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The Stava Valley Tailings Dams Disaster: A Reference Point for the Prevention of Severe Mine Incidents

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Abstract: On July 19, 1985, at Stava near Tesero (Italian Alps), two reservoirs collapsed, causing the death of 268 people and the destruction of many buildings. The two adjacent basins were constructed for the decantation and storage of fine-grained waste material, which was pumped from a nearby fluorite mine. The consequence of the failure was a vast flowslide that found its way downstream along the Stava valley destroying many houses in the village of Stava, eventually reaching Tesero, where more property was wrecked or severely damaged. The Stava valley disaster was one of the most tragic of its kind. This paper aims to give a contribution on the technical aspects related to the causes of this catastrophic event. It also describes alternative technical solutions for the proper management of mining waste disposal and environmental protection proposed by the Stava 1985 Foundation for disseminating knowledge and awareness on how to make these geotechnical structures safer and more profitable and avoid other similar disasters that still keep occurring every year around the world.

Key words: Stava disaster, tailings dam failure, safety measures and incident prevention.

1. Foreword

Mining activities require the use of ore washing plants for separating concentrated mineral ore from the waste rock that will not be used. This is generally attained by means of froth flotation, a process relying upon the capability of finely ground minerals to aggregate with water or reject it.

The processed waste—or tailings—is a liquid mixture of sand, silt and water that is discharged into a purpose-built reservoir, named a tailings dam. A tailings dam can grow progressively to a considerable height (up to over 60 m). Therefore, proper construction and management are of paramount importance in order to guarantee long-term stability [1]. Unfortunately, to date there has been no economic interest in the construction of tailings dams, since very little revenue results from waste material. Therefore, many mining companies tend to spend as little as possible on these geotechnical structures, to the detriment of their stability.

The catastrophic failure in the Stava valley and other similar disasters here reported can teach us an important lesson concerning the safety of tailings dams and new techniques for recovering extra useful minerals from tailings.

2. Introduction

The Stava disaster of July 19, 1985 (Italian Alps) was caused by the collapse of two tailings dams, which stored fine-grained waste (tailings), originated by the beneficiation of fluorite produced at the Prestavèl mine in the upper Stava valley near the village of Tesero (Fig. 1).

This disaster caused the death of 268 men, women and children, destroying also many houses, hotels,

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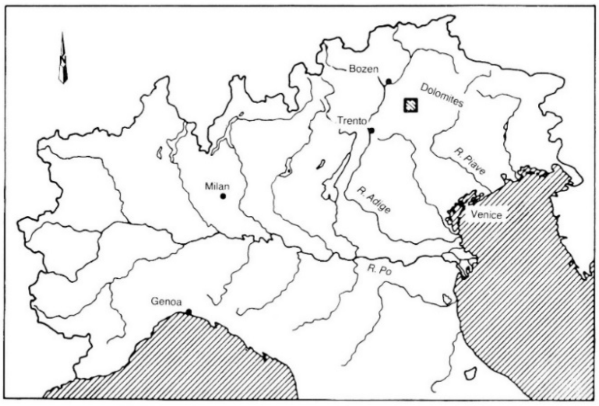

Fig. 1 Location of Stava valley, northern Italy (shaded square indicates disaster area).

bridges, industrial and commercial activities as well as vast environmental devastation.

Following this tragic event, criminal trials were carried out which eventually led to the conviction of ten defendants, guilty of criminal negligence and multiple manslaughter. Before the final verdict, scientific investigations were performed on the failed structures [2, 3].

The "Stava 1985 Foundation"—a registered charity established in 2002—has been spreading information worldwide on the Prestavèl mining activities and the reasons and responsibilities for the Stava valley catastrophe[1]. In addition, particular importance has been given to information about the technical, economic, political and managerial choices, which allowed the construction of tailings dams in an area which was shown, after failure occurred, to be the least suitable from the geomorphological, geotechnical and hydro-geological viewpoint. In addition, there were also planning and construction errors in the two reservoirs, leading to instability and eventually disastrous failure [4, 5].

This paper aims to contribute to the knowledge of the technical causes of this disaster, the mine and beneficiation processes. It also describes the efforts of the Stava 1985 Foundation for the safety of mining activities, mining waste disposal facilities and environmental protection, in order to disseminate knowledge and awareness about the Stava valley catastrophe and other similar disasters that have occurred around the world since then.

3. Mine Description

The mining operations in the Prestavèl fluorite mine, in the upper Stava valley, were carried out in a sub-vertical seam, included in a red porphyry rock mass and metamorphic porphyroid [4].

Access to the seam was given by means of four tunnels, excavated on the slope of the mountain at different levels. The tunnels were on either side of the mining areas in which the working panels were developed. The mineral was exploited in horizontal slices, backfilling the foot of the excavation with the waste material produced during excavation. The raw mineral was dumped into vertical shafts and arrived at the bottom hauling level by gravity. From there, it was transported to the washery by means of a ropeway, where a beneficiation process extracted the fluorite, concentrating the mineral at the acid grade of 97% and eliminating the rock waste by sending it to purpose-built basins (Fig. 2).

In the late period of the life of Prestavèl mine, the ore beneficiation process was based on froth flotation. In earlier times, the concentration was carried out by means of different techniques in order to obtain a grade of about 80% of fluorite, suitable for smelting plant uses.

The capability of useful minerals to aggregate with water or reject it during flotation can be enhanced by using suitable chemicals or natural conditioners. Because fluorite is conditioned to be hydrophobic, it tends to link to air bubbles and float. On the contrary, the tailings sink to the bottom of the vessels and are conveyed to a settlement basin together with the washing water. Once in the pond, the slurry is

[1] The duty of the Stava 1985 Foundation (www.stava1985.it) is to keep alive the historical memory of the Stava valley disaster in order to make sure that 268 innocent people did not die in vain. Its main goal is to strengthen the culture of prevention, correct territorial management and safety since shortcomings and negligence were the cause of this and many other man-induced, foreseeable and avoidable disasters.

Fig. 2 View of the Stava lower basin in 1969.

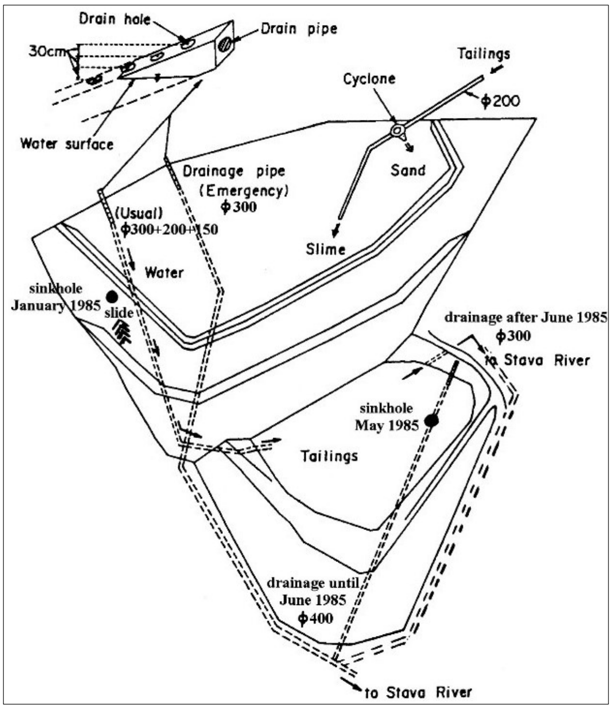

Fig. 3 Location of the drainage pipes through the Stava dams [2].

processed using a hydrocyclone that separates the coarse material (mainly sand) from the finer material (mainly silt). The sand is discharged immediately at the inner edge of the tailings dam, in order to build up the so-called delta or beach and to increase the thickness of the dam itself. The silt, in the form of liquid mud, is pumped in the central part of the basin, where it settles. Vertical shafts are positioned at the center of the pond. The bottoms of the shafts are connected to a drainage pipe that runs through the basin and drains away the water in excess (Fig. 3). The Prestavèl plant had a capacity of 200 t of raw mineral per day.

4. Construction of the Stava Tailings Dams and Causes of the Collapse

In 1961, new mining facilities were constructed adopting the froth flotation system and high-grade fluorite, suitable for use in the chemical industry. At the same time, the first tailings dam was constructed for storing and decanting the waste thus produced (Fig. 2). The downstream slope of this dam was raised with an angle of about 32° to an ultimate height of 25 m. In 1969, in order to deal with increased mining production, it was necessary to construct a second tailings dam just upstream of the first one. The dam of this second basin was raised without any provision either for anchoring it to the ground or for drainage. As the dam grew higher, the base of its embankment grew wider until it eventually rested partially on the silt of the lower basin (Fig. 4). Drainage pipes were placed inside the basins, which discharged the water outside by passing through the dams.

In those days, there was no proper urban planning in the Stava valley and permission was easily granted for the construction of tailings dams at the top of a valley of considerable scenic beauty, highly appealing to tourists. Two incompatible activities were sharing the same territory: on the one hand, the traditional mountain buildings and hotels in a charming Alpine

Fig. 4 The two Stava tailings dams and the Prestavèl mine facilities (October 1981).

valley and on the other, an industrial activity with heavy environmental impact. Technically, this means that together with tourist development also exposure to potentially hazardous events increased, but this was totally ignored by the people in charge of the basins' construction.

The causes of the persisting instability of the tailings dams, which eventually led to their failure, were as follows: (i) the ground on which they had been built was marshy and poorly drained and, as such, unstable and unsuitable to support heavy geotechnical constructions and did not allow the consolidation of tailings; (ii) the dams had been built on a very steep slope, with an average inclination of 25%; (iii) the dam of the upper basin had been raised with an excessive slope (over 80%), was lying in part on the unconsolidated silt of the lower basin and did not allow water drainage or the consolidation of tailings; (iv) the overflow and drainage pipes had been wrongly positioned inside the basins.

Furthermore, in the last three years before disaster the hydrocyclone was no longer moved periodically along the embankment of the upper dam but was located in a fixed position at the corner near the washery. In order to create the sand delta, the coarse tailings were distributed using front-end loaders and trucks, causing heavy vibrations that compromised the correct settlement of the material. In the meantime, the drainage pipe at the bottom of the upper dam was obstructed and could not discharge water to the downstream pond. During the entire life of the two tailings dams, maintenance was poor, there was no control at all over drainage and the general management of the tailings dams was definitely inadequate.

In the end, unnoticed and persisting high-pond conditions weakened the foundations of the upper dam with a progressive increase of pore water pressure, leading eventually to its collapse and causing also the failure of the lower dam. Consequently, 180,000 m^3 of liquefied mud and water spilled out of the failed dams plus nearly 50,000 m^3 of material resulting from soil erosion, destruction of buildings and uprooting of trees. The entire Stava valley was completely devastated (Fig. 5).

Fig. 5 The failed dams and the devastation of the Stava valley (July 1985).

5. Several Cases of Tailings Dam Failures around the World

The continuous occurrence of incidents affecting reservoirs confined by earth dams and, in particular, tailings dams[2] all over the world reproposes the risk of these geotechnical structures for the environment and human settlements. This is not a new problem, and it regularly arouses the interest of the media and the scientific-technical world after every catastrophic failure of earth dams. This was the case for several disasters similar to that of the Stava valley, such as Merriespruit in South Africa[3] (Fig. 6), Aznalcóllar in Spain[4], Baia Mare in Romania[5], Kolontár in

[2] 110 incidents have been recorded from 1960 to date, of which 69 occurred after the Stava valley disaster of 1985. Three tailings dam failures took place just in 2018 with loss of human lives and serious damage to the environment [6].

[3] This incident took place on February 22, 1994 when, following heavy rains, 1,500,000 m^3 of polluted mud overflowed the embankment of a tailings dam. Seventeen persons lost their lives, 80 more were injured and many houses were destroyed in the suburb of Merriespruit, Virginia, Free State.

[4] 4,600,000 m^3 of water and toxic mud, resulting from the working of phosphates, spilled out of a tailings dam on April 25, 1998. Pollution severely affected thousands of hectares of farming land.

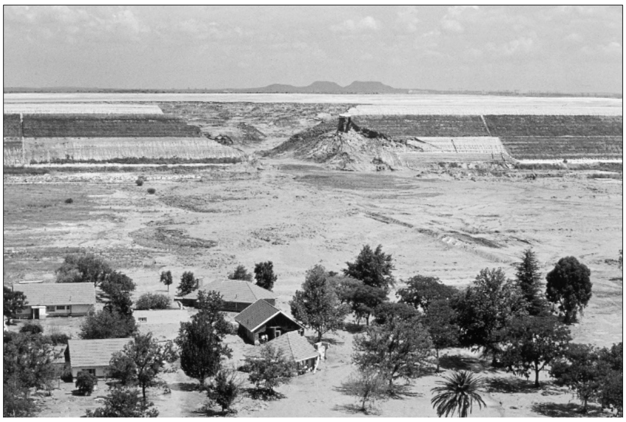

Fig. 6 The devastation of the mudflow following the Merriespruit tailings dam failure, South Africa (February 1994).

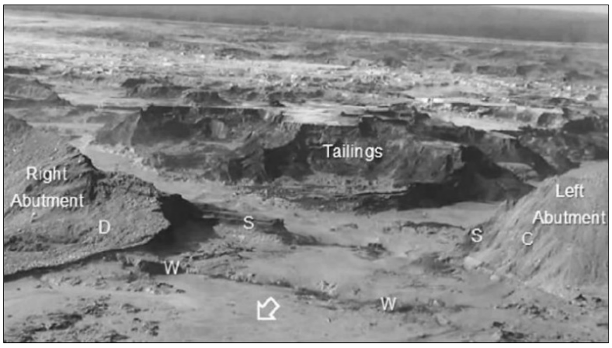

Fig. 7 View looking upstream through the breach at Mount Polley tailings storage facility (arrow shows direction of the outflow) [8].

Hungary [6], Mount Polley in Canada [7] and Bento Rodrigues in Brazil[8].

[5] 100,000 m^3 of cyanide-rich fluids, resulting from the working of gold, spilled out of a tailings dam on January 30, 2000. The Somes Creek, tributary of the Tisza River, was heavily polluted, thousands of fish were destroyed and drinking water supplying over two million inhabitants was contaminated.

[6] 1,500,000 m^3 of toxic mud, resulting from the working of bauxite, spilled out of a tailings dam on October 4, 2010. Nine persons lost their lives and 120 were injured. The consequent heavy pollution required the demolition of numerous houses, which were rebuilt elsewhere, the removal and transport of the contaminated ground to a landfill and its substitution with some 30 cm of fresh soil along the path of the flowslide, which was 40 km long with a front of 300 m.

[7] The flowslide, which spilled out of the tailings dam on August 4, 2014, was made up of 7,300,000 m^3 of tailings and over 17,000,000 m^3 of water.

[8] Over 30,000,000 m^3 of mud flowed out of a basin on November 11, 2015 following the failure of two tailings dams. An entire village was destroyed, 17 persons were killed and 75 injured. Several watercourses were polluted over a total length of 660 km, 15 km^2 of land was contaminated and water supply serving 250,000 inhabitants was interrupted.

A few considerations should be made about the Mount Polley tailings dam disaster since this was the largest documented spill of mine tailings into the environment [6] (Fig. 7).

The Mount Polley Mine is an open pit and underground copper-gold mine, processing an average of 22,450 t per day of ore. The mine is located 8 km southwest of Likely, BC (Canada), approximately 400 km northeast of Vancouver. On August 4, 2014, a failure occurred in the perimeter of the tailings storage facility. The embankment breach released tailings, water and construction materials which affected several bodies of water [7].

According to the results obtained by the Independent Expert Engineering Investigation and Review Panel [8], the breach was induced by the failure of a glacio-lacustrine layer located about 8 m below the embankment's foundation. The Panel concluded in its report that "the dominant contribution to the failure resides in the design. The design did not take into the account the complexity of the sub-glacial and pre-glacial geological environment associated with the perimeter embankment foundation". The breach was interpreted by the Panel to have been caused by shear failure of weak dam foundation materials (i.e. a glacio-lacustrine layer). The Panel identified this weak rock layer in the breach area and stated that past subsurface investigations were not focused on identifying potential complexity of the embankment foundation soil.

The morphology of the Hazeltine Creek, downstream of the Mount Polley tailings storage facility, was intensively altered by the sudden release of tailings due to considerable erosional processes along the creek banks [9].

The environmental clean-up operations were swift: within one year of the event a significant volume of the spilled tailings were removed from the major receiving watercourse and an extensive river restoration scheme was under construction [8].

The Mount Polley spill highlighted the high global environmental risk of these incidents, due to the growing number of mining operations and greater waste produced, and due to the high vulnerability of this type of environment to extreme hydro-meteorological events [10]. In addition, the introduction and deposition of contaminants poses a serious risk to the resident and anadromous fish stocks supporting Native American fisheries [11].

The Mount Polley failure, along with the November 5, 2015 Bento Rodrigues dam disaster in Brazil, has done great harm to the credibility of the mining industry as a whole.

6. Towards Safer Management of Tailings Dams

As previously stated, the Stava 1985 Foundation is pursuing the aim of making public institutions and industrial operators aware of the importance of adopting new approaches and technologies to prevent future disasters. An important target for the Stava 1985 Foundation is to promote initiatives directed to public opinion and technical stakeholders regarding the use of the BAT (Best Available Technologies) for the management of mineral processed waste, having as a primary objective the safety of the population and the conservation of the environment [12].

Recent available technologies allow strategic targets to be attained by reducing pollution and maintaining at the same time high safety standards. Among the methods of dealing with mining waste, forced filtration seems to be very promising, although it is not yet widely used due to its high cost. This process allows the quick separation of the two phases of tailings by means of filter presses, belt filters, disk filters or drum filters. Thus, water is completely recovered and recycled while the hauling of the resulting mud—that has a residual humidity of 15% to 30%—is carried out with standard front-end loader machines and trucks. The advantages of this method are in avoiding hazardous disposal structures, the occupation of large areas of soil, better control of the contaminants and possibility of the stockpiling of dried mud (called filter cake) for recycling or reprocessing [13].

Tailings could be converted by giving them a new life as basic material for civil engineering use, based on the principles of circular economy. This measure would also cut down the need for mineral waste disposal sites and the risk of their collapse. Finally, environmental pollution could be curtailed by reprocessing the tailings in order to recover useful elements.

Apart from new techniques concerning the accumulation and management of processed mine waste, the so-called landfill mining of tailings storage facilities has assumed a role of paramount importance for setting up the safety of tailings dams. Thanks to this practice, economically significant amounts of useful minerals or metals can be recovered from tailings impoundments, thus changing the role of tailings from waste to resource.

In South Africa, important developments have been made regarding the economic convenience of mine mineral waste recovered from no longer active tailings dams. Moreover, at Motlosana (formerly named Klerksdorp) in the North West Province, some tailings dams containing hundreds of millions of cubic meters of mineral waste, resulting from digging out gold[9], are being recovered. In the city's outskirts, a large tailings dam was completely dismantled for safety reasons, considering its proximity to a residential area. Three other tailings dams are now being re-exploited for economic use as landfill mines. According to this practice, the already consolidated tailings are mixed with a large amount of water and turned into an ore-pulp, which is pumped again into the mine plant where some 0.5 grams of gold are recovered out of 1,000,000 kg of tailings. The ore-pulp containing the tailings of the second processing is then conveyed to a vast decentralized storage reservoir. This large

[9] In order to have an idea of the size of gold mines, it is enough to consider that out of a ton of raw mineral only 4 to 5 grams of gold can be recovered.

impoundment already contains several hundred millions of cubic meters of tailings. Finally, the water utilized for the second processing is recuperated and used once more in the working cycle.

The managers of Harmony Gold Mining Company Ltd. entrusted the construction and maintenance of their tailings dams to other specialized companies or consultants in soil mechanics. In addition, they regularly draw up insurance contracts for their tailings dams. This guarantees, on the one hand, certainty and a short liquidation time in case that damage occurs[10] and, on the other hand, proper checks resulting from economic interest.

Both these choices are not due to the respect of mandatory norms but are taken freely as a result of a management philosophy inspired by a strong conscience of the social and environmental accountability of the company. This responsible attitude aims to prevent incidents and consequent negative repercussions on the environment and the residing population. Therefore, in South Africa the use of water for enriching the mineral[11] and the correct management of tailings dams are of paramount importance in order to implement concrete measures for risk mitigation.

Besides applying proper technical management to their tailings dams, South African mining companies do not neglect the fact that possible incidents may always occur. Therefore, they stipulate adequate insurance contracts also for their tailings dams. This responsible free choice bears witness to the awareness that tailings are an element of mining production and should not be considered as useless costly waste. On the contrary, the management techniques previously described make these materials profitable on the market. Similarly, the South Africa experience shows the importance of involving insurance companies in the management of tailings dams, since their recurrent checks, which respond to the company's own economic interest, would be more effective and thorough compared with those carried out by public boards that most of the time intervene only on a bureaucratic level.

It might seem normal that the construction and management of tailings dams is entrusted to qualified technicians. Nevertheless, this was not the rule when the Stava valley disaster occurred. Indeed, only in 2006 did the European Union implement a Directive concerning the management of mineral waste from mining activities (no. 2006/21/CE). This directive declares that "in order to guarantee that reservoirs for storing tailings are properly constructed and subjected to correct maintenance, the member States should intervene adequately to ensure that the planning, location and management of these structures are the responsibility of technically qualified persons".

If the European Parliament and Council considered the implementation of such a rule mandatory from 2006, it obviously means that before this date tailings dams were not necessarily managed in an appropriate way, as demonstrated by too many incidents.

7. Conclusions

There is also a negative legacy left by mining activity. Not only are tailings dams no longer active and abandoned to their destiny[12], often with a load of polluting material, but there is also risk of soil subsidence, resulting from the collapse of tunnels and empty underground spaces, and contamination of

[10] In the case of the Merriespruit incident of 1994, where the tailings dam had been insured, the insurance company liquidated compensation for damages to all the people affected by the disaster within three weeks. In addition, the mining society itself carried out the restoration works [14, 15].

[11] In South Africa, the water used for enriching minerals is usually recovered from the tailings dams and depurated in order to reuse it in the working cycle. At Stava, the processed water and the tailings were conveyed to the reservoirs where, after the settlement of the solid fraction, water was discharged directly into a stream without being depurated.

[12] In Italy, the basins for the storage of tailings make up hundred millions of cubic meters. The provisional inventory published on the ISPRA website [17] lists 650 storage structures, including those that are no longer in activity. They all have "considerable negative repercussions on the environment or can constitute, in the short or long term, a serious threat to human health and the environment".

watercourses and groundwater.

Nevertheless, one should be aware that by means of proper management it is possible to mitigate the negative consequences of mines and their structures no longer in use on the environment and human settlements [16]. These positive goals, which necessarily require higher production costs, can be achieved if the decisions of the mine administrators do not exclusively aim to maximize profits by minimizing costs to the detriment of safety. On the contrary, there should be full awareness of one's own accountability and a widespread culture inspired by civil responsibility and enterprise, always bearing in mind that the cost of prevention is always immensely lower than the cost of damages[13].

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[13] In the case of the Stava valley disaster, the total cost for rescue, environmental restoration, reconstruction and liquidation of damages was one thousand times higher than the investment that would have been necessary and sufficient in order to avoid the failure of the tailings dams.