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The role of capillary water in the stability of tailing dams

María T. Zandarín [a,1], Luciano A. Oldecop [a,*], Roberto Rodríguez [b,2], Francisco Zabala [a,1]

[a] Instituto de Investigaciones Antisísmicas "Ing. Aldo Bruschi", Facultad de Ingeniería, Universidad Nacional de San Juan, San Juan, Argentina, Av. Libertador (Oeste) 1290, 5400 San Juan, Argentina
[b] Departamento de Química, Facultad de Ciencias, Universitat de Girona, Campus Montilvi, 17071 Girona, Spain

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ABSTRACT

Tailings storage facilities are complex geotechnical structures. The present paper focuses on the study of a case-history, a tailing dam from the nickel industry located in Cuba, with the objective of gaining knowledge about the geotechnical behaviour of such structures. The dam behaviour was modelled by means of a coupled hydro-mechanical finite element formulation. Due to the low permeability of tailings, the phreatic surface in the deposit remains high during and after its construction. Steady-state flow regime would be reached only several decades after closure. Moreover, capillary rise causes the saturation degree to stay high in the whole storage. Under the action of rain storms, phreatic levels rise quickly due to the presence of capillary water. Following the end of the storm, phreatic levels fall slowly because of the low hydraulic conductivity. The results of the analysis show that the stability of the dam strongly depends on capillary phenomena. In the light of this conclusion it seems reasonable to propose including the measurement of capillary water in the standard monitoring schedule of tailing dams.

1. Introduction

Tailings storage facilities are complex geotechnical structures. They are commonly built by the discharge of slurry within an impoundment. Most tailings are fine-grained materials. Hence, their permeability is low and unsaturated phenomena play a significant role in their behaviour. Tailing dams are subjected to a number of external actions resulting from their operation and their interaction with the atmosphere and foundation. Moreover, many physicochemical phenomena take place within the tailings deposit. The resulting operation regime has a direct influence on the dam stability and safety.

Fig. 1 summarises actions and phenomena occurring in a typical tailing impoundment. Tailings are discharged, in the form of slurry, from pipes located in the perimeter of the deposit. The slurry usually has liquid to solid ratio higher than 3:1 in volume. Hence, the water volume introduced in the deposit with the tailings discharge is always relevant for its hydraulic operation. Water starts to segregate from the slurry mass at the moment it reaches the surface of the deposit. Part of the expelled water infiltrates into the previously deposited tailings mass, while the rest flows as surface runoff down to the decant pond. The ratio between infiltration and runoff depends on a number of factors such as the properties of the slurry, the discharge rate, the duration of discharge, the permeability of the deposited tailings, their degree of saturation, the presence of retraction cracks, the position of the phreatic level, etc. Moreover, the deposited tailings form a beach gently sloping towards the decant pond (usually less than 5°). As the slurry flows along the tailings beach, a spontaneous sorting by particle size occurs. Large particles settle close to the discharge point while the finer particles are dragged farther away. In fact, this is a favourable effect, since it produces a material with higher hydraulic conductivity in the vicinity of the dam, helping to depress the phreatic surface there, and hence improving the stability conditions of the deposit.

During rainfall or snow melting, additional amounts of water are introduced in the deposit. Part of the precipitated volume will infiltrate, and the rest will flow as surface runoff, finally reaching the decant pond. Evaporation also occurs from the surface of tailings. Usually, the position of discharge points are regularly changed, so as to manage the levels of the tailings within the deposit and to control the position of the decant pond. Therefore, the tailings surface becomes periodically subjected to drying by evaporation. This may induce an ascending flow by capillary rise, fed from the phreatic surface. Drying of a porous material is a complex phenomenon, its rate being controlled by a multitude of factors such as the relative humidity of air, the wind speed, the available heat (mainly contributed by sun radiation), the properties of the material controlling capillary rise, vapour diffusion in the porous media, etc. If drying goes on during enough time, retraction cracking may occur in the surface of tailings. Vertical cracks together with horizontal (or sub-horizontal) layering features dramatically change the hydraulic conductivity of the material (Rodriguez, 2006).

Surface runoff waters may enter the decant pond if the deposit is built in a basin. Modern tailings storage facilities are commonly supplied

* Corresponding author. Tel.: +54 264 422 8123; fax: +54 264 421 3672.
E-mail addresses: maria.teresa.zandarin@upc.edu (M.T. Zandarín), oldecop@unsj.edu.ar (L.A. Oldecop), roberto.rodriguez@udg.edu (R. Rodríguez), fzabala@unsj.edu.ar (F. Zabala).
[1] Tel.: +54 264 422 8123; fax: +54 264 421 3672.
[2] Tel.: +34 972 41 8190; fax: +34 972 41 8150.

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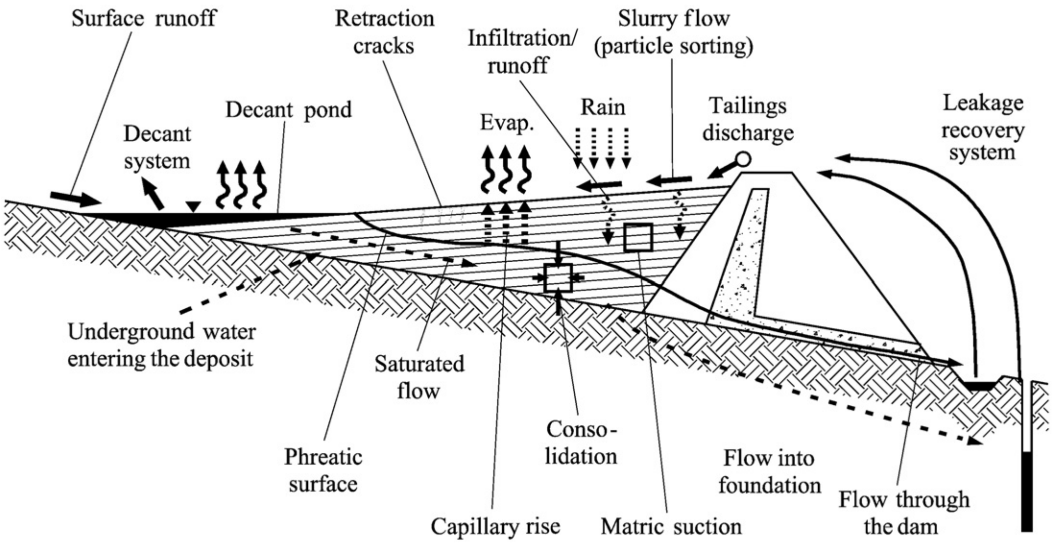

Fig. 1. Scheme of a tailing dam, indicating the factors and phenomena affecting its operation.

with by-pass systems for preventing runoff waters to enter the deposit. The water level in the decant pond is controlled by a decant pipe or a pumping system. Continuous infiltration occurs from the decant pond into the tailings mass. The deposit may drain through the dam and also through the foundation material. In certain cases, where spring conditions exist in the foundation area, underground water may enter the deposit (Chandler and Tosatti, 1995). Modern tailing dams are usually provided with internal drains and watertight barriers in order to keep natural water separated from process water. The steady-regime position of the phreatic surface, within the deposit, basically depends on the saturated hydraulic conductivity of tailings, the free water level in the pond and the drainage conditions of the deposit. However, as shown in this work, transient rise or depression of the phreatic surface may occur, due to the contribution of infiltrated water or evaporation.

Tailings are discharged in the deposit in their loosest condition. A consolidation process follows the deposition, under the increasing overburden weight of deposited tailings. During consolidation, water expelled from the material pores joins the infiltrated water, increasing the amount of water to be drained from the deposit. The reduction of porosity due to consolidation, changes the hydraulic properties of tailings (reduces conductivity and increases capillary rise). On the other hand, tailings above the phreatic surface remain in unsaturated condition. The resulting matric suction leads to the capillary forces acting in the particle contacts, increasing the strength of the material and reducing its compressibility. However such improved mechanical properties are rapidly lost if the material becomes saturated.

Many other phenomena could be considered, such as phase changes of water, vapour diffusion, solute transport, solute precipitation, cementation, crusts formation, etc, complicating more and more the conceptual model proposed. The conceptual model presented above suggests that the study of the operating regime of tailing dams can be a quite complicated task. A large number of physicochemical phenomena of various natures are expected to occur within the deposit during its operation. Some of those phenomena may produce interactions, leading to coupled problems. The main objective of this paper is to try to identify which of the factors listed in the conceptual model are really relevant for the structural safety of a tailing dam and also to measure their relative importance. This was done by developing a numerical model of a real case-history. However, as detailed in section 3, not all of the identified phenomena identified could be included in the model developed. Effort was put in the determination of the parameters of constitutive model, in order to get a numerical simulation as close as possible to real operation conditions.

2. Case history

The tailings dam studied is one of the facilities at Pedro Sotto Alba nickel mine, located in the province of Moa, in the southeast of Cuba. The impoundment is located on a low lying flood plain in the south bank of Moa River (Fig. 2a). It is founded on alluvial sediments of quaternary age, underlain by stiff clays and cretaceous ultramafic serpentine (Fig. 2b). (Greenaway et al., 2002).

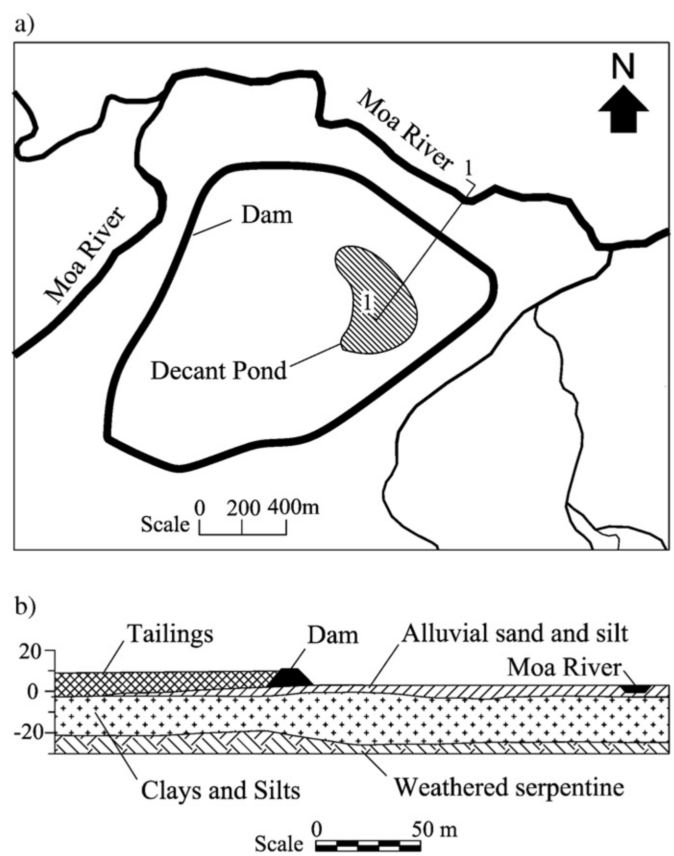

Fig. 2. a) Planimetry of Pedro Sotto Alba tailings impoundment. b) Cross section 1-1 through NE dam (after Chalkley et al., 1999).