# Appendix A.5.5.1

## Blast Feasibility and Exclusion Requirements Note

# File Note

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| Subject | Analysis of Blasting Feasibility and Exclusion Requirements | | |

# 1 Introduction

An assessment was conducted to determine the feasibility of blasting adjacent to sensitive receptors along the proposed N6 Galway City Ring Road. The assessment was conducted by analysing the estimated blast-induced ground vibrations and subsequent exclusion zones based on blasting activities in both the Granite and Limestone bedrock.

The assumptions used and subsequent design are based on best practice and available literature. This note and the results presented herein does not limit or remove the contractor's responsibility to demonstrate the effect or impacts of their proposed blasting activities. While best practice requires conducting trial blasts in the area, these have not been completed to date and will be required by the contractor in order to verify site blast design parameters. It should be noted that the blast exclusions zones presented in this note may change once site specific blast information is obtained and following a specialist review and design by the blasting contractor.

# 2 Target Blast-Induced Ground Vibration Limit

A Peak Particle Velocity (PPV) of 12 mm/s is deemed allowable at the closest part of any sensitive receptor at a frequency range between 10 to 50 Hz. This is based on the following sources:

- **EPA Guidance Environmental Management in the extraction industry (2006)**

  **Section 3.5.2 – *Ground-borne vibration*:** Peak particle velocity = 12 mm/s, measured in any of the three mutually orthogonal directions at the receiving sensitive receptor (for vibration with a frequency of less than 40 Hz)

- **NRA (TII) Guidelines for the treatment of Noise and Vibration in National Road Schemes (2004)**

  There is no published Irish guidance relating to vibration during construction activities. Prior to this, common practice in Ireland has been to use guidance from internationally recognised standards. Vales were subsequently derived through consideration of the following standards,

- BS 7385 (1993): Evaluation and measurement for vibration in buildings Part 2: Guide to damage levels from ground-borne vibration.
- German Standard DIN 4150-3 Structural Vibration – Effects of Vibration on Structures

The Authority recommends that vibration from road construction activities be limited to the values set out in **Table 1**.

**Table 1: Allowable vibration during road construction in order to minimise the risk of building damage**

| Allowable vibration velocity (Peak Particle Velocity) at the closest part of any sensitive property[1] to the source of vibration, at a frequency of | | |
|---|---|---|
| Less than 10Hz | 10 to 50Hz | 50 to 100Hz (and above) |
| 8 mm/s | 12.5 mm/s | 20 mm/s |

# 3 Methodology

The following section outlines the various elements associated with the assessment. These are as follows:

1. **Global Assumptions and Parameters** – A description of some of the assumptions and parameters selected during the assessment process.
2. **Conventional Exponent Model** – The conventional exponent model consists of a rock exponent and a site exponent, which are deemed to categorise the test site for the evaluation of associated blast-induced vibrations.
3. **Empirical Rock Model** – This is an alternative method which relies upon site specific rock data to evaluate the blast-induced vibrations.
4. **Comparison of Models** – A comparison of the two models to delineate the appropriate exclusion zones and feasibility of blasting.

## 3.1 Global Assumptions and Parameters

In order to calculate the estimate ground vibrations, certain assumptions were required. These assumptions were developed based on best practice and adopted a conservative yet realistic approach. The design input value is indicated in the parameter title.

- **Powder Factor (PF = 0.45 kg/m$^3$)**

  The powder factor is a measure of the explosives required to break a cubic meter of rock, or in other words, the higher the value the higher the difficulty in breaking the rock. Ranges are provided in literature, and a medium difficulty was selected.

[1] While no specific definition of the term sensitive property has been provided, BS7385 provides values related to critical buildings, which are defined as premises with machinery that is highly sensitive to vibration or historic buildings that may be in poor repair, including residential properties.

One reference[2] provided a relationship between general rock type and corresponding powder factor (see **Table 2**).

**Table 2: Guide to powder factors for various rock types (Mining and Blasting, 2009)**

| General Category | Rock Type | Powder Factor (kg/m$^3$) |
|---|---|---|
| Hard Rock | Andersite / Dolerite / Granite | 0.7 |
| Medium Rock | Dolomite / Quartzite / Schist | 0.45 |
| Soft Rock | Sandstone / Limestone / Shale | 0.3 |
| Very Soft | Coal | 0.15 – 0.25 |

The Granite did not display very high strength characteristics, with UCS values ranging from 23 to 128 MPa, while the Limestone displayed similar strengths, with UCS values ranging from 17 to 100 MPa.

Correlations between UCS and a powder factor are provided in **Table 3**.

**Table 3: Classification of the uniaxial compressive strength of rocks (Dyno Nobel, 2010 and Schmidt, 1951)**

| Rock Type | UCS (MPa) | Powder Factor (kg/m$^3$) |
|---|---|---|
| Very Low Strength | 1 - 5 | 0.15 – 0.25 |
| Low Strength | 5 - 25 | 0.25 – 0.35 |
| Medium Strength | 25 - 30 | 0.4 – 0.5 |
| High Strength | 50 - 100 | 0.7 – 0.8 |
| Very High Strength | 100 - 250 | |
| Extremely High Strength | > 250 | |

The PF value does not directly impact the vibration limits but rather the quantity of blasting required. In order to reduce the risk of horizontal flyrock, generating from the burden face, the powder factor selected is 0.45 kg/m$^3$.

- **Explosive Density ($\rho_e$ = 1.25 g/cm$^3$)**

  For the purpose of this assessment, bulk emulsion explosives were selected. Emulsion explosives have a very good resistance to water and a low generation of toxic fumes in comparison to the more prevalent blasting agent, ANFO (ammonium nitrate/fuel oil mixture).

- **Burden / Stiffness Ratio (circa 1.8)**

  Various geometrical ratios are required in order to conduct a blast design. These are not discussed in this note. However, the resulting[3] estimated fragmentation of the rock is a function of these

[2] https://miningandblasting.files.wordpress.com/2009/09/blasting-in-surface-excavation.pdf
[3] Note that the Burden / Stiffness Ratio is not selected by the designer. It is a product of the design inputs. The inputs such as burden, spacing or charge can be altered to reflect a desired ratio.

ratios used, the type of rock and the quantity of explosives used. Generally[4], the higher the fragmentation, the more explosives used and therefore the higher the estimated ground vibrations.

The burden/stiffness ratio is a measure of the estimated fragmentation of the rock. Between 2.0 to 3.5 is indicated to be good fragmentation while over 3.5 is indicated to be very good.

- **Rock Bench Height (BH – varied)**

  The height of the rock bench has a significant impact on the estimated ground vibrations due to the nature of the design. All of the blasthole, minus the stem requirement, is assumed to be filled with explosive. Therefore an increase in the length results in an increase in the explosives, and an increase in the weight of explosives per delay has a direct correlation with an increase in the estimated ground vibrations. An increase in rock bench will reduce the number of blasts required, increase the volume of rock breakage per blast and therefore ultimately reduce the blasting construction period. Rock bench height can have a significant effect on both construction time but also ground vibrations.

## 3.2 Conventional Exponent Model

The relationship between PPV and distance can be written as,

(Eq. 1)

$$v = K\left(\frac{d}{\sqrt{Q}}\right)^{-b}$$

where *v* is PPV (mm/s); *d* is the distance to a sensitive receptor or distance from a charge point (m); *Q* is the charge mass (kg); and both *K* and *b* are site and rock exponents respectively.

Site and rock exponents are determined by blast experiments and trial blasts, however these have not been completed yet. It is noted in a number of references that exponents should not be generalised for use for other sites. However, some reference works give ranges of values which can be applied based on site conditions.

**Table 4: Typical values of site and rock exponents according to Richards, Moore (1995)**

| **Site Exponent (*K*)** | | **Rock Exponent (*b*)** | |
|---|---|---|---|
| 500 | Free Face – Hard Rock | 2.1 – 2.4 | Granite |
| 1140 | Free Face – Average to Soft Rock | 2.1 | Limestone |
| 5000 | Heavily Confined Site | 1.9 – 3.0 | Basalt |

The site constant, *K*, is associated with the confinement conditions of the site. The higher the value, the more confined the site is in terms of adjacent receptors. The highest value (5000) was selected, thus representing a highly restricted and confined site. The use of a higher *K* value effectively means that a higher ground vibration is expected at a shorter distance from the blast zone. It's worth noting that a *K* value of 5000 is often applied for shaft mining or shaft sinking, and is therefore considered to be a conservative approach.

The rock exponent, *b*, is associated with the rock type. Typically, the higher the value, the stronger the rock type. The significance of a high rock exponent is that the ground vibration drops off more

[4] However this is not always the case, high hole density can also provide the same effect with the same explosive charge per hole.

rapidly and lower vibration levels result at distance. Various researches by the US Bureau of Mines quote decay exponents ranging from 1.4 to 2.1, depending on the type of material and distance from the blast.

While Limestone is typically 2.1, data available from a nearby quarry was used in the assessment, resulting in a rock exponent of 1.95. For granite the lower and upperbound ranges of 2.1 and 2.4 are assessed. For the purpose of evaluation, exponents of 1.95, 2.1 and 2.4 have all been plotted in Chart 1.

Equation 1, above, was altered to evaluate the minimum distance required from the charge point to produce a PPV of 12mm/s or less. The corresponding equation can be written as,

(Eq. 2) $$d = \left[\sqrt{Q}^{-b}\left(\frac{v}{K}\right)\right]^{-\frac{1}{b}}$$

Equation 2 was utilised to determine the minimum distance required, depending on the size of the bench, in order to achieve a PPV of 12mm/s or less. As mentioned previously, the charge mass has been conservatively assumed to increase with an increase in bench and therefore it is assumed that the minimum distance will increase with an increase in bench height.

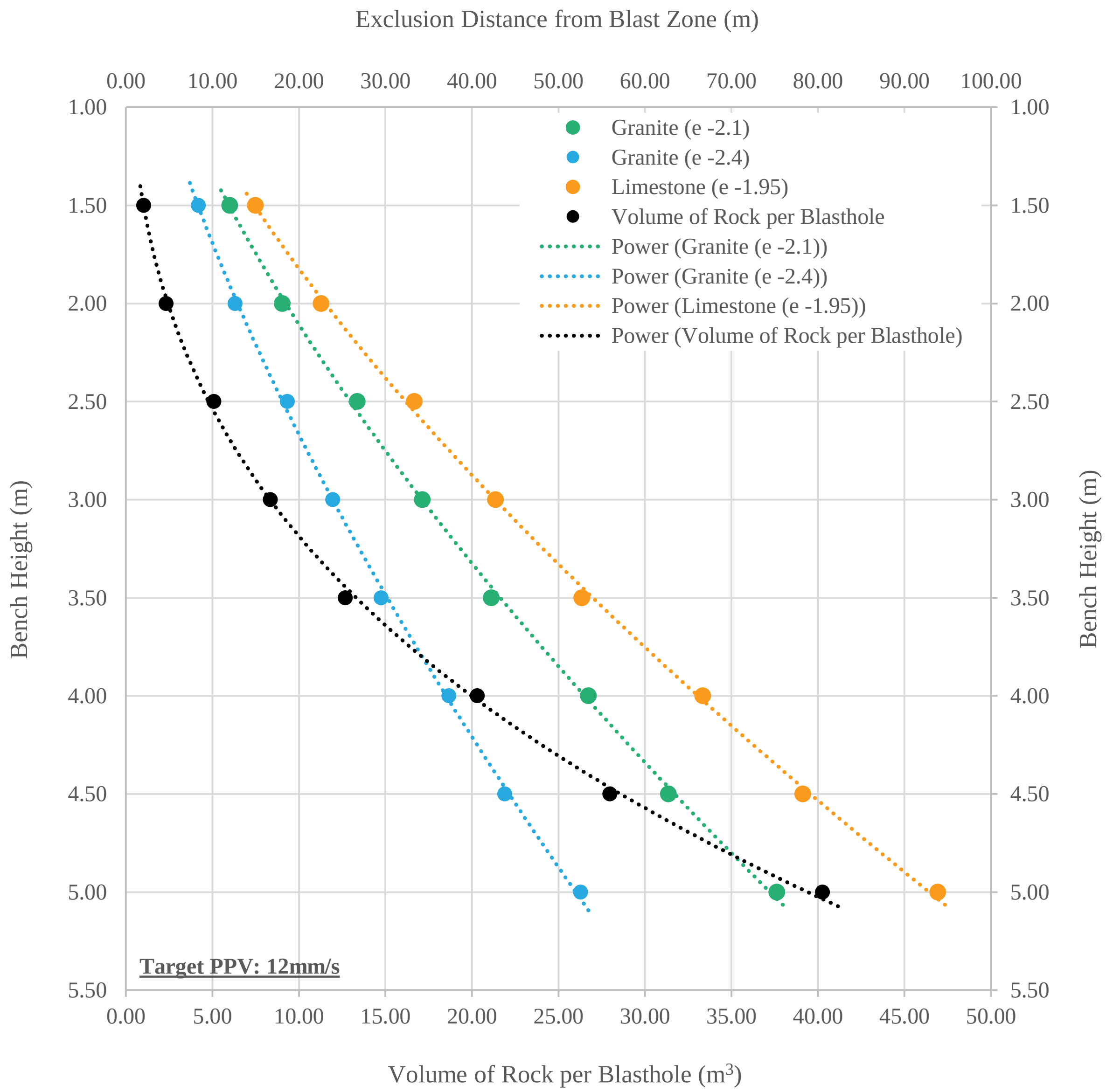


**Chart 1: Conventional Exponent Model – Plot of Exclusion Distance vs Bench Height**

## 3.3 Empirical Rock Model

The following section describes an alternative method for evaluating blast-induced vibrations based on rock specific data. The section includes the following:

- **Empirical Rock Model Formula** – Description of the formula and background to the empirical rock model
- **Evaluation of Constants** – Assessment of rock specific constants and comparison with weighted average constants
- **Summary** – Summation of the constants selected based on the assessment and the corresponding blast exclusion zones required

### 3.3.1 Empirical Rock Model Formula

Various researchers have studied and developed empirical equations for PPV in relation to rock characteristics. Kumar, Choudhury, & Bhargava (2015) developed a model which incorporates various engineering rock parameters such as unit weight and unconfined compressive strength (UCS). The model is based on a total of 1089 published field blast data by 13 different researchers for various rock types. The model equation can be written as,

(Eq. 3) $$v = \frac{{f_c}^c D^b}{\gamma}$$

where *v* is PPV (mm/s); *D* is the scaled distance (m/√kg) which is defined as the ratio of distance, *d*, from a charge point, *Q* (m), to the square root of charge mass (kg); *fc* is the unconfined compressive strength, UCS, of the rock (MPa); γ is the unit weight of the rock (kN/m$^3$); and both *b* and *c* are constant which relate to the rock type characteristics.

The above equation was altered to evaluate the minimum distance required from the charge point to produce a PPV of 12mm/s or less. The corresponding equation can be written as,

(Eq. 4) $$d = \left[\sqrt{Q}^{-b}\left(\frac{v.\gamma}{{f_c}^c}\right)\right]^{-\frac{1}{b}}$$

Kumar, Choudhury, & Bhargava (2015) provide a table which summaries the constants developed according to field blast data from 24 researchers. The rock type and any specific engineering rock parameters are also recorded. A weighted average was determined, producing a *b* of 1.463 and *c* of 0.642.

### 3.3.2 Evaluation of Constants for the Empirical Rock Model

It is evident that the constants used in Eq. 4 may have a significant effect on the final results. Therefore an assessment was conducted of the how the weighted average values used compared against similar empirical rock models.

Kumar, Choudhury, & Bhargava (2015) presented a table which summaried the constant developed for the 24 researchers. The rock type and engineering properties were also provided, allowing a more specific assessment in relation to rock type.

#### 3.3.2.1 Granite

The project specific engineering rock parameters are provided in **Table 6** have been selected from the available ground investigation data along the prosed road development.

**Table 6: Granite Engineering Properties**

| Rock Type | Unit Weight, γ (kN/m$^3$) | Max RQD (%) | Median RQD (%) | Max UCS (MPa) | Median UCS (MPa) |
|---|---|---|---|---|---|
| Granite | 25.6 | 100 | 93 | 128.0 | 55.9 |

The researchers which conducted blast assessment in Granite or similar rock types are summarised in **Table 7**.

**Table 7: Summary of Researchers as presented in Kumar, Choudhury, & Bhargava (2015)**

| Researchers | Rock Type | *c* | *b* |
|---|---|---|---|
| Nicholls et al. (1971) | Diorite | 0.597 | 1.425 |
| Adetoyinbo et al. (2010) | Gneiss | 0.716 | 1.507 |
| Nicholls et al. (1971) | Granite | 0.406 | 1.155 |
| Ak et al. (2009) | Schist | 0.496 | 1.285 |
| Nicholls et al. (1971) | Schist | 0.604 | 1.425 |
| Kahriman et al. (2006) | Schist | 0.74 | 1.62 |
| Kumar, Choudhury, & Bhargava (2015) | Weighted Average | 0.642 | 1.463 |

Using Eq. 4, the various constants were plotted against each other and ultimately compared against the weighted average constants provided by Kumar, Choudhury, & Bhargava (2015). The results are presented in **Chart 2**. Conservatively, the max unconfined compressive strength of the rock was applied.

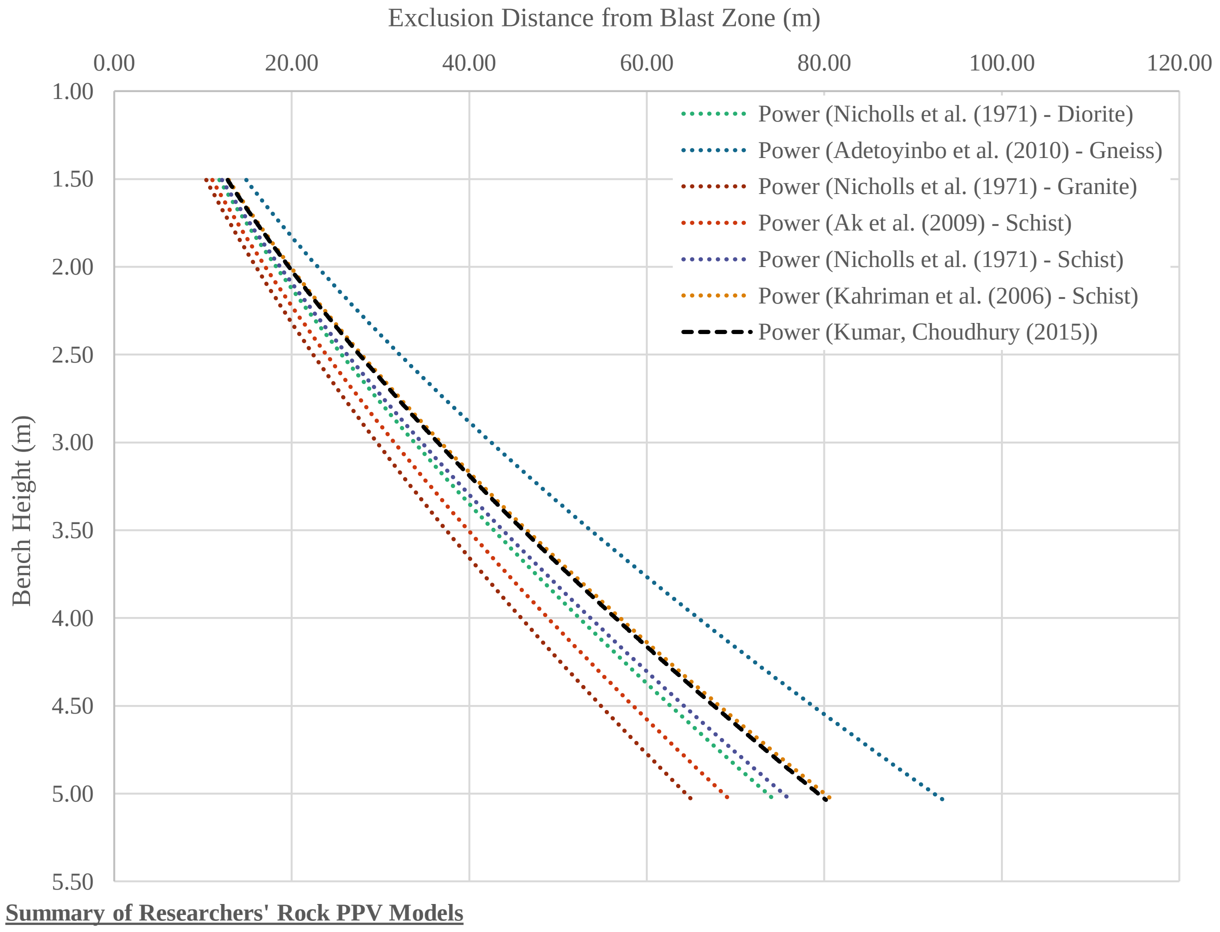


**Chart 2: Comparison of Weighted Average Constants against Granite Specific Constants**

It can be seen that the weighted average constants provided by Kumar, Choudhury, & Bhargava (2015) compare well with granite or similar rock constants. Generally, the weighted average constants produce the most conservative exclusion distance (with the expection of Adetoyinbo (2010) in Gneiss and Kahriman et al (2006) in Schist). It is proposed to use Kahriman et al. (2006) for the empricial rock model in Granite.

#### 3.3.2.2 Limestone

The project specific engineering rock parameters are provided in **Table 8** have been selected from the available ground investigation data along the prosed road development.

**Table 8: Granite Engineering Properties**

| Rock Type | Unit Weight, γ ($kN/m^3$) | Max RQD (%) | Median RQD (%) | Max UCS (MPa) | Median UCS (MPa) |
|---|---|---|---|---|---|
| Limestone | 26.1 | 100 | 85 | 98.8 | 51.3 |

The researchers which conducted blast assessment in Granite or similar rock types are summarised in **Table 9**.

**Table 9: Summary of Researchers as presented in Kumar, Choudhury, & Bhargava (2015)**

| Researchers | Rock Type | c | b |
|---|---|---|---|
| Nicholls et al. (1971) | Dolomite | 0.563 | 1.35 |
| Ozer (2008) | Limestone | 0.606 | 1.388 |
| Mesec et al. (2010) | Limestone | 0.61 | 1.382 |
| Kahriman (2004) | Limestone | 0.695 | 1.698 |
| Nicholls et al. (1971) | Limestone | 0.826 | 1.682 |
| Nicholson (2005) | Limestone | 1.136 | 2.054 |
| Ataei (2010) | Limestone | 1.157 | 2.348 |
| Abdel-Rasoul (2000) | Limestone | 1.346 | 2.565 |
| Kumar, Choudhury, & Bhargava (2015) | Weighted Average | 0.642 | 1.463 |

The results are presented in **Chart 3**. Conservatively, the max unconfined compressive strength of the rock was applied.

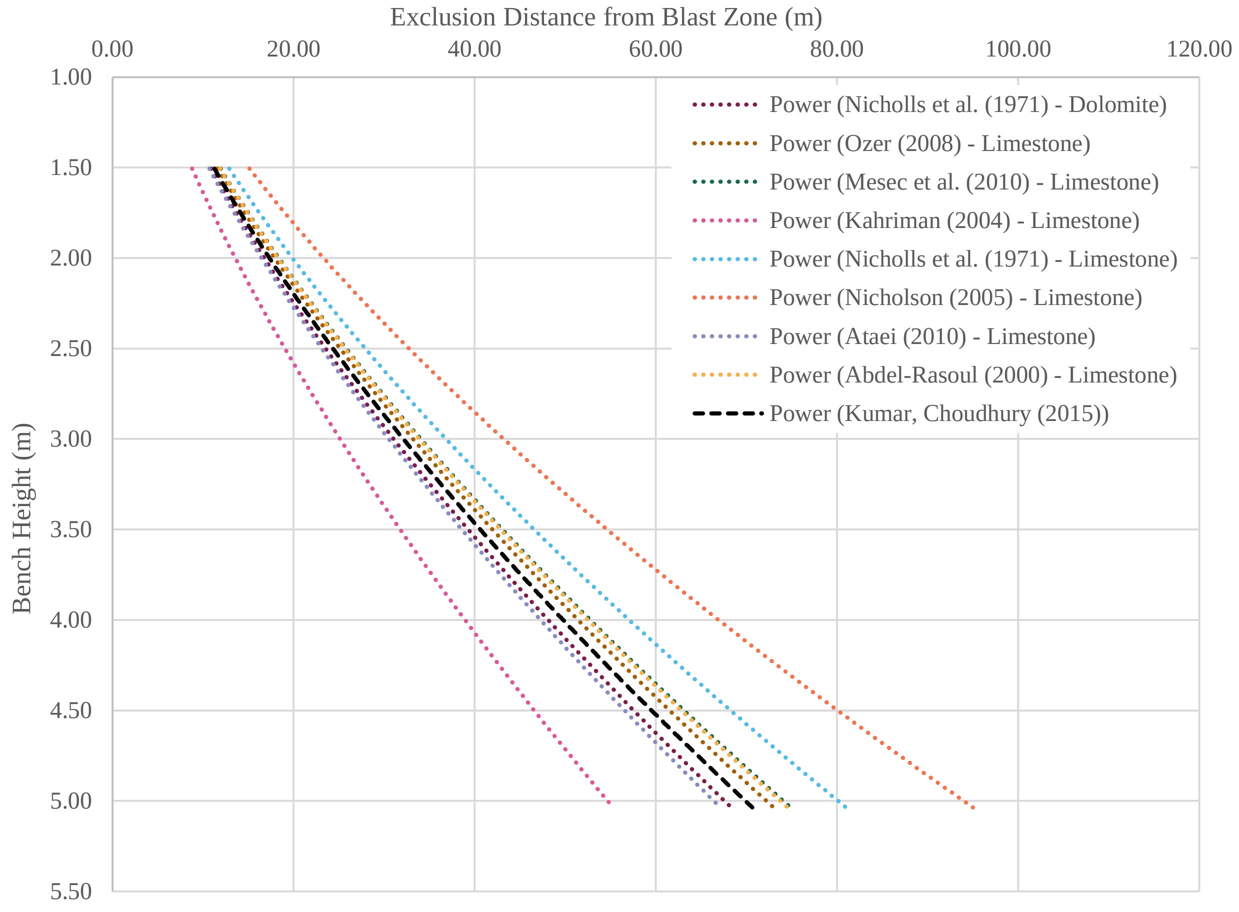


**Chart 3: Comparison of Weighted Average Constants against Limestone Specific Constants**

It can be seen that the weighted average constants provided by Kumar, Choudhury, & Bhargava (2015) are slightly below average when compared with Limestone rock constants. The most onerous plot is produced by Nicholson (2005), who undertook an assessment of the Office of Surface Mines (OSM) standard with blast field data at Bengal Quarry, Jamaica.

### 3.3.3 Summary

After an evaluation of the available data, conservative constants were selected for comparison with the conventional exponent model in Section 3.4. These are presented in Table 10, along with the associated researcher.

**Table 10: Selected Constants for Empirical Rock Model**

| Rock Type | Researcher | c | b |
|---|---|---|---|
| Granite | Kahriman et al. (2006) – Schist – Open pit mine in Turkey | 0.74 | -1.62 |
| Limestone | Nicholson (2005) – Limestone – Blast field data at quarry in Jamaica | 1.136 | -2.054 |

Using the constants presented in Table 10, the minimum distance required for a PPV of 12mm/s was evaluated for each rock type and is presented in Table 11.

**Table 11: Minimum Distance for PPV of 12 mm/s or less**

| Bench | | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum Distance (m)** | Granite | 10.63 | 16.02 | 23.70 | 30.36 | 37.45 | 47.38 | 55.61 | 66.71 |
| | Limestone | 12.49 | 18.82 | 27.83 | 35.66 | 43.98 | 55.64 | 65.30 | 78.35 |

The results of Table 11 have been plotted in **Chart 4**.

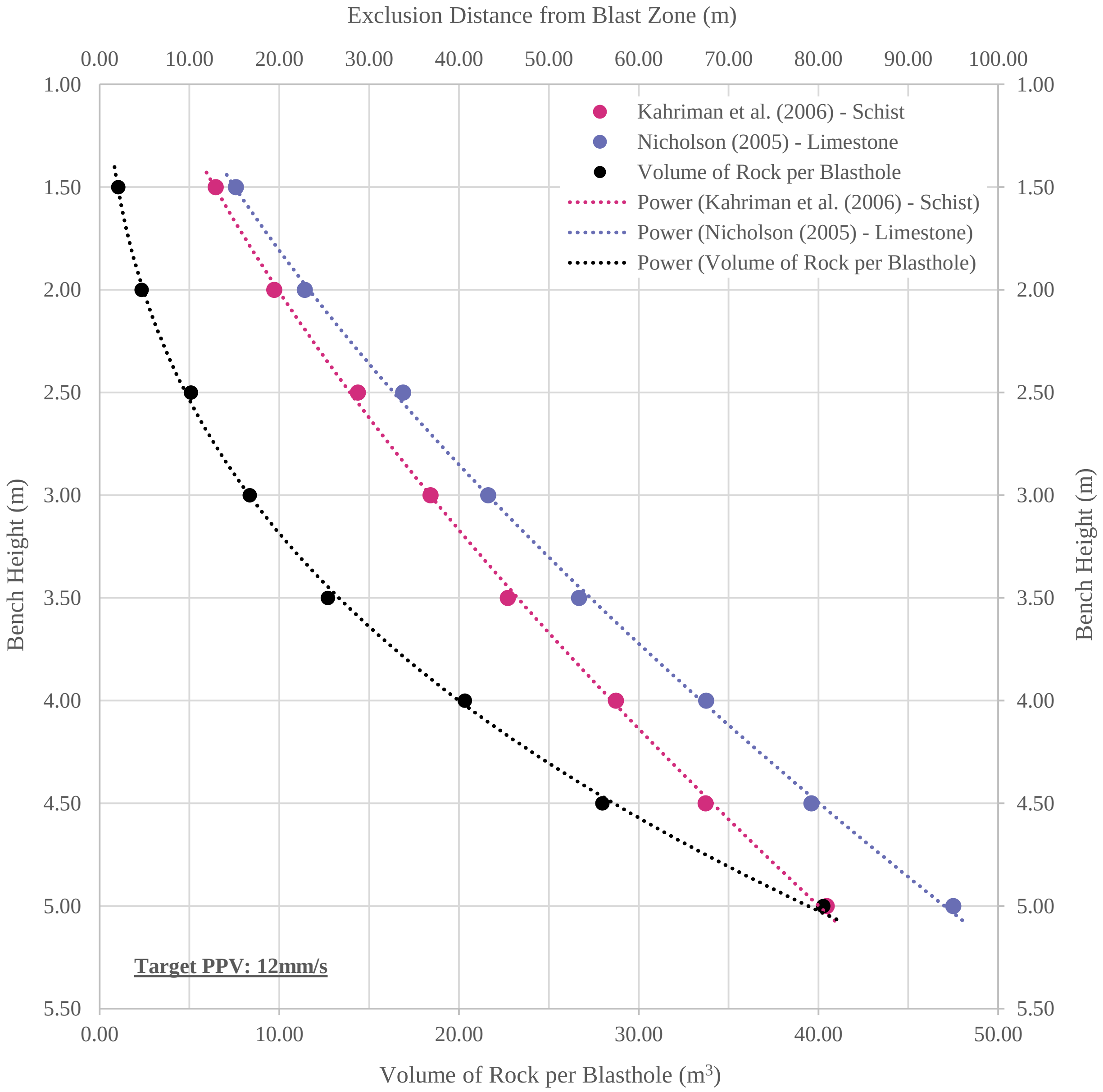


**Chart 4: Empirical Rock Model – Plot of Exclusion Distance vs Bench Height**

Results confirm expectation that the Limestone requires a large exclusion zone, as typical it is not as hard/strong as the Granite rock.

## 3.4 Comparison of Models

In order to establish a reasonable understanding of blast feasibility and the associated blast exclusion zones, a comparison was conducted of the conventional exponent model against the empirical rock model.

### 3.4.1 Granite

A comparison of the two models considered for the granite is presented in **Chart 5**.

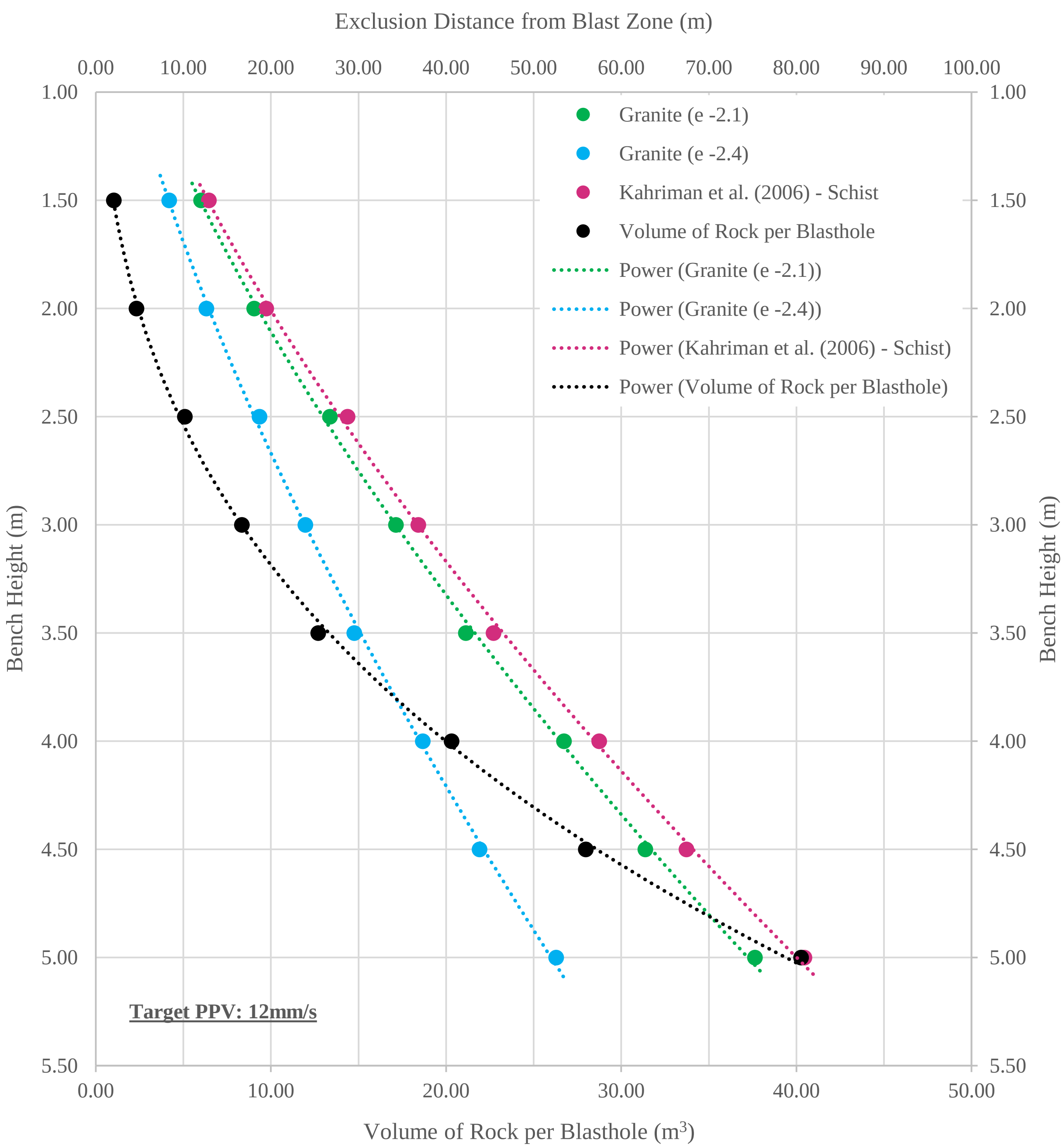


**Chart 5: Granite – Comparison of Conventional Exponent Model with Empirical Rock Model**

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It's deemed from a comparison of the two models that the Empirical Rock Model is the more conservative.

### 3.4.2 Limestone

A comparison of the two models considered for the granite is presented in **Chart 6**.

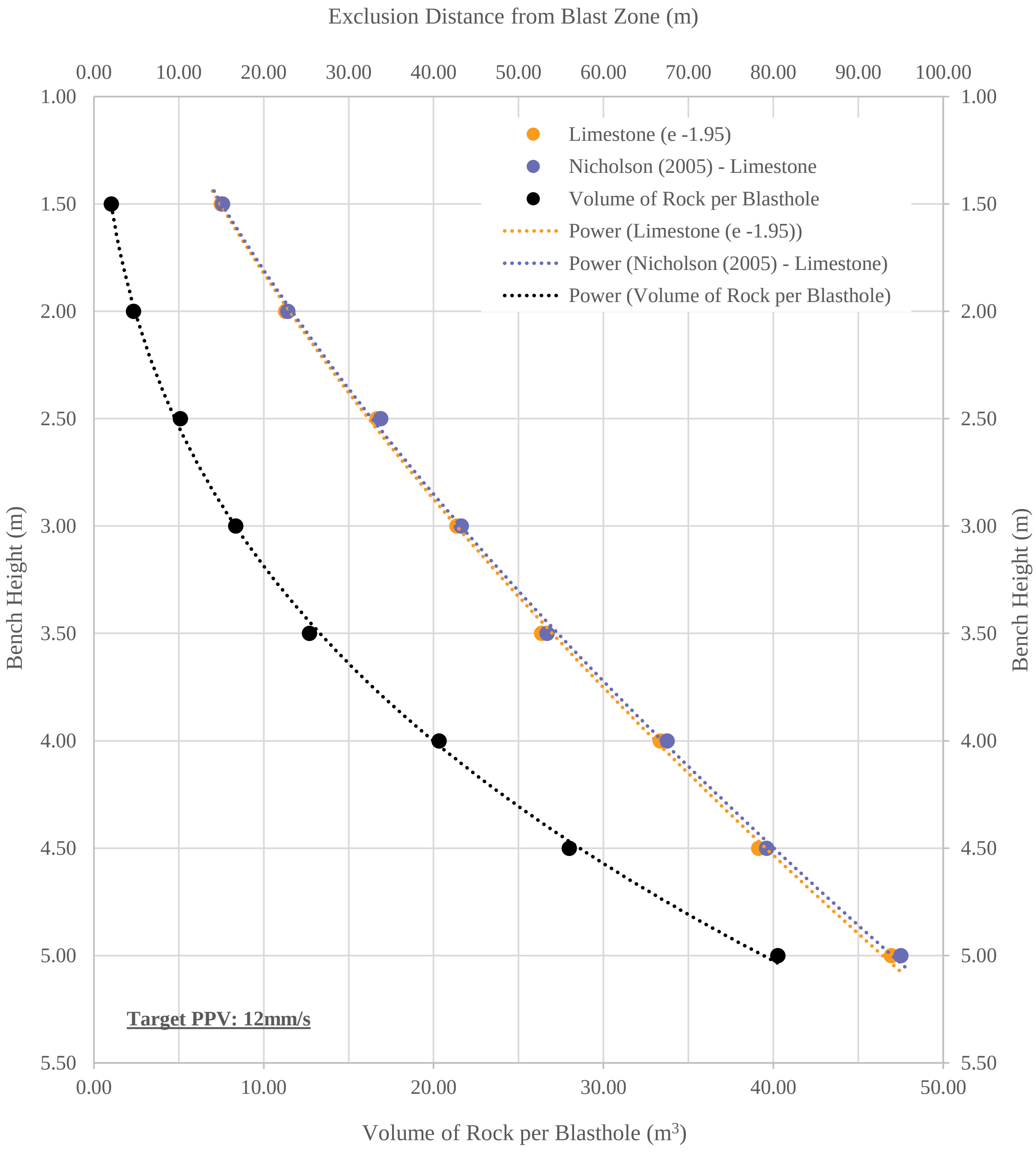


**Chart 6: Limestone – Comparison of Conventional Exponent Model with Empirical Rock Model**

It's deemed from a comparison of the two models that they are practically identical.

# 4 Summary

The information presented in this note has provided background to analysing for blast-induced vibrations, the models available for the assessment and the associated exclusion zones for various blast bench sizes. The information presented in summarised in Section 4.1. It should be noted that the blast exclusions zones presented in this note may change once site specific blast information is obtained and following a specialist review and design by the blasting contractor.

## 4.1 Blast Feasibility

The following charts indicate the blasting feasibility for various bench height.

### 4.1.1 Granite

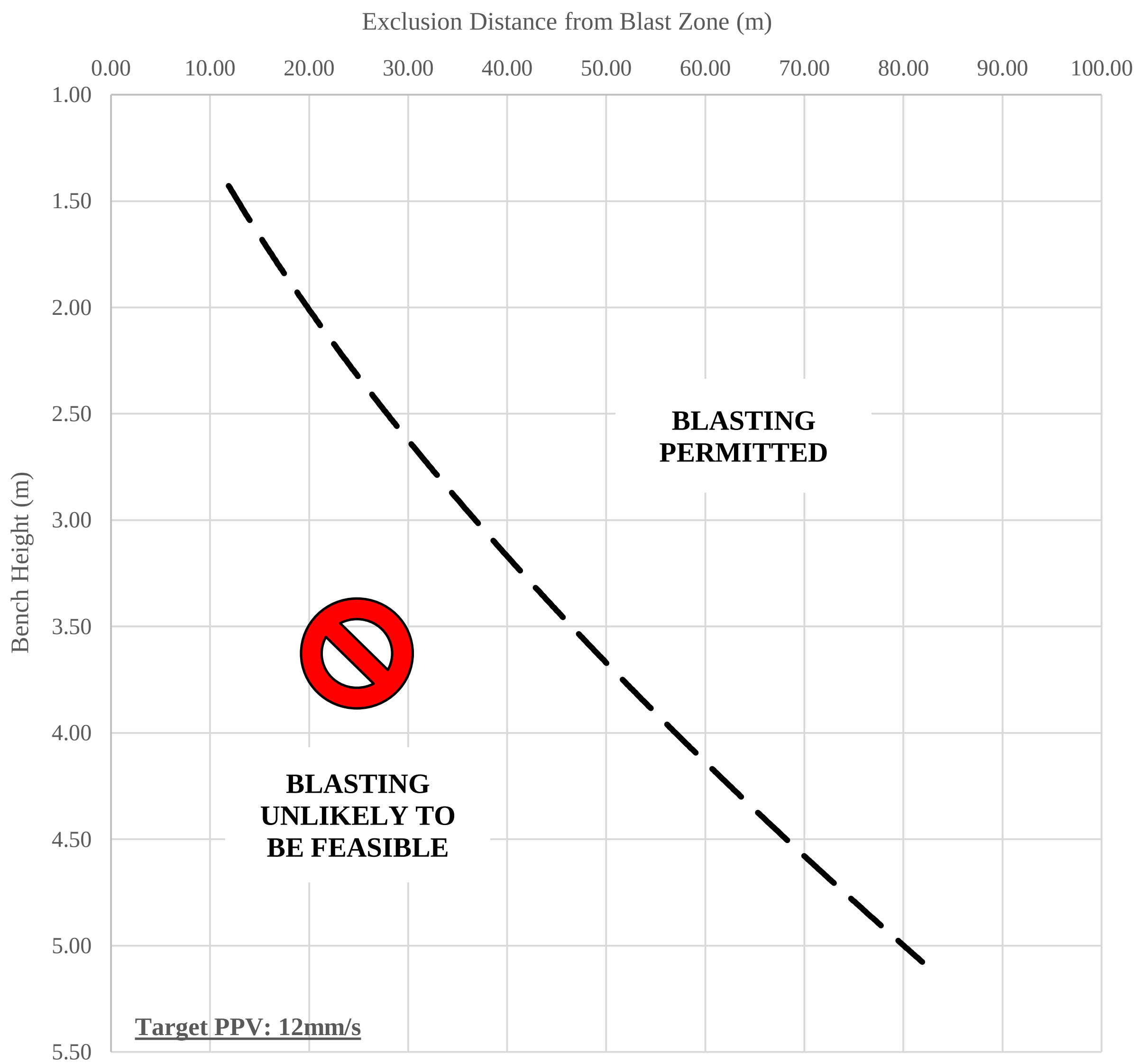


**Chart 7: Granite – Blasting Feasibility for different Bench Heights**

### 4.1.2 Limestone

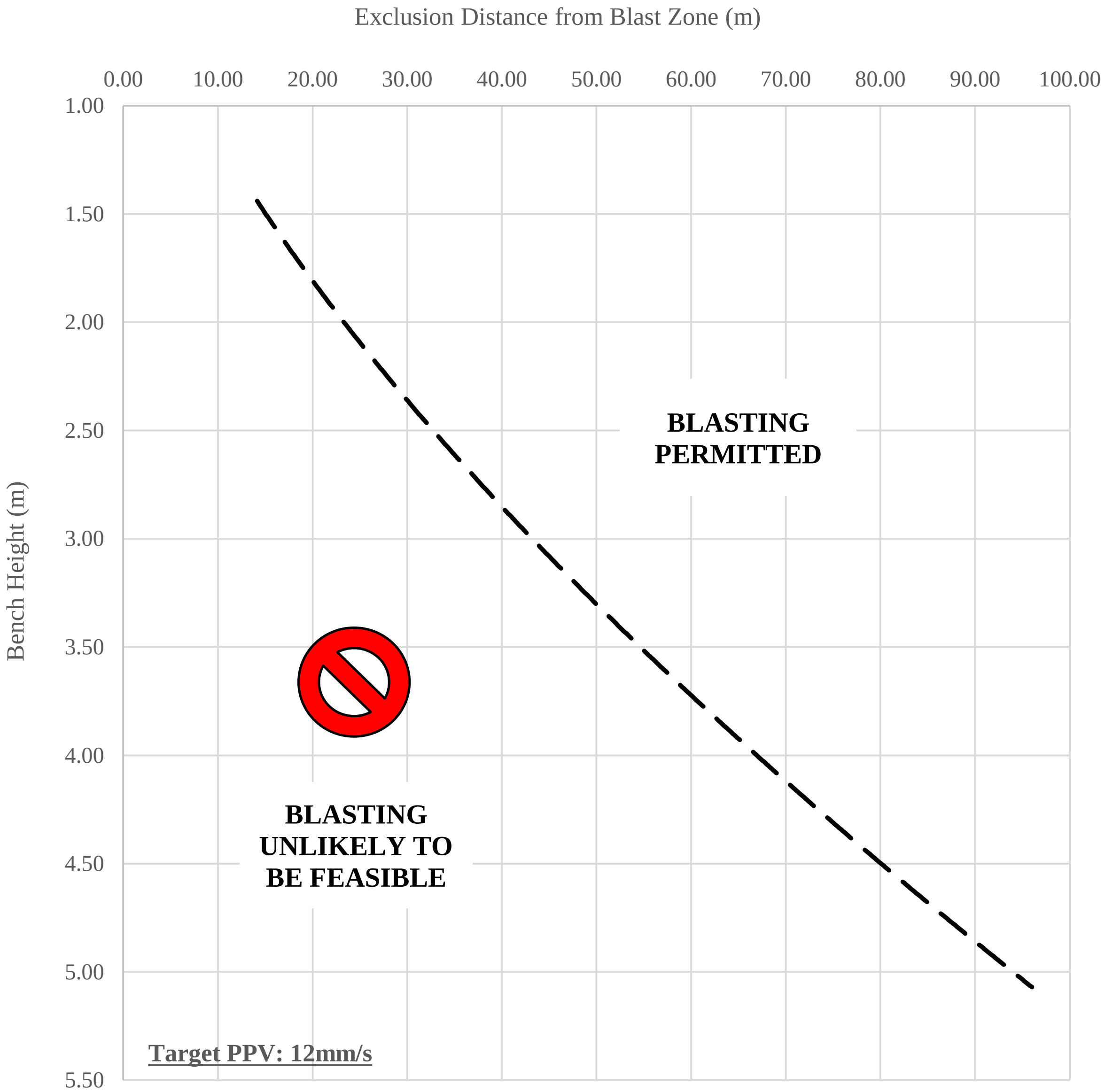


**Chart 8: Limestone – Blasting Feasibility for different Bench Heights**

### 4.1.3 Alternative Measures

In situations where blasting is not feasible, other method will have to be utilised. Some options are discussed below. Note that a cost comparison has not been conducted. However, experience indicates that the following methods are substantially more in terms of cost, when production and programme is considered.

#### 4.1.3.1 Hydraulic Breakers

Hydraulic breakers may be used in areas where blasting is not permitted. It should be noted that while the use of rock/hydraulic breakers does reduce peak particle velocities, it does not eliminate ground vibrations.

As per Chapter 17 Noise and Vibration of the EIS for the proposed road development, AWN Consulting conducted vibration measurements under controlled conditions, during trial construction works, on a site where concrete slab breaking was carried out using hydraulic breakers. Peak vibration levels using a 3 tonne breaker ranged from 0.25 to 0.48 PPV (mm/s) at distances of 10 to 50m respectively while measurements using a 6 tonne breaker ranged from 0.24 to 1.49 PPV (mm/s) at distances of 10 to 50m respectively.

Due to the strength of the rock, it’s likely that a 30 tonne to 50 tonne rock breaker will be required.

#### 4.1.3.2 Hydraulic Splitting

This is a device consisting of a hydraulic cylinder attached to a set of feathers and wedge and a control mechanism. The feather and wedge arrangement is inserted into a drilled hole and as the hydraulic cylinder is activated, it is forcing the wedge between the feathers to generate a lateral force that breaks the rock.

Power units are typically available in three types – Air, Gas and Electric. Air units have no exhaust fumes or gases and the unit is unaffected by water. Electric units are quiet, have no exhaust fumes and less maintenance than the other units is required.

#### 4.1.3.3 Chemical Splitting

This method generally involves a chemical material being poured into a pre-drilled hole in the rock and the subsequent chemical reaction increases the temperature of the compound, which allows the material to volumetrically expand over the period of several hours. Using the existing confinement in a borehole, this volumetric expansion generates an expansive pressure and when it exceeds the tensile strength of the rock, crack form.

One system available is the Cardox System. Tubes are filled with liquid carbon dioxide (exactly the same as a fire extinguisher). When energized by the application of a small electrical charge, the chemical heater instantly converts the liquid carbon dioxide to a gas. This conversion expands the $CO_2$ volume and builds up pressure inside the tube until it causes the rupture disc at the end of the tube to burst. This releases the $CO_2$ - now 660 times the original volume - through a special discharge nozzle to create a powerful heaving force, at pressures up to 3,000 bar. This all takes place in milliseconds.

#### 4.1.3.4 Electrical Disintegration

The electrical disintegration of rock is another fragmentation mechanism used in the mining industry, which is accomplished by sending high voltage electrical pulses into the formation.

Though this has been identified as one of the fragmentation mechanisms with minimal environmental impacts, to date, this technology has however not been largely accepted by the mining and energy industry due to the huge transition that needs to be made from well-established mechanical disintegration processes.

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**DOCUMENT CHECKING (not mandatory for File Note)**

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