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REPORT TO:

JOINT COAL BOARD HEALTH & SAFETY TRUST

Implications of Modified Roof Bolting Sequences on Stability and Safety During Roadway Development

REPORT NO.: JCB0434

MARCH, 1995

REPORT TO	:	**Joint Coal Board Health & Safety Trust** **Box 3842 GPO** **SYDNEY NSW 2001** **Attention: Mr. K. Cram** **Project Manager** **Workplace Environment**
SUBJECT	:	**Implications of Modified Roof Bolting Sequences on Stability and Safety During Roadway Development**
REPORT NO.	:	**JCB0434**
PREPARED BY	:	**Winton J. Gale, G.C. Tarrant, R.J. Guy and S.A. MacGregor**
DATE	:	**13th March,. 1995.**

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SUMMARY

The prime objective of the study is to assess the impact of delayed bolting sequences on roof stability about the face area. A secondary objective was to assess current and alternate bolting methods to provide stability under a range of mining conditions.

The methodology adopted was to combine computer simulation methods and field measurement methods to determine the impact of various face bolting procedures on stability.

Study sites for the work were at -

1. Tower Colliery (BHP Pty. Ltd.)
2. Tahmoor Colliery (Kembla Coal & Coke Pty. Ltd.)
3. Place Changing Colliery

The results of the computer simulations and of field monitoring indicate that in moderate to highly stressed roof conditions, roof strength reduces very rapidly with the onset of rock deformation and failure. Unless the bolts are placed and develop sufficient force within 5mm - 10mm of roof deformation, then significant strength loss in the roof can occur which cannot be simply regained by the addition of extra bolts at a latter stage.

In low stress areas having negligible roof deformation, roof bolting sequences can typically be utilised without detriment. This is due to the fact that strength loss in the roof has not occurred on development, and so long as all bolts are placed prior to additional stresses (possibly associated with extraction) being created, the system will respond similarly to one having all bolts placed at the face.

The computer simulation method used can be applied to assess the behaviour of ground and the effectiveness of rock bolting strategies under various conditions.

It is recommended that if roof bolt patterns involving sequenced installation are utilised, then a routine monitoring system be used which can alert personnel when the behaviour of the roof is out of the desired range.

1. INTRODUCTION

The prime objective of the study is to assess the impact of delayed bolting sequences on roof stability about the face area. A secondary objective was to assess current and alternate bolting methods to provide stability under a range of mining conditions.

The methodology adopted was to combine computer simulation methods and field measurement methods to determine the impact of various face bolting procedures on stability.

Computer modelling methods were used as they can simulate the performance of various bolting systems under a greater range of stress conditions than can be realistically obtained by field measurements alone. Targeted field measurements were undertaken to test the modelling accuracy and to provide field data by which judgement could be made on the suitability of various potential bolting methods.

Study sites for the work were at -

1. Tower Colliery (BHP Pty. Ltd.)
2. Tahmoor Colliery (Kembla Coal & Coke Pty. Ltd.)
3. Place Changing Colliery

1. Tower Colliery

The study conducted at Tower Colliery was undertaken for interbedded siltstone/laminite type strata affected by varying horizontal stresses associated with different driveage directions and local areas of elevated horizontal stress.

The aim of the study was to assess the -

a) behaviour of the roof under various stresses and bolt patterns. This involved both computational modelling and field measurement,
b) feasibility of using a modified bolting procedure of 4 bolts placed at the face and 4 bolts placed outbye.

2. Tahmoor Colliery

The strata was interbedded siltstone/shale/laminite. The aim of the study was to assess the behaviour of the roof under a range of stress conditions and to determine the feasibility of a reduced bolting pattern at the face. This involved both computational modelling and field measurement.

3. Place Changing Colliery

The aim of this study was to use field monitoring techniques to assess the feasibility of place changing operations with regard to bolt patterns and stability.

2. COMPUTER MODELLING PROCEDURE

The computer code used was Flac Version 3.02/3.04. This code was used as it is considered to provide the best available capability to simulate the actual rock behaviour and it allows the addition of various routines to check the behaviour of the strata relative to various deformation mechanisms.

The model utilised ubiquitous elements to simulate bedding planes. All elements had the ability to fail through the material (shear failure due to overstressing) or fail along (horizontal) bedding. Intact and residual properties were simulated on the basis of confining pressure.

The models were developed from detailed rock testing of roof and floor material. Rock properties had been established for Tower and Tahmoor Collieries prior to this project.

The large scale model geometry about the roadway is presented in Figure 1 and the model section for Tower is presented in Figure 2.

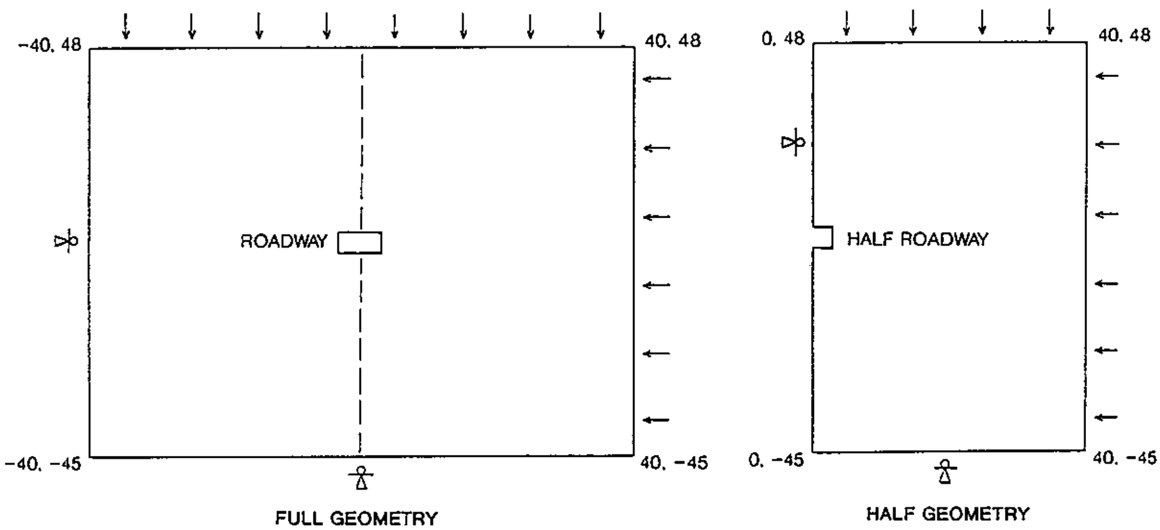

Figure 1 General model geometry and boundary conditions.

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Two model geometries were used to assess various mining geometries. These were:

a) 1/2 symmetry to assess effects where symmetry could be utilised
b) full geometry roadways for development and longwall extraction to simulate potential biased deformation.

The strength properties of laboratory samples are typically greater than those anticipated in the field due to the "scale effect". An appropriate field strength reduction factor (e.g. Hoek and Brown, 1980) has been used to define field strength properties. Once the in situ strata properties are derived, horizontal and vertical stresses are applied to simulate field conditions. The roadway section is then excavated and reinforcement in the form of roof bolts and rib bolts is placed at the appropriate locations.

The bolts modelled were:-

i) X grade bolts in the roof - yield capacity extrapolated as 28t.
ii) rib bolts - 1.5m HS type bar - yield capacity 15t.
iii) strand type bolts - yield capacity - 55t.

A range of properties were used for the load transfer characteristics of the strand bolts as little data is available.

The effects of water pressure and moisture changes of the ground immediately adjacent to the roadway have not been considered separately in these models. It is assumed that the ground behaves in a "drained" manner.

3. ROCK PROPERTY SUMMARY AND MODELLED SECTIONS AT TOWER AND TAHMOOR COLLIERIES

A summary of rock properties (Unconfined Compressive Strength) is presented in association with a core log in Figure 3 for the Tower models.

The modelled rock properties and a typical bolt pattern is presented in Figure 2.

4. FIELD MEASUREMENT METHODS

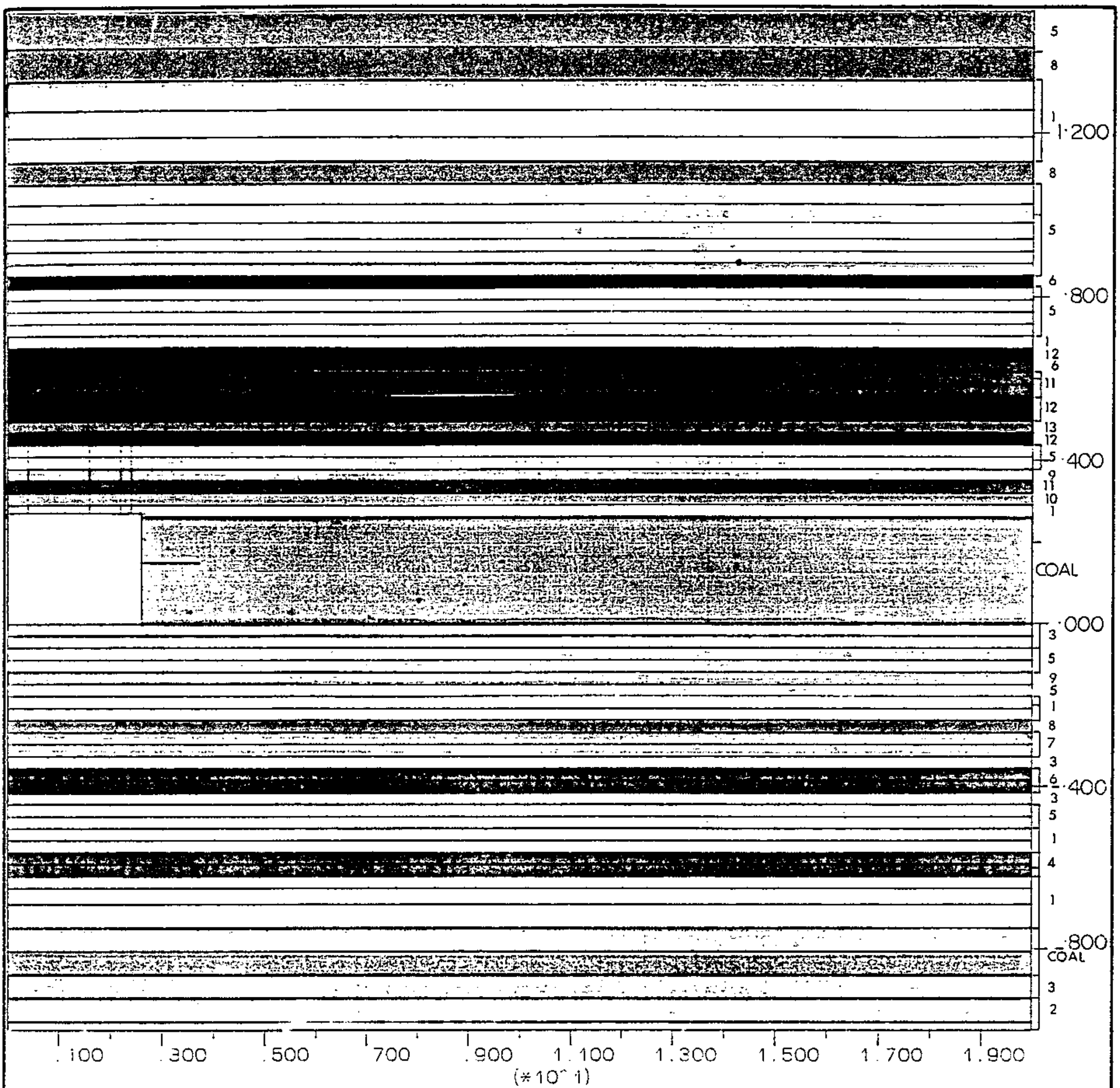
Methods of field measurement used in this study have been -

i) Roof Extensometry

This measures displacement in the strata at up to 20 locations within a 7m - 8m section of strata. An extensometer set is placed in 7m - 8m long borehole drilled at the face of a roadway. An initial set of measurements are made as the "base" set and subsequent measurements made during mining record differences from the initial readings. This allows detailed measurement of roof and rib deformation up to 8m into the strata as the roadway is progressively driven. A typical installation is presented in Figure 4.

ii) Bolt Force Developed as a Result of Installation and Rock Deformation

Measurement of the force developed in bolts is made by installing standard bolts modified by the application of strain gauges such that detailed measurement of bolt elongation can be made at various mining stages. Typically, 9 locations along the bolt can measure axial and bending strain such that the axial force distribution in the bolt can be accurately measured. This method allows the force distribution developed in the bolt to be defined during installation and subsequent mining stages. A typical example is presented in Figure 4 which shows instrumented bolts in a site monitoring study.



UNIT No.	ROCK TYPE	UNIT No.	ROCK TYPE
COAL	COAL	8	LAMINATED SHALE
1	CARBONACEOUS MUDSTONE	9	LAMINITE
2	SANDSTONE	10	LAMINITE
3	CARBONACEOUS MUDSTONE	11	FINE GRAIN SANDSTONE
4	MEDIUM GRAIN SANDSTONE	12	SHALE
5	LAMINATED SHALE	13	LAMINITE
6	MEDIUM GRAIN SANDSTONE		
7	SHALE		

Figure 2 TOWER COLLIERY
Bulli Seam roadway model.

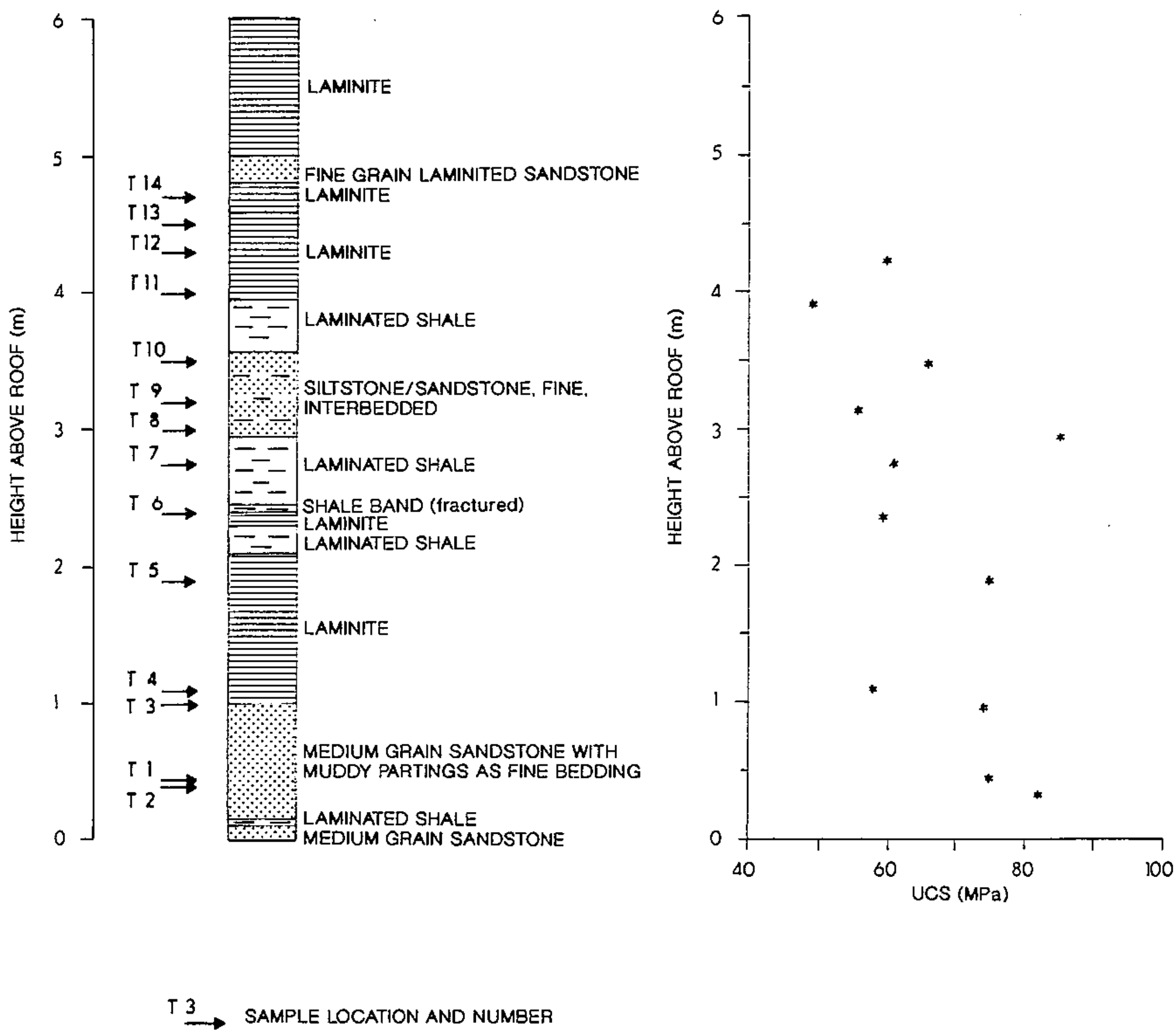


Figure 3 TOWER COLLIERY
Roof core log, B Heading, Nepean Panel.

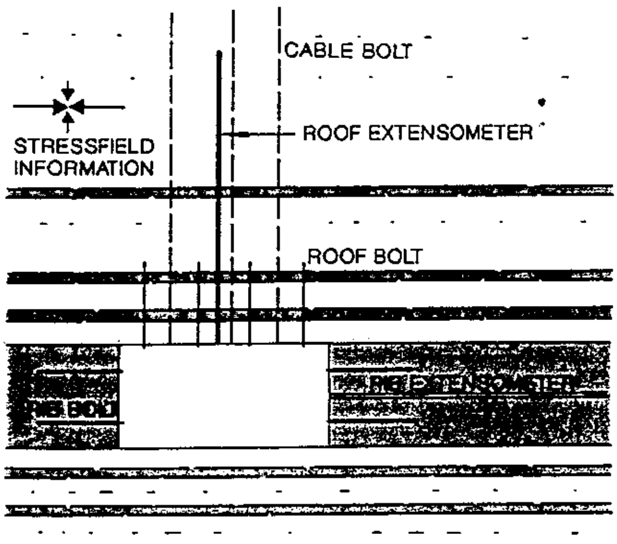


Figure 4 A typical installation.

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iii) Horizontal Stress Distribution in the Fractured (or Unfractured) Strata Above the Roadway

Measurement of the horizontal stress is done once the roadway deformation has stabilised and an equilibrium state is developed between bolt force, rock deformation and fractured rock strength in the roof. The horizontal stress in a fractured roof section typically reflects the residual strength of the fractured rock.

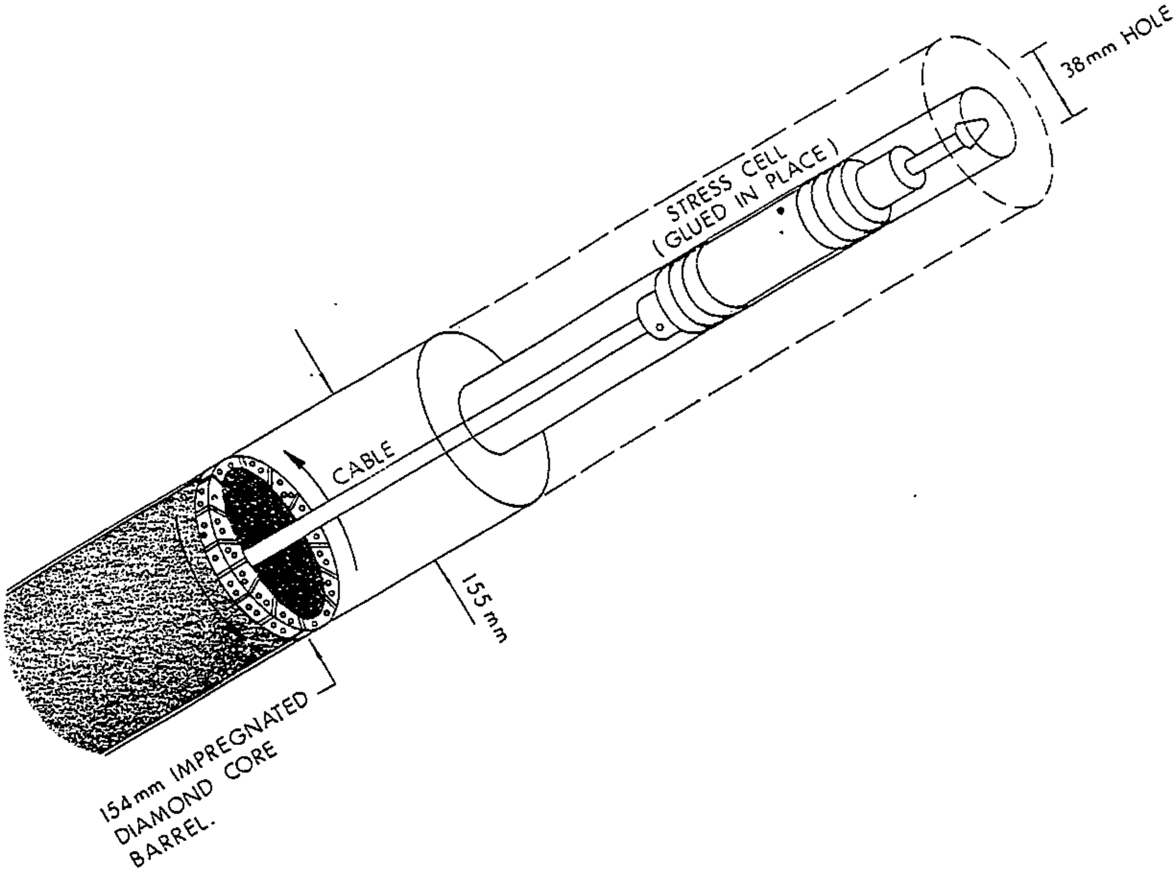
The stress is measured by a USBM stress cell which is subsequently overcored to relieve strain in the rock. The cell measures the magnitude and orientation of strains. Data reduction allows a definition of the stressfield. Typically, a series of measurements are made progressively into the roof to develop a stress profile roof which reflects the roof strength. A typical installation is presented in Figure 5.

5. VALIDATION PROCEDURE FOR COMPUTER SIMULATIONS

To make use of the modelled results as a guide to roadway behaviour characteristics and reinforcement design, the model must realistically simulate these features which can be independently measured during field monitoring. These features are:-

1) Roof extensometer characteristics.
2) Forces developed in rock bolts.
3) Horizontal stress in fractured roof strata.

Correlations obtained from Tower Colliery are presented below. A detailed validation is presented at Tower Colliery to demonstrate the suitability of the methodology.



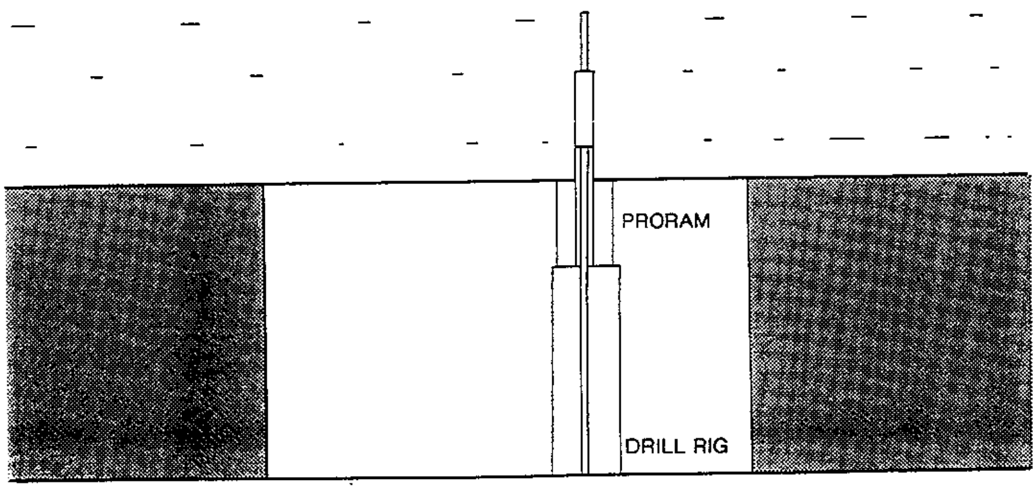


Figure 5 General stress cell arrangement.

Similar correlations exist for Tahmoor Colliery.

Measurement of the in situ stressfield was undertaken in the area of Nepean Panel and the NE Intakes. The stressfield existing in this area was simulated and the results compared to field measurements.

A) Roof Extensometer Data

The simulated roof displacement results, as would be monitored by a roof extensometer, are presented in Figure 6 compared to those measured. Also a characteristic of deformation height and displacement is presented.

The results indicate that the key features of the roof displacement (height of failure and style of failure) are well simulated by the computer model.

B) Roof Bolt Force Data

The bolt forces developed in the roadway simulation and those monitored under various stress conditions, are presented in Figure 7. The results indicate a close correlation.

C) Horizontal Stress Distribution in Fractured Rock

The results of a stress profile through broken rock above a roadway subjected to moderate-high stress conditions is presented in Figure 8. The anticipated distribution from the simulation is presented also. The result demonstrates a very close correlation in trend and magnitude. Field data of this type typically demonstrates local variability due to the fractured nature of the ground, and as such, the "overall" profile is most important.

These three correlations indicate that the model can successfully simulate rock failure and displacement, the interaction of rock bolts in the fractured ground and the strength characteristics of the fractured ground.

This correlation allows the use of such simulation techniques to assess the effectiveness of modified roof bolt patterns and the effect of varied stress conditions on roadway stability.

6. ASSESSMENT OF BOLTING OPTIONS AT TOWER COLLIERY

A feasibility study of the use of a modified roof bolting pattern was undertaken for the 401, 402, NE Intakes area.

A pattern of 4 bolts at the face followed by additional bolts behind the miner was assessed under a range of stress conditions.

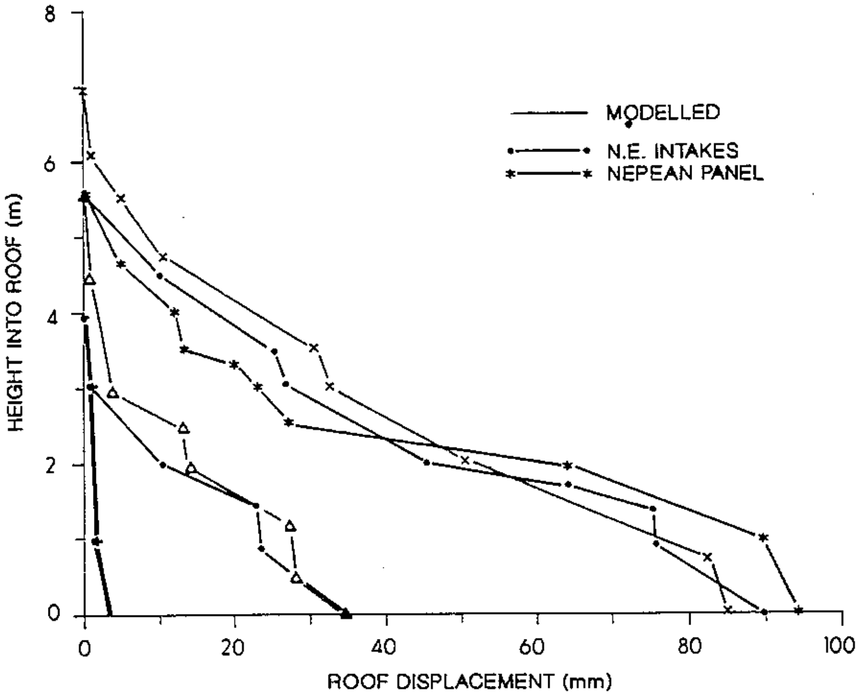


Figure 6(a) **TOWER COLLIERY**
Example of modelled roof extensometer information compared to measured data.

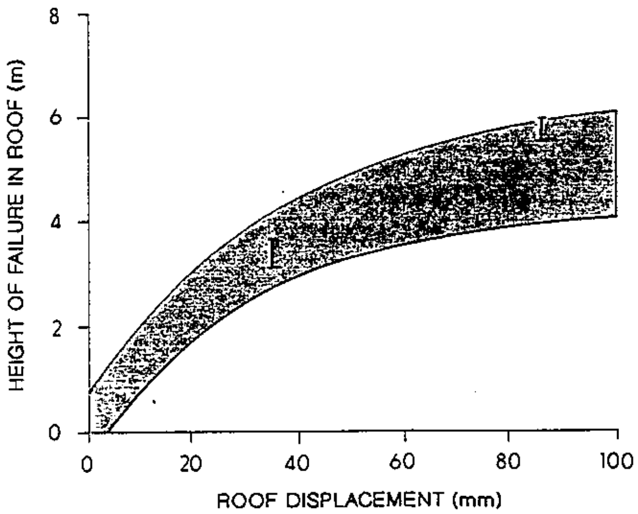


Figure 6(b) **TOWER COLLIERY**
Roof failure characteristics in laminite sections.

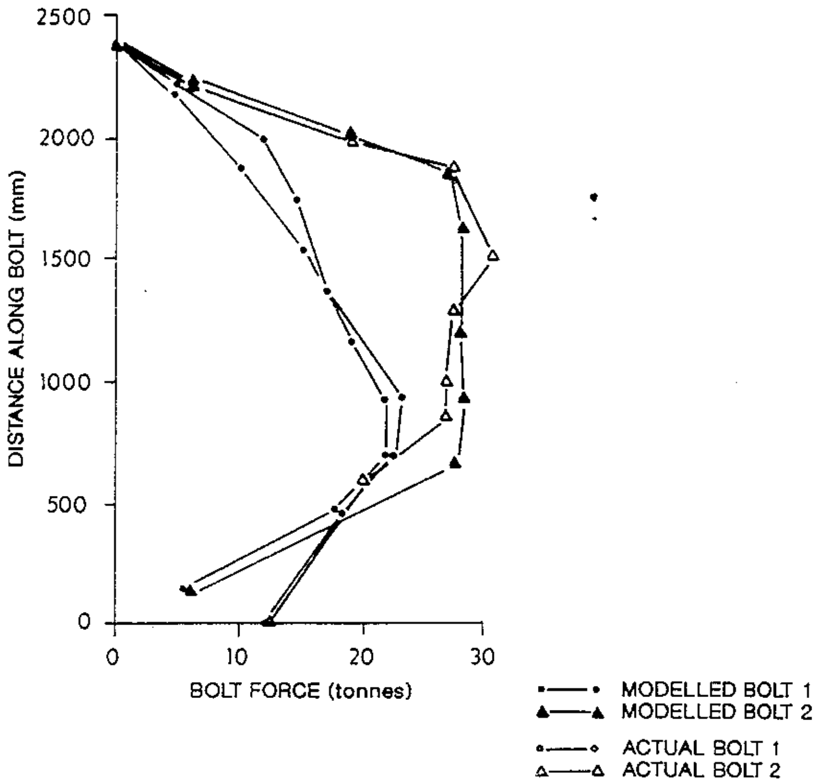


Figure 7 **TOWER COLLIERY**
Validation data of roof bolt force for measured and modelled bolts.

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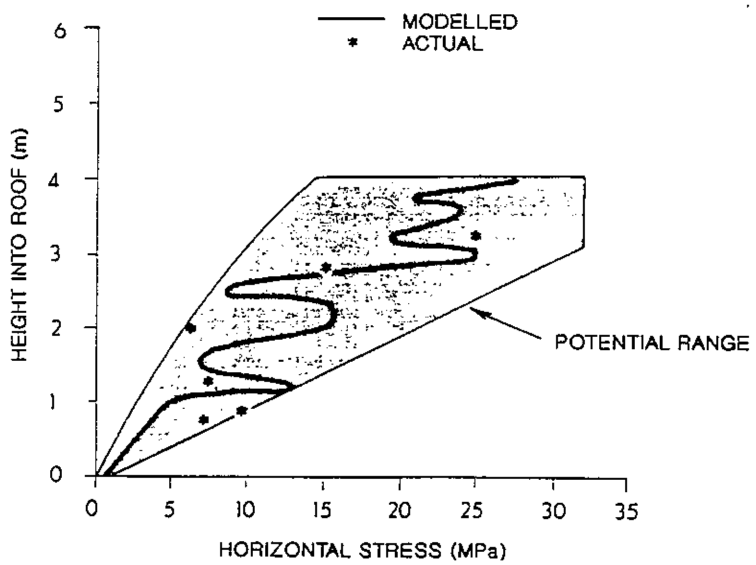

Figure 8 **TOWER COLLIERY**
Comparison of measured stress in roof and that modelled.

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Computer simulations were undertaken to determine the expected performance of various bolting systems under a range of stresses. Confirmatory monitoring was undertaken of a bolting sequence placed in the NE Intakes. The geology and model used has been presented in Section 3.

6.1 Computer Simulation Results

The anticipated roof behaviour characteristics and bolt performance under a range of horizontal stress magnitudes is presented in Figure 9. The stresses influencing headings as opposed to cut-throughs in the NE Intakes is noted on the figures. The direction of major horizontal stress in this area is at a large angle to the cut-throughs and as such is expected to cause greater deformation in cut-throughs than the headings.

The results indicate that under low stress conditions typified by tectonic stress factors, (tsf) less than 0.7m. The roof remained unfailed and a 4 bolt pattern would be suitable.

In areas of elevated stress conditions (tsf above 0.7) rock failure would be expected to initiate at the face and progress as the roadway is driven. A 4 bolt pattern was found to be unsuitable for general stability and an assessment was made of the effect of placing alternate systems of -

a) 8 bolts placed at the face,
b) 4 bolts placed at the face,
c) 4 bolts at the face plus 4 behind the miner,
d) 5 x 50t strand bolts at the face.

The results of the assessment are presented in Figure 10 which depicts a number of stability factors.

The results indicate that:-

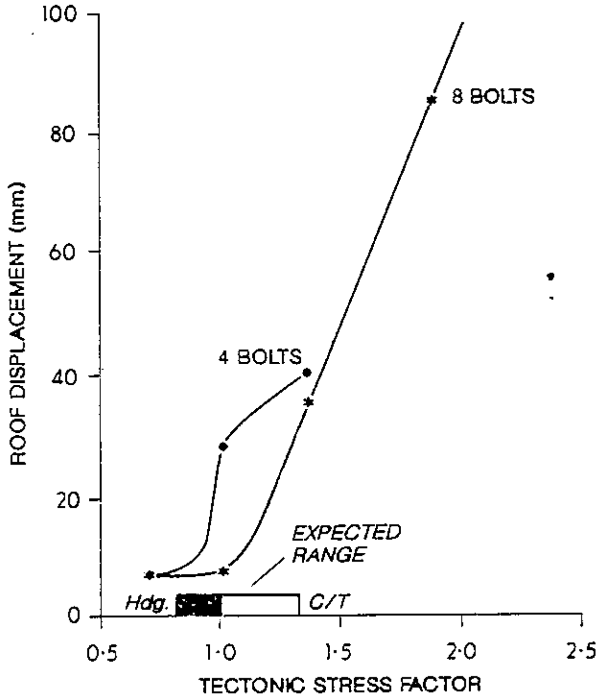
i) The best stability is obtained with an 8 bolt pattern in which all bolts are placed at the face.

ii) The use of a 4 + 4 pattern is better than 4 bolts alone, however, the "strength" of the roof, the amount of rock failure and the height of broken roof was significantly greater than with the 8 bolt pattern.

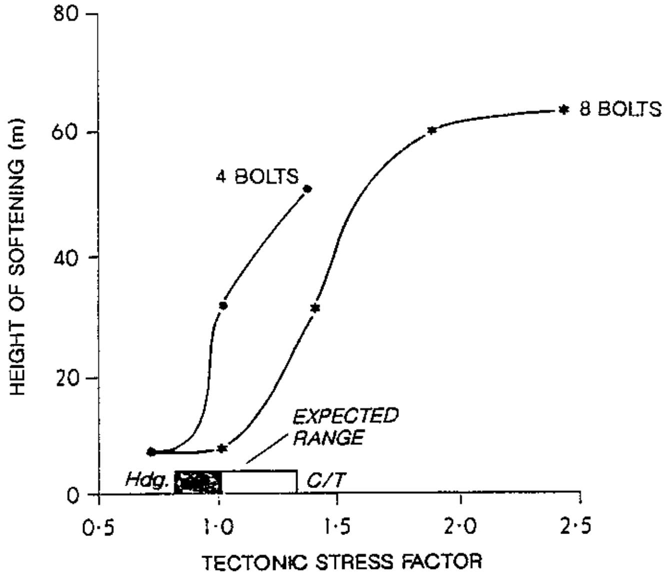
iii) The use of 5 high capacity strand bolts created results between the other two options, despite the higher apparent strength of the strand.

An indication of the sensitivity of rock failure and effective resultant strength of the lower roof obtained, due to delayed bolting, is presented in Figure 11.

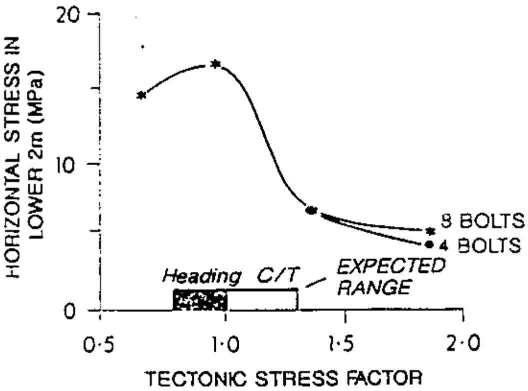
In this figure, the resultant average stress (or effective horizontal strength of the broken roof) is plotted relative to roof displacement for a number of bolting options. The



a) Roof displacement for various stress levels.



b) Height of roof failure for various stress levels.



c) Roof stress transfer for various stress levels.

Figure 9 TOWER COLLIERY
Roof behaviour determined from the model.

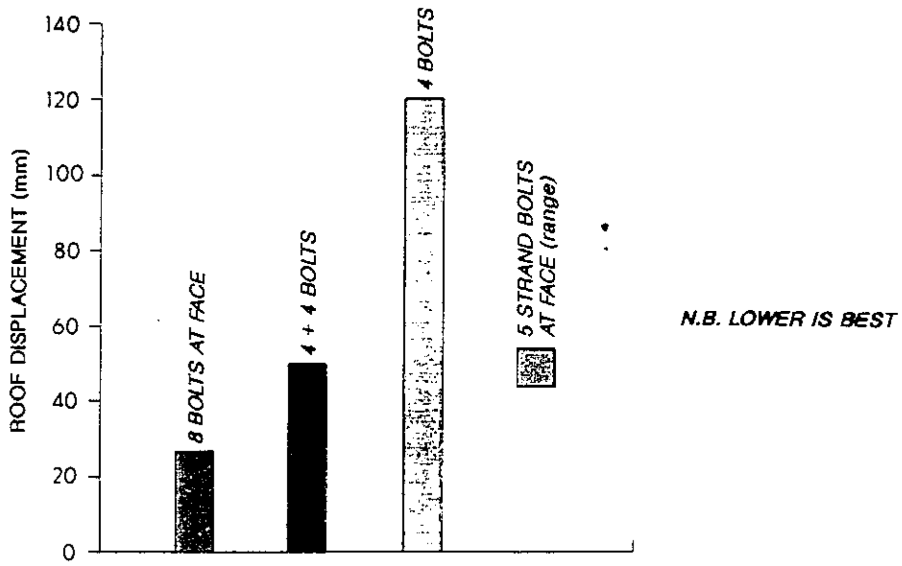


Figure 10(a) TOWER COLLIERY
Roof displacement characteristics of various options.

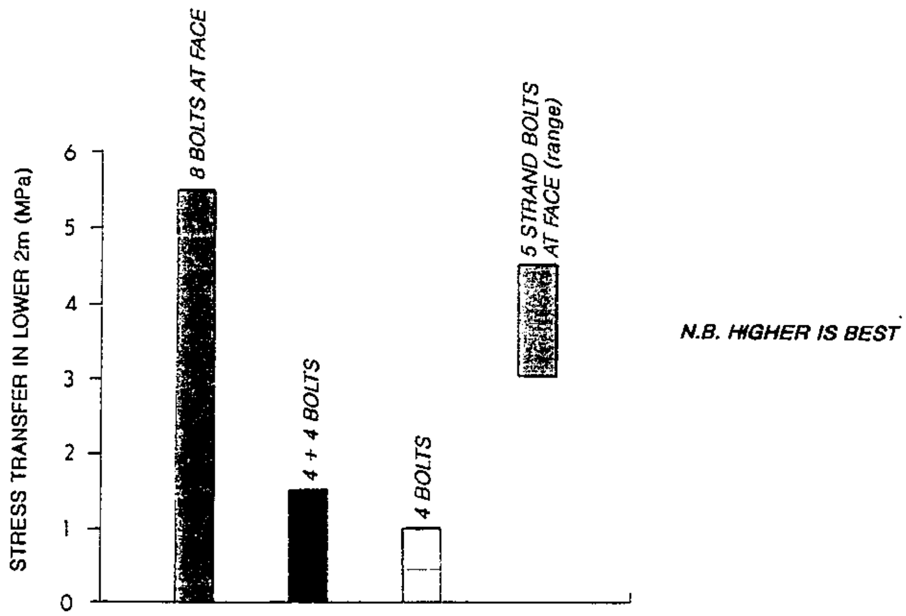


Figure 10(b) TOWER COLLIERY
Roof stress transfer for various options.

results indicate that an 8 bolt system develops forces and comes into equilibrium after approximately 10mm of roof movement.

The behaviour of the 4 bolt system and 4 + 4 system is also presented. The 4 bolt system placed at the face also develops force in the initial 10mm of roof movement, however, the resultant roof strength achieved is very low. Ongoing roof movement was indicated under this condition and ongoing-outbye failure in the roof of actual roadways would be expected.

The 4 + 4 pattern consisted of 4 bolts at the face and an additional 4 placed at a roof deformation level of approximately 10mm - 15mm. The additional bolts loaded and the roof deformation continued to approximately 50mm as opposed to 120mm (minimum) with 4 bolts only.

The results of the computer simulations and of field monitoring indicate that in moderate to highly stressed roof conditions, roof strength reduces very rapidly with the onset of rock deformation and failure. Unless the bolts are placed and develop sufficient force within 5mm - 10mm of roof deformation, then significant strength loss in the roof can occur which cannot be simply regained by the addition of extra bolts at a latter stage.

In low stress areas having negligible roof deformation, roof bolting sequences can typically be utilised without detriment. This is due to the fact that strength loss in the roof has not occurred on development, and so long as all bolts are placed prior to additional stresses (possibly associated with extraction) being created, the system will respond similarly to one having all bolts placed at the face.

It was concluded that the 4 bolt pattern would be suitable in areas of low stress (tsf <0.7) and not in areas of higher stress. It is noted that for gateroads driven under low stress conditions, the 4 bolt pattern may be suitable for development, however, additional reinforcement would be necessary to counteract stress concentrations (increases) occurring during extraction operations. The additional reinforcement (bolts/cable bolts) would need to be placed prior to longwall retreat.

The computer simulation anticipated that headings in the NE Intakes would be stable and suitable for a 4 bolt pattern (in low stress and unfaulted conditions), whereas cut-throughs would suffer deformation and require 8 bolts.

A monitoring program to assess this was undertaken and is discussed below.

6.2 Field Monitoring of NE Intakes

Monitoring of roof displacements, rib displacement and roof bolt forces was undertaken. The location of instrumentation is presented in Figure 12. All instruments were placed at the face and monitored as the roadway advanced.

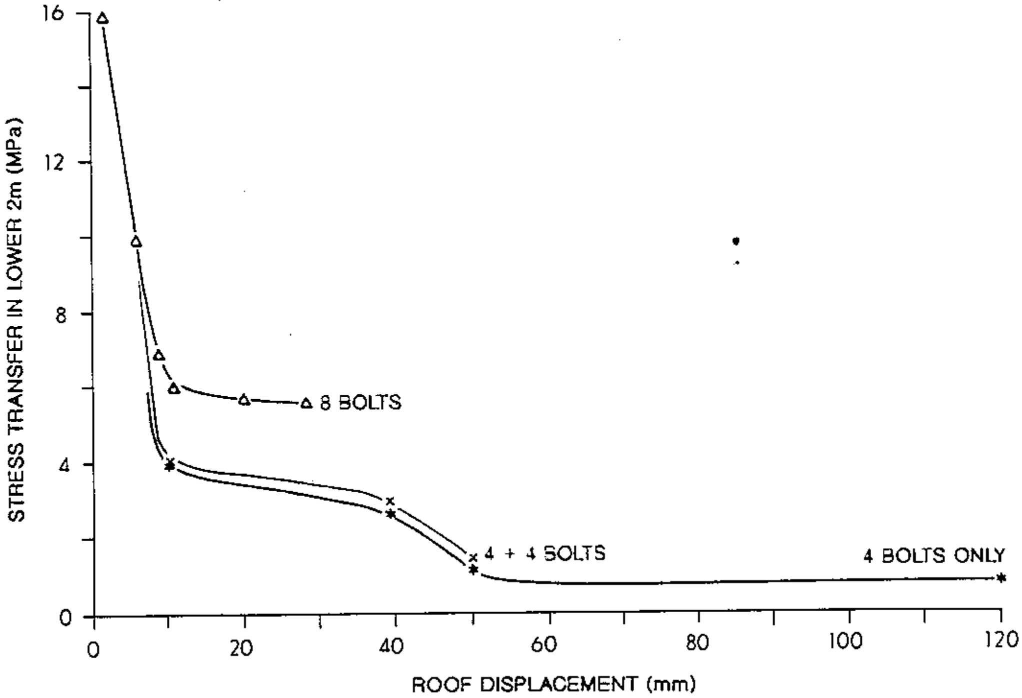


Figure 11 TOWER COLLIERY
Stress transfer versus roof displacement for various bolting options.

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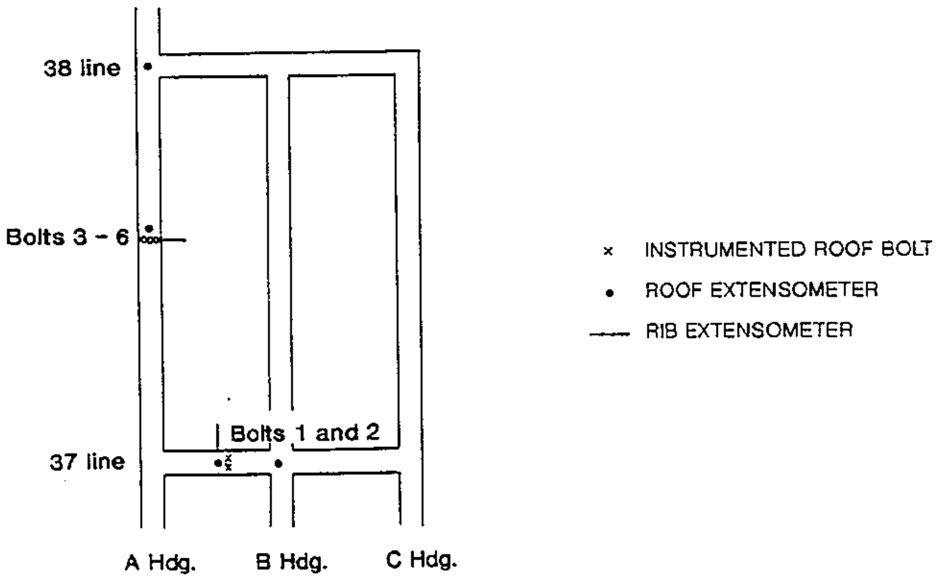

Figure 12 TOWER COLLIERY
Layout of instrumentation, North East Intakes.

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6.3 NE Intakes Headings

A 4 bolt pattern was used in this roadway, together with a spot bolt where necessary to restrict local slabbing. The bolt forces measured are presented in Figure 13. They were typically less than 5t and generally reflected the forces developed during installation. The roof displacement characteristics are presented in Figure 14a and indicate that the roof remained stable with only very localised loosening of the immediate roof. The rib deformation characteristics are represented in Figure 14b and indicate that ribside deformation is restricted to less than 1.0m into the pillar. These results indicate that the roadways remain stable under these stress conditions.

6.4 NE Intakes Cut-throughs

The deformation occurring in the roof of a cut-through and an intersection created in the cut-through is presented in Figure 15a. An 8 bolt pattern was used in these cut-throughs. This shows that roof failure extends 3m to 5.5m into the strata. Roof bolt forces monitored are presented in Figure 15b which indicates that forces above 25t are rapidly developed.

The rib deformation in the cut-through is presented in Figure 14b which indicates that rib failure is limited to the initial 1m of the pillar.

7. OVERVIEW OF RESULTS

1. The computer simulation and field monitoring provide similar results and indicate that modified bolting sequences can be utilised in certain areas of the mine where stress conditions are appropriate.

2. It was noted that sequencing of overdrives from headings prior to breakaways or intersection formation was also important to optimise the stability of intersections formed in the headings. The aim of overdrives is to pre-reinforce the roof in the "good" direction prior to forming intersecting roadways in the "bad" direction which will suffer roof failure.

3. Results from the computer simulation and monitoring indicate that initial roof failure up to 3m into the roof can occur with roof displacements of less than 30mm. This is difficult to resolve by eye and, as such, a routine monitoring system is recommended when utilising low density or modified bolting patterns.

   The monitoring system would provide confirmation of conditions suitable for the system or early warning of changed conditions requiring a change to the bolting patterns placed.

4. The computer simulation method used can be applied to assess the behaviour of ground and the effectiveness of rock bolting strategies under various conditions.

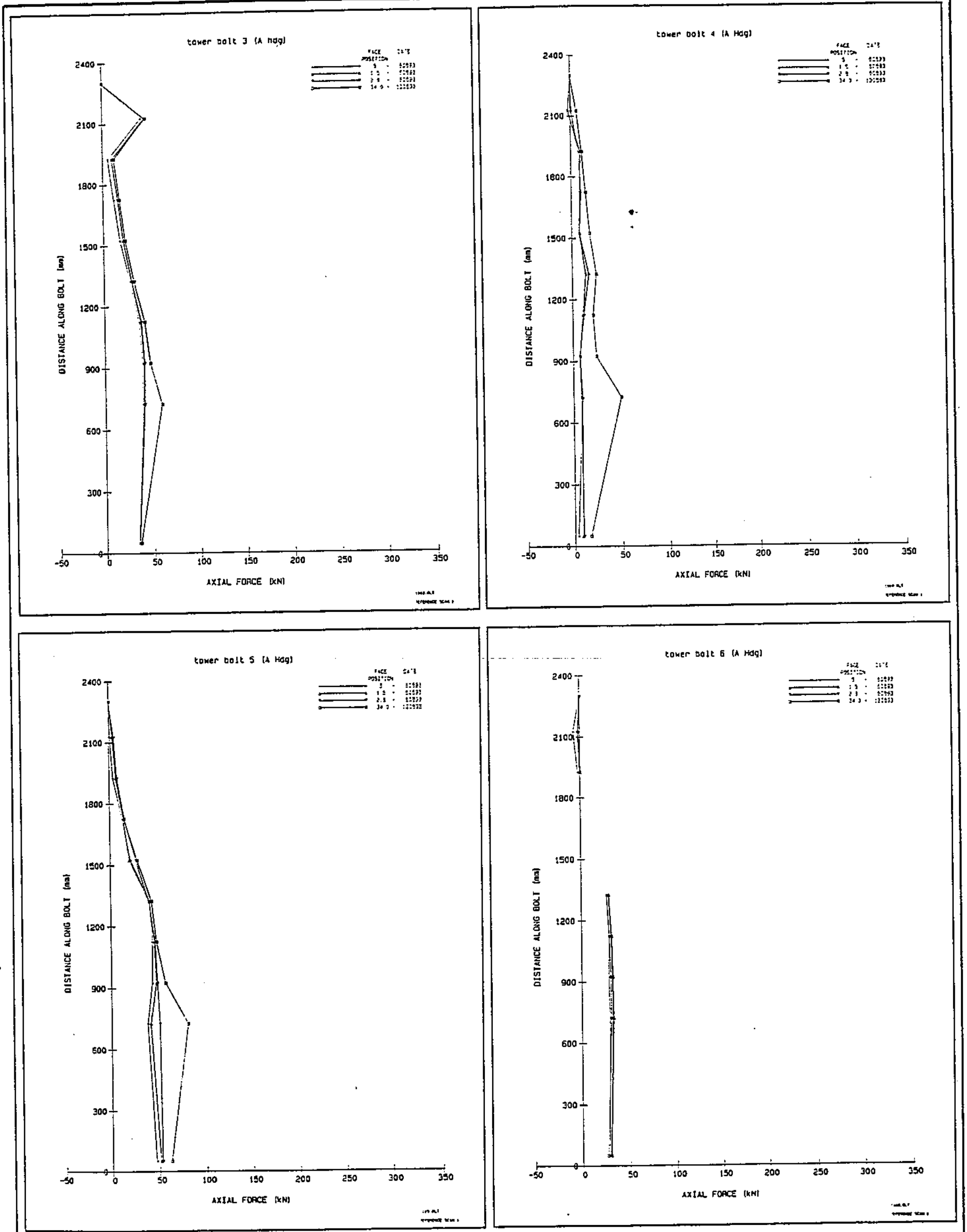
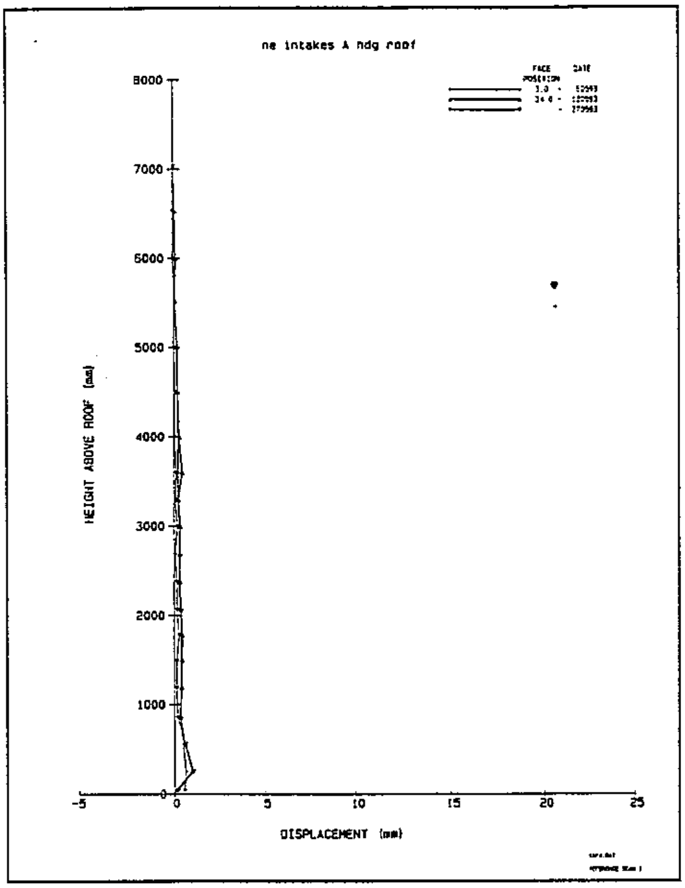


Figure 13 TOWER COLLIERY
Axial forces developed in the bolts for various face advance positions - A Heading.



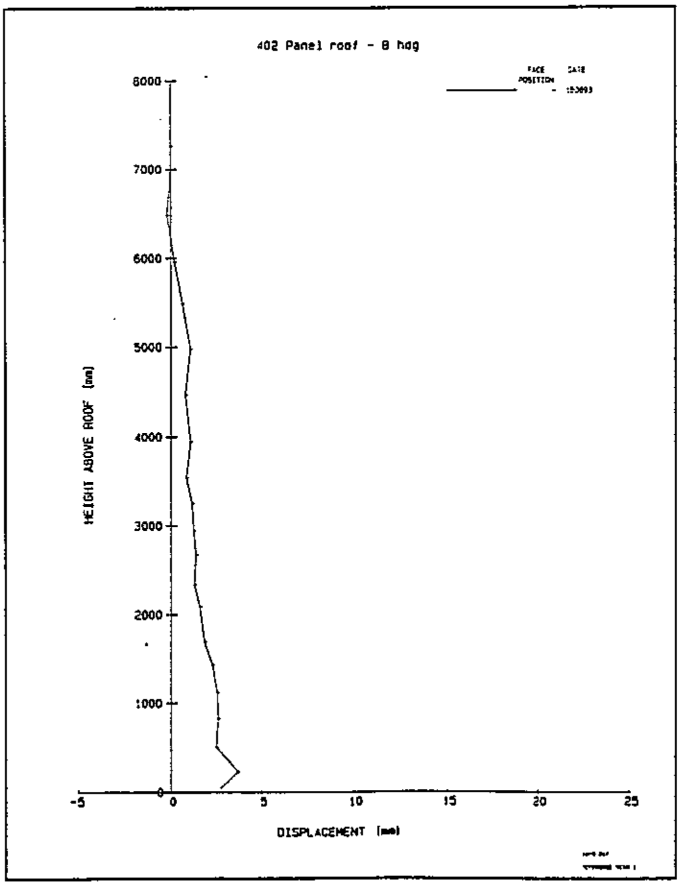
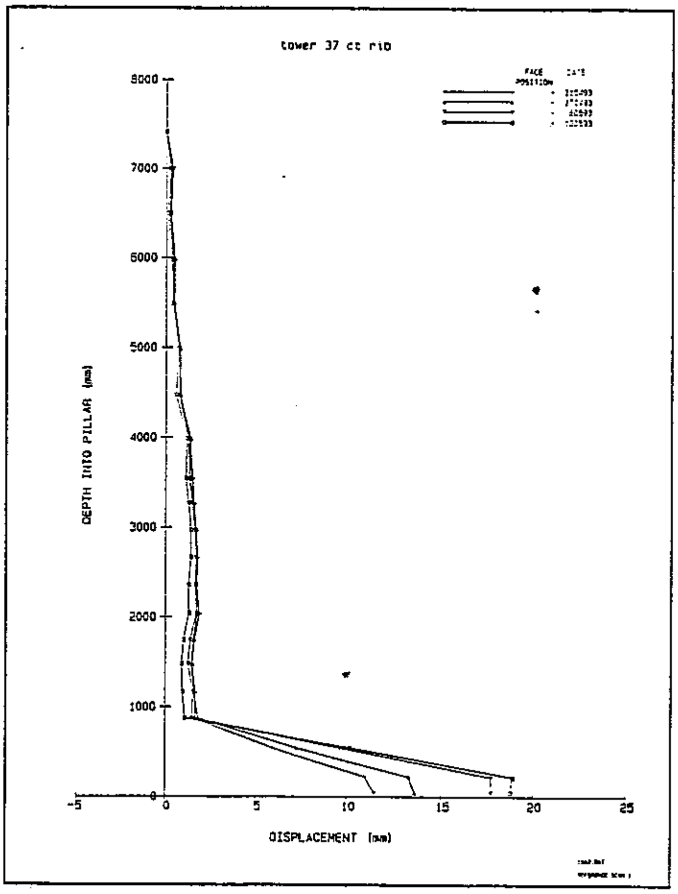


Figure 14(a) TOWER COLLIERY
Roof displacement monitored for heading driveages in 'A' and 'B' roadways.



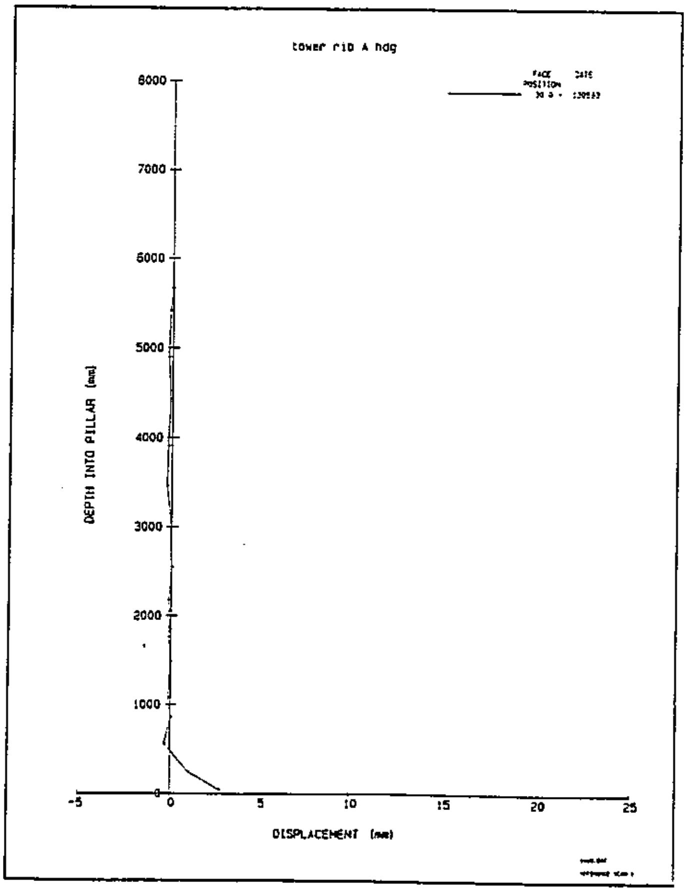


Figure 14(b) TOWER COLLIERY
Rib displacement developed at the monitored sites for various for various face advance positions.

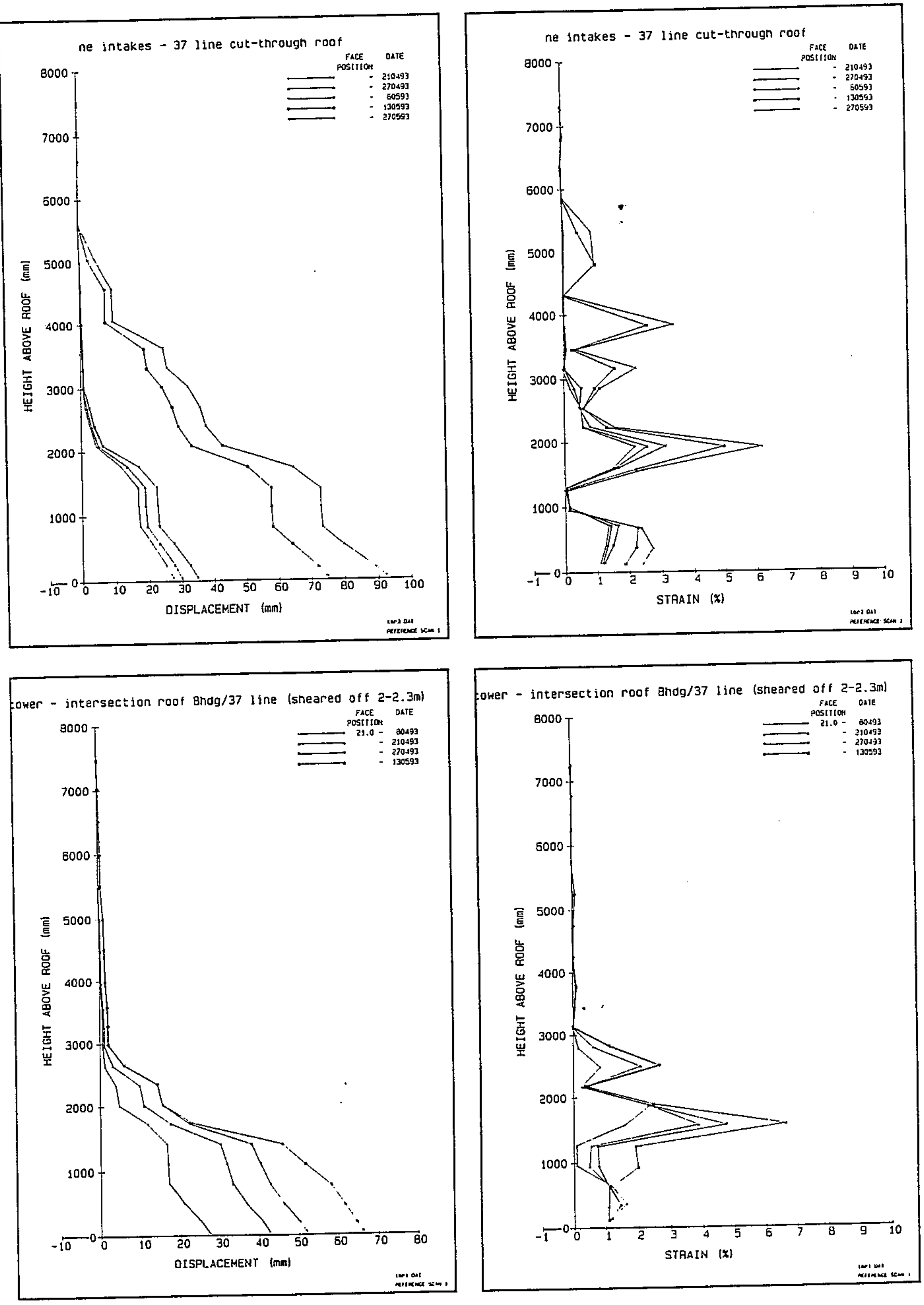
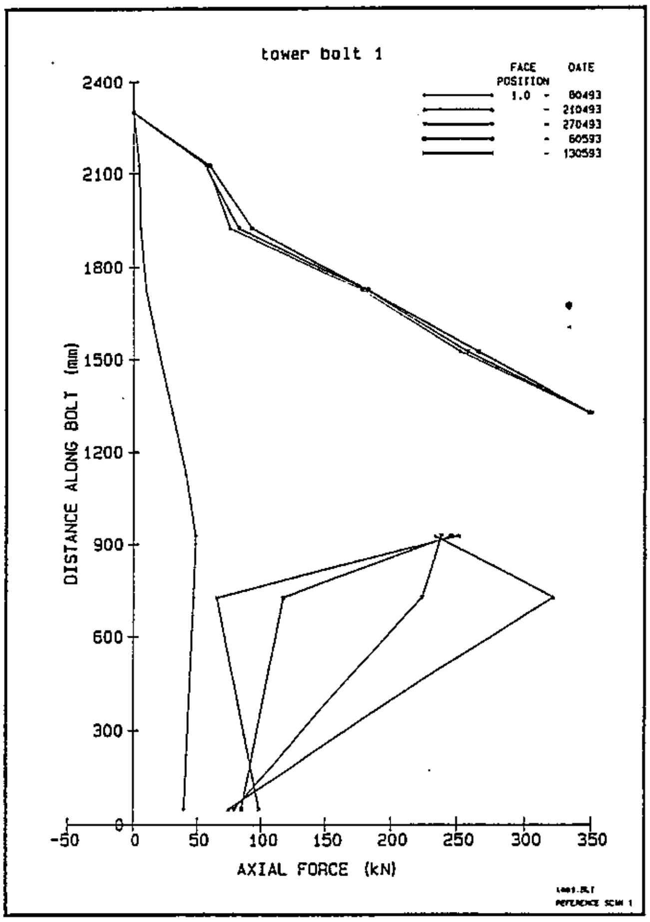


Figure 15(a) TOWER COLLIERY
Roof displacement and strain profile developed at the monitored site for various face advance positions - 37 line cut through.



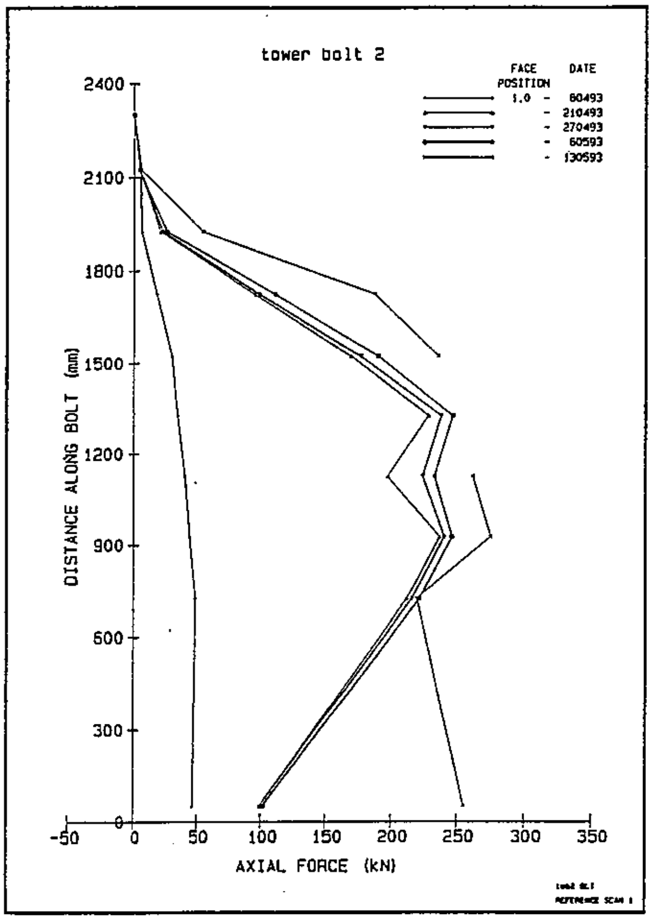


Figure 15(b) TOWER COLLIERY
Axial forces developed in the bolts for for various face advance positions - 37 line cut through.

8. ASSESSMENT OF BOLTING OPTIONS AT TAHMOOR COLLIERY

A feasibility study investigating the use of modified bolting patterns was undertaken for low stress environments at Tahmoor Colliery.

A standard pattern of 6 bolts per strap and a modified pattern of 5 bolts per strap installed behind the miner were investigated under a range of stresses.

Computer simulations were undertaken to determine the expected performance of the bolting systems under a range of stress conditions. Confirmatory field monitoring was undertaken in the 18 and 19 cut-throughs of Longwall 13. 18 cut-through was developed using the modified 5 bolt per strap bolting pattern, while 19 cut-through was developed using the standard 6 bolt per strap bolting pattern. The geology and model used has been presented in Section 2.

8.1 Computer Simulation Results

Modelled roof behaviour and bolt performance under a range of horizontal stress magnitudes is presented in Figure 16. The horizontal stress has been altered by adjusting the tectonic stress factor (tsf). The plots show results for both the 5 and 6 bolt patterns.

During execution of the modelling, it was found that the placement of the central bolts in the 6 bolt pattern had an influence on the magnitude of displacement and height of softening above the roadway. This was more pronounced in higher stress environments, as evidenced by tsf values >1.0. The plot of roof displacement versus tsf shows the 6 bolt roof displacement envelope. The envelope is arrived at by varying the placement of the two centre bolts in the pattern. At lower tsf values, where the roof behaves elastically, the central placement of the bolts has a greater influence on the anticipated roof displacement, although it should be noted that overall deformations are low. At high levels of horizontal stress (tsf >1.2) the 6 bolt pattern records lower magnitudes of roof deformation compared to the 5 bolt pattern.

Thus the results indicate that:-

1. In low stress environments (tsf <0.7) anticipated deformations, for both the 5 and 6 bolt patterns, are low.

2. The modified 5 bolt pattern in low stress environments affords the same roof stability as the 6 bolt pattern.

3. In higher stress environments (tsf >1.2) a 6 bolt pattern offers the best roadway roof stability.

4. The placement of the two central bolts in the 6 bolt pattern is important in minimising roof deformation.

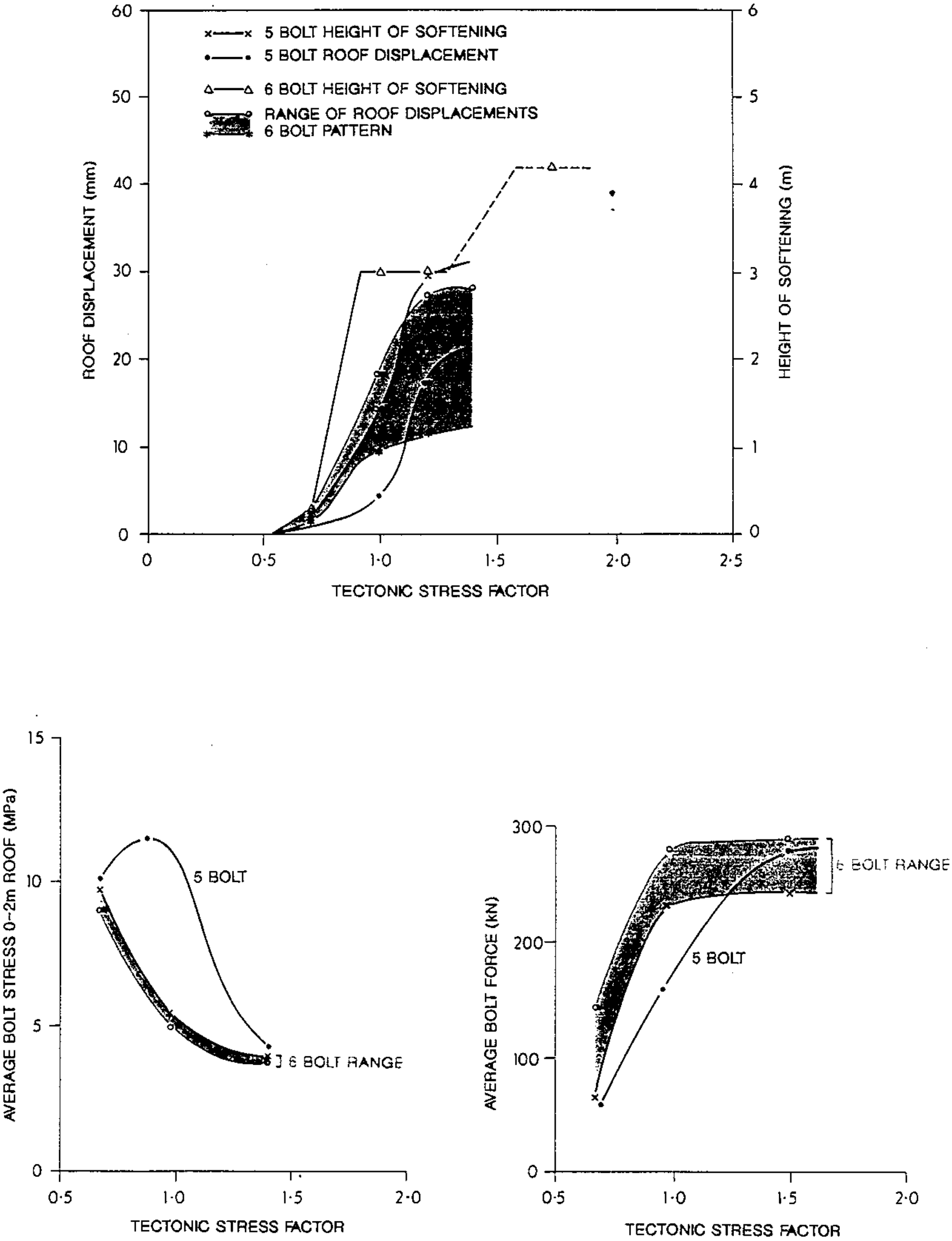


Figure 16 **TAHMOOR COLLIERY**
Comparative anticipated roadway conditions for 5 and 6 bolt bolting patterns.

It was concluded that the performance of roadways developed with the 5 or 6 bolt pattern in low stress environments at Tahmoor Colliery would be stable and perform in a similar manner.

A field monitoring programme to assess and confirm this was undertaken at Tahmoor Colliery and is discussed below.

8.2 Field Monitoring of 18 & 19 Cut-Throughs

An array of instrumented roof bolts and roof extensometers were installed at the face in the 18 and 19 cut-throughs in the Maingate of Longwall 13. Figure 17 shows an instrumentation layout for both headings.

Both headings were instrumented with identical arrays which consisted of:

i) A 20 position, 7m long extensometer installed in the centre of the roadway.
ii) 3 x 2.1m long AX instrumented bolts installed in the roof. Figure 18 details the location of each bolt.

Each instrumented bolt consists of nine pairs of strain gauges to measure axial forces and bending moments developed. The instruments were installed at the face and monitored on driveage and with time.

Each bolt was installed with 1 x 1100mm x 25mm two speed resin cartridge which provided full encapsulation. Each hole was drilled using a 27mm diameter drill bit.

8.3 Roof Displacement Results

8.3.1 18 Cut-Through - Modified Bolting Pattern

The roof displacement and vertical strain profile developed during the three month monitoring period is shown in Figure 19.

The results indicate that recorded roof deformation is minimal, in the order of 3mm - 4mm, and is confined to the immediate 200mm of roof. The vertical strain profile developed indicates that strata softening may have occurred in the immediate 200mm of roof. Strata softening typically occurs at about 0.75%.

8.3.2 19 Cut-Through - Standard Bolting Pattern

The roof displacement results obtained from the standard roof bolting pattern are shown in Figure 20. These occurred over a ten week period from driveage.

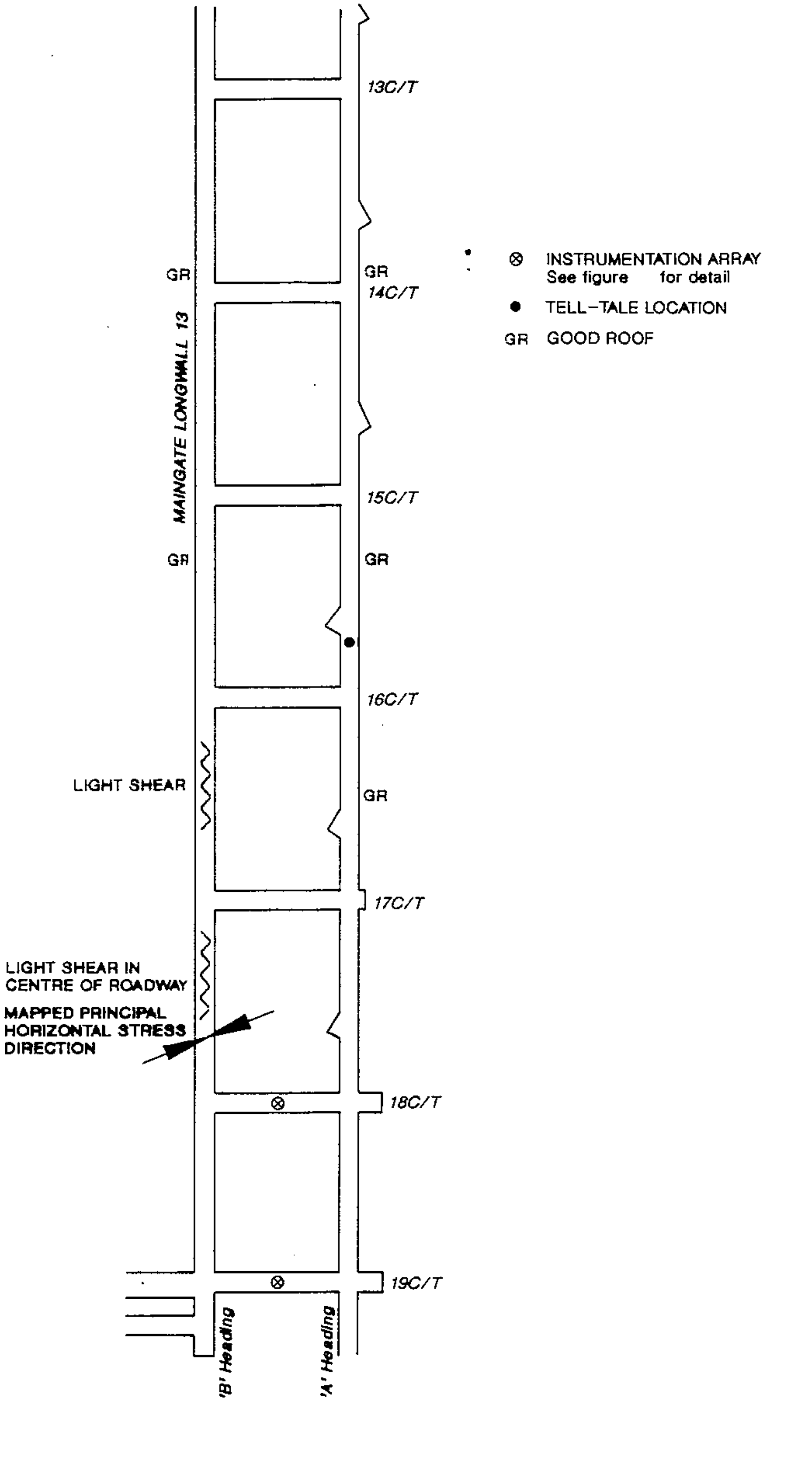


Figure 17 TAHMOOR COLLIERY
Instrumentation layout, mapped roof conditions and stress directions.

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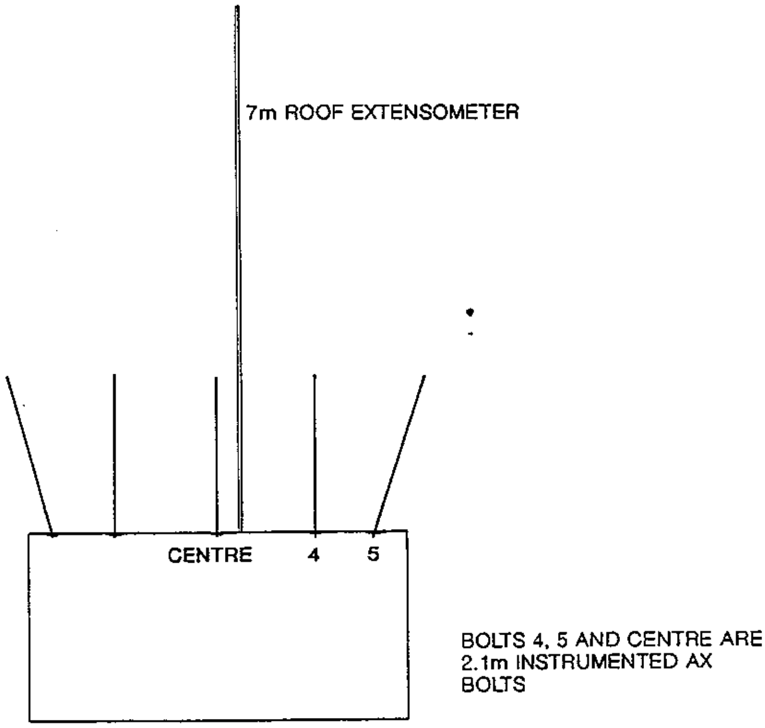
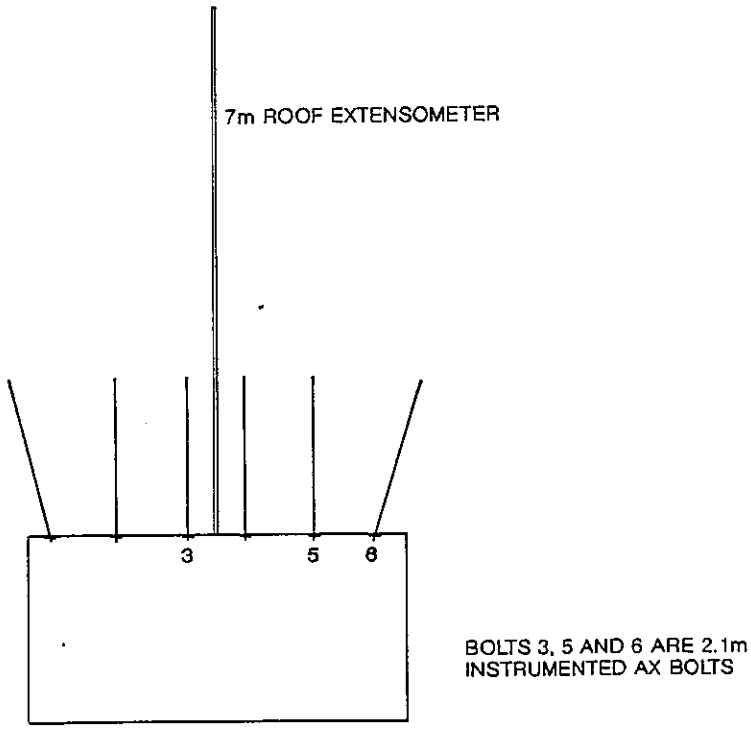
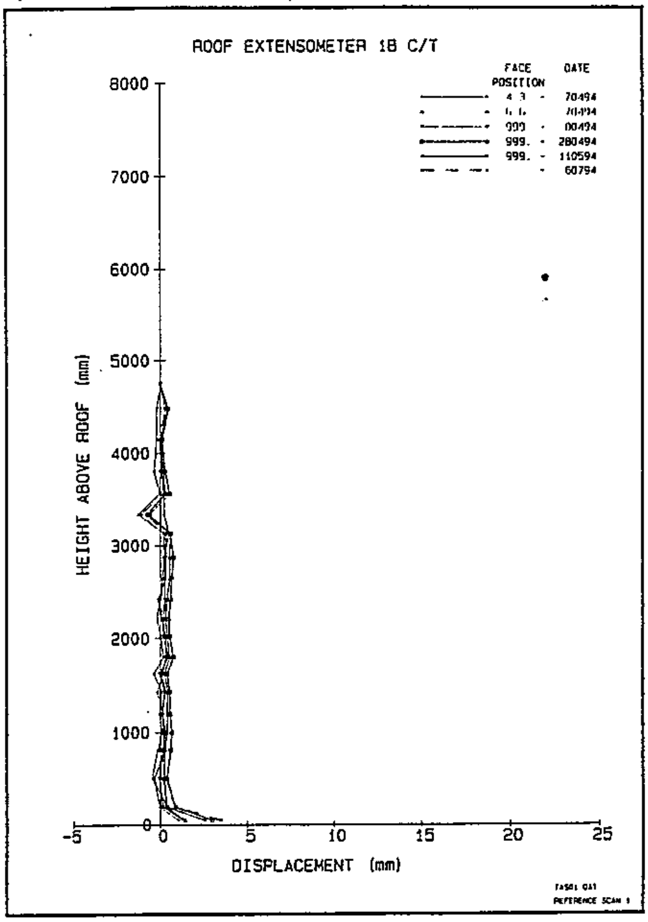


18 CUT-THROUGH
MODIFIED 5 BOLT PATTERN



19 CUT-THROUGH
STANDARD 6 BOLT PATTERN

Figure 18 TAHMOOR COLLIERY
Bolting patterns and instrumentation layout
18 and 19 cut-throughs.



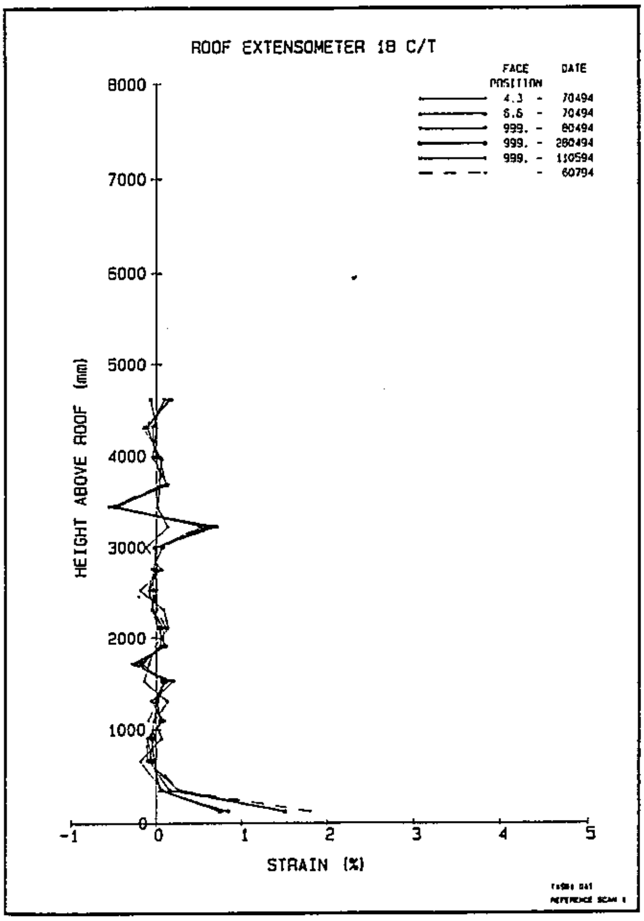
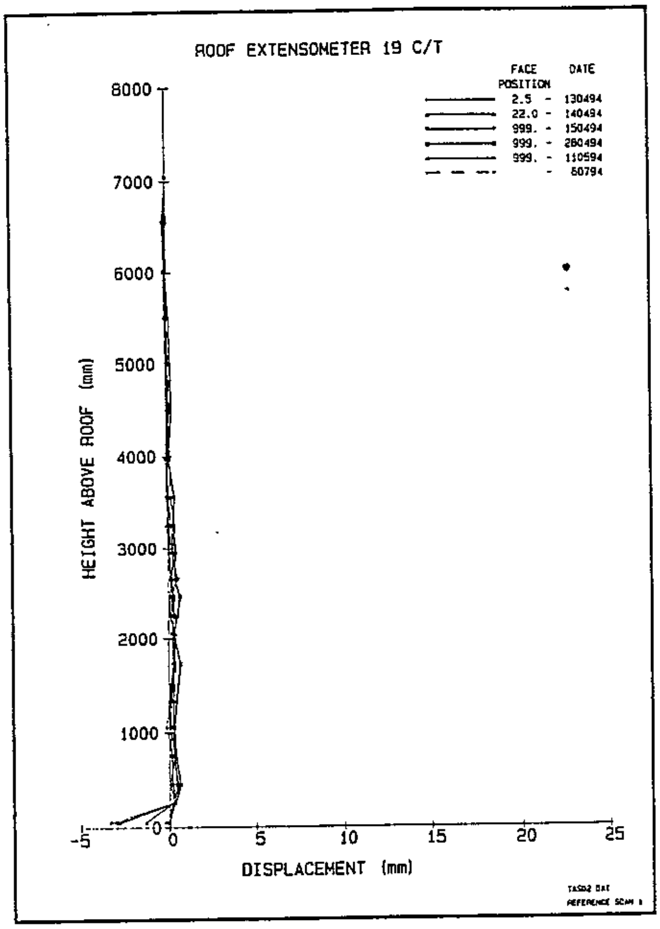


Figure 19 **TAHMOOR COLLIERY**
Roof displacement and strain profile developed at the monitored site for various face advance positions - 18 C/T.



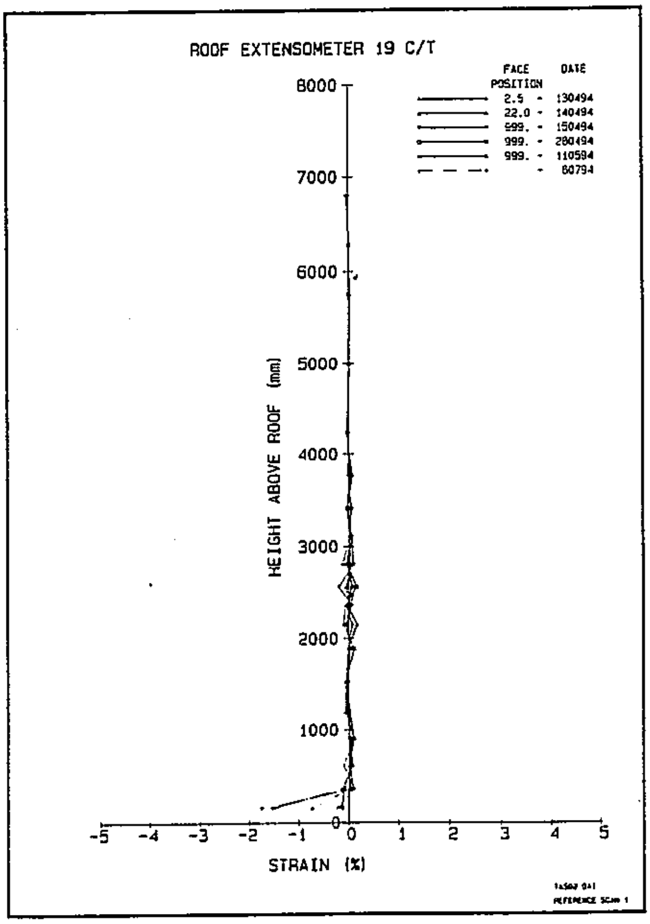


Figure 20 TAHMOOR COLLIERY
Roof displacement and strain profile developed at the monitored site for various face advance positions - 19 C/T.

The results recorded are similar to those recorded in 18 cut-through. Only minor amounts of compressive movement were noted, interpreted as bedding plane closure. Recorded displacements do not extend into the roof, highlighting the low deformation environment in this area.

8.3.3 Summary - Roof Behaviour

i) Both sites showed similar styles of displacement.
ii) Both sites recorded low deformations, both with driveage and time.
iii) Little or no softening into the roof was recorded at either site.

8.4 Roof Bolt Behaviour

The axial forces and bending moments developed in each instrumented bolt are shown in Figure 21.

8.4.1 18 Cut-Through

i) Axial Forces

The results indicate that bolt loading across the roadway has been negligible with heading advance. After an initial pretension of approximately 1-2 tonnes, heading advance resulted in a maximum of 5 tonnes recorded in the bolts. During retreat of the longwall, an increase in bolt loading to 10 tonnes was recorded.

Figure 21 details the bolt force distribution contoured and plotted as a section across the roadway for:
i) installation
ii) longwall retreat.

The figure shows that uniformly low bolt loads were recorded across the roadway, well within the elastic range of the AX bolts.

The centre bolt and bolt 4 recorded data from only the last four pairs of strain gauges, while bolt 5 recorded data from all nine pairs of gauges. The force distribution along bolt 5 is consistent with full encapsulation, with load being transferred along the length of the bolt resulting in low collar loads.

ii) Bending Moments

Little or no bending moments were induced in either of the three bolts, as shown in Figure 21. This is consistent with the low bolt axial loads and recorded roof deformation.

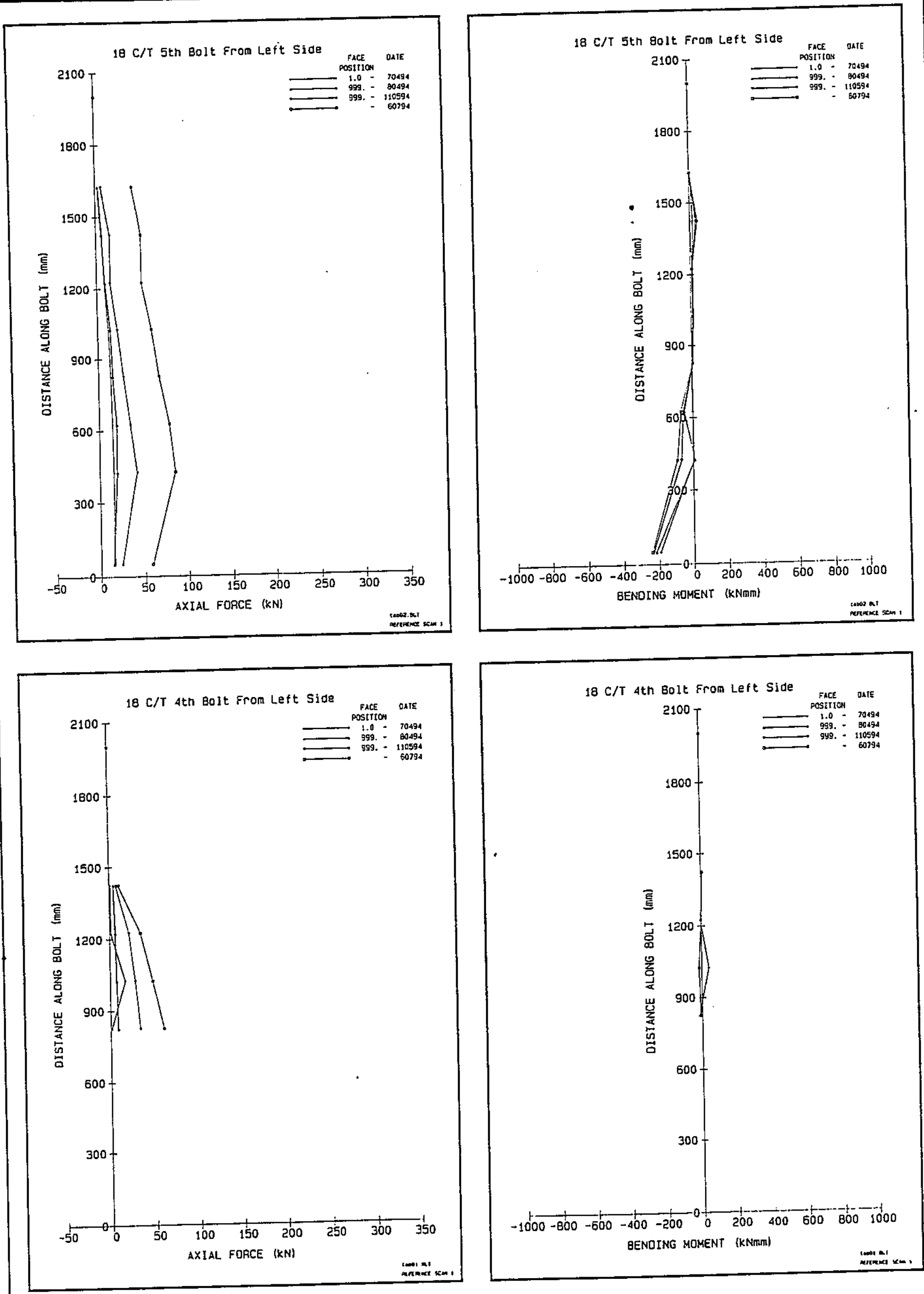
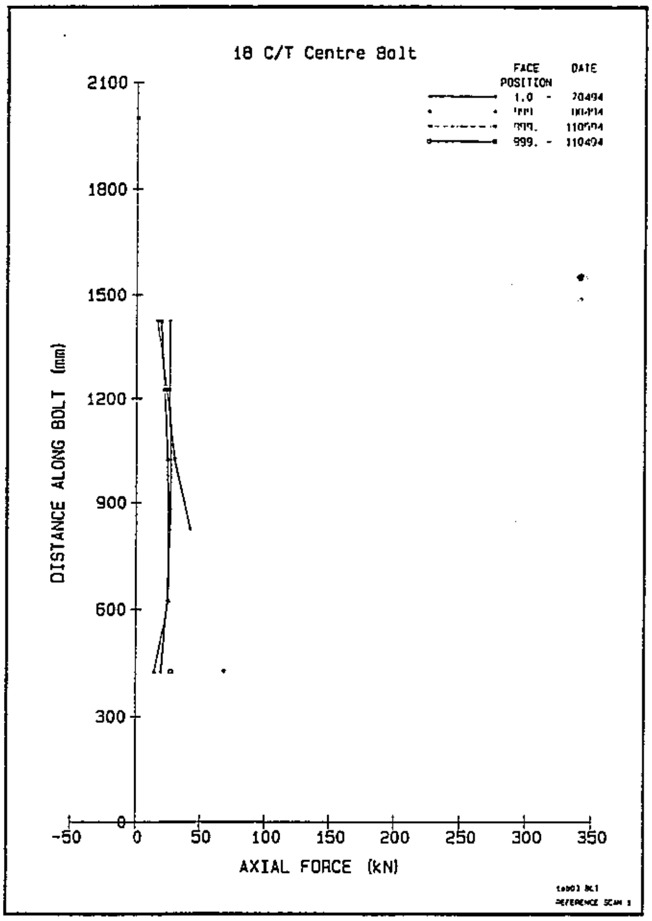


Figure 21 TAHMOOR COLLIERY
Axial forces and bending moment developed in the bolts for various face advance positions - 18 C/T.


18 C/T Centre Bolt
FACE POSITION
DATE
1.0 - 70494
999. - 110494
DISTANCE ALONG BOLT (mm)
2100
1800
1500
1200
900
600
300
0
-50
0
50
100
150
200
250
300
350
AXIAL FORCE (kN)

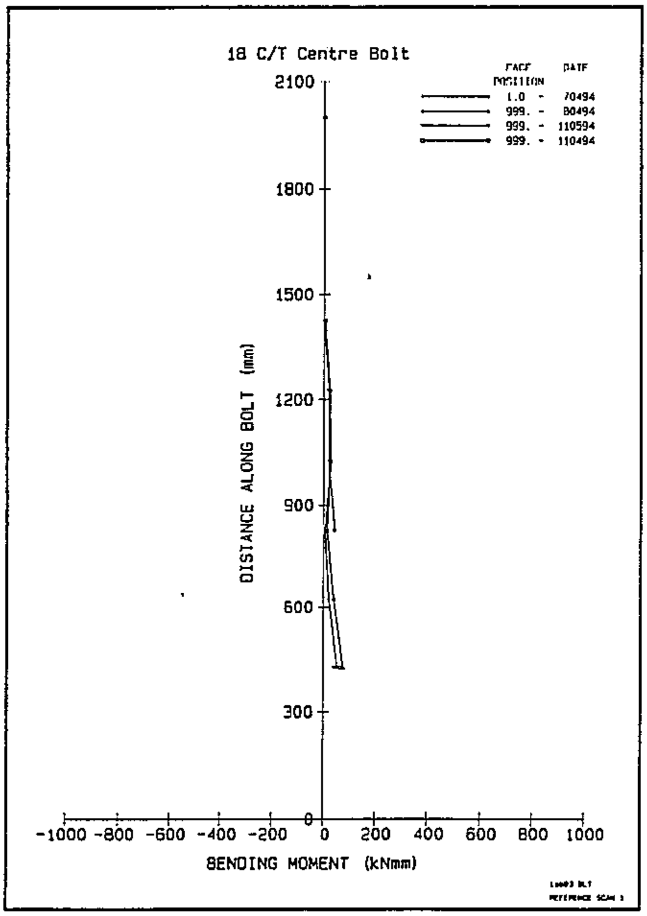

18 C/T Centre Bolt
DATE
1.0 - 70494
999. - 80494
999. - 110594
999. - 110494
DISTANCE ALONG BOLT (mm)
2100
1800
1500
1200
900
600
300
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
BENDING MOMENT (kNmm)

Figure 21

8.4.2 19 Cut-Through

i) Axial Forces

Instrumented bolts placed in the 19 cut-through were monitored during a four week period following heading advance, no results are available for longwall retreat.

Figure 22 details axial loads and bending moments developed in the three bolts. Bolts five and six have a full compliment of nine pairs of gauges, while bolt three has eight pairs of gauges.

All bolts consistently show little or no increase in axial loading with heading advance. The instrumented bolts were installed with a pre-tension of between 2-4 tonnes, and only bolt five showed a slight increase to 5 tonnes.

The bolt force profile, contoured and plotted as a section above the roadway, is shown in Figure 23. It shows that bolt loading is negligible across the roadway during heading advance.

ii) Bending Moment

Recorded bending moments were negligible, reflecting the low bolt forces and roof deformations.

8.4.3 Summary of Roof Bolt Behaviour

i) Recorded axial bolt loads and bending moments were low.
ii) No appreciable difference in bolt performance was noted between the standard and modified bolting pattern, as shown in the results.

8.5 Overview of Results

1. The correlation between recorded field monitoring data and computer simulation is very good. The difference in performance of the standard and modified bolting patterns in low stress environments is negligible.

2. At high horizontal stress the standard 6 bolt pattern offers better roadway roof stability.

3. The computer simulation can be used to evaluate the performance of modified bolting patterns and their performance under a range of stress conditions.

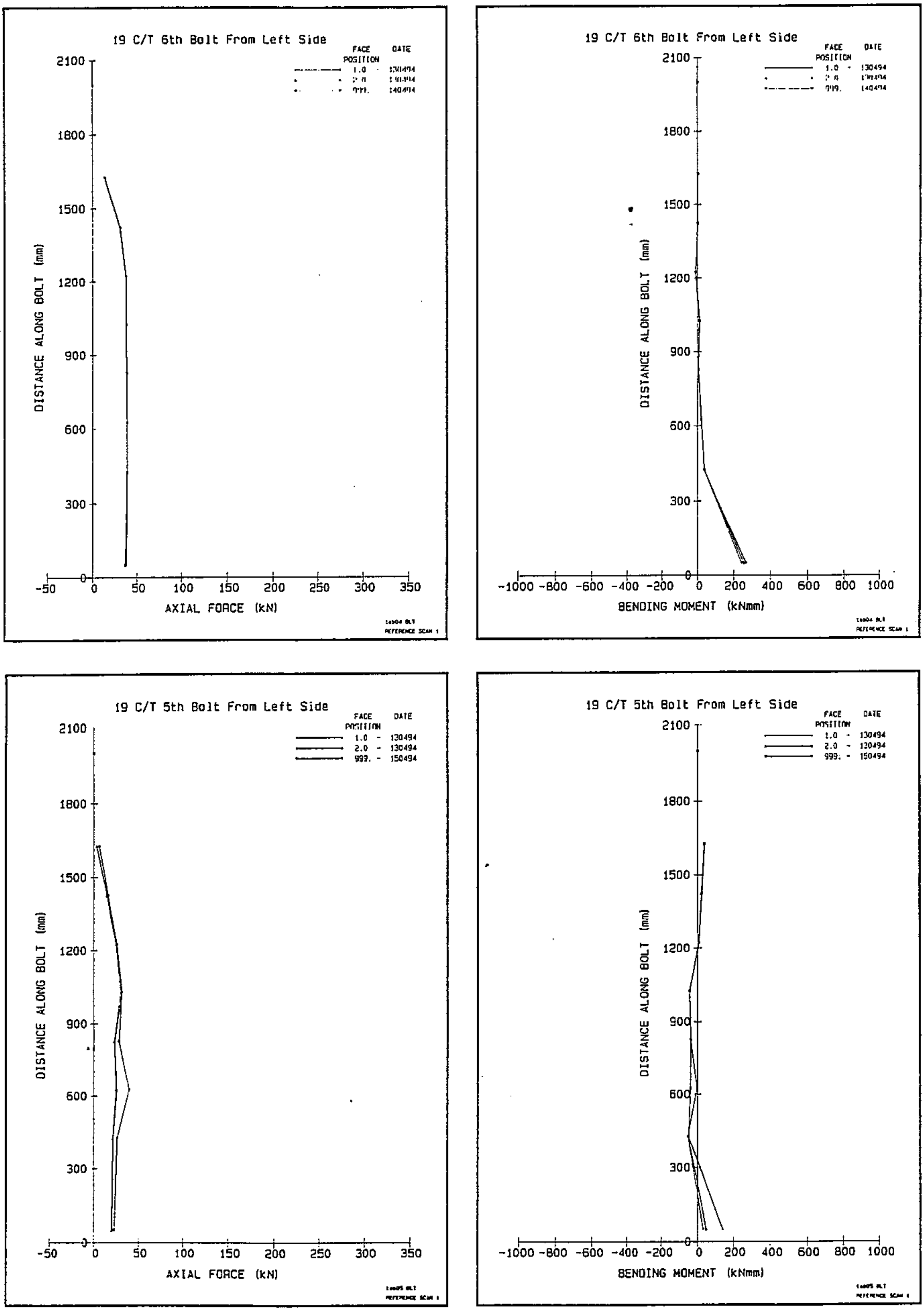
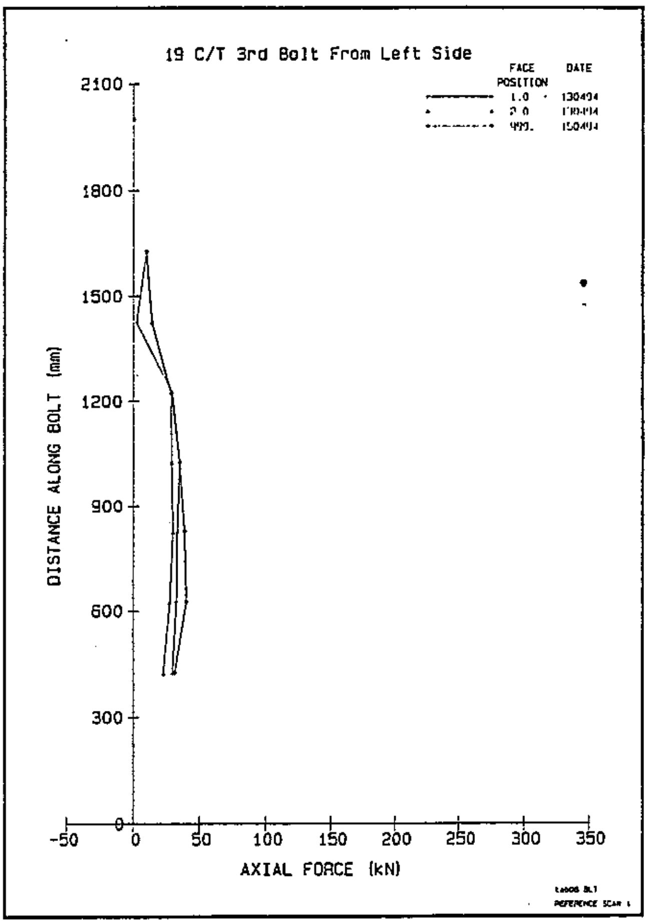
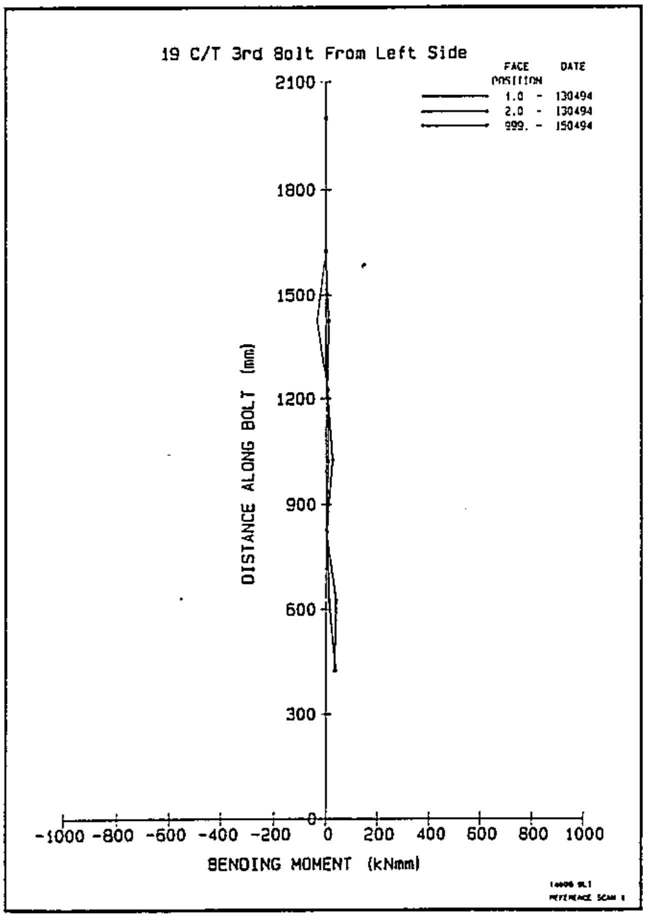


Figure 22 TAHMOOR COLLIERY
Axial forces and bending moment developed in the bolts for various face advance positions – 19 C/T.



19 C/T 3rd Bolt From Left Side
FACE POSITION
DATE
1.0
130494
2.0
999.
150494
DISTANCE ALONG BOLT (mm)
2100
1800
1500
1200
900
600
300
0
-50
0
50
100
150
200
250
300
350
AXIAL FORCE (kN)



19 C/T 3rd Bolt From Left Side
FACE POSITION
DATE
1.0 - 130494
2.0 - 130494
999. - 150494
DISTANCE ALONG BOLT (mm)
2100
1800
1500
1200
900
600
300
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
BENDING MOMENT (kNmm)

Figure 22

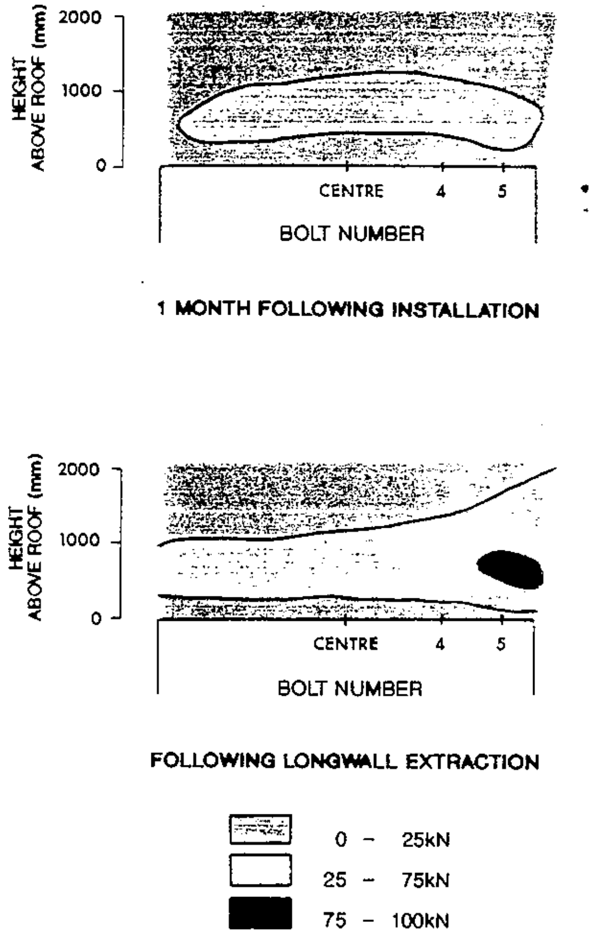


Figure 23(a) **TAHMOOR COLLIERY**
Distribution of axial forces contoured above the roadway – modified bolting pattern, 18 C/T.

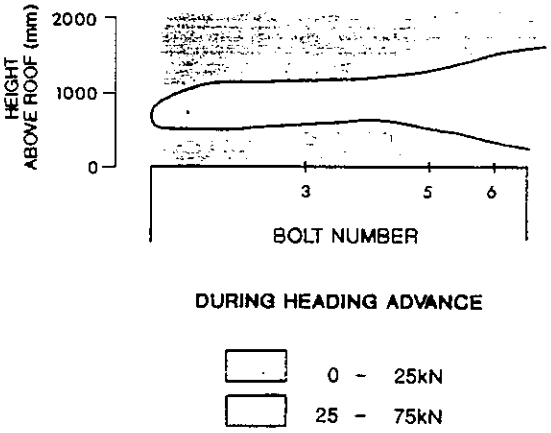


Figure 23(b) **TAHMOOR COLLIERY**
Distribution of axial forces contoured above the roadway – standard bolting pattern, 19 C/T.

9. ASSESSMENT OF BOLTING OPTIONS FOR A PLACE CHANGING OPERATION

9.1 Introduction

The efficiency of the place changing mining method is dependent on the ability to cut out relatively large distances (10m to 14m) to minimise the number of miner and bolter flits. The large cut out distances impose the constraint of delayed placement of reinforcement, the impact of which may severely limit the viability of this method in areas of poor roof conditions.

The feasibility of this method was investigated for a colliery which was experiencing problematic roof conditions.

The primary aim of the field based measurement and monitoring program was to improve the current reinforcement system and to evaluate the areas in which delayed placement of roof bolts would not restrict the place changing system.

The investigation included the evaluation of high capacity roof bolts and the use of stress control methods to maintain roof stability.

9.2 Background Geotechnical Information

An idealised geological roof section is shown in Figure 24. The existing reinforcement pattern comprised 4 x 1.8m long AH grade roof bolts (13.5 tonne yield, 24 tonne capacity) with a strap spacing of approximately 1.2m.

The reinforcement performance and roof behaviour for the existing reinforcement design was measured through use of instrumented bolts and extensometry installed at the face and monitored with face advance and time.

The general style of roadway deformation is shown in Figure 25a,b.

The displacement which occurred in the roof for various face advance positions is shown in Figure 25 which includes a plot of displacement and average bolt load versus face advance and time. The results indicate that within the initial 15m face advance the total roof displacement was 15mm. The range of bolt loads developed in response to this displacement was 8 tonnes to 14 tonnes.

With further face advance and time the roof displacement approached 65mm and the bolt forces developed were well above the onset of yield for the AH grade bolt.

The initial monitoring results indicated the general mechanism of roadway deformation of strain developing along specific horizons prone to failure due to horizontal overstressing. Whilst excessive roof displacement and overloading of roof bolts developed over a period of time, the initial roof movement and bolt loading was moderate.

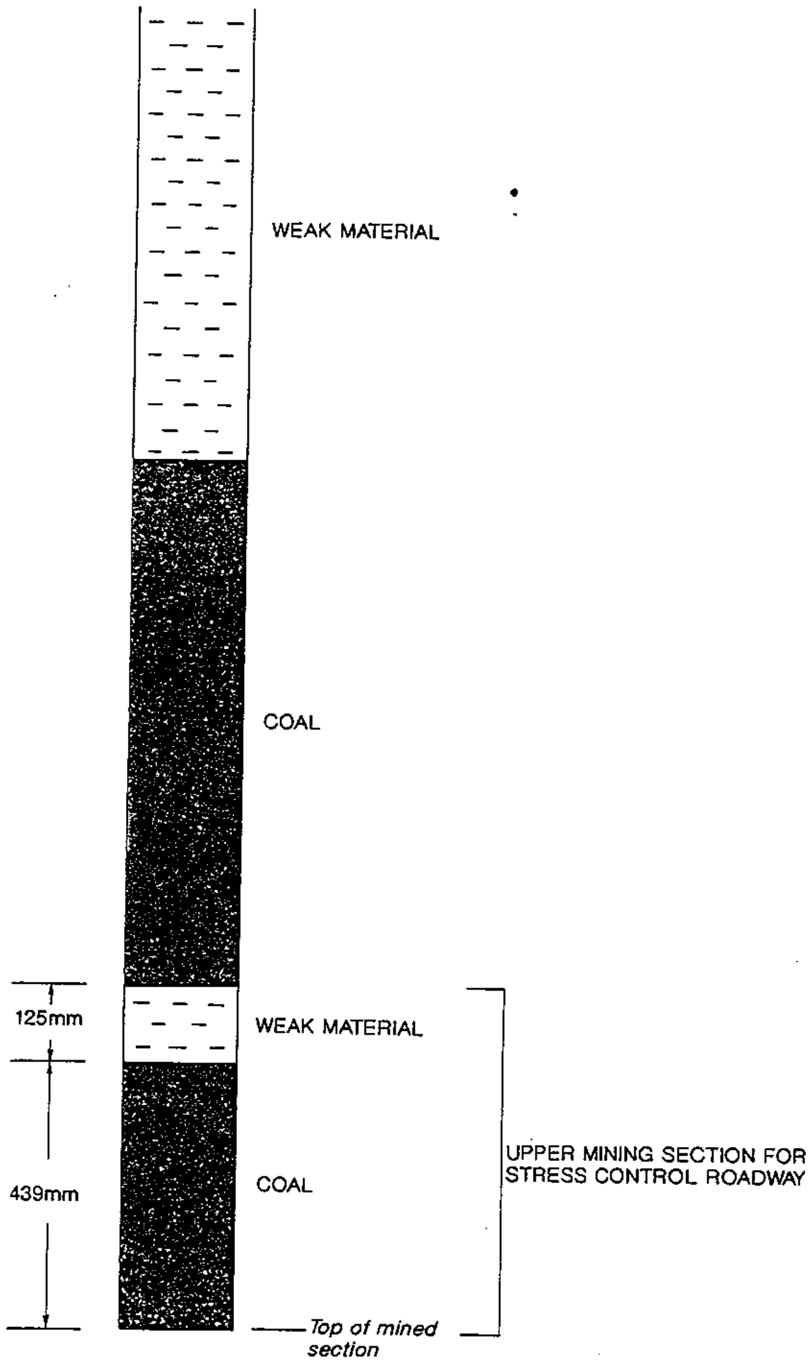
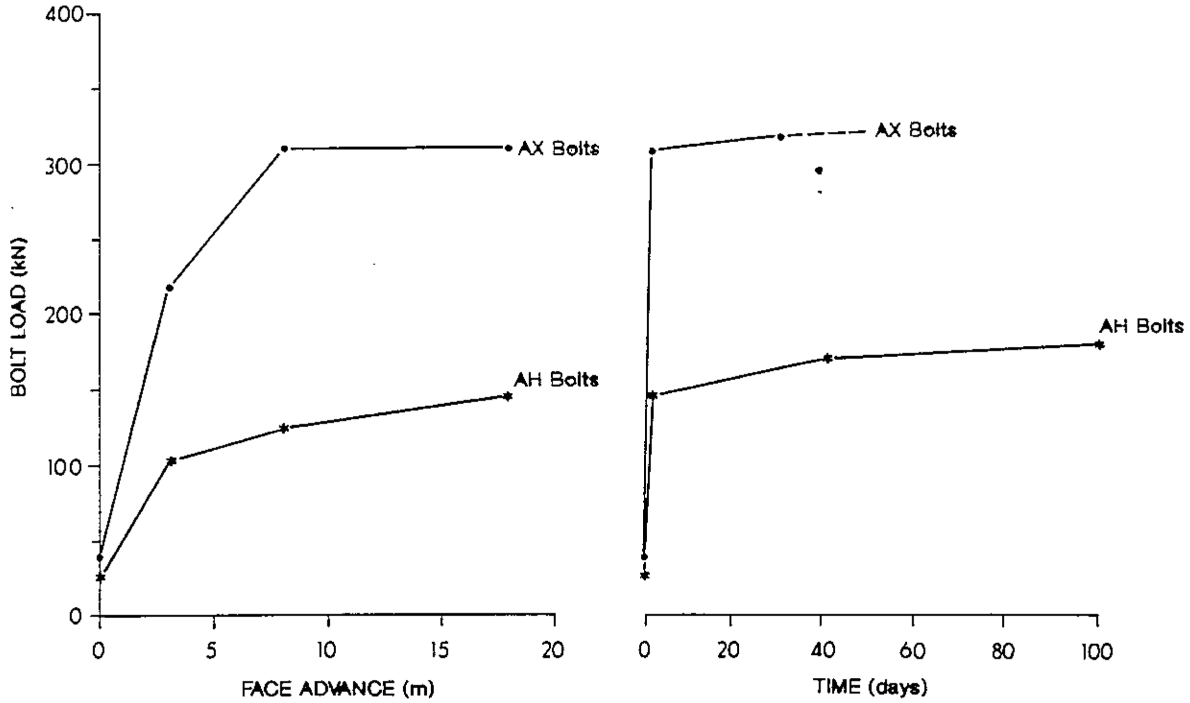
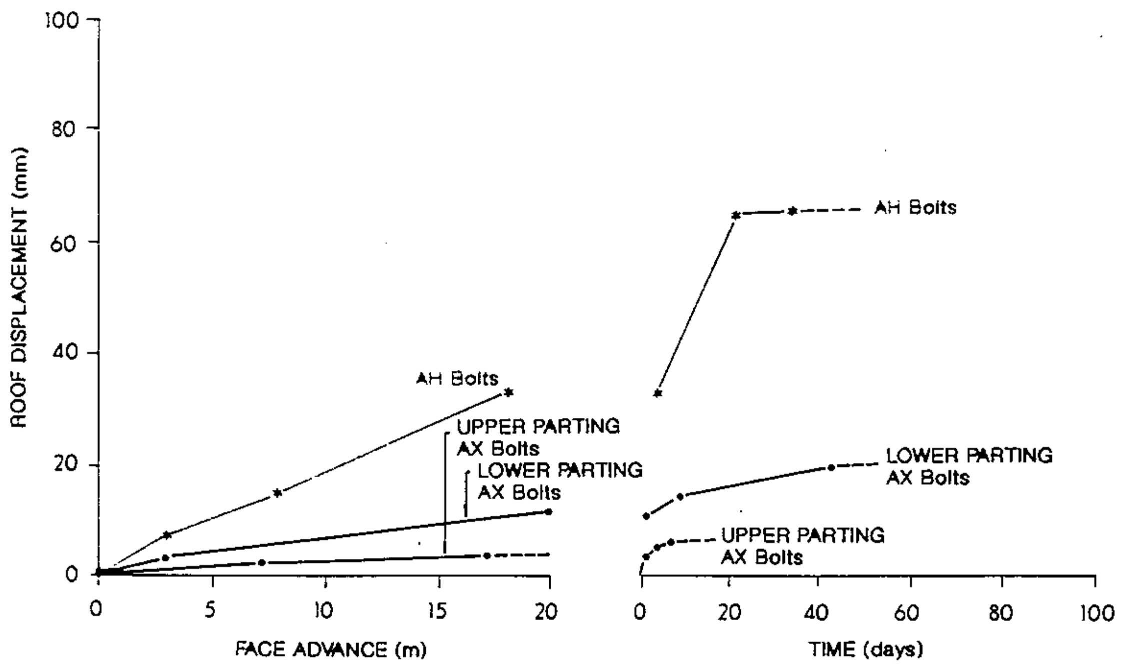


Figure 24 PLACE CHANGING COLLIERY
Generalised geology section.



a) Reinforcement



b) Roof displacement

Figure 25 PLACE CHANGING COLLIERY
Reinforcement and roof displacement versus face advance and time.

The primary modification made to the bolting design was the use of the higher capacity X grade bolt (22 tonne yield, 30 tonne capacity). It was envisaged that the provision of higher bolt forces would provide increased confinement to the deforming units and arrest progressive deformation.

9.3 Comparative Performance of X Grade Bolts Versus AH Grade

The performance of the X grade bolts and impact on roof behaviour was investigated using instrumented bolts and extensometry.

The comparative roof displacement developed in the roadway using X Grade bolts versus the previous bolting system is shown in Figure 25. The results indicate that the total roof displacement which occurred using the higher capacity bolts during initial face advance was approximately 13mm and after 35 days was 22mm. This compares with 25mm and 65mm for the same periods using the lower capacity system.

Whilst the total roof movement was reduced through the use of the higher capacity bolts, mild to moderate guttering was still evident in the first driven roadway of the 7 heading layout. The continued presence of guttering may still have created problematic roof conditions in the place changing method.

A further reduction in roof deformation was investigated using stress control methods.

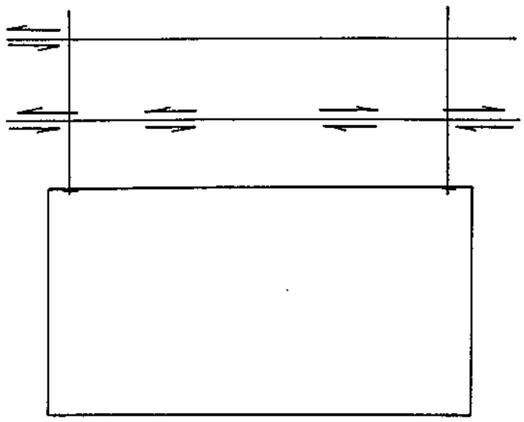
9.4 Effect of Stress Control on Roof Deformation

The principal of stress control is primarily to reduce the magnitude of horizontal stress imposed on specific roadways. The general method typically employed is based on the controlled softening of the first driven roadway which provides a stress relief shadow through which successive roadways are driven.

Whilst the general method would provide improved conditions in the second and subsequent driven roadways, the first driven roadway may have still required bolting at the face to maintain stability. This would impose limitations on the place changing method.

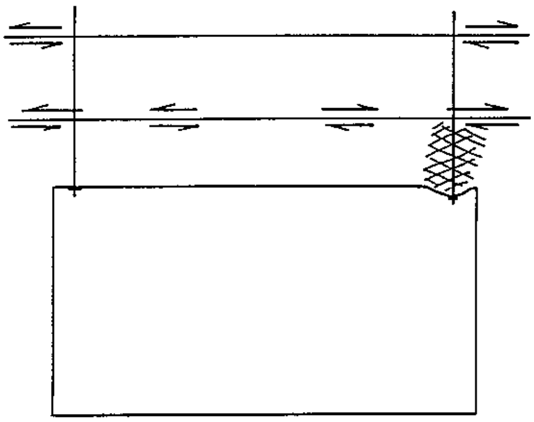
The general mechanism of roof behaviour described previously and shown in Figure 26 indicated that shear movement was occurring along the weak bedding interfaces which subsequently caused the lower roof to gutter.

An investigation was conducted to determine the effect of changing the mining horizon of the first driven roadway to the lower weak interface. It was envisaged that the shear movement along this interface would be increased and thereby provide some relief of the horizontal stress to adjacent roadways. In this way, the horizontal stress relief would still be provided to adjacent roadways without severe deformation experienced by the first driven roadway. The general approach is shown in Figure 27.



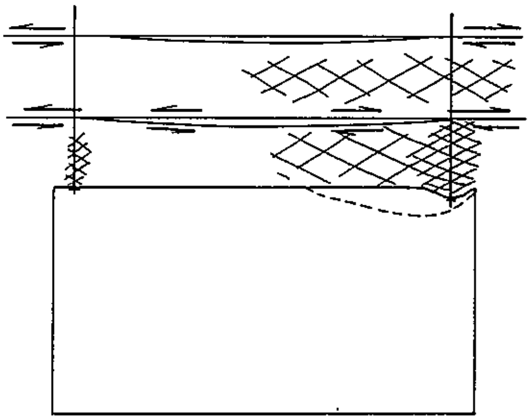
ROOF BEHAVIOUR STAGE 1

- SHEAR ALONG CLAYSTONE CONTACTS
- NO VISIBLE SIGNS
- APPROXIMATELY 5mm OF ROOF DISPLACEMENT



ROOF BEHAVIOUR STAGE 2

- GUTTERING EVIDENT
- FAILURE OF COAL AS STRENGTH EXCEEDED 20mm



ROOF BEHAVIOUR STAGE 3

- DELAMINATION
- CONTINUED DEVELOPMENT OF GUTTERING
- GUTTERING DEVELOPES ON OPPSITE RIBSIDE 40 – 60mm

Figure 26 General model of failure pathway of roof behaviour.

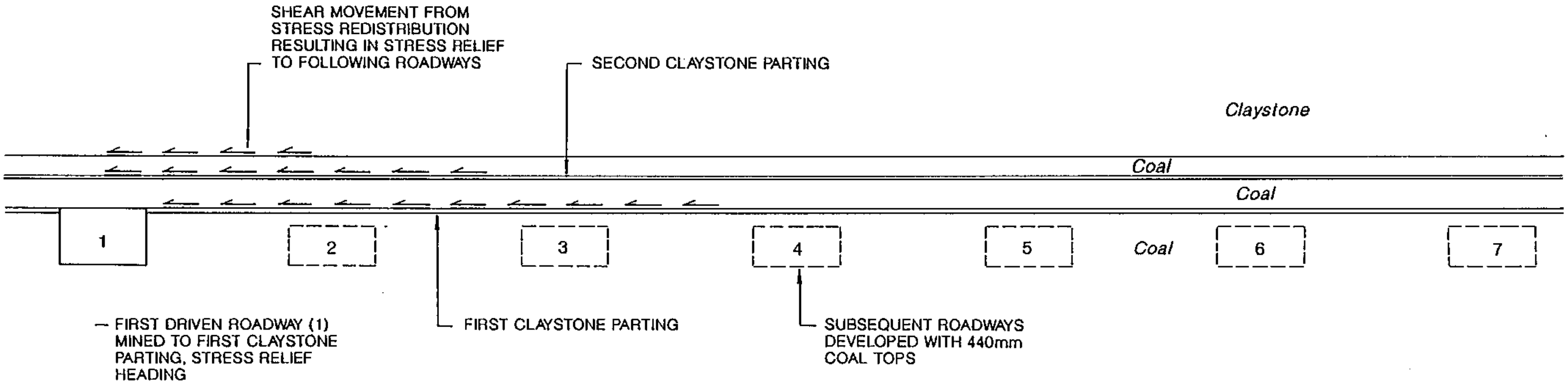


Figure 27 General method of stress control.

Field monitoring of the first driven roadway mined to the new horizon was conducted using extensometry.

The results are shown in Figure 25 which indicates that the first driven roadway experienced less than 10mm of total roof movement. The visual condition of the roof in this roadway was excellent with no guttering evident. Subsequently driven roadways were mined to the usual parting and also experienced excellent driveage conditions as a consequence of the stress relief provided by the first driven roadway.

On the basis of the improved roof conditions achieved through utilising higher capacity roof bolts and employing a stress control method, the impact of delayed bolt placement was minimised.

Subsequent monitoring of the place changing method using tell tales (tell tales are described in Section 10) has confirmed that the impact of delayed placement of the roof bolts has not been detrimental to roof stability given the improvement in the reinforcement design and use of stress control method where considered appropriate.

9.5 Overview of Results

Delayed placement of roof bolts would be expected to have a negative impact on reinforcement performance. This investigation indicated that the negative impact may be overcome through optimisation of other aspects of the reinforcement design to compensate for the impact of delayed placement.

In this instance, improvements in roadway stability were achieved through use of higher capacity roof bolts and utilisation of a method of stress control.

10. DESCRIPTION OF TELL TALE MONITORING SYSTEM

10.1 Dual Height Tell Tales

Tell-tales are a low cost, easily installed monitoring device which will provide a **continuous visual indication** of the roof conditions (see Figure 28). They are capable of resolving roof strata movement within two horizons - typically within the bolted roof horizon and above the roof bolts. The sum of these gives the total roof displacement. The accuracy of the tell tale is 1mm.

Tell tales are typically installed in a 5m - 8m long, 27mm - 29mm diameter hole. They can be easily and quickly installed by operators on a systematic basis.

The role of tell tales is not as a replacement for extensometers, but rather to provide an early indication to mining officials and operators of changing roof conditions, thereby allowing early remedial action to be taken. Tell tales are used in a system, together with detailed monitoring and modelling, to indicate levels of remedial action and response

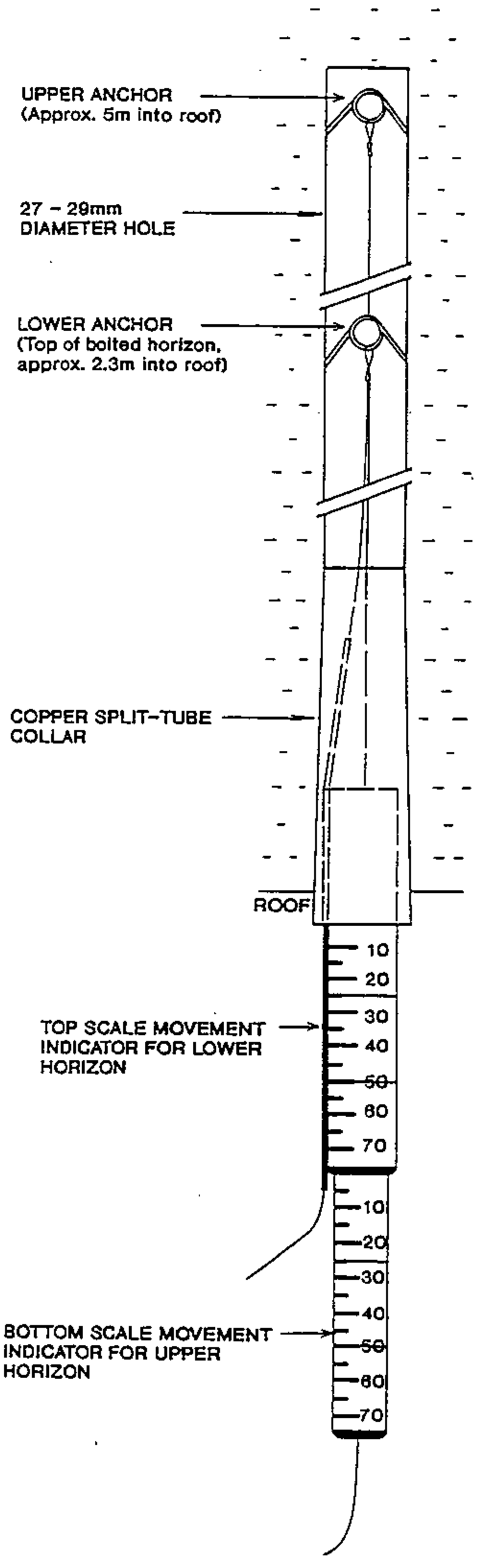


Figure 28 Dual height Tell-tale.

required based on the roof strata deformation exceeding pre-defined limits. Tell tales can also indicate the requirement to undertake more detailed investigation where atypical behaviour is observed.

The systematic use of tell tales can provide increased workforce confidence in the roof bolting support methods.

10.2 Use of Systematic Monitoring and Response Systems

In order to ensure that the application of roof bolting support systems occurs under controlled conditions, it is recommended that roof support monitoring and response systems are developed and implemented. A general model for this approach is shown in Figure 29. The model incorporates the key processes of:

- **Design** of rock bolting support systems.
- **Implementation** of rock bolting support systems.
- **Monitoring** of roadway behaviour and support system performance.
- **Response** procedures for variations in roadway conditions.

As shown in the model, the recommended approach is a continuous cycle of investigation, analysis, design review and verification.

The purpose of this management system is to provide the management, supervisors and operators with a set of guidelines for each mining section which systematically monitor the roof conditions and allow the supervisors and operators to quickly respond to variations in ground conditions by changing the amount of roof support installed. The regular use of tell tales is a key element in these monitoring systems.

As shown in Figure 29, the results and experience from previous investigations would be used to establish system guidelines. The system guidelines would be continually evaluated and updated by monitoring results and experience.

11. OVERALL CONCLUSIONS

1. A methodology to assess the suitability of reinforcement patterns and installation procedures has been developed utilising a combination of computer simulation and field measurement.

2. In the sites studied it was found that:-

a) delayed bolting (cut and flit) or sequenced bolting practices are feasible under ground conditions where roof strata remain essentially unfractured by development mining.

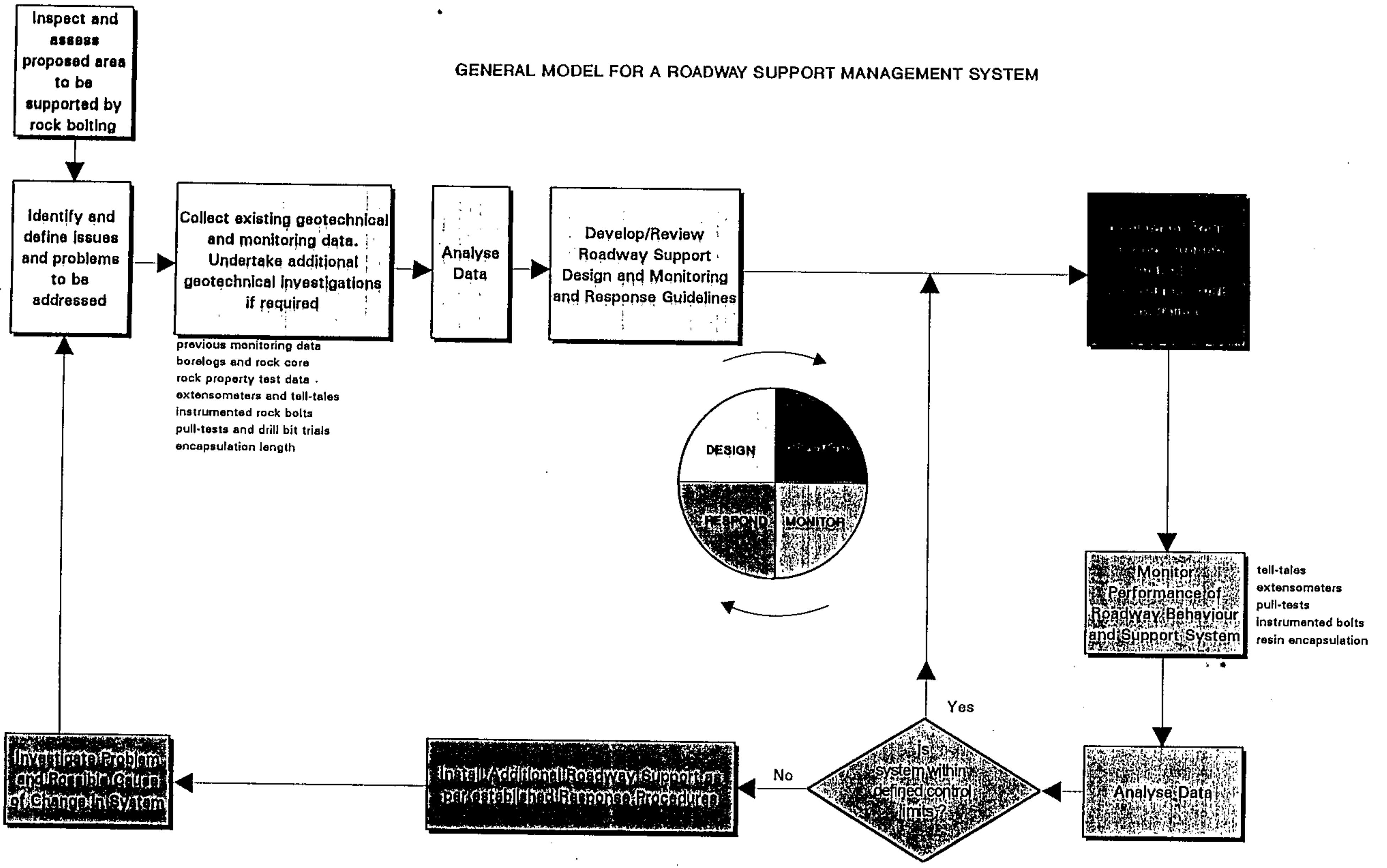


Figure 29 Recommended approach for the use of rock bolting support systems.

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b) The occurrence of roof failure at the face which then rapidly increases in height as the roadway is advanced, requires a complete bolting sequence at the face to optimise roadway stability.

3. Hybrid bolting systems utilising roof bolts and strand or cable bolts can be assessed on a site by site basis by the use of the simulation method applied.

4. A monitoring procedure utilising simple and easily installed "tell tales" can be used to routinely determine if the roof behaviour is within desired limits appropriate to the bolting patterns used.