

SIMRAC

Safety in Mines Research Advisory Committee

Final Project Report

Underground verification of the large deflection performance of fibre reinforced shotcrete subjected to high stresses and convergence and to dynamic loading

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Executive summary

The underground verification of the performance of fibre reinforced shotcrete, subject to high stresses, convergence and dynamic loading, was identified for specific research and this topic was gazetted for the 2000 SIMRAC research programme. The project commenced in May 2000.

The following outputs were defined for the project:

- *In situ* performance comparison between fibre and mesh reinforced shotcrete.
- Confirmation that the fibre reinforced shotcrete performance matches that of the mesh reinforced shotcrete under large deformations.
- A comparative performance of various types of fibre reinforced shotcrete.
- A comparative performance of fibre reinforced shotcrete of various thicknesses.

Other outputs included in the project are:

- Photographic record of the project.
- A qualitative analysis of the corrosive effects of the underground environment on steel fibre reinforced shotcrete.

The nature of this project requires that various types of shotcrete be applied to a tunnel and that the performance thereof under extensive deformation be monitored over a period of time. In order to achieve this, one of the most critical tasks was to obtain an appropriate experimental field site. Finding the best site was of utmost importance to limit the duration of the project. A site needs to be subjected to high mining induced stress increases and associated convergences shortly after application of the shotcrete so that the observations of performance could be completed in the two year time frame proposed.

A suitable site was identified at Hartebeestfontein 6 shaft, the characteristics of which are described in Section 3, and agreement from mine management was obtained during November 2000. Site establishment commenced in December 2000 and was completed in early January 2001, while overstoping was to commence during July 2001.

The field test site is in the 77 level North Haulage, between 24 and 25 crosscuts at a depth of 2336m below surface, 71m vertically below reef elevation, approximately 25m horizontally

from the shaft pillar abutment. Currently the stress levels are very high due to proximity to the shaft pillar abutment. With the mining of the 77 24 line across to the shaft pillar abutment, it was anticipated that significant stress changes, large deformations and possibly seismicity would be experienced at this site.

However, later during May 2001, the mine informed SRK that overstoping of the site had been excluded from the mine plan, due to low grade. The extension of the site was therefore cancelled and primary outputs of the project were amended to exclude the comparison of different thicknesses of shotcrete in agreement with SIMRAC.

The maximum expected magnitude of a seismic event for the region is 3.8. The prediction analysis was updated with seismic events recorded up until 25/04/2002 and very little difference was observed. Very few seismic events were recorded near the field test site, prior to establishment. This is mainly due to the lack of mining nearby. Between March 2001 and July 2001 several large seismic events were recorded near the field test site. This is probably due to the mining of the 23b line. No increase in deformation could be linked with any of these seismic events.

The modelled stress environment prior to the site establishment in December 2000 is represented on a vertical section through the field test site. The high stress "lobe" is caused by the shaft pillar abutment. High stresses extend deep into the footwall, due to the large size of the shaft pillar. The field test site is situated in a zone where σ_1 ranges from 140 MPa to 145MPa. Stresses were calculated at points along the field test site at 2.5m intervals, representing the boundaries and centres of the test sections. The average increase in stress at the field test site between December 2000 and February 2002 was 8.9 MPa.

Although the field stress in which the field test site is situated is very high (>140MPa) the change in stress is not significant. It is expected that there will be deformation, but that these deformations will take place slowly and will not be as large as originally anticipated.

In preparation for the application of shotcrete, the mesh was removed over a 20m length of tunnel, while leaving the lacing intact. Shotcrete was spayed to a minimum thickness of 75mm over this 20m length of tunnel.

The boundaries of each test section were painted in and each section was numbered. A 1.0m square panel was painted on the centre of the hangingwall and sidewalls of each test

section and marked accordingly. Photographs of the panels were taken at intervals to monitor the crack development. A measuring bracket was mounted in each panel for laser distomat closure measurements.

For each test site a core tray and two EFNARC trays were sprayed. These were left to cure at the field test site for approximately 21 days, after which time they were removed for testing at 28 days.

The four test sites with the various reinforced shotcretes remained stable in the estimated field stress of 140 to 145 MPa with a stress change of 10.9 MPa.

The test site was not subjected to extreme seismic episodes during the project period.

The mesh-reinforced shotcrete exhibited the maximum closure measured of 56 mm as well as the higher crack density in the southern panel.

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1 Introduction

The underground verification of the performance of fibre reinforced shotcrete, subjected to high stresses, convergence and dynamic loading, was identified for specific research and this topic was gazetted for the 2000 SIMRAC research programme. The project commenced in May 2000, with the primary output being defined as follows:

An evaluation of the relative effectiveness of steel and polypropylene fibre reinforced shotcrete compared to mesh reinforced shotcrete in tunnels subject to high stresses and convergence and possibly, to dynamic loading. In particular:

- A direct comparison of the *in situ* performance of mesh reinforced shotcrete with that of steel and polypropylene fibre reinforced shotcrete;
- Confirmation that the performance of fibre reinforced shotcrete matches the performance of mesh reinforced shotcrete under large deformation;
- A comparative basis for theoretical analysis of the performance of different types of fibre reinforced shotcrete;
- A comparative basis for theoretical analysis of the performance of fibre reinforced shotcrete of various thicknesses.

Other outputs included:

- Photographic records of all project phases;
- A final report on the *in situ* performance of steel and polypropylene fibre reinforced shotcrete compared with that of mesh reinforced shotcrete;
- A qualitative analysis of the corrosive effects of the underground environment on steel fibre reinforced shotcrete.

The objective of this research is to determine whether fibre reinforced shotcrete provides an adequate replacement for mesh-reinforced shotcrete and which type of fibre is more appropriate, under high stress, large convergence and dynamic loading in the underground environment. Since fibre reinforced shotcrete is installed in a single-phase operation, containment support can be installed close to the tunnel face, with less disruption to the tunnelling operation, thereby improving safety and stability of the tunnel. Mesh reinforced shotcrete is installed in more than one phase, causing greater disruption to the tunnelling operation, and therefore is invariably not installed close to the face.

The contract for the research was awarded to SRK Consulting (SRK), mainly due to our substantial involvement in laboratory testing to assess the performance of shotcrete under

both dynamic and static conditions. A copy of the approved proposal for this contract is included for reference in Appendix A. During September 2001, the contract was amended to exclude one of the primary outputs, "A comparative basis for theoretical analysis of the performance of fibre reinforced shotcrete of various thicknesses", following a proposal submitted by SRK in the July 2001 progress report (Appendix A).

The main content of this report is as follows:

- Selection of a suitable field test site;
- Characteristics of the selected field test site;
- Site establishment;
- Quality control and testing;
- Closure measurements;
- Crack mapping;
- Conclusions; and
- Recommendations for further research

2 Selection of a suitable field test site

The nature of this project requires that various types of shotcrete be applied to a tunnel and that the performance thereof under extensive deformation be monitored over a period of time. In order to achieve this, one of the most critical tasks was to obtain an appropriate experimental field site. Finding the best site was of utmost importance to limit the duration of the project. A site needs to be subjected to high mining induced stress increases and associated convergences shortly after application of the shotcrete so that the observations of performance could be completed in the two-year time frame proposed. Ideally, the site would be overtopped shortly after the support is installed. Full co-operation from the mine was required, since funding is based on the assumption that the mine would carry the cost of support installation, as the mine would require tunnel support anyway.

Initial progress on the project was protracted due to the lack of availability of suitable sites. Such sites are not part of standard mining practice and therefore only occur when circumstances require that the mining sequence be changed, resulting in unfavourable overtopping of tunnels. Through liaison with 14 mines, 24 potential sites were identified, which were investigated for suitability. Most of these were found unsuitable for one or more of the following reasons:

- Support was installed which was not appropriate for the project;
- In sacrificial tunnels, the mine was not willing to install the appropriate support, due to the additional cost involved;
- The mine intended to install support other than which is appropriate for the project;
- The timing with regard to establishment of the site and overstoping was not appropriate. Either the mining faces were often too close and the mining already influences the tunnels, with deformation already taking place, or the overstoping would only take place long after the project should be completed.
- Overstoping cannot be guaranteed due to grade reasons.
- During overstoping of tunnels, where seismicity is anticipated, access to the site would be restricted for safety reasons, requiring sophisticated monitoring equipment, which was not budgeted for.

A list of the potential sites and their characteristics is given in Appendix B.

A suitable site was identified at Hartebeestfontein 6 shaft, the characteristics of which are described in Section 3, and agreement from mine management was obtained during November 2000. Site establishment commenced in December 2000 and was completed in early January 2001 (see Section 4), while overstoping was to commence during July 2001. Initially, it was planned to establish additional sites on other mines, but agreements with mine management could not be established. During March 2001, SRK was informed that overstoping of the Hartebeestfontein site would only commence in December 2001 and the possibility of the extending the site, to achieve the planned primary outputs, was investigated. Initial agreement was obtained, but due to a change in management, the mine no longer supported the project. Additional funding for support installation was requested from SIMRAC during May 2001 and granted. However, later during May, the mine informed SRK that overstoping of the site had been excluded from the mine plan, due to low grade. The extension of site was therefore cancelled and primary outputs of the project were amended to exclude the comparison of different thicknesses of shotcrete in agreement with SIMRAC.

3 Characteristics of the selected field test site

The field test site is sited at Hartebeestfontein 6 shaft pillar, in the 77 level North Haulage, between 24 and 25 crosscuts (Figure 1). It is 2336m below surface, 71m vertically below reef, approximately 25m horizontally from the shaft pillar abutment. Currently the stress levels are very high due to proximity to the shaft pillar abutment. With the originally-planned mining of the 77 24 line across to the shaft pillar abutment, it was anticipated that significant stress changes, large deformations and possibly seismicity would be experienced at this site. Since the 77 24 line will not be mined; only a slight stress increase is anticipated and less significant deformations.

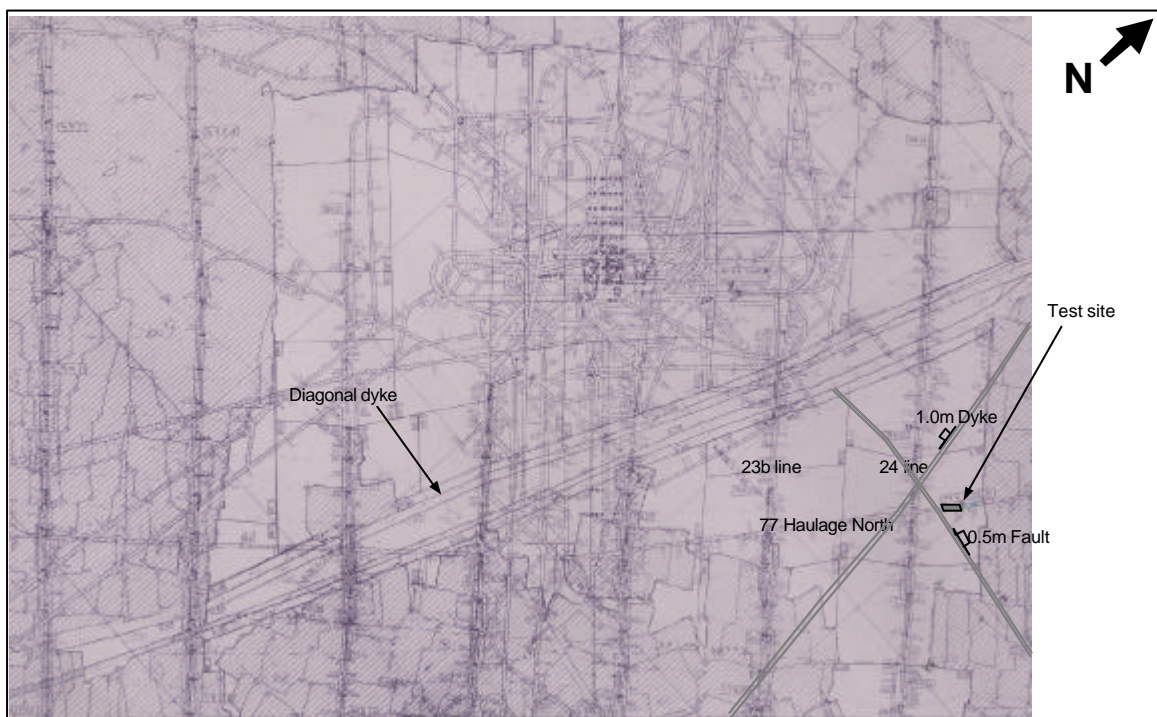


Figure 1: Mine plan of Hartebeestfontein 6 shaft pillar, showing location of test site

The field test site comprises four 5.0m shotcreted test sections, each with a different type of reinforcement. The basic layout is indicated in Figure 2.

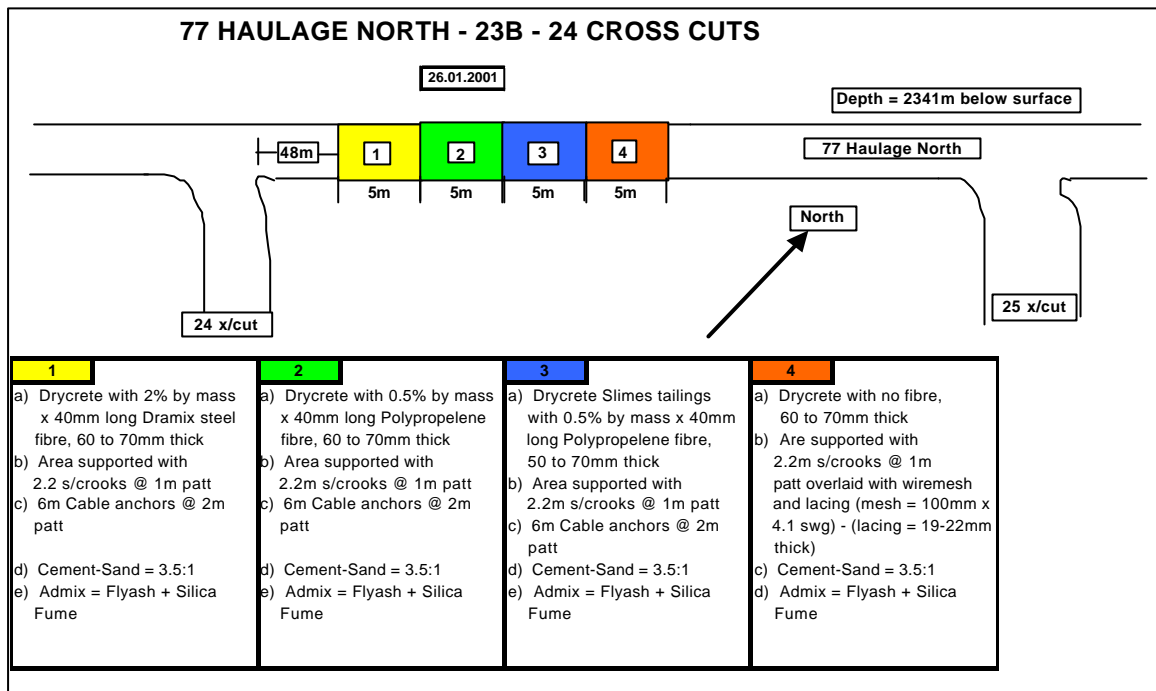


Figure 2: Field test site layout

3.1 Ground conditions

At Hartebeestfontein no. 6 shaft the Vaal reef is exploited. It is situated in the Main Bird series, which is part of the Central Rand Group of the Witwatersrand Supergroup. The Vaal Reef lies between the MB4 and MB5 members of the Main Bird Series. The 77 level North haulage is sited in the MB6 member, which lies approximately 30m below the Vaal Reef and is 80m thick. The MB6 is an argillaceous quartzite with numerous grits and small to medium sized pebbled conglomerates with shale, acid lava, chert, quartz and quartzite pebbles. Average Uniaxial Compressive Strengths (UCS) of 167MPa and 180MPa have been recorded (Bosman et al 2000). Bedding thickness in the MB6 ranges between 20cm and 120cm with well-defined bedding contacts filled with soft shale-like material of varying thickness (Figure 3). This material consists predominantly of a matrix comprising fine grained quartz (40%) and mica (60%). It is these bedding contacts that are mainly responsible for the squeezing behaviour experienced at the mine. The squeezing mechanism is considered to be a combination of time-dependant failure of the intact rock and sliding between bedding planes (Malan and Basson, 1998). Bosman et al (2000) state that "Excavation's sited in the MB6 member in the deeper levels of the mine have been observed to deform at a steady rate until mining operations encroach.

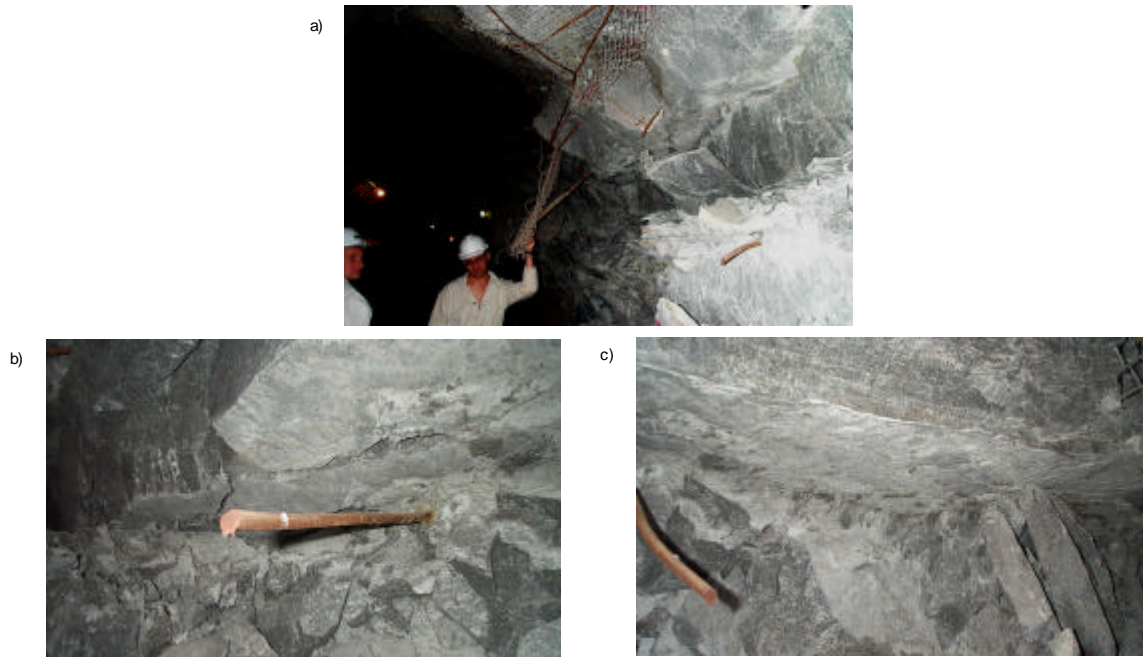


Figure 3: Conditions in the 77 Haulage North near the field test site.

Figure 3 illustrates the conditions in the 77 haulage north near the field test site in the MB6 quartzite [a) large deformations resulting in failure of mesh and lacing. Soft shale-like material visible on bedding planes in b) and c)]

The stress changes brought about by encroaching mining operations accelerate the deformation to a point where constant rehabilitation is required to maintain the operational function of the excavation. Once stress has been relieved and rehabilitation is complete, it has been noted that some deformation still occurs albeit at a much reduced rate”.

Substantial deformation has already taken place as is evident in Figure 4. The failed rock has caused bulging in the mesh and lacing support.

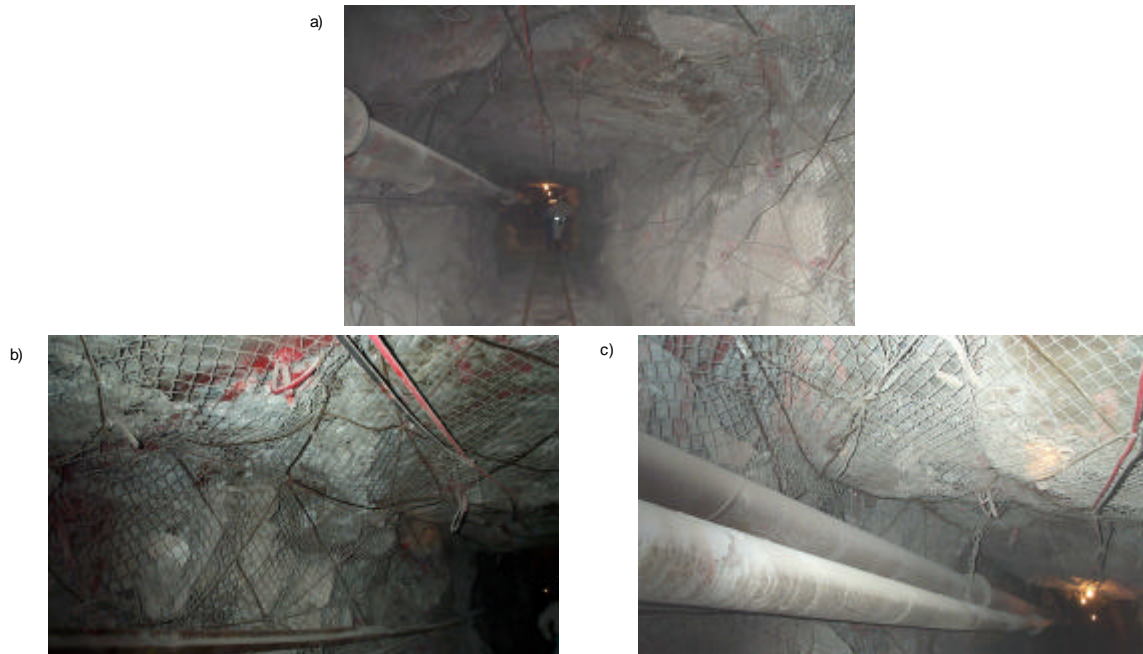


Figure 4: Conditions at field test site prior to site establishment.

Bulging in mesh and lacing is clearly visible in figure 4, [a) Profile looking North East. b) Hangingwall and South sidewall. c) Hangingwall and North sidewall].

3.2 Geological structures and seismicity

There are two geological structures in the immediate vicinity of the field test site (Figure 1). A fault with a 0.5m throw traverses the haulage obliquely about 5m from the test site. A dyke with a 1.0m throw traverses the haulage approximately 45m from the field site. About 200m from the test site, there is a major geological structure, the Diagonal dyke. Many large seismic events have been recorded on the structure as is evident in Figure 5. Seismic activity in the Hartebeestfontein 6 shaft pillar is high.

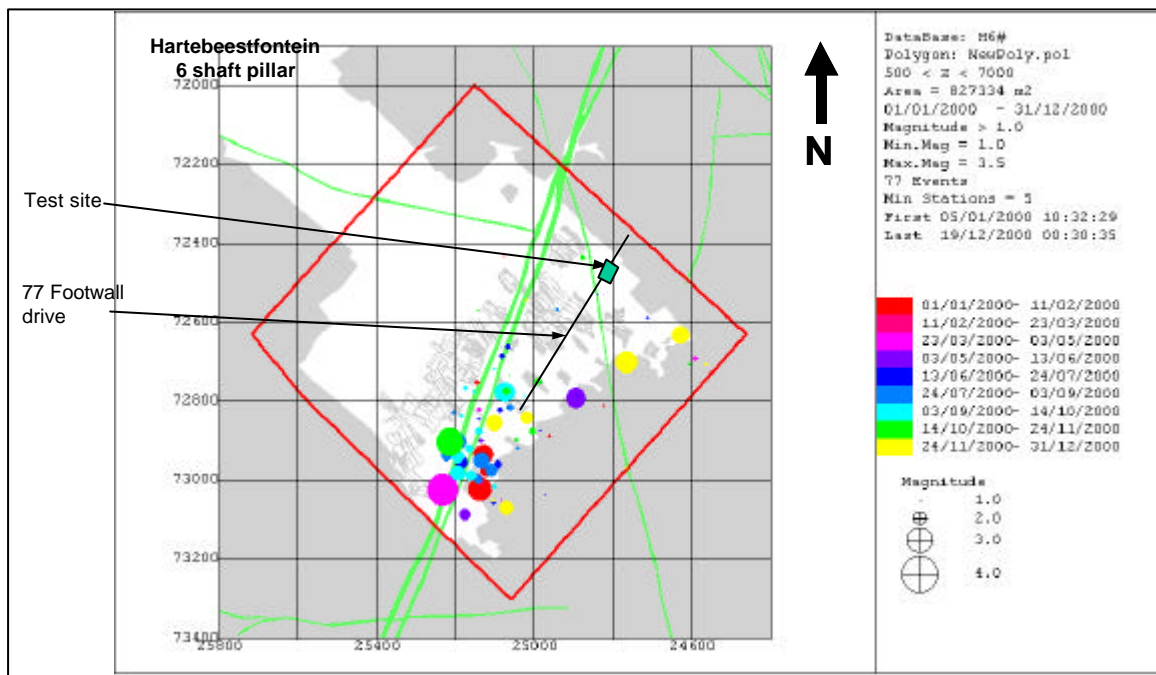


Figure 5: Seismic events recorded at 6 shaft pillar between 01/01/2000 and 31/12/2000.

The following mean return periods for seismic events were determined from seismicity recorded between January 2000 and December 2000, prior to establishment of the field test site:

Table 1. Mean return periods for seismic events in the Hartebeestfontein 6 shaft pillar

Magnitude	Number of events		Return period	
	per month	per year	months	years
>1.0	6.35	76.2	0.158	0.01
>1.5	2.21	26.5	0.453	0.04
>2.0	1.34	16.1	0.746	0.06
>2.5	0.59	7.1	1.693	0.14
>3.0	0.18	2.2	5.438	0.45
>3.5	0.05	0.6	21.751	1.81

The maximum expected magnitude of a seismic event is 3.8. This analysis was updated with seismic events recorded up until 25/04/2002 and very little difference was observed. Very few seismic events were recorded near the field test site, prior to establishment (Figure 6). This is mainly due to the lack of mining nearby.

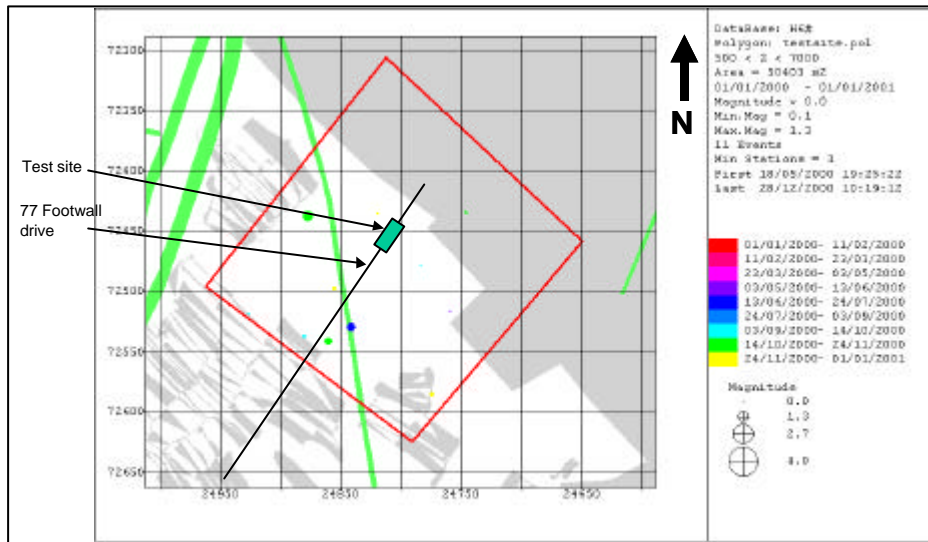


Figure 6: Seismic events recorded near the test site between 01/01/2000 and 31/12/2000

Between March 2001 and July 2001 several large seismic events were recorded near the field test site (Figure 7). This is probably due to the mining of the 23b line (see Figure 1). No increase in deformation could be linked with any of these seismic events.

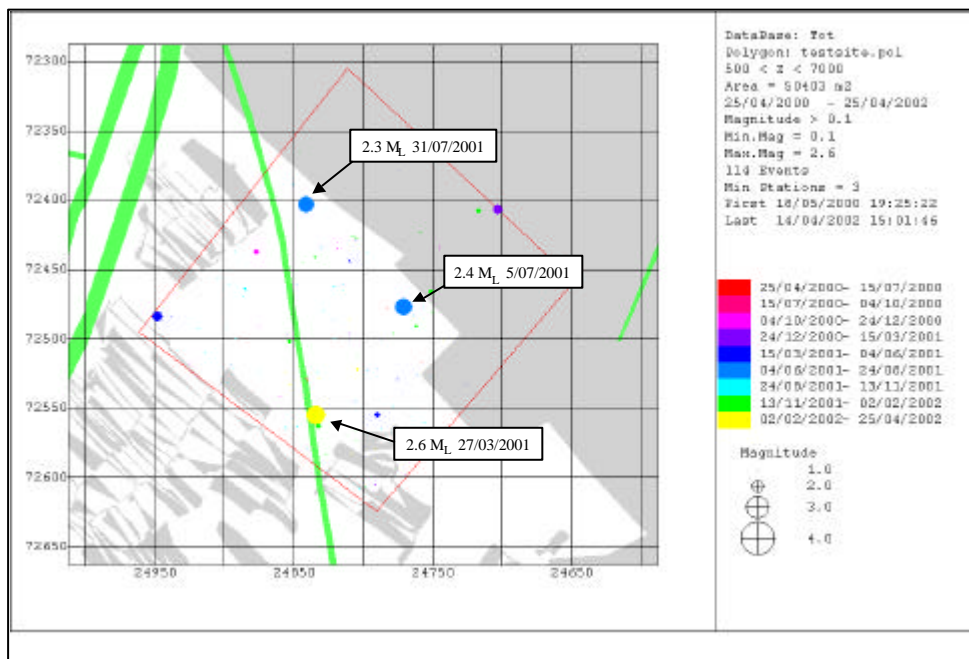


Figure 7: Seismic events recorded near the test site between 25/04/2000 and 25/04/2002

A detailed analysis of the seismic hazard in the Hartebeestfontein 6 shaft pillar is contained in Appendix C.

3.3 Stress environment

Stress modelling was carried out to determine the stress environment, in which the test site is situated, and how it will be affected by mining that has taken place and that which is planned. The numerical modelling showed that the test site was situated in the high stress zone associated with the shaft pillar abutment. Field observations confirmed the high stress environment (figures 3 and 9); all of the Hartebeestfontein 6 shaft mining was modelled with detailed mining sequences in the shaft pillar area.

Figure 8 shows the detailed modelling sequences representing actual surveyed mining face positions at one-month intervals from December 2000 to February 2002. The nearest mining took place at 77 level 23b line and 75 24 line.

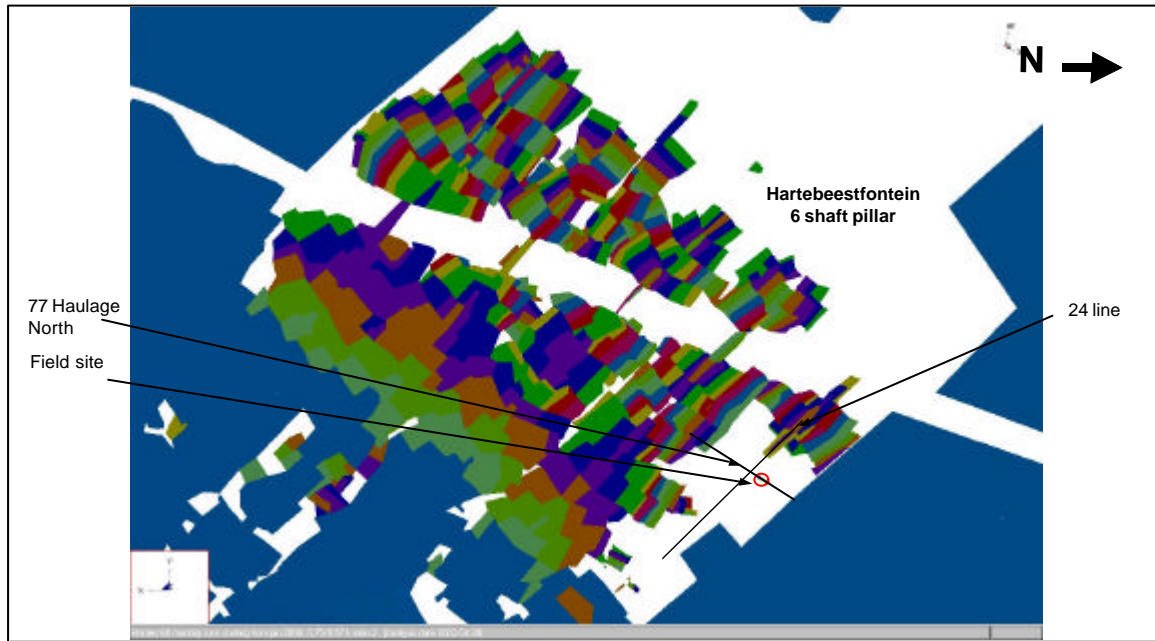


Figure 8: Model of Hartebeestfontein field site – mining from 12/2000 to 02/2002.

The modelled stress environment prior to the site establishment in December 2000 is represented on a vertical section through the field test site (Figure 9 – The four test sections are indicated). The high stress “lobe” is caused by the shaft pillar abutment. High stresses extend deep into the footwall, due to the large size of the shaft pillar.

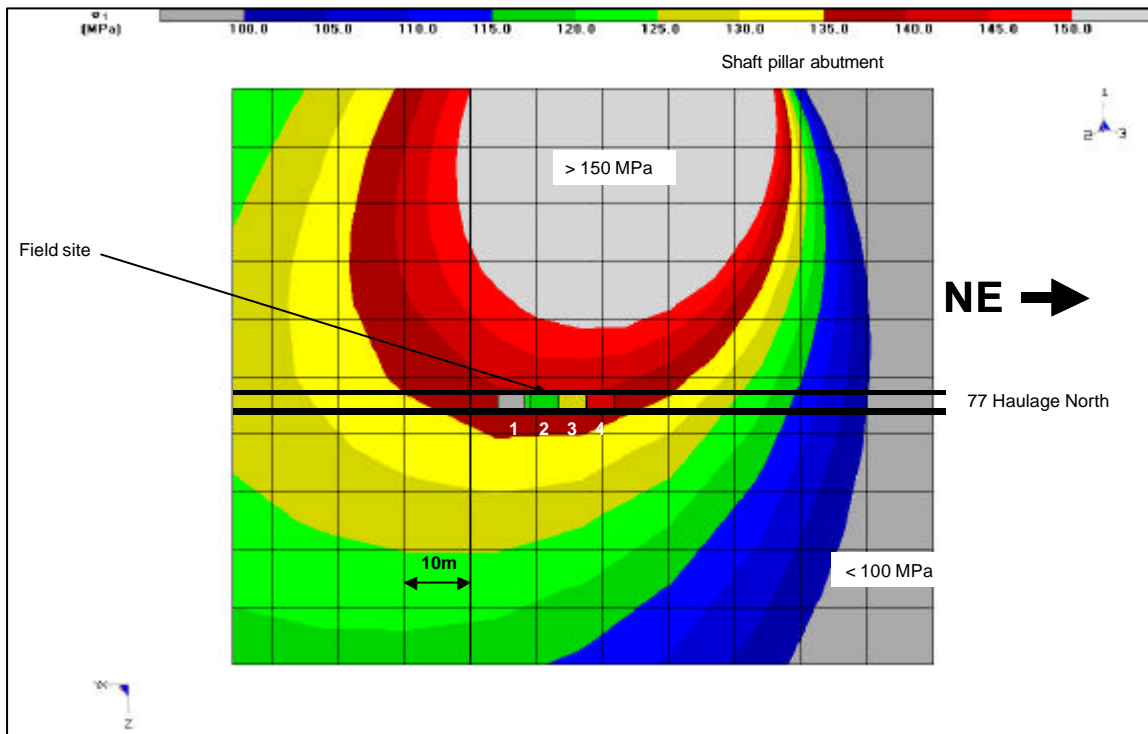


Figure 9: Vertical section showing major principal stress (s_1) in 12/2000.

The field test site is situated in a zone where σ_1 ranges from 140 MPa to 145MPa. The change in stress with mining between December 2000 and February 2001 is indicated in Figure 10.

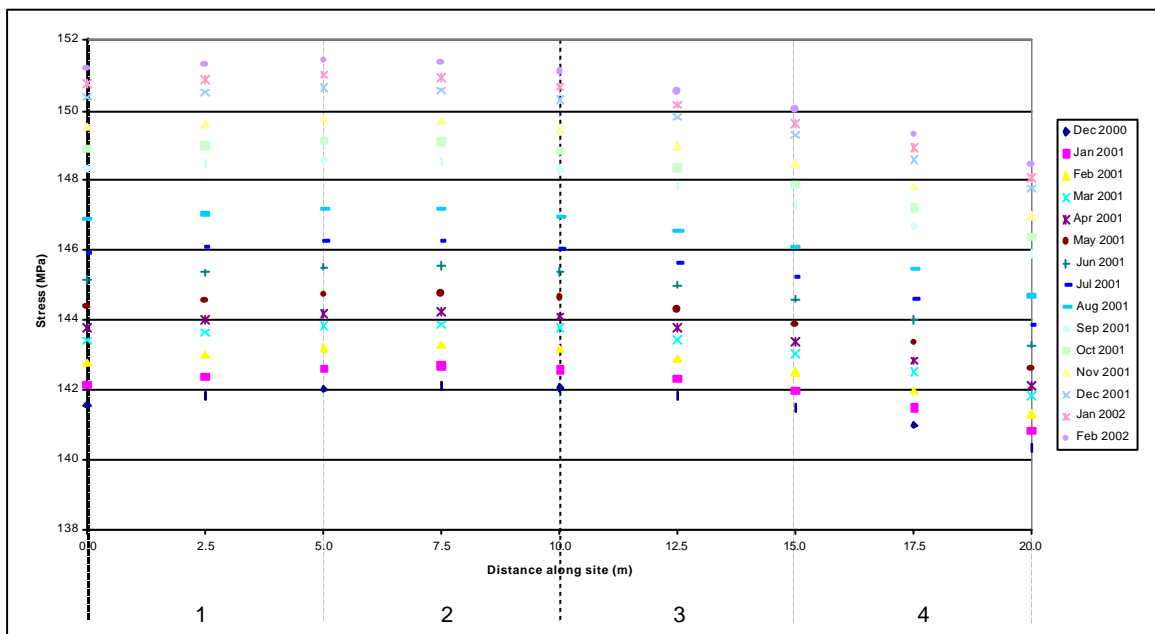


Figure 10: Major principal stress at points along test site from 12/2000 – 02/ 2002.

Stresses were calculated at points along the field test site at 2.5m intervals, representing the boundaries and centres of the test sections. The average increase in stress at the field test site between December 2000 and February 2002 was 8.9 MPa.

Modelling of the mining sequences for the two-year plan, from June 2001, was carried out and the model is represented in Figure 11. The results of this modelling are indicated in Figure 12. The average increase in stress between June 2001 and March 2002 is 6.6 MPa and between June 2001 and March 2003 is 10.9 MPa.

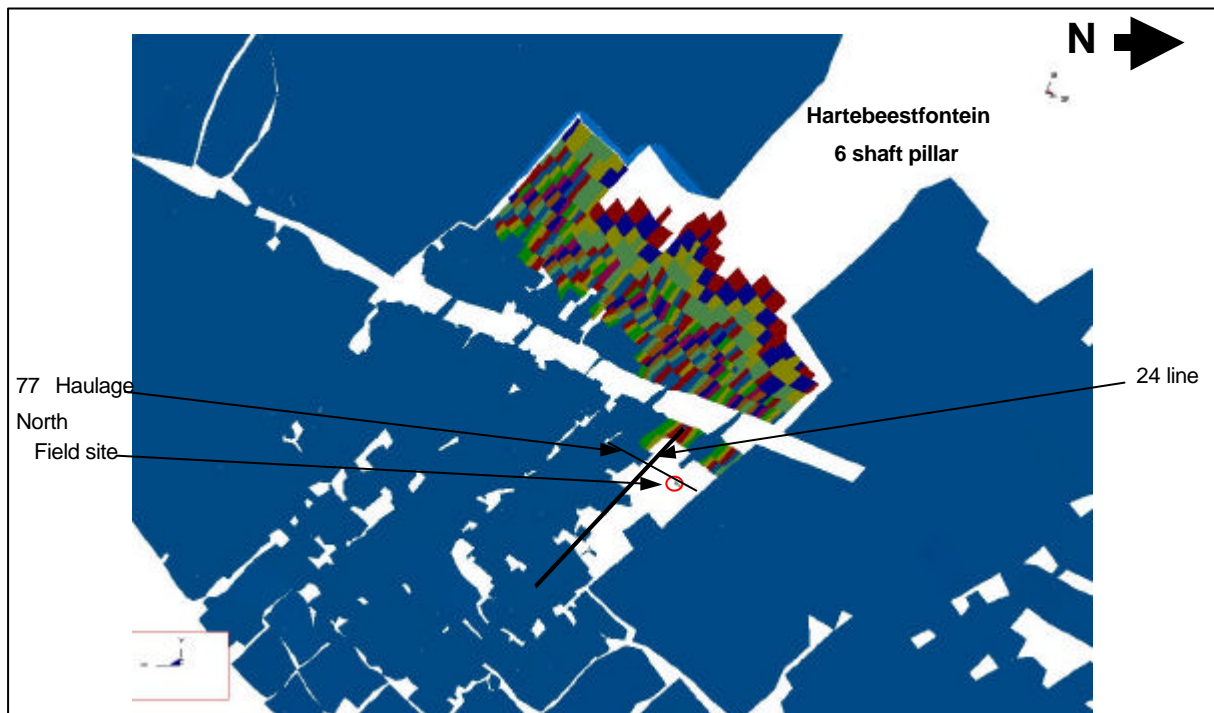


Figure 11: Projected two-year mine plan (June 2001 to June 2003).

Although the field stress in which the field test site is situated is very high (>140MPa) the change in stress is not significant. It is expected that there will be deformation, but that these deformations will take place slowly and will not be as large as originally anticipated.

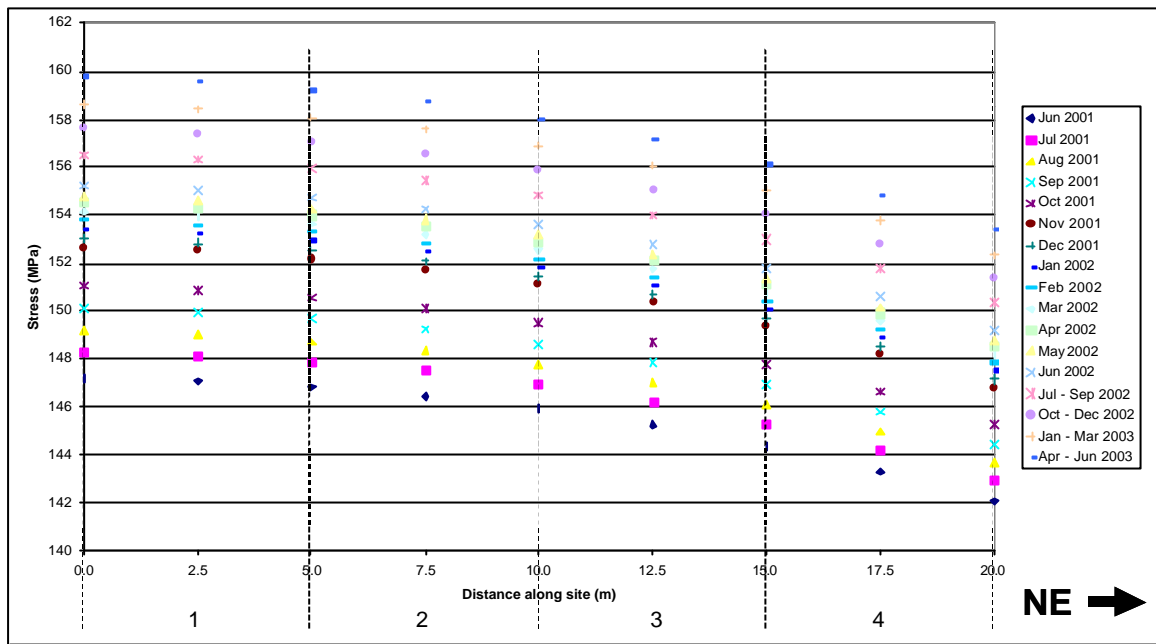


Figure 12: Major principal stress at points along test site from 06/2001 –06/2003)

3.4 Installed support

Primary support comprises rockstuds installed in a 1.0m square pattern. Smooth bars are installed as part of the secondary support in a 1.0m pattern. Wire mesh (3.0mm thickness, 50mm aperture) and lacing (12-15mm diameter de-stranded hoist rope) were installed as containment support. Grouted cable anchors are installed in a 2.0m pattern.

4 Site establishment

In preparation for the application of shotcrete, the mesh was removed over a 20m length of tunnel, while leaving the lacing intact. Shotcrete was spayed to a minimum thickness of 75mm over this 20m length of tunnel. The field test site is composed of four test sections, each 5.0m long. Three of the four sections have ordinary sand aggregate and the fourth has a tailings aggregate. The test section with classified tailings aggregate was not part of the original experiment but was included to investigate the possibility of using classified tailings as a shotcrete aggregate. If the use of tailings as aggregate proves to be successful, this could reduce the logistics involved in transporting material underground considerably. On mines using backfill, it would be possible to tap into existing backfill ranges to require aggregate material, thus eliminating the logistic problem normally associated with transporting bagged material.

Figure 2 shows the layout of the site with the four sections, indicating the type of reinforced shotcrete used.

4.1 Shotcrete materials and mix design

The design mix is that used previously by the shotcrete working group (Kirsten 1993).

River sand	78%
Ordinary Portland Cement (OPC)	16.3%
Unclassified fly ash (pozzfil)	4.3%
Condensed silica fume (CSF 90)	1.3%
GDS-3 powder additive	0.1%

The river sand complied with the SABS 1083:1994. Samples were tested and this is discussed in Section 5.1.1. Moisture is retained in the sand (5%) and the GDS-3 additive allows agglomeration of fines and coarse while pumping. The sand, fly ash, silica fume, GDS-3 additive and fibre (where required) are pre-mixed and supplied in 30kg bags. Where tailings aggregate is used, the tailings replace the river sand in the mix. The aggregate mix is mixed with the OPC in the shotcreting machine using a screw feed process. OPC and the aggregate mix are fed through separate primary augers onto the main auger, which feeds the rotary pump. The shotcreting machine is shown in Figure 13.

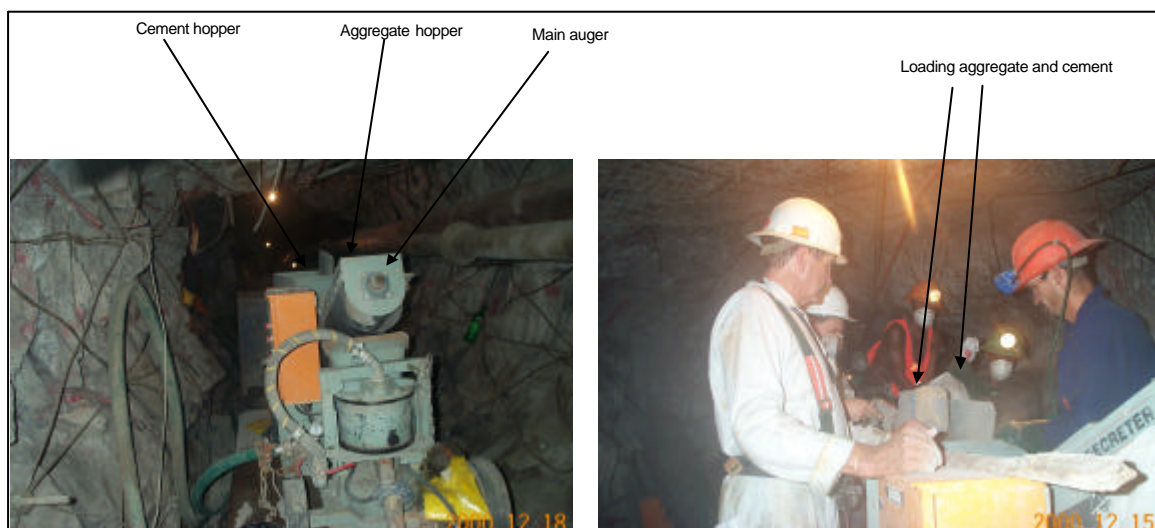


Figure 13: Shotcreting machine

Adjusting the feed rates of the two primary augers sets the proportions of OPC and aggregate mix. The required and achieved portions of aggregate mix and OPC are given below:

Table 2: Proportions of aggregate and OPC

	Aggregate mix	OPC
Required	83.7%	16.3%
Achieved	82.5%	17.5%

Shotcrete with 2% (by mass) Dramix steel fibre was sprayed in the steel fibre reinforced test section (test section 1). Dramix fibres are made of cold-drawn carbon wire with a minimum tensile strength of 1 200 N/mm². They represent thin smooth lengths of wire with kinked ends.

In test sections 2 and 3, 0.5% (by mass) RX polypropylene fibre was added to the mix.

4.2 Quantities

Due to the deformation that had already taken place, the rock surface was uneven with many cavities. In addition compressed air and water pipes are suspended along the North sidewall, which would make spraying very difficult. For these conditions, the contractor recommended 8 bags of aggregate mix per square metre. This translates to 297kg/m² of dry shotcrete material. For an ideal surface only 180kg/m³ of dry shotcrete material would be required. Approximately 40% of this material would be used to fill cavities or would be lost in rebound. For the mesh reinforced section additional shotcrete would be required to cover the mesh and 450 bags of aggregate mix were ordered.

In practice only 7 bags of aggregate mix per square metre were required for the test sections 1, 2 and 3 while 10 bags/m² were used for section 4. This was due to the requirement to adequately cover the mesh. In many areas the mesh was further than 200mm from the rock.

4.3 Shotcrete application

Spraying of the shotcrete commenced on the 13/12/2000. Several difficulties were experienced on the first day, with the result that very little spraying was carried out. These difficulties included typical logistical and preparation problems, high water pressure causing bursting and unclamping of hoses, and a significant blockage. It was also established that the shotcrete machine was feeding incorrect ratios of cement and aggregate, which needed to be rectified before continuing with spraying. Spraying on the second day (14/12/2000) was more successful, with most of the problems being resolved. The mix ratios were corrected at the start of the shift and tested during the course of the day. The ratios given in Section 4.2 were achieved and were maintained for the duration of spraying. Spraying continued until the 19/12/2000 when it was required to break for Christmas. The test site was completed on the 04/01/2001.

Spraying of the steel fibre reinforced shotcrete proved difficult. The steel fibres tend to accumulate at the base of the feeder unit and are then discharged into the rotary valve in a bundle and block the outlet into the spraying hose. These blockages occur frequently and need to be cleared before spraying can continue. The steel fibres wear out the wear pads rapidly, which seal the rotary valve. High levels of dust are experienced due to the excessive wear and the wear pads need to be replaced more frequently.

Preparation of the mesh reinforced test section (4) was a little more involved. The original mesh was removed, as it would have been difficult to spray through the 50mm apertures. The mine insisted that the lacing be left intact, as removal of the lacing would have resulted in extensive re-drilling and re-supporting. 100mm aperture mesh was therefore used and was attached to the outside of the lacing. Prior to attaching the mesh, shotcrete was sprayed to fill the cavities. Wire was attached to the lacing before spraying to fasten the mesh to the lacing. Due to the undulating rock surface and the application of mesh over the lacing, it was difficult to bring the mesh close enough to the initial shotcrete layer. A "Hilti" gun was then used to pin the mesh into the set shotcrete. Shotcrete was then sprayed over the mesh to cover it satisfactorily.

This process is shown in Figure 14. In some areas the mesh could not be pinned to the shotcrete and the mesh could not be covered with shotcrete (Figure 15). This represented only a small portion of the total surface area. Considerably more material was used for the mesh reinforced shotcrete application.



Figure 14: Application of mesh reinforced shotcrete.

Figure 14 illustrates the application process of the mesh reinforced shotcrete [a) wire attached to rope lacing before spraying. b) attaching mesh to wires after spraying. c) mesh not flush with shotcrete due to undulating rock surface. d) pinning of mesh to shotcrete using a Hilti gun.



Figure 15: Areas where mesh could not be pinned to the shotcrete.

Figure 15 shows the areas that could not be pinned and shotcreted [a) prior to final spraying. b) after final spraying].

4.4 Final preparation

After the shotcrete had been applied successfully to all four sections, the field test site was prepared for closure measurements and photographing of crack development. Figures 16 to 19 show profiles of each test section after the site had been established.



Figure 16: Profiles of section 1.

Profiles of section 1 - Steel fibre reinforced shotcrete [Left: looking North East. Right: looking South West] (figure 16).

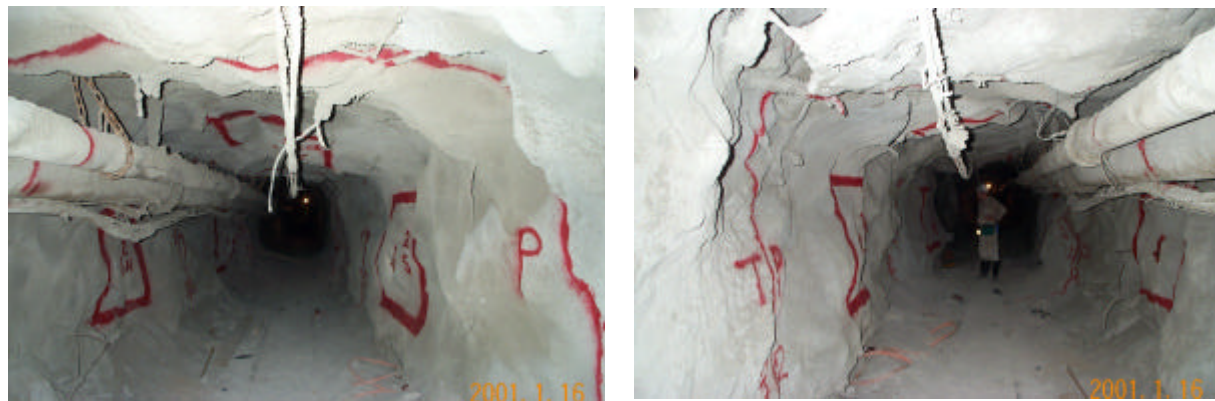


Figure 17: Profiles of section 2.

Profiles of section 2 - Polypropylene fibre reinforced shotcrete, [Left: looking North East. Right: looking South West] (Figure 17).

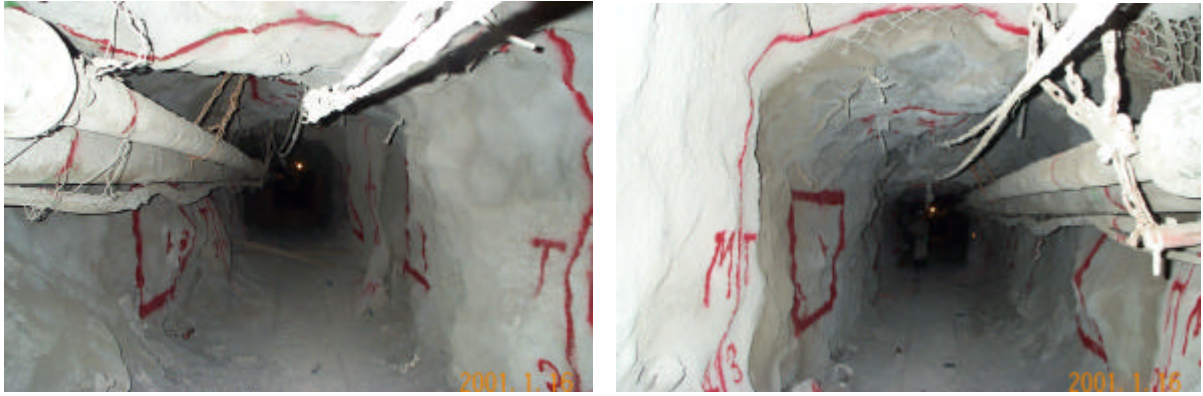


Figure 18: Profiles of section 3.

Profiles of section 3 - Tailings aggregate polypropylene fibre reinforced shotcrete [Left: looking North East. Right: looking South West] (figure 18).

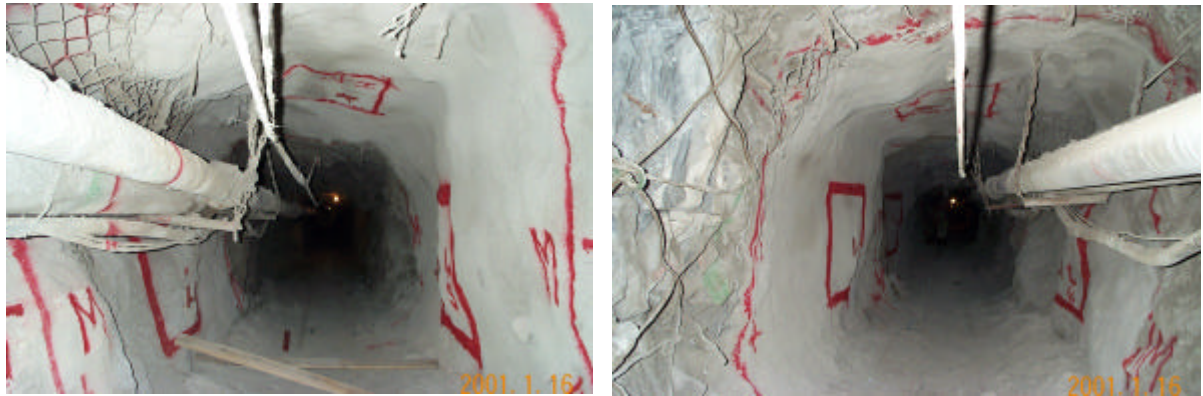


Figure 19: Profiles of section 4.

Profiles of Section 4 - Mesh reinforced shotcrete [Left: looking North East. Right: looking South West] (figure 19).

The boundaries of each test section were painted in and each section was numbered. A 1.0m square panel was painted on the centre of the hangingwall and sidewalls of each test section and marked accordingly (Figures 20 to 23). Photographs of the panels could then be taken at intervals to monitor crack development. A measuring bracket was mounted in each panel for laser distomat closure measurements. These brackets were positioned to ensure that the pipes did not interrupt the line of sight between brackets as detailed in Appendix G.

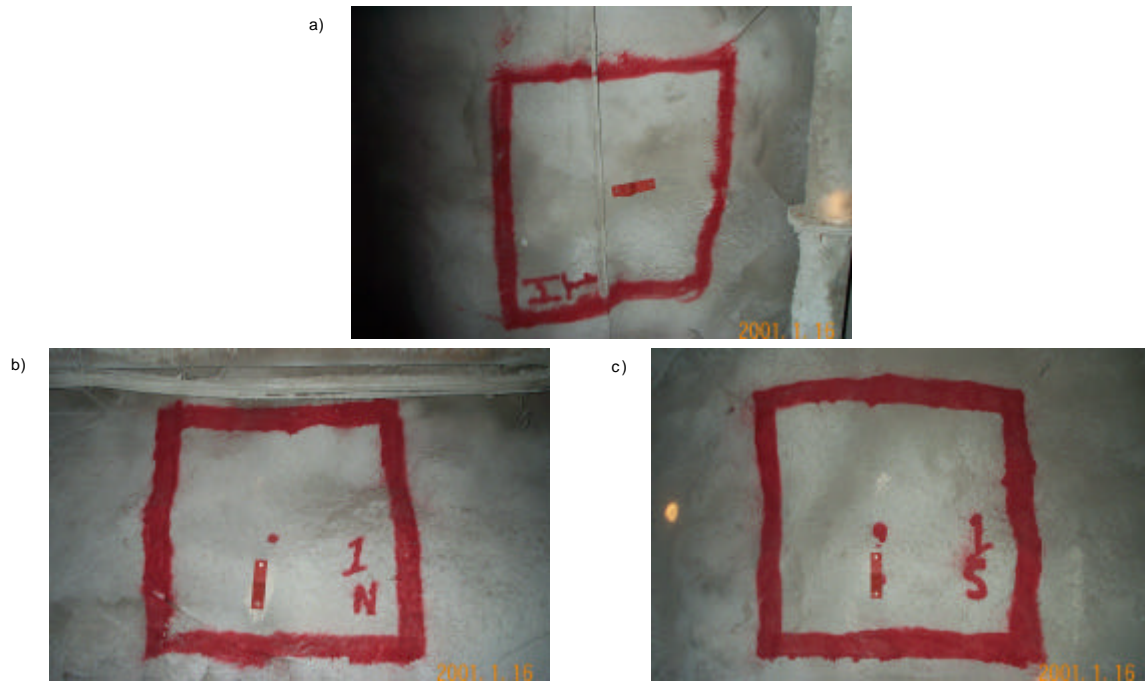


Figure 20: Panels for Section 1.

Figure 20 shows the section 1 panels - Steel fibre reinforced shotcrete [a) Hangingwall b) North West sidewall c) South East sidewall]

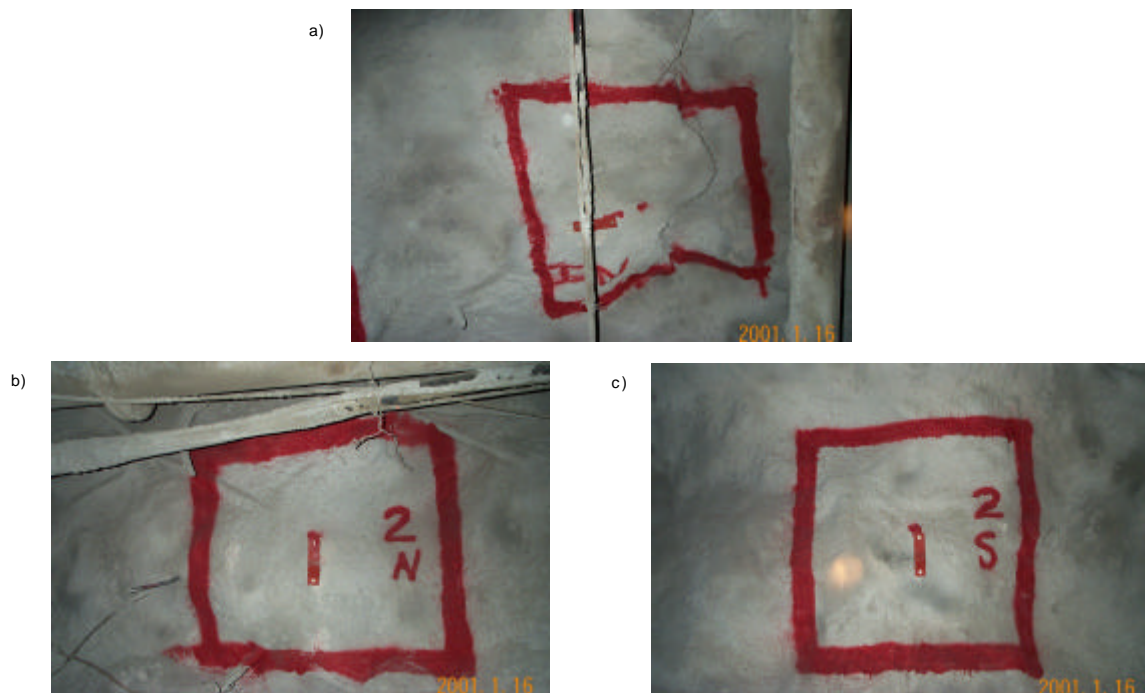


Figure 21: Panels for Section 2.

Panels for Section 2 – Polypropylene fibre reinforced shotcrete [a) Hangingwall b) North West sidewall c) South East sidewall] (figure 21).

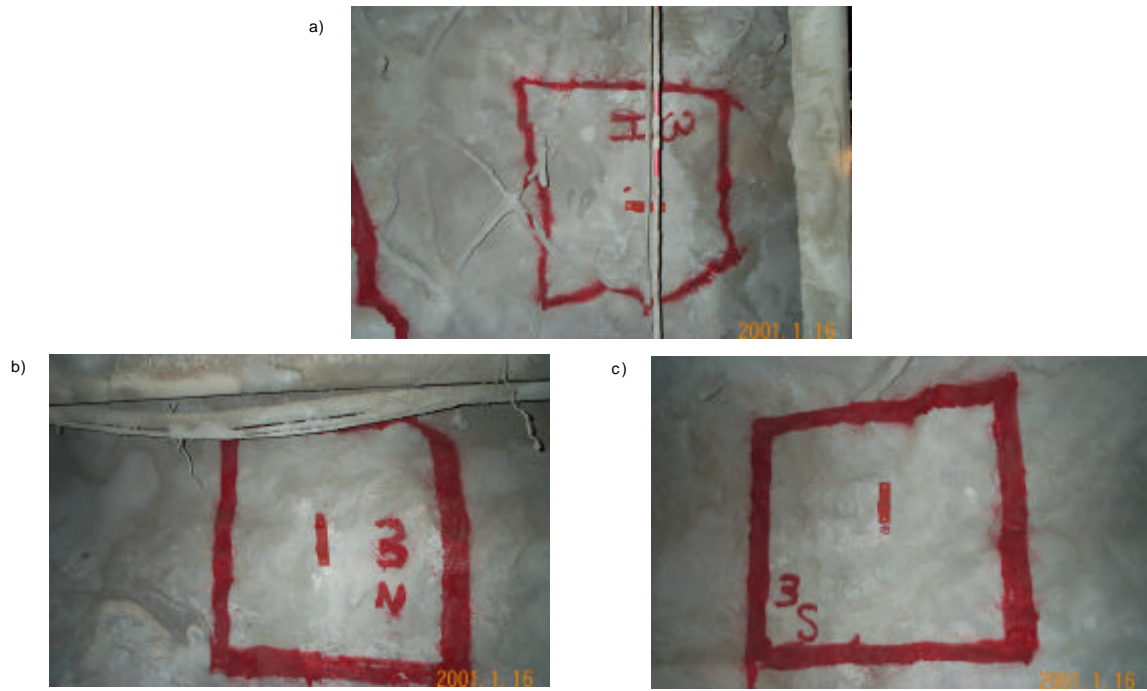


Figure 22: Panels for section 3.

Panels for section 3 - Tailings aggregate polypropylene fibre reinforced shotcrete [a) Hangingwall b) North West sidewall c) South East sidewall] (figure 22).

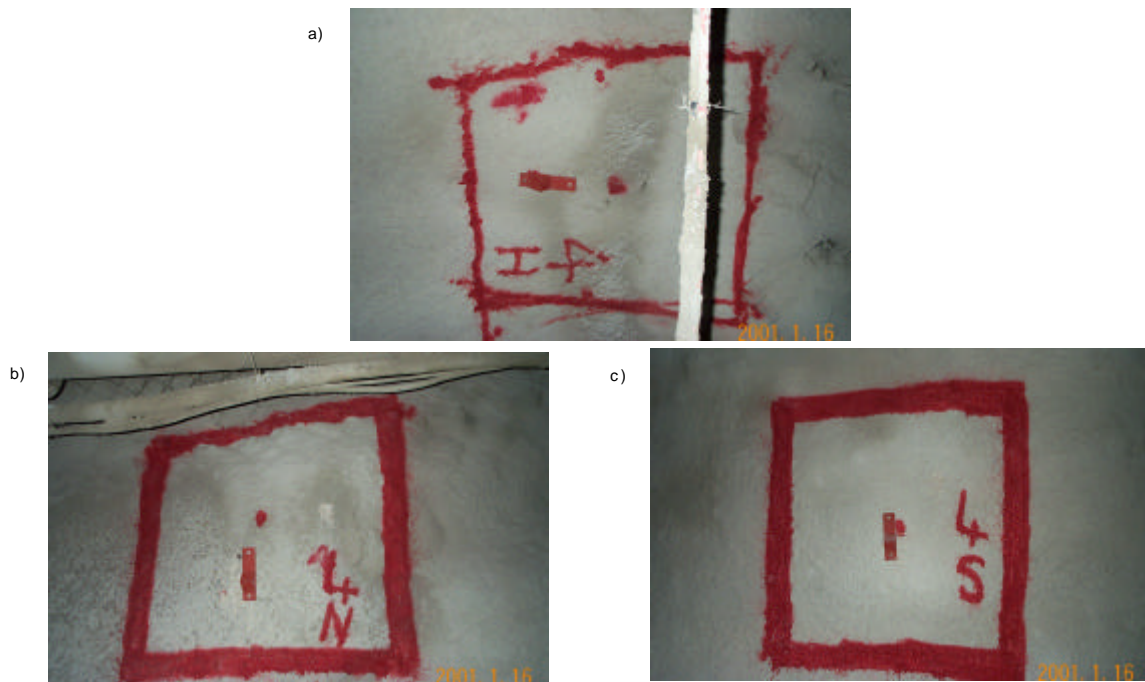


Figure 23: Panels for section 4.

Panels for Section 4 – Mesh reinforced shotcrete [a) Hangingwall b) North West sidewall c) South East sidewall] (figure 23).

5 Quality control and testing

The quality control involved procedures that were carried out during spraying and after the 28 day curing period. During the spraying the minimum thickness was controlled with a measuring tool that is pressed into the wet shotcrete before it has set. This was done by randomly testing, approximately every square metre.

Particle size grading was carried out on sample bags of aggregate to determine their compliance with SABS 1083:1994.

For each test site a core tray and two EFNARC trays were sprayed. These were left to cure at the field test site for approximately 21 days, after which time they were removed for testing at 28 days. Six cores were drilled from each core tray to carry out three Uniaxial Compressive Strength (UCS) tests and three tensile splitting tests. Fibre content and orientation was determined for each core. Two tests were carried out according to EFNARC specifications for test sections 1 to 3 (figures E1 to E6, Appendix E). No EFNARC tests were carried out for test section 4 (mesh reinforced shotcrete).

After 28 days, three cores were drilled from the sidewalls in each test section to carry out UCS tests. The thickness and quality of bonding was assessed from the cores and boreholes.

The results of all laboratory testing are contained in Appendix E.

5.1 Material characteristics

Two 30kg bags of each of normal aggregate (test section 4), normal aggregate + steel fibre (test section 1) and tailings aggregate + polypropylene fibre (test section 3) were analysed to determine the particle grading (SABS Method 829). Unfortunately after completing shotcrete

application, no bags of normal aggregate + polypropylene fibre (test section 2) could be found.

5.1.1 Particle size grading

The normal aggregate (test section 4) and normal aggregate + steel fibre (test section 1) complied with the grading requirements of river sand as per SABS 1083:1994, with the exception of < 0.075mm particles. The tailings aggregate sample (test section 3) does not comply with the grading envelope SABS 1083:1994. The material has excessive fines and too little course aggregate.

5.1.2 Fibre quantities and orientations

The fibre quantities were determined from crushed core after UCS testing. The results are given in Table 3.

Table 3: Fibre content and orientation from core trays

Test Section	Expected fibre content (%)	Fibre content (%)	Fibre orientation
1	2.0	0.98	Perpendicular to direction of spray
2	0.5	0.12	Perpendicular to direction of spray
3	0.5	0.27	Perpendicular to direction of spray
4	0.0	0.42	Perpendicular to direction of spray

It is clear that more than 50% of the fibre is lost during spraying. It is important to note that some steel fibre was still in the shotcreting machine when the core tray for test section 4 was sprayed, as this was done immediately after completing test section 1. This indicates that the strength tests for test section 4 will not be representative.

The fibre contents results obtained by the Shotcrete Working Group (SWG) are given in table 4. The SWG results and laboratory results obtained during this project will be compared.

Table 4: Fibre content (after Keyter and Kirsten 2001)

Aggregate and fibre	Expected fibre content (%)	Fibre content (%)	Range	Number of samples
River sand + 40mm monofilament polypropylene fibre	0.5	0.30	0.15	7
River sand + 40mm monofilament polypropylene fibre	0.5	0.37	0.07	2
River sand + 40mm Dramix steel fibre	2.0	1.28	0.40	6
Platinum tailings + 40mm monofilament polypropylene fibre	0.5	0.41	0.00	1

The fibre contents were measured from core samples drilled in the sidewalls at each section underground. Table 5 shows a comparison between the expected and the measured fibre contents.

Table 5: Fibre content from core drilled from sidewalls

Test Section	Expected fibre content (%)	Fibre content (%)
1	2.0	2.08
2	0.5	0.27
3	0.5	0.29
4	0.0	0.00

There is a favourable comparison between the expected and measured fibre contents obtained during the project when compared to the SWG results. The only difference being the measured steel fibre content was higher than the expected in section 1, where Keyter and Kirsten recorded an expected decrease in percentage shown in table 4.

5.2 Performance characteristics

The performance characteristics were determined from energy absorption testing, compressive strength testing and tensile strength testing. These tests were conducted using core samples from sprayed trays as well as core samples drilled from the sidewalls at the

various sections at the underground site. The EFNARC panels were sprayed and left to cure at the field site before being transported to Geopractica Cc, where the energy absorption tests were conducted according to the EFNARC European Specification for Sprayed Concrete (1996).

5.2.1 Energy absorption

The results of the EFNARC tests are summarised in table 6. The tests were performed on panels sprayed and cured at the field site for 21 days. The EFNARC graphs are in Appendix E, figures E1 to E6.

Table 6: Energy absorption test results

Test section	Energy absorption (J)	ITASCA corrected Energy Absorption (J)	Average thickness (mm)	Density (kg/m ³)	Age (Days)
1	1085	967	111	2009	28
1	2141	1589	122	2034	28
2	557	385	126	1970	32
2	808	484	136	1984	28
3	978	597	134	2014	31
3	851	510	136	1981	31

The results of the energy absorption tests for the various fibres types and aggregate mix are somewhat higher but still compare favourable with those obtained by the SWG presented in table 7. The graphs of the EFNARC tests performed by the SWG are in Appendix E, figures E7 to E13.

Table 7: Energy absorption test results (After Keyter and Kirsten 2001)

Aggregate and fibre	Energy absorption (J)	Age (Days)
River sand + 40mm monofilament polypropylene fibre	331	28
River sand + 40mm monofilament polypropylene fibre	454	28
River sand + 40mm monofilament polypropylene fibre	956	28
River sand + 40mm Dramix steel fibre	1210	29
River sand + 40mm Dramix steel fibre	1004	29
River sand + 40mm Dramix steel fibre	1044	28
River sand + 40mm Dramix steel fibre	1312	28
Platinum tailings + 40mm monofilament polypropylene fibre	1015	28

5.2.2 Compressive strength

A Hilti diamond core drilling machine was used to extract 90mm diameter core from the test trays. The cores were cut with a masonry saw and capped with sulphur mortar and tested according to SABS Method 865.

Table 8: Compressive strength determined from core trays (Appendix E – Results 3.2)

Test section	Average UCS (MPa)	UCS Range (MPa)	Number of tests	Density (kg/m³)	Age (days)
1	27.5	0.3	3	2154	30
2	23.9	1.8	3	2130	34
3	19.9	4.3	3	2273	35
4	24.1	2.1	3	2207	34

Table 9 summarises the results from the SWG for comparison purposes.

Table 9: Compressive strength (after Keyter and Kirsten 2001)

Aggregate and fibre	Average UCS (MPa)	UCS Range (MPa)	Number of tests
River sand + 40mm monofilament polypropylene fibre	27.1	7.2	18
River sand + 40mm monofilament polypropylene fibre	35.6	7.4	3
River sand + 40mm Dramix steel fibre	27.5	3.0	6
Platinum tailings + 40mm monofilament polypropylene fibre	32.8	5.8	3

Geopratica Cc. conducted compressive strength tests, using the core samples drilled from each section at the underground field site. The results are summarised in table 10.

Table 10: Compressive strength determined from core extracted from sidewalls

Test section	Average UCS (MPa)	UCS Range (MPa)	Number of tests	Density (kg/m³)	Age (days)
1	21.0	8.0	2	2121	35
2	20.8	6.5	2	2106	52
3	20.7	8.0	3	2181	52
4	18.6	4.5	2	2139	35

5.2.3 Tensile strength

The Technical Services Department (TDS) of Lafarge Cement (Pty) Ltd, conducted the tensile splitting of the core samples. The results are summarised in table 11 and described in the test report in Appendix E.

Table 11: Tensile strength determined from core trays

Test section	Average Tensile strength (MPa)	Tensile strength Range (MPa)	Number of tests	Age (days)
1	2.99	0.78	3	35
2	2.34	1.10	3	39
3	2.15	0.78	3	40
4	2.02	0.55	3	39

The summarised results of the SWG have been included in table 12 for comparative purposes.

Table 12: Tensile strength (After Keyter and Kirsten 2001)

Aggregate and fibre	Average Tensile strength (MPa)	Tensile strength Range (MPa)	Number of tests
River sand + 40mm monofilament polypropylene fibre	2.23	0.97	18
River sand + 40mm monofilament polypropylene fibre	2.83	0.60	3
River sand + 40mm Dramix steel fibre	2.65	0.50	6
Platinum tailings + 40mm monofilament polypropylene fibre	3.13	0.60	3

5.3 Thickness and bonding

Three cores were extracted from the sidewalls of each of the four sections. It was not possible to extract core from the hangingwall as an electric diamond drill was used and the water used for drilling would enter the motor. An indication of the shotcrete thickness could be obtained from the core lengths and the bonding could be qualitatively assessed from observations Figure 24.

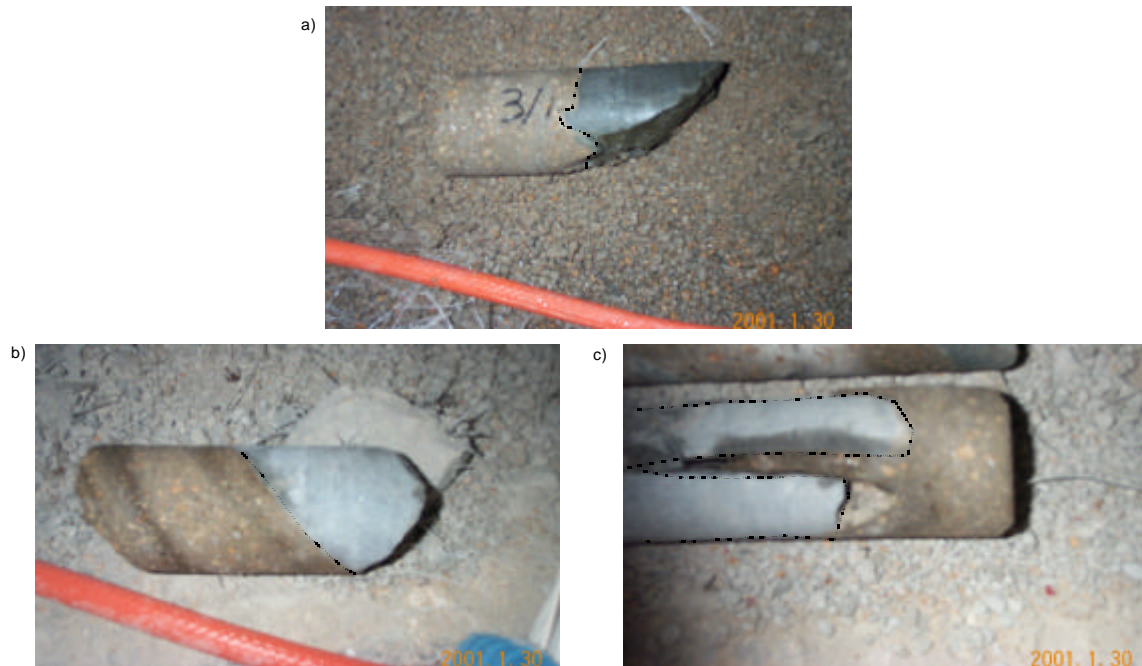


Figure 24: Examples of bonding of sprayed shotcrete.

Examples of good bonding and penetration (dotted line indicates contact between rock and shotcrete) [a) and b) bond remains intact after drilling. c) deep penetration into rock fractures] (figure 24).

5.3.1 Shotcrete thickness

The length of the shotcrete portion of the core was recorded to provide an indication of the shotcrete thickness for the different sections. It should be noted that due to the undulating nature of the rock surface the thickness is highly variable and in many cases was much greater than anticipated. Since the three cores in each section represent 30m² of sidewall, they only provide an indication of the variability in thickness.

Table 13: Shotcrete thickness

Section	Core 1 (mm)	Core 2 (mm)	Core 3 (mm)	Average (mm)
1	140	72.5	80	97.5
2	87.5	260*	120	155.8
3	145	180	120*	148.3
4	170	170	*	170

*Rock was not penetrated during drilling and therefore core length is greater.

5.3.2 Shotcrete bonding

In general the bonding between the shotcrete and the rock surface appeared to be good. Figure 24 shows examples where the bond remained intact after drilling. Figure 24c shows the penetration into rock fractures. Photographs of the boreholes and cores are given Appendix F.

6 Closure measurements

The closure at the test site was measured using a laser distomat and tape. In each test section, targets are mounted on the two sidewalls and the hangingwall (See Appendix G). The closure is measured by taking laser measurements between mounted targets. A vertical tape measurement is taken vertically from the hangingwall target to a string connecting the horizontal targets as a cross check. The error is about 5mm on laser measurements and about 15mm on tape measurements. Nineteen sets of measurements have been taken over a period of thirteen months. Closures are very small as the rate of deformation is slow. The maximum closure measured to date is 56mm, in section 4.

The closure measured in section 1 with steel fibre reinforced shotcrete had a maximum value of 47 mm. Most of the movement occurred in the horizontal direction, with a slight rate acceleration measured from the 12/07/2001.

Section 2 with polypropylene fibre reinforced shotcrete had a maximum closure of 27 mm.

Section 3 with polypropylene fibre reinforced shotcrete with tailings aggregate had a maximum closure measurement of 37 mm.

Section 4 mesh reinforced shotcrete experienced the maximum measured closure of 56 mm in the horizontal direction. The onset of the closure rate increase was identified during the routine measuring on the 12/07/2001.

The closure measurement results are given in Appendix G.

7 Crack mapping

Fracture mapping of the test site panels was conducted during the regular site visits. The cracking was highlighted using black paint and photographed for comparison purposes.

The following crack rating methodology was considered towards the end of the project as a means of quantifying the cracking of each test panel. This needs to be considered and perhaps modified for future monitoring of the test site.

Table 14: Crack rating

Crack width (mm)	Crack description	Number of cracks			Total crack length (m)		
		1	1 - 5	> 5	< 1.0	1.0 – 3.0	> 3.0m
< 1.0	Hairline crack		1			1	
1.0 – 2.0	Small						2
2.0 – 5.0	Medium						3
5.0 – 20.0	Large						4
> 20	Very large*			4			

*Very few fibres spanning crack

Table 15: Hazard rating

Crack rating	Hazard Rating	
	Sidewall	Hangingwall
1	E	D
2	D	C
3	C	B
4	B	A

A is the highest risk

Table 16: Hazard description and remedial action required

Hazard rating	Hazard description	Remedial action
A	Very high risk	Scaling and replacement of shotcrete
B	High risk	Monitoring and minor rehabilitation
C	Moderate risk	Regular monitoring
D	Minor risk	Infrequent monitoring
E	No risk	No action required

Section 4 with the mesh-reinforced shotcrete exhibited the most fracturing in the southern panel.

The photographic logging of the cracking of the test panels is given in Appendix H.

8 Conclusions

On completion of the project “Underground verification of the large deflection performance of fibre reinforced shotcrete subjected to high stresses and convergence and to dynamic loading” the following conclusions are made.

Initial progress on the project was protracted due to the lack of availability of suitable sites. Such sites are not part of standard mining practice and therefore only occur when circumstances require that the mining sequence be changed, resulting in unfavourable overtopping of tunnels.

The four test sites with the various reinforced shotcretes remained stable in the estimated field stress of 140 to 145 MPa with a stress change of 10.9 MPa.

The test sites were not subjected to extreme seismic episodes during the project period.

The mesh-reinforced shotcrete exhibited the maximum closure measurement of 56 mm and the highest crack density was observed in the southern panel of this section. The steel fibre

reinforced shotcrete exhibited the second highest measured closure of 47 mm with the least amount of cracking of all four sections.

From underground measurements and observations the steel fibre reinforced shotcrete performed better than the other reinforced shotcretes.

9 Recommendations for further research

The test site will be monitored every three months during 2002/2003 as per the original proposal.

With the change in the mine planning and the renewed mining in the area of the test site, it is recommended that this project be extended to include regular monthly measuring and photographing of the test site while this mining takes place.

The crack rating methodology be reviewed and implemented to quantify cracking of the shotcrete panels.

10 Acknowledgements

The authors wish to acknowledge the management of Hartebeestfontein Gold Mine (DRD) for making the site available and contributing significantly to the site establishment costs. In addition, the input of several contractors and suppliers must be acknowledged. Hector Snashall of Mash Engineering provided shotcrete aggregate mix and RX polypropylene fibres at cost. Dramix steel fibre was provided at no cost by Andre Erasmus of Bekaert South Africa. Richard Boresjzo of South African Mining and Engineering and Hector Snashall of Mash Engineering were contracted at much reduced cost for shotcrete application. Testing was carried out by Lafarge and Geopractica. OHMS, who are contracted to provide rock engineering services to DRD, assisted with the identification of the site, establishment of the site and are contracted to take closure measurements and photograph the shotcrete panels at the site.

11 References

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Appendix A

DEPARTMENT OF MINERALS AND ENERGY

PROPOSAL FOR A PROJECT TO BE FUNDED IN TERMS OF THE MINERALS ACT

- CONFIDENTIAL -

DME REFERENCE NUMBER

(FOR OFFICE USE ONLY)

1. PROJECT SUMMARY: SIMRAC GAP 710

PROJECT TITLE: Underground verification of the large deflection performance of fibre reinforced shotcrete subjected to high stresses and convergence and to dynamic loading

PROJECT LEADER: Dr H.A.D. Kirsten

ORGANIZATION: SRK Consulting

ADDRESS: P O Box 55291, NORTHLANDS, 2116

TELEPHONE: 011 441 1111

FAXSIMILE: 011 880 8086

TELEX:

PRIMARY OUTPUT¹:

An evaluation of the relative effectiveness of steel and polypropylene fibre reinforced shotcrete compared to mesh reinforced shotcrete in tunnels subject to high stresses and convergence and possibly, to dynamic loading.

HOW USED?²:

- a) As initial safety support immediately behind the blasted face as a single stage application of fibre reinforced shotcrete.
- b) As both temporary and permanent support in tunnels subject to high stresses and convergence.
- c) As a means of repair of damage in highly stressed tunnels as a single stage application of fibre reinforced shotcrete.

This will allow mesh reinforced shotcrete that requires more than one stage of installation, to be replaced by one operation which has immediate safety benefits.

BY WHOM?³:

The mining industry at large and more specifically, the deep gold mining industry in South Africa

CRITERIA FOR USE⁴:

When large tunnel convergence is expected due to static or dynamic loading that would require adequate support to prevent excessive deformation or total collapse of the tunnel. Alternatively when installation of thin fibre reinforced shotcrete is required up to the face as an initial protective measure for the subsequent safe installation of the full complement of support.

POTENTIAL IMPACT⁵:

By increasing the rate of installation of primary support in highly stressed tunnels through single stage application of the primary support, the exposure of personnel to an unsupported tunnel will be greatly reduced. This will have an associated increase in health and safety in the working environment at the face of the tunnel.

FUNDING REQUIREMENTS (R 000s)	YEAR 1	YEAR 2	YEAR 3
TOTAL PROJECT COST	780	82	-
TOTAL SUPPORT REQUESTED FROM SIMRAC	780	82	-

DURATION FROM: April 2000 **TO:** March 2001[§].

Note: § with in-frequent monitoring at 3 monthly intervals up to March 2002.

SIMRAC	SUB-	AU/PT	X	COAL		OTHER		GENERIC
COMMITTEE:								

2. PROJECT DETAILS

2.1 PRIMARY OUTPUT¹

An evaluation of the relative effectiveness of steel and polypropylene fibre reinforced shotcrete compared to mesh reinforced shotcrete in tunnels subject to high stresses and convergence and possibly, to dynamic loading. The following primary outputs in particular, will be achieved:

- a) A direct comparison of the *in situ* performance of mesh reinforced shotcrete with that of steel and polypropylene fibre reinforced shotcrete.
- b) Confirmation that the performance of fibre reinforced shotcrete matches the performance of mesh reinforced shotcrete under large deformation.
- c) A comparative basis for theoretical analysis of the performance of different types of fibre reinforced shotcrete.
- d) A comparative basis for theoretical analysis of the performance of fibre reinforced shotcrete of various thicknesses.

2.2 OTHER OUTPUTS (deliverables)⁶

- a) Photographic records of all the project phases.
- b) A final report on the *in situ* performance of steel and polypropylene fibre reinforced shotcrete compared with that of mesh reinforced shotcrete.
- c) A qualitative analysis of the corrosive effects of the underground environment on steel fibre reinforced shotcrete.

2.3 **ENABLING OUTPUTS**⁷

NO.	ENABLING OUTPUT	MILE- STONE DATE	MAN DAYS
1.	Project initiation and the establishment of cooperation with an appropriate deep gold mine partner.	Month 1	15
2.	Identification of suitable experimental field site/s.	Month 2	15
3.	Completion of negotiations with shotcreting Contractor.	Months 2	10
4.	Establishment of experimental field site/s and monitoring of shotcrete applications.	Month 4	100
5.	Preparation of a report on the different shotcrete applications at the experimental field site/s.	Month 5	20
6.	Regular monitoring of experimental field site/s.	Month 12	60
7.	Final review of data.	Month 12	25
8.	Preparation of a final report.	Month 12	30
9.	In-frequent monitoring at 3 monthly intervals.	Month 24	20
10.	Update/addendum to final report.	Month 24	7
TOTAL MAN DAYS			302

2.4 **METHODOLOGY**³

The nature of this project requires that various types of shotcrete be applied to a tunnel and that the performance thereof under extensive deformation be monitored over a period of time. In order to achieve this, one of the most critical tasks will be to obtain appropriate experimental field sites. Finding the best sites is of utmost importance to limit the duration of the project. The sites will need to be subjected to high mining induced stress increases and associated convergences shortly after application of the shotcrete so that the observations of performance can be completed in the two year time frame proposed. Full co-operation from the mine will be required. The proposed funding is based on the assumption that the mines will not contribute directly to the costs of the project. Any materials and/or labour that the mines may be willing to provide will substantially reduce the funding required from SIMRAC.

NO. OF ENABLING OUTPUT	STEP NO.	METHODOLOGY TO BE USED TO ACCOMPLISH THE ENABLING OUTPUT (INDICATE STEPS/ACTIVITIES)
1	1	Project initiation.
	2	Initial liaison with appropriate deep gold mine partner.
	3	Initial identification of a suitable experimental field site/s
	4	Define respective responsibilities of SRK Consulting and deep gold mine partner.
	5	Draft contractual agreement between SRK Consulting and deep gold mine partner.
2	1	Final selection of a suitable experimental field site/s.
	2	Design of experimental field site/s: - layout, - instrumentation, and - logistics.
3	1	Obtain suitable contractor for supplying shotcrete materials.
	2	Obtain suitable contractor for application of shotcrete.
4	1	Initial inspection of experimental field site/s selected: - geology and geological structures and fracturing, - geometry, - access, and - photographing experimental field site/s before application of shotcrete.
	2	Setting out experimental field site/s: - location of instrumentation, and - location and extent of experimental sections.
	3	Installation of extensometers.
	4	Application of shotcrete by shotcreting contractor.
5	1	Monitoring of shotcrete applications.
	2	Installation of convergence measuring devices.
	3	Installation of rock bolts on predetermined spacing.
	4	Photographing experimental field site/s directly after support installation.

(continues)

6	1	Interpretation of data gathered during monitoring of shotcrete applications.
	2	Report on details of shotcrete applications.
7	1	Regular monitoring and photography of experimental field site/s.
8	1	Interpretation and presentation of monitoring data.
	2	Final review of monitoring data.
	3	Preparation of a final report.
	4	Preparation on a paper for publication.
	5	Presentation of results of study at a workshop.
9	1	In-frequent monitoring and photography of experimental field sites for another year after submission of the final report.
10	1	Review of additional data
	2	Preparation of an updated report/addendum to final report.

Key Facilities and Procedures to be used in the Project:

- a) Liaison with a deep gold mine to identify and establish a suitable experimental field site/s will be the most important factor in completing this project successfully.
- b) Expertise developed by SRK Consulting during the shotcrete development by the Shotcrete Working Group.
- c) Experience with dynamic testing of shotcrete support under SIMRAC GAP 220 and GAP 606
- d) Experience with rockbursts and the rockburst loading of rock support.

2.5 TECHNOLOGY TRANSFER

The technology used in applying the shotcrete as well as the results of the study will be transferred to industry as follows:

- a) through presentations to the mining and rock engineering personnel on the mine,
- b) by means of demonstrations during application of the shotcrete,
- c) through presentation of the results obtained in the study,
- d) by compiling a report on the findings of the study that will be available through SIMRAC, and
- e) by publishing a paper on the findings of the study.

3. FINANCIAL SUMMARY

3.1 FINANCIAL SUMMARY

	COST (R 000s)		
	YEAR 1	YEAR 2	YEAR 3
Project staff costs (from 3.2)	618	45	-
Other costs:			
Operating costs (from 3.3)	66	12	-
Capital & plant costs (from 3.4)	-	-	-
Sub-contracted work (from 3.5)	See note [#]	-	-
Presentations and Papers (from 3.6)	-	15	-
Value added tax*	96	10	-
TOTAL COST OF PROJECT	780	82	-
Less funding from other sources (from 3.6)	-	-	-
SUPPORT REQUESTED FROM SIMRAC	780	82	-

Note: * Only for VAT registered concerns

Note: # It is assumed that the deep gold mine partner will carry the cost of support installation since the mine will have to provide tunnel support anyway should this project not be approved. This budget as well as project performance is therefore subject to obtaining the mine's support in this regard. This aspect will be discussed during the initial negotiations with the deep gold mine partner.

3.2 PROJECT STAFF COSTS

NAME AND DESIGNATION	YEAR 1		YEAR 2		YEAR 3	
	MD	COSTS	MD	COSTS	MD	COSTS
Dr H.A.D. Kirsten – Project Manager	30	218	1	8	-	-
W.D. Ortlepp – Associate Consultant	34	165	1	5	-	-
G.J. Keyter – Geotechnical Engineer	68	150	9	22	-	-
J. Wesseloo – Geotechnical Engineer	15	22	-	-	-	-
B.S. Soffe – Technician	64	38	8	6	-	-
P.N. Moya – Technician	64	25	8	4	-	-
TOTAL (R 000s)	275	618	27	45	-	-

3.3 **OPERATING COSTS** (Running)

ACTIVITY/EQUIPMENT (Items above R10 000)	COST (R 000s)		
	YEAR 1	YEAR 2	YEAR 3
Travelling	23	5	-
Instrumentation (extensometers)	28	-	-
Instrumentation (convergence meters)	5	-	-
Photography	3	3	-
Photocopying and documentation	3	2	-
Communications	4	2	-
Other miscellaneous items	-	-	-
TOTAL	66	12	-

3.4 **CAPITAL AND PLANT COSTS**¹⁰

(i) ITEMS TO BE PURCHASED OR DEPRECIATED FOR MORE THAN R10 000 PER ITEM	COSTS (R 000s)		
	YEAR 1	YEAR 2	YEAR 3
None	-	-	-
Other miscellaneous items	-	-	-
<u>TOTAL</u>	-	-	-

(ii) ITEMS TO BE MANUFACTURED WITH ASSEMBLED COST OF MORE THAN R10 000 INCLUDING MATERIAL AND LABOUR	COST (R 000s)		
	YEAR 1	YEAR 2	YEAR 3
None	-	-	-
Other miscellaneous items	-	-	-
TOTAL	-	-	-
TOTAL (i) and (ii)	-	-	-

3.5 **SUB-CONTRACTED WORK**

		COST (R 000s)		
SUB-CONTRACTOR	ACTIVITY	YEAR 1	YEAR 2	YEAR 3
Material supplier	Supply of shotcrete and fibre	See note [#]	-	-
Shotcreting contractor	Apply shotcrete	See note [#]	-	-
TOTAL		See note [#]	-	-

Note: #

It is assumed that the deep gold mine partner will carry the cost of support installation since the mine will have to provide tunnel support anyway should this project not be approved. This budget as well as project performance is therefore subject to obtaining the mine's support in this regard. This aspect will be discussed during the initial negotiations with the deep gold mine partner.

3.6 **PRESENTATION AND PAPERS**

ACTIVITY	COST (R 000s)		
	YEAR 1	YEAR 2	YEAR 3
Presentation of a paper on the findings of the study	-	15	-
TOTAL	-	15	-

3.7 **OTHER FUNDING**

ORGANISATION	NATURE OF SUPPORT/COMMITMENT	AMOUNT (R 000s)
None	-	-

4. MOTIVATION

The general health and safety of personnel in the deep gold mining industry depends on the speed with which development ends can be advanced. Personnel safety and excavation stability require that the ends be mined and supported close to the face. The shotcrete that is used for this purpose must be installed as a single phase operation complete with reinforcement and must be able to withstand large deflections under static and dynamic loading. Diamond mesh reinforced shotcrete is installed in more than one phase and is therefore not suitable for this purpose. The only way to provide reinforced shotcrete in a single operation is to introduce fibre into the mixture and shoot it simultaneously with the aggregate.

The adequacy of fibre reinforced shotcrete under static loading is currently being investigated by means of full scale laboratory plate tests to large deformation under the auspices of an industrial Shotcrete Working Group under Chairmanship of SRK Consulting. The research is co-sponsored by the Department of Trade and Industry through their THRIP programme and made the establishment of a facility at RAU possible where fibre reinforced shotcrete panels can be sprayed and tested. In addition, the adequacy of fibre reinforced shotcrete under dynamic loading has been investigated by means of laboratory tests by SRK Consulting in SIMRAC Project GAP 221. The behaviour and performance of fibre reinforced shotcrete slabs of various thicknesses and with different bolt spacings under dynamic loading were further recently investigated by SRK Consulting in a DEEPMINE Project. Work by SRK Consulting on the effect of bonding of fibre reinforced shotcrete to the substrate is currently also under investigation for a mining company.

The various test series mentioned above confirmed the large deflection performance of fibre reinforced shotcrete on the assumption that fixed-ended panels subject to artificial loading in the laboratory represent the underground situation. Laboratory testing allows considerable variation of the important parameters and is clearly the first step in demonstrating the adequacy of fibre reinforced shotcrete. However, the performance of fibre reinforced shotcrete applied under working conditions in a tunnel and subject to large mining induced deformation, will provide the final confirmation of its adequacy.

Unreinforced shotcrete is used in thin layers in many instances in mining tunnels to provide temporary safety and stability before substantial support is installed. It is often essential that a thin coat of shotcrete be applied as protection for the subsequent installation of other support components. Thin applications of shotcrete have been shown by experience to perform adequately at first, but in due course to fail and spall from the rock walls. Adding fibre reinforcement can extend the time to failure and will improve safety.

It is proposed that field trials be carried out to:

- confirm the performance of fibre reinforced shotcrete applied under working conditions in a tunnel subject to large mining induced deformation, and to
- confirm the effective reinforcement and consequent enhancement of the performance of thin applications of shotcrete.

Suitable tunnel sites that will in due course be overtopped will be identified. Successive lengths of these tunnels will be supported with various thicknesses of shotcrete reinforced with a range of fibre configurations. Provisional discussions have been held with mining groups in this regard from which it has been established that suitable sites could be found.

CONFIDENTIAL

5. CURRICULA VITAE OF PROJECT LEADER AND RESEARCH STAFF

5.1 **SUMMARY INFORMATION** No details of staffing of the project have been developed at this stage.

Project Leader

NAME & INITIALS: Dr H.A.D. KIRSTEN	AGE: 57 years
QUALIFICATIONS (e.g. degree/diploma, issuing institution and date):	See CV attached.
SPECIAL AWARDS:	See CV attached.

Principal Project Team Members

NAME & INITIALS: W.D. ORTLEPP	AGE: 67 years
QUALIFICATIONS (e.g. degree/diploma, issuing institution and date):	See CV attached.
SPECIAL AWARDS:	
<ul style="list-style-type: none">• Chamber of Mines Gold Medal and Research Scholarship (1952).• Salamon Prize (1995).	

NAME & INITIALS: G.J. KEYTER	AGE: 29
QUALIFICATIONS (e.g. degree/diploma, issuing institution and date):	See CV attached.
SPECIAL AWARDS:	See CV attached.

NAME & INITIALS: J. WESSELOO	AGE: 26
QUALIFICATIONS (e.g. degree/diploma, issuing institution and date):	See CV attached.
SPECIAL AWARDS:	See CV attached.

NAME & INITIALS: B.S. SOFFE	AGE: 60
QUALIFICATIONS (e.g. degree/diploma, issuing institution and date):	None.

SPECIAL AWARDS:

None.

NAME & INITIALS: P.N. MOYA

AGE: 29

QUALIFICATIONS (e.g. degree/diploma, issuing institution and date): None.

SPECIAL AWARDS:

None.

5.2 **RELEVANT EXPERIENCE AND PUBLICATIONS** (one page for each individual listed in 5.1)

NAME: DR H.A.D. KIRSTEN

RELEVANT EXPERIENCE:

- in depth experience in full-scale laboratory testing of representative shotcrete panels;
- founder and chairman of current industry Shotcrete Working Group on the development of fibre reinforced shotcrete for mining purposes;
- previously undertaken extensive testing programme on behalf of Premier Mine on the development of fibre reinforced shotcrete;
- in-depth experience in the development of design technology for bending, shear and thrust capacity of shotcrete sections reinforced with mesh or fibre;
- in-depth experience in the design of tunnel support comprising rockbolts, shotcrete, mesh and lacing in hard and squeezing rock conditions;
- in-depth experience in the development of classification systems for the empirical design of tunnel support; and
- in-depth experience in the use of empirical classification and rigorous numerical systems for the design of tunnel support.

RELEVANT PUBLICATIONS:

KIRSTEN, H A D. An analysis of forces and displacements in fixed arches. Trans S Africa Civ Eng, Vol 17, Part 1, pp 45 and 46, February 1975, Part II, pp 95 and 96, April 1975, Part III, pp 155 and 156, June 1975.

KIRSTEN, H A D. The combined Q/NATM system - the design and specification of primary tunnel support. South African Tunnelling, Volume 6, No 1, pp 18-24, 1983.

KIRSTEN, H A D AND LABRUM, P. Equivalence of fibre and mesh reinforcement in the shotcrete used in tunnel support systems. Jnl S Afr Inst Min Metall. Vol 90, No 7, pp 153 - 171, 1990. (Awarded SAIMM Silver Medal in 1990 and S A National Group of ISRM M.D.G. Salamon Prize 1991).

KIRSTEN, H A D AND BARTLETT, P J. Rigorously determined support characteristics and support design method for tunnels subject to squeezing conditions. Jnl S Afr Inst Min Metall, Vol 92, No 7, pp 195-214, 1992. (Awarded SAIMM Silver Medal in 1992).

KIRSTEN, H A D. Comparative efficiency and ultimate strength of mesh and fibre reinforced shotcrete determined from full scale bending tests. Jnl S Afr Inst Min Metall, Vol 92, No 11/12, pp 303-323, 1992.

KIRSTEN, H A D. Equivalence of mesh and fibre reinforced shotcrete at the large bending deflections found in mining excavations. Canadian Geotech Jnl, Vol 30, No 4, pp 418-440, 1993.

STACEY, T R, ORTLEPP, W D AND KIRSTEN, H A D. Energy absorbing capacity of

reinforced shotcrete, with reference to containment of rockburst damage. *Jnl S Afr Inst Min Metall*, Vol 95, No 3, pp 137-140, 1995.

HOWELL, C G AND KIRSTEN, H A D. Planning the measurement of structural shotcrete in the tunnelling environment: A case study. *Tuncon 95: Tunnelling Environments*, pp 75-80, November 1995.

KIRSTEN, H A D, ORTLEPP, W D AND STACEY, T R. Testing of fibre reinforced shotcrete for tunnel support. *Third Southern African Conference on Polymers in Concrete*, pp 125 - 132, July 1997.

KIRSTEN, H A D, ORTLEPP, W D AND STACEY, T R. Performance of fibre reinforced shotcrete subjected to large deformations. *Sares 97, 1st Southern African Rock Engineering Symposium: Implementing Rock Engineering Knowledge*, pp 1-7, September 1997.

KIRSTEN, H A D. Fibre - reinforced shotcrete. *World Tunnelling and Subsurface Excavation*, Vol. 10, No. 9, pp 411 - 414, 1997.

KIRSTEN, H A D. System ductility of long fibre reinforced shotcrete. *Jnl S Afr Inst Min Metall*, Vol. 98, No. 3, pp 93 -104, 1998.

KIRSTEN, H A D. Design criteria for shotcrete as support membrane. *South African Institute of Mining and Metallurgy School on Shotcrete and Its Application*, pp 1-15, 1998.

STACEY, T R, ORTLEPP, W D AND KIRSTEN, H A D. Practical static and dynamic tests of mesh, mesh/shotcrete and fibre reinforced shotcrete. *South African Institute of Mining and Metallurgy School on Shotcrete and Its Application*, pp 1-18, 1998.

KIRSTEN, H A D. Application of shotcrete in mining tunnels. *Inaugural Australian Shotcrete Conference, Sydney*, pp 1-12, 1998.

NAME: W.D. ORTLEPP**RELEVANT EXPERIENCE:**

- more than 30 years of experience in rock engineering;
- project leader on several SIMRAC projects involving testing of performance of various rock support elements, including GAP220, GAP 423 and GAP 611;
- involvement in a significant research project into the performance of backfill as stope support;
- participation in testing of rock support under simulated rockburst loading.

RELEVANT PUBLICATIONS:

ORTLEPP, WD and COOK, NGW. 1964. The measurement and analysis of the deformation around deep, hard rock excavations, Proc. 4th Int. Conf. On Strata Control in Rock Mechanics, New York.

ORTLEPP, WD. 1968. The mechanism of a rockburst, Proc. 19th U S Rock Mechanics Symposium, Reno.

COOK, NGW and ORTLEPP, WD. 1968. A yielding rockbolt, Bulletin Chamber of Mines of S. Afr., No 14, August 1968.

ORTLEPP, WD. 1969. An empirical determination of the effectiveness of rockbolt support under impulse loading, Proc. Int. Symp. on Large Permanent Underground Openings, Oslo, pp 9.

MULLER, SC and ORTLEPP, WD. 1972. Practical support techniques for minimizing falls of ground on a deep mine, E.R.P.M. Ltd, Ass. Min. Managers S. Afr., Papers and Discussions 1970-71, pp 101-112.

ORTLEPP, WD and STEELE, KE. 1973. Rockbursts, the nature of the problem and management countermeasures on E.R.P.M. Ltd, Ass. Min. Managers S. Afr., Papers and Discussions 1972-73, pp 225-278.

ORTLEPP, WD. 1983a. Chapter 4 in Rock Mechanics in Mining Practice, ed S Budavari, S.Afr. Inst. Min. Metall.

ORTLEPP, WD. 1983b. Chapter 12 in Rock Mechanics in Mining Practice, ed S Budavari, S.Afr. Inst. Min. Metall.

ORTLEPP, WD. 1983c. Considerations in the design of support for deep hard-rock tunnels, Proc. 5th Int. Cong. Int. Soc. Rock Mech., Melbourne, pp D179-D187.

ORTLEPP, WD. 1983d. The design of support for rockburst-prone tunnels, Proc. Symp. Rock Mechanics in the Design of Tunnels, S. Afr. National Group of ISRM, pp 69-78.

ORTLEPP, WD. 1984. Rockbursts in South African Gold Mines: A phenomenological view, Proc. 1st Int. Cong. on Rockbursts and Seismicity in Mines, ed N C Gay and E H Wainwright, S. Afr. Inst. Min. Metall., pp 165-178.

ORTLEPP, WD. 1992a. The design of support for the containment of rockburst damage in tunnels - an engineering approach, Proc. Int. Symp. on Rock Support in Mining and Underground Construction, Laurentian University, Sudbury, June 1992, pp 593-609.

ORTLEPP, WD. 1992b. Implosive-load testing of tunnel support, Proc. Symp. Rock Support in Mining and Underground Construction, ed Kaiser and McCreath, A.A.Balkema, Rotterdam, pp 675-682.

ORTLEPP, WD. 1993. High ground displacement velocities associated with rockburst damage, Rockbursts and Seismicity in Mines, ed R. Paul Young, A.A.Balkema, pp 101-106.

ORTLEPP, WD. 1994. Grouted rock-studs as rockburst support: a simple design approach and an effective test procedure, Jl S.Afr. Inst. Min. Metall., Vol 94, No 2, pp 47-63.

ORTLEPP, WD and STACEY, TR. 1994. Rockburst mechanisms in tunnels and shafts, Tunnelling and Underground Space Technology, v 9, no 1, pp 357-362. (Invited reprinting of paper no 61 above)

ORTLEPP, WD and STACEY, TR. 1994. The need for yielding support in rockburst conditions, and realistic testing of rockbolts, Proc. Int. Workshop on Applied Rockburst Research, Santiago, Chile, Sociedad Chilena de Geotecnia, SOCHIGE, pp 265-275.

STACEY, TR, ORTLEPP, WD and KIRSTEN, HAD. 1995. Energy absorbing capacity of reinforced shotcrete, with reference to containment of rockburst damage, J. S. Afr. Inst. Min. Metall., v 95, May-June, pp 137-140.

ORTLEPP, WD and STACEY, TR. 1996. The performance of rock containment support, such as wire mesh, under simulated

rockburst loading, Proc. Int. Conf. GEOMECHANICS 96, A A Balkema.

ORTLEPP, WD and STACEY, TR. 1996. Dynamic testing of tunnel support, Proc. SIMRAC Symp., S.Afr. Inst. Min. Metall.

STACEY, TR and ORTLEPP, WD. 1996. Performance of rockbolt and wire mesh tunnel support under dynamic loading, Proc. TUNCON 96, S. Afr. National Council on Tunnelling, pp 27-32.

ORTLEPP, WD and STACEY, TR. 1997. Towards total safety in tunnels subject to rockbursts through containment of energy, Proc. 27th Int. Conf. of Safety in Mines Research Institutes, New Delhi, India, ed B B Dhar and B C Bhowmick, Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, Vol II, pp 857-866.

ORTLEPP, WD and STACEY, TR. 1997. Containment of rockburst energy with appropriate tunnel support, Proc. Int. Symp. on Tunnel Support - Applied Solutions for Underground Structures, Lillehammer, Norway, Norwegian Society of Chartered Engineers, pp 609-620.

KIRSTEN, HAD, ORTLEPP, WD and STACEY, TR. 1997. Performance of fibre-reinforced shotcrete subjected to large deformations, Proc. 1st Southern African Regional Rock Engineering Symposium, SARES 97, S. Afr. National Group of Int. Soc. Rock Mech., pp 301-307.

ORTLEPP, WD and STACEY, TR. 1998. Performance of tunnel support under large deformation static and dynamic loading, Tunnelling and Underground Space Technology, v 13, no 1, pp 15-21.

DURRHEIM, RJ, ROBERTS, MKC, HAILE, AT, HAGAN, TO, JAGER, AJ, HANDLEY, MF, SPOTTISWOODE, SM and ORTLEPP, WD. 1998. Factors influencing the severity of rockburst damage in South African gold mines, Jl S. Afr. Inst. Min. Metall., v 98, pp 53-57.

ORTLEPP, WD, STACEY, TR and KIRSTEN, HAD. 1999. Containment support for large static and dynamic deformations in mines, Proc. Int. Symp. Rock Support and Reinforcement Practice in Mining, Kalgoorlie, Australia, March 1999, Balkema, pp 359-364.

STACEY, TR and ORTLEPP, WD. 1999. Retainment support for dynamic events in mines, Proc. Int. Symp. Rock Support and Reinforcement Practice in Mining, Kalgoorlie, Australia, March 1999, Balkema, pp 329-333.

STACEY, TR and ORTLEPP, WD. 1999. The performance of rockbolt support under simulated seismic loading, Proc. 28th Int. Conf. Safety In Mines Research Institutes, Sinaia, Rommania, Vol 1, pp 329-341

NAME: G.J. KEYTER

RELEVANT EXPERIENCE:

- has been involved in assessing the stability of underground excavations;
- has carried out joint surveys and rockmass characterisations in excavations in rock;
- has recently upgraded a method of stability analysis of excavations in jointed rock masses based on jointing occurrence;
- has participated in several projects in which the technique has been used to evaluate the stability (probability of occurrence of unstable volumes of a certain size, appropriate support spacings and lengths, etc.) of a shaft, and underground crusher chamber and orepasses;
- experienced in using probabilistic approaches to take variability of geotechnical properties into account;
- has been involved in static testing of fibre reinforced shotcrete panels and beams for the last 2 years; and
- is currently completing a PhD on the subject of the design of shotcrete linings as support in tunnels.

RELEVANT PUBLICATIONS:

NAME: J. WESSELOO

RELEVANT EXPERIENCE:

- has recently upgraded a method of stability analysis of excavations in jointed rock masses based on jointing occurrence;
- has participated in several projects in which the technique has been used to evaluate the stability (probability of occurrence of unstable volumes of a certain size, appropriate support spacings and lengths, etc.) of a shaft, and underground crusher chamber and orepasses; and
- experienced in using probabilistic approaches to take variability of geotechnical properties into account.

RELEVANT PUBLICATIONS:

NAME: B. SOFFE

RELEVANT EXPERIENCE:

- has been physically responsible for static and dynamic testing of rock support elements over a period of more than 5 years (GAP 220, GAP 423, Shotcrete Working Group funded research on fibre reinforced shotcrete panels, and other Deepmine and privately funded research testing).

RELEVANT PUBLICATIONS:

NAME: P.N. MOYA

RELEVANT EXPERIENCE:

- has physically assisted with static and dynamic testing of rock support elements over a period of more than 5 years (GAP 220, GAP 423, Shotcrete Working Group funded research on fibre reinforced shotcrete panels, and other Deepmine and privately funded research testing).

6. DECLARATION BY THE PROPOSING ORGANISATION

I, the undersigned, being duly authorized to sign this proposal, herewith declare that:

- The information given in this proposal is true and correct in every particular.
- This Organization has the basic expertise and facilities required for satisfactory completion of the project and will adhere to the program of activities as set out in this proposal.
- The costs quoted are in accordance with the normal practice of this Organization and can be substantiated by audit.

Signed on this **Wednesday, 27th of October 1999** for and behalf of **SRK Consulting.**

SIGNATURE: _____

NAME: DR T.R. STACEY

DESIGNATION: PRINCIPAL DIRECTOR

DEPARTMENT OF MINERALS AND ENERGY
DETAILED SIMRAC PROJECT PROGRESS REPORT

(ONE UNBOUND COPY REQUIRED)

1	PROJECT NUMBER	GAP 710
2	TITLE OF PROJECT	Underground verification of the large deflection performance of fibre reinforced shotcrete
3	PRIMARY OUTPUTs	An evaluation of the relative effectiveness of steel and polypropylene fibre reinforced shotcrete compared to mesh reinforced shotcrete in tunnels subject to high stresses and convergence and possibly to dynamic loading
4	PROJECT LEADER	W.C. Joughin
5	ORGANISATION	SRK Consulting
6	CONTRACT PERIOD	April 2000 to March 2001 with infrequent monitoring at 3 monthly intervals up to 2002
7	PERIOD OF REPORT	April 2000 to June 2001
8	DATE	31 June 2001

SUMMARY REPORT

Summary of project progress during period under review

The test site, composed of four 5m shotcreted sections, was established at Hartebeestfontein 6 shaft in January this year. Three of the sections have shotcrete with ordinary aggregate. These sections have different types of reinforcement: steel fibre, polypropylene fibre and wire mesh. The fourth section has tailings aggregate shotcrete, reinforced with polypropylene fibre shotcrete, which was installed at the sub contractors cost. It was planned to extend the site, with different thickness applications of shotcrete.

The site is located within the shaft pillar in the 77 level North haulage (2 336m below surface) near the 24 crosscut. It is near the shaft pillar abutment, approximately 70m in the footwall and the modelled major principal stress on the site is currently in excess of 140MPa. A model of the mining in the shaft pillar up till May 2001 is shown in Figure 1. At the time of establishing the site, the mine's proposed two year mine plan included the mining of the 77 24 raise and mining directly above the site would have commenced in July 2001. In February, SRK was informed that mining would be delayed due to difficulties in re-opening the 77 24 crosscut and this was reported in the March 2001 progress report. During May, the mine updated their two year plan and the 77 24 raise was excluded due to grade considerations. The 75 24 raise is planned to be mined and will be completed by November 2001, but this is not anticipated to cause significant stress changes at

the test site. It is anticipated that the stress will increase by about 1.0MPa per month until November and then by 05.MPa until the pillar extraction is completed. The 77 level North haulage is sited in the MB6 quartzite, which, at Hartebeestfontein, is characterised by bedding contacts with soft shale infill. Under these stress levels it is anticipated that closure will occur at a steady rate. At this stage the maximum closure is 33mm (Figure 7) with significant fracturing taking place in the shotcrete (Figure 11).

Deviations from the programme budget or schedule.

Deviations from the programme schedule have been discussed in the previous reports. Considering that it is no longer planned to mine over the test site, we believe that the extension of the test site is not justified. However we believe that monitoring of the test site as it is until March 2002 is justified.

One of the primary outputs of the project is a comparative basis for theoretical analysis of the performance of fibre reinforced shotcrete of various thicknesses. The extension of the site was intended to enable this objective to be achieved. As this will no longer be possible, we are suggesting that the project should continue with a reduced budget of R670 000. It would then be completed in March 2002.

The infrequent monitoring at 3 monthly intervals during the following year could be continued if the committee feels this is justified.

Detailed Progress Report

Progress is to be reviewed in terms of achieving the planned outputs in accordance with the project plan. Authors should therefore state each of those outputs below, as given in the accepted project proposal and indicate each completion date. Each output statement should then be followed by a concise description of progress during the reporting period, towards achieving the output. Any deviations from programme, budget or schedule summarised on the preceding page, should be elaborated upon here. (Use continuation sheets as necessary.)

Enabling Output No.	Contracted Completion Date	Statements of Output and Progress	Expected Completion Date
1.	30 April 2000	Project initiation and the establishment of cooperation with an appropriate deep gold mine partner: Completed. We have liased with 14 potential industry partners and identified 24 potential sites, which have been investigated for suitability.	30 November 2000
2.	31 May 2000	Identification of suitable experimental field site/s: Of the 24 sites investigated, one has been selected and established at Hartebeestfontein. The difficulties associated with the availability of suitable sites have been discussed in previous report.	31 January 2000
3.	31 May 2000	Completion of negotiations with shotcreting contractor: Completed	31 December 2000
4.	31 July 2000	Establishment of experimental field site/s and monitoring of shotcrete applications: A site has been established at Hartebeestfontein 6 shaft with four test sections. Three of the sections have ordinary aggregate, reinforced with steel fibre, polypropylene fibre and mesh. The fourth section has classified tailings aggregate with polypropylene fibre reinforcement.	11 January 2001
5.	31 August 2000	Preparation of a report on the different shotcrete applications at the experimental field site/s: Preparation of the report has commenced.	31 August 2001
6.	31 March 2001	Regular monitoring of experimental field site/s Monitoring of experimental field sites is in progress.	31 March 2001
7.	31 March 2001		31 March 2002
8.	31 March 2001		31 March 2002
9.	31 March 2002	Final review of data	31 March 2003
10.	31 March 2002	Preparation of a final report Infrequent monitoring at 3 monthly intervals Update / addendum to final report	31 March 2003

INTERIM RESULTS

Closure is measured using a laser distomat and tape. In each test section, targets are mounted on the two sidewalls and the hangingwall (See Figure 3). Laser measurements are taken between targets. A vertical tape measurement is taken vertically from the hangingwall target to a string connecting the horizontal targets as a cross check. The error is about 4mm on laser measurements and about 10mm on tape measurements. Fourteen measurements have been over a period of six months (Figures 4 to 7). At this stage closures are very small as the rate of deformation is slow. The maximum closure to date is 33mm, in section 4. The extent of cracking in the shotcrete and crack patterns is being monitored and recorded photographically (Figures 8 to 11). Cracks are marked with paint to be visible on the photographs. Several cracks are apparent in section 4 on the South sidewall (Figure 11).

PUBLICATIONS

No publications

SIMRAC Project GAP 710
Interim financial statement: 31 December 2000

Total contract amount for 2000 R 780 000

Income during 2000

29/07/2000	78 000
25/08/2000	117 000
25/01/2000	117 000
20/06/2001	117 000
Total Income	429 000

Expenditure up to end of March 2001

Project staff costs

Team member	Days	
HAD Kirsten	13	
TLE Gerritsen	6	
WC Joughin	57	
WD Ortlepp	1	
GJ Keyter	2	
N. Moya	6	
Other	1	
Total days	86	
Total cost		287 908

Operating costs

Travelling	26 891	
Accommodation	3 518	
Instrumentation	0	
Photography	360	
Printing	235	
Communication and IT	7 817	
		35 392

Capital and depreciation costs

0

Sub-contracted work

Lafarge	5 268	
Geopractica	10 390	
Mash Engineering	5 586	
SA Mining	4 440	
OHMS	7 656	
		33 340
Total expenditure		360 068
VAT		50 410
Funds available		18 522

Appendix B

Potential sites

Tau Tona

Contact- Sean Murphy/Paul Brenchly 018 700 2707/3316

116 Replacement haulage East cross cut

The stope face (118-120 longwall East) is currently 40m from the crosscut and will mine over it at a face advance of about 8-9 m per month. At present there are large seismic events on the mining face and the cross cut is not considered safe.

Function-	Sacrificial
Timing-	Too late for site establishment
Depth-	±3400m below surface
Span-	±200m dip span, extensive on strike
Seismicity-	High
Geology-	No major geological structures
Reef-	Carbon leader
Support-	Primary support and shotcrete for part of the cross cut. No plan to install additional support.
Potential-	Timing inadequate

120 cross cut to Reef drive East

The stope face is currently (120E1A and E1B) are approximately 80-100m from the cross cut and will mine over it at about 8-9 m per month.

Function-	Sacrificial
Timing-	±4 months to prepare site, ±10months to mine over cross cut
Depth-	3500m below surface
Span-	±200m dip span, extensive on strike
Seismicity-	High
Geology-	No major geological structures
Reef-	Carbon leader
Support-	Primary support and long anchors, mesh and lacing, part of cross cut is already shotcreted. No plan to install additional support.
Potential-	Current support installations are not suitable.

100 cross cut South and footwall drive

Re-raising below 100E1 to establish new reef intersection. During initial ledging the cross cut and footwall drive will be subjected to stress changes. The cross cut is $\pm 20\text{m}$ from the cross cut and the footwall drive passes under the raise. Ledging will commence in ± 3 months.

Function-	Required to service the ledging. Both tramming and transport.
Timing-	Site establishment required before completion of raise and commencement of ledging.
Depth-	$\pm 2850\text{m}$ below surface
Span-	$\pm 20\text{m}$ strike span at time of over mining
Seismicity-	High
Geology-	Major fault (20m throw) intersects both footwall drive and crosscut
Reef-	Carbon leader
Support-	Footwall drive – primary support only, cross cut – wire mesh and lacing, shotcrete, long anchors
Potential-	Required stress and deformation are not anticipated with this layout

Savuka

Contact- Trevor Rangasamy, Louie Human, Rudan van Eck - 018 700 2257 /2210 /3150

75 30 VCR cross cut (Trevor)

Cross cut to be developed to reef intersection by July 2001, when support will be installed. The stope face (75 31W) is approximately 95m from the planned cross cut position.

Function-	Tramming only
Timing-	Support installation and instrumentation in July 2001
Depth-	2100m below surface
Span-	$>200\text{m}$
Seismicity-	Moderate
Geology-	Minor faults and dykes
Reef-	Ventersdorp contact Reef
Support-	Primary support will be installed during development, Secondary support planned up to 60m from the face
Potential-	Could be used if project is extended

106 Re-establishment cross cut (Louie)

Cross cut is to be developed South under abutment to re-establish beyond the composite dyke. Down dip ledging will take then take place, immediately reducing the stress on the crosscut.

Function-	Transport, tramming. Critical in the short term.
Timing-	2 months for cross cut to pass under abutment, support. 11 months before destressing
Depth-	3250m below surface
Span-	30m
Seismicity-	High
Geology-	Composite dyke
Reef-	Carbon leader
Support-	Planned – wire mesh, lacing, long anchors and possibly shotcrete, concern about alternative support
Potential-	Stress field will be static after tunnel is developed and tunnel is supported.

107.5 Re-establishment cross cut (Louie)

Cross cut to be developed South under abutment to re-establish beyond Christmas dyke. Down dip ledging will take then take place, immediately reducing the stress on the crosscut.

Function-	Transport, tramming. Critical in the short term.
Timing-	2 months for cross cut to pass under abutment, support. 11 months before destressing
Depth-	3300m
Span-	200m
Seismicity-	High
Geology-	Christmas dyke
Reef-	Carbon leader
Support-	Planned – wire mesh, lacing, long anchors and possibly shotcrete, concern about alternative support
Potential-	Stress field will be static after tunnel is developed and tunnel is supported.

Mponeng

Contact- Rob McGill – 018 700 2573

109-56 X/C

Mine West from 109-61 Raise over 109-56 X/C. Face approximately 50m from the X/C

Function- Sacrificial
Timing- Available now, mine over in about 5 months
Depth- 3150m below surface
Span- 150m
Seismicity- High
Geology- No major structures
Reef- Ventersdorp Contact Reef
Support- ?
Potential- Grade is questionable and mining may be stopped before over stoping is completed.

Elandsrand

Contact- Jannie de Lange – 018 782 9318

Ledging scenarios. Possibly change sequence to increase stress?

Deelkraal

Contact- George Brinch – 018 785 5331

All potential sites critical, not willing to experiment.

Bambanani

Contact- Johan Hanekom – 5396

Haulage which will be mined over. Middling approximately 20m? High stress, Seismicity. No agreed to by management.

South Deep

Contact- Sandor Petho / Mariet Nagel / Navine Reddy – 411 1314 / 411 1212 /
Watty 411 1168

95 9W VCR Cross cut

Two panels mining East from 95 10W raise over 95 9W VCR cross cut. 30m away from cross cut currently.

Function- Sacrificial
Timing- Mine over cross cut within 4 months
Depth- 2650m
Span- 200m
Seismicity- Moderate
Geology- ?
Reef- Ventersdorp Contact Reef
Support- ?
Potential- Site layout not ideal

90 9W VCR cross cut

Mine updip and then breast over cross cut. Approximately 25-30m away from cross cut currently. There is a breakaway in the cross cut which may influence the results.

Function- Sacrificial
Timing- Installation immediate, mine over cross cut December 2000 or January 2001.
Depth- 2300?
Span- 200m
Seismicity- Moderate
Geology- ?
Reef- Ventersdorp contact reef
Support- ?
Potential- Breakaway in tunnel restricts potential as an instrumented site. Photographic monitoring.

95 3W EC

Mine West from 93 3W over next cross cut. Approximately 50m from cross cut, but mining only scheduled for 2002.

Function-	Transport and tramming?
Timing-	Mine over X/C at the end of 2002
Depth-	2650
Span-	Currently 50m, will be ± 200 m when overstoping takes place
Seismicity-	Moderate
Geology-	?
Reef-	Elsburg Conglomerates
Support-	?
Potential-	Site only available after project should be completed.

95 1W MB F/ON (E1 and E2)

Follow on haulages. F/ON E2 is under abutment and stress fracturing in sidewalls is evident. F/ON E1 is showing signs of dog earing due to South abutment. Middling less than 40m.

Function-	Transport and tramming
Timing-	N/A
Depth-	2650
Span-	150m
Seismicity-	Moderate
Geology-	?
Reef-	MB
Support-	Mechanical anchors
Potential-	None

95 3W BAC

95 3W Bulk air cooler to be developed when wetcrete is available. Currently mining West from 94 3W X/cut South. Middling is approximately 40m.

Function-	Ventillation
Timing-	To be determined
Depth-	2650
Span-	Currently 50m, will be 100m
Seismicity-	Moderate
Geology-	?
Reef-	EC
Support-	Planned to install wetcrete in required pattern
Potential-	Possible site.

Kloof

Contact- Deon Geysers – 411 8073 Robert Bijman

34 61 FW Drive South X/C

Mine updip and breast over X/C. Current mining distance is 50m.

Function- Sacrificial
Timing- Establish October 2000 – mine over X/C within 5-8 months
Depth- 2700m
Span- Current 65-80m / 150m during overtopping
Seismicity- High
Geology- Major fault and dyke in close proximity
Reef- Ventersdorp Contact Reef
Support- Primary support only in X/C – No intention to install secondary support, but may install support for the project
Potential- Site approved, but mine did not agree to installation of support.

41 53 (4#)

Overtopping during down dip layout. Require plans and more detail.

21 Line (3#)

Cutting of dip stabilising pillars. Timing unlikely to be suitable. Require more information.

Leeudoorn

Contact- Riaan Carstens – 751 5256

39 level capital development

Large deformations due to argillite partings. Polypropylene fibre reinforced shotcrete already installed. Some deformation has already taken place.

Driefontein

Contact- Nico Janse van Rensburg, Eric Scholtz – 018 700 8807 / 8751

5# East

Possible site under dip stabilising pillar in closely spaced dip pillar mining system. Expected stress = 120MPa.

Oryx

Contact- John Keen, Jaco Le Roux – 057 232 2158

Large deformations expected in many tunnels. Smectite (joint infill quartzite bedding planes) deteriorates when in contact with air and water. Rejected after frequent follow up.

Hartebeestfontein

Contact- Koos Bosman – 018 487 3125

77 Haulage North (between 24 and 25 crosscuts

24 line planned to be mined in January 2001. Site near shaft pillar abutment. Effectively, a pillar formed between the abutment and mining from 24 line.

Function-	Sacrificial
Timing-	Establish site during December 2000
Depth-	2200m
Span-	Large
Seismicity-	High
Geology-	Major fault and dyke in close proximity
Reef-	Vaal Reef
Support-	Secondary support comprising mesh, lacing, long anchors.
Potential-	Site approved, mine agreed to pay for removal and installation of support.

Doornfontein

Contact- Jurgens Hamman – 082 563 5090
Henk (Grinaker) - 082 458 1733

34 Haulage East

Strike orientated footwall drive. Mining East from 34-27 line, currently about 50m from potential site. Will be mining West from 34-25 to form a remnant, possibly above potential test site. Middling is approximately 58m. Deformation is apparent where tunnel is influenced by abutment.

Function-	Transport and tramming
Timing-	Establish site during January 2001
Depth-	2700m
Span-	Large
Seismicity-	High
Geology-	Major fault and dyke in close proximity
Reef-	Carbon Leader
Support-	Secondary support comprising mesh, lacing, long anchors.
Potential-	Not agreed to by management.

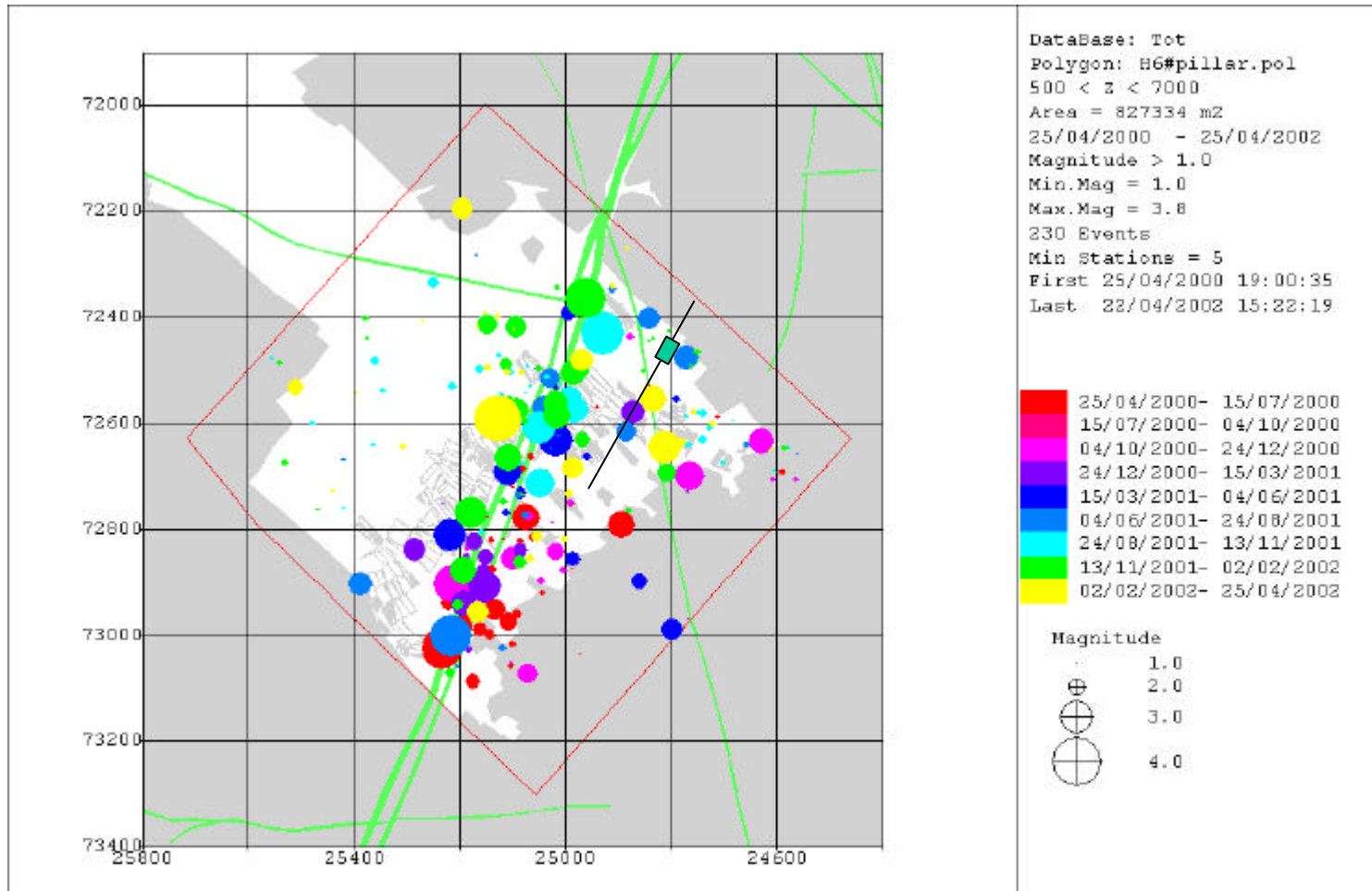
ARM 1

Contact- Gert Judeel – 018 478 2115

4# area

Potential site. However mining only in June next year (earliest) Squeezing ground near Harties. Middling ± 40 m, Seismicity (Magnitude 4.0 previously), Depth ± 2000 m below surface. Rejected by management

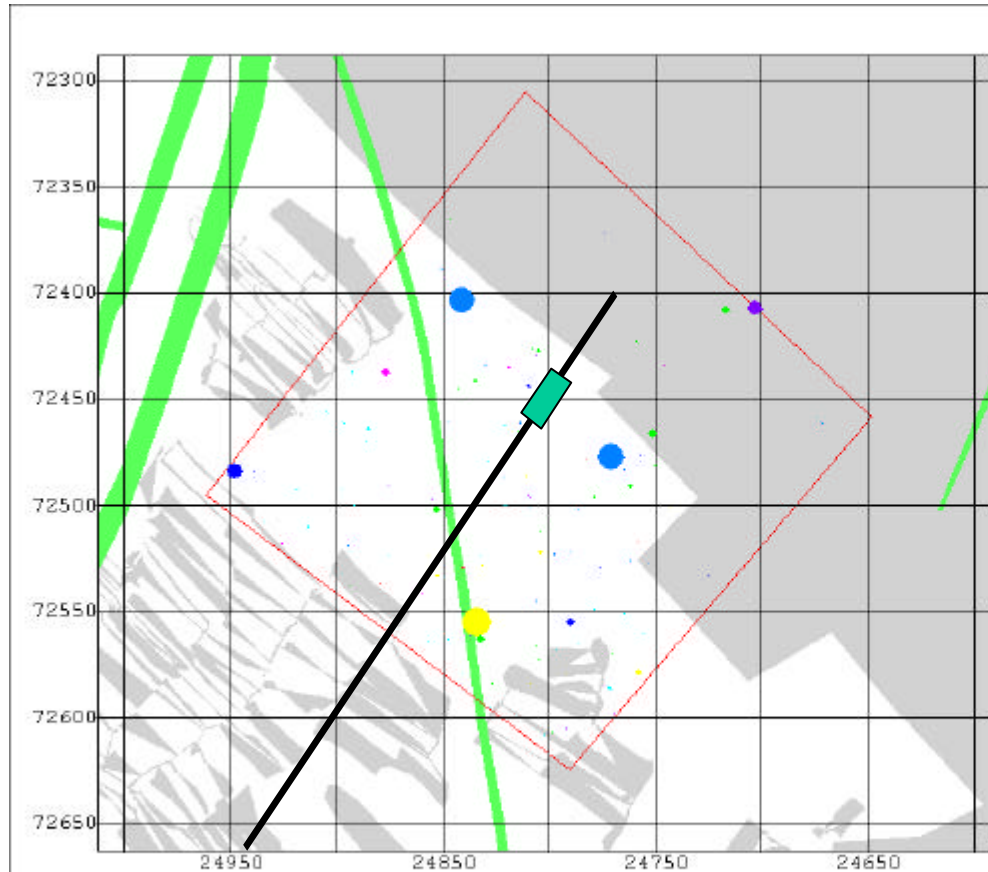
Appendix C



JOB No.
278821

Seismic events > 1.0 local magnitude recorded in the Hartebeestfontein 6 shaft pillar between 25/04/2000 and 25/04/2002.

FIG No.
C1



DataBase: Tot
 Polygon: testsite.pol
 500 < Z < 7000
 Area = 50403 m2
 25/04/2000 - 25/04/2002
 Magnitude > 0.1
 Min.Mag = 0.1
 Max.Mag = 2.6
 114 Events
 Min Stations = 3
 First 18/05/2000 19:25:22
 Last 14/04/2002 15:01:46

Red	25/04/2000- 15/07/2000
Magenta	15/07/2000- 04/10/2000
Pink	04/10/2000- 24/12/2000
Purple	24/12/2000- 15/03/2001
Blue	15/03/2001- 04/06/2001
Cyan	04/06/2001- 24/08/2001
Light Blue	24/08/2001- 13/11/2001
Green	13/11/2001- 02/02/2002
Yellow	02/02/2002- 25/04/2002

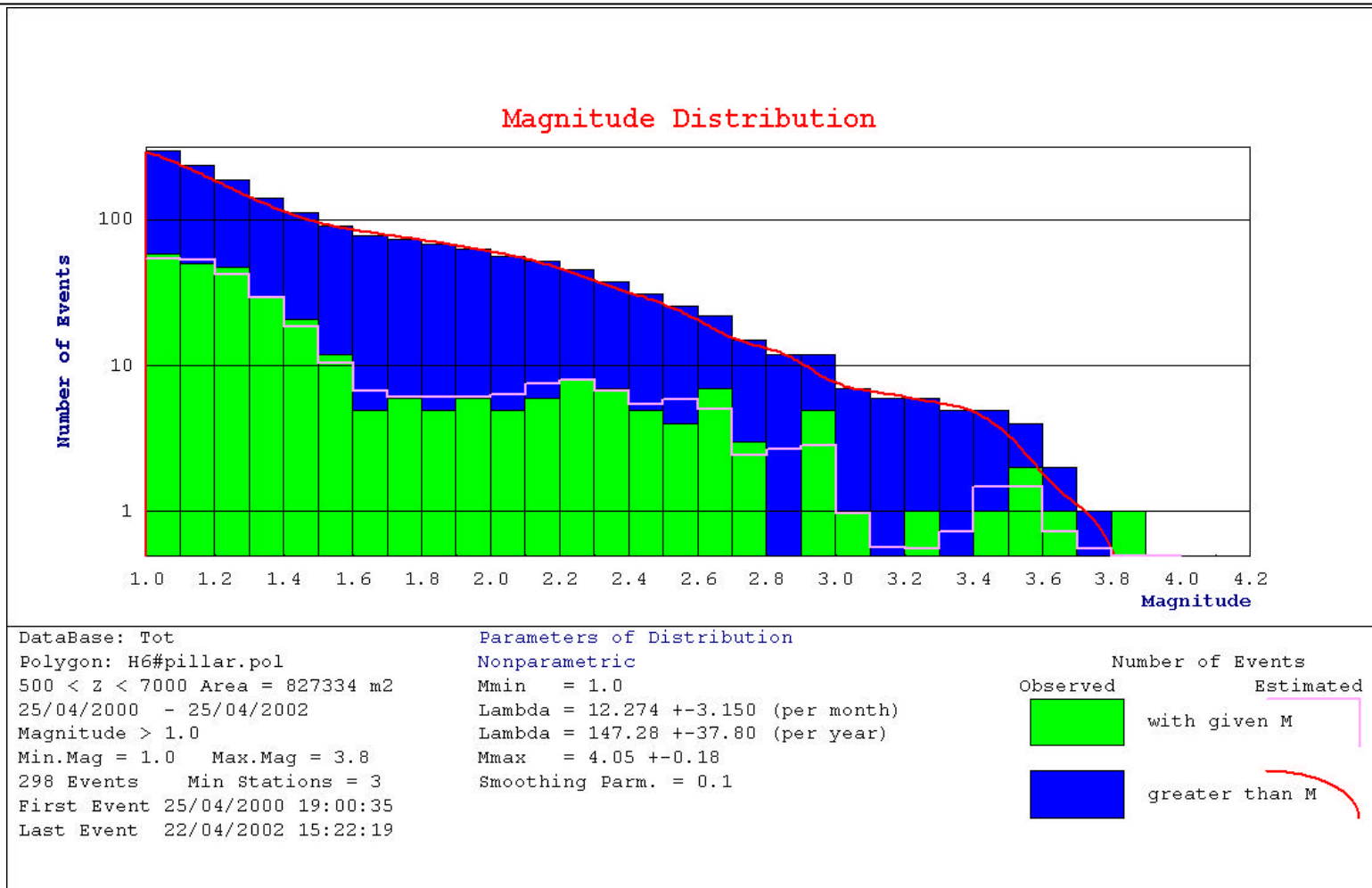
Magnitude

Small circle	1.0
Medium circle	2.0
Large circle	3.0
Very large circle	4.0

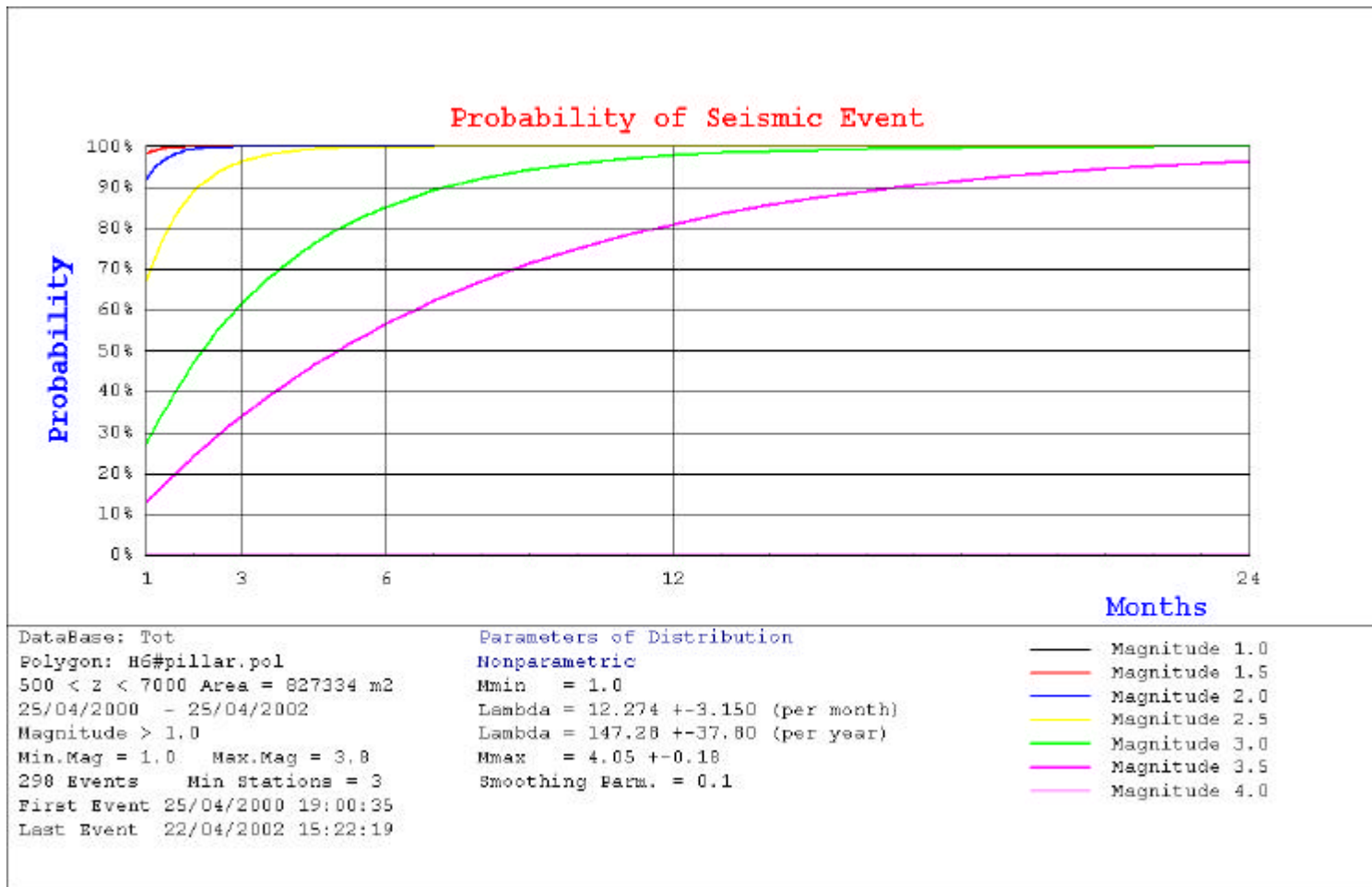
JOB No.
278821

Seismic Events > 0.0 local magnitude recorded near the test site between 25/04/2000 and 25/04/2002

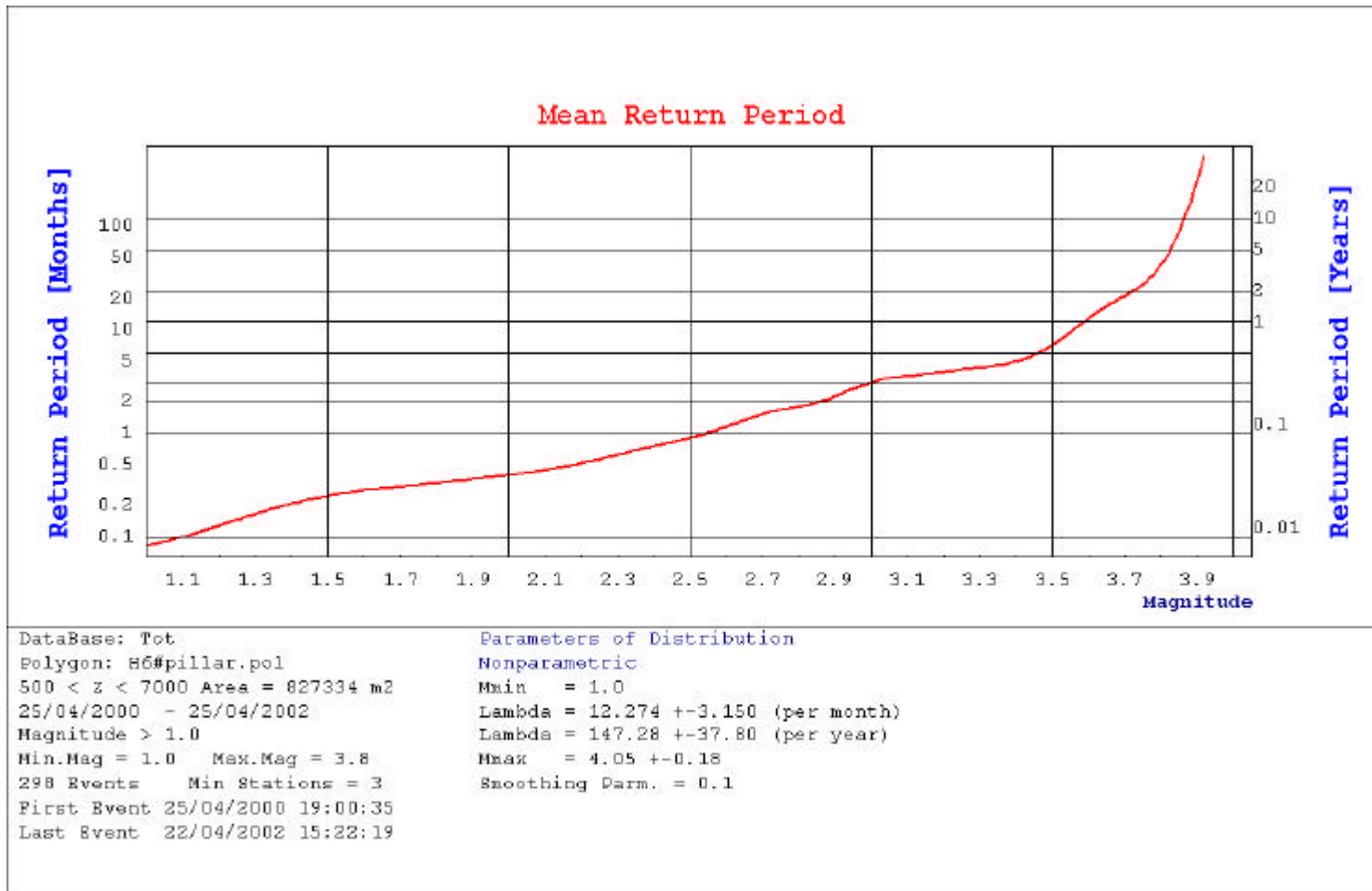
FIG No.
C2



JOB No. 278821	Magnitude distribution of seismic events > 1.0 local magnitude recorded at the Hartebeestfontein 6 shaft pillar between 25/04/2000 and 25/04/2002	FIG No. C3
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JOB No. 278821	Probabilities of occurrence of seismic events based on the distribution of seismic events recorded at the Hartebeestfontein 6 shaft pillar between 25/04/2000 and 25/04/2002	FIG No. C4
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JOB No.
278821

Mean return periods based on seismic events recorded at Hartebeestfontein 6 shaft pillar between
25/04/2000 and 25/04/2002

FIG No.
C5

Seismic Hazard

ita

```

sisHaz\Data\Totalh6#.evp
sHaz\Areas\H6#pillar.pol
2
25/04/100 - 25/04/102
0
in Stations = 3
  Max.Mag = 3.8
04/100 19:00:35
04/102 15:22:19
  
```

Maximum Expected Magnitude

```

In 1 year   M = 3.59
In 2 years  M = 3.72
In 5 years  M = 3.83
  
```

Seismic Events Distribution

Magn >	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Theor.	294	96	60	26	8	3	0.0
Observed	298	91	57	26	7	4	0

: Distribution

```

+-3.150 (per month)
+-37.80 (per year)
ster = 0.1
-0.18
  
```

Periods

Probabilities of Seismic Event

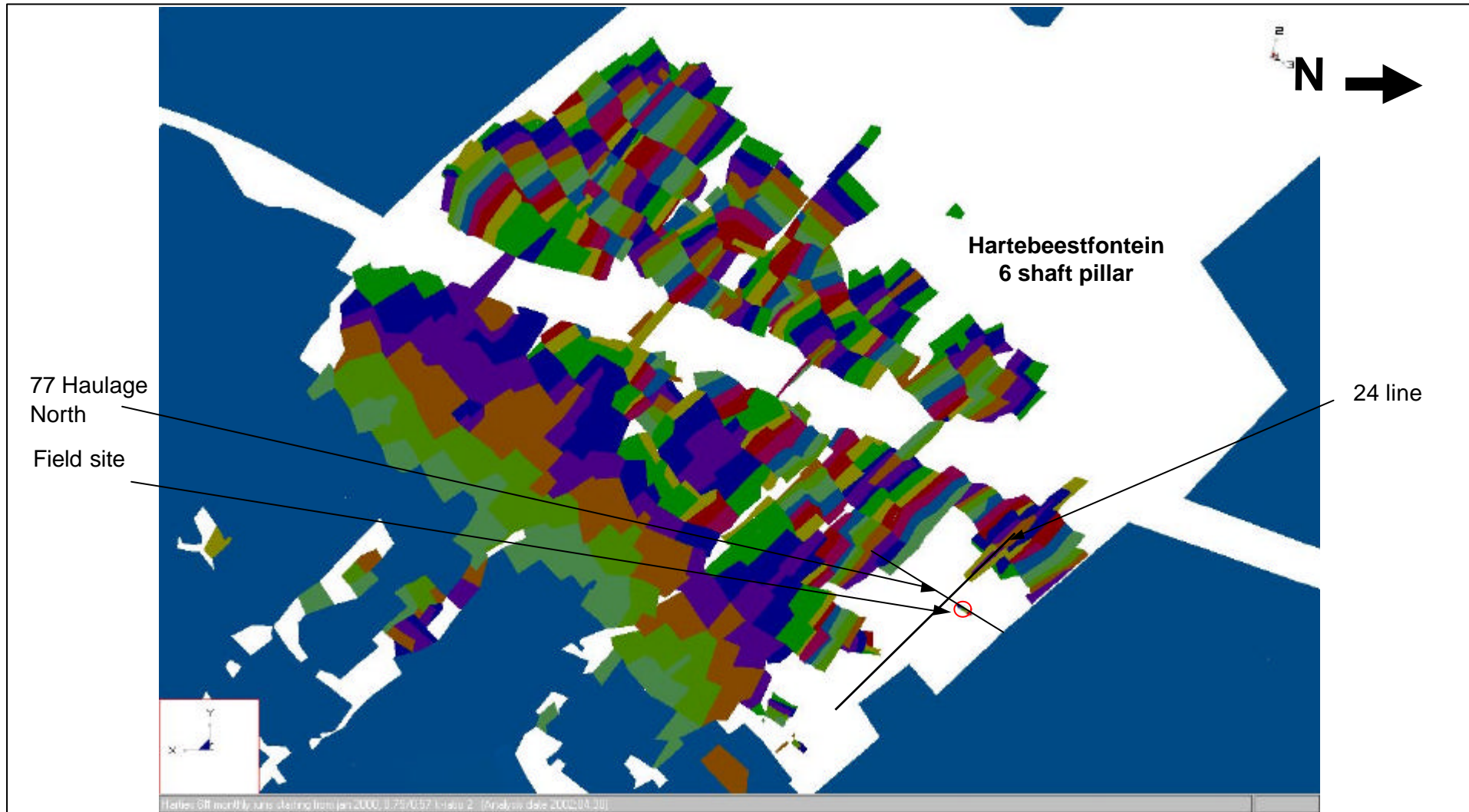
Events /Year	Return Period months	Return Period years	Magn	1 month	3 months	6 months	1 year	2 years	5 years
147.3	0.081	0.01	1.0	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
48.0	0.250	0.02	1.5	98.2%	100.0%	100.0%	100.0%	100.0%	100.0%
30.3	0.396	0.03	2.0	92.0%	99.9%	100.0%	100.0%	100.0%	100.0%
13.3	0.905	0.08	2.5	66.9%	96.4%	99.9%	100.0%	100.0%	100.0%
3.8	3.133	0.26	3.0	27.3%	61.6%	85.3%	97.8%	100.0%	100.0%
1.7	7.196	0.60	3.5	13.0%	34.1%	56.6%	81.1%	96.4%	100.0%

report of seismic hazard based on seismic events recorded at the Hartebeestfontein 6 shaft pillar between 25/04/2000 and 25/04/2002

FIG No.
C6

Appendix D

Geometry	
Stoping width (m)	1.0 – 1.2
Elastic properties	
Young's modulus (E) (GPa)	50
Poisson's ratio (ν)	0.2
Virgin stress	
$\Delta\sigma_{xx}$ (MPa/m)	0.0176
$\Delta\sigma_{yy}$ (MPa/m)	0.0216
$\Delta\sigma_{zz}$ (MPa/m)	0.0285
k_x	0.62
k_y	0.76



77 Haulage
North
Field site

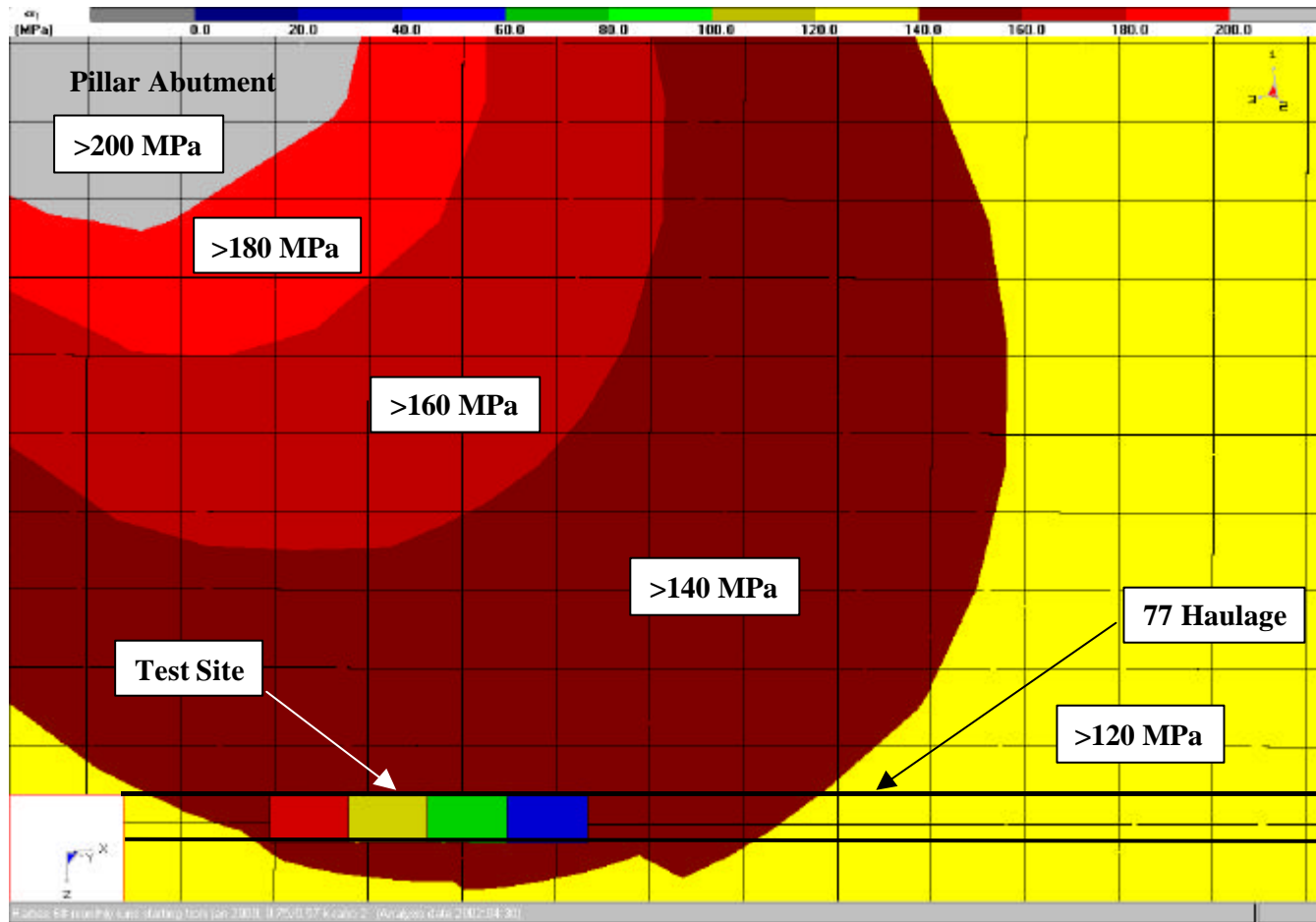
Hartebeestfontein
6 shaft pillar

24 line

JOB No.
278821

Model of Hartebeestfontein field site – mining from December 2000 to February 2002

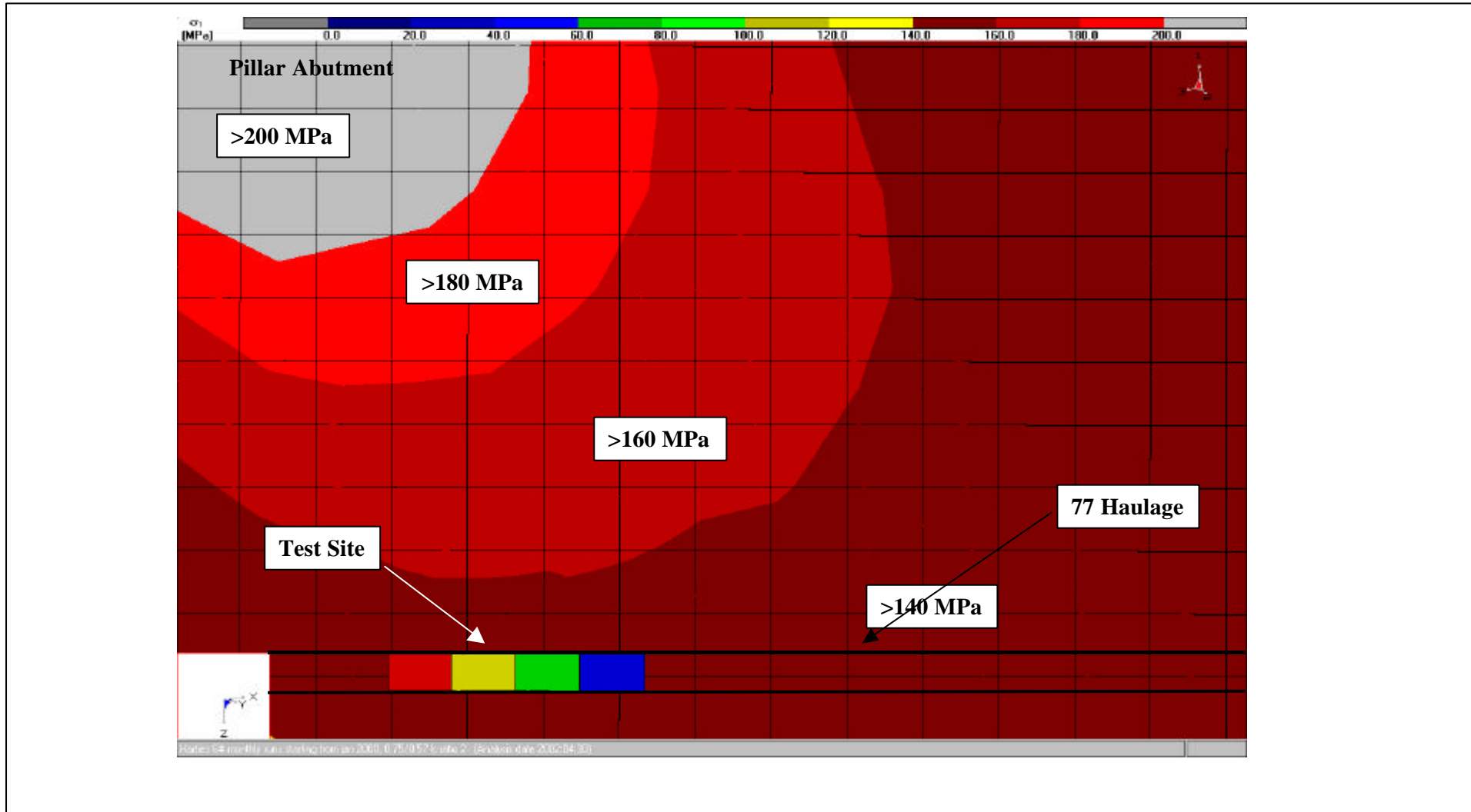
FIG. No.
D2



JOB No.
278821

Major principal stress (σ_1) at the field site during December 2000

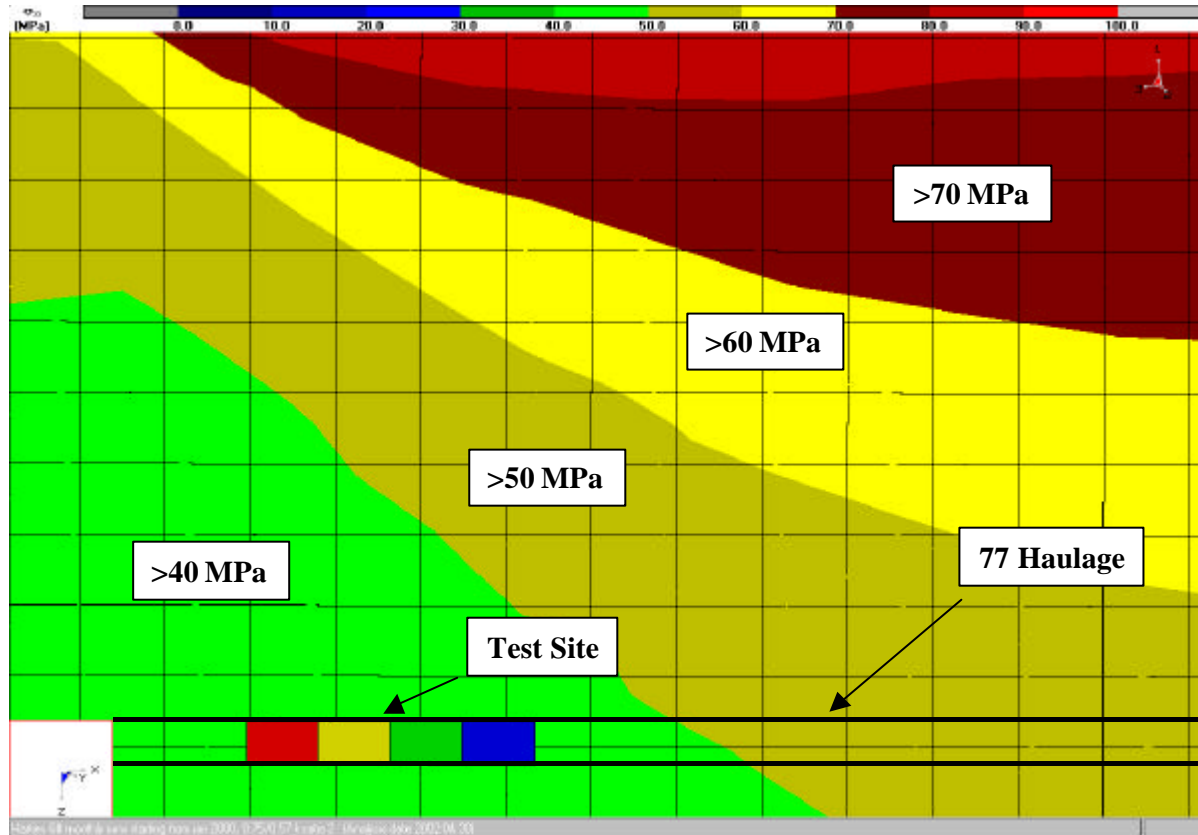
FIG. No.
D3



JOB No.
278821

Major principal stress (σ_1) at the field site during February 2002

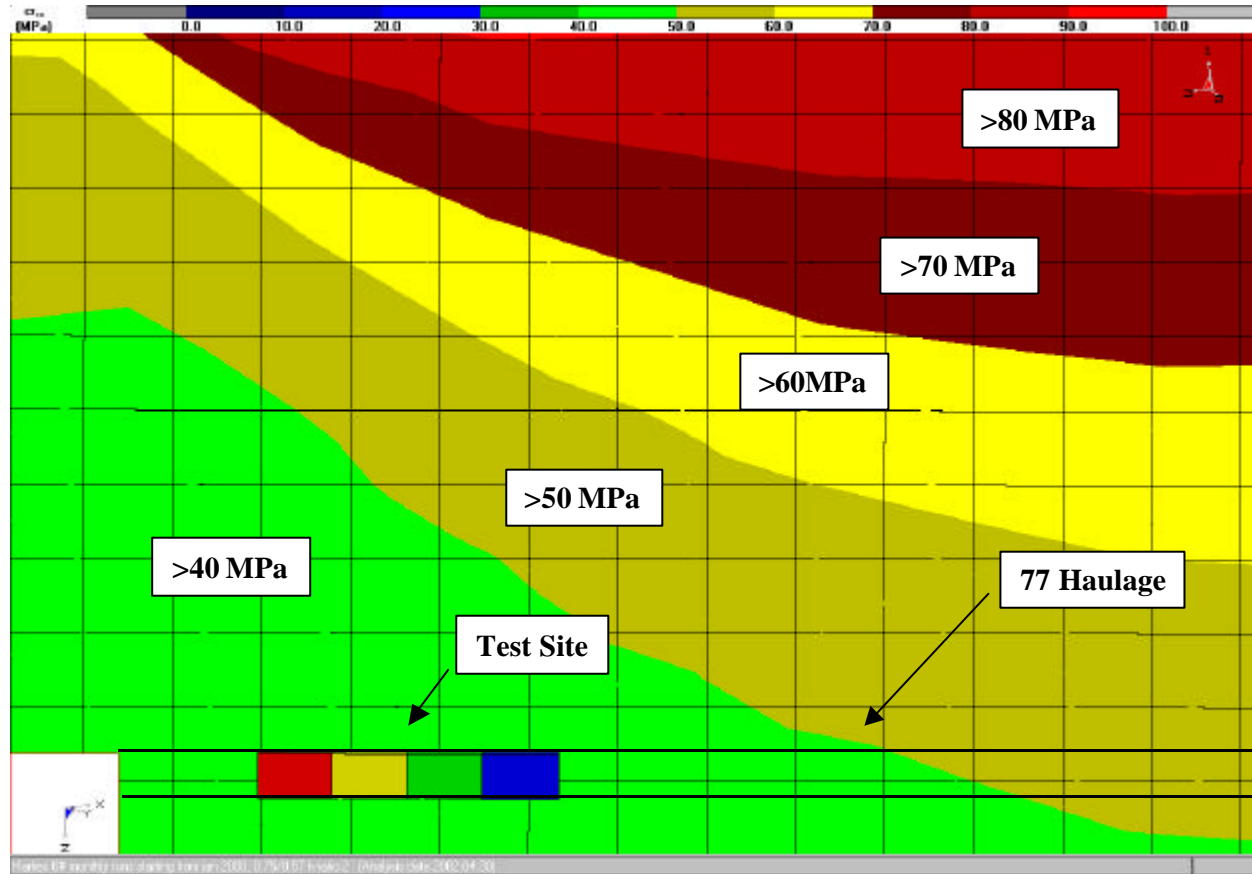
FIG. No.
D4



JOB No.
278821

Horizontal stress (σ_{xx}) at the field site during December 2000

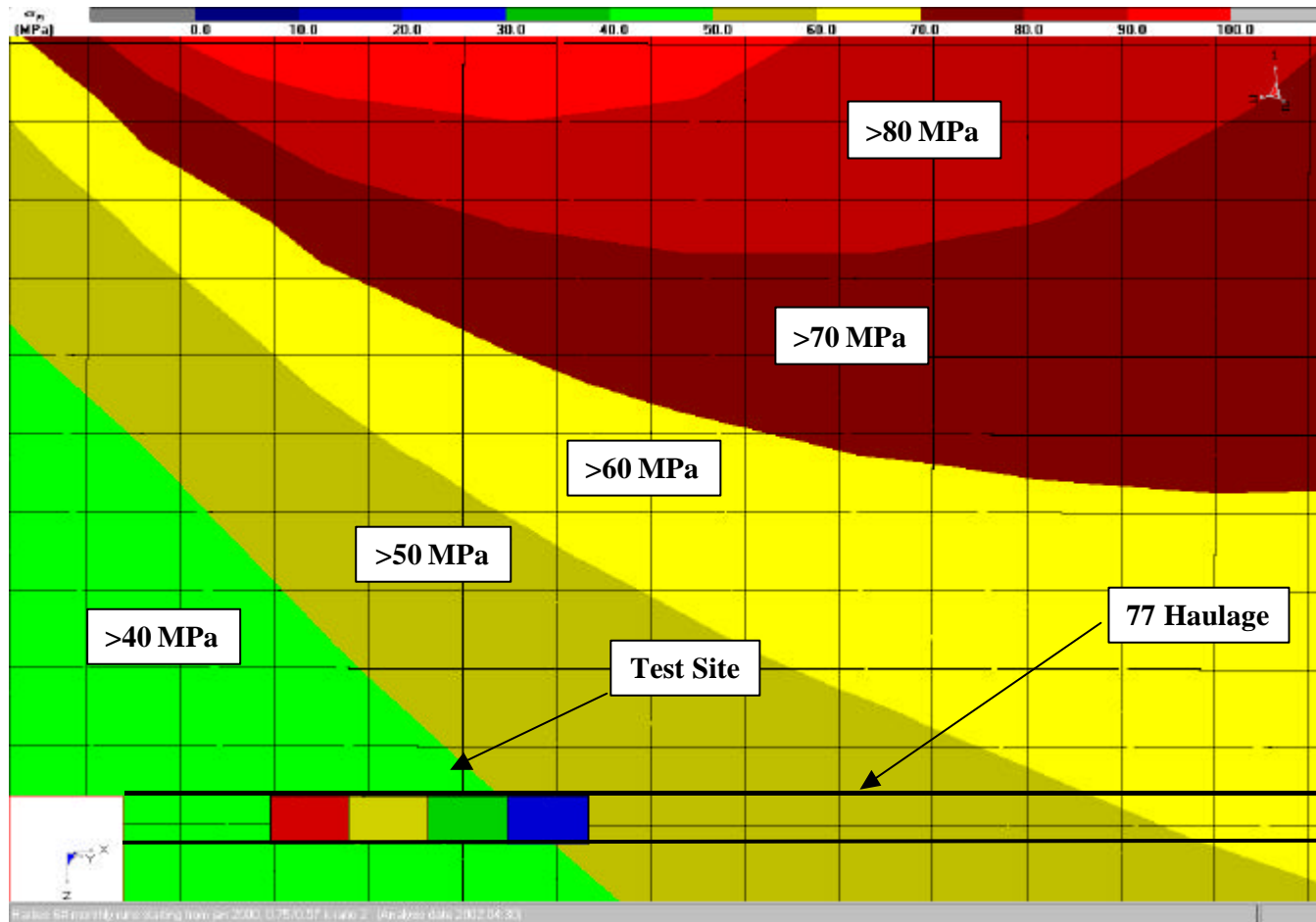
FIG. No.
D5

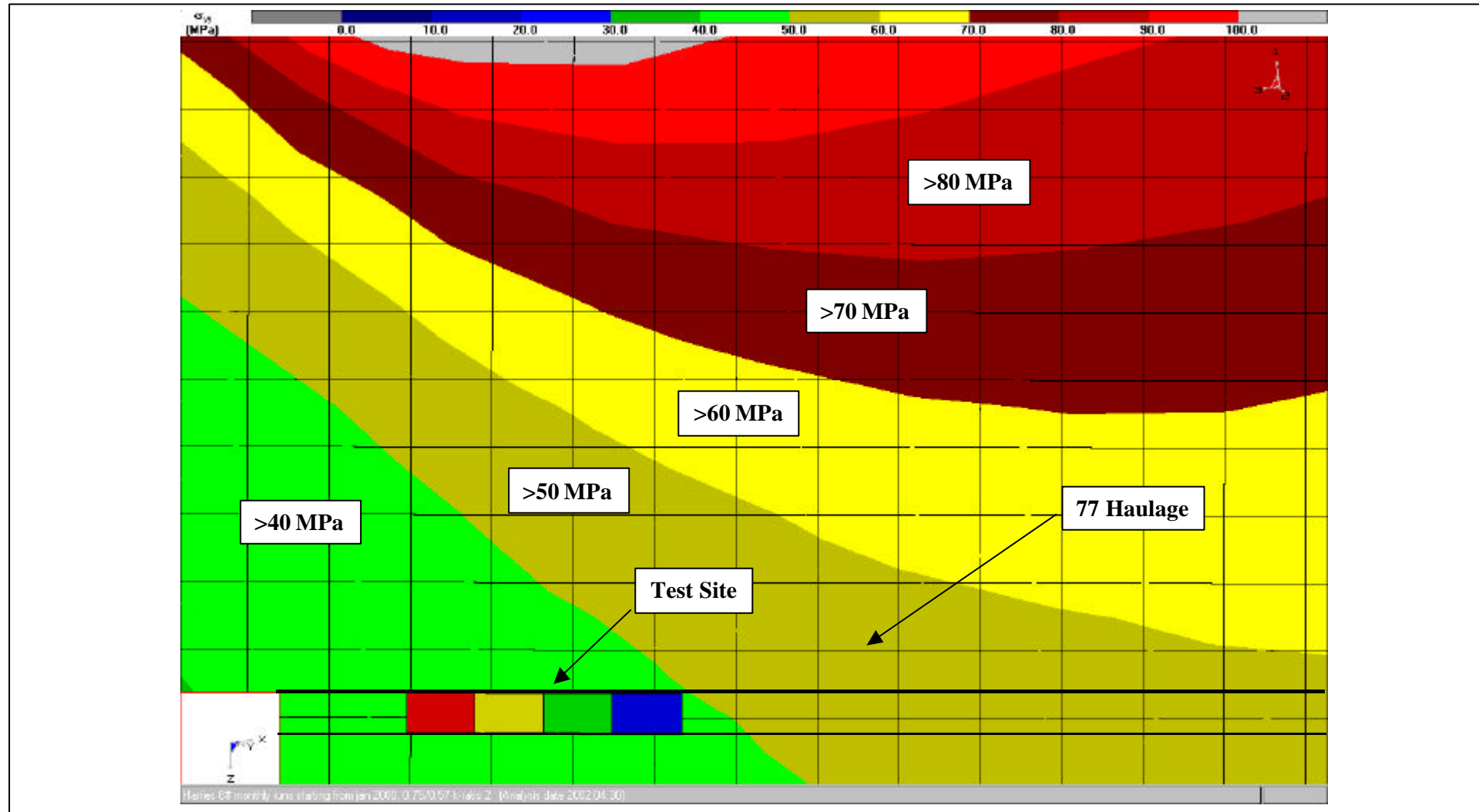


JOB No.
278821

Horizontal stress (σ_{xx}) at the field site during February 2002

FIG. No.
D6

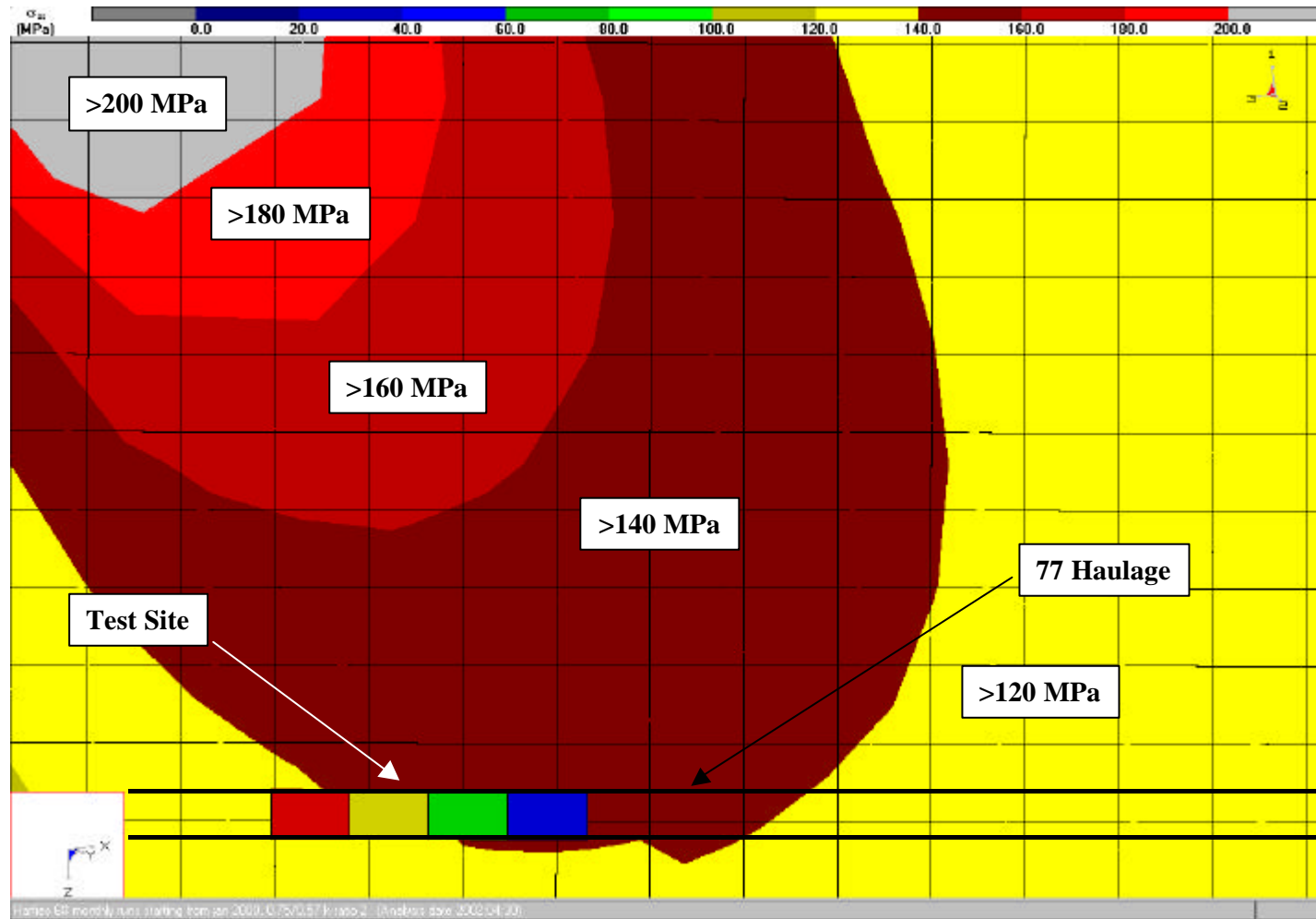




JOB No.
278821

Horizontal stress (σ_{yy}) at the field site during February 2002

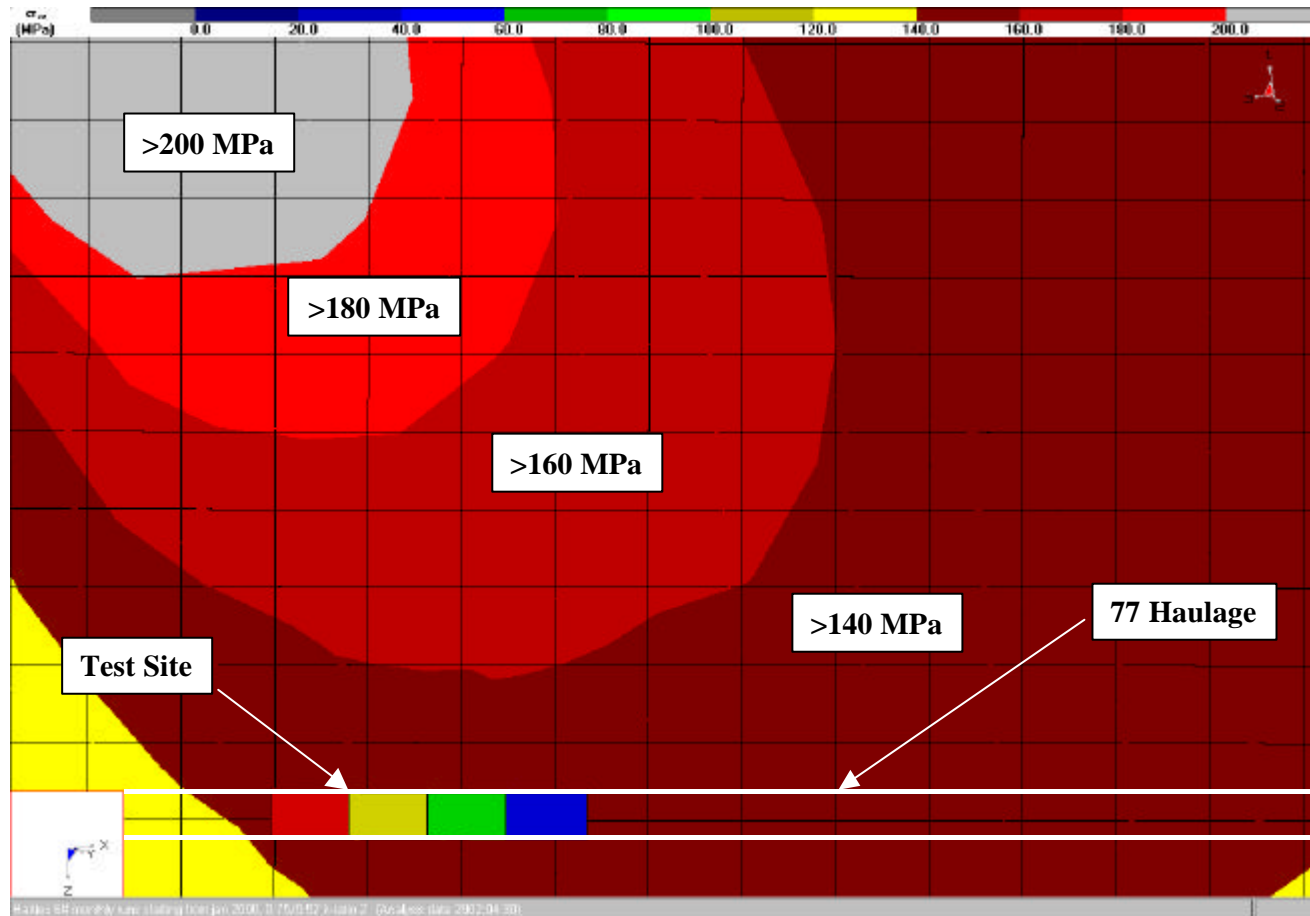
FIG. No.
D8



JOB No.
278821

Vertical stress (σ_{zz}) at the field site during December 2000

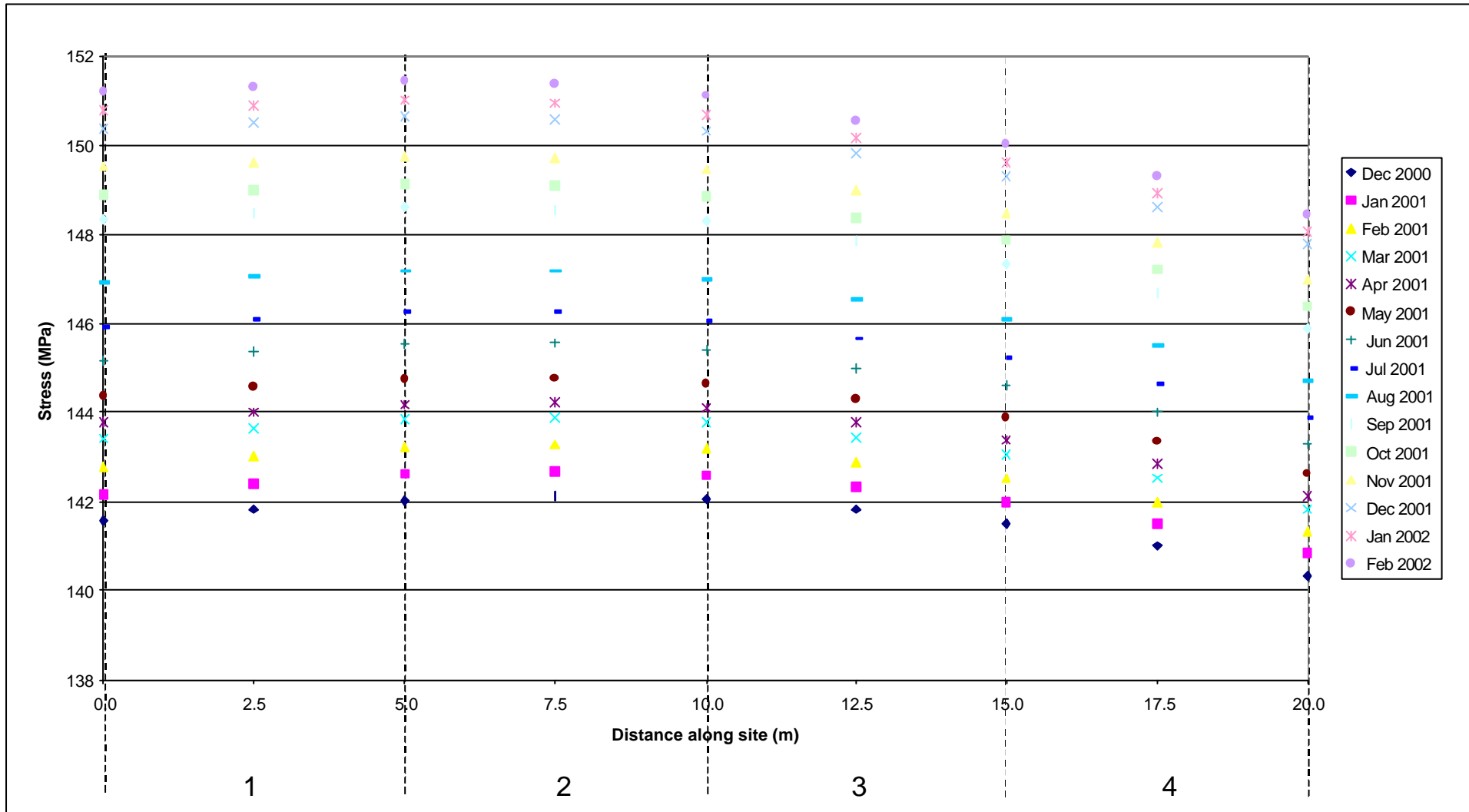
FIG. No.
D9



JOB No.
278821

Vertical stress (σ_{zz}) at the field site during February 2002

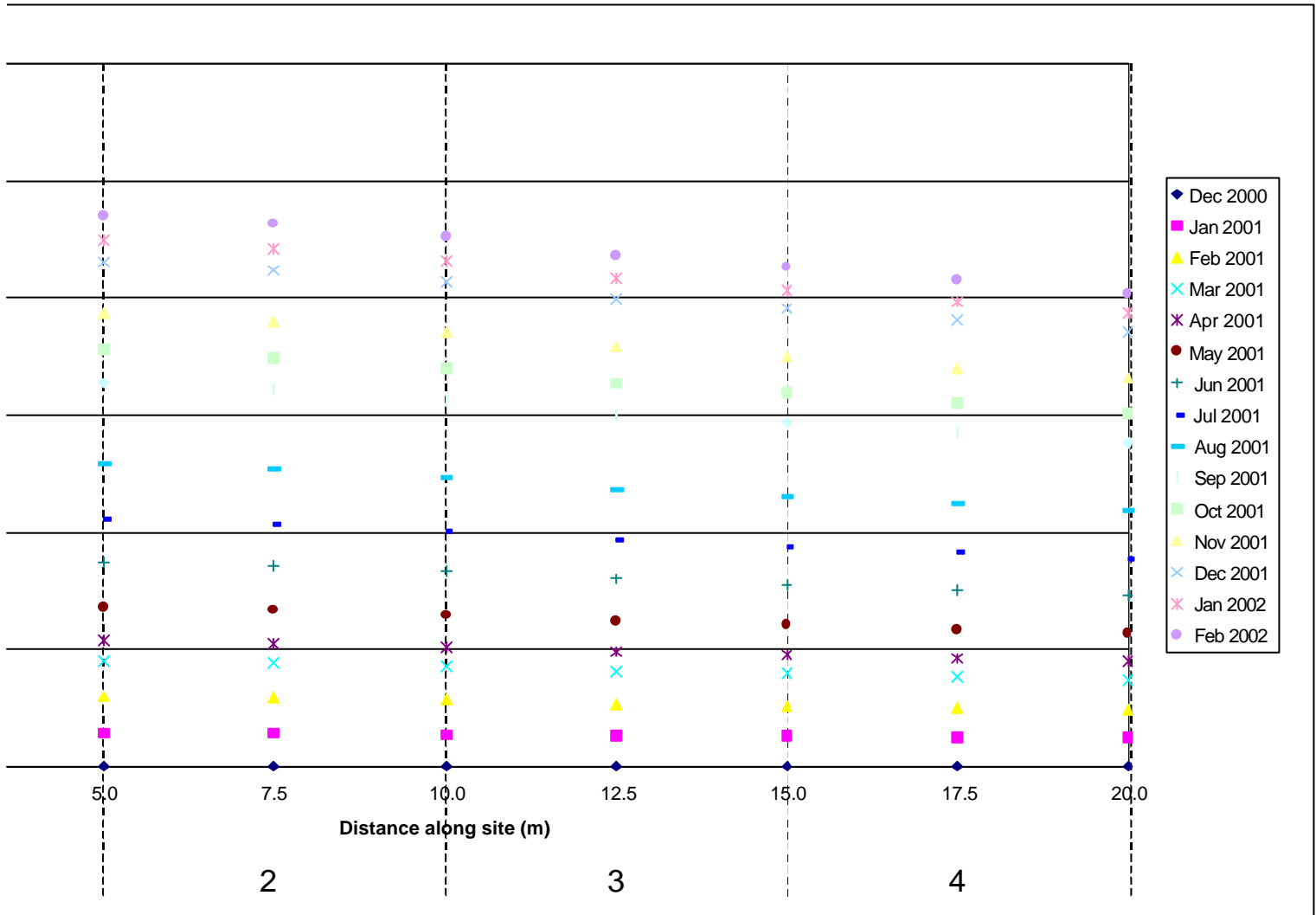
FIG. No.
D10



JOB No.
278821

Major principal stress at points along test site – (mining from December 2000 – February 2002)

FIG. No.
D11



Major principal stress changes at points along test site – (December 2000 – February 2002)

FIG. No.
 D12

Appendix E

**ISO/IEC GUIDE 25/SABS 0259
& EN 45001**

Where indicated thus (*), the results given in this report were obtained from tests conducted within the scope of **SANAS Certificate of Accreditation - Accredited Test Facilities No. T 0041**

TECHNICAL REPORT (Final)

Job No: TSD 01/7

Date: 2001-02-14

Client: SRK Consulting

Contact: Mr William Joughin

Telephone/Fax: Tel. (011) – 447 1126, Fax. (011) – 447 4525

Project: Aggregate and shotcrete evaluations

<u>Sample Suffix</u>	<u>,description</u>	<u>Source</u>	<u>Condition</u>
TSD 01/7/1	Normal aggregate (P)	ex SRK	2 x plastic bags
TSD 01/7/2	Normal aggregate + steel fibre (S)	ex SRK	2 x plastic bags
TSD 01/7/3	Tailings + PP fibre (T)	ex SRK	2 x plastic bags
TSD 01/7/4	Normal aggregate + PP fibre	ex SRK	not received
TSD 01/7/5	Spray panel box T (cast 14 Dec'00)	ex SRK	Sprayed panel box
TSD 01/7/6	Spray panel box S (cast 19 Dec'00)	ex SRK	Sprayed panel box

continue...

<u>Sample Suffix ,description</u>	<u>Source</u>	<u>Condition</u>
TSD 01/7/7	Spray panel box P (cast 15 Dec'00) ex SRK	Sprayed panel box
TSD 01/7/8	Calcium Chloride ex SRK	in plastic bottle
TSD 01/7/9	Mortair D admixture ex SRK	in plastic bottle
TSD 01/7/10	Spray panel box (cast 04 Jan'01) ex SRK	Sprayed panel box

PP – polypropylene

1. OBJECTIVE

The evaluation of aggregates and cores (extracted from shotcrete panels) from SRK.

2. TESTS CONDUCTED

SABS Method 828 Preparation of test samples of aggregate (*).

SABS Method 829 Fines content, dust content and sieve analysis of aggregate (*).

SABS Method 865 Drilling, Preparation and Testing of Cores.

A HILTI Diamond core drilling machine was used to extract Ø90 mm cores from the shotcrete panel. These cores were cut with a masonry saw and capped with sulphur mortar according to SABS 865.

ÖNORM 83303 Tensile splitting of cylinders (cores)

2.1 Deviations from Standard Test Methods

None.

3. RESULTS

3.1 Aggregate evaluation (see gradings attached):

3.1.1 The normal aggregates (TSD 01/7 #1 and #2) comply with the grading requirements of a river sand as per SABS 1083:1994, with the exception on the 0,075mm sieve-size.

3.1.2 The tailing sample (TSD 01/7/3) does not comply with the grading envelope as per SABS 1083:1994. The sample contains too many fines.

3.2 Core results:

Description of test	#1	TSD 01/7/5 (T)	
		#2	#3
Calculated density, (kg/m ³)	2295	2284	2241
Average	2273		
Compressive strength @ 35 days, (MPa)	22,6	18,8	18,3
Average	19,9		
	#4	#5	#6
Tensile strength @ 40 days, (MPa)	2,62	1,97	1,84
Average	2,15		
Fibre content, (%)	0,27		

Fibre orientation: An even distributed fibre was noticed on the cores from panel box TSD 01/7/5 (T). The fibre orientation was mainly in one direction (perpendicular to the direction of spray).

Description of test	TSD 01/7/6 (S)		
	#1	#2	#3
Calculated density, (kg/m ³)	2133	2134	2194
Average	2154		
Compressive strength @ 30 days , (MPa)	27,3	27,6	27,5
Average	27,5		
	#4	#5	#6
Tensile strength @ 35 days, (MPa)	3,15	3,30	2,52
Average	2,99		
Fibre content, (%)	0,98		

Fibre orientation: An even distributed fibre was noticed on the cores from panel box TSD 01/7/6 (S). The fibre orientation was mainly in one direction (perpendicular to the direction of spray).

Description of test	TSD 01/7/7 (P)		
	#1	#2	#3
Calculated density, (kg/m ³)	2126	2136	2129
Average	2130		
Compressive strength @ 34 days , (MPa)	24,4	24,5	22,7
Average	23,9		
	#4	#5	#6
Tensile strength @ 39 days, (MPa)	1,65	2,61	2,75
Average	2,34		
Fibre content, (%)	0,12		

Fibre orientation: An uneven distributed fibre was noticed on the cores from panel box TSD 01/7/7 (P). The fibre orientation was mainly in one direction (perpendicular to the direction of spray).

Description of test	TSD 01/7/10		
	#A	#B	#C
Calculated density, (kg/m ³)	2201	2236	2183
Average	2207		
Compressive strength @ 34 days , (MPa)	23,2	23,7	25,3
Average	24,1		
	#D	#E	#F
Tensile strength @ 39 days, (MPa)	1,73	2,04	2,28
Average	2,02		
Fibre content, (%)	0,42		

Fibre orientation: An uneven distributed fibre was noticed on the cores from panel box TSD 01/7/10. The fibre orientation was mainly in one direction (perpendicular to the direction of spray).

4. DISCUSSION AND CONCLUSIONS

Any discussions, conclusions or interpretations contained in this report are outside the scope of the accreditation.

This report should be read in conjunction with the previous interim report.

The strengths and densities obtained from the sprayed panels TSD 01/7/6 (S) and TSD 01/7/7 (P) were very similar, with the former achieving slightly higher compressive strengths.

The fibre content of panel TSD 01/7/6 (S) was higher compared to the other panels (0,98% and less than 0,30% respectively).

Panel box (TSD 01/7/10) which was received afterwards, showed similar strengths and densities compared to the previous three panel boxes. The fibre content was 0,42%

Additional interpretation to be done by the client.

5. GENERAL

Please note that the results given above refer only to the samples submitted for testing. This report may not be reproduced in part or in full without the written permission of the Technical Services Department of Lafarge Cement (Pty) Ltd.

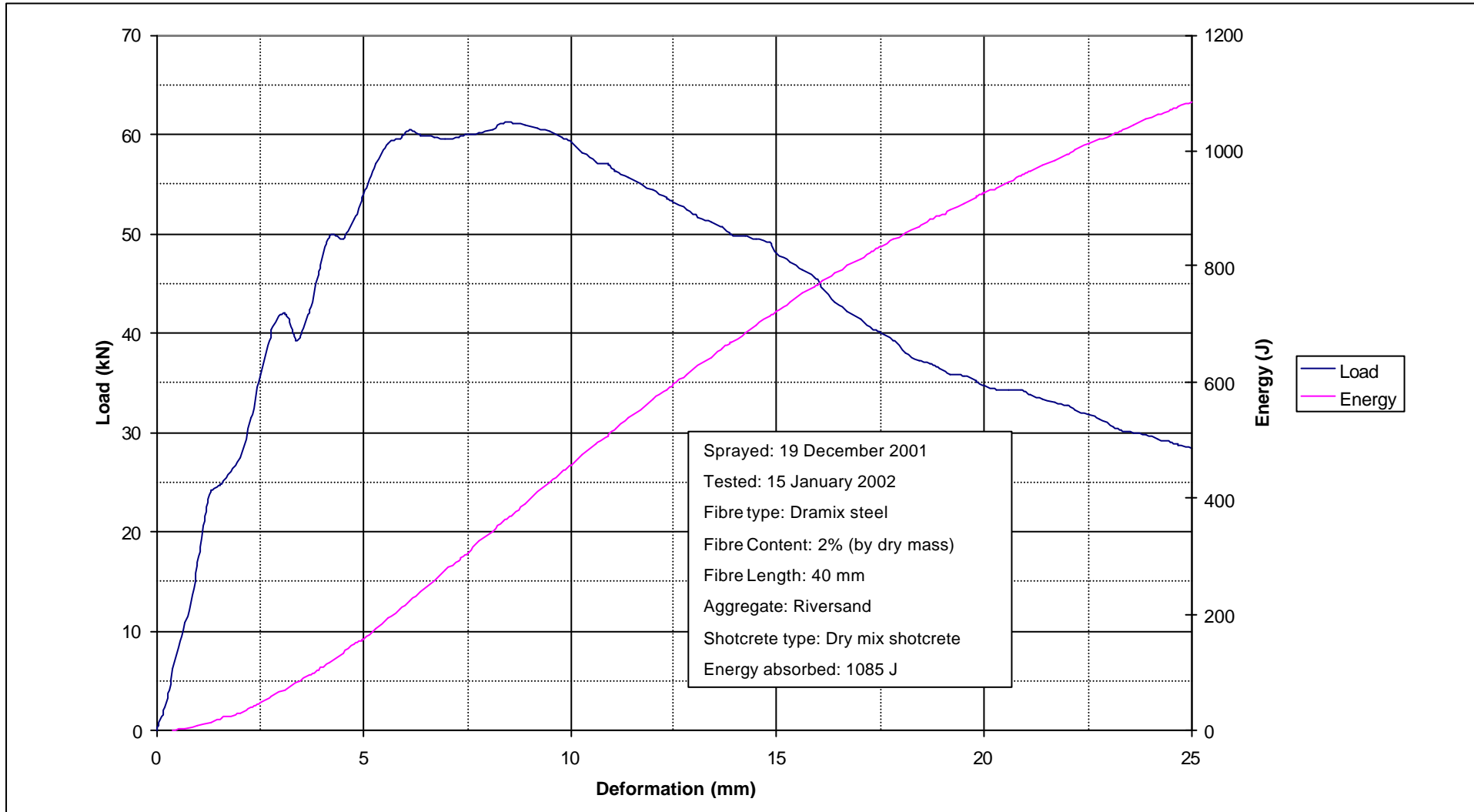
Compiled by: Theo Roelofsz

Theo Roelofsz
Senior Laboratory Technician

Authorised by: Hennie van Heerden

Hennie van Heerden
Laboratory Manager
Cement & Concrete

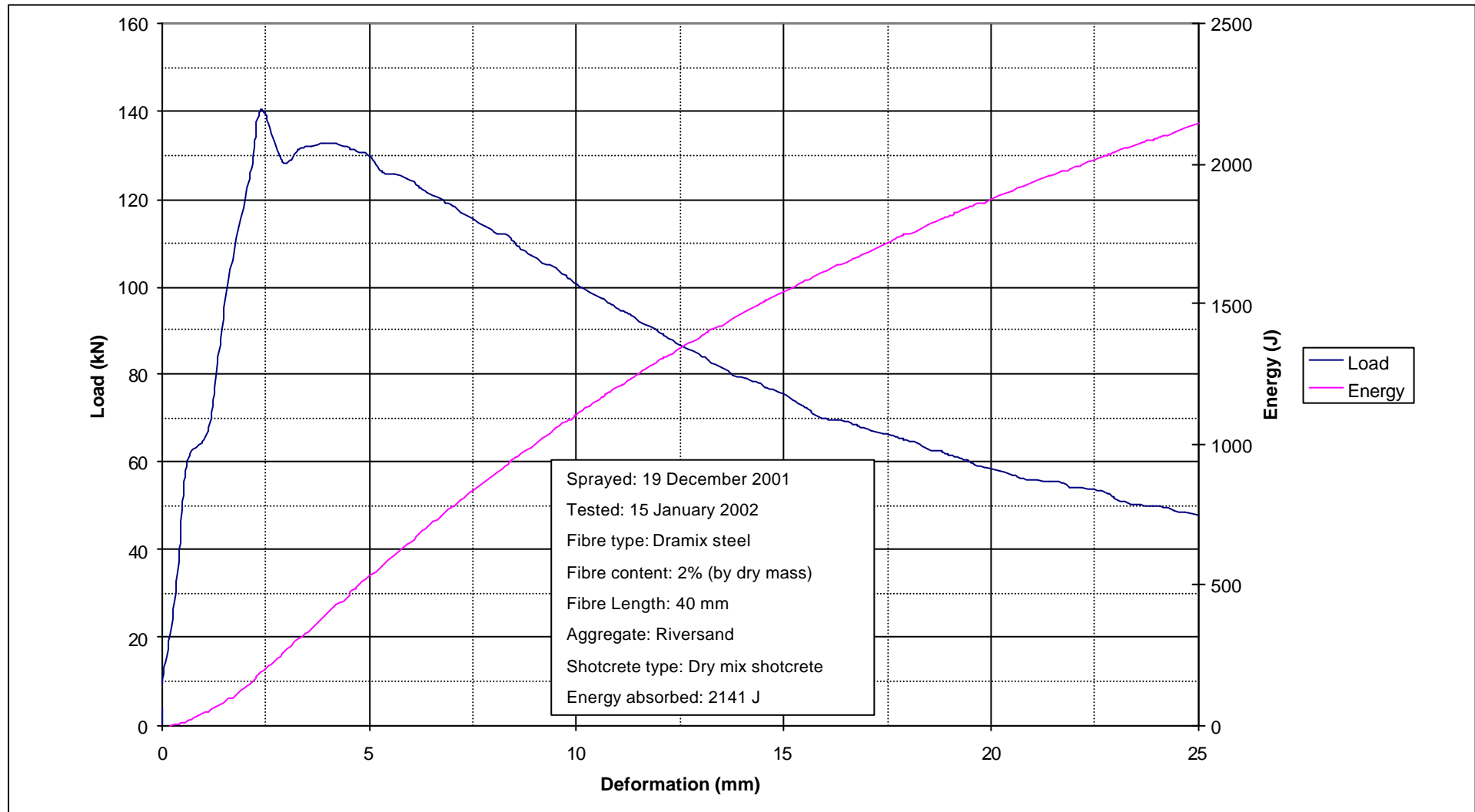
T/TSD/SF 0040



JOB No.
278821

Section 1 (Steel fibre reinforced ordinary aggregate shotcrete)– Test 1

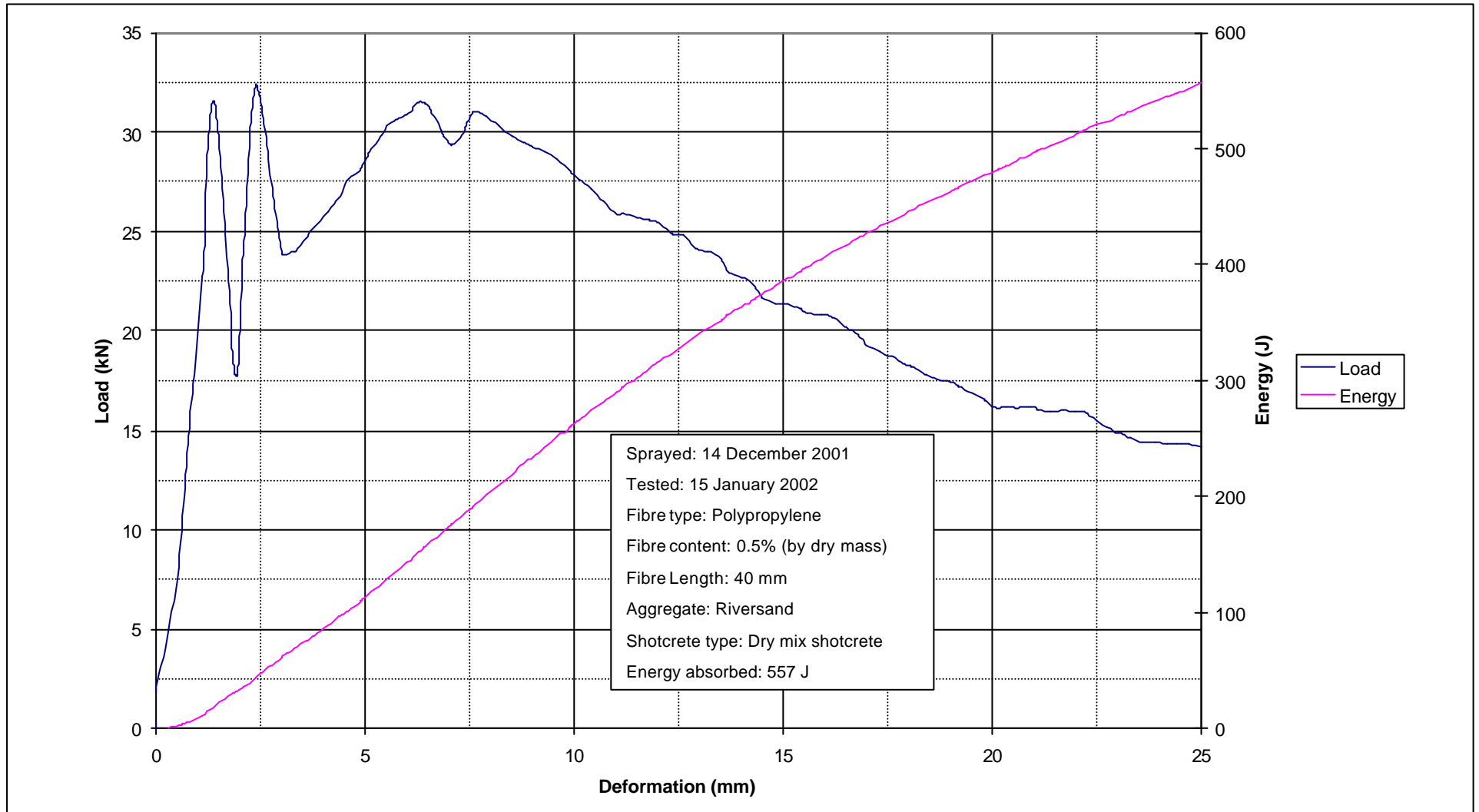
FIG. No.
E1



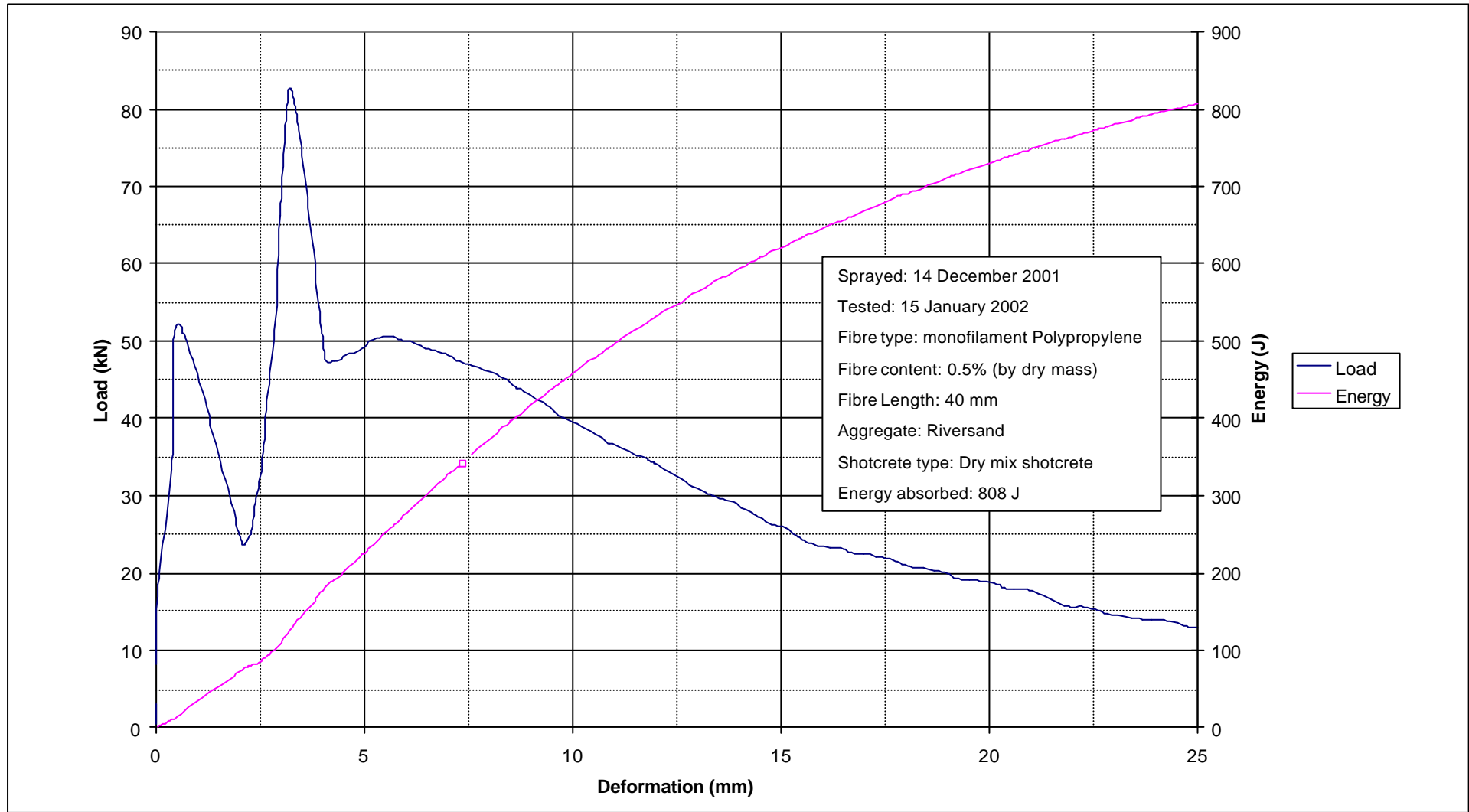
JOB No.
278821

Section 1 (Steel fibre reinforced ordinary aggregate shotcrete)- Test 2

FIG. No.
E2



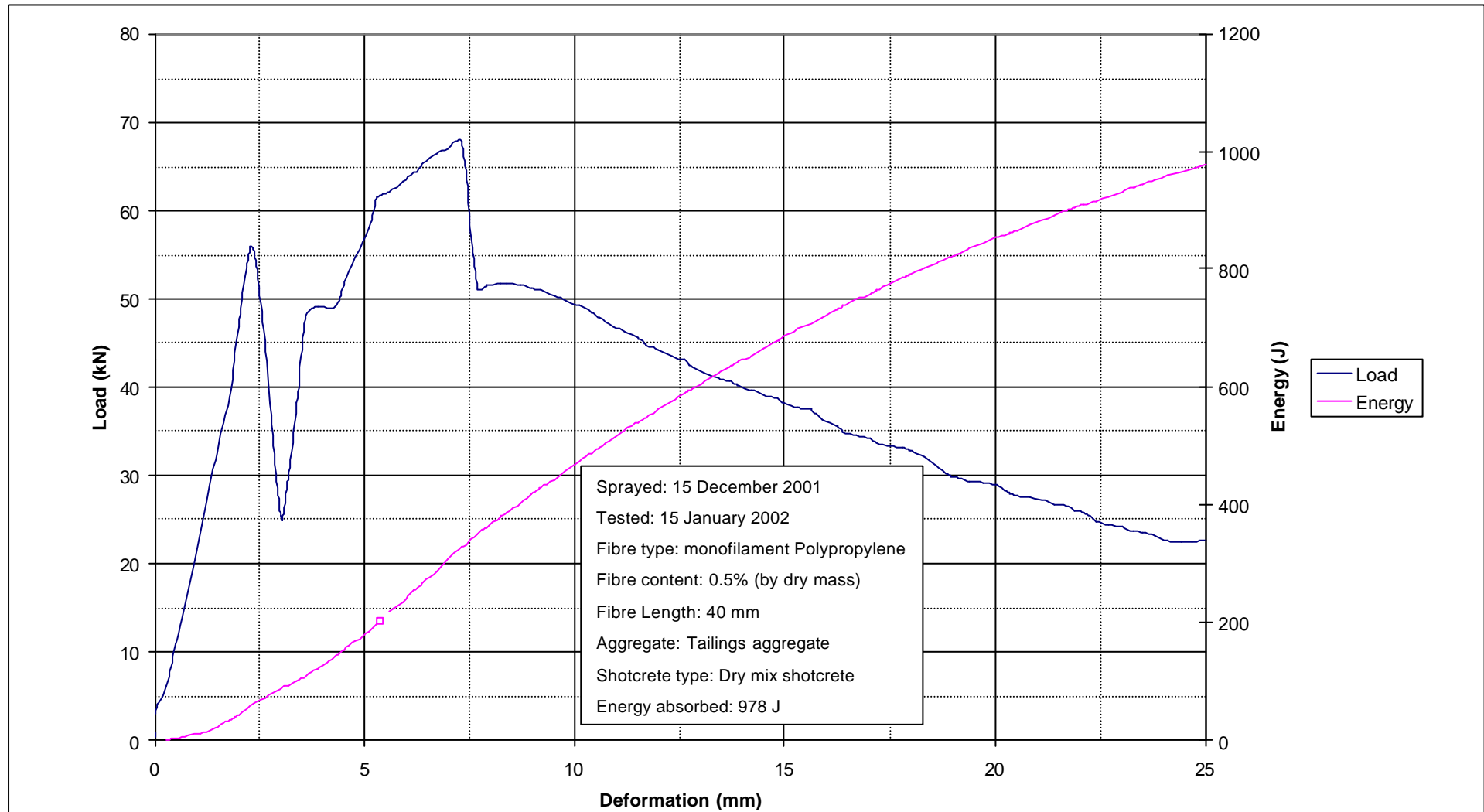
JOB No. 278821	Section 2 (Polypropylene fibre reinforced ordinary aggregate shotcrete)- Test 1	FIG. No. E3
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JOB No.
278821

Section 2 (Polypropylene fibre reinforced ordinary aggregate shotcrete)- Test 2

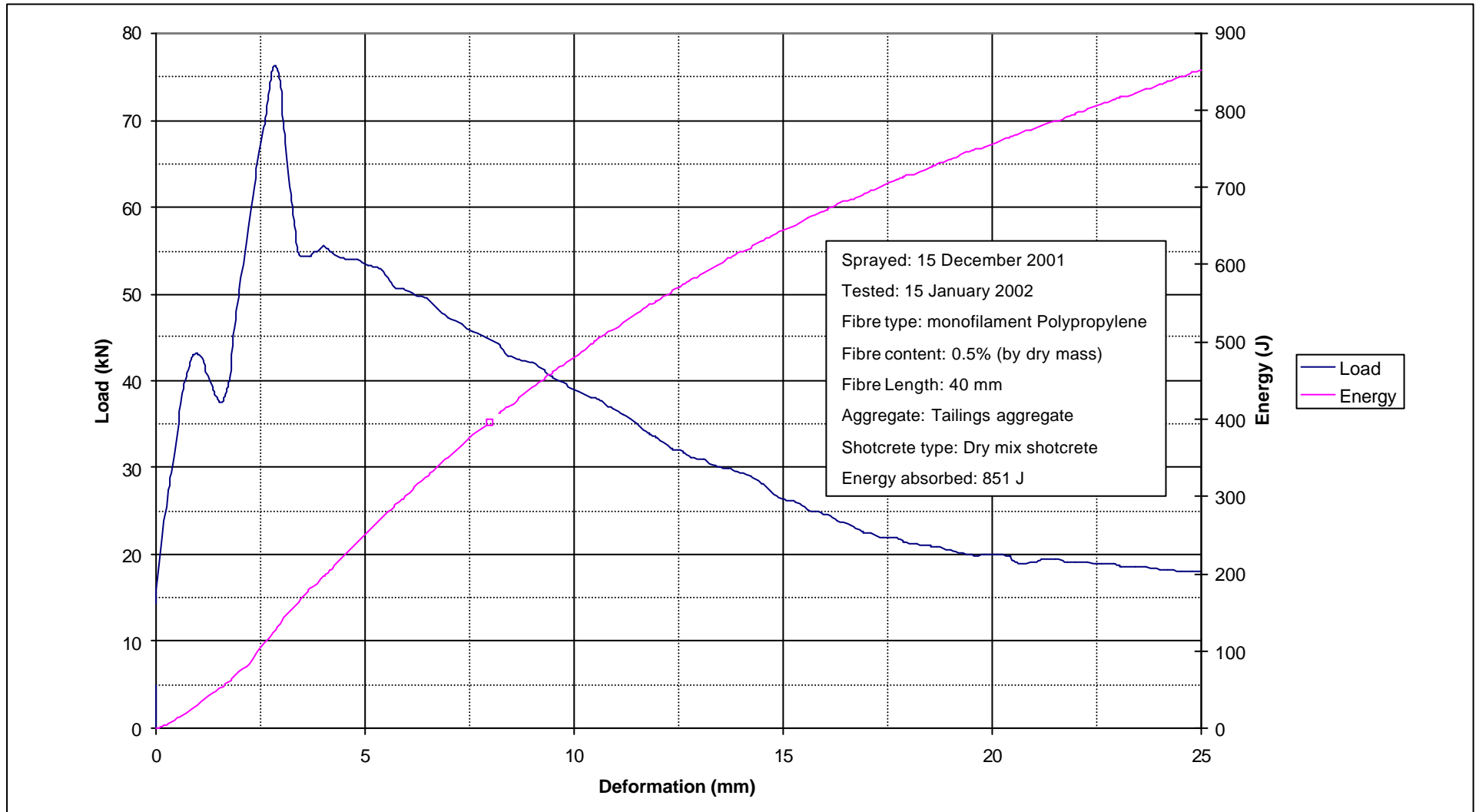
FIG. No.
E4



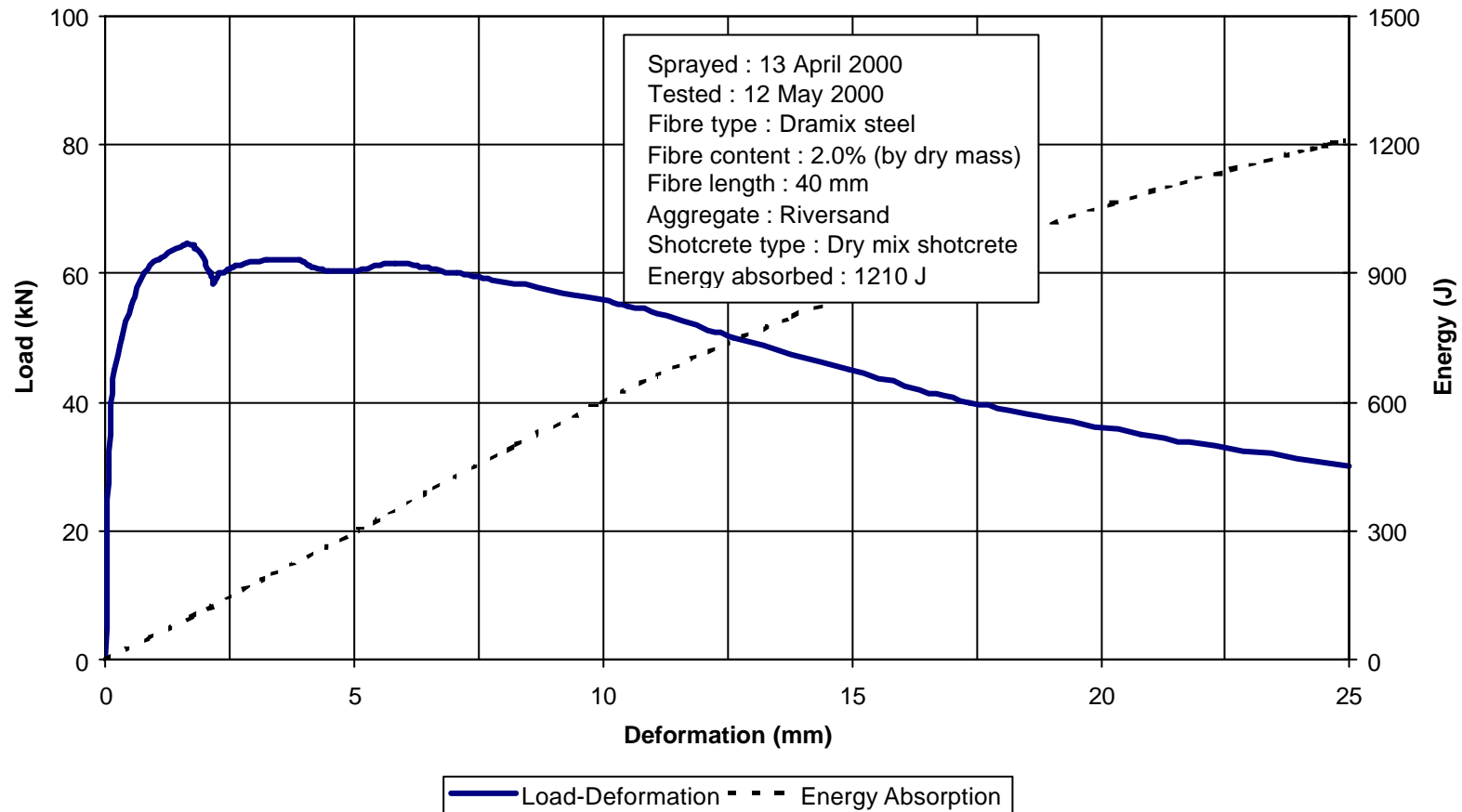
JOB No.
278821

Section 3 (Polypropylene fibre reinforced tailings aggregate shotcrete)- Test 1

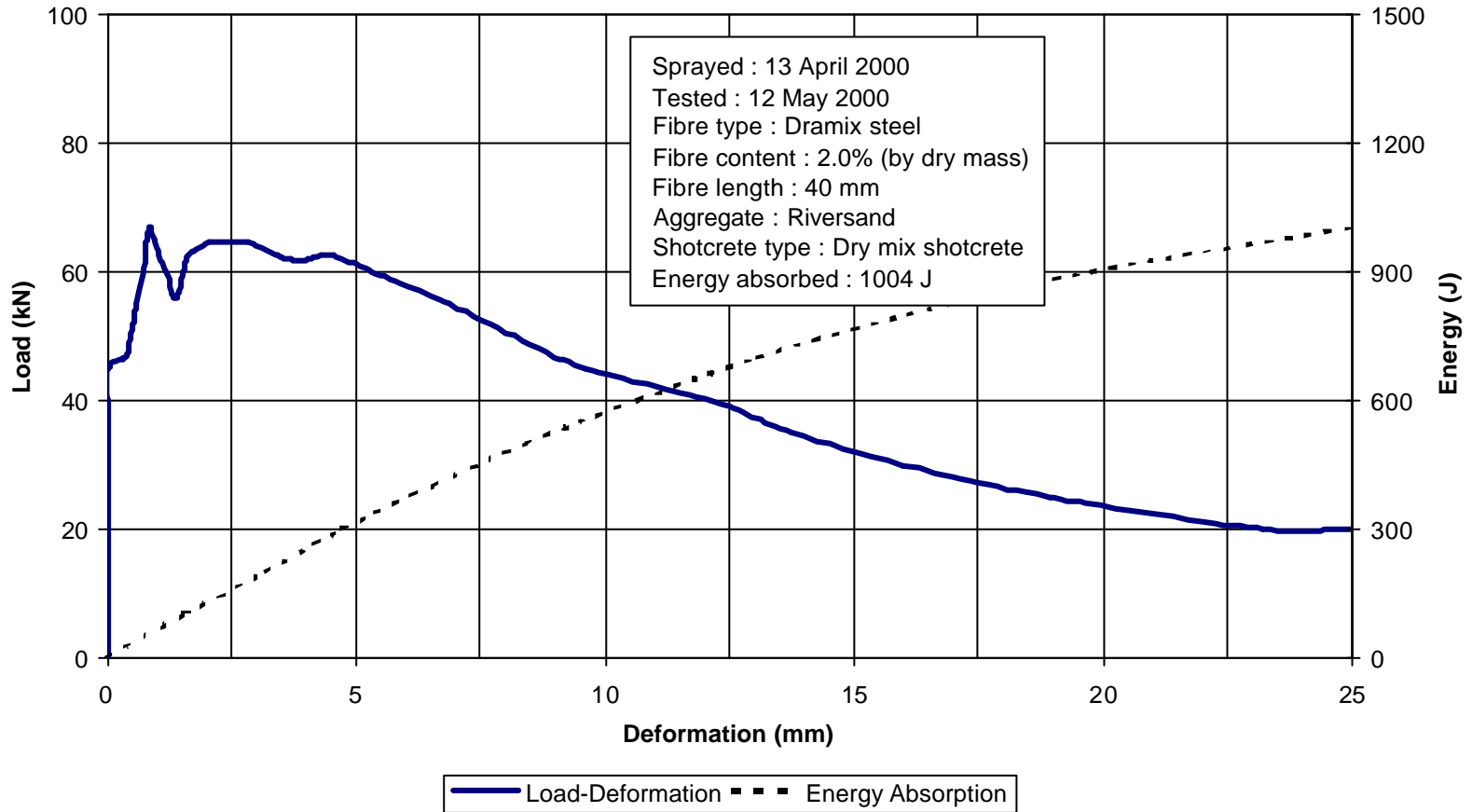
FIG. No.
E5



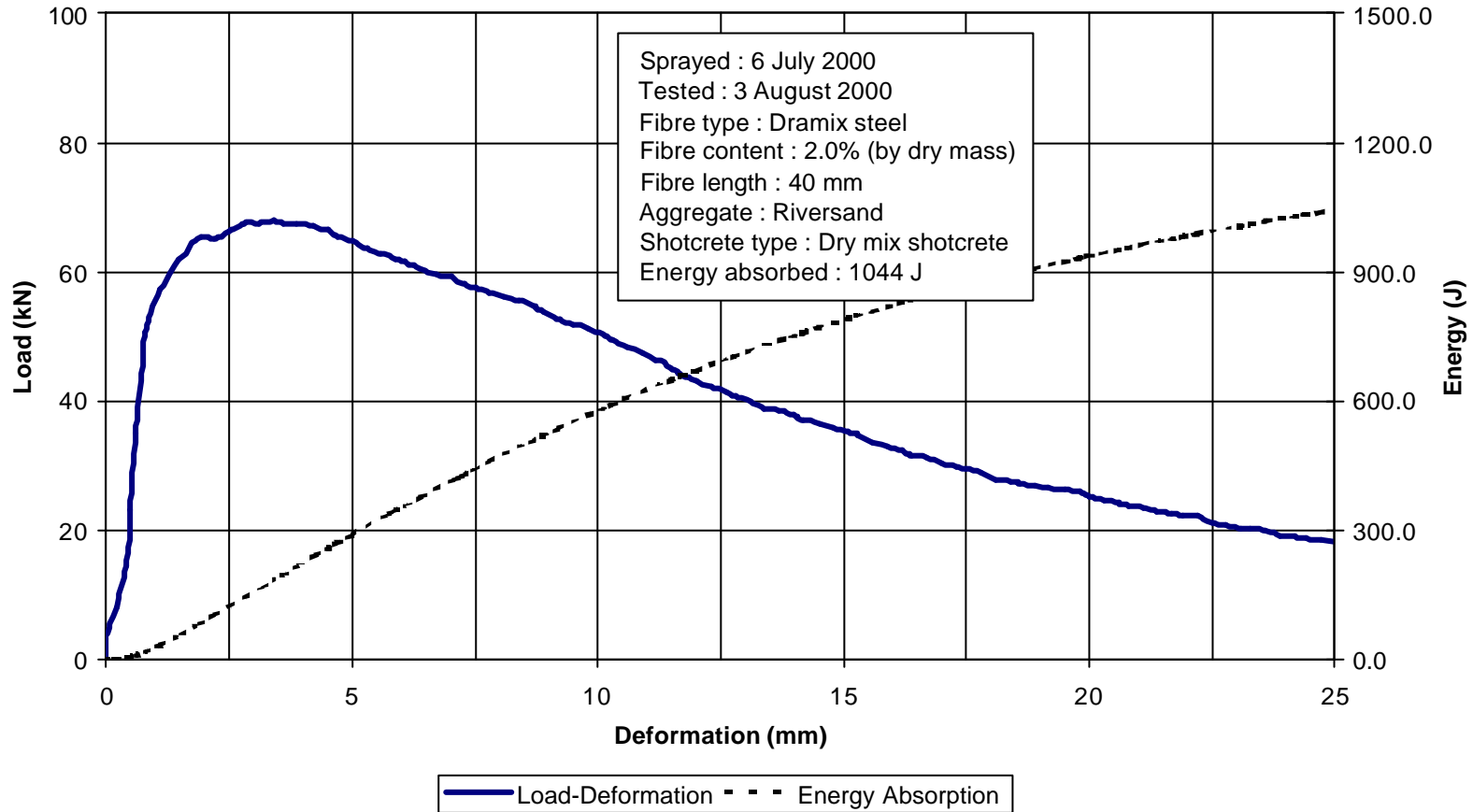
EFNARC Panel O1-AB



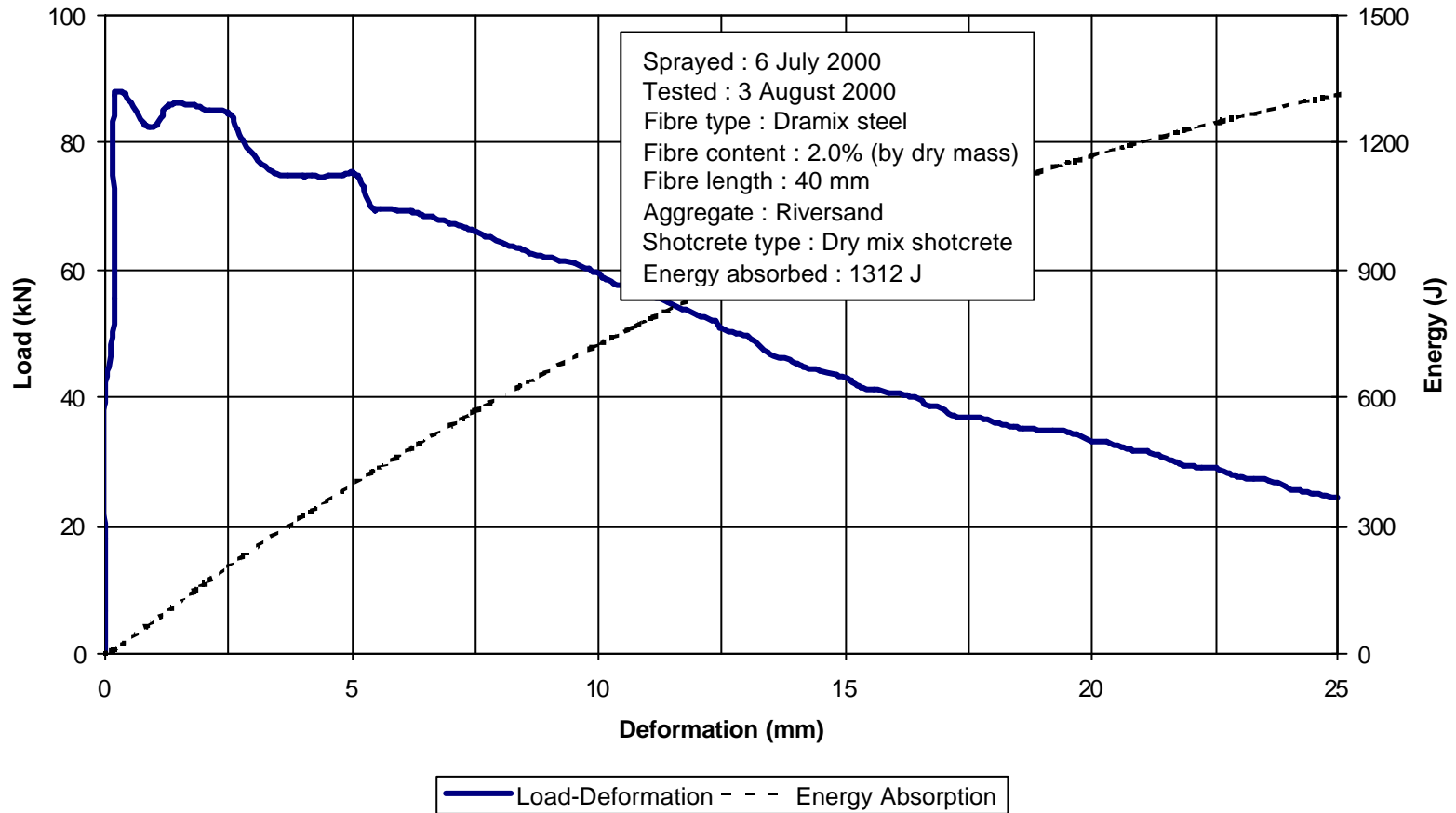
EFNARC Panel O1-CD



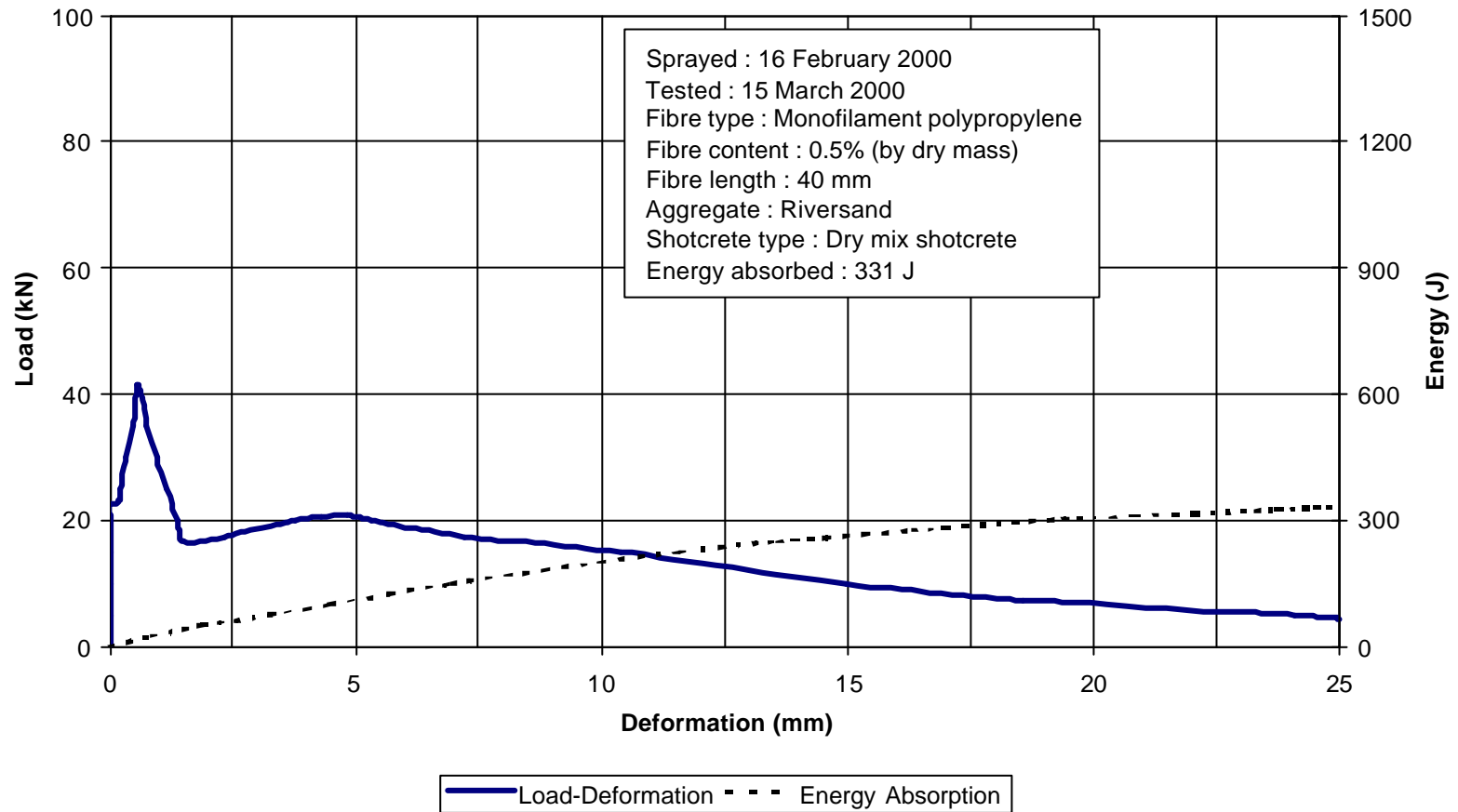
EFNARC Panel O1-F



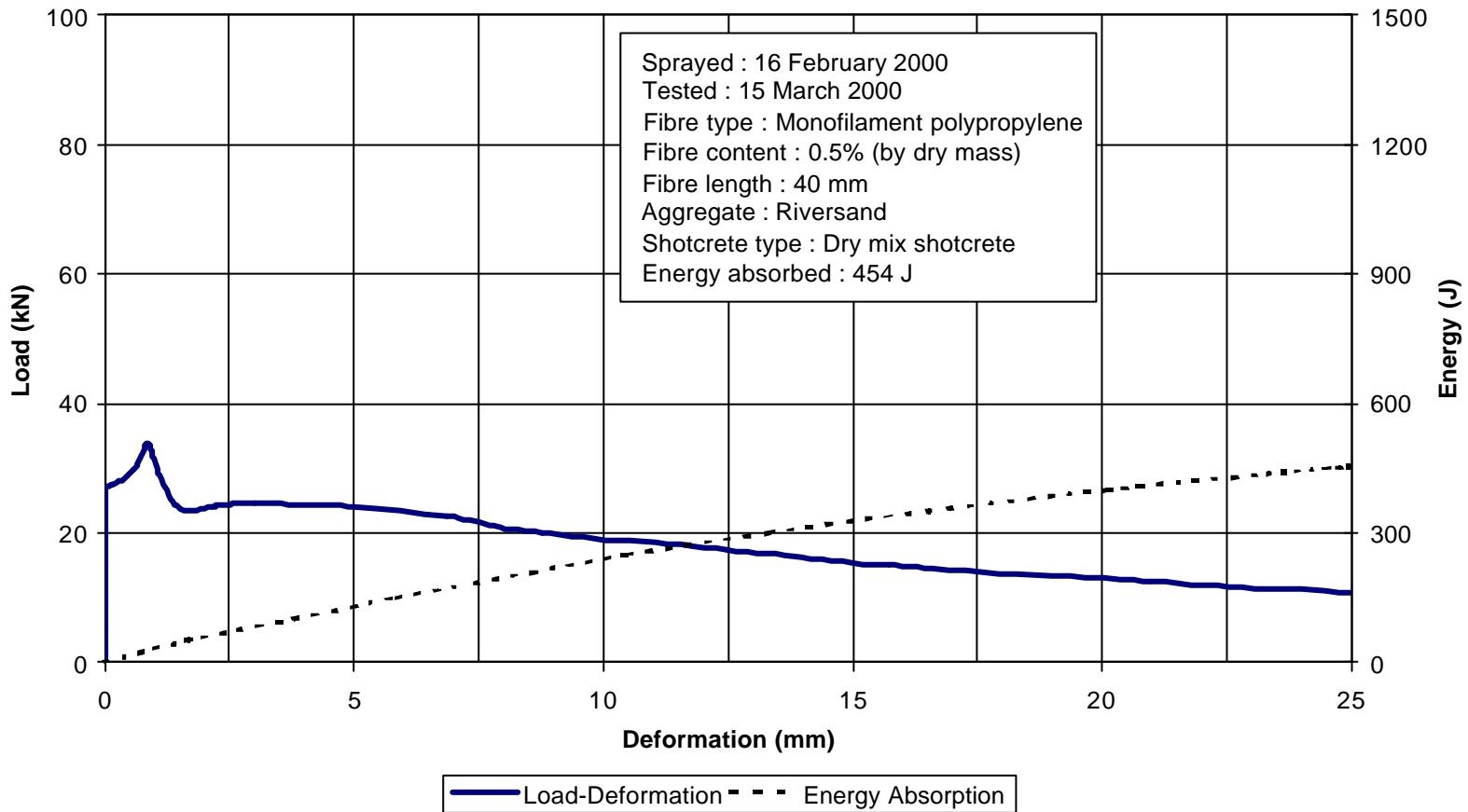
EFNARC Panel O1-H



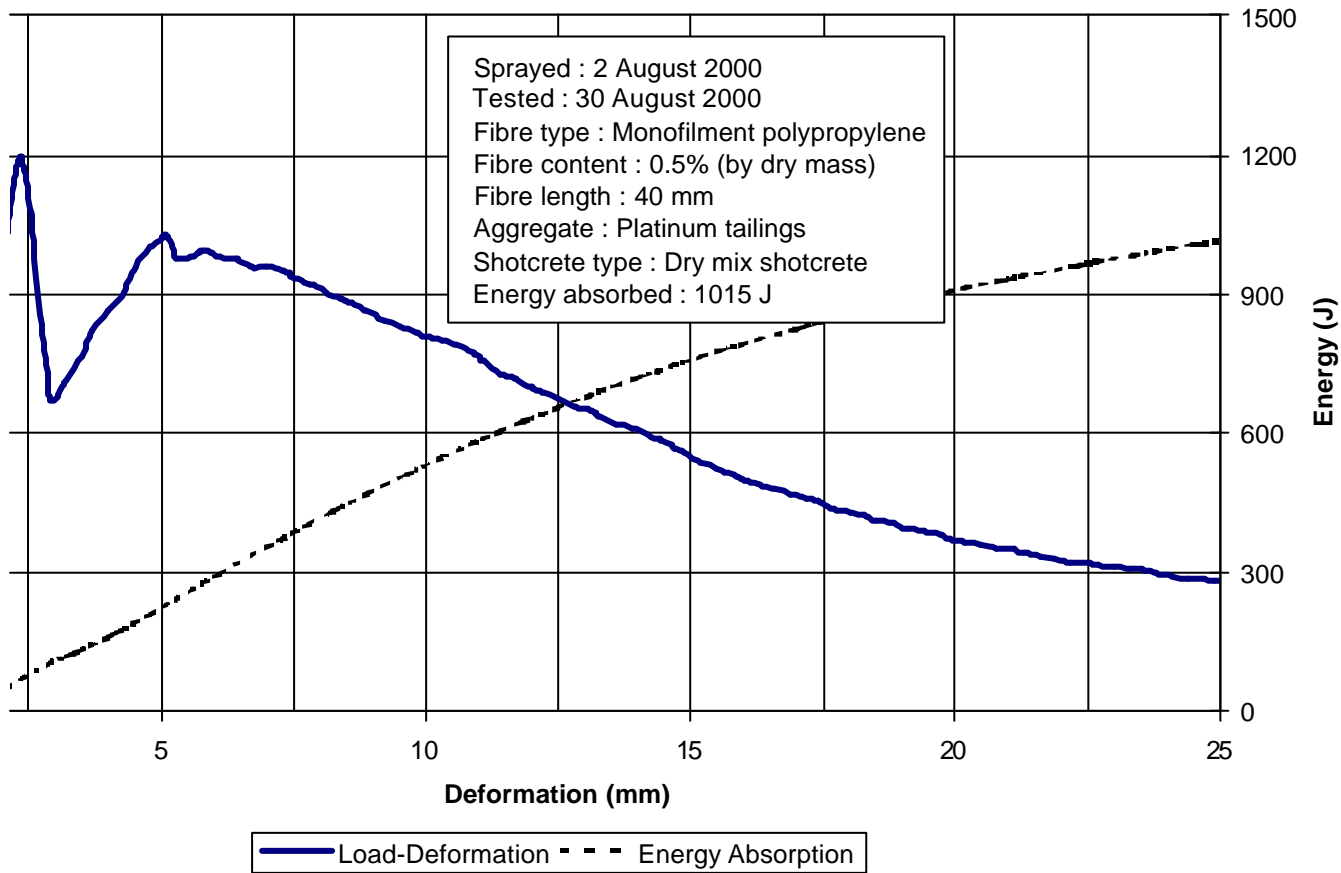
EFNARC Panel A1-IJ



EFNARC Panel A1-KL



EFNARC Panel H5-B



result from the Shotcrete Working Group which is comparable to the sprayed panel for Section 3

FIG. No.
E13

Appendix F

a) Borehole 1/1



b) Borehole 2/1



c) Borehole 3/1



JOB No.
278821

Section 1 (Steel fibre reinforced shotcrete) boreholes (dotted line indicates the contact between shotcrete and rock)

FIG. No.
F1

a) Core 1/1



b) Core 1/1



c) Core 2/1



d) Core 3/1



JOB No.
278821

Section 1 (Steel fibre reinforced shotcrete) cores (dotted line indicates the contact between shotcrete and rock)

FIG. No.
F2

a) Borehole 1/2



b) Borehole 2/2



c) Borehole 3/2



JOB No.
278821

Section 2 (Polypropylene fibre reinforced shotcrete) boreholes (dotted line indicates the contact between shotcrete and rock)

FIG. No.
F3

a) Core 1/2



b) Core 2/2



JOB No.
278821

Section 2 (Polypropylene fibre reinforced shotcrete) cores (dotted line indicates the contact between shotcrete and rock)

FIG. No.
F4

a) Borehole 1/3



b) Borehole 2/3



c) Borehole 3/3



JOB No.
278821

Section 3 (Tailings aggregate polypropylene fibre reinforced shotcrete) boreholes (dotted line indicates the contact between shotcrete and rock)

FIG. No.
F5

a) Core 1/3



b) Core 1/3



c) Core 2/3



d) Core 3/3



JOB No.
278821

Section 3 (Tailings aggregate polypropylene fibre reinforced shotcrete) cores (dotted line indicates the contact between shotcrete and rock)

FIG. No.
F6

a) Borehole 1/4



b) Borehole 2/4



a) Core 1/4



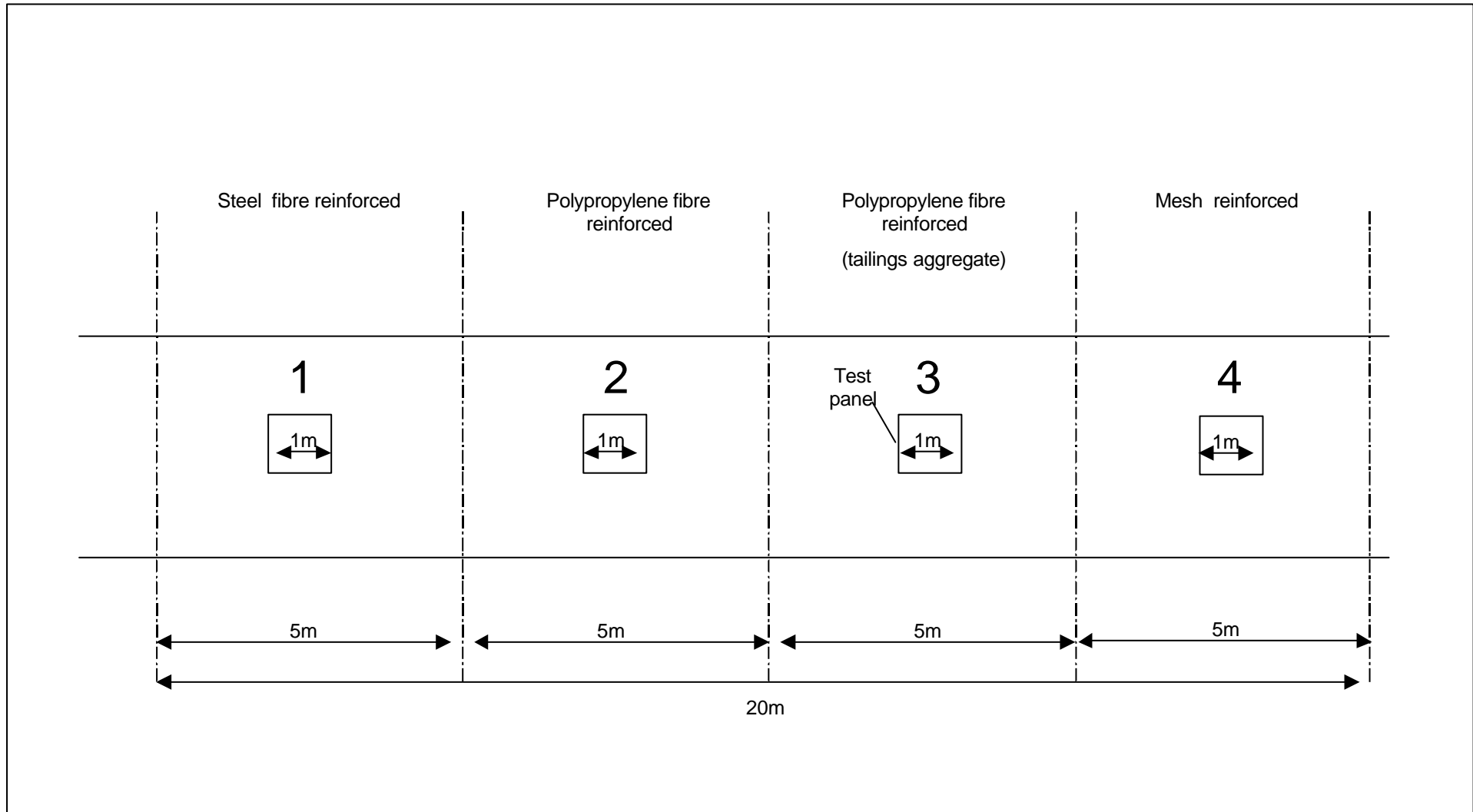
c) Core 3/4



(Mesh reinforced shotcrete) cores (dotted line indicates the contact between shotcrete and rock)

FIG. No.
F8

Appendix G

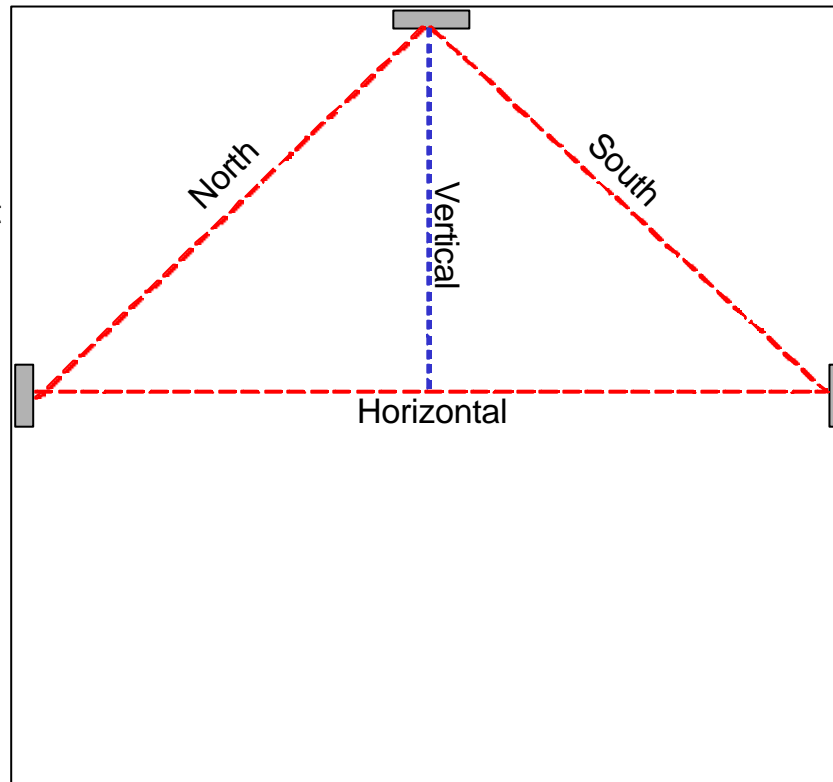


JOB No.
278821

Detailed test site layout

FIG No.
G 1

--- Tape measurement
--- Laser measurement

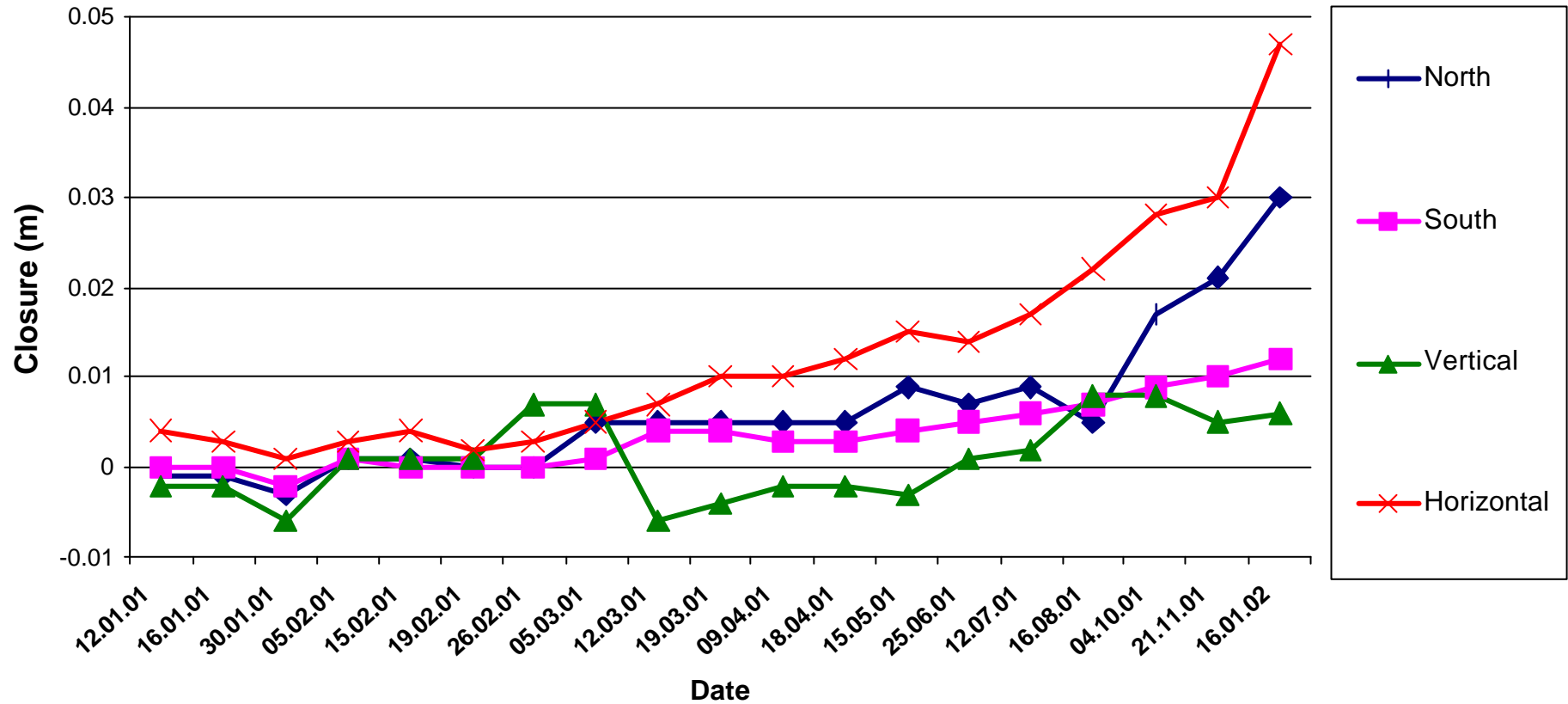


JOB No.
278821

Tunnel cross section showing deformation measurements

FIG. No.
G1

Shotcrete 1

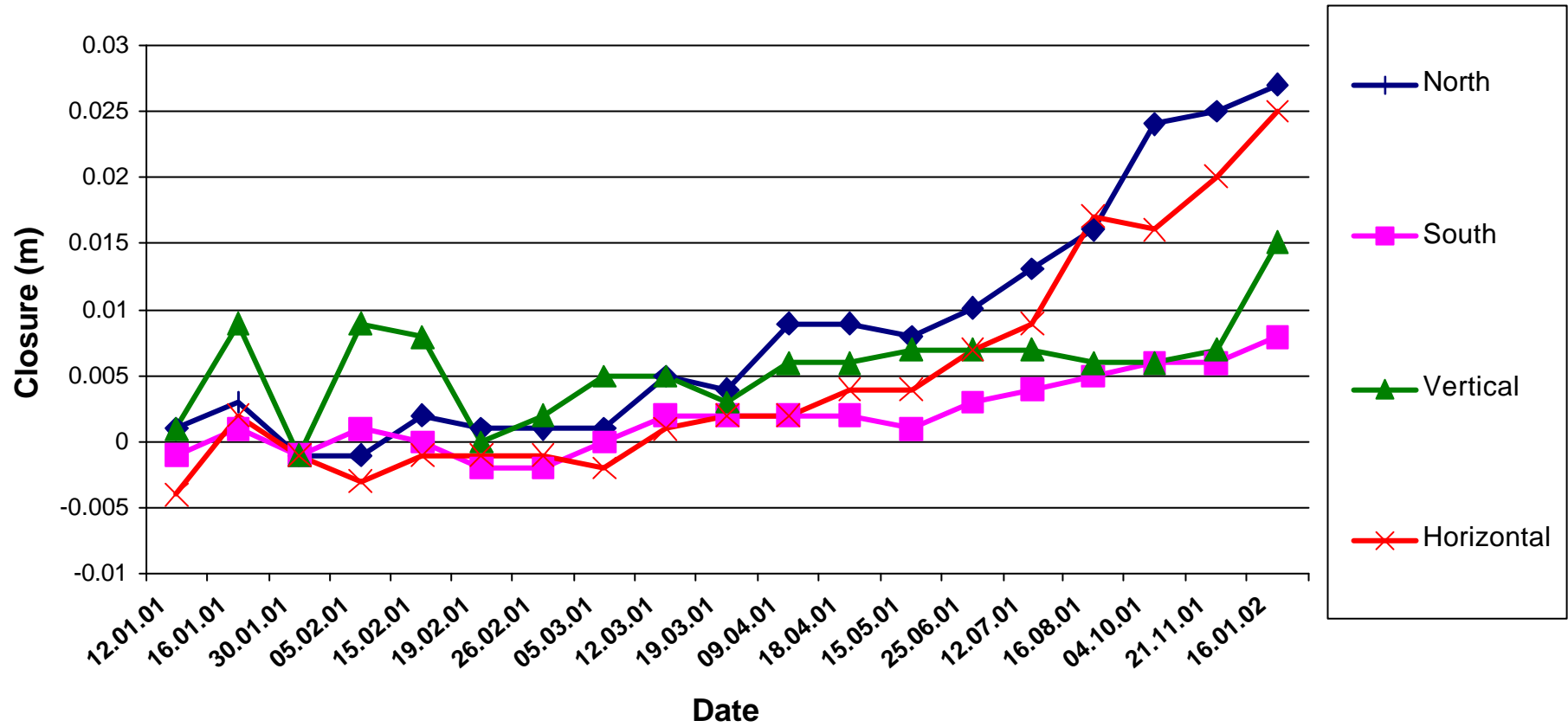


JOB No.
278821

Closure measurements (Section 1 Steel fibre reinforced, ordinary aggregate)

FIG No.
G 3

Shotcrete 2

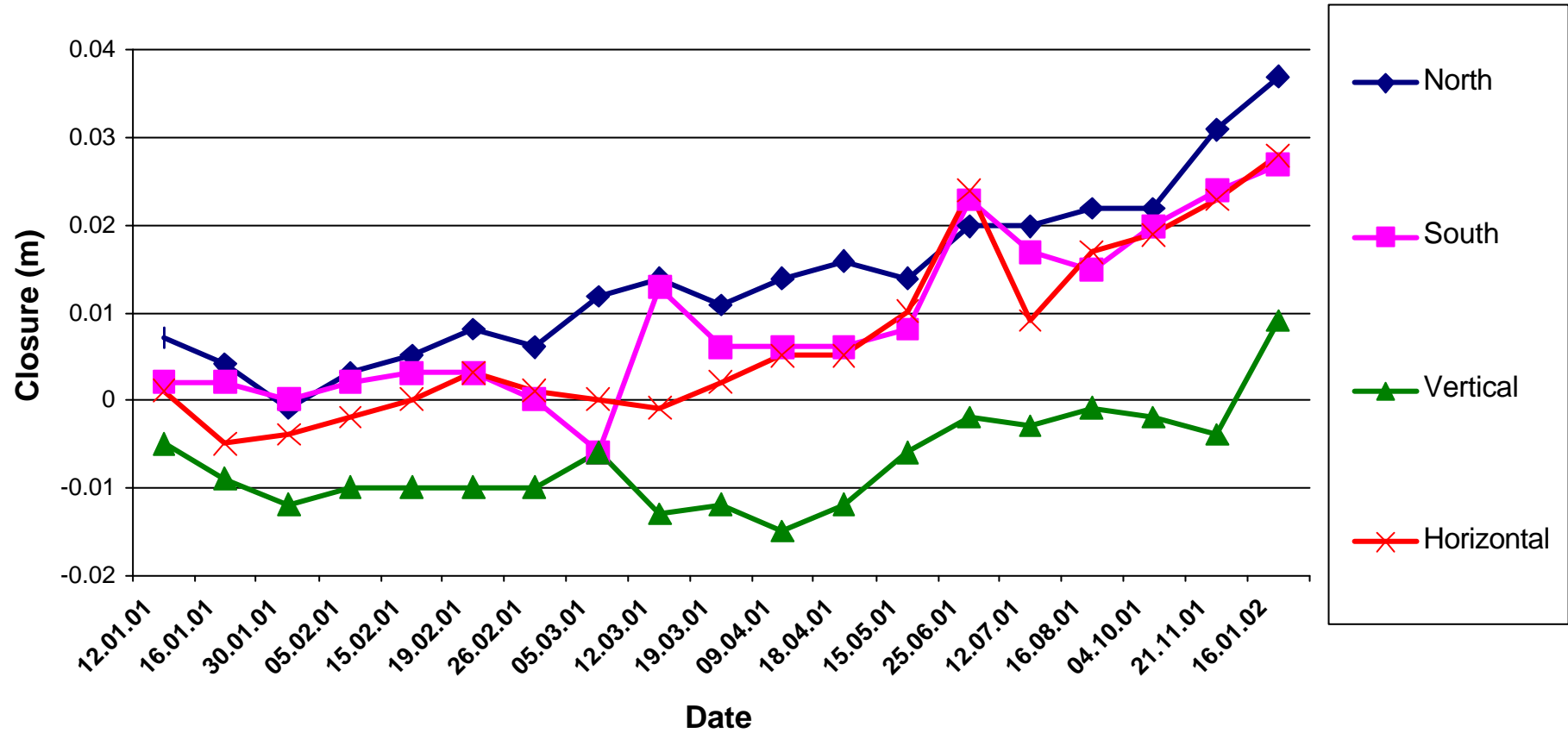


JOB No.
278821

Closure measurements (Section 2 – Polypropylene fibre reinforcement, ordinary aggregate)

FIG No.
G 4

Shotcrete 3

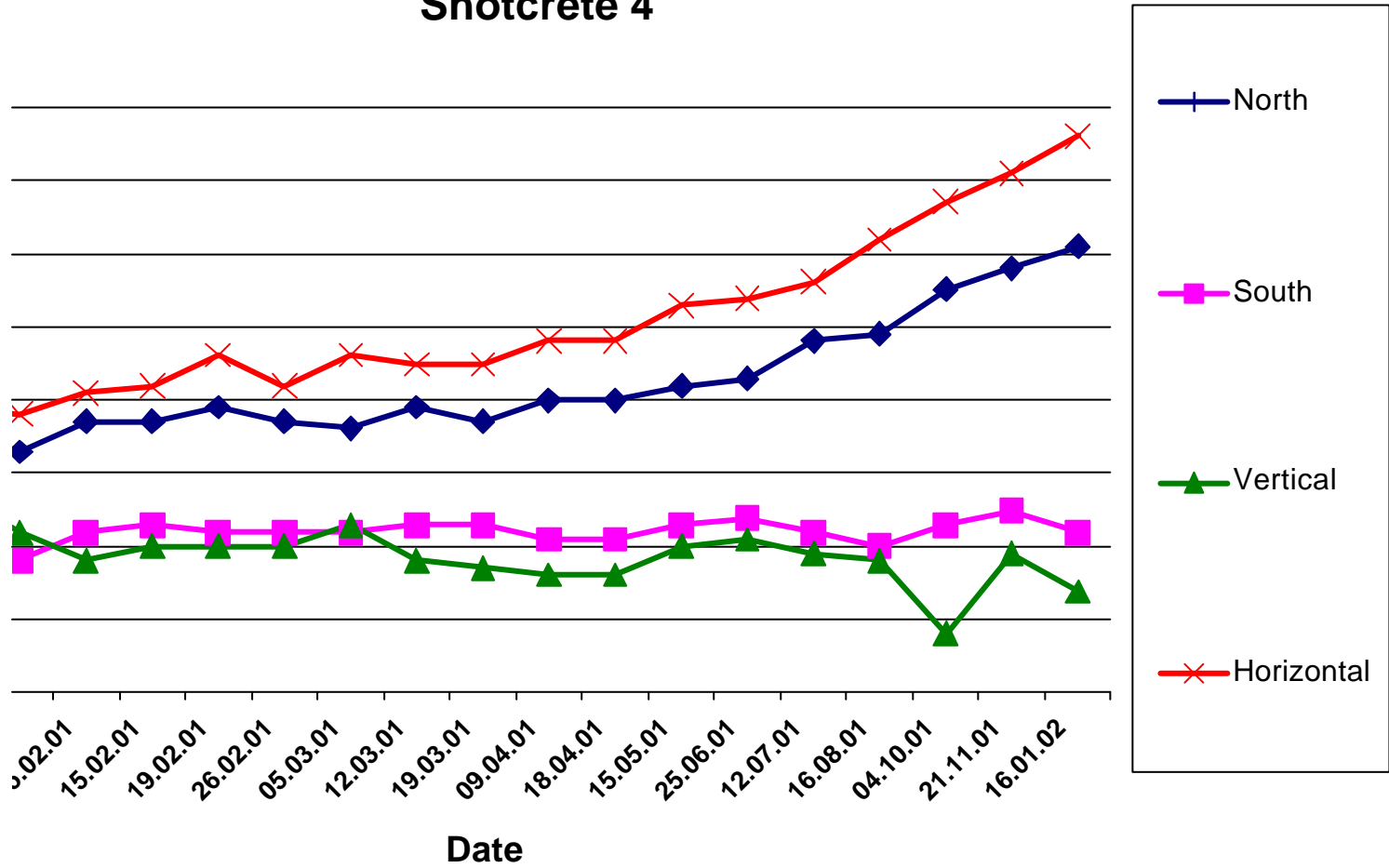


JOB No.
278821

Closure measurements (Section 3 – Polypropylene fibre reinforcement, tailings aggregate)

FIG No.
G 5

Shotcrete 4



Closure measurements (Section 4 – Mesh reinforcement, ordinary aggregate)

FIG No.
 G 6

Appendix H

OHMS (2001-01-16)

Panel 1 North (16/01/2001)



Panel 1 South (16/01/2001)

JOB No.
278821

Section 1 – Steel fibre reinforced shotcrete (OHMS) - 2001-01-16

FIG. No.
H1

Panel 2 North (16/01/2001)



Panel 2 South (16/01/2001)

JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
2001- 01-16

FIG. No.
H2

Panel 3 North (16/01/2001)



Panel 3 South (16/01/2001)

JOB No.
278821

Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001-01-16

FIG. No.
H3

Panel 4 North (16/01/2001)



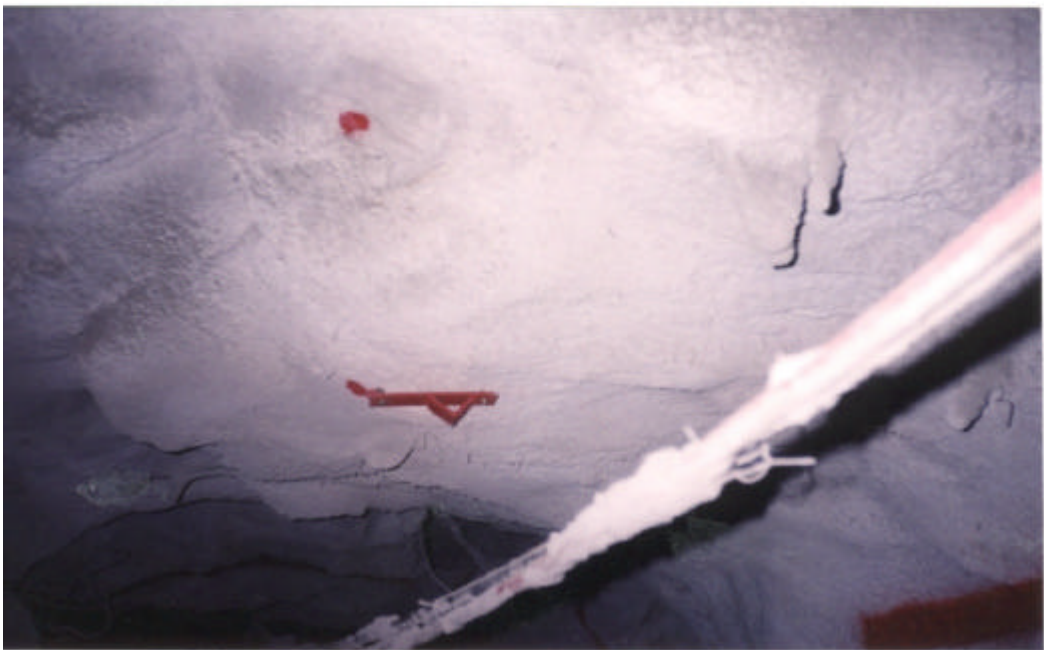
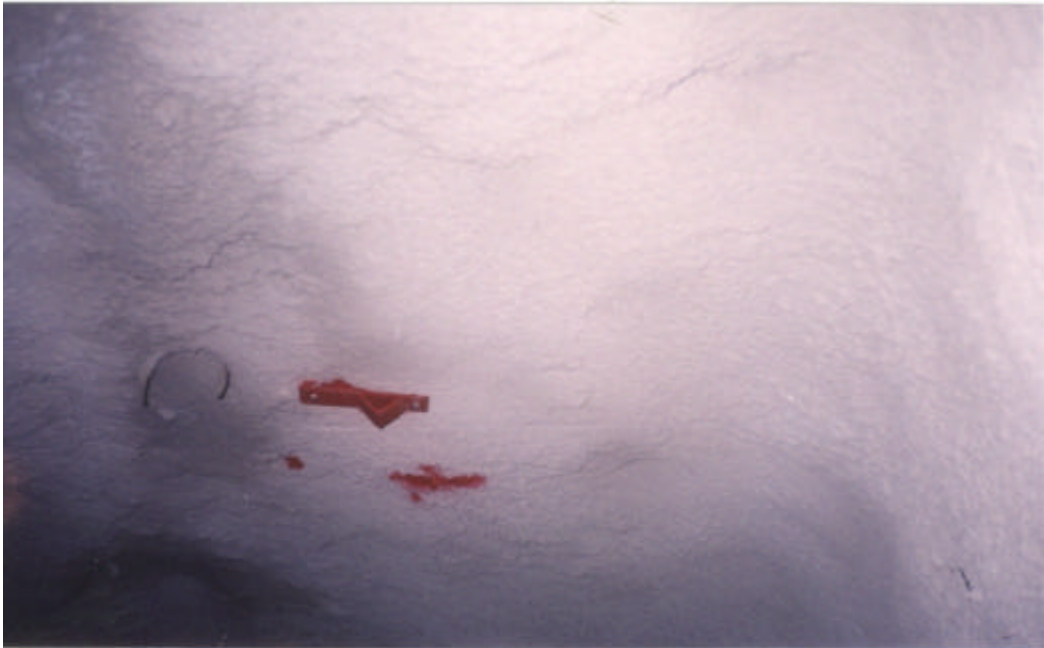
Panel 4 South (16/01/2001)

JOB No.
278821

Section 4 – Mesh reinforced shotcrete (OHMS) - 2001- 01-16

FIG. No.
H4

Hanging wall 1 (16/01/2001)



Hanging wall 2 (16/01/2001)

JOB No.
278821

Hangingwall Section 1 and 2 (OHMS) - 2001-01-16

FIG. No.
H5

Hanging wall 3 (16/01/2001)



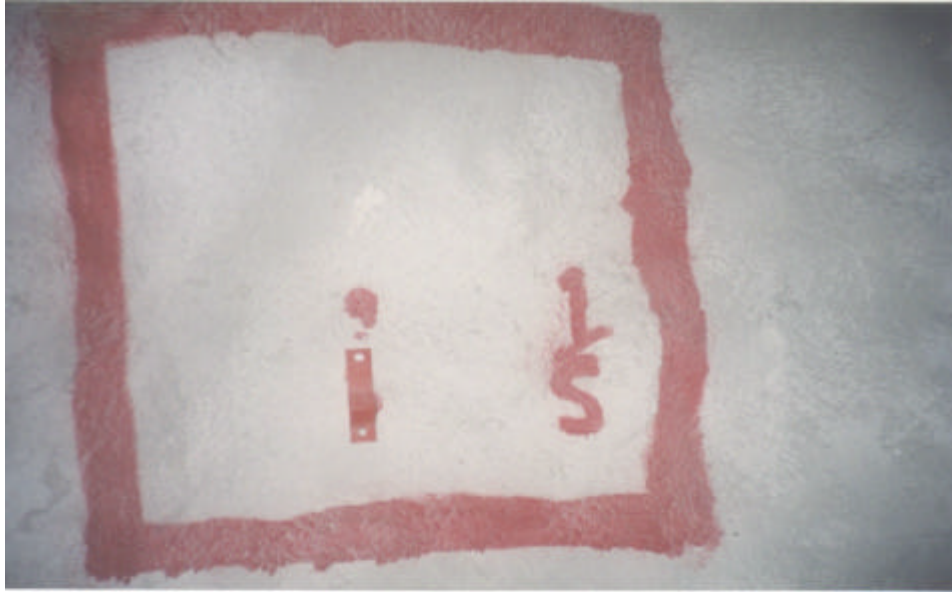
Hanging wall 4 (16/01/2001)

JOB No.
278821

Hangingwall Section 3 and 4 (OHMS) - 2001- 01-16

FIG. No.
H6

OHMS (2001-03-29)



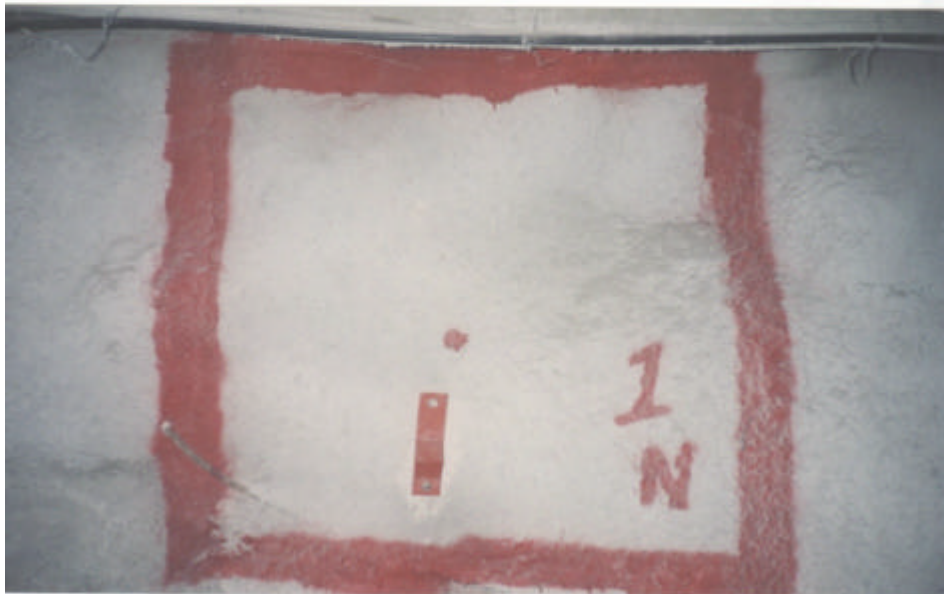
Panel 1 South

Date measured and photo taken: 29/03/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Panel 1 South seems to be stable



Panel 1 North

Date measured and photo taken: 29/03/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Panel 1 North seems to be stable

JOB No.
278821

Section 1 – Steel fibre reinforced shotcrete (OHMS) - 2001-03-29

FIG. No.
H7



Panel 2 South

Date measured and photo taken: 29/03/2001

Crack length: 84cm crack developing

Crack width: 0.5mm crack

Observations: On the left side of the 2 South panel. A crack of 84cm is developing



Panel 2 North

Date measured and photo taken: 29/03/2001

Crack length: No cracks

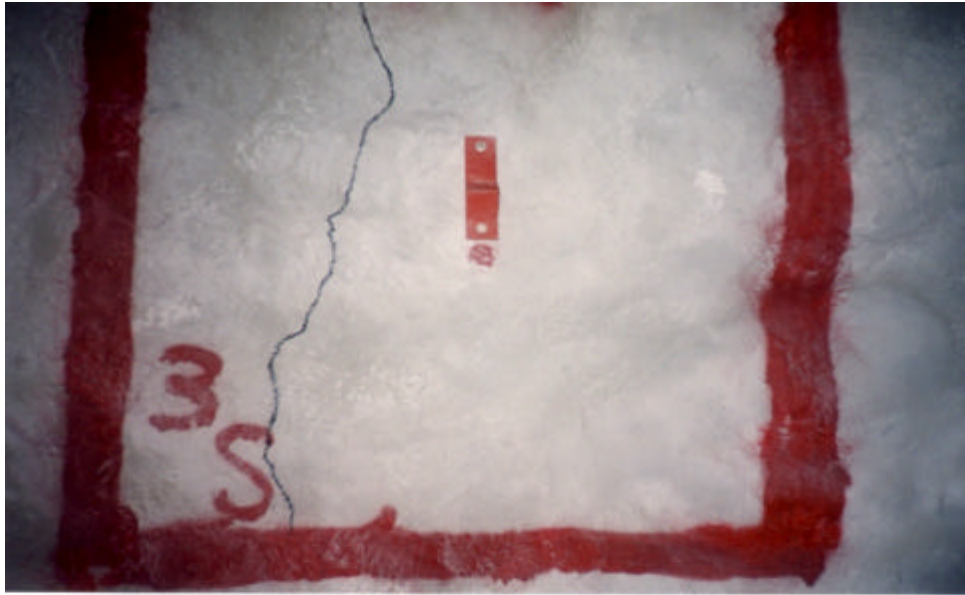
Crack width: No cracks

Observations: No closure was recorded. Panel 2 North seems to be stable

JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
2001- 03-29

FIG. No.
H8



Panel 3 South

Date measured and photo taken: 29/03/2001

Crack length: 97cm long crack developing

Crack width: 0.5mm crack

Observations: A developing crack in the 3 South panel was noticed



Panel 3 North

Date measured and photo taken: 29/03/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Panel 3 North seems to be stable

JOB No.
278821

Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001-03-29

FIG. No.
H9



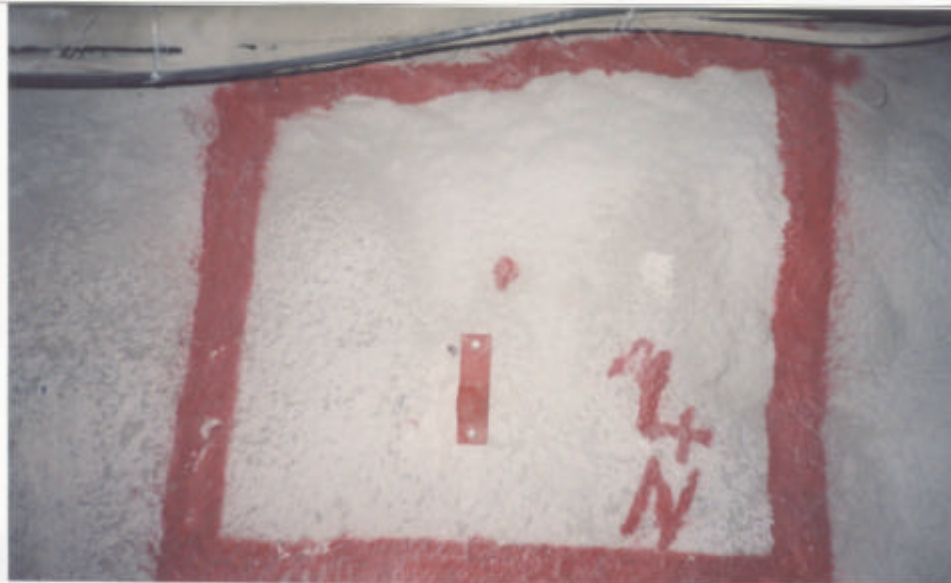
Panel 4 South

Date measured and photo taken: 29/03/2001

Crack length: 110cm long crack and a 20cm long crack

Crack width: Both cracks are 0.5mm wide

Observations: A 110cm crack developing of width 0.5mm runs horizontally across the panel. In the middle of the crack another crack was observed moving in the North-West direction.



Panel 4 North

Date measured and photo taken: 29/03/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Panel 4 North seems to be stable



Hanging wall 1

Date measured and photo taken: 29/03/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Hanging wall No 1 seems to be stable



Hanging wall 2

Date measured and photo taken: 29/03/2001

Crack length: 30cm crack developing

Crack width: 0.5mm crack width

Observations: A crack of 30cm long and 0.5mm wide was noticed on hanging wall No 2

JOB No.
278821

Hangingwall Section 1 and 2 (OHMS) - 2001-03-29

FIG. No.
H11



Hanging wall 3

Date measured and photo taken: 29/03/2001

Crack length: 16cm and a 18cm crack

Crack width: Both cracks are 1mm wide

Observations: A 16cm long and 1mm wide crack was noticed, as well as a 18cm long developing crack of 1mm in width.



Hanging wall 4

Date measured and photo taken: 29/03/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Hanging wall No 4 seems to be stable

JOB No.
278821

Hangingwall Section 3 and 4 (OHMS) - 2001-03-29

FIG. No.
H12

OHMS (2001-04-18)



Panel 1 South

Date measured and photo taken: 18/04/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Panel 1 South seems to be stable



Panel 1 North

Date measured and photo taken: 18/04/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Panel 1 North seems to be stable.

JOB No.
278821

Section 1 – Steel fibre reinforced shotcrete (OHMS) - 2001-04-18

FIG. No.
H13



Panel 2 South

Date measured and photo taken: 18/04/2001
 Crack length: 84cm crack developing
 Crack width: 0.5mm crack
 Observations: On the left side of the 2 South Panel, a crack of 84cm is developing.



Panel 2 North

Date measured and photo taken: 18/04/2001
 Crack length: No cracks
 Crack width: No cracks
 Observations: No closure was recorded. Panel 2 North seems to be stable

JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
2001-04-18

FIG. No.
H14



Panel 3 South

Date measured and photo taken: 18/04/2001
Crack length: 97cm long crack developing
Crack width: 0.5mm crack
Observations: A developing crack in the 3 South panel was noticed.



Panel 3 North

Date measured and photo taken: 18/04/2001
Crack length: No cracks
Crack width: No cracks
Observations: No closure was recorded. Panel 3 North seems to be stable

JOB No.
278821

Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001-04-18

FIG. No.
H15



Panel 4 South

Date measured and photo taken: 18/04/2001
Crack length: 110cm long crack and a 20cm long crack
Crack width: Both cracks are 0.5mm wide.
Observations: A 110cm crack developing of width 0.5mm runs horizontally across the panel



Panel 4 North

Date measured and photo taken: 18/04/2001
Crack length: No cracks
Crack width: No cracks
Observations: No closure was recorded. Panel 4 North seems to be stable



Hanging wall 1

Date measured and photo taken: 18/04/2001

Crack length: No cracks

Crack width: No cracks

Observations: No closure was recorded. Hanging wall No1 North seems to be stable.



Hanging wall 2

Date measured and photo taken: 18/04/2001

Crack length: 30cm crack developing

Crack width: 0.5mm crack width

Observations: A crack of 30cm long and 0.5mm wide was noticed on hanging wall No 2

JOB No.
278821

Hangingwall Section 1 and 2 (OHMS) - 2001-04-18

FIG. No.
H17



Hanging wall 3

Date measured and photo taken: 18/04/2001

Crack length: 16cm and a 18cm crack

Crack width: Both cracks are 1mm wide

Observations: A 16cm long and 1mm crack was noticed, as well as a 18cm long developing crack of 1mm in width.



Hanging wall 4

Date measured and photo taken: 18/04/2001

Crack length: No cracks

Crack width: No cracks

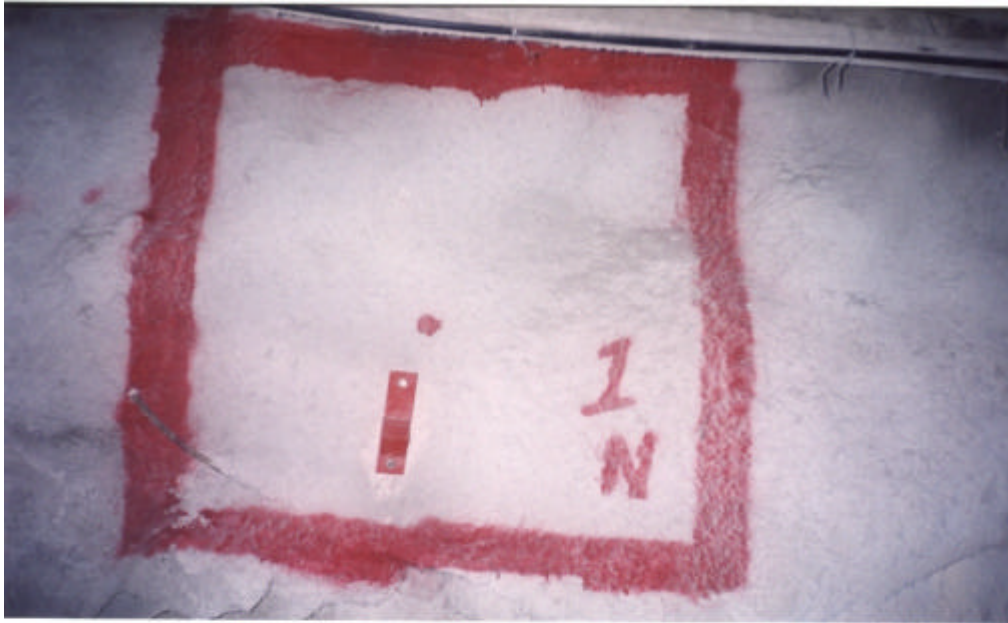
Observations: No closure was recorded. Hanging wall No 4 seems to be stable.

JOB No.
278821

Hangingwall Section 3 and 4 (OHMS) - 2001-04-18

FIG. No.
H18

OHMS (2001-05-15)



Panel 1 North

Date measured and photo taken: 15/5/2001

Observations: No cracks were observed. No closure was recorded.



Panel 2 North

Date measured and photo taken: 15/5/2001

Observations: A 1m long crack of 0.5mm developed from the top of the panel to the bottom on the right side.



Panel 1 South

Date measured and photo taken: 15/5/2001

Observations: No cracks were observed. No closure was recorded.



Panel 2 South

Date measured and photo taken: 15/5/2001

Observations: A small crack of 15cm long extended out of the original crack.

JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
200 -05-15

FIG. No.
H20



Panel 3 South

Date measured and photo taken: 15/5/2001

Observations: The original crack on the left hand side of the panel developed two additional cracks as well as a 0.5mm thick crack on the right hand side of the panel.



Panel 3 North

Date measured and photo taken: 15/5/2001

Observations: No cracks are seen in the No 3 North panel

JOB No.
278821

Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001\ -05-15

FIG. No.
H21



Panel 4 North

Date measured and photo taken: 15/5/2001

Observations: A 20cm crack seems to be developing in the bottom right hand corner of the panel.



Panel 4 South

Date measured and photo taken: 15/5/2001

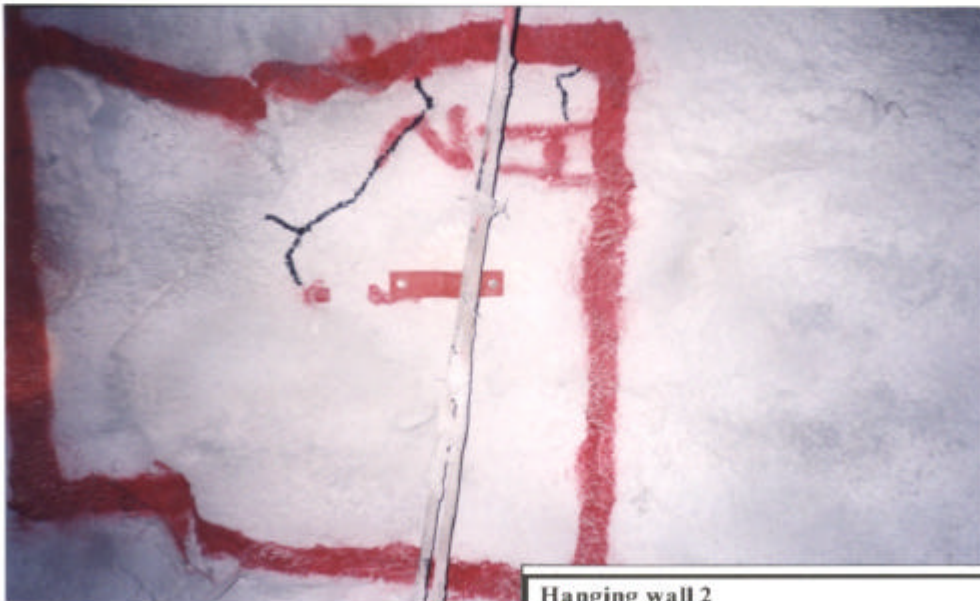
Observations: As seen in the photo, a group of cracks extended from the previous crack.

The bottom left of the panel seems to be cracking the most.



Hanging wall 1

Date measured and photo taken: 15/5/2001
Observations: No cracks observed



Hanging wall 2

Date measured and photo taken: 15/5/2001
Observations: A 20cm long crack was noticed in the center of the hanging wall panel extending to the right.

JOB No.
278821

Hangingwall Section 1 and 2 (OHMS) - 2001 -05-15

FIG. No.
H23



Hanging wall 3

Date measured and photo taken: 15/5/2001

Observations: The same cracks as in the previous photographs are seen.

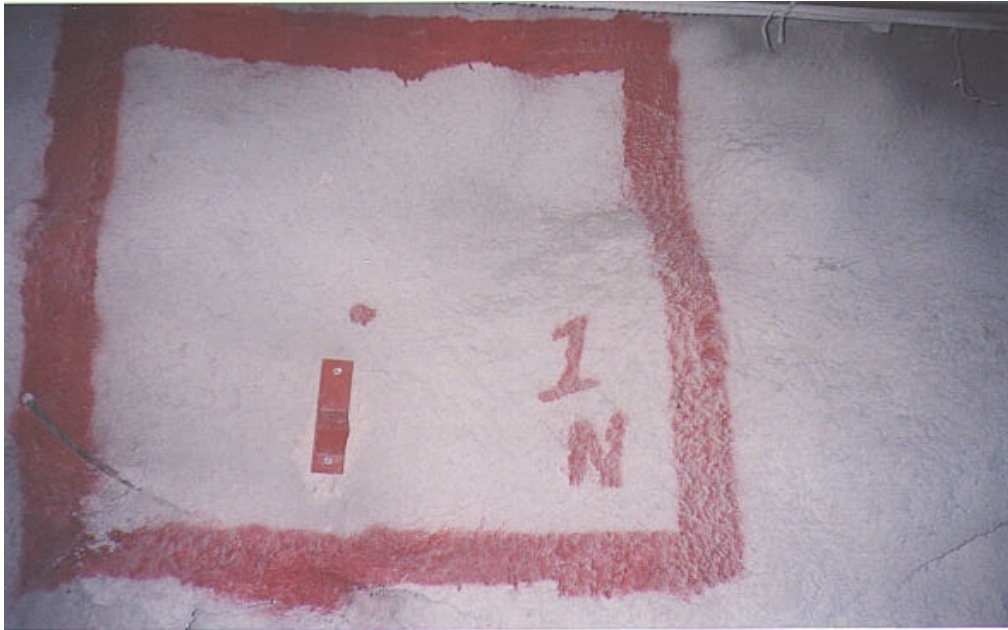


Hanging wall 4

Date measured and photo taken: 15/5/2001

Observations: No cracks can be seen.

OHMS (2001-07-19)



Panel 1 North

Date measured and photo taken: 19/7/2001
Observations: Same conditions as last observed



Panel 1 South

Date measured and photo taken: 19/7/2001
Observations: Same conditions as last observed

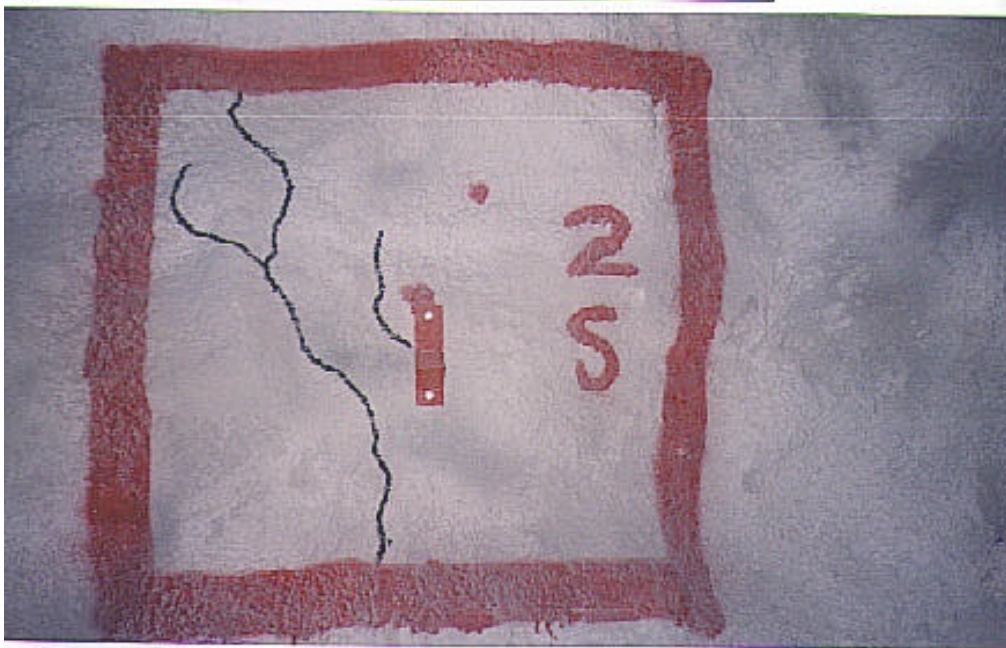
JOB No.
278821

Section 1 – Steel fibre reinforced shotcrete (OHMS) - 2001-07-19

FIG. No.
H25



Panel 2 North
Date measured and photo taken: 19/7/2001
Observations: Same conditions as last observed



Panel 2 South
Date measured and photo taken: 19/7/2001
Observations: Same conditions as last observed

JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
2001-07-19

FIG. No.
H26



Panel 3 North

Date measured and photo taken: 19/7/2001

Observations: Same conditions as last observed



Panel 3 South

Date measured and photo taken: 19/7/2001

Observations: Same conditions as last observed

JOB No.
278821

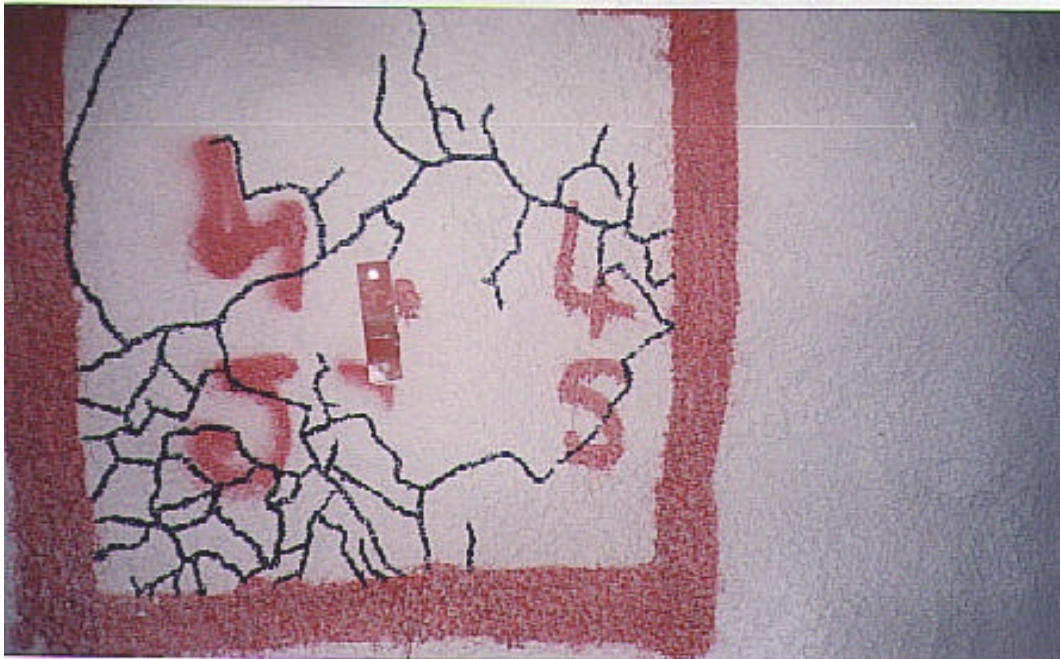
Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001-07-19

FIG. No.
H27



Panel 4 North

Date measured and photo taken: 19/7/2001
Observations: Same conditions as last observed



Panel 4 South

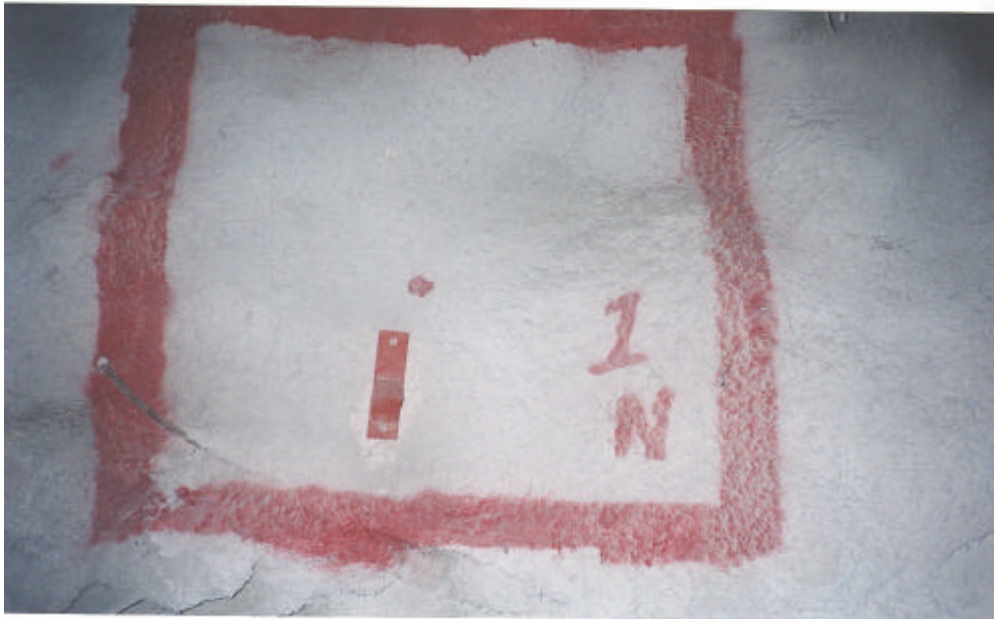
Date measured and photo taken: 19/7/2001
Observations: Same conditions as last observed

OHMS (2001-08-16)



Panel 1 South

Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed



Panel 1 North

Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed

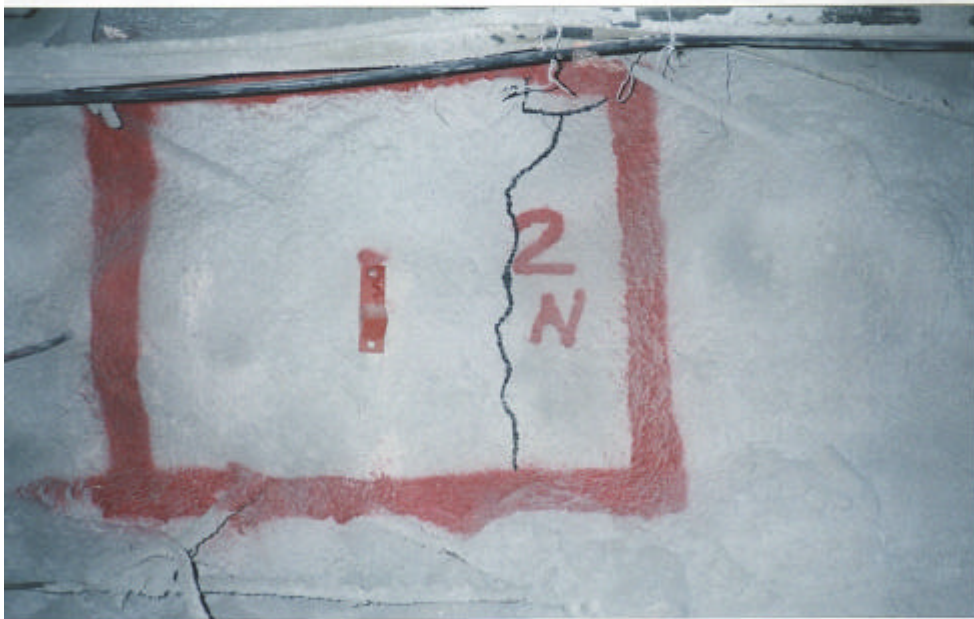
JOB No.
278821

Section 1 – Steel fibre reinforced shotcrete (OHMS) - 2001-08-16

FIG. No.
H29



Panel 2 South
Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed

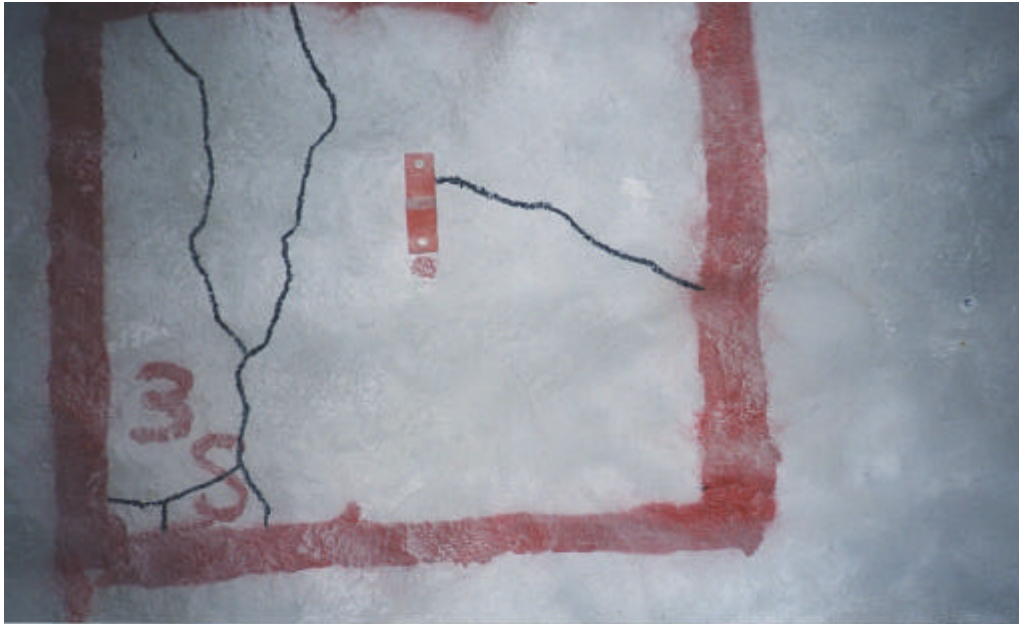


Panel 2 North
Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed

JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
2001-08-16

FIG. No.
H30



Panel 3 South

Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed



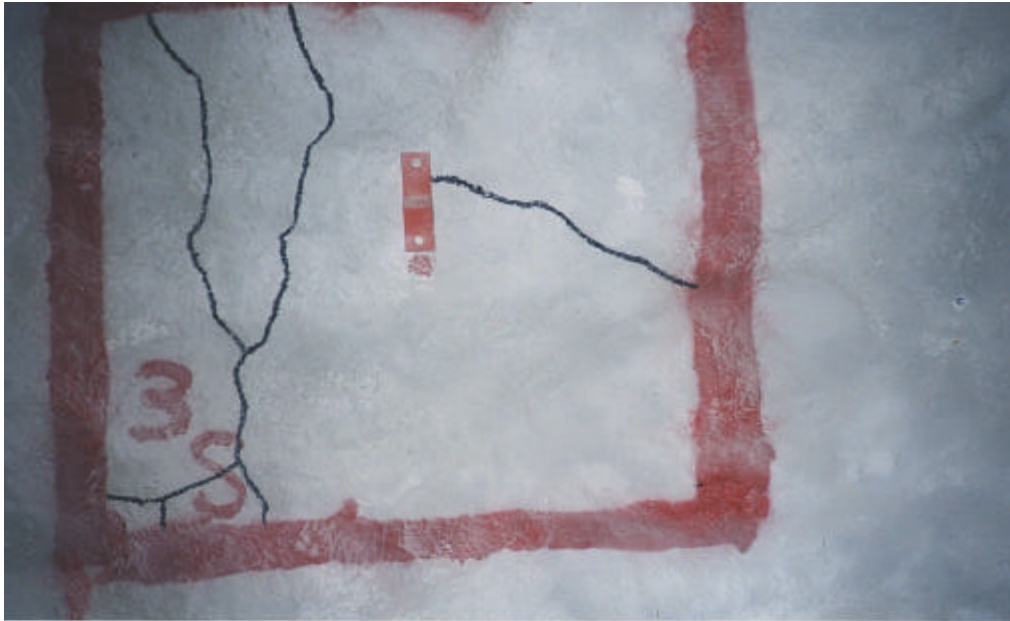
Panel 3 North

Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed

JOB No.
278821

Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001-08-16

FIG. No.
H31



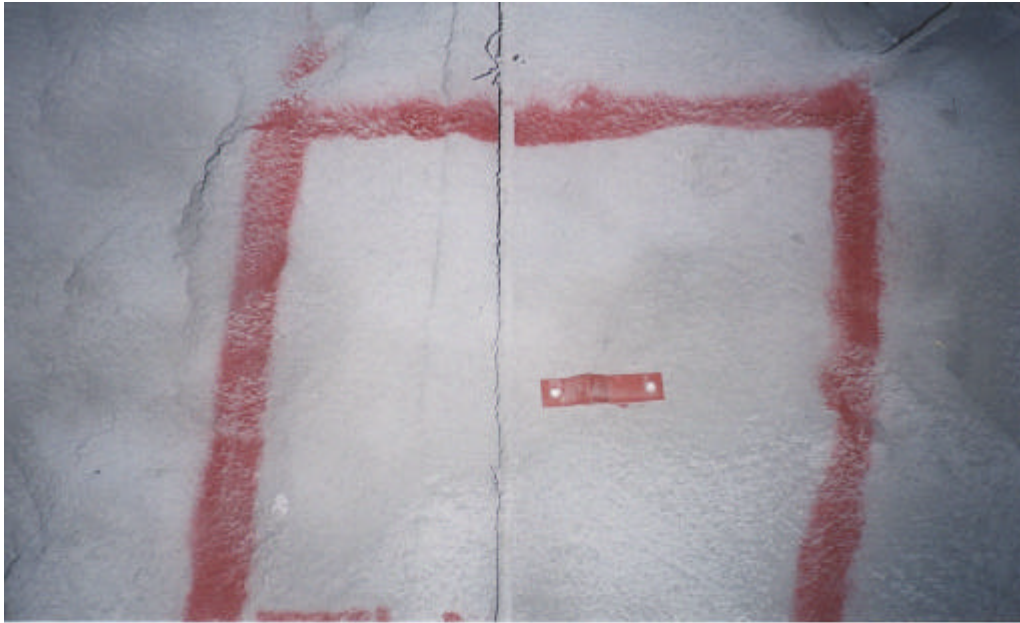
Panel 3 South

Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed



Panel 3 North

Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed



Hanging wall 1

Date measured and photo taken: 16/08/2001

Observations: Same conditions as last observed



Hanging wall 2

Date measured and photo taken: 16/08/2001

Observations: Same conditions as last observed



Hanging wall 3

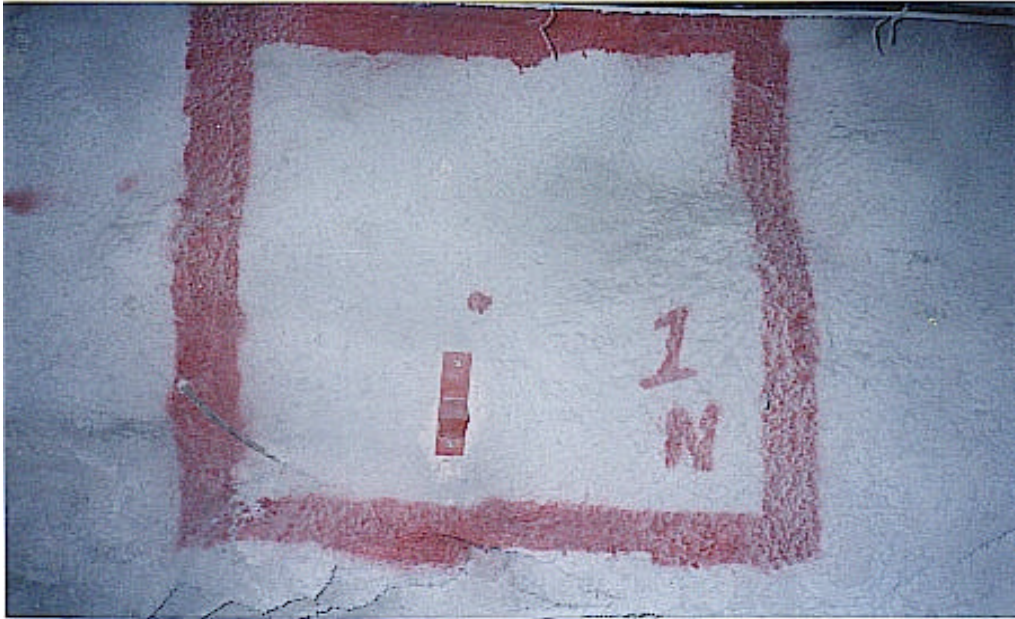
Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed



Hanging wall 4

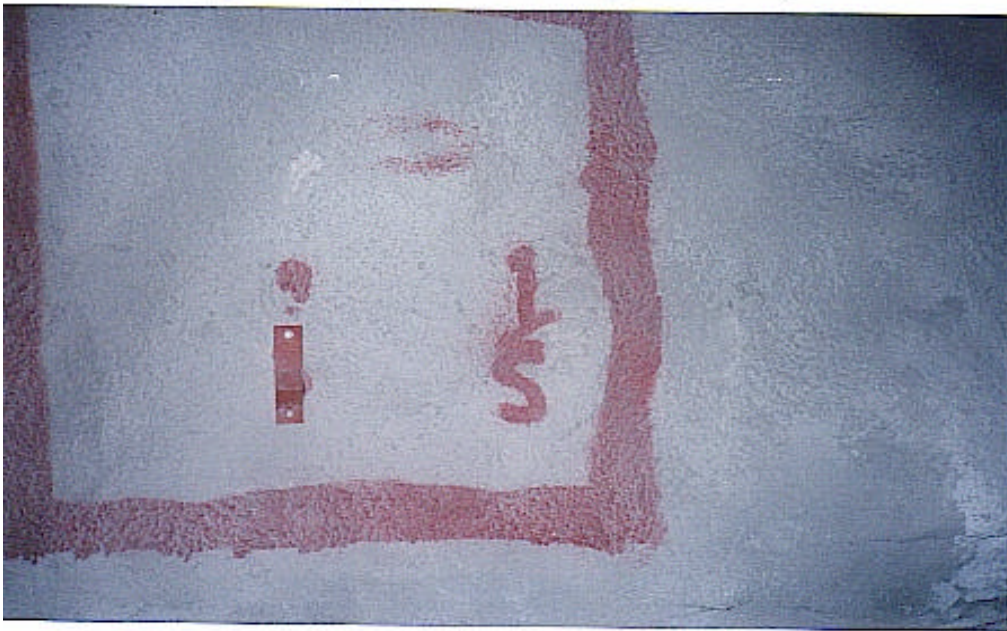
Date measured and photo taken: 16/08/2001
Observations: Same conditions as last observed

OHMS (2001-10-19)



Panel 1 North

Date measured and photo taken: 19/10/2001
Observations: Same conditions as last observed



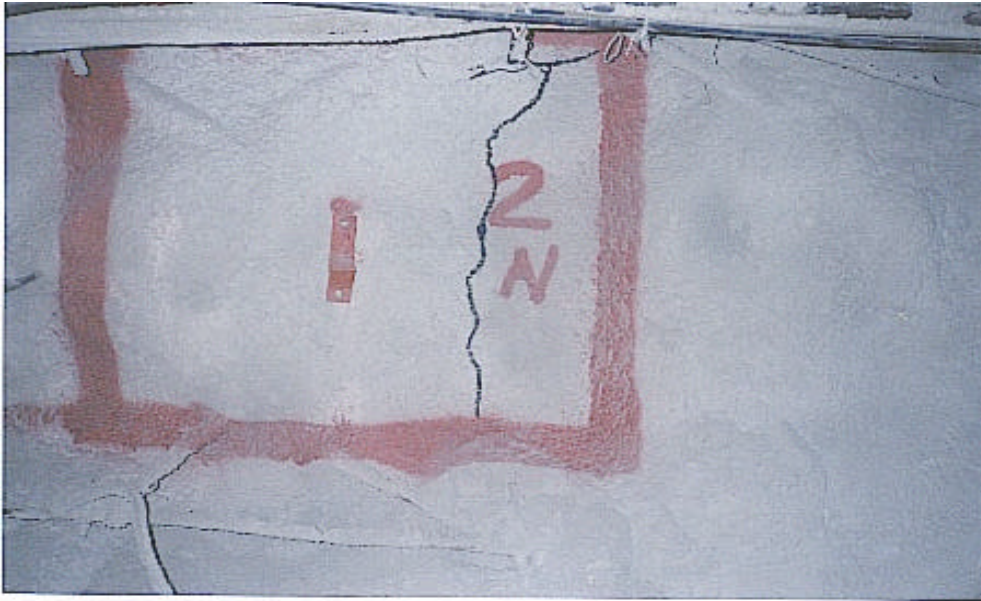
Panel 1 South

Date measured and photo taken: 19/10/2001
Observations: Same conditions as last observed

JOB No.
278821

Section 1 – Steel fibre reinforced shotcrete (OHMS) - 2001-10-19

FIG. No.
H35



Panel 2 North

Date measured and photo taken: 19/10/2001
Observations: Same conditions as last observed



Panel 2 South

Date measured and photo taken: 19/10/2001
Observations: Same conditions as last observed

JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
2001-10-19

FIG. No.
H36



Panel 3 North

Date measured and photo taken: 19/10/2001
Observations: Same conditions as last observed



Panel 3 South

Date measured and photo taken: 19/10/2001
Observations: Same conditions as last observed

JOB No.
278821

Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001-10-19

FIG. No.
H37



Panel 4 North

Date measured and photo taken: 19/10/2001

Observations: Same conditions as last observed



Panel 4 South

Date measured and photo taken: 19/10/2001

Observations: Same conditions as last observed

JOB No.
278821

Section 4 – Mesh reinforced shotcrete (OHMS) - 2001 -10-19

FIG. No.
H38

OHMS (2001-11-22)

Panel 1 South

Date measured and photo taken: 22/11/2001

Observations: Same conditions as last observed



Panel 1 North

Date measured and photo taken: 22/11/2001

Observations: Same conditions as last observed

JOB No.
278821

Section 1 – Steel fibre reinforced shotcrete (OHMS) - 2001-11-22

FIG. No.
H39

Panel 2 South

Date measured and photo taken: 22/11/2001

Observations: Same conditions as last observed



Panel 2 North

Date measured and photo taken: 22/11/2001

Observations: Same conditions as last observed



JOB No.
278821

Section 2 – Polypropylene fibre reinforced shotcrete (OHMS) -
2001-11-22

FIG. No.
H40

Panel 3 South

Date measured and photo taken: 22/11/2001
Observations: Same conditions as last observed



Panel 3 North

Date measured and photo taken: 22/11/2001
Observations: Same conditions as last observed



JOB No.
278821

Section 3 – Tailings aggregate polypropylene fibre reinforced
shotcrete (OHMS) - 2001-11-22

FIG. No.
H41

Panel 4 South

Date measured and photo taken: 22/11/2001

Observations: Same conditions as last observed



Panel 4 North

Date measured and photo taken: 22/11/2001

Observations: Same conditions as last observed

JOB No.
278821

Section 4 – Mesh reinforced shotcrete (OHMS) - 2001 -11-22

FIG. No.
H42