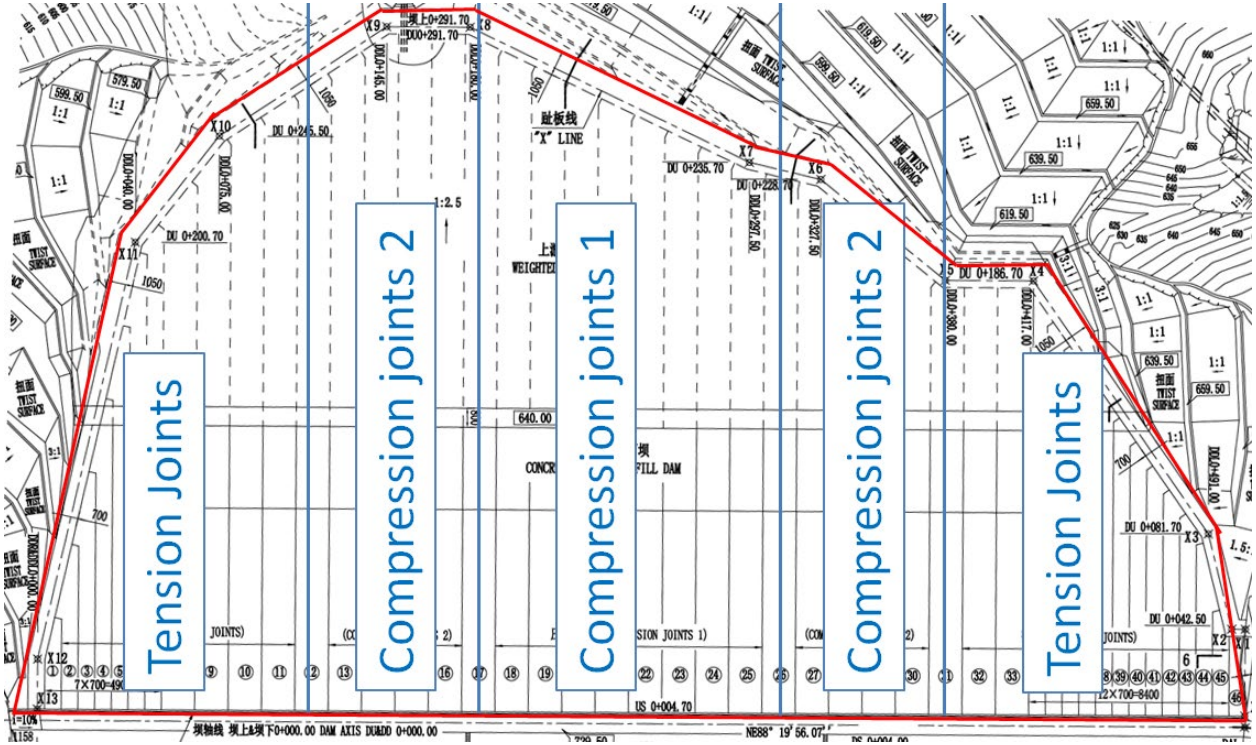
Cross section at El. 620

Cross section at El. 620

ARTELIA
Passion & Solutions

Nam Ngum 3 dam

CONCRETE FACE LAYOUT



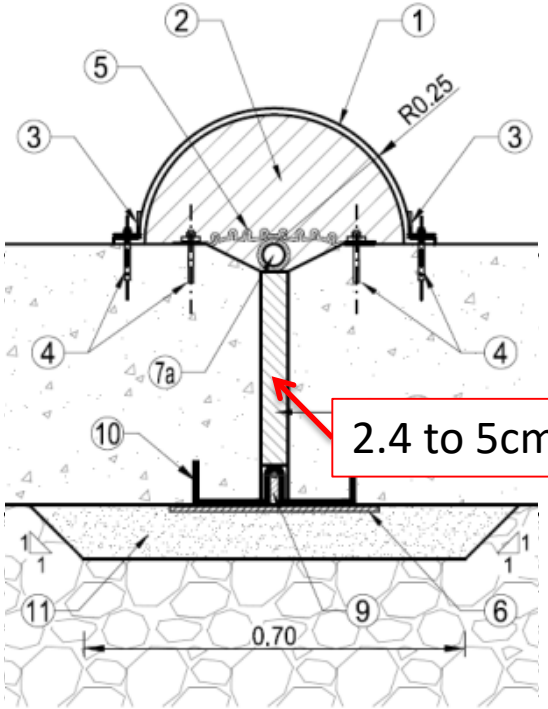
Plane view of the concrete face

ARTELIA
Passion & Solutions

Nam Ngum 3 dam

CONCRETE FACE LAYOUT

- 46 panels
  - From ~ 30 to 100 cm at the dam toe
- Joints
  - Tension joints
  - Compression joints 1: 5cm initial gap
  - Compression joints 2: 2.4cm initial gap

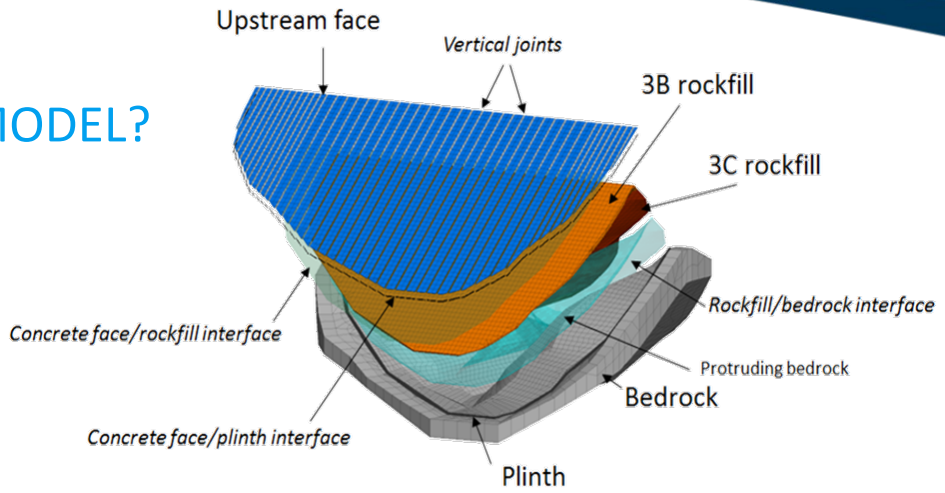


Compression joint Tension joint

Numerical model

OWNER'S ENGINEER NUMERICAL MODEL?

- Existing Contractor's numerical model



FLAC 3D numerical model

- ARTELIA's verification model with major improvements
  - A more rational assessment of scale effect
  - A better simulation of rockfill / bedrock interface
  - Initial gap of compression joints taken into account
  - Delayed deformation based on international feedback and laboratory tests

ARTELIA
Passion & Solutions

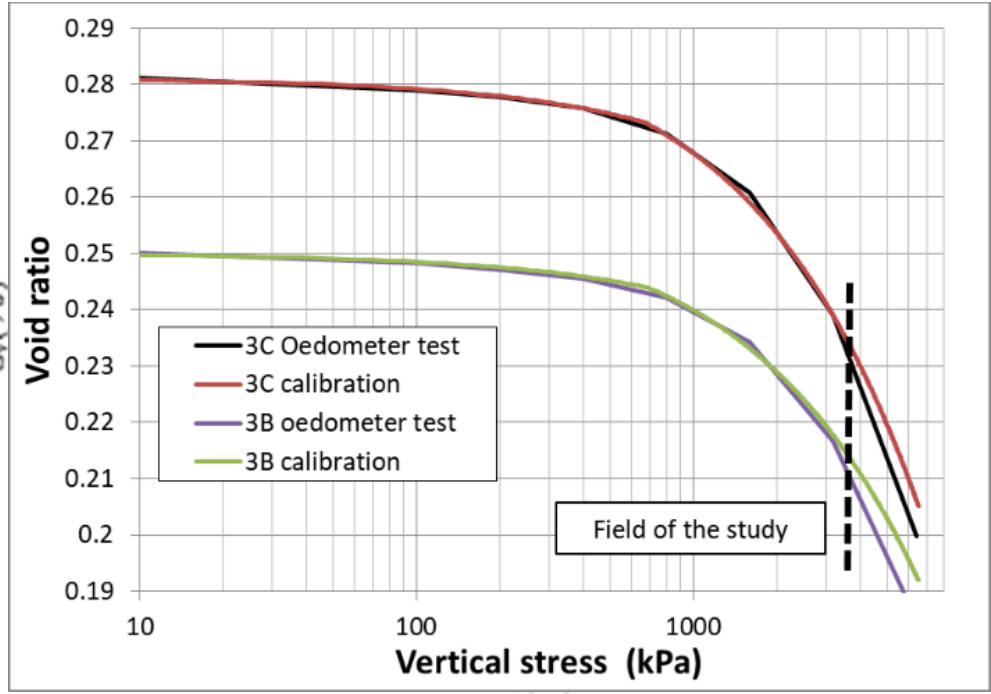
Constitutive laws

ROCKFILL

- 3B and 3C zones modeled (PHM)
- Shear + Volumetric hardening
- Consideration of a stress-dependent friction angle

$$\Phi = \Phi_0 - \Delta\phi \log\left(\frac{-\sigma_3}{p_{ref}}\right)$$

- Good calibration with laboratory tests



Triaxial - Dilatancy

Triaxial - shear

OEdometer

ARTELIA
Passion & Solutions

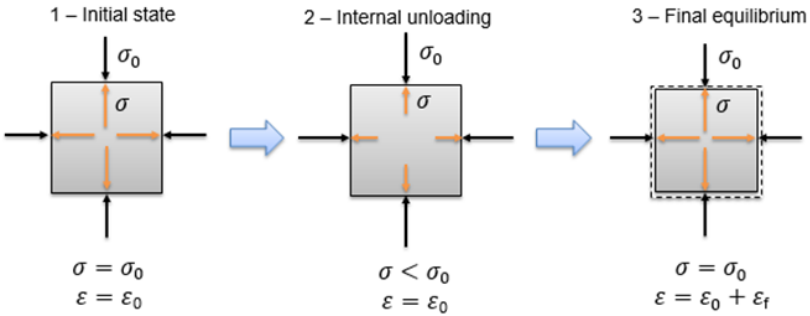
Delayed deformation

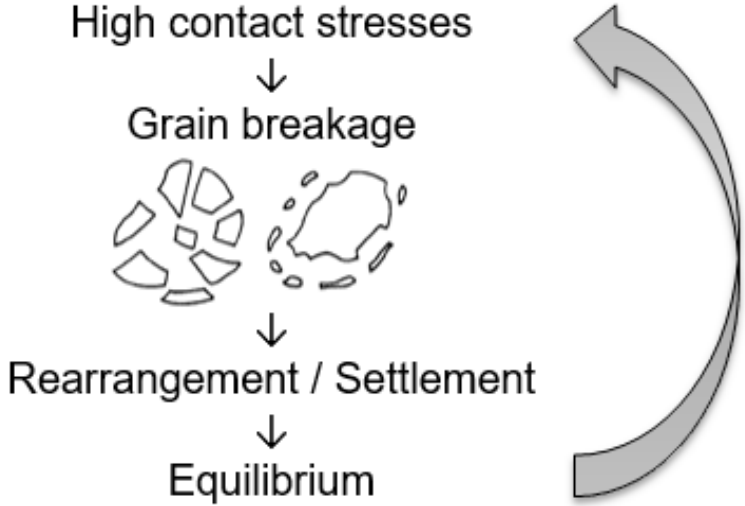
MAIN PRINCIPLES

- Viscosity brought by
  - Saturation
  - Fine materials

- Delayed deformation

  ➔ stress relaxation in the model





ARTELIA
Passion & Solutions

Delayed deformation

ANALYTICAL FORMULATION (SHEN 1991)

- Long-term volumetric strain

$$\varepsilon_{vf} = b\left(\frac{\sigma_3}{p_a}\right)^{m_1} + c\left(\frac{q}{p_a}\right)^{m_2}$$

$$\{\epsilon f\} = \epsilon_{V,f} * \frac{\{I\}}{3} + \gamma_f * \frac{\{S\}}{q}$$

- Long-term deviatoric strain

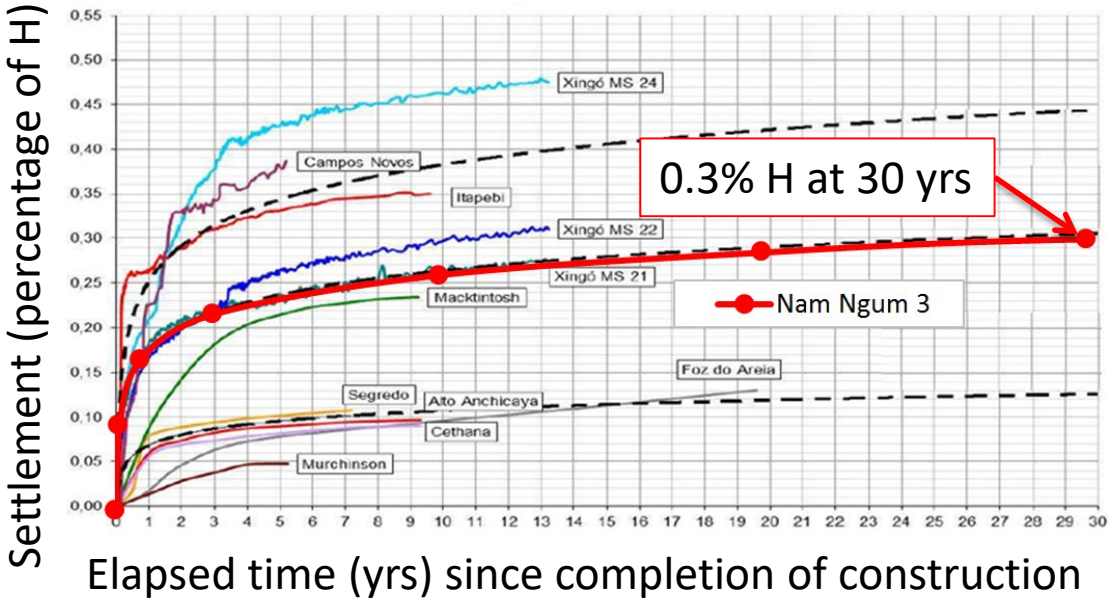
$$\gamma_f = d\left(\frac{S_l}{1 - S_l}\right)^{m_3}$$

- b, c, d, m1, m2 and m3 material parameters calibrated by means of laboratory tests

Delayed deformation

CHOICE FOR NAM NGUM 3

- Average delayed settlement chosen for Nam Ngum 3 dam
  - Based on international feedback (CBDB)
  - Calibrated from laboratory test (stress dependency)

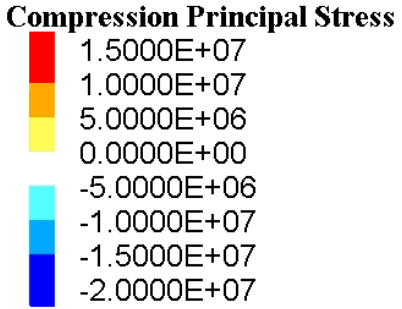


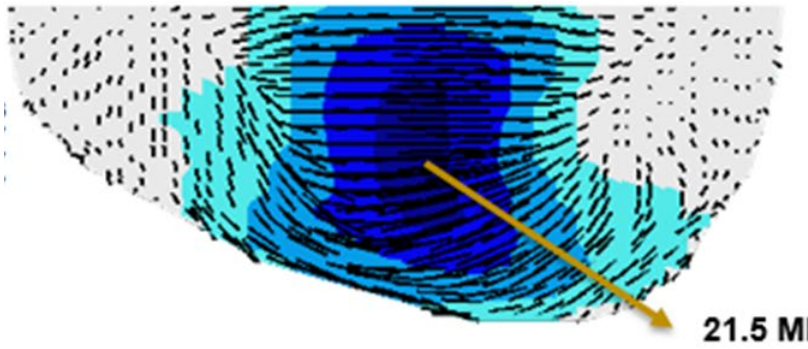
ARTELIA
Passion & Solutions

Results

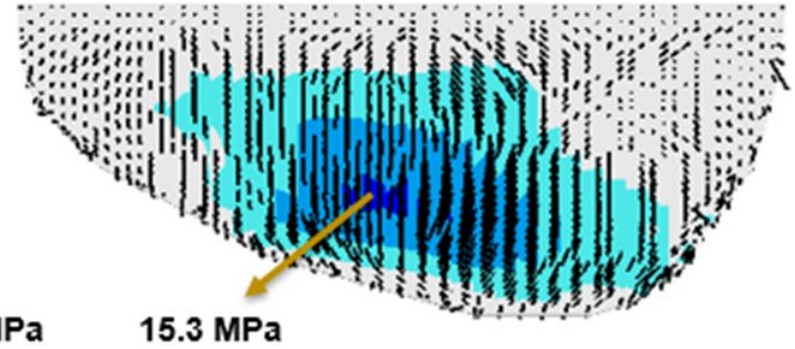
STRESSES IN CONCRETE FACE

- Clear beneficial effects of the compression joints
  - After 30 years of operation





Without compression joints



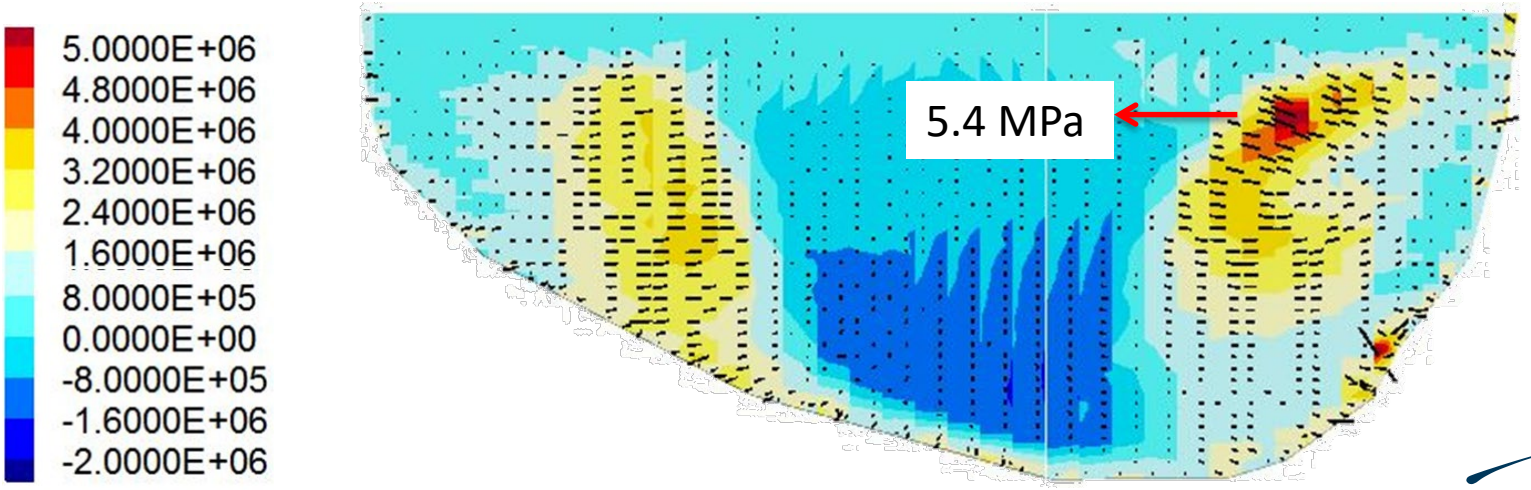
With compression joints

ARTELIA
Passion & Solutions

Results

STRESSES IN CONCRETE FACE

- Diagonal tensile stresses due to the valley shape after 30 years of operation
  - ➔ Structural rebar reinforcement to be provided



Tension principal stresses (Pa)

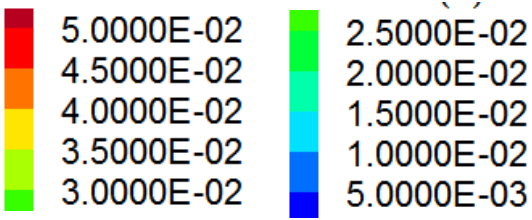
ARTELIA
Passion & Solutions

Results

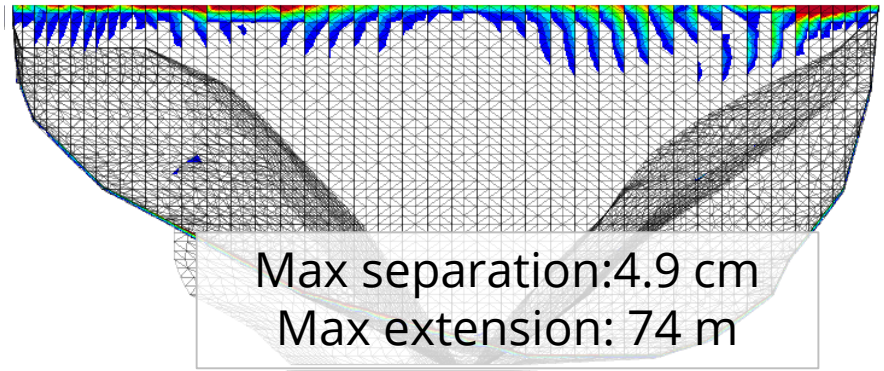
DETACHMENT BETWEEN CONCRETE FACE AND ROCKFILL (M)

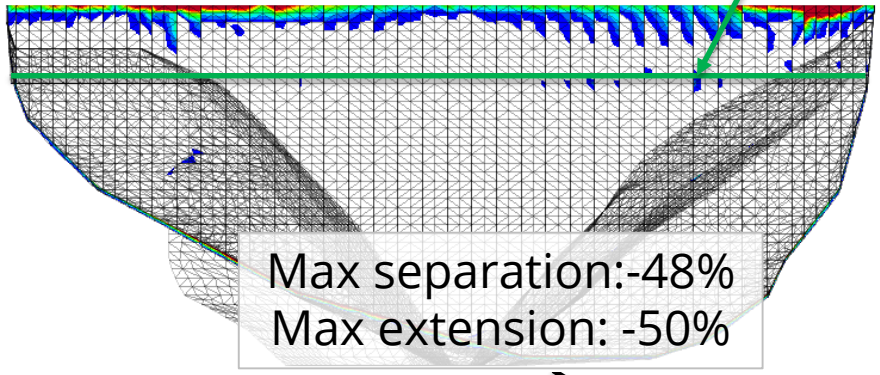
First impounding

30yrs of operation

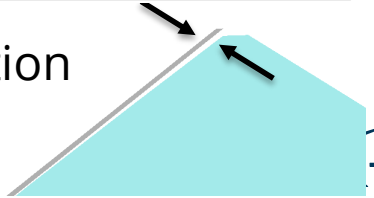


Horizontal joint





- Clear beneficial effects of a horizontal construction joint
- Anti-seismic provision (0.12g SEE)

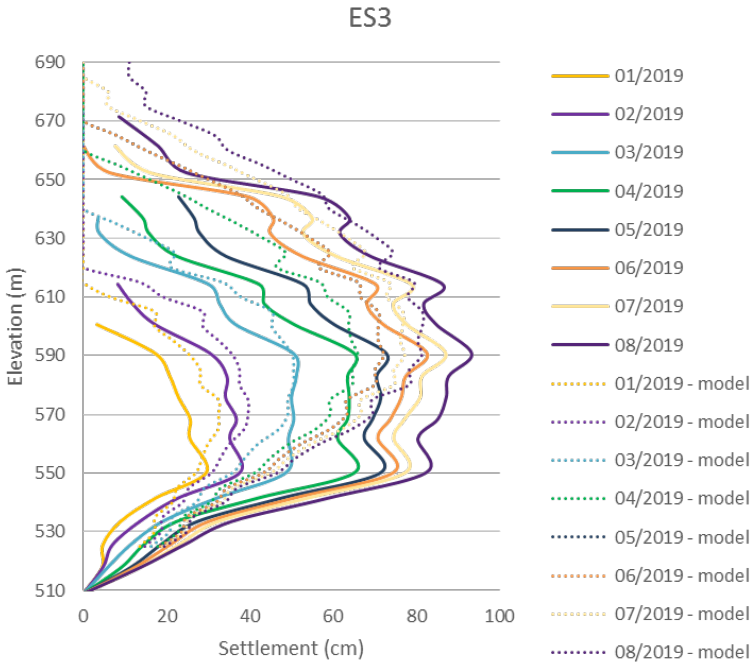


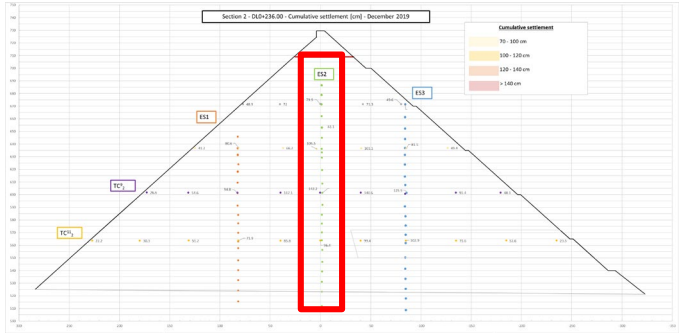
TELIA
Passion & Solutions

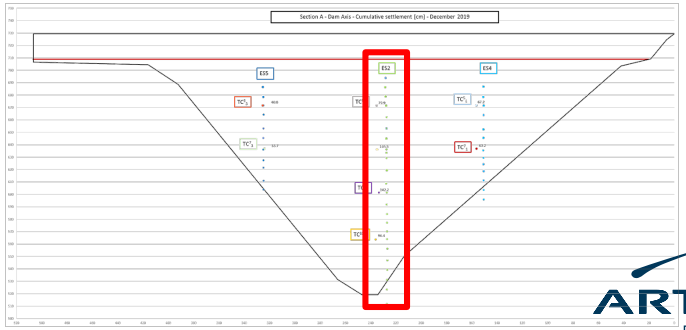
Calibration on the monitoring data

REASSURING BEHAVIOR

- Electromagnetic settlement gauges





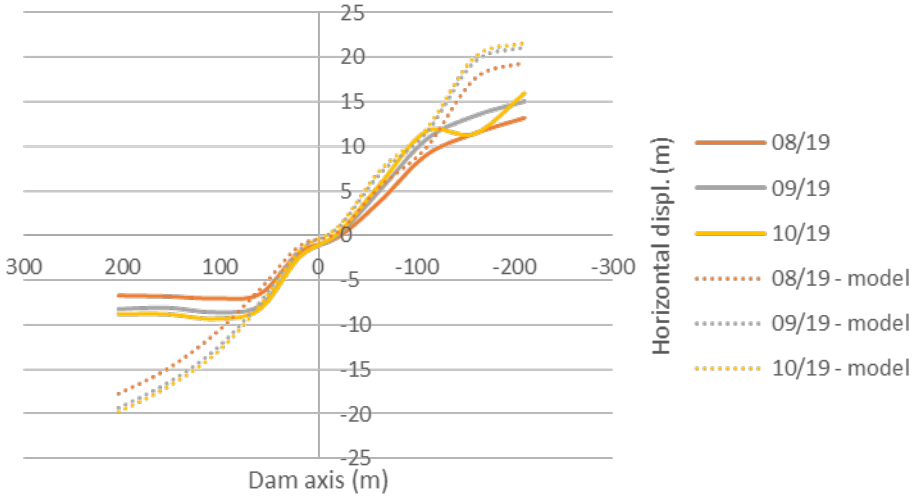


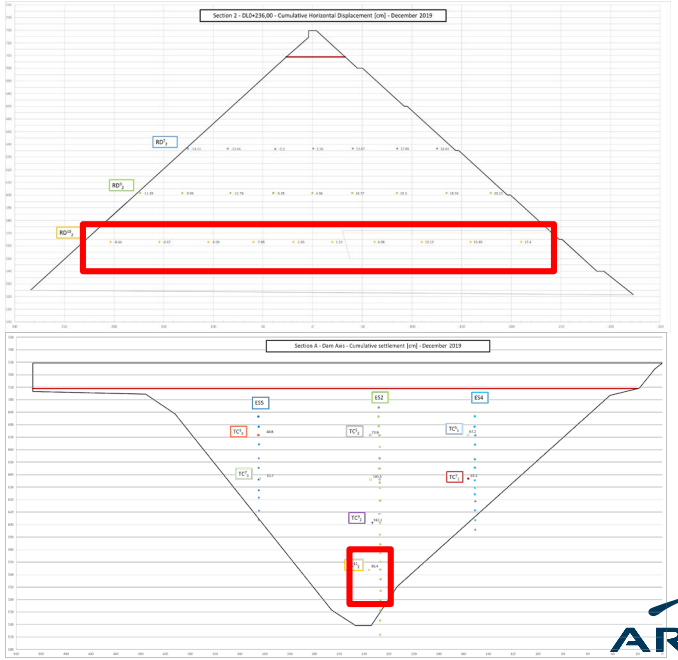
ARTELIA
Passion & Solutions

Calibration on the monitoring data

REASSURING BEHAVIOR

- Horizontal displacement gauges





ARTELIA
Passion & Solutions

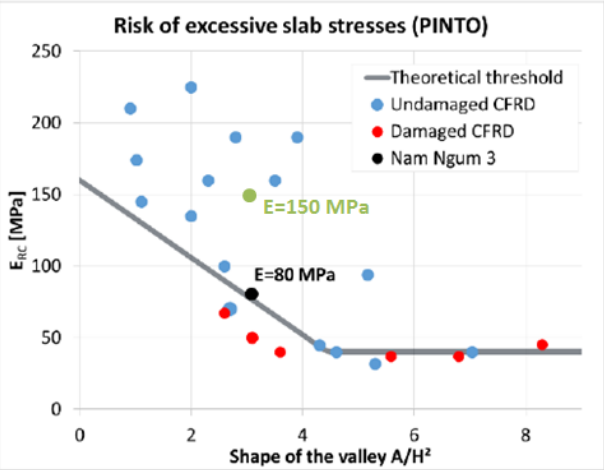
Calibration on the monitoring data

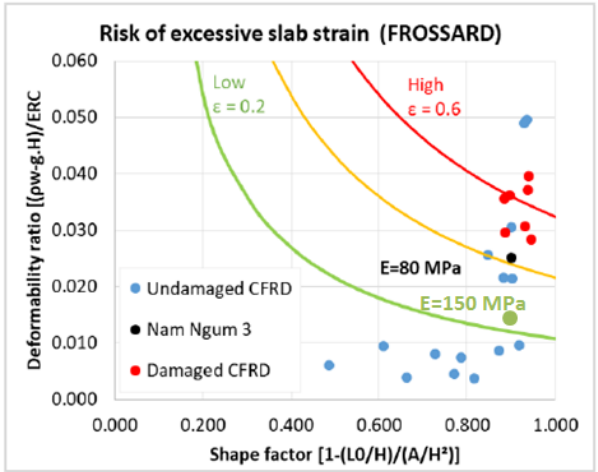
Reassuring behavior

- Compaction: 10 passes of 26t vibrating roller (almost twice as usual)
- 3C zone replaced by 3B very early in the construction

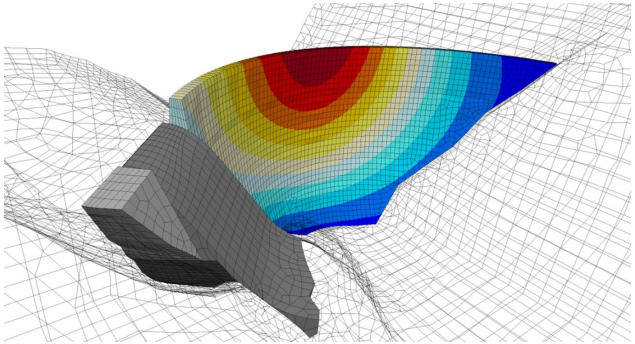
↳ Apparent Young's modulus : 80 MPa expected, 150-180 MPa measured

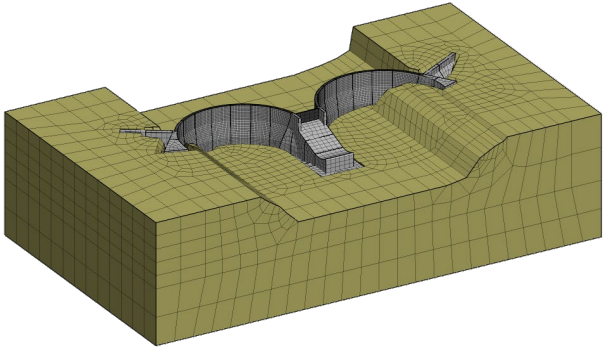
↳ Decreased risk of cracking

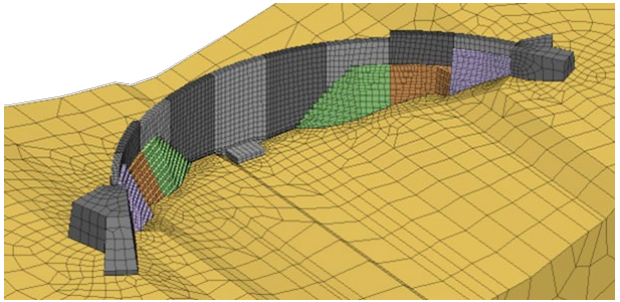


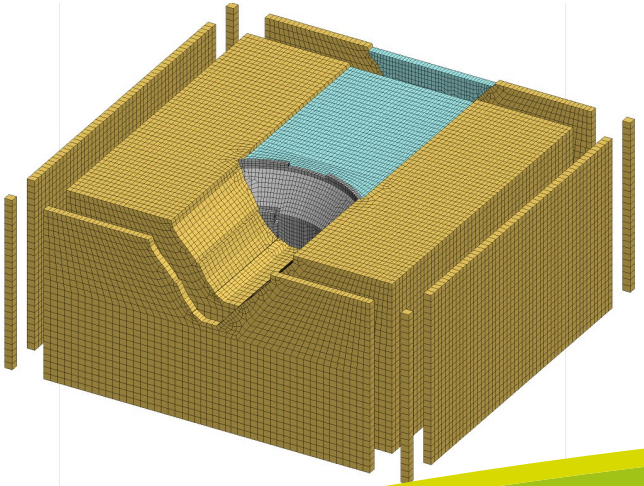


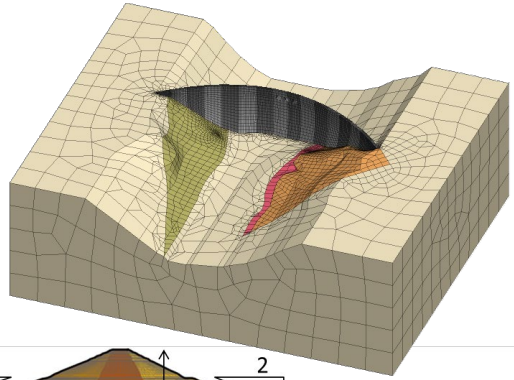
ARTELIA
Passion & Solutions

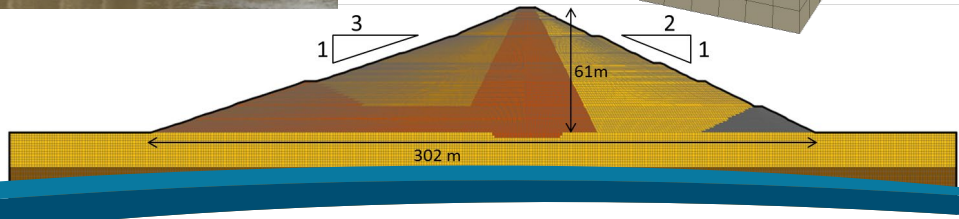












ARTELIA

www.arteliagroup.com