POTENTIAL OF AIRBLAST OVERPRESSURE AND GROUND VIBRATION FROM QUARRY BLASTING TO INCREASE THE FREQUENCY OF ROCKFALLS ON MT. COONOWRIN

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Abstract

Mount Coonowrin located in the Sunshine Coast hinterland north of Brisbane, is one of a scattered group of peaks and hills that constitute the Glasshouse Mountains and which is protected within the Glasshouse Mountains National Park. Concern about visitor safety in relation to rockfalls on the mountain were supported by the results of two geotechnical studies and led to the closure of this section of the National Park. The rockfall problem has become the focus of renewed community concern since 1998, and some sections of the local community believe that blasting from a nearby quarry is causing an increase in the incidence of rockfalls. A.joint study was carried out by the Environmental Protection Agency and the Department of Natural Resources, Mines and Energy to investigate whether the quarrying activities were having an impact on the stability of the mountain.

The report [1] describes the primary investigation which included the monitoring of a series of blasts at four locations on three days and modelling of the results to quantify the ground vibration and airblast overpressure currently occurring at the base of the mountain and at more remote locations. This paper describes the model (in terms of site laws) subsequently used to predict future ground vibration and airblast levels at the mountain as quarrying progressively approaches the National Park. The site laws will be used to optimise blast design, maximising blast efficiency while ensuring that vibration and airblast limits are not exceeded. An extensive literature search of Australian and overseas standards and guidelines has shed no light on 'acceptable' ground vibration and airblast overpressure criteria to avoid triggering rockfalls from potentially unstable natural rock faces.

Introduction

A report 'Current Impacts on Mount Coonowrin of Blasting at the Glasshouse Quarry' by C. Roberts et al [1] describes an investigation carried out to determine whether quarry blasting from Excel Quarry Pty Ltd is having a current impact on the stability of the Mount Coonowrin rock faces. This paper describes further studies undertaken using modelling techniques from blast data obtained in the investigation to predict the potential impact on Mt Coonowrin from future blasting, as the extraction progresses closer to the National Park boundary and Mt Coonowrin.

An additional literature search of Australian and overseas standards and guidelines for recommended maximum levels of ground vibration and airblast overpressure to limit structural damage to rock masses was carried out in an attempt to predict future impacts.

Monitoring equipment and locations

Ground vibration and airblast overpressure were monitored with Blastronics uMX Micro Monitor devices. Details of the location of monitoring sites are given in Table 1.

Geophones were mounted on embedded concrete blocks except at the Mt Coonowrin site where a spiked array was installed. The spiked array consisted of a triaxial detector mounted on fully embedded soil spikes. At each of the sites, an airblast overpressure microphone was positioned approximately 1m above ground level.

Blast data used for modelling

The blast data used for establishing site laws is based on the measurements of ground vibration and airblast overpressure taken on three days. The information obtained on these three days is reproduced from the first report [1] in Table 2 for different distances from the blast site and maximum instantaneous charge (MIC).

Table 1: Details of location of monitoring sites

Monitoring site designation	Distance to blast sites (m)	Description of location
TMP1	350 to 433	At sand blasting pit
TMP2	800 to 990	10m inside Park boundary
TMP3	1420 to 1490	Southern side of base of Mt Coonowrin, within Park
GB3	1185 to 1250	Adjacent to entrance to Park

The geophone at monitoring site TMP3 was not bolted to a fully embedded concrete mount so the overall peak particle velocity (ppv) for this site was corrected downwards by a factor of 0.682 to allow comparison with a non-resonant mount [2]. Airblast overpressure values for the 3rd day (shown in parenthesis) were corrected by +7.5 dB to compensate for different direction of blast. The first two tests (day 1 and day 2 were fired 45 deg to the right of Mt Coonowrin while the third test (day 3) was fired 180 deg. (away) from Mt Coonowrin.

Blast design

Blast design parameters were provided by Kershaw & Co, consultants to Excel Quarries Pty Ltd. Table 3 summarises the data.

Impact modelling technique

In blasting, empirical models have been most popular in the field of predicting surface vibrations and airblast overpressure. A great deal of research has been carried out into the problem of establishing accurate methods for predicting the likelihood of building damage caused by ground vibrations from quarry and open cut mine blasting. Much of this work was carried out by the US Bureau of Mines in the early 1960s and the codes of practice that were developed then are still in current use.

Table 2: Airblast overpressure and ground vibration monitoring results

Day of test	Monitoring location	MIC kg	Distance from blast (m)	Airblast overpressure dB(linear)peak	Overall ground vibration ppv (mms^{-1})
1	TMP1	273	433	123.1 freq 10.5 Hz	4.16
	TMP2		990	112.1 freq. 8.3 Hz	1.24
	GB3		1200	109.6	0.83
	TMP3		1490	103.4	0.71 (0.48)
2	TMP1	263	370	125.0 freq 9 Hz	14.55
	TMP2		880	115.5 freq 9.3 Hz	1.36
	GB3		1185	112.7	1.54
	TMP3		1420	111.0 freq 6.9 Hz	1.22 (0.83)
3	TMP1	322	350	121.3 (128.8)	13.04 <35 Hz: 10.9 >35 Hz: 11.7
	TMP2		800	111.0 (118.5)	1.87 <35 Hz: 1.59 >35 Hz: 0.92
	GB3		1250	112.6 (120.1)	0.95
	TMP3		1490	102.1 (109.6)	1.19 (0.81) <35 Hz: 1.06 >35 Hz: 0.85

Table 3: Blast design parameters

Day of test	MIC (kg)	Design mass of rock removed (t)	Comments
1	273	23,898	Blast fired from east to west; Mt approx. 45 deg to the left of direction of initiation
2	263	33,114	As above
3	322	23,652	Blast fired from west to east; Mt approx. 180 deg to the direction of initiation (behind the blast)

Scaled distance relationships relate the maximum vibration (or airblast) levels to the maximum weight of charge initiating at any instant and the distance from the blast. Scaled distance relationships in this investigation have been termed 'site laws'. Site laws for airblast noise and ground vibration specific to the extraction area have been developed based on the data in Table 2. These site laws enable a site-specific prediction, based on blast design information, of airblast noise levels in dB(linear) peak and overall ground vibration (ppv) in mms^{-1} at any selected distance from the blast site. The site laws can thus be used to optimize blast design, maximizing blast efficiency while ensuring that vibration and airblast limits are not exceeded.

This would enable Excel Quarries to adjust the maximum instantaneous charge (MIC) and number of blast holes as the blast faces progress in a north-westerly direction towards Mt Coonowrin, thereby ensuring that blasting does not result in adverse structural integrity effects on Mt Coonowrin.

There are limitations in applying standard charge weight vibration scaling laws [3]. Blair illustrates that the standard charge weight scaling laws imply that only one particular delay (that with the maximum instantaneous charge) contributes to the ppv. However, his analysis clearly demonstrates that a varying number of blastholes contribute to the ppv. Nevertheless, a literature review uncovered ample evidence that charge weight scaling laws are still being used and can yield a rough estimate of ppv. The method used is considered the most appropriate for the study as it provides a reasonable guide to the scale of ground vibration likely to occur at the mountain.

Ground vibration

The ground vibration prediction curve expresses the relationship between the scaled distance from the blast to the monitoring location (distance/$MIC^{1/2}$) and the vibration level in the ground. Using this curve and with a knowledge of the distance from the nearest blast to critical locations (like Mt Coonowrin) as well as the MIC, it is possible to predict the approximate vibration level at the chosen location. The level predicted in this case is the mean expected level. The predicted error at the 90 percentile confidence limit would be of the order of 2 mms^{-1}.

For the transect between the quarry site and Mt Coonowrin, the ground vibration relationship is:

$$\text{ppv } (mms^{-1}) = K \times (d/m^{1/2})^{-a} = 3737 \times (d/m^{1/2})^{-1.9} \quad (1)$$

where: **ppv** is the instantaneous resultant of the three mutually perpendicular components of peak particle velocity of ground motion;

m is the maximum instantaneous charge (MIC) in kilograms;

d is the distance between blastholes and the monitoring location in metres.

The constants **K** and **a** are site specific parameters derived from the ground vibration curve. They accommodate the influences of local geological conditions and explosive strength.

Airblast overpressure

The airblast prediction curve relates the scaled distance from the blast (in this case, distance/$MIC^{1/3}$) to the overpressure level. This curve allows an approximate prediction of the mean airblast level. The prediction error at the 90 percentile confidence limit would be expected to be of the order of 5 dB. The curve represents the airblast overpressure level 45 degrees to the side of the direct line of blast from the free face. Lower airblast levels are experienced to the sides and rear of the free face as a result of the directional characteristics of the airblast emission and shielding provided by the extraction benches.

For the Glasshouse site, the relationship for airblast overpressure in a direction of 45 degrees to the side of a direct line of fire from a free face is:

$$\text{dB (linear) peak} = C1 - C2 \log (dm^{-1/3}) = 176.2 - 28.4 \log (dm^{-1/3}) \quad (2)$$

where: **d** and **m** are as before; and **C1** and **C2** are site specific constants derived from the airblast overpressure prediction curve.

To estimate airblast overpressure levels directly behind the free face, a correction of –10 dB is made. A correction of +3 dB is made if initiation is directly towards the mountain.

Prediction of future impacts based on site laws

The north-westward expansion of the Excel Quarry over the next 20 years would bring the quarry faces, currently located approximately 1.5 km away, to within 750m of Mt Coonowrin. A major concern is that blasting this close to the mountain would increase the levels of ground vibration and airblast overpressure from those that exist at present (reported in Table 2) to levels sufficiently high to result in an increased possibility of rockfalls.

Consequently, the site laws developed for ground vibration and airblast overpressure, were applied in predicting likely levels at the monitoring locations described previously as quarrying activities progressively approach Mt Coonowrin. Approximate distances from quarry blasts were scaled from maps provided by consultant, Kershaw and Co and together with the maximum instantaneous charges used in the monitoring of the three quarry blasts, inserted into the site laws for ground vibration and airblast overpressure prediction.

Predicted ground vibration

The overall ground vibration levels, ppv likely to occur at three monitoring sites (TMP2, TMP3 and GB3) for the largest maximum instantaneous charge (MIC) used during the investigation, estimated according to the ground vibration site law are given in Table 4. The largest MIC used previously at the quarry for 36 blasts was 560 kg. The ground vibration level for this explosive charge has been estimated and reported in Table 4.

Table 4: Estimated ground vibration levels

MIC (kg)	Monitoring site	Estimated distance to blast site (m)	Descriptive location	Estimated ground vibration level, (ppv), mms^{-1}
322	TMP3	750	South side of base of mountain	3.1
	TMP2	173	10m inside park boundary	50.4
	GB3	495	Adjacent to entrance to park	6.8
560	TMP3	750	As above	5.2
	TMP2	173	As above	85.3
	GB3	495	As above	11.6

Predicted airblast overpressure

The airblast overpressure levels likely to occur at three monitoring sites (TMP3, TMP2 and GB3) in a direction of 45 degrees to a direct line of fire from a free face for the maximum instantaneous charge (MIC) used during the investigation and 560 kg estimated according to the airblast overpressure site law are given in Table 5.

Table 5: Estimated airblast overpressure levels

MIC (kg)	Monitoring site	Estimated distance to blast (m)	Descriptive location	Airblast dB(lin) peak
322	TMP3	750	South side of base of mountain	118
	TMP2	173	10m inside park boundary	136
	GB3	495	Adjacent to entrance to park	123
560	TMP3	750	As above	120
	TMP2	173	As above	139
	GB3	495	As above	127

Assessment of ground vibration predictions

Predictions of ground vibration levels in terms of the overall peak particle velocity (ppv) for future impacts indicate that the level at the mountain will increase by a factor 2.6 compared to the highest measured level using a MIC of 322 kg reported in the 1st report (1.19mms^{-1} compared to 3.1mms^{-1}).

Previously a charge of 560 kg has been used and for this case the ground vibration level is likely to increase by a factor 1.7 compared with the level associated with a MIC of 322 kg. A comprehensive literature search and contact with a number of experts around the world have not shed any light on an acceptable ground vibration limit to impose in a environmental licence so as to avoid the potential for accelerated rockfalls.

For this reason the Precautionary Principle has been applied due to the lack of full scientific certainty and the need to avoid serious or irreversible damage. Of the greatest concern is the level of 50.4mms^{-1} for MIC 322 kg predicted at TMP2, 10m within the boundary of the National Park which exceeds the recommended maximum level for ground vibration of 5mms^{-1} (ppv) prescribed in Australian and New Zealand Environment Council (ANZEC) 'Technical Basis for Guidelines to Minimise Annoyance due to Blasting Overpressure and Ground Vibration' September 1990 and NSW Environmental Noise Control Manual Part J Guideline for Blasting No 154-1 20th January 1988. For a transient vibration due to blasting of this magnitude one would expect cosmetic damage to reinforced or framed structures of an industrial or heavy commercial building at 4 Hz and above [4].

Assessment of airblast overpressure predictions

Predictions of airblast overpressure limits in terms of dB(lin) peak for future impacts indicate that the level at the mountain will increase by 8.4 dB compared to the measured level using a MIC of 322kg reported in the 1st report (118 dB compared to 109.6 dB). Once again a literature search and private communications with recognized experts around the world has not been able to quantify the effects of airblast overpressure on potentially unstable rockfaces. For a charge of 560 kg the airblast overpressure is predicted as 120 dB, an increase of 10.4 dB. Predicted levels at the base of the mountain and all other monitoring locations exceed the limit of 115 dB(linear Peak) prescribed as reasonable in Schedule 2 Section 4 of the Environmental Protection (Noise) Policy 1997 and the ANZEC Guideline referred to previously.

Structural damage criteria

A literature search over a period of seven months revealed that damage criteria for a rockmass having some degree of decay do not exist. Private communications with authorities on noise, vibration and seismology from around the world including Poland, South Africa, United States of America, United Kingdom, Germany and Korea indicate that they consider the Mount Coonowrin issue as a very complex problem with a multitude of factors besides airblast overpressure and ground vibration that can influence the rate of decay of a rockmass (and increased rockfalls). Factors include:

- erosion
- chemical effects
- stress
- slope
- density

It also appears that the mechanisms whereby a surface rockmass can be damaged by blasts is only at this point of time being researched in various countries.

Discussion

The review of Australian and overseas guidelines and literature regarding structural damage criteria for a rockmass already in a state of incipient damage yielded minimum information. The validity of using blasting impact limits developed for man-made structures as described in the 1st report [1] in the assessment of natural rock stability is a matter of some debate. Extensive research failed to identify any directly equivalent studies that might have shed light on the appropriate limits. Each and every case of a similar nature would require extensive and complex analysis.

It should be noted that in order to achieve the limit of 115 dB(lin)Peak inside the National Park boundary (TMP2) in the future when quarry blasting is at its closest to Mt Coonowrin, a MIC not exceeding 4 kg has been estimated using the site law.

Due to the uncertainty which exists at present (and applying the Precautionary Principle, as a matter to be considered under the standard criteria of the Environmental Protection Act 1994) it was recommended that Excel Quarry in its expansion of the quarry over time should continue to research best practice blasting techniques and be required to progressively reduce the size of charges (MICs) and number of blast holes at blast locations as the base of Mt Coonowrin is approached.

Conclusions

It is impossible to state categorically that airblast overpressure and ground vibration from Excel Quarry blasts will not cause future rock falls at Mt Coonowrin. What is certain though, is that Mt Coonowrin has an incipient state of failure to some parts of some rockfaces and that instability can result in landslides and rock falls, whether due to chemical and erosion effects or ground vibration and airblast overpressure.

It is uncertain whether increased airblast shock wave and vibration induced into an ailing structure could not result in a sliding action and ultimately a rock fall. A major concern is that with the expansion of Excel Quarry over the next 20 years in a north-westerly direction, with the possibility of blasts within 750m of the summit of Mt Coonowrin that higher levels of airblast overpressure and ground vibration than exist at present could accelerate deterioration of the rock structure with resultant increased rock falls.

To set airblast overpressure and ground vibration limits with any confidence according to the literature search would require extensive investigation of, amongst other things beside erosion and chemical effects:

- Digital geological mapping to determine shear strength values
- Slope angle of section of mountain likely to fail
- Static Factor of Safety based on:
    1. Friction angle
    2. Cohesion
    3. Mass density of rocks
    4. Thickness of slab and;
    5. Proportion of slab that is saturated
- Threshold Base or yield acceleration (velocity) required to overcome shear resistance and initiate sliding in rocks
- Ground vibration of stimulus (in this case, resulting from a blast)

Licence conditions under the Environment Protection Act were imposed for two permanent monitoring locations, one location 10m inside the National Park boundary (TMP2) monitored for every blast and one at the base of Mt Coonowrin (TMP3), monitored once every six months. The ground vibration and airblast levels incorporated into licence conditions at these two locations will need to be reviewed yearly in view of the impracticability, eventually of using a MIC of 4 kg and to keep abreast of research on structural damage to rockmass. At this time best practice blast technology will be considered in setting realistic ground vibration and airblast overpressure limits for the current blast condition.

References

[1] Cedric Roberts, Bob Barker, Melissa Dagan, 'Current Impacts on Mount Coonowrin of Blasting at the Glasshouse Quarry' Report by Environmental Protection Agency and Department of Mines & Energy, July 2000.

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[4] British Standard 7385 'Evaluation and measurement for vibration in buildings' Part 2. Guide to damage levels from groundborne vibration (1993), British Standards Institute, London 1993.