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THE DUNCAN METHOD OF PARTIAL PILLAR EXTRACTION AT TASMAN MINE

Kent McTyer¹ and Tony Sutherland²

**ABSTRACT:** Mining commenced at Tasman Mine in late 2006. The current method of mining is bord and pillar using continuous miner-bolters and shuttle cars for first workings and secondary extraction using breaker line supports. The two stage process was chosen to accommodate irregular shaped coal deposits, allowing adjustments to be made to extraction ratios for better management of subsidence and to maximise the efficiency of the operation. Following the completion of the first three full/partial extraction panels a change in mining method was undertaken due to variable caving. The adopted partial extraction method involves stripping the developed square pillars on four-sides on retreat to leave a load-bearing remnant coal pillar. The system of partial extraction has been successful in delivering safety, productivity and subsidence targets.

**INTRODUCTION**

Tasman Mine is an underground bord and pillar mine owned and operated by the Donaldson Coal Pty Ltd located 20 km west of Newcastle, NSW (Figure 1). The mine commenced in 2006 and secondary extraction began in the Fassifern Seam in 2008. The 975,000 t per annum consent limit ROM coal is transported by road 20 km to Bloomfield Coal preparation plant for processing and subsequent rail transport to the port of Newcastle for export.

Tasman Mine employs the Duncan method of partial pillar extraction. The mine commenced pillar extraction employing a full-extraction modified Wongawilli system in March 2008. After completion of the first panel a system of secondary extraction was deemed more suitable for the poor caving conditions. A partial extraction design was sought to provide the best balance between safety, productivity and subsidence constraints. The Duncan Method of partial pillar extraction commenced in October 2008. Three pillar extraction panels have since being extracted successfully using this technique.

**RESOURCE**

Tasman, mines the Fassifern Seam beneath the Sugarloaf Range State Conservation Area. The Sugarloaf Range is characterised by steep topography and cliffs. The Fassifern Seam outcrops on three sides of the mining lease (Figure 2). As a result, horizontal stress is low by NSW industry standards.

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Mains development occurs beneath the centre of the Sugarloaf Range at depths up to 250 m. Production panels are developed from the mains toward the outcrop to depths of cover of about 40 m. Production panels are typically less than 800 m long and experience significant change in vertical stress within each panel. The proximity and visibility of the cliff-lines of the Sugarloaf Range State Conservation Area to Newcastle result in strict mine approval conditions regarding subsidence outcomes.

The Fassifern Seam working thickness is typically 2.2 m to 2.5 m. The seam floor consists of 4 m of coal interbedded with claystone. The potential for swelling of the reactive clays has caused isolated areas of floor heave. The immediate seam roof is 0.5 m to 1.4 m of shale overlain by two distinct roof types either side of a NW-SE trending transition zone across the centre of the deposit. On the northeast side of the transition zone the shale is overlain by 1.5 m to 2 m of coal, overlain by 6 m to 10 m of sandy claystone (referred to as the Awaba Tuff). While on the southwest side of the transition zone the shale is overlain by 0.1 m to 0.4 m of coal, overlain by 10 m to 15 m of sandstone and conglomerate. The upper roof is characterised by regular massively-bedded units including a consistent unit of conglomerate greater than 20 m in thickness (Teralba Conglomerate).

INITIAL PILLAR EXTRACTION EXPERIENCE

Pillar extraction commenced at Tasman Mine in March 2008. The panel was developed for full extraction using a modified Wongawilli layout. Full-height caving did not eventuate. During extraction the coal tops were observed to fall but the Awaba Tuff unit was routinely seen to span distances greater than 50 m. Caving of the roof strata may have been hindered by the relatively low indicated horizontal stress and the bridging effect of the overlying conglomerate units (Figure 3). The influence of coal left behind as stooks and webs may also have had a role in delaying the initial roof caving event. Underground observations indicated increasing weight being thrown outbye as the panel neared completion.

PARTIAL PILLAR EXTRACTION REVIEW

The criteria for the new mining layout centred on the balance of safety, reserve recovery and productivity. Subsidence control and the rapidly changing depth of cover were incorporated into the design. A review of other Australian coal mines’ experience with partial extraction was undertaken. As Tasman operates continuous miner-bolters in development there was flexibility available in design of pillar dimensions and partial extraction layouts.

A design was developed to maximize the number of extraction tonnes for each metre of panel development. Focusing on the extraction tonne to development metre ratio was seen to be of benefit to the mine by reducing the development metres for any given panel area whilst still maintaining respectable
resource recovery. In addition, the timing of development and extraction would better suit the mine schedule. With subsidence limitations around the cliff-zones and other surface infrastructure the partial extraction design was required to have flexibility and surety when designing remnant coal pillars. A key safety goal was to avoid pillar splitting during secondary extraction.

Figure 3 - Photograph taken six months after extraction in Panel 2 South. The span is 16.5 m wide by 34.5 m long.

TASMAN PARTIAL PILLAR EXTRACTION DESIGN

Layout of pillar extraction panels was undertaken by referencing the relevant legislation and mine design guidelines. The general principles outlined in MDG 1005 Manual on Pillar Extraction in NSW Underground Coal Mines (NSW Dept. Primary Industries, 1992) were followed as the mine layout and sequence was developed.

Panels are typically five headings with a central belt road and flanking returns. Roadways are nominally 2.3 m high, driven on 45 m by 45 m pillar centres with a 5.5 m bord width. Panels are 300 m to 1200 m long and between 155 m (four-headings) and 252 m wide (six-headings). Secondary extraction is undertaken using a continuous miner modified for pillar extraction, three mobile breaker line supports, and shuttle cars. Pillars within the panel are stripped on four sides during panel retreat and the barrier pillar is also stripped (Figure 4). Lifting left and right is performed on both sides of the roadway from every roadway driven in the panel. The dimension of Stook X is as large as possible – typically greater than 6 m from rib-line - providing it can be totally removed at the start of a subsequent lifting sequence. At the completion of secondary extraction one stook remains for each pillar.

Overburden depth to seam can change by up to 200 m over the length of a secondary extraction panel. To account for the variation in overburden thickness the lift length is changed. Operators use a lift length of up to 10.75 m (measured 90° from rib-line) at shallow depth, and shorter lift length (as short as 7.3 m) at greater depths (Table 1). The length of lift into the barrier pillar remains the same as the lift length into the panel pillar (Figure 5). As a result, a wider barrier pillar is formed as depths increase. By modifying the lift length the remnant panel and barrier pillar dimensions are smaller at shallow depth and larger at greater depth. The decision to change second-workings dimensions on retreat was taken to avoid making changes to pillar dimensions during first-workings. Maintaining routine and regular development dimensions has significant benefits in terms of planning and sequencing. The benefits of a routine development far outweigh the additional controls required during secondary extraction.
Load-bearing remnant coal pillars and inter-panel barrier pillars are designed using the UNSW Pillar Design Procedure (Galvin, et al., 1998). Pillars are designed subject to full tributary area load. The positive influence of the overlying conglomerate is not taken into account when designing the panel pillars. Remnant coal pillar factor of safety within the panel is greater than 1.6. Width to height ratio of the remnant pillars range from 7.2 to 11. Referencing Hebblewhite et al. (2005) and Zipf, (1999) the width to height ratio of the pillars will result in strain-hardening characteristics and limit subsidence to tolerable levels in the unlikely event of pillar overload conditions developing.

As depth increases the percent coal recovery reduces in order to maintain the same pillar stability figures. Theoretical coal recovery ranges from 82% to 67% when stooks and webs are taken into account. The ratio of extraction tonnes to development metres reduces with greater depth and ranges from 51 t/m to 36 t/m. The total tonnes from development and secondary extraction as a ratio of development metres in the 2.4 m Fassifern Seam at Tasman ranges from 70 t/m to 55 t/m.
Table 1 - Duncan method remnant coal pillar dimensions, factor of safety, length of lift, theoretical extraction percentage, and extraction tonnes per development metre at Tasman mine

<table>
<thead>
<tr>
<th>Cover Depth</th>
<th>Remnant Pillar Dimensions (rib-rib)</th>
<th>Remnant Pillar Width to Height Ratio</th>
<th>Remnant Pillar Factor of Safety</th>
<th>Length of Lift (90° from rib-line)</th>
<th>Length of Lift (60° from centre-line)</th>
<th>Percent extraction (within panel)</th>
<th>Extraction tonnes per development metre</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;80 m</td>
<td>18 m x 18 m</td>
<td>7.5</td>
<td>&gt;1.61</td>
<td>10.8 m</td>
<td>15.6 m</td>
<td>82%</td>
<td>51</td>
</tr>
<tr>
<td>&lt;120 m</td>
<td>20.5 m x 20.5 m</td>
<td>8.5</td>
<td>&gt;1.63</td>
<td>9.5 m</td>
<td>14.2 m</td>
<td>77%</td>
<td>46</td>
</tr>
<tr>
<td>&lt;160 m</td>
<td>22.5 m x 22.5 m</td>
<td>9.4</td>
<td>&gt;1.68</td>
<td>8.5 m</td>
<td>13.0 m</td>
<td>73%</td>
<td>42</td>
</tr>
<tr>
<td>&lt;200 m</td>
<td>24 m x 24 m</td>
<td>10.0</td>
<td>&gt;1.68</td>
<td>7.8 m</td>
<td>12.1 m</td>
<td>70%</td>
<td>39</td>
</tr>
<tr>
<td>&lt;240 m</td>
<td>25 m x 25 m</td>
<td>10.4</td>
<td>&gt;1.62</td>
<td>7.3 m</td>
<td>11.6 m</td>
<td>67%</td>
<td>36</td>
</tr>
</tbody>
</table>

TASMAN PARTIAL PILLAR EXTRACTION IMPLEMENTATION

Tasman Mine management adopted the ten hurdles approach to implement the new partial extraction system. The ten hurdles are designed to assist in applying the requisite standard of care called upon by the NSW Coal Mine Health and Safety Act 2002 and NSW Coal Mine Health and Safety Regulation 2006 (Nichols, 2009) and which also aligns with the framework of AS/NZS 4360. The ten hurdles are:

- Consultation;
- Hazard Identification and Hierarchy of Controls;
- Risk Assessment;
- Risk Management- Health Safety Management System (HSMS), Safe Work Procedures (SWP);
- Information;
- Instructions and Training;
- Supervision;
- Monitor System of Work;
- Review the Operation;
- Revise as Necessary.

Consultation commenced in July 2008 with the Tasman workforce. A consultative meeting was held in August 2008 with the NSW Industry and Investment Inspectorate outlining the method and design. Workforce representatives were involved in a risk assessment that was finalised in August 2008. Clause 88 Approval of the bord and pillar system was received from the Inspectorate in September 2008. A selection of the Tasman workforce undertook an underground visit at Duncan Colliery in October 2008 to understand the sequencing and other nuances of the system. Subsidence Management Plan Approval was received and was shortly followed by crew training and commencement of secondary extraction in October 2008.

MINING OBSERVATIONS

Pillar extraction using the Duncan method commenced at Tasman Mine in October 2008. Tasman has a workforce experienced with pillar extraction; however the Duncan method was new to the operators and supervisors. During crew training the sequencing and importance of adherence to the design were emphasized as were the strict supervision requirements developed by the mine. Introduction of the system has resulted in significant improvements in safety, greater confidence in subsidence outcomes and productivity benefits.

SAFETY

No serious safety incidents have occurred at Tasman Mine since the introduction of the Duncan method. Goaf edge load is minimal using this system as evidenced by rare low-level rib spall. Abutment load observations were backed up by low displacements measured on rib and roof extensometers. The development of abutment load at the goaf edge is slow due to the high capacity of the surrounding pillars.
and formation of load-bearing remnant pillars. Figure 6 illustrates the active extraction face zone is typically adjacent to coal pillars with a minimum pillar factor of safety of 2.2. Caving of the immediate roof does not present a serious windblast hazard due the small (less than 27 m wide) extraction voids formed. When the roof does cave it is typically the area from one intersection to the next intersection. Intersection to intersection is a relatively small area - approximately 50 m long by 27 m wide – and to date the impact of caving has been limited to minor interruption to ventilation.

Figure 6 - Pillar factor of safety reduces from greater than 10 to 1.6 as the coal pillar is stripped on four sides

For the given area of the panels there are a reduced number of intersections compared with other pillar extraction methods. As falls in the first or last lift adjacent to intersections are acknowledged to be the leading site of accidents during pillar extraction the reduction in the number of intersections is a significant safety improvement (Mark and Zelanko, 2001). In addition, stook X is far greater in size compared with other pillar extraction methods offering greater confidence in the support provided to intersections (Figure 7). Common to other partial extraction systems coal can be left behind for safety reasons with the only negative impact being reduced coal recovery. Tasman has found the secondary extraction of coal can be switched on or off for shutdowns or maintenance with rare and minor fender deterioration.

Figure 7 - Looking across a four-way intersection at Stook X. The intersection has been extracted on three sides.

The most significant improvements gained relate to the balance of panel development and secondary extraction. Development rates have recovered after a period of workforce acclimatisation and the time taken to complete development of a panel has reduced. Panels are more rapidly developed due largely to the reduction in panel metres. For a similar area of full-extraction the Duncan method development metres are roughly 70% of the same area of full-extraction. Other dedicated partial extraction systems
reviewed may require similar metres for a given area, but do not achieve the same recovery on retreat. Output per shift using two shuttle cars averages about 800 t with peaks of around 1 250 t. One downside of the system is the long wheeling distances to the breaker-feeder from the extremities of the panel. However, the wheeling distance is balanced by the shuttle car change point being no more than 40 m from the continuous miner during extraction.

Coal webs or stooks are rarely left behind to support the roof or stop goaf flushing. This may partly be the result of the low levels of vertical stress experienced at the goaf edge during extraction. The production figures from Panel 3 North suggest the estimated recovery following completion of the panel was within a few percent of the expected theoretical recovery. In areas without subsidence restrictions reduced coal recovery compared with full-extraction can be justified based on improvements to safety and productivity (Myors and Chastons, 2001).

**SUBSIDENCE**

The mine is subject to subsidence constraints are because of natural features such as cliff-lines and steep-slopes and man-made features including a 330 kV power line, a fibre optic cable and three telecommunication towers. To date subsidence has been well below estimates. Tasman changes the remnant coal pillar dimensions to control subsidence beneath sensitive surface features. Sensitive features are assigned a Subsidence Control Zone (SCZ). SCZs are determined by the desired subsidence outcome and implemented by forming pillars of set dimensions with assigned pillar stability. Where the system has some advantages compared with other partial extraction systems is in the large width to height ratio of the coal pillars used to support the overburden. Where seam height reaches 2.5 m the w/h ratio exceeds 7.2. With the large width to height ratios the long-term confidence in the pillar stability is high. In addition, the immediate roof and floor material properties have less impact on pillar stability due to the large contact area of the pillar. Where the system must be used with caution is at shallow depth. To maintain elastic overburden behaviour at shallow depth the bord width must retain sub-critical dimensions.

Panel 3 North is the largest panel extracted to date. The maximum subsidence was measured across the widest part of the panel along the NE-SW survey line (Figure 8). Panel width is 252 m in the area with six headings. Recovery from within the panel is estimated to be close to 80% in the six-heading area beneath the NE-SW subsidence line. Maximum subsidence above Panel 3 North ranges from 51 mm to 101 mm, with maximum tilt of 1.2 mm/m (Figure 9). Back-analysis of Panel 3 North indicates that pillars experience between 70% and 75% of the full-tributary area loading condition in the central portion of the panel.

**SUMMARY**

The Duncan method of partial pillar extraction has been used successfully at two mines with generally similar geological conditions. Both Duncan and Tasman have an upper roof that can span large distances. In the case of Duncan the upper roof consists of dolerite, while at Tasman the upper roof consists of thick conglomerate and sandstone units. In both cases the immediate roof caves routinely if not readily. It is in these geological conditions that the Duncan method has immense merit. Where site
conditions or the control of surface or sub-surface subsidence is a critical mining constraint, the Duncan method may be of benefit.

Tasman Mine has taken an existing partial pillar extraction method and applied it to the site specific conditions and constraints. Since introduction targets have been met and the system continues to be refined and optimized to achieve objectives in the areas of safety, productivity and subsidence.

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