TECHNIQUES FOR REDUCING RISK AND INCREASING SAFETY FROM ROCKFALLS IN OPEN MINES IN AUSTRALIA

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Theme: mine ventilation, occupational health and safety

ABSTRACT

As mine operations progress, early mine excavations may receive a reduced technical focus. However, ongoing weathering can increase the risk posed by unstable surfaces within mine operations. This paper presents two examples where earlier mine excavations caused slope instability which had the potential to impact current mining operations. The examples presented illustrate two different solutions to similar problems. This paper explores the projects and explains why different solutions were selected. Boral Quarry in Adelaide featured an unstable 60 year old, excavated face 90m in height. Rock falls from the slope were affecting mining operations below. Due to limited site access coupled with the size and irregular profile of the slope, a high strength flexible barrier system was selected in favour of the more traditional mesh based remediation.

Austar Coal Mine in New South Wales, featured steep rock cuttings formed in the 1920's to allow the driving of a rail line to connect the mine with the local port. The risk of large rock detachments from the slopes posed a significant safety risk to rail traffic and the economic continuity of mine output. Although the problem was very similar to Boral Quarry, the solution was entirely different. The unstable rock slopes were shrouded in high tensile strength steel geocomposite mesh designed to work in combination with specifically designed rock anchors, to offer a mechanically stiff (low displacement) facing solution. Using this solution rock detachments are contained between the drapery mesh and the existing rock face.

1. BORAL QUARRY ADELAIDE

1.1. Introduction and background information

Boral Resources (SA) Limited's Greenhill Quarry is located on the south-western hillside of Slape's Gully, adjoining Stonyfell Quarry in the Adelaide Hills. Stonyfell Quarry opened in 1837 and is still one of the leading quarries in the Mount Lofty Ranges. In the 1940's, a 90m high rock face (Figure 1) was excavated into one of the quarry walls. This rock slope is located directly above an area where trucks turn to deliver raw material into a conveyor feed bin.

The upper 41m of the slope is naturally vegetated with large trees, bushes and grasses. The slope has a nominal overall angle of 55°. This angle is sufficiently steep to allow rocks exposed at the surface to detach and roll posing a significant threat to the operations and personnel located below.

1.2. Site conditions and geology

The geological formation associated with the Mount Lofty Ranges provided an abundant source of raw material, such as quartzite, freestone and bluestone used for building purposes. Early last century Stonyfell quartzite and Glen Osmond slate were excavated from the lower 49m of the slope. Excavation involved the cutting of three benches using manual techniques. The benches have heights ranging from 12m to 19m at slope angles ranging from 42° to 70°. The shallower angles have arisen from a combination of undercutting of the toe and associated localised slipping of material. All batters have highly irregular profiles and contain a larger number of loose and overhanging rocks.

Figure 1. 90m high rock face

Many of the benches are pervasively and irregularly fractured, a feature consistent with "over-blasting". The majority of flat areas on the quarry slopes are littered with fallen rocks which provide ample evidence of the frequency and nature of rock falls at the site. The majority of these rocks are likely to have become detached due to surficial weathering and jacking of fracture-bound rocks by tree roots.

1.3. Risk assessment and remedial options

In 2007, as part of an ongoing campaign of risk reduction, the site management commissioned the development of a rockfall control strategy in order to mitigate risk to installations and personnel working in the conveyor feed bin area (Figure 2).

A detailed investigation was carried out involving quantitative risk assessments and numerical modelling of rockfall events. Various solutions were considered for reducing the risk, including: a) installation of rockfall mesh drapery over the higher section of the rock-face, b) installation of a reinforced shotcrete facing and c) scaling of the slope and installation of a high strength, flexible rockfall catch fence.

1.4. Remedial Solution

The results of the rockfall control strategy report indicated that the most appropriate and cost effective solution would involve scaling of the slope followed by the installation of a Maccaferri rockfall catch fence 25m above the slope toe.

The 90m high quarry slope had no vehicular access to the proposed crestline work area making it impossible to use cranes. This dictated that all personnel, materials and installation equipment had to be lowered onto the slope using roped access methods. Further site restrictions concerned operational safety in the conveyor feed bin area. For commercial reasons, the plant had to continue normal daytime operations and for safety reasons the contractor was restricted from working during these times (Figure 2).

Figure 2. Trucks in the conveyor feed bin area

The best solution open to the contractor in order to perform the scaling and fence installation works, outside the normal operational hours of the plant, was to use specialised rope access techniques.

Figure 3. Drilling and installation of fence anchors

1.5. Design Methodology

Rockfall simulation (Figure 4) was performed using Rocscience's Rocfall software. The methodology adopts a representative design boulder chosen from an assessment of actual rock measurements. In order to model a realistic simulation, the restitution coefficients needed in the software were empirically adjusted until the boulder arrest points were similar to those observed from the historic rock scatter records. The trajectory analysis was performed with 2000 detachment releases in order to obtain statistically significant results. At the selected location for the barrier, the results indicated that 95% of rocks would have bounce heights less than 3m and velocities lower than 18m/s, suggesting the requirement for a barrier capable of absorbing impacts with energies of approximately 250kJ (Figure 4). The required energy level of the rockfall barrier was calculated using the general equation:

$$(E_b) / \gamma_b > ½ (M / \gamma_m) (v / \gamma_t)^2$$

Here E_b represents the barrier energy absorption, M is the design mass, and v is the maximum velocity at the 95th percentile (Peila et Al, 2006). The symbols γ represent the various safety coefficients. They act to increase the impact velocity (γ_t) and the mass size (γ_m), while reducing the nominal energy level of the barrier (γ_b). The partial factor values take into account the uncertainties affecting the calculations such as the quality of the topographical model, the quality of the rockfall simulation and the quality of the geomechanical survey (see normative UNI, 2011). This conservative approach is adopted because rockfall phenomena are in practice, difficult to describe using engineering models. Additionally, crash tests are "index test" results, the validity of which are specific to the particular test conditions.

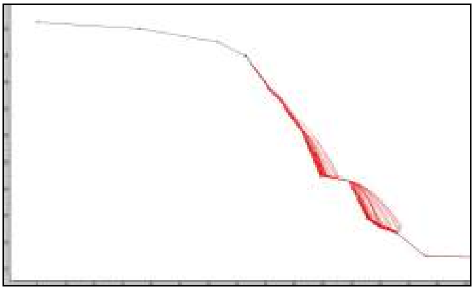

Figure 4. Rock fall simulation

1.6. Catch fence selection and testing

After detailed examination of the design results and the technical merits of various catch fence types, the barrier selected was a 3m high CTR/05/07/B barrier from Maccaferri. This barrier was tested at full scale in compliance with ETAG 027 guidelines (“Falling Rock Protection Kits”, dated January 2008). The full scale crash test comprised a 1610kg boulder impacting the barrier at 25.6m/s in order to produce the Maximum Energy Level (MEL) impact of 528KJ. According to ETAG 027, the fence was also subjected to two successive Serviceability Energy Level (SEL) crash tests, carried out with energy levels equal to 1/3 of the nominal MEL resistance of the barrier. After the first SEL impact the barrier has to maintain a minimum residual height of 70% with negligible damage. The second test is performed without maintenance being undertaken on the barrier or components. In addition to the tests in accordance with ETAG 027, the CTR/05/07/B barrier was subjected to an additional SEL test immediately after the MEL test (without repairs), to ensure the barrier could exceed the required performance even under conditions in excess of those simulated for the ETAG 027 testing.

1.7. System components

The system comprises a steel mesh panel interception structure that is placed on the down slope side of the barrier posts. The steel posts act independently of the mesh and if a post is impacted by a falling block and damaged, the adjacent posts absorb the additional forces thereby ensuring that the energy dissipation performance of the system is not compromised. The energy dissipaters absorb the applied energy by deformation - not by friction (Figure 5), thereby guaranteeing reliable performance. The rockfall barrier meets quality certification standard UNI EN ISO 9001, at each step of design, manufacturing and marketing. During the crash test, the forces acting on foundations were measured with load cells. The deflection and geometric parameters were measured at the moment of maximum elongation and in the residual condition in accordance with the relevant guidelines.

Figure 5. Energy dissipater before (above) and after (below) impact

1.8. System selection

The CTR/05/07/B barrier was chosen due to its capacity to be installed on almost any rock/soil type and profile. Optimum system design enabled the anchor pull-out forces to be reduced, resulting in shorter and more cost effective anchorages. The specific barrier layout and versatile components made it ideal for use on rugged slopes where consistent vertical and horizontal alignment was difficult to achieve. The light tubular posts, aluminum energy dissipaters and shorter anchors mean the system was light enough to be installed on the steep slopes with limited access.

Figure 6. The HEA cable mesh interception structure arresting a number of detachments

1.9. Boral installation

All drilling, grouting and construction activities required the use of roped access techniques. The entire installation was carried out over twelve days without interruption to the mine operations.
Following the installation of the barriers, there have been several rock impacts recorded. All debris detachments were successfully intercepted (Figure 6), causing no injuries to truck operators or damage to mine infrastructure. The rockfall mitigation strategy has performed as required by the client.

2. AUSTAR COAL MINE

2.1. Introduction and background information

The Austar coal mine is located approximately 65 kilometres west of Newcastle in the state of New South Wales. The site comprises a double sided railway cutting which was excavated in the early 1920's predominately using blasting methods. The railway allowed trains to transport coal from several local collieries to the Port of Newcastle. The railway line is currently owned and operated by the mine and has a history of slope instability problems which cause significant safety concerns for train operators. The mine produces and exports approximately 1.7 million tonnes per annum through this port and any closure of this railway would cause a significant commercial impact to the mine.

2.2. Site conditions and geology

The rail cutting varies between 6m and 13m deep with slope angles ranging between 75° and 80°. The cutting was excavated into the Braxton formation of the Maitland Group. This comprises conglomerate and sandstone interbedded with narrow weakly cemented siltstone horizons. The rock mass is moderately weathered on the exterior faces. The estimated strength of the general rock mass (the dominant sandstones and conglomerates) varies from medium to high strength. The interbedded siltstone horizons are of low strength and are prone to mechanical, chemical and meteorological weathering. Weathering of the less durable siltstone interbedded zones results in undercutting of the more competent overlying sandstone units. This process can form overhangs of up to 1.4m as shown in Figure 7.

Figure 7. Undercutting of sandstone units

The stand-off distance between the toe of the cutting and the rail line varies between 2.5m to 3.5m. Numerous joint sets are present within the rock mass, locally forming a blocky to tabular jointing pattern.

2.3. Description of problem and risk assessment

A visual site inspection identified several rocks laying within the cess drains adjacent the railway line. In these areas it was deemed that the cut face had been subject to toppling and minor wedge failures resulting from the intersection of joint sets and bedding horizons. The blocks were tabular in form with the largest from 0.4m to 0.6m across as shown in Figure 8. The locations of the fallen blocks were in close proximity to the erosion related to the undercutting of the more competent units.

In addition to larger block failures, other less significant instabilities were noted along the line, these were typically related to ravelling of smaller blocky debris with individual rock sizes of less than 0.3m.

Figure 8. Rock falls near the railway line

These rock falls in the immediate vicinity of the rail line caused significant safety and commercial concerns for the mine. The possibility of a closure of the railway line was unacceptable to the client. The client therefore required a solution which would reduce the likelihood of rock falls occurring and mitigate the risk of future rock falls closing the rail line. The required design life of the rock fall mitigation solution was twenty years.

2.4. Remedial Solution

A principal requirement of the client (aside from the obvious safety aspects) was that the rail should remain functional throughout the installation of remedial solutions.

In order to achieve this goal as well as providing rock fall protection for the subsequent twenty years, the successful contractor and the scheme engineer, decided that a combination of remedial solutions would be necessary.

Initial roped access rock scaling would reduce the likelihood of small rock falls affecting the works on and below the slope. This would be followed by the selective application of a reinforced shotcrete facing covering only the weaker interbedded siltstone/ sandstone horizons (Figure 9) thereby protecting them from further weathering. All other areas of the slopes would be shrouded in a high strength steel geocomposite mesh system followed by the installation of tensioned rock anchors.

Figure 9. Siltstone before shotcrete application

The design of the system ensured that the less stable rock regions would be consolidated by the rock anchors and steel ropes. Should any rocks fall, the bolts and ropes would be complimented by the presence of the mesh. This would serve an additional function of controlling and directing material to the toe of the slope, preventing it from falling outwards and interfering with the rail line.

2.5. Mesh system selection

The engineer estimated the failure of potentially large blocks from the slope, up to 4m^3. Additionally the situation was complicated by the close proximity of the rail line to the toe of the slope. The engineering solution therefore demanded both a high strength and a very stiff mesh, as this would result in low displacement of the loaded mesh. From the two principal options of HEA panels (knotted steel wire rope panels) and Steelgrid geocomposite, the latter product was chosen for use with the engineer's anchor design.

2.6. Design Methodology

Selection of the appropriate draped mesh was primarily based on the expected loads that the system was required to retain. As rock detachments occur, the loose material is guided down behind the mesh and begins to accumulate at the bottom of the mesh envelope. In order to calculate the total stress formed within the draped mesh, the accumulated debris weight and the weight of the draped mesh must be calculated (Figure 10). A qualitative evaluation was made with regards to the amount of debris which would accumulate behind the draped mesh at the foot of the cutting before routine maintenance cleared the debris in a controlled manner. The allowable debris accumulation width at the base was taken as 1m (measured horizontally). 1m was taken as the limit, because any additional accumulation would start to impose on the rail corridor. Meanwhile, the maximum debris accumulation height was taken as 3m (measured vertically). In calculating the accumulated debris weight (W_D), factors taken into account include the mesh weight (W_m), slope height, slope inclination (β) and the friction angle between the debris and the slope (Figure 10).

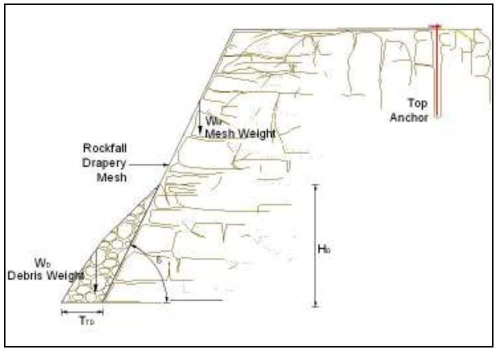

Figure 10. Conceptualisation of a drapery system

The debris external accumulation angle is derived from an equation described in the "Analysis and design of wire mesh/cable net slope protection" (Muhunthan et al., 2005). The geotechnical system has to satisfy the general equation:

$$S > W_d + W_s + W_m$$

Where S is the tensile resistance of mesh, W_d is the load due to debris pocket, W_s is the weight of the mesh and W_m is the load due to the snow thickness (if any). All of these loads must have safety coefficients applied.

Extensive research and testing carried out by Maccaferri led to the development of the design software, MacRO2. This enabled the mine engineers to design their own drapery systems based on the geotechnical model shown above and theoretical accumulations of debris. Using this software for the Austar project, the tensile stress calculated within the draped mesh amounted to approximately 50 kN/m (taking into account permanent and variable load factors). In order to hang the draped mesh over the cut face, top anchors needed to be installed together with a horizontal support cable.

2.7. Installation details – anchors

The design dictated placing the top anchors back from the crest of the slope to prevent undermining of the anchors by erosion during the project design life.

The top anchor calculation takes into account the weight of the mesh as well as the calculated stress within the draped mesh of 50 KN/m. Cement grouted galvanized steel anchors were installed along the crest of the slopes, penetrating a minimum of 1m into competent rock. The top anchors were designed to hold the mesh by supporting a continuous galvanized steel rope which ran along the anchors.

Figure 11. Anchor pattern and the mesh

In order to stabilize the larger blocks and wider unstable surfaces, several galvanised steel rock bolts were installed on the cut faces using a 3m by 3m spacing pattern. Rock bolts varied in length between 3m to 4m depending on the proportions of the tabular blocks present and the spacing of the discontinuities in the rock face. Rock bolts were installed at a maximum inclination of 45 degrees to the horizontal. Figure 11 shows the anchor spacing after the drapery mesh had been installed. Bottom anchors were installed at 3m spacing's, at the toe of the slope at a height of 0.5m above the cess drain. The bottom anchors were designed to work with a horizontal steel wire rope and the mesh in order to contain the debris accumulation at the bottom of the slope.

2.8. Installation details – mesh

The design predicted stresses of around 50kN/m developing within the proposed system. Factors of safety of 1.5 are generally adopted for mesh designs in Australia. This dictated that the engineer would require a mesh with an ultimate tensile strength of at least 78 kN/m. In order to satisfy the design requirements Maccaferri proposed a geocomposite rockfall drapery system: Steelgrid MO.

Steelgrid MO was selected due to its high strength, low strain, favourable cost-benefit ratio and incorporation of double twist mesh technology which was deemed to give it the desired performance characteristics.

Steelgrid MO is a composite product featuring interwoven double twist steel wire mesh with high tensile steel wire ropes. These ropes are 8mm in diameter and are longitudinally woven into the run of mesh, along each side as well as down the centre.

Figure 12. Galvanized steel cables interwoven with double twist mesh within the Steelgrid MO

In Steelgrid MO all mesh wires and steel wire ropes are heavily galvanized for durability. Due to the characteristics of the double twist elements, the Steelgrid mesh can withstand the force of the falling rocks without unravelling in the event of breakage of an individual wire. This durability characteristic was clearly demonstrated in the laboratory by means of a punch test. In this test more than 85% of the strength of the double twist mesh was retained after one of the wires was cut. This characteristic contrasts sharply with comparable strength single twist (or "chain link") products where only 25% of the strength was retained.

A principal economic benefit of Steelgrid MO is the fact that two different products can be installed simultaneously (mesh and steel cables). Thus reducing overall project costs and saving installation time. More importantly, due to the composite nature of the product, less time is spent on the rock face which improved the safety for rope access/installation personnel as well as limiting the risk of disruption to the mine operations.

The wire mesh was attached to the top cable by folding the mesh over the top rope and securing the fold with high tensile attachments. The mesh was then tensioned to allow tight adherence to the cut face. The fixing procedure of the draped mesh at the bottom of the slope was also achieved by folding the mesh over the bottom cable and securing the fold with high tensile attachments (Figure 13). The design required tight adherence of the mesh to the slope to allow for the safe periodic removal of the accumulated debris as part of routine maintenance. To help achieve this, the engineer required the installation of steel rock anchors through the mesh and into the slope as shown in Figure 11.

Figure 13. Bottom cable between bottom anchors

2.9. Austar installation

The complete installation of 1740m^2 of Steelgrid MO, 180 No. 4m long anchors, 150 No. top and 2m long bottom anchors took 15 days to complete. A photograph of the completed project is shown in Figure 14.

Figure 14. Completed Steelgrid MO installation

3. CONCLUSIONS

Rockfall protection and mitigation systems are vital in maintaining the safety and operational continuity of mining infrastructure networks and installations. Over recent years, extensive investment in research and development has yielded many new innovative rockfall products, such as those used on these projects, for the mining industry. The installation of the high specification catch fence at Boral Quarry was completed within the timeframe initially conveyed to the client. Lightweight fence components and a practical installation methodology made for a safe working environment where no disruption was caused to quarry working procedures. Since the fence was installed, a number of rock detachments have been successfully stopped by the fence thereby ensuring the safety of personnel and the operational capacity of mining equipment (Figure 15).

Figure 15. Rock detachment caught by catch fence

The Austar project highlighted how, for drapery applications it is important to have a high strength, highly durable mesh which exhibits very low displacements, especially when working within confined areas such as rail corridors. In the Austar project, the installation of Steelgrid MO improved the safety of the rail traffic, the rail line maintenance operations and helped to ensure the safety of the installation personnel. No delays were experienced during the installation of these Maccaferri rockfall mitigation solutions in the above mentioned projects.

ACKNOWLEDGEMENTS

The authors thank Adrian Moodie from Austar Coal Mine, Leigh Henness from Specialised Geo, Coffey Geotechnics, Anthony Meyers from Rocktest Consulting, Phil Barry from Retaining Wall Solutions and Maccaferri Australia for providing all the technical assistance in completing this paper. This support is greatly appreciated.

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