EROSION AND ANTI-EROSION MEASURES FOR ABANDONED GOLD TAILINGS DAMS[1]

by

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Abstract. This paper briefly describes geotechnical measures for the abatement of air and water pollution from abandoned gold-residue dams. The measures were specified by a set of guidelines for environmental protection formulated for the Chamber of Mines of South Africa in 1979. The results of measured rates of erosion of unprotected tailings surfaces are then given and the effect of various anti-erosion treatments is reported. These treatments include surface stabilization with cement, grassing, and gravel mulching.

Introduction

Unlike Canada and the United States of America, the Republic of South Africa has no legislation specifically directed towards the protection of the environment from the effects of mining. However,there are a number of statutes that affect the design, operation, and abandonment of tailings deposits. To comply with the requirements of these statutes and to achieve effective environmental control over the tailings deposits owned by its members, the Chamber of Mines of South Africa, in 1978, commissioned the author to draft a comprehensive set of guidelines for the design, operation, and closure of tailings deposits. These guidelines were adopted in 1979 and revised in 1983.

Whereas valley dams are common in the United States, most tailings dams in South Africa are ring-dyke structures constructed on relatively flat ground. Because they protrude above the natural ground contours, these dams are particularly exposed to the erosive forces of the atmosphere. Figure 1 shows the layout of a typical ring-dyke gold tailings dam.

The guidelines for the closure of tailings deposits require, prior to the closure of any tailings deposit, an inspection by a geotechnical engineer, who should report on the existing state of the deposit and list all actions needed 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 in consultation with professionals of appropriate related disciplines

Specific Requirements of the Guidelines

The Chamber of Mines Guidelines have a number of specific requirements.

Erosion of Top Surfaces. The guidelines require the best practicable means to be adopted to prevent erosion of top surfaces. Among the measures that have been suggested for control of wind erosion are the following:

(a) the establishment of vegetation on top of a deposit, either by planting directly into the tailings material or by first covering the surface with a layer of top soil of suitable thickness.

(b) covering the top of the deposit with a suitable thickness of broken waste rock.

Water erosion of top surfaces, as well as a requirement that all precipitation should be held on the dam and not discharged into any stream, has been addressed by a system of crest walls that subdivide the surface of the dam into a series of paddocks as shown in Figure 2. The crest walls also prevent precipitation

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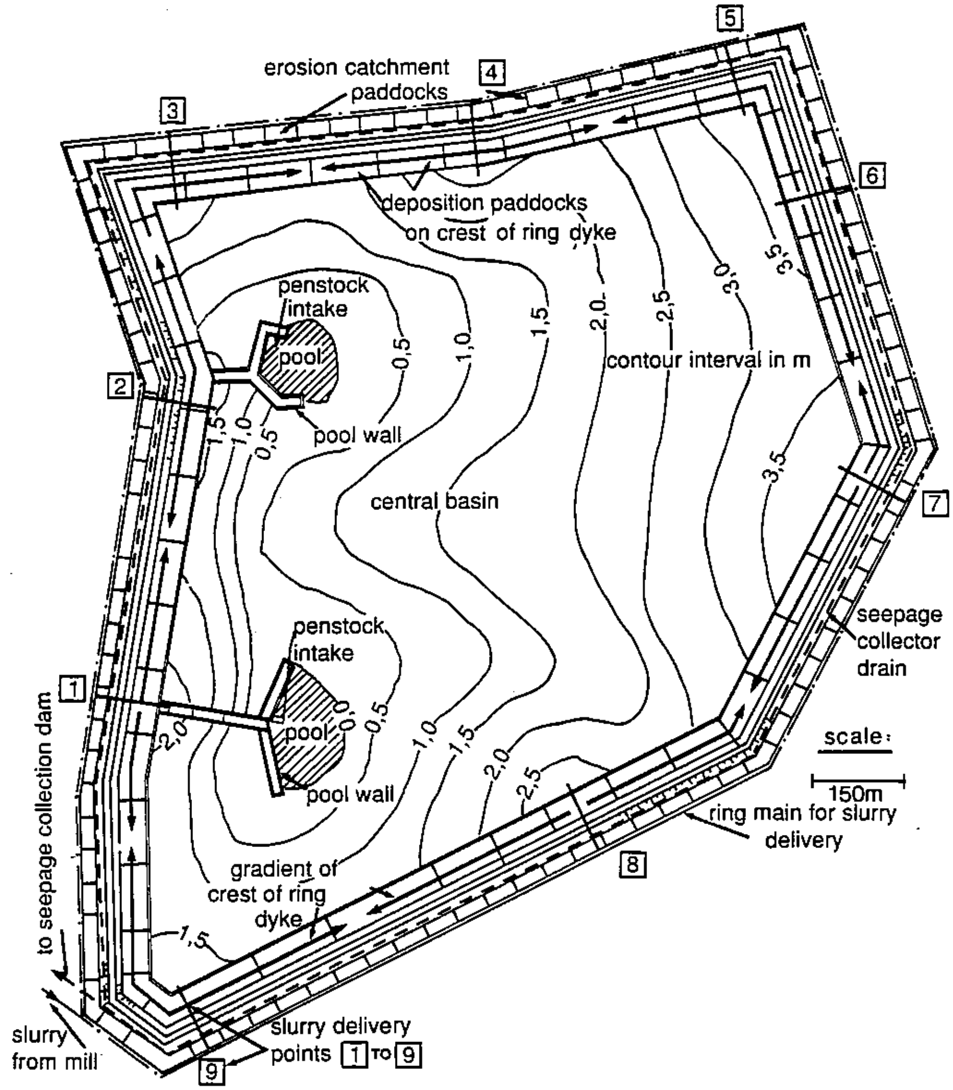

Figure 1 Layout of a typical ring-dyke tailings dam.

on top of the dam from cascading down the outer slopes and increasing the potential for slope erosion. The height of the crest and division walls is designed hydrologically so that the walls will contain the maximum probable precipitation over a period of 24 hours, with a frequency of once in a 100 years. A freeboard of 0.5 m is required throughout the system above the predicted maximum water level. In the Witwatersrand area, as the annual evaporation from a free-water surface vastly exceeds the annual precipitation, there is usually no need to decant water from the top surface of a deposit.

Paddocks must be carefully shaped to prevent water from standing near the crest wall of a dam. Numerous cases of piping erosion have occurred when water has been held on the surface near to the crest of a dam.

The penstocks used to decant water during the operation of a residue dam are plugged when the dam is closed because they otherwise tend to collapse and provide channels for piping erosion. Old dams often have a number of steel delivery or penstock pipes buried in them at various positions. The steel has usually corroded away and the resulting void has been enlarged by erosion. Such a collapsed pipe can result in severe internal erosion and gulleying of the tailings dam.

__Erosion of Slopes.__ The slopes of old residue dams are extremely steep (usually 35° or more) and the

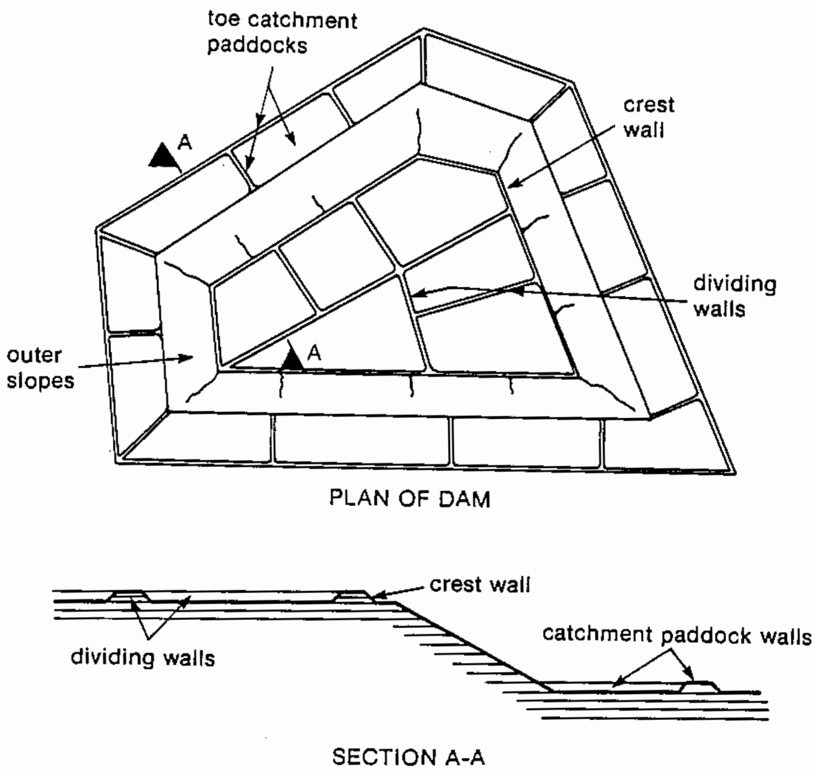

Figure 2 Anti-erosion walls and cathchment paddocks on an abondoned ring-dyke tailings dam

protection of these steep slopes against erosion is very difficult. Sheet erosion of the slopes can be 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 residue deposit. Slopes can be protected against erosion by being covered with a layer of waste rock. However, this requires a large quantity of rock because the angle of repose of the rock seldom, if ever, equals the slope angle. Vegetation has also been used to provide protection against erosion. This practice has not proved entirely successful: some of the steeper slopes are gradually denuded of grass as erosion progresses.

__Containment of Precipitation and Eroded Material__. Run-off and eroded material are contained by a series of catchment paddocks around the perimeter of a dam. These paddocks are designed hydrologically to ensure a freeboard of at least 0.5 m above the maximum predicted water level, which is 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 24 hours for a frequency of once in 100 years. To this is added an additional capacity to allow for the siltation resulting from erosion off the slopes.

__Control of Access__. It has been found essential to prevent access to abandoned tailings deposits by the public, especially those seeking recreation by horseriding or cross-country motorcycling. The trails left by these activities often reduce the freeboard of paddock walls and result in gulley erosion. It is, therefore, considered essential that each abandoned tailings deposit be surrounded by a properly constructed, 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 of slopes with rock, may lead to instability of the slopes. The guidelines require an investigation of potential slope instability as part of the closure report.

Preparation of the guidelines exposed a number of areas in which knowledge was either inadequate or non-existent. The most important of the areas of ignorance were the actual rate of erosion of tailings dams, the parameters that affect erosion, and means of preventing erosion. Rates of accretion in silt-trapping structures were not known either. The relative importance of wind and water as agents of erosion was also unknown. There was an impression, gained from the observation of dust clouds emanating from tailings dams during windy weather, that wind erosion affected mainly the top surfaces of tailings dams and water erosion the slopes. This impression was reinforced by the observation that the slopes of gold-tailings dams are usually hard and crusted, and are apparently impervious to the effects of wind, whereas there are often pockets and areas of loose material lying on the top surfaces of dams.

Rates of Erosion from Gold Tailings Dams

In 1984, the author initiated a programme to measure erosion losses from the slopes of gold-tailings dams. The programme was subsequently extended to include measurements of erosion losses from the top surfaces of dams, and the rates of accretion of material lost from slopes and caught in erosion catch-paddocks.

Measurements of the rates of erosion were made in the field at 10 different sites. At many of these, measurements were made on more than one slope or surface. This was because it was initially thought that the aspect of the slope with respect to the direction of the sun and prevailing winds might be important. However, in only 1 case was such an influence detected.

The experimental measurement plots were each 9 m by 9 m in plan, and consisted of a grid of steel pegs 1 m long and 8 mm in diameter. These were driven in normal to the surface at 3 m intervals to give a 4 x 4 array of 16 pegs. 50 mm of each peg was left protruding from the ground. The erosion loss (or gain) could then be gauged simply from measurements taken at successive times of the distance from the tip of each peg to the tailings surface.

The erosion-measurement plots on slopes were positioned approximately in the middle of the slope length. All pegs were driven in an exact grid. Thus, some were located in erosion rills, some on ridges between rills, and others in intermediate positions.

The results are reported as average values for the whole of each plot. However, observations on individual pegs confirmed the expectation that rates of erosion tend to be progressively higher from the top to the bottom of a slope, and also higher in rills, where the quantity of runoff is larger. In each case, a crest wall was present at the crest of the slope to ensure that no water cascaded down the slope from the top of the dam and that any measured erosion was thus the effect only of water precipitated directly onto the slope.

Originally, each test area was equipped with a rain gauge. However, these were all vandalized within a few weeks of installation, and information from the nearest official meteorological stations was therefore relied on for rainfall data.

For the first year of the experiment, April 1984 to March 1985, the rainfall was 20 % less than the local 30-year average of 750 mm. For the second year, up to March 1986, the rainfall was almost equal to the 30-year average. For the final 2 years, from April 1986 to May 1988, the rainfall was 11 % and 29 % above the 30-year average. For this reason, most of the results are reported in terms of 1-year, 2-year, and 4-year averages.

Distribution of Erosion between Seasons. Figure 3 shows the seasonal distribution of erosion loss from tailings slopes observed over the first year of the experiment. Most of the rainfall occcurs in summer, but there are usually at least 1 or 2 precipitation events during winter. These account for about 10 % of annual precipitation. In Figure 3, the erosion loss quoted in terms of retreat of the slope in millimeters per season, and tons lost per hectare per season has been plotted against the ETCOM index measured on dry surfaces.

The ETCOM index is measured by directing a jet of water 0.8 mm in diameter to impinge normally on the tailings surface. The pressure behind the jet is increased until the surface is penetrated and the pressure (in kilopascals) at which penetration occurs is used as an index of erosivity.

When the ETCOM instrument was developed (by the Chamber of Mines of South Africa), it was expected that the erosion resistance of a surface would be directly related to the ETCOM reading, and that erosion loss would decrease as the ETCOM reading increased. However, it has since been found that high ETCOM readings correspond to high erosion losses, and vice versa.

This is essentially because high ETCOM indices occur on surfaces of fine-grained, desiccated material. Once such a surface has been wetted by rain, it becomes soft and easily eroded. Probably for similar reasons, no correlation was found between the shear strength of tailings surfaces and erosion losses. As Figure 3 shows, erosion loss during the winter amounted to about 80 % of the loss during the summer. For individual plots, the winter erosion was measured at between 40 and 140 % of the summer erosion. This shows that there is a large component of wind erosion in the total annual erosion loss. The visual impression referred to earlier is thus erroneous, and the slopes of tailings dams are indeed subject to considerable erosion by wind.

Figure 3 also shows that erosion losses are very considerable, whether reported in terms of slope

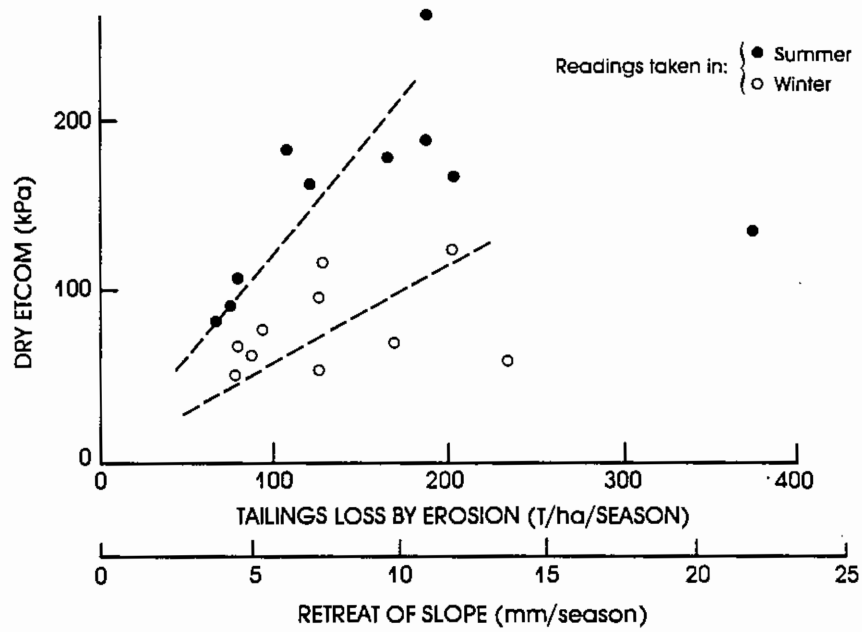

Figure 3 Correlation between seasonal erosion loss and ETCOM erosion index

retreat or tons/ha/yr. Annual erosion losses from agricultural fields rarely exceed 10 to 15 t/ha, whereas annual losses from the slopes of tailings dams are measured in 100 tons/ha.

Slope Length and Erosion Loss. The Universal Soil Loss Equation (USLE) gives the soil loss E as

E = ARKLSCP,

(e.g. Evans and Kalkanis 1977) in which LS is a topographic factor to account for the combined effect of slope length (L) and slope angle (S) and A, R, K, C, and P are factors accounting for other effects. Because the slopes of agricultural land are generally flat, the USLE is not regarded as being valid for slopes steeper than 25 % (about 14°).

Figure 4 shows the measured relationship between slope length and erosion loss. Part of the data show a positive correlation between slope length and erosion loss, and part do not.

The portion of Figure 4 that indicates no correlation between slope length and erosion loss is believed to arise because of the stronger influence of other factors such as surface shear strength or slope angle. It may also arise because certain of the test plots were too small to adequately represent average erosion over the length of some of the slopes, or simply because certain slopes were subjected to more precipitation and, therefore, eroded more than others.

Three grassed slopes were included in the programme. Figure 4 shows 2-year average results for the erosion of 2 of those slopes, a west- and a south-facing slope. The results lie well to the left of the data for bare slopes. The results for the third slope (north-facing) is not shown because it is not eroding but is accreting at an annual rate of 35 t/ha (2 mm). Material blown off the other slopes of the dam is apparently trapped by the grass on the north face, and the rate of erosion by water is insufficient to remove this entrapped material. The maximum observed accretion rate for this slope during the dry winter was 90 t/ha per year (or 5 mm/yr).

Slope Angle and Erosion Loss. All the available data relating erosion loss to slope angle are shown in Figure 5. The data can be regarded as showing the 2-branched relationship indicated in the diagram. As pointed out earlier, the USLE indicates that a positive correlation can be expected between slope angle and erosion loss. A qualitative 2-branched correlation between slope angle and erosion loss was previously noted by Renner (1936), who observed that very little erosion occurs on natural slopes steeper than 80 % (39°) or flatter than 5 % (3°).

The reduced erosion loss at steep slope angles suggested that the erosion of a slope can be reduced if it is terraced in a series of steps with vertical and sub-horizontal surfaces. Each sub-horizontal surface

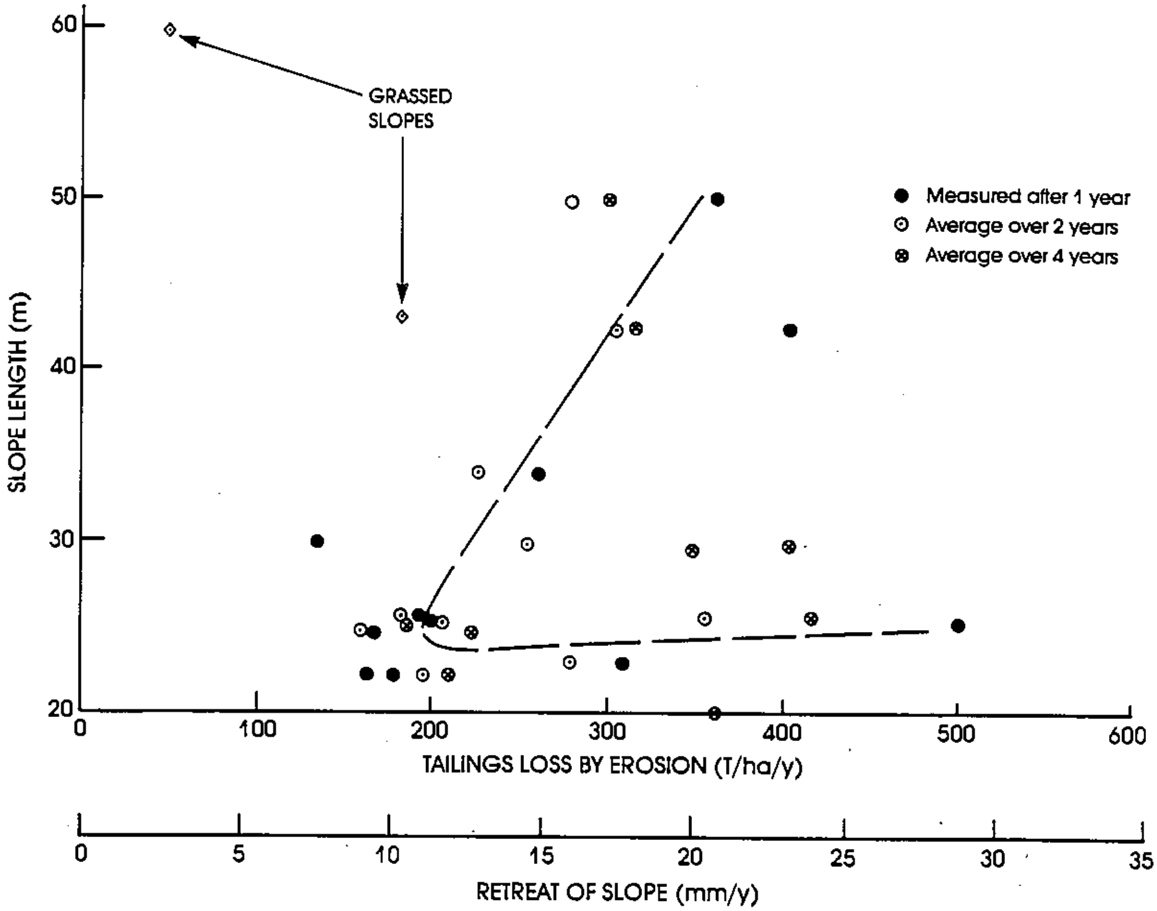

Figure 4 Correlation between slope and tailings loss by erosion

slopes back towards the vertical step above, and is hydrologically designed to retain precipitation on it without spilling down to the next step. The erosion of 2 terraced slopes was observed as part of this programme.

The results of the measurements, shown in Figure 5, confirm that erosion losses from terraced slopes are relatively small. However, the measure is not very practical as severe gulleying occurs if one of the steps overflows. A terraced slope is also not visually pleasing.

Five test plots were established on the untreated horizontal top surfaces of dams. The results of these measurements (see Figure 5) show that there is little or no erosion loss from untreated top surfaces. In some cases, a small accretion occurred. These measurements represent an average over years 3 and 4 of the experiment.

These results, taken with those shown in Figure 3, appear to indicate that the major losses from tailings dams due to wind and water erosion take place from the slopes and not from the flat top surfaces. The dust clouds that appear to emanate from the top surfaces are in reality blown off the windward slope and other slopes that are subjected to a component of wind shear.

The Effect of Anti-erosion Measures

Grassed Slopes. The data for grassed slopes are also shown in Figure 5. Losses for the west and south-facing slopes do not appear to be unusually low when compared with the trend of the other data. (Prevailing winds in winter are south to southwest).

However, the north-facing grassed slope is the only non-horizontal slope for which an accretion was recorded during this investigation.

Gravel-mulched Surfaces. Two sets of measurements are available for the rates of erosion of gently sloping surfaces (11°) that were covered by a layer 1 particle thick of 16 mm crushed rock. As shown in Figure 5, the gravel-mulched surfaces eroded considerably less than the untreated adjacent control plot. However, the position of the data in relation to that for other

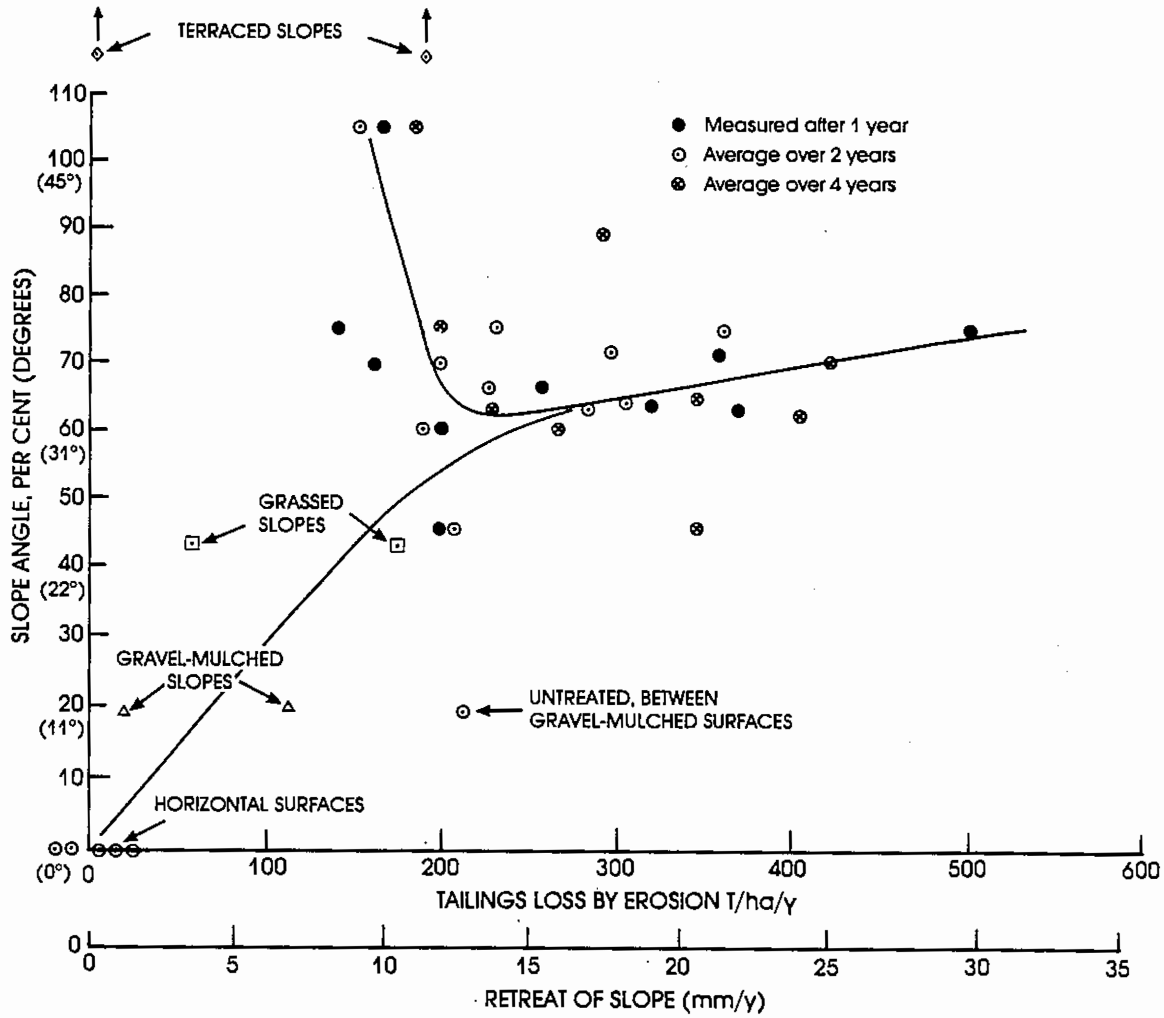

Figure 5 Correlation between slope angle and tailings loss by erosion.

slopes suggests that the control plot was unusually erosive, rather than that the gravel mulch was very effective in preventing erosion. However, there is evidence in the literature that surface obstructions such as closely spaced gravel particles and clods decrease the rates of erosion of soil surfaces by reducing the kinetic energy of runoff passing over the surface (Johnson et al 1979, Jennings and Jarret 1985).

Effect of Stabilizing Dam Top Surfaces. Blight et al(1981) and Blight and Caldwell (1984) reported on the experimental stabilization of the horizontal surface of a tailings dam with Portland cement and road lime. Erosion-measuring plots were set up on these surfaces and on an intervening untreated surface. Measurements on these plots over years 3 and 4 gave the result that the cement-stabilized surface is eroding at a rate of 18 t/ha/yr (a rate of retreat of slightly more than 1 mm/yr). The lime-stabilized surface is eroding at a rate of 3 t/ha/yr, and the adjacent untreated surface is accreting at 6 t/ha/yr. This set of measurements has simply confirmed the conclusion reached above that near-horizontal surfaces are relatively unaffected by erosion.

Accretion in Erosion Catch-paddocks. Rates of accretion were measured in a number of erosion catch-paddocks at the toes of tailings-dam slopes. The measured rates varied from 70 to 150 mm/yr. These accretion rates could not be reconciled with, and generally appeared to be greater than, the losses from the slopes above the paddocks. This is presumably because more material is eroded from near the toe of a slope than from the mid-length area. With hindsight, it would have been better to have measured erosion losses over the full length of the slopes.

Retreat of Crest Walls. The top surfaces of crest walls made of compacted, unstabilized tailings decreased in height by up to 200 mm/yr. The rate of height reduction of crest walls with cement-stabilized crests (5 % nominal cement content) is only about 1 mm/yr. Cement stabilization of the tops of crest walls therefore appears to be well worthwhile as a stabilizing measure.

Conclusions

The main conclusions drawn from this study are as follows:

(1) Both wind and water are major agents in eroding the slopes of gold-tailings dams. Under South African conditions, roughly half of the total erosion loss may result from wind action. Annual erosion losses may exceed 500 t/ha/y (a rate of retreat of 30 mm/yr).

(2) The horizontal top surfaces of gold-tailings dams are relatively little-affected by erosion.

(3) There is a weak positive correlation between the length of a slope and the rate of erosion. The rate of erosion appears to increase from top to bottom of a slope as the volume of run-off increases.

(4) A 2-branched correlation exists between the slope angles of gold-tailings dams and the rate of erosion. Very flat slopes and very steep slopes erode less than slopes of intermediate angle. At the limits of slope, horizontal and vertical surfaces erode very little.

(5) While more data is needed on anti-erosion measures, it appears that grassing, gravel-mulching, or terracing of slopes can considerably reduce erosion losses.

Literature Cited

Blight, G.E.; C.E. Rea; J.A..Caldwell; and K.W. Davidson. 1981. Environmental protection of abandoned tailings dams. Proceedings, 10th International Conference on Soil Mechanics and Foundation Engineering, Stockholm, vol.2. 303-308.

Blight, G.E.; and J.A. Caldwell 1984. The abatement of pollution from abandoned gold-residue dams. Journal of the South African Institute of Mining and Metallurgy, 84,(1) 1-9.

CHAMBER OF MINES OF SOUTH AFRICA .1979. Guidelines for environmental protection, vol 1/1979, The design, operation and closure of residue deposits, Johannesburg, The Chamber (Revised 1983).

Evans, W.R.; and G. Kalkanis 1977. Use of the universal soil loss equation in California. Soil Erosion: Prediction and Control, Proceedings, National Soil Erosion Conference, Soil Conservation Society of America, 1977. 31-40.

Jennings, G.D.; and A.R. Jarret 1985. Laboratory evaluation of mulches in reducing erosion. Transactions of the American Society of Agricultural Engineers, 28(5), 1466-1470.
http://dx.doi.org/10.13031/2013.32461

Johnson, C.B.; J.V. Mannering, and W.C. Moldenhauer 1979 Influence of surface roughness and clod size and stability on soil and water losses. Journal of Soil Science of America. 43, 772-777.
http://dx.doi.org/10.2136/sssaj1979.03615995004300040031x

Renner, F.G. 1936. Conditions influencing erosion on the Boise River watershed. US Department of Agriculture, Technical Bulletin; 528. 1936.