Slimes-dam construction in the gold mines of the Anglo American Group

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SYNOPSIS

Current practices generally in accordance with the principles of design and operation of slimes dams within the Gold Mining Division of the Anglo American Corporation are described. Although many of the details given are either obvious or have been amply dealt with elsewhere, these have been included for the sake of completeness. The selection of suitable ground for the deposition of slimes, the initial design and construction of a slimes dam, and its consequent operation are presented in logical sequence. Emphasis is placed on the code of practice for the construction of slimes dams issued by the Chamber of Mines of South Africa, and draft regulations (Water Act of 1956) dealing with pollution. Operating costs are included, and possible future trends are discussed.

SAMEVATTING

Die huidige gebruike wat oor die algemeen in ooreenstemming is met die beginsels vir die ontwerp en bedryf van slykdamme binne die Goudmynafdeling van die Anglo American groep word beskryf. Hoewel baie van die besonderhede wat verstrek word, voor die hand lê, of elders breedvoerig behandel is, word hulle volledigheidshalwe ingesluit. Die keuse van geskikte grond vir die slykafsetting, die aanvanklike ontwerp en konstruksie van 'n slykdam en die daaropvolgende bedryf daarvan word in 'n logiese volgorde behandel. Daar word klem gelê op die gebruikskode vir die konstruksie van slykdamme wat deur die Kamer van Mynwese van Suid-Afrika uitgegee is en die konsepregulasies (Waterwet van 1956) wat oor besoedeling handel. Die bedryfskoste word ingesluit en moontlike toekomstige neigings word bespreek.

INTRODUCTION

The design, construction, and operation of tailings dams in the gold-mining industry has become of increasing importance in view of the enormous tonnages requiring deposition. The annual tonnage currently being deposited as a result of operations by the Anglo American group of gold mines is calculated at between 25 and 26 million, and the total area set aside for this purpose approaches 2200 hectares.

The introduction of more comprehensive legislation dealing with the prevention of water pollution and the Chamber Code of Practice for dam construction has resulted in the necessity for a more scientific approach than has hitherto been employed.

From the point of view of stability, it is fortunate that we do not have to build dams in mountainous areas, which suffer in some instances from extremes of climate and seismic activity, nor is it necessary to construct such high walls. Therefore the gold-mining industry has not suffered the major disasters involving heavy loss of life that have occurred elsewhere, for example in Chile.

On the debit side, however, the economics of dam construction are at present governed by the labour-intensive methods of wall construction currently employed, whereas spigoting or cycloning to produce a coarser sands fraction for wall building is resorted to elsewhere. Attempts to introduce mechanical methods of wall construction have so far met with little success in South African gold mining.

The capital costs of the initial construction (for example, excavation of toe, effluent, and stormwater trenches) are governed by the topography and the presence of rock requiring the use of explosives. The main elements in the establishment of a new dam are of a civil-engineering nature, and, as considerable variability in capital cost can be expected, no details of this aspect are given. Costs of civil-engineering works, including fencing, trenches, catchment-water dam, piping, and pump station, for a 45 ha dam to be built on gently sloping ground devoid of rock can be expected to be in the vicinity of R180 000.

As a number of publications embodying the principles of soil mechanics, hydrology, geology, and topography are readily available, the emphasis of this paper is on the more practical aspects of residue disposal.

THE DESIGN OF SLIMES DAMS

In the Anglo American Corporation, the design of a dam is normally a collaborative effort between the Civil Engineering and Metallurgical Departments, assistance being sought from the Mechanical and Electrical Departments where necessary.

Companies wishing to establish new slimes dams should consult the first three publications in the list of references[1–3] and should adhere as closely as possible to the principles they outline.

Area Required

To determine the area to be set aside for slimes deposition, the following information is required:

(1) the monthly rate of deposition in tons of solids for a period of five years subsequent to the commencement of operations; from this the initial area required can be calculated;

(2) a rough estimate of the total tonnage of ore to be milled over the life of the mine; from this, the ultimate area can be assessed, and, once the maximum permissible height of the dam is established, quantity-surveying techniques can be employed to deduce the ultimate storage capacity;

(3) the possibility of future reclamation and redeposition for uranium and pyrite recovery; even if ultimate redeposition is in monitored-out areas, the re-

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quirements will be considerably higher; and
(4) the type of slimes: alkaline gold-plant residue containing pyrite, neutralized uranium-plant residue plus neutralized barren solution, or flotation-plant tailings low in pyrite and at the low relative pulp density of 1,3; with neutralized barren solution, the relative density is likely to drop to 1,25 and even less.

The dam requirements for slimes and catchment water can vary according to the type of slimes. For example, flotation tailings from which pyrite has been recovered have the least stability as far as wall building is concerned. Hence, the flattest possible slope—27° or even less—has to be used. The requirements for catchment water and return pumping will also be high.

As a rough guide, an area of 45 ha will allow for the deposition of 100 000 tonnes of solids per month, with a monthly rise of approximately 10 cm.

The average slimes dam compacts at 0,625 m^3 per tonne and contains 10 per cent moisture. At 0,625 m^3 per tonne, the slime would become saturated at 20 per cent moisture. For example, a slimes dam 15 m high constructed on 85 ha of ground would contain nearly 18 million tonne of solids at 10 per cent moisture, and a slimes dam 35 m high constructed on 50 ha would contain 25 million tonnes of slime (wall slope 30°). Obviously, the ultimate area required would not be initially fenced and trenched but would be employed for other purposes until required. In addition to the basic area, an allowance must be made for perimeter services, such as effluent and stormwater control, and an adequately sized catchment-water dam.

Selection of Suitable Ground

The following are the requirements for an ideal site:

(1) gently sloping ground, with the slope away from the treatment plant and towards the area reserved for future extensions,
(2) the absence of wet or marshy ground,
(3) the absence of rock, either on the surface or just below, particularly where trenches are likely to be excavated,
(4) the absence of impermeable subsurface clay strata,
(5) remoteness from inhabited areas, and
(6) remoteness from main roads, power lines, rivers, and streams.

As it is probably impossible to meet all the requirements, the following precautions should be taken to prevent future trouble.

(a) Small-scale topographic maps of the area (scale 1:50 000, 30 m contours) and any available aerial photographs should be studied.
(b) The most promising sites should be inspected on the ground.
(c) After the most suitable site has been selected, the areas on which wall construction is likely to take place should be investigated by the sinking of test pits and trenches so that the nature of the shallow subsurface soils can be determined.
(d) If possible, larger-scale maps (1:2500 with 1,5 m contours, or preferably 1:500 with 1 m contours) should be employed for the detailed design of the slimes and catchment-water dams.
(e) Run-off should be estimated from precipitation records so that diversion stormwater trenches and catchment-water dams can be adequately designed.

General Layout

The layout should take advantage of the contours so that the flow of effluent and stormwater is facilitated, and the necessity for building more than one catchment-water dam with its attendant return-pumping facilities should be avoided. Although dams should preferably be square in shape to provide the maximum capacity and to avoid unnecessary corners, this is rarely possible. Acute angles should be avoided in the laying out of the periphery, since differential lateral pressures develop and may cause cracks to form. Fig. 1 shows an almost ideal site.

Fencing and Trenching

Starting from the boundary, cross-sections are shown in Fig. 2 (walls of dam indicated in Fig. 1) giving the following:

(1) A fence to prevent animals and persons from straying onto the dam site. This fence should be of five-strand wire (for cattle) or six-strand wire (for sheep), with one gate adjacent to the slimes delivery point and another at a low corner within reasonable distance of penstock sites and catchment-dam pumphouse. 'No Entry' and 'Poisoned Water' signs should be prominently displayed.
(2) A stormwater trench to deal with rainfall from any catchment areas above the dam, and to divert it round the dam site and return-water dam, so avoiding any possibility of contamination by effluent.
(3) An effluent-water trench to col-

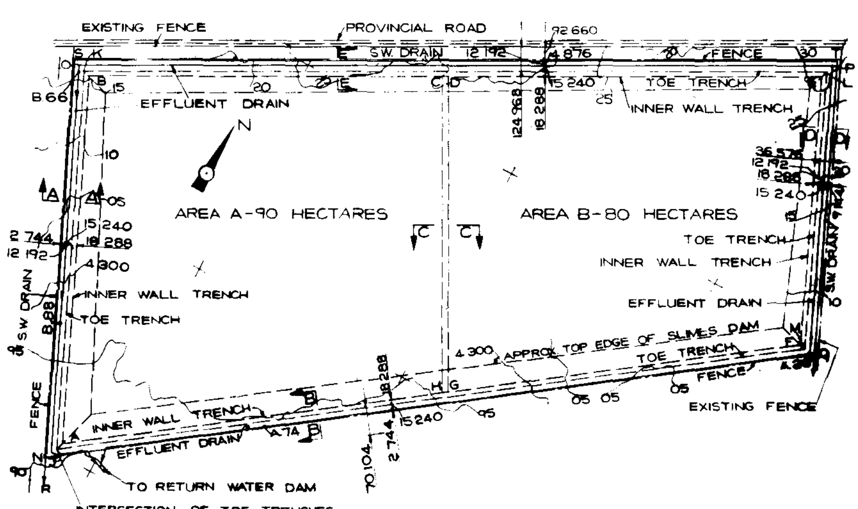

Fig. 1—An ideal slimes-dam layout on gently sloping ground

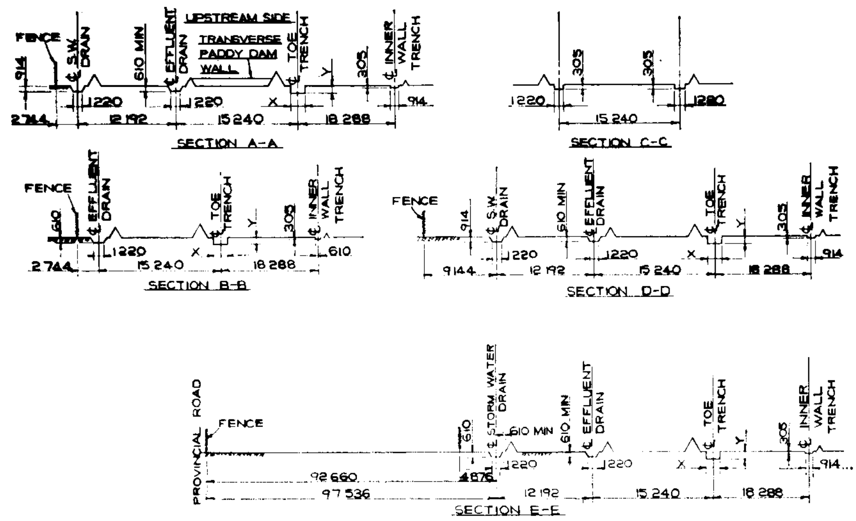

Fig. 2—Typical trenching cross-sections

lect penstock and wall run-off water and to lead it to the catchment water or return dam.

(4) Paddy dams or slimes-entrainment paddocks to contain solids carried down by wall run-off water.

(5) A toe trench for the establishment of the outside face of the outer wall, otherwise known as No. 1 wall trench.

(6) A trench for the establishment of the inside face of the outer wall, otherwise known as No. 2 wall trench.

At a later stage, a third embankment is built inside the dam to create the inside face of the inner wall.

Fig. 2 indicates clearly the nature of the excavations required for the establishment of a dam. Five cross-sections (four main and one centre dividing wall) are shown. Trench distance will vary somewhat, depending on the slope of the ground. On the upstream side of steeply sloping ground, distances should be reduced to prevent accumulations of water against the toe of the wall.

Paddy dams are developed by the erection of transverse walls at intervals between the toe and effluent-water trenches, the purpose being to contain some of the solids washed down from the walls during heavy rain or storms.

French Drains

Wherever walls have to be built on marshy, rocky, or other areas with poor drainage characteristics, special under-drainage precautions are required to prevent 'seepage erosion' of these structures, or to minimize seepage pressure through them. French drains, normally 1 m wide and 0,6 m deep, are constructed at 15 m intervals at right-angles to the intended overlying wall. In some cases, a grid or lattice of drains may be required. The objective is to ensure that seepage is steadily and evenly removed, and that it is not allowed to concentrate in one section or to rise above normal ground level. It will also prevent the water-table from rising up into the base of the wall, with the strong possibility of subsequent liquefaction.

Suitable drainage pipes are installed to lead water to the effluent trench. The filter must meet two requirements: it must be more permeable than the adjacent finer soil so that it will drain freely, and it must have a gradation to prevent the passage of soil and slime particles into the drainage layer.

Details of a typical filter, constituting layers of suitable porous material, are as follows, starting from the bottom:

50 mm stone—150 mm deep
25 mm stone—100 mm deep
12 mm stone—100 mm deep
3 mm washed grit—50 mm deep
Washed crusher sand—50 mm deep

Washed river sand—150 mm deep. These layers must be carefully laid to prevent mixing. Fig. 3 shows a plan and elevation of a French-drainage system for a poorly drained, low-lying area.

Penstock and Drainage Pipes

At least two penstocks should be installed towards the lower wall, about 300 m in, to decant supernatant solution and contained rainfall. If possible, soft ground should be avoided. If only two penstocks are provided, they should be of large cross-section, and preferably built of concrete or material resistant to corrosion and rot. Fig. 4 gives details of the type of penstock normally in use. The structure is provided with rungs on the inside to enable personnel to remove slats or other obstructions that may have fallen down. Access to penstocks is gained on foot along timber walkways. Decantation levels are adjusted by the insertion or removal of reinforced-concrete slats. Penstock water is run through a 600 mm diameter concrete pipe, which discharges direct into the effluent-water trench. If concrete pipes are selected, it is essential that they should be carefully laid, with a down-grade of at least 1 per cent to ensure free flow from the penstock. Special concrete pillars are provided for support of the pipes to prevent movement and leakage at the joints. Iron straps secured to bolts set into the concrete pillars are employed to anchor the pipes to the pillars and so prevent possible dislodgement caused by buoyancy in wet slime, particularly when the pipes are empty.

Before the main penstocks can be brought into use, temporary removable units will normally be employed close to the new wall to remove unwanted accumulations of water.

However, another, possibly more suitable, system is that shown in Fig. 5, in which a number of temporary penstocks made of timber and with steel drainage pipes are employed. These are abandoned as the wall height rises and new penstocks are installed at higher levels in their place.

Catchment or Return-water Dam

The flow through the penstocks can be calculated from the requirements stipulated in the draft regulation[3], i.e., the amount of run-off water to be allowed for should be

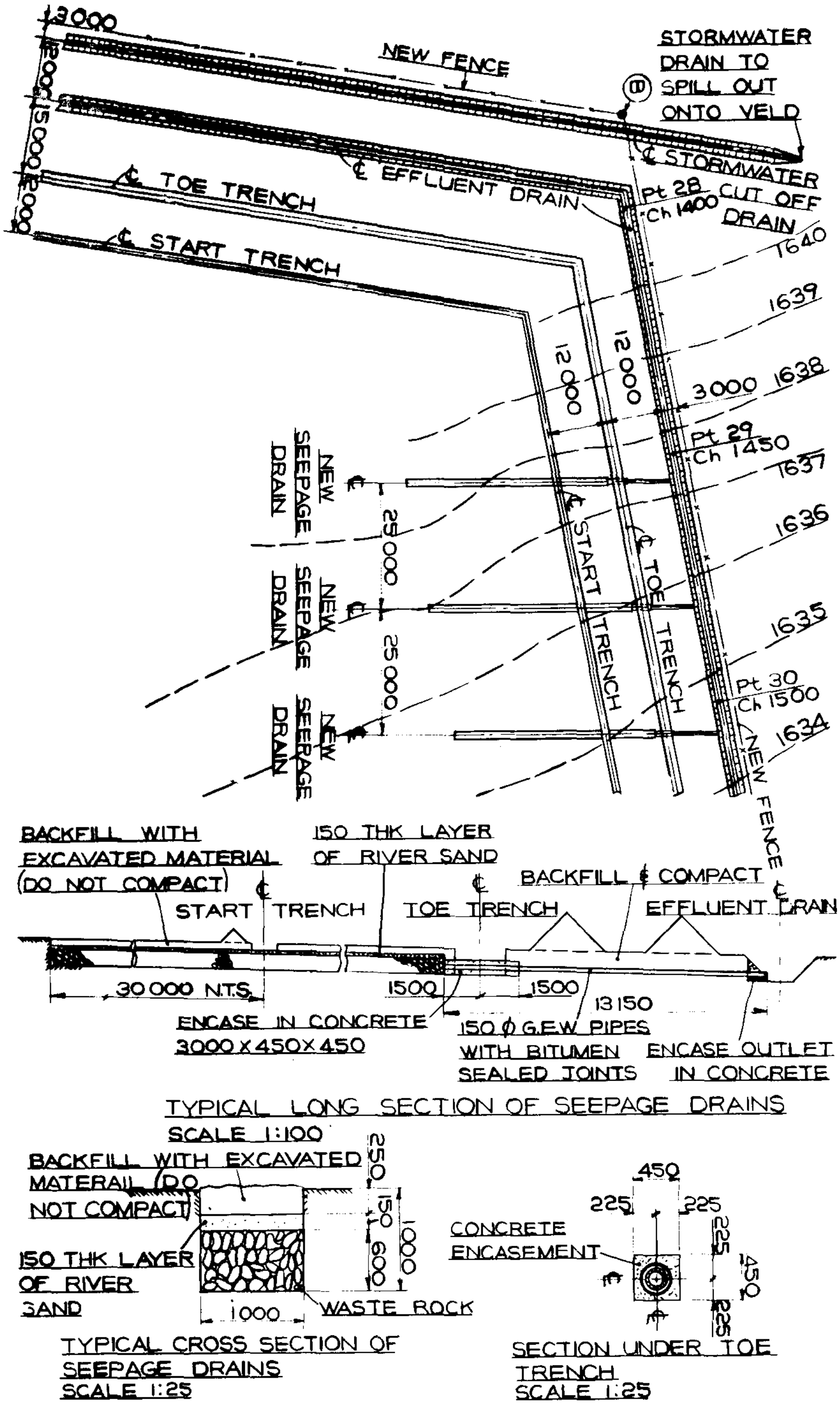

Fig. 3—Details of a typical French-drainage system

the maximum precipitation to be expected over twenty-four hours with a frequency of once in a hundred years. For the Witwatersrand area, this figure approximates 95 mm of rain or 950 m^3 of water run-off per hectare. Therefore, the capacity of the catchment dam to contain this flow can be calculated. In addition, allowance must be made for rain falling on the slopes of the outer walls, on the area between the toe and effluent-water trench, and on any area upstream of the catchment-water dam from which run-off is likely to enter the latter.

Fig. 6 shows a catchment dam provided with a dividing wall to facilitate desludging.

Pump Station for Return or Catchment Water Dam

Fig. 7 depicts an automatically operated return-dam pump station provided with vertical spindle pumps, which were installed to avoid the possibility of their being put out of action by flooding. A tapping on the delivery column provides high-pressure water required for the monitoring out of settled solids via a portable sludge pump back to the slimes dam. If possible, all water entering the catchment dam should be pumped back to the treatment plant for use.

Antipollution Precautions

Every attempt should be made to prevent slimes-dam seepage from by-passing the effluent-water system and emerging down-stream. It may be possible to contain this subsurface seepage by the construction of additional small reclaim dams. It will probably be necessary to conduct down-stream monitoring of the surface and subsurface seepage flows.

Pumping of Residues

The capacity of residue pumps is normally calculated on the total tonnage of solids plus dilution water to achieve a relative density of 1,46 (50 per cent moisture). There are exceptions to this, for example, flotation tailings. An isometric drawing of the residue pipeline, together with estimated solids pumping rate, relative density of pulp, and pipe diameter will enable pump manufacturers to determine the static and friction head and, from this information, to recommend the size and speed of pumps, the power required, the number of stages, and the gland-service pressure.

To prevent cavitation and to maintain a steady flowrate, the final pumping stage should have a variable-speed drive controlled by the level in the residue disposal sump or tank. Speed variation can be achieved through the use of fluid coupling or thyristor drives.

Density control, using either a density gauge or a mass flow meter, is highly desirable. The latter will also measure the flowrate of solids tonnage, plus integrated tonnage if required.

Pipelines are normally of steel, although high-density polyethylene has recently been introduced. The coefficient of friction of this material is much lower than that of steel, and scaling problems are non-existent.

Optimum velocities of flow not only depend on the screen analysis of solids and relative pulp density,

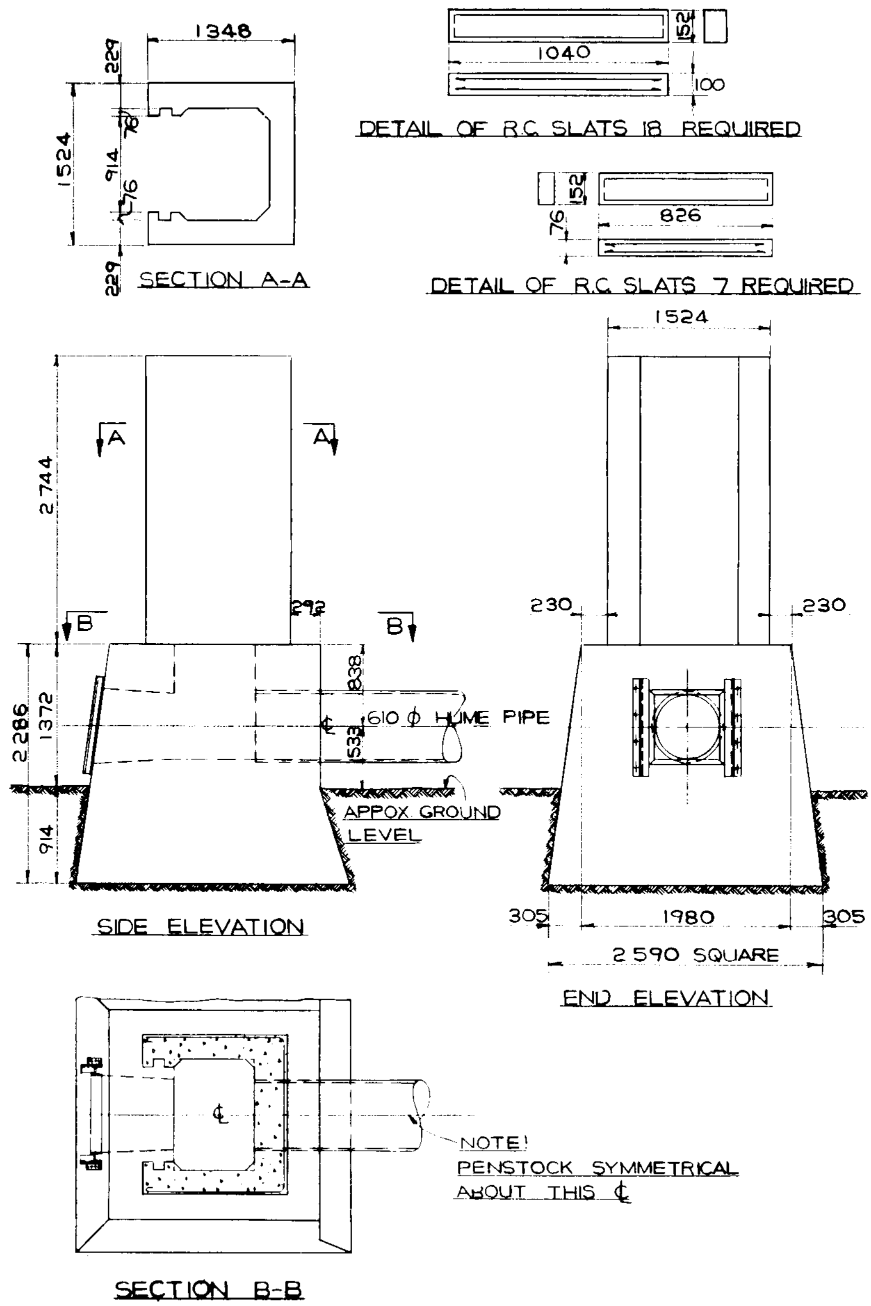

Fig. 4—A concrete penstock

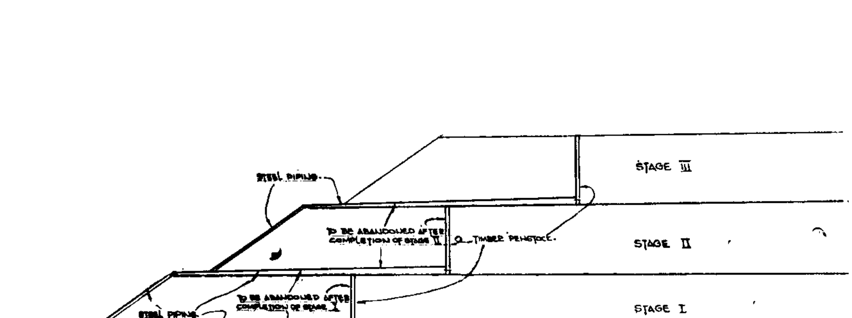

Fig. 5—An alternative penstock system for the decantation of water

but also on pumping distance, the following being a very rough guide:

	Velocity, m/s
Line > 3000 metres long	1,52
Line > 750 metres long	0,76
Line > 300 metres long	0,46

Necessary Approvals

All design drawings are submitted to the Inspector of Mines for approval. In addition, a company applying to the Department of Water Affairs for a permit to use public water for industrial purposes is required to submit for approval all the design calculations and plans for slimes dams, return-water, evaporation dams, and drains, together with a hydrological survey of the area. These details must show that the scheme complies with the prescribed anti pollution requirements.

DAM CONSTRUCTION AND OPERATION

In the Anglo American Corporation, operation is carried out by mine personnel or by an outside contractor. Both have been found satisfactory.

Construction of Station

Slime from the plant is delivered into an area, approximately 25 m square, situated at the top corner of the main dam, and initially bounded by a 2 m high earth wall. This distribution point is designated the station, and its purpose is to facilitate the diversion of slime by controlled gravity flow, initially into the toe and No. 2 wall trenches, and subsequently along the outer and inner walls, or into the interior of the dam itself. The flow gradient is approximately 0,5 to 0,6 per cent. Through the station walls are four L-shaped penstocks constructed of 25 mm timber, 600 mm wide by 300 mm deep, with a vertical section 1500 mm in height and a horizontal portion 3500 mm in length. The vertical section is fitted with a sliding gate to open or close the flow of slime through the penstock.

As the construction of the dam proceeds, the walls of the station should always be kept 1,5 m higher than the adjacent outer wall.

To facilitate operations, two stations are sometimes established.

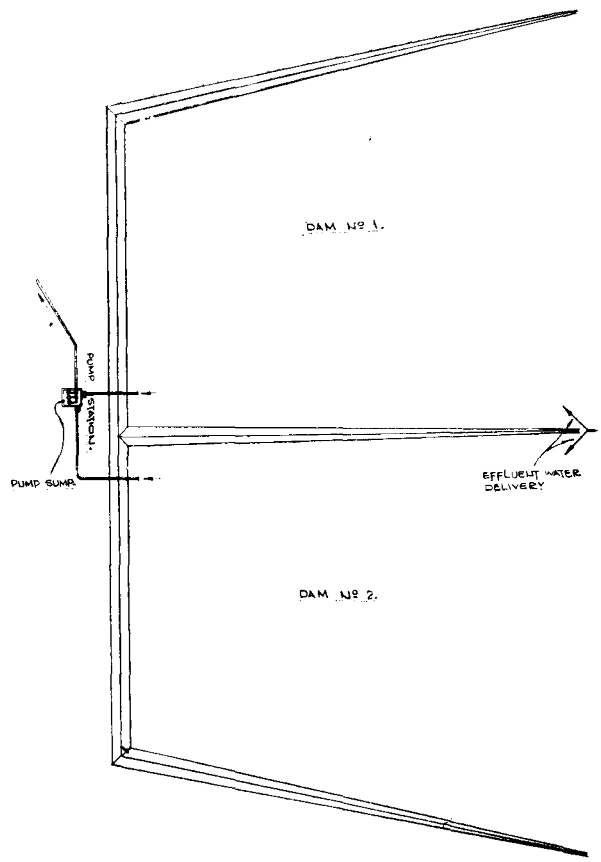

Fig. 6—Plan of catchment-water dam—two sections to facilitate desludging

Construction of Outer Wall

Dam building is commenced by filling up the toe trench to within 0,25 m of the top. When the slime has dried to a suitable consistency (21 per cent moisture), packing is commenced on the outside against the toe-trench spoil by shovelling out moist slime, employing for this purpose the Fox No. 4 lasher shovel with edge ground to knife sharpness. The following gives a good indication of optimum packing density:

- Too wet for packing—25 per cent moisture
- Too dry for packing—16 per cent moisture
- Optimum for packing—21 per cent moisture.

To avoid cracking, individual 'packs' should be limited to 0,2 m high by 0,6 m wide, or 0,25 m high by 1,0 m wide. The 'borrow trench' from which slime is removed for wall construction must not be excavated too close to the wall being built. A ledge 0,2 m wide must be left to support the newly built wall along its side facing inwards towards the dam. This will protect the wall from erosion when new slime is run into the excavated trench. The outside steps should be about 0,3 to 0,4 m wide for each vertical rise of approximately 0,2 to 0,25 m. Natural soil is most unsuitable for wall construction because of its porosity and its inability to consolidate, and should not be used to expedite building.

At a distance of 20 m from the toe trench, a similar slime bank that will rise towards the toe trench is packed of material that has been run into No. 2 wall trench. The two banks thus built will form a channel 0,25 m deep and slightly less than 20 m wide. The space between the toe and the No. 2 wall trench will constitute the outer wall of the dam. This channel is divided by cross-walls into paddocks 120 m in length. At the lower end of each paddock, a drainage pipe is set through the cross wall to control the flow of slime from paddock to paddock.

Because of its lightness, ventilation piping is extensively used for the ducting of slime or water through walls or embankments.

During most of the day, slime is directed into the 20 m wide channel to promote growth of the outer wall. After the slime has settled and sufficient water has been removed by decantation through lightweight piping and by evaporation, wall building is repeated. Excess moisture and fine slime are led to the pond by means of these inward drainage pipes.

It is essential that the area between the toe and No. 2 trench should be kept moist; otherwise, cracks are likely to develop on drying. Slime should be run between these walls at close and regular intervals.

However, care should be taken that the distance between the toe and No. 2 wall (width of outer wall) should not be more than 20 m. Considerable damage can be caused when these walls are too far apart, as the amount of slime deposited at one time will contain too much moisture, thus making the packed walls too wet and preventing them from drying out sufficiently quickly.

Construction of Inner Wall (No. 2 Rise)

Once the outer wall has been established, a secondary wall, 60 m wide, is built in a similar fashion behind the former at a level 1 to 2 m lower. This is commenced as soon as possible as a safeguard against overflow or failure of the outer wall. Here the paddock system is again employed in construction. If the grade of the dam is such that slime refuses to flow, the building of paddocks at successively lower levels of between 0,3 to 0,6 m will overcome the problem. By use of the paddock system it is possible to construct a wall against rising ground.

A general bird's eye view of dam construction, indicating slime and decantation water flow, is given in Fig. 8.

The normal cross-section through a slimes dam would therefore be a 20 m wide outer wall, a 60 m wide inner wall at a level 1 to 2 m lower, and the main body of the dam a further 2 m lower than the inner wall (Fig. 9).

The rate of wall rise has to be

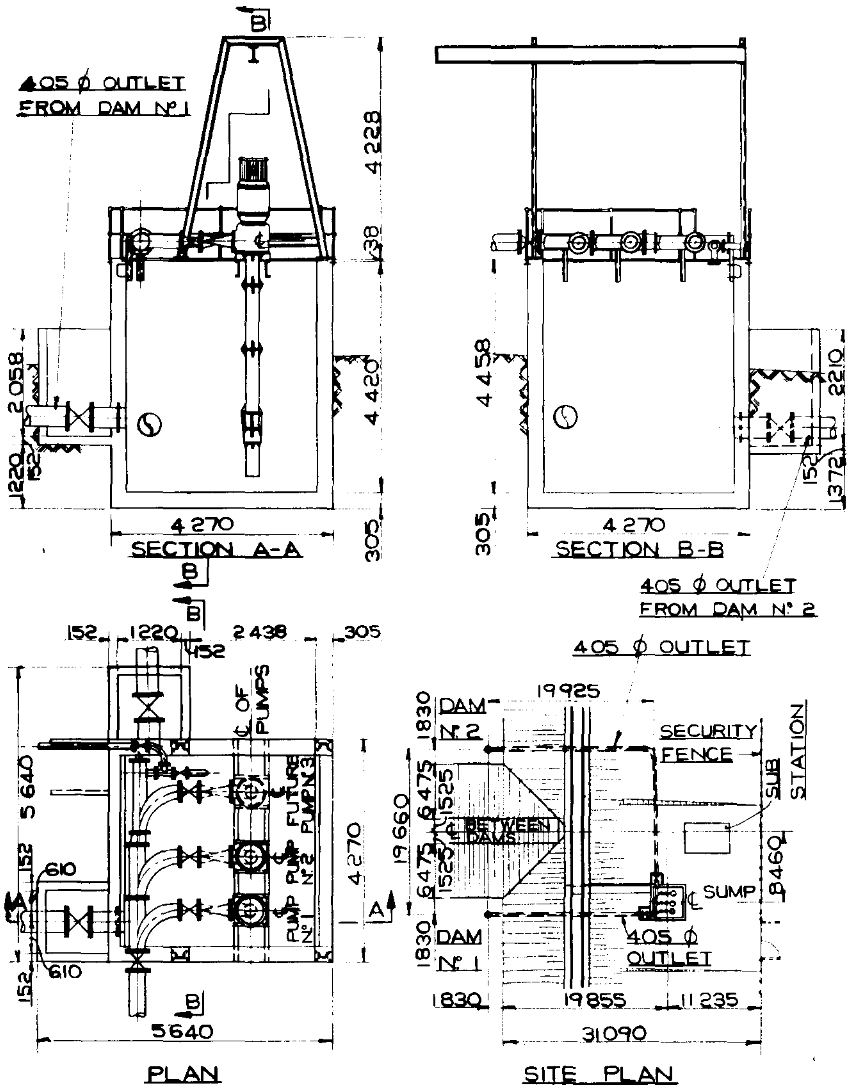

Fig. 7—General arrangement of return-dam pump station

controlled in such a way as to maintain a freeboard of 2 m.

To ensure that shear failure will not occur, it is advisable that the combined width of the outer and inner walls should amount to 80 m.

Wall construction has to be carried out during daylight hours, and uses eight hours or about one-third of the slime being deposited. The remainder is run into the pond, allowing for the creation of a substantial beach of slimes between the inner wall and the free water surface in the pond, where the penstocks are situated. This procedure lowers the seepage line through the walls, reduces seepage flows, and consequently greatly lessens the danger of piping.

Slopes and Berms

Two methods are used.

(1) To reduce the thrust on the toe and to lessen erosion, the outer wall is stepped back 4 to 8 m, depending on the dampness of the wall, after a height of approximately 5 to 6 m has been achieved, leaving a terrace or berm. This stepping back is continued at regular intervals as the height is increased. If a section of wall is found to be particularly damp, the step-back distance is increased even further, thus leaving a much wider terrace.

As soon as the first terrace is

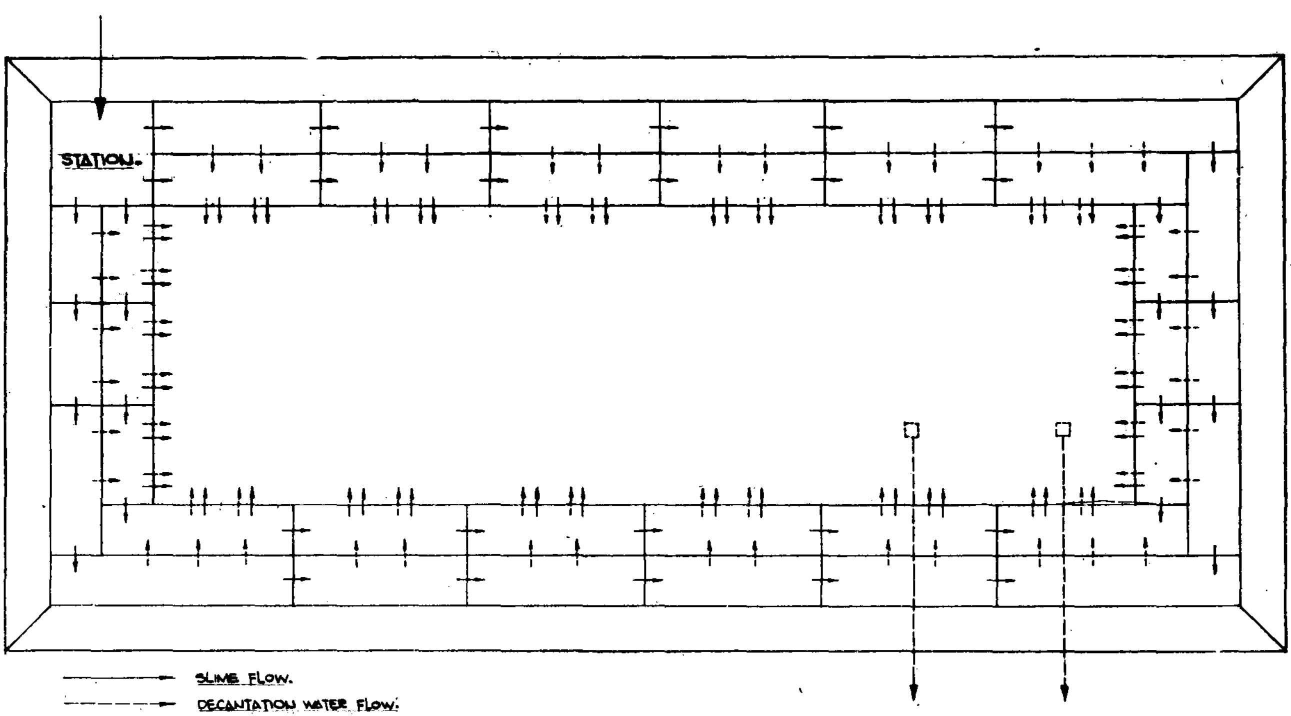

Fig. 8—Method of dam construction, showing slime and decantation water flows

formed, drainage pipes are put in at 350 m intervals to remove rainwater. These pipes should be of sufficient diameter to cope with all the stormwater as the dam rises higher and more terraces are formed. The terraces should be provided with walls about 1 m high along their outer edge to provide a small catchment through which the drainage pipes penetrate. This improves the stability of the walls during heavy storms. Wall slopes vary between 31° and 36°, the average slope including terraces varying between 23° and 30°.

(2) Walls are built without terraces, varying in slope between 27° and 36°. The toe of the outer wall should not be allowed to become water-logged; all water should be drained away as soon as possible by the digging of small furrows 0,6 m away from the toe to the effluent-water trench in order to form a better drainage. These furrows should be about 10 m apart. Obviously, the construction of paddy dams will be affected by this.

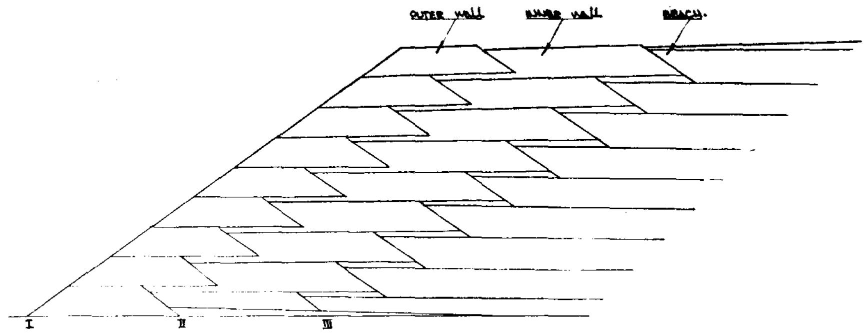

Fig. 9—Idealized section showing stepwise repositioning of II and III to accommodate wall slope (wall without terraces)

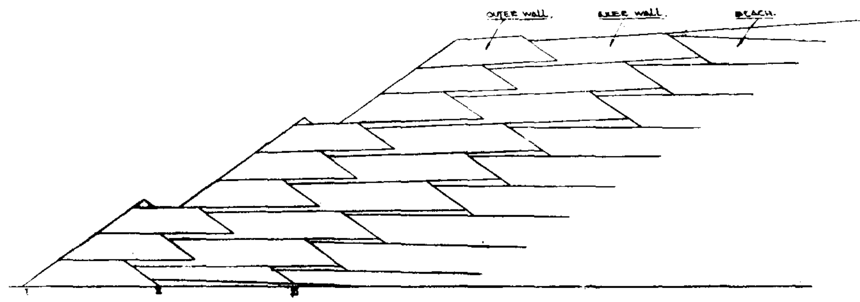

Fig. 10—Idealized section showing repositioning of II and III to accommodate wall slope (wall with terraces)

Maintenance of Wall thickness

As the outer wall rises, it will become narrower owing to its slope, and the inner edges of both the outer and inner walls have therefore to be periodically repositioned to maintain the widths of 20 m and 60 m respectively. The outer wall is widened by the construction of a third wall at an appropriate distance inside the dam. This is done by the building of the usual bank and filling the area between it and the inner wall with slime. When this third wall reaches the height of the second or inner wall, the latter is abandoned and the third wall becomes the second. The construction of the third wall must be started well in advance of the time that the outer wall becomes too narrow. Figs. 9 and 10 indicate the progress of construction.

Freeboard

The slime-containing surface of the dam should have sufficient height of inner wall (i.e., freeboard) to hold the maximum precipitation to be expected over 24 hours with a frequency of once in a hundred years. The height should be approximately 2 m above the pool.

Subdivision of the Dam

After the outer wall is established, the area of the dam is usually divided into two equal sections. Each in turn is isolated for about three to four months to dry out thoroughly, while building and deposition operations proceed on the other section.

In some cases, the separate deposition of tailings high in uranium on an existing dam surface, for subsequent reclamation, complicates the building operation.

Night Operation

When slime is diverted at the end of a day's shift to the interior of the dam, care must be taken to ensure that the change-over is safe and that the slime will not return on its own accord to the day wall, causing considerable damage.

Packing and Other Labour

The labour force for a slimes-dam operation (260 000 tonnes per month) may consist of the following:

Designation	No.
European Supervisor	1
Bantu Production Supervisors	3
Guards	6
Pump and Penstock Attendants (12-hour shifts)	2
Slime Packers (also maintenance of effluent drains, stormwater trenches, and fences, and installation of wooden penstocks and terrace piping)	21
Total	33

Packing is normally done on a task or bonus system, whereby each individual is given a set length of wall to be packed per shift. The distance to be packed is marked off by the Supervisor, and Packers are permitted to go as soon as they have completed their task.

If additional work is needed, it is paid for at overtime rates. On slimes dams belonging to gold mines, the daily task is 150 m per man.

Any pipework such as dismantling, relaying, extending, and repairing is carried out by the slimes-dam gang. Pumps, valves, motors, and switchgear are overhauled on the basis of scheduled maintenance.

Equipment

The following is a typical list of the equipment required for the operation of a large dam:

33 boiler or utility suits (one issued to each person)
33 jerseys (one issued to each person in winter)
33 oilskin suits (one issued to each person)
33 pairs of gumboots (one issued to each person)
1 first-aid kit
1 snakebite kit
40 shovels—No. 4 Lasher
6 picks
4 spare pick handles
1 bicycle
2 wheel barrows
1 ventilation-pipe cutter
2 rolls of mason's line
1 30 m tape
1 fire-extinguisher
2 4 lb hammers
1 set of spanners
2 fencing pliers
1 wire puller
2 soft brooms
6 sickles
1 electric grinder for sharpening tools
1 set of cold chisels
plastic food containers.

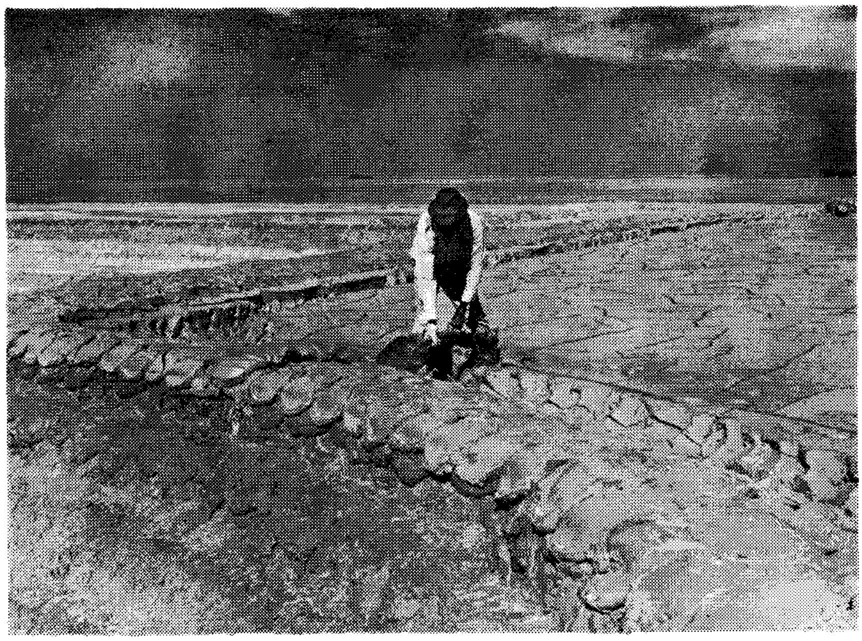

Plate I—Packer at work raising wall

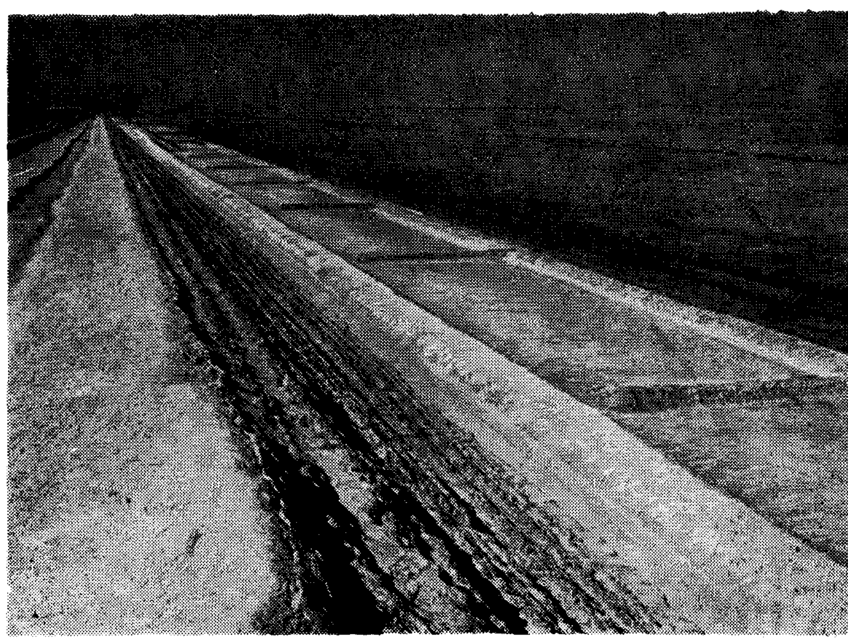

Plate II—Dam wall showing terrace and paddy dams at base

Water Reclamation and Prevention of Pollution

Supernatant water (comprising the solution accompanying deposited residues and rain water) accumulating within the dam is contained by the penstocks and decanted through them via the effluent-water trench to the catchment dam, whence it is delivered via pumps to the treatment plant. As mentioned previously, the amount of rain water to be allowed for should be the maximum precipitation to be expected over 24 hours with a frequency of once in a hundred years.

During rainy weather, the quantity of water accumulating around the penstocks may exceed the amount that can be immediately accepted in the treatment plant. In this event, the water may be retained on the dam but should be removed as soon as possible, particularly if the stability of the walls is threatened. If there is any likelihood of the catchment-water dam being unable to accommodate this large volume of water, provision should be made for it to be run into an evaporation area, whence portion of it can be reclaimed when required for use in the plant. An excessive quantity of water should not be retained on the top of the slimes dam for any prolonged period as this would endanger the stability of dam walls. Water from a rainfall of say 100 mm should not be retained on the dam for more than 48 hours.

Supernatant liquid inside the dam should not be retained too close to the inner walls. Slime should be tapped at fairly close intervals from the inner wall by means of short lengths of piping, and should be allowed to flow into the centre section of the dam in sufficient quantity to form a beach along the walls to force the clear water away from them towards the centre of the dam and thence to the penstocks.

Release of slimes from the slimes dam to the return-water dam or any other catchment area should in no circumstances be condoned. Only clear water should be released to the return dam.

Water reclamation expressed as a percentage of the amount going out with the tailings varies from 10 to 50, with an average of 25. The difference is lost through evaporation and seepage. Evaporative losses amount to 43 m^3/ha over a period of 24 hours when the sky is cloudless and there is no wind. This can increase tenfold during periods of high wind.

One effective method of minimizing down-stream pollution is to maintain the pH of the water in the dam sufficiently high to ensure precipitation of the more injurious metals as hydroxides and allow them to settle out in the dam. To this end, close pH control of residues is desirable.

Water reclaimed from the dam should be tested at regular intervals for pH, and for its content of chemicals and undissolved solids. Where necessary, these tests should be done on the groundwater as well. The latter is particularly important where subsurface seepage is occurring downstream of the dam and is in danger of polluting downstream water.

Examples of Failure and Remedial Steps

The following are the commonest causes of failure: fissures, slip or shear, and erosion.

Fissures. A fissure developing in

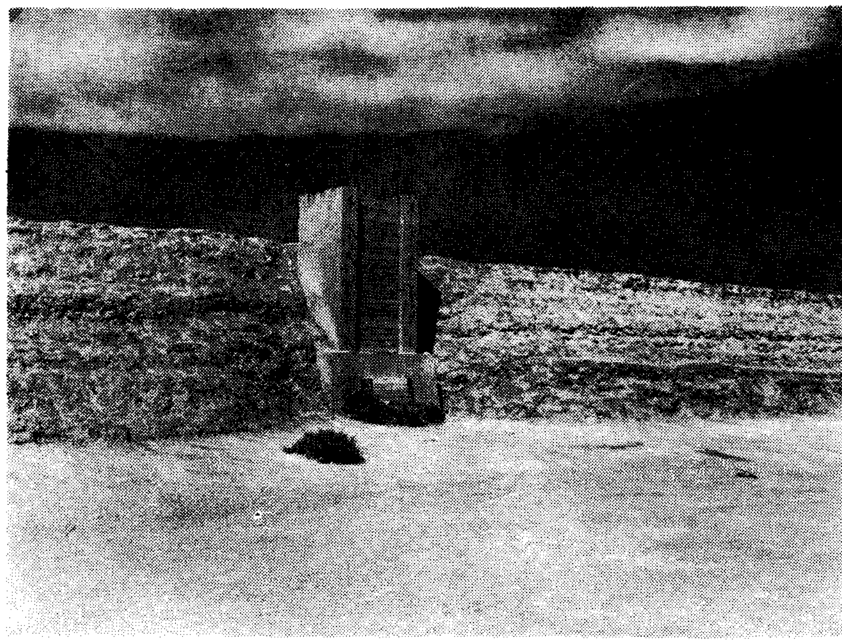

Plate III—Base of main concrete penstock

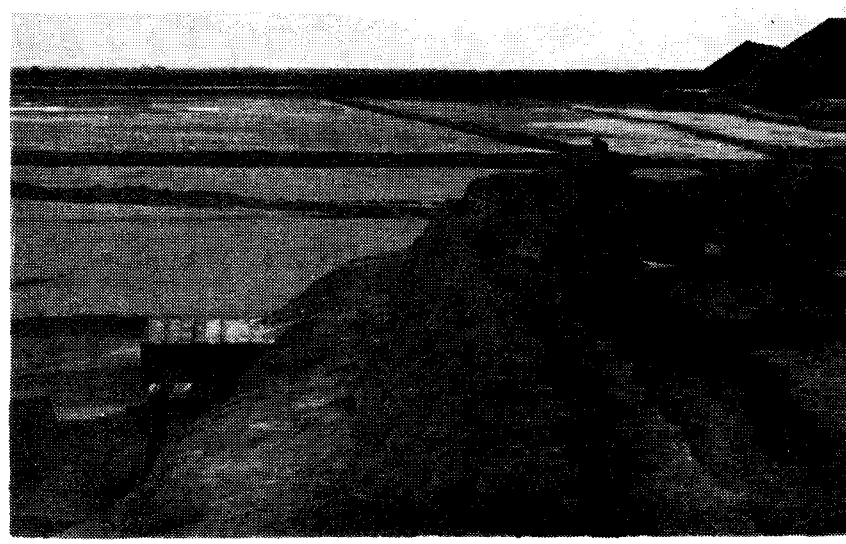

Plate IV—L-shaped penstock employed for leading slime from station to walls and interior of dam

TABLE I
DISTRIBUTION OF OPERATING COSTS

Dam	Monthly tonnage deposited	European attendant and supervision	Bantu labour	Protective clothing, sundry stores, and piping	Total cost R	Cost cent/tonne
1.	235 750	520	1294	276	2090	0,9
2.	166 350	533	1034	322	1889	1,1
3.	170 000	580	840	250	1670	1,0
TOTAL	572 100	1633	3168	848	5649	1,0
Average	190 700	544	1056	283	1883	1,0
Percentage		29,0	56,0	15,0	100,0	1,0

an outer wall should be isolated from the rest of the dam by the construction of a small paddock on top of the wall adjacent to the point where the fissure appears. Slime of higher relative density is then allowed to flow into the fissure until it is sealed. When the slime used for sealing purposes has dried to about 15 per cent moisture, the paddock is removed.

Slip or Shear. The upstream methods of slimes-dam construction suffer from the disadvantage that they are built on previously deposited, unconsolidated tailings of limited shear strength. If these are saturated, the possibility of slip or shear is greatly increased. Wall shear is usually due to faulty ground conditions and can be avoided by the provision of French drains before wall building commences. If a slip occurs in a section of an outer wall, the adjacent interior to the dam should immediately be isolated by running in sufficient pulp from a duct on the inner wall in an endeavour to form a beach that will drive supernatant solution away from the affected area. The opportunity can then be taken to construct a buttress wall that will adequately encompass the area of shear. The slope of the buttress wall should be 27° to 30°, and, if found necessary, should have a suitable French-drainage system underlying it.

Erosion. Surface materials may be removed from wall slopes by wind and rain, and heavy rains may cause severe gullies to form. The most suitable method of combating this is to establish vegetation on the slopes as soon as possible, provided the dam is not to be reclaimed for additional minerals recovery at a later stage. Grassing of the lower slopes of outside walls can therefore be initiated while the dam is in use. However, when dam walls have been eroded away at the base, they should be reinforced by the construction of small buttresses about 2 m high and 2,5 m wide, thus creating an additional terrace, which should be provided with drainage pipes. This method of rehabilitation should be continued until all damaged parts are adequately covered.

Closure of Dam

A closure procedure is provided for in the Code of Practice[2] and will therefore not be discussed here.

Any assistance required in the establishment of vegetation can be obtained from the Chamber of Mines Vegetation Unit, who will undertake to oversee the operation and provide the necessary seed at cost.

OPERATING COSTS

Details of the operating costs of slimes dams are given in Table I.

FUTURE TRENDS

Of prime importance as far as stability and groundwater pollution is concerned is the surficial geology (the geology of all soil deposits overlying bed rock). For this reason, geotechnical engineers or soil mechanics experts are likely to be employed to an ever-increasing extent as consultants to carry out more-thorough geological and subsurface investigations. Other possible future trends are discussed below.

Cycloning

It is likely that more use will be made of cyclones for the separation of sands to be employed for wall building by methods described by Klohn[4] and by Brawner and Campbell[5]. Attempts to build walls mechanically by the use of spigoting and formers have resulted in poor stability and high erosion. If it were possible, a reduction in labour complement to about eight persons could be achieved for a large-scale operation.

Differential Settlement

Table II, which gives an example of differential settlement experienced by pulp flowing along a trench, indicates that there could be something basically unsound in the present system of running slimes for considerable distances along dam walls to areas where they are required for construction purposes.

The higher the relative density, the lower the differential settlement. It can be seen that, with increasing distance from the station, slimes employed for wall building tend to become finer. Although more costly, a ring-main with take-off pipes at approximately 500 m intervals would avoid segregation.

Water Conservation

As described above, residue disposal would be achieved by the installation of a ring-main round the dam, with delivery pipes spaced at approximately 500 m intervals. Each take-off pipe would be provided with two delivery points, one to the wall area and the other into the dam itself. This would enable a pulp of 44 per cent moisture to be pumped to the walls for eight hours a day for wall building, and a pulp of 40 per cent moisture into the interior of the dam for the remaining sixteen hours. High-density pulps normally have difficulty in flowing distances of more than 250 m, hence the necessity for multiple delivery points. If the reduction in the water accompanying residue to the dam exceeds the reclamation water obtained during the dry season, then water savings should be effected.

The use of a secondary dam 2 m

TABLE II

EXAMPLE OF DIFFERENTIAL SETTLEMENT

Pulp sample no.	1	2	3	4	5	6	7	8	9	10	11
Relative density	1,558	1,576	1,558	1,538	1,515	1,520	1,476	1,477	1,442	1,455	1,464
Pyrite, %	1,84	1,78	1,73	1,71	1,73	1,69	1,67	1,63	1,65	1,59	1,59
Grading micrometers:											
> 150	8,1	9,0	7,0	9,1	8,9	7,9	5,6	6,3	5,7	5,6	5,2
> 74	27,3	28,5	29,3	28,3	28,7	27,9	28,0	26,9	25,6	25,3	25,1
< 74	64,6	62,5	63,7	62,6	62,4	64,2	66,4	66,8	68,7	69,1	69,7
Total	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

120 metres between one sample and the next.

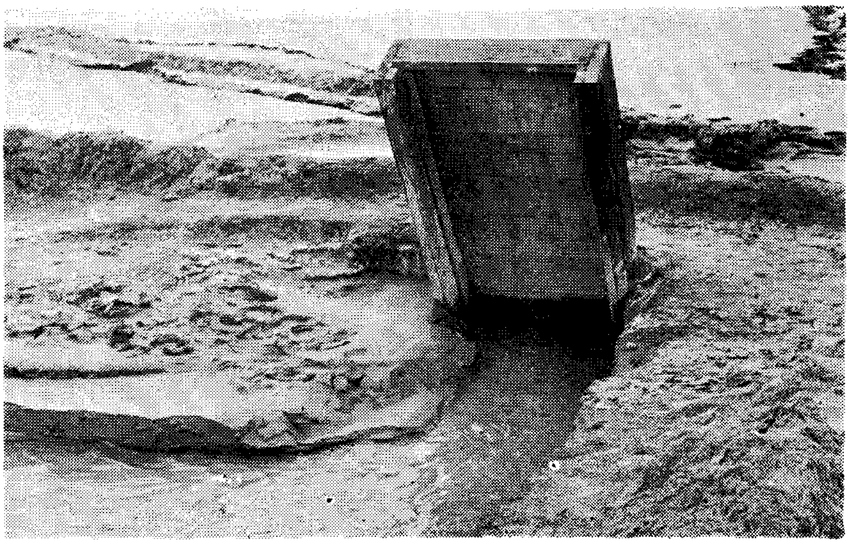

Plate V—Another view of the L-shaped penstock shown in Plate IV

deep and of much less surface area, with walls constructed of slime, into which slimy water is immediately decanted from the main dam, will result in greatly diminished evaporative losses. Clear water is then decanted from this secondary dam via penstocks into the catchment-water dam.

Decantation System

Instead of employing penstocks with ground-level drainage piping, a system similar to that at the Ray Mines Division of Kennecott Copper Corporation in Arizona could be used to advantage (Fig. 11).

It consists of a syphon pipeline of 750 mm diameter extending 300 m into the dam and running down the wall to the effluent-water reclamation facility. The portion projecting into the dam is supported on 426 1500 mm Navy-surplus buoys, the far end provided with a bend that is just submerged in the pond water. Flow is initiated by the application of a vacuum at the highest point into the pipeline, a small vacuum pump being mounted on the pipe itself. Once flow is commenced, the vacuum is turned off. Access to the decantation point in the pond is along a walkway, also supported on the buoys.

The advantage of this system is that there are no submerged penstocks or pipes that have to be abandoned entirely if failure occurs. The tailings deposited daily amount to 22 000 tonnes, and water reclamation approaches 26 500 m^3.

CONCLUSIONS

It is hoped that the descriptions given here of slimes-dam design, commissioning, and operation, generally as practised by the Anglo American Corporation, will serve as a useful supplement to what has already been written on the subject. The problems involved in the successful implementation of the more-mechanized techniques that are briefly discussed are considerable owing to the nature of the topography generally encountered, and to the fineness of gold residues in South Africa, which contain a very small proportion of sands suitable for wall building.

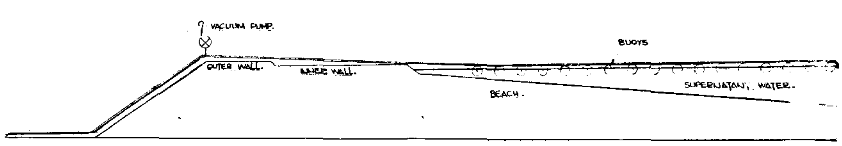

Fig. 11—Syphon system for water decantation

ACKNOWLEDGEMENT

The author is indebted to staff of Anglo American reduction plants for supplying the information necessary for the compilation of this paper.

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