STATE-OF-THE-ART OF MINING UNDER PUBLIC UTILITIES IN NEW SOUTH WALES

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ABSTRACT

The need to prevent the sterilisation of coal stems directly from the fact that it is a non-renewable resource. In N.S.W., a vast amount of coal resource is located under major public utilities such as freeways, railways, stored waters, pipelines carrying gas, water and sewage, and transmission lines. Total extraction has occurred under freeways, transmission lines and pipelines with little or no damage. Where damage has resulted, the cost of restoration was only a small fraction of the value of the coal recovered. However, coal at present is being sterilised and perhaps lost for ever under stored waters and railways. If engineering solutions are available for mining under these improvements economically and with maximum safety, then coal should be extracted and utilised to the benefit of the State.

INTRODUCTION

The symposium is being held to address the issue of ground control in coal mines and the authors of this paper see control exercised over the surface being as important as the need to exercise control during the development and extraction phases underground.

The principal areas of coal extraction in N.S.W. lie within or close to the areas of major urban development and the extension of extraction areas will in a number of cases intrude into areas under existing or future urban development. Associated with urban expansion is the need to provide services such as water, sewage, electricity and natural gas reticulation, roads and railways, schools and hospitals and areas for public recreation.

Responsibility for the planning, construction, operation and maintenance of these many and varied services lies within the sphere of many organisations, including state and local government as well as state government instrumentalities.

The topography of that part of the State below which lies a substantial portion of the underground coal resource can be described as rugged, consisting mainly of bedded sedimentary strata rising to 400m above sea level and incised by steep sided valleys. This makes construction more expensive and adds to the difficulty of selecting preferred routes which will result in less interference to alternative land uses such as coal mining.

Leaving coal in protective pillars under surface improvements not only causes the permanent loss of the resource but also causes the disruption resulting from barriers, which place restrictions on optimal extraction practices. These restrictions include limiting the lengths of longwall panels and increasing development as a percentage of extraction.

In addition, alterations to mine planning and layout and modifications to transport and ventilation arrangements may also be required. Loss of reserves and consequent reduction in mine life may have implications for overall profitability and return on capital investment.

It is accepted that certain improvements be excluded from any potential risk due to underground extraction because of unacceptable damage in terms of economic and social costs. Dam walls, power stations, major water and sewage treatment works, tunnels and bridges crossing deep gorges or in unstable ground conditions may have to be protected until such time when safe engineering solutions are found to ensure their stability and serviceability when undermined.

The authors are of the opinion that areas at present considered inaccucrant to higher levels of resource recovery should be reconsidered for higher extraction levels through...
the application of well-developed design principles and assessed accordingly. Empirical methods are available for predicting subsidence in the two major coalfields of N.S.W. (Holla, 1985 and 1986). Considerable expenditure is currently being incurred by the Department of Mineral Resources in setting up a data base of subsidence survey results which will be used for expanding and improving the empirical prediction techniques. The behaviour of subsurface strata when undermined is being examined by measuring displacements of anchors placed in boreholes.

Having built up and tested our prediction capabilities, the maximum benefit can only be achieved by applying them to providing solutions to improve extraction levels above those being achieved at present. To pretend that the desirable state can be achieved at no cost would be irresponsible. The purpose of this paper is to show that a case exists for the coal to be mined rather than potentially sterilized and that the net benefit from recovery far exceeds the maintenance cost incurred for ensuring the continued viability of the improvement.

TYING UP RESERVES

Ribbon development spreads the benefits of civilisation like an ever-expanding web across the countryside. If the sub-surface has little value except as a support for the surface, eg as a reservoir for liquids whose removal will leave little recognizable change, no conflicts exist. Change this state of equilibrium by underground mining and the surface strains are minimal when compared to the sociological ones. The authors wish to demonstrate how humrous and equilibrium can exist alongside mining in the subsidence mode.

Table 1 gives the amount of coal sterilised by a surface barrier 20m wide providing protection against subsidence for three depths of cover. The calculations are made for one km length using a 35 degree angle of draw, a working seam thickness of 2m and a coal recovery of 60 per cent.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>In-situ Recoverable</th>
<th>Revenue potential reserves</th>
<th>$45/t (S$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200m</td>
<td>0.790mt</td>
<td>0.468mt</td>
<td>$21.06</td>
</tr>
<tr>
<td>400m</td>
<td>1.256mt</td>
<td>0.905mt</td>
<td>$40.73</td>
</tr>
<tr>
<td>600m</td>
<td>2.236mt</td>
<td>1.342mt</td>
<td>$60.04</td>
</tr>
</tbody>
</table>

The figures in Table 1 show how a relatively small area of surface impacts economically on the coal lying beneath it and how the problem is exacerbated by increasing depth of the resource. We must ask ourselves the question: can we afford to allow such a valuable asset to be jeopardised by uncontrolled surface development and where surface development is unavoidable how can we minimise the degree of sterilisation likely to occur.

The authors are of the opinion that sound engineering practice through the application of knowledge gained locally and from overseas sources should be utilised for minimising the degree of sterilisation. The science of subsidence engineering should be expected to increase its sophistication to allow extraction to be undertaken under ever increasing less favourable conditions in the future.

ACCEPTABLE STANDARDS OF DAMAGE

NEW UTILITIES

Mining by underground methods always causes surface disturbance but surface disturbance does not necessarily lead to surface damage. Damage, if it occurs, may take different forms depending upon the level of disturbance, the type of surface installation and whether or not it is designed to withstand movement. Building of new public utilities within the proclaimed subsidence districts is controlled by the Mine Subsidence Board and generally utilities are designed for future subsidence. However, when the cost penalty involved is high and there are no definite plans for mining within the foreseeable future (within the life of the proposed installation), then cost of designing for subsidence may not be justified. In areas outside the proclaimed districts, there is no obligation for the state instrumentalties and departments to design their utilities for subsidence. However, the Department of Mineral Resources strongly recommends that utilities, when proposed over coal measures of economic potential which are likely to be exploited in the foreseeable future, be designed for subsidence. New public utilities which are designed for subsidence do not sterilise coal, and damage, if any, when they are undermined, is insignificant and acceptable.

EXISTING UTILITIES

The problem of subsidence damage is real in cases of mining under utilities which are not designed for subsidence. Objective standards of acceptable damage are difficult to set, as some components of the cost of damage are indirect and/or intangible. In theory, damage is justified if after considering the value of the coal recovered and the economic cost of damage, there is a net economic benefit to the community. However, damage may not be acceptable by the community if it results in temporary suspension or reduction.

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in the level of service. In other words, continued satisfactory operation of communication installations (roads and railways) and utility mains (water, sewage and gas pipelines and transmission lines) during mining is a matter of public interest, and therefore has to be ensured. If reliable engineering solutions do not exist for ensuring the continued serviceability expected of a utility during mining, then it has to be protected against mining damage.

In summing up, damage may be considered as acceptable if serviceability of a utility can be ensured by a programme of repair and maintenance during mining, and unacceptable if it is not possible to ensure its serviceability. If this principle of "acceptable damage" is accepted, then it would not matter if a railway line was subsided by "metres" over a period of time, as long as its safety and efficiency of operation and its trafficability were maintained during that period by rebalasting and other appropriate measures.

MEANS OF ACHIEVING ACCEPTABLE DAMAGE

There are a few cases of mining operations under major public utilities successfully carried out in N.S.W. There are two stages involved in achieving successful results.

1. Recognition of each others obligations and duties. The affected parties must recognise that it is in the best interest of the community to co-operate to ensure that serviceability of public utilities is maintained during mining and that the coal resource is not sterilised by the presence of a utility.

2. Establishment of consultative mechanism. It is required to reach an agreement which includes procedures of consultation, monitoring and surveillance. The main objective of the agreement is to ensure that each is aware of the locations and working patterns of the other. The methods of monitoring ground movement, assessing effects on structures and developing any precautionary measures are included in the agreement.

The utilities underground in N.S.W. include freeways, natural gas pipelines and transmission line towers. Mining under railways is limited and coal recovery is poor. The limited local experience and extensive overseas experience indicate that problems caused by mining can be overcome by the application of sound engineering principles and practices, and that sterilisation of coal to protect public utilities can be avoided in the majority of cases.

NATURAL GAS PIPELINES

Long-distance pipelines carrying natural gas under pressures up to 6MPa have been subsided without any damage. The pipelines of diameters ranging up to 800m were of welded steel construction with yield strength of 450MPa. The wall thickness varied between 5.3mm and 12.8mm depending on the internal pressure. The pipes were provided with thick bitumen wrapping on the outside which reduced the interface friction with the soil. Because of relatively larger diameters which provide high axial resistance and lower friction provided by the lubricating effect of bitumen wrapping, the long-distance pipelines have less potential for damage compared with pipes in a reticulation system within towns.

The procedure for mining under natural gas pipelines generally involves the following stages.

1. When there is a proposal to mine under a pipeline, subsidence prediction is provided to the Australian Gas Light Co. (AGL) for undertaking a theoretical stress analysis in the pipe. Appropriate precautionary measures are taken in case the calculated stresses are above the allowable limit. If stresses are excessive, partial extraction layouts may have to be designed.

2. During mining, subsidence surveying is undertaken and data is provided to the AGL for revised analysis.

3. AGL also undertakes certain field measurement of pipe strain to verify the design assumptions.

There is a good understanding and cooperation between the Department and AGL, and the Department keeps the AGL informed of all mining proposals affecting the pipelines.

Three cases of mining recently undertaken under high pressure natural gas pipelines are given below.

1. Longwall mining - pipe diameter 864mm, depth of cover 500m, maximum subsidence 700mm.

2. Pillar extraction - pipe diameter 508mm, depth of cover 180m, maximum subsidence 200mm.

3. Longwall mining - pipe diameter 508mm, depth of cover 440m, maximum subsidence...
245mm.

Valuable information is being gathered by the Department and AGL from these cases which will be used to increase the level of confidence in dealing with mining-affected pipelines in the future.

FREeways

Subsidence due to future mining operations is taken into consideration when designing all new major roads including freeways in coal bearing areas. The subsidence damage depends upon the type of road surface and is minimal if it is of bitumen construction. Major arterial roads are not subsided below the level of a one in one hundred year flood level. Subsidence may affect the local road drainage. Permanent grade reversals in some cases may make cross drainage structures redundant and some reconstruction of drainage system may become necessary.

As far as possible all new bridge structures in coal bearing areas are designed for subsidence. Where movements are severe, designing major bridges may become impracticable and in such cases measures are incorporated in the design to facilitate preventative or corrective maintenance works being carried out at the time of mining. These measures include:

1. provision for the temporary removal of deck joints as the subsidence wave approaches the bridge, and
2. provision of numerous jacking points for future re-leveling.

Mining has occurred under roads including freeways which were not designed for subsidence. The Southern T流出 (96) extending from Helensburgh to Mount Ousley was undermined within the Coalcliff Colliery during the period between December 1976 and August 1978. The undermined section of the tollway was in a relatively deep cutting and the pavement was constructed using blast furnace slag. The depth to the Bulli Seam was around 470m and the extracted seam thickness was 2.8m. The extraction was by the Wongawilli System with coal recovery as high as 90 per cent. The ground movements experienced by the tollway are given below.

Maximum subsidence = 1.6m
Maximum compressive strain = 2.8mm/m.
Maximum tensile strain = 2.5mm/m.

The changes in the vertical alignment were gradual and travel comfort and safety was not affected by subsidence. The most obvious effects of subsidence are listed below:

1. damage to kerb and guttering involving distortion and fracture,
2. formation of a 50mm step in the surface oriented at an angle to the centreline of the carriageway,
3. damage to a culvert which crossed the tollway near the point of maximum subsidence, and
4. longitudinal and transverse cracking in the road surface.

Repairs were carried out and the trafficability was maintained throughout the mining operation.

The experience gained from undermining the tollway and other sealed roads supports the generally held view that mining under cover depths of say, 400m or more, is unlikely to cause severe damage to the road surface. In the Southern Coalseat the cover depth to the most extensively mined Bulli Seam is more than 400m in most of the collieries and the maximum ground strains resulting from longwall extraction systems with chain pillars are unlikely to exceed 4mm/m. Under these conditions mining under freeways and other sealed roads should not cause unacceptable damage or disruption to traffic.

When cover depth is shallow, subsidence may be severe when the extraction is total. For example, in the Newcastle Coalfield where the cover depth in some collieries is between 100m and 200m, total extraction of one seam of say 2.5m thickness may cause ground strains of 6mm/m to 10mm/m. Significant cracking of the pavement is possible in such cases and if safe traffic conditions cannot be established, extraction may have to be designed to limit surface subsidence. However, experience indicates that travel comfort and safety can be maintained even in such cases by suitable maintenance programmes. In one such instance, total extraction was carried out under a main highway and the depth of extraction was around 120m. The road surface suffered major cracking but temporary repairs ensured traffic safety throughout the mining operation. The cost of repairs was estimated to be only a small fraction of the value of the coal recovered.

RAILWAYS

N.S.W. PRACTICE

Historically, railways were protected from undermining by leaving a protective pillar of width equal to the railway reserve width plus 1.4 times the cover depth, based on 35 degree draw angle. The reserve width varied from site to site and in some cases it was as wide as...
200m. Within this protective pillar, only driving of isolated headings was allowed by the State Rail Authority (SRA) of N.S.W.

In recent times, the SRA has allowed one case of partial extraction and one case of bord and pillar mining within the safety pillar. In both cases mining is yet to occur. The SRA permitted bord and pillar mining only after the concerned mining company undertook mathematical modelling incorporating finite element and displacement continuity techniques and proved that pillar deformation was less than 0.01m (Holt, et al. 1984). In the partial extraction case, the maximum subsidence was limited to 50mm. In both cases mining layouts were designed to limit movement to a level acceptable to the SRA.

The current practice of mining in N.S.W. can be summarised as below.

1. The tracks are to be protected by a safety pillar of width based on an angle of draw determined on the basis of information collected within the collieries.

2. Mining within the safety pillar is to be designed to limit subsidence to a level acceptable to the SRA so that no special maintenance or repairs need to be undertaken. This practice inevitably leads to layouts with poor coal recovery.

3. The acceptable subsidence is related to mining geometries on the basis of subsidence data available within the collieries. If no evidence is available, then mining may not be allowed.

The philosophy of "acceptable movement" within the safety pillar is perhaps based on the concept that safe operation of railways and mining under railways by total extraction methods are mutually exclusive. If this philosophy is to be held sacrosanct, then coal recovery from underneath railways cannot be further improved in the future, and millions of tonnes of coal reserves will have to be sterilised.

In Europe and Britain, railways have been undermined by longwall panels and rail operation was maintained during mining by appropriate surveillance and maintenance programmes (Personal communications, Wilson, 1986; Arcamone, 1985). The argument that the local geology is different, is irrelevant and invalid because irrespective of what the geology is, the fact remains that the tracks are lowered by "metres" in overseas countries as against "millimetres" in N.S.W. If anything, the overburden strata in N.S.W. is much more competent than that in Britain and the maximum subsidence in N.S.W. is only about 70 per cent of that in Britain. However, the more competent strata may pose problems of brittle failure which have to be examined in individual cases.

OVERSEAS PRACTICE

The mining practice under railways in Britain is briefly described below (Personal Communication, Wilson, 1986).

1. Many hundreds of cases of subsidence affecting railways were recorded by the British Railways Board (BRB) in the last century and during this century. Currently, the BRB is considering the impact of about 200 mining panels on the railways. The width of panels would normally lie between 100m and 300m, the usual width being in the region of 200m. The average length of panels would be 1200m.

2. The depth of workings varies between 150m and 1100m and the thickness of seams varies from 1m to 3.5m.

3. Normally, mining layouts in the vicinity of a railway will be designed to maximise coal recovery. BRB does not normally seek to change the layout recognising that changes are unnecessary and would not be feasible from the mining point of view in most cases.

4. At any one time the maximum subsidence that is experienced, allowing the railway to continue in operation, would be around 2.5m. Subsidence could be up to 500mm/month.

5. The introduction of continuously welded track as the standard track in the 1970s has not changed the attitude of the BRB with regard to mining under railways.

6. The National Coal Board (NCB) pays the BRB the agreed contribution towards the cost of repairing the damage. BRB compensates the NCB if a railway line has to be protected by coal sterilisation. As a general rule, the BRB tries to avoid the "purchase of support", and for various reasons prefers the coal to be worked.

RELEVANCE OF BRITISH PRACTICE TO N.S.W.

Improved coal recovery from underneath railways in Britain is made possible through...
agreements between the NCB and BBB, recognising the following principles.

1. The coal extraction from underneath railways is treated as a general rule with a few exceptions when there is a need for protection (Whereas in N.S.W. the reverse situation exists).

2. BBB recognises that maintaining a track subject to "metres" of subsidence is an engineering problem for which civil engineers have developed satisfactory solutions (Whereas in N.S.W. subsiding tracks by "metres" is unacceptable and therefore to be avoided).

3. BBB does not generally want to "purchase the support" for their lines (Whereas in N.S.W. support comes free as the SIA does not have to pay compensation for the sterilised coal).

Unless there are fundamental changes in our current thinking that railways are sacrosanct, improved coal recovery from underneath railways will not be achieved. There is vast amount of experience and knowledge accumulated over long periods of time in Britain and Europe which appear to be sufficient to change our thinking. Whether or not the coal recovery from underneath railways in the future would improve in N.S.W. depends upon our willingness to accept change.

TRANSMISSION TOWERS

EXISTING TOWERS

Transmission towers are flexible and therefore can withstand a considerable degree of ground movement. In Britain, towers are undermined without any adverse effects (Personal communication, Cliffe, 1984). The general view in Britain appears to be that towers need not be designed for subsidence and even though they may tilt when the mining face approaches, they revert back to their original position after the completion of mining.

An experimental study undertaken in South Africa demonstrates the ability of transmission towers to undergo deformation without damage (Schumann, 1984). Four experimental 400kV towers were undermined by 212m wide longwall panels at a depth of 121m. The thickness of extraction was 2.9m. The towers underwent the following movements without experiencing structural damage.

- Maximum subsidence = 1.3m
- Maximum tilt = 35mm/m

Maximum tensile strain = 8mm/m
Maximum compressive strain = 7mm/m

Only one out of sixteen footings showed hair line cracks in the concrete collar.

There are a few recorded cases of mining under towers in N.S.W. of which two are mentioned below.

1. Wongawilli System of mining: depth of cover = 470m; Maximum subsidence = 1.6m; Maximum strain = 3mm/m.

2. Pillar extraction: depth of cover = 260m, Maximum subsidence = 0.25m.

Limited local experience appears to indicate that mining under cover depths in excess of 200m would not cause any structural damage. When the cover is shallow, a detailed subsidence study may have to be undertaken to assess effects of any permanent tilt. When covers are shallower than 100m, partial extraction may be the solution to limit surface subsidence.

Eventhough it is premature to conclude that standard design towers can withstand subsidence in all cases, especially under very shallow cover depths, the evidence to date reinforces the belief that designing the towers for full subsidence is conservative, unnecessary and uneconomic.

NEW TOWERS

In N.S.W., there is no systematic study undertaken to understand the behaviour of towers which were undermined in the past. Lack of knowledge has perhaps led to the belief that towers will have to be designed for subsidence to ensure structural integrity. The average cost of a tower foundation designed for subsidence in a recent case was of the order of $40,000 each, compared with $6,000 each for a standard design foundation. When transmission lines traverse coal bearing areas in which coal extraction is unlikely to occur in the foreseeable future, then designing the towers for subsidence involves incurring expenditure at present. This expenditure may not be justifiable when resources are scarce and may be unnecessary, if the towers are not undermined during the life of the lines. The following interim compromise solution was, therefore, evolved in the case of transmission line towers proposed to be erected within proclaimed mine subsidence districts.

1. Towers which are likely to be mined within the next 5 years because of the fact that there are firm mining plans to mine at this stage, are designed for subsidence.
2. The remaining towers are built with standard foundations but which are capable of being strengthened if and when mining occurs in the future.

In this way, incurring expenditure at present for providing heavy foundations which may or may not be required in the future is avoided. At the same time coal will not be sterilised in the future as the towers are strengthened for subsidence.

OTHER UTILITIES

Major public buildings such as hospitals and schools are designed for subsidence if such structures are likely to be undermined in the foreseeable future.

Mining under and in the vicinity of dams and their storages is controlled by the Dams Safety Committee.

A water supply system being a pressure system is independent of grades. Water mains in the mine subsidence areas are generally provided with flexible rubber joints. The design also provides for isolation of sections of the reticulation grid. Where possible, trunk mains in tidal lake areas are located where the ground surface is at RL 2.4m or below, since these areas are undermined by partial extraction systems. Treatment works and service reservoirs are protected, if it considered that disruptions to the service are of major concern.

A sewerage system, being a gravity system, is sensitive to subsidence induced grades. Reversal of pipe grades presents problems for smooth flow. No rational basis can be seen for steepening sewers to accommodate subsidence effects, especially when future mining details are not known. The current practice is to design and construct systems without considering subsidence induced grades and to accept that some sewers in the future may have to be relaid. Sewers are, however, designed to accommodate horizontal strains.

SUMMARY

Mining by underground methods to extract coal causes surface subsidence but subsidence need not always cause damage to public utilities. In many cases damage may be acceptable if it does not adversely affect the serviceability of a utility. It is not the intention of the authors to advocate mining under all circumstances but to emphasise the need for maximising coal recovery consistent with the safe operation of public utilities.

In N.S.W., mining on a total extraction basis has occurred under freeways, natural gas pipelines and transmission line towers with no or acceptable damage. However, recovery from underneath railways is poor. With the guidance of extensive overseas experience on mining under railways, improved coal recovery is possible, provided there is a willingness to solve the problem in a professional manner.

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