NSW GOVERNMENT | Trade & Investment

GUIDELINE

MDG 3008

Guideline for managing the risk of inrush with hydraulic fill systems

Produced by Mine Safety Operations Branch

Trade & Investment

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Foreword

There have been a significant number of incidents at Australian mines involving hydraulic fill. Although most have not been large scale events or resulted in injury, their occurrence points to significant failure in the operation of management systems. The deaths of three miners at the Bronzewing Mine in Western Australia on 26 June 2000 is a reminder that inrushes of this type can cause catastrophic loss of life.

This guideline provides practical advice on how to design, construct and operate safe hydraulic fill systems to help mine operators, employers and others comply with statutory obligations placed on them by the NSW occupational health and safety legislation.

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1. Introduction

1.1 Title

The title of this publication is the *Guideline for the design, construction and operation of hydraulic fill systems*. It is published by Trade & Investment.

1.2 Purpose

The purpose of this guideline is to give those people working in the mining industry guidance to help them reduce the risk of catastrophic incidents associated with inrushes of hydraulic fill in underground metalliferous mines.

1.3 Scope

This guideline applies to the hydraulic fill systems used in underground metalliferous mines. The term 'hydraulic fill' includes both cemented and uncemented fills and variant fill types which incorporate hydraulic fill including cemented rock fill and hydraulic aggregate fills. A more detailed definition is given at 1.8 below.

The guideline covers a process for managing risk. This involves defining the elements in the process - risk analysis, design, construction, operation, monitoring and review - and setting out what should be included in each element to achieve a safe and robust system.

The guideline does not establish prescriptive standards, nor does it summarise the extensive body of knowledge surrounding mine fill.

The reader is strongly encouraged to use the *Handbook on Mine Fill*, (Potvin Ed. 2005) as a companion text to this guideline.

1.4 Authority

Trade & Investment, the publisher of this guideline, is the regulatory authority responsible for administering the NSW *Occupational Health and Safety Act 2000*, the *Mine Health and Safety Act 2004* and the *Coal Mine Health and Safety Act* 2002 on mine sites in NSW.

1.5 Commencement

This guideline is effective from the date of publication.

1.6 Revocation

To the extent there are any inconsistencies, this guideline supersedes guidance material previously published by Industry and Investment NSW.

1.7 Interpretation

This document is a guideline and as such its provisions are not mandatory, however subject to the rules of evidence, it may be used in legal proceedings to prove breaches of safety legislation.

1.8 Definitions

Hydraulic fill

In this guideline the term 'hydraulic fill' is used to refer to the **class** of mine fill types which are delivered as high density slurry to underground workings (Potvin Ed. 2005). Under this definition the term includes both cemented and uncemented fills.

The term hydraulic fill is sometimes used in industry to refer specifically to uncemented hydraulic fill. Because uncemented fill and cemented fill present different risks at different times, it is critically important to avoid this ambiguity. In this guideline the terms 'uncemented fill' or 'cemented fill' will be used where a distinction based on binder content is relevant.

1.9 Relevant legislation

The main NSW legislation covering mine fill systems is:

- *Occupational Health and Safety Act 2000.*
- *Occupational Health and Safety Regulation 2001.*
- *Mine Health and Safety Act 2004.*
- *Mine Health and Safety Regulation 2007*.

2. This guideline

This guideline highlights the obligations employers and others have under NSW occupational health and safety legislation for the design, construction and operation of safe mine fill systems.

It also provides practical advice for employers and others on how to meet these obligations, without recommending specific technical solutions or setting prescriptive standards.

This guideline is not intended to be a technical reference. The reader is strongly encouraged to use the *Handbook on Mine Fill*, (Potvin Ed. 2005) as a companion text to this guideline.

3. Statutory obligations

3.1 Legislation

The main NSW legislation covering mine fill systems is:

- *Occupational Health and Safety Act 2000.*
- *Occupational Health and Safety Regulation 2001.*
- *Mine Health and Safety Act 2004.*
- *Mine Health and Safety Regulation 2007*.

Relevant provisions

The most relevant provisions include:

- The general duties of employers, self employed persons, designers of plant and controllers of premises contained in the *Occupational Health and Safety Act 2000* Sections 8, 9 and 10.
- The risk management obligations of employers contained in Clauses 9 to 12 of the *Occupational Health and Safety Regulation 2001*.
- The risk management obligations of controllers of premises contained in Clauses 34 to 38 of the *Occupational Health and Safety Regulation 2001*.
- The hierarchy of controls set out in Clause 5 of the *Occupational Health and Safety Regulation 2001*.
- The risk assessment duties of mine operators set out in Clauses 35, 36 and 37 of the *Mine Health and Safety Regulation 2007*
- The duties of mine operators relating to documentation of risk assessments set out in Clauses 44 and 45 of the *Mine Health and Safety Regulation 2007*
- Specific control measures for falls of ground and inrushes contained in Clauses 46 and 47 of the *Mine Health and Safety Regulation 2007*, to the extent these are relevant.
- Duties of mine operators relating to the safe design, construction and maintenance of structure and buildings are set out in Clauses 69 and 70 of the *Mine Health and Safety Regulation 2007*.

Statutory defence

Duties under the occupational health and safety legislation must be considered in the light of the statutory defence provided in *Occupational Health and Safety Act 2000* Section 28. This limits the obligations of duty holders provided they can show:

- it was "'not reasonably practicable" to comply, or
- the failure to comply was "due to causes over which the person had no control and against the happening of which it was impracticable for the person to make provision".

Key requirements

Without paraphrasing the whole legislation, the key requirements are:

- Employers and others have a duty, as far as is reasonably practical, to **ensure** a safe workplace. Some other duty holders have similar obligations.
- The duty to ensure safety is onerous and to discharge their duty employers and certain other duty holders **must actively search for and control risks**.
- Both the *Occupational Health and Safety Act 2000* and the Mine Health and Safety Act 2004 contain provisions relating to risk assessment which formalise the implied requirement to actively identify and manage risks.
- The *Occupational Health and Safety Regulation 2001* contains a requirement to **eliminate risks where this is reasonably practical**. If risks cannot be eliminated a **hierarchy of controls** must be used to manage residual risks.

Specific duties relating to structures

Apart from the general duty provisions and general requirements for risk assessment and control, Clauses 69 and 70 of the *Mine Health and Safety Regulation* 2007 create specific duties in relation to the design and construction of structures, including barricades and bulkheads. These specific duties are:

69 Design, construction and maintenance of structures and buildings

The operator of a mine must ensure that all structures and buildings, including temporary structures, at a mine (including those situated in a construction zone designated under clause 77):

(a) are designed, constructed, and maintained so as to ensure the health, safety and welfare of persons, and

(b) are periodically assessed for integrity by a competent person.

***70* Risk to persons to be controlled**

(1) The operator of a mine must ensure that the design of any structure or building at the mine (including a temporary structure) is such that any person who:

(a) constructs, maintains, repairs or demolishes the structure or building, and

(b) uses the structure or building,

is not, in doing so, exposed to risk.

(2) Where a risk cannot be eliminated from the design of the structure or building, the operator must ensure that appropriate controls are put in place to minimise the risks to such persons.

Legislation cited above can be downloaded from www.austlii.edu.au

4. Technical

While this guideline is not intended to be a technical reference, some understanding of technical issues is a prerequisite for the discussion of the risk management, design, construction, operation and monitoring and review of hydraulic fill systems.

The *Handbook on Mine Fill*, (Potvin Ed. 2005), a recent publication by the Australian Centre for Geomechanics, provides a wealth of technical information on current fill practice and on the science on which it is based. Standard texts on soil and fluid mechanics provide further scientific detail.

The following discussion assumes some knowledge of fill systems and soil mechanics. The reader may wish to refer to the *Handbook on Mine Fill* for this information.

4.1 Classification of fill types

This guideline follows the classification system used in the *Handbook on Mine Fill*, that is:

- Hydraulic fill
- Paste fill
- Rock fill or
- Other fills (including hydraulic aggregate fill).

The definitions set out below are based on those published in the handbook but with some slight modification.

Hydraulic fill Hydraulic fills are a class of mine fills made from material either naturally occurring or produced from mill tailings, with a size ranging from coarse sand, through medium and fine sand, through coarse, medium and fine silt to clay. The fill is placed underground into a mining void as a slurry/ pulp via boreholes and / or pipelines. The content of the particles of clay size must be rigidly controlled to ensure the fill is sufficiently permeable for excess water to drain from the stope. Hydraulic fills may be either cemented or uncemented depending on whether a binder has been added.

Paste fill Paste fill is a fill consisting of ultra high density thickened tailings with a binder or binders added.

Rock fill Rock fill includes quarried rock, open cut over burden, development waste or heavy medium plant reject material delivered to a mining void either from surface or a source underground using passes / conveyor belts or trucks

Other fills This is a 'catch all' category and includes all fill systems not specifically covered elsewhere. Importantly this includes uncemented and cemented hydraulic aggregate fills. These are a mixture of aggregate and hydraulic fill and come within the scope of this guideline.

4.2 Hydraulic fill

Essential features

The essential features of hydraulic fills are:

- They are placed as a slurry or pulp. Typically these fills are transported through pipes and boreholes. For these fills to flow through pipes the water content of the slurry must be significantly greater than the water content of the drained fill after placement. This excess water which is required for transport must drain to prevent the development of a potentially dangerous saturated zone within the fill mass or an even more dangerous build up of 'ponded' water on top of the fill. The presence of undrained water in a filled stope is potentially dangerous because :
    - it is a source of hydraulic pressure which can rupture fill barricades.
    - It can act both as a fluidising medium and a source of energy to allow placed fill to be mobilised in the event of a barricade failure.
- They are composed of particles in the size range from coarse sand to fine silt with very limited amounts of clay sized particles. Control of the clay content is critical for two reasons. Clay sized particles:
    - reduce the permeability of the fill and so inhibit free drainage of water from the fill mass after placement, and
    - reduce the effectiveness of the binder used in cemented fills and may prevent or delay "setting" and or reduce the strength of the cured fill.

Difference between hydraulic and paste fills

The essential features of hydraulic fills contrast with those of paste fills. Paste fills contain a significant quantity of fine particles which allows them to flow through pipes with a water content which is largely or entirely retained within the fill after placement. Paste fills are always cemented and the retention of the entire water content is assisted to some extent by the hydration of the binding agent. Paste fills also pose a risk which has to be managed.

4.3 Inrushes

Required conditions

The conditions required for an inrush are:

- A failure of the structures used to contain the fill – normally a failure of the fill barricade
- The presence of a fluidising medium – normally 'free' water within a saturated fill mass or ponded on the surface of the fill
- Insufficient cohesion in the fill mass to resist its mobilisation.

The last point above explains why inrushes from stopes filled with cemented fill are often smaller than those from uncemented fills. The partially cured cemented fill can resist mobilisation and tends to remain within the stope.

4.4 Barricades

Hydraulic fill is normally contained within stopes by fill ‘barricades’ built at the entrances to the stope. The term ‘barricade’ is used in this guideline to refer to structures which are intended to be sufficiently permeable to ensure the pore water pressure within the stope remains low.

Retaining structures which are not designed to promote free drainage are referred to in this guideline as ‘bulkheads’. These must be designed to withstand the maximum hydrostatic head which would result when the stope was full of saturated fill.

Barricades are often constructed from

- porous concrete blocks
- combinations of shotcrete, mesh and geotextile
- a continuous shotcrete wall with a separate drainage system inside the barricade. In this case the shotcrete wall itself is impermeable, and depends on its associated drainage system to function as a barricade.

4.5 Containment failure

An inrush may occur following a containment failure. In practice, the containment failure usually results from the failure of a fill barricade; however it could also result from the failure of a pillar between stope draw points, or a rock fall adjacent to the fill wall.

A containment failure must occur for an inrush to take place. However, this does not mean that all containment failures will necessarily result in an inrush. Where the fill is well drained, a containment failure may occur without a significant inrush because there is insufficient water to mobilise the exposed fill. Where a containment failure occurs in a cemented hydraulic fill stope the cured fill may be largely unaffected if there is insufficient free water available (with sufficient energy) to overcome the cohesion between the fill particles and to mobilise the fill mass.

4.6 Causes of fill barricade failures and barricade design

Fill barricades fail for the same reason other structures fail - the forces applied exceed the barricades capacity to resist. This may appear obvious but it highlights the necessity for:

- applying engineering design principles to hydraulic fill systems
- constructing and operating fill systems within the design specifications.

An engineering design is based on various given, assumed and specified conditions, which may affect the forces applied, the strength of the barricade or the ‘factor of safety’ required to manage risk.

The following important conditions should be considered:

- **The construction of the barricade** – Material, thickness, bonding to the walls, back and floor of the drive, permeability and curing time before use (for cement based or similar materials).
- **Ground conditions -** Competence of the ground.
- **The size and position of the barricade**- Height, width and set back from the brow of the stope.
- **The properties of the hydraulic fill** - Permeability (a function largely of the size distribution and shape of the fill particles), water content and binder content.
- **Stope geometry** – The number of barricades, their location, the area of the stope and the height of the stope.
- **Fill placement** - Placement rates, water content and fill placement schedule.
- **Other -** Material left in the stope and drill holes or geological structures capable of forming drainage channels.

The design of fill barricades cannot be considered independently of the overall fill system. Many of the conditions listed above are important system parameters. For example placement rates, water content and permeability must be managed to ensure the pressure on a barricade does not exceed design specifications.

The estimation of the stresses imposed on the barricade walls should consider all sources of load, including pore water pressures within the fill mass during filling.

It is imperative that the conditions on which the design is based are fully specified and communicated to operating personnel. It is equally important that the fill system is constructed and operated within specification or variations are properly evaluated and risk assessed, where necessary.

4.7 Mobilisation

As noted previously a containment failure will not automatically produce an inrush. It is also necessary to have sufficient water (and energy) to overcome whatever cohesion exists between the fill particles to mobilise the fill.

In practice it is likely that, in the case of uncemented hydraulic fill, all saturated fill will be mobilised following a barricade failure. In the case of cemented hydraulic fill it is likely that at least all saturated fill placed in the preceding 24 hours will be mobilised.

Two important conclusions follow:

- Minimising the amount of undrained water within a filled stope is arguably the most important part of managing the risk of inrush
- Uncemented hydraulic fill presents a much greater risk of catastrophic inrush than does cured cemented fill, because a much larger amount of material can be mobilised.

It is critically important that uncemented fills are fully drained because they do not have the inherent stability advantages that cemented fills have. Cemented fills on the other hand are not as permeable as uncemented fills and therefore do not drain as readily. Both fill types have intrinsic weaknesses and effective management procedures must be in place to address the critical issue raised by these weaknesses.

5. Management model

5.1 Incidents

Barricade failures followed by inrushes of varying extent have occurred in Australian mines. Investigation of these failures rarely brings any new causes to light. In general the causes are well known and often the incident has resulted from a failure to operate the system within its design specifications.

Incidents of this type are predominantly management failures. Underlying causes often include:

- a failure to have sufficiently robust systems to ensure the filling process is carried out reliably
- a failure to appreciate the risks to both safety and production from sloppy filling practices
- insufficient management attention given to the filling process.

This Guideline sets out a management model based on the following staged process:

- risk analysis
- design
- construction
- operation
- monitoring and review.

5.2 Risk management

Risk management has become the cornerstone of modern occupational health and safety and, as previously discussed, is a mandatory requirement of the NSW occupational health and safety legislation.

Standards and references

AS /NZS 4360:2004 has been superseded by AS/NZ ISO 31000:2009, but the conceptual model set out in the earlier standard is used here to provide consistency with the discussion of risk management contained in the *Handbook on Mine Fill*. Standards will inevitably be superseded from time to time and in practice reference should be made to the latest versions.

The application of the conceptual risk model set out in Australian and New Zealand Standard AS /NZS 4360:2004 to hydraulic fill systems is discussed in detail in the *Handbook on Mine Fill*.

This model is based on the following steps

- Establish the context
- Identify the risks
- Analyse the risks
- Evaluate the risks
- Treat the risks

Additional supporting processes - 'monitor and review' and 'communicate and consult' - take place at each step.

It is important to understand that the model establishes risk management as an ongoing process driven by the 'monitoring and review' element.

Identification of risks – application to hydraulic fill systems

Many of the risks associated with hydraulic fill systems are not obvious to people without specific technical expertise. For example, a common cause of barricade failure is the development of drainage channels within the fill mass. The existence of these channels is not something untrained personnel would suspect. Likewise the conditions necessary for liquefaction would not be known to people who did not have some knowledge of soil mechanics. It is therefore vitally important to use people with recognized expertise to identify and manage the risks associated with hydraulic fill systems.

Risk register

A risk register is a documented record of the risks identified through a risk management process. The *Handbook on Mine Fill* discusses the use of risk registers and provides an example.   The use of a risk register is an excellent method of capturing knowledge of potential failure modes.

Robust processes

The risk management process should identify weaknesses in information and management systems associated with the fill system.

5.3 Design

A stope during filling is a safety critical structure. Therefore, the design of the filling process and the retaining structures must conform to acceptable engineering standards in the same way that the design of a major dam or a bridge would.

This implies that:

- The design is undertaken by competent and experienced people
- The design is based on engineering analysis and addresses all known failure modes
- The design calculations are documented
- A detailed specification is provided to ensure the system is constructed and operated as envisaged

- The design specifications are communicated to all appropriate personnel in an appropriate format
- Where it is necessary to vary the design, appropriate checks are carried out. This includes checks to ensure the changes do not have unforeseen consequences elsewhere in the system.

5.4 Construction and operation

A good design is worthless unless the fill system is constructed and operated in accordance with the specifications.

This implies that

- People working on the fill system are competent and experienced
- Materials used conform to specification
- The people who are operating the systems have the information they need.

5.5 Monitoring and review

There must be systems in place to ensure safety critical parts of the filling process conform to specifications. In particular, the water, fines and cement content of the fill must be monitored to ensure it conforms to specification. Stopes must also be monitored during filling to ensure water does not pond on the fill and there are no leaks of fill material which may lead to the formation of drainage channels.

6. References

Potvin Y (edit.) (2005) *Handbook on Mine Fill* Australian Centre for Geomechanics, Perth.

Standards Australia (2004) *AS/NZ 4360:2004 Risk Management*, Standards Australia, Sydney

Standards Australia (2004) *HB 436-2004 Risk Management Guidelines, Companion to AS/NZ 4360:2004* , Standards Australia, Sydney

Standards Australia (2009) *AS/NZ ISO 31000:2009 Risk Management Principles and Guidelines*, Standards Australia, Sydney

7. Appendices

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