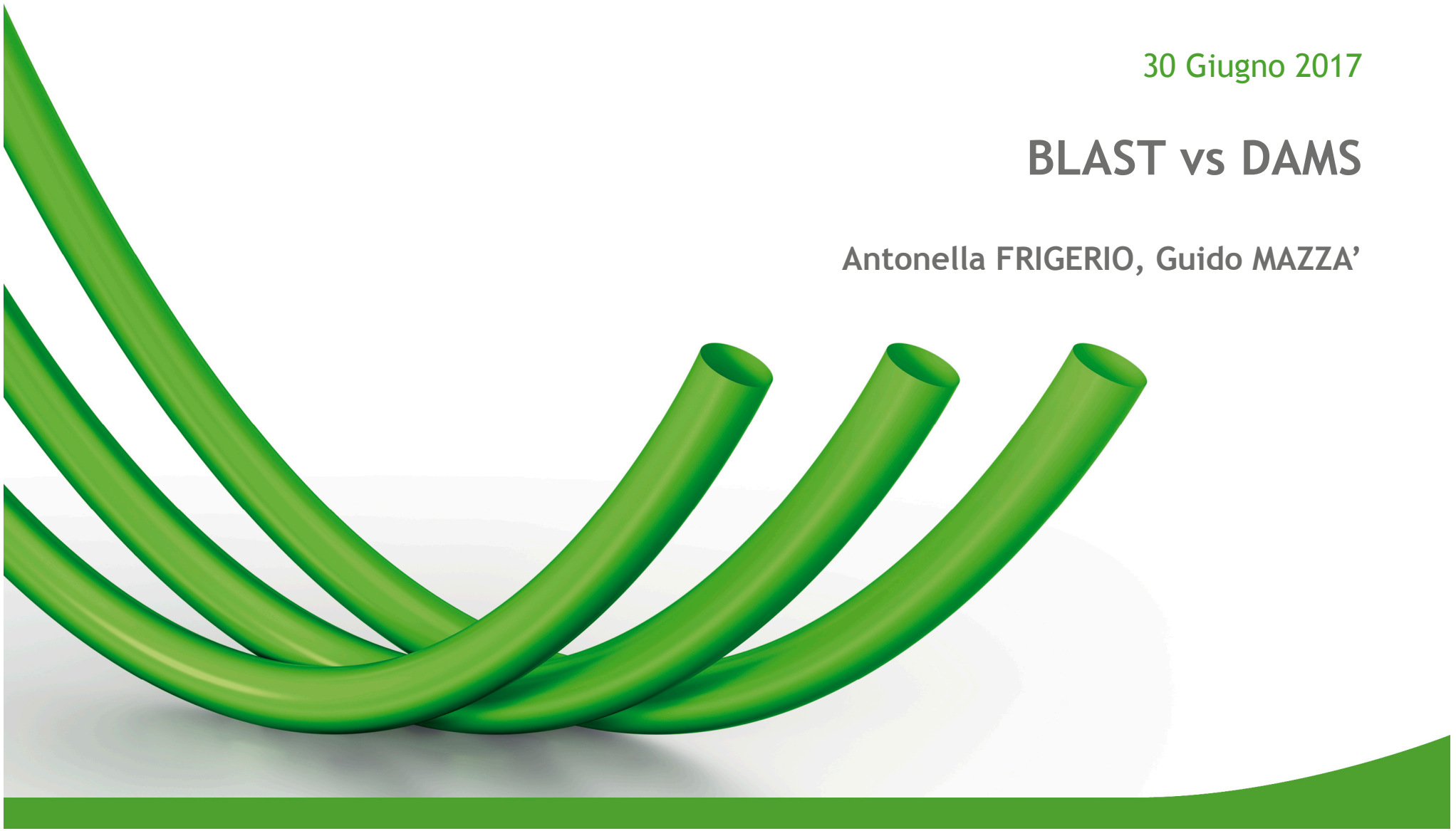
30 Giugno 2017

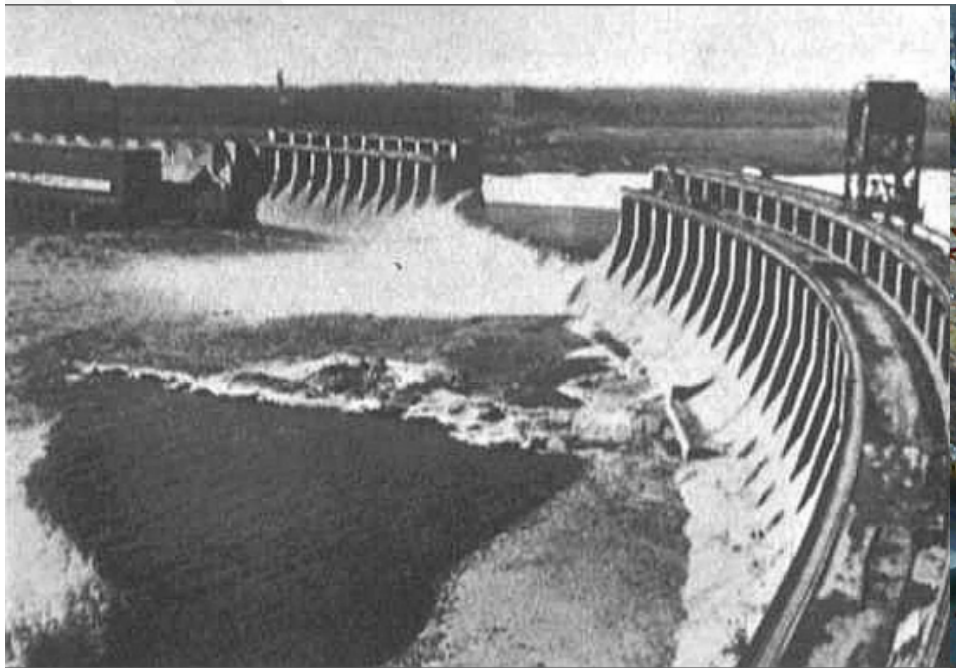
BLAST vs DAMS

Antonella FRIGERIO, Guido MAZZA'



Blast vs Dams

- Which is the level of vulnerability of dams against blast?
- Are there any experiences related to malevolent actions involving blast (war attacks, accidents, terrorism) against dams?
- Are explosives used only as malevolent actions? The experience of Beauregard dam.



Remarks on dam vulnerability

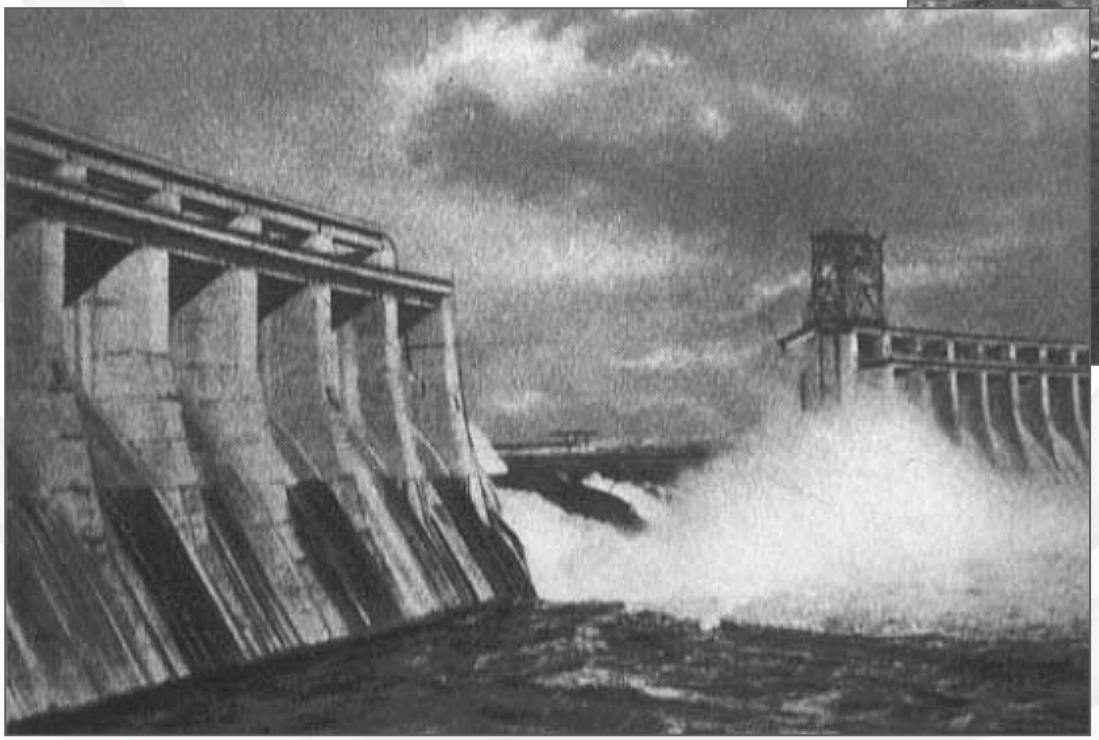
Number of failures by cause and dimension (Vogel, 2003)				
Cause	Small dams	Large dams	Tailing dams	Total
UN	149	23	7	179
OV	145	80	50	275
IE	37	78	28	143
FF	28	34	4	66
CF	26	26	15	67
IS	13	19	19	51
SP	12	8	0	20
CR	7	11	0	18
HA	**7**	**4**	**0**	**11**
IP	7	1	0	8
SE	>>6	4	>3	>>13
SF	6	32	7	45
AB	1	1	0	2
MS	1	1	0	2
Totale	>>445	322	>133	**>>900**

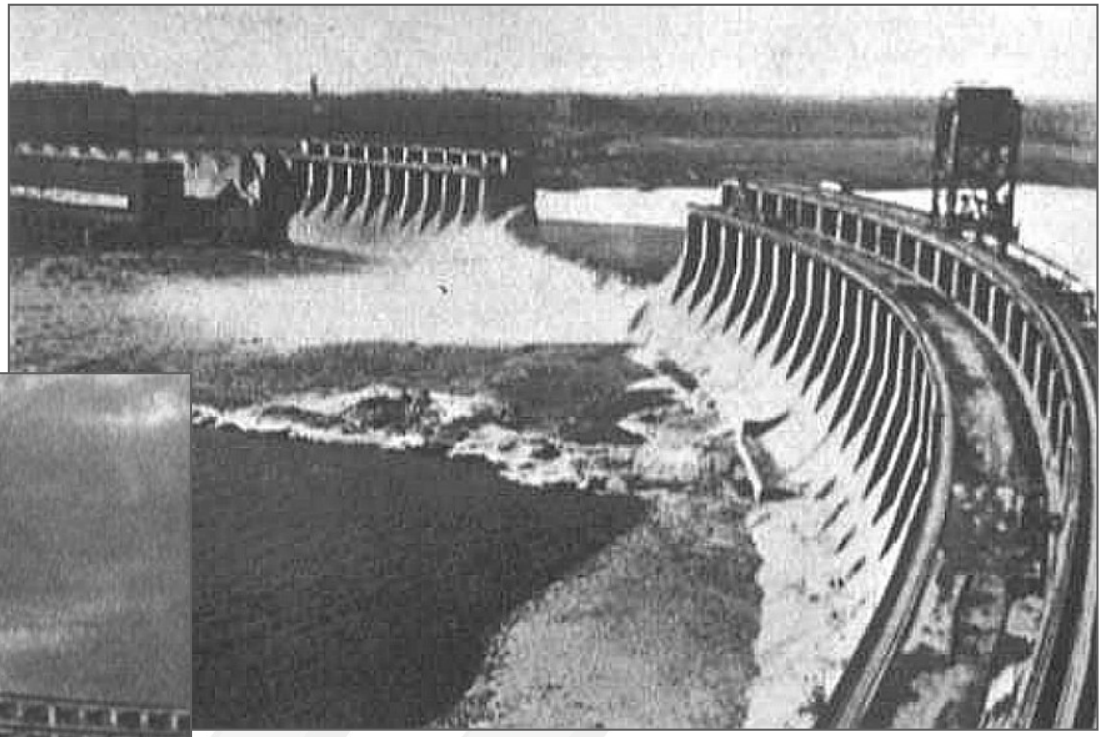
Legenda:

UN: unknown
OV: overtopping
IE: internal erosion
FF: foundation failure
CF: construction failure
IS: insufficient spillway
SP: seepage
CR: cracking
HA: hostile actions
IP: ice pressure
SE: seismic failure
SF: sliding failure
AB: abandoned
MS: mountain slide

Remarks on dam vulnerability

Dnjeprostroj dam (Russia)

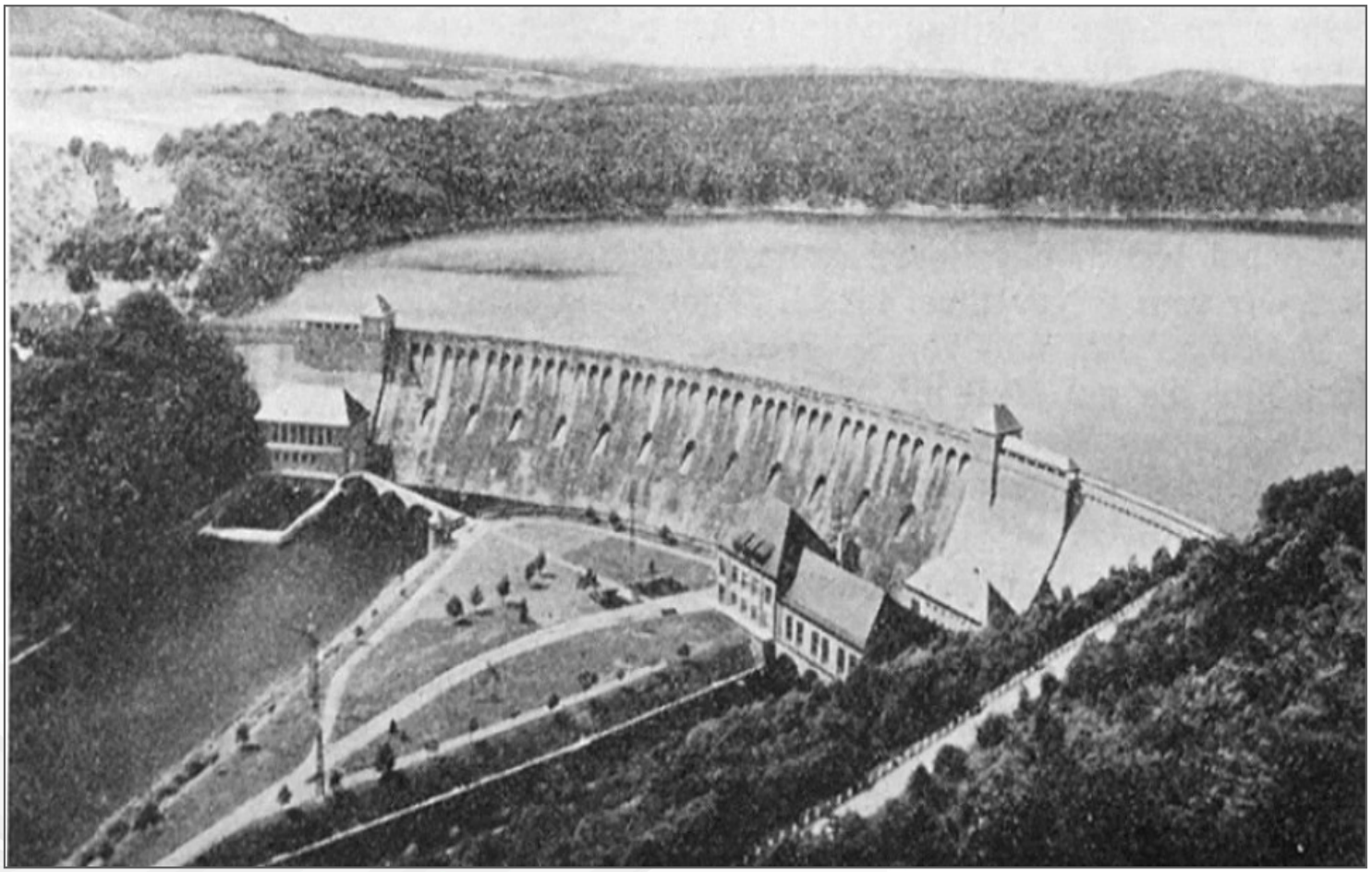




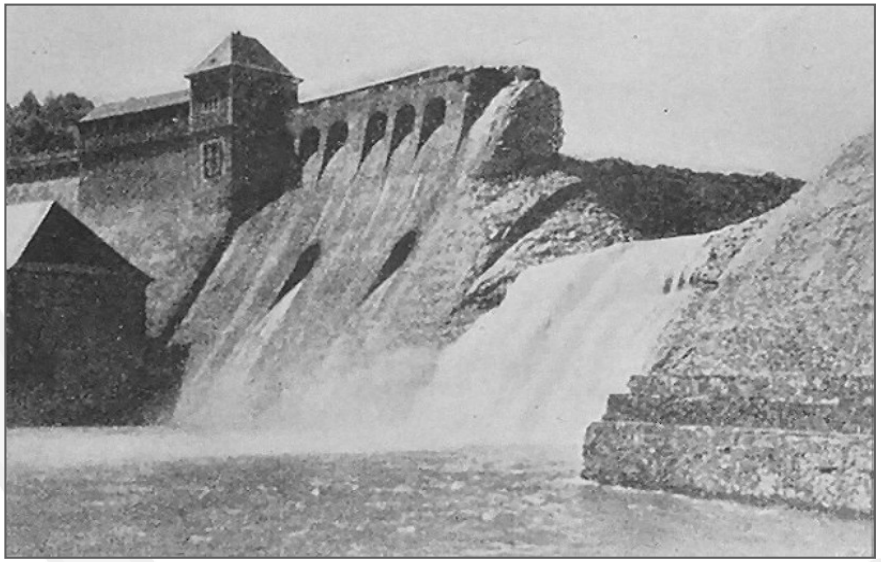
The dam after the first blast in September 1941. The second failure took place in September 1943.

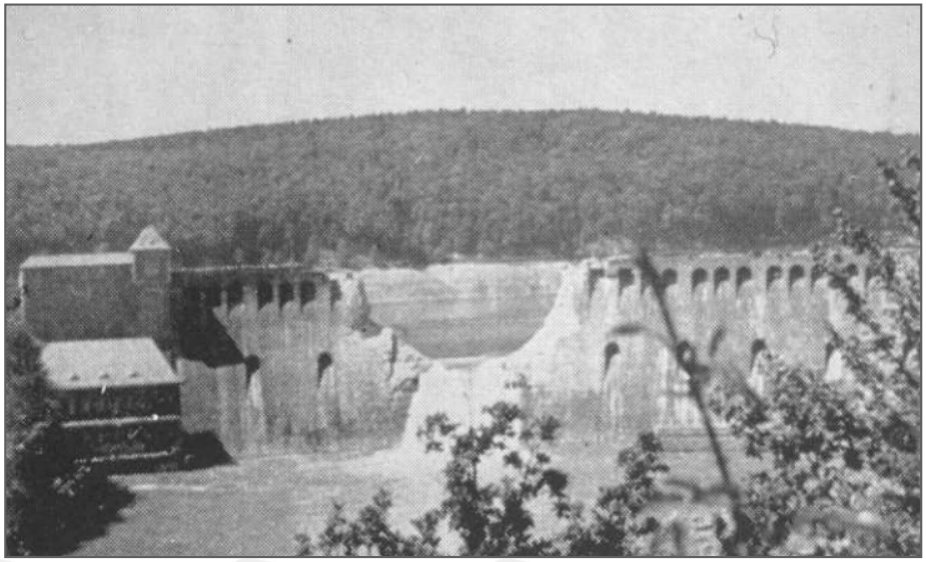
Remarks on dam vulnerability

Eder dam (Germany) before the RAF (Royal Air Force) attack

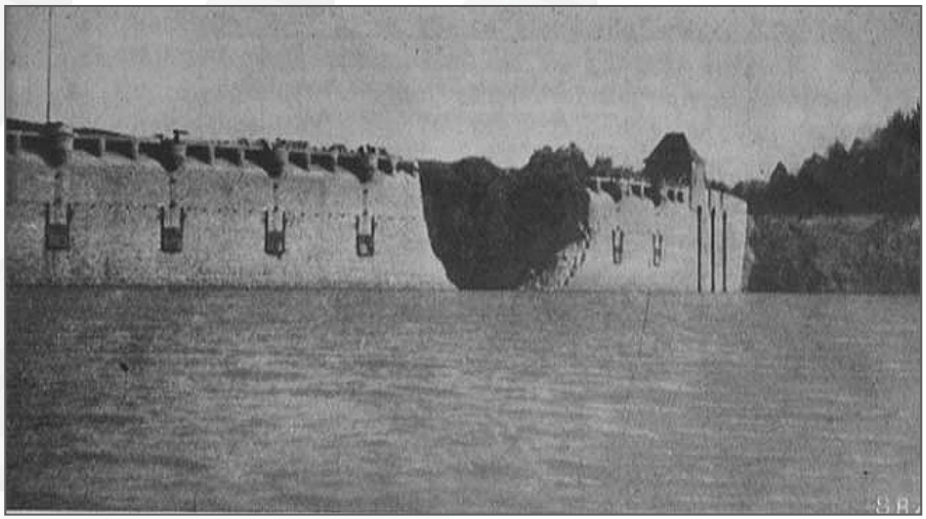


Remarks on dam vulnerability

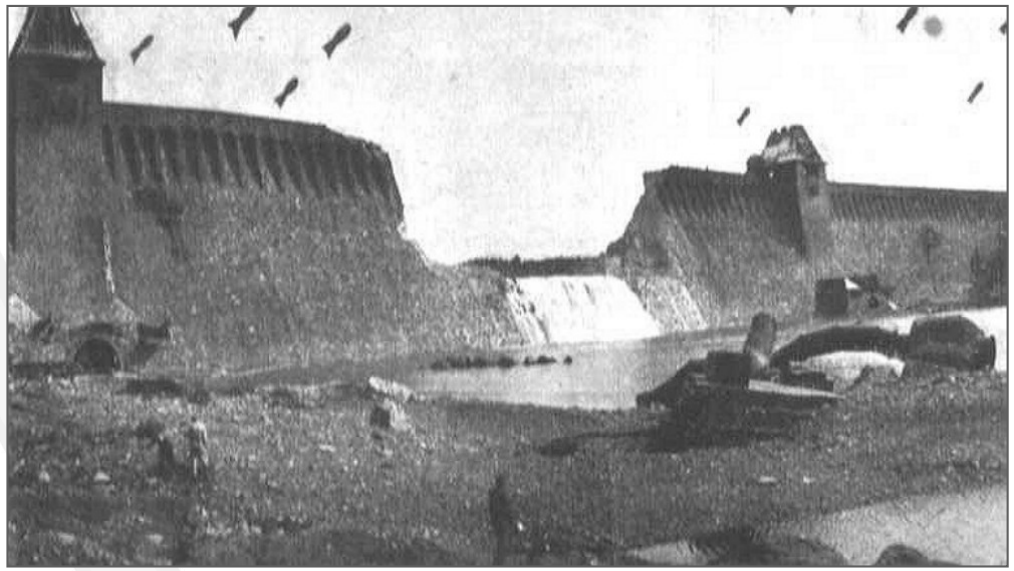




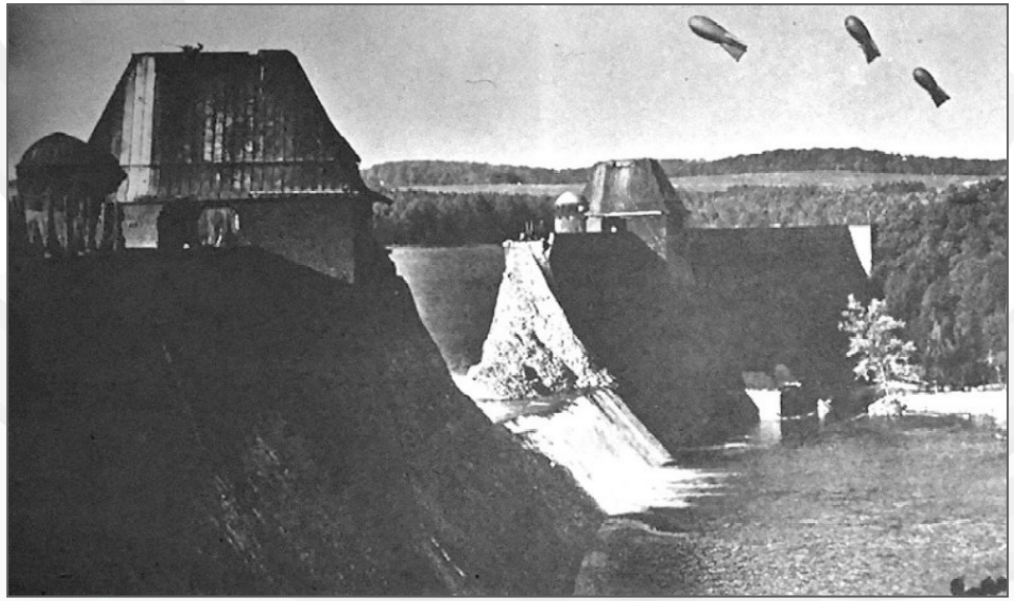
***Eder dam** after the RAF attack in 1943 carried out by means of the so-called "**barrel shaped bombs**"*

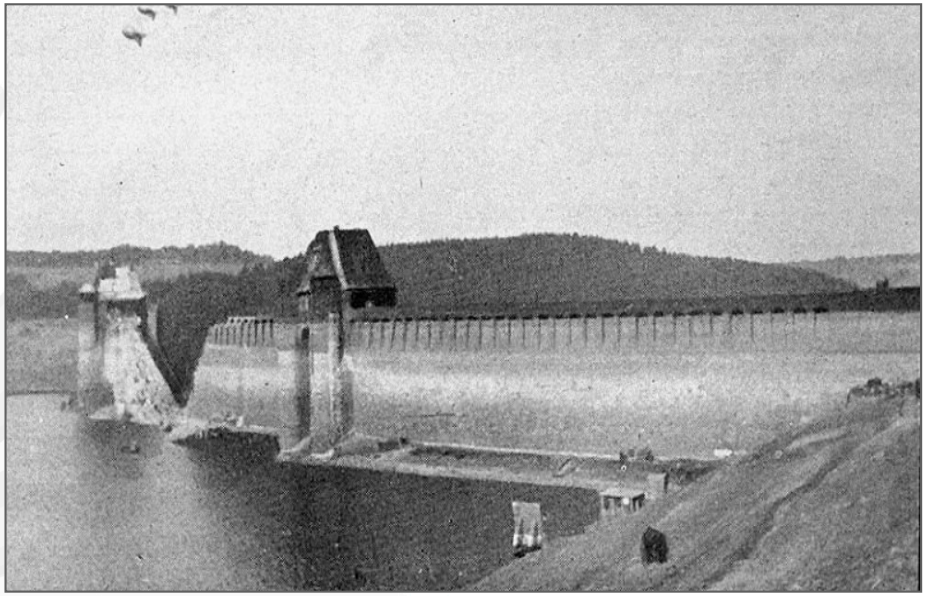


Remarks on dam vulnerability



Mohne dam (Germany)
after the RAF bombing in 1943 carried out by means of "barrel shaped bombs"

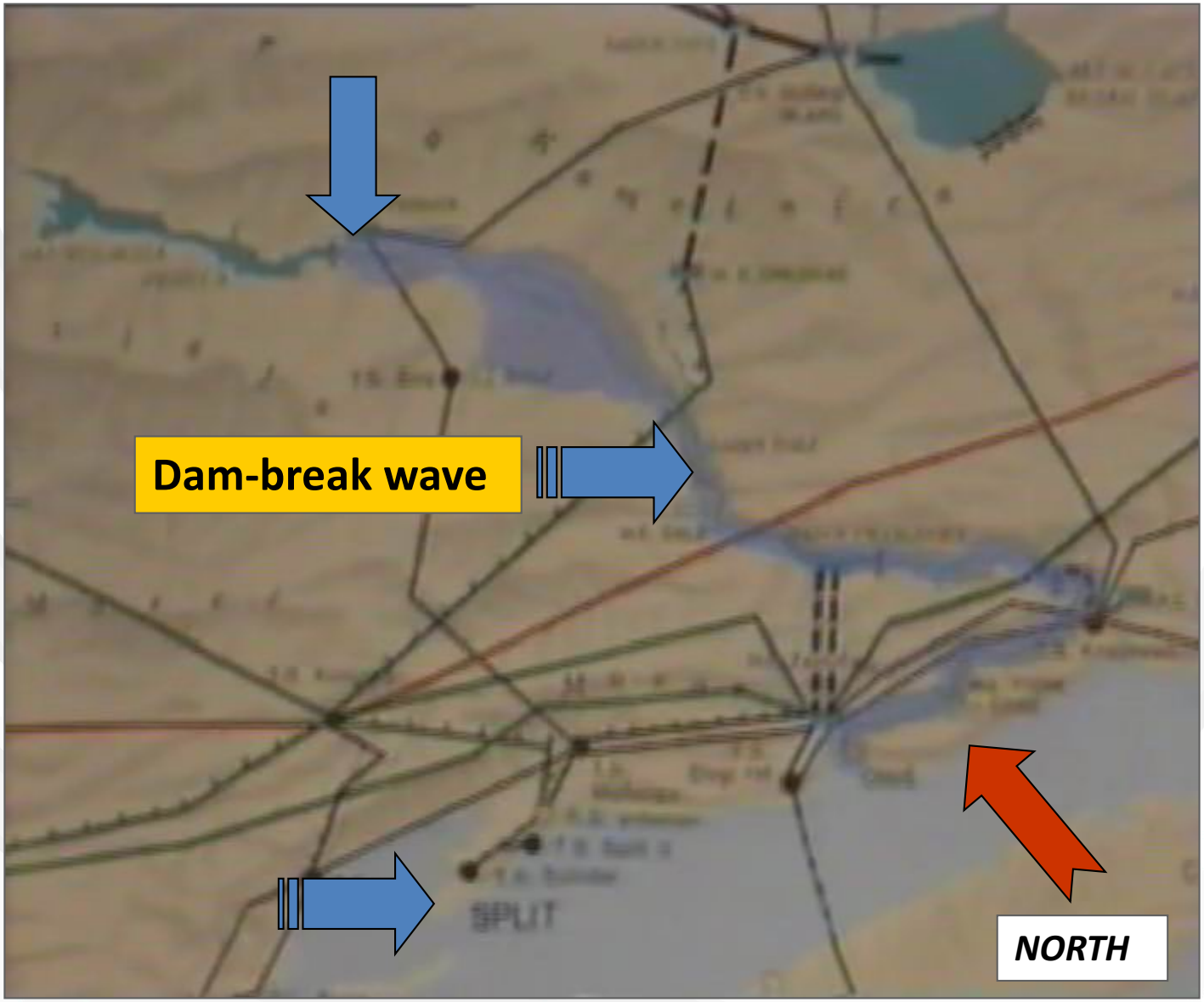




Remarks on dam vulnerability

Sorpe dam (Germany)
after the RAF bombing in 1943.
The craters caused by bombing can be seen on the downstream dam face.
The dam did not fail.

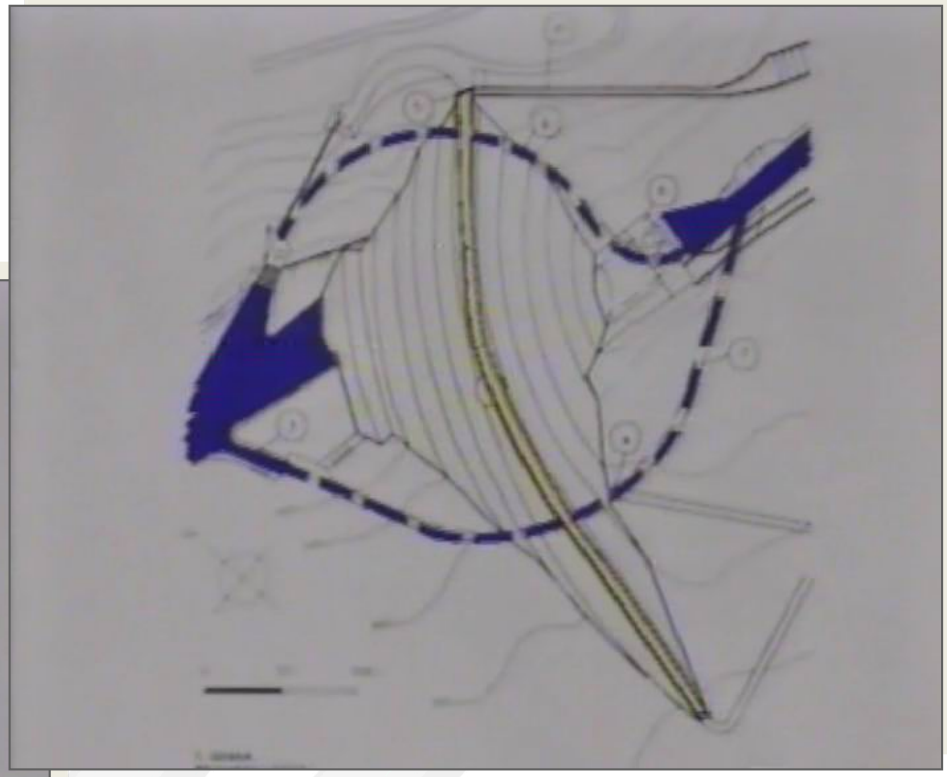
Remarks on dam vulnerability

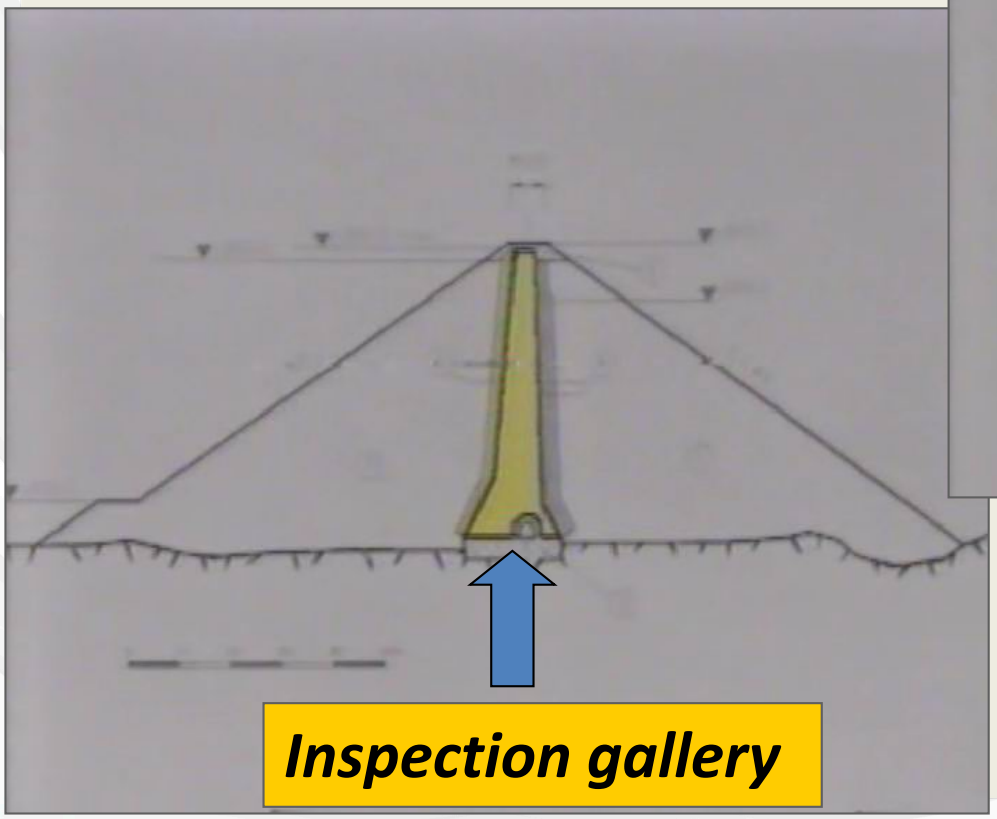


Peruca dam (Croatia)
Location of the dam: Croatia, close to Split. The partial dam failure caused a break wave.

Remarks on dam vulnerability

Cross section and plan view of Peruca dam



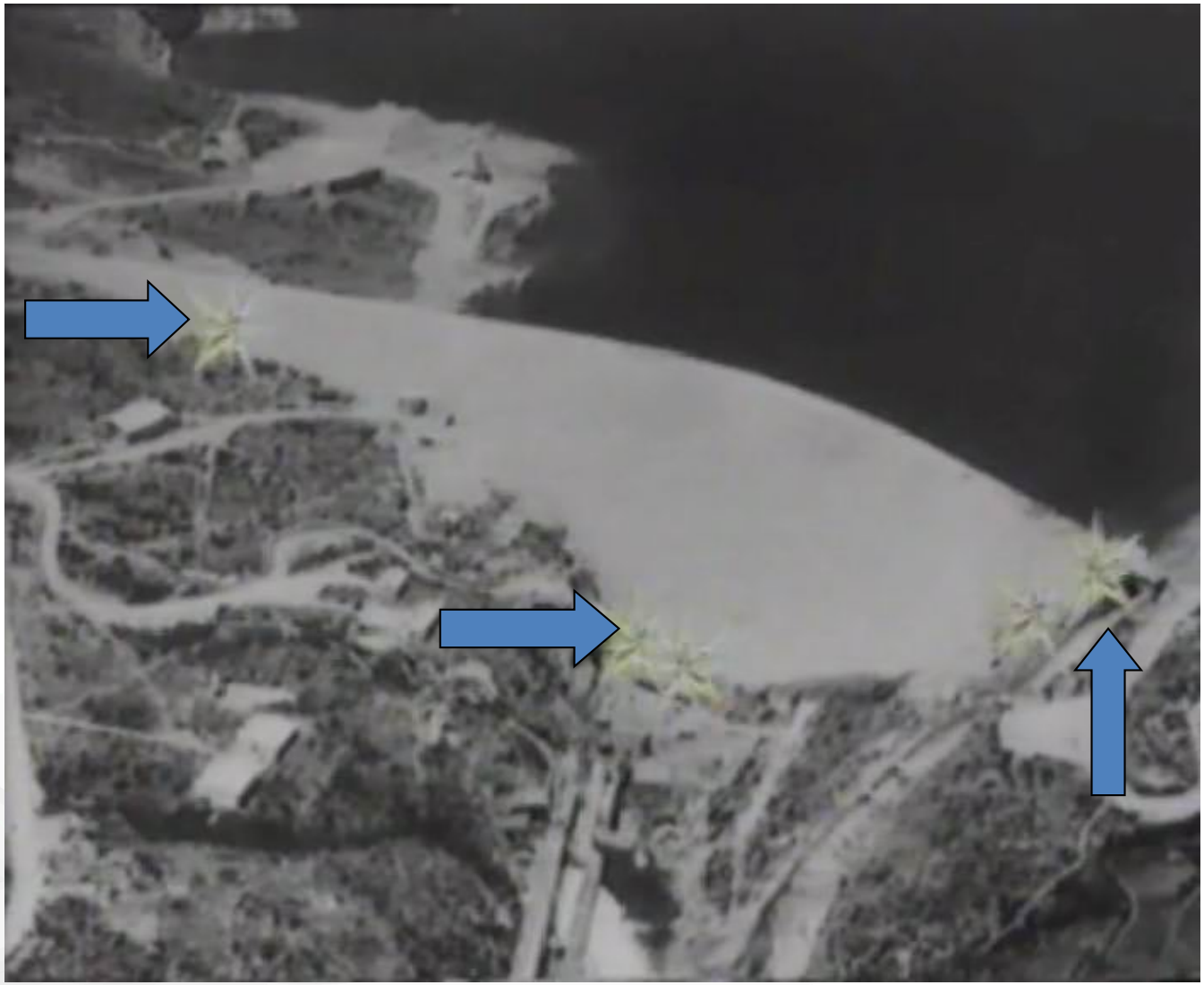


Inspection gallery

Peruca dam is an earthfill structure with clay core.

Remarks on dam vulnerability

The blasting of Peruca dam caused by the Serbian troups in 1993. Bombs have been placed at five locations in the inspection gallery.

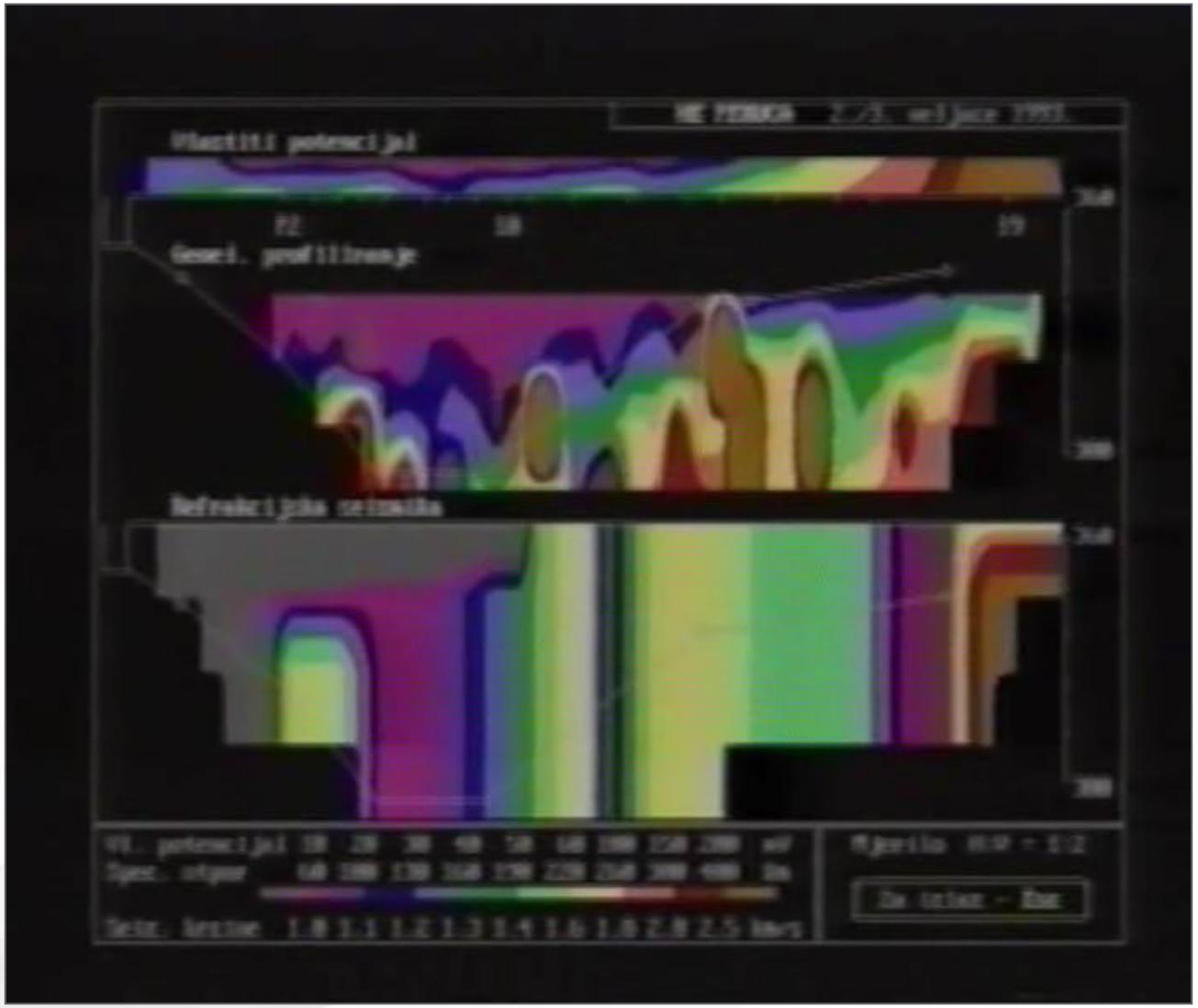


Remarks on dam vulnerability

The effects of Peruca dam blasting: the water flew through a breach in the upper part of the dam and flooded the powerhouse and the downstream valley

Remarks on dam vulnerability

Acustic tomography investigations to check the internal erosion in the dam body caused by blasting and after the rehabilitation works performed by grouting. Peruca dam is presently in operation.



Remarks on dam vulnerability

- Are dams structures capable to cope with blast loadings? Which is their level of vulnerability?

  Generally speaking, dams are structures that can cope with blast in an excellent manner. The level of structural vulnerability is low. Only war attacks are capable to produce significant damages.

  Particular protection has conversely to be done for outlets (e.g. gates) and electro-mechanical equipment.

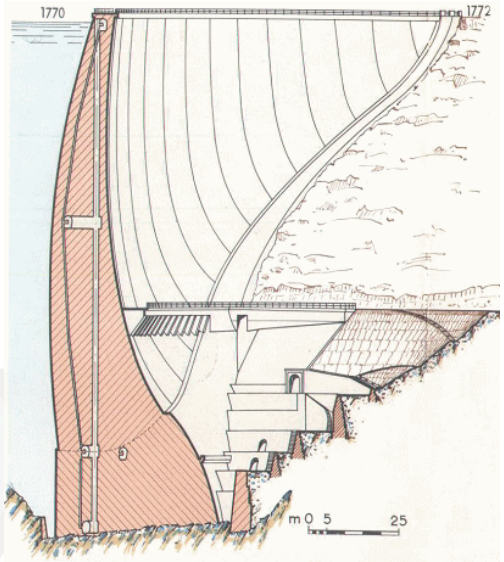
  Risk analysis can help to decide about how, where and when it is necessary to make actions.

- Are explosives used only as malevolent actions? The experience of Beauregard dam.

The use of explosives for dam safety: the experience of Beauregard dam

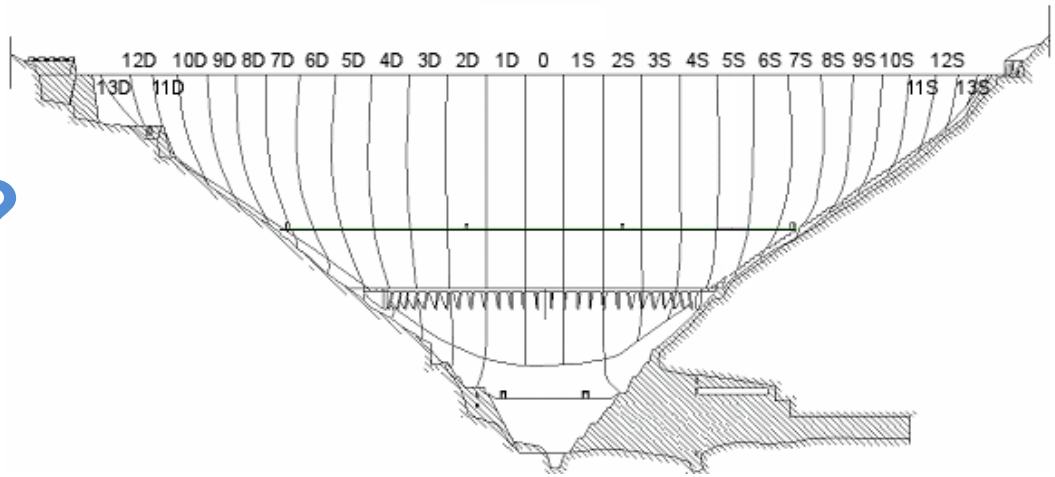
- Main data of Beauregard dam
- What was going on?
- Why numerical modelling?
- Numerical simulation of the demolition and the forecast behaviour
- Scheduled rehabilitation works
- A movie of the rehabilitation works

Main data of Beauregard dam

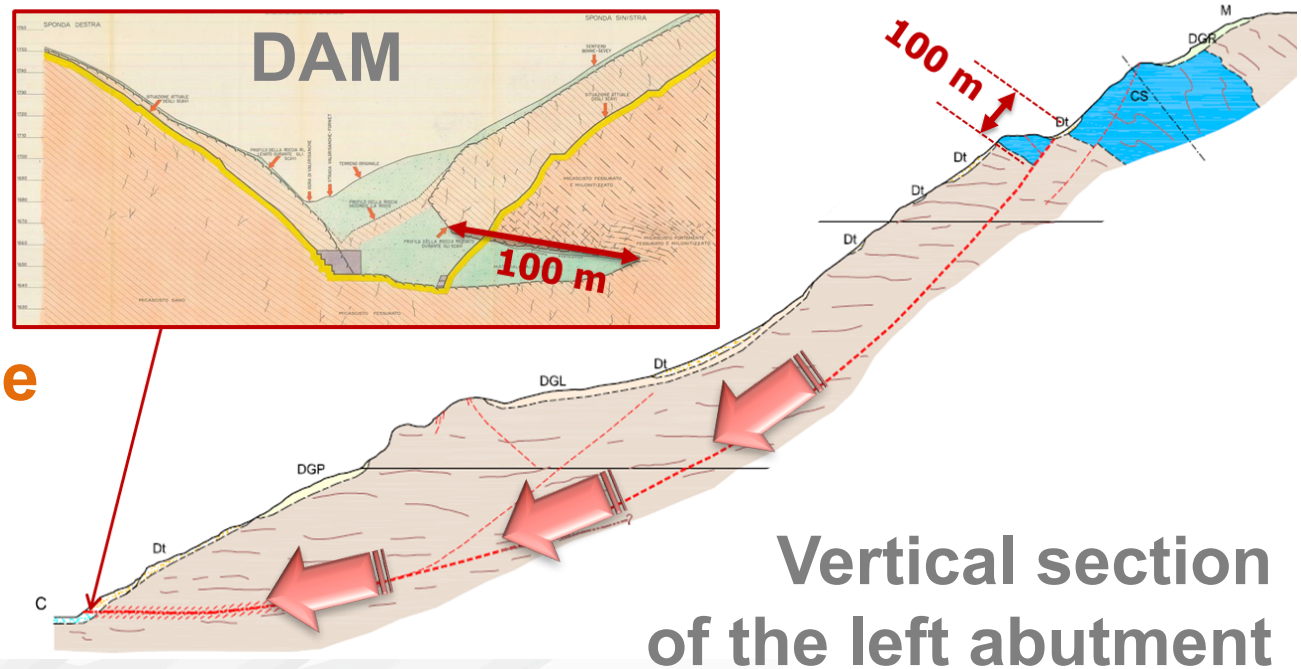


Height	**132,00 m**	**Dam volume**	**70 Mm³**
Base thickness	**45,60 m**	**Max water level**	**1770 m asl**
Crest thickness	**5,00 m**	**Construction period**	**1951-1958**
Crest length	**408,00 m**	**Annual production**	**286,41 GWh**

What was going on?



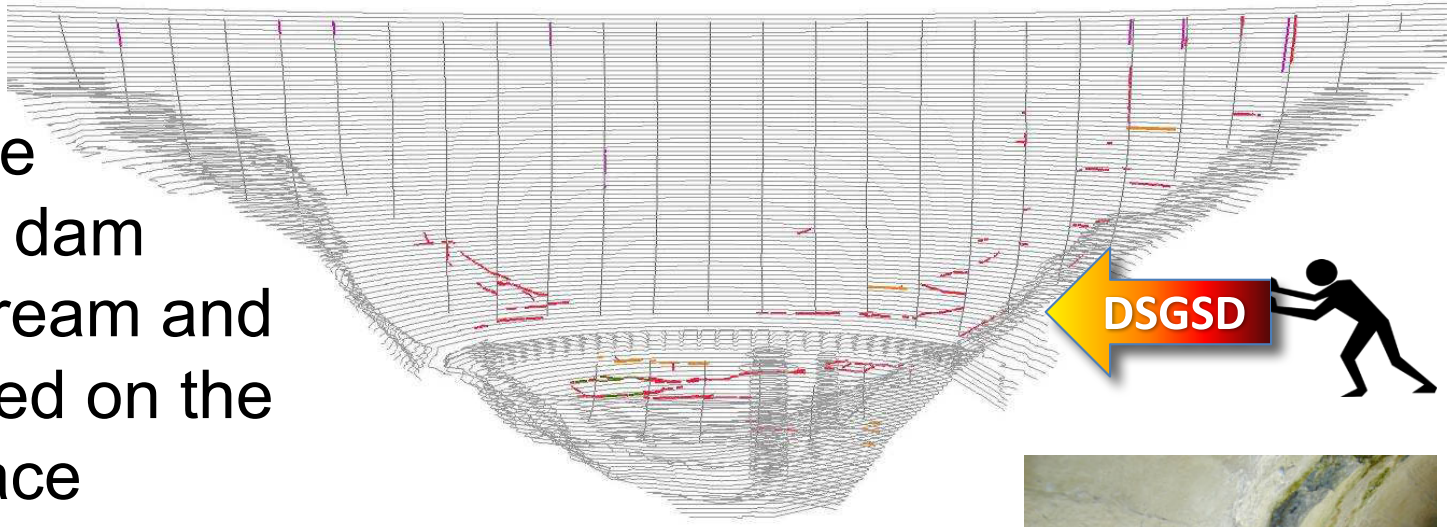
- Geological and geotechnical surveys outlined the presence of a **Deep-Seated Gravitational Slope Deformation** (DSGSD), that has never closed the valley…



Vertical section of the left abutment

What was going on?

Downstream view



- … but since the first fillings the dam deflected upstream and cracks appeared on the downstream face

- In 1969 the operational water level was lowered down by the Italian Dam Authorities from 1770 to 1710 m asl

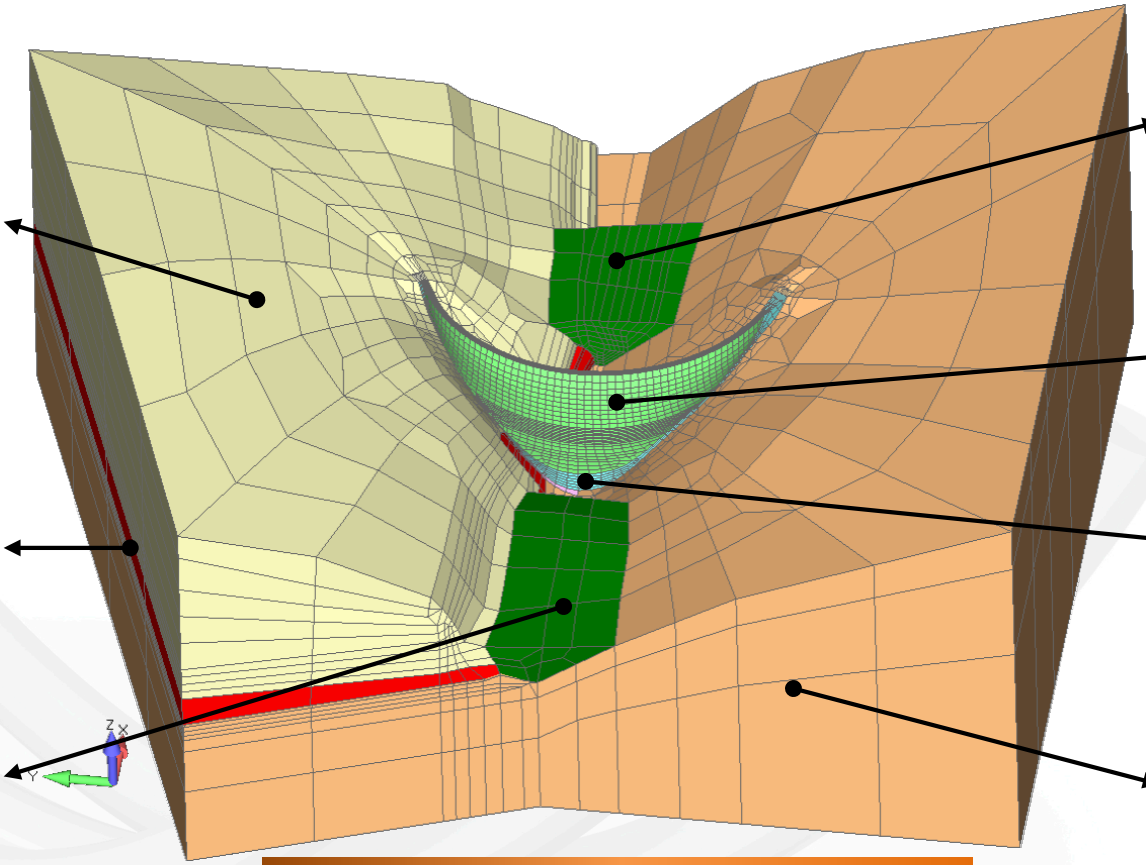
Why numerical modelling?

Identify the material parameters of the numerical model to interpret the dam behavior since its first fillings

Forecast the future dam behavior at short-medium term resorting to the calibrated numerical model

Support the designer to assess different rehabilitation solutions to guarantee the safety long-term operation of the dam

Numerical model



Deep-Seated Gravitational Slope Deformation (DSGSD)

Shear surface of the DSGSD

Upstream embankment

Downstream embankment

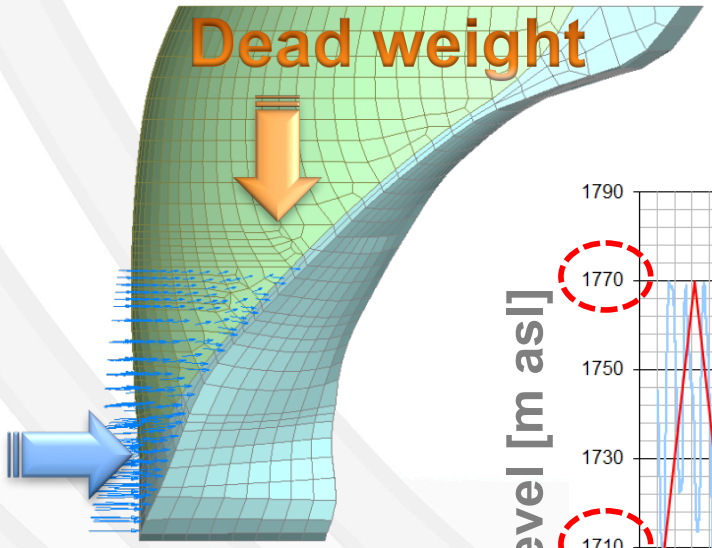
Dam

Pulvino

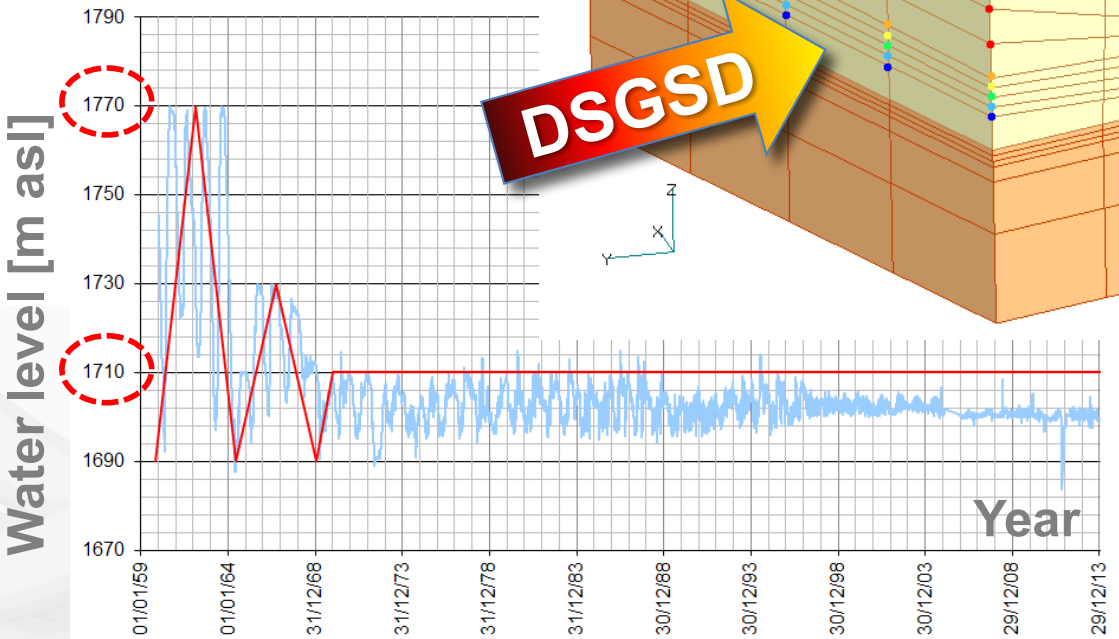
Rock Foundation

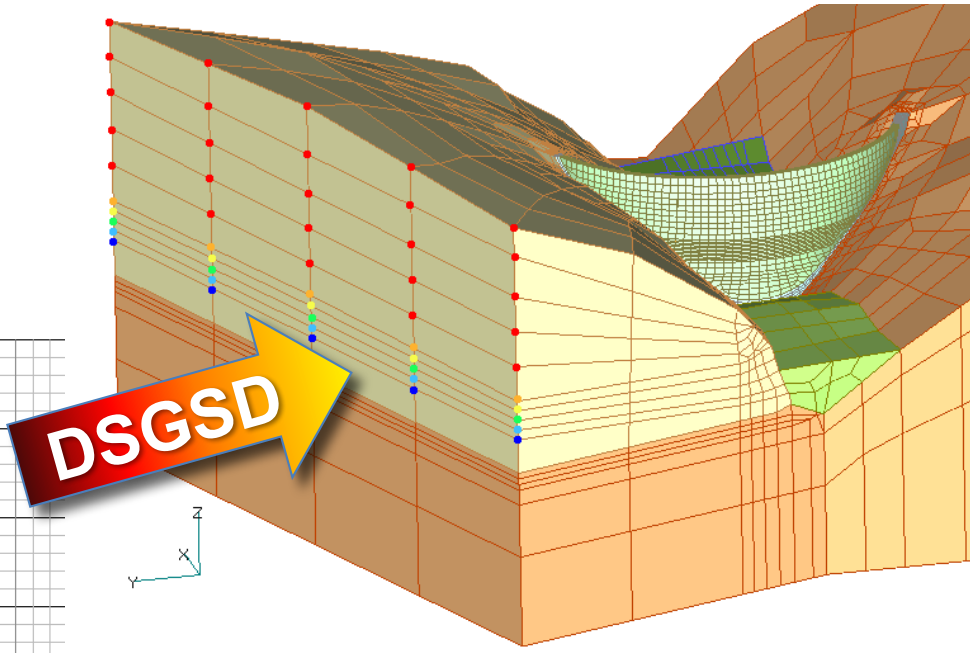
… and 16 contact surfaces

Loading and kinematic conditions

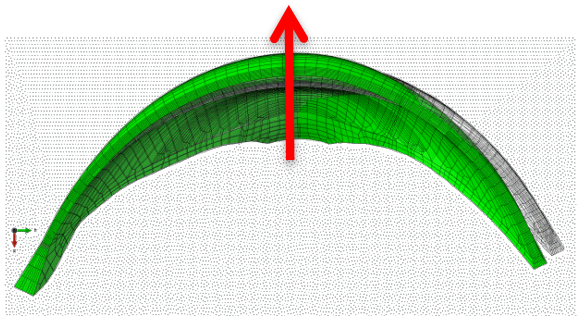


Hydrostatic pressure

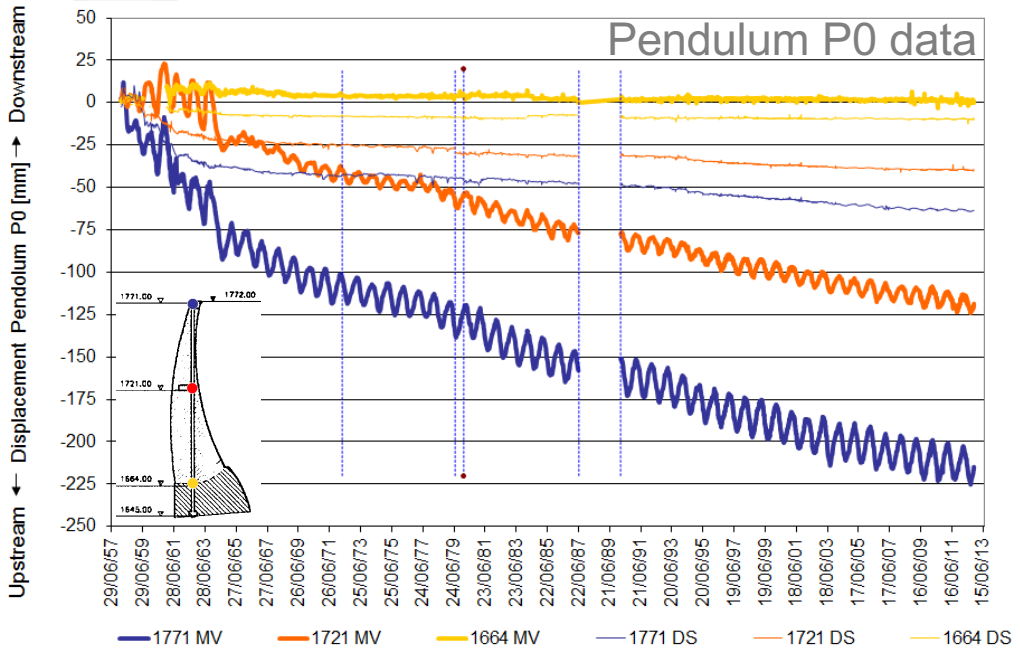


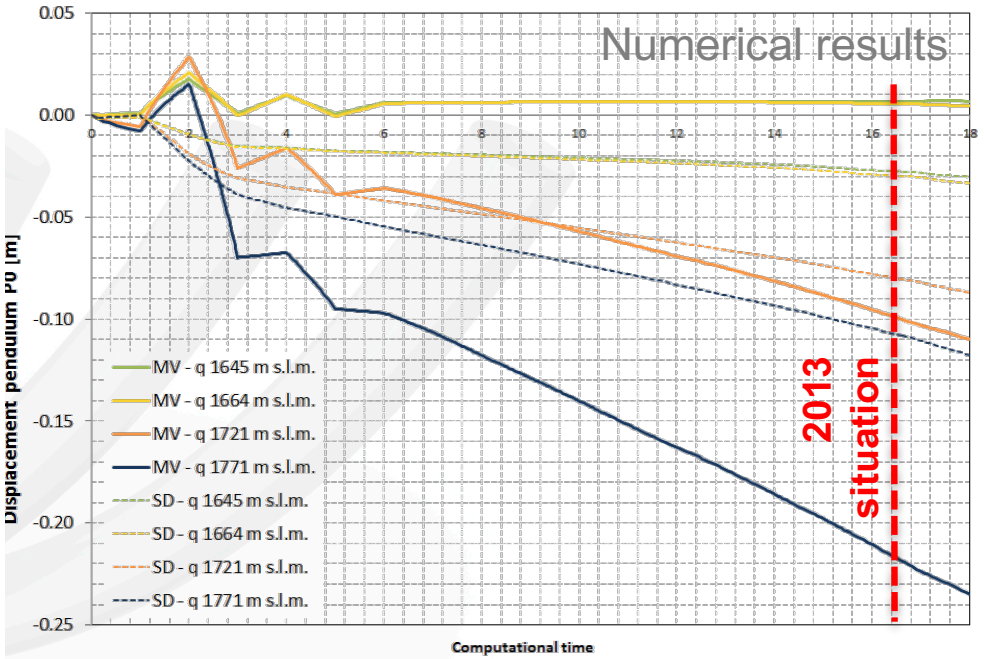


Calibrated numerical model



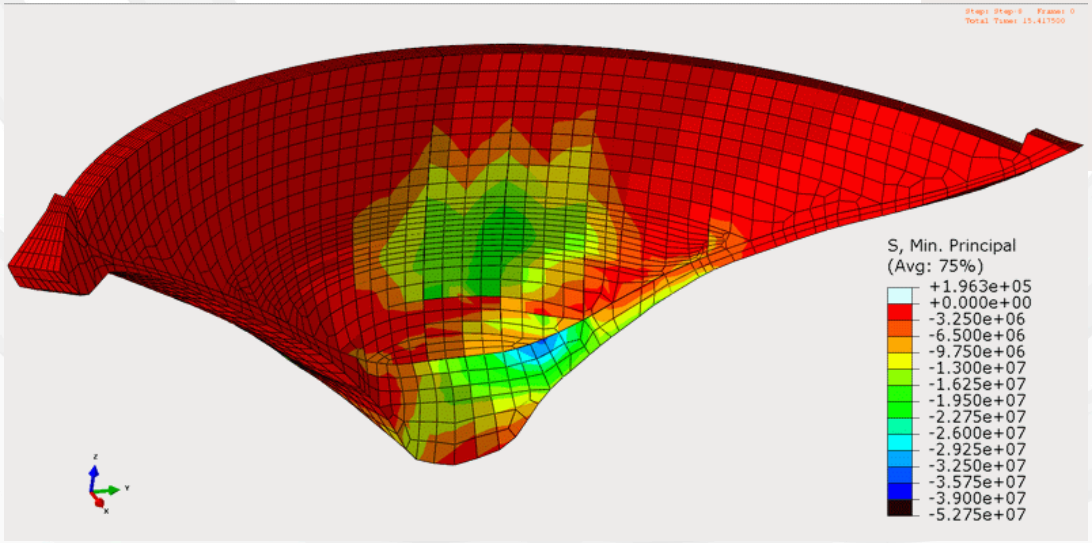
- Upstream displacements on the main vertical section

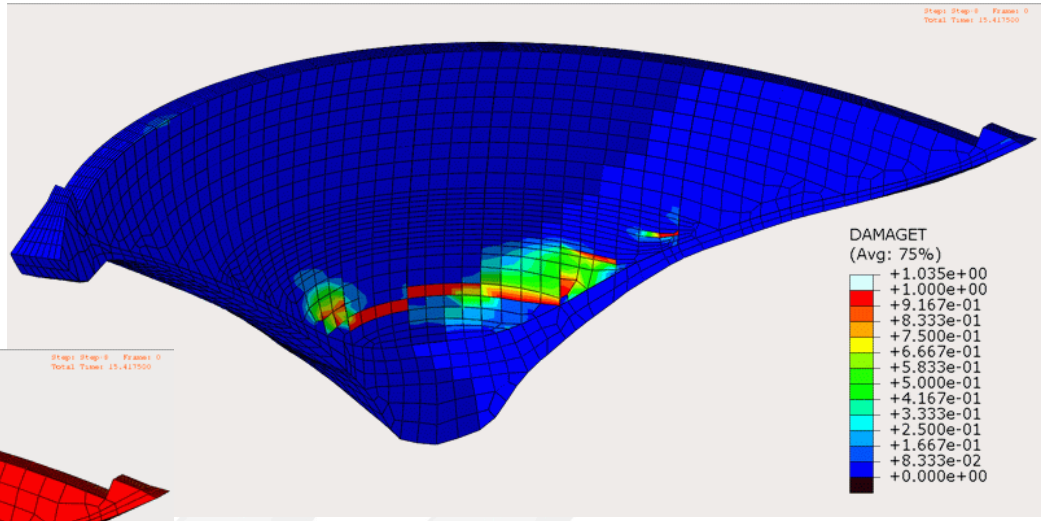




Numerical simulation of the demolition and the forecast behaviour

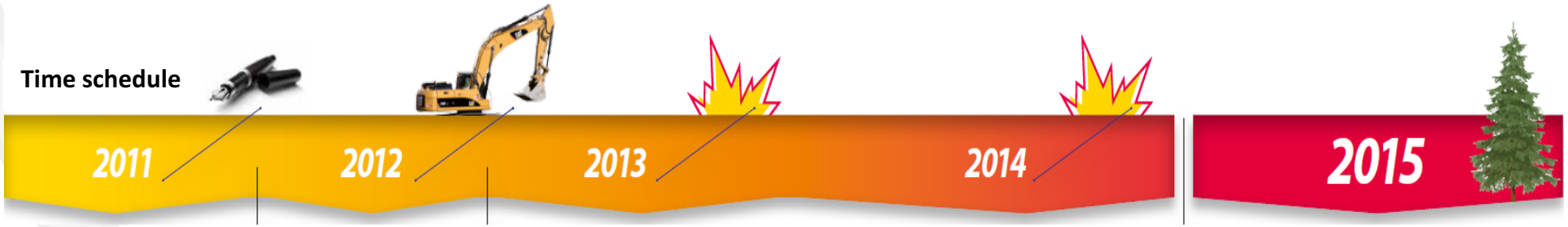
Minimum principal stress (compression)

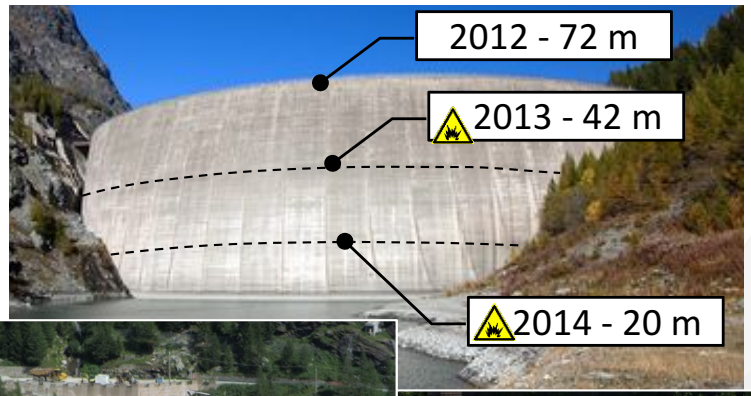




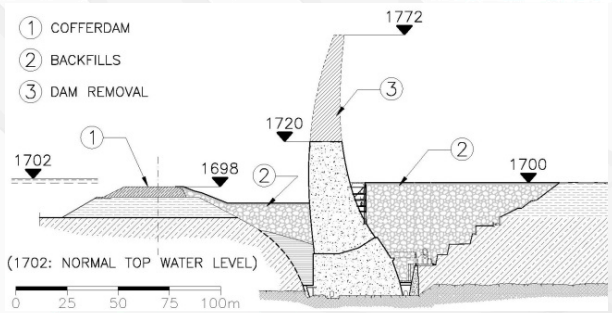
Tension damage (DAMAGET parameter in ABAQUS code)

Scheduled rehabilitation works





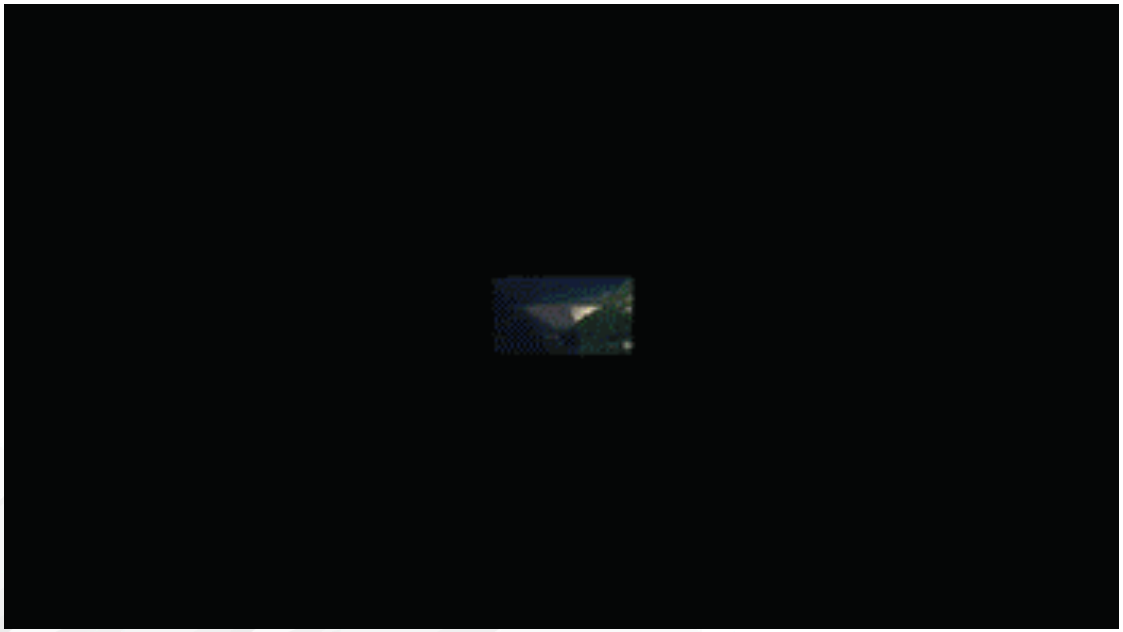
Right slope



Left slope

A movie of the rehabilitation works

- **56** explosions in two years
- **115,200** sticks of ERGODYN
- **160,000 m^3** of demolished concrete
- **52 m** lowering of the crest



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