Development of an Engineering Understanding of Soft Floor Strata Conditions—
A Case Study from Munnorah Colliery

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Abstract: Large areas of underground coal reserves are located above soft strata of varying nature and extent which can result in significant mining problems, ranging from local problems like bogging of equipment and floor heave to regional deformation, collapse and surface subsidence. A significant number of current operating mines are affected as well as potential future mining areas. The extreme variability (in geometry, lithology, mineralogy) of the strata involved poses the main difficulty in finding a solution.

This paper provides an overview of the methodology which the research team at UNSW has adopted in the investigation of case studies of soft floor problems and possible engineering mechanisms involved. The paper presents the results of a comprehensive field monitoring program aimed at developing a more detailed engineering characterisation of the soft strata material properties and their failure characteristics.

Key Words: soft strata, floor heave, characteristic parameters, failure triggers, failure modes.

Introduction

Many cases of significant mining problems have been reported from underground coal mines, in Australia, located in soft strata environments. These range from local operational problems like bogging of equipment and support systems; floor heave leading to disruptions in transportation and ventilation; regional deformations and collapse because of pillar settlement, pillar punching or indirect pillar collapse, and, unplanned regional and surface subsidence (Galvin et. al., 1996).

These problems cost the mining industry dearly, not only in maintaining smooth running of current operations, but also in curtailment of operations under adverse conditions, restrictions imposed on future mineable coal and compensation costs. In order to achieve its objectives of safety, productivity and competitiveness, the coal mining industry needs solutions to the soft strata associated problems.

The research being carried out in this field, at The School of Mining Engineering, UNSW, is aimed at developing a more comprehensive engineering understanding of the soft strata associated problems based on: characterisation of material properties
and failure modes, and development of a validated model for predictive performance analysis.

This paper presents an overview of the research methodology adopted together with the results of a detailed field investigation exercise, and its contribution to the advancement of the understanding of the mechanistic behaviour of soft strata.

Research Methodology

A review of reported coal mining cases influenced by soft strata revealed a wide range of problems, varying in their nature and magnitude (Cundy, 1994). The variations manifest themselves in terms of geometry, lithology and mineralogy. The geometric variations take the form of a range in the thickness, number and depth below the coal seam of the soft layers. Lithologically, they are variously described as tuffaceous bands, siltstones, claystones and mudstones. Minerallogically, the nature and extent of different types of clay content affect their geomechanical behaviour drastically, particularly with regards to their sensitivity to moisture (Bruggemann, 1992). Previous investigative attempts have been site specific and no comprehensive, successful and practical solutions have resulted. Hence an integrated approach was required to encompass and address the wide range of problems.

It was decided to firstly characterise the available information regarding soft strata associated problems on the basis of stratigraphic factors (depth and thickness of strata), geomechanical factors (strength and deformation properties of strata) and geotechnical factors (dimensions of the panel and pillars, abutment loading induced by neighbouring mining and pre-mining stresses). The second step was to identify the failure trigger(s) from the list of characteristic factors and to identify the failure mode(s) (Hayward, 1997; Urie, 1997). The final step was to develop a comprehensive engineering model for the soft strata associated problems which could be used as a predictive tool for potential future mining areas influenced by soft strata.

In order to gain confidence in the model and the methods of site characterisation, specific mine sites were selected for detailed investigations. The Main West Panel at Munmorah Colliery was selected for one such site investigation (Vasundhara et. al., 1997).

Site Monitoring

Site Specifications

Munmorah Colliery is located about 55 km south of Newcastle around the northern edge of Lake Munmorah (Figure 1a). The workings in the Main West Panel comprise of bord and pillar first workings and partial secondary pillar extraction (Figure 1b). The seam mined is the Great Northern Seam of the Newcastle Coal Measures, in the Sydney Basin. The seam is underlain by a tuffaceous claystone ranging from very soft and weak sediments to hard silicified rock (Figure 2) and over lain by a very stiff, thick and competent conglomerate bed. The panel is surrounded by fully extracted areas (mined some years previously) which suffered extensive floor heave (Plate I).
Figure 1 (a) Location Map

Figure 1 (b) Main West Panel

Figure 2. Floor log, Main West Panel
Munmorah Colliery.

Plate 1. Floor Heave in total extraction adjacent to Main West Panel.
Objectives

The site was monitored with the aim to understand the regional load distribution and related stability across the panel as a result of a partial extraction layout. Another objective was to monitor the performance of the panel with time and correlate it with surface subsidence effects.

Instrumentation

Site monitoring was done using simple geotechnical instrumentation to measure load and deformation in the panel. The locations where the instruments have been installed are shown in Figure 3. The instruments used were: Multiple-anchor Wire Extensometers installed across the full width of the pillars (on either side of the main travelling roadway) to measure the horizontal displacement and strain in the pillar as a result of partial extraction and with time; Hydraulic Borehole Flat Jacks installed in the pillars to measure the changes in vertical load in pillars as a result of partial extraction and with time; and Convergence Poles installed in roadways throughout the panel to measure vertical convergence (i.e., sum total of roof displacement and floor heave) of the panel. Before the convergence poles were installed, a precise underground survey was carried out on the roof horizon for the locations where convergence was to be measured. This was done, as repeated roof levelling surveys would give a measure of roof displacement, which when taken out from the convergence reading would enable calculation of the amount of floor heave.

![Figure 3. Location of instruments in Main West Panel.](image)

Results of Instrumentation

Monitoring of the site is still continuing, as the partial extraction pattern is such that long term accessibility to the panel has been maintained. The instruments were installed in the panel while partial extraction was being carried out in the area. The data for the first 448 days since the instruments were installed, has been processed and interpreted. This database will be updated and reinterpreted as more data becomes available in the future.
Extensometer Data

The extensometer data shows large horizontal displacements (up to 60mm) in the ribs of the pillars, much of which took place immediately after adjacent extraction, but has since continued over time at a very low rate (average rate of 0.03mm/day). It also shows that the pillars have maintained an unstrained (confined) core at least 13m wide. Figure 4 shows the horizontal displacement data over time plotted across the width of the pillar, and Figure 5 shows the horizontal strain across the pillar.

Figure 4. Displacement across pillar.

Figure 5. Strain across pillar.
Flat Jack Data

The Flat Jack data shows a slight increase, initially, in the vertical loads in the rib of the pillars following extraction of adjacent pillars. However, over time, the vertical loads throughout the pillars seem to be decreasing with the rib carrying almost no load and only the core of the pillar still carrying some load. Figure 6 is a plot of vertical stress profile across a pillar inferred from stress measurements across one half the width of the pillar (assuming symmetry of stresses along the centre of the pillar). There is a possibility that some of the flat jacks may have leaked over time, and hence would not be reflecting any changes in the vertical load on the pillar, although the flat jacks placed at the central section of the pillars have retained their hydraulic pressure.

![Figure 6. Vertical stress profile across pillar](image)

Load Distribution on Partial Extraction

Other than the possibility of leakage of flat jacks, this behaviour of the entire pillar shedding load, or in other words, overburden load on the pillar being transferred elsewhere can be explained under two circumstances: if the pillar yields completely then the overburden load will be transferred away from the pillar, or, if the pillar punches the floor strata then also the overburden load will be transferred away from the pillar onto adjacent areas (Figure 7).

![Figure 7. Overburden load transferred to neighbouring pillars](image)

The extensometer data shows the presence of unstrained core in the pillar quite distinctly, hence the possibility of the whole pillar having yielded seems unlikely. Further this is also unlikely under the prevailing stress and geometric conditions in the panel. Thus the possibility that the pillars have punched into the floor strata seems more likely.
Convergence Data

The convergence data shows that the whole panel is continuing to converge (Figure 8). The main travelling roadway is converging at a present rate of about 30mm/year. The center of the roadway has converged more than the either sides as would be expected (Figure 9).

![Figure 8. Convergence versus time.](image1)

![Figure 9. Convergence across roadway.](image2)

This may be explained as a result of more of both roof displacement and floor heave in the center of the roadway. The convergence data from the goaf edge shows high amounts of convergence (up to 140mm) both near the edge (may be because of roof cantilevering) and in the center of the initial roadway (may be because of some amount of roof cantilevering coupled with more floor heave centered near the middle of the initial roadway). (Figure 10, 11).

![Figure 10. Convergence adjacent to goaf](image3)

![Figure 11. Probable pattern of convergence adjacent to goaf.](image4)

Only one subsequent roof levelling survey has been done, and that too for only six sites. The roof levelling data available from these six sites shows that the amount of roof sag is much more than the total convergence measured. As the data is limited and three of the six poles to which the data refers were disturbed a couple of times over the course of time the data was collected, hence this preliminary assessment may not be correct. However, if it is correct, i.e., if the roof has moved in a downward direction by an amount which is more than the convergence of the roadway at that
place, it indicates either a deep seated lateral movement of the floor strata and thus a net downward movement of the panel, or consolidation of the floor strata which would also lead to a net downward movement of the panel (Figure 12).

Deep seated lateral movement of floor strata

Consolidation of floor strata

Figure 12. Probable reasons for downward movement of panel

Subsidence Data

The subsidence data collected from above the panel, shows a continuation of subsidence with time. The amount of subsidence has however been controlled by this partial extraction layout, compared to the amount of subsidence over the part of the panel where effectively total extraction was carried out.

Outcomes of Site Monitoring Exercise

It can not be said definitely at this stage that the panel behaviour is in any way influenced by the presence of soft floor as a number of gaps appear in our knowledge base. However, an attempt is made here to identify certain behavioural mechanisms (as suggested by the available instrumentation data) and identifying the causal parameters and modes for each. Table I lists the identified causal parameters and modes with respect to the observed behaviour of the panel.
Table 1: Behavioural Mechanisms

<table>
<thead>
<tr>
<th>Observed behaviour</th>
<th>Failure/ behaviour mode</th>
<th>Causal Parameters</th>
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<tbody>
<tr>
<td>Load over pillar being transferred elsewhere.</td>
<td>Pillar punching.</td>
<td>Low strength of soft strata (may be influenced by high moisture content). Stiff roof strata.</td>
</tr>
<tr>
<td>Net downward movement of the panel.</td>
<td>Deep seated regional horizontal movement.</td>
<td>Low strength of soft strata. Mining geometry of the panel and surrounding areas.</td>
</tr>
<tr>
<td>Net downward movement of the panel.</td>
<td>Consolidation of floor strata.</td>
<td>Presence of water in the floor strata and its subsequent long term drainage</td>
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</table>

Conclusions

Specific conclusions concerning the Munmorah site investigation are:

- As the pillars are shedding load even though they have an unstrained confined core, there is a possibility of the pillars punching into the soft floor.
- Convergence in the panel is still continuing (at a rate of 30mm/year).
- A net downward movement of the entire panel has been inferred from the monitoring data, which indicates the following possibilities:
  - deep seated regional horizontal movement of strata under the panel
  - consolidation of strata under the pillars
- The subsidence data also indicates a continued regional lowering of the area over the panel.

A subsequent model development and its validation being carried at UNSW will further elucidate the operating modes of behaviour.

The case study described above illustrates the approach taken in this research investigation. Without making any preconceived judgment of failure/behaviour modes, the monitoring data has been collected and then back analysed. This back analysis has then suggested a number of possible failure/behaviour modes which may be operating individually or in combination.

As long term deformation is evident in the panel, it is recommended that monitoring of the site be continued to study the time dependent behaviour of the panel. Further, as subsidence surveys carried for neighbouring collieries situated in similar geological and stress environments indicate, subsidence over panels with soft floor strata has a history of continuing with time, hence regular subsidence monitoring of the area is recommended.

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Reference:


