

THERMO-HYDRO-MECHANICAL ANALYSIS OF A DAM USING *FLAC*^{3D} SOFTWARE

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OUTLINE

**1. Context of
the study**

1. Context of the study

**2. Description of
the dam and rock
system**

2. Description of the dam and rock system

3. Methodology

3. Methodology

4. Results

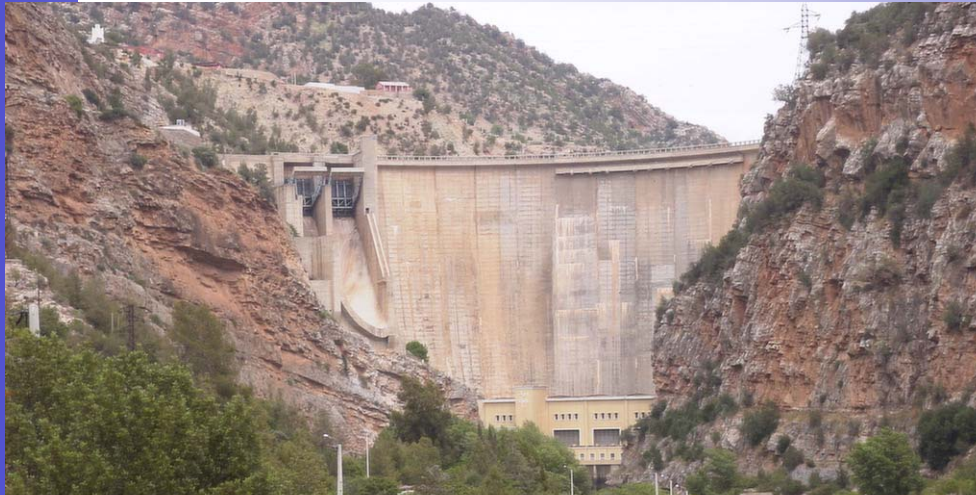
4. Results

5. Conclusion

5. Conclusion

CONTEXT OF THE STUDY

1. Context of the study



2. Description of the dam and rock system



3. Methodology

Source: INGEMA

4. Results

5. Conclusion



16 May 2001

CONTEXT OF THE STUDY

1. Context of the study

Hydrological context : irregularities in spatial / temporal distribution of precipitations → droughts in 1944-1945, 1980-1985, 1991-1995, 1998-2002.

2. Description of the dam and rock system

Remedy for this situation : construction of several dam reservoirs

Among the 110 large dams in operation at present, the **Bin El Ouidane arch dam**

3. Methodology

- constructed between 1948-1952;
- close to the city of Beni Mellal;
- designed for land irrigation (agriculture) and power production.

4. Results

Climatic context of the catchment basin of Oum Er-R'bia

- mean annual rate of precipitation : 550 mm;
- annual temperature variations : 10°C to 40°C;
- annual evaporation : 2000 mm.

5. Conclusion

CONTEXT OF THE STUDY

1. Context of the study

The dam normally strains under variations of:

- Temperatures;
- Reservoir level.

2. Description of the dam and rock system

3. Methodology

In the framework of long term monitoring,

- Simulation of these non-pathological effects;
- Comparison with monitoring results, in order to detect eventual pathological behaviour.

4. Results

5. Conclusion

DESCRIPTION OF THE DAM AND ROCK SYSTEM

The rock system

1. Context of the study

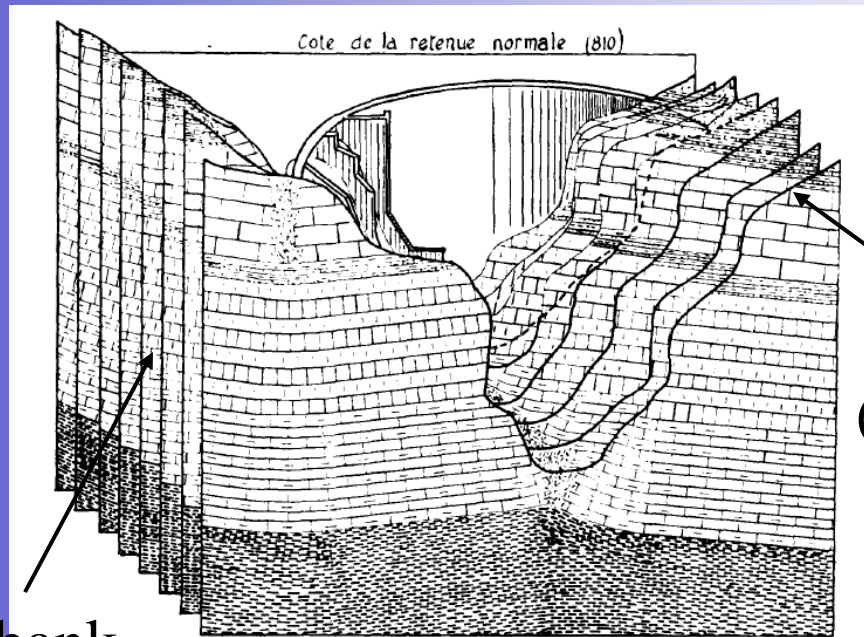
- mainly composed of layered limestone;
- left bank affected by various faults and many joints.

2. Description of the dam and rock system

3. Methodology

4. Results

5. Conclusion



Left bank
(nearly vertical slope)

Right bank
(45° angle slope)



Geological sections on the dam site.

(A) *Outline of the downstream face.*

(B) *Livid marls.*

(C) *Upper limestone banks.*

(D) *Bounding marls.*

(E) *Lower limestone banks.*

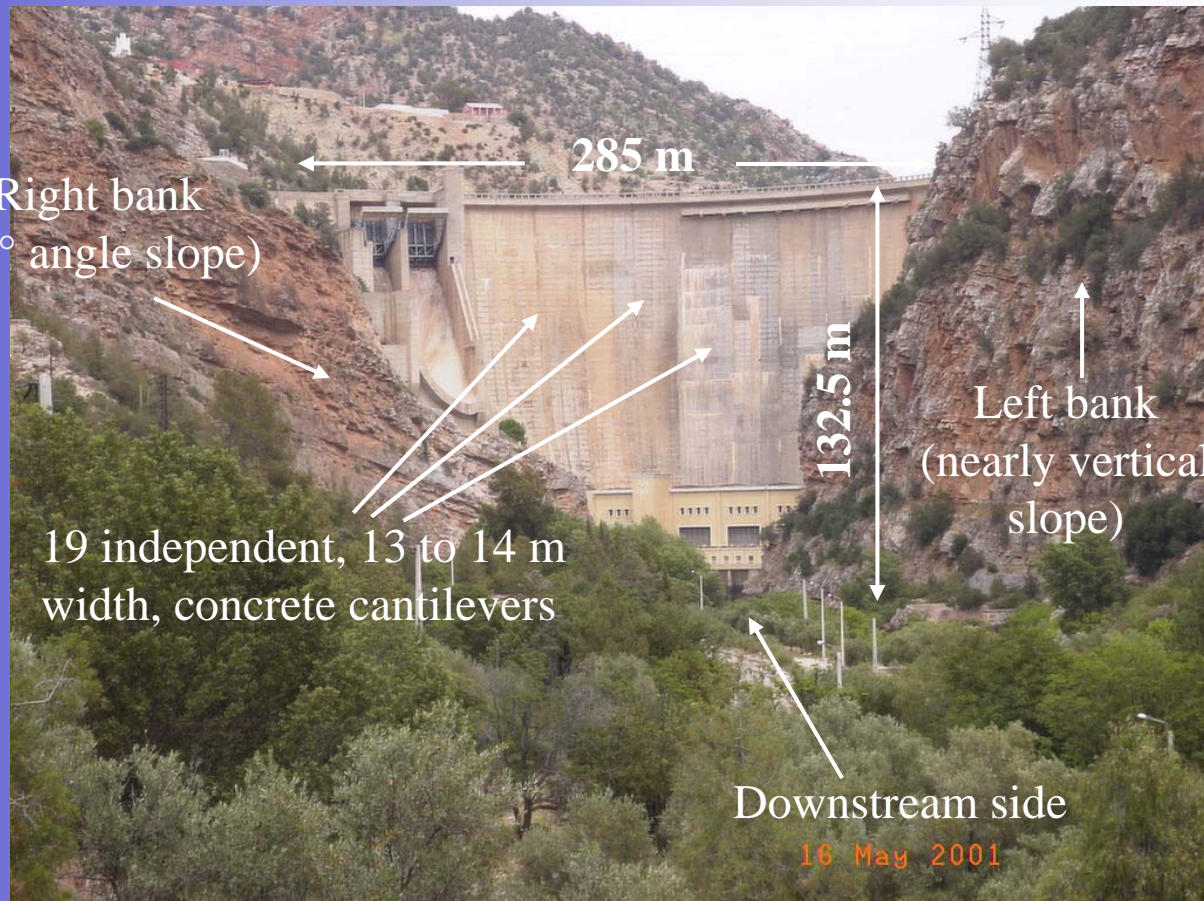
(F) *Lower marly limestone.*

(G) *Red marls with gypsum.*

DESCRIPTION OF THE DAM AND ROCK SYSTEM

The Bin El Ouidane arch dam

equipped with measurement devices (geodesic marks, direct pendulums, strain-meters and inverted pendulums)



Source: INGEMA

1. Context of the study

2. Description of the dam and rock system

3. Methodology

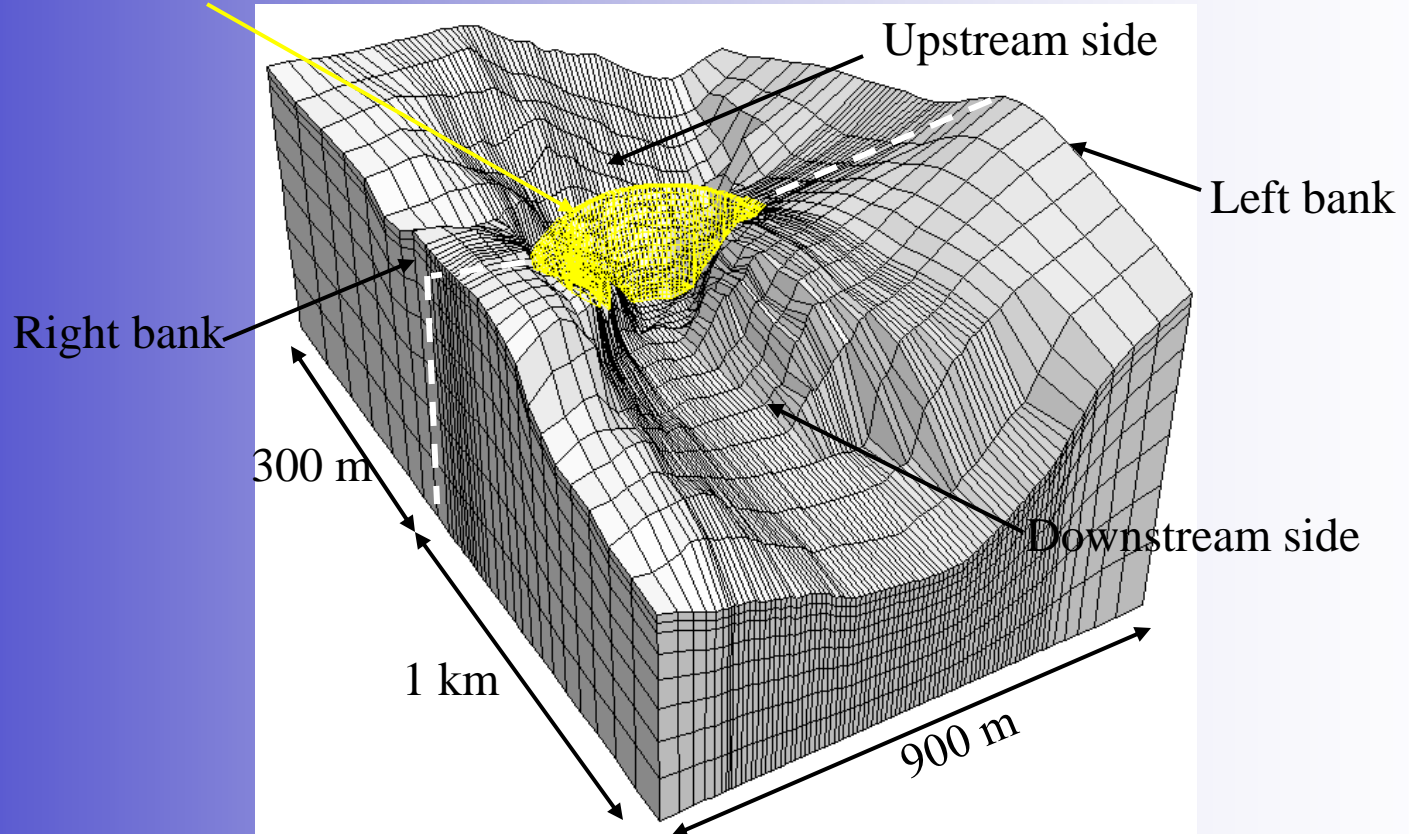
4. Results

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METHODOLOGY

1. Creating a mesh adapted to the shape of the rock mass (23000 zones approximately)

Bin El Ouidane dam



1. Context of the study

2. Description of the dam and rock system

3. Methodology

4. Results

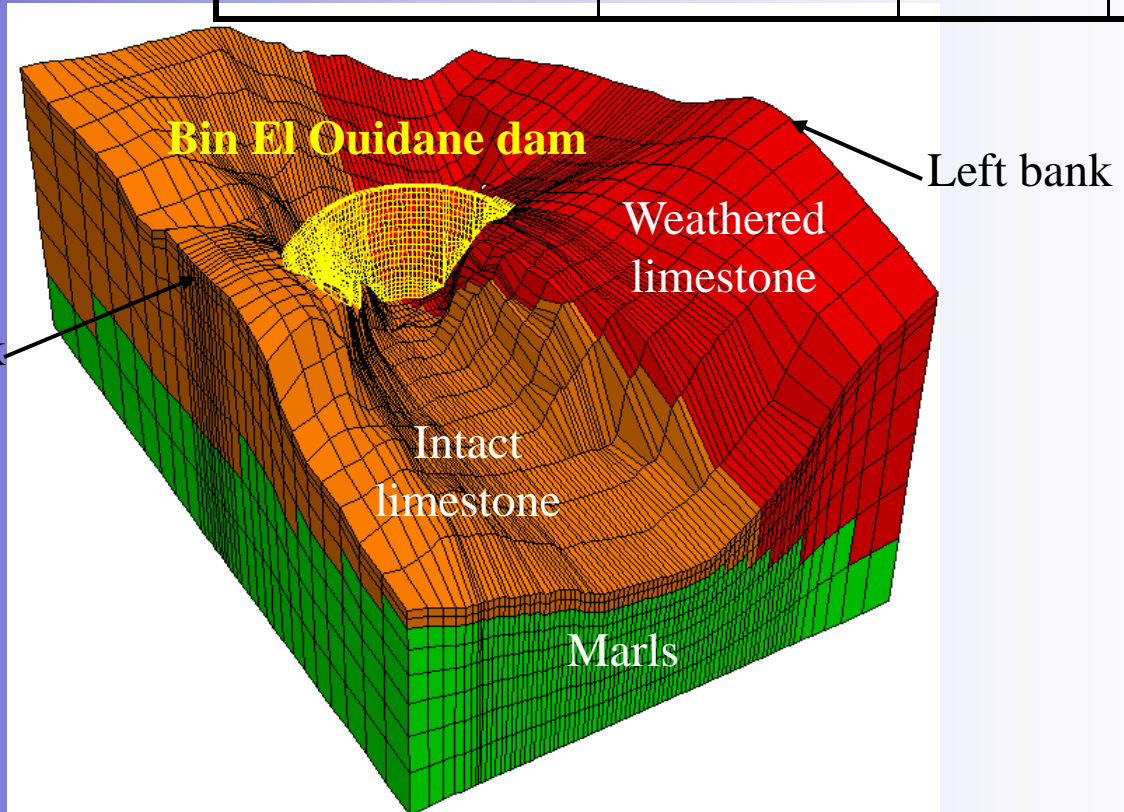
5. Conclusion

METHODOLOGY

2. Setting rock properties

rock mass : elastic

	Young's modulus [GPa]	Poisson's ratio	Density [kg/m ³]
Left bank limestone	5	0.3	2500
Right bank limestone	25	0.3	2500
Marls	5	0.25	2000



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METHODOLOGY

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3. Definition of boundary and initial conditions

- no displacement normal to the boundaries;

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4. Results

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METHODOLOGY

2. Setting rock properties

rock mass : elastic

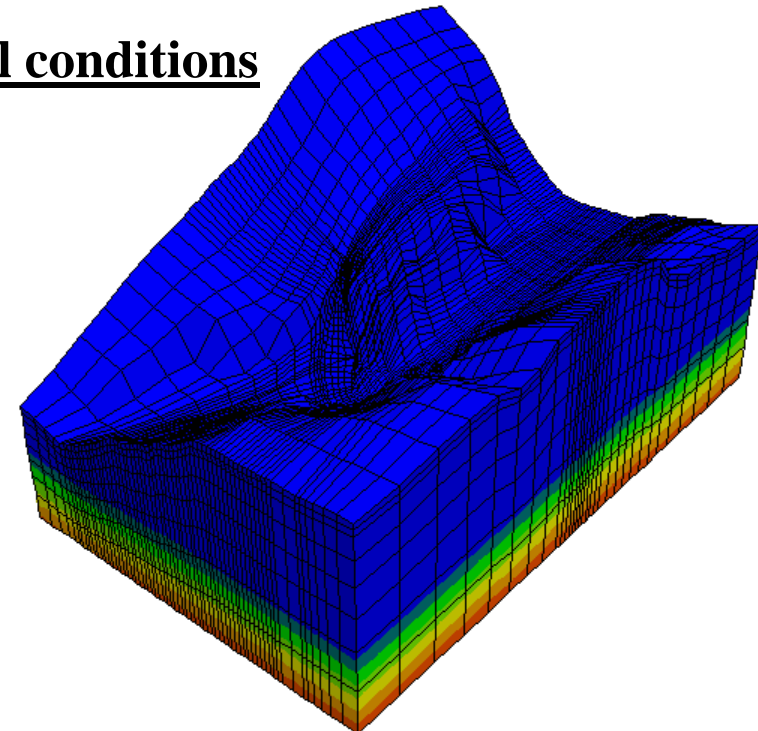
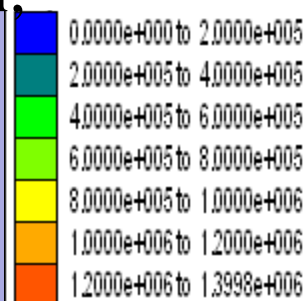
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3. Definition of boundary and initial conditions

- no displacement normal to the boundaries;

- pore pressures : fixed to a realistic distribution.

• Pore pressure (Pa)



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METHODOLOGY

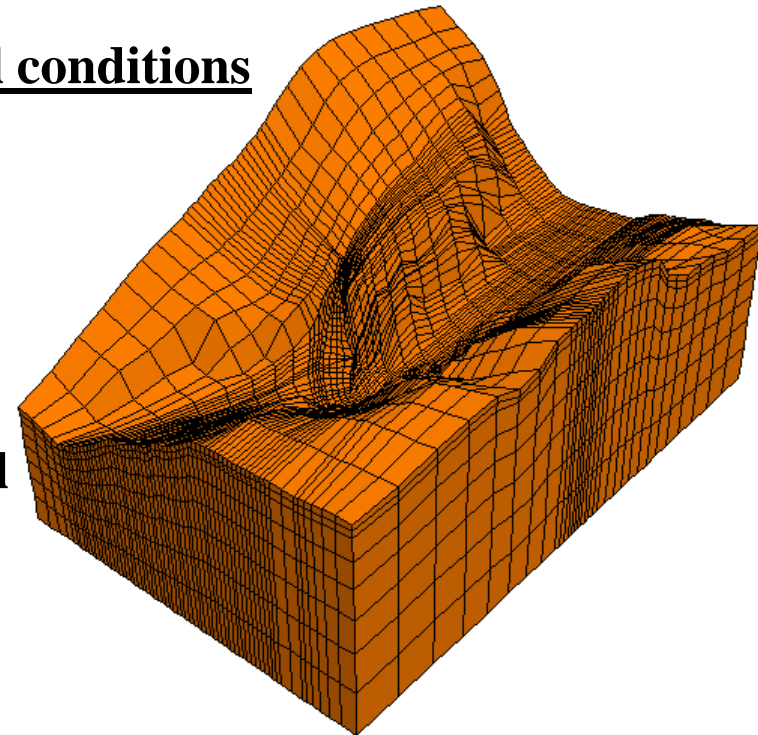
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3. Definition of boundary and initial conditions

- no displacement normal to the boundaries;
- pore pressures : fixed to a realistic distribution;
- temperatures : fixed at their annual mean of 19°C.



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METHODOLOGY

2. Setting rock properties

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Left bank limestone	5	0.3	2500
Right bank limestone	25	0.3	2500
Marls	5	0.25	2000

3. Definition of boundary and initial conditions

- displacements perpendicular to the boundaries : prevented;
- pore pressures : fixed to a realistic distribution;
- temperatures : fixed at their annual mean of 19°C.

4. Stepping (mechanical-only calculation) to reach equilibrium under gravity

1. Context of the study

2. Description of the dam and rock system

3. Methodology

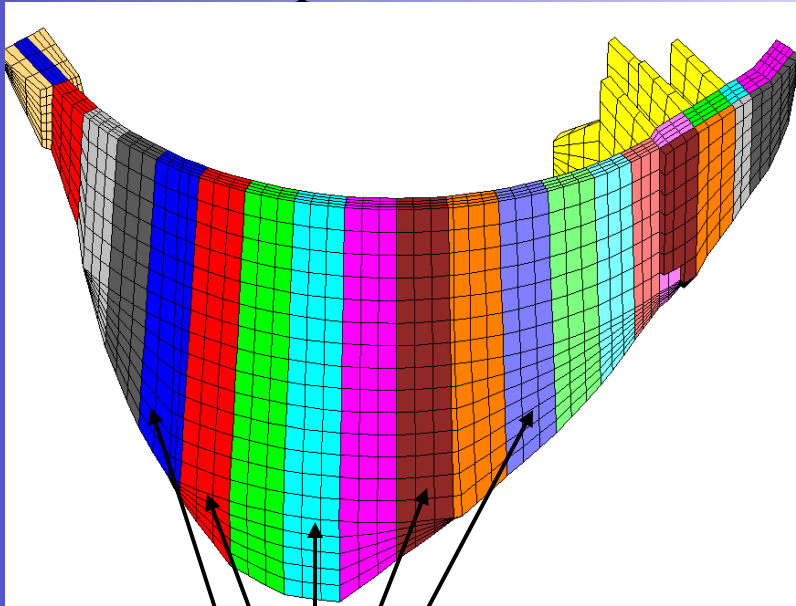
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METHODOLOGY

5. building of the dam

Upstream face



- 4 zones across the thickness of the dam;
- 60 zones along its length.

19 independent cantilevers separated by joints; grouted after a few months cooling period

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2. Description of the dam and rock system

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4. Results

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METHODOLOGY

1. Context of the study



2. Description of the dam and rock system

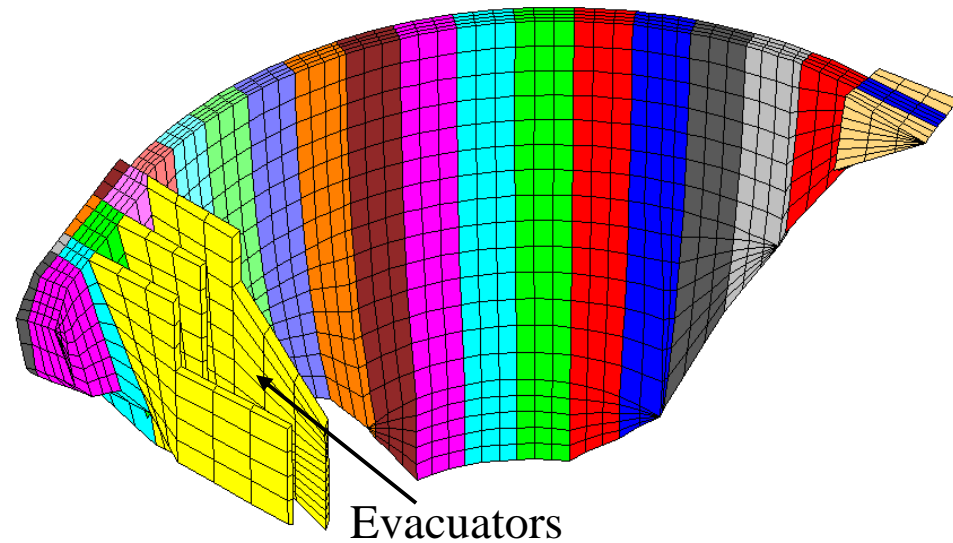
3. Methodology

Source: INGEMA

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Downstream face



METHODOLOGY

6. Setting dam properties : Mohr-Coulomb failure criterion

1. Context of the study

2. Description of the dam and rock system

3. Methodology

4. Results

5. Conclusion

- Cohesion : 7 MPa;
- Friction angle : 30° ;
- Thermal conductivity : $2 \text{ kcal}/(\text{m } ^\circ\text{C})$;
- Specific heat : $0.22 \text{ kcal}/(\text{kg } ^\circ\text{C})$;
- Linear thermal expansion coefficient : $0.75 \cdot 10^{-5} / ^\circ\text{C}$;
- Convective heat transfer coeff. between concrete and air or water : $200 \text{ W } ^\circ\text{C}/\text{m}^2$.

METHODOLOGY

7. Computation of the initial state of the dam and rock system

1. Context of the study

2. Description of the dam and rock system

3. Methodology

4. Results

5. Conclusion

- initial stress field under gravity;
- initialization of temperatures in the cantilevers (40°);
- stepping (thermal-only simulation) to produce the temperature field in the cantilevers at the time of grouting;
- numerical simulation of grouting (mechanical-only calculation) by applying a mechanical pressure between the cantilevers till a pressure of 5 bars or a 1 mm opening of the joints between the cantilevers.
- then, rigid connection between the cantilevers.

METHODOLOGY

8. Analysis of dam behavior under thermal and hydraulic loadings

1. Context of the study

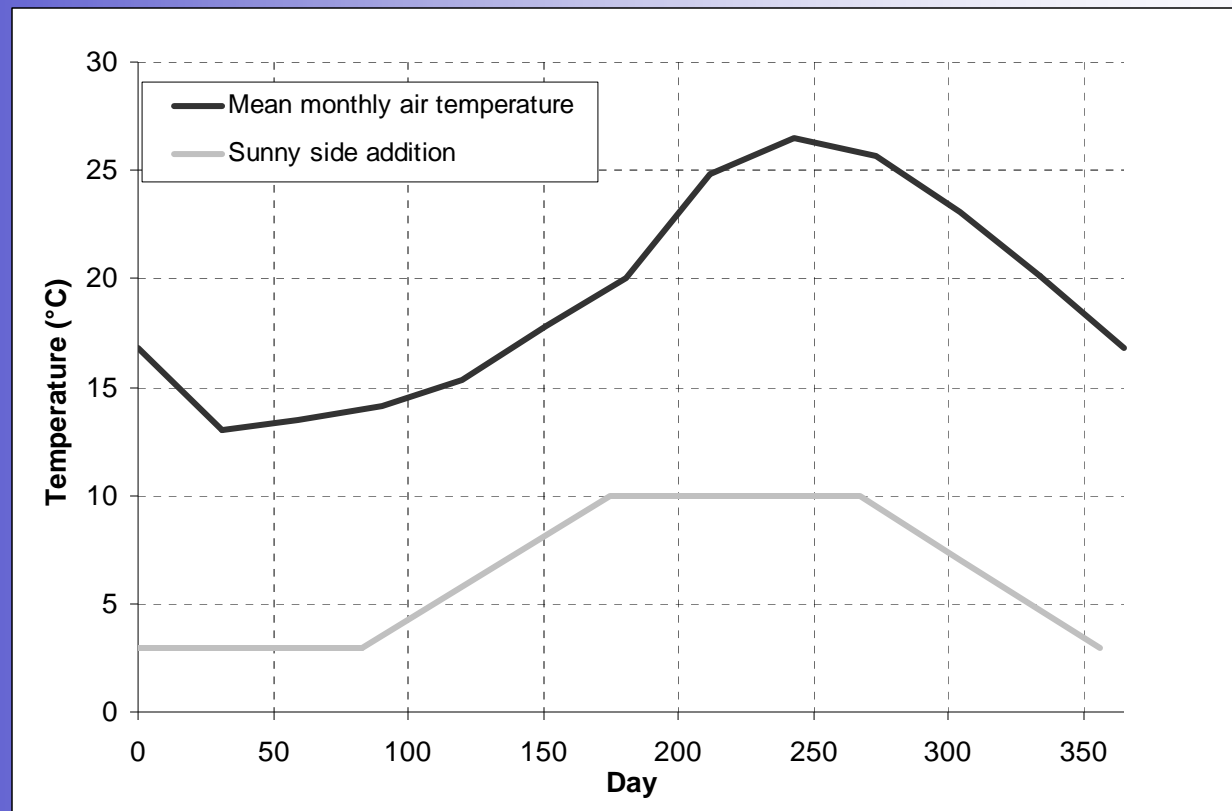
2. Description of the dam and rock system

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Temperatures (T_{air})

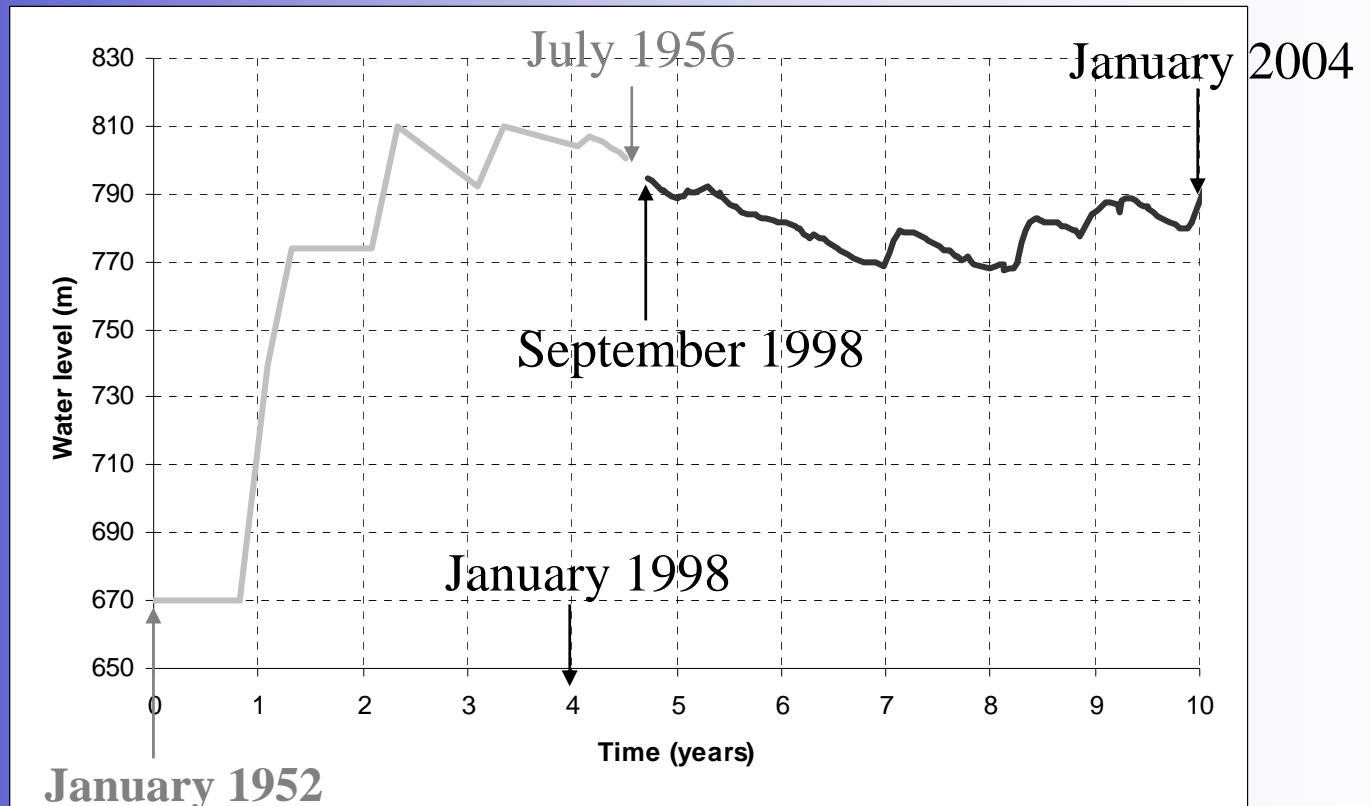


Points located 0 to 20 m below the elevation of the reservoir $T_{\text{water}} (13^{\circ}\text{C}) < T < T_{\text{air}}$.

METHODOLOGY

8. Analysis of dam behavior under thermal and hydraulic loadings

Water level in the reservoir (Z_{water})



1. Context of the study

2. Description of the dam and rock system

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4. Results

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METHODOLOGY

8. Analysis of dam behavior under thermal and hydraulic loadings

1. Context of the study

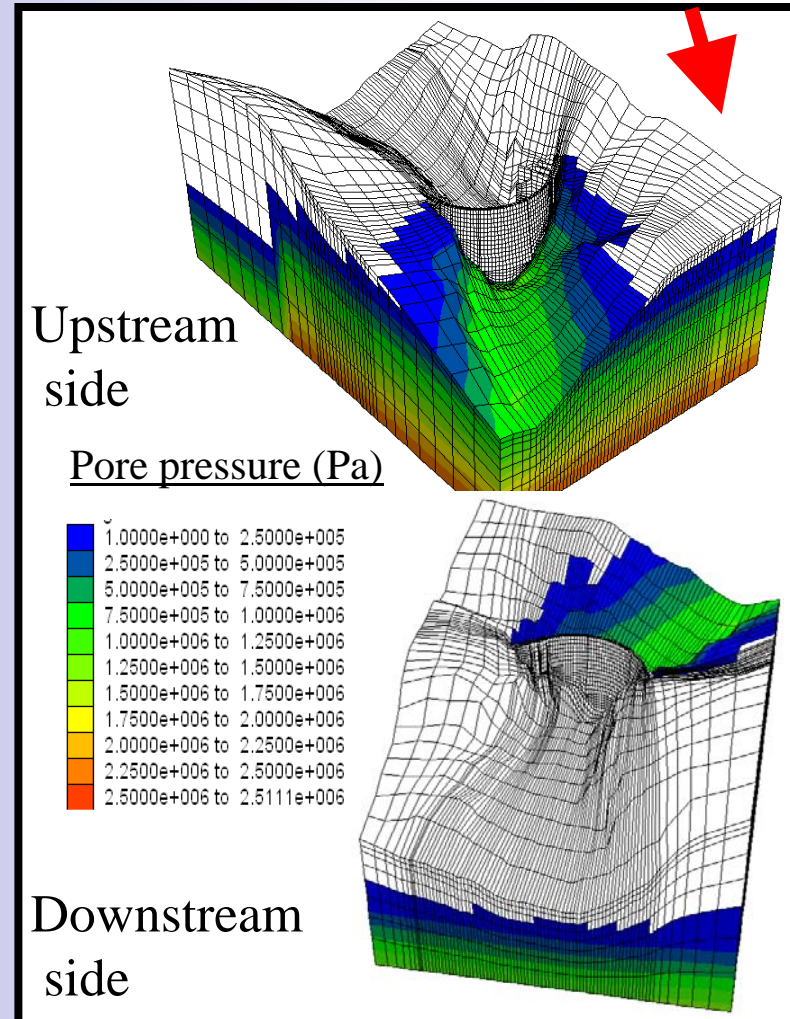
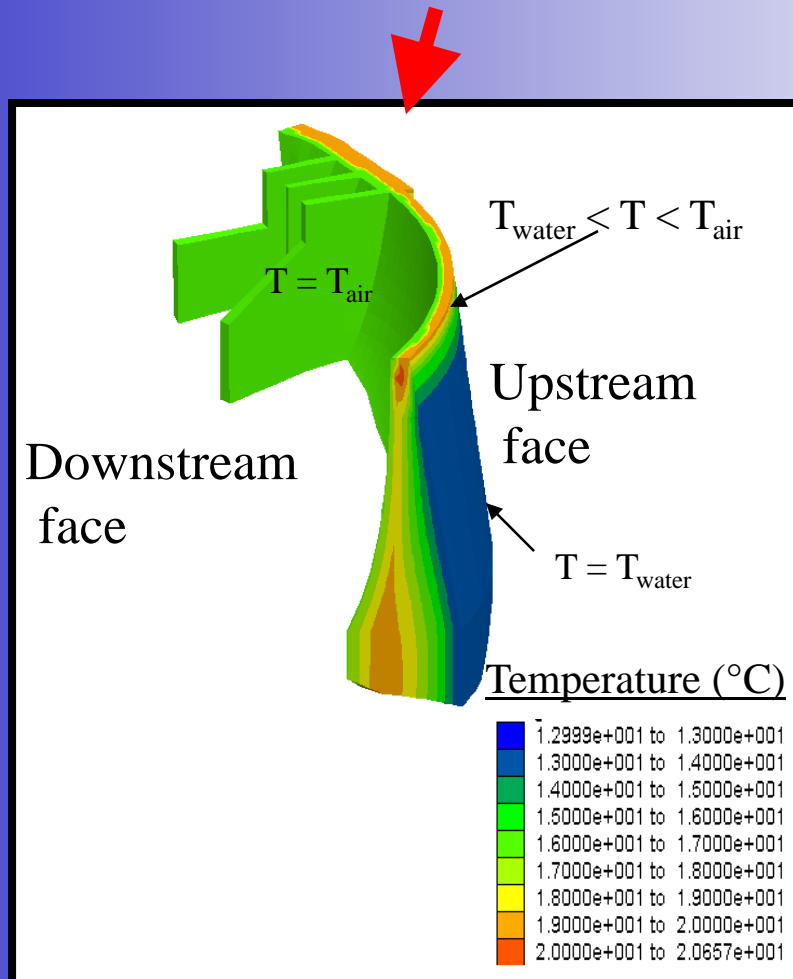
For a given set of parameters (i.e. $T_{\text{air}} = 16^\circ\text{C}$ and $Z_{\text{water}} = 790 \text{ m}$) : calculation of **heat fluxes** (dam/air and dam/water) and **pore pressures**

2. Description of the dam and rock system

3. Methodology

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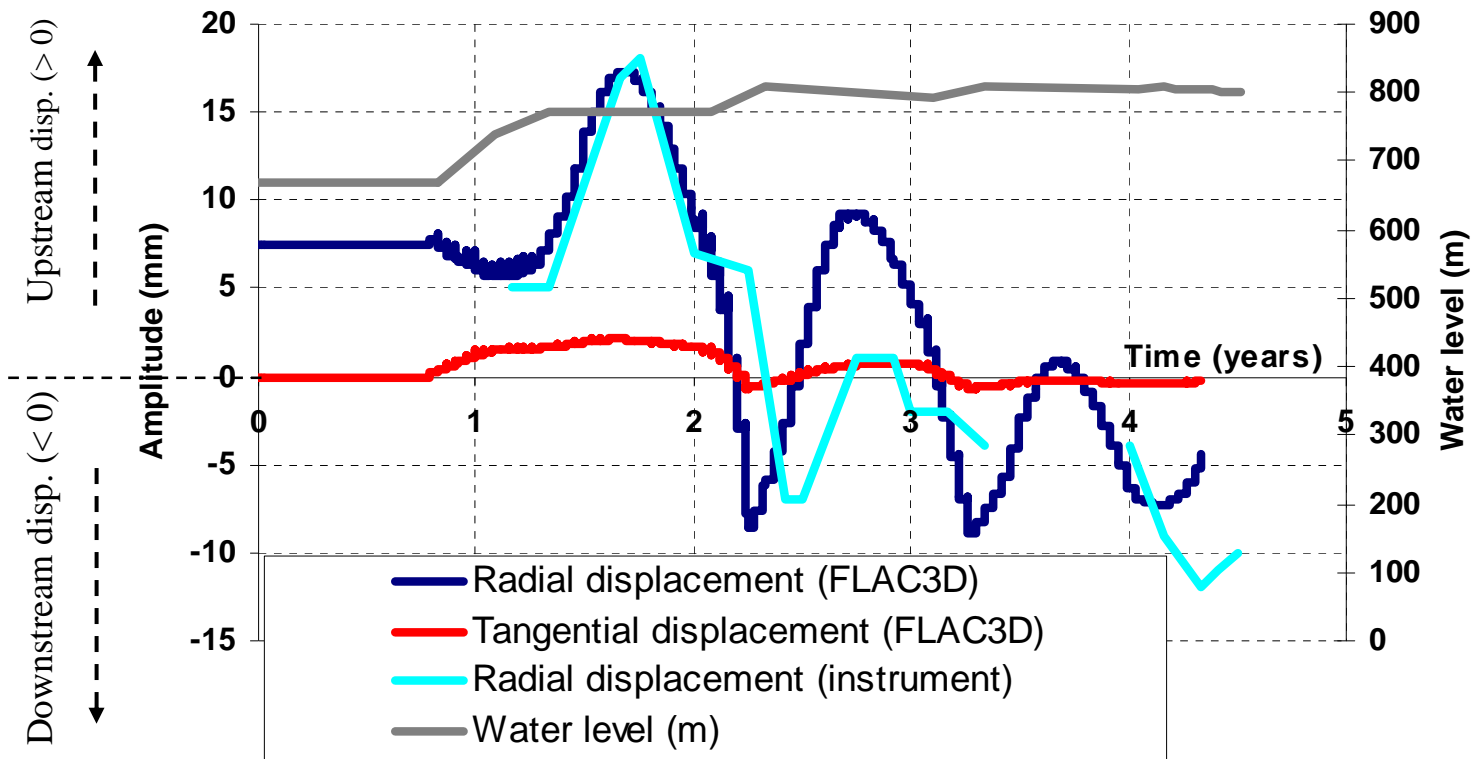


RESULTS

→ Analysis and comparison of the response of the dam (radial and tangential relative displacement histories) with pendulum measurements

1. Calibration of the behavior of the dam between 1952 and 1956

Cantilever 6 (centre), top of the dam



1. Context of the study

2. Description of the dam and rock system

3. Methodology

4. Results

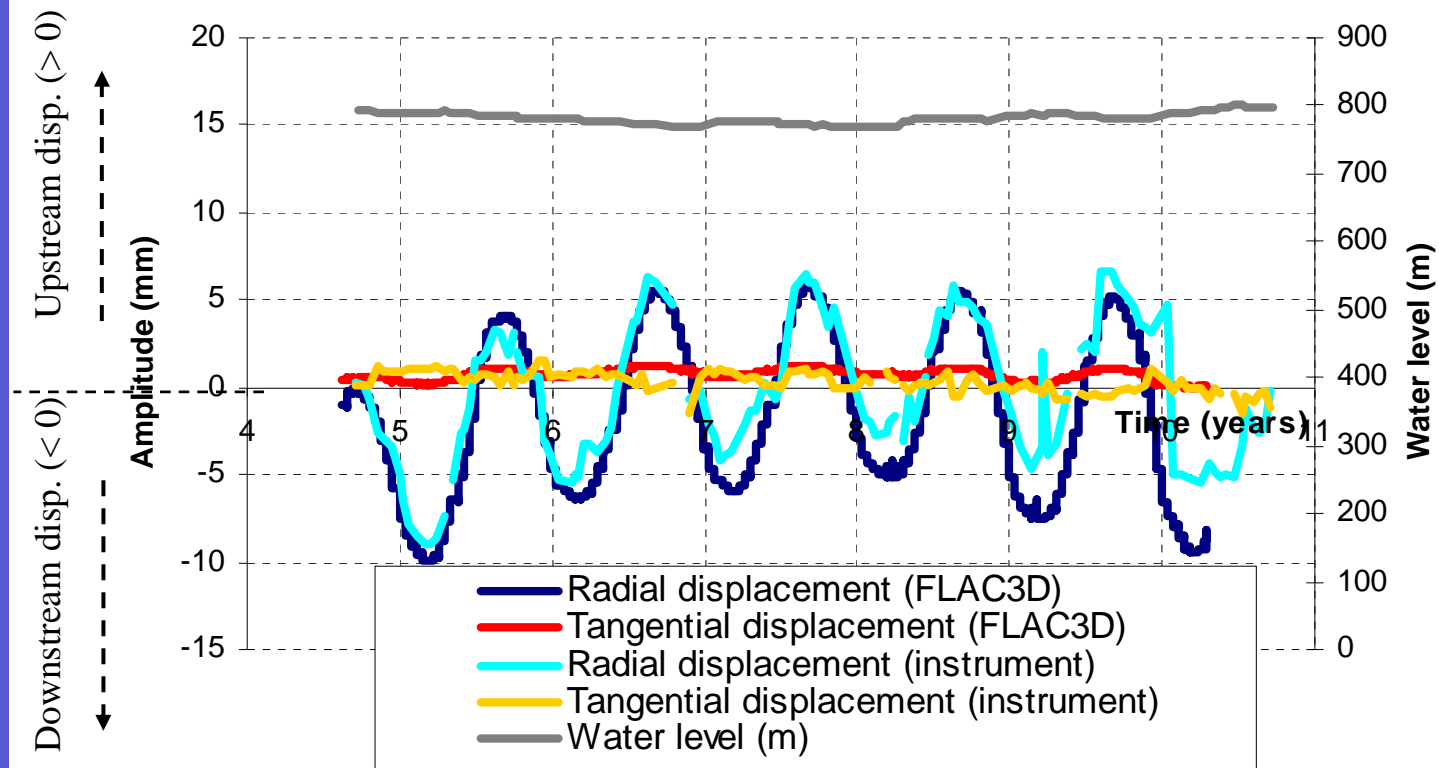
5. Conclusion

RESULTS

→ Analysis and comparison of the response of the dam (radial and tangential relative displacement histories) with pendulum measurements

2. Recent behavior of the dam between 1998 and 2004

Cantilever 6 (centre), top of the dam



1. Context of the study

2. Description of the dam and rock system

3. Methodology

4. Results

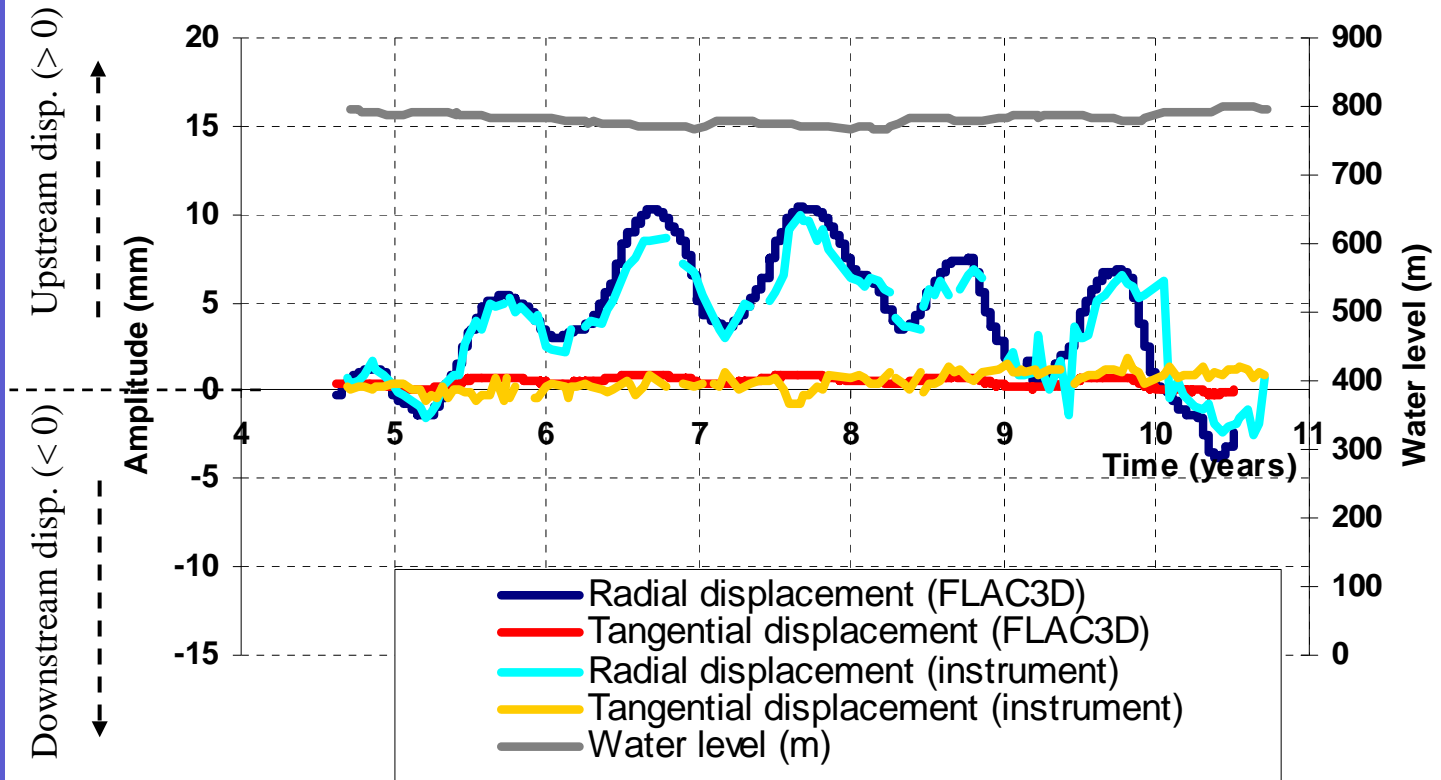
5. Conclusion

RESULTS

→ Analysis and comparison of the response of the dam (radial and tangential relative displacement histories) with pendulum measurements

2. Recent behavior of the dam between 1998 and 2004

Cantilever 6, level 770



1. Context of the study

2. Description of the dam and rock system

3. Methodology

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CONCLUSION

1. Context of the study

A model of the Bin el Ouidane dam was calibrated on the monitoring results available since the building of the dam.

2. Description of the dam and rock system

This model is installed on the dam site. It is systematically used for comparison with bi-monthly instrument readings.

3. Methodology

This project has resulted in a much more precise assessment of the dam stability.

4. Results

5. Conclusion