Burst of a dam

2 December 1959

Malpasset (Var)

France

Dam (failure)
Design
Insufficient preliminary studies
Geology
Checks
Acceptance

THE FACILITIES INVOLVED

The site:

In order to meet the local water demand, a dam was built on the REYRAN river downstream to the confluence with the BUEME river at Malpasset to the north of Fréjus (mileage point 16.625 of C.D.37). The dam was supposed to regulate the rate of flow of the raging river and store 50 million m^3 of water for agriculture (vegetable crop and floriculture), domestic use, as well as for use in the booming tourism sector.

The Reyran river is almost dry in summers but regularly causes floods in the region during the heavy autumn and end of winter downpours.

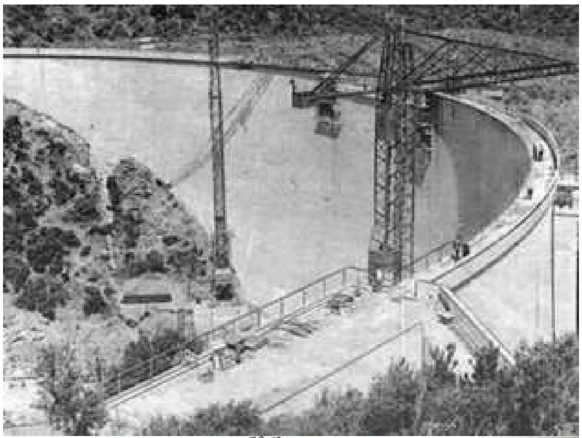
Several successive projects were carried out on the structure between 1865 (a project running at 300 m downstream the Malpasset dam / 25 m high holding 5.6 million m^3) and the project that started on 1st April 1952 and ended in October 1954 (60 m high / 50 million m^3 of water). The site and the height of the structure varied during the projects. All geological studies forecasted optimal conditions of performance.

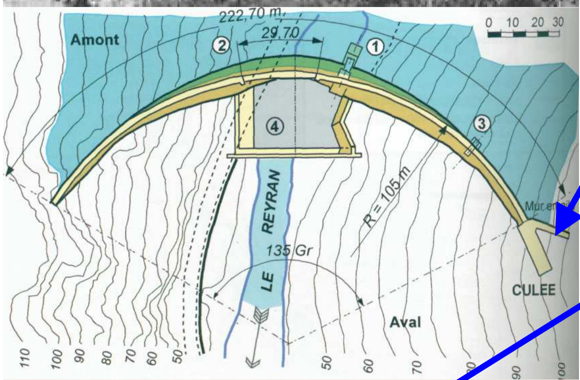
The compensating reservoir was studied by geologists from the science department in Marseille who confirmed its excellent water tightness. However, the storage site was heavily debated upon right from the initial studies. Geologists observed a fault as early as 1946 and underlined the importance of carefully leakproofing the structure including rendering the foundation ground impervious. They also pointed out that in addition to the geological studies, rock excavation and tunnels must be performed on the river banks to check their internal composition and identify unweathered rock in order to ensure the total stability of the supporting slopes. Lastly, they also specified that the seat of the dam must be designed after proper research. The geologists also suggested studying 2 future sites of implantation of the dam.

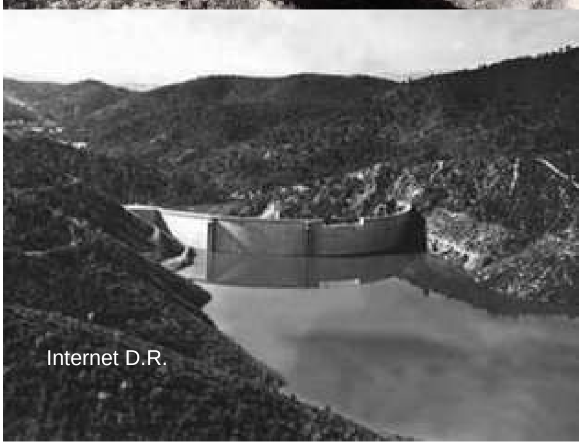
The geological study was resumed in November 1949. However, the firm in charge of the implantation of the dam decided to move the implantation site by 200 m downstream without any additional geological study.

Note: the toponymic meaning of the French word "Malpasset" is "landslide, dangerous ground, friable" (according to the 18th century French dictionary "dictionnaire du XVIIIème") or "bad passage" (according to the dictionary "dictionnaire des idiomes romans"). A meaning that was unfortunately "forgotten" during the construction of the dam.

The involved unit:







Internet D.R.

There are several kinds of dams including:

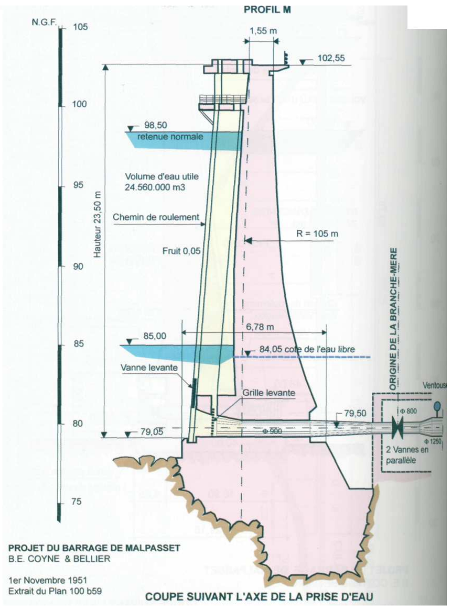
- Massive concrete[1] **gravity dams** designed to resist the water pressure by virtue of their own weight by transferring the pressure to the foundation ground.
- **Embankment dams (earth-fill or rock-fill dams with an impervious core)**. Such dams can be built on weaker grounds that could not resist the concentrated load of concrete dams.
- **Arch dams**, adapted for narrow valleys with solid banks. They are made up of a thin concrete arch that transfers the water pressure to the banks. An arch dam is said to be “thin-walled” when the base width / dam height ratio is less than 1/3. Arch dams help save on concrete as compared to gravity dams.

The first project (1865) was designed using the gravity dam technique. The type of dam retained for economic reasons was an arch dam.

The Malpasset dam is a concrete arch dam with a base width of 6.90 m for a height of 60 m placing it in the thin-walled structures category.

Given the nature of the ground and the topography of the left bank, the dam support was reinforced by an 10 m high abutment as well as a wing wall at right angles with the contour lines.

The structure also includes a spillway (weir) and a draw-off comprising a metal pipe of 1.5 m diameter cutting across the foot of the arch at a height of + 45.5 m and shut by valves (fixed wheel gate upstream that opens automatically when the water level crosses the height of +99.5 m and a butterfly valve downstream).



There was no definite project acceptance as this would mean that the dam could have been filled to its full capacity. The filling process is especially long. In fact priming started in August 1954 and the water level was set at +85 m in 1957. Around mid November 1959, the water level was still 7 m below the crest level when the initial dripping was observed on the right bank of the structure.

[1] The concrete gradually replaced the bricks on such dams.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

The region experienced torrential rains in November 1959. It was decided to allow the dam fill-up instead of emptying it by opening the drain valves to avoid causing any disturbance to the works underway in the Marseille-Nice motorway at 1 km downstream the dam. The four last metres filled-up in less than 24 hours. This crucial phase of filling could not be monitored.

On the evening of 2 December 1959, the water level in the dam reached the top for the very first time. The dam gave in at 9.11 pm.

A 50 million m^3 water wave swept across the Reyran valley destroying everything in its path: 21 minutes later, the city of Fréjus was submerged within a few minutes by a water and mud wave.

The consequences:

The consequences were dramatic. The disaster resulted in 423 victims and left 7,000 people homeless. All road, telephone, electricity and water networks to Fréjus were completely cut off. Several hundred meters of the national road 7 and the railway track were swept away by the flood.

Significant material damage (houses, companies, farms devastated, etc.) was reported. A part of the city (districts of Reyran, Pavadou, railway station and Arènes) was covered with a 50 cm thick layer of mud. Huge blocks of concrete were found at 1 500 m downstream the dam.

The valley of Reyran was “scraped” over 5 km. 1350 hectares of agricultural land (fruit and vegetable farms, vineyards, etc.) were devastated. 80 000 hectolitres of wine was lost.

Railway track “twisted like a toy”

Faced with the disaster and despite the confusion due to the lack of communication resources, rescue services were organised. The hospital is transformed into an assembly point and emergency casualty centre. Its chapel served as a mortuary.

Additional rescue services arrived the following day as early as dawn and included CRS (Reserve French national police force), gendarmerie (French military police), French national police, army, Red Cross, ambulances, Departmental health services, etc.

The crisis control unit lead by the Préfet (departmental head) of the Var department was installed in the city of Les Arcs. The town authorities requisitioned all able-bodied men to assist the impacted population and organised the collection of information on dead and missing people, emergency accommodation and bread and water supplies.

Passes were required to enter the disaster area and people were issued identification cards. Neighbourhood committees undertook the responsibility of assessing damage to claim compensation that was exceptionally managed directly by the city hall of Fréjus following special authorisation from the home and finance ministries.

Internet D.R.

The free administration of anti-typhoid vaccines was made compulsory in the towns of Fréjus and Roquebrune-sur-Argens. Operations were undertaken to quickly re-establish communications, water and electricity networks. Road and rail traffic was resumed on 10 December.

Even though cleaning and reconstruction operations were promptly initiated, it took months for the city to regain a normal appearance.

Temporary prefabricated housing units were set up in the city to accommodate people whose homes were destroyed.

The city hall of attributed 103 millions Francs[2], including 1,5 M for emergency operations, 25 M to farmers, 8 M to repair residential buildings, 12 M as compensation to the victims. The expense report was regularly published in a funds application account whose last statement dates back to 31 December 1970. All available funds were used up 11 years after the accident.

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 the information available, this accident can be characterised by the four following indices:

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

No information on the dangerous materials released during the accident (a petrol pump may have been washed away by the water) was available. The overall rating for the "dangerous materials released" index is not stated (by default).

Three parameters come into play in determining the "human and social consequences" index: H3, H6 and H8.

· The H3 parameter was rated at level 6 due to the 423 deaths caused by the disaster.

· The H6 parameter was rated at level 6 since the number of people rendered homeless of invalid crosses several thousands.

[2] The amounts indicated are in the new French franc that was issued on 1st January 1960 and the data was collected from a report dated 31 December 1970.

· The H8 parameter was rated at 6 since around 10,000 people were deprived of water, gas, electricity and telephone for several days.

The overall "human and social consequences" rating thus stood at 6.

The overall "environmental consequences" rating was 0 due to lack of information on criteria Env 10 to Env 14.

The "economic consequences" index was at 6 (parameter €17) as the material damage was over 100 MF in 1970 (equivalent of 100 M€ in 2006).

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

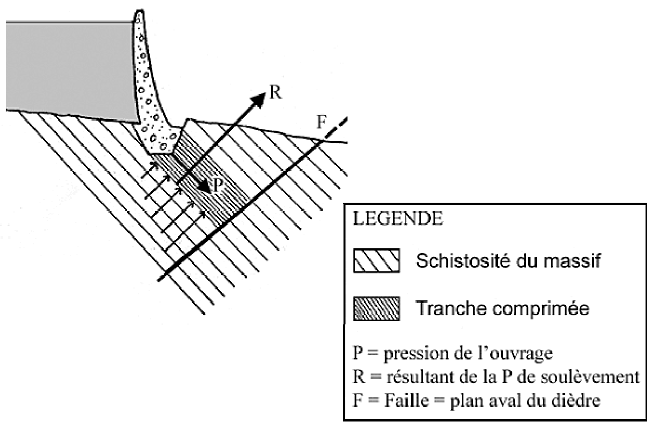
The term "uplift" is used to describe the pressure below the base of the dam resulting from the movement of water in the rocks supporting the structure. Such a pressure is potentially dangerous as it tends to offset the weight of the dam, thus reducing its stability.

At the Malpasset site, a fault (F) located downstream prevented the flow of infiltration water. This water accumulated below the base of the dam.

Moreover, the permeability of rocks decreased with the increase in pressure P as and when the dam was filled[3].

The combination of these elements generated a resulting pressure (R) that led the concrete arch and its anchorage on the left bank to detach from their seat.

The water retained by the dam seeped into the cracks and swept away the structure.



Other additional causes deserve to be mentioned:

- The course of the Reyran river was not diverted during the construction operations because the river remained dry for a large part of the year. These operations were generally carried out by digging a temporary tunnel to allow the water to flow laterally. According to the works carried out during the enquiry, such a tunnel on the appropriate bank would have run across one off the major faults that had a major hand in the breach of the dam. The special flow regimen of the stream suppressed the "alarm signal" that would have certainly gone noticed in such a tunnel.
- The rather dry flow regimen of the stream greatly delayed the filling of the dam. The tests normally carried out on such structures when filled for the very first time (partial filling up to increasingly higher levels followed by draining and systematic measurement of deformations) were not conducted. The only measurement taken the previous summer revealed a significant displacement of 15 mm. However, no action was taken.
- This dam was solely designed for irrigation purposes. It was thus not subject to the same regulatory inspections as hydroelectric dams (review by a specialised commission). The follow-up on the dam was probably not enough, possibly due to the manufacturer's excellent reputation.

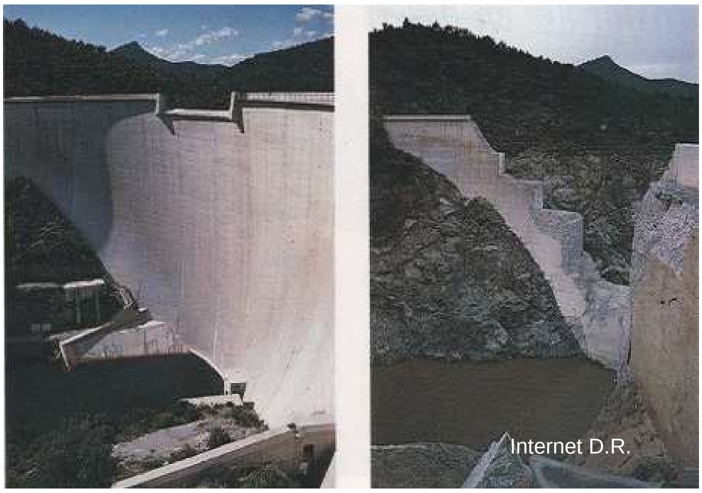
[3] This rheological phenomenon of rock mechanics (stress-based variation in permeability) was not known when the Malpasset dam was built.

ACTIONS TAKEN

Legal enquiries were conducted to determine the causes of the accident and find out parties to any possible offences committed. Investigations, auditions and expertises lasted for over 6 years and the final sentence was given 12 years after the disaster.

All rulings further to the breach of the Malpasset dam (court of first instance of DRAGUIGNAN, rulings dated 25 November 1964 and 17 November 1965, Court of Appeal of AIX-en-PROVENCE, order dated 26 April 1966, Administrative Tribunal of NICE, judgement dated 13 June 1968, Conseil d'Etat (French administrative court of last resort), judgement dated 22 October 1971) cleared the manufacturers of all charges. The Conseil d'Etat noted that the manufacturers were not liable for any of the faults.

The technical principle behind the arch bridge has not been called into question. The accident occurred due to the lack of knowledge of problems caused by the “ground balance” at the base of the dam.



No dam was rebuilt at the site and new water sources were sought. A local authority joint board was set up with the towns of Muy, Puget-sur-Argens and Roquebrune-sur-Argens to draw water from the ARGENS river (flow rate 120 L/s). A water treatment plant was set up in Muy and 17 km of pipelines with a diameter of 400 mm were laid to supply the four towns. The facilities were commissioned in 1963. Today, the local authority joint board comprises eight towns. The plants located in Muy, Gargalon and Fourmel purify the water from several neighbouring catchments (Siagnole, Argens, Fournel and the Saint Cassien dam) to make it drinkable.

The Reyran river was channelled though its course by banks coated with concrete.

The Reyran river channelled today

LESSONS LEARNT

The optimal quality of the arch and the concrete were confirmed by the experts. The reasons behind the disaster can thus only be attributed to problems in the base. This point underlines the importance of not only the geology, orientation of the underground faults, flow regimen of underwater streams in the location of arch dams but also the studies that help identify and provide solutions to potential problems encountered before and during construction. The required financial resources must be gathered to ensure “safe” construction.

Were some signs such as leaks, movement of base, etc. taken into account before deciding to fill the dam to its full capacity?

Lastly, from a regulatory standpoint, the inter-ministerial order dated 13 June 1966 set up the “Permanent Technical Committee on Dams” that was empowered to study and assess projects, monitor the construction of all structures over 20 m in height irrespective of the ministry in charge of the project. Moreover, the regulatory framework was made even more stringent by a circular dated 14 August 1970 and completely amended by an order dated 11 December 2007 based on the legislation on water and aquatic environments of 2006.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REFERENCES

- « Barrage de Malpasset, de sa conception à sa rupture » de V. Valenti et A. Bertini pour la Société d’Histoire de Fréjus et de sa Région, édition LAU, novembre 2003 [ISBN 2-84750-088-X].
- Several websites describing the disaster:
  - http://fr.wikipedia.org/wiki/Barrage_de_Malpasset
  - http://www.ville-frejus.fr/hermes/patrimoine/malpasset.htm
  - http://www.transenprovence.org/article-18201758.html
  - http://pagesperso-orange.fr/minus0202/MALPASSET.htm,
  - http://www.ecolo.org/documents/documents_in_french/malpasset/malpasset.htm
  - …
- Legislation on water and aquatic environments no. 2006-1772 of 30 December 2006 (article 21 on dams).
- Decree no. 2007-1735 of 11 December 2007 on safety of hydraulic structures and on the permanent technical committee on dams and hydraulic structures and amending the French environment code.