THE DESIGN OF MULTI-SEAM WORKINGS
AT SHALLOW DEPTH UNDER TIDAL WATERS

By
James M. Galvin¹ and Kerry G. Anderson²

ABSTRACT
Multi-seam mining under the western portion of Lake Macquarie NSW commenced in 1982. Up to three seams separated by partings ranging from 10 to 50 metres are mined simultaneously by Newcom Collieries. A feature of these workings is the minimal bedrock cover, which ranges from 130 metres down to only 40 metres.

"Surface" subsidence control has an over-riding influence on the design of the workings. Subsidence considerations govern both the selection of the mining method and the dimensioning of the workings.

To date, workings have been designed in accordance with the "Wardell Guidelines for Mining Under Tidal Waters". These guidelines are tabulated and evaluated in the light of advances in rock mechanics knowledge and local subsidence data collected since the Guidelines were formulated in 1974. The local and regional stability of shallow workings designed according to the Guidelines is evaluated.

INTRODUCTION
Multi-seam mining under tidal waters on the western side of Lake Macquarie NSW commenced in 1982. Up to three seams are mined simultaneously by Newcom Collieries to supply Eraring Power Station. A feature of these workings is the minimal bedrock cover, which has an over-riding influence on mine planning and mining practice.

LOCATION AND GEOLOGY
The three seams extracted in Coal Lease 195, Figure 1, are the Wallarah, Great Northern and Fassifern Seams. In the eastern portion of the lease, the area of interest of this paper, these seams underlie tidal waters, whilst in the western portion they underlie low lying land. The deepest workings occur at a depth of 160m in the Fassifern Seam whilst all workings cease when the thickness of "solid" bedrock cover reduces to less than 40m.

Figure 1 - Coal Lease 195

The parting between the Fassifern and Great Northern Seams is comprised of 12m to 30m of weak tuffaceous sediments. The Wallarah Seam lies 25m to 42m above the Great Northern Seam, the parting comprising conglomerate, sandstone and claystone strata rarely exceeding 3m in thickness.

In general, the Fassifern Seam is mined to a height of 3m, the Great Northern Seam to 2.5m and the Wallarah Seam to 2m.

The coal product does not undergo beneficiation. Simultaneous extraction of each seam is essential in order to produce a blend product with an ash content not exceeding 23 per cent throughout the life of the lease area.

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DESIGN GUIDELINES

Surface subsidence control has an overriding influence on the design of mine workings adjacent to and beneath tidal waters. To date, mine design has been based on the "Wardell Guidelines for Mining Under Tidal Waters" (Wardell 1975). Two zones of influence, Figure 2, are identified in these guidelines, namely:

1. High Water Mark (HWM) Subsidence Barrier Zone

In this zone the vertical component, Vz, of subsidence must be controlled to ensure tidal waters do not encroach upon existing land surfaces. Permissible subsidence varies, depending on the land topography. In most areas mined by Newcom Collieries surface subsidence must be restricted to less than 150mm.

2. Tidal Waters Zone

In this zone horizontal strain must be controlled to prevent mining induced fractures forming hydraulic connections between mine workings and tidal waters. Wardell specified a maximum horizontal strain of 7.5mm/m. On the basis of limited subsidence measurements and observations in the Lake Macquarie/Newcastle area at the time (1974), Wardell interpreted this strain value as requiring that the ratio of solid bedrock cover:extracted height be not less than 60:1.

Wardell's guidelines are summarised in Tables 1 and 2.

MINING METHOD SELECTION

To date Newcom Collieries have based mine design on the Wardell Guidelines. A noteworthy exception is that permission has been obtained to work to the 50m solid bedrock contour in accordance with lease conditions.

The only potential for total extraction is in the Passifera Seam. However, much operations sterilize reserves in the overlying Great Northern and Wallarah Seams. Since the Passifera Seam has a very high ash content (22-34 per cent) and the upper seams a low ash content (12-26 per cent) this option is not economically viable. Similar considerations also restrict the potential for "panel and pillar" operations to a negligible portion of the eastern lease area.

Thus, only bord and pillar mining is undertaken in all three seams. On the basis of the Wardell Guidelines, workings in the Great Northern and Passifera Seams within the HWM Subsidence Barrier Zone need to be superimposed. Wardell did not address this problem for Tidal Waters zones but presumably similar considerations apply.

Workings in the Wallarah Seam have also been superimposed. The potential exists to relax this requirement, thereby allowing pillar size to be reduced in the seams. However, most workings to date comprise main development headings. In addition, very little borehole information is available in tidal waters areas. Therefore, it has been

Figure 2 - Zones of Influence

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### Table 1: Guidelines Recommended by Marselli (1978) for Working Coal in Hum Subsidence Barrier Zones

<table>
<thead>
<tr>
<th>Seam</th>
<th>Bord and Pillar</th>
<th>Panel and Pillar</th>
<th>Longwall</th>
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<tbody>
<tr>
<td></td>
<td>For Vs ≤ 150ms</td>
<td>For Vs ≤ 600ms</td>
<td>(i) Vs &gt; 600ms, in general, not tolerable</td>
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<tr>
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<td>[i] Widths of headings and cut-throughs should not exceed 5.5m</td>
<td>(i) The maximum width of any totally extracted panel section should not exceed 0.35D</td>
<td></td>
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<tr>
<td></td>
<td>[ii] No pillar should have a smaller plan dimension than 8 times its height.</td>
<td>(ii) The minimum width of any abutment pillar between extraction panels should be 10 times its height or 0.16D, whichever is the greater.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>For 150ms &lt; Vs ≤ 600ms</td>
<td>(iii) The two preceding recommendations could be applied to bord and pillar first workings as stipulated in this table provided pillar extraction was limited to every third panel and the pillar extracted area did not exceed the maximum width of 0.35D</td>
<td></td>
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</tr>
<tr>
<td>For 150ms &lt; Vs ≤ 600ms</td>
<td>(iii) If the stratigraphic interval between seams is not less than 10 times the extracted thickness of the lower seam, there is no necessity to superimpose pillars.</td>
<td>(iv) The two preceding recommendations could be applied to bord and pillar first workings as stipulated in this table provided pillar extraction was limited to every third panel and the pillar extracted area did not exceed the maximum width of 0.35D</td>
</tr>
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**Notes:**

- Vs = Surface subsidence
- D = Depth below surface (or solid strata cover)
<table>
<thead>
<tr>
<th>Section</th>
<th>Bond and Pillar</th>
<th>Panel and Pillar</th>
<th>Longwall</th>
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<tr>
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<td>No guidelines</td>
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<tr>
<td>Bond B</td>
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**Notes:**
- D - Solid strata cover
- *No total extraction or pillar extraction to be permitted within a distance of 6m of any known fault having a vertical displacement greater than 5m nor any dyke having a width greater than 6m.

**Guidelines Recommended by Kureell (1972) for: Working Coal in Tidal Waters Zones**

1. *D ≥ 45m.*
2. No total extraction or pillar extraction to be permitted within a distance of 6m of any known fault having a vertical displacement greater than 5m nor any dyke having a width greater than 6m.

1. *D ≥ 45m.*
2. To conform to OMAA (1912).

1. *D ≥ 45m.*
2. The maximum width of any totally extracted panel section should not exceed 0.4D.
3. The maximum width of any abutment pillar between extraction panels should be 8 times its height or 0.12D, whichever is the greater.

1. *D ≥ 45m.*
2. Panels and pillars should be superimposed.
3. Panel dimensions should be determined by reference to the shallowest seam such that the maximum width of any totally extracted panel does not exceed 0.4D.
4. The maximum width of any abutment pillar between extraction panels should be 8 times its height in the thickest seam or 0.12 times the depth of the deepest seam, whichever is the greater dimension.

1. *D ≥ 45m.*
2. A minimum of 6m of solid strata cover for each 1m of coal totally extracted.
3. No longwall mining permitted.

1. *D ≥ 45m.*
2. Total or partial extraction in a seam underlying one already extracted must be planned so as to avoid the overlapping of tension zones and the creation of a maximum tensile strain at rockhead exceeding 7.5 mm/m.

- *D* - Solid strata cover
considered prudent to adopt a conservative approach and superimpose all workings until sufficient mining experience has been gained in the area.

Reference to Figure 1 illustrates the scattered land mass/tidal waters distribution within the eastern portion of Coal Lease 19S. Under these conditions it is impractical to change design dimensions each time workings transgress from a SWM Subsidence Barrier Zone to a Tidal Waters Zone and back again. Again a conservative approach has been adopted and all mine design has been based on SWM Subsidence Barrier Zone guidelines.

These guidelines require a minimum pillar width/height ratio of 3, thereby necessitating a 24m wide pillar in the Fassifern Seam. A statutory b.o.d width of 5.5m results in a pillar centre distance (PCD) of 29.5m. As a matter of convenience a PCD of 30m has been adopted.

**MINING STRATEGY**

**MAIN DEVELOPMENTS**

Limited geological information is available within the tidal waters areas. Boreholes drilled in tidal waters are slow, expensive operations with a lower than average success rate. There is no guarantee that holes drilled prior to the granting of the lease do not deviate from their surveyed location nor that backfilling is entirely successful. Thus, they may pose a risk to mining operations. Few structural features can be mapped on land because of the weathered nature of the lake foreshores and residential development. Seismic surveys offer only limited information.

Therefore, to prove the lease area prior to becoming locked in a fixed mining plan, a strategy was adopted to drive a limited number of headings (3 or 5) in the Wallarah Seam in each of the three main development directions. These headings have also served to significantly dewater strata, with subsequent workings in adjacent panels and lower seams being relatively untroubled by water inflow.

**GRID CONCEPT**

To accommodate the effects which variations in geological conditions in each seam can have on panel layout, and thus superimposition of workings, a "grid" system was adopted. The lease area is divided into a checkerboard of 30m squares with both panel pillars and interpanel pillars being 30m wide.

The grid system offers great flexibility, especially in the following regards:

1. Main development directions in the lower two seams can be altered to take advantage of the geological information gained from main development headings in the Wallarah Seam. That is, it provides the option for superimposing main developments in one seam with panel developments in another seam.

2. At least two directions are available for turning panels off main developments. Thus, panels can be developed to take advantage of the dip of a seam or to minimize the adverse effects of geological disturbances. Panel development is not solely dependent on the driveage of one set of main development headings.

3. Provided the grid itself is not altered, the mine layout can be changed without the need to reapply for approval for the mine layout from the relevant statutory departments.

The grid concept can be employed because all panel pillars have been dimensioned to SWM Subsidence Barrier Zone requirements, and are therefore designed to be indestructible. This conclusion is critically evaluated in a later section.

**MINING PRECAUTIONS**

An obvious potential danger when mining under tidal waters, especially at shallow depth, is inundation of workings with water from an "infinite" supply. Although the risk of such an event is reduced in first workings only, it may still occur due to:

1. Fault and dyke planes forming hydraulic connections to the tidal waters.

2. Palaeochannels in the lake bed, resulting in a sudden loss of bedrock cover.

3. Intersection of old boreholes which have not been accurately plotted or which have not been backfilled properly.

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To avoid these occurrences, in-seam boreholes are maintained in advance of all workings in unproven districts. Bedrock cover has been determined accurately by seismic techniques and underground levels are recorded at working faces, thereby enabling an accurate record to be maintained on solid bedrock cover. Protective pillars are left in the vicinity of boreholes whilst major pumps are mounted on frameworks capable of being readily transported by diesel machines. Steel pump lines of either 100mm, 150mm or 200mm diameter are kept within about 100m of all faces.

EVALUATION OF THE WARDELL GUIDELINES

In view of the limited subsidence data available in 1974 and of advances in the rock mechanics and computer sciences, it is not surprising that a number of anomalies and deficiencies exist in the Wardell Guidelines. These need to be evaluated, especially in view of the implications they could have on the stability of multi-seam workings at shallow depth.

BOW SUBSIDENCE BARRIER ZONE

1. Surface Subsidence - The fundamental criterion in the design of workings in this zone is long-term stability. The subsidence values assigned to mining methods in the zone, Table 1, are incompatible with this criterion. A subsidence value of 150mm cannot be equated to stable bord and pillar workings. It is widely accepted that, neglecting adverse floor or roof conditions, a pillar width:height ratio of 8 is sufficient to result in an indestructible pillar. As such, measured subsidence values are only of the order of millimetres.

Similarly, panel and pillar layouts cannot be considered stable in the long-term where surface subsidence in the range of 150mm to 600mm has occurred. Experience gained in the Lake Macquarie region since 1974 indicates that subsidence needs to be restricted to the order of 100mm to 200mm to ensure long-term stability. (Higher subsidence values can be equated to much wider extracted panels.)

2. Superpositioning - Of greater concern is the criterion adopted by Wardell for superimposing multi-seam bord and pillar workings. That is, superpositioning is required when the parting thickness between seams is less than 10 times the mining height in the lower seam.

The primary reason for superimposing workings is to prevent highly stressed zones above and/or below pillars (be they panel,interpillar, protective or remnant) from overlying or underlying excavations in adjacent seams. The primary criteria for determining whether superpositioning is necessary are:

(a) the magnitude and distribution of stress above and below pillars, and

(b) the quality of the parting between the seams.

Numerical analysis provides a quick means for quantifying these criteria.

The mining height in any seam, let alone the lowest seam, has no significance on the need to superimpose. It determines the pillar strength but has a negligible influence on the stress distribution above or below a pillar (i.e. on the pillar load).

3. Panel and Pillar Layout - The recommendation to superimpose panel and pillar workings irrespective of the thickness of strata between seams is reasonable but does have the potential to be relaxed when seams are separated by considerable thicknesses of competent strata. Wardell did not stipulate a minimum strata thickness which needs to be maintained between multi-seam panel and pillar workings. The stability of panel and pillar workings is dependent, among other parameters, on the ratio of panel width:solid rock cover. In the case of multi-seam workings, solid rock cover for a lower seam must be taken to be the distance between the roof of the lower seam and the floor of the upper seam.

It may be argued that provided the upper seam was extracted first, collapse of the parting is of no significance, since the panel width:depth ratio in the upper seam would still be sufficient to arrest caving. However, consideration...
must be given to the effect that such a collapse would have on the stability of the interpanel pillars which carry the load of the bridging strata. Effectively, such a collapse results in a reduction in the pillar width:height ratio and, thus, a reduction in interpanel pillar strength.

TIDAL WATERS ZONES

In order to restrict mining induced changes in the permeability of solid bedrock cover, Wardell adopted the British approach of stipulating a maximum tensile strain at the bedrock head. Under British conditions, this value is 10m/s. Wardell reduced this to 7.5m/s for local conditions in view of the greater predominance of conglomerates and sandstones comprising local strata.

Wardell translated this maximum tensile strain, $\varepsilon_{\max}$, into a depth/extracted height relationship using the following empirical formula:

$$F_{\max} = \frac{S_{\max}}{D}$$

where $F$ = 0.75, an empirical coefficient

$S_{\max}$ = maximum subsidence

$D$ = depth of cover

Solving the equation yields:

$$D = \frac{S_{\max}}{F}$$

The figure of 7.5m/s for maximum tensile strain must be accepted with caution, especially at shallow depth. In the western portion of the lease area pillar extraction has been undertaken under land at shallow depth. This has highlighted that when massive sandstone and conglomerate stratum overlies shallow workings, the subsidence mechanism is one whereby strata caves as slabs. Large strains may occur at the surface expression of the slabs and negligible strains in the centre of the slab. Whilst strains measured over bay lengths of tens of metres may average out to the order of 7m/s, those measured over baylengths of metres may be up to 80m/s, sufficient to result in inundation of workings under tidal waters.

The empirical value of 0.75 for $F$ is also debatable. The figure was based on limited subsidence data at the time and a range of results have since been reported.

LOCAL SUBSIDENCE MONITORING RESULTS

Some 5.8km of subsidence observation lines are being monitored in the low cover (40m - 120m) western area of the lease. The Great Northern Seam is 2m to 3m thick and extracted by the "Modified Old Ben System" using Jeffrey 1200Z continuous miners. The overburden is massive conglomerate with some sandstone.

EFFECTIVE MINING HEIGHT

As pillar extraction with continuous miners is not 100% efficient, the ratio of subsidence to mining height is variable due to the recovery of the method of extraction. With the system used it is estimated that the effective mining height averages 80% of the working section. This figure is not consistent and varies from panel to panel and at times within panels as illustrated in Figure 3(a).

MAXIMUM SUBSIDENCE

The maximum subsidence occurs very quickly after the supercritical area is reached and is generally 65% of the effective mining height.

The goaves have the peculiarity that for a short distance in the subsidence trough a "bump" will appear on the back end of the trough against the solid coal. This bump is in the order of 150mm in 1.4 metres of subsidence, Figure 3(a).

In Figure 3(b) the profile is uneven and "leaning" to the right. This results in surface slope of 5%.

STRAINS

Strain observations are made over five metre bays. The strain profile is the classic shape reaching a maximum tension of 14mm/metre and a maximum compression of 12mm/metre, Figure 3(c).

These high figures are due to fracturing of the overburden through to the surface, with cracks up to 70mm wide occurring over a 5 metre bay length. Strains are higher on the side of the goaf and slightly lower on the face side. Cracks have been a conduit for surface water into the mine and have had to be sealed by dazing earth into them.

A residual strain of -2mm/metre occurs in the centre of the trough. Typical strains are shown in Figure 3(c).
Figure 3 - Typical Surface Subsidence Measurements
ANGLE OF DRAW

The average angle of draw over virgin coal is 20 degrees and over "first workings" 25 degrees. These observations are based on a ±10mm subsidence being the cut off for the affected zone.

EVALUATION OF MINE DESIGN

Significant areas of superimposed bord and pillar workings now exist beneath tidal waters in the lease area. No indications of adverse interaction between these workings have been recorded to date.

LOCAL STABILITY

As previously noted, a pillar width/height ratio of 8 is widely accepted as ensuring long-term pillar stability. It must be recognised, however, that such a ratio can only be maintained by ensuring floor and roof strata stability. The effect of a roof fall, for example, is to reduce the effective width/height ratio of the surrounding pillars. Soft bands at the roof or floor contact or within a pillar can also reduce pillar strength significantly.

Extensive experience of multi-seam bord and pillar workings at shallow depth exists in South Africa. These workings are designed on the basis of the well proven Salamon Pillar Design Formula (Salamon and Oravec, 1976). From personal experience (Galvin), the Great Northern Seam is of a similar competence and toughness to that of South African seams, while the Wallarah and Fassifern Seams are marginally weaker. Therefore, a comparison has been made between the Newcom mine layout and that which would be adopted in South Africa under conditions where surface subsidence has to be restricted to the order of millimetres.

Under South African conditions, workings would be designed to a safety factor of 2.2. The safety factor of Newcom workings ranges from 2.5 to 13.2. Since safety factors of 1 and 1.5 correspond to probabilities of stability of 50 per cent and 99.47 per cent respectively, it is obvious that even allowing for weaker coal strata, local workings are well designed by South African standards. A safety factor of 13.2 arises because the pillar width/height design approach adopted locally makes no allowances for the limited cover load which a pillar has to support at shallow depth.

Deficiencies in the Wardell Guidelines for superimposing workings have had no adverse effects on the stability of current workings. This is because, fortuitously, the lowest seams in the lease area is also the seam extracted to the greatest height, 2m, resulting in a minimum pillar width of 2m and superimposition when the parting thickness is less than 30m.

Consider the consequences had the mine design been based on a 2m mining height in all three seams. Under these circumstances pillars would have been only 1m wide instead of 24.5m wide, whilst superimposition would have been required only where the parting thickness was less than 20m. As a result, average pillar stresses would have been almost 22 per cent higher. While the Great Northern and Fassifern Seam workings would not have been superimposed over a considerable area of the lease, in view of the weak nature of this parting and the higher pillar stresses, bord stability may have been a major problem.

To date, the sequence in which the seams have been extracted has not been critical. Should strata conditions deteriorate significantly in any one seam, the option exists to extract this seam only after the extraction of the other two seams. In this manner, the weaker seam is confined when subjected to the stresses and displacements associated with extraction of the other seams. Correspondingly, strata control problems, especially the need to install secondary support, should be minimised.

REGIONAL STABILITY

The leaving of interpanel pillars on a regular basis to prevent a pillar collapse within a panel from spreading throughout the mine workings is a fundamental design requirement in the layout of extensive bord and pillar workings. These interpanel pillars need to be designed to be indestructible.

This design requirement may not appear to be satisfied by the grid concept, since panel and interpanel pillars are the same width. However, it must be recognised that by usual standards, panel pillars in the great Northern and Wallarah Seams for example having width/height ratios of 9.8 and 12.2 respectively. Similar considerations apply to the interpanel pillars, in addition to the fact that they will be stronger because of their rectangular shape.

In multi-seam workings stability in the upper seams is also dependent on stability

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being maintained in the lower seams. As the workings in all three seams become more extensive, panel and interpanel pillar stability in the lower seams is being monitored carefully.

FUTURE INVESTIGATIONS

It is a well established principle in rock mechanics that the mode of a regional pillar collapse is determined by the ratio of the stiffness of the surrounding strata to that of the coal pillars (Salamon and Oravec, 1976). The greater this ratio the lower the probability that a sudden uncontrolled pillar collapse can occur.

Recently, a pillar collapse occurred under land adjacent to a pillar extraction panel in the western portion of the lease area under land. A feature of the pillar collapse was that it was arrested by pillars having width:height ratios ranging from 8 to 10. One of the main contributing factors to this collapse is believed to be the reduction in the stiffness ratio. The stiffness of the surrounding strata in the area had been reduced by the very weak claystone which comprised the floor strata. This strata lost cohesion rapidly upon becoming wet, in association with high pillar stresses due to adjacent goaf areas, a relatively rapid pillar collapse occurred.

This collapse highlighted the implications which soft roof or floor strata could have on the stability of workings under tidal waters. In an attempt to avoid such a situation and also to release the 32 x 10^6 tonnes of multi-seam reserves currently sterilized by soft claystone roof or floor strata in the western portion of the lease, a research program has been undertaken into the rheological properties of the claystone. Funded by NERSC, the preliminary aim of the project is to establish the mechanism of claystone behaviour when subjected to air, water and stress.

The potential to increase percentage extraction of the Wallarah Seam by reducing pillar size is to be evaluated in an experimental panel. The cost benefit of increasing overall percentage extraction within the seam by about 5 per cent has to be weighed carefully against the corresponding reduction in pillar strength when deciding whether to reduce pillar size throughout the seam.

CONCLUSIONS

Wardell's Guidelines for Mining Under Tidal Waters are limited and must be accepted within the terms of reference of that report. These guidelines need to be reviewed and extended in the light of additional subsidence data and advances in rock mechanics knowledge and analytical techniques since the guidelines were formulated.

Fortuitously, for Newcom Collieries, the adoption of the Wardell Guidelines for multi-seam mining under tidal waters at minimum bedrock cover has resulted in a conservative mine design. The potential exists to modify the mine design to increase volumetric extraction. However, careful consideration must be given to local and regional stability and to subsidence control, especially in view of the minimal bedrock cover, when modifications are being made to the current mine design.

REFERENCES


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