Fowler, Carolyn (D. Gillespie, MP)

From:	John Cassegrain <JohnCassegrain@cassegrainwines.com.au>
Sent:	Monday, 9 December 2019 1:07 PM
To:	majorprojects@planning.nsw.gov.au
Cc:	Gillespie, David (MP); (melinda.pavey@parliament.nsw.gov.au); Leslie Williams
Subject:	Sancrox Quarry Submission from John Cassegrain~Cassegrain Wines
Attachments:	Sancrox Quarry Submission_Cassegrain Wines 0_12_2019.pdf; ViewFromWineryDriveToSancroxQuarryNSW.JPG; FlyrockAttachment_CassegrainWinesSubmission.pdf

Dear Ms Anderson
Please find submission letter attached.

John Cassegrain
Managing Director

Cassegrain
A taste of tradition

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Cassegrain
A taste of tradition

9 December 2019

Ms Melissa Anderson
NSW Government Major Projections

Subject: SSD Application No 7293
Hanson Construction Materials Pty Ltd Application for Sancrox Quarry Expansion

I am writing to express a my considered opposition to the application

Relevant background*

- We operate our wine business at 10 Winery Drive, via Port Macquarie. The wine business was established in 1981, and trading on site since December 1985.
- The 31 hectare property is on the eastern side of the Pacific Highway, opposite land owned by Expressway Spares and the existing Hanson eastern boundary which is located on the western side of the highway
- The eastern boundary of the quarry is about 220 metres from our western boundary and therefore about 235metres from the winery buildings
- The quarry land at its eastern boundary has an elevation above sea level of about 30 metres. Compared to the winery western boundary of 12 metres. In fact the quarry land is the highest point of land within approximately a 2 km radius
- The winery complex includes winemaking facilities, winery administration, Cellar Door and Café Restaurant. In addition we have extensive grounds, gardens, horse riding activity, Nature school, we also regularly hold functions and events within the winery building and in the grounds
- The winery land was rezoned in 2016 to SP3 tourism. There are plans to further develop tourism type activities as permissible on the site including accommodation to complement the existing tourism and business activity
- The Expressway Spares land was rezoned in about 2015/16 to Light Industrial. The land has been cleared and I understand being prepared for development
- Up until late 2017, the Expressway Spares land was timbered. This in effect created a natural barrier; visual, dust and to some extent a noise barrier to the quarry activity
- The Sancrox/Fernbank area (otherwise known as Area 13) has been identified as acrucial growth area for greater Port Macquarie and includes; Light industry, Tourism ,Education and Residential

*NOTE: A more comprehensive background can be found in the submission by Claude Cassegrain. Much of the detail Claude articulates I am familiar with and as such I am happy to support his submission.

Specific Reasons for my Opposition to the application.

Rock Blasting

I am of the understanding that the proposed quarry will require ongoing blasting to obtain rock material from the quarry face
I refer to an incident at the quarry in 1995. A routine rock blast went terribly wrong. I am unsure whether it was the accidental excessive use of explosive, or miscalculation of energy required to blast the quarry face, a combination of both or some other issue. The outcome was rock material (flyrock) from the blast landed on the winery property including punching a hole (about 10cm in diameter) on the western wall of the winery building. Other rocks were found in the winery vineyard. Some of these rocks would have to have flown completely over the winery building, including the outside deck of the winery café. The event happened early afternoon. It was with good fortune no one was hit by a flying rock.

Of additional concern to the winery land, the rock material had to transverse the Pacific highway.(the highway at this point is lower down with a road cutting of around 8 metres that would have given it some protection but not total protection

I have no reason to consider the Quarry operators are nothing but responsible and professional operators (as they were back in 1995) but the reality is that there exists a high degree of risk in quarry blasting.
I have been provided with a copy of the attached flyrock risk paper. There appears to be no assessment of flyrock risk assessment in the application and as a victim of flyrock in the past from the Sancrox quarry I submit that a risk assessment needs to be completed.

It is one thing to manage the existing quarry, (which I believe is nearing the end of its commercial life as a quarry), but another thing when taking into account the land use and the ongoing plans for this area (expansion of tourism, expansion of light Industry and expansion of residential) to grant approval of a new quarry that would effectively extend the quarry activity in the area by a further 30 years, this has to be totally irresponsible.
Especially when there are alternative sources of raw material that are at least as good, or according to some, of a higher quality within the district that could serve the demand

The proposed new quarry is on the western side of the existing quarry. This makes it further away from our winery land and the Expressway Light Industrial land. It is quite possible the quarry face will be south, west ,southwest or northerly facing (I assume this is simply based on the topography of the land whereas the existing quarry face is easterly).
Therefore the chance of a rock incident towards the Expressway Light industry land, the Pacific Highway or the winery (all of which are east of the proposed quarry) would be less if the quarry wall is not facing an easterly direction
However to the north of the quarry there is land zoned light industry (owned by the Dunn family) and to the south and west there exists more industrial land as well as residential land.

Dust

Prevailing winds in our region are generally north easterly during summer and Autumn. Prevailing winds during Winter and Spring tend to be westerly or south westerly. This is also generally our drier time of the year. Despite the quarry shutting its operations from time to time during periods of high wind, and regularly watering their quarry yard, we do experience dust events at the winery from the quarry on quite a regular basis. This has become a more significant issue since Expressway Spares cleared its land located between the existing quarry and the winery.

The new quarry can only exasperate this problem. Not just for the winery. If the quarry is to proceed then they should be made to contain the dust within their property by way of a bund and vegetated buffer within their property

Visual

The rezoning of the Expressway land and the clearing of this land in preparation for development has visually exposed the existing quarry to visitors of the winery and others, and it is not a great look. This is arguably a subjective comment. Meaning what is attractive on one person's eyes is not so attractive in another's. However what has been exposed by the Expressway clearing is the quarry operation has not complied with its existing obligations for screening its operation. On this point it seems they cannot be relied on.
From the perspective of the winery and the tourism activity on our site, this is a material concern. The photos attached show that the quarry has not complied with previous conditions by council to provide a vegetated screen to the neighbouring properties to the east.
Additionally, the application includes a new and quite tall concrete batching plant. There is no visual assessment from the Highway or Winery Drive as to how the quarry proposes to screen this batching plant. Again, what is acceptable to one person, may not be offensive to another and is possibly subjective, but I would have thought such a visually prominent new batching plant along side the Pacific Highway and nestled amongst land zoned tourism SP3 and in the middle of our local government area should be screened and a detailed assessment on how the screening will occur should take place

Water

Cassegrain Wines is renowned for its grounds including its vineyard and gardens. I understand the proposal is for the quarry to go to RL-40 metres. This will obviously cause a significant drawdown of groundwater in the surrounding area. I have been advised a reading of figure 8.4 which simulates the groundwater draw down of at least 2 metres. This is completely unacceptable and could well destroy what is a major asset of our business. The proposal should be at a minimum be made not to drawdown on neighbouring properties and I cannot understand anything less could be considered acceptable

Other

I understand Hanson Constructions are proposing a asphalt plant either at their existing quarry site or at the new proposed project. Unless there has been a significant change in asphalt processing this activity is most inappropriate for the site. The odours and fumes like the dust would go well beyond the boundary of the Hanson property and this type of pollution should not be acceptable in close proximity to residential, tourism and light industry. Apart from the purely sensory aspects, there exists a high risk of the concentrated fumes being toxic.
The application to extend the operating hours to 24 hours a day at the existing operation and the new operation in itself does not have a material impact on the winery operation. However this would have an impact on future accommodation planned for the site (activity anticipated when the land was rezoned) and additionally would have impact on other residents in the area. Therefore I also appose the extension of operating hours for either the existing quarry or the new quarry are not appropriate.

In summary

We have a quarry with existing use rights. While there may be some call for the existing quarry to be closed down, I do not believe it is appropriate to necessarily shut down this plant. Notwithstanding the development and rezoning of the area around the existing quarry. But there is an increased necessity to ensure the quarry operators adhere to their obligations, and most importantly use best practice in their quarry operations. My understanding is the viable life for the existing quarry is reasonably short and as such is not a long term issue

However to approve a new quarry that would extend quarry activity in the area by 30 years, plus the additional asphalt activity at the location should not be considered for one second.
This application is deficient in terms of rock blasting and flyrock assessment, dust containment, visual buffer and screening, containment of odour contamination and ground water draw down that will impact on our agricultural and tourism business activity
As I understand there are a number of alternative locations in our region available to Hanson Constructions or other operators and as such the National importance status as claimed by Hanson should be disregarded as misleading and of self interest in character.

It would seem Hanson Construction themselves have concerns about their quarry project. Why else would they have objected to a residential development (known as the Clos Sancrox development) further to the south, south-west of the proposed new quarry The Sancrox project does not share a boundary with the Hanson property and in fact there are a number of residents that already exist closer to the proposed new quarry.

This has to be an admission from Hanson Construction themselves that the quarry poses a risk and is not compatible with not only its immediate neighbours but those further away.

Yours sincerely

John B Cassegrain

John Cassegrain
Managing Director
Cassegrain Wines

Flyrock Risk

T N Little[1]

ABSTRACT

The issue of flyrock is critical to the operation of all mineral extraction sites that use blasting. This paper takes a risk-based approach to identifying, analysing and managing the flyrock hazard. The basic cause of flyrock generation is a mismatch between the energy available and the work to be done. It should be noted that the energy available depends on the charge confinement. This mismatch can be caused by an abrupt decrease in rock resistance (geological weaknesses), overcharging, inadequate delays between holes and rows, inappropriate blast design and inaccurate drilling.

The mismatch can come about from two sides; either too much energy (charge) for a fixed burden (work to be done), or insufficient burden (work to be done) for a fixed charge. The main mechanisms of flyrock generation are rifling, cratering, face bursting and secondary blasting. Each source mechanism has different characteristics in terms of vulnerable locations and each requires different control measures. However, all controls require a high level of quality control and assurance.

A range of different approaches for managing flyrock risk and determining blast clearance zone dimensions are presented. A prescriptive consequence-based approach is discussed. A conventional risk matrix based approach is outlined with some innovation regarding controls rating and uncertainty ratings. A published semi-empirical approach is discussed. Two examples of quantitative flyrock risk analysis are presented; one involves bench blasting based on a published paper and the second is a cratering example developed by the author based on consulting projects. Finally, a stochastic approach based on published work is presented which simulates cratering superimposed on face bursting mechanisms. Also, a stochastic analysis undertaken by the author of the cratering example is presented.

Effective blast emission management is required for two reasons; firstly to reduce and/or eliminate safety risks and secondly to manage public perception of blasting risks such as flyrock.

The conclusion of the current research is that the wild flyrock risk can be estimated using existing techniques. Furthermore, both qualitative and quantitative risk management methods as discussed in this paper can be used for flyrock management for a given blasting situation. A combination of both is considered to be best practice.

INTRODUCTION AND BACKGROUND

Aim of the paper

Flyrock in rock blasting has been a serious problem since blasting began several hundred years ago. This paper aims to review some different approaches to flyrock risk management used over the last 30 years including those recently undertaken by the author. In this paper only SI units will be used. Terminology relating to flyrock in the literature is inconsistent, so it is necessary to define the three terms: throw, flyrock and wild flyrock as used in this paper (see Figure 1):

- *Throw – the planned forward movement of rock fragments that form the muck pile within the blast zone.*
- *Flyrock – the undesired propulsion of rock fragments through the air or along the ground beyond the blast zone by the force of the explosion that is contained within the blast clearance (exclusion) zone.* Flyrock using this definition, while undesirable, is only a safety hazard if a breach of the blast clearance (exclusion) zone occurs.
- *Wild flyrock – the unexpected propulsion of rock fragments, when there is some abnormality in a blast or a rock mass, which travels beyond the blast clearance (exclusion) zone.* Its generation is due to a combination of factors that are either not well understood or are difficult to quantify (Davies, 1995). Wild flyrock is unsafe for workers and the general public, as precautions are not generally made or required beyond the blast clearance (exclusion) zone.

Using the above terminology and in the context of blast-driven rock movement the owner organisation needs to address three distinct but related risks. One generic example of each type of risk is given using the 'condition' *leading to* 'impact' risk statement format:

- *Throw (operational) risk* – less than adequate blast performance *leading to* inadequate throw and associated slow loading rates.
- *Flyrock (hazard) risk – blast clearance zone breach leading to* flyrock injury or fatality to employees or trespassers.
- *Wild flyrock (hazard) risk* – wild flyrock generated in the blast *leading to* injury or fatality to employees or the general public. This paper is mainly concerned with this type of risk and hence quantitative risk approaches are the most appropriate.

Background information

Ideally for each blasting operation we would have all the required input information required to undertake a quantitative risk analysis. The required information would include:

1. MAusIMM, Principal Consultant, TNL Consultants Pty Ltd (Pythagorisk Solutions), Suite A, 20 Cinnabar Place, Carine WA 6020. Email: tnlc@bigpond.com

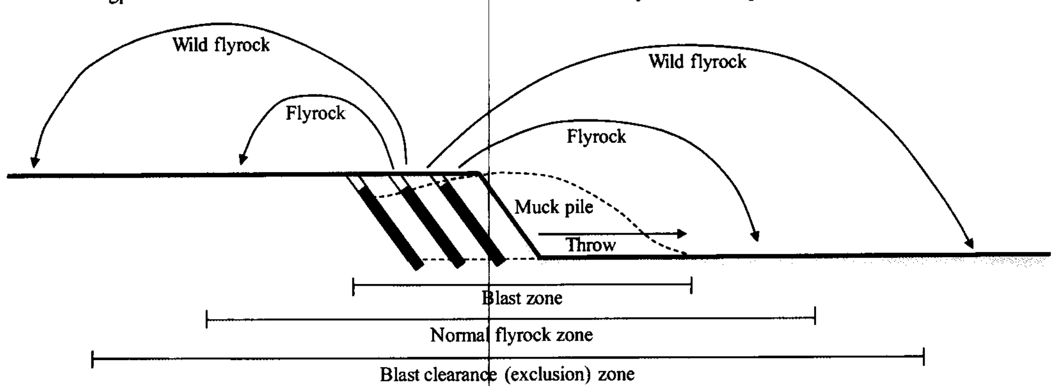

FIG 1 - Schematic flyrock terminology.

- clear definition of throw, flyrock and wild flyrock;
- historic records of flyrock and wild flyrock incident rates;
- knowledge of the source mechanisms, launch directions and travel distance for each incident;
- distribution of flyrock ranges and directions by fragment size;
- distribution of flyrock ranges by fragment shape; and
- acceptability criteria in the same units as the risk analysis uses.

Unfortunately this is rarely, if ever, the case and risk analysts/assessors must rely on information from any available source regardless of where it comes from. In the case of flyrock statistical information, it appears the best readily available 'incident rate' information comes from the United Kingdom (for consistency with elsewhere) and Hong Kong as reported by Davies (1995). Similarly, the best available 'consequence' information appears to have been collected by the Mine Safety and Health Administration (MSHA) database system over a 20-year period as reported by Rehak *et al* (2001). Another aspect of flyrock ranges that is often overlooked is fragment shape. This has been modelled by St George and Gibson (2001) with somewhat surprising yet highly significant results. The information for a particular risk analysis application should be carefully selected and filtered by experienced personnel to match local site conditions, practices and the physical operational environment as much as possible.

Incident rates – Table 1 provides information on flyrock incident rates that can be used in flyrock risk analysis studies. The figures are relatively consistent between the United Kingdom and Hong Kong (Davies, 1995) and Auckland (Gibson and St George, 2001).

In gathering flyrock data, there is a major problem with under-reporting. Only extreme flyrock events are recorded, due to either being noticed by the public or resulting in damage. Davies (1995) considers under-reporting is responsible for five to ten times the actual number of incidents. This imposes a serious bias on any flyrock data collected, as the population of shorter-range flyrock and some long-range events are not included. Davies (1995) argues that final estimates of risk to distant objects are directly proportional to the frequency of flyrock events, hence basic risk calculations can be performed using the raw data with allowances being made for under- reporting.

The historical data do not distinguish in sufficient detail between production blasts, 'small' shots and misfires. Consequently, the use of these data implies an assumption that all blasting operations incur similar proportions of 'small' shots and misfires relative to production blasts.

Safety statistics – using the MSHA statistics the author has attempted to determine two things. The first is the relative significance of blast clearance zone breach injuries, wild flyrock injuries and all surface blasting injuries. This information is given directly for surface blasting for the period 1978 - 1998 in Table 2.

The data show the extreme importance of managing both the *blast clearance zone security risk* and the *wild flyrock risk.*

The second insight to be determined relates to human vulnerability to flyrock impact (see Table 3). This information is not directly available so interpretation is necessary and hence the confidence in this figure needs to be de-rated a little or a conservative figure adopted.

Based on a conservative interpretation of the tabulated estimate, a human vulnerability or the probability of fatality

TABLE 1

Flyrock incident rates by volume of rock, mass of explosive and per blast.

Location	Incidents/m^3	Incidents/kg	Incidents/blast	Source
United Kingdom				
Blasting quarries/mines	3.59×10^{-7}	1.41×10^{-10}	1.30×10^{-3}	Davies (1995)
Hardstone quarry	9.45×10^{-7}	3.64×10^{-10}	1.30×10^{-3}	Davies (1995)
Hong Kong				
Blasting quarries/mines	5.30×10^{-7}	2.0×10^{-10}	1.02×10^{-3}	Davies (1995)
New Zealand				
Auckland (1993 - 2000)	6×10^{-7}	2.2×10^{-10}	8×10^{-4}	Gibson and St George (2001)

TABLE 2

Flyrock injury statistics for 20 year period (1978 - 1998) in USA (MSHA data).

	Total injuries in period	Flyrock injuries (%)	Surface blasting injuries (%)
Blast clearance zone security breach (flyrock risk)	167	59.4	40.5
Flyrock projected beyond blast clearance zone (wild flyrock risk)	114	40.6	27.7
Total flyrock injuries	281		68.2
All surface blasting injuries	412		

Notes:

- Over the 20 year period the contribution of wild flyrock and blast clearance zone security ranged from 58.7 per cent to 77.4 per cent of all surface blasting;
- in the period 1978 - 1993 wild flyrock accounted for 28.3 per cent, lack of blast clearance zone security 41.2 per cent, premature blast 15.7 per cent, misfires 7.8 per cent and all other causes seven per cent;
- over the 20 year period coal mining accounted for 186 (19 fatal and 167 non-fatal) and metal/non-metal mining 226 (19 fatal and 167 non-fatal) blasting-related injuries; and
- over the 20 year period underground mining accounted for 700 (59 fatal and 641 non-fatal), blasting and surface mining 412 (45 fatal and 367 non-fatal) blasting-related injuries.

given that an individual is impacted by flyrock of 15 per cent (0.15) is used in calculations in this paper. In should be noted that St George and Gibson (2001) used 25 per cent for the same figure without detailed explanation.

Flyrock range distribution – the data in Figure 2 from both the United Kingdom and Hong Kong illustrate that flyrock distance is distributed exponentially (Davies, 1995). From this distribution it is possible to estimate the probability of exceeding a certain flyrock distance by a given amount.

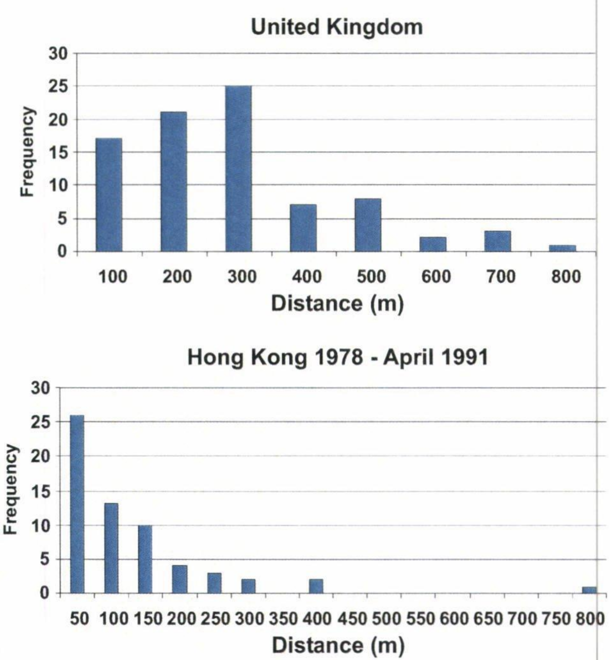

FIG 2 - Reported flyrock distances in United Kingdom and Hong Kong (Davies, 1995).

Fragment shape – St George and Gibson (2001) provides the best insight into the influence of frictional drag on flyrock particles of different shapes (degrees of sphericity). Table 4 clearly indicates that such information is very significant and should be collected when undertaking a routine flyrock assessment. With information on the jointing in the rock mass it may be possible to estimate average block sizes for potential flyrock boulders. These could easily be modelled as stochastic variables and input into risk simulations. For further information the reader is referred to St George and Gibson (2001).

FLYROCK CAUSES AND MECHANISMS

Primary causes of flyrock generation

The basic cause of flyrock generation is a mismatch between the energy available and the work to be done. The mismatch can come about from two sides: either too much energy (charge) for a fixed burden (work to be done), or insufficient burden (work to be done) for a fixed charge. Figure 3 illustrates these two situations and 'how it can happen' for each.

Figure 3 also illustrates the four main flyrock mechanisms which are discussed in the next few paragraphs.

Flyrock mechanisms

Rifling

This occurs when stemming material is inefficient or is absent. Blast gases can stream up the blasthole along the path of least resistance resulting in stemming ejection and sometimes ejection of the collar rock as harmful flyrock. Should the stemming column contain individual rocks that are of disproportionate size to the blasthole diameter these can become lethal projectiles. This mechanism of flyrock manifestation is closely related to the stemming release pulse (SRP) for airblast (Little, 1994).

Cratering

The stemming region of a blast pattern usually contains a weakened layer due to previous subgrade blasting from the bench above. In this region, blast gases easily jet into and propagate cracks to the horizontal free surface and the venting gases cause cratering and associated flyrock. This is particularly significant if insufficient stemming depth is used. This mechanism of flyrock manifestation is closely related to the gas release pulse (GRP) for airblast (Little, 1994). Similar effects can result if insufficient burden relief occurs due to inadequate inter-row delays for a given blast design. In this situation each explosive charge will crater to the upper horizontal free surface as this offers the path

TABLE 3

Estimating human vulnerability to flyrock impact.

	Fatal injuries	Non-fatal injuries	Total (1978 - 1998)
All flyrock injuries	Not given	Not given	281
All surface blasting injuries	45 (10.9%)	367 (89.1%)	412
Estimated human vulnerability to flyrock impact	31 (estimated based on 10.9%)	250 (estimated based on 89.1%)	281

TABLE 4

Calculated travel distances and influence of particle sphericity (St George and Gibson, 2001).

Hole diameter (mm)	Flyrock range (max)[1] (m)	Flyrock size[†] (mm)	Velocity[†] (m/s)	Maximum travel distance (m) for given particle sphericity		
				0.7	0.8	0.9
76	541	208	139	436	579	737
100	655	252	153	517	703	900
115	712	274	159	562	765	980
150	859	330	175	678	924	1189

† Calculated from the equations in Lundborg *et al* (1975).

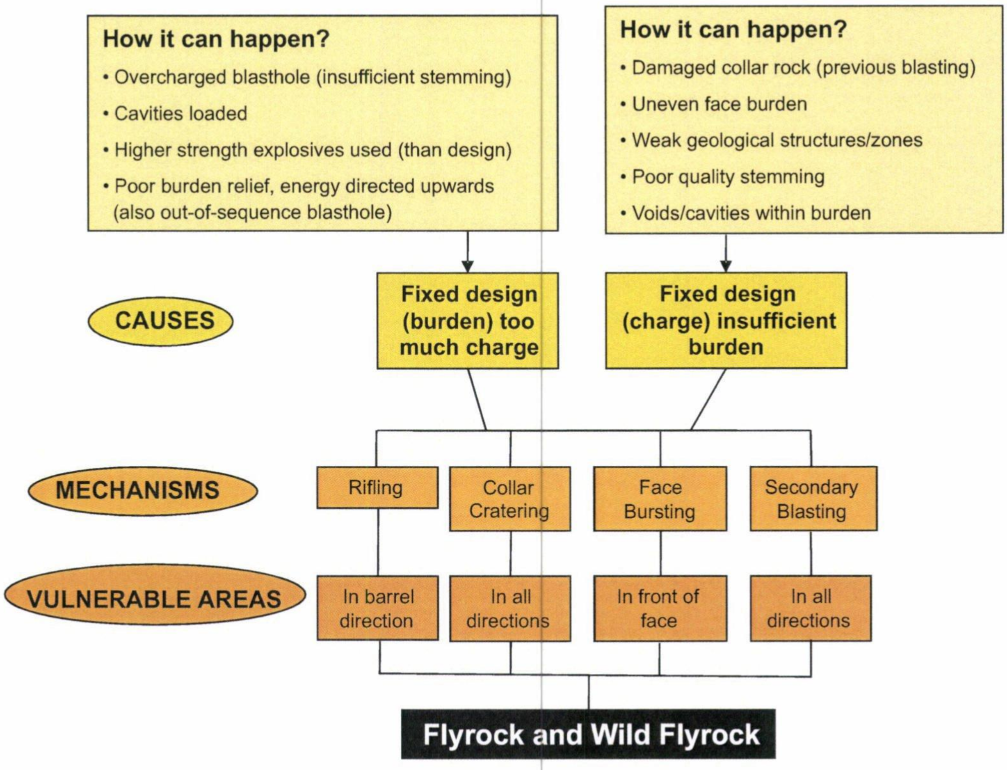

FIG 3 - Flyrock causes and mechanisms.

of least resistance for the escaping high-pressure gases. These gases will produce excessive airblast (GRP) and flyrock. When blastholes are initiated out of sequence (back row before an earlier row) for any reason, a similar cratering effect occurs with associated flyrock.

Face bursting

This occurs when explosive charges intersect or are in close proximity to major geological structures or zones of weakness. The high-pressure gases formed upon initiation of the explosive column seek out and preferentially jet along these paths of low resistance, resulting in a concentration of gas expansion energy. This results in the energy normally used to fragment and heave rock being dissipated as noise, airblast and flyrock. Similar to cratering, this mechanism of flyrock manifestation is closely related to the gas release pulse (GRP) for airblast (Little, 1994). Similar effects can be obtained from front row blastholes where insufficient burden exists due to poor design, drilling deviation towards the free face and when the top of the vertical hole charge is too close to the inclined free face.

Secondary blasting

Secondary blasting can include toe blasts and blasts used to break boulders using explosives. 'Toe' is the burden left on the floor (high bottoms) between, or the rock left unbroken between the bottom of a borehole and the vertical free face of a bench in an excavation. Some primary blasts will result in fragments that are too large to be handled efficiently by the loading equipment and will cause plugging of crushers or preparation plants. Secondary fragmentation techniques must be used to break these oversized fragments. If fragments are too large to be handled, the loader operator will set the rock aside for treatment. If the use of explosives is unavoidable two methods can be used. The first method is called mud-capping, sand-blasting, plastering, or adobe charging: the explosive is packed loosely into a crack or depression in the oversize fragment then covered with a damp earth material and fired. This method is inefficient because of the limited explosive confinement and the relatively large amount of explosives required. Other outcomes are excessive noise, flyrock, and often, inadequate fragmentation. The most efficient method of secondary fragmentation is through the use of small, 25 - 75 mm blastholes. The blasthole is normally collared at the most convenient location, such as a crack or depression in the rock, and is directed toward the centre of the mass. The hole is drilled two-thirds to three-fourths of the way through the rock. Because the powder charge is surrounded by free faces, less explosive is required to break a given amount of rock than in primary blasting. One tenth of a kilogram per cubic metre (0.1 kg/m^3) is usually adequate. All secondary blastholes should be stemmed. Usually, secondary blasts are more violent than primary blasts. Although secondary blasting employs relatively small charges, the potential safety hazards must not be underestimated. Usually, there is more flyrock, and the flyrock is less predictable than with primary blasting. For example, only four out of a total of 23 flyrock incidents investigated by the United Kingdom Mines and Quarries Inspectorate were found to be the result of main production blasts (Davies, 1995). More than 80 per cent of the incidents were associated with single shots or repair shots, such as 'toe' removal and 'trimming' (Davies, 1995).

Summary of source mechanisms

Refer to Table 5.

FLYROCK RISK ASSESSMENT

Prescriptive or consequence-based approaches

Regulations and contracts can be prescriptive and it is not uncommon for a large blast clearance (exclusion) zone to be set around a blasting site. Traditionally, danger zones have been set solely on the basis of consequences, for example the maximum

TABLE 5

Characterisation of flyrock mechanisms and vulnerable areas.

Flyrock mechanism	Launch direction (vulnerable areas)	Flyrock driving forces	Launch angle
Rifling	Equi-probable (360°) if vertical. Centred around projectile pathway if incline holes used.	Stemming release pulse (SRP).	Vertical
Cratering	Equi-probable (360°).	Associated with gas release pulse (GRP).	Subvertical
Face bursting	In front of face.	Associated with gas release pulse (GRP).	Subhorizontal
Secondary blasting (popping, toe)	Erratic – geometry poorly defined.	Explosives in direct contact with projectiles.	Between 0° and 180°

distance of rock projection plus a defined safety margin. The approach is satisfactory where the requirement for distance can easily be accommodated. Increasingly, with the development of sites in ever closer locations to potentially 'sensitive' areas, exclusion zone distances are imposing constraints on blasting specifications. Such constraints tend to incur time and financial penalties.

Advances in risk assessment and its growing acceptance as a tool for safety management have led to the setting of blast clearance zones on the basis of both consequences and frequency of occurrence. This approach allows distances to be optimised with respect to acceptable risk levels rather than the potential consequences of infrequent events. A range of approaches to setting blast clearance zones will be discussed. In the next paragraph a risk matrix approach is dealt with.

Risk matrix-based approaches

It is common for operations to manage the flyrock risk in the same way they manage other health, safety and environmental risks. This involves undertaking a team-based risk workshop using pre-established likelihood, consequence and evaluation criteria and a risk matrix for risk rating purposes. This approach follows the steps from the Australian Standards AS4360 and can culminate in the development of a flyrock risk management plan, a blasting emission management plan or be part of an explosives management plan.

A method developed and owned by the author uses three matrices. The Pythagorisk® method uses a 5 × 5 matrix for risk ratings, a 4 × 4 matrix for control regime ratings, and 3 × 3 matrix for uncertainty ratings. A major advantage of this method is that an information-rich environment is available for risk treatment planning. The results of a hypothetical risk assessment undertaken using this method are shown in Figure 4. It should be noted that in the scheme used to plot Figure 4 small numbers are the least desirable.

Figure 4 illustrates the use of four rating systems. These are the hazard risk ratings (1 - 25), hazard-related business risk rating (1 - 25), control ratings (1 - 16) and uncertainty ratings (1 - 9). Based on these ratings the author has developed risk key performance indicators (KPIs) and Control KPIs. These are then used to motivate people to manage the aggregate risk profile and monitor the control regime.

It should be noted that the hazard-related (conditional) business risk rating provides additional information for decision-making. In the case of a flyrock fatality the conditional business risk would be extreme (risk rating of one in Figure 4). This method has the significant advantage that it is: the same method used to manage most other health, safety and environmental (HSE) hazards; it involves workforce participation; and is understandable to the widest range of employees and community members.

In the author's opinion this approach is perfectly adequate for ongoing operational needs once a safe blast clearance dimension or regime has been established. Like many other parameters for safe and efficient blasting, this can be done by trial and error using an ultra-cautious start-up. Incident reporting, quality control and a learning culture are critical elements in ensuring this approach remains responsive to changing conditions. Other methods of establishing the dimension of a blast clearance zone will be discussed in the next few sections.

Semi-empirical approaches

The recent work of Richards and Moore (2002) is an example of a semi-empirical approach to flyrock range prediction and is briefly reviewed based on published papers. They built on the work of Lundborg (1981), Workman and Calder (1994) and St George and Gibson (2001), and further developed a methodology for quantification of flyrock distances relative to explosive confinement conditions. The establishment of maximum throw distances was then used to determine minimum clearance distances from blasting and personnel, based on the application of appropriate safety factors. Factors of safety of two for equipment and four for personnel have been suggested. Richards and Moore (2002) use a flyrock distance prediction model which is based partly on the fundamental laws of projectile motion coupled with an empirical formulation that relates face velocity to scaled burden. Scaled burden is defined as burden (or stemming) distance divided by the square root of the charge weight per delay. The model needs to be calibrated for each blast site:

Face bursting $$L_{max} = \frac{k^2}{g}\left(\frac{\sqrt{m}}{B}\right)^{2.6}$$

Cratering $$L_{max} = \frac{k^2}{g}\left(\frac{\sqrt{m}}{SH}\right)^{2.6}$$

Rifling $$L_{max} = \frac{k^2}{g}\left(\frac{\sqrt{m}}{SH}\right)^{2.6} \sin 2\theta_0$$

where:

θ = drill hole angle

L_{max} = maximum throw (flyrock range)

m = charge weight/m (kg/m)

B = burden

SH = stemming height (m)

g = gravitational constant (9.81 m/s^2)

k is a constant

This model can also be used to indicate to shotfiring personnel the degree of control that must be exercised during surveying and loading to achieve minimum confinement conditions and the consequences of inadvertent lapses in standards. This is demonstrated graphically in Figure 5.

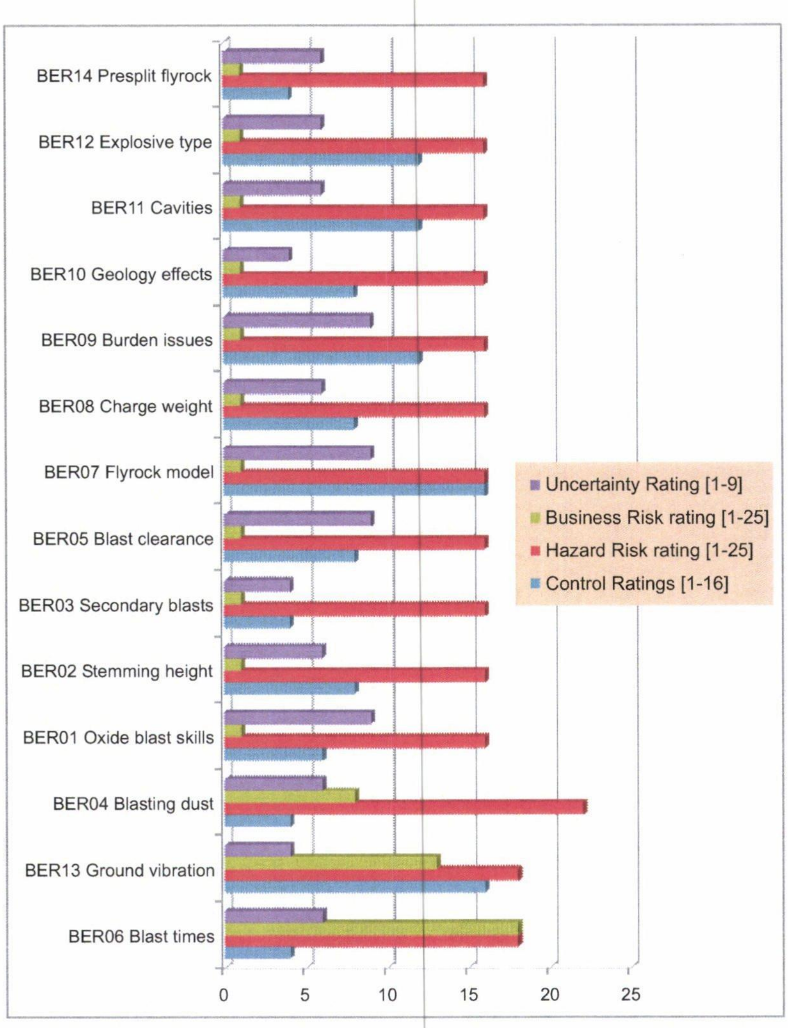

FIG 4 - Summary of risk, control and uncertainty ratings by risk.

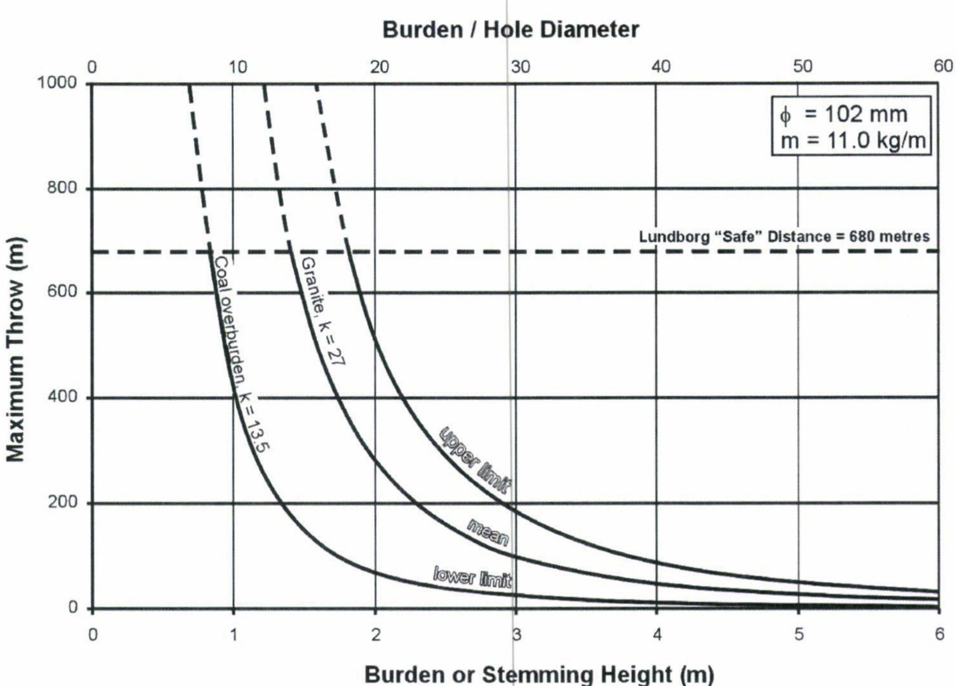

FIG 5 - Maximum throw (flyrock range) versus burden (Richards and Moore, 2002).

Quantitative flyrock risk approaches

Two examples will be given; one involves bench blasting based on a published paper by Davies (1995) and the second is a cratering example developed by the author based on consulting projects.

Bench blasting example – Davies (1995) considered a blast site with a representative rock face 15 m high and 300 m from a single, distant target. Where it faces due north the rock face presents a hazard of concentrated fragment projection to the distant target. The distant target presents a 10 m face that is parallel to the north-facing fragment source. The other potential directions of the rock face (east, south and west) do not present a fragment-projection hazard. In addition, the target is exposed intermittently so that the probability of exposure is approximately 0.05 (it is exposed 20 times per hour). Blasts total 40 per year and can occur at any time during the working day. The predicted throw distance of blasted rock is 40 m and the maximum predicted 'normal' (not 'wild') flyrock distance is 150 m. For a single target at a constant distance the predicted frequency of impact (I) by wild flyrock is approximately:

$$I = N \times f \times p_d \times p_p \times p_e$$

where:

- I is target impact frequency (impacts/year)
- N is total number of blasts per year
- f is frequency of wild flyrock per blast (ie 10^{-3})
- p_d is probability of wild flyrock travelling the target distance (exponential distribution, see Figure 2)
- p_p is probability of wild flyrock travelling on an impact trajectory
- p_e is probability of target exposure

In the example N = 40; f = 10^{-3}, p_d = 0.20 (ie predicted wild flyrock distance > target distance); p_p = 0.01 (ie approximates subtended angle ($2\tan^{-1}\theta$)/180); $\tan\theta = 5/300$, where 5 = half target face, in metres, and 300 = distance, in metres from rock face to target); and p_e= 0.0125 (ie 0.05 × 1/4, where 1/4 equates to fragment source facing one of four directions – north, south, east or west:

$$I = 40 \times 10^{-3} \times 0.20 \times 0.01 \times 0.0125 = 10^{-6} \text{ per year}$$

Hence, the calculated frequency of target impact is 10^{-6} per year at a target distance of 300 m. It should be noted that this risk-based approach relies on the use of criteria from which to judge the 'tolerability' of the calculated target impact frequency.

Cratering mechanism flyrock risk – the author developed a flyrock risk model for cratering from a single blasthole. There are five main questions that need to be answered:

1. What is a realistic distribution for the wild flyrock range?
2. Based on the assumed distribution, what are the best estimates of input parameters?
3. What is the estimated annual probability of fatal injury?
4. How does it compare with published values? (Not covered in this paper.)
5. Is this risk tolerable? (Not covered in this paper.)

Davies (1995) reported an exponential distribution for data he collated on flyrock ranges for both Hong Kong and United Kingdom quarries and mines. The distribution also needs to match reality (distribution of actual flyrock ranges) as closely as possible. Based on that fact and the relative ease of use it was decided to use an exponential probability density function for the current study. The exponential model has high values for zero range values, which implies a rifling type mode for a lot of the flyrock. Such behaviour is not often observed in practice and only occurs when the stemming material does not lock up to contain the explosive gases and stemming ejection takes place. An alternative explanation is that the exponential distribution obtained by Davies (1995) relates only to flyrock outside the expected blast throw zone.

Assumptions made in annual probability of fatal injury calculation, see Figure 6:

- flyrock range assumed to be exponentially distributed with a mean of 20;
- only flyrock behind the blast (target area) needs to be considered, ie cratering mechanism;
- 360 one degree zones have been assumed to be equi-probable: 1/360;
- cratering rate assumed (one in 100 holes): one per cent;
- 45° zone: 47 124 m^2;
- target area in zone: 20 000 m^2;
- people area in target area: 20 m^2;
- holes blasted per year: 3000; and
- vulnerability of people if hit (Based on MSHA estimate): 15 per cent.

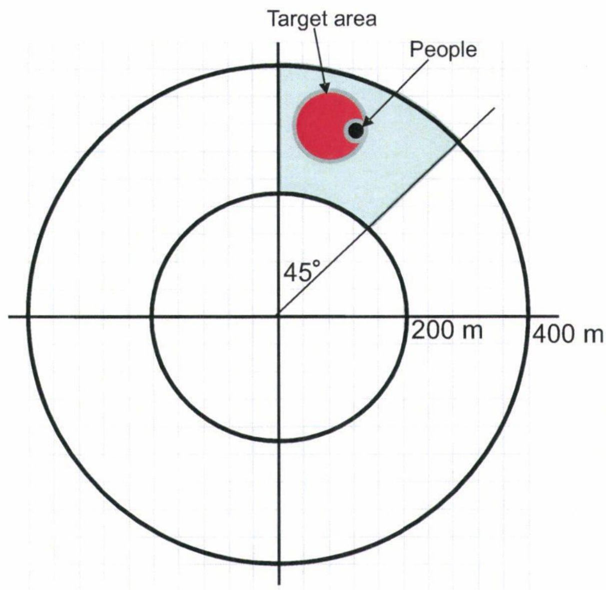

FIG 6 - Cratering assumptions.

Annual probability of fatality (P_f) caused by flyrock landing in residential area:

$$P_f = N \times p_c \times p_d \times p_t \times p_r \times p_e \times v_f$$
$$= 3000 \times 0.01 \times 0.000335 \times 0.125 \times 0.424 \times 0.001 \times 0.015$$
$$= 8.0 \times 10^{-9}$$

where:

- N = number of blastholes per year (3000)
- p_c = probability of cratering (assumed one per cent or one in 100)
- p_d = probability of wild flyrock travelling the target distance (between 200 and 400 m)
- p_t = probability of wild flyrock falling within target sector (45 out of 360 degrees)
- p_r = spatial probability roof area to zone area (20 000/47 124)

p_e = spatial probability of people exposure (20/20 000)

v_f = probability of fatality if person impacted by flyrock (assumed 15 per cent)

Stochastic modelling approach

The launch velocity was derived by Gibson and St George (2001) using an impulse approach. The launch velocity (V_0) is given by:

$$V_0 = \frac{3\rho_E D^2 \Delta t}{32\phi\rho_R}$$

where:

ρ_E = explosive density

D = velocity of detonation

Δt = length of impulse time

ρ_R = density of rock

ϕ = diameter of flyrock particle

A mean Δt of 1.8×10^{-6} seconds was estimated by the analysts. The bench and collar flyrock were considered as separate entities. It was assumed that the probability of flyrock from the collar was 0.1 and from the bench face 0.9. The reasoning behind this assessment was that the collar flyrock is generally more controllable than the bench. The launch angle was modelled as normally distributed with the mean collar angle taken as 90° and bench face as 0°. A standard deviation of launch angle was assumed to be 15.3° in both cases after Persson, Holmberg and Lee (1993). For the bench situation only positive values of launch angle were considered.

The launch direction for flyrock from the collar was calculated from a uniform distribution as there are no controlling factors to bias any particular direction. For the bench it was assumed that it was not possible for the flyrock to travel behind the bench due to the physical constraint of the bench. It was assumed that the average direction was 0° (directly in front of the blast) with an estimated standard deviation of 25°. In this example the size of the flyrock was set to a value of 0.1 m with a particle sphericity of 0.9 to give conservative estimates of maximum throw. A Monte Carlo simulation was run at one location 1000 times, although this is clearly not what would happen in practice. The plot of the flyrock patterns is shown in Figure 7.

As can be seen from the plot, the bench flyrock travels considerably further than the collar material. Over a number of simulations the maximum likely distance that the collar flyrock achieved was 150 m behind the face, while for the bench flyrock one simulation produced a range of 350 m.

Cratering blast simulation – for this paper the author undertook a scenario analysis using a flyrock risk model similar to the one discussed earlier to demonstrate the development of a scatter diagram for a catering source mechanism. Figure 8 shows 1000 iterations for a single hole crater blast, the thousand data points indicate the direction and range of the predicted flyrock.

The advantage of this approach is that graphical output is available for communication, training purposes and a visual check on the calculated risk values.

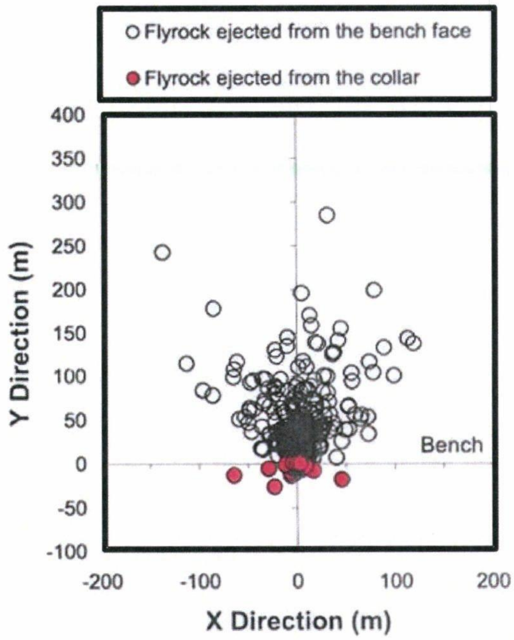

FIG 7 - Plot of flyrock locations from 1000 simulated blasts (St George and Gibson, 2001).

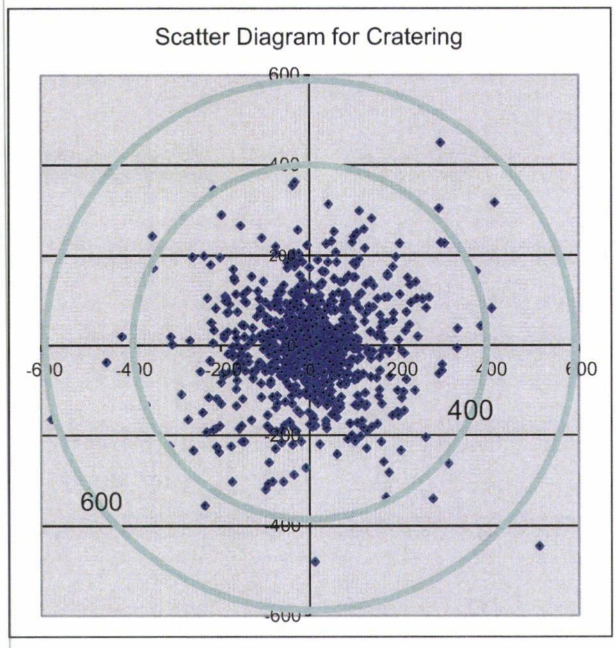

FIG 8 - A cratering scatter plot (1000 simulations).

FLYROCK RISK MANAGEMENT

Risk treatment

Regardless of how a risk assessment is undertaken there are a number of generic risk treatment activities required to ensure company objectives. This is particularly critical if blasting operations are to be undertaken in close proximity to built-up areas and other sensitive locations. Effective blast management is required for two reasons; firstly, reduction and elimination of risks through efficient, effective and proactive management of the blast from design to firing and finally analysis of its effectiveness. Secondly, the requirement to manage the public's perception of blasting risks such as flyrock. Studies of risk perception indicate that laypersons tend to overestimate risks with which they are unfamiliar or have potentially catastrophic consequences. Flyrock falls into both of these categories. If the management of the public's perception is ignored, confidence in the operation will falter, possibly causing problems involving bad press, blast clearance zone breaches, and in the longer term gaining the required resource development approvals.

The author recently facilitated risk workshops and development of a blasting emissions management plan for a client. During the series of risk workshops 14 risks were identified and nine different risk treatment categories were recognised by the risk assessor team. Clearly not all risk treatment strategies apply to each risk. Table 6 shows the relationship between the individual risks and the risk treatment categories. Such information allows effective and efficient risk treatment programs to be devised by the appropriate team. Time and scope do not permit further elaboration of these aspects.

CONCLUSIONS

Despite the considerable progress made over the last three decades significant challenges to the total elimination of flyrock injuries and fatalities still exist. While risk analysis methods have become more widely available and sophisticated they still suffer from deficiencies. These include: limited input data, uncertainty in natural materials (geology), model risk, stakeholder differences in risk perception and user acceptance. The conclusion of this research is that the flyrock risk can be managed for any blasting situation and the use of both qualitative and quantitative risk management methods are suggested.

Unlike airblast or ground vibration damage, which is sometimes open to interpretation (about the relevance of environmental conditions and existing deformations), flyrock occurrence and damage are clear cut and generally cannot be disputed. For this reason, poor past performance (40 per cent of all blasting accidents in USA between 1978 and 1998) and the fact that flyrock has potentially fatal consequences, flyrock management requires special attention from operators and regulators. It is hoped that this paper has achieved its aim by contributing to the 'state-of-the-art' flyrock management knowledge base.

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TABLE 6

Matrix of individual risks versus risk treatment categories.

Risk ID	Competence	Knowledge	Modelling	QA/QC	Design	Investigation	Procedures	Consultation	Monitoring
BER01	**	*							
BER02	*			*	*	**	*		*
BER03	*						*		*
BER04	*						*		*
BER05	*						*	*	
BER06							*	**	
BER07			*			**		*	*
BER08	*					*	*		*
BER09	*								*
BER10	*	*				[illegible]		*	
BER11	*	*						*	
BER12	*			*					
BER13	*							*	*
BER14	*				*	*			*

Legend		
BER01 – oxide blast skills	BER06 – blast times	BER11 – cavities
BER02 – stemming height	BER07 – flyrock model	BER12 – explosive type
BER03 – secondary blasts	BER08 – charge weight	BER13 – ground vibration
BER04 – blasting dust	BER09 – burden issues	BER14 – presplit flyrock
BER05 – blast clearance	BER10 – geology effects	


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