THE UNIVERSITY OF
NEW SOUTH WALES

STRATA CONTROL FOR COAL MINE DESIGN

SCHOOL OF MINES
THE UNIVERSITY OF NEW SOUTH WALES

END OF PROJECT REPORT - DECEMBER 1996

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Research Report RP 2/96

FOREWORD

From a career background of management of underground coal mines, which included a long association with continuous miners and involvement with the first mechanised longwall units in Australia, seven years as an Inspector of Collieries and a period as a Member of the Joint Coal Board, I was only too well aware of accidents and injuries arising from roof control problems. These involved development roadways, the mechanics of various pillar and panel extraction methods and the differences, too often not understood, between working deep seams as distinct from shallow seams. Progression from open-ended lifting to the Wongawilli and Old Ben Systems of extraction certainly reduced accident statistics but did not provide all the answers about good mining design and strata control which the industry needed.

The decision of the Joint Coal Board in 1991 to fund the project on Strata Control for Coal Mine Design was very timely and appealed to me as a move of the greatest importance. It was with pride and keen anticipation that I welcomed the role of Chairman of the Consultative Committee, consisting of representatives of the operational and regulatory sections of the industry, to oversee the progress of the project.

The project was completed in 1996 and details of the work done and conclusions reached are outlined herein by Professor Jim Galvin, the project leader.

The Consultative Committee was very pleased with the progress and results attained and is mainly concerned that the results should be embodied in future instructional courses and workshop studies for the industry.

I congratulate the Joint Coal Board for its initiative and the project team for its enthusiasm and contribution.

M J SMITH
Chairman
Consultative Committee

EXECUTIVE SUMMARY

In the ten years to 1992, falls of roof and rib caused the death of 30 coal miners in New South Wales, Of these, 8 occurred in pillar extraction operations over a 24 month period to 1991. In addition, it was known in 1992 that at least six extensive unplanned collapses of bord and pillar workings had occurred in New South Wales in collieries in recent years.

Against this field record, the New South Wales coal industry's insurers, namely the Joint Coal Board, decided in late 1991 to invest $1.62m over a five year period to improve the strata control knowledge base relating to underground coal mining. The Strata Control for Coal Mine Design Project (SCCMD) was established for this purpose within the School of Mines at the University of New South Wales in 1991.

The prime objective of the project was to improve the understanding of the behaviour of coal pillars and associated roof and floor strata under various loading conditions and to then enhance the engineering base for the design of bord and pillar workings and later longwall workings.

The project aimed to develop practical design principles and to transfer the technology incorporated in them to colliery management and personnel. Given the practical aims of the project, a high emphasis was placed on seeking the active support and participation of the coal industry. A research team comprising a mix of both national and international expertise and of academic and industry experience and expertise was assembled for the project. The project, in turn, was overviewed by an Industry Consultative Committee. The field data collection phases of the project revealed that the need for practical mine design principles was much greater than originally envisaged.

The extent of the problem was able to be gauged more accurately than previously due to:

- access to reports of Inspectors of Coal Mines held by the Department of Mineral Resources
- collation and integration of the information contained in these reports on a state-wide basis rather than a traditional coalfields district basis
- Confidentiality Agreements with mine operators.

Some of the more surprising findings from the data collection process were:

- in the three year period to 1992, 60 continuous miners had been trapped by falls of strata for more than seven hours in New South Wales collieries
- the falls extended back to the driver's cab in over 50% of the cases
- in the last 15 years at least 15 panels of bord and pillar workings had unexpectantly collapsed in New South Wales and Queensland collieries. Six of these collapses occurred in working panels, fortuitously five of which occurred during shut-down periods and the sixth whilst the continuous miner was being flitted to the surface for repairs.

The SCCMD Project has resulted in the strata control knowledge base being developed and advanced in four principal areas, namely:

- **Yield Pillar Mechanics:** An advanced model has been developed which quantitatively describes the behaviour of coal pillars in yield. Whilst the model requires further development and refinement, it already gives significant insight into rib behaviour, fender design and behaviour in pillar extraction, controlled v. uncontrolled pillar collapse and pressure outbursts.

- **Pillar Design Principles and Practice:** A field performance survey revealed 18 cases of unplanned pillar collapses in which mining dimensions and pillar load could be quantified reasonably accurately. This data was subjected to rigorous statistical analysis to produce empirical formulae for calculating pillar strength.

  This aspect of the research has been consolidated and published as the UNSW Pillar Design Procedure. It is a valuable design tool as evidenced by the fact that its application would have predicted all 15 known cases of regional collapse of Australian bord and pillar workings in the last 15 years. An Operator's Manual on Pillar Behaviour and Design Principles has been produced to underpin the procedure.

- **Pillar Extraction Principles and Practice:** Department of Mineral Resources investigation reports relating to all 15 fatal pillar extraction accidents in New South Wales in the ten years to 1992 and 44 of the 60 incidents of buried continuous miners in the 3 years to 1992 were reviewed in detail.

  Taken globally, the reports revealed that a number of factors associated with the mishaps had a surprisingly high frequency. For example, 66% of incidents occurred when taking the first or last lift off a pillar, whilst 50% of persons fatally injured were standing in intersections and were not actively involved with pillar extraction operations at the time.

  With the benefit of the hindsight gained from the global review of all these accidents, it became apparent that the investigations and proposed remedial measures at the time of the accidents were highly focused on active rather than latent causes of failure. Active failures are those typically associated with failing to work to stipulated plans and dimensions. Latent failures, on the other hand, are the hidden drivers behind the mishap and commonly relate to inappropriate stipulated plans of work. An Operator's Manual on Pillar Extraction Design and Practices has been produced to address these issues and to improve the knowledge base of industry operators.

- **Roof Bolting Principles and Practice:** From the numerous site visits made by the research team and the investigations into some mishaps it became apparent that there was a poor understanding in some sectors of the industry of the basic mechanics of roof bolting. This lack of understanding had a significant impact on some of the mishaps investigated. Therefore, a training module on roof bolting mechanics has been produced and integrated into those modules on pillar design and pillar extraction.

Technology transfer has been one of the distinguishing elements of the SCCMD project. It has occurred at all levels from face worker through to superintendent and from undergraduate student through to consultant. Technology transfer initiatives include:

- newsletters comprising 24 000 copies
- teaching modules relating to pillar design, pillar extraction and roof bolting principles
- 1100 person days of training to industry encompassing 11 workshops
- conference presentations
- reports and publications.

The most important measure of the effectiveness of the SCCMD research lies in its impact in improving safety in the underground coal mining industry. Whilst this cannot be quantified categorically, it is significant that there has been no fatal accident in pillar extraction in New South Wales in the last five years. Incidents of buried continuous miners have dropped from 20 per year to 3-4 per year. The advances in the strata control knowledge base and the effectiveness of the initiatives to transfer this knowledge base to the working face are considered major contributors to this improved safety performance.

The project concluded officially in March 1996, however, much of the research will be ongoing in the form of extended or new projects arising from the improved strata control knowledge base developed out the original project. The project has resulted in a new Chair of Mining Engineering and a new Chair of Rock Mechanics being established in the Department of Mining Engineering. Eleven new research projects have developed out of the SCCMD research. The majority of research outcomes are now being integrated into the course work of undergraduate and postgraduate mining engineers at UNSW to improve the industry's knowledge base for the future

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1.0 INTRODUCTION

The Strata Control for Coal Mine Design Project (SCCMD) was initiated in late 1991 under the title of Strata Control for Risk Assessment and Prediction. The project was funded by the Joint Coal Board and planned to run for three years. Changed staffing arrangements associated with the restructuring of the Joint Coal Board and recruiting appropriate staff to the University of New South Wales (UNSW) resulted in the project being rescheduled to run over a five year period but, nevertheless, still within original budget constraints.

The Project concluded officially in March 1996, however, much of the research will be on-going in the form of extended or new projects arising from the improved strata control knowledge base developed out of the original project. In undertaking the research, a high emphasis has been placed on the progressive reporting of research outcomes to industry and, in particular, on technology transfer to both mine sites and to undergraduate students. Hence, project outcomes are already well documented and reported. The principle objective of this End of Project Report, therefore, is to place on record the history, methodology and outcomes of the SCCMD Project as a point of reference for accessing these research outcomes and for planning future research.

2.0 OBJECTIVES OF THE SCCMD RESEARCH PROGRAM

Uncontrolled collapses of strata, usually in conjunction with pillar workings, have been a major hazard of underground coal mining. In the ten years to 1992, falls or roof and rib have caused the death of 30 coal miners in New South Wales. Of these, 8 occurred in pillar extraction operations over a 24 month period to 1991. In addition, it was thought in 1991 that at least six extensive unplanned collapses of bord and pillar workings had occurred in New South Wales in collieries in recent years.

Against this field record, the New South Wales coal industry's insurers, namely the Joint Coal Board, decided to invest $1.62m over a three year period to improve the strata control knowledge base relating to underground coal mining. The Strata Control Risk Assessment and Prediction Project, later to be known as the Strata Control for Coal Mine Design Project, was established within the School of Mines at the University of New South Wales in 1991.

The prime objective of the project was to improve the understanding of the behaviour of coal pillars and associated roof and floor strata under various loading conditions and to then enhance the engineering base for the design of bord and pillar workings and later longwall workings.

The project aimed to develop practical design principles and to transfer the technology incorporated in them to colliery management and personnel. The plan was to effect this technology transfer through face to face contacts in the form of small and industry-wide workshops, seminars and written reports. Given the practical aims of the project, a high emphasis was placed on seeking the active support and participation of the coal industry.

3.0 METHODOLOGY

At the time of the project's formation, recent local incidents had revealed the need to improve the theoretical mine design knowledge base and adaptation of it to the local geological environment and to raise the standard of knowledge of key operators in the field.

The following project structure was devised, therefore, to address classical engineering materials behaviour, field performance and technology transfer to the industry.

1. **Review and Update the World-Wide State of Art on Pillar Mining**

   The development of design guidelines for bord and pillar workings required a critical review and further development of the understanding of the mechanics which come into play during the formation and extraction of pillars. Considerable attention was to be devoted to the clarification of the behaviour of fully or partially yielding pillars. Virtually no sound knowledge base appeared to be available with regard to this aspect of pillar mining.

2. **Collect Field Performance Data of New South Wales Coal Mines**

   Application of design theory required consideration be given to the structural properties (geological and geotechnical) and past performance of the field materials.

3. **Analysis and Back Calculation of New South Wales Mine Data**

   Back analysis of both successful and unsuccessful field experiences was planned to enable local ground conditions and mechanisms to be identified and to highlight problem areas requiring further research.

4. **Develop and Validate Design Methodologies and Procedures**

   This task aimed to transform the research results into a design methodology. Mine planning criteria and procedures were proposed to be developed and validated to enable personnel to optimise layout with regards to safety and efficiency.

5. **Training and Instruction for Implementation of Research Results into Engineering Practice**

   Formal training was to be provided to industry personnel to ensure research results were implemented into engineering practice.

In turn, each of these tasks was broken down into sub-tasks, Table 1. This table summaries the entire planned research program. A flow sheet showing how the various elements of the research program were to be integrated is shown in Figure 1.

Table 1. SCCMD Research Program

TASK DESCRIPTIONS

TASK 1	**REVIEW AND UPDATE CURRENT WORLDWIDE KNOWLEDGE BASE**
Sub Task 1a	Pillar Strength and Stability Prepare a detailed document on the state of the art concerning coal pillar strength and stability.
Sub Task 1b	Bord & Pillar and Chain Pillar Design Review and document current bord and pillar and longwall chain pillar design methodology and procedures for coal mines worldwide.
Sub Task 1c	Strata Deformation and Caving Mechanisms Prepare a detailed document on the state of the art concerning load transfer and subsidence in coal mine strata and the mechanisms of caving behaviour for pillar extraction and longwall systems.
Sub Task 1d	Pillar Extraction Design Review and document current pillar extraction design methodology and procedures for coal mines worldwide.
Sub Task 1e	Regional Mine Stability Prepare a detailed document on the state of the art concerning regional coal mine stability, panel layout and barrier pillar systems.
TASK 2	**COLLATE FIELD PERFORMANCE DATA OF NSW COAL MINES**
Sub Task 2a	Initial Field Data Collection of NSW Coal Mines Collect field data of NSW coal mines, documenting case histories representing both successful and unsuccessful layouts for a) bord and pillar and b) pillar extraction methods of working. Data collected will document mining method, mine plans, geological data on coal, roof and floor, geological structure and anomalies, impact of old workings, subsidence, accidents or "near misses", support methods, caving behaviour and incidents of hang-ups.

Table 1 (ctd)

Sub Task 2b	<u>Additional Data Collection and Review of NSW Bord and Pillar Practise.</u> Collect more detailed data on particular NSW coal mines relating to bord and pillar design practise, in particular unsuccessful designs in a variety of geological and loading conditions. Review available data on these cases and where possible obtain additional observation data either in the immediate area or a similar location at the particular mine site.
Sub Task 2c	<u>Additional Data Collection and Review of NSW Pillar Extraction Practise</u> Collect more detailed data on particular NSW coal mines relating to pillar extraction practise, in particular unsuccessful design in a variety of geological and loading conditions. Review available data on these cases and where possible obtain additional observation data either in the immediate area or a similar location at the particular mine site. Interview mining personnel experienced in pillar extraction and document their experience relating to both successful and unsuccessful design in various NSW geological environments.
Sub Task 2d	<u>Review NSW Coal Mine Accident Data</u> Prepare a report of all relevant data on NSW coal mine accidents involving pillar failure, roof collapse, gas outbursts or windblasts from large falls.
Sub Task 2e	<u>Feedback Reports to Mines Visited.</u> Provide feedback reports to mines visited, when project personnel believe useful data or recommendations would be of assistance to the mine.
TASK 3	**ANALYSIS AND BACK-CALCULATION OF NSW MINE DATA**
Sub Task 3a	<u>Identify and Quantify Relevant Rock Mechanics Mechanisms for Bord and Pillar</u> Identify rock mechanics mechanisms pertinent to analysis and back-calculation of NSW coal mine data collected in Task 2 for bord and pillar workings. Enhance, or develop if necessary, and document procedures for quantification of pertinent rock mechanics mechanisms in the various geological and loading environments.
Sub Task 3b	<u>Analysis and Back-Calculation - Bord and Pillar</u>

Table 1 (ctd)

	Analyse and conduct back-calculations of both successful and unsuccessful layouts of the NSW coal mine data for bord and pillar workings. Determine strength data and loading conditions for the various sites and attempt to correlate data and methodologies in similar geological settings. Detail limitations in the available data and deficiencies in procedures to analyse pertinent mechanisms.
Sub Task 3c	Identify and Quantify Relevant Rock Mechanics Mechanisms for Pillar Extraction Identify rock mechanics mechanisms pertinent to analysis and back-calculation of NSW coal mine data collected in Task 2 for pillar extraction workings. Develop and document procedures for quantification of pertinent rock mechanics mechanisms in the various geological, loading and extraction sequencing environments.
Sub Task 3d	Analysis and Back-Calculation - Pillar Extraction Analyse and conduct back-calculations of both successful and unsuccessful layouts of the NSW coal mine data for pillar extraction. Determine strength data and loading conditions for the various sites and attempt to correlate data and methodologies in similar geological settings. Detail limitations in the available data and deficiencies in procedures to analyse pertinent mechanisms.
TASK 4	DEVELOP AND VALIDATE DESIGN METHODOLOGIES AND PROCEDURES
Sub Task 4a	Bord and Pillar Transform the research results into a design methodology. Develop and validate mine planning criteria and procedures to enable mine personnel to optimise layouts with regard to safety and mining efficiency. Develop manuals and training procedures to disseminate research results to industry. Monitor industry feedback and update/modify design methodology and procedures.
Sub Task 4b	Pillar Extraction Transform the research results into a design methodology. Develop and validate mine planning criteria and procedures to enable mine personnel to optimise layouts with regard to safety and mining efficiency. Develop manuals and training procedures to disseminate research results to industry. Monitor industry feedback and update/modify design methodology and procedures.

Table 1 (ctd)

Sub Task 4c	Subsidence Control Transform the research results into a design methodology. Develop manuals to disseminate research results to industry. Monitor industry feedback and update/modify design methodology and procedures.
Sub Task 4d	Regional Stability Transform the research results into a design methodology.. Develop manuals to disseminate research results to industry. Monitor industry feedback and update/modify design methodology and procedures.
TASK 5	TRAINING AND INSTRUCTIONS FOR IMPLEMENTATION OF RESEARCH RESULTS INTO ENGINEERING PRACTICE Provide formal training to industry personnel to ensure research results are implemented into engineering practice. Document industry comments and criticisms on design methodologies and procedures. Modify and improve design procedures to account for feedback from industry.

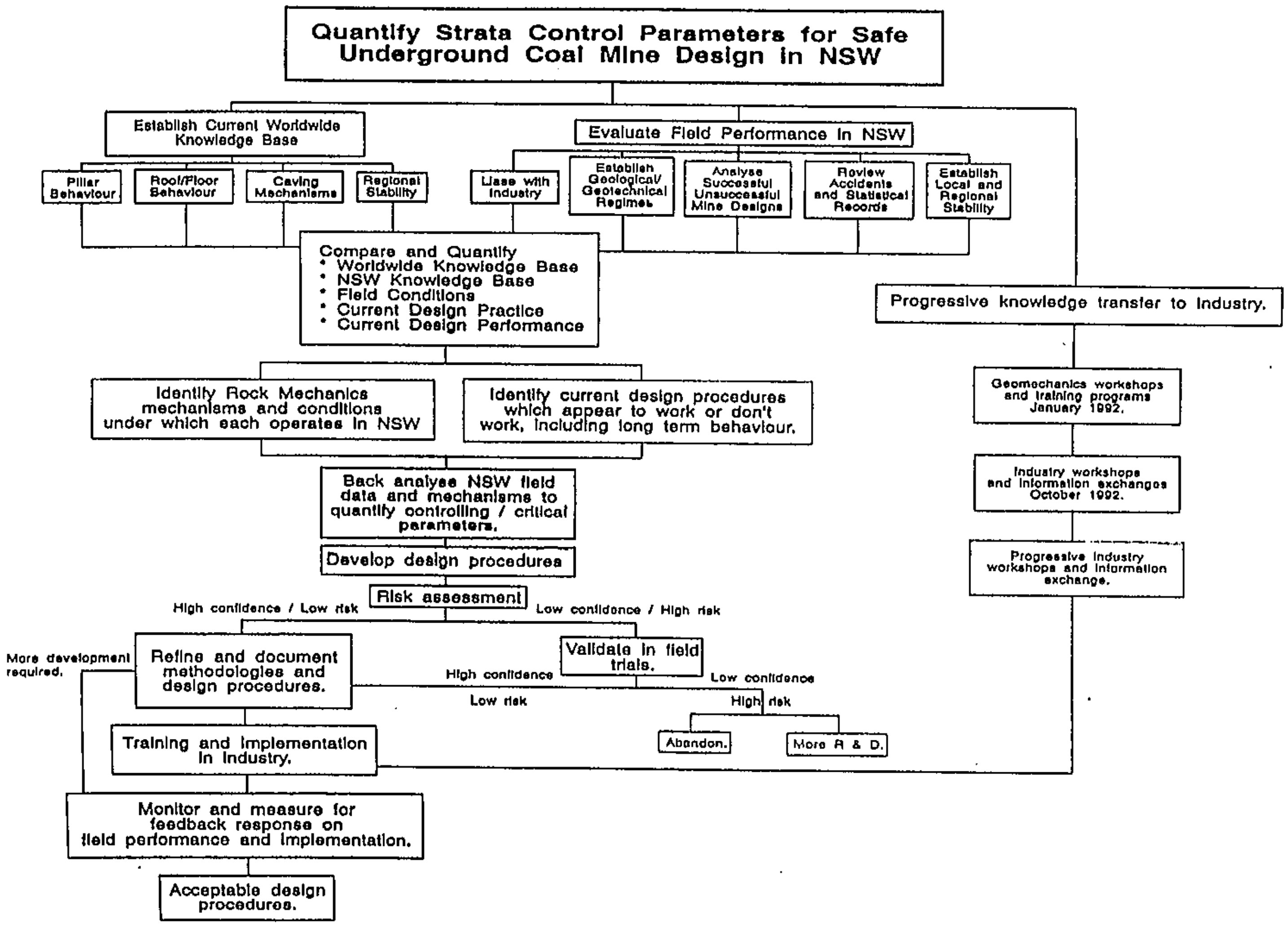

Figure 1. Flow Diagram showing the Integration of Research Elements

4.0 PROJECT TEAM

The project team was originally planned to comprise geologists employed by the Joint Coal Board and research staff employed by the University of New South Wales. Restructuring of the Joint Coal Board resulted in the loss of the services of the geologists in the early stage of the project. Subsequently, a Chair of Mining Engineering within the Department of Mining Engineering was established to lead the project.

Over the project's life the following personnel were to have part-time or full-time involvement:

Professor Jim Galvin, Professor of Mining Engineering and Project Director, UNSW
Professor Frank Roxborough, Professor of Mining Engineering, Head of the School of Mines and Management Committee Chairman, UNSW
Professor M D G Salamon, Professor of Mining Engineering, Colorado School of Mines and Visiting Professor to UNSW
Professor Grant Hocking, Professor of Engineering Geology, Department of Applied Geology, UNSW
Dr John Watson, Senior Lecturer, Department of Mining Engineering, UNSW
Dr Bernard Madden, Geotechnical Engineer, Australian Coal Industries Research Laboratories,
Dr Carlos Quinteiro, Research Scientist, UNSW
Mr Ian Anderson, Senior Inspector of Coal Mines, NSW Department of Mineral Resources
Mr Bin Lin, Professional Officer, UNSW.

A brief CV of each of these persons is contained in the attached Newsletters (Nos. 1 and/or 8). A number of significant features were associated with the project's staffing including:

- The life-long rock mechanics experiences and expertise of Professor MDG Salamon were able to be utilised to provide theoretical input into the project by means of a series of appointments as Visiting Professor to UNSW.

- Field data acquisition and transfer of research outcomes to the field was enhanced by the secondment for periods of extended time, of Mr Ian Anderson, Senior Inspector of Coal Mines.

- Joint Coal Board funding provided the opportunity to attract a person with senior industry operational and research experience to direct the project (and to later head up the Department of Mining Engineering).

An outcome of these and other features was that the research team comprised a rare mix of both national and international expertise and of industry and academic experience and expertise. These mixes were instrumental in the project achieving successful outcomes.

The project was overviewed by an Industry Consultative Committee chaired by Mr M J Smith , former General Manager of Newcastle Wallsend Coal Company Pty. Limited. The Committee comprises representatives from the NSW Coal Association, Colliery Manager's Association, the mining unions and the Inspectorate. The following persons have been members of the Consultative Committee, at various stages, throughout the project:

Mr M J Smith, Chairman
Mr A Fisher, BHP Collieries
Mr B McKensey, Chief Inspector of Coal Mines (NSW)
Associate Professor K Moelle, University of Newcastle
Mr S D Wilkinson, NSW Coal Association
Professor J Galvin, then NSW Coal Association

5.0 STAFFING

The rearrangement of staffing numbers permitted the project to be extended from 3 years to 4.5 years to achieve its planned outcomes whilst still being brought in on budget.

Table 2 summarises actual expenditure against original budgeted expenditure for the full project life.

6.0 RESEARCH OUTCOMES

6.1 Scope of the Problem

The field data collection phases of the project revealed that the need for practical mine design principles was much greater than originally envisaged.

The extent of the problem was able to be gauged more accurately than previously due to:

- Access to reports of Inspectors of Coal Mines held by the Department of Mineral Resources

- Collation and integration of the information contained in these reports on a state-wide basis rather than a traditional coalfields district basis.

- Confidentiality Agreements with mine operators

Table 2. Life of Project Actual versus Budget Expenditure

	SUMMARY	1991/92 Actual	1991/92 Budget	1991/92 Variance	1991/92 Cumulative	1992/93 Actual	1992/93 Budget	1992/93 Variance	1992/93 Cumulative
1	Project Staff	87246.61	87246.61	0.00	0.00	335173.76	387000.00	-51826.24	-51826.24
2	Consultants - Other	31280.76	31280.76	0.00	0.00	93827.86	70000.00	23827.86	23827.86
3	Computing, Lab & Office Expenses	26500.00	26500.00	0.00	0.00	52837.00	30000.00	22837.00	22837.00
4	Equipment	41124.52	41124.52	0.00	0.00	33460.77	39000.00	-5539.23	-5539.23
5	Travel and Subsistence	19856.62	19856.62	0.00	0.00	16846.50	20000.00	-3153.50	-3153.50
6	Matrls, Maint, Advert, Relocat, Misc	16244.92	16244.92	0.00	0.00	40393.15	28000.00	12393.15	12393.15
7	Technology Transfer	2517.16	2517.16	0.00	0.00	11330.59	15000.00	-3669.41	-3669.41
		224770.59	224770.59	0.00	0.00	583869.63	589000.00	-5130.37	-5130.37

	SUMMARY	1993/94 Actual	1993/94 Budget	1993/94 Variance	1993/94 Cumulative	1994/95 Actual	1994/95 Budget	1994/95 Variance	1994/95 Cumulative
1	Project Staff	240878.46	295000.00	-54121.54	-105947.78	197432.32	280000.00	-82567.68	-188515.46
2	Consultants - Other	10828.62	10000.00	828.62	24656.48	15188.91	0.00	15188.91	39845.39
3	Computing, Lab & Office Expenses	16909.87	30000.00	-13090.13	9746.87	18681.09	30000.00	-11318.91	-1572.04
4	Equipment	13932.55	10000.00	3932.55	-1606.68	7490.56	-25000.00	32490.56	30883.88
5	Travel and Subsistence	278.85	48000.00	-47721.15	-50874.65	25099.25	28000.00	-2900.75	-53775.40
6	Matrls, Maint, Advert, Relocat, Misc	5334.65	20000.00	-14665.35	-2272.20	7601.64	24899.41	-17297.77	-19569.97
7	Technology Transfer	20144.24	30000.00	-9855.76	-13525.17	65516.27	30000.00	35516.27	21991.10
		308307.24	443000.00	-134692.76	-139823.13	337010.04	367899.41	-30889.37	-170712.50

	SUMMARY	1995/96 Actual	1995/96 Budget	1995/96 Variance	1995/96 Cumulative	PROJECT LIFE Actual	PROJECT LIFE Budget	PROJECT LIFE Variance	PROJECT LIFE Cumulative
1	Project Staff	120837.52	0.00	120837.52	-67677.94	981568.67	1049246.61	-67677.94	-67677.94
2	Consultants - Other	28333.34	0.00	28333.34	68178.73	179459.49	111280.76	68178.73	68178.73
3	Computing, Lab & Office Expenses	3192.64	0.00	3192.64	1620.60	118120.60	116500.00	1620.60	1620.60
4	Equipment	-14651	0.00	-14651.00	16232.88	81357.40	65124.52	16232.88	16232.88
5	Travel and Subsistence	6000	0.00	6000.00	-47775.40	68081.22	115856.62	-47775.40	-47775.40
6	Matrls, Maint, Advert, Relocat, Misc	3700	0.00	3700.00	-15869.97	73274.36	89144.33	-15869.97	-15869.97
7	Technology Transfer	23300	0.00	23300.00	45291.10	122808.26	77517.16	45291.10	45291.10
		170712.50	0.00	170712.50	0.00	1624670.00	1624670.00	0.00	0.00

Some of the more surprising findings from the data collection process were:

- In the 3 year period to 1992, 60 continuous miners had been trapped by falls of strata for more than 7 hours in New South Wales collieries.
- The falls extended back to the driver's cab in over 50% of the cases.
- In the last 15 years at least 15 panels of bord and pillar workings had unexpectantly collapsed in New South Wales and Queensland collieries. Six of these collapses occurred in working panels, fortuitously five of which occurred during shut-down periods and the sixth whilst the continuous miner was being flitted to the surface for repairs.

A summary of facts and figures relating to buried continuous miners is given in Table 3.

6.2 Enhanced Knowledge Base

The SCCMD Project has resulted in the strata control knowledge base being developed and advanced in four principal areas, namely:

- **Yield Pillar Mechanics**: An advanced model has been developed which quantitatively describes the behaviour of coal pillars in yield. It is important to develop a better understanding of this phenomenon since it can impact on safety in many aspects of coal mining. These include:

  - rib behaviour
  - fender design and behaviour in pillar extraction
  - controlled v. uncontrolled pillar collapse
  - pressure outbursts.

  Whilst the model requires further development and refinement, it already gives significant insight into the behaviour of coal in yield.

- **Pillar Design Principles and Practice**: The field performance survey revealed 18 cases of unplanned pillar collapses in which mining dimensions and pillar load could be quantified reasonably accurately. This data, along with data associated with stable mining cases was subjected to rigorous statistical analysis to produce empirical formulae for calculating pillar strength. The two most common forms of Pillar Strength Formula, namely, the Linear and the Power Law Forms have been evaluated.

  The Pillar Strength Formulae are an important output of the SCCMD Project. This aspect of the research has been consolidated and published as a stand-alone output called the UNSW Pillar Design Procedure. The procedure is summarised in the attached Research Release No. 1.

Table 3. Pillar Extraction - Buried Continuous Miners - Some Facts and Figures

Type of Mining Operation	
• Driving first workings	3
• Driving pillar extraction secondary development	2
• Lifting off pillars	39
Position in Mining Sequence	
• Taking first or last lift off a fender	64%
Extent of Machine Burial	
• 0-30%	1
• +30% - 60%	3
• +60% - 80%	9
• +80% - 90%	7
• +90%	24
Frequency of Driver's Cab Being Buried	
• 25/44 = 57%	
Height of Fall Above Working Roof	
• 0-3m	66%
• 3 - 6m	17%
• Full Goaf	17%
Warning of Impending Fall	
• No	37%
• Yes	63%
Stooks and Fenders	
• Frequency of crushing and over-running:	
Total	55%
Fatal Accidents	60%
Location of Victims	
• Driver on board continuous miner	0
• Driver running from continuous miner	3
• Adjacent to continuous miner	3
• Ribline of intersection outbye of face	6
Prior Activity of Victims	
• Driving continuous miner	3
• **Face Active:** Directly engaged in face operation (inc. acting as cockatoo)	1
• **Face Passive:** Not directly engaged in a face operation of which	8
• **Face Passive:** On ribline of intersection	6
Miner Drivers	
• Protected inside cab	5
• Protected but requiring extended rescue	3
Remote Control Continuous Miners	
• No	31/33
• Yes	2/33

An Operator's Manual on Pillar Behaviour and Design Principles has been produced to underpin the procedure. This manual introduces operators to the basic principles of rock behaviour and proceeds to apply these principles to the various elements of coal pillar design. It contains many practical exercises on pillar design. These exercises are generally case studies.

Because the UNSW Pillar Design Procedure has been developed on a probabilistic basis, it needs to be reviewed periodically as the database expands and the understanding of pillar mechanics advances. It is a valuable design tool as evidenced by the fact that its application would have predicted all 15 known cases of regional collapse of Australian bord and pillar workings in the last 15 years.

- **Pillar Extraction Principles and Practice:** Department of Mineral Resources investigation reports relating to all 15 fatal pillar extraction accidents in New South Wales in the ten years to 1992 and 44 of the 60 incidents of buried continuous miners in the 3 years to 1992 were reviewed in detail. The majority of these reports had been prepared on a local basis by District Inspectors of Coal Mines and this was the first time that the information had been reviewed in total.

  Taken globally, the reports revealed a wealth of information relating to pillar extraction mishaps. A number of factors associated with the mishaps had a surprisingly high frequency. For example, 66% of incidents occurred when taking the first or last lift off a pillar, whilst 50% of persons fatally injured were standing in intersections and were not actively involved with pillar extraction operations at the time.

  Some of these aspects had come in for close scrutiny in the investigations and featured strongly in recommendations to avoid further incidents. With the benefit of the hindsight gained from undertaking a global review of all these accidents it became apparent, however, that investigations and proposed remedial measures were highly focused on active rather than latent causes of failure. Active failures are those typically associated with failing to work to stipulated plans and dimensions. Latent failures, on the other hand, are the hidden drivers behind the mishap and commonly relate to inappropriate stipulated plans of work.

  As an example, the research revealed that intersections are a particular point of weakness in pillar extraction and that over the years much attention has been focussed on support procedures in these areas. In particular, operators place a high importance on stook size and breaker line configurations and placement. Many accidents were attributed to a failure to comply with these support procedures.

  However, the research revealed that the focus on these active failures was inappropriate in many cases. Over 70% of incidents were associated with situations where panel dimensions were critical for inducing full caving. Pillar extraction operations were occurring, therefore, in an environment of very high abutment stress. This latent driver manifested itself at the weakest point in the system, namely the intersections.

To effectively address the problem, employers needed to review their overall mine design, paying particular attention to panel dimensions and to controls and barriers to minimise exposure to high stress situations occurring at times when panel dimensions are critical.

Some aspects of the pillar extraction mishaps find their solution in the UNSW Pillar Design Procedure. For example, at least 2 fatal accidents may have been avoided through the application of this procedure. Other aspects relate to mine design and operating procedures.

An Operator's Manual has also been prepared to address these issues. The manual, similar to the Pillar Design Manual, introduces operators to basic principles of rock behaviour and then proceeds to apply these principles to the various elements of pillar extraction. Case studies based on past pillar extraction mishaps are used to illustrate how these mishaps can be avoided by applying the new knowledge base arising from the project.

- **Roof Bolting Principles and Practice:** Roof bolting was not envisaged as a major sub-task of the project when it was formulated. However, from the numerous site visits made by the research team and by investigations into some mishaps it became apparent that there was a poor understanding in industry of the basic mechanics of roof bolting, especially relating to fully encapsulated roof bolts.

This lack of understanding had a significant impact on some of the mishaps investigated. More generally, however, a better understanding of the mechanics of roof bolting would have avoided many trial and error experiences by some operators and given direction to others on effective roof bolting solutions.

The strata control knowledge base established by the SCCMD Project was utilised to produce a training manual on roof bolting mechanics. This module has been integrated with those on pillar design and pillar extraction.

6.3 Technology Transfer

Technology transfer has been one of the distinguishing elements of the SCCMD Project. Its success is due to the blend of experienced operators and academics comprising the research team. This blend has enable the presentation of research outcomes to be customised to the needs and knowledge base of the recipients.

Technology transfer has occurred at all levels from face worker through to superintendent and undergraduate student through to consultant.

6.3.1 Newsletters

During the course of the SCCMD Project, eight Newsletters were published at regular intervals. Each issue comprised 3,000 copies which were distributed nationally and internationally. In particular, multiple copies were sent to all Australian coal mine sites for distribution to crib rooms.

These Newsletters proved extremely popular and fulfilled three functions, namely

(i) The timely transfer of research outcomes to industry
(ii) The gradual raising of the strata control knowledge base of the industry
(iii) The creation of an awareness of what UNSW could contribute to the industry.

Copies of the eight Newsletters and one Research Release associated with the UNSW Pillar Design Procedure are attached.

6.3.2 Workshop Modules

21 teaching modules relating to pillar design, pillar extraction and roof bolting principles and practice were produced during the course of the project. These modules have been consolidated into the form of two workshop manuals and are available for sale to the public.

6.3.3 Workshops

Three workshops were prepared around the research outcomes of the SCCMD Project, namely

Workshop 1: Pillar and Roadway Mechanics - Introductory Principles and Practice
Workshop 2: Pillar and Roadway Mechanics - Design Principles and Practice
Workshop 3 Modes of Pillar and Ribside Failure - Development and Longwall

Workshop 1 was run on 7 occasions in New South Wales and Queensland. Workshop 2 was run on 3 occasions in New South Wales and Workshop 3 on one occasion coinciding with the visit of Professor MDG Salamon. Workshops 1 and 2 are comprised of the modules referenced in Section 6.3.2.

In total, over 1100 person days of training were provided through the workshops. A profile of persons attending the workshops is shown in Figure 2. The mix of participants is considered quite unique in that it comprises persons form superintendent level through to face worker, university undergraduate and tertiary lecturers and other consultants to the mining industry. The numbers and profiles of attendees demonstrates the effectiveness of the technology transfer undertaken by the project team.

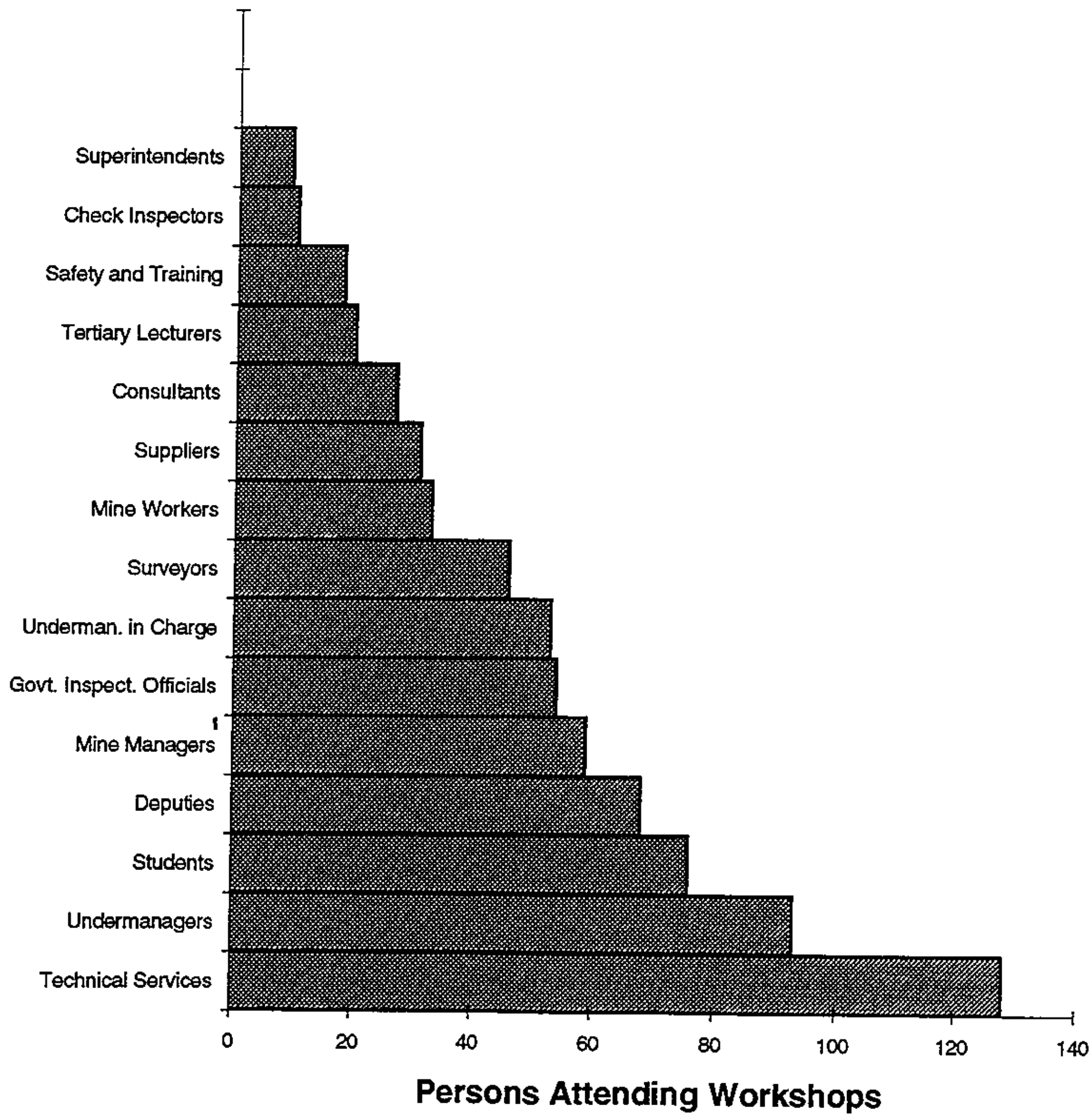

Figure 2. Profile of SCCMD Workshop Attendees

6.3.4 Conference Presentations

Presentations relating to the SCCMD research outcomes were made at six Australian conferences during the course of the project. These presentations were concerned primarily with improving the strata control knowledge base in the Australian underground mining industry in order to improve its safety performance. The conference presentations are listed under Publications (Section 6.3.5).

6.3.5 Publications

In addition to Newsletters, Research Releases and Workshop Manuals, the following publications relate to the SCCMD Project:

QUINTEIRO C, *Behaviour of Strip Pillars under Tributory Load.* School of Mines, UNSW, Sept. 1992, P.R. 1/92.

SALAMON MDG, *A Coal Seam with Strain-Softening Properties Embedded in a Stratified Rock Mass.* School of Mines, UNSW, Nov. 1992, P.R. 2/92.

Pillar Design, Introductory Presentation to NSW Colliery Managers. School of Mines, UNSW, Oct./Nov. 1992, T.T. 1/92.

SALAMON MDG, *A Review* of *Coal Pillar Mechanics and Design,* Vol. 1. School of Mines, UNSW, Nov. 1992, R.R. 1/92. ISBN No. 0 7334 1344 7.

QUINTEIRO C, *Modelling Yield Behaviour of a Strip Coal Pillar.* School of Mines, UNSW, April 1993, P.R. 2/93.

HOCKING G and ANDERSON I, *Case Histories of NSW Coal Mine Design Practice.* School of Mines, UNSW, P.R. 3/93. (Not for distribution).

ANDERSON I, *A Review of NSW Coal Mine Accident Data Pertaining to Strata Control.* School of Mines, UNSW, March 1993. P.R. 1/93.

GALVIN JM, *Application of South African pillar extraction techniques to Australian Conditions* - School of Mines, UNSW, June 1993, P.R 4/93.
ISBN No. 0 7334 1345 5.

GALVIN, JM, *Application of USA Pillar Extraction Techniques to Australian Conditions.* School of Mines, University of NSW, Nov. 1993, P.R. 5.93.
ISBN No. 0 7334 1346 3.

ANDERSON I, *Causes of Buried Continuous Miners and Fatal Pillar Extraction Accidents in New South Wales.* School of Mines, University of NSW, Dec. 1993, R.R. 1/93. ISBN No. 0 7334 1340 4.

QUINTEIRO C, *Modelling Yield Behaviour of Coal Pillars - One Pillar Asymmetric Case.* School of Mines, UNSW, Dec. 1993, P.R. 6/93.

GALVIN JM and HEBBLEWHITE BK, *UNSW Pillar Design Procedure*, Research Release No. 1 School of Mines, UNSW, 1995.

GALVIN JM, *Prosperity with Safety in a Hostile Environment: The Challenge for Underground Coal Mines*. Member of Geotechnical Forum. ACIRL Mining Seminar, Sept. 8-9, 1995, Brisbane, Qld, Aust.

GALVIN JM. *The Role of Rock Mechanics in Mining Operations*. Proc. Colloquium on Mining in Indonesia, Current Development and Future Challenges. Ministry of Mines and Energy. Bandung, Indonesia, Sept. 13-16 , 1995.

HEBBLEWHITE BK and GALVIN JM, *The University of New South Wales Pillar Design Approach and Application to Underground Mine Design Issues in the Bowen Basin*. Follington IL, Beeston JW, Hamilton LH (eds), 1995 Bowen Basin Symp., Mackay, Aust., Oct. 1995, 109-116. ISBN No. 0 9098 6998 7.

QUINTEIRO C, GALVIN JM, and SALAMON MDG, *Coal Pillar Yield Mechanics*. Proc. 8th Cong. on Rock Mech. Tokyo, Japan, Sept. 25-30 1995.

HOCKING G, ANDERSON I and SALAMON MDG, *Coal Pillar Strength Formulae and Stability Criteria*. School of Mines, University of NSW, 1995. ISBN No. 0 7334 1339 0.

SALAMON MDG, GALVIN JM, HOCKING G, and ANDERSON I, Coal Pillar Strength from Back Calculation. School of Mines, University of NSW, 1996, ISBN No. 0 7334 1489 3. Research Report 1/96.

6.4 Seeded Initiatives

The SCCMD Project has seeded many new initiatives and opportunities for the Australian mining industry at large, the Australian underground coal industry in particular and for the Department of Mining Engineering at UNSW. The principal among these have been:

- The opportunity to attract a senior member of industry to UNSW to not only lead the project but to also provide a successor to the Head of the Department of Mining Engineering

- The opportunity to establish a centre of excellence in theoretical and applied strata control research for the Australian mining industry. The reputation that this group is establishing is leading to a significant expansion in research activities. The research base in the underground coal sector has grown to the extent that the strata control group is self-supporting at the end of the Joint Coal Board funding period. Table 4 lists the new research projects which have grown out of the SCCMD research.

Table 4. New Research Projects Eminating from SCCMD Research

YEARS	AMOUNT ($)	SOURCE	STAFF	TOPIC
1995-1998	353,000	ACARP	Galvin Hebblewhite	Engineered mine design in soft strata environment
1994-1996	70,000 70,000	ACARP Collab.Sponsor	Galvin Hebblewhite	Rib mechanics and support systems
1995-1996	26,000	ACARP	Galvin	Cost effectiveness of timber chocks
1996-1997	21,700	ACARP	Hebblewhite Galvin	Strength of irregular and rectangular shaped pillars
1995-1998	30,000	ANI Arnall	Galvin	Roof bolt behaviour
1996-1998	218,000	ARC	Hebblewhite	Development of strata control principles for gas management on longwall faces
1996-1998	246,000	ARC	Galvin Hebblewhite	Structural roof reinforcement for adverse underground geological conditions
1995-1998	30,000	Joy Manufacturing	Galvin	Powered support performance
1995-1996	49,650	BHP Collieries	Hebblewhite	Floor gas inrush at BHP Collieries
1994-1998	240,500	JCB Health & Safety Trust	Galvin Hebblewhite	Elimination of goaf encroachment into the working place
1996	18,900	Powercoal PL	Hebblewhite	Wyee longwall feasibility - Great Northern Seam

- The opportunity to establish an industry funded Chair of Rock Mechanics to provide continued leadership to the research following the appointment of the SCCMD Project Leader to Head of the Department of Mining Engineering. Furthermore, the creation of this Chair has enabled another senior member of industry to be attracted to the Department of Mining Engineering at UNSW. Such industry appointments bring intrinsic values to the Department including an up-to-date knowledge of industry technologies, needs and drivers and industry support for education as well as research initiatives within the Department.

- The majority of research outcomes from the SCCMD Project are now being integrated into undergraduate course work. This provides a most effective means of improving the industry's knowledge base for the future.

- The SCCMD Project and the associated expansion in the research base has provided many mining engineering honour students with an opportunity to undertake a thesis on a live topic of value to industry. This enhances the value of the thesis topic to both the student and to industry.

- The knowledge gained by the SCCMD project team is finding wider application in many associated areas, for example, project team members are represented on the Chief Inspector's Pillar Extraction Committee and the New South Wales Coal Mines Qualification Board. These involvements ensure that the knowledge base is not only maintained and applied but also develops for the future.

6.5 Safety

The most important measure of the effectiveness of the SCCMD research lies in its impact in improving safety in the underground coal mining industry. Whilst, this cannot be quantified categorically, it is significant that there has been no fatal accident in pillar extraction in New South Wales in the last 5 years. Incidents of buried continuous miners have dropped from 20 per year to 3-4 per year. The advances in the strata control knowledge base and the effectiveness of the initiatives to transfer this knowledge base to the working face are considered major contributors to this improved safety performance.

7.0 CONCLUSIONS

Taken on balance, the objectives of the SCCMD Project have been achieved. Some theoretical aspects of the research program were not developed to the extent envisaged when the project was formulated. However, this was primarily because resources were redirected to higher priority areas identified from field investigations.

Two of the most important of these related to the surprisingly high occurrences of collapses of bord and pillar workings and of buried continuous miners during pillar extraction. These issues have been effectively addressed in research outcomes.

A majority of the outstanding aspects of the original research program are elements of new research projects which have grown out of the SCCMD Project. Hence, these aspects continued to be researched and developed.

Research outcomes are basically irrelevant in mining if they are not effectively implemented. The project targeted both operators and undergraduate students in its technology transfer initiatives. These initiatives proved to be successful to the extent that some secondary elements of the research program had to be dropped in order to provide resources to meet technology transfer demands from industry.

Taken on its own, the project has delivered a high rate of return on the dollars invested by the Joint Coal Board. There is little doubt that it has paid for itself many times over in terms of reduced injury rates, deaths and equipment losses. However, the greatest benefits arising from this investment are of a long term nature associated with the new research projects spawned from the SCCMD research and the timely incorporation of research outcomes into university undergraduate and postgraduate programs.

8.0 ACKNOWLEDGMENTS

The support, direction and advice provided to the project team by the Consultative Committee under the Chairmanship of Mr John Smith is acknowledged and appreciated. The Chief Inspector of Coal Mines, Mr Bruce McKensey, made a significant contribution to the Project by providing access to reports held by the Department of Mineral Resources and by making available, on a part-time basis, the services of Mr Ian Anderson.

Management of the project was facilitated through the interest shown by members of the Joint Coal Board, namely, Mr Ian Farrar (Chairman), Mr David Sawyer and Mr Barry Swan. The special interest shown in the Project by the late Mr David Sawyer is acknowledged in particular.

Finally, the project's success is a reflection of the on-going commitment, enthusiasm and diligence of the Project Team members listed in this report.

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STRATA CONTROL FOR COAL MINE DESIGN NEWSLETTERS

Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales

Sponsored by the Joint Coal Board

Issue No. 1

April 1993

What is the Project About?

THIS is the first in a series of Newsletters to be produced by the School of Mines at the University of New South Wales. The purpose is to inform the industry and all interested parties of the progress on a newly established research project on Strata Control for Coal Mine Design and to provide a forum for addressing relevant issues of importance.

The prime objective of the Project is to improve the understanding of the behaviour of coal pillars and associated roof and floor strata under various loading conditions and then enhance the engineering basis for the design of bord and pillar, and later, longwall workings.

Uncontrolled collapses of strata, usually in conjunction with pillar workings, remains a major hazard of underground coal mining. During the past ten years alone, falls of roof and ribs have caused the deaths of thirty miners in NSW. There have been at least eight sudden and extensive collapses of workings.

The aim is to develop practical design principles and transfer the technology incorporated in them to colliery management and personnel. The plan is to effect this technology transfer through face to face contacts in the form of small and industry-wide workshops, seminars and written reports. A major part of the project's effort will be devoted to communication, providing the opportunity for industry personnel to assess and improve the project's outcome. The project team is convinced that an enterprise with such practical aims cannot succeed without the active support and participation of the industry.

Funded by the Joint Coal Board for $1.6million over 3 years, the Project is overviewed by an industry Consultative Committee chaired by Mr M J Smith, former General Manager of Newcastle Wallsend Coal Co. Pty Ltd and with representatives from the NSW Coal Association, Colliery Managers Association, UMFA and the Inspectorate.

For the 3 years to 1992, there were 60 incidents in NSW of continuous miners being buried for periods exceeding 7 hours.

Contents

Project Methodology

Recent local events have revealed a need to improve our theoretical mine design knowledge base and our adaptation of it to the local geological environment and to raise the standard of knowledge of key operators in the field. The following project structure aims therefore, to address classical engineering materials behaviour, field performance and technology transfer to the industry.

1. Review and Update the Worldwide State of Art on Pillar Mining

The development of design guidelines for bord and pillar workings requires a critical review and further development of the understanding of the mechanisms which come into play during the formation and extraction of pillars. Considerable attention is to be devoted to the clarification of the behaviour of fully or partially yielding pillars. Virtually no sound knowledge appears to be available with regard to this aspect of pillar mining.

2. Collect Field Performance Data of NSW Coal Mines.

Application of design theory requires consideration to be given to the structural properties (geological and geotechnical) and past performance of the field materials.

3. Analysis and Back Calculation of NSW Mine Data.

Back analysis of both successful and unsuccessful field experiences enables local ground conditions and mechanisms to be identified and highlights problem areas requiring further research.

4. Develop and Validate Design Methodologies and Procedures

Transform the research results into a design methodology. Develop and validate mine planning criteria and procedures to enable personnel to optimise layouts with regard to safety and efficiency.

5. Training and Instructions for Implementation of Research Results in to Engineering Practice.

Provide formal training to industry personnel to ensure research results are implemented into engineering practice.

ISSUE

Feather Edging

"Feather Edging" is a phenomenon observed adjacent to goaf edges, in which the roof falls as a thin wafer of rock, tapering from perhaps 500mm in thickness, back to a "razor sharp" edge. Feather edges develop without warning, over-ride breaker lines and can run down a bord for distances of up to 15m. Not surprisingly therefore, they have been a major source of injury and multiple fatality accidents, both overseas and locally.

Project site investigations have confirmed that feather edging occurs extensively in the Northern and Western coalfields of NSW. Historically, feather edging has been blamed on goaf falls over-riding poorly set breaker line props or on the presence of pre-existing geological weaknesses. Whilst sometimes the case, investigations now leave little doubt that feather edging is primarily driven by mining-induced stresses.

When strong brittle rocks comprise the immediate roof, caving is often delayed and so high stress concentrations can be induced around and away from the edges of the goaf. When failure occurs, it is sudden and may propagate along lines of high stress for some distance outbye of the goaf.

Hence, in Australia, feather edging is associated primarily with massive sandstone and conglomerate roof and takes on a similar appearance to the failure of glass ie. few signs of load, then sudden failure with curved fracture planes and razor sharp edges.

A better understanding of the mechanism causing feather edging is required in order to develop effective and practical control measures. It cannot be assumed that obvious reactive measures such as mobile breaker line supports or roofbolt breaker lines will automatically be effective when failure is evidently dynamic and capable of running considerable distances back from the goaf edge.

A feather edge in massive sandstone roof which has run down the bord for almost 15m. Note the low angle stress induced curved fracture plane tapering to a razor edge.

ISSUE

Effect Of Pillar Height

The strength of a coal pillar decreases as its height is increased

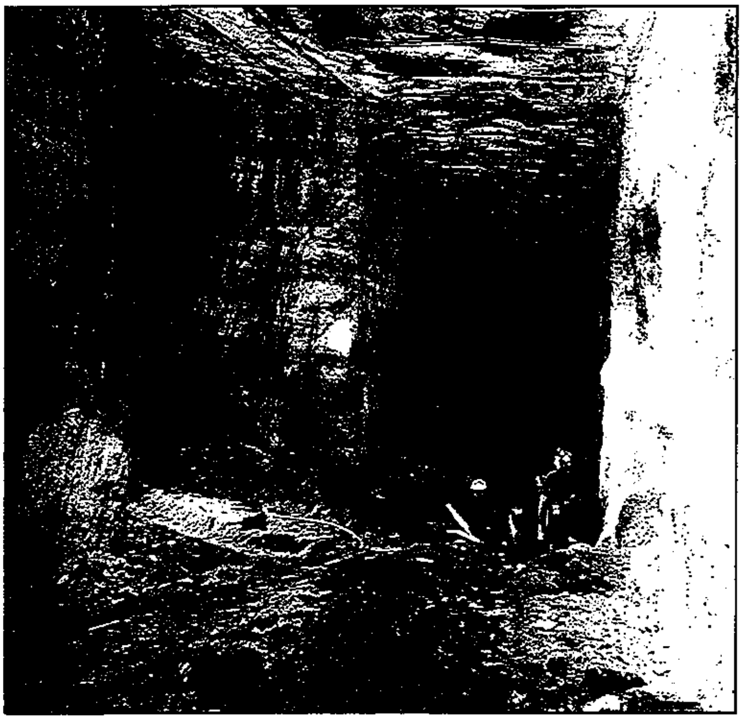
This property has been recognised by rock mechanics engineers for many decades. Nearly all pillar design formulae incorporate this by including a pillar width to height (w/h) factor.

It is surprising, therefore, that the effect of mining height on pillar stability was omitted from the Coal Mines Regulation Act when it was revised in 1982, particularly since it had been taken into account (albeit indirectly) in the 1912 Act.

Since the CMRA (1982) came into effect, there have been at least two extensive collapses of pillars formed to an excessive height. By all acknowledged strength formulae, these pillars were seriously under-designed. This situation has now been corrected by the Chief Inspector of Coal Mines reverting to the requirement of the 1912 Act and restricting pillar height to a maximum of 4m, unless an exemption is granted.

This new requirement means that irrespective of depth, pillars must have a minimum width to height ratio of 2.5. This makes good sense when consideration is given to the geological environment. At smaller width to height ratios, a slip plane such as shown in the accompanying photo, can effectively destroy the load carrying capacity of a pillar. Adjacent pillars must be capable of carrying the additional load that is thrown onto them, otherwise they in turn will fail and a "domino" type collapse initiated.

Good progress is being made by the project towards developing pillar design criteria for local conditions. This progress is being made thanks to the co-operation of collieries in providing data and access to both successful and unsuccessful mine layout sites.



Interested In A Higher Degree But Wish To Remain In Full-Time Employment?

YOU CAN ACHIEVE BOTH!!

Opportunities exist to obtain a Master of Applied Science Degree by undertaking field research into a topic relevant to the Coal Strata Control Project.

In some circumstances, the opportunity also exists to undertake a Ph.D.

NOTE: You do not necessarily have to possess a first degree. Your experience and professional qualifications may constitute an acceptable entry standard.

For further details, fill out the enquiry card on Page 7 or contact:
Professor Jim Galvin Ph: (02) 697 5160,
Fax: (02) 313 8502.

Site Investigations

Recognising that the best testing laboratory and information library is an actual operating coal mine, the project is conducting numerous site investigations. Nineteen underground visits have taken place, across all mining districts. Many historical examples of successful and unsuccessful mine designs have been reviewed, in order to determine which parameters are vital for successful design.

It is becoming apparent that the following are key issues across the industry:

- Pillar design criteria;
- Longterm behaviour of pillars on soft floor;
- Caving behaviour and support requirements in pillar extraction;
- Feather edging at the goaf edge;
- Regional mine stability design criteria.

Further work and inspections will be required, but initial analysis is providing encouraging correlation with known principles and pillar design formulae.

ISSUE

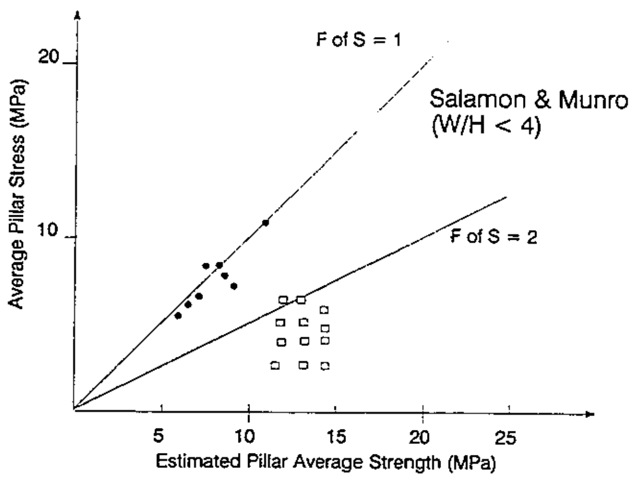
Pillar Performance

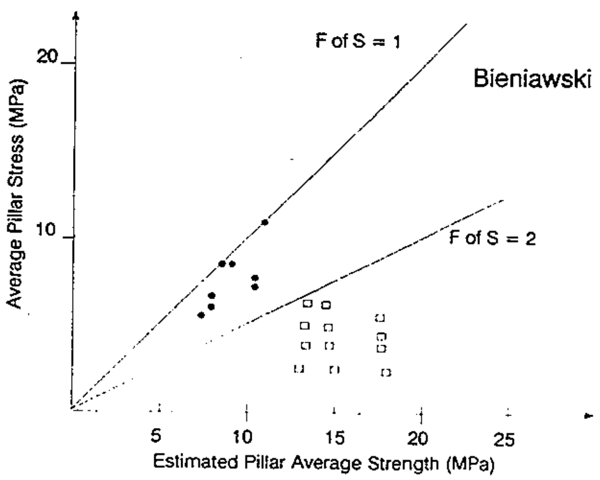
Mine visits to date have identified eight cases of collapsed bord and pillar workings and numerous cases of stable workings.

A preliminary analysis of the data has been undertaken by plotting the average pillar stress against the estimated pillar strength given by two pillar strength formulae. The eight failed cases in the first graph plot close to a safety factor of 1.0. The maximum safety factor for a failed case in this plot is 1.3.

The same data plotted for a second pillar strength formulae has a similar trend to the first formula except that the safety factors are slightly larger for both the failed and unfailed cases.

It should be noted that cases involving soft roof or floor have been excluded in these plots.





ISSUE

Soft Floor

Local and regional stability problems (eg. heave, creeps) can be encountered in Newcastle district mines when Tuff (volcanic ash) comprises the floor strata. Instabilities are associated with either or both:

- excessive floor heave due to the presence of swelling clays (montmorillonites) and water,
- pillar punching into the floor due to either consolidation, plastic failure or creep of the floor material.

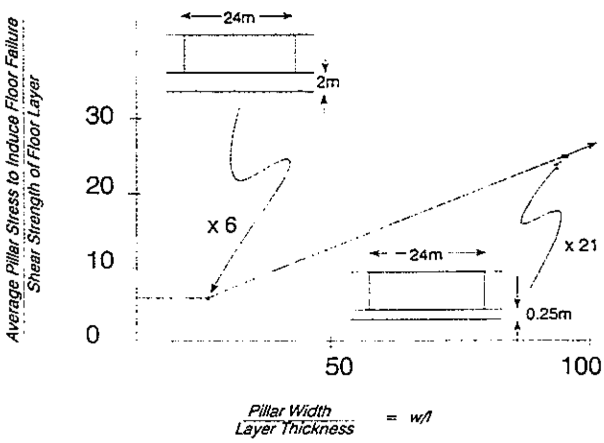
Angle of props and condition of ribs are pointers to the floor failure mechanism.

Recently completed field investigations have highlighted that the composition of Tuff varies greatly both laterally and vertically from almost pure montmorillonite to hard silicified rock. This may account for the considerable confusion that exists at and across mine sites as to floor failure mechanics.

Site investigations indicate that plastic failure is one failure mechanism. In this case, the composition, thickness and relative position of the various layer types affect the structural strength of the floor. The floor strength is governed by the mining layout since, in this failure mode, the bearing pressure capacity of the floor is a function of the ratio of pillar width, w, to the thickness of weak immediate floor layers, l, (ie. w/l).

The attached graph shows that the bearing pressure capacity of the floor decreases almost four fold when the thickness of weak floor layers increase from 0.25m to 2m under a 24m wide pillar. Another mechanism is that of time dependent creep of soft floor. This mechanism is a function of $(l/w)^2$, and for the above example, results in a 500 fold increase in the rate of vertical settlement of a pillar.

Pillar and floor geometrical ratios must be considered when analysing field data, otherwise it is impossible to gain insight into soft floor behaviour mechanisms. In the meantime, however:



One Example of Floor Bearing Pressure Capacity. (A complete series of curves for layer position and thickness are being generated.)

Mine operators need to be aware that:

- "All claystones ain't claystones". Significant variations in the structural strength of claystone floor or roof can occur over short distances.
- The bearing capacity of weak floor is a function of the ratio of the pillar width to the thickness of weak floor. It is not simply a function of average pillar stress.
- A knowledge of the thickness of weak floor strata beneath pillars is imperative to decipher field performance data.

Questions and Answers

■ *What is a sudden uncontrollable pillar collapse?*

This is a collapse of extensive mine workings which gives little, if any, warning and once initiated, cannot be arrested or controlled. Geological and strata control conditions often appear excellent up to or within hours of the collapse occurring.

■ *What examples exist of sudden uncontrolled pillar collapses?*

The best known example is that of Coalbrook Colliery in South Africa in which 4,400 coal pillars failed in a 20 minute period in 1960, killing all 437 men underground. Pillars were not strong enough to carry additional load imposed on them when the stiffness of the roof strata was reduced due to exposing a geological fault. Similar collapses have been documented in metal mines eg. Lorraine Iron Ore Mine in France.

■ *Can a Coalbrook-type collapse occur in Australia?*

Yes — In fact it has occurred on at least three occasions in the last three years. Two continuous miner production sections were lost at a colliery when over 90 pillars collapsed suddenly, fortunately when the mine was idle. A sudden collapse of more than 200 pillars occurred in another colliery, fortunately whilst the section was down for maintenance. Another similar incident involved the sudden collapse of about 50 pillars.

■ *How can sudden uncontrolled pillar collapse be prevented?*

For pillar collapse (controlled or uncontrolled) to occur at all, the load imposed on the pillars must exceed the strength of the pillars. Hence, sound design will prevent pillar collapse. This design should make provision for any changes that are likely to occur in loading conditions over the functional life of the pillars eg. increased pillar height due to roof falls, increased pillar loads due to goaf edge loadings, decreased pillar width due to rib spall, floor heave and pillar punching.

■ *Is pillar failure the only cause of mine collapse?*

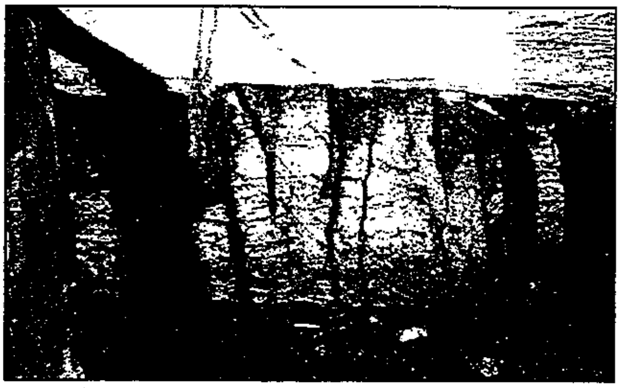
No — Many instances exist, including local, where a collapse was caused by failure (sometimes suddenly) of the roof or floor strata under the load exerted by the pillars.

KEY RULE OF THUMB

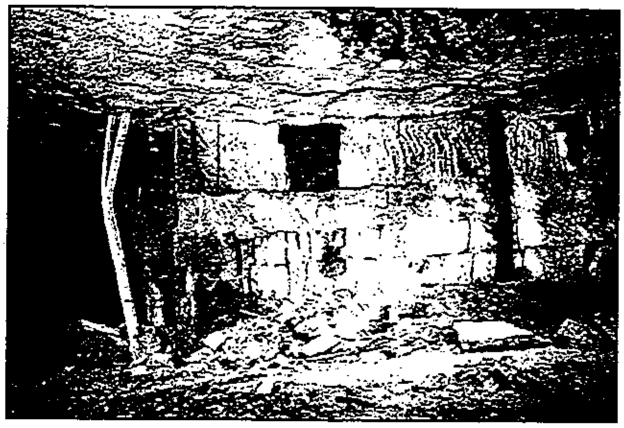
Rocks Are Up To 10 Times Weaker In Tension Than In Compression

Applications in Mining

- The strength of a pillar can be reduced significantly when a soft band is present in or at the top or bottom of the pillar and it squeezes out under load. The movement of the band subjects the pillar to lateral tension and causes it to split vertically.
- The effect of blasting is to generate a compressional wave front, which, upon reaching a free face, is reflected back in tension, thus causing the rock to fracture.
- Cutter heads on mining and tunnelling machinery are designed to break out the rock in tension.



Vertical splitting induced in a coal pillar as a result of soft floor being squeezed out from under the pillar. This mechanism has been responsible for a number of pillar collapses in both metal and coal mines.



Vertical splitting induced in a coal pillar as a result of a soft band being squeezed out of the middle of the pillar

Where Have We Come From ...

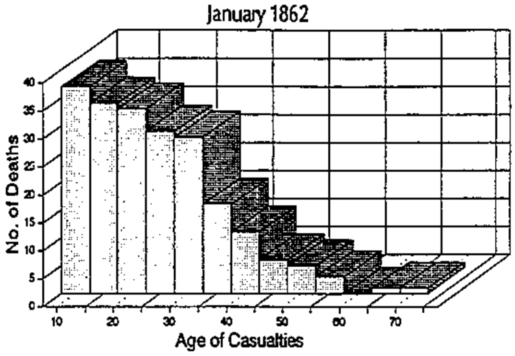
WHERE: Hartley Colliery, Newcastle upon Tyne, England

WHEN: 16 January 1862

WHAT: Half of the 42 tonne beam of the pumping engine snapped off and fell down the colliery's only shaft which was partitioned for furnace ventilation. The shaft sides collapsed blocking egress. The furnace was extinguished by those trapped underground but continued smouldering. It took six days for rescuers to clear and secure the shaft. They found 199 men and boys assembled and awaiting rescue but dead from carbon monoxide poisoning. A further five had been killed in the shaft.

Hartley Colliery Disaster

January 1862



RESULT: Legislation requiring not less than two means of egress for every mine separated by not less than 45 feet.

Publications

The findings of the Strata Control for Coal Mine Design Project are documented regularly as the project progresses. There are three categories of reports:

1. Progress Reports

Brief interim task reports which serve as a record of progress and of the issues examined. Restricted distribution to project affiliates since results are not final.

Quinteiro, C., *Behaviour of Strip Pillars under Tributary Load.* Sept., 1992. P.R. 1/92

Salamon, M.D.G., *A Coal Seam with Strain-Softening Properties Embedded in a Stratified Rock Mass.* Nov., 1992. P.R. 2/92

Anderson, I., *Review of NSW Coal Mine Accident Data Pertaining to Strata Control.* Feb., 1993. P.R. 1/93.

2. Research Reports

Primarily, detailed technical level reports which present final results. General distribution.

Salamon, M.D.G., *A Review of Coal Pillar Mechanics and Design.* Vol. 1. Nov. 1992, R.R. 1/92.

3. Technology Transfer Reports

Reports which transfer research findings to field operators in the form of basic rock behaviour principles and mine design guidelines. General distribution.

Pillar Design. Introductory Presentation to NSW Colliery Managers Oct., Nov., 1992 T.T. 1/92.

Reader Enquiry Service

If you would like further information on any aspect of the Strata Control for Coal Mine Design Project or wish to make a relevant technical contribution or comment, please fill in this enquiry card. A member of the project team will contact you as soon as possible:

NAME:

ADDRESS:

PHONE: FAX:

SUBJECT MATTER:

Mail to:
Professor Jim Galvin, Professor of Mining Engineering, Department of Mining Engineering
The University of New South Wales, PO Box 1, KENSINGTON 2033

PH: (02) 697 5160, FAX: (02) 313 8502

Introducing The Project Team

Professor Jim Galvin

Jim joined the School of Mines as Professor of Mining Engineering in December 1992 and now heads up the Strata Control for Coal Mine Design Project. His previous experience includes 6 years with the Research Organisation of the Chamber of Mines of South Africa, where he was Head of the Coal Strata Control Division. This was followed by ten years in NSW mining operations, the last four of which were as a Colliery Manager. Throughout his operational career, he has maintained a keen interest in strata control research which addresses the needs of the industry.

Professor Miklos Salamon

Miklos is Distinguished Professor of Mining Engineering at the Colorado School of Mines and Visiting Professor at the University of NSW. Educated in Hungary and Britain, Miklos was appointed in 1963 to start research into pillar stability in South Africa in the aftermath of the Coalbrook Colliery disaster. His pioneering work on this case resulted in significant advances in understanding the mechanics of rock behaviour and form the basis for many rock mechanics principles in everyday use. For 12 years prior to leaving South Africa in 1986, he headed up the largest privately funded mining research organisation in the world in his position as Director General, Chamber of Mines Research Organisation.

Professor Grant Hocking

Grant joined the School of Mines in 1987 as Professor of Engineering Geology. Prior to this, he managed a consulting company in the USA, providing services to the petroleum, mining and nuclear industries. During 1973-77, he lectured at the Imperial College, London. He is involved with the project on field investigations and in the development of design theory.

Professor Frank Roxborough

Frank has been Professor of Mining Engineering at the University of New South Wales since June, 1975 and is immediate past Head of the School of Mines. He chairs the internal Management Committee established at the University to co-ordinate and monitor the progress of the project.

Mr Ian Anderson

Ian is a Senior Inspector of Coal Mines with the NSW Department of Mineral Resources. He is responsible for secondary extraction approvals, strata control and related safety issues within the Inspectorate. Previously a Colliery Manager, his experience is utilised by the project on a sub-contracted and confidential basis to assist with site investigations.

Dr. Bernard Madden

Bernard is employed by ACIRL as Manager — Geotechnical Engineering. A graduate in geology, he has considerable local and international experience. Bernard was recently award a PhD for theoretical and field research into updating the Salamon Pillar Design Formula. The project periodically utilises his expertise in this regard on a sub-contracted basis.

Dr John Watson

John is a Senior Lecturer in the Department of Mining Engineering at the University of New South Wales. Previous experience includes development of finite and boundary element software in France and UK and six years as a lecturer at Imperial College, London. His expertise and input to the project is in the areas of structural stability analysis and numerical modelling.

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Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales

Sponsored by the Joint Coal Board

Issue No. 2

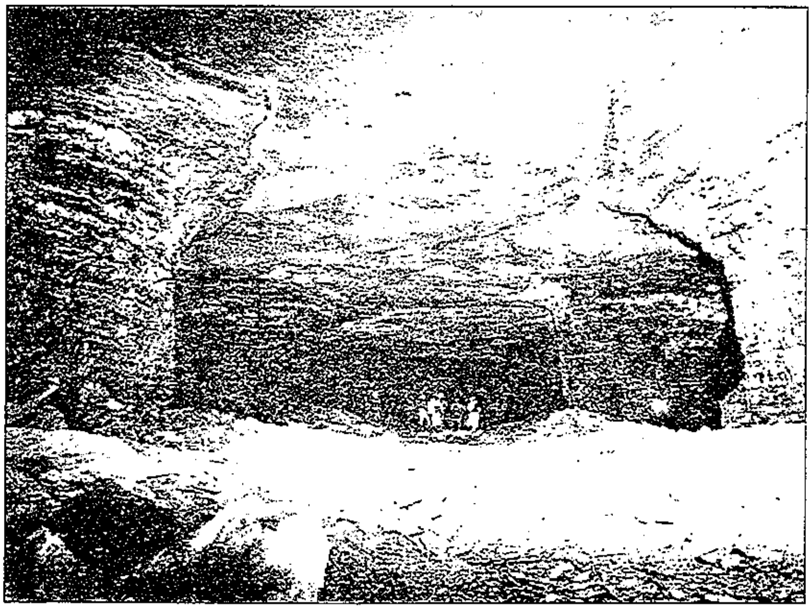
August 1993

WHERE IS THE PROJECT UP TO?

In this second newsletter, several of the issues raised in the first one are further developed. But first, we are delighted to report the arrival onto the Project Team of Dr. Carlos Quinteiro from Colorado School of Mines. Carlos, who joins us as research officer, significantly increases our strength in stress analysis aspects of strata control.

We have now completed some specific project tasks, and are progressing with further mine site visits. Activities that have been completed are:

- A review of worldwide state of the art on pillar mechanics;
- Initial field surveys of NSW collieries to examine the issues critical to strata control;
- A preliminary back analysis of stable and collapsed cases of bord and pillars workings;
- A review of fatal accidents associated with strata control in NSW.



Pillars formed in the 1930's to a width and height of 6m. Depth of mining was 30m. A further 2m of shale tops have since fallen.

A yielding pillar model, incorporating roof and floor strata, has been developed. The model appears to correctly simulate failure and yielding of coal pillars.

Further cases of stable and collapsed bord and pillar workings are being documented. An investigation of causes of buried continuous miners during the past three years is in progress. The aim is to gain insight into the strata control circumstances of these incidents.

To date, we have presented to industry personnel, three introductory seminars and two seminars on pillar design and subsidence control. Further seminars are planned for check inspectors, the inspectorate and mine design engineers.

The particular hazard of feather edging and other dynamic phenomena has come to light from our reviews of fatal accidents and of field data. Some aspects of these important issues are raised in the newsletter.

Contents

ISSUE

PILLAR EXTRACTION

A worldwide review shows that very little research has been directed towards strata control in pillar extraction. This is surprising given that the method is used extensively and that it is widely regarded as the most hazardous of coal mining operations.

During the past three years there have been 7 fatalities in NSW associated with pillar extraction and 60 instances of continuous miners having been buried for more than one shift. The US Bureau of Mines reports that between 1989 and 1992, pillar extraction in the USA accounted for 24% to 37% of fatalities. The first four fatalities in the USA in 1993 occurred during pillar extraction.

Many operators have strongly held views on the technique, dimensions, extraction sequences and practices that should be followed for the safe extraction of pillars. However, these views vary considerably as reflected in the many variations in pillar extraction techniques used worldwide.

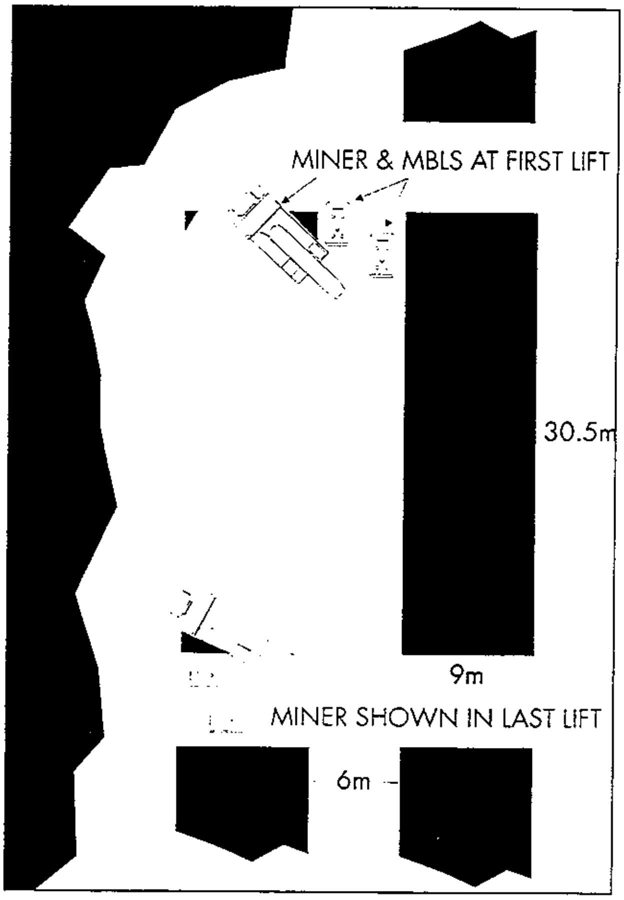
It appears that pillar extraction systems are designed primarily on a basis of geometry (machinery width, operator location, standing pillar sizes etc), operator experience and trial and error. Consequently, a number of contradictions have arisen in pillar extraction; including:

1. The 'mandatory' leaving of stooks in Australia in contrast to a strong emphasis on the removal or destruction of stooks in both South Africa and the USA.
2. The insistence of management and workforce at some NSW mines that timber finger lines be erected in extracted lifts and the equally strong insistence by others that this is an unsafe practice.

Fender width in Wongawilli pillar extraction is a good example from a range of questions that need to be addressed with an open mind. Local and overseas experience, with radio controlled continuous miners and Mobile Breaker Line Supports (MBLS), is indicating benefits of wider fenders under some conditions. One NSW colliery reports better strata control under conglomerate roof since changing from Modified Old Ben to Wongawilli with a 13 m wide fender.

The need to leave or take stooks is also an interesting issue. Of the 60 buried continuous miners noted above, 10 were attributed to premature collapse of stooks. In contrast, over the past 10 years, 10% of US fatalities have resulted from falls of roof or rib during removal of the 'push out' stump or stook.

The experience of operators is an important source of information for improving our understanding of strata behaviour. In this issue an interview with Dan Hanrahan (former manager at Wyee Colliery and Managing Director of Elcom Collieries) tells us how the Old Ben System came to be introduced in Australia. Future newsletters will include similar style interviews with other experienced mining engineers.



A Pillar extraction technique employed in the USA and South Africa using remote controlled continuous miners. In comparison to NSW operations, the fender is wider, the angle of attack is not so great and no Stook 'X' is left. The latter two factors permit quicker entry and exit of the continuous miner, especially during the critical final stages of fender extraction.

Can You Help?

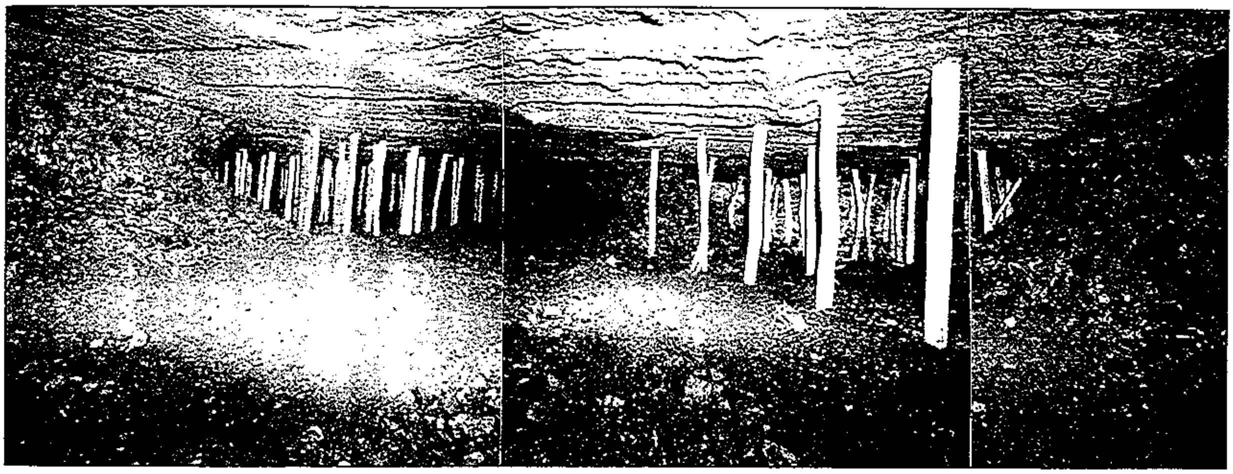
Mine site information is required to help identify the causes and extent of feather edging and dynamic loading so that control measures can be developed. We are keen to contact persons who have experience of:

* Feather Edging.
* Hydraulic and/or structural damage to mechanised supports.
* Violent failure of coal ribs or roof.

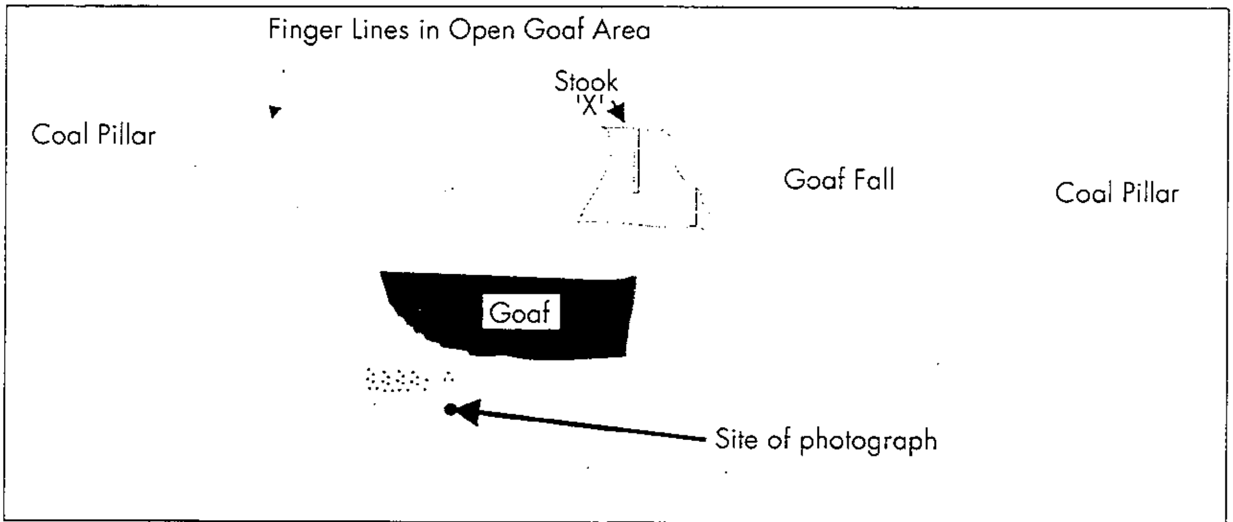
Information on the composition of the roof strata, panel layout, state of the goaf, rate of mining and other related issues would be valuable and greatly appreciated.

NOTE: TOPICS OF THIS NATURE ARE IDEALLY SUITED TO PERSONS WISHING TO UNDERTAKE A HIGHER DEGREE WHILST REMAINING IN FULL TIME EMPLOYMENT AT THEIR WORK PLACE.

EXTRACTION OF STANDING PILLARS BY SPLITTING AND LIFTING



In the case illustrated here, the colliery had a long and successful history of erecting finger lines in splits and not leaving a Stook 'X'. However, Stook 'X' is now compulsory. Operators prefer to use finger lines, stating that they provide a gauge of how quickly weight is coming back onto the face.



Location Plan of Photograph. The curved (concave) shape of the pillar sides is a good example of how the pillar system behaves under load when the top and bottom of the coal pillar are confined by competent roof and floor strata.

CARLOS QUINTEIRO

Carlos joined the Project Team on a full time basis in March, after completing his PhD in Mining Engineering at the Colorado School of Mines (CSM, Denver, USA). His considerable expertise in the mechanics of pillar behaviour finds application to the design of stooks, fenders and yield pillars. His past experience includes the design of partial extraction panels to restrict caving and prevent water inrush.

If you would like further information on any aspect of the Strata Control for Coal Mine Design Project or wish to make a relevant technical contribution or comment, please contact:

Jim Galvin, Professor of Mining Engineering
School of Mines
The University of New South Wales
PO Box 1, KENSINGTON, NSW 2033

Telephone: (02) 697 5160
Facsimile: (02) 313 8502

ISSUE

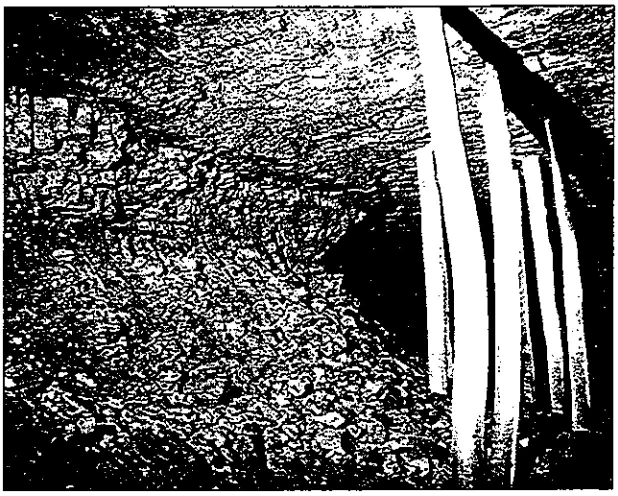
PILLAR PERFORMANCE

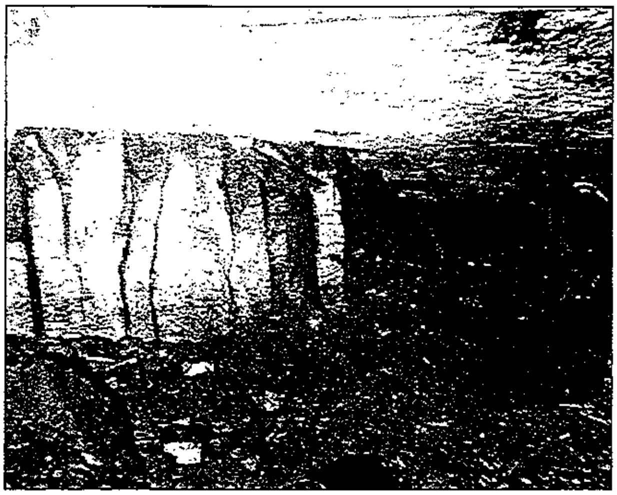
In the previous issue, preliminary strength data for NSW coal pillars was compared with design originating from South Africa and the USA. This field data involved competent roof and floor strata, with the coal being the weakest component of the system. The impact of weak floor or roof strata on pillar performance was also described.

In pillar design, the entire pillar system comprising the coal, the roof and the floor strata must be considered together. Even if the immediate roof or floor strata does not yield, the strength of the coal pillar is to some extent dependent on the overlying and underlying strata. If the immediate roof or floor does yield, its lateral squeeze tends to rip the pillar apart and drastically reduces the strength of the pillar.

Two extremes of pillar behaviour are illustrated by the photographs. In the first case the roof and floor are competent and the pillar is failing due to high compressive stresses. The pillar ribs spall heavily at or near mid-height. In the second case, a weak floor strata has yielded beneath the pillar and induced high horizontal tensile stresses within it. Note the leaning props, which indicate floor movement. This pillar is being weakened by horizontal tension.

Both types of pillar failure can occur. Therefore, the properties of the immediate roof and floor need to be considered in pillar performance as do massive beds in the overlying strata. Back analysis of mine site data provides field scale values of critical strata properties.





Industrial Training – First Year Mining Students

At the University of New South Wales, Mining Engineering students study mining subjects from the very beginning of their course. To improve their understanding of the course work and to encourage their continued commitment to the Mining Engineering profession and the industry, it is important that first year students have the opportunity to undertake Industrial Training during the summer vacation (early December to late February).

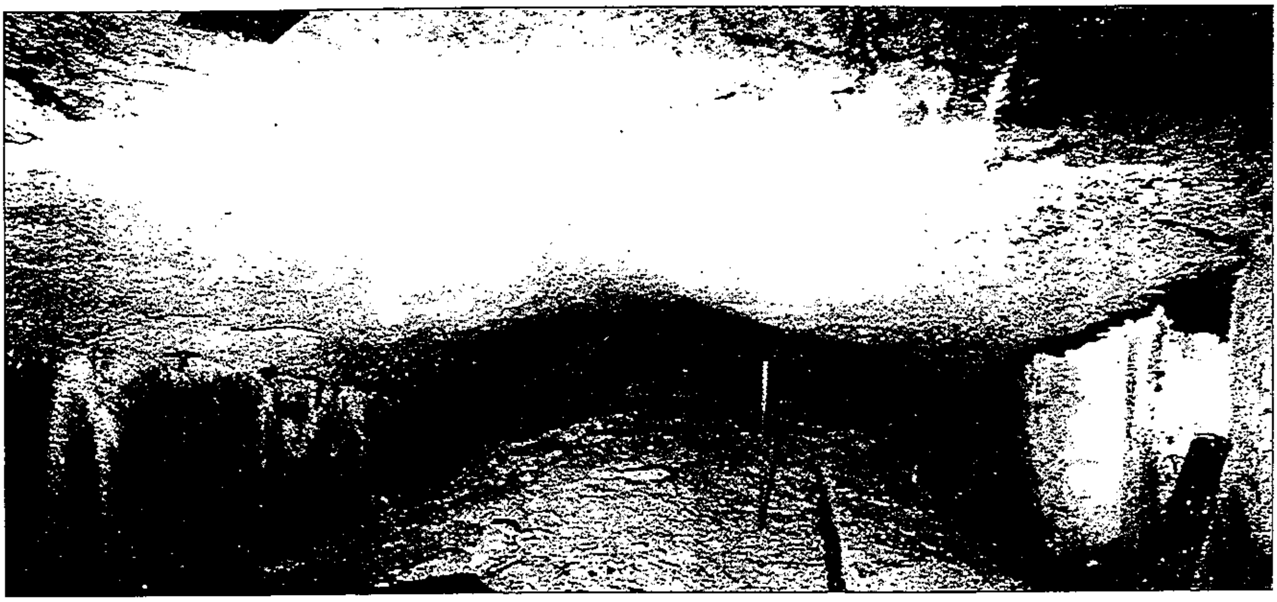
The period of employment can vary between four and ten weeks and as long as students can earn enough to meet their out of pocket expenses, reimbursement is not an issue for most.

A number of students are still seeking summer vacation employment in 1993. If you can offer a vacation work opportunity for one of our students, would you please contact:

Gour Sen
Associate Professor and Head
Department Mining Engineering,
The University of New South Wales
PO Box 1, KENSINGTON, NSW 2033
Telephone No: (02) 697 5345
Facsimile No: (02) 663 4019

ISSUE

FEATHER EDGING



Overseas experience confirms that feather edging occurs frequently in total extraction under strong massive roof. For example, a feather edge running down a bord for two pillar lengths caused the death of five South African miners in a pillar extraction panel.

An investigation recommended that breaker lines should be roof bolted wherever the sandstone roof hung-up and further suggested that longwall chocks should be adapted to pillar extraction operations. Subsequently, the use of Mobile Breaker Line Supports (MBLS) was pioneered in South Africa.

Recently, another South African colliery, with a history of feather edging under sandstone roof, introduced conventional longwall equipment to extract standing pillars. Feather edging still occurs but it is now much better controlled. Regular feather edging under massive sandstone roof has also been observed in the USA during pillar extraction.

Strong massive roofs store a large amount of energy when they don't cave regularly and the brittle or 'glassy' nature of the strata can result in eventual failure taking place suddenly and without warning. Feather edging appears to be one form of energy release. However, our field investigations suggest that energy is also released in other sudden and violent events. Such events have been found to cause significant damage to MBLS and longwall supports.

Some engineers are considering longwall mining directly under massive competent strata. It is important, therefore, that the factors controlling feather edging and other energy release mechanisms are thoroughly investigated.

Publications

The results of the Strata Control for Coal Mine Design Project are documented regularly as the work proceeds. There are three categories of reports, the purposes and distribution of which are indicated below. Reports published since the previous Newsletter are listed under the appropriate category.

1. Progress Reports

Brief interim task reports which serve as a record of progress and of the issues examined. Restricted distribution to project affiliates because the results are not conclusive and are subject to review as the research progresses. Most of these reports are eventually consolidated and produced as Research Reports.

Quinteiro, C.,
Modelling Yield Behaviour of a Strip Coal Pillar. April, 1993. PR. 2/93

Hocking, G, and Anderson, I.,
Case Histories of NSW Coal Mine Design Practice. April, 1993, PR 3/93 (not for distribution)

Galvin, J.M.,
Review of Overseas Pillar Extraction Techniques – South Africa, June, 1993, PR. 4/93

2. Research Reports

Primarily, detailed technical level reports which present final results. These are for general distribution.

3. Technology Transfer Reports

Reports which communicate research findings to field operators in the form of basic rock behaviour principles and mine design guidelines.

Questions and Answers

SAFETY FACTORS

■ *What is the definition of 'Safety Factor'?*

The Safety Factor of any structure or system is defined as its Strength divided by the maximum Load to which it will be subjected i.e.

$$\text{Safety Factor} = \frac{\text{Strength}}{\text{Load}}$$

■ *What does a Safety Factor of 1 mean?*

Ideally, a Safety Factor of 1.01 means that a structure is stronger than the highest load to which it will be subjected and therefore the structure will be stable. Likewise, a Safety Factor of 0.99 means that the load applied to the structure will exceed its strength and therefore the structure will fail. However, in the real world of mining we do not know the exact value of either the strength or the load.

Thus, a Safety Factor value of 1 implies only a 50% probability of stability (in other words, there is an evens chance of the system failing or being stable).

■ *What issues do engineers consider when determining what value of Safety Factor to adopt?*

In deciding what Safety Factor to use in designing, engineers have to take account of:

- How confident they are in determining pillar load.
- How confident they are in the strength formula being used.
- How confident they are of the data they are inputting into the strength formula eg 100 year floods levels.
- The probability for human error in the execution of the design. eg attaching too large a load to a rope.
- The probability of an unplanned event eg ship hitting a bridge pylon or mining encountering a geologically disturbed zone.
- Consequences of failure eg catastrophic loss of life or just minor loss of function.

The value of the Safety Factor is increased if the confidence in the design is low or the consequences of a failure are serious.

■ *What Safety Factors apply to coal pillar design?*

No answers can be given yet to this question. There is no entirely reliable method to determine either pillar strength or load. The problem is exacerbated by the need to compensate for the potentially high variability of the rock and coal properties.

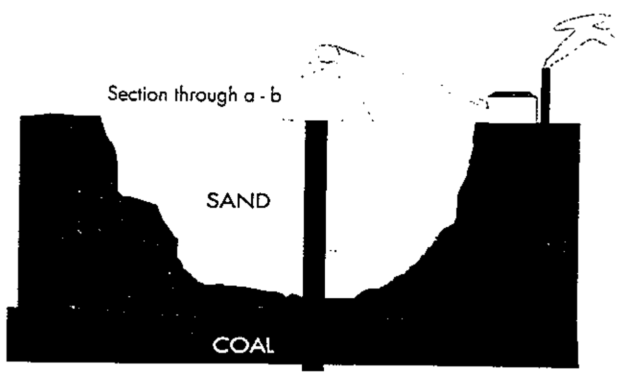
This problem has been overcome in South Africa for bord and pillar workings by working backwards and evaluating the performance of pillars of different sizes in the mine under fairly uniform geological conditions (Salamon and Munro formula, Issue 1). Under normal conditions, first workings in bord and pillar mining are designed to a minimum Safety Factor of 1.6.

Where Have We Come From ...

WHERE: Ferndale Colliery, Tighes Hill, Newcastle, NSW

WHEN: 18th March, 1886

WHAT: A section of workings about 20 m beneath the tidal reaches of the Hunter River and less than 3 km from the centre of Newcastle, collapsed and the mine was inundated with water, mud and sand. Most of the 110 men and boys in the pit escaped but two were later found to be missing, John Jenkins, aged 40 and John Hargraves, aged 30. When the tide receded a 2.5 m wide hole was found at the surface through which about half a hectare of surrounding swamp had been swept into the mine. Miraculously, Hargraves had sur-



Reproduction of Sketch of Ferndale Colliery Shaft from the Royal Commission Report into the 1886 Disaster

KEY RULE OF THUMB

Tensile stresses in the roof increase in proportion to the square of the bord width

Application in Mining

Since rocks are typically ten times weaker in tension than in compression, a small change in bord width can have a major effect on roof stability. For example, an increase from 5.5m to 6.5m increases the tensile stress in the roof by 40%. This explains why a mere 1 m increase in bord width can cause a good roof to become a bad roof. Conversely, a reduction in bord width from 5.5m to 4.5m can result in a significant improvement in roof conditions because the tensile stresses are reduced by one third.

Using single pass continuous miners can lead to improved roof control because they eliminate saw tooth ribs and provide better control of bord width.

In addition to preventing injuries from rib falls, rib support performs the important function of preventing an increase in bord width as a result of rib spalling.

Wider bords offer operational advantage. However, under weak roof conditions, restricting the bord width is one of the most effective roof control measures available. Additional measures include:

(i) installing rib support and replacing it when it fails;

(ii) using single pass continuous miners;

(iii) keeping the number of intersections to a minimum, and

(iv) sequencing driveages to minimise the number of breakaways and avoiding breaking away left and right.

Face operators can play a key role in improving roof control by:

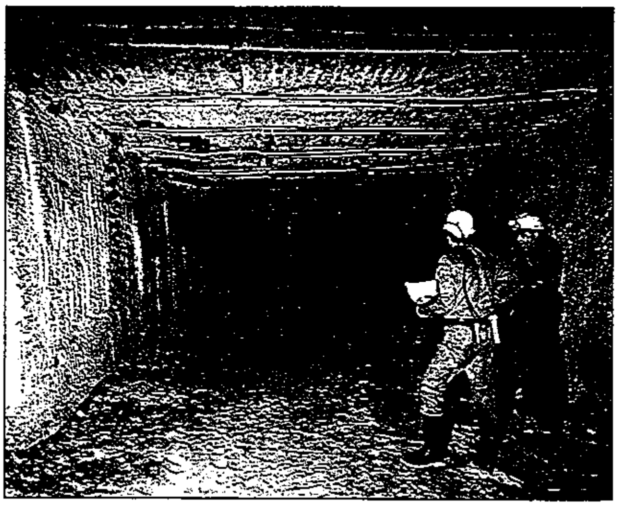
(i) keeping roadway on centre;

(ii) keeping roadway on width;

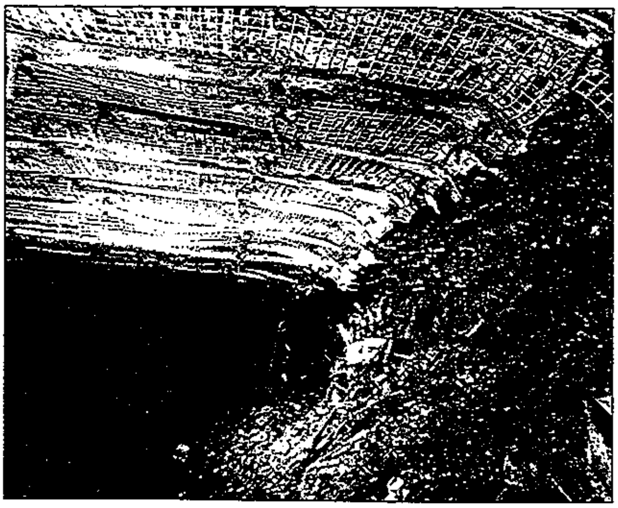
(iii) keeping breakaways tight;

(iv) keeping rib lines smooth, and

(v) avoiding machinery damage to rib support.



A 4.2m wide roadway driven with a single pass continuous miner. Note the smooth ribs and constant roadway width.



Failure of the rib support system has resulted in the roadway width increasing from 4.7m to 6.2m. As a consequence, the tensile stress in the roof has increased by 74%.

vived and was pulled to safety through the hole by a rope. Jenkins was never found. Despite hastily organised efforts to plug the hole and erect barriers, the next high tide re-flooded the workings with such force that neighbouring shafts and tunnels were deluged and had to be abandoned. (See illustration opposite.)

RESULT: Legislation specific to the Prevention of Inrushes such as the minimum rock cover requirements for working under waterbodies and the need to bore ahead under waterbodies. Details of the current provisions in this regard are continued in the Coal Mines Regulations (Methods and Systems of Working – Underground Mines) Regulation 1984.

INTERVIEW WITH MR DAN HANRAHAN

EARLY AUSTRALIAN EXPERIENCES WITH THE OLD BEN METHOD OF PILLAR EXTRACTION

Dan retired as Managing Director of Elcom Collieries in 1988. Born in Lithgow in 1926, he graduated from Sydney University in 1948. During his career, he managed Nymboida, Millfield, Kalingo and Huntley Collieries and Wyee State Mine.

■ *How did the Old Ben System come to be introduced into Australia?*

I believe Bill Seaward of Coal and Allied was the first to try it back in 1948 in the Cessnock Coalfield, but it was unsuccessful. I observed the system in operation in 1962 at the Old Ben No. 21 mine in Illinois under ideal conditions; a hard floor and a uniform seam about 6 feet thick. They had Goodman full face borer miners and were achieving high tonnages. I was impressed and thought the method could offer us safety and productivity benefits and help overcome our soft floor problems at Wyee State Mine.

■ *What results were achieved when Wyee State Coal Mine first introduced the system?*

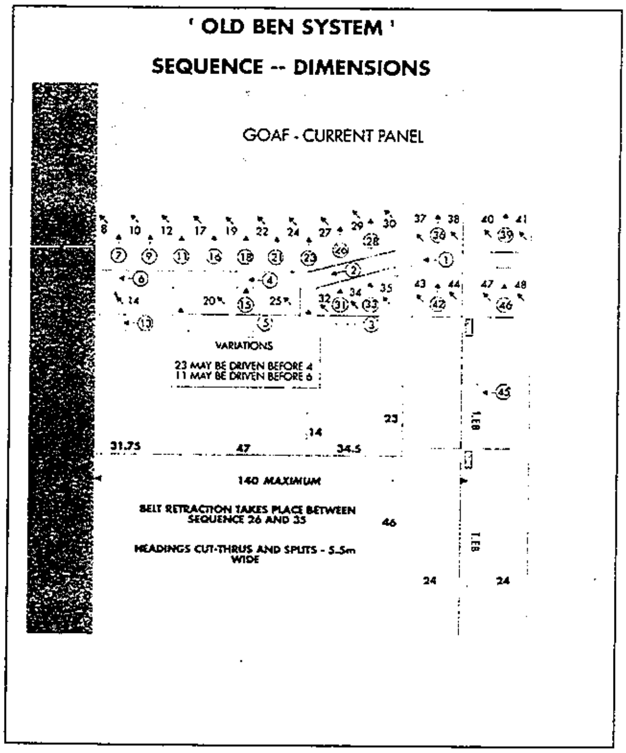
A Goodman borer miner was purchased and a 164m wide panel was tried based on the original Old Ben design. The sequence of operations was carefully planned and enforced. Ventilation was through the goaf with provision for bleeding off small gas accumulations using a regulator in the third development return heading. It was evident however, that although capable of high tonnages, the borer lacked flexibility. It was front heavy causing it to drift into the soft floor.

■ *What was your experience using continuous miners with the Old Ben System?*

Results were excellent and we achieved high productivity from a trial panel. Again, we imposed a strict operational sequence (unaltered without reference to a senior official), and it was possible in the narrow panels for two shuttle cars to change quickly and in sequence behind the miner, each with its own wheeling road of up to 140m. Back spooling was avoided by anchor points placed diagonally at intersections and able to be moved up. All belt road intersection were roof bolted on night shift as a precaution.

■ *What is the modified Old Ben System and how did it come about?*

Extraction was so rapid that we decided to modify the method and provide another line of pillars on the solid side. So the panel width increased by 15%, allowing greater utilisation of the belt and transport roads. We added a second and third line of pillars but with reservations and the panel width was increased by 45%. Floor heave occurred and extensive grubbing of floor stone was necessary to maintain the supply road. The rate of retreat decreased markedly and the coal was no longer 'green' when extracted. We had gone too far. So we reverted to the Old Ben layout, although some collieries adopted the Modified Old Ben layout with one extra pillar on the solid side.



The 'Old Ben' System

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Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales

Sponsored by the Joint Coal Board

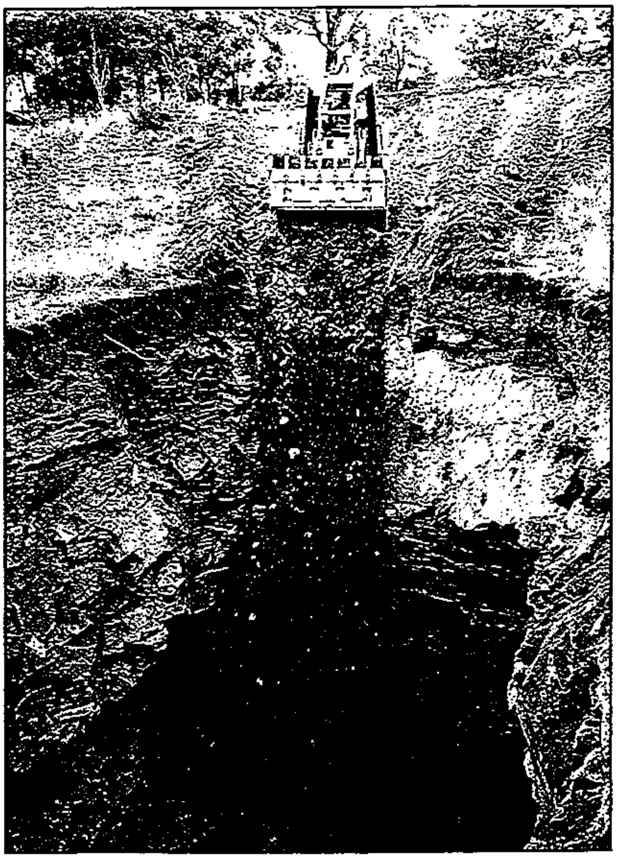
Issue No. 3

December 1993

PROJECT PROGRESS

An analytical review of 44 incidents of buried continuous miners in NSW is nearing completion. Some of the findings are reported in this Newsletter and will be presented in future editions. A number of issues dominate the mishaps, with more than one issue being involved in most cases.

It is encouraging that this field experience base is complemented by progress in developing a theoretical understanding of the mechanisms of yielding coal pillars. Stooks and fenders have a critical impact on stability and thus safety in pillar extraction operations. The theoretical research is providing insight into the circumstances under which stooks and fenders yield in a controlled manner, as opposed to an uncontrolled manner. These investigations are important since over 55% of buried continuous miners and 60% of resulting fatalities have been associated with collapses of fenders and stooks. The research is also relevant to the design of stress relief headings and yielding chain pillars in longwall mining. Reviews of South African and USA pillar extraction practices have been completed. At first glance, the wide range of techniques in use suggests that pillar extraction is still an "art" rather than a "science". However, a closer examination of case studies highlights that the methods are underpinned by scientific principle, albeit that operators are not always conscious of the science, having developed their methods through experience. Quite clearly, developments in our theoretical understanding of yielding pillars are important in progressing from art to science.



Plug Type Subsidence Associated With 8m High Bord and Pillar Workings.

Further data have been collected on the field performance of pillar systems with additional past pillar collapses being brought to our attention. In competent roof and floor environments, pillar performance continues to be consistent with that predicted by established pillar design procedures. Further research is required however, into the impact of soft surrounding strata on pillar stability.

One of the principal objectives of this project is to improve the knowledge base of the industry. It is pleasing to announce that the first technology transfer workshop is to be held in May 1994. Further details appear later in the Newsletter.

Contents

ISSUE

PILLAR EXTRACTION - BURIED CONTINUOUS MINERS

In the eleven years to 1992, 15 fatalities occurred during pillar extraction operations in NSW. Of these fatalities, 12 were associated with events where continuous miners were buried. A total of 60 continuous miners were buried for periods exceeding seven hours in the three year period to 1992. A total of 44 of these documented events have been reviewed to provide insight into:

- the mechanics of pillar extraction and
- appropriate preventative measures.

The statistics raise a number of issues. For instance, the belief that pillar extraction is most dangerous adjacent to intersections appears to be confirmed. Exactly half of those killed were effectively waiting in intersections. Three further victims were adjacent to the continuous miner but without the protection of a steel canopy.

In general, three kinds of environment are associated with pillar extraction in NSW, with each producing a characteristic type of failure.

- Shallow depth (15-50m). A fall progresses suddenly to surface without warning. (Associated with four fatalities.)
- A 2-3m weak immediate roof strata overlaid by a massive competent roof strata which bridges or cantilevers and protects the weak roof strata from load. The weak roof strata masks the state of the upper strata. Factors such as excessive spans and geological features can cause the immediate roof to fall suddenly with little or no warning. Alternatively, falls may be driven by failure of overhanging upper roof strata and therefore, extend higher into the roof. (Associated with most buried continuous miners and fatalities.)
- Massive, brittle, very competent immediate roof strata, which can span up to hundreds of metres without failing. This results in both high abutment stress and a vast amount of potential (fall) energy being stored in the rock. When the load exceeds the strength of the rock, sudden and often violent dynamic failure occurs without warning. Failure may be localised in the form of pressure bursts (bumps) and feather-edges or regional as in a major goaf fall and windblast. Dynamic events occur more frequently than previously appreciated. (Associated with at least two recent fatal accidents.)

Most pillar extraction accidents are due to the coming together of a number of factors. The more important of these are:

- Excessive spans - overwidth bords, lifting left and right, retreating into or from an intersection.
- Geological features - faults, cutters, cleat.
- Loss of rock strength with time - holing old goafs, extracting standing pillars, letting partially extracted pillars stand.
- Subcritical panel widths - high abutment stress, stored energy, changing face conditions, irregular caving.
- Poor control - deviation from approved sequence, failure to learn from past mishaps.

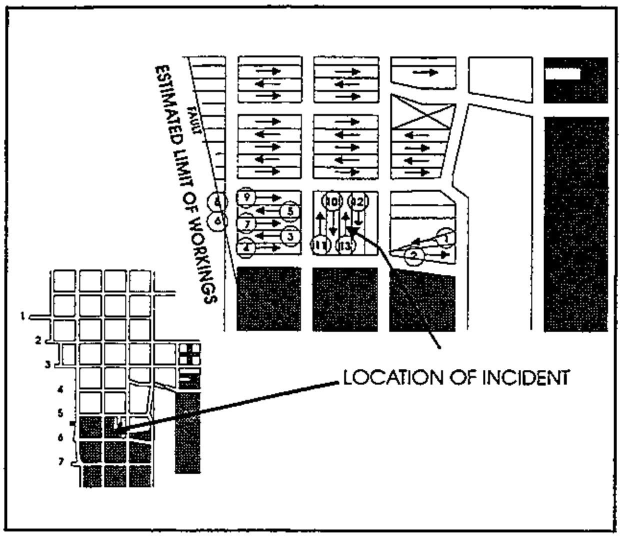
In the past, most accident investigations have focused on active failures i.e. deviation from stipulated rules. Very few investigations have focused on latent failures i.e. appropriate design for the conditions. Research into yield pillar design reported elsewhere in this Newsletter shows that the mode of failure of a fender is a function of depth, mining dimensions and the nature of the surrounding strata. It is important to develop this understanding to avoid some of the subjective and often contradictory conclusions of the past.

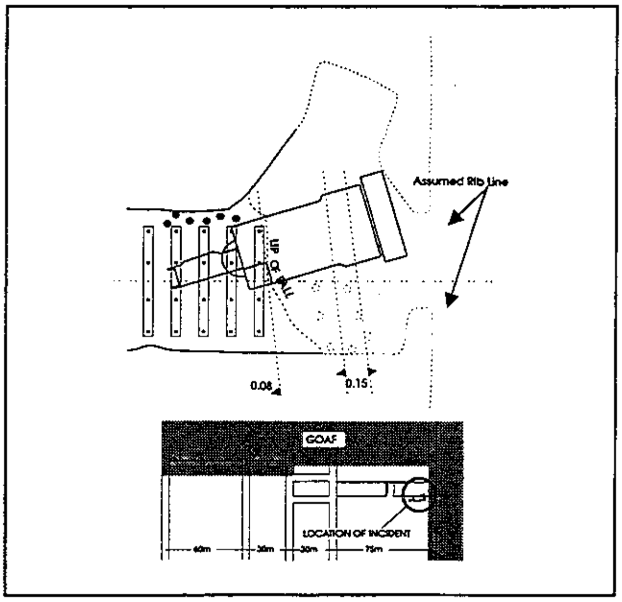
SOME FACTS AND FIGURES

TYPE OF MINING OPERATION	
• Driving first workings	3
• Driving pillar extraction secondary development	2
• Lifting off pillars	39
POSITION IN MINING SEQUENCE	
• Taking first or last lift off a fender	64%
EXTENT OF MACHINE BURIAL	
• 0 - 30%	1
• +30% - 60%	3
• +60% - 80%	9
• +80% - 90%	7
• +90%	24
FREQUENCY OF DRIVER'S CAB BEING BURIED	
• 25/44	57%
HEIGHT OF FALL ABOVE WORKING ROOF	
• 0-3m	66%
• 3 - 6m	7%
• Full Goaf	17%
WARNING OF IMPENDING FALL	
• No	37%
• Yes	63%
STOOKS AND FENDERS	
Frequency of crushing and over-running:	
• Total	55%
• Fatal Accidents	60%
LOCATION OF VICTIMS	
• Driver on board continuous miner	0
• Driver running from continuous miner	3
• Adjacent to continuous miner	3
• Ribline of intersection outbye of face	6
PRIOR ACTIVITY OF VICTIMS	
• Driving continuous miner	3
• **Face Active:** Directly engaged in face operation (inc. acting as cockatoo)	1
• **Face Passive:** Not directly engaged in a face operation *of which*	8
• **Face Passive:** On ribline of intersection	6
MINER DRIVERS	
• Protected inside cab	5
• Protected but requiring extended rescue	3
REMOTE CONTROL CONTINUOUS MINERS	
• No	31/33
• Yes	2/33

POINTS OF NOTE

- A trial was proposed to split all pillars parallel to the goaf and then extract the three fenders formed back across the panel. Trial abandoned when sequence 1 driven off line.
- Effectively goaf on three sides.
- Roof fell after first lift and again on holing second lift, burying continuous miner.
- Height of fall - tapering up to 6m.
- Issue may be one of the roof behaving differently to that which mineworkers were accustomed to reading, due to the change in extraction sequence.



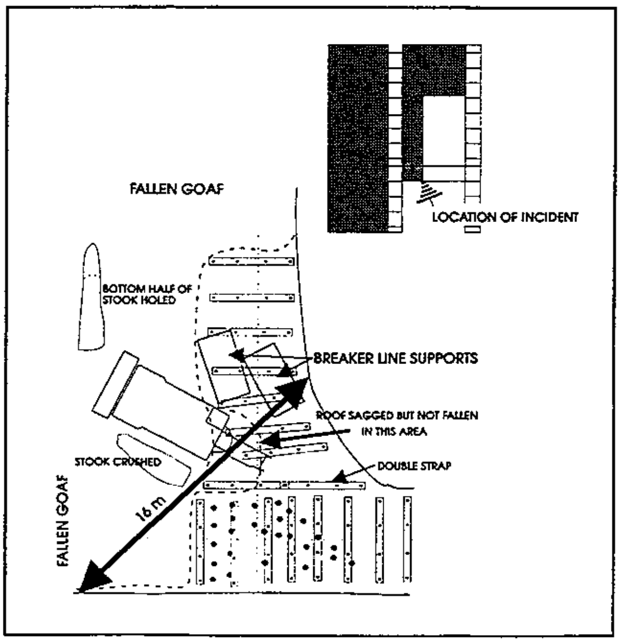


POINTS OF NOTE

- Depth ~ 400m, Mining Height ~ 3.0m.
- Weak mudstone roof overlain by massive conglomerate.
- Offline driveage gave 10m wide fender which could not be holed for ventilation, therefore, goaf intersection was being widened.
- First lift off fender.
- Holing old goaf (effect of time on strength!)
- Goaf on two sides (high abutment stress zone!)
- Numerous small faults in runout had opened up over last 50m.
- Height of initial fall 1.8 to 2.0m.
- Virtually no warning.

POINTS OF NOTE

- Depth - 185m, Mining Height ~ 2.5m to 2.8m.
- 1m to 3m of mudstone roof overlain by massive conglomerate.
- After 250m retreat, the direction of extraction was changed, effectively requiring a new goaf to be established (hence increased abutment stress).
- Last lift off fender.
- Stooks crushed out, goaf fell, virtually no warning.
- MBLS only protected one side of continuous miner and broke off fall.
- Span from MBLS to far rib was 12m. Perhaps MBLS gave a false sense of security?



Where Have We Come From ...

WHERE Hamilton Pit, Glebe, Newcastle, New South Wales

WHEN Saturday 22 June 1889.

WHAT At approximately 8.45 am, a 20 ha area of bord and pillar workings collapsed, killing 11 mineworkers.

The area affected, known as the Cross-Cut District, was located about 1km to the SW of the Hamilton Pit which was a 60m deep shaft pit. The workings in the Cross-Cut District had been developed over a period of about 6 years. Bords nominally 7.3m (8 yds) wide were driven to both sides of the headings to leave long slender pillars that were typically 60m long by 3.6m wide. The pillars were developed to full seam height which ranged throughout the district from 2.3 to 2.7m. Pillar extraction had commenced about 16 months prior to the collapse with a view to retreating eastwards. Over the period leading up to the disaster, there were 11 working places in the cross cut pillars and it is presumed that all were involved with pillar extraction. They were spread across the western extremity of the district and apparently, no more than one full row of pillars had been taken out and with some quite large remnants left in place.

There were 18 men in the district at the time of the collapse, seven or whom escaped. The lights of the fortunate seven had been blown out by the "extreme force of the wind" from the collapse, but they eventually found a way out, albeit a long and tortuous one. Some few others had earlier heeded the several warning signs, reported them to the Deputy and Overman and left the district.


Mine Plan

From evidence given at the inquiry, it was clear that there was no apprehension of a fall until that morning. There was no great extent of goaf where pillars had been extracted and there were no large falls of roof in the goaf areas prior to the collapse. The first serious indication that all was not well occurred on the Saturday morning about two hours before the disaster. The deputy, who was one of those killed, had inspected the various working places earlier that morning and considered them to be safe. When some of the miners reached their work place and others were on their way, they variously described the roof as "working badly", "thundering most awfully", "starting to boom in the pillars". Eventually and after two hours of such warning signs, the collapse started and quickly spread throughout the workings.

The verdict of the jury, although primarily concerned with the cause of death, had the added rider ".... we are of the opinion that the late terrible accident was caused by the weakness of the pillars. We recommend ... that a clause be inserted in the new Mining Bill ... that in future, all pillars on each side of all main ways be 16 yards wide and driven in 6 yards before opening out to 8 yards wide. We consider that (the Overman) neglected his duty in not calling the men out when it was reported to him that the pit was working so badly".

Back Analysis of Hamilton Pillar Collapse

Although the Welsh pillars were rectangular in shape, the strength of the pillars would have been governed by their width, which was only 3.6m. On this basis, the pillars had a width to height ratio of only 1.33. Once pillar extraction commenced (and later when the collapse was triggered), the pillars on the goaf edge were subjected to additional abutment load.

Roof and floor conditions were noted to be good and failure of the coal pillars themselves was quite evidently the cause of the collapse. The table summarises the safety factor of the coal pillars before and after pillar extraction commenced. Although the two safety factor formulae may require modification to take account of local conditions, it is noteworthy that, as with all cases of coal pillar failure studied by the project to date, they are within reasonable working bands for coal mine design.

Case	Formulae		Salamon Probability of Stability
	Bieniawski	Salamon	
First Workings	1.37	1.32	95%
Pillar Extraction	1.01	0.97	42%

Yielding Coal Pillars

When the maximum load carrying capacity of a coal pillar is exceeded, the pillar may fail in a gradual controlled manner, in which case it is said to "yield" or in a sudden uncontrolled manner, such as the Coalbrook Collapse, (see Issue No. 1). Pillar failure mode is important since this affects the stability and performance of stooks, fenders, chain pillars, stress relief headings and pre-developed longwall recovery roadways.

Factors that impact on the behaviour of overloaded pillars are well known, e.g. pillar width to height ratio. However, virtually no sound knowledge appears to be available on the mechanics of a yielding pillar in a mining system environment. Indeed, the term "yielding" pillar has been used loosely in the past and generally outside the classical engineering definition of a material in "yield".

The project has developed a model of coal pillar behaviour which includes the yielding response of an overloaded pillar. Validation of the mechanics of "yielding" pillar behaviour has been based on many case histories. The mathematical model uses realistic input data and does not depend on back-analysis. The model is now being expanded to cater for general total extraction layouts.

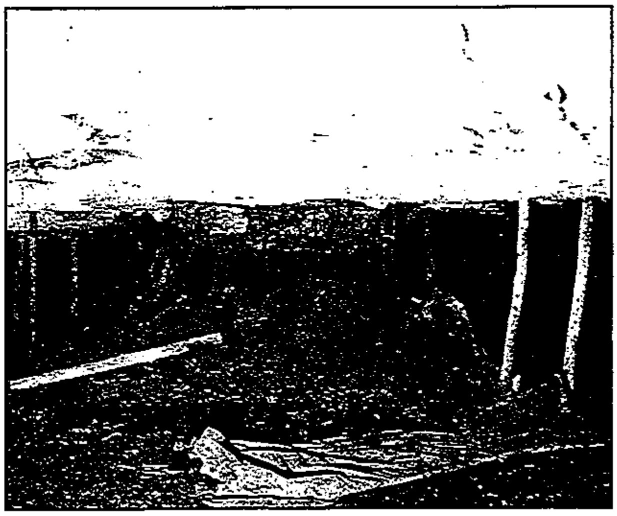
The influence of fender width in a Wongawilli system is clearly shown from the results of the model. Consider the case where panel width is sub critical and so full caving does not develop. In the figure, the average fender stress is plotted against an "equivalent" standing goaf span for a variety of fender widths at a depth of 490m and a mining height of 2.7m.

The model confirms that fenders of 7m width or less yield immediately upon driving. Therefore such fenders shed load early and result in a de-stressed working environment. On the other hand, larger fenders require significant amounts of "equivalent" standing goaf before they yield. These larger fenders are not in a de-stressed environment and attract significant load. Furthermore, the larger fenders shed load abruptly once they start to yield.

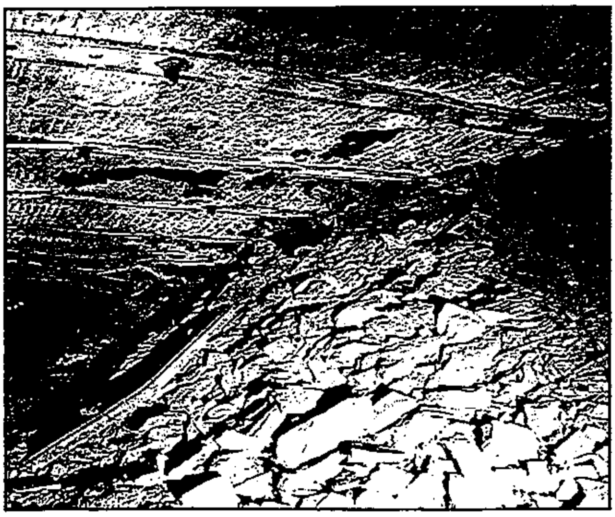
The analysis indicates the importance of fender width:

- Smaller fenders yield and shed load gradually.
- Wider fenders are stiffer and attract greater load.
- Wider fenders will shed load abruptly upon yielding.

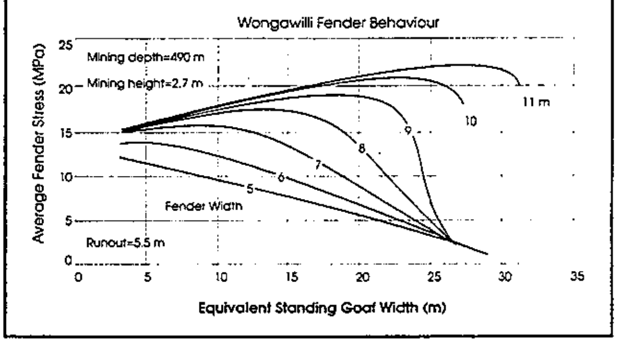
The figure also highlights that a small change in fender width or amount of standing goaf can have a significant affect on fender behaviour. It is important to be able to quantify the effects of these parameters since pillar extraction and longwall operations represent dynamic environments where both parameters are susceptible to change.



An Unyielded Stook at a Depth of 100m.



A Yielded 8m Wide Fender at a Depth of 400m.



Pillar Mechanics Workshop

A workshop to transfer project findings to date to mine personnel is scheduled for:

Tuesday 24, Wednesday 25 May 1994

This first workshop is subsidised by project funds and is therefore being limited to NSW coal industry employees. (Open workshops will be held subject to demand).

Cost: $250.00

Objective: To provide a basic working knowledge of coal pillar design and behaviour for both first workings and pillar extraction.

Structure: Day 1: Pillar Design and Performance
- Theory
- Case Studies
- Design Exercises

Day 2 Pillar Extraction
- Design and Layout Issues
- Case Studies
- Design Exercises

Target Audience: The workshops will be targeted at a broad range of mine personnel but especially those with shift supervisory, mine planning and mine management responsibilities.

Venue: To be confirmed

Questions and Answers

RIB STABILITY

■ ***Do coal ribs present a serious safety hazard in NSW?***
Yes. During the last three years more than 450 miners have been injured by falls of rib. This represents almost 60% of all injuries due to falls of coal and stone.

■ ***How serious are rib fall injuries?***
Rib falls also represent about 60% of all reportable injuries due to falls of coal and stone and accounted for over 300 Lost Time Injuries (LTIs) in the three years to June 1992.

■ ***What do rib fall injuries cost?***
Of course, no value can be ascribed to personal distress and suffering. However, a major coal mining company recently reported that the all-up cost to the company of medical expenses, accident investigation, lost personnel time etc. was $30,000 per LTI. On this basis, rib falls meant the loss of more than $9million over the last three years in NSW.

■ ***What factors cause rib falls?***
There are several factors but the more prevalent ones are:

- The ribs expand when the coal that was previously confining them is removed.
- When a roadway is formed, the weight of the roof is transferred onto the pillar edges, causing the ribs to bulge out under load.
- The ribs fall out due to geological weaknesses.

■ ***How can rib failure be controlled?***
The use of artificial support to replace the confinement previously provided by the extracted coal is the simple answer - but it is not a simple solution. Ribs may fail as soon as the coal confinement is removed. Usually, the roof has to be supported before the rib support can be installed. This may require miners to work near unsupported ribs and it gives the ribs time to deteriorate. Furthermore, anchorage and coverage problems associated with the artificial support mean that it does not always provide the degree of confinement previously provided by the coal.

■ ***What initiatives are being undertaken to improve rib safety?***
There are a number of initiatives including:

- Remotely operated roof and rib bolting machines.
- Geotextile rib support membranes.
- Yielding rib bolts.
- Polyurethane resin (P.U.R.) rib support cartridges.
- Low strength bulk backfills.

Trial Site of a Low Strength Bulk Backfill to Stabilise Ribs by Providing Confinement.

Publications

The results of the Strata Control for Mine Design Project are documented regularly as the work proceeds. Reports published since the previous Newsletter are listed under the appropriate category.

1. Progress Reports

Galvin, J.M., *Review of Overseas Pillar Extraction Techniques,* U.S.A., Nov, 1993. PR 5/93.

Quinteiro, C., *Modelling Yield Behaviour of Coal Pillars - One Pillar Asymmetric Case,* Dec, 1993. PR 6/93.

2. Research Reports

Anderson, I., *Case Studies of Buried Continuous Miners and Fatal Pillar Extraction Accidents in NSW,* Dec, 1993. RR 1/93.

KEY RULE OF THUMB

When subjected to constant load the strength of rock decreases with time

All materials (even high grade steels) contain flaws and micro cracks. If subjected to enough load, these weaknesses propagate over time. In comparison to igneous or metamorphic rocks, like granite or marble, coal measure rocks such as shales and sandstones, have many more intrinsic weaknesses and require less load and less time to cause the weaknesses to grow. The strength of a rock can therefore reduce over time.

Applications in Mining

Secondary Extractions in Old Workings

Roof which was competent and required minimal support when first exposed cannot be assumed to be competent by the time secondary extraction commences. In particular, the roof may no longer be capable of bridging the same unsupported spans.

Pillar Design

Pillar foundations (floor and roof) can lose strength over time under the effect of constant pillar load. A higher pillar safety factor (see Issue No. 2) may be required to reduce pillar load if it is important that stability be maintained over the long term.

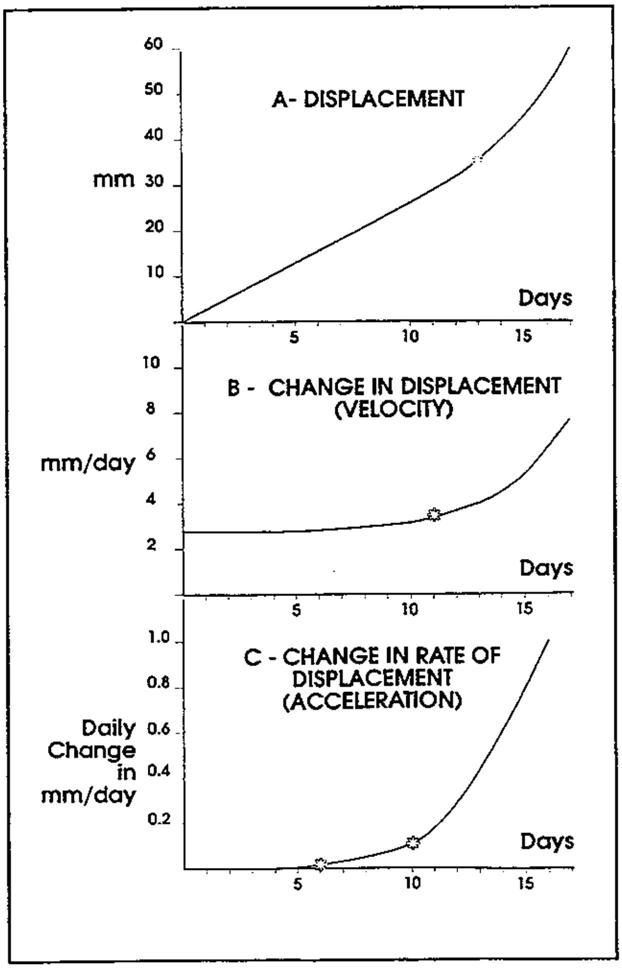
Pillar Extraction and Longwall Mining

The width of panels should be chosen to ensure that a steady rate of retreat is achievable. Pillars should not be left in a partially extracted state.

Extensometer Readings - Early Warning of Impending Failure

Extensometers are used to measure rock displacement (roof, ribs, floor). Usually, "displacement" is plotted against "time" as shown in the "Displacement" Graph, A. Better use and earlier warning of impending failure can be obtained from this data if plotted as "Rate of Change of Displacement" against "Time". This results in a "Velocity of Failure" graph such as B. Even earlier warning is obtained if the "Rate of Change" in the velocity of displacement is plotted to give an "Acceleration of Failure" graph, shown as C. (Day 6/10 *vs* day 11 *vs* day 13)

The reason for this is because the load required to cause a crack to grow reduces in proportion to the square root of the length of the crack. For example, by the time a 1mm long crack grows to 10mm, only 1/3 of the original load is required to cause the crack to continue to grow. However, the load in the mining environment is nearly constant. This means that once failure starts, it will **accelerate** exponentially. The accelerated failure can be detected more easily and sooner if data are plotted in the form shown in graphs B and C.



If you would like further information on any aspect of the Strata Control for Coal Mine Design Project or wish to make a relevant technical contribution or comment, please contact

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**INTERVIEW WITH
MR GEORGE GRANT**

EARLY AUSTRALIAN EXPERIENCES WITH THE WONGAWILLI METHOD OF PILLAR EXTRACTION

George was born in Weston in 1934 and joined the coal mining industry as a Cadet at Richmond Main Colliery in 1951. During his career, he worked for J & A Brown, Bellambi Coal, Coal Cliff Collieries and BP/Clutha in various positions including Surveyor, Undermanager, Manager and Superintendent. He is currently involved in Management projects with various mining companies.

■ ***How did the Wongawilli System of Pillar Extraction come to be developed?***

My association with the system began in the 1960's at Coalcliff Colliery, although the initial concept was established in the Wongawilli Seam at the A.I. & S. mines. The system was pursued in various forms in an endeavour to provide a single working place, to contain workings in a "stress relieved" zone and to improve percentage extraction within the panel. The method was considered repetitive and of advantage in maintaining uniformity and control of operation between face crews.

■ ***What were your early experiences of the method at Coalcliff Colliery?***

A progression of problems with conventional pillar extraction and longwall mining caused the colliery to initially adopt the layout shown in Figure 1. An auxiliary conveyor was installed and extraction blocks were typically 160m wide at a depth of 500m. Problems were continually encountered with this arrangement because splits driven from the conveyor or return heading to the previously formed goaf line were located in a high abutment stress zone. Observations indicated that the abutment loading was 20 to 30m outbye the goaf front. In these conditions, the time taken to extract a sub-panel was critical to maintaining production and maximising production. Under an immediate roof of 1m shale, extraction rate slowed and conditions deteriorated.

■ ***What modifications were made to deal with these problems?***

The system was changed to the Wongawilli concept as we know it today, (Figure 2). The split was driven in the relatively de-stressed area between the goaf edge and the abutment stress zone. (The old miners called this coal "winded coal"). The width of the block was reduced to 70-80m to facilitate brattice ventilation, shuttle car efficiency and extraction times. Fender centres were ultimately fixed at 13m to maintain extraction in the de-stressed zone and to limit the entry distance of the continuous miner into the lift.

■ ***Did the Wongawilli System Improve Performance?***

Yes. Some of the problems previously experienced in splits and lifts such as floor heave, creeps and buried machines, were alleviated. The initial method achieved 500 tonnes per shift which dropped to 300 tonnes under mudstone roof. The subsequent system achieved shift tonnages of up to 1,000 tonnes with up to 2,000 tonnes over 24 hours.

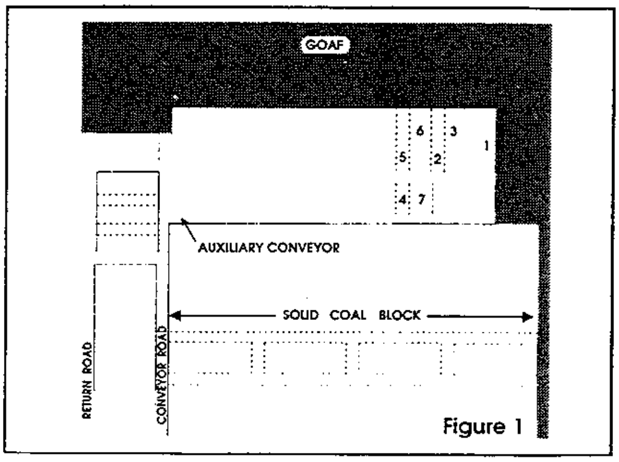


Figure 1

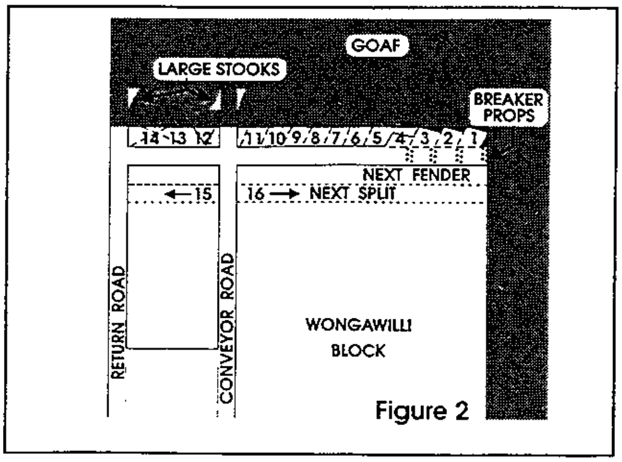


Figure 2

Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales   Sponsored by the NSW Joint Coal Board

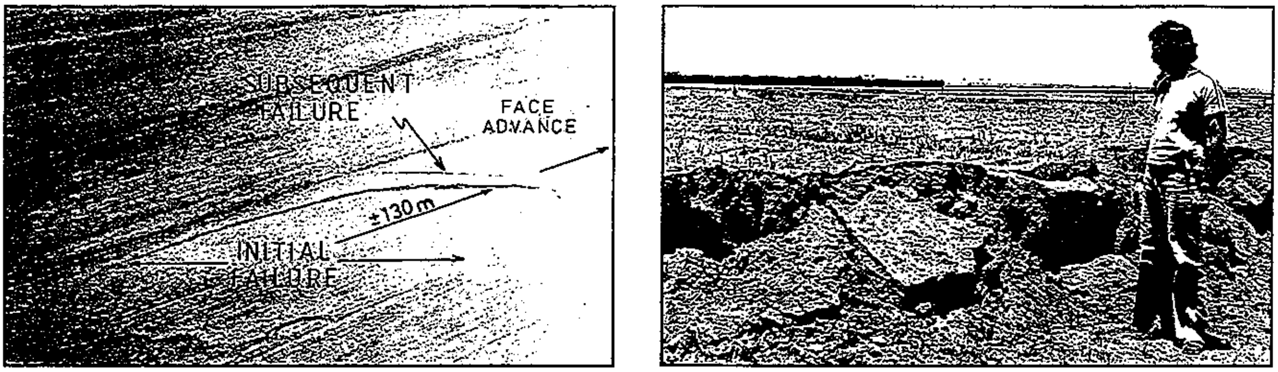
Issue No. 4   April 1994

Project Significance

In Issue 3, some findings of an analytical review of 44 incidents of buried continuous miners were presented. The positive feedback to that Newsletter indicates that such case studies and analyses are an effective means of improving the safety awareness and knowledge base of the industry. It has also led us to expand the forthcoming Pillar Mechanics Workshop, details of which appear later in this Newsletter, along with further case study results.

A principal objective of the Project is to advance our theoretical knowledge of strata behaviour to improve safety. This involves the application of mechanical engineering principles to the geological when reviewing the 44 buried continuous miners investigation reports, a lack of such understanding can lead to a variety of interpretations of events and causes being assigned to a mishap. Some interpretations may be correct and effective in preventing a re-occurrence. Others can be wrong and thereby aggravate the problem.

One of the more complex areas where our theoretical knowledge base is lacking is in the behaviour of a coal pillar once its maximum load carrying capacity has been exceeded. This situation is faced every day by operators in pillar extraction panels. The Project continues to make pleasing progress in this area. The



Subsidence above a 220m wide longwall at a depth of 100m. Empirical prediction techniques (NCB curves) proved inadequate since they did not account for the mechanism of failure of the 45m thick dolerite sill in the roof strata.

environment. Reviews of field performances enable operating mines to be used as our testing laboratory. Soundly engineered outcomes are equally relevant to roadway performance, rib stability and chain pillar design in longwall mining.

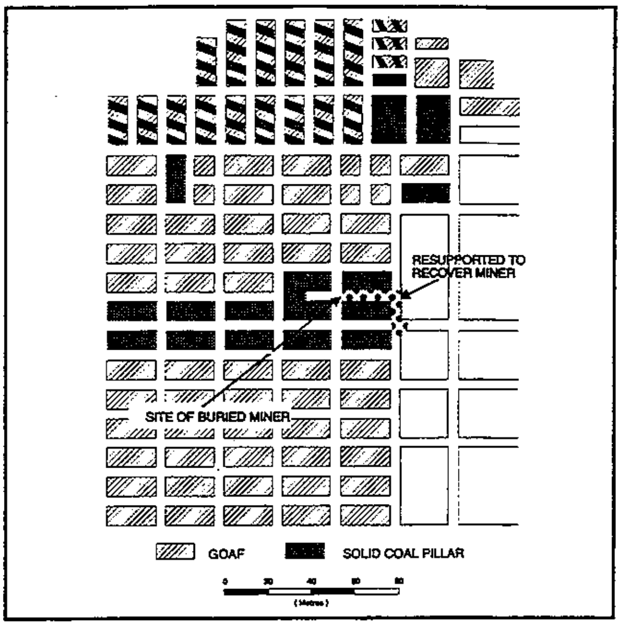
Improved understanding of the mechanics of strata behaviour provides a disciplined approach to investigations, data collection and analysis, design, risk management and the implementation of effective corrective actions. Conversely, as clearly evident reader is referred to the diagrams on Page 3 as an example.

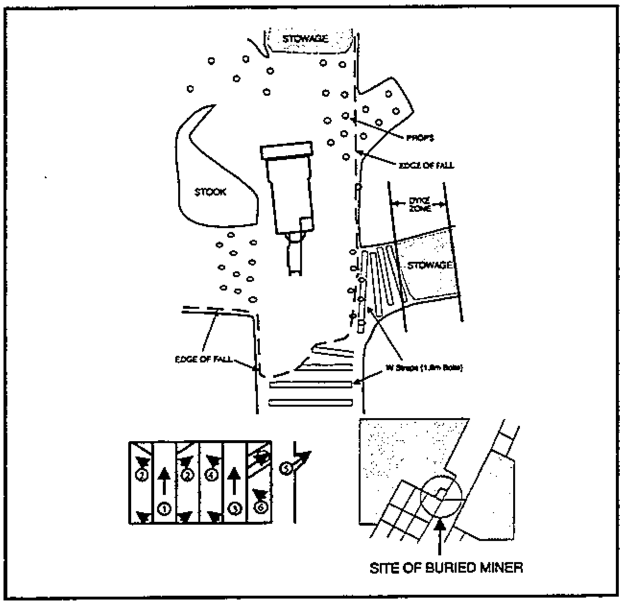
These highlight that even where panel layouts and geology are identical, a Wongawilli fender can be expected to yield in a significantly different manner at a depth of 200m as compared to a depth of 500m. Although still at a qualitative level, this improved understanding is already facilitating more effective accident investigation, design and control measures, geological assessment and field data collection and analysis.

Contents

POINTS OF NOTE

- Depth 70m, mining height 3.5 to 4.0m.
- Extracting panel left and right back to belt road to facilitate use of a continuous haulage system.
- Significant coal left as stooks in Chevron pillar extraction workings to the north. Also some fenders not lifted off.
- Massive conglomerate immediate roof 30m thick, noted for its capacity to bridge large spans. Sandstone floor.
- Severe rib crush prevented lift in inbye pillar from being holed.
- Upon continuous miner holing lift, the roof outbye was heard to "work". This was followed by a fall associated with a feather-edge which partially buried the continuous miner.



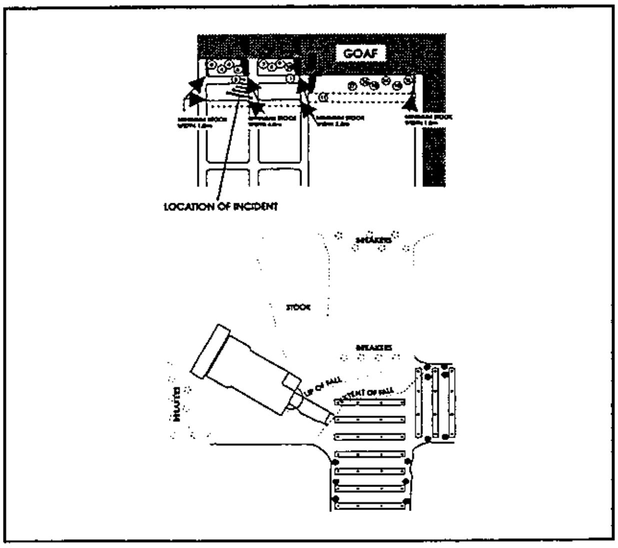


POINTS OF NOTE

- Pillars 38 years old.
- Pillar stood on goaf line for four weeks during shutdown.
- Pillar extracted over a four day period.
- The last fender was left in a partially extracted state (14m stook) over the weekend. Goaf from previous pillar lifts had not fallen.
- Lifts taken left into fender and right into barrier between adjacent goaf.
- Immediate shale roof had thickened considerably, dyke zone adjacent.
- Fell suddenly to 3m height, 7m x 4m x 2m stook crushed to 1.5m height.

POINTS OF NOTE

- 2m of sandstone roof, overlain by 2m of shale, overlain by massive sandstone.
- Sequences 1 to 5 mined without incident or fall of goaf. Sequence 6 holed, stook X began to yield. Roof fell before C/M could be fully withdrawn.
- The goaf fall was initiated at Stook X and then progressed towards sequence 3.
- A comparison between this behaviour and theoretical developments in the yield behaviour of small coal pillars (see opposite page) reveals a number of consistencies, e.g. rapid but controlled yield, with roof "chasing" yielding pillar.



ISSUES

PILLAR EXTRACTION - BURIED CONTINUOUS MINERS

In the past, most accident investigations have focused on active failures (i.e. deviation from stipulated rules). Because these rules have mainly evolved from experience, they usually have some relevance to the accident cause. However, their value is limited if they have not been based on an appreciation of the potential modes of failure applicable to the local conditions. This understanding requires future investigations to focus on latent causes of failure (i.e. appropriateness of design to the conditions).

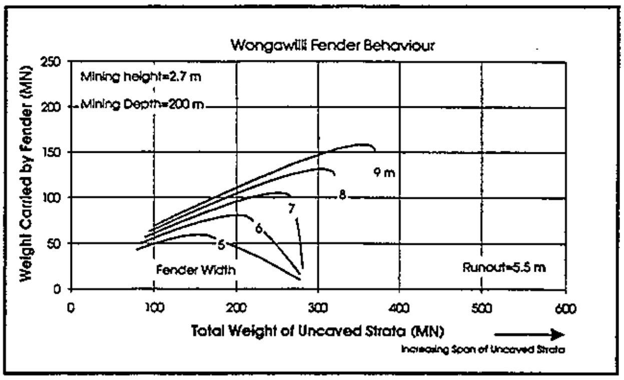
The analytical review of 44 incidents of buried continuous miners is highlighting a number of latent issues that are impacting on the safe and efficient extraction of pillars. One of these is the overall (effective) width of extraction to depth ratio, Weff/H. A primary goaf fall or a choked goaf does not necessarily imply that full caving has occurred. If it has not, then panel width is subcritical and may continue to be so until a number of panels have been extracted. Mining designs and control measures should cater therefore, for:

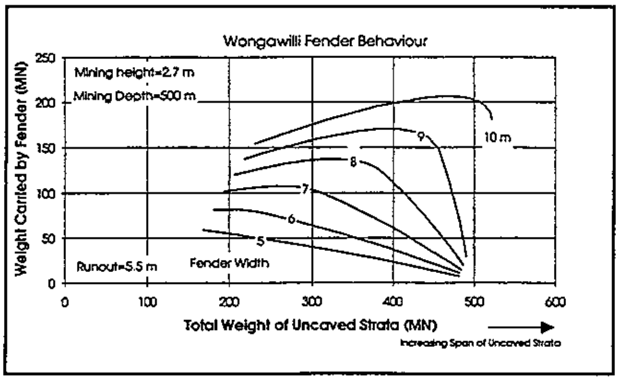
- high abutment stresses and levels of stored energy,
- the release of this energy at a critical Weff/H ratio, and
- changing face and fender behaviour conditions (see diagrams below).

Significant spans are often required to fully cave conglomerate and sandstone strata. Many accidents have been associated with high abutment stress, excessive and hazardous rib spall, windblast, pressure bursts and feather-edging under bridging strata. Surface subsidence versus Weff/H graphs are practical field tools for pre-empting the degree of caving and magnitude of abutment stress associated with total extraction panel designs.

The accident reviews indicate that if "surprises" or "unplanned events" are to be avoided in pillar extraction and longwall operations under massive brittle strata, further research is required into the minimum mining spans required to break the strata, the mode of failure and the mechanics of feather-edging.

YIELDING COAL PILLARS / PREDEVELOPED LONGWALL RECOVERY ROADS





The influence of stiffness of the mining system on strata behaviour is illustrated by these two diagrams which depict Wongawilli pillar extraction at depths of 200m and 500m. The mining layout and geological properties are identical in both cases. Fenders fail at the same load. However, the manner in which they subsequently shed load, or yield, is significantly different. For example, a 7m fender yields more rapidly at 200m depth compared to the same fender at 500m depth.

As the depth of mining decreases, the thickness and stiffness of the roof strata are reduced. The roof is less capable of transferring load from the fender onto the panel abutments. In this softer system, the roof "chases" the fender, causing it to yield more rapidly.

The cases presented assume that all the load is carried by the fender and the abutments. Caving and goaf reconsolidation are currently being incorporated into the analysis to take account of the load carried by reconsolidated goaf. These developments find wider application. In longwall mining, for example, they can be applied to:

- Chain pillar design and behaviour.
- Quantifying the dynamic behaviour during holing operations of predeveloped longwall recovery roadways.

Where Have We Come From ...

WHERE New South Wales, Australia

WHEN Mid 1960's

WHAT During open ended extraction of standing pillars, there was a sudden collapse of conglomerate roof at the working place. The fatal fall comprised a feather edge 0.3 to 0.5m thick and covering an area of 206m^2.

The accident occurred at a depth of 180m in a panel that was approximately 140m wide and 410m long (minimum panel width to depth ratio, W/H, 0.78). Mining height was 2.5m. The first major goaf fall occurred after extraction of a 1.7ha area and involved 1.5ha of roof strata. Some windblast damage resulted and thereafter smaller and more frequent goaf falls occurred as the work proceeded. Surface subsidence of up to 200mm over the area was taken to indicate satisfactory caving, this being the first total extraction panel at the colliery.

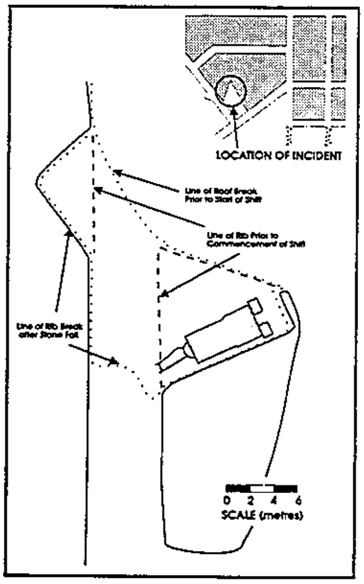
It was during the extraction of the last pillar of the panel that the feather edge roof fall occurred. Two days before the accident, it was noted, during a visit by the District Inspector, that no stooks of any significance had been left in the goaf and that props and lids were breaking well out into the standing goaf.

The pillar being extracted was of irregular shape and approximately 20m long by 10m wide. Extraction involved a succession of open-ended lifts, each about 3.6m wide and up to 13m long. Lifts were supported by props and lids, set about 1.2m apart. Systematic breaker line props were not set and the continuous miner was not fitted with a protective canopy. Extraction of the third lift was nearing completion when the roof collapsed. Prior to these lifts being started, coal had been extracted from the solid barrier pillar to the west. At this time, the goaf had fallen up to the perimeter of the pillar.

The fall was described by eye witnesses in terms such as "the roof peeling away" .... "came in big lumps about one foot thick, ranging from 8 feet square to 10 feet square ... and a lot of dust". Evidently, there had been very little warning, although those killed and two survivors had paused just before the collapse to look and listen. Subsequently, the miner driver noticed dust falling onto the controls and fled as the fall was occurring.

SUBSEQUENT DEVELOPMENTS

- Long (>6.5m) open-ended lifts are no longer permitted using on-board operators.
- Systematic breaker line support is now mandatory.
- Continuous miners must be fitted with protective canopies.
- Pillar extraction must be undertaken in accordance with a planned system of work.
- A W/H ratio of 0.78 is now recognised to be subcritical for the development of full caving under conglomerate roof.
- The mechanics of stress-induced feather edging have yet to be adequately researched and feather edging in brittle roof remains a hazard, both locally and internationally.



The fall comprised a stress induced feather edge characterised by the low angle curved fracture plane.

Pillar Performance

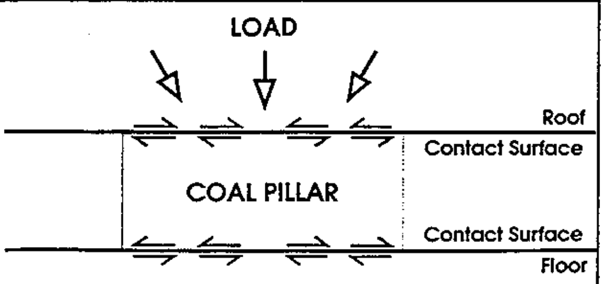
A method for coal pillar design should consider not only the coal but also the strength of the roof and floor strata. Under load, the coal pillar wants to expand laterally. Friction and cohesion along the roof and floor contacts generate resistance to this movement. This resistance increases as the area of the pillar increases. Its strengthening effects decrease with vertical distance away from the contacts towards the mid-height of the pillar. This accounts for why:

- Pillar strength increases as pillar width to height ratio, w/h, increases.
- In strong roof and floor environments, pillar failure is initiated at mid-height, giving an hourglass shape.
- Rib spall can become more prevalent and severe as extracted seam thickness increases.

When the roof and floor contacts are well-bonded, the need of the pillar to expand under load induces horizontal stress in the roof and floor strata. This horizontal stress can cause roof or floor strata to buckle and shear, as illustrated. Upon failure of the roof or floor the entire pillar system is weakened and can thereafter deteriorate (i.e. lose strength, creep) under constant load.

A number of site investigations have enabled the collection of a moderate size database on stable and collapsed cases of bord and pillar workings. To date, the investigations have identified thirteen collapsed cases, some of which are detailed in the accompanying table. The factors of safety for each collapse case are given for the pillar design formulae of both Bieniawski and of Salamon. The cases presented only involve competent roof and floor strata.

It is noteworthy that the safety factors of all failed cases fall outside of the recommendations of these authors for longterm stability (Bieniawski 1.5-2.0; Salamon 1.6. At a mining height of 3m, a Bieniawski S.F. of 2 corresponds almost exactly to a Salamon S.F. of 1.6). Final analysis of the field performance data to adapt both design approaches to local conditions is progressing. In the interim, operators can benefit by applying either of the two existing formula noted to better quantify the long-term stability of current workings.



Under load coal pillar wants to expand laterally. Friction and cohesion on roof and floor contacts generate resistance to this movement.

Depth (m)	Min. Ht (m)	(Pillar) Width / Height	Collapse Event	Safety Factor	
				Bien.*	Sal.+
60	2.7	1.3	Sudden Collapse. Major windblast triggered by abutment loading	1.01	0.97
75	4.5	1.8	Progressive deterioration then surface subsidence.	1.31	1.13
80	7	1.1	Sudden callapse. Major windblast.	1.35	1.07
80	3	2.5	Suddent collapse. Major windblast.	1.08	1
95	1.8	2	Unknown, feather edges at extent of collapsed area.	1.3	1.07
100	6	1.7	Sudden collapse. Major windblast.	1.46	1.27
120	4.5	2.2	Sudden collapse.	1	0.88
140	5	3	Progressive deterioration then collapse.	1.4	1.15

* Bieniawski + Salamon

Roof and floor buckling due to horizontal stress induced by lateral expansion of the coal pillar.

Questions and Answers

System Stiffness - Part 1 - Pillar Stiffness

■ ***What is the definition of stiffness?***

Stiffness, k, is an engineering term which describes the amount of displacement, d, a material will undergo when subjected to a load, L.
i.e. $k = L/d$

■ ***Why is stiffness important in coal mine design?***

The distribution of "load" and the mode of failure in any engineering structure is determined by the relative stiffnesses or "springiness" of the construction materials. A coal mine is no different, with the stiffness of the coal pillars, k_p, and the stiffness of the surrounding roof and floor strata, k_s, being most important. The ratio between these two stiffnesses determines how the load of the superincumbent strata is shared between the pillars and the abutments and, if failure should occur, whether it will be gradual and controlled or sudden and uncontrolled.

■ ***What is the stiffness of a coal pillar?***

The stiffness of a coal pillar, k_p, is given by:

$$k_p = \frac{(E_c A)}{h} = \frac{(E_c w_1 w_2)}{h}$$

Where:

E_c	=	elastic modulus of coal (a relatively fixed coal property)
A	=	area of pillar
w_1	=	pillar width
w_2	=	pillar length
h	=	pillar height

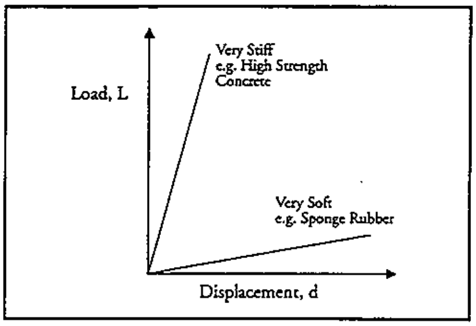
■ ***How can I relate coal pillar stiffness to everyday mining experiences?***

-The equation shows that if the height of a coal pillar is doubled for example, pillar compression will double. Therefore, if bottoms are taken, additional pillar compression (or roof to floor convergence) will result.

-The equation can be written for a square pillar as

$$k_p = E_c w \left(\frac{w}{h}\right)$$

This shows that as the width to height ratio, w/h, of a pillar is reduced, it becomes softer and will compress more under the same load. When the area of mining is very large, the stiffness (rigidity) of the surrounding strata is minimal and the pillars carry the full cover deadweight load. In these circumstances, the probability that a pillar collapse will be sudden and uncontrolled increases as the pillar is made softer. This accounts for why many of the collapses associated with pillars having small w/h ratios (recorded on page 5) were sudden.



If you would like further information on any aspect of the Strata Control for Coal Mine Design Project or wish to make a relevant technical contribution or comment, please contact

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Key Rule of Thumb

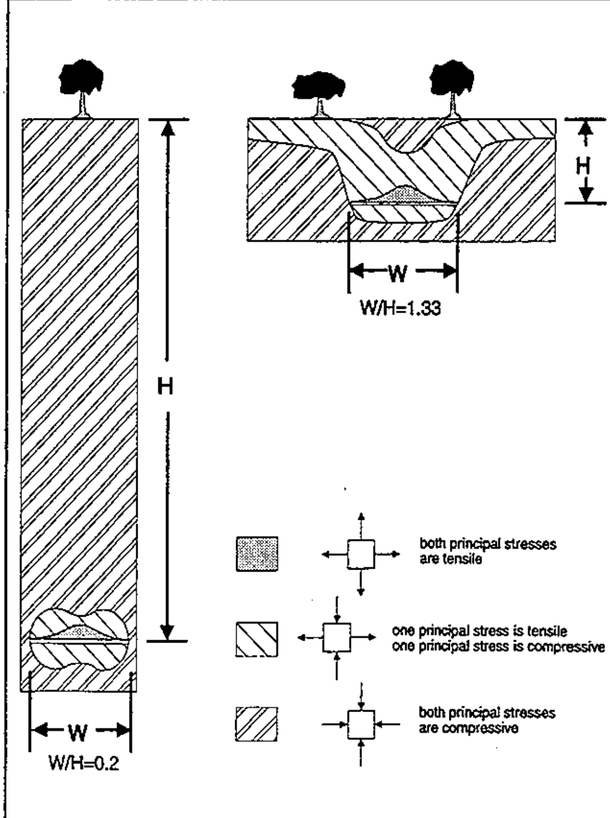
The behaviour of an excavation becomes increasingly unpredictable as the depth of mining decreases

As depth decreases, geological features like joints, faults and dykes are likely to be more weathered, open and continuous between the seam and the surface. Small changes in geometry (for example, an increase in alluvium thickness and a corresponding reduction in solid rock cover) cause a much greater change in loading conditions (or System Stiffness). Most important, however, is that an increasingly large area around the excavation is subjected to tension instead of compression. Rocks are not only about 10 times weaker in tension than in compression (Issue 1) but give less, if any, warning of failure. When all these factors are combined, it becomes increasingly difficult to both predict behaviour and to put early warning systems in place **as depth decreases.**

Applications in Shallow Depth Mining

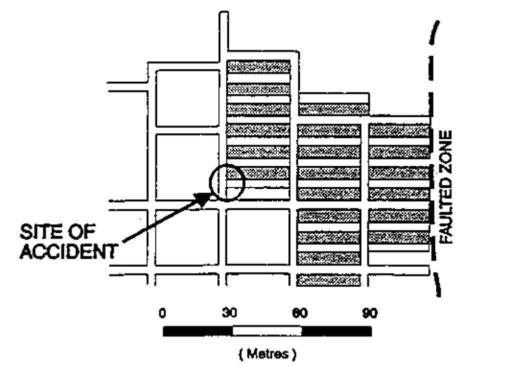
BEHAVIOUR OF STANDING GOAF

The accompanying diagram shows how the zone of tension around an uncaved excavation increases as the ratio of the width, W, to the depth, H, of the excavation increases. The extraction of a pillar at shallow depth results in a much greater increase in the W/H ratio than at depth. For example, if extraction had retreated 42m without a fall, extraction of an additional 14m centre Wongawilli runout would increase the W/H ratio by only 0.05 at a depth of 300m but by 0.47 at a depth of 30m. This almost ten fold difference shows how a small change in geometry at shallow depth can result in a large change in loading conditions and strata behaviour. The case study illustrates this point and also explains the sudden nature of tensile failure at shallow depth. An area measuring in excess of 70m x 90m was standing at a depth of about 30m. The panel deputy was fatally injured during pillar extraction operations when the entire area fell suddenly as a plug to surface. He had apparently positioned himself to watch for warning signs of a goaf fall, of which there appears to have been none.



EFFECT OF FRACTURE PLANES

Similar to picking up a row of bricks, the stability of a jointed roof depends on the friction between the rock elements and the magnitude of the clamping (compressive) forces applied across the joints. Since tensile stress environments prevail at shallow depth, a sudden loss of roof stability can occur if fracture planes are intersected. Similarly, wet weather has triggered many a collapse by lubricating and reducing friction along fracture planes. Plug failures to surface are to be expected.



Depth 20-30m Mining height 2.4m
Standing Goaf >60x90m. Therefore, Minimum W/H>2
No rib spall, roof sag, floor heave or observable deflection of props prior to fall.
Mass vertical movement to surface. Windblast. Conditions excellent around edge after fall.

INTERVIEW WITH
MR STAN COFFEY - PART 1

Early Australian Experiences With Roof Bolting

Stan commenced his mining career as a clipper at Metropolitan Colliery in 1948. He served as a Lodge Secretary during his time as a miner before progressing through Deputy, Undermanager and Colliery Manager positions to become Superintendent of the Coal Division of Peko Wallsend. Stan is noted for his extensive experience and initiatives in the mining of the thick, dipping Greta Coal Measures in the Cessnock District.

When and where did Roof Bolting commence in the Australian coal industry?

Following successes in both the USA Industry and the Australian Snowy Mountains Authority with the use of split and wedge bolts, trials were conducted early in 1949 at Elrington Colliery. These resulted in immediate benefits. With the local manufacture of expansion shell bolts in 1955, the practice of supplementing timber supports with roof bolts spread rapidly as did the various installation methods and bolting patterns.

What was your first experience with chemical resin anchors?

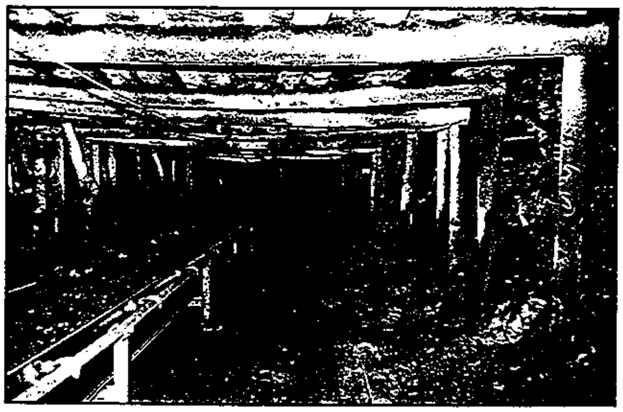
In 1965, attempts to use expansion shell bolts in a particularly heavy roof environment at Pelton Colliery were unsuccessful due to lack of bolt anchorage. Therefore, a trial was undertaken using a glass capsule containing aggregate and hardener. The outcome can only be described as a dramatic success. Roof control improved and productivity increased from 300 to 560 tonnes per shift.

What were your early experiences with integrating roof bolting into the face operation?

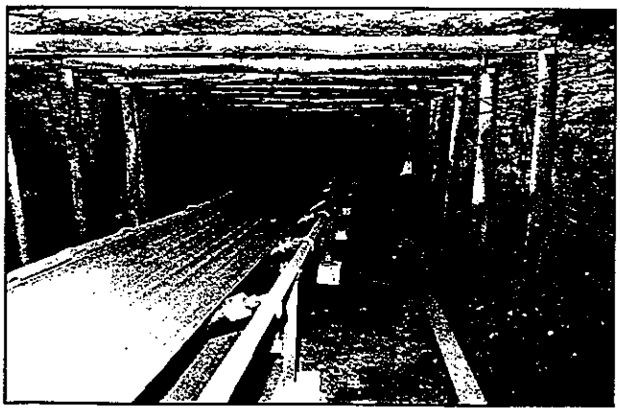
The top coal of the Greta Seam had a high sulphur content and had to be left in place to control quality. The success of selective mining was limited until timber supports were supplemented with expansion shell bolts, as shown in the illustrations. In 1966, a modified "Place Changing" operation was introduced using a Joy 8CM miner and a hybrid roof bolting machine. Temporary support was set during cutting, the continuous miner was flitted and a bolting crew then installed permanent support. Two roof bolts only per slab were required to prevent bed separation and once again, productivity improved.

How effective was post-bolting at depth?

The Greta Measures dip relatively steeply. As cover depth increased, the top coal was not sufficiently competent to allow post-bolting to occur. Face bolting became the requirement of the day. Nevertheless, it would take some 30 years for roof bolting to be universally accepted as a stand-alone means of roof support.



Conditions prior to the introduction of roof bolts, Pelton Colliery



Roof bolted conditions. Note how rib conditions have improved as a result of effective roof control.

Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales

Sponsored by the NSW Joint Coal Board

Issue No. 5

August 1994

PROJECT WORKSHOPS

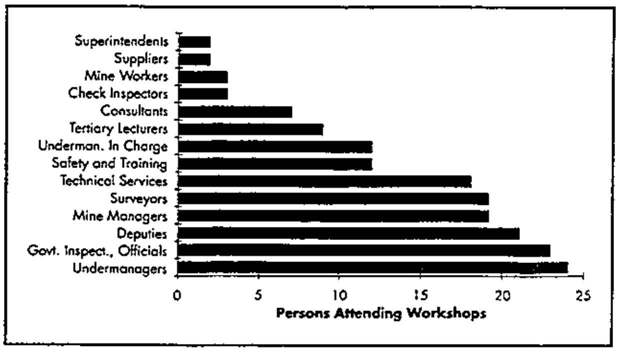
In Issue 4 we announced our intention to hold a two-day Pillar Mechanics Workshop (Stage I - Basic Principles and Practice) in May and to repeat it in June. In the event, demand was so strong that it was presented three times. It will be run in Queensland and again in New South Wales in December and also just prior to the Stage II Workshops.

Such Workshops are a key element of our technology transfer strategy. Stage II and III Workshops deal with further practical applications of the outcomes of our investigations and research.

The breadth of interest in the Workshops can be gauged from the accompanying diagram. This attendance profile is encouraging and is attributable, we believe, to the basic philosophy underlying the Project.

It is often stressed that "safety is an attitude". Perhaps so, but a positive attitude alone is not enough. Safe systems of working need to be "engineered". Engineering is generally defined as the application of physical and analytical sciences to the planning, design and supervision of systems. Thus the principles of engineering science underpin the functions of management to:

- Anticipate
- Plan
- Implement
- Control
- Monitor
- Take effective remedial action



These processes involve, to varying degrees, all members of the workteam. Accordingly, the Workshops are designed to explain the basic engineering principles to participants from various backgrounds. The "hands on" workshop exercises enable them to apply this "theory" to their own experiences and to real practical case studies.

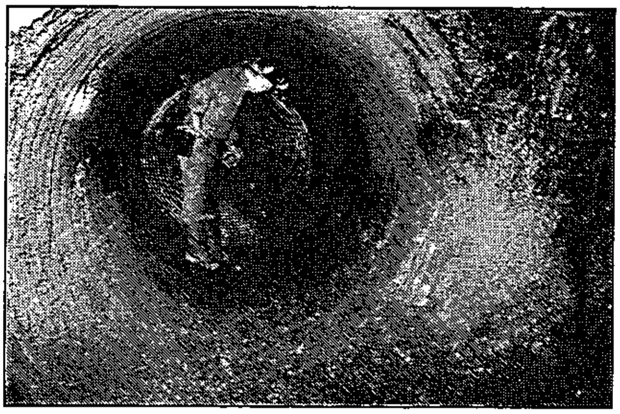
The basic knowledge gained by participants meets two critical needs for improving safety:

(i) It minimises guesswork and provides better insight into the mechanics of observed strata behaviour. Knowledge need no longer be limited to a specific site. The relevance of experience at one location can be more confidently applied to a different location.

(ii) Knowledge stimulates further learning and a reassessment of attitudes.

A comment from one Workshop participant is testimony to this philosophy.

"Its got me thinking about the effects of everything I do on the job".



A 1.5m diameter auger hole in coal. Circular and elliptical shaped roadways have many stress control advantages over rectangular roadways.

Contents

ISSUES

PILLAR EXTRACTION - LATENT FAILURES

As the Project progresses, an improved understanding is developing of the latent causes of failure, that is, appropriate design for conditions (as opposed to active failures or deviations from stipulated rules). Two important facts to emerge regarding buried continuous miners are:

- Over 70% have been associated with subcritical to critical panel widths.
- Over 66% have occurred under weak laminated immediate roof stratum overlain by strong massive stratum.

The fact that 64% of events and 55% of fatalities occur at intersections is related more to latent failures manifesting themselves in intersections since these are the weakest elements in the mining system. A series of topics will be developed over the next few newsletters covering:

- ❑ pillar splits, runouts and finger lines
- ❑ weak roof overlain by strong massive roof
- ❑ stooks and intersections
- ❑ strata behaviour around dykes and faults
- ❑ the effects of critical panel width.

SPLITS, POLICEMEN AND FINGER LINES

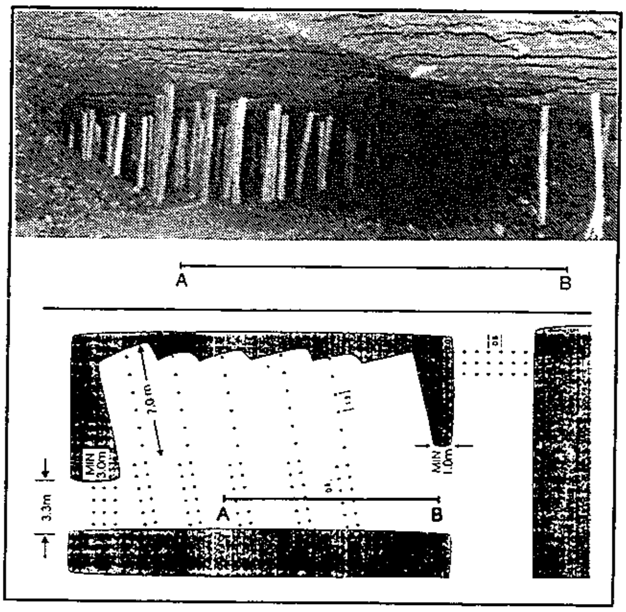
Whilst in strata mechanics circles, there is a pre-occupation with 'stress' as the failure criterion, at the 'coal face' decision making is based almost entirely on 'displacement'. This is logical when one considers the behaviour of a gravity load, clamped beam of thickness, *t*, and span, *b*. The maximum deflection, S_{max}, at the centre of the beam, the maximum shear stress, τ_{max}, at the ends of the beam and the maximum normal stress, σ_{max}, in the beam are given by:

$$S_{max} = \frac{\gamma b^4}{32Et^2} \qquad \sigma_{max} = \frac{\gamma b^2}{2t} \qquad \tau_{max} = \frac{3\gamma b}{4}$$

where: γ = unit mass of beam

E = modulus of elasticity of beam

The equations highlight that roof displacement is most sensitive to changes in span and roof thickness. For example, an increase in bord width from 5.5m to 6.5m, causes roof deflection to increase by 95%, i.e., almost double. Because laminated roofs comprise many thin beams, they deflect more under load. This deflection stretches the rock and puts it into tension. Roof support resists roof deflection and so minimises tensile stresses in the roof. The greater the roof deflection, the higher the loads induced in the support system. This is why it is important to keep roadways tight and to install and maintain roof support to a high standard, especially under laminated strata.



When relatively competent roof cantilevers over the goaf, it is difficult to gauge the amount of roof deflection that occurs out in the goaf. Hence, 'policemen' and sometimes 'finger lines' are set. The miner observes these to see 'when and how the weight is coming on'. At some mines, failure can be pre-empted to within 10 to 20 minutes based on prop behaviour induced by displacement. Miners may feel relatively safe setting finger line props given that this practice is restricted to competent roof. An understanding of the function and behaviour of finger lines gives insight into alternative and safer practices.

PUBLICATIONS

The results of the Strata Control for Coal Mine Design Project are documented regularly as the work proceeds. The following publications are now available for purchase.

Galvin, J.M., Review of Overseas Pillar Extraction Techniques - South Africa, June, 1993. PR. 4/93. $15

Galvin, J.M., Review of Overseas Pillar Extraction Techniques, U.S.A., November, 1993. PR/5/93. $15

Anderson, I., Case Studies of Buried Continuous Miners and Fatal Pillar Extraction Accidents in NSW, December, 1993. RR 1/93. $25

Galvin, J.M., Hocking, G., Anderson, I., and Quinteiro, C., Pillar Mechanics Workshop - Part I - Theory and Practice. T.T. 1/94. $100

For overseas purchases please add $5 per item for postage.

PILLAR MECHANICS WORKSHOPS - MAY, JUNE AND JULY 1994

WHERE HAVE WE COME FROM ...

"Some remarks on Mining Education" by Noah T. Williams, Trans. Institute Mining Engineers, Vol. A9, 1914.

In Britain during the period 1850-1910 changes to the law led to:

- Statutory Certificates for Mine Managers and Undermanagers;
- Two years training at an approved institution plus three years' experience as an alternative to five years' practical training to sit for a Certificate of Competency;
- Elementary Education Act making formal education compulsory for all persons to the age of 13. The minimum age for underground employment was raised to 14.

Significant improvements in mine safety occurred during the period. (See Table below).

Improvement had not occurred "across the board", however, being much less in the area of "falls of ground". It had in fact deteriorated. In 1851, approximately 44% of all fatalities were due to falls of ground. In 1911 the proportion had increased to 70%.

Some comments by Noah T. Williams in 1914 in this regard were:

(i) "Accidents (from falls of ground) are more under the direct control of workers than of management";

(ii) "The miner in the dark recesses of the mine cannot be constantly supervised by the official";

(iii) "There are thousands of boys between the ages of 13 to 14 employed in mines who have, unless they are properly encouraged, done with real education forever and these will be the miners and officials of tomorrow";

(iv) "In other engineering industries .... it has been recognised .... that a systematic training is necessary both in the practice and in the theory of the profession, while the feeling about the education of a Colliery Manager has been *"As it was in the beginning, is now and ever shall be!!"* This prevalent outlook .... has not had a beneficial effect".

A successful manager at a large colliery in South Wales (UK) at the time said, *"I wish now that I could give some of my practical experience for more scientific knowledge, for I am at the mercy of others when the 'rule of thumb' fails me".*

Another remarked, *"Legislation might do much to reduce the accident and death rates in mines but it seems that much more might be accomplished if increased attention was paid to the education of the miners".*

Some of these comments are a far cry from today's situation where the employer, not the employee, has the prime obligation for ensuring occupational health and safety. The onus is now on management to engineer a safe working environment.

						FATAL ACCIDENT RATES			
						Per 1000 employed		Per million tonnes	
Year	Total Fatal Accidents Below Ground	Total Deaths Due to Falls of Ground	% Due to Falls of Ground	Total Persons Employed Below Ground	Annual Output (million tonnes)	Other than Falls of Ground	Falls of Ground	Other than Falls of Ground	Falls of Ground
1851	790	346	43.8%	171,893	53.0	2.58	2.01	8.39	6.5
1911	927	639	68.9%	863,512	271.9	0.33	0.74	1.06	2.3
*NSW	23	10	43.5%	43,830	201.0	0.30	0.23	0.07	0.05

*NSW Underground 1990-1993 (incl.)

A POINT TO PONDER

Since 1911 there has been a significant reduction in fatality rates due to falls of ground. However, in all other areas, there has been no improvement. The impact of new technology (producing more tonnes with less people) appears to have resulted in a reduction in the actual number of persons killed but not in the risk of being killed - 0.33 per 1000 employed in 1911 and 0.3 per 1000 employed in New South Wales in 1993!

If you would like further information on any aspect of the Strata Control for Coal Mine Design Project or wish to make a relevant technical contribution or comment, please contact

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ISSUE

PILLAR PERFORMANCE

The database of stable and collapsed cases of bord and pillar workings have been analysed to quantify pillar strength and stability. Only those cases involving competent roof and floor strata have been considered. In these cases, the coal pillar itself fails. This failure mode has a high probability of occurring suddenly, with no or minimal warning. When failure of the pillar system also involves buckling, shearing and slipping of the roof and floor strata, the failure mode is more gradual and gives ample warning. Emphasis has been placed on those cases in which a sudden collapse could occur without prior warning.

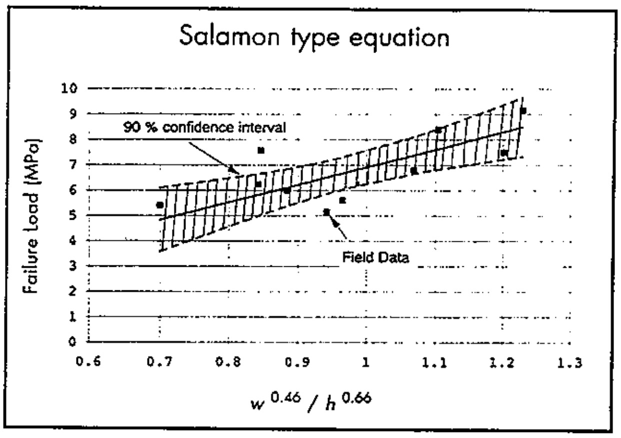
Collapse cases are shown plotted as a function of failure load and pillar width to height ratio. The pillar strength is considered as a functional form similar to Salamon and to Bieniawski.

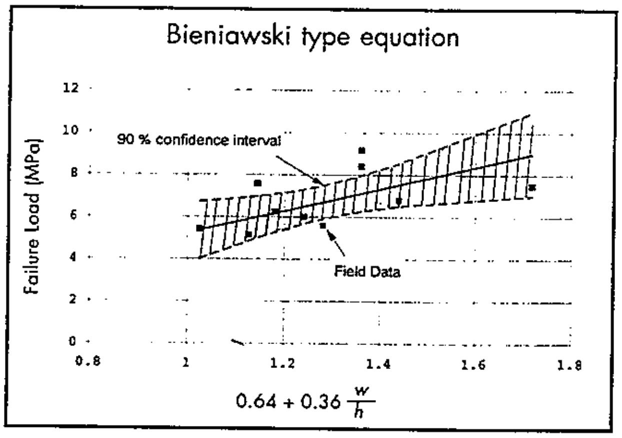
The best linear fit to this data, shown as a solid line, yields in situ strength parameters for New South Wales and Queensland coal pillars. The shaded regions are the 90% confidence limit. The closer the 90% confidence limits are to the best fit line, the less scatter and greater confidence can be placed on relationship.

The appropriate factors of safety for design depend on:

1) The confidence level in the design procedure and parameters.
2) The consequences of failure.
3) Acceptable levels of risk.

An updated review and analysis of recommended factors of safety and their respective probabilities of instability for coal pillar design is currently underway. Recommended guidelines for coal pillar design will be forthcoming from this analysis. In the interim, as stated in the last Newsletter and at the Pillar Mechanics Workshops, the procedures of Salamon and Bieniawski can be used.





EMPLOYMENT AND HIGHER DEGREE OPPORTUNITIES

Employment of a third full-time researcher on the Strata Control for Coal Mine Design Project is sought. The nature of the research requires a person skilled in the analytical and physical sciences with a qualification in physics, geophysics or appropriate branch of engineering preferred. Practical mining knowledge would be an advantage but is not essential.

Opportunities also exist for suitably qualified persons to undertake a part-time external Masters or Doctorate Degree by research through the School of Mines at the University of New South Wales. This research may be related to the Strata Control Project or to any other suitable aspect of Mining Engineering, Mine Management or Earth and Geological Sciences.

Note - You do not necessarily have to possess a first degree. Your experience and professional qualifications may constitute an acceptable entry standard.

For further details contact either:

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Questions and Answers

System Stiffness – Part 2 – Surrounding Strata Stiffness

Revision - Issue 4 - Coal Pillar Stiffness

Stiffness, *k*, is an engineering term which describes the amount of displacement, *d*, a material will undergo when subjected to a load, *L*, i.e., $k = L/d$. The distribution of "load" and the mode of failure in any engineering structure is determined by the relative stiffness or "springiness" of the materials used. In all underground mining, the ratio between the stiffness of the surrounding strata and the stiffness of the pillars determines how load is distributed and, if failure should occur, whether it will be gradual and controlled or sudden and uncontrolled.

❑ **What is the stiffness, k_p, of the surrounding strata?**

The exact formula is complex but, for practical purposes, it is analogous to a simple leaf spring under load as shown in the diagrams. The stiffness of the spring depends on the type of steel it is made of, its span and its total thickness. Likewise, the stiffness of the surrounding rock mass correspondingly depends on E_s and W_p/H where,

E_s = elastic modulus of surrounding strata (c.f. type of steel)

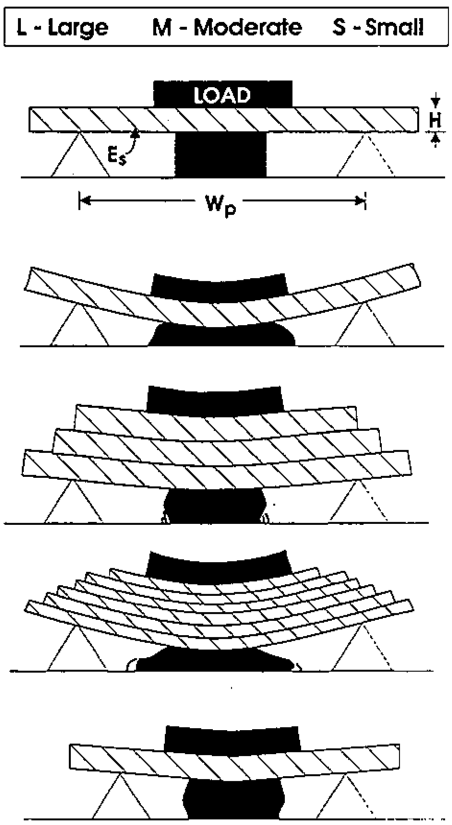
W_p = overall panel width (c.f. span of the spring)

H = solid rock cover (c.f. thickness of the spring)

Stiffness reduces as the effective Elastic Modulus of the roof or floor strata decreases or the overall panel width to depth ratio, W_p/H increases.

❑ **How does the stiffness of the surrounding strata control failure?**

Because of its stiffness or "springiness', the surrounding strata is capable of transferring some overburden load to the panel abutments. If, however, the remaining load exceeds the strength of the coal pillars, the springiness of the surrounding strata will influence whether or not the roof chases the pillars as they yield (causing sudden failure) or whether the roof settles onto the pillars gradually (causing failure to be controlled). The other controlling influence on the rate of failure is the pillar width to height ratio, *w/h* (See Issue 4).



E_s	W_p/H	Failure Mode
L	L	No failure-Pillar load does not exceed pillar strength.
L	L	Uncontrolled-Pillar load exceeds pillar strength. Sudden load transfer.
L	M	Controlled-Load transfer to pillar is gradual.
S	M	Uncontrolled-Load transfer to pillar is sudden.
L	M	Controlled-Reduced span increases roof stiffness and reduces rate of load transfer.

Key Rule of Thumb

A Small Amount of Lateral Confinement Significantly Increases the Compressive Strength of Rock

There is no unique value for the strength of rock. The strength of a sample of rock is a function of its size, its shape and the amount of confinement provided to its sides. Uniaxial Compressive Strength (U.C.S.) refers to the strength of rock in compression when it is not confined. Triaxial Compressive Strength refers to the strength of rock when it is subjected to a specific confining pressure. A small confining pressure causes a magnified increase in compressive strength.

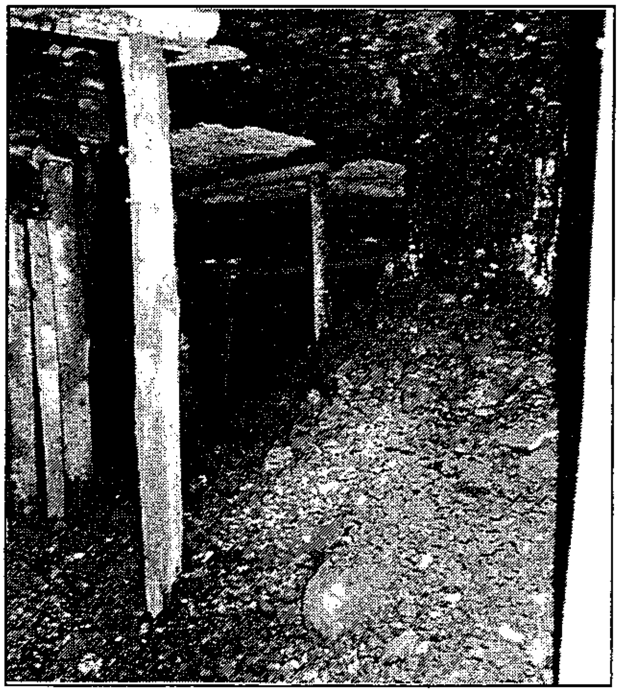
APPLICATIONS IN MINING

Rock Mass Strength

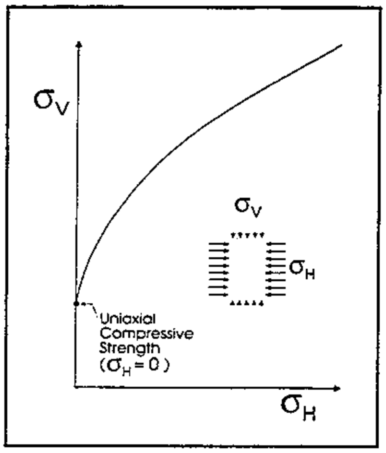
In practice, the only time that rock is not confined is when it forms the surface of an opening (excavation or void), otherwise, it is confined by the surrounding rock mass. Hence, rock mass strength increases with distance away from an excavation surface.

Pillar Strength

Fractured and broken coal around the perimeter of a coal pillar provides confinement to the pillar core. The strengthening effect of this confinement has been measured in a mine (Wagner, 1974, see diagram). Many researchers consider that once pillar width to height ratio exceeds 8 to 10 in competent roof and floor conditions, the confinement provided to the core of the pillar by the surrounding coal is so great that a coal pillar can support any practical load. At high pillar loads, however, even though the pillar is stable, rib and roof deterioration may cause roadways to become unoperational.

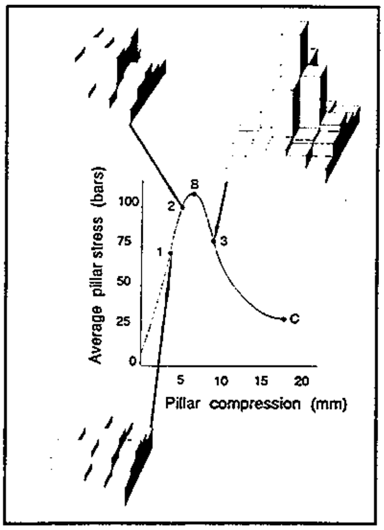


Typical "free slack" coal providing confinement to a pillar.



Pillar Collapse in Old Workings

Many pillar collapses have been initiated when "free slack" coal has been recovered from old workings. This coal, which helps stabilise a pillar, is often a symptom of an already highly loaded pillar.



Pillar Stabilisation

Because of the magnified strengthening effects of confinement, pillar collapses which occur in a stable or controlled manner (see Issues 1-4) can often be arrested through the application of confinement. Chain mesh and wire ropes wrapped around the circumference of the pillars is one such method. Passive backfills such as sand and flyash, placed to only two thirds of the mining height have also proven effective in stabilising pillar workings.

Pressure and Gas Outbursts

The effect of mining towards a weak and/or pressurised zone (fault gauge, mylonite) is to reduce lateral confinement of the zone, leading to a pressure (bump, rockburst) or gas outburst.

INTERVIEW WITH MR JOHN SMITH

Early Australian Experiences With Longwall Mining

John graduated from the University of New South Wales and joined Oakdale Colliery in 1952. Since then he has held appointments as Inspector, Colliery Manager, Joint Coal Board Member, and General Manager of Newcastle Wallsend Coal Company. He was Inspector for Coal Cliff when Australia's first mechanised longwall was introduced in 1963 and was Mine Manager when the second installation was tried in 1965.

■ **Why was longwall mining introduced at Coal Cliff in 1963?**

In 1963 Coal Cliff was using bord and pillar mining at depths of 350 to 400m. It was experiencing serious roof control problems and achieving only 150 to 200 t/unit shift during pillar extraction. Successes with mechanised longwall of up to 500 t/unit shift in Europe presented an attractive alternative.

■ **What was the experience with the first longwall unit?**

It was installed in the Bulli Seam and used a Westfalia plough and 800 mm wide, 2 x 30 tonne leg, "goal post" hydraulic supports. Roof problems were experienced from the outset with extensive roof breaks and severe weighting. Supports were often iron bound. After 6 months the unit was withdrawn.

■ **What was the basis for purchasing and installing the second longwall unit?**

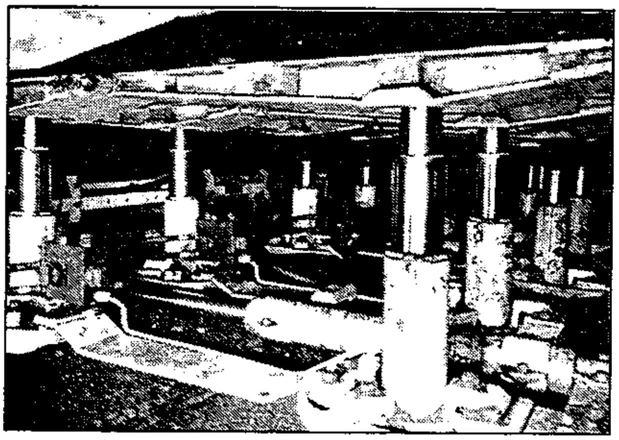
We tried again, this time with a shearer and using supports that exceeded British and European experience. The suppliers eventually agreed to our demands for 4 x 50 tonne leg chocks. Roof control problems persisted. Support settings were raised, but to no avail. This face was also abandoned after 6 months, having achieved 500t/shift on about 3 occasions.

■ **Why were these Units so Unsuccessful when Similar Units Operated Well in Britain and Europe?**

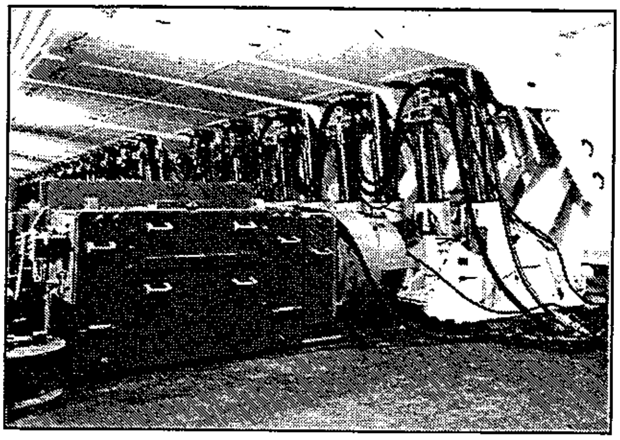
Our strata is massive and stiff. Theirs is pliable and converges more readily. The turning point for successful longwall in Australia came with the advent of massive supports, initially in 1976 with the Japanese Taiheyo unit at South Bulli. Today's supports have 4 or more times the capacity of the second Coal Cliff installation.

■ **When those first longwalls failed, what was the outcome at Coal Cliff?**

Urgent reconsideration was given to the use of continuous miners, leading to the application of the Wongawilli System*. This was successfully applied to depths of 550m (* See Interview - Newsletter, Issue 3).



An early design of a 2 leg "goal post" chock of the type first tried in Australia - capacity 60t, support density approx. $20t/m^2$.



A modern 2 leg shield support of the type used in Australia today - capacity 800t, support density $118t/m^2$.

Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales

Sponsored by the NSW Joint Coal Board

Issue No. 6

December 1994

PROJECT OUTCOMES

THE Stage 1 Workshops (Basic Principles and Practice) have been completed. Three were held in the Newcastle Coalfield, one in the Western Coalfield of NSW and one in the Bowen Basin of Central Queensland. These workshops have laid a foundation for the more advanced Strata Mechanics Workshop (Stage II - Design Principles and Practice) planned for mid July, which will deal with engineering design in regards to philosophy, design procedures, design criteria, risk management and decision making.

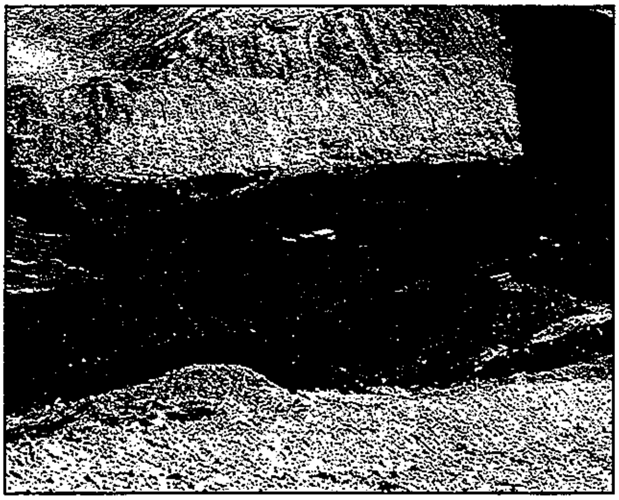
Design practice is often done on a purely empirical basis, relying essentially on past mining experiences. This approach can be satisfactory, but it limits the practitioner both in extrapolating design procedures outside of past mining conditions (depth, strata type, etc) and in being able to anticipate or handle unexpected events. The Stage 1 workshops have developed an understanding of some basic mechanics principles which give participants a better insight into strata behaviour. The Stage II workshop will extend the engineering design approach, with quantified past mining experience coupled to a more refined understanding of the mechanics involved.

In this newsletter, an example is presented of how advances made by the project in understanding and modelling the complete load-deformation behaviour of coal, give insight into the physical processes associated with rib instabilities, pressure bursts and gas outbursts.

Models are most useful in providing insight into the physical processes governing strata behaviour. They are an effective means of:

- Communication
- Interpretation
- Prediction

What makes a good model? An understanding of the mechanisms involved is essential. That is, the model must simulate the correct mechanisms and phenomena that occur in the mine. Just because a model is highly complicated and sophisticated, does not mean it is capable of solving your problem. An optimum approach is to have the simplest model, provided it includes all of the essential features (principal parameters) required to simulate the correct mechanistic behaviour.



Coal pillars exposed by open cut workings at a NSW Colliery

Contents

ISSUE - INTERSECTIONS

Principles which find application:

The strength of rock and coal under load is time dependent - **Issue No. 3.**

The corners of a pillar have a lower load carrying capacity than its sides - **Issue No. 5.**

The deflection of roof strata under gravity increases in proportion to the fourth power of the roof span 'b' (i.e. b x b x b x b) - **Issue No. 5.**

Rock strength decreases with decrease in confinement - **Issue No. 5.**

The amount of strata displacement caused by a load increases as the stiffness of the strata decreases **Issue No. 4.**

Pillar stiffness decreases with decrease in pillar width and with increase in pillar height **Issues No. 1 and 4.**

Roof stiffness decreases with decrease in lamination thickness and with increase in mining span - **Issue No. 5.**

Management functions - **Issue No. 5.**

APPLICATION OF PRINCIPLES

The hazards associated with extracting pillars in the vicinity of intersections are highlighted by NSW field experience where 64% of continuous miner burials have occurred during extraction of the first or last lift off a pillar. Moreover 50% of associated fatalities were victims waiting in intersections.

Although pillar extraction is conducted by retreating a panel, it is not a true retreat operation at the face. This is because pillars are extracted by a series of cuts which advance away from the solid towards the goaf as shown in Figure 1.

Hazards increase significantly as operations approach intersections because:

Protection previously provided by solid coal on one or both sides of the retreat roadway no longer exists.

The span of the exposed roof through which operations have to retreat is increased by at least 40% (see Figure 2) to give a four fold increase in roof convergence and cause parting planes to open higher into the roof.

The roof has usually been subjected to load in an unconfined state for an extended period of time. This can result in fracturing and/or loss of load carrying capacity.

Pillar sides and corners have had time to deteriorate, causing a reduction in load carrying capacity and an increase in effective roof span.

The mining environment is at its most active stage, with each successive lift having an accelerated effect on the redistribution of load. For instance, when the first 3.5m wide lift is taken off a 33m long fender, pillar stiffness reduces by

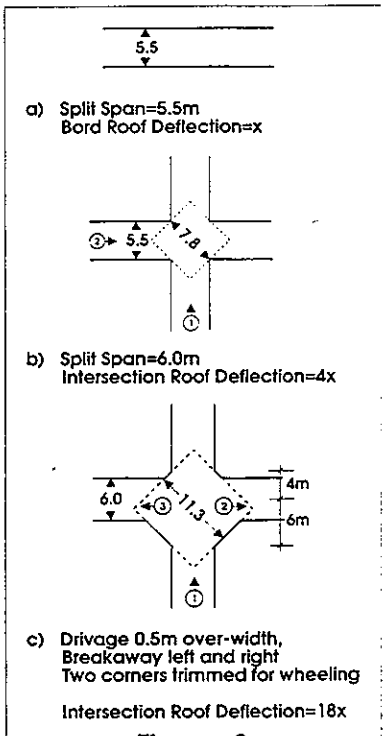


Figure 2

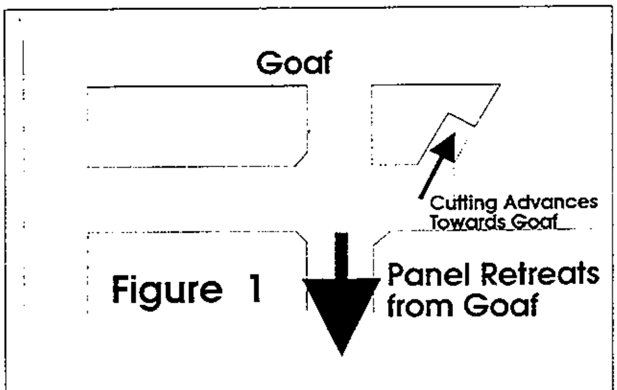


Figure 1

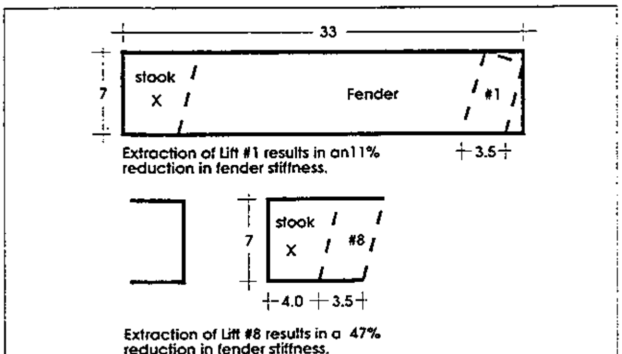
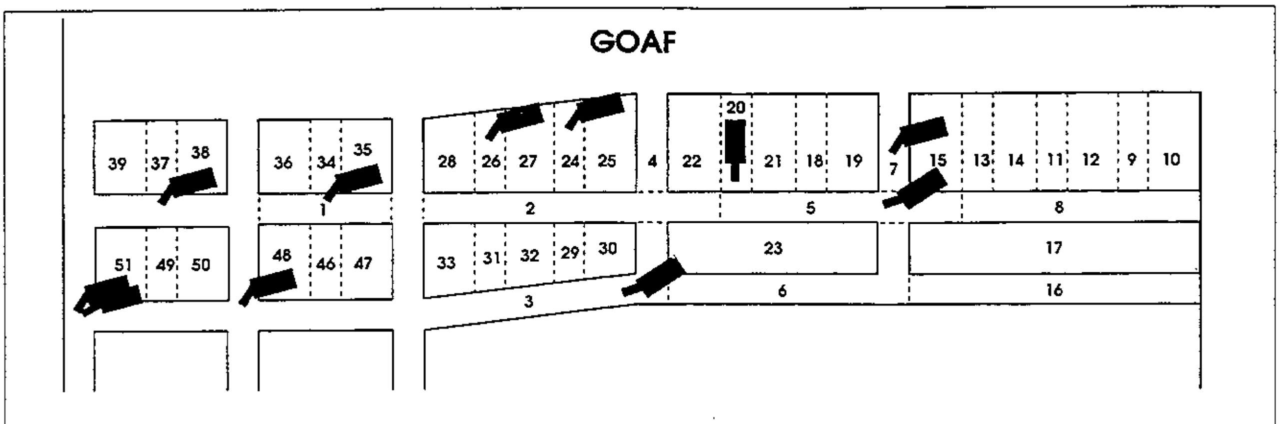


Figure 3

PILLAR MECHANICS WORKSHOPS - MAY, JUNE AND JULY 1994



A 1975 plan showing the location of buried continuous miners over a 5 year period at one NSW Colliery using the Modified Old Ben Method (Issue 2). 9 of the 11 incidents occured taking the first or last lift off a fender.

11% (Figure 3). However, when taking the last lift to leave a 4m wide stook, pillar stiffness reduces by 47%. The stiffness of the roof strata also reduces close to an intersection due to an increase in effective roof span. Thus, in the vicinity of an intersection:

- ❑ small changes in extracted area can trigger large changes in load distribution and therefore, strata displacement,
- ❑ strata can be expected to behave in a significantly different manner to that during the lifting off of splits and runouts.

These factors contribute to "drummy" roof, floor heave, rib spall and roof falls developing quickly at intersections, especially when operations are close by. It is important to implement measures to avoid such instabilities since they can cost time during the final stages of extracting a pillar. This is when rapid access and egress and uninterrupted production are most critical to safe and efficient extraction. These measures include:

- designing panel dimensions to control abutment loadings,
- designing panel layout to minimise intersections and their standing time,
- designing extraction sequences to minimise the number of breakaways and pillar corners that have to be trimmed for wheeling, (see Figure 2c),
- keeping roadways and breakaways on centre at the designed width,
- avoid waiting in intersections,
- monitor face (and adjacent goaf line) intersections frequently throughout the shift,
- maintain roof support in good condition,
- install additional support well ahead of mining at noted problem areas (preferably during development),
- install longer roofbolts in oversize intersections,
- utilise radio remote continuous miners and MBLSs.

Given these measures, stooks still offer one of the most effective forms of intersection control. The function and design of stooks will be addressed in more detail in the next newsletter.

STRATA MECHANICS WORKSHOP

STAGE 2 - DESIGN PRINCIPLES AND PRACTICE

Preliminary Notice and Planning

Date: July 1995

Venue: Newcastle Coalfield

Duration: Two Days

Content:

Revision - Basic Principles and Practice

Pillar System Design

Strata Mechanics and Risk

Risk Management Principles

Post Failure Behaviour

Controlled and Uncontrolled Collapse

Interaction Between Pillars and Roadways

Roadway Behaviour and Support

Caving and Goaf Reconsolidation

Risk Management

Failure Modes Analysis

Probability Estimation

Consequence Assessment

Abutment Stress Around Total Extraction Panels

Design of Trial Mining Layouts

WHERE HAVE WE COME FROM . . .

WHERE **Lady Pit, Workington, Cumberland, NW England**

WHEN **31 July 1837**

WHAT:

Lady Pit, sunk in 1794, was one of a group of three highly productive collieries owned by the Curwen family of Workington located on the Cumbrian coast of North West England. It worked a 3m thick seam of top quality coal lying at a depth of 165m. The workings, which were being developed straight out under the Irish Sea, were bord and pillar and used 4.5m wide bords with 6.5 to 7.5m wide pillars. All went well for several years until the miners realised that the seam had started rising and that the separation to the sea bed was fast reducing. The Manager, Ralph Coxon, disdainfully disregarded the men's advice to change direction and ignored their ensuing protests. Moreover, and despite indications of salt water seeping into an otherwise fairly dry mine, he instructed the men to "thin" some pillars and "rob out" others while advancing. He was breaking production records and wanted to continue impressing the owners.

A disaster was predicted by one of the mine agents named Bowness who wrote to the previous Lady Pit Manager, Matthias Dunn; *"Unless some interference can be made, a very few days or weeks will most assuredly bring down the waters of the sea; and that opinion is now so generally expressed that men are leaving the colliery everyday"*. Dunn himself counselled the owner that the pillars were *"barely sufficient to maintain the roof unbroken"* and stated his belief that *"any attempt to broaden the bords and narrow the pillars is fraught with the gravest risk"*. The advice was ignored by the owner on receiving assurances from Manager Coxon.

On 31 July 1837, the sea broke through and completely flooded Lady Pit and inundated the neighbouring Isabella and Union pits to tide level in just over one hour. Twenty five men, two boys and as many horses perished in the Lady Pit. Miraculously, a further 30 men who had just entered the mine managed to escape despite being flung about by the tremendous force of wind in the workings. It was mere good fortune that there were no men in the Isabella and Union pits at the time.

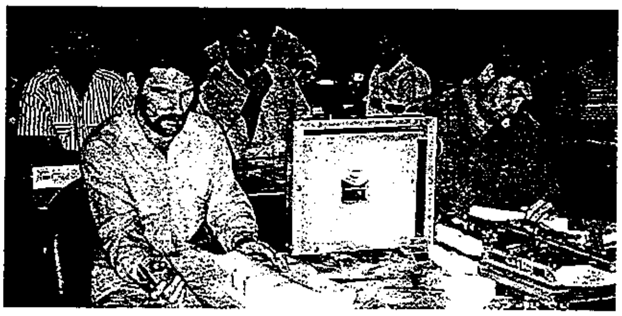
The collapse had occurred 2,500m out to sea and caused an enormous whirlpool from which some nearby vessels were lucky to escape. It was later found that the workings had come within 27m of the sea bed, 10m of which were sand and gravel. The area of collapse was estimated, from the extent of discolouration of the sea, to be 0.6ha.

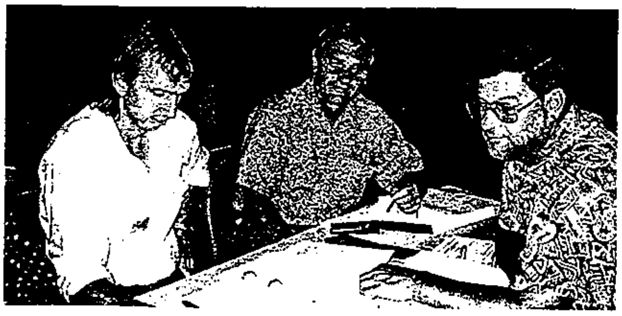
OUTCOMES

(i) Manager Coxon was dismissed on the following day

(ii) It was one of the several coal mine disasters in Britain at about that time that led to the establishment of the Mines Inspectorate.

Pillar Mechanics Workshops - Dec, 1994, Lithgow, New South Wales, and Emerald, Queensland





ISSUE

RIB FALLS, PRESSURE BURSTS, GAS OUTBURSTS

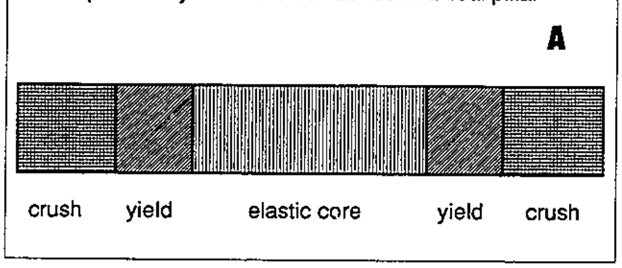
What do these hazards have in common? How can they be controlled? Mechanistic based modelling of coal pillar behaviour gives insight into both questions.

Theoretical advances have enabled the quantification of coal rib behaviour under increasing abutment pillar load. Under high loading, three zones of distinct behaviour occur in a coal pillar or abutment, namely elastic, yield and crush, Figure A. Figure B shows how the yield and crush zones develop in the abutments of a total extraction panel when a significant lateral confinement has been applied to the ribs. Initially, the edges of the pillars go into yield. Depth of yield increases with increasing excavation width. Ultimately, as excavation width increases, the yield zone develops into a crush zone. The extent of the yield zone then decreases whilst the extent of the crushed zone gradually increases.

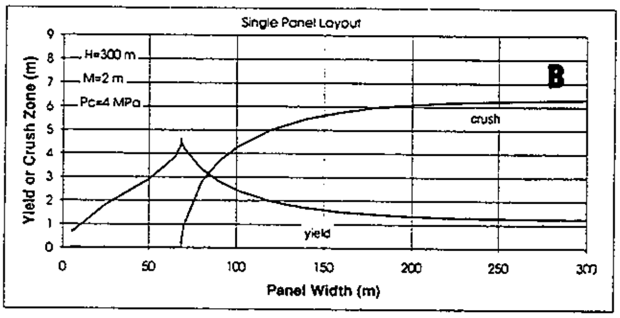
Figure C illustrates abutment behaviour when rib confinement is reduced to 1/5 of the original. The crushed zone now develops virtually instantaneously. The associated stress changes are of sufficient magnitude to cause a dynamic strata displacement (i.e. a pressure burst), to occur under the high abutment loading conditions.

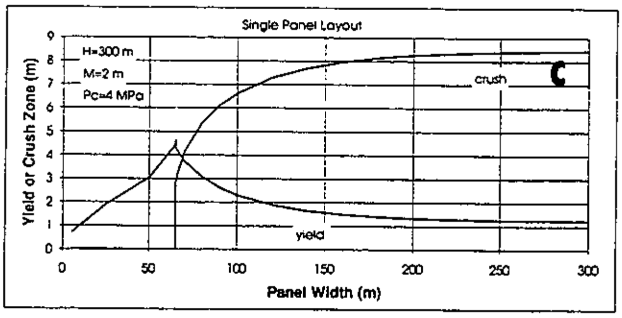
Structured and weak zones associated with gas outbursts can act as abutment stress raisers and represent a loss in rib confinement to cause a sudden transition from Figure B to Figure C type behaviour. The gas pressure acts as "negative" confinement and accelerates the onset of instability. Because gas pressure is analogous to mining at greater depth, gas pressure can cause bursts to occur in first workings at moderate depth.

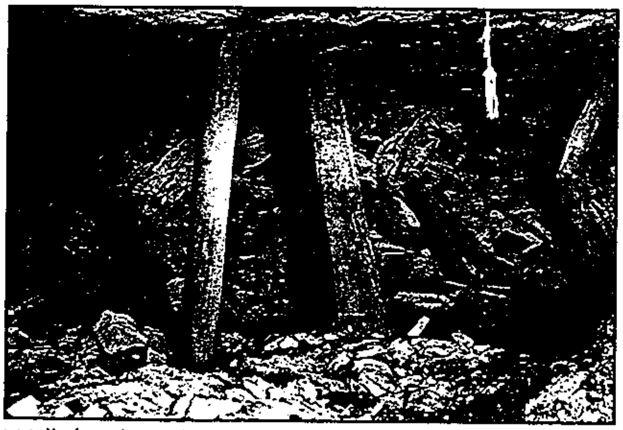
Pillar and abutment behaviour is very sensitive to the degree and effectiveness of rib support. The modelling gives insight into rib control measures (support type. length, deformation properties) appropriate to specific site conditions.



Development of yield and crush zones in a coal pillar






Well developed crush zone at the edge of a highly stressed coal pillar

FACTS AND FIGURE
NEW SOUTH WALES COAL MINES

Falls of rib account for:

Almost 60% of total injuries due to falls of roof and rib.

Over 1,200 lost time injuries in the last nine years

An annual injury cost exceeding $5million.

Pressure Bursts:

Have been an element of two fatal pillar extraction accidents in the last five years.

Gas Outbursts:

Have claimed four lives in longwall development in the last four years.

Questions and Answers

SYSTEM STIFFNESS – PART 3 – IN PRACTICE

■ **What examples are there of system stiffness governing mine stability?**

Seven collapses occurred between 1919 and 1959 in iron ore mines in the Lorraine district of France. All caused severe windblasts and seismic events, indicative of their suddenness. 29 men died in the two incidents which occurred on working days. In 1960, all 437 underground workers at Coalbrook Colliery in South Africa were killed when more than 4,400 pillars failed in a five minute period and over 7,500 failed in a few hours, causing a large seismic event.

■ **Why was the Coalbrook Collapse so sudden?**

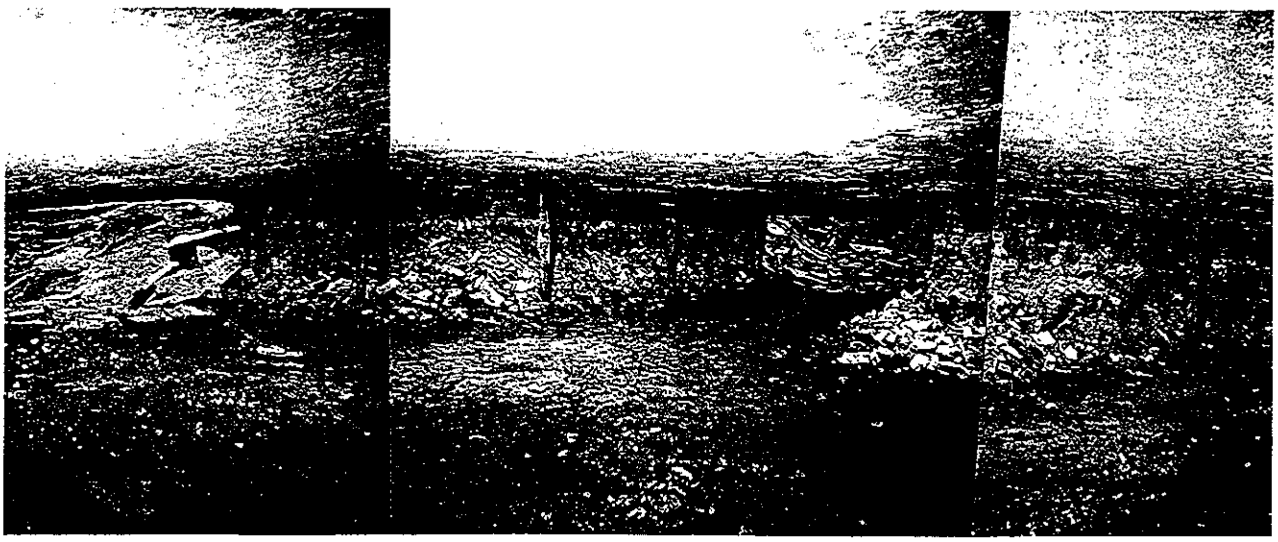
A very stiff 40m thick dolerite sill overlaid the 300 hectares (750 acres) of workings and transferred much of the cover load to the solid abutments. The pillars were underdesigned (Salamon SF 1 to 1.08, prob. failure = 35%), but showed no signs of distress because the dolerite shielded them from full load. Two sides of the workings were bounded by dykes. When the third side approached a compaction fault on a 1.6km front, the dolerite sill sheared off and lost all stiffness, transferring the load to the pillars. The pillars only had a width-to-height ratio of 2.5 to 3. The combination of a soft pillar system and a soft surrounding strata system caused the collapse to be sudden.

■ **Do sudden regional collapses occur in Australian collieries?**

Yes, there have been at least six in the last ten years.

■ **What control measures are available?**

Most important, design the mining layout to ensure pillar load does not exceed pillar strength. Do not rely on stiff upper roof strata to protect pillars from load. Break the mine into compartments using barrier pillars to prevent a collapse from running.



Goaf edge conditions - note feather edging and effect of high goaf abutment stress on the pillar still to be extracted

Key Rule of Thumb

Pillars at a goaf edge should be designed to carry at least twice the tributary area load

Because rock has shear strength (unlike liquids), it does not break off vertically at the goaf edge but cantilevers out over the goaf. When the panel width is small compared to depth (subcritical), full caving does not develop and all the weight of the uncaved undermined overburden has to be carried by the abutments. When panel width is large (supercritical), full caving develops and results in the goaf carrying some of the weight of the undermined overburden. The worst case is immediately prior to full caving when average abutment load is typically twice tributary load.

APPLICATIONS IN MINING

Buried Continuous Miners

Over 70% of buried continuous miners in NSW pillar extraction operations have been associated with subcritical to critical panel dimensions. Maximum load was reached in many cases and full caving was about to occur. However, there were many instances where panel width was not sufficient to induce full caving and high pillar loadings had to be tolerated throughout the life of the panel.

Panel Dimensions

A panel should be designed either sufficiently wide (supercritical) to induce full caving very soon after the commencement of extraction, or else sufficiently narrow (subcritical) to restrict the magnitude of abutment stress throughout its life. The worst loading conditions are associated with panels that are of critical width throughout their life.

Consistent Predictable Mining Conditions

At critical panel dimensions, strata control is not only difficult due to high abutment stress environments, but also very susceptible to small changes in geology. Hence, strata behaviour can be unpredictable and inconsistent and explains why, in panels of critical width, even minor geological features or changes in lithology can trigger unexpected falls.

Periodic Face Weighting

In a low strength environment, abutment loads are relatively constant once a panel becomes super critical. However, in competent strata, the upper roof may cantilever a considerable distance over the goaf before breaking off. This behaviour accounts for periodic face weighting, even when panel widths are supercritical. In massive roof environments, some longwall operators use subcritical panel layouts to avoid this problem.

Pillar Design

When designing pillars which abut on a goaf edge, allowance must be made for the additional abutment loading that they will be subjected to. A number of local pillar collapses can be attributed to this oversight.

If you would like further information on any aspect of the Strata Control for Coal Mine Design Project, or wish to make a relevant technical contribution or comment, please contact:

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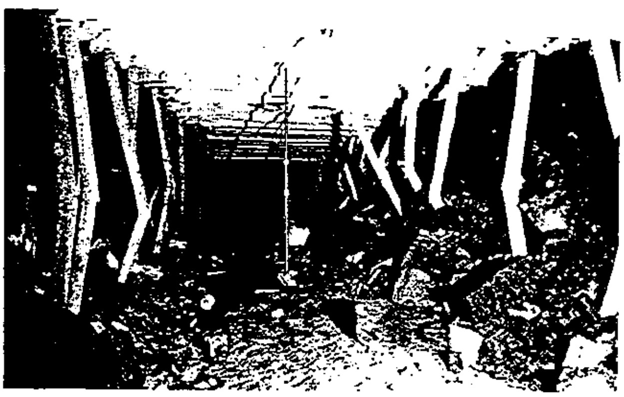


Effect of goaf abutment pressure on fender and pillar rib sides

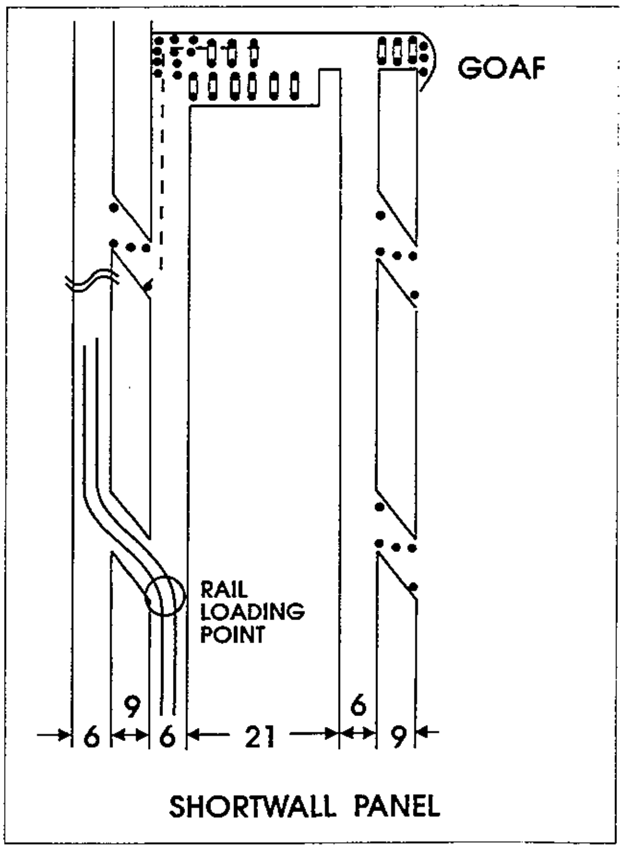
INTERVIEW WITH
MR NORM MONGER

EARLY AUSTRALIAN EXPERIENCE WITH SHORTWALL MINING

After four years war service in the Navy, Norm qualified in both Electrical and Mechanical Engineering. He joined BHP Newcastle in 1948 and gained surveyors, electrical, undermanagers and managers certificates. He managed several collieries in NSW and later became Superintendent of BHP's Newcastle Collieries. Norm retired in 1982.

■ **Why and when was shortwall mining with continuous miners and shuttle cars applied at Burwood Colliery?**

The Victoria Seam was hard coal and production from conventional bord and pillar was about 250 tons per shift from solids and 350 tons per shift from pillars. Also pick usage on solids was greater. The perceived benefit of shortwall, introduced in 1959, was a higher unit output by increasing pillar to solids ratio.



Layout for shortwall mining utilising timber support

■ **Can you briefly outline the method used?**

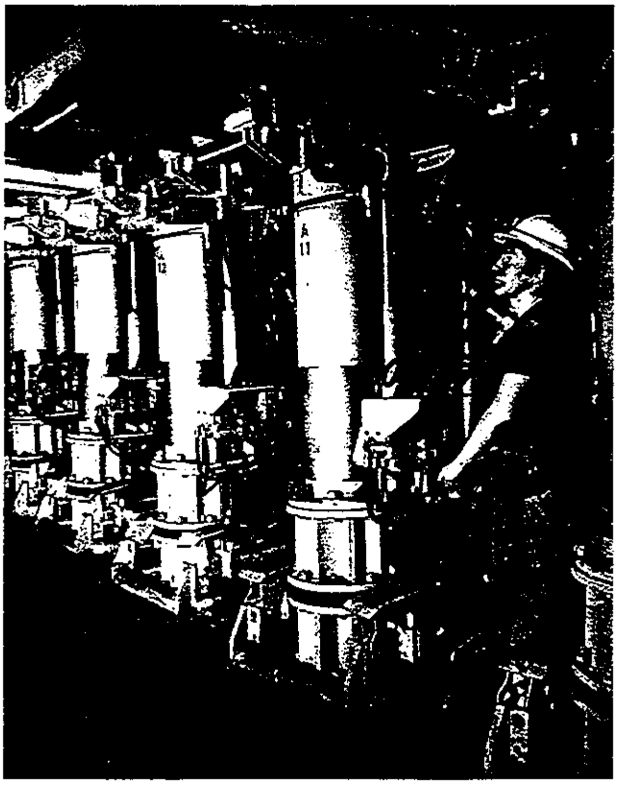
The sketch plan below shows the essential features which included good face ventilation. A requirement of the system was to complete a lift across both pillars every day. Typically a lift would yield 350 tons but this could be varied by widening or narrowing the lift to ensure that the lift was completed in a day.

■ **What about face support?**

The roof was shale. We used 13ft (4m) half round baulks and timber props at the face and at the end of a production shift, two lifts would be standing open on supports. Timber in the inbye lift would be withdrawn on the afternoon shift and placed in the other lift ready for the next shift. Timber recovery was very high with some of the baulks lasting the life of the wall.

■ **Was the method a success?**

All in all it was a most satisfactory method and nine years later, when A G Wild and Co produced hydraulic self-advancing supports for use with continuous miners and shuttle cars, the method was used successfully at pits in both the Newcastle and Wollongong districts.



2 leg Wild hydraulic shortwall supports

Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales

Sponsored by the NSW Joint Coal Board

Issue No. 7

June 1995

UNSW PILLAR DESIGN OUTCOMES

This issue of the newsletter has been expanded to include a stand-alone pull out section entitled ***UNSW Pillar Design Procedure.*** Whilst engineers are often perceived as dealers in "hard" models, this is rarely the case, especially in geotechnical engineering. The Australian Institute of Engineers' publication 'Are You At Risk?' emphasises that *"engineers do not really solve problems. They make choices between options ... in the face of considerable uncertainty and gaps in knowledge. It follows that whatever choice is made, it must be, to some extent, wrong".*

It is important that this risk is quantified and appreciated by end users. Simple curve fitting or highly sophisticated but unproven mathematical models can be fraught with risk. The UNSW Pillar Design methodology is underpinned by rigorous statistical and probabilistic analysis of the actual field performance of full scale coal pillars, both failed and unfailed. Risk has been quantified. The procedure must still be reviewed periodically as our data, experience and knowledge bases improve.

In the mid 1960's Bieniawski and Van Heerden tested small pillars insitu in South Africa by cutting away the upper half of the pillars, casting a concrete platen and jacking against the roof. The testing system comprised a series of 500 ton jacks connected to a common hydraulic supply. This 'load controlled' system resulted in a uniform load and a non-uniform displacement across the pillar.

These issues will be presented in detail in Day 1 of the forthcoming Roadway and Pillar Mechanics Workshop (July 18th and 19th). Day 2 of this Workshop will focus on roadway behaviour and support systems, and integrate these into the overall engineering system. Presentations and discussions will be enhanced throughout the two days by the participation of Professor Horst Wagner, an internationally respected engineer in theoretical and applied rock mechanics.

In the late 1960's Wagner, Salamon and Cook made two significant refinements to the insitu testing procedure. Firstly, a slot was cut at the mid-plane in the pillars to establish symmetric loading and to avoid interfering with end contact conditions. Secondly, the testing system was displacement controlled, whereby all jacks were displaced uniformly to simulate roof displacement. Load distribution across the pillar was measured from pressure gauges connected to each jack.

CONTENTS

ISSUE - STOOKS

STOOK LOAD CARRYING POTENTIAL

What is the load carrying potential of a 6 m long by 4 m wide stook that is 2.0 m high?

Applying UNSW Power Strength Formula,

$$\text{Strength} = \frac{7.4 \times w^{0.46}}{h^{0.66}} = \frac{7.4 \times 4^{0.46}}{2^{0.66}}$$

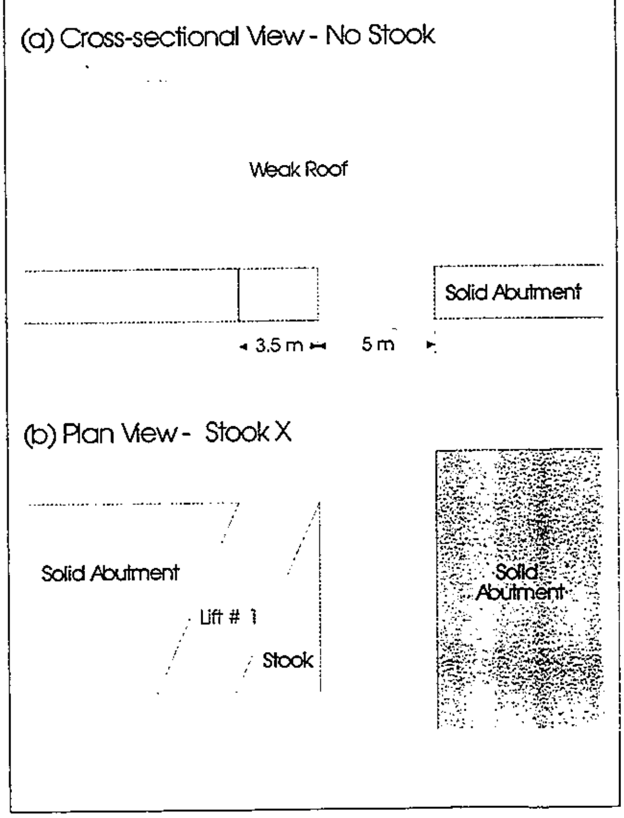
$$= 8.86 \text{ MPa} = 886 \text{ tonnes/m}^2$$

$$\text{Stook area} = 6 \text{ m} \times 4\text{m} = 24 \text{ m}^2$$

∴ Stook load carrying capacity

$$= 886 \times 24 = 21{,}267 \text{ tonnes!}$$

In comparison, the load carrying capacity of
2 Mobile Breaker Line Supports = 1100 tonnes
30 x 150 mm timber props = 900 tonnes
(assuming the highly unlikely situation that all props are loaded equally).



STOOK PERFORMANCE

Stooks offer one of the most effective means of controlling pillar extraction hazards in the vicinity of intersections (see Issue 6). This is because;

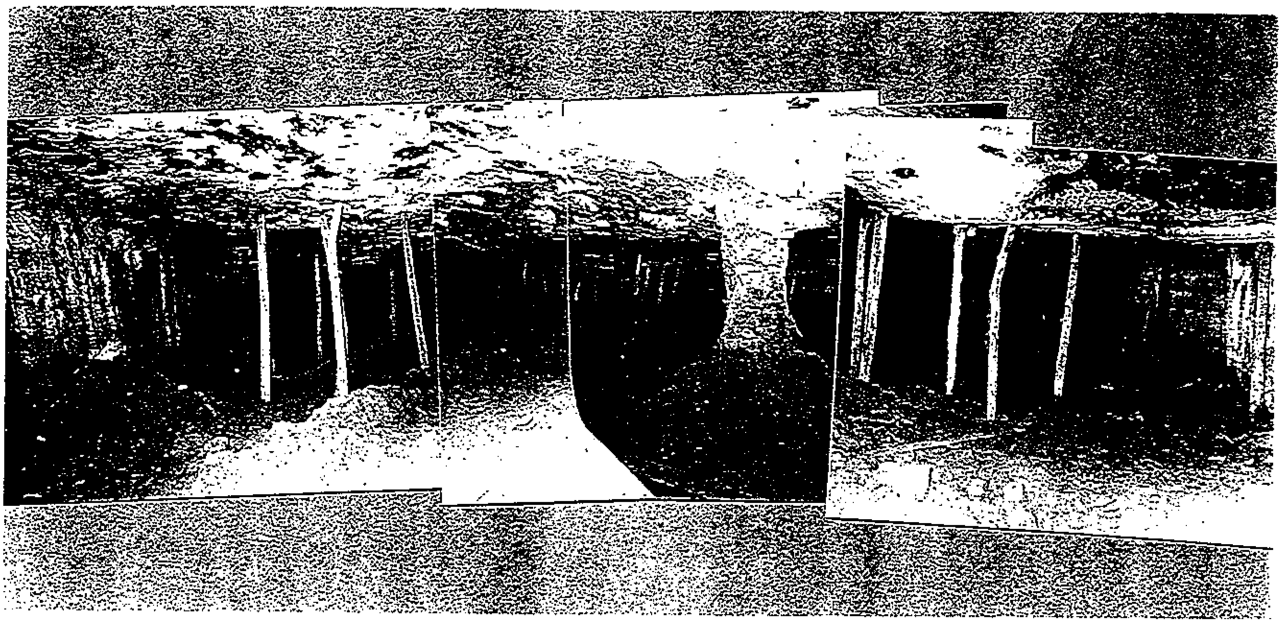
i) stooks have a high load-carrying potential,
ii) stooks are formed in-situ and therefore provide continuous resistance to roof and floor displacement,
iii) stooks are a much stiffer support system than either timber or MBLSs and therefore provide greater resistance against displacement, and
iv) stooks are located in a more effective position for restricting roof span than timber breaker props or MBLSs.

The important role of stooks in weak immediate roof environments is illustrated by the accompanying diagram. The effect of taking the first 3.5 m wide lift when "retreating" from a T intersection is to increase the roof span from 5 m to 8.5 m. This causes;

- a 700% increase in roof displacement,
- an almost 200% increase in tensile stress in the roof, and
- a 70% increase in shear stress at the pillar edges.

A stook acts as a very effective temporary support to limit span in these circumstances. Although the stook in the worked example has a high load carrying capacity, at a depth of 150 m, the deadweight load of a 2.5 m wide unsupported roof area around the perimeter of the stook is sufficient to cause the stook to fail. The load acting on a stook is governed by the stiffness of the roof strata. In weak strata the roof has a low stiffness and quickly loads a stook. Alternatively, the strata may be so weak that it falls around the stooks. Stooks may still fail due to the weakening effect caused by the increase in their effective height. Standard size stooks do not significantly impede caving in weak roof environments.

In strong strata environments, the situation is more complex. Stiff roof can span or cantilever over great distances, causing cyclic loadings. Stiff support reaction is required to induce competent roof to break off. Stooks would need to be very large to achieve this purpose and prevent failure from occurring outbye of face operations around the solid abutments of an intersection. However, large stooks further impede the development of caving and induce higher abutment stresses. They can also function as pillars to reproduce a "mini Coalbrook" collapse situation i.e. very soft under-designed pillars beneath competent roof strata. This generates a false sense of security since, whilst conditions may appear very good, sudden failure can occur without warning, creating additional hazards (windblasts, gas inrush).



A 40 m wide by 120 m long pillar extraction goaf formed under a strong conglomerate roof.

Many examples exist in longwall mining of competent roof strata breaking off at or ahead of the coal face rather that at the rear of a soft hydraulic support system. Likewise, planes of fracture tend to curve around gate-end intersections rather than ingressing into intersection corners. Similarly, pillar extraction layouts under competent roof should be designed to retreat into intersections which are surrounded for 270° (three sides) by solid coal. This utilises the strength of the strata to protect the face operations and reduces the need to leave large stooks. However, intersections need to be carefully inspected for geological features which may act as break-off points. Abutments should not be prematurely weakened by operations such as pre-splitting. Changes in extraction sequences often inadvertently result in this situation.

An understanding of these principles gives insight into field practices developed under competent roof, some of which are listed.

- An almost mandatory requirement in South Africa and the USA not to leave a substantial Stook X.
- Reluctance to leave Stook X but insistence on leaving finger line supports in some Australian operations (see Issue 5).
- The use of Modified Old Ben under conglomerate roof strata in the Newcastle district (large pillars, therefore fewer stooks, always working into a tight corner).
- Conversely, the lack of use of Wongawilli under strong roof (extensive soft abutment fenders, lifting back into relatively open corners).

The research has identified that, for a particular strata type, panel dimensioning is the key principle in controlling roof falls in pillar extraction. This factor, which has great significance to longwall operations, will be developed in the next newsletter.

UNIVERSITY OF NEW SOUTH WALES STRATA MECHANICS WORKSHOP

Stage 2 - **Roadway and Pillar Design Principles and Practice**

Date: Tuesday 18th and Wednesday 19th July, 1995

Venue: Penrith Panthers Leagues Club, Mulgoa Rd, Penrith

Themes:

Day 1 **Pillar Design, Caving and Goaf Reconsolidation**
- UNSW Pillar Design Procedure
- Caving and Goaf Reconsolidation Mechanics

Day 2 **Roadway Reinforcement Principles**
- Roadway Behaviour and Response to Load
- Mechanical Response of Roadway Support Systems

Target Audience:
The workshop is targeted at a broad spectrum of industry and consulting personnel including those with shift supervision, mine planning, technical services and mine management responsibilities.

Costs: \$250 for either day 1 or day 2.
\$400 for both days.

Note:
1. Previous attendance at a Stage 1 workshop is NOT a prerequisite. Relevant key principles developed in Stage 1 will be reviewed in Stage 2.
2. This Workshop comprises two complementary but stand alone themes.
3. Resources are unlikely to permit this workshop to be repeated as frequently as the Stage 1 workshop. Hence, there is no limit on numbers.
4. The workshop is planned to coincide with a visit to Australia by Prof. Horst Wagner. Prof. Wagner is internationally renowned in mine strata mechanics and rock reinforcement in both coal and metalliferous environments. Participants should benefit from his experience and workshop presentations.

Contacts:
Ms Mandy Blacklock, Tel No.: (02) 385 5006, Fax: (02) 313 7269
Prof. Jim Galvin, Tel No.: (02) 385 4515, Fax: (02) 663 4019

WHERE HAVE WE COME FROM ...

MATHEMATICAL MODELLING - PART I

The stresses generated in coal strata are determined by its depth and the geometry of the mine workings. As with other engineering structures such as bridges, dams and jumbo jets, mathematical equations can be used to predict the magnitude and effects of the stresses involved in mining.

These equations, however, can be complex and difficult to solve. Other engineers work with materials that have well defined properties and load environments compared to mining engineers who are at the mercy of nature and rocks having variable geological settings and mechanical properties. Mining engineers have no choice over the materials in which they work, nor do they know, with any comparable deal of reliability, the strength and other mechanical properties of those materials. Rocks are notoriously variable and flawed materials.

Throughout the 1950's and early 1960's, expert mathematicians tried to simplify equations and achieve approximate solutions because the computational power to solve the complex mathematics did not exist. Unfortunately this was rarely, if ever, good enough to provide predictions that came anywhere close to reality. Understandably, strata control became established as an empirical technology and one that was diffident to the role of mathematics and theory.

Things started changing, however, in the 1960's with the appearance of analog and digital computers. Although analog computers were soon to be superseded and made virtually obsolete by digital computers, they did provide the first available means for attempting analytical solutions to strata control problems.

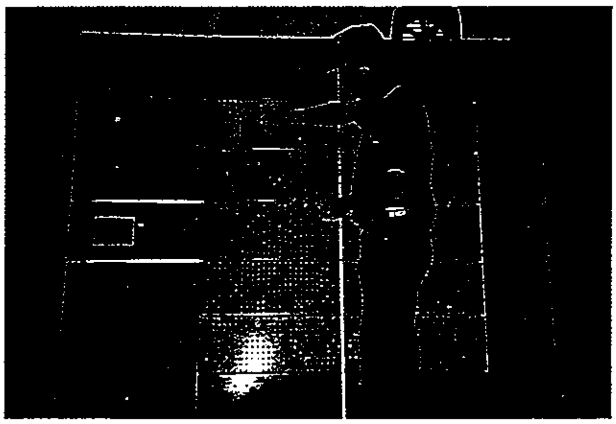
An analog is a physical representation or simulation of a system or process. For instance, the movement of air in a mine ventilation network follows similar laws to the distribution of an electric current in a circuit. So, complex mine ventilation networks can be analysed using corresponding electrical circuitry in which volts represent ventilation pressure, amps represent air flow rate and ohms are a measure of roadway resistance. Basically, the same sort of simulation could be, and was, developed to predict ground displacements in mining.

In 1963 Professor Miklos Salamon (incidentally a key member of our project team) had shown that the distribution of convergence between the roof and floor of a coal seam satisfies what is known as the Laplace equation. It was also known that the electrical potential distribution of a steady current flowing in a continuous conductor likewise satisfies the Laplace equation. So the first "analog computer" (see below) was developed to "calculate" seam convergence using a large tank of tapwater with a metal plate electrode at the base of the tank and a second electrode at the top of the tank. This second electrode had the shape of the mine opening being modelled cut into it. A DC voltage was applied between the electrodes and the distribution of potential in the opening corresponded to the displacements in the actual mine excavation.

Within two years a vastly superior analog had been developed which replaced the electrolytic tank with a three-dimensional network of electrical resistances, the distribution of electrical potential between the junctions (nodes) providing a close approximation to the Laplace solution. The first such electrical resistance analog was built in South Africa. Later, an analog was built in Australia, for the then School of Mining Engineering at the University of New South Wales in 1975 (see below).

(to be continued) ...

An 'Electrolytic Tank Analogue Computer' showing convergence being measured around the edge of gold mine workings.



The 'Electrical Resistance Analogue Computer' constructed for the School of Mining Engineering at UNSW in 1975

ISSUE

CAVING AND GOAF RECONSOLIDATION - PART 1

An understanding of caving and goaf reconsolidation behaviour is important because it determines how overburden load is distributed between the panel abutments (*ie* chain, barrier and face pillars) and the goaf of total extraction panels.

As rock strength decreases, the angle at which it caves (caving angle or angle of break) becomes steeper.

When caving occurs, the rock bulks and occupies a greater volume. The term 'Bulking Factor' (B) defines the ratio of the volume of broken rock V_B to solid rock, V_S :

$$B = \frac{V_B}{V_S}$$

Highly laminated roof strata, such as mudstones, fall in flat slabs like a deck of cards and have a low bulking factor, typically 1.1 to 1.2. Stronger and more massive strata such as sandstones tend to fall in large irregular shaped blocks. Blocks rotate, giving rise to a high void content. Therefore, bulking factors of 1.5 or greater are not uncommon.

The combination of steep caving angle and low bulking factor largely account for why weak strata falls to greater heights than stronger strata before either doming out or choking off.

When an excavation is made in rock, confinement is removed from the roof, floor and sides and they displace into the excavation. The roof also sags under its own weight in proportion to the fourth power of the span (*ie* b^4, see Issue 5). Roof and floor convergence, s_i reduce the mining height, h, of the excavation. The bulking factor (B) and effective height ($h - s_i$) of an excavation determine how high a fall can propagate before it chokes off. This height is called the caving height, h_C,

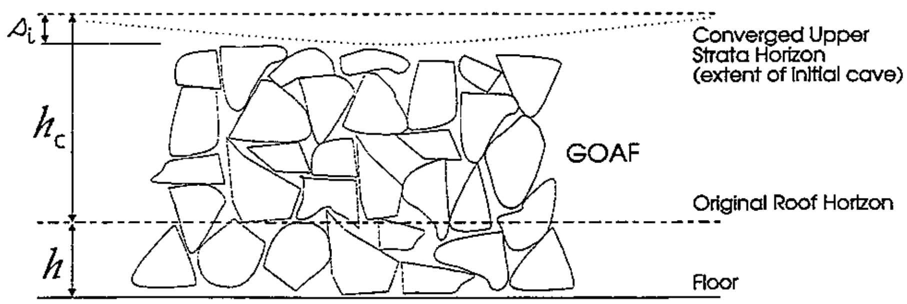
$$h_C = \frac{h - s_i}{B - 1}$$

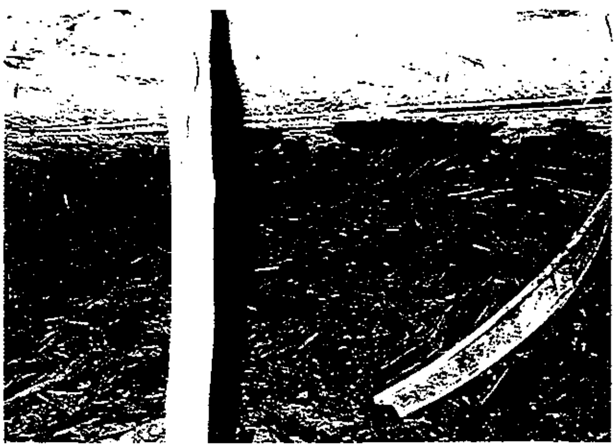
In the case of caving, s_i equates to the convergence between the strata at the top of the fall and the floor.

Example: Mining height = 2.7 m
Convergence = 0.3 m
for B = 1.1, h_C = 24 metres
and for B = 1.5, h_C = 4.8 metres

Until the fall chokes, all the weight of the uncaved overburden is carried by the panel abutments. Thereafter, as excavation width increases, a greater proportion of the weight is transferred to the goaf causing a progressive consolidation of the goaf and a reduction in effective bulking factor.

This topic will be discussed further in the next issue and will be addressed in detail at the Stage 2 Workshop, to be held in July 1995.




A steeply sided fall of very weak laminated strata showing the low bulking factor


A fall of strong sandstone/conglomerate strata showing the flat angle of caving and high bulking factor

QUESTIONS AND ANSWERS

STRESS MEASUREMENTS – PART 1

The measurement of stress has long been one of the most vexing issues in rock mechanics. Most devices do not in fact measure stress. They respond to an imposed strain resulting from stress. The installation of stress measuring devices almost always causes a change in the state of stress that the devices are endeavouring to measure. Anomalous readings are common because outputs are very sensitive to installation procedure, installation horizon and orientation of devices relative to bedding. Measurements are point specific and care and experience is required in extrapolating them to other locations. 'Black box' conversion factors cannot be applied indiscriminately. Increasingly, outcomes and recommendations of many geotechnical investigators are being based on stress measurement. Given the expense associated with stress measurements, the reliability of results and the implications of how these are interpreted and utilised, it is important that operators and end users have an awareness of the basis and limitations of stress measurement.

■ ***What is a load?***

Load is the force generated when a mass is subjected to an acceleration. In mining terms, it is the force generated by the rock mass under the effect of gravity. Weight is another term for load or force.

■ ***What is stress?***

The effect of a load on a material is related to the area over which the load acts. For example, an elephant may weigh more than a person wearing stiletto shoes but its feet will do less damage to a floor because its load (weight) is distributed over a larger area. Stress is a standard used to compare the effects of load.

$$\text{Stress} = \sigma = \frac{\text{Load}}{\text{Area}} = \frac{L}{A} \qquad \text{... (1)}$$

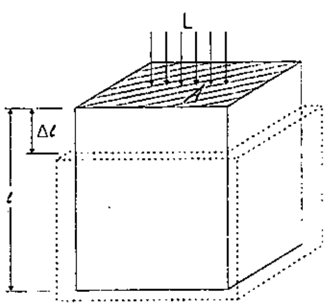
ie

Stress = Load per unit area.

Pressure is another term for stress.

■ ***What is displacement?***

When any material is subjected to a load, it will shorten (compress) or lengthen (stretch), depending on the direction of the load (compressive or tensile). The movement which occurs is called displacement, Δl.



■ ***What is strain?***

The effect which lengthening or shortening has on a material is relative to its original length or height. For example, 40 mm of roof convergence may cause a 1 m long timber prop to fail, but a similar 4 m long prop may show few signs of distress. Strain is the standard used to compare the effects of displacement.

$$\text{Strain} = \varepsilon = \frac{\text{Change in Length}}{\text{Original Length}} = \frac{\Delta l}{l} \qquad \text{...(2)}$$

■ ***How do rocks behave under compressive stress?***

The application of a compressive stress to a typical coal measure rock initially causes the microfractures and pore spaces within the rock to close up, (A-B, in figure below). Thereafter, there is an almost linear relationship between stress and strain until point C is reached, where the rock fabric begins to break down. The maximum strength of the rock is reached at point D, whereafter the rock sheds load with further strain.

■ ***What is Young's Modulus***

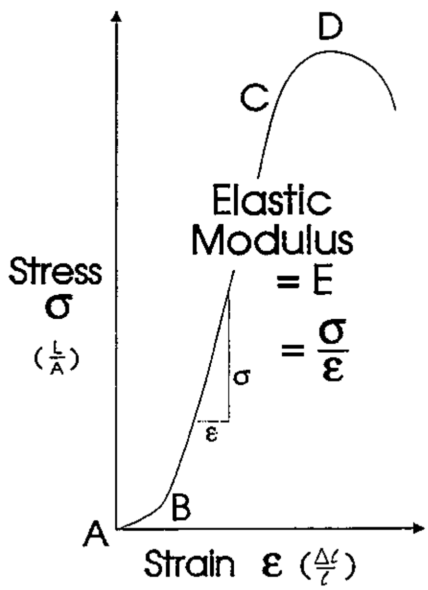
Young's Modulus, E, defines the relationship between stress and strain in the linear range B-C

$$E = \frac{\sigma}{\varepsilon} \qquad \text{... (3)}$$

It is a material property which, unlike stiffness, is effectively independent of geometry and can, therefore, be determined readily from laboratory testing.

■ ***What is the basis of most 'stress measurement'***

Most 'stress measurement' is based on using very sensitive devices to detect rock displacement, Δl, over a small distance, l, *ie* strain ε. By measuring E in the laboratory, Eqn 3 can be used to calculate stress. Anomalous readings occur due to fractures, poor bonding of devices to the rock and non-representative laboratory samples. Quality control procedures must be applied to minimise these anomalous occurrences.



KEY RULE OF THUMB

Strong Roof Can Be More Treacherous Than Weak Roof

Rock failure is usually discussed in terms of critical stress levels. In practice, however, measurements and decision making regarding rock behaviour are nearly always based on displacement. Weak sedimentary strata tend to behave plastically and undergo significant displacement over time prior to failure. Strong sedimentary strata, on the other hand, tend to be brittle and, whilst stronger, undergo much less displacement prior to failure which is often sudden. In weak roof environments, there is a heightened awareness of, and vigilance towards roof conditions. Medium to dense systematic roof support is usually standard. Systematic support is often absent or sparse in strong roof. All these factors can result in the behaviour of strong roof being less predictable and potentially more treacherous than that of weak roof.

APPLICATIONS IN MINING

Failure Mode

Strong brittle rocks, such as conglomerate, can have high compressive and shear strengths. They are most likely to fail in tension, given that the tensile strength of rock is typically only one tenth that of its compressive strength. Conversely, weak rocks can have such low compressive, shear and tensile strength that all three failure modes are common. Roof failure is also governed by the thickness of the individual roof ply. Often the lower strength strata are also highly laminated whilst the high strength strata tend to be massive and therefore constitute stronger structural beams. Failure of these stronger beams is more likely to be induced by the presence of a discontinuity (fracture, plies and partings), which destroy the integrity of the beam, rather than by material failure.

Discontinuities (fractures, plies and partings)

Joint and fracture planes and roof plies and partings represent a hazard with all roof types. However, in weak roof situations they are usually controlled as a matter of routine through the installation of support. In strong roof environments where roof support density may be very low, they represent a special hazard. Sounding the roof to detect plies and partings is only effective to a distance of about 0.5 m, even for an experienced operator. Test hole drilling can also fail to detect thin plies and partings. Fractures can go undetected, especially if they are tightly closed. The roof needs to be subjected only to a minimal amount of tension, for it to part and fall along these planes of weakness. It is critical, therefore, especially in dynamic environments such as around total extraction operations, that the roof is checked regularly.

Warning Signs

Due to their plastic nature, weak roofs usually exhibit many early warning signs of instability. Fretting of roadway corners, delamination and spalling, gutters (cutters), noise and dribbling are examples. Strong roofs may exhibit none of these and simply drop out suddenly in tension, unless adequate additional support has been installed.

Weak roof which has given warning of impending failure, resulting in the progressive installation of mesh, bolts, straps, cross supports, legs, cablebolts and PUR.

If you would like further information on any aspect of the Strata Control for Coal Mine Design Project or wish to make a relevant technical contribution or comment, please contact

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Sydney 2052 Australia
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INTERVIEW WITH MR RICHARD EVELEIGH

MODERN TRENDS IN LONGWALL ROOF SUPPORT DESIGN

Richard Eveleigh's answers to questions on modern trends with longwall supports make a striking contrast to the answers from John Smith in Issue 5 on early experience with longwall in Australia.

Richard is Managing Director of Australian Longwall Pty Limited. He graduated as a mining engineer in 1976 from Leeds University and worked for the National Coal Board and later the Dowty organisation in Britain before coming to Australia in 1983 to join Dowty Wolleng. He became Managing Director in 1989.

■ ***What key factors led to the successful application of longwall in Australia?***

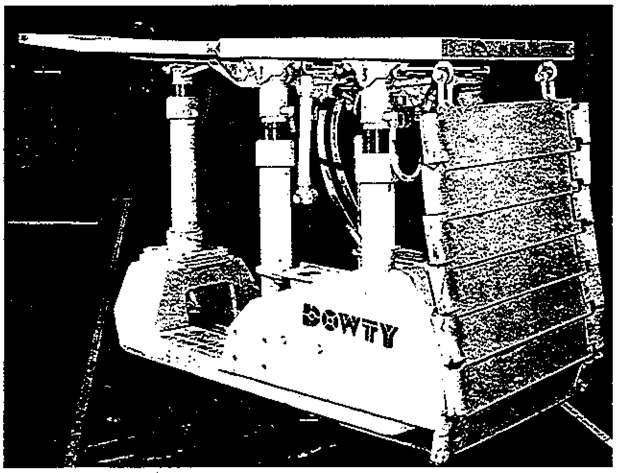
Four-leg chock shield supports of greater than 600 tonnes capacity giving support densities of 80-100 tonnes/m^2 became available in the early 1980's and this was the breakthrough that led to the successful introduction of longwall. They provided the first effective means for supporting and controlling massive sandstone roofs at depth.

■ ***Are four leg chocks still required today?***

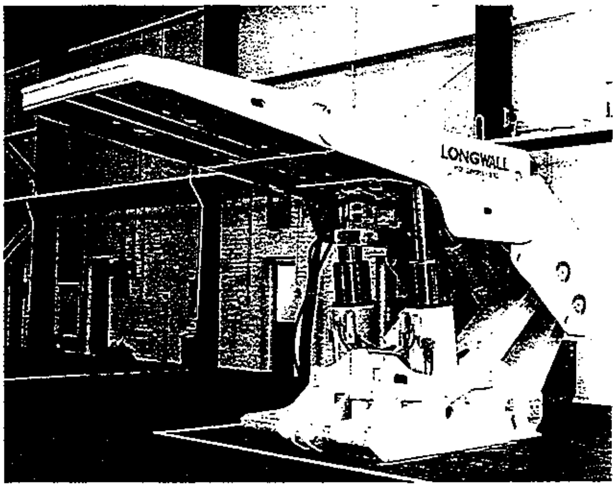
Continuously improving technology has enabled the development of reliable two-leg shields with ratings currently in excess of 900 tonnes and these will be used on most longwalls throughout the 1990's. They provide support densities of over 120 tonnes/m^2 and are ideal for electro-hydraulic control. There are, however, situations where four-leg shields will still be needed such as where a strong roof bridges back into the goaf and support stability becomes critical.

■ ***What about the management of strata control with modern longwalls?***

With reliable electro-hydraulic control systems developed in the 1980's shearer initiated roof supports are now the norm. Development of control systems is now moving more into system monitoring and data collection to inform operators of what is happening both on and around the longwall. This approach will greatly facilitate the management of longwalls in difficult strata conditions.



An early 5 leg chock support having an average support density of about 25t/m^2.



A modern 2 leg shield support having an average support density of over 120t/m^2.

MASTER OF APPLIED SCIENCE IN MINING GEOMECHANICS

Any person who would be interested in undertaking a part-time Masters Degree by course work in this field should contact either:

Professor Jim Galvin or Professor Bruce Hebblewhite

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Strata Control for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales

Sponsored by the NSW Joint Coal Board

RR001 Research Release No. 1 – June 1995

UNSW Pillar Design Procedure

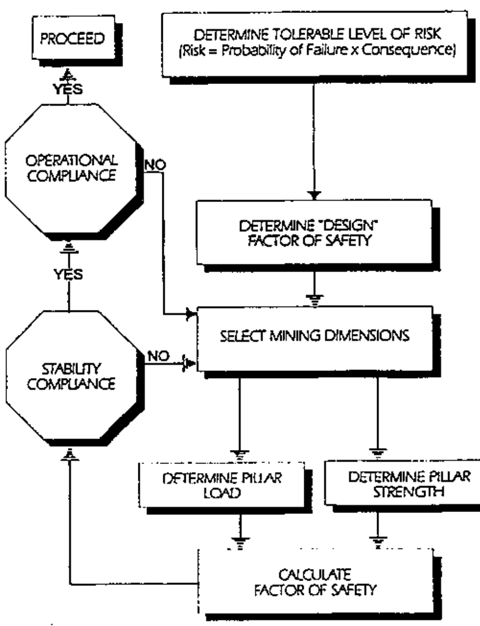
METHODOLOGY

A coal pillar system comprises the pillar itself, the roof and floor strata and the pillar roof and floor contacts. Pillar systems may collapse gradually, in which case there is ample warning, or suddenly to the point of being instantaneous. In general, pillar system failures initiated by roof or floor failure develop gradually. Sudden collapses are usually associated with pillar system failures involving competent roof and floor strata in which the coal pillar itself fails. These failures present the greatest hazard to personnel as evidenced by experience.

The **UNSW Pillar Design Procedure** applies to coal pillar failure mechanisms in a geological environment comprising competent roof and floor strata. Weak roof and floor strata would warrant larger pillar sizes than those computed by this procedure. The design of such pillar systems, however, would need to be conducted utilising specific strata properties.

The overall design methodology follows the logical decision making process illustrated in the flowchart. It consists of the following discrete steps:

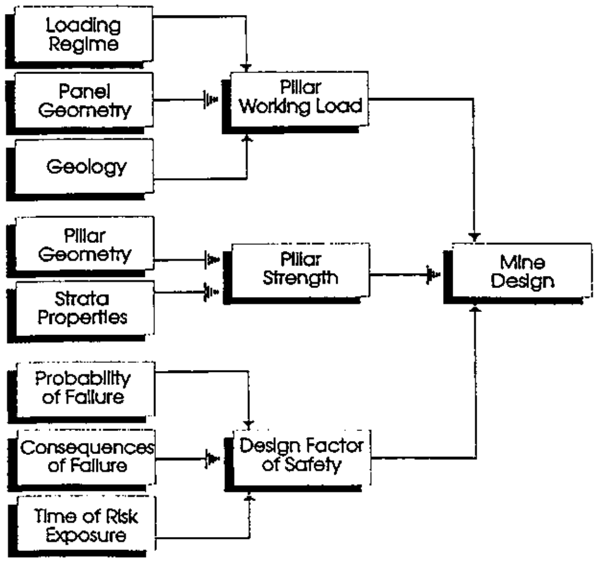
PILLAR DESIGN DECISION PROCESS



- Decide on what is a tolerable, or acceptable level of risk. Risk equals probability of failure x consequence of failure. Both components must be carefully considered.
- Determine an appropriate 'design' Factor of Safety (FOS) which reflects this level of risk.
- Select mining dimensions.
- Determine pillar load and strength for selected mining dimensions.
- Calculate the pillar Factor of Safety.
- Check stability compliance between the calculated and design value of FOS.
- Check pillar dimensions for mining operational compliance, (e.g. wheeling, flit distance, ventilation, spontaneous combustion, etc.).

The design methodology has evolved from a probabilistic analysis of field performance of pillar systems in New South Wales and Queensland. Two forms of pillar strength relationships have been quantified by this analysis; a power law formula, and a linear formula. A marginally higher confidence level is associated with the power law formula.

Principal Influences on Pillar Load, Strength and Factor of Safety



PILLAR WORKING LOAD

REGULAR PILLAR LAYOUTS

The Pillar Working Load is the maximum load that the pillar will be subjected to. This is determined by both the stiffness of the surrounding strata and the stiffness of the coal pillar. When a mining panel is narrow compared to its depth, the roof strata is stiff and it arches across the panel. Therefore, the total dead weight load of the overburden is not transferred to the coal pillar.

As the panel width to depth ratio *(W/H)* increases, the stiffness of the roof strata reduces until it is incapable of arching across the panel. In this case, the full dead weight load of the overburden has to be supported by the pillars.

In an extensive layout comprising pillars of regular size, pillars are of equal stiffness and therefore share the load equally. The Pillar Working Load is the dead weight of overburden within the pillar's area of influence, shown shaded in Figure 1. This is referred to as Tributary Area Load. The load divided by the plan area of the pillar equates to the Average Pillar Stress, σ_p.

In an extensive layout comprising pillars of irregular size, the pillars with the greater width to height ratios are subjected to more load because they are stiffer and, therefore, provide greater resistance to

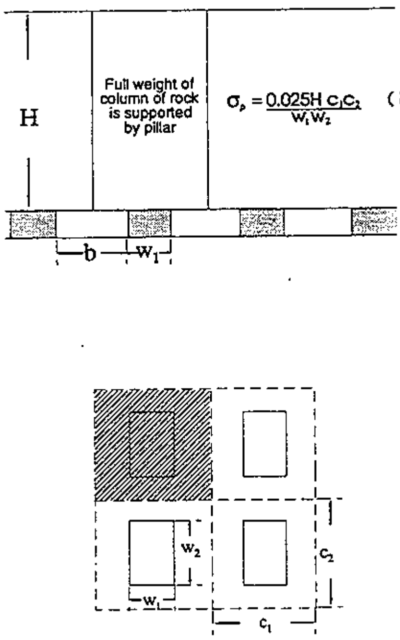


Figure 1. Tributary Area Load

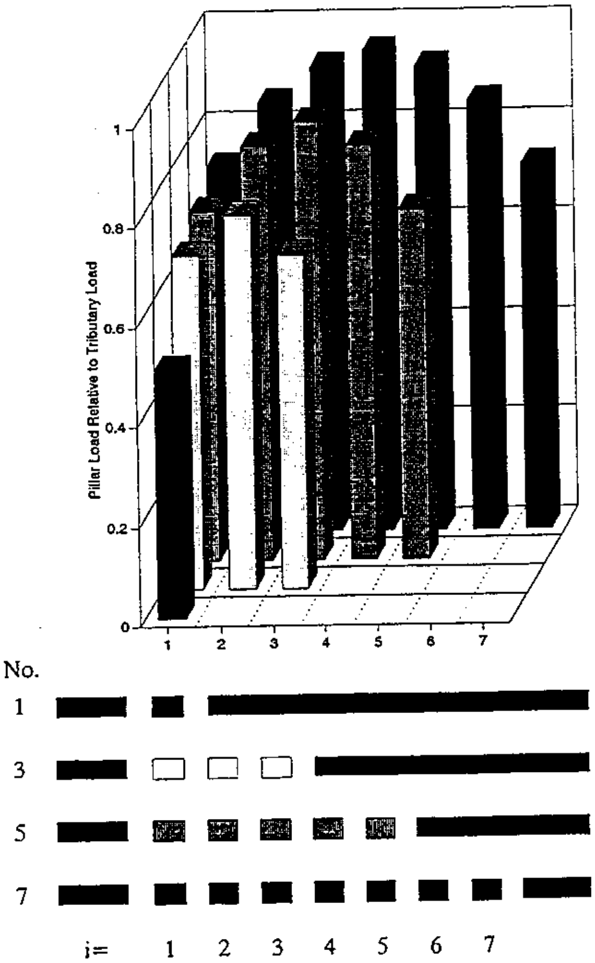


Figure 2. Panel Pillar Loading

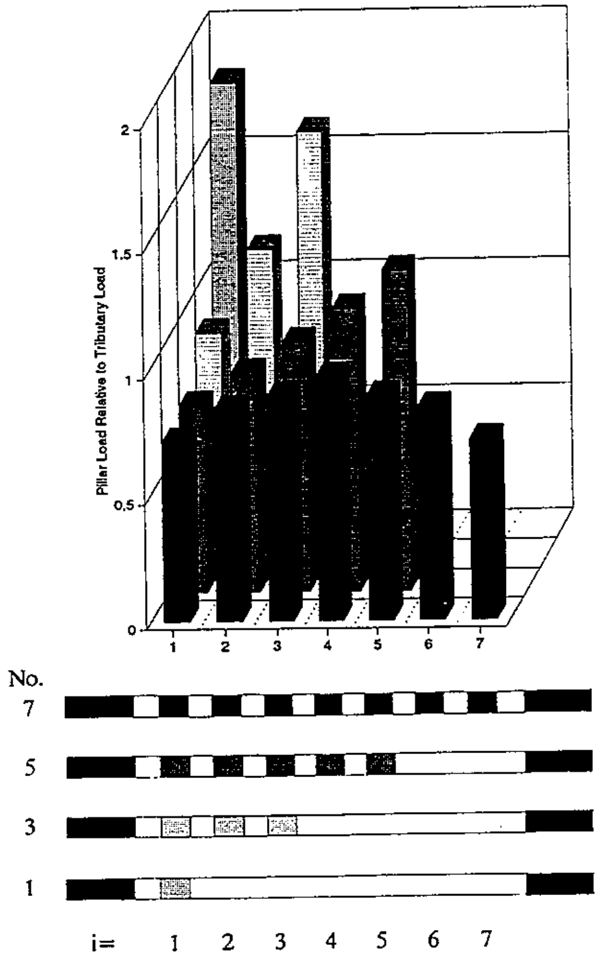


Figure 3. Abutment Loading on Standing Pillars

PILLAR WORKING LOAD (CONTINUED)

roof sag. Advanced numerical techniques may be required to calculate Average Pillar Stress in these layouts.

Pillar loads have been calculated mathematically for various width of panels and are shown as a function of Tributary Area Load, Figure 2. Pillar load ranges from 50% of Tributary Area Load for a single pillar panel to 95% for a 7 pillar wide panel. The extent of load reduction depends on the stiffness of the surrounding strata. Stiffness can be difficult to quantify and may vary considerably. Therefore, pillar design should be based on full Tributary Area Load irrespective of the width to depth ratio *(W/H)* of the panel and the nature of the surrounding strata.

EXTRACTION OF REGULAR STANDING PILLARS

When a panel of regularly sized standing pillars is extracted, the load acting on the pillars adjacent to the goaf is increased. This increase is influenced by the overall span of the goaf, the material properties of the overburden and the sequence and speed of extraction. An extreme situation occurs when the panel width is sub-critical and the superincumbent strata spans across the extracted area, resulting in minimal load transfer to the goaf. Figure 3 shows how in this situation, abutment loading on the face line pillars can increase to at least twice Tributary Area Load.

Close to the active face line, pillar load is constantly changing and is highly dependent on the rate of extraction. Experience suggests that the average pillar loading is typically 1.3 to 1.5 times Tributary Area Load. A Tributary Area Load multiplier of 1.5 is recommended, therefore, except in the circumstance where it is known that a row of pillars will remain standing against a goaf edge for a considerable time. In this latter case, a load multiplier of at least 2.0 should be used to ensure stability.

PILLAR STRENGTH

Strength is defined as the maximum stress a structure can sustain without failing. Laboratory testing has established that the strength of a coal pillar is a function of its material strength, its width and its height. However, strength formulae developed from such tests find limited application because they fail to account for factors such as rock mass variations, geological imperfections, pillar volume and pillar shape, all of which affect pillar strength in the mine.

Quantification of 'field strength', therefore, needs to be based on an analysis of the actual field performance of full scale pillars, both failed and unfailed. Even then, it is still not practical nor realistic to measure all rock mass and geological variations and input them into the design. The established engineering design methodology in these circumstances is to utilise probabilistic statistical methods to quantify the degree of variability and uncertainty in the design due to these factors (Major geological disturbances or features still need to be assessed separately).

A probabilistic analysis of collapsed and stable bord and pillar workings has been performed on field data from NSW and Queensland coal mines. Australian parameters for the two most universal forms of pillar strength formulae, namely the linear form (e.g. Bieniawski) and the power law form, (e.g. Salamon and Munro) were quantified from this probabilistic analysis. The parameters which yield the maximum likelihood of predicting the field performance within the range of the database (width/height *(w/h)* = 1.07 to 10.6) are:

Linear Formula

$$S_p = 5.36\left[0.64 + 0.36\left(\frac{w}{h}\right)\right] \quad \text{(MPa)}$$

(Standard Deviation = 0.0863)

Power Law Formula

(a) For w/h < 5

$$S_p = 7.4\,\frac{w^{0.46}}{h^{0.66}} \quad \text{(MPa)}$$

(b) For w/h ≥ 5
(Squat Pillars)

$$S_p = 19.24\,\frac{\left[0.2373\left[\left(\frac{w}{5h}\right)^{2.5} - 1\right] + 1\right]}{w^{0.1334}\,h^{0.0667}} \quad \text{(MPa)}$$

(Standard Deviation = 0.0735)

The power law formula fits the Australian database slightly better than the linear formula as shown by the lower standard deviation. This is primarily because, unlike the linear formula, the power law formula takes account of:

- the exponential increase in lateral confinement generated within pillars as *w/h* increases;
- the effect of pillar volume on pillar strength, Figure 4.

PILLAR STRENGTH (CONTINUED)

The probabilistic analysis has shown that pillar strength in the field is largely independent of the material strength of the coal seam once *w/h* exceeds 2. This behaviour is consistent with field strength being dominated by the *w/h* ratio and the associated lateral constraint that this parameter generates.

The Australian database is relatively small (30 cases) and it is plausible that some critical factors may be absent. The largest database of collapsed and stable pillars assembled is that of Salamon and Munro in South Africa (125 cases). Because pillar strength is largely independent of coal seam material strength, it is reasonable to compare and to combine both databases in order to check for inconsistencies.

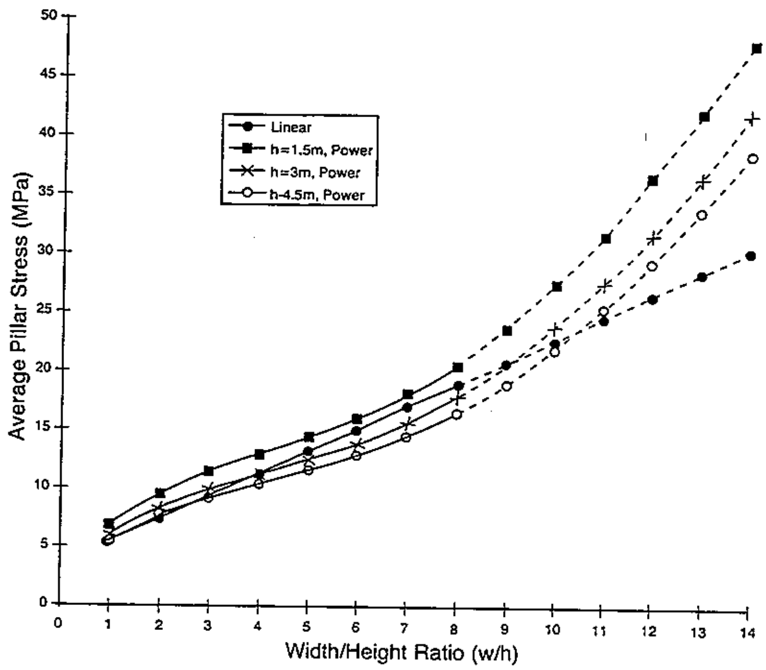


Figure 4. Strength v. Width/Height Ratio

Close correlations were obtained in both cases, with the strength parameters for the linear and the power law formulae differing by only 5% and 3%, respectively. In all cases, a lower standard deviation was associated with the power law formulae (0.0689 to 0.0735) than the linear law formulae (0.0776 to 0.0863).

Probabilistic analysis is a far more rigorous mathematical process than curve fitting. It assigns a statistical significance to stable as well as to collapsed cases, although collapsed cases carry a much higher weighting. Neither the Australian nor the South African databases contain a collapsed case above a *w/h* ratio of 8.2, hence there are no checks on the upper limits to which the formulae find application.

Either formula may be used up to a *w/h* ratio of 8 although the power law form is more flexible and preferred on the basis of statistical trends and conformity to physical principles. The power law formula is recommended for *w/h* ratios greater than 8 recognising, however, that there is a lack of data to validate either formula at *w/h* ratios greater than 8 and, especially, greater than 10.6 (upper stable case).

RECTANGULAR PILLARS

Sensitivity analysis indicates that at small *w/h* ratios, rectangular pillars are capable of carrying a greater load per square metre than square pillars of the same minimum width dimension. However, at large *w/h* ratios, the minimum pillar width may be the controlling factor, irrespective of whether pillars are rectangular or not. Until more data become available, it is recommended that the minimum pillar width be used as the basis for calculating the strength of rectangular pillars.

If you would like further information on any aspect of the Strata Control for Coal Mine Design Project, including the UNSW Pillar Design Procedure, or wish to make a relevant technical contribution or comment, please contact either:

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The financial support of the Joint Coal Board and the contributions of the following members of the Strata Control for Coal Mine Design Project Team in the development of this procedure are acknowledged:

Mr Ian Anderson, Professor Jim Galvin, Professor Bruce Hebblewhite, Professor Grant Hocking, Dr. Carlos Quinteiro, Professor Frank Roxborough, Professor Miklos Salamon

DETERMINATION OF FACTOR OF SAFETY

The use of Factor of Safety (FOS) is a means of incorporating acceptable and tolerable levels of risk into engineering designs.

Risk = Probability x Consequence

Risk is the product of the probability and the consequence of an unwanted event, in this case, a pillar instability or failure.

When the consequences of failure are serious, a reduced probability of failure needs to be adopted in order to achieve an acceptable level of risk. For example, when mining a panel of pillars, the normal acceptable level of risk in terms of probability of failure is 3 in 1000. However, this probability of failure would be unacceptable for a more serious consequence of failure, such as sudden flooding of the workings. In this case, a probability of failure of at least 1 in 100,000 may be chosen as representative of the tolerable level of risk, considering the seriousness of the consequences.

For coal pillars:

$$\textit{Factor of Safety} = \frac{\textit{Pillar Strength}}{\textit{Pillar Load}}$$

A probabilistic analysis of pillar performance data from mines in New South Wales and Queensland has produced two alternative pillar strength formulae - the 'UNSW Linear Formula' and the 'UNSW Power Law Formula'. This analysis has defined the relationship between Probability of Failure and Factor of Safety (FOS). The table below lists the appropriate FOS to be used with either formula in order to achieve the required Probability of Failure which is consistent with the acceptable or tolerable level of risk for the pillar design.

On the basis of previous mining experience, a probability of 3 in 1000 is regarded as representing an acceptable level of risk with respect to a bord and pillar based production panel (where pillar life expectancy is in the 1-3 year range). As pillar requirements, with respect to lifetime or consequence increase, lower probabilities of failure are required to minimise the risk and hence, higher values of FOS need to be adopted.

In some instances the two forms of pillar strength formula generate nearly identical values. Nevertheless the table of Probability of Failure and Factor of Safety indicates that a higher risk is assigned to the use of the linear formula. This apparent anomaly is a consequence of the greater scatter of data (hence, higher standard deviation) associated with the linear formula. This is one of the reasons why the **UNSW Pillar Design Procedure** recommends the use of the power law formula in preference to the linear formula. Because the **UNSW Pillar Design Procedure** has been developed on a probabilistic basis, it needs to be reviewed periodically as the database expands and the understanding of pillar mechanics advances. The examples which follow are all based on using the UNSW Power Law Formula.

Probability of Failure	FOS (Linear)	FOS (Power)
8 in 10	0.84	0.87
5 in 10	1.00	1.00
1 in 10	1.29	1.24
1 in 100	1.59	1.48
3 in 1,000	1.72	1.59
1 in 1,000	1.85	1.69
1 in 10,000	2.09	1.88
1 in 100,000	2.33	2.06
1 in 1,000,000	2.57	2.23

LIMITATIONS

It should be recognised by users of the UNSW Pillar Design Procedure that it has been developed using probabilistic methods applied to the currently available database. As with most engineering design systems, pillar design involves an element of uncertainty. Care should be taken in the application of this procedure to ensure that all parameters which may have a bearing on the performance of a pillar system are taken into account, and that an appropriate probability of failure is selected as a measure of acceptable risk. The probability should reflect the level of uncertainty and variability of information; any extreme, or non-standard input parameters and influencing factors; the purpose and anticipated life expectancy of the pillar(s); and the potential consequences of pillar failure.

The UNSW Pillar Design Procedure is an aid to design and should always be supplementary to sound engineering judgement.

EXAMPLES

1. Calculate the FOS and Probability of Failure for an existing panel of standing square pillars.

Depth (H):	150 m
Actual bord width (b):	6.5 m
Actual pillar dimensions (w):	16 m x 16 m
Mining height (h):	3.3 m

Pillar Working Load:

$$\sigma_p = \frac{0.025HC_1C_2}{w_1\ w_2} = \frac{0.025 \times 150 \times 22.5 \times 22.5}{16 \times 16}$$

$$\sigma_p = 7.42 \text{ MPa}$$

Width/Height Ratio *(w/h)*: 4.8

Pillar Strength:

$$S_p = 7.4\left(\frac{w^{0.46}}{h^{0.66}}\right) = 7.4\left(\frac{16^{0.46}}{3.3^{0.66}}\right)$$

$$S_p = 12.05 \text{ MPa}$$

$$FOS = \frac{S_p}{\sigma_p} = 1.62$$

Referring to the table, the corresponding Probability of Failure for this FOS lies between 1 in 1000 and 3 in 1000 (i.e., a lower probability of failure than 3 in 1000, but higher than 1 in 1000).

2. Calculate the FOS and Probability of Failure for an existing panel of standing rectangular pillars.
Same parameters as for Example 1 except that, Pillar dimensions (w_1, w_2): 16m x 24m

Pillar Working Load:

$$\sigma_p = \frac{0.025HC_1C_2}{w_1\ w_2} = \frac{0.025 \times 150 \times 22.5 \times 30.5}{16 \times 24}$$

$$\sigma_p = 6.70 \text{ MPa}$$

Using minimum width, pillar strength is as in (1),

$$S_p = 12.05 \text{ MPa}$$

$$FOS = \frac{S_p}{\sigma_p} = 1.80$$

Referring to the table, the corresponding Probability of Failure for this FOS is lower than 1 in 1000, but higher than 1 in 10,000.

3. Determine the required dimensions for a production panel of square pillars which will be extracted within the next two years.

Depth (H):	180m
Bord width (b):	6.0m
Mining height (h):	2.8m
Tolerable level of risk:	3 in 1000 probability of failure.

Design FOS required:	1.59 (power formula)
Initial selection of dimensions:	18m x 18m
Width/Height Ratio (w/h):	6.4

Pillar Working Load:

Allowing for 1.5 x tributary load for goaf edge pillars, then

$$\sigma_p = \frac{0.025HC_1C_2}{w_1\ w_2} \times 1.5 = \frac{0.025 \times 180 \times 24 \times 24 \times 1.5}{18 \times 18}$$

$$\sigma_p = 12.00 \text{ MPa}$$

Pillar Strength:

$$S_p = 19.24\ \frac{\left[0.2373\left[\left(\frac{w}{5h}\right)^{2.5} - 1\right] + 1\right]}{w^{0.1334}\ h^{0.0667}}$$

$$= 19.24\ \frac{\left[0.2373\left[\left(\frac{18}{5 \times 2.8}\right)^{2.5} - 1\right] + 1\right]}{18^{0.1334} \times 2.8^{0.0667}}$$

$$S_p = 14.75 \text{ MPa}$$

$$FOS = \frac{S_p}{\sigma_p} = 1.23$$

This is a lower FOS than the required design FOS of 1.59. According to the table, these pillars would have a Probability of Failure of approximately 1 in 10.

The pillars need to be larger than 18m x 18m, so

Select new dimensions:	22m x 22m
Width/Height Ratio (w/h):	7.8

Pillar Working Load:

$$\sigma_p = \frac{0.025HC_1C_2}{w_1\ w_2} \times 1.5 = \frac{0.025 \times 180 \times 28 \times 28 \times 1.5}{22 \times 22}$$

$$\sigma_p = 10.93 \text{ MPa}$$

Pillar Strength:

$$S_p = 19.24\ \frac{\left[0.2373\left[\left(\frac{w}{5h}\right)^{2.5} - 1\right] + 1\right]}{w^{0.1334}\ h^{0.0667}}$$

$$= 19.24\ \frac{\left[0.2373\left[\left(\frac{22}{5 \times 2.8}\right)^{2.5} - 1\right] + 1\right]}{22^{0.1334} \times 2.8^{0.0667}}$$

$$S_p = 17.81 \text{ MPa}$$

$$FOS = \frac{S_p}{\sigma_p} = 1.63$$

This complies with minimum design FOS of 1.59.

Strata Control
for Coal Mine Design

Undertaken by the School of Mines, The University of New South Wales   Sponsored by the NSW Joint Coal Board

Research Technology Transfer Bulletin – No. 8   January 1996

RESEARCH EXPANSION

Joint Coal Board funding for the Strata Control for Coal Mine Design Project (SCCMD) expired in December 1995. However, technology transfer initiatives will continue for another 12 months. Several important milestones have been achieved during the Project's four year life including:

1. significant internationally recognised advances in the mechanistic understanding of coal pillar and rib behaviour in yield;
2. development of the UNSW Pillar Design Procedure;
3. development of pillar extraction design guidelines;
4. eight Industry workshops providing over 1,000 man-days of training and technology transfer;
5. publication of nine technology transfer bulletins comprising over 30,000 copies; and
6. ten research reports and nine conference presentations.

Wiley Mine Portal, 1898, illustrating the benefits of restricting bord width to control roof stability (reproduced from AusIMM Monograph 21 with permission from photo source, Mr. Jack Southern).

The Project was conceived to address the unacceptably high rate of serious and fatal injuries due to strata instabilities in New South Wales underground coal mines. It is believed that the improved industry knowledge base arising from the project has contributed significantly to there being no fatal accidents due to strata instabilities in these mines since July 1993.

The engineering knowledge developed from the Project is providing a basis for researching other strata control problems. Professor Miklos Salamon conducted a Workshop in December 1995 on applying the Project's knowledge base to a broader range of strata instability issues. Several new research projects have been initiated as a follow-on to the successful SCCMD Project. A list of the new research projects is given on page 2.

University based research led by experienced industry practitioners provides an opportunity to *"tap"* into the broad range of engineering and science disciplines located on university campuses. This is reflected in the current composition of the research team which is profiled on page 8.

In concluding this phase of the Project, the support of the Industry Consultative Committee established to monitor the Project, chaired by Mr John Smith, and the support of members of the Joint Coal Board (Mr Ian Farrar, Mr David Sawyer and Mr Barry Swan) are acknowledged and appreciated.

CONTENTS

ISSUE - PANEL WIDTH

Two significant statistics to emerge regarding buried continuous miner incidents are:

- over 66% have occurred under weak laminated immediate roof stratum overlain by strong massive stratum;
- 64% of events and 55% of fatalities have occurred at intersections when taking the first or last lift off a pillar.

To a large degree, these statistics are outcomes of a more fundamental design issue, namely that of panel width. Panel width may be described as:

Supercritical: Equal to or in excess of that necessary to induce full caving.

Subcritical: Less than that necessary to induce full caving.

Critical: Borderline where the width may or may not be just sufficient to induce full caving.

Between 60% and 80% of buried continuous miner incidents in New South Wales have been associated with subcritical to critical panel dimensions. When panels are first commenced in a new section of the mine, all operations have to progress through the critical range where abutment stress may be very high with caving irregular and incomplete.

Once full caving develops, abutment stresses are reduced and caving can regularly occur. Subsequent panels are extracted under supercritical conditions. Some of the mine layouts reviewed resulted in panel widths always being subcritical to critical. In a number of cases, continuous miners were buried three or four times in the life of a single panel.

The effect of panel width on periodic weighting, fracturing and caving around longwall faces has been documented over the years. Similar effects can be expected in pillar extraction. The regular layout, clean systematic extraction and a solid stiff face abutment associated with longwall mining make these features relatively easy to observe and track. Conversely, in pillar extraction, an irregular panel layout, a softened face abutment and irregular coal extraction both aggravate and hide the effects of subcritical to critical panel widths. These features encourage problems to express themselves in falls of roof, especially at intersections.

Factors such as length of shuttle car cable and ventilation services should be only secondary considerations in designing panel dimensions. Operators need to be forewarned and vigilant in the early stages of extracting panels because roof convergence and load redistribution may not follow a regular pattern until full caving has developed. If an initial panel cannot be dimensioned to induce full caving, it may be advisable to restrict panel width to control abutment stress and wait until mining of the adjacent panel to induce full caving.

PROJECT	FUNDING	DURATION (YRS)	TOTAL VALUE
Elimination of Goaf Encroachment	JCB Health and Safety Trust	3	240,000
Engineered Design for Soft Strata Environments	ACARP/Powercoal	3	353, 000
Rib Mechanics and Support Systems	ACARP/ANI Arnall/SCCMD	2	70,000
Performance Characteristics of Timber Chocks	ACARP	1.5	26,000
Roof Reinforcement in Weak Structured Environments	Australian Research Council/ Springvale Coal/Powercoal	3	242,000
Control of Longwall Floor Gas Inrush	Australian Research Council/ BHP Collieries Div.	3	218,000
Strength of Rectangular and Irregular Shaped Pillars	ACARP	1.5	21,000
Chair of Rock Mechanics	ACIRL/BHP Collieries/Oakbridge/ Powercoal/Shell Australia/ Springvale Coal/Ulan Coal	5	750,000

ISSUE

ROCK BOLTING MECHANICS - PART 1

Figure 1 shows a single parting plane developed at some point along the length of a fully grouted roof bolt. As the strata below the parting plane moves down, axial load is induced in the section of the bolt that spans the parting plane. The load induced in the fully encapsulated bolt is progressively transferred through the grout to the rockmass.

The rate of load transfer is a function of many parameters including elastic modulus of rock, elastic modulus of grout and grout thickness. Typical load transfer figures range from 20t/m to 40t/m of bolt length either side of the crack, with 30t/m being assumed in this example. Figure 1 shows how load is distributed further along the bolt as the load in the bolt increases across the parting.

The load transfer lines are parallel since the rate of load transfer is effectively constant at 30t/m, i.e., 15t/0.5m (in reality, the rate of load transfer is not quite linear but decays exponentially as it approaches zero). The load transfer lines are also effectively symmetrical on each side of the crack (Newton's Law - Equal and Opposite Forces).

If the load transfer lines progress to the back of the hole, the anchorage system is free to slip, above the parting, and the bolt can pull out without there being any external signs of loading on the bolt, Figure 2.

If no plate is installed at the mouth of the hole and the load transfer lines progress to the mouth of the hole, the anchorage system is free to slip below the parting and, therefore, the rock below the parting plane can slide along the bolt, Figure 3(a).

If a plate is installed at the mouth of the hole and the load transfer lines progress to the mouth of the hole, the excess load is transferred onto the plate (collar) of the bolting system. Figure 3(b). Should the bolt collar fail, the rock below the parting plane is free to slide along the bolt.

If the load induced in the bolt at the parting exceeds the ultimate bolt strength prior to the anchorage system failing, the bolt will break at the parting, Figure 4. In a multiple parting plane environment, a combination of all of these mechanisms can operate.

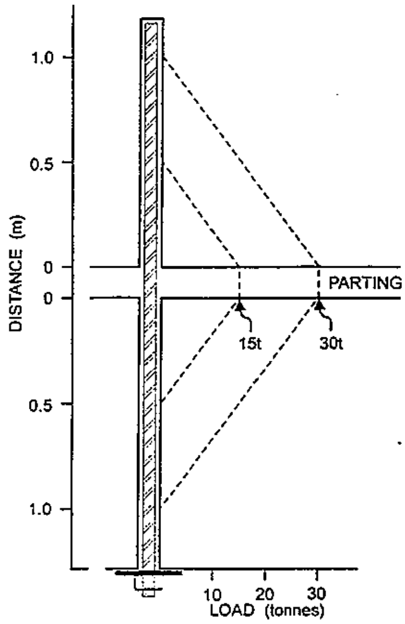


FIGURE 1:
LOAD TRANSFER TO BOLT

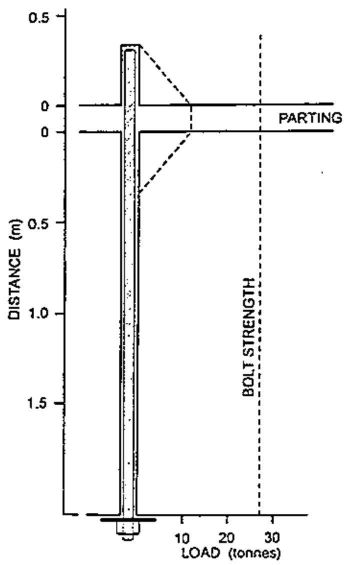


FIGURE 2:
ANCHOR SLIPS AT BACK OF HOLE

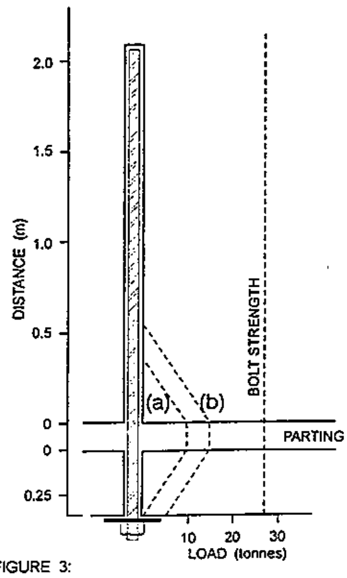


FIGURE 3:
(a) ANCHOR SLIPS AT FRONT OF HOLE
(b) LOAD TRANSFERRED TO PLATE

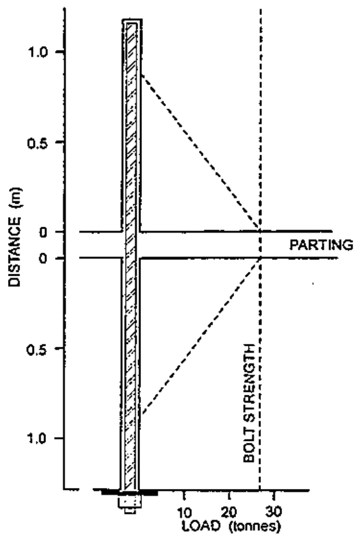


FIGURE 4:
BOLT BREAKS BEFORE ANCHOR FAILS

ISSUE

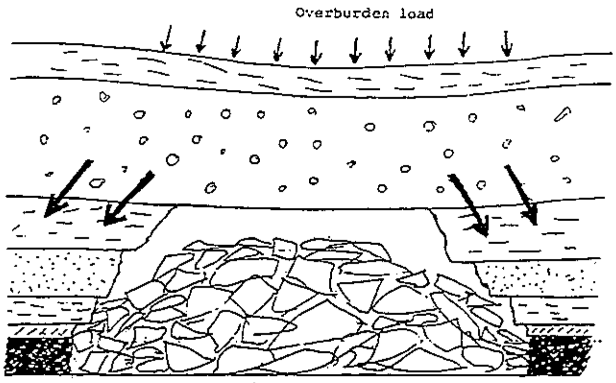
CAVING AND GOAF RECONSOLIDATION - PART 2

In Issue 7, the influence of bulking factor on height of caving was discussed and a simple formula presented for estimating the maximum caving height. In this issue, some important situations which can alter the caving process are discussed.

MASSIVE STRATA

Consider the case where a massive stratum exists somewhere above the working section and is competent enough to span the extraction width without failing, i.e., panel width (or stratum beam width) is less than the critical caving span at which the particular stratum will fail. The result is:

- All strata below the competent bed subsides
- The height of the subsided material does not fill the void below the competent bed
- An air gap or void remains between the caved material and the upper (competent) stratum.
- No vertical load is transferred through the caved rubble due to the air gap - all the original vertical cover load above the extracted area is transferred to the solid ribs beyond the edges of the excavation.



Feather-edging in a conglomerate roof, prevented from running into bord by roofbolts.

GOAF RECONSOLIDATION

Once a goaf is formed, it will undergo a degree of reconsolidation depending on the width of the excavation, mining height, depth and the nature of overlying strata. As it reconsolidates, due to stress applied from deforming strata above it and its own weight, the voids within the broken goaf material progressively close.

The consequences of increasing reconsolidation are:

- Increased stress transmitted through the goaf (representing weight of overlying strata carried by the goaf)
- Increased modulus (and related stiffness) of goaf material with strain/compaction.

LOAD REDISTRIBUTION ADJACENT TO GOAF

Why is an understanding of caving height and goaf reconsolidation important?

- The behaviour of the goaf and the amount of load it carries has a major impact on the amount of load carried by adjacent blocks of coal, e.g., chain pillars or barrier pillars.
- The total amount of load generated by the weight of overburden across a region is constant. Its distribution is not constant.
- Goaf areas can carry anything from zero load to something approaching full cover load.
- The caving angle or angle of break has a significant impact on adjacent pillar loading. Weak, highly laminated materials, such as mudstones, generally have a high angle of break while more massive sandstones and conglomerates have a low angle of break (which can also cause *"feather edging"* to extend into the adjacent roadways).
- The issues which are impacted by the behaviour of goaf and its level of reconsolidation are:
  - chain pillar and barrier pillar design
  - reactivation of partially caved goaf and further load redistribution on current working areas (e.g., longwall extraction under a goaf)
  - effect on overlying sub-surface strata, particularly water-bearing or other hazardous zones
  - effects on surface subsidence.

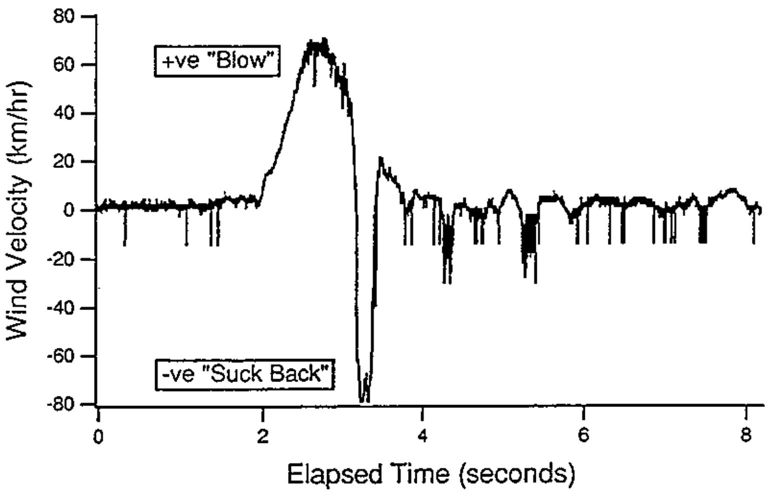
ISSUE

WINDBLAST FIRST

HOW FAST DOES THE WIND BLOW UNDERGROUND?

Windblasts caused by massive sudden roof failures in underground coal mines have been reported for many years. The impetus to *"catch"* a windblast came about in 1990 as the result of personal injury accidents in a number of New South Wales collieries.

Researchers at UNSW led by Dr Chris Fowler first had to develop windblast monitoring equipment. This was deployed at five mines with the first significant windblast being recorded in a longwall panel at a colliery in the Lake Macquarie district of the Newcastle Coalfield in November 1995. The event, which lasted less than two seconds, was measured in both the maingate and the travelling road. Wind velocity peaked at 22m/s or 79kph in the outbye direction, followed immediately by a *"suck back"* of similar magnitude.



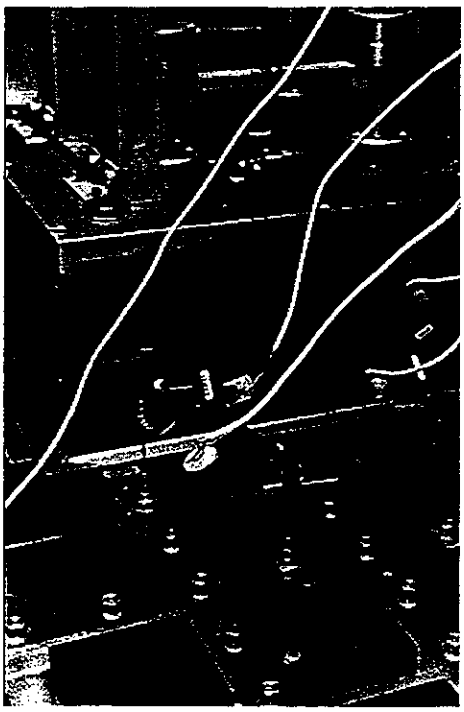
TIME TRACE OF WINDBLAST EVENT

Subsequently, a second larger event has been recorded; this time with a duration of over six seconds and a peak velocity of 40m/s or 144kph. By comparison, a hurricane, force 12 on the Beaufort Scale, blows at 118kph or above. It is believed, from eyewitness' accounts and from the evidence of damage, that even stronger windblasts have occasionally occurred underground.

Further monitoring will be undertaken as part of the Windblast Project which also includes simulation of windblasts using a laboratory physical model and the development of a computer program to predict windblast effects. The overall objective of the project is to minimise the hazards associated with windblasts by optimising panel layouts and by developing safe working practices.

The Windblast Project was initially funded by a grant under the National Energy Research, Development and Demonstration Program together with financial contributions from three participating coal companies; Newcom Collieries Pty. Limited and Elcom Collieries Pty. Limited (now merged as Powercoal Pty. Limited) and Coal & Allied Operations Pty. Limited. Subsequent funding has been provided by the Joint Coal Board Health and Safety Trust.

In massive competent roof caving develops at a low angle. A *"piston effect"* due to sudden, slab-like failure over a large area can generate windblasts.



The UNSW physical model for windblast research.

QUESTIONS AND ANSWERS

STRESS MEASUREMENTS - PART 2

WHAT IS *"PRIMITIVE STRESS"*?

When a material is loaded, for example vertically, it will shorten in the vertical direction and try to expand in the horizontal direction (Poissons Effect). If lateral expansion is resisted, a horizontal stress is generated. Prior to mining, the rock mass which is loaded by its own weight, is confined in all directions and therefore subjected to compressive stresses in all directions. These stresses are referred to as *"primitive, insitu or virgin"*. Natural features such as erosion, plate tectonics and faulting can also affect the distribution of primitive stresses.

WHAT IS *"MINING INDUCED STRESS"*?

Mining removes support to the overlying rock mass. The weight of this unsupported rock has to be redistributed to the side walls of the excavation. Mining also removes confinement to the rock mass around the excavation. This causes a change in the rock stress and a consequent reduction in strength (Issue 5). The new state of stress is referred to as *"resultant stress"*

Mining Induced Stress = Resultant Stress - Primitive Stress

HOW DOES ROCK RESPOND TO STRESS?

Rock mass response to stress varies according to the physical state of the rock. The rock may be in a crushed state at the excavation edges progressing through a yielded state and into an elastic state some distance into the rock mass (Issue 6). Rock mass response also depends on factors such as the degree of stratification (lamination) of the strata and the direction of stress relative to the stratification.

WHAT FACTORS AFFECT THE MEASUREMENT OF PRIMITIVE STRESS?

To avoid measuring mining induced stress levels, primitive stress measurements have to be made well away from mining excavations (typically a distance of at least three excavation widths). However, all traditional stress measurement techniques require an installation hole to access these locations. The act of drilling a hole in itself changes the state of stress one is trying to measure. Mathematical techniques need to be applied to *"correct"* the measurements. Confidence levels reduce when holes are angled relative to stratification.

WHAT FACTORS AFFECT MEASUREMENT OF *"MINING INDUCED STRESS"*?

Most stress measurement techniques, in fact, measure rock displacement (Issue 7). Conversion factors are extremely sensitive to the state of rock failure. Fracturing close to instruments produces anomalous results. Conversion factors also need to be applied for angled holes.

A stress measurement cell showing strain gauges around the circumference of the cell to measure changes in strain on the borehole wall.

WHERE HAVE WE

MATHEMATICAL MODELLING - PART 2

(Continues from No. 7 Newsletter)

In the early 1970's, the first electrical resistance analog *"computers"* were constructed. These consisted of a network of 2500 nodes, each occupied by a variable resistance plug set to a valve representing the compressibility of a particular coal. Removing a plug was equivalent to extracting a portion of the seam and causing a corresponding response to the distribution of electrical potential. The situation being modelled in the photograph is recognisable as pillar extraction. An important facility with the electrical analog was the ability to vary its scale so that, for instance, the full matrix of 2500 nodes could also be made to represent a single pillar or part of a pillar.

The analog had serious deficiencies, however, and worked on the assumption that the seam and strata were isotropic, elastic and continuous media. It also had difficulty in handling multiple and inclined seams and strata variations in seam depth and gave only two-dimensional solutions.

It was also technically possible, in those days, to provide two-dimensional numerical solutions to

KEY RULE OF THUMB

THE HORIZONTAL STRESS REQUIRED TO CAUSE BUCKLING OF THE ROOF OR FLOOR STRATA DECREASES IN PROPORTION TO THE SQUARE OF THE BORD WIDTH.

Buckling is a dynamic process, that is, it can develop suddenly. The horizontal stress, σ_B, required to induce buckling of a beam is given by the formula:

$$\sigma_B = \frac{Kt^2}{S^2}$$

where *K* is a proportionality factor, *t* is the beam thickness, *S* is the beam span.

APPLICATIONS IN MINING

Roadway Width

When roadway width is increased from 5.5m to 6.5m, the horizontal stress required to cause buckling reduces to only 71% of that required to buckle the 5.5m width roadway.

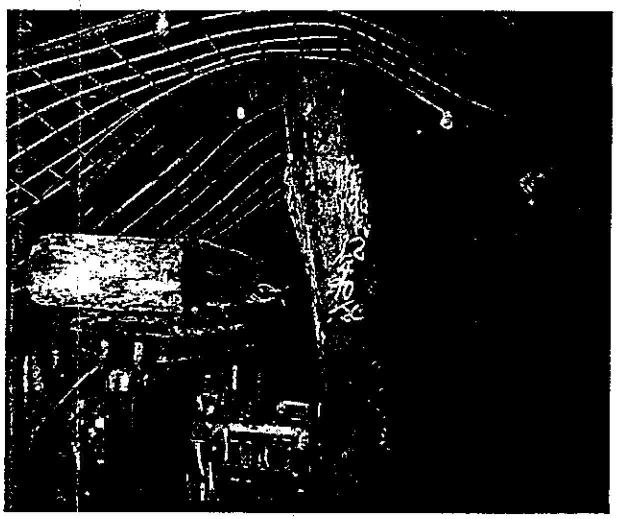
In an intersection formed by the driveage of 5.5m wide roadways, the horizontal stress required to cause buckling drops to 47%. This is another reason why roof falls and floor heave tend to occur in intersections and over-width driveages.

Roof Bolting

The resistance of the roof (or floor) to buckling increases in proportion to the square of the roof ply thickness. Roof bolting acts to increase the resistance of laminated strata to buckling by building a thicker beam. Resistance increases in direct proportion to the effective thickness of the roof beam.

Centre Support

One of the most effective means of controlling buckling is to reduce effective roadway width. This can be achieved by installing stiff supports, e.g., large timber legs or concrete-based chocks, in the centre of the roadway. Long tendons can also be used for this purpose but they must be anchored above the buckling horizon if they are to be effective. Early installation of these tendons significantly improves their effectiveness.



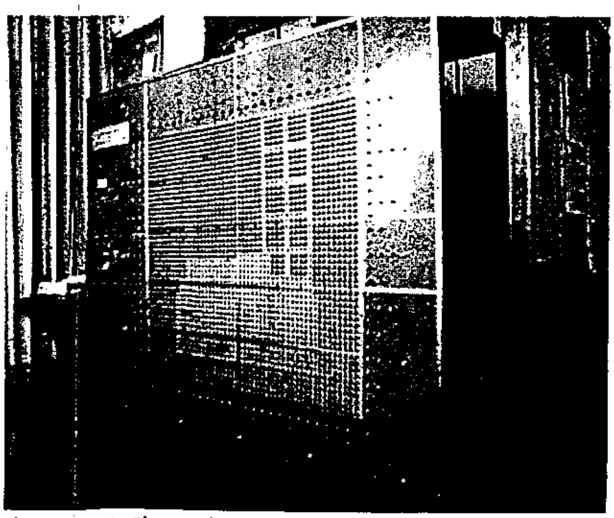
A single pass continuous miner *"trapped"* at the face of a longwall development heading.

COME FROM ...

the equations using digital computers. However, the number of repetitive calculations to solve quite simple mining problems were astronomically large and required tying up very big computers for many hours, sometimes days, at a time.

Fortunately, since the days of the electrical resistance analog, digital computer technology has developed at an enormous rate along with programming methods and analytical techniques such that the most complex mathematical equations are now capable of quick solutions. Moreover, the effects of geological complexities such as non-elastic and jointed ground and multiple strata of various thickness and properties can be readily taken into account by using one or more of a range of special programming techniques such as the Finite Element Method and the Boundary Element Method.

We are now at the stage where reliable predictions can be made of strata behaviour involving complex mining geometries in prescribed geological conditions using desk-top computers and, in many instances, PC's. Strata control is well on the way to becoming a scientifically based engineering process.



The UNSW Electrical Resistance Analog modelling a pillar extraction layout.

RESEARCH TEAM

PROFESSOR JIM GALVIN

Jim is Professor and Head of the Department of Mining Engineering and Project Director for the Strata Control for Coal Mine Design Project. Previous experience includes the Research Organisation, Chamber of Mines of South Africa where he was Head of the Coal Strata Division. This was followed by ten years in NSW underground coal mining operations, the last four of which were as a Colliery Manager. He joined the University of NSW (UNSW) in December 1992.

PROFESSOR BRUCE HEBBLEWHITE

Bruce was appointed as Professor of Rock Mechanics at UNSW during 1995. A Mining Engineering graduate from this university, Bruce gained his Ph.D in Rock Mechanics from the University of Newcastle-upon-Tyne, UK, in 1977. He has a long and distinguished career in the Australian coal mining industry founded on his time as Manager of Mining Division for ACIRL Ltd. He is project leader for many of the new research projects listed on page 2.

PROFESSOR FRANK ROXBOROUGH

Frank has been Professor of Mining Engineering at UNSW since June 1975 and is immediate past Head of the School of Mines. He played a pivotal role in establishing the project and has a close involvement with technology transfer publications.

PROFESSOR MIKLOS SALAMON

Miklos is a Distinguished Professor of Mining Engineering at the Colorado School of Mines and Visiting Professor to UNSW. Educated in Hungary and Britain, Miklos was appointed in 1963 to initiate research into pillar stability in South Africa in the aftermath of the 1960 Coalbrook diaster. His pioneering work in many aspects of rock mechanics forms the basis of his involvement in strata control research at UNSW.

MR IAN ANDERSON

Ian is a Senior Inspector of Coal Mines, NSW Department of Mineral Resources. In this role he is responsible for secondary extraction approvals, strata control and related safety issues. Since 1993 he has been seconded to the Project on a part-time basis and has made valuable contributions in research and in effecting technology transfer to the industry.

DR JOHN WATSON

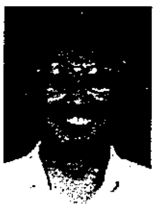
John is a Civil Engineer and is a Senior Lecturer in the Department of Mining Engineering at UNSW. Previous experience includes development of finite and boundary elements techniques in France and the United Kingdom and six years as a Lecturer at Imperial College, London. His experience is utilised in areas of soft strata behaviour and fracture development around longwall faces.

DR NOUNE MELKOUMIAN

Noune recently arrived in Australia from Armenia. A graduate both in Mathematics and Civil Engineering, her principal research interest is fracture development and gas inrush around longwall faces. This research is related to an Australian Research Council Collaborative Research Grant involving BHP Collieries and UNSW.

VASUNDHARA

Vasundhara joined the Project team in April 1995. She is a Geophysicist. After gaining an Overseas Post Graduate Research Scholarship to study for three years in Australia, she is undertaking a Ph.D. in soft strata behaviour, associated with bord and pillar workings. This research is a component of a major ACARP Research Project.



BIN LIN

Bin is a Professional Officer within the Department of Mining Engineering at UNSW. A graduate Mining Engineer, he is about to submit his Ph.D. on high pressure water jet cutting. He is principally concerned with undertaking numerical analyses and laboratory research for the project team.

MARC KIRSTEN

Marc recently graduated from the UNSW with a B.App.Sc. (Hons.) in Applied Geology. He is concerned principally with soft strata behaviour in the Newcastle Coalfield.

For further information or inquiries, please contact Professor Jim Galvin or Professor Bruce Hebblewhite, School of Mines, Uni. NSW, Sydney 2052 Australia. Tel 02 385 4515 Fax 02 313 8502.

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Editors: J.M. Galvin and B.K. Hebblewhite.

KEY CENTRE FOR MINES
Education and Research for the Minerals Industries

UNIVERSITY OF NEW SOUTH WALES UNIVERSITY OF WOLLONGONG

Pillar and Roadway Mechanics Workshop

Stage 1 - Introductory Principles and Practice

Course Coordinator: Professor Jim Galvin
Department of Mining Engineering
University of New South Wales

13 - 14 December 1994

UNIVERSITY OF NEW SOUTH WALES

The University of New South Wales, PO Box 1, Kensington, NSW 2033, Australia
Key Centre for Mines Phone (02) 697 5006 Fax (02) 313 7269

ISBN No. 0 7334 1337 4

PILLAR AND ROADWAY MECHANICS WORKSHOP
Stage 1 - Basic Principles and Practice
13-14 December 1994

DAY 1	COAL PILLARS
8.00am - 8.30am	Registration and Coffee
8.30am - 8.45am	Introduction **Jim Galvin**
8.45am - 9.00am	• History of Pillar Design in Australia **Ian Anderson**
9.00am - 9.30am	• Review of Field Performance **Grant Hocking**
9.30am - 10.30am	• Fundamental Principles • Physics • Materials Science • Rock Mechanics • Exercise 1 **Jim Galvin**
10.30am - 10.45am	*Morning Tea*
10.45am - 11.15am	• Pillar Load • Exercise 2 **Jim Galvin**
11.15am - 12.00pm	• Pillar Strength • Exercise 3 **Jim Galvin**
12.00pm - 12.30pm	• Factors of Safety • Exercise 4 **Jim Galvin**
12.30pm - 1.30pm	*Lunch*
1.30pm - 2.00pm	• Presentation of Design Exercises **Ian Anderson/Grant Hocking/Carlos Quinteiro**
2.00pm - 3.00pm	• Design Exercise Groups
3.00pm - 3.15pm	*Afternoon Tea*
3.15pm - 4.15pm	• Group Report Backs and Review
4.15pm - 4.30pm	• Consolidation of Issues **Grant Hocking**
4.30pm - 5.00pm	• Load Distribution around Roadways **Jim Galvin**

DAY 2	- ROADWAY DESIGN - SECONDARY EXTRACTION

8.00am - 9.30amm	• Roadway Response to Loading
	  • Stress Contours
	  • Vertical Load
	  • Horizontal Load
	• Exercise 5
	Jim Galvin

9.30am - 10.15am	• Abutment Load and its Effects • Exercise 6 • Time Dependent Strength of Rock **Grant Hocking**
10.15am - 10.45am	• Effect of Excavation Width and Depth on Stress Distributions • Exercise 7 **Jim Galvin**
10.45am - 11.00	*Morning Tea*
11.00am - 11.15am	• Review of Pillar Extraction **Ian Anderson**
11.15am - 12.00pm	• Stiffness of Roof Strata • Some Applications of Roof Stiffness Principles in Pillar Extraction **Jim Galvin**
12.00pm - 1.00pm	*Lunch*
1.00pm - 1.45pm	• Intersections and Stooks • Exercise 8 **Jim Galvin**
1.45pm - 2.00pm	• Presentation of Design Exercises

2.00pm - 2.45pm	• Design Exercise Groups
	  • Roadways
	  • Pillar Extraction
	Ian Anderson/Jim Galvin/Grant Hocking

2.45pm - 3.00pm	*Afternoon Tea*
3.00pm - 3.45pm	• Group Report Backs and Review **Ian Anderson/Jim Galvin/Grant Hocking**
3.45pm - 4.00pm	• Consolidation of Issues and Close **Jim Galvin**

COORDINATOR:

Jim Galvin is the course coordinator and will present and contribute to several sessions. He has both a research and operational background which includes experience as head of Coal Strata Control Section of the Chamber of Mines of South Africa Research Organisation and as a Colliery Manager in NSW. Jim is now Professor of Mining Engineering at UNSW and Director of the Strata Control for Coal Mine Design Project.

PRESENTERS:

Sessions will be presented by the following personnel associated with the Strata Control for Coal Mine Design Project:

Mr Ian Anderson, Senior Inspector of Coal Mines, Department of Mineral Resources, NSW. Ian is a mining engineer with operational experience which includes having been a Colliery Manager in NSW.

Prof Grant Hocking, Professor of Engineering Geology, University of New South Wales. Grant has industrial experience in both civil and mining applications in the UK and USA.

Dr Carlos Quinteiro, Mining Engineer, Strata Control for Coal Mine Design Project, University of New South Wales. Carlos' expertise is in pillar mechanics and extends to the design of yield pillars and partial extraction panels in deep salt mines.

Industry personnel complement the above presenters in lecture and design exercises.

SCHOOL OF MINES
THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY NSW 2052
Phone: (02) 385 4515 Fax: (02) 313 8502

Strata Control for Coal Mine Design

ROADWAY AND PILLAR MECHANICS WORKSHOP

Stage 2 - Design Principles and Practice

Course Coordinator: Professor Jim Galvin
Department of Mining Engineering
University of New South Wales

18 - 19 JULY 1995

facilitated by:

Key Centre for Mines
University f New South Wales
SYDNEY NSW 2052
Phone (02) 385 5006 Fax (02) 313 7269

ISBN No. 0 7334 1338 2

ROADWAY & PILLAR MECHANICS WORKSHOP

STAGE II - Design Principles and Practice

Tuesday 18th - Wednesday 19th July 1995
Penrith Panthers Leagues Club
Mulgoa Road, Penrith NSW 2750

DAY 1: Pillar Design, Caving and Goaf Reconsolidation

9.00-9.10am	Opening Address	I Farrar (Chairman Joint Coal Board)

SESSION 1: ENGINEERING DESIGN PHILOSOPHY

9.10-9.20am	1. Introduction	J Galvin
9.20-9.35am	2. Implications of Pillar Design to Mine Planning	J Galvin
9.35-9.55am	3. Review of Basic Principles	J Galvin
9.55-10.10am	4. Are You At Risk?	J Galvin
10.10-10.30am	*Morning Tea*	
10.30-10.45am	5. Field Performance Data Bank	I Anderson
10.45-11.05am	6. Simple Statistics to Manage Uncertainty	J Galvin

SESSION 2: UNSW PILLAR DESIGN PROCEDURE

11.05-11.15am	7. Methodology	B Hebblewhite
11.15-11.30am	8. Pillar Working Load	I Anderson
11.30-11.40am	• Exercise 1	
11.40-12.10pm	9. Pillar Strength	H Wagner/J Galvin
12.10-12.20pm	• Exercise 2	
12.20-12.50pm	10. Probability and Factor of Safety	B Hebblewhite
12.50-1.00pm	• Exercise 3	
1.00-2.00pm	*Lunch*	

SESSION 3: APPLICATIONS

2.00-2.30pm	11. Caving Height and Goaf Reconsolidation	B Hebblewhite
2.30-3.00pm	12. Pillar Behaviour Considerations	J Galvin
3.00-3.30pm	13. Functional Approach to Pillar Design	B Hebblewhite
3.30-3.45pm	14. Mine Design Exercise - Introduction	B Hebblewhite
3.45-4.40pm	• Exercise Groups *(+ Afternoon Tea)*	
4.40-4.50pm	15. Group Exercise Summary	J Galvin
4.50-5.00pm	16. Consolidation of Issues	H Wagner

DAY 2: Roadway Behaviour and Reinforcement

8.30-8.35am	Objectives	J Galvin

SESSION 1: FUNDAMENTALS OF ROADWAY BEHAVIOUR

8.35-8.45am	1. Review of Basic Principles	J Galvin
8.45-9.30am	2. Sources of Loading around a Roadway	J Galvin
9.30-10.15am	3. Roadway Response to Load	J Galvin
10.15-10.30am	• Exercise 1	
10.30-10.50am	*Morning Tea*	

SESSION 2: MECHANICS OF ROOF REINFORCEMENT

10.50-12.20pm	4. Roof Bolt Mechanics - end anchor systems - partial/full column encapsulation systems - friction systems	H Wagner
12.20-12.45pm	• Understanding of Roof Bolt Mechanics	H Wagner
12.45-1.45pm	*Lunch*	
1.45-2.10pm	• Exercise 2	

SESSION 3: GROUND CONTROL MANAGEMENT

2.10-2.25pm	5. The Management Process	B Hebblewhite
2.25-2.35pm	6. Geotechnical Environment	I Anderson
2.35-2.45pm	7. Mining Geometry	I Anderson
2.45-2.55pm	8. Reinforcement System	I Anderson
2.55-3.10pm	9. Strata Response	J Galvin
3.10-3.25pm	• Exercise 3	
3.25-3.45pm	*Afternoon Tea*	

Session 4: Open Forum

3.45-4.30pm	11. Open Forum Discussion	B Hebblewhite plus all delegates
4.30-4.45pm	12. Consolidation of Issues	J Galvin

COORDINATOR:

Professor Jim Galvin is course coordinator and will present and contribute to several sessions. He has both a research and operational background which includes experience as Head of the Coal Strata Control Section of the Chamber of Mines of South Africa Research Organisation and as a Colliery Manager in NSW. Jim is now Professor and Head of the Dept of Mining Engineering at UNSW and Director of the Strata Control for Coal Mine Design Project.

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Mr Ian Anderson, Senior Inspector of Coal Mines, Department of Mineral Resources, NSW. Ian is a mining engineer with operational experience which includes having been a Colliery Manager in NSW.

Professor Horst Wagner, Head, Dept of Mining Engineering and Mineral Economics, Montan University, Austria and previously Director General, Chamber of Mines Research Organisation, South Africa. Horst is internationally renowned in mine strata mechanics and rock reinforcement in both coal and metalliferous mining.

Professor Bruce Hebblewhite, Professor of Rock Mechanics, University of New South Wales. Bruce recently joined the Strata Control for Coal Mine Design Project Team after an extensive research and consulting career with ACIRL Ltd where he was Manager, Mining Division.

The University of New South Wales
School of Mines

Strata Control for
Coal Mine Design

Modes of Pillar and Ribside Failure

— Development and Longwall

Advanced Workshop

13 December 1995

to be held at

The School of Mines,
University of New South Wales

facilitated by

Key Centre for Mines

ISBN No. 0 7334 1336 6

1 # ADVANCED PILLAR MECHANICS

by

Miklos D.G. Salamon

2

- Do we have satisfactory answers to questions like?
  - Should we support ribs?
  - Does working height effect strata control in:
    - pillar extraction?
    - longwalling?
  - What does the term "yielding pillar" describe?

3 ## Topics to be discussed

- Basic concepts
- Conditions in and around a single panel
- Narrow pillars or potential yield pillars
- Wide or "squat" pillars: Indestructible pillars?
- Intermediate pillars: Treacherous pillars?
- Where do we go from here?

4 ## Basic Concepts: Rock Behaviour

- Brittle Rock: Coal
- Load-Deformation Relationship
  - Elastic region
  - Yielding region
  - Crushed region
- *In Situ* Coal Strength
- Strain Softening

5 ## Yielding Coal

- Coal softens as it is strained further
- Its cohesion and strength diminishes with strain
- If unconfined, it disintegrates when its cohesion is lost
- If confined, eventually it becomes "crushed" coal

6 ## Crushed Coal

- It has no cohesion
- Can only survive in this state if it is supported or "confined"
- It has no residual unconfined compressive strength

7 ▢ Mathematical Model

- *Roof & floor:* Stratified elastic mass
- *Seam:* Strain softening coal
- *Contact planes:*
  - Adhesive or
  - Sliding: Friction without cohesion
- *Goaf:*
  - Unsupported or
  - Caved, thus filled with rubble

8 ▢ Rock Mass Stiffness

- Elastic modulus and effective layer thickness of the rock mass
- Elastic modulus of the seam
- Seam thickness or working height

9 ▢ Stiffness Values [in GPa]

10 ▢ Pillar Stiffness

- Coal modulus
- Pillar's cross section
- Pillar height

11 ▢ Basic Concepts: In Pillar Mechanics

- Pillar load estimation:
  - Tributary pillar load
  - Pillar load on the basis of "Roof Arch"
  - Pillar load from numerical modelling
- Rock mass stiffness versus pillar stiffness

12 ▢ Have +90% Tributary Pillar Load (M = 2 m)

13 ▢ Have +90% of Tributary Pillar Load (M = 4 m)

14 ▢ SINGLE PANEL Coal in the Ribside

- In shallow depth the coal may remain elastic throughout
- As the span is increased, yielding commences
  - Once yield starts the vertical stress at the rib starts to decrease
  - If no support is applied to the face the stress becomes zero at a critical span

15 ☐ SINGLE PANEL

Critical Span - No support

- At the critical span the coal disintegrates and slumps
- The *effective* span of the panel increases
- Further slumping or toppling occurs
- The rock pile on the floor, through friction, develops side constraint

16 ☐ SINGLE PANEL

From Two to Four Zones

- Up to the *critical span* there are two zones only: yielding and elastic (no support)
- At the critical span this state transforms into four zones
- The transition is expected to be sudden and may even be violent, leading to a coal bump

17 ☐ SINGLE PANEL

Large Spans

- Once the critical span is reached suddenly four zones appear in the ribside:
  - Innermost zone: slumped
  - Second zone: crushed
  - Third zone: yielding
  - Outermost zone: elastic

18 ☐

SINGLE PANEL

Effect of Working Height

19 ☐ SINGLE PANEL

Face Support

- The application of face or rib support could improve conditions appreciably
- Considerable improvement may be expected if the support is applied at or near the critical span
- Initial investigation suggests that instability may not be avoided by the use of support

20 ☐ PILLARS

Lessons to be Transferred

- Pillar sides or edges undergo changes similar to those observed in the ribsides of a panel
- As the roof to floor convergence increases in a pillar, the vertical

stress at the pillar edge diminishes

- At the same time yielding penetrates deeper into the pillar.

21 ▢ PILLARS

Subdivision of Pillars

- Much can be learned about a pillar by observing *simultaneously* the reduction in stress at the edge and the inward migration of yield zone
- Examine the behaviour of:
  - wide pillars
  - narrow pillars and
  - intermediate pillars

22 ▢ WIDE PILLARS

- Vertical stress reduces to zero at the edge, while a wide elastic core still in existence in the centre of the pillar
- Sudden rearrangement occurs at this point: from two to four zones
- Although the pillar edge may topple suddenly, the pillar's overall integrity is not threatened by this event

23 ▢ WIDE PILLARS

Pillar Edge Failure

- Wide pillars are loaded to the point of slumping at the edges *only* if they are adjacent to a large extracted area (pillar extraction or longwall panel)
- The sudden degradation of the pillar sides might be associated with some risk: *pillar bump*

24 ▢ Applications of WIDE PILLARS

- <u>Protective pillars</u>: to shelter gates from the abutment of a passing longwall face
- <u>Barrier pillars:</u> separate high extraction bord and pillar panels.
- Note: Wide pillars are not suitable as yield pillars

25 ▢ NARROW PILLARS

- In narrow pillars (width-to-height ratio less than three or so) the two yield zones coalesce before the vertical stress is reduced to zero at the rib
- From this point onwards the whole pillar is yielding: there is no elastic core

26 ▢ NARROW PILLARS

Load-Deformation Curve

- The ascending and the descending branches of the load-deformation curve of a narrow pillar are well developed
- The maximum of this curve distinctly define the pillar's strength
- In the descending branch additional deformation is associated with load shedding

27 Applications of YIELD PILLARS

- A pillar becomes a <u>*yield pillar*</u> when its state is defined by a point on the descending branch of its load-deformation curve
- A yield pillar can be in stable equilibrium *only* if it can shed load
- This can be achieved only if the loading system is relatively stiff

28 YIELD PILLARS in High Extraction

- A combination of panels supported by yield pillars and separated by wide barrier pillars, may yield higher extraction than conventional bord and pillar mining
- The requirement of a stiff loading system (narrow panel) limits the scope of application for such systems

29 YIELD PILLARS in Longwall Development

- Multiple entry development in deeper US collieries increasingly involve smaller and wider pillars
- Such systems are often referred to as "yield pillar developments"
- Should be noted that the pillars used here are not necessarily yield pillars in the sense defined during this workshop

30 INTERMEDIATE PILLARS

- A pillar is of *intermediate* width if the width of its elastic core is small when the vertical stress at its edge reduces to zero
- When toppling of the sides of such pillars starts, there is no room for the development of *stable* slumped, crushed and yield zones around an elastic core

31 INTERMEDIATE PILLARS Failure

- Once pillar sides are de-stressed, failure of the whole pillar is unavoidable
- The failure progresses from the sides inwards
- The destruction of the pillar is rapid
- Intermediate width pillars are *not* suitable as yield pillars