GOLDER
MEMBER OF WSP

TECHNICAL MEMORANDUM

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TO Shawn Tylee, C.E.T., Manager of Procurement and Corporate Affairs
Rankin Construction Inc.

FROM Daniel Corkery
Sean McFarland

EMAIL **Daniel_Corkery@golder.com**
Sean_McFarland@golder.com

FLYROCK IMPACT ASSESSMENT
PORT COLBORNE QUARRIES INC., PORT COLBORNE QUARRY EXPANSION
PORT COLBORNE, ONTARIO

The Port Colborne Quarries Inc. (PCQ) is proposing to establish an extension to Pit 3 of their existing aggregate quarry in the Port Colborne, Ontario. Blasting is part of the routine operations of a quarry in order to extract the limestone bedrock. Golder Associates Limited (Golder), a Division of WSP, was retained to provide an assessment of the potential effects of the ground and air vibrations that will be produced by the proposed quarry's blasting operations on adjacent receptors such as residences, structures, bedrock strata, water wells and fish spawning depressions. The Blast Impact Assessment (BIA) report, dated July 21, 2020, also reviewed the provincial and federal guidelines for the assessment of environmental impacts from blasting and provided recommendations for blasting design and monitoring.

Members of the Joint Agency Review Team (JART) and the peer review consultant retained by the JART, DST Consulting Engineers Inc. (DST), reviewed the information submitted within the BIA. As part of their peer review, DST attended the quarry site to obtain addition information regarding the proposed extension. On July 28, 2021, the JART provided a comment letter that summarized DST's review and listed a number of items that DST requested. One of the suggested items was to prepare a flyrock range assessment should be prepared as part of the impact assessment. PCQ retained Golder to provide a flyrock range assessment for the proposed extension to Pit 3. This technical memorandum is intended to provide a description of flyrock, its risk potential and PCQ's plan to prevent ejection of flyrock from the Site.

FLYROCK

The movement of rock from a blast is a predictable and necessary component of any blast. The distinction must be made between 'flyrock' being the normal projection of broken rock from a blast and 'wild flyrock', the unplanned and unexpected violent projection of rock fragments at a great velocity from a blast. Wild flyrock can be considered as the ejection of rock fragments through the air or along the ground beyond the blast zone. It occurs when the explosive within the blasthole is either excessive or poorly confined and high-pressure gas propels broken rock fragments. For simplicity, the term flyrock in the remainder of this study will mean wild flyrock. Flyrock generally results from a mismatch between the available energy and the work to be done. This results from either too much energy for a fixed burden (rock mass in front of the explosive charge) or insufficient burden for a fixed charge. The movement of rock from a blast is a predictable and necessary component of that blast. As such, it requires that every blast have an exclusion zone established within which no persons or property which may be harmed are permitted. Numerous researchers have studied the mechanisms by which flyrock occurs, developed models to estimate the maximum range for a given site and blast design and provided suitable safety factors. Published empirical models have been employed to estimate the maximum flyrock for the proposed Quarry.

Causes and Mechanisms

Flyrock is caused by a mismatch of energy released by the detonated explosive and the confining rock mass. The main causes of flyrock in quarry operations are as follows:

- Design faults;
- Deviations from designs; and
- Geological conditions.

Flyrock occurs when explosives in a hole are poorly confined by the stemming or rock mass and the high-pressure gas breaks out of confinement and launches rock fragments into the air. The three (3) main flyrock mechanisms are listed below and shown graphically illustrated in Figure 1:

- Face burst;
- Cratering;
- Rifling.

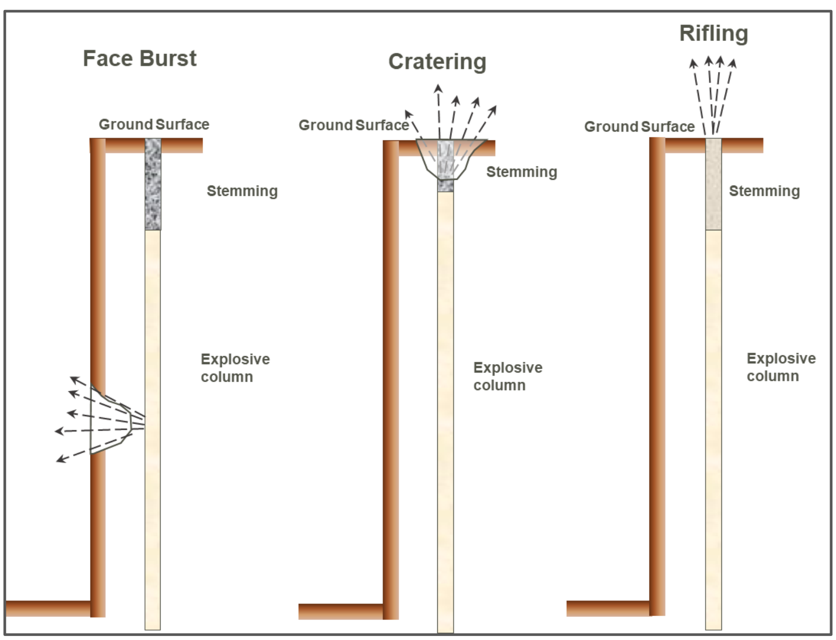

Figure 1: Flyrock Mechanisms

Face burst results from insufficient confinement by the rock mass in front of the blast holes at the face. This can result from the blast design or a zone of geological weakness. Cratering results from insufficient stemming height or weakened collar rock that results in a crater being formed around the hole collar with rock projected from the top of the hole. This can be exacerbated by poor inappropriate blasthole timing. Poor stemming practice can result in a high angle throw of the stemming material and loose rocks from the blasthole wall and collar. This is known as rifling and is most commonly the result of insufficient or poor-quality stemming. For vertical blastholes, the maximum rifling range will be negligible (throw will be primarily vertical or up-down).

Flyrock Range Models

The model for estimating the flyrock range is based the fundamental laws of projectile motion and empirical formulae that relate face velocity to the scaled burden. While standard assumptions for site-specific constants provide initial estimates, the model is ultimately intended to be calibrated for each site (Little, 2007). Richards and Moore (2004) presented a model which is partly based on the fundamental laws of projectile motion coupled with the empirical relationship between face velocity and scaled burden. The procedure for estimating the maximum flyrock range can be summarized as follows:

Face Bursting $R_1 = \frac{k^2}{g}\left(\frac{\sqrt{m}}{B}\right)^{2.6}$

Cratering $R_1 = \frac{k^2}{g}\left(\frac{\sqrt{m}}{SH}\right)^{2.6}$

Rifling $R_1 = \frac{k^2}{g}\left(\frac{\sqrt{m}}{SH}\right)^{2.6} \sin 2\theta_{DH}$

where: V_0 = fragment launch velocity (m/s)

θ_{LA} = launch angle from horizontal

B = burden (m)

SH = stemming height (m)

m = charge weight per m (kg/m)

k = is a constant (13.5 for softer competent rocks and 27 for harder competent rocks (Richards and Moore, 2004))

Given limestones bedrock in the area, we have applied a “k” value of 20. Within this report, we will assume the blastholes are vertical and the maximum rifling range will be approximately zero. Thus, we will consider only the cases of Face Bursting and Cratering.

Once the maximum projection distance has been calculated, an appropriate factor of safety should be applied. MacKenzie (2009) proposed that if the nearby sensitive structure is occupied, then the factor of safety (FOS) of 1.5 should be retained. However, the US Office of Surface Mining (Dick et al., 1989) prohibit throwing flyrock more than one-half the distance to the nearest dwelling or occupied structure, demanding that a minimum FOS of 2 be used in the US. In this report we have used the more conservative FOS of 2.

McKenzie (2009) suggested that the recommended procedure is to use the prediction of the maximum projection range as the basis for determining clearance distance, with an appropriate Factor of Safety applied. Clearly, this estimation must be conducted with full knowledge of the length of stemming and actual charge configurations in every blasthole, and distances adjusted according to the particular charge configuration with the largest estimated projection distance.

FLYROCK RANGE ESTIMATES

The estimates provided within this section are based on the theory presented above and the proposed blast designs presented in Table 1. As noted in above, the range of rifling will be negligible, and we will consider only the cases of Face Bursting and Cratering. As the blasting operations proceed toward the nearest sensitive receptor, it may be necessary to reduce the blasthole diameter to limit the range of flyrock throw. We have assumed an example of 76 mm diameter holes on a 2.4 m x 2.4 m pattern, with total holes depths of up 10.5 m and stemming lengths from 2.1 m to 2.8 m.

Table 1: Estimated Maximum Flyrock Range for a Range of blast Designs for the Proposed Extension to Pit 3

Blasthole Diameter (mm)	Burden [4] (m)	Stemming (m)	Maximum Throw (m) [1]		Minimum [2) 3)] Separation (m)
			Face Burst	Cratering	
102	2.4 [5)]	1.5 [5)]	78	276	552
102	3.3 [6)]	1.7 [6)]	36	199	399
102	3.3	2.0	36	131	262
102	3.3	2.3	36	91	182
102	3.3	2.5	36	73	146
76	2.4	2.3	38	42	85
76	2.4	2.5	38	34	68
76	2.4	2.8	38	25	50

1) *Horizontal throw.*
2) *Minimum separation distance between the blast and the nearest residence assuming a FOS of 2.0*
3) *Assuming retreat toward to residences and face burst away from the residences.*
4) *Front row burden*
5) *Currently design for Brown Bench (Quarry Name).*
6) *Currently design for Gray Bench (Quarry Name).*

The analysis indicates that the initially proposed blast would have a maximum horizontal flyrock range of 199 - 276 m from bench top of the Brown and Gray Bench, respectively. Cratering is predicted to be the dominant mechanism for the development of flyrock for the blast designs considered.

Through proper blast design and diligence in inspecting the geology before every blast, flyrock can be maintained within the proposed quarry extraction limits. As shown in Table 1, it may be necessary to reduce the blasthole diameter and increase the stemming lengths when blasting along the perimeter. The operational plan for the quarry has been designed to retreat towards the closest receptors thereby projecting flyrock and overpressures away from the receptors.

MITIGATION

Appropriate blast design, diligent quality control and training of drill and blast personnel are the main means to mitigate flyrock from leaving the site. These are summarized as follows:

- Blast design should be routinely reviewed as the blasts retreat toward sensitive receptors. Design modifications should be based on the separation distance to the receptors as well as observations made. Flyrock can be mitigated by one or combination of the following design modifications:
  - Increase the stemming length.
  - Reduce the borehole diameter with a corresponding reduction in the drill pattern parameters.
  - Reduce the loading density in the upper portion of the hole, commonly achieved via a satellite charge.
- Strict on-going quality control will prevent unnecessary deviation. Deviations must be approved with consideration for flyrock control.
- Training of drill & blast team to recognize the and report geological irregularities. Detailed drill logs and diligence in inspecting the geology before every blast allow for the identification of any potentially problematic zones within the rock mass.

The maximum projection distance of flyrock fragments depends on blast design parameters as well as fragment size, rock density, and fragment shape factor. These parameters are all included in this flyrock assessment. The model used provides realistic clearance distances for known charge configurations and provides the ability to adjust charging configurations to suit situations where sensitive receivers such as houses at fixed distances must be protected against flyrock damage.

Flyrock Control at the Proposed Extension to Pit 3

PCQ is committed to preventing flyrock from leaving the site and the following measures will be taken to ensure that commitment:

- Assessment of proposed blast design(s) for flyrock potential using industry standard flyrock model will be conducted
  - Prior to commencement of blasting.
  - Following required future modifications of the blast design.
- Orientation of blast to direct flyrock away from residences
- Training of drilling and blasting crew(s) to ensure the understanding of the PCQ's approach to flyrock prevention.

- Quality control of drilling and blasting operation
  - Prior to loading any shot, blast designs shall be reviewed and approved by an engineer with experience in quarries and blasting.
  - Drilling accuracy and deviation will be monitored. The use of face mapping tools (e.g., laser contouring) is suggested to ensure that face burdens are controlled.
  - The use of high-speed video is suggested to enable estimation of the fragment launch velocity which is helpful in the refinement of flyrock models (i.e., bench top and bench face).
  - Detailed drill logging program will be designed. Anomalies indicating potential problematic zones will be recorded and communicated to the blasting supervisor so that measures can be taken to prevent the potential impact of those zones.
  - The blast site will be reviewed to ensure compliance with design.
  - All blasts will be videoed and reviewed to ensure blast performance quality.
- Periodic third-party audits, carried out twice per year, to compliment continuous quality control.

SUMMARY

Wild flyrock are rocks propelled beyond the blast zone by the force of the blast. It occurs when the state of confinement of an explosive change is insufficient for the applied evacuation radius. The resulting excess energy may cause a projection of rock fragments beyond the clearance radius. The main causes of flyrock in quarry operations are a) design faults, b) deviations from blast designs, and c) a zone of geological weakness.

Government regulations strictly prohibit the ejection of flyrock off of a quarry property. The regulations regarding flyrock are enforced by the Ministries of Natural Resources, Environment and Labour. In the event that flyrock does leave a site, the punitive measures include suspension / revocation of licences and fines to both the blaster and quarry owner / operator. Fortunately, flyrock incidents are extremely rare due to the possible serious consequences of such an event. It is in the best interest of all to ensure that dangerous flyrock does not occur, including stakeholders and non-stakeholders.

Through proper blast design and planning, diligence in inspecting the geology before every blast, quality control, appropriate training and periodic audits flyrock can and will be readily maintained within the quarry limits. It may be necessary to increase collars when blasting along the perimeter. The operational plan for the quarry has been designed to retreat towards the closest receptors thereby projecting flyrock away from the receptors.

CLOSURE

We trust that this technical memorandum meets your current requirements. If you require any additional details or information, please do not hesitate to contact the undersigned.

Golder Associates Ltd.

Daniel Corkery
Associate, Senior Blasting Consultant

Sean McFarland, PhD., PGeo.
Principal

DC/SM/jl

https://golderassociates-my.sharepoint.com/personal/jrlee_golder_com/documents/desktop/projects/temp files -1/21457143/21457143 final rtm pcq flyrock assessment 2022january07.docx

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