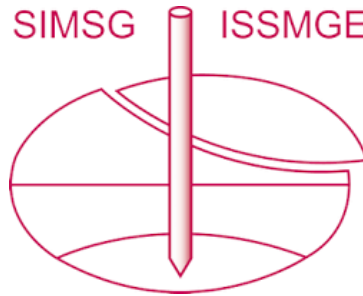


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Stockton mine ridgeline project: the impact of the geological and geotechnical conditions on the environmental risk management

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ABSTRACT

Mining of the high value coal below the Stockton Escarpment requires removal of up to 30 m of sandstone overburden above the 10 m thick low ash, coal seam. Management of the mining risk started with a thorough understanding of the geological and geotechnical conditions of the rock mass that would govern stability during the deconstruction process. This paper describes the process and results of assessing the geological and geotechnical conditions along the Ridgeline and incorporating them into the design of the deconstruction measures. It examines the expected geological conditions and details methods of monitoring that enable unexpected conditions to be identified. The impacts on the risk management process, details of the geotechnical analysis and the design process are discussed. This includes the description of identified modes of slope instability and their relative contribution to natural rockfall. The anticipated processes of deconstructing the sector are described. It is concluded that no matter how detailed the field assessment and office design work, the deconstruction process on site requires intelligent modifications to take account of the actual ground conditions as they become apparent.

1 INTRODUCTION

Stockton opencast coal mine, 30 km north of Westport, is the largest coal mine in New Zealand (Figure 1). High value, low-ash bituminous coking coal is mined at a current rate of 2.1 MT per annum. The coal occurs as a single seam that is commonly 10 m thick, overlain by 20 to 30 m thick sandstone that requires blasting prior to stripping with conventional heavy earthmoving equipment.

The Stockton Mine Ridgeline forms the western edge of the mine and the Coal Mining Lease (CML) adjoins Department of Conservation (DoC) administered land along the boundary. Mining of the Ridgeline with the conventional mining techniques used elsewhere on the mine could lead to excessive, uncontrolled discharge of stripped overburden and mine runoff across the CML and onto DoC land. The Ridgeline Mining Project (RMP) involves deconstruction of the escarpment mining blocks using several unconventional mining techniques to manage the risk of undesirable environmental effects.

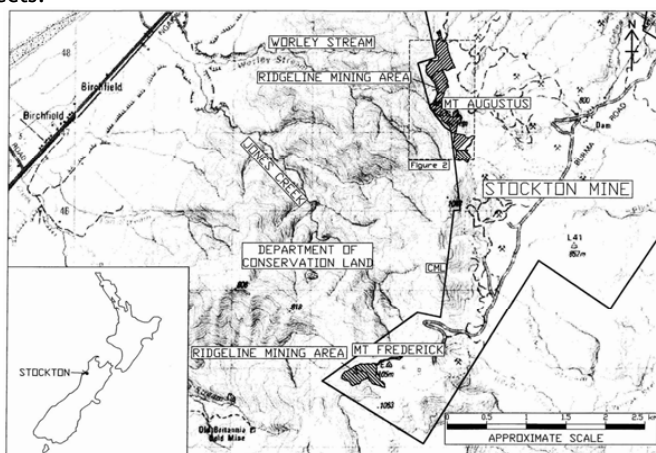


Figure 1: Mine location showing Ridgeline mining area

Deconstruction of the 16 m wide strip along the top of the RMP escarpment is undertaken by a specialist contractor (Geotech Limited), with technical support and supervision provided by URS New Zealand Ltd (URS). The Stockton mining contractor, Doug Hood Mining Limited (DHML), is responsible for the removal of overburden from between the 16 m mark and the mine limit of the

block (Figure 2). Both areas are carefully supervised and monitored by URS to ensure that the discharge of rock towards the CML is controlled and that mining practices conform to the RMP protocol.

2 SETTING

The RMP consists of an escarpment whose total length is approximately 2500 m. It includes the western boundary of the Mt Augustus mining block and the northern boundary of the Mt Frederick mining block, mining areas that are about 2.5 km apart (Figure 1). An elevation difference of up to 1100 m between the Ridgeline and the Tasman Sea, which is about 4 to 5 km away, results in steep, often heavily vegetated topography. The upper 20 to 40 m of the escarpment is typically a very steep, rugged rock slope comprising sandstone overburden. Below this is a gentler, vegetated slope of surficial colluvium and rockfall debris, which overlies the economic coal seam. Mean rainfall in the region is high, at between 5 and 7 m per year.

2.1 Geology

The basement lithology of the Stockton Plateau is a weak, weathered Paleozoic age granite with overlying Eocene age Brunner Coal Measures, a unit that consists of moderately strong, coarse to fine quartz-rich sandstone, minor carbonaceous mudstone, siltstone and coal. The economic coal reserves mined at Stockton are located in the lower part of the Brunner Coal Measures sequence (Figure 2).

Bedding is oriented into the escarpment and typically dips 10° to the east. Joints form two distinctive, subvertical sets that strike north and east, orthogonal to bedding. Rare cross bedding can dip unfavourably out of the slope at 25° to the north. Bedding and joint spacing may range between tens of centimetres to several metres in scale. The various combinations of discontinuity spacing result in intact, unfractured, orthogonal rock blocks that vary in size and volume from cobbles to 100 m^3 . The rock is generally unweathered to slightly weathered and is moderately strong to strong.

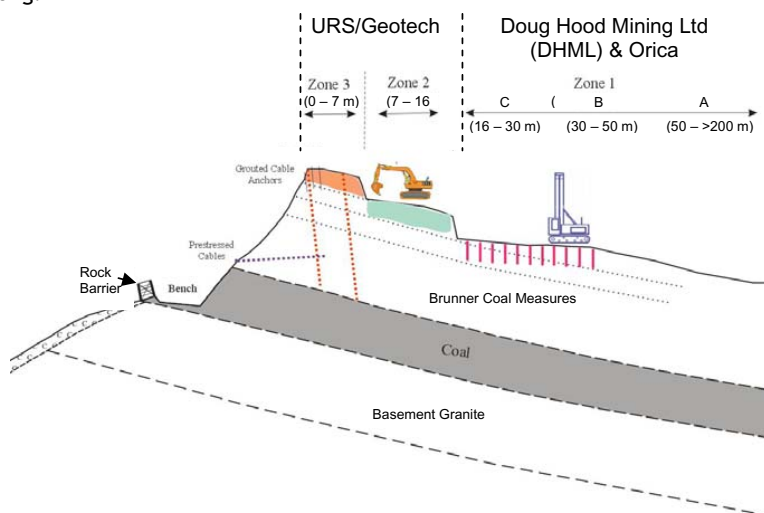


Figure 2: Schematic section showing blasting zones, simplified geology and location of rockfall catch bench and barrier.

3 SLOPE INSTABILITY

3.1 Slope failure mechanisms

The present steep escarpment topography can be attributed to the relatively erosion resistant nature of the sandstone overburden in this location. Stability is enhanced by the orientation of the bedding, which dips favourably into the slope at a shallow angle. However, material is regularly

shed from the escarpment due to the steep angle of the rock face, extreme weather environment, regular earthquake shaking and lack of stabilising vegetation. Historic slope failures are recognised where boulders up to 50 m³ can be observed on the slopes below the escarpment. Discontinuity spacing is critical in defining the block shape, with equally spaced orthogonally oriented discontinuities giving cube-shaped boulders, and elongate boulders resulting where jointing is relatively closely spaced.

The recognised mechanisms of slope failure are:

- **Toppling** - this is the most common failure scenario due to the discontinuity distribution.
- **Pseudo wedge failure** - The presence of overhanging rock results in an unsupported rock mass that may fail along intersecting joint sets that daylight out of the slope in a pseudo-wedge fashion. During failure the block may topple or slide. This type of failure has been observed on the slope, but is relatively uncommon.
- **Sliding** - This is generally observed along tectonically sheared bedding planes, which is favourably oriented down dip, towards the mine, rather than towards the CML. For this mechanism to result in a failure mass moving towards the CML, the addition of an external force would be required (e.g. earthquake loading, blasting or earthmoving equipment). However, where cross bedding is present there is the potential for sliding.
- **Debris flow** - the mobilisation of colluvial soils on a significant scale is uncommon due to the limited distribution of these materials and the relatively well-drained nature of the jointed rock.

3.2 Background rates of slope failure

Prior to mining, a baseline rate of slope failure from the escarpment was assessed. Between 10 and 20 rockfall scars, estimated to be less than 20 years old were identified along the escarpment adjacent to Mt Augustus. The scars are areas with little or no vegetation cover and are likely to be related to recent, historical earthquakes. The largest scars are estimated to represent 500 to 1000 m³ of material, but most are less than 100 m³. Based on the evidence observed at the site, one 100 to 200 m³ failure of this volume occurs on average every year. It is expected that the discharge rate is highly variable from year to year as the bulk of discharge occurs as a result of large earthquakes or heavy rainstorms.

4 MECHANISMS FOR MANAGING ROCKFALL RISK

The study of the geology and existing slope failure mechanisms concluded that an unacceptably high risk existed of rock crossing the CML if the normal mining methods were used. To reduce this risk to an acceptable level a variety of new techniques were adopted for use in different combinations according to the dictates of the local geology and slope topography. These techniques are described individually below.

4.1 Mechanical stabilisation of rocks

An important aspect of managing the risk of rockfall is the retention of potentially unstable boulders. In the short term the untouched escarpment is essentially stable, made unstable only by deconstruction activities, in particular blasting. Stabilization must be sufficient to counter the lateral loading that is placed on a particular boulder by blasting. Anticipated stabilization measures included rock bolting (using grout or resin), rock anchoring, netting and strapping.

4.2 Blasting zones

As detailed in Section 1, a line offset by 16 m from the Ridgeline is the boundary between deconstruction controlled by Geotech Limited (Zones 2 & 3) and that of DHML (Zone 1a, b & c). For most non-RMP mining blocks at Stockton, the priority for blasting by the contractor (DHML) is to fracture significant quantities of rock so that the shot overburden may be efficiently removed by large-scale earthmoving equipment. In this case, flyrock is mainly a concern as it is a health and safety issue and affects blast efficiency. For the RMP, the greatest priority when blasting is that no rock crosses the CML from either flyrock or from blast-induced rockfall. A series of zone based

restrictions have been placed on DHML blasting activities in order to modify usual mine practice so that this is achieved.

Using data from test blasting prior to the commencement of RMP mining, it was decided that all blasting in RMP mining blocks must not generate a peak particle velocity (PPV) at the Ridgeline of more than 200 mm/s. This restriction is the greatest limiting factor when planning for a blast as it affects the maximum instantaneous charge (MIC) and therefore the number of simultaneously detonated holes. Restricting the PPV also limits the generated gas heave, which has the potential to destabilize the escarpment. All blasts must have a free face, heave must be away from the Ridgeline and hole stemming must be sufficient to ensure that flyrock does not pass the Ridgeline crest. The stepped profile that places Zone 3 higher than Zone 1 ensures that a free face is maintained and that the Ridgeline is partially shielded from the larger Zone 1 (DHML) blasts. In addition there are zone specific restrictions on depth and hole spacing.

In Zone 3 blasts are conducted using low gas shear cord product in closely spaced holes. This results in splitting of the rock along pre-existing fractures with little rock movement.

4.3 Rockfall catch bench

A catch bench is an alternative or complement to the rockfall barrier (see Figure 2). As with the barrier, the aim of the bench was to absorb the kinetic energy of the rocks that may fall during deconstruction.

The following are positive points of bench construction:

- Deconstruction can be carried out more aggressively, especially with a wide, deep excavation;
- There is no limit to the capacity of the bench as long as mucking out takes place when required;
- The bench acts as a positive drainage and sediment control, eliminating the risk of discharge across the CML.
- Geology that is exposed during excavation is a useful tool in building the geological model.

Undesirable aspects of catch benches include the following:

- The removal of the stabilizing toe may inadvertently encourage slope failure - careful geological mapping and slope assessment during the excavation of the bench is essential to prevent this;
- Mucking out of the bench can be time consuming. Deconstruction activity above the bench must be suspended when this takes place;
- Falling rocks may bounce on rocks already on the bench. Regular mucking is required to prevent this;
- The minimum bench width needed to accommodate the slewing excavator is 8 m. This unnecessarily increases the risk of slope instability through undercutting the slope above where a narrower bench may be sufficient for machine travel along the bench.

The risks associated with the undesirable aspects of catch benches are managed by the geological mapping of unfavourably oriented potential planes of weakness; unloading the top of the slope prior to bench excavation to maintain an acceptable level of stability, and; advancing benches only so far as necessary to remove the next accessible potentially unstable section of rock slope. After the successful experience of using benches in the initial RMP mining block, they are now a critical part of the management of rockfall, taking the form of small benches cut beneath rock outcrops wherever possible.

4.4 Rockfall barrier / catch fence

In the RMP planning stage it was decided that due to the high profile nature of the project a rockfall barrier would be installed below the Ridgeline at the base of the economic coal seam prior to deconstruction. The barrier is made by Geobruigg of Switzerland and consists of a post and ring netting fence that is between 4 to 7 m in height and is specified with the capacity to absorb the kinetic energy generated by a 5 m³ (15 tonne) boulder released from the top of the escarpment. The cost of installing a barrier could be justified by Solid Energy New Zealand (SENZ) as it

significantly reduced the risk of rock discharge over the CML by complementing the careful technical planning and processes.

The success of Ridgeline deconstruction has resulted in less than twenty boulders with a total volume of less than 20 m³ reaching the rockfall barrier in over 18 months of operations.

5 MONITORING

Geotechnical monitoring of the Ridgeline is an important part of the RMP as it allows the better management of risk of uncontrolled loss of overburden rock across the CML and reduces the associated safety risk. The following methods are being used for the RMP to monitor the effect of these activities on slope stability:

- **Geological mapping** - The mapping of geological structure (faults, joints, bedding) during earthworks is critical in order to anticipate instability problems, e.g. prior to the excavation of a rockfall catch bench beneath a slope.
- **Site Inspection** - this is a simple, yet fundamental aspect of slope assessment and involves observation of the escarpment for signs of instability such as the presence of tension cracks, ground movement or ground water.
- **Automated Survey Monitoring** - To supplement physical inspection, a range of survey grade 'total station' theodolite systems have been installed in active mining blocks along the Ridgeline. Depending on the topography, the total stations are located at approximately 400 m intervals on the seaward side of the escarpment. They are programmed to measure the 3D position of a series of prisms that are attached to geotechnically sensitive areas of the Ridgeline on an hourly basis. The telemetered data may be graphed and viewed as monitoring takes place. The benefit of this system is that past data can be compared with recent readings in order to establish trends of slope movement. This can be a particularly useful tool in assessing the effects of local blasting on the escarpment. Disadvantages of the system are its high cost and the lack of measurement during the frequent foggy days, when line of sight between the total station and the prisms cannot be maintained.
- **Physical Monitoring Pins** - If an area of potential failure is identified, 12 mm reidbar "pins" can be quickly installed to monitor the movement across a failure plane or crack. In some cases this is used where the potentially unstable block does not contain any survey prisms. However, in most cases pins have been used to supplement prism data to provide an instant, tangible measure of movement that is unrelated to visibility. The absence of total station data usually corresponds to wet weather, which ironically, is when the data is most required to assess slope stability.

6 RISK MITIGATION DESIGN PHILOSOPHY

The major geotechnical risk is unacceptable amounts of rock and colluvium crossing the CML and compromising environmental values on DOC land during the overburden removal process. The likelihood of this occurring was determined from assessment of the geological conditions and techniques for overburden removal. It was readily apparent that utilising the normal overburden removal techniques (i.e. drill, blast, excavate to Caterpillar 777D dumpers) was not an option due to the high risk (likelihood × consequences) of losing rock over the CML.

Therefore the design philosophy for project risk mitigation required the selection of new or modified techniques (Section 4) for overburden removal which significantly reduced the risk of rock-loss to predetermined acceptable levels. Consequently the deconstruction system comprises a series of risk reduction "tools" which when combined together and used in a particular mining block reduce the total risk of rock-loss to those acceptable levels. Assessment of the risk followed the methodology SENZ has developed for use on its projects (Ref SENZ "Risk Assessment Standards"). Space limitations do not allow for reproduction of the risk assessment.

6.1 Deconstruction Risk Assessment

SENZ assesses risk in four principal categories: Value, Health and Safety, Reputation, and Environment. The likelihood and consequences of particular hazards e.g. rock-loss over the CML are estimated qualitatively and assigned a numeric score. Risk is then simply the product of these two

scores and this product is compared to predefined tolerability criteria to determine the required course of action to manage the risk. Assessment of each hazard to SENZ yielded the following:

- **Value** (prevent loss of)- the coal underlying the escarpment is worth millions of dollars so that SENZ was willing to invest heavily in environmental protection measures to preserve its legal right to extract the coal.
- **Health and Safety (H&S)**- the dangerous nature of the work and risk of accidents has required careful assessment of how to maintain high H&S standards.
- **Reputation** - The public maintains a high interest in this project particularly given the presence of Powelliphanta snails. SENZ must adopt techniques which preserves its reputation as a responsible miner.
- **Environment** - An important criteria is to maintain rock-loss over the CML to less than the natural annual erosion rate ($100 \text{ m}^3/\text{annum}$).

6.2 Tolerable Risk Criteria for Design

Tolerable risk criteria were developed based on discussions with key SENZ staff about risk tolerance and SENZ's Risk Assessment Standards. These had to be met or exceeded by the deconstruction system.

6.3 Risk Reduction Achieved

Each deconstruction technique is designed to reduce the likelihood of rock "escaping" across the CML. Primary risk reduction methods are controlled blasting and mechanical extraction of overburden back into the mine. It is at this point that the greatest control can be exerted on reducing the risks to health and safety and the environment. This includes selection of an experienced contractor with the specialist skills in the type of work required. Lower down the slope measures such as the rock catch bench and rock barrier are designed to arrest the downslope progress of loose rock after it has been "lost" from the ridge crest during blasting or excavation.

In all risk areas the required risk reduction can be achieved with the exception of Health and Safety. In this area it is acknowledged that the very nature of the work (working on steep slopes with large loose rock in often inclement weather) makes total mitigation of all H&S risk sources very difficult to achieve. Consequently significant effort is placed on managing all aspects of H&S (from site induction through reporting all levels of incidents and modifying work procedures) to actively minimise this risk.

7 CONCLUSIONS

The following conclusions can be drawn from the deconstruction work carried out along the Ridgeline to date:

Careful geological assessment and the identification of the relevant failure mechanisms associated with the geological conditions on the Ridgeline escarpment has enabled the development of a successful risk management strategy.

By identifying the components of risk from the geological study it has been possible to design a risk management system which allows a combination of individual deconstruction techniques to be used to reduce the rock-loss risk according to the particular geological and topographical conditions within a mining block.

With the high environmental values within and adjacent to the mining area SENZ is demonstrating that through the adoption of a sound risk assessment and risk reduction approach to deconstruction design that it is possible to minimise the external environmental impact outside the mining area while maximising the value that can be obtained from mining the coal.

REFERENCES

Solid Energy New Zealand Ltd - Risk Assessment Standards (draft 2004)