

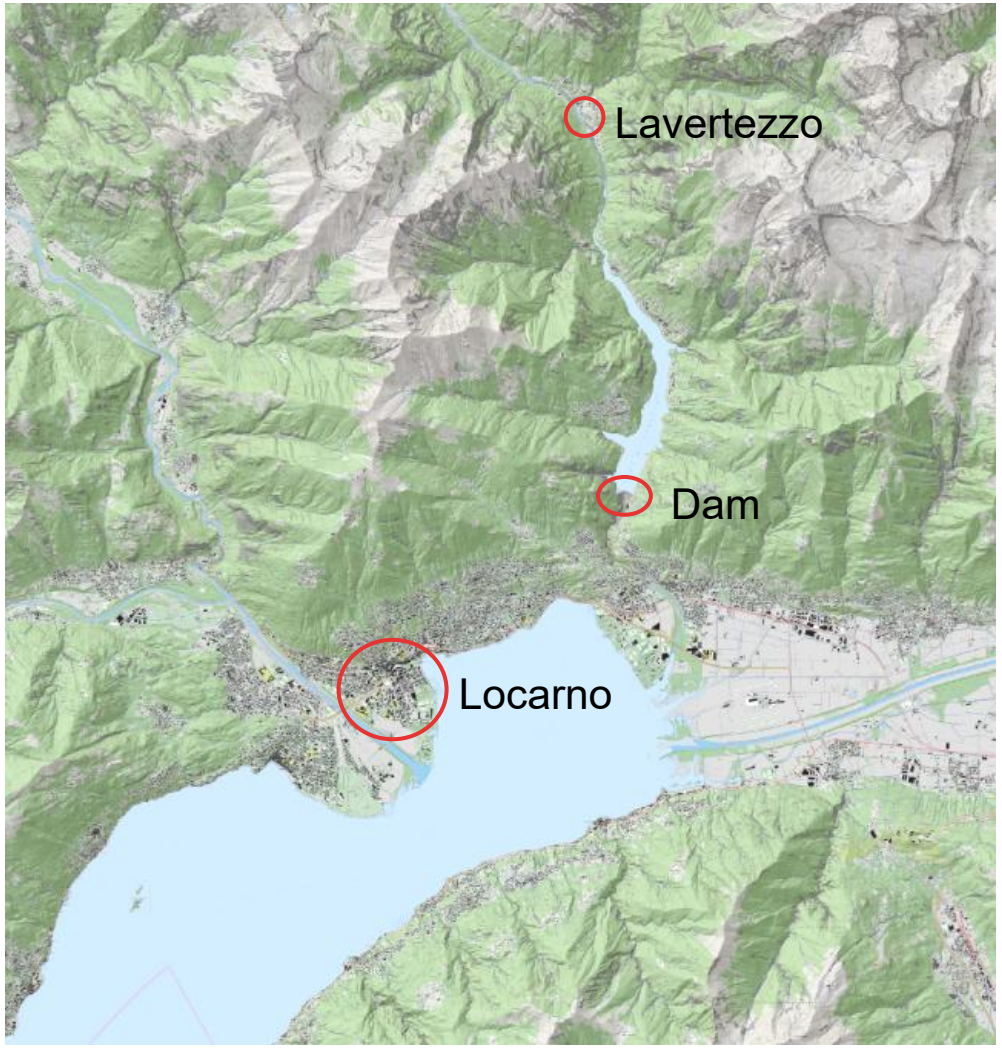
Verzasca Dam – A Story of Vision, Courage, and Scientific Rigor

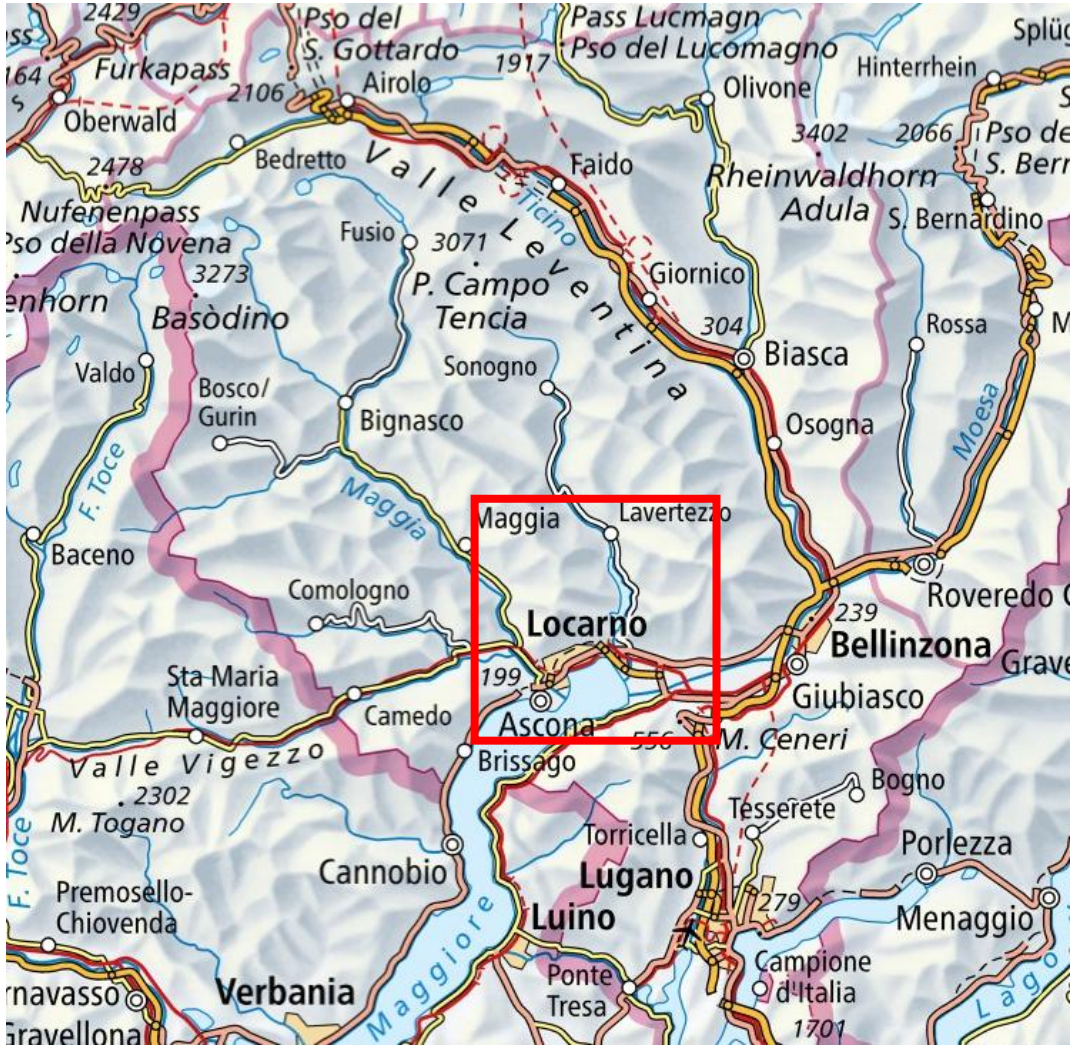
SGEB general assembly
BedrettoLab, 12 June 2026

Francesco Amberg

Lombardi

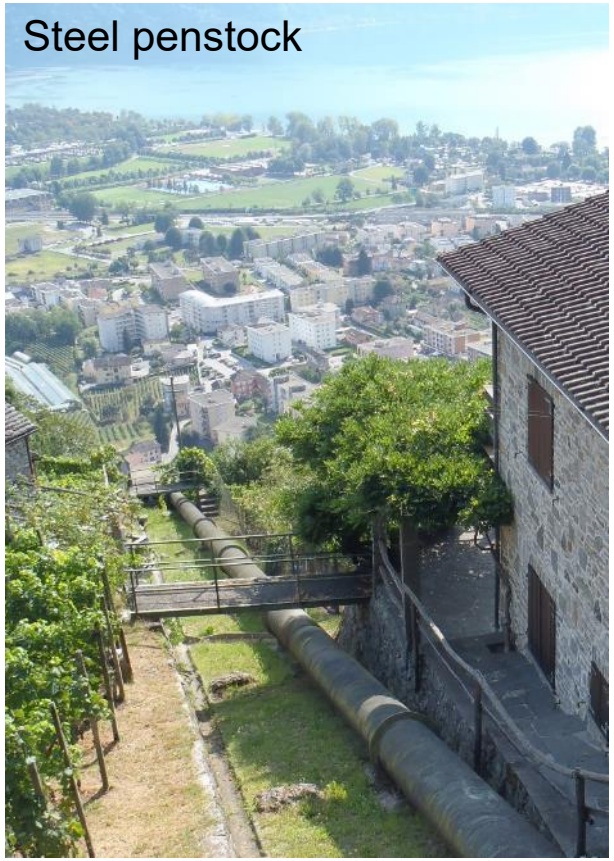
Contra dam in Verzasca valley





First powerplant of Tenero

Since 1907, the City of Lugano has been harnessing the hydropower potential in the Verzasca Valley through the Tenero power plant.







Headrace tunnel L=7 km

Steel penstock h=255 m

Powerhouse (8.5 MW)

The origin of the project – Year 1955

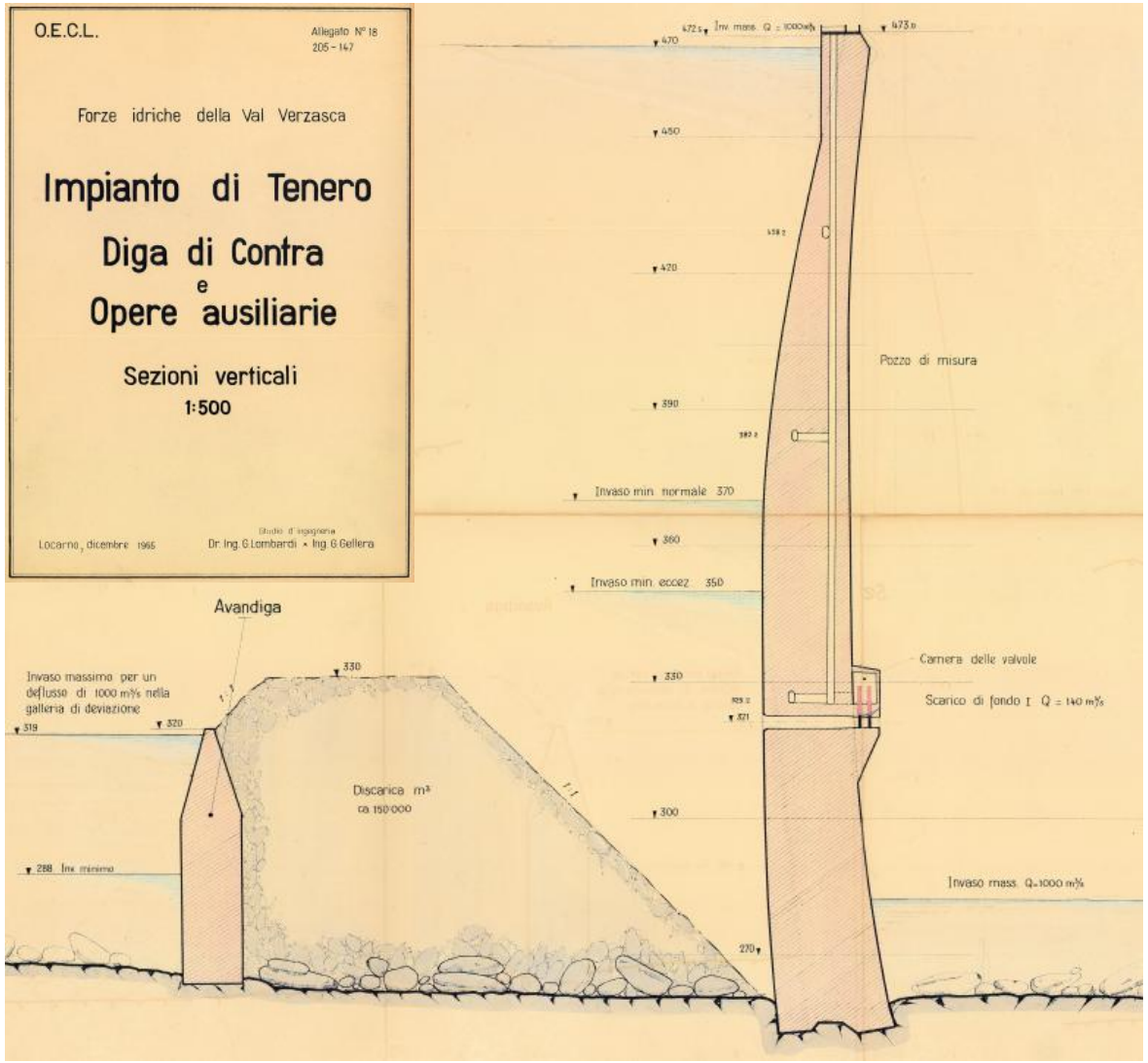
- In 1955, Giovanni Lombardi and Carlo Gellera, both aged 29, opened their engineering office in Locarno. Previously, the two civil engineers had worked together at Käch office in Bern.
- The city of Lugano planned the rehabilitation of the nearly 50-year-old hydropower plant of Tenero and asked Lombardi and Gellera for a second opinion on a recently submitted project prepared by another engineering company.
- Dr. G. Lombardi did not limit himself to answering the request he had received, but instead began evaluating all possible options, analyzing them from every point of view (optimal return on investment).
- The best option included (quite similar to the one we know today):
  - 220 m high thin arch dam, to create a reservoir with maximum water level at 470 m a.s.l.
  - Short headrace tunnel (L=200 m, ∅=2.7 m), to avoid surge shaft
  - Inclined pressure shaft (72%, ∅=2.7-2.4 m)
  - Underground powerhouse (72 MW) on the right bank (4 Francis turbines, each 18 MW)
  - Tailrace tunnel (L=1760 m)

The origin of the project – Year 1955

Criteria considered for the feasibility design:

- The original run-of-river powerplant was able to produce up to 1/4 of the hydropower potential without any possibility to regulate and satisfy the peak demand. By overcoming this limitation, the energy produced could be sold at higher prices when the demand is high.
- The lower part of Verzasca valley is steep and V-shaped, ideal for an arch dam, while the upper part is wide and open, less favorable for a dam.
- With the new powerplant the energy production increased fourfold (from 60 GWh to 235 GWh) and the capacity increased by a factor of 8.5 (from 8.5 MW to 72 MW).
- The volume of runoff during the 6 months of summer season is 300 mio m^3 and during winter season is 100 mio m^3. With a reservoir storage capacity of 100 mio m^3 it is possible to deliver for the production a water volume of 33 mio m^3 each month constantly during the whole year.
- The head of the powerplant is mainly given by the dam height. To ensure the economic viability of the power plant, the dam volume should be minimized, the waterways as compact as possible (total length from intake to outlet 2.2 km).
- Availability of aggregates of good quality for the concrete were confirmed by preliminary tests.

First layout (1955)

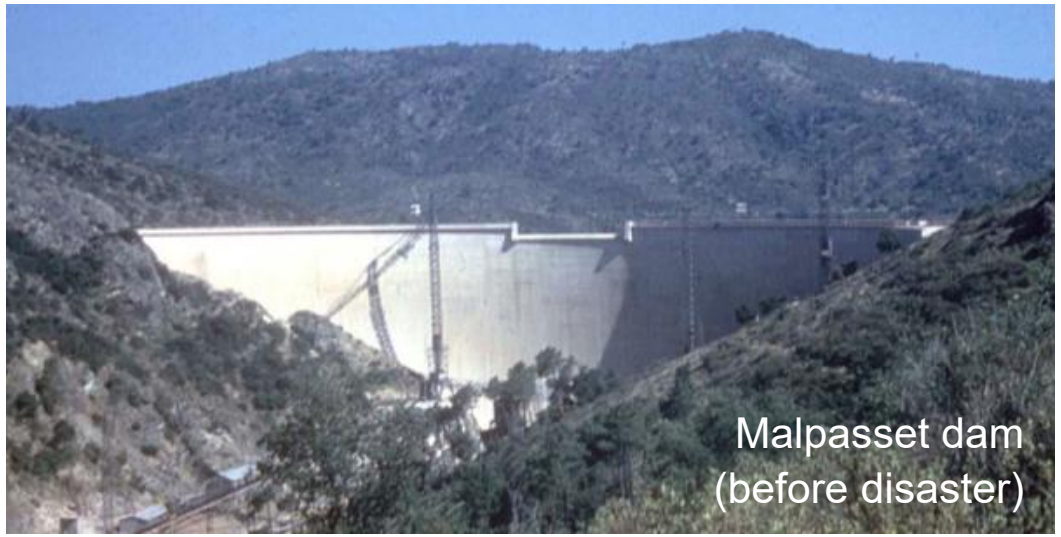




Issuance of concession (1959)

— On 3 December 1959, the newly created Verzasca SA, owned 1/3 by the Azienda Elettrica Ticinese and 2/3 by city of Lugano, received the concession to use the water resources of the Verzasca valley according to the project proposed by Lombardi and Gellera.

— On 2 December 1959, at 21:13, the 66 m high Malpasset arch dam, located north of Fréjus in the French Riviera, collapsed when the reservoir reached for the first time its maximum level. A water volume of 50 mio m^3 was released by the dam break creating a wave, 40 m high and moving 70 km/h, destroying two small villages and killing 423 people.

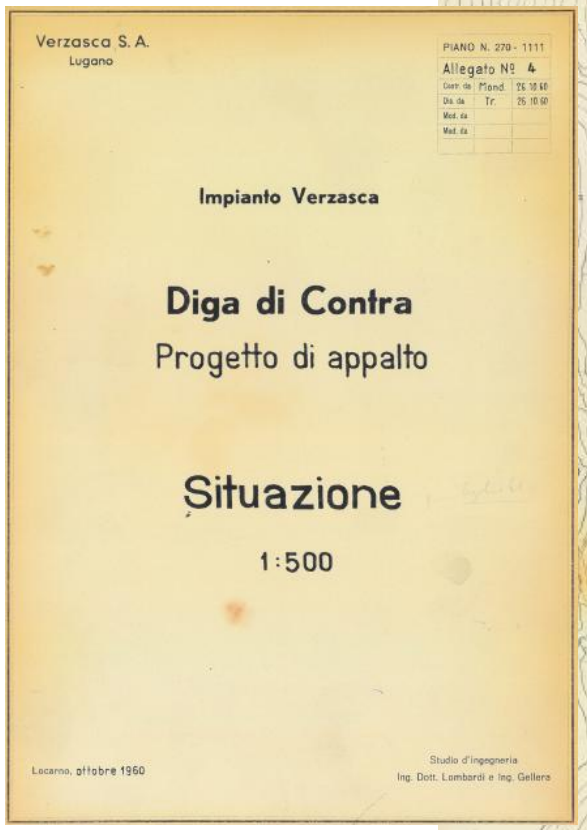


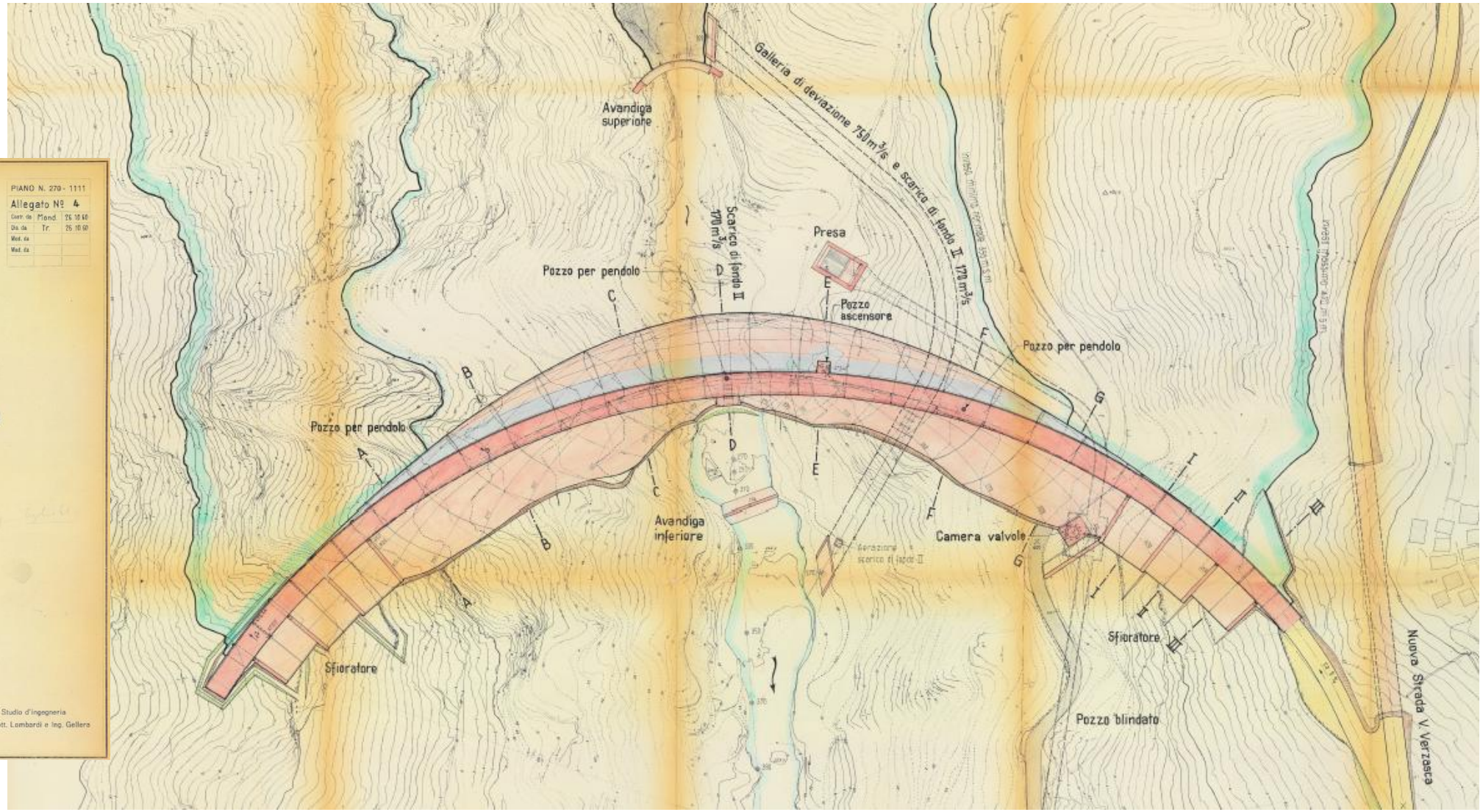
Malpasset dam
(before disaster)



Malpasset dam
(after collapse)

Final design (1960)





Final design (1960)



Arch dam :

— Maximum water level	470 m a.s.l.
— Reservoir storage capacity	85 mio m^3
— Dam height	220 m
— Crest length	380 m
— Crest thickness	7 m
— Thickness at the base	25 m
— Concrete volume	660’000 m^3
— Spillway discharge capacity	1’000 m^3/s

Underground powerhouse :

— Francis turbines	3
— Maximum head	277 m
— Design flow (total)	50 m^3/s
— Installed capacity	105 MW
— Annual energy production	227 GWh

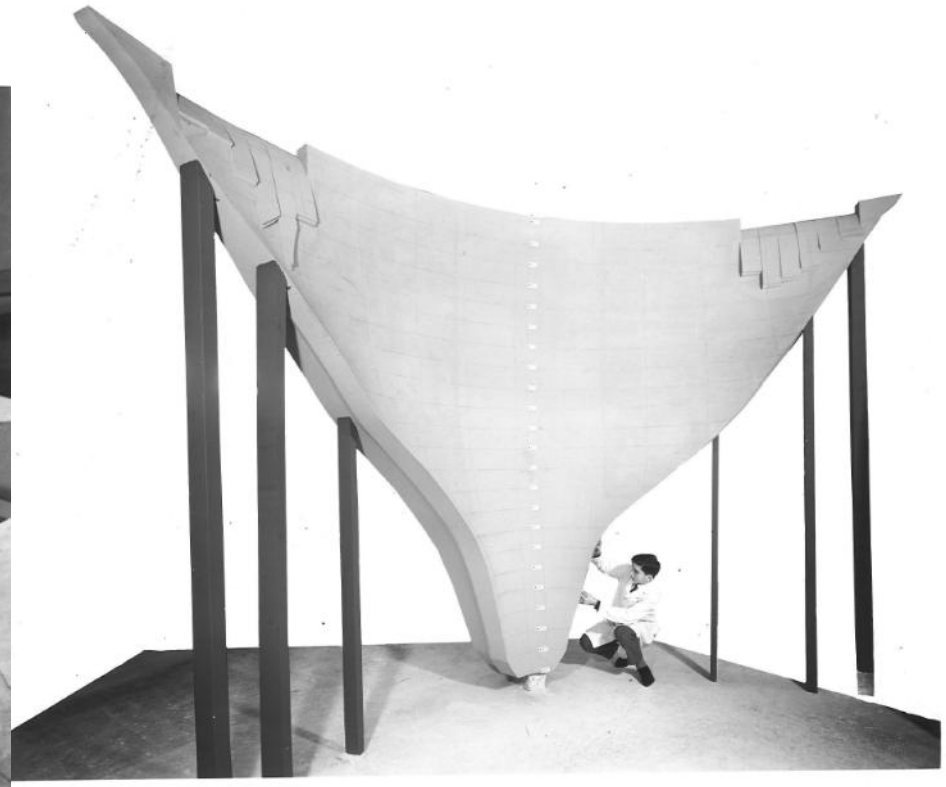
Advanced numerical analyses



- The dam was calculated with the support of computers applying the theoretical approaches developed by Dr G. Lombardi in his doctoral thesis “Thin arch dams”.
- In fact, the Contra Dam was one of the first dams in the world calculated with computers. Three modules were prepared for the first scientific computer at IBM Zürich while the system of equations was solved at ETH Zürich (probably with ERMETH).
- Before 1960, structural analyses were carried out manually by two engineers working in parallel with Monroe calculators. Each evening, they compared the results obtained and decided if the next day they could continue or if they had to repeat the analyses performed during the day.
- Basically, only static analyses were performed. For the full water level, the maximum stresses should not exceed the concrete strength divided by a safety factor of 4.0.
- Despite these advances in numerical analysis, the structural behaviour of the dam was still verified using physical models, as was common practice at the time.

Structural check with physical models





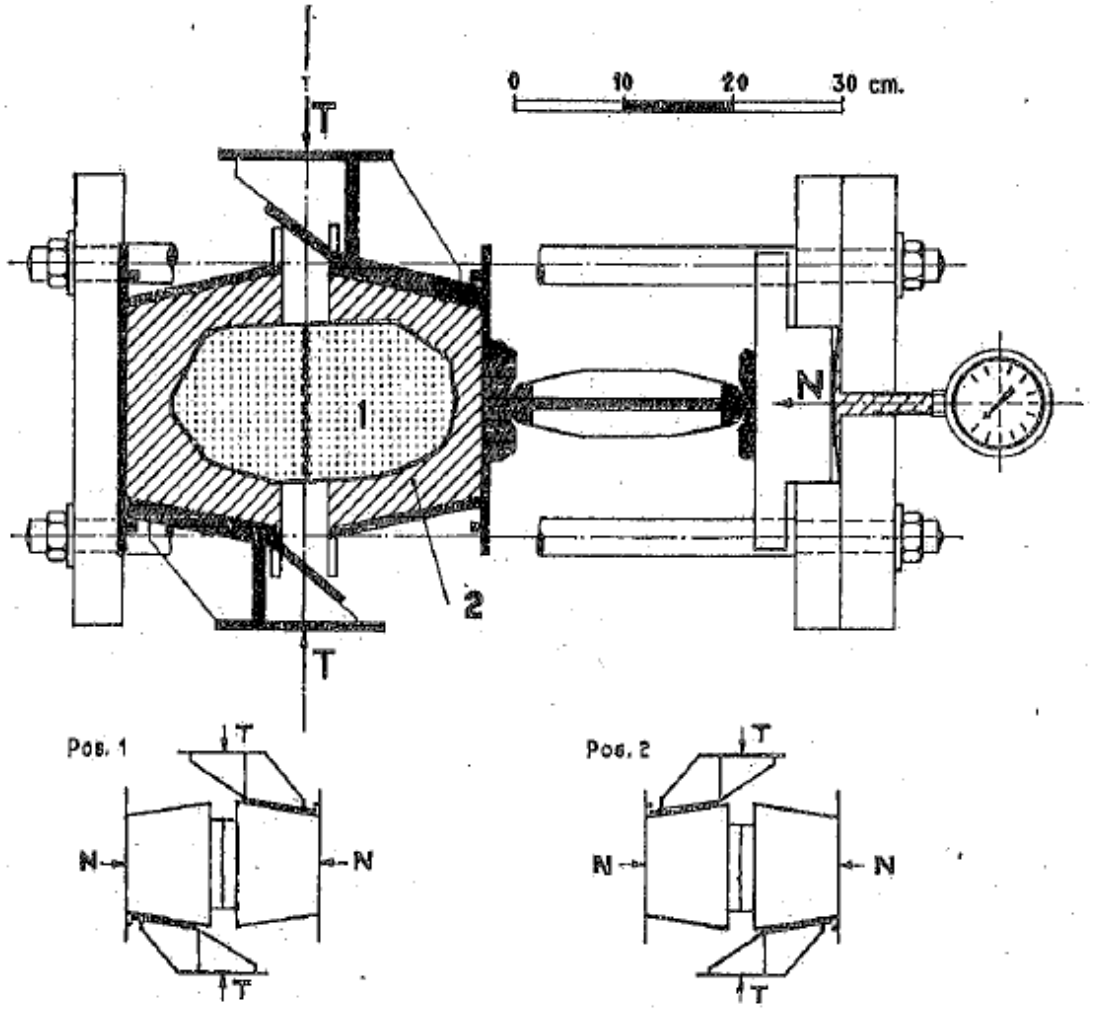
Static model at ISMES Bergamo

— Water pressure simulated with hydraulic cylinders

— Measurement of displacements in 52 points

Innovations in rock mechanics

- The collapse of Malpasset arch dam, caused by the failure of the rock mass on the left abutment, clearly showed how the approach of some pioneers to assume the rock foundation stronger than the concrete dam was no longer acceptable.
- The young design team paid particular attention to the stability and safety of the rock abutment:
  - Lombardi contributed to the development of a procedure and apparatus to measure the shear strength along discontinuities in the rock mass. Still today, at EPFL exists an apparatus called “Lombardi”.
  - The obtained parameters (friction and cohesion) were used in calculating the stability of the dam abutment.

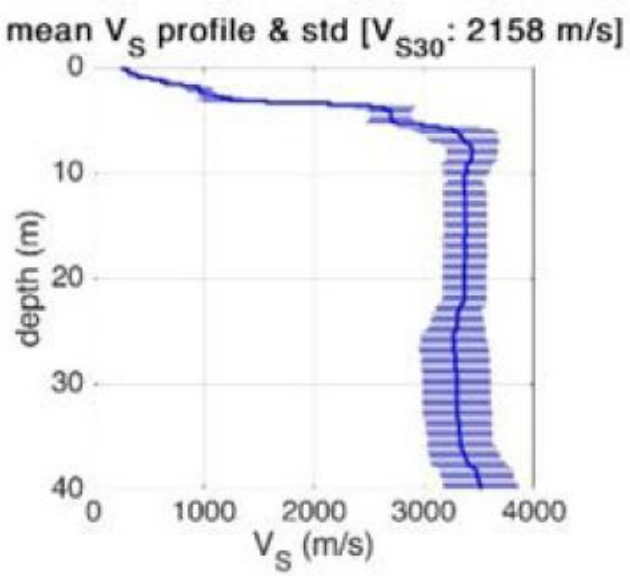


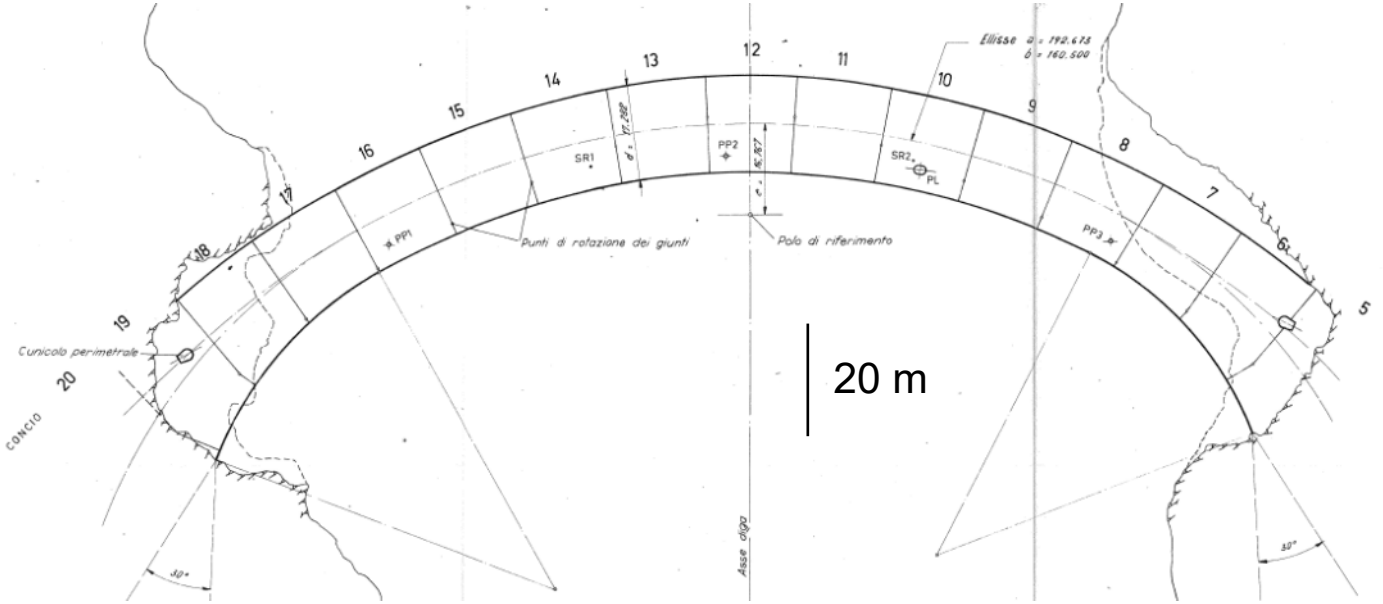
Stability of rock abutment

— The large arch dam needed safe abutments, requiring the excavation of the superficial rock, characterized by open joints.

— The geometry of the excavation was defined based on the investigations (geophysics, 5 exploratory adit, large scale jacking test, direct shear test) and on stability analyses.

— The excavated rock volume reached 300’000 m^3. Compared with the concrete volume of 660’000 m^3, the excavation volume is relatively high, in particular for a thin arch dam.





Monitoring of rock abutment

Definition of the monitoring system, with great attention to the behavior of the rock abutment.

(1) Original ground surface

(2) Excavation limit

(3) Grout curtain (level of water table downstream of dam controlled by piezometers)

(4) Exploratory adits

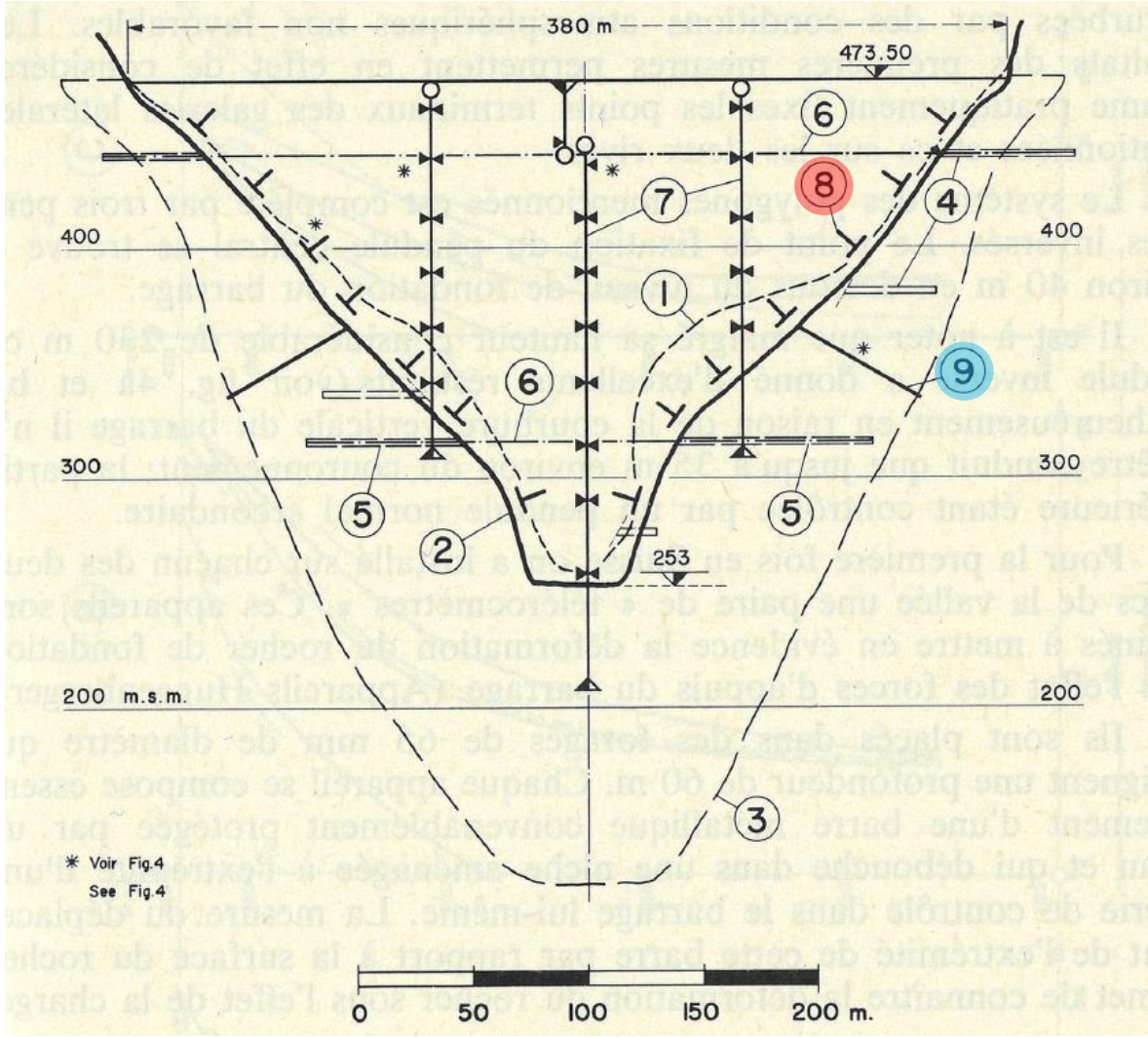
(5) Grouting heading

(6) Geodetic polygonal (extended into the rock)

(7) Pendulum (reference point into the rock)

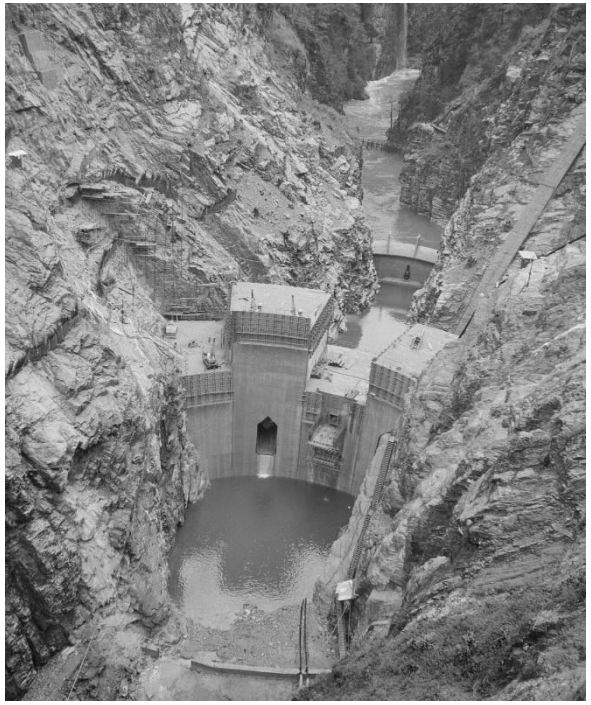
(8) Telepressmeters (to monitor the pressure transmitted by the dam on the abutments)

(9) Rockmeters (first in a Swiss dam)

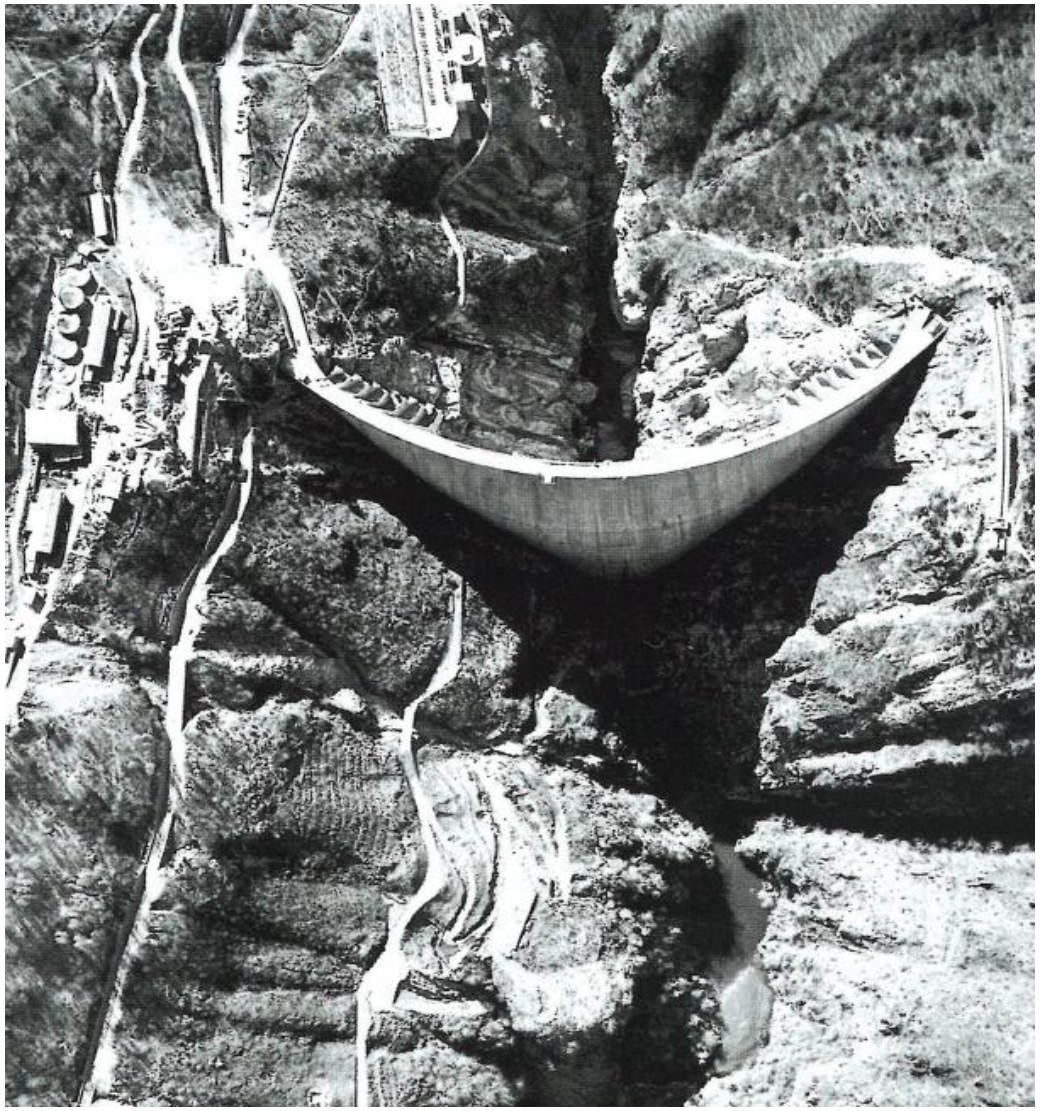


Construction of the powerplant

— 1960-62: Construction of the new access road for the valley
— 1961-63: Diversion tunnel and dam foundation excavation
— 1962-65: Water tunnels and powerhouse
— 1963-65: Dam construction (concrete placement)







First impounding

- The impounding started slowly in August 1964 and after 1 year reached the elevation of 440 m a.s.l., i.e. 30 m below full water level.
- From mid-August 1965, a rainy period caused the filling of the reservoir with the increasing of 30 m of the water level in less than 1 month. The last 10 m were filled in only 7 hours during the night between 8th and 9th of September. At 5:00 am the spillway started to discharge water. Even with the bottom outlet in operation, it wasn't possible to control the water level, due to the relevant flood event. According to the impounding program, the last 10 m should have been filled within 40-50 days.
- After this flood event, it was immediately clear, that the flood adopted for the spillway design had been underestimated.
- The night was emotionally intense, with the uncontrolled reservoir filling, one pendulum showing unusual readings and the ongoing reservoir induced seismic activity.
  One should also consider the critical situation regarding dams in Europe at that time: the already mentioned Malpasset dam disaster, in 1959, but also the Vajont disaster, which occurred on 9 October 1963 in Italy. During the first filling of the reservoir, a massive landslide plunged at high velocity into the basin, causing the overtopping of the arch dam with 50 mio m^3 of water and resulting in the deaths of more than 2000 people.

First impounding

Finally, everything went well and the powerplant was concluded just 10 years after the initial idea emerged in the minds of young engineers.

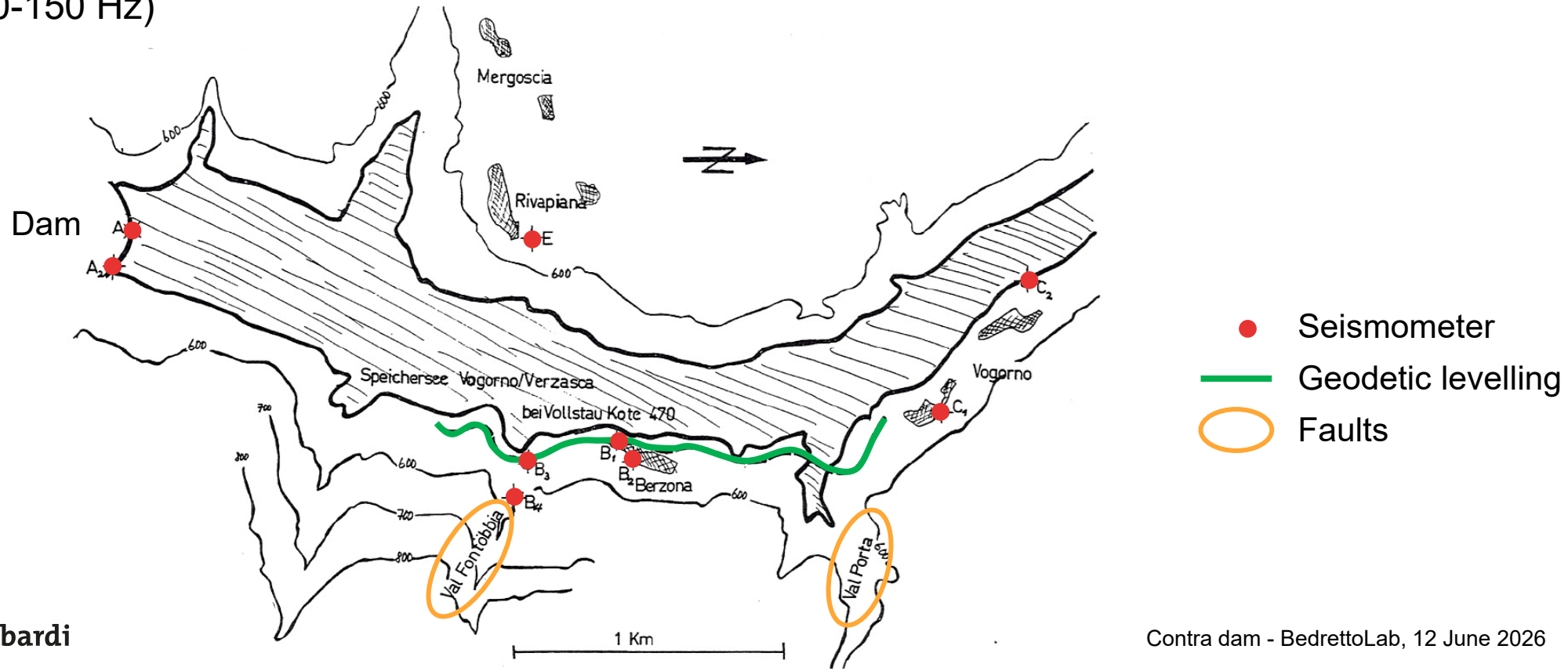




Reservoir induced seismicity

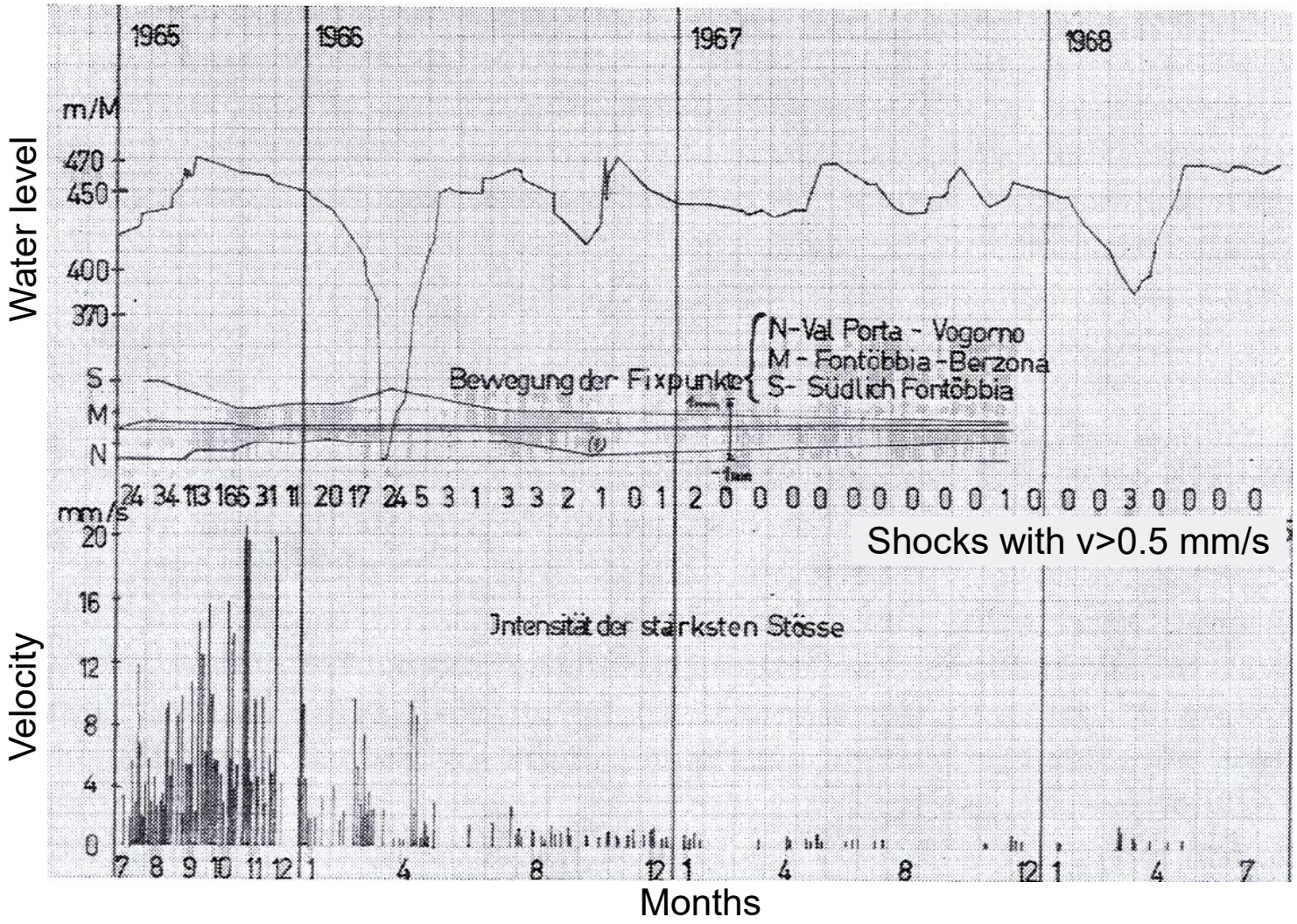
— During summer 1965, with the reservoir at elevation above 400 m a.s.l., unexpected shocks associated with explosive noises were perceived by the population.

— Seismographic records confirmed local earthquakes, at a depth of 100-400 m below the surface, along two young faults (Val Fontöbbia and Val Porta). The shocks were short (0.2-0.3 s) and at high frequency (50-150 Hz)



Reservoir induced seismicity

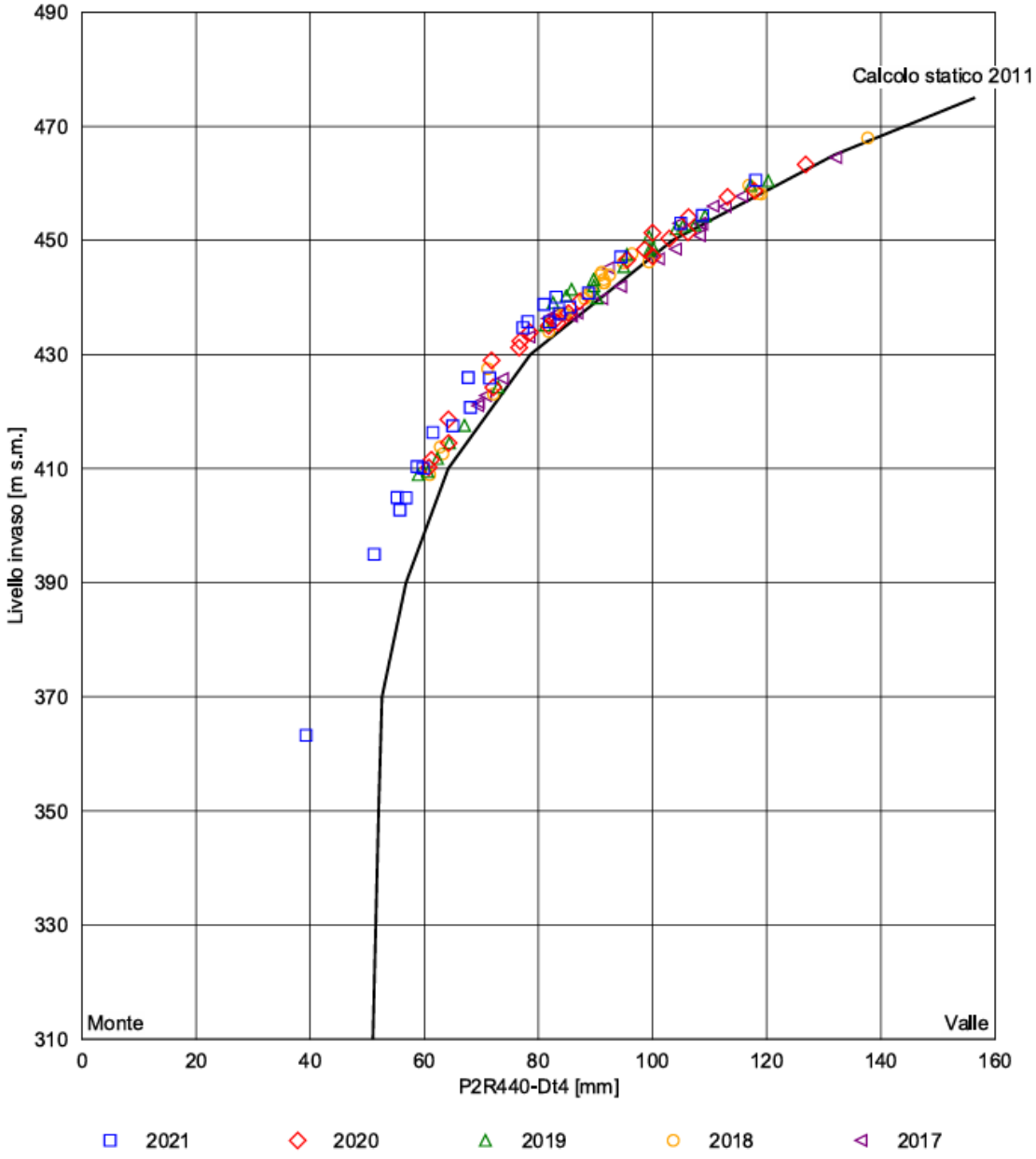
- Measured velocity until 20 mm/s
- Shocks comparable with lighting of 100-200 kg explosive at 100 m distance.
- During 1965, until 25 shocks per day perceived by the population.
- After the first reservoir emptying in March-April 1966, the seismic activity reduced considerably.
- The last appreciable shocks were recorded in March 1968.
- The region situated to the south of Fontöbbia settled by 0.5-1 mm, while the zone north of Val Porta lifted by 0.5 mm.



Dam behavior

— Maximum crest displacements reach 100 mm due to the water pressure and +/- 20 mm for the seasonal temperature variations.

— The displacements are well reproduced by structural analyses considering $E_{Concrete}$= 24 GPa , E_{Rock}= 17 GPa

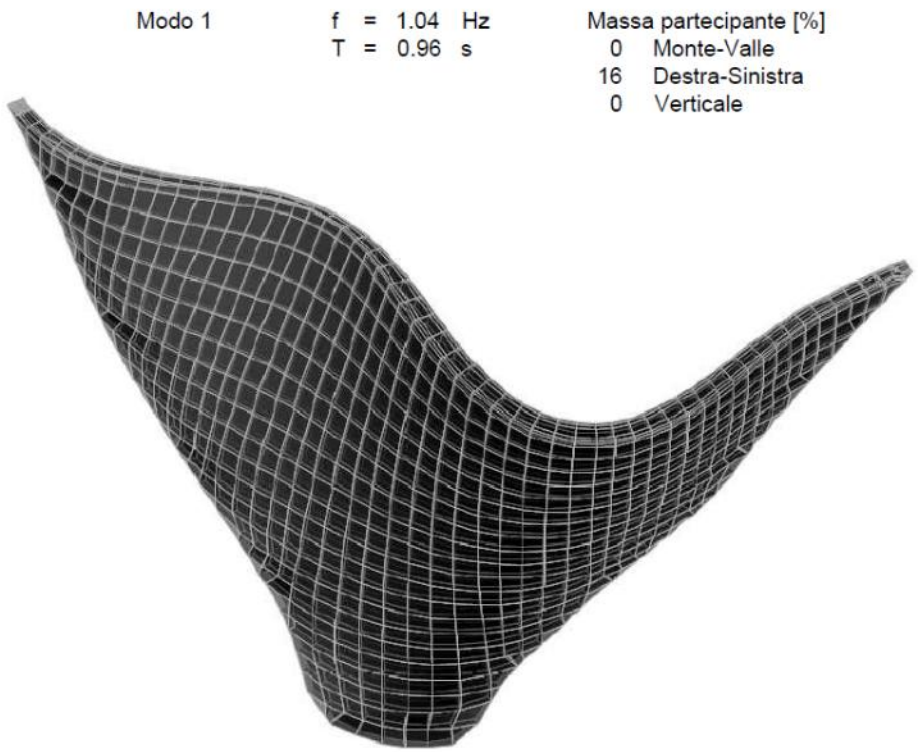


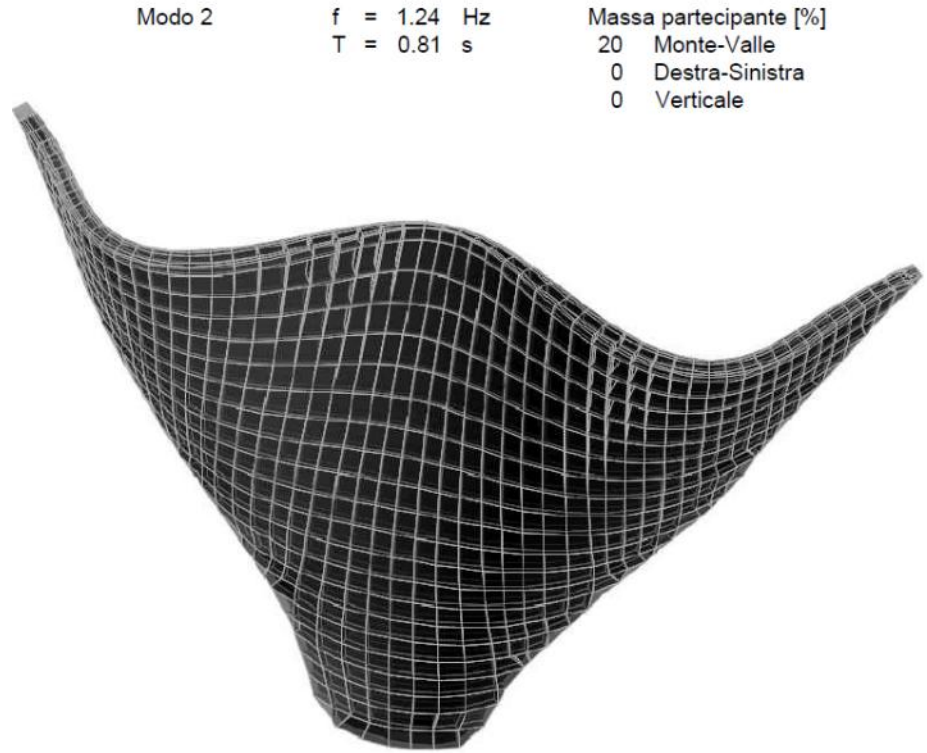
Measured displacements corrected by the thermal effect and represented in function of water level

Seismic verification 2012

— The first dynamic verification of the dam was performed with modal response spectrum analysis according to the specific guideline of Federal Office for Water and Geology (version 1.2, March 2003).

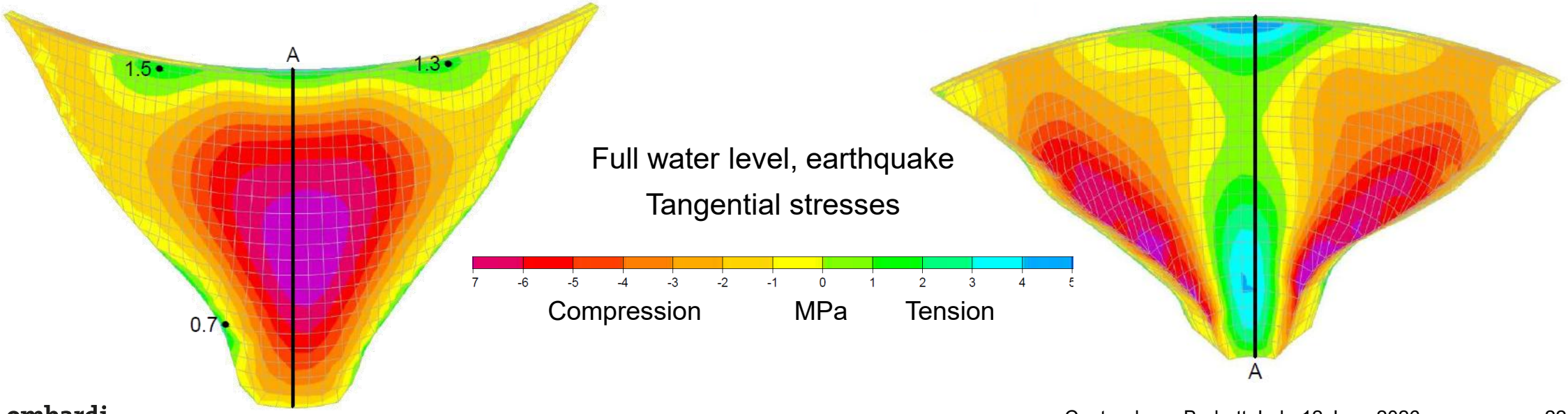
— The adopted PGA is 0.17 g for the 10’000-year return period earthquake. The maximum spectral acceleration reaches 0.43 g for foundation class A (Vs>400 m/s) and dumping 5% of critical value.





Seismic verification 2012

- The dynamic verification gave positive results: the maximum stress reaches 13 MPa in compression and 4.8 MPa in tension. The concrete strength is 48 MPa in compression and 4.0 MPa in tension. The limited exceeding in tension is negligible.
- Although the dam was originally designed considering only static loading conditions, the seismic verification is positive. This relatively common outcome is due to two main reasons:
  - Dams are structures conceived since the beginning to withstand horizontal loads (water pressure).
  - Sufficiently large safety factors are adopted for usual load combinations (4.0 for full water level).



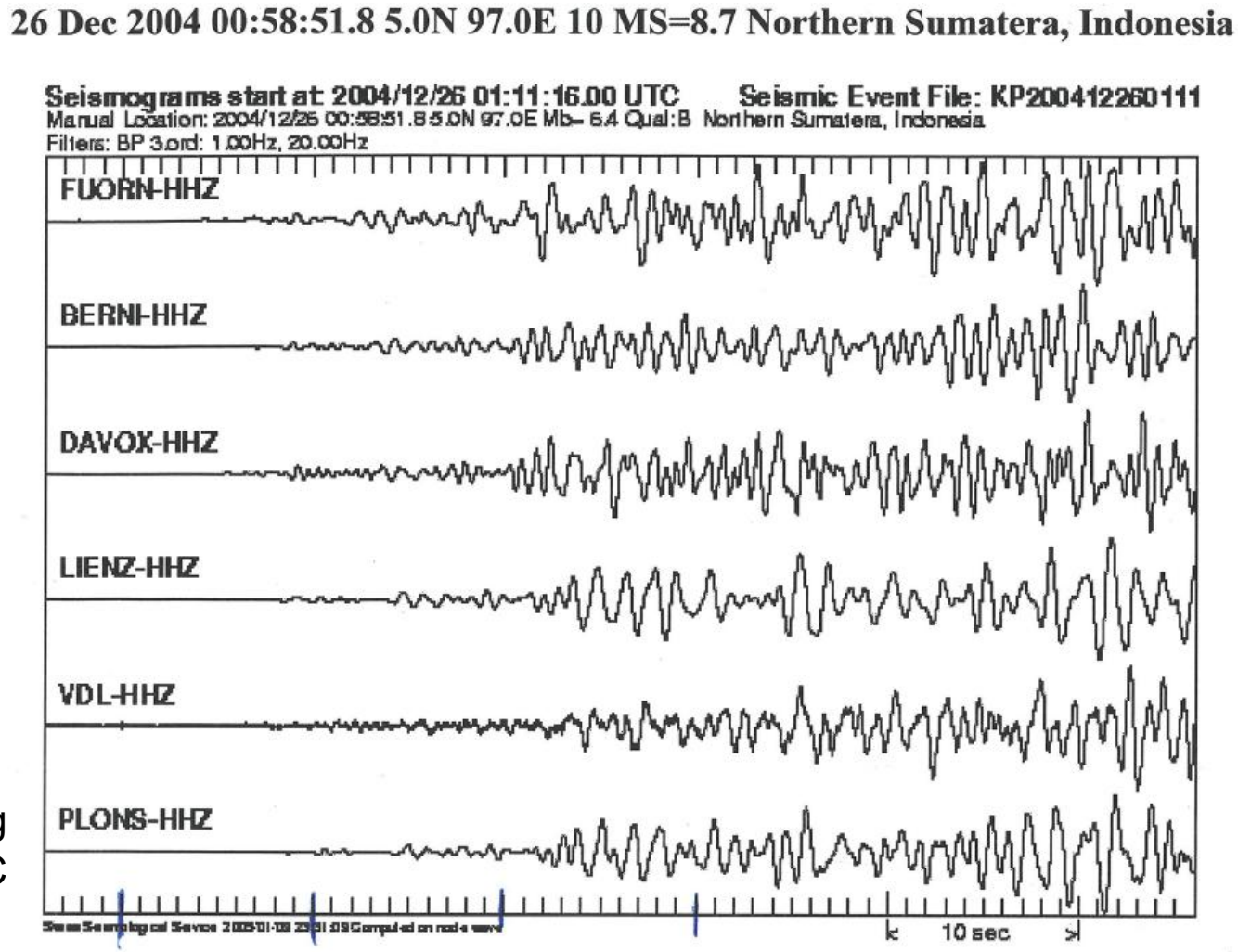
Upcoming seismic verification

- Due date: 31.12.2029
- According to guideline C3 of Federal Office of Energy (version 3.0, April 2025), the PGA is 0.197 g for the 10’000-year return period earthquake.
- Geophysical site investigation (2025) for foundation class determination :
  - Vs30 > 2300 m/s (average value for dam foundation)
  - Vs (direct rock) > 2’300 m/s (average value for dam foundation)
    > 900 m/s (ground surface)
  - Absence of relevant impedance contrasts
- …

Sumatra Earthquake of December 2004

— On 26 December 2004, at 07:58:51 local time (UTC+7), a Mw 9.2–9.3 earthquake struck in northern Sumatra, Indonesia.

— 12’30’’ later, the first Swiss seismic stations recorded the event.

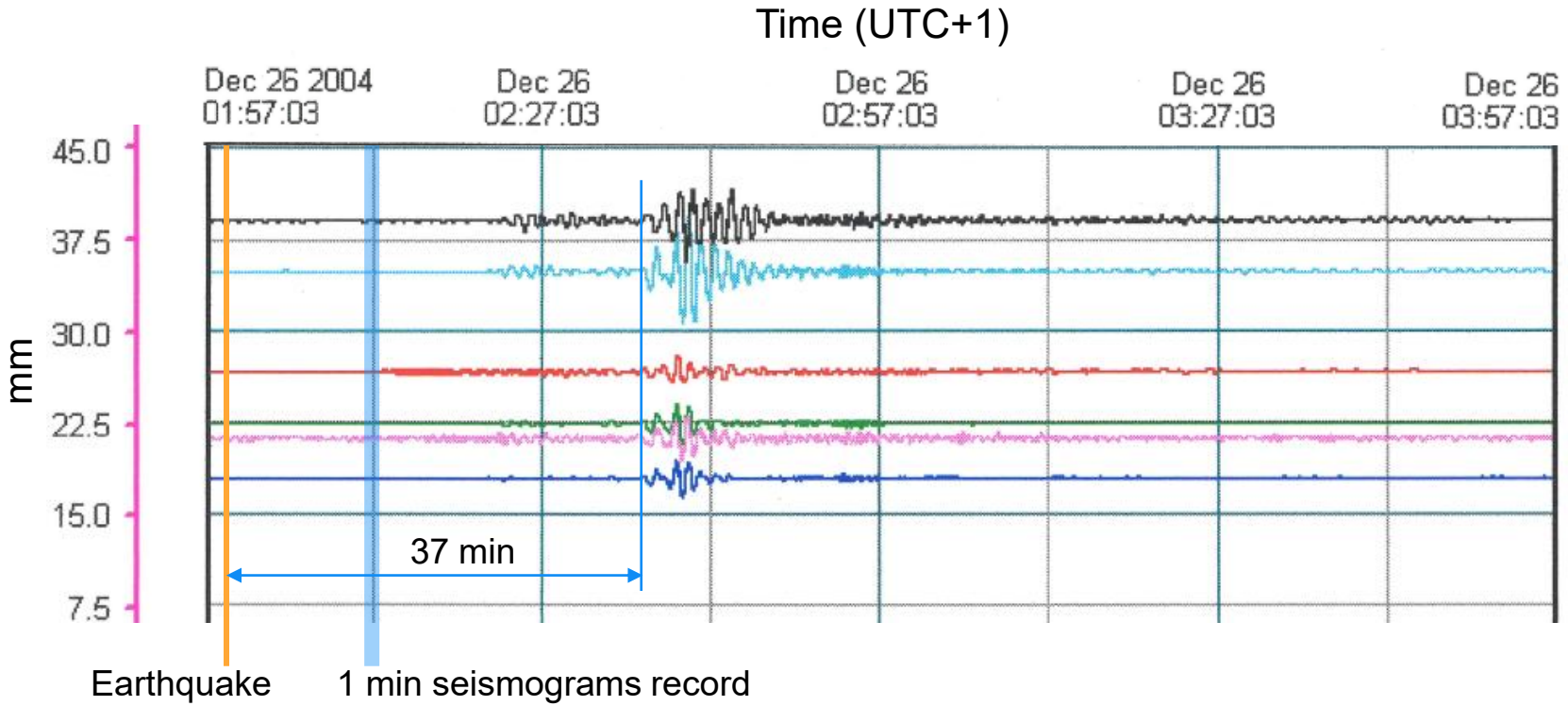


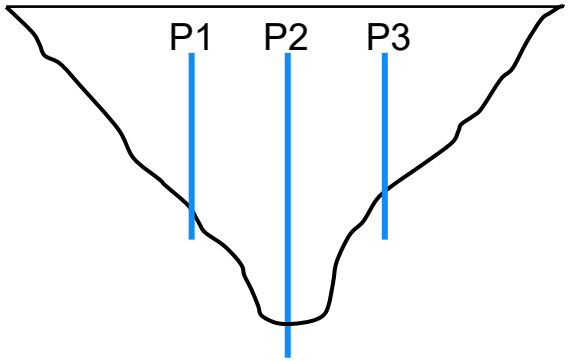
1 min record starting from 01:11:16 UTC

Sumatra Earthquake of December 2004

The pendulums of the Contra Dam also started to oscillate, initially less than 1 mm, while 37 minutes after the earthquake clearly more, with 6-8 mm amplitude.

The recorded displacements are related with the oscillation of the pendulums, with periods of roughly 80 s.







Vision, Courage and Scientific Rigor

The Verzasca powerplant and the associated Contra dam exist thanks to:

- **Vision** of two young engineers who, on their own initiative, envisioned something greater than what had initially been requested by the client.
- **Courage** shown by:
  - the client in assuming the project risks,
  - the society, which supported its realization at a time when public opinion in Europe was becoming increasingly critical of large dam projects, and
  - the design team that was able to face the technical challenges of the project.
- **Scientific rigor** applied throughout every stage of the design process: the preliminary feasibility study, the structural analysis, the stability assessments of the abutment, and finally the monitoring of its actual performance. The result is a solid structure that still meets today safety requirements.


Lombardi