Trim Blasting – State of Practice

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ABSTRACT One of the techniques used to remediate rock slopes is trim blasting. Trim blasting is often used with scaling, rock bolting, rock fall netting installation, and other stabilization measures to control rock fall hazards and remediate slopes. Where an undesirable mass of rock exists that is too large, too fractured, too weak or too unstable to be rock bolted or supported by another method, trim blasting can be used. This also fits well into the hierarchy of hazard reduction. Trim blasting necessitates carefully controlled blasting techniques to ensure that the rock mass is removed without disturbing the rock face behind the feature. This paper presents some of the key geological and geotechnical characteristics of the rock that must be assessed when planning and carrying out a trim blast, as well as how the site characteristics affect the trim blast pattern, explosive requirements and contractual elements. Good trim blasting requires careful construction review throughout the drilling process, particularly while loading and charging the boreholes, to minimize rock mass disturbance. The paper also details case studies using unusual trim blasts where over air pressure, vibration and fly rock needed to be controlled.

Introduction

Rock slope engineering generally addresses the formation of new slopes or remediates existing cut or natural slopes. This paper focuses on slopes in British Columbia, but also draws on the Authors' experience of working on slopes in the UK, Alberta, and Northwest Territories.

In rock slope remediation, trim blasting is used to remove unstable rock masses on slopes that are too large for removal using scaling bars and jacks. It can also be used to remove portions of slopes that could act as features to project falling rocks from the face towards a sensitive structure.

Trim blasting usually involves drilling the rock with a pattern of holes using a hand-held, or 'plugger', drill. The boreholes are then loaded with explosives and stemming, and tied into a sequence according to the blast plan. Delays are also tied in to throw the resultant blast rock in a certain direction. Apart from the delays, this method is relatively similar to blasting techniques used as far back as the 1890s

As is the trend with rock slope remediation techniques, the site conditions and rock mass properties play a large role in how blasts are planned and executed, and site-specific conditions are considered before undertaking successful trim blasting.

Definition of Terms

Trim blasting – removal of a relatively small rock mass using explosive charges
Nonel or *EZ Dets* – shock tube detonator designed for initiating blasts
Blaster (Blaster of Record) – person who holds a valid blaster's certificate and is legally responsible for carrying out the blast
Burden – distance from a single row to the face of the excavation, or between rows when rows are fired in sequence
Spacing – distance between boreholes
Powder Factor – mass of explosive per cubic metre of bank rock
Delay – a method of blasting by which explosive charges are detonated in a given sequence with short time intervals, used in blasting to create free faces that allow material to move and be thrown in a given direction
Backbreak – rock broken beyond the limits of the rear row of holes in a blast pattern
Charge – explosive materials which may or may not contain a primer, and which are placed for the purpose of detonation
Primer – an explosive to which a detonator or other initiating device has been attached
Stemming – inert material in the portion between the top of the explosive column and the collar of a boreholes, intended to confine the explosive gases for an effective blast
Bank Volume – volume of material as measured before blast
Bulk Volume – volume of material as measured after blast, usually about 30% more than bank volume. However, the range could be 10% to 40% larger.

Risk Assessment

Conducting a risk assessment can be a useful exercise for determining an effective and cost efficient rock slope remediation method. The approach to risk management is summarized in the following risk hierarchy, generally ranked from most to least effective.

1. Elimination
2. Substitution
3. Engineering Controls
4. Administrative Controls
5. Personal Protective Equipment (PPE)

Elimination of the feature usually gives the desired outcome of highest hazard reduction. However, sometimes it is inadvisable to remove a key rock because removing the block may mobilize a substantially larger volume of material at higher elevations on the slope. In that situation, we would usually support the mass with rock bolts, netting, or shotcrete buttresses (Engineering Controls). Administrative Controls may be useful in the short term to keep people or machinery away from the potential harm zone. Substitution and PPE are not applicable to manage hazards involved with trim blasting.

A number of papers have been published stating that it is possible to model and predict the failure of a feature to within a week, or even a day. The Authors believe that the time and effort taken to predict failure for discrete blocks or pillars using this model could better be spent in providing infrastructure protection and eliminating or supporting the hazard.

Contractual, Geological, and Geotechnical Considerations

The Authors believe there should always be a clear outline of roles on a blasting project. There is a chance that engineers and geoscientists may instruct an apparently small change in the blast plan which may have long reaching effects. In this regard, the Authors do not recommend instructing the Blaster to change a portion of the blast. This will put the Engineer/Owner in an exposed contractual position.

Since it is very difficult to measure bulked rock, bank cubic metres of rock is recommended as the contractual pay item. This should also include clean-up of the ditch below the trim, as it is quite common for contractors to use existing ditch material to protect the asphalt when blasting above a highway. Ideally, the Owner or Owners Representative will measure out the desired trim dimensions with the contractor so the limits of the trim are well defined. This also promotes a thorough understanding of what is expected by both parties.

After the blast, often times the scaling contractor has to undertake some safety scaling or rock bolting for their workers to access the trim blast location safely. The Authors advise against compiling this effort into the unit rate. Instead, it is suggested that over the whole project there is a line item of “access scaling for trim blasts” so this enables each contractor to assess their own level of risk tolerance.

Geological conditions have to be considered when developing blast designs. These conditions affect borehole spacing, stemming length, powder factor, and expected vibrations.

If possible, the blaster can use the geological structures at the site to their advantage. For example, dominant, persistent structures can be used as backbreak planes.

The degree of heterogeneity within the rock mass is also important when developing a blast design. Discontinuities (joints, bedding, foliation, or faults, for example) can allow the explosive’s energy to be wastefully dissipated along the weakness plane (Wylie and Mah, 2004). Optimum fragmentation is usually obtained when the face is parallel to a major discontinuity set.

Developing a Blast Plan

According to the International Society of Explosive Engineers (ISEE) (2011), a blast plan should contain all of the information the blaster needs to effectively and efficiently administer a blasting project. Blast plans should be provided to the Engineer of Record for review prior to drilling commencement. This should include:

- Lines of Communication: Each party involved with the blasting job should have a contact person and a phone number.
- Blasting Maps: The spatial relationship between the planned blast and surrounding infrastructure is often critical in civil applications. A blast map should show the desired blast sequence as well as the surrounding utilities that require protection.
- Geological Conditions: The specific lithology should be considered for blast design, but the blast plan should at a minimum outline the general rock lithology and the depth of rock to be excavated. Any benching or geological anomalies should be discussed in this section.
- Safety Procedures: Hazard potential and mitigation actions assumed by the Blaster should be outlined.
- Explosive Storage and Security: Discuss where the explosives are stored and their security if blasting is ongoing.
- Permits and Licenses: Permits can be attached as an appendix to the blast plan.
- Anticipated Blast Design: The anticipated blast design provides a record of the blast before it occurs. The blast design should outline borehole spacing, burden, and delay pattern.
- Blast Initiation and Post Blast Assessment: A short description of the blasters location at the time of the blast and how the results of the post blast assessment will be communicated.
- Control of Adverse Effects: Monitoring plans and mitigation measures for the following items can be discussed within the blast plan:
    - Air Overpressures
    - Ground Vibration Limits
    - Fly rock
    - Dust
    - Fumes
- Pre-blast survey: A pre-blast survey should be completed to document the condition of nearby

infrastructure. An overview of findings may be included in the blast plan.

- Blasting Schedule and Warnings: The blast plan should outline the blasting schedule and warnings that will be issued both on site and to the general public if applicable.
- Signage, Blast Area Security and Access Control: Control of the blast area should be outlined to ensure safety of on-site personnel and general public.

As-Blasted Record

Once a blast has been drilled and shot, a blast record or as built (as blasted) should be issued which outlines deviations from the original blast plan. The results from the blast should also be commented on, for example if the powder factor and borehole spacing produced the desired fragmentation, and whether excessive vibrations were recorded on the vibration monitor.

Blast records are produced by the Blaster and should be looked over by the Engineer on site. These records are an excellent way to learn for future trimming projects as errors can be reflected upon and hopefully resolved.

Construction Issues

Occasionally when a trim blast is planned, issues can arise that may cause the contractor to deviate from the blast plan. This is completely acceptable, so long as the blaster is aware of the issues and modifies the design accordingly. An example of these issues may be borehole collapse, safety issues as a result of drilling a marginally stable rock mass, and health and safety of the workers undertaking the drilling.

Borehole collapse can occur when drilling poor quality rock. If a borehole does collapse, the blaster should be notified and a new borehole can be drilled nearby. The collapsed hole should be stemmed using appropriate stemming material. This change should be recorded in the blast record.

Drilling a marginally stable rock mass can also be a concern when trim blasting. This can be alleviated by installing mesh between the potentially unstable rock mass and the workers. The mesh is usually pinned above the rock mass that is being drilled and can provide separation between the workers and failing rock, should failure appear imminent. With mesh in place the workers are still at risk, however they will be separated from the failing rock mass. If the rock mass is not considered to be safe to drill from ropes, drilling can be undertaken by or from an excavator, man basket, or spider drill.

Other construction issues that may become apparent include drilling a sliver cut, or irregularly shaped rock mass. In these instances, it is important to field fit a borehole pattern and note where boreholes are placed. The blast record document should outline changes from the blast plan and expected geotechnical conditions. If there are high risks associated with the blast performance, use protective measures such as blast mats and vibration monitoring to protect and monitor important infrastructure.

Hand Arm Vibration Syndrome (HAVS) can also be an issue in personnel who extensively use percussive tools, such as pneumatic drills, over extended periods of time. The vibration from drills often used to drill boreholes causes a frequency of vibration that damages nerve endings in the hand and can be painful or lead to numbness for the workers. Worksafe BC Occupational Health and Safety Regulation Guidelines 7.11 limit the exposure time allowed for workers and this should be monitored during drilling.

Control measures for HAVS are published in the Occupational Health and Safety Regulations and can be discussed with the contractor if this is a concern. The Authors also suggest caution in the use of vibration dampening gloves as not all the harmful frequencies may be attenuated.

Control of Fly Rock and Vibrations

According to Wyllie and Mah (2004), fly rock can be caused by the following:

- Inadequate front row burden
- Borehole misalignment resulting in a concentration of explosives
- Weak seams venting gas to the rock face
- Insufficient stemming depth or lack of stemming in the borehole
- Blocked holes
- Too high of a Powder Factor

However, even when a blast is designed properly, fly rock can be difficult to manage, particularly around sensitive utilities. For this reason, the use of blast mats is highly encouraged to protect nearby infrastructure. If there is uncertainty as to the stability of the blast mats, they can be weighted down with local material or anchored to the bedrock prior to the blast.

Vibration estimation is something that is vital for blasting anywhere near humans and human infrastructure. The Author has been involved in defending an Owner from a damage claim. The trim blast was about 2.5 km away from the property attesting to damage. The charge weight per delay was about 13 kg of explosive. Using Equation [1] below this gave an estimate of 0.032 mm/s which is similar to human footsteps on a wooden floor.

[1] $$PPV = k\left(\frac{D}{\sqrt{W}}\right)^{\beta}$$

Where;
k and β are dimensionless site constants
D – Distance from blast (m)
W – Charge weight per delay (kg)
Initial values of k and β are 1140 and -1.6 respectively.

In the Author's experience seismograph recorded PPV at a given distance are typically less than the estimates.

Vibration shadow

An important property of the blast is the geometry of the rock between the blast and the sensitive receptor. Blast vibrations travel through intact rock material in pressure and shear waves, which do not travel through air. This should be considered when estimating the expected vibrations on sensitive structures. It should also be considered that pressure and shear waves are emitted from the detonation point in a spherical manner, and can be reflected and refracted around corners. A diagram to illustrate this concept is below.

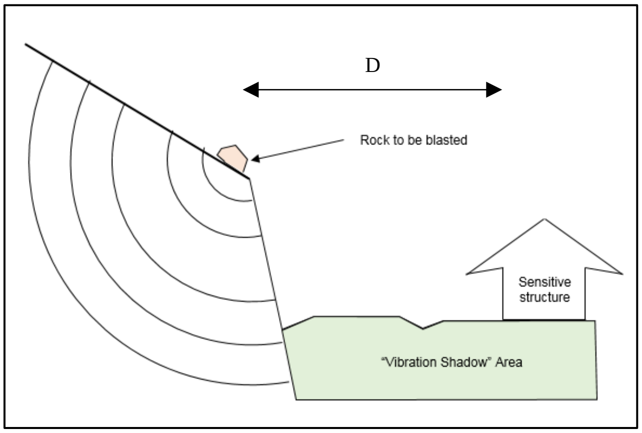

Figure 1- Vibration shadow of a trim blast

Case Study 1 – Large Trim Blast

The Long Lake Hydro Project is a 32 MW Independent Power Producer located about 35 km north-west of Stewart, BC. The project comprises a 20 m high sheet pile core rock fill dam. A 7.2 km long 1.219 m diameter penstock carries water from the head pond to the power house and exploits a haul road originally cut into the hillside in the late 1920s. During the initial assessment of the penstock route a detached 1,300 cu m 'shield' of volcanic rock was observed during the initial investigations.

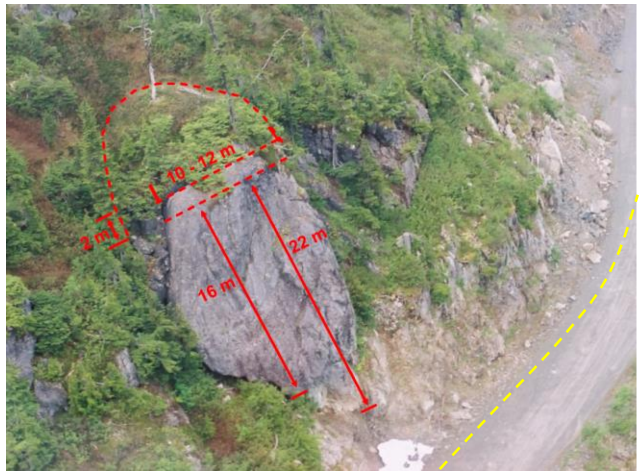

Figure 2 - Aerial Photo of the shield – Yellow dashed line shows centre line of the penstock

The section of the penstock route beneath the shield was relatively close to the surface and therefore the Owner requested the hazard elimination approach to be taken.

A scaling Contractor was mobilized to site to undertake slope remediation along the historical haul road. The scaling Contractor elected to use inclined boreholes drilled normal to the vertical face. This was in preference to drilling from the top as drill string deviation was considered an issue. The deviation may have reduced the burden, which may have increased the likelihood of fly rock.

For the main shield the burden and spacing was about 1.1 m in both dimensions. The distal end of about every seventh or tenth hole was progressed through to the discontinuity forming the back face. This gave an indication that the final face was overhanging. Therefore not all the front shield was taken in the blast.

Most of the shield was massive rock, however, the lower right portion of the rock had started to fail under its own mass. This section of the blast was drilled where possible and loaded with a far higher powder factor than the main shield.

Figure 3 - Photograph mid blast showing good fragmentation

Most of the blast fragmented well and was easily managed by the equipment on site. A small portion required secondary blasting, or 'boulder busting' but that was undertaken using a track mounted drill.

As designed, the final face was the pre-existing discontinuity that was probed throughout the drilling.

Figure 4 - Final face and blast pile

Case Study 2 – Medium Sized Trim Blast and Control of PPV

Blasting in sensitive areas can be undertaken, but each case requires careful consideration of many aspects during the blast planning and execution. In this case study, a blast was required for a 600 cu m rock mass located ~150 m from Radium Hot Springs in south-eastern British Columbia. The Owner was concerned with the blasting affecting the hot springs and was insistent that the trim not interfere with the source of the thermal water.

The infrastructure of concern was located 150 m from the blast area, therefore both vibrations and fly rock from the blast were of concern, as the hot springs were to stay open during the event.

The geological setting of the area consists of highly faulted and sheared limestone which has self-cementing properties. However, the rock mass in this location is fractured and has a Rock Quality Designation (RQD) around 40%. The blast was recommended as the rock mass was acting as a launch feature for the poor quality rock above and as a visual impediment for vehicles using the highway.

In this case, the poor quality of the rock was beneficial when considering the blast vibrations, as highly fractured rock allows blast vibrations to dissipate more quickly than competent, intact rock.

The blast dimensions were 18 m along the road, about 8 m high and 5 m into the rock face to the back break plane. 38 mm holes were drilled at about 45° to a length of 3 m to 6 m depending on the distance to the desired back break plane. The Blaster's estimated Peak Particle Velocity (PPV) was around 4 mm/s. This location also had a fibre-optic cable approximately 2 m from the toe of the blast buried about 0.75 m below the surface and a cast iron water pipe of unknown condition and unknown age.

Figure 5 - View of sensitive trim blast from across highway

Following drilling, the boreholes were loaded with Unimax (60% nitro-glycerine explosive) and each row was tied in with delays such that material was initially exhumed towards the free face, in this instance away from the hot pools. Boreholes further from the free face were detonated last so as to prevent a cut-off. Stemming comprised local sand and gravel sourced near the blast site.

Prior to blast detonation, the ground above the fibre optic cable was padded with local material (mostly gravel sized and organic material) in an attempt to minimize vibration caused by both the explosives and the rock mass falling onto the ground.

A blast monitor was set up between the hot springs and the blast about 150 m away. Recorded PPV was 3 mm/s, which fell within the contractual limit of 5 mm/s and was less that the blaster's estimate.

Due to the careful planning this trim blast was considered a success with minimal fly rock. The bank volume of the shot was previously measured with both the Blaster and Contractor on the site so as to ensure accurate payment.

Conclusions

Trim blasting is an effective method of removing potentially unstable rock masses. Effective trims are undertaken by experienced blasters who are in contact with the Engineer on site as well as the Owner.

Other key considerations in trimming include analysing the geological and geotechnical properties and noting nearby sensitive structures or other nearby features that may be affected by blasting. When estimating PPV at a sensitive structure the Engineer should be cognizant of the effects of a blast shadow on PPV. The blast plan and post blast record are also important documents that should be provided by the blaster and reviewed by involved parties.

Every borehole should be considered an investigation hole, and the blast should be designed to the conditions of the rock mass rather than the conditions in the blast plan.

It is the Authors' recommendation to be present on site when drilling and loading of blasts is being conducted. This way there is a deeper understanding of the rock mass and construction issues that may arise. It can also be verified that the blast plan is being followed, including how the boreholes are delayed and where delays are being placed.

Trim blasting is an effective way to remove potentially unstable blocks of rock that may be endangering public safety and critical infrastructure.

References

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