Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)

doi:10.36487/ACG_repo/2315_045

Open pits, underground mines and tailings storage facilities—geotechnical and legislative aspects at closure in Western Australia

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Abstract

All mining proposals (MP) submitted with mine closure plans (MCP) to be accepted by the Department of Mines, Industry Regulation and Safety (DMIRS) in Western Australia (WA) must comply with strict engineering, environmental and legislative requirements, as overseen by the regulatory agency, WorkSafe Western Australia. To meet all legislative requirements, including engineering and environmental laws, mine closures must face and meet these challenges. The Work Health and Safety Act 2020 (WHS Act), the Work Health and Safety (Mines) Regulations 2022 (WHS Mines Regulations), the Mining Act 1978, the Mining Regulations 1981 and the Environmental Protection Act 1986 provide clear and consistent guidelines for exploration, design and construction, operation, and closure of mines across WA. The Mining Act 1978 requires mining activities to be rehabilitated and closed in a manner that leaves the land safe, stable and non-polluting without unacceptable liability to the state. A mine closure plan is required under the Mining Act 1978 and enforced via tenement conditions applicable to the mining lease. Traditional land owner's involvement on the land used for mining applies from the beginning of the project during the exploration and mining phases and continues onto the closure considering post mining land use which may also include the land access for cultural and ceremonial use. The legislation regarding mining and environmental protection were also developed with the intention of minimising environmental damage, enforcing professional commitments on ore reserve exploitation and upholding traditional land owner's interests to their lands.

When planning the post mining closure of open pit mining operations many geotechnical engineering aspects related to perpetual pit slope stability, the stability of waste dumps, pit lakes and access controls using abandonment bunding for the safety of people as well as wildlife will need to be applied. Planning for the closure of underground mines, depending on the mining method, will need to address the elimination of any potential unplanned subsidence by well-proven geotechnical modelling. Other areas to address may be impacts on changes to the surface water flow and ground water table and inadvertent access to any mining areas through shafts or portals. Dealing with tailings facilities could be the most challenging aspect of a mine closure. The mine closure plan regarding tailings will need to address embankment stability, ground water contamination and liquefaction potentials, seepage and dust. The closure will be required to promote the regrowth of natural endemic plants that were impacted by the mining operation in order to bring the location back to the pre-mining natural environment as much as possible. Tailings could contain materials having the potential of acid mine drainage (AMD) which will need to be effectively managed to prevent any environmental impacts.

Keywords: *geotechnical, underground, open pit, tailings, subsidence, mine closure, WHS, environmental, AMD, stability, liquefaction, tenements*

1 Introduction

This paper will review some important geotechnical, environmental, and regulatory requirements related to the design, construction, operation and closure of open pit and underground mines, waste rock dumps (WRD) and tailings storage facilities (TSF) from a Western Australian perspective. There are many other technical and regulatory compliances needed in the design, construction, operation and closure of mining operations which are not within the scope of this paper.

Mine pits, WRDs and TSFs represent the key mining landforms that remain post closure. The environmental commitments for operation and closure are regulated by legally binding conditions that are applicable and relevant to the project under State Legislation. Closure outcomes provide the basis against which closure performance will be measured. Closure outcomes set out the long-term goals for closure and establish the foundation for the development of completion criteria. The closure aim must be to return the area for post mining land use as agreed during the stakeholder consultation. Compliance with closure obligations is a requirement for the Government's sign-off before relinquishing the mining tenement. It is also mandatory for mining companies to engage traditional land owners in this process to avoid or proactively resolve any conflicting issues related to their interests.

Design of an open pit mine needs to follow resource and geotechnical drilling and assessment. Decisions on placement of TSFs follows completion of sterilisation drilling that confirms that the facility will be constructed in areas void of any ore bodies and mineral economic potentials. Furthermore, few other significant aspects which need attention and due diligence during planning, operation and mine closure are surface drainage and water flows, ground water, preservation of natural soil conditions and wild life and habitat, control of inadvertent access as well as any impact on the land beyond the mining boundaries. Successful mine closure can be accomplished if the above-mentioned aspects are duly managed, professionally assessed and the necessary due diligence is exercised during their respective stages.

The closure of TSFs attracts significant attention due to worldwide historical TSF failures and disasters. Such incidents have paved the way for numerous research and studies, increasingly stringent regulations such as inclusion of TSFs under Principal Mining Hazard Management Plans and classification of TSF lift construction as a High Risk Mining Activity are some such new additions to WHS (Mines) Regulations. It is crucial to manage TSFs within environmental guidelines and legislative requirements due to their impact on the environment and society.

Underground mines have a different set of requirements for closure where post closure inadvertent access, subsidence and any interactions with surface infrastructure need greater considerations to demonstrate their closure accomplishments for regulatory approvals and post mining land use stakeholders acceptance.

It is important to have a robust and effective mine closure plan (MCP) for all mining operations since its design phase to accomplish closure obligations without compromising technical, stakeholders and legislative interests.

2 Open pits

Open pits are the most visible mining operations and as such attract the attention of environmentalists as well as regulators. The design of open pits requires a rigorous approach with well-defined resources, geotechnical and hydrogeological investigations. Pit slopes need to be designed with optimum overall slope angles, with the best batter berm geometry selected to optimise the strip ratio and maximise ore recovery. Geotechnical core drilling and other associated investigations need to be planned and designed to achieve these objectives. The final design is reliant on the preceding drilling, testing and data modelling work. In an open pit, there could be many geotechnical domains defined by the properties of many factors, such as rock mass rating, weathering, structures and water. Therefore, strategies based on the geotechnical domains are required to manage the slopes safely. This is also relevant to the closure requirements.

WorkSafe Western Australia provides regulatory oversight of mine closure activities and ensures compliance with the relevant Western Australian legislation including the *Work Health and Safety Act 2020* (WHS Act), and the Work Health and Safety (Mines) Regulations 2022 (WHS Mines Regulations). In the WHS Mines Regulations, the stability of geotechnical structures are cited under principal mining hazards [r. 613] and geotechnical structures [r. 631B and r. 631C], with an emphasis on their design aspects and corresponding implications. The WHS Mines Regulations also outlines mine closure requirements [r. 675UI].

In addition to legislative compliance, one of the major aspects that regulators emphasise when considering the post closure abandonment of completed open pits is the safe, stable, non-polluting state. There are a number of options available for open pit closure that includes backfill, formation of shallow pit slopes to a pit lake or constructing an abandonment bund around the open pit at a suitable height using competent material outside the unstable zone and aimed at preventing inadvertent access to the mined out area.

For open pits that have been dewatered, it is expected that groundwater will rebound after mining activities ceases. These pits will become pit lakes. The closure consideration for pit lakes involve water quality changes and impact of acid mine drainage for some mine sites. It may take water levels in pit lakes many decades to fully rebound. In addition, the effects of evaporation and chemical conditions changes in the water column in the pit lake mean that it may take decades to centuries for water quality to reach equilibrium conditions. As these changes depend on many site-specific factors, they are difficult to predict. This creates a problem for regulators who have to consider the long-term environmental impacts during closure.

DMIRS as the government regulatory body has produced and published guidance material, in collaboration with the Mining Industry Advisory Committee (MIAC), for the safe design, construction, operation and closure of open pits. These include the Code of practice: *Ground control for Western Australian mining operations* (2019) and the Guideline: *Ground control for Western Australian mining operations* (2019). Guideline materials for specific closure requirements are also available that include the Guideline: *Acid mine drainage* (2009) to assist mine sites to develop constructive plans for the disposal of PAF (Potentially Acid Forming) materials as well as other wastes/tails containing acidic contaminants.

3 Underground mining

Underground mines typically have many impacts on the surface that need to be considered for closure, including potential subsidence, impact on the ground water table, and open holes. Effective control of these can be achieved with carefully considered design and safety practices.

Caving operations can be managed with the optimum caving cone that provides the best subsidence profile without any air gaps, and effective fragmentation of the overburden. The design concepts, which outline cavability of rock mass, need to be defined with precision to achieve effective management of the cave. This is clearly defined in the WHS Mines Regulations as "properties of material associated with the geotechnical structures, and operational factors and their influence on stability of geotechnical structures" [r. 631B (c) and (d)].

In underground mining where block caving or sub-level caving is adopted for mining the orebody, it is important to accurately define the shape of the cave for the demarcation of subsidence profile boundaries on the surface to plan the construction of abandonment bunding for closure requirements. Here it is also worthwhile to mention the fundamental principles and best practice methods used in Caving. The most universally applied methods for cavability prediction include the empirical stability graph approach developed by Mathews and Laubscher (1994). Furthermore, there are more complex geotechnical modelling work that could also be used to predict rock mass cavability such as SRM (Synthetic Rock mass Model) and the use of insitu stress levels and hydraulic radius. Well-established rock mass classification methods have been used as the basis for empirical as well as numerical approaches, which include the Synthetic Rock Mass (SRM) model. The most crucial factors affecting the cavability are found to be in-situ stress and hydraulic radius. Considering all these methodologies, it is important to define the subsidence profile of the caving operation for mine closure requirements to define potential unstable zones which could be used to define mining impacted zones on the surface topography for mine closure planning.

Impacts of underground mining on the ground water table needs to be accounted for mining and closure planning. Dewatering needs may arise if there are underground aquifers in the mining area. Dewatering could be a continuous process during the life of a mine where aquifers are depressurised, affecting the virgin ground water levels. This could also have impacts on the surface as well as on vegetation.

Open holes, including main shafts, ventilation shafts and portals used to access the underground mine, are some other most visible features of mining, and may remain indefinitely. These need to be effectively isolated for closure to prevent any unwarranted access that could have serious consequences. This may be done by completely isolating the opening with high windrows, capping with concrete, walling or sealing the decline access portals with suitable methods.

4 Tailings storage facilities

The majority of Western Australia is located in a seismically stable region, and mines are generally located in areas of relatively flat topography away from populated areas. Accordingly, the majority of the TSFs are located in upstream constructed paddock style facilities, although there are also a minor number of valley and hillside facilities. An increasing number of TSFs are being constructed as in-pit facilities, with tailings discharging into mined out open pits, which is preferred due to the lower risk profile and reduced environmental footprint on the mining lease. Mining companies are making use of technological advances to construct dry stack facilities with integrated waste landforms (IWL) where tailings and waste rock are co-disposed. TSFs provide opportunities for encapsulation of hazardous materials or potentially acid forming (PAF) tailings or waste. This highlights the importance of adequate design and construction methods to achieve a safe, stable, non-polluting post-closure landform.

Due to the potential for significant environmental impact, WA legislation requires that TSFs are effectively managed throughout the design, construction, operation and closure phases. Regulations in Western Australia require a series of approvals and notifications to ensure that mining companies are meeting their legislative obligations and following good industry practices. Facilities in Western Australia must be designed in accordance with the Australian National Committee on Large Dams (ANCOLD), the Code of practice: *Tailings storage facilities in Western Australia* and associated guidelines, which outline requirements to inform the construction of a safe, stable, non-polluting TSF. Closure is considered in the initial design phases. This is done alongside other applicable assessments of location, foundation condition, material characterisation, potential for seismicity and liquefaction, ground water and seepage, and many other engineering, environmental, ecological and traditional land owner factors that need comprehensive assessments. The requirement to submit a mining proposal that includes a mine closure plan including rehabilitation of the land is included in the *Mining Act 1978* [section 74(1) (ca) (i)].

Ground movement, surface water flow and erosive forces will continue to impact in perpetuity on these man made landforms. The geotechnical design for the TSF must therefore meet minimum design stability criteria during the construction stage, short and long-term scenarios. Modelling of liquefaction potential of the tailings under dynamic and static forces has to be considered with seismic forces being applied to demonstrate that the TSF could remain stable in worst-case scenarios. This needs to be supplemented by "dam-break analysis" which is used to identify potentially impacted areas in the case of an embankment collapse or overtopping to assign a risk category (ICOLD Bulletins 153 and 181) . There is an expectation that TSFs are designed to accommodate extreme weather events with application of probable maximum precipitation (PMP) and probable maximum flood (PMF) rainfall events modelled to understand and define storage allowances, and the erosion of the exterior embankments during operation and closure stages.

The required outcome for closure of a TSF is a safe, stable, erosion resistant and non-polluting landform with no requirement for ongoing maintenance. The geotechnical design process must consider the weather patterns, environmental settings etc. in the choice of capping material that reduces infiltration, the potential for dust generation as well as resistance to erosion. In return, this will facilitate the effective management of surface water flows and prevent the degradation of these landforms especially where the facility has been used to store hazardous or acid generating materials.

Additional legislation that applies to closure of tailings facilities is captured in the WHS Act and WHS Mines Regulations, which address worker and public safety during all stages of the mining operation. A geotechnical structure is defined in the WHS Mines Regulations [r. 5] as inclusive of a structure constructed by placing tailings. Further regulations are specific to managing risks to health and safety in relation to all geotechnical structures applying to closure of the mine are also defined in WHS (Mines) Regulations r. 631B.

Furthermore, WHS (Mines) Regulations include requirements for the management of TSFs under Principal Mining Hazards where there is a reasonable potential to result in multiple deaths in a single incident, such as geotechnical structure instability or inrush of any substance (WHS (Mines) Regulations. Schedule 19). Hence, any mining activity having a reasonable potential for the occurrence of incidents as described above must have a principal mining hazard management plan that covers all matters that must be considered in its management and safe closure.

5 Waste rock dumps

Waste Rock Dumps (WRD) are generally built from overburden waste coming from open pits or underground development work. These wastes are generally dumped as above ground landforms having few lifts with stable batter angles matching the rill angle (angle of repose) of the waste and a berm sufficient to form an overall stable slope angle. Back filling of pits is also widely used depending on the mining sequence and future mining potentials.

These waste dumps need to comply with closure requirements right at the beginning for effective closure of the WRD. The design and construction of the landform should be site-specific based on climate and type of waste materials. The design and construction of the dump must account for difficult materials (e.g. potentially acid forming (PAF), dispersive, fibrous), to limit the percolation of rainfall and exposure to oxygen.

On all these waste rock landforms, the promotion of the growth of native plants can be achieved by carefully grading the slopes to suitable slope profiles preventing excessive erosion and then protecting soil properties nurturing the plant growth. The cover system must be designed to cater the materials used in the landform construction and the final agreed land use.

Monitoring of the rehabilitation performance is key to validate the design model for erosion, runoff and impacts to surface and groundwater. In addition, it will flag any remedial works to achieve the environmental outcomes approved in the mine closure plan. Rehabilitation trials are encouraged throughout the life of mine project to verify the capacity of the cover system to support the proposed revegetation species mix. The trials should consider efficacy of controls as well as the required rehabilitation resources to implement the treatments. This will provide an early indication of whether the mine closure plan needs to change to meet closure outcomes and whether closure outcomes are realistic and achievable. DMIRS has published the Guideline: *Waste rock dumps* Version 2.1 (2021).

6 Legislation in Western Australia

In Western Australia, application for a mining lease and subsequent mining operations start with applying for a tenement agreement/s. Applications are accompanied by a mining proposal as per requirements of the *Mining Act 1978,* which also comprises a mine closure plan.

A mine closure plan submitted for approval under the *Mining Act 1978* must meet the form and content requirements of Part 1 of the *Statutory Guidelines for Mine Closure Plans*. This guidance document provides additional detail on how to prepare a mine closure plan that meets those statutory requirements. Furthermore, the *Environmental Protection Act 1986* also provides legislative requirements for emissions and discharges to the environment. The mine closure plan requires a stakeholder consultation that includes the Traditional Land Owners.

It is also important to note that “Registered Native Title claimants and determined “Native Title holders” have certain rights under the provisions of the *Native Title Act 1993* when governments intend to conduct business, such as the granting of mineral tenure. Disturbance of aboriginal heritage sites requires approval under the *Aboriginal Heritage Act 1972* [s. 18], which is done after the tenement agreement phase.

The WHS Act and WHS Mines Regulations provide the primary legislative requirements for safety of workers and public at mining operations in Western Australia. Design, construction, operation and closure legislative requirements are provided under many sections of the act and regulations and include management of principal mining hazards and mine closure (WHS (Mines) Regulations. Schedule 19).

Non-compliance to Western Australian legislative Acts and regulations can result in penalties to the mine operator or individual depend on the situation. One such example in the WHS Mines Regulations provides for a penalty in relation to non-compliance with providing information on the closure of the mine to meet safety requirements as outlined below:

Section 675UI Information about closure of mine

(3) If the mine, or a part of the mine, will close, the relevant person in relation to the mine must ensure that the mine or part is not closed unless -

(a) measures are taken to ensure that, so far as is reasonably practicable, the mine or part is made safe and secure on a permanent basis; and

(b) after the measures required under paragraph (a) are taken, the relevant person gives the regulator a written notice stating -

I. a description of the closure; and
II. a description of the measures taken under paragraph (a); and
III. any information or document relating to the closure that the regulator requires;

and

(c) the regulator has given the relevant person a notice under sub regulation (6) authorising the closure.

There is a penalty for non-compliance and hence all mining operations need to be conducted with highest level of accountability for their effective closure. The above-discussed legislation is the most relevant among many other statutory requirements under applicable legislation for mine closure.

7 Conclusions

Mining operations need to comply with many state regulations for their safe closure. There are many guidelines, codes of practices and legislative requirements to follow for their design, construction, operation and effective closure. The requirements under the WHS Act 2020, WHS (Mines) Regulations 2022, *Mining Act 1978* and *Environmental Protection Act 1986* provide the minimum requirements and commitments expected from mine operators by the regulators.

Guidelines and codes of practice provide a framework of guidance from design to closure, which facilitates the safe closure of structures and post closure environmental remediation. Geotechnical aspects are mainly covered under codes of practices and guidelines. The correct use of data and modelling techniques for safer designs are beneficial for closure at the end of the life of the mine. Therefore, technical excellence in design, construction, operation and closure will add greater value for the closure of mining operations to comply with legislative and regulatory requirements of the state. This professional approach will invariably lead to the ultimate objective of mining at right cost and safe closure of mining operations.

8 Acknowledgement

Authors wish to acknowledge Department of Mines, Industry Regulation and Safety (DMIRS) for the support extended for the publication of this paper.

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