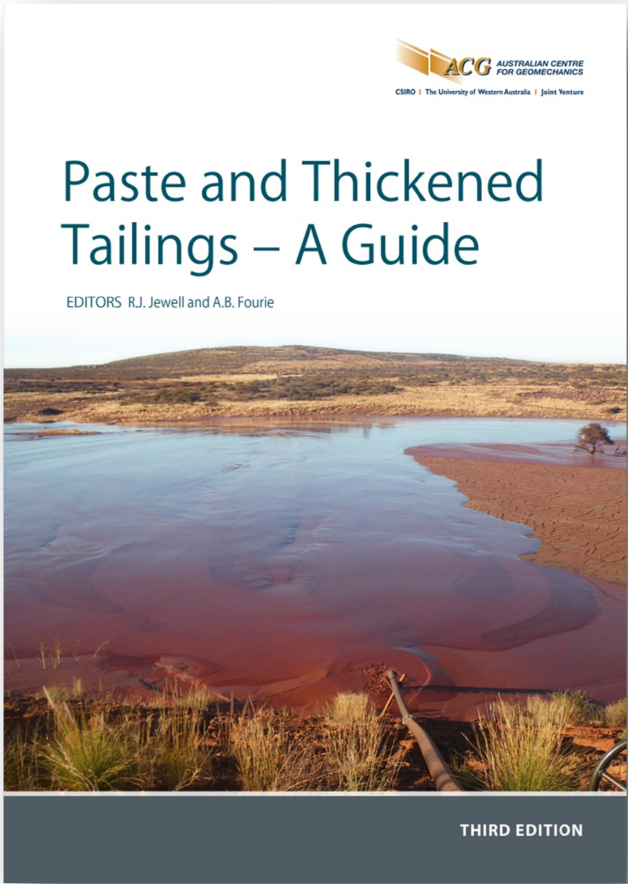
ACG AUSTRALIAN CENTRE FOR GEOMECHANICS
Paste and Thickened Tailings – A Guide
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THIRD EDITION

CHAPTER 1

INTRODUCTION

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CHAPTER 1

Introduction

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1.1 OBJECTIVES OF THE GUIDE

The primary aims of this Guide are to lay out in simple terms the technologies available for thickening tailings to a higher concentration or density than that achieved as underflow from conventional plant thickeners, the advantages and disadvantages of doing so, and to provide a technical resource about the application of thickening technology prior to deposition for surface disposal. The ultimate objective has been to provide guidance and advice to those in the industry interested in finding out what is meant by thickened tailings and 'high-density slurry' or 'paste' tailings, and in determining whether the effort of thickening tailings to a density higher than that achieved in the underflow of normal plant thickeners can add value to their own operations. Rather than being a design manual, the Guide will enable those interested to understand the implications of the technology and equip them to brief their design consultants.

Extra effort is involved in producing and disposing of these higher density tailings. The processes involved in thickening and transporting the tailings and the techniques for depositing the tailings are covered in considerable detail in the Guide. The rheology of tailings thickened to the consistency of a high to very high density dramatically influences the thickening, transporting and deposition processes. This, along with the material characteristics, is covered in detail so that an appreciation may be obtained as to why the material behaves as it does, and to outline the inherent differences between using the tailings in mine backfill as against surface deposition.

There are a number of key reasons why the additional thickening of tailings prior to deposition may be of benefit to a mining operation, and these drivers are noted in this introduction and then expanded upon in subsequent chapters. Significant advances have been made in the thickening equipment in recent years and new techniques developed and implemented. A prime justification for preparing this third edition of the Guide is to cover these advances in the technology and bring the Guide up-to-date.

1.2 BACKGROUND

Under the guidance of Dr E. Robinsky, the first attempt to produce thickened tailings for surface disposal was made in 1973 at the Kidd Creek Mine in Canada. Implementation of the first central thickened discharge (CTD) operation commenced using a conventional thickener, but it was not until 1995, after several iterations of thickener upgrade and as the technology developed, that the original vision was achieved at Kidd Creek. In the mid 1980s, the alumina industry in Western Australia set a goal of converting existing wet red mud storages to dry storages. This was accomplished with new generation thickeners, and in a relatively short period the *modus operandi* for the alumina industry globally became dry stacking. It is, however, only since the beginning of the 21st Century that the concept of surface deposition of high-density slurries has been more widely adopted by the general mining industry and it is this technique that is emphasised in this Guide.

In parallel with developments for surface disposal, the technique for underground disposal of tailings as a component of cemented backfill was being developed utilising techniques adapted from the concrete industry in the 1970s at the Bad Grund Mine in Germany. In this application, backfill strengths in the MPa region were required, orders of magnitude higher than those associated with surface disposal. There are considerable differences between surface and mine backfill disposal in terms of transport and disposal systems, yet the production of the thickened tailings can be identical. A comprehensive section on mine backfill is provided in Chapter 14.

1.3 THE CURRENT SITUATION

Thickening essentially involves a reduction of the water content of slurried tailings. The techniques adopted to remove the water include the conventional mechanical approaches of packing the solid particles closer together under gravity as in a thickener, sucking or pressing the water out by filtering, or by manipulating slurry chemistry properties in order to, for example, modify the structure of the solid particles to improve the self-draining potential of the slurry. A full range of these techniques, as currently applied, are presented in this Guide.

Generally, the consistency (solids content or density) required of tailings thickened in a conventional gravity thickener will be limited by the capability of a centrifugal pump to drive the material through a pipeline. Over the past decade, centrifugal pumps have developed to the extent that very much higher pressures can be developed for pumping thickened tailings. Nevertheless, positive displacement (PD) pumps will pump much higher density materials at correspondingly higher discharge pressures and this technology may be needed to transport thickened tailings. The cost of installing and operating PD pumps has to be evaluated over the lifetime of the project to permit a meaningful comparison with a system using multiple centrifugal pumps (or pump stations) required to generate a comparable pump discharge pressure. On the other hand, filtered tailings, unless conditioned back to a lower density slurry, will generally be too stiff to pump and can be transported by conveyor or conventional truck and shovel operation.

The equipment now exists to make and to transport very high density tailings. In general, it is the economics, practicability, and environmental and social advantages of any system that will determine whether it will be adopted by the industry. A practicable above ground disposal system will require that the tailings flow away from the point of discharge for a sufficient distance to avoid the need to locate the discharge points at very close intervals, or the installation of a discharge system that is excessively expensive to construct or to operate. The thickened tailings slurries used in most CTD projects will have minimal segregation, but a limited amount of water may separate from the deposited tailings and flow downslope as supernatant, as in the operation shown in Figure 1.1.

Figure 1.2 illustrates above ground stacking of high-density slurries from the Bulyanhulu Mine in Tanzania which clearly stack at a relatively steep beach angle. The author emphasises, however, that the tailings at Bulyanhulu are thickened by filtering for use as cemented backfill in the underground mine and only tailings excess to the underground needs are discharged above ground. The filtered tailings to be discharged above ground are conditioned back to a water content that is suitable for pumping and, as a consequence, can be brought to an unvarying consistency. As a result, the beach slopes achieved on the above ground storage facility at Bulyanhulu are considerably steeper than those that have been measured at any other operating mine. Even when underflow densities comparable to those discharged at Bulyanhulu can be obtained from conventional thickeners, the variations in density obtained over time, due to the reasons outlined in Section 1.3.1, inevitably result in lower overall beach slopes at those operations.

The thickened tailings shown in Figure 1.3 illustrate the consistency that can be achieved from the underflow of deep cone thickeners that would probably form relatively steep beach slopes if that consistency could be maintained over the long term.

1.3.1 Practical limitations

Tailings management deals with a waste product from plants designed and operated to maximise the recovery of valuable minerals from the feed ore, and there is little if any regard for the properties of or uniformity of the waste over time. The ore is invariably subject to comminution processes to maximise the surface area per unit weight of solids available to the process reagents. This results in the waste stream consisting of a slurry

FIGURE 1.1 Relatively uniform beach slope from CTD discharge ramp in background

FIGURE 1.2 Bulyanhulu – an example of high-density thickened tailings deposition

of fine-grained solid particles and process water. The consistency of the tailings stream emanating from the plant can range from dirty water when the system is being purged, through to a slurry with a significant solids content when operating optimally.

Very few orebodies are homogeneous, and as a result the properties of the ore fed into the process plant will be inconsistent. Hence, the properties of the reject tailings can also vary significantly over time. To exacerbate the challenge of dealing with the variable nature of the waste product, the operators managing the disposal and storage of the tailings are rarely given notice of changes in the tailings stream and have no option but to accept everything as delivered and to store the waste safely and securely for a very long time.

Those designing and operating thickening plants need to be aware that thickener design is not a precise art and that throughputs derived by upscaling from laboratory tests may not be consistent with the laboratory results. Then again, once a thickener is commissioned, it may take operators some time to achieve the design consistency in the thickener underflow while the bed of tailings develops and the optimum dosage of flocculants is determined. Even then, the variability of the feed ore and human factors involved in maintaining output at a consistent level with that variability very often results in underflow densities falling short of a design value, sometimes for long periods. This is why filtering tailings to some higher density and then conditioning them back to some uniform moisture content is probably the only way in which a uniformly consistent density product can currently be achieved.

1.3.2 The ultimate objective

At a minimum, tailings storage facilities (TSFs) should be designed and operated to ensure that there is very little, if any, potential for uncontrolled release of tailings or impact on the environment. The social licence to operate mining ventures will increasingly depend upon demonstrating to stakeholders that these facilities will perform adequately in the long term and operators need to be aware that the criteria defining ‘adequate’ will almost certainly be a moving target. For example, in some areas of the world regulators are currently requiring that TSFs are designed to be capable of remaining safe and stable for 1,000 years (ANCOLD, 2012; European Commission, 2009). To put this into perspective, probably the only

FIGURE 1.3 Examples of ultra-high density (paste) thickened tailings

remaining recognisable man-made earthen structures of that vintage are ancient burial mounds found in some parts of the world, and the strength properties of most mine tailings are inferior to the material forming burial mounds.

1.4 THE DRIVERS

The implementation of paste and thickened tailings (P&TT) technology on any mining operation can only be justified if it is cost-effective. The cost of the plant required to thicken tailings, transport and then discharge them is not insignificant and it is only when full lifecycle costs are taken into account that a true economic comparison is possible. The implementation of P&TT technology, however, can provide a number of specific benefits to the extent that these become the reasons or drivers for adopting the technique.

The reasons for implementing the thickening of tailings varies between sites, but the common denominator in all operations is to reduce the costs of storing the tailings safely while ensuring minimum potential for pollution of the environment. Reducing costs satisfies the need of the operator to optimise profit. The provision of a safe and stable storage facility contributes to meeting the demands of stakeholders while minimising the financial risks and assisting in maintaining the long-term 'licence to operate' of the mining company.

To fully evaluate the benefits of P&TT technology, an economic study based on full lifecycle costs is needed. Capital operating costs, timing and the time value of money need to be applied across the full spectrum of the mine plan, including closure. Often, complete mine and/or tailings plans need to be run to closure to truly understand the benefits of this technology. Non-monetary benefits like improved public perception and the potential for the reduced likelihood of catastrophic failure should also be evaluated, using appropriate qualitative measures.

Savings are possible in water, energy and reagent conservation, reduced impoundment needs, improvements in impoundment and embankment stability, more rapid closure and reduced financial provisions. Additional capital and operating expenses for thickening equipment, pumps and piping may partially offset these savings.

When the first two editions of the Guide were published, it was felt that there was a need to alert mine planners and owners to the potential benefits of thickening tailings prior to disposal in order for the concept to be included in any evaluation of possible options; hence a separate chapter was included to cover the key business issues. However, the authors are not aware of any feasibility study in recent years for which thickened tailings has not automatically been included as an option for the tailings storage. Accordingly, the section of earlier editions of the Guide justifying the reasons for and the advantages and disadvantages of adopting the concept of thickening tailings has been removed from this edition in order to free up space for several emerging technologies. If any reader is interested in having access to a concise appraisal of the key business issues for and against this technology, it is recommended that they refer to the second chapter in the second edition of the Guide (Jewell and Fourie, 2006).

As indicated in the history of TSF failures reported in the aforementioned chapter of the 2006 edition, the loss of life and environmental damage resulting from embankment failures of TSFs for conventional (low-density) slurry tailings over the past half century has been significant and a major driver for the application of thickening technology. These failures are still occurring as for instance at the Mt Polley Mine in British Columbia in August 2014, albeit without loss of life, and the failure in September 2014 in Minas Gerais, Brazil, that unfortunately did result in fatalities. The potential for the increased structural stability and safety of the confining embankments for above ground storages was the prime objective of the TSF at the Kidd Creek Mine and a key driver for many operations that adopted thickened tailings technology in the early years. Increasingly over the past decade, however, the potential for water recovery and reuse in the process that reduces the volume of additional water needed by the operation from other sources has been an important driver. In arid areas such as the Atacama Desert in northern Chile, top-up water supplies for new mining operations are being sourced from desalination plants at the coast and pumped inland for hundreds of kilometres at significant cost, and reducing the volume needed is an important consideration.

Another major consideration has been the challenges faced by industries in which the fine particle size and surface charges inherent in clays associated with the economic mineral (e.g. the phosphate mining industry) and hydrocarbons (e.g. oil sands mining industry) inhibits consolidation of deposits of the fine fractions of these tailings. In these cases, the tailings can remain at very low densities for long periods, during which the storage facility is susceptible to failure. The emphasis in these industries has been more about finding means by which water can be removed by thickening than on the benefits of being able to reuse the water recovered. The technology of achieving this by means of inline polymer injection is covered in Chapter 13.

1.5 CLOSURE

Closure issues are a very important consideration for tailings storages and are covered in Chapter 15. Closure needs to be considered as an integral part of any feasibility study and associated works implemented as scheduled during the life-of-mine. The costs of closure and rehabilitation are often considerable and the lowest cost option will inevitably be one that is initiated at the commencement of operations and taken into consideration throughout the life-of-mine. Unfortunately, when other work commitments are given priority during operations or changes to the priority of allocation of capital result in work associated with closure being deferred, the initially planned closure solution is often rendered impracticable. When this occurs, changes have to be made to the closure strategy and in the majority of cases the remaining solutions will all be more expensive. If this practice continues, the lower cost solutions are progressively eliminated and the ultimate result will be that the closure costs will be significantly greater than originally planned.

1.6 CLASSIFICATION AND THE TAILINGS CONTINUUM

The concept of implementing the thickening of tailings to take advantage of any of the potential benefits was developed relatively independently in a number of different sections of the mining industry at around the same time, coinciding with the development of effective gravity thickeners. As a result, a variety of terminology arose in some countries, industries and even specific organisations to describe similar processes and to label the range of states to which the tailings were thickened. This state of affairs inhibited the transfer of ideas and the general advancement of the technology, and was seen to be an issue that needed to be addressed. An attempt to standardise the terminology thus became the focus of a workshop held in Perth, Western Australia in April 2000 attended by people from around the world working in this field. A major outcome of that workshop was the preparation of the Guide (first published in 2002), in which a logical system for labelling thickened tailings on the basis of consistency was outlined.

Coverage of the terms, tests and boundary limits that apply to different consistency states of thickened tailings in the proposed classification system, within a tailings continuum, is detailed in Chapter 2.

1.7 ABOUT THE GUIDE

This Guide is presented as a series of self-contained chapters that follow a sequence first established by the authors at the 2000 workshop and added to in subsequent editions of the publication as additional technologies justifying inclusion have evolved. The various chapters have been prepared by authors selected for their expertise in each specific area and to represent the mining industry around the world. These included a mix of operators, consultants and regulators, with a lead author given the responsibility of coordinating the preparation of his or her chapter. These chapters were then edited by an editorial peer group to provide a coordinated coverage of the topic. All of those who have contributed significantly to the preparation of this Guide have been acknowledged in their associated chapter.

For this third edition of the Guide, all chapters have been substantially revised and updated by the authors — some of them quite significantly — to take account of new information and understanding of the various technologies in the nine years since the second edition was published. In some cases, this has involved the inclusion of new chapters covering topics that were originally associated with other work but now justify separate coverage. For example, Chapter 7 on thickening equipment has been split into two and a separate chapter (Chapter 8) on filtering included. Also, the emerging understanding of beach slope prediction has justified this topic, being taken from the chapter on above ground deposition to form a new stand-alone chapter (Chapter 12). As indicated earlier, the classification system proposed for the different states to which tailings may be thickened has been taken from this introduction and given greater emphasis as a separate chapter in order to place due importance on this aspect of the topic. The emergence of polymer injection prior to, or at discharge, to enhance the release of supernatant water through flocculation of the discharged tailings slurry is a promising concept that is the subject of a new chapter. Another new chapter has been included to present the manner in which different thickening concepts can and are being used in combination to optimise the effort required to thicken tailings efficiently, at least cost, in different environments.

Following this introduction, the chapters cover the *Tailings classification system* and then *Rheological concepts* and *Material characterisation* that are fundamental to our understanding of the technology and relevant to all chapters. Rheology, in particular, has been recognised by those developing the outline of the Guide as the single most important issue influencing our ability to thicken, transport and deposit paste and thickened tailings.

The following chapters then cover *Slurry chemistry*; *Reagents* (flocculants and coagulants), *Thickening equipment* (gravity thickeners); *Filtering*; *Thickening plant concepts*; *Transport systems* (pumps and pipelines); *Above ground deposition*; *Beach slope prediction* and *Inline polymer injection* (flocculation at discharge). The chapter entitled *Mine backfill* (below-ground disposal) primarily covers the issues of transporting, distributing and containing the cemented paste underground, and illustrates the variety of operations around the world that have adopted this technology. A chapter on *Closure considerations* and another that presents a number of relevant Case Studies follows; the cases included are new, except where significant new information regarding a case study featured in earlier editions has been provided. The final two chapters include a *Glossary of terms* and then a list of *References* that provides a comprehensive listing of the references used by the various authors.

In a number of chapters, the authors refer to specific mining operations at which the equipment or process to which they are referring is in operation. These are operations with which they are familiar, and there is no inference that these are the only operations around the world using each specific equipment or process. They do, however, show that the concepts discussed are being used successfully in practice.

It must be stressed that this is a guidance and advice publication, and in no way is intended to be a design manual. As indicated in the preface, the intention has been to provide sufficient information such that the principles and terminology are understood to the extent that a competent briefing can be prepared for a consultant commissioned to provide a feasibility study for an operation.

AUTHOR DETAILS

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Richard retired as an Associate Professor from The University of Western Australia and as Director of the Australian Centre for Geomechanics in 2000. Richard has worked on mine tailings issues for over 40 years and continues to work with the ACG and as a review consultant for industry.