The Stava catastrophic failure of July 19, 1985 (Italy): technical-scientific data and socioeconomic aspects

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Abstract

On July 19, 1985 at Stava near Tesero (Trento Region, northern Italy), two impoundments 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 (tailings), which was pumped from a nearby fluorite mine. The consequences of the failure was a vast mudflow that found its way downstream along the Stava valley. The failure occurred as a result of the collapse of the upper basin, which overwhelmed the lower basin. The mudflow continued down the valley destroying many houses in the village of Stava, eventually reaching Tesero, where more property was destroyed or severely damaged. The disaster in the Stava valley was one of the most tragic of its kind. With its high toll of lives lost and over 133 million euros in damage, it was one of the worst industrial catastrophes anywhere in the world. This paper examines the technical errors, shortcomings, responsibilities and consequences of this disaster.

Introduction

Mining activities require the use of ore washing plants for separating concentrated mineral ore from the waste rock or *gangue* 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.

The processed waste – or tailings – is a liquid mixture of sand and silt that is discharged through a pipe into a purpose-built basin, 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. Unfortunately, there is no economic interest in the construction of tailings dams, since no revenue can result from the waste material, so many mining companies tend to spend as little as possible for these geotechnical structures to the detriment of their stability.

The catastrophic failure of the Stava valley and other similar disasters can teach us an important lesson concerning the long-term stability and safety of tailings dams.

History of the Stava tailings dams

Stava is a hamlet in the municipality of Tesero, in the province of Trento (Fig. 1). Since the 16th century, a mine was active on Mt. Prestavèl for the extraction of small amounts of fluorite and, to a lesser extent, silver galena (Giordani, Lucchi, Salghetti Drioli, and Tosatti 2003). In 1961, a new plant was constructed adopting the froth flotation system in order to obtain high-grade fluorite suitable for use in the chemical industry. At the same time, a first basin was constructed for storing and decanting the tailings thus produced (Fig. 2). Once a small starter dam was constructed of locally available material, the lower dam was raised by the use of two moveable hydrocyclones. Sands deposited by the hydrocyclones formed the shell of the dam, with finer particles carried further onto the beach areas (Lucchi 2005). The sand shell was never compacted. Supernatant water collected in a pond at a distance from the dam and was decanted and recycled. The downstream slope of the lower dam was raised with an angle of about 32° to an ultimate height of about 25 m.

The beginning of new mining activities at an industrial level (early 1960s) brought about some urban development of the Stava valley, with the construction in Tesero of accommodation facilities for the Montecatini mineworkers (Fig. 3). These miners and technicians came from other Italian areas, in particular Tuscany and Belluno province, where mining was thriving and had a long tradition (Morra, and Vighi 1964). In 1980, Fluormine gave back its mining concession and sold the accommodation facilities to a building society, which later turned them into tourist residences.

In 1969, in order to deal with increased mining production, it was necessary to construct a second basin 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 draining. As the dam grew higher, the base of its embank-

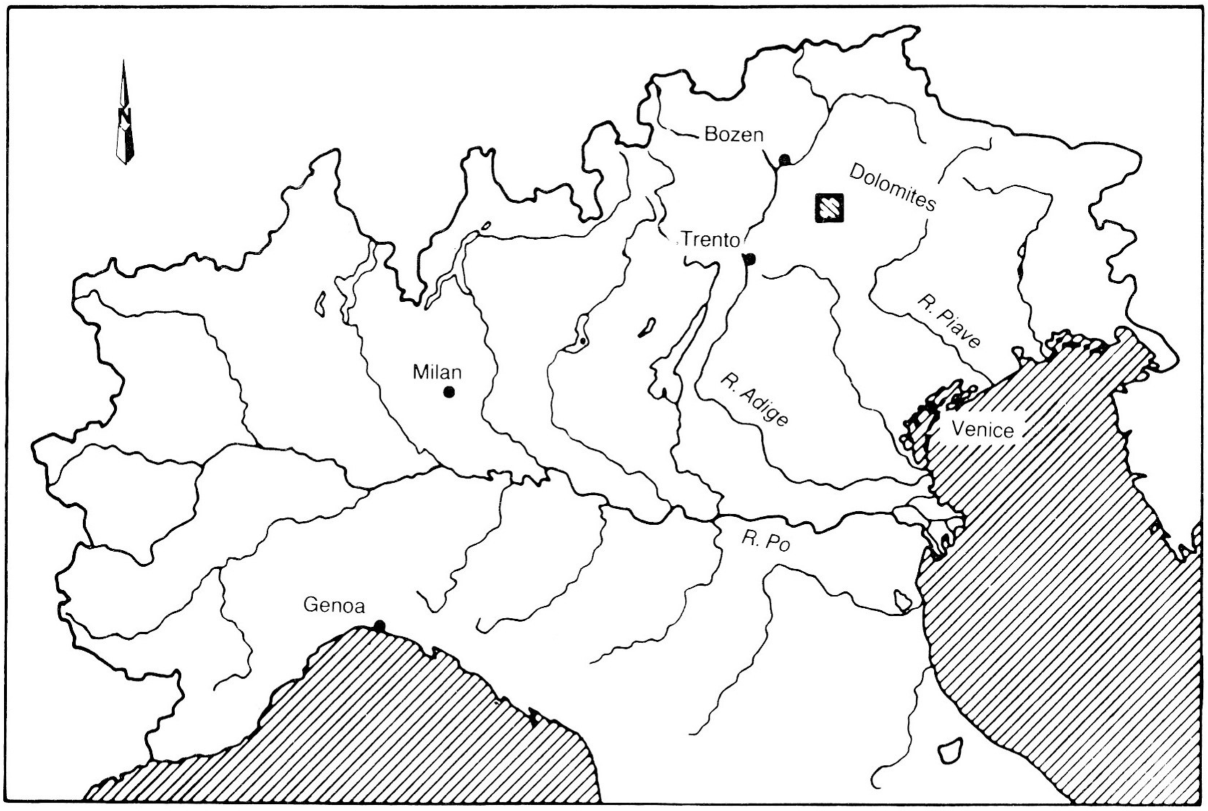

Figure 1 – Location of Stava, northern Italy (shaded box indicates area of disaster).

ment grew wider until eventually it rested partly on the silt of the lower basin. The decant pipes were placed inside the basins and discharged outside by passing through the dams. For a period (1978 to 1982), the basins were not in use. Activity resumed in 1983 and continued until the collapse of the structures in July 1985 (Lucchi 2005).

Proper urban planning was completely lacking at Stava, since the mining plant and the tailings dams had been built in a valley highly appealing to tourists, considering the scenic beauty of the area. Therefore, two incompatible activities

Figure 2 – The lower Stava basin in April 1985.

were sharing the same territory: on the one hand, the traditional mountain buildings and hotels in a charming Alpine 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 was totally ignored.

Dynamics of the catastrophic failure

When failure occurred, the lower dam was 25 m high and the upper dam was over 34 m high. Together, they made up an earth structure nearly 60 m high. The upper dam had a berm at about 2/3 from its base, which partially rested on the silt of the lower dam. The upper dam's slope was 38°÷39° below the berm and about 32° above the berm (Fig. 4).

At 12 hours 22' 55" of July 19, 1985, the upper dam collapsed, causing also the failure of the lower dam.

Failure occurred suddenly without any warning. A loud rumble and the raising of a thick cloud of whitish dust accompanied the collapse of the two dams. It was followed by the quick propagation of a 180,000 m^3 flow slide of semi-fluid slime, which shortly attained a velocity of 90 km/h, running a distance of 4.2 km, as far as the riverbed of the River Avisio in Fiemme valley, where eventually it depleted its devastating energy (Alexander 1986, Takahashi 1991, Govi, and Luino

Figure 3 – The accommodation facilities for the mineworkers in Tesero (early 1960s).

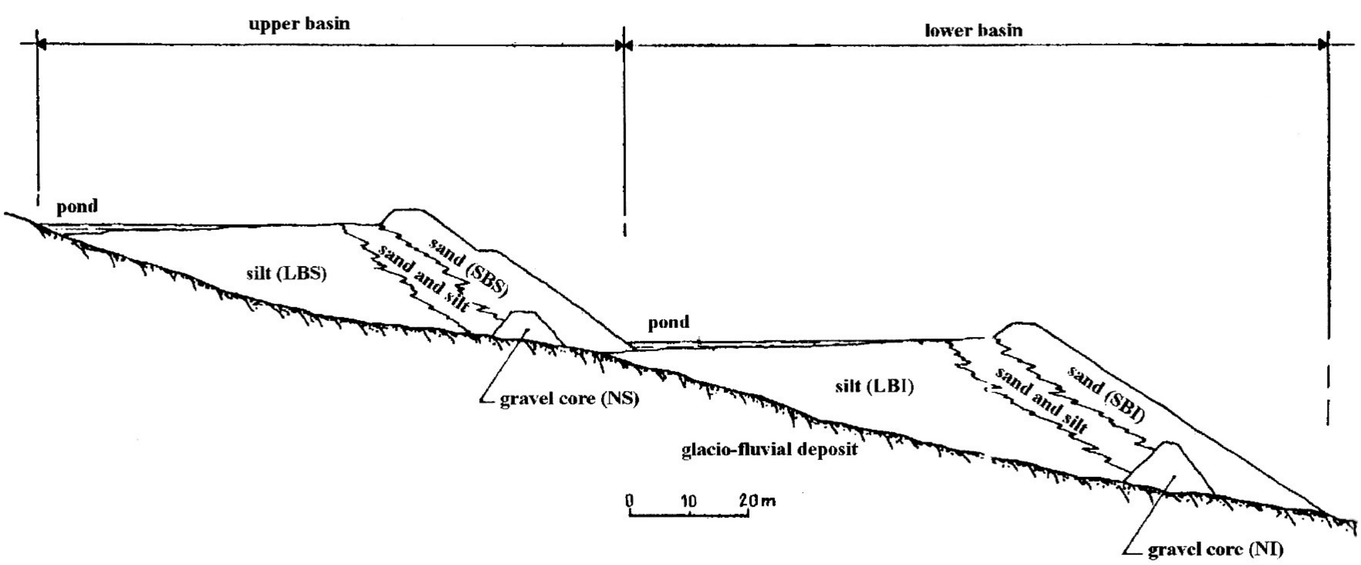

Figure 4 – Section sketch of the Stava tailings dams (after Colombo, and Colleselli 2003).

2003). Hundreds of trees were broken or uprooted because of the air blast that preceded the flowslide (Fig. 5).
Along its route, the flowslide caused the death of 268 people, the complete destruction of 53 houses, three hotels, six industrial buildings and eight bridges, seriously damaging several other buildings. Of the two bridges of Tesero, the first was overflowed and damaged by the flowslide, although it stood 16 m high over the valley floor. Total damage amounted to over 133 million euros (Lucchi 2011).

Geotechnical aspects of the collapse

The size of a tailings dam depends on the quantity of tailings to be disposed of and, in turn, this quantity depends on the estimated amount of waste material that fluctuates continuously as mining development progresses. Accordingly, the final size and design of tailings impoundments can differ substantially from the initial project and may often reach tens of meters in height and cover several square kilometers. Costs are often directly related to the amount of fill material used in the dam or embankment (i.e., its size) built to contain the slurry. Therefore, major savings can be obtained by minimizing the size of the dam (for example by constructing the impoundment against natural slopes) and by maximizing the use of local materials, particularly the coarse part of the tailings that can be obtained by separation with a hydrocyclone. The use of raised embankments is therefore much more common than the use of retention dams (designed and constructed at full height from the beginning of disposal activities), and, therefore, the stability of tailings dams should be a major concern for designers. At the same time, the phased nature of raised embankments makes it possible to attempt to address problems that may arise during the life of a tailings dam and accomplish engineering solutions without taking the impoundment out of service.
As an example, the Żelazny Most tailings storage facility in southwestern Poland, which is one of the largest tailings dams in Europe, at the end of 2013 stored $527x10^6$ m^3 of tailings, consistent with an average storing rate of $17x10^6$ m^3/year. At that time, a maximum dam height approaching 63 m and a covered area of 12.4 km^2 were attained. In 1972, at the beginning of mining activities, the disposal was planned to be in service for an overall period of over 70 years and, since 1992, a four-member international board of experts, in cooperation with a Polish geotechnical engineer, was assigned the task of overseeing the safe development of the tailings dam by applying the observational method.
The application of the observational method, as conceived by the board of experts, consists of the following stages (Jamiolkowsky 2014):

Figure 5 – The devastating effects of the flowslide on the Stava valley (July 1985)

a) Continuous enhancement of the monitoring network and of the communication system between the monitoring groups and the end users of the results of monitoring.
b) Geotechnical analyses of the observed displacements of the dams to predict their further evolution with the increase of dam height with time.
c) Modification of the plans for design and construction in

the light of the monitoring results and stability analyses.
Raised embankments can be constructed using upstream, downstream, or centerline methods (Fig. 6). With the upstream method, the embankment axis moves backwards and the beach that develops during the deposition of the tailings becomes the foundation of the next dam. With the centerline method, the coarse part of the tailings is placed on both the beach and the downstream face.
The upstream method was used in Stava to raise the embankments of both the lower and the upper basins. For the lower basin (built from 1961 to 1971), it was used alternately to the centerline method, while for the upper basin (built from 1969 to 1985) the upstream method was adopted after an initial construction stage using the centerline method (Colombo, and Colleselli 2003). It follows that initially the upper basin was partially founded on the inner, and then finer, part of the tailings of the lower basin (Fig. 4).

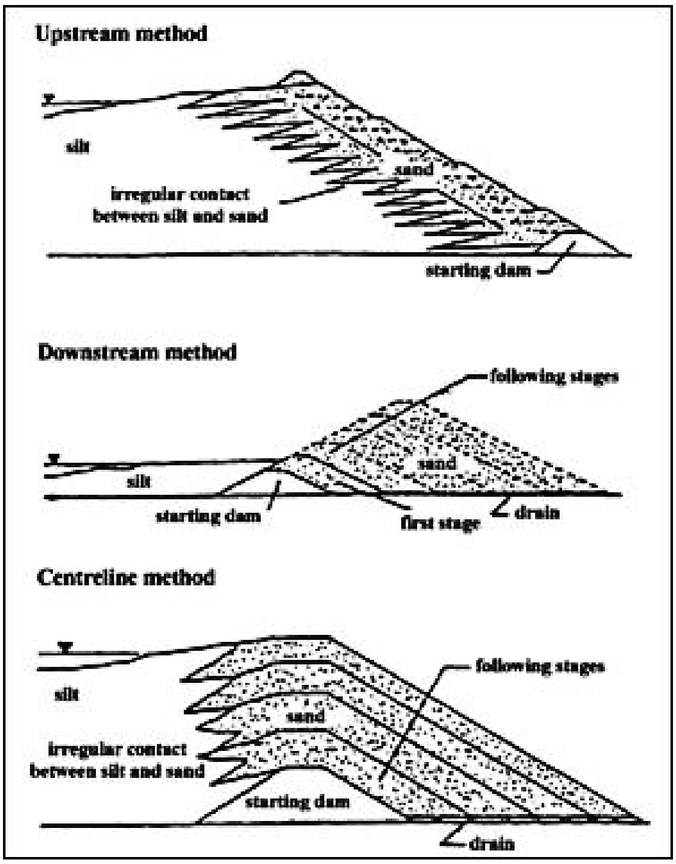

Figure 6 – Construction methods of tailings dams (after Colombo, and Colleselli 2003).

Geotechnical site investigations were not carried out either before the construction or during the management of both the lower and the upper basins. Furthermore, there was no calculation for the stability conditions of the embankments (Chandler, and Tosatti 1995) except for the dam of the upper basin when in 1975 it was decided to increase its height from 19 m to 34 m. An angle of shear strength of 35° was estimated in the laboratory for the sandy part of the tailings, while an angle of 30° was assessed for the silt. Two slope stability analyses by using the Fellenius method and supposing two different potential sliding surfaces gave factors of safety slightly higher than 1 (1.14 for a circular sliding surface, mainly developing in the sand of the embankment, and 1.26 for a circular sliding surface, mainly involving silt). Although the factor of safety was not significantly greater than one, the embankment was raised up, and in July 1985 it attained a height of 34 m.
At least two limitations affected those slope stability analyses: 1) pore-water pressure was assumed to be null everywhere in the embankment and below it; 2) the most critical sliding surface was not identified.
The two impoundments were built on a natural slope made of heterogeneous glaciofluvial soil, 60 to 70 m thick, made of boulders, cobbles and gravel set in a finer matrix. The bedrock directly underlay this deposit. The water table and seepage were affected by rainfall and snow melt. Before the construction of the lower basin, water ponds were identified in the area and a 9 m high starter dam was built with locally won soil, i.e. cobbles, gravel, sand and silt, probably with the purpose of improving drainage through the growing embankment and therefore its stability. In fact, in order to reduce the probability of occurrence of failure due to rotational slide or piping through the embankment, it is of primary importance to maintain a low water table near the embankment face. This task may be achieved by increasing the relative hydraulic conductivity of the embankment in the direction of flow (Vick 1983), but for the embankment of the upper basin the starter dam was built with no regard to the role of relative hydraulic conductivity. As a consequence, occasionally, overtopping had occurred causing the water table to rise. The most serious limitation, however, was the lack of the critical sliding surface identification. For the embankment of the upper basin, Ricceri (2001) obtained an unsatisfactory factor of safety of 0.95 with a circular sliding surface passing through the toe, demonstrating that the embankment built until 1975 was not in safety conditions.
The geological setting and the geotechnical properties of the tailings and of the foundation soil were investigated after the disaster by means of laboratory and field tests (Colombo, and Colleselli 2003). It should be pointed out that results refer to the material that was not directly involved in the failure because, for safety reasons, investigations were carried out away from the unstable area, such as the central part and the toe of the upper basin.
The embankments were made of cycloned fine sand and, behind them, cycloning resulted in the deposit of silty sand and sandy or clayey silt and further inside the impoundment in clayey silt and silty clay. Numerous laboratory (drained

triaxial tests, shear box tests and torsional shear tests) and penetrometer (SPT and CPT) tests were carried out to calculate the shear strength of soils. For the sand of the embankments, the angle of shear strength was estimated in the interval of 32°-38°, quite close to the value of the slope of the downstream banks, which was between 34° and 39°. As regards the shear strength of the clayey silt, undrained shear strength resulted different for the lower and the upper basins. For the lower basin vane tests gave c_u=5 to 60 kPa, with values predominantly in the 20 kPa to 40 kPa range. For the upper basin, vane tests gave generally smaller values, ranging between 3 and 30 kPa. Finally, the estimation of the volumetric compressibility m_v versus the vertical effective stress σ′ made it possible to estimate an average degree of consolidation of 50%, with minimum values of 20-22% (Colombo et al. 1986, ISMES 1986). These values were found consistent with the theory proposed by Gibson (1958).

Consolidation of tailings can be improved by providing adequate internal drainage. At Stava, water drain pipes were used for the two impoundments (Fig. 7), but they proved to be inadequate and dangerous for stability. In fact, early in 1985, two failures were caused by the malfunctioning of the decant pipes at the toe of the right bank of the upper basin (January 1985) and in the left bank of the lower basin (May 1985). Moreover, pore-water pressure measurements carried out in the foundation deposit after the disaster indicated that pressure increased in the rainy period. Therefore, it is likely that in some periods, especially in spring and the beginning of summer (when precipitation is maximum, cf. Fig. 8), the foundation soil was not able to drain but, on the contrary, water was seeping upward in the tailings and in the embankments reducing their safety.

The increment of pore-water pressure distribution in the foundation soil played a major role in the failure of the Aznalcóllar tailings dam (Gens, and Alonso 2006) occurring in 1998 in Spain. In this case, pore-water pressure increased for the undrained behavior of the foundation high-plasticity clay and, in addition to its brittle behavior, a progressive failure in the embankment foundation took place.

Foundation failures are not uncommon among earthfill structures. For example, in August 2014, the Mount Polley tailings dam in Canada failed because of a weak layer of soil at shallow depth in the foundation below the structure (Morgenstern, Vick, and Van Zyl 2015). Given that dam failures are not rare, the Independent Engineering Review Board for the Mount Polley disaster recommended promoting unsaturated conditions in the tailings in order to reduce the potential of their failure due to liquefaction. For the same reason, at the Żelazny Most tailings storage facility many efforts were made to identify and control the location and trend of the water table (Jamiolkowsky 2014).

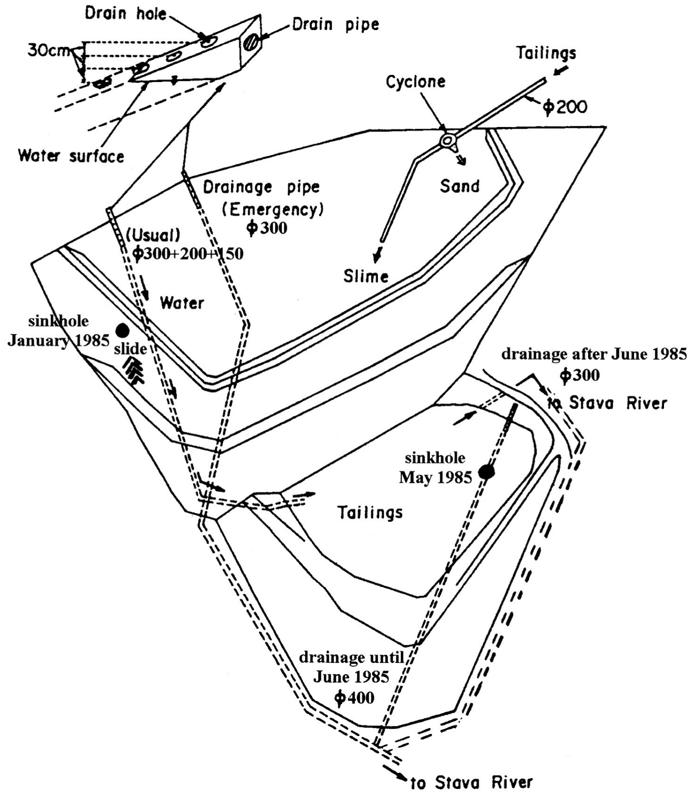

Figure 7 – Location of the decant pipes through the Stava dams (Colombo, and Colleselli 2003).

As for the Stava valley disaster, the fast flowslide of semi-fluid slime, which followed the collapse of the two impoundments, can be explained by considering a well-known phenomenon in soil mechanics: soil liquefaction due to static loading. The soils susceptible to liquefaction are those in which shear strength is mobilized only by particle friction, i.e., cohesionless soils (sand and silt) such as those which made up the Stava tailings dams. In the case examined, liquefaction is ascribable to water fluctuations that eventually led to a high piezometric surface. Although several scientific papers had already been published on the potential liquefaction of silty-sandy tailings that make up earth dams (Rossi 1973, Vick 1983), this hazardous tendency was completely ignored at Stava.

Among other factors predisposing the Stava tailings dams to instability and, eventually, failure, the first substantial error was the mistaken belief that the silt deposited in the dams could consolidate soon after deposition (Genevois, and Tecca 1993). This optimistic assessment influenced the construction operations of the embankments, which were inadequate, and their location upstream of the villages of Stava and Tesero, without ever considering the risks due to their persisting instability. Based on the data collected on the upper basin after failure, it resulted that its soil composition was rather inhomogeneous, with negative feedback on the

shear strength parameters and horizontal and vertical hydraulic conductivity (Carrera, Coop, and Lancellotta 2011).
In addition, the area where the basins stood was marshy and poorly drained and, as such, unstable and unsuitable for supporting these geotechnical constructions.
Finally, the overflow and decant pipes had been wrongly placed inside the basins and they sagged under the increasing weight of the silt deposits. This caused significant leaks inside the ponds in two different circumstances, early in 1985, when substandard repairs were carried out. This last mismanagement of the drainage system inside the upper basin is considered to be the triggering cause of its eventual failure (Chandler, and Tosatti 1995).
In conclusion, the geotechnical processes that were recognized to have caused the failure and collapse at the tailings impoundments at Stava may be summarized as follows (Colombo, and Colleselli 2003):
1) Local slope failure at the downstream face of the upper basin embankment caused by a temporary rising of the water table; 2) failure-induced liquefaction of the sandy and sandy-silty soil of which the raised embankment was made and 3) undrained failure of the silt deposited behind the embankment.
The collapsed part of the upper basin was about 100 m long and its downward movement caused the collapse of the lower embankment with the result that a volume of about 180,000 m^3 of tailings flowed downstream causing the complete destruction of the Stava valley.

Meteorological characteristics

From a meteorological point of view, the mean annual precipitation in the area studied is 820 mm. This value corresponds to the 1921-1987 observation period and was measured at the Cavalese weather gage, located at about 4 km SW of Stava at an altitude of 990 m. Fig. 8 shows the trend of the mean monthly precipitation and points out that the maximum rainfall is concentrated between May and August. Since the annual mean temperature is about 7 °C, the real evapotranspiration according to Turc should correspond to 52% of the year total precipitation in the period considered. With reference to the precipitation of the year 1985 (Fig. 8), when the dams' failure occurred, it can be noticed that the precipitation in the first six months was 465 mm, compared with the general mean value of 365 mm. In particular, in June of the same year the rainfall was 115 mm, compared with a mean value of 98 mm.

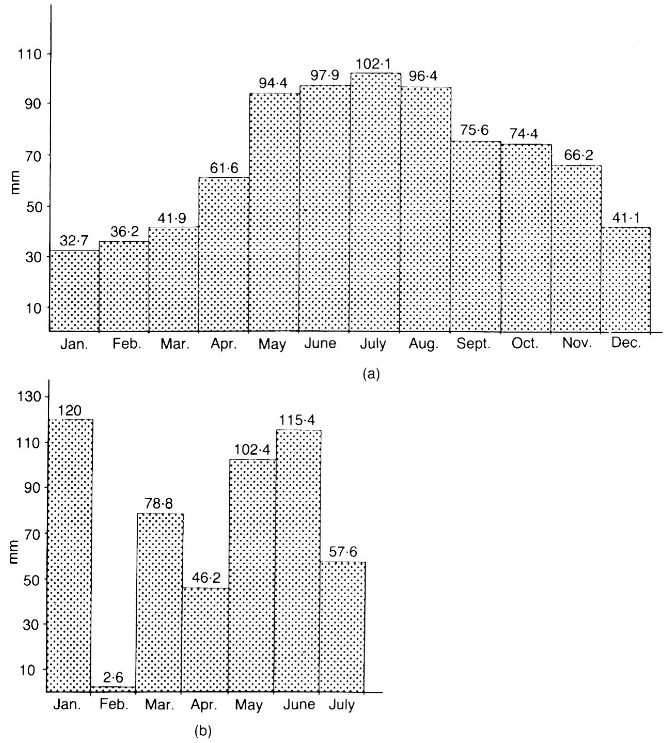

Figure 8 – (a) Mean monthly precipitation at Cavalese gage, near Stava, 1921-1987; (b) precipitation from January 1985 to July 19, 1985.

Geological setting and hydrogeological characteristics

The Stava valley ranges in height between 835 m a.s.l., at the bottom of the valley, and 2,490 m a.s.l., maximum altitude of the Torrent Stava catchment basin, which is a right-hand tributary of the River Avisio. In particular, the two basins were located at an altitude of 1340 m and 1375 m, respectively, on a slope variably inclined at between 12° and 16°, along the small valley of a secondary brook, called Rio Porcellini. This watercourse is a right-hand tributary of the Torrent Stava, which is characterized by a poorly defined and cut riverbed.
Geologically, the area belongs to the sequence of the "Piattaforma Atesina" in the Southern Calcareous Alps, which characterizes the Dolomite region. The oldest rocks cropping out in the study area are the volcanic Lower Permian Porphyry Formation, with a thickness exceeding 800 m, from which fluorite was extracted. These are overlain by a typical Dolomite sedimentary sequence ranging from the Permian to the Ladinian Marmolada limestones, cropping out on the eastern flank of the Stava valley, which constitute the terminal member of the sedimentary succession. Finally, the Quaternary sediments consist of slope deposits and moraine and glaciofluvial deposits, while Holocene fluvial deposits are found along the main watercourses (Fig. 9).
The above succession, is affected by an important structural feature, the so-called Stava line (Doglioni 1987). This regionally

important tectonic lineament has lifted the porphyries that make up the northern block, whilst the southern lowered one is characterized by the presence of quartz-porphyries and Permian-Ladinian sedimentary formations. In particular, in the Stava area this discontinuity is accompanied by mainly reverse faults, with NE-SW or E-W directions, which determine the lowering of the southern blocks. Other fault systems are present in the upper Stava valley with prevalent N-S and NW-SE trends. These local tectonic features have an important meaning from the hydrogeological standpoint since they bound formations with diverse water conductivity and with possible presence of confined aquifers (Tosatti 2007).

The Prestavèl mine tailings dams were constructed on Würm moraine and glaciofluvial deposits in the Rio Porcellini valley. The latter have a thickness of 50 m to 100 m, and are extremely heterogeneous in their particle-size distribution, with boulders, cobbles and gravel surrounded by a more or less abundant fine matrix. These highly permeable deposits are often in direct contact with more recent talus debris and fluvial deposits.

Following the directions of the Trento Court's Team of Experts (Colombo et al. 1986), in the basins' area some mechanical borings were performed. Of the three deep borings, driven up to a depth of 70 to 85 m, the two eastern ones found the porphyries below the Quaternary deposits, whilst the boring more to the west reached a bedrock made up of limestones and marlstones of the Lower Triassic Werfen Formation.

Given the above data, together with information from more recent geological investigations (Various Authors 2017), it was possible to construct the two sections illustrated in Fig. 9. It is interesting to note, in section B – B', that there appears to be physical continuity in the moraine cover between the deposits of the nearby Rio Gambis valley and those of the Stava valley through a pre-Quaternary buried channel beneath the Rio Porcellini stream.

Until the investigations following the failure, there was little hydrogeological data concerning the study area.

In the Stava valley and surrounding areas, about 110 springs have been identified although knowledge of their flow-rates is very sparse, and only applies to the 1974-1989 period. The few available continuous flow-rate measurements show that the flows closely follow the precipitation trend, with maximum values in the summer months (Fig. 8). Nearly all the springs occur at the foot of the slopes along the main valley trenches, and are linked to the presence of Quaternary slope deposits or, less frequently, to superficial flow within the upper fractured levels of the porphyries and limestones of the Marmolada Formation. These factors enable the correlation between the hydrological regime of the springs, the precipitation trend, the annual total flow and the catchment basin surface, the latter practically coinciding with the hydrogeological basin. Additionally, surface runoff is virtually zero due to the extensive forest cover, predominately made up of conifers such as spruces, larches and fir trees.

Several systematic flow measurements were made at these springs (Colombo et al. 1986) demonstrating that the annual

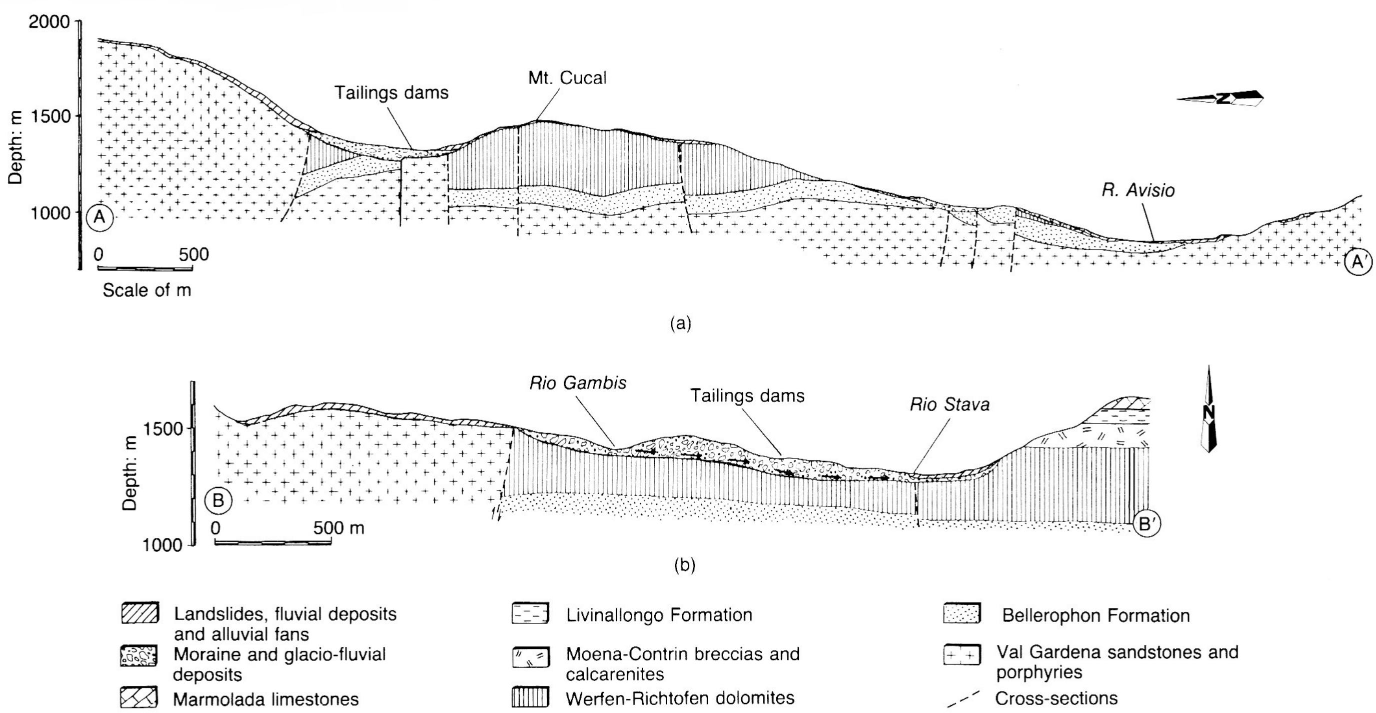

Figure 9 – Geological cross-sections across the failure area at Stava (after Chandler, and Tosatti 1995).

total discharge (c. 1,007,000 m^3/year) is slightly less than the annual precipitation infiltration (less evapotranspiration) into the basin (c. 1,022,000 m^3/year).

These data can be explained if the geometrical and structural characteristics proposed in the geological sections of Fig. 9 are accepted. According to this interpretation, there is a water circulation from the Gambis valley into that of the Rio Porcellini, resulting in the emergence of the Pozzole springs, where the tailings dams stood.

Phreatic fluctuations within the surface layer are closely connected with rainfall, showing maximum values in the May to August period, with a very rapid rise in groundwater level (up to 18 m in May-July). Apart from direct infiltration of rainfall, this particular situation can result also from the high gradient talus debris, which covers the lower part of the slopes, being also characterized by high permeability. Indeed, these slope deposits are geometrically and hydraulically contiguous to the glaciofluvial deposits placed at the bottom of the valley, thus allowing a direct exchange of groundwater.

In summary, the local groundwater conditions in the area of the tailings dams appear to be closely related to rainfall and snowmelt, but are also influenced by flow from adjacent talus debris, and by an underground contribution from the nearby Rio Gambis basin. Such conditions bring about extreme ground water levels in the June-July period: it was in fact in July 1985 that the failure of the tailings dams took place.

At Stava the two earth dams which contained the fluorite mine tailings were raised without considering the negative influence that the marshy nature of the ground and the presence of several water springs would have on the stability of these geotechnical structures. Furthermore, the tailings dams had been built on a very steep slope, with an average inclination of 25%, the dam of the upper basin had an excessive outer slope (over 80%) and did not allow water drainage or the consolidation of the tailings therein contained.

Both dams were poorly built with inhomogeneous materials, with the upper tailings dam resting on the unconsolidated silt of the lower basin. In addition, the overflow and decant pipes had been wrongly placed inside the upper basin and sagged under the increasing weight of the silty deposits, causing significant leaks inside the pond (Fig. 7). Finally, proper stability analyses were never carried out and the soil's susceptibility to failure-induced liquefaction was completely ignored, notwithstanding the good level of technical knowledge that was available from literature (Luino, Tosatti, and Bonaria 2014). In this way, when failure occurred, there was a very fast, destructive flowslide, leaving no chance of escape to whoever was in its course (Fig. 5).

The responsibilities

Ten years had passed from the Stava catastrophe when the book "Stava perché" was written (Lucchi 1995), in which the origin, causes and responsibilities of this disaster are described as they appeared in the committal for trial and in the sentences of the trials. The author was aware that he was unable to write an objective report. He therefore decided to describe exclusively what was written in the report of the Civil Defense Ministry enquiry, which was accepted by the court judges, and in the motivations of the sentences handed out at the trials. "Stava perché" is the story of a sentence that has become final, since none of the defendants or the persons responsible for the disaster ever asked for a review of the trial. As such, this document is incontrovertible and true in a State subject to the rule of law.

According to the preface of this book (De Battaglia 1995), *«the true monument to the 268 innocent Victims of Stava is the silent suffering and resilient and constant commitment that the survivors have transmitted over all these years to keep the memory of their deceased relatives alive. In this way, they could free themselves from the despair of their loss, express true civil redemption with new, more sincere relations among human beings and disseminate the knowledge that the Stava disaster was not an inevitable fatality»*.

These words do not represent just the commitment of the relatives of the Stava Victims, but also show the true cause of the disaster. This is to be found in people's relationships that in the years before and after the Stava catastrophe were characterized by superficiality, lack of care, approximation and hastiness, mere economic interest and arrogance, accompanied by subjection and complete lack of professional ethical responsibility.

The top managers of Montecatini, who in the early 1960s constructed the plant for treating the fluorite ore in a zone that was defined "perfectly functional" from the economic standpoint, showed all these negative attitudes. Although they were aware that the site chosen was the least suitable for a tailings dam, they did not hesitate to construct it on a steep marshy slope. Indeed, this was the worst place from the technical viewpoint and ten years before failure, some of their technicians had warned them that the stability of the upper basin was close to breaking point. Notwithstanding this, they ignored this alarm and continued to raise the dam.

The same negative attitudes were found also in the top managers of Prealpi Mineraria, who ignored the leakage problems that affected the basins in January and May 1985, when it should have been obvious that they were a premonition of impending failure.

The same firms that constructed and managed the Stava tailings dams again showed arrogance and presumptuous-

ness when they accused the inhabitants of the Stava valley for having built their homes near the basins, without worrying for their stability. As if those homes had been destroyed because of those who had built them, when in fact they had been constructed long before the tailings dams.
Subjection was shown also by the local authorities, which, in the early 1960s, favored the construction of the mining plant of Montecatini on Mt. Prestavèl in the name of industrialization, which – according to them – would have brought social and economic progress to the Stava valley. In particular, the administrators of the Autonomous Province of Trento, who were responsible for mining activities and should have considered the risks related to the conservation of the environment, totally ignored the hazard resulting from these high tailings dams. Furthermore, they never worried about the pollution of the watercourses caused by mining activities, as they never cared about the landscape ruined by the constant growth of these geotechnical monstrosities. These so called 'qualified technicians' submitted their expertise to economic choices, thus betraying their professional integrity.
We shall never get tired of exhorting these technical experts to claim dignity and responsibility in their professional activities. We shall never get tired of promoting new relationships among human beings, based on reciprocal respect, accountability and complete awareness of the risks involved. Hazardous industrial activities, such as the exploitation of mining resources and the use of water for economic purposes, should be based on the respect of rules, the care for the safety of people, the integrity of the environment and the correct use of natural resources. Therefore, in order to avoid the repetition of other, similar disasters, it is necessary to establish higher standards for the civil responsibility of all those who are in charge of the construction and management of potentially hazardous structures like tailings dams.

The aftermath: reconstruction, recovery of memory and social commitment

Today the Stava valley no longer shows the wounds that it received on July 19, 1985. The rebirth of a community is not measured only by the capability to restore the places where they live. Grass regrows quickly. On the contrary, human relations, the social texture and the will to look forward need time, tangible signs, practical actions and constant confrontation in order to reaffirm themselves after a tragedy of such proportions.
The rescue operations that were activated immediately after the Stava catastrophe were a first example of the active and positive reaction of the Tesero community. The subsequent vast interventions carried out by the rescue volunteer structures, which in the Alpine regions claim a centuries-old tradition, offered a demonstration of a high efficiency based on a strong human solidarity, although it was not possible to save many human lives.
At the same time, the population of Tesero started the reconstruction of the village of Stava and of all the structures that had been destroyed by the mudflow. This was carried out according to new urban planning (Fig. 10), which took into account the exposure of property to hydrogeological risks such as floods and landslides, though mining activity is no longer carried out in this valley. All the hotels were rebuilt in new, more favorable positions and the inflow of tourists is now higher than before the disaster (Viola 2011).
In the aftermath of this catastrophe, the relatives of the victims and all those who had suffered moral and material damage founded the "Victims of the Stava Valley Association". This association supported the claims of over 180 plaintiffs during the various stages of the trials that followed, with the assistance of a team of experts formed by university scientists from Italy, Great Britain and the United States. In addition, it promoted many cultural and commemoration initiatives aiming at preserving the memory of this disaster and prepared the ground for the establishment of the "Stava 1985 Foundation" (charity).
Indeed, preserving memory is a crucial duty at the service of the communities struck by catastrophic events that unfolds into several functions, as follows: 1) a healing function in the elaboration of bereavement and losses; 2) an ethical function warning against the repetitions of similar tragedies; 3) an educational function that facilitates prevention; 4) an aggregating function supporting the wounded identity of single persons and communities; 5) a generative function capable of activating new and resilient energies and 6) an exorcising function against the repetition of similar disasters also by means of rites, ceremonies, monuments (Fig. 11) and plaques.
An extraordinary event striking an entire community is inevitably an element of historical discontinuity. References to July 19, 1985, although not explicit, have entered daily relations, so much so that at Tesero the "before" and "after Stava" frequently emerge from the conversations, similarly to what was common for our parents and grandparents when they talked about "before" or "after the war".
Inevitably, living in the place where this tragic event took place, together with the desire to look beyond, has led the local inhabitants to live this tragedy with reservedness verging on modesty.
Diametrically opposed is the situation of the relatives of the victims from outside the village – nearly three quarters of the total – who were tourists from various Italian regions. For these, the opportunity to come to terms with what happened at Stava has come only in rare moments linked to the tragedy

Figure 10 – Houses and hotels in the new village of Stava (early 2000s).

Figure 11 – The monument to the Stava Victims in Tesero cemetery.

anniversaries, apart from the family sphere.
The Victims of the Stava Valley Association has been the main point of reference for overcoming bereavement thanks to the organization of the anniversaries and their meaningful contents, carried out together with the institutions. For this purpose, particularly significant was the visit of Pope John Paul II, which in 1988 brought together the community on the third anniversary of the Stava catastrophe (Various Authors 1989).
In 2002, the relatives of the Victims of the Stava Valley disaster established the "Stava 1985 Foundation", so that the 268 innocent people killed on July 19, 1985 did not die in vain. This Foundation is a non-profit organization of social utility. Its main goal is to maintain the active historical memory of the Stava catastrophe and strengthen the culture of prevention, correct management of the territory and safety of these structures in order to avoid other similar disasters.
Since the opening of the Information Centre – the seat of the Foundation – thousands of visitors, among them many students, have spent a day of environmental education in Stava, reflecting upon the importance of individual accountability (Fig. 12). These topics are dealt with daily in university institutes and high schools, thanks also to the Foundation's rich archives, where it is possible to find in-depth information about the origins, causes and responsibilities of this disaster. Most of these archives have been stored in digital format and are available on line (www.stava1985.it).
The Stava 1985 Foundation promoted and supported the post-university Master in "Analysis and Management of Geotechnical Systems" at Trento University, which was organized in order to disseminate knowledge in the field of Civil and Environmental Engineering, Geological Sciences, Sociological and Economic Sciences (Simeoni, and Tosatti 2010).
Owing to the potential hazard of tailings dams and considering also the norms established by the European Union concerning the management of earth dams and disposal of mining waste (CE Directive 2006/21), these topics have been discussed in detail.
One of the most relevant scientific events organized for the 30th anniversary of the Stava catastrophe (July 2015) was a cycle of high-formation seminars entitled "The safety of earth structures: tailings dams, fills and landfills" that the Foundation organized at Stava together with the Italian Geotechnical Association (AGI) and the Engineers Association of Trento Province.
Thanks to its constant commitment, in 2010 the Stava 1985 Foundation was awarded the Alexander Langer International Prize and in 2015 was presented with the "Green Flag" of Legambiente. The Stava 1985 Foundation is also a founding member of the "Fondazione Museo Storico del Trentino".

Figure 12 – The Information Center of the Stava 1985 Foundation (www.stava1985.it).

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The Authors wish to dedicate this paper to the memory of all the innocent Victims of the Stava valley disaster.

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