Environmental Protection of Abandoned Tailings Dams

Protection Environnementales des 'Halde de Déchets Abandonnée

G.E. BLIGHT[1] Professor of Construction Materials, University of the Witwatersrand, Johannesburg, South Africa
C.E. REA
J.A. CALDWELL Steffen, Robertson and Kirsten, Inc., Consulting Geotechnical Engineers, Johannesburg, South Africa, and Vancouver, Canada
K.W. DAVIDSON Northern Lime Company, Johannesburg

SYNOPSIS The Metropolitan Area of the Witwatersrand in South Africa has grown up around the Witwatersrand gold mines that stretch in an unbroken line over a distance of 100 km from the city of Springs in the east to Randfontein in the west. The area is now completely built up and consists of an unbroken chain of urban and industrial development. The mines have largely been worked out and abandoned, but their deposits of waste material remain, and have been surrounded, and in some cases, covered by urban and industrial sprawl.

The paper describes measures currently being taken to prevent air and water pollution from abandoned tailings dams in the Witwatersrand area. The measures are largely of a geotechnical nature and include:
(i) The construction of catchment walls and dams
(ii) The terracing of slopes to minimize erosion, and
(iii) The stabilization of the surfaces of the dams using cement and lime to prevent wind and water erosion.

The work is being carried out in terms of a set of guidelines for environmental protection adopted by the Chamber of Mines of South Africa.

INTRODUCTION

Unlike the United States of America and Canada, the Republic of South Africa has no legislation specifically directed towards protection of the environment. However, there are a number of statutes that have relevance to the design, operation and abandonment of residue deposits. These are the Air Pollution Prevention Act, the Health Act, the Mines and Works Act, the Soil Conservation Act and the Water Act. In order to comply with the requirements of these various Acts and to achieve effective environmental control over tailings deposits owned by its members, the *Chamber of Mines of South Africa in 1978 commissioned two of the authors to draft a comprehensive set of guidelines for the design, operation and closure of tailings deposits.

After a brief description of the requirements of the guidelines pertaining to the closure and aftercare of tailings deposits, this paper will describe measures put into effect to bring a number of abandoned tailings dams in the Witwatersrand area of South Africa into compliance with the guidelines. The measures to be described do not involve high technology, but incorporate a number of interesting and possibly novel features.

* The Chamber of Mines of South Africa is an association of mining houses which has as one of its functions the development of technology for the benefit of the South African mining industry as a whole.

REQUIREMENTS OF THE GUIDELINES FOR THE CLOSURE OF TAILINGS DEPOSITS.

Prior to the closure of any tailings deposit, the guidelines require an inspection to be made by a professional engineer who should report on the existing state of the deposit and list all actions that are required to ensure that the deposit complies with the provisions of the guidelines. In addition to the state of the tailings deposit itself, the report should note the presence of any adjacent structures or development and the extent to which they may be affected by abandonment of the deposit. Recommendations to minimize the impact of abandonment or of possible failures of the deposit after abandonment should also be made.

Erosion of the Top Surfaces

The Air Pollution Prevention Act requires that steps be taken to prevent dust originating from any waste deposit from becoming a nuisance by dispersion in the atmosphere, while regulations under the Mines and Works Act require that any waste deposit be dealt with in a satisfactory manner so as to prevent the dissemination of dust or sand therefrom. The Water Act requires all rain water precipitated on a waste deposit to be retained thereon, together with any of the waste material that becomes displaced by the action of the precipitation. To comply with these requirements, the guidelines require the best practicable means to be adopted to prevent erosion of top surfaces. Amongst measures that are suggested for

controlling wind erosion are the following:
a) Establishing vegetation on the top of the deposit either by planting directly into the tailings material or by first covering the surface with a layer of top soil of suitable thickness, or
b) covering the top of the deposit with a suitable thickness of broken waste rock.

Water erosion on top surfaces as well as the requirement that all precipitation be held on the dam is taken care of by a system of crest walls that sub-divide the surface of the dam into a series of paddocks. The crest walls also serve the purpose of preventing precipitation on the top of the dam from cascading down the outer slopes and adding to the potential for slope erosion. The heights of the crest and division walls are designed hydrologically to contain the maximum probable precipitation over a period of twenty-four hours with a frequency of once in a hundred years. A freeboard of 0,7m is provided throughout the system above the predicted maximum water level.

In the Witwatersrand area, annual evaporation from a free-water surface exceeds annual precipitation so there is usually no need to provide for drawing off precipitation on the top surface of a deposit. The penstocks or decant towers used for drawing off water during the operation of a hydraulic fill tailings dam are plugged once the dam has been deposited, as they otherwise tend to collapse and provide channels for piping erosion.

Erosion of Slopes

The slopes of tailings dams built in South Africa are extremely steep (usually about 35°). The protection of these steep slopes against erosion is very difficult to accomplish. The sheet erosion of the slopes is reduced and gulley erosion virtually eliminated by the provision of crest walls which prevent water from cascading off the top and down the slopes of a tailings deposit. If the material is available, slopes can also

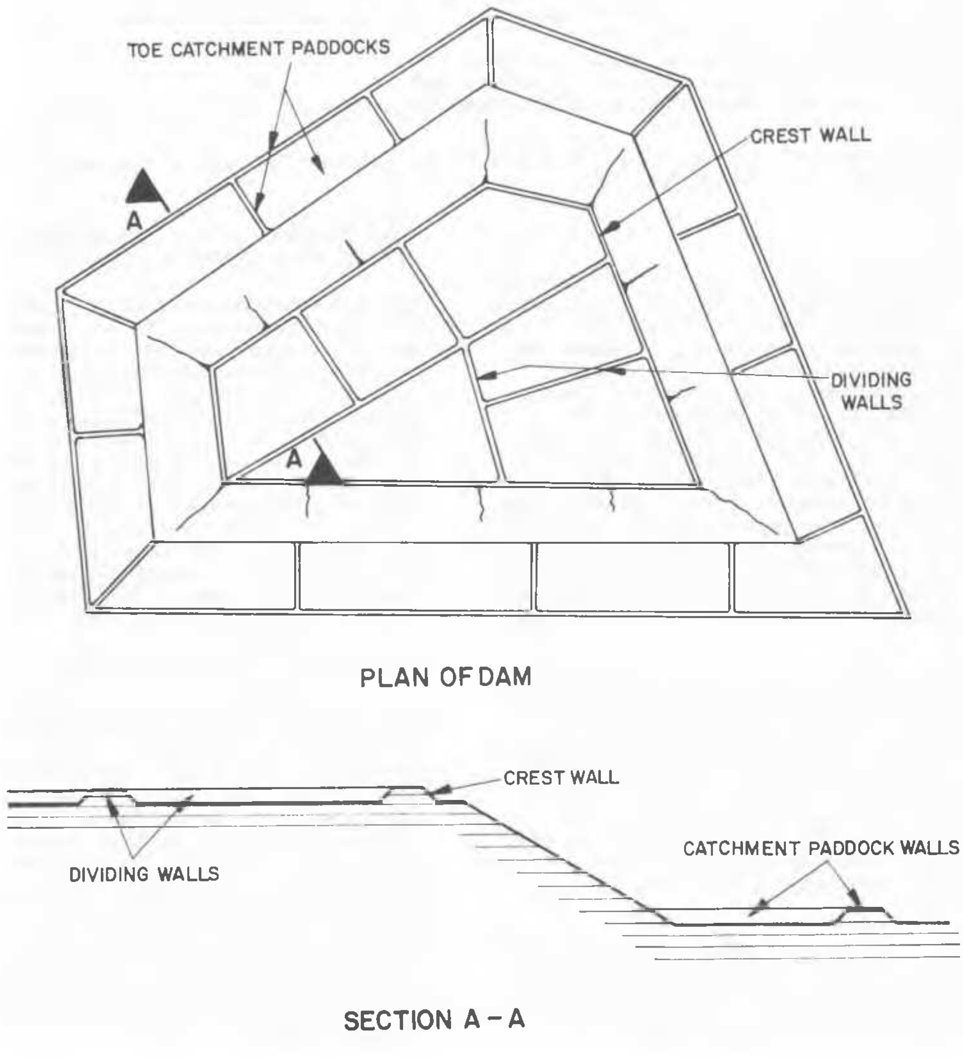

FIGURE 1a Diagram showing measures taken to minimize water erosion of abandoned tailings dams.

be protected against erosion by covering them with a layer of waste rock. On flatter slopes vegetation has been used in the past to provide some protection against erosion. However, it has not proved entirely successful as the slope gradually becomes denuded as erosion progresses.

Containment of Precipitation on Slopes and Material Eroded from Slopes.

Runoff and eroded material is contained by means of a series of catchment paddocks around the perimeter of a dam. These paddocks are designed hydrologically to ensure a freeboard of at least 0,7m above the maximum predicted water level based on the average monthly rainfall for the area concerned less the gross mean evaporation for the area plus the maximum precipitation to be expected over a period of twenty-four hours for the frequency of once in a hundred years. To this is added an additional capacity to allow for siltation.

Control of Access.

It has been found essential to prevent access to abandoned tailings deposits by members of the public and especially those seeking recreation by horseriding or cross-country motorcycling. The trails left by these activities, often locally reduce the freeboard of paddock walls and result in gulley erosion. It is therefore considered essential to surround each abandoned tailings deposit with a properly constructed and well maintained security fence.

Stability of Slopes.

The retention of water on the top surface of a tailings deposit as well as measures such as erosion protection by covering slopes with rock may cause instability of the slopes.

FIGURE 1b Abandoned, badly eroded tailings dam provided with crest and dividing walls.

The guidelines require an investigation of potential slope stability as part of the closure report.

Figure 1a shows diagrammatically some of the features mentioned above, while Figure 1b shows the crest and dividing walls on the top of a dam.

CURRENT PRACTICE FOR THE CLOSURE OF TAILINGS DEPOSITS.

A considerable number of abandoned tailings deposits exist within the Witwatersrand metropolitan area. The area has been almost completely built up and the tailings deposits in question are surrounded by residential and industrial development. In most cases the mining companies responsible for the tailings deposits are defunct and the South African Government has accepted responsibility for the rehabilitation of these dams to comply with the Chamber of Mines guidelines. To date, five dams have been or are in the process of rehabilitation and the rehabilitation measures for a number of other deposits are currently in hand. During the course of the work a number of rehabilitation features have been developed which differ from those originally envisaged when the guidelines were prepared. These will now be described:

Cement Stabilization of Top Surfaces of Dams:

It appears that much of the difficulty with vegetation on the top surfaces of dams arises because of the unstable nature of the surface which enables wind action to undermine the root systems of vegetation. For this reason it was decided to stabilise the top surfaces of a number of dams on an experimental basis using either slaked lime or Portland cement. Although the gold mine tailings which were being dealt with were highly acid (pH of 3,5) Eades' tests showed that relatively little stabilizer was required to raise the pH to a stable level of approximately 12,5. Figure 2 shows typical results of Eades' tests using ordinary Portland cement. It is also known that although the tailings contains no clay minerals, it does contain a certain amount of amorphous silica which could be expected, at values of pH above 12, to react with hydrated lime and form calcium silicates. Because it is essential to keep the costs of rehabilitation as low as possible, and also because the object was to achieve an erosion-resistant skin on the surfaces of the tailings deposits without achieving much strength, it was decided to experiment with very small stabilizer contents. Accordingly, a series of large test panels measuring 30 m in length by 5 m in width and stabilized to a depth of 150 mm were laid out using 2%, 3% and 4% by mass of both lime and cement. After spreading the required quantity of stabilizer on the surface of the tailings deposit, it was mixed in using a rotary mixer. After adjusting the moisture content to the optimum for compaction, the panels were compacted by pneumatic rolling. The completed stabilized panels were moist-cured for six days using water sprays. The erosion resistance of the stabilized tailings

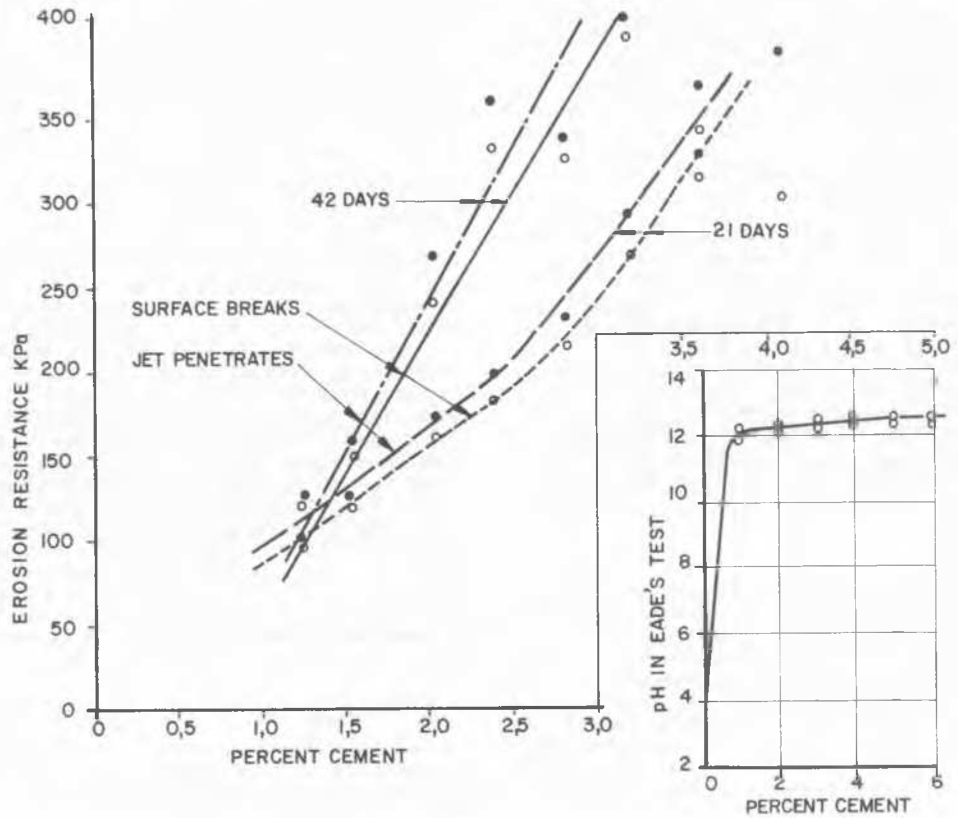

FIGURE 2 Results of experimental stabilization of tailings with Portland cement.

surface was assessed using a portable erosion tester that directs a 0.8 mm diameter jet of water at the surface from a distance of 25 mm. The pressure behind the jet is increased at a steady rate until the surface breaks up - the pressure at which the disruption occurs being recorded as a measure of the erosion resistance. Figure 3 shows the erosion

FIGURE 3 'COMET' erosion tester in use on a tailings dam.

tester in action while Figure 2 shows the measured erosion resistance plotted against percentage cement at times of twenty-one days and forty-two days after stabilizing. It became apparent from these results that (at least at early ages) cement was more effective than lime, and it was decided to stabilize the top surfaces of a number of tailings dams using 3% of cement to a depth of 150 mm and to observe the performance of these surfaces over a number of years. Four tailings deposits have been stabilized in this way. They still have to complete a year of service, but appear to be meeting the requirements of preventing wind and water erosion quite successfully so far. It is also noticeable that wind-born seeds are taking root in the stabilized material and it is hoped that the stabilized surface will ultimately support an appreciable plant cover.

Prevention of Slope Erosion by Terracing.

The authors had noticed at a number of locations that where vertical faces have been cut in the slopes of tailings deposits, these faces appear to be unaffected by erosion. It was therefore decided to carry out an experiment in which the slope of a tailings deposit is terraced into a series of vertical faces separated by approximately horizontal steps or berms. To retain precipitation on the berms, these are sloped back towards the dam and are subdivided at intervals by cross-walls so that all precipitation on the berms is held and allowed to evaporate. Figure 4a shows a design section to such a terraced slope, while Figure 4b is a photograph of the experimental terraced slope. The effectiveness of this procedure has yet to be tried as the slope shown in Figure 4b has not yet passed through a wet season.

<ins>Filter Dams to Retain Polluted Runoff.</ins>

Runoff from tailings deposits which is polluted by material eroded from the deposit is retained at strategic positions by dams designed to retain the silt content of the runoff while allowing clear water to seep

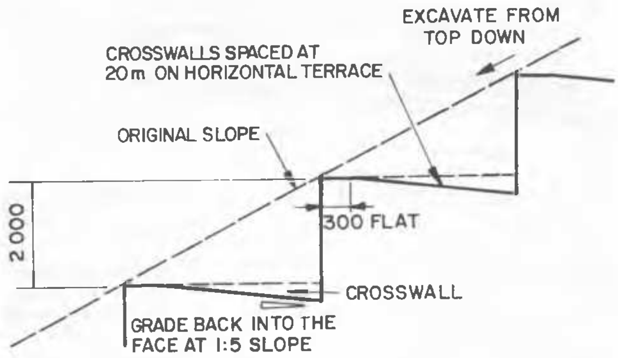

FIGURE 4a Design section of terraced slope shown in Figure 4b.

away. Figure 5a shows typical details of such a filter dam. The upstream slope of the dam is underlain by a filter blanket that acts as a collection drain and filter for the polluted water retained behind the dam. After entering the filter blanket, the water drains to the central collecter drain and is allowed to excape downstream. Figure 5b shows a photograph of one of these dams together with its emergency spillway protected from erosion by means of a gabion mattress.

<ins>Fabric-Reinforced or Cement-Stabilized Dams.</ins>

In tailings dam rehabilitation work it often occurs that a narrow valley with a limited capacity has to be crossed by a filter dam. If a conventional dam of compacted tailings is constructed, it is found that too much of the capacity of the valley is occupied by the filter dam embankment. In situations like this, it is advantageous to build dams having steeper slopes and in fact, a gravity section is ideal in such instances. A gravity section dam can be built either of cement-stabilized tailings or of fabric-reinforced tailings.

Figure 6a shows the design of a fabric-reinforced gravity section embankment. This latter embankment has actually been built and is illustrated by the photograph in Figure 6b. The dam illustrated in Figure 6b

FIGURE 4b Experimental terraced slope in course of terracing. Note surrounding urban development.

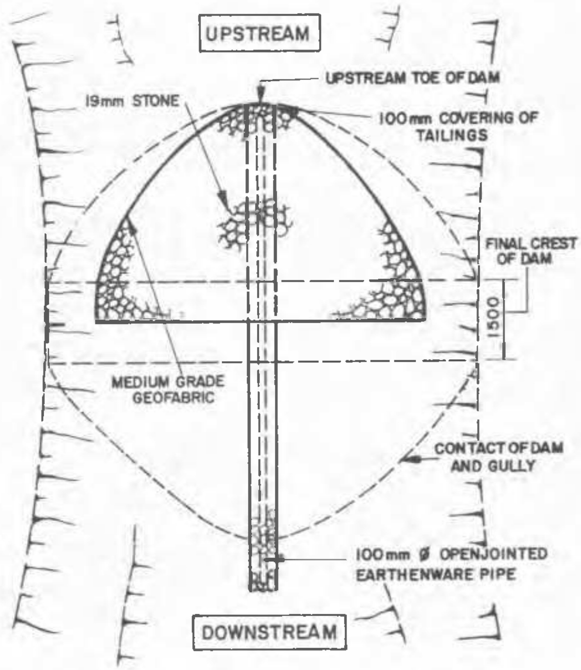

FIGURE 5a Plan showing details of filter dam.

spans a valley between two tailings deposits down which a natural stream flows. The stream has been by-passed through a culvert which runs down the valley and under the gravity section dam, while the gravity section dam itself acts as a filter dam for precipitation running off the slopes of the tailings dams on either side of the valley.

FIGURE 5b Filter dam with emergency spillway

AFTER-CARE OF ENVIRONMENTALLY PROTECTED TAILINGS DAMS.

It is recognised that the environmental protection measures specified by the Chamber of Mines guidelines will require continuing inspection and maintenance if they are to remain effective.

1) Any erosion damage to crest or dividing walls, filter dams or catchment paddocks must be repaired.

2) Catchment paddocks and filter dams must be de-silted periodically or must be raised in order to maintain their capacity.

3) Continuing inspection must take place lest problems of slope stability, the collapse of old drainage conduits or penstock outfalls and similar degeneration should cause breaches in the anti-pollution defences of the protected dam.

4) Access by animals and the public must continually be prevented. This last requirement contains something of a sociological problem as the existence of the large abandoned inaccessible areas represented by environmentally protected tailings dams within urban environments makes them attractive not only as playgrounds for teenage children, but also as hiding places for the lawless element of the community.

ACKNOWLEDGEMENT.

This paper is published by kind permission of The Chamber of Mines of South Africa. The fabric for the fabric-reinforced dam shown in Figure 6b was donated by Messrs. Extruded Fabrics (Pty) Limited.

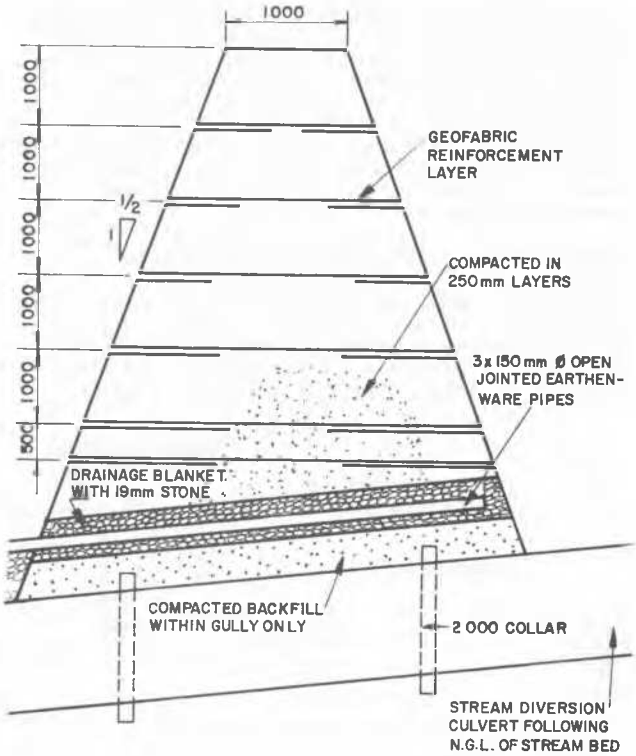

FIGURE 6a Section through geofabric-reinforced gravity section dam.

FIGURE 6b Completed geofabric-reinforced dam

REFERENCE.

Chamber of Mines of South Africa, (1979) Guidelines for Environmental Protection, Vol 1/79, The Design, Operation and Closure of Residue Deposits.