SafeWork NSW

NSW GOVERNMENT

Draft Health and Safety Risk Management of Tunnels and Shafts in Construction Code of Practice

October 2025

Editorial note

When reading this Code of practice (this Code), please be aware that any reference to:

- the '*Work Health and Safety Act*' refers to the Work Health and Safety Act 2011 (NSW), or any successor legislation,
- the '*Work Health and Safety Regulation'* refers to the Work Health and Safety Regulation 2025 (NSW), or any successor regulation,
- a code of practice refers to the relevant NSW Code of practice, or any successor code of practice.

This Code may contain references to relevant withdrawn or superseded Australian Standards or Australian/New Zealand Standards.

Acknowledgment

SafeWork NSW wishes to acknowledge the contribution and collaboration of industry and social partners through the public comment period and technical development of this Code.

Additionally, the cooperation of other WHS regulators and Safe Work Australia is acknowledged for aligning materials where appropriate, particularly from Safe Work Australia's Guidance Material.

Contents

Foreword

This Code of Practice (the 'Code' or 'Code of Practice') on the Health and Safety Risk Management of Tunnels and Shafts in Construction is an approved Code of Practice under section 274 of the *Work Health and Safety Act 2011* (the WHS Act).

An approved code of practice provides practical guidance on how to achieve the standards of work health and safety required under the WHS Act and the Work Health and Safety Regulation (the WHS Regulation) and effective ways to identify and manage risks.

A code of practice can assist anyone who has a duty of care in circumstances described in the code of practice. Following an approved code of practice will assist the duty holder to to achieve compliance with the health and safety duties in the WHS Act and WHS Regulation, in relation to the subject matter of the code of practice. Like regulations, codes of practice deal with particular issues and may not cover all relevant hazards or risks. The health and safety duties require duty holders to consider all risks associated with work, not only those for which regulations and codes of practice exist.

Codes of practice are admissible in court proceedings under the WHS Act and WHS Regulation. Courts may regard a code of practice as evidence of what is known about a hazard, risk, risk assessment or risk control and may rely on the code in determining what is reasonably practicable in the circumstances to which the code of practice relates. For further information see Safe Work Australia's *Interpretive Guideline: The meaning of 'reasonably practicable'*.

Compliance with the WHS Act and WHS Regulation may be achieved by following another method if it provides an equivalent or higher standard of work health and safety than the code.

An inspector may refer to an approved code of practice when issuing an improvement or prohibition notice.

Scope and application

The Object of the Work Health and Safety Act (2011) is to protect workers and other persons from harm to their '*health, safety and welfare'*.

As an industry Regulator, SafeWork NSW aims to support the creation of safer workplaces and this includes the publication of industry guidance such as this Code of Practice.

This Code is intended to be followed by all involved in the civil tunnelling industry in New South Wales including any person conducting a business or undertaking (PCBU), Officers, tunnel workers and their representatives. It is intended to apply to all activities, and decisions that may impact health and safety for Tunnels, Shafts and all associated underground structures, including caverns, cut-and-cover tunnel excavations, portal structures and trenches, howsoever constructed that facilitate underground construction and that create health and safety risks from underground construction.

The responsibility for identifying and managing risks rests with the Person Conducting a Business or Undertaking (PCBU), who is best placed to assess the unique hazards of their work environment and to implement control measures accordingly. This Code of Practice supports that duty by outlining areas for consideration with respect to risks and risk management and providing guidance and minimum requirements based on good industry practices.

As a PCBU, the standard you must meet to fulfil your WHS duties is to do what is 'reasonably practicable' to ensure the health and safety of workers and others. You must first try and eliminate risks to health and safety, so far as is reasonably practicable. If that is not possible, you must minimise the risks so far as is reasonably practicable. What is reasonably practicable is an objective test. This means that you must meet the standard of behaviour expected of a reasonable person in your (the duty holder's) position and who is required to comply with the same duty.

To identify what is (or was) reasonably practicable, all relevant matters must be taken into account and weighed up and a balance achieved that will provide the highest level of protection that is both possible and reasonable in the circumstances. The model WHS Act sets out the issues you must, at minimum, consider:

- the likelihood of the hazard or risk occurring

- the degree of harm from the hazard or risk
- knowledge about ways of eliminating or minimising the hazard or risk
- the availability and suitability of ways to eliminate or minimise the risk, and
- cost associated with available ways of eliminating or minimising the risk, including whether the cost is grossly disproportionate to the risk.

This Code provides guidance and minimum requirements for planning, design and construction of Tunnels and Shafts, their excavation, ground support and lining, mechanical and electrical plant installation and commissioning, maintenance, repair or renovation.

Other SafeWork NSW approved codes of practice as listed in Appendix A should also be referenced for further guidance.

This Code does not apply to mining, excavation work or quarries intended for purposes of extracting minerals. Mining is addressed in specific Work Health and Safety (WHS) mining legislation.

How to use this Code of Practice

This Code includes various references to the legal requirements under the WHS Act and WHS Regulation. These references are included for convenience only and should not be relied on in the place of the full text of the WHS Act or WHS Regulation. The words 'must', 'requires' or 'mandatory' indicate a legal requirement exists that must be complied with.

The word 'should' is used in this Code to indicate a recommended course of action, while 'may' is used to indicate an optional course of action.

Definitions

Term	Description
Client Organisation or Owner	The 'commissioner'[1] of construction work and final owner of the project to be constructed and/or the procurer of goods or services including design services whether a public entity or a private agency or developer. If a person conducting a business or undertaking (PCBU) commissions a construction project and engages a principal contractor, they must • Identify high-risk construction work and ensure appropriate controls are in place. • Ensure safe work method statements (SWMS) are prepared and followed. • Consult, coordinate and cooperate with other duty holders on site. Including providing any information (design or interpretation) they have in relation to the hazards and risks at the workplace • Ensure workers are trained and informed about WHS procedures relevant to their tasks
Competent person	A person who has acquired through training, qualification or experience the knowledge and skills to carry out a task.

[1] Refer Model WHS Regulations 2024

Term	Description
	Competency may be assessed by consideration of relevant experience and skill, development training and academic qualifications and/or certifications.
Confined Space	An enclosed or partially enclosed space that: • Is not designed or intended to be occupied by a person, • Is intended to be at normal atmospheric pressure while any person is in the space, and • Is or is likely to be a risk to health and safety due to one or more of the following: - Unsafe oxygen levels, - Contaminants including airborne gases, vapours, and dusts that may cause injury from fire or explosion, - Harmful concentrations of airborne contaminants, - Engulfment
Contract Agreement	For the purposes of this Code of Practice, a Contract Agreement is a legally binding arrangement between parties that outlines roles, responsibilities, and obligations, including compliance with Work Health and Safety (WHS) legislation, to ensure the health and safety of all persons involved in or affected by the contracted work. This may include: • Embedding non-delegable legal duties into contract terms. • Requiring certified safety systems and WHS plans. • Appointing Principal Contractors with defined responsibilities. • Incentivising compliance through audits, reporting, and penalties.
Crystalline Silica Substance (CSS)	A material containing at least 1% crystalline silica (by weight)
Dangerous incident	An incident in relation to a workplace that exposes a worker or any other person to a serious risk to a persons health or safety emanating from an immediate or imminent exposure to— (a) an uncontrolled escape, spillage or leakage of a substance, or (b) an uncontrolled implosion, explosion or fire, or (c) an uncontrolled escape of gas or steam, or (d) an uncontrolled escape of a pressurised substance, or (e) electric shock, or (f) the fall or release from a height of any plant, substance or thing, or

Term	Description
	(g) the collapse, overturning, failure or malfunction of, or damage to, any plant that is required to be authorised for use in accordance with the regulations, or (h) the collapse or partial collapse of a structure, or (i) the collapse or failure of an excavation or of any shoring supporting an excavation, or (j) the inrush of water, mud or gas in workings, in an underground excavation or tunnel, or (k) the interruption of the main system of ventilation in an underground excavation or tunnel, or (l) any other event prescribed by the regulations.
Designer	The individual/organization appointed as a PCBU to undertake the planning and design process and defining the limits of the design and the observations and monitoring necessary to validate the design assumptions. Different designers may be appointed for different stages of the design process. Responsible for being competent in their area of practise as applied to the design (and safe construction thereof) and conversely not practising outside their area of competency and adhering to the code of ethics of their practice. The designer of a structure or any part of a structure that is to be constructed must give the person conducting a business or undertaking who commissioned the design a written report that specifies the hazards relating to the design of the structure that, so far as the designer is reasonably aware: (a) create a risk to the health or safety of persons who are to carry out any construction work on the structure or part; and (b) are associated only with the particular design and not with other designs of the same type of structure.
Dogger	A person who performs dogging work, which includes selecting and inspecting lifting gear, determining load characteristics (such as weight and centre of gravity), and directing crane or hoist operators during lifting operations when the load is out of the operator’s view. A dogger must hold a valid Dogging High Risk Work (HRW) Licence issued under the Work Health and Safety Regulation.
Duty holder	Any person who owes a work health and safety duty under the WHS Act including a PCBU, a designer, manufacturer, importer, supplier, installer of products or plant used at work (upstream duty holder), officer or a worker.
Fit for purpose	Something that is sufficient to do the function it was designed to do, for the intended use, over its specified design life.
Fresh Air	Air that contains sufficient oxygen, and is sufficiently free of airborne contaminants such as dust, fumes, vapours, gases, and mists, to sustain safe working conditions when used as part of a

Term	Description
	mechanical ventilation system (or available naturally) over the period of exposure whilst at work.
Good Industry Practice (s)	Means the standards, practices, methods, and procedures that comply with applicable laws and reflect the level of skill, care, diligence, prudence, and foresight reasonably expected from a competent person or organisation engaged in a similar undertaking, under comparable circumstances.
Grossly Disproportionate – in relation to 'reasonably practicable'.	A determination that further risk control measures are not required because the cost, effort, or complexity of implementing them would be grossly disproportionate to the expected health and safety benefits. This assessment involves weighing: • The severity and likelihood of potential harm, • The availability and effectiveness of additional controls, • The costs and practical implications of implementing those controls. The judgment of disproportion may vary depending on: • The level of risk, • Who is exposed to the risk, • Whether exposure is voluntary or involuntary, • The potential consequences of the risk event.
Hazard	A situation or thing that has the potential to harm a person. Hazards at work may include: noisy machinery, a moving forklift, chemicals, electricity, working at heights, a repetitive job, bullying and violence at the workplace.
Health	The physical, mental and social well-being of personnel.
Health and safety committee	A consultative body established under the WHS Act. The committee's functions include facilitating cooperation between workers and the person conducting a business or undertaking to ensure workers' health and safety at work, and assisting to develop work health and safety standards, rules and procedures for the workplace.
Health and safety representative	A worker who has been elected by their work group under the WHS Act to represent them on health and safety matters.
Health and Safety Risk Management	A systematic approach to identifying health and safety risks, assessing and implementing controls, monitoring conditions and worker health, and engaging workers to prevent harm and promote well-being.
Irrespirable Atmosphere	An irrespirable atmosphere contains air that cannot be safely breathed due to insufficient oxygen or the presence of harmful substances such as toxic gases, smoke, or dust. Air is considered irrespirable when it: • Contains less than 19.5% oxygen, or

Term	Description
	• Contains toxic gases (e.g., carbon monoxide, hydrogen sulphide) at dangerous levels, or is contaminated with smoke, dust, or fumes that may exceed defined exposure limits.
May	‘May’ indicates an optional course of action.
Must	‘Must’ indicates a legal requirement exists that must be complied with.
Occupational Hygienist	An individual who is recognised as a certified occupational hygienist (COH) by the Australian Institute of Occupational Hygienists (AIOH); or holds an equivalent competency under an international certification scheme (e.g. Certified Industrial Hygienist).
Officer	An officer under the WHS Act is: - an officer under section 9 of the Corporations Act 2001 (Cth) - an officer of the Crown within the meaning of section 247 of the WHS Act, and - an officer of a public authority within the meaning of section 252 of the WHS Act. A partner in a partnership or an elected member of a local authority while acting in that capacity, are not officers.
Person conducting a business or undertaking (PCBU)	A person conducting a business or undertaking: (a) whether the person conducts the business or undertaking alone or with others, and (b) whether or not the business or undertaking is conducted for profit or gain. A PCBU includes: - public and private companies, - partners and partnerships - government departments and authorities - local government councils - independent schools, universities - not for profit organisations and cooperatives - unincorporated body or associations with more than one employees - sole trader or self-employed person. Individuals who are in a partnership that is conducting a business will individually and collectively be a PCBU. A volunteer association (defined under the WHS Act) or elected members of a local authority will not be a PCBU.

Term	Description
	Note – A person may be both a PCBU, within the meaning of section 5 of the WHS Act, and a worker within the meaning of section 7 of the WHS Act.
Place of Safety	A place where workers can shelter in the case of an emergency where there is a respirable atmosphere and protection from the effects of fire.
Principal Contractor	A person who is, under section 293 of the Work Health and Safety Regulation 2025, appointed or taken to be the principal contractor for a construction project. Refer also WHS Act section 20 and WHS Regulation sections 293, 299, 301 and 307-315.
Psychosocial hazard	Psychosocial hazards at work are aspects of work and situations that may cause a stress response which in turn can lead to psychological or physical harm. These stem from: • the way the tasks or job are designed, organised, managed and supervised, • tasks or jobs where there are inherent psychosocial hazards and risks, • the equipment, working environment or requirements to undertake duties in physically hazardous environments, and • social factors at work, workplace relationships and social interactions.
Psychosocial risk	A risk to the health or safety of a worker or other person arising from a psychosocial hazard.
Reasonably Practicable (see also Gross Disproportionality)	According to Section 18 of the Work Health and Safety Act 2011 (NSW): That which is, or was, at a particular time, reasonably able to be done in relation to ensuring health and safety, taking into account and weighing up all relevant matters including: a) the likelihood of the hazard or the risk concerned occurring; and b) the degree of harm or damage that might result from the hazard or risk; and c) what the party concerned knows, or ought reasonably to know, about— i. the hazard or risk; and ii. ways of eliminating or minimising the risk; and d) the availability and suitability of ways to eliminate or minimise the risk; and e) after assessing the extent of the risk and the available ways of eliminating or minimising the risk, the cost associated with available ways of eliminating or minimising the risk, including whether the cost is grossly disproportionate to the risk.

Term	Description
Reference Design	For the purposes of this Code of Practice, a *reference design* is a preliminary design prepared by or on behalf of the Client Organisation. It serves as a basis for tendering and provides sufficient detail to enable contractors to understand the scope, intent, and key requirements of the proposed tunnel construction works in sufficient detail to enable health and safety.
Respirable	Particles or contaminants that are small enough to be inhaled deeply into the lungs, reaching the alveolar region where gas exchange occurs.
Risk	The possibility that harm (death, injury or illness) might occur when exposed to a hazard.
Risk Management	The coordinated activities required to direct the scope, provide the context and define the criteria that will control planning, design and construction in relation to risk.
Risk Register	A formalised record of Risks identified from a risk assessment process including details of risk sources (hazards) risk controls and risk owners. A Risk Register is the means of recording and monitoring the Risk Management process.
Safety	Safety is the process of actively managing hazards, systems, and behaviours to eliminate or minimize risks to the health and well-being of workers and others in the workplace. It involves continuous assessment, control implementation, and engagement to prevent injury, illness, and harm.
Safety Critical System	A system whose failure or malfunction may result in death or serious injury to people.
Serious injury or illness	An injury or illness requiring the person to have – (a) immediate treatment as an in-patient in a hospital, or (b) immediate treatment for— (i) the amputation of any part of his or her body, or (ii) a serious head injury, or (iii) a serious eye injury, or (iv) a serious burn, or (v) the separation of his or her skin from an underlying tissue (such as degloving or scalping), or (vi) a spinal injury, or (vii) the loss of a bodily function, or (viii) serious lacerations, or (c) medical treatment within 48 hours of exposure to a substance,

Term	Description
	and includes any other injury or illness prescribed by the regulations but does not include an illness or injury of a prescribed kind.
Shaft	A shaft is defined in the WHS Regulations as 'vertical or inclined way or opening, from the surface downwards or from any underground working, the dimensions of which (apart from the perimeter) are less than its depth'. For the purposes of this code a shaft is a vertical or steeply inclined passage cut through the ground at an angle greater than 20 degrees from the horizontal A shallow shaft can be constructed from surface using civil engineering methods limited by the safe operational limits of cranes. A deep shaft is more common in mining and requires a headframe and associated infrastructure.
Should	'Should' indicates a recommended course of action.
Similar Exposure Group (SEG)	SEGs are used to identify a group of workers who have the same general exposure to risks. This can include: the similarity and frequency of the tasks performed; the types of materials and processes used to complete tasks; and / or the similarity of the way tasks are performed.
Tender	A response to a procurement process for design or construction services that is typically competitive in which suppliers or contractors submit proposals including a costed offer demonstrating how their resources, capabilities, and methodologies will meet the specified outcomes and requirements of a procuring entity. The tender submission should enable the client to evaluate and select the most suitable provider based on value, alignment with objectives, and compliance with procurement criteria including for example risk management.
Toxic Gas	A gas that, when inhaled, can cause acute or chronic adverse health effects such as respiratory distress, poisoning, nerve damage, or other systemic harm. Toxic gases are classified as hazardous chemicals under the Work Health and Safety Regulation and must be managed to prevent exposure above prescribed exposure standards.
Tunnel	A tunnel is defined in the WHS Regulations as 'an underground passage or opening that is approximately horizontal and starts at the surface of the ground or at an excavation'. For the purposes of this code of practice a tunnel includes all associated underground structures, including caverns, cut-and-cover tunnel excavations, portal structures and trenches, howsoever constructed that facilitate underground construction and that create health and safety risks from underground construction.

Term	Description
Unsupported Ground	Unsupported ground refers to any area within an underground excavation where the natural ground has been exposed by excavation and has not yet been stabilized or supported by engineered ground support systems and/or has not been deemed safe for entry or occupation by a competent person
Ventilation Officer	A Ventilation Officer (VO) is a designated specialist responsible for the implementation, monitoring, and maintenance of ventilation systems within tunnel construction environments. The VO ensures that air quality meets regulatory and safety standards, manages risks associated with airborne contaminants, and supports emergency response protocols. The role requires demonstrated competency in ventilation system design, change management, airflow and contaminant monitoring, confined space safety, and compliance with Work Health and Safety (WHS) legislation, including relevant Codes of Practice issued by SafeWork NSW. The VO should possess appropriate technical qualifications, practical experience, and maintain ongoing professional development to ensure safe and effective ventilation throughout all phases of tunnelling operations.
Verification Activities	Verification activities: The process of checking the extent to which the performance requirements set for a risk control are being met in practice. Company safety and health management systems might use a variety of terms for “verification” activities. Common terms include audit, review, monitoring and active monitoring.
Vitiated Air	Air that has been contaminated or depleted of oxygen due to the presence of harmful gases, dusts, fumes, or vapours, and is no longer suitable for safe breathing without ventilation or respiratory protection. Part of the atmosphere that must be continuously replaced by fresh air to maintain safe working conditions underground
Volunteer association	A group of volunteers working together for one or more community purposes where none of the volunteers, whether alone or jointly with any other volunteers, employs any person to carry out work for the volunteer association. Most large volunteer organisations employ people.
Work group	A group of workers established to facilitate the representation of workers by one or more health and safety representatives. A work group may be all workers at a workplace but it may also be appropriate to split a workplace into multiple work groups where workers share similar work conditions or are exposed to similar risks and hazards. For example, all workers on night shift.
Worker	Any person who carries out work for a person conducting a business or undertaking, including work as an employee, contractor or subcontractor (or their employee), self-employed person, outworker, apprentice or trainee, work experience

Term	Description
	student, employee of a labour hire company placed with a 'host employer' or a volunteer. *Note* – A person may be both a worker, within the meaning of section 7 of the WHS Act, and a PCBU within the meaning of section 5 of the WHS Act.
Workplace	Any place where work is carried out for a business or undertaking and includes any place where a worker goes, or is likely to be, while at work.

1 Introduction

1.1 Health and Safety Risk Management in Tunnelling and Underground Construction

In comparison to other forms of construction, underground construction is highly complex. This complexity arises from the use of highly specialised construction plant and equipment in typically constrained working areas and from variable, uncertain ground conditions[2] and behaviour.

Managing and controlling the safety of a tunnel construction site and maintaining the health of workers, engineers, managers and frontline supervisors required for construction, requires clear allocation of responsibilities, cooperation, good communication and clearly defined objectives.

Safe working requires a high degree of competence for all those involved from the earliest stages of planning through procurement, construction, commissioning and for maintenance and renovation. It also requires continuous monitoring and review.

This updated NSW Code of Practice highlights the importance of planning decisions in relation to health and safety risks and provides requirements for managing health and safety risks of construction given there has been significant change and technological development in the industry since 2006, a greater awareness of risks to health, and changes to Legislation.

1.2 Who has health and safety duties in relation to this Code of Practice?

Duty holders with a role in managing the risks of tunnelling under construction in the workplace, include those listed below. A person can have more than one duty and more than one person can have the same duty at the same time.

Who	Duties
Person conducting a business or undertaking (PCBU) **WHS Act sections 19, 46 and 47**	A PCBU must eliminate risks to health and safety arising from tunnels under construction, or if that is not reasonably practicable, minimise the risks so far as is reasonably practicable. This includes: • the provision and maintenance of safe plant and structures, • the safe use, handling, and storage of plant, structures and substances, • the provision of information, training, instruction and supervision, • monitoring the health and conditions of the workplace to prevent illness and injury, • the provision of adequate facilities for the welfare at work of workers, • managing psychosocial hazards. PCBUs operating in a contracting chain will have shared health and safety duties with other PCBUs in that contracting chain (known as overlapping

[2] Including the risks from groundwater

	duties). All PCBUs, so far as is reasonably practicable, must consult, cooperate, and coordinate together to manage their overlapping duties. (see Section 1.2 below)
Designers, manufacturers, importers, installers and suppliers of plant, substances or structures WHS Act sections 22-26	Must ensure, so far as is reasonably practicable, the plant, substances or structures they design, manufacture, import, supply or install is without risks to health and safety including carrying out testing and analysis and providing information about the risks posed to users of the plant, substances or structures.
Persons with management or control of plant at a workplace WHS Act section 21 WHS Regulation Part 3.1, sections 203 – 215 and 219 - 220	A PCBU with management or control of plant must: • manage health and safety risks associated with the plant, • ensure that any mobile plant doesn't collide with pedestrians or other powered mobile plant, • so far as is reasonably practicable, prevent unauthorised alterations or interference with plant, • take all reasonable steps to ensure that the plant is used only for the purpose it was designed.
Principal contractors WHS Act section 20 WHS Regulation sections 293, 299, 301 and 307-315	Principal contractors are a PCBU who holds additional duties under the WHS Regulation, including that they must: • prepare a written WHS management plan for the workplace, • ensure, so far as is reasonably practicable, that each worker is made aware of the content of the WHS management plan before they start work, • review and as necessary revise the WHS management plan to ensure that it remains up to date, • establish and maintain consultation arrangements with other PCBUs, contractors, subcontractors and workers, • manage risks associated with the construction project • ensure a Safe Work Method Statement (SWMS) is prepared for high-risk construction work, • take all reasonable steps to obtain a copy of the SWMS and ensure it is followed,

	• maintain a safe working environment including providing sufficient access, sufficient space, and sufficient time for works to be completed safely. When engaging specialist businesses and or workers to deliver specific works, a Principal Contractor should: • verify that moving plant supplied is suited to task and maintained, • ensure there are processes for the verification of worker competency in the operation of moving plant, • ensure workers are inducted to the site requirements.
Subcontractors WHS Act Section 19	Subcontractors must: • work within the requirements of the WHS management plan, • ensure a SWMS is prepared for the high risk construction work that they control, • verify that works are being completed in accordance with SWMS, • verify that any mobile plant used or supplied is suited to work and maintained, • ensure workers are provided with suitable and adequate information, training and instruction to complete the work.
Officers WHS Act section 27	Officers of the PCBU must exercise due diligence to ensure the PCBU complies with the WHS Act and WHS Regulation. This includes maintaining up to date WHS knowledge and taking reasonable steps to ensure the business or undertaking has and uses appropriate resources and processes to eliminate or minimise risks to health and safety from tunnels under construction work. Further information on who is an officer and their duties is available in Safe Work Australia's *Interpretive Guideline: The health and safety duty of an officer*.
Workers WHS Act section 28	While at work, workers must: • take reasonable care for their own health and safety, • take reasonable care that their actions or omissions do not adversely affect the health and safety of other persons, • comply with any reasonable instructions given by the PCBU, as far as they are reasonably able, • cooperate with any reasonable health and safety policies or procedures of the PCBU. If personal protective equipment (PPE) is provided by the PCBU, the worker must, so far as they are reasonably able, use or wear it in accordance with the information and instruction and training provided.
Other persons at the workplace WHS Act section 29	A person at a workplace must: • take reasonable care for their own health and safety, • take reasonable care that their acts or omissions do not adversely affect other people's health and safety, • comply, so far as they are reasonably able, with reasonable instructions given by the PCBU to allow the PCBU to comply with the WHS Act.

1.3 What is Consultation?

Duty / Provisions	Application
Consulting workers WHS Act section 47 - 49	• PCBUs have a duty to consult with workers on WHS matters and not just provide information • Consultation is a two-way process with workers to identify WHS issues, share information, and contribute to the management health and safety. • If workers are represented by a health and safety representative, the consultation should involve that representative. • PCBU must consult with workers when: — identifying hazards and assessing risks, — making decisions about ways to eliminate or control risks, — changing or updating workplace facilities, — proposing changes that may affect the health and safety of workers, — making decisions about consultation procedures, resolving safety issues, monitoring workers' health and conditions, and providing information and training, — selecting new equipment, — introducing new tasks, changing existing tasks or carrying out work in new environments. • Workers should be informed of the outcomes of the consultation process as soon as reasonably practicable, ensuring transparency and fostering trust in decision-making.
Consulting, cooperating and coordinating activities with other duty holders WHS Act section 46	• PCBUs must, as far as reasonably practicable, consult, cooperate and coordinate activities with all other persons who have a WHS duty in relation to the same matter. • Duty holders should exchange information about who is doing what to ensure effective coordination of works and management of risks including — the PCBUs that engage and/or direct workers for work tasks, — consideration of other persons that may be put at risk from work carried out in their business or undertaking, — the PCBU that manages or controls a workplace or the fixtures, fittings or plant at a workplace, — the PCBUs that are designing, manufacturing, importing or supplying plant, substances or structures for use at a workplace, — the PCBUs that are installing, constructing or commissioning plant or structures at a workplace.

Further guidance on consultation requirements is available in the Code of practice: *Work health and safety consultation, cooperation and coordination.*

1.4 What is Information, training, instruction, and supervision

Duty / Provisions	Application
Information, training, instruction or supervision WHS Act section 19 WHS Regulation section 39	• PCBU's must provide any information, training, instruction, or supervision necessary to protect all persons from health and safety risks, including when using plant. • The information, training and instruction: — must be suitable and adequate for the nature of works, risks and control measures implemented, — must be readily understandable to the person it is being provided to, so far as is reasonably practicable, — should be supported by relevant safe work procedures, ie. emergency procedures, traffic rules, PPE. • Workers need to be competent to carry out tasks safely. • Training for competence needs to be provided by a competent person. • Training programs should be practical and 'hands on' and take into account the particular needs of workers.
	Induction Training • Inform workers of site-specific hazards. • Familiarise workers with tunnelling under construction operations and safe work procedures. • Topics covered should include: - site-specific tunnelling hazards and controls, - tunnel ventilation - occupational hygiene - emergency procedures, and self rescue - safe operating and work procedures, - communication systems, - first aid and amenities, - fatigue management, - hazard and incident reporting, - record keeping, - consultation arrangements and issue resolution processes,
	Refresher training • Ensure key WHS requirements are understood, competencies are verified, and maintained in view of current best practices • Monitor work techniques and practices to maintain standards.
	Effective supervision • Is essential for maintaining a safe and healthy working environment. • The level and type of supervision required depends on the: - skills and competence of the worker - risk levels and risk controls to be applied including monitoring systems and communications - precedence and novelty of the methods to be used - working conditions. • Requires systematic oversight and experienced personnel

2 Health and Safety Risk Management

> **WHS Regulation sections 34 – 38**
>
> Duties to identify hazards, implement risk control measures using the hierarchy of controls, and then maintain and review control measures

2.1 Overview

Risk management is a systematic process to eliminate or minimise the potential for harm to people.

Risk management should be a continuous process that starts at the earliest stages of project concept definition, extends through planning and procurement, construction, operation and beyond. It requires a structured, systematic approach to identifying hazards, assessing risks, applying effective risk control measures, maintaining them and review (Refer Figure 2,1 below).

It is important to consider risks that may be unlikely to occur but that have significant consequences (low probability high consequence risks).

Risk control measures should be proportionate to the risk such that significant risks require more effort and resources in order to assess and control them. Risk allocation should be made to the party that is best able to manage the risk during construction.

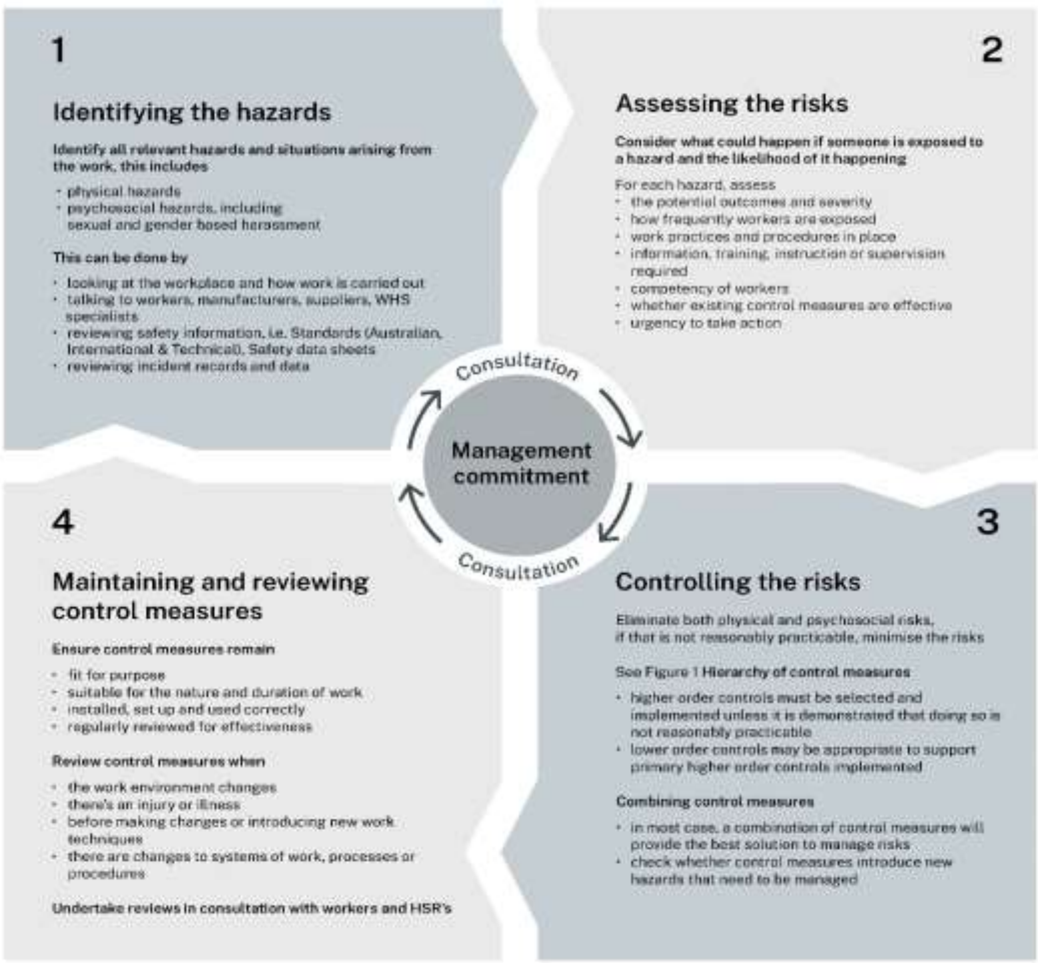


Figure 2,1

Further risk management guidance is available in the Safework NSW *Code of Practice: How to manage work health and safety risks.*

2.2 A Hierarchy of Risk Control Measures

The hierarchy of control measures set out in Part 3.1 of the WHS Regulation can be applied in relation to any risk.

The WHS Regulation makes it mandatory for duty holders to work through this hierarchy when managing certain risks. The sections that require the process in Part 3.1 to be followed are set out below.

WHS Regulation reference
Chapter 3 General risk and workplace management, Part 3.2 General workplace management
Division 6 Remote or isolated work, Section 48 Remote or isolated work
Division 8 Hazardous atmospheres, Section 51 Managing risks to health and safety
Division 8 Hazardous atmospheres, Section 52 Ignition sources
Division 10 Falling objects, Section 54 Management of risk of falling objects
Division 11 Psychosocial risks, Section 55C Managing psychosocial risks
Chapter 4 Hazardous work, Part 4.1 Noise
Section 57 Managing risk of hearing loss from noise
Chapter 4 Hazardous work, Part 4.2 Hazardous manual tasks
Section 60 Managing risks to health and safety
Chapter 4 Hazardous work, Part 4.3 Confined spaces
Division 3 Duties of person conducting business or undertaking, Section 66 Managing risks to health and safety
Chapter 4 Hazardous work, Part 4.4 Falls
Section 78 Management of risk of fall
Chapter 4 Hazardous work, Part 4.7 General electrical safety in workplaces and energised electrical work
Division 2 General risk management, Section 147 Risk management
Chapter 4 Hazardous work, Part 4.8 Diving work
Division 3 Managing risks-general diving work, Section 176 Management of risks to health and safety
Chapter 5 Plant and structures, Part 5.1 General duties for plant and structures
Division 7 General duties of a person conducting a business or undertaking involving the management or control of plant, Section 203 Management of risks to health and safety
Division 7 General duties of a person conducting a business or undertaking involving the management or control of plant, Section 214 Powered mobile plant — general control of risk
Chapter 6 Construction work, Part 6.3 Duties of person conducting business or undertaking
Division 1 General, Section 297 Management of risks to health and safety
Division 3 Excavation work, Section 305 Management of risks to health and safety associated with excavation work
Chapter 6 Construction work, Part 6.4 Additional duties of principal contractor
Section 315 Further health and safety duties — specific risks
Chapter 7 Hazardous chemicals, Part 7.1 Hazardous chemicals
Division 5 Control of risk-obligations of persons conducting businesses or undertakings, Section 351 Management of risks to health or safety
Division 9 Pipelines, Section 391 Management of risks to health and safety by pipeline operator
Chapter 8 Asbestos, Part 8.4 Management of naturally occurring asbestos
Section 431 Naturally occurring asbestos

To ensure compliance with the Work Health and Safety Act (2011) and the Work Health and Safety Regulation (2025) duty holders must either ‘eliminate’ or ‘minimise so far as is reasonably practicable’ risks to health and safety in the workplace. Minimisation using the ‘hierarchy of controls’ may consist of one or more of the following steps:

'(3) (a) substituting (wholly or partly) the hazard giving rise to the risk with something that gives rise to a lesser risk,

(b) isolating the hazard from any person exposed to it,

(c) implementing engineering controls.

(4) If a risk then remains, the duty holder must minimise the remaining risk, so far as is reasonably practicable, by implementing administrative controls.

(5) If a risk then remains, the duty holder must minimise the remaining risk, so far as is reasonably practicable, by ensuring the provision and use of suitable personal protective equipment.'

The following elements of risk management are iterative requiring continuous maintenance, monitoring and revision.

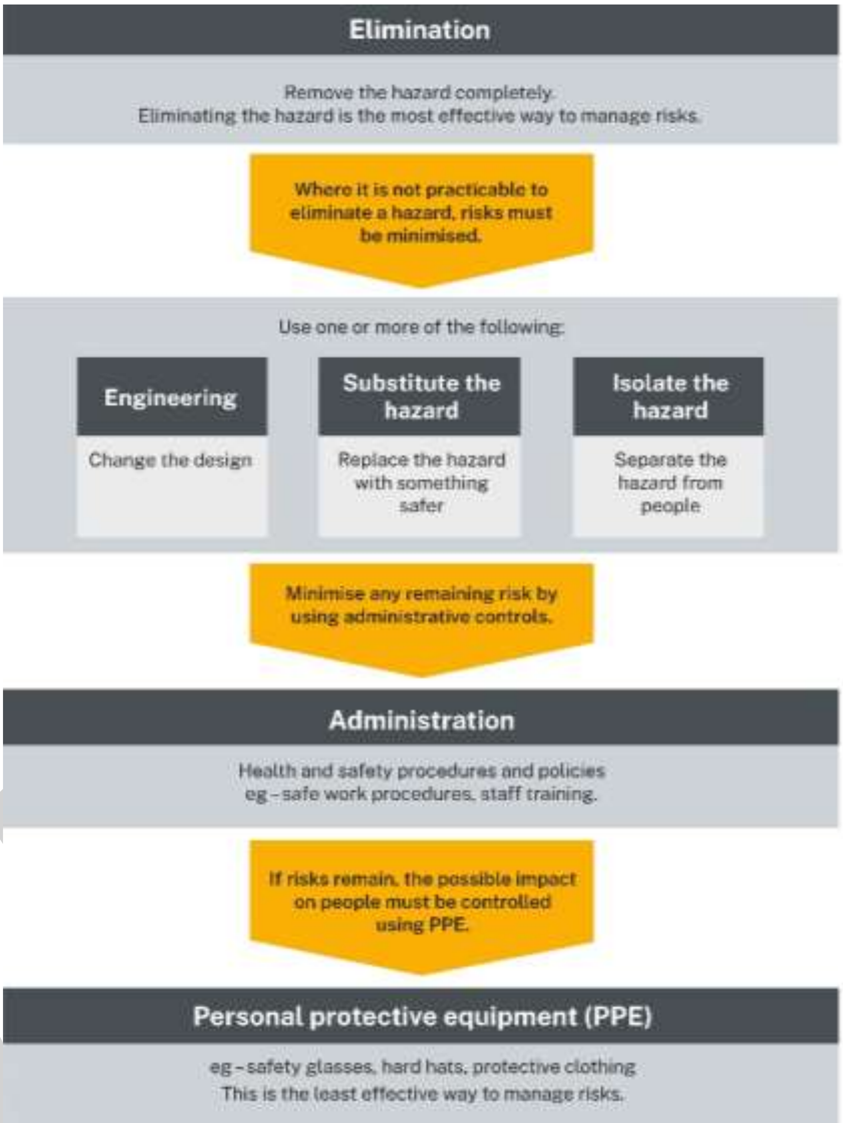


Figure 2,2: An overview of the hierarchy of control measures

- **Identifying hazards** — Assess potential risks associated with the work, including physical, chemical, and psychosocial hazards.
- **Risk assessment and control** — Eliminate or minimize risks using the **hierarchy of controls** (elimination, substitution, engineering controls, administrative controls, and personal protective equipment).
- **Safe work procedures** — Develop and communicate clear procedures for carrying out tasks safely.
- **Emergency planning** — Ensure appropriate emergency response plans are in place, including evacuation procedures and first aid provisions.
- **Consultation with workers** — Engage employees in safety discussions, ensuring they have input into risk management decisions.
- **Training and supervision** — Provide adequate training and supervision to ensure workers understand safety requirements.
- **Monitoring and review** — Regularly assess the effectiveness of safety measures and update plans as needed.

These duties also apply to PCBUs involved in planning tunnel construction. This is discussed in Section 2.3 and 3 below.

2.3 The Role of Client Organisations

Some decisions to eliminate risks may only be made early in the project life cycle, and this elevates the significance of decisions made in the early phases of planning before a Contractor is appointed. Such decisions, for example regarding alignment may commit a project to a set of risks such that only enable minimisation of risks to occur subsequently.

Typically, risk assessment and the evaluation of control measures can only be completed when methods of construction are detailed and final in terms of construction staging, programme, inspection and testing. This highlights the importance of the transfer and acceptance of risks at preliminary planning and design stages as and when risks are allocated, retained or shared under construction Contract Agreements. It also highlights the role of clients in selecting competent Managing Contractors and supporting health and safety performance throughout the construction or renovation process, so that contractual arrangements enable effective health and safety risk management.

The planning and design documentation prepared by or on behalf of Client organisations should demonstrate that safe working conditions in construction can be achieved. Accordingly, Client organisations should establish a health and safety risk management framework for proposed or existing underground assets in line with current guidance, good practice, technological trends, and applicable local, national, and international standards, regulations, and requirements. This framework should apply throughout the design, construction, and operational lifecycles. As part of this process, clients should assess their own competence in procuring, operating, and maintaining underground assets. Where necessary, they should supplement their corporate experience with personnel who have expertise in underground design and construction, procurement, risk management, and operations and maintenance.

Client organisations should implement and maintain oversight of health and safety processes for activities undertaken by them or on their behalf by formal review throughout design phases for the assets and throughout construction, operations and maintenance or whenever design changes are made.

At each design stage, and before procurement of construction, clients should conduct a health and safety review (review). The review should be informed by persons with experience in the construction, operation and maintenance of the assets. Risk registers should be used to record the following items:

- safety and health issues identified during the design reviews and actions taken;
- risks that cannot be removed through design changes; and
- primary responsibility for risk ownership.

The risk register should be a live document which will be updated as and when new risks are identified. Individuals involved in the review should be competent in their area of expertise and named in the review documentation. (see also Section 2.5 below, Overlapping Duties of PCBU's).

2.4 Competence

An essential aspect of effective health and safety risk management is role definition and role competence. Accordingly, it is essential that each person involved in the project is competent to carry out their role and that each organisation involved in the project should ensure that their employees or agents are competent to carry out the work required of them. A culture of competence starts with Client Organisations and should inform how they procure required services (see Section 3.3 below).

Specific competencies for appointment of Ventilation Officers and Occupational Hygienists are included in the definitions section above.

2.5 Overlapping duties of PCBU's

PCBUs such as Client Organisations and Managing Contractors operating in a contracting chain will have shared health and safety duties with other PCBUs in that contracting chain (known as overlapping duties).

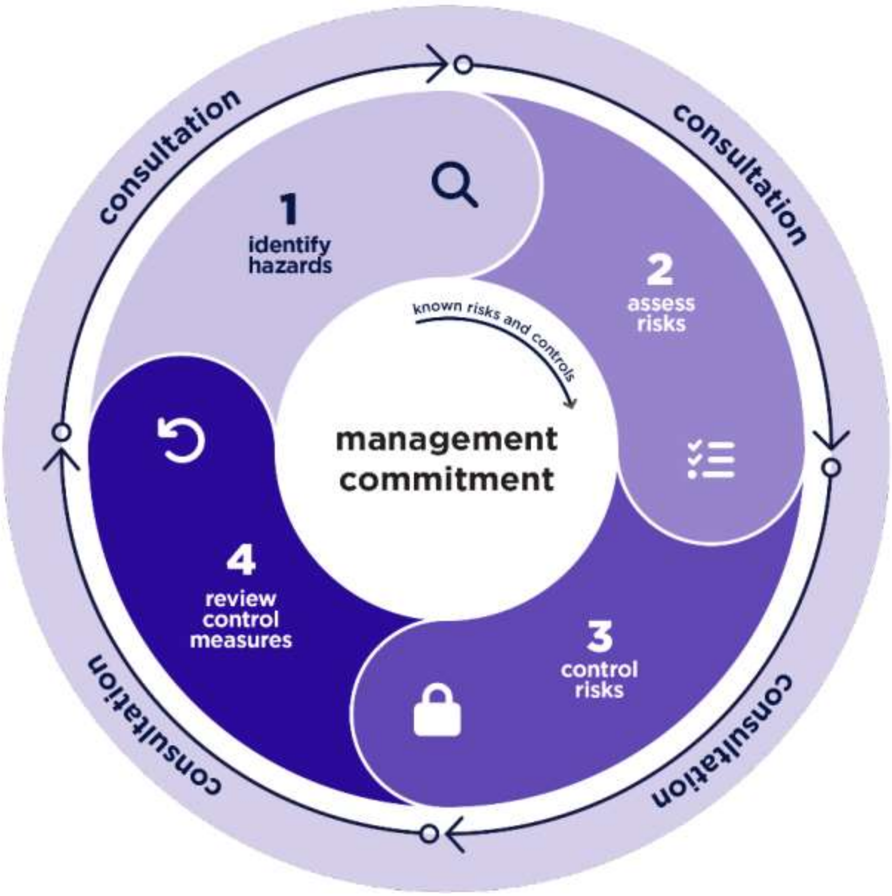
PCBUs have a duty to consult, cooperate with, and coordinate activities with all other PCBUs they share overlapping duties with, so far as is reasonably practicable.

PCBUs cannot contract out of their health and safety duties to others in a contracting chain.

PCBUs can enter into reasonable agreements with other PCBUs to make sure that everyone's health and safety duties are met[3]. However, PCBUs must monitor each other, to make sure each PCBU continues to do what was agreed. The greater the influence and control a PCBU has over a work site or a health and safety matter, the more responsibility they are likely to have.

It is more likely that a business will successfully meet their duty to consult, cooperate and coordinate if they:

- plan ahead, by thinking through every stage of the work, and recognising how the work could affect other businesses and the public,
- identify the health and safety risks that need managing,
- consult other businesses to agree how to control each risk,
- consult other businesses to decide which business, or businesses, are best placed to control each risk,
- clearly define roles, responsibilities and actions, and explain these so everyone knows what to expect.



[3] Section 16(3)(b) NSW Work Health and Safety Act 2011

3 Design

3.1 General

Health and safety considerations should inform the concept development of structures when making decisions about:

- the design and its intended purpose,
- materials to be used,
- possible methods of construction, maintenance, operation, demolition or dismantling and disposal, and
- the legislation, codes of practice and standards that need to be complied with.

Health and Safety in design or 'Safety in Design' is a continuous process with the following principles:

- Persons with Control – persons who make decisions affecting the design of products, facilities or processes are able to promote health and safety at the source.
- Product Lifecycle – safe design applies to every stage in the lifecycle from conception through to disposal or decommissioning of assets. It involves eliminating hazards or minimising risks as early in the lifecycle as possible.
- Systematic Risk Management – the application of hazard identification, risk assessment and risk control processes to achieve safe design.
- Safe Design Knowledge and Capability (Competence) – should be either demonstrated or acquired by persons with control over design.
- Information Transfer – effective communication and documentation of design and risk control information between all persons involved in the phases of the lifecycle is essential for the safe design approach.

At all design and construction stages, where risks cannot be eliminated by design, they should be managed by the implementation of risk controls described in risk management plans.

For more information on good work design, see Safe Work Australia *Principles of good work design: A work health and safety handbook.*

For information on the safe design of structures see the SafeWork NSW *Code of Practice: Safe design of structures.*

3.2 Site Investigations

The investigations should provide sufficient information to undertake assessments that inform the alignment and spatial definition of the structures required to be constructed, and also to assess the risks associated with design and construction.

Ground, utility and existing building and structure investigations should consider the type, extent and location of the tunnelling work and local environmental conditions. Investigations should be carried out by suitably qualified and experienced people competent in conducting investigations for similar purposes and in similar ground conditions. The investigations should include:

- Weather conditions: hydrology and the potential for and magnitude of fluvial and pluvial flooding including the definition of any probable maximum flood level.
- Local topography: geomorphological influences upon design and construction.
- Existing infrastructure: Accurate location, condition evaluation and assessment of the potential influence of nearby buildings, structures, utilities and old mine workings or wells.

- Ground and groundwater characterisation: To identify soils and rocks their variability and the potential influence on the design and construction methods, and the potential influence of groundwater including changes arising from construction and during operation. This should include assessments of risk and reliability of these assessments.
- The proportion of crystalline silica in the ground materials.
- Potential for contaminated environments: groundwater, hazardous gases such as methane, industrial waste liquids and solids like naturally occurring or dumped asbestos and review of previous relevant land use and historical data for the area.

3.3 Design Development for Construction

Client organisations should assess the competence of design organisations in relation to the construction and constructability of underground structures when selecting professional advisors. Only design firms with proven, relevant experience in underground construction should be engaged.

Client organisations, using competent advisors to supplement their capabilities as required, should assess and evaluate health and safety risks prior to releasing procurement tender documentation for construction, renovation, or maintenance. To do this, client organisations should prepare or have prepared for them reference designs that are sufficiently integrated and detailed to enable the planning of health and safety including the definition of minimum requirements and risk assessments and provide this information to potential contractors irrespective of the procurement model selected.

The main objective of this evaluation should be the identification of foreseeable risks throughout the lifecycle of the assets, assessed with respect to risk management criteria established by the client organisation in respect of applicable standards and workplace exposure limits. Reference designs should demonstrate how safe construction and maintenance can be achieved.

The selection of tunnelling methods has significant implications for health and safety risk management. Health and safety risks associated with alternative design options and alternative construction methodologies should be compared and recorded.

When planning tunnel construction and procurement, a process for developing the detailed design, suitable for construction, should be selected. Whilst there are some variations[4], in principle terms this is most commonly either:

- design-bid-build, where the Client retains the responsibility for the detailed design, or
- design and build, where detailed design responsibility is transferred[5] to the Contractor from a reference design.

The basis for the design should include assessments of:

- the expected range of geotechnical, hydrogeological and hydrological conditions and associated risks,
- construction methodologies and processes assumed to be used, within any constraints provided by the design,
- any interfacing or schedule constraints of the client requiring underground construction activities to be performed in parallel,
- temporary ventilation during the construction of underground working areas,
- electrical systems and supplies
- access requirements for operation and maintenance stages,

[4] Contractors may become involved earlier in the design process for example under 'Early Contractor Involvement' (ECI). Whilst this has many potential benefits, ultimately the scope and control of the permanent works design and necessary elements that require design to construct the permanent works, have to be allocated between Client or Contractor. (refer Section 7 below)

[5] Note also overlapping duties as PCBU's. Refer Section 2.5

- incident and Emergency plans for fire and other emergency scenarios in conjunction with local emergency services,
- personal protective equipment (PPE) assessments.

With respect to ventilation system design, the client should be satisfied that:

- Reference design documents clearly incorporate minimum requirements for the design and specifications of any temporary ventilation system.
- Contractor submissions meet these specifications or demonstrate how the requirements can be achieved through any alternative approaches proposed.

The hierarchy of controls must continue to be applied throughout the development of designs and works planning including procurement of Principal Contractors. This may result in avoiding certain methods of working that may be acceptable above ground or that require the use of specialised plant and engineering technologies to ensure that risks are managed using higher-order controls.

When bidding or negotiating Managing Contractors should assess the designs in relation to health and safety risks to establish their view of the suitability and adequacy of designs for construction from a health and safety risk management perspective. If valid potential risk reduction measures are identified by the contractors in a procurement process these should be acknowledged by client organisations in order to avoid creating a commercial disadvantage in the procurement process. Similarly, Clients should be vigilant with respect to innovations that increase safety risks.

Prior to appointment, client organisations should assess the requirements for health and safety risk management and request a construction phase plan and associated risk management documentation that addresses the risks identified by the Client and any others that they identify.

In addition to documents that should be provided as part of any tender submission for underground construction under NSW procurement rules and regulations, there should be evidence of a certified health and safety management system, a draft Occupational Health and Hygiene Plan (see Section 4.10) and a draft Ventilation Control Plan (see section 11.9 below).

3.4 Design verification

The main purpose of design verification (checking) should be to confirm that the design satisfies the design requirements and is safe to construct. Design checks should only be undertaken by competent engineers.

The requirement for independent design verification for temporary and permanent works should be undertaken based on risk levels. Design checks on works should be proportional to the risk of failure of those works and reflect the risk inherent in their execution. If a design is amended after checking, the risks and materiality of the change and/or the cumulative effect of multiple design changes should be re-considered based on risk levels. The checker should be advised accordingly and should re-certify the revised design if required.

The design of all ground support and lining works should take account of the constructability of the works and any associated temporary works and the changes that may arise during construction.

Management of change is a key risk factor in underground construction (refer Section 4.2).

3.5 Updating Design Assumptions

During construction, the assumptions regarding ground conditions and behaviour should be confirmed and as necessary updated. The process of validation should incorporate new geological and geophysical investigations, geological logging and monitoring data. This is necessary to provide continuous assessment of the potential for ground risks to impact tunnel safety for example to prevent ground instability and loss of excavation control and inform the Permit to Tunnel process (see Section 4.2 and 8.3.5).

4 Quality Assurance in Health and Safety

4.1 Overview

Quality assurance (QA) is a critical component of effective health and safety management in tunnelling projects. It ensures that all systems, procedures, and practices are consistently applied and meet the required standards throughout the lifecycle of the project.

Key QA measures include:

- Documented Procedures: All health and safety processes should be documented, including risk assessments, safe work method statements (SWMS), inspection and test plans (ITPs), and emergency response procedures.
- Competency Verification: All personnel involved in tunnelling activities should be verified as competent through qualifications, training, and experience with respect to their role within a project. This includes engineers, supervisors, plant operators, safety officers, Ventilation Officers, and Occupational Hygienists.
- Inspection and Testing: Regular inspections and testing of plant, equipment, ground support systems, and ventilation should be conducted in accordance with approved plans. Results should be recorded and reviewed.
- Audit and Review: Internal and external audits should be scheduled to assess compliance with the code of practice, project-specific safety plans such as the Ventilation Control Plan and the Occupational Hygiene Plan, and legal obligations under the WHS Act and Regulation.
- Continuous Improvement: Non-conformances must be documented, investigated, and used to inform corrective actions and system improvements.

4.2 Change Management

Change management is essential to ensure that any modifications to design, construction methods, equipment, or work processes do not introduce new or unmanaged health and safety risks.

Change management procedures should include:

- Formal change evaluation: All proposed changes should be assessed for their potential impact on health and safety. This includes changes to tunnel alignment, excavation methods, support systems, or ventilation design.
- Consultation and Communication: Changes must be communicated to all affected parties, including workers, contractors, and designers. Consultation should be documented and include opportunities for feedback.
- Risk Reassessment: Significant changes should trigger a review of existing risk assessments and SWMS that should be re-assessed regularly in any case. New hazards must be identified, and control measures updated accordingly.
- Approval and Documentation: Changes must be formally approved by a competent person or authority (e.g., project manager, principal contractor) and documented in the project's OHS management system.
- Training and Induction: Where changes affect work practices or introduce new risks, affected workers must receive updated training or induction before the change is implemented.

5 Occupational Health and Welfare

5.1 Overview

In Australia, as in many other countries, the impacts from occupational illness are significantly greater than those from workplace accidents[6]. Chronic conditions like hearing loss, respiratory diseases[7], and musculoskeletal disorders develop over time and often go unnoticed until they become debilitating.

It is necessary that systems are established to eliminate or otherwise minimise exposure to health hazards such that health risks are managed. In addition, systematic approaches are required to facilitate the interpretation of relevant data and to avoid underreporting and underdiagnosis of occupational illnesses and diseases. This requires the involvement of Occupational Hygienists and ventilation engineers during the planning stages to establish performance criteria and project specific requirements. Further involvement is required during construction, to assist in the development and implementation of health risk assessments, exposure control plans, and exposure monitoring programmes and development of an occupational health and hygiene plan (refer Section 5.12 below).

It is noted that occupational health issues for tunnelling workers may be exacerbated as they are often required to live away from home for extended periods and this increases the potential impact of psycho-social hazards (Refer Section 6).

5.2 Dust and Other Airborne Contaminants

Exposure to dust is a significant occupational health hazard during construction of underground works with serious debilitating and potentially fatal consequences. Control of exposures using the hierarchy of controls should be a health and safety priority. Refer Section 17-20 below and Appendix B and C.

5.3 Noise and Hearing Loss

Noise-Induced Hearing Loss is a widespread issue in the construction industry. It is one of the most common and costly occupational injuries — but it is also preventable.

Noise exposure must be minimised as far as is reasonably practicable using the hierarchy of controls. Control measures for noise may include:

- selecting plant and equipment with lower-noise outputs,
- use of variable speed drives to reduce noise outputs if appropriate
- fitting sound-absorbing material (e.g. workshop walls),
- initiating blasts from a distance (e.g. from the surface),
- constructing sound-deadening structures around static plant,

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[6] https://www.safeworkaustralia.gov.au/media-centre/news/safer-healthier-wealthier-economic-value-reducing-work-related-injuries-and-illnesses

[7] For example, silicosis is an irreversible lung disease that reduces the lungs' ability to take in oxygen and can be fatal.

- fitting sound-attenuating silencers to fans, and fresh air intakes,
- fitting and maintaining mufflers to exhausts,
- applying sound-proofing material to walls and around equipment,
- selecting plant with lower noise output,
- increasing efficiency of silencers,
- fitting additional mufflers to exhausts.
- limiting exposure times,
- enforcing PPE hearing-protection use.

Most workers in tunnelling environments are required to wear hearing protection while working underground due to the high levels of noise generated by plant and equipment. Under section 58 of the Work Health and Safety Regulation 2025, a Person Conducting a Business or Undertaking (PCBU) must provide audiometric testing for any worker who is frequently required to wear hearing protection due to exposure to noise that exceeds the exposure standard (LAeq, 8h of 85dB(A) or peak of 140dB(C)).

Testing must be provided:

- Within 3 months of the worker commencing work requiring hearing protection.
- At least every 2 years thereafter.

Hearing protection forms an essential part of the overall noise control program and must be worn consistently to be effective to reduce the risk of noise-induced hearing loss. Further information on the selection, use and maintenance of hearing protection is provided in Section 20.

For more information refer to SafeWork NSW *Code of Practice: Managing noise and preventing hearing loss at work.*

5.4 Manual Working, and Vibration Exposure

Vibration exposure is a significant hazard in tunnelling and can workers through hand-arm vibration (HAV) from power tools (e.g. grinders, hammer drills, pneumatic tools) and/or whole-body vibration (WBV) from vehicles, plant, or standing on vibrating platforms. In tunnelling, HAV is most likely during precast segment construction and tunnel fit-out tasks, while WBV may occur among plant operators travelling over uneven surfaces or when standing on a platform attached to vibrating plant.

Health effects include hand arm vibration syndrome from prolonged HAV exposure, and musculoskeletal disorders (particularly lower back pain, neck, and shoulder problems) from WBV. Both forms of vibration can also contribute to fatigue, other health system impacts, and increased risk of injury.

Contributing factors include vibration level, frequency, and duration of exposure; poor tool or plant design and maintenance; hard work materials; cold environments; repetitive or forceful postures; and individual susceptibility.

HAV can be measured on tools or work pieces in contact with the operators hand, while WBV can be measured where vibration enters the body (e.g. operator's seat). When measurements are conducted, a competent person should carry out measurements following recognised standards (*AS ISO 5349.1/2:2013* for HAV; *AS 2670.1-2001* and *EN 14253:2003* for WBV). Manufacturer data can also help estimate exposure. Risk may be assessed against the EU Physical Agents Directive (2002/44/EC), which sets daily exposure action and limit values.

Under Section 19 of the WHS Act 2011, a PCBU has a primary duty to eliminate, so far as is reasonably practicable, worker exposure to vibration, or if elimination is not practicable, to minimise the risk. Section 60 of the WHS Regulation 2025 requires PCBUs to manage risks of musculoskeletal disorders from hazardous manual tasks, including vibration. This involves identifying tasks that expose workers, applying the hierarchy of control to eliminate or reduce risks, and reviewing measures to ensure effectiveness. When determining controls, factors such as posture, vibration, frequency and duration of exposure, cold environments, and workplace design should be considered.

Control measures include:

- Substitution and task design: automate tasks, improve road surfaces, reduce travel distances, or use conveyors instead of mobile plant.
- Equipment selection and design: use fit-for-purpose tools, low-vibration equipment, anti-vibration handles, suspension seats, and ergonomic cabin layouts.
- Purchasing policies: prioritise low-vibration tools and plant, factoring in emissions, ergonomics, and operational needs.
- Maintenance: regularly service and maintain tools, plant, vehicles, and roadways.
- Work organisation: implement work/rest cycles, rotate tasks, and provide warm clothing in cold environments.
- Training and information: provide training in understand vibration risks and safe practices.

PPE: anti-vibration gloves may help with high-frequency tools, though their benefit is limited.

For more information refer to SafeWork NSW *Code of Practice: Hazardous Manual Tasks.*

For more information on good work design, see Safe Work Australia's *Principles of good work design: A work health and safety handbook*.

5.5 Heat stress

Heat stress occurs when circumstances including a worker's environment, work activity, clothing and PPE interact to produce core body temperature rises.

Factors and sources of risk that may lead to a heat stress risk must be identified and the associated risk must be eliminated or minimised through the application of the hierarchy of control measures.

Controls for minimising heat stress include:

- providing adequate ventilation,
- reducing items of heat-producing equipment underground,
- relocating hot processes away from high-access or enclosed areas,
- installing barriers or reflective barriers to absorb or deflect radiant heat,
- using mechanical aids to reduce metabolic workload for heavy or moderate activities,
- limiting exposure times,
- fitting enclosed mobile plant with air conditioning,
- delivering heat stress awareness training,
- reducing work intensity during high thermal risk periods,
- providing heat acclimatisation programs,
- supplying cool drinking water (including ice machines),
- providing access to air-conditioned rest areas,
- encouraging self-paced work and reporting of heat stress symptoms,
- verifying plant air-conditioning is operational and maintained.

Researchers have developed an index for Thermal Work Limits (TWL) (Miller & Bates, 2007) for an equivalent metabolic rate that hydrated, acclimatised individuals can maintain within a specific thermal environment, for a safe deep body core temperature (<38.2°C) and sweat rate (<1.2 kg/hr).

This has led to the development of the following recommendations, limits and interventions as reported by the AIOH:

Table 5.1 Thermal Work Limit (TWL) Risk Categories and Controls

Risk Level	TWL (W/m²)	Comments & Controls
Low	>220	- Unrestricted self-paced work - Ensure adequate fluid replacement
Moderate Low	181–220	- Acclimatisation Zone - Self-paced work possible for well-hydrated, acclimatised workers - No unacclimatised worker to work alone - Ensure adequate fluid replacement
Moderate High	141–180	- Acclimatisation Zone - No worker to work alone - Ensure adequate fluid replacement
High	116–140	- Buffer Zone - Workload exceeds TWL; heat storage limits work time - No unacclimatised worker to work - No worker to work alone - Increase airflow >0.5 m/s - Redeploy workers where practicable - Ensure adequate fluid replacement - Hydration testing; withdraw if dehydrated - Apply work-rest cycling - Work only with authorisation and management controls
Critical	<116	- Withdrawal Zone - Essential maintenance to fix or implement additional controls to improve conditions and rescue work only - No worker to work alone - No unacclimatised worker to work - Ensure adequate fluid replacement - Apply work-rest cycling - Consider physiological monitoring

Note: Unacclimatised workers are defined as new workers or those who have been off work for more than 14 days due to illness or leave (outside the tropics).

For more information, and recommendations for managing heat stress refer SafeWork NSW *Fact Sheet (2018): Work in hot environments* and NSW Resources Regulator's *Legislative obligation: health control plans – NSW mining and extractives industry*. Fact Sheet PUB18-36.

5.6 Fatigue

Fatigue results from prolonged working, heavy workload, insufficient rest and inadequate sleep. This can result in impairment from being less able to process information, slower reaction times, and greater vulnerability to human error.

To mitigate risks from fatigue, a risk assessment should be undertaken that assesses, as a minimum work demands, work environment, work scheduling/planning and shift length. Workers should be advised regarding fatigue risk factors and their responsibility to ensure they are fit-for-work and encouraged to self-identify unfitness where appropriate.

PCBU's should follow up when a worker identifies difficulties they may have and encourage workers to seek medical advice to manage both temporary illnesses and chronic health conditions which may cause fatigue.

PCBU's should ensure workers' temporary residential accommodation arrangements are conducive to sleep when workers need to work away from home. Consideration should be given to the effects of shift length and shift pattern on health and safety and the prevention of fatigue. Factors which should be considered when determining shift length include travel time to the workplace on site, hand over and travel time to and from living accommodation. The importance of physical and mental wellbeing and personal preferences should be recognized. (Refer also Section 6 Psycho-Social Hazards).

5.7 Skin Health

Construction workers generally are at increased risk of developing occupational contact dermatitis, from irritants and allergies. A structured skin care regime should be implemented for all workers and addressed as part of the site's risk assessment and health surveillance program.

5.8 Hazardous Chemicals

Tunnelling work can involve exposure to a wide range of hazardous chemicals that are either introduced into the workplace or generated during construction activities. These substances can cause serious harm if that exposure is not eliminated or not effectively controlled. Examples include:

- Gases such as ammonia which may be released from old sewer pipes or during excavation involving explosives while blasting.
- Chemical burns – from substances such as grout.
- Exposure to hexavalent chromium when working with concrete and shotcrete.
- Exposure to isocyanates from waterproofing products.
- Exposure to volatile organic compounds (VOCs) from waterproofing, concrete curing agents, and paints.
- Exposure to hazardous chemicals that are generated as part of work activities such as RCS, diesel exhaust and welding fumes and gases.

To manage these risks, PCBUs should follow the processes outlined in the SafeWork NSW *Code of Practice: Managing risks of hazardous chemicals in the workplace*.

5.9 Welfare Facilities

Welfare provisions on site should include potable water, toilet, washing and drying, and kitchen facilities readily accessible to underground workers. Clothes storage, laundry, and drying facilities should also be provided.

All underground workers should have access to showering/change and laundry facilities.

5.10 Biological Hazards

Biological hazards such as mould and legionella can be present in tunnelling work environments.

Mould can develop in tunnels and underground structures or plant where organic material is present and has been stored in damp or wet conditions and ventilation is insufficient. Sources of moisture include groundwater ingress, water used in dust suppression, and condensation on surfaces. Poor ventilation prevents effective drying and increases humidity, creating conditions favourable to mould growth. To prevent mould, water ingress should be controlled, ventilation maintained to reduce humidity, and contaminated materials promptly removed or cleaned. Periodic inspection of the tunnel environment specific to identification or mould or conditions favourable to mould growth (food source cardboard, timber etc) should be undertaken.

Legionella bacteria can grow in water systems where water is stagnant, stored, or recirculated, particularly in the temperature range of 20°C to 45°C. Poorly maintained systems increase the likelihood of Legionella proliferation, which can cause Legionnaires' disease if contaminated aerosols are inhaled. Water systems must therefore be designed, operated, and maintained to minimise stagnation and biofilm build-up, with regular cleaning, disinfection, and monitoring carried out in accordance with recognised standards.

5.11 Health Monitoring

Heath monitoring may be required where there is exposure to a health hazard that may present a significant risk.

Schedule 14 of the WHS Regulation 2025 lists hazardous chemicals for which health monitoring is required when a worker's exposure may present a significant risk to their health.

A PCBU when considering fitness for a particular task, should consider the health monitoring requirements. The initial exposure risk assessment and results of personal exposure monitoring from previous projects should be used by occupational hygienists to determine which workers are likely to require health monitoring, including audiometric testing.

A PCBU should provide records of personal exposure to the registered medical practitioner to inform the health monitoring.

Workers should be made aware of the symptoms of relevant health conditions, exposure levels and associated risk control measures and what to do should they develop symptoms.

A PCBU must arrange health monitoring before a worker starts work, so any future changes in health status can be detected. From the initial health monitoring date, a worker's health should then be monitored in accordance with the frequencies specified in the WHS Regulations or where not specified, as per the frequencies recommended in health monitoring guides published by Safe Work Australia.

Some workers may not want to participate in health monitoring due to anxiety about the testing and medical results or the impact the results may have on their job. If a worker initially refuses to participate in health monitoring, a PCBU can encourage and support workers by:

- explaining the benefits of health monitoring,
- making the process easy to follow,
- providing interpreters where English is not their first language, and
- reminding them that their workplace, family, and community want them to be as safe and healthy as possible.

If the worker still refuses health monitoring, a PCBU may need to consider providing the worker with other duties. When providing the worker with other duties, the PCBU should seek advice to ensure any action taken is consistent with other workplace laws. PCBUs should have private conversations with workers about their individual health monitoring to maintain confidentiality. A PCBU must also consult with their HSRs about the arrangements for health monitoring. A PCBU should provide workers with a copy of their health monitoring report as soon as practicable after receiving the report, and when requested.

Specific requirements regarding health monitoring for crystalline silica are provided in section 13.

5.12 Development of an Occupational Health and Hygiene Plan

An Occupational Health and Hygiene Plan for a tunnel under construction should, at a minimum, address the following matters:

a) accountabilities, responsibilities and relevant authority, including nomination of the Occupational Hygienist,

b) the development of procedures for the control of occupational health hazards, the use, maintenance and inspection of those procedures and control measures and validation of their effectiveness,

c) the competencies of those who undertake exposure / air monitoring of occupational health hazards,

d) the processes that will ensure that only those with the required competencies perform the identified tasks,

e) the processes for assessment and evaluation of health risks, including the identification of workers, or groups of workers, to participate in exposure / air monitoring, respirator fit testing, medical assessment and health monitoring activities,

f) identification of similar exposure groups,

g) criteria for exposure acceptability, including relevant workplace exposure limits and trigger action response plans for exposure monitoring and real-time monitoring,

h) criteria for equipment and instrumentation inspection, maintenance, testing and calibration,

i) the processes to assess and verify the adequacy of control measures implemented to eliminate or otherwise reduce exposure,

j) the standardised methods for the assessment of occupational health hazards such as dusts, noise, and other hazards,

k) the minimum frequency of exposure / air monitoring,

l) the processes to re-sample following any exposure / air monitoring result that was deemed to be 'invalid' as per the standardised method selected,

m) the methods to determine compliance with the workplace exposure standards,

n) training needs, including hazard-specific training, accredited or approved crystalline silica training,

o) the reporting procedures relating to exposure / air monitoring, including methods to communicate the results to workers, their representatives, and the workforce,

p) the procedures to be followed in the event of an exceedance of an exposure standard and/or the failure of control measures implemented to eliminate or minimise risks to health, including relevant notifications,

q) the reporting procedures relating to health monitoring, including methods to communicate the results to workers,

r) the procedures to be followed in the event of an adverse result from health monitoring, including relevant notifications.

6 Psychosocial hazards

WHS Regulation sections 55A – 55D

Psychosocial risks

Workers can be exposed to a combination of work-related psychosocial hazards and risks factors. A PCBU has a duty to manage the risk of psychosocial hazards in the workplace. A PCBU must eliminate psychosocial risks, or if that is not reasonably practicable, minimise them so far as is reasonably practicable.

In determining the control measures to implement to manage the psychosocial hazard, PCBUs must have regard to all relevant matters including:

- duration, frequency and severity of exposure and how hazards may combine or interact,
- design of work and system of work,
- design, layout and environmental conditions of workplace,
- workplace interactions or behaviours,
- information, training, instruction and supervision provided to workers.

Some examples of psychosocial hazards may include:

- high job demands (e.g. high levels of physical, mental or emotional effort are needed to do the job),
- poor physical environments (e.g. performing hazardous work, conditions that affect concentration or are unpleasant),
- remote or isolated work (e.g. working extended periods alone),
- working in camps (Refer to Draft Code of Practice Worker Accommodation SafeWork NSW 2025)
- bullying and sexual harassment.

Further information on how to manage psychosocial hazards in the workplace can be found in the *Code of Practice: Managing psychosocial hazards at work*. The code provides guidance on duties and practical strategies to manage and promote a mentally healthy workplace.

7 Communications, Signs and Signals

7.1 Communications

In minimising risks to the health and safety of a worker underground a person conducting a business or undertaking must provide a system of work that includes effective communication with the workers.

It is important for people working above and below underground to be in contact with each other. People above ground should know where underground workers are in case an incident occurs.

A reliable, effective communication system should be provided between surface and underground work areas where workers are present underground. The system must be maintained in working order and tested regularly.

The communication system should be used to link:

- remote or isolated workers
- major workplaces
- tunnel portal and faces
- top and bottom of shafts
- restricted spaces, like smoke ducts and conduit passages
- site offices
- safety critical locations like first aid and emergency control rooms.

Determining whether communication with vehicles including personnel transporters is needed should be done through a risk assessment. Where electronic non-voice communication methods are used at the point of communication reception, for example by the control room, they should be monitored at all times by people who have been trained in the emergency plan.

When selecting the communication system consider the:

- size and length of the tunnel
- number of people in the tunnel
- system of tunnelling work used especially material supply and muck handling
- potential hazards including the speed of operations.

Details about audible or visual signal code used, call signs and channel allocations and how to use them should be explained to and practised by all workers as required by their role and subject to task induction, training and risk assessments as part of SWMS (refer Section 7.2).

A communication system should be able to operate independently of any tunnel power supply using an uninterruptible power supply (UPS). It should be installed such that if one unit fails it will not interrupt the other units in the system. Communication cables and wiring, especially those used to transmit warnings in an emergency, should be protected from fire, water and mechanical shock.

There should be an effective warning system capable of being activated quickly in an emergency to alert people underground to evacuate the tunnel. Emergency warning systems should be tested using emergency evacuation drills. Emergency communication protocols must be established and included in the Emergency Management Plan (refer Section 23).

7.2 Information, Training, Instruction and Supervision

A person conducting a business or undertaking must provide, so far as is reasonably practicable, any information, training, instruction or supervision necessary to protect all persons from risks to their health and safety arising from work carried out.

A person conducting a business or undertaking must ensure that information, training and instruction provided to a worker is suitable and adequate having regard to:

- the nature of the work carried out by the worker
- the nature of the risks associated with the work at the time the information, training or instruction is provided
- the control measures implemented.

So far as is reasonably practicable, the information, training and instruction is provided in a way that is readily understandable by any person to whom it is provided.

Workers must be trained and have relevant skills to carry out a particular task safely. Training should be provided to workers by a competent person.

Before issuing people a tag or other permit to enter the tunnel, they must be given information, instruction, training and supervision to protect them from risks to their health and safety arising from the tunnelling work.

7.3 Signs and Signals

Safety signs should be used to warn of hazards, indicate safe pathways, and provide emergency information. Audible and visual signals should be used for movement of plant and vehicles and emergency evacuation alerts. Signage should comply with *AS 1319:1994 – Safety Signs for the Occupational Environment.*

8 Safe Access, Transit and Egress

8.1 General

Safe access and egress must be provided for and maintained for all personnel at all times. This should include:

- Clearly marked and unobstructed routes
- Protection from mobile plant and equipment
- Controlled access to underground areas
- Prohibited areas securely covered or barricaded with appropriate signage.

Tunnel portals must be designed and constructed to prevent collapse, control water ingress, and restrict unauthorised access.

Shafts and inclines used for access or ventilation must be constructed and maintained to prevent falls or entrapment. They must include safe means of access and egress via fixed ladders, stairways, or hoisting systems, and be equipped with communication systems and emergency lighting.

8.2 Transport Systems and Walkways for Personnel

Personnel transport systems should be designed to prevent collision or entrapment, include emergency stop mechanisms, and be operated only by trained personnel.

Walkways should be provided alongside transport routes where practicable. Walkways within tunnels and shafts must be clearly delineated, slip-resistant, and free from obstructions. They must be adequately illuminated and ventilated and include handrails or barriers where there is a risk of falling. Where walkways are used for emergency egress, they must be clearly signed and lead to a safe exit point.

8.3 Tunnel Entry Procedures

A tunnel entry control procedure should be available at all times when personnel are underground to prohibit unauthorised access underground and ensure accurate accounting of personnel underground at all times during construction, operation, maintenance, or should an emergency occur (refer Section 23).

Lighting, drainage, and ventilation systems should be operational, and project induction requirements should be completed before entry is permitted.

The induction process should ensure that workers are competent for the tasks they are required to undertake. As part of entry procedures, personnel, including visitors, should confirm they understand the project health and safety provisions affecting them. Such requirements may include:

- Accessibility limitations and prohibitions
- Contraband items
- Correct use of PPE
- Emergency response procedures
- Confirmation they are unimpaired and fit for entry.

9 Temporary Works

9.1 Overview

Temporary works are an essential element of safety risk management during tunnel construction and are described in some detail in this Code of Practice accordingly.

The scope and procedural requirements for verification checks for temporary works designs and the process for managing required changes to the designs should be established as part of the quality assurance process, prior to construction and be proportionate to the risks of failure (refer Section 3 and 4 above).

Safe Work Method Statement (SWMS) must be developed for all high-risk activities, including in accordance with SafeWork NSW *Construction Work Code of Practice* and the Work Health and Safety Regulation 2025 (NSW).

9.2 Organisation

The principal contractor should appoint competent personnel to ensure safety in the design, checking, construction/installation and use of temporary works and ensure cooperation and coordination between contractors in the interests of safety.

9.3 Examples of Temporary Works

Examples of temporary works associated with tunnelling include:

- Access and egress systems: Temporary access and egress systems, such as scaffolding, ladders, and stairways, used to provide safe entry and exit points for workers. This may be connected to shaft inundation protection systems. Walkways, scaffolds and staircases including barriers and restraints. (Refer Section 8)
- Shafts, walls and propping. (Refer Section 10)
- Temporary tunnel linings and ground support. (Refer Section 11)
- TBM, or pipejacking machine jacking frames. (Refer Section 11)
- Shuttering / formwork and falsework. (Refer Section 11)
- Dewatering systems to remove water from the excavation area and prevent flooding from groundwater. (Refer Section 12)
- Haulage and transportation systems such as conveyor belts, rail systems, multi-service vehicles (MSVs) and cranes to move materials in and out of the tunnel. (Refer Section 13.11)
- Gantry crane and all mobile crane foundations or supporting ground. (Refer Section 13 and 16)
- Ventilation systems to control the air quality and temperature inside the tunnel. (refer Section 17 and 18).

10 Shafts and Portals

10.1 Overview

Tunnelling or pipejacking inevitably require construction of shafts or portal structures that connect to the surface and provide access, egress and services to the underground operations such as electricity and ventilation. Tunnel shafts and portals may comprise inclined trenches that may be subsequently covered (cut and cover tunnels), vertical or inclined shafts or declines.

These surface connections are potential vulnerabilities to the tunnel operations and may introduce flooding or inundation risks, risks from utilities, from unknown artificial obstructions such as existing but unanticipated piled foundations or from ground disturbance/interaction between the structures.

Shafts and portal structures maybe vulnerable to flooding from adjacent waterways subject to intense rainfall or in remote areas from natural terrain hazards such as landslides.

The shape, size and depth of a shaft depends on the application and purpose of the shaft. Similar to a tunnel, these functional requirements, in view of the ground and groundwater conditions will then inform the design approach and shaft construction method. Ground support systems must be adaptable to the method adopted and suit the range of ground groundwater conditions that are anticipated and the performance of the support system that should be validated using observations and monitoring data during construction.

Drainage systems must be designed to prevent water accumulation and erosion.

Excavation methods may include drill and blast, roadheaders, mechanical excavators, raise-boring machines, caissons (Refer Section 11.8.3), shaft sinking machines or specially adapted tunnel boring machines. Accordingly, they should be subject to the same rigorous safety considerations regarding risk management and provision of adequate controls as for tunnelling described elsewhere in this Code.

For further discussion of the issues, options and advantages and disadvantages of shaft construction methods, shaft support options, groundwater control options and permanent linings refer to ITA Report 36[8].

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with shaft construction and operation. Safe Work Method Statement (SWMS) must be developed for all high-risk activities in accordance with SafeWork NSW *Construction Work Code of Practice* and the Work Health and Safety Regulation 2025 (NSW).

10.2 Security and Edge Protection

Risks from vertical or steeply inclined shafts increase the risks of falling objects from activities above, at surface or in adjoining underground works. This should require specific assessments of access requirements, manual working and lifting techniques and equipment.

A protective barrier should be erected around the shaft top to prevent people or materials falling into the shaft.

The barrier should also prevent surface water draining into the shaft in view of flooding risks.

If a shaft is to be left unattended, protective covers or a suitable and secure fence should be used to prevent unauthorised access.

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[8] ITA Report N° 36 / July 2025 TUST-D-24-02789R1

10.3 Safe Access and Egress

All shafts must always have safe means of access and egress during shaft construction and operation considering depth, frequency of use, and emergency requirements (refer Section 23).

Ladders, stairways, or mechanical hoists should be used depending on depth and frequency of use.

Access systems (e.g., fixed ladders or staircases) must comply with *AS/NZS 1657:2018*[9].

Emergency escape routes must be planned and maintained, with consideration for smoke, fire, and flooding scenarios.

Fall protection systems (e.g., harnesses, guardrails) should be provided if there is a risk of falling.

Lighting and communication systems should be installed to ensure visibility and coordination during access and evacuation.

Mechanical access systems such as hoists should be design operated and maintained by competent personnel.

10.4 Material Transport

Personnel and materials must be transported separately unless specifically designed systems are in place to ensure safety. Material only hoists should be clearly marked with “No Riders Allowed” signage.

Dual-use systems (for both personnel and materials) should have:

- Separate operating modes.
- Interlocks to prevent simultaneous use.
- Emergency override systems.

Entrances to hoistways must be guarded with gates or barriers and marked with high-visibility warnings.

Communication systems must be installed in shafts to coordinate transport and respond to emergencies.

10.5 Services

All services including ventilation, lighting and communication should be securely attached to the shaft wall and protected from damage.

[9] AS/NZS 1657:2018: Fixed platforms, walkways, stairways and ladders – Design, construction and installation

11 Tunnel Excavation and Support

11.1 Overview

All reasonably practicable measures should be taken to maintain control of an underground excavation and ensure stability to prevent any person being struck by objects falling into the tunnel or from collapse.

In addition to competent designers, suppliers and contractors, this should involve informed oversight by or on behalf of the Client (refer Section 2.5 and 8.3.6).

For the purposes of this Code two broad tunnelling excavation methods are described along with commonly used ground support methods:

- Bored tunnelling using tunnel boring machines (TBMs) with or without a segmental lining. Often preferred where tunnels are longer with a consistent cross section such as for metro running tunnels, hydraulic conveyance or other utility tunnels. It is rare that a tunnel project is built by mechanised tunnelling alone and normally there will be a component of conventional tunnelling for functional requirements such as cross passages or for changes in geometry.
- Conventional tunnelling that includes drill and blast, roadheaders and other mechanical excavation methods. The method follows a cycle of excavation and support allowing for variable ground and complex geometries. It can offer programme and productivity advantages for shorter tunnels by utilising multiple working faces (headings) and is typically more labour intensive.

Safe Work Method Statement (SWMS) must be developed for all high-risk activities that includes in accordance with SafeWork NSW *Construction Work Code of Practice* and the Work Health and Safety Regulation 2025 (NSW).

11.2 Tunnel Boring Machines (TBMs)

11.2.1 TBM Selection

Tunnel Boring Machines (TBMs) should be designed, specified, and selected to suit the full range of expected ground and groundwater conditions. The selection process is critical to ensuring safe and efficient tunnelling operations and should be informed by a comprehensive geotechnical assessment and risk analysis.

Safe operation of TBMs requires competency at both corporate and individual levels. This includes appropriate design, procurement, operation, and maintenance practices. After manufacture, TBMs are subject to factory acceptance testing (FAT) and are then commissioned on-site by driving an initial section of the tunnel under the supervision of the supplier.

There are two principal types of TBMs:

- Open Gripper TBMs – Typically used in hard rock environments. These machines do not provide continuous ground support and rely on conventional support systems such as rock bolts, steel sets, and shotcrete, installed as required by the ground conditions.
- Shielded TBMs – These machines use a segmental lining ring to thrust off and advance through the ground. Shielded TBMs are suitable for a wide range of ground and groundwater conditions. They include:
    - Hard Rock Shielded TBMs.

- Pressurised Face TBMs, which are subdivided into:
    - Earth Pressure Balance Machines (EPBMs)
    - Slurry TBMs.

Pressurised or 'closed face' machines differ primarily in how they control face pressure and manage spoil removal. Hybrid or multi-mode TBMs are also available and can be configured to operate in different modes depending on the encountered ground conditions.

The selection of a TBM must consider not only the anticipated geology but also the potential for variability, the tunnel alignment, diameter, depth, and the need for face pressure control. The selected TBM must be capable of adapting to changing conditions and should be supported by a robust operational and maintenance strategy.

11.2.2 Sources of risk for TBM tunnelling

The most comprehensive guide to safety requirements for TBM's and associated machinery is *BS EN 16191*[10]. It addresses significant hazards and prescribes protective measures including:

- mechanical risks (e.g. moving parts, crushing, entanglement),
- electrical hazards,
- fire and explosion risks,
- hazardous atmospheres (e.g. gas monitoring within the TBM),
- noise and lighting,
- ergonomics and operator access,
- emergency stops and evacuation systems.

Common Hazards, risks and control measures of TBM's are included in Table 11.1 below. Mechanical and operational hazards are also described in Section 13 and further risk prompts provided at Appendix G.

Table 11 .1 TBM's Common Hazards, Risks and Example Control Measures

Hazards and Risks	Example Control Measures
Access restrictions	• Designing TBMs so there is safe access to maintainable parts including access for screw conveyor repair or blockage • Ensuring emergency plans are in place for recovery of injured people • Planning exit routes
Chemical exposure	• Limiting underground chemical storage • Providing training and relevant information, like SDS Using PPE
Crush areas, around rams, grippers, walking feet or shields	• Using visual lock out devices • Using cameras increase visibility • Ensuring operators can clearly see when grippers and pads are deployed and if there are obstructions

[10] BS EN 16191 Tunnelling machinery – Safety requirements

Cutter head interventions	• Planning interventions within areas of better ground or where ground treatment has improved conditions • Using a control procedure for cutter head access and maintenance • TBM tooling with rear loading cutters that can be undertaken under atmospheric pressure • Restricting other maintenance when work on the cutter head or cutter head entry is in progress • Ensuring adequate ventilation for the task
Dust	• Isolating dust generating processes • Using dust suppression, air filtration and scrubbers units • Using water sprays and dust suppression on conveyor belts
Electricity	• Using cut-off switches and lock out systems • Reporting actual or suspected damage to electrical plant including cables, immediately Implementing procedures for power failure Installing warning signs
Face collapse including risks from changing ground conditions, mixed face	• Careful selection and operation of TBM in view of credible range of ground and groundwater conditions to be encountered. • Use of Permit to Tunnel process
Fire	• Providing automatic fire detection and fire suppression systems (foam injection and water spray barriers) • having individual electrical cabinet fire detection and suppression systems • installing aqueous film forming foam systems at locations where grease, oil and fuel lines and tanks are present • designing tunnel lining for fire durability • substituting equipment to reduce diesel and oils • having detailed safe work method statements (SWMS) for hot works • using fire resistant hydraulic fluid and fire resistant power cables for high voltage supply • use of fire retardant tail shield grease
Gas accumulation	• using gas detection and lock out devices
Ground support installation including access, ring build, segment handling with cranes, annulus void filling and vibration	• using remote control bolting • correctly operating segment feeder and handling devices including having operators visually check area before use

	• ensuring: workers are competent in the use of segment handlers and follow manufacturer's instructions • ensuring the ring builder can visually see rams when moving them • use of exclusion zones so no work is done under unsupported ground • ensuring limbs are kept well clear of plant • inspecting installed ground support
Heat exposure	• Supplying adequate and effective ventilation • Supplying chilled drinking water • Managing fatigue
Irrespirable atmosphere including toxic fumes	• providing self-rescuers and checking their operation regularly • using emergency seals
Tunnel collapse including ground and rock fall for open TBM's lining failure or support failure	• Use of Permit to Tunnel • Having quality assurance programs for lining and annulus void filling

The main areas of ground risk for TBMs are unanticipated ground conditions and/or groundwater conditions or poor management of the TBM in respect to the ground and groundwater conditions encountered. Ground conditions not anticipated by the design or TBM specification may result from either inadequate ground investigation and/or assessment of the risk of ground variability.

For larger diameter TBMs, the interaction of TBM operating parameters and the ground becomes increasingly complex as do the weight and power requirements of the TBM. The potential for geotechnical variability across a tunnel face also increases with scale, which increase the risk of encountering mixed face conditions. Risks may arise from not anticipating the need to change operational parameters before the issues become critical or not incorporating the feedback of data generated from the operation of the TBM.

Review of the data gathered by the TBM to make adjustments to drive parameters or undertake additional ground investigations should be undertaken as part of the Permit to Tunnel Process (refer Section 8.3.4) modified to suit a TBM operation.

Table 11.2 Pressurised Face TBM Hazards, risks and example control measures

Hazards and Risks	Example Control Measures
Working with compressed air	• Use compressed air management plans and procedures[11] • Ensure correct EPB and compressed air pressure calculations • Select and train workers properly, including recovery protocols and use of hyperbaric chambers

[11] AS 4774.1-2003: Work in compressed air and hyperbaric facilities and ITA WG5 Health and Safety in Works Guidelines for Good Working Practice in High Pressure Compressed Air ITA Report 10 March 2018

Incorrect Earth Pressure Balance (EPB)	• Verify EPB pressure calculations • Monitor ground conditions and adjust EPB settings accordingly
Working with high pressure slurry	• Establish communication protocols at both ends during pigging of lines • Conduct separate risk assessments for slurry tasks • Use interlocks to prevent bowl opening while spinning

Poor maintenance of elements such as cutter tools, bearing oil lubricants or tail seal brushes all may have health and safety risk implications.

Other health and safety risks may arise from:

- damage to segments or gaskets,
- loss of effectiveness of seals at the back of the TBM,
- flotation under shallow cover,
- face blow-out to surface in the case of pressurised face (closed face) TBMs during operation or maintenance in low cover situations,
- over-excavation leading to face collapse especially during launch and receival of TBM's,
- unanticipated voids or fault zones and inundation,
- excessive wear or damage to the cutter head requiring interventions from surface,
- inundation via inability to close earth pressure balance screw conveyor,
- geological materials and airborne contaminants such as silica and naturally occurring asbestiform minerals or hydrocarbons,
- breakouts from the segmental lining into soft ground or incomplete sections of ground treatment,
- drilling through the segmental lining into soft ground.
- planned and unplanned face interventions especially those requiring compressed air[12].

TBM design should include a range of safety features including:

- automatic fire detection with foam suppression systems and water spray barriers
- storage facilities for safety equipment like breathing apparatus, self-rescuers, first aid and resuscitation equipment
- audible and visual pre-start warning systems on major moving parts
- isolation locks on major moving parts and electrical and pressure systems
- conveyor belts with pull cords for emergency stop
- guard rails on moving machinery like conveyor belts and pumps
- emergency lighting on walkways
- continuous tunnel environmental monitoring giving direct readout to the control cabin with alarms at key locations including above ground

[12] Refer ITA WG5 Health and Safety in Works Guidelines for Good Working Practice in High Pressure Compressed Air ITA Report 10 March 2018

- closed-circuit television in the control cabin with cameras fitted in the cutterhead during interventions, in areas where spoil is discharged onto the conveyor belts, into the muck skips and in areas where locomotives are moving within the confines of the TBM
- effective communications systems between the control cabin and critical locations
- air-conditioned control cabins
- electrical isolators and lock-off devices fitted on items containing dangerous moving parts
- if mucking uses locomotives, traffic lights systems at the rear of the trailing gantry to control the shunting of rolling stock during segment unloading and muck skip filling
- walkways with non-slip surfaces, fitted with handrails with headroom along the entire TBM length
- access from one trailer to the next without having to step into the segment unloading area or ring build area
- working platforms in build areas should allow segment erector operators maximum visibility
- lifting devices for segments and other equipment secured against free fall
- back-up power supplies for a main power failure for critical safety systems.

11.3 Conventional Tunnelling

11.3.1 Overview

This method is highly adaptable to large and varying tunnel geometries and geological conditions, and suitable for complex structures, alignments or smaller-scale projects.

11.3.2 Drill and Blast

Drill and blast tunnelling is a conventional excavation method used primarily in hard rock conditions. It involves drilling holes into the rock face, loading them with explosives, and detonating to fracture the rock. After blasting, the broken material (muck) is removed, and ground support systems such as rock bolts, mesh or sprayed concrete installed as required by the design.

Blasting requires careful planning and control to manage ventilation and other safety risks, particularly the location of workers to the blasting face. The use of explosives in NSW requires a user license for blasting explosives authorising purchase use and disposal of explosives from SafeWork NSW and is subject to existing legislation, standards and codes of practice. [13]

Following blasting or re-entry to the tunnel face, the walls, sides, face and support systems should be inspected before normal work commences.

If support is necessary, it should be provided as soon as practicable after scaling (refer Section 11.11) to maintain the overall integrity of the rock mass and to prevent rock falls.

11.3.3 Other Mechanical Excavation

Mechanical excavation methods, including the use of excavators, roadheaders and hydraulic breakers, should be selected, operated, and maintained in view of risks to safety.

Risk assessments should consider:

- ground stability and support requirements,
- interaction with other plant and personnel,

[13] These include NSW Explosives Act, NSW Explosives Regulation, Australian Explosives Code, Australian Standard AS 2187, Australian Standard AS 4326, Australian Dangerous Goods Code.

- vibration, noise, and dust emissions, and
- fire (refer Section 24).

11.3.4 Manual Excavation

Most tunnelling work is partly or totally mechanised but this may not always be possible for smaller scale excavations. Excavating manually should be limited to situations where access and or other constraints prohibit mechanisation and the options regarding the need for manual excavation should be considered during design development.

The hazards of this type of work which should be mitigated include those for larger scale conventional tunnels but requiring specific attention to confined space working, noise, hand-arm vibration, manual handling, dust, working at height and heat. Short shifts and/or frequent rotation of persons around different tasks should be considered, in order to limit exposure to noise, vibration and manual handling risks.

Adequate working space and as necessary working platforms should be provided.

11.3.5 Sources of Ground Risk for Conventional Tunnelling

These include:

- unanticipated changes in ground and groundwater conditions leading to instability or inundation,
- failure of ground support due to under estimation of demand from ground loads or from excessive introduced loads (e.g., grouting) or from material deficiencies,
- geological materials and airborne contaminants such as silica and naturally occurring asbestiform minerals or hydrocarbons.

11.4 Ground Behaviour During Excavation[14]

Table 11.3 Ground Behaviour

Descriptor	Potential Failure Modes/ Scale /Comment
Stable	Potential for small scale gravity-induced falling of blocks during excavation. Does not threaten overall tunnel stability but requires risk controls.
Block Fall Under Gravity	Discontinuity-controlled, gravity-induced falling and sliding of blocks; occasional local shear failure on discontinuities.
Stress Induced Failures	Influenced by discontinuities and local strength and stiffness variations. High in-situ stresses are present in NSW that can also adversely affect installed ground supports.
Rock Burst	Sudden and violent failure of the rock mass, caused by highly stressed massive rocks.
Ravelling Ground	Ravelling of dry or moist, intensely fractured, poorly interlocked rocks or soil with low cohesion.
Flowing Ground	Weak ground and groundwater flow combine to erode and transport external ground into excavation.
Mixed Ground/Heterogeneous Ground	Variable behaviours, stresses and deformations due to heterogeneous ground

[14] For additional guidance, refer Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation Austrian Society for Geomechanics (2010)

	(soil/rock or in combination) strength and stiffness, influence of faults or intrusions.

11.5 Excavation Support and the Permit to Tunnel

The support system performance should be validated by observations of ground, groundwater, and the installed support itself. This should involve:

- A design with:
    - Support Types that cover the range of anticipated ground conditions that are to be selected under a formal process involving the designer during construction based on the observed conditions and the pre-defined range of system behaviour. Designs should present selection criteria for a range of ground support types and excavation sequencing to match specific ground conditions and anticipated behaviour.
    - Definition of the monitoring and observational requirements that are required to validate, i.e., confirm the suitability of the design; and
    - Any provisions for additional investigations if required - for example ahead of the tunnel in anticipation of transition to a zone of different behaviour if the uncertainty is a material risk.
- Review of ground and groundwater data that enabled hazards and risks to be identified and assessed by the design including assessment of the limitations of the site investigations and residual uncertainty associated with the available data. Subject to risk assessment this may inform the requirements for further investigations prior to, or concurrent with construction.
- The availability of a reliable and accurate system of monitoring and observations from the design and for the excavation methods to be adopted during construction.
- Observational limits (‘Trigger values) and the actions associated with them established by the design to provide an integrated set of responses in relation to the observed behaviour of the support system. This Trigger Action and Response Plan (TARP) should include modifications anticipated by the design in relation to monitoring frequency, additional support or limiting further excavation. Whilst serviceability considerations and third party implications may have more stringent limits, a ‘red trigger’ level should be set to avoid exceeding the ultimate capacity of the support system and thereby ensure stability and excavation risk control.
- Regular review of the monitoring data by an integrated project team from the designer, contractor and client as required by risk assessment.
- Quality assurance via regular independent auditing, review and quality control.

A Permit to Tunnel (PTT) is commonly used in NSW as a means to manage construction safety risks and quality underground. It should involve frequent (as required by risk assessment) review by competent personnel of geological and monitoring data, excavation staging and support installation against the requirements of the design and the anticipated system behaviour. It should include review and performance of quality requirements such as the required extent or capacity of the applied ground support and/or a prescribed construction sequence and advance length. It should include entry requirements for work and any project specific definition of ‘supported and unsupported ground’ for example if these are affected by time requirements to gain strength for currently active excavation faces.

The conditions at the face combined with probing or other investigation methods ahead of the tunnel face (‘look ahead’) should be established and logged in accordance with the site-specific ground classification scheme to inform the Permit to Tunnel.

In case of anticipated changes in ground conditions or variable ground conditions it may be necessary to provide a minimum zone of ‘look ahead’ of the ground conditions ahead of the face position to enable effective interventions to control ground conditions, groundwater flows and generally minimise ground risks and maintain excavation control.

The PTT is a risk management and procedural quality control document and whilst it should not modify the design, the PTT may identify the need for design changes under formal design change processes. Frequent design changes may introduce delay that may be significant with respect to risk management, either individually or progressively. A PTT that identifies conditions outside of the design, that threaten stability or has implications for excavation control should implement steps required to make the excavation safe and/or stop further excavation.

Following a formal design change management process the PTT can serve as the process to both release the 'hold point' on excavation and implement a changed design. In this way excavation and support is always subject to a duly approved design and control of the excavation is always assured.

In addition to competent contractor staff that have primary responsibility for workplace safety and designer representatives, the Client or their representatives should monitor performance and implementation of the PTT process. The extent of the Clients involvement should be determined from an assessment of risks.

11.6 Cross Passages, Sumps and Ancillary Excavations

Cross connections between parallel tunnels or adjacent shafts are secondary tunnelling activities typically but not always undertaken using conventional tunnelling methods but can also be undertaken using small diameter TBM's and segmentally lined box jacks.

Cross passages can be used for permanent or temporary plant and equipment, or to facilitate movement between two tunnels. Necessarily, they involve more complex geometry and the opening of the ground behind the initial lining of the first tunnel or shaft, and this may involve significant ground or support instability and inundation risks.

Several significant catastrophic tunnelling failures have occurred in cross-passage excavations and sumps that can have just as severe consequences as a collapse of the main tunnels but maybe less well-resourced or investigated.

Ground and support risks should be controlled by design and by using the Permit to Tunnel Process described above.

11.7 Pipe Jacking

Pipe jacking is a trenchless method of tunnel construction where pipes are hydraulically pushed through the ground from a drive shaft to a receival shaft. It is suitable for small diameter pipelines and tunnels and is commonly used for utility installations.

Foreseeable hazards of pipejacking, include manual handling, noise, heat, vibration and confined space working. There should be adequate space to allow a safe means of access and egress along with adequate working space within the pipejack if personnel entry is envisaged for maintenance.

The minimum diameter required for construction may therefore be determined by the construction methodology and emergency scenario's rather than by consideration of the requirements for or the intended use of the pipejack[15] alone.

The risks associated with worker intervention in the mechanical excavation process should be carefully considered and the physiological demands of small diameter working and ability of workers to self-rescue or to be rescued should be carefully considered and documented.

[15] Pipejacking is a broad term and may also include direct pipe injection. Similar considerations should also apply to small diameter tunnels.

Table 11.4: Hazards, Risks and Example Control Measures – Pipejacks and Microtunnel TBMs

Hazards and Risks	Example Control Measures
Injuries when maintaining or repairing the micro-TBM	Preventing worker entry below minimum pipe diameters without specific risk assessment and emergency procedures Using lock outs and isolation procedures Using camera and communication systems Setting up exclusion zone during operation and maintenance Setting up exclusion zones during maintenance Checking emergency planning is in place including planning of safe retreats
Loss of Control of the micro TBM	Real-time monitoring: Use of telemetry systems to monitor TBM position, thrust, torque, face, plenum or slurry pressure, and cutterhead speed. Steering protocols: Clear procedures for steering adjustments, including allowable deviation limits and correction methods. Use of competent operators: Skilled personnel trained in microtunneling operations and emergency procedures.
Damage to pipes such that the excavation cannot advance	Design verification: Ensure pipes are designed for expected jacking loads and ground pressures. Quality assurance: Inspection and testing of materials and dimensional tolerances. Lubrication systems: Use of bentonite or polymer to reduce friction and jacking forces. Installation Controls Alignment monitoring: Continuous tracking of segment position and orientation during installation. Controlled jacking pressure: Monitoring and limiting jacking forces to avoid overstressing segments. Proper bedding and joint sealing: To prevent point loading and water ingress.
Failure of jacking and pipe handling system	Assessing and verifying temporary lifting design requirements and procedures Inspecting pipes, seals and packing before pushing Using designed lifting systems

Disconnecting and reconnecting electric and air pressure services	Use of controlled procedures for electrical installation, energisation and disconnection. Checking air hoses are connected correctly and use of whip restraints
Shaft access and egress	Using access control, camera and communication systems Checking emergency planning is in place including planning safe retreats
Crush areas including near pipe jacking rams	Setting up exclusion zones during operation Checking body parts are clear when jacking pipes

11.8 Commonly Used Materials and Support Systems

11.8.1 Sprayed Concrete or Shotcrete

Shotcrete support is used across a wide range of ground conditions from relatively soft ground, soils such as clay or weathered rock, to weak and hard rock applications. Shotcrete is a flexible and commonly support system and can incorporate fibres, steel mesh, steel sets, lattice arch girders and even deformable elements in heavy 'squeezing' ground.

Shotcrete is often used to provide initial support in advance of a permanent lining and is also used in as a composite structural material for permanent support as it can be sprayed in layers to suit capacity requirements and excavation staging.

Profile control requirements, the thickness and smoothness of the sprayed concrete layers and the extent of any exclusion zone to be observed whilst strength is gained should be established from specifications and shotcrete trials and other requirements of the lining designer. Shotcrete trials should develop the shotcrete mix designs to be used in the works, and the quality control and assurance requirements for construction that may include trial panels, laboratory and in-situ tests.

Operators must be trained and competent in shotcrete application, for example national training units (e.g., RIIUND310E Apply shotcrete underground) Refer also Australian Shotcrete Society. (2010). *Shotcreting in Australia: Recommended Practice* (2nd ed.). Concrete Institute of Australia.

An exclusion zone should be established during the excavation and the spraying operations to prevent exposure to hazards from unsupported ground or from falling shotcrete affected by ground loads or groundwater.

11.8.2 Cast In Situ Linings

Cast in situ linings involve placing concrete directly into formwork within the tunnel.

Formwork systems should be capable of being moved along the tunnel and reused where appropriate. Their strength and rigidity must be sufficient to withstand the loads imposed by wet concrete and handling operations. Inadequate formwork can lead to construction difficulties, unsafe conditions, and poor-quality linings. Formwork should not be struck until the concrete has achieved the specified strength. Where formwork is erected manually, it should be designed to be lightweight and easy to handle.

Concrete should be specified, produced, transported, and tested in accordance with:

- *AS 1379 – Specification and supply of concrete*
- *AS 1012 series – Methods of testing concrete.*

Formwork should be designed and constructed in accordance with *AS 3610 – Formwork for concrete* and relevant structural design actions under the *AS/NZS 1170 series* and used in view of applicable *Formwork Codes of Practice*, such as those issued by SafeWork NSW.

The use of concrete pumps and placing booms should comply with *AS 2550.15 – Safe use of concrete placing equipment.*

11.8.3 Pre-Cast Concrete Linings (Segmental Linings)

Segmental linings consist of pre-cast concrete, steel or less commonly spheriodal graphite iron (SGI) assembled within the tunnel. They are typically used with tunnel boring machines (or shafts) in rings and provide rapid installation and rapid high structural integrity.

Necessarily, segmental tunnel and shaft linings have multiple joint surfaces that may enable water and fine material into the tunnel or shaft without effective controls. Risks should be anticipated by the design process and managed during construction. Minimisation of damage to segments and control of water and fines ingress especially in soft silty sands under water pressure may become critical to safety.

Segment design for TBM's should consider ring length limitations due to gantry frame access and tunnel clearance and segment taper and width, which can affect TBM performance, especially on curves. Handling and erection should be mechanical, using vacuum pads or purpose-designed lifting frames. Designers should also assess lifting, transport, storage and erection.

Segments should be handled using positive attachment systems or shaped cradles so that they cannot shift, fall, or become dislodged during lifting, transport, or installation and avoid abnormal loads that could compromise segment integrity.

Erection procedures should be planned and supervised by competent personnel, designed to keep workers clear of danger zones.

Operators of erection equipment must have a clear view of the operation, and shove ram thrust should not be the sole support method. Segments must be positively secured using bolts or dowels until design assessments enable their removal.

Erection gantries must provide a safe working platform and access and egress in accordance with *AS/NZS 1170 series* and *AS 1657 – Fixed platforms, walkways, stairways and ladders*.

11.8.4 Rockbolts and dowels

Rock bolts and dowels are used in variety of ground conditions from weathered and faulted rock to hard rock. They are typically installed to provide immediate reinforcement by transferring load from potentially unstable ground to more competent strata and may be used in conjunction with other support systems such as shotcrete or mesh.

- Rock bolts are tensioned or grouted steel elements installed in drilled holes to reinforce the rock mass and control movement.
- Dowels are passive reinforcing bars, usually fully grouted, that provide resistance to displacement and enhance overall ground stability.
- Split Set bolts consist of a slotted steel tube driven into a slightly undersized hole, creating frictional contact with the rock over the full length of the bolt
- Swellex bolts are hollow steel tubes inserted into a borehole and expanded using high-pressure water, conforming to the borehole shape and providing frictional anchorage.

An exclusion zone should be established during drilling, installation, and any tensioning operations to prevent exposure to hazards from unsupported ground, falling rock, or movement of equipment and materials.

The length, diameter, spacing, and installation method for bolts and dowels should be determined from project specifications, site trials, and any relevant laboratory or in-situ testing, as well as the requirements of the ground support designer.

All installed bolts and dowels should be inspected and, where required, tested (e.g., pull testing) to verify correct installation and load capacity. In high stress environments drillholes may require inspection using endoscopes prior to installation of the rockbolt.

Any defects or non-conformances with the quality assurance system may require rectification as part of the permit to tunnel process before further excavation or support installation proceeds.

11.8.5 Steel Sets and Lattice Arch Girders

Steel sets and lattice arches are structural support elements used in underground excavations to provide ground support. These can be used to help maintain the shape of the excavation and distribute ground. Steel sets are typically higher capacity and stiffer than lattice arches. Lattice arches are always integrated within a shotcrete lining.

Safe work method statements should be developed for the handling, assembly, and installation of arches to prevent exposure to hazards from unsupported ground, falling objects, or movement of heavy components and equipment.

The size, spacing, and installation sequence of arches should be established from project specifications, site trials, and any relevant laboratory or in-situ testing, and the requirements of the ground support designer.

All installed arches should be inspected for correct alignment, secure connections, and overall stability. Significant non-conformances should be risk assessed with respect to required duty by the designers and may require rectification as required by the permit to tunnel process before further excavation or support installation proceeds.

11.9 Waterproofing Systems

Waterproofing systems maybe required to prevent water ingress into the tunnel and increase the durability and performance of tunnel systems, fixtures and fittings.

The level of waterproofing required at each construction and operational stage should be specified by the design along with the selection of the waterproofing system to be adopted.

Methods of waterproofing and include PVC membranes and associated geotextiles, chemical coatings (spray membranes) and joint sealants (refer also Section 8.6.3 above).

Membranes should not sustain burning after flame exposure nor propagate fire or produce flaming droplets.

Spray-applied waterproofing membranes maybe available in powder or liquid forms and may contain reactive chemicals such as:

- Isocyanates (e.g., MDI or TDI) – known respiratory sensitizers and potential carcinogens.
- Solvents– including VOCs that can cause neurological effects and contribute to poor air quality.
- Epoxies or bituminous compounds– which may contain skin irritants or toxic additives.

These substances pose risks through inhalation, skin contact, and environmental exposure, especially during application when atomization increases airborne concentrations.

If membranes are not eliminated using the hierarchy of controls, then the design and execution of the membrane spraying process should minimize exposure such that secondary protection for other tunnel workers is unnecessary.

11.10 Re-Profiling

Re-profiling involves reshaping the tunnel surface to meet design geometry or improve stability.

It may include trimming overbreak or correcting misalignment.

Given that ground support is being modified by the re-profiling process, re-profiling excavation control should be subject to a Permit to Tunnel process.

11.11 Scaling

Scaling is the removal of loose or unstable rock from the tunnel surface. It is critical for worker safety. Scaling should be done remotely by mechanical means where practicable or with the use of suitable overhead protection systems. Scaling activities should be subject to risk assessments with documented control procedures defining exclusion zones, the plant to be used, and operator and worker protection from the risk of uncontrolled debris fall.

Scaling should be carried out systematically, working towards the face. In addition to the ground exposed by blasting and excavation, areas that have previously been scaled should be re-checked. Scaling should be carried out regularly by competent and trained personnel and should be checked by a supervisor.

11.12 Geotechnical Instrumentation and Monitoring

Geotechnical monitoring provides data on ground behaviour and ground support performance.

Instruments may include extensometers, inclinometers, piezometers, strain gauges, fibre optics, optical survey and laser distancing and scanning instruments used for convergence monitoring.

Monitoring requirements during construction should be developed from design risk assessments and the results of monitoring data should be reviewed as part of the permit to tunnel process.

Systems should be fit for purpose, calibrated and maintained, reliable and accurate.

12 Groundwater

12.1 Groundwater Controls

12.1.1 Overview

It is necessary to adapt working methods to control the risks arising from groundwater during construction of shafts and tunnels. Any system of groundwater control, if it has an ongoing function during construction, should consider the consequences of system shutdown/failure and the reliability and resilience of any back-up systems.

12.1.2 Groundwater Control by Reducing Ground Permeability

These methods reduce the ability of water to flow through the ground.

- Permeation Grouting injects fluids (grouts or resins) under-pressure to fill voids (or fissures) in the ground with typically cementitious materials and can be used to reduce permeability and improve strength outside the tunnel.
- Jet grouting and soil cement mixing are forms of ground improvement that cuts and mixes the ground with cement to form overlapping cylinders of engineered ground of defined strength and permeability that form a barrier to groundwater flow.
- Ground freezing uses either saltwater or nitrogen in closed systems of injection pipes to freeze the groundwater in-situ. It is extremely specialised and effects must be integrated with structural designs given the heave associated with the expansion of water during freezing. It is the least commonly adopted method for groundwater control.

All methods are workmanship dependent and thus require competent, experienced personnel for implementation and rigorous validation via monitoring feedback through construction.

The use of groundwater control methods may be a source of risk to the tunnelling operation, and ground support systems. These risks should be acknowledged, controlled and integrated with the permit to tunnel process.

12.1.3 Compressed air tunnelling

Compressed air working (hyperbaric works) is a means to counterbalance groundwater pressures to reduce flows to manageable levels. Hyperbaric works (manual interventions) are sometimes required in the maintenance of TBMs and compressed air is used as a short-term measure to limit groundwater flows during such an operation.

High Pressure Compressed Air is "work in compressed air at pressures above historical statutory limits in the range 3 to 4 bar (gauge), and which involves the use of breathing mixtures other than compressed natural air and can involve the use of saturation techniques". [16]

The need for hyperbaric work is a sign of a highly technical tunnelling operation requiring highly trained operatives and a very technical management regime to ensure safety.

[16] ITA Report No. 010-V2 (April 2015) – Guidelines for Good Working Practice in High Pressure Compressed Air

12.1.4 Dewatering Systems

Dewatering approaches reduce groundwater pressures by drainage ahead of an advancing tunnel or a cross passage and may comprise simple probeholes drilled ahead of the tunnel face).

Dewatering by systems requires detailed hydrogeological assessments and may be done from the surface using pumps or vacuum wells or underground using passive drains.

All dewatering activities, including the excavation of any tunnel or opening that allows the ground to drain has the potential for third-party risks from ground settlement above.

Health and safety risks maybe associated with contamination or land uses such as tanks for underground hydrocarbon storage for example (refer Section 10.5 below).

12.2 Tunnel Drainage

Effective tunnel drainage is essential to maintain safe working conditions. Drainage systems should be designed to manage both groundwater ingress and surface water runoff, accounting for:

- Geological and hydrogeological conditions.
- Tunnel gradient and alignment.
- Anticipated water inflows during excavation and operation.

Drainage infrastructure may include:

- Collection sumps and pumping systems.
- Graded invert channels or pipes to direct water to collection points.
- Redundancy in pumping systems to manage peak inflows or pump failure.

Drainage systems should be maintained to prevent blockages, overflows, or flooding. This includes:

- Regular inspection and cleaning.
- Monitoring of pump performance and water levels.
- Emergency backup power for critical drainage equipment.

Contaminated water (e.g. from drilling fluids, fuel spills) must be treated or contained in accordance with environmental regulations.

12.3 Inundation

Inundation refers to the uncontrolled entry of water into the tunnel, which can pose serious risks to life, equipment, and tunnel stability.

A risk assessment must be conducted during the design and planning phase to identify potential sources of inundation, including:

- Aquifers or water-bearing strata,
- Proximity to rivers, lakes, or the sea,
- Surface water drainage patterns,
- Existing underground works that have the potential to be flooded, or
- Dams.

Control measures may include:

- Probing ahead of the tunnel face,
- Control measures to reduce ground permeability,

- Bulkheads or water-tight doors in high-risk areas,
- Continuous water ingress monitoring systems.

Indications of an early stage of inundation or inrush might include the following:

- obvious changes in water,
- unusual strata/ground behaviour,
- changes in ground water flow,
- change in water quality, i.e. colour, suspended solids, chemical analysis,
- release of irrespirable atmospheres or flammable gases into the ventilation system,
- significant unexpected decrease in surface or other water.

Emergency response plans should address:

- Rapid evacuation procedures.
- Communication protocols.
- Location and access to refuge chambers or safe zones.
- Exit routes and refuge locations should exits be blocked.
- Use of transport considering inrush and inundation conditions.
- Special equipment to assist in exit or rescue etc.

Training and drills should be conducted regularly to ensure all personnel understand the inundation response procedures.

Further details are contained within the NSW Trade & Investment Mine Safety *Code of Practice: Inundation and inrush hazard management* for detailed requirements.

12.4 Contaminated land and ground water

The potential for chemical contaminants should be assessed from a desk study of previous uses of the site and surrounding area to inform the scope and extent of ground investigation, hydrogeological assessment and laboratory testing. This data for the assessment should be sufficient to quantify both occupational exposure during construction and environmental exposure.

The presence of a range of chemical contaminants associated with heavy industrial legacy industries including gas production, metal processing and chemical industries should be considered. Contaminants to be considered should include hydrocarbon fuel residues, tar and its residues, polychlorinated biphenyls, volatile organic compounds and heavy metals and organic solvents. Whilst contamination can be found both in the ground and in groundwater, plumes of contaminated groundwater should also be expected to extend some distance from the source of the contamination.

13 Machines & Plant Safety

13.1 General Operations

Only trained and competent operators should operate plant and machinery.

The systems that support plant safety should include defining operational plant zones. Plant zones should be defined, categorised in risk assessments and SWMS and applied on-site. The following zones generally apply - Plant only zones, Plant operating and restricted personnel zones, and Plant hazardous zones.

Effective communication systems (e.g. radios, visual signals) should be used to coordinate activities when there are adjacent activities.

Equipment must be operated in accordance with manufacturer instructions and site-specific procedures.

13.2 Moving Plant

The Work Health and Safety (WHS) Regulation 2025 (NSW) requires PCBUs to manage risks associated with powered mobile plant, including overturning, falling objects, and operator ejection. Control measures such as Roll-Over Protective Structures (ROPS) and Falling Object Protective Structures (FOPS) must be implemented where these risks cannot be eliminated.

Common causes of harm involving moving plant on construction sites include.

- Damage to health and safety infrastructure including services and ventilation ducts.
- Pedestrians / workers on foot being struck by moving plant while sharing the same work area such as access roads / paths, loading / unloading areas and entry / exit points.
- Moving plant coming into contact with workers on foot whilst reversing.
- Slewing moving plant (for example excavators) coming into contact with other plant and workers on foot.
- Workers on foot being struck or crushed while assisting the operation of moving plant (e.g. doggers, off siders, traffic controllers, line hands, spotters).
- Light vehicles being crushed or struck while interfacing with heavy vehicles.
- Workers on foot and plant operators being distracted by electronic devices (e.g. phones, tablets, headphones, etc) giving rise to the risk of collision with other plant or persons.
- Inadequate communication methods between operators of moving plant and workers on foot contributing to the risk of persons being struck by moving plant.
- Poorly constructed, planned, designed and / or maintained access / exit roads, haul roads and / or loading and unloading areas, affecting the safe control and stability of moving plant, including failure to undertake risk assessments of these areas following weather events.
- Poorly maintained plant causing potential failure of brakes, steering and / or hydraulic systems, risking uncontrolled movements.
- Using mobile plant that relies solely on operators to apply park brakes (or other similar such as maxi brakes) to prevent roll aways.
- Conducting repairs and servicing to moving plant on-site where conditions increase risks. This can include uneven surfaces, gradients that place the moving plant at risk of roll away, unexpected movement of auxiliary attachments or systems, and / or exposure to stored energy within the mobile plant.

- Failure to use systems provided by the manufacturer to manage risks associated with ejection and moving plant roll-over. This includes failure to use a seatbelt.
- Failure to provide appropriate protective structures, such as roll over / falling objects protective structures, to prevent being struck / crushed while operating moving plant.
- Moving plant used outside its design parameters or intended use, such as:
  - overloading or exceeding the rated capacity,
  - extending loads outside the safe working radius,
  - exceeding slope and gradient capability,
  - use of plant on unsuitable supporting ground or structures,
  - alteration, modification or use of unapproved attachments.
- Moving plant transiting or operating near live overhead power lines, resulting in contact or arcing. Mobile cranes, excavators, piling rigs, EWPs and dump trucks experience higher power line contact rates.
- Failing to provide adequate working structures or pads to prevent plant overturning.
- Recovery operations (bogged, rolled, or otherwise immobile vehicles), particularly those without specialist recovery equipment or planning by a competent person.
- Working with moving plant near embankments, cuttings, cross slopes, or on elevated positions (e.g. cliff edges) resulting in plant overturning or falling.
- Loading and unloading moving plant on and off transporting vehicles.
- Operator entrapment between the moving plant and obstructions.
- Inexperienced operators, reckless actions of operators, and / or operators being unfit for work.

In addition to the common causes of moving plant incidents, PCBUs must identify any other site-specific hazards for each individual site and eliminate or minimise these risks.

Further guidance on establishing systems for the safe use of moving plant including confirming the suitability of plant, systems to verify operator competence to address unsafe operation of moving plant, requirements for communication systems, plant zoning and restrictions, specific controls loading and unloading is included in the SafeWork NSW Code of Practice *Moving Plant on construction sites*.

13.3 Standards for Rollover and Falling Object Protective Structures (ROPS and FOPS)

Risk assessments should determine the need for ROPS/FOPS based on terrain, overhead hazards, and rollover likelihood. ROPS/FOPS must be certified by the manufacturer or a competent engineer. Annual inspections are recommended to ensure structural integrity. Damaged ROPS/FOPS must not be repaired without Original Equipment Manufacturer (OEM) approval and should be replaced if compromised.

ROPS and FOPS should conform to the following standards

- *AS 2294 Series – Earth-moving Machinery – Protective Structures*
- *AS 2294.1: General requirements for ROPS and FOPS*
- *AS 2294.2: Test procedures for ROPS*
- *AS 2294.3: Test procedures for FOPS.*

13.4 Mobile Elevated Work Platforms MEWP

MEWPS should conform to the requirements of *AS/NZS 1418.10:2011 – Design of MEWPs*. This covers structural design, guarding, and access systems and requires safety devices such as harness anchor points, tilt alarms, and emergency lowering systems.

For further guidance refer to the EWPA (Elevating Work Platform Association of Australia) Good Practice Guide for the safe use of Mobile Elevating Work Platforms (MEWPs). The Guide recommends risk-based selection of MEWPs with ROPS/FOPS and emphasizes operator training, inspection, and maintenance and consultation with manufacturers for compliance.

13.5 Specifying plant for use underground

Equipment must be specifically designed or suitably modified for use in underground environments. This includes the use of fire-resistant materials, low-emission engines, and intrinsically safe components where required.

Where practicable, underground mechanical plant, including locomotives should be fitted with automatic fire suppression systems and use fire-resistant hydraulic fluids to reduce fire risk and enhance operational safety.

Table 11.1 – Typical Machine Hazards and Controls

Hazard Category	Example Control Measures
Mechanical Hazards	Guarding of moving parts, interlocks, emergency stop systems
Electrical Hazards	Compliance with AS/NZS 4024, insulation, grounding, lockout/tagout procedures
Fire and Explosion Risks	Fire suppression systems, fire resistant and flame-retardant materials, monitoring of flammable gases. (Refer 13.10.2)
Falling Objects / Ground Collapse	Protective canopies, structural reinforcement, geotechnical monitoring
Poor Visibility / Lighting	Installation of adequate lighting systems, reflective markings
Hazardous Atmospheres	Gas detection systems, ventilation, use of AS/NZS 60079 for zoning of explosive atmospheres
Noise and Vibration	Noise dampening materials, vibration isolation, operator exposure limits
Ergonomic Hazards	Accessible controls, safe access and egress, operator seating and layout
Maintenance Hazards	Safe access platforms, lockout/tagout, maintenance procedures and training
Misuse Scenarios	Operator training, warning systems, design limits and fail-safes

13.6 Blind spots

Blind spots can occur due to plant design and / or the site environment.

PCBUs should consider:

- blind spot diagrams contained in the manufacturer's operating manual,
- additional control measures, such as reversing cameras and proximity sensors,
- setting up the work site with view to minimising blind spots,

- separation and delineation systems, such as physical barriers, boom gates, etc.,
- establishing systems to have moving plant operators:
  - slow to no more than walking speed when negotiating blind spots,
  - identify the plant before negotiating the blind spot (for example, sound horn, radio calls, or similar),
- use of spotters as part of controlled working procedures,
- blind spots when workers on foot are approaching moving plant during operation. Before approaching moving plant, workers need to confirm verbal communication (e.g., via a two way radio) with the plant operator.

13.7 Pre-start & maintenance checks

Pre-start checks should be conducted, including inspection of safety critical systems that may include for example brakes, hydraulics, lighting, and emergency system.

A preventive maintenance program should be implemented, and any defective equipment must be immediately withdrawn from service.

13.8 Fluid Power Systems

Hydraulic systems are integral to tunnelling machinery such as tunnel boring machines (TBMs), roadheaders, and excavators.

The fluids used in these systems pose potential risks including fire, environmental contamination, and mechanical failure and personal injury.

Effective management of hydraulic fluids and compressed air is essential to ensure worker safety and should be subject to SWMS for operation and maintenance.

Further detail may be found in Hydraulic Safety published by NSW Department of Planning and Environment[17] and TRG 41 Technical reference guide: Published by the NSW Department of Primary Industries and Regional Development[18].

13.9 Remote Control Operations

Remote-controlled plant and equipment can reduce exposure to high-risk environments, but they introduce unique hazards that must be managed.

Remote operation and / or automated moving plant can be an effective control to prevent harm in hazardous environments. Remote operated and / or automated plant may be suited to works around shafts watercourses, unstable ground, demolition, or other identified high-risk environments. Where remote control plant is used:

- it must be fit for purpose,
- it must be designed to fail to safe if connectivity is lost or in the event of a malfunction,
- operators of remote control plant should have suitable unobstructed vision - this could be achieved from controller positioning, cameras, sensors, spotters or other suitable means.
- Remote control systems must be fail-safe and include emergency stop functions.
- Operators must be trained and competent in the use of remote systems.

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[17] Hydraulic safety Mining design guideline | MDG 3007

[18] TRG 41 Technical reference guide: Fluid power safety systems at mines

- A clear line of sight or real-time video monitoring should be maintained where possible.
- Exclusion zones should be established around the operating area to prevent inadvertent entry.
- Systems should be designed to fail to a safe state in the event of signal loss or malfunction.

Where automated plant is used it must have appropriate systems to reliably detect and stop before:

- colliding with workers or other objects,
- encroaching on circumstances likely to cause harm (such as geofencing, proximity to power lines, explosive environments, water inundation, over capacity movements or other similar harm).

13.10 Transport Systems for Spoil and Materials

13.10.1 General

Transport systems in tunnels must be designed and operated to ensure the safety of workers and the integrity of the tunnel environment. All transport systems must be risk assessed and included in the site's traffic management plan.

Segregation of personnel and vehicles should be maintained wherever practicable. Warning systems (audible and visual) should be fitted to all mobile plant.

Speed limits and right-of-way rules must be clearly defined and enforced.

13.10.2 Belt Conveyors

Belt conveyors must be guarded to prevent entanglement or contact with moving parts. Emergency stop pull cords or buttons must be accessible along the length of the conveyor. Regular inspection and maintenance must be carried out to prevent mechanical failure or fire risk.

Dust suppression and ventilation should be provided to control risks of dust generation where the operation of belt conveyors has the potential to generate airborne contaminants such as belt transfer locations.

Conveyor belts should be made from fire rated anti-static (FRAS) materials[19].

13.10.3 Trucks

Trucks used underground should be fitted with reversing alarms and cameras and their engines fitted with fire suppression systems. They should utilise low-emission engines or exhaust treatment systems (refer Section 13.2 and 15 below).

Designated loading and tipping areas should be established and maintained. Operators must be trained and authorised.

13.10.4 Railways

The use of railways underground require safe operating procedures be developed that reflect the complexity of the railway system and the tunnelling operations.

Operating procedures should include as a minimum:

- Lighting,

[19] Refer for example MDG 3608: Non-Metallic Materials for Use in Underground Coal Mines – Fire Resistant and Anti-Static (FRAS) Materials, EN 1366 AS/NZS 1530.3 & AS/NZS 1530.4

- load capacity with respect to alignment, gradient, braking and traction control,
- train control procedures including required stopping distances and emergencies,
- communications and signalling controls,
- visibility aids,
- train speeds and temporary speed restrictions,
- clearances,
- pedestrian separation,
- driver containment,
- walkways and crossing points,
- other tunnelling activities,
- passing points and junctions,
- carriage of persons and/or materials,
- driver competence and authorization,
- locomotive and rolling stock maintenance,
- track inspection and maintenance, and

Further information may be found within the Crossrail Best Practice Guide "Construction Railways Operations".

13.11 Use of Batteries

13.11.1 Overview

Whilst this Code cannot account for all possible battery applications, a systematic approach taking into account the particular circumstances and the latest relevant technical information, should be adopted. The risk of injury due to a batteries can be reduced by:

- Risk assessing all activities involving batteries, including:
    - location of where the equipment will be operated,
    - introducing or changing a battery use application (mobile and stationary plant),
    - selecting or changing the type of battery,
    - the characteristics of the charging circuit,
    - the extent and frequency of maintenance, inspection and audits,
    - the control procedure to be adopted in case of battery failure.
- Following original equipment manufacturers' (OEM) recommendations for the battery and/or equipment.
- Using correct personal protective equipment when working with batteries.
- Using the correct type and rating of battery for the application e.g. for some applications, a 'deep cycling' battery may be more appropriate.
- Ensuring regular, appropriate battery inspection and maintenance.
- Following correct charging characteristics. Do not overcharge batteries. Standby equipment e.g. fire pumps and generators, may use continuous float (trickle) charging instead of charging at a higher current.

- Before removing terminal clamps, ensure current isn't being drawn from the battery e.g. open the battery isolator switch. Sparking at disconnection can be an ignition source.
- Noting that metal objects such as tools may cause sparks (and ignition) if they simultaneously touch a positive battery lead and the vehicle body.
- Safely discarding batteries with distorted plates which may cause internal shorts and ignition.
- In multiple battery sets, ensuring all units in the set are of similar rating, type and condition. Do not mix old and new. When needed, exchange all batteries in the set at the same time.
- Determining if battery-charging stations need explosion protected electrical equipment.
- Establishing and maintaining a register of batteries used on site.
- Establishing a site standard on battery types and their applications.
- Regular auditing to ensure conformance to the operating requirements.

13.11.2 Charging Risks

Charging stations if they cannot be located at surface should be well ventilated and designed to prevent overheating, arcing, and other electrical faults that could lead to ignition.

13.11.3 Lead Acid batteries

Charging of lead acid batteries can produce hydrogen and oxygen that can be an explosion hazard. Lead-acid batteries have been in use underground for over a century but are limited by their lower specific energy (a ration of their weight to energy storage) long charging times, maintenance demands and fire and explosion risks.

13.11.4 Lithium Battery Electric Vehicles (BEV’s)

Newer battery chemistries are being developed and used given better energy density and lifecycle performance. The adoption of lithium batteries (particularly lithium iron phosphate) to power large mobile underground plant and equipment is increasing in underground environments as they offer reduced carbon and diesel particulate emissions. Their use introduces specific health and safety risks associated with the large volume of energy stored in the batteries, requiring specific risk controls. It is noted that alternatives to lithium batteries are being developed and their use may require different approaches and controls than the guidance provided below.

Lithium batteries can overheat or catch fire due to damage, overcharging, or manufacturing defects. Battery fires or malfunctions may release hazardous gases such as hydrogen fluoride and carbon monoxide. These gases may accumulate, posing health risks to personnel.

A battery thermal management system should be designed to prevent thermal runaway, a dangerous situation where a battery cell's temperature increases uncontrollably, potentially leading to fire or explosion. Electric vehicles used underground should incorporate safe cell designs that minimize exothermic reactions. Additionally, fire-retardant materials should be included within battery modules.

A BEV should be fitted with a high voltage interlock loop (HVIL) conforming to ISO 17409 a safety system that monitors and controls the high-voltage electrical system in the vehicle. An HVIL connector is another safety-critical component that is responsible for safely connecting and disconnecting the high-voltage battery system.

BEV’s should include external fire shielding. Battery packs should be equipped with integrated fire suppression systems, equipped with the most effective extinguishant for the battery chemistry.

High-voltage systems in BEVs present risks of electric shock, particularly during maintenance or in the event of water ingress. Manual service disconnect switches should be available for lock-out/tag-out procedures during maintenance.

BEVs should support emergency operation modes such as 'limp home' capabilities for safe evacuation in case of partial system failure. Responding to incidents involving BEVs underground is complex. Emergency plans must account for battery-specific hazards and ensure safe evacuation procedures.

To protect against rock falls and mechanical impacts, BEVs should feature robust top plates and cooling systems that act as impact shields. Batteries should be securely mounted inside the vehicle frame to reduce exposure and enhance crash protection.

Battery systems should be sealed to IP65 standards to withstand dust, moisture, and vibration. Vibration resistance should be equivalent to other machine components.

Relevant international standards for developing safe systems of working with BEV's include:

- ISO 17409:2020 Electrically propelled road vehicles — Conductive power transfer — Safety requirements.
- IEC 62485-6 / IEC 62619: Safe design, installation, and operation of battery systems.
- IEC 61000 series / ISO 13766: Electromagnetic compatibility standards.
- ISO 13849-1: Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design.
- IEC 60529: Degrees of protection provided by enclosures (IP ratings).
- IEC 62281 / UN 38.3: Safety of primary and secondary lithium cells and batteries during transport and Recommendations on the Transport of Dangerous Goods: Manual of Tests and Criteria.

14 Electrical Supply and Safety

As the safety of persons and works can be dependent on the continuity of power supplies to safety critical equipment a reliable main supply to the works is essential. The time for which any interruption of supply can be tolerated, should be determined according to the particular tunnel and its method of construction. In planning mains power supplies, these matters should be fully examined and discussed with the electrical network operator.

If necessary, subject to risk assessments, essential standby power should be provided by a second independent mains connection or generator. Switchgear and circuits should be planned so that essential circuits are not broken when other circuits are disconnected or fail.

Once supplied, control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with electrical hazards.

Electrical equipment can be damaged from high temperature, pressure, humidity, dust, from hazardous and explosive chemicals and the effects of blasting. Electrical equipment should be protected from these exposures.

Safety critical plant and equipment like fire fighting equipment, pumps, ventilation, communications and atmospheric monitoring should remain operational even in an explosive atmosphere and where there is an explosion.

Electrical installations on tunnelling sites must comply with *AS/NZS 3012* and *AS/NZS 3000*.

All electrical equipment must be inspected, tested, and tagged by a competent person.

Work on or near live electrical equipment must not be carried out unless absolutely necessary and authorised under a risk-assessed procedure.

Residual Current Devices (RCDs) must be used for all portable electrical equipment.

Detailed information on electrical safety is in the Code of Practice: *Managing electrical risks in the workplace*[20].

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[20] Code Of Practice Managing Electrical Risks in the workplace Safework NSW

15 Lighting and Illumination

15.1 General

Lighting underground is an important part of establishing safe conditions in the workplace. Lighting levels should be such that any personnel or obstructions on walkways and tracks can be seen easily.

Lighting should be provided that allows workers and others to move and work safely within the workplace, not create excessive glare and enable safe entry and exit from the workplace including emergency exits. Adequate lighting must be provided in all work areas, including tunnel faces, shafts, inclines, walkways, and escape routes. Higher lighting levels should be provided locally, at the face and other working areas. If fixed lighting systems are not practicable, hand lamps or cap lamps should be provided.

Lighting levels should be sufficient and reliable to allow safe performance of tasks and navigation and should be regularly checked and maintained.

The use of LED lighting should be considered in preference to other types because of its low power demand and low operating temperature.

Emergency Provisions

Emergency lighting should be installed and maintained in areas where loss of light could pose a risk.

Where it is foreseeable that potentially explosive gas could enter the tunnel, the lighting and emergency lighting installation should be protected to at least Zone 2 requirements[21] so that in the presence of a potentially explosive atmosphere, evacuation can be undertaken with the main tunnel lighting system operational.

15.2 Light Levels

The lighting level at a surface is expressed in lux. In a tunnel, the lighting level is a function of the output and location of the light fittings (luminaires), the dimensions of the tunnel, the light absorbency of the surrounding surfaces and the tunnel atmospheric conditions.

Lighting levels can be measured with a light meter and should be as high as is reasonably practicable. The recommended average lighting levels should be as set out in Table 15.1.

Table 15.1 — Minimum average lighting levels

Area	Lighting level
Walkways and tracks	30 lux at walkway level
General working areas	100 lux at working surfaces
Tunnel face, excavation areas, areas with lifting operations	100 lux illuminated from at least two widely separated sources to avoid shadows

15.3 Temporary Lighting for Maintenance and Renovation

[21] Per AS/NZS 60079

If carrying out essential inspection, maintenance, renovation, and repair in tunnels that are not fitted with permanent lighting, work should be lit by temporary lighting and subject to risk assessments, necessary provisions made for emergencies.

16 Lifting Operations

16.1 General

All lifting operations must be planned and supervised by a competent person. The appointed person should determine what is required in terms of a generic or specific plan for each lift. The hazards of heavy lifts along with repetitive lifting and lowering to considerable depths below ground level should be factored into the planning of lifting operations.

The lift plan should be briefed to the lifting supervisors, machine operators and doggers.

The lift plan should contain, as a minimum, information on the lifting equipment and accessories to be used, description of the load and the lifting arrangement and the maximum working radius when lifting the load, including the weight of the lifting accessories.

The movement of loads by lifting equipment should be, at any stage, under the control of one person.

Where lifting operations involve tandem lifting or the use of cranes of significantly greater capacity than the crane normally servicing the shaft, PCBU should consider the involvement of heavy lift specialists.

16.2 Use of Cranes at Shafts

Where possible, the plant operator should have an uninterrupted view of the load while it is within the shaft. Where full visibility is not possible there should be visibility aids and a safe system of work in place to allow the operator to see and control the load and/or be instructed in moving the load. To enhance safety, CCTV should be used where appropriate to link the crane operator at the surface with the shaft bottom. Where appropriate there should be a hand-over between the signallers at the pit top and pit bottom as the load moves into and out of camera view. CCTV should be used to enhance operator visibility rather than to replace normal visual checks of shaft operations by the slinger/signaller.

Crane selection should take into account the nature of the work, which could require frequent highspeed hoisting and lowering, potentially with heavy loads. The crane supplier should be made aware of the exact duty cycles so that they can supply plant which is not regularly working at or near the design limits for prolonged periods, which could affect crane reliability.

When siting a crane in the vicinity of any shaft, care should be taken to ensure the imposed ground loads from the crane do not adversely affect the proposed shaft or tunnel works or that shaft sinking does not affect crane stability. A platform for siting a crane should be designed and constructed in order to minimize settlement, to spread crane loads as widely as possible, and to avoid excessive loading on tunnels or lateral thrust from the ground against the shaft lining or other structures.

With mobile cranes that are not restricted to predetermined locations, loadings imposed upon the ground should be kept within safe limits considering the variability of the ground. Rope lengths should be checked to confirm that at least three full turns of rope remain on the hoist drum when the hook is at full depth in the shaft bottom, including any sumps. The hoist drum should be fitted with a "last wrap" roller which cuts out the lowering when it is tripped but allows the operator to hoist back up the shaft.

The weight of the rope should be considered when determining the safe working load at full depth. Loads must be secured and lifted in a controlled manner to prevent swinging or dropping.

The shaft should be cleared of persons other than those essential to the lifting operation while the lift is in progress. These persons should be safely positioned with exclusion zones around lifting areas established.

16.3 Use of Winches

Only winches intended for lifting and fitted with powered-off brakes, should be used for hoisting loads. Safe working load and that of their mountings should be clearly marked and strictly adhered to. Their mountings or anchorage points should be specifically designed and tested. A system for inspection and maintenance of winches and associated equipment should be adopted and records of inspections maintained.

16.4 Arch and mesh installation

Steel arches for roof support should be lifted using a purpose-built clamp or similar attachment, mounted on machine with sufficient lifting capability.

16.5 Lifting with excavators

Excavators should only be used for lifting where:

- they have been designed for that purpose, and the surrounding conditions are considered safe;
- the manufacturer's instructions and recommendations are followed; and
- their designated lifting points are used.

17 Ventilation

S 51 – Hazardous atmospheres

A hazardous atmosphere is where the:

• the atmosphere does not have a safe oxygen level

• the concentration of oxygen is > 23% or greater and so increases the fire risk

• the concentration of flammable gas, vapour, mist, or fumes exceeds 5 percent of the lower explosive limit (LEL) for the gas, vapour, mist, or fumes, or

• combustible dust is present in a quantity and form that would result in a hazardous area.

17.1 Temporary Ventilation System Design and Operation

Underground construction requires effective ventilation to maintain air quality and control exposure to potential airborne contaminants. These may include dust, diesel exhaust emissions, gases from blasting, gases released from the oxidation of organic substances, or through desorption from, or interaction with, the surrounding geology.

Underground spaces are usually at risk of atmospheric contamination because:

- excavations can be a receptacle for gases and fumes that are heavier than air,
- gases and fumes may be generated by construction processes such as methane and sulphur dioxide, engine fumes, such as carbon monoxide and carbon dioxide,
- gases may be introduced via leakage from gas bottles, fuel tanks, sewers, drains, gas pipes and LPG tanks,
- oxygen in a non-ventilated area can be depleted due to internal combustion plants, oxidation or other natural processes,
- most flammable gases and fumes can be ignited if not sufficiently diluted,
- dust and fumes in the air can cause acute illness, as well as chronic disease, and reduce visibility,
- hazardous contaminants can arise from tunnelling activities and in emergencies. For example, chlorine, hydrogen chloride, hydrogen cyanide and phosgene may be produced from the combustion of synthetic materials such as PVC belting or refrigerants. Ammonia may derive from explosive use and some types of cement-based grouts and from proximal sewerage works or works within wasterwater systems,
- Granitic rocks can generate radon which is a radioactive, naturally-occurring, gas that is heavier than air and so may collect in sumps. Due to its radioactive properties, can have long term health effects on people after exposure,
- heat and humidity can reach hazardous levels.

These hazards can also be encountered in excavations for foundations, bored and drilled pier holes, shafts, drives, pits and trenches. The detrimental effects of inadequate ventilation can be short-term, or cumulative and long-term.

A mechanical ventilation system to ensure that sufficient oxygen is available for respiration (from fresh air) and dilutes and transports harmful atmospheric contaminants away from work areas, should be used.

The air flow needs to be sufficient to manage the conditions and control the potential effects of contaminants to provide a clean and safe atmosphere for work, and adequate cooling for people working in warm and humid environments.

Temporary ventilation system design and operation requires careful consideration of fresh air supply, contaminant sources and interactions with componentry, to ensure safe and adaptable airflow throughout tunnel construction and until permanent systems are commissioned. Accordingly, the ventilation requirements for construction, including performance criteria such as airflow voumes and rates with respect to workplace exposure limits, should be clearly understood.

The requirements will be unique for each tunnel project given variation of:

- Tunnel size, and length, excavation methods and plant used.
- Staging of excavations and concurrent activities.
- Infrastructure and services needed to support ventilation performance.

The temporary ventilation system should be designed by competent ventilation engineers to enable effective control of airborne contaminants throughout all phases of construction.

Ventilation systems should be maintained and monitored to confirm performance against the design, to manage changes to the ventilation system design and other requirements of the Ventilation Control Plan during construction by the Ventilation Officer.

Designers and design verifiers of installation, commissioning, operation, and maintenance of any temporary ventilation system, should have access to all relevant information to assess:

- each purpose (e.g., capture of contaminants, supply of fresh air) for which the temporary ventilation system is to be designed for,
- the results of any calculations, analysis, testing or examination,
- any conditions or monitoring and design validation steps required to ensure the temporary ventilation system is operated without risks to health and safety when used for the purposes which it was designed for.

17.2 Ventilation system requirements

Ventilation systems should be designed to maintain consistent air quality whilst the tunnel is occupied (see also Section 18) and be based upon the anticipated sequence of construction. The ventilation system should be designed to be moved forward or extended with the progress of tunnelling. After breakthrough or junctioning, the performance of the ventilation system should be reassessed and adjustments made as necessary.

Ventilation systems may consist of either a forced supply of fresh air to the face, or extraction of vitiated air from the tunnels or a combination of supply and exhaust (overlap systems). Overlap systems may include filters / dedusters and air movers to assist locally and to eliminate stagnant areas.

For overlap systems, because of the very limited zone of influence of an extraction duct, multiple intakes should be considered to ensure adequate dust capture across the working face. Extraction ducts should be placed as close as practicable to the source of any contaminant. To avoid the need to enter under unsupported ground, mechanical handling or extension of the ducts should be considered.

The ventilation system should be designed and operated to achieve the following minimum criteria:

- Fresh air intakes should be located to avoid sources of contamination or recirculation. Portal and shaft ventilation discharges should be designed to prevent secondary exposure or a risk of exposure to the area around the site. The fresh air as supplied should be as cool and dry as is reasonably practicable.

- The tunnel atmosphere should be considered as oxygen-deficient when the concentration of oxygen falls below 19.5%. Trigger Action and Response Plans (TARPs) should be set accordingly (Refer Table 18.2)
- Airflow volumes should be determined for the purposes of the Ventilation Control Plan based on the number of workers, equipment used, and contaminant generation rates, and the volumes provided should be adjusted dynamically as conditions change.
- For active excavation under conventional tunnelling operations, a minimum average air velocity of 0.5 m/s should be maintained across the tunnel cross-section in the direction of the working face to prevent dust backflow. This velocity should be measured as a cross-sectional average using spot or traverse surveys, at representative locations allowing for the potential for operating machinery turbulence effects.[22] It should be noted that dilution maybe a determining factor in reducing exposure to atmospheric contaminants, particularly RCS, such that the minimum velocity above is unlikely to achieve compliance by itself. Sufficient dilution may only be achieved if additional fresh air can be added to the ventilation system[23].
- Air recirculation should be avoided so far as is reasonably practicable.
- Air velocity and contaminant concentrations should be monitored continuously or at regular intervals using calibrated instruments.
- Airflow volumes including additional fresh air by way of dilution as required should be provided as necessary to maintain contaminants below workplace exposure standards and ensure compliance with exposure limits for airborne contaminants (e.g., respirable crystalline silica, diesel particulate matter, CO, NO_2) and to maintain oxygen levels above 19.5%.
- Where methane or other flammable gases may be present, airflow velocities and volumes should be increased
- The design must account for blockage effects from plant, equipment, and stored materials that may impede or redirect airflow.
- In large excavations (e.g., caverns >200 m^2), additional localised ventilation may be required to ensure effective contaminant control and thermal comfort level requirements.
- Ventilation systems must be designed to accommodate emergency scenarios, including maintaining critical air velocities to prevent smoke backlayering.
- Continuous air quality monitoring and ventilation performance checks should be implemented, with alarms and contingency plans in place for exceedances.
- Ventilation systems should incorporate dust filters as necessary to clean the air before readmission to the general body of airflow. Recirculation that reduces air quality should be avoided.

The ventilation system should be considered alongside other dust control measures. These include suppression systems, dust collectors positioned near the excavation face, remote operation of equipment, and pressurised cabins for mobile plant operators. A list of control measures for Respirable Crystalline Silica is provided in Appendix C.

17.3 Ducting and Airflow Regulation

Airflow should be managed using a combination of ducting systems. These include rigid ducting — typically made of steel, fibreglass or HDPE — for main ventilation lines operating under negative

[22] For further information refer to Ventilation During Tunnel Construction Industry Considerations. Air Quality Working Group Information Package 7 of 12 December 2018

[23] Ibid S 1.2.3 Dilution of Contaminants

pressure. Flexible ducting, made of PVC, polyethylene, or coated fabric is generally used for forced air ventilation. In hazardous, flammable, or explosive environments, flameproof and specialised ducting is required.

Airways may consist of shafts or ventilation raises that conduct fresh air from the surface or expel vitiated air from the ventilation system. They can also include service drives or headings.

Airflow can be regulated in several ways. These include adjusting fan settings, using booster or auxiliary fans to increase flow to specific areas, and installing brattice or fabric stoppings and brattice wings to direct airflow as needed.

17.4 Earthing & Bonding of Ventilation System Components

As the movement of dust and gases through a ventilation system can cause a dangerous build-up of static electricity, all ventilation system components should be bonded and earthed and use fire rated anti-static (FRAS) materials[24].

17.5 Repairs, Maintenance and Cleaning

WHS Regulation Section 37 Maintenance of control measures

17.5.1 Testing for Effectiveness

Procedures should outline the process for regularly testing the operation and efficiency of each ventilation system, particularly in long tunnels. The tests should also be used to determine whether the system continues to meet operational requirements, taking account of changes in tunnel length or configuration since the previous check with appropriate modifications made as necessary.

17.5.2 Repairs

PCBUs should undertake regular inspection and maintenance of ventilation systems with any leaks, or damage, or restrictions to airflow remedied as soon as possible.

17.5.3 Replacement of Bag filters and dust collectors

Air filters and collectors including bag filters fitted to drills, engine air intake filters, and particulate filters that have the potential to generate airborne dust during filter replacement or maintenance should be removed and cleaned in a controlled area to prevent the release of dust into the work environment.

Compressed air for cleaning down enclosures during maintenance activities will generate excessive airborne dust and should therefore be avoided. Controls that avoid the use of compressed air for cleaning may include prevention of dust from entering enclosures through design, pressurisation of enclosures and sealing, use of vacuum systems and alternate cleaning methods.

17.6 Alarm Settings and Responses

When alarms are triggered, there should be clear procedures in place to support a prompt and effective response; a Trigger Action Response Plan or TARP. The TARP should provide the project specific criteria for stopping work and evacuation should be clearly defined, understood and communicated as part of overall worksite planning and pre-start procedures.

This should include provision for immediate communication to all affected workers, safe evacuation or relocation to a lower-risk area where required, and investigation of the cause of the alarm by competent personnel. The response protocols should be documented in the project's risk management procedures, tested through regular drills, and reinforced through worker training to ensure alarms are treated as a priority health and safety measure.

In case of Level 2 limit exceedance for oxygen deficiency or the presence of toxic gas, self-rescuers should be put on immediately.

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[24] Refer for example MDG 3608: Non-Metallic Materials for Use in Underground Coal Mines – Fire Resistant and Anti-Static (FRAS) Materials, EN 1366 AS/NZS 1530.3 & AS/NZS 1530.4

Subject to pre-planned protocols that ensure a safe working environment that are regularly reviewed and updated as part of ongoing risk assessment, a two level system of warning may enable interventions or adjustments of the system operation or adjustments within working areas.

Table 17.1 Air Quality Alarm Settings (Refer also Section 18)

Alarm settings and responses		
Level 0 Normal Operation	**Level 1 Alarm (Warning)**	**Level 2 Alarm (Evacuation)**
Maintain required resources for adequate ventilation and monitoring	There is a threat to safety from the atmosphere but it remains safe without donning a self-rescuer and evacuating. Actions should be taken in accordance with the TARP to ascertain the cause of the threat, with respect to the rate of change and to implement pre-planned control measures as required.	There is an atmospheric problem. Tunnel should be evacuated in accordance with the emergency plan that includes locations of refuges and/or places of safety. (Refer S23) Alarm setting exceedances may require self-rescuers to be put on immediately.

All personnel should be within range of visual and/or audible alarms protecting their work area. Consideration should also be given to alarms for personnel who may be traversing the work areas of others.

17.7 Development of Ventilation Control Plans

The requirements and procedures for operating and maintaining a ventilation system should be documented in a site-specific Ventilation Control Plan. This should, at a minimum, address the following matters:

a) the installation of ventilation control devices to manage the supply and distribution of air underground and the procedures used to prevent uncontrolled changes,

b) the development of procedures for the construction, installation, use and maintenance of ventilation control devices,

c) the placement of fans, and provision of devices for fan operation such as measuring or monitoring devices,

d) the maintenance of return airways in a suitable condition so that they are accessible to those who must inspect them or maintain them or travel through them in an emergency,

e) certification and testing requirements for earthing and bonding of the ventilation system,

f) the competencies of workers who design, operate, maintain, or adjust any part or the whole of the ventilation system,

g) the processes that will ensure that only workers with the required competencies operate, maintain, or adjust any part or the whole of the ventilation system in operation,

h) the means by which heat stress conditions will be monitored, reviewed and controlled,

i) reporting procedures relating to proposal and acceptance of necessary changes to the ventilation system,

j) the maintenance and frequency of revision and update of ventilation records and control plans,

k) ensuring that no person enters any area that is not ventilated, unless for the purposes of installing ventilation and only then subject to risk assessment and confined space control procedures,

l) how exposure to airborne pollutants in the atmosphere operation will be controlled, including the provision of sufficient ventilation to dilute harmful dust, airborne particulates and exhaust pollutants (see also Section 13, 14 and 15), This should include a specific drill and blast ventilation control plan if explosves are to be used.

m) control procedures for starting, stopping and adjusting ventilation fans,

n) the levels of methane and other flammable gases at which a detector will activate its alarm and the procedures to be followed when that occurs, (Trigger, Action and Response Plans or TARPs),

o) measures to be taken to monitor and maintain TWL above 140W/m2 (refer Table 5.1) and ensure air velocity is => 0.5m/s,

p) the procedure regarding the action to be taken when monitoring identifies the presence of noxious gases,

q) the criteria for determining that ventilation is inadequate at any underground worksite in relation to the quality, quantity, and velocity of air provided by the ventilation system such that workers must be evacuated from the affected part to an unaffected part or completely from the underground works,

r) the procedures to be followed and the actions to be taken to ensure the safety of workers if the ventilation system fails in part or totally, and

s) the safe withdrawal of workers from the underground to a place of safety when it is necessary to withdraw them from the underground parts under fire emergency or any other circumstances, and

t) how the management system will ensure an alarm is given in the event of failure of critical elements of the ventilation system in relation to minimum operating parameters for health or safety.

18 Airborne Contaminants and Air Quality

s 49 – Ensuring exposure limits for substances and mixtures are not exceeded
s 50 – Monitoring airborne contaminant levels
s 351 Management of risks to health and safety (hazardous chemicals)
s 352 – Review control measures
s 529CE - Monitoring in relation to processing of a Crystalline Silica Substance (CSS) that is high risk (Refer Section 20)

18.1 Overview

PCBUs must eliminate, so far as reasonably practicable, risks to health and safety from hazardous atmospheres. This includes the risk from any ignition sources that may be present in a hazardous atmosphere. Where it is not reasonably practicable to eliminate the risks, they must be minimised so far as is reasonably practicable using the hierarchy of controls.

An atmosphere is a *hazardous atmosphere* if:

- the atmosphere does not have a safe oxygen level,
- the concentration of oxygen in the atmosphere increases the fire risk,
- the concentration of flammable gas, vapour, mist, or fumes exceeds 5 percent of the lower, explosive limit for the gas, vapour, mist or fumes, or
- combustible dust is present in a quantity and form that would result in a hazardous area.

There are also many airborne contaminants in tunnelling work from numerous sources including the:

- generation of dust from breaking or cutting rock and face excavation,
- generation of dust and gases from blasting activities,
- emission of naturally occurring gases e.g., methane, hydrogen sulphide, radon,
- generation of gases (e.g., carbon monoxide, nitrogen dioxide and sulphur dioxide) and fumes or particulate matter from diesel engines and thermal processes such as welding,
- emission of gases or vapours from services or external sources e.g., fuel tanks, sewers, drains, gas pipes and LPG tanks,
- storage or use of hazardous chemicals for ancillary work e.g., water treatment chemicals,
- generation of dust or emission of vapours in any contaminated soil or water.

PCBUs must, so far as reasonably practicable, eliminate the risks to health and safety from exposure to hazardous chemicals and airborne contaminants. Where it is not reasonably practicable to eliminate the risks, they must be minimised so far as is reasonably practicable using the hierarchy of controls. However, no one can be exposed to an airborne contaminant or mixture in a concentration exceeding the exposure limit for the contaminant or mixture.

The hazardous nature of gases in the tunnel atmosphere should be considered, as some are toxic, flammable, potentially explosive, radioactive or asphyxiant while some display a combination of these properties. It should be recognized that the monitoring and control of such gases in a tunnel atmosphere can be difficult because the concentrations rarely remain constant throughout a working day. Due to the nature of tunnelling work, contaminants generated in one area of the tunnel will move to other areas.

There is generally no physiological warning of oxygen depletion. Oxygen-deficient atmospheres can be caused by gas emission, oxygen displacement or the consumption of oxygen by oxidation. Confined spaces, or areas where ventilation is inadequate, are particularly at risk of becoming hazardous due to layering of methane in the roof, or carbon dioxide in the floor. Gases that can cause suffocation are methane, carbon dioxide and nitrogen (blackdamp). Some gases such as methane and nitrogen are not poisonous in themselves but if they occur in sufficient quantity they will displace the oxygen content of the air to a hazardous level. Low concentrations of carbon dioxide are generally not regarded as being hazardous to health, but high concentrations can affect breathing rate.

Naturally occurring flammable gases include methane, hydrogen sulphide and hydrogen. Propane, Butane and Acetylene may be present as part of the construction process due to welding or steel cutting (refer Section 18.6).

Carbon monoxide is flammable under high heat but is more hazardous as a toxic gas (see below) and may be produced by incomplete combustion and decomposition of hydrocarbons.

Carbon monoxide occurs predominantly in the exhaust of diesel engines and in fumes from shotfiring. It also results from burning and welding. Oxides of sulphur and nitrogen (nitric oxide and nitrogen dioxide) also occur in the exhaust from diesel engines and in fumes from shotfiring.

Hydrogen sulphide is colourless and tasteless and has a powerful odour of rotten eggs at low concentrations. Hydrogen may also be given off during charging and discharging of electric storage batteries and also occurs naturally.

Other toxic gases may be present underground in special circumstances:

a) Chlorine, hydrogen chloride, hydrogen cyanide and phosgene may be produced from the combustion of synthetic materials such as PVC belting or refrigerants.
b) Ammonia may derive from explosive use and some types of cement-based grouts and within and emanate from sewer systems.
c) Radon is a radioactive, naturally-occurring, gas that can be desorbed from granitic rocks via groundwater movements and is heavier than air ad so may collect in sumps. Due to its radioactive properties, including the release of ionising radiation it can have long term health effects on people after exposure.

Refer to Safe Work Australia's *Workplace Exposure Standards for Airborne Contaminants* and *Hazardous Substances Information System* for further information.

PCBUs should carry out a risk assessment prior to the start of tunnelling work or using hazardous chemicals. Hazardous chemicals and those that are generated by construction work can be identified by referring to contaminated land assessments, geotechnical reports, product labels and safety data sheets. The risk assessment should identify the type and level of airborne contaminants and hazardous chemicals that workers may be exposed to during various stages of construction. The risk assessment should consider the acute and chronic health effects of exposure, all routes of exposure (inhalation, skin absorption, ingestion) and effects from direct skin or eye contact. PCBUs should involve competent persons in the risk assessment including an Occupational Hygienist and ventilation engineers.

The risk assessment can be used to inform the following:

- the necessary control measures,
- health monitoring requirements,
- air monitoring requirements,
- the level of respiratory protection, if required.

18.2 Use of Combustion Engines (Diesel Plant)

Petrol engines should not be used underground under any circumstances. So far as is reasonably practicable, diesel engine exhaust emissions should be limited to minimise exposure to gases such as compounds of nitrogen and diesel particulate matter (DPM).

As exhaust emissions from diesel engines are sources of risks to health, the use of alternative electrically powered plant and equipment should be considered and risk assessed as part of construction method development prior to designing ventilation systems. If diesel combustion is necessary only lower-emission engines (Tier 4 Final or EU Stage V compliant) should be used. These engines should be in optimum service condition and operated with high quality, low sulphur uncontaminated diesel (see also Section 14).

To control exposure to diesel engine exhaust emissions, ventilation system design should be based on actual emissions, number and type of machines and operating patterns. Ventilation system requirements will depend on:

- the number and power rating of machines and plant used,
- worksite arrangements, working conditions, durations and machine workrates,
- the mechanical condition and emissions from the machines.

Where diesel-powered equipment is used, real-time monitoring of diesel particulate matter should be integrated into the ventilation control system.

18.3 Drill and blast operations

When explosives are used, extraction ventilation for removal of blasting fume and dust is preferable to forced ventilation airflow that entrains dust and combustion compounds into the tunnel. Timing of blasts should take advantage of dispersion of fume and dust during times when the tunnel is unoccupied.

In drill and blast tunnels with extraction ventilation, the first length of rigid duct back from the face is subject to frequent damage and hence should be a sacrificial length to be replaced regularly.

18.4 Methane and Other Flammable Gases

References to methane should be taken to include all flammable gases that can be encountered underground such as ethane, propane, carbon monoxide, hydrogen sulphide and hydrogen.

If there is a foreseeable risk of methane occurrence, the design and construction of the system should take into account the hazard of methane passing through fans and fan motors. As part of any risk assessment the ventilation system should be zoned in accordance with the requirements of AS/NZS 60079 series for explosive atmospheres. The ventilation system should remain operable at concentrations up to 25% LEL in the duct, at which point all tunnelling activity should cease and all personnel should be withdrawn.

If methane or another potentially explosive gas is present, the air supplied should mix and dilute the gas, to levels significantly below the LEL. A nominal airflow velocity of 2.0 m/s is required to prevent layering of methane where it occurs.

18.5 Cooling through ventilation

A sufficient flow of air should be provided to keep the TWL above 140W/m^2 in all working areas (refer Table 5.1)

18.6 Welding fumes and Gases[25]

Refer to Safe Work NSW *Code of Practice Welding Processes* and *Manage the Risks of Hazardous Chemicals in the Workplace*

Whenever possible welding and other hot works should be undertaken at surface.

Propane, butane and acetylene are commonly used for welding. They may form potentially explosive mixtures in air and cylinders containing them and may fail if subjected to heat or impact. A particular risk is that propane and butane are denser than air hence leakage can accumulate in tunnels in sumps drains and confined spaces.

18.7 Chemical Reactions

The use of chemicals such as grouts as part of the tunnelling process may produce toxic or otherwise harmful emissions by themselves or via interaction with the ground being excavated such as estuarine organic soils.

The potential for such chemical interactions or simply release of inherent toxic or harmful gases during excavation should be considered during the planning stages of a tunnel through screening of the geotechnical conditions and suitable materials that may or should not be used as part of the project.

18.8 Air Quality Monitoring

18.8.1 Overview

Air monitoring provides data on the concentration of harmful substances in workplace air. Data from the monitoring system must be stored for the duration of the contract and retained for a minimum of 30 years in accordance with WHS Regulation section 50 (2). Exceedances of the Workplace Exposure Standard must be reported to SafeWork NSW within 14 days, and relevant data may be provided to Safe Work Australia for statistical purposes.

Air monitoring must[26] be carried out to determine the airborne concentration of a substance or mixture at the workplace to which a workplace exposure standard applies if:

- it is not certain on reasonable grounds whether the airborne concentration of the substance or mixture at the workplace exceeds the relevant exposure limit, or
- monitoring is necessary to determine whether there is a risk to health and safety.

A tunnel under construction should have an air monitoring program that is based on a risk assessment.

The Occupational Hygienist should establish and use similar exposure groups (SEGs) based on observations and exposure risk estimates of specific work groups. Logical associations, for example work or function groups, physical location, activity or equipment used should also be considered when establishing SEGs. (Refer Appendix D)

The air monitoring program should be representative of worker numbers, shifts worked, tasks performed and conditions at the workplace and be established in accordance with recognised methods (e.g. EN689:2018 Workplace Exposure - Measurement Of Exposure By Inhalation To Chemical Agents - Strategy For Testing Compliance With Occupational Exposure Limit Values or

[25] Refer to Safe Work NSW Code of Practice Welding Processes and Manage the Risks of Hazardous Chemicals in the Workplace

[26] WHS Regulation section 50

other statistically valid method as outlined in the AIOH Occupational Hygiene Monitoring & Compliance Strategies). Air monitoring should be conducted using sampling equipment that is fit for purpose and maintained to achieve the objectives obtained in the relevant sampling methodology (e.g. *AS2985*) and analysed by a laboratory accredited by the National Association of Testing Authorities (NATA).

18.8.2 Personal air monitoring

Tunnel construction is a dynamic environment where work tasks, locations, and conditions change frequently. The frequency of exposure monitoring to assess worker exposure and verify the effectiveness of controls should reflect this and be documented as part of the planning documents. The repeat frequency for personal air monitoring per SEG during tunnel construction should be determined by an Occupational Hygienist through a risk assessment that considers factors such as the likelihood and potential consequences of exposure.

Air monitoring to determine workers' exposure to airborne contaminants involves measuring the level of the contaminant in the breathing zone of workers using a personal sampler during their usual shift activities including routine breaks. Figure D1 shows an approximation of the workers breathing zone.

Samples that do not meet the minimum sampling or quality requirements are void or invalid and cannot be used for estimating personal exposure. The reason for deciding a sample is void or invalid should be documented. Sampling should be promptly collected for the relevant SEG to replace any void or invalid samples.

Figure 18.1 – Sampling in workers breathing zone

Air monitoring should be undertaken by a person who has acquired the knowledge and skills to carry out the task, from training, qualification or experience. The table below provides a breakdown of air monitoring tasks and who is suitably competent to perform them.

Table 18.1 Air Quality Tasks

Task	Who is qualified to do air monitoring
Plan air monitoring at the workplace (including establishing similar exposure groups and develop a sampling plan)	Occupational Hygienist
Conduct personal exposure monitoring at the workplace	· Occupational Hygienist; · Occupational hygiene technician[27].
Interpreting the results of air monitoring, and drawing conclusions	Occupational Hygienist

Compliance can be demonstrated only when the exposure of individual workers or groups of workers is known, with an accepted degree of certainty, to be below the exposure standard. Where it has been determined that RPE must be worn to minimise the risk of exposure to (an) airborne contaminant(s), the protection provided by the RPE can be taken into account when determining compliance with an exposure standard, provided all other reasonably practicable higher order controls in the hierarchy of control measures have been implemented, and the RPE is worn correctly. This requires that the RPE was worn during the period of exposure, including being fit-tested where close face fitting RPE was utilised.

The person who does the air monitoring and produces the results should include information in the report about if the WEL has been exceeded and recommended next steps.

[27] A person with relevant qualifications and experience under the supervision of an Occupational Hygienist

PCBUs must communicate the results of exposure monitoring to workers. Where the exposure monitoring has been undertaken to determine whether a WEL has been complied with or to determine if there is a risk to health, the records must be kept for 30 years. Results must be provided to anyone on whom personal monitoring has been conducted and to anyone who has been (or might be) exposed. Where the monitoring results exceed the workplace exposure limit the control measures must be reviewed and revised if necessary (cl 352).

Exposure limits are usually set for a standard 40 hour working week, therefore during periods of extended work or overtime that requires working longer than 40 hours in a week, exposure limits must be adjusted. For shorter working days or working weeks, it is not permissible to adjust the exposure limit.

Airborne hazards in tunnelling can occur simultaneously, with workers potentially exposed to RCS, diesel particulate matter, welding fumes, gases and/or other dusts at the same time. These exposures can have additive or combined health effects, meaning the overall risk may be greater than the impact of each substance considered individually. Risk assessments and control programs should evaluate combined exposures and ensure that protective measures are adequate to control the risk to worker health.

18.8.3 Other Monitoring Types

These sampling methods can be used to assist with risk assessments, monitoring and working out the size of exclusion zones. However, they are not suitable substitutes for personal air monitoring as outlined above. (Refer also Section 14.2.10 for RCS)

Static air monitoring

Static (or fixed) sampling can be used to measure area-specific dust or gas levels and identify sources and causes of dust or gas generation. Data collected from static sampling points should not be compared to an exposure standard but can be used to assess the effectiveness of process controls.

Stationary real-time monitoring

Continuous atmospheric monitoring should be undertaken for oxygen concentration along with monitoring for the presence and concentration of all foreseeable atmospheric contaminants such as gases and particulates with instrument locations taking account of the buoyancy of gases as shown in Appendix B.

Static monitoring systems should have multi-level alarm and data logging capability, connected to the tunnel data and communications network. Monitoring stations should normally incorporate an alarm sounder. Portable monitoring instruments should be used to supplement the fixed monitoring network.

For TBM tunnelling, there should be monitoring stations on the TBM. Additional monitoring stations should be provided as necessary. Real time concentrations should be displayed locally at the monitoring station, to machine operators at the access control point to the tunnels and in the site offices.

Portable real-time monitoring

Portable real-time sampling uses a direct reading device to measure concentrations such as dusts, gases or DPM and can be used in conjunction with gravimetric sampling to detect changes in instantaneous concentrations and assessment of the source of dust exposure, the effectiveness of controls and positioning of workers.

PCBUs should use real time portable monitoring to monitor dust levels to detect failures in control measures or changing conditions which allow for a more rapid response e.g. an increase in ventilation airflow. Personal direct reading instruments such as respirable dust monitors and multigas detectors may also be necessary due to the changing work environment.

Continuous atmospheric monitoring should be undertaken for oxygen concentration along with monitoring for the presence and concentration of all airborne contaminants that may create a hazardous atmosphere. Monitoring should be undertaken in real-time by also means of fixed or static monitoring stations. The system should have multi-level alarm and data logging capability. Monitoring stations should be connected to the tunnel data and communications network and incorporate an alarm.

In mechanised tunnelling, there should be monitoring stations on the TBM whilst in conventional tunnelling there should be a monitoring station close to the face. Additional monitoring stations should be provided in all tunnels as necessary. Real time concentrations should be displayed locally at the monitoring station, to the TBM operator, at the access control point to the tunnels and in the site offices. Data from the monitoring system should be stored for the duration of the contract.

After blasting, monitoring should be carried out before workers re-enter the tunnel. The tunnel should be monitored for respirable dust, carbon monoxide, carbon dioxide and nitrogen oxides.

18.9 Reporting compliance and non-compliance

Where the personal air monitoring results exceed the workplace exposure standard the control measures must be reviewed and revised. Controls should be checked to ensure they have been maintained properly and are working as intended.

Over-exposures to any health hazard, including above established workplace exposure limits, should be considered a health and safety incident, so that ‘health’ incidents are considered in the same manner as ‘safety’ incidents and reported to managers with procedures for investigation and root cause analysis and additional controls if required to prevent recurrence.

19 Diesel Plant – Emissions Management

19.1 Engine Selection and Baseline Testing

PCBUs should implement a maintenance strategy that includes establishing a baseline for all diesel engines that will be used underground. A baseline test is an in-vehicle test of a diesel engine system when an engine is in an ‘as new’ or ‘good condition’. This may occur at the introduction to site or may be part of any engine overhaul. The purpose of the test is to establish the nominal engine operating parameters and normal emissions for each engine, taking into consideration the vehicle and its transmission. The test may then be used as a benchmark for deterioration in the emission performance of an engine from the baseline.

The PCBU supplying diesel vehicles/plant should provide this information. The baseline test should include results for:

- engine at load, idle and hi-idle operating condition,
- oxides of nitrogen, carbon monoxide carbon dioxide and diesel particulate matter
- engine speed, inlet, exhaust, and boost pressures,
- engine exhaust flow rate, where practicable,
- raw exhaust and tailpipe emissions.

The maintenance strategy should contain the corrective actions required when unacceptable deviations from the baseline occur based on the manufacturer’s recommendations or the suppliers baseline. All records and test results should be kept in a central emissions database.

19.2 Fuel Quality, Handling and Re-fuelling

Only high-quality, uncontaminated low-sulphur diesel (<10 ppm sulphur) should be used. Fuel storage and transfer systems should prevent contamination from water or particulates.

Wherever practicable re-fuelling should be done above ground. If this is not practicable the handling of diesel fuel in the tunnel should be at locations where spillages can be contained and where ventilation is provided as diesel vapours present both toxic and fire and explosion hazards. Such locations should form part of any zoning assessment under *AS/NZS 60079*.

PCBU’s must establish controls to ensure safety, including workers trained and competent in safe work procedures, spill containment, and emergency procedures, including the use of fire suppression systems and extinguishing equipment.

Some items of plant require cool down periods before refuelling and if required, such plant should be readily identified, systems of work should include suitable cool down times considering the type of plant, its running temperature, length of operation before cooling down, and the ambient temperatures’ effect on cool down times.

19.3 Emissions Control Technologies

Use of diesel engines underground in accordance with Section 19.1 and 19.2 above should also incorporate effective exhaust treatment systems to minimise harmful emissions. These may include technologies such as Diesel Particulate Filters (DPFs), catalytic converters, Diesel Oxidising Catalysts, and Selective Catalytic Reduction (SCR) systems. Any systems that are implemented are to be properly maintained and regularly inspected to ensure continued effectiveness.

19.4 Portable generators

The use of portable diesel generators underground should be minimised wherever possible, as they contribute to both airborne contaminants such as diesel exhaust and increased heat load in the working environment.

Where power supply is required, preference should be given to fixed electrical systems or alternative energy sources that do not generate exhaust emissions. If portable diesel generators must be used, they should be fitted with effective emission controls, located in well-ventilated areas, and operated in a way that minimises worker exposure to exhaust gases and particulates. Consultation with the ventilation engineer must take place to ensure that appropriate airflow and extraction systems are in place to manage emissions and protect worker health.

19.5 Operational Controls

Operators should be required to minimize idling, avoid unnecessary acceleration, implement engine shut-off policies during idle periods and report engine performance issues.

19.6 Maintenance and Monitoring

PCBU's should develop a preventive maintenance schedule based on baseline data, monitor emissions regularly and take corrective action when deviations occur and keep detailed records for compliance and performance tracking.

Monitoring diesel exhaust emissions should occur at the manifold prior to any emission control measures and then at the tail pipe. Tail pipe raw exhaust emissions from a diesel engine should never exceed 1100 ppm of carbon monoxide or 750 ppm of oxides of nitrogen, at either load, high idle or idle. If emissions exceed these values, then the engine should be placed out of service for maintenance or repair at the earliest opportunity.

20 Respirable Crystalline Silica (RCS) Dust

20.1 Overview

Dust and in particular RCS is a significant health hazard for workers in NSW. A person is exposed to RCS whenever the RCS is airborne and the person can breathe it in. When airborne, workers can breathe RCS particles deep into their lungs where they can lead to a range of respiratory diseases.

WHS Regulation 529A (2) defines a Crystalline Silica Substance (CSS) as a material containing at least 1% crystalline silica (by weight). This definition includes almost all natural ground found in NSW, as well as all concrete and other cementitious products.

WHS Regulation 529CA defines high risk, in relation to the processing of (CSS) as the processing of a CSS that is reasonably likely to result in a risk to the health of a person at the workplace and also defines processing in this context as:

- 'the use of power tools or mechanical plant to carry out an activity involving the crushing, cutting, grinding, trimming, sanding, abrasive polishing or drilling of a CSS,
- the use of roadheaders involving material that is a CSS,
- quarrying involving material that is a CSS,
- mechanical screening involving material that is a CSS,
- tunnelling involving material that is a CSS, or
- a process that exposes, or is reasonably likely to expose, a person to RCS during manufacture or handling of a CSS (for example cleaning and maintenance processes such as sweeping that may disturb settled RCS).'

There are many sources of RCS in tunnelling such as:

- when rock or concrete is broken, drilled, cut or blasted or wherever ground is disturbed,
- when rock cutting with road headers or TBMs,
- when loading broken rock at the face,
- when transporting spoil on conveyor belts,
- when working at spoil transfer points,
- installing or removing ventilation ducts,
- concreting and shotcreting, spraying and handling bagged ingredients,
- moving plant,
- loading out spoil.

PCBU's should assess, monitor and control exposure to RCS using the following steps as outlined in the Occupational Hygiene Management Plan (refer Section 5):

- Potential sources of silica dust generation should be identified in all areas of the construction site, during demolition, construction and fit-out.
- Development of a response plan for the purpose of mitigating personal exposure when dust controls are non-compliant.
- Discussion of the effectiveness of dust control measures into pre-start shift meetings.
- Systematic review and continuous oversight of the effectiveness of controls by competent ventilation engineers and occupational hygienists.
- Only using competent personnel to inspect, maintain, and monitor controls and equipment.

20.2 Controlling Exposure

S. 529C - PCBU must not carry out, or direct or allow a worker to carry out, processing of a CSS unless the processing is controlled.

S. 529B – The processing of a CSS is controlled if:

(a) control measures to eliminate or minimise risks arising from the processing are implemented so far as is reasonably practicable; and

(b) at least 1 of the following measures are used during the processing:

(i) the isolation of a person from dust exposure,

(ii) a fully enclosed operator cabin fitted with a high efficiency air filtration system,

(iii) an effective wet dust suppression method,

(iv) an effective on-tool extraction system,

(v) an effective local exhaust ventilation system, and

(c) a person still at risk of being exposed to respirable crystalline silica after 1 or more of the measures in paragraph (b) are used:

(i) is provided with respiratory protective equipment, and

(ii) wears the RPE while the work is carried out.

20.2.1 Planning

The most effective way to prevent silica-related disease is to eliminate exposure. This requires careful planning to avoid generating dust wherever practicable. By addressing RCS risks during health and safety in design processes, tunnelling projects can substantially reduce dust at the source and avoid over-reliance on downstream administrative measures and PPE.

Examples of control measures that should be considered during the design and planning phase include:

- Designing cast-in systems (such as channels) into precast tunnel lining to allow anchor installation, thereby removing the need for manual or automated drilling into the lining after it is installed.
- Automating drilling operations through using drilling robots fitted with on-tool HEPA extraction, rather than through hand-held drilling.
- Substitution of high-crystalline silica containing substances with those that contain no or low crystalline silica (e.g. no or low-silica grout,)
- Designing excavation sequences, plant and equipment to minimise worker exposure to dust. This should include an assessment of the interaction between method, dust generation sources, ventilation systems and other engineering and administrative controls including remote operation of excavation plant and equipment as this allows the operator to work from an enclosure. Any changes to the sequence, plant or equipment which results in a reduction in dust control effectiveness (including dust suppression or maintenance issues) should be avoided wherever practicable.
- Temporary roadways for underground plant movements have considerable potential to re-mobilise dust generated by preceding activities. Accordingly, the type of plant used, and the required frequency of plant movement should be assessed as part of planning for construction logistics, spoil and personnel transport systems and tunnel construction method options. This may for example favour the use of conveyors instead of wheel-based plant for many health and safety risk management reasons not just RCS control. However, where conveyors are not practicable sealing temporary road surfaces underground can minimise dust remobilisation when used with water sprinkler dust suppression systems and should be

adopted subject to development of suitable systems of collection and control of drainage run off.

20.2.2 Worker Enclosures

Enclosed cabins on mobile plant isolate workers from air that is contaminated with airborne particles. Protection against dusts and RCS depends on the effectiveness of filters, internal contamination of the cabin combined with the integrity of the seals for all openings of the enclosure.

All enclosed cabins should be engineered with filtration systems with sufficient sealing capacity to achieve positive pressurisation against contaminant penetration. *AS/NZS ISO 23875* sets minimum standards for:

- pressurization of cabins to prevent ingress of contaminants,
- control of respirable particulate matter,
- monitoring and control of carbon dioxide (CO_2) concentrations.

Where the emission of RCS arises from the operation of an excavator, road header or other machine, the operator of that machine should be protected by a cab that meets the requirements of *AS/NZS ISO 23875*. A lower level of protection may be used if an Occupational Hygienist, in consultation with management and workers, determines through a risk assessment that it is suitable.

The principles of *AS/NZS ISO 23875* may also be applied to underground spaces such as crib rooms and respite stations to control airborne contaminants, including RCS. This includes HEPA filtration, positive pressurisation and associated pressure monitoring, and continuous air quality monitoring. Workers should have access to respite areas underground where they can safely remove their RPE to eat and drink water.

Seats and other soft furnishings in tunnelling plant and equipment should have impervious materials, or be fitted with plastic covers, as fabric surfaces can harbour dust, including RCS and other contaminants. Fabric is difficult to clean effectively and can release dust back into the air when disturbed, increasing the risk of worker exposure. Impervious materials and plastic covers are easier to clean, allow for regular decontamination, and reduce the accumulation and re-suspension of hazardous dusts.

Operating procedures for underground excavation work should incorporate requirements for operatives to allow sufficient time for external dust extraction systems to remove airborne dust from the work area before exiting any enclosure. Emergency evacuation considerations also need to be considered.

20.2.3 Dust suppression

Dust suppression involves the wetting of airborne contaminants such that the weight of each airborne particle increases, thus decreasing its ability to remain in the air. Droplet size is considered the most critical when selecting wet dust suppression systems.

Fixed dust suppression sprays should be installed where dusts may be generated, such as:

- on transfer points of conveyor systems, where materials drop on to other conveyor belts,
- within buildings such as structures designed to house the storage and transport of spoil,
- within tunnels to minimise disturbance of deposited dust located in the tunnel invert as a result of tunnel traffic movement (e.g. misting water spray bars).

Other uses of dust suppression include:

- wet drilling,
- integrating dust suppression on mobile plant that generate dust – for example, breakers, hammers, saws,
- wetting spoil heaps after blasting and while loading,

- wetting muck piles,
- using water carts to wet down roadways,
- washing down cutting picks prior to changing out,
- washing down vent cans prior to relocation,
- washing down walkways and stairs regularly,
- washing down the TBM regularly.

20.2.4 On-tool dust suppression and extraction

Power tools generating RCS must be fitted with effective dust suppression, on-tool extraction and collection, or used with an effective local exhaust ventilation system. Dust extractors/vacuums used with power tools should meet the M- or H- class requirements of *AS/NZS 60335.2.69:2017* and used in accordance with manufacturer's instructions.

20.2.5 Work scheduling

Workers may be exposed to RCS either directly from tasks they are performing, or indirectly from nearby activities, such as being positioned upwind of dust-generating work. These secondary exposures are harder to control because the affected workers have no direct influence over the source of contamination.

Activities known to generate significant airborne contamination should, where possible, be scheduled at times when the fewest workers are present, and when the least number of workers are likely to be exposed to secondary contamination.

When planning work that generates airborne contaminants, the following principles should be applied:

i. Assign the smallest number of workers necessary to complete the task safely.

ii. Rotate workers within crews to reduce the duration of individual exposures.

iii. Reschedule nearby work to prevent secondary exposures.

20.2.6 Housekeeping

RCS can settle on floors, equipment, and workers' clothing, from where it can easily become airborne and inhaled. Regular cleaning is crucial to prevent dust build-up. This includes cleaning floors, walls, scaffolds, plant, tools, vehicle cabins, common areas, and walkways as often as required.

Cleaning should be performed using wet methods (such as wet-vac, damp cloths, hosing down), or with class M or H vacuums.

Dust extractors/vacuums should undergo annual testing to ensure it maintains H-Class or M-Class certification. All H- and M-Class extractors/vacuums should be maintained on a register to ensure compliance to annual servicing and testing conducted by an approved certified third party.

Dry sweeping, using compressed air or blowers, or high-pressure water blasters should not be used to remove dusts that may contain RCS.

Laundry facilities should be provided to tunnelling and excavation workers. Laundry facilities reduce the potential for cross contamination of dust into other areas. Facilities should be assessed by occupational hygienists and staffed by trained personnel.

20.2.7 Exclusion zones

Dust control zones may be used to isolate high dust exposure areas with specific safe work procedures required for workers to enter designated dust control zones. Access should be subject to entry control procedures such that access is restricted during high dust activities such as mining, shotcreting, and overhead drilling for example.

20.2.8 Control measures relevant to conventional tunnelling

Mined tunnelling activities present the highest risk of worker exposure to RCS. Effective dust control requires careful planning and the consistent application of engineering, isolation, administrative and PPE measures across excavation, support and spoil handling.

Ventilation and dilution with fresh air are critical controls, (refer Section 17 and 18 above) and sufficient fresh air must be supplied in accordance with project-specific ventilation plans.

Extraction systems such as scrubbers should be advanced prior to cutting to support effective dust removal and prevent rollback over the operator's cabin, with placement at the front of the roadheader to avoid dust engulfing the cabin.

Ventilation ducting, fans and vent bags should be regularly inspected and maintained, and shutdown procedures implemented to prevent dust accumulation in the event of fan stoppage.

Substitution methods, such as using remote-controlled equipment for breaking or cutting, should be adopted where practicable.

Isolation controls are also essential, including maintaining positive pressure in work areas and operator cabs, installing brattice with dedicated ventilation to prevent secondary exposures, and cabins meeting the requirements of *AS/NZS ISO 23875*. Cabins should be cleaned using wet methods or HEPA-filtered vacuums.

Dust suppression and extraction systems should be fitted to roadheaders, excavators and other dust-generating tools, targeting both the cutting head and rear tail conveyor, and roadway dust should be suppressed through regular wetting by water carts.

Where blow piping or blinding is necessary, dual compressed air–water systems should be used.

Work sequencing should minimise worker presence in dusty areas and avoid overlapping activities that increase secondary exposure, supported by adequate supervision to ensure all dust controls are applied correctly and consistently.

20.2.9 Control measures relevant to TBM tunnelling

Careful consideration of RCS controls is required at the design stage of a TBM project. The design of a TBM should minimise the need for retrofitting by ensuring the TBM can effectively supply fresh air and extract contaminated air containing RCS. Ventilation systems should be engineered to capture and remove dust at the point of generation, maintain sufficient airflow throughout the tunnel, and protect workers both inside the TBM and along the tunnel alignment.

The design should also provide areas on the TBM, such as the operator's cabin and crib rooms, where RPE can be safely removed. These areas are likely to require HEPA filtration, positive pressure, and continuous air quality monitoring to enable the removal of RPE.

Regular washdowns of the TBM and other machinery using a hand-held hose should be carried out to prevent the accumulation of dust and debris.

Following each TBM breakthrough, and before any maintenance work begins, the TBM should be washed down to reduce the risk of worker exposure to dust that may be released when deposits are disturbed.

Where compressed air use on crystalline silica substances cannot be reasonably avoided, such as at the TBM Quick Unloader area, compressed air and water may be used to clean dust and debris from segments to ensure safe operation of the vacuum lifter. To minimise airborne RCS, segments should be hosed down with water before compressed air is applied, and appropriate extraction ventilation and RPE should be provided.

20.2.10 Real time air quality monitoring for RCS

Real-time or direct-reading monitoring devices provide continuous measurement of dust levels, offering immediate feedback on worker exposures and the effectiveness of control measures. Because respirable dust and RCS particles are so small that they are invisible to the naked eye, these devices are useful for detecting exposure risks that workers cannot see. These devices allow for early identification of high exposure tasks, activities, or work areas and support timely intervention to prevent over-exposure. While they are not a substitute for compliance sampling, direct-reading monitoring devices are a valuable tool for managing dust risks in tunnelling, particularly when used alongside personal monitoring. Their use should be incorporated into dust control programs to verify the performance of engineering controls, guide work practices, and provide workers with greater awareness of dust exposure in real time.

When real-time monitoring is used, the results do not typically specifically reflect RCS levels. To estimate RCS exposure, a correction factor is applied to the respirable dust fraction based on the proportion of RCS in the dust. The correction factor applied in real-time dust monitoring should be specific to the material and task. For example, a Safety Data Sheet for concrete may indicate it contains 30 per cent crystalline silica, which would be used as the minimum correction factor when cutting into that product. For natural materials such as sandstone or shale, crystalline silica content may need to be obtained from geotechnical reports. Where multiple sources of silica dust are present, the highest proportion of crystalline silica is typically applied. Previous exposure data collected by the occupational hygienist for similar work activities can also help determine an appropriate correction factor. The Certified Occupational Hygienist should determine and document the correction factor(s) used.

Typical activities where real time monitoring is used include:

- after blasting, to determine when it is safe for workers to re-enter the tunnel,
- during workplace inspections to detect if control measures are operating as designed,

during personal air monitoring to identify high exposure tasks.

20.3 Health monitoring

Under section 529CE(c) and in accordance with Part 7.1 Division 6, a PCBU must provide health monitoring for all workers involved in high-risk CSS processing, including tunnelling and shaft construction. Under Schedule 14 Table 14.1 of the WHS Regulation the minimum requirements for health monitoring for crystalline silica are:

- demographic, medical and occupational history,
- records of personal exposure,
- standardised respiratory questionnaire,
- standardised respiratory function test (e.g. FEV1, FVC and FEV1/FVC),
- chest X-ray full size PA view.

All full size PA chest x-rays should be taken and read consistent with ILO guidelines by a B reader or a radiologist trained under Royal Australian and New Zealand College of Radiologists approved training equivalent to the B Reader accreditation. A B-reader is a radiologist trained to detect dust lung diseases such as silicosis, coal workers' pneumoconiosis, mixed dust pneumoconiosis and progressive massive fibrosis.

All lung function tests should be performed according to the Thoracic Society of Australia and New Zealand (TSANZ).

Safe Work Australia's Crystalline silica health monitoring guide provides further information on frequency of chest X-rays.

High-resolution computed tomography (HRCT) has been demonstrated to be more sensitive than X-rays in detecting early dust lung disease. Use of a HRCT scan of the chest may be considered instead of a chest X-ray depending on the worker's history and levels of exposure.

21 Incident Response

Part 3 of the WHS Act,

WHS Act, Section 35

What is a “notifiable incident”

WHS Act Section 38

Duty to notify of notifiable incidents

21.1 Incident Response and Notification

All serious incidents, regardless of severity, should be responded to promptly to ensure the safety of all personnel. Immediate actions should include securing the site, providing first aid, and preventing further harm. A designated incident controller should coordinate the response and ensure communication with emergency services if required.

Under Section 35 of the WHS Act, a 'notifiable incident' includes:

- The death of a person.
- A serious injury or illness.
- A dangerous incident that exposes someone to serious risk.

Section 38 of the WHS Act requires that notifiable incidents must be reported to SafeWork NSW.

You must take care not to disturb the incident scene until an inspector arrives at the site, or until direction is given by an inspector. You can help an injured person and ensure safety of the site.

The incident must also be reported to the workers compensation insurer within 48 hours.

21.2 Record Keeping

A register of injuries must be maintained and accessible to all workers. The register must include details such as the name of the injured person, date and time of the incident, nature and cause of the injury. All incident investigations and corrective actions should be documented and retained.

21.3 Reporting Non-Compliance

Any breach of safety procedures or regulatory requirements should be reported to the site supervisor or safety officer. Reports should be investigated and addressed through corrective actions to prevent recurrence. Workers should be encouraged to report hazards or unsafe behaviours without fear of reprisal.

22 Emergency planning and preparedness

22.1 Preparation and Maintenance of the Emergency Plan

Under section 43 of of the Work Health and Safety Regulation 2025 Duty to Prepare, Maintain and Implement Emergency Plan, a PCBU must prepare an emergency plan for the workplace that includes:

- Emergency procedures, such as:
  - Effective response to emergencies,
  - Evacuation procedures,
  - Notifying emergency services promptly,
  - Medical treatment and assistance,
  - Communication between the emergency coordinator and all persons at the workplace.
- Testing of emergency procedures (including frequency).
- Information, training, and instruction for relevant workers.

Maintain the emergency plan so it remains effective.

Consider relevant factors, including:

- Nature of the work and hazards.
- Size and location of the workplace.
- Number and composition of workers and others present.

Implement the emergency plan in the event of an actual emergency.

Where a workplace is shared by multiple duty holders the emergency plan must be developed through consultation and cooperation with all relevant parties, including workers. The person with management or control of the workplace, typically the principal contractor, should coordinate this consultation process that should include emergency services.

A site-specific Emergency Management Plan (EMP) should be developed as part of the Safety Management System. This should

- Identify potential emergencies and define response strategies.
- Ensure the EMP is accessible to all workers and emergency services.
- Regularly review and update the EMP based on operational changes or incidents.

An emergency plan must provide for emergency procedures including:

- an effective response to an emergency,
- evacuation procedures,
- notifying emergency service organisations at the earliest opportunity,
- medical treatment and help,
- effective communication,
- testing emergency procedures including the frequency of testing, and
- information, training and instruction to relevant workers about implementing the emergency procedures.

All types of emergency and rescue scenarios should be considered when developing emergency procedures. Information from a risk assessment will help in this task and will depend on control measures implemented. Table 23.1 sets out some questions to consider when establishing emergency procedures.

Table 22.1 Developing emergency procedures

Issue	Considerations
Coverage of plan	How will the safety of people at the workplace including visitors or people who need help to evacuate in an emergency, be considered in the plan?
Emergency Events	What emergencies could happen? What control measures can be implemented to reduce the severity of the emergency? What equipment will be needed to identify and manage emergencies? What specific elements and procedures should be included to maintain critical functions?
Evacuations	What situation or circumstances should trigger an evacuation? How will the controlled evacuation of people from the workplace be handled? Are the personnel underground trained in the emergency evacuation procedures? When was the last emergency evacuation drill undertaken? Are there any lessons learned from previous drills that need to be incorporated into the procedures?
Workplace location	Is the work carried out in a remote or isolated place? How accessible is it in an emergency and how far away is it from medical facilities? Can a person be rescued immediately without relying on emergency services? Are there areas where special emergency provisions and the means to extract people from difficult locations like the base of a shaft needed? Have safe places and assembly points been identified?
Escape routes	Refer Table 23.3 lists questions and information on escape routes.
Roles and responsibilities	Who should be allocated roles and responsibilities in an emergency e.g. area wardens? Who has the relevant skills for specific actions in an emergency?
Training	Who requires regular and on-going training? When should this be provided? Does the training include an understanding of the emergency plan and actions to be taken in an emergency, escape options and emergency equipment? How will workers who enter the tunnel be trained in entrapped procedures, like remaining calm, alert and making conservative decisions?
Communication	How: - can workers doing tunnelling work communicate in an emergency - will clear lines of communication between the person authorised to co-ordinate the emergency response and people at the workplace be maintained, and - will alarms be activated and who will notify people at the workplace? Is there a system in place to identify who is underground, like tag boards or electronic tagging? Have you clearly displayed the workplace site plan showing where

	fire protection equipment is stored, the location of emergency exits, assembly points and emergency phone numbers?
Rescue equipment	Has rescue equipment been selected based on the nature of the work and the control measures used? Can it carry out the planned emergency procedures? Is rescue equipment kept close to the work area so it can be used quickly?
Capabilities of rescuers	Are rescuers properly trained, fit to carry out their task and capable of using rescue equipment? Have emergency procedures been tested to demonstrate they are effective?
First aid	Is first aid available for injuries associated with falls, cuts and crush injuries? Are trained first aiders available to use the equipment?
Consulting, cooperating and coordinating with local emergency services	Are the emergency procedures co-ordinated with local emergency services? If not, why? Does the emergency plan include the emergency services involvement in a trial rescue early in the construction? How will the local emergency services be notified of an incident? Can you ensure that the necessary accurate information is available to emergency services if needed?
Administration, maintenance and review	Does the emergency plan contain instructions on how it is to be administered, maintained and reviewed and how workers will be involved in these reviews?

Once established, a Competent person should report to the Client Organisation at intervals to be reviewed and justified by risk assessment, on the measures in place for the prevention and management of emergency events such as fires and explosions; flooding; chemical release; gassing; or engineering emergencies and the circumstances under which evacuation is required such as the failure of critical safety systems.

22.2 Escape and Rescue

Rescue procedures including the circumstances for self-rescue and where rescue will be assisted should be described in detail in the emergency plan and be practiced by workers. There should be sufficient equipment and infrastructure to accommodate the maximum number of people who may at risk in an emergency. Further considerations are provided in Table 23.2 below.

Table 23.2 Escape Route Planning

Issue	Considerations
Identifying escape routes	Have all: • possible escape routes like parallel tunnels, shafts or other connections to the surface been identified? • escape routes been clearly marked? • escape routes that maintain fresh air flow during a fire emergency been identified? Have you considered control measures to ensure the integrity of escape routes or safe places in an emergency? Are escape routes dimensions suitable for stretchers and rescue teams? What is the impact of low visibility during an emergency? Should there be strategic placement of lighting, ropes or chains to guide workers?

Securing an immediate supply of respirable air and SCSRs	How will an immediate supply of emergency respirable air for workers be provided and maintained for the duration of the emergency, or that will enable self-rescue? When developing escape routes while using SCSRs have you assessed how far a person, in a reasonable state of physical fitness, can travel?
Refuge chambers (See Section 19.3 above)	An underground refuge chamber provides a safe place for people if the atmosphere becomes unbreathable. When choosing where to put a refuge chamber and how many to put in, have you taken into account: • the risks from the work activities? • how long it will take workers to get to the chamber from where they are working? • whether it can fit everyone in and is there an effective communication system inside? • how long the air will last based on a risk assessment? Does the risk assessment take into account types of emergencies e.g. fire as well as equipment, accessibility, alternative air supplies and how long it takes to get to safety?
Vehicles and plant in the tunnel	How: • have the risks from vehicles and plant contributing to an emergency been addressed in the emergency plan? • will workers be provided with information, instruction and training for operating plant to keep escape routes and emergency entry clear?
Escape route signage	Are emergency escape route signs legible and understood[28]? Further information on signage maintenance and marking is in AS 1319-1994: Safety signs for the occupational environment.

22.3 Alternative personnel egress

A secondary means of egress from the underground works should be provided in case the primary method becomes unavailable, e.g. a ladder, a second crane or a purpose-built emergency egress device such as a winch and davit system.

22.4 Injured persons

A suitable means should be provided for hoisting injured persons from any shaft.

22.5 Refuges and Changeover Stations

An assessment must be made on the location of refuges including travel distances from any place of work, escape route gradients / staircases / scaffold egress, distances of inbye workings relative to the shaft or surface portal, heat/humidity, physical limitations of individuals and incident characteristics. As the provision of refuge chambers is more difficult in smaller diameter tunnels due to spatial constraints an assessment of refuge chambers and emergency egress procedures should be undertaken as part of the safety in design risk assessment during tunnel feasibility studies.

[28] Further information on signage maintenance and marking is in AS 1319-1994: Safety signs for the occupational environment.

23 Fire and Smoke Control

23.1 Overview

The consequences from underground fires are more serious than for similar fires on the surface.

Fire underground rapidly consumes oxygen and produces noxious fumes and gases making an atmosphere irrespirable. Any fire will produce smoke that will reduce and may eliminate visibility and hinder egress by blocking exit pathways.

As with any risk, fire and smoke control should begin with risk elimination where possible. However, effective control measures typically include the following:

- Controlling the availability of fuel and combustible materials, e.g., non-flammable hydraulic oils, fire-resistant belt conveyors, etc.
- Controlling the sources of ignition and paying attention to concentrated energy sources and electrical installations.
- Regular and routine inspections of fixed installations and plant.
- As all plant and equipment used underground constitutes a major source of both fuel and potential source of ignition, the use of fire-hardened underground plant (approved for site use) with fixed fire suppression systems.
- Use of control procedures such as ‘hot works’ permits.
- Maintenance of fire control systems and equipment.
- Monitoring and assessment, especially gas monitoring to detect hazardous atmospheres.
- Risk assessments by competent fire engineering specialists.
- Establishing clear and co-ordinated emergency procedures (refer Section 23).

The following table outline considerations, questions, hazards, risks, and control measures related to fire and explosion safety.

Issue	Considerations
Combustible materials and sources of ignition	• What are the potential ignition sources? • How can the volume of combustible and flammable materials, such as from waste be minimised? • Has a hot work permit been issued? • Is all electrical equipment tagged for use? • Is all diesel plant maintained and suppression systems functioning correctly? • Are there sources of static electricity? • Is smoking and vaping prohibited on site? If not, why not? • Are sources of ignition such as lighters considered contraband? If not, why not?
Fire-fighting facilities	What fire-fighting equipment should be available. Who is competent to use it, and where should it be located?
Training	How will training upon basic awareness of fire hazards and fire prevention be delivered? Does the training include: - the selection and use of extinguishers - when and how to use self-rescuers and their limitations - safe use of refuge chambers if present?

23.2 Hot Works and Fire Watches

There is a high risk of fire associated with welding and cutting (including disc cutters and so whenever possible, welding and cutting should be undertaken at the surface or cold processes should be adopted underground.

Welding, the process of permanently joining two or more materials together by heat or pressure or both, is a potentially hazardous activity and precautions are required to avoid electrocution, fire and explosion, burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation (Source: SafeWork NSW Code of Practice – *Welding processes*).

The identification of reasonably foreseeable hazards that could give rise to health and safety risks should be conducted by a team of knowledgeable and competent personnel, including those who have demonstrable knowledge, experience and skills in facilitating risk assessments and personnel who have subject matter expertise in the hot-work related activity such as welding or cutting.

Different hot works processes also influence the risk. For example, the risk of electric shock is lower using gas metal arc welding (GMAW) than manual metal arc welding based on the fact that the open circuit voltages are lower, only direct current is used and the power is switched off at the hand piece.

A "permit to work" system should apply to any underground welding or cutting (a 'hot works' permit). This should specify the conditions for storage, transport and use of equipment, the fire precautions required and the impact of the hot work on the safety of others in the vicinity. The system should also cover the return of the equipment to surface storage, have specific dates, as an open-ended permit can be abused.

A hot work permit is a written authority issued by an authorised worker (not the worker performing the work). The following need to be checked prior to issuing the permit:

- flammable atmosphere, gases and dusts;
- flammable and combustible materials;
- access and egress locations;
- adequate ventilation; and
- suitable fire-fighting equipment, making sure it is available and tested prior to hot work being undertaken.

There may be a need to develop specific procedures for welding or cutting in a hazardous atmosphere or hazardous area. For example, the WHS Regulations requires a 'confined spaces entry permit' for work in a confined space. When welding in an area that is not a confined space, specific procedures should still be documented, including ensuring that all activities are covered by a relevant SWMS.

A fire watcher must be in attendance whenever a hot work permit has been issued. Responsibilities of the fire watcher include continuously monitoring the area during hot work, remaining on site for at least 30 minutes after completion of the hot work and ensuring the correct fire-fighting equipment is present and accessible throughout the hot work duration.

24 Use of Personal Protective Equipment

S. 44 – Provision to workers and use of personal protective equipment

24.1 Overview

PPE should not be relied on as the only way to eliminate or minimise risk. It should only be used in conjunction with other control measures to further minimise risks. When and how to use PPE should be specified in a site specific safety management plan. PPE should be regularly inspected, maintained and replaced as necessary. It should fit and be comfortable for the worker wearing or using it. Users should be instructed in the correct use of PPE and its use should be supervised. Facilities for cleaning and storing PPE should be provided. Maintenance including cleaning and/or replacement should be managed with records kept. Respiratory Protective Equipment (RPE) should be considered only after all other higher-order control measures have been evaluated and applied (refer 25.6 below).

24.2 Head protection

All persons on site should wear suitable head protection at all times in accordance with *AS/NZS 1801: Occupational protective helmets* and *AS/NZS 1800:1998: Occupational protective helmets – Selection, care and use.*

24.3 Foot protection

Footwear should be worn at all times in accordance with *AS/NZS 2210.1: Safety, protective and occupational footwear.*

24.4 Hand protection

Gloves should be worn where a person is at risk from cuts, abrasions or puncture injuries in accordance with *AS/ NZS 216: Occupational protective gloves*. Pre-work (barrier) creams should be made available and used by site personnel. Moisturisers and adequate facilities for good skin hygiene should also be provided.

24.5 Eye protection

Where eye protection is required to be worn throughout the working shift, optical quality lenses should be used. Prescription glasses should be provided for users who routinely wear spectacles.

Safety goggles, face shields and fixed shields conforming should be worn by site personnel whenever there is a foreseeable risk of facial injury. This includes pressurized air and water cleaning, spraying concrete, grinding or chipping, metal cutting, grout mixing and placing, breaking, cutting or drilling concrete or stone or similar material, and by persons handling or injecting hazardous liquids under pressure. For protection whilst burning and welding, additional protection should be used.

24.6 Respiratory protection

Like any other PPE, respiratory protective equipment (RPE) should be used when all other control measures for airborne contaminants under the hierarchy of controls have been applied. RPE is the lowest form of control for airborne contaminants and is not always reliable in practice. Tunnel worker over-exposures to airborne contaminants such as RCS have occurred due to the absence of fit testing, interference from facial hair, and the use of RPE with insufficient protection factors.

Where respiratory protective equipment is used to minimise the risk to health and safety the PCBU providing the RPE must ensure that the equipment is:

a) suitable regarding the nature of the work and any hazard associated with the work,

b) of a suitable size, fit and comfort for the worker,

c) clean and hygienic,

d) in good working order.

PCBUs should select RPE that is manufactured in accordance with *AS/NZS 1716: 2012 Respiratory Protective Device* or equivalent international standards. This is to ensure that the RPE is suitable for the nature of the work and any associated hazards. Other factors that must be considered when selecting and using RPE include whether the worker has facial hair, comfort, fit and compatibility with other personal protective equipment.

An adequate face seal is required to prevent contaminants leaking into the respirator, and workers must be clean shaven if their facial hair will interfere with the face seal. Otherwise, workers with facial hair can be provided with loose fitting head top powered air purifying respirators which do not rely on a close-fitting face seal.

Quantitative fit testing should be carried out by a competent person (e.g., a RESP-FIT accredited Fit Tester) to ensure workers can achieve an adequate face seal with close fitting facepieces (also referred to as masks). Fit testing should be carried out before the respirator is used and then annually, or as soon as practicable if the wearer's facial features change which affect the face seal. The assessment and determination of requirements for and selection of RPE for each task and SEG should be carried out under the supervision of an Occupational Hygienist.

Underground workers should be provided with RPE that has a minimum protection factor of 50, with a powered air purifying respirator (PAPR) with particulate filters unless a risk assessment involving an Occupational Hygienist determines that a lower level of protection is appropriate.

When selecting RPE, PCBUs must take into account the need for workers to communicate effectively. RPE can affect a worker's ability to speak, hear, or be heard, which may create additional risks, particularly in high-noise or safety-critical environments such as tunnelling. Selection should therefore prioritise RPE that maintains both protection and communication, for example through designs that minimise speech interference or by incorporating compatible communication systems

Control procedures for charging (as required), storage, maintenance and repair facilities for RPE should be developed.

Respiratory protective equipment should be used in accordance with *AS/NZS 1715 Selection, use and maintenance of respiratory protective equipment* and *AS/NZS 1716 Respiratory protective devices*.

Refer also Safe Work Australia's *Working with crystalline silica substances Guidance for PCBUs*.

24.7 Hearing protection

Personal hearing protectors should be selected and maintained in accordance with *AS/NZS 1269.3:2005: Occupational noise management – Hearing protector program*. You should involve your workers in the selection process and offer a reasonable choice from a range of types.

When workers are required to wear both hearing protection and RPE, the two must be compatible. Poorly matched equipment can reduce the effectiveness of the respirator seal or the hearing protector's attenuation. It is equally important that workers are still able to communicate clearly and hear warning signals while using both. Where possible, integrated solutions or compatible systems should be selected to ensure protection is maintained without reducing operational effectiveness.

Refer to the Safe Work Australia *Code of Practice Managing noise and preventing hearing loss at work*.

24.8 Whole-body protection

Any person working underground should wear flame retardant clothing. Additional protective clothing should be provided and used where appropriate to the risk, for example in excessively wet conditions, when burning or welding, when handling hazardous substances or working in contaminated ground. High visibility requirements should be in accordance with *AS/ NZS 4602.1: High visibility safety garments – Garments for high risk applications.*

24.9 Self-rescuers

Everyone working or visiting underground should be trained in the use of self-rescuers (see 7.2).

Where there is a foreseeable risk of smoke, fire, or toxic gas and where safe egress conditions cannot be assured before the onset of an Irrespirable Atmosphere, then all persons underground should have immediate access to an oxygen self-rescuer.

If the nature of the work is such that carrying a self-rescuer incurs a risk due to a confined working area then the rescuer can be located at a suitable place within easy reach of the operative's work station. Workers should be cognisant of the location of the supply of SCSR's at all times if they are not being carried. The location of the SCSR's and whether they are to be carried or not should be determined by risk assessment in consultation with workers and re-evaluated during pre-start meetings.

A self-rescuer should provide the user with a supply of oxygen for at least 30 min nominal duration while walking. Where such oxygen supplies are likely to be needed for longer periods, stockpiles of additional rescuers, possibly including longer duration and consequently heavier sets, should be provided at intervals determined by risk assessment and or site drills.

When planning for emergencies, a realistic assessment of likely speeds of escape is essential and should be made. Note that the air supply in the SCSRs will be used more quickly by agitated users, and physical difficulties may be encountered while travelling. There are limitations to how long a wearer can endure wearing a self-rescuer in escape conditions and this should be factored into emergency planning. Self-rescuer changeover should take place in a dedicated "change-over station" incorporating long duration breathing supply (effectively to refuge chamber standard).

25 Tunnel Repair and Renovation

Undertaking tunnel renovation and repair may entail the majority of the risks described above for tunnel construction but with added complexity due to the operational status of many tunnels and the challenges of assessing aged infrastructure.

Similar to the construction for a new tunnel a systematic approach to risk management, including site-specific planning, ventilation, ground support, and supervision should be adopted. Other general principles shared with tunnel construction include:

- Hazard identification and control using the hierarchy of controls.
- Air quality management.
- Emergency preparedness.
- Competent supervision and training tailored to tunnel environments.

Tunnel repair and renovation differs in important ways from new construction.

- Uncertain condition of the existing structures, their relative strength, general condition and capacity reserves and response to loading or unloading and the potential presence of voids hidden behind lining due to the actions of groundwater. Typically, records of construction, prior repair or renovation are incomplete.
- Operational constraints: Many renovations occur during possessions (scheduled closures) or under live traffic/rail conditions, requiring precise coordination and minimisation of disruption.
- Legacy systems: Older tunnels may contain hazardous materials or require bespoke design solutions.

Renovation risk profiles vary significantly across tunnel types depending upon the asset management regime, operational environments and the associated risks. For example, rail tunnels will require close coordination with rail operators may include track interface hazards and electrical hazards. Hydropower tunnels may be remotely located and may require dewatering and associated water management and hydrogeological risks.

Remotely operated machines with camera's such as drones or submersibles may be useful in assessing conditions prior to personnel entry.

Toxic gases, mixtures deficient in oxygen, or explosive mixtures can accumulate in unventilated tunnels, shafts, sumps or headings. Such risks are higher when disused or abandoned tunnels or shafts need to be entered, but they are also present when a tunnel or shaft is re-entered after a brief shutdown, such as a weekend.

No one should enter an unoccupied tunnel unaccompanied. Persons entering should be in possession of atmospheric monitoring and personal protective equipment having first established that conditions are safe to enter.

Additional personnel should be on call and such operations should be planned on a "permit to work" and "confined spaces entry" basis.

Sewers, whether in use or abandoned, can be particularly hazardous and should be entered only with the approval of the local water authority and in accordance with their entry control procedures.

Appendices

Appendix A Relevant codes of practice

The following Codes of Practice listed may be involved in tunnelling work and should be referred to for considering

SafeWork NSW Codes of Practice:

- *Work health and safety consultation, cooperation and coordination*
- *How to manage work health and safety risks*
- *Safe design of structures*
- *Managing noise and preventing hearing loss at work*
- *Hazardous manual tasks*
- *Managing risks of hazardous chemicals in the workplace*
- *Draft Code of Practice: Worker accommodation*
- *Managing psychosocial hazards at work*
- *Construction work*
- *Formwork*
- *Moving Plant on Construction sites*
- *Managing electrical risks in the workplace*
- *Welding Processes*

Other Codes of Practice:

- National Transport Commission's: Australian Code for the Transport of Dangerous Goods by Road & Rail
- Trade & Investment Mine Safety NSW Code of Practice: Inundation and inrush hazard management
- Safe Work Australia's Australian code for the transport of explosives by road and rail

Appendix B Airborne Contaminants

Contaminant	Toxic?	Asphyxiant?	Flammable?	Buoyancy	Comment/Origin
Acetylene (C_2H_2)	✓	✓	✓	Positive	Compressed gas cylinder leak
Ammonia (NH_3)	✓	✓	✓	Positive	From concreting or grouting leak from refrigeration equipment
Asbestos	✓			Negative	Thermal lagging, old pipes, building materials (demolition or renovation)
Butane (C_4H_{10})	✓	✓		Negative	Compressed gas cylinder leak
Carbon Dioxide (CO_2)	✓	✓		Negative	Initially buoyant if a hot product of combustion
Carbon Monoxide (CO)	✓	✓	✓	Neutral	Incomplete combustion of diesel fuel
Hydrogen Sulphide (H_2S)	✓	✓		Negative	Decomposition of organic matter
Methane (CH_4),	✓	✓		Positive	Natural ground contaminant, or from compressed gas leak
Nitric Oxide				Neutral	Produced by explosives and engines
Nitrogen Dioxide (NO_2)	✓			Negative	Produced by electric arc welding and from NO in atmosphere
Oxygen depletion	✓			Neutral	Oxygen may be consumed or displaced
Oxygen enrichment				Neutral	Enhanced risk of ignition and fire. Due to compressed gas cylinder leak
Ozone (O_3)	✓			Negative	From electric arc welding
Propane		✓	✓	Negative	Fire and explosion hazard
Respirable Silica	✓			Negative	Concrete, shotcrete, ground, cement
Sulphur Dioxide (SO_2)	✓	✓		Negative	Bacterial activity, blasting, diesel combustion
Diesel Particulate Matter (DPM)	✓	✓		Negative	Fine particles of elemental carbon with adsorbed organics (e.g., PAHs); emitted from diesel engines
Polycyclic Aromatic Hydrocarbons (PAHs)	✓			Negative	Carcinogenic organics adsorbed onto DPM
Volatile Organic Compounds (VOCs)	✓		✓	Negative	Includes benzene, formaldehyde, and others
Metals (e.g., nickel, chromium)	✓			Negative	Engine wear and fuel/lubricant additives

Appendix C Respirable Crystalline Silica

Control Hierarchy	Example Control Measure
Elimination	Use of prefabricated concrete structures to remove the need for saw-cutting and similar works, reducing RCS exposure
Elimination	Use of non-drill guardrail systems to eliminate drilling into concrete
Isolation	Cleaning air filters from heavy plant/equipment inside a purpose-built extraction unit with a closed-loop collection process
Engineering	Provision of fresh air supply to underground work areas
Engineering	Use of mobile/fixed local extraction ventilation with scrubbers near the source to remove airborne particulates
Engineering	Extraction ventilation adjacent to the source with minimum air velocity of 0.5 m/sec where workers are located
Engineering	Use of brattices to assist ventilation extraction system efficiency
Engineering	Enclosed cabins on mobile plant with filtration systems and positive pressurisation against contaminants
Engineering	HEPA filtration in control rooms and crib rooms underground
Engineering	Interlock systems on cabin doors of mined tunnelling equipment that stop cutting if cabin becomes unsealed
Engineering	Fixed dust suppression sprays on conveyor belt systems
Engineering	Conveyor wash boxes to remove residual dust and debris
Engineering	Misting water spray to minimise dust disturbance from traffic
Engineering	Heavy plant attachments fitted with fixed dust suppression (e.g., hammers, excavators) Validated LEV system fitted to tunnel trenching machines. Dual pressurised water and air delivery system for piping blinding slab preparation.
Isolation	Remote-operated excavators to increase operator distance and reduce exposure Positively pressurised enclosed plant cabins with HEPA filtration system
Engineering	Dedicated dust suppression or extraction ventilation systems for hand-held cutting tools
Engineering	Water spray systems used during jackhammering
Engineering	Use of water carts for dust suppression in tunnels, roadways, and stockpile areas
Engineering	Spray application of polymer to seal potentially dusty surfaces

Administration	Real-time monitoring to assess effectiveness of control measures and identify areas needing additional controls
Administration	Heavy plant operators to allow minimum time for airborne dust to clear before exiting cabins
Administration	Work planning to minimize number of workers exposed
Administration	Worker rotation to reduce exposure duration
Administration	Rescheduling proximal crews to avoid secondary exposures
Administration	Prohibition of dry sweeping or compressed air cleaning; use HEPA vacuum or wet methods instead
Administration	Periodic washing of plant, machinery, and surfaces (e.g., daily)
Administration	Boot storage areas to prevent RCS-laden mud transfer
Administration	Provision of boot washing facilities
Administration	Regular wet cleaning of heavy plant cabins
Administration	Health monitoring for workers at significant risk of crystalline silica exposure
Administration	Monthly personal exposure monitoring for RCS to inform control improvements
Administration	Signage at hazardous work areas indicating required PPE
Administration	Training on RCS risks and control measures
Administration	Clean-shaven policy for users of close-fitting respiratory protection
Administration	Fit testing for all users of close-fitting respiratory protection
PPE	Mandatory respiratory protection with a minimum protection factor of 50 for most underground activities
PPE	Mandatory Powered Air Purifying Respirators (PAPRs) for specific tasks (e.g., cross-passage excavation, mined tunnelling, filter cleaning)

Appendix D Similar Exposure Groups (SEGS)

Above ground workers

SEG	Location	Generalised description
Carousel personnel	Precast	Persons involved in the operational activities associated with manufacture of precast concrete segments on the carousel lines.
Cleaner	Precast, general site	Persons involved in cleaning site offices, crib rooms, and laundry
Crane operations	Precast, general site	Persons who operate crawler or mobile cranes or perform dogman or rigger duties.
Form, reo, pour	Precast, general site	Formworkers, steelfixers, and concreters involved in form, reo or pour activities.
Gantry crane operator	Precast, spoil shed	Operation of an overhead crane for the purpose of lifting heavy loads of materials.
General labourer	Precast, general site, spoil shed	Persons on-foot conducting a range of tasks including spotting, jackhammering, or using hand-held tools.
Ground support	General site	Persons involved in ground support works including piling, drilling, mesh installation and shotcrete.
Heavy plant operators	Precast, spoil shed, general site	Operators of heavy plant such as loaders, excavators, bobcat etc.
Management and professional services	Precast, general site	Client representatives, engineers, occupational hygienists, laboratory technicians, archaeologists or other consultants.
Other surface workers	Precast, general site	Other personnel not otherwise classified, including scaffolders and light plant operators, store persons and warehouse operations.
Processing facility	Precast, general site	Persons who work or operate the batch plant, grout plant, slurry plant or water treatment plants.
Supervisors and surveyors	Precast, spoil shed, general site	Includes area supervisors, foreman or leading hands as well as persons nominated as a surveyor.
Trades services	Precast, spoil shed, general site	Trades including electricians, fitters, boilermakers, carpenters, plumbers or those otherwise classified as maintenance workers.
Traffic control	General site	

Underground workers

SEG	Location	Generalised description
Crane operations	Cut and cover	Persons who operate crawler or mobile cranes or perform dogman or rigger duties.
Form, reo, pour	Mined tunnelling, cut and cover, TBM tunnelling	Formworkers, steelfixers, and concreters involved in form, reo, pour activities.
Ground support	Cut and cover, drill and blast, mined tunnelling	Persons involved in ground support works including piling, drilling, mesh installation and shotcrete.
Heavy plant operators	Cut and cover, drill and blast, mined tunnelling, TBM tunnelling	Operators of heavy plant such as articulated haul trucks, excavators, dozers, etc.
Management & professional services	Precast, tunnel site(s), workshop	Client representatives, engineers, occupational hygienists, geotechnical or other consultants.
Profiler, surface miner operators	Mined tunnelling	Operators of other mined-tunnelling equipment including Brokk excavators, profilers or surface miners, being medium or large size plant for the excavation of hard surfaces.
Roadheader operators	Mined tunnelling	Operators of roadheaders. Further categorised into those with or without enclosed cabins.
Supervisors and surveyors	Cut and cover, drill and blast, mined tunnelling, TBM tunnelling	Includes area supervisors, foreman or leading hands as well as persons nominated as a surveyor.
TBM operators	TBM tunnelling	Persons who are primarily stationed on, and operate, the TBM from within a cabin.
TBM ring builders	TBM tunnelling	Persons who are primarily stationed on, and work at the front of the TBM building the rings.
TBM backend	TBM tunnelling	Persons who are primarily stationed on, and work on the TBM including those who extend services and conveyors, handle segments and perform grouting activities.
Trades services	Cut and cover, mined tunnelling, TBM tunnelling	Trades including electricians, fitters, boilermakers, carpenters, or otherwise classified as maintenance workers.
Tunnellers	Drill and blast, mined tunnelling, TBM tunnelling	Persons on-foot in tunnels under construction conducting a range of tasks.
Traffic Controllers, ancillary maintenance and cleaning labour	As required underground	Persons on-foot in tunnels under construction conducting a range of tasks.
Waterproofing	Cut and cover, mined tunnelling	Personnel involved in activities associated with waterproofing.

Appendix E Use of Observational Methods

Overview

To quote the HSE investigation into the safety of observational methods (OM) in relation to excavations in clay (1996) [29]:

> "The 'observational method' is a process in which a pre-determined design is reviewed during construction… Design review is a process of critical examination of product performance; review is not a process for design modification as work proceeds."

The collapse of NATM tunnels at Heathrow in 1994 prompted this investigation. The HSE found that the observational method had not been consistently or correctly applied. Key failings included insufficient monitoring, poor documentation, lack of contingency planning, and a weak design–construction interface that lead to miscommunication and escalating risk. The investigation also identified inadequate ground investigation, over-reliance on deformation monitoring without robust baseline predictions, and a lack of competence and training in OM principles.

The HSE recommended a risk-based approach to tunnelling, improved collaboration between designers and constructors, enhanced monitoring systems, robust emergency procedures, and stronger quality assurance. It also called for greater emphasis on buildability, risk management, and clear design accountability.

Observational methods have long been used in geotechnical engineering, largely attributed to Peck (1969)[30], and later refined by Nicholson (1999)[31] following the Heathrow collapse. Peck's original method was based on several core principles:

- Availability of sufficient site investigation to establish the general nature and properties of the ground.
- Establishment of a design for both the most probable and the most unfavourable ground conditions.

Nicholson's work developed these concepts further, emphasizing:

- Starting with a design based on the most probable ground conditions.
- Establishing predicted behaviours, trigger values, and contingency plans.
- Using monitoring to verify predictions and adjusting the design only if actual behaviour deviates.

He also identified four key requirements for successful application:

- Define acceptable limits of behaviour.
- Assess the range of possible behaviours.
- Plan monitoring to detect deviations early.
- Prepare contingency actions in advance.

To summarise, monitoring and review are essential tools for validating design assumptions when adopting OM, but they should not be used as a substitute for proper design development or to justify ad hoc design changes during construction. Any modifications should occur within a structured framework of predefined trigger levels and contingency plans. An observational method

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[29] Health and Safety Executive (1996). Safety of New Austrian Tunnelling Method (NATM) Tunnels: A Review of Sprayed Concrete Lined Tunnels with Particular Reference to London Clay. HSE Books, ISBN: 978 0 7176 1068 6.

[30] Peck R.B, Deep Excavation and Tunnelling in Soft Ground, 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City, (1969)

[31] Nicholson, D. (1999). *The Observational Method in Ground Engineering: Principles and Applications*. CIRIA Report C185, Construction Industry Research and Information Association (CIRIA), London.

requires the design to define limits of acceptable behaviour for the ground and support system. There must be a pre-planned “way out” that can be implemented quickly and effectively to prevent instability, so far as is reasonably practicable. The design should assess the sequence of construction and the stability of the excavation, and include contingency measures based on the range of probable conditions that may be encountered. [32] The successful use of observational methods depends on effective communication and collaboration across the project team, with clearly defined roles and responsibilities.

Limitations of the Observational Method

Eurocode 7 (EN 1997-1)[33] outlines conditions where OM application may be inappropriate. PCBU should carefully consider the following issues regarding the use of OM on their projects

- Ground conditions are well known and predictable:
  If geotechnical behaviour can be reliably predicted through calculations or prescriptive measures, the observational method may introduce unnecessary complexity.
- High failure consequence structures:
  For structures with high failure consequences the uncertainty inherent in the observational method may be unacceptable.
- Monitoring capabilities:
  The method relies on real-time monitoring of parameters such as displacement, pore pressure, stress and or/strain. If the instrumentation to monitor critical parameters and the system responses cannot be reliably installed or maintained, the method should not be used.
- Clear definition of acceptability limits:
  Limits of acceptable behaviour should be defined before construction begins. If these cannot be established, the method is unsuitable.
- Implementation of contingencies to prevent failure:
  The method requires pre-planned contingency measures to meet safety requirements.
- Construction schedules:
  There should be sufficient time for iterative adjustments to supports and sequencing based on monitoring results.
- Lack of competence:
  The method demands experienced and competent engineers capable of interpreting monitoring data and making timely decisions.

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[32] Refer for example Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation Austrian Society for Geomechanics (2010)

[33] For further reference refer EN 1997-1: Eurocode 7 – Geotechnical Design – Part 1: General Rules, Institution of Civil Engineers (ICE) Guidance on Observational Method, British Standards Institution (BSI) Commentary on Eurocode 7.

Appendix F TBM Hazard Prompt Table

Hazard Category	Hazard Description
Mechanical/Operational Hazards	Failure of TBM thrust or steering systems
Mechanical/Operational Hazards	Hydraulic system failure
Mechanical/Operational Hazards	Power supply failure
Geotechnical Hazards	Ground heave or settlement beyond design predictions
Geotechnical Hazards	TBM entrapment in boulders or hard inclusions
Geotechnical Hazards	Unexpected ground chemistry
Water/Pressure Hazards	Hyperbaric working risks
Water/Pressure Hazards	Failure of bulkheads or pressure doors
Human Factors	Operator error in pressure control or steering (machine attitude)
Human Factors	Inadequate communication between TBM and surface teams
Human Factors	Fatigue or cognitive overload
Fire/Explosion/Contamination Hazards	Fire in TBM electrical or hydraulic systems
Geotechnical Hazards	Explosion risk from methane or other flammable gases
Mechanical/Operational Hazards	Damage to segments or gaskets
Mechanical/Operational Hazards	Loss of effectiveness of seals at the back of the TBM
Mechanical/Operational Hazards	Flotation under shallow cover
Mechanical/Operational Hazards	Face blow-out to surface in the case of pressurised face (closed face) TBMs during operation or maintenance in low cover situations
Mechanical/Operational Hazards	Over-excavation leading to face collapse especially during launch and receival of TBMs
Geotechnical Hazards	Unanticipated voids or fault zones and inundation
Geotechnical Hazards	Excessive wear or damage to the cutter head requiring interventions from surface
Mechanical/Operational Hazards	Inundation via inability to close earth pressure balance screw conveyor
Geotechnical Hazards	Geological materials and airborne contaminants such as silica and naturally occurring asbestiform minerals or hydrocarbons

Geotechnical Hazards	Breakouts from the segmental lining