GUIDE FOR TUNNELLING WORK

NOVEMBER 2013

safe work australia

Safe Work Australia is an Australian Government statutory agency established in 2009. Safe Work Australia consists of representatives of the Commonwealth, state and territory governments, the Australian Council of Trade Unions, the Australian Chamber of Commerce and Industry and the Australian Industry Group.

Safe Work Australia works with the Commonwealth, state and territory governments to improve work health and safety and workers' compensation arrangements. Safe Work Australia is a national policy body, not a regulator of work health and safety. The Commonwealth, states and territories have responsibility for regulating and enforcing work health and safety laws in their jurisdiction.

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TABLE OF CONTENTS

1.	**INTRODUCTION**	**3**
1.1	What is tunnelling work?	3
1.2	Who has health and safety duties associated with tunnelling work	3
1.3	Managing health and safety risks	5
1.4	Consultation, co-operation and co-ordination	5
2.	**PLANNING AND PREPARATION**	**6**
2.1	Roles in the design stage	6
2.2	Developing a tunnel design	6
2.3	Inspection planning	10
2.4	Planning and preparation specific to the workplace	11
2.5	Emergency planning	15
3.	**COMMON HAZARDS AND RISKS ASSOCIATED WITH TUNNELLING WORK**	**22**
4.	**CONTROLLING RISKS IN TUNNELLING WORK**	**26**
4.1	Excavation by hand	26
4.2	Excavation using plant	27
4.3	Tunnel boring machines	27
4.4	Drill and blast	33
4.5	Portal protection	34
4.6	Inspections and scaling	35
4.7	Ground support	36
4.8	Sprayed concrete	37
4.9	Shafts	38
4.10	Shaft sinking	39
4.11	Raise boring	40
4.12	Raised shafts	40
4.13	Caissons	41
4.14	Ground freezing	42
4.15	Pipe jacking	43
4.16	Compressed air tunnelling	44
4.17	Pressure grouting	45
4.18	New Austrian Tunnelling Method (NATM) or 'Observation Method'	46
4.19	Personal protective equipment	47
5.	**AIR QUALITY AND VENTILATION SYSTEMS**	**49**
5.1	Quantity of air to be supplied or extracted	49
5.2	Mechanical ventilation	49
5.3	Atmospheric contamination in tunnelling work	50
5.4	Dusts and silica	51
5.5	Monitoring air quality	52
5.6	Using respirators	53
5.7	Diesel emissions	54
5.8	Managing heat stress	54
6.	**PLANT**	**56**
6.1	Procedures for moving plant	57
6.2	Surface and underground fuelling	57
6.3	Specialist and other plant	58
7.	**OTHER TUNNELLING RISKS**	**61**
7.1	Fire and explosion	61
7.2	Hazardous chemicals	63
7.3	Health monitoring for hazardous chemicals	63
7.4	Visibility and lighting	63
7.5	Working with compressed air	64
7.6	Electrical safety	66
7.7	Falls from heights	67

TABLE OF CONTENTS

7.8 Falling objects 67

7.9 Vibration 67

7.10 Eye injury 69

7.11 Radiation 70

APPENDIX A – OTHER REFERENCE MATERIAL 71

APPENDIX B – DEFINITIONS 74

APPENDIX C – EXAMPLE HAZARD IDENTIFICATION CHART 76

APPENDIX D – TUNNEL BORING MACHINES 77

APPENDIX E – VENTILATION METHODS AND EQUIPMENT 79

APPENDIX F – ATMOSPHERIC CONTAMINANTS 83

APPENDIX G – HAZARDOUS CONTAMINANTS AFFECTING AIR QUALITY 85

1. INTRODUCTION

This Guide provides practical guidance for a person conducting a business or undertaking and workers on managing health and safety risks associated with tunnelling work.

It should be read together with the Code of Practice: *Construction work* and other codes of practice relevant to tunnelling work. A list of useful resources is at Appendix A.

This Guide applies to constructing:

- tunnels, caverns, shafts and associated underground structures, and
- cut-and-cover excavations - those physically connected to ongoing underground construction tunnels and those cut-and-cover operations that create conditions characteristic of underground construction.

This Guide does not apply to mining. When some materials are excavated, like coal, the process is considered mining. In those circumstances the Work Health and Safety (WHS) Regulations for mining and related codes of practice apply.

1.1 What is tunnelling work?

Tunnelling work includes constructing a tunnel and supporting systems and associated temporary work. A supporting system means a system necessary to construct the tunnel, for example a ventilation system.

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.

Excavation associated with tunnelling includes vertical and inclined shafts providing access to tunnels, portals where tunnels emerge at the surface or at a shaft, underground chambers and caverns.

Construction work carried out in or near a tunnel or associated excavation is high risk construction work under the WHS Regulations.

Other key terms used in this guide are defined at Appendix B.

1.2 Who has health and safety duties associated with tunnelling work

The complexity of tunnelling work means there are often many people involved. Everyone involved in tunnelling work has health and safety duties when carrying out the work and more than one person often has the same duty. For example, contractors and subcontractors can have the duties of persons conducting a business or undertaking but they may also be workers.

Table 1 Health and safety duties in relation to tunnelling work

Who	Duties	Provisions
A person who conducts a business or undertaking	Ensure, so far as is reasonably practicable, workers and other people are not exposed to health and safety risks arising from the business or undertaking. Eliminate health and safety risks so far as is reasonably practicable, and if this is not reasonably practicable, minimise those risks so far as is reasonably practicable. Manage risks to the health and safety of a worker associated with remote or isolated work.	WHS Act s 19
	Manage other risks under the WHS Regulations including those associated with hazardous chemicals, airborne contaminants and plant, as well as other hazards associated with tunnelling work like noise and manual tasks.	WHS Regulations r 48
A principal contractor – the person who commissions the tunnel	Appoint one principal contractor for each construction project valued at $250 000 or more. Specific duties in relation to signs, work health and safety management plan, construction materials and waste, storing plant, essential services, traffic management and general workplace management.	WHS Regulations r 293
Designers, manufactures, importers, suppliers or installers of plant, substances or structures	Ensure, so far as is reasonably practicable, the plant or structure they design, manufacture, import or supply is without risks to health and safety including carrying out testing and analysis and providing information about the plant or structure.	WHS Act s 22-26
Officers such as company directors	Exercise due diligence including by taking reasonable steps to ensure the business or undertaking has and uses appropriate resources and processes to eliminate or minimise risks from tunnelling work.	WHS Act s 27
Workers	Take reasonable care for their own health and safety Take reasonable care not to adversely affect other people's health and safety Co-operate with reasonable work health and safety policies or procedures, and Comply, so far as they are reasonably able, with reasonable instructions.	WHS Act s 28

Who	Duties	Provisions
Other people at the workplace, like visitors	Take reasonable care for their own health and safety Take reasonable care not to adversely affect other people's health and safety, and Comply, so far as they are reasonably able, with reasonable instructions.	WHS Act s 29

More information about health and safety duties for tunnelling work is in the Code of Practice: *Construction work* and the Code of Practice: *Safe design of structures*.

1.3 Managing health and safety risks

This Guide explains how to manage the risks associated with tunnelling work by following a systematic process which involves:

- identifying hazards – find out what could cause harm in tunnelling work
- assessing risks if necessary – understand the nature of the harm that could be caused by the hazard, how serious the harm could be and the likelihood of it happening
- controlling risks – implement the most effective control measures that are reasonably practicable in the circumstances, and
- reviewing control measures to ensure they are working as planned.

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

1.4 Consultation, co-operation and co-ordination

Consultation involves sharing information, giving workers a reasonable opportunity to express views and taking those views into account before making decisions on health and safety matters.

Sometimes you may share responsibility for a health and safety matter with other business operators who are involved in the same activities or who share the same workplace. In these situations, you should share information to find out who is doing what and work together in a co-operative and co-ordinated way so risks are eliminated or minimised so far as is reasonably practicable.

Further guidance on consultation is in the Code of Practice: *Work health and safety consultation, co-operation and co-ordination.*

2. PLANNING AND PREPARATION

2.1 Roles in the design stage

The persons conducting a business or undertaking commissioning the tunnelling design or construction work are in key positions to influence the safe design, construction, use, maintenance and de-commissioning of the tunnel. This is because they usually develop the concept design for the tunnel and engage the designer and principal contractor to construct the tunnel.

Many aspects of tunnel design influencing whether a tunnel is constructed safely, like tunnelling in rock or soft ground, are decided in the concept design stage. During this phase duty holders should consult and plan to manage risks which may occur when constructing, using and maintaining the tunnel. Consultation between duty holders will give a better understanding of the time needed for geotechnical investigations, tender preparation, construction and potential delays. Not all hazards and risks associated with tunnelling work will be obvious during the concept design phase so there should be ongoing consultation between duty holders.

The principal contractor must ensure a work health and safety management plan is prepared for the tunnelling work before tunnelling work starts. The client should include this requirement in contract documents.

For further information on principal contractor duties see the Code of Practice: *Construction work.*

The designer must give the results of calculations, analysis, testing and examinations necessary to ensure the design is without risks to health and safety to:

- the person conducting a business or undertaking commissioning the design, and
- any person who is provided with design information.

The assumed geotechnical conditions used in the design should also be provided to the principal contractor by the designer to allow these to be monitored and compared with the actual conditions experienced during the tunnelling work. This will allow for more accurate reassessment of the design where the actual geotechnical conditions differ from the design assumptions.

Further information on designer duties is in the Code of Practice: *Safe design of structures.*

2.2 Developing a tunnel design

Tunnel design is different to plant or structure design because it is difficult to accurately pre-determine geological conditions, properties and variability along the tunnel. Therefore tunnel design is based on less reliable assumptions than other designs. To minimise the associated risks, so far as is reasonably practicable, the following tasks should be carried out:

- Reviewing existing geological information and conduct a workplace investigation to determine whether existing information is accurate and sufficient.
- Consulting with national bodies about environmental and geological conditions, mineral workings, planning and transport issues.
- Reviewing specifications of the geological conditions assumed in the design.
- Implement an inspection plan to compare the actual geological conditions as the excavation progresses with the assumed conditions.

- Implementing procedures to assess and manage changes in conditions and the adequacy of the tunnel design and ground support so the changes do not create a risk to health and safety. This may include stopping tunnelling work to reassess the changed conditions and reviewing risk control measures.

WORKPLACE INVESTIGATION

Safe tunnel design and construction depends on pre-construction investigation of the ground conditions, the workplace and proper interpretation of this information. Designers should be:

- provided with available and relevant information
- told of gaps in the information for planning and construction
- involved in collecting data during workplace investigations, and
- included in on-site investigations.

Workplace investigations should consider the type, extent and location of the tunnelling work and local environmental conditions. The investigation should allow realistic assessments of different tunnelling designs and methodologies.

The workplace investigation should be carried out by suitably qualified and experienced people competent in conducting investigations of similar ground conditions. The workplace investigation may include:

- climatic and prevailing weather conditions
- local topography - location, condition and influence of existing structures, services and old workings
- geophysical conditions - drilling boreholes or examining existing borehole results, laboratory assessment of soil and rock properties, rock cutting, dust production and blasting trials, and
- hydrology - ground water conditions including location, volume and possible changes due to tunnelling and other activities.

The workplace investigation will provide information to assist the geotechnical risk assessment of ground and other conditions. The assessment should consider:

- rock mass geology
- planes of weakness
- mechanical properties of rock including the influence of planes on the rock mass
- in-situ rock stress field magnitude and orientation
- induced rock stress field due to excavation
- potential rock failure mechanisms
- blast damage effects to the rock mass if blasting is being considered
- likely scale and nature of the ground behaviour e.g. movement
- possible effects on other work places or installations
- groundwater presence and quantity
- possible contaminated environments including groundwater, hazardous gases like methane, liquids like industrial waste and solids like naturally occurring or dumped asbestos, and
- previous relevant experience and historical data for the area.

DETERMINING THE EXCAVATION METHOD

The workplace investigation including geotechnical investigations, risk assessments, the tunnel design, entry limitations and other local factors should be used to establish the most suitable excavation methods.

The excavation methods should allow the designed ground support to be installed as planned as well as installing more ground support if conditions are found to be worse during excavation work.

To determine the most suitable excavation methods the following should be considered:

- tunnel design including dimensions, shape, excavation tolerance of the excavation and tunnel supports and lining design
- timeframes for excavation work
- contractors expertise
- entry to the excavation site
- risks during past excavations under similar conditions
- water table levels and possibility of flooding from
  - surface run-off, tidal water, rivers, dams, reservoirs, lakes or swamps
  - leaking stormwater drains, water mains or flooded communications conduits
  - intersection of old flooded workings or an underground water-bearing structure e.g. a fault, cast or perched water table
- where existing underground services like water mains, sewerage drainage, electricity, gas and telephone services are laid
- ground conditions including reclaimed ground
- soil nails, rock anchors, basement underpinning or other pre-existing ground support
- whether there are other excavations like shafts, tunnels or trenches nearby
- other hazards, either natural or man-made e.g.
  - heavy loadings above or adjacent to the tunnel like roadways, railway lines or buildings
  - rivers or planned or existing spoil stockpiles
  - chemical contamination from past dumping, leaking tanks, pipes or natural deposits
  - the presence of methane or other hazardous or flammable gases and vapours
  - where vegetation has decayed in the soil or hydrocarbon contamination from historical fuel leaks exist
- dynamic loads or ground vibration near an excavation from
  - road or rail traffic
  - excavation plant
  - explosives
- dust production and dust control measures, and
- airborne contaminants.

GROUND SUPPORT DESIGN

Most tunnels and open excavations need some form of temporary and permanent ground support that should be specified in the tunnel design.

Removing material causes unbalanced soil or rock stresses that reduce the capacity of the tunnel to support itself. Varying geological conditions mean control measures that have worked previously may not be satisfactory under these changed conditions.

The person conducting a business or undertaking should carry out a detailed analysis of existing geophysical conditions and the design requirements to identify the most suitable temporary ground support that may be installed without requiring workers to work under unsupported ground.

When designing ground support systems you should consider structural design and soil and rock mechanics. Ground support designed for the unique circumstances of the tunnel is essential to control the risk of a collapse or tunnel ground support failure.

Design specifications for engineering control measures like shoring support structures should be prepared by a competent person in accordance with relevant legislative requirements, Australian Standards and codes of practice.

VENTILATION SYSTEM DESIGN

The ventilation system should be designed to provide ventilation throughout the tunnel during construction, use and maintenance. This includes providing extra localised extraction ventilation for dust, heat or fumes during excavation, post-blasting, operating large plant or other activities like maintenance.

The design should include being able to install ventilation equipment or ducting during excavation to maintain air supply to the working face.

Further information on ventilation system design is in Chapter 5.

DETAILS TO BE INCLUDED IN THE TUNNEL DESIGN

Information from the workplace investigation and the likely excavation methods to be used should be considered in preparing the tunnel design.

The design should detail the:

- excavation methods and ground conditions
- tunnel dimensions and allowable excavation tolerances
- limitations for installing ground support during excavation e.g. maximum and minimum distances from the tunnel face
- temporary ground supports during construction
- ventilation systems
- final ground support and lining requirements for each location within the tunnel, and
- other requirements for the finished tunnel.

If a different excavation method is chosen or the assumed ground conditions change, the design should be reviewed before starting to excavate.

REVIEWING THE TUNNEL DESIGN BEFORE CONSTRUCTION

The person conducting the business or undertaking who commissioned the design and the principal contractor should review the design for construction and tell the designer where amendments are needed or if in their opinion the tunnel cannot be constructed safely.

The designer will then make amendments or modifications to the design before construction starts.

This review should consider a range of tunnelling work issues including the:

- excavation method
- extra excavation for temporary entry
- ventilation systems
- construction phase electrical systems
- materials handling systems including spoil removal
- loadings from roof mounted spoil conveyors and ventilation systems, and
- places of safety including refuge chambers.

DESIGN INFORMATION TRANSFER

Uncertainty about ground and environmental conditions means design changes may be needed during construction. Understanding the health and safety risks and what has been done to eliminate or minimise them through the planning, investigation, design and construction stages is important. This can be achieved more easily by involving a single designer throughout the process. If the designer changes they should be provided with information collected at each stage of the design and construction process.

2.3 Inspection planning

Tunnelling work should be inspected regularly to ensure the tunnel and supporting systems remain stable, intact and work can be carried out safely. The inspection should compare the actual conditions with those assumed in the original or amended designs, excavation method or safety management plan and the adequacy of control measures.

Inspection plans should be developed collaboratively with the person conducting the business or undertaking and the principal contractor. The inspection plans should include a section for the principal contractor to confirm support elements have been installed in accordance with the design specifications and the corresponding construction sequences.

A risk assessment should be used to determine how often to inspect the tunnel and what competencies the person inspecting the tunnel should have. When setting how often to inspect the tunnel, whether based on time or on how far the tunnel face has moved, you should consider the delay due to the assessment and reporting procedures so identified issues are dealt with before becoming a risk to health and safety.

Table 2 Inspection plan activities

Activities for inclusion in inspection plan	Extra considerations for open excavations

■ mapping and visually assessing actual ground conditions and excavated shape as exposed by the tunnel excavation
■ monitoring ground support performance including:
  ■ possible support failures
  ■ evidence of excessive load
  ■ anchoring or pulling out tests on rock bolt type supports
■ falling or fretting ground
■ monitoring time-based deterioration, like spalling or slaking from weathering through temperature and humidity changes or exposure to air
■ monitoring water entry quantity, quality and location
■ measuring closure or subsidence of roof or walls by installing extensometers or by regular survey and testing core rocks
■ measuring in-situ ground stresses
■ reviewing results of the most recent monitoring of:
  ■ tunnel atmosphere
  ■ surface settlement
	■ excavated and other material being placed within the zone of influence of the excavation
	■ plant operating within the zone of influence of excavations causing weight and vibration influences
	■ surface soil falling into the excavation
	■ water seeping into excavations from side walls or base
	■ changes to soil and weather conditions
	■ surface water or run-off entering the excavations or accumulating on the surface near the excavation
	■ subsidence alongside the excavations

Review and if necessary modify the inspection plan after tunnel inspections, collapses, material falls or changes in weather conditions which may increase groundwater levels or groundwater inflows into the tunnel.

Further information on excavations is in the Code of Practice: *Excavation work.*

2.4 Planning and preparation specific to the workplace

WORKPLACE FACILITIES

Regulation **41(1)(2)**

A person conducting a business or undertaking at a workplace must ensure, so far as is reasonably practicable:

- the provision of adequate facilities for workers including toilets, drinking water, washing facilities and eating facilities, and
- the facilities are maintained in good working order, clean, safe and accessible.

When considering how to provide and maintain facilities that are adequate and accessible, a person conducting a business or undertaking must consider:

- the nature of the work being carried out at the workplace
- the nature of the hazards at the workplace
- the size, location and nature of the workplace, and
- the number and composition of the workers at the workplace.

Underground eating facilities also known as crib rooms, should be away from dusty environments and if possible have filtered air under positive pressure.

Non-potable water should be clearly identified and drinking water should be regularly tested for contaminants.

The facilities cleaning regime should consider shift work arrangements to ensure the facilities are cleaned more often if needed.

Further information on workplace facilities is in the Code of Practice: *Managing the work environment and facilities.*

INFORMATION, INSTRUCTION, TRAINING AND SUPERVISION

Section **19(3)(f)**

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.

Regulation **39**

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, and
- the control measures implemented.

The person must ensure, 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.

UNDERGROUND ESSENTIAL SERVICES

Regulation **304(1)(2)**

A person with management or control of the workplace must take all reasonable steps to obtain current underground essential services information about a part of a workplace where excavation work is being carried out and any adjacent areas before directing or allowing the excavation work to commence.

Essential services include the supply of gas, water, sewerage, telecommunication, electricity, chemicals, fuel and refrigerant in pipes or lines. The principal contractor must manage the risks associated with essential services at the workplace.

Finding out the general location of underground services can be done by:

- contacting organisations that assist in locating underground services e.g. Dial Before You Dig
- using remote location devices
- using gas detectors, and
- being alert for signs of disturbed ground, warning tape or pavers.

The person with management or control of the workplace must provide information about underground essential services to anyone engaged by the person to carry out excavation work.

Available information about existing underground essential services may not be accurate. It is important excavation methods include an initial examination of the area to be excavated, for example sampling the area by exposing a short section of underground services using water pressure and a vacuum system to excavate or 'pothole' the area.

Other workers who may be affected by underground essential services should be told of their location.

Excavating by hand near underground electrical services not removed or de-energised should only be done using tools with non-conductive handles and while wearing rubber boots and insulating gloves.

Further information on underground essential services is in the Code of Practice: *Excavation work* and Code of Practice: *Construction work*.

Further information on underground electrical services is in the Code of Practice: *Working in the vicinity of overhead and underground electrical lines.*

LOCATING AND COMMUNICATING WITH WORKERS

Regulation **48(1)(2)**

> A person conducting a business or undertaking must manage risks to the health and safety of a worker associated with remote or isolated work.
>
> In minimising risks to the health and safety of a worker associated with remote or isolated work, a person conducting a business or undertaking must provide a system of work that includes effective communication with the worker.

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.

COMMUNICATION SYSTEMS

A communication system should allow a person using it to efficiently and effectively:

- distribute information and instructions
- control operations like lifting, transporting people, materials and plant
- monitor plant and systems like ventilation and help co-ordinate maintenance, and
- manage an emergency including contacting emergency services.

The communication system may also be used to pass on information on safety-related matters like plant-condition, instrumentation and atmospheric monitoring and fire alarms.

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, and
- 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, and
- potential hazards including the speed of operations.

A system of signalling by bells or coloured lights can be suitable for routine communications, like controlling train movements or requesting lining segments or other materials be sent forward.

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 everyone affected by the tunnelling work. For shafts this applies to the doggers, winch and hoist drivers and those working in or about the shaft itself.

The communication system should be able to operate independently of the tunnel power supply through an uninterruptible power supply, known as a UPS. It should be installed so if one unit fails or a collapse occurs 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.

Working shafts should have a standby means of communication which can be operated from throughout the shaft.

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.

IDENTIFYING AND LOCATING PEOPLE IN THE TUNNEL

A system should be in place to quickly and accurately determine the names and working locations of each person in the tunnel. This can be done by a tag board checked by supervisors at the start and end of every shift and by using shift timesheets. For large complex tunnelling work tag boards should be located at sections or branches of the tunnel.

The presence or absence of tags or missing or incomplete timesheets can help determine search and rescue criteria for tunnel rescue teams. If the system is not used properly or maintained it will not be of use in an emergency as it can lead to wasted resources looking for people who are not in the tunnel and overlook someone who is missing. The system should be checked regularly to ensure it is being used properly.

In an emergency it may be necessary to implement a procedure for people exiting from an alternate exit so they can tag out or be accounted for.

2.5 Emergency planning

WHO PREPARES THE EMERGENCY PLAN?

Where a workplace is shared by a number of duty holders, for example contractors, subcontractors and suppliers, the emergency plan should be prepared in consultation and co-operation with these people. Workers should also be consulted when developing the emergency plan. The person with management or control of the workplace, like the principal contractor, should co-ordinate the consultation.

WHAT TO INCLUDE IN AN EMERGENCY PLAN

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 between the person authorised by the person conducting the business or undertaking to co-ordinate the emergency response and people at the workplace
- 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 3 sets out some questions to consider when establishing emergency procedures.

Table 3 Developing emergency procedures

Considerations	Questions
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?
Emergencies	What emergencies could happen with the tunnelling work? How will you respond to emergencies like collapse, fire, flood or failure of ventilation systems? Table 4 below lists more examples of possible tunnelling work emergencies. What control measures can be implemented to reduce the severity of the emergency, like self-closing bulkheads to eliminate or minimise, so far as is reasonably practicable, the risk of water inrush? What equipment will be needed to deal with emergencies, like: ■ spill kits ■ fire extinguishers ■ early warning systems like fixed gas monitors or smoke detectors, and ■ automatic response systems like sprinklers. Should there be specific procedures included in the plan for critical functions, like a power shut-off?
Evacuations	What triggers for an evacuation, like a confirmed or suspected underground fire, should be considered in the plan? Table 4 below lists more examples of possible evacuation triggers. How will the controlled evacuation of people from the workplace be handled? Are there planned regular evacuation drills at least every 6 months or as soon as practicable after the plan is changed?
Workplace location	Is the tunnelling 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 like emergency rescue cages 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	Table 5 lists questions and information on escape routes.

Considerations	Questions
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?

Considerations	Questions
Roles for the local emergency services	Can you rely on local emergency services for rescue? Other arrangements should be made if they cannot respond within a suitable time. How will the local emergency services be notified of an incident? Are there entry issues for emergency services like ambulances and their ability to get close to the work area? Are there ways to ensure accurate information is available on: ■ site location ■ entry problems ■ personal details of the casualty including relevant medical history ■ time of the incident ■ treatment given, and ■ any chemicals involved?
Consulting, co-operating and co-ordinating with local emergency services	Have emergency services been consulted when preparing, maintaining and implementing the emergency plan? Has a copy of the emergency plan been provided to the emergency services before starting work or after revising the emergency plan? Does the emergency plan include the emergency services involvement in a trial rescue early in the construction? Is there is a role for the emergency services in the emergency plan? If not, did a risk assessment document why?
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?

Table 4 Emergencies and evacuation triggers to be considered in an emergency plan

Types of emergencies	Triggers for an evacuation

■ treating and evacuating seriously injured people
■ sudden flooding like inrush from an underground water feature
■ underground:
  ■ fire including plant fires
  ■ explosion through methane ignition or other airborne gases, vapours and dusts
■ harmful concentrations of airborne contaminants or an unsafe atmosphere
■ tunnel collapse resulting in people being trapped
■ power or water failure
■ above ground emergencies compromising tunnel safety like a fire or chemical spill
	■ confirmed or suspected underground fire irrespective of size
	■ ineffective primary ventilation system including fans, intakes and ventilation controls which impact on the effectiveness of emergency procedures
	■ failure of fire fighting systems like the loss of water supply, even through maintenance, if the tunnels partly rely on sprinkler systems
	■ a surface fire or chemical spill which could affect fresh air intakes
	■ ineffective emergency system equipment like communication equipment, breathable air systems, emergency lighting, recall of self-rescuers
	■ major water inrush
	■ seismic event
	■ imminent weather event which could impact on the tunnel

ESCAPE ROUTES AND SAFE PLACES

Information on general workplace facilities including safe entry and exit to, from and within the workplace is in the Code of Practice: *Managing the work environment and facilities.*

The remote nature of tunnelling work should be considered when establishing emergency procedures. A risk assessment including the implemented control measures will help in this task.

Table 5 sets out questions and information to consider when including escape routes and safe places in emergency procedures.

Table 5 Escape routes and safe places

Considerations	Questions
Identifying escape routes	Have all: ■ possible escape routes like parallel tunnels, shafts or other connections to the surface been identified ■ escape routes been marked including travelling in parts of the tunnel not normally used by some workers ■ floor openings been fenced, and ■ 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 using breathing apparatus? 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? Have the supply and use of oxygen-generating self-contained self-rescuers (SCSRs) which allow a person to travel from an endangered position to the surface or a safe place been considered? When developing escape routes while using SCSRs have you considered how far a person, in a reasonable state of physical fitness, can travel at a moderate walking pace, using 50 percent of the nominal capacity of the SCSR? Are you aware this capacity should be regarded as an absolute maximum because: ■ the air supply in the SCSRs will be used more quickly by agitated user's ■ physical difficulties may be encountered while travelling, and ■ thick smoke may make crawling the only feasible means of movement?
Safe places and refuge chambers	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 types of tunnelling activity? ■ how long it will take workers to get to the chamber from where they are working and your evacuation procedures and routes?

Considerations	Questions
Safe places and refuge chambers	■ 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 above ground? What else can be put in place to allow longer stays? Does induction training and emergency procedures: ■ tell workers whether to go to a refuge chamber or an escape route if there is a fire, and ■ include instructions for people in refuge chambers or fresh air bases to remain there and to communicate if their safety conditions change or other people arrive?
Vehicles and plant in the tunnel	How: ■ have the risks of vehicles and plant blocking escape routes in an emergency been addressed in the emergency plan? ■ will workers be provided with information, instruction and training for operating plant within the tunnel including to keep escape routes and emergency entry clear?
Escape route signage	Are emergency escape route signs in places everyone can see? Are they near ground level so they are more visible in smoke? Further information on signage maintenance and marking is in AS 1319-1994: *Safety signs for the occupational environment.*

RESCUE MEASURES IN THE EMERGENCY PLAN

Rescue procedures including self-rescue and where rescue is assisted from outside the tunnel should be described in detail in the emergency plan and be practiced by workers. Self-rescue is important where it may take too long and be very difficult for emergency services to reach people.

When selecting which self-rescue measures to include consider the expected maximum time between the incident and when emergency services can reach the incident site. Consider the maximum number of people who may be in the tunnel when planning and providing safety equipment and facilities. It is important there are enough breathing apparatus, sealable self-contained atmosphere refuges and rescue capacity to accommodate them.

Further information is in the *Emergency Plans Fact Sheet*, the Code of Practice: *Managing the work environment and facilities* and the Code of Practice: *First aid in the workplace*.

3. COMMON HAZARDS AND RISKS ASSOCIATED WITH TUNNELLING WORK

Control measures should be identified to eliminate or minimise, so far as is reasonably practicable, risks associated with tunnelling work. These mostly arise from working underground and can be identified during consultation and the risk assessment process.

There should be procedures for the handover of safety critical information at the beginning and end of each shift. A written record of this information should be maintained.

Table 6 Common tunnelling work hazards, risks and control measures

Hazards or risks	Control measures
Confined spaces with build-up of gas and fumes	■ planning and implementing tasks in accordance with Code of Practice: *Confined spaces* and AS 2865-2009: *Confined Spaces* ■ using suitable ventilation and dust extraction systems ■ monitoring atmospheric conditions ■ developing rescue procedures including use of self-rescuers ■ having training and certification for work in confined spaces ■ using personal protective equipment (PPE)

Rock falls	■ inspecting the tunnel regularly and scaling where needed
	■ mechanically scaling and bolting
	■ installing ground support:
	  ■ as soon as possible
	  ■ with overhead protection if done manually
	■ changing ground support methods

Failure of floor or roadway	■ providing hard floor and roadway surfacing ■ ensuring drainage

Scaling	■ using:
	  ■ mechanical equipment
	  ■ overhead protection
	■ working from an:
	  ■ elevating work platform basket
	  ■ area of supported ground

High water and mud inflow	■ grouting old drill holes ■ pre-grouting before excavation starts ■ injecting grouting ahead of the face ■ probing, drilling and draining ■ dewatering and pumping from surface bores ■ using other forms of ground treatment e.g. freezing ■ installing sump and drainage systems ■ setting limits on maximum height of water and mud flow during work e.g. less than boot height

Hazards or risks	Control measures
Gas inrush	■ increasing face ventilation and extraction ■ probing drill hazard areas through check valves ■ monitoring for gas ■ installing automatic plant cut-off and flame-proofing plant in possible flammable atmospheres ■ restricting smoking to designated areas

Falls from height	■ planning and implementing tasks in accordance with Code of Practice: *Managing risks of falls at workplaces*
	■ using:
	  ■ guardrails wherever possible e.g. on maintenance platforms and landings
	  ■ fall-arrest systems
	  ■ PPE

Loss of lighting	■ providing emergency lighting and cap lamps

Moving plant	■ isolating and restricting contact with moving plant
	■ using:
	  ■ audible plant reversing alarms
	  ■ spotters for vehicle movements
	  ■ a system to warn workers when plant is reversing or special loads like explosives are being moved
	■ providing lighting for safe movement
	■ planning vehicle and pedestrian movements

Manual tasks like handling air tools, drill rods, supports, cutters	■ planning and implementing tasks in accordance with Code of Practice: *Hazardous manual tasks*
	■ selecting lighter plant and equipment
	■ using:
	  ■ mechanical equipment with automatic feed like drilling jumbos
	  ■ lifting aids
	  ■ vibration insulation on handles
	■ implementing
	  ■ lifting procedures
	  ■ engineering and ergonomic solutions
	  ■ manual handling procedures and training

Hazards or risks	Control measures

Heat stress	■ reducing use of high heat output plant
	■ increasing ventilation
	■ providing:
	  ■ air conditioned offices and meal rooms
	  ■ cool water
	■ using:
	  ■ cool suits
	  ■ heat acclimatisation strategies
	■ scheduling frequent rests

Noise	■ insulating plant ■ using hearing protection ■ silencing engines to achieve a noise level not exceeding LAeq 85 dbA at a distance of 1 metre

Dust, hazardous chemicals	■ increasing face extraction ventilation
	■ using water sprays on cutting equipment or over muck heaps and spoil conveyors
	■ providing:
	  ■ information like safety data (SDS) sheets
	  ■ spill kits
	■ using PPE

Electricity	■ planning and implementing tasks in accordance with the Code of Practice: *Managing electrical risks at the workplace*
	■ installing:
	  ■ hazard reducing devices like cut-out, earth-leakage and isolating devices
	  ■ back-up power supplies in case of power loss to critical systems like ventilation, pumping, emergency lighting and fire fighting systems
	■ inspecting equipment before use
	■ implementing lock-out procedures

Hazards or risks	Control measures
Fire or explosion, flammable gases and vapours	■ eliminating ignition sources underground where practicable ■ isolating fuel sources from remaining ignition sources ■ removing potential fuel sources from the work area ■ monitoring atmospheric conditions ■ storing only necessary fuel underground ■ implementing fire fighting training and procedures ■ ensuring availability of fire fighting resources ■ restricting smoking to designated areas ■ using a hot work permit system
Workplace security and visitors	■ implementing security measures like immobilising plant and locking fuel dispensers ■ erecting signs showing the name and contact telephone numbers of the principal contractor ■ locating offices, parking and delivery areas away from hazardous areas ■ isolating hazardous areas with perimeter fencing, barricades, screens, barriers, handrails or covers ■ installing hazard warning lights, signs, markers or flags

A checklist to assist in identifying hazards in tunnelling work is at Appendix C.

4. CONTROLLING RISKS IN TUNNELLING WORK

Safe systems of work and effective control measures should be put in place for tunnelling work. The system of work and control measures should be determined through consultation and the risk management process outlined in section 1.3. Designers and other relevant duty holders should participate in this process.

The following section describes most tunnelling methods and activities and provides examples of specific hazards, risks and control measures to be considered in addition to the common hazards, risks and control measures.

Specific guidance on risk control measures for excavation and construction work is in the Code of Practice: *Excavation work* and the Code of Practice: *Construction work*.

4.1 Excavation by hand

Most tunnelling work is partly or totally mechanised. Excavating by hand is generally limited to small sections within larger workplaces like a small shaft, sump or drive-in area with limited access and possibility for mechanisation.

Control measures must be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with excavation by hand.

Table 7 Specific hazards, risks and control measures – excavating by hand

Hazards and risks	Control measures

■ small work areas
■ hazardous manual tasks e.g. extra physical lifting and activity
■ falls from heights from non-mechanised access
■ falling objects from working:
  ▪ near the worked face
  ▪ under unsupported ground
■ installing bolts, sets and lattice girders for ground support
■ vibration effects on the body from using hand tools like rock drills or jack picks
■ noise from working near air tools and drills
■ contaminated ground or groundwater
■ dust from working near the face
■ heat stress from physical exertion
■ crush injuries from small mobile plant
■ contact with electric lines including electrical shock from services not removed or de-energised
	■ implementing regular face and scaling inspections
	■ using:
	  ▪ tools with non-conductive handles
	  ▪ mechanical lifting gear, winches, rigging systems
	  ▪ PPE like rubber boots, insulating gloves and hearing protection
	■ restricting entry to work area
	■ reducing worker numbers in work party
	■ monitoring daily exposure limits on vibration
	■ providing training and information like SDS
	■ supplying:
	  ▪ lighting and ventilation adequate for the task
	  ▪ drinking water and managing fatigue

4.2 Excavation using plant

Control measures must be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with excavating using plant.

Table 8 Specific hazards, risks and control measures - excavating using plant

Hazards and risks	Control measures

■ being hit by flyrock from roadheader or scaling activities
■ moving plant and components causing crush, nip or shear injuries
■ working at height on plant e.g. high service entry points
■ restricted operator visibility and communication from blocking view and loud continuous noises
■ fire from flammable liquids and materials
■ high pressure liquids or gases
■ exposure to high levels of noise
■ heat e.g. burns from localised heat sources or heat exhaustion from general heat
■ air contamination from excavation dust or exhaust emissions
■ radiation from lasers
	■ using:
	  ■ lock-out and security mechanisms including power isolation
	  ■ remote operations or having operators in protective cabins
	  ■ dust suppression sprays
	  ■ spotters, mirrors, cameras and feelers
	  ■ fire suppression equipment
	■ providing training to operators and other workers
	■ supplying lighting, ventilation and communication systems adequate for the task
	■ setting exclusion zones
	■ ensuring:
	  ■ plant maintenance
	  ■ effective traffic control
	■ having automatic plant cut-off in flammable atmospheres
	■ reducing stored flammable materials

Further guidance on specific types of plant used in tunnelling work is in Chapter 6.

4.3 Tunnel boring machines

There is a wide variety of tunnel boring machines (TBMs). The following features are common to many TBMs:

- Cross sectional circular cutting head with either cutting discs, scrapers, rippers or a combination to excavate the ground. The cutting head contains openings to allow excavated material to pass back through the cutting head, often to a conveyor or screw.
- A chamber behind the cutting head which may be under pressure (closed machine) or open to the ambient tunnel pressure (open machine).
- No shields, one shield or two shields with large metal cylinders the diameter of the cutter head. Propulsion rams and cutter head motors are commonly in the shield area.
- Trailing gantries containing support equipment and systems.

Further information on specific types of TBMs is in Appendix D.

The ability to combine features of several types of TBM and other mechanical excavation methods to create hybrid TBMs may eliminate risks but can also introduce new hazards which must be addressed. Control measures should be identified to eliminate or minimise, so far as is reasonably practicable, the risks and hazards associated with the TBM. Tables 9, 10 and 11 set out hazards, risks and control measures associated with the various types of TBMs.

Table 9 Common hazards, risks and control measures – TBMs

Hazards and risks	Control measures
Access restrictions	■ designing TBMs so there is safe access to maintainable parts including access for screw conveyor wear repair ■ ensuring emergency plans are in place for recovery of injured people ■ planning exit routes
Chemical exposure	■ limiting underground chemical storage ■ providing training and information, like SDS ■ using PPE

Crush areas, around grippers, walking feet or shields	■ using:
	  ■ visual lock out devices
	  ■ cameras and alarms to increase the visual field
	■ ensuring operators can clearly see when grippers and pads are deployed and if there are obstructions

Cutter head transport and access including heat exposure	■ using:
	  ■ an isolation process for cutter head access
	  ■ rear loading cutters and protecting cutter rings
	■ restricting other maintenance when work on the cutter head or cutter head entry is in progress
	■ ensuring ventilation for the task
	■ instigating safe manual handling procedures

Dust	■ isolating dust generating processes
	■ using:
	  ■ dust suppression, air filtration and scrubbers units
	  ■ 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

Hazards and risks	Control measures
Face collapse including risks from changing ground conditions, mixed face and preferential excavation of soft ground leading to risk of settlement	■ selecting plant through geotechnical modelling ■ ongoing assessment of ground conditions with geologists and designers during excavation ■ increasing monitoring ■ pre-treating and consolidating ground ■ assessing settlement and potential damage

Fire	■ providing fire suppression
	■ 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, like oxy cutting and welding
	■ using:
	  ■ fire resistant hydraulic fluid and fire resistant power cables for high voltage supply
	  ■ 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
	  ■ the ring builder can visually see rams when moving them
	  ■ use of exclusion zones so no work is done under unsupported ground
	  ■ limbs are kept well clear of plant
	■ inspecting installed ground support

Heat exposure	■ supplying:
	  ■ ventilation
	  ■ supplying chilled drinking water
	■ managing fatigue

Irrespirable atmosphere including toxic fumes	■ providing self-rescuers and checking their operation regularly ■ using emergency seals

Hazards and risks	Control measures
Noise exposure	■ using: ▪ hazard lights ▪ audible alarms ▪ hearing protection
Pressurised hydraulic systems including pressure release through screw conveyor discharge gate	■ using tunnel brackets designed to ensure the service pipes and cables are correctly supported ■ marking cut off valves clearly ■ inspecting hoses regularly for wear and replacing them if necessary ■ establishing communication protocols when pigging the slurry lines ■ having a sealable spoil screw conveyor tube ■ inspecting pipes, seals and packing before commencing operations ■ maintaining separation between workers and hose joints where reasonably practicable ■ using eye protection for operators
Slip and trips including risks from greasy walls and spillage from polymer use	■ ensuring housekeeping procedures are followed ■ using grated walkways ■ having spill kits available
TBM operation	■ isolating TBM access during maintenance ■ using: ▪ lock out systems to prevent accidental starting ▪ auto cut-offs for TBM roll and friction pads on grippers ■ deeming TBM operators competent by an independent party or the TBM supplier ■ developing and practising contingency plans
Tunnel collapse including ground and rock fall near shields and fingers; lining failure leading to potential ground and rock falls and degradation of excavated ground through drying, flaking and support failure	■ using geotechnical assessment during TBM design ■ ongoing assessment of ground conditions and ground support with geologists and designers during excavation ■ using finger shields including hoods ■ mapping ground conditions immediately behind shields ■ designing tunnel lining using geotechnical data and assessment including faults (shearing) and seismic activity including liquefaction ■ having quality assurance programs for lining and annulus void filling

Hazards and risks	Control measures
Water inrush including flooding	■ using: ■ flood doors, tunnel portals and shafts designed to prevent inundation ■ water spray barriers ■ bulkheads between face and workers with sealable doors ■ sealable spoil screw conveyor tube ■ automated or remote operated pumping systems ■ designing dewatering systems through geotechnical modelling ■ implementing emergency exit plan ■ monitoring groundwater inflow ■ probing under sea or river ■ estimated hydrostatic pressure input into tunnel lining design ■ alignment design incorporates known geotechnical data ■ having quality assurance programs for lining and annulus void filling ■ designing the tunnel to prevent flotation ■ calculating pressure for groundwater control

Table 10 Hazards, risks and control measures - slurry shield and earth pressure balance (EPB) TBMs

Hazards and risks	Control measures
Working with compressed air including incorrect EPB	■ using compressed air management plans and procedures ensuring: ■ correct EPB and compressed air pressure calculations ■ proper worker selection and training including worker recovery and the use of hyperbaric chambers
Working with high pressure slurry	■ establishing communication protocols for each end when pigging slurry lines ■ carrying out a separate risk assessment for the task ■ ensuring the centrifuge has a clear panel to allow visual inspection of spinning bowl ■ incorporating an interlock to prevent bowl opening if spinning
Working in high pressure atmospheres	■ implementing suitable controls from AS 4774.1-2003: *Work in compressed air and hyperbaric facilities - Work in tunnels, shafts and caissons*

Table 11 Hazards, risks and control measures - microtunnel TBMs

Hazards and risks	Control measures

■ Injuries when repairing the TBM
■ Failure of jacking and pipe handling system
■ Disconnecting and reconnecting electric and air pressure services
■ Shaft access
■ Crush areas including near pipe jacking rams
	■ preventing worker entry to the tunnel below minimum pipe diameters
	■ using lock outs and isolation procedures
	■ assessing lifting requirements
	■ using
	  ■ camera and communication systems
	  ■ Using designed access systems
	■ setting up exclusion zone during operation and maintenance
	■ checking:
	  ■ emergency planning is in place including planning safe retreats
	  ■ air hoses are connected correctly and use whip restraints
	  ■ body parts are clear when jacking pipes
	  ■ pipes are correctly handled
	■ inspecting pipes, seals and packing before pushing

TBM design should include a range of safety features including:

- automatic smoke detectors 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
- closed-circuit television in the control cabin with cameras fitted in the 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

- traffic lights 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
- easy 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

4.4 Drill and blast

Using the drill and blast method for tunnelling work is often limited by environmental constraints characteristic of many tunnel locations. In particular dust, noise and vibration concerns often limit blasting activities in urban locations.

Explosives laws require the storage, use and handling of explosives to be licensed. The person conducting a business or undertaking has responsibility for the control, safe and secure storage, use and handling of the explosives.

Only a competent certificated shotfirer should be allowed by the person conducting a business or undertaking to handle and use explosives. A blasting plan should be drawn up before blasting is carried out.

Only enough explosives for immediate use should be transported to the working face. Explosives should be transported in containers and vehicles specially designed for the purpose. They should be clearly marked and should always be accompanied by a competent person. Vehicles should be checked regularly to ensure they do not present a risk when transporting the explosives.

Charging should not start until drilling is completed and electric plant like water pumps are switched off and removed from the area.

In the threat of a thunderstorm, charging with electric detonators should be stopped immediately and the working face evacuated.

Where drill and blast operations are to be used specific SWMSs must be developed to cover the complete work process.

Detailed information on the handling, storage, transport and use of explosives is in AS 2187 (Series)[1]: *Explosives – Storage, transport and use.*

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with excavation by drill and blast. Some control measures to consider are provided in Table 12.

1 AS 2187 (Series): Explosives – Storage, transport and use -1996, 1998, Amendment 1-2000 and 2006

Table 12 Specific hazards, risks and control measures - drill and b

Hazards and risks	Control measures

■ storage, transport and use of explosives
■ unsupported ground including ground support requirements
■ ground vibrations and overpressures from blasting
■ fly rock
■ competence of explosives contractors and operators
■ effect on surrounding strata
■ face instability
■ injury from drilling and charging faces
■ firing times and preventing entry to firing areas
■ blasting fumes and dust
■ misfires
■ plant hitting people, plant or structures, like muck out loaders
■ water entry including flooding and collapse
	■ providing:
	  ■ a coating of shotcrete, known as a 'flash coat', for immediate ground support
	  ■ protection exclusion zones and safe places
	  ■ engineered ventilation
	  ■ geotech inspection and mapping
	  ■ defined procedures for explosive handling
	■ undertaking:
	  ■ scaling to minimise risk of rock fall
	  ■ drilling of lifter holes first where necessary
	  ■ vibration monitoring
	  ■ smooth blasting
	  ■ muck out using operators and spotters with traffic management plans
	  ■ gas monitoring
	■ controlling entry to the face
	■ using:
	  ■ mechanical scaling
	  ■ explosive management systems including computer control electronic blasting, blast and initiation design and approval processes
	  ■ dust suppression sprays
	  ■ competent, experienced and licenced workers
	  ■ re-entry procedures
	  ■ lighting
	  ■ deck loading
	  ■ using split face excavation - heading and bench
	  ■ PPE like hearing protection

4.5 Portal protection

Before tunnelling work starts portal entries not constructed in a permanent way—for example the final concrete structures are not in place—need support and protection from vehicles.

This support and protection will vary but should at a minimum include:

- ground support for the high wall above the portal entrance
- support for the portal brow or lip

- protecting the portal so it protrudes far enough out from the tunnel to protect people entering or leaving the tunnel from being hit by material falling from the high wall above the portal entrance, and
- diverting surface water from the portal and providing dewatering resources.

A fence or other barricade should be provided above the portal to stop entry above the portal.

Where the risk assessment has identified overheight vehicles, like dump trucks with tubs or trays up that may enter the tunnel you:

- should install clearance and advance warnings signs, and
- consider installing advance protective barriers and warnings, like ‘dangle bars’, to warn users that a vehicle will not fit under the structure or tunnel ahead.

4.6 Inspections and scaling

The roof and walls should be inspected immediately after blasting or a short section has been excavated and scaling loose rock carried out.

As rock surfaces deteriorate over time, regular follow up inspections and scaling should be conducted on unlined tunnel areas. A risk assessment with ongoing revisions based on the inspection results should be used to determine a suitable period for initial and regular inspection and scaling.

At shift changes there should be a handover discussion about the status of inspections and scaling including the areas not yet inspected and where drummy ground has been identified as this will require scaling or ground support.

Scaling should take place:

- for drill and blast excavation after each blast when the face, roof and wall areas and spoil heap have been washed down, and
- for other excavation methods
  - at times determined by the risk assessment
  - during the ground support cycle if more loose rock is revealed and as the ground support installation moves forward from supported ground, and
  - whenever the inspection shows there could be loose rock on a wall or roof.

The excavation should be washed down, for example with high pressure water before the initial inspection. Regular inspections should continue in the unlined tunnel areas to a schedule determined by the risk assessment.

Inspections and scaling should be conducted from supported and scaled areas. Where possible machine scaling is preferred to hand scaling. Hand scaling at heights should be from an elevated work platform (EWP).

Where hand scaling is done from beneath partially completed ground support, the EWP and people working on it should be protected from falling rocks. Where ground support is needed it should always be installed immediately after an inspection and scaling.

Drummy ground that cannot be scaled down should have ground support installed.

Particular attention should be taken at breakthroughs as the previous excavation and stress changes may weaken the ground. Where drummy ground needs support, mechanical means should be used so workers do not work under unsupported ground.

Table 13 Specific hazards, risks and control measures - inspections and scaling

Hazards and risks	Control measures
■ rock falls ■ tunnel collapse in unsupported ground ■ access	■ working in towards the face ■ scaling 'down dip' ■ always standing beneath supported ground ■ ensuring tools and materials are kept out of walking and working areas ■ inspecting with trained and experienced people

4.7 Ground support

Most tunnels need permanent ground support. The permanent lining can be installed as the excavation progresses or temporary support installed followed by a permanent lining. A second lining may also be installed.

Extra ground support or overhead protection may be needed to provide protection during the construction phase. Often the planned ground support varies as the tunnel dimensions or ground conditions change. The locations of changes should be included in the design documentation.

The ground support installed as a tunnel progresses will often alter with exposure. This change may be from actual ground conditions or experience gained from monitoring the performance of the supports.

Installing ground support should be done from areas where ground support has already been installed or using equipment which provides overhead protection for the operator or installer. Control measures should be implemented to avoid ground or materials like shotcrete falling on people. Risks from falling objects should be minimised, so far as is reasonably practicable, by providing effective barricading to stop people from accessing high risk areas. The potential for serious injuries from falling shotcrete is equal to those from falling rock.

The ground conditions should be inspected in line with the inspection plan as the excavation progresses. The results should be assessed and if conditions have changed from the original design the ground support control measures may need to change. A competent person should inspect, test and assess the ground support system including anchor testing of rockbolts, strength tests for shotcrete and concrete linings so necessary changes can be made to the specification. Each ground support method or type has its own hazards and risks during the installation process which must be eliminated or minimised, so far as is reasonably practicable.

Table 14 Specific hazards, risks and control measures - ground support

Hazards and risks	Control measures
■ rock falls or tunnel collapse when installing ground support ■ dust from drilling ■ mobile plant ■ collapse of fresh shotcrete	■ providing: ■ a coating of shotcrete, known as a 'flash coat', for immediate ground support ■ exclusion zones under freshly sprayed shotcrete ■ undertaking: ■ wet drilling of holes for dust suppression ■ daily checks of the condition of drill sets and tools and carrying out relevant maintenance ■ using: ■ procedures for flushing holes with water or air including keeping hands and face clear of pressurised water and air ■ procedures when working around plant ■ suitable PPE

4.8 Sprayed concrete

Sprayed concrete—known as shotcrete—uses high-powered hydraulic, pneumatic or electric plant to apply concrete by projecting it through the air.

Shotcrete application should only be carried out by a competent person. Shotcrete mixture should be designed to meet the strength and workability specified and to minimise dust levels. A wet mix shotcrete should be used along with non-caustic accelerators.

Surfaces contaminated with oil, dust or mud should be cleaned before shotcrete application and water entry is diverted.

During shotcreting no other activities should be carried out.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with sprayed concrete.

Table 15 Specific hazards, risks and control measures - sprayed concrete

Hazards and risks	Control measures
Transporting concrete in large plant, usually in confined spaces with poor lighting	■ providing: ■ exclusion zones and traffic management planning ■ lighting on the plant and at the work face ■ plant reversing alarms ■ using suitable PPE including high-visibility protective clothing
Transferring the concrete to the conveyor	■ providing guarding to prevent entry to the conveyor unit ■ using suitable PPE including splash protection for eyes

Hazards and risks	Control measures
Conveying the concrete	■ providing: ■ regular servicing of the plant according to the maintenance plan including checking conveyor tubes and hoses ■ relevant training to plant operators and mechanics
Applying concrete	■ providing exclusion zones and restricting entry to only workers involved in the concrete application ■ using suitable PPE including impact-resistant goggles, helmet, gloves, breathing apparatus, hearing protection, safety boots and full body clothing
After applying concrete	■ ensuring no entry to unprotected, unstabilised freshly sprayed areas

4.9 Shafts

Shafts are constructed to provide entry for people, materials, equipment and ventilation to a tunnel. Shaft construction methods and excavation techniques vary depending on conditions and their purpose. Shafts may be vertical or inclined and lined or unlined of various shapes.

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. When the shaft is unattended protective covers or a suitable fence should be used to prevent unauthorised access.

Access to the shaft bottom should be provided by either ladders, hoist or skip riding. If access is provided by ladder then landings are required at not more than 10 metre intervals. Ladders should be inclined and secured. If ladders are vertical they should be provided with safety cages.

Conveyances for people should be of substantial construction, prevent any part of a person therein protruding and be provided with a proper roof and inward opening doors that cannot open unintentionally. The conveyance should be clearly marked with its safe working load determined using a safety factor of ten.

An alternative means of access should also be provided for use in an emergency. For deep shafts a winder with its own power supply should be considered.

Materials transport should be separated from personnel transport with a suitable barrier. When units are used to transport personnel as well as materials and equipment the simultaneous transport of the two should not be carried out. Only an authorised person like a dogger should be allowed to travel in a personnel conveyance with material, with the exception of a person transporting explosives. Explosives must be transported according to the *Australian code for the transport of explosives by road and rail (Third edition).*

Equipment and materials should not protrude above the sides of the skip or kibble unless properly secured. Specially designed lifting units should be considered.

The safe working load of a headframe or lifting device must be clearly indicated.

Conveyors should be guarded and provided with an audible prestart alarm.

People operating mechanical hoists should be competent and authorised in writing to operate the equipment. The authorisation should be kept in a safe place and a copy displayed in the engine room.

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

The more common types of shafts and their construction techniques and excavation methods are discussed below.

4.10 Shaft sinking

Shaft sinking involves excavating a shaft from the top with entry and spoil removal from the top. Entry to the shaft is by ladder or hoist or other mechanical means. Alternative entry should be provided for use in an emergency. For deep shafts a winder with its own power supply should be considered.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with shaft sinking.

Table 16 Specific hazards, risks and control measures - shaft sinking

Hazards and risks	Control measures
■ shaft dimensions limits clearance ■ failure of hoisting equipment like winches, ropes and hooks ■ falls from heights ■ falling objects including fine material and water from the shaft wall ■ hoisting and winching people, materials, spoil and plant ■ working platforms or material kibbles hang up ■ communications ■ dewatering ■ ventilation ■ emergency exit	■ cleaning: ▪ spills off doors, stages and steelwork ▪ the underside of kibbles before lifting ■ lining the shaft early ■ avoiding overfilling kibbles ■ closing shaft doors before tipping ■ guiding the working platforms and kibbles ■ installing shaft barricades ■ inspecting equipment regularly ■ providing: ▪ alarms for systems failure and back-up systems including power supply, dewatering and gas detection ▪ emergency plans ▪ entry to the shaft including emergency exits ▪ procedures for carrying materials and workers ▪ signage, and ▪ fall protection and fall arrest systems

4.11 Raise boring

Raise boring is a method of constructing a shaft. A 'raise' is where underground entry has already been established. Raised bored shafts can be from the surface or from one level to another underground. The method is remote and does not require people to enter the shaft. It involves:

- installing a raise borer rig at the top of the planned raise above the existing tunnel or other underground excavation
- drilling a pilot hole down into the tunnel
- attaching a reaming head and back reaming to the rig to create the raise, and
- supporting the completed hole if it is needed by lining or installing ground support.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with raise boring.

Table 17 Specific hazards, risks and control measures - raise boring

Hazards and risks	Control measures

■ poor surface materials for rig set up
■ breakthrough causes unexpected rock fall
■ rock fall if the breakthrough area is not secured before bit removal
■ manual task problems with bit removal and reamer head attachment
■ spoil 'mud rush' after a hang up
■ falling into the shaft when removing reamer head or rig
■ working platforms or material kibbles hang up
■ cmmunications
■ dewatering
■ ventilation
■ dust
■ emergency exit
	■ monitoring the spoil flow and stop reaming if hang up occurs to reduce potential mud rush
	■ extracting and suppressing the dust using water sprays and ventilation
	■ co-ordinating the spoil clearance to reduce the likelihood of hang ups or falling material entering the tunnel
	■ undertaking:
	  ■ detailed geological mapping
	  ■ pre-drilling and pre-grouting
	  ■ pad preparation
	■ barricading:
	  ■ the bottom area with signage and limiting entry to authorised people
	  ■ restricting access to the breakthrough area well before breakthrough

4.12 Raised shafts

From underground entry a raised or a vertical or sub-vertical excavation may be needed to the surface or to another level. Methods available include:

- blind methods where no top entry is available including:
  - conventional or ladder raise may have application for some inclined excavations

  - a raise climber working off rail segments
  - shrink method for short excavations working off broken spoil
- other methods where top entry is available, for example:
  - cage or gig rise using a moving cage or platform hoisted through a rope in a pilot hole
  - long-hole rise using drill and blast, and
  - underhand benching or rise stripping.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with raised shafts.

Table 18 Specific hazards, risks and control measures - raised shafts

Hazards and risks	Control measures

■ working and entering below the excavated face before its inspection and scaling
■ working upwards as material can enter the eyes
■ falling objects, fine material and water from the shaft wall
■ communications
■ ventilation
■ poor air quality
■ isolation
■ access including emergency entry and exit
	■ providing entry using a two-level cage with the top level providing overhead protection when not at the face
	■ drilling a large diameter pilot hole for the cage rope and establishing ventilation up the hole
	■ barricading:
	  ■ the bottom area with signage and limiting entry to authorised people
	  ■ restricting entry to the breakthrough area well before breakthrough
	■ testing air quality

4.13 Caissons

Caissons are used when sinking shafts in very soft or wet ground conditions. This method is suitable for shafts generally larger than bored shafts. The caisson method involves:

  - stacking concrete or steel sections on each other at the surface with the lower or leading section having a cutting edge, and
  - excavation of the shaft bottom undercuts the edge of the leading caisson and the sections move downward together under their own weight or are driven down.

The shaft remains fully supported and lined for its entire length. Caissons may be pressurised in certain circumstances with compressed air to provide temporary ground support and reduce water entry at the shaft bottom.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with caissons.

Table 19 Specific hazards, risks and control measures - caissons

Hazards and risks	Control measures

■ working:
  ■ with compressed air
  ■ at height or over water
■ over excavation leading to ground loss
■ loss of annulus causing choking
■ shaft becoming buoyant in final state
■ lack of control of caisson including leaning, moving, loss of free board and uncontrolled movement
■ leaking joints
■ damage to air lock from spoil removal
	■ undertaking:
	  ■ detailed geotechnical investigations and mapping
	  ■ profile measurement and control
	■ ensuring:
	  ■ drainage and pumping
	  ■ procedures for compressed air work
	■ providing:
	  ■ air lock protection
	  ■ entry systems
	  ■ buoyancy aids

Further information on the requirements and control measures for working in a pressurised atmosphere with this method is in AS 4774.1-2003: *Work in compressed air and hyperbaric facilities – Work in tunnels, shafts and caissons*.

4.14 Ground freezing

Ground freezing is used in tunnelling, sinking shafts in very soft and wet ground conditions and where there is free running saturated sands. It can also be used for temporary ground support and preventing groundwater flow.

The wet ground where the shaft is to be sunk is artificially frozen, excavated as though it were solid rock, then lined and sealed before being allowed to thaw. The process can also be applied to horizontal development. Specific hazards and risks arise from the reduced temperature.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with ground freezing

Table 20 Specific hazards, risks and control measures - ground freezing

Hazards and risks	Control measures

■ effect from cold on:
  ■ people, equipment and materials
  ■ services including ground swelling and settlement on thawing
■ spoil removal melting or resolidifying
■ collapse from localised or general thawing or ineffective freeze due to moving ground water
	■ using:
	  ■ excavation and spoil-removal
	  ■ equipment adapted for cold operation
	  ■ heated operators' cabins and rest areas
	■ scheduling job rotation and rest periods

Hazards and risks	Control measures
■ increased nitrogen and decreased oxygen levels	■ monitoring: ■ temperature and refrigeration plant ■ ground movements ■ oxygen levels ■ providing cold-work PPE

4.15 Pipe jacking

Pipe jacking is mostly used in soft tunnelling conditions but may be carried out in rock. The tunnel is lined with a pipe installed in sections, pushed or jacked into the increasing tunnel length from the portal. It consists of a typical sequence where:

- A jacking pit is excavated, supported and reinforced to resist the jacking forces.
- Excavating a small section of tunnel takes place ahead of a leading pipe.
- The continuous line of pipe sections is jacked by hand or machine into position pushing the leading pipe up to the face.
- The face is excavated and as the pipe is pushed further sections are added at the rear as space permits.

The support and lining is provided by the pipe. Some face support may be needed in extreme conditions.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with pipe jacking.

Table 21 Specific hazards, risks and control measures - pipe jacking

Hazards and risks	Control measures
■ restricted entry and dimensions including the pipe-positioning area ■ jacking operation and jacking forces ■ soft material which leads to face failure ■ water, liquefied soil or mud inflow ■ pipe binds leaving face and excavated section exposed for longer than planned ■ visibility	■ using mechanical rather than manual lifting where possible ■ locating jack power pack away from work area in the pit ■ supporting the face during jacking ■ dewatering or grouting to reduce water inflow ■ lubricating pipes or installing intermediate jacking stations in longer tunnels ■ providing lighting ■ implementing procedures to not allow people under suspended loads

4.16 Compressed air tunnelling

This method is used to provide extra temporary ground support in very soft and extremely wet ground conditions. It is also used where other ways of stopping excessive water entering the tunnel or the ground collapsing into the tunnel are not possible. The pneumatic support process involves:

- providing a bulkhead with air locks for entry into the tunnel, and
- pressurising the tunnel with compressed air to hold back the water and weak strata.

Rigorous decompression procedures should be progressively introduced where compressed air working is carried out in tunnelling.

The risk of fire is higher than in normal tunnel operations from the increased oxygen present in the compressed air. Fires will ignite more easily and burn more vigorously making them more difficult to extinguish. Fixed fire extinguishing systems should be an integral part of tunnelling equipment when using compressed air.

Compressed air is used to gain entry to the cutterhead in slurry and occasionally EPB TBM tunnelling to keep the pressure on the face to support it and allow a person entry for maintenance. Only the head area is pressurised, not the entire tunnel as would be done in traditional compressed air tunnelling. It is rare for the entire tunnel to be compressed. However where the cutterhead area is compressed it carries with it the same risks and should be dealt with in the same way as compressed air tunnelling.

The lowest possible air pressure should be used.

Only suitably trained people should enter a compressed air environment. A person conducting a business or undertaking should check the person is competent and has proof of hyperbaric medical fitness before allowing them to enter the pressurised tunnel or cutterhead area.

Ventilation should be provided with a minimum of 40 m^3 (at working pressure) per hour per worker at the workplace and should have a capacity of at least 50 percent higher than normal flow requirements. The air temperature should be maintained between 15 and 30 ° C.

The safety lock should provide enough room for workers to move, sit normally and lie down and have dry warm clothes, first aid facilities, telephone communications, a window of at least 0.075 m diameter and non-radiant heaters. It should be fitted with thermometers and pressure gauges and be under the control of an attendant.

If the shift lasts for more than 4 hours a break of at least 30 minutes per hour should be taken.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with compressed air tunnelling.

Table 22 Specific hazards, risks and control measures - compressed air tunnelling

Hazards and risks	Control measures

■ fire
■ surface blow out
■ underground structure blowout or damage
■ ground stability failure during operations
■ recovery of injured people from a compressed air environment
■ poorly designed or commissioned systems leading to injury or loss of life
■ lack of medical facilities close by
■ health risks including the bends or bone necrosis
	■ installing fixed fire extinguishing systems
	■ implementing emergency rescue procedures
	■ ensuring:
	  ■ secure and stable air supply
	  ■ air locks have at least two compartments—one lock normally opens into the tunnel to permit workers into the face area and to escape to a safe place in an emergency and the other lock is open to free air to allow quick entry by an emergency team if needed
	  ■ constant air flow to provide ventilation and temperature control
	■ designing and operating air locks strictly governed by statutory compressed air regulations
	■ ensuring key people are on duty including:
	  ■ an appointed specialist doctor is on call
	  ■ lock attendants to control the routine compression and decompression of people
	  ■ compressor attendants to look after the plant and equipment
	  ■ emergency surface medical lock attendants
	■ emergency rescue team
	■ use of decompression tables
	■ providing fully manned medical airlock on site during compressed air tunnelling work
	■ providing fully manned medical airlock on site during compressed air tunnelling work

Further information on working in a pressurised atmosphere is in AS 4774.1-2003: *Work in compressed air and hyperbaric facilities – Work in tunnels, shafts and caissons*

4.17 Pressure grouting

Pressure grouting involves pumping a grout like a cement slurry or chemical grout under pressure into a void or porous ground. Pressure grouting:

- fills voids behind a tunnel or shaft lining to increase the integrity and strength of the lining or to reduce water inflow
- stops or reduces direct water inflows into the excavation, and
- improves ground conditions by cementing unstable areas.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with pressure grouting.

Table 23 Specific hazards, risks and control measures - pressure grouting

Hazards and risks	Control measures
■ cement or chemical grout dust ■ eye or skin contact with grout which causes chemical burns, poisoning and other toxic effects ■ ground fracturing ■ damage to nearby services, buildings or structures ■ high pressure hoses and connections ■ slips, trips and falls ■ mixing grout including manual handling ■ plant electrical supply	■ providing: ■ easy to read pressure gauge to assist in reducing the risk of exceeding specified grout pressure ■ washing and eyewash facilities at the grout site ■ manual handling procedures, team work and rotating duties ■ documenting the grout plan listing specified grout pressures and patterns ■ limiting: ■ hose lengths to minimise tripping hazards ■ cement bag size ■ ensuring: ■ plant is isolated for maintenance ■ electric leads are clear of water ■ using: ■ suitably rated pressure hose ■ hose clips on pressure hose connections ■ pressure release valves ■ PPE like gloves, dust masks and full face eye shields

4.18 New Austrian Tunnelling Method (NATM) or 'Observation Method'

Applying the tunnel ground support—in the form of rockbolts and shotcrete—as determined by the deforming ground as the excavation is carried out is known as the New Austrian Tunnelling Method (NATM) or 'Observation Method'.

This method relies heavily on inspections and monitoring by engineers from the design team. Surveying and installing sophisticated measuring instruments like load cells, extensometers and reflectors measures every deformation of the excavation.

The primary shotcrete lining is thin and the tunnel is strengthened by a combination of rock bolts, wire mesh and lattice girders. Closing the invert should be done as early as possible to complete the arch action and create a load-bearing ring. This is crucial in soft ground tunnelling work.

The design is dynamic during the tunnel construction. The participation of expert rock mechanics engineers or geologists is important to determine the primary ground support as well as the further design of ground supports during the excavation and classification of the rock mass.

4.19 Personal protective equipment

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 the risk. It may be used as an interim measure while higher level control measures are being implemented.

When and how to use PPE may be specified in the 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.

Table 24 sets out questions and information to consider for PPE in tunnelling work.

Table 24 Personal Protective Equipment

Considerations	Questions
Selecting PPE.	What PPE does the risk assessment recommend be provided to people carrying out the tunnelling work or visiting the workplace?
Respiratory protective equipment.	Are people exposed to harmful atmospheric contaminants like siliceous dust, diesel particulate matter and welding fumes? Should respiratory protective equipment be provided in combination with other control measures? How will people using respiratory protective equipment be provided with information, instruction and training in their use? Do workers know for the equipment to be effective a person needs to be clean shaven? Further information on respiratory protective equipment is in AS/NZS 1715:2009: *Selection, use and maintenance of respiratory protective equipment* and AS/NZS 1716:2012: *Respiratory protective devices.*
Self-rescuers.	Could people be exposed to harmful atmospheric contaminants beyond the capacity of the ventilation system or respiratory protective equipment? If so, should self-rescuers be provided to each worker? Self-rescuers allow a person to walk to the surface, a safe place or a respirable air equipped refuge chamber. The time the self-rescuer can be used needs to match the maximum distance the worker may have to walk to a safe place of refuge or the surface. Self-rescuers should be provided where tunnelling work involves: ■ tunnel excavation ■ combustible material that if ignited is likely to overwhelm the capacity of the ventilation system, and ■ processes with the potential to cause the atmosphere to become irrespirable.

Considerations	Questions
Clothing to protect against chemical exposure.	Is there a risk of people being exposed to chemicals or contaminated environments in the tunnelling work? What control measures should be implemented to protect workers? Information on protection against hazardous chemicals is in the Code of Practice: *Managing risks of hazardous chemicals in the workplace.*
Eye protection.	What tunnelling work activities will cause dust and flying objects? Will there be cutting, or chipping of rock concrete or metal, chemical handling or welding? Where should eye protection be required? Further information on selecting, using and maintaining eye protection is in AS/NZS 1336:1997: *Recommended practices for occupational eye protection.*
High visibility garments.	Is the tunnelling work near mobile plant or equipment? Is high visibility clothing being used? Have workers been instructed that clothing not covered by the high visibility garment should be light coloured and garments should be selected for best contrast with the surrounding background? Information on selecting, using and maintaining this clothing is in AS/NZS 4602.1:2011: *High visibility safety garments – Garments for high risk applications.*
Safety helmets.	Have safety helmets been selected in accordance with AS/NZS 1801:1997: *Occupational protective helmets* and AS/NZS 1800:1998: *Occupational protective helmets – Selection, care and use.*
Footwear.	Has footwear including wellingtons and waders been selected in accordance with AS/NZS 2210.1:2010: *Safety, protective and occupational footwear - Guide to selection, care and use?*
Waterproof clothing.	Are high visibility features incorporated into waterproof clothing? For further information on the high visibility requirements see AS/NZS 4602.1:2011: *High visibility safety garments – Garments for high risk applications*
Safety gloves.	Is there a risk of hand injury like cuts, abrasions or burns through exposure to a harmful substance, excessive heat or cold or to a mechanical device? If so, hand protection in accordance with AS/NZS 2161:2008: *Occupational protective gloves* should be used. Are different gloves required for different work activities?

5. AIR QUALITY AND VENTILATION SYSTEMS

The workplace must be ventilated to enable workers to carry out work without risk to health and safety. The consequences of poor ventilation include:

- exposure to:
  - excessive heat
  - fumes, substances or mixtures which can lead to unconsciousness, acute or long-term health problems and even death
- oxygen depletion, and
- fatigue and impaired judgment.

5.1 Quantity of air to be supplied or extracted

The quantity of air supplied or extracted from the face should be so the average air velocity at a full cross section of the tunnel or shaft is between 0.3 m/s and two m/s at all times.

The minimum quantity of air for people should be 1.5 m^3 per minute per worker and 4 m^3 per minute per kW of rated diesel power.

Workers in areas with a wet globe bulb temperature in excess of 27 ° C should be provided with control measures like those listed in section 5.8.

5.2 Mechanical ventilation

Mechanical ventilation is one way to:

- ensure oxygen is available for respiration from fresh air
- dilute and transport harmful atmospheric contaminants away from work areas
- have enough air flow to eliminate or minimise contaminants, so far as is reasonably practicable, and
- provide cooling for people working in warm and humid environments.

The ventilation design should check there is:

- no dead spots
- no low air speed areas
- no flow reversals
- no areas of dust concentration
- no recirculation, and
- inspection points are fitted where blockages are likely to occur.

When a mechanical ventilation system is used to eliminate or minimise, so far as is reasonably practicable, the risk of exposure to a contaminated atmosphere the system should be:

- located as close as possible to the source of the contaminant to minimise the risk of inhalation by a person at work
- used for as long as the contaminant is present
- kept free from accumulation of dust, fibre and other waste materials and maintained regularly, and

- designed and constructed to prevent the occurrence of fire or explosion if the system is provided to eliminate or minimise, so far as is reasonably practicable, contaminants arising from flammable or combustible substances

Further information on ventilation methods and equipment is in Appendix E.

5.3 Atmospheric contamination in tunnelling work

Atmospheric contamination in tunnelling work can occur because:

- excavations can be a receptacle for gases and fumes heavier than air
- gases and fumes like methane, sulphur dioxide, carbon monoxide and carbon dioxide leak from gas bottles, fuel tanks, sewers, drains, gas pipes and LPG tanks into the tunnel particularly when other work is taking place nearby
- oxygen in a non-ventilated area can be depleted due to internal combustion plants, oxidation or other natural processes, and
- through blasting activities.

The ventilation requirements should be determined through a risk assessment.

Due to the nature of tunnelling work, contaminants generated in one area of the tunnel will move readily to other areas. Protection against airborne hazards should be provided to workers.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with atmospheric contaminants.

Table 25 Sources and control measures - atmospheric contaminants

Hazards and risks	Control measures

■ silica dust, refractory ceramic or other mineral fibres and diesel particulate material
■ toxic gases, fumes and vapours
■ explosive and asphyxiant gases
Sources of hazardous contaminants
■ tunnelling work like drilling and cutting or from existing excavations
■ produced in situ e.g. exhaust gases from compression ignition engines, welding or shotcreting or from blasting activity like carbon monoxide
■ introduced into the tunnel from the external environment e.g. liquid fuels or chemicals
■ fires or explosions
■ oxygen absorption from rotting vegetation or fires
	■ storing materials on the surface in places away from where ventilation fresh air intakes could be compromised through a surface fire or chemical spill
	■ using a ventilation system which is:
	  – monitored and upgraded to ensure air flows are always provided to the workplace
	  – promptly repaired and maintained
	■ ensuring bore holes and other penetrations are sealed
	■ providing re-entry testing procedures including re-entry times after blasting
	■ installing warning signage for areas without adequate ventilation

Hazards and risks	Control measures
	■ providing personal or machine-mounted continuous monitoring devices that sound an alarm when dangerous gas levels are reached ■ monitoring air flows for explosive gases and atmosphere contaminants regularly ■ protecting plant and using cut-offs in explosive atmosphere

Further information on atmospheric contaminants is in Appendices F and G.

5.4 Dusts and silica

Dust in tunnelling work should be eliminated or minimised, so far as is reasonably practicable. Airborne respirable dust particles too fine to be filtered by the nasal cavity can be inhaled or breathed deep into the lungs.

Long-term exposure to respirable dusts can lead to diseases ranging from bronchitis to cancer. Even if the dust is not at harmful levels it can cause irritation to the eyes and throat and increase the risk of physical injury due to poor visibility.

Dust can be generated about the workplace or underground by dry roadways, bare soil or rock, vegetation removal, traffic and wind.

Silica is the most common hazardous dust particle found in tunnelling work. A risk assessment should consider the presence of silica and the likely generation of dust containing silica. Exposure to respirable crystalline silica is known to cause silicosis, a respiratory lung disease that can be fatal.

Possible sources of the generation of dust in a tunnel should be identified and control measures implemented to eliminate or minimise, so far as is reasonably practicable, the generation of the dust at the source.

Table 26 Sources and control measures - dusts and silica

Sources of dusts and silica	Control measures
■ mineral dust can be generated and released into the atmosphere during tunnelling work when: ■ rock or concrete is broken, drilled, cut or blasted or wherever ground is disturbed ■ rock cutting with roadheaders or TBMs	■ using an exhaust ventilation system ■ maintaining extraction at or close to the point of generation by using brattice curtains or half-curtains to reduce dust roll-back ■ using extractors or dust collection devices in-line near the face ■ increasing ventilation capacity by increasing the extraction rate when and where needed

Sources of dusts and silica	Control measures
▪ loading broken rock at the face ▪ transporting spoil on conveyor belts ▪ working at spoil transfer points ▪ installing or removing ventilation ducts ▪ concreting and shotcreting, spraying and handling bagged ingredients ▪ moving plant ▪ muck piles dry out ■ respirable crystalline silica is a common mineral present in sandstone, clay, granite and many other rocks as well as in the overburden and spoil ■ dusts produced from cement during grouting and shotcreting	■ using wet spraying to suppress dust at the point of generation, e.g. conveyors, spoil heaps after blasting, while loading and on roadways ■ adding detergent to dust suppression water ■ using tools fitted with dust extraction or water attachments ■ using wet drilling ■ installing water applicators onto the plant rather than using hand-held applicators ■ keeping vehicle cabins: ▪ dust sealed and fitted with air filtering systems ▪ wet cleaned regularly ■ limiting exposure times to dust ■ assessing and eliminating or minimising, so far as is reasonably practicable, the risk of cross contamination between workplaces, work processes or workers' clothing ■ providing PPE like respirators rated for the concentration and duration of exposure ■ using special procedures and facilities for shotcreting

The method to clean workers' clothes at the end of each shift should not create a risk to the health and safety of the person cleaning the clothes. Compressed air 'blow-down' should never be used to clean dust from people and plant. Further guidance on laundering workers clothes is in the Code of Practice: *How to safely remove asbestos.*

5.5 Monitoring air quality

WHEN MUST AIR MONITORING BE DONE?

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

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

HOW DO YOU DETERMINE IF AN ATMOSPHERE IS HAZARDOUS?

Risks to health and safety associated with a hazardous atmosphere at the workplace must be managed. An atmosphere is a hazardous atmosphere if:

- the atmosphere does not have a minimum oxygen content in air of 19.5 percent by volume under normal atmospheric pressure and a maximum oxygen content of air of 23.5 percent by volume under normal atmospheric pressure
- 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
- a hazardous chemical in the form of a combustible dust is present in a quantity and form that would result in a hazardous area.

A risk assessment may be carried out to determine:

- the engineering control measures, work practices and on-site atmospheric or biological monitoring needed, and
- the monitoring program for airborne contaminants like dust and fumes including taking air samples and ensuring the relevant exposure standard is not exceeded or people are not exposed to a hazardous atmosphere.

WHAT AIR MONITORING SHOULD BE DONE?

After blasting, tests should be carried out before people are allowed to re-enter the tunnel. The tunnel should be monitored throughout the work period in accordance with a suitable procedure. The workplace should be examined by suitably qualified people using detection and measuring equipment.

The monitoring should include air testing for:

- flammable fumes or gases
- oxygen deficiency and the presence of asphyxiant gases
- unsuitable temperature and humidity, and
- airborne contaminants like toxic gases, fumes or respirable dusts.

The person conducting a business or undertaking must ensure air monitoring results are recorded and provided to people who may be exposed to an atmospheric contaminant.

No worker is to be exposed to a substance or mixture in an airborne concentration exceeding the exposure standard for the substance or mixture. Exposure standards are usually set for a standard 8 hour working day and a 5 day working week. Therefore during periods of extended work, like shift work or overtime that requires working longer than 8 hours per day or more than 40 hours in a week, exposure standards must be adjusted in order to comply with the WHS Regulations. For shorter working days or working weeks, it is not permissible to adjust the exposure standard.

Information on exposure standards is in Safe Work Australia's Workplace *Exposure Standards for Airborne Contaminants* or the Hazardous Substances Information System.

5.6 Using respirators

Where higher order control measures fail to eliminate or minimise, so far as is reasonably practicable, hazardous chemicals or respirable dust exposures the lower order control measure of PPE may have to be used. When respirators are supplied they should be capable of preventing people inhaling hazardous dust or other airborne contaminants at the concentration and duration of the exposure.

Information on the selection, use and maintenance of respirators is in AS/NZS 1715:2009: *Selection, use and maintenance of respiratory protective devices.*

5.7 Diesel emissions

Internal combustion engines other than diesel engines should not be used underground because of the higher level of carbon monoxide contamination and increased risk of creating an ignition source in hazardous atmospheres. However, the exhaust emissions from diesel engines are still a major source of contamination and oxygen depletion to a tunnel atmosphere and this should be considered when selecting, designing, operating and monitoring plant and ventilation systems.

Where diesel engines are used the tunnel ventilation should be monitored by testing the air for the products and effects of diesel engines including:

- oxygen deficiency and presence of asphyxiant gases like carbon monoxide, and
- airborne contaminants like toxic gases and fumes like diesel particulate.

To minimise the irritant effects of exposure, the underground work industry exposure standard of 0.1 mg per m^3 for submicron diesel particulate matter measured as elemental carbon should be achieved.

To determine whether carbon monoxide, carbon dioxide and nitrogen oxides emissions are below the specified limits, the performance of diesel engines should be tested at the exhaust before being approved for underground use. Testing should then be at monthly intervals.

Where diesel engines are used underground exhaust conditioners with particulate filters like water baths, scrubbers or catalytic converters can be installed and maintained as well as dilution and extraction provided by the ventilation system.

Catalytic converters are most suited to large engines used for heavy workload conditions like materials handling. Catalytic converters need cleaning or replacing at intervals recommended by manufacturers.

Smaller engines and those subject to intermittent running like service vehicles are more suited to water bath type exhaust conditioners. These types require regular and often daily filling up to remain operational. Low level shut down devices may be installed to stop operation before the conditioner becomes ineffective.

Diesel engines should not be operated close to underground air compressors connected to compressed air breathing systems. Diesel engines should not be left idling.

Overcrowding plant may cause excessive emission levels. Risk assessments can be used to identify these areas and the maximum emissions. Emission levels should be monitored through full load exhaust gas testing on the plant and by testing the diluted tunnel atmosphere.

5.8 Managing heat stress

To determine the level of heat-related risks for a worker the following should be assessed:

- environmental conditions like air temperature, radiant heat, high humidity and air flow
- physical work e.g. strenuous or light work
- work organisation e.g. exposure to heat and time of day, and
- what PPE and clothing like heavy protective clothing, is worn by workers.

A combination of these factors can cause heat stress or heat stroke and the effects can range from simple discomfort to life-threatening illnesses. Heat stress reduces work capacity and efficiency.

Table 27 Signs of heat stroke and heat stress

Signs of heat stress	Signs of heat stroke
■ tiredness	■ high body temperature
■ irritability	■ no sweating
■ clammy skin	■ hot and dry skin
■ confusion	■ loss of consciousness
■ light-headedness	■ convulsions
■ inattention	■ confusion
■ muscular cramps	

High temperatures and low air velocities provide little cooling effect. The potential for heat stress because of variability in environmental and work conditions should be assessed by using the basic Thermal Risk Assessment as described in the Australian Institute of Occupational Hygienists *Heat Stress Standard, March 2003*.

Control measures should be identified to eliminate or minimise, so far as is reasonably practicable, the risks associated with heat stress and heat stroke. They may include:

- providing extra ventilation in enclosed environments that may become hot
- reducing items of heat-producing equipment in the tunnel
- regulating air flow or modifying ventilation to ensure cooling
- refrigerating the air supply or water supply in extreme conditions
- providing extra ventilation fans to create air flows in low-flow areas
- implementing work and rest regimes relating to the physical fitness, general health, medication taken and body weight of each worker exposed to heat
- providing cool drinking water and suggesting that in line with industry practice workers drink half a litre of water each hour when hot environments cause excessive sweating
- carrying out a risk assessment and determining a monitoring regime
- monitoring air speed, wet bulb humidity and temperature regularly to determine the cooling effect
- rotating people in hot areas
- educating people to recognise symptoms of heat stress and heat stroke
- providing PPE like shade hats or shade structures for surface heat exposure and using cooling vests, either circulating liquid or gel pack style, and
- allowing workers to acclimatise to heat.

6. PLANT

Tunnelling work uses a variety of plant. Plant includes machinery, equipment, appliances, containers, implements and tools, and includes any component or anything fitted or connected to those things. Plant includes items as diverse as lifts, cranes, computers, machinery, conveyors, forklifts, vehicles and power tools.

People have duties under the Work Health and Safety (WHS) Act and Regulations to eliminate or minimise, so far as is reasonably practicable, workplace risks arising from plant use. All people involved with plant from its design through to its use and eventual disposal have duties. A person can have more than one duty and more than one person can have the same duty at the same time.

Control measures to eliminate or minimise, so far as is reasonably practicable, people being injured during the use and maintenance of plant used in tunnelling work should be provided and maintained as part of a safe system of work.

Table 28 Hazards, risks and control measures - plant

Hazards and risks	Control measures

■ confines of underground work
■ restricted visibility
■ noise
■ congestion
■ roadway conditions
■ pedestrian traffic
■ runaway plant
	■ selecting plant that is:
	  ■ designed for use underground or can be safely used if modified
	  ■ safe and easy to operate and maintain
	  ■ able to contribute to a safe working environment e.g. the ability to erect ground support immediately behind the excavated face or ability to eliminate or minimise dust
	  ■ suitable for the tunnelling work considering:
	    – dimensions for clearance purposes
	    – operational aspects like ventilation requirements and power and water usage
	    – the plant levels of emissions e.g. exhaust, noise, vibration and heat
	■ providing devices to divert and stop runaway plant
	■ ensuring the plant complies with regulations and standards like electrical standards
	■ delivering training to operate and maintain the plant safely
	■ using plant with automatic cut-off in flammable atmospheres

Powered mobile plant used in tunnelling work must include, so far as is reasonably practicable, devices protecting the operator against roll-over, falling objects or ejection and have warning devices for those at risk from moving plant. These devices are more easily included when the powered mobile plant is being designed.

Further information on how to use plant safely is in the Code of Practice: *Managing risks of plant in the workplace.*

6.1 Procedures for moving plant

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with plant movement.

Table 29 Specific hazards, risks and control measures - moving plant

Hazards and risks	Control measures
■ transporting and installing fixed plant like transformers ■ moving self-relocatable plant like roadheaders, TBMs, drill rigs and rock bolters ■ moving other vehicles in the tunnel like haul trucks, service and delivery vehicles, personnel carriers, locomotives, rail cars and loaders	■ reducing vehicle movements by using conveyors to remove spoil ■ providing pedestrian shelters ■ cleaning windows and lights ■ lining or regularly maintaining the tunnel floor ■ co-ordinating deliveries to and from the workplace to reduce empty or near empty journeys through back loading ■ scheduling activities to reduce traffic congestion ■ using a traffic management system ■ having vehicle operators remain in the cabin during loading and unloading if there is no risk and they are not needed to assist with loading and unloading ■ managing traffic to ensure vehicles and mobile plant park in a way that prevents potential runaway vehicles, enables clear access at all times and minimises reversing ■ providing high visibility reflective clothing and cap lamps ■ using track mounted vehicles where possible ■ ensuring plant has reversing alarms, mirrors and feelers

Tunnelling work where there is movement of powered mobile plant is high risk construction work. A SWMS must be prepared before the work starts.

6.2 Surface and underground fuelling

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated for surface and underground fuelling.

Table 30 Surface and underground fuelling considerations and control measures

Considerations	Control measures
Fuelling procedures	■ developing fuelling procedures that include fuelling: ▪ on the surface where practicable ▪ in a fuelling bay where there is no naked flame or lighting ▪ where smoking is prohibited ▪ when the engine is turned off ▪ where spill kits are available
Fuelling should only be conducted in designated fuelling bays	■ constructing designated fuelling bays with: ▪ safe distances from mobile plant traffic ▪ ventilation ▪ non-flammable materials ▪ leak proof reservoirs ▪ traffic barriers ▪ a sill or bund to prevent spilt fuel escaping to other areas ■ providing designated fuelling bays with ▪ oil-absorbent material to clean up spills and methods to dispose of used material promptly ▪ suitable fire extinguishers ▪ a hose and pump with a self-closing nozzle and a shut off tap to prevent fuel leakage when unattended. The gravity-method of fuelling may also be considered ■ ensuring designated fuelling bays are: ▪ not used for vehicle repairs or servicing ▪ without naked flames ▪ properly signposted ▪ locked when not in use
Fuels used in underground fuelling	■ transporting and storing fuel in strong leak-proof containers ■ limiting the amount of fuel stored to that needed for efficient operations ■ using diesel: ▪ that does not have a flash point below 61.5 °C ▪ containing less than ten ppm sulphur ■ further information on diesel fuel is in the *Australian Diesel Fuel Standards* under the *Fuel Quality Standards Act (2000)*

6.3 Specialist and other plant

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with specialist and other plant.

In addition to control measures for general plant Table 31 sets out other considerations and control measures.

Table 31 Specialist and other plant

Plant	Control measures

Specialist plant - like shotcrete rigs, jumbos, roadheaders, tunnel muckers, formwork, liner-segment handling equipment, spoil-car tipping station	■ having ventilation close to the tunnel face to remove dust
	■ locking-out plant according to manufacturer's instructions, like isolating power or discharging accumulators before accessing the face or carrying out maintenance, repairs or pick changes
	■ implementing procedures to avoid standing:
	  ■ under unsupported ground unless protected by overhead protection, either on the plant or in the work area
	  ■ near movable parts of the plant e.g. gathering arms, tail conveyors and booms and when the operator's vision is restricted

Locomotives and rail cars - often used to carry materials and people in tunnelling work	■ using:
	  ■ fail safe brakes with dead man control speed limiters and governors
	  ■ buffer stops
	  ■ anti-tipping and derailment systems
	■ restricting pedestrian access
	■ you should consider the following when selecting control measures:
	  ■ the maximum grade of the track
	  ■ diesel or electric powered system
	  ■ couplings and track type
	  ■ signalling and communication systems type

Conveyors - used in tunnelling work to transport spoil from the face to muck cars or directly to the spoil stockpile or disposal area on the surface	■ using:
	  ■ automatic shut down for choking or broken conveyors
	  ■ guarding to prevent people becoming entangled
	■ isolating conveyors from normal work areas
	■ implementing:
	  ■ power isolation procedures to allow for maintenance, spillage clean-up and cleaning the rollers
	  ■ procedures after shutdown and maintenance
	■ preventing:
	  ■ people from riding on conveyors by using barriers
	  ■ oversize material entering the conveyor system
	■ providing fire extinguishers

Plant	Control measures
Conveyors - used in tunnelling work to transport spoil from the face to muck cars or directly to the spoil stockpile or disposal area on the surface	■ reducing spillage from overloaded conveyors, for example by regulating the conveyor's feed rate, belt speed and size of material placed on the conveyor ■ suppressing dust with water sprays at drop points, extraction ventilation at drop points and enclosed conveyors ■ further information on conveyor safety is in AS 1755-2000: *Conveyors – safety requirements* which sets out the minimum safety requirements for the design, installation, guarding, use, inspection and maintenance of conveyors and conveyor systems
Personnel-riding vehicles - people should be transported in vehicles designed for this purpose	■ using vehicles that have: ■ seating for each person ■ overhead protection and an enclosure to ensure passenger safety ■ suitable entry and exit with doors and steps ■ ways for passengers to signal the driver, particularly if the driver is unable to see the passengers ■ communication systems ■ enough space for a stretcher and the ability to transport injured people ■ been assessed as having no risk to people where spoil or construction materials are transported together

7. OTHER TUNNELLING RISKS

7.1 Fire and explosion

Risks of fire and explosion during tunnelling work must be eliminated or minimised, so far as is reasonably practicable.

Fire underground rapidly consumes oxygen and produces noxious fumes and gases. The fire will reduce and in some cases eliminate visibility. There is a significant risk the fire will block at least one tunnel exit forcing workers to seek an alternate exit or a place of safety. Table 32 sets out questions and information to consider when selecting controls measures for fire and explosion.

Table 32 Fire and explosion

Considerations	Questions
Combustible materials	Are there combustible materials in the workplace? If so, the risk of fire is always present and you should prepare for it. Have potential ignition sources near flammable substances, dusts or waste materials been identified? These include: ▪ naked flames ▪ hot work like welding, cutting and grinding ▪ electrical equipment ▪ sources of static electricity, and ▪ people smoking.
Hot work procedures	Are blow torches, welding, cutting or other hot work equipment used where a resulting fire may endanger a tunnel entrance or exit or where the fumes from the fire may jeopardise the safety of people in the tunnel? Have procedures for these types of situations like the use of work permit systems in critical or identified fire risk areas been successfully implemented?
Fire fighting facilities	What fire fighting equipment should be available and where should it be located? Has fire fighting equipment been located on the ventilation intake side of the hazard wherever possible?
Training	How will training on basic recognition of fire hazards and prevention be delivered? Does the training need to include: ▪ the selection and use of extinguishers ▪ when and how to use self-rescuers and their limitations, and ▪ safe use of refuge chambers and fresh air bases?

FIRE AND THE PLANT AND EQUIPMENT

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with fire and plant and equipment.

Diesel equipment operating within the tunnel should be inspected for fire risk by a competent person. Table 33 sets out the hazards, risks and control measures associated with diesel equipment.

Table 33 Specific hazards, risks and control measures - fire and plant and equipment

Hazards and risks	Control measures
■ hydraulic or fuel hose failures allowing oil or fuel to spray on to hot parts ■ sparking from abraded direct-current (dc) power leads damaging fuel lines ■ hot surfaces like exhausts and turbochargers and binding brakes causing grease fires in wheel hubs and igniting tyres	■ installing fire suppression solutions on loaders, trucks, turbocharged vehicles and other vehicles larger than 125 kw like a fixed aqueous film forming foam (afff) or film-forming fluoroprotein (fffp) system ■ installing brake drag and brake temperature indicators ■ insulating high current electrical systems ■ using fail safe engine shut down systems ■ installing engine fire walls, particularly in loaders ■ relocating electrical wiring and hydraulic hosing from the engine compartment ■ shielding hot parts from possible oil or fuel spray

FIRE PREVENTION CONTROL MEASURES

The following control measures should be considered when implementing fire prevention procedures.

Table 34 Specific control measures - fire prevention and control

Considerations	Questions
Workplace emergency procedures	Have workplace emergency procedures for the level of fire risk been developed and practiced? Have escape routes, safe places and emergency assembly areas been established?
Removing hazards	Can tunnelling work activities generating flammable or explosive atmospheres be eliminated? Could they be eliminated or minimised, so far as is reasonably practicable, by providing ventilation? Are procedures in place to remove unnecessary flammable substances, dusts or waste regularly? Have flammable goods storage areas, identified with warning signs, been provided? If smoking is allowed are designated smoking areas provided?
Fire extinguishers	Are the required number and type of fire extinguishers strategically located around the workplace including flammable goods storage areas? Are there signs showing where fire extinguishers, fire hoses and hydrants are? Is the equipment easy to get to? Are training programs in place on fire fighting equipment?

Considerations	Questions
Breathable atmosphere	When should self-rescuers, breathing apparatus and sealable, self-contained atmosphere refuge chambers be provided? How will people be trained to use them safely?
Automated fire protection	Has providing automated fire protection been considered? This may depend on the type and size of plant used, the nature of the tunnel, difficulty of exiting underground work areas and the potential for fire.

7.2 Hazardous chemicals

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with hazardous chemicals.

When hazardous chemicals are used in tunnelling work care should be taken to minimise the risk of spillage or loss of containment. Only enough hazardous chemicals for use during one day or shift should be held below ground. A risk assessment should be conducted before a new chemical is introduced to the underground workplace. This should show if there is a potential for the chemical to cause hazardous contamination of the air or ground during normal use, storage and if containment is lost.

The SDS supplied by the manufacturer or importer will provide information on the hazards associated with the chemical including how to deal with spills, leaks and fires. Written procedures to use and handling chemicals safely including emergency procedures, should be prepared for chemicals posing a significant risk. Training should be given to anyone using these chemicals.

Further information on using hazardous chemicals safely is in the Code of Practice: *Managing risks of hazardous chemicals in the workplace.*

7.3 Health monitoring for hazardous chemicals

Tunnelling work may create environments which require health monitoring. Health monitoring is when you monitor a person to identify changes in their health status to certain hazards, like noise or hazardous chemicals. The type of health monitoring required depends on the hazard at the workplace.

Detailed information on health monitoring requirements is in the following guides:

- *Health monitoring for exposure to hazardous chemicals - guide for workers*
- *Health monitoring for exposure to hazardous chemicals - guide for a person conducting a business or undertaking, and*
- *Health monitoring for exposure to hazardous chemicals - guide for medical practitioners.*

7.4 Visibility and lighting

Lighting should be provided that:

- allows workers and others to move and work safely within the workplace

- does not create excessive glare, and
- allows safe entry and exit from the workplace including emergency exits.

Where static plant is used the work area should be light enough so moving parts are clearly visible. An emergency lighting system should be provided.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with poor visibility and lighting.

Table 35 Specific hazards, risks and control measures - visibility and lighting

Hazards and risks	Control measures

■ collisions
■ people being struck or run over by plant
■ inability to assess ground and plant conditions and other potential hazards
■ slips, trips and falls and fatigue
	■ providing hard-wired lighting at:
	  ■ transformer installations
	  ■ workshops or service bays
	  ■ fuelling points, pump stations or sumps
	  ■ stores areas and meal rooms
	  ■ loading and unloading points
	  ■ shaft and tunnel intersections
	  ■ plant rooms
	  ■ the transition zone some distance into the tunnel.
	■ providing:
	  ■ extra lighting at the face area including lighting on the platform of mobile plant
	  ■ lighting for detailed work, hazardous processes and where plant is being operated
	  ■ emergency exit lighting.

If there is a chance lighting and in particular the emergency lighting may fail then every person entering the tunnel should be issued with a cap lamp. There should be:

- lamps for each person underground
- cap lamps that do not increase ignition risks, and
- cap lamps that produce enough light to guide the user in a fire.

Further information on lighting is in the Code of Practice: *Managing the work environment and facilities.*

7.5 Working with compressed air

Tunnelling work often uses plant with compressed air systems. These include air compressors and receivers known as pressure vessels that may be stand-alone or be contained within the compressor unit, water traps, reticulation components and valves and hoses supplying compressed air powered tools and equipment. These systems create risks during installation and use.

Using compressed air involves risks and hazards uncommon to other power sources. Proper maintenance and frequent inspections of compressors and air-powered equipment is vital to ensure their safe operation.

Compressed air entering a body opening can rupture the area causing serious injury or death. Compressed air should not be misused to blow down dust from clothes, work areas or floors.

Oils in compressed air can contaminate ventilating air and control measures should be in place. To avoid fires low flash point lubricants should be used.

Air lines should be:

- manufactured with suitable materials and rated accordingly
- connected with suitable couplings and safety clips
- maintained, and
- supported and restrained at joints.

Air lines should not be:

- disconnected unless the supply has been cut off, and
- the pressure reduced to zero.

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with working with compressed air.

Table 36 Specific hazards, risks and control measures - working with compressed air

Hazards and risks	Control measures

■ sudden release of pressure due to a failure with pressure vessels or pipes, flexible hoses and tools
■ incorrect installation of pipes, inadequate pressure rating and stressed joints
■ incorrect work methods e.g.:
  ▪ pressure not bled before working on reticulation
  ▪ checks not made before pressurisation
  ▪ uncoupling hoses under pressure
  ▪ not fitting clips or chains
■ unsafe acts like cleaning with compressed air with unsuitable or no PPE
■ absence of or unsuitable PPE
■ breakdown products of oils in compressed breathing air including carbon monoxide
	■ ensuring:
	  ▪ compressed airlines have relevant colour coding or signage
	  ▪ traffic has clearance around plant including valves
	■ installing labelled isolation valves 200 m apart and at intersections
	■ supporting pipes at each end before a joiner and to the wall or roof
	■ maintaining:
	  ▪ equipment e.g. maintaining lines, repairing leaks promptly and placing receivers in protected positions
	  ▪ ventilation and cooling of equipment to prevent the dieseling effect of the air compressors internal lubricating oil and the potential risk of fire
	■ fitting hose restraint devices i.e. whipchecks to clip hoses and chain joints for hoses with diameters more than 25 mm or the operating pressure more than 760 kpa and according to manufacturers' instructions

Hazards and risks	Control measures

■ contamination of the atmosphere by air compressor lubricating oils, compressed air water condensate or exhaust in compressed air	■ storing equipment safely e.g. keeping compressor outlets away from diesel exhausts
	■ conducting periodic checks including:
	  ■ checking pressure gauges on receivers
	  ■ checking valves before turning on air
	  ■ clearing water traps and drains daily
	  ■ bleeding pressure from systems before disconnecting
	  ■ re-pressurising slowly
	  ■ checking pressure fittings for tension or other loads
	■ using suitable:
	  ■ equipment e.g. correct pressure-rated equipment like hoses, valves and pipe work and compressors supplying contaminant-free air
	  ■ PPE like safety goggles, face shields, dust masks and hearing protection

7.6 Electrical safety

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with electrical hazards in tunnelling work.

Electrical equipment in tunnelling work 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.

Detailed information on electrical safety is in the Code of Practice: *Managing electrical risks in the workplace* and Code of Practice: *Working in the vicinity of overhead and underground electric lines.*

PORTABLE GENERATORS

Portable generators should not be used in tunnelling work unless they are diesel-powered and fitted with exhaust scrubbers.

Detailed information on portable generators is in AS 2790-1989: *Electricity generating sets – Transportable (up to 25 kW)*, AS/NZS 3012:2010: *Electrical installations – Construction and demolition sites* and AS/NZS 3010:2005: *Electrical installations – Generating sets.*

7.7 Falls from heights

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with falls from heights in tunnelling work.

Table 37 Specific hazards, risks and control measures - falls from heights

Hazards and risks	Control measures
■ wet, slippery or uneven ground ■ inadequate lighting ■ unsecured and unstable ladders ■ shafts, excavations and elevated platforms ■ unsuitable PPE	■ providing fall protection while working near: ▪ shafts, pits, trenches and sumps ▪ cuttings and benches ▪ elevated structures like ventilation ducts, working platforms, service platforms, ladders, stairs, formwork, lifts and scaffolding ▪ bins, roofs, portal walls and batters ▪ plant, tanks and loader buckets

Further information on falls from heights is in the Code of Practice: *Managing the risks of falls at workplaces.*

7.8 Falling objects

Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with falling objects in tunnelling work.

Table 38 Specific hazards, risks and control measures - falling objects

Hazards and risks	Control measures
■ shafts including working stages or platforms within them ■ pits, trenches, sumps and benches ■ equipment, bins, tanks, kibbles, spoil stackers, lifts and plant ■ building roofs or walls of the tunnel, cuttings, portal walls or batters ■ rock and other material falling from passing trucks or during spoil loading and unloading ■ elevated structures like conveyors, hoisting facilities, bins, tipping mechanisms for spoil, working platforms, formwork, ladders and scaffolding	■ installing ground support quickly ■ changing design e.g. including kick and toe boards, chutes and splash plates ■ installing screens, overhead protection, protected walkways and lock-out danger areas ■ not allowing work above other people ■ using lanyards or thongs on tools

7.9 Vibration

Some types of plant when used in tunnelling can expose people to vibration. Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with that exposure.

Risk assessments should be prepared and control measures implemented based on the number of workers and work shift patterns, including exposure to the vibration risk likely to occur during the work.

In the absence of Australian exposure standards, vibration exposure limits are based on the European Directive: *Directive 2002/44/EC*.

Further information on vibration is in Safe Work Australia's fact sheets on hand-arm and whole-body vibration.

HAND-ARM VIBRATION

Hand-held plant that can cause exposure to vibration includes rock drills, jack picks, concrete vibrators and air tools.

Control measures to reduce hand-arm vibration exposure include:

- checking 'tool in use' vibration emission data from manufacturers or tool suppliers to identify and select those with the lowest vibration levels suitable for the job
- replacing hand-held tools and equipment with mechanised or remote controlled systems like rock-drilling jumbos or slide-mounted drills
- fixing 'out-of-balance' items
- regularly servicing plant to the manufacturers' specifications to reduce vibration
- using vibration-absorbing handles or rubber-type vibration insulating devices between the tool and the hands
- issuing suitable clothing and gloves to assist blood circulation by keeping the worker's hands warm, and
- providing workers with training and instruction before work starts about
  - keeping vibration exposure down to avoid hand-arm vibration syndrome
  - keeping tools sharp through a tool maintenance regime
  - handling tools
  - job sharing
  - keeping hands warm and dry, and
  - the increased risks of vibration health effects caused by smoking.

Hand-arm vibration exposure should be managed, controlled and maintained below 2.5 m per s^2 over the entire 8 hour shift, so far as is reasonably practicable. If vibration exposure exceeds this limit workers should have regular health monitoring as determined by a medical practitioner. Hand-arm vibration exposures should never exceed 5.0 m per s^2 over an 8 hour shift.

WHOLE-BODY VIBRATION

Mobile plant can expose workers to whole-body vibration.

Control measures to reduce whole-body vibration exposure include:

- using foot-pusher plates for sinking drills
- using suspended or vibration-absorbing seating in plant
- using suspension dampened and padded seating in personnel-riding vehicles, and
- travelling at reduced speed when travelling over uneven surfaces.

Whole-body vibration exposure should be managed, controlled and maintained below 0.5 m/s^2 over an entire 8 hour shift so far as is reasonably practicable. If vibration exposure exceeds this limit the exposed worker should have regular health monitoring as determined by a medical practitioner. Whole-body vibration exposures should never exceed 1.15 m/s^2 over an 8 hour shift.

Plant operators who are pregnant or have recently given birth should not be exposed to work involving:

- whole-body vibration, particularly at low frequencies, micro traumas and shaking that exceed an 8 hour daily exposure of 0.5 m/s^2, and
- shocks, jolts or blows delivered to the lower body.

7.10 Eye injury

Tunnelling creates a range of hazards which can result in eye injuries. Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with eye injuries in tunnelling work.

Table 39 Specific hazards, risks and control measures - eye injury

Hazards and risks	Control measures
Agents ■ physical - rock, metal shards, glass, mud, dust and polluted water ■ chemical - acids, fuel, cement powders, oil and ammonium nitrate ■ high pressure and compressed air ■ high pressure water ■ electromagnetic fields and radiation ■ laser beams **Actions** ■ repairing plant and equipment like pumps and water lines ■ installing ground support ■ hammering steel ■ welding ■ dropping objects or handling substances	■ using automated tunnelling methods and not drill and blast ■ covering substances when they are handled ■ using fitting guards and screens ■ avoiding pouring or improvising when handling hazardous chemicals ■ providing training, instruction and information ■ using PPE

7.11 Radiation

LASERS

Lasers are often used in tunnelling work. Uncontrolled exposure to laser beams can cause severe eye damage including cataracts. Control measures should be implemented to eliminate or minimise, so far as is reasonably practicable, the risks associated with laser use.

A plan including the location of sites where lasers are used and rules for their safe operation should be developed and implemented. Exposures should be eliminated or minimised so far as is reasonably practicable by limiting access to lasers, the use of them to only trained operators and restricting unauthorised movement near sites where lasers are used.

The following should be considered when selecting control measures:

- conditions under which the laser is used
- service and maintenance procedures
- level of safety training of people using the lasers
- results of medical surveillance, and
- other environmental factors.

The use of laser systems should be evaluated by those who are trained in this area and are familiar with the requirements for laser safety. Requirements for laser safety include:

- laser certification in accordance with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) standards
- assigning laser safety officers
- proper classification of lasers
- warning signs and labels
- medical surveillance, and
- the use of PPE.

Further information on laser classification and safety is in AS 2211 (Series)[2]: *Safety of Laser Products* and the Safe Work Australia fact sheet *Laser classifications and potential hazards.*

IONISING RADIATION

Geologic investigations often use gamma ray and gamma ray density measurements, for example to establish a model of the geology at tunnel level. Risk assessments should be carried out and health and safety procedures developed for the use of gamma ray equipment. A radiation and protection plan should be produced before ionising equipment is used in tunnelling work.

For further information on radiation safety in general contact ARPANSA or your state or territory government organisation dealing with ionising radiation.

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2 AS 2211 (Series) – Safety of laser products - 1997, 2002, 2004, 2006

APPENDIX A – OTHER REFERENCE MATERIAL

The following list of published technical standards provide guidance only and compliance with them does not guarantee compliance with the WHS Act and Regulations in all instances. This list is not exhaustive.

ISBN 978-2-9700623-0-0 ITA Report No.1	*Guidelines for good occupational health and safety practice in tunnel construction – ITA Working Group - Health and Safety in Works*
BS 6164:2001	*Joint Code of Practice for Risk Management of Tunnel Works in the UK*
ISBN 978-0-7277-2986-5	*BTS ICE specification for tunnelling - International Tunnel Insurers' Group (ITIG): A Code of Practice for Risk Management of Tunnel Works*
EN815	*Safety of unshielded tunnel boring machines and rodless shaft boring machines for rock*
EN12111	*Tunnelling machines, roadheaders, continuous miners, and impact rippers - Safety requirements*
EN12336	*Tunnelling machines, shield machines, auger boring machines, lining erection machines – safety requirements*
EN1710	*Equipment and components intended for use in potentially explosive atmospheres in underground mines*
EN12110	*Tunnelling machines, air locks, safety requirements*
L96 HSE Books	*A guide to Working in Compressed Air Regulations 1996*
EN791	*Drill rigs – safety*
VSN 189	*Instruction of design and work in artificial ground freezing metro and tunnel construction*
CIA Z5-2010	*Shotcreting in Australia*
ACI 506.5R-09	*Guide for Specifying Underground Shotcrete*
AS 1270-2002	*Acoustics – Hearing protectors*
AS/NZS 3666 (Series):2011	*Air-handling and water systems of buildings – microbial control*
AS 1418 (Series)-2011	*Cranes, hoists and winches – General set*
AS 2550 (Series)-2011	*Cranes, hoists and winches - Safe use set*
ISO 2374	*Lifting appliances - Range of maximum capacities for basic models*
AS/NZS ISO 6529:2006	*Protective clothing – Protection against chemicals – Determination of resistance of protective clothing materials to permeation by liquids and gasses*
AS/NZS 4503.2:1997	*Protective clothing – Protection against liquid chemicals – Test method: Determination of resistance to penetration by a jet of liquid (Jet Test)*
AS/NZS 4503.3:1997	*Protective clothing – Protection against liquid chemicals – Test method: Determination of resistance to penetration by spray (Spray Test)*
AS/NZS 1210:2010	*Pressure vessels*
AS 2294.1-1997	*Earth-moving machinery - protective structures - general*

AS 2958.1-1995	*Earth-moving machinery – Safety – Wheeled machines – Brakes*
AS 2958.3-1992	*Earth-moving machinery – Safety – Roller Compactors – Brake systems*
AS/NZS 3000:2007, Amendment 1:2009, Amendment 2: 2012	*Electrical installations (Australian/New Zealand Wiring Rules)*
AS 3745-2010	*Planning for Emergencies in Facilities*
AS 2985-2009	*Workplace atmospheres – Method for sampling and gravimetric determination of respirable dust*
AS/NZS 1873 (Series):2003	*Powder-actuated (PA) handheld fastening tools*
AS/NZS 1337 (Series):2010, Amendment 1-2011, 2012	*Eye and face protectors*
AS/NZS 1336:1997	*Recommended practices for occupational eye protection*
AS/NZS 1891.4 (Series):2001, 2007, 2008	*Industrial fall-arrest systems and devices – Selection, use and maintenance*
AS 2030 (Series) -1985, 1996, 1999, 2000, 2009	*Gas cylinders*
AS 2337- 2004, 2006, Amendment 1-2007	*Gas cylinder test stations*
AS 3509-2009	*LP (liquefied petroleum) gas fuel vessels for automotive use*
AS 2359 (Series) -1995, 1996, 2005	*Powered industrial trucks*
AS4488. (Series) - 1997	*Industrial rope access systems*
BS EN 1263-1	*Safety nets – Safety requirements, test methods*
BS EN 363	*Personal fall protection equipment – Personal fall protection systems*
BS EN 365	*Personal protective equipment against falls from a height – General requirements for instructions for use, maintenance, period examination, repair, marking and packaging*
AS 2211 (Series) - 1997, 2002, 2004, 2006	*Safety of laser products*
AS 2397-1993	*Safe use of lasers in the building and construction industry*
AS 1735 (Series) – 1986, 1989, 1993, 1995, 1998, 1999, 2000, 2001, 2002, 2003, 2006	*Lifts, escalators and moving walkways*
AS 4024 (Series) - 2006	*Safeguarding of machinery*
AS 1657-1992	*Fixed platforms, walkways, stairways and ladders – Design, construction and installation*
AS 1788.1-1987	*Abrasive wheels – Design, construction and safeguarding*

AS 1788.2-1987	*Abrasive wheels – Selection, care and use*
AS 1893-1977	*Code of practice for the guarding and safe use of metal and paper cutting guillotines*
AS 2661-1983	*Vapour degreasing plant - Design, installation and operation - Safety requirements*
AS 2939-1987	*Industrial robot systems - Safe design and usage*
AS 3947 (Series) – 2000, 2001	*Low-voltage Switchgear and Control Gear*
AS 61508 (Series) – 2006, 2011, 2012	*Functional Safety of Electrical / Electronic / Programmable Electronic Safety-Related Systems*
BS EN 61496-1	*Safety of Machinery – Electro-sensitive protective equipment – General requirements and tests*
AS/NZS 1269.3:2005	*Occupational noise management – Hearing protector program*
AS/NZS 1200:2000	*Pressure equipment*
AS 2593-2004, Amendment 1-2007	*Boilers – Safety management and supervision systems*
AS 2971-2007	*Serially produced pressure vessels*
AS/NZS 3788:2006	*Pressure equipment - In service inspection*
AS 3873-2001	*Pressure equipment - Operation and maintenance*
AS 3920-1993, Amendment 1-1995, Amendment 2-1999	*Assurance of product quality – Pressure equipment manufacture*
ISO/11439	*High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles*
AS 2225-1994, Amendment 1-1996	*Insulating gloves for electrical purposes*
AS 4041-2006	*Pressure piping*
AS/NZS 1680.0:2009	*Interior lighting – Safe movement*
AS 2293.1-2005 AS 2293.1-2005/Amdt 1-2008	*Emergency escape lighting and exit signs for buildings – System design, installation and operation*

APPENDIX B – DEFINITIONS

Anchor means a device or thing by which a lanyard, static line or other line may be attached to a building or other structure, and includes the part of the building or structure to which the device or thing is attached.

Examples:

- a stainless steel eyebolt, set in a concrete floor, to which a lanyard may be attached
- a sling around a steel I beam, with padding under the sling, joined by a shackle or other joining device to which a lanyard may be attached, and
- a plate for a travel restraint system fixed by screws to a roof component to which a lanyard may be attached.

Barricade means a self-supporting fence, or a self-supporting series of continuous plastic, concrete or other solid barriers, usually temporary, erected or placed to restrict the entry of people or plant to a workplace. Examples include:

- steel pickets joined by chain wire of a height to restrict entry
- steel pickets joined by rows of wire a height to restrict entry, and
- steel pickets joined by taut plastic webbing commonly known as para-webbing.

Batter is the face or side of a wall of an excavation at an angle, usually less than the natural angle of repose, to prevent earth slippage.

Caisson means a structure that provides an underground passageway or a passageway through water.

Compressed air means air under greater pressure than atmospheric pressure. It is used to power or drive a mechanical device, or in the case of drilling to remove debris from the point of drilling to prevent fouling or a premature failure of the drill.

Deck loading is a method of loading blast holes in which the explosive charges, called decks or deck charges, in the same blast hole are separated by stemming or an air cushion.

Dogger means a person who:

- uses techniques including selecting or inspecting lifting gear and to safely sling a load, or
- directs a crane or hoist operator to move a load when the load is out of the operator's view.

Place of safety means a place where workers can shelter in the case of an emergency. A place of safety can only be where there is ventilation and protection from fire.

Repair means to restore plant to an operating condition, but does not include routine maintenance, replacement or modification.

Scrubber is a pollution control device, usually installed on air exhaust systems of plant.

Self-rescuer is a respirator generally designed to be belt-mounted and put on immediately to provide a breath-activated oxygen supply according to demand. Self-rescuers provide certain duration (minutes) of breathable air under specific work rate conditions. They also need regular inspections and have a maximum storage life limit.

Shotcrete is a commonly used term for sprayed concrete. Shotcrete is mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface.

Split face excavation - heading and bench is separating a large excavation into two or more faces, usually a top heading tunnel excavation with horizontal holes followed by a bench excavation with vertical holes.

Static line means a flexible line, to which a lanyard is attached, supported by at least two anchor points located so the angle between the horizontal and an imaginary straight line between an anchor point and the other or nearest anchor point is:

(a) if the manufacturer of the flexible line has specified the size of the angle—not more than the size specified, or

(b) if the manufacturer has not specified the size of the angle - not more than 5 degrees.

Unsupported ground means ground that is not, through its own strength and additional support provided, able to remain stable for the required time.

Zone of influence means the volume of soil around the excavation affected by an external load, for example vehicles, plant or excavated material.

APPENDIX C – EXAMPLE HAZARD IDENTIFICATION CHART

The following table is a sample hazard identification chart for hazards and risks to workers associated with tunnelling work.

Table 40 Hazard identification chart

Item	Explosion	Fire	Rock burst or fly rock	Objects into eye	Gas dust	Injury from electricity	Fall injuries	Traffic	Pinch injury
Drilling									
Blasting									
Loading									
Charging holes									
Scaling from pile									
Machine scaling									
Storing explosives									
Storing gas									
Ventilation work									
Grouting of bolts									
Electrical work									
Hot work									

APPENDIX D – TUNNEL BORING MACHINES

OPEN OR UNSHIELDED TBMS

Open TBMs—also known as unshielded TBMs—install temporary or permanent ground support, if needed by geological conditions, to maintain the integrity of the excavation.

The TBM is braced radially with grippers against the tunnel wall, with hydraulic cylinders pressing the cutter head against the tunnel face to enable a section of tunnel to be excavated. After each excavation stroke excavation is halted as the TBM moves forwards.

SINGLE OR DOUBLE SHIELDED TBMS

Single shield TBMs use a tapered cylindrical shield to provide overhead protection behind the cutting head. The TBM is commonly propelled by thrusting hydraulic rams against the last ring of a precast concrete or steel segmental lining which has been installed within the shield. Due to this process the TBM cannot excavate while the lining is being installed. Note that until a full ring has been completed the ring of segments is inherently unstable and temporary support should be used.

Single shield TBMs are used when rock strength is low and the tunnel walls cannot react against the action of the gripper pads. It uses the concrete lining ring to advance, so installing lining segments and excavation cannot be done simultaneously.

Double shield TBMs typically combine grippers and shields to enable continuous excavation in optimal conditions. Grippers are used to transfer force to the tunnel wall while the cutting head is extended to excavate. A rear shield provides protection to install a segmental lining concurrently with excavation.

Ground support may include steel sets or rockbolts and mesh similar to a hard rock TBM. The hazards and risks with respect to tunnel excavation are similar to hard rock TBM excavation. Hazards and risks for segmental lining are as per soft ground TBMs. The hazards and risks associated with the use of single shielded TBMs are similar to double shields and soft ground TBMs

EARTH PRESSURE BALANCE (EPB) TBMS

The ability to use EPB TBMs in hard and soft ground makes them suitable for excavation through variable strata. EPB TBMs are suitable for excavation where soil at the excavation face is unstable. To prevent collapse of the excavation face, positive pressure is created by maintaining spoil under pressure with compressed air in the cutter head. Spoil from the face is typically removed by screw conveyor. Spoil can then be removed from the tunnel by numerous methods including conveyor belt and skips.

SLURRY TBMS

The ability to use a slurry TBM in hard and soft ground makes them suitable for excavation through variable soil and rock formations. Slurry TBMs are suitable for excavation where soil at the excavation face is unstable, particularly in unstable water-logged ground utilising hydrostatic pressure. The excavated spoil is mixed with slurry at the excavation face to create positive pressure to counteract the pressure exerted by the earth and groundwater preventing loss of stability at the excavated face. Spoil is removed by pumping the soil mixed with slurry to plant located outside the tunnel that separates the slurry from the spoil allowing recirculation of the slurry.

Compressed air is used to gain entry to the cutterhead in slurry and occasionally EPB TBM tunnelling to keep the pressure on the face to support it and allow person entry. Only the head area is pressurised, not the entire tunnel as would be done in traditional compressed air tunnelling. Compression of the entire tunnel is not often used. However compression of the cutterhead carries with it the same risks and should be dealt with the same as for compressed air tunnelling.

MICROTUNNEL TBMS

Microtunnel TBM excavation includes various low diameter forms of TBM excavation including pipe jacking, direct pipe and horizontal directional drilling. Features common to most forms of microtunnelling include propulsion of the machine from the launch site with thrust transferred to the face through the tunnel lining. The tunnel lining is inserted into the tunnel from the launch site as the TBM excavates though the ground with spoil transferred through pipes back to the launch site. Additional thrust jacking stations may be inserted in the tunnel with the lining at intervals to increase the range of the TBM.

APPENDIX E – VENTILATION METHODS AND EQUIPMENT

In considering the design and capacity of a tunnelling ventilation system a number of configurations and types of equipment may be used. The following are some of the main alternatives.

TYPES

Types of ventilation systems include:

- forced supply
- extraction
- alternating or a combination of extraction and forced supply, and
- overlap systems.

FANS

Fans are used to force or extract air in the methods above. Fans may be:

- single, double or multiple stage
- contra-rotating or non contra-rotating normally in matched pairs
- direct driven with the motor within the fan casing or driven with motor outside the fan casing, and
- flameproof type suitable for use in hazardous atmospheres or non-flameproof type.

Fans are generally designated to be:

- primary fans
  - located either on the surface or underground but providing the main ventilation airflow or basic ventilation capacity to the tunnelling work
  - may be centrifugal or axial
  - are electrically powered, sometimes adjustable and often monitored, and
  - are often remain installed in a fixed position during the works.
- auxiliary fans
  - located underground in the proximity of the tunnel face providing the required flows at the active areas particularly in blind or dead-end headings
  - used for regulating the airflows about the tunnelling work
  - may be installed in-line as booster fans to increase the whole airflow in that line
  - are often moved forward as work progresses or ventilation needs alter, and
  - are generally axial flow and electric but may be compressed air powered for small short-term airflow applications.

Fans are:

- usually fitted with an evasé[3] if they are exhausting fans to increase efficiency and also with a shroud with a screen to prevent people or materials coming in contact with the blades
- available for special circumstances, like potentially flammable or explosive atmospheres, with very specific safety features, motor types and requirements

3 An evasé is a flow diffuser that converts kinetic energy into pressure energy

- selected to meet the demands of the tunnel work including equipment, smoke clearance, air velocity requirements, leakage losses, inefficiency and extra future needs, and
- valued for fan pressure and delivered air capacity against resistance or friction in the duct, the excavations or the workings.

DUCTING

As the airflow in a system will otherwise take the route of least resistance it is directed to the required tunnel areas by a combination of:

- ducting including
  - rigid ducting of steel or fibreglass for the main ventilation lines used in the extraction
  - system for lines under negative pressure—i.e. suction
  - flexible ducting of canvas and polythene for face ventilation and sometimes the main flows
  - for forced air flows under positive pressure—i.e. blowing, and
  - flameproof, special ducting for hazardous, inflammable or explosive atmospheres.
- airways including
  - shafts or ventilation rises conducting air to or from the surface, and
  - service drives or headings carrying ventilation intake or exhaust air.

REGULATING AIRFLOW

The airflow may be regulated by a combination of the following:

- barricades built of timber, steel, concrete, or bricks
- ventilation doors that can be opened or adjusted
- ventilation regulators that can be adjusted – usually fitted in a barricade
- booster or auxiliary fans to increase flows to selected areas
- brattice or fabric stoppings and brattice wings for directing low pressure flows to areas with little air movement like pump stations or refuge chambers, and
- altering fan settings to change flows.

MONITORING THE VENTILATION SYSTEM

Ventilation systems are monitored by measuring a number of atmospheric conditions. This can be done by using instruments including:

- a mercury or aneroid barometer to determine air pressure differences at different points in the system
- wet and dry thermometers to determine the temperature and humidity in the tunnel
- a sling psychrometer to more accurately determine the relative humidity in the tunnel
- a Kata thermometer to determine the cooling effect of air
- a water gauge for measuring air pressure differences e.g. across a fan and normally used with a pitot tube
- an anemometer (usually mounted on a stick) to measure the air velocity in the tunnel
- continuous dust and gas monitoring equipment, and
- handheld electronic gas monitors or gas test tubes to determine the concentration of contaminants or other gases in the air.

FORCED VENTILATION SYSTEM

In a forced ventilation system fresh intake air is drawn from the outside and pushed through ducting or other headings by in-line fans to the working faces. This system has the following advantages:

- the air flow can be distributed through flexible ducting that is cheaper and easier to install than rigid ducting
- there is generally no need for an extra overlap system at the face as a sacrificial section of flexible ducting can be used at the high wear section near the tunnelling activity, and
- activity behind the face like trucking or service works in the access do not become a source of contaminants at the working face as the airflow is away from that face.

Some of the disadvantages of this system include:

- the work activity, apart from near the fresh air discharge points, takes place in 'return' air that has been contaminated with dust or fumes from the working places
- the system relies simply on the dilution of the contaminants or heat to provide a safe environment
- the principle of capturing the contaminants as close as possible to the source is not possible
- flexible ducting tends to suffer more damage and have higher maintenance than rigid ducting
- the system is not readily boosted with in-line fans, and
- auxiliary ventilation of other areas consists of forcing diluted contaminated air into these areas.

EXTRACTION VENTILATION SYSTEM

In an extraction ventilation system contaminated exhaust air is drawn from the working faces or places through rigid ducting or headings to the surface by the fans, either fitted in-line, into barricades or on shaft tops. This system has the following advantages:

- the contaminants from the face tunnelling activity are captured in the ventilation system very close to the point of generation
- there is little contact with contaminants from the face activity
- leakage occurs into the duct only
- an overlap system is readily installed at the face to protect ducting and to allow face advance and ventilation extension
- it can be incorporated with dust filter systems behind TBMs or roadheaders
- in-line boosting is readily done by fitting an axial fan in-line subject to power availability and pressure considerations, and
- auxiliary ventilation of other areas is possible by breaking into the ducting and installing tee or y pieces.

This system has some disadvantages which should be considered including:

- the rigid ducting is harder to repair or replace than flexible ducting
- installation rates are slower for rigid ducting

- costs are higher for rigid ducting as it is harder to store and takes up more room
- more leaks are possible due to the greater number of joints and the need to align and sleeve each joint
- a forcing system or overlap is still needed at the face generally to allow flexibility and to reduce the number of set-ups to install rigid ducting that is ideally done from some distance behind the face
- it is heavier than flexible ducting and can contribute to manual task risks and crush risks
- the "capture zone" in front of the duct inlet is small, and
- the dust, fumes or gases from activity behind the face is drawn to the face first before being exhausted to the surface.

Combination systems of forced and exhaust ventilation are possible.

OVERLAP SYSTEM

In an overlap system:

- a forcing fan and ducting with the forcing fan set behind the end of an extraction system is used
- the forcing fan must have a lesser capacity than the extraction capacity at this point. If not, recirculation will occur, and
- the forcing fan will push fresh intake air to the face where it will return with the contaminants to the exhaust duct and be removed to the surface.

VENTILATION SYSTEM NOISE

As ventilation fans are a major source of noise underground, the noise levels generated by the ventilation systems should be limited to those levels determined in the regulation. Common industry practice is to limit the noise levels associated with ventilation equipment to below 100 dBA for intermittent exposures. Various silencers are available or can be built for noise abatement. Fans can also be mounted within sound reducing structures.

APPENDIX F – ATMOSPHERIC CONTAMINANTS

Gases or fumes commonly found in excavations are listed in Table 41.

Table 41 Origins of gases and fumes

Gases or fumes encountered	Origin
Methane, hydrogen sulphide	Peaty ground and decaying organic matter
Carbon dioxide, hydrogen sulphide	Filled and made ground
Carbon dioxide, methane, hydrogen sulphide	Reclaimed land and tip fills
Natural gas and carbon dioxide	City streets, leading gas reticulation pipes
Carbon monoxide, carbon dioxide, hydrogen sulphide, sulphur dioxide, methane	Thermal areas, combustion
Petrol fumes, LPG, kerosene	Petrol installation, service stations, underground filling stations

Common sources for hazardous atmospheric contaminants are listed in Table 42.

Table 42 Origins of other atmospheric contaminants

Activity	Contaminant	Harmful component
Hot work	Welding or cutting fumes	Metal oxides, oxides of nitrogen, ozone, fluorides.
Operation of internal combustion engines	Exhaust fumes	Carbon monoxide, carbon dioxide, diesel and other particulates, oxides of nitrogen, fuel vapours, aldehydes and hydrogen sulphide. Oxygen depletion can occur.
Excavation	Rock dust	Crystalline silica and other mineral dusts.
Shotcreting, rock bolting, concreting, grouting	Cement dust or accelerator	Cement dust, ammonia and chemical accelerating compounds.
Battery charging	Vapours	Flammable gas, acid fumes.
Shot firing	Blasting fumes	Crystalline silica dust, ammonia, oxides of nitrogen, carbon monoxide, sulphur dioxide, carbon dioxide.

Table 43 provides a guide to the effects and consequences of some common atmospheric contaminants at various concentrations.

Table 43 Effects and consequences of some common atmospheric contaminants

Common contaminants	Range of typical effects at increasing levels of exposure above acceptable limits
Carbon dioxide	Increased depth of breathing within 15 minutes of exposure. Feeling of inability to breathe, headache, dizziness, sweating and disorientation. Nausea, strangling sensation, stupor and loss of consciousness within 15 minutes. Many deaths reported from exposure above 20 percent.
Carbon monoxide	Headache within a few minutes. Possibility of collapse in half hour, coma in one hour and possible death in 1.5 hours.
Hydrogen sulphide	Initial eye irritation then loss of sense of smell. Rapid breathing, respiratory arrest, collapse, death. Immediate collapse and respiratory paralysis, death.
Nitrogen dioxide	Considered dangerous for short-term exposure. Moderately irritating to eyes and nose. Fatal within 30 mins. Death is due to fluid build-up in lungs (pulmonary oedema) leading to asphyxia.
Sulphur dioxide	Irritation of the eyes, nose and throat; choking and coughing within 5 to 15 minutes. Immediately dangerous. A ten minute exposure has been fatal at high concentration.
Crystalline silica dust	Cumulative exposure leads to lung damage and disease. Silica is carcinogenic. Can occur after 15 to 20 years of moderate to low exposure, or after a few months of very high exposure. Death can occur from respiratory failure.
Non contaminants	**Range of typical effects at increasing levels of exposure below acceptable limits**
Oxygen depletion	Rate of respiration increased. Fatigue on exertion, disturbed respiration. Nausea, inability to move freely, collapse. Respiration stops, heart stops within a few minutes.

APPENDIX G – HAZARDOUS CONTAMINANTS AFFECTING AIR QUALITY

Contaminant	Hazard			Buoyancy in air (as a pure substance at ambulant conditions) ↑ - Buoyant ⇔ - Neutral ↓ - Non-buoyant	Comment/Origin
	Toxic?	Asphyxiant?	Flammable?		
Acetylene C2H^2)	✓	✓	✓	↑	Due to compressed gas cylinder leak
Ammonia (NH^3)	✓	✓	✓	↑	From concreting or grouting leak from refrigeration equipment
Asbestos				↓	Thermal lagging, old pipes, building materials
Butane (C_4H_{10})		✓	✓	↓	Due to compressed gas cylinder leak
Carbon Dioxide (CO_2)	✓	✓		↓	Initially buoyant if a hot product of combustion
Carbon Monoxide (CO)	✓	✓	✓	⇔	Initially buoyant if a hot product of combustion
Hydrogen Sulphide (H_2S)	✓		✓	↓	From decomposition of organic matter
Kerosene, Diesel and other low vocality organic solvents	✓		✓	↓	Can usually be handled in confined areas without risk of explosion but can pose a fire and toxicity risk
Methane (CH_4), Natural gas		✓	✓	↑	Natural ground contaminant, or from compressed gas leak
Nitric Oxide				⇔	Produced by explosives and engines
Nitrogen Dioxide (NO_2)	✓			↓	Produced by electric arc welding
Oxygen depletion		✓		⇔	Oxygen can be consumed or displaced
Oxygen enrichment				⇔	Enhanced risk of ignition and fire. Due to compressed gas cylinder leak
Ozone (O_3)	✓			↓	From electric arc welding
Petrol and other highly volatile organic solvent vapours	✓	✓	✓	↓	Fire, explosion and toxic hazard

Contaminant	Hazard			Buoyancy in air (as a pure substance at ambulant conditions) ↑ - Buoyant ⇔ - Neutral ↓ - Non-buoyant	Comment/Origin
	Toxic?	Asphyxiant?	Flammable?		
Propane		✓	✓	↓	Fire and explosion hazard
Respirable Silica				↓	Rock dust
Sulphur Dioxide (SO_2)	✓			↓	Produced bacterial activity upon dissolved sulphide minerals

THIS GUIDE PROVIDES PRACTICAL GUIDANCE ON HOW TO MANAGE HEALTH AND SAFETY RISKS ASSOCIATED WITH TUNNELLING WORK.