

THE USE OF VOIDFILL BARRIERS AS AN ALTERNATIVE TO A GROUT PACK SUPPORT SYSTEM IN PLATINUM MINE CONVENTIONAL STOPING

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1 Abstract

An evaluation of the support resistance capacity of a void fill rib based support system was done in a conventional Merensky stoping face at RPM Rustenburg section, Turffontein shaft. The project was a sub component of a larger project evaluating the feasibility of replacing ventilation curtains by a cement-based product. This paper describes the conceptual thinking as well as the practical installation of a cement based void fill rib in an actual working stoping environment. Data was collected in order to objectively evaluate the void fill rib support performance. The void fill rib support performance was evaluated against the currently used grout pack based support system(s), taking into account load generated, the timing of the load generated and costs, demonstrating the system to be viable, although the financial feasibility work requires further refinement.

2 Background

The depth of platinum mining operations in the Bushveld Igneous Complex is increasing. With this increased depth, the stress regime under which mining operations take place is expected to change. The associated Rock Mass Response to Mining is also expected to change to the point that some of the currently used support methods will no longer be adequate.

One of the alternative support techniques currently being investigated is the use of a yielding cementitious-based material to replace currently used stiff grout packs. This support method is an additional benefit of a ventilation project investigating the use of ribs of cementitious material to seal off the worked out or back area, concentrating ventilation on the face and reducing cooling requirements. The high capital and operational costs associated with this process, (due to associated engineering infrastructure, logistical requirements and possible adverse impact on mining operations) led to a search of additional uses for the system. The modification for support purposes was developed as part of this process and, if proven effective, the support method could progressively replace grout packs, as the depth of mining increases.

3 Site Selection and Establishment

The test site needed to be easily accessible and to meet the logistical requirements for the test, namely access to grout ranges, logistical capacity for the handling of additional persons in the stope environment, and for transport of additional material. It was also established upfront that the assistance of the face crew and supervisors in the area would be of utmost importance.

Once all test parameters, logistic requirements and support from operational personnel had been discussed and agreed upon, it was decided to conduct the test at Turffontein shaft. This shaft is part of Rustenburg Platinum Mines – Rustenburg Section, a platinum mining complex situated in close proximity to the city of Rustenburg in the Northwest Province (Figure 1 and Figure 2). The site chosen was a Merensky stope, TF 26W4 Stope 6 West face, a conventional stope face with a stoping width of approximately 1.0 m. The Merensky reef geological succession can be seen in Figure 3.

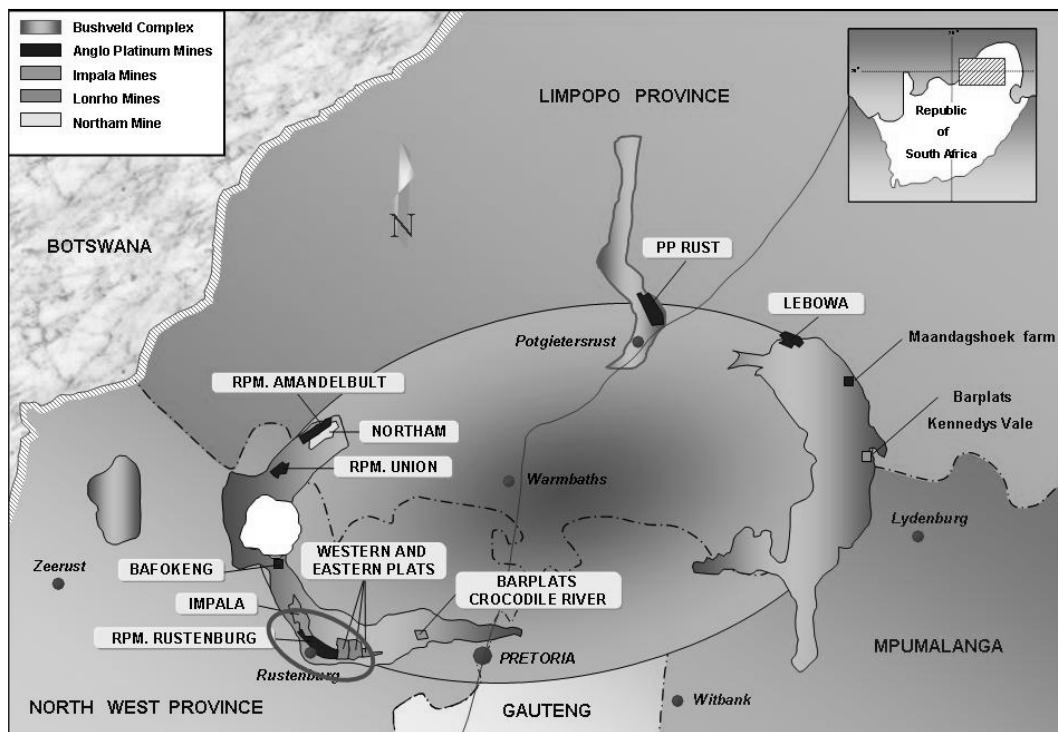


Figure 1 - Overview of Platinum Mines in South Africa

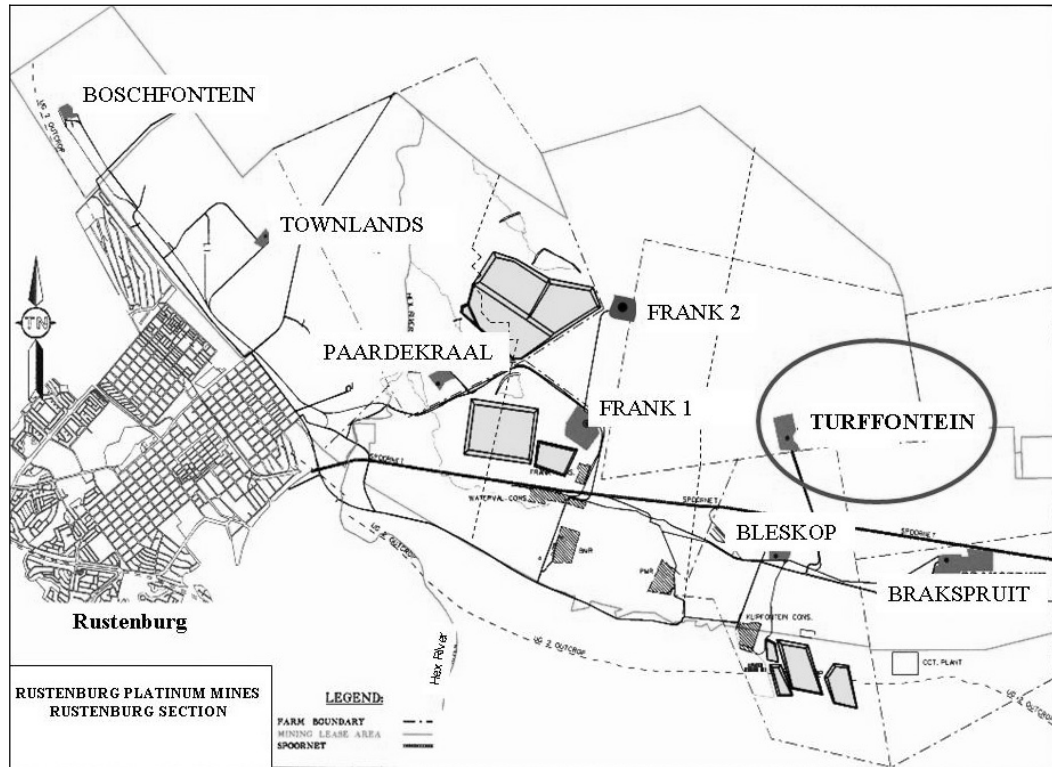


Figure 2 - Detail of platinum mines in RPM - Rustenburg section

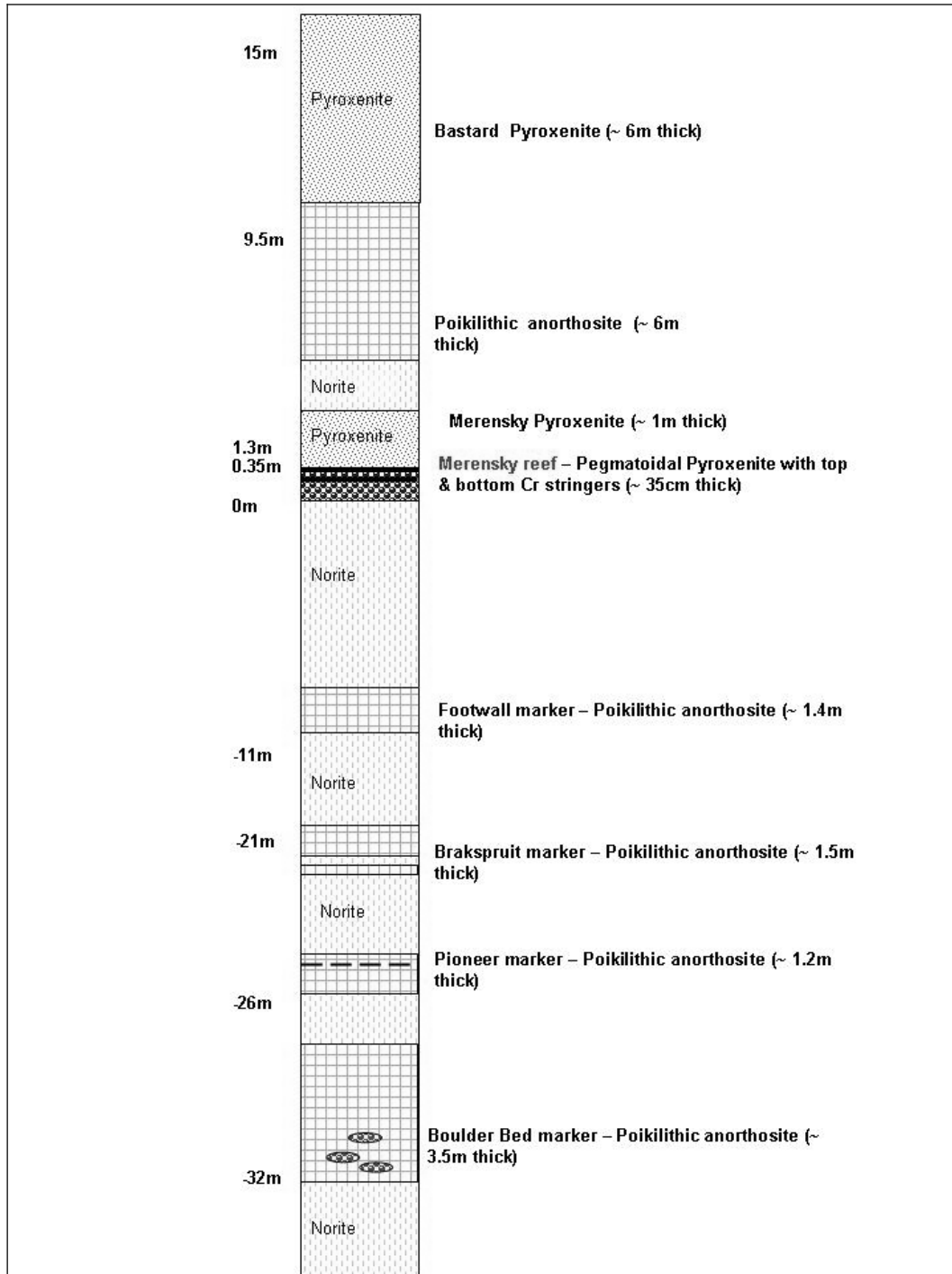


Figure 3 - Merensky reef geological succession

3.1 Test Site Mining Environment

Turffontein shaft exploits the Merensky reef by means of conventional breast stoping, at intermediate depth, varying between 750 m and 1300 m depth below

surface. The shaft was designed initially as a longwall mining operation. However, within the last three years was changed to conventional scattered breast mining. The regional support system consists of dip stabilizing pillars, often replaced by local geological loss. Crush/yield pillars 32 m apart skin to skin and 4.0 m long on strike by 2.5 m on dip with a 4.0 m holing are used to stabilize the ground between the regional pillars.

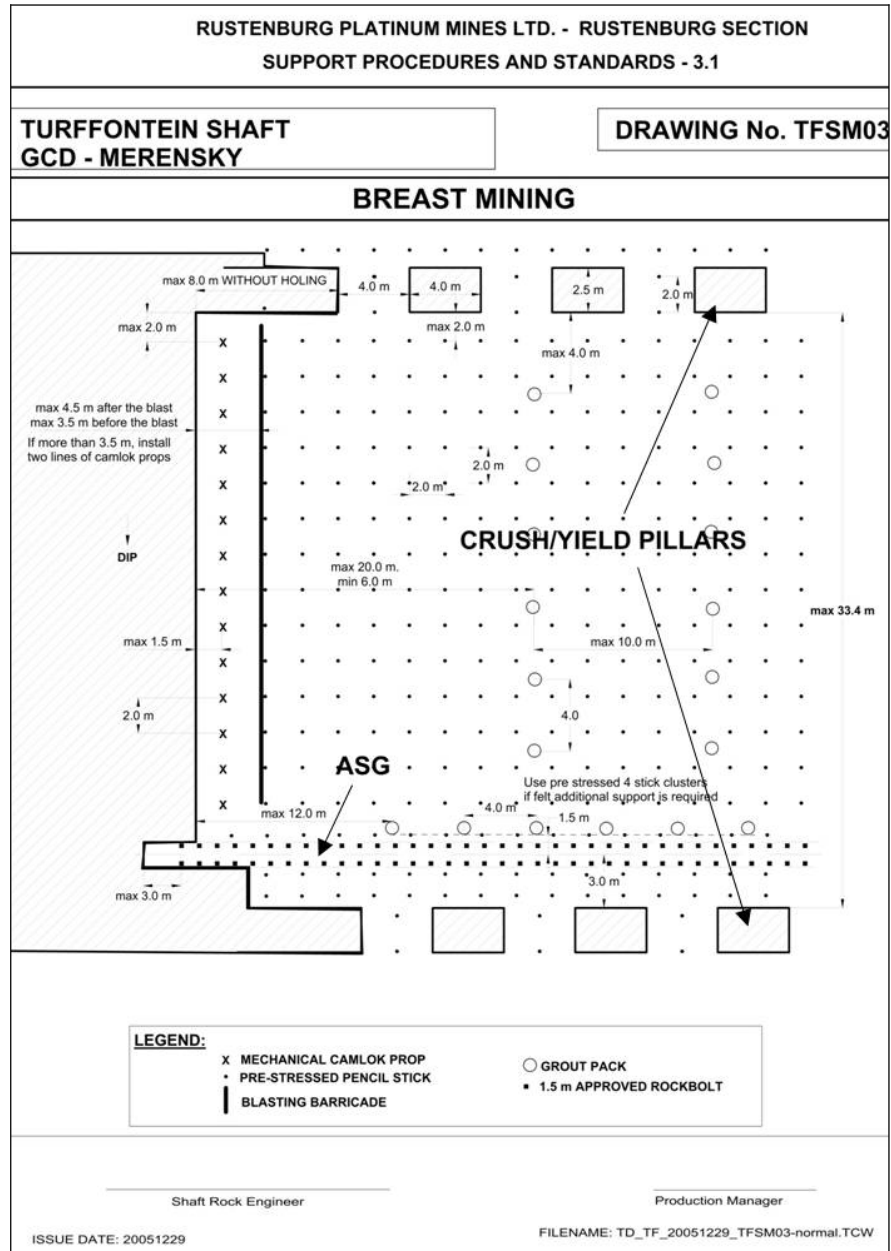


Figure 4 - Schematic view of the stope face support standard

The Codes of Practice to Combat Rockfall and Rockburst Accidents in RPM Rustenburg Section (2007) require a support resistance of at least 95 % of the cumulative fall out thickness. While the fallout thickness will vary with time, at the time of the test the fallout thickness for the Merensky reef horizon is was 1.6 m. However, the highest point of the arch created between the two rows of crush/yield pillars is 2.2 m and that is the height to be supported. Thus, the required support resistance is achieved by a support system comprising temporary support (installed 1.5 m apart on dip and strike), pre-stressed elongates (installed 2.0 m apart on dip and strike) and grout packs (installed 4.0 m apart on dip and 10.0 m apart on strike, centre to centre). The temporary support units and the pre-stressed elongates support the working area close to the face. The grout packs have a back area and tensile zone support function. The purpose of the void fill rib is to replace the grout packs, in addition to its ventilation control function.

In order to ensure the safety and health of workers during the test work, the installation of the on-dip void fill rib was positioned in between previously installed standard support units. Figure 5 shows the underground plan for the test stope, including the position of the rib. The position chosen for the void fill rib was 29.4 m from the face at the time of the installation, as indicated in Figure 5.



Figure 5 - Underground plan of rib installation

4 Material Optimization

4.1 Rib Construction

The primary function of the overall test work being done was to investigate the use of a cementitious material for ventilation control, with the support function being an added benefit. A large portion of the initial work was aimed at the successful building of a stable 10 cm thick ventilation seal rib. Several cement mixtures and bags were tested in different combinations. This included the use of the grout currently used for grout pack construction, dedicated cement transported in bags underground and reinforcement of plastic walls by means of a Thin Skin Lining(TSL).

An aerated cement mixture, installed inside a permeable geotextile, was the most successful combination, due to its low bleeding, ease of installation, setting time and ease of logistics. Once the nature of the material to be used had been agreed, the process towards the optimization of its properties could begin.

4.2 Cement Mixture Optimization

An initial series of small-scale laboratory tests was done for the different cement mixtures, followed by the large scale mine based test.

Small-scale testing was done in the laboratory to assess the following properties:

- dosage rate of different aeration chemicals;
- compatibility of aeration chemicals with the slimes and site water;
- water content to achieve typical flow in a Marshall cone of 17 seconds;
- binder content and combinations to achieve the required strengths;
- engineering properties of the different slimes;
- mix proportions to obtain the required density, aeration and flow ability.

As there are different sources of slimes dam materials in Rustenburg Platinum Mines – Rustenburg Section available to the project team, these were tested for suitability. Although all were found to be suitable, the different properties and particle distribution associated with different sources required that a range of acceptable particle sizes be defined (Table 1).

Sieve aperture size, μm	Percentage passing	
	Maximum	Minimum
4750	100	90
2360	100	70
1180	80	30
600	60	20
300	50	10
150	40	10
75	30	10

Table 1 - Slimes Grading Limits

Environmental requirements stipulated an air content of between 10% and 35% for fresh grout with a target wet-density between 1400 kg/m^3 and 1800 kg/m^3 in order to achieve the required thermal properties. In addition, Rock Engineering stipulated a minimum width of 1.0 m and a minimum final strength of 1.0 MPa be achieved in order to perform its support function. To achieve this, a minimum strength of 0.7 MPa at 7 days and 1.0 MPa at 28 days is required.

Additional requirements were the ability of the grout mix to be transported through Turffontein shaft's grout supply network with a minimal bleeding/weeping of free water (less than 5% by mass).

5 Rib Construction

The rib was built in three phases:

- the two outer walls (on dip) were built (in order to identify and deal with teething problems as soon as possible);
- the paddock was built;
- finally the inner rib was filled.

The conceptual design of the test site and the rib's outer walls are shown in Figure 6 and Figure 7 respectively. The outer walls would be built by suspending the 10 cm wide geotextile bag from the hanging wall and reinforcing it with pre-stressed elongates or laggings, installed 0.8 m apart centre to centre.

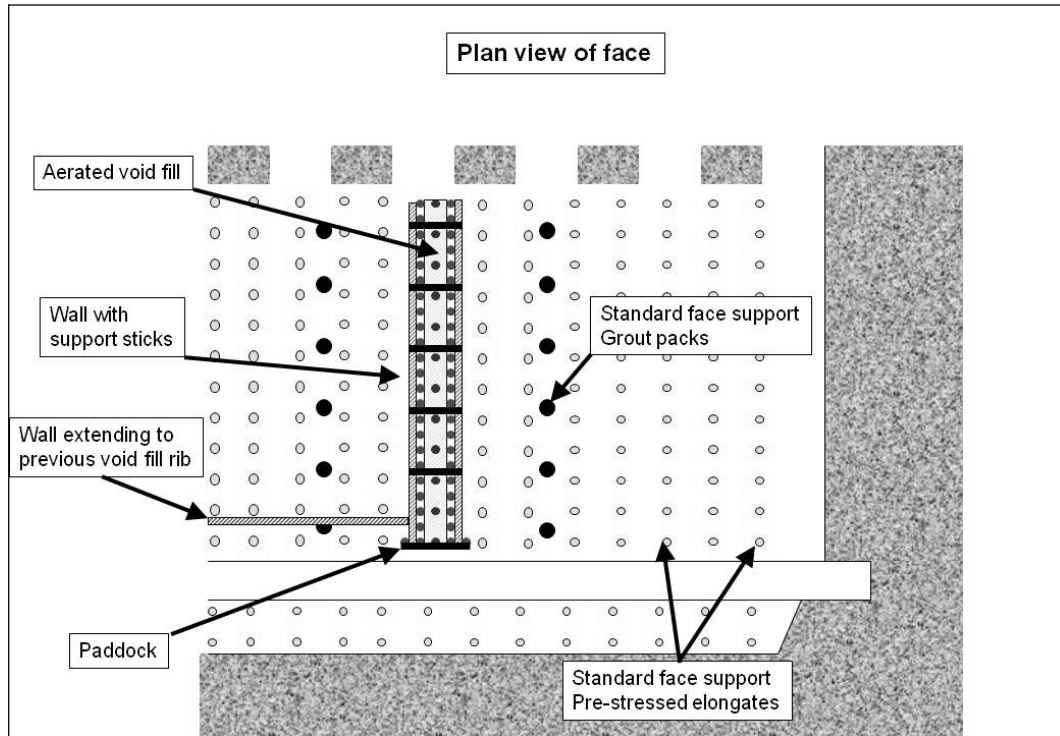


Figure 6 - Sketch of underground installation site.

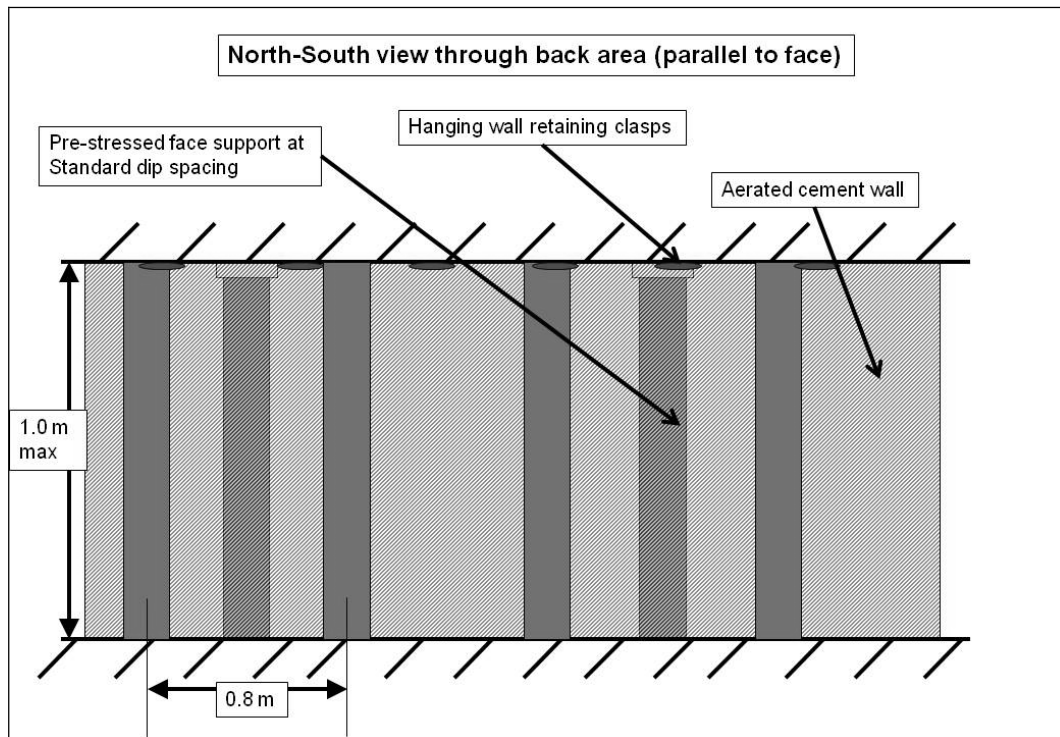


Figure 7 - Conceptual design of rib walls (on dip, view looking East)

In the actual underground installation, the rib was installed by using one of the previously installed support lines to act as one of the wall support units, as shown in Figure 8. One of the reasons for this was that the support lines were installed at smaller spacings than required by the standard, and therefore the construction of two rib walls was not required.

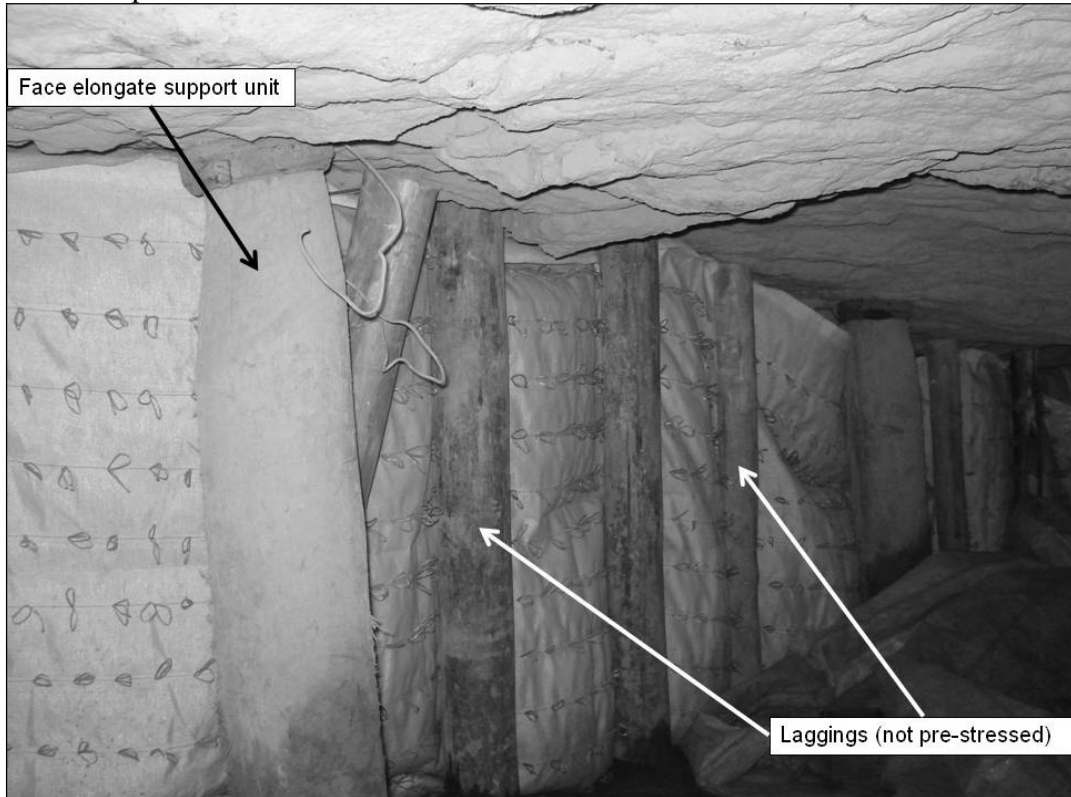


Figure 8 - View of rib walls underground installation

The conceptual design of the paddock is shown in Figure 9 and the actual underground construction in Figure 10. The conceptual design called for a reinforcing of the geotextile material by means of a steel mesh and a closer installation of the reinforcing timber units. This was to prevent the hydraulic head created by the cement mixture during filling from causing the paddock to fail and inundate the ASG.

The actual underground installation differed from the conceptual design due to the size of the elongate units available for construction. Only four pre-stressed elongates were used on the paddock, instead of the planned five due to the large diameter of elongates available.

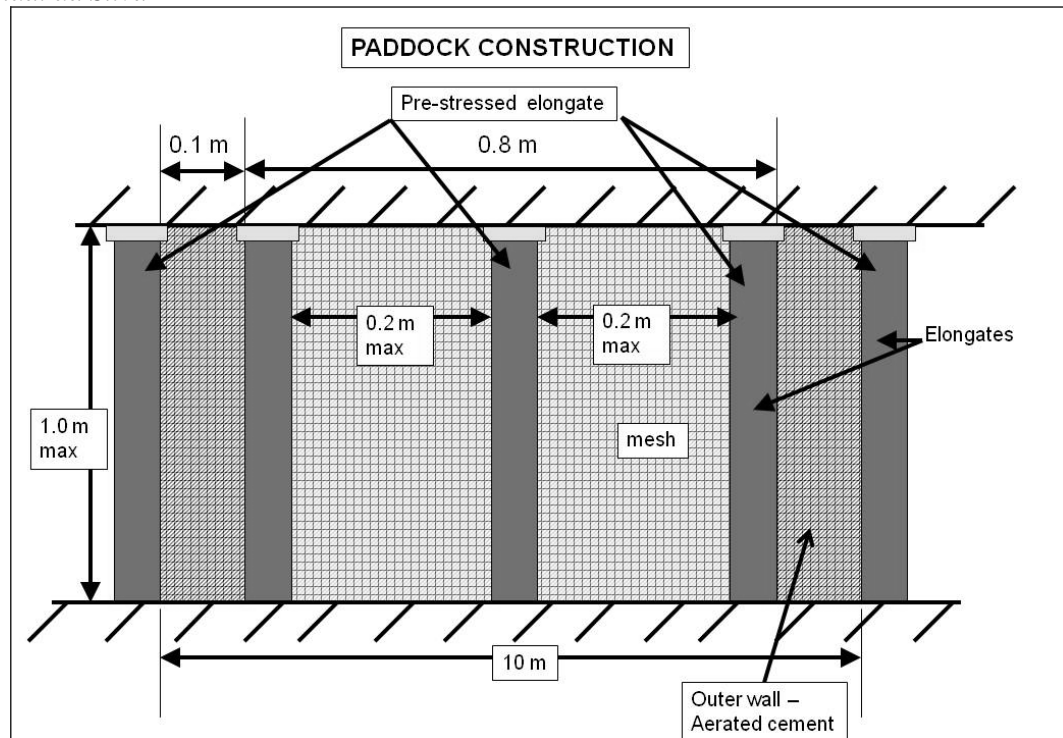


Figure 9 - Conceptual design of paddock construction (view looking South)

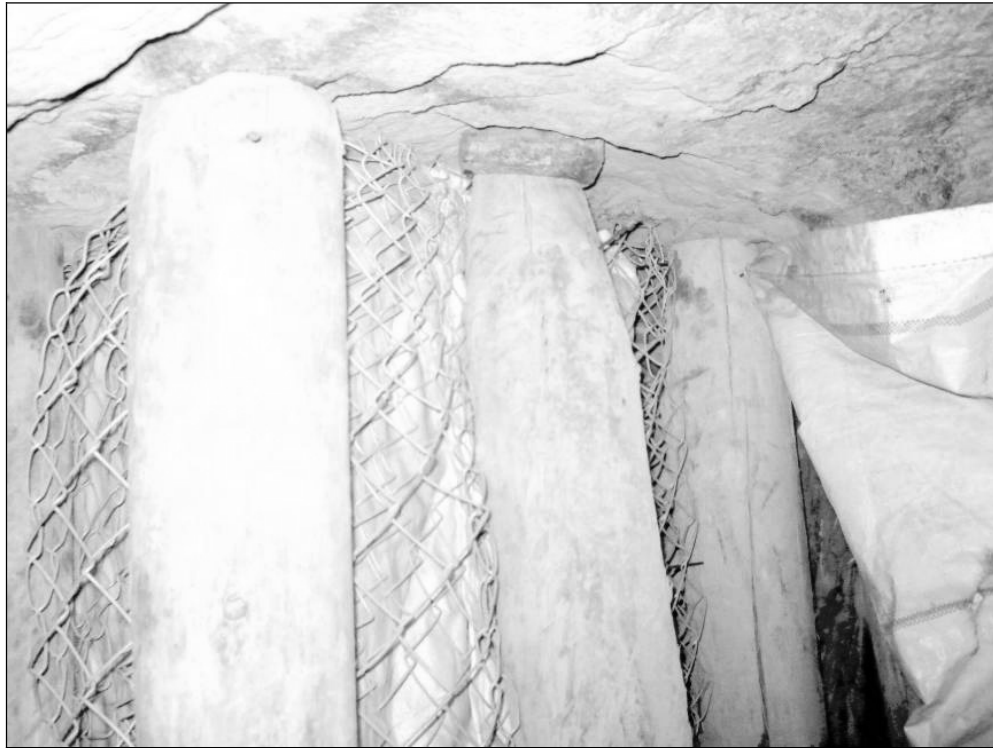


Figure 10 - View of actual underground paddock construction

The rib's on-dip outer walls were fully pumped and allowed to settle. Once the outer walls were completed, the paddock was filled. Before filling of the inner rib took place, the instrumentation as described in Section 6, was installed inside the rib.

To ensure the safety of the persons in the area and to prevent building of an excessive hydraulic head, the inner rib was pumped in portions of 5.0 m along the dip direction. Each 5 m portion was allowed to settle settled for a minimum of 12 hours before pumping of the next section took place. Due to the operational requirements pumping of the outer wall, paddock and inner rib took place only on night shift.

6 Instrumentation and Data Collection

Instrumentation was installed in the void fill to record the horizontal (dip and strike) and vertical loads generated, as well as the associated convergence. Additionally, it was also decided to record the load generated on a commonly used face support unit (150-180 mm diameter pencil stick). The purpose of both load recordings was to compare the theoretical calculation of the load generated with an actual underground installation. The instruments used were: extensometer (continuous monitoring), elongate load logger (continuous monitoring), backfill load cells (gauge reading) and a remote download unit (able to retrieve data from the elongate and convergence loggers at a distance of 15 m, so all data retrieval could be done from the Advanced Strike Gully).

6.1 Instrumentation - Underground Installation

Figure 11 shows a schematic of the underground instrumentation installation. Four load cells were installed inside the rib. Two of the cells (cell 1 and cell 4) were installed parallel to the reef plane, to measure the vertical stress field component within the rib. The other two cells (cell 2 and cell 3) were installed perpendicular to the reef plane, with cell 2 measuring the stress field component on the dip(North-South) direction and cell 3 on the strike (East-West) direction. The extensometer was installed immediately East of the void fill rib above the ASG, and the elongate load cell immediately West of it, at the middle of the face. Figure 12 and Figure 13 show the instrumentation used installed underground.

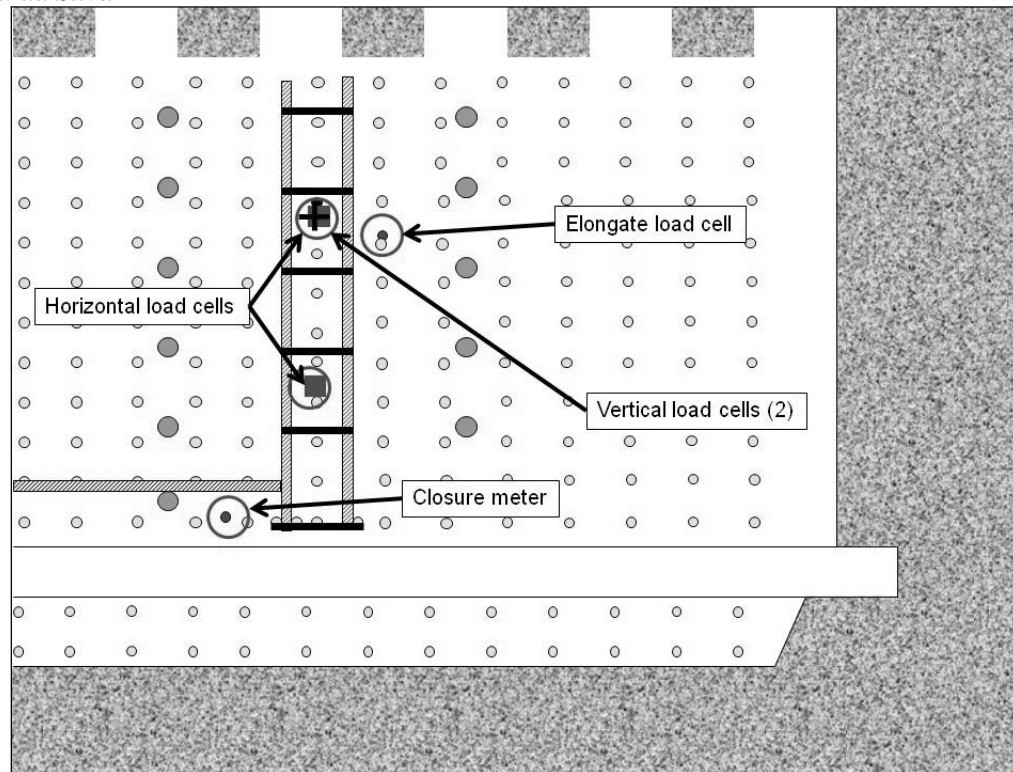


Figure 11 -Schematic of instrumentation installed in the rib



Figure 12 - View of load cells installed inside rib, prior to pumping

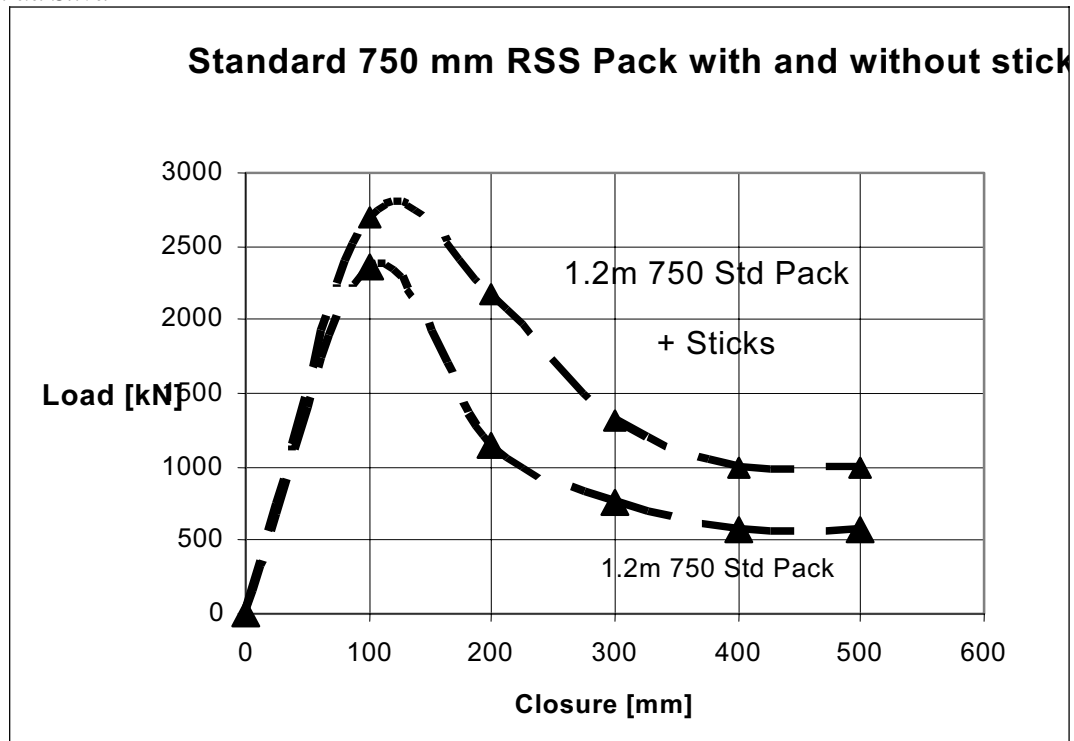


Figure 13 - Installed closure meter at test site

Data was collected between 2006/10/30 and 2007/03/08. During this period, the face was advanced 30 m.

7 Grout Pack Performance

The stopping standard at Turffontein shaft specifies 750 mm diameter grout packs, installed with a pre-stressed elongate inside the rings. These packs are installed on a pattern of 10 m on strike by 4 m on dip, centre to centre.



**Figure 14 - Grout pack performance figure
(CSIR, 2005)**

Typical laboratory load deformation behaviour of 750 mm standard packs, with and without sticks used as part of the building process are shown in Figure 14. Note that the initial point of these curves reflects the moment contact takes place between the platen and the pack. On the underground situation, as packs are installed without pre-stressing units, the bleeding of the water from the grout mixture always creates a gap between the top of the pack and the hanging wall. Such gap must be closed by elastic or inelastic convergence (if no other devices to close it are installed), before the pack can generate load. From the graph in Figure 14, it can be seen that a peak load of approximately 2750 kN at a convergence of approximately 125 mm is generated during laboratory tests.

The laboratory pack performance of the pack is downgraded to take into account the underground conditions, using the formula (Ryder and Jager, 2002)

$$F_{ug} = F_{lab} (1 + 10/100)^{\log (V_{ug}/V_{lab})}$$

Where,

F_{ug} – Adjusted load

F_{lab} – Original load generated

V_{ug} – Underground convergence in m/sec

V_{lab} – Laboratory test velocity in m/sec

The laboratory peak load of an individual pack is downgraded from 2750 kN to 1841 kN.

The calculation of the load generated by the grouted pack support system is detailed in Table 2.

Grout pack support resistance calculation		
Rock Density	3.4	t/m ³
Gravitational Constant	9.81	m/s ²
Grout pack Strength	2750	kN
Down rated to:	1841	kN
Underground installation		
Dip Spacing	4.0	m
Strike spacing	10.0	m
Area Supported per pack	40.0	m ²
Support resistance	46.03	kN/m²

Table 2 - Support resistance calculation

Therefore, a pack system installed 10 m apart on strike and 4.0 m apart on dip centre to centre will generate a support resistance of 46.03 kN/m², once all the packs in the stope face are in contact with the hanging wall. A void fill rib would need to generate the same or a higher support resistance as the grout pack system, for the same amount of convergence, i.e., a minimum support resistance of 46.03 kN/m².

8 Data collected

Figure 15 (convergence profile) and Figure 16 (void fill load) show normalised results for the data collected.

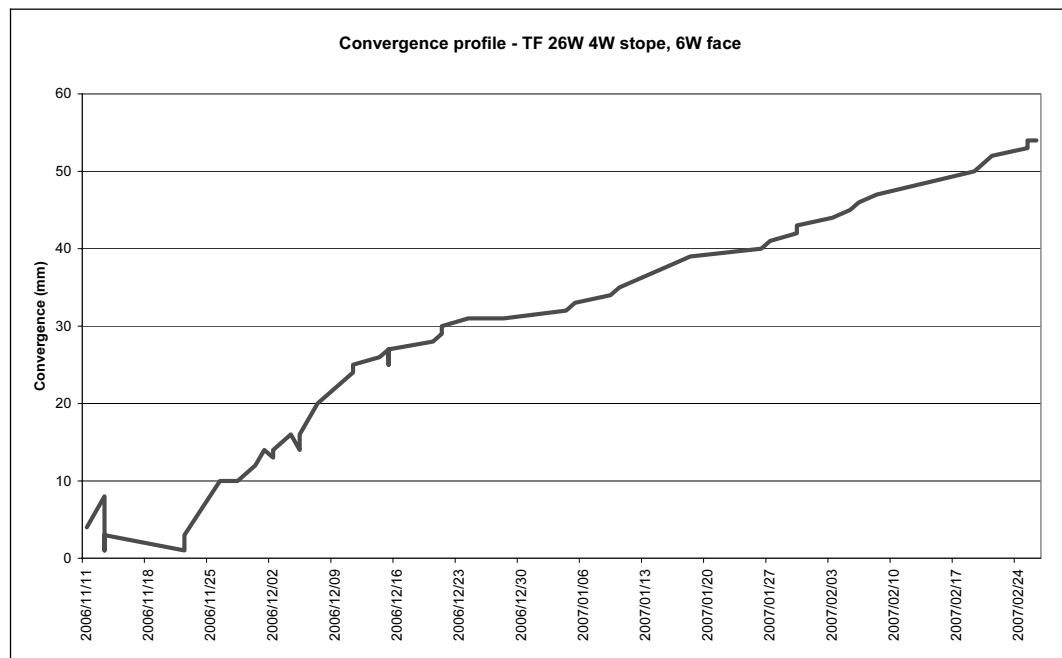


Figure 15 - Recorded stope convergence profile

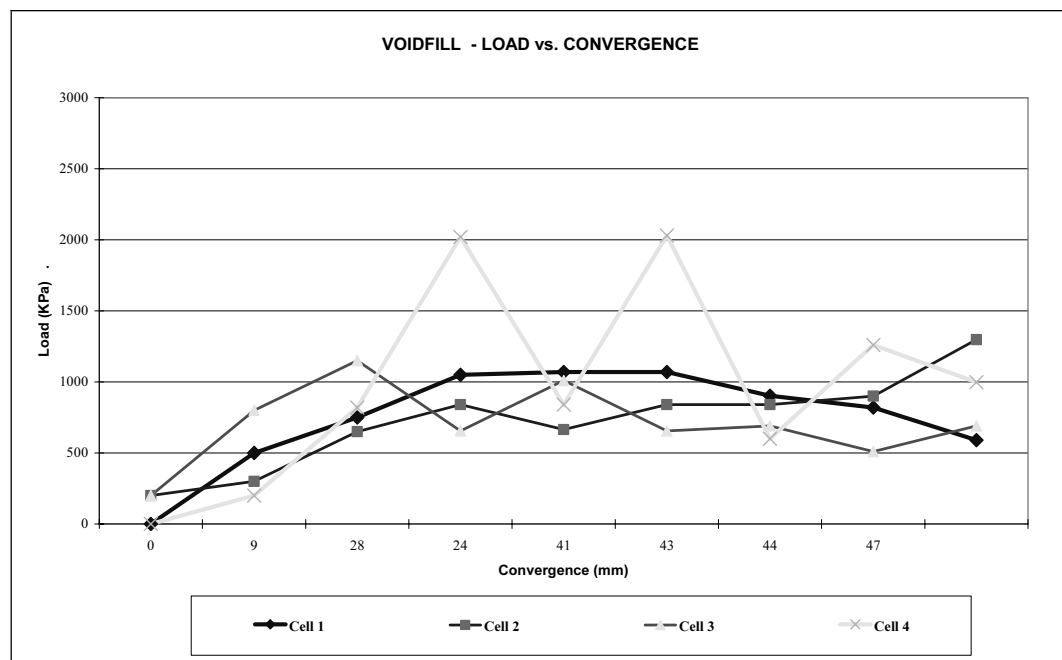


Figure 16 – Load generated within void fill against convergence

9 Interpretation And Discussion

A analysis of Figure 16 indicates that the recorded values of load generated within the backfill did not show a constant progression, with the load values obtained from Cell 4 showing a much higher variation pattern than the values recorded by Cells 1, 2 and 3. It is proposed that this can be attributed to the nature of the void fill material used and the following micro scale sequence of events is postulated:

- the grout consists of a multitude of micro air bubbles in a cement compound matrix;
- each bubble will build a resistance and generate a load as convergence occurs;
- at some point the load capacity of the bubbles in immediate contact with the hanging wall is exceeded;
- the bubble in immediate contact with the hanging wall will collapse into themselves;
- a temporary drop in the load generated takes place.

To be able to compare the performance of the void fill rib and a grout pack support system, the loads generated need to be expressed in the same units. In order to achieve this, the load generated into the void fill rib as recorded by the load cell units was expanded to the total hanging wall contact area. To avoid overstating the support effect of the void fill rib it was assumed that only 80% of the rib would be in contact with the hanging wall. It was further decided to separate the recorded loads generated in the void fill into vertical and non vertical (dip and strike direction) components, which were plotted against the convergence.

The load generated by a line of grout packs as closure occurs was calculated. The curve shown in Figure 14 was interpolated and load values calculated for each convergence point equivalent to a measurement point (Figure 17). The exercise was repeated for the downgraded load values for the grout packs and is shown in Figure 18.

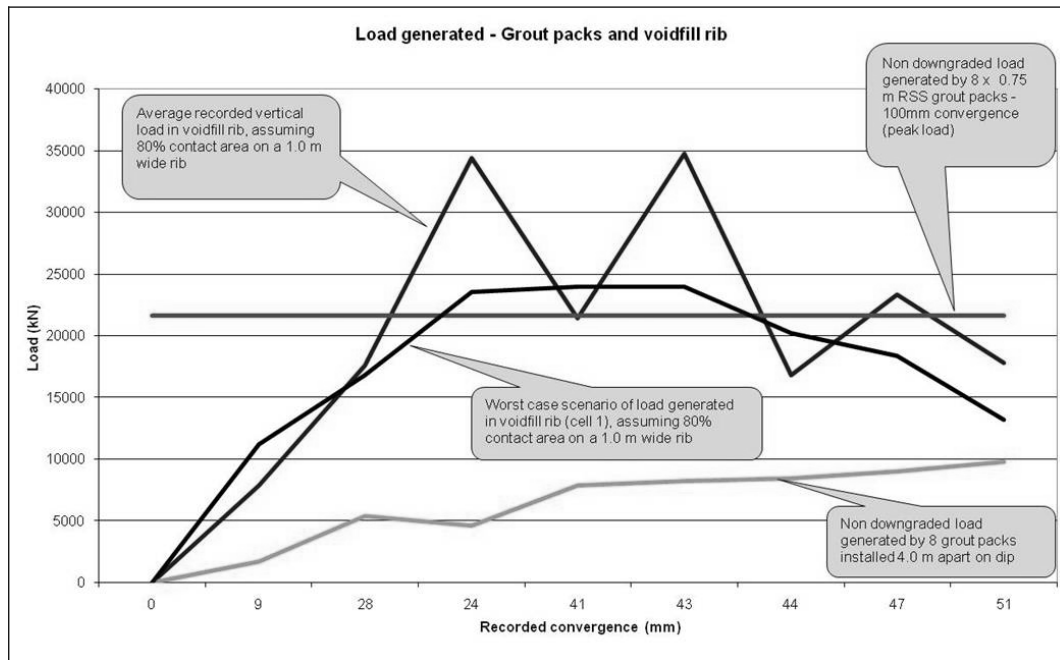


Figure 17 - Comparison using laboratory grout pack load values

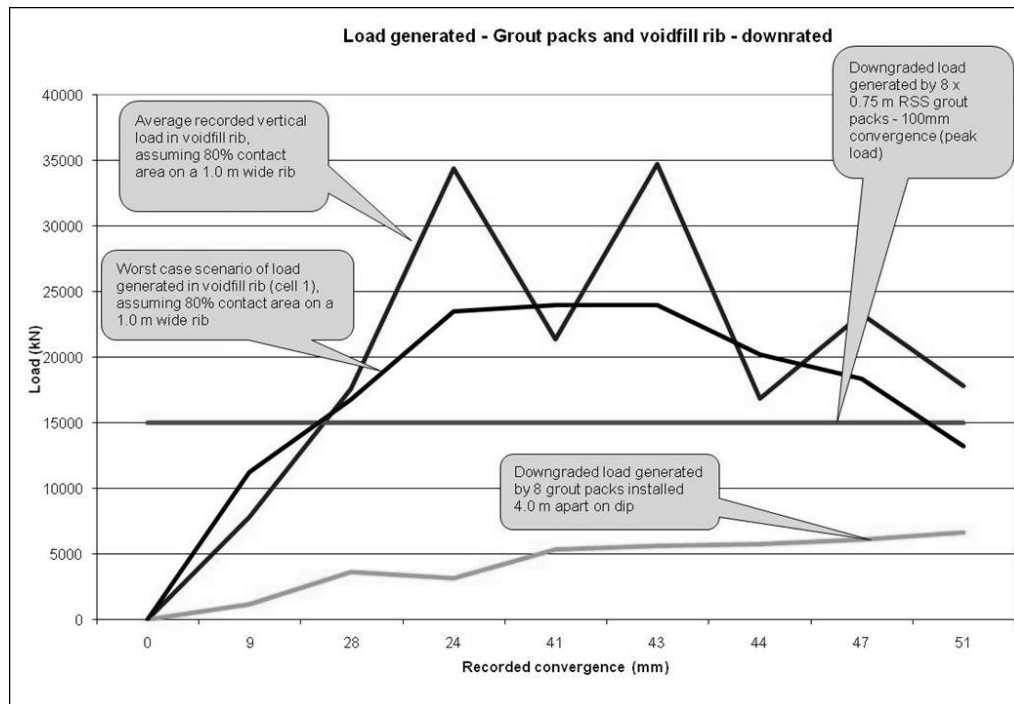


Figure 18 - Comparison using downrated grout pack load values

Even taking into account the worst-case scenario of Cell 1 and the non downrated load values for grout packs, the load generated in the void fill rib is higher than the load generated by a line of grout packs installed under similar conditions. This statement hold true even when non downrated values are used. When taking into account the fact that the void fill rib support system generates an immediate load virtually from the moment of installation, it can be safely stated that hanging wall movement control with a void fill rib installation takes place at a much earlier stage in the closure profile, when compared with the grout pack support system. A point of concern is the drop on the load generated in the final stage of the convergence. This might indicate a reduction in the rate of convergence in the hanging wall at this particular point, or a reduction in the effectiveness of the support provided by the rib. In either event, it requires clarification.

10 Logistic and financial

The main issue identified during the test that will need to be addressed is the reduction of the amount of ore left behind in the stopes, if the method is to be successful. There will be a need for a tight control, as the combination of the ventilation and the support functions of the aerated void fill ribs will cause back areas to be permanently closed off within 20 m from the face. This however is successfully achieved in other tabular mining operations and is a matter of discipline.

Although the initial results are that this method poses a significant increase in the cost of mining, the financial analysis of the system is not yet complete and, on its final form it must include both direct and indirect costs. These must be weighed against quantifiable direct and indirect benefits of using the system. These benefits will include but not be limited to:

- effective sealing-off of old back areas,
- reduction of the area to be examined and made safe,
- reduction of the risk workers are exposed to,
- the financial benefit of a “forced” continuous removal of ore from the face with associated earlier income generation
- reduction of future expenses associated with reclaiming operations, coupled with the possibility of ore loss (and higher safety risk) associated with a fall of ground.

Non financial benefits will include the yielding capacity of the aerated cement, which will become a requirement as mining progresses into deeper and increasingly seismic conditions.

Further work to be done as follows:

A second test on an independent site will be done to demonstrate repeatability and consistence of results. If such test is successful, a large scale test of the void fill rib system will be done, in conjunction with time and logistics studies.

An accurate determination of all costs and benefits incurred will be done. This will include logistical, direct and indirect costs, as well as a financial evaluation of the benefit of earlier access to ounces and reduction of ore left in back areas.

11 Conclusion

The initial tests have indicated that the usage of void fill ribs as a replacement to a grout pack based support system is technically feasible. The measured performance of the void fill rib has exceeded that of a standard grout pack based system, within the observed convergence range. The yielding capacity and immediate support provided from time of installation are beneficial and will be required when mining a greater depths.

Overall, the system offers a higher level of performance than the grout pack based system. In addition the system offers the following advantages:

- reduction of area to be examined and made safe;
- “forced” removal of broken ore from the stope, provided appropriate controls are implemented and no back areas are sealed while containing broken ore;
- even distribution of load generated into the hanging wall beam, unlike the discrete load application of a grout pack based system;
- load generation from beginning of convergence after installation;
- yielding capacity, required in the event of dynamic convergence;
- ease of application, as the same system will be used for both ventilation and support purposes, eliminating labour duplication.

12 Acknowledgements

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