SUBSIDENCE AND STRATA CONTROL UNDER STORED WATERS IN THE SOUTHERN COALFIELD NEW SOUTH WALES

By

W.A. Kapp¹ and P. Kennerley²

ABSTRACT

A significant part of the reserves of the Southern Coalfield lie beneath major water storages and their impounding dam structures. One of the functions of the NSW Government's Dams Safety Committee is to specify the particular mine layouts which can be used beneath the stored waters according to certain guidelines. A study was made of examples of the two different methods of extraction used under the stored waters as proposed by the mining company according to the guidelines and approved by the Dams Safety Committee. Using both pillar monitoring and mathematical modelling approaches it was shown that the recovery of coal from these layouts could be improved while still ensuring the long term stability of both the underground support pillars and the body of the strata. The integrity of the water storages and their impounding structures would therefore not be affected.

INTRODUCTION

The annual production of coal from the Southern Coalfield is around 12 million tonnes per annum. It is premium quality hard coking coal, mainly from the Bulli seam. The coal is exported and it is also used in the domestic steel industry.

There are five major dams located in the Southern Coalfield and together with their water storages they affect the recovery of an estimated 450 million tonnes of coal. In order to preserve the integrity of the dam structures, no mining is allowed beneath and around them. Where the depth of cover is greater than 60 m under the stored waters, the bord and pillar layout can be used, with pillars of specified minimum dimensions.

The panel and pillar layout is specified for use under and around the stored waters where the depth of cover is greater than 120 m. This particular layout involves narrow subcritical extraction panels separated by long rows of wide pillars and results in small maximum subsidence values.

The mine layouts specified for mining beneath stored waters are examined in relation to examples at two Southern Coalfield collieries. The first example involved the underground monitoring of large pillars in a bord and pillar layout beneath the stored waters of the Avon Reservoir. The second example was the use of surface subsidence investigations in association with mathematical modelling to study a panel and pillar layout with pillar extraction beneath the stored waters of the Cataract Reservoir.

In both cases, the stabilities of the pillars were examined. This was done to demonstrate the integrity of the existing mining layouts and then to investigate the possibility of modifying the geometries of the mining layouts in order to improve recovery without risk to the dams or the water storages.

GEOGRAPHY, GEOLOGY AND MINING

The prominent topographical feature of the Southern Coalfield is the Illawarra Escarpment which rises to 400 m above sea level. The escarpment is mainly sandstone and the weathering of the cliff line has resulted in a covering of talus material at its base. Several collieries are located on the outcrop of the escarpment along the escarpment.

On a regional scale the surface dips gently to the west from the top of the escarpment and most of the rivers flow in a general north westerly direction, sometimes forming steep gorges in the sandstone. Some dams have been constructed over the Southern Coalfield and with one large dam further to the west, their stored waters provide the needs of the Cities of Sydney and Wollongong and the surrounding districts. Some of these

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![Map of the Southern Coalfield](image)

Fig. 1 Part of the Southern Coalfield

The coal seams of the Southern Coalfield lie within the Illawarra Coal Measures. They contain high rank coking coal used in the local steel industry and for export. The Bulli seam is mined extensively throughout the Southern Coalfield with the lower Wongawilli seam being second in importance with regard to coal production. The Bulli seam is of high quality and its thickness varies around 2 m in the areas where it is mined. The cover varies from less than 100 m at Wongawilli Colliery in the south to 500 m at Appin Colliery to the north west. The Wongawilli seam is a banded seam generally around 10 m thick. The worked section, at the base of the seam, is from 2 to 3.5 m thick. Where both seams are mined, the bottom of the Wongawilli seam is generally around 30 m below the Bulli seam. A third seam, the Balgownie seam, has been mined where it thickens to 1.5 m. It is located between the Bulli and Wongawilli seams but is not workable over much of the coalfield.

The Narrabeen Group, of Triassic Age, lies directly above the Coal Measures strata, and consists of thick interbedded sandstones and shales which outcrop along the escarpment. The total thickness varies from 200 m to 300 m in the areas where coal is mined. The Hawkesbury Formation, above the Narrabeen Group, is made up of massive cliff forming quartzose sandstones with occasional

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thin, lenticular shale beds. The Hawkesbury Sandstone is nearly 200 m thick in the northern and western part of the Southern Coalfield.

The different mining methods result in different degrees of subsidence at the surface for a given geological setting. The three broad classifications of extraction can be given as

(a) first workings with either no subsidence or insignificant subsidence, provided that pillars are designed for permanent stability,

(b) panel and pillar mining where supercritical extractions with low w/h values to give small maximum subsidence are separated by wide stable barrier pillars, and

(c) total extraction of coal over supercritical areas where high values of subsidence occur.

It is the obligation of the mining industry to maximise the recovery of coal from any given lease area. This means that total extraction, classification (c) above, is the preferred option. However there may be surface constraints, geological features, early mining in other seams or other factors which may not allow total extraction. Under these circumstances either panel and pillar mining or first workings, if economic, would be the mining system used.

MINING UNDER STORED WATER

Five major dams of the Metropolitan Water Sewerage and Drainage Board are located in the Southern Coalfield. They form a major part of the water supply to Sydney and supply the Wollongong and south coast area. Three of these dams are shown in Fig. 1. Initially the Board's attitude was that there should be no mining under or around these dams in order to prevent any subsidence so that there would be no risk to the dams or their storages. This would have denied any commercial exploitation of the affected coal reserves which were calculated to be 450 million tonnes. The Department of Mineral Resources (DMR) maintained that a large proportion of the coal underlying the stored waters could be safely worked without danger to the water supply or to the mine. This led to the appointment of Mr. Justice Reynolds in July 1974 as a commissioner to hold an inquiry and to make a recommendation on whether mining should be permitted beneath the stored waters and if so, to what extent.

The Dams Safety Act (NSW Government, 1978) was legislated in order to deal generally with the safety of dams and storages including the effects of mining. The Dams Safety Committee was established under the Act. One of the functions of the Committee is to review applications for mining. Applications are made to the DSR from mining companies with proposals for coal mining, and these are in turn referred to the DSC.

The guidelines used by the DSC are based on the recommendations and findings of the Inquiry (Reynolds, 1977). In the areas being mined or currently under consideration and where it is intended to mine in one seam only, as is the usual situation, the guidelines can be briefly and generally summarised as follows.

1. Broad and pillar mining is allowed at depths greater than 80 m with bords of a maximum width of 5.5 m and pillars of a minimum width of 15 times the extraction height or one tenth the depth of cover, whichever is the greater.

2. Panel and pillar mining is allowed at depths greater than 120 m with panel widths not greater than one-third the depth of cover and pillar widths not less than one-fifth of the depth of cover or 15 times the height of extraction, whichever is the greater.

3. The marginal zone around stored waters is determined by an angle of draw of 3° taken down from the boundary of the stored water at full storage level. The restricted zone includes the marginal zone and extends out for a further distance from the marginal zone equal to half the depth of cover from the storage full supply level.

4. There is to be no mining or driving of access roadways beneath a dam structure within a coal pillar defined by the restricted zone.

The restricted zone around each of the impounding structures of the MWSDB varies. At the dam structure with greatest cover (Moronora) the restricted zone is defined by a radius of 1.5 km, for the other dam structures it is 1 km and for two small dams on the upstream side of the Cordeaux Dam, the restricted zone is defined by a radius of 350 m. The DSC is to be notified of any mining proposals within the restricted zone and is required to make recommendations to the Government Minister regarding the extent of mining.

The DSC reviews mining proposals referred to it and, as part of its recommendations to
the Government Minister, the DSC usually requires that surface subsidence and strain measurements and other subsurface or underground monitoring and geological investigations be carried out at prescribed intervals during the mining.

PILLARS UNDER THE AVON STORAGE AT WONGAWILLI COLLIERY

Mining and Geology

Mining has taken place in both the Bulli and Wongawilli seams at Wongawilli Colliery. The water in the waters of the Avon Dam overlie the colliery holdings (Fig. 1) and a significant part of the recoverable reserves are included within the marginal zone around the stored waters. In recent years, mining has been in the Wongawilli seam which is a banded seam around 10 m thick. The worked section of 3 m is at the base of the seam.

Around the time of the Inquiry into mining under stored waters, bord and pillar mining was taking place in Blue Panel in the Wongawilli seam under the Avon storage (Fig. 2) according to the particular conditions of mining at that time. These conditions allowed for pillars at 30 m centres with bord widths of 5.5 m, which gave a recovery of 33%. Mining continued pending a decision being made by the Minister on varying the conditions relating to coal leases under and around stored waters. Following further considerations and discussions pillars at 50 m centres as recommended under the DSC guidelines were subsequently adopted. Stability calculations were carried out and a programme of pillar monitoring was organised in order to examine the performance of existing pillars in the light of the new requirements for larger pillars.

The depth of cover over the Blue Panel to the bed of the Avon storage varied from 95 m to 140 m. The stratigraphic section in Fig. 3 is from the bore located in Blue Panel. Zones of dyke and sill material are located in the Blue Panel area. Minor faulting in other locations did not affect the development of the panel.

There is one example at Wongawilli Colliery at a different location under the Avon storage where pillars formed 45 years ago show no signs of deterioration. The depth of cover is 130 m, the mining height is 2.3 m and the pillars are rhomboidal in plan with sides of 28 m. The pillars remain competent and continue to provide effective support of the overburden strata. A recent inspection showed that the pillars and the surrounding roadways are standing well.

Pillar Stability Calculations

A study was made of the stability of pillars in different layouts using the same working height and depth of cover as the Blue Panel, Wongawilli Colliery. One of the methods used to examine pillars in a bord and pillar layout is based on actual field studies of failed and stable pillars with factors of safety being chosen appropriate to the purpose of the pillars (Salomon and Wagner, 1985). Pillars in main development layouts where long term stability is required, similar to first workings under stored waters, would be given a factor of safety of 2. The method is applicable to a critical area of pillars and with a limited number of pillars at Wongawilli of specified size being flanked by solid coal, the actual factor of safety will be greater than that calculated.

The factors of safety of pillars at 30 m and 50 m centres were calculated according to Salomon's method. The pillar width required to result in a factor of safety of 2 was also calculated. In all cases the depth of cover h was 120 m and the mining height H was 3.0 m. The results are given in Table 1.

Both the 30 m and 50 m centre pillars have unnecessarily high factors of safety and for first workings without pillar extraction a pillar centre distance of 19.5 m would be appropriate for long term pillar stability under the conditions pertinent to Salomon's approach. Although local factors have not been considered in the application of the method, this exercise has shown that pillars much smaller than what are required under the current DSC guidelines would satisfy the normally accepted criterion for long term stability.

<table>
<thead>
<tr>
<th>Pillar Width (m)</th>
<th>Cover (m)</th>
<th>Height (m)</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.5</td>
<td>0.20</td>
<td>8.2</td>
<td>3.3</td>
</tr>
<tr>
<td>44.5</td>
<td>0.37</td>
<td>14.8</td>
<td>5.3</td>
</tr>
<tr>
<td>14.0</td>
<td>0.12</td>
<td>4.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

TABLE 1: Stability of Pillars, Wongawilli

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Fig. 2 Blue Panel, Wongawilli Colliery

Fig. 3 Section at Bore 13

Fig. 4 Strains in pillars, Wongawilli

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An alternative method to study the stability of pillars in first workings is that originally published by Wilson and Ashwin (1972) and applied to the Southern Coalfield by Hulla (1985). It was shown that pillars with Wilson’s factor of safety of 1.5 had long term stability. For a mining height of 3.0 m at a cover depth of 120 m, a pillar width of 14.0 m would give a factor of safety of 1.5.

The NSW Coal Mines Regulation Act (CMRA) (NSW Government, 1982) requires that the widths of pillars in the bord and pillar layout should not be less than one tenth of the cover depth or 10 m, whichever is the greater. Under the CMRA, the pillars at Wongawilli would be 12 m wide (pillar centres of 17.5 m) and would have a factor of safety less than Salamon’s 2.0 or Wilson’s 1.5. Such pillars would still be stable but their factor of safety may not satisfy the criterion adopted for long term stability.

Monitoring of Pillars

Two of the 30 m pillars were monitored in order to study their behaviour over time. These pillars were chosen since they are smaller than the DSC required size and are located in a sensitive area, directly below the Avon stored waters. Information on pillar deformation was obtained by means of multiple point borehole extensometers installed in horizontal boreholes drilled into the core of each pillar at the mid height position. The locations of the boeholes are shown as Holes 1 and 2 in Fig. 2.

In the first pillar, extensometer anchors were located at depths of 1, 2, 6, and 12 metres. The rib experienced a maximum outward deflection of 0.48 mm during the 8 months of regular monitoring. The strains between each of the anchors in Borehole 1 are shown in Fig. 4. The contribution to the rib deflection occurring in the outer 2 m was 0.36 mm and the overall tensile strain in that zone was 0.022.

The second pillar was similarly monitored but with anchor points at depths of 2, 4, 6 and 12 metres. In this case the rib experienced a maximum deflection of 1.45 mm. The strain plots for Borehole 2 are somewhat unusual in that there are tensions between the anchors at 4 and 12 m which are to some degree balanced by the compressions indicated between the anchors at 4 and 6 m. Slippage of the anchor at the 6 m location would account for this apparent anomaly.

The yield zone around the pillar core is made up of coal which has passed its failure limit and is in effect a skin composed of broken and unrestrained coal. Its width is given by the distance from the side of the pillar to the location of the peak stresses and was considered by Wilson and Ashwin (1972) to be 0.005 h metres. For the 30 m pillars at Wongawilli, this distance would be 1.0 m. Inside this zone the pillar core is restrained and should reveal little movement. This is in general agreement with the results of the extensometer monitoring.

MINING UNDER THE CATARACT STORAGE
AT BULLI COLLERY

Mining and Subsidence

The stored waters of the Cataract Dam overlie the Bulli Collery holdings (Fig. 1) where one seam, the Bulli seam, is being mined under the stored waters. This is the first instance of pillar extraction under a major South Coast reservoir according to the requirements of the DSC. Extensive geological, hydrological and subsidence studies were required to be carried out in association with both the underground development and the subsequent extraction of panels. The subsidence work and the associated finite element modelling are discussed here. The various hydrological studies associated with borehole monitoring are described by Wilson, 1985.

The South West Panels lie beneath the northern arm of the Cataract Reservoir (Fig. 5) where the depth of cover h varies between 230 m and 330 m. The predominant stratigraphic horizon is the massive Bulgo Sandstone. The layout of the panels was planned according to the DSC requirements, based on the findings of the Inquiry into Mining under Stored Waters. The rib to rib width of each extracted panel was one-third of the minimum cover depth, and the solid width of each pillar separating the panels was one-fifth of the maximum cover depth. Where there is a significant variation in cover depth over the length of a panel, the extracted panel width is narrower than 0.33 h at the greater depths and the pillar width is much larger than the necessary 0.2 h at the lower depths of cover. The application of the guidelines meant that mining erred on the conservative side.

It was originally intended to mine four panels but later rationalisation of Bulli Collery with the emphasis on higher production and the more efficient longwall extraction methods meant that only the first three of the SW Panels were mined. The Wongawilli lift and fender method of pillar extraction was used and due to the variation in cover depth, the minimum panel width was

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Fig. 5 South West Panels, Bulli Colliery

Fig. 6 Subsidence across SW Panels, Bulli

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The hydrological studies showed that the reservoir did not suffer any loss to the groundwater regime nor was there any leakage from the reservoir to the mine. The bores at the three sites which were used for this work included monitoring stations at 12 m intervals down to within 100 m of the mean (Wilson, 1985). Differential subsidence did not occur, indicating that the body of the strata subsided massively with no detectable bed separation.

A dyke zone intersected the South West Panels. The definition of this zone in each of the main headings showed it to diminish in magnitude in a southerly direction from the 1SW towards the 4SW Panel. The dyke material is a hard dolerite which becomes soft on exposure. It is not known how far this feature extends up into the strata. Several lineaments appear at the surface but field inspections did not produce any evidence that the dyke reaches to the surface. It was not possible to mine through this feature as shown by the strips of coal remaining around it in 1, 2 and 3SW Panels (Fig. 5). The exposures of this dyke in the headings and panels were dry during and after mining operations.

### Table 2

<table>
<thead>
<tr>
<th>Panel</th>
<th>Extn. width (m)</th>
<th>Cover H (m)</th>
<th>w/h</th>
<th>Total Subs. (mm)</th>
<th>Mining Height (m)</th>
<th>Sp (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1SW</td>
<td>86</td>
<td>315</td>
<td>0.27</td>
<td>35</td>
<td>35</td>
<td>2,400</td>
</tr>
<tr>
<td>2SW</td>
<td>79</td>
<td>310</td>
<td>0.25</td>
<td>75</td>
<td>45</td>
<td>2,400</td>
</tr>
<tr>
<td>3SW</td>
<td>79</td>
<td>308</td>
<td>0.26</td>
<td>105</td>
<td>50</td>
<td>2,500</td>
</tr>
</tbody>
</table>

78.9 m and the maximum pillar width was 67.2 m. The overall recovery was calculated to be 40%, rather low for a panel and pillar layout under normal conditions and the method of pillar extraction as practised in the 1, 2 and 3 SW panels did not satisfy the required productivity or efficiency parameters.

Subsidence predictions were made, based on the empirical curves already developed for the Southern Coalfield (Kapp, 1980 and Frankhn and Nolla, 1984). The maximum expected subsidence was 100 mm, very small in comparison with the mining height of 2.5 m. Subsidence surveys were carried out as one of the conditions pertaining to the extraction approval. Both levels and distances were monitored for the subsidence and strain calculations. There were six lines of survey stations, each around 1 km long. The main grid lines were over the longitudinal centre line of each of the extraction panels. The interpolated subsidence profile across the extraction in Fig. 6 show the maximum subsidence profile after the mining of each panel. The mining details at the section line, the total subsidence and the increase in subsidence due to the mining of each panel are shown in Table 2.

The tensile and compressive strains were quite low. The values were generally much less than 0.6 mm/m, and did not exceed this value. There were some anomalous strains up to 1.6 mm/m which occurred down the steep sections of the grid near the edge of the stored water. The maximum slope change due to subsidence was 0.04%. The minimum (sharpest) radius of curvature corresponding to this maximum slope change would be greater than 200 km.
then imposed. It was required that the Company, BHP Collie, organise to have mathematical modelling carried out in progressive stages of extraction up to the 4SW Panel, firstly without a geological defect, and then with a hypothetical continuous defect extending from the seam to the surface.

The services of Australian Coal Industry Research Laboratories Ltd (ACIRL) were engaged to carry out the required modelling. The finite element computer program ISOFIN used in this work was developed by ACIRL and its application is described by Holt and Mikula (1984). There was a series of meetings with BHP, ACIRL and the DSC to decide on procedures and on the various properties of the strata and dyke materials, and on the assumed dyke configuration and stress levels.

The half geological section which was modelled is shown in Fig. 7. The mean extracted panel width was 80 m and the mean solid pillar width was 66 m. The immediate 4 m of both roof and floor is shale. An assumed continuous vertical defect was included in two locations, firstly over the pillar between SW3 and 4 (Position A), and then over the SW4 panel under the stored water (Position B).

For the no defect case, and for the cases of an assumed defect in Position A and B, four models were analysed. These models were of the extraction of SW1 Panel only, extraction of SW1 and 2, then SW1, 2 and 3, and finally SW1, 2, 3 and 4. Analysis results for three characteristic patterns were obtained for each model. The failure pattern showed which elements around the excavation either partly or totally failed and the failure mode. The displacement pattern showed the direction of the movement of all points within the rock mass and the magnitudes of the displacement around the excavation and on the surface. The stress pattern showed the directions and magnitudes of the principal stresses at each element within the rock mass due to the pertinent extraction layout. In addition, surface subsidence and strain profiles were produced for each model.

The models of the situation where there was no hypothetical vertical continuous defect showed that after extraction the strata remained intact with the stresses throughout the rock mass being highly compressive in both the horizontal and vertical directions. The maximum height of caving, sagging and non elastic strata disturbance was 4 m and reached to the base of the Scarborough Sandstone. Above this level, the strata remained elastic and competent. The goaf areas above each extracted panel were separate and discrete and the pillars between the panels remained fully intact and unfailed. The values of maximum subsidence were in general agreement with the data in Table 2. There was no significant increase in subsidence with the extraction of the fourth panel. The maximum surface strains calculated from the finite element models varied from 0.2 to 0.5 mm/m.

There were no significant changes to the above findings for the models with the assumed vertical defect in either Position A or Position B. That is, the defect had no significant effect on the goaf formation, nor on the displacements and stresses within the

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Modelling of Variation in Mine Geometry

It is considered by the mining companies that long term stability can be achieved by having pillars that are not as large as those required by the DSC. Once the basic model had been set up for the Bulli SW Panels, it was decided to rerun the finite element models without the discontinuity but with smaller pillars between the 80 m wide panels. Program runs were also carried out with wider extraction panels. Modelling was carried out with six extracted panels rather than four to simulate a more extensive mine layout.

The sizes of pillars required in panel and pillar layouts in the Southern Coalfield was one of the topics discussed by Holla (1985). For a panel width of 0.3 times the cover depth, and using the approach of Wilson (1982), Holla calculated the widths of pillars required at various depths of cover so that the pillar factor of safety was 1.5, a value at which the pillar was shown to have long term stability. Using the information from Table 2 and the method from Holla (1985) a solid pillar width of 50 m would be adequate for long term stability. At the minimum depth of cover below the Cataract at Bulli of 230 m, a solid pillar width of 40 m separating 80 m extraction panels would be adequate.

Four different models were studied using the ACTRL finite element program. The program was run with six 80 m goafs separated by solid pillars each of the same width. The pillar sizes considered were 65, 55, 45 and 35 m respectively. The centre line of the model was through the central pillar using the same axis of symmetry as in Fig. 7. The depth of cover over these panels varied from 230 m to 300 m.

The coal pillars remained intact in all cases but the higher stresses which developed in the 45 m and 35 m pillars and in the overlying strata resulted in some failure into the Coalcliff Sandstone above the central pillar of the six panel layout. The study indicated that a model with four goafs rather than six would show a reduced amount of disturbance of the sandstone strata above the central pillar. For instance it is quite possible that 45 m solid pillars separating four 80 m panels would provide long term stability for the conditions modelled at Bulli.

Two additional models were run to examine the effects of mining wider panels on the stability of the overlying strata. The first model was of 100 m goafs separated by 55 m solid pillars. The pillars and the associated overlying strata remained intact and competent and the height of disturbed strata just reached into the Scarborough Sandstone. The second model of six 120 m goafs separated by 65 m solid pillars showed some isolated shear fractures appearing in the Stanwell Park claystone over four of the six panels, and some failure of the Coalcliff Sandstone over the centre pillar only. The higher strata deformed elastically and were not disturbed.

SUMMARY

In 1977 certain guidelines were set out for mining under and around stored waters in the Southern Coalfield of NSW, based on submissions to a Judicial Inquiry. These guidelines were understandably conservative given the circumstances at that time. Since then, information has come from various investigations and from the monitoring of mining layouts set out in accordance with the requirements based on these guidelines. This work has shown that there is scope for modifying the guidelines in order to improve the recovery of coal while at the same time maintaining the integrity of the water storages.

A study was made of the stability of a bord and pillar layout under the Avon storage. The pillars were larger than required for long term stability, but smaller than required under the guidelines adopted by the DSC. The extensometer monitoring of these pillars indicated a substantial internal core more than capable of taking the applied load as shown by the high calculated factors of safety. Two methods used to calculate the pillar stability were in agreement that a pillar size substantially smaller than what is required under the DSC guidelines would be adequate for long term stability of the bord and pillar layout.

Pillars have been extracted beneath the stored waters of the Cataract Dam according to the required panel and pillar layout design. An extensive programme of surface, subsurface and underground monitoring was carried out. Pillar stability calculations indicated that pillars not as large as those specified would be sufficient for long term stability. This was confirmed by a series of finite element models. In addition to this, the mathematical modelling showed that the body of the strata would still remain competent and in compression even with wider extraction panels. Such a configuration could enable consideration to be given to the more efficient longwall extraction methods.
CONCLUSIONS

Current guidelines specify the pillar sizes and extracted panel widths to be used for mining under and around the stored waters of major dams in the Southern Coalfield of N.S.W. Since the guidelines were formulated, sufficient additional evidence has accumulated to justify a study into whether they can be modified to enable more productive and efficient coal extraction.

Two different mine layouts under the stored waters were studied. The work showed that the present requirements are too conservative and that a greater production of coal can be obtained without risk to the long term stability and integrity of the support pillars or of the overlying rock mass.

ACKNOWLEDGEMENTS

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Acknowledgement is made of the work of the Survey Department of BHP in establishing and surveying the subsidence grids and in the associated subsidence and strain computations. The cooperation and assistance of the Managers and surveyors at Wongawilli and Bulli Collieries, and officers of the Coal Geology Department are acknowledged.

The Mining Division of ACIEL applied their finite element modelling technique to the Bulli situation. Their cooperation, and in particular the work of Dr. P. A. Mikula, during the course of these investigations is acknowledged. The subsidence work also required liaison with the Departments of Industrial Relations and Mineral Resources and with the DSC.

The cooperation of those associated with the subsidence work makes these investigations possible. Their assistance is gratefully acknowledged.

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