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:

\[
MdV = F dt
\]

(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 \( \gamma \) 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:

\[
F = \gamma AV^2 g^{-1}
\]

(2)