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# Field monitoring of an undercut paste backfill and implications for analysis and design

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## Abstract

*Mining underneath previously placed backfill can offer important operational efficiencies for underground mines. However, determining the strength of backfill that can be safely undercut has posed a long-standing design challenge. Mitchell (1991) proposed an analysis method involving 4 independently evaluated failure mechanisms, the most commonly cited involving assumed flexural bending. Curiously, an earlier publication also included a fifth failure mechanism involving stope wall closure, although this was later omitted for failure analysis but included as a mitigating term in the flexural analysis. Subsequently, Grabinsky et al. (2024) presented a method to assess rock mass closure–backfill interaction which broadly delineates conditions where closure will be dominant, negligible, or intermediate. Field verification of actual conditions is therefore important, with two existing field studies showing the extreme conditions postulated by Grabinsky et al. (2024). The proposed paper features a heavily instrumented underhand cut-and-fill stope at Macassa mine. The experimental design, instrumentation layout and installation details, undercutting details, and field results will be presented. This case study demonstrates the intermediate condition postulated by Grabinsky et al. (2024) where the closure effect dominates the Mitchell flexural effect, yet is not so extensive as to crush the backfill. The paper concludes with recommendations for analysis and design of future undercut backfills.*

**Keywords:** *cemented paste backfill, instrumentation, underhand cut-and-fill*

## 1 Introduction

The stability and performance of backfilled stopes in underground mining operations are critical for ensuring both operational efficiency and mine safety. The use of cemented paste backfill (CPB) has become increasingly prevalent due to its ability to provide support, facilitate efficient ore recovery, and minimise surface tailings disposal (Landriault 1995; Brackebusch & Shillabeer 1998; Potvin et al. 2005). In undercut and backfill stopes, understanding the geomechanical response of CPB to excavation and stress redistribution is essential for optimising stope design, mitigating operational risks, and ensuring long-term ground stability. However, the complex interaction between the backfill material, the surrounding rock mass, and mining-induced stresses presents significant challenges in accurately predicting stope behaviour (Grabinsky et al. 2024). These complexities arise from factors such as backfill placement sequences, curing time, cement hydration, and interactions with excavation-induced stress changes (Fall & Benzaazoua 2005; Klein & Simon 2006; Ghirian & Fall 2013; Fang & Fall 2020; Jafari et al. 2020a, 2020b, 2021, 2025; Jafari & Grabinsky 2021; Pan et al. 2021; Grabinsky et al. 2022; Shahsavari et al. 2022, 2023). Such complexities make it more difficult to predict the response of CPB under different loading scenarios. Therefore, in situ measurements, both through instrumentation and field testing, are essential to verify the accuracy of any empirical or theoretical predictive design models.

Early field investigations on CPB behaviour were conducted at the Chimo Mine in Quebec, Canada (Hassani et al. 2001). In this study, 3 adjacent stopes were mined in a primary–secondary–tertiary sequence, with the

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central one excavated last. Interestingly, the induced stresses recorded in situ were considerably higher than those predicted using laboratory-derived elastic properties, emphasising the limitations of conventional uniaxial testing in replicating in situ stress conditions. These findings were broadly consistent with earlier field observations reported by Corson (1971), Gay et al. (1988), Bruce & Klokow (1988), and Clark (1988). However, 2 case studies directly relevant to the work presented here are from the Lucky Friday and Turquoise Ridge mines in the United States. Seymour et al. (2017) report host rock wall closures and backfill induced stresses in a vertical orebody at Lucky Friday, mined using cut-and-fill techniques. An air gap was left at the top of each fill mass. Stress and displacement changes were monitored during several undercut stages. Observable incremental closures were measured over several undercuts, leading up to 15% closure over the monitoring period. Stresses generally peaked to the expected backfill unconfined compressive strength (UCS) on the first or second undercut, and either stayed about the same (i.e. behaved 'perfectly plastically') or decreased (i.e. strain softened) on subsequent undercuts, leading to the conclusion that the backfill was behaving in the post-peak regime. Vertical rebar support was installed in the stope prior to backfilling, and these were effective in containing the failed backfill. In contrast, the Turquoise Ridge field experiment (Seymour et al. 2019) involved cut-and-fill of 6 adjacent stopes, each 3.8 m wide by 4.6 m high, followed by undercutting of the central 4 stopes. Cemented rockfill was used. Pressure and displacement transducers were installed in the sidewalls, multipoint borehole extensometers were installed in the roof and backfill, vertically oriented stress cells were installed in the backfill, and crack opening meters were installed across 2 interfaces of adjacent backfills. Relatively small (mm scale) end wall displacements were measured resulting in a horizontal closure strain of only about 0.04% over the 22.2 m wide total span. The vertical stress cells registered no appreciable stress change, and the extensometers indicated detachment of the backfilled sill from the overlying rock. The crack extensometers indicated small opening at centre-span. This behaviour can be interpreted as elastic behaviour of a Voussoir beam. These field studies represent the 2 extreme cases described by Grabinsky et al. (2024) who examined backfill–rock mass interactions under various combinations of rock mass stress and stiffness and backfill stiffness. For Lucky Friday, the squeezing potential of the rock mass is so significant that any backfill will fail (Lucky Friday has some of the strongest paste backfills recorded) and for Turqoise Ridge the opposite is true and the backfill behaves elastically in a way that can be idealised using Voussoir beam theory (where vertical cold joints in the backfill must be considered) or beam theory as suggested by Mitchell (1991).

Building on these previous studies, this research implements an advanced field instrumentation program in an undercut backfilled stope to monitor the real-time response of CPB at Macassa mine, which is thought to be a case intermediate between the Lucky Friday and Turquoise Ridge cases. The instrumentation system includes pressure cells to measure total stress development within the backfill, piezometers to track porewater pressure evolution, and an extensometer to assess displacement and deformation patterns over time. These measurements provide valuable insights into the stress transfer mechanisms, drainage behaviour, and consolidation processes of the backfill, which are crucial for refining numerical models and improving stope design methodologies. By capturing real-time data, this study aims to bridge the gap between theoretical predictions and actual field performance, enabling a more comprehensive understanding of backfill behaviour under in situ conditions.

The objectives of this study are 3-fold:

1. To evaluate the effectiveness of the selected instrumentation in capturing key geomechanical responses of CPB in an active mining environment.
2. To analyse the stress and deformation trends observed throughout the monitoring period.
3. To interpret the implications of these findings for stope design and mining operations.

A detailed discussion of the field monitoring methodology, data interpretation, and key findings is presented in this paper.

## 2 Macassa cemented paste backfill mechanical properties

The Macassa mine, situated in the Town of Kirkland Lake, Ontario, was considered for this fieldwork. The backfill used in this fieldwork consists of binder (Lafarge 90/10 slag/cement), mine process water, sand, and mine tailings. In this study, the CPB mixture was prepared with a binder content of 10% (mass of binder relative to the total mass of solids, including sand, tailings, and binder) and a water content of 19–20% (mass of water relative to the total mass of the mixture) and had 27 cm slump. Also, the weight ratio of the dry sand to the dry tailings in the mixture was 2:1. The average UCS of the 28-day cured control specimens (the expected undercut was anticipated to occur in 28 days) was 3,800 kPa. Figure 1 shows the variation of deviator stress with respect to axial strain obtained from drained triaxial tests. All specimens exhibited a similar stress–strain response, characterised by an initial elastic regime, followed by a noticeable reduction in stiffness beyond the yield point, leading up to peak strength. This was subsequently followed by a brittle post-peak behaviour, marked by a sudden drop in stress. This brittle behaviour is typical of cemented or structured materials in which bond breakage leads to a sudden loss of strength (Clough et al. 1981; Coop & Atkinson 1993; Jafari & Grabinsky 2022). The friction angle and cohesion were calculated as 30° and 1.1 MPa, respectively.

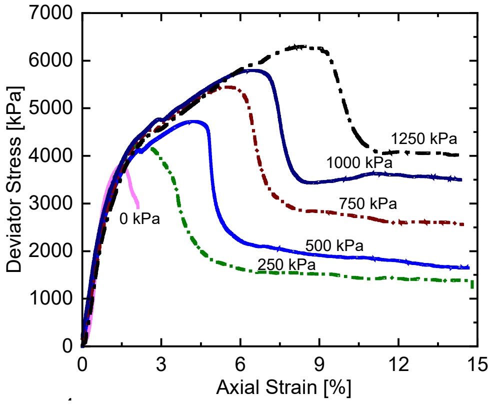



**Figure 1 Deviator stress versus axial strain for studied cemented paste backfill**

## 3 Test stope location

Stope LN 554 133 at approximately 1.7 km depth was considered for this study. The average span and height of the opening in the tested area of the stope are 6 and 4.2 m, respectively, and the floor is nominally horizontal. The plan and cross-sectional views of the test stope are presented in Figure 2.

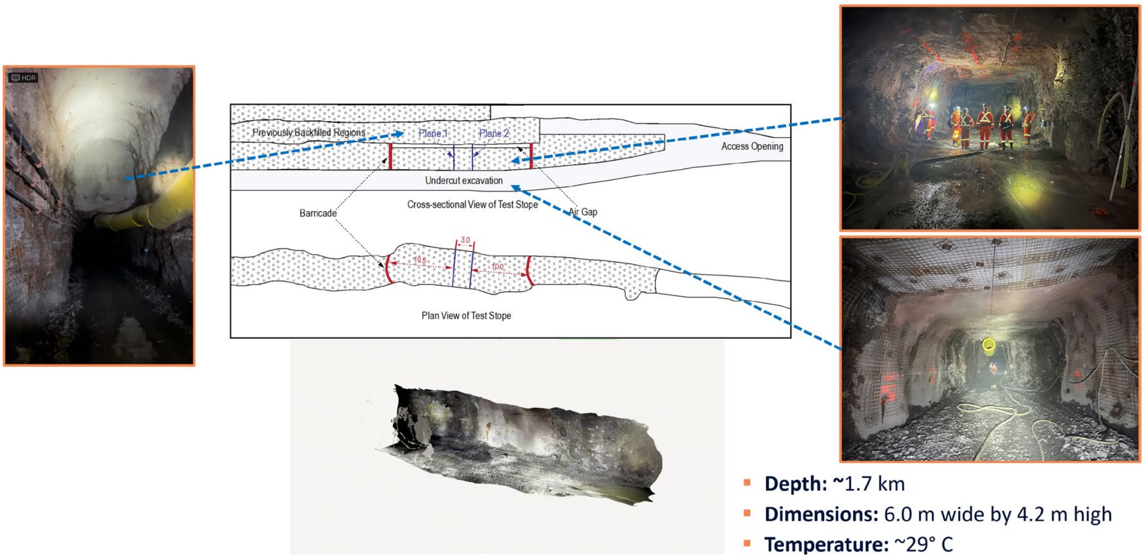



**Figure 2 Plan and cross-sectional views of the tests stope**

Creating a 6 m span for this project was challenging, as the mine's historical seismicity data indicate that the majority of significant seismic events have occurred beyond the point where the planned 6 m width is located. The elevated seismic activity and associated hazard in this area are attributed to complex geology, including fault splays, tuff-porphyry contacts, and mineralised splays (Figure 3). These features are situated within an abutment zone, where stress concentrations are naturally higher. To safely create the test section, both face de-stress blasting and de-stress drilling in the lower wall were implemented. Additionally, the time interval between successive blasting rounds was increased to 48 hours, compared to the routine 12-hour interval, to reduce the risk of triggering seismic events. The advance per blasting round was also limited to 2.4 m as an added precaution to mitigate the potential for events such as rockbursts.

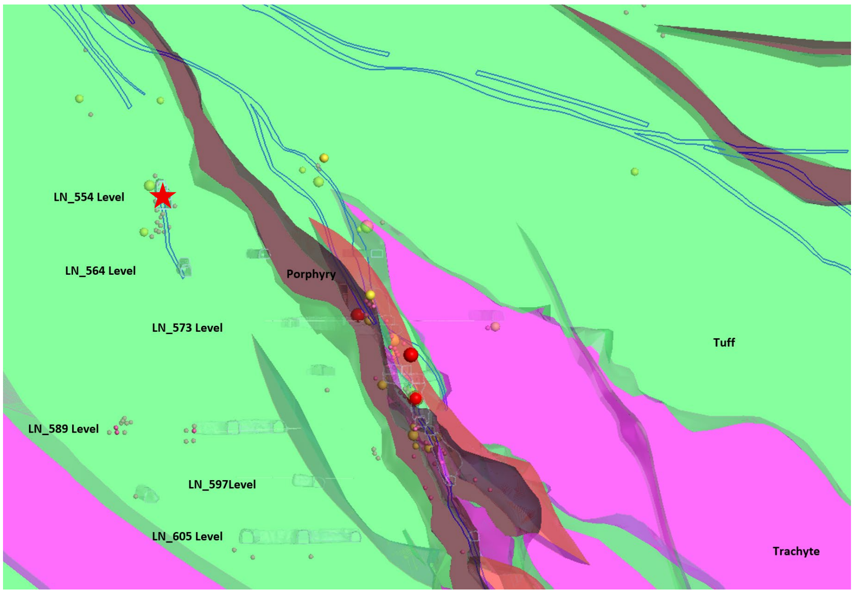



**Figure 3 Geological units in the proximity of the test stope (LN_554 Level location is indicated by red star)**

# 4 Instrument installation procedure

Two instrumentation planes, spaced 3 m apart, were designated for this study within the test stope, as indicated by the blue line in Figure 2. The instrumentation setup for both sections includes the following sensors: 6 multipoint extensometers (to measure the deformation along height of the backfill), 4 multipoint extensometers (to measure the deformation along the width of the backfill), 8 piezometers, and 22 total pressure cells. Six 5-channel vibrating wire nodes for LS-G6 system along with 3 RS485 Digital nodes were used to record data. The recorded data then were connected to the mines network using 4G PoE (Power over Ethernet) ruggedised gateway for LS-G6 wireless system. This provided the users getting access to real-time data allowed the undercutting process to be managed safely for the studied span.

In general, the instruments in each instrumentation plane can be divided into 5 clusters:

- Total pressure and porewater pressure measurement: 3 clusters of sensors were used in each instrumentation plane; 2 clusters on both sides each contained 2 total earth pressure cells (TEPCs) installed with 45˚ angle and one piezometer, and a cluster in the middle of the plane consisting of 3 TEPCs to measure horizontal pressure, 3 TEPCs to measure vertical pressure, and 3 piezometers.
- Horizontal deformation in the backfill measurement: this cluster consists of 2 multipoint extensometers with 6 measuring anchor points. One installed near to the top of the backfill and another one installed in the bottom of the backfill in a way to be far enough from the blast zone.
- Vertical deformation along the height of the backfill measurement: this cluster consists of 3 different 6 points multipoint extensometers. The vertical deformation was measure in the location with potential maximum deformation (i.e. in the middle of the backfill) and also 2 more symmetrical locations with respect to the centre of the backfill.

The locations of instruments in each cluster were determine based on different conducted numerical simulations based on the following target points:

1. The pressure should be measured in the locations that the stress trajectories were in compression when the backfill would be undercut since locating this sensor in the area that would go to tension during the undercutting would not provide useful information in the study of the backfill stability.
2. Measure the possible maximum deformation in the horizontal direction and making sure that we do not install the extensometers near neutral plane of the backfill beam.
3. Minimise the impact of blasting due to undercutting the backfill. Studying the pattern of the blasting to create undercut in the studied mine shows that there is a chance of losing 0.6 m from the bottom of the backfill due to blasting which means that there is a high chance of losing the sensors installed in that blasting area.

To ensure precise positioning and prevent movement during backfilling, all sensors were installed within prefabricated wire cages. Figure 4 provides representations of the instrument placement within the sections. Additionally, 2 TEPCs were specifically installed in the air gap above the backfill in this stope to measure pressure during the over-pressurisation of the backfill.

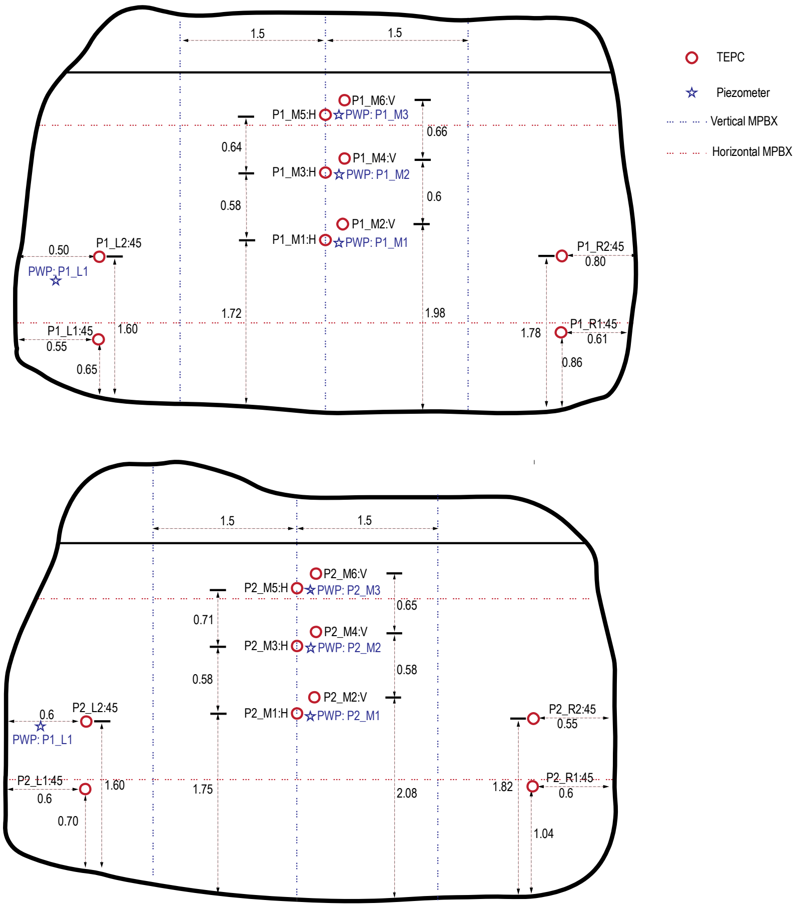
The arrangement of these TEPCs and deformation transducers was optimised to capture the expected stress distribution with a bending predominant response mode. In particular, horizontal compressive stresses should be maximum at the mid-span near the crown (top) of the backfill 'beam' and diminish below. Numerical modelling indicated the compressive stresses should drop to near zero close to the beam's mid-height, with a low tensile stress regime below that (Grabinsky & Jafari 2015). The modelled tensile stresses remained below the expected backfill tensile strength, based on direct tensile strength measurements in the controlled laboratory environment. Similarly, the TEPCs proximate to the sidewalls were inclined to be normal to the expected direction of maximum compressive stress in that region.

To conduct such extensive instrumentation during mining operations, the mine must be fully committed to the study and supported by well-experienced construction crews and engineers on site. Since time is critical in operations, all precautionary actions should be anticipated and put in place before the project begins.

In general, the locations of the required boreholes for MPBXs, as well as the positions of TEPCs and piezometers, should be determined in advance. If cages are used to mount these instruments, it is preferable to prepare the mounting locations on the cages beforehand to ease the installation process in the stope.

One of the main challenges in projects like this, where a large number of sensors must be installed in a limited space, is managing and protecting the wires against different loading conditions such as blasting or the impact of flying rock. The installer must have a clear plan for wire routing before starting sensor installation. For example, in this project, due to the undercut, approximately the bottom half of the stope would potentially be exposed to compression loading. Therefore, all wires installed on the stope walls were routed along the upper half portion of the stope.

The most critical sections of wiring are those exposed to blasting and interaction with mining equipment. To mitigate this, a 250 mm diameter plastic pipe was routed from the barricade to the logging system to protect the wires. While the plastic pipe generally provided protection against flying rock during blasting, in one case, a coupling between two pipes failed, resulting in the severing of 2 sensor wires. For this reason, it is recommended to carefully check the couplings, particularly near blasting zones, after each blast. Additionally, using rubber blankets and extra precautionary chains around the blasting zone is strongly advised (as shown in Figure 5).




**(a)**

**(b)**

**Figure 4** (a) Schematic of the relative locations of sensors used in this study; (b) A view of installed sensors in the test stope


**Figure 5 Precautionary procedures to secure wires near the blasting face. (a and b) Decoupling of conduit pipes due to blasting-induced waves caused damage in wires; (c) Use of rubber blankets and additional precautionary chains around the blasting zone**

# 5 Filling process

A total volume of 994 tonnes backfill was poured into the test stope over 14 hours. Based on the stope dimensions, the average filling rate was calculated to be 25 cm per hour. To allow for water injection above the backfill and ensure the required pressure could be applied through pressurisation to fail the backfill later, an air gap above the backfill was necessary. The survey team determined the backfilling end point to maintain an air gap of approximately 45 cm above the backfill. Pressurising the backfill after undercutting is intended to determine the ultimate in situ failure level of the test stope, which will not be discussed in this paper.

To ensure precise control of the backfill height, a camera was installed in the stope, providing a live feed that allowed operators to monitor the filling process (Figure 6). The backfill feeding pipe was shut off once the desired height was reached.

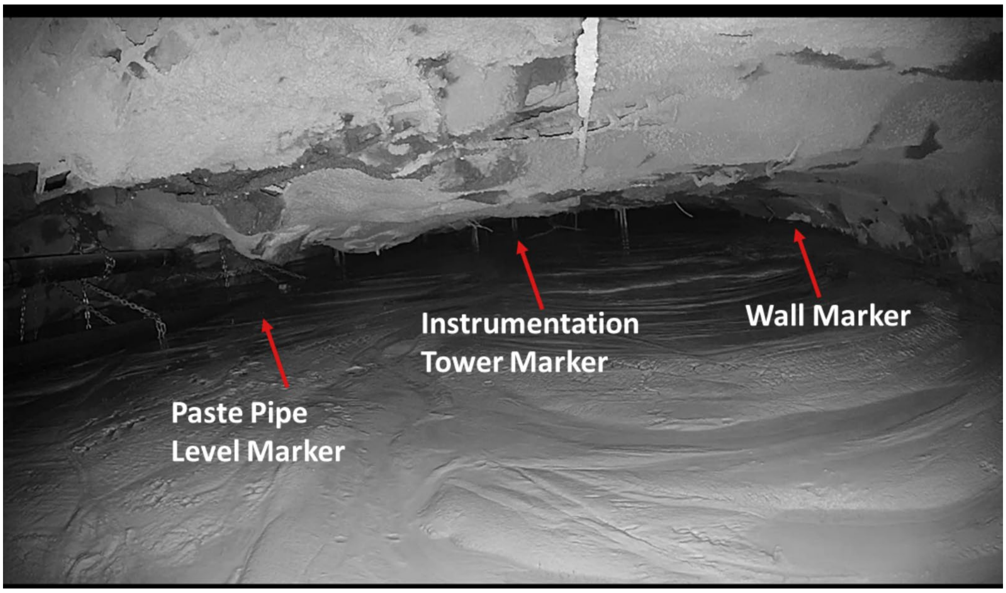



**Figure 6 A view of backfilled stopes captured by installed camera in the stope**

# 6 Results and discussion

Stress and temperature monitoring results are shown in Figure 7 for planes 1 and 2 at the backfill beam's mid-span. The horizontal axes show time (in hours) since the start of backfilling. The vertical axes show measures of stress (major axis) or temperature (minor axis). The cell numbering conventions are shown in Figure 4: cells M2, M4 and M6 measure vertical stress; cells M1 measures horizontal stress at approximately mid-height, M3 just above, and M5 closest to the beam's top surface. The backfill initially reaches the transducers depending on their installation heights and is placed relatively quickly (within approximately 14 hours). The early backfill response during this period is consistent with previous studies by Thompson et al. (2011, 2012) and Helinski et al. (2011), showing that both the pore water pressure (PWP) transducers and TEPCs record similar pressures at the beginning. These pressures correspond to the hydrostatic load exerted by the paste column above the sensors. Over time, as cementation progresses and inter-particle bonding develops, effective stress begins to form, leading to a gradual reduction in porewater pressure. Reviewing the provided data shows there is a significant temperature rise immediately after backfilling due to the exothermic reaction of binder hydration and also the higher temperature of surrounding rock. Since this behaviour has been extensively studied elsewhere and is not the primary focus of this paper, further discussion is deferred here.

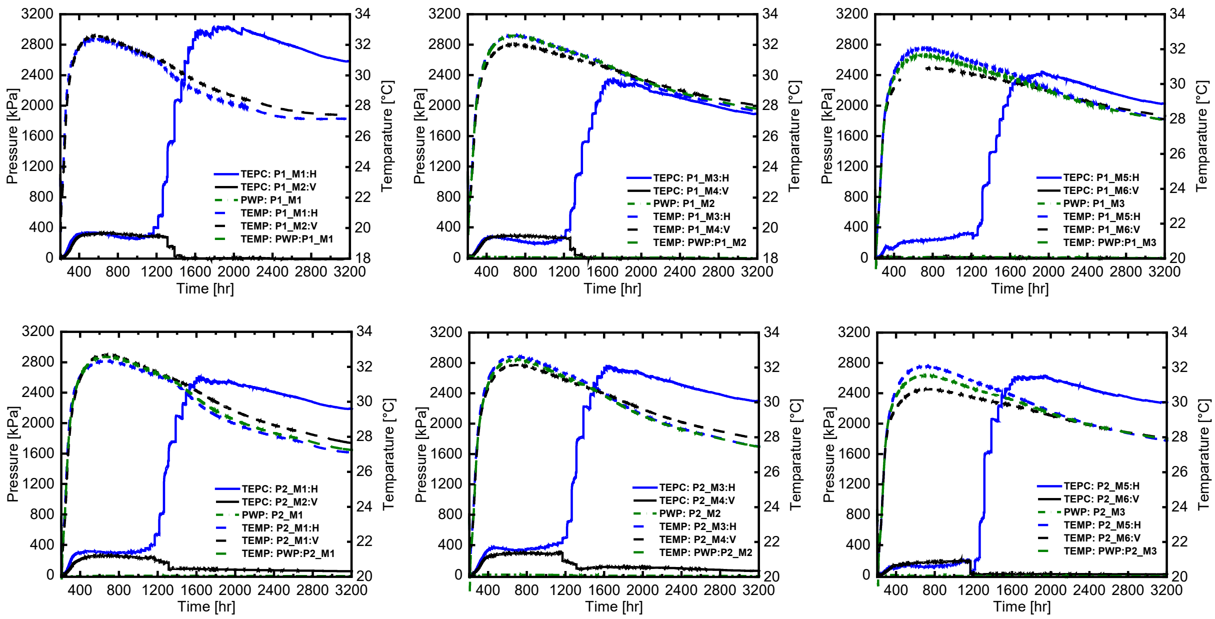



**Figure 7 Stress and temperature monitoring results for instruments installed in the middle span for planes 1 and 2**

The backfill then cures for about 30 days (to about time 1,000 hours) before the undercutting stage is initiated. During this period, the monitored porewater pressures become insignificant, probably due to the self-desiccation effect of binder hydration (i.e. hydration consumes some of the free water). The horizontal and vertical total stresses are generally approximately equal during this period, and much larger than would be expected based on backfill self-weight effects (i.e. the largest measured vertical stress should be about 40 kPa whereas the measured values are an order of magnitude larger). These effects of elevated temperature, diminished porewater pressures, and anomalously high total stress measurements are consistent with previous monitored CPB campaigns (Thompson et al. 2014).

The process of undercutting begins at around time 1,250 hours and continues until about time 1,750 hours. During this process, the measured vertical stresses drop significantly and to essentially zero in some cases which is expected due to undercutting when there is an air gap overlying the backfill beam. As mentioned, the horizontal total stress measurement array was designed to capture the potential bending effects in the beam, in which case the expected stresses are highest at the top (M5) and least at the mid-height (M1).

Furthermore, the modelled horizontal stress at the M5 location is expected to be a few hundred kPa (the exact magnitude depending on values used for the different input modelling parameters). In contrast, all of the measured horizontal stresses are many times (perhaps up to an order of magnitude) more than this. Also, in plane 2, the horizontal stresses are essentially equal (about 2,600–2,800 kPa) throughout the beam's height and, in plane 1, the stresses show a trend inverse to that expected from bending effects, with the highest stress at mid-height and the least stress closest to the beam's top surface. Given these observations, it is concluded that the horizontal stress distribution must be dominated by wall-to-wall closure as opposed to bending mechanisms.

To test the above hypothesis, numerical simulations were first conducted assuming no closure, with stresses developing solely from the self-weight of the backfill, resulting in induced stresses of a few hundred kPa at mid-span. Additional simulations incorporating different closure levels showed a significant increase in horizontal stresses as observed in this study. The parameters used in these simulations were based on extensive laboratory testing. Considering the air gap above and the free space below the backfill due to undercutting, the stress path falls between uniaxial compression and one-dimensional strain conditions. Assuming a UCS-like loading path allows the calculated Young's modulus to be consistent with expected behaviour.

As a further check of this hypothesis the closure measurements are used in conjunction with the measured average horizontal total stresses to infer what the as-placed backfill stiffness must be. Note that the horizontal stresses induced during undercutting are much more significant than those occurring during the initial filling and curing period, and so effects of initial placement and temperature induced apparent stress can be effectively ignored in this analysis.

The wall-to-wall displacements recorded by the horizontally-oriented contractometers were about 3–3.5 mm after undercutting. Assuming the backfill beam is essentially acting as a uniaxial compression sample loaded in the horizontal direction, this means the Young's modulus is about 5.2 GPa. Laboratory prepared samples were tested in a specialty digital imaging correlation system (Trilion SNAP v.2. 8.5.0.0 acquisition system software [Trilion Quality Systems 2025]) at the University of Toronto laboratories and the effective Young's modulus determined to be 4.8 GPa. This result is also consistent with the Young's modulus of Lucky Friday CPB samples of similar UCS, where that material's stiffness was determined using strain gauges applied to the specimen's mid-height. Similarly, researchers at Lucky Friday monitored wall-to-wall closures during undercutting and correlated these with measured induced backfill stresses, also finding consistency between laboratory results and the field scale backfill properties. However, whereas the closure strains at Lucky Friday were significant (up to 15%) the closure strains measured at Macassa are much smaller.

# 7 Practical implications and recommendations for analysis and design of future undercut backfills

The conceptual model of the interaction between rock mass stress and stiffness and backfill stiffness described by Grabinsky et al. (2024) is shown diagrammatically in Figure 8. Rock mass stiffness is approximated by geological strength index in this figure. The interpretation of this diagram is as follows:

1. At high stress and low rock mass stiffness (i.e. the lower left zone in Figure 8), the backfill cannot be engineered to resist rock mass closure, and it should be expected that the wall-to-wall induced closure strains will be sufficient to fail the backfill as was observed in the Lucky Friday case. Under these circumstances, the backfill must be mechanically supported so that the failed backfill is safely retained in the stope.
2. At low stress relative to the rock mass stiffness (i.e. the upper right zone in Figure 8), the stope wall closure strains will be sufficiently small that little horizontal closure stress will be induced, as was observed in the Turquoise Ridge case. These backfills can then be designed using elastic models such as Voussoir beam theory or Euler beam theory as suggested by Mitchell (1991).

3. The intermediate case, where closure strains should not be ignored but will not be so large as to fail the backfill, is represented by the bounding curved lines running diagonally through Figure 8. This appears to be the case for Macassa, unlike the position Macassa is shown to occupy in Figure 8; therefore, additional explanation is required.

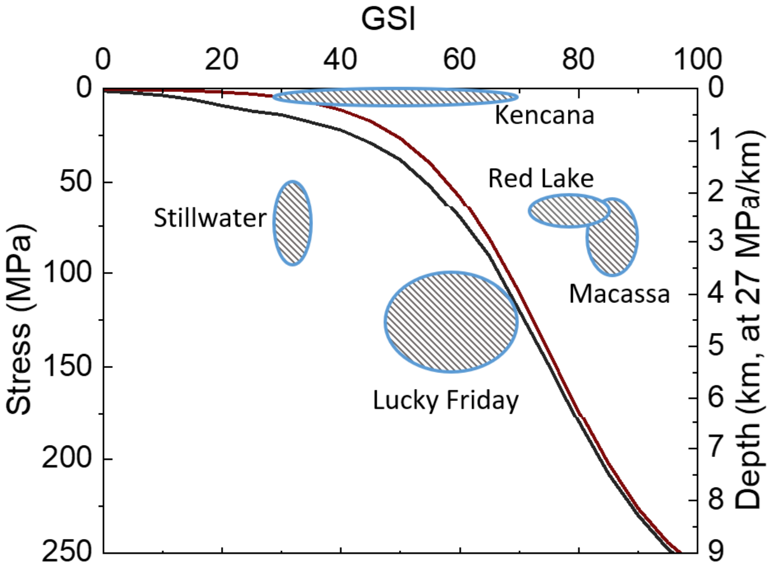



**Figure 8 Hypothesised interaction between rock mass stress and stiffness and backfill stiffness, with example case studies superposed**

The original model presented by Grabinsky et al. (2024) was indicated as conceptual and not intended for detailed design. It was based on a series of square stopes mined sequentially in either a vertical or horizontal sequence. The intermediate case represented by the bounding diagonal lines in Figure 8 was based on 2% closure strain; larger closure strains would imply greater separation between these bounding lines. Critically, it assumed that the backfill stiffness (Young's modulus) to UCS ratio is a constant 250 which represents an average through composite data from about 25 publications of such correlations on different CPB materials (Grabinsky et al. 2022). At the high end of these correlations is Lucky Friday, where the ratio is closer to 1,000. This is probably also the case for Macassa backfill materials based on the information presented in the previous section. As indicated in the original publication, Grabinsky et al. (2024) recommend using their approach to understanding the rock mass; backfill interactions on a case-specific basis that incorporates more realistic excavation geometry and backfill sequencing, rock mass stress and stiffness, and backfill material properties.

Until a better model than presented in Grabinsky et al. (2024) and shown in Figure 8 is developed (which may require incremental improvement over many years and many more case studies), it is suggested that Figure 8 be used for preliminary design to guide the engineer on the extent to which rock mass closure may be an issue for a particular site. Undercut analyses can be carried out using conventional elastic beam theories for preliminary design, recognising that these may provide an upper bound strength if the rock mass closure is slight and beneficial to reducing stress concentrations in the undercut backfill 'beam'. The 'closure term' in the Mitchell (1991) flexure equation provides the basis for a sensitivity analysis, but the user must bear in mind that including arbitrary closure values can result in non-sensical computed backfill strengths. At the other extreme, if the combination of rock mass stiffness and stress places the site in below the diagonal lines in Figure 8 (e.g. the Stillwater and Lucky Friday cases), then backfill failure to some extent should be anticipated, and pre-support in the form of screen and reinforcing bars placed in the stope prior to backfilling will need to be considered.

# 8 Conclusion

Although Mitchell's proposed design approach for undercut backfills was made over 35 years ago, the engineering community is still learning much about how undercut backfills behave under different conditions of rock mass stiffness and stress, and different mining methods requiring backfill to be undercut. Thorough back-analyses of quality monitored field case studies will be essential in developing more refined models than the one proposed by Grabinsky et al. (2024) and shown in Figure 8. Hopefully the successes achieved in the monitored backfills at Lucky Friday, Turquoise Ridge, and now Macassa mines will encourage others to do more to monitor and assess undercut backfill response at their mine sites. Until then, the preliminary design guidance suggested in the previous section may be helpful for design engineers undertaking new designs, or trying to better understand observed behaviour of their undercut backfills.

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# References

Brackebusch, F & Shillabeer, J 1998, 'Use of paste for tailings disposal', *6th International Symposium on Mining with Backfill*, Australasian Institute of Mining and Metallurgy, Victoria, pp. 53–58.

Bruce, MFG & Klokow, JW 1988, 'A follow-up paper on the development of the West Driefontein tailings backfill project', *Symposium on Backfill in South Africa Mines*, South African Institute of Mining and Metallurgy, Johannesburg, pp. 473–490.

Clark, IH 1988, *The Strength and Deformation Behaviour of Backfill in Tabular Deep-Level Mining Excavations*, PhD thesis, University of the Witwatersrand, Johannesburg.

Clough, GW, Sitar, N, Bachus, RC & Rad, NS 1981, 'Cemented sands under static loading', *Journal of the Geotechnical Engineering Division*, vol. 107, no. 6, pp. 799–817.

Coop, MR & Atkinson, JH 1993, 'The mechanics of cemented carbonate sands', *Géotechnique*, vol. 43, no. 1, pp. 53–67, https://doi.org/10.1680/geot.1993.43.1.53

Corson, DR 1971, *Field Evaluation of Hydraulic Backfill Compaction at the Lucky Friday Mine, Mullan, Idaho*, report of investigation no. 7546, US Department of Interior, Bureau of Mines, Washington, D.C.

Fall, M & Benzaazoua, M 2005, 'Modeling the effect of sulphate on strength development of paste backfill and binder mixture optimization', *Cement and Concrete Research*, vol. 35, no. 2, pp. 301–314, https://doi.org/10.1016/j.cemconres.2004.05.020

Fang, K & Fall, M 2020, 'Shear behavior of the interface between rock and cemented backfill: effect of curing stress, drainage condition and backfilling rate', *Rock Mechanics and Rock Engineering*, vol. 53, no. 1, pp. 325–336, https://doi.org/10.1007/s00603-019-01909-2

Gay, NC, Jager, AJ & Piper, PS 1988, 'Quantitative evaluation of fill performance in South African gold mines, backfill in South African Mines', *Symposium on Backfill in South Africa Mines*, South African Institute of Mining and Metallurgy, Johannesburg, pp. 167–202.

Ghirian, A & Fall, M 2013, 'Coupled thermo-hydro-mechanical–chemical behaviour of cemented paste backfill in column experiments. Part I: physical, hydraulic and thermal processes and characteristics', *Engineering Geology*, vol. 164, pp. 195–207, https://doi.org/10.1016/j.enggeo.2013.01.015

Grabinsky, M & Jafari, M 2015, 'Determining stable spans of undercut cemented paste backfill', *GeoQuebec*, Canadian Geotechnical Society, Quebec.

Grabinsky, M, Jafari, M & Pan, A 2022, 'Cemented paste backfill (CPB) material properties for undercut analysis', *Mining*, vol. 2, no. 1, pp. 103–122, https://www.mdpi.com/2673-6489/2/1/7

Grabinsky, MW, Thompson, B, Jafari, M, Counter, DB & Bawden, WF 2024, 'Understanding rock mass–backfill interaction in support of deep and high-stress mining', in P Andrieux & D Cumming-Potvin (eds), *Deep Mining 2024: Proceedings of the 10th International Conference on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 1349–1364, https://doi.org/10.36487/ACG_repo/2465_89

Hassani, F, Ouellet, J & Servant, S 2001, 'In situ measurements in a paste backfill: Backfill and rock mass response in the context of rockburst', *Seventeenth International Mining Congress and Exhibition of Turkey- IMCET2001*, Ankara, pp. 165–175.

Helinski, M, Fahey, M & Fourie, A 2011, 'Behavior of cemented paste backfill in two mine stopes: measurements and modeling', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 137, no. 2, pp. 171–182, https://doi.org/10.1061/(ASCE)GT.1943-5606.0000418

Trilion Quality Systems 2025, *Trilion Snap User's Manual, v.2.8.5.00,* Pennsylvania, PA**,** USA

Jafari, M & Grabinsky, M 2021, 'Effect of hydration on failure surface evolution of low sulfide content cemented paste backfill', *International Journal of Rock Mechanics and Mining Sciences*, vol. 144, p. 104749, https://doi.org/10.1016/j.ijrmms.2021.10474

Jafari, M & Grabinsky, M 2022, 'Predicting the isotropic volumetric compression response of hydrating cemented paste backfill (CPB)', *Geotechnical and Geological Engineering*, vol. 40, no. 9, pp. 4821–4836, https://doi.org/10.1007/s10706-022-02186-7

Jafari, M, Shahsavari, M & Grabinsky, M 2020a, 'Cemented paste backfill 1-D consolidation results interpreted in the context of ground reaction curves', *Rock Mechanics and Rock Engineering*, vol. 53, no. 9, pp. 4299–4308, https://doi.org/10.1007/s00603-020-02173-5

Jafari, M, Shahsavari, M & Grabinsky, M 2020b, 'Experimental study of the behavior of cemented paste backfill under high isotropic compression', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 146, no. 11, p. 06020019, https://doi.org/10.1061/(ASCE)GT.1943-5606.0002383

Jafari, M, Shahsavari, M & Grabinsky, M 2021, 'Drained triaxial compressive shear response of cemented paste backfill (CPB)', *Rock Mechanics and Rock Engineering*, vol. 54, no. 6, pp. 3309–3325, https://doi.org/10.1007/s00603-021-02464-5

Jafari, M, Song, X & Grabinsky, M 2025, 'Development of a method to predict the nonlinear mechanical response of cemented paste backfill to mining induced closure strains', *Rock Mechanics and Rock Engineering*, vol. 58, no. 8, pp. 9435–9457, https://doi.org/10.1007/s00603-025-04595-5

Klein, K & Simon, D 2006, 'Effect of specimen composition on the strength development in cemented paste backfill', *Canadian Geotechnical Journal*, vol. 43, no. 3, pp. 310–324, https://doi.org/10.1139/t06-005

Landriault, D 1995, 'Paste backfill mix design for Canadian underground hard rock mining',9*7th Annual Meeting of the C.I.M. Rock Mechanics and Strata Control Session*, Canadian Institute of Mining, Metallurgy and Petroleum, Halifax, pp. 229–238.

Mitchell, RJ 1991, 'Sill mat evaluation using centrifuge models', *Mining Science and Technology*, vol. 13, no. 3, pp. 301–313, https://doi.org/10.1016/0167-9031(91)90542-K

Pan, A, Jafari, M, Guo, L & Grabinsky, M 2021, 'Hybrid failure of cemented paste backfill', *Minerals*, vol. 11, no. 10, p. 1141, https://www.mdpi.com/2075-163X/11/10/1141

Potvin, Y, Thomas, E & Fourie, A 2005, *Handbook on Mine Fill*, Australian Centre for Geomechanics, Perth.

Seymour, JB, Raffaldi, MJ, Abraham, H, Johnson, JC & Zahl, EG 2017, 'Monitoring the in situ performance of cemented paste backfill at the Lucky Friday Mine', *Minefill 2017: The 12th International Symposium on Mining with Backfill*, Society for Mining, Metallurgy and Exploration, Engelwood, pp. 19–22.

Seymour, JB, Martin, LA, Raffaldi, MJ, Warren, SN & Sandbak, LA 2019, 'Long-term stability of a 13.7 × 30.5-m (45 × 100-ft) undercut span beneath cemented rockfill at the turquoise ridge mine, Nevada', *Rock Mechanics and Rock Engineering*, vol. 52, no. 12, pp. 4907–4923, https://10.1007/s00603-019-01802-y

Shahsavari, M, Jafari, M & Grabinsky, M 2022, 'Influence of load path and effective stress on one-dimensional deformation of cemented paste backfill (CPB) during deposition and curing', *Geotechnical and Geological Engineering*, vol. 40, pp. 2319–2338, https://doi.org/10.1007/s10706-021-02030-4

Shahsavari, M, Jafari, M & Grabinsky, M 2023, 'Simulation of cemented paste backfill (CPB) deposition through column experiments: comparisons of field measurements, laboratory measurements, and analytical solutions', *Canadian Geotechnical Journal*, vol. 60, no. 10, pp. 1505–1514, https://doi.org.10.1139/cgj-2020-0597

Thompson, BD, Grabinsky, MW, Veenstra, R & Bawden, WF 2011, 'In situ pressures in cemented paste backfill — a review of fieldwork from three mines', in R Jewell & AB Fourie (eds), *Paste 2011: Proceedings of the 14th International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 491–503, https://doi.org/10.36487/ACG_rep/1104_42_Thompson

Thompson, BD, Bawden, WF & Grabinsky, MW 2012, 'In situ measurements of cemented paste backfill at the Cayeli Mine', *Canadian Geotechnical Journal*, vol. 49, no. 7, pp. 755–772, https://doi.org/10.1139/t2012-040

Thompson, BD, Simon, D, Grabinsky, MW, Counter, DB & Bawden, WF 2014, 'Constrained thermal expansion as a causal mechanism for in situ pressure in cemented paste and hydraulic backfilled stopes', in Y Potvin & T Grice (eds), *Mine Fill 2014: Proceedings of the Eleventh International Symposium on Mining with Backfill*, Australian Centre for Geomechanics, Perth, pp. 365–378, https://doi.org/10.36487/ACG_rep/1404_29_Thompson