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Investigation of Feather Edging Caving and Bolted Breakerlines in Split and Lift Pillar Extraction at Blue Mountains Colliery, NSW

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FOREWORD

This report has been prepared by Dr John Shepherd (Shepherd Mining Geotechnics) in collaboration with the UNSW Mining Research Centre as part of a UNSW research project entitled *"Elimination of goaf encroachment into the working place"* funded by the Joint Coal Board Occupational Health and Safety Trust.

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SUMMARY

A geomechanics investigation at Blue Mountains Colliery near Lithgow (NSW), in a pillar extraction production panel (6 North), operating a traditional split and lift method, has shed new light on the caving process in the Lithgow Seam strong sandstone roof.

A 3-stage roof fracture process eventually leads to low angle caving that produces feather edges resulting in breaker prop overruns. These fracture stages are "driven" by a relatively long-standing goaf, gradually sagging across a saucer-shaped area and elevating lateral compressive roof stresses close to the edges of the solid pillars. The sandstones fail in low angle shears that form the feather edge failures highly prone to topple breaker props and commonly encroach by 5-15m into the working places.

As an experiment to determine if this feather edging could be stopped, two sites were prepared using 2 rows of 4 x 1.5m long roof bolts. The "front" (goaf side) row was fully resin grouted and instrumented. The results from both sites was definite: the bolts generated significant loads (up to 18.9 tonnes) and cut off the shear fracture/feather edge propagation. At each site the standard pattern of breaker props (set behind the bolts) remained unharmed during the main caving event.

This Report contains a detailed account of the underground work performed, discusses the results and concludes that feather edge goaf caving can be safely controlled.

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I. Blue Mountains Colliery Support Rules

II. Strata Control Technology instrumented rock bolts information sheet

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IV. Sites 1 and 2 convergence monitoring details

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1.0 INTRODUCTION

Feather edge caving is a widespread phenomenon affecting full pillar extraction methods under "massive" sandstone roofs. It invariably results in the goaf encroaching into the working area and it is characterised by low angle roof fracturing that forms an irregular breaker line and "thin" slabs of sandstone detaching. The feather edge process favours strong sandstone roofs containing various types of geological features.

The School of Mines (1993) reported that this type of caving occurred in South Africa and the USA and attention was drawn to it by Williams (1973) in the Newcastle Coalfield of NSW and by Shepherd and Chaturvedula (1991).

Various mine managers have found feather edging puzzling, but they recognised the risky nature of sandstone roof detaching suddenly in thin slabs at the goaf edge and often over-running the working place.

Collieries affected by such goaf edge conditions in the recent past and present include the Lake Macquarie (Newcastle) district mines eg. Cooranbong, Wyee and Munmorah and Western Main and Blue Mountains Colliery in the Western Coalfield at Lithgow. The latter colliery provided suitable goaf edge conditions for this study (see Figure 1 for location after Yoo *et al,* 1995). Typical examples of feather edging at Blue Mountains are shown in Plate I.

McCosh *et al* (1989) in South Africa reported a bord and pillar study comparing timber versus roof bolt breakerlines where they successfully extracted 500 pillars with roof bolts as the sole means of breakerline support. It was found that operators tended to install the breakerlines right on the goaf edge, and in these cases the bolts were taken out by the goaf. This problem was overcome by moving the breakerline bolts 1.5-2.0m back. This study was important and was carried out on the basis of trial and error, there being no rock mechanics instrumentation installed at the sites.

1.1 Goaf edge support practices

This outline is confined to mentioning temporary supports set at the goaf edge either in the split or in the lifts as retreat takes place.

A variety of extraction methods are currently in use in New South Wales (see Figure 2) including split and lift (Figure 2a), pocket and fender, a variation of split and lift (Figure 2b), Wongawilli (Figure 2c) and modified Wongawilli (Figure 2d).

Temporary support consists of either timber props or mobile roof supports (MRS's).

Timber props

These have been the traditional passive support method since pillar extraction began. Prop diameter is generally in the 100-200mm range, irrespective of height. Props are set at the previous goaf edges and generally after each lift (see Figure 2a). The details are specified on Manager's Support Rules as at Blue Mountains Colliery (Appendix I).

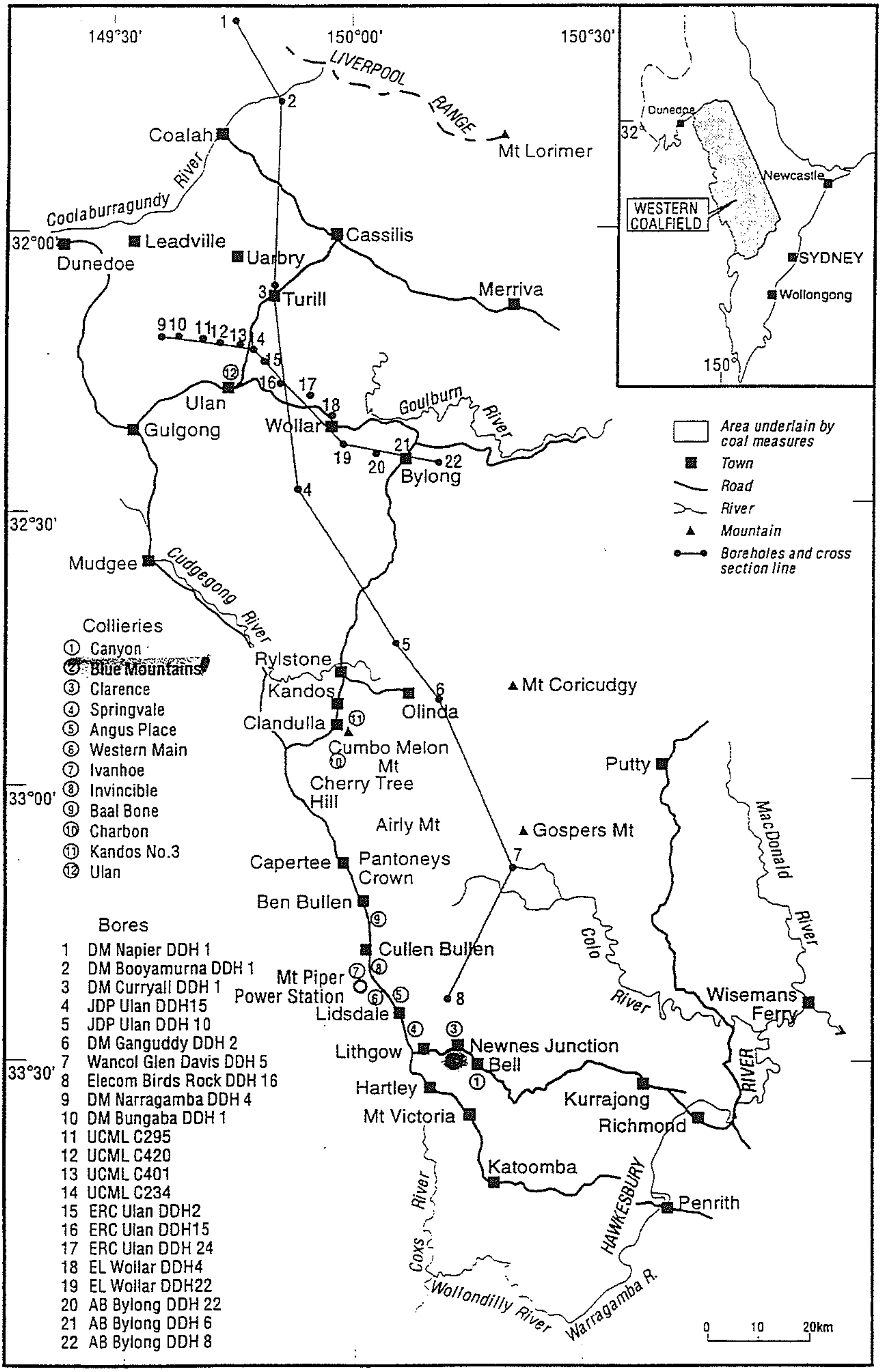


Figure 1. **Location of Blue Mountains Colliery, Western Coalfield, NSW (after Yoo *et al*, 1995)**

Plate I

Examples of Blue Mountains Colliery feather edges in 6 North Panel: top left at 18 c/t, top right at 19 c/t,and bottom at 22 c/t, showing stepping and low angle cave.

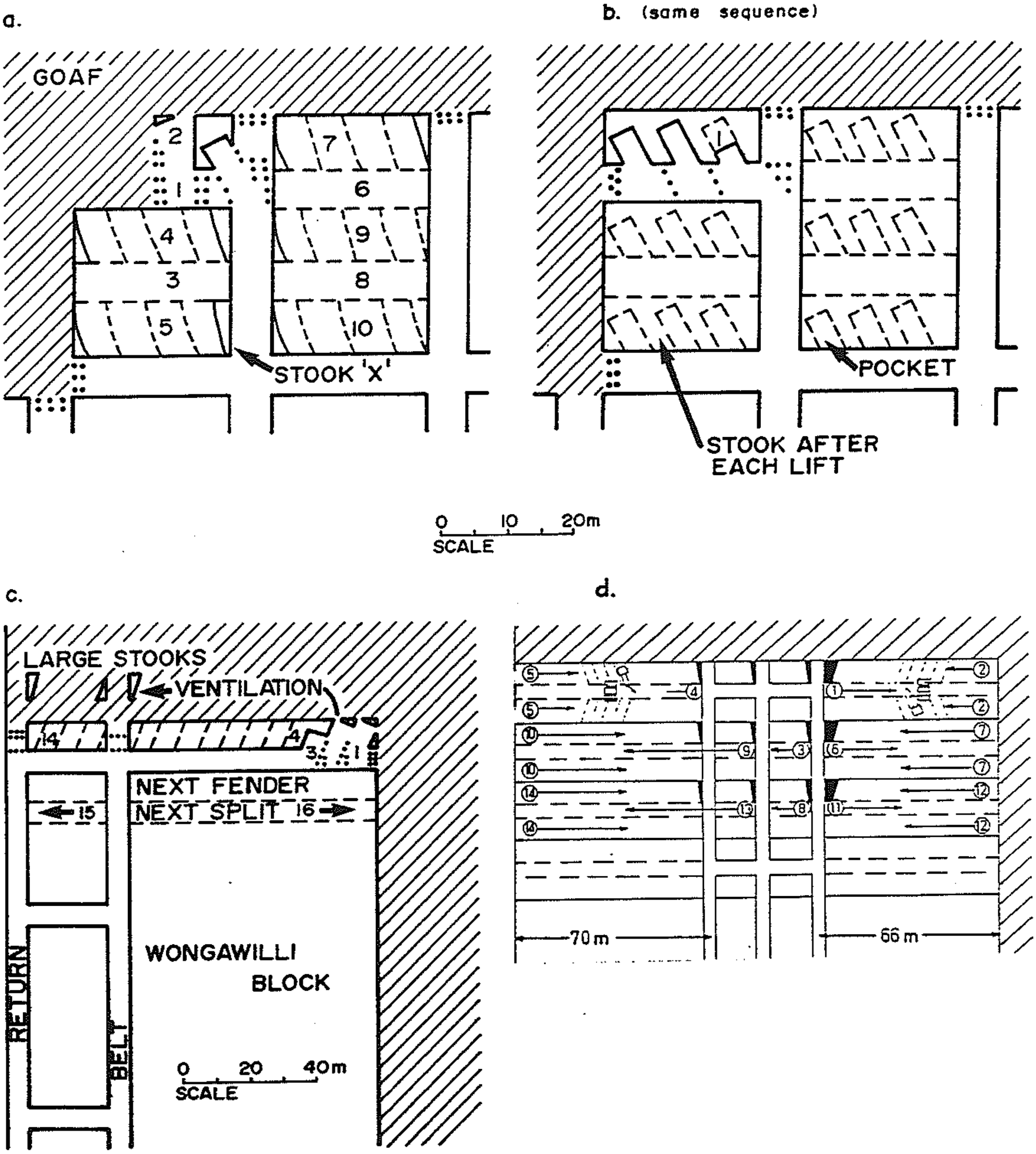


Figure 2 PILLAR EXTRACTION LAYOUTS
a. Open Ended Lifting
b. Pocket and Fender
c. Wongawilli
d. Modified Wongawilli

At some mines a row of props is set out into each lift known as a "fingerline" (School of Mines, 1993 and 1994). These are used at Blue Mountains Colliery. Timber is still used at pillar extraction mines as a "barrier" against existing goaf edges where the last fender was removed. Generally 2 or 3 rows of props with 4 or 5 per row are used. They are sawn to length on site with straight ends and wedged usually at the roof. Props are still widely used as an indicator of roof to floor convergence and for detecting standing goaf and goaf edge closure preceding falls. The average strength of NSW hardwood props is not known, but some measured to failure in the goaf edge gave approximately 30 tonnes (Shepherd and Lewandowski, 1994) and one took 50 tonnes up to cracking.

Mobile roof supports

MRS's (also known as BLS's or ABLS's, derived from those manufactured by the Voest-Alpine Company) came into common usage in the late 1980's in Australia. Previous use in South Africa was followed here with their introduction at several mines and they were quickly evaluated by ACIRL (Brown and Geddes, 1989 and McCowan and Brown, 1990).

Early experiences were favourable and modifications quickly followed to strengthen the canopy linkages and side curtains because of the impact damage of large sandstone roof slabs. The USA coal industry also quickly adapted their use in 1988 and both ABLS and Fletcher sourced units have been used. Recently Hewitson (1995) reviewed their usage in the USA.

Local experience showed that MRS's were best suited to the long fender method (Wongawilli) to minimise flitting time. In nearly all cases they have been used for temporary support during lifting off either one side (2 supports) or both sides (left and right with 3 supports), the latter in the United States known as the "Christmas tree" layout (Chase *et al*, 1997). At Clarence Colliery (The Staff, undated) two ABLS`s were used for lifting off and two were "parked" against the goaf instead of timber props.

Recently at NIOSH in Pittsburgh, the ABLS and Fletcher supports were tested for support performance (Barczak and Gearhart, 1997). Both types were rated at 600 tonnes each, but provide an active roof support of 500 tonnes, and their operating vertical stiffnesses found to be 3,002 kN/cm (ABLS) and 2,140kN/cm (Fletcher). In contrast, the stiffness of a local prop measured in situ by Shepherd and Lewandowski (1994, p.128) was only at best 3.17 t/mm, whereas the ABLS support in a test rig provided 30 t/mm! - an order of magnitude better than the timber.

2.0 AIMS OF STUDY

The geomechanics investigations at Blue Mountains Colliery are a part of a wider study by the School of Mining Engineering into goaf edge encroachment during pillar extraction.

This study is based on the installation of instrumentation into normal production panel pillars where the caving is prone to feather edging.

There were 2 main objectives:

1. to attempt to determine a feather edge caving mechanism
2. to install roof bolted breakerlines to determine if the feather edge could be controlled and prevented from encroaching outbye.

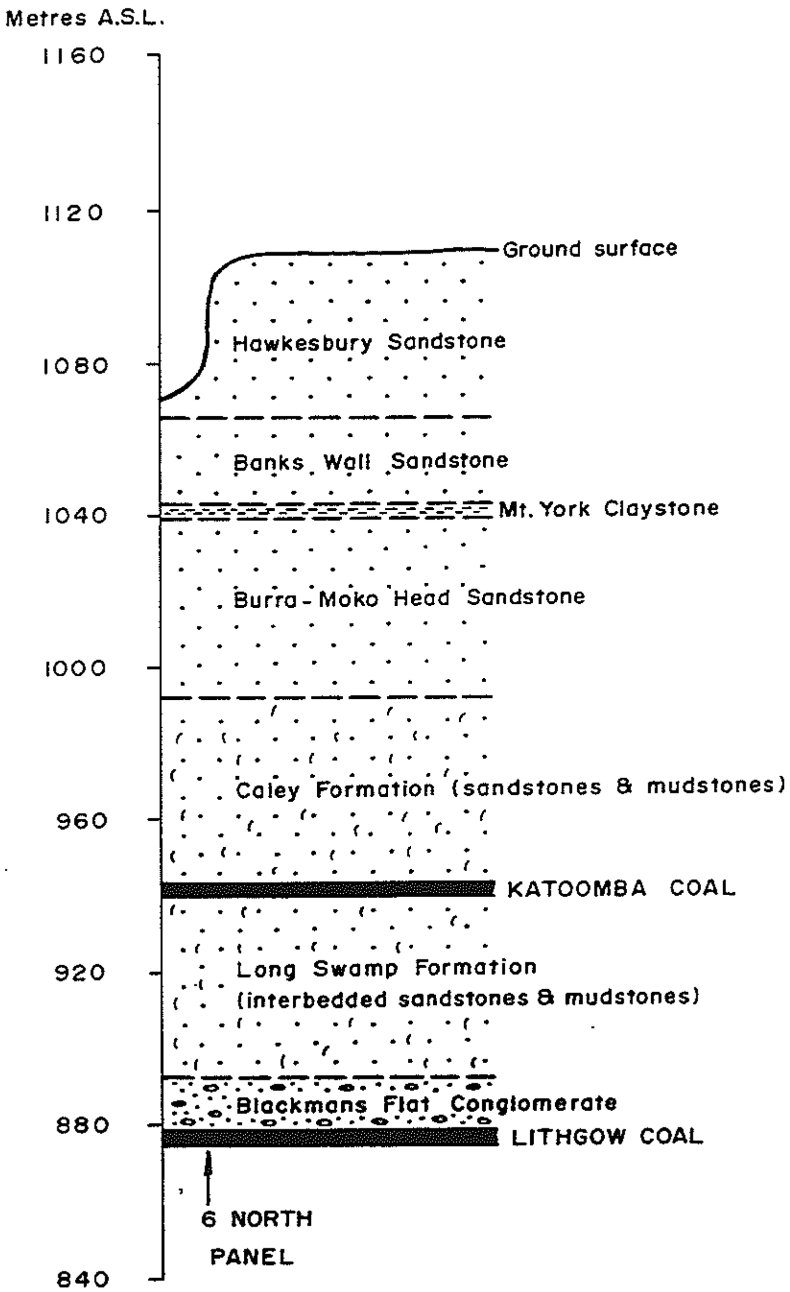


Figure 3 GENERALISED STRATIGRAPHIC SECTION FOR BLUE MOUNTAINS COLLIERY, 6 NORTH PANEL

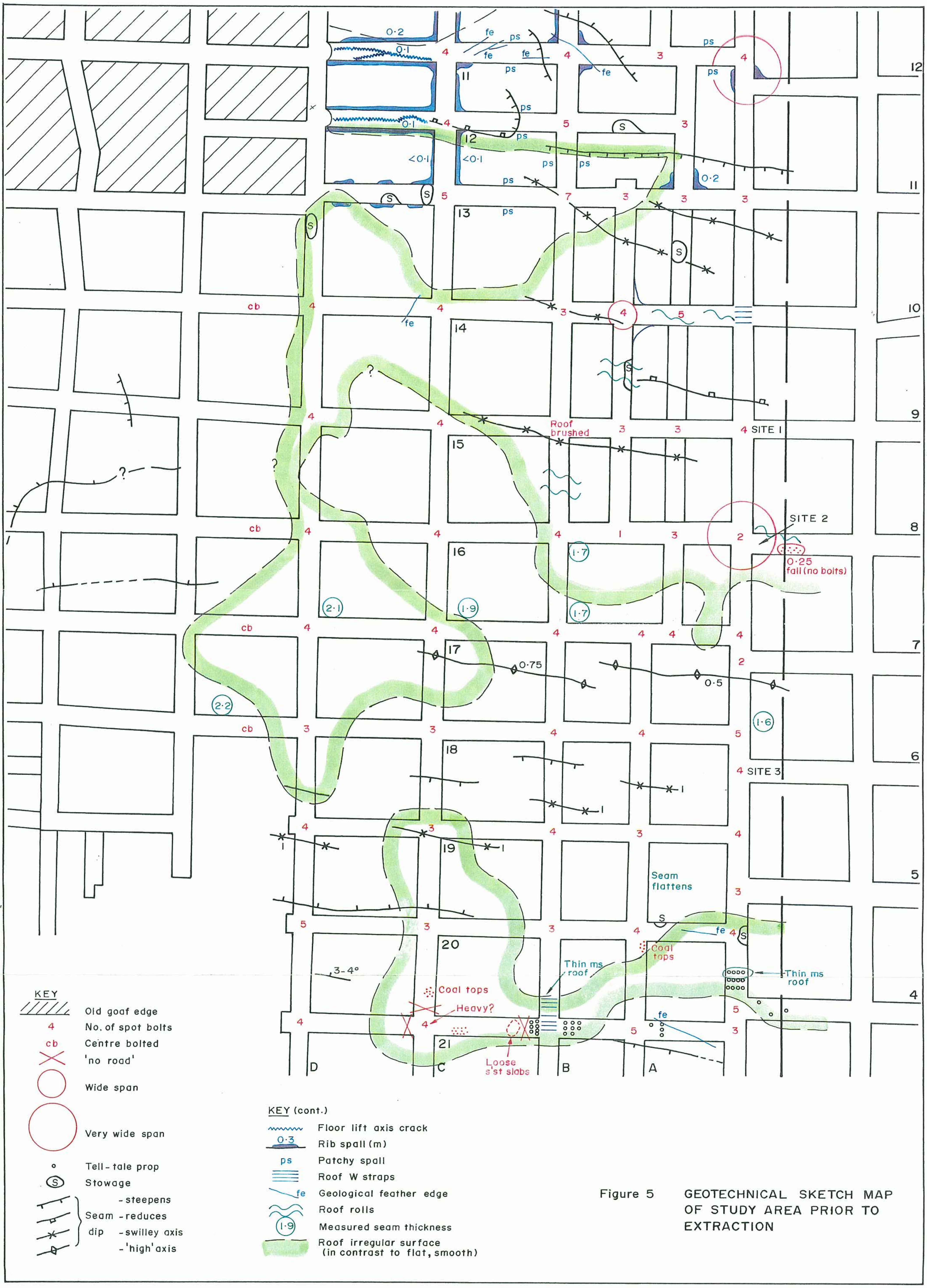


Figure 5 GEOTECHNICAL SKETCH MAP OF STUDY AREA PRIOR TO EXTRACTION

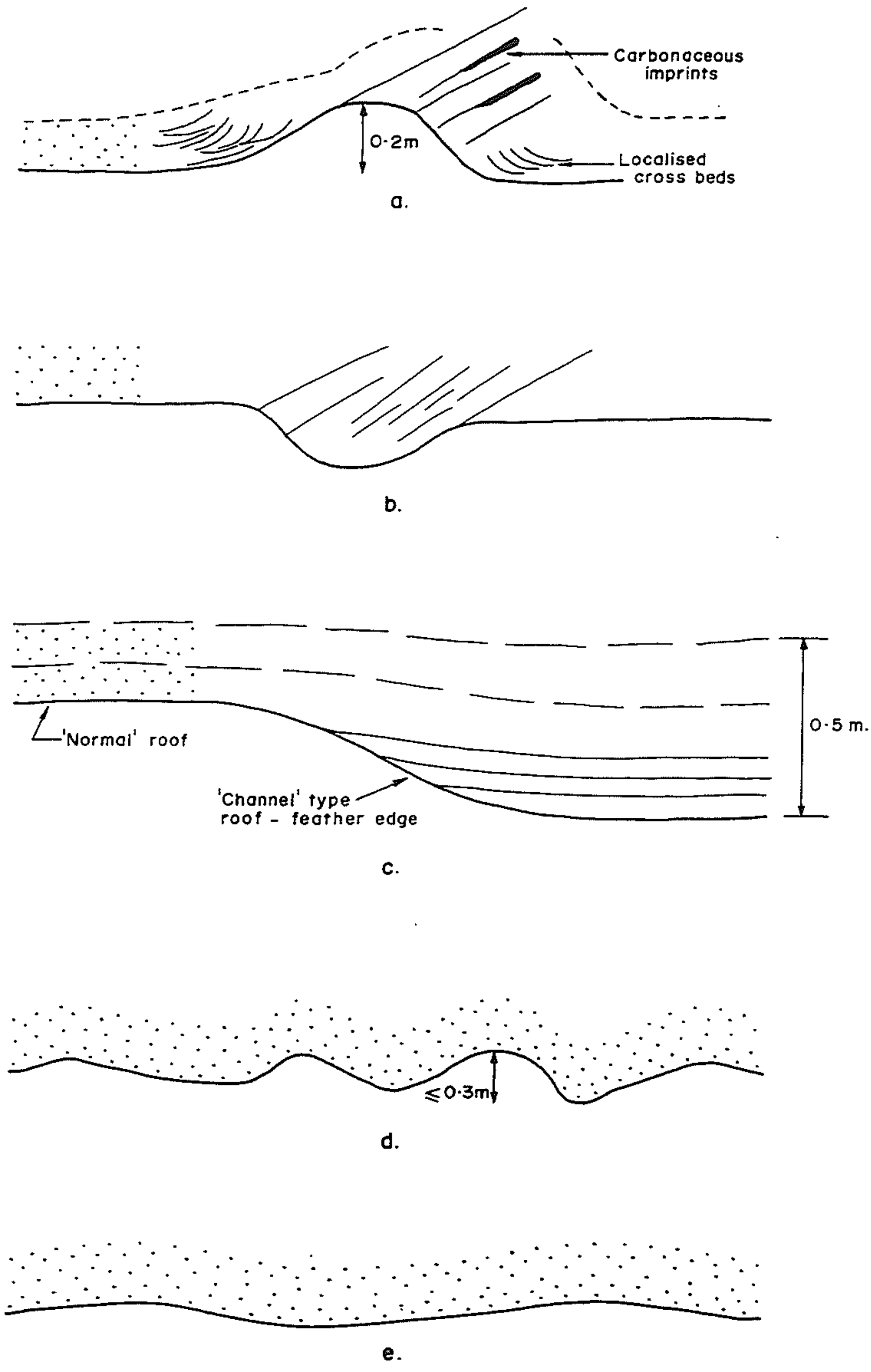


Figure 4 LITHGOW SEAM - SANDSTONE ROOF CONTACTS
a. fluted roof b. mini channel
c. channel type d. undulating / irregular
e. flat (smooth)

3.0 GEOLOGICAL SETTING

The Blue Mountains Colliery extracts the Lithgow Seam in the Western Coalfield under a strong sandstone roof facies, almost identical to that found when Western Main Colliery operated to the west of Lithgow. This roof type is typical for the Seam to the south of the Lithgow/Lidsdale Seams convergence zone (Shepherd and Temby, 1997). The overall strata section at the Colliery to the actual ground surface is shown in Figure 3.

The first 5m of "immediate" roof strata are not massive in the strictest sense because they contain abundant bedding surfaces, sandstones of variable grain size up to conglomerate (present in thin 50-100mm thick) beds and thin (mm scale) carbonaceous layers and partings irregularly distributed. Common types of sedimentary features in this roof are shown in Figure 4 and they form local protrusions or indentations usually <200mm deep at the roof horizon. They are indicative of the presence of localised inclined bedding and cross beds. As such if the bedding partings crack during extraction, they can be regarded as "geological feather edges" as distinct from stress-driven failures discussed below.

3.1 Panel geology

The Panel workings were mapped prior to extraction starting for the purposes of the mine management's application to the Department of Mineral Resources under Section 138 of the Coal Mines Regulation Act. A map at a scale of 1:1000 was produced, a portion of which is given in Figure 5 representing the study area. A number of features were recorded by walking around each pillar and consist of:

- seam dip changes and swilleys
- presence of either planar (regular) roof or undulating/rolling roof
- geological feather edges
- rib spall or scaley/cracked roof
- wide intersections
- number of spot bolts (with butterfly plates) per intersection

The following points can be made:

1. Sites 1 and 2 were in areas of undulating roof
2. Site 3 was in planar roof
3. Swilleys are present in both roof types, but were absent at the 3 sites
4. Geological feather edges were absent from all 3 sites
5. The Seam was 1.7m high at the 3 sites and the dip gradient was very slight to the ENE, 1 in 64 at sites 1 and 2 and 1 in 44 at site 3.

Experience in 6 North Panel showed that almost every goaf fall produced low angle stress-driven feather-edging that over-ran the breaker props at the goaf-edge by a distance up to 15 meters.

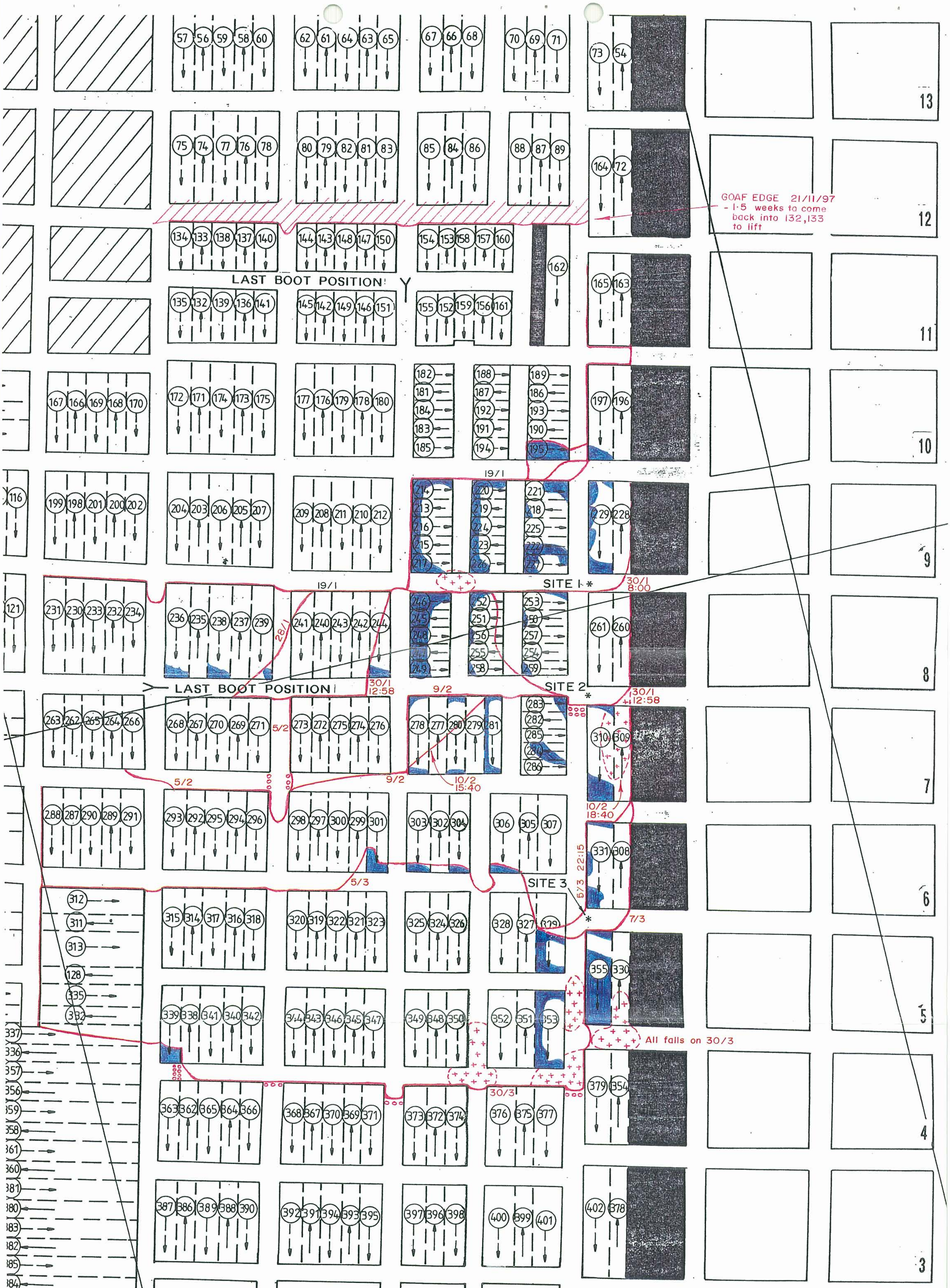


Figure 6 SUCCESSIVE GOAF EDGE POSITIONS WITH RESPECT TO SITES 1-3

4.0 MINING METHOD AND INVESTIGATION METHODOLOGY

4.1 Mining method

Split and lift pillar extraction has been practised for many years at Blue Mountains. 6 North Panel was fairly typical in this regard except for some smaller pillars along the eastern side of the Panel.

Sequences are arranged to "fit" the old pillars as in Figure 6. Each pillar is extracted, row by row with splits generally driven perpendicular to the goaf edge. However, splits driven parallel to the goaf edge are also used and it appears that either way is satisfactory.

Details of the Manager's Support Rules are in Appendix 1. Pillar splits are not roof bolted and roof stability relies on self support and brattice props. Five bolts and butterfly plates are installed on each outbye intersection and props are set after each lift is taken, including a fingerline. Depending on the fender width, the lifts are fully open-ended or holed at one side. Stook "x" has a minimum frontal width of 0.5m and it has not to be reduced.

As a general rule, caving is delayed, typical of sandstone roofs. One to two pillar areas of standing goaf is often present, so that in a panel like 6 North, only 2 or 3 falls will occur as the row is extracted. Initial caving is not high, possibly a maximum of 3-4m and takes an unusual form with low angles and dome-shaped cavities (fully described below).

The Panel and layout dimensions are summarised in the following list:

- panel width (W) : 145m, nominally
- cover depth (D) : 229 – 237m
- W:D : ~0.62
- extraction (and seam) height : 1.6 - 2.1m (1.7m at study sites)
- pillar sizes : various centres as follows, 37.5 x 35m, 37.5 x 20m and 30 x 17.5m (because of old splitting)
- fender width : 6.5 - 7.0m
- bord width : nominally 6m
- equipment used : Joy 12 CM/6 and 22 SC shuttle cars
- roof bolts : Celtite G7, 330mm point resin anchor, flat plates, 1.5m long and butterfly plates

4.2 Nature of investigations

Three sites were chosen along the eastern edge of the Panel. This edge was the most suitable because it survives as a goaf edge long after extraction, protected by solid pillars (see Figure 6). Previous observations in the Panel had also shown that feather edge caving was common, virtually in every pillar row.

By the time this study was underway, the Panel had retreated from 22 C/T back to about 11 C/T. therefore, as good a goaf as possible had formed prior to the start of investigations.

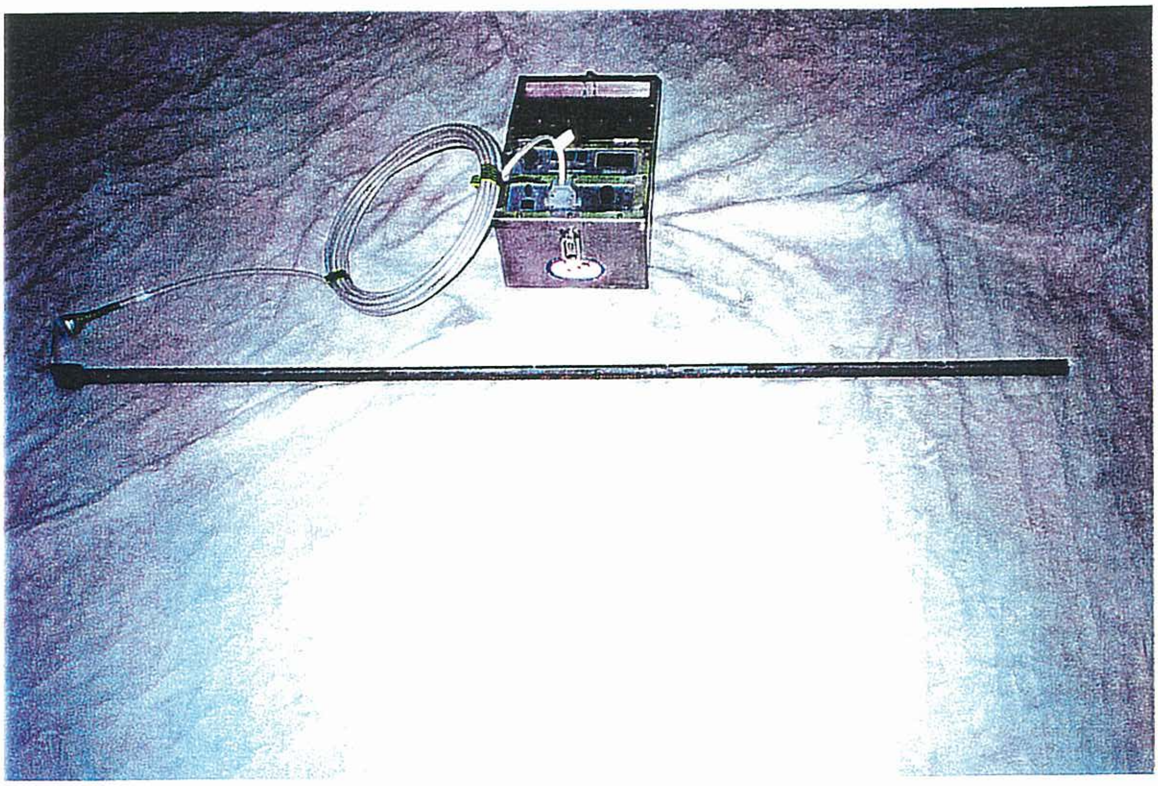


Plate II

Instrumentation used: Top left to right, tube shear, convergence rod and resistance wire extensometer; Bottom, SCT instrumented bolt and the readout unit.

Geomechanics work was started in November 1997 and continued until May 1998. The methodology was:

1. To make detailed observations frequently as caving occurred
2. To set up 3 sites for instrumentation to obtain empirical data about roof displacements and bolt behaviour.

The linkage between observations and measurements is a powerful research tool for finding out goaf edge strata mechanics. Instrumentation was installed about 2 pillar lengths outbye of the goaf edge and monitored as the extraction passed. Frequent visits recorded the position and nature of the caving edge.

4.2.1 Type of instrumentation used

Telescopic convergence rods, resistance wire roof extensometers, tube-shear rods and fully strain-gauged roof bolts were used. All of these except the tube-shear rods were operated through remote cables about 25m long from a safe station (see Plate II).

Convergence rods

These rods are based on the Uni-Rod pogo sticks and were described originally by Shepherd *et al* (1990). A 50kΩ, rotary, resistance potentiometer is installed into the rod and monitored using an approved (IS) multimeter. The potentiometer and pulley are designed to provide a range of 199 k.ohms or 199 mm of travel closure.

A rod is generally set as soon as a lift is finished to measure the closure through to caving.

Roof extensometers

Resistance wire units originally developed for goaf edge measurements (Shepherd *et al*, 1990) were used in this study. Lightweight, stainless steel wires are connected to 6 x PVC "shuttlecock" type anchors and at the roof a tubular PVC mount station contains extension springs and 6 x 50kΩ rotary potentiometers with pulleys. As with the convergence rods, a range of 199 k.ohms and 199mm of travel is attainable with 1mm accuracy.

The extensometer is installed into a 55mm diameter hole drilled with lightweight rods from a Cram bolter.

For ease of reading the rods and extensometer, a switchbox is connected up at the safe station.

Tube-shear rods

These rods are made from 1.5m lengths of white, electrical PVC conduit with a transverse bolt fitted to contact the mine roof. A black marker pen is used to add reference marks each 0.1m along the rod. Each rod fits into a bolt hole drilled for the purpose. The idea behind these is to have a cheap deformable tube inserted into the roof where it is likely to shear during the caving. The black on white scale markings are easily seen in the goaf after caving.

Strain gauged roof bolts.

These are a strain gauged mild steel, 1.5m long bolt with 9 pairs of gauges bonded into long slots along the bolt. Strain values are measured using a strain bridge monitor (refer Appendix II). Computer analysis of the data enables various parameters to be evaluated: axial force, axial strain, bending movement and bending strain. This study is the first application of instrumented bolts to breaker line formation.

4.3 Instrumentation sites

Three (1-3) quite closely spaced sites were used at 9, 8 and 6 C/T`s in order of retreat. All 3 had a relatively thin seam of 1.7m, the seam thickening progressively westwards across the Panel to ~2.1m.

Site 1.

This was located at 9 C/T (see Figure 6). The following instruments were installed:

- a roof extensometer
- 4 tube-shear rods
- 3 convergence rods

The locations of these are shown in Figure 7.

Sites 2 and 3

These sites were at 8 C/T and 6 C/T respectively (see Figure 6). Similar devices were installed consisting of:

- roof extensometer
- 2 tube-shear rods
- a bolted breaker line comprising a goaf-side row of 4 fully-encapsulated, strain-gauged bolts and 4 point anchored bolts 0.3-0.4m behind them
- various convergence rods

The details are shown in Figures 8 and 9. The bolted breakerline was placed approximately in line with the coal pillar edge with the normal 3 rows of breaker props placed about 1m behind them.

4.4 Monitoring schedule

Regular visits after the site installations were carried out depended upon the timing of the various extraction sequences. At least one visit per week was made throughout the life of the study except for the Christmas period when the Colliery was on holiday. When the final fender in each pillar row next to our sites was lifted off, continuous monitoring was performed and detailed sketch plans of the lifting process drawn up.

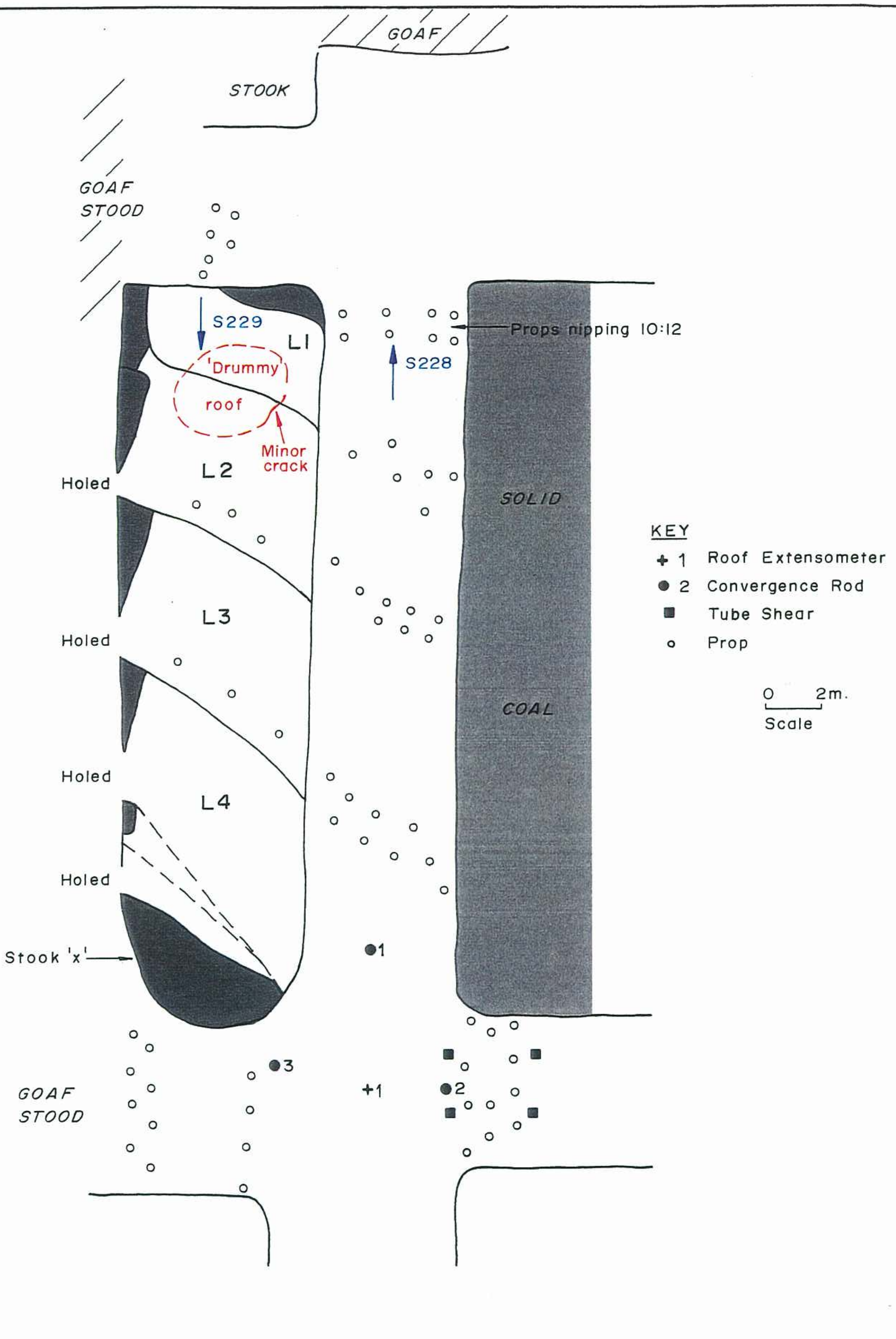


Figure 7 LIFTING BACK TO SITE 1 (Sketch map)
(30.1.98)

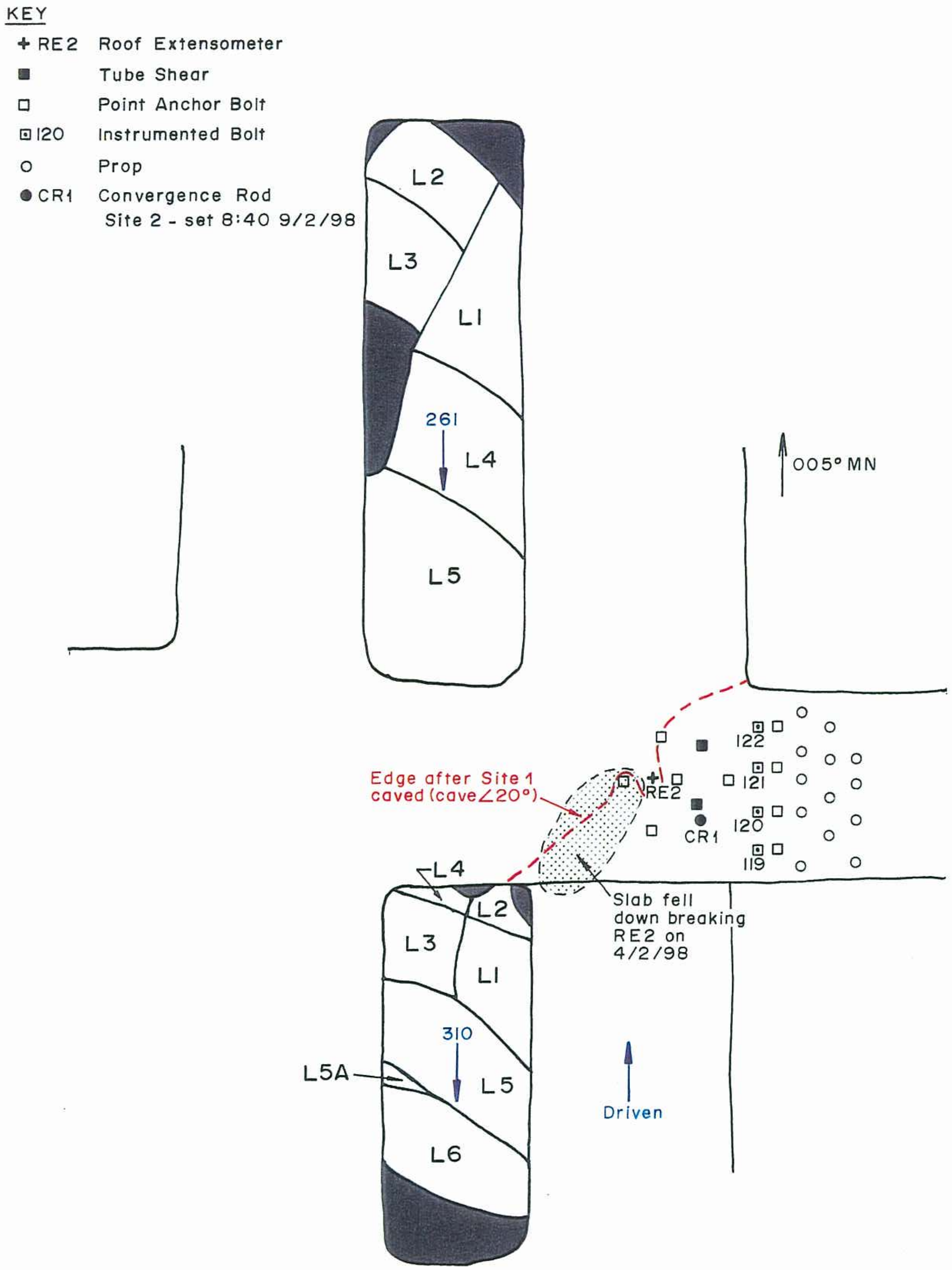


Figure 8 LIFTING IN THE VICINITY OF SITE 2 (9.2.98)

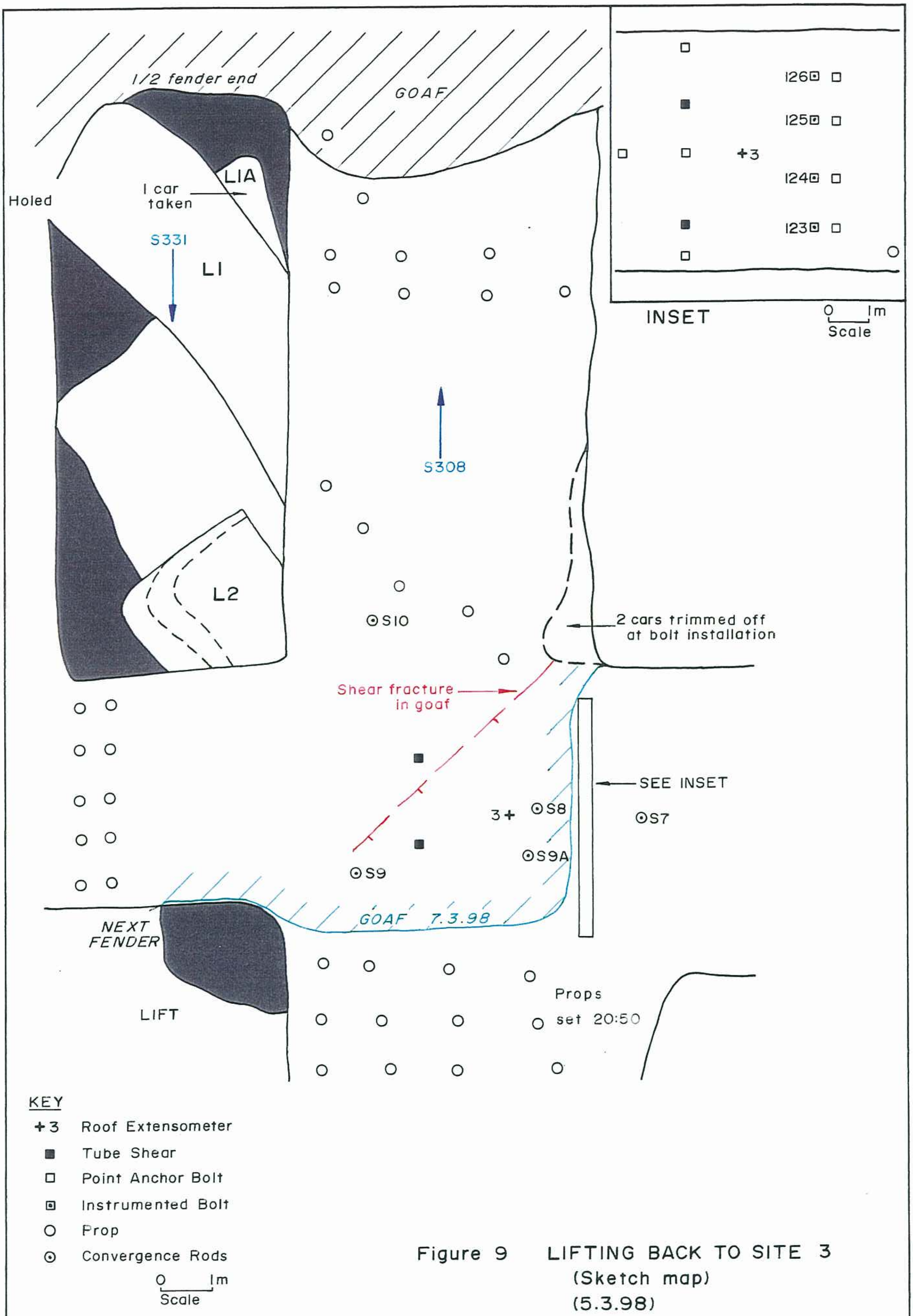


Figure 9 LIFTING BACK TO SITE 3
(Sketch map)
(5.3.98)

At most visits the goaf edge was mapped on to a 1:1000 scale plan and caving observations recorded. Discussions with the Deputies were also very useful. The various instruments were also read.

On 6 separate occasions, the goaf edge was photographed to assist in building up some knowledge of the feather edges and to make a permanent record. A SLR camera, tripod and blue-filtered wide angle lens were also used to permit timed exposures using a cap lamp.

5.0 SITES 1 AND 2 RESULTS

The overall sketch map of the progressive formation of the goaf edges and site positions is shown in Figure 6. These two sites are grouped together because the goaf hung up and when it fell, it caved both sites.

5.1 Extraction near sites 1 and 2

Site 1 was installed on 11 Dec. 1997 when the goaf edge was inbye of 11C/T, approximately 2 pillar lengths away.

The Christmas break at the colliery intervened and there was no production from 21 December to 5 January. Extraction resumed in S175 on 5 January 1998, one row inbye of site 1.

In pillar row 9-10C/T, the sequence was varied (sequences 213-227 were deleted) in the small pillars to lift them off from the old headings (see Figure 6).

In S227 a large stook was left (see Figure 6 and Appendix III, sheet 2).

After lifting S229, three convergence rods were set in the intersection at site1 and only one survived (see Figure 7).

Over the next week in the pillar row 8-9c/t up to the 30 January, sequences were changed in the small pillars as in the previous row and the following ones were deleted: 250-259. Some big stooks were left in this row (see Figure 6 and Appendix III, sheet 5).

At the end of lifting (revised S249), a pre-split was driven at S309 (to provide a wheeling road) to access lifting in S261 back to site 2 (Figures 6 and 8).

On 30 January as a consequence of lifting S261 fender, a goaf fall occurred producing dome-shaped roof cavities into site 1. This destroyed the roof extensometer and 2 convergence rods. The extensometer recorded zero displacement up to 28 January, prior to caving after the end of the last shift.

5.2 Site 1 convergence

The convergence plot is shown in Figure 10 and the details logged are in Appendix III. The final convergence rate was 2-3 mm/minute with a sustained acceleration over a period of only 1 minute before failure. Prior to this the goaf roof sagged at the start of the final lift and continued for the next ~40minutes.

5.3 Site 2 convergence

The goaf fall at site 1 "ran" southwards approaching site 2, when ~4 800m^2 of roof caved (the equivalent of 6 small pillars, see Figure 6 and Appendix III, sheet 6).

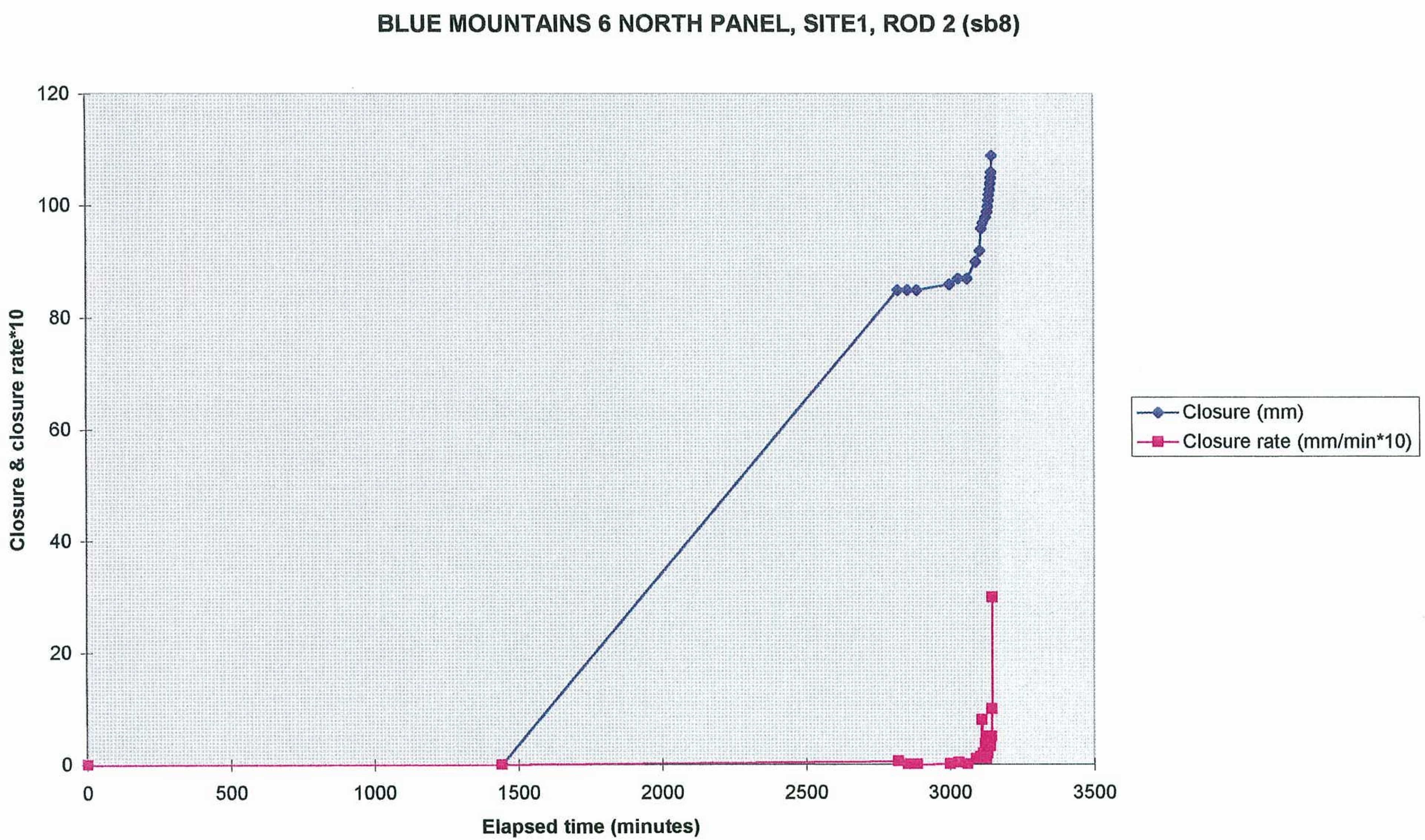


FIGURE 10. CLOSURE MAGNITUDE AND RATE AT SITE 1 PRIOR TO GOAF FALL

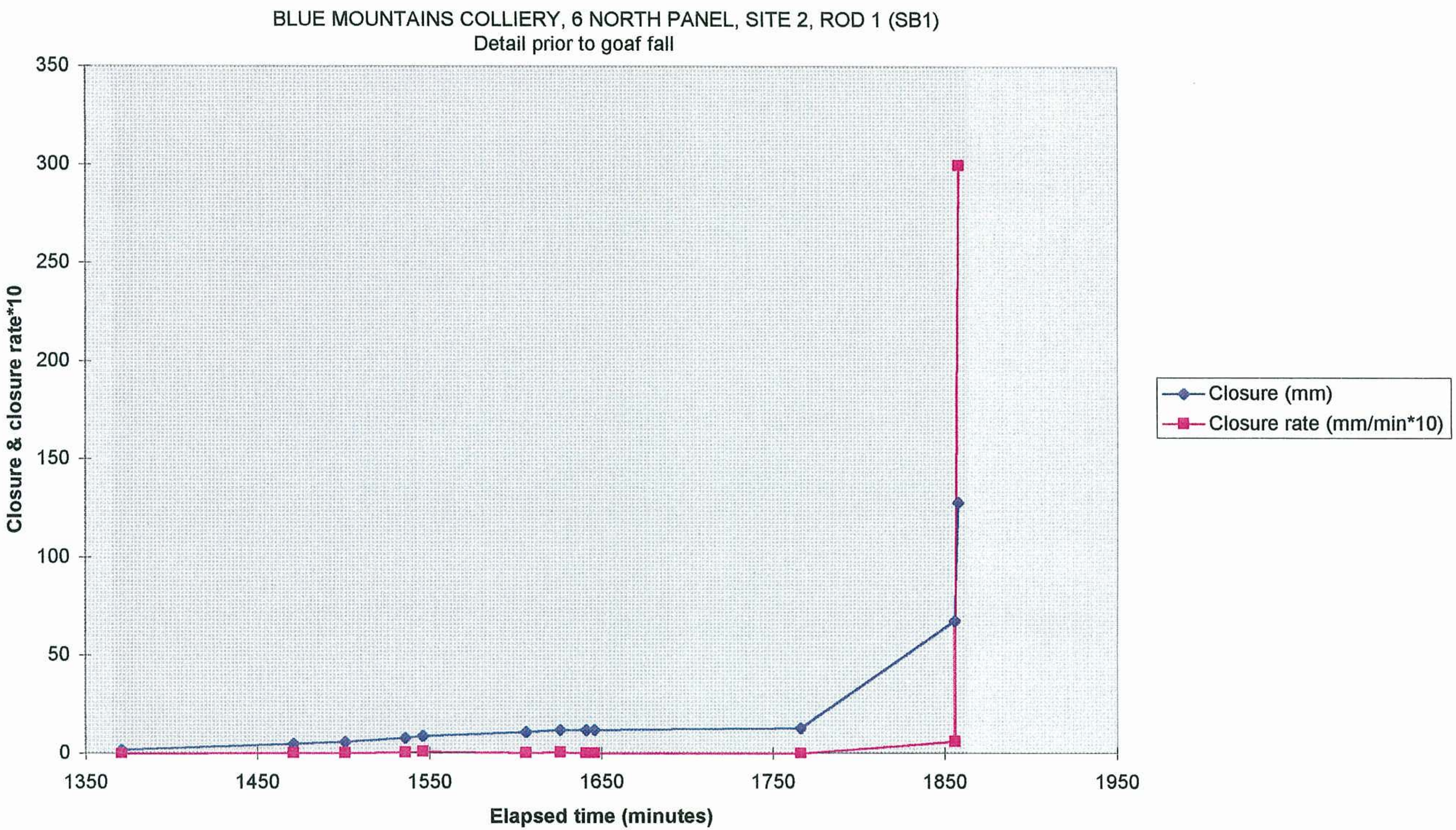
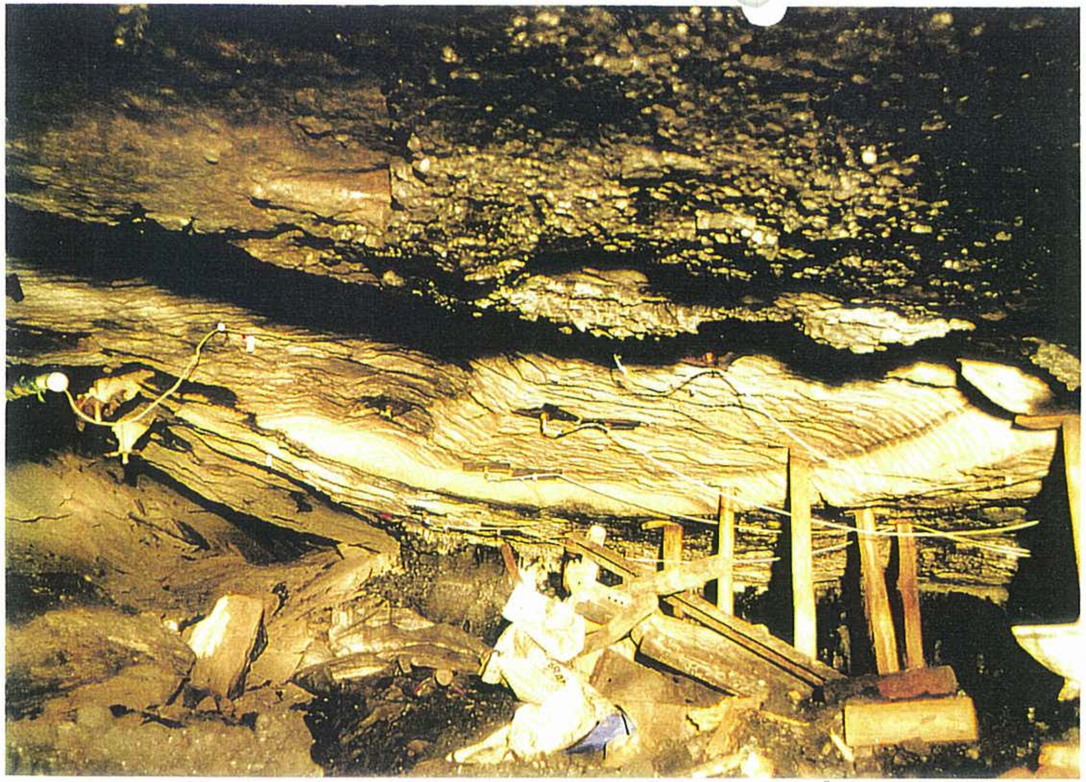
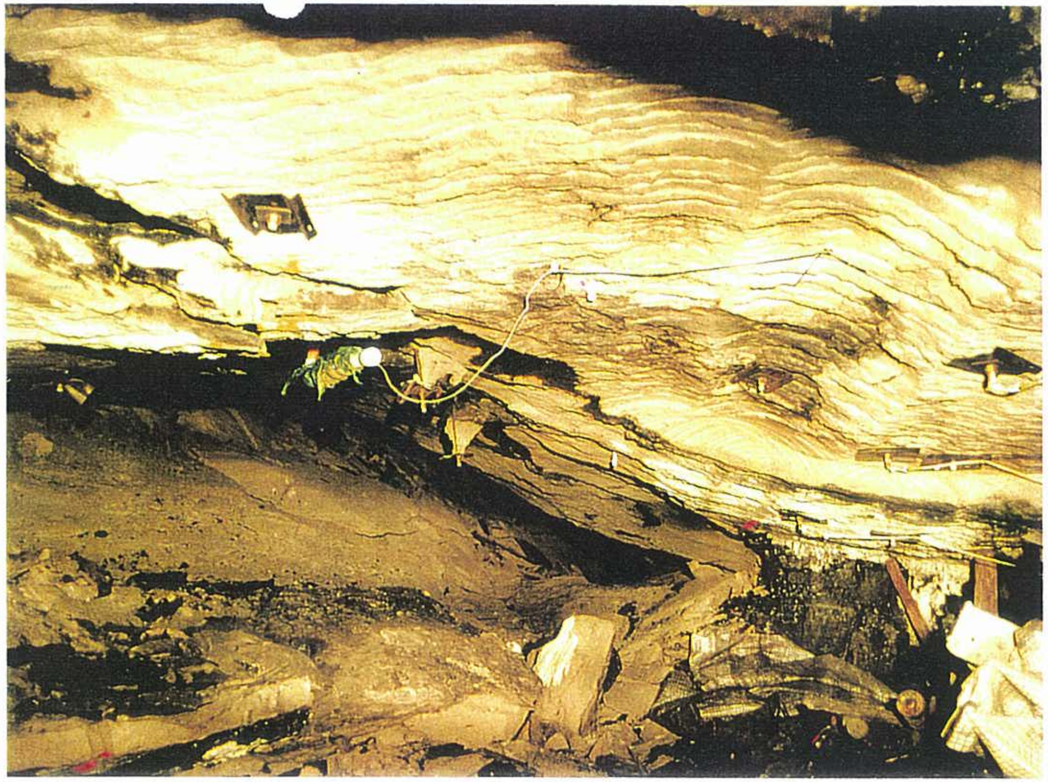


FIGURE 11. CLOSURE MAGNITUDE AND RATE AT SITE 2 PRIOR TO GOAF FALL





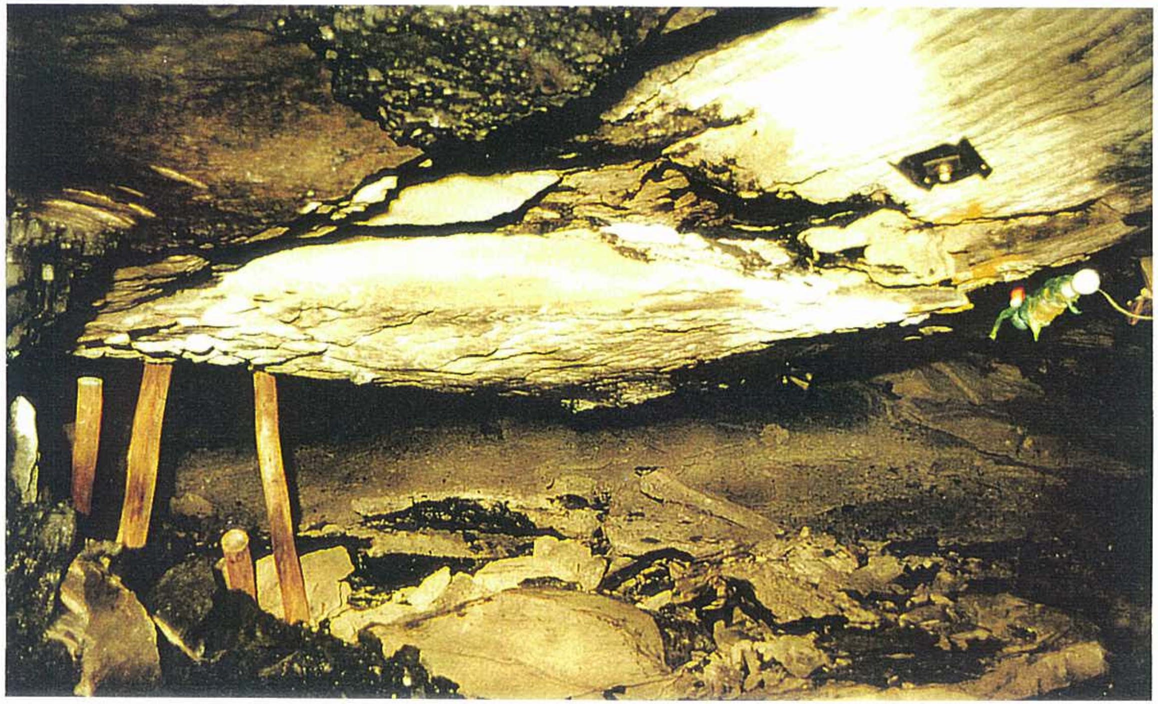


Plate III

Site 2 feather edge stopped by the bolted breakerline, showing the roof extensometer. Bottom picture shows arch-shaped slab detaching prior to it falling and destroying the extensometer.

This dislodged the site 2 extensometer leaving a lozenge-shaped slab adjacent to it. This device was reset, but the slab detached further damaging it.

As at site 1, this extensometer recorded zero displacement before it was damaged.

Because of the premature goaf fall (linked to site 1), one convergence rod was set between the goaf edge and the instrumented bolts. The convergence plot is shown in Figure 11 and some details logged are in Figure 8. For a long period there was minimal closure so the last 500 minutes have been plotted in Figure 11. As at site 1, the goaf closed gradually before suddenly accelerating just prior to falling. In this case the warning provided by the rod was 2 minutes reaching a very high closure rate of 30mm/minute.

5.4 Site 2 instrumented bolts – results

The bolted breaker line comprising a goaf-side row of 4 fully-encapsulated bolts and 4 point anchored bolts as described in section 4.3, stopped the goaf overrunning the working 8 C/T (see Plate III). Low-angle caving inbye of this bolted breaker-line did not result in a feather edge. In all probability without bolts a feather edge cave would have occurred. In the process of stopping the feather-edge caving, there is a discernible change of axial loads, bending moments, bending strains and axial strains of the bolts as in plots in Appendix IV; the representative plots are presented in Figure 12 for the details of the performance of bolt #122 in the location shown in Figure 8.

Even long after the goaf fall, it was possible to take readings of the instrumented bolts at site 2, useful for understanding the goaf edge behaviour and the related mechanism, as described in detail in section 7.0 of this report.

Preceding the large goaf fall affecting sites 1 and 2, the bolts deformed considerably. Thus, the best information can be extracted form the strain plots rather than axial load and bending moment data.

However, the maximum axial loads sustained by bolt #119, bolt #120, bolt #121 and bolt #122 are 13.3 tonne, 12.1 tonne 18.9 tonne and 10.6 tonne respectively. Bolt #121 was aligned with the gauges normal to the pillar rib line and it was, therefore, most likely to record extremes in loading. After the goaf had fallen, the gauges in the immediate roof recorded high negative axial load, but this was a response to high bending moment at the same horizon of ~250mm into the roof and probably subsequently de-bonding of the gauges. Table 1 suggests bending strain-line and maximum axial strain-line cutting the bolts at different roof heights.

It is clear from the tables and plots related to bolts 119, 120, 121, and 122 (ref. Appendix V) that there were no significant axial loads/ bending moments, exerting on the bolts before the goaf-fall of 10.02.'98 at 18.40 p.m. Readings observed, plotted and analysed showed that there were two phases of loading-axial and bending, primarily related to pre- and after- goaf fall situations. The changes sustained by bolts were quite appreciable and suggest as to how the bolts have sustained load and thus prevented feather-edging as in Table 2.

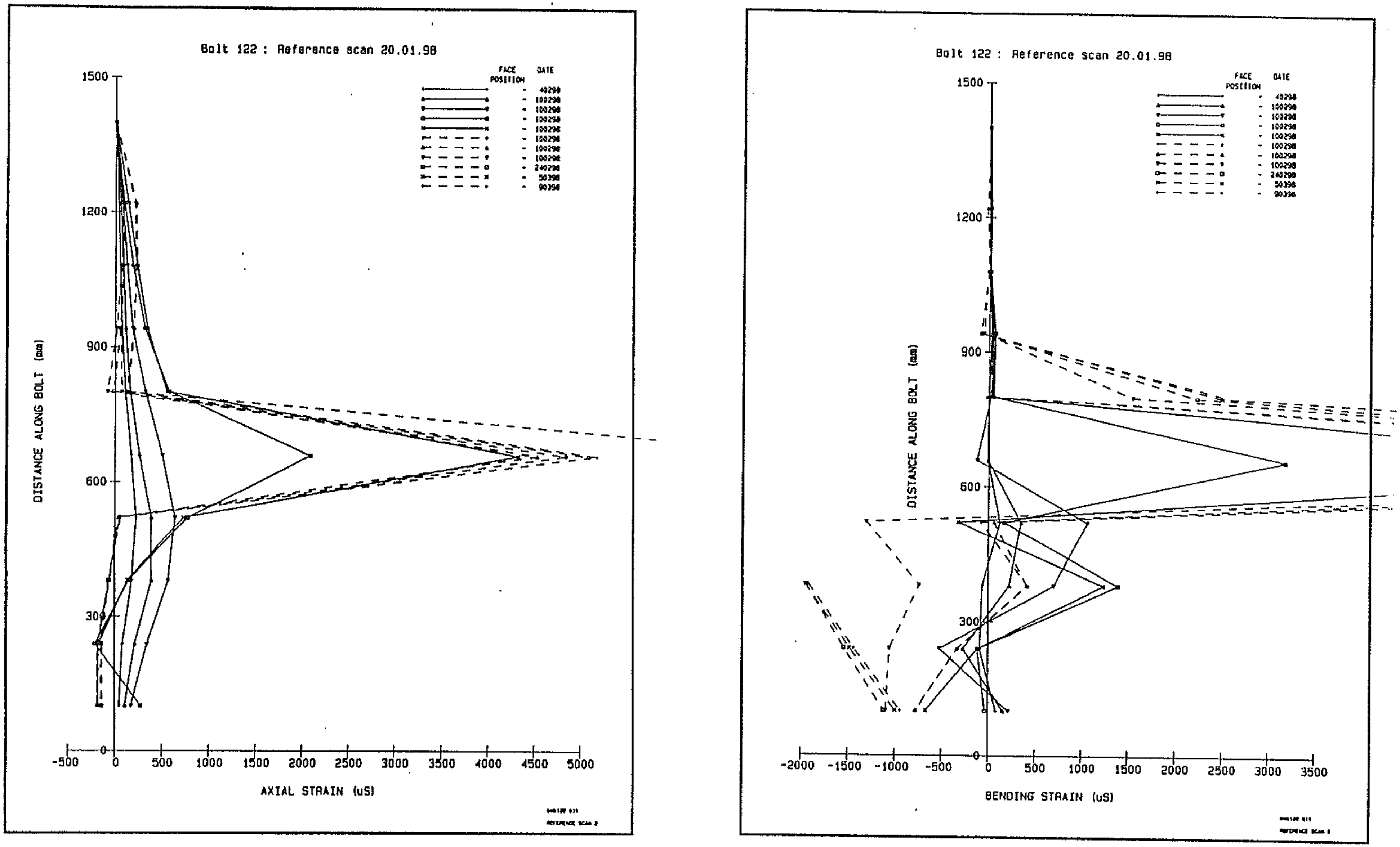


Figure 12. Measured strains in bolt #122 at site 2

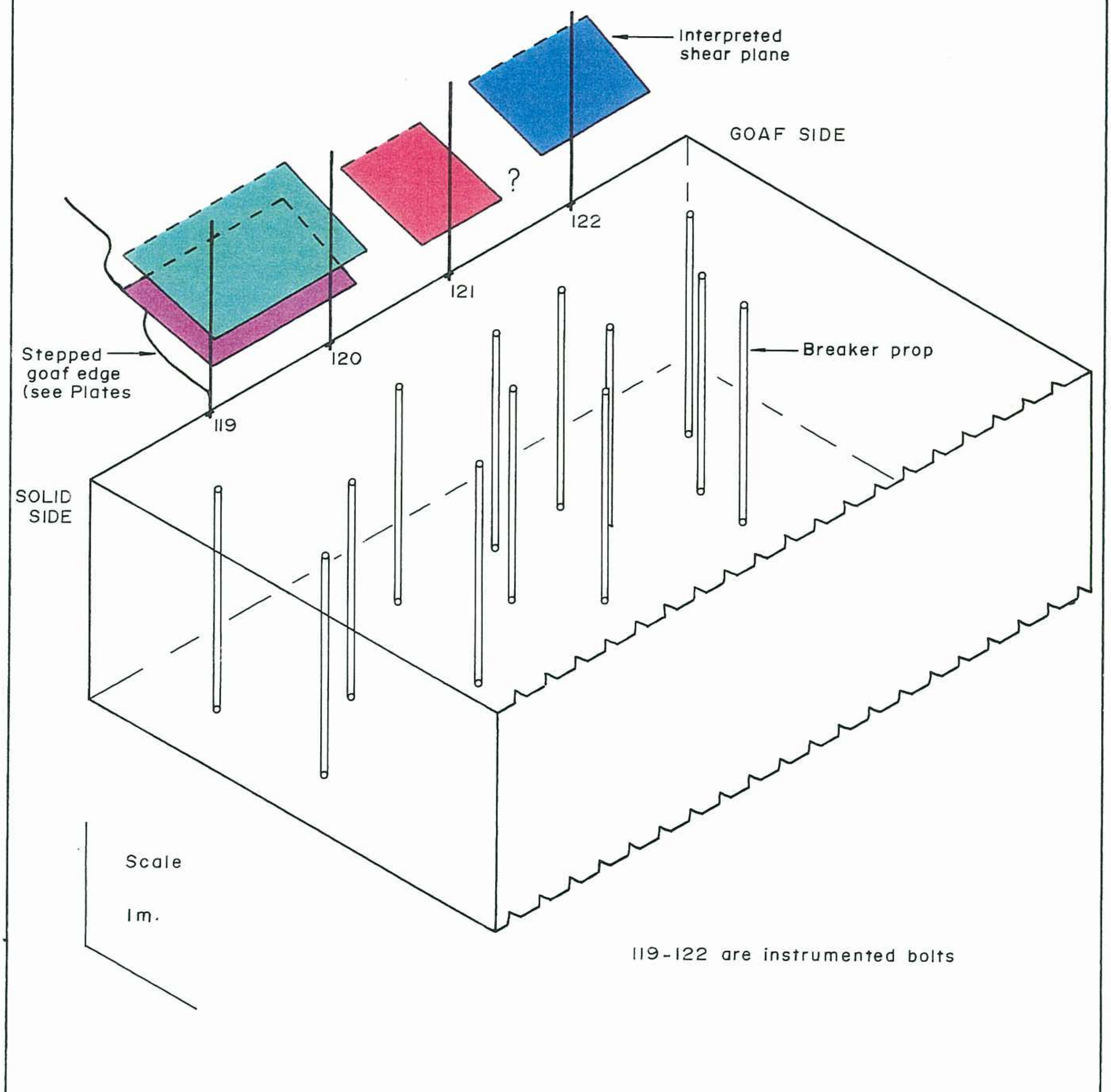


Figure 13 DIAGRAMMATIC 3-D VIEW OF INTERPRETED PLANES INTERSECTING INSTRUMENTED BOLTS AT SITE 2 (see Table I for data)

6.0 SITE 3 RESULTS

6.1 Extraction near site 3

Site 3 was installed on 10 February 1998 before the goaf fall at site 2 and before the place was made a 3-way intersection, near 6C/T. The goaf edge was inbye of 8C/T, approximately 2 pillar lengths away.

On 5 March 1998, the site 3 became a four way junction. The part of the fender S331 (left on 24 February 98) was taken, leaving stooks as shown in Figure 9 and at 9:15pm four convergence rods were set (see Plate IV). The sound of roof rocks and weighting on props suggested an imminent goaf fall. However, this was the end of the shift and the end of work for that date, which was followed by a weekend holiday. Although 7 March 98 was a holiday, underground readings were taken. However the goaf had already fallen on the 6 March 98 and the roof extensometer and convergence rods were destroyed. The bolt readings showed no appreciable change. One convergence rod by the side of the timber breaker props survived, but because of the weekend gap in monitoring useful results were not obtained.

On 9 March 1998, another convergence rod was set at a suitable location between the goaf edge and the bolt-breaker line (see Figure 9, rod S9A). Near site 3, when only 1 lift was taken from fender S355, the cutting operation had been stopped due to lack of water pressure. A delay of 4 hours was needed to rectify this, and the continuous miner/cables were shifted. This delay hindered the monitoring .

On 30 March 1998, (after the weekend) it was found before the start of the shift that a goaf fall had occurred tol to 2 metres in height in the area near 5C/T and between the 330 shift and the yet to be completed 354 split ($^3/_4$ only completed on 27 March 98). In view of the fact that the debris clearance and re-attempting of fender S355 would necessitate a lot of unproductive work, management decided to leave the rest of fender S355 unextracted and shift the production away from site 3.

6.2 Site 3 instrumented bolt results

The bolted breaker line at site 3 was similar to that of site 2, except that its position was not at the rib line, but 1.15m out into the intersection. This position would have exposed the bolts to higher loading than if they had been in line with the pillar ribs.

The feather edge goaf was stopped at the bolted-line as shown in Plate V and demonstrated its superior performance compared with props. A general view of the goaf edge and some reset convergence rods is shown in Plate VI. The 4 bolts (#123-#126) gave maximum axial loads of 1.24 tonnes, that is much lower than at site 2. The probable reason for this is that less coal was extracted prior to the goaf falling.

Bolt #125 was bent during installation when the bolter was pushing it into the hole. Despite this some results were gained (see Table 3), but at higher strains some gauges where the bolt had bent were de-bonded up to a height of 600mm (see Appendix IV).

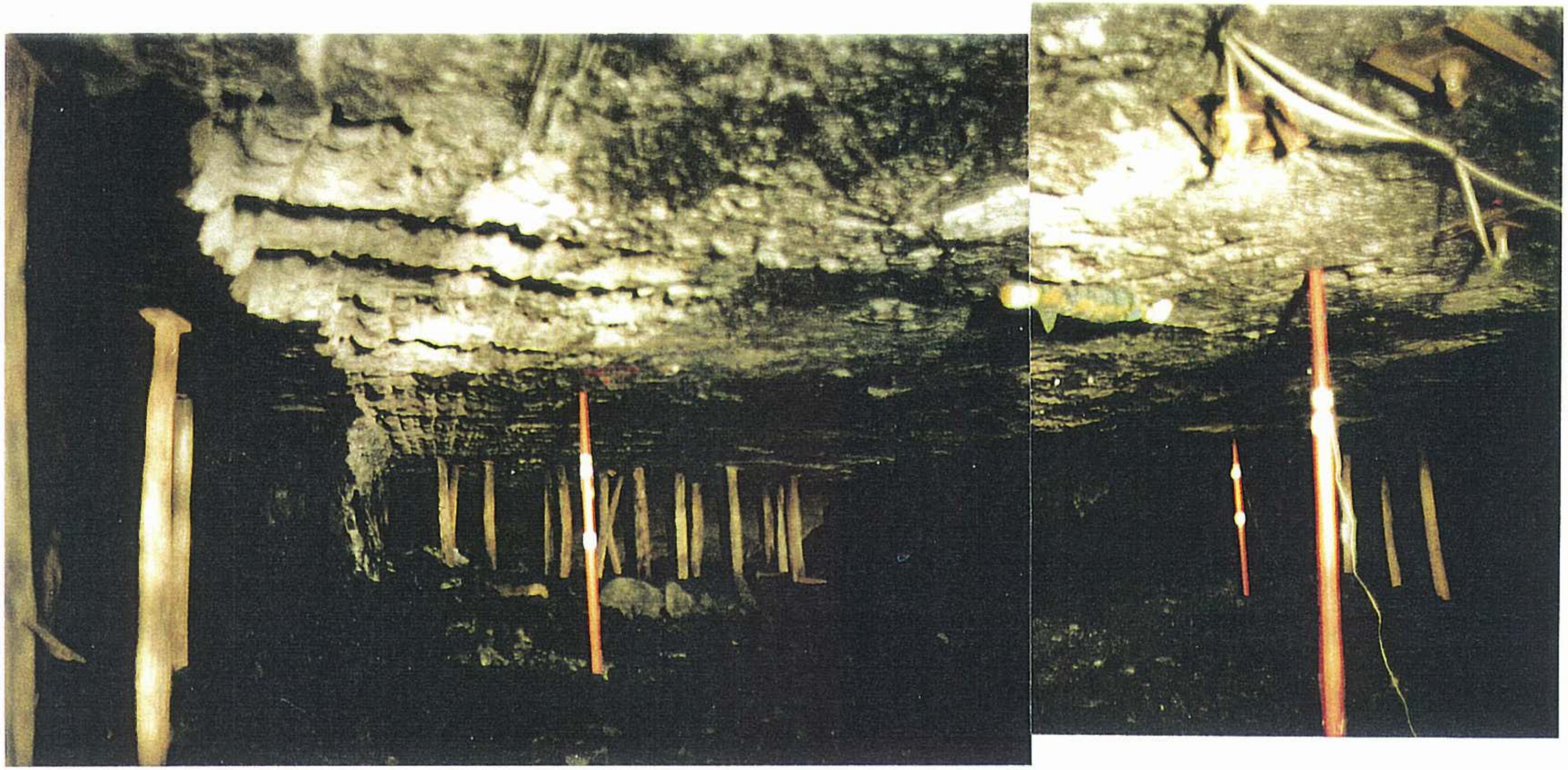


Plate IV

Site 3 before the goaf fall and weekend break, showing convergence rods installed.
the goaf edge is behind the breaker props, one pillar distant.

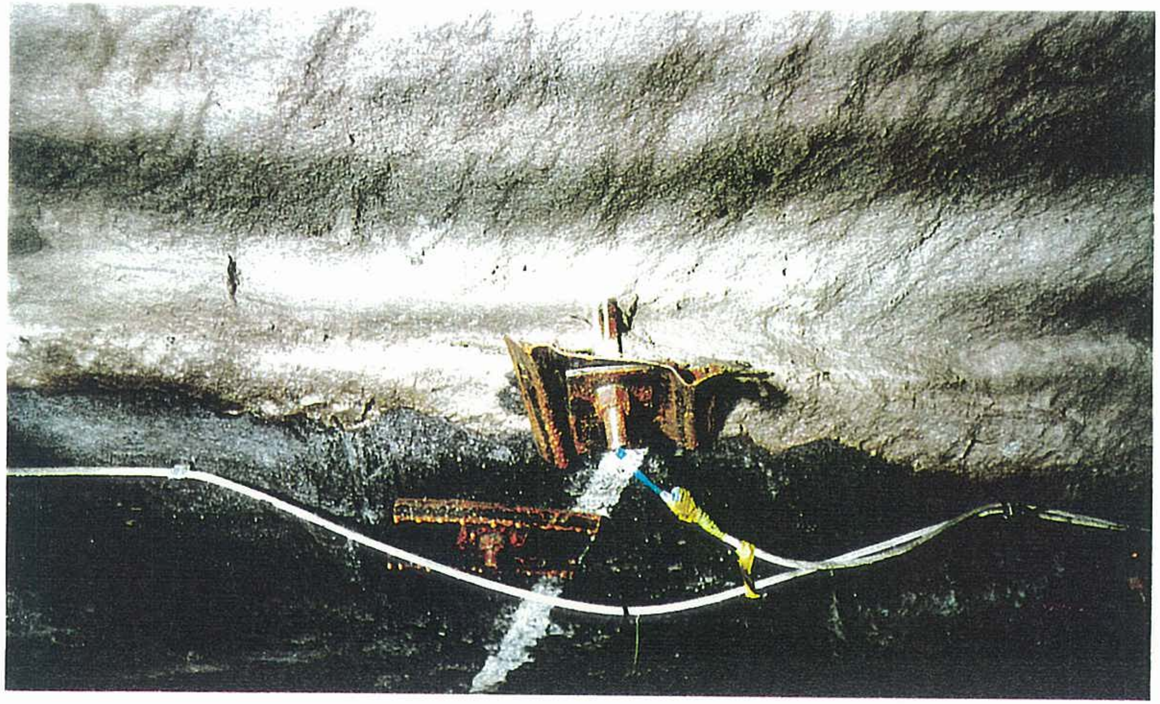


Plate V

Site 3 after weekend goaf fall: top left is low angle cave stopped at the bolts line. Remains of extensometer and two tube shears are visible. Top right and bottom show details of the feather edge at the bolts and exposed resin of the full column grout.

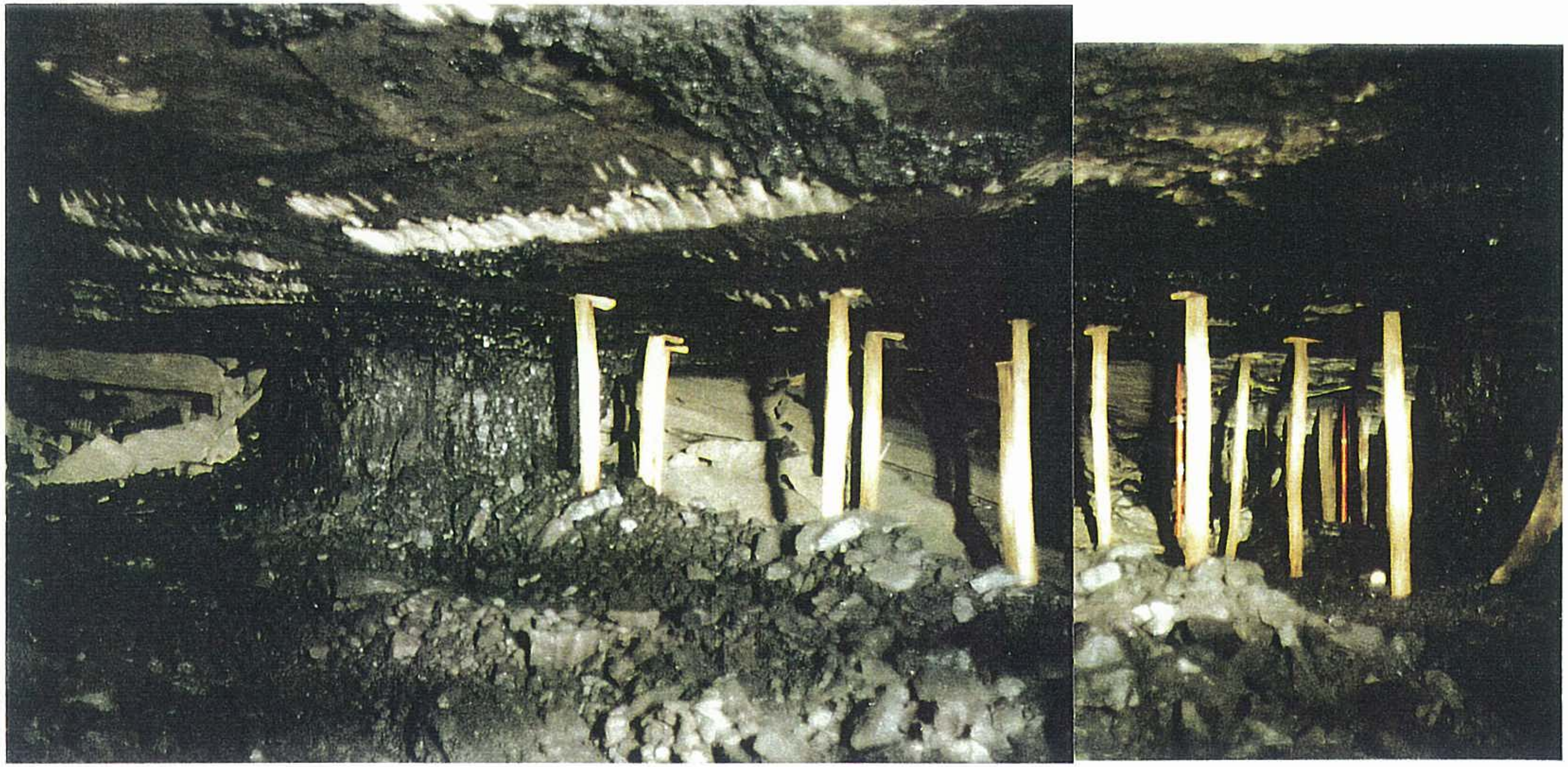


Plate VI

General view of site 3 goaf edge showing the goaf restrained by stook x on the left and the favourable roof conditions immediately outbye.

Table 3. Site 3 bolted breakerline: strains up the bolts

	Heights into roof (mm)	
Bolt no.	Bending strain "cutting" roof bolt	Max. axial strain along bolt
123 (solid side)	1129, 711, 213	- - 229
124	1176, 1002, 347.4	1232 - 237 (-ve direction)
125 (damaged)	900, - 308	797
126 (goaf side)	1145, 616, 300	947

Bolt #124 appears to be a special case. The axial strain and axial forces generated along the bolt changed markedly when the goaf fell. While moderate axial loads above 900mm into the roof were generated (0.5 tonne), below this negative forces and strains were recorded. An explanation for this would be that a shear surface developed at ~900mm height and effectively de-coupled the roof and bolt by shearing. Hence the roof is divisible into 2 blocks or slabs behaving differently (see Appendix IV). A laboratory study by Gale and Fabjanczyk (1987) subjected roof bolts in a special rig to direct shear. They showed that the bending moment distribution was quite localised and within ~100mm of the imposed shear force and that this effectively divided the bolt up into two parts.

The roof behaviour at site 3 is typified by bolt #126 (see Figure 14). This bolt showed 3 levels where shearing is inferred (see Table 2) and a broad zone of higher axial strains (Figure 15) from 300mm up to 1200mm.

In this respect site 3 differed from site 2 where the sheared zones were generally lower in the roof. Another difference can also be seen in comparing the shear planes from both sites and comparing Figures 13 and 15. At site 3 (Figure 15), shear planes were laterally more pervasive and at a greater number of heights into the roof. A comparison of the pre- and post-goaf fall bolt loading at site 3 did not show the same contrast as at site 2 (ref. Table 2). The reason for this is that coal near site 3 were not extracted and consequently bolts were subjected to less goaf loading.

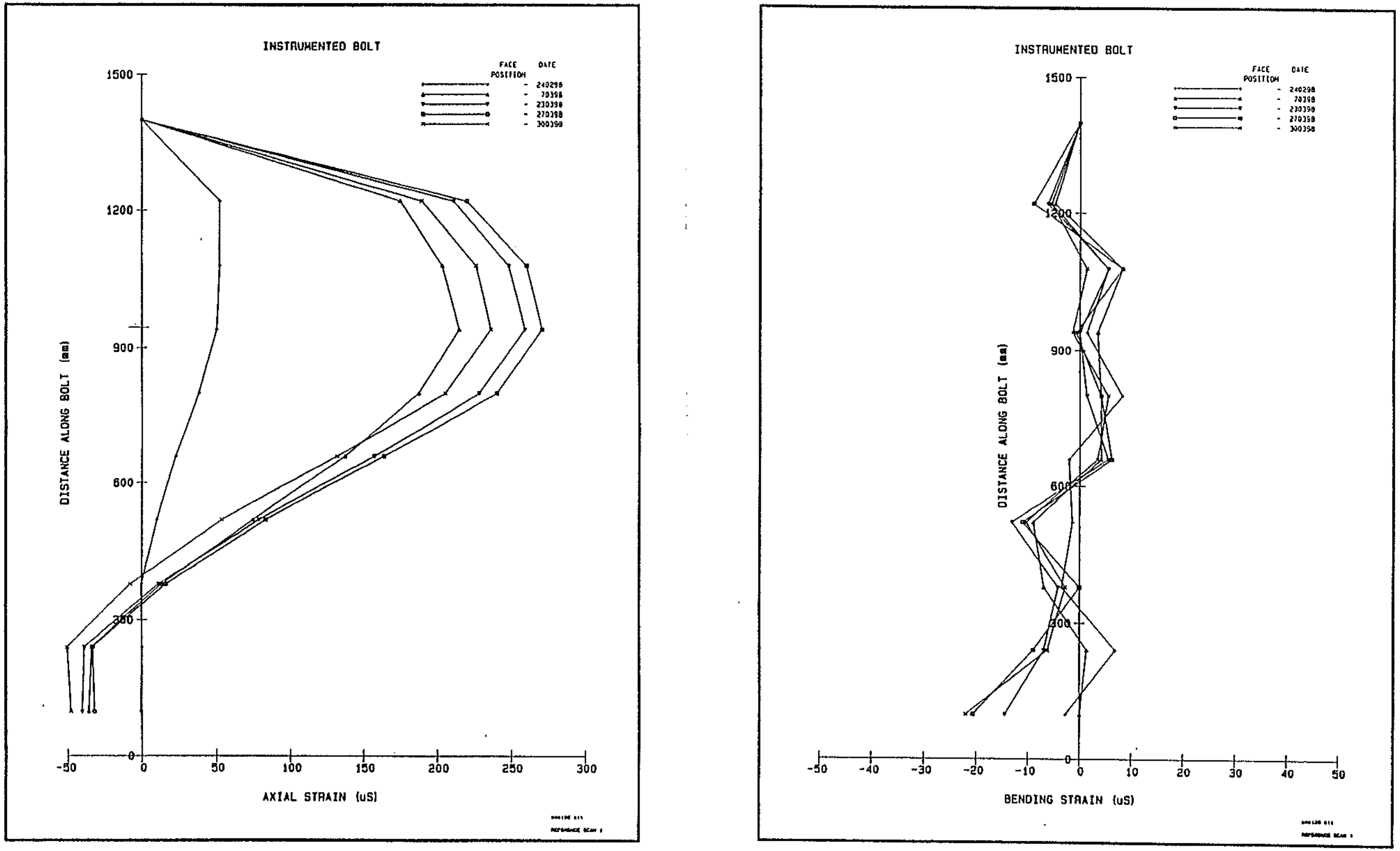


Figure 14. Measured strains in bolt #126 at site 3

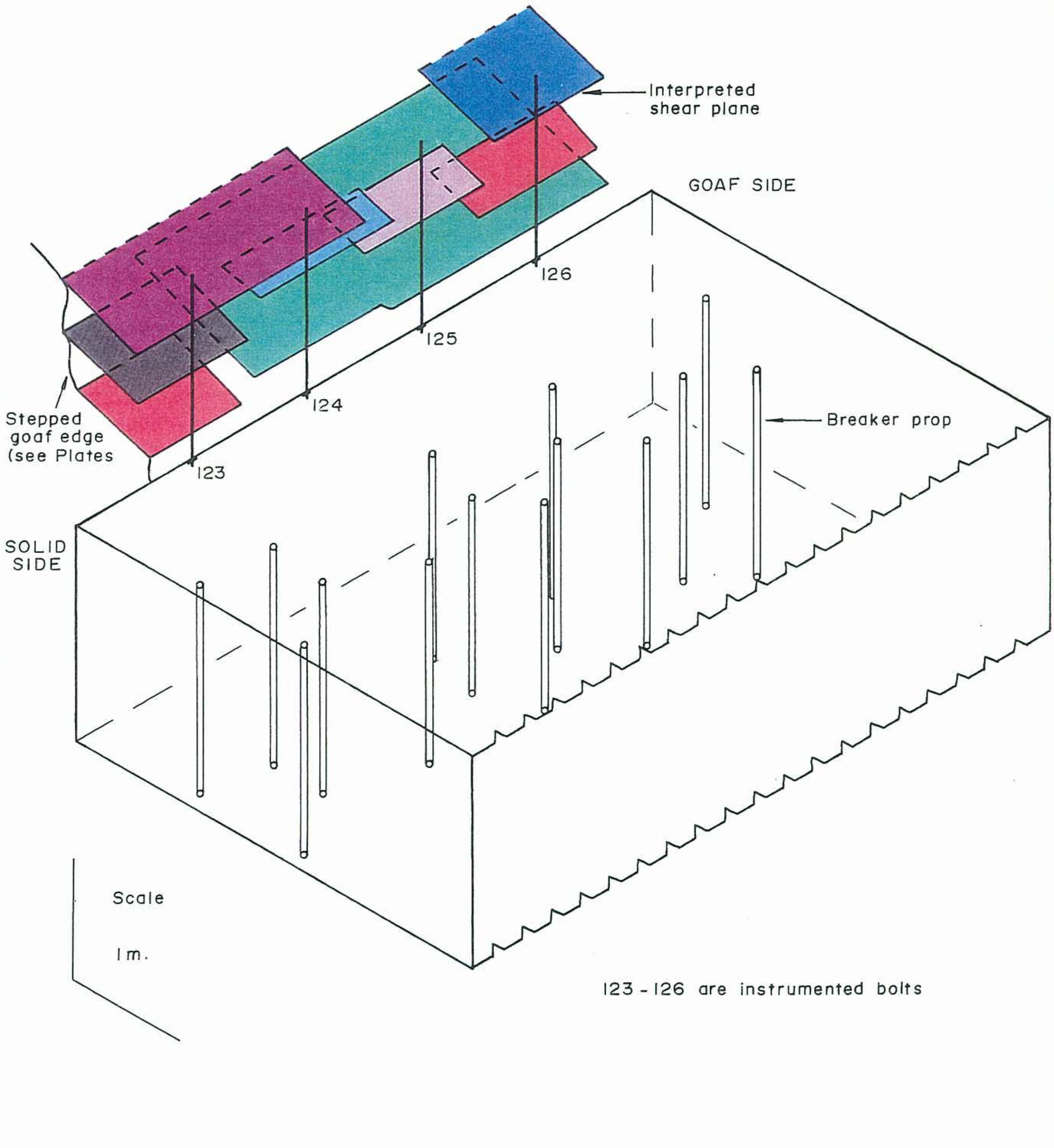


Figure 15 DIAGRAMMATIC 3-D VIEW OF INTERPRETED PLANES INTERSECTING INSTRUMENTED BOLTS AT SITE 3 (see Table II for data)

7.0 GOAF EDGE BEHAVIOUR

The pattern of feather edge goafs at Blue Mountains is consistent and well developed. In 6 North Panel there were few joints or faults and, there were no sub-vertical, geological discontinuities to break off the goaf.

The typical goaf fall produces a low angle caved edge of 10°-30°, often stepping upwards across sandstone bedding surfaces (not always planar) up to a relatively low height of <2m rising gradually to possibly 3-4m some distance into the goaf (Plates I and III).

The sandstone bedding is typically in the range of 0.2m up to ~1.0m with some pebbly (conglomerate) horizons. In addition, some of these bedding partings show 1-2mm of coaly material. There are also localised cross beds developed in certain roof horizons, but these are not laterally persistent.

High caving was not seen anywhere in 6 North goaf edges from 22C/T outbye to the study sites. Observations repeatedly showed that the low angle caving was developed after a series of roof cracking events and these link to the mechanistic process discussed below.

7.1 Initial roof cracking in the headings

Hairline cracks are commonly developed from 1 -2 pillars distance (30m centres) outbye of the goaf edge (see Figure 16). For example, cracks were mapped in the heading between S318 and S320 when S278 was being lifted (see Figure 6 and Plate VII). Concurrently, stooks at the goaf edge were 'crushing', all indicating a significant area of sagging roof.

The cracks are open from <1mm-3mm and are segmented with left offsets. There were also signs of shear displacement on some of them showing a right sense. This was detected, because opposite sides of the crack walls would not exactly match up (see Figures 16 and 17).

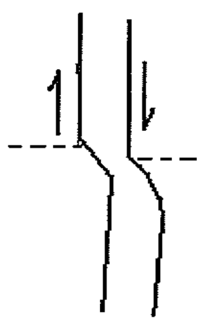


Figure 17. Offset hairline cracks showing movement sense

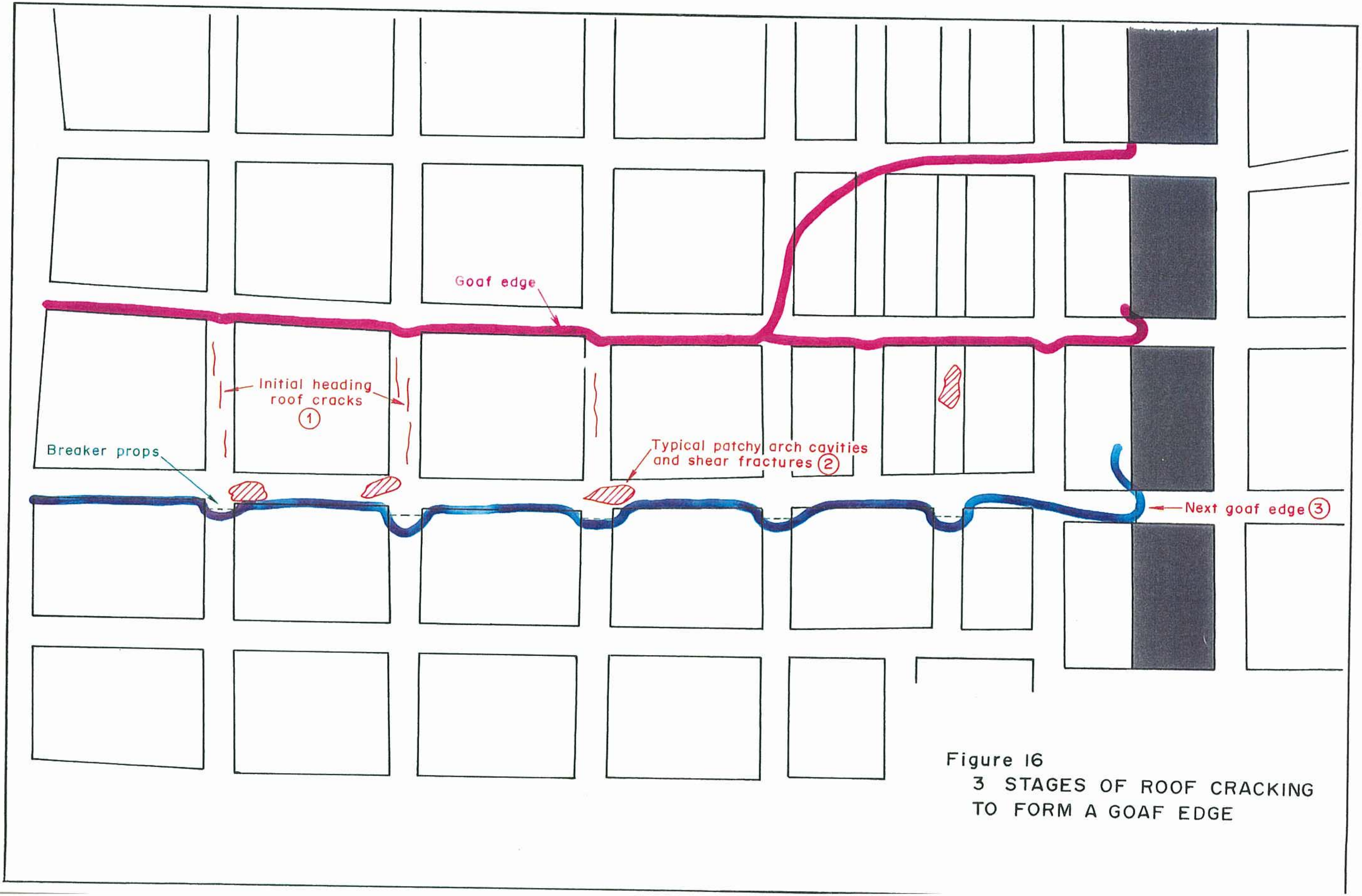


Figure 16
3 STAGES OF ROOF CRACKING TO FORM A GOAF EDGE

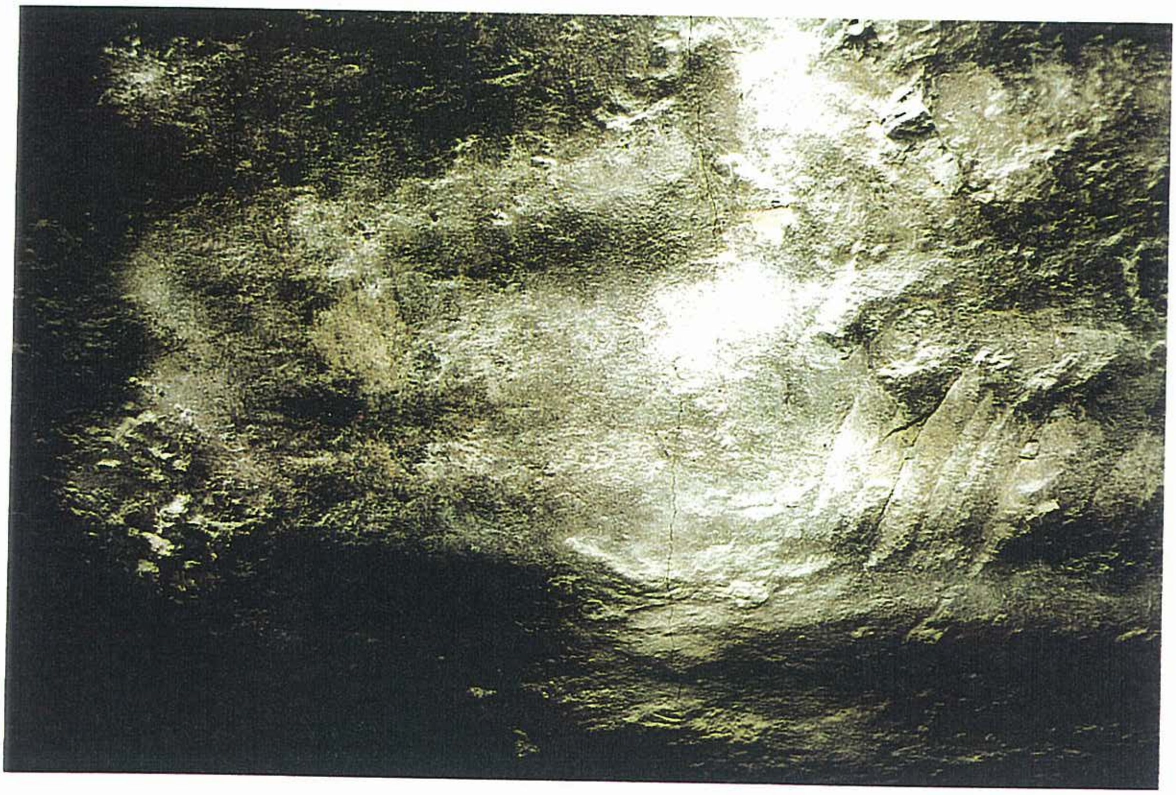
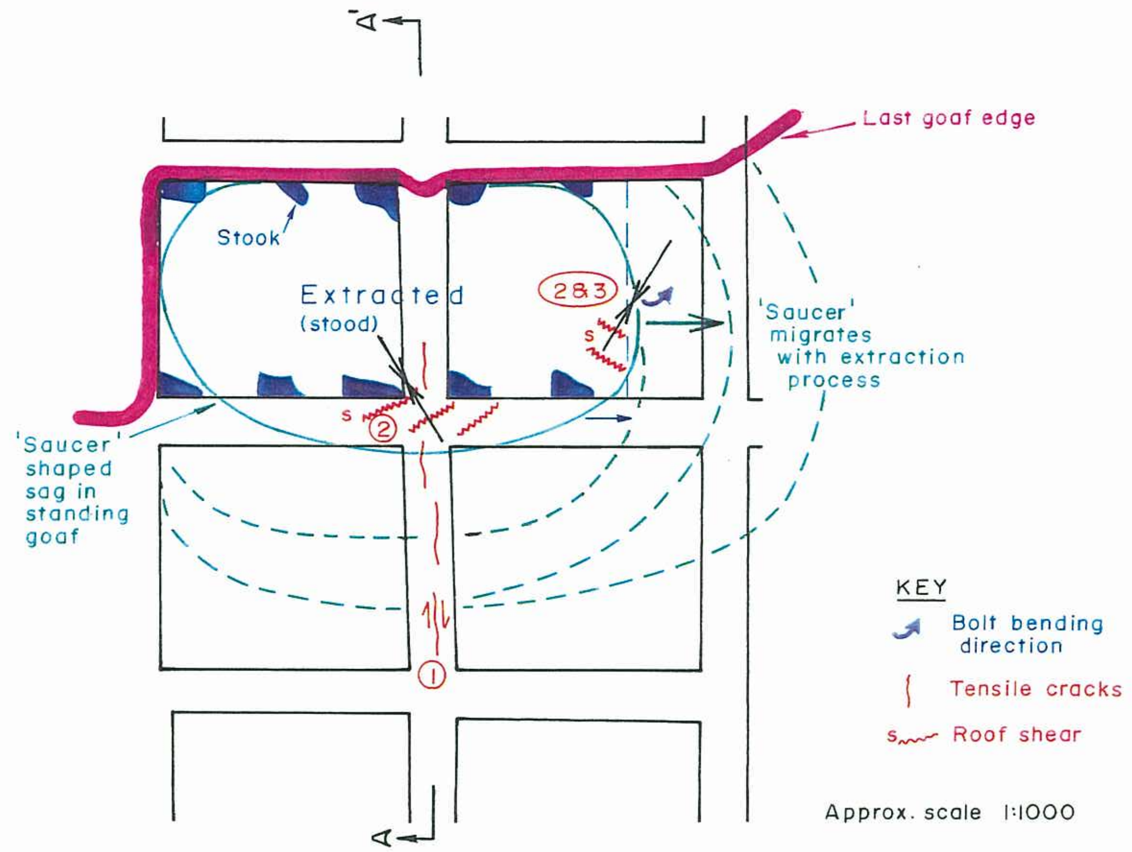


Plate VII

Heading axial roof cracks (hairline) outbye of the goaf edge. Top, general view, bottom, closeup showing offset segments.



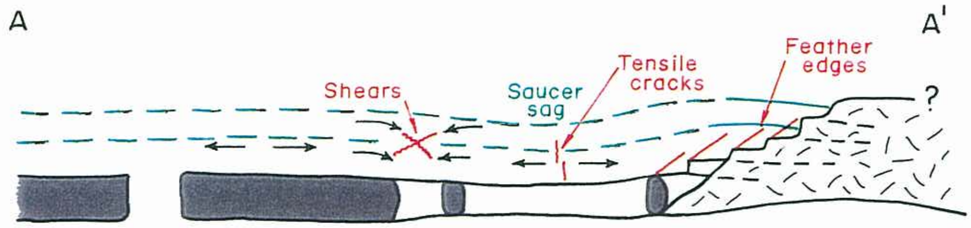


Figure 18 MECHANISM OF FEATHER EDGE FRACTURING INDUCED BY SAGGING, STANDING GOAF CONCENTRATING SUB-HORIZONTAL STRESSES.
A - A', CROSS SECTION
①-③ FRACTURE EVENTS (cf. Figure 16)

Some of the cracks were later observed to cross the goaf edge where feathering had occurred and extended upwards for ~2m.

7.2 Patchy roof cavities in the goaf

Goaf falls generally occurred after at least 2 pillar areas had been extracted (~2000m^2) and commonly this was considerably larger. However, prior to this, after lifting a particular fender, small patches of goaf roof up to ~15m^2 in area would fall forming a distinct arch-shaped cavity and the location of these was as shown in Figure 16, about 30m out from the pre-existing goaf edge. In some cases the breakers would also be damaged.

The long axes of the cavities were formed by inclined fracture surfaces aligned either 030°MN (NE) along the cut-throughs and 310°MN near the eastern barrier and instrumentation sites (see Figure 18). These inclined surfaces produced low, arch-shaped cavities and feather edges outbye of and detached from the actual (previous) goaf (caved) edge.

In one case at 10 C/T (inbye of the instrumentation sites) where the end of the last fender was abandoned, caving initially occurred on cracks aligned NE with intersection bolts bent in the same direction towards the coal left behind (see Figure18). Similar bent roof bolts had been observed in feather edge goaf falls at Cooranbong Colliery by Shepherd and Chaturvedula (1991).

7.3 Feather edge caving

At some time after the patchy falls occurred in the "standing" goaf, a significant "main" goaf fall event would occur as discussed above in 7.0 and these typically over-rode the breaker props and the outbye pillar edge, sometimes by as much as 10-15m, but commonly approximately 5-6m.

The props would be completely destroyed or broken. A typical caved edge is shown in Plate I. This would occur in over 90% of goaf falls. The steepest caved edge measured was <50° (down from horizontal).

8.0 FEATHER EDGE CONTROL BY ROOF BOLTS

The double row of equally spaced roof bolts installed at sites 2 and 3 were located 0.5-1m "in front" of the normal 3 rows of breaker props. The rows were 300-400m apart with standard butterfly plates and domed washers installed (see Plate VIII).

When the feather edge caving occurred (as discussed in 7.3), as the third event leading to goaf roof failure, the low angle fractures stopped exactly at the first row of bolts (instrumented) and the roof and breaker props behind them remained in good condition (see Plates III and V).

The bolts prevented the roof fracturing from dislodging the immediate roof by a clamping (confinement) effect, stopping the roof slabs from sliding under shear and increasing the frictional resistance along the fracture surfaces. The bolts generated significant loads in the range 10-18 tonne.

The properties of the sandstones are not known, but the fracture surfaces have a high roughness, in which case the confinement provided by the bolts only needed to raise the frictional resistance slightly to prevent sliding in shear.

8.1 Analysis of instrumented bolt data

The bulk of the data from the two sites (total of 8 bolts) is provided in Appendix V. From a goaf edge mechanism viewpoint the important parameters are axial strain and the bending strain. The 2 goaf-side bolts, #122 and #126 are chosen to demonstrate the goaf edge behaviour. Bolt #122 at site 2 shows very high axial strain at 650-700mm into the roof and a series of "zones" of high bending strain at various heights (see Figure 13). These strains are summarised in Table 1 and represent the effects of low dip angle fracture planes in the sandstones stopping at the bolts. A useful interpretation of this is given in Figures 13 and 15. At site 3, 5 levels of shear fractures can be interpreted from the data in the graph of Figure 15.

It is believed that these low angle fractures form very rapidly when the goaf fall occur. The fracture planes form, the roof separates, and then the planes are sheared all in quick session.

It is precisely these "stacked up" shear fractures that produce a stepped, low angle goaf as the sandstones break off at the various levels (Figures 13 and 15 and Plates I and III). The horizon of shear planes interpreted from Table 1 was confined to within 1 meter (and hence low angle caving) in roof-horizon at the goaf-edge in 6 North panel. But, Table 3 indicated that the shear planes were laterally more pervasive and at a greater heights (~1.2 meter). In view of the above, for bolted breakerlines, it is, therefore, advisable to install two rows of grouted bolts at the goaf-edge where the conditions lead to feather-edging goaf-falls. The highest shear planes were at ~1.2 meter horizon which is close to 1.5 high bolt. Therefore, it is possible that 1.8 meter bolts would be more satisfactory in this situation.

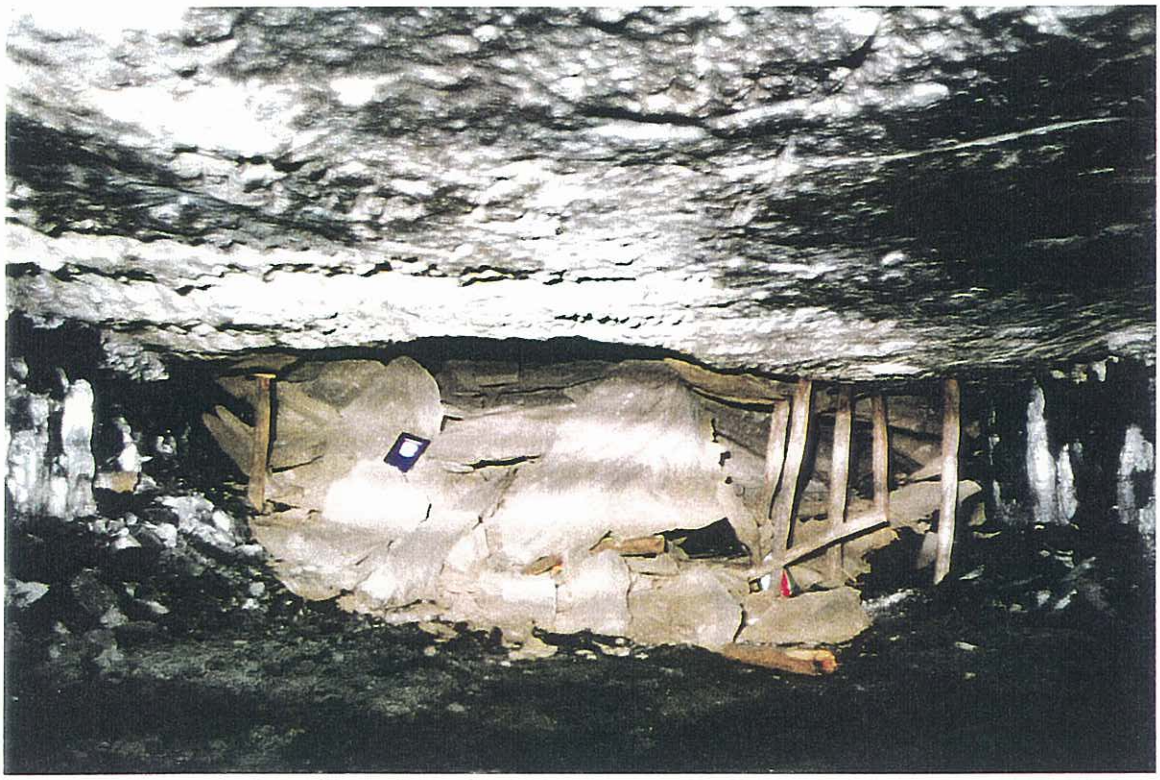


Plate VIII

Comparison of the goaf edge at 7 and 8 c/ts. Top shows bolted breakerline effect at 8 c/t (site 2) and bottom shows typical feather edge uncontrolled by breaker props at adjacent 7 c/t.

9.0 MECHANISM

A number of aspects stand out of this investigation consistent with findings at some other sites under strong sandstone roofs (Shepherd *et al*, 1990), that is:

1. Caving in terms of substantial goaf falls and the formation of a proper breaker line is delayed. As a result the area of standing goaf at Blue Mountains generally exceeds one pillar area and often reaches 2 or 3.
2. There is a relative common occurrence of pre-goaf failure "tensile" roof cracks extending away from the goaf edge area perpendicular to the goaf edge (see Figures 16 and 18).
3. Stooks carry the standing goaf roof during 1.

The behaviour of this standing goaf is the key to determining the probable goaf mechanism. Shepherd and Chaturvedula (1990, p.307, Figure 12.5) considered a number of scenarios to explain caving at goaf edges including 2 suggestions for "massive" roof beams involving sag on "large" stooks and cantilevering on smaller stooks. There is no doubt that the cantilever roof behaviour is the most common in goaf edges, but where caving is inordinately delayed because of strong strata and/or large stooks, an area of sag can develop outbye of the previous goaf edge.

This has been observed at Blue Mountains in 6 North, but also at other sites especially Metropolitan and Oakdale Collieries when they were pillar extracting. At Metropolitan, when caving delayed, cracks also developed along the headings outbye of the goaf edge, and these were associated with roof sag (see Plate IX). Another worker (Davidson, 1983) based on work by McKavanagh and Gray, also distinguished 3 classes of caving edge behaviour at pillar extraction sites at the Collinsville No. 2 Mine: flexure, shear and cantilever; flexuring is akin to our observations at Blue Mountains. Collinsville was also notorious for delayed caving followed by sudden, huge goaf falls. At Blue Mountains the evidence for pre-goaf fall flexure (or sag) is provided by stooks spalling and semi-crushing, together with visible roof convergence in the standing goaf. There is also slight floor lift and the closure measured by the convergence rods includes this.

This sagging or flexuring process by the roof is believed to extend outbye of the goaf edge some 1-2 pillars distance (see Figure 16) and opens up the roof cracks in the heading direction between the pillars. At some stage minor shear also occurs on these cracks (Stage 1). As the sag develops compressive stresses elevate around the rim of the sagged area and patchy roof shearing begins (Stage 2). Over time this sagging continues, more standing goaf is opened up as lifting continues and eventually a goaf fall occurs with abundant low angle shear planes controlling the low angle cave (see Plate I). The height of this caving is probably not more than 3-5m. (Three roof extensometers were lost so that this information was not obtained). These shear planes propagate from the roof downwards and outwards and normally overrun the pillar edges as a "feather edge". At Sites 2 and 3 where the bolts were installed, the fracture propagation was halted. Monitoring the bolts continued after the goaf fell for approximately 2 months. During this time the bolts retained a steady residual loading but fresh cracks developed between the bolt rows (see Plate XIII). However, this cracking did not overrun the back row of bolts. This can be regarded as a very satisfactory performance by the bolts.

Plate IX

Heading axial cracking outbye of a Metropolitan colliery goaf edge in Bulli Seam sandstone roof, similar to the Blue Mountains cracking.

10.0 CONCLUSIONS

This investigation has to a large extent clarified the mechanism of feather edge caving and it has also demonstrated the efficacy of the use of bolted breakerlines at the goaf edge. This is consistent with the South African experience. 3 sites were instrumented in a normal production panel and by making regular observations and readings high quality empirical data were gathered.

The main results from the investigation were:

1. The Blackmans Flat conglomerate roof of the Lithgow Seam is prone to feather edge caving in 80-90% of goaf falls at Blue Mountains Colliery.

2. Caving occurs after a period of days or even weeks and can be related to a 3-stage fracture-forming sequence as a result of roof sag over areas as large as 1-3 pillars.

3. A saucer-shape sag area (flexure) develops as extraction proceeds after the last goaf fall. Vertical tensile (and some shear) cracks develop (Stage 1) followed by patchy low angle shear fractures (Stage 2) eventually extending on a more widespread basis to produce a proper goaf fall (Stage 3). Even this caving, however, is not equivalent to a steep sided caved edge as in most pillar extraction goafs. Such caving appears to take place after weeks or months at Blue Mountains according to anecdotal reports. Subsidence measurements could check this.

4. The goaf edge low angle (shear) fractures fail the roof and topple over the breaker props when stage 3 fracturing forms. This was prevented at 2 sites by the use of bolted breakerlines consisting of 8 x 1.5m mild steel bolts, the front (goaf side) row being fully encapsulated and the back row being point anchored. The spacing between these 2 rows was 300-400mm.

5. The two bolted breakerline sites (2 and 3) were located at 8 and 6 c/ts respectively. At both these sites the feather edge caving was halted exactly at the goaf – side row of bolts. At 7 c/t, however, between these sites, the normal breaker props were overrun when the goaf fell (see Plate VIII).

6. The front rows (goaf-side) grouted bolts sustained the change of loading due to goaf-falls. The two rows of bolts can prevent shearing by putting normal stress into the roof on low angle fracture planes.

7. It is recommended to adopt two rows of grouted bolts with more 'concentration' and high density at the goaf-edge than normal bolting pattern.

11.0 ACKNOWLEDGEMENTS

We are indebted to the owners and management of Blue Mountains Colliery for providing the sites and maintaining interest in this study. In particular we should thank Mr David Facchina (Managing Director of Hartley Valley Coal Company) and Mr Peter Costa (mine manager). The mine deputies were also a great help: Messrs Steve Mays, Bob Holmes and Geoff Smith. The colliery donated the roof bolts and labour for installing the instrumentation. The financial support of the Joint Coal Board Occupational Health and Safety Trust for this research project is gratefully acknowledged.

SCT instrumented the bolts and kindly assisted with the data reduction. Mrs Ann Roberts drafted the report figures.

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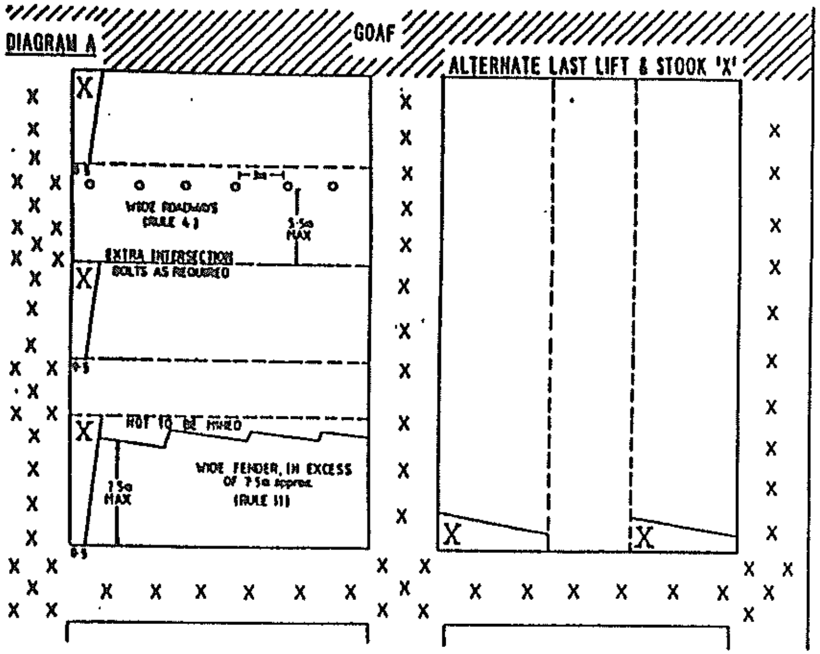
BLUE MTS COLLIERY

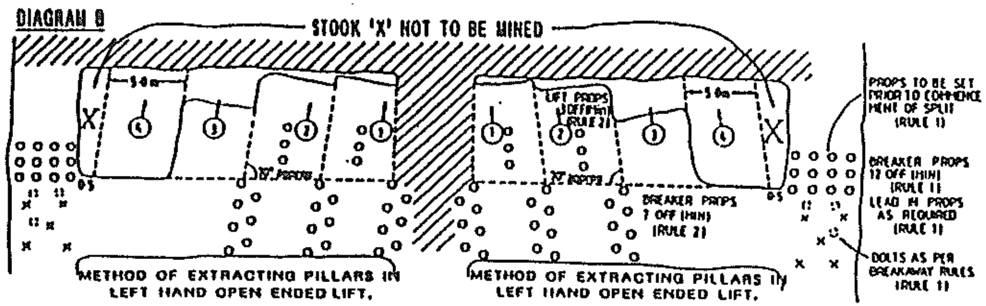
SUPPORT RULES

MANAGERS SUPPORT RULES IN PURSUANCE OF
A) SECTION 102(1) OF THE COAL MINES REGULATION ACT 1982 N°67 &
B) CLAUSES 16 & 18 OF THE COAL MINES REGULATION ACT 1984
(SUPPORT - UNDERGROUND MINES.)



LEGEND

o o o	SET OF BREAKERS PROPS
X	ROOF BOLTS INSTALLED (1500mm)
o	PROP TO BE INSTALLED



APPENDIX I
SMG 610/1

PILLAR EXTRACTION SUPPORT RULES:

1. During the breakaway for a pillar split the intersection being so formed is to be bolted as per the mines breakaway rules and also see Diagram B. Before commencing to lift any fender twelve (12) breaker props and sufficient lead in timber is to be set to minimise the size of the intersection, as much as practical. See Diagram B

2. Seven (7) breaker props and three (3) lift props must be set on the completion of each lift prior to the commencement of the next lift in that fender. See Diagram B

3. Nothing in these rules shall prevent workmen from setting additional supports where necessary to ensure a safe workplace. When directed by a mining official to set support then that support must be installed as directed. As well as setting extra support some conditions may warrant the setting of more support at closer intervals than shown in the diagrams.

4. Roadways and splits formed are to be no wider than 5.5 metres. Where a roadway or split is wider than 5.5 metres extra support is to be set to close the width into 5.5 metres. See Diagram A.

5. Breaker props are not to be undermined, breaker props are to be set on solid floor and to roof. Props are to be spaced evenly in roadways and lifts.

6. Where an existing prop is required to be removed, then that prop is to removed safely by moving the stationary head of the continuos miner or the rear end of a shuttle car. All workmen shall retire to a safe distance i.e. no closer than the machine operator of that machine.

7. All employees are to ensure that they make regular inspections of the roof for any discontinuities e.g. potarses, loose tops, floaters, cutters, joints, faults etc. Where practical tops and pot arses are to be trimmed down or cut out. If this is not possible then extra support is to be set as required.

8. The miner driver shall ensure that the splits he is driving are being driven to surveyed (or temporary) sights, as the case may be. He is to make regular checks to ensure that the driveage is on line to the sights. The Deputy is to make regular checks to ensure that the driveage is on line and the correct width.

9. DO NOT remove or mine STOOK 'X'. Minimum of 0.5 metres to be left on Stook X See Diagram B.

10. All lifts are to be driven to approximate angle of approximately 70 degrees and a maximum width of 5.0 metres See Diagram B.

11. The miner driver is not to proceed beyond the rib line of the fender being extracted at that time. Where a fender is in excess of 7.5 metres wide then it is to be extracted as per Diagram A

12. Dimensions on the attached diagrams are approximate

SIGNED [signature] DATE 14-4-97
MINE MANAGER

SIGNED [signature] DATE 12/6/97
DISTRICT INSPECTOR OF COAL MINES

BLUE MTS COLLIERY PILLAR EXTRACTION DETAILS			
CRAVEN, ELLISTON & HAYES (LITHGOW) PTY. LIMITED LAND, ENGINEERING & MINING SURVEYORS "Astrolabe" Rutherford Lane, Lithgow 2790 Phone: (063) 512201 Fax: (063) 521230			
SURVEY: DRAWN: R.D.T. CHECK:	DATE: 19-4-96 REVISION:	SCALE: N.T.S.	DRAWING NO. 9/547.1

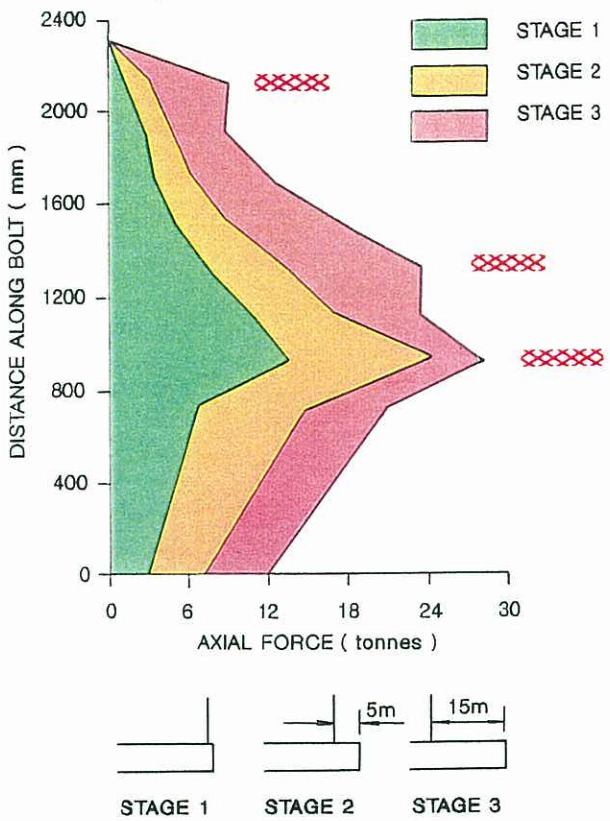
INSTRUMENTED ROCK BOLTS

The instrumentation to monitor the behaviour of rock bolts is manufactured in-house by SCT. The instrumented roof bolt allows the reinforcement performance of the bolts to be measured during the various mining stages.

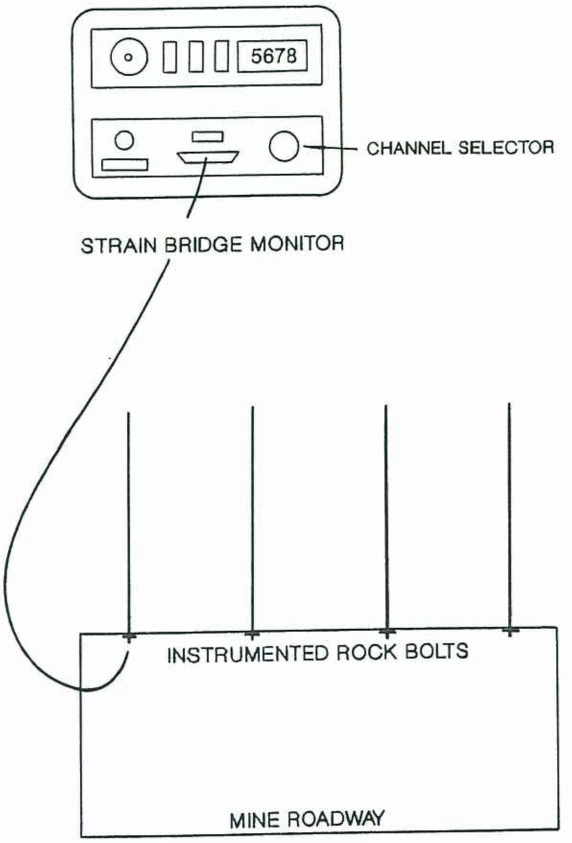
The instrumented rock bolt is essentially a strain gauged bolt which measures the strains developed in the bolt at up to 9 locations along the length of the bolt. At each of the 9 locations, a pair strain gauges is bonded into two small slots which run along the length of the bolt.

The strain values measured for each of the gauges are processed by a computer programme to calculate:

- the axial force generated in the bolt
- the bending moments generated in the bolt



TYPICAL EXAMPLE OF AXIAL FORCES IN A ROOF BOLT MEASURED USING AN INSTRUMENTED BOLT



INSTRUMENTED ROCK BOLT MONITORING EQUIPMENT

Instrumented bolts are typically installed at the face of the roadway as part of the normal cycle of roadway support. They are connected via a cable to read-out locations approximately 10-15m away from the installation site. This enables the instruments to be monitored during mining operations without causing delays to production.

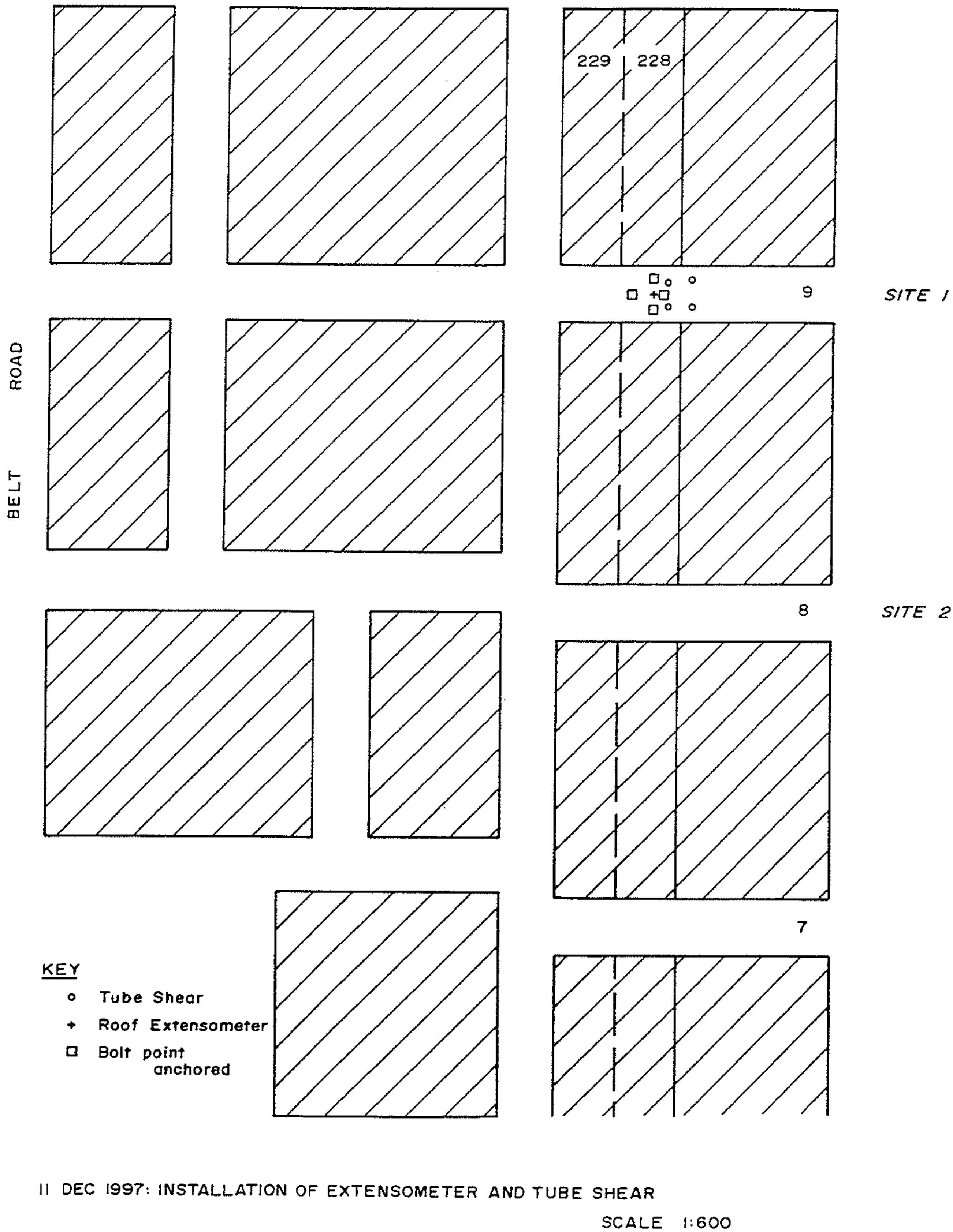
As with extensometers, the instrumentation is monitored frequently until initial stabilisation of conditions and then at less frequent intervals to measure any time-dependent characteristics.

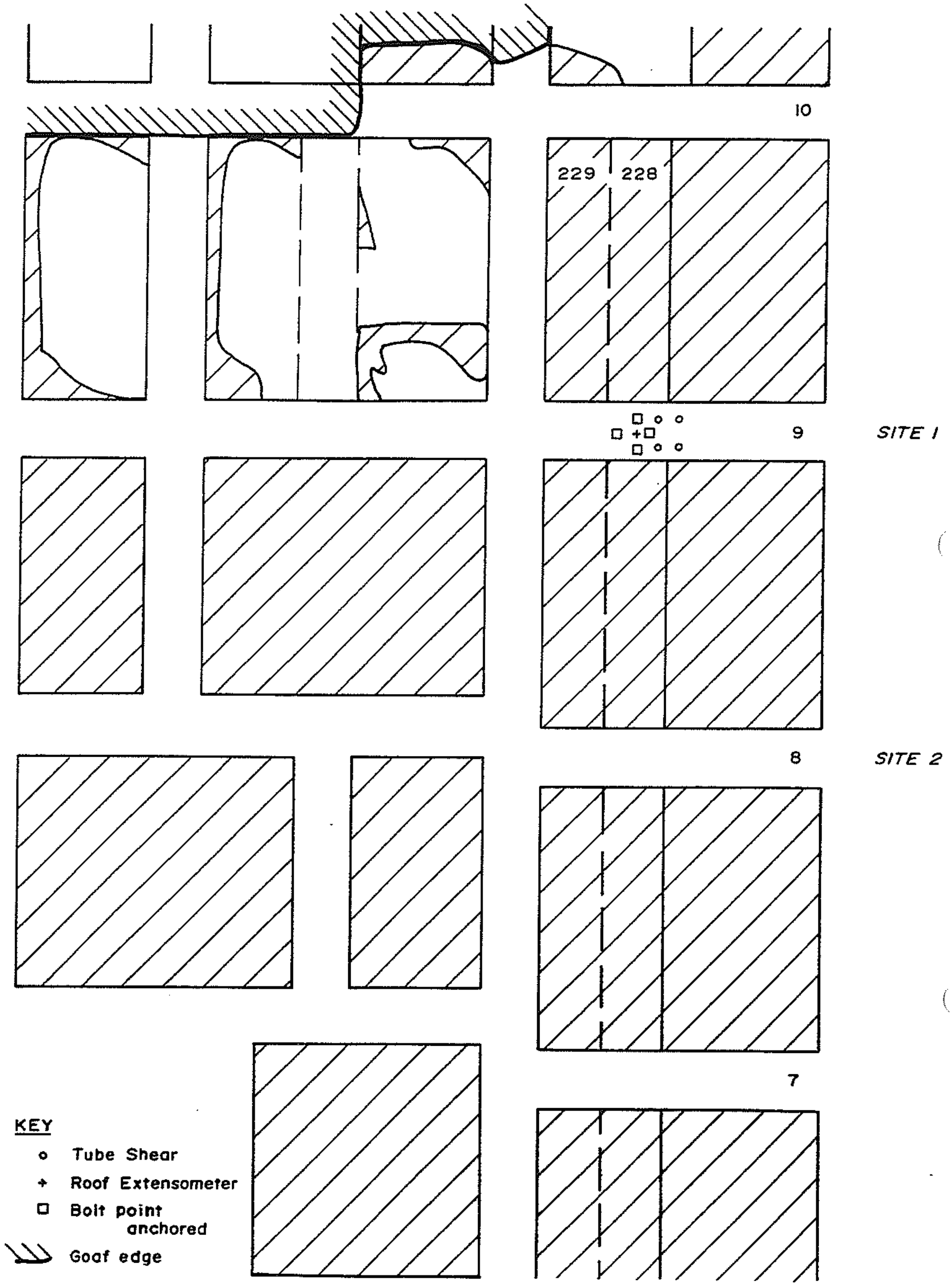
APPENDIX II

SMG 610/1

APPENDIX III

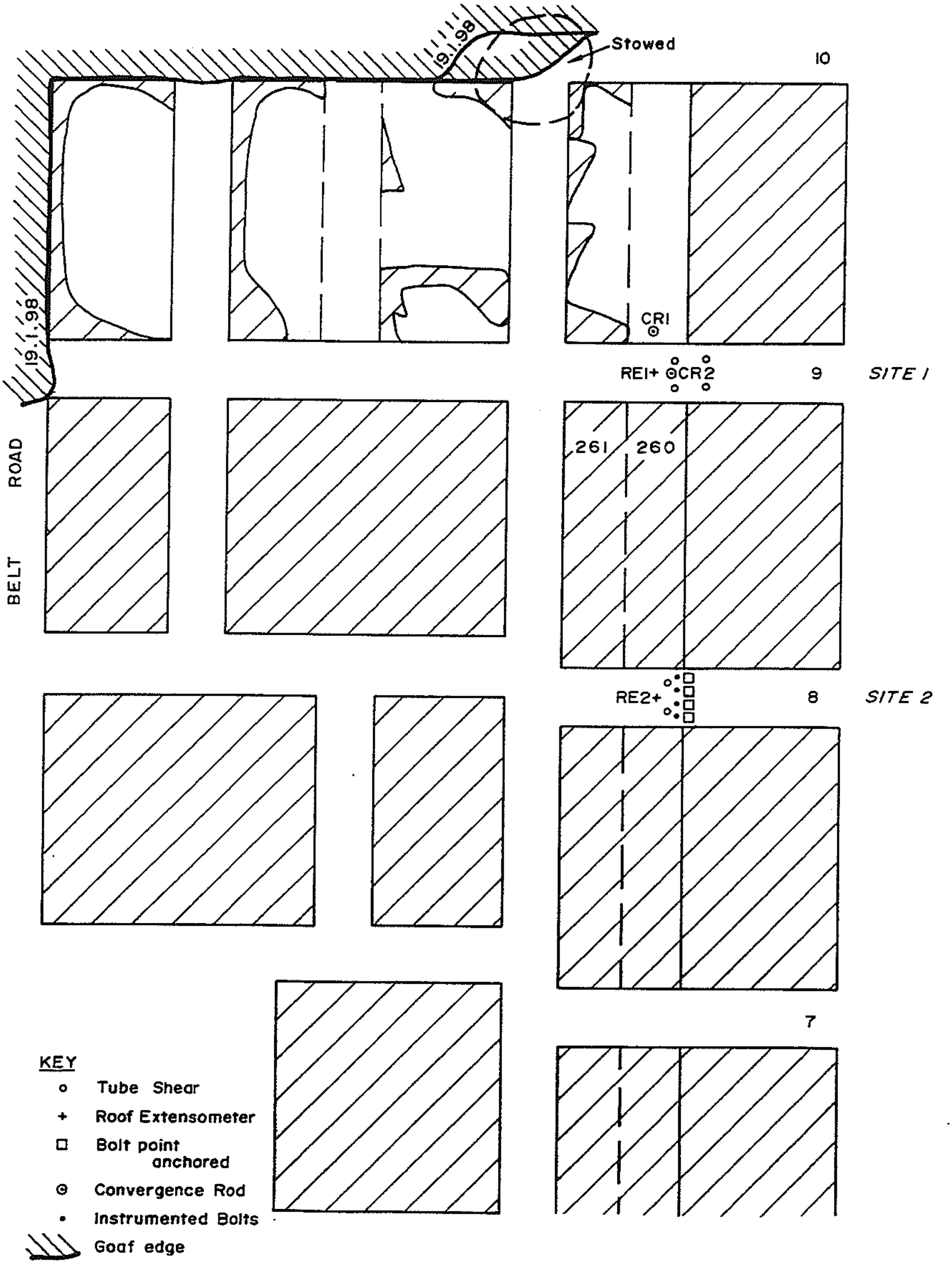
Detailed sketch maps of goaf edges – Sheets 1-11





16 JAN 1998: NO CHANGE IN EXTENSOMETER READING

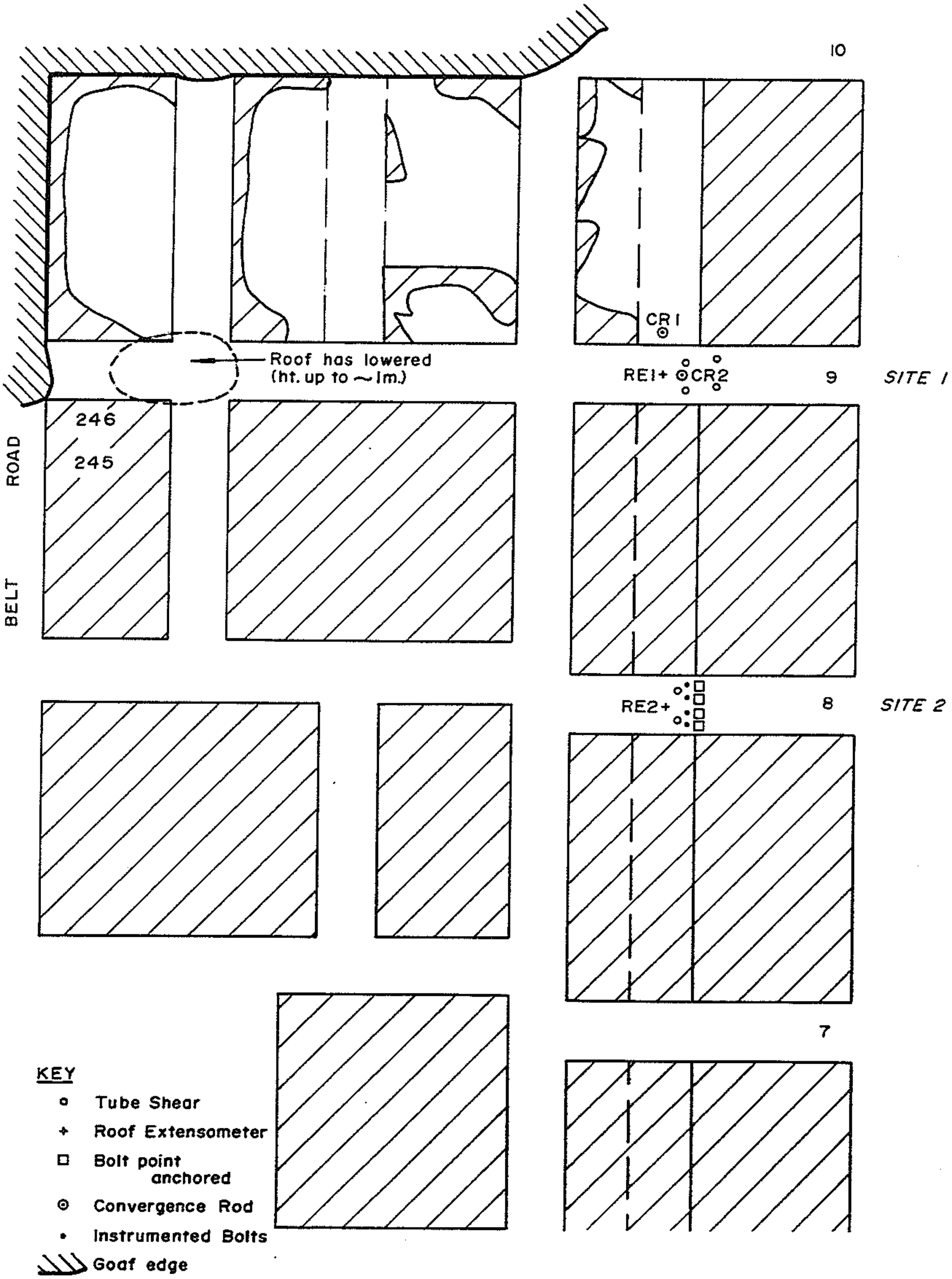
SCALE 1:600



20 JAN 1998: CONV.RODS INSTALLED AT SITE 1

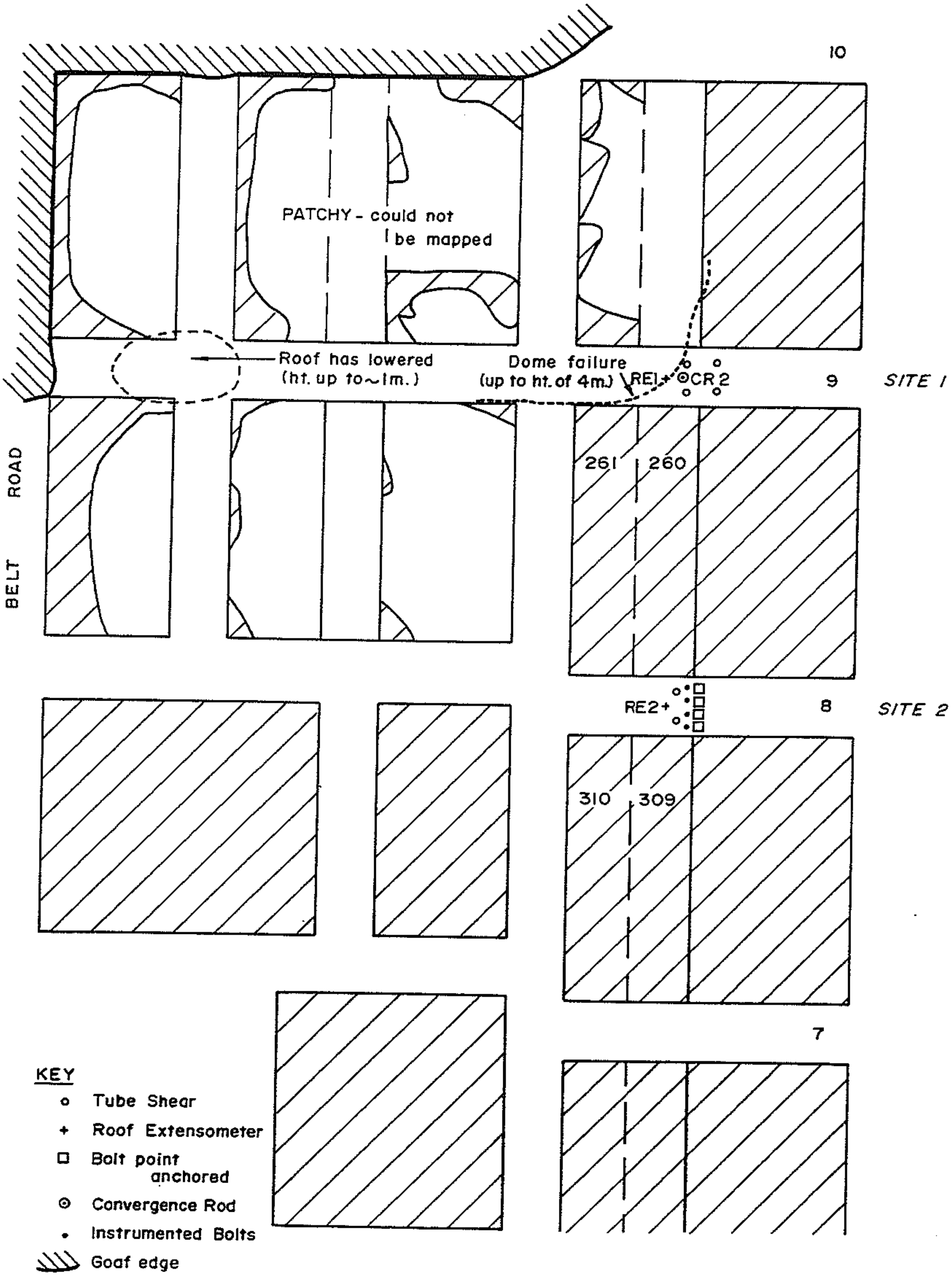
Note: CR1 showed floor heave of 20mm.

SCALE 1:600



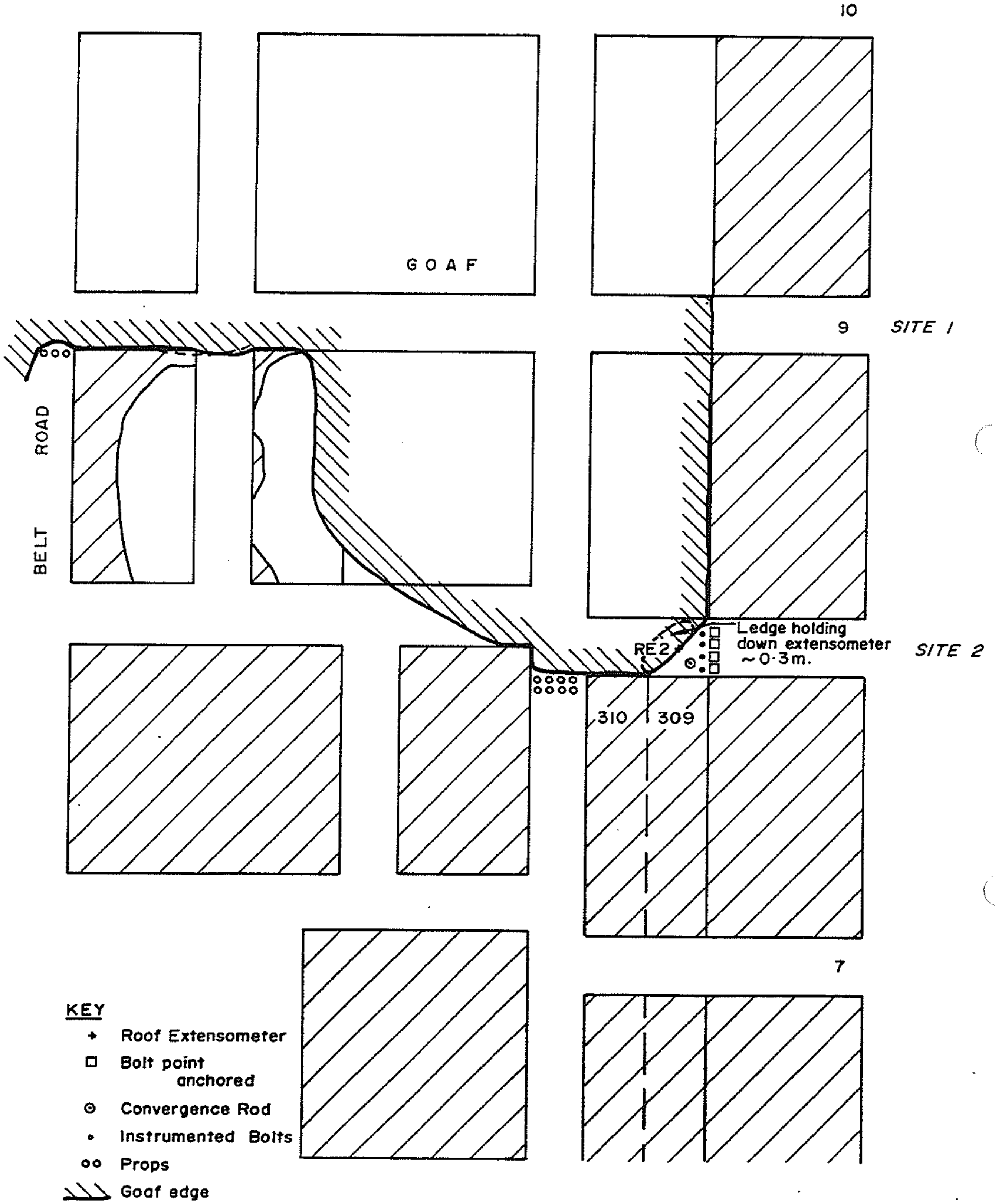
27 JAN 1998 : SPLIT 240 COMPLETED A/S
28 JAN 1998 : FENDER 242 TO START D/S

SCALE 1:600



30 JAN 1998: FENDER 261 TO START D/S

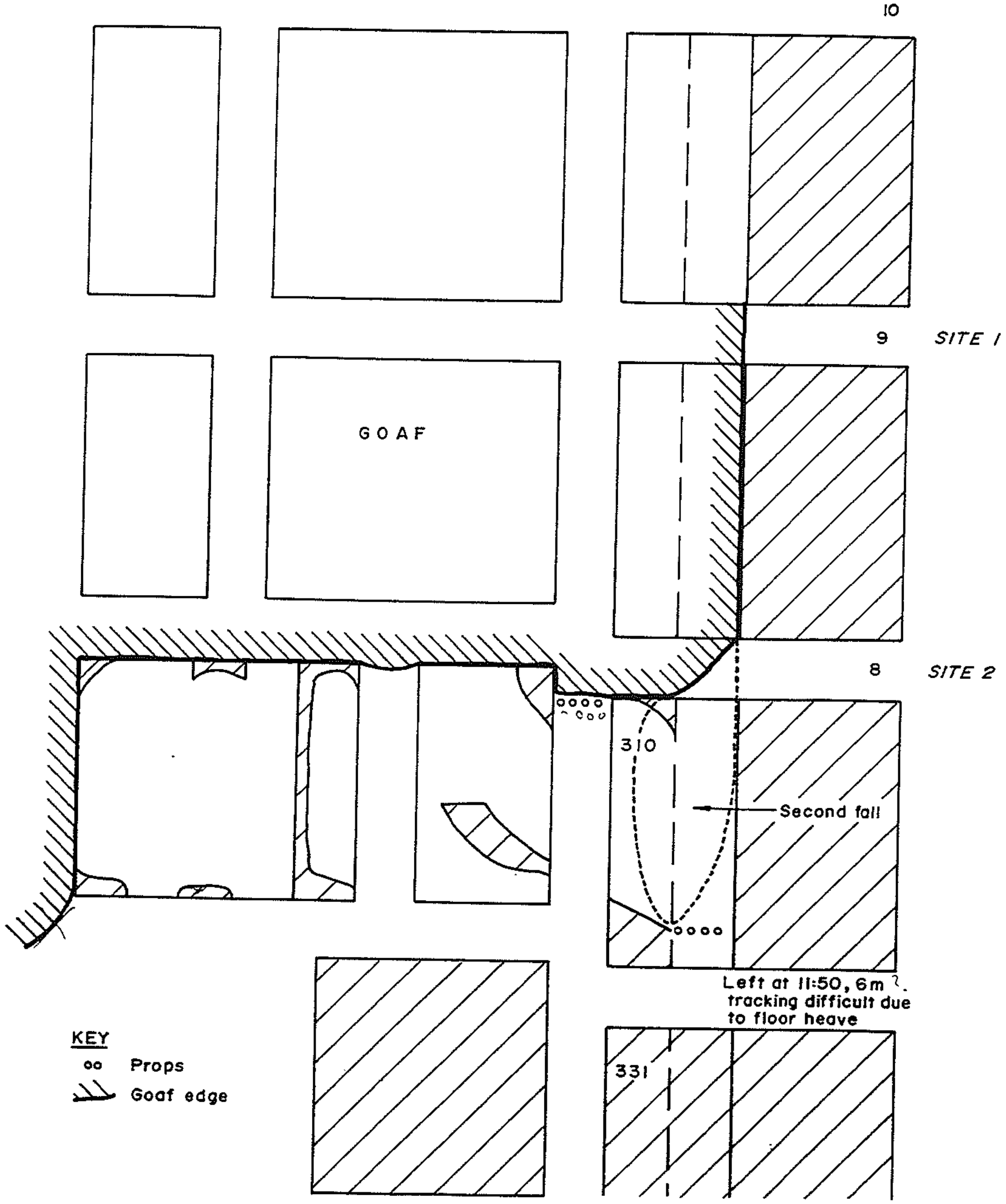
SCALE 1:600



30 JAN 1998: FINAL GOAF FALL SITE 1
FENDER 261 LIFTED

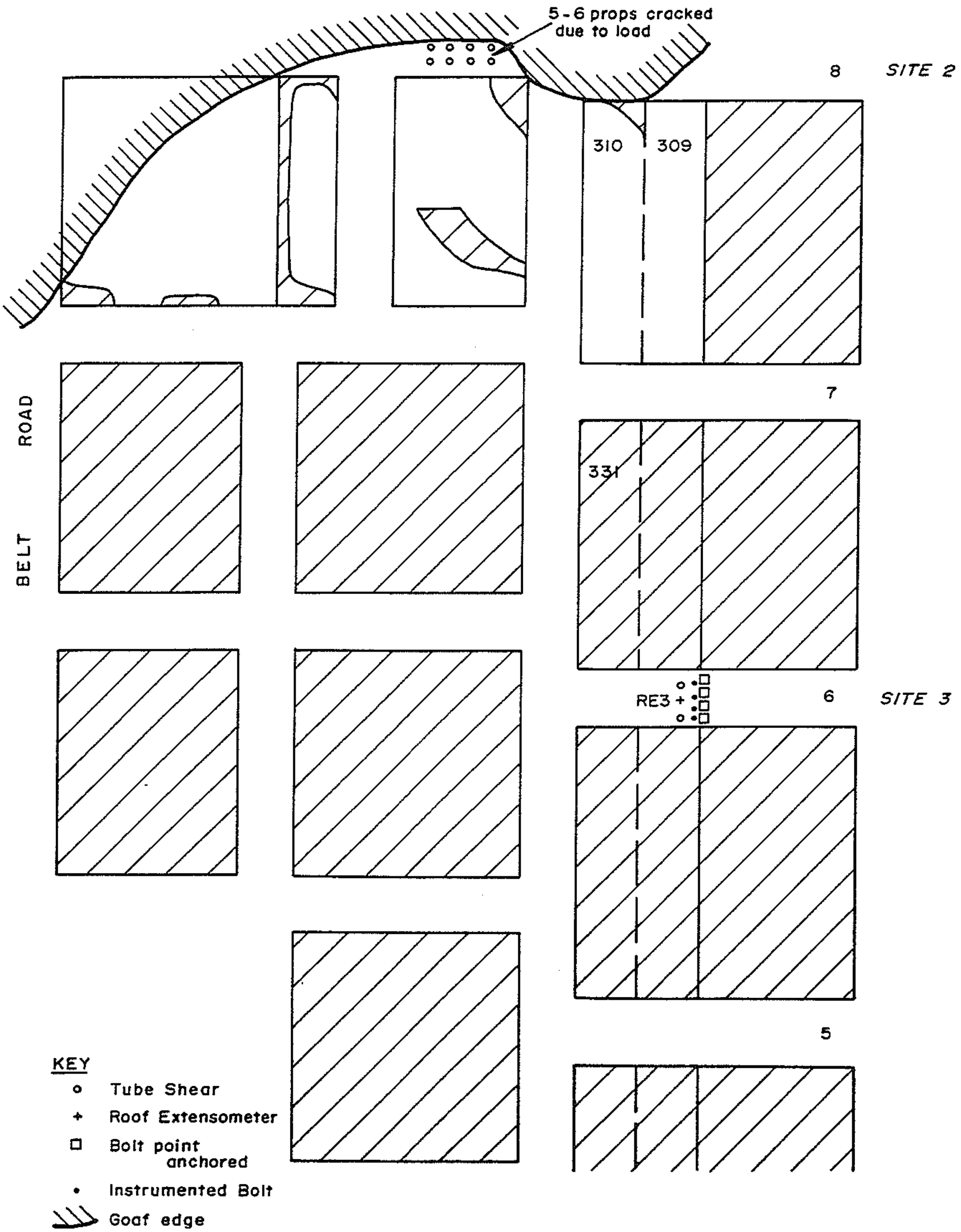
2 FEB 1998: RE2 RESET

SCALE 1:600



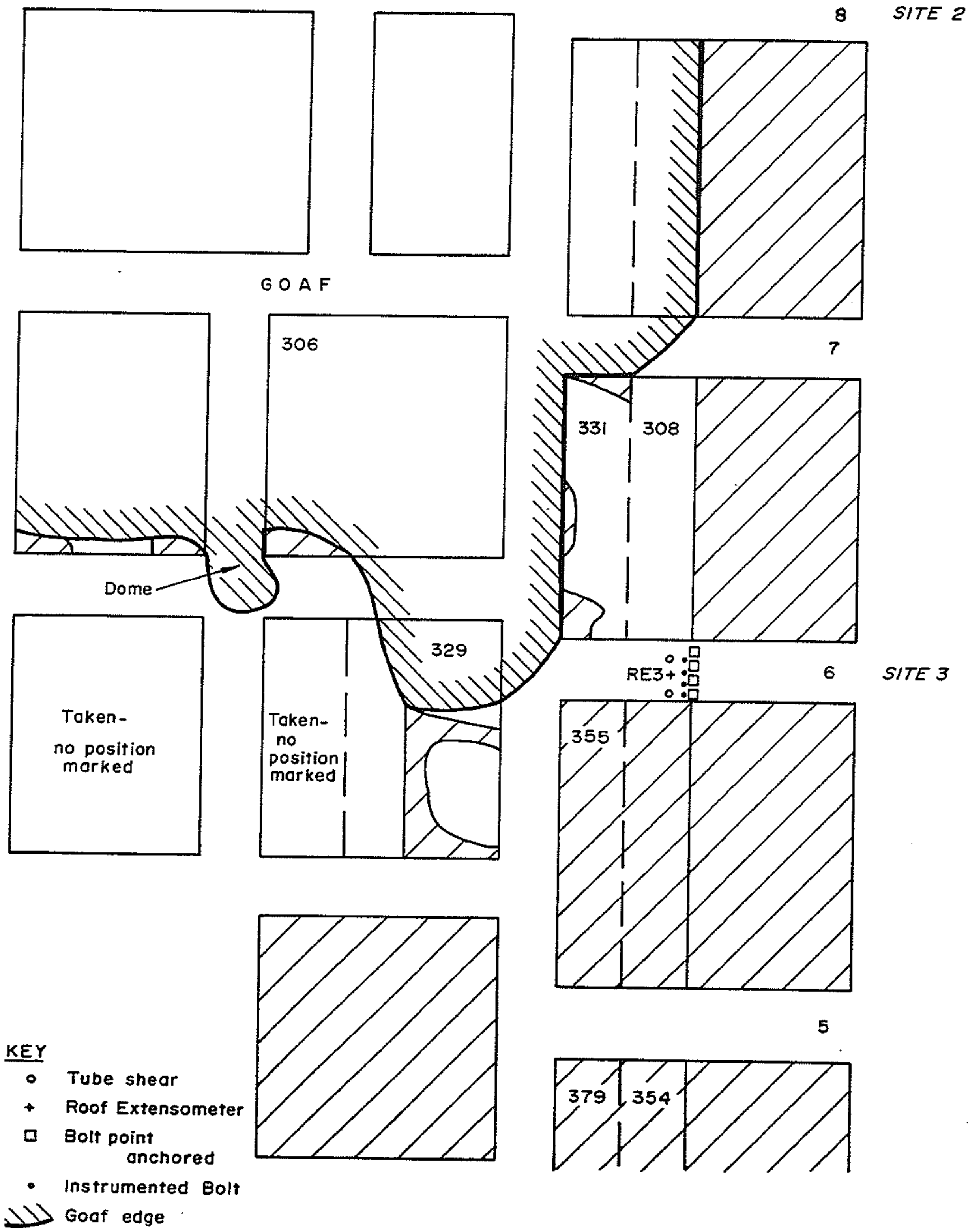
10 FEB 1998: 15:40 FIRST FALL
18:40 SECOND FALL

SCALE 1:600



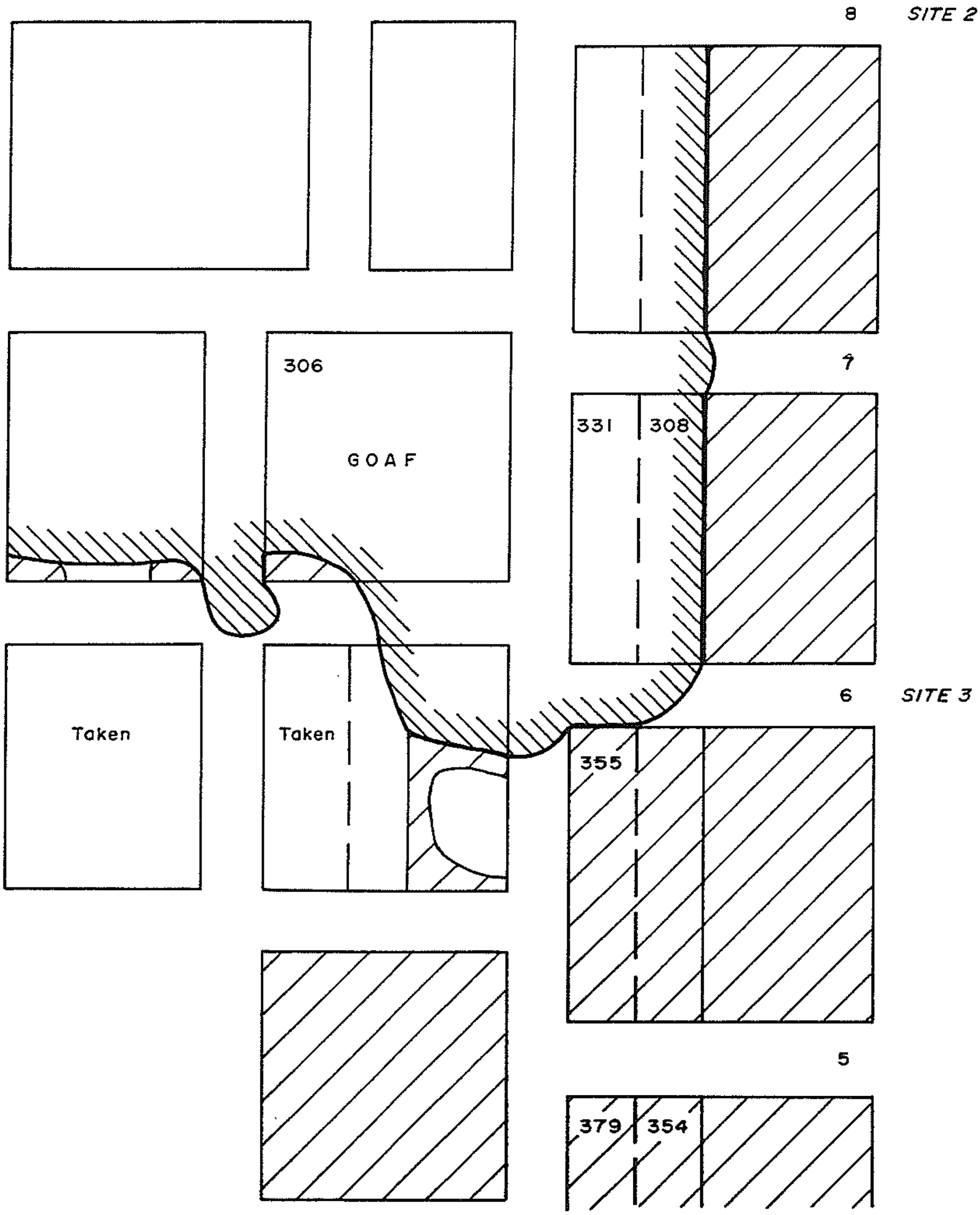
10 FEB 1998: RE3 AND INSTRUMENTED BOLTS AT SITE 3

SCALE 1:600



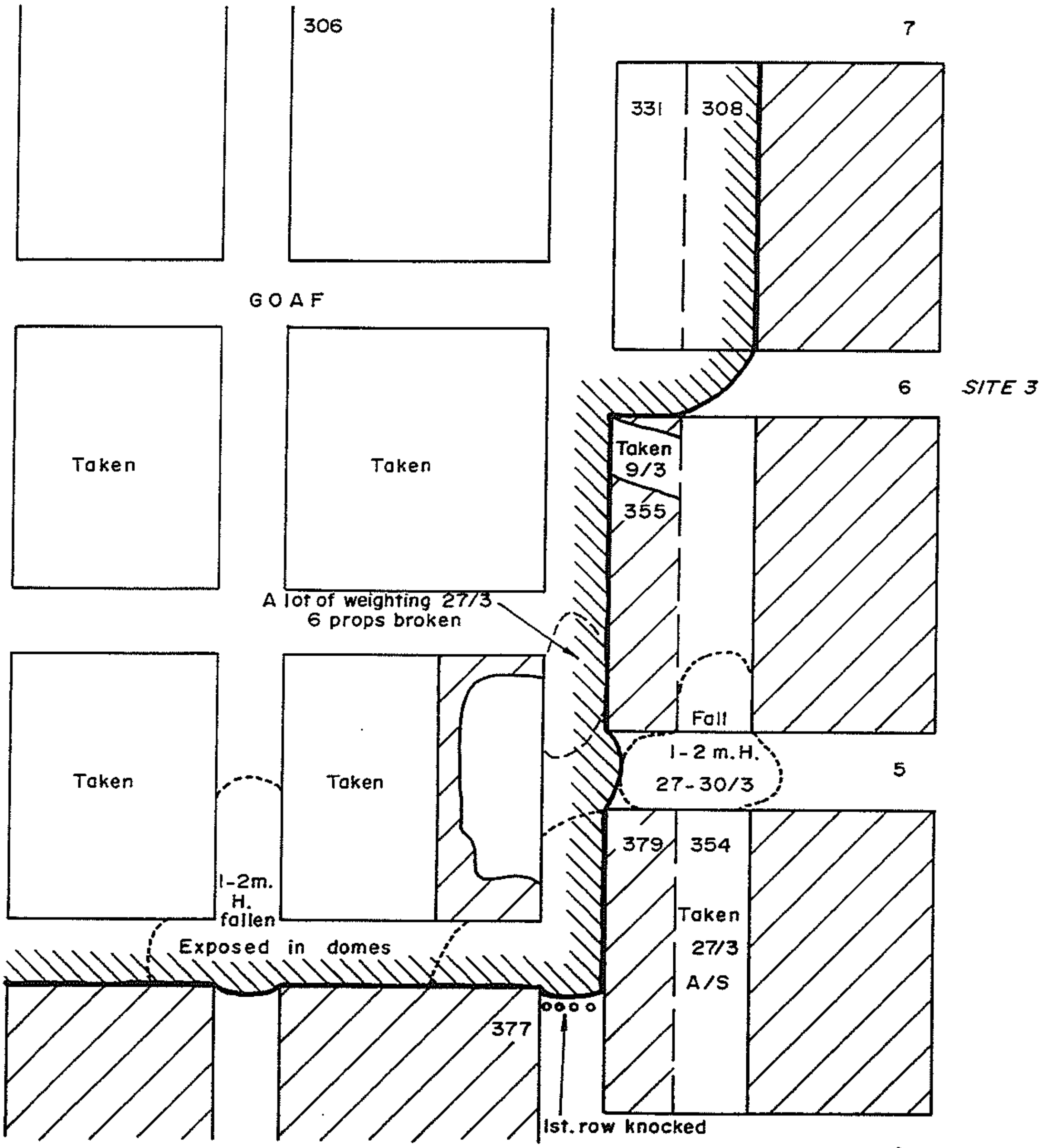
5 MAR 1998 : BEFORE KNOCKING DOWN OF RE3
AND CONVERGENCE RODS (22:15)

SCALE 1:600



7 MAR 1998: RE3 AND 3 CONVERGENCE RODS KNOCKED DOWN

SCALE 1:600



SCALE 1:600

SHEET 11

APPENDIX IV

Date	Activities
11.12.97	Installation of Extensometer & Tube Shears, Goaf edge 2 pillar length
	Christmas break
19.01.98	3 Conv. Rods fixed at site 1, only one gave reading.
20.01.98	3 Conv. Rods fixed at site 1(only one survived) after lifting S229.
20.01.98	Extensometer, Tube Shears & 4 instrumented bolts set at site 2.
30.01.98	**Fender lifting 261, Conv. Rod at site 1 final reading, goaf fall affecting (site :2) RE2 also, Sequence 245-259 changed on 28.01.98**
02.02.98	Reset RE2 but of no use.
05.02.98	14.30 : Reset RE2 but of no use.
09.02.98	Fender 284(in revised plan) taken, no change in Conv. Rod.
10.02.98	RE3, Tube shears & Instrumented bolts set at site 3, F-310 (3/4th taken), **goaf fall at 15.40** knocking Conv. Rods at site 2 , **Followed by another fall at 18.40** (bolt readings only at site 2). Site 3 not even 3-way junction.
05.03.98	Site 3 become 4-way junction, part of fender 331 left, Conv. Rods set.
06.03.98	Holiday
07.03.98	**Goaf fall,** 3 Conv. Rods and **RE3** knocked down, bolt readings- no appreciable change.
09.03.98	Water pressure problem for Continuous Miner & fender (355) left after 1 fender cut. 1 Conv. Rod set at Site 3.
30.03.98	(During the weekend, roof fall in 5 C/T area,) left-fender355 abandoned.
28.04.98	Final bolt-readings taken at site 2 and site 3. Conv. Rod near the breaker-lines Gives no reading-change and inconclusive reading-change for the other Conv. Rod.

APPENDIX IV

Site 1 SB 8 (Conv. Rod) Site 1, Rod 2 30 January 1998

Time (in hr.)	Reading	Remarks
7.30	8.9	Fender lifting in S261 to be started
8.05	8.9	Belt-shifting, supporting breaker-line props at intersection 9 c/t and S260
8.35	8.9	Lift 1 started
10.30	9.0	Lift 2 holed-up 10.25
11.00	9.1	20 mins. breaks & lift 3 started at 10.55
11.30	9.1	Lift 4A and 4 started 11.15
12.00	9.4	Lift 4 holed-up at 11.35
12.15	9.6	Lift 5 started at 12.15
12.20	10.0	Rolling fragments & goaf sounds clear and intermittent
12.25	10.1	
12.35	10.2	Break in cutting operation for 10 mins., weighting on props
12.40	10.3	
12.43	10.4	
12.45	10.5	
12.47	10.6	Break for supporting (10 mins)
12.50	10.7	
12.52	10.8	
12.54	10.9	
12.55	11.0	Break in cutting operation for 15 min. 2 props broken
12.56	11.3	
12.58	---	Total goaf fall dislodging the Rod & knocking RE2 of site 2

Site 2 SB1 (Conv. Rod) Site 2 9 February 1998

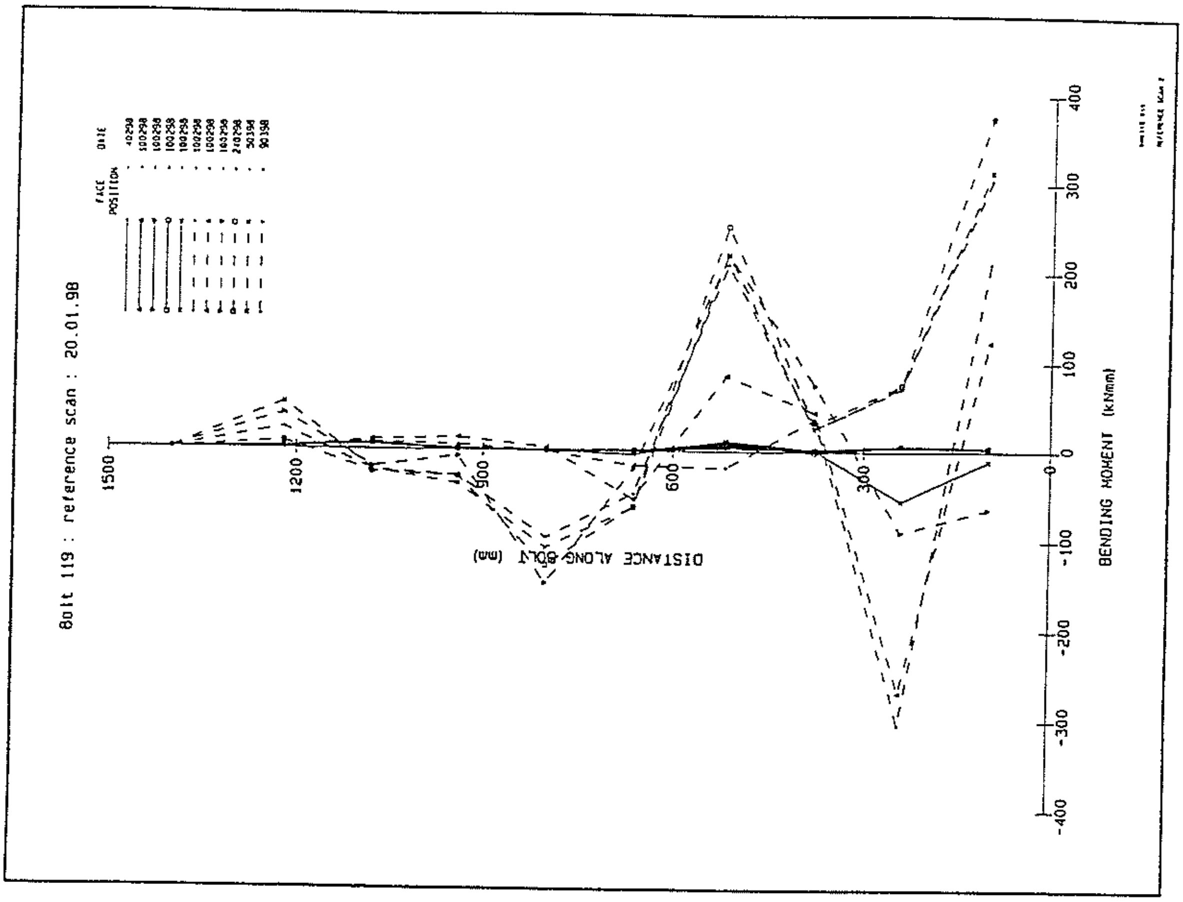
Time (in hr.)	Reading	Remarks
8.45	0.4	Installed today when a part of fender S280 is yet to be taken
17.45	0.4	Split S282 (revised plan) holed up to the goaf
18.25	0.4	Fender S283 part holed
19.25	0.5	Fender S283 partly holed again finishes fender 283
21.00	0.5	End of the production shift

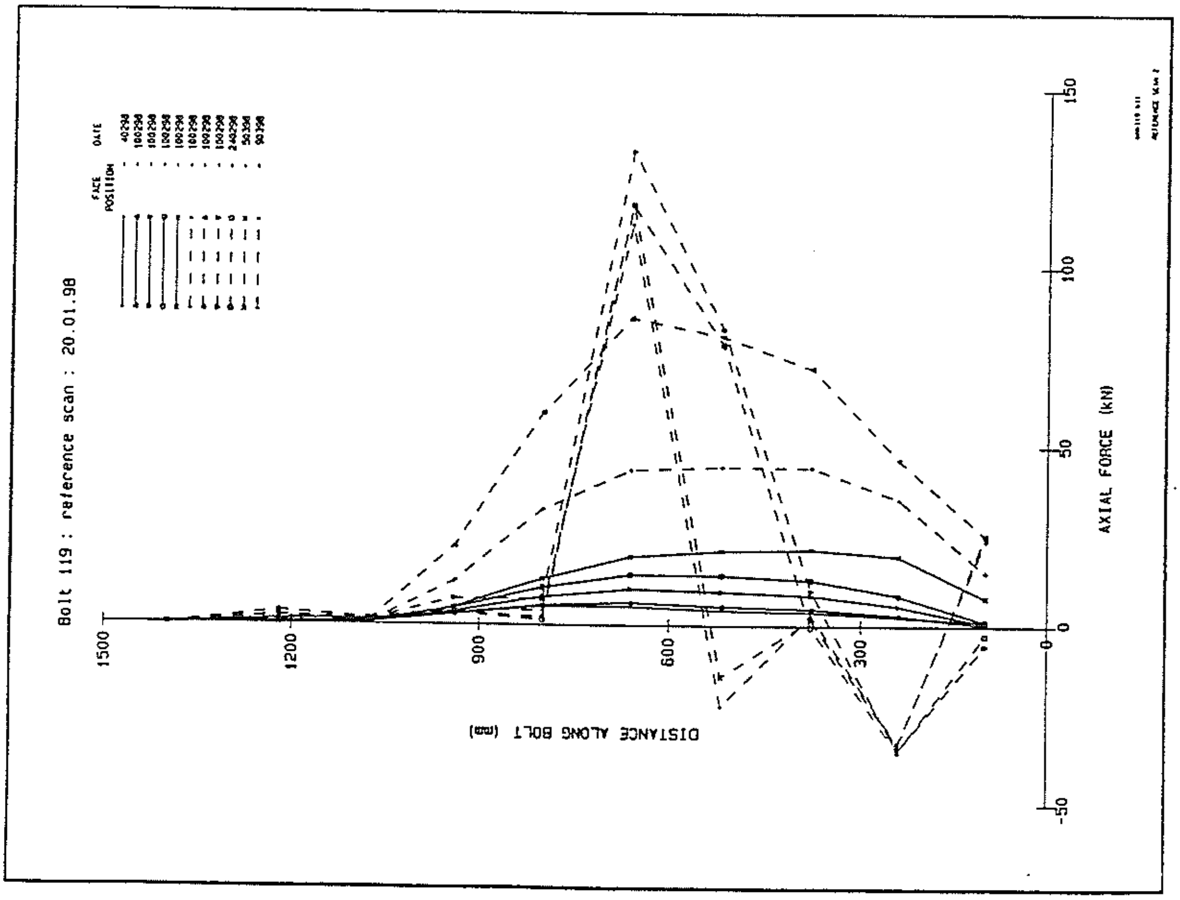
Site 2 SB1 (Conv. Rod) Site 2 10 February 1998

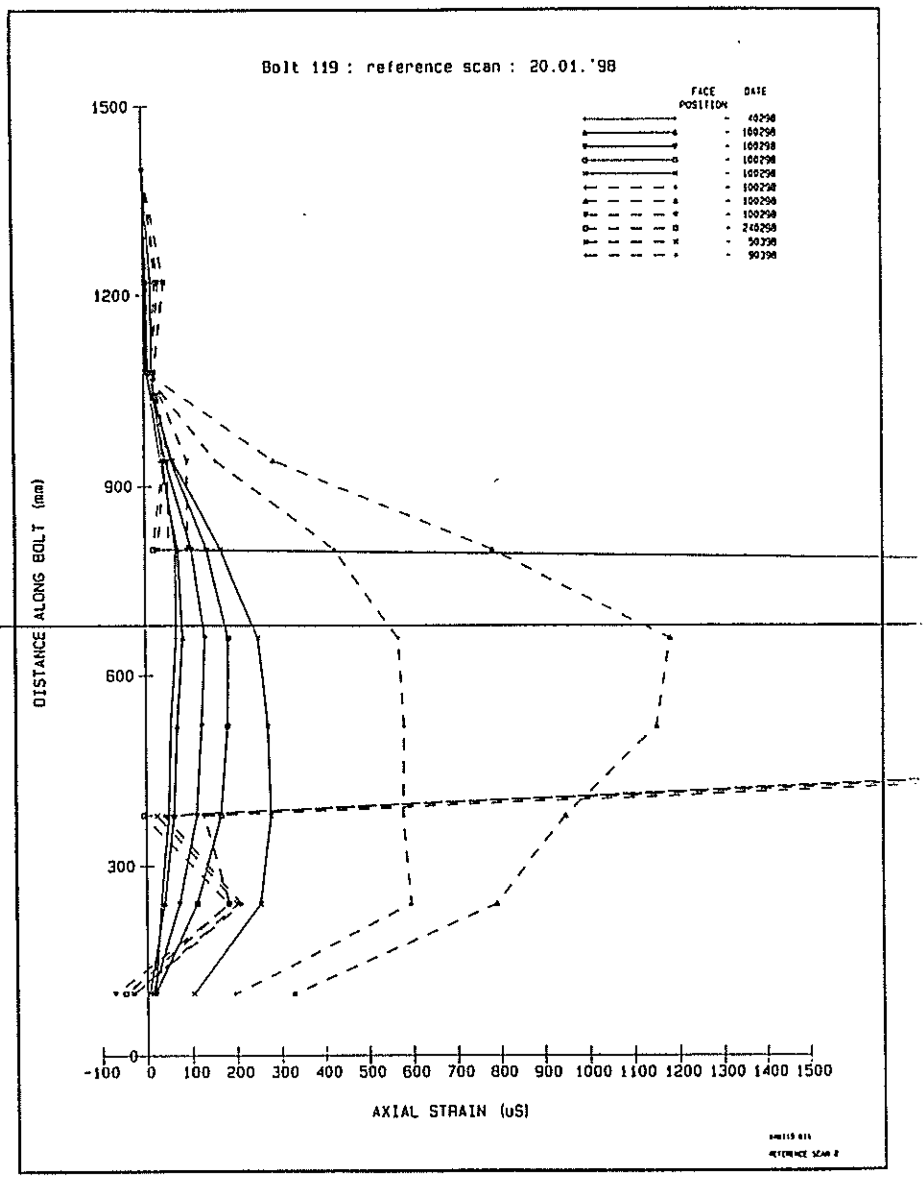
Time (in hr.)	Reading	Remarks
7.35	0.6	Fender S310 (renamed S285) started at 8.30 to be taken as per plan
9.15	0.9	Lift 3 holed up at 9.10
9.45	1.0	Lift 5 started 9.35
10.20	1.2	
10.30	1.3	Sound of fall in goaf
11.30	1.5	Lift 6 started 10.50
11.50	1.6	6 holed up 11.50, large stooks left
12.05	1.5	Break for supporting (10 mins.)
12.10	1.5	
14.10	1.7	
15.40	7.2	Goaf fall at 15.40, suggesting recent secondary fall to follow
15.42	13.2	Knocked down by the goaf fall

APPENDIX V

Instrumented bolt data plots, raw and analysed tabulated data







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FACE POSITION
DATE
40298
100298
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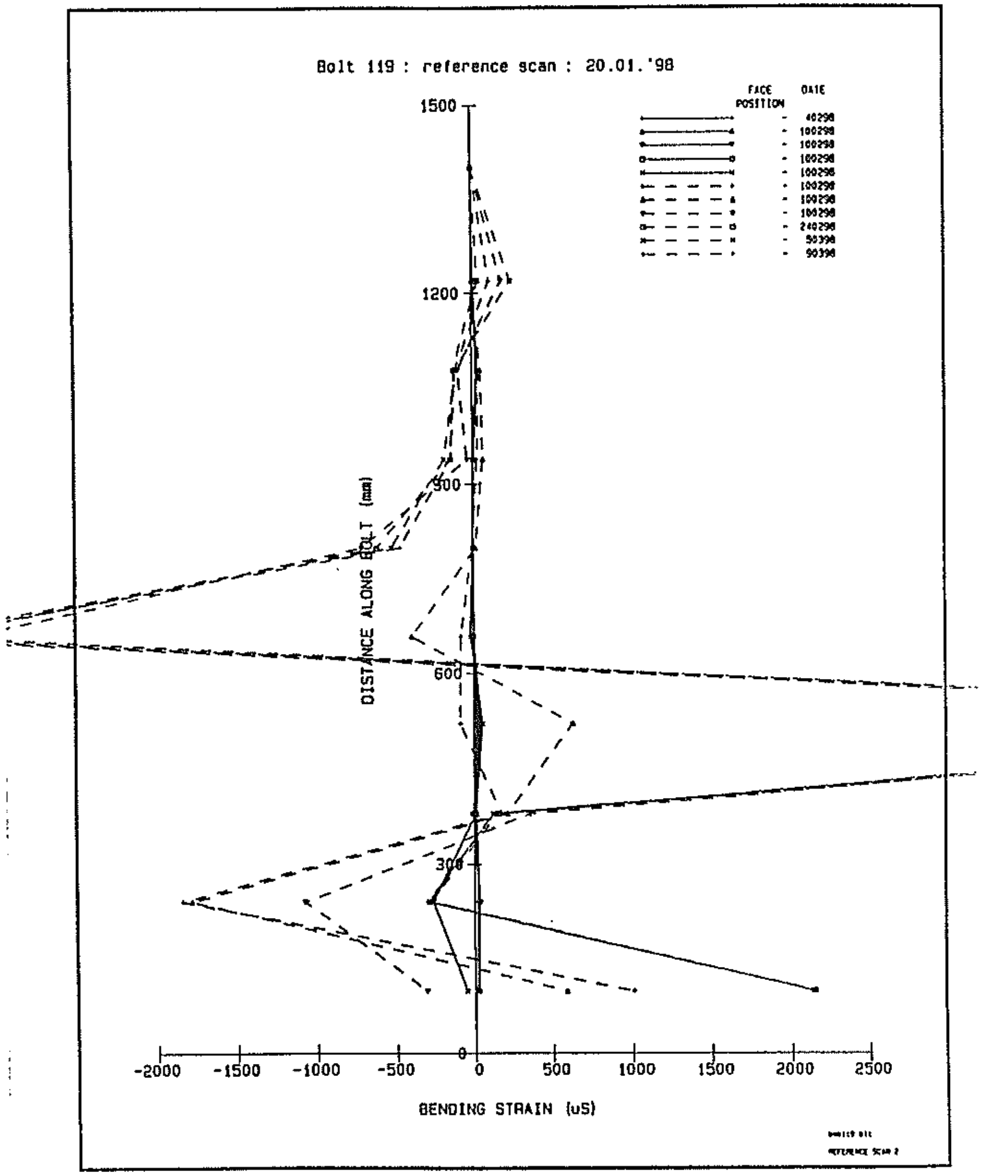
90398
DISTANCE ALONG BOLT (mm)
AXIAL STRAIN (uS)



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FACE POSITION
DATE
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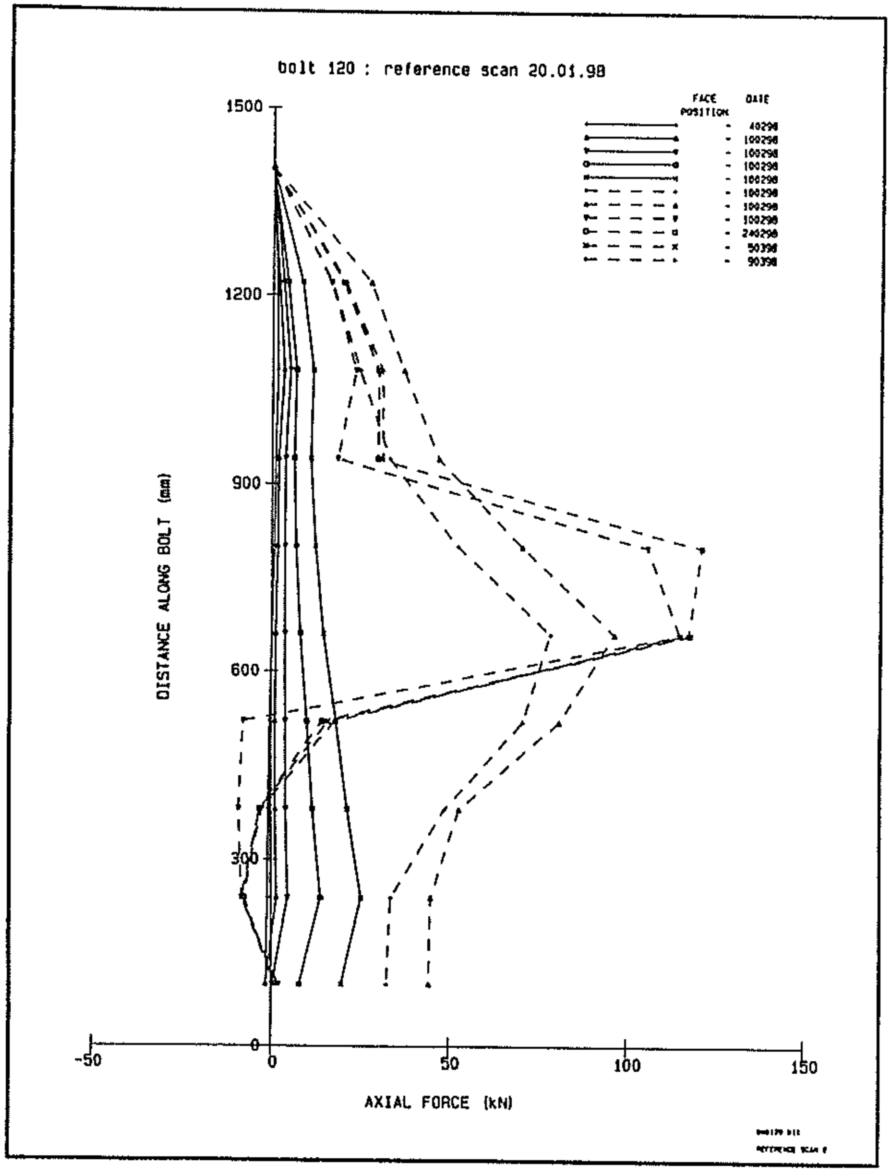
DISTANCE ALONG BOLT (mm)
BENDING STRAIN (uS)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100298
100298
240298
50398
90398
DISTANCE ALONG BOLT (mm)
1500
1200
900
600
300
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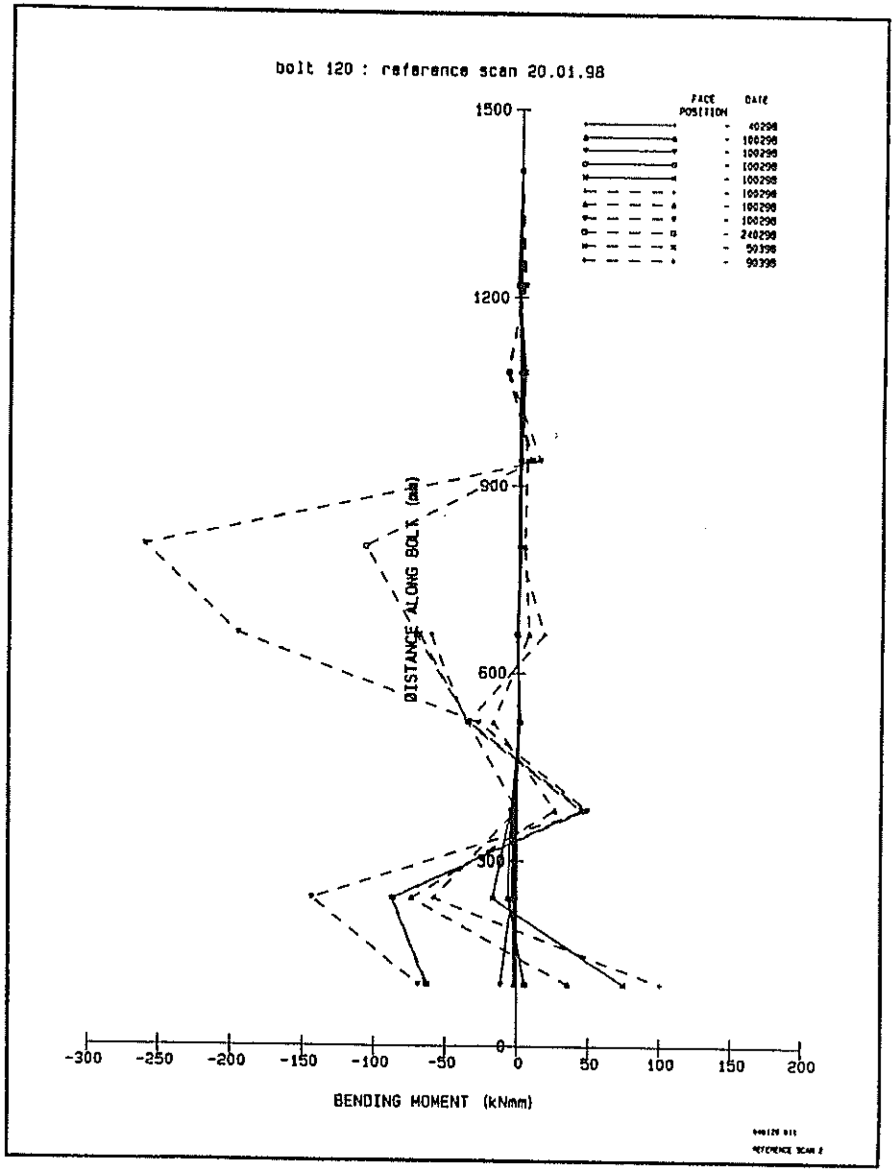
-50
0
50
100
150
AXIAL FORCE (kN)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FACE POSITION
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240298
50398
90398
DISTANCE ALONG BOLT (mm)
1500
1200
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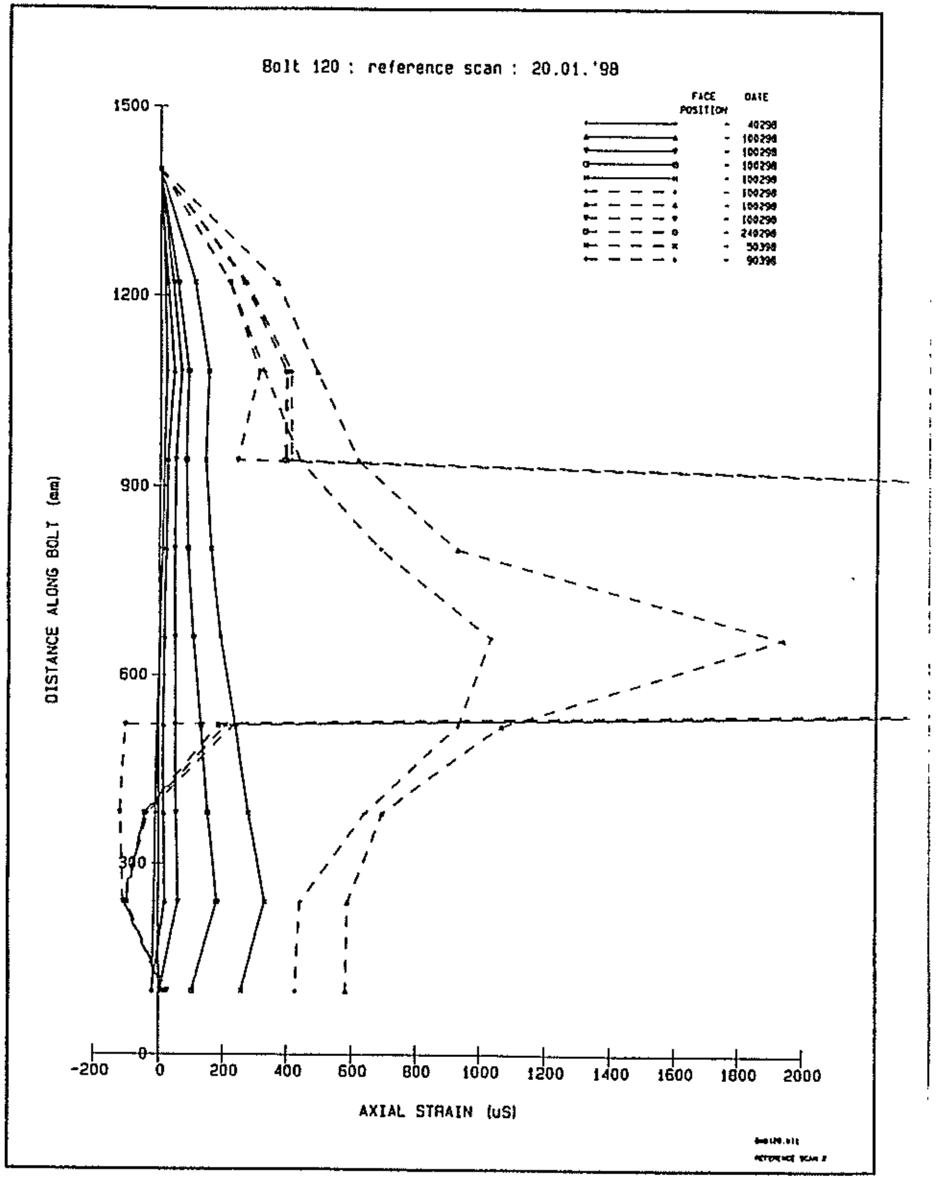
BENDING MOMENT (kNmm)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FACE POSITION
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90398
DISTANCE ALONG BOLT (mm)
AXIAL STRAIN (uS)
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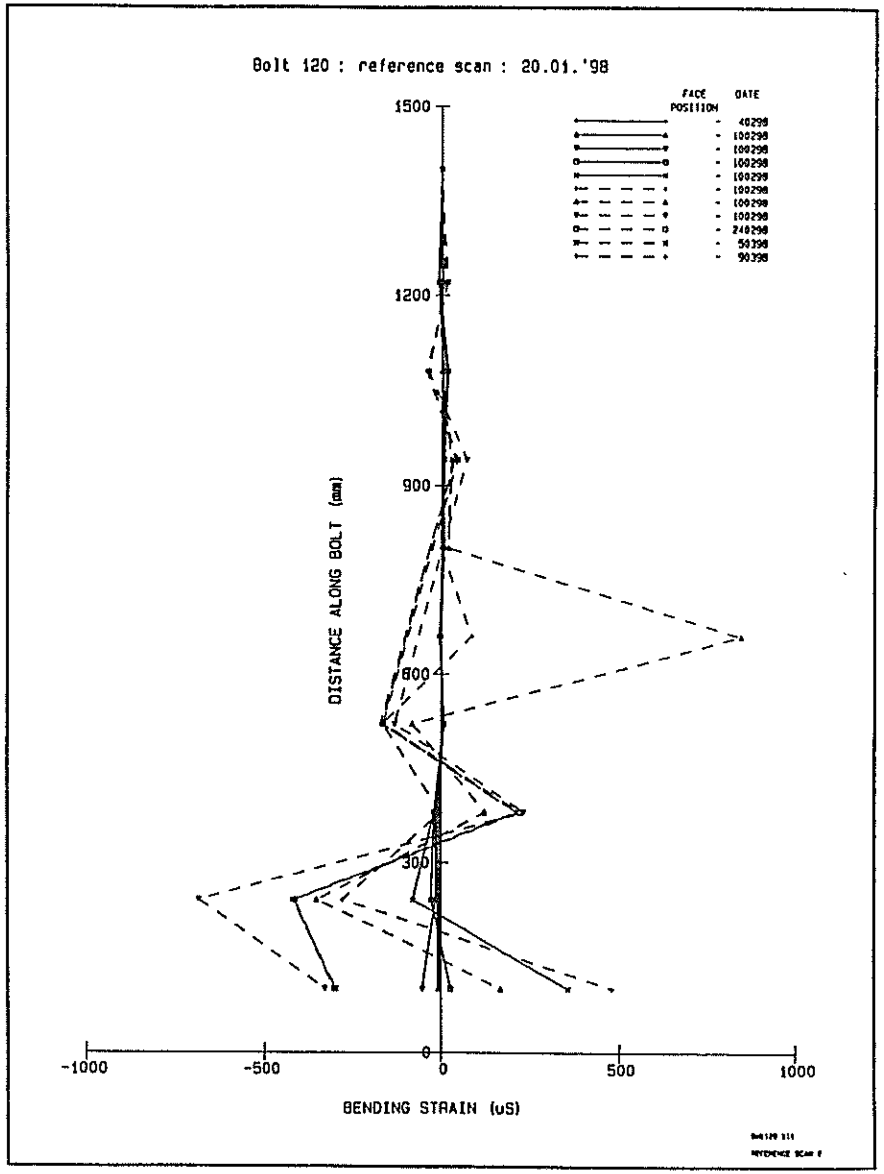
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FACE POSITION
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DISTANCE ALONG BOLT (mm)
BENDING STRAIN (uS)
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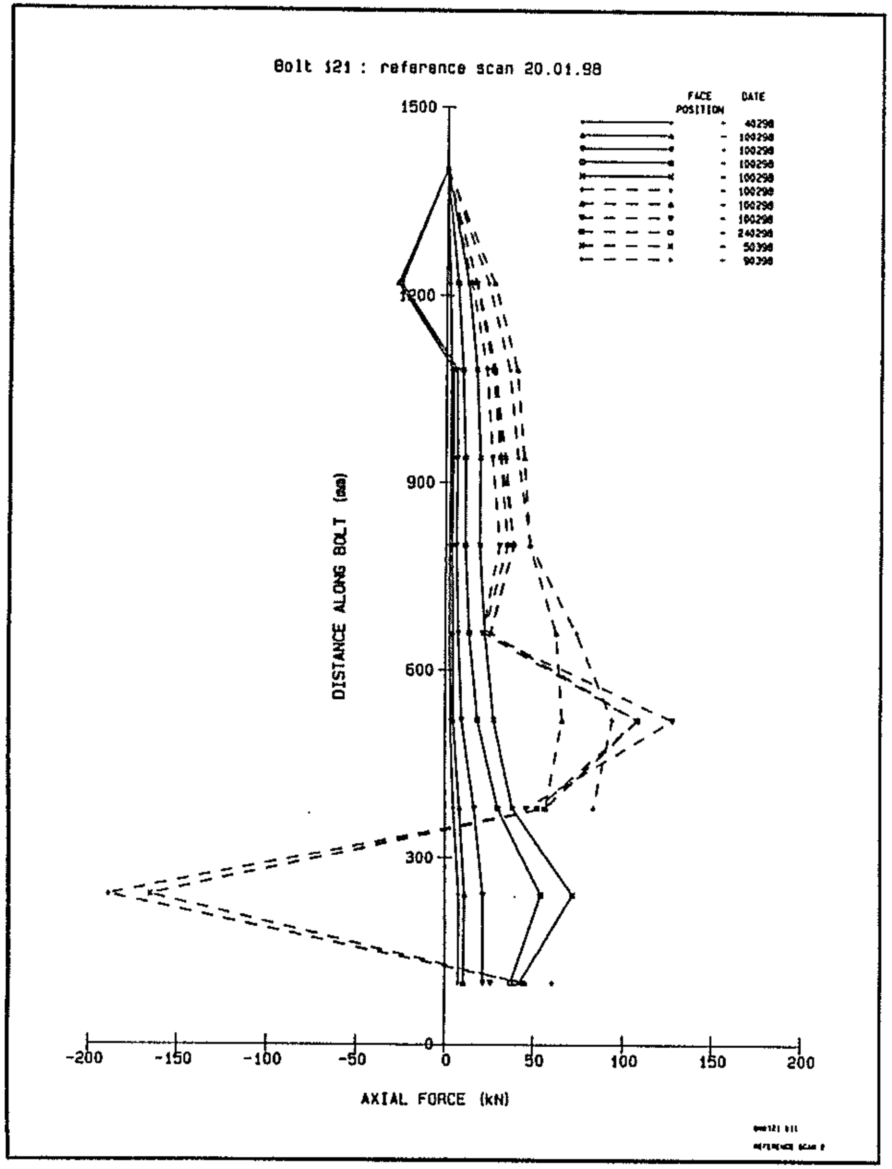
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90398
DISTANCE ALONG BOLT (mm)
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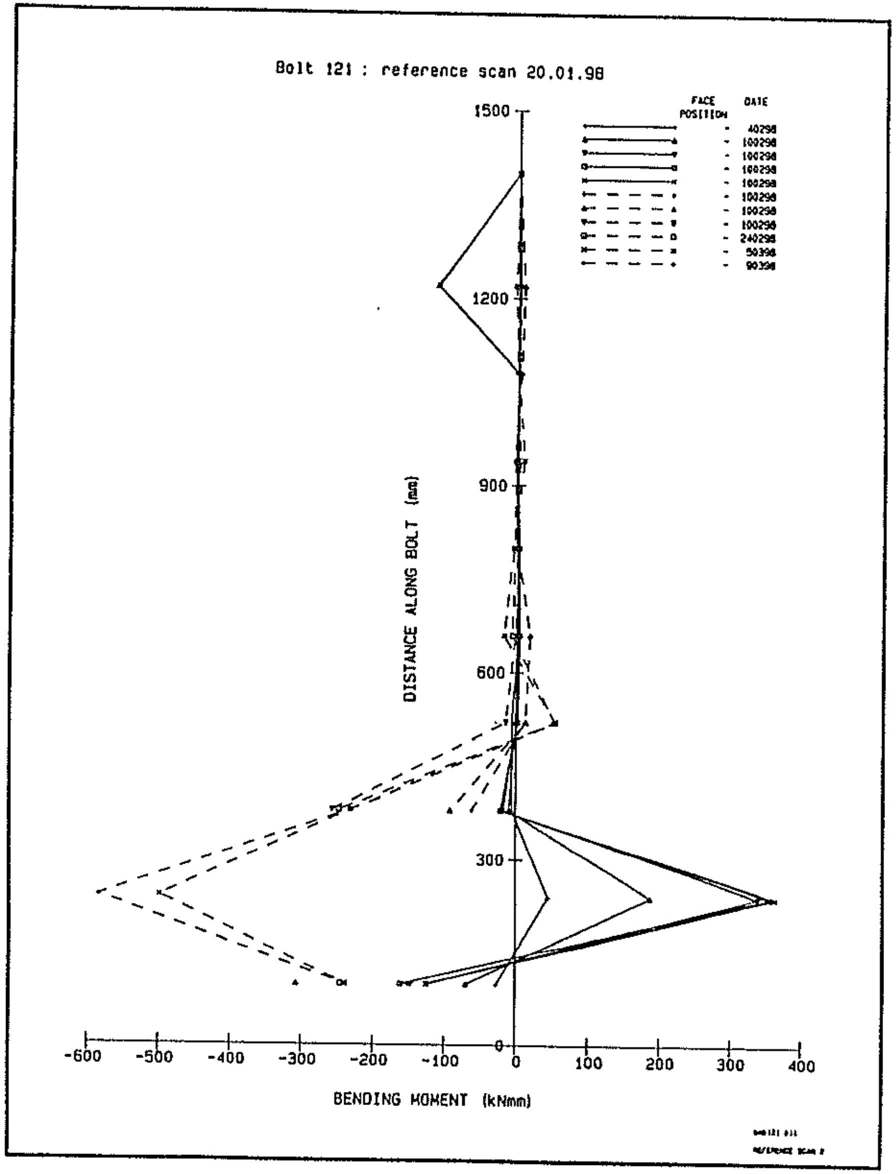
200
AXIAL FORCE (kN)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90398
DISTANCE ALONG BOLT (mm)
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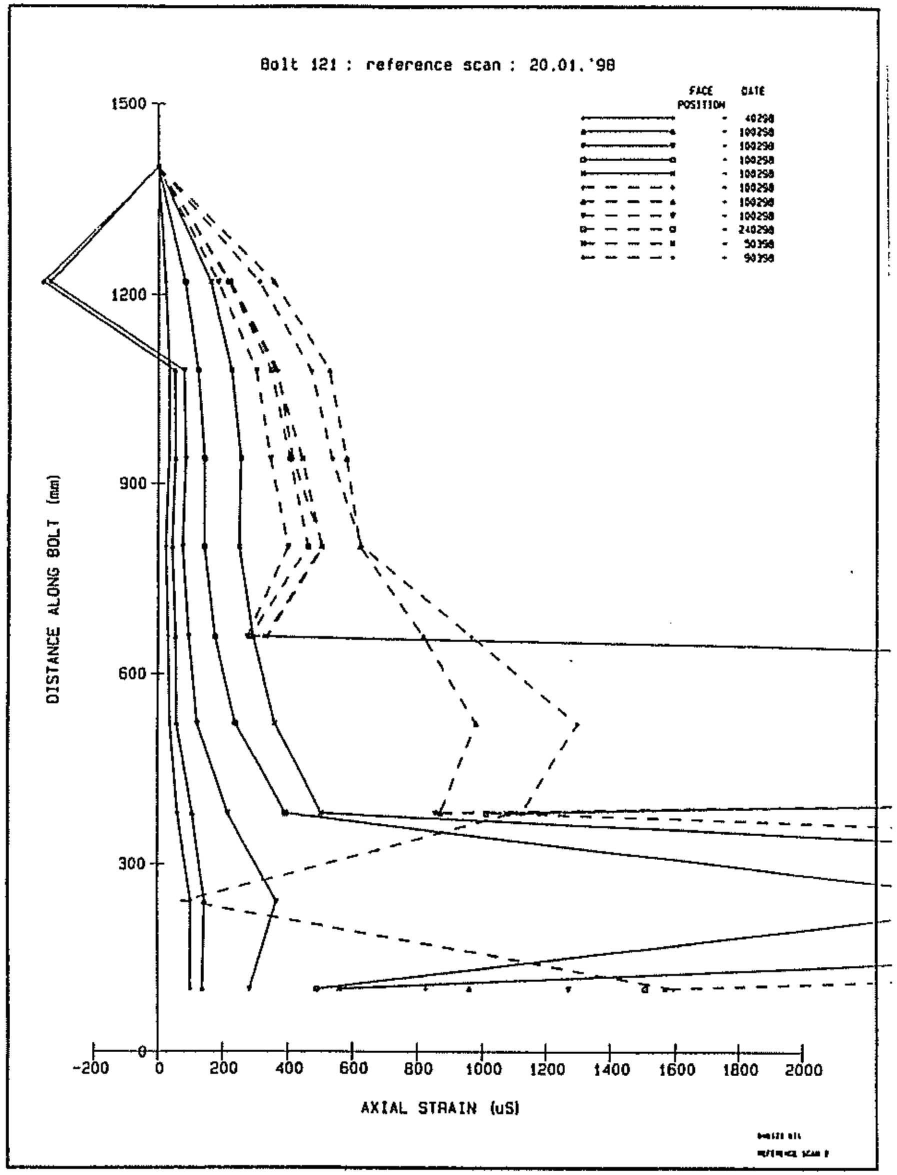
BENDING MOMENT (kNmm)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50398
90398
DISTANCE ALONG BOLT (mm)
AXIAL STRAIN (uS)
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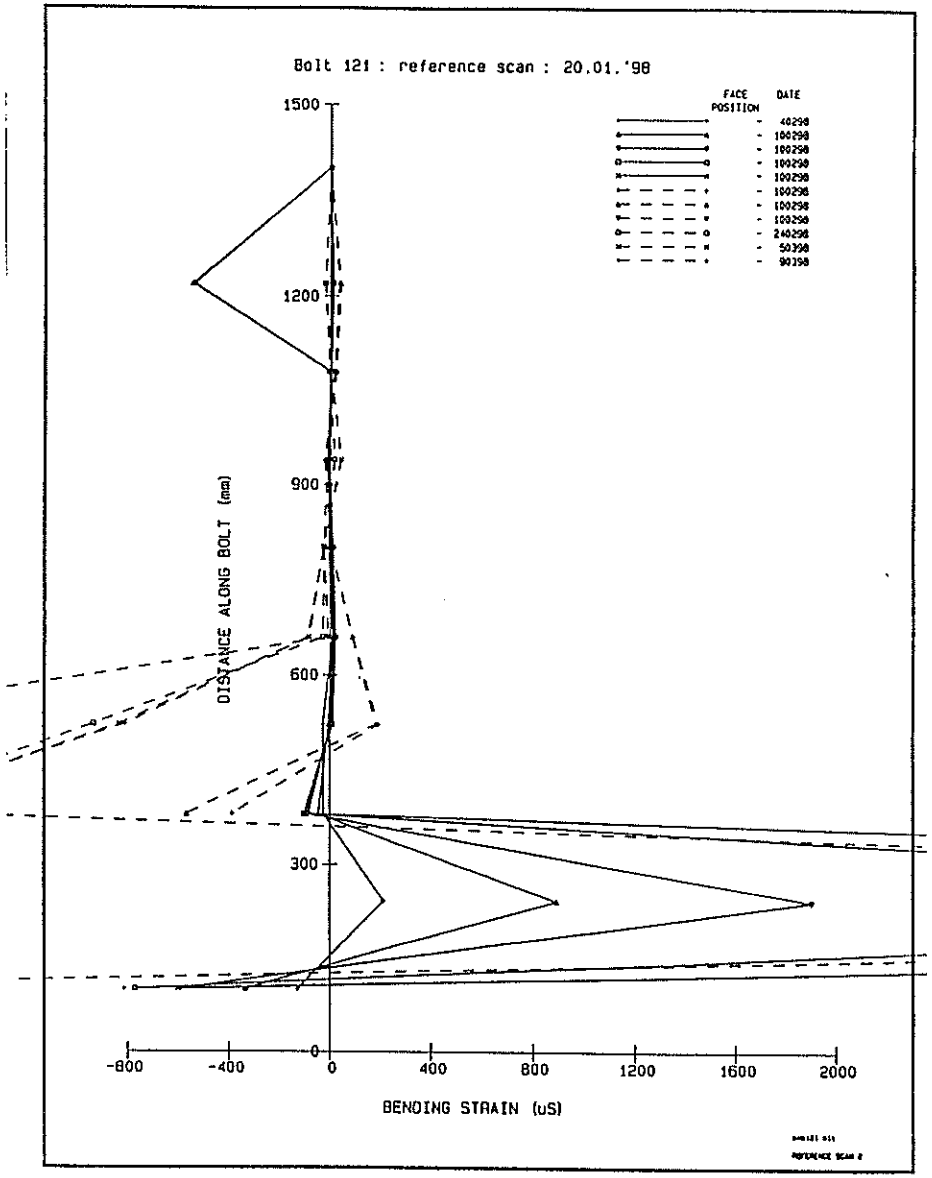
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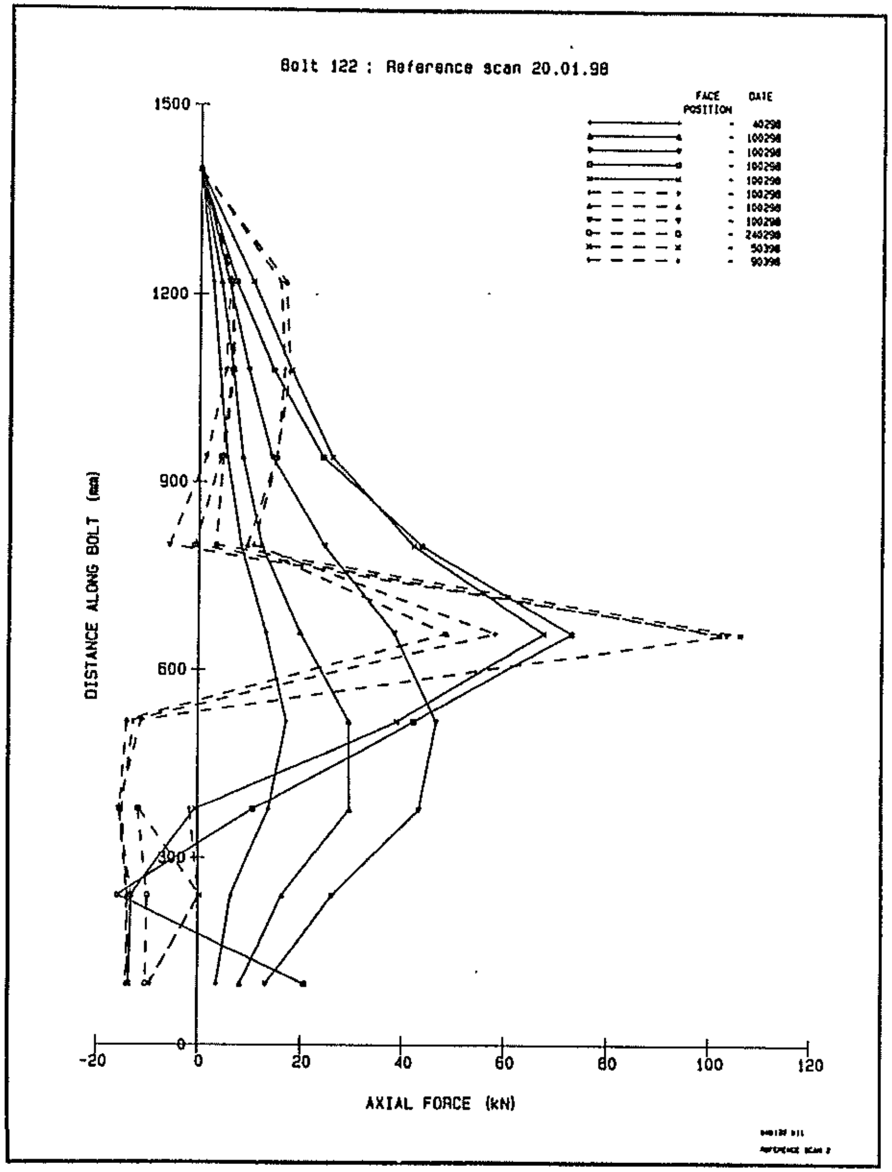

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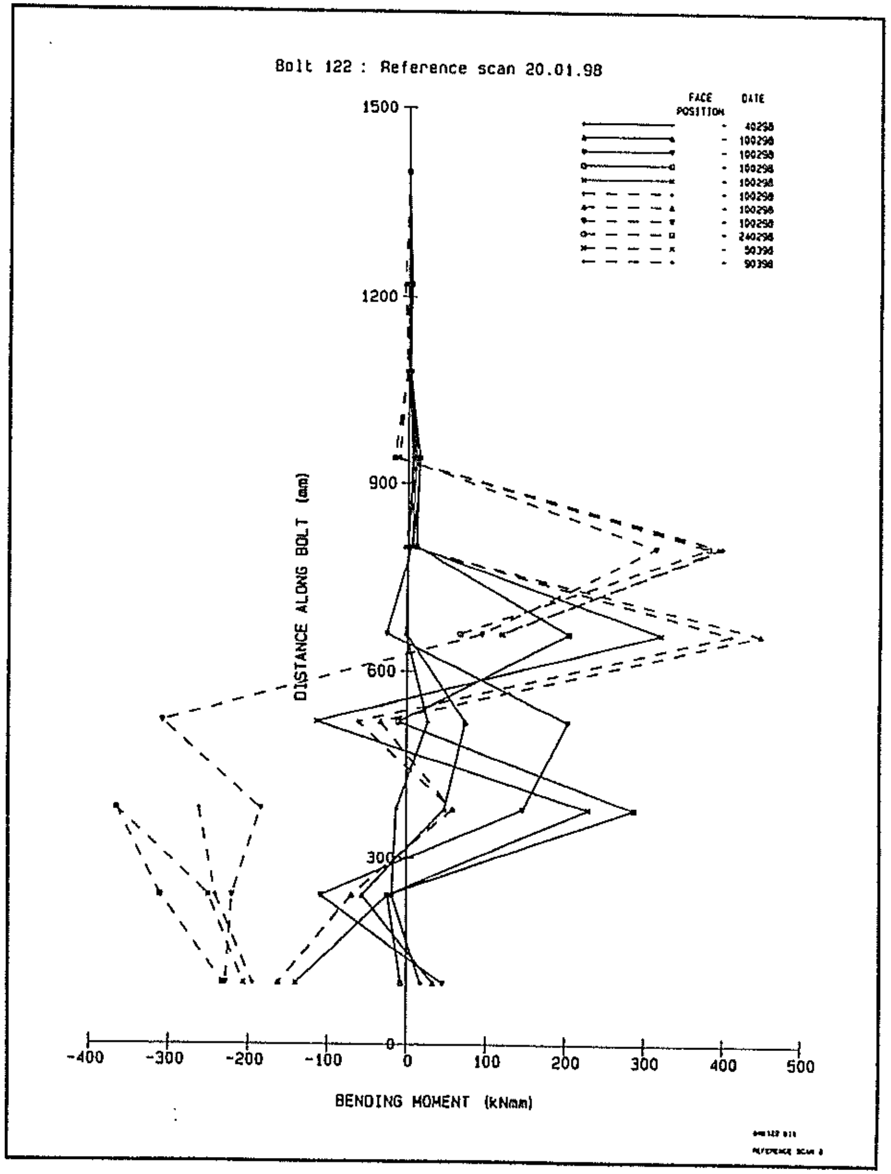
AXIAL FORCE (kN)



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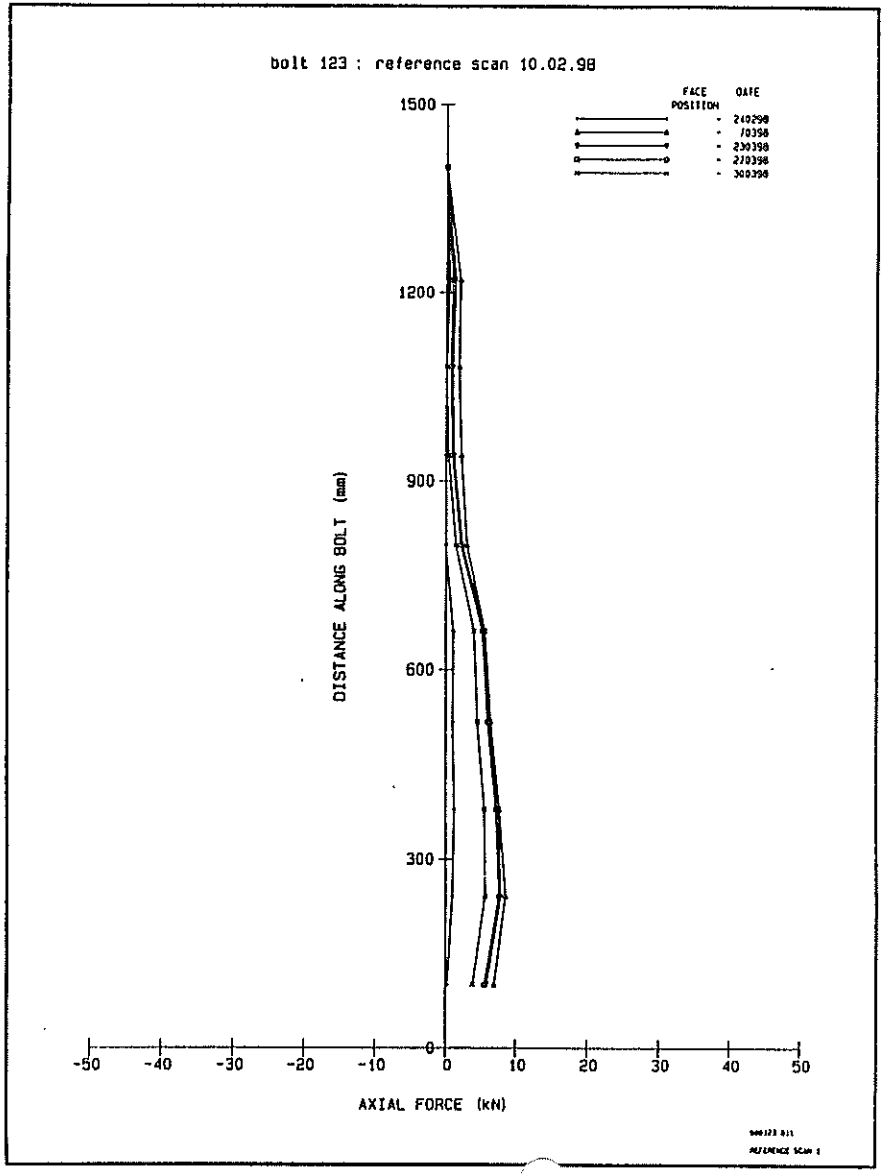
BENDING MOMENT (kNmm)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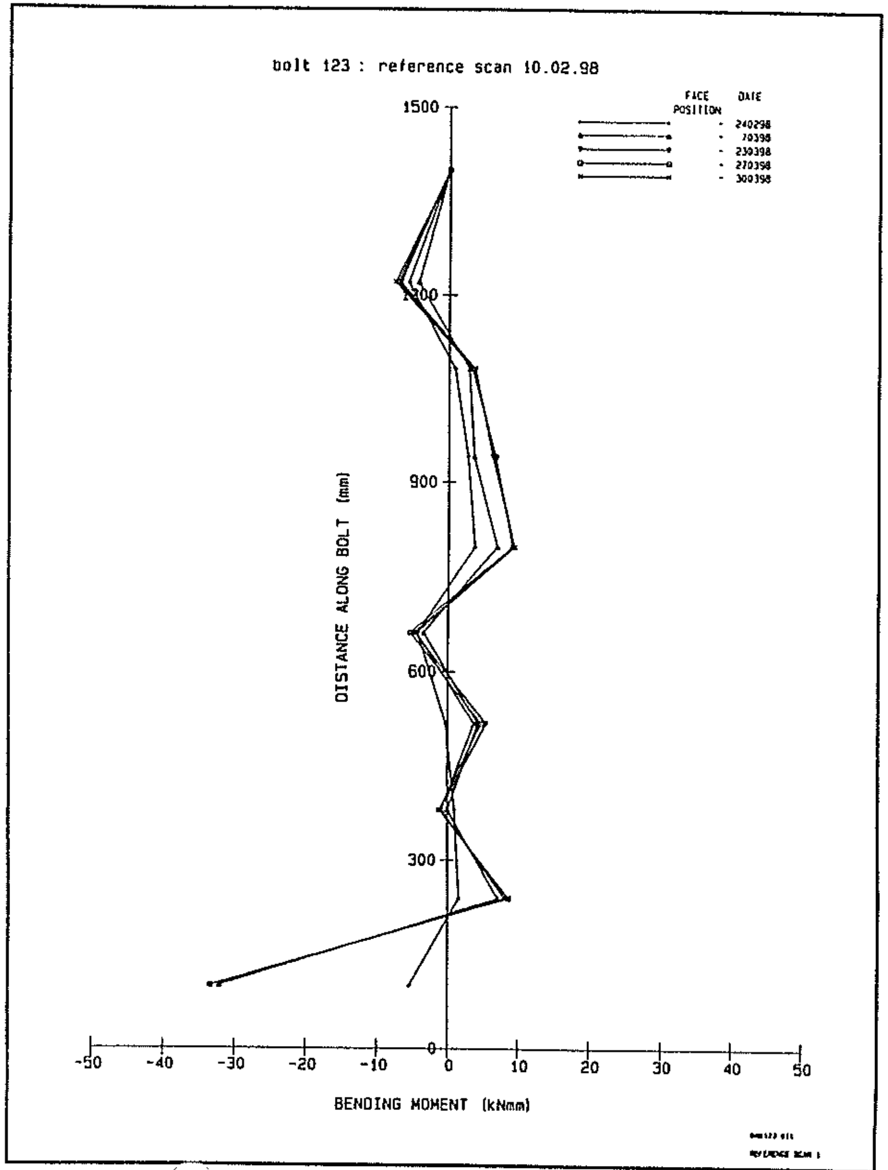
DISTANCE ALONG BOLT (mm)
AXIAL FORCE (kN)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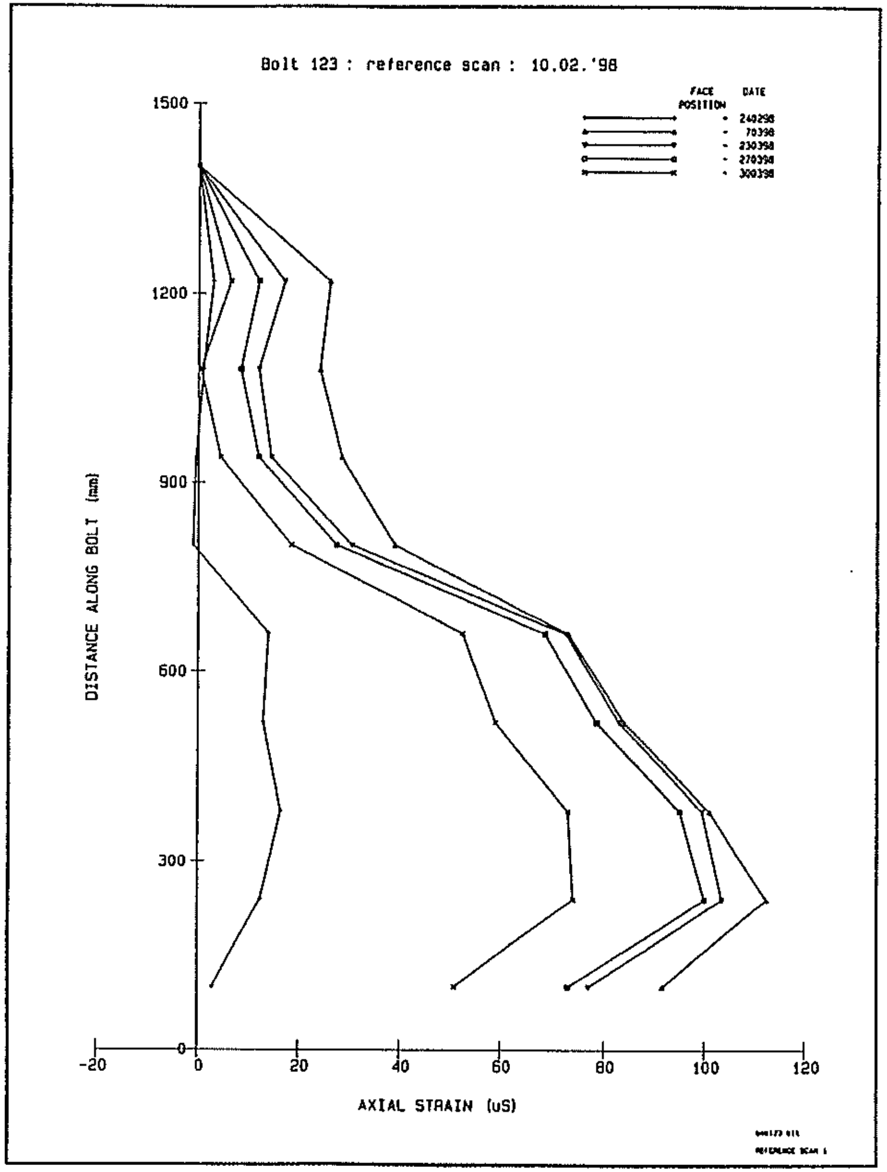
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DATE
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230398
270398
300398
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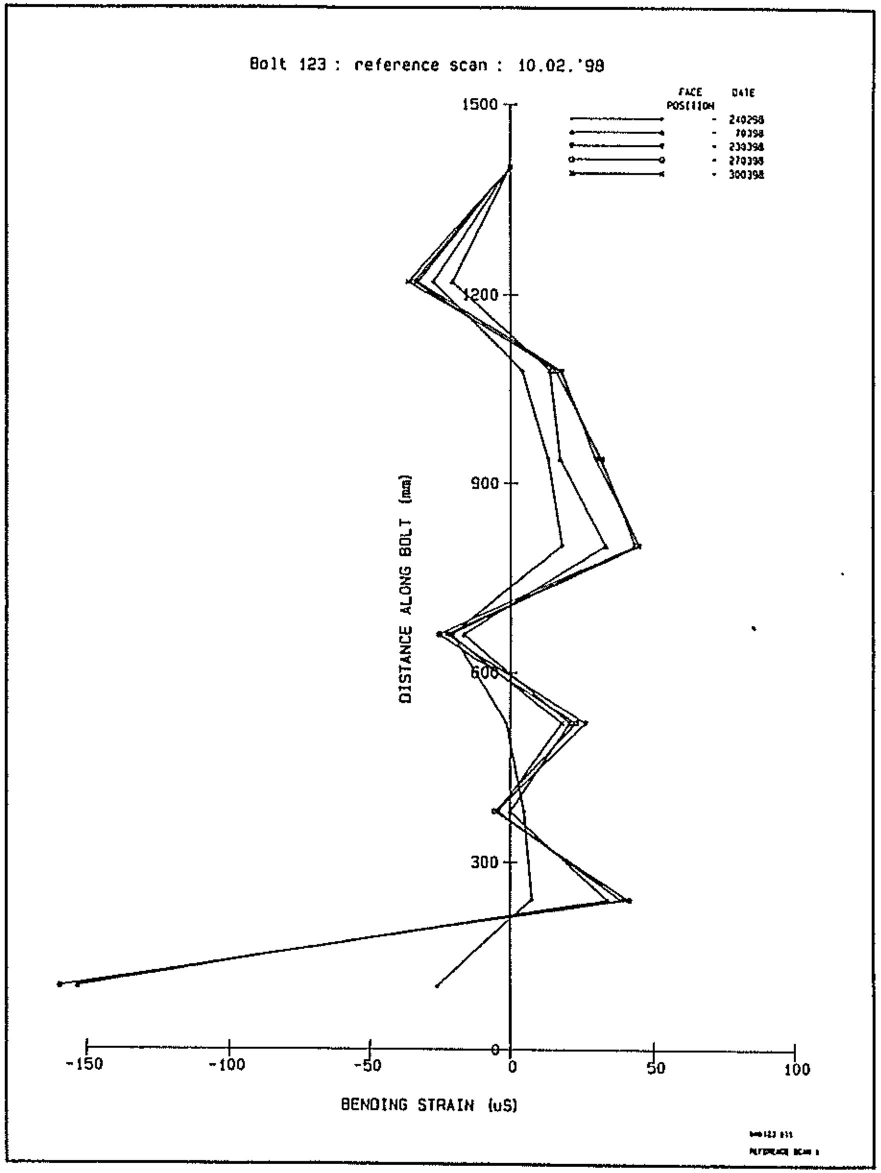
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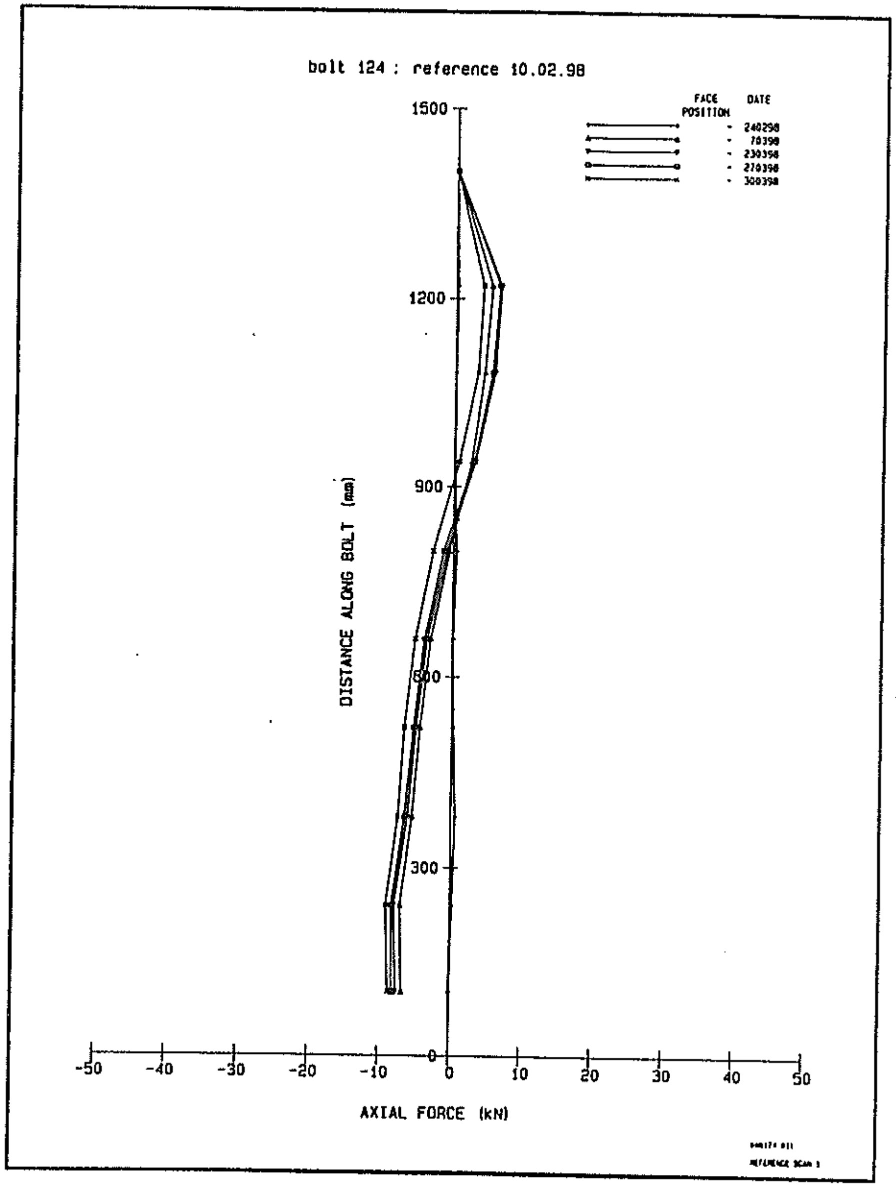
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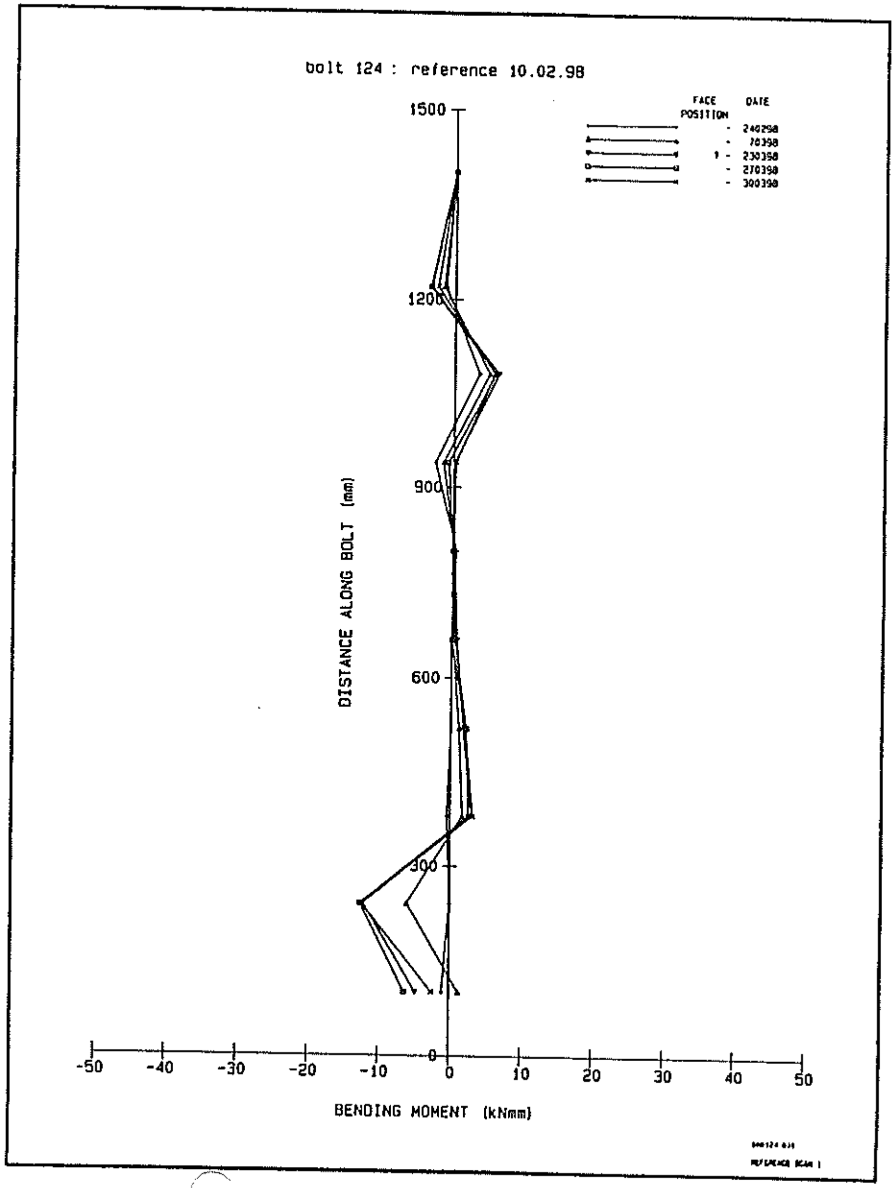
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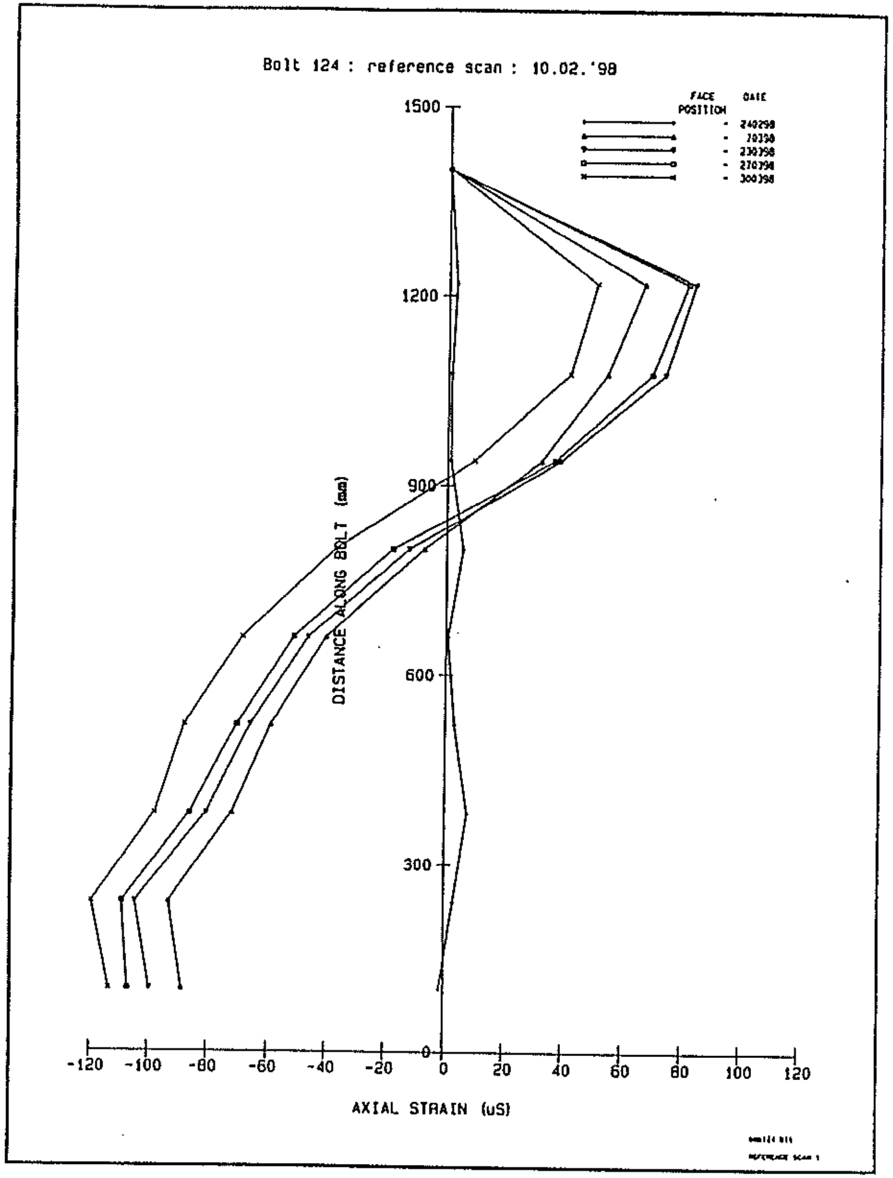
BENDING MOMENT (kNmm)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300
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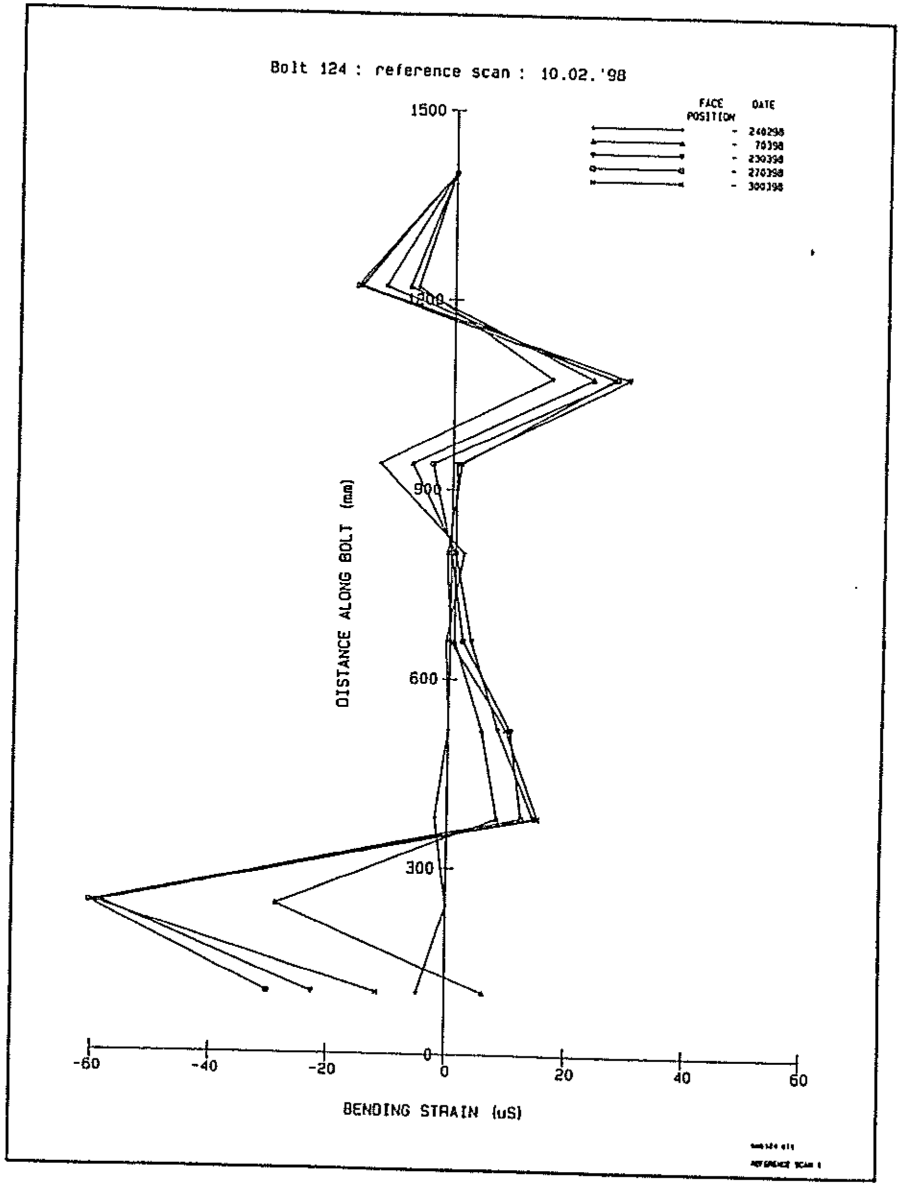
-120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120
AXIAL STRAIN (uS)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FACE POSITION DATE
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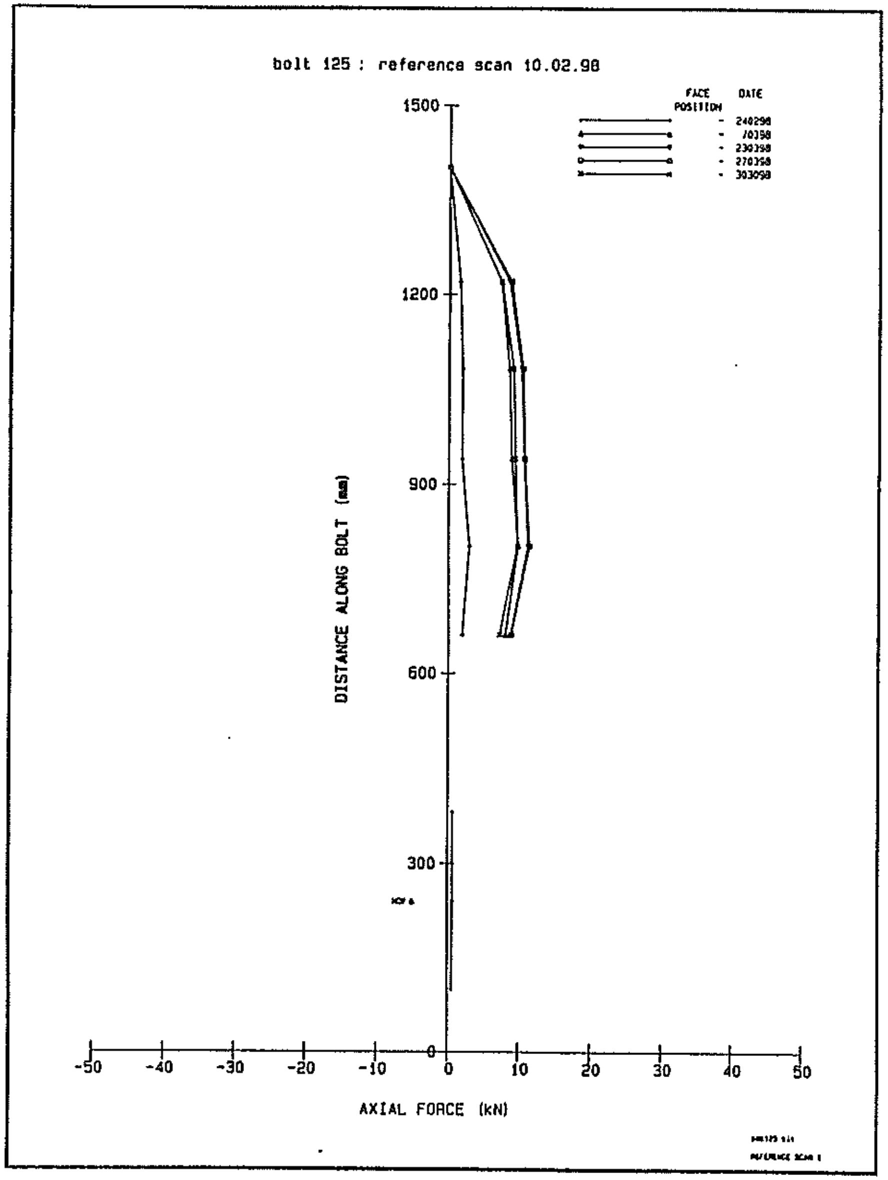
BENDING STRAIN (uS)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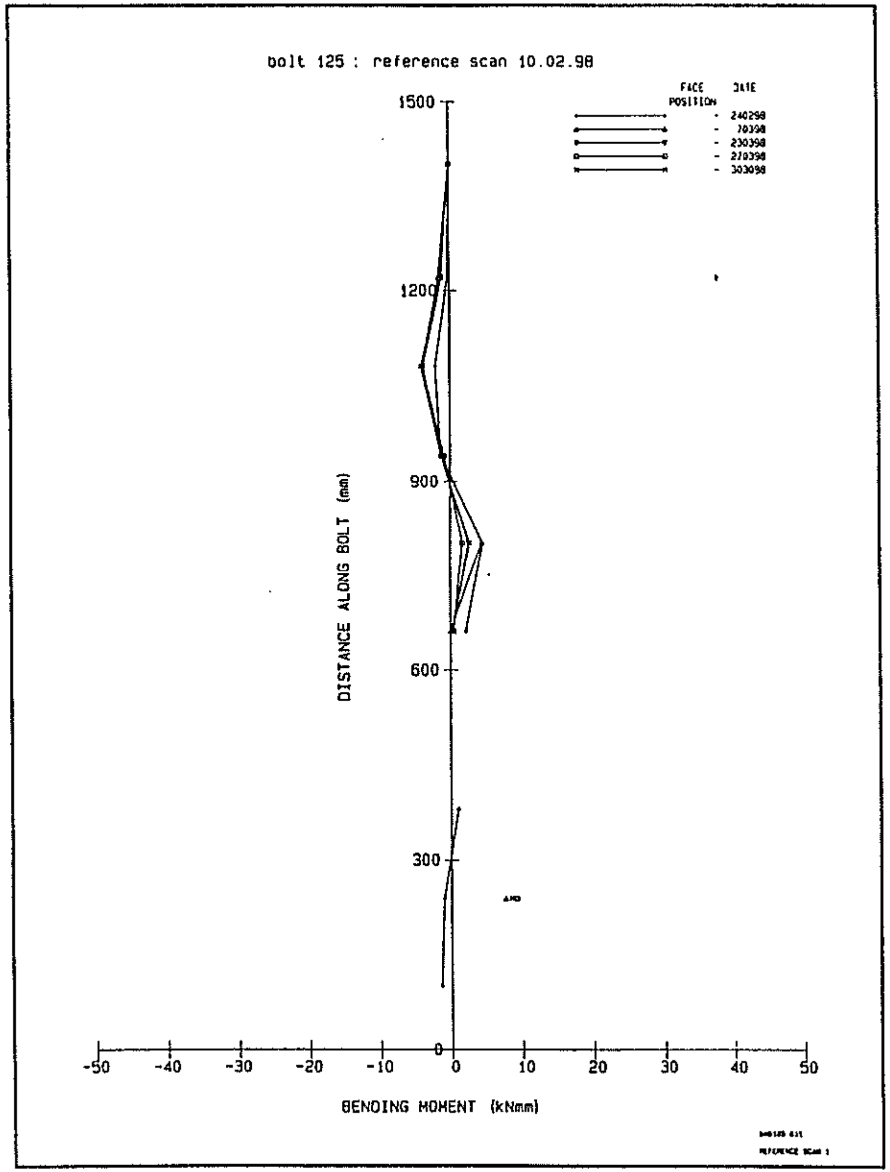
AXIAL FORCE (kN)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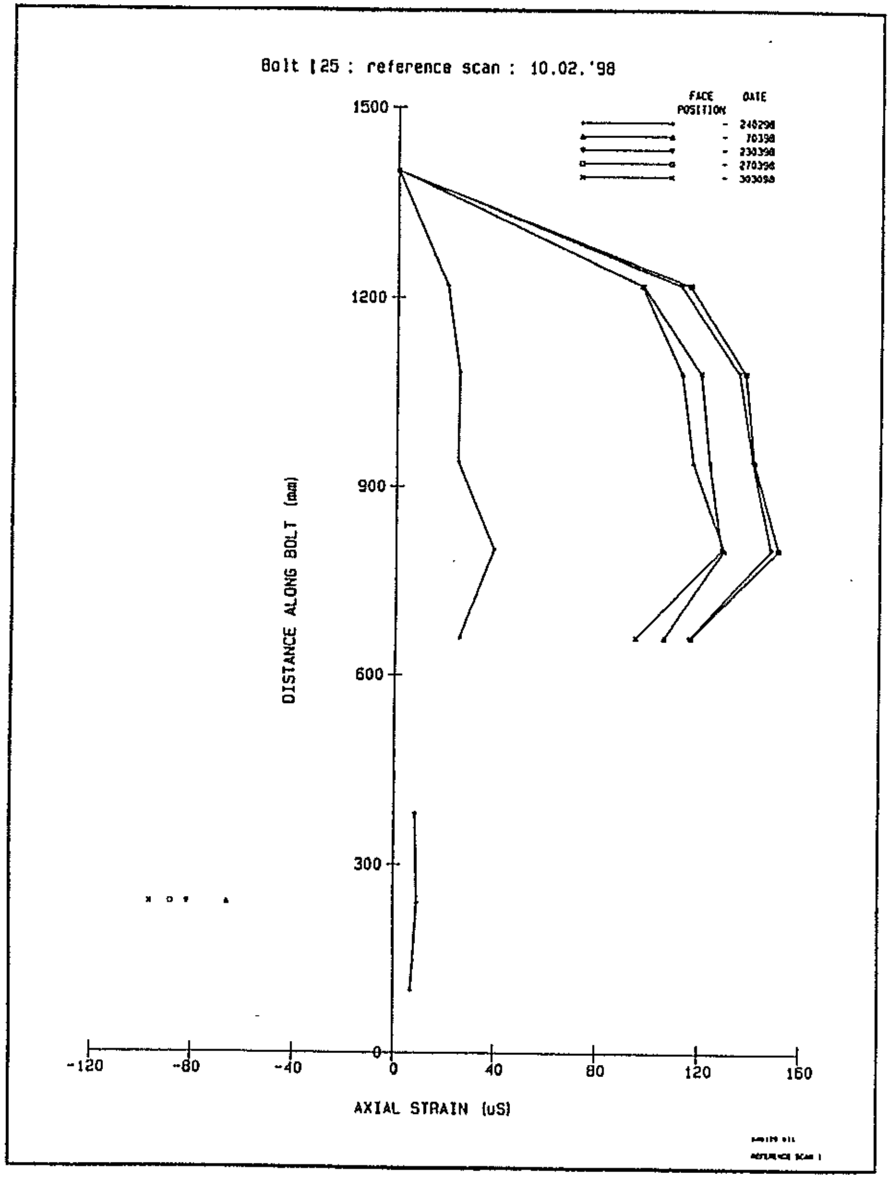
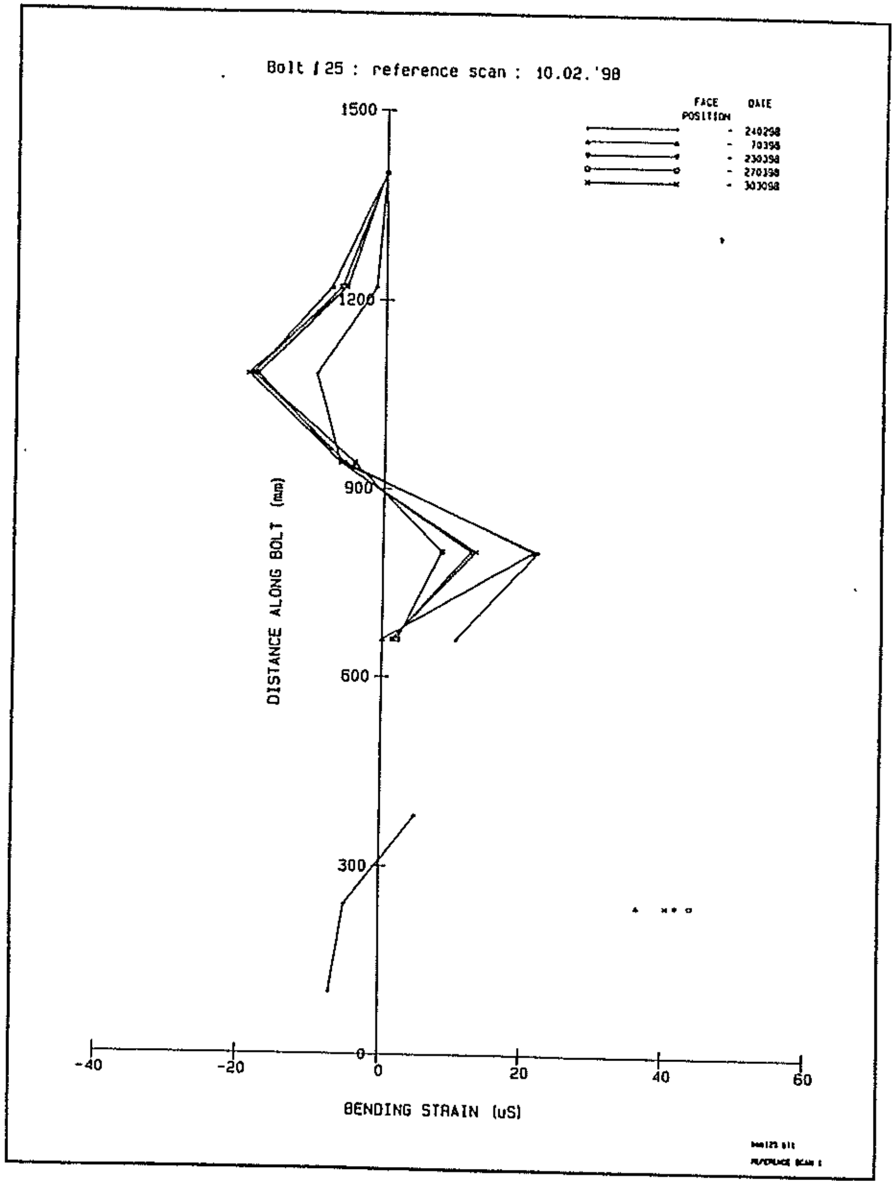
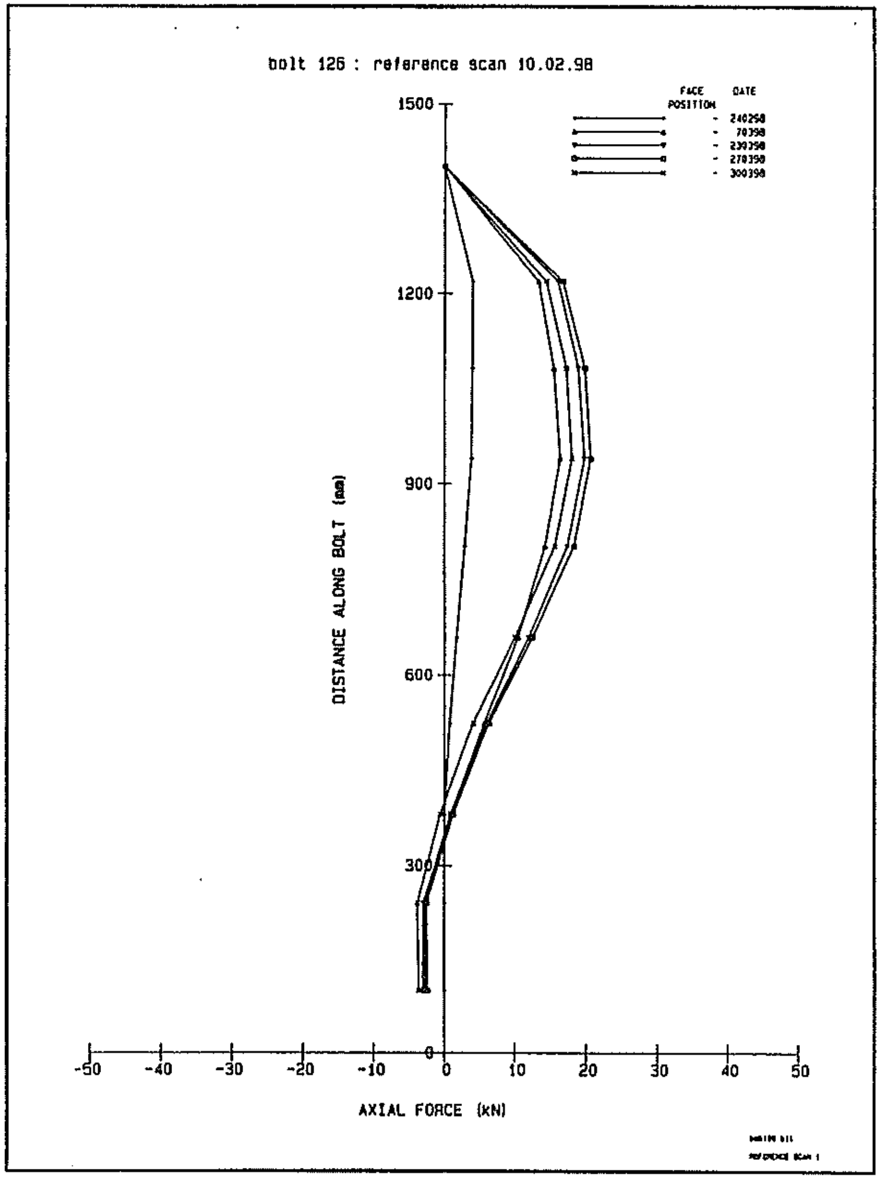
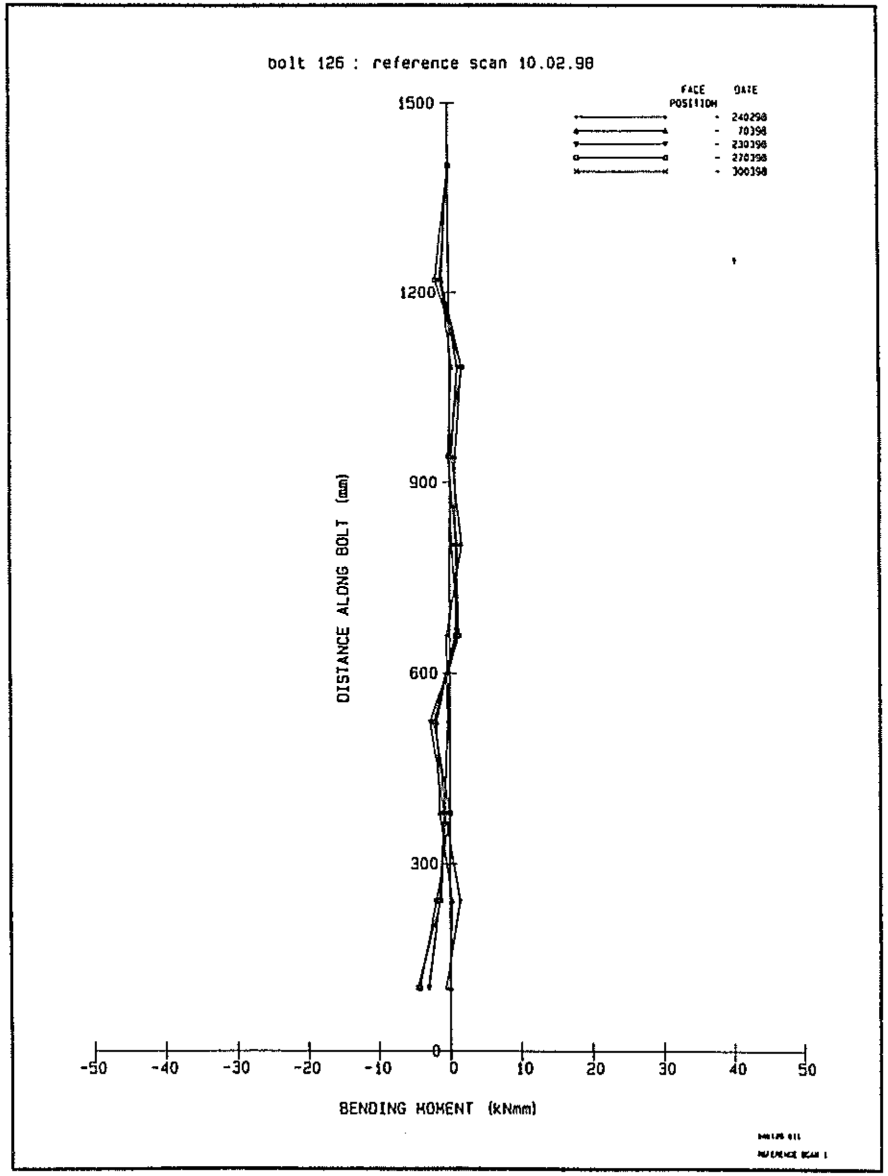
- 240298
- 70398
- 230398
- 270398
- 303098
DISTANCE ALONG BOLT (mm)
1500
1200
900
600
300
0
-50
-40
-30
-20
-10
10
20
30
40
50
BENDING MOMENT (kNmm)


Bolt [25 : reference scan : 10.02.'98
FACE POSITION
DATE
- 240298
- 70398
- 230398
- 270398
- 303098
1500
1200
900
600
300
0
DISTANCE ALONG BOLT (mm)
-120
-80
-40
0
40
80
120
160
AXIAL STRAIN (uS)


Bolt [25 : reference scan : 10.02.'98
FACE POSITION
DATE
- 240298
- 70398
- 230398
- 270398
- 303098
1500
1200
900
600
300
0
DISTANCE ALONG BOLT (mm)
-40
-20
0
20
40
60
BENDING STRAIN (uS)


bolt 126 : reference scan 10.02.98
FACE POSITION
DATE
- 240298
- 70398
- 230398
- 270398
- 300398
DISTANCE ALONG BOLT (mm)
1500
1200
900
600
300
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
AXIAL FORCE (kN)


bolt 126 : reference scan 10.02.98
FACE POSITION
DATE
- 240298
- 70398
- 230398
- 270398
- 300398
DISTANCE ALONG BOLT (mm)
1500
1200
900
600
300
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
BENDING MOMENT (kNmm)

Date	140198	200198	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Time	1200	1610	1645	915	1035	1150	1410	1550	1800	1900	930	1740	1700
Dummy channel	-767	-744	-754	-743	-742	-744	-739	-742	-740	-743	-737	-748	-749
Channel no.1	1494	1856	1877	1874	1882	1889	1925	2785	2615	1561	3374	3373	3369
Channel no.2	2862	2963	3002	3026	3059	3097	3028	2220	2459	2367	2949	2949	2949
Channel no.3	1134	1182	1231	1254	1299	1343	1471	1890	2286	1571	1289	1290	1308
Channel no.4	2139	2168	2224	2257	2319	2384	2485	2687	3784	12236	12397	11772	11624
Channel no.5	2195	2121	2183	2207	2256	2305	2362	2633	3019	17285	16842	16753	16780
Channel no.6	2684	2526	2585	2599	2631	2662	2697	2948	3324	2106	2105	2173	2235
Channel no.7	2345	2120	2152	2159	2171	2181	2194	2300	2459	2191	2067	2029	2067
Channel no.8	2920	2692	2719	2721	2726	2727	2724	2729	2743	2643	2625	2632	2631
Channel no.9	2045	1856	1871	1868	1870	1870	1869	1875	1867	2028	1919	2079	1980
Channel no.10	1558	1269	1264	1263	1269	1271	1415	734	1173	1423	-331	-318	-315
Channel no.11	1890	1847	1853	1865	1900	1935	2298	3786	3939	2813	2239	2257	2271
Channel no.12	2076	2124	2155	2177	2233	2295	2400	2578	2921	1992	2019	2056	2068
Channel no.13	1391	1361	1396	1413	1460	1509	1597	2009	2054	963	589	530	460
Channel no.14	2186	2130	2184	2211	2262	2314	2398	2759	3601	22000	22000	22182	22060
Channel no.15	2668	2733	2789	2807	2837	2870	2908	3163	3508	3343	3204	3135	3121
Channel no.16	2939	2868	2897	2903	2915	2926	2930	3007	3110	2988	3020	3042	3015
Channel no.17	2924	2783	2772	2769	2768	2769	2768	2761	2757	2867	2890	2878	2882
Channel no.18	3507	3439	3439	3437	3439	3439	3440	3445	3446	3338	3446	3301	3400

Note :The value on 14.01.'98 determined at SCT laboratory

Date	140198	20198	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Time	1200	1800	1645	915	1035	1150	1410	1550	1800	1900	930	1740	1700
Dummy channel	-768	-741	-752	-746	-747	-746	-744	-746	-744	-748	-743	-748	-751
Channel no.1	939	1128	1095	1096	1087	1246	1643	1898	1831	908	920	917	911
Channel no.2	1167	1217	1191	1225	1261	1374	1488	1451	1547	602	815	797	799
Channel no.3	1280	1318	1295	1320	1355	1451	1581	1952	2100	1363	1436	1427	1430
Channel no.4	1585	1729	1717	1743	1780	1860	1971	2533	2732	1524	1793	1809	1826
Channel no.5	2452	2539	2529	2549	2580	2636	2722	3629	5086	5204	6637	6816	6853
Channel no.6	2085	2219	2223	2241	2265	2306	2381	2899	3157	2006	2567	2573	2591
Channel no.7	2844	2889	2893	2912	2935	2969	3033	3321	3520	3175	3307	3304	3316
Channel no.8	2949	2923	2935	2974	2993	3014	3083	3240	3404	3196	3283	3281	3287
Channel no.9	3089	2984	2980	2993	3010	3026	3083	3189	3341	3195	3251	3249	3253
Channel no.10	1507	1343	1316	1324	1380	1422	1339	1416	1799	1601	1575	1565	1569
Channel no.11	1385	1344	1323	1367	1411	1542	1732	1984	2186	1729	1545	1534	1534
Channel no.12	1854	1852	1835	1870	1911	2014	2144	2488	2452	1556	1645	1648	1653
Channel no.13	2115	1956	1934	1960	1997	2077	2185	3004	3078	1943	2260	2280	2305
Channel no.14	2925	2728	2721	2739	2773	2832	2920	3692	4049	29000	29000	29056	28998
Channel no.15	3245	3102	3096	3113	3140	3182	3255	3784	4011	29000	29000	9999	9999
Channel no.16	3026	2871	2870	2885	2910	2943	3004	3297	3463	3054	3224	3228	3241
Channel no.17	3413	3222	3227	3247	3271	3296	3356	3539	3705	3551	3639	3637	3650
Channel no.18	3252	3221	3232	3248	3262	3278	3332	3439	3582	3423	3469	3464	3468

Note :The value on 14.01.'98 determined at SCT laboratory

Micro-strain value vs channel

Instrumented bolt : 121

Date	140198	200198	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Time	1200	1610	1645	915	1035	1150	1410	1550	1800	1900	930	1740	1700
Dummy channel	-770	-747	-752	-750	-747	-746	-746	-748	-746	-749	-743	-750	-752
Channel no.1	1743	1492	1492	1382	1343	1420	1613	1725	711	1442	1224	1276	1285
Channel no.2	1918	2052	2306	2843	3799	9496	18542	9999	9999	9999	9999	20501	237
Channel no.3	1833	2022	2060	2092	2175	2340	2454	2863	2480	1621	1689	1785	1784
Channel no.4	2500	2602	2616	2654	2726	2847	2971	4042	3718	16553	17205	17353	17384
Channel no.5	1902	1934	1966	1993	2039	2124	2242	2964	2816	2200	2200	2200	2200
Channel no.6	1735	1747	1763	1786	1825	1900	2003	2373	2370	2127	2195	2227	2230
Channel no.7	2186	2164	2189	2208	2239	2303	2415	2679	2728	2495	2583	2632	2564
Channel no.8	2667	2630	2658	2678	2710	2754	2859	3108	3172	2930	2975	2986	2990
Channel no.9	3488	3441	3456	2678	2710	3530	3610	3772	3824	3608	3644	3642	3643
Channel no.10	1428	1985	2173	2363	2699	3035	2984	3402	4688	4573	5277	5332	5372
Channel no.11	1385	1564	1504	1057	547	-402	-1470	-459	-1816	105	2523	3489	3523
Channel no.12	1203	1296	1371	1432	1575	1764	1870	2701	2582	3407	3664	3680	3700
Channel no.13	1903	2038	2091	2098	2157	2273	2390	3196	2887	19144	18000	18000	18000
Channel no.14	1796	1903	1923	1947	1986	2065	2181	2802	2659	2182	2212	2291	2299
Channel no.15	3283	3387	3411	3432	3462	3523	3633	4013	4009	3801	3867	3905	3906
Channel no.16	2219	2296	2328	2353	2390	2444	2555	2847	2893	2649	2692	2704	2709
Channel no.17	2372	2347	2379	2398	2427	2471	2572	2804	2858	2645	2702	2703	2710
Channel no.18	3572	3497	3518	3531	3550	3576	3653	3782	3825	3694	3734	3729	3729

Note :The value on 14.01.'98 determined at SCT laboratory

Micro-strain value vs channel

Instrumented bolt : 122

Date	140198	200198	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Time	1200	1410	1645	915	1035	1150	1410	1550	1800	1900	930	1740	1700
Dummy channel	-769	-746	-752	-747	-750	-747	-747	-753	-747	-750	-745	-748	-748
Channel no.1	949	1563	1665	1784	1889	1810	896	810	810	584	604	698	741
Channel no.2	1028	1327	1339	1344	1287	1034	1068	896	899	383	63	113	141
Channel no.3	1051	1134	1263	1686	2209	2294	2167	1378	1374	528	-353	-357	-335
Channel no.4	1681	1741	2051	2381	3150	2636	2233	1733	1820	845	-10241	-12118	-13292
Channel no.5	2517	2521	2680	2773	2929	6920	12924	17000	17000	17000	17000	22986	22982
Channel no.6	2172	2201	2305	2360.	2534	2811	2776	2332	2310	3236	3810	4088	4160
Channel no.7	2627	2572	2654	2708	2789	2937	2963	2800	2809	2546	2569	2571	2569
Channel no.8	3272	3223	3270	3313	3353	3420	3462	3426	3453	3281	3302	3305	3298
Channel no.9	2945	2846	2870	2899	2919	2945	2993	3026	3045	2913	2925	2925	2923
Channel no.10	1144	702	682	693	714	998	1010	1078	1082	1314	1372	1287	1250
Channel no.11	1270	1166	1308	1574	1884	1040	1077	1218	1225	1757	2142	2103	2070
Channel no.12	2115	2266	2487	2490	2321	1398	1500	1899	1902	2737	3609	3614	3587
Channel no.13	1904	2032	2161	2163	1896	2682	2998	2133	2023	3036	9999	9999	9999
Channel no.14	2579	2625	2798	2890	3216	2400	870	-1512	-2799	-2175	-1683	-1697	-1693
Channel no.15	2102	2191	2290	2350	2492	2728	2720	2323	2326	981	554	441	373
Channel no.16	2688	2713	2761	2796	2858	2980	3003	2868	2867	2767	2829	2833	2832
Channel no.17	3091	2987	3031	3066	3100	3166	3215	3203	3216	3056	3077	3077	3076
Channel no.18	3573	3511	3541	3565	3577	3594	3633	3727	3747	3589	3595	3595	3593

Note :The value on 14.01.'98 determined at SCT laborato

Date	100298	240298	70398	230398	270398	300398
Time	1520	730	1010	1130	1600	745
Dummy channel	-740	-743	-754	-747	-745	-739
Channel no.1	702	683	668	656	654	638
Channel no.2	1413	1428	1536	1539	1538	1516
Channel no.3	1136	1153	1223	1225	1222	1207
Channel no.4	1502	1511	1587	1597	1592	1575
Channel no.5	1958	1954	2005	2007	2003	1996
Channel no.6	2558	2567	2607	2614	2612	2610
Channel no.7	2560	2566	2587	2589	2590	2588
Channel no.8	2811	2812	2831	2829	2826	2825
Channel no.9	3818	3798	3815	3804	3800	3799
Channel no.10	1762	1781	1951	1948	1946	1930
Channel no.11	1918	1922	1992	1985	1983	1965
Channel no.12	2024	2034	2111	2120	2118	2101
Channel no.13	2508	2519	2563	2565	2565	2555
Channel no.14	2158	2184	2229	2240	2240	2227
Channel no.15	2188	2171	2189	2179	2179	2175
Channel no.16	1657	1644	1659	1643	1641	1640
Channel no.17	3307	3302	3307	3299	3299	3296
Channel no.18	3063	3083	3090	3097	3095	3097

100298	240298	70398	230398	270398	300398
1520	730	1010	1130	1600	745
-743	-744	-757	-749	-746	-739
1190	1184	1092	1068	1058	1072
1833	1835	1705	1680	1677	1674
1510	1515	1430	1434	1430	1427
2238	2240	2169	2172	2172	2161
2365	2364	2311	2315	2312	2300
2355	2361	2334	2337	2334	2321
2715	2706	2728	2748	2746	2729
3097	3109	3154	3186	3183	3162
3606	3603	3653	3672	3672	3652
1689	1690	1582	1600	1601	1588
1623	1625	1537	1555	1555	1551
1457	1465	1365	1360	1359	1352
2468	2470	2391	2390	2387	2377
1930	1930	1875	1875	1874	1865
2278	2281	2256	2259	2257	2245
2909	2918	2932	2941	2945	2921
2907	2895	2930	2953	2953	2933
2058	2064	2116	2147	2148	2121

Date	100298	240298	70398	230398	270398	303098
Time	1520	730	1010	1130	1600	745
Dummy channel	-706	-744	-755	-746	-746	-743
Channel no.1	1431	1395	9999	9999	9999	9999
Channel no.2	2061	2029	1973	1970	1965	1957
Channel no.3	1503	1477	1472	1460	1452	1440
Channel no.4	9999	9999	9999	9999	9999	9999
Channel no.5	2779	2774	2836	2856	2857	2838
Channel no.6	2705	2722	2801	2822	2822	2806
Channel no.7	2714	2696	2778	2810	2812	2796
Channel no.8	3228	3208	3278	3310	3312	3297
Channel no.9	4039	4020	4081	4107	4110	4095
Channel no.10	1671	1645	9999	9999	9999	9999
Channel no.11	1896	1871	1755	1744	1736	1733
Channel no.12	1471	1438	9999	9999	9999	9999
Channel no.13	3163	3080	3130	3123	3116	3105
Channel no.14	1975	1955	2032	2050	2050	2032
Channel no.15	3013	2998	3078	3112	3118	3095
Channel no.16	2502	2493	2574	2607	2606	2593
Channel no.17	2498	2492	2575	2606	2609	2595
Channel no.18	3351	3334	3404	3427	3431	3415

Micro-strain value vs channel   Instrumented bolt : 126

Date	100298	240298	70398	230398	270398	300398
Time	1520	730	1010	1130	1600	745
Dummy channel	-747	-743	-754	-749	-748	-747
Channel no.1	1384	1385	1341	1331	1336	1320
Channel no.2	1670	1679	1630	1624	1629	1615
Channel no.3	1753	1754	1754	1759	1768	1743
Channel no.4	1447	1460	1508	1514	1521	1493
Channel no.5	1879	1904	2012	2038	2046	2013
Channel no.6	2451	2499	2634	2678	2693	2660
Channel no.7	2888	2943	3098	3145	3157	3123
Channel no.8	2979	3039	3181	3229	3244	3206
Channel no.9	3435	3487	3599	3639	3647	3620
Channel no.10	1470	1475	1427	1438	1452	1438
Channel no.11	1490	1489	1448	1454	1462	1444
Channel no.12	2244	2250	2255	2256	2259	2238
Channel no.13	2582	2597	2656	2668	2672	2643
Channel no.14	3024	3052	3151	3175	3182	3153
Channel no.15	2552	2588	2729	2777	2788	2753
Channel no.16	3262	3315	3467	3519	3532	3499
Channel no.17	3137	3189	3327	3379	3390	3362
Channel no.18	2653	2713	2824	2866	2878	2846

Result of instrumented bolt

No. 119

Appendix :V

Number of Scans	13										
Datum Scan	2										
Bolt Length	1.5										
Number of Gauge Pairs	9										
Gauge Position (mm)	(GP)										
Axial Force (Kn)	(AF)										
Axial Strain (microstrain)	(AS)										
Bending Moment	(BM)										
Bending Strain	(BS)										
Date	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Elapsd	15.024	20.712	20.767	20.819	20.917	20.986	21.076	21.118	34.722	44.063	48.035
GP	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
1400	0	0	0	0	0	0	0	0	0	0	0
1220	1.3	0.3	0.4	0.5	0.2	0.8	0.4	2.6	2.1	3.5	3.6
1080	1.4	0.5	0.6	0.8	0.3	0.4	0.6	1.3	1	1.6	1.8
940	3.1	2.7	3.6	4.5	4.8	12	21.8	7.2	3.2	3.5	4
800	5.1	5.5	7.8	10.4	12.8	32.2	59.5	7.1	1.4	2.2	4.1
660	5.2	6.3	10	14	19	43.2	85.9	132.6	117.5	117.6	112
520	4.2	5.3	9.4	13.8	20.6	44.2	80.9	83	78.6	-14.3	-22.5
380	3.8	4.7	8.4	12.6	21.1	44	72	9.7	-0.5	1.8	3
240	2.5	3	5.5	8.4	19.2	35.2	46.3	-34.9	-35	-33.5	-32.9
100	1.4	0.4	0.8	1.3	7.8	14.8	24.9	-5.4	-2.6	25	23.6
GP	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	17.5	4	5	7	2	10.5	5	34.5	28	46.5	47.5
1080	18	6.5	7.5	10.5	3.5	5.5	8.5	16.5	13	21.5	24
940	40.5	36	47	59.5	63	157.5	286.5	94.5	42.5	45.5	52
800	67.5	72.5	102.5	136.5	168	424	782.5	94	18	28.5	53.5
660	68	82.5	131.5	184	249.5	568.5	1180.5	17516	17288.5	17346	17299.5
520	55.5	69.5	123	182	271.5	581.5	1150.5	4834	4721.5	4390.5	4282.5
380	50	61.5	111	166	277.5	579	946.5	127.5	-6	24	40
240	32.5	39.5	72.5	111	253	596	790	184	182	202	210
100	18	5	11	17.5	102.5	195	327.5	-71.5	-48	-31	-30.5

GP	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM
1400	0	0	0	0	0	0	0	0	0	0	0
1220	2.2	2	2	2	1.7	1.9	0.6	39.3	8.1	52	23.5
1080	5.5	6.2	7.1	7.1	6.8	8.5	11.1	-19.1	-25	-22.3	-23
940	0.4	0.6	0.6	0.4	1.7	5.9	14	-7.1	-29.5	-38.1	-28.8
800	0.4	-0.1	0.1	-0.1	-0.6	-1.2	3.3	-148.3	-128.4	-108.7	-97.7
660	1.2	0.7	0.4	0	-3.9	-16.8	-54.3	-20.5	-62.6	-64	-48.2
520	3	5.3	7.5	9.8	11.7	-18.6	85.4	220.2	251.9	220.3	209
380	2.6	2.7	1.2	-1.4	1.9	36.6	44.2	75	30.5	25.3	26.2
240	4.8	6.5	6.2	6.6	-55.6	-304.6	-269.1	-90.4	76	73.5	71.4
100	3.7	3.5	3.7	4.5	-11.1	210.7	123.1	-64.6	374.7	313.7	304.1
GP	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	10.3	9.6	9.6	9.6	8.2	8.9	2.7	187.7	38.5	248.2	112.1
1080	26.1	29.6	33.7	33.7	32.3	40.6	52.9	-91.4	-119.6	-106.6	-110
940	2.1	2.8	2.7	2.1	8.3	28.2	66.7	-33.7	-140.9	-182.2	-137.5
800	2.1	-0.7	0.7	-0.7	-2.7	-5.5	15.8	-708.1	-613.2	-519.1	-466.8
660	5.5	3.4	2.1	0	-18.6	-80.4	-393.9	-3235.4	-3539.9	-3726.3	-3623.8
520	14.4	25.4	35.7	46.7	55.7	-88.7	634.6	7195.4	7563.2	7174.1	7120.4
380	12.4	13.1	5.5	-6.9	8.9	174.6	211.1	358.2	145.7	121	125.1
240	22.7	30.9	29.6	31.6	-265.4	-1843.9	-1784.8	-1073.9	-279.1	-291.5	-301.1
100	17.9	16.5	17.9	21.3	-52.9	1006.5	587.8	-308.7	2143.6	2134	2129.2

Number of Scans	13										
Datum Scan	2										
Bolt Length	1.5										
Number of Gauge Pairs	9										
Gauge Position (mm)	(GP)										
Axial Force (Kn)	(AF)										
Axial Strain (microstrain)	(AS)										
Bending Moment	(BM)										
Bending Strain	(BS)										
Date	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Elapsd	14.948	20.635	20.691	20.743	20.84	20.91	21	21.042	34.646	43.986	47.958
GP	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
1400	0	0	0	0	0	0	0	0	0	0	0
1220	1.1	1.7	3	4.1	8.2	16.5	27.5	16.2	19.7	19.9	20.4
1080	1.5	3.3	5	6.7	11.4	24.5	36.9	23.4	29.7	29.9	30.9
940	1	1.8	3.7	6.2	10.8	33	46.7	18.4	29.5	29.9	31.1
800	0.8	1.6	3.7	6.7	12.2	52.2	70.5	105.6	120.9		
660	0.2	1.2	3.7	8	14.5	78.5	96.4	114.7	117.2	117.7	115
520	-0.5	1.1	4	10	18.1	70.8	81	-7.8	14.1	15.9	17.7
380	-0.7	1.1	4.1	11.6	21.3	48.7	52.8	-9	-3.2	-3.1	-2.5
240	-1	1.6	4.7	13.9	25.3	33.6	44.8	-8.2	-7.5	-8.2	-7.9
100	-1.4	-1.6	0.3	7.9	19.7	32.4	44.3	2	1.1	1	1.1
GP	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	14.5	23	39.5	54.5	108	216.5	362	213.5	259.5	261	268
1080	19.5	43	65.5	87.5	150	322	485	308	390.5	393.5	406
940	12.5	23.5	48.5	81	141.5	434	614.5	241.5	387.5	393	408.5
800	10	21.5	48	88.5	160.5	686	926.5	12849.5	13125		
660	2.5	15.5	49	105.5	190.5	1032	1937	14475.5	15187	15309.5	15302
520	-6	14	52	131	238.5	931	1065.5	-102	186	209	233
380	-9	15	54	152.5	280.5	640	694	-118.5	-42.5	-40.5	-33.5
240	-12.5	20.5	61.5	182.5	332.5	442	589	-108	-98.5	-108	-104
100	-19	-20.5	4	103.5	258.5	426.5	582.5	26	14	12.5	14.5

GP	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM
1400	0	0	0	0	0	0	0	0	0	0	0
1220	-2.2	-2.6	-2.2	-2.2	-1.7	-1.9	-0.6	1.3	2.7	3.2	3.2
1080	1	3.7	3	2.4	3.7	0	-0.3	-8.1	-8.2	-8.2	-9.2
940	0.7	1.3	1	1.2	1.6	0.9	5.6	14.8	9.4	8.3	8.2
800	1.4	1.6	1.2	1	1.3	-0.3	4.2	-260.8	-107.3		
660	-0.4	-0.1	-0.6	-1	-1.3	18.1	7.6	-195.8	-71.3	-69	-61.1
520	1.4	1.4	1.4	1.4	1.9	-35.1	-17.1	-27.6	-34.5	-35.1	-36.3
380	-0.9	-2.3	-3.2	-4.2	-4.2	-0.3	26.2	49.1	46.8	45.1	44.8
240	-0.7	-2.2	-3.3	-5.9	-16.8	-58.4	-73.7	-144	-86.8	-87.8	-87.5
100	-0.9	-1.9	-11.2	5.6	74.7	100.3	35.6	-68.8	-63.3	-62.3	-63.8
GP	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	-10.3	-12.4	-10.3	-10.3	-8.2	-8.9	-2.7	6.2	13.1	15.1	15.1
1080	4.8	17.9	14.4	11.7	17.9	0	-1.4	-38.5	-39.2	-39.2	-44
940	3.4	6.2	4.8	5.5	7.6	4.1	26.8	70.8	44.7	39.9	39.2
800	6.9	7.6	5.5	4.8	6.2	-1.4	19.9	%-17951.	%-17565.6		
660	-2.1	-0.7	-2.7	-4.8	-6.2	86.6	842.9	%-16229.	%-15244.	%-15160.	%-15094.8
520	6.9	6.9	6.9	6.9	8.9	-167.7	-81.8	-132	-165	-167.7	-173.2
380	-4.1	-11	-15.1	-19.9	-19.9	-1.4	125.1	234.4	223.4	215.2	213.8
240	-3.4	-10.3	-15.8	-28.2	-80.4	-279.1	-352	-687.5	-414.6	-419.4	-418
100	-4.1	-8.9	-53.6	26.8	356.8	479.2	169.8	-328.6	-302.5	-297.7	-304.6

Number of Scans	13										
Datum Scan	2										
Bolt Length	1.5										
Number of Gauge Pairs	9										
Gauge Position (mm)	(GP)										
Axial Force (Kn)	(AF)										
Axial Strain (microstrain)	(AS)										
Bending Moment	(BM)										
Bending Strain	(BS)										
Date	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Elapsd	15.024	20.712	20.767	20.819	20.917	20.986	21.076	21.118	34.722	44.063	48.035
GP	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
1400	0	0	0	0	0	0	0	0	0	0	0
1220	1.7	-27.5	-25.8	6.3	12.3	23.5	27	14	16.4	16.7	16.9
1080	2.7	4	6.1	9.4	17.2	35.6	40	22.9	26.3	27.3	27.9
940	2.5	4.1	6.4	10.8	19.3	40.6	44.1	26.2	30.7	33.5	31.3
800	1.9	3.4	5.8	10.9	19	47.7	47.3	30.3	35	38.2	38.5
660	2.4	4.1	7.1	13.3	22.2	73.4	62.2	20.9	21.6	25.1	25.6
520	2.9	4.5	9.2	18.2	27.3	93.7	65.7	127.7	107.8	108	108
380	4.7	8.1	16.4	29.8	38.2	83.1	56.6	45.7	52	55.8	56.1
240	7.8	11	21.4	54.1	71.6					-165.2	-188.9
100	7.5	10.4	21.5	37.1	42.2	60.4	45.3	25.9	40	43.6	45
GP	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	23	-361.5	-339	83	161.5	309	354.5	184	216	219.5	222
1080	35	52.5	80	123	226	468.5	525.5	301	346	359	366.5
940	33.5	53.5	84.5	142.5	254	534	579.5	344	403.5	441	411.5
800	25	45	76.5	143.5	250	627	621.5	399	460	502	506
660	31	54.5	94	175	292	965.5	818	274.5	283.5	330	336
520	38.5	59	121.5	239	359.5	1300	981.5	15530.5	15278.5	15359.5	15377
380	61.5	106	216	392	502	1124	871	857	1013.5	1076.5	1088
240	102	145	365	2738	6727					10190	77
100	99	137	282.5	488	559	826	960	1271	1508	1568.5	1595

GP	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM
1400	0	0	0	0	0	0	0	0	0	0	0
1220	-0.9	-114.7	-112.9	1.4	1.9	6.6	7.9	-4.3	-4.9	-4.5	-4.3
1080	-0.6	-0.4	0	0	0.6	3	4.5	0.3	-1.4	0	-0.4
940	-1	-1.9	-2.7	-1.3	-1.2	-5.2	-4.8	-3.2	3.3	8.6	-1.9
800	-1.2	-0.9	0.4	2.4	1.4	0	0.1	-4.9	-4.6	-5.5	-5.2
660	1.7	2.2	3.2	4	4.3	18.9	18.1	-1.9	-6.2	-17.6	-18.7
520	-5.6	-1.2	0.7	1.4	2.4	12.6	13.7	-14.5	53.7	54.6	54.8
380	-5.3	-9.5	-18.1	-21.6	-20.4	-62.4	-92.6	-257.5	-247.8	-231.6	-231.3
240	45.2	186.8	338.4	355.8	363.3					-498.6	-584.4
100	-27.1	-70.2	-124.2	-161.5	-125.4	-151.2	-307.5	-147.2	-246	-239.2	-238.6
GP	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	-4.1	-547.9	-539	6.9	8.9	31.6	37.8	-20.6	-23.4	-21.3	-20.6
1080	-2.8	-2.1	0	0	2.7	14.4	21.3	1.4	-6.9	0	-2.1
940	-4.8	-8.9	-13.1	-6.2	-5.5	-24.8	-22.7	-15.1	15.8	41.3	-8.9
800	-5.5	-4.1	2.1	11.7	6.9	0	0.7	-23.4	-22	-26.1	-24.7
660	8.2	10.3	15.1	19.2	20.6	90.1	86.6	-8.9	-29.6	-83.9	-89.4
520	-26.8	-5.5	3.4	6.9	11.7	193.9	183.6	-2169.1	-934.3	-832.6	-811.3
380	-25.4	-45.4	-86.6	-103.1	-97.6	-387.7	-569.2	-1727	-1856.9	-1801.9	-1816.4
240	215.9	892.4	1900.3	6469.4	13422.8					11360.3	-2594.6
100	-129.2	-335.5	-593.3	-771.4	-603.6	-814	-2395.3	-1813.6	-2447.5	-2449.6	-2470.9

Number of Scans	13										
Datum Scan	2										
Bolt Length	1.5										
Number of Gauge Pairs	9										
Gauge Position (mm)	(GP)										
Axial Force (Kn)	(AF)										
Axial Strain (microstrain)	(AS)										
Bending Moment	(BM)										
Bending Strain	(BS)										
Date	40298	100298	100298	100298	100298	100298	100298	100298	240298	50398	90398
Elapsd	15.108	20.795	20.851	20.903	21	21.069	21.16	21.201	34.806	44.146	48.118
GP	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
1400	0	0	0	0	0	0	0	0	0	0	0
1220	2.5	4.1	5.6	7	10.3	15.6	16.6	5.8	6.1	6.4	6.2
1080	3.9	6.5	9.5	14.4	17.8	16.5	17.5	5.1	6.4	6.7	6.4
940	5.4	8.4	14.1	24.1	26	15.1	14.9	1.4	4.2	4.7	4.6
800	8.2	12.2	24.4	43.7	42.1	10.5	9.4	-5.7	-0.8	3.3	3.3
660	13.1	19.7	38.3	73	67.6	58	48.5	103.3	101.9	106	106.1
520	17.2	29.4	46.6	42.1	38.8	-12.6	-14	-11.2			
380	13.8	29.6	43.3	10.7	-0.5	-14.9	-15.4	-15.6	-11.7	-11.5	-1.6
240	6.3	16.2	26.1	-15.9	-13.2	-13.9	-14	-13.1	-10	0.3	0.1
100	3.6	8.1	13.2	20.7	-13.6	-13.8	-14.1	-13.7	-10.2	-9.6	-9.4
GP	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	33	54.5	73.5	92	135.5	205	218.5	76.5	80.5	83.5	81.5
1080	51.5	85.5	125.5	189	234.5	216.5	230.5	67.5	83.5	88	84
940	71	110.5	185	317	341.5	198.5	196.5	18	55.5	61.5	60
800	107.5	160	321	574.5	553	138.5	123	-83.5	-15	70.5	72.5
660	172	259.5	503.5	2088	4325	5178	4528.5	4843.5	5084.5	8073.5	8073.5
520	225.5	386.5	640.5	773.5	730	53.5	36	58			
380	181	389	569	147	134.5	-54.5	-61	-63.5	-73	-69.5	-72
240	83	213.5	343	-208.5	-173	-182.5	-183.5	-172.5	-145	-136.5	-139
100	47	107	173	272.5	-178.5	-181.5	-185.5	-179.5	-145.5	-138	-135

GP	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM	BM
1400	0	0	0	0	0	0	0	0	0	0	0
1220	-0.9	-0.1	1	2.3	3.6	-5.2	-5.3	-1.6	-0.7	-0.7	-0.7
1080	0.4	1.6	2.4	2.6	1.6	-1.9	0.1	-1.6	-1.6	-1.2	-2
940	4.9	7.6	10.4	14.1	14.5	10.5	11.9	-11.5	-17.1	-17.4	-17.6
800	0.7	0	4.6	10.5	6.6	-0.1	-3.7	313.4	380.5	394.3	398.6
660	-2	-1.9	-26.3	203.5	320.5	409	447.2	93.6	66.1	119.5	116.8
520	26.1	73.3	203.2	-10.7	-114.2	-61.6	-33.3	-307.8			
380	-13.2	47.2	146.8	287.1	229.4	58.4	57.4	-184.6	-365.6	-366.2	-262.5
240	-18.7	-56.3	-109.1	-24	-24.5	-69.5	-70.1	-221	-310.8	-250.8	-242
100	17.6	33.1	45.2	-7.1	-140.4	-162.5	-163.1	-229	-232.1	-206.4	-194.8
GP	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS
1400	0	0	0	0	0	0	0	0	0	0	0
1220	-4.1	-0.7	4.8	11	17.2	-24.8	-25.4	-7.6	-3.4	-3.4	-3.4
1080	2.1	7.6	11.7	12.4	7.6	-8.9	0.7	-7.6	-7.6	-5.5	-9.6
940	23.4	36.4	49.5	67.4	69.4	50.2	57.1	-55	-81.8	-83.2	-83.9
800	3.4	0	22	50.2	31.6	-0.7	-17.9	1543.4	2231.6	2500.4	2596.7
660	-9.6	-8.9	-125.8	3179	8358.6	12798.5	13683.3	13254.3	12916.1	17041.1	17035.6
520	124.4	349.9	1062.2	168.4	-325.9	-74.9	60.5	-1306.3			
380	-63.2	225.5	701.3	1394.3	1236.8	420.1	415.3	-740.4	-1945.6	-1951.8	-1918.1
240	-89.4	-268.8	-521.1	-114.8	-116.9	-332.1	-334.8	-1055.3	-1540	-1478.8	-1436.9
100	83.9	158.1	215.9	-33.7	-670.3	-776.2	-778.9	-1093.8	-1119.9	-996.9	-941.9

Number of Scans	6					
Datum Scan	1					
Bolt Length	1.5					
Number of Gauge Pairs	9					
Gauge Position (mm)	(GP)					
Axial Force (Kn)	(AF)					
Axial Strain (microstrain)	(AS)					
Bending Moment	(BM)					
Bending Strain	(BS)					
Date	240298	70398	230398	270398	300398	
Elapsd	13.674	24.785	40.84	45.028	47.684	
GP	AF	AF	AF	AF	AF	
1400	0	0	0	0	0	
1220	0.2	2	1.3	0.9	0.5	
1080	0.1	1.8	0.9	0.6	0	
940	0	2.2	1.1	0.9	0.3	
800	-0.1	3	2.3	2.1	1.4	
660	1.1	5.6	5.5	5.2	4	
520	1	6.4	6.3	6	4.5	
380	1.3	7.7	7.6	7.2	5.6	
240	1	8.6	7.9	7.6	5.6	
100	0.2	7	5.9	5.6	3.9	
GP	AS	AS	AS	AS	AS	
1400	0	0	0	0	0	
1220	3	26	17	12	6.5	
1080	1	24	12	8.5	0.5	
940	-0.5	28.5	14.5	12	4.5	
800	-1	39	30.5	27.5	18.5	
660	14	73	72.5	68.5	52.5	
520	13	84	83	78.5	59	
380	16.5	101	99.5	95	73	
240	12.5	112.5	103.5	100	74	
100	3	91.5	77	73	51	
GP	BM	BM	BM	BM	BM	
1400	0	0	0	0	0	
1220	-5.8	-4.3	-6.9	-7.2	-7.6	
1080	0.9	2.9	3.7	3.3	3.6	
940	2.7	3.6	6.2	6.6	6.5	
800	3.7	6.9	9.4	9.1	9.4	
660	-4.3	-3.5	-4.8	-5.3	-4.5	
520	-0.3	4.3	5.5	4.8	3.7	
380	1	0	-1	-1.2	-0.9	
240	1.6	7.1	8.5	8.6	8.1	
100	-5.5	-32.1	-33.4	-33.4	-33.4	

GP	BS	BS	BS	BS	BS	
1400	0	0	0	0	0	
1220	-27.5	-20.6	-33	-34.4	-36.4	
1080	4.1	13.8	17.9	15.8	17.2	
940	13.1	17.2	29.6	31.6	30.9	
800	17.9	33	44.7	43.3	44.7	
660	-20.6	-16.5	-22.7	-25.4	-21.3	
520	-1.4	20.6	26.1	22.7	17.9	
380	4.8	0	-4.8	-5.5	-4.1	
240	7.6	33.7	40.6	41.3	38.5	
100	-26.1	-153.3	-159.5	-159.5	-159.5	

Number of Scans	6					
Datum Scan	1					
Bolt Length	1.5					
Number of Gauge Pairs	9					
Gauge Position (mm)	(GP)					
Axial Force (Kn)	(AF)					
Axial Strain (microstrain)	(AS)					
Bending Moment	(BM)					
Bending Strain	(BS)					
Date	240298	70398	230398	270398	300398	
Elapsd	13.674	24.785	40.84	45.028	47.684	
GP	AF	AF	AF	AF	AF	
1400	0	0	0	0	0	
1220	0.2	5.1	6.4	6.2	3.8	
1080	0.1	4.1	5.6	5.2	3.2	
940	0.1	2.4	2.9	2.8	0.7	
800	0.4	-0.6	-1	-1.4	-2.9	
660	0	-3.1	-3.5	-3.9	-5.2	
520	0.2	-4.5	-5	-5.4	-6.7	
380	0.6	-5.5	-6.1	-6.5	-7.5	
240	0.2	-7.1	-7.9	-8.3	-9.1	
100	-0.1	-6.7	-7.6	-8.1	-8.6	
GP	AS	AS	AS	AS	AS	
1400	0	0	0	0	0	
1220	2.5	66.5	83.5	81	50.5	
1080	1	54	73.5	69	41.5	
940	1	32	38.5	36.5	9	
800	5.5	-7.5	-12.5	-18	-37.5	
660	0.5	-40.5	-46.5	-51.5	-69	
520	3	-59	-66	-70.5	-88	
380	7.5	-72	-80.5	-86	-98	
240	3	-93	-104.5	-109	-119.5	
100	-1.5	-88.5	-99.5	-107	-113.5	
GP.	BM	BM	BM	BM	BM	
1400	0	0	0	0	0	
1220	-1.3	-1.6	-3.3	-3.5	-2.4	
1080	3.5	4.9	6.2	5.8	5.6	
940	-2.6	-1.4	0.1	-0.7	0.3	
800	0.4	0.1	0.1	0	-0.1	
660	-0.1	0.1	0.7	0.4	0	
520	0	1.2	1.7	2.2	2	
380	-0.4	1.7	3	2.6	3.2	
240	0	-6	-12.2	-12.7	-12.5	
100	-1	1.3	-4.8	-6.3	-2.4	

GP	BS	BS	BS	BS	BS	
1400	0	0	0	0	0	
1220	-6.2	-7.6	-15.8	-16.5	-11.7	
1080	16.5	23.4	29.6	27.5	26.8	
940	-12.4	-6.9	0.7	-3.4	1.4	
800	2.1	0.7	0.7	0	-0.7	
660	-0.7	0.7	3.4	2.1	0	
520	0	5.5	8.3	10.3	9.6	
380	-2.1	8.2	14.4	12.4	15.1	
240	0	-28.9	-58.4	-60.5	-59.8	
100	-4.8	6.2	-22.7	-30.3	-11.7	

Number of Scans	6					
Datum Scan	1					
Bolt Length	1.5					
Number of Gauge Pairs	9					
Gauge Position (mm)	(GP)					
Axial Force (Kn)	(AF)					
Axial Strain (microstrain)	(AS)					
Bending Moment	(BM)					
Bending Strain	(BS)					
Date	240298	70398	230398	270398	303098	
Elapsd	13.674	24.785	40.84	45.028	873.684	
GP	AF	AF	AF	AF	AF	
1400	0	0	0	0	0	
1220	1.5	7.3	8.5	8.8	7.4	
1080	1.9	8.6	10.3	10.5	9.1	
940	1.9	8.9	10.7	10.7	9.4	
800	3	9.8	11.3	11.5	9.8	
660	1.9	8.1	8.8	8.9	7.2	
520						
380	0.6					
240	0.7	-5	-6.2	-6.7	-7.3	
100	0.5					
GP	AS	AS	AS	AS	AS	
1400	0	0	0	0	0	
1220	20	96.5	112	115.5	97	
1080	25	112.5	135	137.5	120	
940	24.5	117	140.5	141	123.5	
800	39	129.5	148	151	128.5	
660	25.5	106	116	116.5	95	
520						
380	8.5					
240	9.5	-65.5	-81.5	-88	-96.5	
100	7					
GP	BM	BM	BM	BM	BM	
1400	0	0	0	0	0	
1220	-0.3	-1.6	-1.2	-1.3	-1.2	
1080	-2	-3.9	-3.7	-3.9	-4	
940	-1.3	-1.2	-1.3	-0.9	-1.3	
800	4.6	4.5	2.6	1.7	2.7	
660	2.2	0	0.3	0.4	0.3	
520						
380	1					
240	-1	7.6	8.8	9.2	8.5	
100	-1.4					

GP	BS	BS	BS	BS	BS	
1400	0	0	0	0	0	
1220	-1.4	-7.6	-5.5	-6.2	-5.5	
1080	-9.6	-18.6	-17.9	-18.6	-19.2	
940	-6.2	-5.5	-6.2	-4.1	-6.2	
800	22	21.3	12.4	8.2	13.1	
660	10.3	0	1.4	2.1	1.4	
520						
380	4.8					
240	-4.8	36.4	41.9	44	40.6	
100	-6.9					

Number of Scans	6					
Datum Scan	1					
Bolt Length	1.5					
Number of Gauge Pairs	9					
Gauge Position (mm)	(GP)					
Axial Force (Kn)	(AF)					
Axial Strain (microstrain)	(AS)					
Bending Moment	(BM)					
Bending Strain	(BS)					
Date	240298	70398	230398	270398	300398	
Elapsd	13.674	24.785	40.84	45.028	47.684	
GP	AF	AF	AF	AF	AF	
1400	0	0	0	0	0	
1220	4	13.3	16	16.7	14.4	
1080	4	15.4	18.9	19.8	17.2	
940	3.8	16.3	19.7	20.6	17.9	
800	2.9	14.2	17.3	18.3	15.6	
660	1.7	10.4	11.9	12.4	10	
520	0.8	5.7	6	6.3	4.1	
380	0	1	0.8	1.2	-0.6	
240	0	-2.6	-3	-2.5	-3.8	
100	-0.1	-2.7	-3.1	-2.4	-3.7	
GP	AS	AS	AS	AS	AS	
1400	0	0	0	0	0	
1220	52	174.5	210.5	219.5	189	
1080	52	203	248	260	226	
940	50	214.5	259	270.5	236	
800	38	187	228	240	205	
660	22.5	137	157	163.5	131.5	
520	10	74.5	78.5	83	53.5	
380	-0.5	13	11	16	-8	
240	0	-34	-39	-33.5	-50.5	
100	-1	-36	-40.5	-32	-48	
GP	BM	BM	BM	BM	BM	
1400	0	0	0	0	0	
1220	-1.2	-1	-1.3	-1.9	-1.2	
1080	1.2	1.7	1.2	1.7	0.3	
940	0.3	0.7	0	-0.1	-0.3	
800	1.7	0.9	0.3	0.9	1.2	
660	-0.4	0.9	1.2	1.3	0.7	
520	-0.3	-1.9	-2.7	-2.3	-2.2	
380	-0.7	-1.4	-0.9	0	-0.6	
240	1.4	0.3	-1.4	-1.9	-1.3	
100	-0.6	0	-3	-4.3	-4.6	

GP	BS	BS	BS	BS	BS	
1400	0	0	0	0	0	
1220	-5.5	-4.8	-6.2	-8.9	-5.5	
1080	5.5	8.2	5.5	8.3	1.4	
940	1.4	3.4	0	-0.7	-1.4	
800	8.3	4.1	1.4	4.1	5.5	
660	-2.1	4.1	5.5	6.2	3.4	
520	-1.4	-8.9	-13.1	-11	-10.3	
380	-3.4	-6.9	-4.1	0	-2.7	
240	6.9	1.4	-6.9	-8.9	-6.2	
100	-2.8	0	-14.4	-20.6	-22	