

In Situ Instrumentation of a Cemented Paste Backfilled Stope at George Fisher Mine

Ryan L. Veenstra

George Fisher and Lady Loretta Mines, Glencore, Australia

ABSTRACT

George Fisher Mine (GFM) is currently in the process of optimizing its backfilling placement and backfill barricade designs. Part of this process involves the installation of in situ and barricade instrumentation to monitor the loads being placed on the barricade and the response of the barricade to these loads. This paper presents the first installation at GFM, which involved total earth pressure cells and piezometers installed immediately upstream of the CPB barricade wall, and ShapeAccelArray instruments installed on the downstream side of the barricade.

The results obtained showed that the pressures experienced by the barricade were lower than anticipated and significantly lower than GFM's current barricade design stress. The isotropic stress period (i.e. the backfill's fluid state) of approximately 5 hours was also shorter than expected. The instrumentation also measured some periods in which pressures increased even through the paste plant was not in operation. There also appears to be a positive correlation between pressure and temperature may indicate thermal expansion. Overall, this test is a first step in helping characterize GFM's in situ backfill behavior, providing encouragement that efficiencies can be found within the backfilling system. Further tests featuring more comprehensive installations are in preparation.

INTRODUCTION

George Fisher Mine (GFM) is an underground (UG) lead-zinc operation located approximately 15 km north of the town of Mount Isa, located in Queensland, Australia (Figure 1). GFM consists of two different mines: the southern P49 Mine and the northern L72 Mine.

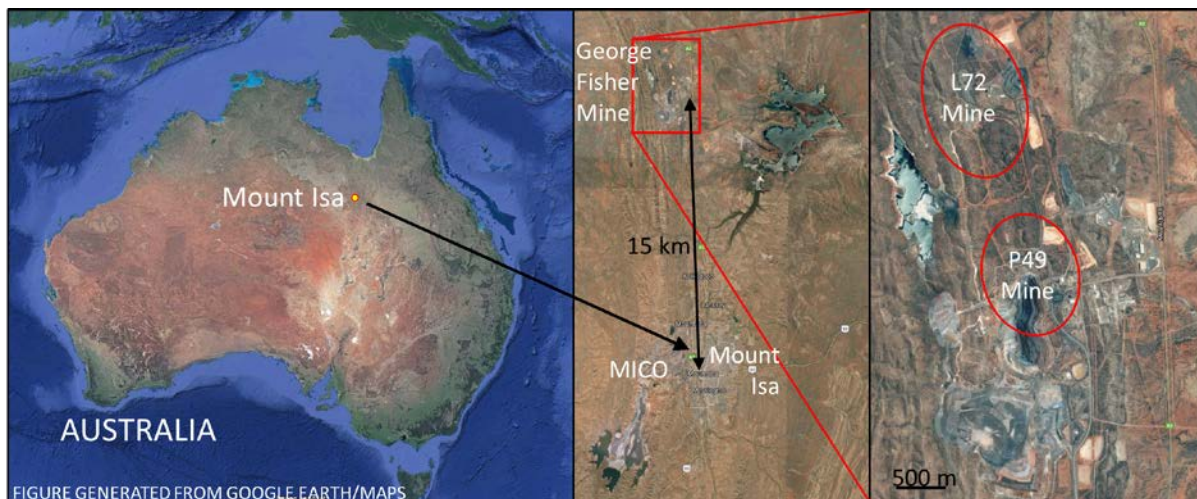


Figure 1. Location of George Fisher

GFM extracts ore using longhole open stoping. The mining method varies throughout the mine but historically had a primary-secondary stoping sequence. Primary stopes were backfilled with cemented paste backfill (CPB) while secondary stopes were ideally filled with waste rock (it is not uncommon for these stopes to be filled with CPB). However, the mine is now transitioning into a retreating panel method in some areas due to geology constraints. This change means that the schedule has tightened up and this tightening, subsequently, means that the stope cycle times will need to be reduced while increasing the overall demand for CPB. This reduction impacts the backfilling placement pour design of the CPB.

GFM's current pour design involves a two-stage stope pour utilizing a single CPB stream designed to be vertically stable when exposed on up to three sides. The backfill barricade is protected by allowing the plug pour to cure until it reaches an unconfined compressive strength of 100 kPa. This design is currently being changed to feature a higher binder content plug. This will theoretically provide faster attainment of adequate strength within the plug, enabling a reduction in plug curing time and reducing impacts on the mine schedule.

In order to help validate and optimize these designs, an in situ stope instrumentation program is in progress at GFM, looking at determining what loads GFM's backfill barricades experience. The initial phase involves establishing a database of "typical" pressures experienced at GFM. The next phase will then be followed by larger scale, continuous pour tests (as previously conducted by Hasan et al. 2014, Hassani et al. 1998, Thompson et al. 2011) to determine the feasibility of continuously pouring stopes without a plug cure period.

This work is also valuable as fieldwork provides in situ data that is critical for the proper framing and calibration of laboratory testing and numerical models (Li and Aubertin, 2009; Helinski et al. 2007; Veenstra et al. 2014). This site-specific in situ data will be used to optimize GFM's pour and barricade designs.

BACKGROUND

Figure 2 shows a long section view of the L72 Mine. This view shows the mine levels and infrastructure and highlights the main mining areas of the mine. The instrumented stope (16L-17C 721C) is located in the Lower Mining Block (LMB) at approximately 1 km depth below surface.

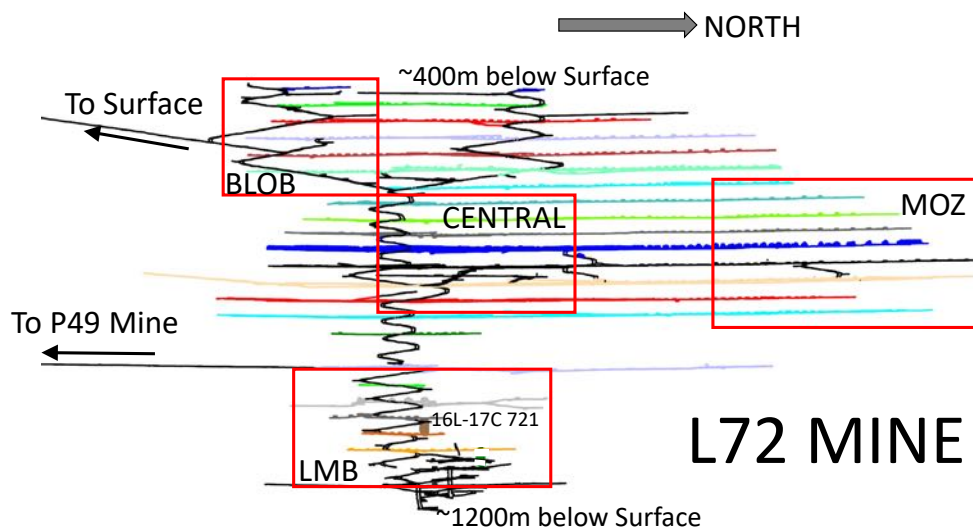


Figure 2. Long section of L72 Mine

This stope is approximately 30 m high, 15 m across strike, and 16 m against strike. The orebody, at this location, dips at about 55°. The stope volume was approximately 6,000 m³ according the cavity monitoring survey taken of the stope. Figure 3 shows the general shape of the stope and its spatial relationship with its fill and barricade levels.

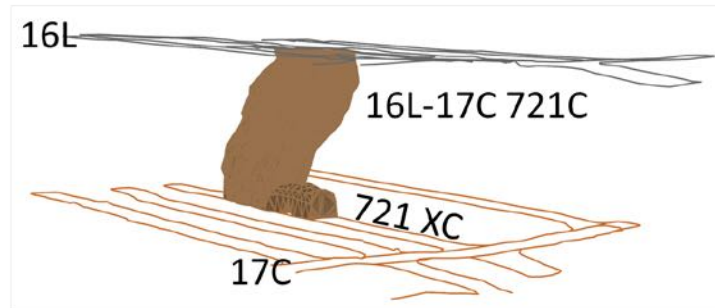


Figure 3. Stope geometries for 16L-17C 721C

The stope was filled with a plug pour consisting of a 6% (M_c/M_s) binder CPB and a body pour consisting of a 4% binder CPB. The plug was to be cured for a minimum of three days prior to the body being poured.

Cemented Paste Backfill

GFM produces backfill from mixing tailings harvested from Mount Isa Copper Operation's (MICO) Tailings Dam 5, a general purpose cement, and raw site water. Samples taken at the plant and from the overcut during pouring had an average wet density of 1.93 g/cm³ and corresponding percent solids of approximately 74% (M_s/M_t).

In Situ Instrumentation

The in situ instrumentation consisted of total earth pressure cells (TEPCs) and piezometers (for the measurement of pore water pressure). The featured TEPCs and piezometers had a measurement range of up to 350 kPa. The TEPCs were manufactured by RST instruments and the piezometers were manufactured by Geokon. These instruments were mounted on wire cages for mounting in the stope. Figure 4 is a photograph showing these instruments.



Figure 4. Total earth pressure cell and piezometer used in the installation

Barricade Instrumentation

As part of this program was to optimize GFM's barricade design it was necessary to measure the response of the backfill barricade to the filling of the stope. To this end a displacement monitoring instrument, called a ShapeAccelArray (SAA), was used (Measurand, 2015). These instruments have been

used in similar applications, such as measuring the deflection of retaining walls (Lipscombe et al., 2012) or tunnel convergence (Measurand, 2015).

The SAA cables used consisted of fifteen 30 cm segments. Each segment contains a MEMs (MicroElectroMechanical system) accelerometer which allows the segment to determine its 3D position in relation to the head unit. Prior to an underground installation a trial was conducted on surface. Figure 5 shows the results of this trial.

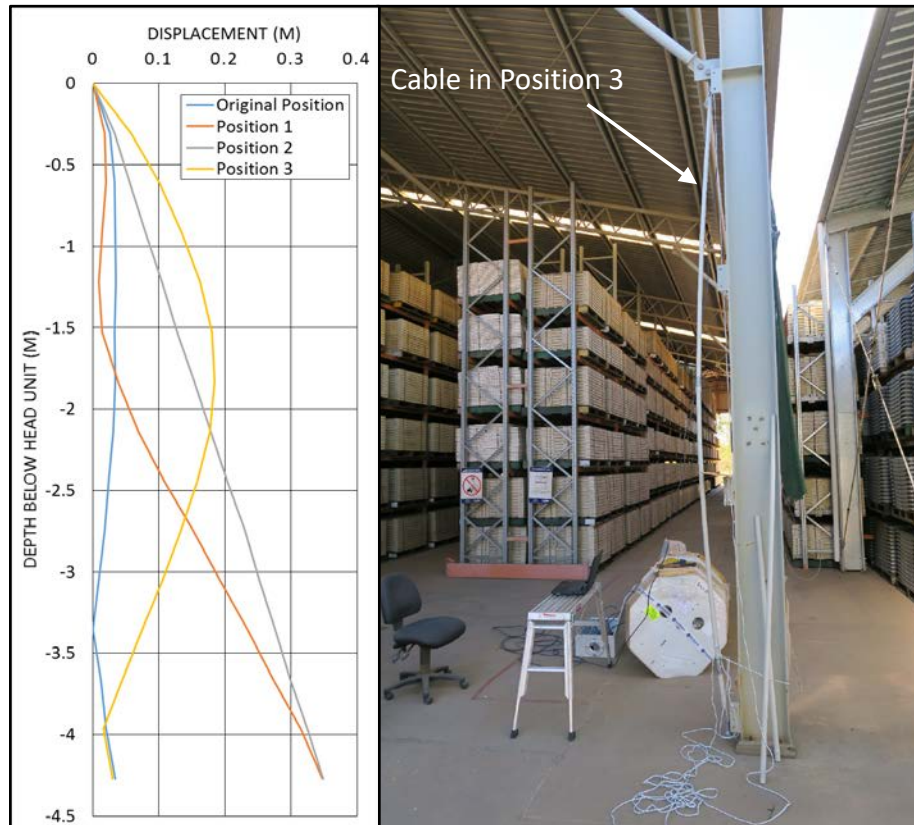


Figure 5. Surface trial of SAA cable

The instrument was hoisted and held next to the beam shown in the photograph. Position 1 restrained the cable at a height of approximately 2.5 m and placed a 30 cm block approximately 50 cm from the bottom of the cable. This corresponds well to the results obtained from the cable. Position 2 removed the restraint and allowed the cable to straighten, which is also shown in the results. Finally a 15 cm block was placed at approximately 1.5 m from the end of the cable and the cable was restrained at its bottom (photograph in Figure 5). Again this correlates well to the data obtained from the cable.

INSTALLATION AND RESULTS

The in situ installation setup for the 721C stope was kept relatively simple in order to test the installation methods. It also meant that all of the instruments could be placed by hand, reducing the need to involve operations or production personnel. It consisted of installing two pairs of TEPCs and piezometers. The TEPCS were oriented to measure pressures parallel with the long axis of the 721 crosscut. The installation is shown in the photographs below (Figure 6).



Figure 6. In Situ instruments installed in the 721 XC

Once the backfill barricade was constructed, five SAA cables were installed on the downstream side of the barricade. This installation is shown in Figure 7. The cables were installed as vertically as possible but the two end cables (SAA 1 and 5) needed to be installed on a slight angle due to the shape of the drive and the barricade. The thickness of the shotcrete was approximately 70 cm.

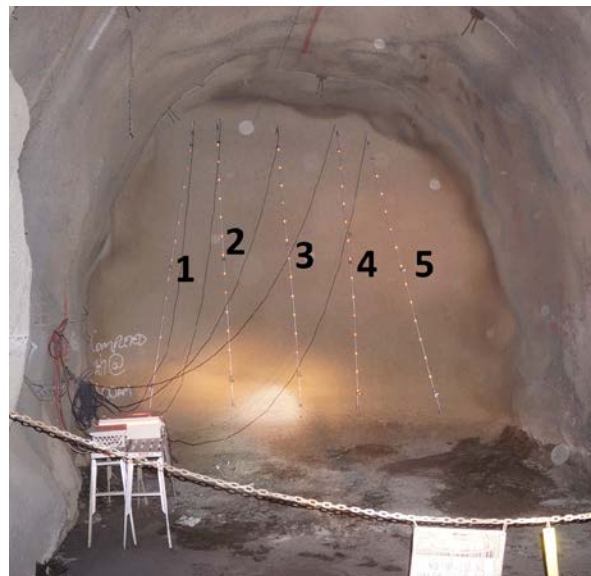


Figure 7. SAA cables installed on the 721C barricade wall

Instrumentation Results

The in situ instrumentation results are shown in Figure 8. Figure 8a) shows the entire 21 days of data collected, with pour times highlighted. The data includes total earth pressure, pore water pressure, and the temperature recorded by the thermistors in each vibrating wire unit. Figure 8b) highlights the pour itself. Both figures show a dashed and dotted black line which represent the rise rate within the stope expressed as isotropic pressure. The dashed line is for the upper instruments and the dotted line for the lower.

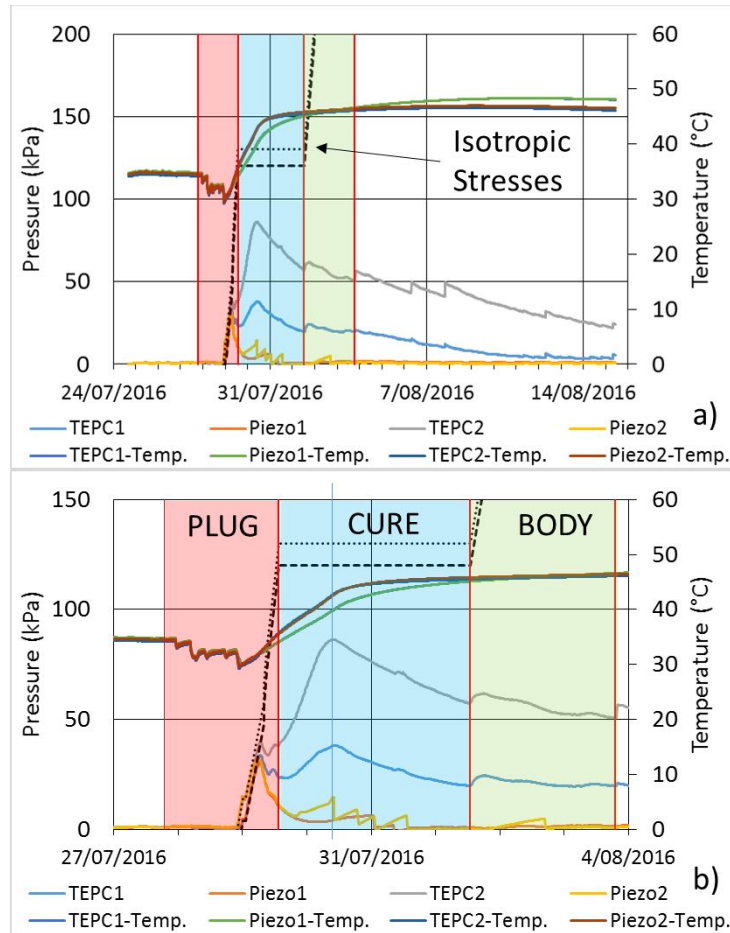


Figure 8. Instrumentation plots showing a) all collected data and b) data from the pour

The plug pour started on night shift of July 27, 2016 and ran for approximately 40 hours. This is denoted by the changes in temperature as the CPB approaches the instruments. Pressures started to be recorded on July 30, 2016. A relatively consistent initial rise in pressure is measured. During this time the pressures remained isotropic for between 4 to 5 hours. After this the horizontal and pore water pressures start diverging from the isotropic, signifying that the CPB is starting to generate effective stresses.

The maximum pressures seen by TEPC 1 and 2 during the plug pour were 33 kPa and 40 kPa respectively just prior to the plug pour finishing. There was a decrease in the stress rise rate observed between when these maximum values were achieved and the end of the plug pour. This is attributed to the CPB rising past the brow.

Almost immediately following the onset of the plug cure period (when the slope is not being filled), TEPC 2 starts to show an increase in pressure despite having no additional vertical load applied. TEPC 1 shows a similar increase in pressure approximately 4 hours later. TEPC 1 registers an increase of 15 kPa from its end-of-plug pressure while the stress registered by TEPC 2 more than doubles its end-of-plug pressure. Similar increases in pore pressure were measured by Piezo 2 but not by Piezo 1.

The increase in total stress is possibly explained by temperature driven expansion of the CPB due to the rapid increase (+13°C in 27 hours) in temperature during this time and due to it being highly confined by the drive walls and barricade. This was previously postulated by Thompson et al (2014).

These authors measured similar pressure increases within CPB that showed a positive correlation with temperature. This behavior was observed more frequently in higher binder CPB and is more pronounced in drives, both of which are true of the GFM case. However, the total stresses start decreasing before the temperature plateaus whereas it would logically be expected that stresses would only start to decrease once the temperatures began to reduce. As postulated by Thompson et al. (2014), such a decrease in stress may be attributed to shrinkage of the CPB.

Both TEPCs show limited response (less than 5 kPa increase in pressure) when the body pour commences on July 1, 2016. The piezometers do not register any response to the commencement of the body pour. Note that blasting in an adjacent drive may account for some of the observed increase in total stress.

The barricade displacement results are shown in Figure 9. Only results from SSA 1 through 3 are shown (the SSA 4 and SAA 5 results were discounted due to installation errors). SAAs 1 through 3 show an initial increase in wall displacement between the installation time and when the pour starts. This is attributed to the changes in the shotcrete as the instruments were installed less than 12 hours after the shotcrete was applied.

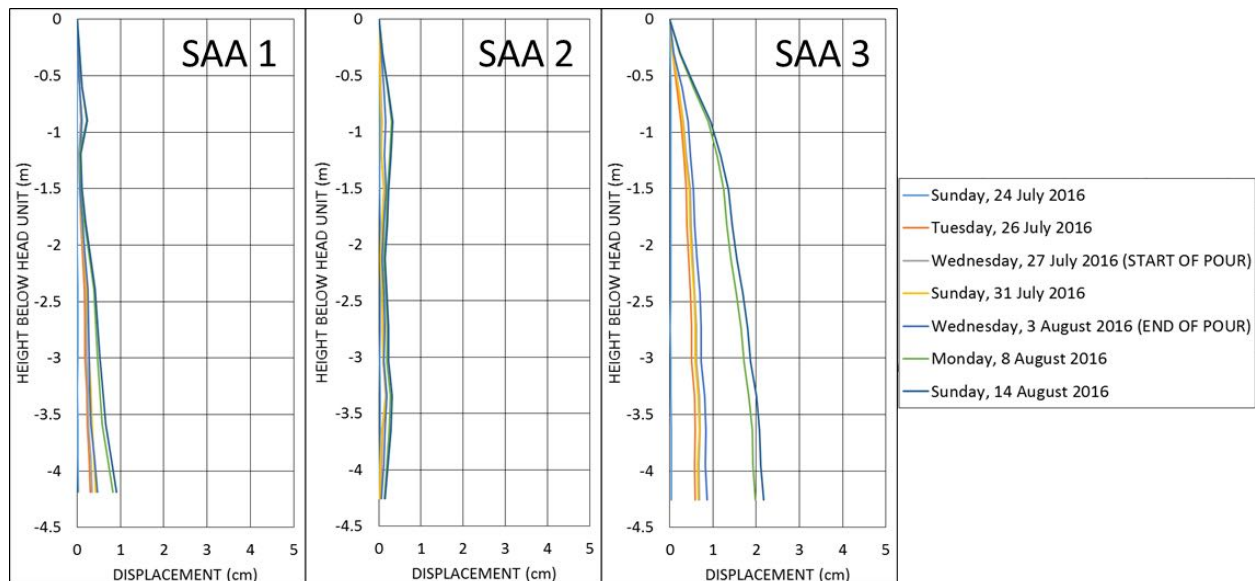


Figure 9. Plots showing the measured displacement in the three SAA cables

In general, the SAAs registered very little change in displacement while the stope filled (less than 0.2 mm). This small amount of displacement correlates to the displacement-load relationships shown in previous design work conducted for GFM (AMC, 2014). Figure 11 shows the displacement results from the centerline of the barricade (SAA 3) during the pour. The results were normalized to the recorded SAA displacements at the start of the pour. This figure shows the progression of displacement during the filling, with the maximum displacement occurring when the CPB reached the brow and then decreasing over the rest of the pour. It is interesting that there is no direct correlation between the proposed thermal expansion related pressure increase and the movement of the barricade. This said, given the significant strength of the barricade compared to the applied load, and that the measured displacements are very small and close to minimum measurement range of the instrument it is possible that the wall did not move enough to show this relationship.

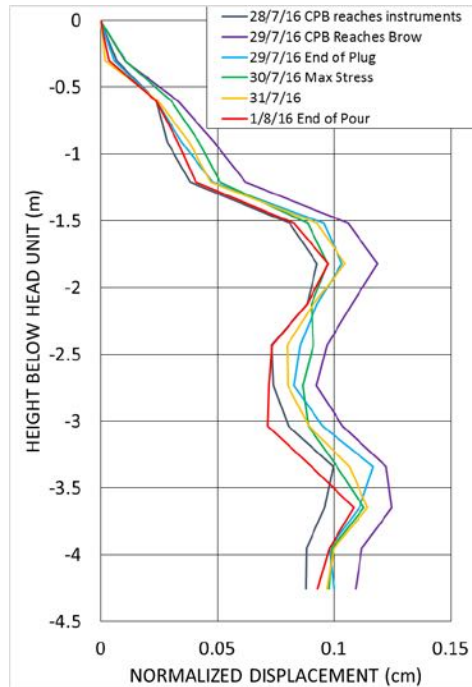


Figure 10. Plot showing the normalized displacement of SAA 3 during the pour

Some large deformations were noted after the pour was finished. For example, SAA 3 had less than 1 mm of maximum displacement after finishing the pour (August 3, 2016). However, by the time the instruments were taken off the wall (approximately 10 days later) the same part of the wall had moved over an additional millimeter. These large displacement increases are attributed to nearby blasting.

Figure 10 overlays TEPC data and displacement data recorded from SAA 3. These show a correlation between blasts inducing pressure changes, measured by the TEPCs and large increases in measured SAA displacement.

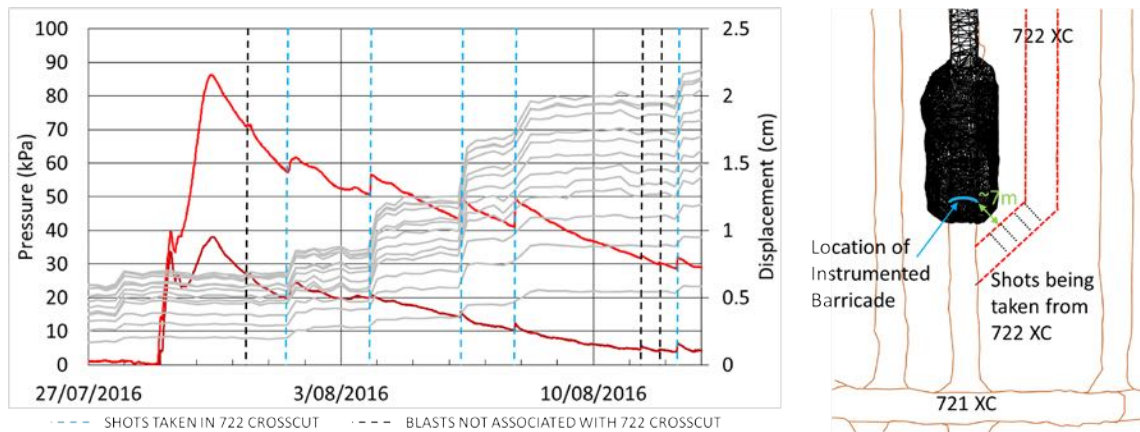


Figure 11. Plot showing correlation between blasts seen in the total stress measurements and displacements observed in SAA 3, and schematic of 722 XC development

The larger changes in displacement generally correlate to blasts taken to develop the 722 crosscut (Figure 11). Each of these shots displaced the SAA by approximately 0.38 cm. The minimal distance between the 722 crosscut development shots and the barricade was approximately 7 m. Note that there

is some ambiguity about the second blast as it does not have the same sharp pressure increase noted in the other blasts, does not precisely correspond to a known blast time, and coincides approximately with to the start of the body pour.

CONCLUSIONS

This paper summarizes the first in situ stress instrumentation installation completed at GFM. The primary focus of this installation was to obtain some barricade load data while refining techniques to ease more complicated future installations. However, even such a simple installation yielded some interesting results:

1. The TEPCs registered relatively low pressures induced by backfilling. GFM's current barricade design uses a design load of 500 kPa. Previous modelling indicates that GFM's barricade design has an additional safety factor of 3 on this load (An ultimate barricade capacity of approximately 1500 kPa). If the measured pressures are used the safety factor for this design would be between 19 and 37 depending which pressure result was used.
2. The low pressure generation is encouraging as it indicates that the CPB is gaining strength quickly. This correlates to the relatively short period of isotropic pressure. This means that it is likely that GFM can pour continuously, subject to additional testing and adequate QA/QC processes being designed.
3. Both TEPCs showed an increase in pressure during the plug's curing period. A possible explanation is thermally driven expansion as this increase in pressure correlates to the rapid increase of temperature due the hydrating cement. However, more work (and additional installations) will be required to determine the validity of this explanation.
4. The barricade instrumentation registered very little change in displacement due to the stope being filled. This instrumentation showed more response to the shotcrete curing and development blasting in an adjacent stope. Part of this attributed to the 70 cm thickness of the barricade wall meaning the barricade strength was significantly greater than the applied load.

Further instrumentation of backfilling stopes is planned at GFM over the next 6 months. It is expected that a further ten installations similar to the one reported here will be completed as well as five full stope installations featuring instruments installed within the open stope. These installations will allow GFM to generate a database of measured barricade pressures and to characterize the in stope behavior of GFM's CPB. The data presented in this paper and the data to be collected in the future will be used to achieve GFM's goal of optimizing both GFM's pour and barricade designs, and determining the feasibility of moving to a continuous pour.

ACKNOWLEDGEMENTS

The Author would like to thank GFM's management team for supporting both the instrumentation project and the writing of this paper. He would also like to thank Justin Enderby and Claire Chauvier for their help during the installation and removal of the instruments.

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