Formation of tailings dam beaches

Formation de la plage des barrage de stériles

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ABSTRACT: Hydraulic fill tailings dams are usually constructed by distributing a slurry of tailings along the length of the tailings containment wall. The slurry gravitates towards a pool, remote from the wall, thus forming an hydraulic-fill beach. The predictable formation of this beach, the shape of the beach surface profile and the particle deposition that occurs on the beach are the keys to successful operation of the tailings dam. The paper describes some of the essential features of hydraulic-fill beaches, namely:

- the energetics of beach formation for deposition in air;
- beach formation for deposition through and under water; and
- beaches formed in air that run into water.

The aim is to provide some understanding of tailings dam beach geometry, including some of the effects of the deposition regime.

RÉSUMÉ: Les barrages de résidus à pompe hydraulique sont souvent construits en distribuant un coulis de résidus aux long de la longueur du mur de retention du résidus. Le coulis gravite vers une bâche, s'éloigne du mur pour ainsi former une plage par remplissage hydraulique. La formation prévisible de cette plage, la forme du profil de la surface de la plage et la déposition des particules qui y prend lieu sont d'une importance capitale pour la réussite de l'opération du barrage de résidus. L'article descrit quelques importante traits des plages, principalement:

- les énergies de formation de la plage par déposition à l'air;
- la formation de la plage par déposition à travers et sous l'eau; et
- les plages à l'air qui coulent dans l'eau.

Le but est de fournir quelques interprétations de la géométrie de la plage du barrage de résidus, y compris les effets du régime de déposition.

1 INTRODUCTION

Hydraulic fill beaches, formed of particular tailings, assume profiles that are geometrically similar, irrespective of the length of the beach or the difference in elevation between the point of deposition or discharge and the pool of the tailings impoundment (Blight, 1994, 1998). The characteristic formation of a so-called "master beach profile", enables the beaching characteristics of tailings to be studied realistically by means of laboratory-scale model beaches. Most of the research on the form and formation of hydraulic fill beaches has been concerned with beaches of tailings deposited in air. However, in certain situations, tailings beaches are deposited in water, or partly in air and partly in water. Limited investigations (Blight, 1994, 1998) have indicated that beaches formed under water also assume a master profile. This paper will investigate the formation of beaches in air as well as under water, and the change in beach profiles when tailings, initially deposited in air, flow into water to form a beach partly in air and partly under water. All of the studies are based on experiments at model scale. However, there is ample evidence that characteristics observed at model scale also apply at prototype scale (e.g. Blight, 1994).

2 THE MASTER PROFILE

The phenomenon of the master profile for hydraulic fill beaches was first reported by Melent'ev et al. (1973), who observed and recorded beach characteristics while working with hydraulic fill water retaining embankment dams built of natural materials.

Two types of mathematical expression have been used to describe the master beach profile (see Figure 1): If the length of the beach, h, can be clearly defined as the horizontal distance from the point of deposition to the edge of the pool at the end of the beach, the expression

$$y/v = (1 - x/h)^C \qquad (1a)$$

can be used. In this expression, y is the height of a point at a horizontal distance x from the point of deposition, and v is the height from the level of the pool to the point of deposition. C is a constant that describes the degree of concavity of the beach. If the length of the beach is not clearly defined, for example, when there is no pool, the expression

$$y/v = \exp[-(cx/h)] \qquad (1b)$$

can be used. In this expression, c describes the degree of concavity of the beach. McPhail and Blight (1998) have shown that an exponential expression for the shape for an hydraulic fill beach can be derived by considering energy changes down the beach for a maximized change of entropy. Equation (1b) is therefore to be preferred to equation (1a), as it has some rational basis.

It is also possible for beach profiles to be convex, or partly concave and partly convex. Examples of such profiles were given by Blight (1994).

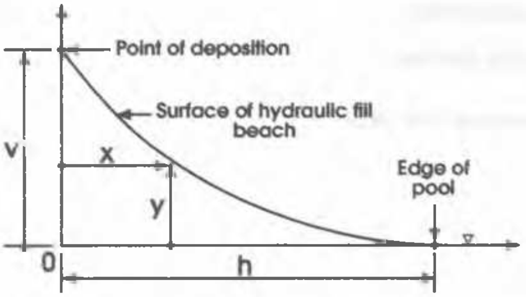

Figure 1. Basis for defining the shape of an hydraulic fill beach.

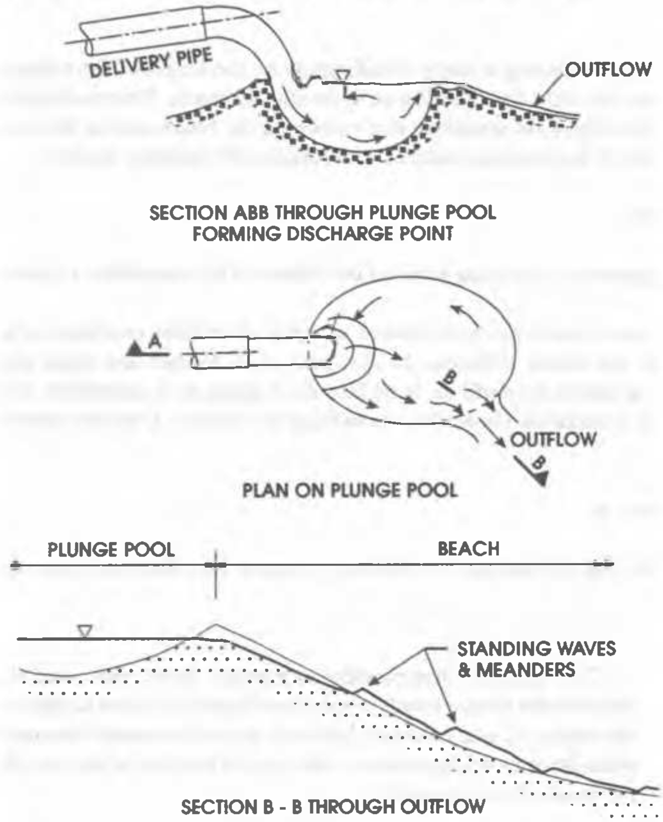

Figure 2. Geometry of plunge pool and initial part of tailings beach.

3 ENERGETICS OF THE DEPOSITION PROCESS

Tailings slurry is transported to the discharge points on a tailings dam at a velocity sufficient to keep all particles in suspension. The power necessary to overcome the frictional resistance and maintain particles in suspension is the power applied to the system by the delivery pumps. On discharge, much of this power is dissipated and the available energy of the tailings stream reduces to a residual amount. The delivery line ends above the beach level and where the discharge stream contacts the beach a "plunge pool" develops as illustrated in Figure 2 (McPhail and Blight, 1998). Within this plunge pool much of the energy of the discharge stream is dissipated. The slurry plunge pool and the geometry of the stream beyond the plunge pool down to the pond is regulated by the difference between the levels of the plunge pool and the tailings pond, the pond location and the rate at which tailings are deposited. As the level of tailings increases, the stream meanders down the beach and from time to time the position, width and depth of the overflow from the plunge pool may change. Standing waves commonly develop in the tailings stream and then disappear to reappear elsewhere, as it runs down the beach, showing the instability of the flow regime.

At all times during the discharge period deposition occurs in the plunge pool (which may also change depth and diameter), at each point along the beach and in the pond. Hence the beach and the floor of the plunge pool aggrade progressively. The loss of energy from one point on the beach to the next determines the mass of tailings deposited on the beach between those points and hence the rise in beach surface. Since large particles require more energy to be maintained in suspension than smaller particles, larger particles tend to be deposited close to the discharge point, while finer particles are transported further down the beach towards the pond.

4 VARIATION OF ENERGY DOWN THE BEACH

Along the tailings beach, kinetic energy is a maximum at the point of discharge from the delivery pipe and a minimum at the end of the beach. Within the delivery pipeline the kinetic energy is maintained at a level that prevents settling out of particles. On discharge, however, the kinetic energy in the plunge pool, and all the way to the pool (at the end of the beach) is always too low to prevent particles from settling out. Also, water may seep into the beach surface, further reducing the available energy. The flow rate and slurry density therefore vary down the beach. Hence the stream power will also vary down the length of the beach.

By modelling the energy variation down the beach, it can be shown (McPhail and Blight, 1998) that the value of stream power P that will maximise the entropy S of the system is:

$$P = -\frac{1}{\mu}\ln\left[(1-e^{-\mu P_o})\frac{x}{L} + e^{-\mu P_o}\right] \quad (2)$$

Equation (2) allows the variation of stream power P with distance x to be determined from a knowledge of the three parameters: P_o, μ and L.

- L, the length of the beach is determined by the geometry of the tailings dam;
- P_o, the initial stream power at exit from the plunge pool can be determined by the discharge quantity and velocity; and
- the parameter μ depends on the initial gradient of the stream power.

5 PREDICTING THE BEACH PROFILE

Under steady flow conditions, the kinetic and potential energy of the tailings stream will decrease progressively down the beach. Unlike the flow in the delivery pipe, where velocities, and therefore energy levels, are maintained high enough to prevent silting, the beach stream flows under open channel, gravity-controlled, conditions and is unable to maintain particles in suspension, so that tailings are deposited along the flow path. However, because of deposition on the beach and aggrading of its surface, the potential energy at every point along the beach increases with time. The local potential energy increase represents the loss in total energy at that point. In other words, the rate of aggradation of the beach per unit time represents the rate of energy loss per unit time, or the stream power. Therefore the slope of the beach surface represents the slope of the stream power curve, or

$$\frac{dy}{dx} = \frac{dP}{dx} \qquad (3)$$

Differentiating equation (2) yields

$$\frac{dP}{dx} = \frac{-(1 - e^{-\mu P_o})}{L\mu e^{-\mu P_o}} \qquad (4)$$

At the discharge from the plunge pool, $P = P_o$ and dP/dx will depend on the rate of energy loss of the tailings stream as it exits the plunge pool, i.e.

$$\frac{dP_o}{dx} = \text{initial slope} = \frac{-(1 - e^{-\mu P_o})}{L\mu e^{-\mu P_o}} \qquad (4a)$$

Having established a value for μ from equation (4a) it is possible to calculate the beach profile by integrating equation (4) numerically to give

$$y = H - \sum_{0}^{x} \left[\frac{1 - e^{-\mu P_o}}{L\mu e^{-\mu P}} \right] \Delta x \qquad (5)$$

Figure 3 illustrates the application of equation (5) to a number of full-scale beaches covering a range of tailings products of differing particle size distributions, particle specific gravities, slurry relative densities (RD) and beach lengths (McPhail, 1995).

6 DEPOSITION OF TAILINGS THROUGH WATER AND UNDER WATER

To form an underwater beach, the tailings can either be deposited through water (i.e. the particles fall freely through water from a deposition or discharge point at the water surface), or the deposition point can itself be underwater. The deposition through water described by Blight et al. (1995), took place from a spigot pipe supported at the surface of the water by means of a line of pontoons. An alternative situation for underwater deposition would be to have the spigots extended by means of flexible pipes that discharge the tailings like a series of tremie tubes onto the underwater tailings surface. Figure 4 shows beach profiles formed by deposition through water at three flow rates. The flow rates are given in mm per hour of deposition as an average over the plan area of the test flume in which the beach was formed. The dimensional beach profiles (Figure 4a) were found to flatten progressively as the rate of deposition was increased. At the slowest rate of deposition, 300 mm/h, the slope of the initial portion of the beach was 26° and this flattened to only 3° at the highest rate of deposition of 2 000 mm/h. The non-dimensional beach profiles in Figure 4b show a progressive reduction in concavity as the flow rate was increased.

It appears from this rate effect that, at the slowest rate, the tailings were settling slowly enough for the material to be deposited in close to a fully consolidated state. As the flow rate was increased, however, water was entrapped by the falling tailings which could not fully consolidate. Therefore the tailings had a progressively lower strength as they were deposited and consequently came to rest at progressively flatter slope angles.

Figure 5 shows the results of similar tests for deposition

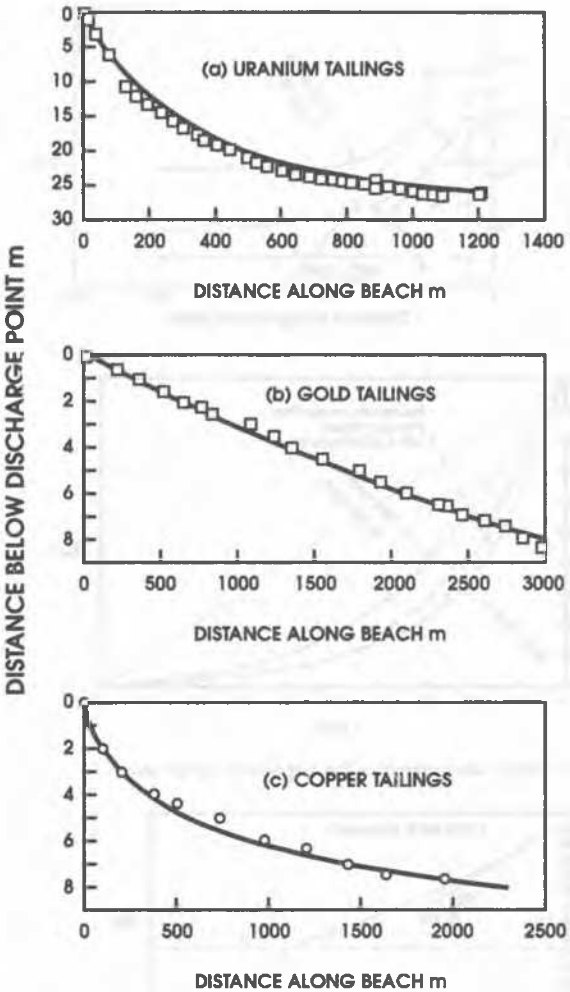

Figure 3. Comparison of observed and predicted tailing beach profiles for three types of tailings.

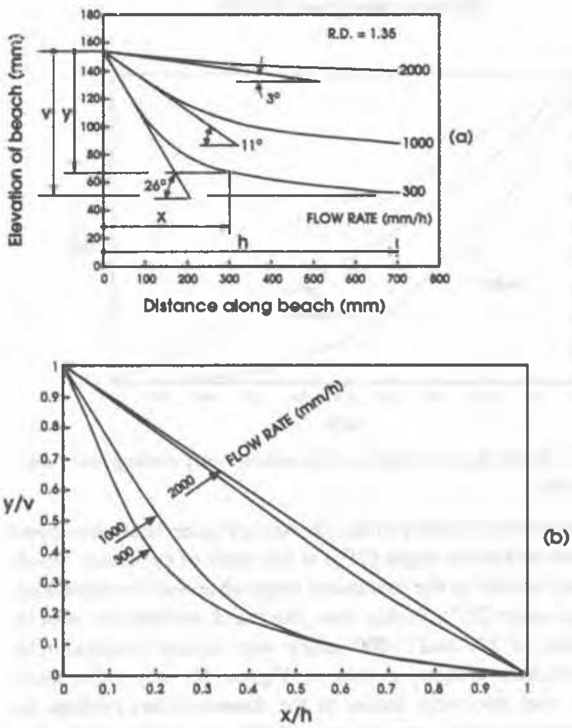

Figure 4. Beach characteristics for deposition through water.

under water. The plunge pools formed by underwater deposition are very similar in shape and dimensions to those formed in air.

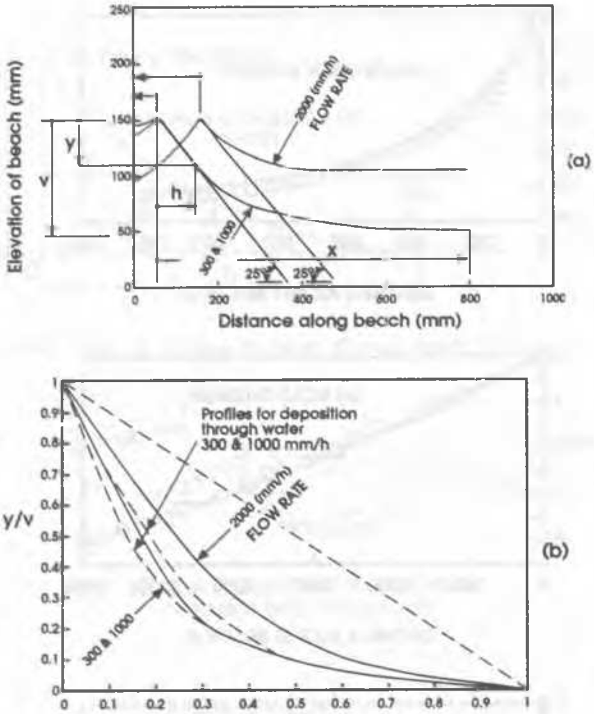

Figure 5. Beach characteristics for disposition under water.

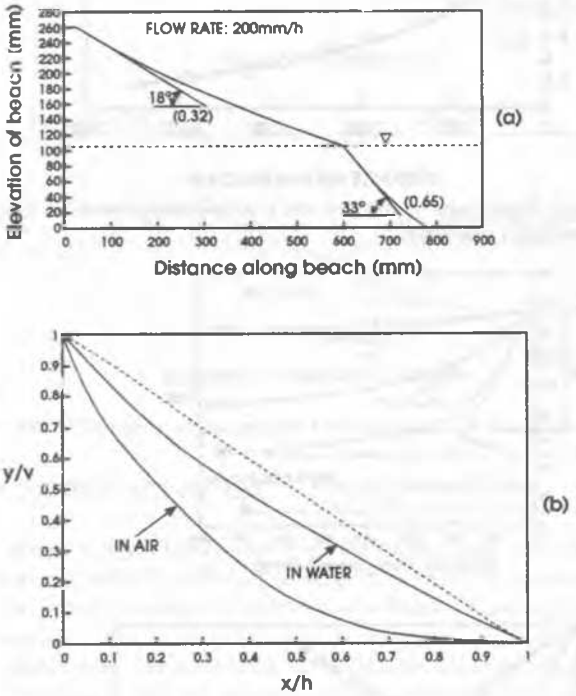

Figure 6. Beach characteristics for deposition in air, running into water - 100% sand.

The dimensional beach profiles shown in Figure 5a all developed the same maximum angle (25°) at the head of the beach which was very similar to the maximum angle observed for deposition through water (26°). In this case, the beach profiles for rates of deposition of 300 and 1 000 mm/h were almost identical. The dimensionless profiles shown in Figure 5b were also quite similar, and also very similar to the dimensionless profiles for deposition through water at rates of 300 and 1 000 mm/h. It is obvious from Figure 5a that the size of the plunge pool depends on the rate of tailings flow and is related to the reduction of energy caused in the tailings stream. Once the de-energized tailings stream overflows the rim of the plunge pool, it has a very similar energy per unit volume regardless of flow rate, and therefor forms beaches with very similar profiles. Because of the reduction of energy that occurs in the plunge pool, the progressive beach flattening with increased flow rate, that occurs with deposition through water, does not occur with underwater deposition.

7 BEACHES IN AIR THAT RUN INTO WATER

It often occurs in hydraulic fill construction that material is deposited in air, forms a beach, and then runs into water. In normal tailings dam construction, the underwater portion of the beach is usually only a small part of its total length and (thus) unimportant. However, in hydraulic fill land-building or land-reclaiming the underwater beach may be as important, or more important than the beach in air.

Figure 6 shows the results of a model beaching test in which a beach of fine sandy tailings, formed in air, runs into water. Figure 6a shows that the beach had a sharp discontinuity where the tailings entered the water. The initial slope of the beach in air was 18°, while that of the underwater portion of the beach was 33°. Figure 6b shows that the dimensionless underwater beach profile was much less concave than the profile of the beach in air. Further examples of such air/water beaches are given by Blight (1998).

8 DISCUSSION AND CONCLUSIONS

.1 The phenomena involved in hydraulic fill beach formation in air are complex. Although a concave beach profile, for example, can be interpreted in terms of changes of energy and entropy, this does not explain the formation of convex or concave/convex beaches such as those discussed elsewhere by Blight (1994, 1998). It is also obvious that deposition of tailings through or under water involves even more complex processes than the formation of beaches in air.

.2 The use of the entropy maximisation takes into account both the apparent disorder of the deposition process as well as the extent to which the process is ordered. Predictions of beach profiles can never be exact, but use of the entropy equation constitutes an attempt to make the least biased estimates of beaching characteristics.

.3 During the deposition of tailings through water, the initial slope of the beach depends very greatly on the rate of deposition. At slow rates the material settles on the beach in a consolidated state and the initial slope approximates an "angle of repose in water". As the rate of deposition increases, the tailings settle, still in slurry form, and spread to form a near-horizontal beach surface.

.4 Deposition under water has more similarity with deposition in air. A plunge pool forms at the point of deposition and the tailings slurry overflows the rim of the plunge pool to form the beach. Most of the energy of the tailings is dissipated in the plunge pool, and because of this, much the same shape of beach results regardless of rate of deposition.

.5 When a tailings beach formed in air enters the pool, the slope steepens sharply. In the case of the sand tested here, the initial slope of the underwater beach was double the initial slope of the beach in air. Similar observations also apply to other types of tailings.

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