DEVELOPMENTS IN GEOSCIENCES FOR OVERCOMING THE CONSTRAINTS ON HIGH PRODUCTION UNDERGROUND MINING

By

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ABSTRACT

At present some man-made improvements and natural features are constraints on unlimited underground mining. They will continue to remain as constraints on the future high production mining systems as well. Unless these constraints are overcome by research, where possible, future high production systems may become unacceptable. The areas of future research include improved subsidence prediction techniques applicable to future mining systems, subsurface subsidence behaviour, mining systems capable of producing no surface subsidence and subsidence damage assessment.

INTRODUCTION

Coal extraction by underground mining methods causes surface and subsurface disturbance. The disturbance, if large, could damage man-made structures and the natural surface environment. Water resources such as rivers and lakes on the surface and those within the undermined strata such as aquifers could also be adversely affected. Mine safety is an important consideration when mining underground water bodies, which requires limiting strata disturbance to acceptable levels.

Subsidence of the overlying land is in fact a constraint on underground mining in many cases even at present. In the Southern Coalfield of NSW, for example, vast reserves of coking coal are located under stored waters and their impounding structures and coal extraction under stored waters is generally limited to first workings only and in rare cases to panel and pillar mining. In the Newcastle Coalfield, even though mining has been taking place under tidal waters and the Pacific Ocean, the extraction is planned conservatively, especially in multi-seam extraction situations. Natural features like escarpments and cliffsline pose serious difficulties in mine layout planning throughout NSW. There is a need to protect subsurface water resources from the damaging effects of subsidence. But subsurface subsidence behaviour is still not clearly understood at present and mine layout planning to some extent has become arbitrary.

Subsidence will continue to be a serious issue which will confront the planners of the future high production mining systems. The future systems create critical and supercritical extraction conditions, rapid subsidence development rates and large subsidence movements. The decision as to whether or not mining should take place in a particular case will be made, as it is currently being made, on the extent of likely damage. If damage assessment is to be undertaken realistically prior to mining, a clear understanding of the subsidence behaviour of future high production mining systems is essential.

The paper discusses some important subsidence issues which, if not resolved satisfactorily, could make otherwise feasible future mining systems unacceptable. Some solutions for overcoming the constraints are examined. Areas of future research are also indicated.

STATEMENT OF THE ISSUES

FUTURE MINING ENVIRONMENT

Capabilities of future high production underground mining systems have been set around 40,000 tonnes per day. The authors accept the anticipated levels of production and hope that others will resolve the problems associated with such high levels of production in the areas of development, extraction, ventilation, transportation and reject disposal. The authors recognise the quantum leap in technology being proposed and feel an obligation, to both the industry and the community, to identify problems and suggest solutions, in order to minimize the surface and subsurface environmental disturbance resulting from such advances in technology.
Achieving 40,000 tonnes per day production from seams with a physical thickness of between 2m and 5m imposes a set of working conditions. Two cases of mining have been considered as a basis for demonstrating the impacts on the easily viewed surface and the less easily seen subsurface.

1. In the first case, a high capacity one district production unit is assumed. A tandem face arrangement of two 200m long faces is proposed with separate shearers on each face and the two face conveyors feeding to a central gate road belt conveying system.

2. The alternative to a high capacity one district production unit is to have two districts, each producing 20,000 tonnes per day. This is already a proven technology.

EXTENT OF DISTURBANCE

The first case has to accommodate a production rate of 1000 tonnes per metre of advance, assuming a 2m extraction thickness. This means the face has to advance by 200m per week or 1km every five weeks. A 5km long panel then would have a life expectancy of six months. This would result in a major disturbance of the overlying surface of 2km² in area. An additional area between the panel edge and the limit of subsidence trough is also subjected to disturbance, though to a lesser extent. The latter area depends upon the angle of draw and the depth of extraction, and could easily amount to a further 1km² of disturbed ground. One year of production will therefore affect about 5 km² of ground surface. A colliery with a life expectancy of 20 years can disturb some 100 km² of ground surface and all that stands on the surface.

The second case using two separate districts for production will not change the area finally affected but simply allows for any one area to be mined at half the rate.

Thicker seams and multi-seam extractions will result in a lesser area being affected, but the area affected will be subjected to increased disruption.

SURFACE AND SUBSURFACE CONSTRAINTS

Uncumbered crown land containing no significant natural features and surface improvements provides ideal conditions for undertaking underground coal mining on a total extraction basis. The surface can be lowered in such cases with impunity, provided this does not create any dangerous effects such as wide open cracks. But these ideal mining conditions are seldom encountered and will occur only very infrequently in the future as added pressures encourage alternative land uses. We have to consider coming to grips with surface and subsurface constraints imposed on mining, similar to many that we have today. Some constraints are of less concern as mining induced movements can be accommodated without damage or with acceptable damage. Others, however, need fundamental solutions as mining may cause unknown, undesirable or unacceptable effects. It is the problems raised by this latter category of constraints which need to be addressed. The constraints and the desirable solutions are given below.

1. Railways - Mining should not affect the servicerability.
2. Stored waters - Mining should not lead to loss of stored waters. Dam structures, however, are excluded from subsiding.
3. Major water courses - Mining should not interfere with riparian rights.
4. Satellite town subdivisions - Damage to structures, if any, should be acceptable.
5. Natural water bodies - Mining should not cause entry of unacceptable volumes of water into mine workings. Furthermore, flooding of foreshore lands should be avoided.
6. Major aquifers, hydrocarbon gas or oil reservoir beds - Natural resources should not be disturbed as far as possible.
7. Natural environment including escarpments and cliffs - It is essential to prevent damage, as damage cannot be repaired to restore the pre-mining environment.

SUBSIDENCE ISSUES TO BE ADDRESSED

From the subsidence point of view, the future high production mining systems raise several issues, which have to be resolved. Some of the issues are listed below.

1. Can future high production mining systems be accommodated within the existing surface and subsurface constraints imposed?
2. By what means can disruption be contained within acceptable limits without affecting the contemplated production?
3. Is the current knowledge in the areas of subsidence prediction, subsurface strata behaviour and damage assessment sufficient to handle the problems created by the future mining systems? If the answer is no, what are the areas in which more research is required in the
Unless the above issues are resolved satisfactorily, severe constraints will be imposed on mining layouts, which may lead to sterilisation of non-renewable coal resources.

STRATEGIES FOR OVERTAKING THE CONSTRAINTS

It is recognised that any solution for overcoming a constraint has to be economically justifiable. This, however, should not prevent new solutions from being considered, even if they may not be economically justifiable in today’s climate but hopefully may be justifiable in the 21st century. It is hoped that technical solutions presented here can also generate informed discussions and lead to new or improved variations.

The solutions for overcoming the subsidence constraints centre around the following areas:

1. extending the current techniques or developing new ones, if required, for the prediction of surface subsidence and associated parameters applicable to high production mining systems.
2. understanding subsurface subsidence behaviour of the undermined strata including caving characteristics.
3. developing techniques for mining with no subsidence.
4. establishing the relationship between subsidence and damage for different classes of structures.

SURFACE SUBSIDENCE PREDICTION

REVIEW OF CURRENT METHODS

Figures 1 and 2 show the empirical curves for predicting surface subsidence and strains for the two major coalfields of NSW, the Southern Coalfield and the Newcastle Coalfield (Holla, 1985, 1976a). The curves give the maximum values of subsidence (SSmax) as a function of the extracted seam thickness (T) for any width to depth ratio (W/H) of the extracted panel (Fig. 1), and strains and tilt for critical extraction conditions (Fig. 2).

The curves are derived from subsidence survey data collected by the Department of Mineral Resources and the various collieries over the last 25 years. The curves can be used to predict ground movements prior to mining, which are primarily required for two purposes.

1. When new structures are proposed to be erected in future coal mining areas, predicted movements are used for designing these structures.
2. When existing surface improvements are proposed to be undertaken, an assessment of damage likely to result from the proposed mining operation can be made from the predicted movements.

Fig. 1 - Maximum subsidence for isolated panels

Fig. 2 - Maximum strains and tilt for critical extraction conditions

ACURACY OF PREDICTIONS

There is significant scatter around the prediction curves in Figs. 1 and 2. The scatter is not unique to NSW. Researchers in the UK and USA have also experienced similar scatter in their investigations. In the UK, a maximum error of plus or minus ten percent was considered acceptable in subsidence prediction, remembering that the error in the measured subsidence could be as high as ten percent (Orchard, R.J., 1964). The prediction curves in Fig. 1 embrace most of the observed points under them and therefore are upper-bound curves, overestimating subsidence by up to ten percent in most cases.

It may be argued that subsidence prediction can be and should be improved by further collection and analysis of field data. The argument appears to be dubious on three grounds.

1. The incremental improvement in accuracy may be at an excessive cost.
2. Subsidence prediction is not an end in itself. It is required for subsidence damage assessment and...
subidence design purposes. Many more variables influence the severity of damage at a given site, and small improvements in subidence accuracy are unlikely to improve significantly either damage assessment or subidence design.

3. More data do not necessarily mean reduction in the scatter. Variations in the observed values are inevitable because of variations in the extracted seam thickness, the cover depth, the effects of emplaced coal in the goaf and the local geological conditions.

In summing up, future research in the area of subidence prediction for improving the existing prediction techniques is justified, only if it is cost-effective and if it addresses the problems created by the future high production mining systems.

EFFECTS OF FASTER EXTRACTION RATES

As discussed earlier, future high production mining systems are most likely to have critical and super-critical face widths and rapid face advance rates. The existing prediction curves are applicable to any mining geometry, but only to extraction rates not exceeding 50m to 60m per week. If face advance rates are going to be significantly faster than 60m per week in the future, then the current methods of subidence prediction and damage assessment may need re-examination.

The undamaged strata generally behave visco-elastically and the rate of settlement therefore depends upon the period of influence on a surface point. A rapid rate of face advance means a brief period of influence, and consequently the dynamic subidence and straining travelling with a moving face are less than those with slower rates of advance. The subidence troughs become flatter as shown in Fig. 3. This means that the ground surface over an extraction panel, which undergoes only transient movements, suffers less deformation with faster face advance rates.

Damage to a surface structure does not only depend upon the magnitude of ground movements. The dynamic wave accompanying a moving face consists of tension followed by compression and this reversal of strains is an important factor influencing the extent of damage. According to Kratzsch (1983), the rapid face advance has the effect of increasing the damage to structures because both the reversal of strains and the development of peak strains occur within a relatively shorter period of time as shown in Fig. 4. A faster re-arrangement occurs of external forces acting on the structure and internal forces within the structure, leading to damage in the structure.

**Fig. 3 - Dynamic trough profiles for different extraction rates**

![Dynamic trough profiles for different extraction rates](image)

**Fig. 4 - Dynamic strain profiles for two extraction rates**

![Dynamic strain profiles for two extraction rates](image)

On the basis of the foregoing remarks, it appears that there is an optimum rate of face advance which minimises surface damage because of the combined effect of the slower rate and smaller magnitude of ground deformation. Extraction rates exceeding the optimum rate cause more damage because of faster re-arrangement of forces in a structure, and extraction rates slower than the optimum rate cause more damage because of larger ground deformations. This phenomenon requires a detailed investigation.

**SUBSURFACE SUBSIDENCE BEHAVIOUR**

**STUDY OBJECTIVES**

Subsurface strata movement merits detailed study for several reasons, but two areas are worth highlighting.

1. Improved knowledge of the pattern
and magnitude of subsurface movement will enable a better understanding of the behaviour of the undermined strata. The data can be used for developing new and more realistic empirical models for defining the surface and subsurface movement. The data can also be used for designing efficient mining layouts.

2. If vertical movements can be related to strata fracturing and fracture permeability, then it may be possible to make an estimate of changes in strata fracturing and fracture permeability of the undermined strata due to mining. This information will be invaluable when dealing with mining projects which affect surface and subsurface bodies of water.

A comprehensive investigation into subsurface subsidence is being undertaken by the Coal Mining Engineering Branch of the NSW Department of Mineral Resources. The project is financed by the Commonwealth Department of Resources and Energy, Canberra under a NSWDC grant.

vertical borehole, which extended from the surface to the coal seam. The anchors were connected to the suspended weights on the surface by stainless steel multi-wire strands as shown in Fig. 5. The downward movement of an anchor caused by the mining induced strata movement would result in an identical upward movement of the corresponding suspended weight. The movement of anchors was monitored throughout the mining phase.

Permeability monitoring

The fracture permeability of strata before and after mining was measured separately in two adjacent boreholes. The boreholes were pressure tested by injecting water into sections formed by mechanical packers. The method was simple and quick, and provided information on the permeability variations within rock formations.

PATTERN OF SUBSURFACE MOVEMENT

Case 1 - Deep cover

In this case, the borehole was drilled and equipped over a series of longwall panels at a depth of 369m. The borehole was located over the second longwall panel and the extraction seam thickness was 3.5m. The panels were 150m wide with roughly 35m chain pillars separating them. The immediate roof of the extracted seam consisted of coarse to pebbly sandstone, fine sandstone and interlaminated sandstone, siltstone and mudstone in ascending order. The overburden strata between the immediate roof and the surface consisted of massive beds of sandstone, siltstone and conglomerate.

Figure 6 shows the absolute vertical movement of the various horizons in the borehole. The strata movements, as reflected by the movement of anchors, are shown separately after the extraction in the second and third longwall panels. The following observations are made.

1. The strata up to a depth of 320m below the surface underwent a rate of subsidence which was markedly different to that experienced by the strata below the depth of 320m. The horizon of abrupt change in the subsidence rate is the upper limit of the region of caving and bed separation, which extends downwards to the roof of the seam. The height of this region is 46m which corresponds to roughly 13 times the extracted seam thickness.

2. The surface at the borehole subsided by 970mm after the completion of extraction in the third longwall
panel resulting from a vertical dilation of the overburden strata by 2.53m. Most of the dilation occurred within the zone of caving and bed separation (87 percent).

3. The average dilation within the caving zone was 57.3 mm/m. In the remaining depth, the average dilation was 1.23mm/m.

![Diagram of vertical movement within strata (case 1) with labels: Strata depth (m), Cover depth = 308 m, (a) after extraction in LW 1, (b) after extraction in LW 2.]

Fig. 6 - Vertical movement within strata (case 1)

According to Fanner and Altounyan (1980), the tensile strains in excess of 2.0mm/m may be said to represent fractured rock which has deformed non-elastically. If this criterion is accepted, then the overburden of at least 150m thickness below the surface would be free from inelastic deformation and the strata maintain their integrity even after undermining. Even though more work will have to be undertaken to come up with definitive statements, it appears that aquifers located in the upper horizons of overlying strata or bodies of surface water are unlikely to be disturbed because of longwall mining.

Case 2 - shallow cover

The second borehole was drilled over a longwall panel 143m wide. The depth of cover was 116m and the extracted seam thickness was around 2.7m. The immediate roof consisted of 1m thick predominantly mudstone beds overlain by a 7m thick bed of sandstone. The strata above the immediate roof consisted of beds of mudstone, coal, siltstone and sandstone.

Figure 7 shows the strata movement within the overburden. Unlike the movement pattern in the first borehole, the movement was non-uniform. The following observations are made:

1. The pattern of movement tended to be much more closely related to stratigraphy than to proximity to the goaf. Movement variation within the more competent sandstone beds was steeper than that within the relatively weaker mudstones and coal beds.

2. Following from the above, sandstone beds suffered higher vertical strains, whereas mudstones only low strains. The sandstone beds appear to contain strong bedding plane shear and the mudstones appear to have collapsed in single units.

3. The immediate roof beds, 23m in thickness, caved into the void, which represented roughly 9 times the extracted seam thickness.

![Diagram of vertical movement within strata (case 2) with labels: Strata depth (m), Cover depth = 126m, Vertical movement = 13.5mm/m, Extracted seam thickness = 23m.]

Fig. 7 - Vertical movement within strata (case 2)

The surface subsidence at the borehole was 1.06m, which was 40 percent of the extracted seam thickness. The panel was sub-critical with the width to depth ratio (W/H) of 1.25. The total vertical dilation of the overburden was 1.64m. Most of the dilation occurred in the sandstone strata, the dilation being as high as 10mm/m in the top 30m.

The preliminary analysis of permeability test results indicates that mining has caused increased fracturing of the strata and consequently increased permeability. This is to be expected, considering the shallow cover depth. Attempts are being made to quantify fracturing so that relationships between vertical movements, fracturing and permeability can be established.

PREVENTION OF SUBSIDENCE

Considerations such as shallow cover depths, sensitive surface improvements or natural features may only allow mining on a partial...
SOME MINING AREAS have an extraction basis or in some cases may even have mining totally unacceptable. In such cases the only option available, if coal is to be sterilised, is to prevent caving of the immediate roof beds by stowing. Stowing has been successfully used in many countries as a means of controlling surface subsidence. Australian experience in stowing is limited, and the resolution of conflict of competing alternative land uses may necessitate the introduction of stowing in future high production mining systems.

The introduction of stowing in Australia will no doubt raise some complex economic issues, which have been discussed elsewhere (Hughson, Tymianski and Holla, 1987). Stowing increases the cost of production, but mining interests should not be allowed to recognize that without stowing a significant part of the available coal resource is liable to be sterilized. The high production mining systems, which are otherwise feasible, may become unacceptable because of unwillingness to introduce stowing.

DAMAGE ASSESSMENT

Damage assessment is an important pre-requisite for approval of any mining proposal. It follows subsidence prediction and is more complex than subsidence prediction, in view of several variables associated with structures, soils and soil-structure interaction. In NSW, the subsidence-damage database is limited and the Coal Mining Engineering Branch is actively engaged in pursuing this area. At this stage, some limited information on likely damage to man-made improvements is available in the following areas:

1. The response of dwellings when undermined has been reasonably well studied and reported (Holla, 1987a and 1988a). Damage depends upon the level of ground movement and the type of structure. In many cases, it may be possible to undertake longwall mining without significant damage.
2. Major roads including freeways have been undermined in the past without endangering traffic safety. With deep covers, longwall mining can take place, though some damage is unavoidable (Holla, 1988b).

Damage assessment and subsidence prediction are independent research areas, but simultaneous development of knowledge in both areas is essential. Too much emphasis on one at the expense of the other would defeat the end objective of making rational decisions with regard to mining proposals affecting surface improvements. At this point in time, in NSW, damage assessment lags behind subsidence prediction. It is time this was recognized and the situation was rectified.

CONCLUSION

The purpose of this paper is to highlight the point that subsidence is a serious issue confronting mine planners today and will continue to be so in the future. There is a tendency among some mining engineers to overlook the subsidence issues hoping that they will go away and concentrate upon solving the "real" problems of the high production mining systems. Such an attitude may result in subsidence issues ultimately determining the future of such systems and may even limit their introduction.

From the subsidence point of view, the current high production mining systems are not much different to the current mining systems. Both systems disturb the overlying surface and strata. In the former case, the disturbance is more concentrated both in time and space.

At present, mining is limited under many man-made improvements and natural features. This is partly due to the fact that our limited knowledge in some areas of subsidence engineering does not allow the prediction of the effects of mining on the environment to be made with confidence. It may be that in some cases coal sterilisation may be inevitable, but in many other cases coal recovery can be improved with a better understanding of the subsidence issues.

More research has to be undertaken to address both the current subsidence issues and the additional ones caused by the high production mining systems. The areas of research include improving the current prediction techniques, obtaining a better understanding of subsurface subsidence, studying the available stowing techniques and establishing criteria for damage assessment. The multi-disciplinary approach used in this research is now being undertaken to study subsurface subsidence due to longwall mining. The method has enormous potential for overcoming the constraints on the future high production mining systems and should be used extensively in the future.

Damage assessment is another important area of research which should be given equal emphasis with surface and subsurface subsidence research.

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