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The Use and Behavior of Geotextiles in Underdrainage Systems of Gold Mine Tailings Dam in South Africa

L'emploi et la réaction des géotextiles envers les systèmes pour les sous—égouts des residus des mines d'or en Afrique du Sud

The paper describes the design and function of underdrainage systems in gold tailings dams.

The cost effectiveness, practical implications and potential problems associated with the incorporation of geofabrics in these underdrains are discussed.

Reference is made to the observed performance of geofabric underdrains in tailings dams which have been operational for the past six years.

The paper concludes that geofabrics can be successfully used in this application and provide both economic and constructional benefits when compared to natural drainage media.

Le papier décrit le dessin et la fonction d'un système de sousdrainage dans un barrage de retenue des tailings d'or.

On discute l'efficacité du coût, les implications practiques et les problèmes potentiels liées à l'incorporation des géotextiles dans ces sousdrains.

On fait mention du fonctionnement des géotextiles observé sous des drains dans les barrages de retenue des tailings qui ont été en plein activité dupuis six ans.

Le papier dit en terminant que des géotextiles peuvent être employé avec succès dans cette application et qu'ils donnent en comparaison avec des moyens de drainage naturel des avantages economiques et de construction.

1 INTRODUCTION

For the past six years, the Authors of this paper have been involved in the design of tailings dams for Gold Mines located in the north-eastern area of the Orange Free State Province of South Africa. Increasing land costs in the Orange Free State Goldfields, as the area is commonly called, have contributed to the need for depositing high tonnages of gold tailings on relatively small land areas.

The flat nature of the local topography and engineering characteristics of the gold tailings material enable the tailings dams to be constructed employing what is known as the 'ring dyke' method. This method allows for point deposition at predetermined 'delivery stations' around the dam perimeter. Tailings is deposited in a slurry form with a 1:1 water:solids ratio by mass. During the day shift the tailings is deposited within the ring dyke, a system of adjoining paddocks around the dam perimeter. The coarse fraction of the tailings is allowed to settle out within the ring dyke between delivery stations and the fine fraction is decanted in a slurry form into the dam basin, thereby allowing the ring dyke to be raised using the coarser fraction of the tailings only. When building of the ring dyke is not being carried out, typically during the night, the tailings is deposited directly into the dam basin. Perimeter freeboard is achieved by ensuring that the rate of rise of the ring dyke exceeds that of the tailings within the dam basin.

The existing trend of increased deposition tonnages on relatively small land areas has two major implications, viz:

- a substantial increase in the quantity of water deposited per hectare, and
- a substantial increase in the rate of rise in vertical elevation of the tailings surface.

To ensure the stability of the ring dyke, the need for an underdrainage system beneath the tailings dams has become necessary in order to:

- accelerate the rate of consolidation and consequent gain in strength of the material deposited within the ring dyke, thus allowing the outer walls to be constructed at a relatively higher rate of rise
- accelerate the rate of dissipation of water pressure against the ring dyke by drawing down the phreatic surface within the tailings mass, thereby improving the stability of the outer walls

The paper describes the design philosphy adopted and discusses the detailed design, economic and constructional considerations which have led to the successful use of geotextiles in underdrainage systems of gold tailings dams in the Orange Free State Goldfields.

2 DESIGN PHILOSOPHY

The underdrainage system is designed to cater for both above surface and subsurface flow components. A brief description of these components are:

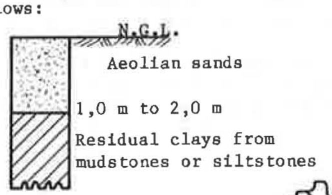
2.1 Above surface component

The above surface component of flow is that which is generated by the development of a phreatic surface within the tailings mass. Conventional flow net theory is applied to determine the order of magnitude of this component, thus providing a means of designing an adequate drain section. The most commonly used drain section for drawing down the vertical flow component is a rectangular 'blanket' section with the width being much greater than the height (w ≈ 16h) to allow for a large area of interface.

The location of the blanket section is of màjor importance with respect to the stability of the ring dyke and is determined by considering factors such as the permeability of the tailings, the final height of the tailings dam and the location of the pool of surface water formed within the dam basin.

2.2 Subsurface component

A typical geological profile of the surface in situ soils underlying the Free State Goldfields tailings dams is as follows:



The permeability of the surface aeolian sands is greater than that of the underlying clay resulting in a tendency for the majority of seepage water to flow in a horizontal direction within the sand layer. In order to minimize seepage outside the boundaries of the tailings dam, a vertical cut-off trench drain section is considered necessary in the underdrainage system. The depth of the cut-off drain section is determined according to the depth of the aeolian sand layer. The optimum location for the cut-off drain section is around the extreme boundaries of the tailings impoundment, thus minimizing contamination of the surrounding environment with seepage water.

2.3 Conceptual design

In order to cater for both the above flow components and to simultaneously satisfy stability and environmental requirements, an underdrainage system as shown in Fig 1 has been adopted. Fig 1 conceptually shows the locations of the blanket drain section, toe/cut-off drain section and outlet drains in relation to the ring dyke.

The toe/cut-off drain section is situated immediately adjacent to the starter wall.

The main function of this drain is to minimize seepage through the starter wall and outer slimes walls during the initial establishment of the dam and to cut-off subsurface seepage in the upper aeolian sand horizons.

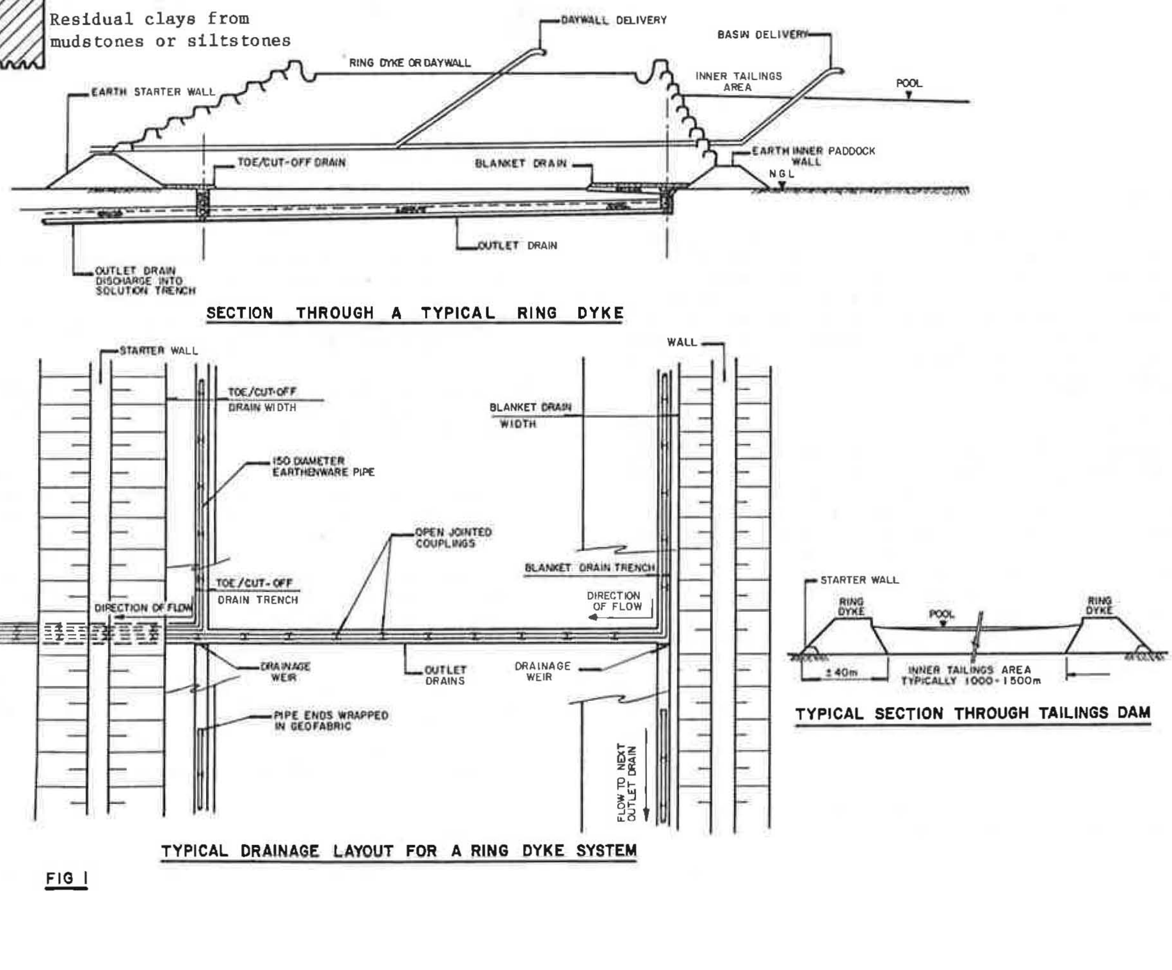


FIG I

The toe drain thus controls the position of the phreatic line until the dam is high enough to permit the blanket drain to do so. Furthermore, during the entire life of the dam, the toe drain will be available as a back-up drainage system to the blanket drain should a section of the latter, at any stage, be rendered inoperational due to blinding or blockages.

The blanket drain section is situated well within the outer boundaries of the dam in order to control the position of the phreatic line after the development of a centrally located pool, thus minimizing seepage through the ring dyke and ensuring a stable perimeter wall.

The water flowing into the blanket and toe drains is transported out of the drainage system by means of a series of outlet drains interconnecting the blanket and toe drains. The frequency of outlet drain locations is determined according to the carrying capacity of the blanket and toe drains. The outlet drains discharge into the externally located solution trench which gravitates away from the tailings dam to a storage reservoir or sump for recycling back to the Mine.

3 DETAILED DESIGN AND ECONOMIC CONSIDERATIONS

3.1 The blanket drain

Fig 2 shows the typical cross-section adopted in the design of the blanket drain.

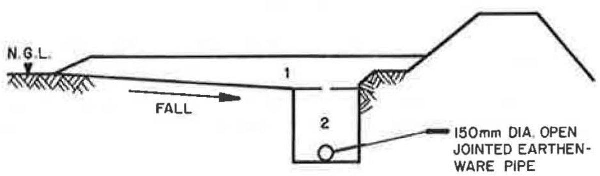


FIG 2

The drain has two components, viz:

- the blanket section for phreatic line drawdown, and
- the trench section which acts primarily as a means of transporting water to the outlet drain junctions, whilst simultaneously providing an additional area of attraction to subsurface seepage water.

In order to encourage flow, the natural ground below the blanket section is graded towards the trench section.

The open jointed drainage pipe is provided to increase the capacity of the drain where required, ie

- At drainage outlet junctions
- When, due to adverse topography, the frequency of outlet drains is insufficient to cater for the expected blanket drain flow.

Figs 3 and 4 show details of alternative drainage media considered, excluding the use of geofabric.

Figs 5 and 6 show details of alternative drainage media incorporating geofabric.

In determining the relative material and installation costs of the individual alternatives, the Authors have assumed that overall cross-sectional dimensions, viz width and thickness of blanket and depth of trench, are identical for each case. The relative implications of this assumption are noted in the text describing each alternative. The costs quoted in the text are based on current material supply and placing costs in the Orange Free State Goldfields.

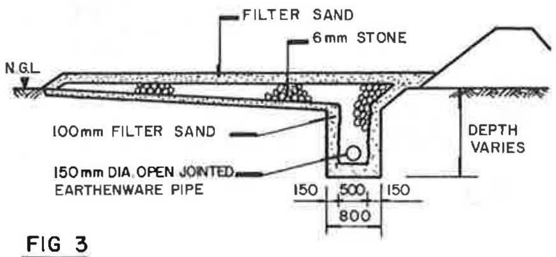


FIG 3

The drainage media in Fig 3 consists of filter sand and 6 mm stone. The filter sand is included to prevent migration of tailings and in situ soil into the 6 mm stone which is the main water transporting medium. The relatively low permeability of the 6 mm stone necessitates the installation of a larger quantity of trench pipes and/or a greater number of outlet drains than required by the other alternatives. The installation of this drain requires back shuttering and careful supervision in order to eliminate mixing of the different media. Installation costs are thus relatively high.

The estimated cost for supply and installation of materials is \$45,00* per linear metre.

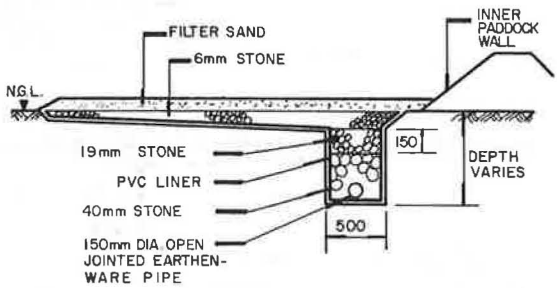


FIG 4

The drainage media in Fig 4 consists of filter sand, 6 mm, 19 mm and 40 mm stone and PVC liner. The filter sand prevents migration of the tailings into the stone, whereas the PVC liner is included to prevent migration of the in situ soil into the stone. The inclusion of the PVC liner, however, reduces the available area of attraction by creating an impervious layer adjacent to both the blanket and trench sections of the drain. The installation of this drain is relatively easy although careful attention and ground surface preparation is required prior to placing the PVC liner. The estimated cost for supply and installation of materials is \$40,00 per linear metre.

* Costs are calculated in South African Rands and the U S Dollar equivalent quoted.

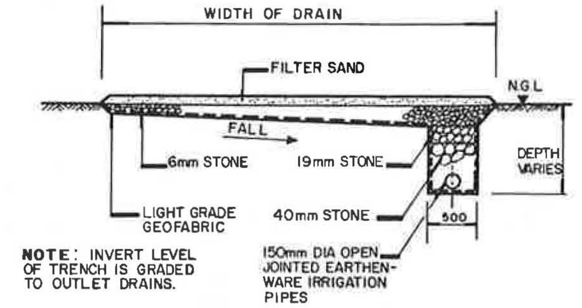


FIG 5

The drainage media in Fig 5 consists of filter sand, 6 mm, 19 mm and 40 mm stone, and geofabric. The filter sand again prevents migration of the tailings material into the stone, whereas the geofabric provides an effective filter between in situ soil and stone, preventing migration of the soil but allowing through flow of seepage water. Good supervision is required during installation to prevent mixing of the different media. Surface preparation of in situ soil adjacent to the geofabric is important to ensure the removal of loose material which may clog the geofabric and prevent through flow of seepage water. The estimated cost for supply and installation of materials is $30,00 per linear metre.

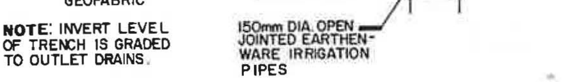
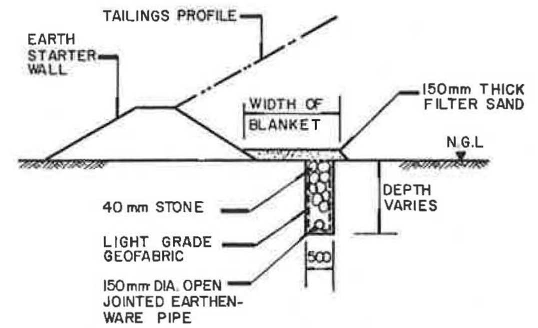


FIG 6

The drainage media in Fig 6 consists of filter sand, 40 mm stone and geofabric. The filter sand is required to exclude the possibility of fine tailings either clogging or migrating through the geofabric. The geofabric beneath the blanket section and lining the trench serves the same purpose as in Alternative 3. Stringent quality control is required during installation to ensure that proper lapping and stitching of the geofabric is carried out.

The relatively high permeability of the 40 mm stone allows for a lesser quantity of trench piping and/or a reduced number of outlet drains than required by the other alternatives. The estimated cost for supply and installation of materials is $35,00 per linear metre.

3.2 The toe/cut-off drain



The toe/cut-off drain has two components, viz:

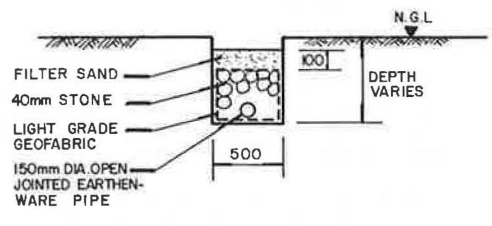
- The vertical trench section, which is lined with geofabric and backfilled with 40 mm stone. The geofabric is then stitched so as to fully enclose the stone. Apart from fulfilling its function as a cut-off to subsurface seepage water, the trench section serves as a means of transporting seepage water to the outlet drains. The open jointed drainage pipe is provided to increase the capacity of the drain as in the case of the blanket drain.

- The horizontal sand blanket serves two functions, viz:

  - to draw down the phreatic line in the ring dyke, particularly during initial stages of deposition.

  - to eliminate the possibility of tailings material either clogging or migrating through the geofabric at the 40 mm stone interface.

3.3 The outlet drain



The outlet drain consists of a trench section lined with geofabric, equipped with an open jointed pipe, and backfilled with 40 mm stone. A sand layer is placed above the geofabric to eliminate the possibility of the fine tailings material passing through the geofabric. This sand layer also protects the geofabric from ultra violet light exposure during the period prior to commissioning. The 40 mm stone has been included to ensure that the outlet drain is at no time rendered completely unoperational due to breakage and/or blockage of the pipe.

4 OBSERVED BEHAVIOUR OF UNDERDRAINS

4.1 Periodic visual monitoring of outlet drain flows from underdrainage systems which incorporate geofabric as a filter medium have been undertaken to estimate underdrainage efficiency for the tailings dams in question.

These observations indicate that underdrainage systems incorporating either blanket drain Alternatives 3 or 4 (Figs 5 and 6) perform equally well for a period of observation stretching over approximately 6 years.

4.2 Stand pipe piezometers have been installed in a number of tailings dams to determine the position of the phreatic surface with respect to underdrain location and outer wall geometry. Readings are taken monthly and results plotted on surveyed cross-sections at the piezometer locations. At each section, three piezometers are installed, one in the vicinity of the toe/cut-off drain location, one in the vicinity of the blanket drain location and one within the dam basin.

Fig 9 below represents the cross-sections at two piezometer set locations on the same tailings dam.

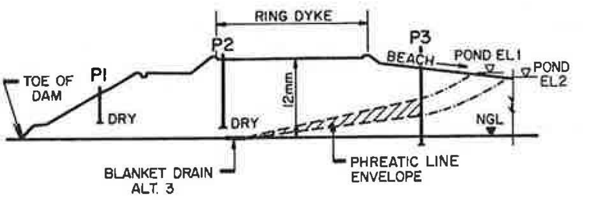


FIG 9a

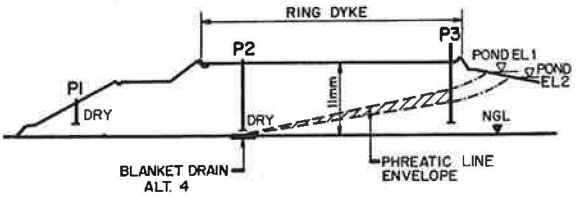


FIG 9b

When the underdrainage system for this tailings dam was designed, blanket drain Alternative 3 was specified, ie a blanket drain incorporating sand, 6 mm, 19 mm and 40 mm stone, with the underside of the blanket section and the base and sides of the trench section lined with geofabric (Ref Fig 9a). However, due to a severe shortage of 6 mm and 19 mm stone during construction, a section of this drain was constructed as on Alternative 4 blanket drain, ie a blanket and trench section of 40 mm stone completely enclosed with geofabric, overlain by filter sand (Refer Fig 9b).

In both cases, piezometers P1 and P2, located near the toe and blanket drain respectively, have been consistently dry for the past 12 months. Both P3 piezometers indicate an annual variation in phreatic surface of 2 m as illustrated by the plotted phreatic line envelope.

The above data have been interpreted to imply that the phreatic surface has been drawn down by both types of blanket drain with equal efficiency.

Where piezometers have been installed on tailings dams with either blanket drain Alternatives 3 or 4, similar results have been obtained.

5 CONSTRUCTION AND POST CONSTRUCTION PROBLEMS RELATED TO THE USE OF GEOFABRICS IN UNDERDRAINS

The Authors' involvement in the supervision of construction of underdrainage systems incorporating geofabric has led to the identification of several construction problems associated with the placing of the geofabric and post-constructional problems encountered during commissioning stages of the dam. These problems and suggested remedies are discussed briefly below.

5.1 Stitching or lapping of geofabric joints

The method of joining is of major importance when constructing toe, outlet and blanket drains and in particular at all junctions of these drain sections. Stitching, as opposed to lapping, is definitely the preferred alternative, being the more positive method of ensuring that there are no gaps or holes in the geofabric prior to and after placing of filter media. Several drain failures have been experienced during the drain covering operations with tailings material on drains which specified lapped joints.

5.2 Blanket bed and trench preparation

Trimming and compaction of the blanket drain bed and trimming of the trench base is necessary prior to placing the geofabric in order to minimise the quantity of loose in situ material at this interface. Light compaction of the stone within the trench is recommended to improve the uniformity of the stone/geofabric/in situ soil interface.

5.3 Weeds and vegetation

The germination and growth of weeds and other vegetation beneath the blanket section has resulted in both the puncturing of the geofabric and the loosening of in situ soil. To avoid this occurrence, treatment of the prepared blanket bed with weed killer is recommended.

5.4 Filter sand cover to geofabric drains

A filter sand cover to the geofabric surface of the drain is considered necessary for the following reasons:

- The time period between completion of construction of the underdrains and the total covering with tailings material can be substantial (typically 6 to 12 months). In order, therefore, to minimize unnecessary exposure to sunlight and consequent ultra violet attack on the geofabric, the sand covering is recommended.

- Transported in situ fine sand often contaminates the drain surface. Prior to covering the drains with the tailings material, it is essential that these contaminants are removed to ensure maximum drain efficiency. It is considerably easier for those involved in covering the drains with tailing slurry to skim off the contaminants from a layer of sand, using rakes, than to effectively remove them from a geofabric surface.

5.5 Rodents

Holes formed in geofabric lining to underdrains by rodents (rats and ground squirrels) have been identified in several cases.

This problem generally only arises during the construction period and the time prior to the deposition of tailings material. Rodents cannot survive after commissioning due to the resulting environmental changes.

The only practical method of locating these holes is, therefore, to undertake careful visual inspection of the sand covered drains immediately before covering with the tailings material. Rodent activity can be generally located by the detection of disturbed areas of the surface sand layer in the form of holes and mounds. Repairs should be undertaken by exposing and patching the damaged geofabric.

5.6 Recommended geofabric grades for various applications related to tailings dam construction

The following recommendations regarding the choice of geofabric grade for the various applications associated with tailings dam construction based on observations made during construction supervision, are:

- Underdrainage system to tailings dams as previously described - due to economic considerations the light grade (bursting strength approximately 2 000 kPa) is generally specified. This is normally acceptable provided the filter stone size does not exceed 40 mm diameter and stringent site control is continually exercised.
- Pollution cut-off drainage trenches - the depth of these trenches is often of the order of 3 m in order to effectively intercept the more permeable surface geological horizons. After lining the trench with geofabric, clean mine waste rock (approximately 150 mm average diameter) is commonly utilized as a backfill material in preference to the more expensive concrete aggregate stone. Hence, if rock is backfilled in trenches to depths greater than approximately 1 m and, in particular, if mine waste rock is used, it is recommended that medium to heavy grade geofabric is specified (bursting strength 2 500 to 3 000 kPa).
- Heavy grade geofabric (bursting strength 4 000 - 5 000 kPa) should always be specified when used as a filter layer below rock rip-rap wave protection to upstream faces of water reservoirs associated with tailings dams.

  This application is also applicable when rock toe buttresses are constructed to improve the stability of the outer slopes of tailings dams.

  In both these cases, mine waste rock having an average diameter of 150 mm is generally used.

6 CHEMICAL EFFECTS ON GEOFABRIC PERFORMANCE

In addition to the problems related to the use of geofabrics in underdrains, discussed in Section 5 of the paper, a potential exists for chemically-induced blockage and chemical attack of geofabric materials. These effects are related to the chemical composition of the liquid discharged from the tailings to the drains.

Typically, tailings liquids from gold tailings dams will be chemically saturated and carry high levels of total dissolved solids. However, the chemical composition of these liquids are subject to variation depending on the following:

- the level and extent of neutralisation of tailings after gold removal
- the pyrite (iron sulphide) content of the tailings
- the residual levels of pyrite in the tailings, when floatation removal of pyrite is practised

The general case for the most recent established gold mines in South Africa is that tailings are neutralised to pH7 or greater and pyrite removal is practised.

Iron levels in tailings solutions can be relatively high despite the above processes. It is observed that iron can be precipitated from gold tailings solutions in contact with air, by the oxidation of ferrous to ferric iron, the latter species having a considerably lower solubility product. If precipitation occurred in or on the geofabric, blinding of the fabric could occur.

In practice, however, no examples of such precipitation have been found on operational tailings dams. Exposure of fabric forming part of a toe drain showed no iron precipitation in the fabric initially. With the drain uncovered, a red iron precipitate began to be formed on the fabric with time, indicating that the potential for ferric iron formation existed. This would appear to support the proposition that tailings solutions from gold dams are chemically reduced systems whilst in the tailings dam itself, but that they become relatively oxidised after discharging from the underdrain into the solution trenches where iron precipitation can be observed.

In addition, as practice in South Africa has shown, geofabrics appear to be immune to chemical attack by liquids from gold tailings. It may be that, in the unneutralised tailings case, liquids with pH values less than $\pm$ 2, resultant from sulphuric acid leaching of gold ore, could degrade geofabric with time. This is the subject of further study.

CONCLUSIONS

In view of periodic difficulties experienced in obtaining sufficient quantities of natural filter media, in particular 6 mm and 19 mm stone, geofabric has been extensively used as an alternative filter medium in underdrainage systems of gold tailings dams in the Orange Free State Goldfields

The relative supply and installation costs indicate that the use of geofabric in underdrains is economically viable. The cost savings are primarily due to the simplification of drain construction techniques and consequent shorter construction periods.

Visual observations and piezometer readings indicate that gold tailings dams underdrainage systems incorporating geofabric operate efficiently in the medium term (6 years to date) and achieve their design functions in terms of accelerating the rate of consolidation of material within the ring dyke and ensuring the overall stability of the outer dyke walls by drawing down the phreatic surface within the tailings mass.

Most problems associated with the use of geofabric in underdrainage systems can be eliminated by ensuring adequate site control during construction and immediately prior to and during initial tailings deposition.

Observations to date suggest that the performance of geofabrics in underdrains is not adversely affected by the chemistry associated with gold tailings solutions.