Release of 50 million m³ of water at the Vajont Dam

October 9, 1963

Erto e Casso (PN)

Italy

Arch dam
Rockfall / landslide
Water wave
Precursors
Geology

THE FACILITIES INVOLVED

The site:

Built between 1956 and 1959 and inaugurated in 1960, the Vajont Dam is located within Italy's Pordenone province (PN), in the Friuli-Venezia Giulia Region 100 kilometres from Venice, at the foot of Mount Toc along the Vajont torrent.

Mount Toc : Coordinates : 46° 14′ 19″ North / 12°20′17″ East [6]

This double-curved arch dam made of concrete was 261 m high and featured a retention capacity of 169 million m³. The facility was designed to produce hydroelectric energy for the region, where demand had been soaring. At the time of its construction, the Vajont Dam was the world's tallest.

[8]

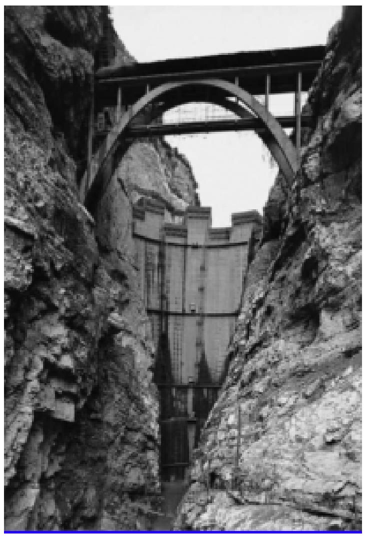
The unit involved:

This dam project was first explored during the 1920's, but Italy was preoccupied by other priorities regarding the world's geopolitical conflicts. The project was rekindled in 1948, against the backdrop of post-Word War II with a demand for electricity "through the roof"; the concessionary contract was signed by Italy's sitting President.

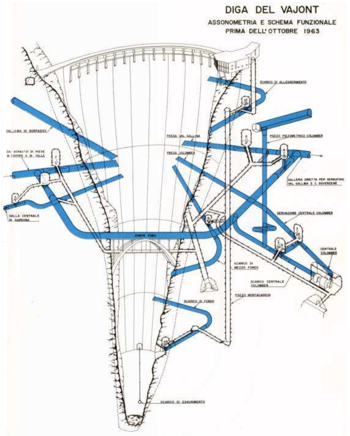
An extensive program of earthworks was undertaken as of 1956, with a crew of over 400 in a valley with 2,000 population. Several sources reported that these works had not been officially authorised [1,4]. In 1957, the project operator requested a building permit for the dam to be raised by 61 m, making it the world's largest with a retention capacity of 169 million m^3 vs. the 58 million m^3 initially indicated. The reasons cited for this ambitious expansion were rooted, according to sources, in the economic benefit of producing a greater quantity of electricity.

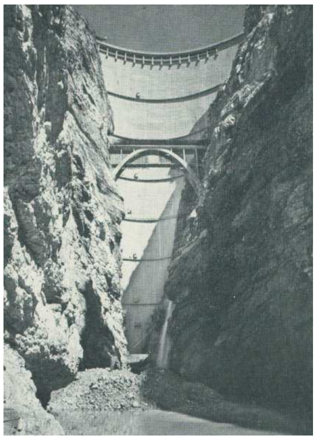
The 4th Section of the country's High Council on Public Works approved the permit application on June 15, 1957. Concreting started in 1958 despite local resident protests.

During the construction period, two major accidents occurring within just a couple months of each other fuelled concerns over the project on the part of both residents and workers: the Pontesei rockfall on March 22, 1959 (see insert on page 2), followed by failure of the Malpasset Dam (destroying part of the city of Fréjus on December 2, 1959 [13]).



During construction [7]





The dam project and once completed [1]

Preliminary geological studies *[3]*

A series of geological studies were conducted beginning in 1928 when producing the initial design for a hydroelectric power plant and dam project in this valley. More detailed studies performed in 1948 demonstrated the need to extend geological investigations throughout the valley where the future water basin was to be located, including a campaign of drilling boreholes and galleries, which got underway in January 1957 [3]. This latest round of studies focused mainly on water retention and only paid slight attention to the issue of stability along the basin banks.

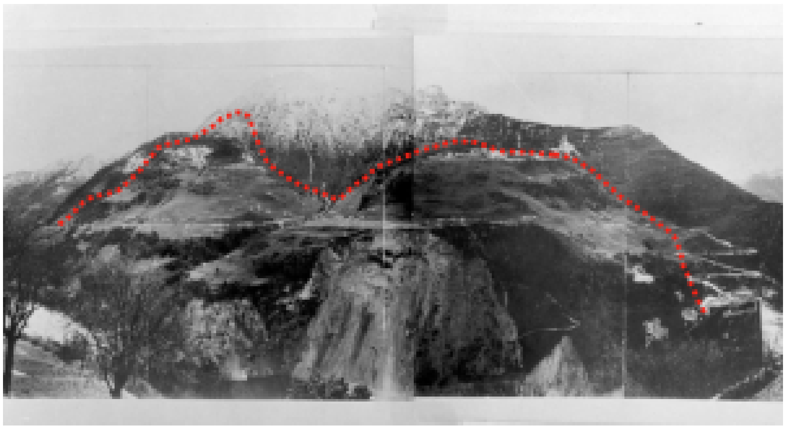
In August 1957, a German geologist identified a vulnerable zone on Mount Toc. In July 1959, he proposed then conducted, in collaboration with an Italian geologist, a geological and technical assessment of this zone. At the end of August 1959, they discovered a fault and identified the risk of landslide along a plane shaped like a "chair". The two geologists submitted their results on instability around the dam banks to the project sponsors. The father of the Italian geologist, who himself was an architect and involved in the project, asked his son to moderate some of the report conclusions by impressing upon him the notion that such hypotheses need to be confirmed by another round of studies. On October 10, 1959, the pair of geologists proposed a complementary study programme. According to the Italian geologist who helped discover the fault, the concern over fault exposure that has become widespread today simply did not exist at the time [3].

A precedent: the Pontesei accident

Less than 10 km from the Vajont site, the operator manages the Pontesei Dam (10 million m^3, 1/16th the size of Vajont). During spring 1959, a number of alarming signs were noticed: loud thuds followed by yellowish clouds hovering along the reservoir banks, bubbles, small rockslides along the banks, etc.

The lake was partially emptied (13 m below the maximum height) as a precautionary measure. It is possible that lowering the water level caused the sliding phenomenon to accelerate [3]: approx. 3 million m^3 collapsed on **March 22, 1959**, generating a 20-m high wave that drowned the site watchman on duty and destroyed a bridge below [1].

This tragic event led to resuming geological studies on the future Vajont dam site.



The vulnerable zone identified by geological experts as of 1960 [3,7]

The first filling of the reservoir began in February 1960. The measurements recorded during May 1960 already revealed small earth movements on the northern section. During May and June 1960, three boreholes were drilled but failed to cross a sliding plane at the anticipated depth, a finding that led several project managers to dismiss the magnitude of the fault. Another geologist, who had been working onsite since the project got underway, denied the existence of the fault and minimised its associated risks in a correspondence dated July 9, 1960 addressed to the site operator [3].

Around the end of July and beginning of August 1960, the Italian geologist was pursuing his investigations and detailing the fault's potential shape. According to his estimations, the fault line was 2 km long and close to 600 m deep. He indicated moreover that due to its presence, nearly 200 million m^3 of materials were at risk of collapsing at any time into the retention basin. In October 1960, ground movement exceeded the 3 cm/day threshold and led to a landslide of some 700,000 m^3 on November 4, 1960 (see Section below entitled "*Initial filling of the reservoir*").

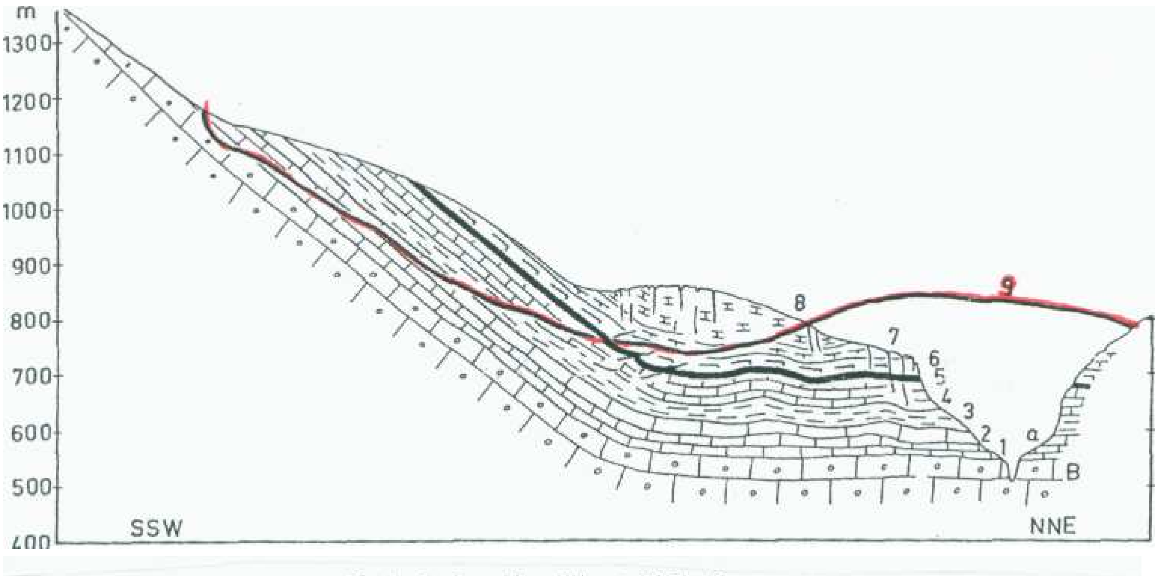
Several meetings were held by the team of geologists responsible for discovering the fault, inciting the operator to slowly lower the lake's retention level and build a bypass channel, which was completed in October 1961.

On February 3, 1961, the German geologist described in his 15th report the unique features of this fault, by differentiating several zones, and forwarded an array of methods (with varying economic feasibility) to keep ground movements under control [3], i.e.:

- prevent or drastically reduce the penetration of rainwater or thaw into the crack,
- induce partial rockfalls,
- drain the rock mass by building galleries,
- cement the rock mass to make it impermeable,
- build an obstacle at the base of the potential rockfall by blasting rock masses from the other bank,
- all in the aim of slowly lowering the lake's water level.

He also proposed completing the job of installing existing piezometers, albeit with insufficient results, to study both the behaviour of water on the slope and associated drainage possibilities. These piezometers were to be installed between July and October 1961.

During spring 1961, the dam operator initiated a hydraulic study on the basis of reduced-scale (1/200) model testing conducted at the University of Padoue. The first 5 tests took place between August and September 1961, while the remaining 17 were held during the first few months of 1962. The results of this testing campaign were submitted to the operator on July 3, 1962; despite erroneous input data on the mass of a potential rockslide and on its compactness, the onsite team came to the conclusion that the 700-m height limit should not be exceeded for safety reasons, given that the slide was capable of generating a wave overflowing the reservoir and threatening the town of Longarone below. Experts called for additional testing and research in order to validate these initial conclusions. Though these results were considered useful for predicting ultimate consequences, the design and research work was shelved and study results were never disseminated.

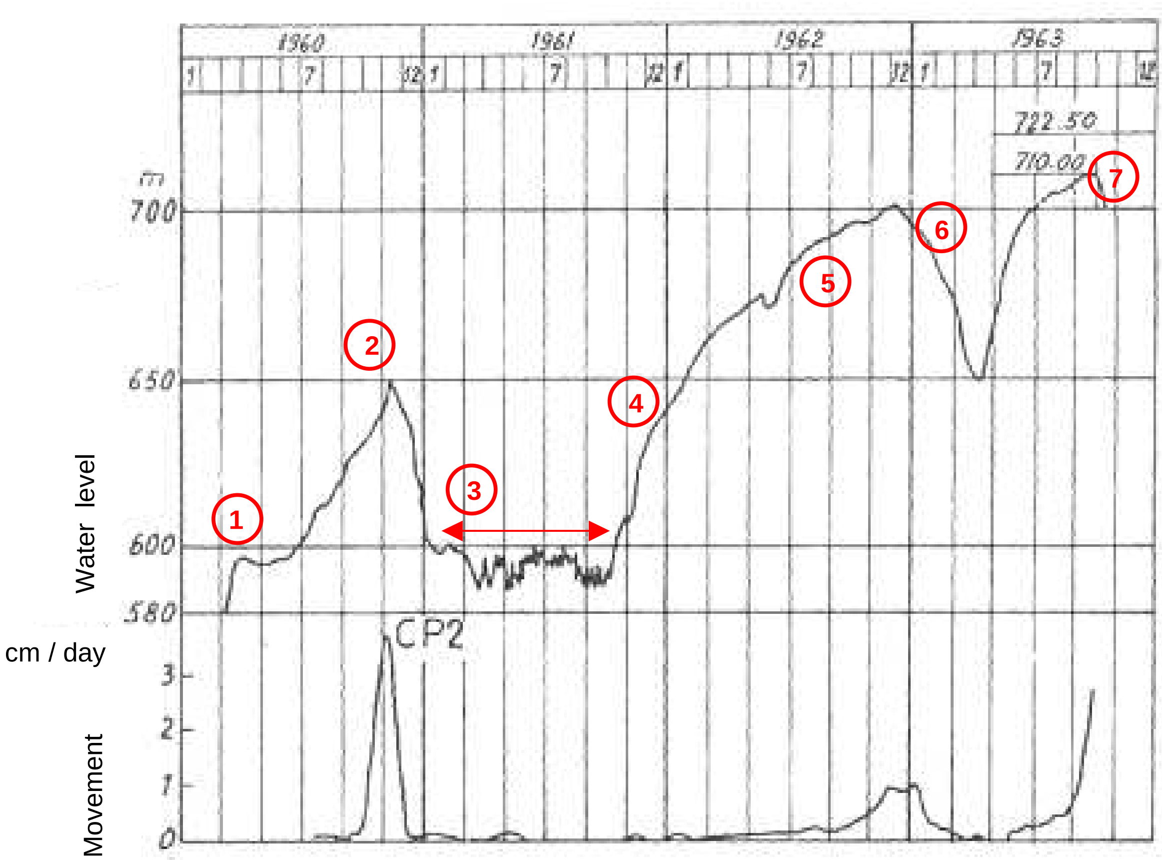


Geological section (about B-B), BROILI, 1967.
Idealised reconstruction of a geological section through the banks of the Vajont reservoir.

(a) Vaiont gorge.
(B) Dogger-Malm formation (oolitic limestone formation).
(1) Malm in general formation.
(2) Upper-Malm-Lower-Cretaceous-formation.
(3) Lower-Cretaceous-formation.
(4) Lower-Cretaceous-formation.
(5) Lower-Cretaceous-(Albian-) formation.
(6) Upper-Cretaceous-(Cenoman-) formation.
(7) Upper-Cretaceous-(Cenoman-) formation.
(8) Upper-Cretaceous-(Tur, Senon)-formation.
(9) Rock escarpment after the rock slide.

[2]

Initial filling of the reservoir



Lake level and ground movement speed [2,3]

Crack, Nov. 4th, 1960 [3]

1 - First appearance of the surface crack in March 1960.

2 - On November 4, 1960, after a week of heavy rains, an initial 700,000 m^3 rockslide occurred. Though limited in magnitude, this slide further opened the crack into an "M" shape, making it easily visible. In spite of these developments, the hypothesis of a "surface" fault was still given priority.

3 - Following the slide, the operator decided to excavate a bypass channel connecting both parts of the lake on either side of the potential slide zone, in order to ensure the dam's water supply should a rockslide split the lake into two. The operator allocated 1 billion lire to building this 4.5-m diameter bypass, with construction completed in October 1961.

4 - During the extremely cold 1961-62 winter period, conditions began to stabilise. The fracture expanded by 6 m, yet the mountainside remained intact without any slide activity.

5 - With summer 1962 approaching, the dam operator undertook a second dam filling. Reports mentioned the presence of disturbing seismic activity throughout the first part of the year, and the number of cracks detected on homes in the valley had increased multi-fold, raising serious concerns on the part of local residents. Measured ground movement reached 1.5 cm a day once the reservoir height had climbed to 700 m during winter 1962-63.

6 - At this point, the operator decided to lower the reservoir level, and seismic activity ceased.

7 - The dam was filled to its limit of 715 m during 1963. According to some sources [1,12], the operator was seeking to maximise output from the facility prior to its transfer to Italian Government control, by virtue of the December 1962 creation of the national electric company.

Once again, earthquake-type phenomena became apparent and the fracture widened. Additional ground movement tended to confirm the German geologist's hypothesis, whereby the level of water saturation in material layers at the dam site when raising the reservoir water level are correlated with these movements.

The official Website devoted to the disaster reports that the town hall spokesperson, in a final letter addressed to the private and national electric companies as well as to the local Prefecture and Public Works Ministry expressing valley residents' concerns, issued the following request: "remedy the zone's safety issues and protect the local population before we all witness irreparable damage". For emphasis, the letter added: "If you're not able to guarantee safe operating conditions, we urge you to refrain from operating the Vajont Lake Reservoir."

The national electric company, which had since been assigned to operate the dam, opted to lower the water level, but the procedure to drain the thousands of cubic metres necessary for an equivalent lowering of 15 m took quite some time.

Ground movement gradually accelerated until reaching 20 cm a day on the eve of the disaster.

On Sunday October 6, 1963, the road bordering the lake had become completely deformed and was no longer usable. The day after, a site watchmen noticed trees bent and the appearance of new cracks. Residents closest to the lake were evacuated. At 5 pm on Wednesday, October 9, the Italian police closed traffic on the dam road; trees had fallen one by one above the rockslide zone…

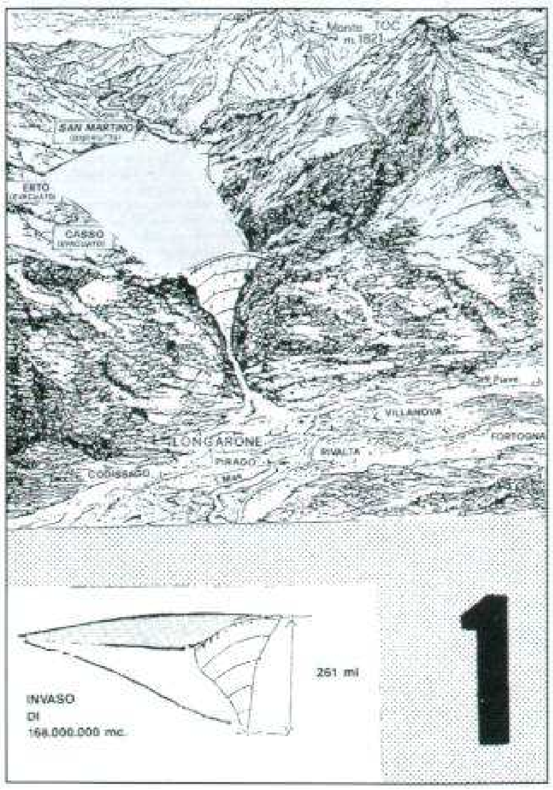
THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

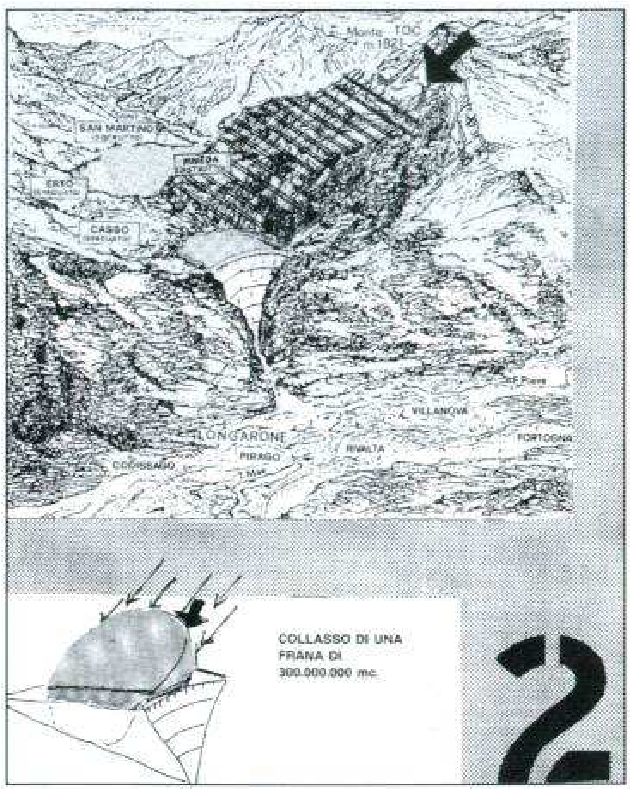
The accident:

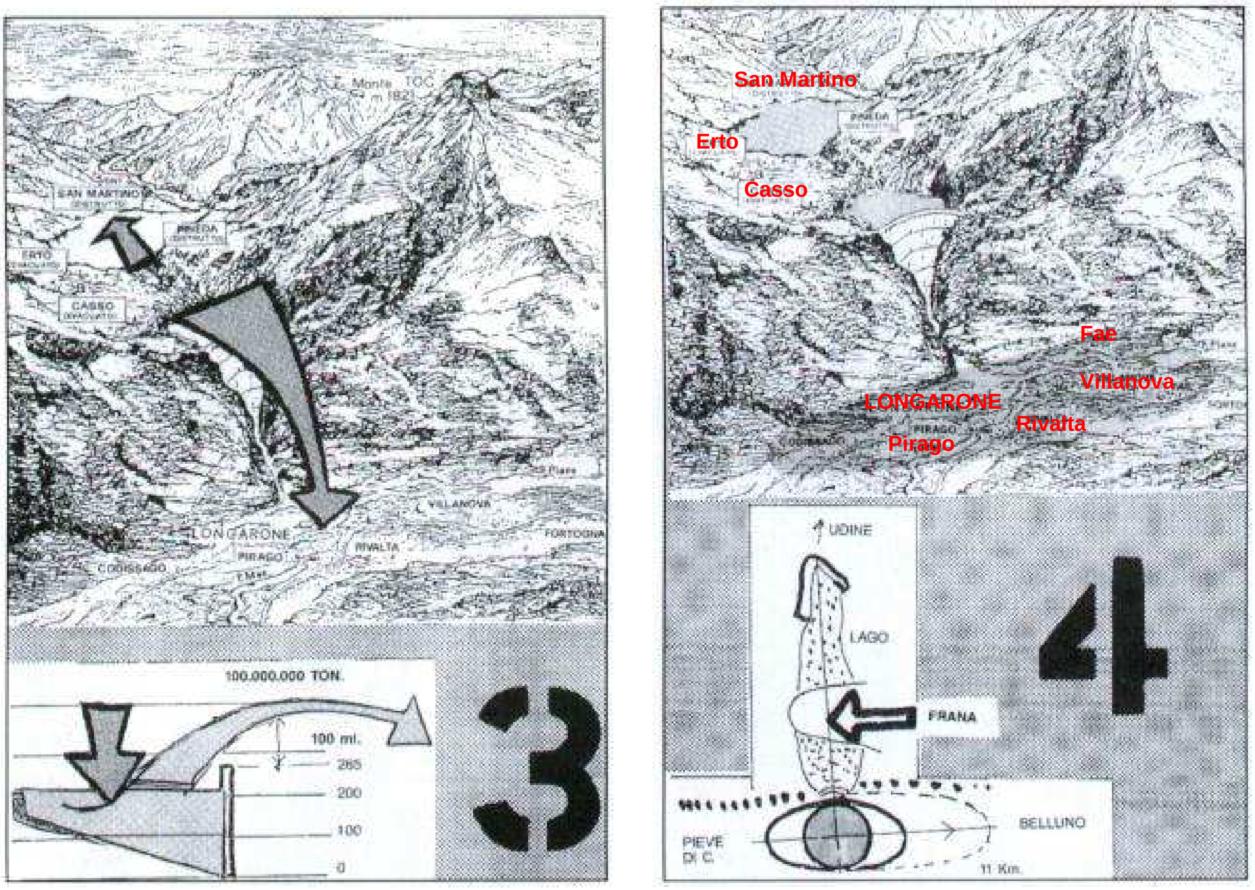
On October 9, 1963 at 10:39 pm, the landslide occurred; over 260 million m^3 of earth and rock rushed down the mountain at speeds upwards of 90 km/hr and into the retention dam. The roar of this event was deafening, as the rockslide carried with it electric supply lines, plunging Longarone into total darkness.

In a matter of moments, landslide material filled the lake. Two waves of 25 million m^3 of water each washed over the land both upstream and downstream of the retention zone. Another wave over 150 meters high topped the dam and raced into the narrow valley in the direction of Longarone.

The thrust of this water mass into the valley caused a series of incredibly violent phenomena: powerful air streams suddenly propelled by the water formed a pressure wave that began to destroy the town, then came the water mass carrying loads of debris levelling many structures in its wake.





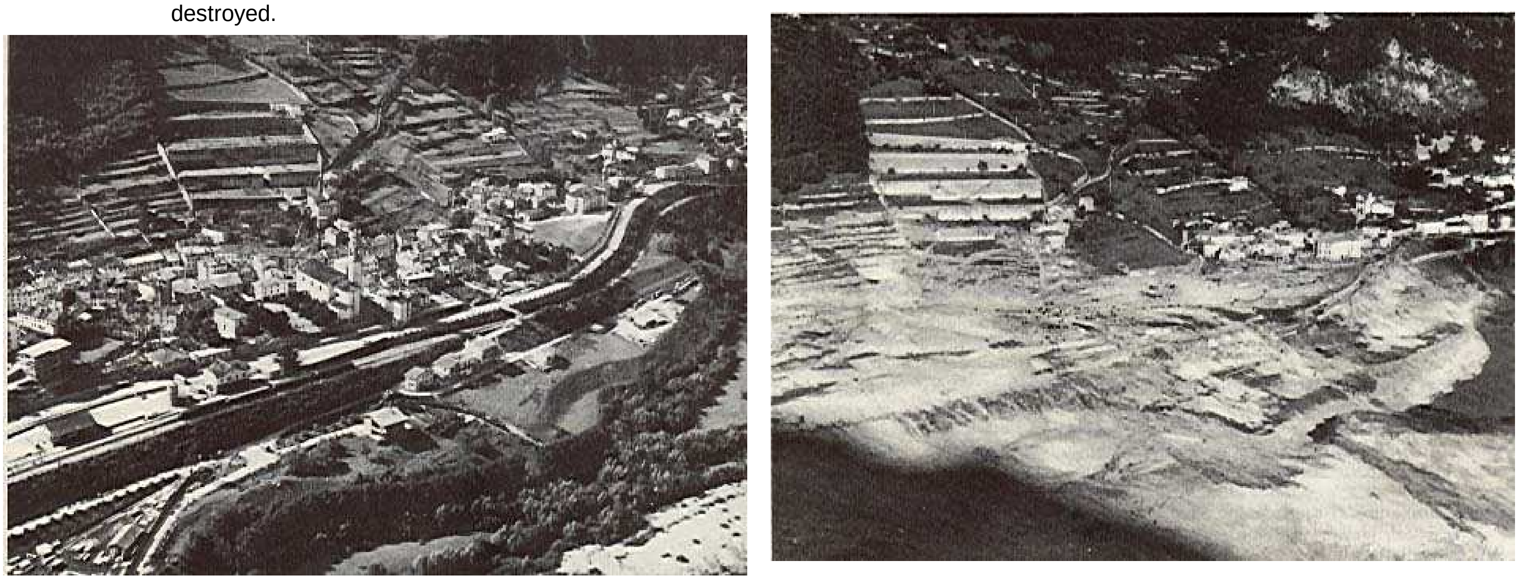


Accident dynamics [1] (see also the video in ref. [14])

Consequences of this accident:

The "downstream" water mass submerged the towns of Longarone, Pirago, Rivalta, Villanova and Faè. Many small neighbouring villages lay along the trajectory of the "upstream" wave reaching elevations above the lake. The human consequences were of catastrophic proportions: depending on estimations, between 1,900 and 2,100 people lost their lives. The social impacts would also be devastating. The total destruction of these towns and villages was tragic for the region: families and activities disappeared, social ties were shattered, and an entire community history was washed away.

The dam remained for the most part intact; only the outlying installations (control room, technical facilities, etc.) were destroyed.



The town of Longarone before and after the wave's passage [1]


CORRIERE DELLA SERA
LE VITTIME SAREBBERO DUEMILADUECENTO
L'ONDA DELLA MORTE

In coping with the magnitude of the disaster, emergency services under Italian army supervision were quickly organised. Tremendous resources and a deployment of over 10,000, including thousands of volunteers, were dispatched to the site to rescue the local population; these resources consisted of: amphibious vehicles, bulldozers, power shovels for excavating rubble, tractors, electric generating sets, photoelectric units, lorries, ambulances, health and sanitation supplies, tanker trucks, mobile kitchens, tents, food relief and basic survival gear.

More than 850 fire-fighting crews accompanied by 3 helicopters and 271 pieces of machinery and equipment (small boats, tow trucks and power shovels) were also deployed in order to rescue, assist and clear debris, which entailed moving hazardous items left onsite. One source mentioned having to recover potassium cyanide and sodium, most likely stemming from submerged industries once located along the Piave River [1].

73 people were saved from the waters and rubble, but some 1,600 drowned bodies were found with barely half of them eventually being identified.

On October 10th, the site of the cemetery dedicated to disaster victims was chosen on farmland in Fortogna. The collective burial ceremony, a slow procession of coffins forming a seemingly endless chain, was held on Sunday, October 13th [1].

Rescue teams remained mobilised onsite through December 21st, 1963.

The European scale of industrial accidents:

By applying the rating rules applicable to the 18 parameters of the scale officially adopted in February 1994 by the Member States' Competent Authority Committee for implementing the '*SEVESO*' Directive on handling hazardous substances, and in light of information available, this accident can be characterised by the four following indices:

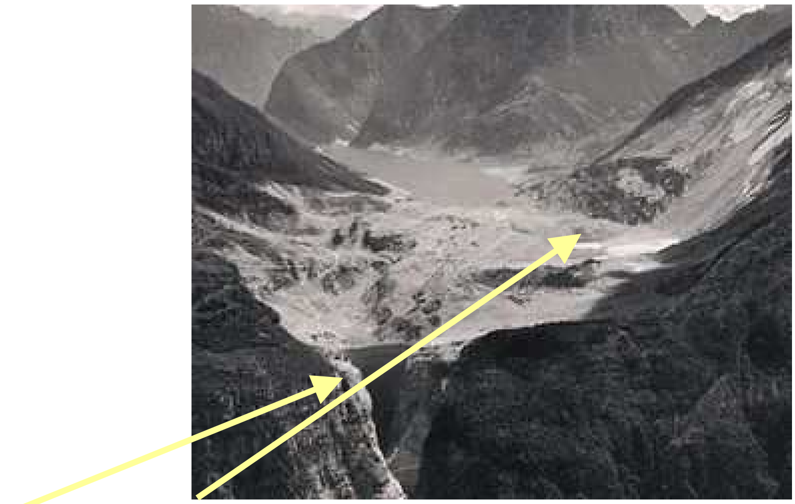
No precise information was available on the hazardous materials released at the time of the accident, except for the reported recovery of potassium cyanide and sodium. As a default, the overall rating of the "hazardous materials released" index was assigned a "1" for these substances.

The overall score given to the "human and social consequences" index hit the highest value of "6" on the scale, since the accident caused 1,900 deaths, a huge number of injured and cuts to water supply, gas, electricity and phone service for several days.

The "environmental consequences" index could not be rated due to a lack of information relative to criteria Env 10-14.

The "economic consequences" index also scored a "6", since the amount of property damage surpassed a billion lire in 1963 currency value (above the €200 million threshold for a "6" on the scale, as established in 1993).

The parameters composing these indices and their corresponding rating protocol are available from the following Website: http://www.aria.developpement-durable.gouv.fr.



The dam and rockslide zone after the disaster [1], as seen from the same angle as the initial view on page 1

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

Thanks to the various geological studies and tests conducted on reduced-scale models subsequent to the November 1960 rockslide and prior to the accident (see Section above entitled "*Preliminary geological studies*"), the causes were relatively well-defined.

They originated from a combination of several unfavourable factors, as confirmed by post-accident investigations:

- the site's complex geological configuration, with the north-facing slope of Mount Toc featuring a "chair"-shaped sliding surface along a curved bedding plane,
- water level variations in the retention basin,
- rainfall characteristics: heavy rains during the week preceding the accident made the ground heavier and partially lubricated the sliding plane [1,3,14].

These factors played out against a unique backdrop. Several sources [1,5,7,12] noted that the testing commission and inspection authorities never received any final reports, especially the studies by geologists who had identified the fault, nor any of the results from model tests and their ensuing recommendations, which emphasised the retention dam's water level. These same sources underscored the considerable economic stakes behind this project and clearly stated that irregularities had been committed with respect to the administrative authorisation procedure. The same would apply to the decision to pursue construction of the bypass channel after the November 1960 rockslide without waiting for official approvals: various reservoir filling levels would have been authorised, even though the corresponding water heights had already been exceeded. Lastly, these sources spoke of pressure exerted on a journalist reporting the hazards inherent in this project; she was sued for "defamation and spreading false information". The court ruled in her favour on November 30, 1960 [1,5,12].

ACTIONS TAKEN

The town of Longarone was rebuilt on the same site. The Italian government allocated a total of 1,800 billion lire, 61% of which was used for reconstruction and industrial development efforts, 24% for public assistance programmes, 6% for emergency management services, 5% for residential rebuilding and 4% for municipal actions.

On October 11, 1963, Italy's Public Works Minister along with the Council President appointed an investigation commission to determine the causes of this catastrophe. Penal proceedings were filed against the dam operator, the oversight commission and the Ministry.

On February 20, 1968, the assigned Belluno magistrate summoned 11 implicated individuals to stand trial on counts of negligent manslaughter on grounds that the rockslide and flooding were indeed foreseeable. One of these individuals committed suicide, while two others died before sentencing. Most of the other defendants, whether on the political or technical side, were absolved of wrongdoing for lack of evidence, outside of the project's lead engineer, who was sentenced in 1977 to 5 years of jail time (which would be commuted to just one year).

On December 3, 1982, the Florence Appellate Court sentenced both the private firm that first owned the project and the national electric company that subsequently took control to compensate the Italian government and municipality of Longarone for damages. The Supreme Court upheld this verdict on December 17, 1986.

On February 15, 1997, the Belluno Civil and Penal Court sentenced the private company to compensate the town of Longarone for damages totalling 55.66 billion lire, which included property, non-property and moral damages, plus another 526 million lire for fees and 160 million for other expenditures related to court proceedings. The ruling was effective immediately.

Also during 1997, the appeal filed by the national electric company was rejected: the company was obliged to compensate the municipalities of Erto, Casso and Vajont to the tune of: 481 million lire for the public property and lands lost, 500 million for property damage related to the partial loss of these towns' population and activities, and another 500 million for ecological disruption [1].

LESSONS LEARNED

The Vajont disaster brought worldwide reaction and became a topic of many studies. This tragedy raised the level of knowledge on dam construction and heavily influenced the field of geological engineering.

Besides the dam's physical characteristics, the stability of slopes surrounding the retention basin served as a determinant safety component. The study carried out on the behaviour of these slopes has since been systematically included as part of any such project [3,11].

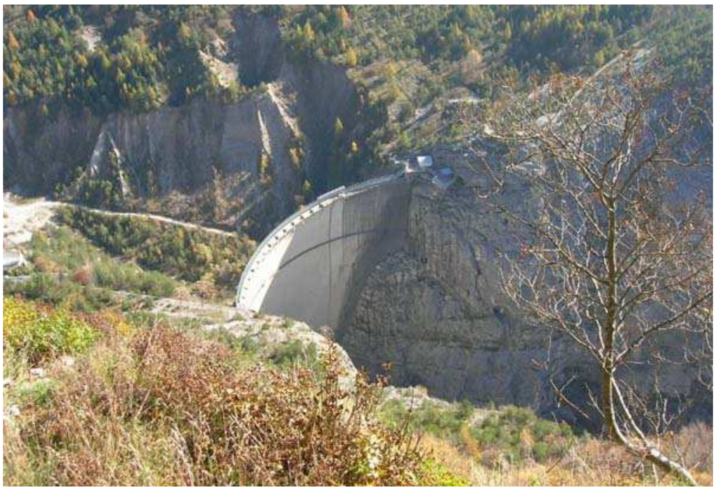
The in-depth study of this disaster by an American geological team wound up averting a similar situation in Canada during the 1970's on a tremendous dam project for the Columbia River near Revelstoke (British Columbia). Once the *Downie* fault had been identified, by incorporating feedback from the Vajont disaster, stability along the lake's banks could be ensured thanks to galleries and drainage tubes, thus making it possible to proceed with building the dam that is still operating to this day.

Beyond the strict causality focusing on site geology, the economic context likely played a major role in the eventual occurrence of the Vajont accident.

The private electric company had every incentive to build a large-capacity facility and quickly initiate service, from the perspective of Italy's upcoming nationalisation of electricity services. This economic motivation led to increasing the size of the dam and circumventing the sequence of steps required before being able to operate at full capacity.

The company overlooked unfavourable findings and precursors revealed in these studies, evaluations and field measurements. Pursuing this economic objective actually led to withholding a number of study results.

The potential for underhanded practices by parties involved in industrial projects cannot be overlooked, especially when economic stakes are high. Feedback from projects like Vajont Dam confirms the benefit of transparent and competitive procedures that provide sufficient room for multiple expertise and multi-party oversight including representatives from civil society for all installations with significant risk exposure.


[9]

SOURCES (INCLUDING PHOTO CREDITS)

[1] http://www.vajont.net/: Official Website devoted to the disaster (in Italian, with a few articles in French)

[2] *Lessons from dam incidents,* ICOLD/CIGB

[3] *La Storia del Vaiont racontata dal geologo che a scoperto la frana*, Edoardo Semenza, Tecomproject Editore Multimediale, May 2002 [in Italian]

[4] http://it.wikipedia.org/wiki/Diga_del_Vajont

[5] http://it.wikipedia.org/wiki/Disastro_del_Vajont

[6] http://fr.wikipedia.org/wiki/Mont_Toc

[7] http://cozop.com/demain_commence_aujourd_hui_le_blog_de_valerio_motta/le_vajont_genese_une_catastrophe

[8] http://www.itinerariveneti.it/province/belluno/Il%20Vajont%20e%20Longarone.htm

[9] http://www.timetotravel.it/friulivg/pordenone/valle_del_vajont.htm

[10] http://mcs.epfl.ch/webdav/site/mcs/users/104495/public/MASTER/Eboulement%20du%20Vajont.pdf

[11] Summary of proceedings from the daylong CFGI-CFMR workshop – FEEDBACK ON GEOLOGICAL AND GEOTECHNICAL DISASTERS IN EUROPE – CNAM - Thursday October 22, 2009.

[12] Merlin, Tina; Sulla pelle viva. Come si costruisce una catastrofe. Il Caso del Vajont, Verona 1997.

[13] Detailed fact sheet on the Malpasset accident, December 2, 1959. ARIA no. 29490: http://www.aria.developpement-durable.gouv.fr/barpi_4650.jsp

[14] 3D digital animation of the disaster sequence: http://www.youtube.com/watch?v=uqkFXm2HtMA

VIDEOS:

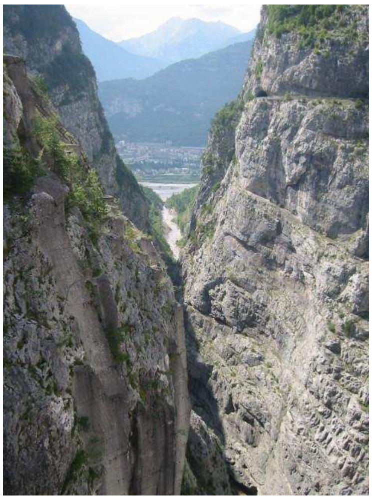
Documentaries on the disaster:

- √ http://www.youtube.com/watch?v=UCK_BVwHl30 Part 1: Dam construction
- √ http://www.youtube.com/watch?v=IGXb1W7055M Part 2: The disaster, emergency response and reconstruction
- √ http://www.youtube.com/watch?v=ejR9eSymzc8 Part 3: Historical archive (The dam and Longarone today)
- √ http://www.youtube.com/watch?v=VmvOKFQYs08 Trailer of a documentary broadcast on the History Channel

Marco Paolini, Vajont, October 9, 1963. Orazione Civile, Registrazione della diretta su Rai 2 dalla Diga del Vajont, produzione televisiva a cura di Moby Dick per Rai 2; 1997, 158 min (available on YouTube / in Italian)

La Folie des hommes (« la digua del disonore »), a Franco-Italian film by Renzo Martinelli loosely inspired by the story of the Vajont Dam accident (2001).

The dam, as seen from Longarone [5]



View from the dam arch. In the background, the rebuilt town of Longarone [1]