LESSONS LEARNT FROM THE SGORIGRAD AND STAVA DISASTERS

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Sgorigrad – Stava: identical disasters

The catastrophe of Sgorigrad and Vratza, in Bulgaria, and the catastrophe of the Stava Valley in the Municipality of Tesero, in Italy, are to date the worst disasters caused by the failure of tailings dams worldwide. On 1st May 1966 the failure of the tailings dam of the Placalnica zinc and lead mine, uphill of the village of Sgorigrad, gave rise to a flowslide, which ran as far as the town of Vratza and caused the loss of hundreds of lives, as well as vast material and environmental destruction.

On 19th July 1985 the failure of two tailings dams of a fluorite mine, uphill of the hamlet of Stava, gave rise to a flowslide which ran as far as the village of Tesero and caused the loss of 268 lives, as well as vast material and environmental destruction.

The Placalnica mine and the construction of the tailings dam

In 1958 the Placalnica mine in the Western Balkan Mountains, opened in 1902, was equipped with a flotation plant, built on the mountain slope, in order to extract minerals containing zinc, lead and, to a lesser degree, copper and silver. In order to decant and store the residual waste produced by the flotation process, a tailings dam was constructed in a lateral valley overhanging the village of Sgorigrad. The tailings thus produced were conveyed to the basin by means of a pipeline. The stream running on the valley floor was dammed with an embankment and its water was pumped back upstream of the tailings basin. In 1966 the basin attained the approximate height of 60-70 m. The retaining embankment for damming the torrent, the overflow towers and segments of the pipes are still visible today, together with small amounts of decanted mud, which remained in place [1] (Fig. 1).

The Prestavel mine and the construction of the tailings dams

The Prestavel mine started to be exploited on an industrial level in 1934. In 1961 it was equipped with a flotation plant and a water-supply pipeline, constructed on the slope of the mountain. A first tailings dam was built in 1961 on the slope of Mt. Prestavel, on marshy ground with an average inclination of 25%. The residual mud resulting from processing the rock was conveyed to the tailings dam by means of a pipe.

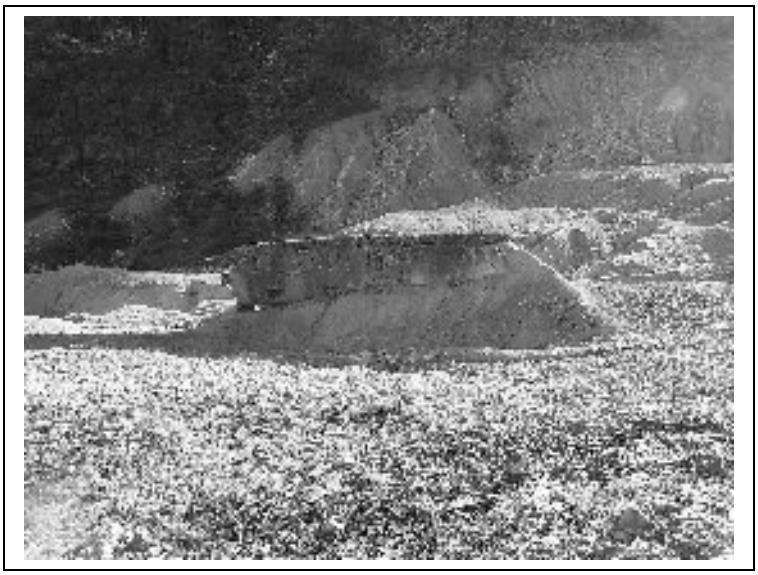

Fig. 1 – The remains of an overflow tower and mine waste where the Sgorigrad tailings dam stood

Construction of the dam of the first basin was undertaken with a small starting embankment which was anchored to the ground by means of a reinforced concrete frame. On top of this embankment the sand dam was progressively raised by means of the uphill method. The dam of the second basin was started uphill of the previous one without any provision either for anchoring it to the ground or for draining. The dam was initially raised by means of the centre-line method: as the dam grew higher the base of its embankment grew wider until eventually it rested in part on the silts of the lower basin. Subsequently the growth of the dam continued by means of the upstream method. The overflow pipes were placed inside the basins and discharged outside by passing through the dams. At the time of failure the two tailings dams were nearly 60 m high.

Sgorigrad and Stava: stability analyses

A year before disaster, stability analyses had been carried out on the safety of the Sgorigrad tailings dam. In June 1965 the engineer who carried out the investigations – Professor Pavel Evdokimov – wrote a report in which he stressed the potential danger of fissures at the foot of the basin's downstream dam (probably due to water infiltration inside the basin) and forecast the impending failure of the dam by stating, with amazing precision, that it would occur – as in fact it did – in April or May of the following year [2]. He also urged that any further storage of tailings inside the basin should be stopped immediately. The managers in charge of the mine and of the tailings dam, however, did not take into any account whatsoever Professor Evdokimov's serious warning.

In 1974 the Municipality of Tesero officially required confirmation of the safety of the Stava tailings dams. The Mine District of the Autonomous Province of Trento entrusted the concessionary company itself with stability analyses, which were carried out in 1975. Although these stability analyses neglected several indispensable

investigations, their results nevertheless showed that the slope inclination of the upper dam was exceptionally high and stability was at danger point. However, the reply of the mining company to the Mine District and therefore to the Municipality was positive. This led to further growth of the dam although this was carried out with a lower degree of inclination.

The failure of the Sgorigrad tailings dam

Failure took place on 1st May at 11:15 hours. A 220,000 m^3 flowslide, in some places over 3 m high, ran a distance exceeding 6 km, causing considerable material and environmental destruction (Fig. 2).

The mudflow destroyed most of the village of Sgorigrad, and eventually reached the town of Vratza. Rescue operations and recovery of casualties lasted several weeks. The corpses of the victims were taken to Vratza's stadium and their identification was a particularly difficult task [3]. The fact that the dam's collapse occurred around midday of 1st May probably limited the number of casualties. However, this number was still rather high as most of the inhabitants of Sgorigrad were in the town centre taking part in the celebrations of Workers' Day. Officially, the number of lives lost was declared as 107 [4]. Over 2,000 persons were injured, 576 families were affected, 156 houses were destroyed together with Vratza's Zoological Garden.

Fig. 2 – The area of Sgorigrad after the tailings dam failure (May 1966)

The failure of the Stava tailings dams

At 12:23 hours of 19th July 1985 the dam of the upper basin failed and collapsed onto the lower basin, which also failed. The flowslide composed of water and sand from the dams and the whitish silts they had contained descended downstream at a velocity of nearly 90 km/h [5], sweeping away people, buildings, trees and whatever it met in its path as far as the main valley floor.

Along its path the flowslide caused the death of 268 people, the complete destruction of 3 hotels, 53 houses, 6 industrial buildings and 8 bridges whereas some more buildings were seriously damaged. A layer of mud,

some 20 to 40 cm thick, covered an area of some 435,000 m^2 over a length of 4.2 km. Some 180,000 m^3 of waste material spilled out of the tailings dams, to which another 45,000 m^3 of debris should be added resulting from erosional processes, destruction of buildings and uprooting of hundreds of trees (Fig. 3). The area where the dams stood and the path of the mud flow were completely reclaimed some years after failure.

Fig. 3 – The Stava Valley completely devastated by the flowslide (July 1985)

Sgorigrad and Stava: causes of the failures

The failure of the Sgorigrad tailings dam occurred after three days of heavy rains. The basin was in "high pond" conditions and the tailings were saturated. The decant towers had a low spillway capacity and the pond water level had risen dangerously. In order to avoid overflowing, the operation staff dug two trenches on both sides of the dam but this desperate action was of no help. The dam failed suddenly and a large mass of tailings and water went down like a fast-moving wave of mud. According to eye-witnesses, the dam did not overflow. This was recorded also by aerial photographs. The cause of failure was the sudden loss of stability and the ensuing liquefaction of saturated tailings. For this reason the dam collapsed like a wall. If it had been overtopped, erosion would have taken some time and the failure wave would not have been so vast and fast. On the other hand, failure could have occurred due to water percolation inside the dam coming from a spring located inside the basin which had not been detected before. Very likely, considering the meteorological situation in the days preceding the disaster, failure occurred as a combination of both circumstances [4].

In the case of Stava, the cause of failure was due to inadequacy and shortcomings concerning the construction of the upper tailings dam which collapsed first. In particular, the stability conditions were never satisfactory and the silts deposited within the basin were not properly consolidated owing to: i) the marshy

nature of the foundation ground, which hindered the consolidation of the muds; ii) the erroneous construction of the upper basin's dam, which did not allow adequate drainage at its foot; iii) the position of the upper basin just uphill of the lower one: as it grew in width the dam came to rest partially on the silts of the lower basin, thus worsening drainage and stability conditions. Other reasons for failure are to be sought in the excessive height and inclination of the dam of the upper basin, which was 34 m high. The gradient of its outer slope was 39°, corresponding to nearly 80%. Furthermore, although the "upstream" method is the quickest and most economical means of raising a dam, it is also the most unsafe. Finally, the poor stability conditions of the upper dam were due also to the wrong location of the water pipes at the bottom of the basins and passing through the dams [6]. For over 20 years, there was no monitoring, nor were any adequate stability analyses ever performed by the public authorities in charge of the Prestavel tailings dams [7].

Finally, the fast flowslides of semi-fluid slime which followed the sudden collapse of the tailings dams both in Sgorigrad and Stava can be explained by considering a well-known phenomenon in soil mechanics: "flow liquefaction due to static loading". This term refers to the loss of shear strength of saturated soils under static loading. As a consequence, a soil reaches a fluidity condition comparable to that of a viscous body. The static equilibrium of a soil is therefore destroyed and its strength is no longer sufficient to withstand the static stresses that were acting before disturbance occurred. The soils susceptible to liquefaction are those in which shear strength is mobilized only by particle friction, i.e. cohesionless soils (sand and silt). Liquefaction is therefore ascribable to water fluctuations that lead to a high piezometric surface; a situation that was well documented both in Sgorigrad and Stava in the days immediately preceding the failures of their respective dams.

Sgorigrad – Responsibility for failure

The trial was heard in camera in Vratza and lasted less than one year. In May 1967, four managers and engineers were found guilty and condemned to 5 to 12 years' imprisonment. None of those convicted appealed against the verdict. Besides the responsibilities of the engineers, also the role of the managers was of paramount importance in causing the disaster since they did not seem to be aware of the safety of the plant or the serious consequences that a failure might have on the population and the environment.

Stava – Responsibility for failure

The first trial was concluded in July 1988 when ten managers and engineers were found guilty of the crimes of multiple manslaughter and culpable disaster. Legal proceedings ended with the final conviction pronounced by the Supreme Court in June 1992. This verdict confirmed the sentences of the first trial. Nevertheless, imprisonment was eventually remitted and none of the persons convicted was actually sent to jail. The Stava disaster was caused by a concurrence of conducts going beyond the judicial sphere, which put economic profit

before the safety of third parties. Therefore, both the mining companies and the public boards in charge of the conservation of the territory and safety of the population were equally guilty of this disaster.

Sgorigrad – The aftermath and the educational activities

The area affected by the flowslide was covered by a 30 to 50 cm thick layer of mud for a long time. Reclamation works carried out by the Bulgarian Army started in 1968 and lasted for many years. In the years following the collapse the residual tailings were discharged directly into the stream that flows through Sgorigrad, causing serious pollution damage. Subsequently, a second containment basin was constructed on the opposite slope of the mountain. The mine remained active until 1996. Up to the present day the water of the stream turns yellow when strong precipitation occurs, owing to rill wash action caused by rain water on the residual tailings remaining in the site where the failed basin stood. On the 40th anniversary of the Sgorigrad catastrophe, 1st May 2006, the "Path of the Stava-Sgorigrad Brotherhood" was inaugurated on the mountain overlooking the centres of Sgorigrad and Vratza. Several explanatory panels written in Bulgarian, English and Italian provide visitors with information on the analogies between the Sgorigrad and Stava Valley catastrophes. This path seals the link of solidarity and brotherhood uniting the Sgorigrad and Tesero communities, both struck by similar disasters. In 2008, under the patronage of the Stava 1985 Foundation, the Italian State Television (RAI) produced a short documentary film describing the Sgorigrad disaster entitled "The Stava of the Balkans", which points out the analogies with the Stava Valley failure. On the initiative of the Municipalities of Vratza and Sgorigrad, on 1st May 2009, the anniversary of the Sgorigrad catastrophe, a little monument in memory of the Sgorigrad Victims was unveiled outside the church of Sgorigrad. Finally, in May 2010 the main square of Sgorigrad was entitled "Tesero Square", in remembrance of the Victims of the Stava disaster which occurred in that Municipality.

The people of Sgorigrad, whose main source of income came from mining activities, are now trying to develop the natural and landscape resources of the area in order to promote tourism as their principal revenue source.

Stava – The aftermath and the educational activities

The area affected by the flowslide was reclaimed immediately after failure whilst the area where the tailings dams stood was reclaimed three years later. Reconstruction was completed in about 15 years. In the aftermath of the catastrophe, the relatives of the victims formed the Association of Victims of the Stava Valley Disaster. Among other activities, this Association played an important role in drawing up certain Laws of the State and of the Autonomous Province of Trento which granted tax relief and credit facilities to survivors in order to rebuild the houses and firms which had been destroyed [8]. In February 2002 the Stava 1985 Foundation (a non-profit organization) was officially established by the relatives of the Victims of the Stava Valley disaster with the patronage of the Municipality of Tesero in order to make sure that the deaths of 268

innocent people had not happened in vain. The duty of the Foundation is to keep alive the historical memory of the Stava Valley and other similar disasters and strengthen the culture of prevention, correct territorial management and safety in order to avoid other man-induced disasters of this kind. In 2003 the Documentation Centre of the Stava 1985 Foundation was inaugurated in Stava (Fig. 4). It offers various information displays to explain the origin, causes and responsibilities for the July 1985 catastrophe: from pictorial panels to a short fictional documentary and the website www.stava1985.it [9]. In 2007 a nature trail and educational footpath was inaugurated. Explanatory panels have been erected along its course to provide visitors with information on the role of water in mining activities. Eventually the path leads to the entrance of the mine tunnel where fluorite-rich rock was extracted, to the abandoned mine facilities and to the site where the tailings dams stood.

Final remarks

Apart from the catastrophic failures of Sgorigrad and Stava, the sad remark is that since 1986 – the year following the Stava disaster – to date, there have been over forty failures of tailings dams worldwide. On the whole, they have caused the loss of over 500 lives and extremely serious socioeconomic and environmental damage. This demonstrates that a lot remains to be done for the safety of these geotechnical structures and prevent disasters that could be avoided. The primary goal of the Stava 1985 Foundation is to increase the level of awareness and competence of those who have responsibilities.

To date, the main educational activities carried out by the Foundation are as follows: i) publication of books, pamphlets and folders to keep alive the memory of Stava and other similar disasters [10]; ii) production of short films and recording of music and theatre performances staged during commemoration events; iii) twinning ceremonies with delegates from other places where similar disasters have occurred; iv) a travelling exhibition explaining the causes and responsibilities of the Stava tailings dams failure; v) patronage of a 2nd level University Master course enabling young engineers and geologists to qualify in the proper construction and management of large geotechnical structures and make them aware of the risks involved; vi) seminars and conferences for both the general public and young students.

In particular, since it opened, the Documentation Centre of the Stava 1985 Foundation has been visited by over 35,000 people, with an average of 7,000 visitors per year. The Centre's location was chosen for its particular significance: it was built on the path of the disastrous flowslide.

Finally, after the positive conclusion of the 2nd level University Master course at Trento University, which was patronised and partially funded by our Foundation, we express the wish that European universities and research Institutions, in particular in Italy and Bulgaria, will organize post-graduate courses for young graduates and technicians from mining societies and public administrations who are to be in charge of the safety of geotechnical structures and, in particular, of active and abandoned tailings dams in Europe and elsewhere in the world.

Fig. 4 – The Documentation Centre of the Stava 1985 Foundation

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