IMPACTS OF TAILINGS FLOW SLIDES

Technical Communication by:
O. Sammarco
Italian Bureau of Mines, Ministry of Industry
Corpo delle Miniere, Via Goldoni 6
58100 Grosseto, Italy

ABSTRACT

This paper describes characteristics of tailings ponds, highlighting situations and events that weaken such facilities, and provides a method for calculating the destructive capacity of tailings flow slides from failed facilities. There are generally two classes of failures. The first type is caused by water flowing over the tailings, causing erosion and transportation of the material (overtopping), as well as by piping, which weakens the mechanical characteristics of the dam fill. In such cases, the eroded material is progressively deposited down-gradient. In the second class, dam failures can produce violent flow slides that rush downhill and cause devastation. This extreme effect is caused by liquefaction of the material contained in the ponds and/or the dams, with failure of the latter. The consequences of the flow slide are considered by making comparisons between the pressures the flow exerts on downstream structures, and the pressures required to cause such structures to collapse. Some precautionary measures are proposed to limit damages if failure occurs. Given the similarity between such failures and other landslides, it may also be desirable to apply the measures suggested here to natural slopes.

INTRODUCTION

The material deposited in tailings ponds can turn into a viscous liquid in the presence of water and rapidly move downhill if the dams confining them fail. The destructive energy released is determined by the potential energy of the mass (elevation change). It is imperative to evaluate the risks and seek to identify all the possible negative circumstances that could cause flow slides, so as to prevent such occurrences or at least attenuate their effects.

Two flow slides that resulted in numerous deaths and destruction of structures are considered. A violent flow slide occurred on 19 July 1985 following failure of two tailings dams of the Prestavel fluorite mine near Stava in northeastern Italy. The flow slide caused the death of 263 people living in the nearby hamlets (Genevois and Tecca, 1993). Flow slides on 5 and 6 May 1998 flowed into the country towns of Sarno and Quindici in southern Italy killing over 200 people. These slides occurred after heavy and prolonged rain liquefied volcanic ash (from Vesuvius) that had been deposited on the nearby hillsides.

CHARACTERISTICS OF TAILINGS PONDS

Tailings ponds are generally built close to the mine in valleys that are closed off by the construction of dams. Streams that previously crossed the valley are diverted to prevent them from coming into contact with the tailings, or they are made to flow through the pipes or drainage channels underneath the tailings (Rossi, 1973). The tailings consist of host rock and gangue. The nature of these materials varies from mine to mine and may even vary appreciably from one excavation site to another of the same mine. Often the tailings come from flotation plants, and so they often consist of sands and silts of varying types mixed with clays (Kelly and Spottiswood, 1982).

The fundamental methods for erecting tailings dams are (Klohn, 1972):

- Upstream method: this is the most cost-effective but also the least safe among those listed here; as the height of the tailings dam rises, each successive dyke moves further upstream, and so overlies an unstable bed of unconsolidated tailings (Figure 1a).
- Downstream method: this is an obvious improvement over the former (Ciccu et al., 1987). With this method, each successive layer of coarse particles from the tailings is deposited on a base of coarse, free-draining particles (Figure 1b).
- Downstream method with mine waste rock: the downstream face of the dam consists of mine waste rock (Figure 1c).
- Centerline method (Gipson, 1998): the crests of the layers of coarse particles are aligned along the same vertical line (Figure 1d).

FLOW SLIDES: AN ASSESSMENT OF THE CONSEQUENCES

The force with which flow slides move downhill is determined by the volume of flow, the elevation at which the pond is located, the characteristics of the breach in the dam, and the slope of the hillside. In order to calculate the destructive capacity of such slides, it is necessary to quantify their action on man-made structures. The flow slide rushing downhill from a tailings pond can cause extensive areas to be buried or can cause massive destruction due to the energy of the flow. In the case of the latter, it is the transformation of the potential energy of the flow down the slope into kinetic energy that causes problems. To calculate the consequences of the action of the flow, it is necessary to determine the stresses caused and compare them with the maximum stresses that man-made structures can withstand. A flow that moves downstream and hits a fixed obstacle consisting of a plane that is perpendicular to the direction of the flow, at velocity V, will hit the obstacle with a force that can be inferred from the approximated expression that relates momentum variation to impulse energy:

$$MdV = Fdt \qquad (1)$$

where M is the mass whose velocity varies, dV, over time, dt, and F is the force acting on the obstacle that causes the velocity variation.

Now supposing that the velocity V of the flow is cancelled out upon impact with the obstacle, by using γ to indicate the specific weight of the flow material, A the cross-sectional area of the stream and g the gravity acceleration; then (1) may be written as:

$$F = \gamma A V^2 g^{-1} \qquad (2)$$

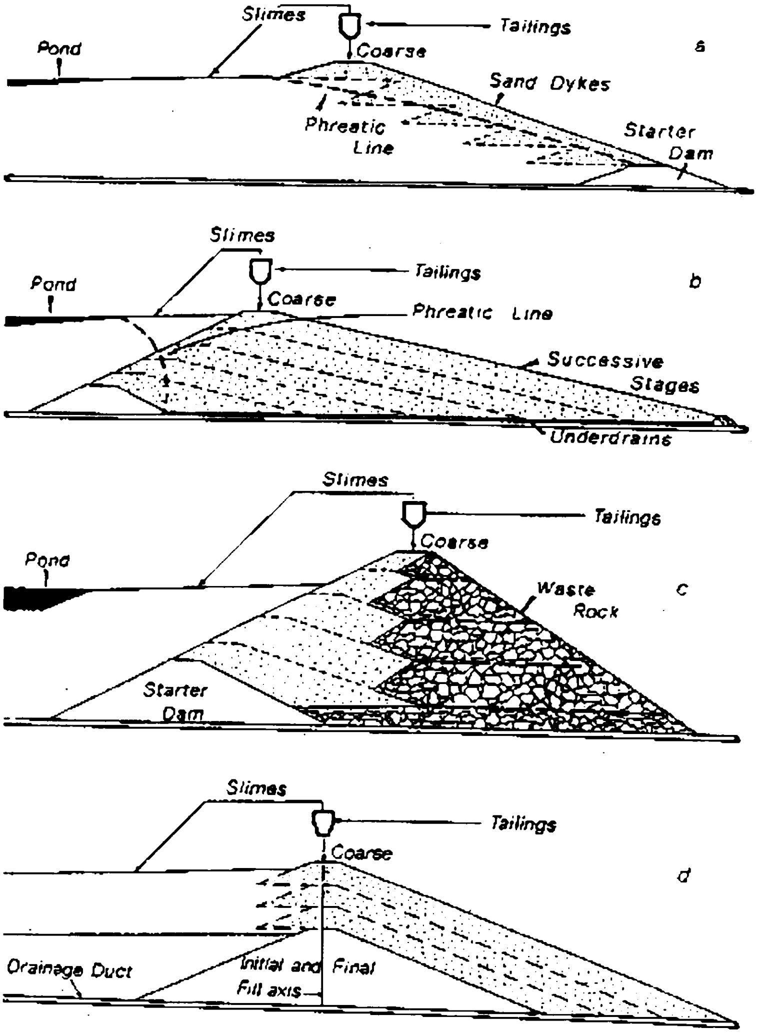

Figure 1. Basic methods of tailings dam construction: a, upstream method; b, downstream method; c, downstream method with mine waste rock; d, centerline method.

So, if the specific weight of the flow material, its cross-sectional area and the velocity of the stream were to be equal to 1,300 kg m^{-3}, 1 m^2 and 10 ms^{-1}, respectively, the force acting on the obstacle would be:

$$F = 1{,}300 \times 1 \times 10 \times 10 \times 9.81^{-1} = 13251.78 \text{ kg} = 130 \text{ kN}$$

Figure 2 shows the force versus the velocity of the flow obtained from (2), acting on the obstacle consisting of a plane surface orthogonal to the direction of the flow where the density of the material is assumed to be 1,300 kg m^{-3}, the cross-sectional area is equal to 0.50, a, 1.00, b, 2.00 m^2, c, respectively, and the velocity is offset upon impact. If the flow were not to hit the obstacle perpendicularly, ignoring the shear stresses on the surface of the obstacle, it would exercise a force given by:

$$F = AV^2g^{-1} \cos \theta \qquad (3)$$

where θ is the angle between the direction of the flow slide and the normal to the surface of the obstacle. Therefore, assuming a unidirectional flow, diagrams can be drawn up to analyse the risks to which an obstacle would be exposed depending on its orientation at a given velocity and cross-sectional area of the flow slide.

The method suggested to infer the force presupposes that the velocity of the flow at the time of impact is known and that the velocity is offset as a result of the impact. The velocity at which the flow will hit the obstacle can only be approximated. Besides considering the elevation difference between the pond and the obstacle, it is also necessary to take into account the energy attenuation to which the flow slide is subjected as it flows. This is difficult to measure or calculate because of the flow viscosity, the deformations that it and the surface on which it flows undergo, and of the resistance of vegetation on the flow path. Furthermore, the velocity of the mud will not be completely offset upon impact, and consequently the forces calculated will be greater than the effective forces. The forces thus calculated will only provide an order of magnitude (conservative) estimate of the effective forces, but will in any case be useful for making a gross evaluation of the potential effects such an event could have on the structures downstream.

To determine the resistance of man-made structures, it was assumed that 1 m high flow slides with a specific weight of 1,300 kg m^{-3} would impact a portion of the structures in the perpendicular direction; approximate pressure values and velocities of the flow slide required to make such structures fail were then calculated. Such values are shown in Table 1. The forces and velocities calculated and the effect of such failures are consistent with the effects produced by the flow slide of 19 July 1985 that emanated from the tailings pond of the Prestavel mine. A total of 240,000 m^3 of material rushed downstream for 5,000 m with an average inclination of 10%, destroying the villages of Stava and Tesero and killing 263 people.

CONCLUSIONS

To avoid the disastrous effects that have just been inferred at the theoretical level, it is imperative to prevent the failure of tailings dams due to weakening of the dams by erosive action of water and/or other factors such as earthquakes and piping. Even well constructed tailings ponds can become vulnerable over time; therefore, it is necessary to impose precautionary

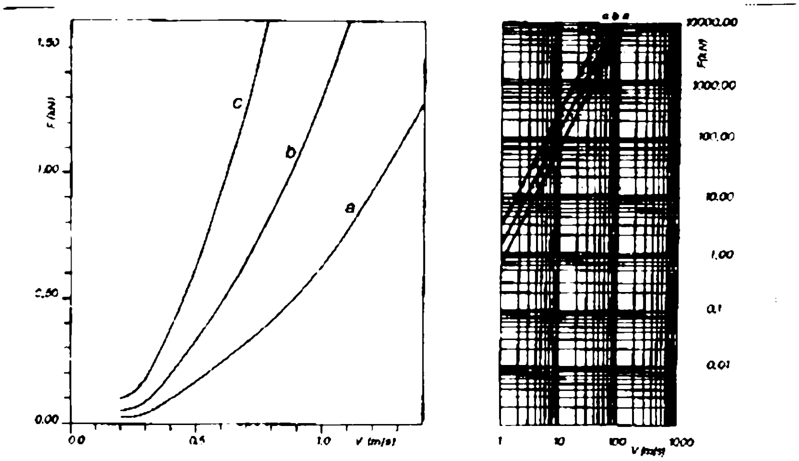

Figure 2. Force of a flow slide on a surface perpendicular to the flow obstacle versus flow velocity, V, for values of the flow slide section of 0.50, 1.00 and 2.00 m^2, assuming that V is negated by the impact.

measures to avoid catastrophes. Suggested measures include:

- not authorising homes (Genevois and Tecca, 1993) or adits to underground mines (Rossi, 1975) to be constructed downstream from most tailings ponds;
- in cases in which the impact energies would not be high, man-made structures could be allowed downstream from the ponds, but their geometry and orientation would have to be such as to oppose sufficient low resistance against a flow slide;
- if man-made structures that could be damaged by a flow slide are present, protective channels and embankments should be constructed so that flow slides would move along a predefined route.

Flow slides with catastrophic effects have occurred not only because of failure of tailings dams, but also as a result of landslides of natural slopes made of non-cohesive materials. Given the striking similarity of circumstances, settings and mechanics of the slide events, the precautionary measures envisaged for tailings ponds could also be applied to areas of slope instability where a landslide could produce destructive effects for people and structures.

ACKNOWLEDGEMENTS--The author thanks Messrs C. Maida and S. Tassoni of this District for their active and kind collaboration.

Table 1. Man-made structures and the dynamic characteristics of flow slides that will result in structure collapse.

Structure	Type of collapse	Values sufficient for collapse	
		Pressure	Velocity
		(kPa)	(m s^{-1})
Roof	Breakthrough	0.98	0.87
Curtain walls	Knocking down	1.47	1.06
Reinforced concrete pillars with section 0.30x0.30 m^2	Failure mainly from bending	21.90	4.10
Two floor stone dwellings with horizontal section of 20x10 m^2 and long side normal to flow direction of the flow slide	Overturning	8000.00	78.45

REFERENCES

Anon.,1985. Dopo la tragedia di Val di Fiemme. Epoca. 2 Agosto, Anno XXXVI. In Italian.

Ciccu R., P. P. Manca and G. Massacci, 1987. La stabilità dell'argine del bacino di decantazione della miniera di Mont'Ega (Sardegna occidentale). L'Industria Mineraria, n. 4, pp. 15-25. In Italian.

Ciccu R., F. Di Gregorio, P. P. Manca, G. Massacci, E. Massoli and R. Novelli, 1987. I bacini di contenimento degli sterili di flottazione in Sardegna : problemi di sicurezza e necessità di intervento. Atti Convegno Le Scienze della Terra nella Pianificazione Territoriale. Chieti. In Italian.

Genevois R. and P. R. Tecca, 1993. The tailings dams of Stava (Northern Italy) : An analysis of the disaster. Proc. Environmental Management Geo-Water and Engineering Aspects. 8-11 February, Wollongon, Australia. Balkema A.A., Rotterdam, pp. 23-36.

Gipson A. H. (1998). Tailing disposal - The last 10 years and the future trends. Proc. of the Fifth International Conference on Tailings and Mine Waste '98. 26-28 January, Fort Collins, Colorado, USA. Balkema, Rotterdam. pp. 127-135.

Kelly E.G. and D. J. Spottiswood, 1982. Introduction to Mineral Processing. John Wiley & Sons, New York, p. 490.

Klohn E.J., 1972. Design and Construction of Tailings Dams. CIM Bull., 65, pp. 28-44.

Rossi G., 1973. I bacini di decantazione dei rifiuti degli impianti di trattamento dei minerali. L'Industria Mineraria. Ottobre e Novembre, pp. 465-480 e 525-545, In Italian.