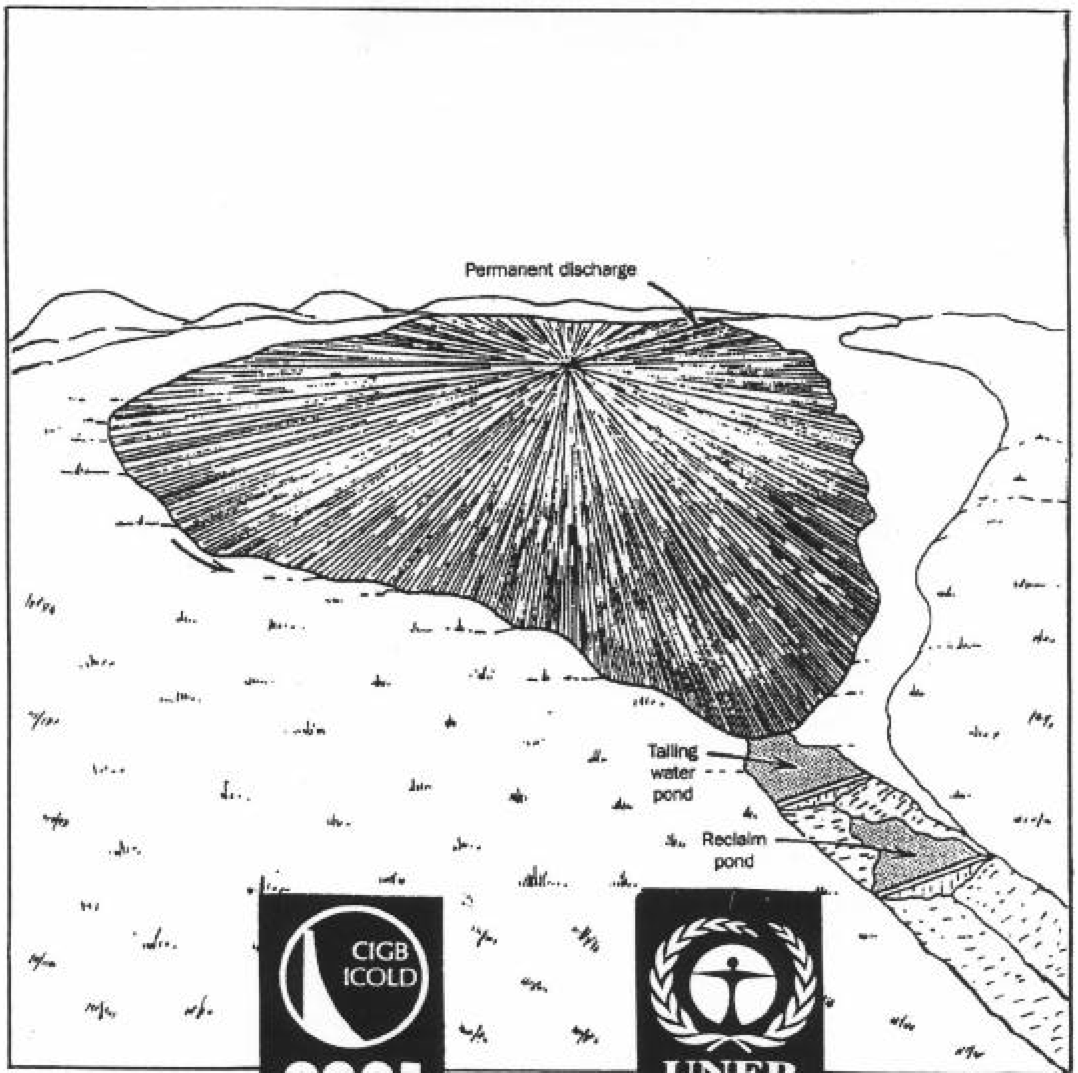
TAILINGS DAMS
RISK OF DANGEROUS OCCURRENCES

Lessons learnt from practical experiences

Bulletin 121



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Lessons learnt from practical experiences

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TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

Tailings dams are built to retain impoundments of tailings, and when possible, material extracted from the tailings themselves is used in their construction. They have many features in common with embankment dams built to retain water reservoirs, and in many cases are built as water retaining dams, particularly where there is a requirement for the storage of water over the tailings, or the stored tailings have to be protected by a covering of water to prevent aerial pollution.

While the methods used for the design and construction of embankment dams can be applied to tailings dams, there are major differences between the two types. Embankment dams are prestigious structures used to profitably store water, whereas tailings dams are required for the storage of unwanted waste, desirably at minimum cost. Embankment dams are usually built to full height during one period of construction, having been designed and their construction supervised by competent engineers (controlled by law in many countries). Modern tailings dams are often designed by competent consulting engineers, but because they are built slowly in stages over many years, and conditions may also change with time, supervision of their construction may become faulty.

Guidelines for the design, construction and closure of safe tailings dams have been given by many publications, including ICOLD Bulletins Nos. 45 (1982), 74 (1989), 97 (1994), 98 (1995), 101 (1995), 103 (1996), 104 (1996), 106 (1996), ANCOLD (1999). If the recommendations given in these guidelines were to be closely followed, the risk of a failure or dangerous occurrence with a tailings dam and impoundment would be greatly reduced. Unfortunately the number of major incidents continues at an average of more than one a year. During the last 6 years the rate has been two per year.

With the intention of trying to determine the causes of these incidents, 221 case records have been collected. They are given both in brief detail and discussed in general terms. The main causes of these reported cases of failure and incidents were found to be lack of control of the water balance, lack of control of construction and a general lack of understanding of the features that control safe operations. There were one or two cases of unpredictable events and other cases caused by unexpected climatic conditions, including earthquakes, although it can be argued that with today's knowledge, allowance should have been made for these events.

Water retaining dams in most countries are controlled by legislation, and in some countries the legislation applying to embankment dams retaining water are equally applied to tailings dams. There appears to be a requirement for a more extensive application of legislation to the non-revenue raising activity of storing waste tailings, in order to reduce the occurrences of tailings dam failures and unsatisfactory behaviour. Up-to-date information can be obtained from a "Chronology of major tailings dam failures" compiled by WISE Uranium Project that can be found on the website http://www.antenna.nl/wise-database/uranium/mdaf.html

RÉSUMÉ

Les barrages de stériles sont construits pour le stockage de stériles et, dans la mesure du possible, des matériaux extraits des stériles eux-mêmes sont utilisés pour la construction. Ces ouvrages ont beaucoup d'aspects comparables à ceux des barrages en remblai classiques créant des retenues d'eau, et dans bien des cas ils sont construits de la même façon, particulièrement lorsqu'il est exigé de retenir l'eau au-dessus des stériles ou lorsque les stériles mis en dépôt nécessitent une protection par une nappe d'eau afin d'éviter une pollution par voie aérienne.

Bien que les méthodes de conception et de construction des barrages en remblai classiques puissent s'appliquer aux barrages de stériles, ces deux types d'ouvrage présentent d'importantes différences. Les barrages en remblai sont des ouvrages prestigieux stockant l'eau dans un but utilitaire, alors que les barrages de stériles sont nécessaires pour la mise en dépôt des rejets et ce au moindre coût. Les barrages en remblai sont habituellement construits en une seule étape, leur conception et leur construction étant supervisées par des ingénieurs compétents (avec application de prescriptions légales dans beaucoup de pays). Les barrages de stériles modernes sont souvent conçus par des bureaux d'études compétents mais, du fait de leur construction lente par étapes s'étendant sur de nombreuses années, et du changement possible de conditions dans le temps, le contrôle de leur construction peut devenir défectueux.

Des recommandations relatives à la conception, à la construction et à la fermeture des barrages de stériles ont été présentées dans plusieurs publications ; on peut citer notamment les Bulletins de la CIGB n° 45 (1982), 74 (1989), 97 (1994), 98 (1995), 101 (1995), 103 (1996), 104 (1996), 106 (1996), et ANCOLD (1999). Si les recommandations données dans ces documents étaient suivies de près, les risques de rupture ou d'incident grave concernant les barrages et dépôts de stériles seraient beaucoup réduits. Malheureusement, le nombre d'incidents majeurs continue à dépasser en moyenne un taux de un par an. Au cours des six dernières années, ce taux a été de deux par an.

En vue de déterminer les causes de ces incidents, 221 cas de ruptures et d'incidents ont été répertoriés. Ils sont décrits brièvement et analysés en termes généraux. On a déduit que les principales causes des ruptures et incidents répertoriés ont été : un manque de maîtrise du bilan hydraulique, un mauvais contrôle de la construction et un défaut général de compréhension des principes dont dépend la sécurité des opérations. On a recensé un ou deux cas d'événements imprévisibles et d'autres cas dus à des conditions climatiques exceptionnelles et à des séismes, malgré la grande attention portée à de tels événements grâce aux connaissances actuelles.

Dans la plupart des pays, les barrages stockant de l'eau sont soumis à une législation, et dans certains pays la législation relative aux barrages en remblai s'applique également aux barrages de stériles. En vue de réduire les risques de rupture ou de mauvais comportement des barrages de stériles, il apparaît nécessaire

The ICOLD Tailings Dams Committee has concluded that effective reduction of the cost of risk and failure can only be achieved by a commitment from Owners to the adequate and enforced application of available engineering technology to the design, construction and closure of tailings dams and impoundments over the entire period of their operating life.

d'étendre l'application de la législation aux activités non rentables de stockage des stériles. Des informations mises à jour peuvent être obtenues en consultant le document « Chronology of major tailings dam failures » établi par WISE Uranium Project et disponible sur le site web http://www.antenna.nl/wise-database/uranium/mdaf.html

Le Comité des Barrages et Dépôts de Stériles de la CIGB a conclu qu’une réduction effective des coûts de risque et de rupture ne pouvait être obtenue que par un engagement des maîtres d’ouvrage et une stricte application des technologies disponibles à la conception, à la construction et à la fermeture des barrages et dépôts de stériles pendant toute leur durée d’exploitation.

FOREWORD

The disposal of wastes in our overcrowded world has become a serious problem. Even domestic wastes in the developed countries presents a difficult disposal problem. Due to the nature of mining and mineral processing, the volumes of mining wastes are significantly larger than those of both domestic and industrial wastes. The chemical characteristics of the waste (particularly mobility of metal constituents) are often of concern. The volumes of mine waste greatly exceed the total volumes of materials handled by civil engineering throughout the world. The crushed rock passed through the processing plant to extract the desired product is discharged from the tail end of the plant as the waste tailings, and in many parts of the world forms the greatest volume of mine waste, although at open-pit mining operations the volume of waste rock may exceed the volume of tailings. The fine particulate tailings are commonly stored in impoundments retained by tailings dams. The material is placed hydraulically and so is loose and nearly saturated. Any major movement of the retaining boundaries of the impoundment can induce shearing strains that disturb the structure of the tailings mass, inducing a rapid rise of pore water pressures and liquefaction of a section of the impoundment, causing even greater pressures to be applied to the retaining boundaries. Failure of the retaining dam can release liquefied tailings that can travel for great distances, and because of its greater weight, destroying everything in its path. Water will flow through and around buildings, but liquefied tailings can destroy the structures. The tendency is for tailing dams to become ever higher and impoundments ever larger.

Similarities between tailings dams and embankment dams designed to retain water, have enabled many of the design techniques used with embankment dams to be applied to produce safe tailings dams, but despite great improvements, there has been a reported failure of a tailings dam almost every year for the past three decades. The damage caused by these failures in the form of human casualties, destruction of property, disruption of communications, pollution of the environment and economic loss to the mining industry is enormous. The purpose of this Bulletin is to discuss some of these failures and see what lessons can be learnt from them, to identify improvements that would reduce the occurrence of these failures.

The Bulletin was prepared by the British Sub-Committee on Tailings Dams, using with permission and agreement, the USCOLD collection of 185 case records published in 1994, the 26 cases found by Mining Research Services for UNEP, published in 1996, and 12 examples known by members of the ICOLD Committee. During final compilation of the case records, some duplications were found, so that the total number became 221. All members of the ICOLD Committee contributed to the final draft and liberal use has been made of their publications, e.g. Askari et al (1994), Penman et al (2000), Strachan (1999) and Williamson (1999). Special mention must be made of Mr Kulesza who categorised the 221 cases given in the Appendix. The Bulletin has been reviewed both by the ICOLD Committee on Tailings Dams and Waste Lagoons and by UNEP. Valuable comments have also been received from the National Committees of ICOLD and we are grateful to everyone involved.

A.D.M.Penman
Chairman, ICOLD Committee on Tailings Dams
and Waste Lagoons

PREFACE

D'Appolonia (1976) said, ‘Any attempt at construction of a tailings embankment that does not take into account the design-construct process is in my opinion doomed to great distress.' He pointed out that construction goes on for very many years, during which time many conditions may change, so it is essential to maintain a flexible approach and amend the design as required.

Rev Michael West (1998) said, “It is my own view that many mine accidents, and perhaps especially the most serious arise from over-familiarity with a potential hazard. Some of the worst accidents which have been associated with mud rushes and tailings movements are terrible examples - Mufulira, Stava, Harmony”.

Pierre Londe, President of ICOLD in a lecture given at AIT in 1980, about lessons from earth dam failures, said that man learned little from success but a lot from his mistakes: learning from our errors is vital for improving our knowledge and promoting safer design. He gave eight recommendations applicable to tailings dams. These were:

(1) Look out for over-consolidated clay formations, and use residual strength parameters;
(2) Look out for loose saturated sandy formations and study their liquefaction potential;
(3) Analyse the floods in terms of probability of occurrence and corresponding probability of damage downstream;
(4) Use the most recent hydrological methods;
(5) Provide ample and well graded filters and drains for preventing piping;
(6) Test for dispersion potential of fine clayey soils;
(7) Incorporate instrumentation as a vital part in the design of a dam for monitoring its safety;
(8) Provide a thorough and careful surveillance of dams and appurtenant structures on a continuing basis.

Guidelines for the safe design and construction of tailings dams and waste lagoons have been published in the following ICOLD Bulletins:

a)	No.45.	Manual on Tailings Dams and Dumps.	1982
b)	No.44a.	Bibliography.	1989
c)	No.74.	Tailings Dam Safety.	1989
d)	No.97.	Tailings Dams – Design of Drainage.	1994
e)	No.98.	Tailings Dams and Seismicity.	1995
f)	No.101.	Tailings Dams. Transport, Placement and Decantation.	1995
g)	No.103.	Tailings Dams and the Environment.	1996
h)	No.104.	Monitoring of Tailings Dams.	1996
i)	No.106.	A Guide to Tailings Dams and Impoundments.	1996

Knowledge about the factors that control the behaviour of tailings dams has improved greatly during the past 20 years, also the consequences and public perception of tailings dam failures has increased considerably, causing managers and owners to become more aware of the risks involved in the construction of impoundments. Many factors influence the behaviour of tailings impoundments; accidents and other incidents are often the result of inadequate site investigation, design, construction, operation, or monitoring of the impoundment, or a combination of these.

Every site and dam is unique so direct application from one to another is seldom possible. However, there are a number of common principles and the lessons learned from incidents at one dam can be applied in general terms to other situations. This Bulletin is intended to give general advice that can be of help to all those responsible for impoundments and tailings dams.

1. INTRODUCTION

1.1 OBJECTIVES

The aim of this Bulletin is to highlight and learn from some of the difficulties commonly encountered to help owners, managers, contractors and other personnel responsible for the day to day construction of tailings dams, to avoid similar difficulties. It is intended to be of help to all those connected in any way with tailings dams and waste lagoons: government officials concerned with regulations, planning officials concerned about the requirements needed for planning permission, and those concerned about the continuing stability of existing tailings dams.

Examples are given of accidents and failures, together with some examples of effective remedial measures.

1.2 BACKGROUND

In 1964 ICOLD approved a proposal for a ‘Study of known failures and incidents arising from rock foundations for dams'. This title was modified during 1965-6 to ‘Failures and accidents to large dams'. The ICOLD Committee on Failures and Accidents to Large Dams expanded its report to include events occurring during construction and major repairs. At the 1973 Executive Meeting of USCOLD, the Committee was authorised to proceed with a report covering incidents to USA dams during the period 1960 to 1972. *The report specifically excluded mine tailings and refuse dams.* Questionnaires were sent to a large number of dam owners in 1966 and 1973, resulting in information on 349 significant incidents. These were catalogued under 8 headings:

- F1 Major failure of a dam during operation, resulting in complete abandonment.
- F2 Major failure of a dam during operation that could be repaired.
- A1 Accident to dam that had been operating for some time, that was rectified before failure occurred.
- A2 Accident during initial filling.
- A3 Accident before filling began.
- AR Accident in a reservoir during operation, that did not cause trouble to the dam itself.
- DDC Damage to a partly constructed dam.
- MR Major repair required due to deterioration, or upgrade to comply with more modern standards.

The effect of improving understanding of the behaviour of dams that has resulted in improved methods of design and construction, is shown by the recorded failures during various periods.

During the 50 years 1850 to 1900, 13% occurred
During the decade 1900 to 1910 there were 7% failures
During the decade 1910 to 1920 there were 4.8 % (*)
During the decade 1920 to 1930 there were 2%
From 1930 to 1940 and 1940 to 1950 there were less than 1%
During the decade 1950 to 1960 there were about 0.2%.

Fuller details about this study of incidents to dams, excluding tailings and refuse dams, can be found in ICOLD (1974), as well as in ASCE (1975) and (1988).

The ICOLD Committee on Tailings Dams and Waste Lagoons has attempted a similar approach for tailings dams, but has encountered a reluctance amongst the owners of tailings dams to expose incidents or failures unless they came into the public domain through the media or published papers. In North America, the Tailings Dams Committee of USCOLD collected data about tailings dam incidents from published literature, responses to questionnaires and anecdotal information. They collected 185 cases and published their findings in USCOLD (1994). The Committee agreed that this publication could form the basis of this present report, which is published jointly between ICOLD and UNEP (United Nations Environmental Programme). This latter organisation sponsored a literature search by the Mining Journal Research Services, going back only to 1980. The Research Services contacted 52 organisations in 18 countries. Of this group, 23 agreed to participate and were sent questionnaires from which 20 replies were received. A list of 26 incidents was compiled, in addition to the cases collected by USCOLD. The ICOLD Committee also collected published cases, many passed on to the Research Services, making a grand total of 221 cases.

(*) In the main text and the appendix, the Anglo-Saxon usage (full stop and comma) has been adopted for the quantities.

2. PRE-REQUISITES FOR SAFE TAILINGS DAMS

Satellite imagery has led us to the realisation that tailings impoundments are probably the largest man-made structures on earth. Their safety, for the protection of life, the environment and property, is an essential need in today's mining operations. These factors, and the relatively poor safety record revealed by the numbers of failures in tailings dams, have led to an increasing awareness of the need for enhanced safety provisions in the design and operation of tailings dams. The mining industry has a less than perfect record when tailings dam failures are reviewed. Examples of notable failures that have been costly to life, the environment and to asset value, are given by Table 1.

Table 1. Examples of tailings dam failures

October 2000	Martin Country Coal Corporation, Kentucky, USA. 0.95 million m^3 coal waste slurry released into local streams. Fish kill in River Tug and drinking water intakes had to be closed.
Sept 2000.	Aitik mine: Sweden: 1.8 million m^3 water released.
March 2000	Borsa: Romania: 22,000 t tailings contaminated by heavy metals released.
Jan 2000	Baia Mare: Romania: 100,000 m^3 cyanide contaminated water with some tailings released.
April 1999	Placer, Surigao del Norte: Philippines: 700,000 t cyanide contaminated tailings released; 17 homes buried.
Dec 1998	Haelva: Spain: 50,000 m^3 acidic and toxic water released.
April 1998	Aznalcóllar: Spain: 4-5 million m^3 toxic water and slurry released.
Oct 1997	Pinto Valley: USA: 230,000 m^3 tailings and mine rock.
Aug 1996	El Porco: Bolivia: 400,000 t involved.
March 1996	Marcopper: Philippines: 1.5 million tonnes tailings released.
Sept 1995	Placer: Philippines: 50,000 m^3 released, 12 killed.
Aug 1995	Omai: Guyana: 4.2 million m^3 cyanide slurry released.
Feb 1994	Merriespruit: South Africa: 17 lives lost, 500,000 m^3 slurry flowed 2 km.

July 1985	Stava: Italy: 269 lives lost, tailings flowed up to 8 km.
Jan 1978	Arcturus: Zimbabwe: 1978: 1 life lost, 20,000 m^3 flowed 300 m.
Nov 1974	Bafokeng: South Africa: 12 deaths, 3 million m^3 slurry flowed 45km.
Feb 1972	Buffalo Creek: USA: 125 lives lost, 500 homes destroyed.
Sept 1970	Mufilira:Zambia: 89 deaths, 68,000 m^3 into mine workings.

Other examples:

Saaiplaas:	South Africa	1992
Jinshan:	China	1986
Pica Sao Luiz:	Brazil	1985
El Corbre:	Chile	1965

Attention at the design stage to the critical issues that can affect the long term safety of a tailings dam, will pay dividends throughout the life of the dam. The primary features affecting the design of a tailings disposal facility include:

a) The rate of tailings delivery and potential future changes.
b) The properties of the tailings and potential future variations.
c) The influence of additives on the properties, e.g. thickener flocculants.
d) The properties of the disposal area site foundations.
e) Possible influence of seismic loading.
f) Rainfall and evaporation rates.
g) Requirement for water cover and its depth.

From the point of view of the dam itself, factors affecting stability include:

1) Detailed foundation conditions.
2) Ultimate height and angle of the outer slope.
3) The rate of deposition and the detailed properties of the tailings.
4) Provision of adequate drainage. *See Bulletin No. 97 (1994).*
5) Seismic influences. *See Bulletin No. 98 (1995).*
6) Control of hydrology to avoid overtopping or dangerous rises of the phreatic surface within the dam body. *See Bulletin No. 101 (1995).*

To begin at the beginning, the choice of site is all important. In general tailings are transported as a slurry in a pipeline or, sometimes, in an open flume where flow can be caused by gravity alone, so that the disposal site can economically be some distance from the processing plant, giving a fairly wide choice of site position. The selected site must be of adequate size so that the tailings can be deposited throughout the life of the impoundment at safe rates of rise or embankment staging and with a final volume to satisfy the predicted volume of mineral extraction.

The filter under-drainage system is a critical facility that has often been overlooked in the past, resulting in dangerously high phreatic surfaces within the body of the tailings dam. As is well known, the outer slopes of a tailings dam are very sensitive to the level of the phreatic surface. Capillary rise above the measured position of the phreatic surface can make the tailings in this zone to be close to full saturation. This condition can produce unexpectedly large rises of the phreatic surface from remarkably small amounts of rainfall.

From the point of view of the tailings delivery and deposition system, safe design will incorporate the appropriate selection of a system that will ensure that breakages, wear and tear and maintenance be kept to a minimum, and that the supernatant pool is always contained safely, with adequate statutory freeboard. This is of particular importance in the early deposition stages of a new facility, where careful design is required. With paddock type construction, tailings must always be deposited first into the outer paddocks to build up the surrounding dam to safely contain the impoundment at all times. The outer banks can, if necessary, be raised more rapidly by use of hydro-cyclones, or by influencing the deposited beach slope.

Effective quality control and monitoring of the construction process for compliance with the design and works specification will ensure long-term effectiveness of these components, i.e. the starter dam; the filter drains; the decant facility; installed instrumentation *(see Bulletin No. 104, 1996)* and the tailings delivery system.

Controlled management of the deposition process and the operating functions of a tailings dam will significantly enhance the safety of a tailings disposal facility. Tailings dams usually have a significant deposition life, commonly more than twenty years, so safety management and checking for compliance with the design, or modifying the design to accommodate changed circumstances is an essential component of the operation. The safe day to day operation must be managed by correct planning procedures, that involves measurement of the volume and properties of the tailings slurry being delivered to the impoundment, and monitoring the construction activities in detail.

The process of implementing decisions associated with the assessment, toleration and reduction of risks can be termed safety management. Owners and operators have specific responsibilities for their dams and the need to formulate safety management procedures. Technical and managerial approaches should be utilised to improve safety and reduce risk. Continuing day to day safety of the dam-impoundment system will depend on some form of observational method involving surveillance and monitoring, using suitable instrumentation to reveal internal conditions.

An increase in safety is provided at an increase in cost and a balance has to be found between dam safety and economy. Cost effective risk reduction involves defining the acceptable level of risk, reducing the risk of the dam breaching to an acceptable value and implementing emergency management procedures to endeavour to ensure that there is no loss of life should the dam breach. The approaches to risk reduction for the dam-impoundment system can include structural improvements to the dam and ancillary works, improved surveillance, monitoring and maintenance. The approaches to risk reduction for the downstream valley system include the preparation of inundation maps, estimation of the time of arrival of flood wave at different locations and the duration of inundation and the implementation and maintenance of emergency warning procedures and systems. Unlike water, liquefied tailings do not drain away and the deposits left on roadways can seriously hamper emergency services. The weight of tailings is such that it can cause great damage, much greater than that of an equivalent flood of water, demolishing buildings rather than just flowing through them. The difficulty in knowing when to give warning makes the operation of emergency procedures very difficult.

Planning and management activities should include:

a) Staff training.
b) Planning of deposition cycles and positions.
c) Planning for dam geometry control.
d) Planning for maintenance activities.
e) Planning of measurement and monitoring activities.
f) Planning for responses to emergencies and for contingencies.

Recorded measurements made during dam construction will include:

a) The volumes and properties of delivered tailings slurry.
b) Levels of the dam crest and of the water pool, giving freeboard values.
c) Position of the phreatic surface.
d) In situ properties of the deposited tailings.
e) Seepage discharge flows from the filter drains.
f) Record of any uncontrolled toe seepage or other signs of distress.

Monitoring will include:

a) Regular visual inspections of the dam and its facilities from ground level and possibly also from the air.
b) Inspection of all measurement records with checks for compliance.
c) Recording and reporting all non-compliances and arranging remedial action.
d) Close liaison with designers.
e) Close liaison with the controlling authorities.

When judging the condition and safety of a tailings dam on the basis of instrumentation results and observations, consideration must be given to the possibility of unusual loading conditions, particularly from extreme meteorological events, which must be met by the reserves inherent in the structural system.

In conclusion it can be said that the provision for safe tailings dams can be made by careful attention to the critical components of the dam at the design stage, by effective quality control of the pre-deposition works construction and to professional management and monitoring of the deposition and operating process, all by experienced engineers and operators.

3. OVERVIEW OF DAM AND TAILINGS DAM INCIDENTS

The International Commission on Large Dams (ICOLD) and the National Committees of its 81 member countries, provides a forum for technical interaction amongst dam designers and constructors, and has recognised the importance of learning from failures and accidents with dams. ICOLD has numerous technical committees that publish Bulletins giving guidance to various aspects of dam design, construction and monitoring. One committee studied cases of failures and incidents amongst the dams of the world, and published 'Lessons from Dam Incidents' (ICOLD 1974). ICOLD also holds a congress every three years, and the Transactions of these Congresses contain extremely valuable information: they can be described as milestones along the path of progress in our subject. The U.S. Committee on Large Dams (USCOLD) conducted an incident survey of dams in the United States, updated by their Committee on Dam Safety with the results published in 1988 (USCOLD 1988). Over 500 incidents were tabulated, consisting of dam failures, accidents and major repairs to dam facilities. Embankment dams comprise approximately 73% of the dams in operation, and about 75% of the recorded incidents were related to this type of dam. Approximately 24% of the incidents were failures, and about 42% of the incidents were major repairs, with the remaining 34% described as accidents. This incident data is summarised graphically in Fig.1, where the type of incident has been compared with its cause. Conclusions that can be drawn from Fig.1 [(*)] are that the majority of dam failures are associated with overtopping, and the majority of incidents are associated with spillways and other facility structures.

Designers and operators of tailings dams also gain important information from both the satisfactory and unsatisfactory behaviour of both existing embankments and tailings dams. The focus of assessing dam performance is not to pass judgement on an industry or attach blame to the designer or constructor involved with a failure or an accident, but to gain knowledge from the records of performance and apply that knowledge to the next design or project. An ICOLD technical committee on tailings dams was formed following the Mexican Congress of 1976, and it has published several manuals and guides on tailings dams based on experience with tailings dam performance. A list of these publications is given in the Preface.

In addition to their incident survey of dams in the United States, USCOLD also made a tailings dam incident survey, updated in 1994. It contained 185 tailings dam incidents consisting of failures, accidents, seepage and examples of behaviour that did not meet design criteria, that had occurred during the period 1917 to 1989. This collection has been supplemented by a recent tailings dam incident survey made by the United Nations Environmental Programme (UNEP), and has added 26 cases to the 185 incidents.

The historical record of the incident survey data is shown by Fig.2 in terms of the number of incidents per five-year period, and differentiates between the USCOLD and

(*) All the Fig. are given at the end of the main text (Chapter 10) the UNEP/ICOLD collected data. It should be noted that all the figures showing tailings dam data are plotted with the number of incidents as the dependent variable. Fig.2 shows an increase of incidents starting in the mid-1960s. This increase is most likely due to the larger number of tailings dams constructed after 1960 combined with the more thorough documentation of tailings dam operation. The USCOLD and UNEP surveys have provided a total of 211 incidents for comparison. Clearly all incidents have not been reported, and this collected number form a subset of the actual number of tailings dam incident that have occurred from the early 1900s to 1996. The following discussion of results is presented in terms of the number of incidents, rather than downstream effects or cost of repair or remediation. A comparison of the number of incidents with tailings dam height is given by Fig.3, where it will be seen that about 57% of the incidents occurred in dams less than 20 m high. A comparison of actual dam failures with dam height is given by Fig.4 which shows that approximately 63% of the failures occurred in dams lower than 20 m.

When an impoundment has become completely filled, or when tailings production ceases, the tailings dam and its retained impoundment is described as inactive. This does not make them immune to accidents or failures and, as shown by Fig.7, relatively few incidents were associated with inactive dams. A cause of failure of inactive dams is increase of pool water level, bringing the pool closer to the dam crest thereby bringing the phreatic surface to the downstream slope, leading to eventual slips and overtopping. A method to avoid the overtopping of closed impoundments consists of building a subsidiary dyke some distance back from the crest of the tailings dam to permit the level of the pond water to rise during an emergency without risking the main dam. The section of such a dam in Germany is shown by Fig.5.

As can well be imagined, the type of construction of the tailings dam must play a part in its behaviour. One of the earliest and the most common types of construction is by the upstream method: tailings dams constructed with tailings by the upstream method have been documented in South Africa in the early 1900s *(types of construction have been described in Bulletin 106)*: traditional embankment dams when used to retain impoundments, are referred to as water retaining type dams. Because of the risk of failure of dams built by the upstream method, particularly when subject to earthquake shaking, the downstream method was developed; and there is a centreline method that is a compromise between the former two methods. As Fig.6 shows clearly, there are many more incidents with dams built by the upstream method than with other types, but also there are many more of these type of dam than of other types amongst the examples that we are considering.

An indication of the causes of incidents, for active and inactive tailings dams are given by Fig.7, where it will be seen that the leading cause of incidents for active dams are slope instability, overtopping and earthquake. For inactive dams, the leading causes of incidents are overtopping and earthquake. Fig.8 similarly shows incident cause for active dams, separating failures form accidents. Finally, Fig.9 shows the total incidents with their cause separated by tailings dam type. This figure also indicates that the leading causes for incidents are slope instability, earthquake and overtopping: particularly so for dams constructed by the upstream method. The incidents must be reviewed in terms of the number of particular dam types in operation. The upstream method is the oldest and most commonly used method of tailings dam construction. This method, as pointed out by Mittal and Morgenstern (1977), was used at sites prior to the use of foundation investigation and slope stability analyses. On the other hand, dams built by the newer centreline method show relatively few incidents, but it must be recognised that significantly fewer dams of this type exist as compared with the number built by the upstream method.

From the review of water-storage dam incidents, key design factors include regional conditions (climatic conditions, design storm event for spillway sizing, and the design earthquake) and site specific conditions (dam and reservoir foundations and slope conditions, and on-site construction materials). Water storage dams are designed to retain and release water over a range of operating level conditions, as well as pass flows from large storms. Key periods of observation include dam construction, initial reservoir filling, and the response time to initial filling. Maintenance and repair become more important as exposed structures, such as spillways and gates age and wear.

With tailings dams, key design factors include the same regional and site-specific conditions, but also include the mill production schedule and tailings characteristics. Tailings dams and impoundments are designed to retain material that is initially discharged into the impoundment as a slurry, and operated to provide separation of the tailings solids from the transporting water. Upon successful reclamation, the impoundment is essentially a storage facility for solid materials, with as little impounded or entrained liquid as possible, although it is very difficult to reduce the considerable volume of water retained within the pore space between the small particles constituting the tailings. Additional drainage can be provided either by including drainage layers into the impoundment during construction or by installing vertical and/or horizontal sand drains at a later stage. Research work on the effect of water chemistry on the density of settling tailings and the effects of colloids in the water has been described by Vaughan (1999). The application of vibrations of audio frequency during sedimentation was found to increase the density of the deposit.

The impoundment is typically designed to contain water from a range of operating water-level conditions, as well as contain impounded water from large storm events. The containment capacity for free water must be maintained despite the ever increasing level of the retained tailings solids. To reduce capital costs, tailings dams and associated impoundment areas are usually constructed in stages or phases. Protection from storms is maintained by diversion of upstream drainage and providing adequate capacity for precipitation directly on the impoundment area.

In comparison with water storage dams, the key period of observation for a tailings dam is the entire operating life of the impoundment to its completion and during its reclamation. This differs completely from water-storage dam operation, because tailings dam construction and impoundment filling are taking place throughout the mill operation period. Settlement, consolidation and drainage of the tailings is occurring throughout the operation, as well as for a period afterwards. Maintenance and repairs take place during operation, and become less important after reclamation as operating features are closed or removed.

The design and operation of a tailings dam has been described as an example of the observational approach in geotechnical engineering, as discussed by Peck (1969), where the design is based on the best information available at the time, with planned contingencies and subsequent modifications based on careful observation and monitoring of the initial construction and operation. This is the case if the initial design was based on the key design factors listed above, followed by careful observation and monitoring. The tailings dam incidents discussed here reflect deficiencies in this observational approach.

The incident survey results show that there is no overriding cause or mechanism for all tailings dam incidents, but it is intended that readers may find examples close to cases under their control, and benefit from the experiences recorded here. As shown by Fig.9, incidents are due to a number of factors including overtopping, static and seismic instability, seepage and internal erosion, external erosion, structural and foundation conditions. In addition, no type of tailings dam or operational condition is particularly immune from incidents. Although the majority of tailings dam incidents are associated with active tailings impoundments, a range of types of incidents have been recorded at inactive impoundments.

4. COMMON REASONS FOR FAULTY BEHAVIOUR

Water is used in the grinding and processing of mineral ore for the extraction of the required metals, so that at the tail end of the processing, the discarded tailings is in the form of a slurry of water and mineral particles that will flow in a channel or pipeline. Tailings that come from chemical and other plants is often stored in a similar way, but the material is not always suitable for dam construction.

A great deal of water is included in mineral tailings that come to an impoundment. The material in its wet form is unsuitable for dam construction. Water can be removed by drainage under the downward pull of gravity, by evaporation to the atmosphere and by consolidation caused by gravitational action on the mineral particles, which settle inside the mass of the impoundment, leaving free water that can be decanted or pumped from the surface. The coarsest particles used for the construction of the dam have the highest permeability of the tailings material so that the water in the pores can escape when there are adequate drainage outlets.

With a dam being built by the upstream method, the coarsest particles settle out nearest to the crest, with reduction of particles sizing with advancement down the gently sloping beach until only the finest particles are left to be carried into the pond where they settle. While the surface of the water in the pond is visible, with distance moving downstream towards the dam crest, the level of the water within the tailings, referred to as the phreatic surface, falls as it approached the downstream slope where it can drain out or evaporate. In some early dams, built without drains, the positions for the phreatic surfaces under various conditions, are shown by Fig.10. Variations of placement, particle sizes etc., cause the body of an impoundment to be extremely anisotropic with regard to permeability. This results in equi-potential lines that are far from vertical, which can cause an incorrect measurement of the position of the phreatic surface by open standpipes that have long intake filters. Also layers of materials of low permeability can produce perched phreatic surfaces, as indicated by Fig 11(e). In fact it is essential for the stability of the dam that the phreatic surface is kept well back from the downstream slope. When it is allowed to move downstream by allowing the pond to move too close to the dam crest, local small rotational slips will occur where the phreatic surface meets the downstream slope.

Downstream slopes may suffer slight gullying caused by rainfall, and first signs of a close phreatic surface may be given by water issuing into one of these gullies. If there is no remedial action, small slips may develop, deepening the gully and moving the surface of that part of the downstream slope even further back into the phreatic surface. This leads to larger slips that continue to eat away the base of the slope, until the whole downstream face becomes unstable. In the extreme the slips may reach up as far as the dam crest, removing sufficient of it to permit of overtopping and failure of the dam. Thus it can be seen that complete control of the water regime is of the utmost importance to maintain the stability of the dam and impoundment.

Dams built by the downstream method use the coarsest fraction from the tailings, usually separated by the use of hydro-cyclones. These simple machines, illustrated by Fig.11, have no moving parts. The tailings supply enters the cylindrical shaped body tangentially, producing rapid rotation, throwing the coarse fraction to the periphery where it moves down to discharge from the bottom nozzle, which is made of adjustable diameter so that the sizes of the discharged particles can be controlled. The smaller the rate of discharge permitted, the larger the sizes. The finest fractions from the centre of the swirling mass pass through a central pipe to discharge from the top of the hydro-cyclone, usually connected by delivery pipes to be discharged into the impoundment.

Not all tailings contain a sufficient volume of coarse (sand size) particles for the construction of a downstream type dam and changes have to be made in the construction method to incorporate imported fill and/or change to the upstream method from time to time. Provision must be made at all times during construction to ensure that good drainage is being built into the dam to ensure that there is no danger of the phreatic surface from advancing to the downstream slope. In general, dams built by the downstream or centreline method are much safer than those built by the upstream method, particularly when subject to earthquake shaking.

In the exceptional circumstances of the dam being constructed of material that, when in place, proved to be less permeable than the tailings it was retaining, the phreatic surface in the dam can rise to dangerous levels, causing instability. An unidentified case has been reported of the failure of a downstream slope due to this cause. Clearly extensive drainage should have been provided in this dam fill.

It must be pointed out that a permeability value is not a property of a particular material. The value varies with the density of the fill, its degree of saturation and particularly with the values of existing effective stresses.

Appropriate remedial measures carried out at the right time can prevent expensive and often fatal occurrences. The responsibility for the safety of tailings dams must lie with the owner or operator. The owner or operator of the tailings dam and retained impoundment has to ensure that a competent person is engaged to have overall charge of construction and that he is given the power to make modifications to the methods of construction being used and in the extreme to stop further materials from being delivered to the dam and impoundment. This may require the enterprise to operate an emergency (or just a second) disposal facility into which the tailings flow could be diverted, although in North America, emergency impoundments may not be considered feasible due to the cost of obtaining permits, provision of a liner and the freeboard requirements demanded for an emergency impoundment. It is often said that there should be an operations manual for each tailings dam, written by the designer and modified by him during the years of operation to ensure that it always provides practical advice. In North America an operations manual is a required part of the permitting process, and it is modified into standard operating procedures or simplified guidelines for operational personnel. This approach can be dangerous if the personnel operating construction do not fully understand the implications of some of the recommendations. The manual may also have become a lengthy document and staff may not have time to re-study the manual and from it work out the correct response to an emergency. There is no substitute for a competent engineer to be fully responsible for the safe construction of the dam.

Regular inspection is an important part of checking that the construction procedure is correct and that no hidden mistakes are being built into the structure. Combined with regular inspection is the correct and regular monitoring of all instrumentation and the taking of measurements etc. Aerial photography and satellite imagery can be of great help to obtain the overall view of the way the impoundment is developing. But, apparently efficient inspection may prove deceptive. There is a case where failure occurred, with an inspector driving on and around the dam, inspecting it on a semi-continuous basis. Unless the inspector has a good knowledge of the behaviour of tailings dams and has at his disposal instrumentation to reveal to him the conditions within the body of the dam and its foundations, such inspection may be not only useless but also highly dangerous by giving to management a false sense of security. An example of the weakness and danger of such inspection was given by the example of Incident No.206; further details are given in Section 6.

5. RISK MANAGEMENT

The failure of a tailings dam and the uncontrolled release of the impounded waste may have serious consequences for the public safety, the environment and the Owner or Operator. Some of the types of consequences can include the following:

- Economic Consequences: Included under this heading are the costs of repair or reconstruction of the dam and impoundment and the effects on the operator of the facility of a temporary lack of storage for waste.

- Public Safety: Public attention has increasingly focused on matters relating to safety and a hazard which may affect a large number of people in a single catastrophe is less acceptable than every day hazards which may in aggregate cause far more deaths but in each incident affect only one or two individuals. An imposed and involuntary exposure due to living close to some hazard is much less acceptable than a voluntary exposure to a high risk activity.

- Environmental Damage: The release of a substantial quantity of waste material which then flows over a large area of surrounding ground may cause massive environmental damage, particularly if the waste is toxic. There are also risks associated with incremental events over a longer term such as dust dispersion, groundwater contamination, landslide or ground instability.

- The Risk Management process involves carrying out a Risk Assessment to assess the potential failure modes and consequences, a Risk Management Plan to reduce the risks through design or operations, and a Contingency Plan to develop an optimal response to failures.

5.1 RISK ASSESSMENT

Risk analysis can be qualitative or quantitative. The term quantitative risk assessment (QRA) refers to the technique of assessing the frequency of an unwanted event and its measurable consequences in terms such as number of fatalities or cost of damage (Dise & Vick, 2000). QRA techniques are advocated by many regulatory bodies to assess the safety of modern complex plants and their protective systems (U.S. Department of the Interior, Bureau of Reclamation, 1999) It can be questioned whether QRA, as used in the process industries, involving large numbers of fault trees and event trees is appropriate for the assessment of the safety of tailings dams and waste impoundments. Qualitative Risk Assessment techniques are commonly based upon the Failure Modes Effects Analysis (FMEA) which was developed as a result of the Bhopal and Challenger disasters. McLeod and Plewes (1999) further developed the methodology to quantify the environmental and socio-economic consequences of failure for tailing facilities.

The risk assessment process has many variables and approaches (Vick, 1999). The ICOLD subcommittee on Dam Safety is currently preparing a Bulletin on Risk Assessment and, although it is addressed towards water storage dams, the same principles apply to tailing facilities.

Risk analysis should consider the main components of the facility which include:

Dam and Foundations:

- Has the dam been designed by competent engineers, with due regard for foundation conditions, internal drainage, slope stability, seismic loading, and contaminant containment?
- Where tailings or cycloned sand are used for construction, has the structure been assessed with the same rigour as an earth/rockfill dam?
- Is the dam instrumented and/or monitored, so as to reveal any abnormal behaviour?

Water Management Systems:

- Are the decant systems secure and have all pipes through the dam or foundation been adequately sealed and/or protected against piping failure?
- Is there sufficient flood storage capacity?
- Are spillways and/or diversions adequate for the design floods?
- Are there any hazards associated with the tailing delivery lines and water reclaim lines?

Closure:

- Has the structure been designed to accommodate potential changes in operating conditions over the closure period, e.g. erosion, floods, sediment inflows or natural landslides, etc.?
- Are the closure works suitable to reduce the potential for contaminant transport?

5.2 RISK MANAGEMENT

There is increasing recognition of the role that risk management has in dam safety assessments (Bowles et al, 1997). The risk assessment process will identify a number of risks associated with the tailings facility. The objective of the Risk Management Plan is to apply compensating factors to reduce the level of risk. The main areas of compensating factors include the following:

- Design: These may be civil works to increase the safety (e.g. berms), additional technical and environmental studies to increase the level of confidence in the assessment.

- Security: This could include both passive and active security systems to safeguard the public and the operating facilities.

- Monitoring and inspection systems: This allows early response to changes and identifies conditions which may be changing over the life of the facility. This includes the requirements of quality assurance and quality control(QA/QC) throughout the operations.

- Maintenance programs: These include such items as maintenance of diversion and water management structures, collection or treatment facilities, access roads, etc.

- Management: This includes supervision requirements, training of staff, reporting and Corporate/Public assurance.

Trade-off studies are required to optimise the cost/benefit of various compensating factors with the proportionate reduction in risk. Owners and operators have specific responsibilities for their dams and the need to formulate risk management procedures.

5.3 RISK CONTINGENCY PLAN

All facilities carry some degree of risk, even after risk management plans have been implemented. A risk contingency plan is therefore required to address those risks which cannot be eliminated. Contingency plans are required to address the required action and to mitigate the consequences if the event occurs. Contingency plans are needed to address issues of responsibility, notification, emergency response, technical monitoring and technical response, and other issues.

As with any structure theoretically capable of catastrophic failure, tailings dams require a contingency plan to be developed to deal with a possible accident. As tailings accidents may involve either physical and chemical consequences for persons and the environment, both of these aspects need to be considered. In addition to the requirements for support equipment it is necessary to have a clear communications and coordination plans in order to manage the response.

Emergency response plans necessarily require that the potentially affected community understands what it must do in case of accident. Public anxiety after a spill from tailings is greatly reduced if understanding of the real consequences has been built before an incident. Such understanding is impossible to achieve after an incident because learning ability is diminished by high anxiety levels, and a low level of trust at that time.

Emergency response plans are required components for new tailings impoundments in the United States of America and some other countries. The

UNEP's APELL (Awareness and Preparedness for Emergencies at the Local Level) Program has been designed to help companies, local government and the emergency services put a coordinated plan together to improve public preparedness in case of industrial accidents, including those that may arise at mine sites. The APELL program involves all the affected partners and actors, it is not a unilateral plan on the part of only the company or the emergency services.

An informed public will initially question the acceptability of any externally imposed risk. It is common for the company to undertake a thorough risk management plan and it can be a very valuable tool to incorporate the local stakeholders into the process (McLeod and Plewes, 1999). This allows the potentially affected community as well as the "response" organisations to properly understand the issues and the best emergency preparedness arrangements.

The APELL program has been applied in many industrial situation around the world. The APELL handbook and supporting material is available in over 20 languages, and there is a pool of United Nations and national experts to assist companies and communities in developing emergency preparedness plans. The procedure is directly applicable to tailings facilities.

6. LESSONS LEARNT FROM THIS STUDY

6.1 GENERAL ASSESSMENT OF THE LESSONS LEARNED

A study of the case records contained in this Bulletin may give an insight into the behaviour of a particular tailings dam of concern to the reader. It is expected that all readers will find items of interest that can be applied to dams and impoundments for which they are responsible. A general assessment of the lessons learnt from this collection of case records are given by the several points that follow:

- Although our understanding of the behaviour of embankment dams has improved to the extent that they can be designed to behave correctly, and many of the design features can be applied to the design of tailings dams, tailings dams continue to fail. During the decade 1979 to 1989 there were 13 failures. The decade before, 1969 to 1979 had at least one failure every year, and the most recent decade, 1989 to 1999 suffered 21 reported failures. It must be emphasised, however, that failures can occur without reaching the public domain. Only the more serious cases that attract media attention are the ones we hear about.

  These numbers of failures may well simply reflect the ever increasing numbers of tailings dams being constructed together with the increasing numbers of closed tailings dams. Consideration of the total number of operational and closed impoundments, the percentage of failures would be seen as decreasing with advancing time. This, unfortunately, is of little comfort to the owner of one of the dams that fails, although it would give an indication that the methods used by the profession for the design and construction of tailings dams are steadily improving.

- It can be argued that failures are due to inadequate management. The art and science of geotechnical engineering and geology, plus the detailed research studies of the behaviour of embankment dams, has given designers sufficient information to enable of the design of safe tailings dams. Major differences between embankment dams built to retain water reservoirs, and tailings dams, are that the embankment dams are designed by specialist consultants, who supervise their construction, certify their correct completion and supervise the first filling of the reservoirs. Subsequently in Britain and in many other countries, dams by law, are continuously supervised to check on their continuing satisfactory behaviour. This is done with the aid of instrumentation, installed in the dams during their construction, as well as visual observations and checks on valves, spillways and other auxiliary works. Partly because of the slow rate of construction this approach is not used with tailings dams, and many of their failures are caused by lack of attention to detail. Often there appears to be no responsible person in full charge of the tailings dams, and it is unusual for them to be well instrumented.

In many very advanced countries, such as those of North America, tailings dams are designed, constructed and operated under similar regulations and reviews as water storage dams. A difference between the two types relate to physical loading from: (1) the staged manner in which tailings dams are typically constructed, and (2) the progressively increasing loading of the tailings on the impoundment foundation with time.

- Lack of control of the hydrological regime is one of the most common causes of failure. Of the cases reported here, the majority of failures were due to overtopping, slope instability, seepage and erosion; all caused by a lack of control of the water balance within the impoundments. Correctly placed piezometers and open tube standpipes can show the levels of the phreatic surface and give warning of dangerously high conditions. There should always be provision for diverting water and tailings discharge away from an impoundment in difficulties. Alternative discharge, possibly into another impoundment, should always be available. Removal of water from the pond should be an uninterrupted continuous process and blockage or damage to pump barge or any form of decant should not be allowed to occur. Damage to vertical decants can be caused by consolidation of the tailings and negative skin friction inducing high vertical loading. Ice, attaching itself to a decant tower can impose damaging bending and twisting moments caused by water level changes and wind forces. The ever increasing loading on culverts passing under a dam and impoundment, particularly when height has been increased to give above design capacity, crushing damage may prevent adequate discharge, particularly during exceptional conditions. Unsatisfactory amendments to the designed outlet arrangements, as occurred with Incident No.117, should not be allowed. Second decant facilities and/or standby pump barges should be available for emergencies. Any such standby facilities must be regularly tested to ensure that they will work when required. Culverts should be monitored and inspected regularly to detect first signs of distress.

  All impoundments and their retaining dams need to be able to accommodate extreme hydrologic events, up to the Probable Maximum Flood. Water retaining dams are normally provided with spillway facilities designed to pass the PMF (older dams are being modified to accord with modern law). With many tailings dams, however, the tailings fluids are not permitted to be discharged, so upstream flood waters must be fully diverted so as not to enter the impoundment and storage capacity (adequate freeboard) and careful management of tailings pond water must be sufficient to accept all flood waters falling directly on to the impoundment or entering via incorrectly diverted streams.

- Unsatisfactory foundation conditions can not always be detected by the site investigation made for the design stage, and some deep conditions have been missed, as illustrated by examples Incident No. 207 and 209. Careful measurements of movements, the use of deep inclinometers and knowledge of the pore pressure conditions in the foundation soils might be expected to show up unsatisfactory conditions, but with brittle soils there may be very little forewarning.

- Many older dams were not provided with adequate drainage and often, particularly when mine ownership has changed hands, records of design assumptions are not available. In these circumstances it is advisable for the condition of the dam to be determined by a full inspection and site investigation; when absent, instrumentation can be installed, so that the behaviour of the dam can be observed during its continuing use and raising. Sometimes additional drainage can be obtained by the use of horizontal boring to install tube-well type filtered pipe drains.

- Remedial measures, as may be derived from the above examples of unsatisfactory behaviour, include toe weighting with rockfill placed over correctly designed filter layers, over the downstream slope to improve stability. When there is time, and imminent slope failure is not expected, stability can be improved by drainage. Horizontal drains can be installed from the downstream slope, and the foundation can be partially drained with vertical drains installed through the lower part of the downstream slope.

- Many of the cases represent a lack of care. In retrospect the actions that were the cause of failure were due to a lack of appreciation of the mechanisms that trigger failure. Considering the cost to the mine owners of these failures, it might be expected that a much greater care would be taken of the tailings dams. Having someone in charge of the dams at all time, supported by good instrumentation and regular inspection and review would be a minimum requirement. The cost of insurance against dam failure and its consequences must be extremely high. The action of the insurance companies in demanding correct control of tailings dams, with the incentive of lower premiums for those mine owners who establish a satisfactory approach to their tailings dams may be a way towards a reduction in the numbers of failures that continue to occur.

  It should be noted that in North America and elsewhere, a tailings impoundment cannot start operation without prior approval from regulatory agencies who typically require both an internal technical review as well as a public review of the design, operation and reclamation plans for the impoundment. A reclamation bond placed with the regulatory agency by the mining company sufficient to cover the cost of site reclamation is also required. Large projects outside North America seeking external financing, require approval of the technical aspects of the design, as well as approval of construction, operation and reclamation.

6.2 SPECIFIC CONSIDERATIONS, WITH EXAMPLES OF INCIDENTS

6.2.1 Site selection and investigation

The position of the mine is fixed by the position of the ore body, but the position for the impoundment may be controlled by several factors including environmental considerations, local regulations, consideration of the local hydrological and seismic conditions, as well as the geographical and geotechnical conditions.

Published papers and a book about site selection methods include Robinson et al (1980), who provide a qualitative and semi-quantitative method; Robinson and Moss (1981) describe the use of these methods for several mill sites, while Keeney (1980) deals with site selection for power plants and other civil works. A successful example of the site selection process for mine facilities has been documented by Crouch and Poulter (1983). Comprehensive coverage of site selection and site investigation has been given by Clayton et al (1982).

Consideration of the position for a new impoundment must take account of the risk of damage to life, property and the environment should failure occur both during operation and after closure. It could be argued that the site for the tailings dams at Stava, Incident No 117, had been badly chosen in view of the vulnerability of the downstream town and hotels. The Merriespruit tailings dam, Incident No.202, had been sited very close to an existing township on ground sloping down into the town, apparently with no regard to the risk it imposed.

Tailings can usually be transported over considerable distances relatively cheaply, so that the choice of site may not be as limited as might at first appear to be the case. This can result in greater freedom to select a site which is relatively free of constrains and where the consequences of failure can be reduced considerably. There may also be benefits to the mining operation as a whole and not just to that element related to tailings disposal.

<u>Example</u>. As an example, rock containing copper is mined high in the Andes in Chile, and many mines crushed, ground and processed this ore near the mine. Lorries brought the copper concentrate down the narrow mountain tracks, distances exceeding 160 km to smelters or for export. In winter they could be held up for long periods. The narrow, steep sided valleys near the mines were used for the impoundments, but fairly high dams were needed for the storage of appreciable volumes of tailings, and there was a growing risk of downstream damage if the dams should fail. Much better sites for large impoundments could be found on the flatter land at the foot of the Andes where the rainfall was less and the rate of evaporation greater than in the mountains. In some cases low hills could be joined by tailings dams to enclose large areas.

The ore was still crushed and ground at the mine, ready for processing, but was then carried by pipeline or concrete flumes, distances exceeding 80 km, down to the flatter land, where the processing plant was constructed adjacent to the site for the impoundment. In this way the distance that the concentrate had to be carried was greatly reduced, could be continued though the winter, and tailings storage was greatly simplified, with provision for much greater storage than had been possible adjacent to the mines. The better climate at the lower levels was also an advantage for the construction of the tailings dams.

<u>Example</u>. At the McLaughlin mine in North America, the processing plant and tailings impoundment were sited approximately 7 km from the mine. This was done so that the tailings impoundment was in a location with favourable topography and founded on clayey subsoils for tailings solution containment. The ore was crushed

and ground at the mine and conveyed as a slurry by pipeline to the processing plant and tailings impoundment. The site selection process for the project is described by Crouch and Poulter (1983).

Before the proposed site for a tailings dam can be confirmed, it is essential that the site is thoroughly investigated to check on predicted seismic activity and, if the impoundment is to be situated within a river valley, to determine the Probable Maximum Flood.

Example. The Sarcheshmeh tailings impoundment situated in a valley 20 km north of the Sarcheshmeh Copper Plant of Iran, was mainly constructed for the purpose of storing the tailings from the copper plant, as well as providing a source of water for the plant. Inaccuracy in the estimated total annual discharge of the river made during the feasibility studies has resulted in a change of use for the impoundment. Instead of the retaining dam being considered as a tailings dam, it has had to become a water reservoir, and this change has posed various problems. The actual flow during the first 7 years of operation has been more than 2 ½ time the estimate and this has necessitated release of water downstream, despite some environmental limitations. This, combined with the continuing output of tailings from the plant, has necessitated raising the heights of both the main and saddle dams by 15 m. Details have been given by Askari (1991) and Askari et al (1994).

Information about the geotechnical properties of the foundation are an essential pre-requisite for the design of the dam.

Example. Ok Ma, Papua New Guinea. A major landslide occurred on the left bank of the river Ma during early stages of the construction of an embankment dam intended for tailings retention. The site was in one of the most favourable valleys hydrologically in the area, even though it was about 18 km from the processing plant. According to Fookes and Dale (1992) the site investigation had been made by well known site investigation specialist companies over a period of six months. 23 boreholes were made, together with 3 test pits and a geophysical survey using 20 seismic refraction lines. During the period there were 10 professional geologists and geotechnical staff on the site.

The early stages of construction involved excavation of the colluvial and taluvial materials from the base of the valley to obtain an effective cut-off. Due to concern about the residual shear strength of the Pnyang Mudstones, further investigation was to proceed in parallel with the excavation and 44 more boreholes were drilled. During this time a highly professional review team made visits to the site on behalf of the Government. Their reports, although expressing concern about problems associated with the excavation, gave no indication of any concern about the possibility of the major landslide that occurred.

The main site investigation began in March 1982 but prior to completion of an access road in September 1983, access to the site had been by long treks through the jungle or by helicopter. Excavation at the left abutment had reached a depth of 14 m when a landslide developed on 16th December 1983, moving 6 m towards the river and involving an area of 11 ha. Shortly afterwards, during the night of 6th-7th January 1984 a much larger landslide occurred covering an area of 122 ha, resulting in the abandonment of the site.

This example is given to demonstrate the very great difficulty in making accurate predictions about the behaviour of a site. Fortunately the majority of sites chosen for the storage of waste tailings and the construction of tailings dams do not involve such complications.

Sinkholes, old mine shafts and weaknesses above active underground mine workings are very difficult to detect during site investigations. Karstic foundation bedrock can offer the opportunity for the surface overburden to collapse when its bridging action over a cavity is broken by increases of stress or softening due to increased water that could be introduced through the presence of a tailings dam and impoundment.

Example. Londe (1976) described a case of rotational failure of a part of the toe of a tailings dam caused by collapse into an old and disused mine shaft that had not been effectively sealed when abandoned.

Example. Incident No. 73. The failure of the Iwiny tailings dam in Poland, described by Wolski (1996), was thought to have been caused by a sink hole forming underneath the dam due to loss of ground into a highly fractured and faulted red sandstone bedrock. The dam had been built across a fault with a fracture zone 20 m thick, and it was here that failure occurred. The underground mine had advanced to within 200 m of the dam axis, pumping from it had lowered the water table and rock blasting in the mine caused small earth tremors. The failure, during the night of 13th December 1967, released about 4.6 x 10^6 m^3 of tailings, more than 20% of the stored volume, causing 18 deaths.

Example. Incident No.88. Mufilira Mine, Zambia. The depression formed in the ground surface by the extraction of materials from the underground mine was being used as an apparently convenient storage basin for tailings. Under the weight of the tailings and the increased water soaking down from the impoundment, on 25th September 1970 the ground gave way, releasing a large volume of liquefied tailings into the mine workings. 68,000 m^3 of tailings funnelled down into the mine workings 600 m below in 15 minutes, killing 89 miners. The remaining mass was stabilised by de-watering with tube wells to enable mining to continue.

6.2.2 Starter dam

Starter dams are commonly constructed from locally obtained fill, that may be soil and/or rock, including coarse waste and overburden from the mining operation if that is close enough to the tailings dam site. Design may require the dam to function as a drain or to form an impervious barrier and the fill chosen should reflect these requirements. If acting as a drain, pore water from the impounded tailings passing into the starter dam should be collected in a seepage collection pond outside the toe of the embankment and pumped back into the tailings pool or directly back to the processing plant. When the pore water from the tailings is toxic, containing such chemicals as cyanide, regulations may require the whole impoundment to be lined with clay or a synthetic liner, when a drainage blanket would be placed between the liner and the impounded tailings to promote drainage from the tailings. Seepage from the impoundment directly into the ground would only be allowed if the pore fluid did not affect the quality of the groundwater. Permitted seepage from the tailings would either have an initial water quality similar to that of the groundwater or have mobile constituents removed from solution by attenuation in the soils between the tailings and the groundwater. In practice such an ideal approach can not always be applied.

Example. A tailings impoundment was needed to accept tailings from a rock washing plant. A site was chosen where there was a 20 m high mound of refuse consisting mainly of stripped overburden, that could act as a starter dam. The land sloped gently towards this mound that was parallel to a double track railway line. A site investigation showed that the mound was not homogeneous and it was difficult to define representative soil parameters. In view of this, conservative design parameters were derived from a back analysis of the existing situation. In considering the stability of the whole scheme when tailings would be placed behind this starter dam, and then raised by the upstream method, the position of the phreatic surface, which was almost impossible to predict, was crucial. A stability analysis was used to determine a maximum height position for a developing phreatic surface, and to measure this a large number of standpipe piezometers were installed.

The impoundment was put into operation and filled with tailings to the crest level of the mound, when the first of the supplementary dykes was built above and upstream of the crest and the level of the tailings continued to rise. Standpipe readings were taken weekly and the phreatic surface remained comfortably low. But suddenly, between two of the weekly readings, the level came up by several metres. This caused the downstream slope of the mound to begin moving downstream towards the railway line. Because of the risk of a sudden slide, the railway was closed and some people living nearby were evacuated. Large cracks appeared in the downstream slope as the toe continued to move towards the railway, as indicated by Fig.12. The movement was arrested by removing the upper part of the supplementary dyke, loading the toe with 10 000 tonnes of rockfill and drawing water from the moving mound and from the tailings immediately upstream of it. The subsequent study revealed a layer of rock fragments within the mound. Water from the tailings had reached the level of the upstream edge of this layer, permitting the rapid entry of water into the body of the mound.

Problems can arise when the initial starter dam is not constructed to a sufficient height. The capacity that will be impounded by a starter dam of a given height must be balanced against the predicted rate of tailings delivery to the new impoundment to ensure that the expected rate of rise of dam height by the method of construction that will be used, will enable the storage capacity of the impoundment to increase at or above the expected rate of tailings delivery. It should be noted that because the rate of delivery of suitable tailings for dam construction from a new mine cannot be relied upon, the initial starter dam height should be made greater than might be expected.

6.2.3 Unsatisfactory foundations

This is allied to site investigation because the weaknesses revealed by the dam failures should have been detected during the site investigation. This does not necessarily imply that the site investigation was inadequate, but the dam designer may not have made the correct assumptions from the site investigation reports. Karl Terzaghi's biography [Goodman 1999] contains numerous examples of how he evaluated foundation problems from a detailed engineering and geomorphological standpoint in ways that previous engineers had overlooked.

Example. Incident No. 187. Prior to the construction of this dam the surface layers of clayey soil had not been stripped. The result was that the base of the dam slid forwards, causing failure.

Example. Incident No. 183. The 8 m high tailings dam had been built on gently sloping ground on a clay stratum about 6 m thick overlying a shale/mudstone bedrock. Its impoundment had been filled completely 8 years before it failed, releasing a flow of liquified tailings that travelled 100 m, covering a main road to a depth of 3 m. The failure was attributed to artesian water pressure in the bedrock developed by the seepage of water from other impoundments further up the slope, combined with tensile strains induced in the clay stratum by old underground mine workings. A line of relief wells was installed to control the groundwater pressures in the area.

Example. Incident No. 68. A clay layer in the foundation of this dam sheared when the dam reached a height of 79 m. This caused a 240 m long section of the dam to slump. It was stabilised by the use of rock drains and toe weighting.

Example. Incident No. 207. This dam was founded on about 50 m depth of material overlying lava flows. There appears to have been a layer of weaker material lying over the lava flows, and when the dam had reached a height of 25-30 m, the dam slid forwards on this deep layer. The dam was stabilised by draining the layer into excavated tunnels from the existing underground mine workings, and constructing a rock buttress at the dam toe that would act as toe weighting.

Example. Incident No. 209. The Aznalcóllar tailings dam at the Los Frailes mine near Seville in Spain, begun in 1978, failed in April 1998 when it had reached a height of 27 m. A length of the dam of about 600 m swung forwards like a door, forming a breach about 45 m wide. The dam section remaining intact, releasing an estimated 5.5×10^6 m^3 of acidic tailings that flooded over an area of approximately 2.6×10^3 hectares of farmland. The dam was founded on about 4 m thickness of alluvium, overlying marl which may have contained pre-formed slip surfaces, developed during earlier geological conditions. The impoundment, about 2 km long and 1.2 km wide, was along one side of the flat valley of the river Agrio. The tailings in the impoundment was particularly heavy, with a bulk density of 28 kN/m^3; almost three times the weight of water.

The failure occurred where a dividing dam met the main dam. In 1995 some grouting had been carried out from the main dam crest to reduce leakage. 42 relief wells were placed towards the end of 1997 along the downstream toe, through the alluvium and about 1-1½ m into the marl, and for several months they collected 1000 m^3/hr that was pumped back.

There were no eye witnesses because failure developed during the night, but there was some evidence to suggest that the main dam failed north of the dividing dam, prior to the bodily movement of the main dam adjacent to and south of the dividing dam, on a shear plane deep in the marl, as indicated by Fig.13. In addition to the physical conditions at the breach, the river flow measurements showed two peaks, one at 03.25 hours with a second at 08.30, indicating that failure occurred in two stages. Subsequently piezometric heads in the marl were found to be above dam crest, as indicated by Fig.13. This may have been due to the high density of the impounded tailings producing construction pore pressures in the heavily overconsolidated marl that had migrated horizontally towards the river and come underneath the dam. Deep boreholes have disclosed an aquifer 80 m below the dam, showing a head of 80m, that would have restricted drainage from the marl. According to Eriksson and Adamek (2000) the cause of the failure was a fault in the marl 14 m below ground surface. Bodily movement of the marl, carrying with it the intact dam towards the river, would be assisted by the reduction of effective stresses on the horizontal feature caused by the high pore pressure. Several eminent geotechnical engineers have expressed the view that such behaviour would have been extremely difficult to predict.

Example. Fort Peck dam. This 76 m high hydraulic fill dam on a sand foundation overlying weathered shale bedrock containing seams of bentonite, was in effect a tailings lagoon between two shoulders of coarser hydraulic fill. It failed two weeks after it had reached full height, on 22nd September 1938, producing a flow slide. 8 million m^3 of fill and foundation sands moved out a maximum distance of 430 m in 3 minutes on a level surface and 80 men were lost. As with the Aznalcóllar tailings dam at the Los Frailes mine, Incident No 209, a massive section of the dam swung out upstream like a great earthen gate hinged on the east abutment. The failure was attributed to the fact that the shearing resistance of the weathered shale and bentonite seams was insufficient to withstand the shearing forces imposed by the spreading action of the dam. This case is given as an example because it has been extensively studied and has become a classic. It has been described by Casagrande (1965, 1971).

6.2.4 Lack of stability of the downstream slope

The dangers of allowing the phreatic surface to move so far downstream as to intersect the downstream slope of a dam are very well known. Some of the earliest work during the 1930s of the United States Bureau of Reclamation in instrumenting their dams was for the purpose of finding the position of the phreatic surface. They installed standpipe piezometers in homogeneous dams as soon as construction was complete so that the rise of phreatic surface during reservoir impounding could be monitored. In some dams they were surprised to find that water rose in the standpipes before water had been put in the reservoir. This was due to construction pore pressures, created by the weight of new fill which compressed the lower fill and built up a pressure in the water trapped in the pores of the soil. The rate of construction increased the weight faster than the pore water could escape from the soil. At the end of construction, the continuing escape of pore water from the fill lowered the pore pressure, but the rise of water in the reservoir could increase it again.

The same thing happens in a tailings dam, except that usually the rate of construction raises the vertical height sufficiently slowly so that construction pore pressures can dissipate, and appreciable pressures seldom develop within the dam itself. Pore pressures are raised however by the rising impoundment, which usually rises at the same rate as dam construction; ie the dam is raised only to keep a freeboard distance above the level of the rising impoundment. A normal situation, with a dam being built by the upstream method, is indicated by Fig.14. By maintaining a wide beach, the pool of visible water is kept well away from the longitudinal axis and crest of the dam and there is more opportunity for the coarse fractions from the tailings to settle out on to what is becoming the body of the dam; only the finest fraction being carried into the settling pool. The rate of settlement depends on size of particle, its specific gravity, and its activity: an assessment can be obtained from Stoke's Law. The rate of clearance, i.e. the time for the smallest particles to sink below the surface to leave some clear water, can be so small that a large area of pond is needed to cater for the volume of tailings being discharged into the impoundment, and a compromise has to be reached between the area of the surface of the pond, and its closeness to the dam crest.

Trouble can arise when pond level rises, saturating the beach and bringing the edge of the open water closer to the dam axis. When rain erosion has cut gullies in the downstream slope of the dam, the phreatic surface, pushed downstream by the advancing pond, can reach the deepest of these gullies, causing water to issue into the base of the gully. This is an extremely dangerous situation because the issuing water loosens and carries away material from the dam slope, thereby steepening it locally until a small rotational slip occurs, bringing more material down into the gully to be washed away by the flow of water which increases as the effective slope of the dam is moved ever further back below the position for the phreatic surface. If this behaviour continues for too long, unobserved, larger and larger rotational slips occur, endangering the stability of the whole dam. Kealy and Busch (1979) analysed the effect of a high phreatic surface using circular slip surfaces as a simple illustration of the effect described above. They showed that the factor of safety against the occurrence of a rotational slip fell from 2.6 to only 1.1 when the phreatic surface reached the downstream slope of their dam.

The phreatic surface can be moved back from the slope to improve stability by the installation of horizontal bored drains. The California Division of Highways has been using such horizontal drains since 1939, according to Smith and Stafford (1957). They drilled holes near the base of the slope with a slight upward inclination so that water could flow out by gravity. Holes of 80 to 150 mm diameter were drilled then fitted with perforated metal pipes. In some cases the hole collapsed before the pipes could be inserted. Currently slotted PVC pipes are installed with the aid of a hollow stem continuous flight auger, which acts as a casing while the slotted drain pipes are inserted. Another method uses expendable fishtail bits on 75 mm hollow drill rods, using flush water. After the hole is drilled, the drain pipe is inserted and the fishtail bit dropped off so that the drill rods can be removed. The optimum length and spacing for the drains to lower the phreatic surface below the failure surface has been determined by Kenny et al (1976). As a remedial measure, additional drainage has been installed in the form of pumped vertical wells (Incident No.25), but the installation of horizontally bored under drainage, although clearly attractive, has not yet been applied extensively to tailings dams.

Example. Incident Nos. 124 and 125. The British Clean Waters Acts required coal mines to collect the waste fines previously discharged from their processing plants into rivers. At the Ty Mawr colliery in South Wales lagoons were formed in the existing dumps of coarse discard on the valley side, without any true design considerations. The tailings was pumped up to these lagoons in the expectation that surplus water would seep into the coarse discard. The downslope bank of the first of these lagoons ruptured in December 1961, and the released flow damaged an overhead ropeway that carried the coarse discard to the mountainside tips. A second lagoon, built in the same way, failed in March 1965, releasing a greater volume of tailings that reached the colliery yard, damaging cars and almost going down the shaft. These incidents are illustrated by Fig.15.

Example. Incident No. 184. A 15 m high tailings dam at the Zletovo lead mine in Yugoslavia failed in March 1976 due to a high phreatic surface reaching its steep downstream slope of 1 on 1.5. Prior to failure there were signs of leakage issuing from the slope quite high up. The flow of released tailings contaminated the nearby river and the water supply from this river to the town of Stip had to be discontinued for more than 24 hours.

Example. Incident No.7. Bafokeng, 1974. 3 million m^3 of liquefied tailings escaped and travelled 45 km. The flow destroyed mine buildings, some went down the shaft carrying with it the cage and killing 12 miners. The case has been described by Jennings (1979).

Example. Incident No.25. Castle Dome, USA, 1950. Sand dyke failed due to excessive seepage and high phreatic conditions. Pumped vertical wells were used to drain the sand and reduce the height of the phreatic surface.

Example. Incident No. 202. Merriespruit, Virginia, South Africa. This 31 m high tailings dam had been constructed just up slope of the township of Merriespruit. Dampness on the downstream slope and some small slips had caused the impoundment to be closed. It continued to be used for the occasional discharge of waste water containing some tailings. This continued for some time, the extra tailings slowly pushing the pond further towards the dam and reducing the freeboard. The movement of the pond was recorded by satellite imagery (by chance a satellite passed over the site on a regular basis) and it was seen that the decant became isolated so that no further discharge could come from the pond. A rainstorm when 30 to 55 mm fell in ½ hour was the last straw and the dam failed during the evening of 22nd February 1994. A description of this failure was given by Blight (1997b).

Example. Incident No. 213. Fernandinho tailings dam, Brazil. This 40 m high dam failed very suddenly. The failure was blamed on the very steep downstream slope of 1 on 1.11 combined with high pore pressures within the dam. This case is mentioned under "6.2.7. Flow slides" below.

Example. Incident No. 214. Minera Serra Grande tailings dam, Brazil. The impoundment was formed in a natural valley 3 km from the processing plant, retained by the dam constructed from cycloned tailings. Construction began in 1989, and the downstream slope of the tailings dam suffered a major slip on 26th February 1994. The slip did not sever the dam crest so there was no release of tailings, but the mining operation was suspended until the safety and integrity of the dam was re-established. Emergency repairs took 3 weeks, resulting in a revenue loss equivalent to 8500 ozs of gold.

The failure was attributed to a rise of the phreatic surface caused by badly constructed and ineffective filter drains under the starter dam, exacerbated by heavy rainfall during late 1993 and early 1994. The 27m high starter dam had been made impervious through being constructed from unsuitable fill which, in an attempt to construct a strong dam, had been well compacted. Mistakenly following the practice used for water retaining dams, a grout curtain had been constructed under the starter dam, preventing drainage of pore water. Contributory factors were that the design and operating manuals had not been developed so that there was no short or long term strategy. Operating staff were inexperienced in the adopted method of dam construction and thus were unable to interpret the warning signs that were being given by the piezometer readings. Initial construction was supposed to be by downstream cycloning from the crest of the starter dam. Unfortunately the cyclones did not arrive until 8 months after operations began and meanwhile tailings had been discharged freely into the impoundment and due to operator inexperience, freeboard was rapidly lost, causing the starter dam to be raised by 3 m in July 1991. The method of deposition was changed to the upstream method in September 1991 thereby restoring freeboard. During 1993 the outward appearance of the tailings dam looked reasonably healthy, aside from the common problem of too much water in the pool. There was minimum seepage from the downstream slope; also minimum seepage from the filter drains which should have been discharging freely. The rising phreatic surface rose above the crest level of the impervious starter dam and then exited from the slope above it, resulting in the large slip.

Example: Incident No.54. Grootvlei gold mine, South Africa, 1956. Downstream slope failure occurred after a prolonged period of rain, when the pond spread over the tailings beach and encroached on the dam crest. The dam breached releasing a flowslide of tailings that carried away about a third of the impoundment contents.

Example: Incident No.62. Kennecott copper mine, USA, 1941. Rainfall was thought to have increased the saturation of the downstream slope, causing minor rotational slips which initiated breaching and released tailings from the impoundment.

Example: Incident No.100. Ray copper mine, USA, 1972, 52 m high dam. Slope instability over a 150 m length of the dam was thought to have been associated with a perched water table above a layer of slimes of low permeability deposited on the dam 20 years earlier. A wetted zone had been observed on the downstream slope for some time before a rotational slip occurred, leading to a breach. Released tailings covered a section of an adjacent railway.

Example: Incident No.185. Arcturus tailings impoundment, Zimbabwe. This rectangular impoundment , 310 x 150 m serving a gold mine and in operation, was retained by dams that had been built by the upstream method from the coarse fraction of the tailings obtained by the usual beach separation. It had been built over a very slight ridge that ran under the long direction on the east side so that the land sloped at about 1 on 10 towards the west side, causing base drainage to flow to the dam forming that side. There appeared to be no under-drainage layer. The downstream slopes were 1 on 1.3 to 1 on 1.1 (vert on hor). There were two decant towers each 448 mm diameter, on the central axis of the impoundment and about 100 m apart, with the surface of the tailings impoundment sloping uniformly towards them with a fall of about 1.5 m from the beach. Six years prior to the failure a large arcuate scar 60 m wide, 1.5 m across and 10 m deep, formed in the slope of the west dam at about mid length, suggesting the beginning of a rotational slip. It was stabilised with 1040 tons of rock waste. A week before failure, cavities developed in the west dam and were filled with waste rock. There was evidence that the surface of the impoundment was beginning to slope towards the west side and to keep pond water away from the dam crest, four days before failure, a low bund was built parallel to and 17 m east of the west dam crest. Delivery pipes were moved to enable spigotting from the bund. During these last four days, following a period of heavy rain, 183 mm of rain fell and was trapped between the dam crest and the new bund. Sink holes developed in this 17 m wide strip. At 19.30 on 31st January 1978 with a reported loud bang, the west dam failed where the scar had formed six years earlier, releasing a flow slide that formed a breach 55 m wide in the dam.

Boreholes put down through the 25 m height of the impoundment just upstream of the dam, revealed tailings 16 to 20 m deep with about 70% silt and 8% clay, at a voids ratio of 0.96 to 1.05. Attempts had been made to improve drainage by driving steel pipes into the dam during the two or three years before the failure. It is possible that as a remedial measure, provision of horizontally bored drains through the toe of the dam and into the bottom of the impounded tailings might have lowered the phreatic surface sufficiently to have prevented the formation of the large rotational slip.

Further details of this event have been given by Shakesby and Whitlow (1991). In general, preventative measures consist of proper tailings water management. Remedial measures include reducing the water level in the impoundment, placing free draining, coarse material as toe weighting over the lower part of the downstream slope, and improving drainage. This has been done in some cases by installing horizontal drains into the toe of the slope.

Advice on drainage is given by ICOLD Bulletin No 97. Original design may have included drainage and drains of various kinds may have been built into the dam body during construction. Choking or other malfunction of these drains can seriously affect the position of the phreatic surface, and could endanger stability. Blockage can be caused by inadequate filters around the drains, allowing fine tailings to get into the drain. Drains that exit to the atmosphere and carry relatively small flows can allow chemical oxidation of the draining fluids, producing solid precipitates that can slowly block the drains with a well cemented hard material that cannot be cleaned away by surging. To avoid oxidation, a drain can be kept full of water by placing a small weir at its outlet, raising the water level around the drain by a small amount; insufficient to affect the draining function of the drain.

Dagenais (1976) warned that lack of drainage is the main cause of failures and requires great attention. ICOLD Bulletin 97 concludes, 'Careful and correct drain construction during the early stages of dam construction constitutes a cheap insurance against future expensive remedial work'.

Consideration of the Minera Serra Grande tailings dam failure concluded that a tailings dam must be recognised as a sensitive structure involving high risk to life, the environment, property and profitability of the company (the failure resulted in a revenue loss equivalent to 8500 ozs of gold). Consequently, tailings disposal must be subjected to the appropriate levels of design, management and supervision in relation to the risks. Specifically, the design should be inclusive of the conceptual and feasibility detail, construction and operating procedure and closure aspects. No phase can be done in isolation of the others and continuity and responsibility must be maintained through the entire process. The operating procedures manual is the vital link between design and operation and must be generated together with the necessary pre-operational programs for operating personnel.

Example. Incident No.34. Cyprus Thompson Creek, USA, 1989. An original drain included a 15 cm diameter PVC pipe wrapped in filter cloth. Fine tailings were seen to be being discharged from the drain, and a sinkhole of 2.5 m diameter and 1.2 m depth developed in the downstream slope. It was assumed that the filter cloth protection had failed, allowing piping into the drain.

Example. Incident No.154. Gypsum tailings impoundment, USA, 1966. Dam breached due to choking of the under-drains.

Preventative measures include careful drain and filter material design, sizing of drains and filters with adequate factors of safety, and proper water management during operations.

Lack of stability can also be caused by a variety of conditions in addition to those of the phreatic surface reaching the downstream slope, as described above; which is perhaps the most common cause of instability that can lead to dam failure. Excessive height at a given slope angle, exacerbated by gullying and high rainfall, can cause local slope failures which if repaired in time, need not lead to dam failure in the sense of the formation of a breach. Toe erosion causes local steepening and can result in local rotational slips. Freezing of the downstream slope can prevent evaporation from the slope and so increase pore pressures within the body of the dam. Prolonged freezing can also cause ice lenses to form, drawing pore water towards the surface of the slope. During thaw the released water can initiate slope instability.

The following examples relate to toe erosion.

Example. Lead and zinc mine at Mojkovac, Montenegro, 1992. Tailings retained by a 20 m high embankment dam built alongside the Tara river, a tributary of the Drina which in turn, joins the Danube. The dam of fill consisting of a clay with sand and gravel, had been covered on the upstream side by plastic sheeting to prevent water from the tailings from polluting the river. Floods raised river level 3 m, bringing it to the dam toe where sufficient erosion occurred to cause a rotational slip that reduced the 3 m wide crest to only 1 m. The plastic sheeting prevented water from the impoundment from entering the fill and the dam did not breach. Remedial work consisted of diverting the river to a course away from the dam toe, and rebuilding the downstream shoulder to a flatter slope.

Example. Incident No.95. Pinchi Lake, British Columbia, 1971. A 13 m high dam of homogeneous section built of compacted glacial till. Water decanted from the impoundment flowed in an unlined channel parallel with the downstream toe. Erosion of the channel produced downcutting of 4 m, causing cracking and deformation of the downstream slope of the dam. Movements were seated within the lacustrine foundation sediments at the depth of the eroded channel. Movements were stabilised by construction of a toe weighting berm and relocation of the channel.

6.2.5 Superimposed loads

Loads can be added to dams retaining tailings by increasing the height of the dam, retaining the same slope angle, and by adding materials to the surface of the tailings impoundment.

Example. Incident No.72. Lower Indian Creek lead mine, USA, 1960. Earthfill dam built in 1953 to a height of 14 m and subsequently raised several times by the addition of earthfill. In 1960 slumping occurred in the 1 on 2 downstream slope. The dam was saved by the addition of rockfill toe weighting, placed with an outer slope of 1 on 3. The dam remained in service and was raised between 1971 to 1976 with cycloned sand fill, ultimately reaching a height of 25.3 m.

Example. Incident No.75. Maggie Pye china clay, UK, 1970. Dam 18 m high suffered slope failure immediately after completion of a dyke to raise the dam, following a period of heavy rain. High pore pressures, together with the added weight of the new fill, were thought to be the causes for the failure. 15 000 m^3 of tailings were released.

Example. Incident No. 206. Failure of Manila Mining Corporation's Tailing Pond No 5 - Philippines. Failed into sea, extending 200 m seawards, at 09.30 on 2nd Sept 1995, about 50,000 cubic metres of material was released. 17 people were working on the tip at the time, and a farmer with his wife were walking along the shore. Of these 12 were killed, including MMC's Environmental Inspector, Nelson Cayomo, whose daily inspection reports of the impoundments indicated no signs of failure. The farmer was killed but his wife was saved. Lots of heavy plant lost too. Dam was built 1985/6 by the shoreline of Placer Bay. On 21st Dec 1986, Typhoon Ameng washed away a portion of the dam at the seafront. Another collapse occurred on 9th July 1987, both incidents releasing effluent with high levels of cyanide resulting in fishkill. The impoundment had been filled to capacity by July 1995, when dam crest was 17 m above sea level. The crest was about 10 m wide and was used as a two way road for heavy plant. The closed impoundment began being used as a dump for mine waste rock, and at collapse contained more than a million cubic metres of mine waste, earth, boulders, rock and leach pad debris plus seven 10 wheel trucks, 32 dump trucks, 3 dozers, 1 loader and a land cruiser (carrying the inspector). Failure was thought to be due to high rainfall raising the phreatic level, but the toe of the dam was over reclaimed land, and the breached portion coincides with the former shoreline.

6.2.6 Problems with decants

Water ponded in a tailings impoundment is removed by evaporation, pumping from a floating barge, or decanting into a tower that exits the impoundment through a culvert or pipe beneath the tailings dam.

One of the most common causes of unintended dangerous rises of pond water levels is inadequate behaviour of decants. This may be produced by debris blockage, crushing and/or fracture of the outlet passing under the dam, or by unanticipated flood.

Damage to decant towers caused by ice are discussed in Section 6.2.9 below.

Example. Incident No.23. Casapalca, Peru. Several tailings dams built by upstream method, up to 107m high used a complex array of pipe type decant structures and inadequately sized stream bypass channels. Five separate dam failures resulted from failures in these systems.

Example. Incident No.16. Blackbird, USA. Cobalt mine. Metal culvert under the dam corroded and partially collapsed. Suspended tailings discharged into downstream drainage. No embankment breach.

Example. Incident No.49. Galena silver mine, USA, 1974. Three tailings impoundments had been built in sequence within a narrow valley. During a rain on snow event that caused a 100 year flood, a blockage diverted a large portion of the flood into the uppermost impoundment. Its decant could not accept this large flow, causing the upper dam to fail by overtopping, leading to a cascade failure of the others. Released tailings covered about 5 acres of land, including part of a highway and main line railway.

Example. Incident No.119. Sweeney, USA, 1980. The dam was breached due to piping around the decant outlet conduit.

Example. Incident No.117. Stava, Italy, 1985. Two tailings dams were built for a fluorite mine in the mountains of northern Italy. They were built one above the other on sloping ground formed by fluvio glacial sediments, using starter dams with construction at later stages by the upstream method. The tailings contained sufficient coarse, angular sand to enable the downstream slope to be built at an inclination of 1 on 1.2. Special drainage for natural runoff at the site was not provided. Concrete pipes were laid on the ground to be under the lower impoundment, encased in concrete to form a square section. Upward facing openings were made in each length of pipe to act as decants for tailings water, and as the height of the impounded tailings rose, one by one these opening were closed by concrete plugs. When the first dam reached a height of 26 m, a second dam was begun upstream of the first impoundment, with the starter dam founded on natural ground at the limit of the existing impoundment. Similar encased concrete pipes were laid under the footprint for the starter dam, and continued up the slope to act as decants for the second impoundment. But when the second impoundment had reached a certain level, a blockage occurred in the decant concrete pipe. The blocked length was by-passed with a steel pipe laid on the surface of the tailings and connected to the concrete pipe through a small vertical tower, as indicated by Fig.16. When the second dam reached a height of 29 m it suffered a rotational slip and breached. The released tailings produced the failure of the lower dam. The combined contents of the two impoundments flowed at speeds up to 60 km/hour sweeping away the village of Stava with its several hotels and engulfed part of the small town of Tesero, about 4km downstream. 269 people were killed.

Six months prior to this failure in July 1985, a small slip had occurred in the lower portion of the upper dam in the area where the decant pipe passed underneath, as a consequence of freezing, and water was observed to seep from the area until March. In June a large sink hole developed in the lower impoundment due to failure of the decant pipe and tailings slurry from the sink hole flowed out to the river Stava. Water levels in both impoundments were lowered so that repairs could be carried out. Only four days before the fatal failure, both ponds had been refilled. It is thought that the length of steel pipe sagged under the weight of the settling tailings and pulled out from the vertical short concrete tower, permitting the decanted water to discharge into the body of the lower part of the upper dam. The resulting rise of pore pressure caused the rotational slip and the failure. Further details of this case are given by Berti et al (1988), Chandler (1991) and Chandler & Tosatti (1995).

6.2.7 Flow slides

Failure of a tailings dam itself, while causing an inconvenience, may not have seriously damaging consequences nor cause any loss of life. The serious danger of a breach is the possibility of a subsequent flow slide of liquefied tailings. The stability of embankments against slips is controlled by the available shear strength of the fill and foundations. The shear strength of particulate materials is usually expressed simply and, for the present purpose, quite adequately by the Mohr-Coulomb relationship in terms of effective stress:

$$_f = c' + ó' \tan ö'$$

where $_f$ and ó' are the shear strength and normal effective stress respectively on a failure surface in the material, and c' and ö' are the effective cohesion and effective angle of shearing resistance of the particulate material. The above equation can also be expressed as:

$$_f = c' + (ó - u) \tan ö'$$

which demonstrates that as the pore pressure u increases, the available shearing resistance decreases, provided the total stress does not change.

The pore pressure is often expressed as a dimensionless ratio (r_u) defined as:

$$r_u = u / \; z$$

where is the bulk unit weight of the material (soil or tailings) and z is the depth of the considered position below fill or ground surface.

A granular soil in a dense state will generally exhibit a greater maximum or peak effective stress shear strength ($ö'_p$) than the same soil in a loose condition, although this effect is suppressed at large normal stresses. When the dense granular soil is strained beyond the peak strength, there will be a fall in strength to the constant volume or critical state strength ($ö'_{cv}$). This constant volume strength is similar to the maximum strength of the soil in a loose condition where little or no post-maximum fall in strength will occur. For a granular soil, $ö'_{cv}$ should be similar to the angle of repose. From a literature review, Bolton (1986) found that for sands $ö'_{cv}$ ranged from 30° to 37°.

In a truly undrained condition a saturated granular material with particles in the sand and silt grain sizes i.e. material typical of tailings, behaves as a ö = 0 material.

This was demonstrated by Bishop and Eldin (1950) and Penman (1953). When shearing strains are applied such material can dilate or contract, depending on its density. This means that as shear strains occur the undrained strength of the saturated material can be respectively higher or much lower than its drained shear strength. With contractive material even a small shock can trigger flow liquefaction: the shearing strains imposed on a saturated tailings impoundment caused by deformations of the retaining dam can readily result in a flow slide composed of liquified tailings. This material has the fluidity of water but is very much heavier making its destructive capacity large.

Very loose, normally consolidated saturated material as are tailings in an impoundment, exhibit a peak strength higher than the residual strength at greater strains, when tested in apparatus using strain control. This effect is shown more vividly in stress controlled tests, i.e. tests in which the shearing force is applied by weights: an example given by Castro (1969) is shown by Fig.17. The tests were made on a fine uniform sand with a D_{10} size of 0.1 mm at a relative density of 29% using a confining pressure of 400 kN/m^2. Load was applied in small increments and peak deviator stress was reached in 14 minutes at a strain of 1%, during which time the pore pressure increased to half the confining pressure. But once the peak strength had been reached the strain increased to 19% in 0.17 seconds. The pore pressure climbed to almost the value of the confining pressure and as a consequence the strength fell to almost nothing. This is the mechanism of a flow slide.

Bishop (1972) described tests simulating the conditions in a tailings impoundment when yield of the retaining dam reduces ó$_3$ while ó$_1$ remains constant. Although the average effective principal stress decreased, so did the volume and he pointed out that this behaviour gave a warning of the probability of the flow slide phenomena.

Blight (1997a) described the failures of five tailings dams in southern Africa, Bafokeng, Arcturus, Saaiplaas, Merriespruit, and Simmergo. He shows that the occurrence of a mudflow is closely associated with the condition of the ground on to which the escaping tailings move. If the ground surface is dry, it is likely that the tailings will not move far whereas if it is wet, a flowslide is much more likely to ensue.

<u>Examples</u>. These are numerous and result from failure of the retaining tailings dam that may be caused by inadequate shear strength or the additional loading created by earthquake shock. They include Bafokeng [Incident No.7]; Barahona [Incident No.9]; Bilbao [Incident No.15]; the El Cobre dams [Incidents Nos.43 & 45]; Kimberley [Incident No.66]; Mochikoshi [Incidents No 84 & 85]; Stava [Incident No.117]; Merrespruit [Incident No.202]; Iwiny [Incident No.73]; Fernandinho [Incident No.213].

6.2.8 Earthquakes

Dams built by the upstream method are particularly susceptible to damage by earthquake shaking. There is a general suggestion that this method of construction should not be used in areas where there is risk of earthquake. Dams built by the downstream method, in cases where there are sufficient volumes of the coarser fraction in the tailings, or those built from borrowed clayey fill as water retaining dams, are much less prone to damage by earthquake shaking. Seed (1979) said that it was noteworthy that no failures have been reported in dams built of clayey soils even under the strongest earthquake shaking conditions imaginable, and that all cases of slope failure reported have involved sandy soils. Advice on earthquake resistant design of tailings dams is given by ICOLD Bulletin No 98.

Example. Incident No.9. Barahona, Chile, 1928. 61 m high dam built by the upstream method with downstream slopes of 1 on 1. The dam failed during the Talca earthquake of magnitude 8.3, producing a breach 460 m wide. The released tailings flowed down the valley, killing 54 people.

Example. Incident No.12. Bellavista, Chile, 1965. A 20 m high dam built by the upstream method with downstream slope of 1 on 1.4, failed during the La Liqua earthquake of 7.7 magnitude. At the time only 8 m separated the edge of the pond water from the dam crest.

Example. Incident No.57. Hokkaido, Japan, 1968. A 12 m high dam built by the upstream method with a 1 on 3 downstream slope, failed during the Tokachi-Oki earthquake of 7.8 magnitude. 90 000 m^3 tailings flowed from the breach, crossing and blocking a river near the downstream toe.

Example. Incident No.84. Mochikoshi No.1, Japan, 1978. A 28 m high dam built by the upstream method with a downstream slope of 1 on 3, failed during the Izu-Oshima-Kinkai earthquake of 7.0 magnitude. 8 000 m^3 of tailings were released and reached and flowed down a river valley for 7 to 8 km, causing one fatality.

Preventative measures (as mentioned above) include dam construction with cohesive materials, provision for water drainage in the dam, and proper water management.

6.2.9 Ice and faulty water balance

Sufficient freeboard under all circumstances and all along a tailings dam is one of the most important prerequisites for safety. Tailings dams are extremely sensitive to high levels of the phreatic surface that can cause small slips leading to overtopping. Tailings dams built by the upstream method require a dry beach of coarse tailings solids above the pond water level upstream of the dam crest. The beach must never be flooded with water otherwise dangerous seepage conditions can develop. This calls for a sound water balance of the tailings disposal system taking into account all the components of inflow under the varying conditions of operation and the climatic conditions in their seasonal variations. Extreme situations with low frequency of re-occurrence need also to be checked.

In parts of the world subjected to long periods of frost, failures have occurred as an indirect result of freezing.

Example. Incident No.66. Kimberley iron mine, British Columbia, 1948. Slope failure occurred during a period of high snowmelt and spring runoff that raised the phreatic surface while the surface of the slope was frozen. A large tailings flowslide developed and frozen blocks of material were seen in the flowing mass.

Example. Details are given by Casagrande and McIver (1971) of extensive sloughing of downstream slope attributed to freezing and growth of ice lenses, accompanied by the development of piping during the first few days of a spring thaw.

Example. Incident No.221. Baia Mare, Romania. A new impoundment about 1 km wide and 1.5 km long was begun on relatively flat land that rose 7 m uniformly over its length. An outer perimeter bank 2 m high was built from old tailings taken from a disused deposit. Inside this perimeter, a starter dam was built from the same material, in general about 1 m high, but higher on the low side of the impoundment. When tailings came from the processing plant it was put through cyclones on the crest to build by the downstream method to the perimeter bund, when further construction would use the upstream method.

Three old disused impoundments were to be re-worked by cutting into them with water jets, to extract remaining gold and silver. The resultant slurry was pumped to a new processing plant, and the processed tailings, containing high concentrations of cyanide (total approx. 400 mg/l, free about 200 mg/l), pumped a further 6 ½ km tothe new impoundment. Decanted water was pumped back to the old impoundments to provide the water jets, with the aim of forming a closed system with no discharge into the environment.

During the first summer, construction of the dam along the low side of the impoundment and partly up the long sides, progressed well and an ample freeboard was maintained. Evaporation from the disused and new impoundments exceeded precipitation, but this situation changed when winter set in and the volume of circulating water increased. When the temperature fell below freezing, it was no longer possible to operate the cyclones and the whole tailings was discharged into the impoundment, which became covered by ice, in turn covered by the precipitation in the form of snow.

On the last day of January 2000, a change of wind direction brought heavy rain and a sudden increase of temperature to above freezing. Water liberated from the ice and snow, supplemented by the rainfall raised the water level in the impoundment until it overflowed, part way up one of the long sides where dam construction was quite low, cutting a breach 20 to 25 m wide permitting a spill of about 100,000 m^3 of heavily contaminated water.

Decant towers. In regions subject to long periods of frost, unequal ice thrust against a decant tower can generate excessive movements in the tower stem or at the stem to base contact. Lowering the water level below the ice can generate large moments in the tower section and wind plus wave forces across an irregular ice flow can generate torsion forces sufficient to shear off the tower stem. Large releases of water caused by tower failure under these conditions have on occasion transported significant volumes of tailings away from the impoundment. Many of these difficulties can be overcome by coating the tower with rigid closed-cell foam panels fixed around the exterior of the tower to prevent the formation of bond between the ice and the tower.

6.2.10 Impoundments not retained by a dam

a). Tailings discharged into a worked out pit or other depression can be expected to have no greater bulk density than those put into a traditional impoundment: if anything slightly less because there may be no special provision for drainage for the pore water in the tailings. Because of this they are just as susceptible to liquefaction and, should the opportunity arise, will rapidly escape through any opening. Even water, when inadvertently stored then allowed to escape suddenly can cause trouble.

Example. A quarry in Scotland drained through a tunnel into a catchment area above an earthfill dam. During a storm in 1925 the tunnel choked with debris and the quarry filled with water. The increasing pressure of water eventually forced through the debris blockage releasing a large volume of water into the water reservoir. This flood overtopped the dam, causing a breach which released, in addition to the contents of the quarry, the contents of the reservoir, that flowed into the town of Skelmorely killing 5 people. This accident in 1925 contributed to the formation of the British Reservoirs (Safety Provisions) Act of 1930.

Example. Mine tailings from the San Antonio ore deposit have, since 1993, been put into an old open cut mine site (Tapian ore reserve) known as the Tapian Pit. A drainage tunnel leading from this pit was sealed with a concrete plug prior to placing the tailings, so as to make the old pit into a watertight basin. The mine tailings were a fine material, about 75% by weight of less than 63 micron size and 95% less than 200 microns. The tailings were deposited at a consistency of 70/30% solids/liquid, and about 20 million cubic metres had been placed by early 1996.

On 24th March 1996, large quantities of tailings began escaping from the drainage tunnel into the Makulapnit and Boac Rivers. During the following 4 to 5 days, approximately 2.4 million tons of tailings were released. Subsequently the flow of tailings from the tunnel was reduced, but during the following 6 weeks, the total weight lost was approximately 3 million tons. The Makulapnit and Boac Rivers below the failed drainage tunnel were reported to have been severely affected, with the tailings reaching as far as the coastal area adjacent to the mouth of the Boac River. As well as the rivers being degraded as a result of smothering by mine tailings, the area covered by a thick layer of tailings is estimated to extend approximately 3 km along the coast and at least ½ km from the shore line.

A United Nations Expert Assessment Mission who investigated this event, as one of their conclusions, pointed out that the mine owners had an inadequate environmental management structure. No apparent risk assessment of the Tapian tailings pit was carried out and consequently, no effective contingency plan, seepage and/or downstream monitoring programmes were in place at the time when the tunnel plug failed. Both these factors contributed significantly to the Marinduque environmental disaster and the failure of the mine owners to rapidly and effectively stop the flow of the mine tailings into the rivers. Clearly the original design of the concrete plug had failed to adequately consider the very high pressures that would be developed as the level of the tailings in the pit rose. It had not considered the seepage forces that would develop in the ground surrounding the plug, nor the strength and deformation properties of that ground. Had the matter been given consideration prior to placing the plug, a site investigation made from the surface or from within the tunnel itself would have enabled a satisfactory design to have been evolved for the construction of the plug.

b). Thickened Tailings Disposal (TTD) System. The aim of the TTD system is to eliminate the possibility of dam failures and prevent the pollution attributed to conventional impoundments. It also aims to reduce the cost of reclaiming conventional impoundments after closure. These aims are achieved by depositing thickened tailings from a topographical high, or from central ramps or towers, so as to form a self supporting mound or ridge of the stored tailings. This minimises the requirement for confining dams, eliminates the need for a settling pond, and shapes the discharged tailings into a self-draining, easily reclaimable shape, having slopes of 2 to 6 percent.

The removal of much of the process water from the tailings is achieved by passing the tailings through high compression thickeners. $^2/_3$ to $^4/_5$ of the process water is decanted from the thickeners as clear overflow and is recycled back into the process. The thickened tailings do not segregate, so that all the particle sizes stay together forming a homogeneous material with a high capillary suction: when placed layer by layer, it dries to near its shrinkage limit and becomes dilative under earthquake strains, thus preventing liquefaction. It tends to remain saturated almost to the surface, thus preventing the development of acid drainage and so becomes suitable for eventual topsoil and vegetation. Detailed description of the system has been given by Robinsky (1999).

Example. The Falconbridge Ltd 12,000 ton/day copper/zinc Kidd Creek mine in Ontario, Canada, was converted in 1972 to use the TTD system to avoid having to build traditional tailings dams on very soft and sensitive clay foundations. The disposal area of 1420 ha, with an average diameter of 1.5 km is on a topographical high surrounded on three sides by a river. Initially discharge was from a series of spigots from a central ramp, but later a single point discharge was placed at the north end of the area with the intention of moving it progressively to the south to create a ridge so as to allow of progressive reclamation from the north end while deposition continues. The slopes formed are between 2.5 and 3 percent and the only retaining dam required is 10 m high across a small valley. This Kidd Creek operation was the first TTD project and while considered experimental at first, the system has progressively evolved to form a successful method of tailings deposition, now operating in its 24th year.

Example. The open pit nickel sulphide mine at the Mount Keith operation in Western Australia produces 11.5 x 10^6 tonnes of tailings a year. The area is relatively flat and semi-arid, with an average annual pan evaporation of 3800 mm, while the rainfall is only 220 mm. As a cheaper and potentially safer method of tailings storage than the traditional paddock method, mine management chose the thickened tailings disposal system, originally proposed by Professor Robinsky in 1968. Following an intensive field and laboratory investigation, they designed the storage facility to be able to accommodate 250 x 10^6 tonnes of tailings at a rate of up to 15 x 10^6 tonnes/year. The storage area is 1700 ha, with an average diameter of 4.6 km on land with a very slight fall of only 12 to 14 m from west to east. A perimeter bund 14 km long surrounds the site to prevent the spread of any materials that might be carried by rainfall run-off. There is a central riser pipe surrounded by 8 other risers 35 to 45 m high and a fully automated three-train, two stage pumping station able to deliver the thickened tailings to any riser at a rate of 3 x 10^3 m^3 per hour. Underdrainage was installed in the ground surrounding each riser, plus open drainage to collect decanted water. There are back-up systems including spare risers, bypass line, dump valves etc., and the facility is monitored remotely continuously by telemetry. A computer programme gives comparison between predicted and actual mound development using aerial photography. The facility was commissioned in December 1996 and has been operating continuously since. This information was supplied by the mine owners, WMC Resources Limited, Perth.

Example. The Thickened Tailings Disposal (TTD) System has been used at the Peak Gold Mine at Cobar, New South Wales. This underground mine, established in 1992, produces gold together with copper, lead, zinc, but mainly 0.3×10^6 tonnes of fine tailings a year. The absence of any significant amount of waste rock from the underground mine made the idea of an impoundment requiring no large dams particularly attractive, and the central discharge avoids the considerable work of having to move the discharge points as required during the construction of the other types of tailings dams. The general arrangement for the storage is shown by Fig.18.

6.3 SAFETY MANAGEMENT

The process of implementing decisions associated with the assessment, toleration and reduction of risks can be termed safety management. Owners and operators have specific responsibilities for their dams and the need to formulate safety management procedures. Technical and managerial approaches should be utilised to improve safety and reduce risk. Continuing day to day safety of the dam-impoundment system will depend on some form of observational method involving surveillance and monitoring, using suitable instrumentation to reveal internal conditions.

An increase in safety is provided at an increase in cost and a balance has to be found between dam safety and economy. Cost effective risk reduction involves defining the acceptable level of risk, reducing the risk of the dam breaching to an acceptable value and implementing emergency management procedures to endeavour to ensure that there is no loss of life should the dam breach. The approaches to risk reduction for the dam-impoundment system can include structural improvements to the dam and ancillary works, improved surveillance, monitoring and maintenance. The approaches to risk reduction for the downstream valley system include the preparation of inundation maps, estimation of the time of arrival of flood wave at different locations and the duration of inundation and the implementation and maintenance of emergency warning procedures and systems. Unlike water, liquefied tailings do not drain away and the deposits left on roadways can seriously hamper emergency services. The weight of tailings is such that it can cause great damage, much greater than that of an equivalent flood of water, demolishing buildings rather than just flowing through them. The difficulty in knowing when to give warning makes the operation of emergency procedures very difficult.

7. CONCLUSIONS AND RECOMMENDATIONS

a) Introduction. Failures of tailings dams continue to occur despite the available improved technology for the design, construction and operation. The consequences of these failures have been heavy economic losses, environmental degradation and, in many cases, human loss.

b) Main reasons for failure. Causes in many cases could be attributed to lack of attention to detail. The slow construction of tailings dams can span many staff changes, and sometimes changes of ownership. Original design heights are often exceeded and the properties of the tailings can change. Lack of water balance can lead to "overtopping": so called because that is observed, but may be due to rising phreatic levels causing local failures that produce crest settlements.

   Causes include problems of foundations with insufficient investigations, inadequate or failed decants, slope instability, erosion control, structural inadequacies and additional loading of closed impoundments. Most situations have already been solved by engineering technology, indicating that a more systematic application of the specialized knowledge is required.

c) Conclusions. The ICOLD Tailings Dams Committee conclude that the adequate application of available technology of engineering to the design, construction, operation and closure can provide the required cost effective risk reduction.

d) Recommendations. Owners and operators have specific responsibilities to apply safety management procedures to achieve safety improvement and risk reduction. The design, construction, operation and closure of dams and impoundments with risk potential to downstream shall include the following requirements:

   1) Detailed site investigation by experienced geologists and geotechnical engineers to determine possible potential for failure, with in situ and laboratory testing to determine the properties of the foundation materials.

   2) Application of state of the art procedures for design.

   3) Expert construction supervision and inspection.

   4) Laboratory testing for "as built" conditions.

   5) Routine monitoring.

   6) Safety evaluation for observed conditions including "as built" geometry, materials and shearing resistance. Observations and effects of piezometric conditions.

7) Dam break studies.

8) Contingency plans.

9) Periodic safety audits.

Regulatory Authorities should be more concerned about the safety of tailings dams that come under their jurisdiction and should require periodic reviews carried out by appointed specialists. In some countries approval had to be obtained for specific stages of construction, causing the stability, general condition and safety to be automatically checked from time to time.

8. LESSONS LEARNED : IMPLICATIONS FOR POLICY – A UNEP VIEW

Improvements are made by learning the lessons of experience and using them to avoid repeating the mistakes of the past.

This Bulletin is intended to be of help to all those connected in any way with tailings storage facilities including owners, managers, contractors, engineers, personnel responsible for day to day construction, and government officials concerned with regulation. In highlighting accidents, the aim is to learn from them, not to condemn. UNEP commends ICOLD for its thorough work in compiling and analysing this extensive data base of accidents, incidents and remedial action.

The Bulletin clearly shows that many of the tailings dam accidents which have occurred have been preventable. Also that the factors which have contributed to failures have often been common to different sites and over time. It makes the point that the technical knowledge exists to allow tailings dams to be built and operated at low risk, but that accidents occur frequently because of lapses in the consistent application of expertise over the full life of a facility and because of lack of attention to detail.

This is an unsatisfactory situation for an industry under public scrutiny, whose products are an essential part of daily life and which contributes to many economies around the world. Major accidents naturally destroy community and political confidence. By highlighting the continuing frequency with which they are occurring and the severe consequences of many of the cases, this Bulletin provides *prima facie* evidence that commensurate attention is not yet being paid by all concerned to safe tailings management. This is surprising given the high risk which tailings dams demonstrably pose to life, the environment, property and the profitability of companies.

UNEP has seen awareness of the problem escalate dramatically in the last 3 or 4 years within leading companies, industry bodies, governments and community groups. The World Wide Fund for Nature, for instance, commenced a major campaign in 1998 to focus attention on mining waste lagoons in Europe. The International Council on Metals and the Environment (ICME) has partnered with UNEP in mounting two major tailings workshops, in Sweden in 1997 and in Buenos Aires in 1998. In 2000, ICME commissioned Golder and Associates to review the adequacy of existing tailings management guidelines to see if there is a need to consolidate and strengthen codes and guidelines for international use. (The conclusion was that it would be beneficial). In 2000, the Government of Australia and UNEP co-hosted the first intergovernmental Workshop on Environmental Regulation for Accident Prevention in Mining: Tailings and Chemicals Management. UNEP is working with interested governments to establish an ongoing Regulators Forum – with the safety and environmental performance of tailings facilities and approaches to their regulation as a continuing theme.

All of this work will undoubtedly bear fruit over time since it involves a discussion of solutions at the same time as driving home the seriousness of the problem.

Market forces are also escalating the issue, with financiers and insurers now more concerned with the risks and financial consequences of tailings accidents. This is not surprising since in some of the recent cases companies have gone into receivership as a direct result of the costs of an accident, including interrupted production, clean-up costs, reengineering and reconstruction costs and legal proceedings. Criteria for lending will increasingly include requirements for strong safety and environmental management systems and assurance processes, coupled with technical competence.

In addition to the financial imperative, companies also have other drivers, including shareholder and employee concern and reputation in the community at large.

In recent years many companies have taken new approaches to ensure diligence and quality control in the management of tailings. For example, major mining companies have established expert teams, either from within the company or involving external experts, to undertake regular audits of tailings facilities and tailings management systems at their operations. These audits have covered closed facilities as well as operating facilities, since, as this Bulletin also shows, failures occur in both. Safety reports to management, independent of the site operator, have uncovered some emerging problems resulting in remedial action being taken.

At the same time, the mining industry operates with a continual imperative to cut costs due to the relentless reduction in real prices for minerals which has been experienced over the long term, plus the low margins and low return on capital which are the norm. The result has been a shedding of manpower to the point where companies may no longer have sufficient expertise in the range of engineering and operational skills which apply to the management of tailings. Continuity of management and loss of history of operations are related issues.

Greater recognition of the importance of the safe management of tailings and the attention being paid to it is encouraging. Yet both UNEP and ICOLD believe that still more needs to be done, and that arguably the most important area for action may lie at this time with the regulators.

Stuart Cale, a member of the British Sub-Committee of ICOLD and one of the authors of this Bulletin, wrote in an article published in UNEP's *Mining and sustainable development II* special 2000 issue of **industry and environment**,

> "Experience of a wide range of systems for inspection and auditing of tailings management facilities around the world indicates that where policies for regular expert auditing by competent persons have been enforced, failures have been reduced and incidences of untoward discharges have been significantly reduced.
>
> …"The major driving force in reducing the number of tailings dam incidents is, firstly, the adoption of regulations that require regular independent auditing and certification of a facility and, secondly, the recognition of the need for a competent person to undertake the audits, and that the competent person must have experience of tailings management facilities, rather than having general

competence in water dams or civil engineering."

In a Bulletin about Lessons Learned it is appropriate to consider not only the physical lessons but also the policy lessons, whether for companies or for governments. Sound policy can undoubtedly play a role in accident prevention. UNEP is not simply advocating the adoption of more or tougher regulation but, rather, the review of the structure of regulation to assess its effectiveness specifically against the particular goal of ensuring the safe management of tailings dams. In some cases, effective implementation of existing regulation may be the more important factor; in others it may be the further training and skills of regulators to exercise their oversight duties effectively. The result needs to be that governments play their part as one of the agents contributing to the goal of accident prevention.

In putting the spotlight onto the role of regulators, UNEP does not want in any way to downplay the role of the owner and operator. The unequivocal statement made in this Bulletin that "the responsibility for the safety of tailings dams must lie with management" is universally applicable.

The Workshop on Environmental Regulation for Accident Prevention in Mining: Tailings and Chemicals Management, which was co-hosted by the Government of Australia and UNEP in Perth in October 2000, brought together regulators and experts from 20 countries to share latest thinking on effective approaches to regulation of the high hazard aspects of mining. That meeting heard from governments which had experienced major tailings accidents about what they see as important to prevent a recurrence. Despite a diversity of situations in different countries – climates, nature of ore-bodies, size of mines and numbers of mines to be regulated, differing expertise either in the companies or in the government, and so on - common elements emerged in the discussion of what is universally required to make a difference.

The discussion was much more about regulatory tools to ensure diligence and to strengthen quality assurance, than it was about specific standards or technical requirements. There was a recognition that site- and ore specific operational differences must be accommodated and that no two tailings dams are the same. Regulators were generally seeking to strengthen their systems of review, reporting, inspection, oversight and sanction, rather than to prescribe operational parameters for engineers and managers.

The Workshop highlighted a set of things to which regulators need to pay attention in order to reduce the risks and the consequences of accidents. Foremost amongst these were:

Governments should evaluate the design of tailings systems proposed by operators and inspect those systems. Some specify certain safety factors or weather return periods to be incorporated in design. Independent certification of design was seen as a fundamental requirement, with regulators using expert advice at arm's length from the company. Governments have to address not only sound design but also correct operation, with all aspects of the life of tailings dams being important. Repeated inspection and certification of stability may be warranted and governments should consider requiring independent inspections of the dam against design at adequate intervals, as a condition of approval.

Some governments already have a role in approving all phases – design, construction, certification, surveillance, closure, emergency planning. The post – closure phase is of particular importance to governments because the stability of closed tailings facilities must be maintained in perpetuity. Also, all aspects of tailings systems need to be covered, since accidents occur in tailings pipelines as well as in dams. Governments need to take a holistic approach to the regulation of tailings dams since a range of expertise and different agencies will be involved. Attention to coordination and integration is therefore important to ensure that no aspects are overlooked.

Also as a permit condition, continuous monitoring should be required, using instrumentation as appropriate, which gives meaningful information on the safety performance of the facility. Governments may require operating changes to reduce risk in the light of monitoring results and operational experience. In the long operating phase of tailings dams, conditions can change substantially and unforeseen circumstances arise which require a flexible response by both operator and regulator.

Regulators and companies need to focus on risk reduction and contingency planning as well as on design, operation and compliance. Regulators need to consider requirements for risk reduction to be cost-effective as well as to allow acceptable levels of risk. Governments should require emergency plans to be developed in high risk situations and include emergency procedures in site inspections. In the case of orphan sites, there needs to be a process of risk assessment and prioritisation leading to preventative remedial action at high risk/high consequence sites.

Governments need to be empowered to act to require corrective action in the case of a problem arising - before it becomes an emergency (if the company has not already done so). Regulators need adequate expertise and access to competent advice in taking these decisions. Requirements to report "near-misses" or critical events can assist governments to be proactive.

Regulators need to be trained and to gain on-ground experience in tailings dam matters in order to be able to interpret signs, reports and data and to take competent decisions. Experience is required to be able to visualise emerging problems and their consequences. Inspection and monitoring protocols should be developed by experienced regulators. Adequate resources need to be available for regulatory purposes and regulators also need to have both the power and the political support to take action or to apply sanctions when necessary.

More generally, it was agreed that regulators should encourage or find ways to reward companies adhering voluntarily to tailings and other codes and guidelines plus formal management systems. Also that regulation should be developed in an open and transparent manner, in consultation with communities, in order to meet concerns and to build support for projects based on an accurate understanding of their risks.

In some countries and in some cases many of these things are already the norm or are on the agenda of regulators. In other jurisdictions they are not. UNEP is of the view that this list is worth promulgating for further discussion and further elaboration as to how some of these things are actually being done or could be done by regulators.

One proposal which was raised but not fully explored concerned the possibility of requiring tailings facility operators to be certified for competency in different aspects of tailings management. UNEP believes this is worthy of further discussion involving the industry, governments and training institutions. The proposed Regulators Forum will provide an opportunity to take some of this thinking to the next level as well as to spread it more widely amongst countries.

UNEP values its association with ICOLD as the leading global authority on tailings dam technical management. We will continue to work with ICOLD and with other partners to ensure that sound engineering knowledge and techniques are applied in the field and that hard-won lessons are not learned only by the specialists. UNEP commends this Bulletin to all owners, operators and regulators.

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10. FIGURES

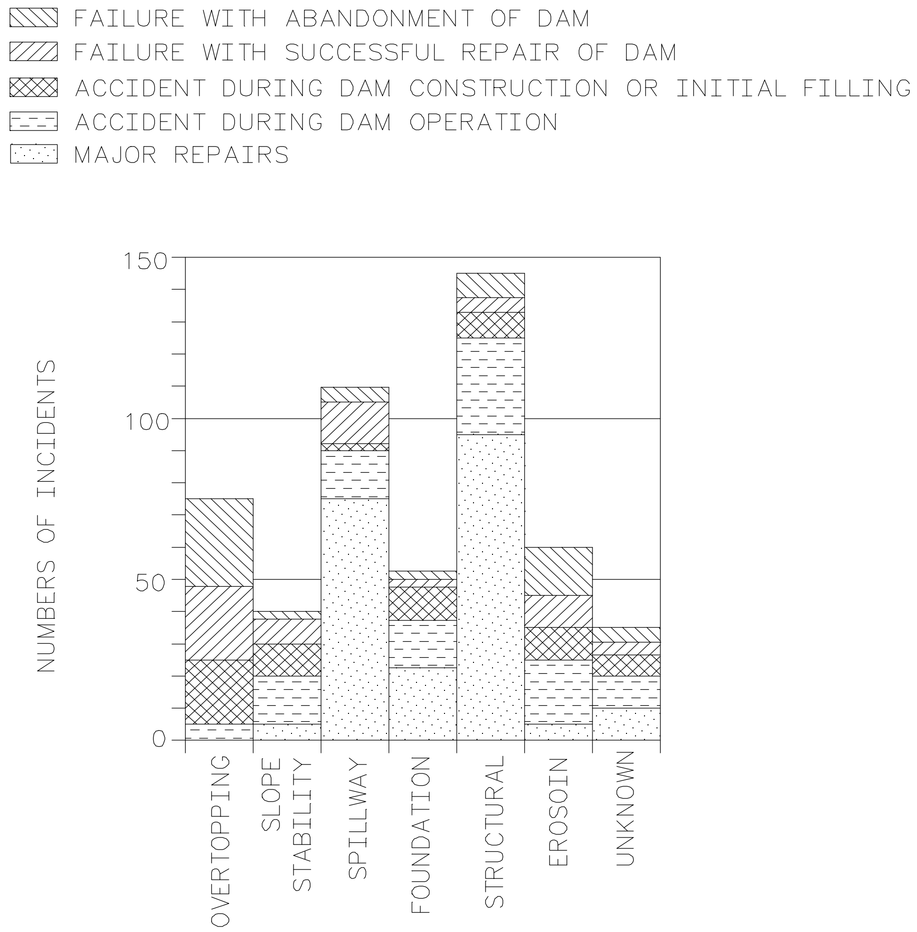


Figure 1. Water storage dam incident comparison.

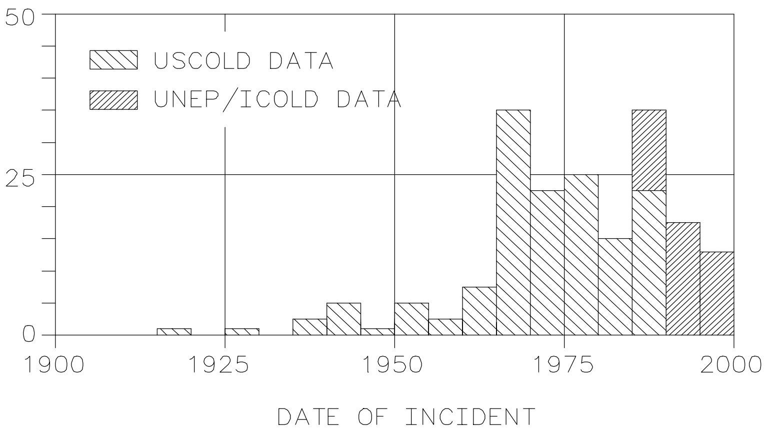


Figure 2. Tailings dam incident history summary: number of incidents per 5 year period.

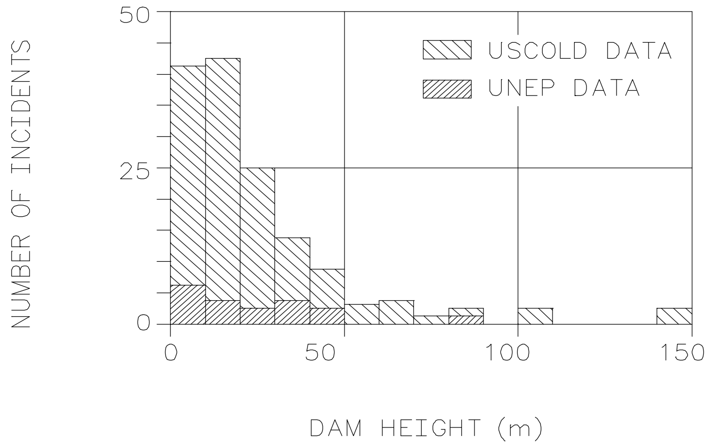


Figure 3. Tailings dam incident and height comparison.

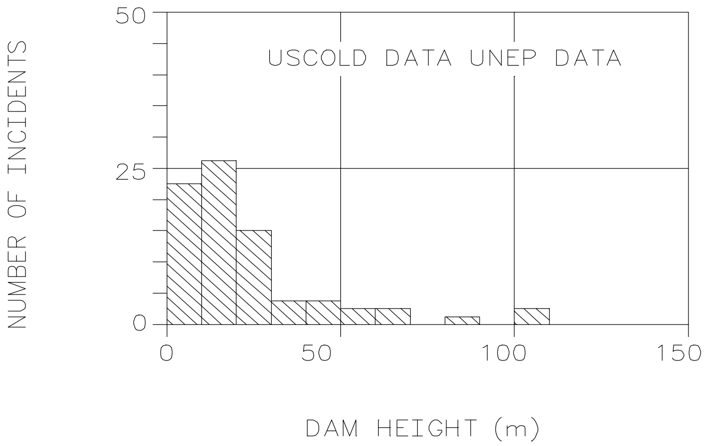
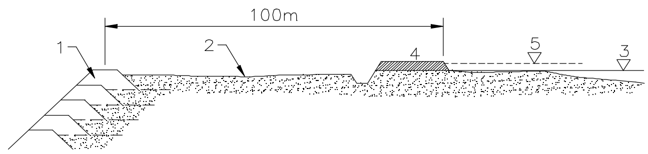


Figure 4. Tailings dam failure and height comparison.



1. DAM (HEIGHT APPROX. 70m)
2. BEACH
3. SUPERNATANT POOL
4. EXTRA DYKE
5. FREEBOARD LEVEL

SECTION (SCHEMATIC)

Figure 5. Extra dyke on a closed tailings impoundment.

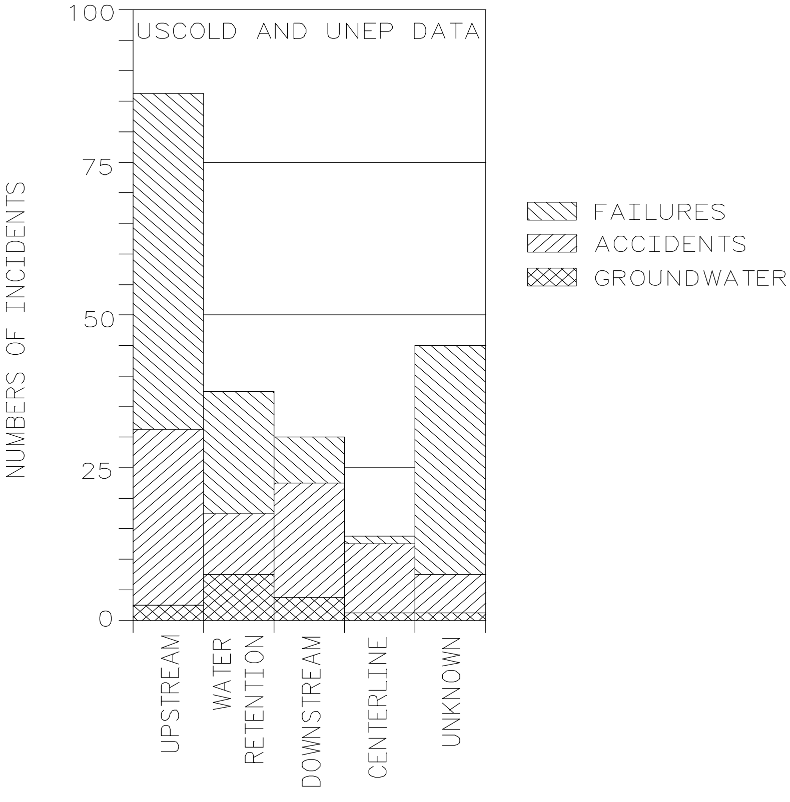


Figure 6. Tailings dam type comparison.

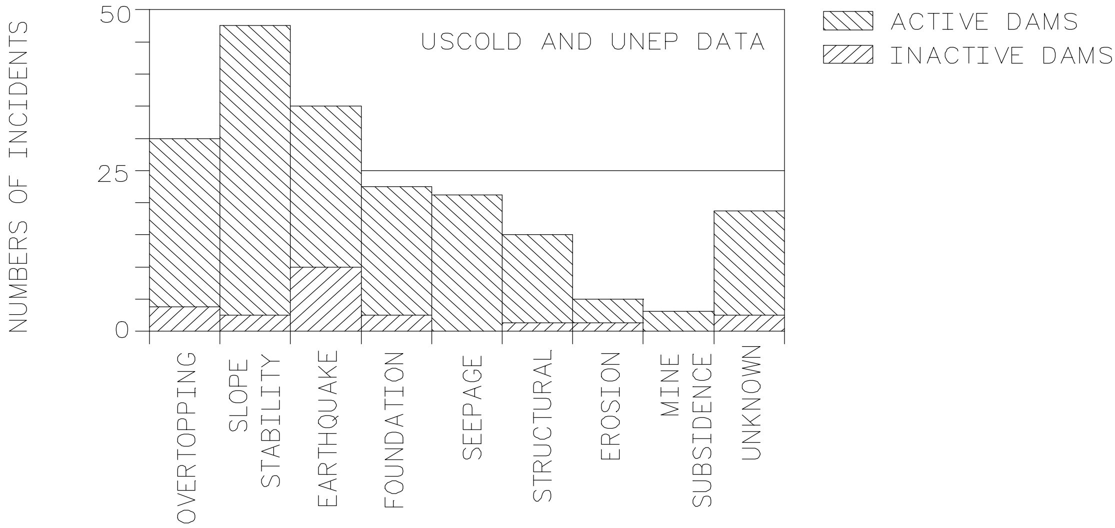


Figure 7. Tailings dam incident cause comparison with dam status.

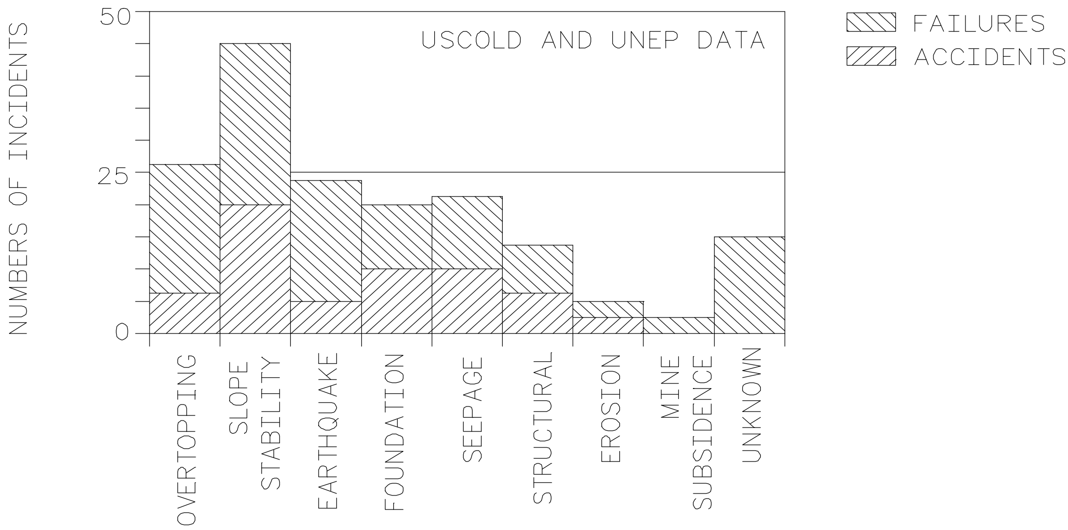


Figure 8. Tailings dam incident cause comparison with incident type for active dams.

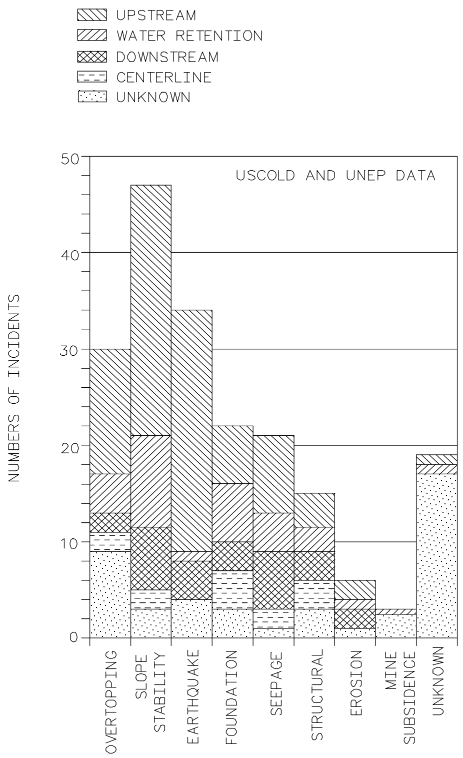


Figure 9. Tailings dam incident cause comparison with dam type.

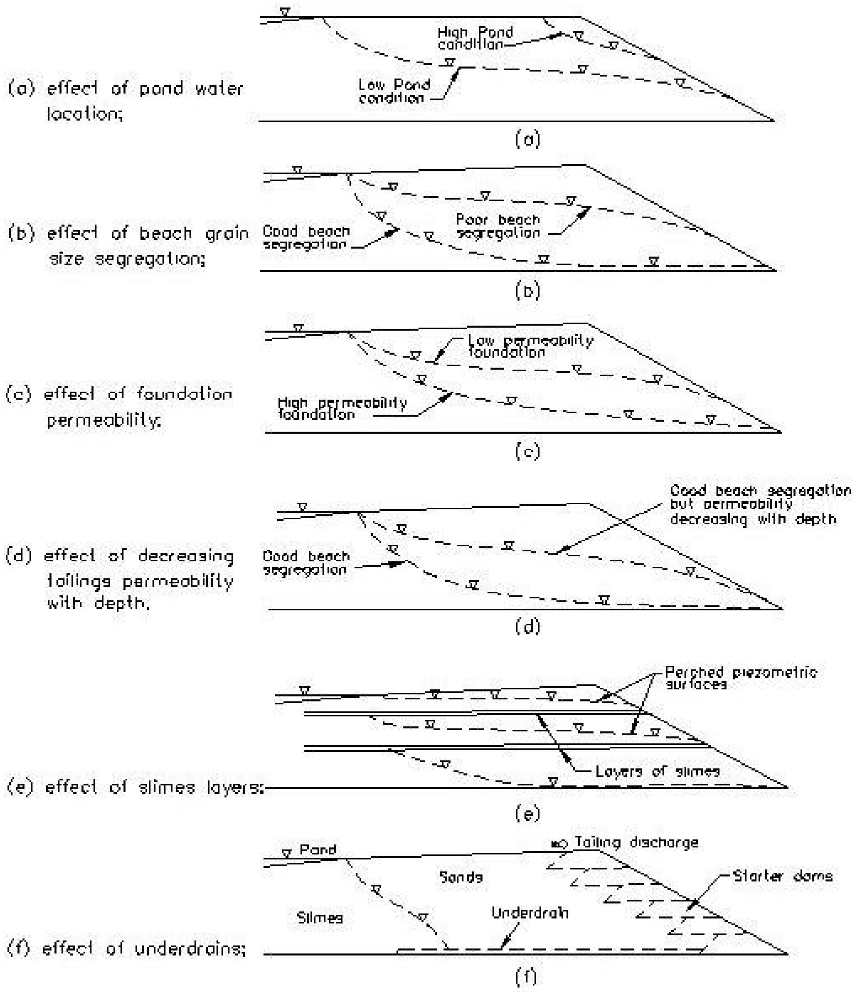


Figure 10. Factors influencing the position of the phreatic surface in dams built by the upstream method.
Shows effect of lack of drainage and layers of low permeability producing perched water surfaces. (After Fell et al 1992)

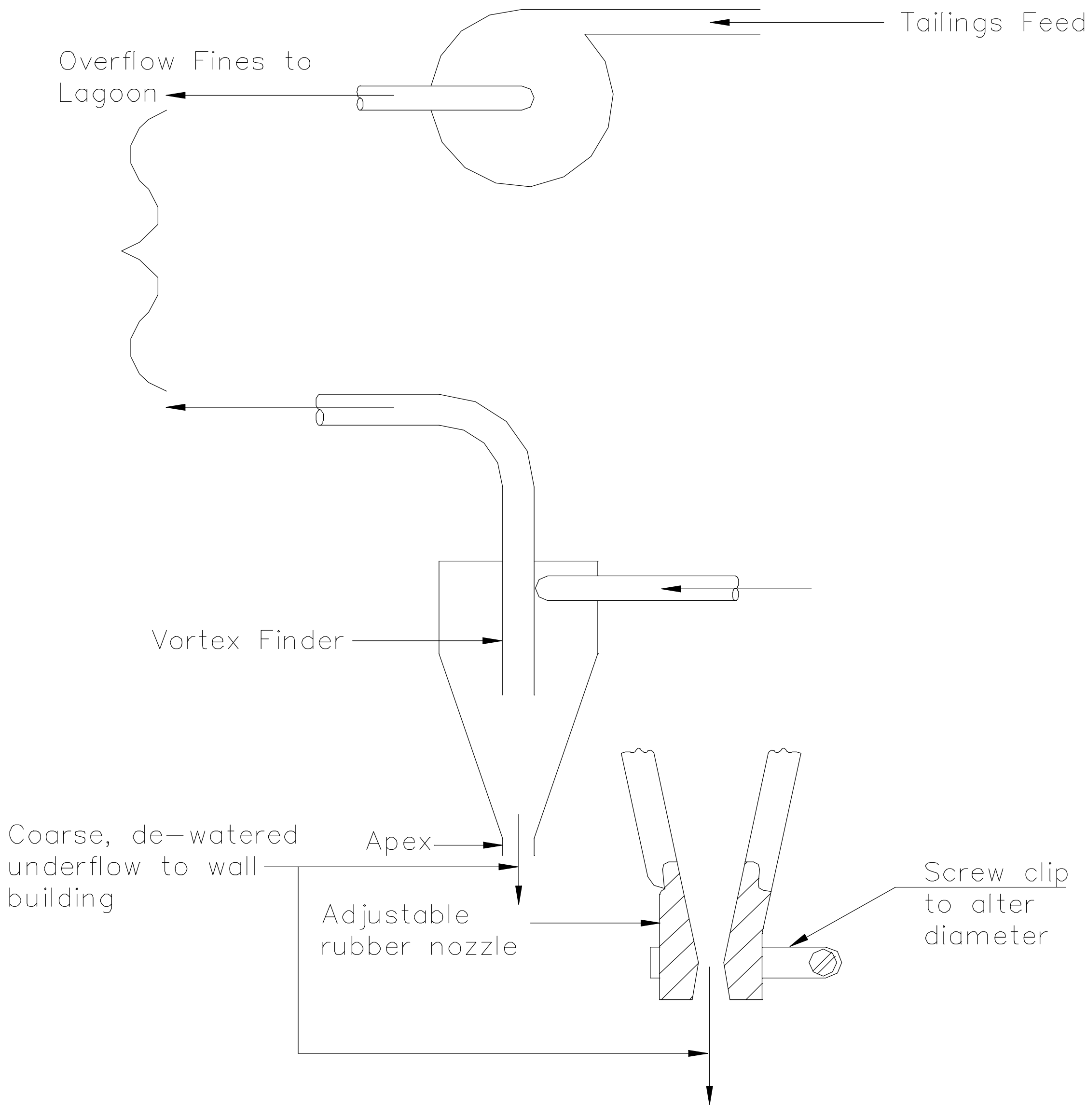
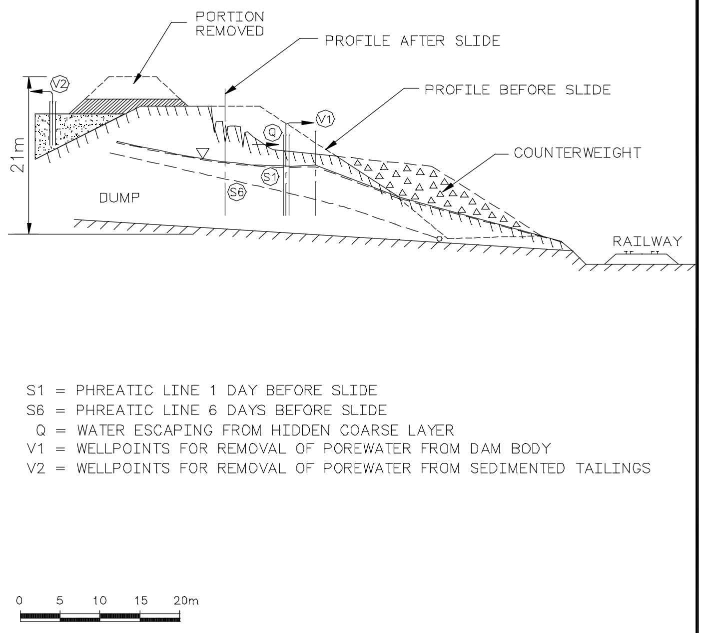


Figure11. Hydro-cyclone.



S1 = PHREATIC LINE 1 DAY BEFORE SLIDE
S6 = PHREATIC LINE 6 DAYS BEFORE SLIDE
Q = WATER ESCAPING FROM HIDDEN COARSE LAYER
V1 = WELLPOINTS FOR REMOVAL OF POREWATER FROM DAM BODY
V2 = WELLPOINTS FOR REMOVAL OF POREWATER FROM SEDIMENTED TAILINGS

Figure 12. Section of starter dam formed by an existing dump.

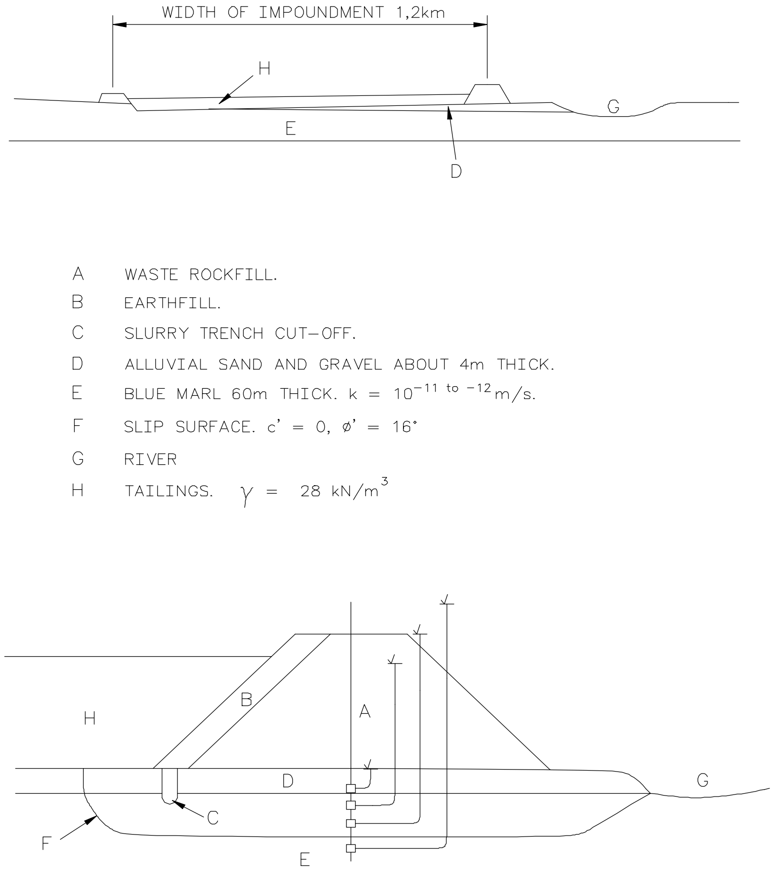


Figure 13. Section of Aznalcóllar Tailings Dam.

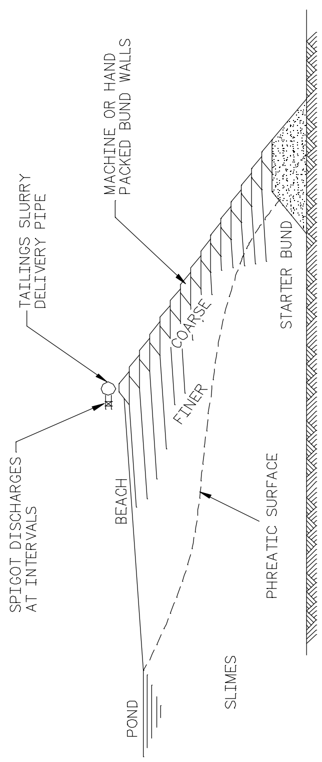


Figure 14. Upstream method of construction with spigots.

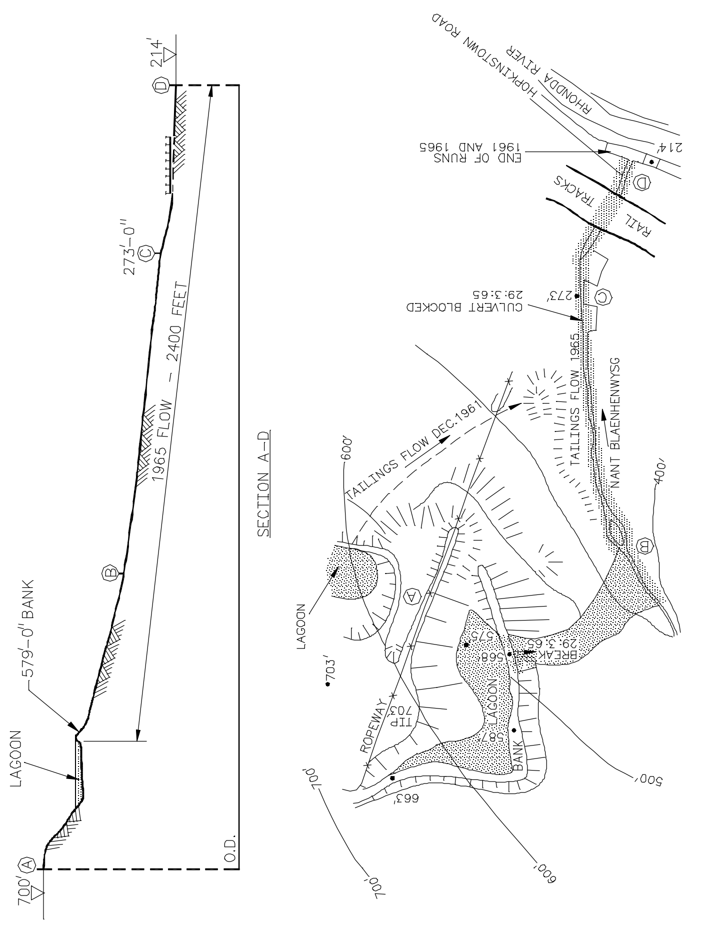


Figure 15. Tailings flows at Ty Mawr colliery, South Wales, in 1961 and 1965.

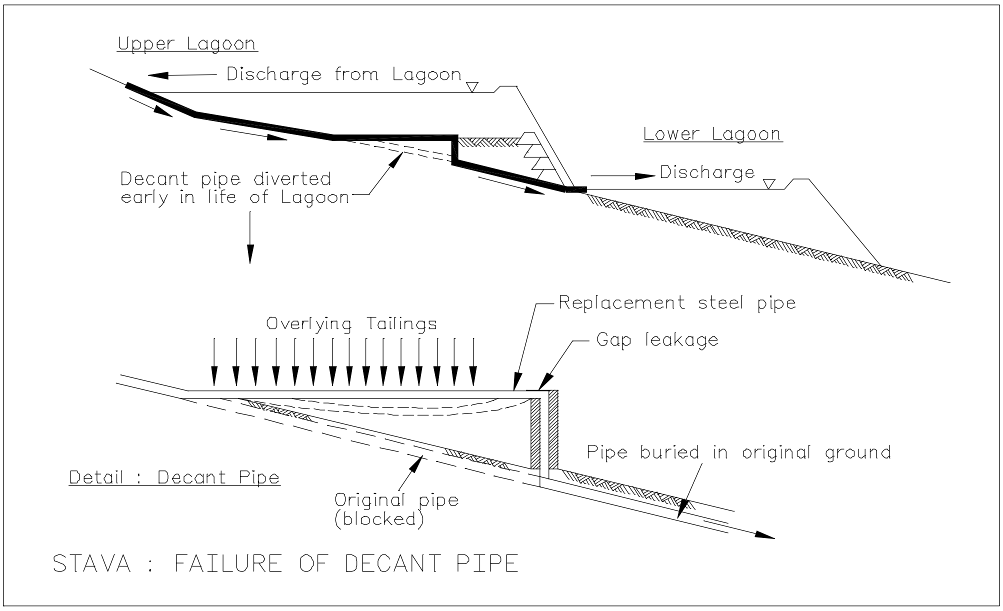


Figure 16. Failure of the decant pipe at Stava.

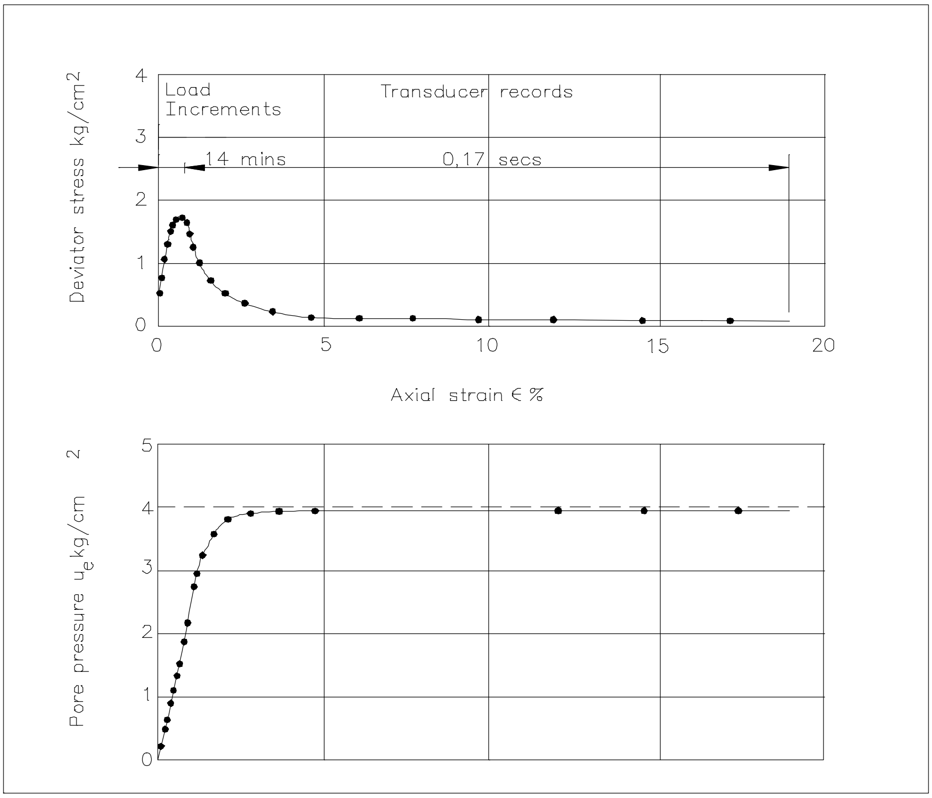


Figure 17. Stress–strain curve for stress controlled consolidated undrained test on saturated loose sand.

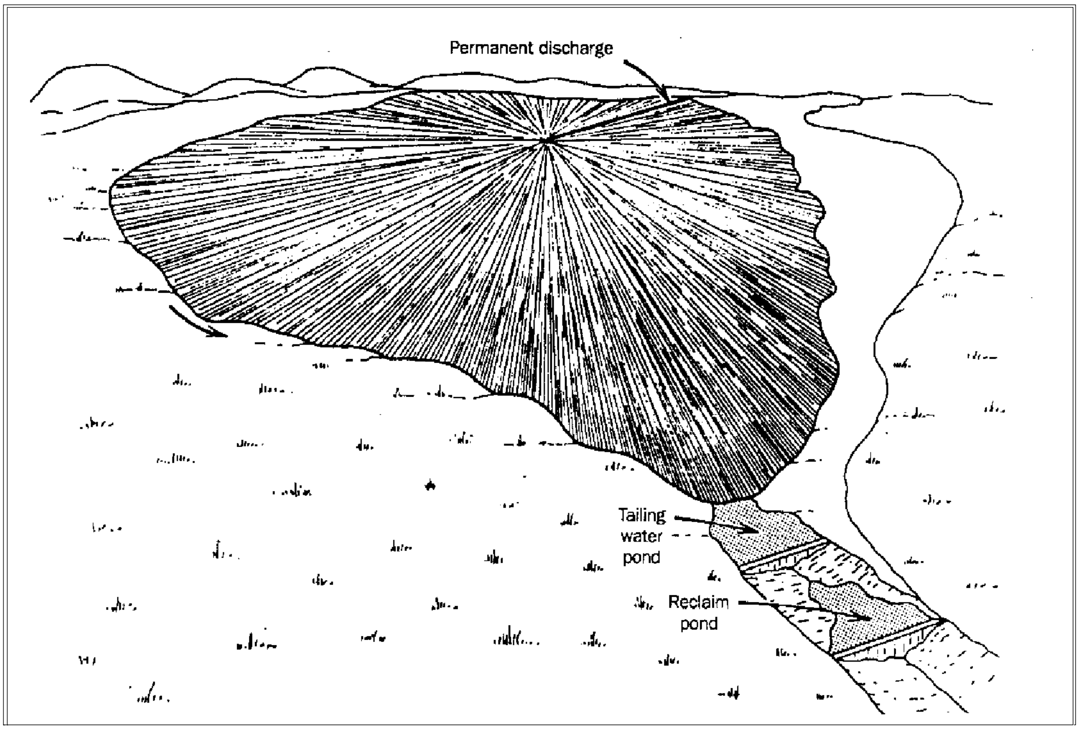


Figure 18. Tailings storage using the Thickened Central Discharge Method. (Reprinted from Robinski 1979)

APPENDIX

TAILINGS DAMS – INCIDENT CASE RECORDS

1. Introduction.
2. Abbreviations.
3. List of tailings dams for which incident cases were collected.
4. Brief descriptions of the 221 cases.

TAILINGS DAMS – INCIDENT CASE RECORDS

1. INTRODUCTION

This Appendix contains individual records for each incident included in the compilation. The abbreviations used are listed in Section 2. The tailings dams for which incident case histories are provided are listed in Section 3, with summary data. Section 4 provides more detailed data and sources for each case, with a brief description of the circumstances of the incident.

The case records were collected by:

Case Nos. 1 to 185:	USCOLD
Case Nos. 186 to 221:	UNEP and ICOLD

2. ABBREVIATIONS

Dam Type

US	upstream
DS	downstream
CL	centerline
WR	water retention
NR	not reported

Dam Fill Material

T	tailings
CST	cycloned sand tailings
MW	mine waste
E	earthfill
R	rockfill

Incident Type

1A	failure, active impoundment
1B	failure, inactive impoundment
2A	accident, active impoundment
2B	accident,inactive impoundment
3	groundwater

Incident Cause

SI	slope instability
SE	seepage
FN	foundation
OT	overtopping
ST	structural
EQ	earthquake
MS	mine subsidence
ER	erosion
U	unknown, or
NR	not reported

3. LIST OF TAILINGS DAMS FOR WHICH INCIDENT CASES WERE COLLECTED

Provided on the pages that follow. Dates are in the format month-day-year.

Note: Summary Page Numbers shown in the List refer to Section 4 “Brief descriptions of the 221 Incident Cases collected.

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
1	Agrico Chemical,Florida, USA	140	phosphate					1A-U	1968		
2	Alcoa, Texas, USA	142	bauxite			19	4,500,000	1A-U	10-01-1964		
3	American Cyanamid, Florida	141	gypsum					1A-U	1962		
4	American Cyanamid, Florida	141	phosphate					1A-U	1965		
5	Atlas Consolidated, Phillippines	140						1A-MS			
6	Avoca Mines, Ireland	127	copper	WR	T			1A-SI			
7	Bafokeng, South Africa	104	platinum	US	T	20	13,000,000	1A-SE	1974	3,000,000	45,000
8	Bancroft, Ontario, Canada	143	uranium					3-			
9	Barahona, Chile	110	copper	US	CST	61	20,000,000	1A-EQ	10-01-1928	2,800,000	
10	Berrien, France	104	kaolin	US	R	9		1A-SE	1974		
11	Battle Mt. Gold, Nevada, USA	122	gold	DS	E	8	1,540,000	2A-SI	1984		
12	Bellavista. Chile	109	copper	US	T	20	450,000	1A-EQ	03-28-1965	70,000	800
13	Big Four, Florida, USA	119	phosphate	CL	E	18		2A-ST	1986		
14	Big Four, Florida, USA	119	phosphate	CL	E			2A-FN	08-01-1989		
15	Bilbao, Spain	136			R			1A-SI		115,000	
16	Blackbird, Idaho, USA	119	cobalt	CL	MW	15	1,230,000	2B-ST			
17	Bonsal, North Carolina, USA	129	sand & gravel	WR	E	6	38,000	1A-OT	08-17-1985	11,000	800
18	Cadet No. 2, Montana, USA	118	barite	CL	E	21		2A-SI	09-01-1975		
19	Captains Flat Dam 2, Australia	118	copper	CL	E	22		2A-SI			
20	Captains Flat Dump 3, Australia	141	copper		T			1A-U	1942	40,000	

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
21	Captains Flat Dump 6A, Australia	102	copper	US	T			1A-SI	1939		
22	Carr Fork, Utah, USA	138	copper			10		1A-ST	02-01-1975		
23	Casapalca, Peru	107	Lead/zinc	US	T	107		1A-ST			
24	Casapalca	110	Lead/zinc	US	T	107		1A-EQ			
25	Castle Dome, Arizona, USA	104	copper	US	T			1A-SE		150,000	100
26	Cerro Blanco de Polpaico, Chile	133	limestone	WR	R	9		2A-EQ	03-28-1965		
27	Cerro Negro No. 1, Chile	116	copper	US	T	46		2B-EQ	03-28-1965		
28	Cerro Negro No. 2, Chile	116	copper	US	T	46		2B-EQ	03-28-1965		
29	Cerro Negro No. 3, Chile	109	copper	US	T	20	500,000	1A-EQ	03-28-1965	85,000	5,000
30	Cerro Negro No. 4, Chile	108	copper	US	CST	40	2,000,000	1A-EQ	03-03-1985	500,000	8,000
31	Cities Service, Florida, USA	131	phosphate	WR	E	15	12,340,000	1A-U	12-03-1971	9,000,000	120,000
32	Clayton Mine, Idaho, USA	119	silver	CL	T	24	215,000	2A-ST	02-06-1983		
33	Climax, Colorado, USA	140	uranium					1A-U	07-02-1967	12,000	
34	Cyprus Thompson Creek, Idaho, USA	118	molybdenum	CL	CST	146	27,000,000	2A-SE	1989		
35	Incident No. 1, Elliot Lake, Ontario, Canada	134	uranium	WR	E	9		3-	1979		
36	Dashihe. China	115		US		37		2A-EQ	1976		
37	Deneen Mica Yancey County, North Carolina, USA	101	mica	US	CST	18	300,000	1A-SI	06-01-1974	38,000	30
38	Derbyshire, United Kingdom	121	coal	DS		8		1B-FN	1966	30,000	100
39	Dixie Mine, Colorado, USA	142	gold					1B-U	04-01-1981		

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
40	Dresser No. 4, Montana, USA	117	barite	CL	E	15		1A-FN	08-15-1975		
41	Earth Resources, N M, USA	106	copper	US	T	21		1A-OT	1973		
42	El Cerrado, Chile	116	copper	US	T	25		2B-EQ	03-28-1965		
43	El Cobre New Dam, Chile	121	copper	DS	CST	19	350,000	1A-EQ	03-28-1965	350,000	12,000
44	El Cobre No. 4, Chile	125	copper	DS	CST	50		2A-EQ	03-03-1985		
45	El Cobre Old Dam, Chile	109	copper	US	T	35	4,250,000	1A-EQ	1965	1,900,000	12,000
46	El Cobre Small Dam, Chile	116	copper	US	T	26	985,000	2B-EQ	03-28-1965		
47	GCOS, Alberta, Canada	112	oil sands	US	T	61		2A-SI	1974		
48	Galena Mine, Idaho, USA	115	silver	US	E	14		2A-ER	1972		
49	Galena Mine, Idaho, USA	106	silver	US	MW	9		1A-OT	01-15-1974	3,800	610
50	Golden Gilpin Mine, Colorado, USA	143	gold			12		1B-U	11-01-1974		
51	Golden Sunlight, MT, USA	120	gold	CL	CST			3-	05-01-1983		
52	Granisle, BC, Canada	123	copper	DS	MW	24		2A-SE			
53	Grey Eagle, California, USA	126	gold	DS	E			3-	1983		
54	Grootvlei, South Africa	102	gold	US	T			1A-SI	1956		
55	Hierro Viejo, Chile	109	copper	US	T	5		1A-EQ	03-28-1965	800	1,000
56	Hirayama, Japan	126	gold	DS		9	87,000	2B-EQ	1978		
57	Hokkaido, Japan	108		US	T	12	300,000	1A-EQ	1968	90,000	150
58	Hollinger, Canada	104	gold	US	T	15		1A-FN	1944		
59	Homestake, N. Mexico, USA	107	uranium	US	T	21		1A-ST	02-01-1977	30,000	

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
60	IMC K-2, Saskatchewan, Canada	117	potash	US	T	30		3-	1968		
61	Irelyakh, USSR	133		WR	E	10		2A-ST			
62	Kennecott, Garfield, Utah, USA	102	copper	US	T			1A-SI	1941		
63	Kennecott, Utah, USA	105	copper	US	T			1A-FN	1942		
64	Kerr-McGee, Churchrock, New Mexico, USA	129	uranium	WR	E	9		1A-FN	04-01-1976		
65	Keystone Mine, Crested Butte Colorado, USA	142	molybdenum					1B-U	05-01-1975		
66	Kimberley, BC, Canada	102	iron	US	T			1A-SI	1948	1,100,000	
67	Kyanite Mining, Virginia, USA	143	kyanite			11	430,000	2A-OT	1980		
68	La Belle, Pennsylvania, USA	124	coal	DS	MW	79	1,230,000	2A-FN	07-17-1985		
69	La Patagua New Dam, Chile	109	copper	US	T	15		1A-EQ	03-28-1965	35,000	5,000
70	Los Maquis No. 1, Chile	116	copper	US	T	15		2B-EQ	03-28-1965		
71	Los Maquis No. 3, Chile	110	copper	US		15	43,000	1A-EQ	03-28-1965	21,000	5,000
72	Lower Indian Creek, MO, USA	112	lead	US	E			2A-SI	1960		
73	Iwiny, Lower Silesia, Poland	130	copper	WR	E	25		1A-MS			
74	Madison, Missouri, USA	129	lead	WR	E	11		1A-OT	02-28-1977		
75	Maggie Pye, United Kingdom	101	china clay	US	T	18		1A-SI	1970	15,000	35
76	Marga, Chile	142	copper					1B-OT	1985		
77	Marianna Mine #58, PA, USA	111	coal	US	E	37	300,000	2A-SI	11-19-1986		
78	Miami Copper, Arizona, USA	113	copper	US	T			2A-SE			
79	Mike Horse, Montana, USA	111	Lead/zinc	US	T	18	750,000	1B-OT	1975	150,000	

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
80	Mines Development, Edgemont, South Dakota, USA	141	uranium					1A-U	06-11-1962	100	
81	Mir, Bulgaria	110	Lead/zinc	US	T			1A-U	1966		
82	Missouri Lead, Missouri, USA	125	lead	DS	CST	17		2A-ST			
83	Mobil Chemical, Florida, USA	140	phosphate					1A-U	1967	250,000	
84	Mochikoshi No. 1, Japan	108	gold	US	T	28	480,000	1A-EQ	01-14-1978	80,000	7,000
85	Mochikoshi No. 2, Japan	108	gold	US	T	19	480,000	1A-EQ	01-15-1978	3,000	150
86	Monsanto Dike 15, TN, USA	122	phosphate	DS	E	43	1,230,000	2A-SE	1969		
87	Montana Tunnels, MT, USA	126	gold	DS	MW	33	250,000	3-	1987		
88	Mulfilira, Zambia	139	copper			50		1A-MS	1970		
89	N'yukka Creek, USSR	132		WR	E	12		2A-FN	1965		
90	Norosawa, Japan	125	gold	DS		24	225,000	2B-EQ	01-14-1978		
91	Ollinghouse, Nevada, USA	128	gold	WR	E	5	120,000	1A-SE	1985	25,000	1,500
92	PCS Rocanville, Saskatchewan, Canada	117	potash	US	T	12		3-	1975		
93	Park, United Kingdom	130	china clay	WR	T	3		1A-OT	1970		
94	Phelps-Dodge, Tyrone, New Mexico, USA	100	copper	US	CST	66		1A-SI	10-13-1980	2,000,000	8,000
95	Pinchi Lake, BC, Canada	133	mercury	WR	E	13		2A-ER	1971		
96	Pit No. 2, Western Australia	100	rare earth	US	T	9		1A-SI	1977		
97	Portworthy, United Kingdom	121	china clay	DS	R	15		1A-ST	1970		
98	Rain Starter Dam, Elko, Nevada, USA	134	gold	WR	ER	27	1,500,000	3-	1988		

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99	Ramayana No. 1, Chile	139	copper	US	T	5		1A-EQ	03-28-1965	150	
100	Ray Mine, Arizona, USA	101	copper	US	T	52		1A-SI	12-02-1972		
101	Ray Mine, Arizona, USA	112	copper	US	T	52		2A-SI	02-05-1973		
102	Royster, Florida, USA	104	gypsum	US	T	21		1A-FN	1982		
103	Santander, Spain	137						1A-FN			
104	Sauce No. 1, Chile	115	copper	US	T	6		2A-EQ	03-28-1965		
105	Sauce No. 2, Chile	115	copper	US	T	5		2B-EQ	03-28-1965		
106	Sauce No. 3, Chile	115	copper	US		5		2B-EQ	03-28-1965		
107	Sauce No. 4, Chile	115	copper	US	T	5		2B-EQ	03-28-1965		
108	Silver King, Idaho, USA	124	copper	DS	E	9	37,000	2A-OT	08-05-1989	Small	
109	Silver King, Idaho, USA	121	copper	DS	E	9	37,000	1A-OT	01-16-1974	6,000	
110	Simmer and Jack, South Africa	103	gold	US	T			1A-SI	1937		
111	Soda Lake, California, USA	114	sand & gravel	US	E	3		2A-EQ	10-17-1989		
112	Southern Clay, Tennessee, USA	127	clay	WR	E	5		1A-SE	09-07-1989	300	
113	Southwest US, USA	113		US	T			2A-SI			
114	Spring Creek Plant, Borger, Texas, USA	137	sand & gravel			5	30,000	1A-OT	08-01-1986		
115	St. Joe Lead, Flat River, Missouri, USA	106	lead	US	T	15		1A-OT	1940		
116	Stancil , Maryland, USA	99	sand & gravel	US	E	9	74,000	1A-SI	08-25-1989	38,000	100

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
117	Stava, North Italy	99	fluorite	US	CST	29	300,000	1A-SI	07-19-1985	190,000	4000
118	Suncor E-W Dike, Alberta, Canada	132	oil sands	WR	MW	30		2A-SI	1979		
119	Sweeney Tailings Dam, Longmont, Colorado, USA	136	sand & gravel			7		1A-SE	05-01-1980		
120	Syncrude, Alberta, Canada	119	oil sands	CL	T			2A-FN	1978		
121	TN Consolidated Coal No. 1, Tennessee, USA,	124	coal	DS	MW	85	1,000,000	2A-ST	01-19-1988		
122	Texasgulf 4B Pond, Beaufort Co., North Carolina, USA	131	phosphate	WR	T	8	12,300,000	2A-SI	04-01-1984		
123	Texasgulf No. 1 Pond, Beaufort Co., North Carolina, USA	132	phosphate	WR	E		24,700,000	2A-SI	1981		
124	Tymawr, United Kingdon	137	coal					1A-U	12-1961		800
125	Tymawr, United Kindom	137	coal			12		1A-OT	03-29-1965		700
126	Unidentified	103		US				1A-SI			
127	Unidentified	130		WR	E			1A-ST			
128	Unidentified	114		US	T			2A-ST			
129	Unidentified	103		US	MW			1A-SI			
130	Unidentified	113		US	T			2A-SE			
131	Unidentified	112		US				2A-SI			
132	Unidentified	134	gold	WR	E	8		3-			
133	Unidentified	126	gold	DS	E			3-			
134	Unidentified, Europe	133		WR	R	24		2A-FN			

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135	Unidentified, Peru	139						1A-EQ	1962		
136	Unidentified, South Africa	141	gold					1A-U	1917		
137	Unidentified, South Africa	114	gold	US	T			2A-FN			
138	Unidentified, South Africa	113	gold	US	T			2A-SE			
139	Unidentified, South Africa	103	gold	US	T			1A-SI			
140	Unidentified, USA	112	copper	US	CST	60		2A-SI			
141	Unidentified, USA	132	magnesia	WR	E	6		2A-FN			
142	Unidentified, United Kingdom	141			R	12		1A-U			
143	Unidentified, United Kingdom	125	coal	DS				2B-SI			
144	Unidentified, United Kingdom	120	coal	DS		20		1A-SI	1967		
145	Unidentified, United Kingdom	122	coal	DS	MW	14		2A-SI	1967		
146	Unidentified, United Kingdom	123	sandstone	DS	E	30		2A-SE	1967		
147	Unidentified, Arizona, USA	113	copper	US	CST	18		2A-SE			
148	Unidentified, Colorado, USA	135		WR	E			3-			
149	Unidentified, Idaho, USA	122	phosphate	DS	E	34		2A-SI	1976		
150	Unidentified, Idaho, USA	122	phosphate	DS	E	18		2A-SI	1965		
151	Unidentified, Indiana, USA	142	coal					1B-OT			
152	Unidentified, Mississippi, USA	106	gypsum	US	T	15		1A-OT	1970		
153	Unidentified, Mississippi, USA	114	gypsum	US	T	20		2A-FN	1974		
154	Unidentified, Texas, USA	104	gypsum	US	T	16		1A-SE	1966	130,000	300
155	Unidentified, Wyoming, USA	134	trona	WR	E	24		3-			

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156	Unidentified, Alfaria River, Florida, USA	127	phosphate	WR	E	8		1A-SI	02-01-1952		
157	Unidentified, BC, Canada	123		DS	CST			2A-SE			
158	Unidentified, BC, Canada	123		DS	MW	30		2A-SE			
159	Unidentified, Canaca, Mexico	106	copper	US	T	46		1A-OT	1974		
160	Unidentified, Eastern USA	143	coal		MW	150		2A-SI			
161	Unidentified, Green River, Wyoming, USA	134	trona	WR	E	18		3-	1975		
162	Unidentified, Hernando County, Florida, USA	119	limestone	CL	E	6		2A-FN	1977		
163	Unidentified, Hernando County, Florida, USA	105	limestone	US	E	12	3,300,000	1A-OT	09-01-1988	4,600	
164	Unidentified, Hernando County, Florida, USA	124	limestone	DS	E	12		2A-FN	1988		
165	Unidentified, Peace River, Florida, USA	127	phosphate	WR	E	8		1A-SI	03-01-1952		
166	Unidentified, Peace River, Florida, USA	128	phosphate	WR	MW	30		1A-SE	07-01-1951		
167	Unidentified, Peace River, Florida, USA	128	phosphate	WR	MW	6		1A-SE	09-01-1951		
168	Unidentified, Peace River, Florida, USA	120	phosphate	DS	E			1A-SE	02-01-1951		
169	Unidentified, Southern USA	101	copper	US	E	43	500,000	1A-SI	1973	170,000	25,000
170	Union Carbide, Green River, Utah, USA	138	uranium					1A-OT	08-19-1959	8,400	
171	Union Carbide, Maybell, Colorado, USA	141	uranium					1A-U	12-06-1961	280	

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172	Union Carbide, Uravan, Colorado, USA	111	uranium	US	T	43		2A-SI	03-01-1979		
173	United Nuclear, Churchrock, New Mexico, USA	129	uranium	WR	E	11	370,000	1A-FN	07-01-1979	370.000	110,000
174	Utah construction, Riverton, Wyoming, USA	143	uranium					2A-OT	06-16-1963		
175	Vallenar 1 and 2, Chile	142	copper					1B-OT	1983		
176	Veta de Aqua A, Chile	139	copper					1A-EQ	1981		
177	Veta de Agua B, Chile	139	copper					1A-EQ	1981		
178	Veta de Agua No. 1, Chile	108	copper	US	T	24	700,000	1A-EQ	03-03-1985	280,000	5,000
179	Virginia Vermiculite, Louisa County, Virginia, USA	130	vermiculite	WR	E	9		1A-ST	1984		
180	Western Nuclear, Jeffrey City, Wyoming, USA	135	uranium					1A-SI	1977	40	
181	Western Nuclear, Jeffrey City, Wyoming, USA	139	uranium					1A-ST	03-23-1971		
182	Williamsport Washer, Maury County, Tennessee, USA	140	phosphate			21		1A-U	1970		
183	Williamthorpe, United Kingdom	136	coal					1A-FN	1966		
184	Zlevoto No. 4, Yugoslavia	101	lead/zinc	US	T	25	1,000,000	1A-SI	03-01-1976	300,000	
185	Arcturus, Zimbabwe	105	gold	US	T	25	1.7-2.0 Mt	1A-OT	01-31-1978	39,000 t	300
186	Heath Steele main dam, New Brunswick, Canada	132	copper/zinc	WR	R, E	30		2A-FN	Since 1970s		

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
187	No.3 Tailings Pond, Sipalay, Phillippines	129	copper	WR	MW		37 Mt	1A-FN	11-08-1982	27Mt	
188	Mineral King, BC, Canada	118		CL	CST	6	Small	1B-OT	03-20-1986		
189	Itabirito, Minas Gerais,Brazil	135	iron ore	Gravity	Masonry	30		1A-ST	05-1986	100,000	12,000
190	Rossarden, Tasmania	131		WR	E	7.5	200,000	1B-OT	05-16-1986		
191	Story's Creek, Tasmania	135		Valley side		17	30,000	1B-OT	05-16-1986	Minimal	
192	Pico de Sao Luis, Minas Gerais, Brazil	140			T	20		1A-ER	10-02-1986		
193	No.3 Tailings Pond, Mankayan, Luzon, Phillippines	138	copper		E			1A-ST	10-17-1986		
194	Xishimen, China	99	iron	US	T	31		1A-SI	03-21-1987	2,230	
195	Jinduicheng, Shaanxi Province., China	105	molybdenum	US		40		1A-OT	04-30-1988	700,000	
196	Iron Dyke, Sullivan Mine, Kumberley, BC, Canada	99		US		21		1A-SI	08-23-1991		
197	No.2 Tailings Pond, Padcal, Luzon, Philippines	136	copper				80Mt	A1-FN	01-1992	80Mt	
198	Kojkovac, Montenegro	133	lead/zinc	WR	E		3,500,000	2B-ER	11-1992	none	
199	Itogon-Suyoc, Baguio gold district,Luzon, Phllippines	137	gold					1A-OT	06-26-1993		
200	TD 7, Chingola, Zambia	105	copper	US	T & E	5		1A-OT	08-1993	100t	
202	Merriespruit, nr Virginia, South Africa	111	gold	US paddock	T	31	10Mt	1B-OT	02-22-1994	2.5Mt	2,000
203	Riltec, Mathinna, Tasmania	118		CL	E	7	120,000	2A-SE	01-06-1995	40,000	

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204	Middle Arm, Launceston, Tasmania	117		CL	E	4	25,000	1A-OT	06-25-1995	5.000	
205	Tailings dam No 1, Omai, Guyana	130	gold	WR	R	44	5,250,000	1A-ER	08-19-1995	4,200,000	
206	Placer Bay, Surigao del Norte, Philippines	131		WR	E	17		1B-SI	09-02-1995	50,000	Out to sea
207	Golden Cross, Waitekauri Valley, New Zealand	136	gold		R	25-30	3Mt	1A-FN	12-1995	None	
208	Marcopper, Marinduque Island, Philippines	138	Copper					1A-ST	03-24-1996	2.4Mt	25,000
209	Los Frailes, nr Seville, Spain	128	Zinc-lead-copper	WR	R	27	15,000,000	1A-FN	04-24-1998	6,800,000	40,000
210	Mirolubovka, Southern Ukraine	111	Iron	US	E and T	32	80,000,000	2A-SI	01-15-1984	none	
211	Balka Chuficheva, Russia	100	Iron	US	CST	25	27,000,000	1A-SI	01-20-1981	3,500,000	1,300
212	Bekovsky, Western Siberia	99	Coal	US	Argillite, aleurolite	53	52,000,000	US	03-25-1987	None	
213	Fernandinho, nr Belo Horizonte, Brazil	103	Iron	US	T	40		1A-SI			
214	Minera Sera Grande: Crixas, Goias, Brazil	121	Gold	DS then US	CST	41	2.25 Mt	2A-SI	02-1994	None	
215	Forquilha, Brazil	138	Iron					1A-OT			
216	Williamthorpe, UK	137	Coal		MW			1A-OT	03-24-1966		
217	Stoney Middleton, UK	136						1A-SI	02-08-1968		
218	Maritsa Istok 1, Bulgaria	110	Ash/cinder		Ash	15	52,000,000	1A-ER	03-01-1992	500,000	

ID No.	Mine Name/Location	Summary Page No. (See Note above)	Ore Type	Dam Type	Dam Fill Material	Dam Height (meters)	Storage Volume (Cubic Meters)	Incident Type	Incident Date	Tailings Released (cubic meters)	Tailings Travel (meters)
219	Madjarevo, Bulgaria	107	Lead/zinc/ gold	US	T	40	3,000,000	1A-ST	04-1975	250,000	
220	Sgurigrad, Bulgaria	102	Lead/zinc/ copper/silver	US	T	45	1,520,000	1A-SI	05-01-1996	220,000	6,000
221	Baia Mare, Romania	107	Gold	DS then US	T	A few m	800,000 (estimate)	1A-ST	01-30-2000	100,000 (estimate)	See Appendix

APPENDIX (continued)

4. BRIEF DESCRIPTION OF THE 221 CASES

- The described cases are those listed in Section 3 of the Appendix.
- Organizations that collected the case histories, and the corresponding Incident Nos. are listed in Section 1 of the Appendix.
- For Abbreviations, see Section 2 of the Appendix
- In the incident summaries that follow, the incidents were sorted in the following order:

Dam Type
and for each Dam Type, Incident Type
and for each Incident Type, Incident Cause
and for each Incident Cause, Date of incident, in reverse chronological order
(most recent listed first)

Where no information is available (NR or U), the cases are listed at the end of each category.

Incident Summaries provided on the pages that follow.

DAM TYPE: US INCIDENT TYPE: 1A
INCIDENT CAUSE: SI

Incident No.: 196
Dam/Mine Name: Iron Dyke
Mine Location: Sullivan mine, Kimberley, British Columbia Ore/Tailings Type:
Dam Height (m): 21;
Dam Type: US Dam Fill Material:
Impoundment Volume (Cu. m):
Incident Information:
Date: 23rd August 1991
Incident Type: 1A Cause: SI
Quantity of Tailings Released (Cu. m):
Tailings Travel Distance (m):
Incident Description:
A length of 300m out of a ring dyke 1,500m long, failed by rotational slip. A foundation embankment of tailings had been built in 1951, and the new ring dyke built in 1975. It was raised every year and heavy construction equipment was running on the dyke. Failure thought to be due to excess pore pressures developed in old foundation embankment due to weight of machines and raised height of dyke. Out of action for a year, cost of remedial works over a million Canadian dollars.
Source: Cominco Ltd., Vancouver, Canada.

Incident No.: 116
Dam/Mine Name: Stancil
Mine Location: Perryville, MD, USA
Ore/Tailings Type: sand & gravel
Dam Height (m): 9
Dam Type: US Dam Fill Material: E
Impoundment Volume (cu. m): 74,000
Incident Information:
Date: 08-25-1989 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 38,000
Tailings Travel Distance (m): 100
Incident Description:
Capping of the tailings was in progress when slope failure breached the embankment over a width of 280 feet. The clayey silt cap, which ranged from 8 to 12 feet thick, is thought to have elevated pore pressures in the clayey tailings impounded by the embankment. A contributing factor may have been saturation of the embankment fill by above- -normal precipitation prior to the failure. The tailings flowslide blocked a creek near the embankment toe, diverting creek discharge, dislodging trees, and destroying tidal vegetation over an area of 1.2 acres beyond the embankment toe.
Source: Maryland Dept. of Nat. Res., Dam Safety Div.

Incident No.: 212
Dam/Mine Name: Bekovsky
Mine Location: Kuznetsk coal basin, Western Siberia, Russia
Ore/Tailings Type: coal/loam, clay
Dam Height (m): 53
Dam Type: US Dam Fill Material: Argillites, aleurolites, loam, clay - hydraulic fill
Impoundment Volume (Cu. m): 52,000,000
Incident Information:
Date: 3-25-1987 at 16:45
Incident Type: lA Cause: SI
Quantity of Tailings Released (cu. m): none
Tailings Travel Distance (m):
Incident Description;
Starter dam 20m high. Raised with 5m high dykes. 7th dyke was being placed over a frozen beach, to raise dam height to 53m. Rotational slip 15m high x 250m long lowered crest 3m and bottom of slip moved 3m downstream. Caused by high rate of filling (260,000 cu m during 2 ½ months). Produced high pore pressures retained under frozen layer that reduced shear strength to very low value. Inspection of 7th dyke in June 1988 showed body completely destroyed by longitudinal cracks, indicating continuing movement. Piezometers were installed and the dam was stabilized with toe weighting. When the dam reached 60m high, no deformations reported.
Source: ICOLD Tailings Committee

Incident No.: 194
Dam/Mine Name: Xishimen
Mine Location: China
Ore/Tailings Type: iron
Dam Height (m): 31
Dam Type: US; Dam Fill Material: T
Impoundment Volume (Cu. m):
Incident Information:
Date: 3-21-1987 at 02:40
Incident Type: lA Cause: SI
Quantity of Tailings Released (cu. m): 2,230
Tailings Travel Distance (m):
Incident Description:
Blocked decant caused pond water to rise too high, causing failure of downstream slope, formation of a breach and escape of tailings
Source: ICOLD Tailings Committee.

Incident No.: 117
Dam/Mine Name: Stava
Mine Location: Northern Italy
Ore/Tailings Type: fluorite
Dam Height (m): 29.5 upper and 26.0 lower Dam Type: US lower, CL upper.
Dam Fill Material: CST

Impoundment Volume (cu. m): 300,000
Incident Information:
Date: 07-19-1985 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 190,000
Tailings Travel Distance (m): 4,000
Incident Description:
Two upstream-type impoundments had been constructed with the upper embankment founded partially on the slimes deposit of the lower. Embankment slopes ranged from 1.2:1 to 1.5:1. Failure of the upper embankment caused the lower embankment to also fail, with the loss of 269 lives in the resulting tailings flowslide. Mechanisms that triggered the failure may have included excess pore pressures in soft foundation tailings due to embankment raising, seepage of ponded water into embankment sands, pressurization of a blocked decant conduit, or excess pore pressures in natural foundation soils in response to rainfall or embankment seepage. For more details, see Section 6.
Source: Berti, et al, 1988; Chandler RJ and Tosatti G (1995*)* The Stava tailings dam failure, Italy, July 1985. Geotechnical Engineering, Pub Instn Civil Engrs, London, vol. 113, no 2, pp 67-79.

Incident No.: 211
Dam/Mine Name: Balka Chuficheva
Mine Location: Lebedinsky (Kursk Magnetic Anomaly), Russia
Ore/Tailings Type: iron/chalk, sand
Dam Height (m): 25
Dam Type: US
Dam Fill Material: Hydraulic fill sand
Impoundment Volume (cu. m): 27,000,000
Incident Information:
Date: 1-20-1981 at 06:30
Incident Type: lA Cause: SI
Quantity of Tailings Released (cu. m): 3,500,000
Tailings Travel Distance (m): 1,300
Incident Description:
The dam retained hydraulically placed chalky and sandy overburden from mine stripping. A breach, which occurred at right end of dam where it joined the valley side, became 55m wide. Resulting ravine formed in the impoundment up to 20m deep, max. width 400m and 1km long. Primary cause: violation of technology in performing hydrodumping works caused pond to be moved down to the dam.
Source: ICOLD Tailings Committee.

Incident No.: 94
Dam/Mine Name: No.3 Tailings Dam, Phelps-Dodge
Mine Location: Tyrone, NM, USA
Ore/Tailings Type: copper
Dam Height (m): 66
Dam Type: US Dam Fill Material: CST
Impoundment Volume (cu. m): 2,500,000
Incident Information:
Date: 10-13-1980, night
Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 2,000,000
Tailings Travel Distance (m): 8,000
Incident Description:
The embankment was being raised continuously by constructing perimeter dikes of cycloned sand tailings and discharge of slimes cyclone overflow to the impoundment. During the night, flowsliding occurred through a breached section 215m wide and 35m deep. Tailings flowed down slope and up opposite side, then 8km down the valley. The failure is attributed to a rapid raising rate and insufficient dissipation of pore pressures in the embankment. Alternative explanations advanced include breach due to pipeline rupture as a triggering mechanism for the flowslide.
Source: New Mexico State Engineers Office; Phelps Dodge, Phoenix.

Incident No.: 96
Dam/Mine Name: Pit No. 2
Mine Location: Western Australia, Australia
Ore/Tailings Type: rare earth
Dam Height (m): 9
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1977 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Tailings produced by mining of ocean beach sands for ilmenite, rutile, and zircon were deposited in a mined-out pit. The pit bottom sloped upward at a 3-4 degree angle, and deposition of tailings by direct spigotting proceeded from the lowest end of the pit and progressed upward in increments behind low tailings dikes. This procedure resulted in deposition of slimes beneath the dikes. An initial localized dike failure in 1976 was attributed to a high phreatic surface in the dike resulting from rainfall and high pond operating levels. A larger failure one year later showed evidence of upthrusting at the toe of the pit, block-type downslope movement of tailings and sand boils within the failed mass. This larger failure had no obvious trigger mechanism, and it was concluded that excess pore pressures in permeable layers

within the tailings or the pit floor initiated liquefaction
Source: Williams, 1979

Incident No.: 184
Dam/Mine Name: Zlevoto No. 4
Mine Location: Yugoslavia
Ore/Tailings Type: lead/zinc
Dam Height (m): 25 Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m): 1,000,000
Incident Information:
Date: 03-01-1976 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 300,000
Tailings Travel Distance (m):
Incident Description:
Four tailings impoundments had been constructed in a sidehill configuration by the upstream method using direct tailings spigotting. Embankment slopes ranged from 2:1 to 2.5:1. Failure was attributed to a high phreatic surface and seepage breakout on the embankment face produced by high fines content of the spigotted tailings and insufficient permeability of starter dike materials. The tailings flowslide reached and polluted a nearby river.
Source: Sandic, 1979

Incident No.: 37
Dam/Mine Name: Deneen Mica
Mine Location: Yancey County, NC, USA
Ore/Tailings Type: mica
Dam Height (m): 18
Dam Type: US Dam Fill Material: CST
Impoundment Volume (cu. m): 300,000
Incident Information:
Date: 06-01-1974 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 38,000
Tailings Travel Distance (m): 30
Incident Description:
The dam was constructed of cycloned sands which were hauled by truck and received variable compaction. Slimes were spigotted from the rear of the impoundment, resulting in very soft materials beneath the upstream sand raises. These conditions, combined with the steep 1.5:1 embankment face, resulted in marginal stability. During a heavy rain, the dam overtopped and deep gullies were eroded into the embankment face. This loss of support caused sliding of the downstream slope over its full height and over a width of 200 ft. Slimes were released to an adjacent river. The breached section was reconstructed to prevent further release of tailings, and the impoundment was abandoned due to marginal stability of the remaining portions of the embankment.
Source: Brawner, 1979; North Carolina Dept. of Environ. Health and Nat. Res., Land Quality Section

Incident No.: 169
Dam/Mine Name: Unidentified
Mine Location: Southwestern US, USA
Ore/Tailings Type: copper
Dam Height (m): 43 Dam Type: US
Dam Fill Material: E
Impoundment Volume (cu. m): 500,000
Incident Information:
Date: 1973 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 170,000
Tailings Travel Distance (m): 25,000
Incident Description:
The dam included a 60 foot high zoned earthfill starter dike. Prior to failure, two 15-foot high upstream raises had been added using perimeter dikes of uncompacted clayey soils derived from weathered shales. A third raise of cycloned sand tailings was under construction when the uncompacted shale dikes slumped from increased load and pore pressure. The resulting embankment breach took the form of a narrow gulley down to the level of the starter dike crest, and released about one-third of the impoundment contents in the form of a tailings flowslide. Tailings reached streams and rivers as far as 15 miles away.
Source: Wahler and Schlick, 1976; Lucia, 1981

Incident No.: 100
Dam/Mine Name: Ray Mine
Mine Location: Hayden, AZ, USA
Ore/Tailings Type: copper
Dam Height (m): 52 Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 12-02-1972 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Slope instability along a 500-ft section of the embankment caused failure to occur. Instability is believed to have been related to saturation and perched seepage conditions along a layer of slimes deposited within the embankment 20 years earlier. A wetted zone had been present on the embankment face at the location where failure occurred. Released tailings covered a small section of an adjacent railroad.
Source: Anecdotal

Incident No.: 75
Dam/Mine Name: Maggie Pye
Mine Location: United Kingdom

Ore/Tailings Type: china clay
Dam Height (m): 18
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1970 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 15,000
Tailings Travel Distance (m): 35
Incident Description:
Slope failure occurred immediately after completion of a perimeter dike to raise the embankment and following a period of heavy rainfall. High pore pressures and addition of the perimeter dike fill, possibly also supplemented by vibrations of construction equipment, are thought to have been contributing factors.
Source: Ripley, 1972

Incident No.: 220
Dam/Mine Name: Sgurigrad
Mine Location: Western Bulgaria
Ore/Tailings Type: Lead, zinc, copper, silver
Dam Height (m): 45 Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m): 1,520,000
Incident Information:
Date: 05-01-1966
Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 220,000
Tailings Travel Distance (m): 6,000
Incident Description:
A rise in pond level during 3 days of heavy rains caused a sudden loss of stability of the dam and liquefaction of the tailings, although the dam was not overtopped. The wave destroyed half of village 1 km downstream, with 107 victims. For more details see Section 6.
Source: ICOLD Tailings Committee

Incident No.: 54
Dam/Mine Name: Grootvlei
Mine Location: South Africa
Ore/Tailings Type: gold
Dam Height (m): Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1956 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An embankment slope failure occurred after a prolonged period of rain when water covered the tailings beach and encroached upon the embankment crest. About one third of the impoundment contents were lost in the ensuing tailings flowslide.
Source: Donaldson, et al, 1976

Incident No.: 66
Dam/Mine Name: Kimberley
Mine Location: British Columbia, Canada
Ore/Tailings Type: iron
Dam Height (m): Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1948 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 1,100,000
Tailings Travel Distance (m):
Incident Description:
The embankment was constructed by direct spigotting of tailings using upstream raising procedures. The foundation is believed to have consisted of low-permeability glacial till. The failure is attributed to freezing of the dam face during a period of high snowmelt and spring runoff that raised the phreatic surface and caused slope instability. A large tailings flowslide was triggered that moved toward, but apparently did not reach, the St. Mary River a few miles away. Frozen blocks of material were observed in the flow failure mass.
Source: Robinson and Toland, 1979

Incident No.: 62
Dam/Mine Name: Kennecott
Mine Location: Garfield, UT, USA
Ore/Tailings Type: copper
Dam Height (m): Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1941 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Breach of the embankment triggered a tailings flowslide. Accounts indicate that rainfall proceeding the failure which may have increased dike saturation, and that "minor shearing" may have initiated the failure.
Source: McIver, 1961; Smith, 1969

Incident No.: 21
Dam/Mine Name: Captains Flat Dump 6A
Mine Location: Australia
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1939 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:

No details of the failure are available, but released tailings were deposited in an adjacent river and caused widespread damage to river flats up to 10 miles downstream.
Source: Ash, 1976

Incident No.: 110
Dam/Mine Name: Simmer and Jack
Mine Location: South Africa
Ore/Tailings Type: gold
Dam Height (m): Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1937 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Embankment breach occurred after a period of rain and in an area weakened by excavation. The tailings flowslide traveled a considerable distance and engulfed a mine train.
Source: Donaldson, et al, 1976

Incident No.: 213
Dam/Mine Name: Fernandinho
Mine Location: nr Ouro Preto highway, 40km from Belo Horizonte, Brazil
Ore/Tailings Type: iron
Dam Height (m): 40
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: lA Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam had not been raised since 1984. A central dyke had been built to divide the impoundment. Tailings were placed in one while the other drained and dried. Dried tailings then dug out and placed elsewhere. A truck was on the crest and became stuck in the mud. Two others sent to help and while this going on slip failure began. The crest was 2m above the tailings, but they were placed away from the dam, which had water against it. The rotational movements soon allowed overtopping. A strong noise was heard and the staff of a laboratory 500m d/s ran for their lives up the valley side. The liquefied tailings swept down the zigzag valley like water, but stripping all vegetation. D/s slope of dam was 1 on 1.1 ($\varphi=42^0$)For more details, see Section 6.
Source: ICOLD Tailings Committee

Incident No.: 126
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type:
Dam Height (m): Dam Type: US
Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A liquefaction flowslide is illustrated that is believed to be related to lateral strains, differential movements, and cracking that occurred at a high-angle corner of the tailings embankment.
Source: Casagrande and McIver, 1971

Incident No.: 129
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type:
Dam Height (m): Dam Type: US
Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The upstream embankment was being raised on an overall slope of 4:1 by constructing perimeter dikes of hauled fill. Instability of the embankment was attributed to vibrations produced by the mine railroad transporting and dumping perimeter dike fill. Tailings flowsliding resulted.
Source: Casagrande and McIver, 1971

Incident No.: 139
Dam/Mine Name: Unidentified
Mine Location: South Africa
Ore/Tailings Type: gold
Dam Height (m): Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A failure is illustrated whereby a rotational slide in the embankment face triggered partial liquefaction of the retained slimes. The slide was related to long-term retention of water on the impoundment surface at variance with conventional operating practice in South Africa.
Source: Blight and Steffen, 1979

DAM TYPE: US INCIDENT TYPE: 1A
INCIDENT CAUSE: SE

Incident No.: 7
Dam/Mine Name: Bafokeng
Mine Location: South Africa
Ore/Tailings Type: platinum
Dam Height (m): 20
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 13,000,000
Incident Information:
Date: 1974 Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m): 3,000,000
Tailings Travel Distance (m): 45,000
Incident Description:
The embankment failed by concentrated seepage and piping through cracks. Embankment breach released a flow failure that reached a river, transporting tailings far downstream. The tailings flowslide inundated a mine shaft, killing 12 miners underground.
Source: Jennings, 1979; Rudd, 1979; Lucia, 1981

Incident No.: 10
Dam/Mine Name: Berrien
Mine Location: France
Ore/Tailings Type: kaolin
Dam Height (m): 9
Dam Type: US Dam Fill Material: R
Impoundment Volume (cu. m):
Incident Information:
Date: 1974 Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The starter dike for an upstream embankment partially breached due to seepage and piping after heavy rains. Damage was repaired and plans were made for raising the dam an additional 20 m by upstream methods.
Source: Londe, et al, 1976

Incident No.: 154
Dam/Mine Name: Unidentified
Mine Location: TX, USA
Ore/Tailings Type: gypsum
Dam Height (m): 16
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1966 Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m): 130,000
Tailings Travel Distance (m): 300
Incident Description:
Operation of the impoundment began in 1962 with the construction of a clay starter dike and a sand underdrainage system. The failure is attributed to seepage-related slumping and piping that initiated at the toe and progressed until breach of the embankment and tailings flowsliding occurred. The drainage system is believed to have been ineffective due to insufficient permeability of the sand.
Source: Kleiner, 1976; Lucia, 1981

Incident No.: 25
Dam/Mine Name: Castle Dome
Mine Location: AZ, USA
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m): 150,000
Tailings Travel Distance (m): 100
Incident Description:
The failure of a sand dike occurred due to excessive seepage and high phreatic conditions. The repaired section incorporated many pumped vertical wells to improve internal drainage.
Source: Lenhart, 1950

DAM TYPE: US INCIDENT TYPE: 1A
INCIDENT CAUSE: FN

Incident No.: 102
Dam/Mine Name: Royster
Mine Location: Mulberry, FL, USA
Ore/Tailings Type: gypsum
Dam Height (m): 21
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1982 Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The gypsum embankment was built on soft phosphatic clay slimes, which caused a 900-ft section of the embankment slope to fail. An unknown quantity of low-pH process water was released.
Source: Anecdotal

Incident No.: 58
Dam/Mine Name: Hollinger
Mine Location: Canada
Ore/Tailings Type: gold
Dam Height (m): 15
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1944 Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m):

Tailings Travel Distance (m):
Incident Description:
The dam was constructed on 5 to 17 feet of muskeg overlying alluvial sands, clays, and clayey silts. Between 1936 and 1944, 17 separate episodes of foundation sliding occurred, producing subsidence of the embankment crest and lateral spreading. Failures occurred rapidly (within a few minutes) and without warning. Crest subsidence ranged from 4-8 feet when the embankment height was about 15 feet to 20-25 feet, after embankment raising to a height of 50 ft.
Source: Blackshaw, 1951

Incident No.: 63
Dam/Mine Name: Kennecott
Mine Location: Garfield, UT, USA
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1942 Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam breach was caused by shear failure in weak foundation materials.
Source: McIver, 1961

DAM TYPE: US INCIDENT TYPE: 1A INCIDENT CAUSE: OT

Incident No.: 200
Dam/Mine Name: TD 7
Mine Location: Chingola, Zambia
Ore/Tailings Type: copper
Dam Height (m): 5
Dam Type: US Fill Material: T and E
Impoundment Volume (cu. m):
Incident Information:
Date: 08-1993
Incident Type: 1A Cause: OT
Quantity of Tailings Released (tonnes): 100
Tailings Travel Distance (m):
Incident Description:
Rainstorm caused overilow at time when rate of tailings deposition had increased. Part of dam collapsed. Spillway not adequate for flood.
Source: ZCCM Ltd., Kalulushi, Zambia.

Incident No.: 163
Dam/Mine Name: Unidentified
Mine Location: Hernando County, FL, USA
Ore/Tailings Type: limestone
Dam Height (m): 12
Dam Type: US Dam Fill Material: E
Impoundment Volume (cu. m): 3,300,000
Incident Information:
Date: 09-01-1988
Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m): 4,600
Tailings Travel Distance (m):
Incident Description:
The embankment was raised with clay fill over tailings similar in nature to phosphatic clay slimes derived from limestone washing operations. Local shear failures and displacement of soft tailings occurred during construction of upstream raises, and downstream embankment slopes were as steep as 1.3:1. Overtopping of the embankment occurred due to excessive water accumulation during heavy rainfall. Overtopping may have been promoted by settlement of the portion of the embankment constructed on soft tailings, or by shear failures on the steep downstream slope. The narrow breach that resulted released all of the impounded water (about 2 million gallons) but only a limited quantity of tailings, and a major flowslide did not occur. The absence of flowsliding was attributed to abnormally high consolidation and undrained shear strength in the lower portion of the impounded clayey slimes due to underdrainage by a pervious foundation sand layer.
Source: Anecdotal

Incident No.: 195
Dam/Mine Name: Jinduicheng
Mine Location: Shaanxi province, China
Ore/Tailings Type: molybdenum
Dam Height (m): 40
Dam Type: US Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 04-30-1988 at 03:00
Incident Type: lA Cause: OT
Quantity of Tailings Released (cu. m): 700,000
Tailings Travel Distance (m):
Incident Description:
Spillway blockage raised phreatic surface, causing rotational slip in central part of dam: a catastrophic failure; 20 killed
Source: ICOLD Tailings Committee.

Incident No.: 185
Dam/Mine Name: Arcturus
Mine Location: Zimbabwe
Ore/Tailings Type: Gold
Dam Height (m): 25
Dam Type: US paddock Fill Material: T
Impoundment Volume (Mt): 1.7 - 2.0
Incident Information:
Date: 01-31-1978 at 19:30

Incident Type: lA Cause: OT
Quantity of Tailings Released (tons): 30,000
Tailings Travel Distance (m): 300
Incident Description:
Early in the morning, following continuous rain over several days (seasonal total rainfall above average), a breach 55m wide suddenly developed, releasing a flow slide of tailings, blocking and contaminating public waterway. Minor damage to local village. One child killed and another injured.
Source: Chamber of Mines, Harare, Zimbabwe.

Incident No.: 159
Dam/Mine Name: Unidentified
Mine Location: Cananea, Mexico
Ore/Tailings Type: copper
Dam Height (m): 46
Dam Type: US   Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1974 Incident Type: 1A   Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Embankment perimeter dikes were constructed of and upon fine tailings discharged from the rear of the impoundment. Overall embankment slopes were 1.5:1. Overtopping resulted in breach of the embankment, loss of impounded water, and erosional-type gullying of tailings within the impoundment. Flow sliding of the tailings mass, however, did not occur.
Source: Anecdotal

Incident No.: 49
Dam/Mine Name: Galena Mine
Mine Location: Wallace, ID, USA
Ore/Tailings Type: silver
Dam Height (m): 9 Dam Type: US
Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: 01-15-1974
Incident Type: 1A   Cause: OT
Quantity of Tailings Released (cu. m): 3,800
Tailings Travel Distance (m): 610
Incident Description:
Three tailings impoundments in a sidehill configuration adjoined each other within a narrow valley with a creek at their toe. During a rain-on-snow event, flooding on the creek reached estimated 100-yr. recurrence interval flows. A culvert in the creek upstream from the impoundments became blocked by debris, diverting a large portion of the streamflow into the uppermost impoundment. Lacking sufficient decant spillway capacity for these flows the uppermost embankment breached by overtopping, resulting in cascade failure of all three impoundments. Tailings released in the failure covered about 5 acres, including a short section of highway and railroad track. This incremental damage was insignificant in relation to general flood damages to public and private property.
Source: Montana Div. State Lands

Incident No.: 41
Dam/Mine Name: Earth Resource
Mine Location: Cuba, NM, USA
Ore/Tailings Type: copper
Dam Height (m): 21
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1973 Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Improper operation and inadequate tailings beach deposition allowed ponded water to encroach on the embankment crest and overtopping failure to occur. No flood or extreme precipitation event was associated with this failure.
Source: New Mexico State Engineers Office

Incident No.: 152
Dam/Mine Name: Unidentified
Mine Location: MS, USA
Ore/Tailings Type: gypsum
Dam Height (m): 15
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1970 Incident Type: 1A   Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Overtopping occurred due to accumulation of water in the impoundment from hurricane rainfall. The embankment breached and water was released, but flow failure of the tailings did not develop. The breach was repaired and the embankment placed back into service.
Source: Anecdotal

Incident No.: 115
Dam/Mine Name: St. Joe Lead
Mine Location: Flat River, MO, USA
Ore/Tailings Type: lead
Dam Height (m): 15
Dam Type: US   Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1940 Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m):

Tailings Travel Distance (m):
Incident Description:
During embankment raising, a portion of the tailings was discharged from the rear of the impoundment producing a narrow sand tailings beach and accumulation of water near the embankment crest. This water was decanted with a vertical-riser decant system, but inattention to flashboard placement allowed ponded water to rise and overtop the embankment. A narrow breach resulted, with loss of some tailings. The breach was filled with mine waste rock, the impoundment was placed back into service, and the embankment was raised to an ultimate weight of 110 feet without further incident.
Source: Anecdotal

DAM TYPE: US INCIDENT TYPE: 1A
INCIDENT CAUSE: ST

Incident No.: 221
Dam/Mine Name: Aurul S.A. Mine
Mine Location: Baia Mare, Romania
Ore/Tailings Type: Gold
Dam Height (m): A few m; future final height 20 m Dam Type: Initially DS, later US
Dam Fill Material: T (cycloned)
Impoundment Volume (cu. m): Approx. 800,000
Incident Information:
Date: 1-30-2000
Incident Type: 1A Cause: ST
Quantity of contaminated effluent released (cu. m): 100,000 (Estimate)
Tailings Travel Distance (m):
Incident Description:
After extreme weather conditions (ice and snow on the tailings pond, high precipitation: 36L/m^2), the tailings deposited on the inner embankment (starter dam) became saturated. Stability was affected, causing local displacement, and this subsequently developed into a breach of approximately 23 m in length. The effluent released through the breach filled the area between the starter dam and the outer perimeter dam, both surrounding the impoundment (93 hectares in area), and spilled over the outer embankment. Around 100,000 m^3 of cyanide-rich (50-100 tonnes) effluent contaminated also with some heavy metals was released into the Somes and Tisza rivers and then into the Danube, finally reaching the Black Sea. Significant contamination occurred over a stretch of 150 to 180 m, then became more and more diluted. It caused significant fishkill and destruction of aquatic species in the river system.
Source: UNEP/OCHA Assessment Mission Report, 2000

Incident No.: 59
Dam/Mine Name: Homestake
Mine Location: Milan, NM, USA
Ore/Tailings Type: uranium
Dam Height (m): 21 Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 02-01-1977
Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m): 30,000
Tailings Travel Distance (m):
Incident Description:
A tailings slurry pipeline on the dam crest ruptured due to a blockage by freezing and pressure buildup. The slurry released eroded a "v"-shaped breach in the embankment, which in turn released tailings and an estimated 2 to 8 million gallons of impounded effluent. All released materials were contained on the mine site.
Source: Teknekron, 1978; New Mexico State Engineers Office.

Incident No.: 219
Dam/Mine Name: Madjarevo
Mine Location: Eastern Rodope Mountain, South-Eastern Bulgaria
Ore/Tailings Type: lead, zinc, gold
Dam Height (m): 40
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 3,000,000
Incident Information:
Date: 04-1975 Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m): 250,000
Tailings Travel Distance (m):
Incident Description:
Rising of tailings above design level caused overloading of the decant tower and collectors, resulting in structural failure. Tailings flowed through tower and collector into river and backwater of a water retention downstream. For more details see Section 6.
Source: ICOLD Tailings Committee

Incident No.: 23
Dam/Mine Name: Casapalca
Mine Location: Peru
Ore/Tailings Type:
Dam Height (m): 107
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A number of tailings dams up to 350 ft in height

were developed over the 50-year mine life in steep, narrow valleys. All utilized a complex array of pipe-type decant structures and inadequately-sized stream bypass channels. Five separate dam failures resulted from failure of these bypass or decant systems.
Source: Brawner, 1979

DAM TYPE: US INCIDENT TYPE: 1A INCIDENT CAUSE: EQ

Incident No.: 30
Dam/Mine Name: Cerro Negro No. 4
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 40
Dam Type: US Dam Fill Material: CST
Impoundment Volume (cu. m): 2,000,000
Incident Information:
Date: 03-03-1985
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 500,000
Tailings Travel Distance (m): 8,000
Incident Description:
The dam was constructed using a combination of upstream and centerline methods, with downstream slopes of 1.7:1. The dam failed by liquefaction during the M7.8 earthquake of March 3, 1985. Slimes flowed through a narrow breach, reached a creek, and were deposited downstream for a distance of 8 km.
Source: Castro and Troncoso, 1989; Troncoso, 1988

Incident No.: 178
Dam/Mine Name: Veta de Agua No. 1
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 24
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 700,000
Incident Information:
Date: 03-03-1985
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 280,000
Tailings Travel Distance (m): 5,000
Incident Description:
The dam was constructed using both upstream and centerline methods with downstream slopes of 1.5:1. During the M7.8 earthquake of March 3, 1985, the dam failed by liquefaction.
Source: Castro and Troncoso, 1989; Troncoso, 1988

Incident No.: 84
Dam/Mine Name: Mochikoshi No. 1
Mine Location: Japan
Ore/Tailings Type: gold
Dam Height (m): 28
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 480,000
Incident Information:
Date: 01-14-1978
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 80,000
Tailings Travel Distance (m): 7,000
Incident Description:
The embankment was constructed with a rockfill starter dike and had slopes of about 3:1. Failure occurred by liquefaction during the M7.0 Izu-Oshima-Kinkai earthquake. The flowslide reached and flowed down a river for 7-8 km, causing one fatality.
Source: Marcuson, 1979; Okusa, et.al., 1980

Incident No.: 85
Dam/Mine Name: Mochikoshi No.2
Mine Location: Japan
Ore/Tailings Type: gold
Dam Height (m): 19
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 480,000
Incident Information:
Date: 01-15-1978
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 3,000
Tailings Travel Distance (m): 150
Incident Description:
The embankment was constructed with rockfill starter dikes, and had slopes of 2.5:1 to 3:1. Liquefaction failure occurred the day after the January 14, 1978 M 7.0 Izu–Oshima– Kinkai earthquake, and about 5 hours after the two after shocks of M 5.4 and M 5.8.
Source: Marcuson, 1979; Okusa, et. al., 1980

Incident No.: 57
Dam/Mine Name: Hokkaido
Mine Location: Japan
Ore/Tailings Type:
Dam Height (m): 12
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 300,0
Incident Information:
Date: 1968 Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 90,000
Tailings Travel Distance (m): 150
Incident Description:
The embankment included a low rockfill starter dike at the toe, and was constructed with 3:1 slopes. The embankment failed by liquefaction during the M7.8 Tokachi-Oki earthquake, and the resulting flowslide reached and crossed a river at the downstream toe of the embankment.
Source: Ishihara, et. al., 1990

Incident No.: 12
Dam/Mine Name: Bellavista
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 20
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 450,000
Incident Information:
Date: 03-28-1965
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 70,000
Tailings Travel Distance (m): 800
Incident Description:
At the time of the M7-7 1/4 1965 La Liqua earthquake, only 8m separated the edge of the ponded water from the crest of this upstream-type embankment with slopes as steep as 1.4:1.0. According to eyewitness accounts, the face of the embankment slid first, followed by flowsliding of the tailings behind the breach.
Source: Dobry and Alvarez, 1967

Incident No.: 29
Dam/Mine Name: Cerro Negro No. 3
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 20 Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m): 500,000
Incident Information:
Date: 03-28-1965
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 85,000
Tailings Travel Distance (m): 5,000
Incident Description:
The upstream type dam experienced strong shaking during the M7-7 1/4 La Ligua earthquake. Eyewitness accounts indicate that surface waves were generated on the liquefied slimes for as long as 1-1/2 minutes after shaking ceased. These waves of liquefied slimes eroded the small perimeter dike on the embankment crest, breaching the embankment and producing a tailings flowslide.
Source: Dobry and Alvarez, 1967

Incident No.: 45
Dam/Mine Name: El Cobre Old Dam
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 35
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 4,250,000
Incident Information:
Date: 1965 Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 1,900,000
Tailings Travel Distance (m): 12,000
Incident Description:
The embankment failed catastrophically in the M7-7 1/4 La Ligua earthquake of March 28, 1965 by liquefaction. The dam had been constructed according to the upstream method by spigotting from flumes on the crest and was in use as an emergency impoundment at the time of the earthquake. Embankment slopes as steep as 1.2:1.0 and the presence of slimes layers near the face suggest that static stability may have been marginal even before the earthquake. The tailings flowslide destroyed the town of El Cobre, killing more than 200.
Source: Dobry and Alvarez, 1967

Incident No.: 55
Dam/Mine Name: Hierro Viejo
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 5
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 1A   Cause: EQ
Quantity of Tailings Released (cu. m): 800
Tailings Travel Distance (m): 1,000
Incident Description:
This upstream dam experienced liquefaction flow failure during the M7-7 1/4 La Ligua earthquake. The liquefied tailings traveled a distance of 1 km on the gently sloping valley floor without doing any damage.
Source: Dobry and Alvarez, 1967

Incident No.: 69
Dam/Mine Name: La Patagua New Dam
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 15
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 35,000
Tailings Travel Distance (m): 5,000
Incident Description:
The New Dam was being used to retain mill process water at the time of the M7-7 1/4 1965 La Liqua earthquake, and pond water levels retained by the upstream-type embankment were relatively high. Embankment slopes were a maximum of 1.4:1.0. The dam failed by liquefaction during the earthquake, but no damage was reported.
Source: Dobry and Alvarez, 1967

Incident No.: 71
Dam/Mine Name: Los Maquis No. 3
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 15
Dam Type: US   Dam Fill Material:
Impoundment Volume (cu. m): 43,000
Incident Information:
Date: 03-28-1965
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 21,000
Tailings Travel Distance (m): 5,000
Incident Description:
The embankment failed during the M7-7 1/4 La Ligua earthquake by liquefaction. The dam was constructed by the upstream method with slopes as steep as 1.4:1.0. No damage from the resulting flowslide was reported.
Source: Dobry and Alvarez, 1967

Incident No.: 9
Dam/Mine Name: Barahona
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 61
Dam Type: US Dam Fill Material: CST
Impoundment Volume (cu. m): 20,000,000
Incident Information:
Date: 10-01-1928
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 2,800,000
Tailings Travel Distance (m):
Incident Description:
The dam was constructed by cycloning sand tailings to form the outer shell. Embankment slopes were as steep as 1:1, and at the time of failure the last perimeter dike on the embankment crest had been constructed to a height of 55 feet. The dam failed by liquefaction during the M8.3 Talca earthquake of October 1, 1928. A tailings flowslide developed through a breach section approximately 1500 feet wide and flowed down a valley, killing 54 people.
Source: Dobry and Alvarez, 1967; Brawner, 1979; Jigins, 1957

Incident No.: 24
Dam/Mine Name: Casapalca
Mine Location: Peru
Ore/Tailings Type:
Dam Height (m): 107
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A number of tailings dams up to 350 feet in height were developed over the 50-year mine life in steep, narrow valleys. One of these dams failed by seismic liquefaction; no further details are reported
Source: Brawner, 1979

DAM TYPE: US INCIDENT TYPE: 1A
INCIDENT CAUSE: ER

Incident No.: 218
Dam/Mine Name: Ash-Cinder Tailings Dam of Thermal Power Plant "Maritsa Istok 1", 3rd section
Mine Location: Near Stara Zagora, Central Bulgaria
Ore/Tailings Type: Ash/Cinder
Dam Height (m): 15
Dam Type: Dam Fill Material: Crushed Ash and Cinder
Impoundment Volume (cu. m): 52,000,000
Incident Information:
Date: 03-01-1992
Incident Type: 1A Cause: ER
Quantity of Tailings Released (cu. m): 500,000
Tailings Travel Distance (m):
Incident Description:
Inundation of the beach of the uppermost section of the dam caused erosion failure, with the slurry discharge causing failure of the lower dam sections by piping and overtopping. For more details see Section 6.
Source: Abadjiev and Dimitrov, 1997.

DAM TYPE: US INCIDENT TYPE: 1A
INCIDENT CAUSE: U

Incident No.: 81
Dam/Mine Name: Mir
Mine Location: BulgariaOre/Tailings Type: lead/zinc
Dam Height (m):   Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1966 Incident Type: 1A   Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The tailings dam failed with loss of life. No other details are available.
Source: Abadjiev, 1990

DAM TYPE: US INCIDENT TYPE: 1B
INCIDENT CAUSE: OT

Incident No.: 202

Dam/Mine Name: Merriespruit
Mine Location: Merriespruit, nr Virginia, South Africa
Ore/Tailings Type: Gold
Dam Height (m): 31
Dam Type: US paddock Dam Fill Material: T
Impoundment Volume (Mt): 10
Incident Information:
Date: 02-22-1994;
Incident Type: lB Cause: OT
Quantity of Tailings Released (Mt): *2.5*
Tailings Travel Distance (m): 2,000
Incident Description:
Impoundment had been closed following signs of instability of part of ring dam closest to township. Mine continued to use it for storing waste water, containing tailings. This reduced freeboard and isolated decant. Heavy rain caused overtopping during evening. Personnel from mine tried to release water and warn population, some m bed. High phreatic surface caused failure of dam adjacent to houses. 17 killed.
Source: Official inquiry report.

Incident No.: 79
Dam/Mine Name: Mike Horse
Mine Location: MT, USA
Ore/Tailings Type: lead/zinc
Dam Height (m): 18
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 750,000
Incident Information:
Date: 1975 Incident Type: 1B Cause: OT
Quantity of Tailings Released (cu. m): 150,000
Tailings Travel Distance (m):
Incident Description:
During extreme runoff from a rain-on-snow event, the slopes of a sidehill diversion ditch became saturated and failed, directing the diverted streamflow into the abandoned impoundment. The decant capacity was insufficient to discharge the inflow, and the embankment was breached by overtopping
Source: Toland, 1977

DAM TYPE: US INCIDENT TYPE: 2A INCIDENT CAUSE: SI

Incident No.: 77
Dam/Mine Name: Marianna Mine # 58
Mine Location: Washington County, PA, USA
Ore/Tailings Type: coal
Dam Height (m): 37
Dam Type: US Dam Fill Material: E
Impoundment Volume (cu. m): 300,000
Incident Information:
Date: 11-19-1986 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A slide occurred in the upstream slope as a raise was being constructed of clayey fill over the fine coal refuse (tailings)beach. The cause was undrained shear failure due to rapid loading. The raise was about 14 ft. above the tailings elevation when the slide occurred. Sliding took place over a period of 1-2 minutes. The resulting scarp was about 14 ft. high and 550 ft. long, with as much as 20 ft. of lateral movement. The raise was later successfully constructed to a height of 25 ft. with careful monitoring of piezometers and controlled placement rates.
Source: Pennsylvania Dept. of Environmental Resources, Div. of Dam Safety

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Incident No.: 210
Dam/Mine Name: Mirolubovka
Mine Location: Krivoj Rog iron ore basin, Southern Ukraine
Ore/Tailings Type: iron
Dam Height (m): 32
Dam Type: US Dam Fill Material: E, T and R (crushed quartzite)
Impoundment Volume (cu. m): 80,000,000
Incident Information:
Date: 01-15-1984 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m): none
Tailings Travel Distance (m):
Incident Description:
Starter dam of loam 22m high. Two sand dykes above to raise to 32m. Phreatic surface allowed to rise and ditch cut in crest of starter dam to collect seepage. Starter dam became saturated. Rotational slip developed, said to be caused by incompatibility between real and design values for shear characteristics of foundation soil. Stabilized by toe weighting with rockfill.
Source: ICOLD Tailings Committee.

Incident No.: 172
Dam/Mine Name: Union Carbide
Mine Location: Uravan, CO, USA
Ore/Tailings Type: uranium
Dam Height (m): 43
Dam Type: US Dam Fill Material: TImpoundment Volume (cu. m):
Incident Information:
Date: 03-01-1979 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Two slides occurred on the 1.5:1 embankment slope due to snowmelt and internal seepage. Both were shallow, measuring 30-80 ft top width, 150-200 ft base width, and 80-100 ft length. Interim stabilization measures included horizontal

drains and a geofabric-protected drainage blanket. Long-term stabilization that followed consisted of a rockfill berm and underlying drainage zone which flattened the slopes to 2.0:1 to 3.0:1.
Source: Berry and Valarde, 1981; Robinson and Toland,1979; Colo. Div. Water Res.

Incident No.: 47
Dam/Mine Name: GCOS
Mine Location: Alberta, Canada
Ore/Tailings Type: oil sands
Dam Height (m): 61
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1974 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Several episodes of instability occurred within compacted fill that was being placed over spigotted beach sand tailings during construction of upstream raises. All showed evidence of local liquefaction of the spigotted beach tailings, and took the form of subsidence of the compacted fill accompanied by shearing scarps. These failures were attributed to excess pore pressures that developed in the loose beach sand tailings in response to rapidly-applied loading during fill placement. No lateral translation occurred during failure and overall embankment stability was not jeopardized.
Source: Mittal and Hardy, 1977

Incident No.: 101
Dam/Mine Name: Ray Mine
Mine Location: Hayden, AZ, USA
Ore/Tailings Type: copper
Dam Height (m): 52
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 02-05-1973 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Instability occurred along a small section of the embankment near the location where embankment failure had previously occurred on Dec. 2, 1972. No tailings were released. The previous failure was related to perched seepage conditions along a slimes layer, and the subsequent accident may have resulted from similar conditions.
Source: Anecdotal

Incident No.: 72
Dam/Mine Name: Lower Indian Creek
Mine Location: Washington County, MO, USA
Ore/Tailings Type: lead
Dam Height (m):
Dam Type: US Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1960 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The original earthfill dam was constructed in 1953 to an initial height of 45 feet and raised several times with additional earthfill. In 1959, the spillway washed out in a flood, causing some release of tailings but no breach or damage to the dam embankment. In 1960, the dam was reported to have shown signs of slumping on its 2:1 downstream face and was buttressed with a rockfill toe berm at a 3:1 slope. The dam remained in service was raised from 1971 to 1976 with cycloned sand tailings, and reached an ultimate height of 83 feet.
Source: Missouri Dept. of Nat. Res., Dam and Reservoir Safety Program

Incident No.: 140
Dam/Mine Name: Unidentified
Mine Location: USA
Ore/Tailings Type: copper
Dam Height (m): 60
Dam Type: US Dam Fill Material: CST
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Slope instability caused a 15m wide section of the embankment slope to drop 8m. This condition was produced when saturated material was bulldozed in an oversteepened condition on the upper portion of the slope. Shortly after, seepage emerged on the unstable section and began to cause retrogressive failure, but dam beach was averted by prompt remedial action.
Source: Wahler and Schlick, 1976

Incident No.: 131
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type:
Dam Height (m):
Dam Type: US Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):

Incident Description:
Freezing and growth of ice lenses on the embankment face produced extensive sloughing of the embankment slope accompanied by development of piping during the first few days of spring thaw.
Source: Casagrande and McIver, 1971

Incident No.: 113
Dam/Mine Name: Southwest US
Mine Location: USA
Ore/Tailings Type:
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An embankment slope failure that breached the crest of the dam occurred after an unusually heavy rainfall. Ponded water was well back from the embankment crest at the time of failure, and no slimes or water were released.
Source: Klohn, 1972

DAM TYPE: US INCIDENT TYPE: 2A
INCIDENT CAUSE: SE

Incident No.: 138
Dam/Mine Name: Unidentified
Mine Location: South Africa
Ore/Tailings Type: gold
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Severe seepage and piping eroded a considerable portion of the embankment slope, leaving near-vertical scarps.
Source: Donaldson. Et al. 1976

Incident No.: 78
Dam/Mine Name: Miami Copper
Mine Location: AZ, USA
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Extensive damage to the embankment occurred due to seepage-related slumping and ravelling of the face, accompanied by piping and erosional transport of embankment tailings materials.
Source: Hazen, 1924

Incident No.: 147
Dam/Mine Name: Unidentified
Mine Location: AZ, USA
Ore/Tailings Type: copper
Dam Height (m): 18
Dam Type: US Dam Fill Material: CST
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The initial starter dike was constructed to a height of 45 feet of relatively impervious sand and gravel on an impermeable foundation. Upstream raising used cycloned sands spigotted from the dam crest, with slimes discharged in the rear of the impoundment. When the embankment reached a height of 60 feet, malfunction of the stationary cyclone system caused uncycloned tailings to be discharged from the rear of the impoundment, with accumulation of ponded water and slimes near the embankment face. This caused seepage to emerge on the embankment face above the starter dike crest and raised the phreatic surface within the embankment to critical levels. Remedial measures included installation of french drains on the embankment face to collect surface seepage, and instituting perimeter discharge of whole tailings from the embankment crest to eliminate accumulation of ponded water in this area.
Source: Robinson and Toland, 1979

Incident No.: 130
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type:
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A large piping cavity developed in the embankment due to seepage breakout on the embankment face. Piping progressed through the

entire width of the perimeter dike in one day, and severe damage was narrowly averted.
Source: Casagrande and McIver, 1971

DAM TYPE: US INCIDENT TYPE: 2A
INCIDENT CAUSE: FN

Incident No.: 153
Dam/Mine Name: Unidentified
Mine Location: MS, USA
Ore/Tailings Type: gypsum
Dam Height (m): 20
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1974 Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The embankment was constructed and raised with overall slopes of about 3.5:1. When the embankment reached a height of 65 feet, slope instability occurred due to undrained shearing in soft foundation clays that had reached normally-consolidated conditions under the applied embankment loading. Further raising was discontinued, and the impoundment was subsequently abandoned.
Source: Anecdotal

Incident No.: 137
Dam/Mine Name: Unidentified
Mine Location: South Africa
Ore/Tailings Type: gold
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Wedge-type sliding on a thin layer of very soft foundation soil resulted in instability of the embankment, but the crest was not breached and no tailings were released.
Source: Donaldson, et al, 1976

DAM TYPE: US INCIDENT TYPE: 2A
INCIDENT CAUSE: ST

Incident No.: 128
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type:
Dam Height (m):
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A reinforced concrete decant conduit extended beneath the tailings dam and impoundment. In response to deterioration of the conduit, timber supports were added. Nevertheless, the conduit collapsed under excessive external water pressures, forming a crater on the surface of the impounded slimes. Tailings and timber debris formed a plug inside the collapsed conduit that allowed water pressures inside the plugged section to increase, cracking the conduit and producing concentrated seepage within coarse tailings comprising the embankment. This seepage caused piping of tailings into the rockfill starter dike at the downstream embankment toe. Damage was repaired by removing the debris plug, repairing the conduit, and adding filter zones to the rockfill.
Source: Smith and Connell, 1979

DAM TYPE: US INCIDENT TYPE: 2A
INCIDENT CAUSE: EQ

Incident No.: 111
Dam/Mine Name: Soda Lake
Mine Location: Santa Cruz, CA, USA
Ore/Tailings Type: sand and gravel
Dam Height (m): 3
Dam Type: US Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 10-17-1989
Incident Type: 2A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A small saddle dike impounding tailings from rock washing operations experienced strong shaking during the Loma Preita earthquake. The dike was located 29 miles from the epicenter and 1400 feet from the main trace of the San Andreas fault. At the time of the earthquake, the impoundment contained little or no ponded water. Extensive sand boils and liquefaction-related features were observed within impounded sediments. Damage to the dam consisted of a large wedge of embankment fill that slid in an upstream direction and extended through the embankment out to the downstream face near the toe. Post-earthquake investigations revealed that the dam incorporated an upstream raise that underwent sliding due to liquefaction of underlying tailings. Adjacent dams confining the

same impoundment that did not incorporate upstream raises experienced no damage.
Source: California Dept. Water Resources., Div. of Safety of Dams.

Incident No.: 36
Dam/Mine Name: Dashihe
Mine Location: China
Ore/Tailings Type:
Dam Height (m): 37
Dam Type: US Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1976 Incident Type: 2A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The upstream type embankment was constructed to a height of 37m on 1.6:1 slopes at the time of the1976 Tangshang earthquake. The area experienced a M7.8 main shock, a M7.1 shock 15 days later, and numerous aftershocks of magnitude greater than 5. The dam was located 40 km and 15 km from the first two shocks, respectively. Damage consisted of cracks on the downstream embankment face and tailings beach, accompanied by boils and fissures near the ponded water. The dam did not fail and remained in service.
Source: Morgenstern and Kupper, 1988

Incident No.: 104
Dam/Mine Name: Sauce No. 1
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 6 Dam Type: US
Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 2A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The No. 1 dam had been constructed with 1.7:1 slopes and was in active operation at the time of the M7-7 1/4 La Ligua earthquake. Serious cracking occurred at one corner, but the embankment did not fail.
Source: Dobry and Alvarez, 1967

DAM TYPE: US INCIDENT TYPE: 2A
INCIDENT CAUSE: ER

Incident No.: 48
Dam/Mine Name: Galena Mine
Mine Location: Osburn, ID, USA
Ore/Tailings Type: silver
Dam Height (m): 14 Dam Type: US
Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1972 Incident Type: 2A Cause: ER
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description: Flooding on the stream adjacent to the toe of four sidehill type impoundments caused erosion damage to the embankments. Damage was repaired and the embankments riprapped.
Source: MHSA

DAM TYPE: US INCIDENT TYPE: 2B
INCIDENT CAUSE: EQ

Incident No. 105
Dam/Mine Name: Sauce No. 2
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 5
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 2B Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The No. 2 dam was inactive at the time of the M7-7 1/4 La Liqua earthquake, and suffered minor cracking.
Source: Dobry and Alvarez, 1967

Incident No.: 106
Dam/Mine Name: Sauce No. 3
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 5
Dam Type: US Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965 Incident Type: 2B
Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The No. 3 dam was inactive at the time of the 7-7 1/4 La Ligua earthquake, and suffered minor cracking.
Source: Dobry and Alvarez, 1967

Incident No.: 107
Dam/Mine Name: Sauce No. 4
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 5

Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 2B Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The No. 4 dam was inactive at the time of the M7-7 1/4 La Ligua earthquake, and suffered minor cracking.
Source: Dobry and Alvarez, 1967

Incident No.: 70
Dam/Mine Name: Los Maquis No. 1
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 15
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 2B Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam experienced strong shaking during the M7-7 1/4 La Ligua earthquake and was adjacent to the active Los Maguis No. 3 dam which failed. The No.1 dam had been out of service for many years, and experienced only slight cracking along the crest and small slides in dry tailings on the sideslopes.
Source: Dobry and Alvarez, 1967

Incident No.: 42
Dam/Mine Name: El Cerrado
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 25
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965 Incident Type: 2B
Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The impoundment, incorporating 3 levels, had been abandoned for 10 years at the time of the M7-7 ¼ La Ligua earthquake. The embankments were constructed with 1.4:1 slopes. The earthquake produced cracks up to 6 feet deep along the entire crest accompanied by several circular slides, especially at corners of the embankment. Crest deformation up to 1 foot also occurred.
Source: Dobry and Alvarez, 1967

Incident No.: 27
Dam/Mine Name: Cerro Negro No. 1
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 46
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965 Incident Type: 2B
Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The Cerro Negro No. 1 dam was inactive at the time of the M7-7 1/4 La Ligua earthquake and adjacent to the No. 3 dam which failed. Its slopes were as steep as 1:1. The No. 1 dam experienced cracking, especially along the crest, and some small slides.
Source: Dobry and Alvarez, 1967

Incident No.: 28
Dam/Mine Name: Cerro Negro No. 2
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 46
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 2B Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The Cerro Negro No. 2 dam was inactive at the time of the M7-7 1/4 La Ligua earthquake and adjacent to the No. 3 dam which failed. Its slopes were as steep as 1:1. The No. 2 dam, like the adjoining inactive No. 1 dam, experienced cracking along the crest and small slides.
Source: Dobry and Alvarez, 1967

Incident No.: 46
Dam/Mine Name: El Cobre Small Dam
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 26
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m): 985,000
Incident Information:
Date: 03-28-1965
Incident Type: 2B Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:

The El Cobre Small Dam was adjacent to the New Dam and Old Dam, both of which failed during the M7-7 1/4 La Ligua earthquake. The Small Dam was similar in construction to the Old Dam with steep (1.2:1.0) slopes, but was abandoned at the time of the earthquake, with a desiccated surface crust about 5 m deep. Damage in the form of local slides is reported, but the dam remained essentially intact.
Source: Dobry and Alvarez, 1967

DAM TYPE: US INCIDENT TYPE: 3
INCIDENT CAUSE: NR

Incident No.: 92
Dam/Mine Name: PCS Rocanville
Mine Location: Saskatchewan, Canada
Ore/Tailings Type: potash
Dam Height (m):12
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1975 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The impoundment is underlain by a surficial aquifer and a deeper aquifer separated by a till layer. During initial impoundment construction, puncturing of its polyethylene liner was reported due to placement of cover material. As a result, a second liner and cover were placed on top of the first. During operation, leakage of brine into the shallow aquifer was detected. A collector ditch was installed, and improvement in downgradient water quality in the shallow aquifer was reported. Contamination of the lower aquifer was detected several years later. Two downgradient pumpback wells were installed, and water quality improvements occurred.
Source: Tallin and Pufahl, 1983

Incident No.: 60
Dam/Mine Name: IMC K-2
Mine Location: Saskatchewan, Canada
Ore/Tailings Type: potash
Dam Height (m): 30
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1968 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The starter dike for the impoundment was constructed of compacted till on a foundation of oxidized till which was jointed and contained sand seams. A cutoff trench of compacted clay underlies the dike to a depth of 4 ft, and a shallow collector ditch was constructed at the toe. The collector ditch proved to be too shallow to completely control seepage. Extension of the ditch down through the oxidized till was planned as a remedial measure.
Source: Kent, et al., 1983

DAM TYPE: CL INCIDENT TYPE: 1A
INCIDENT CAUSE: FN

Incident No.: 40
Dam/Mine Name: Dresser No. 4
Mine Location: Washington County, MO, USA
Ore/Tailings Type: barite
Dam Height (m): 15
Dam Type: CL Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 08-15-1975
Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The apparent cause of failure was embankment sliding along residual and alluvial foundation soils. The tailings flowslide reached a nearby drainage and from there entered a creek.
Source: Missouri Dept. of Nat. Res., Dam and Reservoir Safety Program

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DAM TYPE: CL INCIDENT TYPE: 1A
INCIDENT CAUSE: OT

Incident No.: 204
Dam/Mine Name: No 1 tailings dam
Mine Location: Middle Arm, Launceston, Tasmania
Ore/Tailings Type:
Dam Height (m): 4 Dam Type: CL Dam Fill Material: E
Impoundment Volume (cu. m): 25,000
Incident Information:
Date: 06-25-1995
Incident Type: lA Cause: OT
Quantity of Water Released (cu. m): 5,000
Tailings Travel Distance (m):
Incident Description:
Crest formed of tailings, eroded by wave action. Water containing 95mg/litre released into Tamar river. Cause: retained tailings allowed to rise above crest. Cost of remediation estimated A$ 20,000 - 30,000
Source: Inspector of Mines, Tasmania

DAM TYPE: CL INCIDENT TYPE: 1B

INCIDENT CAUSE: OT

Incident No.: 188
Dam/Mine Name: Mineral King
Mine Location: Invermere, British Columbia
Ore/Tailings Type:
Dam Height (m): 6 Dam Type: CL Dam Fill Material: CST
Impoundment Volume (cu. m): small
Incident Information:
Date: 03-20-1986
Incident Type: 1B Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam breach caused by high pond overtopping crest. Diversion ditch blocked by ice during onset of spring snowmelt
Source: Energy and Minerals Division, Ministry of Employment and Investment, Victoria V8V 1X4, Canada

DAM TYPE: CL INCIDENT TYPE: 2A
INCIDENT CAUSE: SI

Incident No.: 18
Dam/Mine Name: Cadet No. 2
Mine Location: Washington County, MO, USA
Ore/Tailings Type: barite
Dam Height (m): 21
Dam Type: CL Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 09-01-1975
Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
During initial raising of the starter dike, sand and gravel mill reject with excessive fines content was used as fill in the downstream portion of the raise. This did not provide sufficient drainage, and a slide resulted due to the high phreatic surface. A 10-foot wide berm of gravel and rock fill was placed to a height of about 40 feet to stabilize the area.
Source: Missouri Dept. of Nat. Res., Dam and Reservoir Safety Program

Incident No.: 19
Dam/Mine Name: Captains Flat Dam 2
Mine Location: Australia
Ore/Tailings Type: copper
Dam Height (m): 22
Dam Type: CL Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was constructed of uncompacted clayey sand and gravel with downstream slopes of 1:1. Considerable seepage at the embankment toe occurred, with damage consisting of multiple cracks and scarps parallel to the crest having a cumulative vertical displacement up to one meter.
Source: Ash, 1976

DAM TYPE: CL INCIDENT TYPE: 2A
INCIDENT CAUSE: SE

Incident No.: 203
Dam/Mine Name: Riltec
Mine Location: Mathinna, Tasmania
Ore/Tailings Type:
Dam Height (m): 7 Dam Type: CL Dam Fill Material: E
Impoundment Volume (Cu. m): 120,000
Incident Information:
Date: 1-6-1995
Incident Type: 2A Cause: SE
Quantity of Water Released (cu. m): 40,000
Tailings Travel Distance (m):
Incident Description:
Leakage of cyanide-contaminated water from base of impoundment into ground water. Dam 1:2 downstream slope, 4m wide crest. Built 3 months before in compacted layers, clay lined. Polluted streams; fish kill. Cessation of operations; owner bankrupt.
Source: Inspector of Mines, Tasmania.

Incident No.: 34
Dam/Mine Name: Cyprus Thompson Creek
Mine Location: Custer County, ID, USA
Ore/Tailings Type: molybdenum
Dam Height (m): 146
Dam Type: CL Dam Fill Material: CST
Impoundment Volume (cu. m): 27,000,000
Incident Information:
Date: 1989 Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An auxiliary drain at the embankment toe originally installed to drain a spring (900 gpm flow) was noted to be discharging fines. Further inspection revealed a sinkhole 8 ft in dia. and 4ft deep on the downstream slope of the embankment. The original drain included a 6-inch dia. PVC pipe wrapped in filter cloth, and it is thought that some form of failure of the filter cloth may have allowed piping into the drain and sinkhole formation to occur.
Source: Idaho Dept. Water Res., Dam Safety Section

DAM TYPE: CL INCIDENT TYPE: 2A
INCIDENT CAUSE: FN

Incident No.: 14
Dam/Mine Name: Big Four
Mine Location: Polk County, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m):
Dam Type: CL Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 08-01-1989
Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The accident was related to sinkhole-induced subsidence in the karstic limestone foundation of the dam, which retained phosphatic clay slimes. No further details are available.
Source: Anecdotal

Incident No.: 120
Dam/Mine Name: Syncrude
Mine Location: Alberta, Canada
Ore/Tailings Type: oil sands
Dam Height (m):
Dam Type: CL Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1978 Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The embankment is founded on pre-sheared clay shales of low residual strength. Measured foundation movements indicated the potential for foundation instability, and portions of the embankment were re-designed with slopes as flat as 9:1.
Source: Morgenstern, et al, 1988

Incident No.: 162
Dam/Mine Name: Unidentified
Mine Location: Hernando County, FL, USA
Ore/Tailings Type: limestone
Dam Height (m): 6
Dam Type: CL Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1977 Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description: The impoundment was used to retain tailings from limestone washing operations of similar nature to phosphatic clay slimes. When the embankment reached a height of about 20 feet, concentrated seepage and piping in karstic foundation limestone occurred at the embankment toe. A small ring dike was constructed around the area, and water within it was allowed to rise until pressure head balanced seepage exit pressures. No further piping occurred.
Source: Anecdotal

DAM TYPE: CL INCIDENT TYPE: 2A
INCIDENT CAUSE: ST

Incident No.: 13
Dam/Mine Name: Big Four
Mine Location: Polk County, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m): 18
Dam Type: CL Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1986 Incident Type: 2A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A metal pipe outlet conduit penetrated the dam, which impounded phosphatic clay slimes. Corrosion of the pipe caused internal erosion of embankment fill soils into it. Remedial measures included repair of the pipe, backfilling of embankment soils, and regrading.
Source: Anecdotal

Incident No.: 32
Dam/Mine Name: Clayton Mine
Mine Location: Custer County, ID, USA
Ore/Tailings Type: silver
Dam Height (m): 24
Dam Type: CL; Dam Fill Material: T
Impoundment Volume (cu. m): 215,000
Incident Information:
Date: 02-06-1983
Incident Type: 2A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A tailings pipeline on the dam crest broke during the night, eroding a gully 2-3 ft wide and 5-6 ft deep on the downstream face of the embankment. No impounded tailings were released and the dam was repaired and placed back in service.
Source: Idaho Dept. Water Res., Dam Safety Section.

DAM TYPE: CL INCIDENT TYPE: 2B
INCIDENT CAUSE: ST

Incident No.: 16
Dam/Mine Name: Blackbird

Mine Location: Cobalt, ID, USA
Ore/Tailings Type: cobalt
Dam Height (m): 15
Dam Type: CL Dam Fill Material: MW
Impoundment Volume (cu. m): 1,230,000
Incident Information:
Date: Incident Type: 2B Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The impoundment was constructed in the 1940's and 1950's with a metal culvert to pass perennial streamflows beneath the dam and impoundment. The culvert corroded under the influence of acidic tailings effluent, and at least partially collapsed. No embankment breach resulted, but suspended tailings were discharged to the downstream drainage during periods of high flow through the damaged culvert..
Source: Montana Dept. State Lands

DAM TYPE: CL INCIDENT TYPE: 3
INCIDENT CAUSE: NR

Incident No.: 51
Dam/Mine Name: Golden Sunlight
Mine Location: Whitehall, MT, USA
Ore/Tailings Type: gold
Dam Height (m):
Dam Type: CL Dam Fill Material: CST
Impoundment Volume (cu. m):
Incident Information:
Date: 05-01-1983 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The seepage control system constructed for the tailings dam included a primary bentonite-slurry cutoff wall, together with drains beneath the impounded tailings and foundation preparation of clayey soils in the impoundment area. The cutoff wall extended as deep as 60 feet to an impermeable stratum. Tailings discharge began in Feb. 1983, and contamination was detected in downgradient monitor wells in May, 1983. It is estimated that 160,000 gal. of cyanide-bearing effluent leaked past the slurry cutoff between April 1983 and June, 1984, with average concentrations of 1.5 mg/l total and 0.3 mg/l free cyanide. The reason for the leakage is presumed to be an undetected landslide-related discontinuity in the impermeable stratum that was not penetrated by the cutoff. Remedial measures included repair of the cutoff and installation of pumpback wells that returned 400 gpm to the impoundment. It is believed that these measures were effective in containing further seepage. Continued migration of the original contaminant plume was not expected to result in detectable levels of contamination in adjacent surface waters.
Source: Montana Dept. State Lands

DAM TYPE: DS INCIDENT TYPE: 1A
INCIDENT CAUSE: SI

Incident No.: 144
Dam/Mine Name: Unidentified
Mine Location: United Kingdom
Ore/Tailings Type: coal
Dam Height (m): 20
Dam Type: DS Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1967 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The failure occurred during regrading operations to stabilize bulging and deformation of the downstream dam slope that had occurred two months previously. Contributing to the failure may have been rise in impoundment fluid levels due to displacement by mine waste being regraded from an adjacent pile. The tailings flow failure covered an area of 4 ha.
Source: Thompson and Rodin, 1972

DAM TYPE: DS INCIDENT TYPE: 1A
INCIDENT CAUSE: SE

Incident No.: 168
Dam/Mine Name: Unidentified
Mine Location: Peace River, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m):
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 02-01-1951
Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam had been raised in height several months prior to the failure using sand fill. At the time of failure, water at least 5 feet deep was in direct contact with the upstream face of the dam, including the interface between the new and old fill. The failure is thought to be related to either the incorporation of logs and brush in the original portion of the structure, or an old decant pipe found at the bottom of the breach. In either case, seepage and piping were the eventual cause of failure. The phosphate clay slimes released produced suspended solids concentrations as high as 8000 ppm in the Peace River.

Source: Anecdotal

DAM TYPE: DS INCIDENT TYPE: 1A
INCIDENT CAUSE: OT

Incident No.: 109
Dam/Mine Name: Silver King
Mine Location: Adams County, ID, USA
Ore/Tailings Type: copper
Dam Height (m): 9
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m): 37,000
Incident Information:
Date: 01-16-1974
Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m): 6,000
Tailings Travel Distance (m):
Incident Description:
Rain on heavy snowpack caused the impoundment to fill to capacity, and emergency pumping was insufficient to prevent overtopping with the loss of 2 million gallons of water and about 20% of the impounded tailings. Downstream damage consisted of silting of streambeds. The embankment was subsequently repaired and placed back into service.
Source: Idaho Dept. Water Res., Dam Safety Section

DAM TYPE: DS INCIDENT TYPE: 1A
INCIDENT CAUSE: ST

Incident No.: 97
Dam/Mine Name: Portworthy
Mine Location: United Kingdom
Ore/Tailings Type: china clay
Dam Height (m): 15
Dam Type: DS Dam Fill Material: R
Impoundment Volume (cu. m):
Incident Information:
Date: 1970 Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam breach occurred due to structural failure of a decant conduit.
Source: Ripley, 1972

DAM TYPE: DS INCIDENT TYPE: 1A
INCIDENT CAUSE: EQ

Incident No.: 43
Dam/Mine Name: El Cobre New Dam
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 19
Dam Type: DS Dam Fill Material: CST
Impoundment Volume (cu. m): 350,000
Incident Information:
Date: 03-28-1965
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 350,000
Tailings Travel Distance (m): 12,000
Incident Description:
The dam was constructed by cycloning and is inferred to have been raised according to the downstream method with a downstream slope of 3.7:1.0. The impoundment had undergone rapid filling immediately prior to the M7-7 1/4 La Ligua earthquake of March 28, 1965. Eyewitness accounts indicated that the impounded slimes completely liquefied, with waves generated on the surface. Inertial forces combined with increased pressure from the liquefied slimes opened a breach near the abutment, which was rapidly enlarged by the flowslide. The failure, combined with that of the adjacent Old Dam, destroyed the town of El Cobre and killed more than 200 people.
Source: Dobry and Alvarez, 1967

DAM TYPE: DS INCIDENT TYPE: 1B
INCIDENT CAUSE: FN

Incident No.: 38
Dam/Mine Name: Derbyshire
Mine Location: United Kingdom
Ore/Tailings Type: coal
Dam Height (m): 8
Dam Type: DS Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1966 Incident Type: 1B Cause: FN
Quantity of Tailings Released (cu. m): 30,000
Tailings Travel Distance (m): 100
Incident Description:
The impoundment had been inactive for 8 years at the time of failure. Foundation materials consisted of 20 feet of clay overlying shale/mudstone bedrock. Failure by foundation sliding was attributed to artesian foundation pore pressures produced by seepage from adjacent active impoundments and natural recharge, with subsidence from underground workings as a possible contributing cause.
Source: Thompson and Rodin, 1972

DAM TYPE: DS INCIDENT TYPE: 2A
INCIDENT CAUSE: SI

Incident No.: 214
Dam/Mine Name: Minera Serra Grande Mine
Location: Crixas, Goias, Brazil
Ore/Tailings Type: gold

Dam Height (m): 41
Dam Type: DS over US Fill Material: CST
Impoundment Volume (Mt): 2.25
Incident Information:
Date: 02-1994 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m): none
Tailings Travel Distance (m):
Incident Description:
Major rotational slip in downstream slope that did not lower the crest. Mine closed for 3 weeks during emergency repairs. Revenue loss equivalent to 8,500 ozs of gold. Starter dam across the valley built of compacted earthfill that was fairly impervious. Filter drains underneath badly constructed and ineffective. Grout curtain cut-off under this earth dam. Abnormal behaviour of the piezometers was no diagnosed. Heavy rainstorms late 1993 and early 1994 brought phreatic surface above starter dam to 'daylight' 20m above downstream toe. For more details, see Section 6.
Source: ICOLD Tailings Committee

Incident No.: 11
Dam/Mine Name: Battle Mt. Gold
Mine Location: Battle Mt., NV, USA
Ore/Tailings Type: gold
Dam Height (m): 8
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m): 1,540,000
Incident Information:
Date: 1984 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Instability of the downstream slope was caused by poor compaction of fill. The slope was reconstructed and flattened
Source: Nevada Dept. of Conservation and Nat. Res., Div. Water Res.

Incident No.: 149
Dam/Mine Name: Unidentified
Mine Location: ID, USA
Ore/Tailings Type: phosphate
Dam Height (m): 34
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1976 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was constructed with downstream slopes of 1.4:1 and a dam raise had been added the previous winter. During the spring thaw, severe sloughing on the downstream face of the dam occurred, accompanied by extensive downslope creep of heavily saturated fill containing blocks of frozen soil. These conditions were attributed to snow and ice having been incorporated during winter construction of the previous raise.
Source: Anecdotal

Incident No.: 145
Dam/Mine Name: Unidentified
Mine Location: United Kingdom
Ore/Tailings Type: coal
Dam Height (m): 14
Dam Type: DS Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: 1967 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A slide occurred in the downstream slope after aperiod of heavy rain and one week following widening of the dam crest by dumping of uncompacted mine waste fill. Both the original and newly-constructed slopes were at the angle of repose, and a high phreatic surface existed within the embankment.
Source: Thompson and Rodin, 1972

Incident No.: 150
Dam/Mine Name: Unidentified
Mine Location: ID, USA
Ore/Tailings Type: phosphate
Dam Height (m): 18
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1965 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was initially constructed and raised using clay and gravel soils with downstream slopes of 1.5:1.0. Slope instability occurred due to lack of internal drainage and the steep embankment slopes. An internal drainage zone was incorporated for subsequent raises of the dam.
Source: Anecdotal

DAM TYPE: DS INCIDENT TYPE: 2A
INCIDENT CAUSE: SE

Incident No.: 86
Dam/Mine Name: Monsanto Dike 15
Mine Location: Colombia, TN, USA
Ore/Tailings Type: phosphate
Dam Height (m): 43
Dam Type: DS Dam Fill Material: E

Impoundment Volume (cu. m): 1,230,000
Incident Information:
Date: 1969 Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The tailings dam was constructed as a conventional water-retention type structure with an internal core, clayey gravel shells, and a blanket drain. Operation of the dam was such that ponded water accumulated directly against the upstream face of the dam. Excessive seepage through the dam occurred during the first few years of operation. The reservoir was lowered, an asphalt emulsion was placed on the upstream face, and seepage was substantially reduced. During operation of subsequently constructed downstream dam raises, tailings were spigotted from the embankment crest as a primary seepage-control measure.
Source: Smith, et. al., 1977

Incident No.: 146
Dam/Mine Name: Unidentified
Mine Location: United Kingdom
Ore/Tailings Type: sandstone
Dam Height (m): 30
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1967 Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Shortly after filling of the first stage of the dam, small slips on the downstream slope, high piezometer pressures, and a break in the decant pipe passing through the dam occurred. These conditions were repaired by placing a filter and buttress on the downstream slope. Following subsequent downstream raising of the dam, seepage occurred at the interface between the new and original fill on the downstream dam slope during impoundment of runoff. This was repaired by placing a synthetic membrane on the exposed upstream face of the dam.
Source: Little and Beavan, 1976

Incident No.: 52
Dam/Mine Name: Granisle
Mine Location: British Columbia, Canada
Ore/Tailings Type: copper
Dam Height (m): 24
Dam Type: DS Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The initial stage of the tailings dam was constructed across a bay of a large lake by dumping mine waste, and tailings were discharged into the bay from the dam crest. A sudden piping failure occurred when the tailings beach reached a level one foot above the lake tailwater elevation, carrying a significant quantity of tailings and effluent through the mine waste and into the lake. The condition was repaired by placing a wide zone of cycloned sand over the spigotted tailings beach, thereby pushing ponded water back from the dam. The combined effects of drainage by cycloned sands and reduction of internal seepage gradients prevented further piping, and subsequent dam raises incorporated an upstream filter zone against the placed mine waste.
Source: Klohn, 1979; Klohn, 1980

Incident No.: 157
Dam/Mine Name: Unidentified
Mine Location: British Columbia, Canada
Ore/Tailings Type:
Dam Height (m):
Dam Type: DS Dam Fill Material: CST
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Piping developed at the abutment of a cycloned sand tailings dam when ponded water rose in response to spring runoff and came into direct contact with the sand tailings embankment fill. This condition had been predicted, and an upstream impervious zone had been added to prevent its occurrence. However, careless spigotting of tailings had eroded this zone at the abutment contact. Repairs consisted of dumping impervious fill on the upstream dam face and filling the downstream eroded piping exit area with sand and gravel filter material.
Source: Klohn, 1979

Incident No.: 158
Dam/Mine Name: Unidentified
Mine Location: British Columbia, Canada
Ore/Tailings Type:
Dam Height (m): 30
Dam Type: DS Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):

Incident Description:
Piping developed in the sand beach of a tailings dam constructed of mine waste, resulting in the discharge of 10,000,000 gallons of ponded water at a peak rate flow of 48,000 gpm. Considerable property damage occurred. Subsequent investigations revealed that an intended upstream filter zone was either absent or improperly placed by end-dumping, and that water had been allowed to pond too close to the dam face with insufficient beach development. Seepage fluctuations and development of sinkholes on the beach prior to the incident were not properly interpreted as indicating the occurrence of piping because no tailings were observed to be present in downstream seepage discharge. Repairs consisted of spigotting tailings from a new dike constructed on the tailings beach far removed from the main dam. The resulting reduction of internal seepage gradients was sufficient to allow the dam to be completed to full height of about 200 feet.
Source: Klohn, 1979.

DAM TYPE: DS INCIDENT TYPE: 2A
INCIDENT CAUSE: FN

Incident No.: 164
Dam/Mine Name: Unidentified
Mine Location: Hernando County, FL, USA
Ore/Tailings Type: limestone
Dam Height (m): 12
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1988 Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):Tailings Travel Distance (m):
Incident Description:
Tailings similar in nature to phosphatic clay slimes were impounded behind a dam constructed of clay fill. Downstream raises of the dam were constructed on a foundation that contained slimes from a previous tailings spill. Slope instability occurred during construction of the final raise, with shearing through the weak foundation slimes.
Source: Anecdotal

Incident No.: 68
Dam/Mine Name: La Belle
Mine Location: Fayette County, PA, USA
Ore/Tailings Type: coal
Dam Height (m): 79
Dam Type: DS Dam Fill Material: MW
Impoundment Volume (cu. m): 1,230,000
Incident Information:
Date: 07-17-1985
Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Movements on the downstream slope were first noticed on July 17, 1985, and small movements occurred daily over the following two weeks. During or after a rain on July 31, 1985, further sliding occurred leaving a scarp up to 4 ft high and 800 ft long. Thirteen families were evacuated for a short period of time. Movements were caused by translation-type sliding along a residual foundation clay layer that dipped in a downstream direction. Repairs included rock drains on the downstream face and a buttress of rock and coarse refuse. There had been no further movement through 1989.
Source: Pennsylvania Dept. of Environ. Div. of Dams Safety; LaBelle Processing Company, Uniontown, PA 15401

DAM TYPE: DS INCIDENT TYPE: 2A
INCIDENT CAUSE: OT

Incident No.: 108
Dam/Mine Name: Silver King
Mine Location: Adams County, ID, USA
Ore/Tailings Type: copper
Dam Height (m): 9
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m): 37,000
Incident Information:
Date: 08-05-1989
Incident Type: 2A Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The tailings impoundment was being used for water retention when a mine waste dump founded on a portion of the tailings in the impoundment failed, displacing about 1-2 ac-ft of water and overtopping the dam. The tailings dam was not significantly damaged. Only some silting of downstream stream channels was reported.
Source: Idaho Dept. Water Res., Dam Safety Section; Alta Gold Co., Salt Lake City, UT 84109, USA.

DAM TYPE: DS INCIDENT TYPE: 2A
INCIDENT CAUSE: ST

Incident No.: 121
Dam/Mine Name: TN Consolidated Coal No.1
Mine Location: Marion County, TN, USA
Ore/Tailings Type: coal
Dam Height (m): 85
Dam Type: DS Dam Fill Material: MW
Impoundment Volume (cu. m): 1,000,000

Incident Information:
Date: 01-19-1988
Incident Type: 2A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam contained an abandoned 3-ft diameter outlet conduit that had been plugged at both ends with concrete, with the conduit interior drained by an 8-inch bleed pipe. The upstream end of the conduit developed a leak which produced inflow greater than the capacity of the 8-inch bleed line to drain it, and water began seeping out on the downstream face of the dam near the toe. The accident drained all 6.5 million gallons of water impounded by the dam and produced severe erosion of the downstream face which exposed the buried conduit. The conduit was completely backfilled with concrete and the dam placed back in service.
Source: Division of Water Pollution Control, Tennessee Department of Health and Environment;

Incident No.: 82
Dam/Mine Name: Missouri Lead
Mine Location: MO, USA
Ore/Tailings Type: lead
Dam Height (m): 17
Dam Type: DS Dam Fill Material: CST
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
In conjunction with raising of the dam using cycloned sand tailings, a foundation drainage system consisting of 6-in dia. Perforated corrugated metal pipe surrounded by filter gravel was installed. When the cycloned sand fill had reached a height of 55 feet above the pipe, a sinkhole 25 ft. in diameter and 20 ft. deep developed on the sandfill surface. The sinkhole was attributed to collapse of the drainage pipe, and investigations showed the pipe to be severely corroded by the slightly acidic pH of the seepage effluent. The pipe ends were plugged, and internal drainage was directed to pervious in-situ foundation soils to the downstream toe of the dam.
Source: Brawner, 1979

DAM TYPE: DS INCIDENT TYPE: 2A
INCIDENT CAUSE: EQ

Incident No.: 44
Dam/Mine Name: El Cobre No. 4
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 50
Dam Type: DS Dam Fill Material: CST
Impoundment Volume (cu. m):
Incident Information:
Date: 03-03-1985
Incident Type: 2A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was constructed with upstream slopes of 1.9:1, downstream slopes of 4.6:1, and with a blanket drain. Cycloned sands received some compaction during spreading with a bulldozer. During the M7.8 earthquake of March 3, 1985, minor damage occurred in the form of a sloughing of sands in the upper part of the downstream slope and shallow slides in the upper 6 ft of the unsubmerged upstream slope.
Source: Castro and Troncoso, 1989

DAM TYPE: DS INCIDENT TYPE: 2B
INCIDENT CAUSE: SI

Dam ID Number: 143
Dam/Mine Name: Unidentified
Mine Location: United Kingdom
Ore/Tailings Type: coal
Dam Height (m): Dam Type: DS Fill Material:
Impoundment Volume (cu.m):
Incident Information:
Date: Incident Type: 2B Cause: SI
Quantity of Tailings Released (cu.m):
Tailings Travel Distance (m):
Incident Description:
Sliding of the upstream slope of the dam occurred during excavation of the impounded tailings to a depth of 40 ft intended to allow re-use of the impoundment. The failure was attributed to rapid-drawdown conditions on the upstream slope following removal of the tailings.
Source: Thompson and Rodin, 1972

DAM TYPE: DS INCIDENT TYPE: 2B
INCIDENT CAUSE: EQ

Incident No.: 90
Dam/Mine Name: Norosawa
Mine Location: Japan
Ore/Tailings Type: gold
Dam Height (m): 24
Dam Type: DS Dam Fill Material:
Impoundment Volume (cu. m): 225,000
Incident Information:
Date: 01-14-1978
Incident Type: 2B Cause: EQ
Quantity of Tailings Released (cu. m):

Tailings Travel Distance (m):
Incident Description:
The dam had been abandoned for 13 years at the time of the M7.0 Izu-Oshima-Kinkai earthquake. Boils appeared on the surface of the impounded slimes and the dam was cracked, but no failure occurred.
Source: Okusa, et al, 1980

Incident No.: 56
Dam/Mine Name: Hirayama
Mine Location: Japan
Ore/Tailings Type: gold
Dam Height (m): 9
Dam Type: DS Dam Fill Material:
Impoundment Volume (cu. m): 87,000
Incident Information:
Date: 1978 Incident Type: 2B Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam experienced ground accelerations estimated to be 0.2-0.35 g from the M7.0 Izu-Oshima-Kinkai earthquake. The impoundment had been inactive for about 20 years. The dam experienced cracking and impounded tailings exhibited sand boils, but no failure occurred.
Source: Okusa, et al, 1980

DAM TYPE: DS INCIDENT TYPE: 3
INCIDENT CAUSE: NR

Incident No.: 87
Dam/Mine Name: Montana Tunnels
Mine Location: Jefferson City, MT, USA
Ore/Tailings Type: gold
Dam Height (m): 33
Dam Type: DS Dam Fill Material: MW
Impoundment Volume (cu. m): 250,000
Incident Information:
Date: 1987 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The impoundment bottom was lined with a compacted soil-bentonite liner underlain by a sand filter blanket. The liner was eroded at several locations due to (1) concentrated runoff from high-intensity rainstorms prior to tailings deposition, and (2) initial spigotting of tailings and emergency release of reclaim water into the impoundment. Damage to the liner was repaired, but some of the damage may not have been detected, and the integrity of the liner in repaired areas may not have been completely restored. When tailings deposition resumed following liner repairs, routine groundwater monitoring detected elevated levels of process solution immediately downstream from the embankment. Impoundment seepage was estimated as 450 to 650 gpm. A recovery system of pumpback wells was installed downstream from the embankment. This was effective in intercepting the contaminated groundwater and has contained the contaminant plume within the mine site boundaries.
Source: Clark, et al, 1989; Montana Dept. State Lands

Incident No.: 53
Dam/Mine Name: Grey Eagle
Mine Location: Siskiyou County, CA, USA
Ore/Tailings Type: gold
Dam Height (m):
Dam Type: DS Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1983 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam contained an upstream-sloping clay core with granular shells, and was constructed on a jointed rock foundation. Provision was made for installation of a dam seepage collection and pumpback system to return contaminated fluids to the impoundment. Unforeseen problems resulted in higher effluent cyanide concentrations than anticipated, and unprecedented precipitation produced high seepage return flows. Three months after filling began, dam through-seepage and infiltration into the downstream shell reached 400 gpm. Undiluted cyanide concentrations within the internal drainage system reached 20 ppm free and 100 ppm total. This seepage and unattenuated cyanide was not anticipated, and its return to the impoundment had adverse effects on the system water balance. To prevent contamination of surface and groundwater, surface diversion and drainage of downstream-shell infiltration; enlargement of the seepage pumpback system; construction of a treatment plant for dam seepage; and measures to reduce impoundment inflows were proposed.
Source: Hutchinson, et al, 1985; Centurion Gold Ltd., Vancouver

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Incident No.: 133
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type: gold
Dam Height (m):

Dam Type: DS   Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An initial zoned earthfill dam was constructed of borrow excavated from within the impoundment. The impoundment was not lined, and complete cutoff of foundation seepage could not be guaranteed at the dam site selected. Seepage mitigation measures incorporated in the design included an extensive underdrain system within the impoundment, a trench drain along the downstream toe of the dam, and extensive piezometer instrumentation. Filling of the impoundment resulted in excessive seepage around the abutments and beneath the trench drain through interconnected zones of sands and gravels within the impoundment area. Remedial measures included construction of a deep trench drain system incorporating pumpback wells downstream from the raised dam toe.
Source: Anecdotal

DAM TYPE: WR   INCIDENT TYPE: 1A
INCIDENT CAUSE: SI

Incident No.: 165
Dam/Mine Name: Unidentified
Mine Location: Peace River, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m): 8
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 03-01-1952 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam failed by sliding of the downstream and possibly also the upstream slope. Contributing causes may have included (1) retention of clear water above the level of the impounded phosphate clay slimes and directly against the upstream face of the dam, (2) active mining and blasting at adjacent locations downstream from the dam; and (3) inadequate stripping and grubbing of the dam/foundation contact.
Source: Anecdotal

Incident No.: 156
Dam/Mine Name: Unidentified
Mine Location: Alafia River, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m): 8
Dam Type: WR   Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 02-01-1952 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam incorporated a return-water canal at its downstream toe that impounded water against the downstream face of the dam. Failure occurred when water in the canal was released by a break in its confining dike. The rapid reduction in canal tailwater level probably caused rapid-drawdown instability of the downstream slope of the impoundment dam. The breach was about 100 feet wide, and the resulting release of phosphatic clay slimes impounded behind the dam produced suspended solids concentrations as high as 20,000 ppm in the Alafia River.
Source: Anecdotal

Incident No.: 6
Dam/Mine Name: Avoca Mines
Mine Location: Ireland
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: WR   Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Tailings were confined by dikes of primarily tailings fill placed with a dragline and levelled with a bulldozer. The fill received little or no compaction, and dike slopes ranged from 33 to 38 degrees at or near the angle of repose of the material. Multiple failures of the dikes occurred, depositing impounded tailings into the nearby Avoca River.
Source: Brawner, 1979

DAM TYPE: WR   INCIDENT TYPE: 1A
INCIDENT CAUSE: SE

Incident No.: 112
Dam/Mine Name: Southern Clay
Mine Location: TN, USA
Ore/Tailings Type: clay
Dam Height (m): 5
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 09-07-1989
Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m): 300
Tailings Travel Distance (m):
Incident Description:

A low berm was constructed along the rim of an abandoned clay pit used for retention of process fines and clarification of process water. The berm fill was not compacted and incorporated brush and debris. The failure occurred due to uncontrolled seepage at the foundation contact after a period of rapid impoundment rise. About 80,000 gallons of process water was released.
Source: Division of Water Pollution Control, Tennessee Dept. of Health and Environment

Incident No.: 91
Dam/Mine Name: Ollinghouse
Mine Location: Wadsworth, NV, USA
Ore/Tailings Type: gold
Dam Height (m): 5
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m): 120,000
Incident Information:
Date: 1985 Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m): 25,000
Tailings Travel Distance (m): 1,500
Incident Description:
With no engineering supervision during construction, the dam fill was essentially uncompacted (less than 80% maximum dry density). Collapse of the fill occurred as saturation developed resulting in loss of freeboard, slumping of the slope, and breach of the dam.
Source: Nevada Dept. of Conservation and Nat. Res., Div. Water Res.; Centurion Gold Ltd., Vancouver

Incident No.: 167
Dam/Mine Name: Unidentified
Mine Location: Peace River, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m): 6
Dam Type: WR Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: 09-01-1951
Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was constructed of mine waste, probably sands and clays. At the time of failure, the impoundment contained about 12 feet of phosphatic clay slimes and 1.5 feet of water in direct contact with the upstream embankment face. Failure occurred by seepage and piping on the downstream face of the embankment, with a possible contributing factor being 1.6 inches of rainfall prior to failure. The released slimes produced suspended solids concentrations of 15,000 ppm in a creek immediately adjacent to the impoundment and 800 ppm in the Peace River farther downstream.
Source: Anecdotal

Incident No.: 166
Dam/Mine Name: Unidentified
Mine Location: Peace River, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m): 30
Dam Type: WR Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: 07-01-1951
Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam had been constructed to a height of 100 feet using draggling-cast mine waste, probably consisting of sands and clays. At the time of failure, phosphate slimes and clear water were impounded to a depth of 25 feet, and failure is believed to have been due to seepage and piping, perhaps exacerbated by considerable rainfall just prior to the failure. The released slimes produced suspended solids concentrations as high as 800 ppm in the Peace River.
Source: Anecdotal

DAM TYPE: WR INCIDENT TYPE: 1A
INCIDENT CAUSE: FN

Incident No.: 209
Dam/Mine Name: Los Frailes
Mine Location: 45 km west of Seville, Spain
Ore/Tailings Type: pyretic zinc-lead-copper
Dam Height (m): 27
Dam Type: WR Dam Fill Material: R
Impoundment Volume (cu. m): 15,000,000
Incident Information:
Date: 01.00 on 04-24-1998
Incident Type: lA Cause: FN
Quantity of Tailings Released (cu. m): 6,800,000
Tailings Travel Distance (m): 40,000
Incident Description:
Dam built of waste rockfill was designed to have an upstream sloping earth core connected to a slurry trench cut-off passing through the alluvial gravels into underlying marl. A 600m long section slid forwards and opened like a gate, the body of the dam remaining intact. Subsequent site investigation indicated that failure occurred along a shear plane about 14m below the base of the dam. Water leakage through an adjacent section may have been a contributory factor.
Source: Boliden News Release 25th to 28th April 1998 and other reports.

Incident No.: 187
Dam/Mine Name: No 3 tailings pond
Mine Location: Sipalay, Negros Occidental, Philippines.
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: WR Dam Fill Material: MW
Impoundment Volume (cu. m): 37 Mt
Incident Information:
Date: 16.00 on 11-08-1982
Incident Type: lA Cause: FN
Quantity of Tailings Released (cu. m): 27Mt
Tailings Travel Distance (m):
Incident Description:
Failure of section of dam due to slippage of foundation on clayey soil; surface materials not removed prior to construction. Inadequate anchoring of starter dam; use of mixed mine waste of very variable particle size.
Source:

Incident No.: 173
Dam/Mine Name: United Nuclear
Mine Location: Churchrock, NM, USA
Ore/Tailings Type: uranium
Dam Height (m): 11
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m): 370,000
Incident Information:
Date: 07-16-1979
Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m): 700
Tailings Travel Distance (m):
Incident Description:
Differential foundation settlement, aggravated by a high operating pond level and narrow tailings beach, caused embankment cracking and failure by piping. Post-failure Investigations showed that some foundation soils were subject to in excess of 10% collapse upon saturation. The absence of an adequate sand beach and direct contact of water with the embankment fill allowed piping to occur through cracks in the fill that developed in response to foundation settlement. Roughly 80 million gallons of released effluent traveled to the Rio Puerco, through Gallup, NM, and into Arizona for a distance of 60-70 miles before completely infiltrating into the streambed alluvium.
Source: Nelson and Kane, 1980; Sautter, 1984

Incident No.: 64
Dam/Mine Name: Kerr-McGee
Mine Location: Churchrock, NM, USA
Ore/Tailings Type: uranium
Dam Height (m): 9
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 04-01-1976
Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Differential settlement of foundation soils caused embankment cracking and piping failure. A minor quantity of effluent was released.
Source: New Mexico State Engineers Office

DAM TYPE: WR INCIDENT TYPE: 1A INCIDENT CAUSE: OT

Incident No.: 17
Dam/Mine Name: Bonsal
Mine Location: Anson County, NC, USA
Ore/Tailings Type: sand & gravel
Dam Height (m): 5
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m): 38,000
Incident Information:
Date: 08-01-1985
Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m): 11,000
Tailings Travel Distance (m): 800
Incident Description:
A rainfall of 7 to 9 inches in 12 hours caused an overtopping failure that released clay tailings and 3 million gallons of water into an adjacent stream. The dam is reported to have had an outlet or spillway of unknown type, and the breach occurred at this location. The materials released caused some damage at the sand and gravel plant immediately downstream but were contained in the plant's freshwater pond located downstream from the plant. The dam was repaired and placed back in service.
Source: North Carolina Dept. of Environ. Health and Nat. Res., Land Quality Section

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Incident No.: 74
Dam/Mine Name: Madison
Mine Location: Madison County, MO, USA
Ore/Tailings Type: lead
Dam Height (m): 11
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 02-28-1977
Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam overtopped during an intense 6-inch rainfall due to inadequate spillway capacity.

Tailings flowsliding did not develop, although tailings were eroded by the impounded water flowing through the breach. These tailings were subsequently deposited throughout the city of Fredricktown.
Source: Missouri Dept. of Nat. Res., Dam and Reservoir Safety Program

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Incident No.: 93
Dam/Mine Name: Park
Mine Location: United Kingdom
Ore/Tailings Type: china, clay
Dam Height (m): 3
Dam Type: WR Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1970 Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Overtopping failure occurred due to ice blockage of a decant structure.
Source: Ripley, 1972

DAM TYPE: WR INCIDENT TYPE: 1A INCIDENT CAUSE: ST

Incident No.: 179
Dam/Mine Name: Virginia Vermiculite
Mine Location: Louisa County, VA, USA
Ore/Tailings Type: vermiculite
Dam Height (m): 9
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1984 Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A pipe spillway through the clay-shale embankment collapsed and caused the dam to fail A downstream impoundment contained the tailings released. The dam was repaired by plugging the old spillway and installing a new spillway.
Source: Virginia Dept. Mines, Minerals and Energy, Div. Mined Land Reclamation

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Incident No.: 127
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type:
Dam Height (m):
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam consisted of a homogeneous section of well-compacted clay shale and sandstone- derived fill. The decant pipe, which penetrated the embankment, ruptured due to minor differential settlement. Embankment failure occurred rapidly.
Source: Casagrande and McIver, 1971

DAM TYPE: WR INCIDENT TYPE: 1A INCIDENT CAUSE: MS

Incident No.: 73
Dam/Mine Name: Iwiny
Mine Location: Lower Silesia, Poland
Ore/Tailings Type: copper
Dam Height (m): 25
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m): 16,000,000
Incident Information:
Date: 09-17-1967
Incident Type: 1A Cause: MS
Quantity of Tailings Released (cu. m): 4,600,000
Tailings Travel Distance (m): about 15,000
Incident Description:
The dam was constructed on alluvium underlain by a 20-m wide fault zone, in a general area of underground mining. 3rd stage of dam was almost completed, no signs of defects, e.g. cracking, seepage, or wet areas were detected. Underground mining was approaching the fault and pumping from the mine had lowered the water table. The dewatering and vibrations from rockbursts are thought to have loosened the fault gouge such that upward stopping created a cavity and ultimately a sinkhole beneath the upstream slope of the dam. A breach occurred near S end of dam: liquefied tailings swept down the valley with a width of 50m to 220m, covering 7 small villages, destroying the railway and killing 18 people. Dam breach and loss of impoundment contents resulted
Source: Wolski, et al, 1976; ICOLD Tailings Committee.

DAM TYPE: WR INCIDENT TYPE: 1A INCIDENT CAUSE: ER

Incident No.: 205
Dam/Mine Name: Tailings dam No 1
Mine Location: Omai gold mine, Guyana
Ore/Tailings Type: gold
Dam Height (m): 44
Dam Type: WR Dam Fill Material: R
Impoundment Volume (cu. m): 5,250,000
Incident Information:

Date: 23.55 on 08-25-1995
Incident Type: lA Cause: ER
Quantity of Tailings Released (cu. m): 4,200,000
Tailings Travel Distance (m):
Incident Description:
Dam of waste rockfill with compacted saprolite core supported by sand filter. Raised above original height progressively to match the impoundment. Rear deposition with water against dam. Piping failure, initially around construction drain pipe, carried core and materials through rockfill. Cyanide contamination caused minor fish kill in Omai river. Pollution of the much larger Essequibo river negligible: Canadian drinking water standards not exceeded.
Source: Reports from Guyana and Vick 1996.

DAM TYPE: WR INCIDENT TYPE: 1A
INCIDENT CAUSE: U

Incident No.: 31
Dam/Mine Name: Cities Service
Mine Location: Fort Meade, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m): 15
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m): 12,340,000
Incident Information:
Date: 12-03-1971 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m): 9,000,000
Tailings Travel Distance (m): 120,000
Incident Description:
Breach of the dam allowed the phosphatic clay slimes to enter the Peace River, where they were carried in suspension for 120 km. Although the slimes are non-toxic to humans, a vast fish kill occurred when the slimes coated the gills of fish, causing them to suffocate. The cause of the failure is unknown, although the dam was observed to have been intact and with no signs of distress 15 minutes before the failure occurred.
Source: Lucia, 1981; Environmental Science and Technology, 1974

DAM TYPE: WR INCIDENT TYPE: 1B
INCIDENT CAUSE: OT

Incident No.: 190
Dam/Mine Name: Rossarden
Mine Location: Rossarden, Tasmania
Ore/Tailings Type:
Dam Height (m): 7.5
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m): 200,000
Incident Information:
Date: 05-16-1986 Incident Type: lB Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam built in 1931 on a valley side l90 m above the river, of layered earth and tea-tree matting, in an uncontrolled manner. Water breached the main side of the impoundment area, swept through the impoundment and overtopped the front dam causing failure. The river was polluted.
Source: Inspector of Mines, Tasmania.

DAM TYPE: WR INCIDENT TYPE: 1B
INCIDENT CAUSE: SI

Incident No.: 206
Dam/Mine Name: Placer Bay, Tailing Pond No.5
Mine Location: Surigao Del Norte, Philippines
Ore/Tailings Type:
Dam Height (m): 17
Dam Type: WR Dam Fill Material: E
Impoundment Volume (Cu. m):
Incident Information:
Date: 9:20 on 09-02-1995
Incident Type: lB Cause: SI
Quantity of Tailings Released (Cu. m): 50,000
Tailings Travel Distance (m): out to sea
Incident Description:
Inactive impoundment. Waste rock being placed on top of tailings for storage when dam failed into the sea forming 100m breach. Cause partly toe erosion and foundation on reclaimed land. 12 killed including safety inspector, and 14 pieces of heavy equipment that had been working to place waste rock on the impoundment.
Source: Reports from Republic of the Philippines

DAM TYPE: WR INCIDENT TYPE: 2A
INCIDENT CAUSE: SI

Incident No.: 122
Dam/Mine Name: Texasgulf 4B Pond
Mine Location: Beaufort County, NC, USA
Ore/Tailings Type: phosphate
Dam Height (m): 8
Dam Type: WR Dam Fill Material: T
Impoundment Volume (cu. m): 12,300,000
Incident Information:
Date: 04-01-1984 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A 200-ft long shallow slide occurred on the downstream slope of this slimes dam at the point of transition where the slope flattened from 3H:1V to 6H:1V. Clay spoil from adjacent ditch excavation placed on the embankment slope had blocked seepage, which caused the phreatic surface to rise and slope instability to occur. The

slope was repaired by installing filtered drainage trenches.
Source: North Carolina Dept. of Environ. Health and Nat. Res., Land Quality Section; Texasgulf Inc., Raleigh

Incident No.: 123
Dam/Mine Name: Texasgulf No. 1 Pond
Mine Location: Beaufort County, NC, USA
Ore/Tailings Type: phosphate
Dam Height (m):
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m): 24,700,000
Incident Information:
Date: 1981-1983 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Several slides occurred from 1981 through 1983 along a several thousand foot section of the downstream slope of the phosphate slimes pond dike. The instability was caused by seepage related to clay layers deposited in the dredged dike fill. The slope failures were repaired by installation of filtered drains.
Source: North Carolina Dept. of Environ. Health and Nat. Res., Land Quality Section

Incident No.: 118
Dam/Mine Name: Suncor E-W Dike
Mine Location: Alberta, Canada
Ore/Tailings Type: oil sands
Dam Height (m): 30
Dam Type: WR Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: 1979 Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Slope instability occurred during construction of the dam. Remedial measures included slope flattening and incorporation of horizontal internal sand zones to enhance pore pressure dissipation.
Source: Morgenstern, et al, 1988

DAM TYPE: WR INCIDENT TYPE: 2A
INCIDENT CAUSE: FN

Incident No.: 186
Dam/Mine Name: Heath Steele main dam
Mine Location: Bathurst, New Brunswick
Ore/Tailings Type: Copper/zinc
Dam Height (m): 30
Dam Type: WR
Dam Fill Material: Rock, glacial till & clay core
Impoundment Volume (cu. m):
Incident Information:
Date: Since 1970s
Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m): Seepage of contaminated water
Tailings Travel Distance (m):
Incident Description:
Leakage of water containing copper and zinc. Dam built on fractured bedrock, with no liner or grouting.
Source: DoE, Canada

Incident No.: 89
Dam/Mine Name: N'yukka Creek
Mine Location: USSR
Ore/Tailings Type:
Dam Height (m): 12
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1965 Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was constructed as a starter dike for subsequent upstream raising, and operated initially to retain water. During first filling, sinkholes appeared in both abutments, and were initially treated by covering with tailings. When this proved ineffective, a concrete cutoff wall was constructed through the embankment and into the foundation. Sinkhole development was attributed to thawing of foundation permafrost that allowed ice-filled joints in foundation rock to transmit seepage and piping to occur.
Source: Biyanov, 1976

Incident No.: 141
Dam/Mine Name: Unidentified
Mine Location: USA
Ore/Tailings Type: magnesia
Dam Height (m): 6
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Confining dikes were constructed on soft tidal flats foundation materials by casting fill with a dragline and later hauling it with trucks and spreading with bulldozers. The dikes experienced severe deformation and cracking, slumping, and bulging at the toe. Emergency remedial action averted failure.
Source: Wahler and Schlick, 1976

Incident No.: 134

Dam/Mine Name: Unidentified
Mine Location: Europe
Ore/Tailings Type:
Dam Height (m): 24
Dam Type: WR Dam Fill Material: R
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A concrete faced rockfill starter dike was constructed on a karstic limestone foundation. Although a grout blanket was placed over exposed limestone within the impoundment area, a number of sinkholes developed during initial filling that drained the reservoir. One area of sinkhole formation was at the upstream toe of the concrete facing, and investigations revealed interconnected solution cavities in this area as well as extensive caverns in the dam abutment near the crest. Repairs included careful excavation of solution features and plugging with a mixture of mine waste and concrete accompanied by placement of a 10-foot thick mine waste layer over treated areas to bridge and plug potential future sinkholes that might develop.
Source: Robinson and Toland, 1979

DAM TYPE: WR INCIDENT TYPE: 2A INCIDENT CAUSE: ST

Incident No.: 61
Dam/Mine Name: Irelyakh
Mine Location: USSR
Ore/Tailings Type:
Dam Height (m): 10
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was being built as a starter dike for subsequent upstream embankment raising. Used initially to retain water, excessive seepage developed at the contact of the wooden spillway and the foundation. This was attributed to the poor quality of winter construction.
Source: Biyanov, 1976

DAM TYPE: WR INCIDENT TYPE: 2A INCIDENT CAUSE: EQ

Incident No.: 26
Dam/Mine Name: Cerro Blanco de Polpaico
Mine Location: Chile
Ore/Tailings Type: limestone
Dam Height (m): 9
Dam Type: WR Dam Fill Material: R
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 2A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The rockfill dam with slideslopes of about 1.5:1.0 was subjected to the M7-7 1/4 La Ligua earthquake. Damage consisted of shallow longitudinal cracking on the crest.
Source: Dobry and Alvarez, 1967

DAM TYPE: WR INCIDENT TYPE: 2A INCIDENT CAUSE: ER

Incident No.: 95
Dam/Mine Name: Pinchi Lake
Mine Location: British Columbia, Canada
Ore/Tailings Type: mercury
Dam Height (m): 13
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1971 Incident Type: 2A Cause: ER
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The tailings dam consisted of a homogeneous section of compacted glacial till. Water decanted from the impoundment flowed in an unlined channel parallel to the downstream toe of the dam. Erosion of the unlined channel produced downcutting of as much as 12 feet. This triggered cracking and deformation of the downstream embankment slope, with movements seated within lacustrine foundation sediments at a depth coincident with the eroded channel bottom. Movements were stabilized by placement of a berm and relocation of the channel.
Source: Brawner, 1979

DAM TYPE: WR INCIDENT TYPE: 2B INCIDENT CAUSE: ER

Incident No.:198
Dam/Mine Name: Kojkovac
Mine Location: Majkovac, Montenegro.
Ore/Tailings Type: lead/zinc
Dam Height (m):
Dam Type: WR Dam Fill Material: E
Impoundment Volume (Cu. m): 3,500,000
Incident Information:
Date: 11-1992 Incident Type: 2B Cause: ER

Quantity of Tailings Released (cu. m): none
Tailings Travel Distance (m):
Incident Description:
Earthfill dam with plastic liner built about 1970 alongside Tara river. Dam toe eroded by flooded river, caused slip that halved thickness of crest, but no overtopping. River diverted and toe protected by gabions under UN emergency project to prevent pollution that would have affected Danube.
Source: UNDRO, Geneva.

DAM TYPE: WR INCIDENT TYPE: 3
INCIDENT CAUSE: NR

Incident No.: 98
Dam/Mine Name: Rain Starter Dam
Mine Location: Elko, NV, USA
Ore/Tailings Type: gold
Dam Height (m): 27
Dam Type: WR Dam Fill Material: ER
Impoundment Volume (cu. m): 1,500,000
Incident Information:
Date: 1988 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Unanticipated seepage occurred through the impoundment bottom that resulted in an effluent spring downstream from the dam discharging 5 gpm. Seepage was retained by a catchment dam and pumped back to the impoundment.
Source: Nevada Dept. of Conservation and Nat. Res., Div. Water Res.

Incident No.: 35
Dam/Mine Name: Dam No. 1
Mine Location: Elliot Lake Ontario, Canada
Ore/Tailings Type: uranium
Dam Height (m): 9
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1979 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Measures to reduce seepage were undertaken in conjunction with abandonment and closure of the impoundment. These included an embankment buttress with an internal synthetic impervious membrane, and cement-bentonite grouting of selected zones of the rock foundation. Post-construction monitoring indicated seepage of less than 1 gpm.
Source: Reades, et al, 1981

Incident No.: 161
Dam/Mine Name: Unidentified
Mine Location: Green River, WY, USA
Ore/Tailings Type: trona
Dam Height (m): 18
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 1975 Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was constructed to retain tailings and provide evaporation of effluent from trona mined for soda ash processing. Foundation conditions consisted of highly fractured rock with open joints, and the dam initially incorporated a nominal cutoff. When seepage containing high salt concentrations emerged on the surface downstream from the dam, foundation grouting was performed but failed to stop the seepage. Subsequently, an interceptor trench was excavated at the downstream toe to depths up to 60 feet and backfilled with drainage material. Pumping from wells installed in the interceptor trench was effective in preventing further downstream seepage migration.
Source: Anecdotal

Incident No.: 155
Dam/Mine Name: Unidentified
Mine Location: WY, USA
Ore/Tailings Type: trona
Dam Height (m): 24
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was constructed to retain tailings and evaporate effluent from trona processed for soda ash, and included a cutoff to reduce seepage through highly fractured foundation bedrock. Approximately 150 gpm of underseepage occurred, somewhat greater than anticipated quantities and of environmental concern due to deposits it produced on the ground surface. No remedial measures were adopted due to the presence of a secondary pond downstream where seepage was collected and returned to the main impoundment.
Source: Robinson and Toland, 1979

Incident No.: 132
Dam/Mine Name: Unidentified
Mine Location:
Ore/Tailings Type: gold

Dam Height (m): 8
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The impoundment was lined with a 40-mil PVC geomembrane without an overlying soil cover. During initial tailings deposition when tailings had accumulated over the liner to an average depth of less than one foot, an air bubble developed beneath the liner and lifted it about 20 feet over a 100-ft diameter area. The cause of bubble formation was not determined but may have been related to formation of water vapor from subgrade soil moisture. The liner over the bubble ruptured, allowing a small quantity of tailings and retained fluid to escape. The liner was repaired after decontamination and cleanup. Other smaller bubble areas were vented using a special apparatus.
Source: Anecdotal

Incident No.: 148
Dam/Mine Name: Unidentified
Mine Location: CO, USA
Ore/Tailings Type:
Dam Height (m):
Dam Type: WR Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A soil-bentonite slurry cutoff was constructed to reduce unacceptable quantities of contaminated foundation underseepage. The cutoff was installed to the greatest depth possible without expensive rock excavation. Remaining zones of underseepage through fractured rock below the bottom of the cutoff were identified by piezometers and locally grouted, effectively stopping the seepage.
Source: Taylor and Achhorner, 1984

DAM TYPE: GRAVITY INCIDENT TYPE: 1A INCIDENT CAUSE: ST

Incident No.: 189
Dam/Mine Name:
Mine Location: Itabirito, Minas Gerais, Brazil
Ore/Tailings Type: Iron ore
Dam Height (m): 30
Dam Type: Gravity Dam Fill Material: Masonry
Impoundment Volume (cu. m):
Incident Information:
Date: Late 05-1986
Incident Type: lA Cause: ST
Quantity of Tailings Released (tonnes): 100,000
Tailings Travel Distance (m): 12,000
Incident Description:
Dam of masonry construction using bricks made from clay and iron ore tailings burst, it is said, due to saturation of the brickwork. Loss of mining equipment and infrastructure: 7 dead.
Source: Engineering News Record, 5th June 1986.

DAM TYPE: VALLEY SIDE INCIDENT TYPE: 1B INCIDENT CAUSE: OT

Incident No.: 191
Dam/Mine Name: Story's Creek
Mine Location: Tasmania
Ore/Tailings Type:
Dam Height (m): 17
Dam Type: Valley side Dam Fill Material:
Impoundment Volume (cu. m): 30,000
Incident Information:
Date: 05-16-1986
Incident Type: lB Cause: OT
Quantity of Tailings Released (Cu. m): minimal
Tailings Travel Distance (m):
Incident Description:
Dam built in 1931 in an uncontrolled manner, mainly of tailings, with crest width of 1m and downstream slope 1:1. Overtopped during 1 in 100 year flood. Dam failed, spillway shifted; slimes released; pipeline washed out causing further pollution of waterway.
Source: Inspector of Mines, Tasmania.

DAM TYPE: NR INCIDENT TYPE: 1A INCIDENT CAUSE: SI

Incident No.: 180
Dam/Mine Name: Western Nuclear
Mine Location: Jeffrey City, WY, USA
Ore/Tailings Type: Uranium
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1977 Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 40
Tailings Travel Distance (m):
Incident Description:
The dam slopes were steeper than 3:1, and melting of snow incorporated into the dam fill caused sufficient slumping to allow overtopping to occur. About 2.3 million gallons of effluent was released along with a small quantity of tailings, but no offsite contamination occurred.

Source: Teknekron, Inc., 1978

Incident No.: 217
Dam/Mine Name:
Mine Location: Stoney Middleton, UK
Ore/Tailings Type:
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (Mt):
Incident Information:
Date: 02-08-1968
Incident Type: lA Cause: SI
Quantity of Tailings Released (tons):
Tailings Travel Distance (m):
Incident Description:
The retaining dam of a settling pond burst and there was damage to property and roads.
Source: Penman and Charles 1990

Incident No.: 15
Dam/Mine Name: Bilbao
Mine Location: Spain
Ore/Tailings Type:
Dam Height (m):
Dam Type: Dam Fill Material: R
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: SI
Quantity of Tailings Released (cu. m): 115,000
Tailings Travel Distance (m):
Incident Description:
Sloughing of the rockfill dam following heavy rains caused large strains in the saturated tailings deposit that induced liquefaction and tailings flowsliding, with major downstream damage and loss of life.
Source: Smith, 1969

DAM TYPE: NR INCIDENT TYPE: 1A INCIDENT CAUSE: SE

Incident No.: 119
Dam/Mine Name: Sweeney Tailings Dam
Mine Location: Longmont, CO, USA
Ore/Tailings Type: sand and gravel
Dam Height (m): 7
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 05-01-1980
Incident Type: 1A Cause: SE
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam breached due to piping around outlet conduit.
Source: MHSA

DAM TYPE: NR INCIDENT TYPE: 1A INCIDENT CAUSE: FN

Incident No.: 207
Dam/Mine Name: Golden Cross
Mine Location: Waitekauri Valley, New Zealand
Ore/Tailings Type: gold
Dam Height (m): 25-30
Dam Type: Dam Fill Material: R
Impoundment Volume (Mt): 3
Incident Information:
Date: 12-1995
Incident Type: lA Cause: FN
Quantity of Tailings Released (cu. m): none
Tailings Travel Distance (m):
Incident Description:
Dam was on valley side and slipped bodily on plane of weakness about 50m deep at junction between lava flows and later material on which the dam was founded. Cost of repair NZ$ 5,000,000.
Source: Mine Manager, Coeur Golden Cross.

Incident No.: 197
Dam/Mine Name: No 2 tailings pond
Mine Location: Padcal, Luzon, Philippines.
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Fill Material:
Impoundment Volume (Mt): 80
Incident Information:
Date: 01-1992
Incident Type: 1A Cause: FN
Quantity of Tailings Released (Mt): 80
Tailings Travel Distance (m):
Incident Description:
Dam collapsed. Thought to relate to earthquake in July 1990 (6 months beforehand)
Source: Philex Mining Corp.

Incident No.: 183
Dam/Mine Name: Williamthorpe
Mine Location: United Kingdom
Ore/Tailings Type: coal
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1966 Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The failure is thought to have been triggered by excess foundation pore pressures.
Source: Bishop, 1973

Incident No.: 103
Dam/Mine Name: Santander

Mine Location: Spain
Ore/Tailings Type:
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: FN
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam had been constructed on a foundation containing old tailings. Lateral spreading and foundation strains triggered liquefaction, and a tailings flowslide occurred.
Source: Smith, 1969

DAM TYPE: NR INCIDENT TYPE: 1A INCIDENT CAUSE: OT

Incident No.: 199
Dam/Mine Name: Itogon-Suyoc
Mine Location: Baguio gold district, Luzon, Philippines.
Ore/Tailings Type: Gold
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 07-26-1993
Incident Type: lA Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Diversion tunnel taking river around the impoundment, blocked, causing flood water to enter impoundment and overtop dam. Partial failure, i.e. collapse of part of the dam. Contributory cause; typhoon.
Source: Itogon-Suyoc Mines

Incident No.: 114
Dam/Mine Name: Spring Creek Plant
Mine Location: Borger, TX, USA
Ore/Tailings Type: sand and gravel
Dam Height (m): 5
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m): 30,000
Incident Information:
Date: 08-01-1986
Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A seven-inch rainfall caused overtopping and breach of the dam due to inadequate spillway capacity.
Source: MHSA

Incident No.: 216
Dam/Mine Name: Williamthorpe
Mine Location: UK
Ore/Tailings Type: coal
Dam Height (m):
Dam Type: Dam Fill Material: MW
Impoundment Volume (Mt):
Incident Information:
Date: 03-24-1966
Incident Type: lA Cause: OT
Quantity of Tailings Released (tons):
Tailings Travel Distance (m):
Incident Description:
A slurry pond that had been built into the Old Dirt Tip collapsed, sending a flow of tailings over an adjacent road which was covered to a depth of 3m and remained closed for 10 days.
Source: Penman and Charles 1990.

Incident No.:125
Dam/Mine Name: Tymawr
Mine Location: Rhondda valley, South Wales, UK
Ore/Tailings Type: coal
Dam Height (m): 25
Dam Type: Dam Fill Material:
MWImpoundment Volume (Mt):
Incident Information:
Date: 03-29-1965
Incident Type: lA Cause: OT
Quantity of Tailings Released (tons):
Tailings Travel Distance (m): 732
Incident Description:
Lagoon has been formed in heaps of colliery waste on mountain side. When tailings level reached 175m, the downslope bund breached and the released tailings flowed down towards the river and entered the colliery car park at elevation 65m where it smashed two or three cars. It could easily have gone down the shaft. Cost to the Coal Board about £20,000 (1966 prices).
Source: Aberfan Report, Her Majesty's Stationery Office, 1967.

Incident No.: 124
Dam/Mine Name: Tymawr colliery.
Mine Location: South Wales, UK.
Ore/Tailings Type: coal
Dam Height (m):
Dam Type: Dam Fill Material: MW
Impoundment Volume (Mt):
Incident Information:
Date: 12-1961
Incident Type: lA Cause: OT
Quantity of Tailings Released (tons):
Tailings Travel Distance (m): 643
Incident Description:

Lagoon had been formed in the toe of a pile of colliery waste on a valley side at an elevation of about 183m, and washery tailings pumped to it by pipeline. The downslope bund overtopped and breached, releasing tailings that flowed down to an elevation of 65m near the Rhondda River.
Source: Aberfan Report, Her Majesty's Stationery Office, 1967.

Incident No.: 170
Dam/Mine Name: Union Carbide
Mine Location: Green River, UT, USA
Ore/Tailings Type: uranium
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 08-19-1959
Incident Type: 1A Cause: OT
Quantity of Tailings Released (cu. m): 8,400
Tailings Travel Distance (m):
Incident Description:
The tailings dam failed during a flash flood, with tailings and mill effluent reaching a creek and river. No increase in dissolved radium was noted in the river.
Source: US AEC, 1974

Incident No.: 215
Dam/Mine Name: Forquilha Mine Location: Brazil
Ore/Tailings Type: iron
Dam Height (m):
Dam Type: Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: lA Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The lower impoundment of this disposal scheme was under construction, in a valley adjacent to the active upper one. A saddle between the two valleys had a small dam to prevent overflow. At a time of maximum water level in the upper impoundment, a piping failure occurred at the left end of the saddle dam, releasing water into the lower impoundment, causing overtopping of the tailings dam under construction, washing out a considerable amount of fill. The accident caused significant delay to the operation of the scheme.
Source: ICOLD Tailings Committee.

DAM TYPE: NR INCIDENT TYPE: 1A INCIDENT CAUSE: ST

Incident No.: 208
Dam/Mine Name: Marcopper Mine
Location: Marinduque Island, Philippines
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 03-24-1996
Incident Type: lA Cause: ST
Quantity of Tailings Released (Mt): 2.4
Tailings Travel Distance (m):
Incident Description:
Tailings being stored in a worked-out pit that had been drained through a 2,250m long tunnel to the river Makulapnit. This had been plugged with concrete and the plug failed. Flow of tailings started at 5 to 10 m^3/sec and continued for 4 days. Released tailings affected waterways downstream. Heavy sedimentation for 14 km, and some material washed to rivermouth *25* km from mine.
Source: Placer Dome Inc., Vancouver V7X 1P1, Canada.

Incident No.: 193
Dam/Mine Name: No 3 tailings pond
Mine Location: Mankayan, Luzon, Philippines
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Dam Fill Material: E
Impoundment Volume (cu. m):
Incident Information:
Date: 10-17-1986
Incident Type: lA Cause: ST
Quantity of Tailings Released (Cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam was on an ancient slide area, and slopes of the dam too steep. After 8m extra height had been added, the dam failed. Decant tower was too close to the dam.
Source: Lepanto Consolidated Mining Co., Makati, Philippines.

Incident No.: 22
Dam/Mine Name: Carr Fork
Mine Location: Tooele, UT, USA
Ore/Tailings Type: copper
Dam Height (m): 10
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 02-01-1975
Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:

The embankment breached due to overtopping when a slide blocked the spillway structure.
Source: MHSA

Incident No.: 181
Dam/Mine Name: Western Nuclear
Mine Location: Jeffrey City, WY, USA
Ore/Tailings Type: uranium
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 03-23-1971
Incident Type: 1A Cause: ST
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A break in the tailings discharge line caused the dike to breach and tailings to flow for a period of 2 hours. No offsite contamination occurred.
Source: US AEC, 1974

DAM TYPE: NR INCIDENT TYPE: 1A INCIDENT CAUSE: EQ

Incident No.: 176
Dam/Mine Name: Veta de Agua A
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1981 Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A dam adjacent to Veta de Agua No. 1 (designated Dam A) is reported to have failed during an earthquake in 1981. No other details are available.
Source: Castro and Troncoso, 1989

Incident No.: 177
Dam/Mine Name: Veta de Agua B
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1981 Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A dam adjacent to Veta de Agua No. 1 (designated Dam B) is reported to have failed during an earthquake in 1981. No other details are available.
Source: Castro and Troncoso, 1989

Incident No.: 99
Dam/Mine Name: Ramayana No. 1
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m): 5
Dam Type: US Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 03-28-1965
Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m): 150
Tailings Travel Distance (m):
Incident Description:
Two nearly identical upstream type dams were located on a 30 degree mountainside slope and used alternately. Dam No. 1 was breached during the M7-7 1/4 Ligua earthquake, releasing a small flowslide from the upper portion of the impounded tailings.
Source: Dobry and Alvarez, 1967

Incident No.: 135
Dam/Mine Name: Unidentified
Mine Location: Peru
Ore/Tailings Type:
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1962 Incident Type: 1A Cause: EQ
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An earthquake of M6-3/4 that occurred in northern Peru following 3 weeks of heavy rainfall caused liquefaction failure of a tailings embankment located in the vicinity of the epicenter.
Source: Smith, 1969

DAM TYPE: NOT REPORTED INCIDENT TYPE: 1A CAUSE: MS

Incident No.: 88
Dam/Mine Name: Mulfilira
Mine Location: Zambia
Ore/Tailings Type: copper
Dam Height (m): 50
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1970 Incident Type: 1A Cause: MS
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):

Incident Description:
Some 1,000,000 tons of tailings liquefied and flowed within 15 minutes into underground mine workings where mining was in progress beneath the impoundment, resulting in death of 89 miners. It is believed that voids in the rock above the workings propagated upward to the tailings due to unequal extraction of ore or differential settlement of the caving rock. The tailings deposit was stabilized by dewatering and the mining method was changed.
Source: Brawner, 1979; Sandy, et. al., 1976; Lucia, 1981

Incident No.: 5
Dam/Mine Name: Atlas Consolidated
Mine Location: Philippines
Ore/Tailings Type:
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: MS
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Coarse, saturated tailings deposited in an abandoned open pit liquefied and flowed into underground mine workings beneath the impoundment where mining was in progress. It is believed that voids in the rock above the workings propagated upward to the impoundment due to unequal extraction of ore or differential settlement of the caving rock.
Source: Brawner, 1979

DAM TYPE: NOT REPORTED
INCIDENT TYPE: 1A CAUSE: ER

Incident No.: 192
Dam/Mine Name: Pico de Sao Luis
Mine Location: Minas Gerais, Brazil
Ore/Tailings Type:
Dam Height (m): 20
Dam Type: Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 10-02-1986
Incident Type: lA Cause: ER
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Water flowing over spillway eroded dam toe on soft clay foundation, causing failure of downstream slope. Tailings released.
Source: ICOLD Tailings Committee.

DAM TYPE: NOT REPORTED
INCIDENT TYPE: 1A CAUSE: U

Incident No.: 182
Dam/Mine Name: Williamsport Washer
Mine Location: Maury County, TN, USA
Ore/Tailings Type: phosphate
Dam Height (m): 21
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1970 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
No details provided.
Source: MHSA

Incident No.: 1
Dam/Mine Name: Agrico Chemical
Mine Location: Payne Creek, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1968 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam breach resulted in pollution of a nearby creek and the Peace River. No further details are available.
Source: Anecdotal

Incident No.: 83
Dam/Mine Name: Mobil Chemical
Mine Location: Ft. Meade, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1967 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m): 250,000
Tailings Travel Distance (m):
Incident Description:
Dam breach and release of phosphatic clay slimes resulted in pollution of the Peace River. No further details are available.
Source: Anecdotal

Incident No.: 33
Dam/Mine Name: Climax
Mine Location: Grand Junction, CO, USA
Ore/Tailings Type: uranium
Dam Height (m):
Dam Type: Dam Fill Material:

Impoundment Volume (cu. m):
Incident Information:
Date: 07-02-1967 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m): 12,000
Tailings Travel Distance (m):
Incident Description:
Failure due to unreported causes released 58,000 gallons of effluent into an adjacent river. There was no indication that dissolved radium concentrations in the river exceeded regulatory standards.
Source: US AEC, 1974

Incident No.: 4
Dam/Mine Name: American Cyanamid
Mine Location: Lithia, FL, USA
Ore/Tailings Type: phosphate
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1965 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Release of impounded phosphatic clay slimes caused pollution of an adjacent creek and the Alafia River. No further details are available.
Source: Anecdotal

Incident No.: 3
Dam/Mine Name: American Cyanamid
Mine Location: Brewster, FL, USA
Ore/Tailings Type: gypsum
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1962 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Dam breach caused release of 10 million gallons of acid water and pollution of the Alafia River. No further details are available.
Source: Anecdotal

Incident No.: 80
Dam/Mine Name: Mines Development
Mine Location: Edgemont, SD, USA
Ore/Tailings Type: uranium
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 06-11-1962 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m): 100
Tailings Travel Distance (m):
Incident Description:
The dam failed from unreported causes. Tailings released reached a creek and some were carried 25 miles to a reservoir downstream.
Source: US AEC, 1974

Incident No.: 171
Dam/Mine Name: Union Carbide
Mine Location: Maybell, CO, USA
Ore/Tailings Type:
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 12-06-1961 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
280Tailings Travel Distance (m):
Incident Description:
The dam failed from unreported causes. No damage was reported, and effluent released did not reach any flowing stream.
Source: U.S. AEC, 1974

Incident No.: 20
Dam/Mine Name: Captains Flat Dump 3
Mine Location: Australia
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Dam Fill Material: T
Impoundment Volume (cu. m):
Incident Information:
Date: 1942 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m): 40,000
Tailings Travel Distance (m):
Incident Description:
No details of the failure are available, except that the tailings liquefied and the resulting tailings flowslide reached a nearby river.
Source: Ash, 1976

Incident No.: 136
Dam/Mine Name: Unidentified
Mine Location: South Africa
Ore/Tailings Type: gold
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1917 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Mention is made of a failed tailings dam. No further details are provided.
Source: White, 1917

Incident No.: 142
Dam/Mine Name: Unidentified

Mine Location: United Kingdom
Ore/Tailings Type:
Dam Height (m): 12
Dam Type: Dam Fill Material: R
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An old tailings dam constructed within a quarry breached and was subsequently repaired. The cause is not reported.
Source: Little and Beavan, 1976

Incident No.: 2
Dam/Mine Name: Alcoa
Mine Location: Point Comfort, TX, USA
Ore/Tailings Type: bauxite
Dam Height (m): 19
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m): 4,500,000
Incident Information:
Date: 10-01-1964 Incident Type: 1A Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
Cause of the failure is not reported. Released material was contained in a downstream impoundment.
Source: MHSA

DAM TYPE: NOT REPORTED
INCIDENT TYPE: 1B CAUSE: OT

Incident No.: 76
Dam/Mine Name: Marga
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1985 Incident Type: 1B Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The cross-valley abandoned dam had a decant structure but no abandonment spillway. Overtopping failure occurred due to insufficient decant capacity for routing streamflows through the impoundment.
Source: Troncoso, 1990

Incident No.: 175
Dam/Mine Name: Vallenar 1 and 2
Mine Location: Chile
Ore/Tailings Type: copper
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 1983 Incident Type: 1B Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The two abandoned dams contained cross-valley impoundments in series, and incorporated only decant structures with no abandonment spillways. Overtopping caused failure of the upper dam and cascade failure of the lower dam.
Source: Troncoso, 1990

Incident No.: 151
Dam/Mine Name: Unidentified
Mine Location: IN, USA
Ore/Tailings Type: coal
Dam Height (m): Dam Type:
Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 1B Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An abandoned coal slurry impoundment was breached by overtopping during heavy rains. No other details are available.
Source: Wobber, et al, 1974

DAM TYPE: NOT REPORTED
INCIDENT TYPE: 1B CAUSE: U

Incident No.: 39
Dam/Mine Name: Dixie Mine
Mine Location: Clear Creek County, CO, USA
Ore/Tailings Type: gold
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 04-01-1981 Incident Type: 1B Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
No details provided.
Source: MHSA

Incident No.: 65
Dam/Mine Name: Keystone Mine
Mine Location: Creste Butte, CO, USA
Ore/Tailings Type: molybdenum
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:

Date: 05-01-1975 Incident Type: 1B Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
No details provided.
Source: MHSA

Incident No.: 50
Dam/Mine Name: Golden Gilpin Mine
Mine Location: Blackhawk, CO, USA
Ore/Tailings Type: gold
Dam Height (m): 12
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 11-01-1974 Incident Type: 1B Cause: U
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
No details provided.
Source: MHSA

DAMTYPE: NOT REPORTED
INCIDENT TYPE: 2A CAUSE: SI

Incident No.: 160
Dam/Mine Name: Unidentified
Mine Location: Eastern US, USA
Ore/Tailings Type: coal
Dam Height (m): 150
Dam Type: Dam Fill Material: MW
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 2A Cause: SI
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
An embankment of coal refuse constructed with uncompacted, train-dumped fill retained impounded coal tailings and water. Downstream slope movements of 20 m/yr, accompanied by a high phreatic surface and large quantities of seepage, resulted in severe cracking and deformation of the embankment slope.
Source: Wahler and Schlick, 1976

DAMTYPE: NOT REPORTED
INCIDENT TYPE: 2A CAUSE: OT

Incident No.: 67
Dam/Mine Name: Kyanite Mining
Mine Location: Prince Edward Co., VA, USA
Ore/Tailings Type: kyanite
Dam Height (m): 11
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m): 430,000
Incident Information:
Date: 1980 Incident Type: 2A Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was overtopped, but no breach occurred and tailings were not released. The dam was placed back in service with minor repairs.
Source: Virginia Dept. Mines, Minerals and Energy, Div. Mined Land Reclamation

Incident No.: 174
Dam/Mine Name: Utah Construction
Mine Location: Riverton, WY, USA
Ore/Tailings Type: uranium
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: 06-16-1963
Incident Type: 2A Cause: OT
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
The dam was intentionally breached and a 2-foot depth of effluent was released to prevent uncontrolled release of the impoundment contents during heavy rain.
Source: US AEC, 1974

DAM TYPE: NOT REPORTED
INCIDENT TYPE: 3 CAUSE: NR

Incident No.: 8
Dam/Mine Name: Bancroft
Mine Location: Ontario, Canada
Ore/Tailings Type: uranium
Dam Height (m):
Dam Type: Dam Fill Material:
Impoundment Volume (cu. m):
Incident Information:
Date: Incident Type: 3 Cause:
Quantity of Tailings Released (cu. m):
Tailings Travel Distance (m):
Incident Description:
A grout curtain installed in alluvial deposits was used to control seepage containing radium-226 from an existing, reactivated tailings dam. It was constructed by injecting a mixture of clay, water, cement, bentonite and occasionally calcium chloride through slotted pipes installed in small diameter boreholes drilled through the alluvium and into bedrock. Pump tests conducted after completion of the grout curtain showed that a thin zone along the bedrock surface remained ungrouted and that seepage through only the upper part of the alluvium was retarded. It was observed that the total effect of the curtain in reducing seepage was minimal. Yet the content of the dissolved radium-226 in the ground water

was greatly lowered in passing through and beneath the grout curtain. The decrease in contaminant concentrations was attributed to ion exchange between the effluent seepage and chemicals in the grout curtain.
Source: Dodds, 1979

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