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Geotechnical aspects of the Pike River mine drift recovery

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GEOTECHNICAL ASPECTS OF THE PIKE RIVER MINE DRIFT RECOVERY

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ABSTRACT: The Pike River mine exploded on the 19 November 2010. Thirty-one (31) men were working underground at the time of the explosion and only two men were able to escape. The Pike River Recovery Agency was established in January 2018 to conduct a safe manned re-entry and recovery of the Pike River mine drift to gather evidence to better understand what happened in 2010.

SCT Operations Pty Ltd (SCT) have been engaged to assist with the management of strata control hazards as part of the planning and implementation phases of the drift recovery. Initial geotechnical assessments comprised review of available historical geological and geotechnical information to develop a geotechnical baseline report and hazard map to assist with future planning and risk management. A range of controls have been implemented to manage geotechnical risk to acceptable levels and to ensure that adequate levels of inspection, mapping, monitoring, assessment, and review are maintained at all stages of drift recovery. Additionally, 3D FLAC modelling, surface tunnelling simulations and field loading trials have been conducted to support proposed tunnelling through a Rocsil plug located at the top end of the drift to provide access the rock fall area which marks the end of the mandated drift recovery. Given most of the drift had not been physically inspected following the explosion a range of drillhole assessments comprising downhole camera and laser scanning was also conducted to improve understanding of the drift environment both prior to and during re-entry.

As part of operational implementation and continuous improvement processes modifications were made to both ground support systems and bolting equipment which significantly improved support cycle installation times. SCT also supplied real-time roof monitoring instrumentation to the site which supplies an almost continuous data feed to the mine control room for interpretation and automatic alerting if Trigger Action Response Plan (TARP) threshold levels are exceeded.

INTRODUCTION AND BACKGROUND

Pike River Mine is an underground coal mine, located 46 km north-northeast of Greymouth on the South Island's West Coast of New Zealand (Figure 1). Access to the mine workings is through a single 2.3 km stone drift which is developed to the rise at an average grade of approximately 1 in 9. The tunnel was driven through metamorphic Gneiss basement rocks to a point where it intersects the approximately 600 m throw Hawera Fault at around 2100 m. Inbye the Hawera Fault the tunnel passes into geologically structured coal measures to intersect the Brunner Coal Seam near the top of the drift about the rockfall location.

An explosion at 3:44 pm on Friday 19 November 2010 resulted in the loss of twenty-nine (29) miners. Two men, who were in the access drift some distance from the mine workings, managed to escape.

On 24 November 2010, a second explosion occurred, and this suspended any consideration for re-entering the mine. A third explosion occurred at 3:39 pm on the 26 November and a fourth explosion occurred on the 28 November at 1:55 pm.

In January 2011, the mine was sealed by Mines Rescue personnel, and the recovery attempt abandoned. No one has entered and physically inspected the drift following the explosion except for mines rescue personnel who reached around 300 m as part of assessment and construction of the 170 m seal. A large rockfall, which occurred sometime following the first explosion, is located at the top end of the drift around 2260 m and prevents access into the mine workings.

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Figure 1: Pike River Mine location plan

The mine was sold by the receivers of Pike River Coal Ltd in 2012 to Solid Energy New Zealand Ltd (Solid Energy) with the Government agreeing to fund a re-entry project on the basis any plan was safe, technically feasible and economically viable. The detailed plan developed by Solid Energy was rejected on the basis that it did not satisfy those criteria and the mine was subsequently sealed at 30 m inbye the portal by Solid Energy in November 2016.

The Pike River Recovery Agency *Te Kāhui Whakamana Rua Tekau mā Iwa* (the PRRA) was established by the NZ Government as a stand-alone government department on 31 January 2018 to work in close partnership with the Pike River families and other key stakeholders to plan for decisions on the safe manned re-entry of the Pike River mine drift.

The PRRA strategic objective is to conduct a safe manned re-entry and recovery of the Pike River mine drift (access tunnel) to:

- Gather evidence to better understand what happened in 2010 with an eye to preventing future mining tragedies and promoting accountability for this mining tragedy;
- Give the Pike River families and victims overdue closure and peace of mind; and
- Recover remains where possible.

The PRRA works in close partnership with the Family Reference Group and their technical experts who together play a central role in the planning, decision making and implementation on the safe manned re-entry of the Pike River Mine drift.

The evidence gathering processes are directed by the NZ Police Investigation team who provide onsite oversight to all the forensic processes conducted in the drift and on surface as part of the staged drift recovery. The PRRA also operates in a publicly transparent and open fashion with rigorous assessment of risks and control measures associated with manned re-entry of the drift.

SCT Operations Pty Ltd (SCT) were engaged by the Agency to assist with the management of strata control hazards as part of the planning and implementation phases of the drift recovery process. This paper summaries the geotechnical aspects of the Pike River Mine drift recovery.

INITIAL PLANNING WORKSHOPS

Between April and October 2018, the PRRA consulted a wide range of technical advisors from the UK, Australia and New Zealand to develop and risk assess potential re-entry and recovery options for the Pike River Mine drift. The drift recovery comprised recovery of the drift up to a large rockfall located at around 2260 m as well as an additional approximately 600 m of side tunnels which formed the Pit Bottom in Stone (Figure 2). The workshops involved family group members, advisors, Worksafe NZ and independent reviewers who developed three distinct operational re-entry plans. The planning process included rigorous assessment and integration of the forensic examination processes to be conducted at every stage of the drift recovery process.

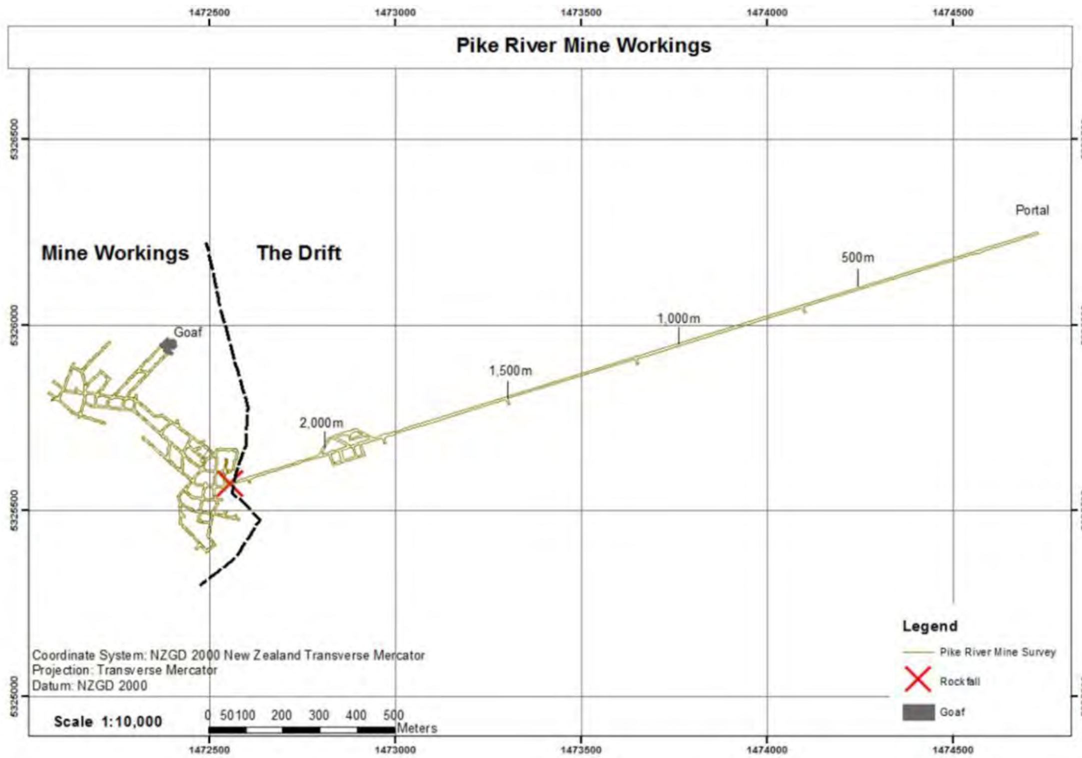

Figure 2: Pike River Mine workings and drift recovery extents

The three options considered for safe drift re-entry included:

- **Option A** - Driving a short, small diameter access tunnel into the drift (near Pit Bottom in Stone) from a suitable location on the side of the drift to provide a second means of egress and ventilation circuit to ventilate the drift with fresh air.
- **Option B** - Single-entry option (using the existing drift) without a new access tunnel or large diameter borehole and using forced ventilation with alternative safety provisions such as a refuge chamber and facilities for refilling breathing apparatus.
- **Option C** - Drilling a large diameter borehole of 600mm or greater from above, and into, the drift to provide an emergency escapeway. The borehole would not meet the legal requirements of a second means of egress.

The PRRA assessed each option and preferred re-entry of the single-entry drift which was considered both technically feasible and safe. Relative to the other options it was also considered the simplest method and the preferred approach to ventilation and egress whilst the drift work was being conducted.

On 14 November 2018, the Minister for the PRRA formerly confirmed the Government’s intent to recover the Pike River Mine drift and confirmed Single Entry (Option B) as the preferred re-entry option. Risks associated with single entry drift recovery are managed through best practice risk management and planning processes.

As part of the single-entry drift recovery a forcing ventilation system was considered the safest and most effective option. This resulted in the drift acting as the mine return. In addition, and as part of more detailed planning, a Rocsil plug was remotely placed into the drift down a borehole at the top of the drift to assist with mine ventilation and to separate, via a physical barrier, the mine workings from the drift. The Rocsil plug was installed approximately 10 m outbye the rockfall. Due to the ventilation system adopted an exemption was sought from the mining regulations that specifies that an escapeway from the mine must be in an intake airway. Drift recovery efforts could not proceed past the mines rescue seal located at 170m until the exemption was approved. The exemption was approved, following additional risk assessment and planning, in December 2019 for drift recovery up to the Rocsil plug. The 170m seal was breached in late December 2019 with drift recovery operations commencing in January 2020.

GEOTECHNICAL BASELINE REPORT

A range of geotechnical assessments have been conducted to assist the PRRA with safe and efficient drift recovery. Prior to drift recovery efforts commencing a factual Geotechnical Baseline Report (GBR) was compiled by review of readily available information. The GBR formed an important part of the workflow as there was uncertainty surrounding the actual ground conditions, stability of the drift and the integrity of the installed support elements. The GBR included review of construction records and shift reports including bolt installation audits, detailed geotechnical mapping records and rock mass classification data captured during drift development. The GBR was developed to reduce uncertainty, assist with more detailed planning and allow for the identification and management of several key strata control risks.

The key hazards identified as part of the GBR which required suitable management as part of the drift recovery included:

- The single-entry nature of the drift and the subsequent risk of entrapment due to rockfall.
- The very poor to extremely poor ground associated with faulted and geologically structured areas.
- Areas, particularly about mapped faults, that appear to be under supported for the rock conditions encountered.
- Potential for significant fire related damage to the roof (including potential for falls of ground) in the weaker Coal Measure Strata.
- Time dependant deterioration (i.e. corrosion) of black steel bolts, given the drift was constructed 14 years prior to the recovery, and reduced capacity of support elements including shotcrete.
- Areas of poorly installed support quality; resin mixing issues were commonly noted in various shift reports and, in the coal measure section of tunnel, highlighted several concerns in relation to both the quality of the installed support and deviation away from the recommended mining system, support design and tunnel monitoring plan.
- Areas of over dimension roadway noting the nominal design profile was rarely achieved due to over break in the gneiss and coal measure section of the tunnel.
- The potential for time dependant weathering of the rock mass particularly in areas of shallow cover (<50 m) which may provide for modes of ground failure associated with the blocky rock mass.
- Areas that exhibit large signs of actual or visual deformation resulting in a higher instability risk.

The GBR provided input for operational implementation of safe manned re-entry including the following controls; initial ground support design, design assistance and procurement of fit for purpose bolting rigs and bolting systems, the development of geotechnical principle hazard management plans, operating procedures, geotechnical Trigger Action Response Plans (TARPs) with included provision for bolt integrity testing, hazard plans and workforce training material. The information contained in the GBR was also summarised and included in the mines Permit to Recover documents for the various stages of drift recovery.

DRIFT DEVELOPMENT AND GEOTECHNICAL CONDITIONS IN THE DRIFT

Construction of the 2.3 km long Pike River drift commenced in September 2006 and was completed in late 2008. The drift was designed with a nominal width of 5.5 m and a nominal height of 4.5 m with an arched profile across the crown. Between chainage 1880m and 2035 m a series of approximately 600 m of additional tunnels were developed off the main drift to establish pump stations and coal handling infrastructure - this area is known as the Pit Bottom in Stone. The tunnel profile in the pit bottom in stone varied to suit the installed infrastructure with resultant profiles ranging from 5.5 m to 8m wide and from 4.5 m to 11 m high. The drift was constructed almost entirely by conventional drill and blast methods using a twin boom jumbo and conventional explosives. Figure 3 shows the jumbo in the drift highlighting the typical tunnel profile, water inflows and the often-wet tunnelling conditions.

Figure 3: Pike River drift during construction highlighting the ground conditions, water inflows and often-wet conditions

The entire tunnel East (outbye) of the Hawera Fault has been excavated in Metasedimentary Gneiss from the portal to chainage 2098 m where the Hawera Fault was intersected in the drift (Figure 4). Field estimates of the Gneiss strength along the drift are typically moderately strong (50 MPa) to very strong (150 MPa). Some areas of low strength, weak to very weak rock is noted in the tunnel mapping records particularly around areas of faulting and shearing with the rock often described as broken and fragmented. Notably the Gneiss section of tunnel was impacted by 3 to 4 main joint sets, many containing clay infill, with numerous shear zones and a total of 11 faulted areas and associated fault gouge consisting of clay infill and occasionally altered rock fragments. The zones either side of the fault structures were noted as being broken, very blocky and heavily sheared.

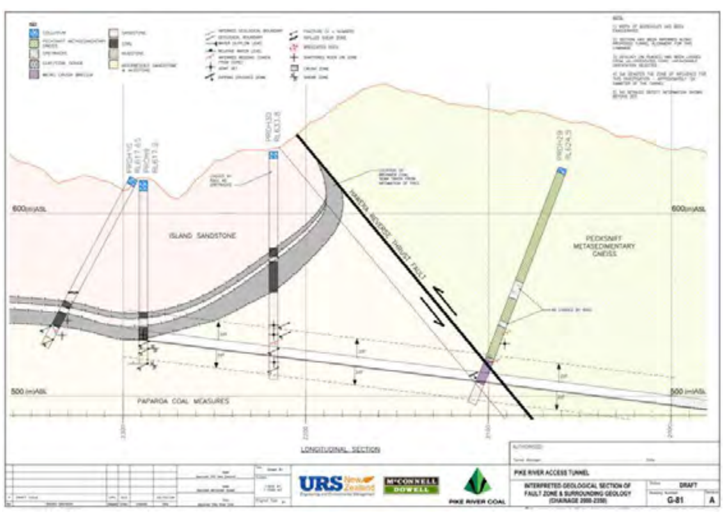

Figure 4: Geological section of Hawera Fault and surrounding geology showing drift location and the structured nature of the ground

The Hawera Fault is a large 500 m to 600 m throw reverse fault that hades over the coal measure section of tunnel and is orientated at a near 45° angle to the alignment of the drift. At the Hawera Fault, Cretaceous Paparoa Coal Measure sediments (>100 m thickness) are found, juxtaposed against older Palaeozoic rocks belonging to the Metamorphic Gneiss, due to reverse downward faulting of the Hawera Fault (Figure 4).

The Coal Measure rocks encountered towards the end of the drift are folded upwards due to drag on the Hawera Fault which overturned the Brunner Seam near outcrop. This deformation resulted in the section of tunnel between the Hawera Fault and first coal being driven in the Paparoa Coal Measure Strata underlying the Brunner Coal Seam. These rocks typically comprise very weak to moderately strong well interbedded sandstones, mudstones, carbonaceous bands, altered grit, conglomerate and coal. Given its proximity to the fault and deformed and structured nature the ground conditions were found to be exceptionally poor to poor and containing steep bedding, many slick joints, sheared zones and areas of clay alteration and associated gouge.

The overall rock quality encountered in the drift was of significantly poorer quality than anticipated from the pre-development surface mapping and Geological Report and required the installation of higher levels of support than expected to manage ground conditions. The rock mass classification and support classes for the drift as constructed are highlighted in Figure 5. Typically, the drift was supported with 6 x 2.1 m bolts at a 1.5 m spacing in Class IV rock with Class V rock incorporating up to 120 mm of fibre reinforced shotcrete and a 1.0 m bolt spacing. Figure 6 highlights some of the poorer ground conditions encountered during coal measure development.

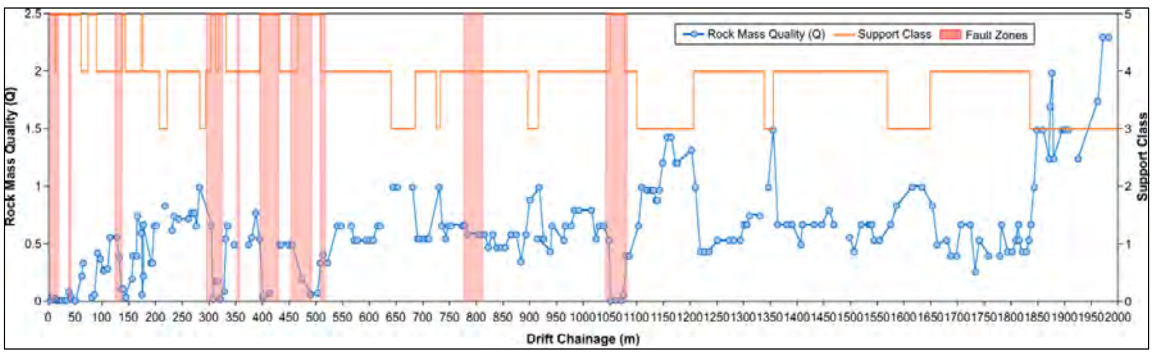

Figure 5: Pike Drift mapped Q values, faulted zones, and support classes, 0 to 2000m

Figure 6: Paparoa Coal Measures east of the Hawera Fault showing the typically weak and tectonically deformed nature of the ground

CONTROL OF GEOTECHNICAL RISK DURING DRIFT RECOVERY OPERATIONS

The drift recovery process was advanced in stages not exceeding 20 m intervals to allow for adequate levels of ventilation, forensic inspection, and geotechnical assessment. Safety of the workers and underground environment was a priority throughout recovery and forensic inspections.

Given the uncertainties relating to the condition of the drift and support elements prior to re-entry the management of geotechnical risk during the drift recovery was an essential aspect and was achieved through multiple controls which included:

- Having fit for purpose strata support equipment hardware and support plans.
- Ensuring people are trained and competent noting that the PRRA was a new organisation that employed mine workers immediately prior to the re-entry who needed training in all aspects of the recovery processes and systems.
- The drift re-entry TARP which included provision for drift conditions, support condition and density, explosion related impacts comprising blast and heat impacts, a seismic response and incorporation of roof monitoring data.
- Regular drift inspections and assessment of the integrity of the existing support which included a geotechnical mapping sheet and bolt testing plan (pull testing and over-coring) being incorporated into the daily statutory shift reports.
- Development of a Strata Management Team who conducted monthly meetings to discuss and approve on any changes required to achieve safe drift recovery.
- Development of suitable controls to manage the risk the single-entry nature of the drift including entrapment which comprised CABA, laying air and communication pipes on the floor of the drift and advancing a refuge chamber and roof fall recovery gear in the operational zone.

GROUND SUPPORT DESIGN FOR DRIFT RE-ENTRY

Ground support design to support the re-entry processes was initially assessed from review of construction records compiled in the GBR including mapped rock mass classification data, bolt testing data and information contained on the engineers shift reports. Additionally, geotechnical information obtained from selected boreholes were reviewed as part of the coal measure support design assessments. Zones of higher relative geotechnical risk were established and noted on hazard maps based on assessment of ground conditions, the adequacy of the existing support design and quality of the installed support.

The installation of additional ground support during re-entry was recommended and was broadly determined and as follows:

- Prescribed areas for rock bolting on advance in all faulted areas inbye the 170 m seal where ground conditions were extremely poor to exceptionally poor and specific areas where the installed ground support quality appears poor based on review of shift information in the gneiss section of drift;
- Systematic re-support of all areas of drift from the Hawera Fault inbye in Coal Measures during drift recovery; and
- Following a Geotechnical TARP response and based on observation and monitoring of encountered geotechnical conditions and results of ground support testing in the drift during re-entry.

Gneiss Support Design

In the Gneiss sections of drift, the faulted areas are typically associated with poorer rock mass conditions than unstructured areas of drift and were considered zones of higher relative geotechnical risk which required specific assessment for support design. Review of the mapping data (Q-system) indicated that in the poorest areas associated with faulting (where $Q \leq 0.1$) the drift was under-supported on the basis of the consistent use of Excavation Support Ratio (ESR) value of 1.6 used in the initial design. An ESR of 1.0 was used for design of re-entry support in the faulted areas, consistent with the Q-system recommendations but to also provide a lower risk profile as part of the single entry nature of the recovery, and to mitigate potential uncertainties relating to the installation quality of the existing support in the wet, weak and faulted ground noting that resin “mixing and taking” issues were noted on some shift reports.

Unwedge analysis was also conducted on each fault zone using mapping data that indicated the support design would provide adequate levels of safety for both static and dynamic loading cases. The initial ground support design assessment comprised 6 x 3 m long grouted CT bolts at a 1.0 m spacing which was later optimised as part of continuous improvement processes following underground inspection, more detailed review of site specific conditions and various bolting trials. Subsequently recommendations were made for prescribed and systematic support to all faulted areas in the drift with 5 x 2.7m long resin encapsulated Posimix bolts at a 1.2 m to 1.3 m spacing dependant on site conditions.

Coal Measure Support Design

The coal measure section of drift contains very weak to moderately strong inter-bedded sediments that have been structurally deformed and adversely impacted by the Hawera Fault. Conditions both through and inbye the fault were mapped as poor to exceptionally poor with low to very low RMR values and estimated CMRR values relative to most coal mines. Existing support design in Coal Measures was based on an empirical system which comprised the Q Index classification system with verification using the RMR system. Following review of construction data it appeared that the coal measure section of tunnel had not been, in many locations, supported to the design standards, and it was difficult to accurately comment on the adequacy of the installed support given the lack of any quality roof monitoring and mapping data. Given the exceptionally poor conditions benchmarking against other sites was considered difficult and potentially extended empirically based design tools outside their intended usage domains. That said, SCT adopted a first principles design approach to coal measure support design coupled with operational and support design experience in reasonably similar conditions at the nearby Spring Creek Mine. This included assuming a 5m high softened zone exists in the roof strata, consistent with the estimated roof fall height (the roof fall is estimated to be approximately 5 m above the tunnel roof as observed in drillhole PRDH50) and dead weight loading assumptions estimated as 75 t/m which were also adopted for standing support design for areas inbye the Rocsil plug.

A support plan was developed and incorporated 8 m long high capacity (60 t) pre-tensioned cable bolts on a 2:1 pattern at a 1.0 m spacing. Grouted cables were expected to provide better levels of support in the weak, broken ground and are likely extend above the likely height of roof softening. Grouted cable bolts were also expected to avoid most of the potential performance issues commonly associated with resin-based primary support systems in weaker clay rich ground and the quality of installation (i.e. pre-tension and grout quality and grout return) could be easily assessed and noted on bolt audit sheets. The installation of additional primary support for the roof and ribs was not prescribed in revised coal measure support plans. This was based on operational experience that showed adequate levels of skin control were frequently being provided by the existing primary support elements and shotcrete where installed. Installation of additional primary support is installed as required following inspection and assessment of conditions and linked to a revised Coal Measure Geotechnical TARP.

BOLTING SYSTEMS AND CONTINOUS IMPROVEMENT PROCESSES

Two bolting rigs were procured by the PRRA for the drift recovery:

- ALFABs Boar Bolter - a hydraulic powered (via LHD) QDS platform rotary bolting rig without a Temporary Roof Support (TRS); and
- Clarke Drifter - an air over hydraulic powered crawler type bolting rig with rotary percussive drilling capabilities and a TRS fitted.

The rigs were specifically configured for Pike River Mine based on the support types to be installed in the tunnel, variation in rock types along the drift and the drift geometry which dictated the operating envelope for bolting machines. No power was installed in the drift as part of the recovery which limited gear selection to hydraulic (LHD powered) and air powered machines only. The rigs were designed to bolt 90% of the drift's length noting that drift height ranged from approximately 4.5 m to 6.0 m based on as-built construction drawings.

The Clarke Rig was initially envisaged to be the prime bolting machine in the hard rock sections of tunnel and was fitted with a rotary percussive drifter to improve drilling performance and increase the durability of drilling consumables in the hard and aggressive rock conditions. The ALFABs was envisaged to be the prime bolting unit in the softer coal measure rock with typically smaller diameter rotary drilling capabilities.

It quickly become apparent that less than adequate air pressures being available in the drift were impacting the Clarke Rigs drilling performance. In addition, the specified mast length made operating the rig difficult as the tunnel opening was typically a lot smaller than that shown on the as built construction drawings as up to 600 mm of gravel had been placed on the floor. This resulted in the initial hard rock section of drift being supported with the rotary Boar Bolter which proved time consuming and hard on drilling consumables. As bolting was one of the key elements in the drift recovery process a solution was needed to improve both drilling and bolting cycle times. After some onsite optimisation work comprising different drilling configurations cost estimates and design solutions were sought from ALFABs to replace the rotary drill head on the Boar Bolter with a percussive drifter unit. At the same time various resin based bolt types were trialled as the grouted CT bolts being used at that time were adversely impacting the water quality leaving the mine which required additional treatment at the portal prior to being discharged into the Pike Stream which now forms part of the Paparoa National Park. Resin was also now preferred to grout as it reduced the potential for contamination of any forensic evidence which was a key aspect and consideration at all stages of the recovery work.

A Montabert HC25 hydraulic drifter was recommended for the ALFABs drill head replacement which, along with a resin based Posimix bolting system, delivered the following key benefits:

- Faster drilling and bolt installation times (no requirement for post grouting, smaller hole diameter and faster drilling rates);
- Better, more ergonomic work platform for operators (elevated work platform);
- Standardise hard rock bolting consumables and processes across the site; and
- Deliver cost savings by using fit for purpose hard rock drilling consumables.

Bolt installations were routinely measured during support cycles in the drift. In the hard rock section of drift, a total of 844 bolts were installed as part of the drift recovery; 569 bolts were prescribed with the balance (275) installed as a TARP response typically into mapped shear zones, areas of blocky and spalling rib and at other locations where the quality of the existing installed support was proven as less than adequate via testing (pull testing) and observation.

Notably a 400% reduction in bolting time was observed in prescribed areas following the changes to the bolting systems. This result was largely contributed to the bolting plant and bolt type modifications and to a lesser degree improved operator experience and familiarity on the bolting rig noting that some of the operators had no or limited experience with this type of bolting plant prior to the project commencing. The rotary drill head was placed back on the ALFABs once the Coal Measures were reached and a head replacement cable feeder fitted to assist with safe and efficient installation of 62 t megabolts up to the Rocsil plug.

REAL TIME MONITORING AND ALERTING

A roofAlert remote Tell-Tale monitoring system (Figure 7) was installed in the drift as part of the re-entry to continuously monitor roof movements. A total of thirty-two (32) instruments were installed during the re-entry advance at approximately 70 m centres or located to monitor higher risk areas including faulted zones and larger excavations. The Tell-Tales provided both automatic and visual read out that could be monitored manually if power supply were disrupted.

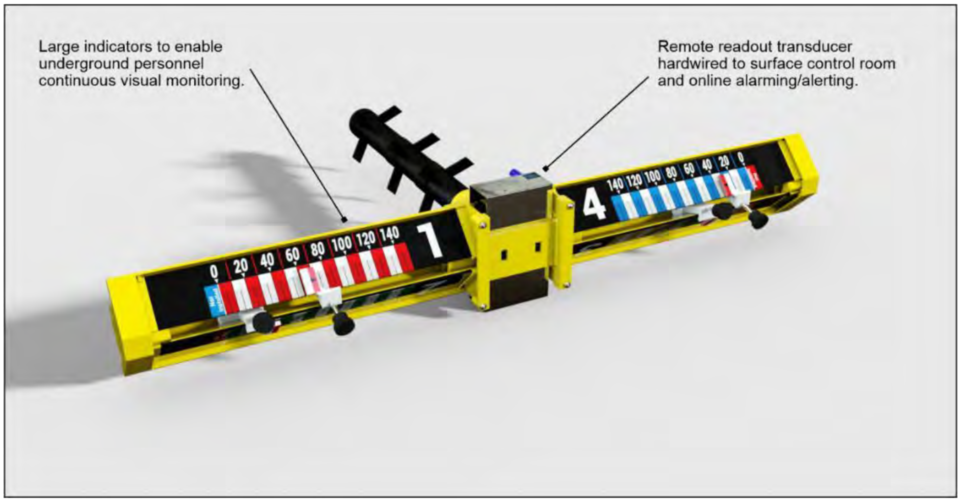

Figure 7: roofAlert Tell-Tale monitoring system

Given the nature of the drift recovery conservative trigger levels were established. The wired system comprised a backbone cable and junction boxes at each Tell-Tale which sent an almost continuous data feed (Tell-Tales were read every 15mins) back to standalone computers set up in the control room. The computers in the control room were configured to send out email and text messages if trigger levels were exceeded and to sound an audible alarm that would allow suitable control room response. A remote Tell-Tale was also wired into the system on surface that could be manually “displaced” to allow weekly testing of automatic alerting as part of the quality assurance processes. The continuous remote monitoring capability was also an important aspect of the sites COVID-19 response when the tunnel could not be physically inspected during the extended lockdown period. Coupled with the sites remote gas monitoring systems it provided almost uninterrupted underground monitoring data and confidence for the safe restart of drift recovery operations and the end of the extended lockdown period.

ROCSIL TUNNEL TRIALS AND GEOTECHNICAL ASSESSMENTS

An approximately 10m thick Rocsil plug was installed into the drift remotely down drillhole PRDH48 some 10 m outbye the roof fall (Figure 8). Access to the fall requires breaching the plug, wearing breathing apparatus in an irrespirable atmosphere, with a small tunnel of approximately 1.0 m wide by 1.8 m high excavated using hand tools. Geotechnical assessment formed part of the planning processes for the seal breaching activities and consisted of surface tunnelling simulations, 3D FLAC modelling and field loading trials.

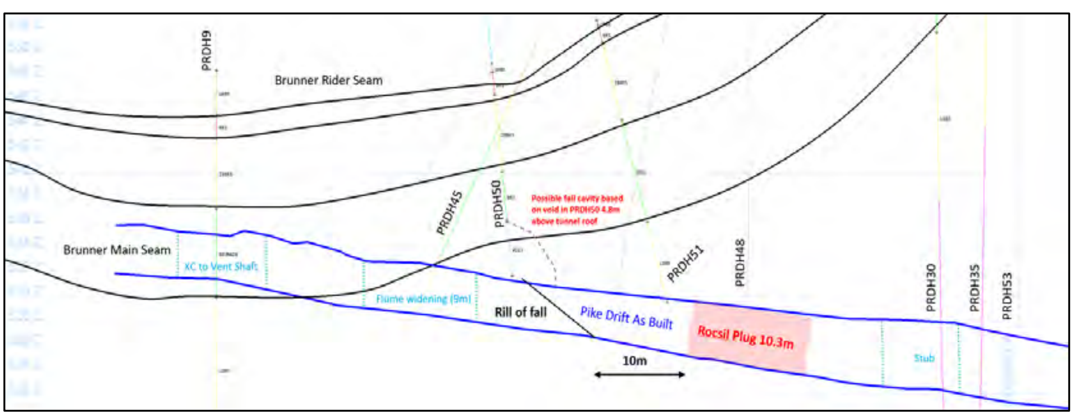

Figure 8: Cross section about Rocsil plug and roof fall locations

Rocsil Tunnelling

As part of small tunnelling field simulations, a small tunnel was excavated through Rocsil that had been pumped into a 6 m (20 ft) shipping container on surface between 12 and 13 March 2020. The tunnelling trial was conducted to simulate the proposed excavation geometry and methodology to be used underground during the Rocsil plug breach. This involved two workers using BG4 breathing apparatus to advance a small tunnel of 1.0 m width and 1.8 m height with an arched roof profile using hand tools. The trial geometry is the planned excavation size to be used when tunnelling through the Rocsil plug. The Rocsil material was easily excavated using a hand saw, pelican pick and spade with excavated material initially loaded into a skip and subsequently wool bags to simulate the proposed handling and storage methods underground. The approximately 6 m long Rocsil tunnel was fully excavated quickly, in around 4hrs, given the very weak material strength (average 60 kPa), easy cuttability and very low density (37 kg/m3) which made for efficient material handling. A bulking factor of around 1.5 was estimated from the trial. Figure 9 shows the tunnel being excavated through the shipping container and the tunnel at completion.

Field Scale Load Testing and Validation of 3D FLAC Modelling

A field scale loading test was completed over the tunnel cut through the Rocsil foam in the shipping container on 3rd June 2020. The field test was, in part, used to validate a 3D FLAC modelling assessment and to better assist with an understanding of Rocsil foam deformation characteristics about the tunnel opening under various loading conditions. Information collected during the trial was also used for development of TARPs to enable adequate response to changing conditions during Rocsil breaching operations.

Loading of the ~600 mm thick tunnel roof septum was conducted using a thick 750 mm diameter plate and calibrated hydraulic ram fitted to an engineered support frame (Figure 11). Loading of the roof septum was completed incrementally until complete failure occurred with measurements of both load and displacements captured during the testing.

Figure 9: Tunnel excavation in shipping container wearing BG4 using hand saw, pelican pick and spade (left) and completed tunnel showing profile (right)

Figure 10: Loading test general arrangement showing loading plate and displacement monitoring

The Rocsil foam septum above the tunnel was able to withstand peak loads of 80.6 kPa equal to 8.2 t/m^2 or 3.1m of rock head (dead weight loading) at around 15mm convergence. Notably the load – displacement graphs show the tunnel roof septum was able to sustain relatively high residual loads, following peak load being obtained, for reasonably large displacements. High residual loads of approximately 72.5 kPa were maintained to 55mm of roof convergence. Following this the load (strength) of the material dropped off very quickly with high angle shears observed on the rib lines and a “loss of structural integrity” noted during the test. The results suggest that the Rocsil material is able to resist load post peak strength for relatively high levels of displacement but once critical levels of stability are reached (as evident by the development of high angle shear failures) strength is rapidly lost and the load carrying capacity or the Rocsil roof septum is substantially reduced (Figure 11).

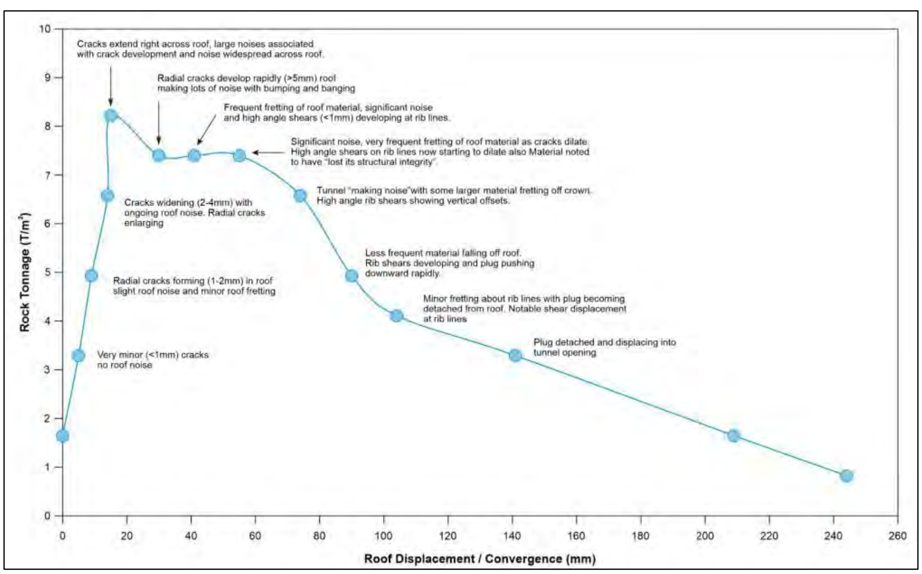

Figure 11: Tonnage displacement graph highlighting the Rocsil tunnel deformation loading characteristics

Importantly the Rocsil material was noted to deform in a behaviour consistent with expectation and the 3D modelling results and provided confidence that the in-situ behaviour of the Rocsil plug would behave in a reasonably predictable fashion which allowed for the development and implementation of TARPs with conservative trigger levels. The TARP included deformation aspects established from the field test comprising displacement (roof convergence), visual deterioration (tension / radial cracks and shear failures) and noise as highlighted in Figure 12.

Qualitatively, the deformation observed in the field trial was markedly aligned with anticipated deformation modes simulated by the 3D FLAC Pike River Rocsil Tunnel model. This was identified through similarities indicating an onset of high angle extensional shear surfaces along the rib lines coinciding with maximum support load prior to ultimate failure being reached. In addition, back analysis of field test results indicated material property strength values that were comparable to those used in the modelling which were originally derived from a relationship of the laboratory UCS testing results of Rocsil cube samples obtained from the shipping container.

Downhole Camera and Laser Scanner Assessments

Prior to breaching the Rocsil plug with the small tunnel a downhole camera and C-ALS scanner was placed down PRDH51 as the drift recovery approached the Rocsil plug. This information was used to assist with more detailed planning relating to better understanding the drift geometry for standing support placement, the assessment of ground conditions, including the potential for any time dependant deterioration, about the rockfall area. This aspect of the drift recovery was considered a high risk area for the recovery operations given the proximity of the rockfall and potential for further instability and needed a high level of detailed planning given the crews would be working in breathing apparatus in a low oxygen (~2%) atmosphere to reach the rockfall.

SUMMARY

The Pike River drift recovery process has been a complex and challenging task that has required detailed preparation and risk assessment at all stages of planning and execution. The main purpose of the drift recovery was to gather forensic evidence to assist with the police investigation. The forensic aspects have required careful consideration at all stages of planning and execution.

Development of a factual Geotechnical Baseline Report assisted with detailed planning and allowed for the identification and management of several key strata control risks. The GBR was important as there was uncertainty relating to both drift and support conditions and the drift had largely not been physically inspected following the explosion. The GBR provided input for operational implementation of safe manned re-entry including; initial ground support design, design assistance and procurement of fit for purpose bolting rigs and bolting systems and the development of geotechnical principle hazard management plans, operating procedures, geotechnical TARPs, hazard plans and workforce training material. Routine geotechnical assessment, mapping, monitoring and a bolt testing regime also formed part of the statutory reporting during the staged recovery process to ensure operations progressed safely.

Several geotechnical efficiencies were implemented following operational experience and inspection of conditions. This included optimising bolting systems which delivered significant improvements to bolting cycle times whilst minimising potential for environmental and forensic contamination.

In addition, surface tunnelling simulations and field load testing were conducted on Rocsil foam that was placed into a shipping container to assist with Rocsil seal breaching activities. This was supported by 3D FLAC modelling of the proposed Rocsil tunnel breach which was validated by the field load testing. Boreholes intersecting the drift were used to obtain information, and to inform decision making, via downhole camera inspections and 3D laser scanning technology.