Resources Regulator
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Technical reference guide

Pillar extraction in NSW underground coal mines

Guidelines for the management of pillar extraction and pillar reduction activities in underground coal mines

(MDG 1005)

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Amendment schedule		
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October 2023	1	Replaces Mine Design Guideline (MDG) 1005 Parts 1 and 2 – Manual on pillar extraction in NSW underground coal mines

Foreword

Pillar extraction is classified as a form of secondary extraction and regulated as a **high risk activity** under section 17, Part 3 of Schedule 3 of the Work Health and Safety (Mines and Petroleum Sites) Regulation 2022.

The case studies in the Appendix to this technical reference guide (TRG) highlight the dangers of pillar extraction. There have been numerous fatalities associated with pillar extraction, including incidents involving attempts to retrieve remote control continuous miners. Appropriate planning and design and risk assessment is crucial to manage the real and significant risks associated with pillar extraction.

It is acknowledged that many parts of the mining industry are changing to pillar reduction rather than using full pillar extraction methods. Given the high risk of injury and fatality with pillar extraction, it is still critical to maintain expertise and knowledge of the significant risks in planning and designing for pillar extraction. Some of the risk management lessons from pillar extraction are also relevant to pillar reduction.

Table of Contents

1. Introduction

1.1. Purpose

This document guides mine operators in developing and documenting a pillar extraction management plan that forms part of the mine's principal hazard management plan (PHMP) for Ground and Strata. It replaces the Mining Design Guideline MDG 1005 parts 1 and 2 – Manual on pillar extraction in NSW underground coal mines.

The purpose of a TRG is to provide industry with a good practice benchmark on technical and engineering controls to support mine safety.

1.2. Acronyms and definitions

Table 1 - Acronyms and definitions

Acronym/term	Definition
ACARP	Australian Coal Industry's Research Program
Bord	underground roadway or working face
CCM	critical control management
ICMM	International Council on Mining & Metals
MRS	mobile roof support
Pillar	an area of coal left to support the overlying strata in a mine
PCBU	person conducting a business or undertaking
PCP	principal control plans
PHMP	principal hazard management plan
SMS	safety management system
TARPs	trigger action response plans
TRG	technical reference guide
WHS	work health and safety
Windblast	the term windblast is interchangeable with airblast

1.3. Scope

Pillar extraction is a secondary extraction mining system. System design **must** address the issues of roof, floor and pillar instabilities as well as panel and regional instabilities.

Mine operators **must** consider other hazards that may emerge through pillar extraction or pillar reduction activities. These include windblast, explosion, spontaneous combustion and expulsion of flammable or irrespirable gases and dusts.

1.4. Interaction with the safety management system

A mine's safety management system (SMS) documents how the mine operates safely. The SMS brings together the procedures and policies to enable a mine operator to follow a systematic approach to achieving and monitoring an effective level of health and safety. This includes PHMPs that are required to manage a range of hazards, including pillar extraction[1].

[1] *Work Health and Safety (Mines and Petroleum Sites) Regulation 2022* s.4

The SMS must be documented. It must be clear and accessible to those who need to read it. It should be written in plain language.

The SMS must form part of the overall mine management system.

The pillar extraction plan forms part of the Ground and Strata PHMP. The mine operator should consider the pillar extraction plan's integration and interaction with other plans including:

- ventilation control plan
- spontaneous combustion PHMP
- fire and explosion PHMP
- emergency plan
- inrush and inundation PHMP
- subsidence management plan
- windblast management plan.

1.5. Consultation

A mine operator has a duty to consult with workers on matters that relate to work health and safety that are, or are likely to be, directly affected.[2]

Mine operators must consult workers in accordance with the agreed arrangements at the mine, such as consulting with HSRs, SHR and or any health and safety committee.

The mine operator must, so far as is reasonably practicable, consult, cooperate and coordinate with other people who also have a duty to consult. Consultation must include other persons conducting a business or undertaking (PCBUs) and workers (e.g., contractors)[3].

The following documents offer further information on consultation, cooperation and coordination:

- NSW SafeWork *Code of practice - Work health and safety consultation, cooperation and coordination* (December 2022)
- Resources Regulator *Guide - Preparing a principal hazard management plan*
- Resources Regulator *Guide - Contractors and other businesses at mines and petroleum sites*
- Resources Regulator *Fact sheet: Consulting workers.*

2. Fundamentals of pillar extraction

Integral elements of pillar extraction design include:

- **geotechnical knowledge** – A comprehensive understanding of pillar mechanics and excavation behaviour, supported by advances in numerical modelling, results in safer mine designs and ground support systems
- **mining equipment technology -** This may include the use of remote-controlled continuous miners and mobile roof supports (MRS) to reduce operator exposure to the working face, goaf falls and manual handling hazards
- **ground support technology and practices**
- **risk assessment -** This is effective when embedded into all aspects of pillar extraction.

[2] *Work Health and Safety Act* 2011 s.47

[3] *Work Health and Safety Act* 2011 s.46 & s.47

2.1. Terminology of pillar design

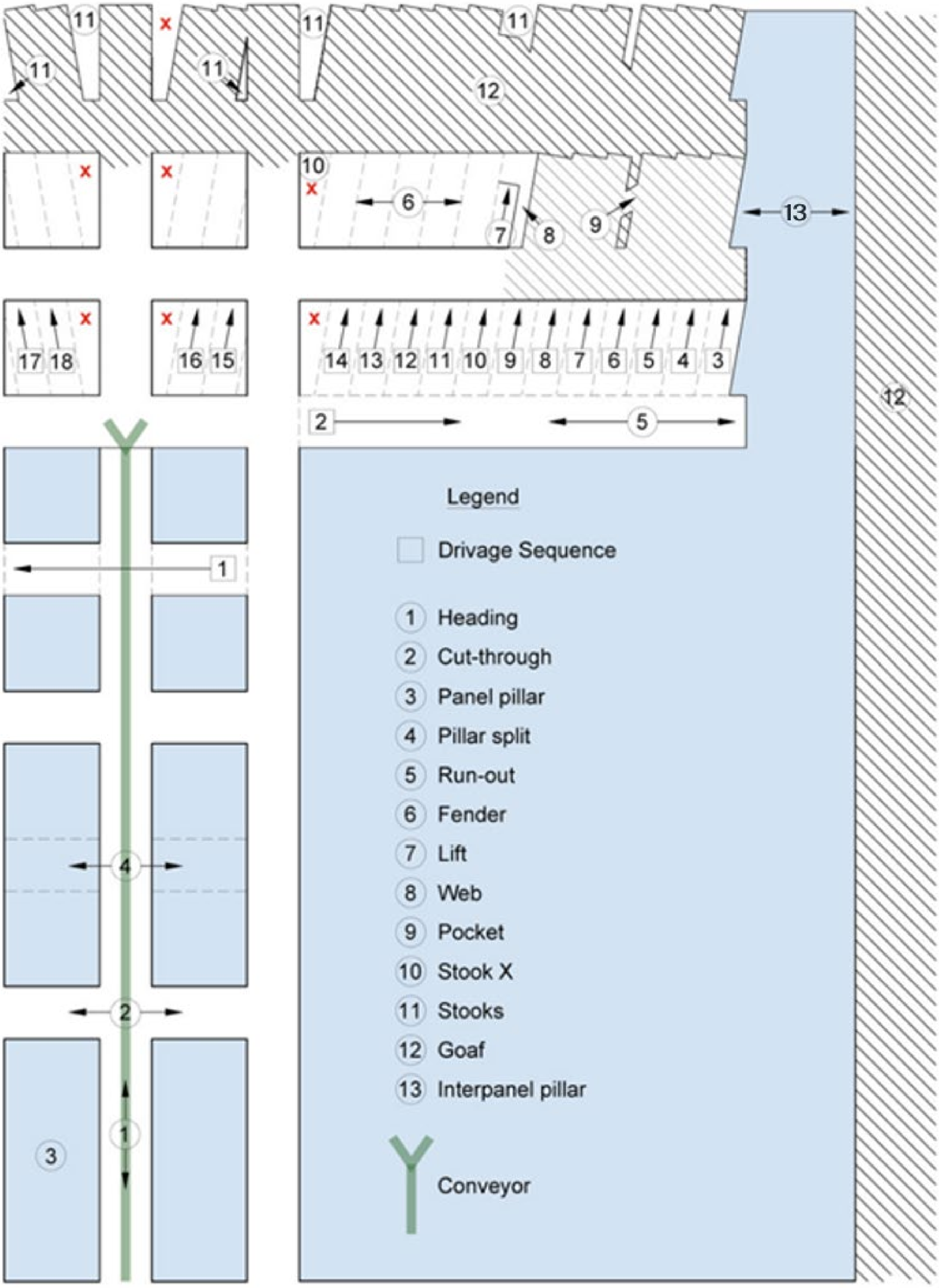
Table 2 and Figures 1 and 2 below outline the terminology used in pillar design and extraction. These are noted here to assist mine operators when developing a pillar extraction plan for purposes of consistency.

Table 2 – Basic pillar extraction terminology[4]

Term	Definition
Split	A roadway developed within a pillar to divide it into smaller portions. May also be referred to as a pocket.
Run-out	A long split driven from the main development to the flanks of a pillar extraction panel.
Lift	A slice of coal mined from a pillar for the purpose of extracting the pillar. A lift may be mined from a heading, cut-through or split.
Fender	A long rectangular or slender web of coal separating a split or lift from the goaf. Also referred to as a wing or a web in some situations. A fender may or may not be subsequently extracted, or only partially extracted.
Web	A thin fender of coal left between two lifts, usually as a temporary support measure. Portions of a web may be extracted (pocketed) on retreat out of a lift.
Stook	A term used in Australian pillar extraction operations to describe the remnant of a pillar not extracted. When the stook is adjacent to the last lift in a pillar, it is referred to as a snook in South Africa and as a stump or pushout in the USA, the extraction of which is not necessarily prohibited in these two countries.
Stook X	A remnant portion of a pillar that is not permitted to be extracted in Australian pillar extraction operations. It always includes remnant coal adjacent (outbye) to the last lift and often remnant coal inbye of the first lift in a pillar.
Stripping	The process of reducing the size of a pillar by mining lifts from its perimeter. Also referred to as slabbing.
Sequence	The order in which pillars are developed and/or lifted off.
MRS	A mobile roof support, which includes both Voest Alpine Mobile Breaker Line Supports (MBLS) and Fletcher Mobilised Roof Supports (FMRS).

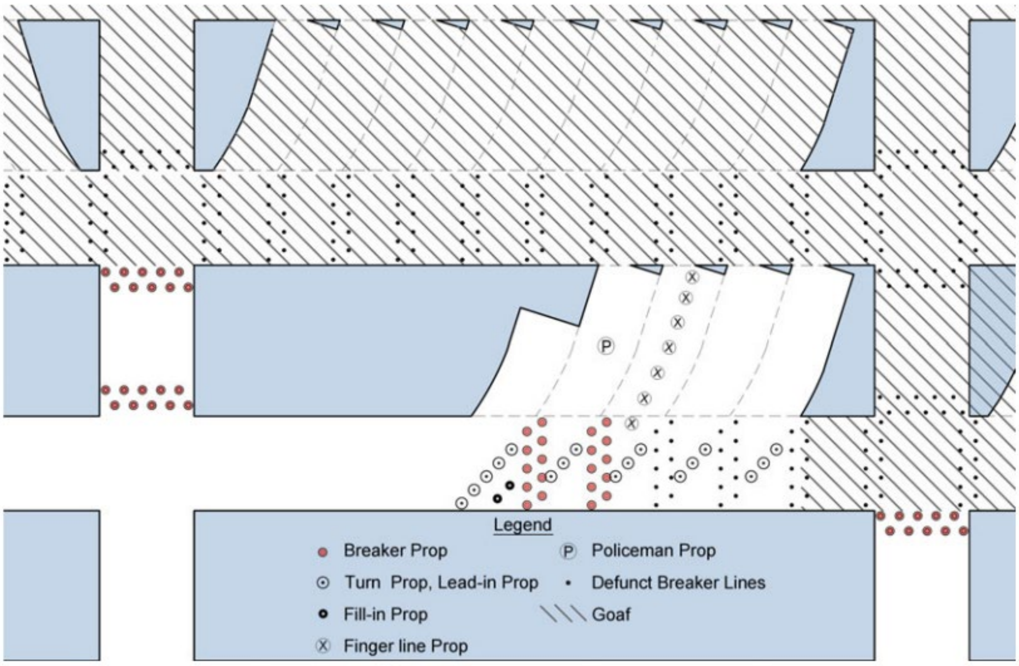
[4] Galvin 2016 - Chapter 8, Section 8.3.1 - Table 8.1

Figure 1 -Terminology relating to pillar extraction layouts[5]



[5] Galvin 2016 - Chapter 8, Section 8.3.1 - Fig. 8.2

Figure 2 - Terminology relating to support in pillar extraction (not all props in the goaf are shown)[6]



2.2. PillardDesign

This section deals with the technical details and ground engineering issues around pillars. Pillars perform four basic functions in underground coal mining[7]. They provide:

- natural temporary or permanent support to the surrounding strata;
- a buffer zone between adjacent excavations to control interaction between their respective stress fields;
- a physical barrier to restrict fluid flow between excavations; and
- a control for managing the magnitude and extent of surface subsidence.

2.2.1. Risk-based functional approach to design

Mine operators must apply a risk-based, functional approach to pillar system design and monitoring for safety and fitness for purpose. Figure 3 below illustrates the steps involved.

As part of this approach it is important to:

- obtain accurate geological and geotechnical reports and testing, to ensure that any pillar design calculations and decisions account for the specific circumstances of the mining operation.
- apply appropriate theories and formulas and use accurate local data when calculating working stress, system strength and determining operational requirements and relevant precautionary principles for faults and joint-sets and seams
- review and monitor the design on an ongoing basis.

Mine operators must also consider the following when developing the control measures to manage the risks of pillar extraction or pillar reduction:

- the potential for associated risks to occur from the pillar extraction or pillar reduction activities, including by:
  - evaluating the history of pillar extraction or pillar reduction activities at the mine

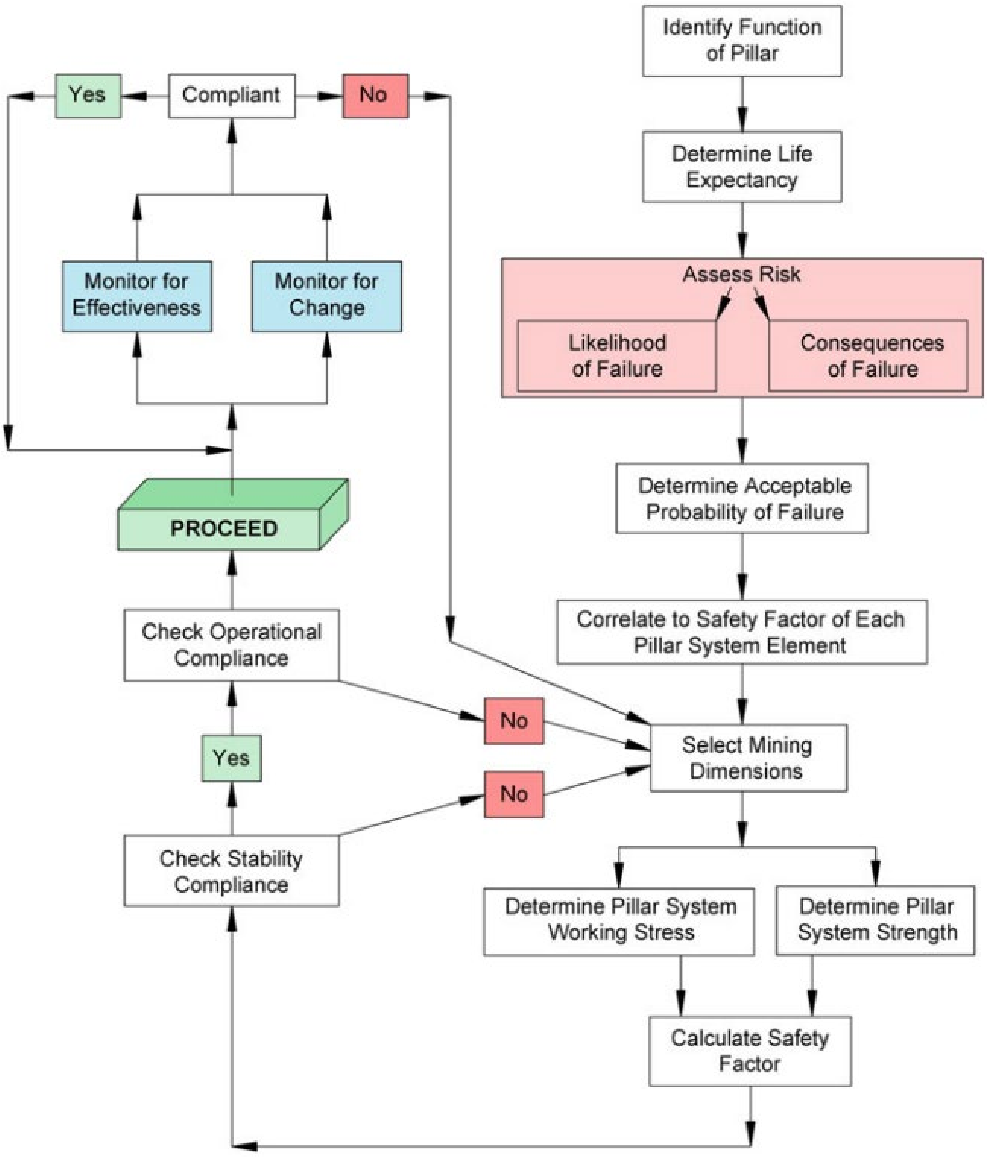
[6] Galvin 2016 - Chapter 8, Section 8.3.1 - Fig. 8.3

[7] Galvin 2008

- evaluating any adjacent or previous mining operations in the same seam
- evaluating any other mining operations using similar pillar extraction or pillar reduction systems
- evaluating any other mining operations that have similar geological and geotechnical properties

- mine ventilation practices
- mine design must address the issue of pillar instabilities as well as panel and regional instabilities
- the impact of associated risks from pillar extraction or pillar reduction activities such as windblast, explosion, spontaneous combustion and expulsion of flammable or irrespirable gases and dusts, on mine environmental conditions.

Figure 3 - The steps associated with a risk-based, functional approach to pillar design[8]



[8] Galvin 2016 - Chapter 4, Section 4.2 - Fig. 4.1

2.2.2. Pillar life expectancy

Table 3 below shows the typical life expectancy of coal pillars depending on their types and functions.

Table 3 - Types, functions and typical life expectancy of coal pillars[9]

Type	Range of functions	Typical life expectancy
Protective	Provide a zone of protection against ground movement near sub-surface and surface infrastructure and natural features.	From life-of-infrastructure to permanent.
Barrier	• Provide a zone of separation of sufficient width between two sets of workings to limit interaction between their respective stress fields • Provide a solid barrier against inrush, gas migration and spontaneous combustions • Protect sub-surface and surface natural and man-made infrastructure from mining-induced ground movement.	From life-of-mine (10-40 years) to permanent.
Main development	• Local or regional load bearing structure • Restrict strata displacement around main development roadways to safe and serviceable levels • Act as ventilation stoppings • Protect sub-surface and surface natural and man-made infrastructure from mining-induced ground movement.	Life-of-mine (10-40 years), Or from life-of-infrastructure to 'permanent'.
Panel	• Local load bearing structure • Provide roof, rib and floor stability within a panel for duration of production • Restrict sub-surface and surface ground movement.	Life-of-panel (1-2 years), Or from life-of-infrastructure to permanent.
Interpanel	• Regional load bearing structure between adjacent panels • Provide a sufficiently wide separation between two adjacent panels to limit the interaction of their respective stress fields • Restrict the spread of a pillar system instability • Provide a solid barrier against inrush, gas migration and spontaneous combustion.	Life-of-mine (10-40 years), Or from life-of-infrastructure to permanent.
Chain	• Protect companion gateroads from abutment stress • Provide a ventilation pathway and 2nd egress • Function as a goaf seal • Sometimes used to provide regional support and restrict sub-surface and surface ground movement.	1-3 years., or Life-of-infrastructure, up to permanent for partial extraction systems.

[9] Galvin 2016 - Chapter 4, Section 4.2 -Table. 4.1

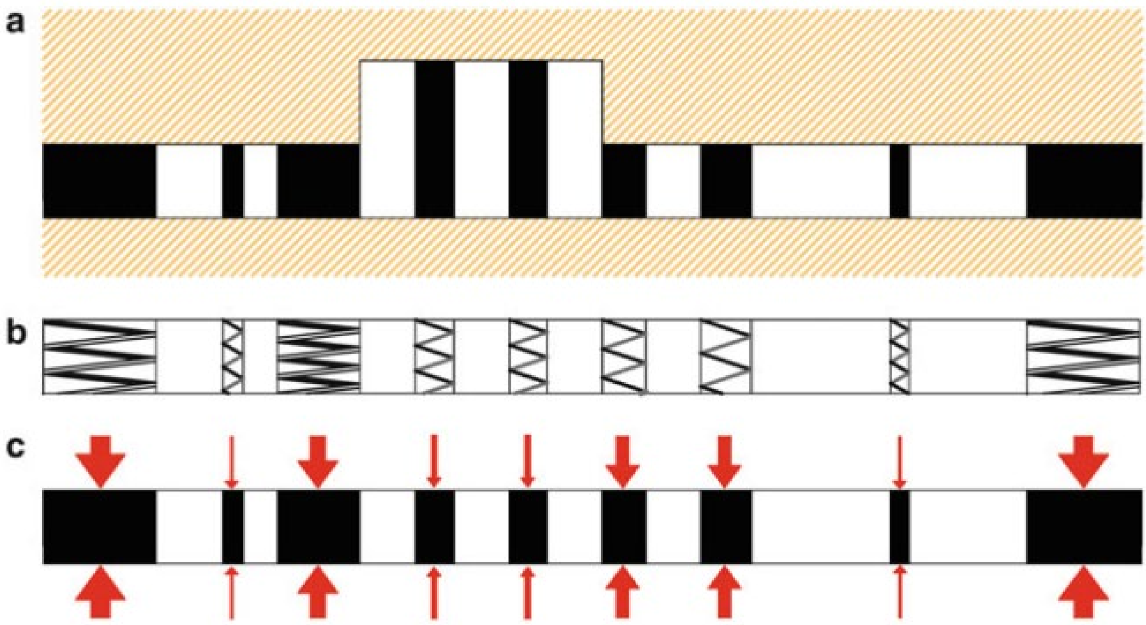
Type	Range of functions	Typical life expectancy
Yield	• Localised, low stiffness support • Limit damage to immediate rood and floor strata, mitigate pressure bursts (coal bumps, rock bursts) • Provide localised stress relief around a roadway • Improve percentage extraction in some bord and pillar mining layouts.	1-3 years.
Highwall	• Temporary, local support to current drivage or punch • Sometimes used to provide regional support.	Hours to days. Sometimes permanent.
Fender	• Local support and goaf edge control • Break off point for cantilevering roof • Barrier against a goaf fall.	3-5 days, then encouraged to fail.
Stook	• Local support to protect retreat path from or through an intersection • Goaf edge control.	1-3 days, then encouraged to fail.

2.2.3. Pillar forces and loads

Figure 4 below illustrates the forces acting on different pillars based on their varying heights, widths and loads. These forces form the basis of some numerical modelling techniques, which may be used as part of the risk-based functional design approach referred to in 2.2.1 of this TRG. It illustrates how the stiffer pillars attract load and shield the smaller adjacent pillars from load[10].

Figure 4 - Visualisation of load sharing in a pillar system utilising a beam and spring model[11]

In the figure below: (a) Variation in pillar area and height; (b) Equivalent spring stiffness; (c) Load distribution.



[10] Galvin 2008, 2016

[11] Galvin 2016 – Chapter 4, Section 4.3.1 - Fig. 4.3

2.2.3.1. Tributary area theory

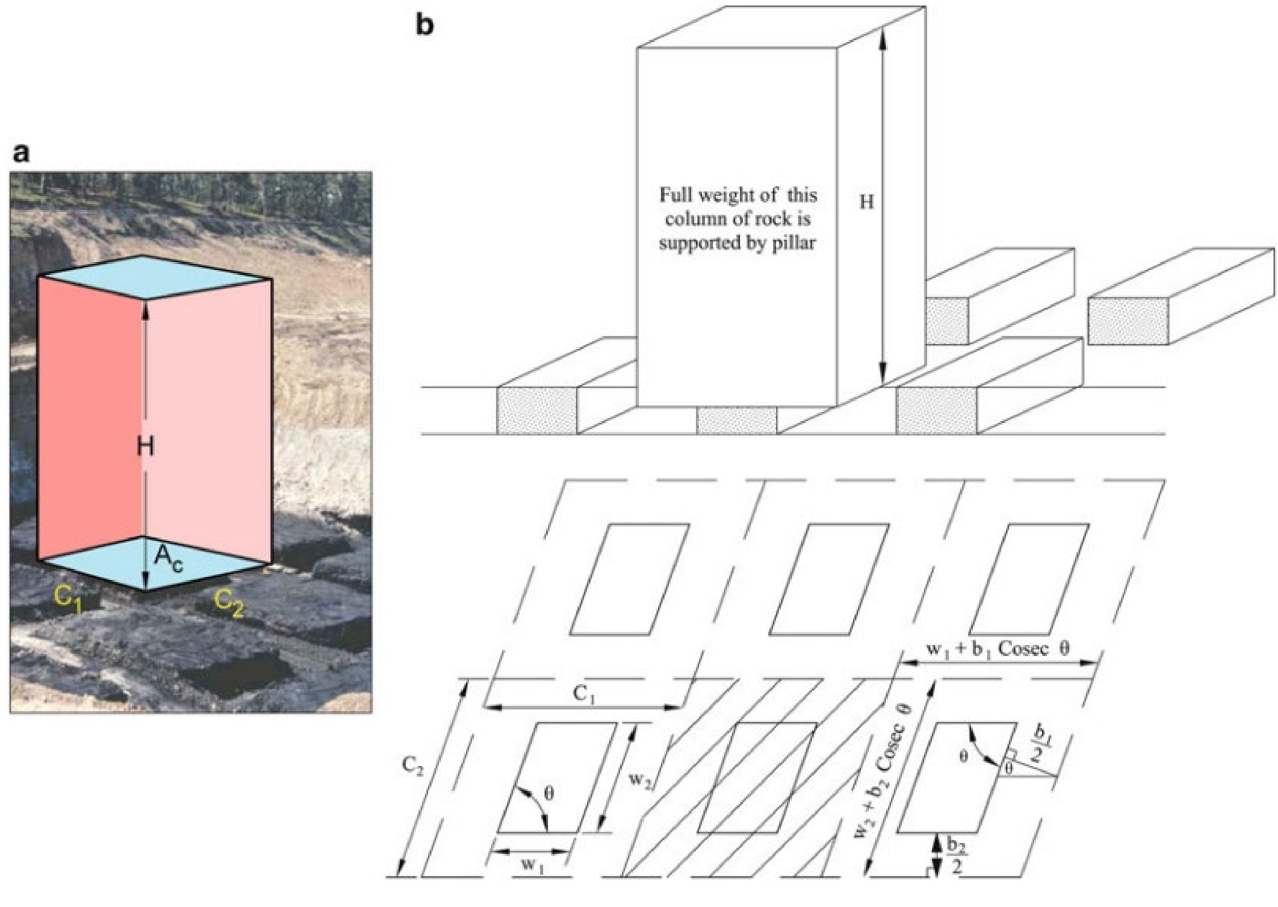
Tributary area theory, illustrated in Figure 5 below assumes that each pillar carries an equal share of the dead-weight load of the overburden[12]. The concept enables the calculation of average vertical stress in the pillars but not the way vertical stress is distributed across the pillar.

Tributary area theory is premised on the stiffness of the overburden being zero. This results in deadweight loading that can lead to overestimating the load on all pillars in a panel that is narrow relative to its depth[13].

Regardless of panel width-to-depth ratio, in most situations tributary area theory overestimates pillar load towards the perimeter of a panel. This is due to the effects of panel abutments on the displacement of the superincumbent strata close to the edges of an extraction panel[14].

Figure 5 - The concept of tributary area theory[15]

In the figure below: (a) Square pillars, (b) Parallelepiped pillars.



The plots in Figure 6 below[16] show the variation in numerically calculated pillar load as panel width is increased. This is expressed as a proportion of tributary area load. The pillar loads range from 50% of tributary area load when the panel is one pillar and two bords wide, to 95% for a panel that is seven pillars and eight bords wide.

[12] Galvin 2016

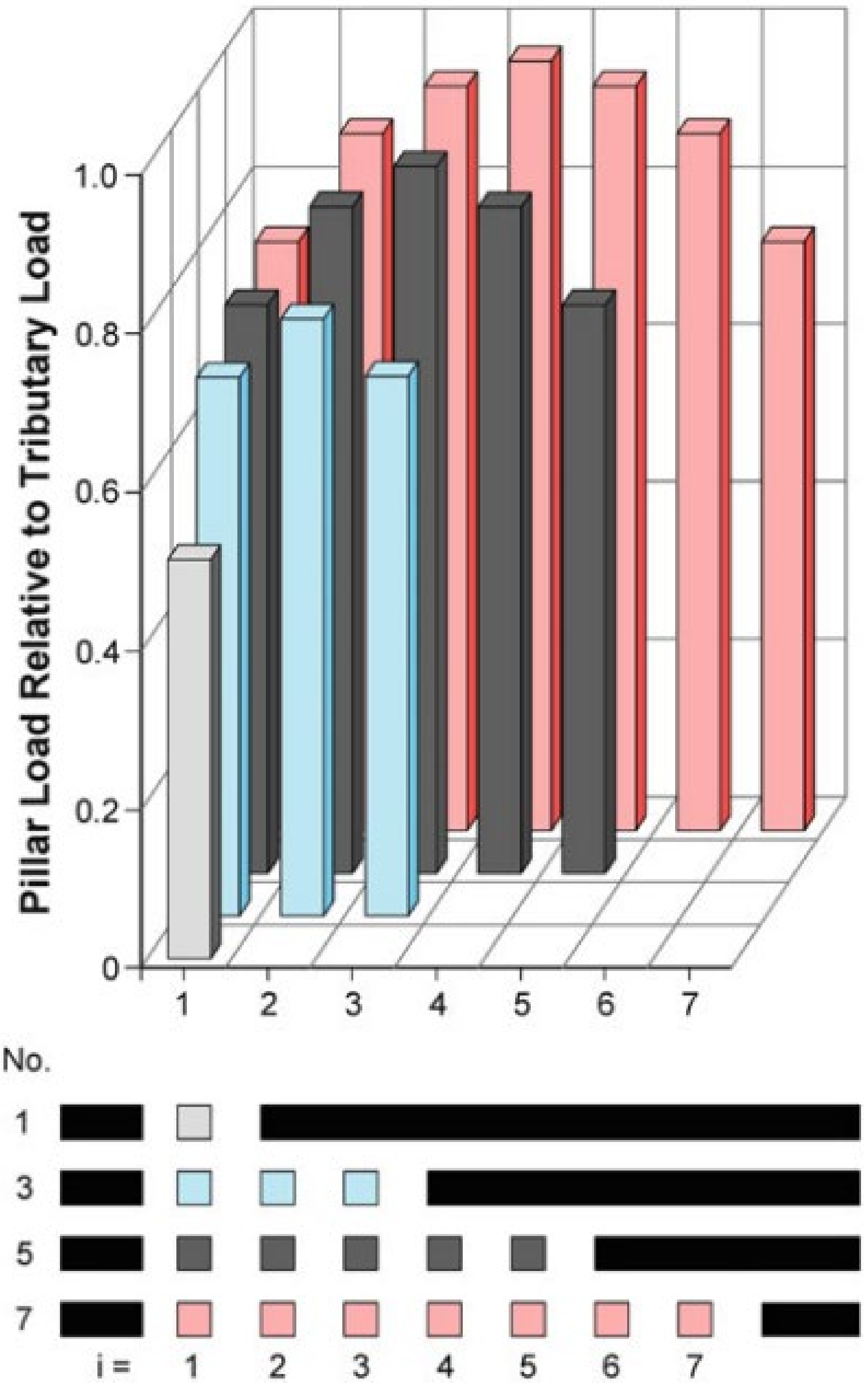
[13] Galvin 2016

[14] Galvin 2008, 2016

[15] Galvin 2016 – Chapter 4, Section 4.3.2 - Fig. 4.6

[16] Galvin 2016

Figure 6 - An example of the influence of panel width on pillar load[17]



The loads acting on pillars in the centre of a panel of pillars generally approach full deadweight loading once overall pillar panel width (Wp) exceeds 1–1.5 times depth. Larger panel spans may be required to achieve full deadweight loading when the overburden contains massive, stiff strata.

2.2.3.2. Pillar stress with changing depth

In some cases, the mine operator has determined that the superincumbent strata is consistent across the mining layout. In most cases, regardless of the nature of the surrounding strata and the overall pillar panel width-to-depth ratio, mine operators should take a risk-based approach and base the pillar design on full tributary area load.

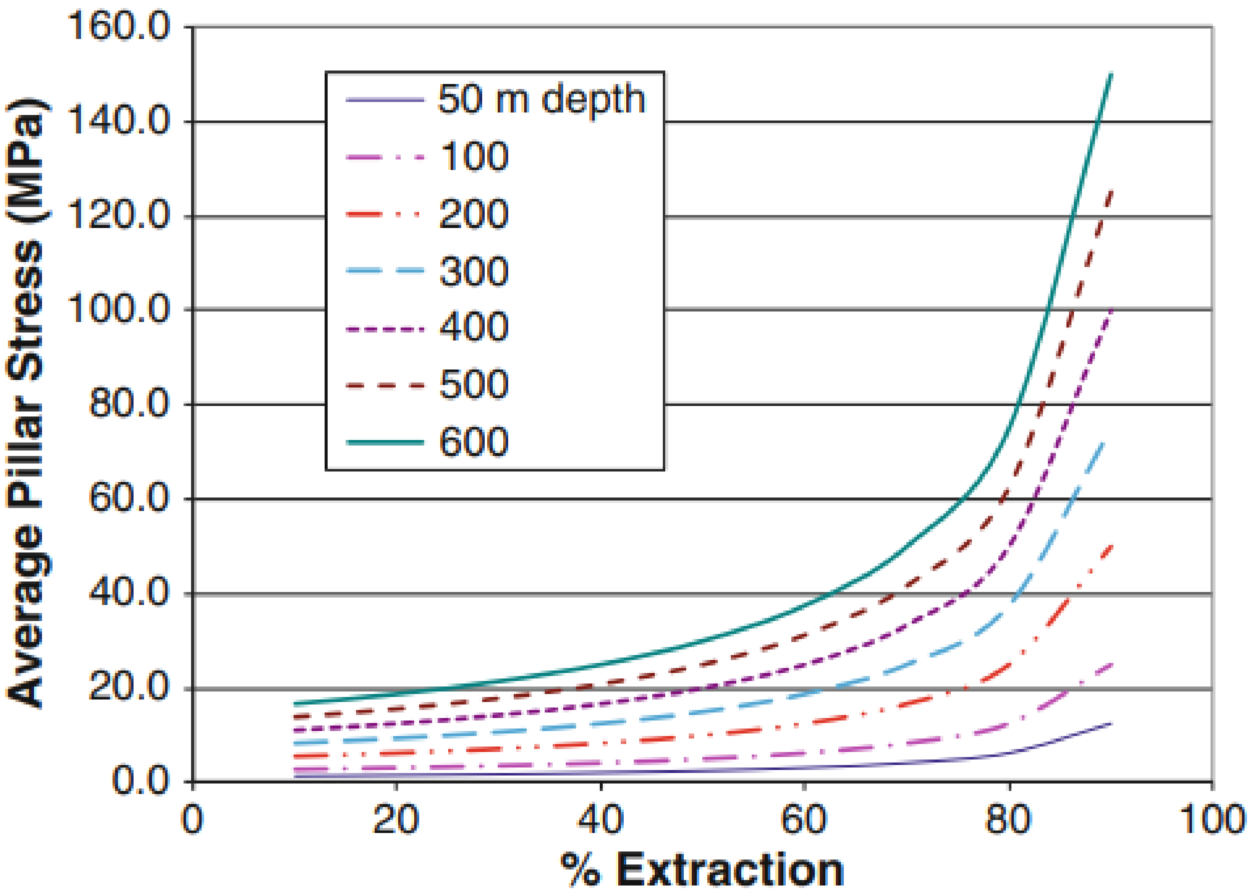
[17] Galvin 2016 – Chapter 4, Section 4.3.2 – Fig. 4.7 - After Salamon 1992

Pillar working stress increases exponentially with percentage extraction. The greater the depth, the greater the incremental change for a given increase in extraction (see Figure 7 below).

For example, while a 10% increase in extraction from 30 to 40% results in a 16.7% increase in average pillar stress, the same 10% increase in extraction from 70 to 80% results in a 50% increase in pillar stress.

Contrary to what Figure 7 might suggest, mine operators should note that problems arising from over-extraction are most common and serious in shallow mine workings. This is because pillars tend to be small at shallow depth and the impact of over-extraction on pillar stability is greater. In addition, high percentage extraction bord and pillar layouts are not feasible at depth as the coal pillars cannot support the very high overburden loads. Careful management of mining dimensions is particularly important at shallow depth[18].

Figure 7 - Plots showing how average pillar stress increases exponentially with increasing percentage extraction and depth[19]



[18] Galvin 2008, 2016

[19] Galvin 2016 - Chapter 4, Section 4.3.3 - Fig. 4.8 - After Galvin 2008

Figure 8 - Effect of width-to-height ratio on the stress-strain characteristics of a coal pillar[20]

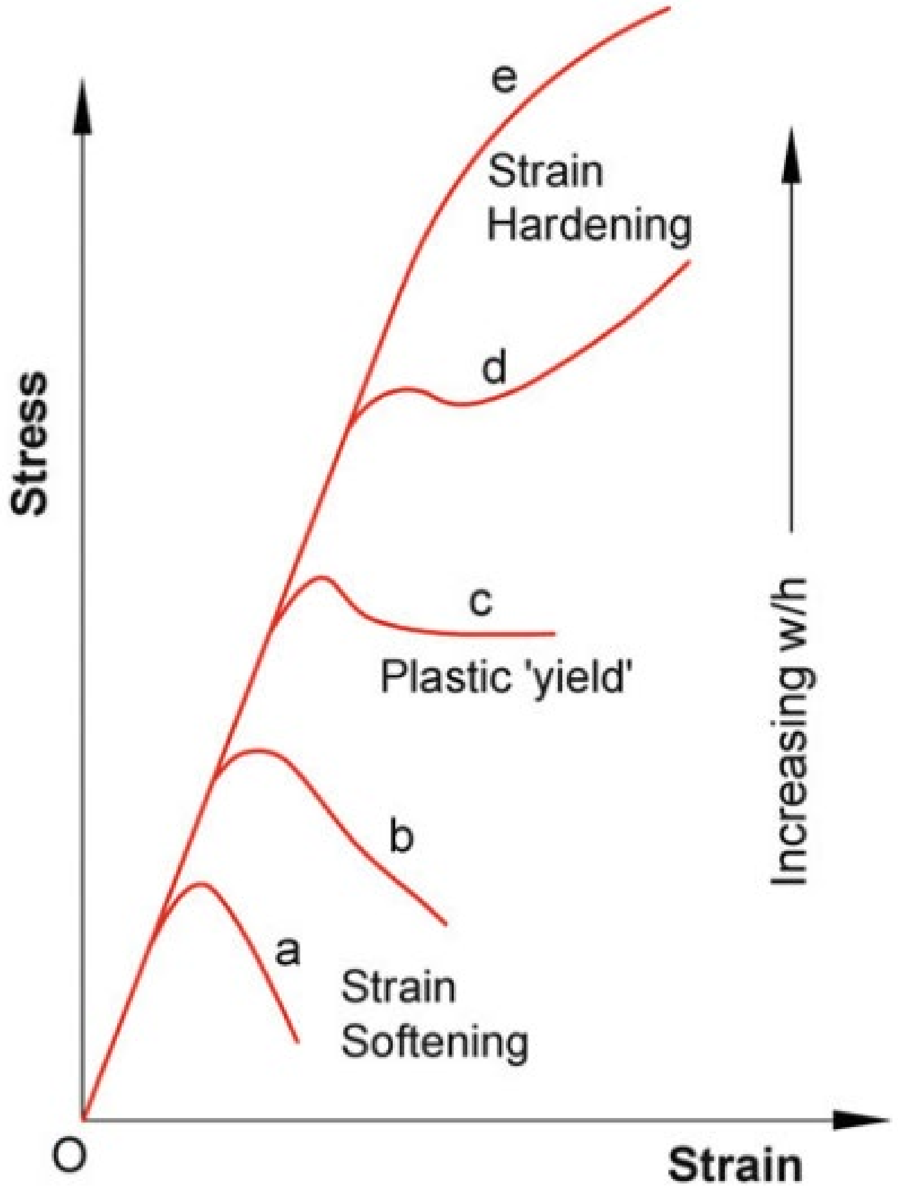


Figure 8 above shows the way that pillar width-to-height ratio influences its behaviour. After a pillar with a low width-to-height ration exceeds its maximum resistance to deformation, it undergoes strain softening and progressively and permanently unloads with ongoing displacement. This is depicted by curve (a).

Once pillars of this geometry start to unload, they are usually no longer able to perform their intended function and are generally considered to have 'failed'.

As pillar width-to-height ratio increases between curve (a) and curve (c), a pillar still sheds load when its strength is exceeded. It then unloads at an increasingly slower rate as width-to-height ratio increases.

Curve (c) is the pillar width-to-height ratio that results in the pillar reaching a state of near constant load carrying capacity, or plastic 'yield'.

Curve (d) shows how with further increases in width-to-height ratio, pillar resistance to deformation may still initially peak and drop, resulting in load shedding. The pillar then goes on to show strain-hardening characteristics and accepts load indefinitely. If the pillar width-to-height ratio is large

[20] Galvin 2016 - Chapter 4, Section 4.4.1 - Fig. 4.10

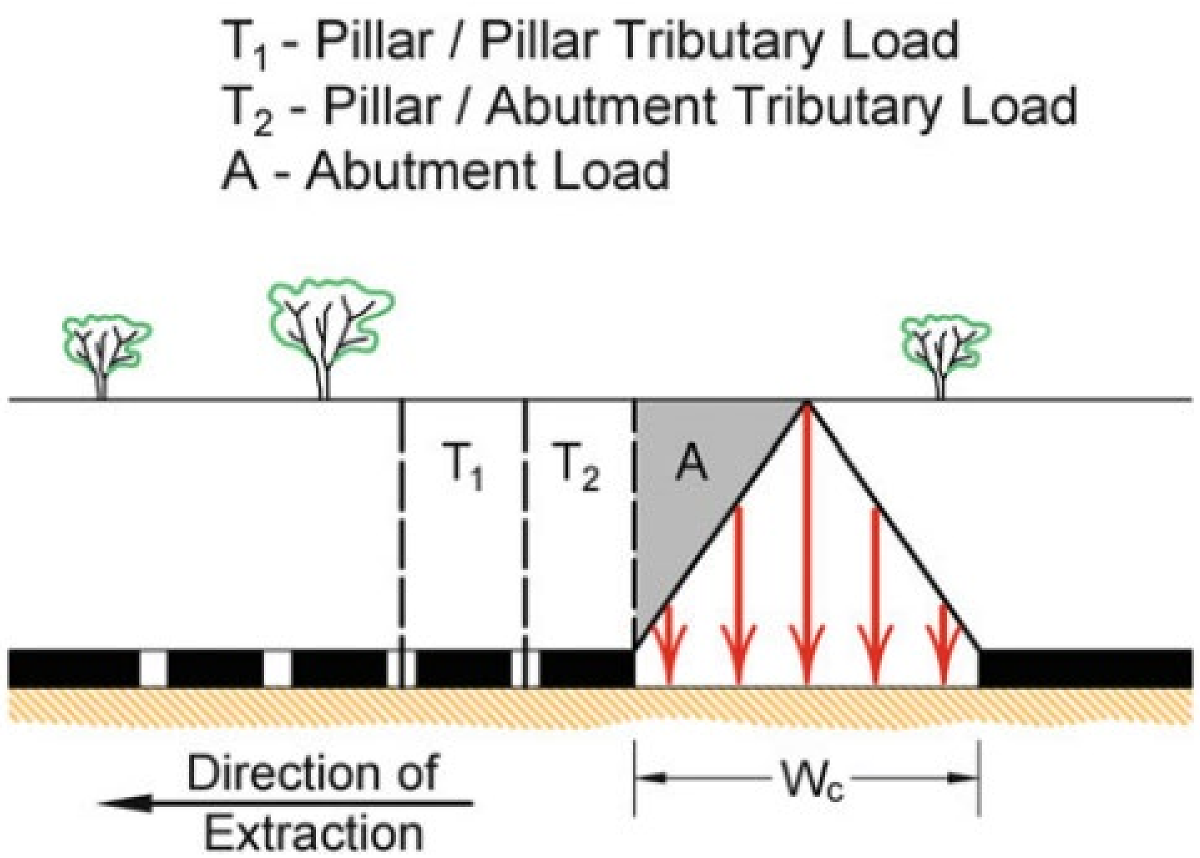
enough, the pillar effectively behaves as an abutment. As shown in curve (e), strain hardening may develop without the pillar shedding load[21].

2.2.3.3. Pillar stress – abutment load

Figure 9 below shows the state of loading once the critical span, Wc, is reached and the superincumbent strata have fully subsided to produce maximum subsidence.

The panel pillars at the extraction face line are subjected to the original tributary area load (T1) They are also subjected to a portion (A) of the load of the superincumbent strata that overhangs the goaf but is not supported by it. An allowance for caving extending up to one side of the pillars (T1 – T2) is then subtracted.

Figure 9 - A representation of sources of pillar load around the perimeter of a pillar extraction goaf of critical width-to-depth ratio[22]



Bridging superincumbent strata can adversely affect pillar extraction operations because it increases abutment stress and the propensity for windblast and gas inrush[23].

2.2.3.4. Width to height ratios

Modelling of the stress-stain and ground response for pillars at varying depths is a complex but important consideration in Pillar Design.

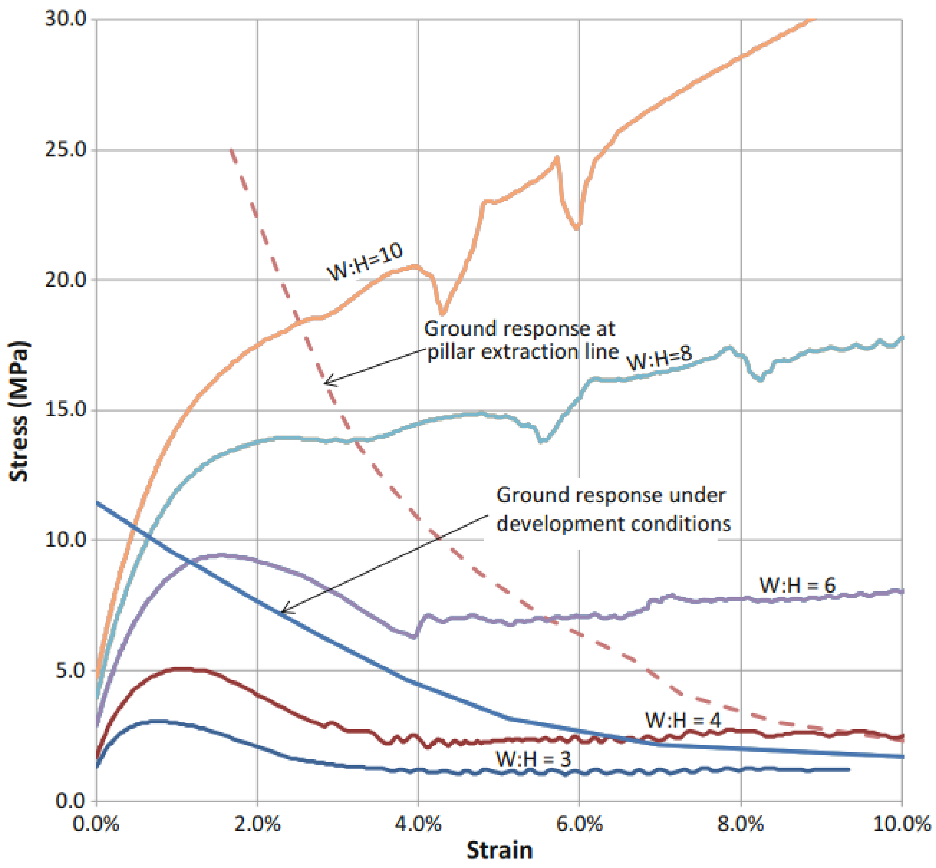
Figure 10 below shows the stress-strain and response curves at mid-span of a 2.4m high, 150m wide, 450m deep panel under strong overburden.

[21] Galvin 2016

[22] Galvin 2016 - Chapter 8, Section 8.4.2.1 - Fig. 8.21

[23] Galvin 2016

Figure 10 - Pillar stress-strain curves and ground response curves at mid-span of a 2.4 m high, 150 m wide, 450 m deep panel under strong overburden, both immediately after development and during pillar extraction[24]



The modelling predicts that pillars with a width-to-height ratio of 8 would be in a pre-peak stress state under development conditions. Post-peak yielding occurs as the extraction line approaches and the pillars are loaded beyond their initial peak. At these relatively high stress values, the ground response is stiff, and equilibrium is reached at a vertical strain value of 3.2%.

To achieve some abutment stress relief, an extraction panel should be wide enough to induce full overburden caving and subsidence very soon after secondary extraction starts. Otherwise, extraction panes should be narrow enough to restrict abutment stress. This may not always be practical, particularly at depth[25].

An extreme situation can arise when secondary extraction occurs at relatively shallow panel depth (typically less than 200 m), where the span is only marginally less than that needed to induce full caving. In these cases, the face extraction line can be subjected to high abutment stress throughout the life of the panel. Ground control is very susceptible to small changes in geology and localised caving may occur on an irregular basis.

Strata behaviour is unpredictable and inconsistent, with even minor changes in lithology enough to trigger an unexpected fall of ground. When the panel span is supercritical, the presence of strong and stiff strata in the overburden may still delay caving. This can result in periodic face weighting and the risk of windblast[26].

It is important to consider the propensity for spontaneous combustion when selecting panel span. This is because pillar extraction operations must retreat at a rate sufficient to cause coal left in the goaf to be smothered within its incubation period. Mine operators need to strike a balance when

[24] Galvin 2016 - Chapter 8, Section 8.4.2.1 - Fig. 8.22 - After Esterhuizen et al. 2010

[25] Galvin 2016

[26] Galvin 2016

designing panel width. Panels that are too wide may not achieve the required rate of retreat. Panels that are too narrow may inhibit caving and compaction needed to prevent the ingress of air to the goaf[27].

The manner and sequence of pillar extraction directly influences the safety of the underground working environment and is critical for maintaining a safe workplace. There are two primary objectives for safe pillar extraction. First, to provide workplaces for personnel that are located between solid coal abutments, under the protection of supported ground, and removed from the immediate vicinity of coal ribs, pinch points and goaf edges. Second, to maintain a relatively straight face line to minimise the opportunity for high stress concentrations and variable ground behaviour.

2.2.3.5. Additional design considerations for extraction

The design of the manner and sequence of extracting pillars needs to have particular regard to fender stability and to intersection and stook behaviour.

As pillar extraction operations approach an intersection, each successive lift has an accelerated effect on the redistribution of load.

In the final stages of extracting a fender, the immediate roof of an intersection progressively reverts from being a quasi-plate supported at four corners, to a long cantilever with its fulcrum located outbye of the intersection. This is illustrated in Figure 11 below.

Figure 11 - Conceptualisation of working face located beneath cantilevered roof at a goaf edge[28]

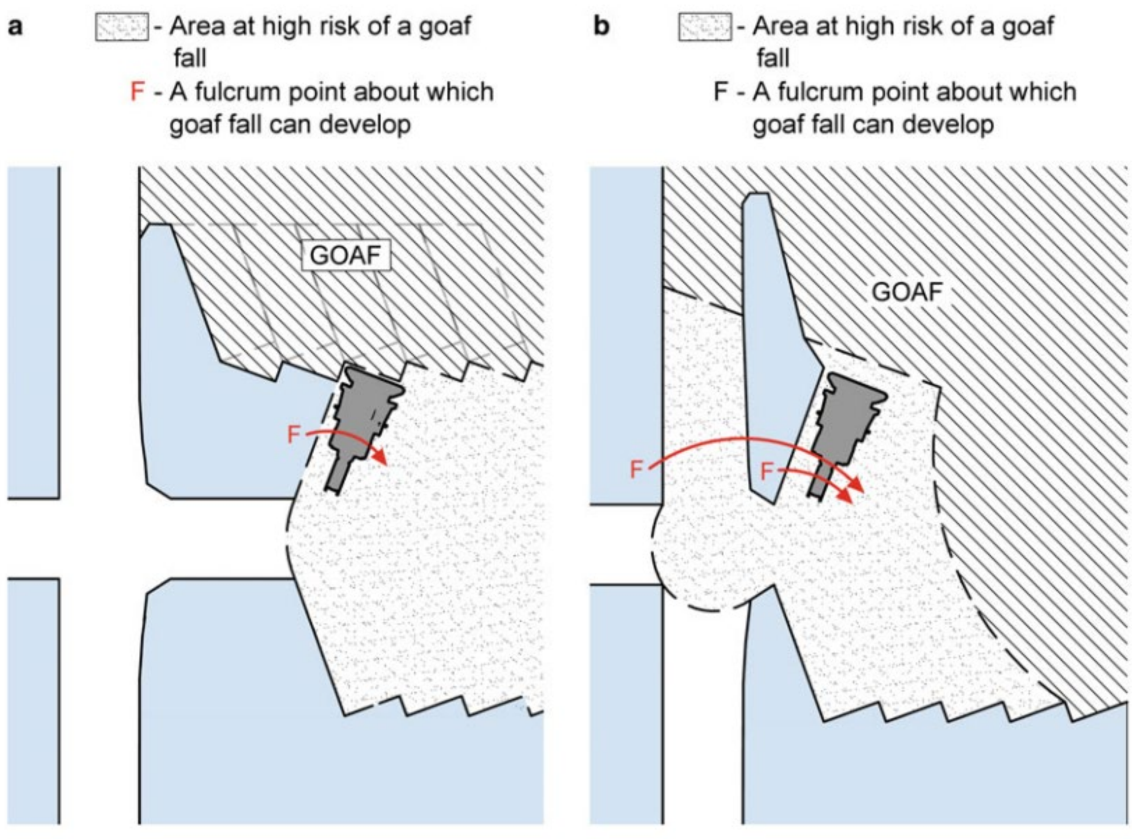


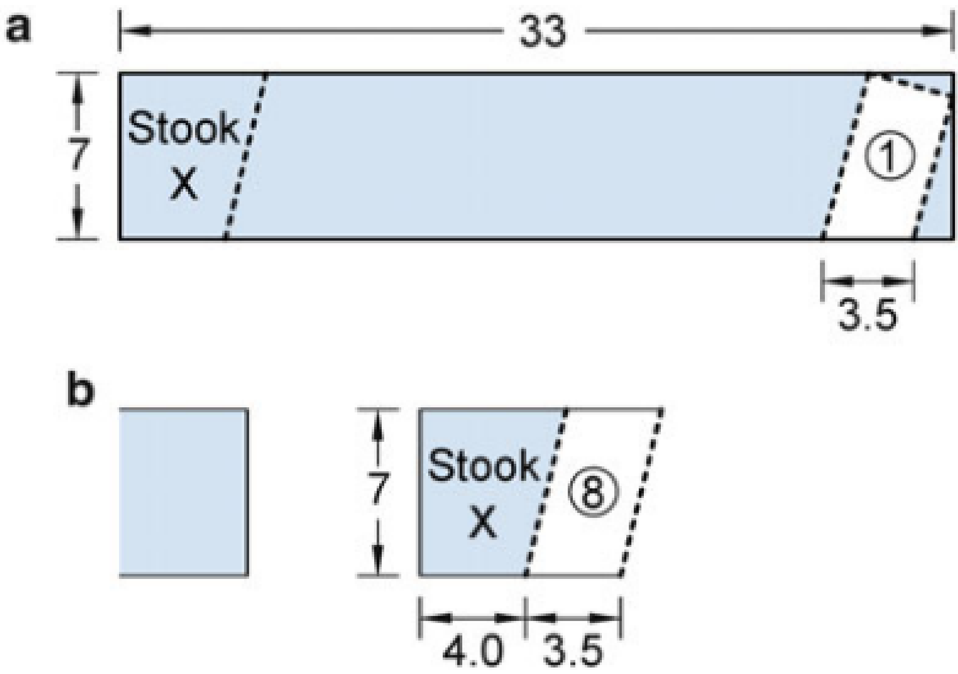
Figure 12 is a sub-sequence of the example in Figure 11. As the length of the fender is reduced, Stook X has more load placed upon it.

[27] Galvin 2016

[28] Galvin 2016 - Chapter 8, Section 8.4.3.5 - Fig. 8.28

Figure 12 - Illustration of accelerated change in fender stiffness with progressive extraction of the fender[29]

In the figure below: (a) Fender stiffness changes by 11% due to extraction of Lift #1; (b) Fender stiffness changes by 47% due to extraction of Lift #8.



There are two key considerations for stook design. A stook needs to be strong enough to function as an effective roof support until operations have retreated from the immediate area. It also needs to be weak enough to fail soon after and not hinder caving.

The consequences of not fully extracting coal pillars tend to increase in severity with increases in the roof strata spanning capacity, or competence. Where immediate roof strata is more competent,large stooks promote extensive strata overhang. This then causes a deterioration in strata conditions in and about the face line; promotes development of periodic weighting, and increases the risk of violent roof collapses and associated consequences.

It is established mining practice to construct a fulcrum or breaker line to prevent the cantilevered strata snapping off on the outbye (solid) side of the workplace. These usually comprise timber props, rock bolts or Mobile Roof Support (MRS) units immediately on the inbye side of the roadway leading to the active face. Each time a lift is completed and whenever operations retreat through an intersection, a new breaker line is established.

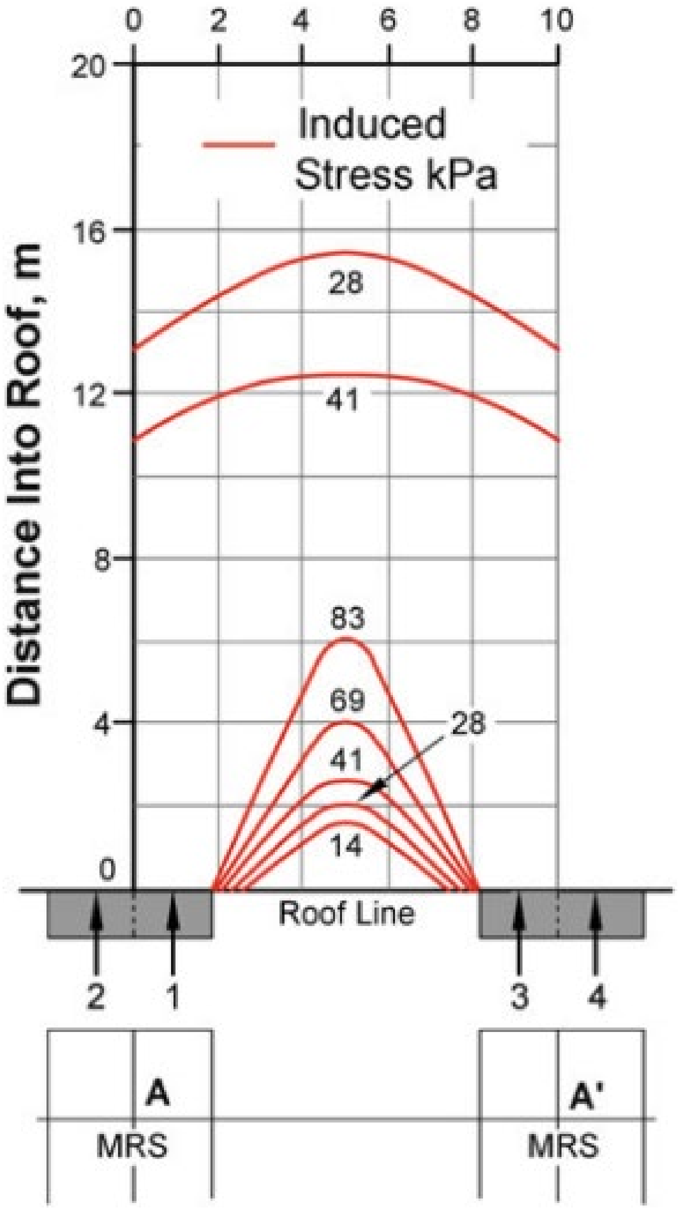
MRS units are deployed in a range of configurations. Generally, there are two in use at the face line in single sided lifting and three in double side lifting.

The effectiveness of MRS units is highly dependent on their location relative to the workplace and on their mode of operation. They should be clustered about the centreline of the split to take advantage of the pre-supported roof. They should also be set as close as possible to the continuous miner without impeding its passage into and out of the lift.

[29] Galvin et al 1994

Figure 13 below analyses roof stresses resulting from two pairs of MRS units.

Figure 13 - Isobars of stress induced in the superincumbent strata by two pairs of MRS set 6 m apart[30]



The example analysis in Figure 13 predicts that the units generate more than 40 kN (4 t) of upward force per square metre some 12 m up into roof between the midpoint of the pairs of MRS.

The MRS units provide very little support to the first metre or so of immediate roof between the two sets of supports. They instead act as abutments to reduce the span of the bridging immediate roof strata. It should therefore be assumed that an MRS unit does not provide any support to the immediate roof around the MRS when this roof is fractured and when there is no abutment in close vicinity for this strata to bridge if it is not fractured.

[30] Galvin 2016 - Chapter 8, Section 8.4.4.3 - Fig. 8.33 - Adapted from Maleki et al. 2001

2.3. Pillar extraction or reduction methods

This TRG includes examples of various methods for pillar extraction and reduction systems to guide mine operators on the foundational principles. The full extraction method has declined in NSW as pillar reduction systems at some underground mines have increased.

NOTE: Section 2.3 is based on summary extracts from Ground Engineering – Principles and practices for underground coal mining (Galvin, 2016), unless otherwise stated. The reader should refer to this text for full details.

As each mining operation is unique, mine operators need to consider all relevant factors when assessing risk and determining the appropriate method or combination of methods and for what purpose.

2.3.1. Conventional pillar extraction methods

2.3.1.1. Open end lifting (not recommended for full extraction)

Under the open end lifting method, the pillar is progressively reduced in size by mining lifts that may be up to 30 m long off the perimeter of the pillar. This method is not recommended for complete pillar extraction because it places operators in the goaf, creating an unacceptable fatality risk. In certain circumstances, it may be appropriate to use the open end lifting method (see Section 2.3.2.1 of this Guide).

2.3.1.2. Conventional split and lift

The split and lift method involves driving one or more splits into the pillar to form substantially wide fenders that are then lifted off on the retreat. This avoids many of the risks associated with the open ended lifting method. There are many variants of the method, each with unique descriptive terminology. These variants are summarised below and described in some detail .

The **Modified Old Ben** or **Munmorah method** (see Figure 14 below). Panel widths range between 100 to 250 m, with 160 – 180 m being typical[31]. This method requires good roof and floor conditions and facilitates good face ventilation. As depth of mining increases, abutment loading can cause problems because much of the working area falls within the abutment stress zone. For this reason, in Australia the use of this method has been limited to depths less than around 250 m.

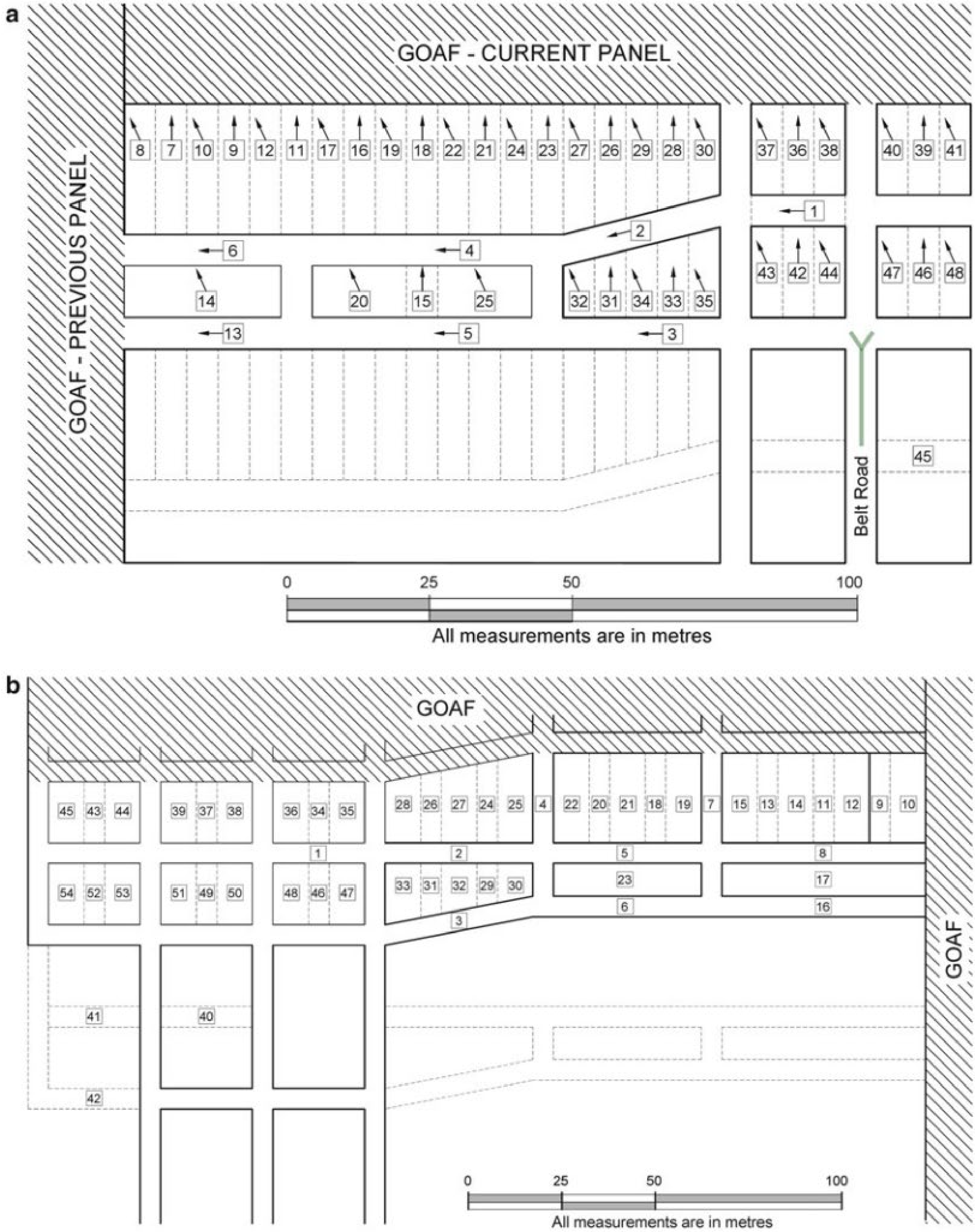
The **Wongawilli method** (see Figure 15 below) of pillar extraction evolved in Australia in the late 1950s[32]. It involved driving and supporting very long splits off the main development headings to form fenders some 7 – 9 m wide. These were then lifted off on retreat together with the main development pillars. There are several disadvantages to the Wongawilli method. They include susceptibility to off-centre drivage; a lack of ventilation at the coal face in long splits; egress impeded by deteriorating ground conditions; and long haulage distances between shunts (passing points) when mining the run-outs.

[31] Galvin 2016 - Hanrahan 1993

[32] Galvin 2016 - Sleeman 1993

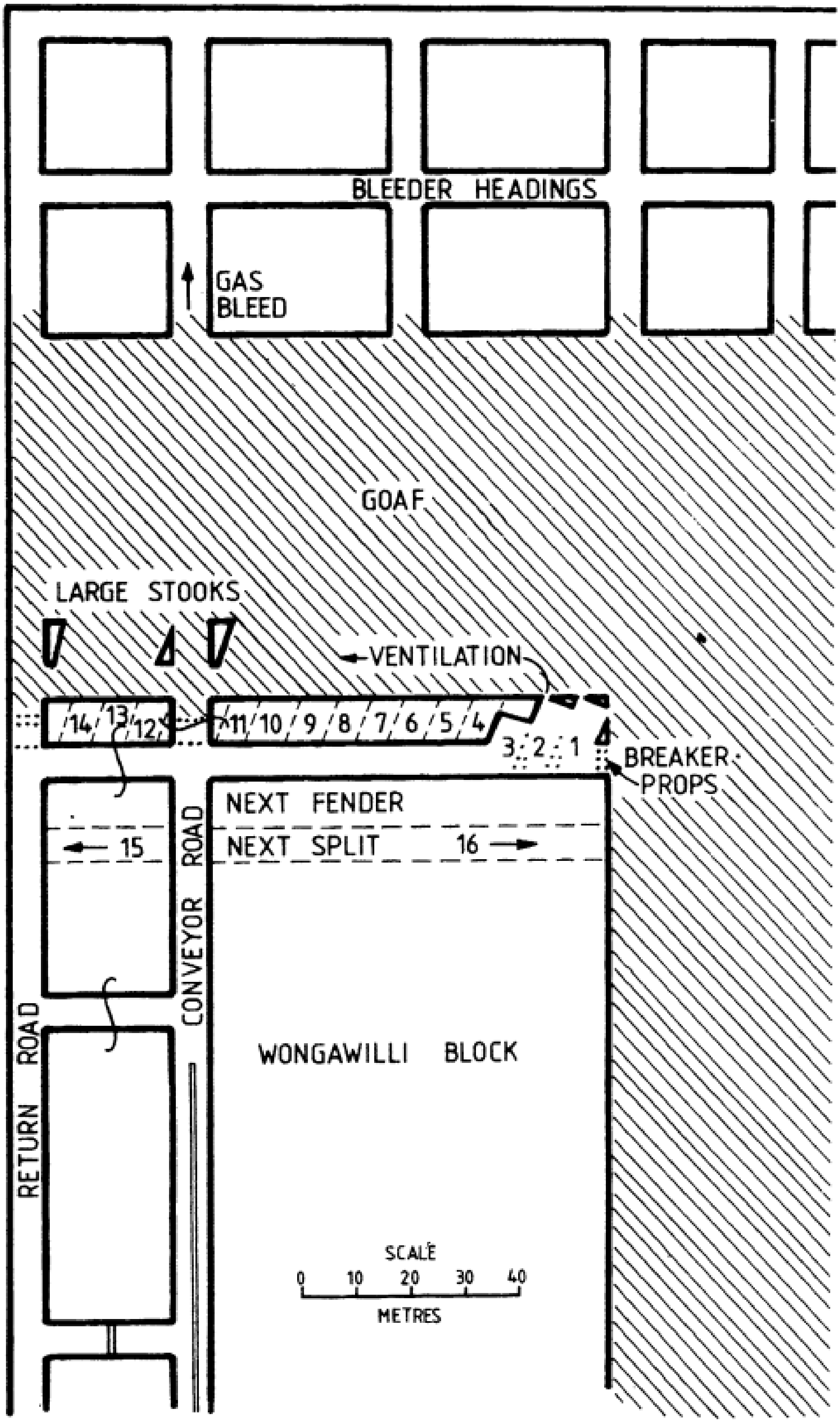
Figure 14 - Old Ben and Modified Old Ben (Munmorah) methods of split and lift pillar extraction[33]

In the figure below: (a) Old Ben method; (b) Modified Old Ben method.



[33] Galvin 2016 - Chapter 8, Section 8.3.2.1 - Fig. 8.10

Figure 15 – Wongawilli method of pillar extraction[34]

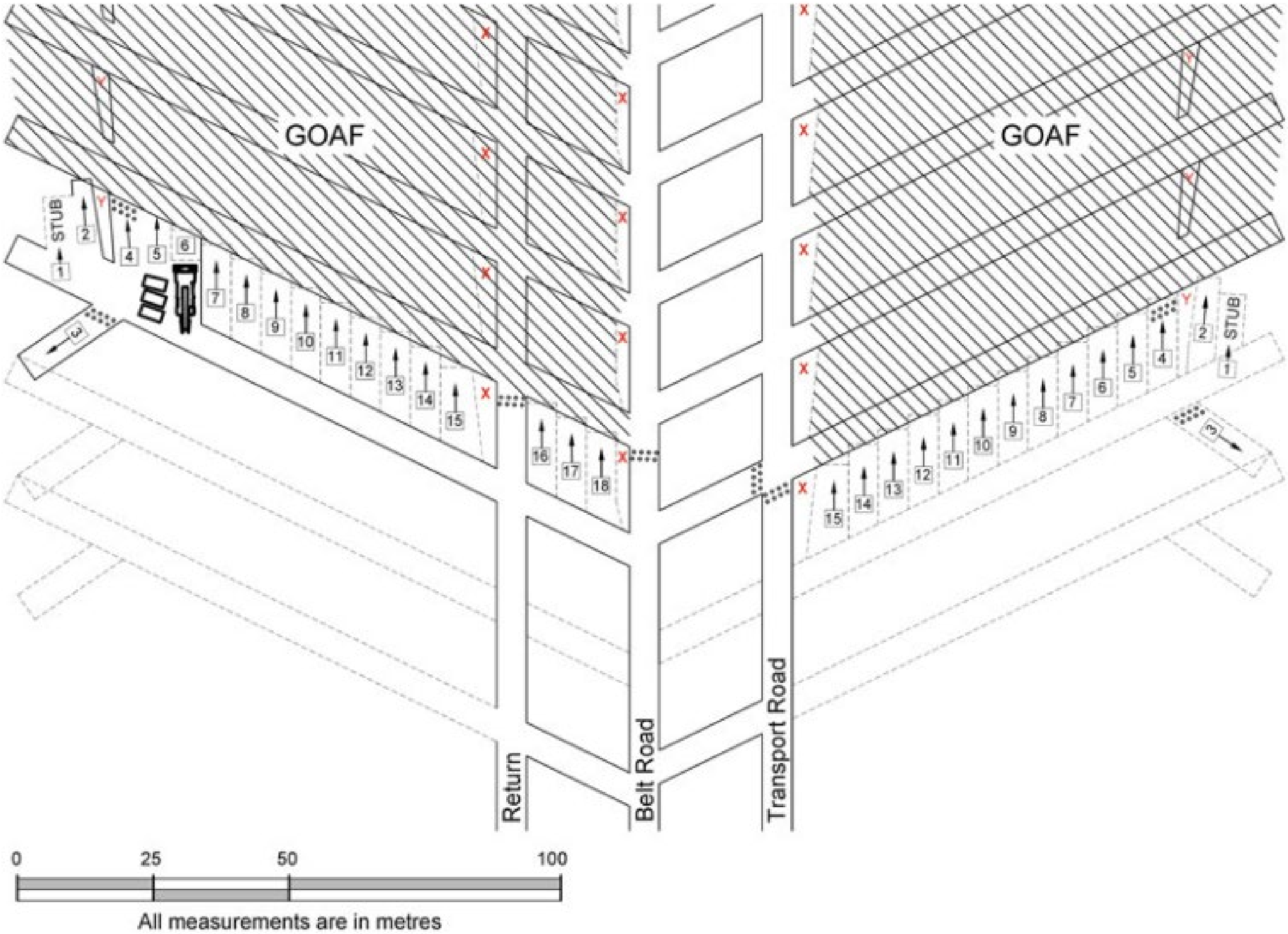


[34] Galvin 2016 - Chapter 8 Section 8.3.2.1 - Fig. 8.11 - After Sleeman 1993

2.3.1.3. Continuous haulage systems

Continuous haulage systems usually result in the panel being worked from the left and the right towards a centrally located belt road, rather than towards the side of the panel remote from the previously extracted panel. Pillar extraction increases the risk of spalling in the acute ends of diamond shaped pillars. This can result in both an increase in roof span and an increased risk of rib fall injuries. Spalling risk increases for several reasons. First, because the pillars are located in an abutment stress zone. Second, some acute pillar corners are exposed to abutment stress on two sides since they project into the goaf. Third, the acute ends of fenders can be subjected to abutment stress from a previously extracted adjacent panel. In a continuous haulage operation, the last pillars extracted in each row usually project into the goaf at the centre of the panel. Therefore, these pillars may be under higher abutment stress.

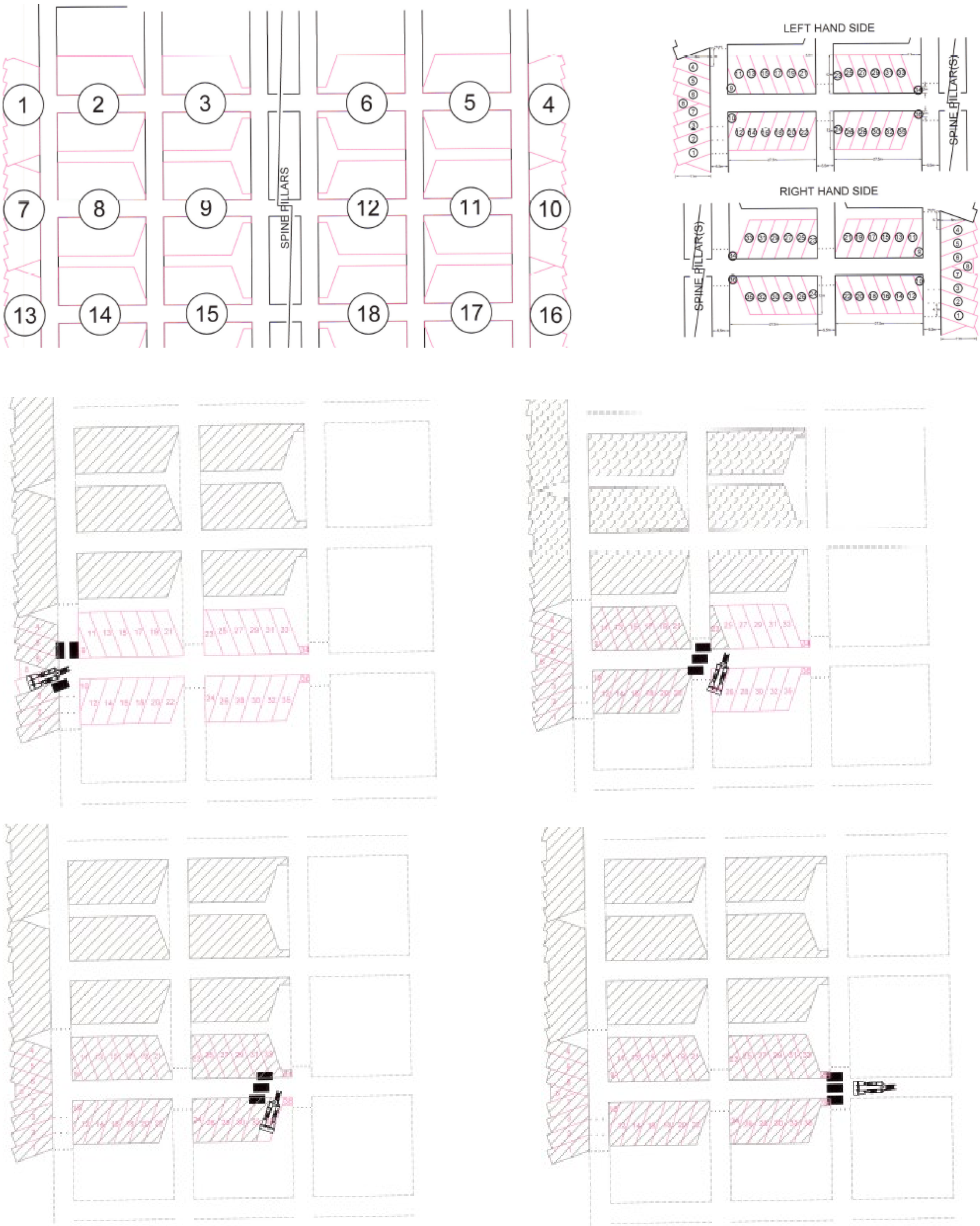
Figure 16 – An example of an Australian pillar extraction layout and sequence plan when using continuous haulage[35]



[35] Galvin 2016 - Chapter 8, Section 8.3.2.1 - Fig. 8.15(b)

2.3.1.4. Example of a design for pillar extraction

Figure 17 – Example of extraction at Clarence Colliery[36]



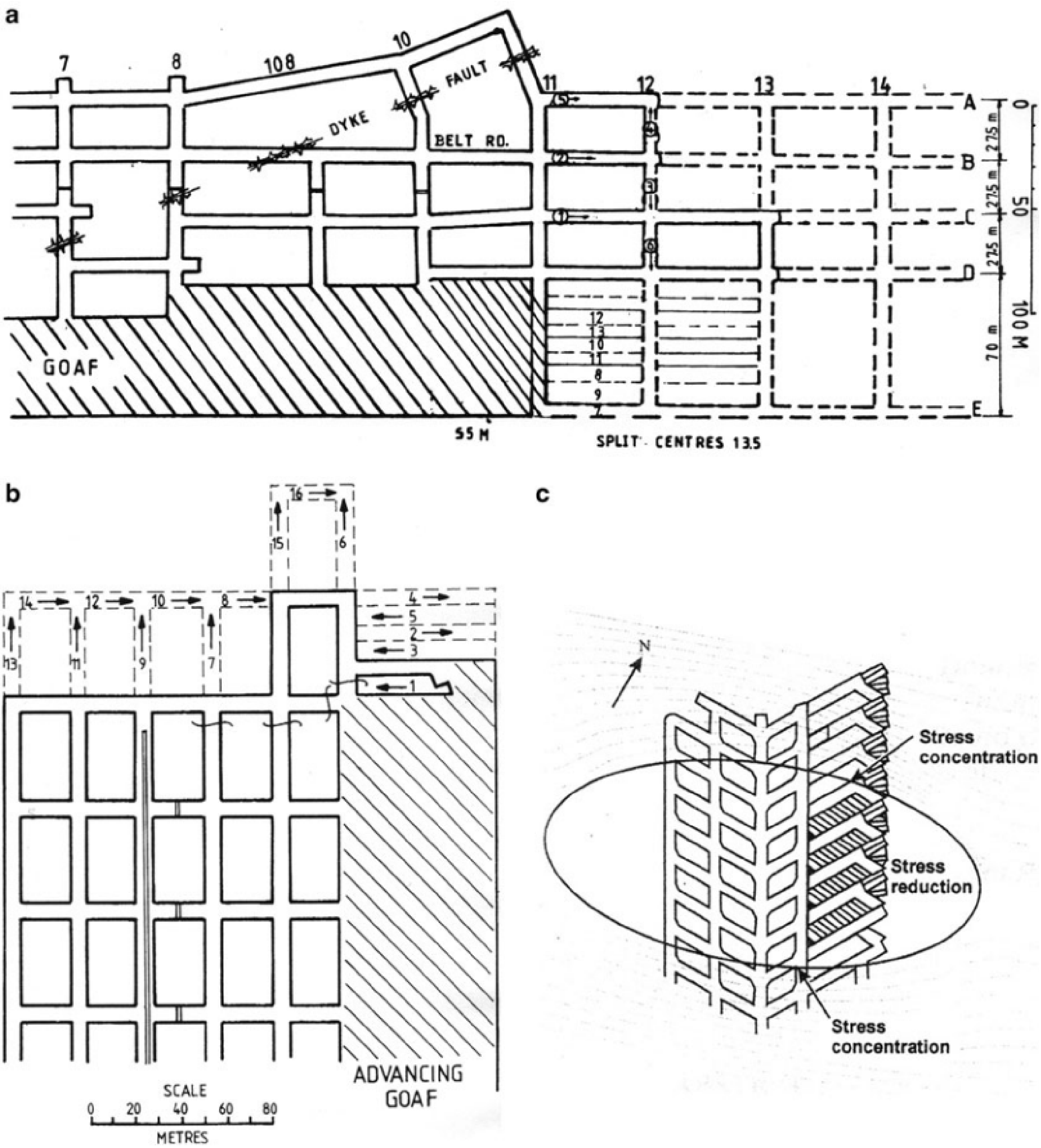
[36] Reproduced with permission from Centennial Coal

2.3.1.5. Design for pillar extraction on the advance

Pillar extraction on the advance involves extracting pillars on one side of a panel as it is being developed. This approach aims to improve ground control in high lateral stress environments by extracting some pillars as the panel is being developed. This is so the remaining pillars can be placed within a horizontal stress shadow when extracted. This concept has been met with mixed success.

Figure 18 – Various layouts for conducting pillar extraction on the advance[37]

(a) Layout associated with trials at Tahmoor Colliery, Australia (After Skybey 1984); (b) Layout based on the Wongawilli method (After Sleeman 1993); (c) Layout reported by Dolinar et al. (2000).



[37] Galvin 2016 - Chapter 8, Section 8.3.2.3 - Fig. 8.16

2.3.2. Partial extraction and pillar reduction methods

Partial extraction and pillar reduction methods extract only certain rows of pillars or portions of pillars in each row. While based on the same techniques as total extraction systems, they restrict goafing, abutment stress and overburden subsidence. The strength and stability of the unextracted pillars in the goaf is critically important. Their sudden failure can result in regional uncontrolled collapse with serious safety and environmental implications. Mine operators should take particular care to ensure the long term stability of the unextracted and remnant pillars.

When designing partial extraction layouts it is important not to limit the focus to the strength of the coal pillar element. Mine operators must carefully consider:

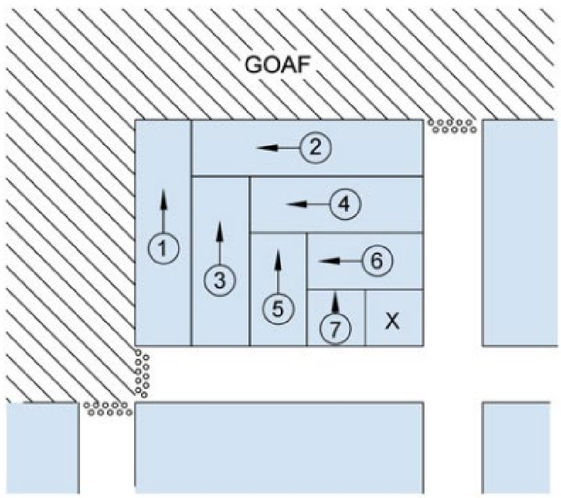
- the serviceability of the roadways in the abutment stress zone. Although the maximum loading capacity of the coal pillars themselves may not have failed, rib spall and convergence can still present serious direct and indirect safety risks.
- foundation failure. Pillar extraction can cause events such as floor heave, especially at depth.
- excavation behaviour. Depending on the nature of the immediate roof and excavation span, partial extraction layouts can increase windblast risk. Mine operators must assess the potential for plug failure through to the surface when mining at shallow depth (less than 100m but especially at depths less than 50m).
- pillar failure modes. Partial pillar extraction does not always eliminate the risk of sudden pillar collapse and pressure bursts.
- goaf edge control, including the merits of leaving stooks at intersections. Pillar failures in the Lake Macquarie region of NSW highlight that stable partial pillar extraction layouts can be deceptively complex. Partial extraction layouts warrant detailed geotechnical investigation before implementation. This should account for factors such as the impact of roof falls and flooding on the long-term stability of the workings.

2.3.2.1. Open end lifting (for pillar reduction)

Open end lifting is one of the earliest (and most hazardous) forms of pillar extraction. While not recommended for complete extraction, it may be considered for pillar reduction. The pillar is progressively reduced by mining lifts that may be up to 30m long off the perimeter of the pillar, effectively placing operators in the goaf.

Open end lifting may potentially be used for pillar reduction, but only where there is no goaf present.

Figure 19 – A general form of open lifting[38]



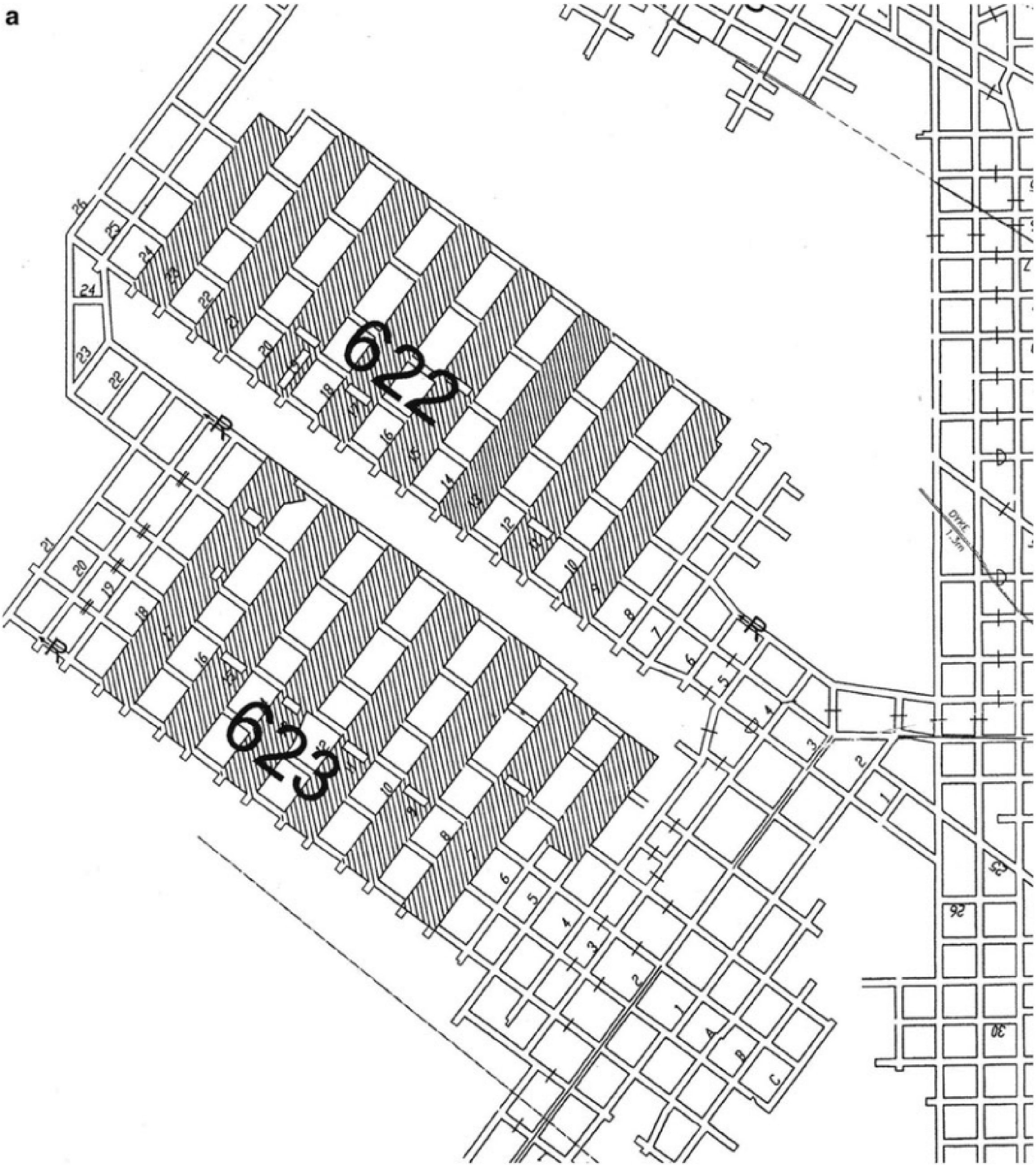
[38] Galvin 2016 - Chapter 8, Section 8.3.2.1 - Fig. 8.7

2.3.2.2. Examples of pillar reduction methods

Figures 20 (a), (b) and (c) and Figure 21 below show a variety of panel designs for pillar reduction methods.

Figure 20 – Examples of partial pillar extraction methods[39]

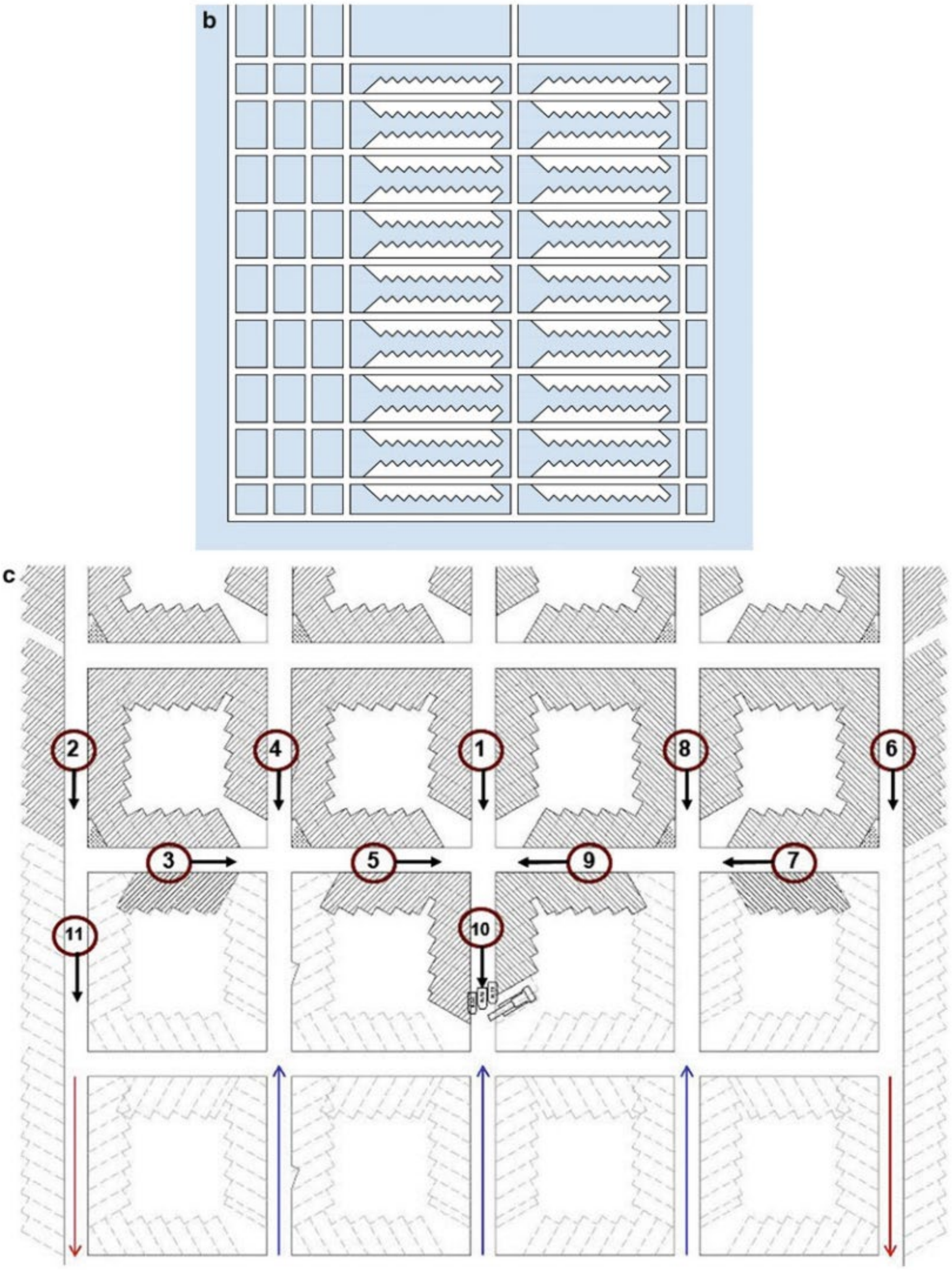
In the figure below: (a) - Panel and pillar mining based on 'take a row, leave a row', Myuna Colliery, Australia.



[39] Galvin 2016 - Chapter 8, Section 8.3.3 - Fig. 8.19(a) (Reproduced with permission from Centennial Coal)

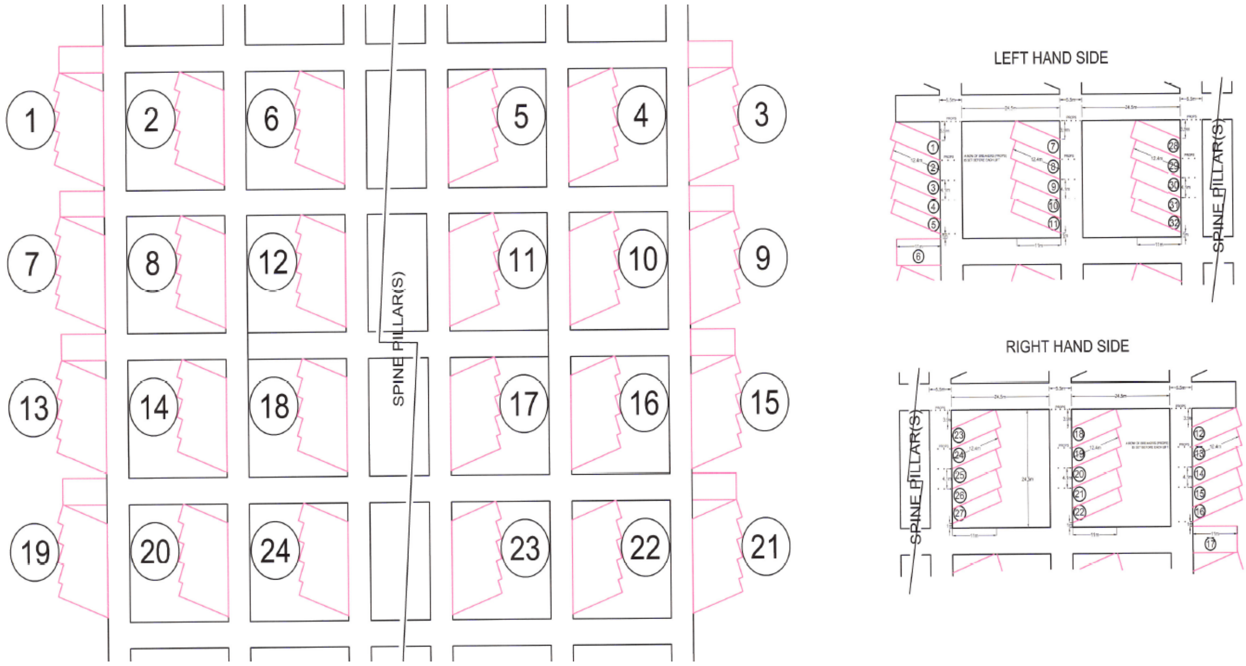
Figure 20 (Continued)[40]

In the figure below: (b) Concept of lifting left and right on two sides to form the final pillar size, based on a mine layout employed at Cooranbong Colliery, Australia; (c) - Lifting left and right on four sides to form the final pillar size, Tasman Mine, Australia (after Tyler and Sutherland 2011).



[40] Galvin 2016 - Chapter 8, Section 8.3.3 - Fig. 8.19 (b); and Galvin 2016 - Chapter 8, Section 8.3.3 - Fig. 8.19 (c), such last figure being after Tyler Sutherland 2011

Figure 21 – Example of partial extraction at Clarence Colliery[41]



[41] Reproduced with permission from Centennial Coal

3. Risk management

3.1. Risk management process

Mine operators must follow the four-step risk management process when developing a pillar extraction plan:

- **Identify hazards**– determine what could cause harm
- **Assess risks**– understand the nature of the harm that the hazard could cause, the chance of it happening, and its severity
- **Control risks**– implement any mandatory control measures, or the most effective and reasonably practicable control measure in the circumstances
- **Review control measures** to ensure they are working as planned.

It is essential that any risk management processes are applied with the specific circumstances or risk context in mind.

Effective ground control in pillar extraction requires regional, panel and workplace level stability assessment. Some primary factors that impact on stability are interactive. Some operate at all three levels[42].

Mine operators must consider the impact of associated risks from pillar extraction or pillar reduction activities on the mine environment. These include windblast, explosion, spontaneous combustion and expulsion of flammable or irrespirable gases and dusts.

3.2. Hazard identification

Mines undertaking pillar extraction or reduction activities must fully and systematically investigate and analyse health and safety risks.

The mine operator needs to thoroughly identify and consider all the secondary hazards associated with any identified risk controls. This ensures that the complete mine risk profile is understood.

3.3. Risk assessment

Those assessing risks must be competent to do so, considering the nature of the hazard. The Guide - Preparing a principal hazard management plan provides further details around competent persons and risk assessment techniques.

Once hazards have been identified, their risk and management controls need to be assessed. This can be an iterative process, as the risk assessment may identify hazards that pose an unacceptable risk and require additional controls to be developed. The assessment needs to consider all risks and needs to determine management controls for each of those risks.

The following documents may be useful:

- NSW code of practice: How to manage work health and safety risks (August 2019)
- National Minerals Industry Safety and Health Risk Assessment Guideline and
- RISKGATE, an interactive online risk management tool designed to assist in the analysis of priority unwanted events unique to the Australian Coal Mining industry.

For further information on managing risks under the Regulation, see Managing risks in mining and petroleum operations. This guideline includes specific obligations for conducting risk assessments.

[42] Galvin 2016

Mine operators should document and maintain their risk analysis methods including:

- describing identification methods for the level of risk, threats, controls and consequences (e.g. risk assessments, bow-tie methodology)
- describing scientific testing methods used to assist risk evaluation
- justifying the use of those methods (i.e., why they were considered valid and reliable)
- recording the most recent risk assessments.

3.4. Risk controls

3.4.1. Hierarchy of controls

Mine operators must apply the hierarchy of controls set out in the relevant work health and safety laws. The mine operator must try to eliminate risks so far as is reasonably practicable. Risks that cannot be reasonably eliminated must be minimised so far as is reasonably practicable.

The more effective control measures should be used first. Several control measures can be used at once, and they should be proportionate to the risk. Control measures include equipment, processes, procedures or behaviour to minimise risk. For further details see the Guide – Preparing a principal hazard management plan.

3.4.2. Preventative controls

Preventative controls reduce the likelihood of an unwanted event occurring.

Examples of preventative controls include:

- risk assessments that consider all pillar extraction or pillar reduction hazards
- ensuring there is a good geological and geotechnical understanding of the area and process, including time
- good mine design process that also incorporate regional, mine, panel and pillar design aspects
- appropriate equipment that is fit for purpose to conduct the activities
- a well developed pillar extraction or pillar reduction method and sequence
- operational discipline
- good education and training processes.

Trigger action response plans (TARPs) summarise the overall mine environment monitoring arrangements. They include planned actions ready to implement when monitoring detects certain trigger or alarm points. TARPs should only be put in place after a risk assessment has verified the selection of the most effective control measures.

Monitoring alone is not a control. The control is the action that is triggered when the monitoring system detects a change and activates a trigger/alarm. TARPs represent a staged response to a changing situation. For example, a situation that may deteriorate from simply being abnormal, through to elevated. TARPs should specify all worker actions and responsibilities at each level.

3.4.3. Mitigating controls

Mitigating controls eliminate or reduce the impact of the unwanted event. A useful guide on critical control management is the International Council on Mining and Metals' (ICMM) Health and Safety Critical Control Management: Good Practice Guide.

A comprehensive risk assessment should also identify mitigating controls.

Examples of mitigating controls include:

- designing interpanel barrier pillars to prevent over run in the event of a pillar collapse event

- ensuring adequate width to height ratios for panels and pillars
- TARPs
- current emergency plans
- good housekeeping
- limiting the number of workers in airblast prone zones (if applicable)
- locating infrastructure outside of airblast prone zones were possible (if applicable)
- maintenaning a high level of stonedusting in the mining panel at all times
- maintenaning a good education and training refresher process.

3.4.4. Review of controls

Mine operators should regularly review controls to ensure the work environment remains without risks to health and safety, as reasonably practicable[43].

Controls should be reviewed before workplace practices are changed or new or modified equipment is introduced to workplace.

If incidents occur, mine operators must respond by reviewing and revising their control measures. Reviews are also required by the Work Health and Safety (Mines and Petroleum Sites) Regulation.

3.4.5. Measuring and improving the effectiveness of controls

Controls should be measured and evaluated for effectiveness. A mine's SMS must include:

- performance standards for measuring the effectiveness of the safety system
- steps to continually improve the safety system
- a system for auditing the effectiveness of the safety management system, which must include the methods, frequency and results of the audit process.

Any identifed areas to improve controls should be implemented where reasonably practicable.

3.5. Records and training

3.5.1. Documentation and training

Mine operators must document their pillar extraction plan within the Ground and Strata PHMP.

All pillar extraction workers must complete training on the applicable controls before commencing extraction works. The training must ensure that each worker can safely and effectively carry out their duties and understand their responsibilities. This includes using equipment appropriately and following procedures (including the use and application of personal protective equipment and first response equipment and procedures). Mine operators must also keep records of training completion.

Mine operators should also provide additional training where pillar extraction risks and controls change. Refresher training should be provided to workers commensurate with the level of risk.

[43] *Work Health and Safety Regulation 2017* s38.

Appendix A – Case studies

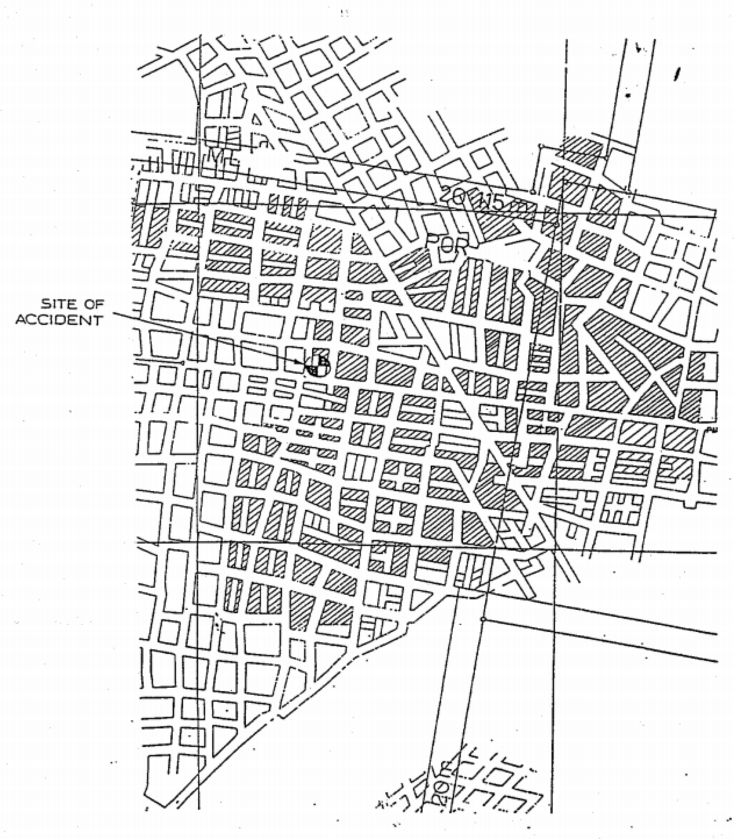
Case study 1 – Shallow depth extraction in a NSW underground coal mine – 3 fatalities[44]

Depth of cover 22 m, panel width 200 m, pillar height 2.1 m to 2.3 m.

Roof strata – 4 m of coarse-grained sandstone, then interbedded sandstone, siltstone and mudstone.

Floor strata – sandstone.

Figure 22 – Plan showing Site of Incident for Case study 1



The operation was extracting 40-year-old pillars, of varying dimensions. Nominal fender widths were 6m. Roadway widths varied from 5 – 7m, averaging 6m. Extraction had proceeded to a point as shown on the plan in Figure 22 above. Significant sub pillars had been left in the goaf. Approximately 40m by 40m of goaf was standing immediately adjacent to the face. This goaf collapsed while the second lift from a fender was being taken, riding over the fender. This caused three fatalities, entombed two workers and buried the continuous miner.

Extraction had developed to a point where goaf had surrounded the face operations on three sides. Elevated loads were present on the goaf edge. Shallow cover increases the risk of uncontrolled goaf collapse considerably. For various reasons, large amounts of coal were left in the goaf. These sub pillars and stooks definitely delayed caving. At shallow depths, even relatively small stooks can delay caving. The fender at the face collapsed. Its height had been reduced by 0.5m after the fall. The fender width was variable from 3-4m. This results in width to height ratios of 1.4 – 1.8. Suggested minimum fender width is 5m, or a width to height ratio of at least 2, whichever is greater.

[44] NSW Department of Mineral Resources 1992 – Case 4

Case study 2 – NSW underground coal mine – 1 fatality[45]

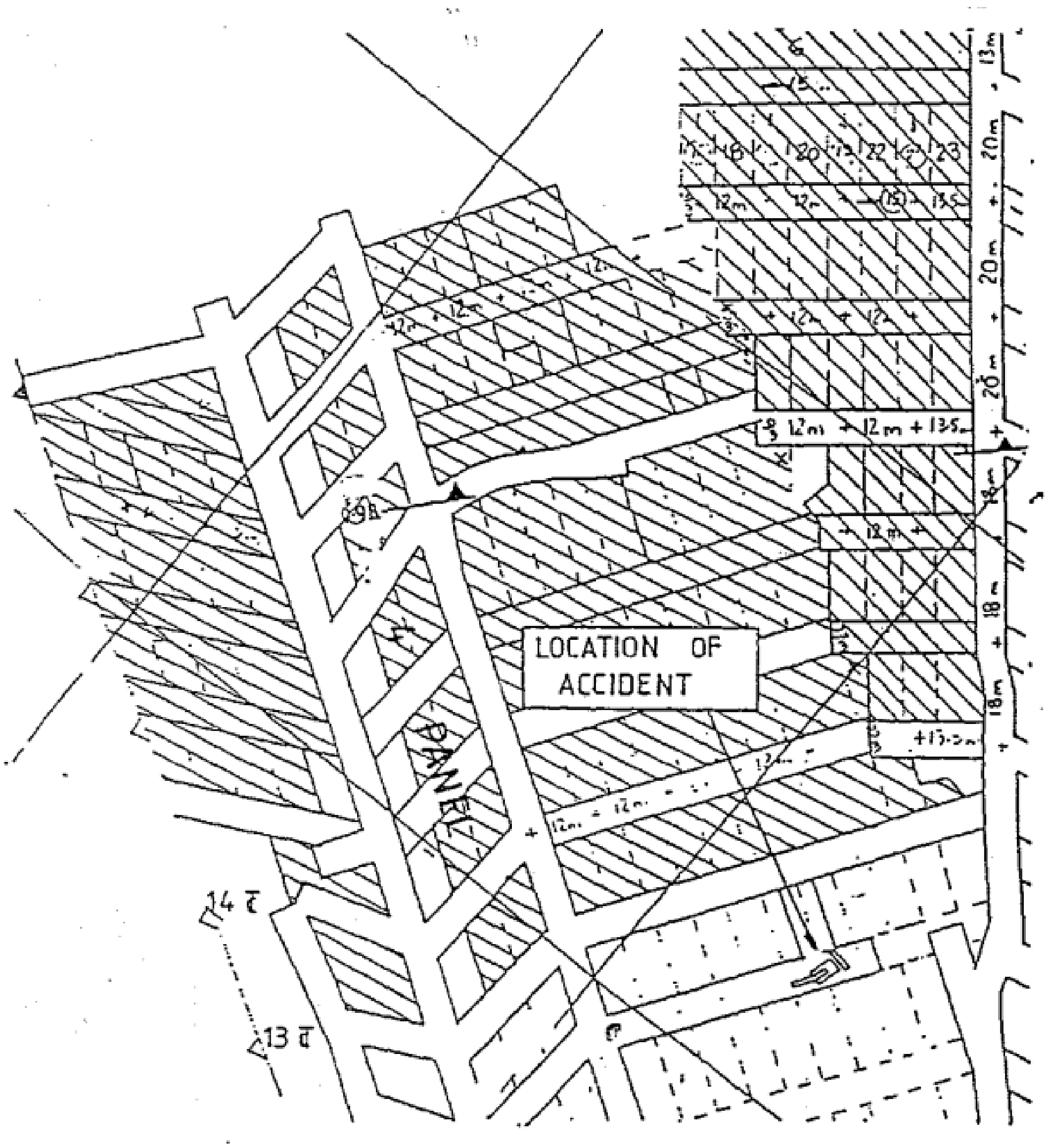
Depth of cover 130 m, panel width variable from 120 to 160 m, pillar height 2.8 m.

Roof strata - 30 m conglomerate.

Floor strata – 3 m claystone.

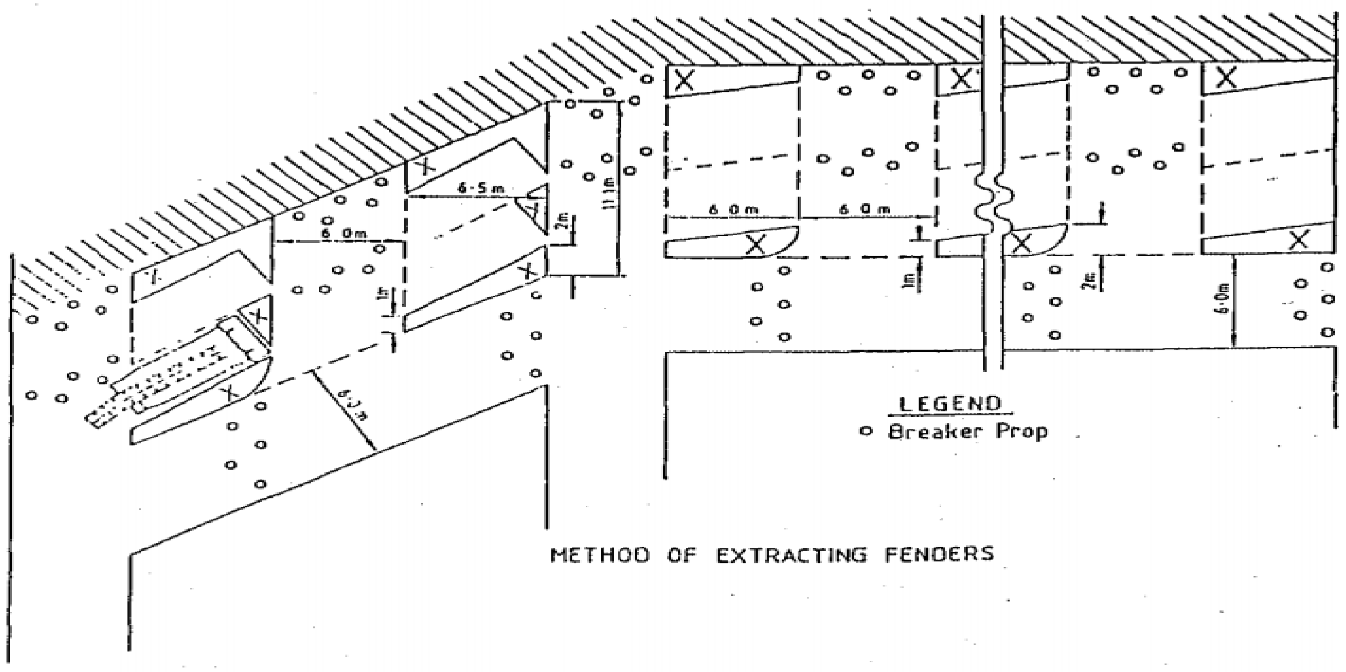
Figures 23 and 24 below show the Extraction Layout.

Figure 23 - Plan showing the Extraction Layout and Location of Incident for Case study 2



[45] NSW Department of Mineral Resources 1992 – Case 3

Figure 24 - Plan showing Extraction Layout for Case study 2



The operation was extracting pillars using a long split and fender method. The first three panels in the block being mined were regular in shape but a large fault meant the final panel would be triangular. Caving was poor from the outset of extraction. Before the incident at least 20m of goaf was standing. Heavy rib spall was constantly dislodging brattice timber whilst driving a long split to hole the previous panel goaf. A ventilation window was driven through the fender. As soon as the long split was recommenced, an enormous “bump” occurred tearing away the roof and coal ribs causing one fatality.

The panel started adjacent to a fault to help induce a quick cave. Extraction allowed for the extension of an existing goaf, to further assist early caving and maintain goaf continuity. Extraction provided for lifting on both sides of the original three access roadways. To achieve this, a sub pillar 6m by 11m was left where the two extraction directions meet. The effect of the 6m by 11m sub pillars plus other stooks delayed caving. The 16m by 10m chain pillars left against the previous panel goaf delayed the linking of these goaves. Irregular panel widthsometimes leads to inconsistent or unpredictable goaf formation. This is created by retreating on a decreasing front.

The layout adopted probably concentrated stress levels at the goaf edge above that normally expected. The fender width between the face road and the goaf was 11m with a width to height ratio of 4. Although heavily loaded when the event occured, this fender did not collapse. It continued to protect the face road. Driving of the ventilation window through the fender weakened the fender at that point and formed a 3-way intersection. The subsequent roof collapse occurred in this intersection and nowhere else along the split.

Case study 3 – NSW underground coal mine – 1 fatality[46]

Depth of cover 140 m, panel width 140 m, pillar height 2.4 m.

Roof strata – 30 m conglomerate.

Floor strata – 2 m claystone.

The operation was extracting a panel of 12 year old standing pillars. The new goaf being formed was to link with an existing goaf. Pillars were being split and then lifted, with nominal fender widths of 6.5m. Five rows of pillars had been extracted when the mine shut down over Christmas. Shortly after mining resumed in the new year, a sudden and unexpected goaf collapse occurred. This caused one fatality, buried the continuous miner, and entombed the driver for several hours.

Figure 25 below shows that the panel was started adjacent to a geological weakness (a large dyke) to help induce a quick cave. The extraction plan also allowed for the extension of an existing goaf to further assist in creating an early cave and maintain goaf continuity. Due to poor floor conditions, as well as several seam rolls, numerous large stooks and sub pillars were left in the goaf. This coal delayed caving. On the solid barrier side of the panel, between 23 and 25 cut-through whole pillars were abandoned. In addition to delaying caving these pillars reduced the panel width and may have interrupted normal goaf formation. On the old goaf side of the panel, considerable amounts of coal had been left adjacent to the dyke. This coal effectively prevented the two goaves from linking together. (It is also believed that more coal was actually left in the old goaf than shown on the plan). The overall result was that the goaf being formed did "hang up" and then fell in thin sheets, only 3m thick. These shallow falls sometimes created windblasts.

As a result of the factors mentioned above, the effective panel width to heaight ratio was 1, a critical width for caving. This created the potential for unpredictable goaf formation.

Figure 25 below indicates that the row of pillars at the goaf edge was pre-split across the full width of the panel, markedly reducing the size of pillar cores. This loss of core led to greater pillar compression, more strata movement and a reduction in strata integrity at the goaf edge. Rib crush shown on Figure 26 was caused by pillar compression and roadway strata movement (i.e., floor heave).

The shutdown of operations over Christmas resulted in a three week break in production. Time dependent behaviour of the goaf edge pillars and roadways further reduced strata integrity at the goaf edge. This meant that the 12 year old pillars and roadways had already deteriorated since they were first mined. Remedial support was required, especially at intersections.

There was some doubt that the plans of adjacent goaf areas accurately reflected the amount of coal left in the goaf. While Figure 26 appears to show a regular pillar layout, in fact there were variation in pillar dimensions, intersection size and roadway widths. An accurate plan is essential for careful design and controlled extraction.

[46] NSW Department of Mineral Resources 1992 -Case 1

Figure 25 – Plan showing panel was started adjacent to a geological weakness

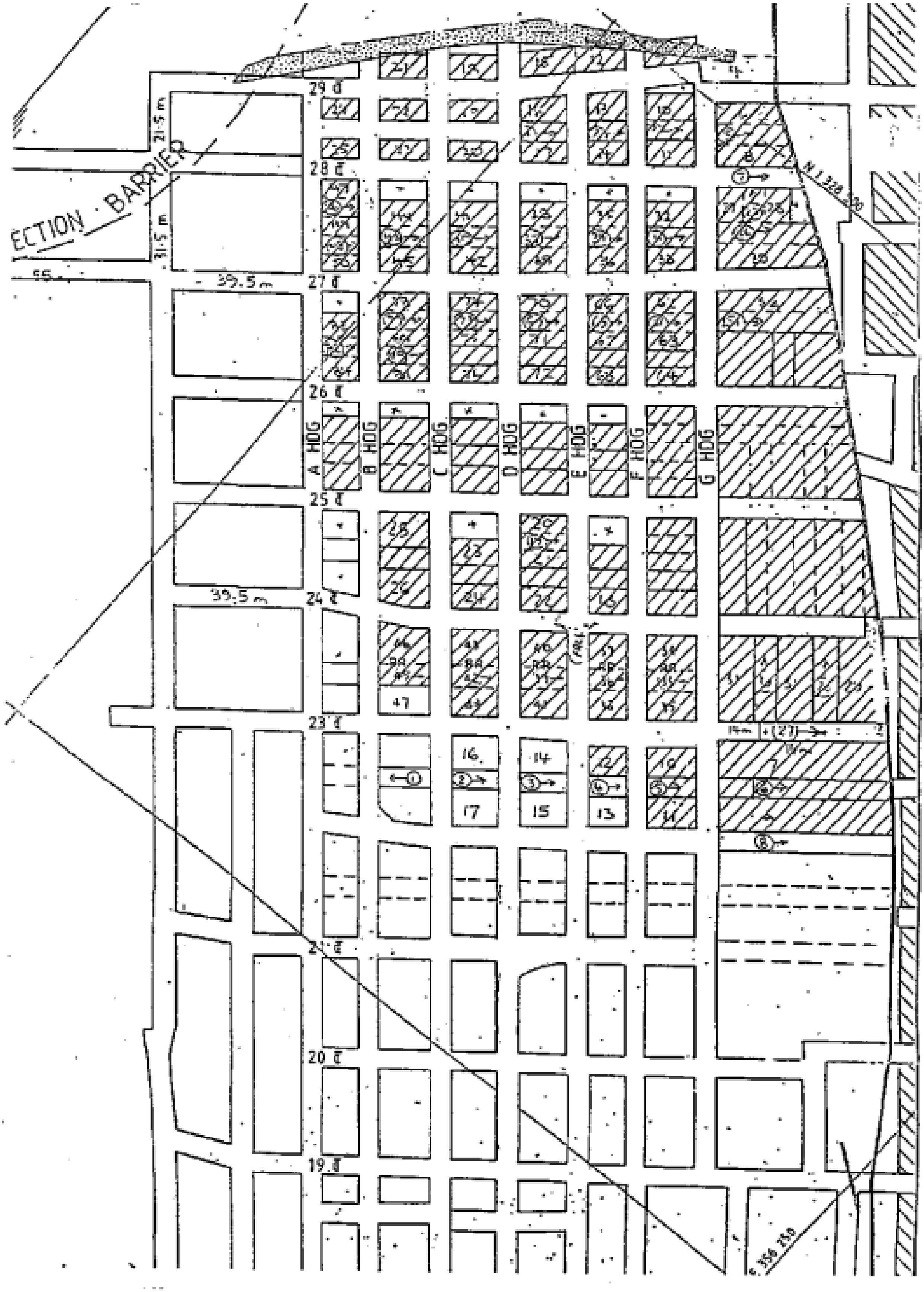
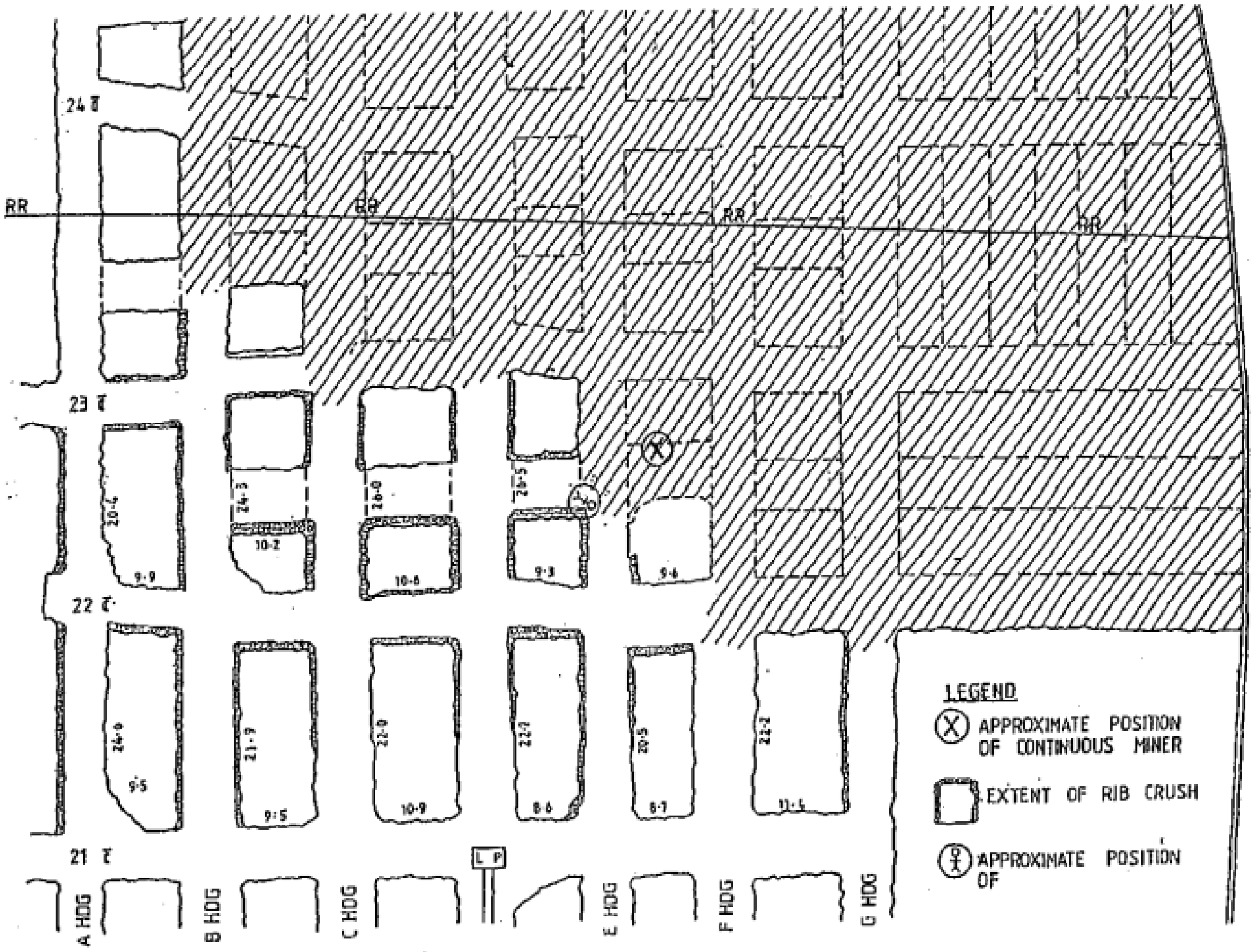


Figure 26 - Plan showing ribcrush

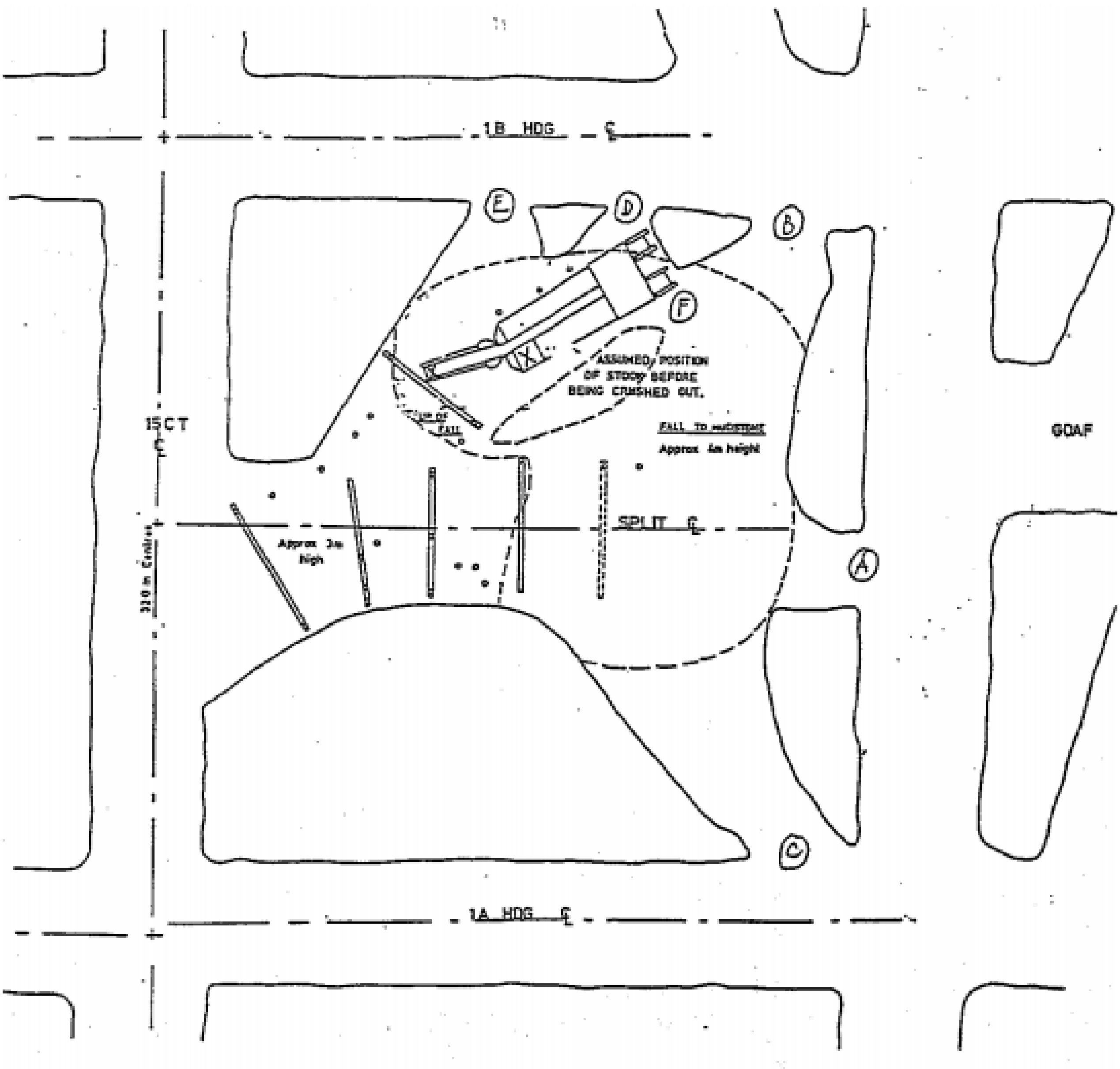


Case study 4 – NSW underground coal mine – 1 fatality[47]

The incident shown in Figure 27 below, caused one fatality and the continuous miner buried. Relevant factors were:

- a decision to vary the sequence of extraction from lifting one side of the split to lifting both sides of the split.
- failure to specify how the fenders were to be extracted in a controlled fashion.

Figure 27 - Plan of Case study 4 Incident Site



[47] NSW Department of Mineral Resources 1992 – Case 5

Case study 5 – Bord and pillar stability - Australian underground coal mine – no fatalities[48]

Figure 28 below shows an experimental panel used for assessing the effect of driving stubs in square pillars on overall pillar strength. The panel span to depth ratio, width to height, was 1.1 and the pillars had a width to height ratio of 4.4 before stubbing.

In response to the positive initial outcomes of the experimental trial, the mine operator applied these methods in the mine plan shown in Figure 29 below. The mine operator used diamond shaped pillars on one side of the production panel to minimise the impact of cleat on rib stability. The mine operator did not use interpanel pillars against adjacent extracted panels.

The mine usually designed panels to a safety factor of 1.6 using the UNSW power pillar strength formulae. Due to the positive outcomes of the experimental panel the mine operator reduced the designed safety factor to 1.2 for the new production panel.

The mine operator audited the new production panel's safety factor when it had only retreated a distance equal to depth (i.e., a width to height ratio of 1). The production panel's safety factor was calculated as only 0.8, with a probability of collapse of 90% due to:

- the size of the stubs not matching the size required by the plan
- a discovery of a calaculation error
- the severe deterioration of the acute corners of the diamond shaped pillars.

The mine operator immediately changed the mine plan to elevate the safety factor to 1.6.As planned, the mine ceased production soon after completion of the panel. Some months after the mine closed, the experimental panel violently collapsed, blowing out seals in the mine.

Lessons from this case study include:

1. Experimental panels
    a. Experimental panels should face similar loading conditions to those found in routine production operations. The irregular outline and small width to height ratio of the experimental panel in the case study did not generate the same full deadweight loading conditions that would occur in production panels.
    b. The impacts of a change in design need to be properly identified and evaluated. In the case study the irregular arrangement of stubs and the final shape of the pocketed pillars created irregular pillar loadings. This added complexity to the calculations.
    c. The time dependant strength of rock needs to be considered when assessing the outcome of experimental panels. The experimental panel in the case study failed two years after it was developed.
    d. One successful outcome from an experimental panel does not mean that all future outcomes will be successful.
    e. Pillars of small width to height ratio can fail violently, generating large windblasts.
2. Operational panel
    a. If an operational panel is to rely on the outcomes of an experimental panel, then the design should reflect the layout of the experimental panel.
    b. Diamond shaped pillars are particularly prone to rib spall on their acute corners. When pillars are small, this can result in a significant increase in pillar stress.

[48] Galvin 2008

c. Irregularly shaped portions of a coal pillar should not be assumed to have the same average load carrying capacity per unit area (strength) as the rest of the pillar. The safety factor of the pocketed pillars in the case study was incorrectly inflated by assigning the average pillar strength to the irregular sections.

d. The pocketing of pillars needs to be undertaken very carefully. Small increases in extraction can greatly reduce the stability of the pillar system, especially when the pillars are already relatively small.

3. General

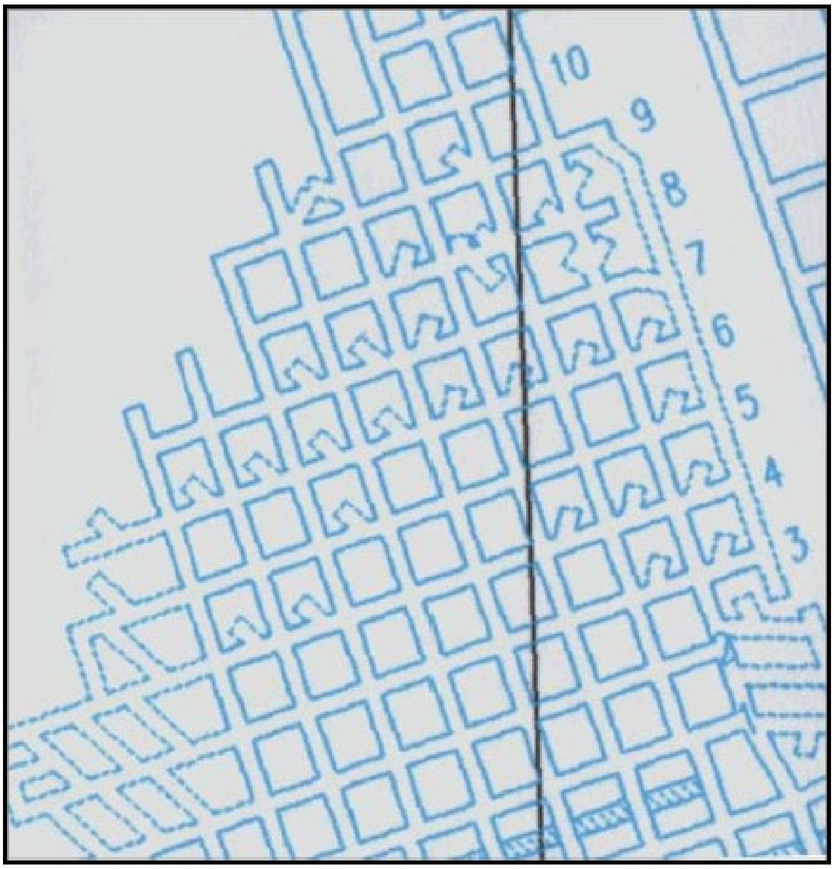
    a. Visual observations of pillar system stability can be misleading and should not be relied on. Measurements and calculations are required.

    b. Interpanel pillars are essential controls to allow for unknowns, errors and the unplanned.

    c. Good mine design principles must be followed

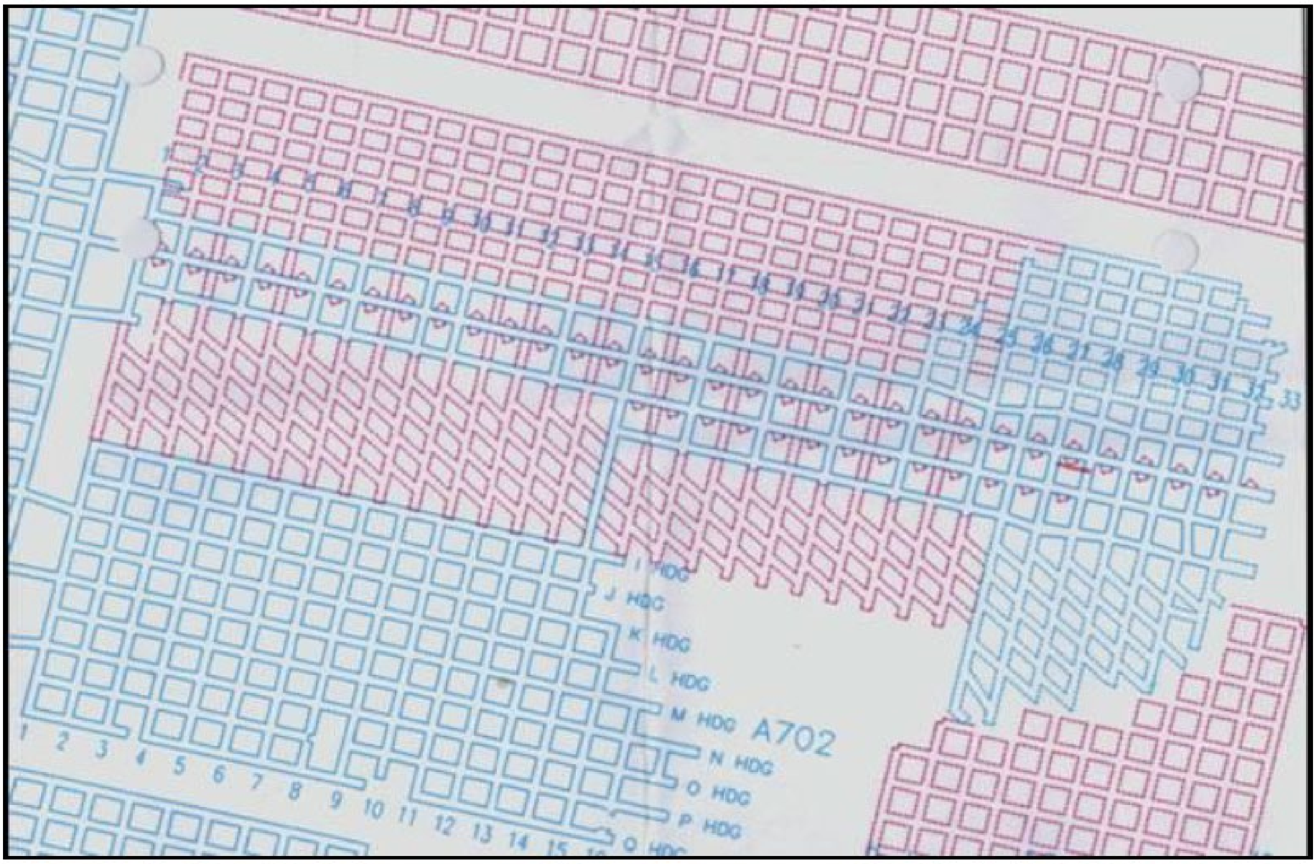
    d. Mine design based on cautious experience is important. Pushing the limits may result in failure.

Figure 28 – The layout of the experimental panel used to assess the impacts of pillar system stability of driving stubs in pillars.[49]



[49] Galvin 2008 p. 165

Figure 29 – The production plan incorporating outcomes of the experimental panel. (Actual workings in blue, planned workings in red)[50]



[50] Galvin 2008 p. 166

Case study 6 – Strong roof, weak floor - NSW underground coal mine Awaba Colliery 1977 – no fatalities[51]

In 1977, pillar system failure occurred over a period of days at very shallow depth in the Great Northern Seam at Awaba Colliery. The roof strata comprised massive strong conglomerate roof and the floor comprised soft and weak Awaba Tuff. Figure 30 below shows the affected area, with the instability extending to a well-defined fault zone, shown on the right side of the mine plan. The regional instability terminated against this faulted zone as shown in Figure 31 below.

Figure 30 below shows the irregular pattern of extraction of some pillars and the amount of coal left in the pillar extraction panels. There was also a massive roof bridging over adjacent pillar extraction panels. This means that although the workings were at shallow depth, the pillars would have experienced considerable abutment stress. . Back analysis indicates that the pillars abutting the pillar extraction panels are likely to have had a UNSW power safety factor of 1.3 to 1.6.

Figure 30 – Mine plan showing area involved in pillar instability event at Awaba Colliery[52]

[51] Galvin 2008

[52] Galvin 2008 p. 167

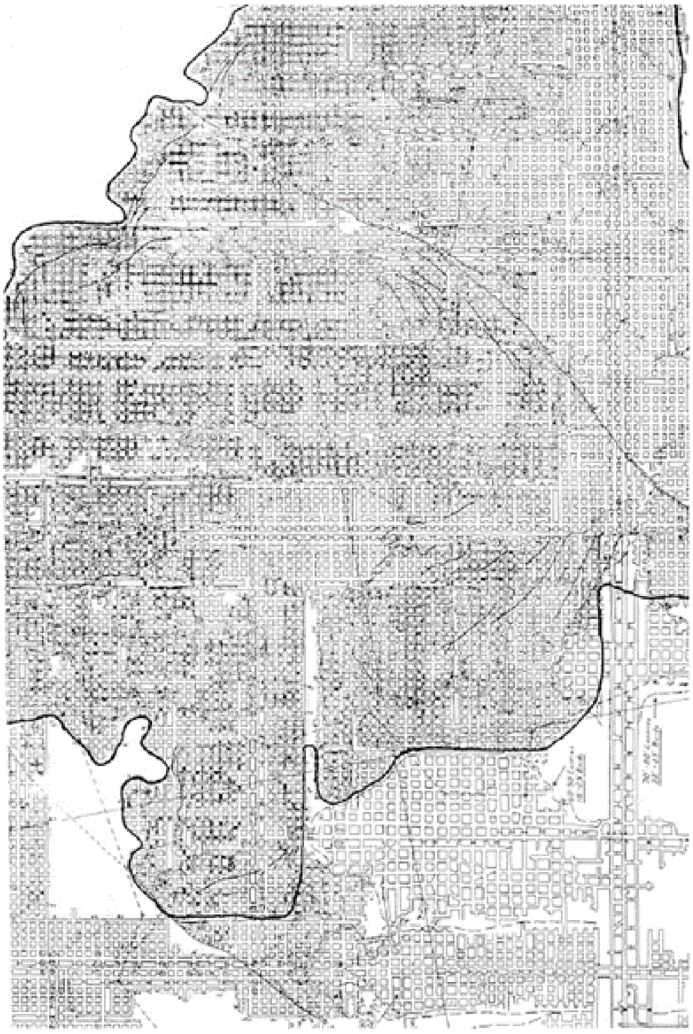
Figure 31 – Surface expression of fault plane on which the pillar system failure terminated[53]

[53] Galvin 2008 p. 168

Case study 7 – Bord and pillar stability - South African underground coal mine – 437 fatalities Coalbrook Colliery 21 January 1960[54]

There were 437 fatalaties at the Coalbrook Colliery in South Africa in one incident in 1960. Over 7,500 pillars in a bord and pillar mining layout failed, with 4,400 failing within a space of 5 minutes. The collapse was ultimately arrested by interpanel pillars and larger size panel pillars. Figure 32 below shows the incident area..

Figure 32 - Mine plan of area involved in Coalbrook Colliery pillar collapse within the black boundary[55]



The mine was under pressure to meet increased production targets to satisfy a new contract. The mine operator established a number of experimental panels to trial higher percentage extraction mining systems. These trials involved the formation of higher and narrow pillars. Interpanel pillars were not left and extraction occurred in existing interpanel pillars. A previous collapse had occured three weeks before, and was arrested by interpanel pillars. This did not prevent the subsequent fatal incident, as the interpanel pillars were also in the process of failing.

An important finding by the inquiry was that "*Mining should be carried out in panels surrounded by barriers of unworked coal of dimensions which will limit subsidence to a single panel in the event of pillar collapse.*"

Regional barrier pillars and interpanel pillars are essential to limit the extent and consequences of a pillar system failure.

[54] Moerdyk 1965 and Galvin 2008 p. 163

[55] Galvin 2008 p. 163

Case study 8 – Bord and pillar stability - USA underground coal mine – 9 fatalities – Crandall Canyon Colliery August 2007[56] [57]

On 6 August 2007 at 2:48am, a catastrophic coal outburst incident occurred at the Crandall Canyon Mine in Utah. This incident occurred during pillar recovery in the South Barrier sectionnear crosscut 139. The outburst started near the section pillar line (the general area where the miners were working) and spread toward the mine portal.

Within seconds, overstressed pillars failed throughout the South Barrier section over a distance of approximately 0.5 miles (800 metres) . The pillar failure triggered a magnitude 3.9 seismic event. Coal was expelled into the mine openings on the section, likely causing fatal injuries.. The barrier pillars to the north and south of the South Barrier section also failed. Oxygen-deficient air entering from the adjacent sealed area(s), may also have contributed to the fatalities. Telephone communication to the section was destroyed.

Initial attempts to reach the miners were unsuccessful. The mine operator developed a rescue plan, involving loading burst debris from the South Barrier section No. 1 entry using a continuous mining machine. These efforts began on August 8 at crosscut 120.

On 16 August 162007 at 6:38 pm, a coal outburst occurred from the pillar between the No. 1 and No. 2 entries. This was next to where the rescue workers were completing the installation of ground support behind the continuous mining machine. Coal that was ejected from the pillar dislodged standing roof supports, steel cables, chain-link fence, and a steel roof support channel. This struck the rescue workers and filled the entry with debris. Three fatalities occured and six workers were injured.

Ventilation controls were damaged and heavy dust filled the clean-up area, reducing visibility and impairing breathing. Also, air containing approximately 16% oxygen rentered the area where the injured rescue workers were. Nearby rescue workers started digging out the injured rescuers and repairing ventilation controls. T

Figure 33 below shows were mine workers were located at the time of the first incident. Figure 34 below shows the location of both incidents. Figure 35 below shows the location of the rescue attempts.

The circumstances of the Crandall Canyon incident were relatively unique. The circumstances involved extracting panel pillars and barrier pillar coal in a remnant area between flanking longwall panels at a depth range of around 450–680 m. It is likely that these circumstances resulted in:

- pillars having to bear abutment load from adjacent total extraction workings
- very high pillar loads
- the large extent of mining in the region.. This significantly reduced the stiffness of the overburden, possibly to the extent that the pillars were subjected to full deadweight load
- the load acting on the pillars was sustained as the pillars yielded.

Investigations revealed panel pillars with a width-to-height ratio of almost 8 had failed within seconds over a distance of 800m.The barrier pillars to the north and south also failed[58]. The barrier pillar to the south had a width-to-height ratio of about 6.2 at the point where failure was initiated, increasing to 15.4 further outbye. The outbye barrier pillars displayed severe signs of damage but the extent of internal fracturing is unknown.

The day after the initial pillar failure event, a pressure burst occurred in No. 3 entry/roadway (of four). This entry/roadway had been cleared of rubble in an attempt to reach the missing miners. The investigation report describes the entry (at No. 120 - crosscut/cut-through) as having been refilled with rubble as shown in Figure 36 below.

[56] Mine Safety and Health Administration (2008)

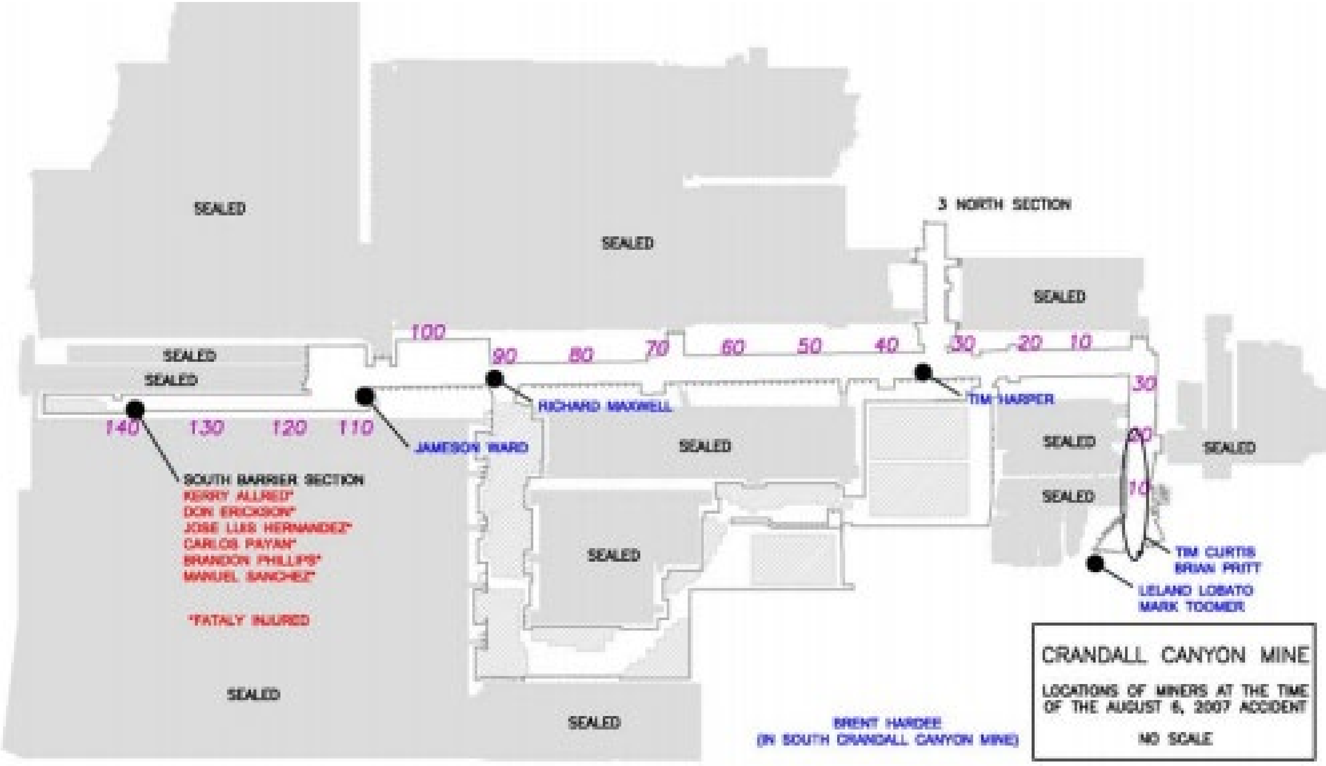
[57] Galvin (2016) - pages 155 -157.

[58] Galvin 2016 - Gates et al. 2008

A continuous miner was then used to clear No. 1 entry abutting the barrier pillar. The continuous miner was loading from a rubble pile that resembled an unmined coal face. During this process (and ten days after the first event), a pressure burst occurred at the re-mining face (inbye No. 126 crosscut). This caused a further three fatalities.. This incident generated a very high, deadweight load on large width-to-height ratio pillars.

Based on the UNSW power formula, and disregarding additional abutment loading associated with adjacent total extraction workings, the safety factor of the failed pillars ranged from around 0.8 to 1.3. The extent of fracturing within the pillars is unknown.It is possible that the failure process may have been modified by the bords choking off and providing confinement to the pillars.

Figure 33 - Mine plan showing the extent of previously extracted areas at Crandall Canyon mine and location of personnel when the first incident occurred on 6 August 2007[59]



[59] Mine Safety and Health Administration 2008 – Figure 2 p . 10

Figure 34 - Plan showing incident sites for both 6 August 2007 and 16 August 2007 incidents at Crandall Canyon Mine[60]

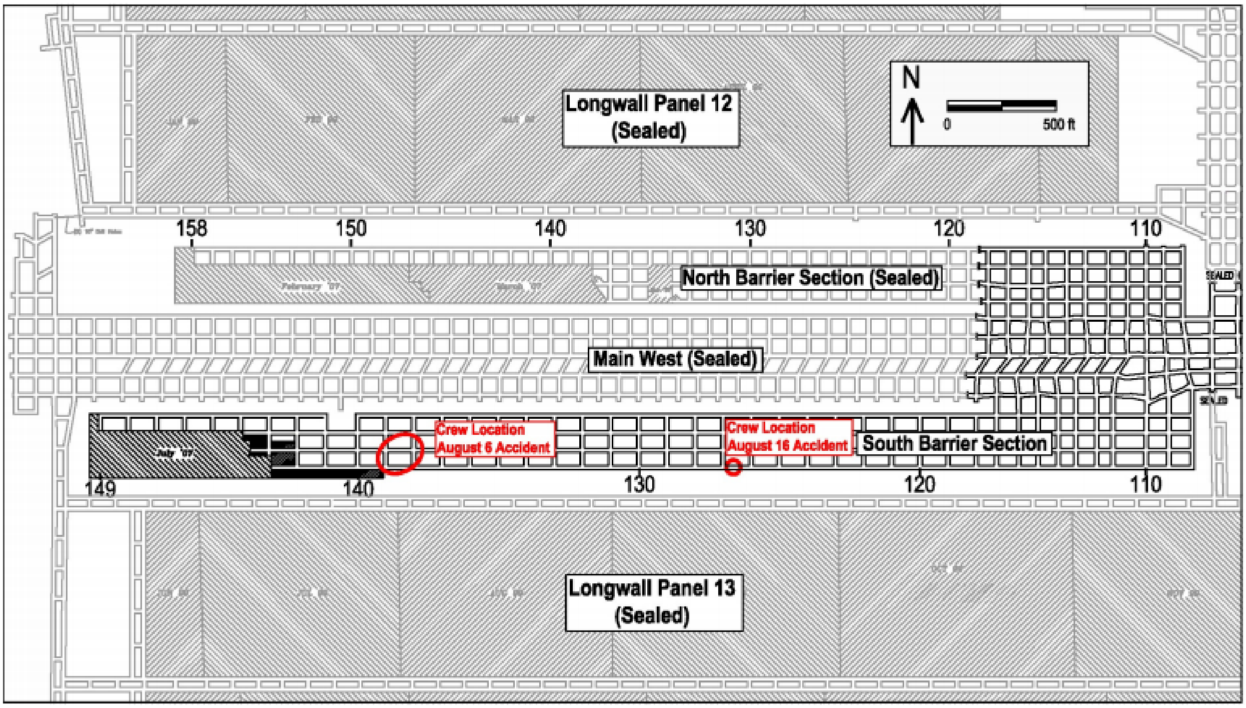
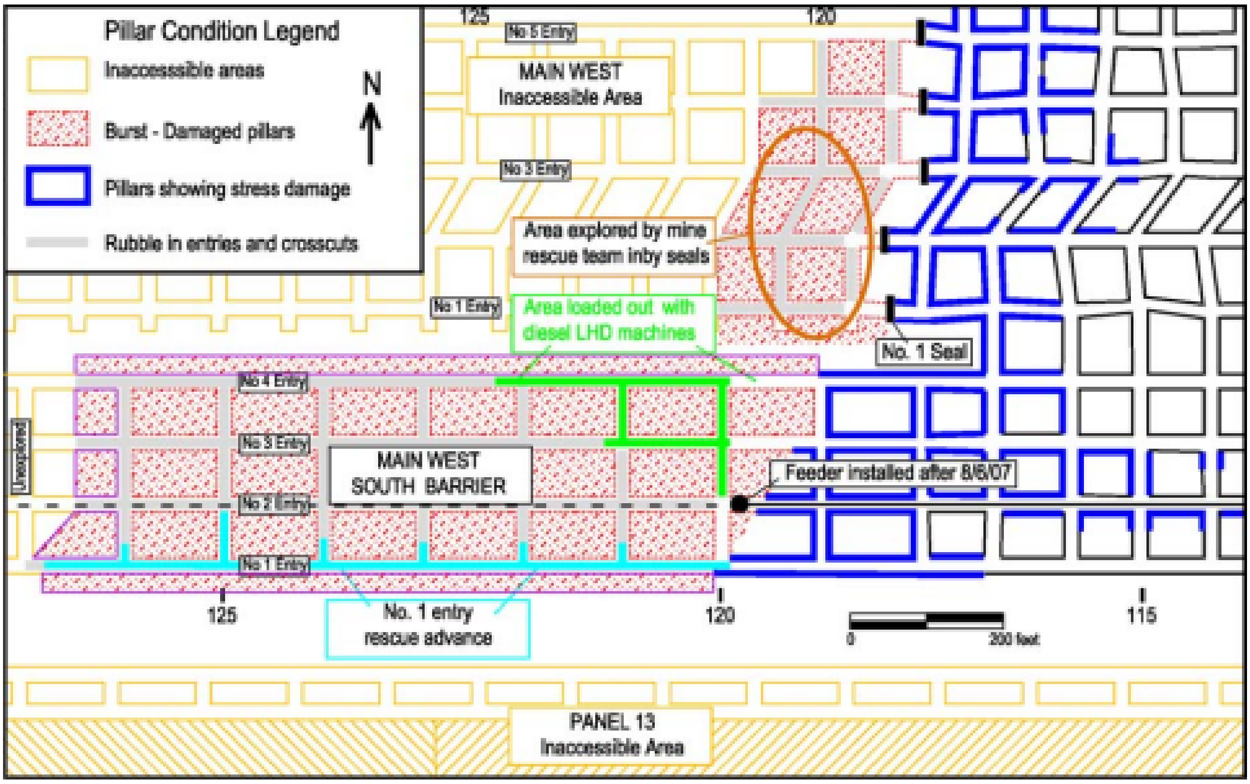


Figure 35 - South Barrier Section Rescue Area Showing Ground Conditions and Rescue Attempts[61]



[60] Mine Safety and Health Administration 2008 - Figure 1 – p. viii

[61] Mine Safety and Health Administration 2008 - Figure 3 – p. 19

Figure 36 - View of No. 3 Entry after August 7 Burst Entry cleaned by diesel loaders refilled with rubble (view indicated by arrow in index map insert)[62]

The investigation report is available at Crandall Canyon investigation report.

Several videos are available on youtube in relation to the rescue attempt.

https://www.youtube.com/watch?v=BexHucodJrI

https://www.youtube.com/watch?v=kKGNAhNPGpc

https://www.youtube.com/watch?v=Uk6HfFzJJT8

https://www.youtube.com/watch?v=RciA_IxnYJc

[62] Mine Safety and Health Administration 2008 – Figure 4 – p. 17

Case study 9 – Bord and pillar stability - NSW underground coal mine – 1 fatality - Chain Valley Colliery 3 June 2011[63]

At 1.55pm on 3 June 2011 a 4.8m slab of coal fell from the rib (wall) onto a mine worker. The slab broke in two when it hit the ground trappingthe mine worker under a 2.3m piece weighing about 1.3 tonnes. While the crew freed the injured mine worker within eight minutes of the incident, he was unable to be rescuscitated.

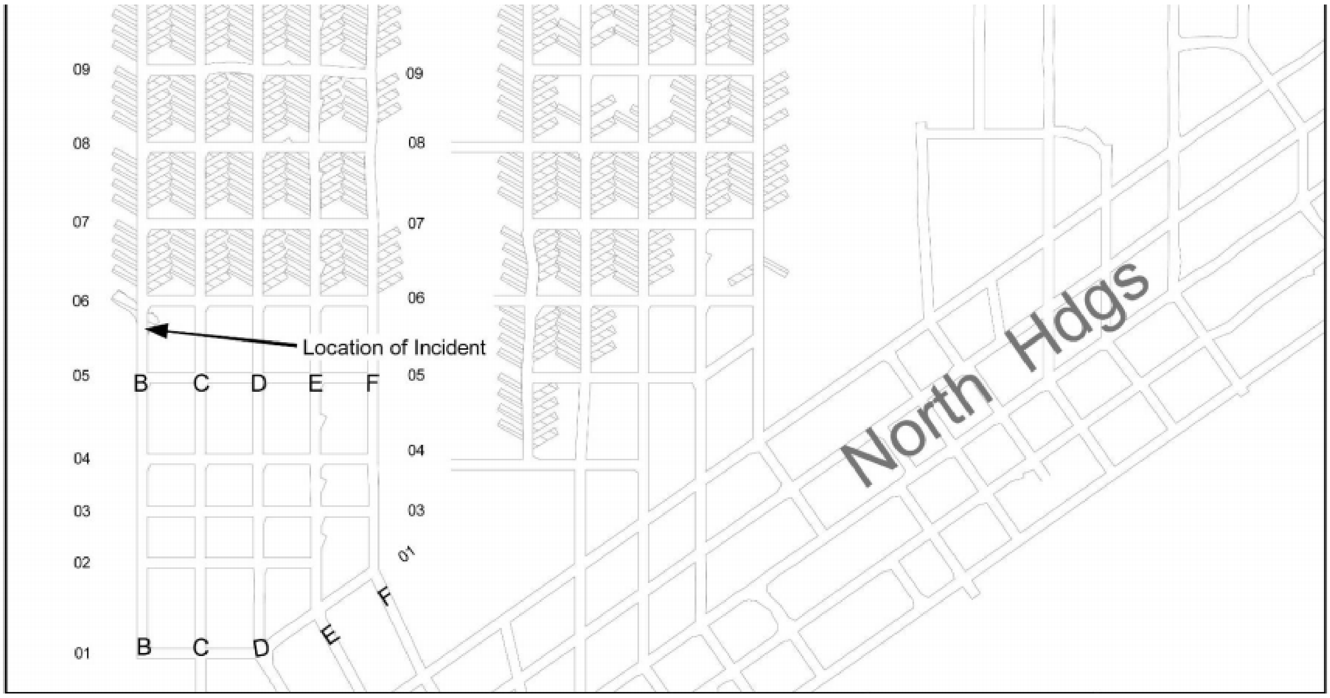
The investigation report describes the rib failure as follows:

> *It was observed that the slab which fell … did not contain any rib bolts as were observed inbye and outbye of the fallen section of rib. The fallen slab was wedge shaped and had very weak natural support as it was bounded by several planes of separation. A very thin column of coal at the base of the slab was the only material supporting the weight of the slab in place. The final impetus to this slab toppling over by gravity was considered to be induced vibrations from the movements of the machine (being) operated.*

The Safe Standing Area Plan for single-sided lifting using two breaker line supports indicated that the mine worker was within a safe standing area, ifthe rib side was appropriately supported. . However the slab of rib coal was not adequately supported (bolted) as required by the documented Pillar Extraction Management Plan or Authority to Mine.

The investigation report is available at Chain Valley investigation report.

Figure 37 - Plan showing incident site for case study 9



[63] NSW Department of Trade and Investment, Regional Infrastructure and Services (Trade and Investment) (2011)

Figure 38 - Detailed plan of incident site for case study 9

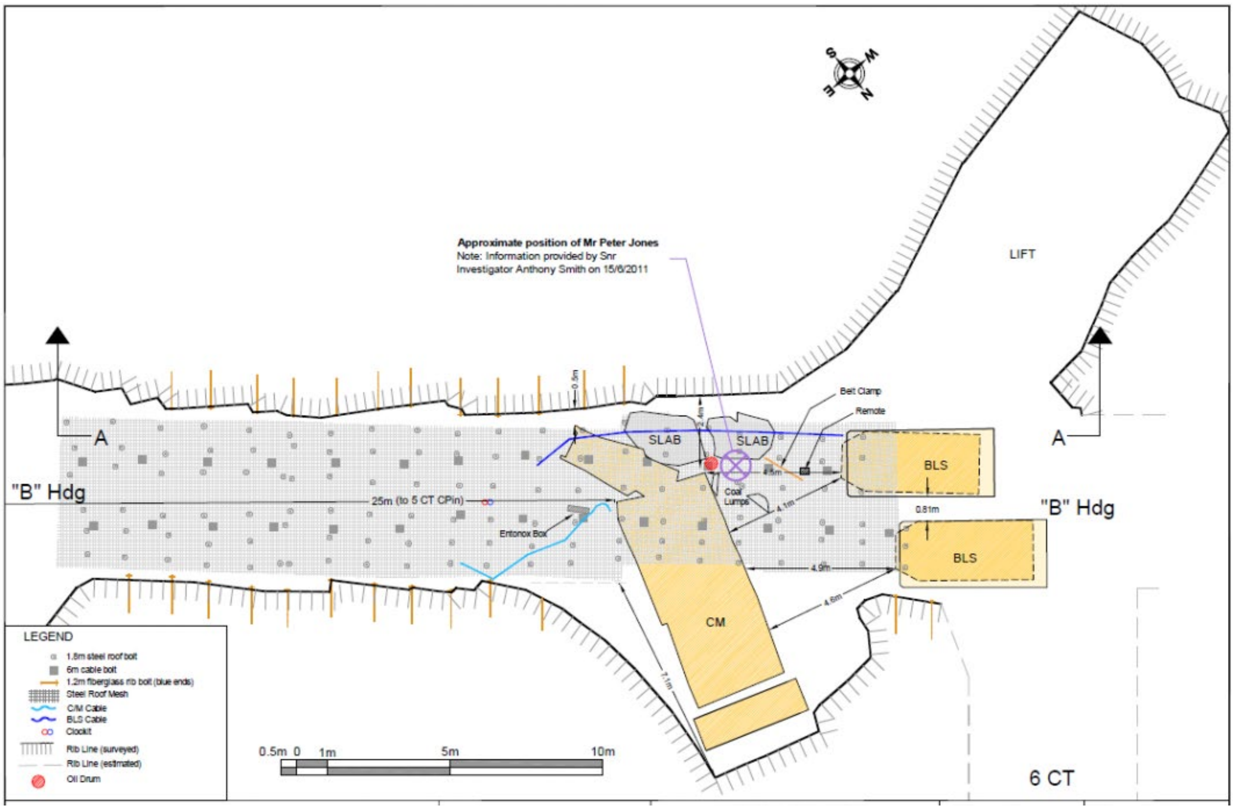


Figure 39 - Photo of incident scene looking inbye towards goaf showing rib slabs on the floor

Figure 40 - Photo of incident scene from inbye of the miner showing rib slabs

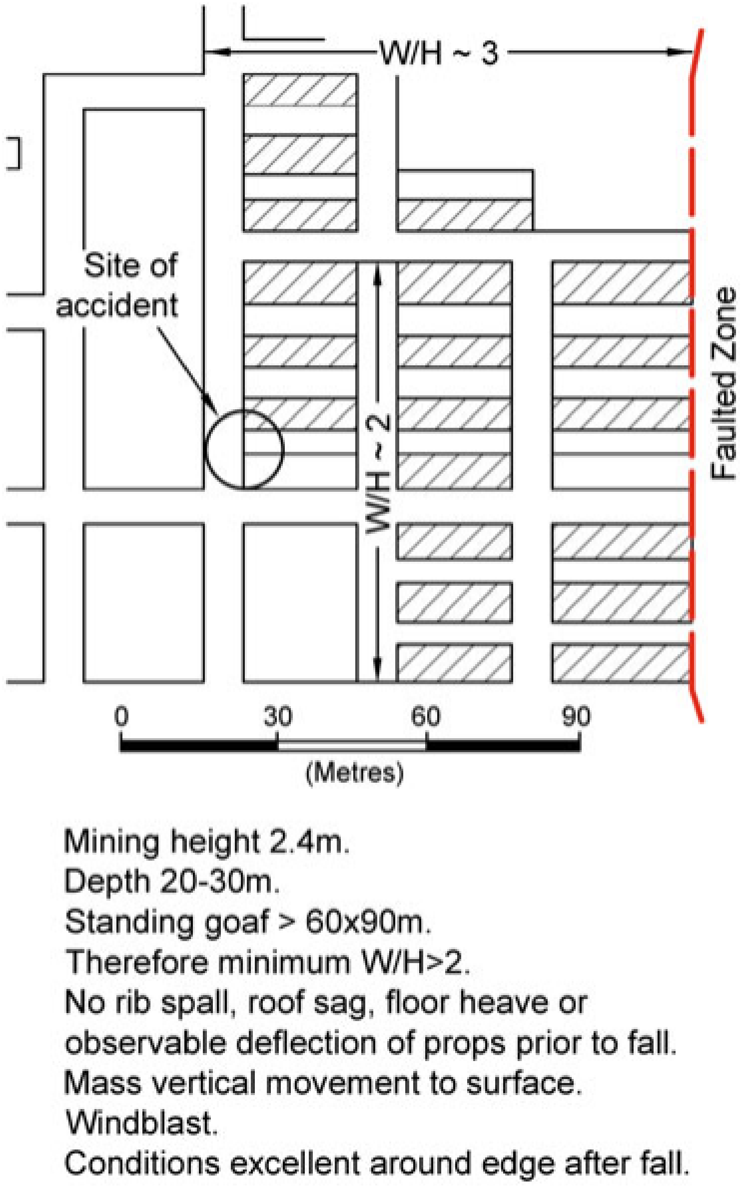
Case study 10 – Shallow depth extraction and windblast – 1 fatality[64]

Figure 41 below shows an incident involving pillar extraction at a depth of 30m. This incident resulted in an open goaf measuring in excess of 70 m by 90 m.

During the process of extracting a 6m wide lift from the pillar, the entire area fell suddenly, generating a large windblast and causing . one fatality.

The panel had been commenced against a fault plane in order to encourage early caving. Heavy rainfall at the time of the incident, leading to water ingress down the fault plane was a contributing factor.

Figure 41 - Other hazards case Study 1: Fatal sudden collapse incident at shallow depth[65]



[64] Galvin 2016 - Galvin et al. 1994 p. 115-117

[65] Galvin 2016 – p. 117 - adapted from Galvin et al. 1994

Case study 11 – Explosion following goaf fall - Moura No. 4 underground coal mine Queensland 16 July 1986 – 12 fatalities

The following extract from the Wardens Inquiry report summarises this incident:

"At about 11:05 a.m. on 16th July 1986 an explosion occurred in Moura No. 4 Underground Mine in Central Queensland. The 12 miners who were extracting pillars in the Main Dips Section were killed. Their bodies were recovered on 23rd July 1986 after an extensive recovery operation.

.... the upper part of the seven-metre-thick seam was being worked and that the strata between the seam worked and the seam approximately sixty metres above it consists mainly of massive bands of sandstone. The seam was described by witnesses as "fairly gassy".

The Inquiry found that the mine was well ventilated, and stone dusted and return airways were continuously monitored for carbon monoxide and methane. Methane detecting instruments were also available to the section's deputies.

The Inquiry found that a roof fall had occurred in the goaf and that the wind blast from the fall blew a mixture of methane, air and coal dust into the working area. An explosive atmosphere developed in the working area and in particular around the deputy's flame safety lamp. An ignition occurred creating a violent explosion which caused extensive damage throughout the section. The explosion was quenched by the presence of a water barrier in the belt roadway and substantial quantities of water in swilleys in other roadways. Some eight possible sources of ignition were considered.

The Inquiry considered that the flame safety lamp, although properly assembled, was the most likely source of ignition."[66]

The investigation report is available at Moura No. 4 investigation report.

[66] Wardens Inquiry 1987

Additional case studies

The following incidents were caused by other hazards which are relevant when planning pillar extraction:

- An explosion following a goaf fall at Endeavour Colliery underground coal mine NSW on 28 June 1995 (no fatalities). The investigation report is available at Endeavour investigation report.
- A spontaneous combustion at Kianga underground coal mine Queensland on 20 September 1975 (13 fatalities). The investigation report is available at Kianga investigation report.
- A spontaneous combustion at Moura No. 2 underground coal mine Queensland on 7 August 1994 (11 fatalities). The investigation report is available at Moura No. 2 investigation report.

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Links

Reference	Address
Chain Valley investigation report	https://www.resourcesregulator.nsw.gov.au/sites/default/files/documents/published-report-chain-valley-fatality.pdf
Code of practice - Work health and safety consultation, cooperation and coordination	*https://www.safework.nsw.gov.au/__data/assets/pdf_file/0013/50071/Code-of-practice_WHS-consultation-cooperation-and-coordination_February-2022.pdf*
Crandall Canyon investigation report	https://arlweb.msha.gov/fatals/2007/CrandallCanyon/FTL07CrandallCanyonNoAppendix.pdf
Endeavour investigation report	http://www.mineaccidents.com.au/uploads/endeavour-explosion-1995.pdf
Fact sheet: Consulting workers	https://www.resourcesregulator.nsw.gov.au/__data/assets/pdf_file/0008/537290/consulting-workers-factsheet.pdf
Guide - Contractors and other businesses at mines and petroleum sites	https://www.resourcesregulator.nsw.gov.au/__data/assets/pdf_file/0009/537291/contractors-guide.pdf
Guide - Preparing a principal hazard management plan	https://www.resourcesregulator.nsw.gov.au/sites/default/files/2022-09/guide-preparing-a-principal-hazard-management-plan.pdf
Health and Safety Critical Control Management: Good Practice Guide	https://www.icmm.com/website/publications/pdfs/health-and-safety/2015/guidance_ccm-good-practice.pdf
Kianga investigation report	http://www.mineaccidents.com.au/mine-event/26/kianga-no-1-mine-explosion-1975
Managing risks in mining and petroleum operations	https://www.resourcesregulator.nsw.gov.au/sites/default/files/2022-09/guide-managing-risks-in-mining-and-petroleum-operations.pdf

Reference	Address
Moura No. 2 investigation report	https://www.publications.qld.gov.au/dataset/moura-mining-disaster-inquiry-reports/resource/a8e96409-52a3-4075-b4a6-b1224ecc8e63
Moura No. 4 investigation report	https://www.publications.qld.gov.au/dataset/moura-mining-disaster-inquiry-reports/resource/2c4d43e7-5448-44b9-b1c8-b11d2a534c41
National Minerals Industry Safety and Health Risk Assessment Guideline	http://www.nost.edu.au/icms_docs/286339_National_Minerals_Industry_Safety_and_Health_Risk_Assessment_Guideline_-_Jim_Joy.pdf
NSW code of practice: How to manage work health and safety risks	https://www.safework.nsw.gov.au/__data/assets/pdf_file/0012/50070/How-to-manage-work-health-and-safety-risks-COP.pdf
RISKGATE	https://smi.uq.edu.au/project/riskgate