Profiles of hydraulic-fill tailings beaches, and seepage through hydraulically sorted tailings

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SYNOPSIS

It is shown that the profiles of beaches of hydraulic-fill tailings dams can be predicted with good accuracy by the use of small-scale laboratory deposition tests on materials from a prototype tailings dam. Although the slope of a tailings beach at any point is related to the shear strength of the settled slurry, there are severe practical difficulties in the prediction of beach profiles from shear strengths measured in the laboratory. The hydraulic sorting of particle sizes that occurs on a tailings beach results in a gradient of permeability along the beach, and this gradient has the significant effect of lowering the phreatic surface in the tailings dam.

SAMEVATTING

Daar word getoon dat die profiele van die strandevan die strande van hidroulies gevulde uitskotdamme baie akkuraat voorspel kan word deur die gebruik van kleinskaalse laboratoriumafsettingstoetse met materiaal afkomstig van 'n prototipe uitskotdam.

Hoewel die helling van 'n uitskotstrand op enige punt met die skuifsterkte van die afgesakte flodder verband hou, is daar verskeie praktiese probleme in verband met die voorspelling van strandprofiele aan die hand van skuifskerkwesie wat in die laboratorium gemee is.

Die hidroulies gesorteerde partikelgroottes wat op 'n uitskotstrand voorkom, lei tot 'n deurlatingheidsgradient langs die strand en hierdie gradient het die belangrike uitwerking dat dit die grondwaterstand in die uitskotdam verlaag.

Introduction

In a recent paper, Blight and Bentel (following Melent'ev et al.) showed that the profiles of a series of dam beaches of hydraulic-fill tailings can be represented by a single dimensionless 'master profile'. It followed from this, that the profile of any beach of a particular tailings can be predicted accurately from the elevation of the point at which the tailings are deposited, and the elevation and distance of the edge of the pool. Examples were given for beaches of copper, diamond, gold, and platinum tailings, and it was shown that the principle is also applicable to the profiles of cones of underflow material deposited by cyclone.

The prediction of the profile of a beach is important in the design of tailings dams because it allows the designer to predict the position of the pool, to assess the stormwater storage capacity of the top of the dam, and to assess the tailings storage capacity more accurately.

The principle of the dimensionless master profile is illustrated in this paper for a series of beach profiles measured on a uranium-tailings dam: Fig. 1 shows five profiles (numbered 1, 3, 4, 5, and 6) for beach lengths from 293 to 718 m, and for differences in elevation between the point of deposition and the pool from 17 to 24 m. In Fig. 2, the profiles were replotted on a dimensionless basis, in terms of the length ratios \( h/Y \) and \( H/X \). It will be seen that all the measured data cluster about the master profile with equation

\[
\frac{h}{Y} = (1 - H/X)^n,
\]

where \( n = 2.0 \) in this case.

The previous study left a number of questions unanswered.

(i) Can the exponent \( n \) in equation (1) be obtained from small-scale laboratory tests, or must it be determined from measurements of full-scale hydraulic beaches?

(ii) What factors affect the value of \( n \)? Is it unique for each type of tailings, or does it vary with the fineness of the material and the density or water content at which it is deposited?

(iii) There is a theoretical relationship between the shear strength of settled tailings and the beach angle at that point. Can beach profiles be predicted on the basis of laboratory measurements of shear strength?

This paper sets out to provide answers to these questions.
Blight and Bentel also showed that the hydraulic sorting of particles that occurs on a tailings beach can be predicted from the relationship

\[ \frac{AH}{X} = M, \]  

(2a)

in which \( A = \frac{D_{50} (\text{at } H \text{ down the beach})}{D_{50} (\text{of the total product})} \)  

(2b)

\( X \) is as defined in Fig. 2, \( M \) is a characteristic of the tailings, and \( D_{50} \) is the particle size at which 50 per cent by mass of the solids at any point is finer than \( D_{50} \).

The permeability, \( k \), of a granular material can be related to a characteristic particle size by an equation such as that due to Hazen. Hazen's formula is

\[ k = D_{10}^2 \text{ cm/s}, \]  

(3)

in which \( D_{10} \) has a similar definition to \( D_{50} \) and is measured in millimetres.

Hence, the gradient of particle sizes along a beach, which is predicted by equations (2a) and (2b), can be translated into a gradient of permeability. This paper explores the effect of the permeability gradient on the position of the phreatic surface in a tailings dam. It shows that a significant lowering of the phreatic surface occurs because of the progressive increase in permeability from the edge of the pool towards the wall of the dam.

**Model Tests for the Prediction of Beach Profiles**

Observations on full-scale tailings dams had indicated that the master profile is applicable regardless of the length of the beach. However, it seemed likely that the profile would not apply once the beach length became less than a certain minimum value. It would, naturally, be most useful if a very short beach length, say 1½ to 3 m, could be used in the laboratory to establish the master profile for the beaches of a projected full-scale dam.

The beach of an active gold-tailings dam was selected as the prototype, and its profile was surveyed. Material was collected from the dam for the laboratory model to represent the total tailings, the fine material from close to the pool, and the coarse material from close to the point of deposition. The particle-size distributions for these three materials are shown in Fig. 3.

The arrangement for the formation of the model beach in the laboratory is illustrated in Fig. 4. As the diagram shows, it was very simple, consisting merely of a Perspex-sided tank or short flume with a facility for the charging of tailings slurry into the tank at one end and the decanting of water from the other. In falling into the tank, the slurry formed a plunge pool that overflowed to form the model beach, which had an effective length of only 1500 mm.

**Profiles of the Model Beach**

Fig. 5 compares the observed dimensionless profiles of the model beaches with the dimensionless profile of the prototype beach.

It will be seen from Fig. 5(a) that the field profile is in excellent agreement with the laboratory profile for the total material deposited at 50 per cent solids, which corresponds approximately to the conditions for field deposition. As the solids content increases and the shear strength of the slurry correspondingly rises (see later), the beach
profile becomes steeper at small values of $H/X$ and flatter at larger values.

**Relationship between Shear Strength and Beach Angle**

The factors that tend to increase the initial steepness of a beach profile, namely increasing solids content and increasing coarseness, could be expected to result in increases in the shear strength of the settled slurry. Blight and Bentel suggested that the slope of a beach at any point could, in principle, be predicted from the expression

$$2i = \sin^{-1} \frac{\tau_0}{\rho \delta},$$

where $i$ is the slope angle of the beach, $\tau_0$ is the shear strength of the settled slurry, $\rho$ is the density of the settled slurry, and $\delta$ is the depth of the settled slurry layer.

The shear strength of slurries is difficult to measure and the results tend to be erratic, as shown in Fig. 6, which represents the variation of shear strength measured along the length of a model beach by means of a co-axial cylinder viscometer. The diagram illustrates the tendency for the shear strength to decrease with distance along the beach, i.e. to decrease as the slope angle decreases. However, the slope angle, $i$, cannot be calculated because $\delta$, the thickness of slurry appropriate to equation (4), is not known. The effective value of $\delta$ is not easily determined, and seems to vary far more than would be expected. This is illustrated by Fig. 7, which shows observed relationships between the inclination of the slurry surface in the model beach-profile tests and the corresponding shear strength measured over a depth of 25 mm. Again, this diagram demonstrates how erratic measurements of shear strength on slurries tend to be. Lines of best fit were drawn through the experimental data, and the corresponding values of $\delta$ were calculated. It will be seen that $\delta$ increased from 11 mm for the coarse slurry, to 17 mm for the total material, to 33 m for the fine slurry. These are all perfectly reasonable values, but they cannot be predicted.

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*Equation (4) appeared as equation (9) in reference 1, where it was incorrectly given as $\tau_0 = \sin^{-1}\frac{\rho \delta}{\tau_0}$. 

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**Fig. 5—Comparison of the field beach profile (Fig. 3) with beach profiles modelled in the laboratory**

Fig. 5(b) shows profiles for model beaches of the fine material. Here again, good agreement was obtained between the field profiles and the laboratory profile for a solids content of 50 per cent. The profile for 60 per cent solids differed little from that for 50 per cent solids, but the profile for 70 per cent solids was very similar to the 70 per cent solids profile for the total material.

As shown by Fig. 5(c), the profiles for the model beaches of coarse material all fell below the profile for the prototype beach. As for the fine material, profiles for 50 per cent and 60 per cent solids contents were very similar, but the profile for 70 per cent solids was steeper at small values of $H/X$.

Hence, somewhat to the surprise of the writers, it appears that the profile of a full-scale hydraulic-fill tailings beach can be predicted by the use of a small-scale model in the laboratory. Agreement between model and prototype appears excellent, provided the same material is used and it is deposited at a similar solids content.

The models also show that, as the solids content of the tailings increases, the beach profile becomes steeper close to the point of deposition, while the same applies if the coarseness of the material is increased at a fixed solids content.
Fig. 7—Observed relationship between the inclination of a slurry surface on a model beach and the shear strength of the slurry

Theoretical Relationship: \[ \sin \beta = \frac{\gamma}{\gamma_s} \]

Fig. 7: Observed relationship between the inclination of a slurry surface on a model beach and the shear strength of the slurry

The Effect of Particle Sorting

The unusually low position of the phreatic surface in tailings dams has been noted and commented on. Blight and Steffen, for example, were unable to account for the low phreatic surfaces observed in most tailings dams on the basis of the ratio of the permeability of the tailings to the permeability of the foundation, or the ratio of horizontal permeability to vertical permeability of the tailings. However, they appear to have paid insufficient attention to a paper by Abadjiev, which showed that, if the permeability of a tailings dam increases towards the toe of the dam, the phreatic surface is depressed. Mechanistically, the explanation of the depression is as follows. Continuity of flow requires that the flowrate should be the same through the low-permeability material near the pool as through the higher-permeability material near the outer slopes of the dam. It follows from D’Arcy’s law that the flow gradient must decrease progressively from the pool outwards; that is, the phreatic surface must be steeply inclined close to the pool and then progressively flatten towards the outer slopes of the dam.

In a ring dyke dam (the type of most South African tailings dams), the fact that the flow is radial, from a relatively small pool to a much larger dam perimeter, also causes the phreatic surface to be depressed. Fig. 8 shows an example of a depressed phreatic surface in a gold-tailings dam. The upper curve in the diagram represents the phreatic surface that would be expected in an embankment of constant isotropically permeable material, and the lower curve shows the actual phreatic surface as observed in a series of stand-pipe piezometers. The depression amounts to nearly 4 m of water head, and would have a significant stabilizing effect on the outer slope of the dam.

Fig. 9 shows the variation of permeability along the beach of a platinum-tailings dam based on the application of the Hazen formula to the observed variation of \( D_{y/} \). The point determinations are scattered, but a curve of the type

\[ k = a e^{bH} \]

fits the data reasonably well. In equation (5), \( a \) and \( b \) are characteristics of the beach, and \( H \) is the distance down the beach from the point of deposition (Fig. 2).

Fig. 8—Comparison of an observed phreatic surface in a gold-tailings dam with the phreatic surface predicted on the assumption of isotropic constant permeability

Fig. 9—Variation of permeability along a beach, based on the observed variation of particle sizes

For this particular beach,

\[ a = 2.72 \times 10^{-3} \text{ m/s and } b = 0.0315/\text{m}. \]

The position of the phreatic surface was calculated by the application of a finite-element method to seepage through a dam with the above permeability profile. Full details of the method, which is suitable for use on a personal computer, are given by Vorster. Only the result of the analysis, shown in Fig. 10, is considered here.

Fig. 10 shows the considerable difference between the phreatic surface calculated for values of permeability varying according to equation (5) and that based on the assumption of an isotropic constant permeability. In the case considered, the permeability of material upstream of the current point of deposition (A in Fig. 10), i.e. closer to the toe of the dam, was assumed to have a constant isotropic permeability equivalent to \( a \) in equation (5). From point A downstream, the permeability was assumed to be isotropic but to vary with distance according to equation (5). The depression of the water table for the example considered was no less than 15 m or 38 per cent of the maximum height of the dam.

This demonstrates the considerable influence that hydraulic particle sorting can have on the position of the phreatic surface in a dam. The method developed by Vorster enables the depressed phreatic surface to be located and the depression to be taken into account when a dam is being designed for stability.
**Conclusion**

Small-scale laboratory models of beaches of hydraulic-fill tailings provide an acceptably accurate method for the prediction of the beach profiles of full-scale tailings dams. However, laboratory measurements of the shear strength of settled slurries do not offer a practical means for this prediction.

Hydraulic particle sorting results in a gradient of permeability along a beach that, in turn, causes the phreatic surface in a dam to be significantly depressed.

**Acknowledgements**

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**References**


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**Egyptian research institute**

The Desert Research Institute is an arm of the Egyptian government whose activities are largely devoted to research in the deserts and newly reclaimed areas. It was officially inaugurated in 1951. The research work emphasizes water resources, soil resources, and plant and animal production.

Most of the work is performed in five geographical areas. The first of these is the northern part of the Sinai Peninsula, where there is an average rainfall of 100 mm each winter and there is adequate soil and range plant cover. Work is also done in the New Valley, a string of oases west of the Nile Valley in the Western Desert. A major artesian aquifer, the Nubian Sandstone, underlies the New Valley, which contains soil of lacustrine origin and is an area of planned agricultural development. A third area of interest is the marginal gravel plains of the Nile delta, where there is a major groundwater basin. Work is also being done in the Mediterranean littoral zone, which has winter rainfall, extensive soils, and natural vegetation, and along the fringes of Lake Nasser behind the Aswan Dam to reclaim land in several valleys.

The Institute maintains an experimental station covering about 50 ha at Mariut, 30 km west of Alexandria in the Mediterranean sub-arid belt. The station specializes in animal husbandry, especially sheep breeding, range management, reclamation of saline soils, and utilization of saline water for irrigation.

A new research station of about 10 ha has been established in the arid belt of the Sinai peninsula, about 30 km southeast of the city of Suez.

The administrative offices, laboratories, and library are in El Mataria, a suburb of Cairo. The *Desert Research Bulletin* and special publications are published. They are not for sale but are given free on request to interested organizations. The Bulletin is exchanged with about 200 societies.

Research is carried out in collaboration with universities and includes post-doctoral as well as graduate research. In addition to work in Egypt, the Desert Research Institute has participated in studies of the Artesian Basin of North Africa with UNESCO, soil studies on the fringes of Lake Nasser with FAO, studies on the utilization of saline water for irrigation, and the preparation of the *Sheep Encyclopedia of the World* with ACSAD.

All the known Egyptian mineral deposits occur in extremely arid regions. Any consideration of the infrastructure associated with mineral development will involve detailed hydrological studies. These will be performed by the Desert Research Institute as part of the Minerals, Petroleum and Groundwater Assessment Programme. A heavy-duty mobile drill rig has been ordered. The rig will be especially designed for use in extremely hot dry regions, and will be able to drill hydrological test holes to a depth of 500 m. Shops capable of repairing and maintaining this and similar equipment in Cairo are in the advanced design stage, and construction should commence in the next few months.

The address of the Desert Research Institute is c/o Egyptian Geological Survey and Mining Authority, 3 Salah Salem, Abbassia, Cairo, Egypt. Telephone: 835617-31620-31644. Telex: 22695 GEOSU.
The Institute has concluded an agreement with the Chamber of Mines whereby the Chamber Librarian will establish and maintain a section in the library for the Institute.

Books that are published by the Institute or received for review are placed in this library. A list of new books will be published in the Journal. The first list appeared in the February 1985 issue, and the second list is published below.

Apart from a few exceptions, these books can be borrowed by members through an inter-library loan. If you have suitable books that you would care to donate to the library, please contact our publications secretary. Publications marked with asterisks* may only be consulted in the Library.

SAIMM: SUNDRY PUBLICATIONS

*Symposium on Rock Mechanics & Strata Control in Mines
606pp; 180 x 250mm; illus; hard cover; 1965

*Uranium in South Africa 1946-1956
2 volumes; 1029pp; 110 x 255mm; illus; hard cover; index; 1957

AUSTRALASIAN INSTITUTE OF MINING AND METALLURGY

Monograph 11: Victoria's Brown Coal — A Huge Fortune in Chancery
ISBN 0 909520 79 8; 204pp; 190 x 240mm; illus; hard cover; index; 1984
Review: March 1985

*A Principles of Flotation
By: I.W. Wark
346pp; 150 x 235mm; illus; hard cover; index; 1938

THE CANADIAN INSTITUTE OF MINING AND METALLURGY

The Geology of Industrial Minerals in Canada
Edited by: G.R. Gaillat & Wendy Martin
ISBN 0 910986 04 7; 350pp; 210 x 285mm; illus; hard cover; 1984
Review: March 1985

INSTITUTION OF MINING & METALLURGY — NORTHERN RHODESIAN SECTION

Technical Proceedings of the 75th Commonwealth Mining & Metallurgical Congress
Edited by: W.G. Watts
521pp; 210 x 265mm; illus; hard cover; index; 1962

INSTITUTION OF MINING & METALLURGY

Transactions of The I.M.M. — Vol. 75
Section A — Mining Industry
Section B — Applied Earth Science
Section C — Mineral Processing & Extractive Metallurgy
960pp; 215 x 300mm; illus; hard cover; index; 1966

Transactions of The I.M.M. — Vol. 76

MINING JOURNAL BOOKS LTD — U.K.

Tungsten: 1982
ISBN 0 900117 34 6; 179pp; 150 x 225mm; illus; 1982
Review: March 1985

The Uranium Equation — The Balance of Supply and Demand 1980–1995
The Uranium Institute
ISBN 0 900117 27 3; 57pp; 150 x 230mm; illus

THE METALS SOCIETY

The Role of Crack Growth in Metal Fatigue
By: L.P. Pook
ISBN 0 904357 63 5; 147pp; 150 x 210mm; illus; index; 1983
Review: March 1985

Directionally Solidified Materials for High Temperature Service
By: M. McLean
ISBN 0 904357 52 X; 337pp; 155 x 235mm; illus; hard cover; index; 1983

An Encyclopaedia of Metallurgy & Materials
By: C.R. Tottle
ISBN 0 7121 0571 9; 380pp; 280 x 220mm; illus; hard cover; 1984
Review: March 1985

BRITISH GEOLOGICAL SURVEY — U.K.

Overseas memoir 2: The Geology of the Country Around Neyaungga and Ye-ngan, Southern Shan States, Burma
ISBN 0 11 880715 3; 70pp; 325 x 285mm; illus; hard cover; index; 1976

Overseas memoir 3: The Geology of the Maya Mountains, Belize
ISBN 0 11 880765 X; 43pp; 225 x 285mm; illus; hard cover; index; 1977
Precious metals

This tenth anniversary year of the founding of the International Precious Metals Institute promises to be a 'gala celebration' according to Dr M. El Guindy, General Chairman of the 10th Conference, and President of Precious Metals Industries, Inc.

The theme for the conference which is to be held from 8th to 13th June, 1986, at Lake Tahoe, will be 'Interactive Precious Metals Technology—Producer to User', according to Dr U. V. Rao, Technical Papers Chairman and Executive Vice President of Gemini Industries, Inc. A tour of the United Mining Company Mine in Virginia City, Nevada, will be a highlight of the Conference.

Members and non-members are invited to submit titles and abstracts pertaining to the use of precious metals in the categories outlined:

- Petroleum and Petrochemical
- Chemical and Pharmaceutical
- Human Health Care
- Environmental
- Advances in Analytical Techniques, Including Laboratory Computerization
- High Technology Areas, Including Microelectronics and Space
- Energy Applications—Fuel Cells, Fixation of Atmospheric Nitrogen, etc.
- Photographic
- Ceramic
- Glass.

In addition to the above categories, mining, metallurgical and economic aspects of precious metals will be included.

Mail information to IPMI, Government Building, ABE Airport, Allentown, Pennsylvania 18103, U.S.A. Abstract deadline is 1st August, 1985.
Continuous casting

The Deutsche Gesellschaft für Metallkunde (Technical Committee—Continuous Casting) is organizing a Symposium on Continuous Casting in Bad Nauheim on 28th and 29th November, 1985.

Every year there are new improvements related to all areas of continuous casting that are aimed at improving the economics of the system, the quality of the product, and general working conditions. Practical experience still has to be gained in many of the new developments.

The Symposium will report on the present state-of-the-art from industry and on areas of research and development. The following main themes will be covered:
- Use of scrap and remelting techniques
- Melt treatments
- Continuous casting processes
- Process control
- Quality control.

The Symposium will deal primarily with industrial problems, and is intended for engineers and technicians connected with continuous casting, quality control, and research and planning operations. It is hoped that the Symposium will lead to in-depth discussions and intensified personal contacts between those engaged in the manufacture and testing of continuously cast products.

The programme will be available in September 1985 and can be obtained from the Conference Secretary, Deutsche Gesellschaft für Metallkunde e.V., Adenauerallee 21, D-6370 Oberursel, West Germany. Telephone: 06171/4081.

Photomicrograph competition

A photomicrograph competition will be held during the Metallography Conference 1985 from 9th to 11th October, 1985, in Trier. Black-and-white and coloured photomicrographs may be submitted for the following categories:
1. Optical microscopy—macro and microstructures
2. Electron microscopy—scanning
3. Electron microscopy—transmission
4. Information and teaching material
5. Failure analysis
6. Micrographs of outstanding artistic or aesthetic appeal.

The micrographs will be exhibited during the Conference and will be judged by the conference participants. In categories 1 to 5, the solution to the problem illustrated should be well documented metallographically and explained schematically or with an accompanying text. In addition to the prizes for each category, a special prize will be presented for the best trainee entry. Trainee entries must be accompanied by a statement from their advisors that they are trainees.

How to enter:
- All entries on white or coloured card.
- On the face of the mount: Title and test, exposure, and magnification.
- On the back of the mount: Name and address of entrant, and suggested category.
- Each competitor may submit up to two entries.

Submit entries by 15th August, 1985, to Deutsche Gesellschaft für Metallkunde e.V., Adenauerallee 21, D-6370 Oberursel 1, West Germany. Telephone: 06171/4081.

Design and development of materials

The Technical Committee on the Constitution of the Deutsche Gesellschaft für Metallkunde is organizing a meeting on the above topic, which is to be held in Bad Nauheim on 5th and 6th December, 1985.

Knowledge of the constitution of metallic and nonmetallic materials is an important basis for understanding their properties and behaviour. In addition, it provides a basis for well-defined further development of these types of materials. New experimental methods, as well as improved and extended techniques covering theoretical procedures and calculations, lead to a rapidly increasing wealth of data covering a wide range of different groups of materials. Therefore the highest priority is given to data collection, processing, and applications.

This Symposium will be of particular interest to those involved in this field in research and development at universities, research institutes, and industry. The Symposium will deal with applications covering steels, ceramics, composite materials, wear-resistant materials, and coatings. The thermodynamics of the phases present, phase diagrams of multicomponent systems (computed and determined experimentally), and the documentation of data will be included.

The programme will be available in October 1985 from the Conference Secretary, Deutsche Gesellschaft für Metallkunde e.V., Adenauerallee 21, D-6370 Oberursel, West Germany. Telephone: 06171/4081.