Chapter 3.0

Underground monitoring of roof and support behaviour

3.1 Introduction

One of the most important prerequisite in the design of a support system is to understand the roof and support behaviour in different geotechnical environments. An extensive monitoring programme was therefore undertaken in order to establish the behaviour and the interaction between the support units and the roof. Critical deformations beyond which the roof fails will occur was also investigated.

A total of 29 sites at five collieries were monitored using sonic probe extensometers and in order to cover as much of the roof strata as possible, and avoid losing what could in time turn out to be valuable information, the full string of 21 anchors with the top anchor at approximately 7.3 m was installed at all the monitoring sites.

To process the monitoring data as quickly and efficiently as possibly, a customised program was written as part of this study, culminating in an easy to understand set of graphic results. The basic function of this program is to compare all subsequent sets of readings with the original set and produce displacement-with-time graphs. Various modifications and improvements were introduced to include the option of producing velocity and acceleration graphs to assist with the interpretation of the results.

3.2 Underground monitoring procedure

In this monitoring programme sonic probe extensometer is utilised. The sonic probe extensometer system is a sophisticated electronic device. It generates a pulse that travels at the speed of sound, and is able to accurately determine the distance between magnetic fields, set up by magnets which are integral to the extensometer anchors.

The cylindrical magnetic anchors are locked in place at predetermined locations in a borehole and have a plastic tube inserted through their centres. This tube acts as a guide for a flexible probe that is then inserted through the entire string of anchors. The readout unit is connected to the probe and the distances between the magnetic fields are individually displayed and manually recorded.

In order to record all the information relevant to roof strata deformation prior to the installation of any roof support, would necessitate the installation of instrumentation a few metres ahead of the face. Since this is clearly not possible the next best scenario is to install the instrumentation at the face. However, due to practicalities such as not working under unsupported roof and the limitations on how close the roofbolters can get to the face, it is not usually possible to drill closer than about 0.5 m from the face. This results in the monitoring hole being in or close to the last row of support.

Drill bit sizes, resin quantities and support types and lengths were also monitored. In the underground situation the quality of roof support installation is dependent on a number of factors. With resin bonded bolts the bond length and quality are dependent on the actual average hole diameter, the overdrilling of holes and deviations from the recommended resin spin and hold times. It was not practical or possible to monitor or control the support installation at the monitoring sites. The support performance monitored is therefore a true representation of the support systems as installed underground and includes any effects linked to imperfections in the installation of the support.

At the monitoring site, close to the face, and situated in the middle of the advancing roadway, an 8.0 m deep hole was drilled vertically with a roofbolter into the roof and reamed out to 50 mm in diameter to accommodate the sonic probe magnetic anchors. Although most of the drilling process was carried out with water flushing, the final reaming of the hole is done dry, as the modified custom made reaming bits cannot accommodate water channelling. The hole was cleaned by inserting a water hose to the top or by spinning one of the smaller drill bits up the hole with the water switched on. A petroscope was then inserted into the hole and the lower 2.5 m was examined to detect the presence of any open laminations or fractures. However, final reaming of the holes to enlarge the hole by a few millimetres was carried out dry. During this process, the moisture left in the hole by the original wet drilling mixed with the powdered coal duff and form a paste that was then smeared into any openings by the reaming process. Therefore, the petroscope monitoring of the holes did not result in reliable information and was taken out of the monitoring programme.

A full string of 21 anchors was then installed in each hole at predetermined intervals (approximately 250 mm apart) using a set of installation rods. The top anchor, the first to be installed, is placed at approximately 7.3 m. An extra anchor that does not have a magnet fitted is installed in front of the last anchor, a short distance from the collar of the hole. This is a prerequisite in a vertical hole and is used to suspend the sonic probe to prevent it moving during the reading process.

Depending on the mining method and speed of face advance, the time lapse between further sets of readings varied from hours to days apart. In a typical development section underground three or four sites close to the centre of the panel were monitored. Where possible, the sites included both roadways and intersections to be able to evaluate and compare the strata behaviour and support performance in the two different locations. Prior to any development of the intersection taking place, the instrumented hole was positioned at the face so as to be as close as possible to the centre of the proposed intersection.

Survey levelling was used in conjunction with the sonic probe to assist in assessing the accuracy of the probe. The relative displacement measured between points anchored at 0.1 m in from the roof skin and at an elevation of approximately 1.8 m should ideally be compared against displacements measured between anchors at similar elevations by the sonic probe. However, at most of the monitoring sites where levelling was implemented, all the roof displacements took place within 1.8 m of the immediate roof. The levelling results have therefore been compared with the "total relaxation" measured by the sonic probe. The total relaxation is the overall displacement between a stable elevation in the roof and the anchor closest to the roof skin. In the five cases (Colliery D area 2) where displacements occurred up to 2.5 m into the roof, a note concerning the comparative probe and levelling displacement values has been included in the appropriate figures. These values have also been included in Table 3-1 where direct comparisons can be made between the sonic probe results and all the sites where back up levelling was successfully implemented.

In some cases it was not possible to make use of the survey levelling backup system due to factors such as the dip of the seam and the mining method and sequence. Levelling monitoring points that were damaged during the monitoring period were excluded from the results. Levelling backup was successfully implemented at approximately half the monitoring sites. The survey levelling results were included in the sonic probe displacement graphs. In excess of 90 per cent of the cases, the levelling results recorded similar or higher values than those of the sonic probe. A higher value levelling result is perfectly acceptable since the levelling skin anchor is usually about 0.1 m closer to the roof skin than the lowest sonic probe anchor, which is usually placed 0.2 m into the roof. Any displacement that occurs between their respective elevations would only be recorded by the levelling results.

3.3 Processing of information

The initial readings were taken as soon as the installation was completed. These comprise a minimum of three sets which were screened for any obvious anomalies or booking errors. They were then entered into the program where they were averaged, and the calculations carried out to produce the graphic results necessary for interpretation. All the subsequent sets of readings were treated in a similar manner with the program comparing them to the first (datum) set of readings from which the displacements were calculated.

The original displacement graphs included all the anchors in the hole up to the 7.3 m elevation. However since the main focus of the investigation was in the vicinity of the support horizon all the support performance graphs have been cropped at the 2.5 m elevation. This does not infer that displacements above the 2.5 m elevation were discarded or ignored.

Included alongside the 2.5 m vertical axis on each graph is a shaded block representing the section of strata column under investigation. The patterns within the block represent the approximate location of the different strata types, typically sandstone, shale and coal. These patterns are included and labelled in Figure 3-1. The stratigraphic column included with each individual displacement graph is representative of the area under investigation.

Although in some cases as many as 15 site visits were carried out and sonic probe readings taken, individual composite graphs have been limited to a maximum of five sets of readings for reasons of clarity.

In order to present the results of the individual site investigations in a simple and efficient manner, a graphic classification system was used. An explanation of this system and the relevance of other information included with it are given in Figure 3-1.

Although the displacements usually start at the roof skin and are evident for some distance into the roof, the section of the strata column under investigation does not extend down to the roof skin. The reason for is that the bottom magnetic anchor of the anchor string has to be approximately 0.2 m into the roof to allow the dummy anchor, used as a suspension point for the sonic probe, to be installed in front of it.

The displacements recorded by the final set of sonic probe readings taken at a particular site are transferred to the strata column. Here they are shown as individual lines approximately midway between the anchors from which each relative displacement value was calculated.

Table 3-1 Sonic probe, levelling and stable roof elevation results

Colliery and Roof strata	**Mining method**	**Support type**	**Monitoring Position**	**Probe relaxation (mm)**			**Levelling (mm)**	**Stable roof elevation**	
				Total	**Averages**	**1.8 m - skin**	**1.8 m - skin**	**(m)**	**Averages**
A	C M	Full column	Roadway	2.5		2.5		1.1	
Shale		resin	**Roadway**	0.2	1.3	0.0		0.0	0.6
B	D&B	Partial	Roadway	2.0		1.2		2.2	
Coal roof		column	Roadway	0.5		0.5	1.0	2.0	
0.3 m		resin	Roadway	2.5		2.3	2.5	2.0	
shale			**Roadway**	3.0	2.0	3.0		2.2	2.1
then coal			*Intersection*	*4.0*		*3.8*	*4.2*	*2.0*	
above			***Intersection***	*6.0*	*5.0*	*6.0*		*2.0*	*2.0*
C	D&B	Mechanical	Roadway	1.5		1.5	1.5	2.5	
0.3m coal		end	**Roadway**	0.5	1.0	0.5		1.9	2.2
with shale		anchored	*Intersection*	*3.5*		*3.5*	*5.7*	*1.9*	
above			**Intersection**	*1.0*	*2.3*	*1.0*		*2.2*	*2.1*
	D&B	Full column	Roadway	0.5		0.5	1.0	1.4	
		resin	**Roadway**	1.0	0.8	1.0	2.0	1.1	1.3
	Area 1		*Intersection*	*6.5*		*6.5*	*7.0*	*1.4*	
D			***Intersection***	*2.5*	*4.5*	*2.5*	*4.0*	*1.9*	*1.7*
Inter	C M	Partial	**Roadway**	2.5	2.5	2.0	3.7	2.0	2.0
laminated		column	*Intersection*	*2.0*		*2.0*		*1.8*	
sandstone	Area 2	resin	*Intersection*	*12.0*		*11.5*	*11.2*	*2.5*	
and shale			*Intersection*	*12.0*		*9.5*	*12.5*	*2.5*	
			Intersection	*6.0*	*8.0*	*5.0*	*10.0*	*1.9*	*2.2*
	C M	Full column	Roadway	1.0		1.0		0.8	
		resin	**Roadway**	0.5	0.8	0.5		1.0	0.9
	Area 3		**Intersection**	*1.0*	*1.0*	*1.0*		*1.2*	*1.2*
E	C M	Full column	Roadway	1.0		1.0		0.5	
Sandstone		resin	**Roadway** x 4	0.2	0.2	0.0		0.0	0.1

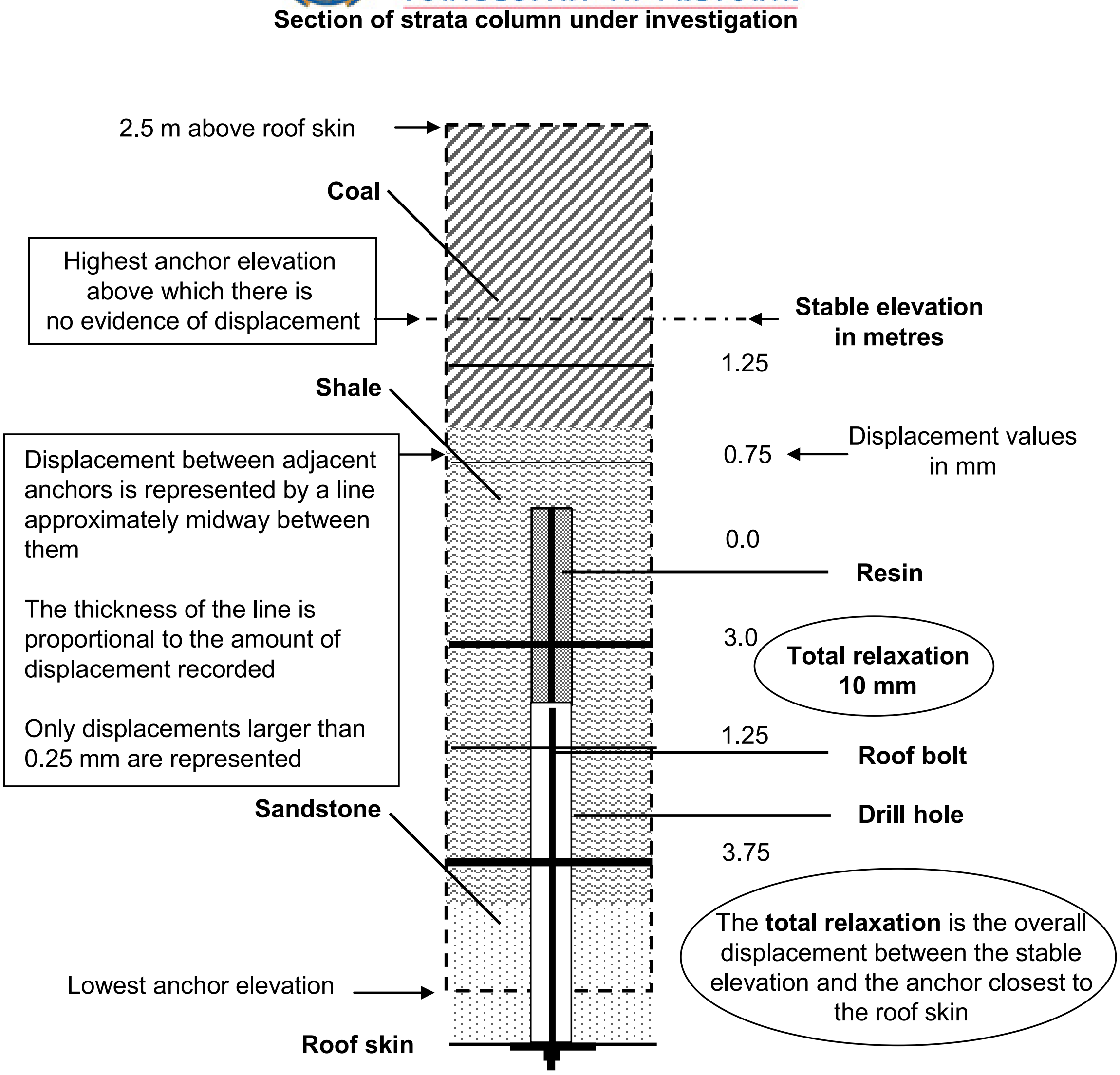


Figure 3-1 Graphic representation and explanation of a typical geological profile, support type and final roof strata behaviour

In order to establish a uniform approach to assist in simplifying the interpretations, the following criteria were introduced:

- Only readings outside the accepted error band were accepted.
- Differential displacements between adjacent anchors had to exceed 0.5 mm to be considered, except in the case of a trend involving three or more anchors where displacements down to 0.25 mm were included.

Displacements of 0.25 mm and larger are therefore represented by a line. In order to emphasis the different magnitudes of the various displacement zones, each line has been designated an appropriate thickness proportional to the value. These lines represent the total displacement recorded within the zone (between the two anchors) and do not infer that all the displacement took place at one particular elevation or parting plane; they are primarily an indication of relative magnitudes.

In Figure 3-1, to assist in explaining this concept, the anchor string showing individual anchor elevations is included. Alongside each displacement line the individual displacement values have been recorded. Where no displacement was observed, a zero value (0.0) is evident, as is the lack of a displacement line. The method used to indicate a negative displacement is also indicated. The anchor string and displacement values are included in Figure 3-1 primarily to assist with the explanation. They are not recorded in the graphic presentations of the individual monitoring site figures, as this information is already present in a slightly different form in the sonic probe graph.

To assist in assessing the effectiveness of the various roof support systems, a single support member is also included as part of the shaded strata column block alongside each sonic probe graph. The length of both the support member and the anchoring mechanism is drawn in at the same scale as the vertical axis of the sonic probe graph. A partial column resin anchored bolt is shown in Figure 3-1.

The roof displacements measured by the sonic probe are superimposed on the relevant roof support member for comparison purposes. This does not necessarily infer that these displacements are occurring in or at the support tendon hole, particularly where the hole is full of resin. The sonic probe hole varied between 0.3 to 1.0 m away from the closest support tendon hole.

The anchor height above which no displacements were recorded in a strata column is indicated as the 'stable elevation'. In cases where some doubt exists it may be referred to as the 'estimated stable elevation'. The 'total relaxation' value indicates the overall displacement between the stable elevation and the bottom anchor in the string.

Included with each displacement graph is a list of notes covering the monitoring site position, layout and mining method as well as a description of the roof strata and support system installed.

3.4 Colliery 'A'

Two sites, both in the same roadway 43 m apart, were monitored at Colliery 'A'. Guttering on one side of the roof/sidewall contact appeared to develop one or two pillars back from the face in roadways travelling in the same direction as the roadway where the monitoring sites were installed. Although in some cases the guttering was semi continuous for two or three pillars, its general appearance appeared to be random in nature. A number of intersections had collapsed and some roadways had been barricaded off due to dangerous roof conditions, usually associated with the guttering. Petroscope holes, drilled into the roadway roof where there were obvious roof problems, detected displacements up to a height of 1.6 m into the roof. Within this zone a number of openings in excess of 10 mm were observed.

The colliery was situated in the Vereeniging Coalfield mining the 2b Seam at a depth of 70 to 80 m with a mining height of 3.0 m. Mining was carried out using a continuous miner with onboard roofbolters. The roof was shale supported by 2.1 m long AX bars 21 mm in diameter with full column resin in a 25 mm diameter hole. The 5.0 m wide roadways were supported with five to six bolts per row with ‘W’ straps. The rows were 1.0 m apart.

The monitoring results from the two holes are presented in Figure 3-2 and Figure 3-3. The monitoring hole installation positions relative to the face were governed by how close the continuous miner with its onboard roofbolters could get to the face. Face advances in excess of 60 m took place during the two month monitoring period. At site 1 (Figure 3-2) displacements were only recorded below the 1.1 m elevation. The total relaxation of the lowest anchor was 2.5 mm bearing in mind that this displacement is relative to the stable elevation. At site 2 (Figure 3-3) no displacements were detected. Unfortunately, it was not possible to install the survey levelling backup system at either site.

While the failures were visually observed in other parts of the section, there was no visual evidence at either of the two sites to indicate the presence of a high horizontal stress regime. These results clearly illustrated the site specific nature of each monitoring site. The support system installed was adequate to control the shale roof in the regions where it was not subjected to the buckling effects of a high horizontal stress regime. Unfortunately it was not possible to repeat the monitoring exercise in the hope of selecting a site that would later be subjected to the effects of a high horizontal stress.

3.4.1 Site performance summary Colliery ‘A’

Coalfield:	Vereeniging	Seam:	2b
Sites:	Two	Positions:	Roadway
Road widths:	5.0 m	Pillar widths:	24 x 48 m
Mining height:	3.0 m	Depth:	70 to 80 m

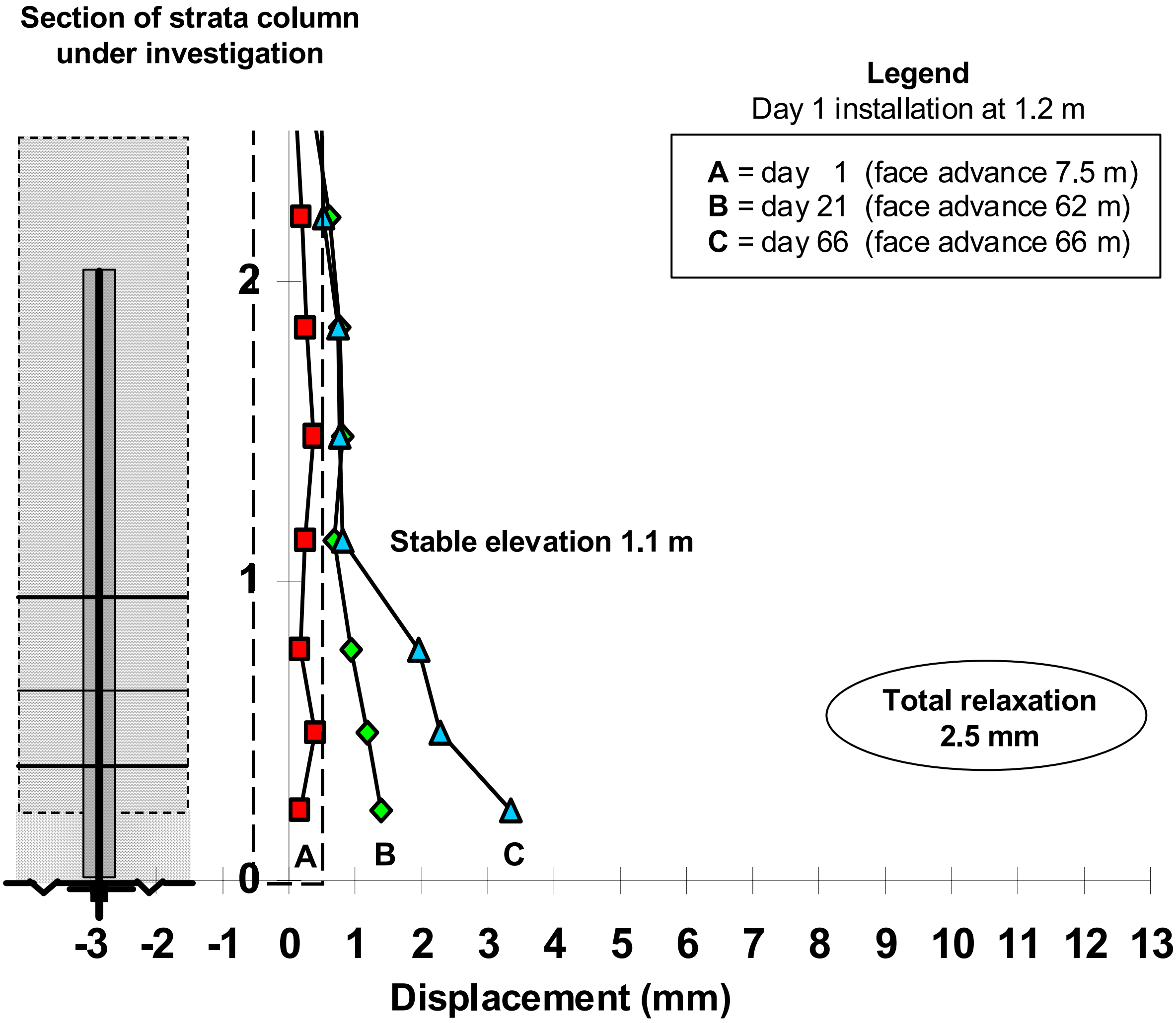
Mining method: Continuous miner, onboard roofbolters

Roof strata: Shale/mudstone

Support: 2.1 m x 21 mm AX bar, full column resin in 25 mm hole
Five to six bolts per row 1.0 m apart with "W" straps

Performance: Although there were indications of the presence of high horizontal stress within the section, there was no visual evidence to indicate its development at either monitoring site.

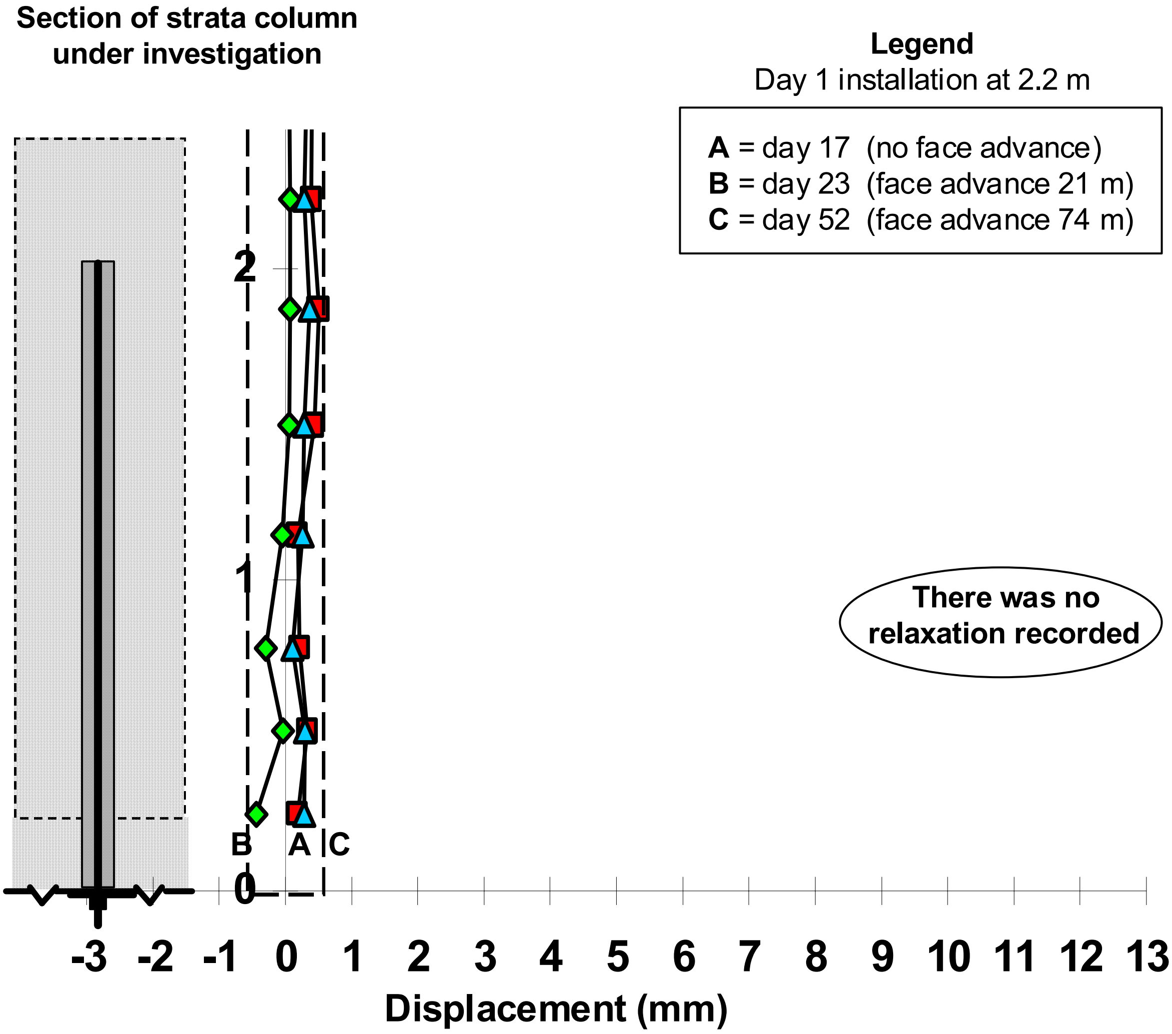
Roof separation was only measured at one site up to a maximum of 1.1 m into the shale allowing the roof skin a total relaxation of 2.5 mm after a face advance of 66 m over a 66 day period.



Notes

Coalfield : Vereeniging **Seam** 2b **Position** Roadway
Roof : Shale
Support : 2.1 m AX bar 21 mm diameter with full column resin in a 25 mm diameter hole. Five to six bolts per row 1.0 m apart with 'W' straps.
Layout : Depth 70 to 80 m **Bord** 5.0 m **Pillar** 24 x 48 m **Mining height** 3.0 m
Mining : Continuous miner with an onboard roof bolter.
Although there were indications of the presence of high horizontal stress within the section there was no visual evidence to indicate its development at this particular monitoring site.

Figure 3-2 Colliery 'A' site 1 (bord)



Notes

Coalfield : Vereeniging **Seam** 2b **Position** Roadway

Roof : Shale

Support : 2.1 m AX bar 21 mm diameter with full column resin in a 25 mm diameter hole. Five to six bolts per row 1.0 m apart with 'W' straps.

Layout : Depth 70 to 80 m **Bord** 5.0 m **Pillar** 24 x 48 m **Mining height** 3.0 m

Mining : Continuous miner with an onboard roof bolter.

Although there were indications of the presence of high horizontal stress within the section there was no visual evidence to indicate its development at this particular monitoring site.

Figure 3-3 Colliery 'A' site 2 (bord)

3.5 Colliery 'B'

Colliery 'B' is situated in the Witbank Coalfield and mines the No 2 Seam using conventional drill and blast mining method at an approximately 40 m depth below surface.

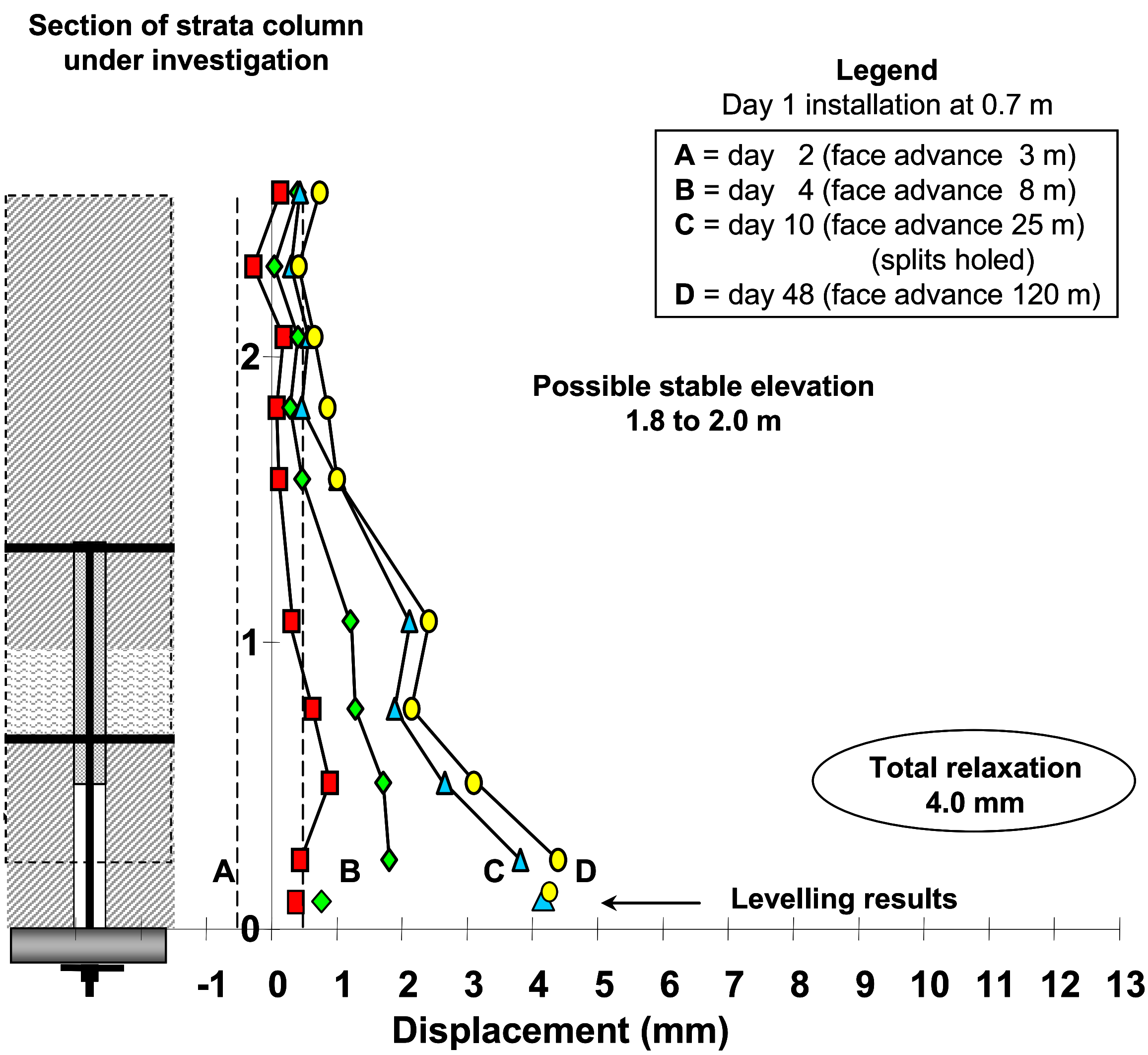
Six sites, four in roadways and two in intersections, were monitored at Colliery 'B'. The results are presented in Figure 3-4 to Figure 3-9. Note that the displacements appeared between 1.2 m to 2.2 m into the roof in Figure 3-5 are anomalies of the sonic probe extensometer, which thought to be caused by moving the anchors in the hole during pushing the probe into the hole to take readings.

In area 1, the installation and initial readings of sites 2 and 3 were taken on the same day as reading B (day four) at site 1. Similarly, in area 2 the installation and initial readings of sites 2 and 3 were taken on the same day as reading B (day six) at site 1. The monitoring in area 2 was carried out six months after the monitoring at area 1.

At three of the six monitoring sites, backup levelling was installed and monitored in conjunction with the sonic probe investigation. At all three sites, as is evident in Figure 3-4, Figure 3-6 and Figure 3-8, the levelling results agreed very closely with, and confirmed the final position and displacements of the sonic probe anchor closest to the collar of the hole at various stages during the monitoring period.

The immediate roof strata consisted of 0.5 to 1.0 m of coal, followed by a shale band approximately 0.3 m thick above which there is a further 3.0 m of coal. In the figures the 'typical' roof strata profile shows a shale band 0.3 m wide positioned at 0.7 m to 1.0 m into the roof. On a site specific basis the exact thickness and position of the shale band are not known. When comparing the six sonic probe graph results against the 'typical' strata column section, this unknown shale band elevation should be borne in mind.

Monitoring of the first three sites at area 1, an intersection and two roadways, was carried out to establish the characteristics of the particular strata combination and support performance. The opportunity to do additional monitoring at area 2 came about as the result of a dyke. In adjacent sections of the mine, separated by a dyke, there appeared to be differences in the competency of the roof although the roof strata were similar. Again an intersection and two adjacent roadways were monitored. There was a slight difference in the mining sequence at area 2 site 3 where the roadway was only advanced 3.0 m before being holed into from the opposite direction.



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection
Roof : 0.5 to 1.0 m coal, 0.3 m shale then coal to approximately 4.0m.
Support : 1.5 m x 16 mm diameter 'V' bar with partial column resin in a 24 mm diameter hole with 0.1 x 0.1 x 0.9 m headboards. Two bolts 4.0 m apart with 3.0 m between rows. Halfway between these rows is a single centre bolt in a dice five pattern.
Layout : Depth 40 m **Roadway** 6.0 m **Pillar** 9.0 m **Mining height** 3.0 m
Mining : Conventional drill and blast.
The major displacements appear to extend to just above the bolt horizon.

Figure 3-4 Colliery 'B' area 1 site 1 (intersection)

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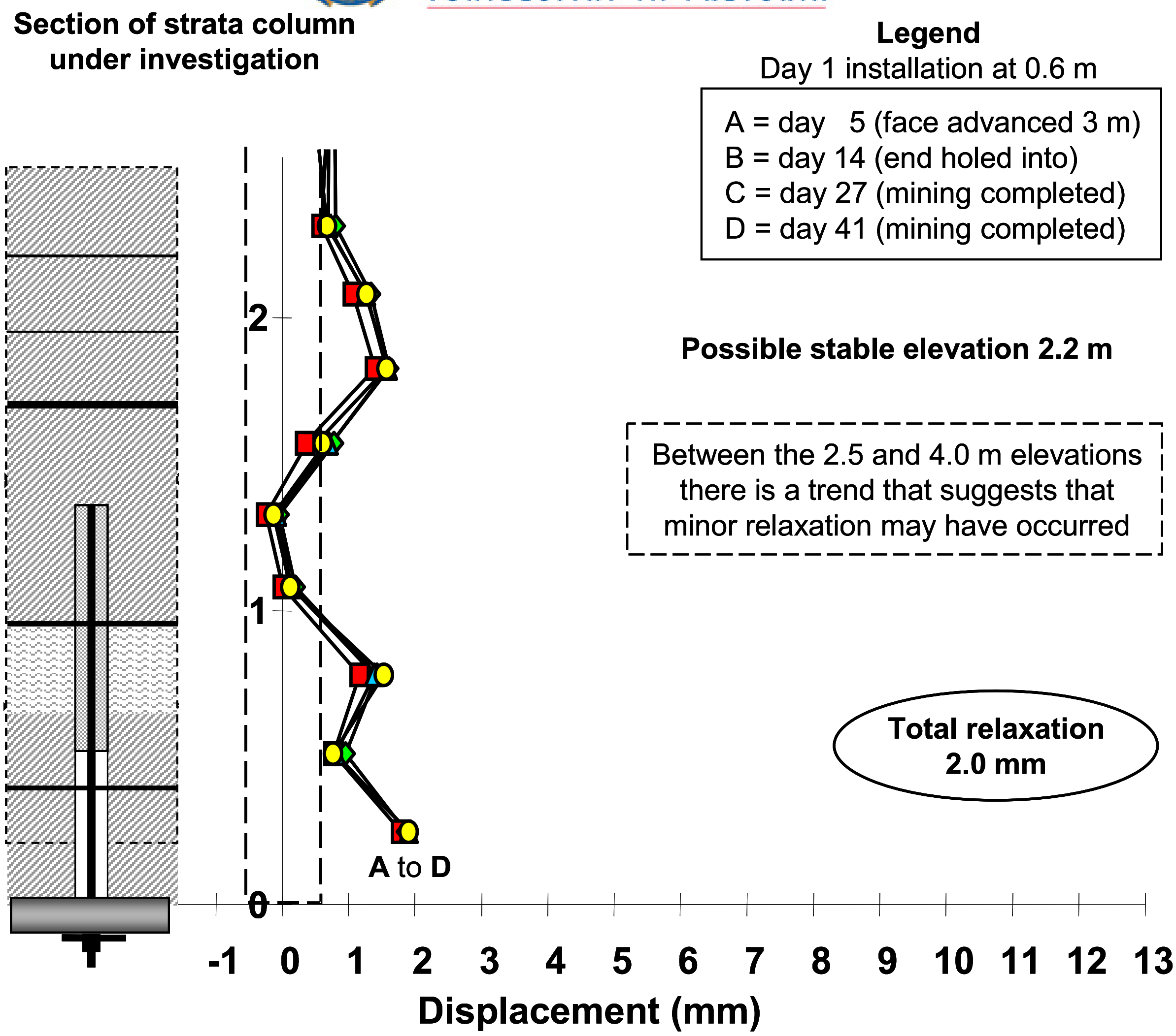


Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : 0.5 to 1.0 m coal, 0.3 m shale then coal to approximately 4.0 m.

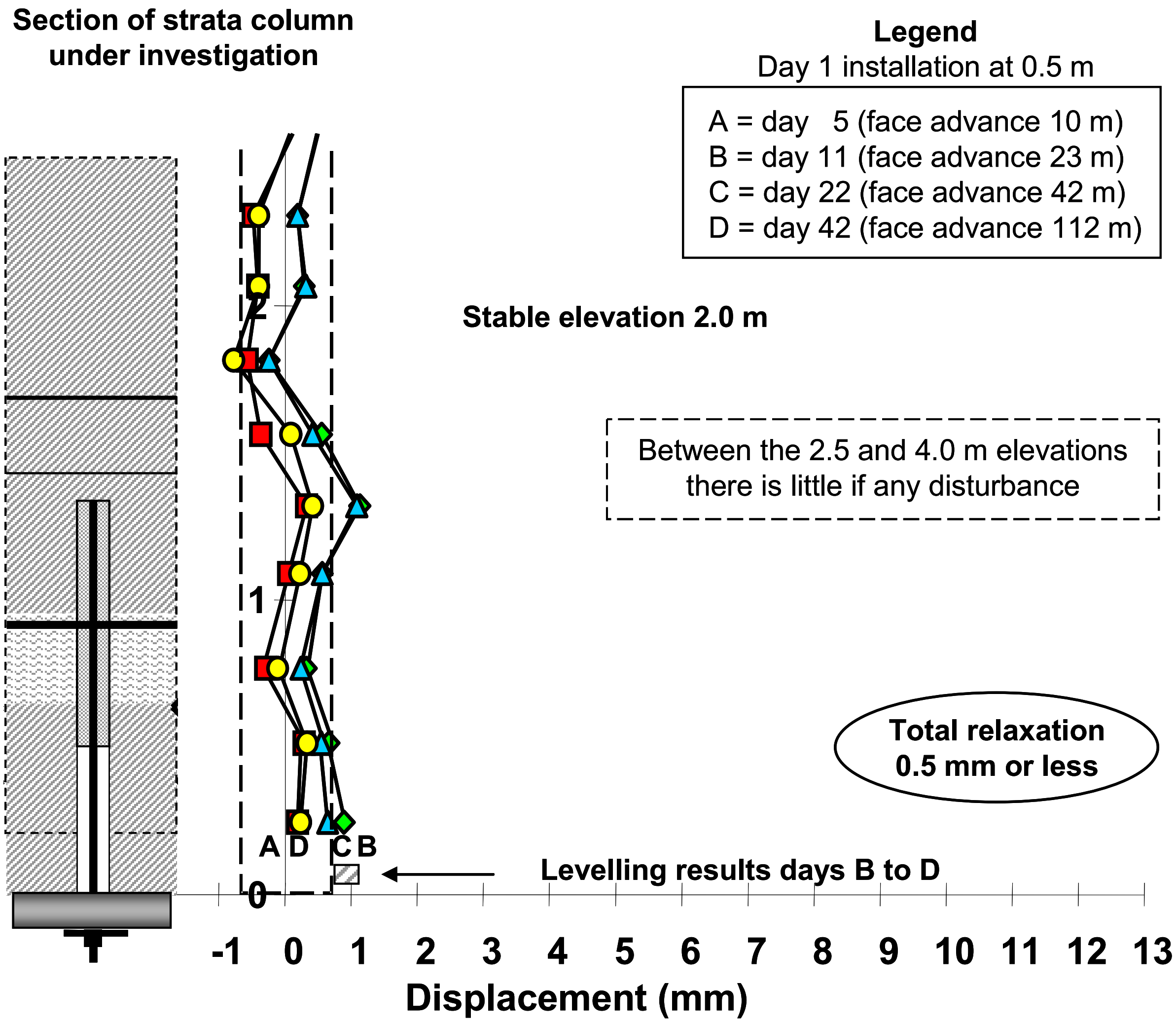
Support : 1.5 m x 16 mm diameter 'V' bar with partial column resin in a 24 mm diameter hole with 0.1 x 0.1 x 0.9 m headboards. Two bolts 4.0 m apart with 3.0 m between rows. Halfway between these rows is a single centre bolt in a dice five pattern.

Layout : Depth 40 m **Roadway** 6.0 m **Pillar** 9.0 m **Mining height** 3.0 m

Mining : Conventional drill and blast.

The major displacements extend up to the 2.2 m elevation, 1.0 m above the bolt horizon.

Figure 3-5 Colliery 'B' area 1 site 2 (roadway)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : 0.5 to 1.0 m coal, 0.3 m shale then coal to approximately 4.0 m.

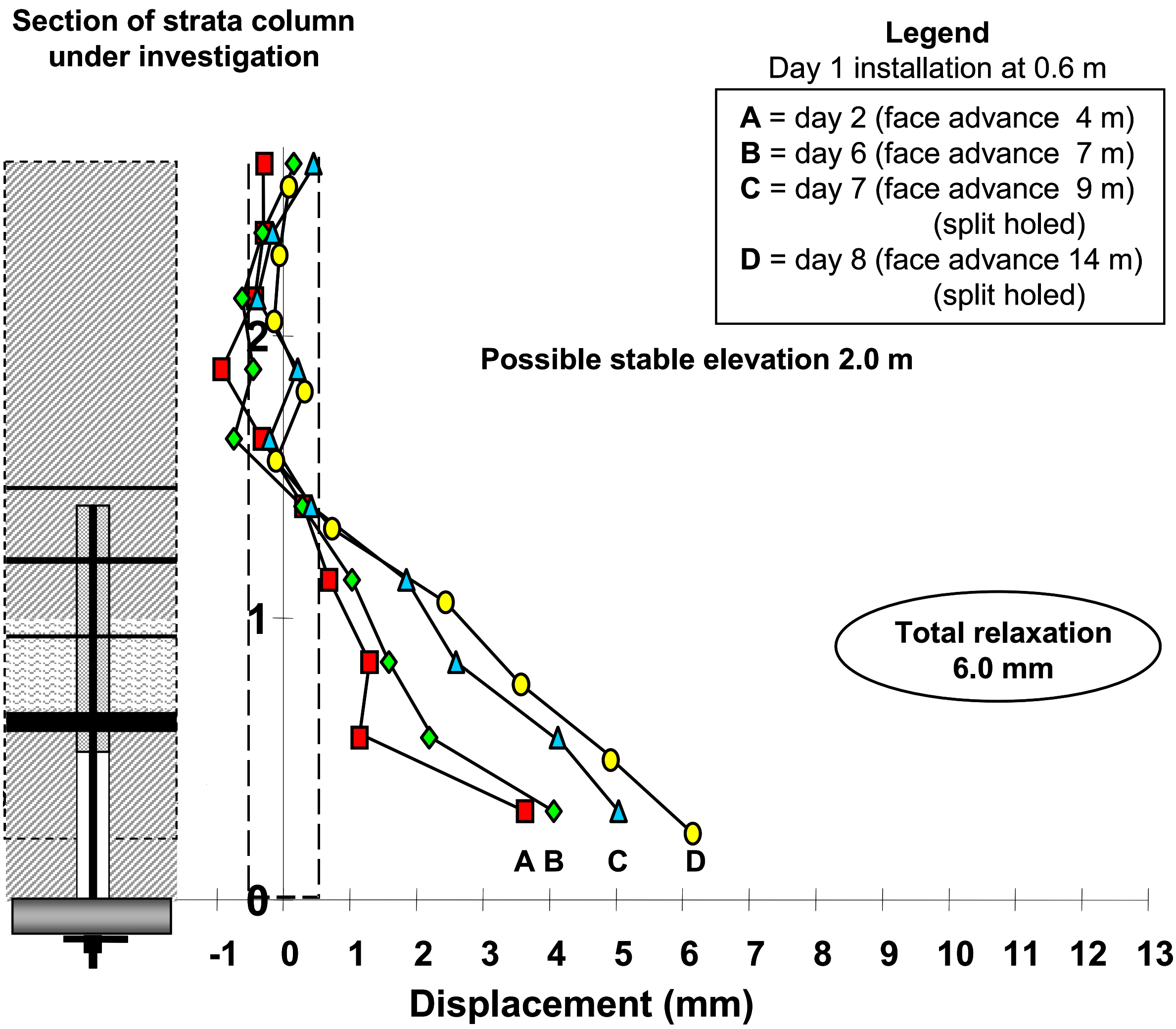
Support : 1.5 m x 16 mm diameter 'V' bar with partial column resin in a 24 mm diameter hole with 0.1 x 0.1 x 0.9 m headboards. Two bolts 4.0 m apart with 3.0 m between rows. Halfway between these rows is a single centre bolt in a dice five pattern.

Layout : Depth 40 m **Roadway** 6.0 m **Pillar** 9.0 m **Mining height** 3.0 m

Mining : Conventional drill and blast.

The major displacements appear to extend up to about 0.5 m above the bolt horizon.

Figure 3-6 Colliery 'B' area 1 site 3 (roadway)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

Roof : 0.5 to 1.0 m coal, 0.3 m shale then coal to approximately 4.0 m.

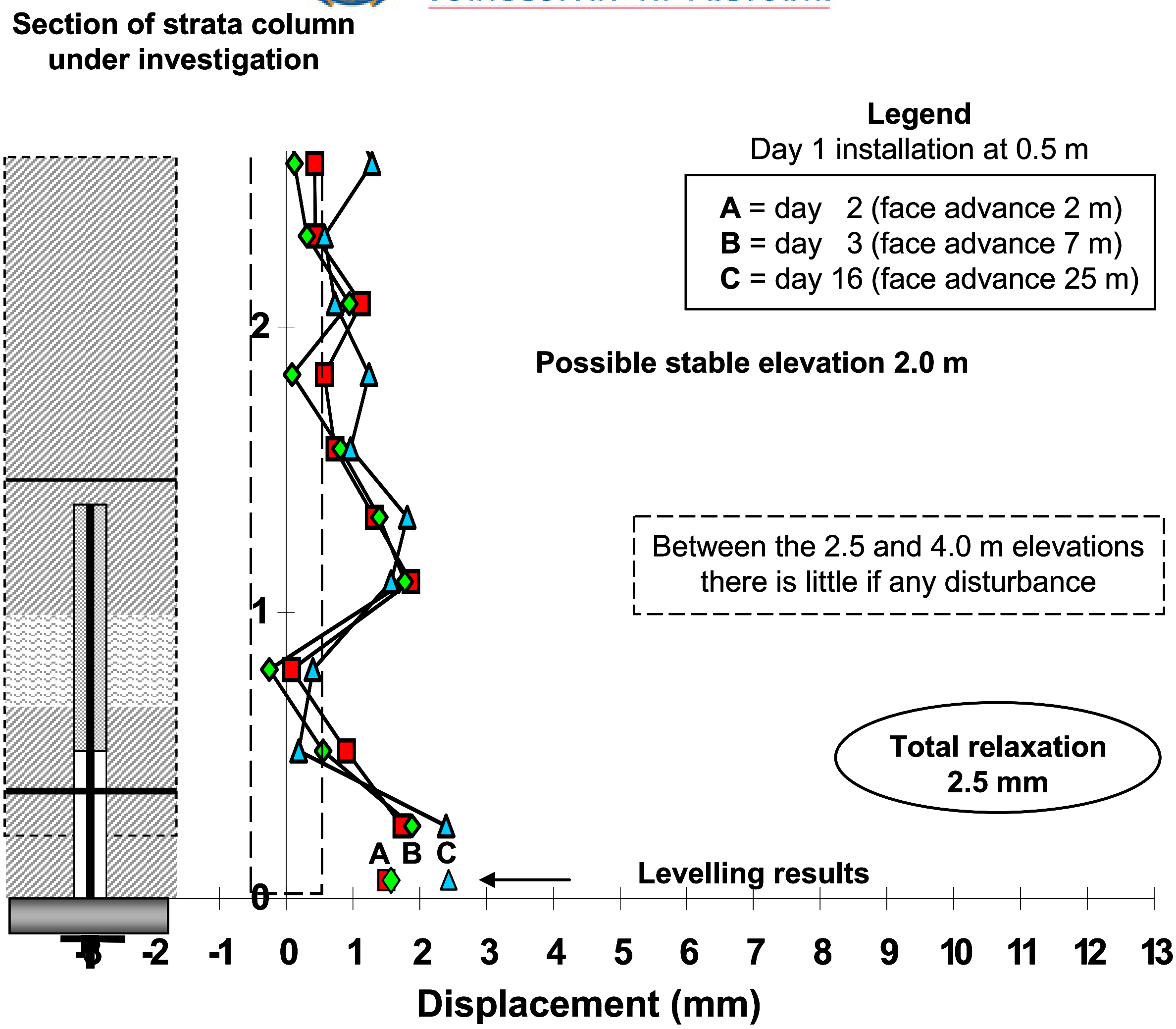
Support : 1.5 m x 16 mm diameter 'V' bar with partial column resin in a 24 mm diameter hole with 0.1 x 0.1 x 0.9 m headboards. Two bolts 4.0 m apart with 3.0 m between rows. Halfway between these rows is a single centre bolt in a dice five pattern.

Layout : Depth 40 m **Roadway** 6.0 m **Pillar** 9.0 m **Mining height** 3.0 m

Mining : Conventional drill and blast.

The major displacements appear to be confined to within 0.2 m above the bolt horizon.

Figure 3-7 Colliery 'B' area 2 site 1 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : 0.5 to 1.0 m coal, 0.3 m shale then coal to approximately 4.0 m.

Support : 1.5 m x 16 mm diameter 'V' bar with partial column resin in a 24 mm diameter hole with 0.1 x 0.1 x 0.9 m headboards. Two bolts 4.0 m apart with 3.0 m between rows. Halfway between these rows is a single centre bolt in a dice five pattern.

Layout : Depth 40 m **Roadway** 6.0 m **Pillar** 9.0 m **Mining height** 3.0 m

Mining : Conventional drill and blast.

The major displacements extend up to the 1.6 m elevation, approximately 0.2 m above the bolt horizon. A kickback of approximately 1.0 mm is situated at the 1.0 m elevation.

Figure 3-8 Colliery 'B' area 2 site 2 (roadway)

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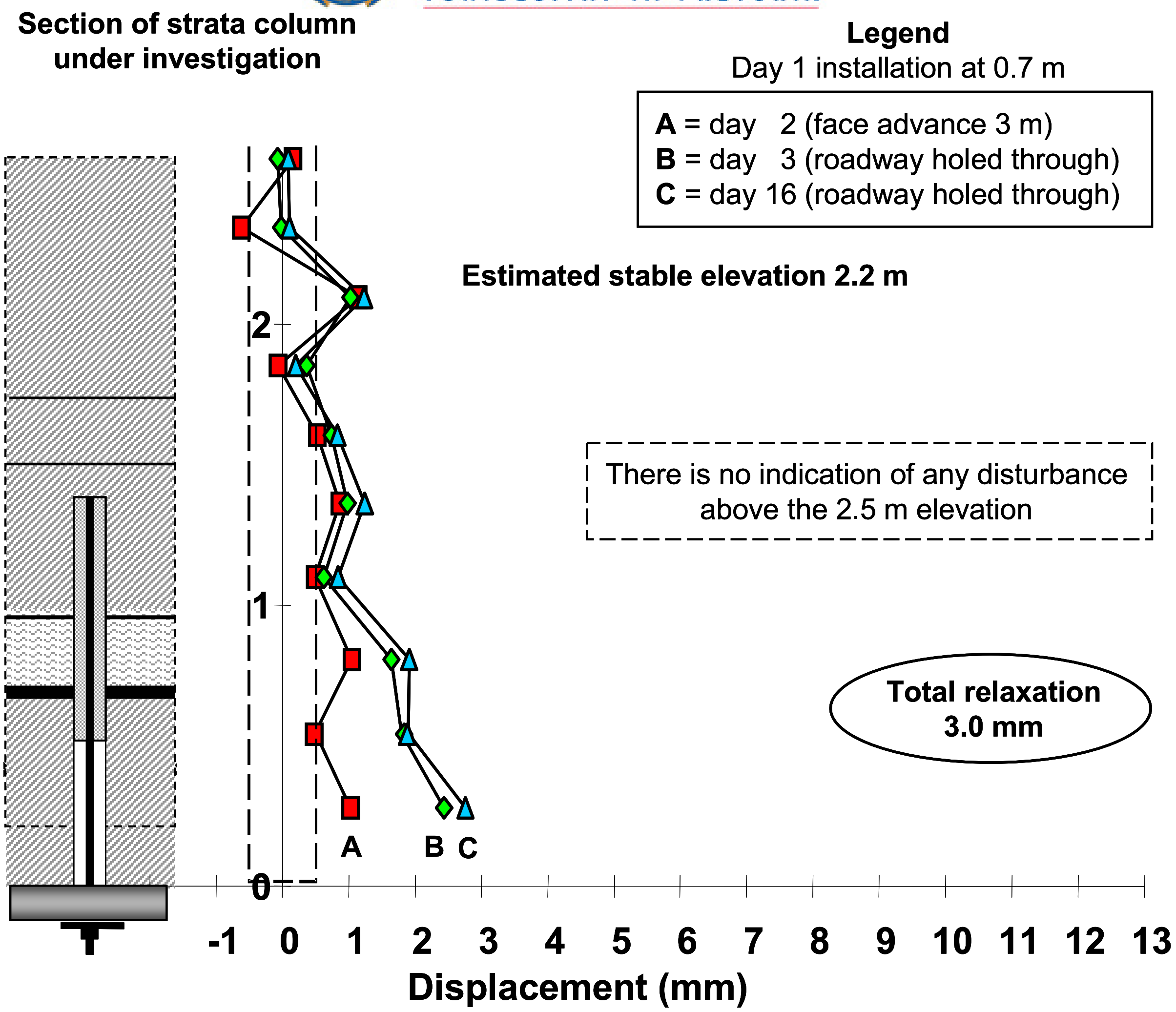


Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : 0.5 to 1.0 m coal, 0.3 m shale then coal to approximately 4.0 m.

Support : 1.5 m x 16 mm diameter 'V' bar with partial column resin in a 24 mm diameter hole with 0.1 x 0.1 x 0.9 m headboards. Two bolts 4.0 m apart with 3.0 m between rows. Halfway between these rows is a single centre bolt in a dice five pattern.

Layout : Depth 40 m **Roadway** 6.0 m **Pillar** 9.0 m **Mining height** 3.0 m

Mining : Conventional drill and blast.

The major displacements extend up to the 1.9 or 2.2 m elevation.

Figure 3-9 Colliery 'B' area 2 site 3 (roadway)

The comparative roof performance of all six sites is illustrated in Figure 3-10. From the results, the roadway in area 1 at site 2 appears to exhibit a different behaviour pattern to the other five sites with respect to the strata above the roof bolt horizon up to the 2.5 m elevation. Most of the activity in the roof strata at the other five sites is within the roof bolt horizon. The major positive opening displacements tend to be within the upper and lower limits of the 0.3 m shale band, i.e. between 0.5 and 1.3 m into the roof. This is the region where the bolts were fully resin grouted to consolidate the shale band. Although displacements are indicated in general up to 0.5 m above the bolt horizon, the magnitudes are considerably less than those recorded within the bolt horizon. The upper displacement levels at both intersections are closer to the bolt horizon than some of the roadway sites. The additional 40 per cent increase in the span across the intersection diagonals appears to have had little or no effect on crack propagation between the top of the roof bolts and the 2.5 m elevation.

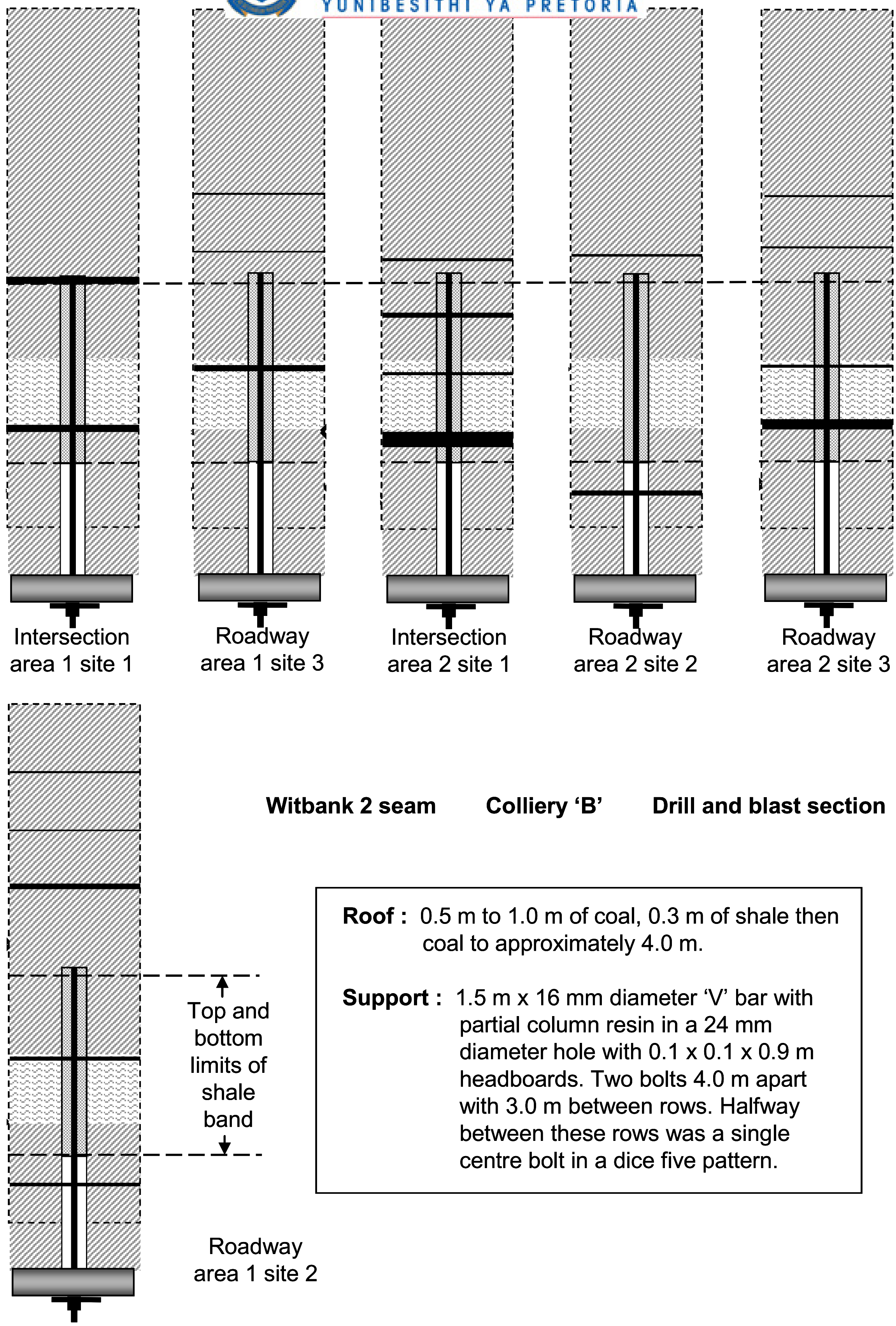


Figure 3-10 Colliery 'B' comparative roof behaviour

The mining of the splits to form an intersection allowed the roof displacements to reach larger magnitudes than in the roadways. After completion of the mining cycle, the roadways and the intersections both stabilised very quickly. This is illustrated in Figure 3-11 where a comparison between the roof skin displacements, derived from the backup levelling results, at the intersection at area 1 site 1 and the roadway at area 1 site 3 are presented. The displacements of the bottom anchor near the collar of the hole in the intersection at area 1 site 1 are presented in Figure 3-12. Figure 3-13 shows the velocity profile of the same anchor. Stability was reached shortly after the splits were holed through at the 25 m face advance. The final reading was taken approximately 50 days after the initial indication that the roof had stabilised.

The overall total relaxation at the roof skin in area 2 was about 50 per cent higher than in area 1. From visual observation both roof conditions appeared to be similar with falls of ground being limited to isolated cases between the headboards.

3.5.1 Site performance summary Colliery 'B'

Coalfield:	Witbank	Seam:	2 Seam
Sites:	Six	Positions:	Two intersections four roadways
Road widths:	6.0 m	Pillar widths:	9.0 m
Mining height:	3.0 m	Depth:	40 m

Mining method: Drill and blast

Roof strata: 0.5 m to 1.0 m coal, 0.3 m shale then coal to approximately 4.0 m

Support: 1.5 m x 16 mm diameter 'V' bar with partial column resin in a 24 mm diameter hole with 0.1 x 0.1 x 0.9 m headboards. Two bolts 4.0 m apart with 3.0 m between rows. Half way between these rows is a single centre bolt in a five dice pattern

Performance: Indications are that displacement occurred in the roof strata when the face was advanced with the blast, increasing the unsupported roof span up to 3.0 m. Further displacements, mainly within the roof bolt horizon, occurred quickly, within one or two blasts as the face advanced. The overall stability of the roof occurred quickly in the bords and intersections once the splits had been mined.

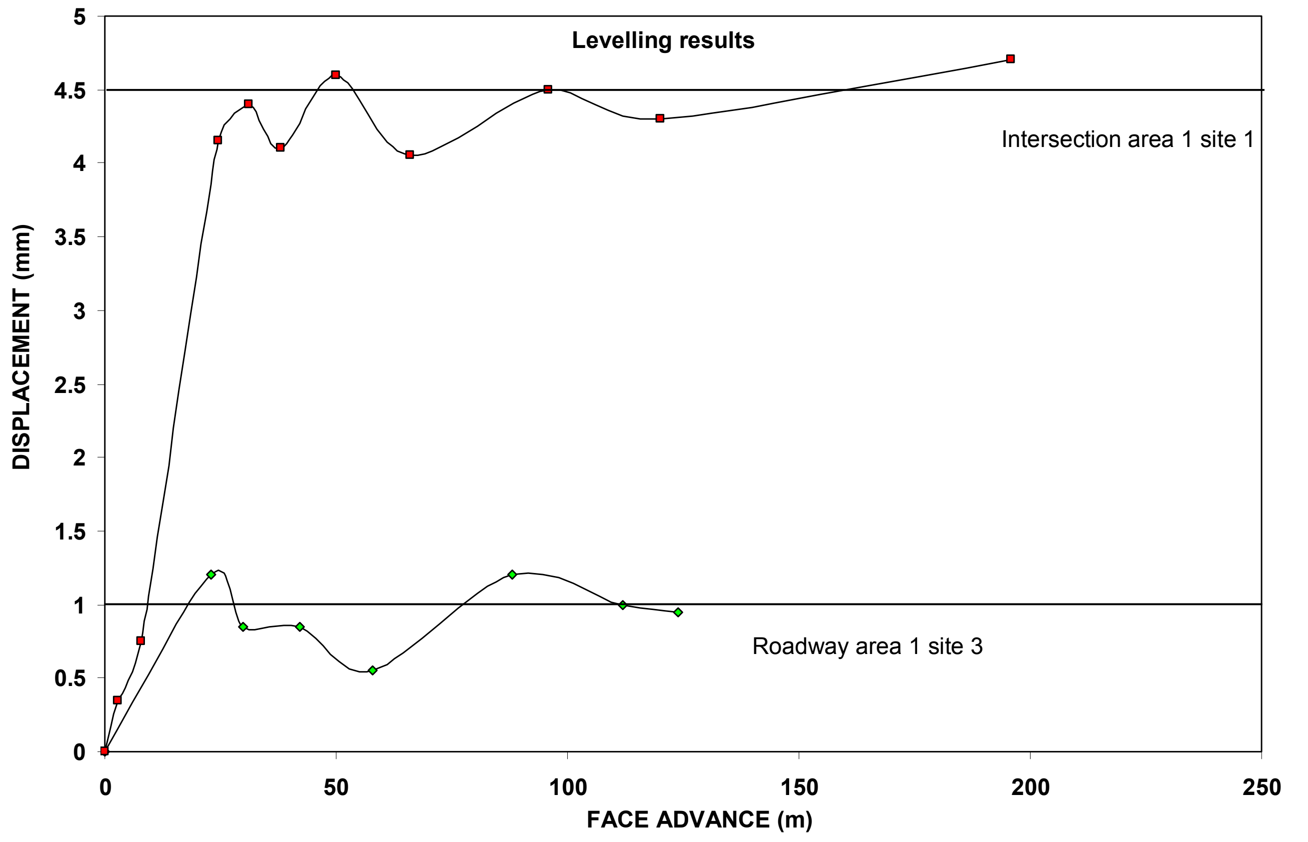


Figure 3-11 Colliery 'B' comparison between roadway and intersection roof skin displacement

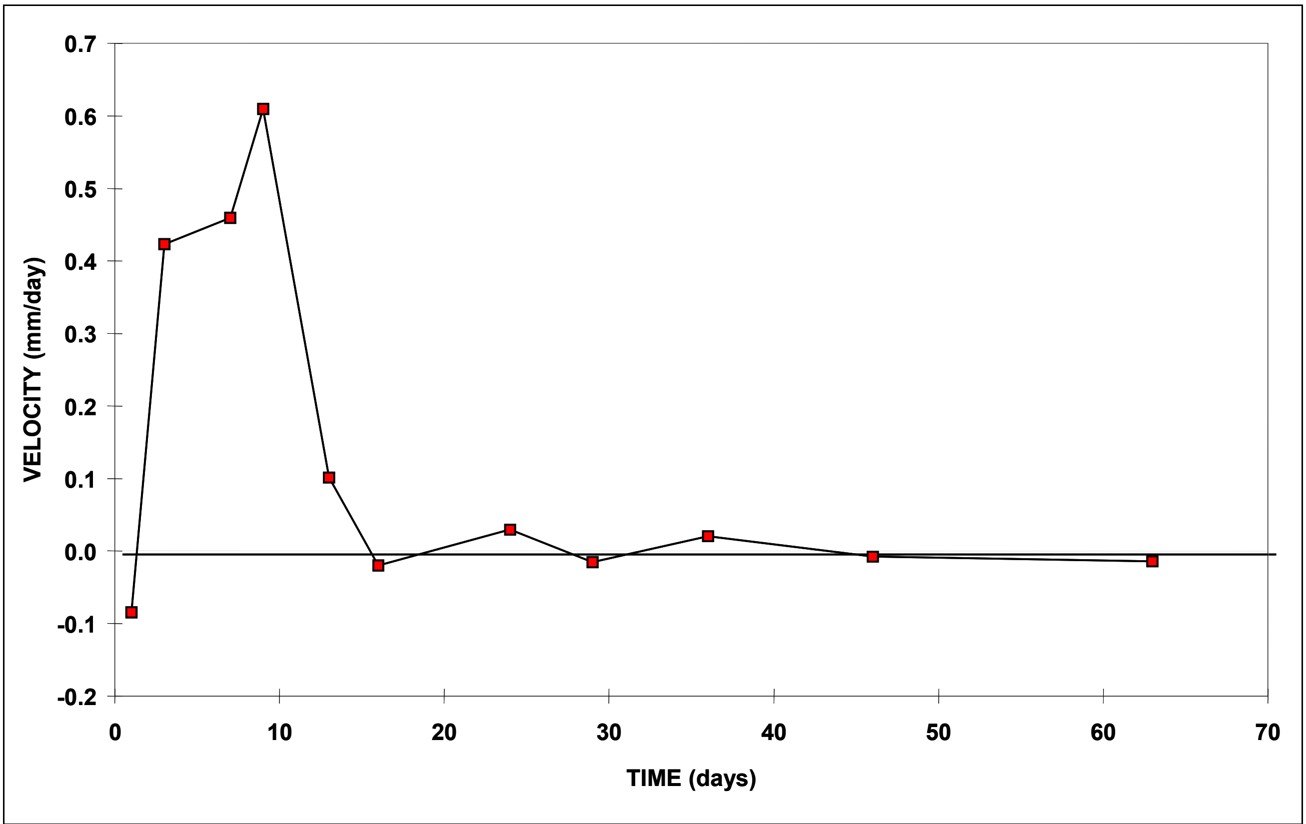


Figure 3-12 Colliery 'B' area 1 site 1 (intersection) collar anchor displacement

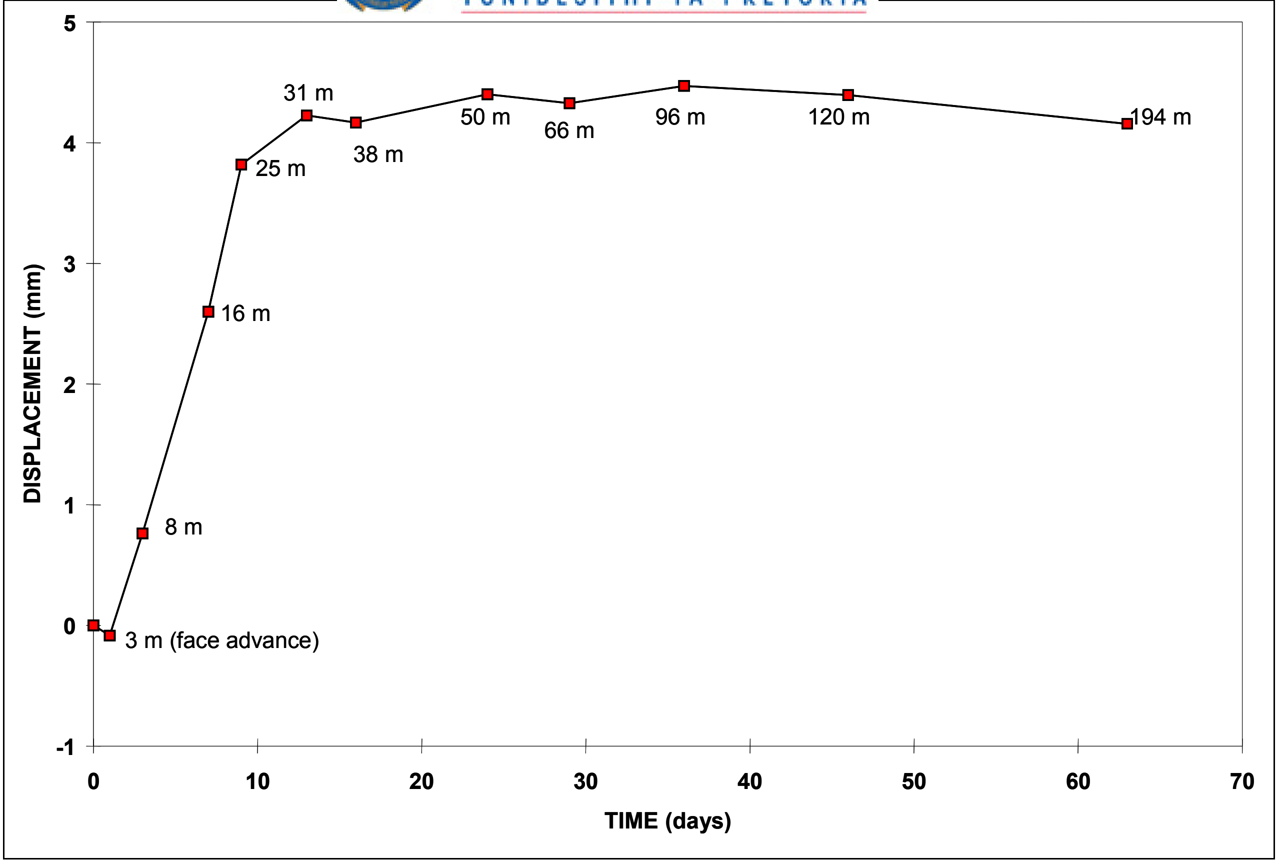


Figure 3-13   Colliery 'B' area 1 site 1 collar anchor velocity

3.6 Colliery 'C'

At Colliery 'C', which mines the No 2 Seam in the Witbank Coalfield, back up levelling results were only viable at two of the four sites as a result of blast damage to levelling installations.

Sites 1 and 2, an intersection and adjacent roadway respectively, were situated approximately 25 m away from sites 3 and 4, another intersection and roadway. The immediate roof consisted of a coal layer approximately 0.3 m thick with shale above it. The standard support was 1.8 m x 16 mm mechanical end anchored bolts, three in a row with the rows 2.0 m apart. The boltholes were drilled with electric hand held drills. The bolts were installed and tensioned by using the electric drills.

The results from Collier 'C' are presented in Figure 3-14 to Figure 3-17. The total relaxation, which occurred within or close to the roof bolt horizon, was very small. The largest displacements were recorded at the intersection in site 3, Figure 3-16, where the total relaxation was 3.5 mm. The final levelling result value was 30 per cent larger than indicated by the lowest sonic probe anchor close to the collar of the hole. This indicates the presence of an additional displacement of approximately 1.5 mm between 0.1 and 0.2 m in from the roof skin. These were the elevations of the levelling skin anchor and the bottom sonic probe anchor, respectively. At site 2 the levelling results and the lowest sonic probe anchor close to the collar of the hole gave near identical values.

As was the case in Colliery 'B', roof displacement in the form of open fractures or bedding planes appeared to occur very close to the face (within 0.5 m) as the blasting extended the unsupported roof span up to a maximum of approximately 3.0 m. Most of the subsequent displacements that occurred after the installation of the support and instrumentation were close to or within the roof bolt horizon, as illustrated in Figure 3-18. In general, the roof displacements appeared to have stabilised when the face had advanced by the bord width i.e. 6.0 m.

3.6.1 Site performance summary Colliery 'C'

Coalfield:	Witbank	Seam:	2 Seam
Sites:	Four	Positions:	Two intersections two roadways
Road widths:	6.0 m	Pillar widths:	9.0 m
Mining height:	2.2 m	Depth:	50 to 60 m

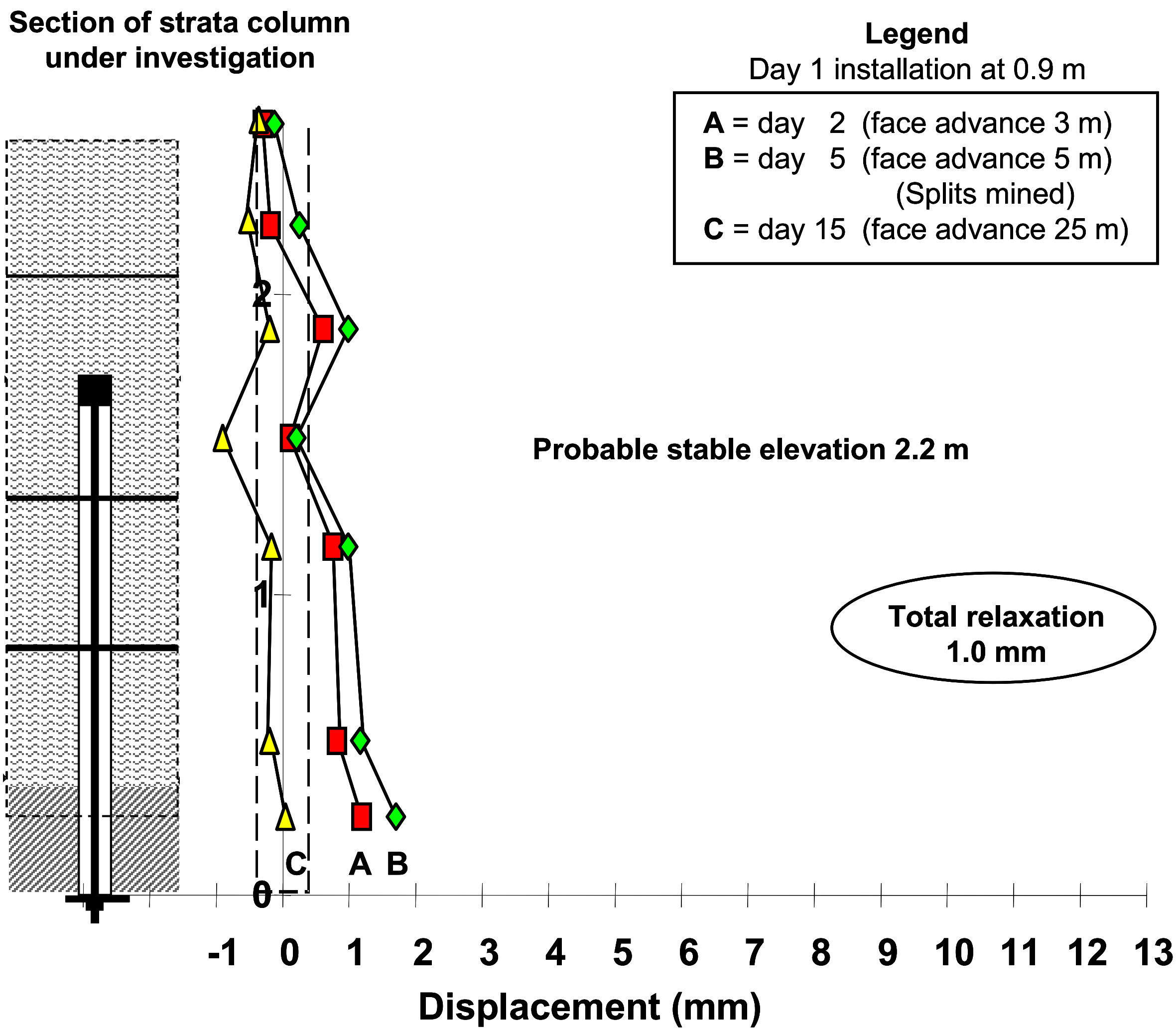
Mining method: Drill and blast

Roof strata: Approximately 0.3 m of coal with shale above it

Support: 1.8 m x 16 mm diameter mechanical end anchored bolts.
Three bolts per row with rows 2.0 m apart.

Performance: Indications are that displacement occurred in the roof strata when the face was advanced with the blast, increasing the unsupported roof span by up to 3.0 m. This resulted in open parting planes and fractures being present as close as 0.5 m from the face prior to the installation of the support and instrumentation.

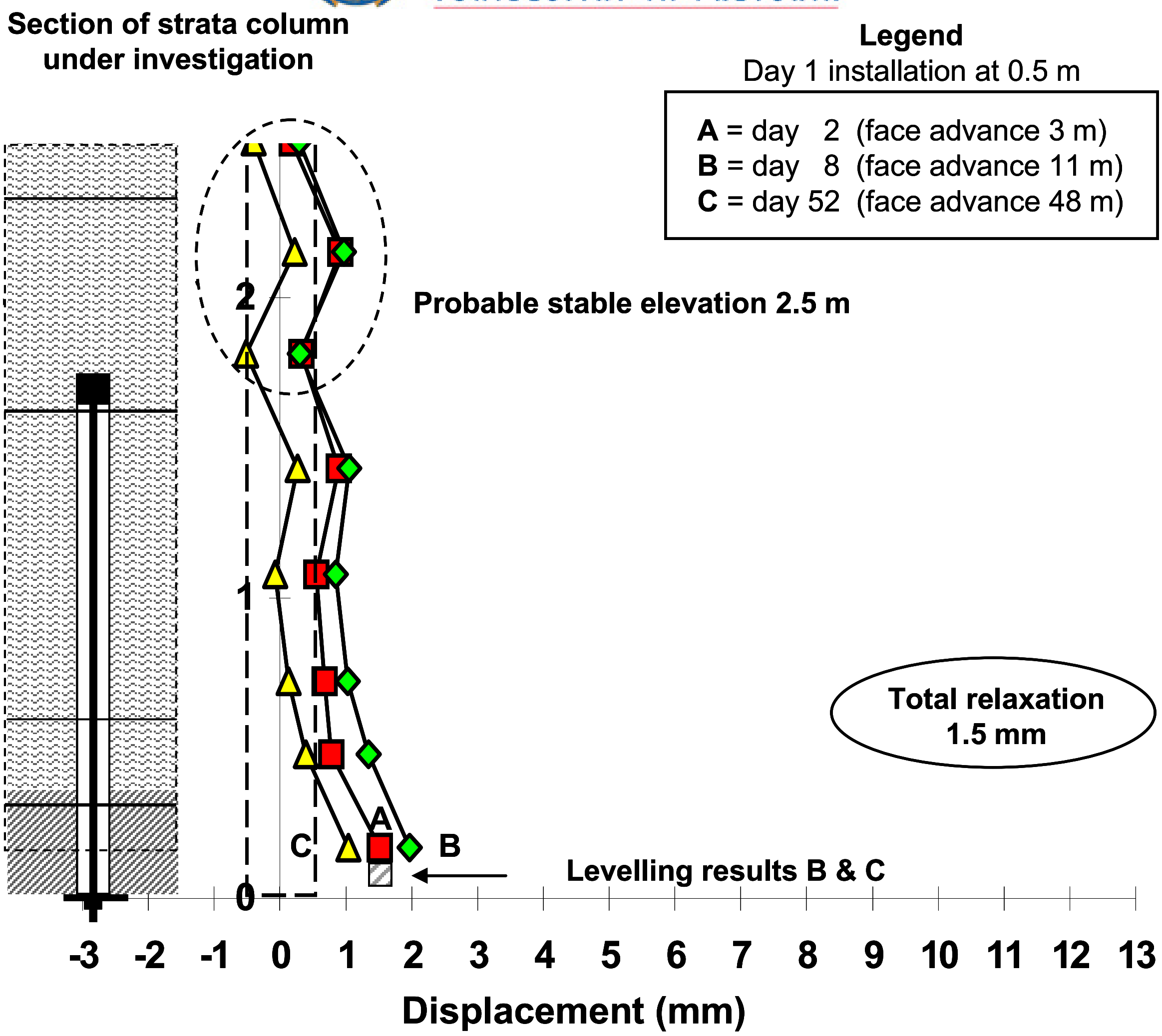
Although there were isolated cases of openings restricted to approximately 0.3 m and 1.0 m into the roof, three of the four sites indicate the presence of an opening around the 2.0 m elevation just above the bolt horizon. Further small displacements, mainly within the roof bolt horizon, occurred during the first one or two blasts as the face advanced. However, stability of the roof also occurred quickly. In the intersections this was attained once the splits had been mined.



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection
Roof : Approximately 0.3 m of coal with shale above it.
Support : 1.8 m x 16 mm mechanical end anchored bolts 3 in a row with rows 2.0 m apart. Bolt holes drilled with electric hand held drills.
Layout : Depth 50 to 60 m **Roadway** 6.0 m **Pillar** 9.0 m
Mining : Conventional drill and blast **Mining height** 2.2 m
Displacements appeared to have occurred up to 0.4 m above the bolt horizon.

Figure 3-14 Colliery 'C' site 1 (intersection)



Notes

Coalfield :Witbank **Seam** 2 seam **Position** Roadway

Roof : Approximately 0.3 m of coal with shale above it.

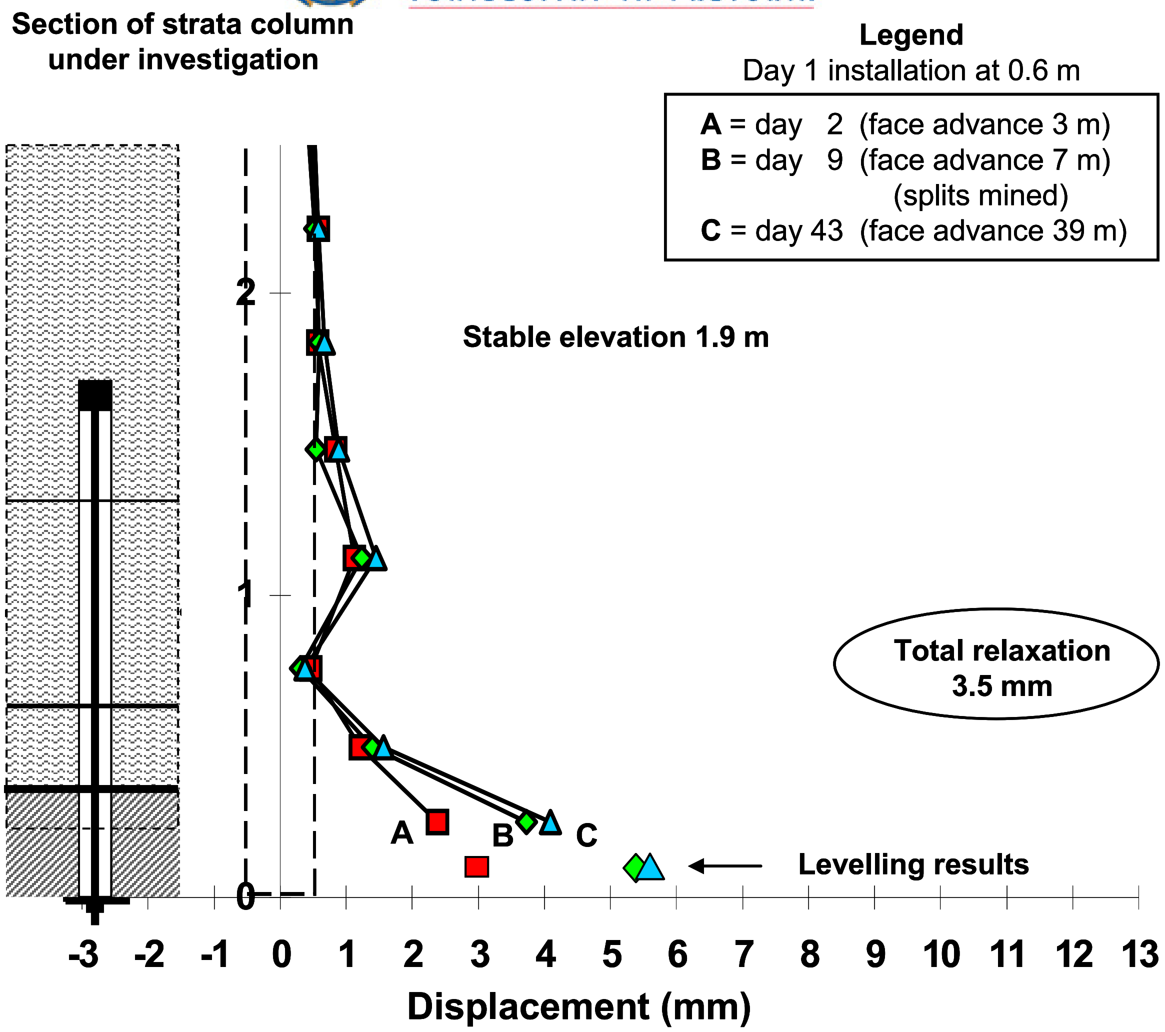
Support : 1.8 m x 16 mm mechanical end anchored bolts 3 in a row with rows 2.0 m apart. Bolt holes drilled with electric hand held drills.

Layout : Depth 50 to 60 m **Roadway** 6.0 m **Pillar** 9.0 m

Mining : Conventional drill and blast **Mining height** 2.2 m

Displacements appear to have occurred as high as 0.7 m above the bolt horizon with a single kickback close to the 2.0 m elevation.

Figure 3-15 Colliery 'C' site 2 (roadway)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

Roof : Approximately 0.3 m of coal with shale above it.

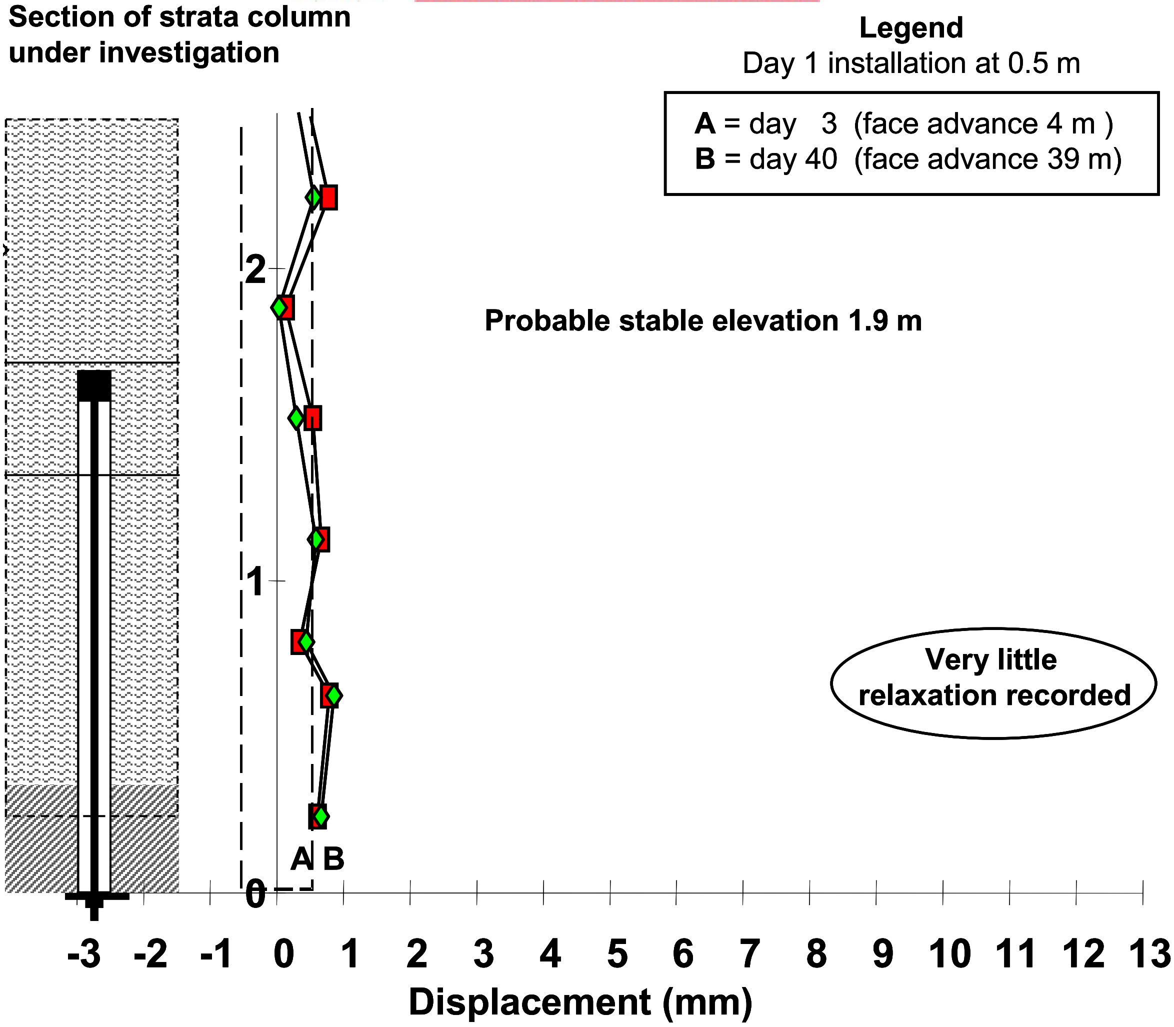
Support : 1.8 m x 16 mm mechanical end anchored bolts 3 in a row with rows 2.0 m apart. Bolt holes drilled with electric hand held drills.

Layout : Depth 50 to 60 m **Roadway** 6.0 m **Pillar** 9.0 m

Mining : Conventional drill and blast **Mining height** 2.2 m

All the displacements appear to have taken place within or close to the bolt horizon. There was a kickback at approximately the 1.0 m elevation. Positive opening displacements of about 4.0 mm in total occurred within the initial 0.8 m of roof strata.

Figure 3-16 Colliery 'C' site 3 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : Approximately 0.3 m of coal with shale above it.

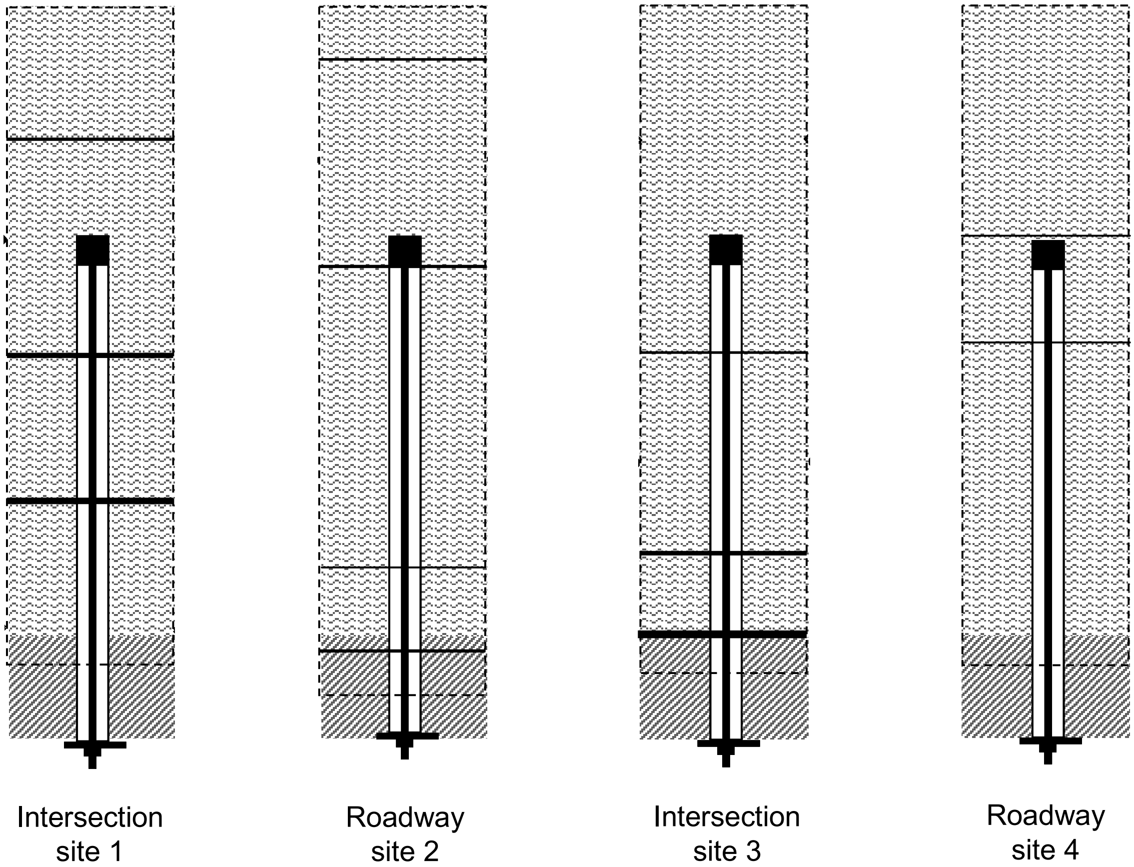
Support : 1.8 m x 16 mm mechanical end anchored bolts 3 in a row with rows 2.0 m apart. Bolt holes drilled with electric hand held drills.

Layout : Depth 50 to 60 m **Roadway** 6.0 m **Pillar** 9.0 m

Mining : Conventional drill and blast **Mining height** 2.2 m

The overall displacements recorded, although very small, extended to just above the bolt horizon.

Figure 3-17 Colliery 'C' site 4 (roadway)



Roof : Approximately 0.3 m of coal with shale above it.

Support : 1.8 m x 16 mm mechanical end anchored bolts three in a row with rows 2.0 m apart. Bolt holes drilled with electric hand held face drills. Bolts tensioned using the electric drill.

Figure 3-18 Colliery 'C' comparative roof behaviour

3.7 Colliery 'D'

Monitoring was carried out at three different locations at Colliery 'D'. A total of 12 sites were monitored covering four support combinations and two mining methods. The roof consisted of laminated sandstone and shale with variable bedding thicknesses. The support pattern of four bolts per row with rows 1.5 m apart remained the same at all the sites. Backup levelling was carried out at eight of the sites.

In the first area, two intersections and two roadways were monitored. The support method used was 1.5 m long 15 mm spiral bars. These were installed in 22 mm diameter holes using three 19 x 380 mm resin cartridges giving a full column resin bond. The mining method used was conventional drill and blast. As is usual practice, each blast advanced the full face width of 6.0 m by approximately 2.0 m. This resulted in unsupported maximum exposed roof distances, from the last row of support up to the face, of approximately 3.5 m. The monitoring hole was always within 1.0 m of the nearest roof bolt.

The individual monitoring results from site 1 are presented in Figure 3-19, Figure 3-20, Figure 3-21 and Figure 3-22. The levelling results at all four sites were similar to, but generally had slightly larger values than those indicated by the lowest sonic probe anchor.

The intersection at site 1 (Figure 3-19) was the only site that appeared to have experienced displacements above the bolt horizon. It is difficult to determine if there was any displacement in the 0.5 m above the bolt horizon in the other intersection at site 3 (Figure 3-21) due to what appear to be anomalous readings. The average total relaxation experienced at the intersections was 4.5 mm whereas that in the roadways was less than 1.0 mm.

In the roadway at site 4 there were indications of very small displacements. These were however all less than the accepted accuracy band of the sonic probe extensometer and were therefore not transferred onto the strata column. The smallest face advance that took place before the second set or readings were taken was 4.0 m at site 4. The displacements that were recorded had virtually all taken place by the time of the second visit.

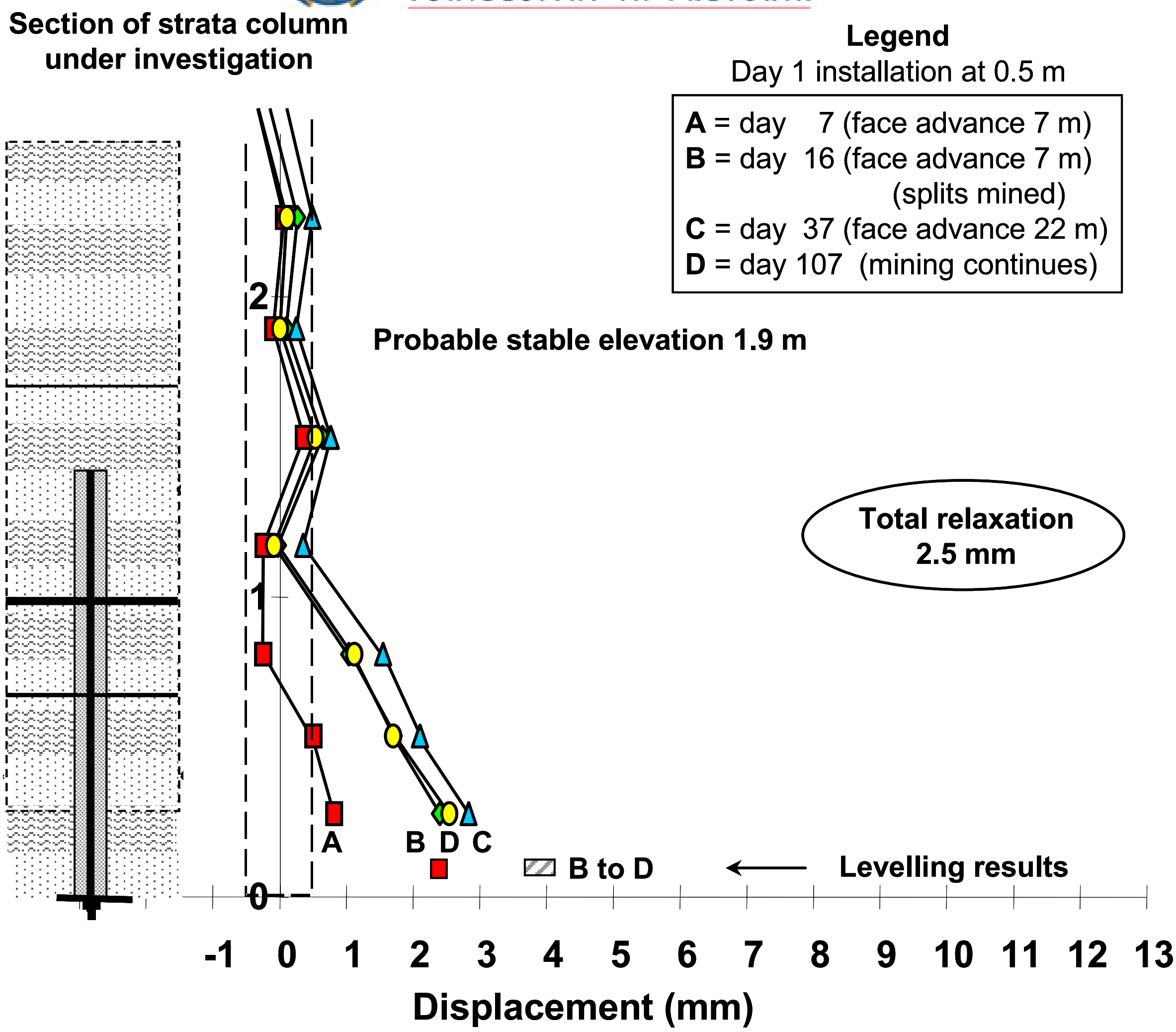
All four sites have been grouped together in Figure 3-23.

The levelling results of the roof skin behaviour relative to the 1.8 m datum, for all four sites, have been plotted and are presented in Figure 3-24. To compare roadway roof behaviour it is easy and probably more accurate to use face advance as opposed to time as one of the axes. The complex nature of "face advance" during the development of an intersection introduces complications, particularly when comparing the development of an intersection to a roadway, as well as one intersection to another. Although not ideal, displacement with time is considered to be the better option in this case.

At site 1 and two, between days 20 and 40, readings which were larger magnitudes than the accepted accuracy of the levelling system of 0.5 mm were recorded, Figure 3-24. In both intersections, at sites 1 and 3, the step like behaviour of the displacements can be seen between days 8 and 13 during the time when the splits were being developed.

At the second area monitored at Colliery 'D', both the support system and mining method were different. The support pattern and tendon type remained the same as in area 1, however, the resin was reduced to two 19 x 380 mm cartridges. This resulted in a partial column resin bond length of approximately 1.04 m. This left the initial 0.4 m of roof bolt in from the roof skin resin free. Mining was carried out using a continuous miner.

Four of the five sites were intersections. The intention was to install 0.1 X 0.1 x 0.9 m wooden headboards (areal coverage used with roof bolts in stead of metal washer) in two intersections to determine what affect this had on the roof behaviour. Unfortunately, due to a shortage of headboards at the time, they were only installed at site 1. Adding the headboards appeared to reduce the effective roof bolted horizon from 1.45 m to 1.35 m. Backup levelling to confirm this was installed at four of the five sites.



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

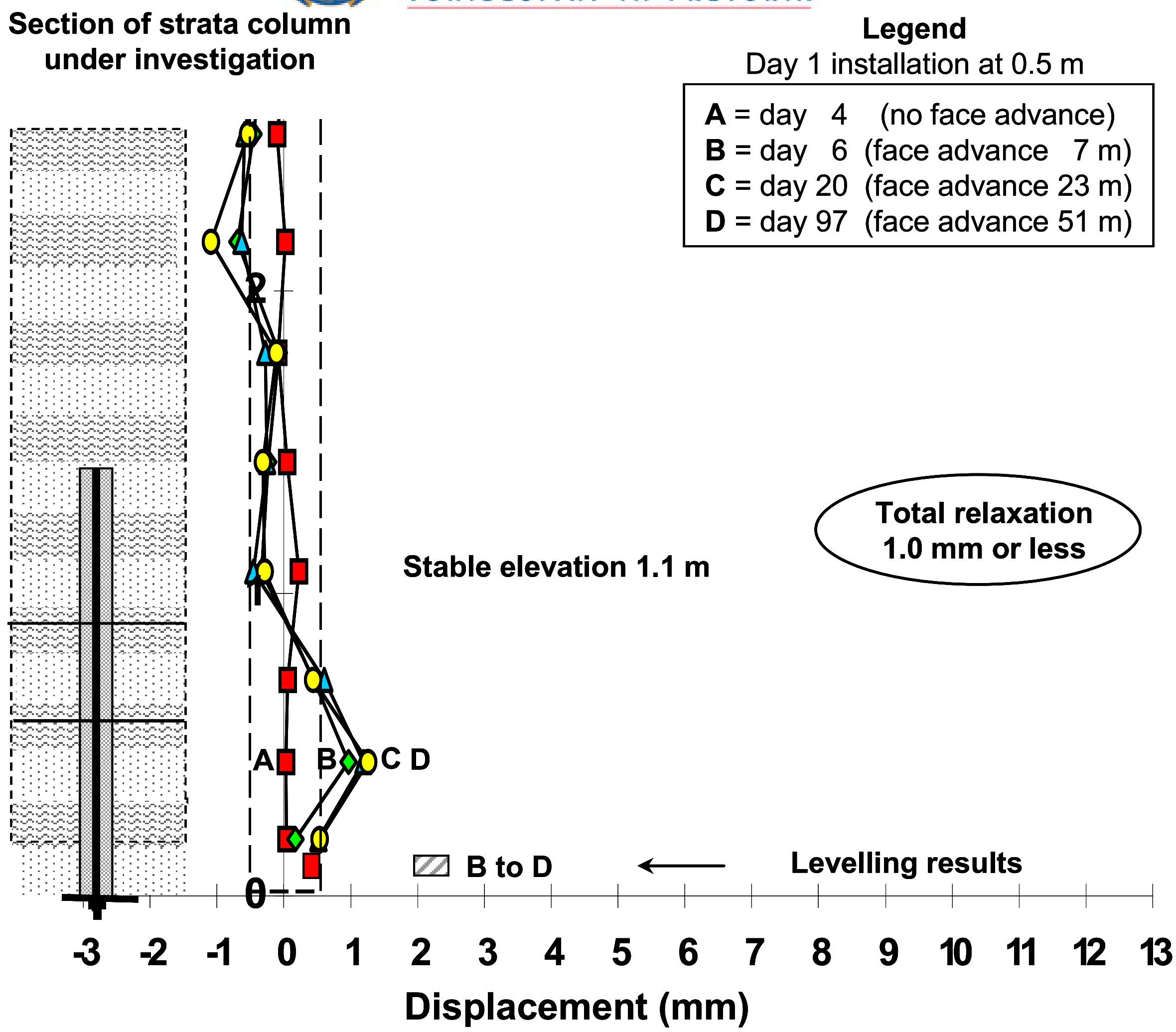
Roof : Laminated sandstone & shale with highly variable bedding thicknesses

Support : 1.5 m x 15 mm spiral bars with full column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Conventional drill and blast **Mining height** 2.1 m

Figure 3-19 Colliery 'D' area 1 site 1 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

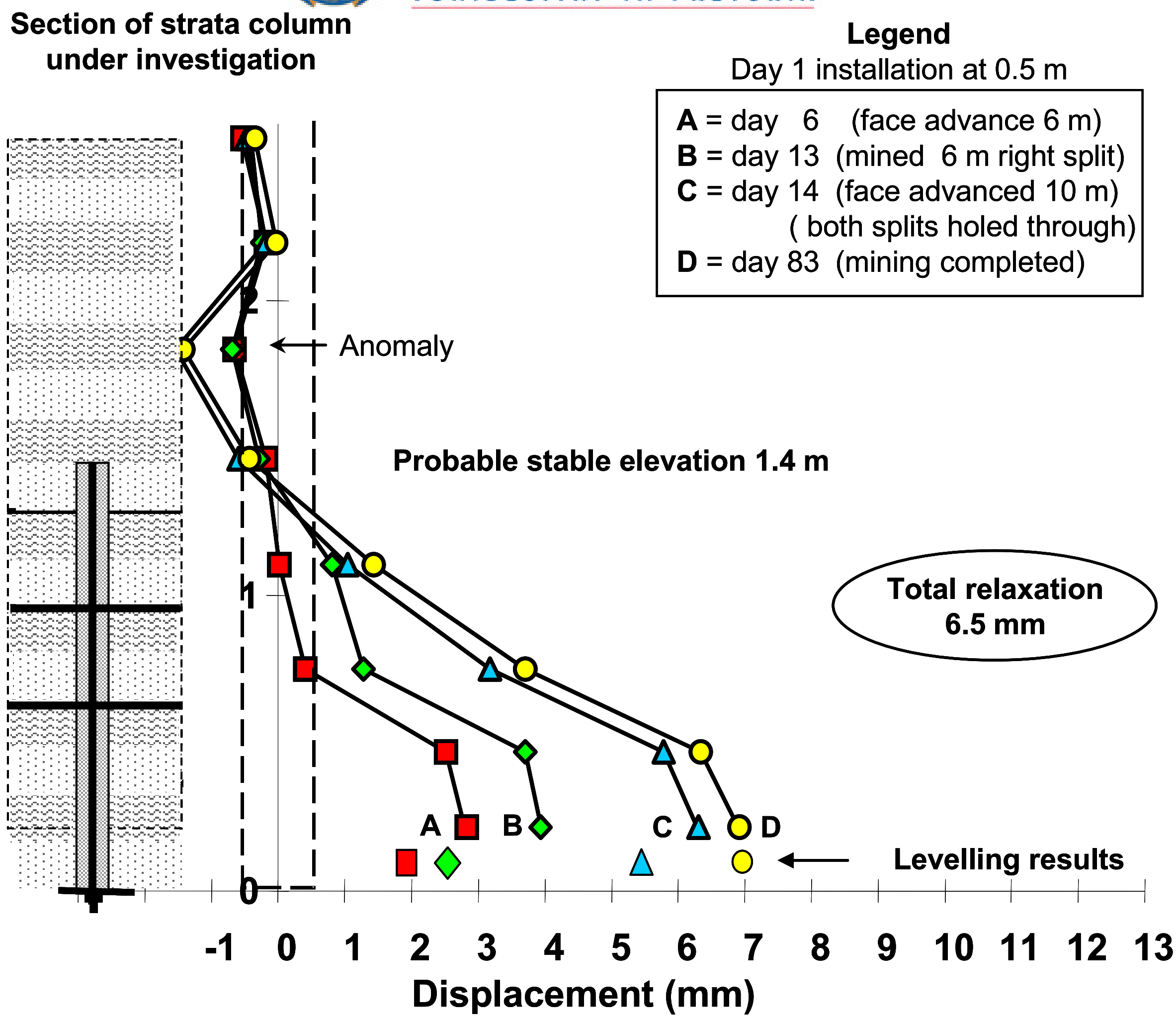
Roof : Laminated sandstone & shale with highly variable bedding thicknesses

Support : 1.5 m x 15 mm spiral bars with full column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Conventional drill and blast **Mining height** 2.1 m

Figure 3-20 Colliery 'D' area 1 site 2 (roadway)



Notes

Coalfield :Witbank **Seam** 2 seam **Position** Intersection

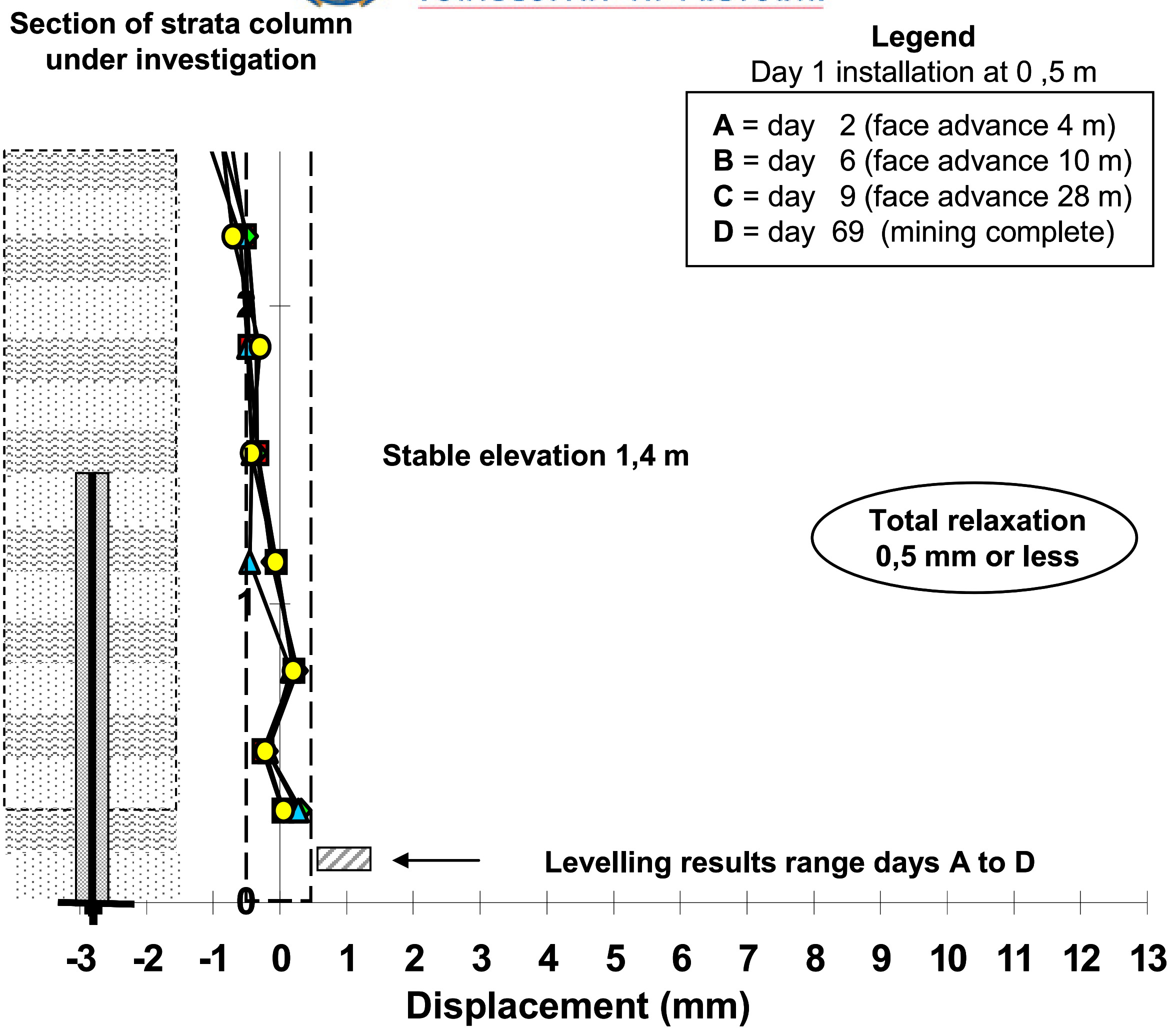
Roof : Laminated sandstone & shale with highly variable bedding thicknesses

Support : 1.5 m x 15 mm spiral bars with full column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : **Depth** 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Conventional drill and blast **Mining height** 2.1 m

Figure 3-21 Colliery 'D' area 1 site 3 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : Laminated sandstone & shale with highly variable bedding thicknesses

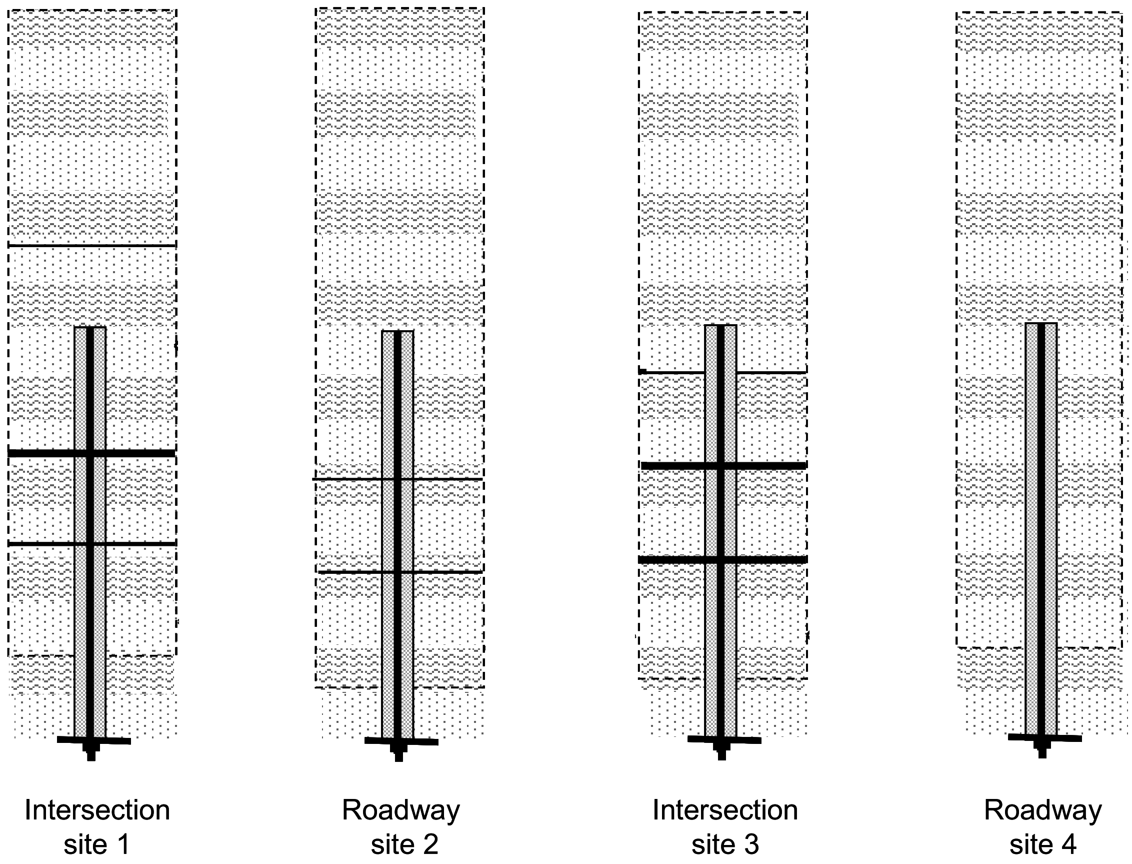
Support : 1,5 m x 15 mm spiral bars with full column resin in 22 mm diameter holes. Four bolts per row with rows 1,5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6,0 m **Pillar** 6,0m

Mining : Conventional drill and blast **Mining height** 2,1m

Figure 3-22 Colliery 'D' area 1 site 4 (roadway)

Witbank 2 Seam **Colliery 'D'** **Drill and blast section**



Roof : Laminated sandstone and shale with highly variable bedding thicknesses

Support : 1.5 m x 15 mm diameter spiral bars in 22 mm diameter holes with full column resin. Four bolts per hole with rows 1.5 m apart.

Figure 3-23 Colliery 'D' area 1 comparative roof behaviour

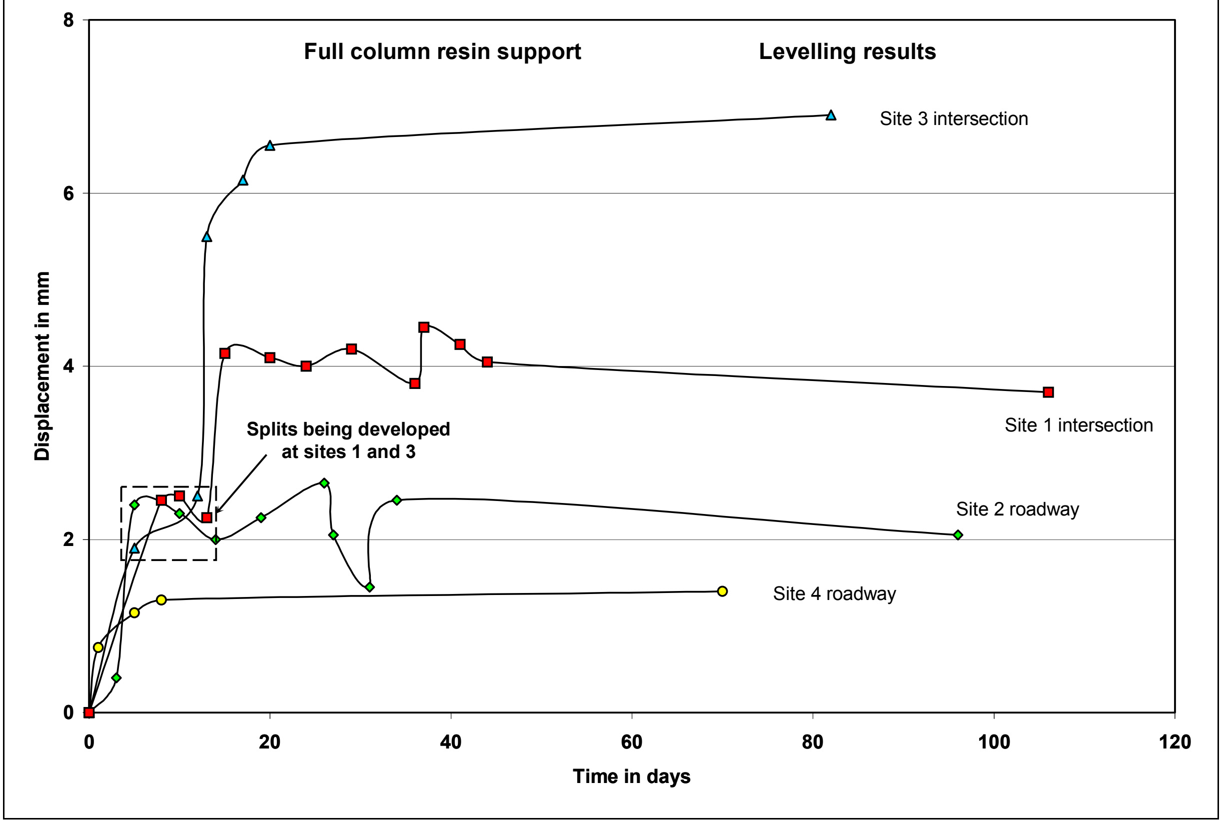


Figure 3-24 Colliery 'D' area 1 comparison of roof skin displacement

In the continuous miner (CM) cutting cycle approximately half the road width was mined for 7.0 m before the support was installed. The support consisted of two bolts per row with the rows 1.5 m apart. The adjacent side of the roadway was then mined up to the face after which the additional two bolts were added to each row.

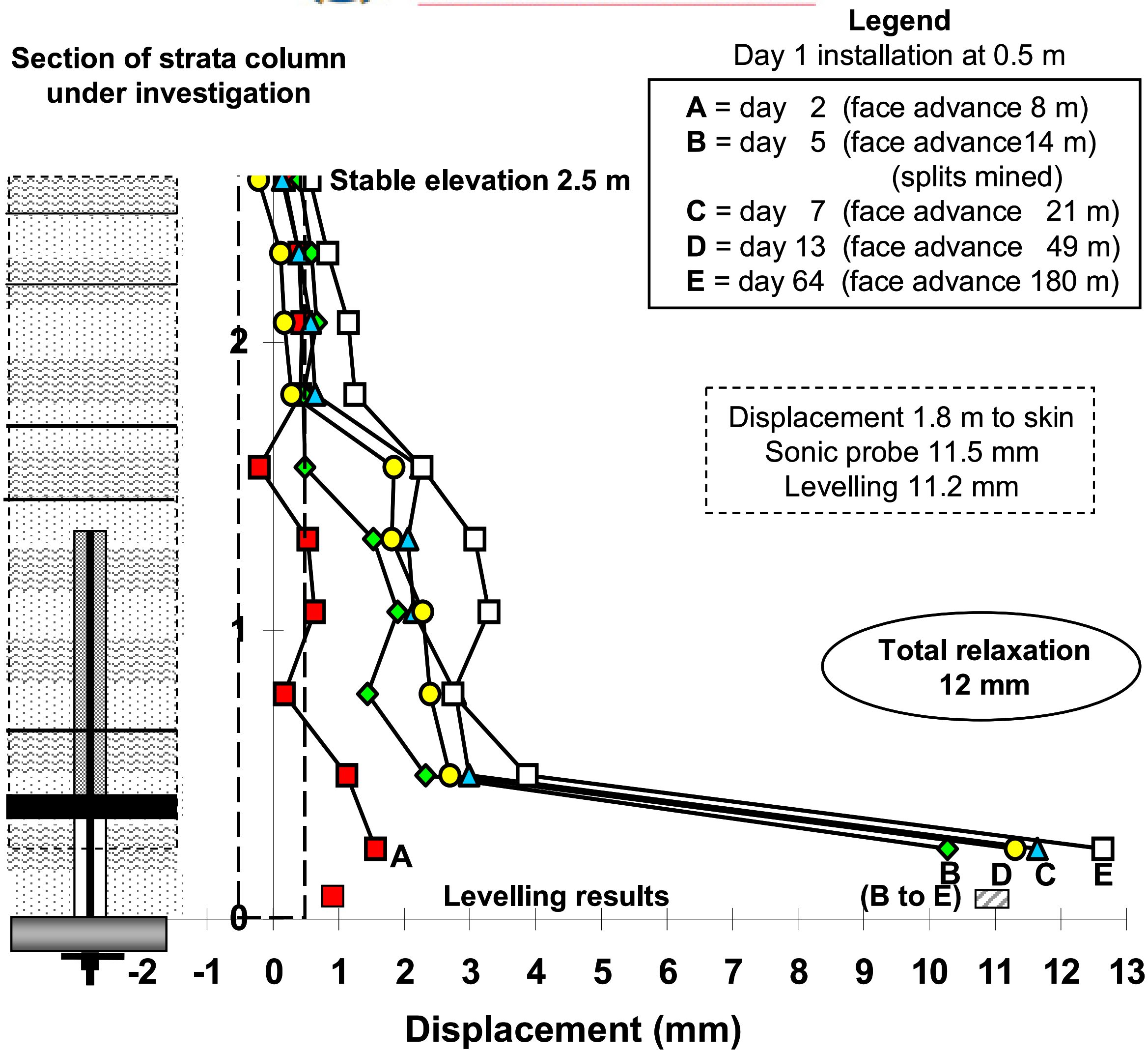
At three of the four sites in area 2, the levelling results were close to the values indicated by the lowest anchor in the sonic probe string. The exception was site 3 (Figure 3-27) where the levelling results were nearly 4.0 mm larger, indicating the presence of additional displacements below the sonic probe bottom anchor.

In the intersection with the headboards, site 1 (Figure 3-25), there are indications of some small displacements in excess of 1.0 m above the bolt horizon, up to the 2.5 m elevation. There were large displacements totalling 9.0 mm in the 0.3 m immediate skin of the roof below the resin column. These displacements occurred relatively quickly after the splits were mined. Contributing factors could have included a lack of stiffness of the headboard and irregular contact with the roof. However, since 80 per cent of the total displacement took place within the first four days, a more likely cause could have been insufficient tension applied to the bolts during installation. Timber shrinkage with time is unlikely to have had any real effect over such a short time period.

In the intersection at site 2 (Figure 3-26), the total relaxation of 12 mm, at the lowest anchor was identical to site 1, as was the stable elevation at 2.5 m into the roof. The behaviour of the roof strata was however completely different. The displacements within the 2.5 m zone tended to be more linear. The resin column within the bolt horizon appeared to be ineffective as the two largest displacements occurred within this region. A large portion, approximately 75 per cent, of the final displacement occurred within 24 hours when the face had advanced 7.0 m and the first split had holed through.

When compared to the other two intersections at sites 3 and 4 (Figure 3-27 and Figure 3-28) with the same support systems, the site 2 (Figure 3-26) intersection roof strata was by far the most active. The apparent ineffectiveness of the resin bond column suggests that the support may not have been correctly installed. The levelling results agree fairly closely with the sonic probe bottom anchor, with the exception of day 2, which is so far out that it is in all probability an erroneous reading.

The overall roof strata behaviour at site 3 (Figure 3-27) was similar to that at site 1. The largest displacements were below the resin column. The levelling results indicate the presence of additional displacements of approximately 4.0 mm situated within 0.1 to 0.2 m of the immediate roof skin. This is not included on the strata column diagram and would increase the total relaxation to at least 10 mm. Unlike sites 1 and 2, there is no evidence of displacements above the 1.9 m elevation.



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

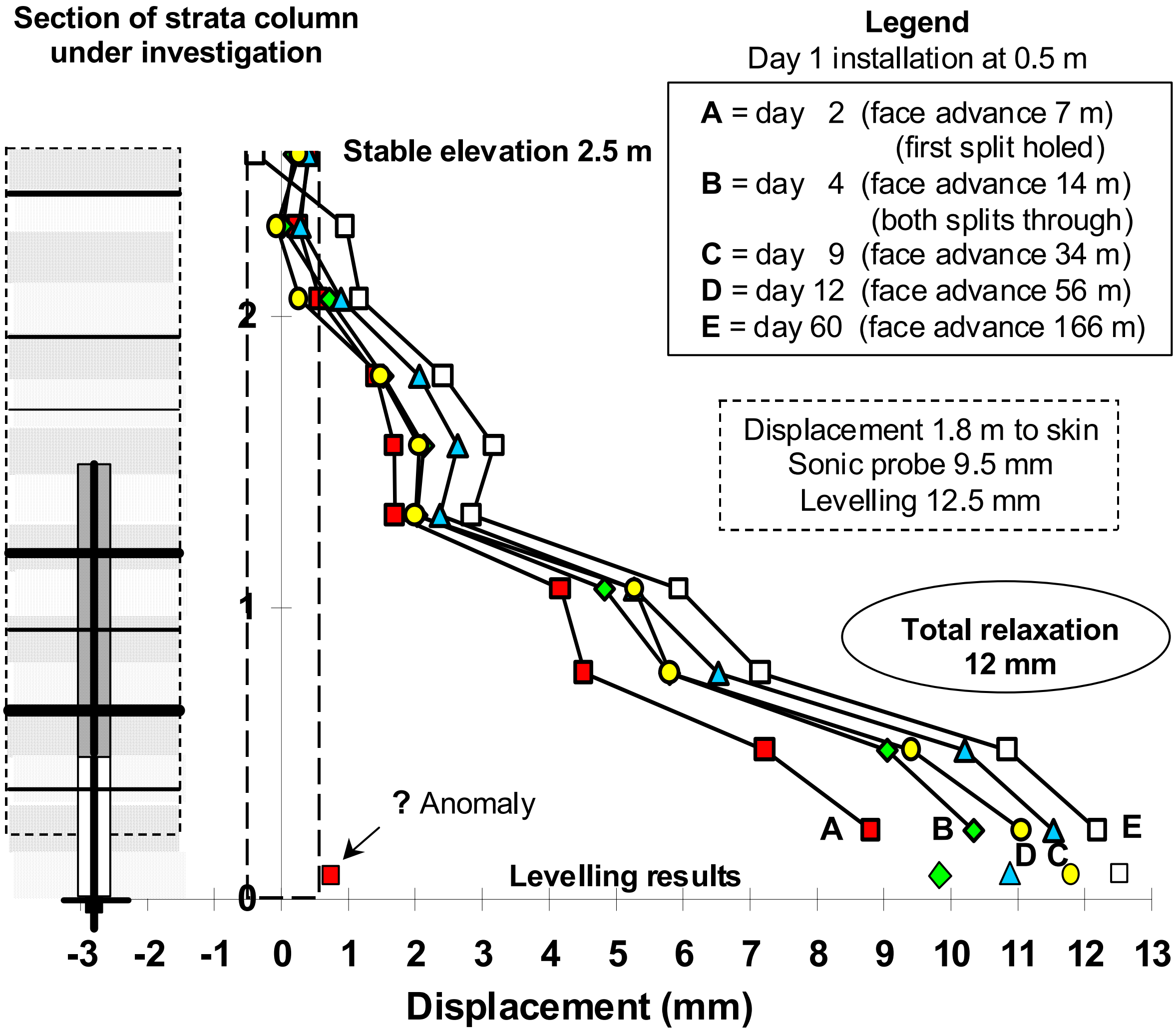
Support : 1.5 m x 15 mm spiral bars with partial column resin with head boards in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

Although there appear to be some small displacements above the bolt horizon, there are large displacements below the resin column, most likely as a result of the lack of stiffness of the headboard or insufficient tension applied to the tendon.

Figure 3-25 Colliery 'D' area 2 site 1 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

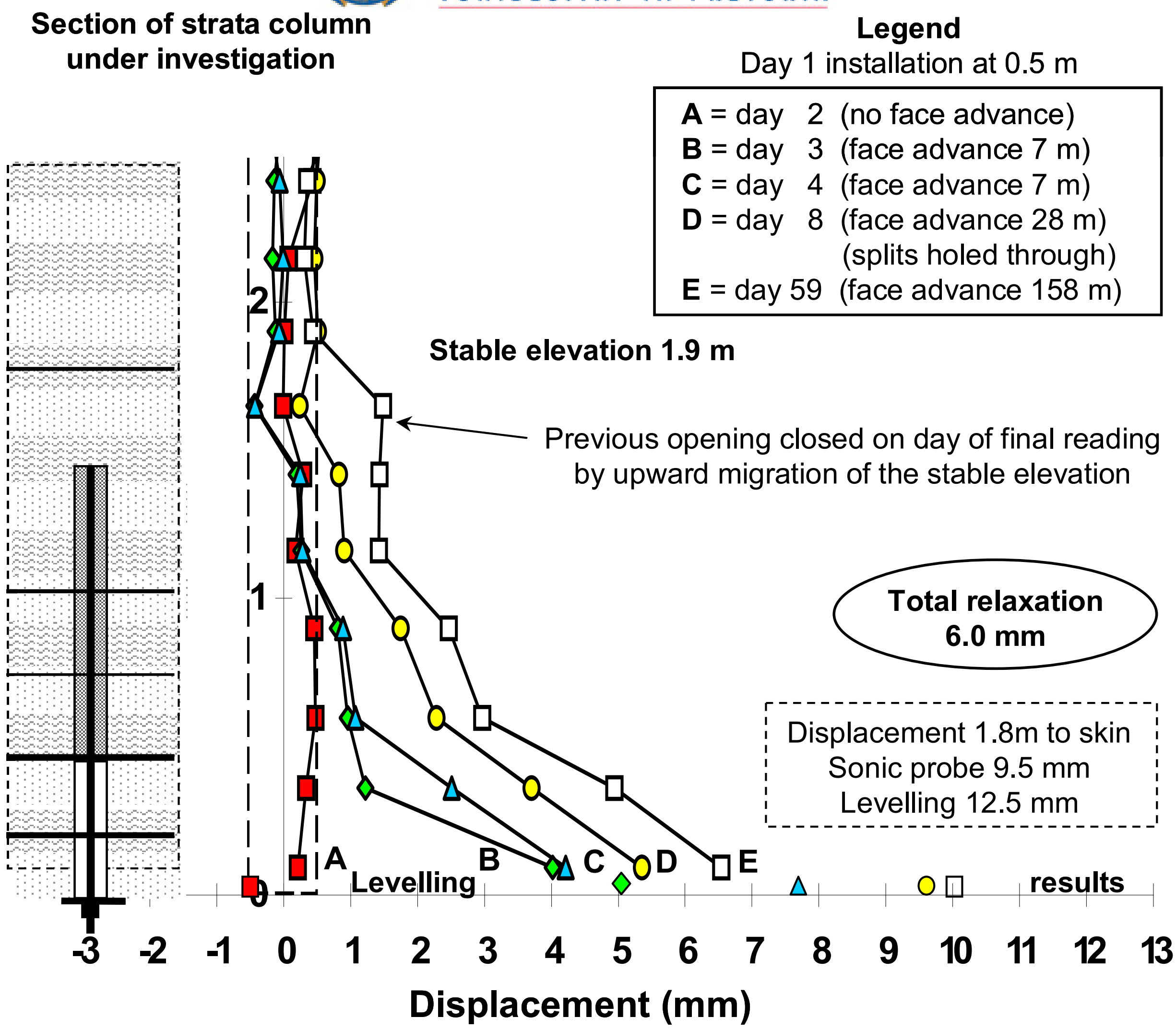
Support : 1.5 m x 15 mm spiral bars with partial column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

The displacements extend to above the bolt horizon. The relatively large displacements recorded within the resin column horizon indicate that the support system was ineffective and suggest that the support may not have been correctly installed.

Figure 3-26 Colliery 'D' area 2 site 2 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

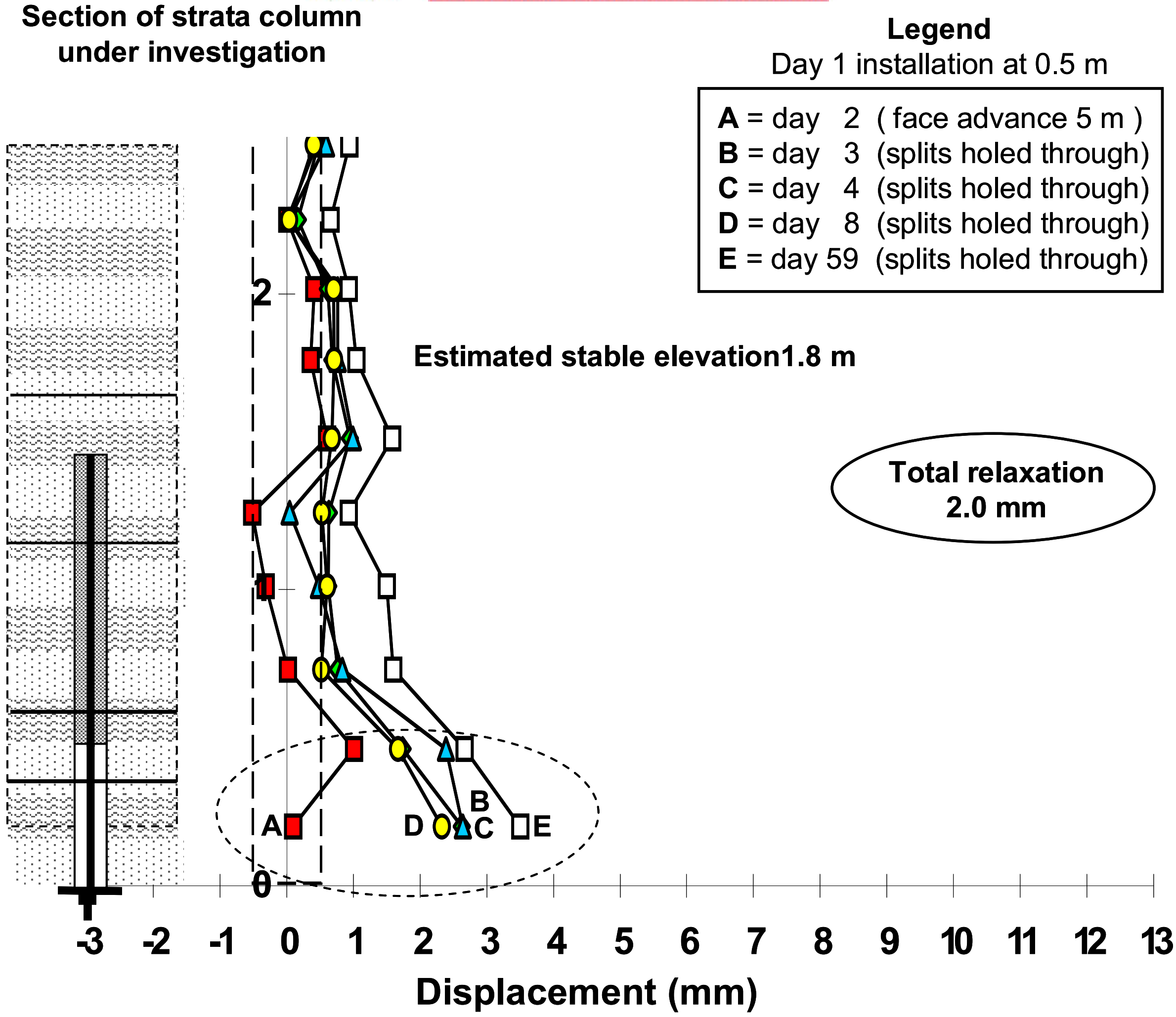
Support : 1.5 m x 15 mm spiral bars with partial column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

Although the displacements extend to about 0.3 m above the bolt horizon. Most of the displacement occurred close to the roof skin below the resin column.

Figure 3-27 Colliery 'D' area 2 site 3 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

Support : 1.5 m x 15 mm spiral bars with partial column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

The displacements extended to about 0.3 m above the bolt horizon.

Figure 3-28 Colliery 'D' area 2 site 4 (intersection holed into)

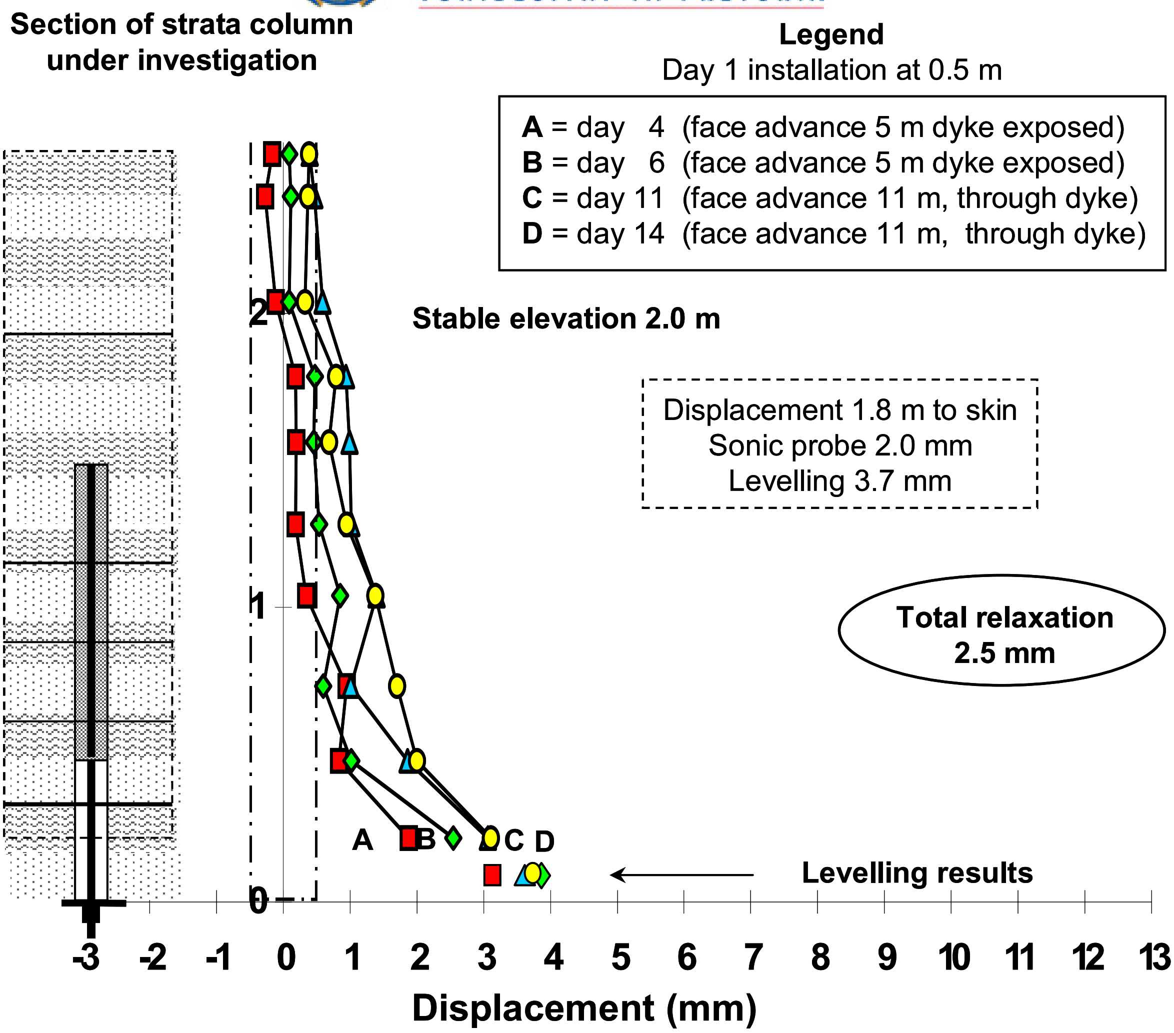
The displacements were limited to the 1.8 m elevation and the total relaxation, recorded at 2.0 mm, was the lowest of all four intersections. However, since there was no levelling backup at this site, it is not known if there were additional displacements in the immediate roof below the bottom sonic probe anchor.

Site 5 of area 2 (Figure 3-29) was in a roadway approaching a dyke. The road width was reduced to approximately 5.0 m, which resulted in the roof bolts being closer together in the rows. Although there appears to be small displacements up to the 2.0 m elevation, the majority of the displacements were within the initial 1.2 m of roof strata and were 2.5 mm in total. Although slightly higher in value, the levelling results agreed fairly closely with the bottom sonic probe anchor.

For comparison purposes the results of all five sites are grouped together in Figure 3-30. The strata performance at sites 3, 4 and 5 were similar showing the roof to have been active below the 2.0 m elevation, approximately 0.5 m above the bolted zone. As previously mentioned, the roof behaviour at the intersections at sites 1 and 2 produced larger displacements than at the intersection at site 3. Headboards were used in site 1 and the quality of support installation at site 2 is suspect.

The total relaxation within the initial 1.8 m of roof strata, as recorded by the levelling results at four of the five sites, have been plotted together and are presented in Figure 3-31. The overall relaxation at sites 1 and 2 were approximately 10 and 20 per cent higher than the site 3 values.

The last site, site 5, investigated in area 2 was in a continuous miner section. The support pattern remained the same. The support system was changed to 1.5 m x 18 mm rebar installed in the smallest hole diameter of 22 mm, using two 19 mm x 380 mm resin cartridges. This resulted in full column resin support. The difference between this support and the support installed in area 1, apart from the increase in the cross sectional area of the steel tendon by approximately 26 per cent, was the use of 200 x 200 mm dome washers in place of the usual 150 x 150 mm washers.



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

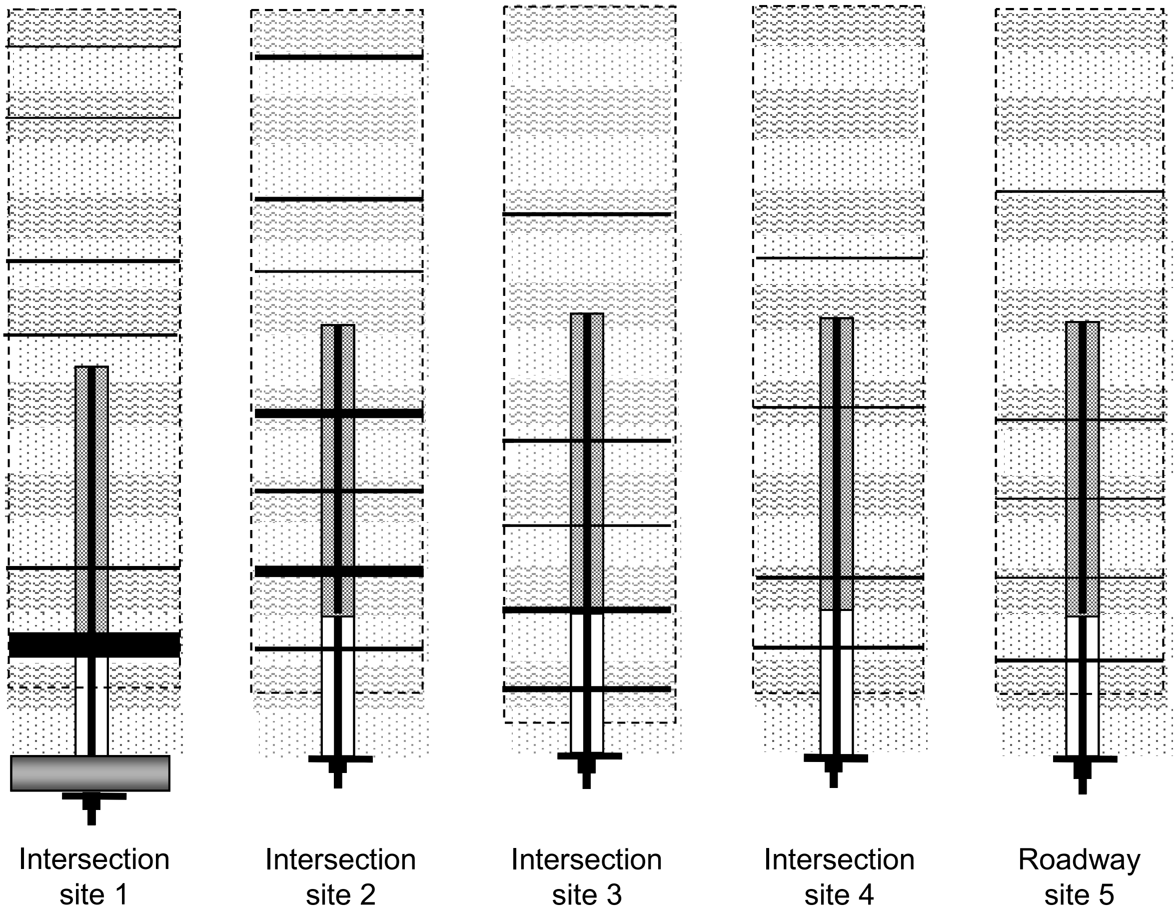
Support : 1.5 m x 15 mm spiral bars with partial column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 5.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

The displacements extended to about 0.4 m above the bolt horizon.

Figure 3-29 Colliery 'D' area 2 site 5 (roadway approaching dyke)



Roof : Laminated sandstone and shale with highly variable bedding thicknesses

Support : 1.5 m x 15 mm diameter spiral bars in 22 mm diameter holes with partial column resin. Four bolts per row with rows 1.5 m apart.

Figure 3-30 Colliery 'D' area 2 comparative roof behaviour

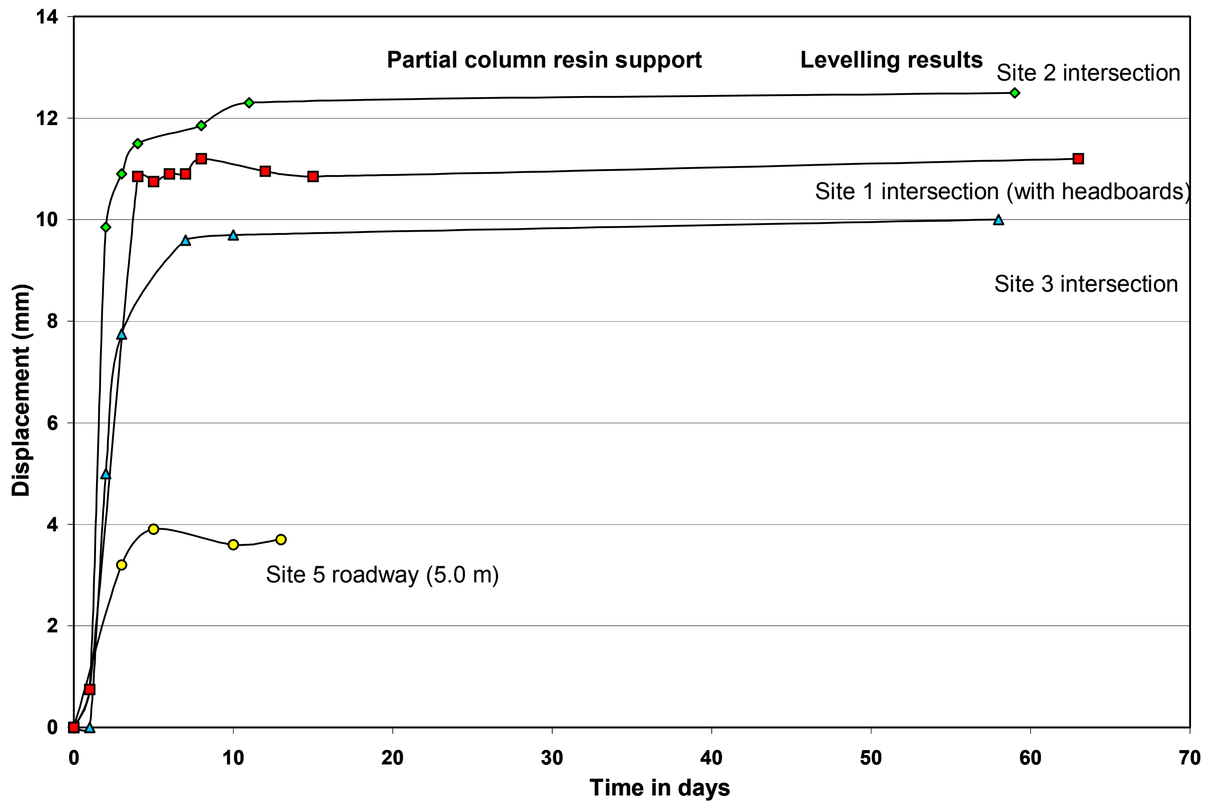
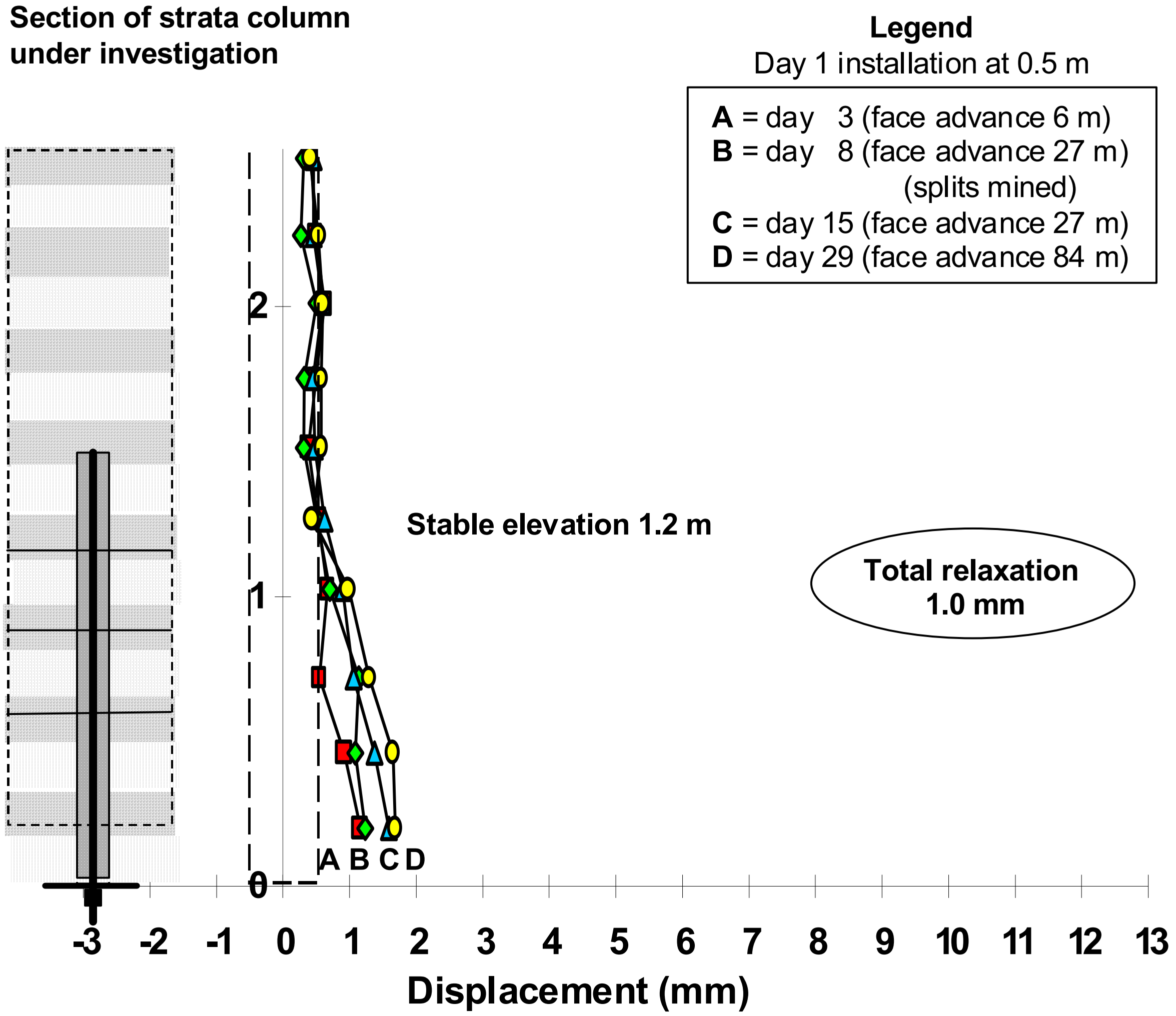


Figure 3-31 Colliery 'D' area 2 comparison between roadway and intersection roof skin displacement

The typical set of three sites was monitored, one intersection and two adjacent roadways. At site 3 after the installation of the instrumentation, the blind end of the roadway was not advanced. It was holed into from the other side. There was no backup levelling at any of the three sites.

There was very little displacement recorded at any of the sites as indicated in Figure 3-32, Figure 3-33 and Figure 3-34. The difference between the roof behaviour in the roadways and the intersection was hardly discernible. The stable elevation of the intersection increased slightly from on average less than 1.0 m in the roadways to about 1.2 m with a total relaxation of 1.0 mm. All the displacements recorded were well within the bolted zone. The comparative roof behaviour of the three sites in area 3 is presented in Figure 3-35.



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Intersection

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

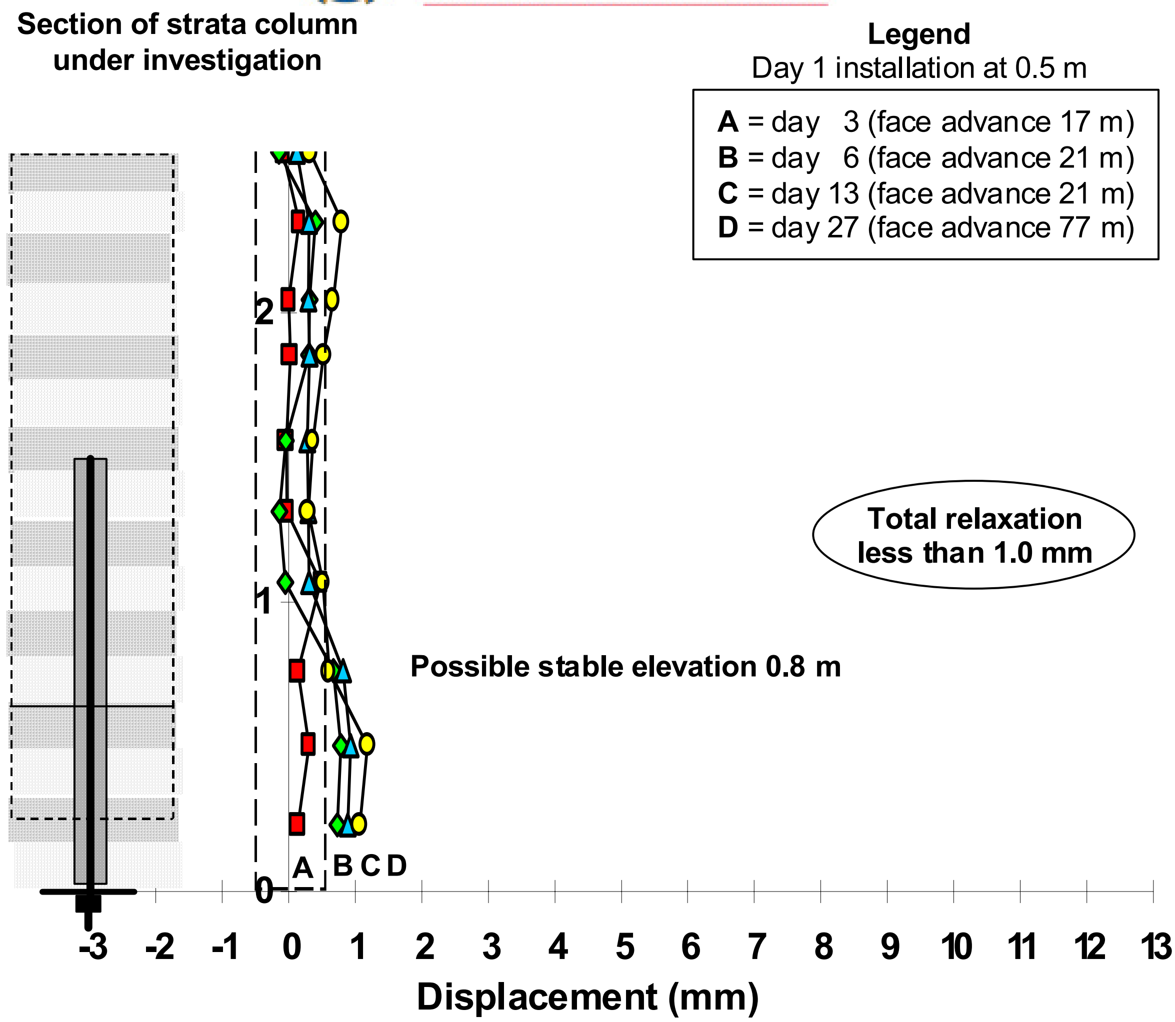
Support : 1.5 m x 18 mm rebars with 200 mm x 200 mm dome washers
full column resin in 22 mm diameter holes.
Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

Very small displacements all within the bolt horizon.

Figure 3-32 Colliery 'D' area 3 site 1 (intersection)



Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

Support : 1.5 m x 18 mm rebars with 200 mm x 200 mm dome washers
full column resin in 22 mm diameter holes.
Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

Hardly any displacements recorded.

Figure 3-33 Colliery 'D' area 3 site 2 (roadway)

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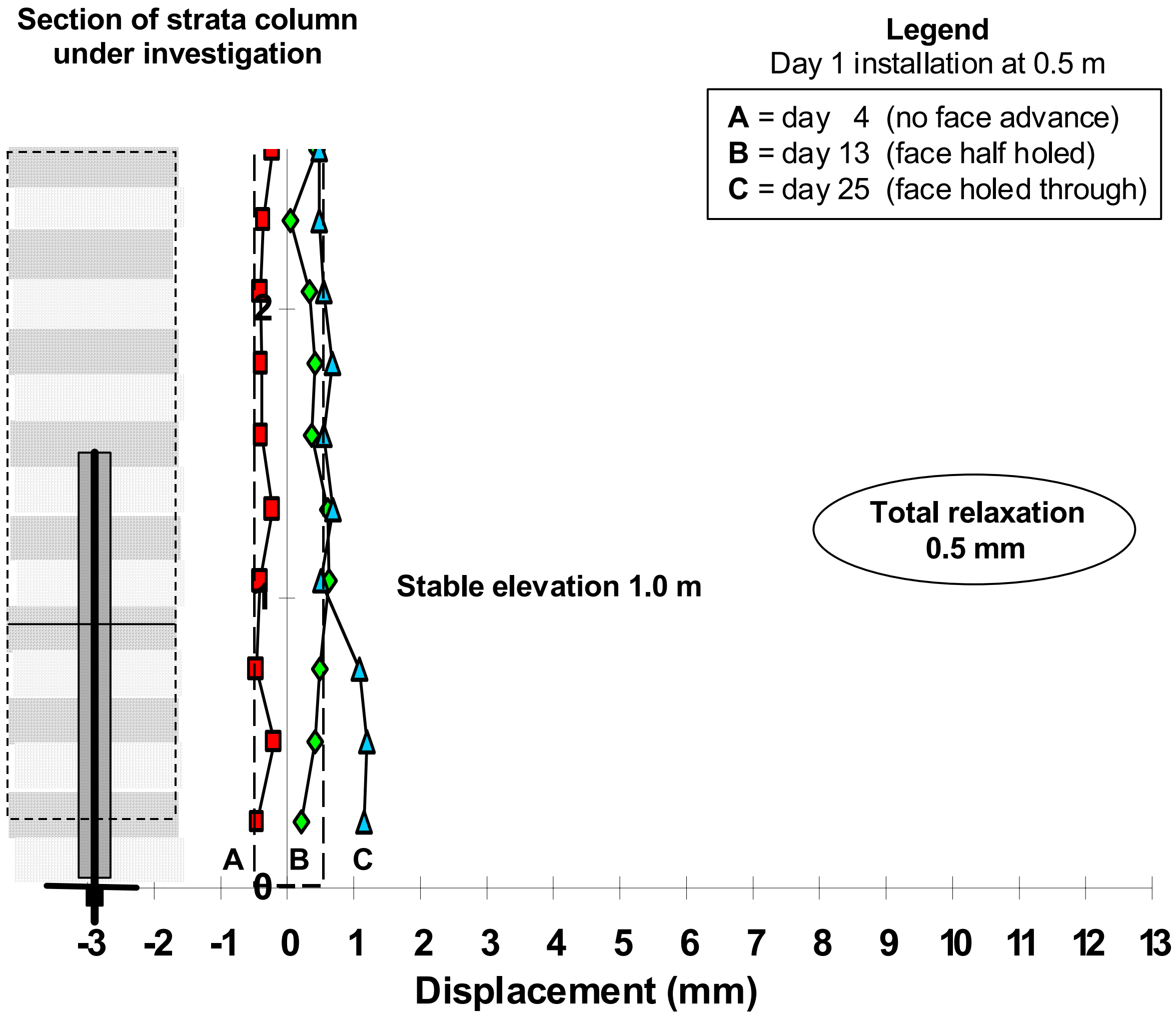


Notes

Coalfield : Witbank **Seam** 2 seam **Position** Roadway

Roof : Laminated sandstone & shale with highly variable bedding thicknesses.

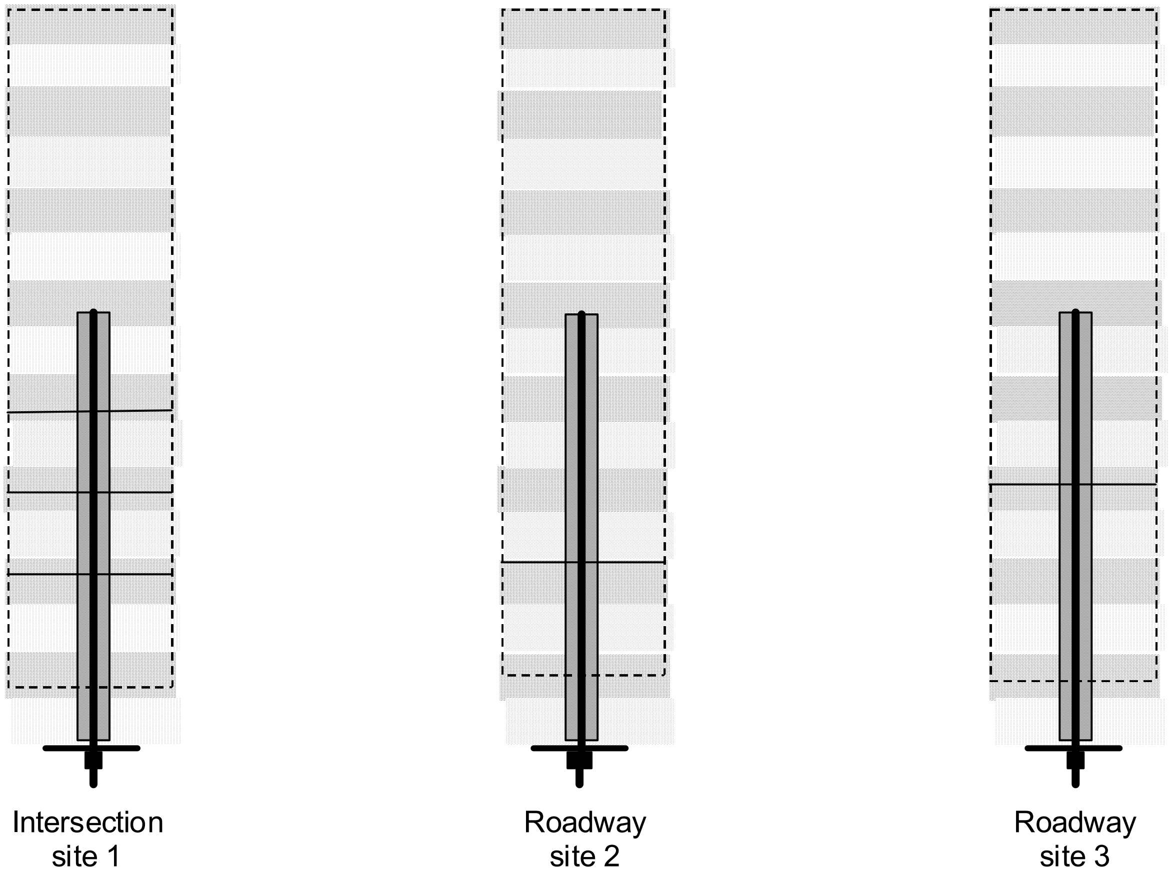
Support : 1.5 m x 18 mm re-bars with 200 mm x 200 mm dome washers
full column resin in 22 mm diameter holes.
Four bolts per row with rows 1.5 m apart.

Layout : Depth 55 to 60 m **Roadway** 6.0 m **Pillar** 6.0 m

Mining : Continuous miner **Mining height** 2.1 m

Hardly any displacements recorded.

Figure 3-34 Colliery 'D' area 3 site 3 (roadway blind end holed into)



Roof : Laminated sandstone and shale with highly variable bedding thicknesses

Support : 1.5 m x 18 mm diameter re- bars in 22 mm diameter holes with full column resin and 200 mm x 200 mm dome washers.
Four bolts per row with rows 1.5 m apart.

Figure 3-35 Colliery 'D' area 3 comparative roof behaviour

3.7.1 Site performance summary Colliery 'D' area 1

Coalfield:	Witbank	Seam:	2 Seam
Sites:	Four	Positions:	Two intersections two roadways
Road widths:	6.0 m	Pillar widths:	6.0 m
Mining height:	2.1 m	Depth:	50 to 60 m

Mining method: Drill and blast

Roof strata: Laminated sandstone and shale with highly variable bedding thicknesses.

Support: 1.5 m x 15 mm diameter spiral bars with full column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Performance: Displacement occurred in the roof strata when the face was advanced with the blast, and the unsupported roof span was increased up to a maximum of 3.5 m. This resulted in open parting planes or fractures being present as close as 0.5 m from the face prior to the installation of the support and instrumentation. These openings appeared to be mainly within the immediate 0.4 m of the roof. By and large, the roof displacements were contained within the bolt horizon.

3.7.2 Site performance summary Colliery 'D' area 2

Coalfield:	Witbank	Seam:	2 Seam
Sites:	Five	Positions:	Four intersections one roadway
Road widths:	6.0 m (5.0 m site 5)	Pillar widths:	6.0 m
Mining height:	2.1 m	Depth:	50 to 60 m

Mining method: Continuous miner

Roof strata: Laminated sandstone and shale with highly variable bedding thicknesses.

Support: 1.5 m x 15 mm diameter spiral bars with partial column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Performance: In general, there were small displacements above the bolt horizon up to the 2.0 m to 2.5 m elevations. There were also small displacements within the resin bond horizon with somewhat larger displacements in the unbounded

0.3 m to 0.4 m of immediate roof. The exception was site 2 where the major displacements were within the resin bond horizon. The overall performance of the only intersection with headboards indicated that 75 per cent of the displacements were within the 0.3 m of unbounded immediate roof

3.7.3 Site performance summary Colliery 'D' area 3

Coalfield:	Witbank	Seam:	2 Seam
Sites:	Three	Positions:	One intersection two roadways
Road widths:	6.0 m	Pillar widths:	6.0 m
Mining height:	2.1 m	Depth:	50 to 60 m

Mining method: Continuous miner

Roof strata: Laminated sandstone and shale with highly variable bedding thicknesses.

Support: 1.5 m x 18 mm diameter rebars with full column resin in 22 mm diameter holes. Four bolts per row with rows 1.5 m apart.

Performance: There were only a few small displacements all contained within the bolt horizon.

3.8 Colliery 'E '

Colliery 'E' was the last colliery investigated. Five sites were monitored in the gateroads and associated splits at the edge of a shortwall panel. The mining was carried out by continuous miner. The laminated sandstone roof was supported by 1.8 m long 16 mm diameter full column resin rebar. The support pattern was four bolts per row with the bolts 1.0 m apart and 1.5 m between rows. Although backup levelling was attempted, it proved impractical to monitor due to the installation of the belt and the dumping of rubble. In addition to monitoring the effects of the development of the roadways, attempts were also made to monitor the dynamic effects of the approaching shortwall face.

Overall, very little if any displacement was recorded as the roof remained stable throughout the mining process. The only site to record what appeared to be a real displacement was site 1, Figure 3-36, where a total relaxation of approximately 1.0 mm occurred within 0.3 m of the roof skin. The results from the other four sites are presented in Figure 3-37, Figure 3-38, Figure 3-39 and Figure 3-40.

3.8.1.1 Site performance summary Colliery 'E'

Coalfield:	Highveld	Seam:	2 Seam
Sites:	Five	Positions:	Four roadway one split
Road widths:	6.5 m	Pillar widths:	Chain pillar 50 m centres
Mining height:	3.0 m	Depth	50 m

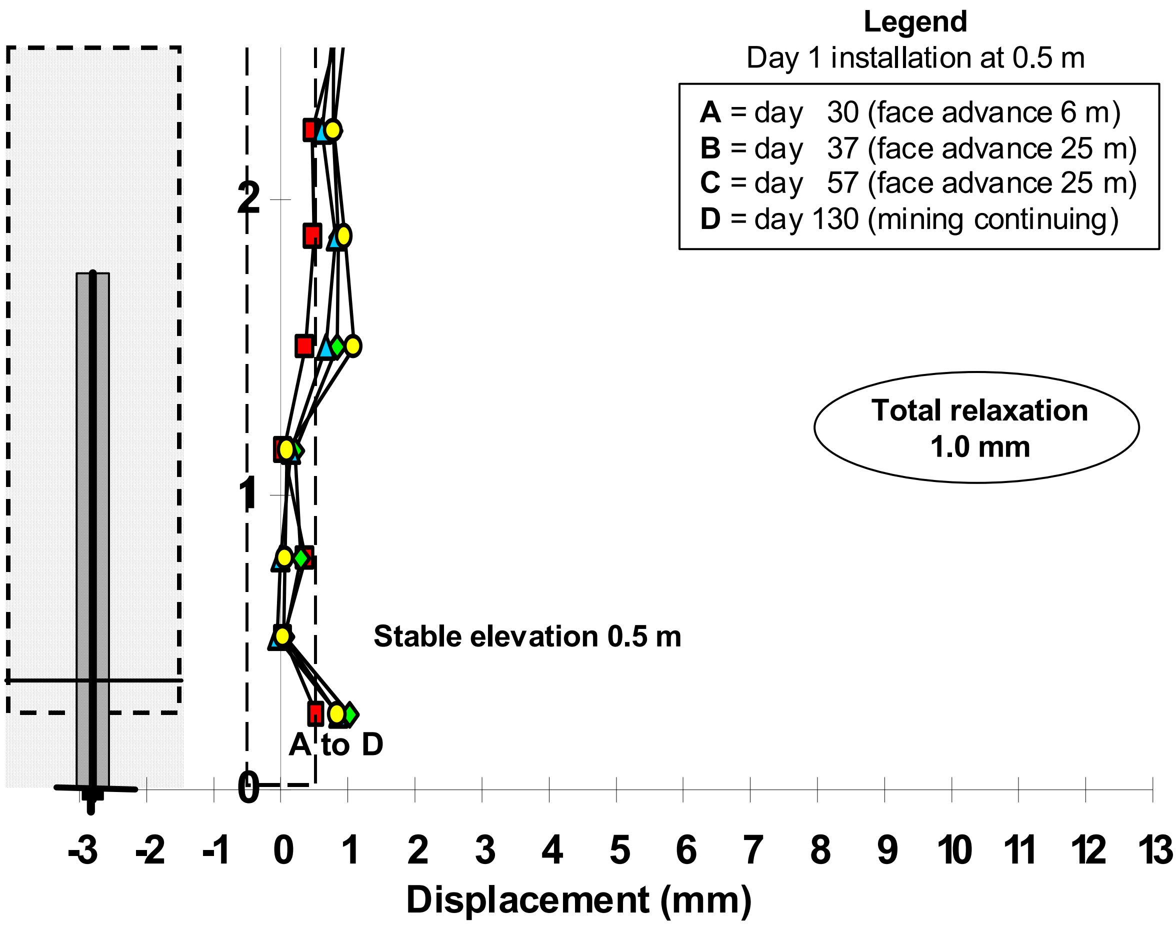
Mining method: Continuous miner

Roof strata: Laminated sandstone.

Support: 1.8 m x 16 mm diameter rebar with full column resin. Four bolts per row with bolts 1.0 m apart and 1.5 m between rows.

Performance: Only one site recorded a very slight relaxation of 1.0 mm.

Section of strata column under investigation



Notes

Coalfield :Highveld **Seam** 2 seam **Position** Shortwall gate road

Roof : Laminated sandstone

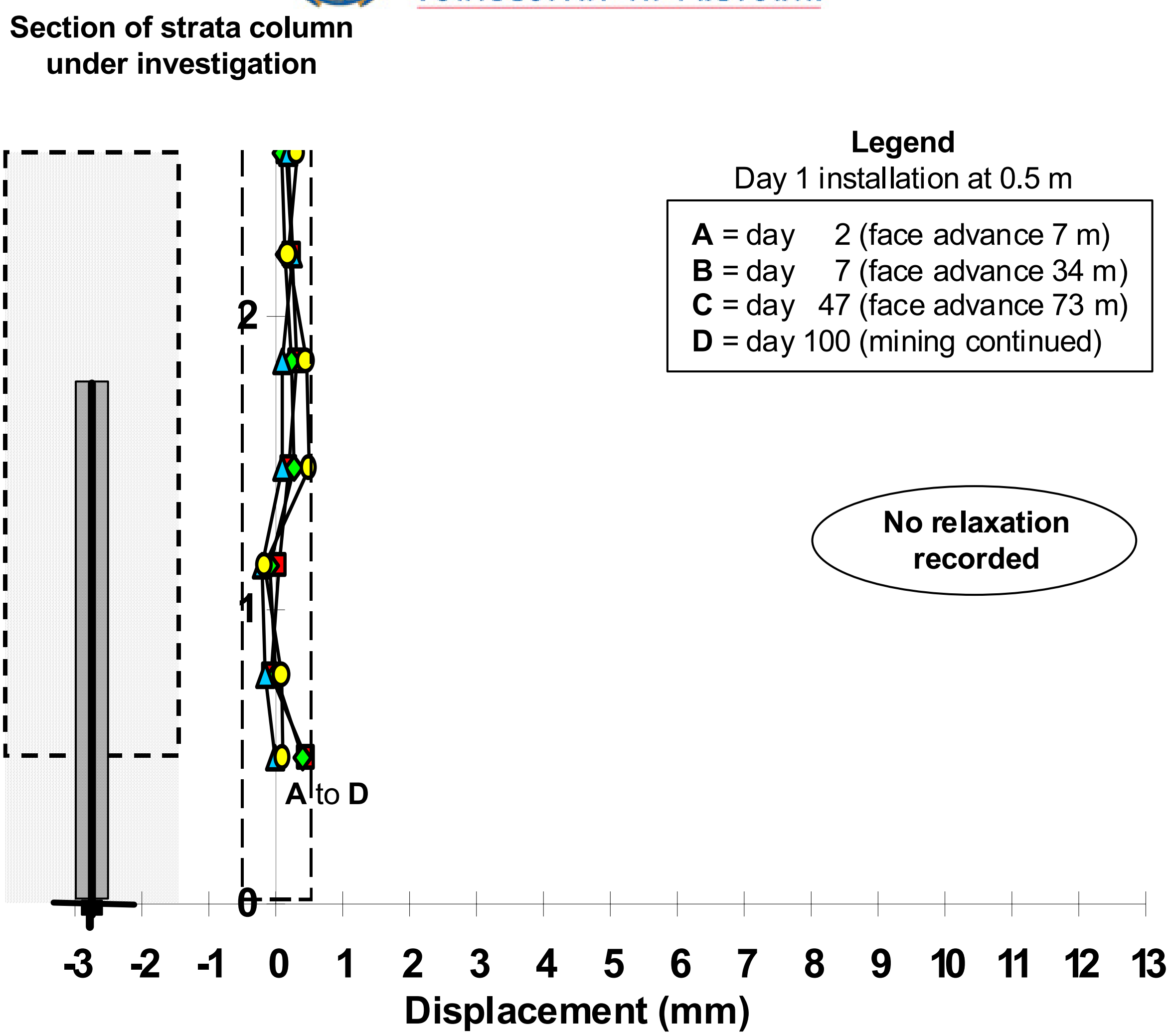
Support :1.8 m x 16 mm full column resin bolts four in a row (1.0 m apart) across the roadway, 1.5 m between rows.

Layout : Depth 50 m **Roadway** 6.5 m **Pillars** chain pillars 50 m centres

Mining : Continuous miner **Mining height** 3.0 m

Very small displacements were recorded

Figure 3-36 Colliery 'E' site 1 (gate road)



Notes

Coalfield :Highveld **Seam** 2 seam **Position** Shortwall gate road

Roof : Laminated sandstone

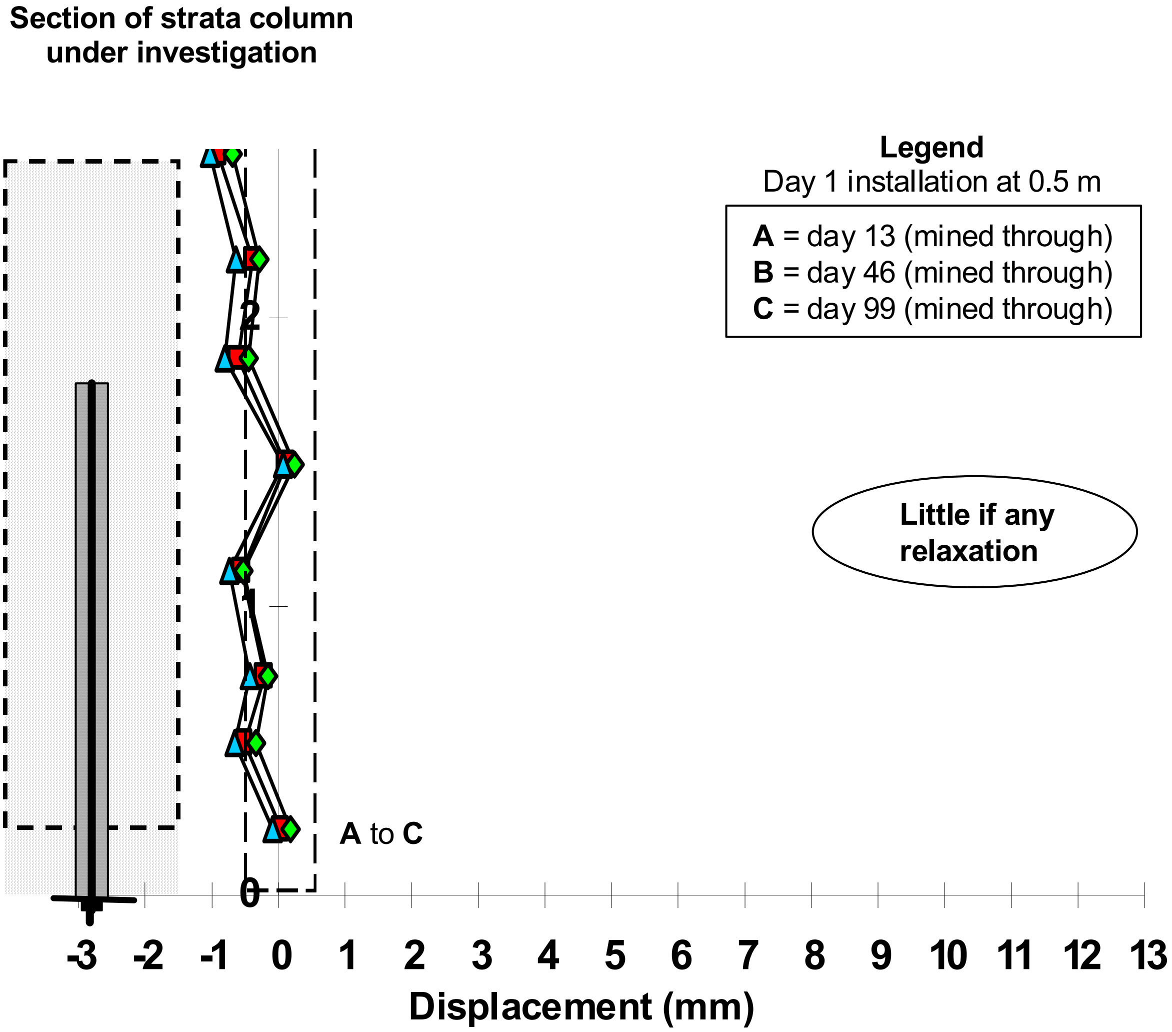
Support :1.8 m x 16 mm full column resin bolts four in a row (1.0 m apart) across the roadway, 1.5 m between rows.

Layout : Depth 50 m **Roadway** 6.5 m **Pillars** chain pillars 50 m centres

Mining : Continuous miner **Mining height** 3.0 m

No displacements were recorded

Figure 3-37 Colliery 'E' site 2 (gate road)



Notes

Coalfield :Highveld **Seam** 2 seam **Position** Shortwall gate road split

Roof : Laminated sandstone

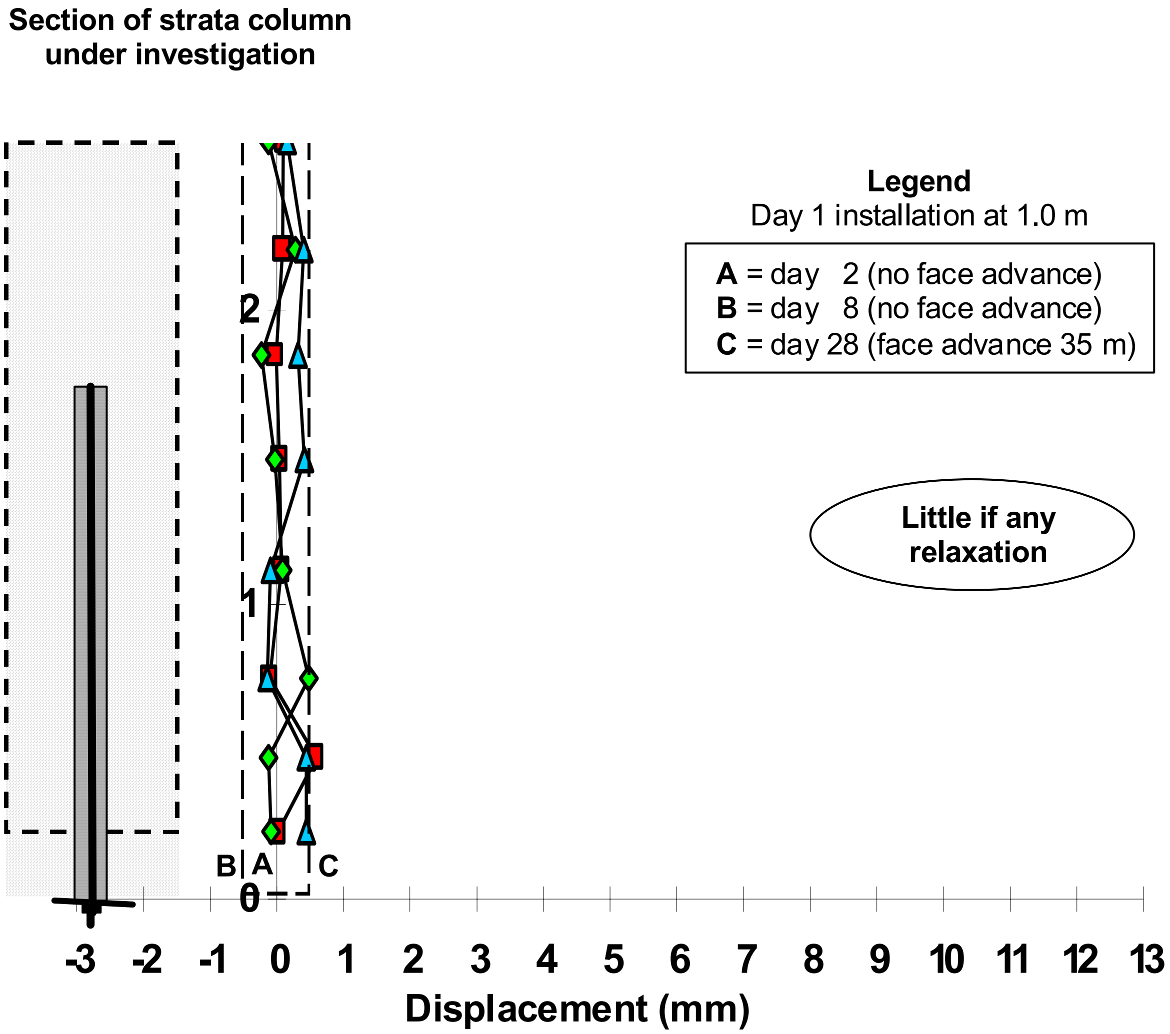
Support :1.8 m x 16 mm full column resin bolts four in a row (1.0 m apart) across the roadway, 1.5 m between rows.

Layout : Depth 50 m **Roadway** 6.5 m **Pillars** chain pillars 50 m centres

Mining : Continuous miner **Mining height** 3.0 m

No displacements were recorded

Figure 3-38 Colliery 'E' site 3 (split between gate roads)



Notes

Coalfield :Highveld	**Seam**	2 seam	**Position**	Shortwall gate road	

Roof : Laminated sandstone

Support :1.8 m x 16 mm full column resin bolts four in a row (1.0 m apart) across the roadway, 1.5 m between rows.

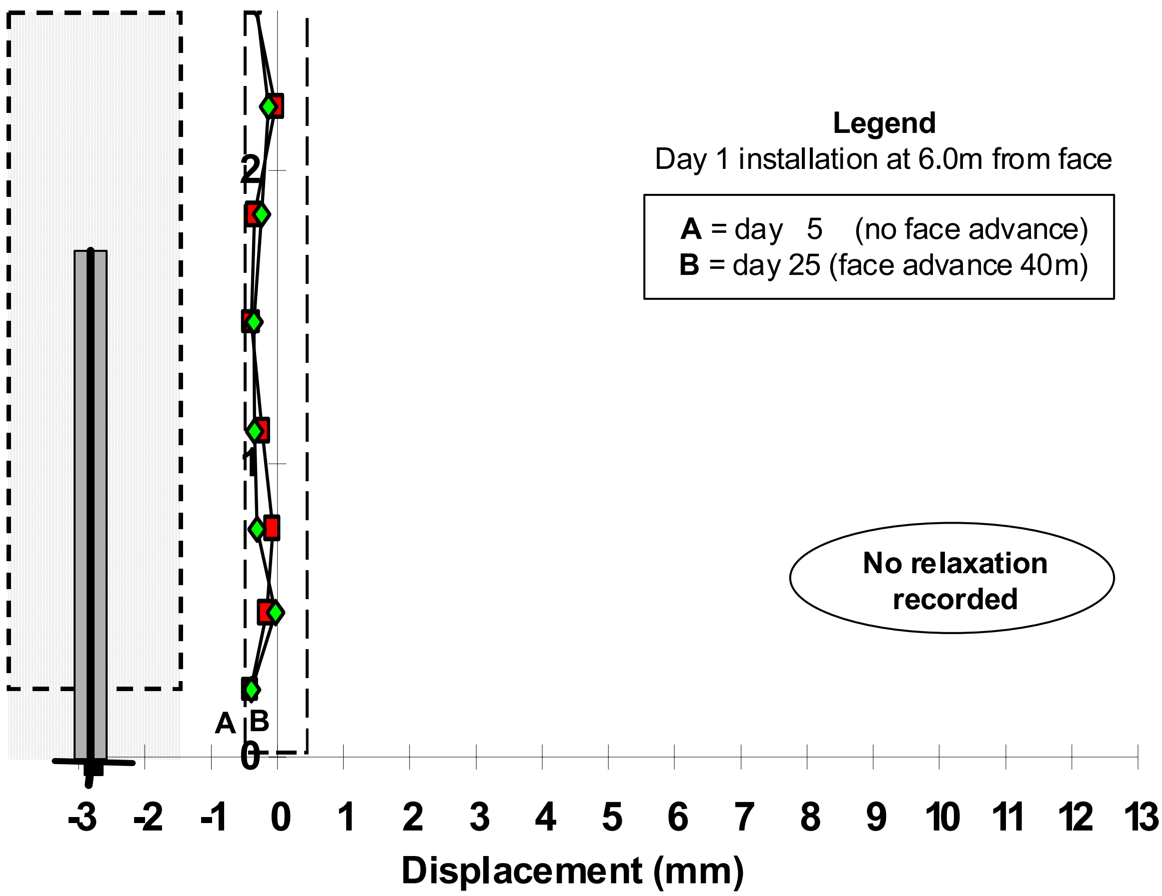
Layout : Depth 50 m **Roadway** 6.5 m **Pillars** chain pillars 50 m centres

Mining : Continuous miner **Mining height** 3.0 m

No displacements were recorded

Figure 3-39 Colliery 'E' site 4 (gate road)

Section of strata column under investigation



Notes

Coalfield :Highveld **Seam** 2 seam **Position** Shortwall gate road

Roof : Laminated sandstone

Support :1.8 m x 16 mm full column resin bolts four in a row (1.0 m apart) across the roadway, 1.5 m between rows.

Layout : Depth 50 m **Roadway** 6.5 m **Pillars** chain pillars 50 m centres

Mining : Continuous miner **Mining height** 3.0 m

No displacements were recorded

Figure 3-40 Colliery 'E' site 5 (roadway)

3.9 Analysis of underground field measurements

In Table 3-1 the roof strata, mining method, support type and monitoring position of all the underground sites at the five collieries are listed. At Colliery 'E', where four of the sites were completely stable, they have been recorded in a single line as "Roadway x 4". The background information with regard to the sonic probe results, levelling measurements and the stable roof elevations are also listed.

For comparison purposes the roadway and intersection information at each colliery or area within a colliery has been averaged separately. The stable roof elevations have been averaged in a similar manner. A breakdown of the displacements recorded between the 1.8 m elevation and the lowest sonic probe anchor has been calculated for a more accurate comparison with the levelling results.

In Table 3-2 comparisons are made between the intersections and roadways with regard to the total relaxation and stable roof elevations. The percentage increase in the values recorded at the intersections, in relation to the roadways, were calculated and varied between 25 and 460 per cent. The overall average of the five different areas was 197 per cent. This indicates that, for a 40 per cent increase in the span taken across the diagonal of an intersection, relative to the roadway span, the magnitude of the displacements in the roof increased by a factor of four.

The other factor linked to, and affected by an increase in span, is the height to which the openings migrate in the roof, i.e. the stable roof elevation. The intersections were again compared to the roadways with the differences being converted to percentages. These changes were relatively small varying between – 5.0 and 33 per cent with the overall average being 13 per cent.

The areas that exhibited the highest percentage change of around 30 per cent were areas one and three at Colliery 'D'. Both areas were supported by full column resin bolts with an effective bolt length of 1.45 m. Although, in percentage terms, the changes appear relatively large the average stable elevations were the lowest recorded of the five areas where roadway and intersection comparisons could be made. Viewing the reactions of the five areas as a whole, the 40 per cent increase in span from the roadway width to the intersection diagonal had very little effect on the stable roof elevation. There was no evidence of a dramatic increase in the stable elevations.

Table 3-2 Total relaxation and stable roof elevation averages

Colliery and Roof strata	Mining method	Support type	Monitoring Position	Total relaxation averages (mm)	Intersection percentage increase (%)	Stable roof elevation averages (mm)	Intersection percentage Change (%)
A Shale	C M	Full column resin	**Roadway**	1.3		0.6	
B Coal roof 0.3 m shale then coal above	D&B	Partial column resin	**Roadway**	2.0		2.1	
			Intersection	5.0	***150***	*2.0*	***-5***
C 0.3m coal with shale above	D&B	Mechanical end anchored	**Roadway**	1.0		2.2	
			Intersection	2.3	***130***	*2.1*	***-5***
D Inter laminated sandstone and shale	D&B Area 1	Full column resin	**Roadway**	0.8		1.3	
			Intersection	4.5	***460***	*1.7*	***30***
	C M Area 2	Partial column resin	**Roadway**	2.5		2.0	
			Intersection	8.0	***220***	*2.2*	***10***
	C M Area 3	Full column resin	**Roadway**	0.8		0.9	
			Intersection	1.0	***25***	1.2	***33***
E Sandstone	C M	Full column resin	**Roadway**	0.2		0.1	
			Overall average percentage change		**197**		**13**

3.9.1 Time effects of a static face on bord stability

Although each site was visited as often as possible particularly immediately after the instrumentation was installed, it was not always possible to make direct comparisons between a large portion of the sites. The main reasons include different face advance rates for drill and blast and continuous miner sections, and the erratic nature of particular mining sequences and breakdowns. It was however possible to extract valuable information even though it may only have been recorded at a small number of sites. A typical example is the time effect on a static face.

All three examples were observed at Colliery 'D'. At area 1 site 2 (Figure 3-20), in a drill and blast section three days after the installation of the instrumentation, a second set of sonic probe and levelling readings were taken. The face had not been advanced. The results of both monitoring methods showed that the roof 0.5 m from the face was also static during this period. At area 3 site 3 (Figure 3-34) in a continuous miner section, where the face was not advanced for four days, the sonic probe readings all fell within the accepted accuracy band indicating static roof conditions.

In area 2 at site 5 (Figure 3-29) in a continuous miner section, the conditions were different in so far as the face was advanced 5.0 m to expose a dyke where it remained static over a two day period. It was then advanced through the dyke to the 11 m position and again remained stationary for three days until the final set of readings were taken. At the 5.0 m position, both the sonic probe and levelling recorded an increase in displacement of approximately 0.8 mm over the two day period. At the 11 m face position, over a three day period, no additional displacements were recorded.

These results indicate the following: close to a static face (within 0.5 m), the roof does not deform significantly. If a face remains static, the roof within its zone of influence (approximately 5.0 m away) experiences some degree of creep with time. An area of roof outside the zone of influence of the face (11 m away) is not affected by the face irrespective of whether it is stationary or advancing.

3.9.2 Migration mechanism

In the vast majority of cases, the final height at which the displacements in the roof stabilised was fully developed a short distance behind the face. In the drill and blast sections, the stable elevation was reached after a single blast and the face advance had increased the unsupported span to 3.0 m on average.

In the continuous miner sections, it was difficult to accurately determine at what point the stable elevation had fully developed. The reason was that half the face was usually advanced by up to 7.0 m in a single cutting sequence. After the installation of the support, the other half of the face was then advanced a similar amount before it was practical to access the sonic probe hole and take a set of readings. However, at some of the sites where the face was only advanced by 4.0 or 5.0 m (Colliery 'D' area 1, site 4; area 2, site 4, and area 2, site 5. Figure 3-22, Figure 3-28 and Figure 3-29), the stable elevations were already fully developed.

The only two monitoring sites that indicated obvious increases in the height at which displacement occurred in the roof as further mining occurred, were both in the partial column resin supported roof at Colliery 'D' (area 2 - sites 2 and 3, Figure 3-26 and Figure 3-27). Both sites were in intersections that had total relaxations amongst the highest recorded. Their total relaxation values had reached 11 mm and 5.0 mm respectively prior to the migration of the stable elevation occurring. Both the stable elevations increased quite significantly by approximately 0.5 m and 0.25 m, respectively. Since this occurred well outside the face advance zone of influence at between 56 m and 166 m and 28 m and 158 m respectively, it was time dependent behaviour.

The full displacement with time profile of a variety of elevations up to 2.5 m into the roof at site 2, area 2, Colliery 'D' are presented in Figure 3-41. Between days 11 and 59, the face was advanced from 56 m to 166 m. During this period all the strata between the 0.24 m and 2.31 m elevations in the roof deflected downwards in unison (upwards on the graph). There was no evidence of any relative displacements occurring within the 0.24 m to 2.31 m strata horizon. With time, the roof within this region deflected by about 1.0 mm allowing an additional 2.31 m elevation to become detached and deflect by a similar amount. This upward migration of the stable elevation is evident from the divergence of the 2.31 m and 2.56 m anchors in Figure 3-41.

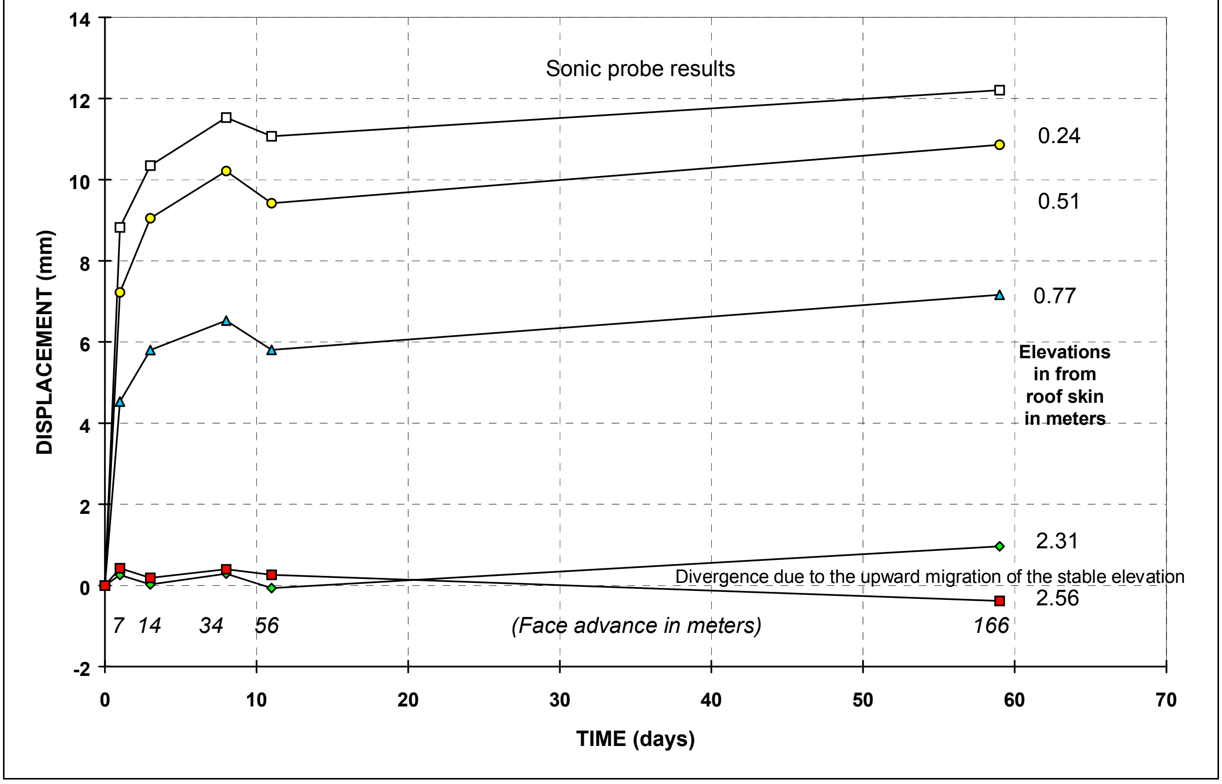


Figure 3-41 Colliery 'D' area 2 site 2 displacements

The roof strata at area 2, site 3, behaved in a similar manner. Two minor differences were observed. Of the approximate 1.0 mm of additional roof deflection measured close to the roof skin, about half was attributed to continued displacement within the bolt horizon. The stable elevation migration released a thinner beam that appeared to lack stiffness and came to rest on the beam below it effectively closing the parting that had existed between them as indicated in Figure 3-27. The laminated sandstone and shale roof strata at this particular colliery with its highly variable bedding thicknesses appeared to be an ideal medium for this stable elevation migration mechanism.

Awareness of this mechanism has important implications as far as roof behaviour monitoring is concerned, particularly with respect to visual indicators such as tell-tales. In the suspension support method a weaker layer of roof strata is pinned to a stiffer stronger layer above it. By positioning the top anchor point of a simple tell-tales in the stronger layer, preferably above the bolt horizon, the support performance can be monitored and remedial measures taken if it becomes necessary.

With the beam building roof support mechanism however, the choice of a suitable elevation for the top anchor point is both more complex and critical. In order to quantify a suitable elevation for a particular geotechnical area and support system, a roof behaviour monitoring programme should be initiated to build up a database.

Assuming that the “typical” roof strata was reasonably consistent in all three monitoring areas of Colliery ‘D’, the performance of the different support systems can be compared. The same support pattern was used in all three areas. The least effective support system was the partial resin column based support used in area 2. This was in spite of the fact that the roof, being in a continuous miner section, was not subjected to the disturbance associated with the drill and blast mining method.

In Table 3-1 the average displacement recorded in the intersections in area 2 compared to the intersections in area 1 was approximately 80 per cent larger. Even if the intersection with the headboards in area 2 is excluded, the displacement values are still on average 50 per cent larger. In addition, the displacements in the single roadway monitored in area 2 were three times the average value recorded in the two roadways in area 1.

By averaging the displacements, single curves for the intersections and roadways in each area of Colliery ‘D’ were produced and are presented in Figure 3-42. The support that performed best overall was the full column resin bolts in the continuous miner section (area 3). The apparent creep with time exhibited in the area 3 roadway curve is a function of the averaging process. There is no evidence of creep occurring at individual sites. The only curve that indicates time dependent creep is the one representing the already discussed intersections in the continuous miner partial resin column supported area 2.

Included in Figure 3-42 is the average height of the stable elevation with respect to each curve. The link between the height to which the stable elevation is restricted and the effectiveness of the support in maintaining the integrity of the roof strata within the bolt horizon is apparent in the continuous miner sections. The full column resin support in the drill and blast section however appears to be slightly out of phase with the continuous miner sections. The reasons for this are unclear but could be related to the effects that the pre-existing openings in the roof strata had on the monitoring results.

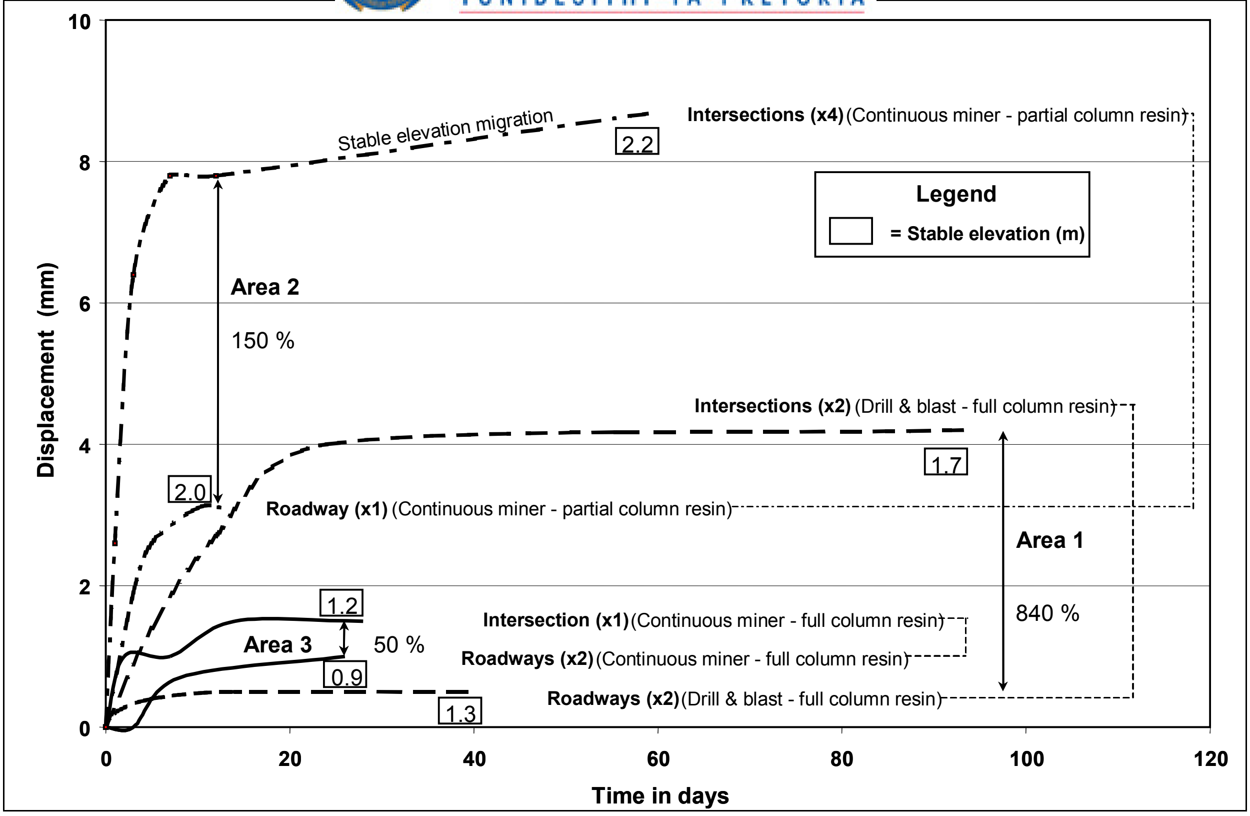


Figure 3-42 Mining method and comparative support performance at Colliery 'D'

3.10 Roadway widening

A site was located at Colliery 'A' where a section of roadway was widened from 5.1 m to approximately 12 m.

As previously mentioned, the roof in some areas of this colliery has damaged, in the form of guttering, appears to be random in nature. In the area selected for the roadway widening experiment, there was no guttering or any other obvious evidence of high horizontal stress.

The immediate roof was thick, competent sandstone unlike the roof within a couple of meters from the experiment site. Bearing in mind that in order for failure to take place the stress acting on a material should be greater than the strength of it. Therefore, although the stress was probably (not measured) same as anywhere else on the mine, because of this competent sandstone the stress damage may have not been seen in the area.

The proposed site was an existing cubby used as a waiting place. The cubby and adjoining roadways were carefully examined. No significant geological features were observed that could adversely affect the roof stability in the immediate area. The roof was supported using 20 mm diameter, 1.8 m long full column resin bolts, four bolts in a row with the rows 2.0 m apart. The mining operation was carried out by a continuous miner.

3.10.1 Instrumentation

The cubby was 5.1 m wide and 8.0 m long. Two sets of instrumentation were installed in the roof approximately 1.0 m from the face. Each set consisted of a 7.3 m deep sonic probe extensometer and three fixed levelling points anchored at 2.7 m, 1.8 m and close to the roof skin. Two tell-tales were also installed at each position to monitor the strata between the roof skin and the 1.8 m and 2.7 m elevations. The instrumentation layout is shown in Figure 3-43. One set of instrumentation was positioned on the centreline of the 5.1 m wide original excavation. The other approximately 1.0 m from the right hand sidewall so that it would in time be closer to the final centreline of the widened roadway. Prior to the start of the experiment, the final roadway width was unknown. The roof and sidewall conditions could only be assessed during the widening operation and a decision taken when to stop.

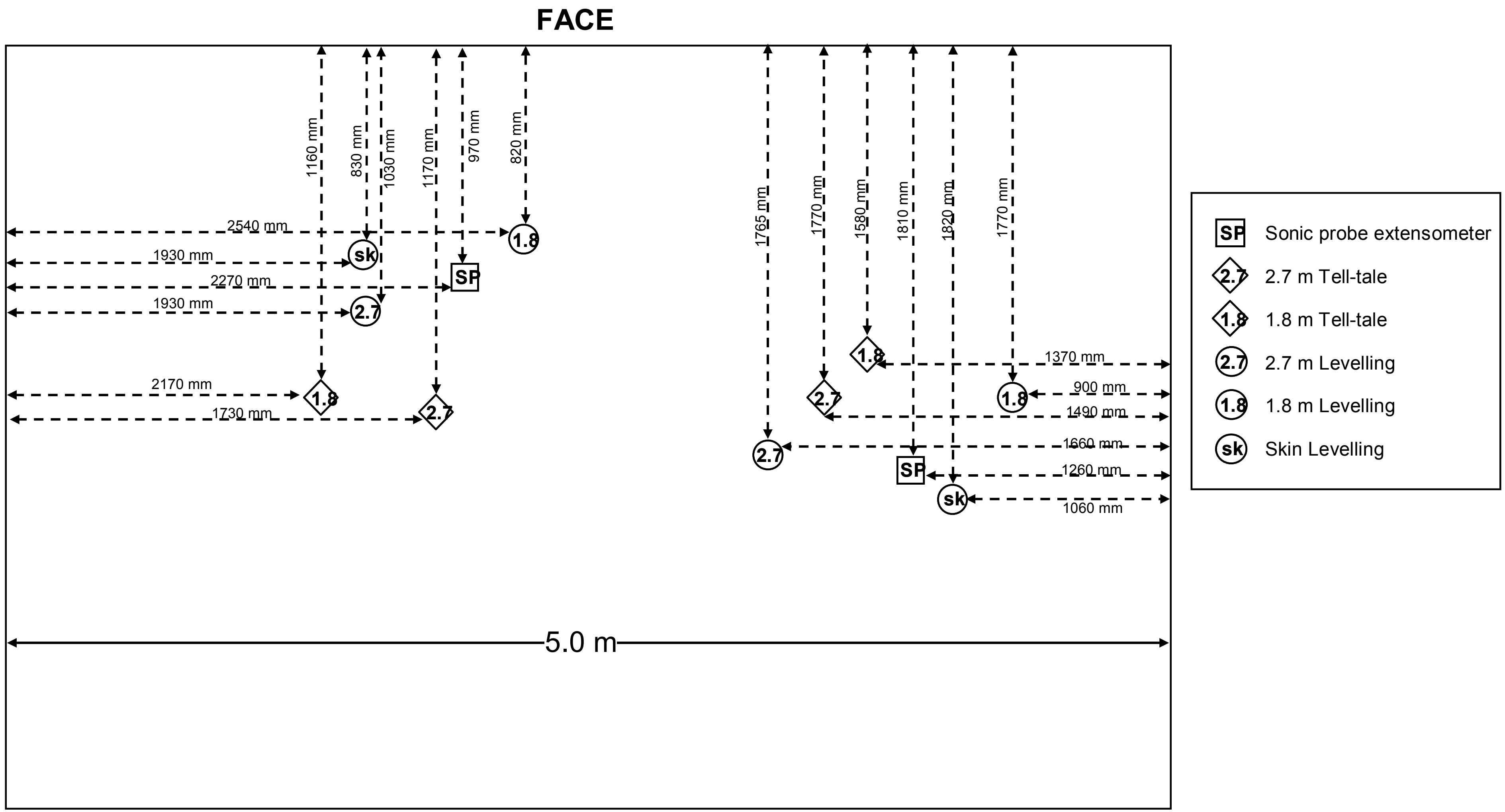


Figure 3-43 Instrumentation layout

The purpose of the sonic probe installations was to gather detailed information of the roof behaviour as the cubby face was advanced and the roadway formed (in a similar manner to the other 29 sites investigated). It was also anticipated that some additional readings would be taken as the roadway widening commenced and for as long as it was safe to enter the area, if temporary support was installed. However, both sonic probe installations were damaged and were abandoned after the initial roadway was formed and the face advanced away from the site.

When the face was advanced, very small displacements were recorded close to the roof skin at both the sonic probe hole locations. The total value at the side hole was 1.0 mm while 2.0 mm was recorded at the centreline hole.

The fixed levelling points were installed primarily to be able to continue to monitor the roof remotely, during and after the roadway widening operation. To accomplish this requirement permanent levelling staves were attached to the individual fixed points protruding from the holes in the roof, immediately prior to the first widening cut with the continuous miner. These staves remained in position for the duration of the monitoring period. Four tell-tales were also installed to monitor the same sections of roof as the fixed levelling points.

A month after the initial installation, one of the fixed levelling points and most of the tell-tales were found to have been damaged. This appeared to have been as a result of the tramming of loaded shuttle cars through the site, which had a relatively low mining height of approximately 2.1 m. As a result, both the 2.7 m levelling point and telltale at the original roadway centreline site were irreparably damaged and were abandoned.

3.10.2 Widening procedure

The outline and dimensions of the original cubby, as well as those of the subsequent development in the immediate area, are indicated in Figure 3-44. Included are the positions of the two sets of instrumentation.

The roadway was widened in three stages as illustrated in Figure 3-45. Because of the element of risk involved, the first two cuts were stopped slightly short of breaking through into the roadway perpendicular to the one being widened. The intention was to use the behaviour of the slender pillar formed to assist in assessing the overall general stability of the area as widening of the roadway continued. Cut three was planned so as to get the sidewall as close as possible parallel to the centreline of the roadway. Based on the lack of load induced spalling on the slender pillar the third cut was extended until it just broke through into the roadway. This reduced the slender pillar, to becoming a snook estimated to be 0.8 to 0.9 m wide and 3.0 m long. Although it did not appear to be carrying any excessive load at the time, the risk involved in removing it was considered too high and it was left intact.

During the widening process no additional roof support was installed. At the 12 m final width, only the initial 40 per cent of the span had been supported with roof bolts.

Taking the surrounding pillars as the boundaries, the span of the final excavation was 12 m x 25 m. Even if the snook is considered as being an effective support element and boundary, the minimum dimensions are reduced to 12 m x 19 m. The monitoring was limited to the supported 40 per cent of the final roadway width. The opposite side of the widened roadway was unsupported and in all probability would have experienced larger differential displacements. Nevertheless the roof remained intact without even any minor falls being noted.

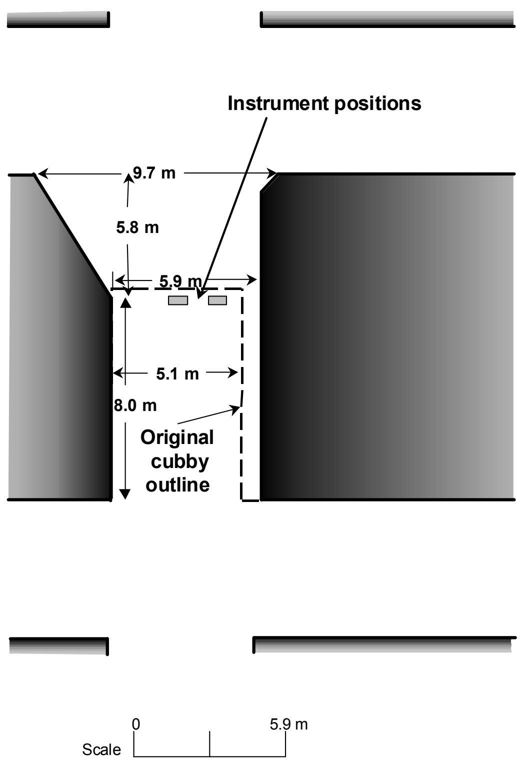


Figure 3-44 Roadway and adjacent intersections prior to widening

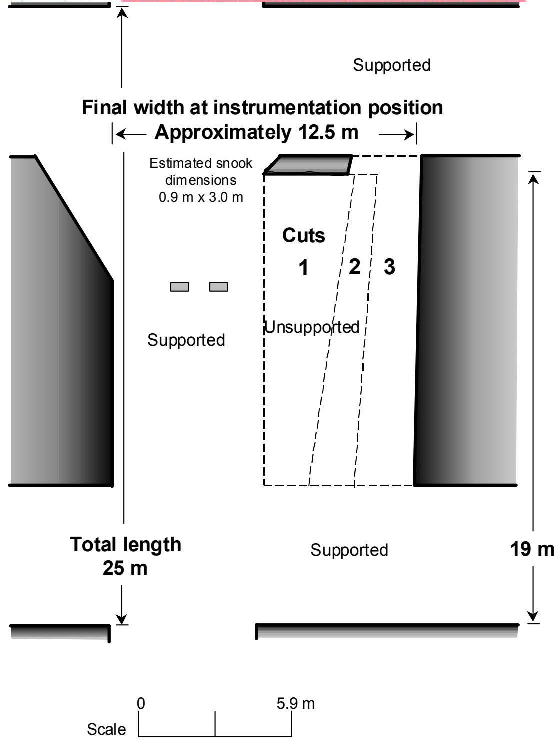


Figure 3-45 Cutting sequence and final roadway shape

3.10.3 Results

The monitoring of the roof deflection has been divided into two sections. The first is the short term dynamic performance during the widening process and the second, the longer term behaviour of the 12 m wide roadway with time. With the exception of Figure 3-48 the roof deflection and differential displacements have been given negative values.

The roof deflection recorded during the widening phase is presented in Figure 3-46. On the horizontal scale the left hand sidewall is fixed at zero, while the position of the right hand sidewall is indicated for each set of readings taken. The positions of the five levelling points are also plotted relative to the left hand sidewall. In this dynamic situation it was difficult to determine if any differential displacements, such as bed separation, were occurring. The change in shape and increase in displacement values towards the mobile centreline of the roadway occurred in the anticipated sequence in all three deflection profiles. Although not conclusive, this suggests that during this period, the 2.7 m thick roof beam being monitored remained intact.

Figure 3-47 covers the time period from day one, when the first set of readings were taken in the road once the width had been opened to 12 m, up until the final reading on day 38. The horizontal axis indicates the position of the measuring stations relative to the left hand static sidewall. In this graph two different mechanisms can be seen. The 2.7 m levelling point, being the deepest in the roof, traditionally gives the best indication of the overall roof deflection and is the least likely to be influenced by the unravelling effects of delamination, which usually starts close to the roof skin. The deflection of this point can be seen to increase with time. The change in shape of the five point levelling profile indicates that differential displacements were also occurring in the roof beam during this time period. These can be seen more clearly in Figure 3-48. In this Figure, the relative displacement of both the 1.8 m and skin anchor points were plotted using the 2.7 m levelling point as a static reference. The separation between the skin and 1.8 m elevation on the right hand side had started within 14 hours of the roadway reaching the 12 m width. The same comparison at the centreline showed no evidence of differential displacement at this time. This could either be as a result of an opening, once initiated, migrating towards the edge of the roadway or that the displacements were localized and not interconnected. By day nine the displacements at both instrumentation positions were well defined and tended to stabilize from day 24 onwards. The maximum differential displacements values recorded were 1.0 mm at the right hand position and 2.0 mm at the centreline. The fact that the greater value occurred closer to the sidewall suggests that these displacements may have been more localized than continuous across the roof beam.

A point worth noting, which is apparent in Figure 3-46, Figure 3-47 and Figure 3-48, is the behaviour of the 1.8 m centreline levelling point. It appears to have undergone less overall displacement than the 2.7 m point, which is anchored higher in the roof strata. This is a true reflection of the situation, which is as a result of the widening of the roadway, the 2.7 m point ended up closer to the centreline of the widened roadway. The roof deflection over the larger span influenced the 2.7 m point to a higher degree than the 1.8 m point closer to the sidewall. This was also the case with the skin anchor situated even closer to the sidewall, up until day two, when it also still recorded less deflection than the 2.7 m point.

Figure 3-49, shows the behaviour of all five points with time. After starting with relatively rapid displacement, as a result of the roadway widening process, up until day two, they continued at a fairly constant rate until day 24. From that point until when the final readings were taken on day 38, the velocity dropped 75 per cent on average.

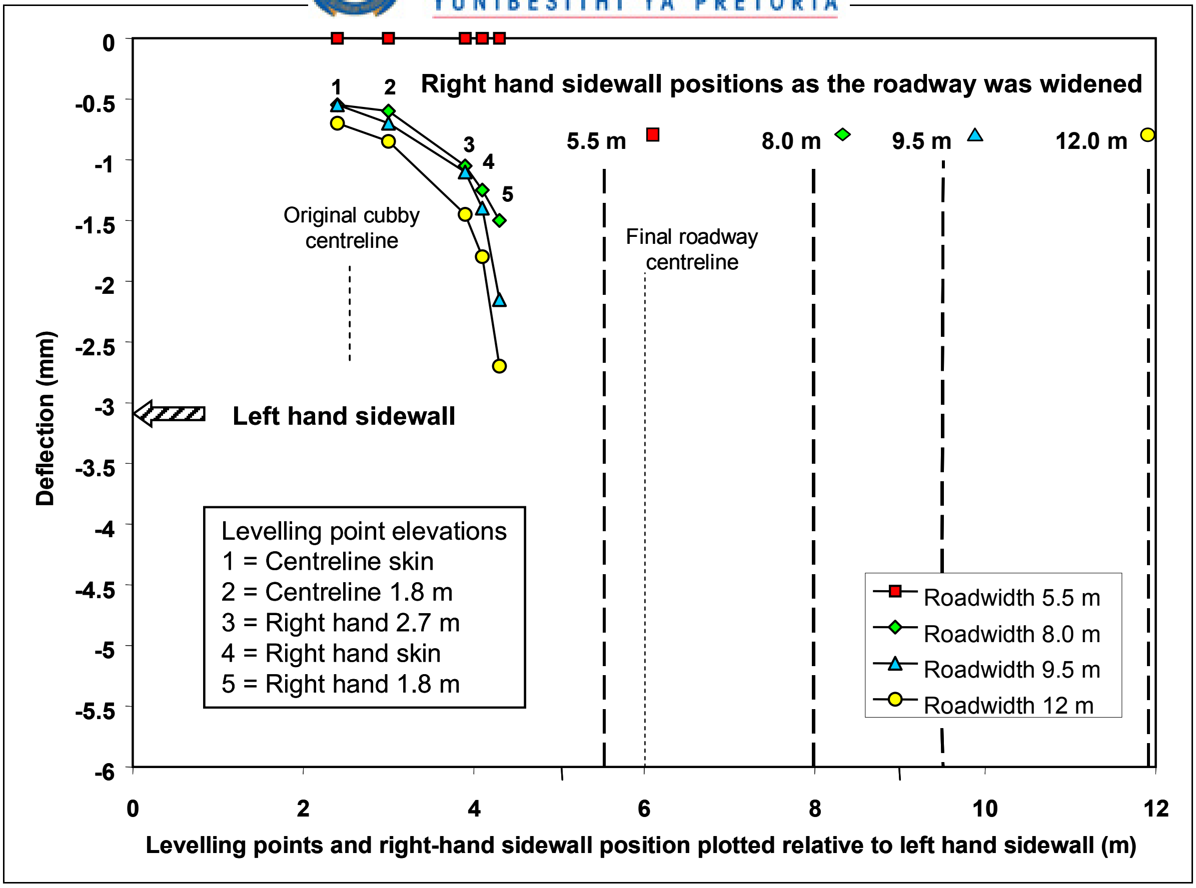


Figure 3-46 Increase in roof deflection with widening of roadway

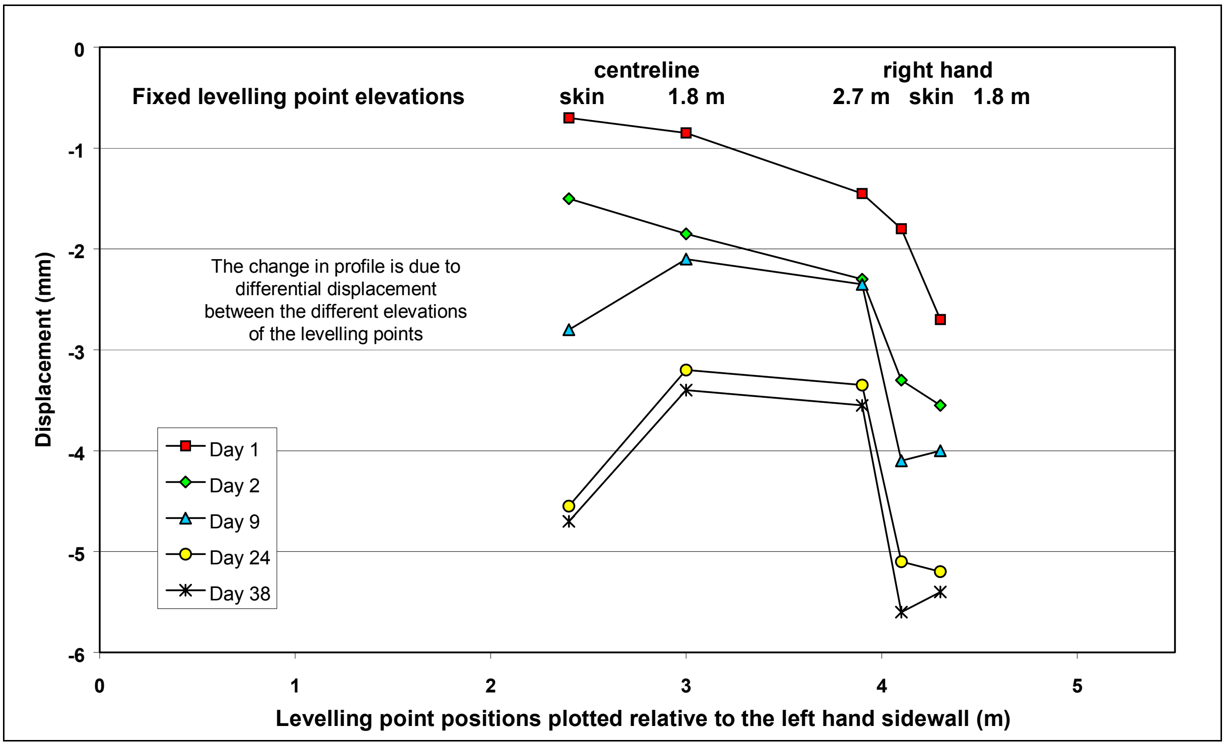


Figure 3-47 Roof behaviour of the 12 m widened roadway with time

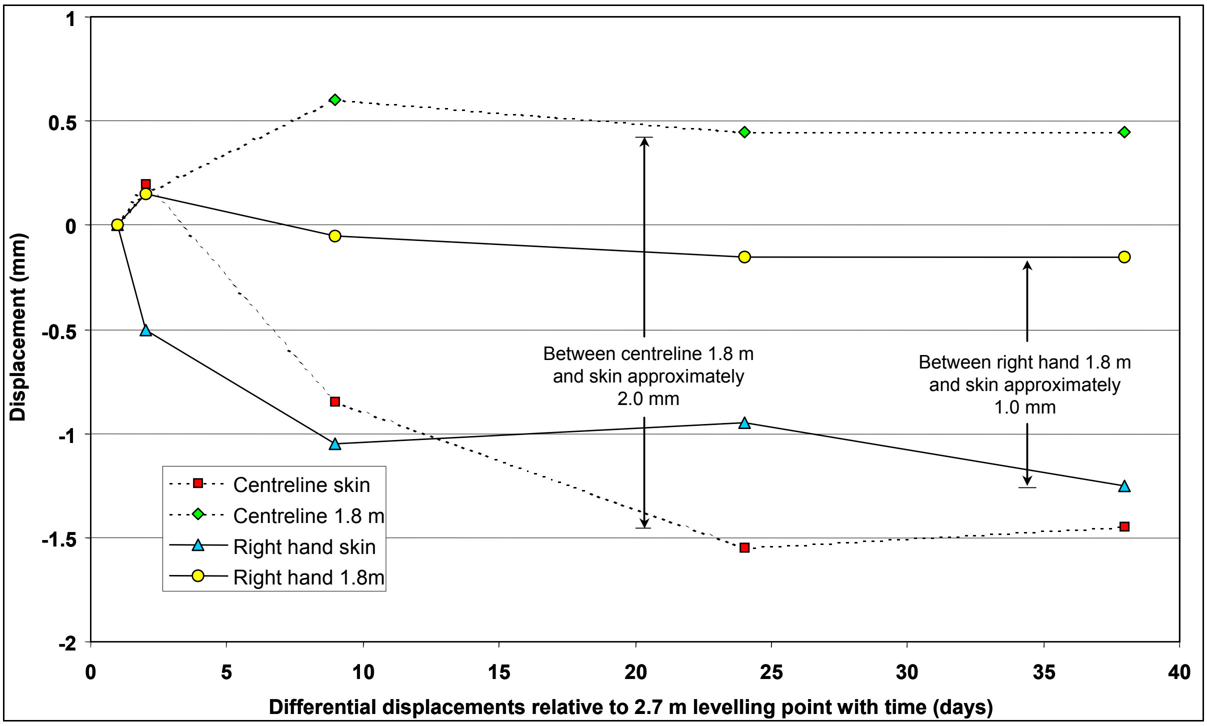


Figure 3-48 Separation within the roof beam with time

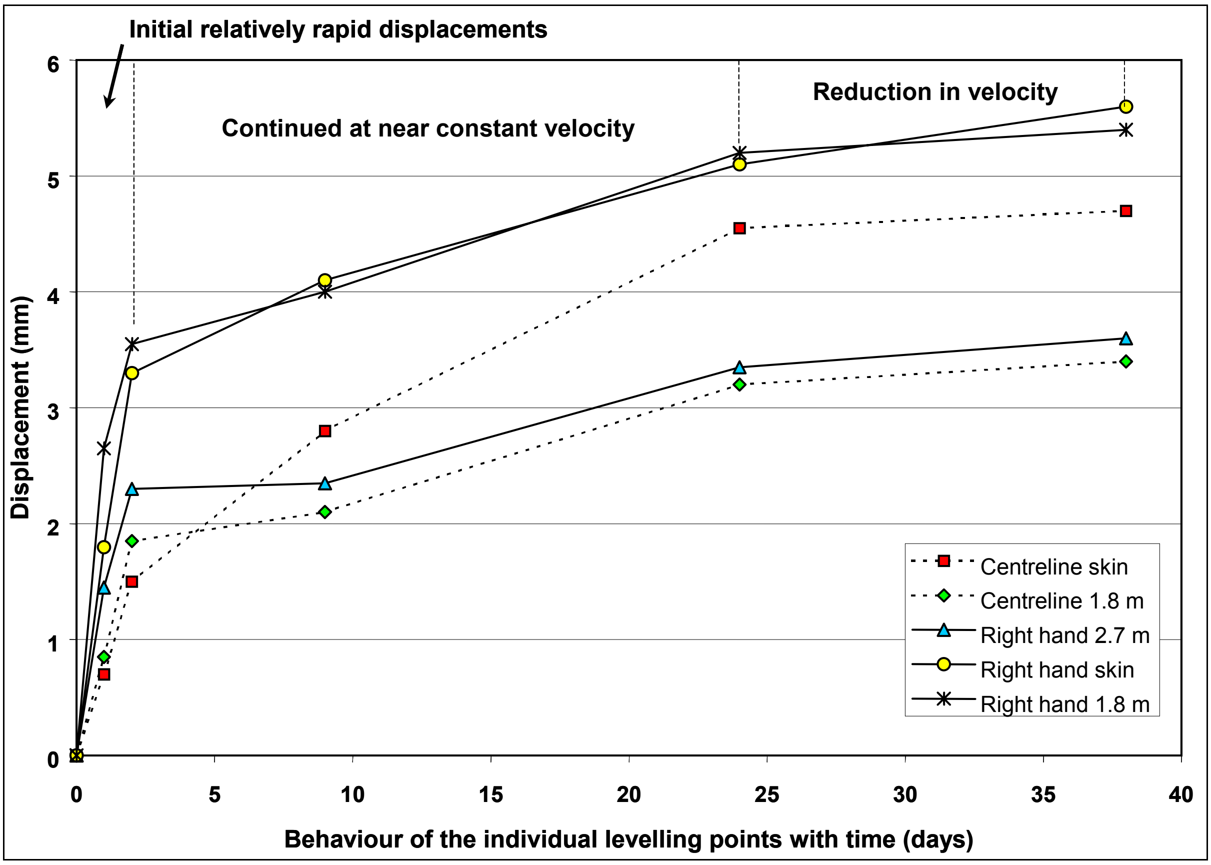


Figure 3-49 Displacement rates as a function of time

The photograph shown in Figure 3-50 was taken on day nine. The general stability of the area is evident from the intact corners of the snook and the clean cut edges of the break through hole to the right of it. The five permanent levelling staves and the three tell-tales can be seen in the original supported roadway on the left hand side.

Because of the distance involved, the tell-tales were observed using the telescope in the survey level. Estimates of the indicated displacements were made relative to a 5.0 mm graduated scale on each tell-tales. These were then compared to the appropriate levelling results once they had been calculated. Even though the differential levelling results were very small, the largest being 2.0 mm, they were evident and the estimated values were close to the values derived from the levelling.

The last visit was made to the site on day 52 as the area was about to be sealed off. Unfortunately all five permanent staves were missing so it was not possible to get a final set of measurements. The tell-tales were however still in position and there was no evidence of any even minor roof falls in the area. The snook was intact and appeared to have changed very little, if at all since the photograph shown in Figure 3-50 was taken on day nine.

From the tell-tales observations, the differential displacements between the two roof skin and the 1.8 m elevation had not changed and were much the same as it had been since day 24.

3.10.4 Conclusions

This experiment highlighted that the variations that can occur in a single mining area. Other parts of the section exhibited guttering and horizontal stress driven roof failures in supported roadways as narrow as 5.0 m.

The fact that the personnel intimately involved in the underground conditions at this particular colliery were able to identify this area as being unlikely to be influenced by high horizontal stress is significant. The signs they use to assess the presence of relatively high horizontal stress levels were absent in this particular area.

The ultimate aim of this experiment was to establish the critical roof deformations prior to roof failures. However, due to competent nature of the roof, it could not be established.

The horizontal stress driven buckling, or shearing effect, compounds the displacements induced into the roof strata by a purely gravitational loading system. This is well documented in some

Australian collieries where it is sometimes particularly severe with roof skin displacements of hundreds of millimetres being initiated as high as 5.0 m into the roof. In South Africa the cause and effects are far less dramatic as a result of which they are often not recognised as being present or taken into account in the support design procedure.

During the monitoring period no roof falls occurred at any of the 29 sites, even where 12 mm displacements were measured. As a result it was not possible to try and establish critical roof displacement values for any of the geological regions.

Figure 3-50   Experiment site taken on day nine

3.11 Conclusions

The sonic probe extensometer, which was found to be the most accurate and reliable instrument capable of monitoring roof behaviour up to 7.2 m into roof, was used throughout the underground monitoring programme. To process the monitoring data as quickly and efficiently as possibly, a customised program was written, culminating in an easy to understand set of graphic results.

A preliminary study into the height to which the openings migrate in the roof (height of roof softening), i.e. height to which instabilities could occur was conducted. In all monitoring sites all the displacements measured in the roof were confined to within 2.5 m of the roof skin. The height of instability in the intersections was compared to that in the roadways with the elevation differences being converted to percentages. These differences were relatively small, varying between -5.0 and 33 per cent with an overall average of 13 per cent.

In the vast majority of cases the stable elevation in the roof was fully developed a short distance behind the face. In the drill and blast sections, the stable elevation was reached after a single blast, where the face advance increased the unsupported span to 3.0 m on average.

In the continuous miner sections, it was difficult to accurately determine at what point the stable elevation had fully developed. The only two monitoring sites that indicated obvious increases in the height at which displacement occurred in the roof as further mining occurred, were both in the partial column resin supported roof at Colliery 'D' (area 2 - site two). Both sites were in intersections that had total relaxations amongst the highest recorded. Their total relaxation values had reached 11 and 5.0 mm respectively prior to the migration of the stable elevation occurring. Both the stable elevations increased quite significantly by approximately 0.5 m and 0.25 m, respectively. Since this occurred well outside the face advance zone of influence, at between 56 m and 166 m and 28 m and 158 m respectively, it appeared to be time dependent behaviour.

An investigation into the time effects of a static face indicated that close to a static face (within 0.5 m), the roof does not deform significantly. If a face remains static, the roof within its zone of influence (approximately 5.0 m away) experiences some degree of creep with time. An area of roof outside the zone of influence of the face (11 m away) is not affected by the face irrespective of whether it is stationary or be advanced.

The monitoring results also showed that there was no evidence of a dramatic increase in the stable elevations as is the case in the high horizontal stress driven beam buckling mechanism experienced in overseas collieries. It is thus concluded that in the sites monitored relatively high horizontal stress played little, if any role in increasing the deformations measured.

A roadway widening experiment was carried out to establish the critical roof displacements. The maximum width attained was 12 m at which stage ± 5 mm displacement was measured. No roof falls had occurred. However, in the same panel falls had occurred at 5 m widths. Also, falls took place in some of the areas where evidence of high horizontal stress had been noted. This indicates the significant variations that occur in a single mining area.

During the monitoring period no roof falls occurred at any of the 29 sites and road widening experiment site, even where 12 mm displacements were measured. As a result it was not possible to try and establish critical roof displacement values for any of the geological regions.

In conclusion, these results showed that the roof conditions in South African collieries can be classified as gravity loaded beams.

Relatively high horizontal stresses have been reported in South African collieries; however it is believed that these areas are isolated small areas probably affected by geological features. It is therefore important to note that when the mining is approaching towards a major geological structure, relatively high horizontal stresses may be expected and necessary precautions should be taken to reduce the effects of it on the roof deformations.