METROLINK

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A5.20 Blasting Strategy

Contents

1. Purpose ... 4
2. Legislation and Standards ... 5
2.1 Legislation ... 5
2.2 Environmental Standards ... 5
3. Environmental Assessment ... 8
3.1 Environment Impact Assessment ... 8
3.2 Building and Structural Assessment ... 8
3.2.1 Introduction and Purpose ... 8
3.2.2 The Assessment ... 8
3.2.3 Conclusion and Any Recommendations ... 9
3.3 Utilities Assessment ... 9
4. The Blast Designs ... 12
4.1 Case Studies – Correlation Between MIC and PPV in Quarry and Construction Applications ... 13
4.2 Case Study – Use of Blasting for Urban Development Overseas ... 14
4.2.1 Tunnel Boring Machine Launch Shaft for Tan Tah Kee Station at DTL2 – C918 Site; Singapore ... 15
4.2.2 DTL2 – C916 Site; Singapore ... 16
4.3 Case Study – Use of Blasting for Projects in Ireland ... 17
4.3.1 Dundrum Shopping Centre ... 17
4.3.2 Huntstown Quarry ... 18
4.3.3 Dublin Port Tunnel ... 18
4.4 Proposed Blasting Patterns at Each Construction Site ... 18
4.5 Programme Implications: Blast Design Patterns ... 19
5. Blasting Restrictions ... 20
5.1 Ground Vibration ... 20
5.1.1 Ground Vibration and Structures ... 20
5.1.2 Human Response to Ground Vibration ... 22
5.2 Air Overpressure ... 22
5.3 Flyrock ... 23
5.4 Blast Time ... 23
6. Mitigation Measures ... 24
6.1 Ground Vibration ... 24
6.2 Air Overpressure ... 24
6.3 Flyrock ... 25
7. Conclusions ... 26
8. Appendices ... 27
Appendix A. Blast design patterns A1 to A3 ... 28

Appendix B – Estimate volume of explosives 34
Appendix C – Not Used 35
Appendix D: Huntstown data: Review and refinement used in this assessment 36
Appendix E: Building and Structural Assessment 39

List of Tables and Figures

Figure 3-1: Transient Vibration Guide Values for Cosmetic Damage (Reference: BS 5228-2:2009) *Note 2 7
Figure 5-1: Distribution of Predominant Frequency of Ground Motion Observed From Mining Blasts and Construction Blasts (Gupta & Tripathy, 2013) 14
Figure 5-2: Schematic View of Blasting Design (left) and Blasting Area After Charging Stage (right) 16
Figure 5-3: Site Location in Congested Area (left) and Blasting Area Under Third Party Structures (right) 16
Figure 9-1: Blast Design Terminology (Dyno Nobel, 2010) 29

Table 3-1: Transient and Continuous Vibration Guide Values for Cosmetic Damage to Properties 6
Table 5-1: Summary of Theoretical Designed Patterns Produced for the EIAR Assessment 12
Table 5-2: Summary of Blasting Details in C918 site, Singapore 15
Table 5-3: Summary of Blasting Details in Dundrum Shopping Centre (Received by Email from Blasting Contractor) 17
Table 5-4: Summary of Possible Theoretical Blasting Patterns at Each Location 18
Table 5-5: Construction Programme - Drill and Blast Progress Rate, per Gang 19
Table 6-1: Vibration Levels Generated by Everyday Activities (Reference: Use of Explosives in Quarrying) 21
Table A-1: Summary of Two Blasting Patterns Based on 2m Deep Holes 31
Table A-2: Summary of a Blasting Pattern Based on 1.5m Deep Holes 32
Table A-3: Summary of Charge per Delay for Each Pattern 32
Table A-4: Summary of Ground Vibration (PPV) From a Blast, Based on Different Weights of Explosives per Delay 33

1. Purpose

The purpose of this report is to provide the summarised information for the EIAR assessment supporting the RO.

The blast designs in this report are derived on the basis that the damage category at the closest sensitive receptor should not exceed the threshold of ‘minor’ or ‘cosmetic’.

This report also identifies:

- The applicable legislation and standards that will govern the progression of the blasting requirements.
- Potential mitigation measures that might be deployed to mitigate the effects from blasting.

The designed patterns at this stage are preliminary and based on cartridge emulsion. The availability and potential constraints on the usage of cartridge emulsions should be explored and the relevant authorities.

2. Legislation and Standards

There are many applicable legislations and standards that directly relate to the use of blasting in Ireland. While this section provides an overview of those most directly linked to blasting, other legislation and standards also apply and will need to be considered during the project.

2.1 Legislation

The storage and transport of explosives is regulated by the Department of Justice and the use of explosives in the workplace is regulated by the Health and Safety Authority (H&SA).

The Explosives Division of the Department of Justice has responsibility for the administration of the Explosives Act 1875 and related legislation. It also has responsibility for ensuring compliance with market surveillance requirements in respect of explosives and pyrotechnics and for the transposition and implementation of EU explosives legislation, including obligations arising under various EU Directives and Regulations relating to explosives, pyrotechnics, and explosive precursors.

Primary legislation related to explosives in Ireland are:

- Explosive Act, 1875.
- Explosive Substances Act, 1883.
- Explosive Act, 1923.
- Dangerous Substances Act, 1972.
- Carriage of Dangerous Goods by Road Act 1998; and
- Criminal Justice Act 2006.

2.2 Environmental Standards

Peak particle velocity (PPV) is the commonly used parameter used to predict the structural response of buildings to vibration. The following documents have been referenced to determine initial appropriate PPV limit values on MetroLink:

- British Standard BS7385: 1993: Evaluation and measurement for vibration in buildings Part 2: Guide to damage levels from ground-borne vibration.
- British Standard BS5228-2: 2009 + A1: 2014: Code of practice for noise and vibration control on construction and open sites – Vibration.
- German Standard DIN4150-3:2016-12 Vibrations in buildings – Part 3: Effects on structures; and
- Environmental Protection Agency (EPA) Guidance.

Standards BS7385-2:1993 and BS5228-2:2009+A1:2014 advise that, for soundly constructed residential property and similar structures that are generally in good repair, the threshold for minor or cosmetic (i.e., non-structural) damage should be taken as a peak component particle velocity (in the frequency range of the predominant pulse) of 15mm/s at 4Hz, increasing to 20mm/s at 15Hz, and 50mm/s at 40Hz and above for transient vibration.

Where the dynamic loading caused by continuous vibration is such as to give rise to dynamic magnification due to resonance, especially at the lower frequencies where lower guide values apply, the guide values for limits in Table B.2 of BS 5228-2:2009 might need to be reduced by up to 50% of the transient value, as indicated in Table 3-1.

If any building is in an unstable state, then it may be more likely that damage will occur and/or that the damage arising from vibration or any other ground-borne disturbance will be greater. It is assumed that known buildings and structures of this kind will be subject to condition surveys well in advance of the works, and any defects identified and repaired. If, during these surveys, buildings are found to be structurally deficient or unstable (vulnerable), then the allowable limits can to be reduced.

Minor damage may be more difficult to repair in buildings of historical importance, ho and although these buildings may not be more sensitive unless they are structurally unsound a conservative limit was set in the EIAR. The allowable vibration limit for these buildings was reduced by 50% of those for light-framed buildings, depending on their structural integrity.

Table 3-1 sets out the limits as they apply to vibration frequencies at 4Hz where the most conservative limits are required. At higher frequencies, the relevant limit values for transient vibration within Table B.2 of BS5225-2:2009 and Figure 3-1 (Figure B.1 of BS5228-2:2009+A1:2014) will apply to these structure types: reinforced and unreinforced, framed and light-frame structures and buildings.

In the case of 'Structure Types: Protected, Historic or Vulnerable Structures and Buildings', reference to DIN4150-3:2016 will apply.

Table 3-1: Transient and Continuous Vibration Guide Values for Cosmetic Damage to Properties

Structure Type	Allowable Vibration (in terms of PPV) at the Closest Part of Sensitive Property to the Source of Vibration, at a Frequency of 4Hz	
	Transient Vibration	**Continuous Vibration**
Reinforced or framed structures. Industrial and heavy commercial buildings	50mm/s	25mm/s
Unreinforced or light-framed structures. Residential or light commercial-type buildings	15mm/s	7.5mm/s
Protected and historic buildings *Note 1	6–15mm/s	3–7.5mm/s
Identified potentially vulnerable structures and buildings with low vibration threshold	3mm/s	

Note 1: *The relevant threshold value to be determined on a case-by-case basis. Where sufficient structural information is unavailable at the time of assessment, the lower values within the range will be used, depending on the specific vibration frequency.*

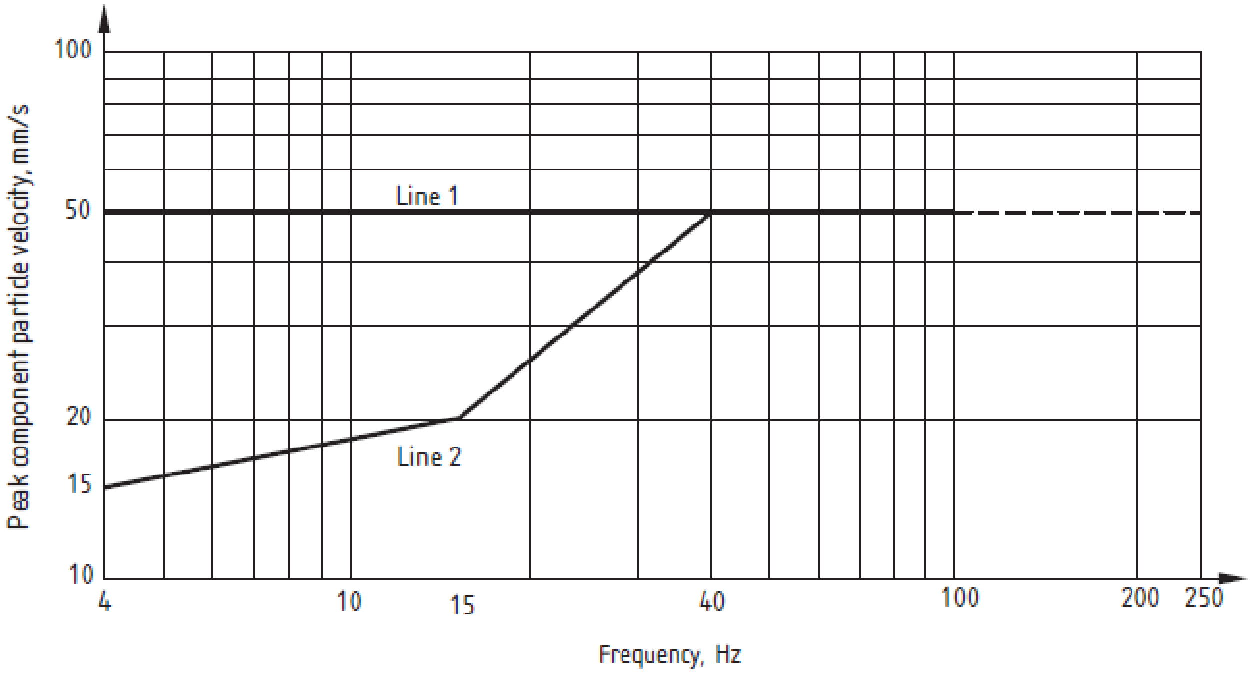

Figure 3-1: Transient Vibration Guide Values for Cosmetic Damage (Reference: BS 5228-2:2009) *Note 2

Note 2: *For line 2 of Figure 3.1, at frequencies below 4Hz, a maximum displacement of 0.6mm (zero to peak) should not be exceeded.*

3. Environmental Assessment

3.1 Environment Impact Assessment

The environmental team has been party to the development of the outline blasting strategy presented in this report. The environmental team has advised the outline strategy development in terms of the following:

- Identification of sensitive receptors to noise and vibration arising from the proposed blasting strategy.
- Advice on the appropriate criteria for noise and vibration assessment required to be adhered to by the blasting strategy; and
- Detail required in the outline blasting strategy to allow for a full and robust assessment in the EIAR with regard to ground-borne noise and vibration impacts.

Chapter 14: Ground-borne Noise & Vibration of the MetroLink EIAR contains the full details of the assessment of the blasting strategy undertaken, and the criteria used based upon the full range of international guidance and standards given in Appendix 14.1 of the EIAR.

This report provides theoretical blast designs in Section 5 that could be used on MetroLink. However due to the data available (Huntstown Quarry), as discussed in Section 5, and the requirement to meet 95% confidence of outcome, the assessment model only considered Blast Pattern A2.

The further work proposed in the conclusion of this report is recommended to realise the opportunity for increased output parameters and programme certainty for the progression of the Blasting Strategy, in line with the PPV requirements set out in Table 3-1.

Information on the Huntstown Quarry data used in the analysis, calculations and assessment within this report is provided in Appendix D.

3.2 Building and Structural Assessment

3.2.1 Introduction and Purpose

The building and structural assessments undertaken for the Blasting Strategy were to identify all affected buildings and structural assets within the zone of influence (ZOI) of the station works, to classify them according to their probable reaction and tolerance to vibrations and set them appropriate PPV limits. Furthermore, the assessment also identified buildings or assets of architectural heritage interest.

The Building and Structure Assessment undertaken for this report is provided in detail within Appendix E.

3.2.2 The Assessment

Building and structural assessments were made for key buildings and buildings that were a representative sample of all other buildings in the vicinity of each of the stations where blasting as a means of excavating rock is proposed.

The assessment is based on building classification and allowable vibrations in terms of peak particle velocity.

The classification of buildings and structures assets is made according to BS ISO 4866:2010 Annex B, considering the information provided by the building survey data.

The appropriate PPV limit values are taken from BS7385-2:1993 and BS5228-2:2009+A1:2014.

The blasting impacts on partially completed structures, or permanent works in a temporary works situation, must also be considered in the design and planned phasing of the works.

For these situations the Main Works Contractor appointed with design responsibilities must ensure that the blasting cause no damage, or adverse influence, to the permanent structures. Control of blasting and its impact on the permanent structures must follow an established review and assurance process including ongoing validation by agreed monitoring activities with regular follow-up procedures.

3.2.3 Conclusion and Any Recommendations

Most of the buildings are classified as a building class between 1 and 11, which corresponds to reinforced or framed structures, industrial and heavy commercial buildings, unreinforced or light-framed structures, and residential or light commercial-type buildings. For them the appropriate PPV limit is between 7.5 and 25mm/s.

There are only a few buildings classified as a building class between 12 and 14 or identified as potentially vulnerable. For them the appropriate PPV limit is 3 mm/s.

For any protected and historic buildings identified it is recommended that an additional review from an Architectural Heritage Specialist takes place to determine if any additional mitigation measures are required before blasting activities take place. In the case of temporary work, the Main Contractor should guarantee, with monitored processes, that no damage is caused to the permanent works during any blasting activities.

3.3 Utilities Assessment

The findings of an initial settlement study showed that approximately 70% of utilities should not require any mitigation works, other than normal settlement monitoring to ensure that the tunnel boring and other excavations are operating within their predicted settlement limits.

The utility type most impacted by settlement was brick which is typically used for sewer construction. Brickwork is a brittle substance and may crack at the mortar joints when subjected to settlement. Such cracks are easily repaired following cessation of movement. However, if the cracking exceeds 3mm some form of internal temporary support may be needed to keep the structure in place. Any cracks can then be repaired following cessation of ground movements.

Further settlement analysis will be carried out of potentially affected utilities on a case-by-case basis at the detailed design stage. Proposals for monitoring, strengthening works and possible renewal of sections of pipelines or utility structures will be discussed and agreed with each of the utility companies.

Similarly, for vibration standards, in the absence of an agreed criteria with each of the utility companies, the standard approach to be taken will be to work in accordance with DIN 4150, summarised below.

For civil engineering structures such as reinforced concrete constructions used as abutments or block foundations, a value of 80 mm/s shall be used as a guideline value, provided no hazards arise as a result of soil mechanical processes in the ground.

For evaluating the effects on linings of tunnels, galleries and cavities in rock, the guideline values given in Table 2 of DIN 4150-3:201612 shall be used (Table 4.1 below). It shall be assumed that the lining has been manufactured and applied using current technology; otherwise, lower values will need to be applied.

Table 2 — Guideline values for $v_{i,\,max}$, for evaluating the effects of short-term vibration on the lining of underground cavities

Line	Lining material	Guideline values for $v_{i,\,max}$, in mm/s perpendicular to lining surface
1	Reinforced or sprayed concrete, tubbing segments	80
2	Concrete, stone	60
3	Masonry	40
NOTE The guideline values were measured during nearby mine blasting operations and apply only to the lining of underground structures, but not to any associated installations.		

Table 4 1: Table 2 of DIN 4140-3:2016-12

For buried pipework, it shall be assumed that the pipes have been manufactured and laid using current technology; if this is not the case, special considerations will have to be made. This also applies if soil mechanical processes in the ground could have deleterious effects on pipes, where there are different conditions of restraint (e.g.at junctions with structures, lower values will need to be applied.

The guideline values for foundations also apply to the first 2m (Nearest to the building) of services pipes connected to premises (for further information regarding gas supply pipes, see DIN EN 1594).

Table 3 — Guideline values for $v_{i,\,max}$, for evaluating the effects of short-term vibration on buried pipework

Line	Pipe material	Guideline value for $v_{i,\,max}$, in mm/s at the pipe
1	Steel, welded	100
2	Vitrified clay, concrete, reinforced concrete, prestressed concrete, metal (with or without flange)	80
3	Masonry, plastics	50

Drain pipes shall be evaluated using the values given in Table 3, line 3.

Table 4 2: Table 3 of DIN 4140-3:2016-12

Further details are provided in the EIAR Assessment report, Chapter 22: Infrastructure & Utilities, sections 5 and 6, and the Ground & Vibration Chapter 14, section 2.7.

4. The Blast Designs

The blast designs in this report are derived on the basis that the damage category at the closest sensitive receptor may not exceed the threshold of 'minor' or 'cosmetic'. PPV is the commonly used parameter used to predict the structural response of buildings to vibration and the limits for this are set out in Table 3-1.

For the design of the blast design a more simplified approach to PPV was adopted: 3mm/s for sensitive structures; and 8mm/s for non-sensitive structures.

Different theoretical drill and blast patterns have been developed for each construction site, considering the proximity of the blasting locations to residential buildings/third party structures, so that they do not exceed the PPV limits. The predicted vibration level is calculated from a maximum instantaneous charge (MIC) in each designed blast pattern.

To best represent local geological conditions, blasting data (MIC) with measured concurrent vibration levels (PPV) from Huntstown Quarry (Finglas, Dublin 11) were used as the basis for the calculations.

The blasting patterns produced for the EIAR assessment have been summarised in Table 5-1 and are referenced in the following documents:

- Initial Drilling and Blasting Patterns for MetroLink Technical Note (ML1-JAI-CNP-ROUT_XX-RP-X-032) – See Table 5-1 - Patterns 1 to 3.
- Supplementary Drill and Blast Patterns Technical Note (ML1-JAI-CNP-ROUT_XX-RP-X-031). See Table 5.1 - Patterns A1 to A3; and
- Specific Drill and Blast Pattern for Charlemont Station Technical Note (ML1-JAI-CNP-ROUT_XX-RP-X-033). See Table 5-1 - Pattern A4.

Table 5-1: Summary of Theoretical Designed Patterns Produced for the EIAR Assessment

Pattern	No. of Holes	Length of Holes (m)	Weight of Explosives in Each Hole (kg)	No. of Holes on Each Delay	Weight of Explosives on Each Delay (kg)	Total Weight of Explosives (kg)	Volume of Excavation (m^3)	Powder Factor (Kg/m^3)
Pattern 1	60	3	0.6	1	0.6	36	270	0.13
Pattern 2	60	3	1.2	1	1.2	72	270	0.27
Pattern 3	60	3	1.8	1	1.8	108	270	0.4

Pattern	No. of Holes	Length of Holes (m)	Weight of Explosives in Each Hole (kg)	No. of Holes on Each Delay	Weight of Explosives on Each Delay (kg)	Total Weight of Explosives (kg)	Volume of Excavation (m^3)	Powder Factor (Kg/m^3)
Pattern A1	60	2	0.25	1	0.25	15	70.2	0.21
Pattern A2	60	2	0.375	1	0.375	22.5	70.2	0.32
Pattern A3	70	1.5	0.188	1	0.188	13.16	47.25	0.28
Pattern A4	76	1.1	0.125	1	0.125	9.5	19.8	0.48

An example of drill and blast patterns A1 to A3, included in Table 5-1, is included in Appendix A.

To support the calculation outputs, a series of high-level desk studies of other completed projects where blasting was utilised was carried out. These various studies are summarised in Sections 5.1 to 5.3 and provide further confidence that the required PPV limits set out in Table 3-1 can be met during construction on MetroLink.

4.1 Case Studies – Correlation Between MIC and PPV in Quarry and Construction Applications

This desk study identified a distinct difference in blasting used in construction projects, where blasting is more controlled, to that typically used in mining where the volume of material generated from the blast is a higher priority.

A review of different construction and mining blasting projects identified that mining blasts generally produce much higher PPV for the same scaled distance, but the construction blasts show a somewhat wider zone of attenuation at very closed scaled distance (Gupta & Tripathy, 2013).

Construction project blasts generally consist of holes with shallower depths and smaller diameters, a small charge per delay, and a more competent rock mass with smaller distances from the structures to be safeguarded. These result in a larger amplitude of ground vibrations with high frequency content and a smaller duration of motion.

In comparison, mining blasts are carried out using holes of deeper depth and larger diameter, and a large quantity of charge per delay in relatively softer strata. The ground vibrations observed from mining blasts are characterised by small amplitude, low frequency, and longer duration. The predominant frequency content of vibrations from mining and construction blasts are compared in Figure 5-1. Low frequency vibrations have a higher potential for damaging structures. The damage caused to a structure due to ground vibrations with a predominant frequency greater than 25Hz may be only due to high intensity ground vibration.

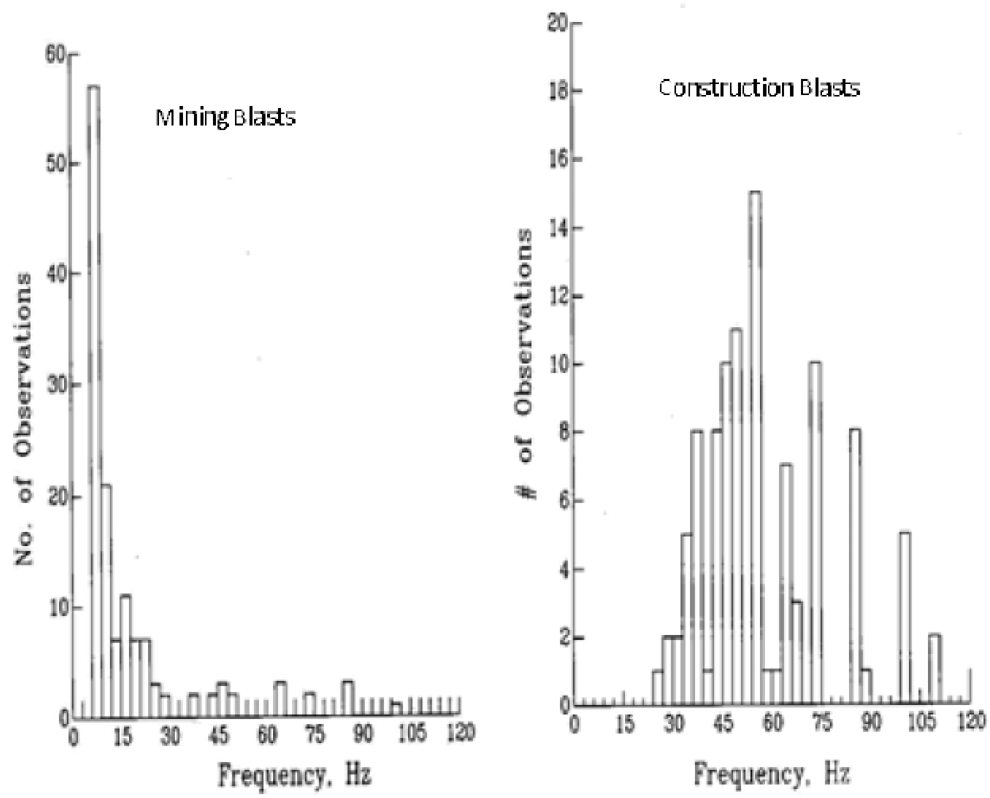

Figure 5-1: Distribution of Predominant Frequency of Ground Motion Observed from Mining Blasts and Construction Blasts (Gupta & Tripathy, 2013)

The frequencies due to construction blasts are generally beyond the range of most civil engineering structures, which can be gainfully used in defining the safety criteria for construction blasts (Gupta & Tripathy, 2013).

Based on the research outlined above, the use of the data from Huntstown quarry in the correlation of PPV to MIC results in a higher predicted impact than should be expected from a controlled application for a construction project. Furthermore, data representing the 95%ile of the Huntstown dataset (rather than the mean) was used in the calculations. The use of the 95%ile data from a quarry site is considered a conservative approach for the basis of the blast designs in this paper.

During the construction process, tighter blasting controls will likely result in a reduced impact on the surrounding buildings and structures, with increased levels of MIC possible while maintaining the PPV limits set out in Table 3-1. This assumption will be further tested during future blast trials, proposed to be undertaken as part of Workstream 3 of the Blasting Strategy.

4.2 Case Study – Use of Blasting for Urban Development Overseas

The study of drill and blast methods in urban areas in similar projects worldwide indicates that blasting can be an effective method in densely populated urban areas if performed and monitored appropriately.

Two examples from other projects that adopted a similar approach to those proposed for MetroLink are outlined below.

4.2.1 Tunnel Boring Machine Launch Shaft for Tan Tah Kee Station at DTL2 – C918 Site; Singapore

The geology on this project is different from the geology in MetroLink but the project and methodology have a lot of similarities.

The total excavation volume for the Tan Tah Kee Station project was approximately 7000m^3 and the rock excavation depth 12–14m. The total blasting area was divided into smaller blasting areas which had a maximum of 30 blast holes each depending on the location of each blast.

Drilling was mainly by pneumatic rigs operating vertically with a small angle towards the free face. The blast hole diameter was 64mm (or 32mm depending on location and ability of the drill rigs to manoeuvre) with an initial blast hole depth of 2.7m that progressed to 4m per round. The blasting column charge was between 0.9m to 1. m and the rest of the hole was stemmed. The powder factor (weight of explosives per volume of excavated material). was between 0.45–0.60 with a usual charge weight of around 2.5kg using both primers and Ammonium Nitrate Fuel Oil. A summary of the blasting design details is presented in Table 5-25-2.

Table 5-2: Summary of Blasting Details in C918 site, Singapore

Blast details	Round 1	Round 2 and 3
Number of blast holes	20	20
Diameter	64mm	64mm
Spacing	1.4	1.4
Depth	2.7m	4m
Charge weight per delay (MIC)	2.5kg	6kg
Powder factor	0.53 kg/m^3	0.7 kg/m^3

Figure 5-2 (left) shows a schematic view of the blasting design with relief holes close to the diaphragm wall.

Figure 5-2 (right) illustrates the blasting area after the charging stage and before blasting.

Figure 5-2: Schematic View of Blasting Design (left) and Blasting Area After Charging Stage (right)

On this project the actual vibration values recorded were smaller than the values estimated using the theoretical calculations, showing a successful use of blasting.

4.2.2 DTL2 – C916 Site; Singapore

This contract was for the design and construction of beauty world station and associated tunnels. Located along upper Bukit Timah Rd (off Jalan Ju-rong Kechil), this site sits in one of the busiest and most congested urban environments with multiple eating establishments and busy shopping centers with continuous human traffic. Figure 5-3 (left) shows the location of the site. Figure 5-3 (right) shows the blasting immediately under third-party structures.

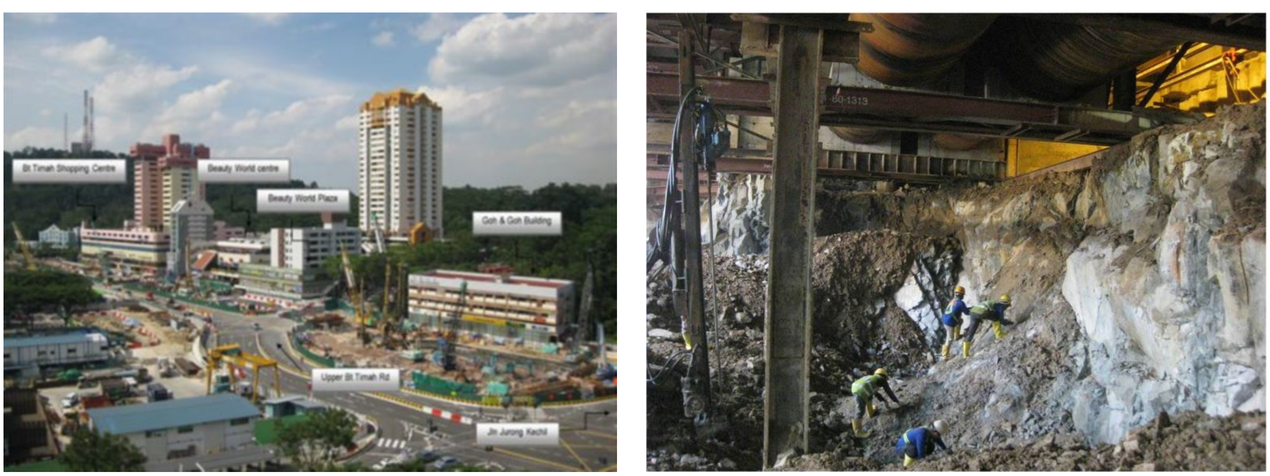

Figure 5-3: Site Location in Congested Area (left) and Blasting Area Under Third Party Structures (right)

Blasting was required just beneath the twin storm water diversion pipes which run through the station box. The other challenges were the proximity of blasting to the existing kingpost, secant bored piles, struts and other existing services running parallel to the station box, with the heavy human and vehicular traffic just above the blasting area.

The total excavation volume was in the range of 60,000m^3; the rock excavation depth ranged from 6–15m. The total blasting area was excavated via the bench blasting technique to reach the final depth. To maintain the programme, the contractor used three to four blasts per day resulting in the excavation of over 8,000m^3 per month in a highly residential and populated area. The blasting design used was like that discussed in Section 5.2.1.

Despite the project being in a congested urban area, the blasting was successful and effective with minimum impact to the nearby infrastructure.

4.3 Case Study – Use of Blasting for Projects in Ireland

4.3.1 Dundrum Shopping Centre

In the excavation of Dundrum Shopping Centre in Dublin almost 100 blasts in an existing urban environment within 40m of an existing apartment complex were undertaken successfully. Unfortunately, documented data of the blasting and monitoring results for this project are not available, apart from an email communication summarising the blasting details. A summary of blasting in this project is presented in Table 5-3.

Table 5-3: Summary of Blasting Details in Dundrum Shopping Centre (Received by Email from Blasting Contractor)

Number of holes per blast	100-150
Hole depth	3.5m
Spacing and burden	2m x 2m
Hole diameter	110mm
MIC	5kg
Vibration limit at the nearest residential property	12.5mm/s
Powder factor	0.416kg/m^3

The data presented in Table 5-3 indicate a high MIC for blasting was used at this location. However, the impact of the use of high MIC is unknown as the information available lacks any monitoring results to provide evidence on the impact to surrounding structures during that blasting operation.

To provide more control during blasting with expected lower vibration, the designed patterns for MetroLink outlined in this report are more conservative than those used on this project with:

- Lower MIC.
- Shorter hole depth and diameter; and
- Smaller spacing and burden.

4.3.2 Huntstown Quarry

Detailed information from blasting in Huntstown quarry in Dublin has been analysed and used for the vibration calculation and as the basis for the design of drill and blast patterns. Please refer to Appendix D for further details.

4.3.3 Dublin Port Tunnel

Blasting was undertaken during the construction of Dublin Port Tunnel which would provide a good basis to validate the blast design for MetroLink. Unfortunately, limited blasting information has been found from this project, so we have not been able to incorporate it in the current design.

4.4 Proposed Blasting Patterns at Each Construction Site

Following the blast pattern design and considerations of receptors around each construction site, possible blasting patterns at each location are identified to ensure the specified PPV limits are not exceeded.

The desk studies outlined in Section 5.1, together with discussions with experts from similar projects in different countries, indicate that the 95%ile results for PPV (correlated to MIC) from Huntstown quarry are higher than would be expected. However, we have used the 95%ile data from Huntstown in the initial designs summarised in Table 4-4 and hence consider them to be conservative.

The drill and blast patterns are designed to meet the PPV limits with respect to the sensitive receptors in proximity to each station location. Each pattern is based on a MIC, but the limiting factor is the PPV requirement at each sensitive receptor and the contractor should be able to adjust their pattern and MIC if the PPV at the receptors does not exceed the allowable values set out in Table 3-1.

Table 4-4: Summary of Possible Theoretical Blasting Patterns at Each Location

Location	**Level of Rock from Street Level**	***Closest Building (horizontal)***	***Distance***	***Patterns (95%ile)***	***Note***
Dublin Airport	4m	*30m*	*32.7m*	A1, A2, A3, 1 &2	*Church is assumed to be sensitive and car park not sensitive.*
Northwood	16m	*40m to residential, 60m to petrol station*	*Petrol 62m, residential:43m*	A1, A2, A3, 1, 2, 3	*Petrol station is considered sensitive.*
Ballymun	22m	40m	*47.9m*	A1, A2, A3, 1, 2, 3	
Collins Avenue	23m	8m /20m	*Church 32.1m, Albert College Court: 25.2m*	A1, A2, A3	Church is 20m away. Albert College Court is 8m away (assuming limit of 3mm/s for church and 8mm/s for Albert College Court)

Location	Level of Rock from Street Level	*Closest Building (horizontal)*	*Distance*	*Patterns (95%ile)*	*Note*
Albert College Park	20m	50m	*56.2m*	A1, A2, A3, 1, 2, 3	
Griffith Park	12m	26m	*30.9m*	A1, A2, A3, 1 &2	Assuming dressing room/shops can be replaced and is not a receptor. Assuming houses are not sensitive.
Mater: church end	24m	5.4m	*25.2m*	A3	Assumed church is sensitive.
Mater: north end	24m	16m	*30.3m*	A1, A2, A3, 1 &2	Assuming Hospital is not sensitive
O'Connell Street	23m	0m	23m	A1, A2, A3, 1	
Tara Street Station	9m	4m	*11.1m*	A1 & A3	Mechanical excavation for less than 100m^3 then A1 & A3. Railway arches: assuming not sensitive
St Stephen's Green	11m	22m	*26.9m*	A3	Assuming Buildings are sensitive
Charlemont	11m	0m	11m	Mechanical excavation or A4	Mechanical breaking or pattern A4 can be used for the first 4m from top of rock (11mbgl) to 15mbgl. Then from 15mbgl to 20mbgl patterns A1 and A3 can be used. Lower than 20mbgl all patterns can be used.

4.5 Programme Implications: Blast Design Patterns

Prior to the production of site-specific blast patterns that take sensitive receptors into account, the baseline construction programme for the EIAR had been produced using a series of conservative production rates for the excavation of the stations with blasting. The assumed production rates applied in developing this programme are provided in Table 5-5.

Table 5-5: Construction Programme - Drill and Blast Progress Rate, per Gang

Drill and Blast Access Condition	Progress rate (m^3/day)
Free	150
Reduced (e.g rock located beneath roof slabs)	100
Restricted (e.g rock located around tunnels or sumps)	75

5. Blasting Restrictions

The effects of blasting that cause the most concerns are:

- Ground vibration.
- Air overpressure.
- Flyrock; and
- Blast times.

These are described in the following sections.

5.1 Ground Vibration

Ground vibration is generally considered to be the most concerning of the effects of blasting. Ground vibration from the blast can be significant but is very short-term. Ground vibration also occurs from the drilling operation but, whilst this operation may be much more continuous, the magnitude of the ground vibration is anticipated to be much lower.

The main causes of ground vibration are:

- Maximum charge per delay, length of delay and distances between charges.
- Distance between blasting site and monitoring point.
- Geological conditions; and
- Blast design parameters.

There is considerable practical and theoretical research that has been undertaken into the damage potential of blast-induced ground vibration.

5.1.1 Ground Vibration and Structures

Fears that vibration from blasting events are unsafe should be considered in the context of the typical strains a property experiences through daily environmental changes and domestic activities. In this context, and as noted in the Institute of Quarrying publication, "the 1987 United States Bureau of Mines (USBM) report quotes that daily changes in humidity and temperature can readily induce strain…that is equivalent to blast induced vibration of between 30mm/s and 75mm/s".[1]

Vibration levels between 0.6mm/s PPV and 50mm/s PPV are routinely experienced in everyday life within a property and are considered wholly safe. When similar levels are experienced through blasting operations though, it is apparent that it is not unusual for such a level to give rise to concern. Table 6-1 gives examples of vibration levels routinely generated in a property.

[1] Bureau of Mines Technology Transfer Seminar (1987, Chicago Ill) Surface Blast Mining – Effects of Blast Vibration on Construction Material Cracking in Residential Structures – Mark S. Stagg and David E. Siskind.

Table 6-1: Vibration Levels Generated by Everyday Activities (Reference: Use of Explosives in Quarrying)

Activity	Vibration Level, PPV (mm/s)
Walking, measured on a wooden floor	1.0–2.5
Door slam, measured on a wooden floor	2.0–5.0
Door slam, measured over the doorway	12.0–35.0
Food stamps, measured on a wooden floor	5.0–50.0

Therefore, many domestic properties will exhibit cracks that may be wrongly attributed to blasting activities. There are many additional reasons why properties will develop cracks, for example:

- Fatigue and aging of wall coverings.
- Drying out of plaster finishes.
- Shrinkage and swelling of wood.
- Chemical changes in mortar, bricks, plaster, and stucco.
- Structural overloading; and
- Differential foundation settlement – particularly after times of prolonged dry spells.

With regards to physical damage to properties, extensive research has been carried out around the world, the most prominent being undertaken by the USBM and the British Standards Institute. Damage to a structure could occur if the dynamic stresses induced in the structure by vibration exceed the allowable design stress for the specific building material. Classifications of building damage range from very fine plaster cracking up to major cracking of structural elements. When defining damage to buildings, the following classifications are used:

- Cosmetic or threshold: the formation of hairline cracks or the growth of existing cracks in plaster, dry wall surface or mortar joints.
- Minor: the formation of large cracks or loosening or falling of plaster on dry wall surface, or cracks through bricks/concrete blocks; and
- Major or structural: damage to structural elements of the building.

Studies by the USBM concluded that vibration levels more than 50mm/s PPV are required to cause structural damage. The onset of cosmetic damage can be associated with lower vibration levels. Vibration levels between 19mm/s PPV and 50mm/s PPV for open-pit blasting are generally considered safe in the UK. It should be noted that these limits are for the worst-case structure conditions and that they are independent of the number of blasting events and their durations. No damage has occurred in any of the published data at vibration levels of less than 12.7mm/s PPV.

5.1.2 Human Response to Ground Vibration

Human response to blast-induced vibration is a relatively complex phenomenon and is dependent upon a range of factors, of which the actual vibration level is one. The susceptibility of individuals to vibration will vary from person to person depending on factors such as age, health, physical attitude, and, to a large extent, previous exposure.

In general terms, a person will become aware of blast-induced vibration at levels of around 1.5mm/s PPV, although under some circumstances this can be as low as 0.5mm/s PPV. However, humans are very poor at determining relative magnitudes of vibration; for example, the difference between 4mm/s PPV and 6mm/s PPV is unlikely to be perceived by a person. When the vibration level is greater than the individual's perception threshold, then it is possible for concerns to be raised. In relation to the number of blasting events at any site and the adverse public response, the Department of the Environment, Transport, and the Regions report notes that there is no correlation.[2]

Irish EPA guidance for mines identifies 8mm/s as the limit at which people will be impacted.

5.2 Air Overpressure

An air overpressure (air blast) is an atmospheric pressure wave emanating from the explosion in air. This wave comprises:

- The audible part of the airblast (acoustic): higher frequency (from 20 to 20,000Hz); and
- The sub-audible part of the airblast (infrasound): low frequency (below 20Hz).

Unlike the audible air overpressure (acoustic), which is classified as noise, the air overpressure at frequencies below 20Hz is called concussion. These are classified as an 'over pressure' when the air blast pressure exceeds atmospheric pressure. Air overpressure exerts a force on structures and in turn causes a secondary and audible rattle within a structure. It is very often confused with vibrations transmitted by the ground.

The severity of an air overpressure is dependent on the explosive charge, the distance from the source and, especially, the explosive confinement.

The main causes of airblast are summarised below:

- Ground vibration brought on by the explosion (Rock Pressure Pulse).
- Escape of gases from the blasthole when the stemming is ejected (Stemming Release Pulse).
- Escape of gases through the fractures created in the rock mass face (Gas Release Pulse).
- Displacement of the rock at bench face as the blast progresses (Air Pressure Pulse).
- Collision between the projected fragments; and
- Detonation of the initiating cord in the open air.

[2] '' The Environmental Effects of Production Blasting from Surface Mineral Workings, Vibrock. Published by the Stationery Office 1998 (ISBN 0-11-753412-9)''

5.3 Flyrock

Flyrock (also called rock throw) is the uncontrolled propelling of rock fragments produced by blasting.

Flyrock is caused by a mismatch of the distribution of explosive energy, confinement of the explosive charge, and mechanical strength of the rock. Proper blast design is the most important tool to prevent blasting problems, including flyrock. The drilling and blasting pattern are designed to optimise the balance between rock properties, explosive energy distribution, and explosive energy confinement considering the geological condition and any geological abnormality. This will improve the fragmentation and minimise flyrock, ground vibration, and airblast.

If required, a further mitigation measure is the use of blasting mats to cover the blasting area to prevent flyrock.

The main causes of flyrock are summarised below:

- Geometry of blast design.
- Type of explosive and charge weight per delay.
- Charging performance (that includes correct positioning of explosives in the hole and stemming).
- Drilling of blast hole (angle, accuracy).
- Inadequate stemming (material, length of stemming).
- Insufficient delay timing and poor pattern design.
- Geological conditions; and
- Dealing with misfires.

5.4 Blast Time

Any period in the working day, referred to as a blast time, during which blasting may occur will be agreed in advance and properly notified through community forums, business associations and letter-drops. A ‘blast time’ is not when a blast will take place, but when one may take place. If the site is not ready to blast at the anticipated time, they must simply wait for the next agreed blast time.

Ideally, two blast times per day should be agreed, typically morning and afternoon. The exact time should be agreed with local authorities and stakeholders. Blasting is not expected to be undertaken more than once a day, except for special circumstances where there is an absolute need because of an unforeseen condition. Blast warning procedures will be followed in accordance with BS 5607:2017 and local requirements prior to each blast.

6. Mitigation Measures

Measures to control the impacts of blasting are critical and are summarised in the following sections.

6.1 Ground Vibration

- Correct blast design is essential and should include a survey of the face profile prior to design,ensuring appropriate burden to avoid over-confinement of charge.
- Initial blasting at lower explosive levels to verify impacts
- Minimise the explosive charge per delay. This could involve the following:
  - Reducing the drilling diameter.
  - Shortening the length of the holes;
  - Decking charges in the holes and initiating them at different times; and
  - Using the maximum number of detonators possible.
- Choose an effective delay time between holes and rows which would avoid wave interaction and give good rock displacement.
- Set the initiation sequence in a way that it progresses away from the structures to be protected.
- Use an adequate powder factor (weight of explosives per volume of excavated material). When the powder factor is lower than what is needed, the increase in charge confinement leads to an increase in intensity of vibrations. Excessive consumption will create an unnecessary overload, accompanied by great disturbing effects.
- Ensure that the pattern has a stiffness ratio (BH/B) greater than two.
- Control drilling so that the patterns coincide with the nominal ones.
- Typically blast from the longest face (resulting in fewer rows per blast).
- Create shields or discontinuities between the structures to be protected and the blasting.
- Correct charging of holes.
- Correct stemming will aid the control of ground vibration. Controlling the length of the stemming column is also important.
- Monitoring of blasting and re-optimising the blast design considering the results, changing conditions and experience should be carried out as standard.

6.2 Air Overpressure

- Minimise the explosive charge per delay. This could involve the following:
  - Reducing the drilling diameter.
  - Shortening the length of the holes.
  - Decking charges in the holes and initiating them at different times; and

  - Utilising the maximum number of detonators possible.

- Choose delay times so that the blast progresses along the face at a velocity lower than that of sound in the air.
- Increase confinement of the explosive charges with a long stemming height (more than 25 times the hole diameter, but not excessive) and use adequate, inert material.
- Avoid using detonating cord, and when it is necessary cover it with fine sand of a minimum thickness of 100mm.
- Always consider ambient wind speed at time of blasting.
- Select patterns and sequences that avoid cooperative wave interaction.
- Inspect the state of the faces before blasting to ensure the correct charges are placed in the blast holes with burdens that are under the nominal.
- Control the explosive charge in ground with solution cavities to eliminate pocket concentrations.
- Place barriers between blasting area and sensitive receptors if required.
- Cover the blasting area carefully with a blast mat or similar.
- Cover the voids and use acoustic sheds, if required.

6.3 Flyrock

As the blasting in MetroLink would be within the station structures, flyrock is not a major concern but it should be strictly controlled to ensure safety.

The measures that can be put in place to control flyrock are summarised below:

- Proper delay pattern.
- Proper stemming.
- Proper blast design and implementation.
- Correct selection of drilling angle and blasting direction.
- Covering and protection of blasting area (blasting mat).
- Well trained and skilled staff; and
- Evacuation from potential unsafe area.

7. Conclusions

At this stage the focus of activity has been to support the assessment and control of the blasting nuisance to complete the EIAR assessment and the RO application.

Based on the work performed to date, the assessment of predicted blast-induced vibration indicates that blasting is a feasible option at all construction sites on MetroLink.

Due to insufficient blasting and monitoring data in Dublin, as outlined in Sections 5.2 to 5.3, a conservative approach to blasting has been taken for the EIAR Assessment. To improve the accuracy of the calculations and assumptions set out within this report, it is recommended that trial blasting (i.e. the initial blasts on each sites with low explosive loads) should be undertaken to validate parameters prior to the construction phase.

For information purposes, an estimate of the volume of explosives required for MetroLink is given in Appendix B.

8. Appendices

A. Blast design patterns A1 to A3

B. Estimate volume of explosives

C. Not Used

D. Huntstown data: Review and refinement used in this assessment

E. Building Assessment

Appendix A. Blast design patterns A1 to A3

Introduction

For the EIAR Assessment the following drill and blast patterns were produced to compliment those previously presented to meet the peak particle velocity (PPV) requirements.

- Patterns A1 and A2 the hole length has been reduced from 3m to 2m to allow the maximum instantaneous charge (MIC) to be reduced.
- Pattern A3 the length of the holes has been further reduced to 1.5m.

All blast patterns are preliminary only and the contractor will be responsible for producing and assessing ‘for construction’ designs that meet all the project, site, and location specific requirements and constraints or any preferences the contractor has (e.g., to suit existing equipment or a specific explosive supplier).

Further information on how these drill and blast patterns were derived, can be found in the following documents:

1. Initial Drilling and Blasting Patterns for MetroLink Technical Note (ML1-JAI-CNP-ROUT_XX-RP-X-032), and
2. Supplementary Drill and Blast Patterns for MetroLink Technical Note (ML1-JAI-CNP-ROUT_XX-RP-X-031).

Design of Drill and Blast Pattern

General

There are many variables in blast design. It is not a precise science. The use of complex equations can give the impression that it is, but these equations generally define a variable in terms of one or more other variables (that have already been chosen) and can, at times, introduce further variables, such as a geotechnical parameter.

The selection of values for these many variables strongly depends, therefore, on:

- An assessment of the geotechnical properties of the rock.
- Experience; and
- Contractor preference and availability (e.g., drill diameter to suit the equipment available and cartridge diameter to suit the local, most easily available, explosives).

Blast design is therefore very feedback orientated, and a key design input is the effect of the previous blast. The vibration is monitored and compared to the theoretical prediction, and the efficiency of the blast is also reviewed (broken to the full hole depth, overbreak, rock damage, size of rocks, % fines, etc.).

The sections below derive and describe what is considered a reasonable starting point for a blast design.

Assumptions

The preliminary blast pattern is designed based on the following assumptions and information. Where no source is given for the assumed value (e.g., hole diameter), this is a typical value (based on experience) for this type of blast pattern.

- Diameter of hole: 32mm.
- Length of hole: 2m.
- Density of rock (SGr): 2.7gr/cm3 (an average taken from the Geotechnical Design Report ML1-JAI-GEO-ROUT_XX-RP-Y-00004).
- Explosives to be used: cartridge emulsion.

- Diameter of explosive (De): 25mm.
- Length of one cartridge emulsion: 200mm.
- Weight of one cartridge emulsion: 125g.
- Density of explosives (SGe): 1.15-1.23g/cm3.
- Relative bulk strength of explosives compared to ammonium nitrate/fuel oil (ANFO) @ 0.8g/cm3: 176%.
- Relative bulk strength of explosives compared to ANFO @ 0.95g/cm3: 133%; and
- Relative bulk strength of explosives compared to ANFO used in calculation (Stv): 161%.

Figure **A-4** illustrates the terminologies used.

The calculations below assume an available free face (as shown in Figure 9-1). However, the free face needs to be created prior to applying the main blasting.

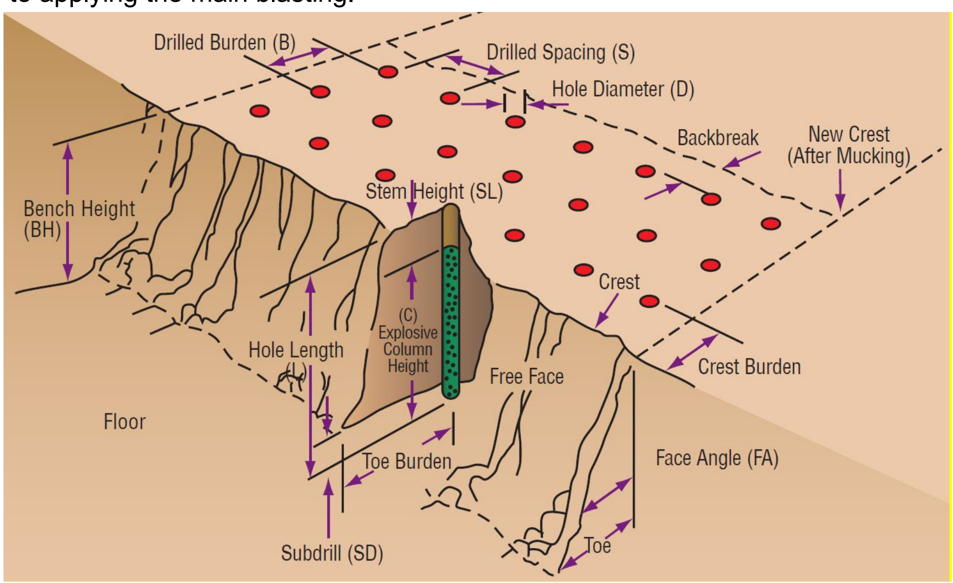

Figure A-4: Blast Design Terminology (Dyno Nobel, 2010)

Burden (B)

The 'burden' (hole spacing in the direction away from the free breaking face) can be calculated using the formula below. This is based on the strength of explosives and the rock density (Konya, 1995).

$$B = 8 \times 10^{-3} D_e \times \sqrt[3]{\frac{St_v}{SG_r}}$$

Based on this equation, B is **0.78m**.

Spacing (S)

The 'spacing' (hole spacing parallel to the direction of the free breaking face) can be calculated using the formula below.

S = 1.15 x B

Therefore, S is **0.9m**.

Stiffness Ratio

The ‘stiffness ratio’ is the bench height divided by the burden distance, or BH/B.

A stiffness ratio of less than two often results in a high airblast, flyrock, and ground vibration with poor to fair fragmentation, none of which are desirable. A stiffness ratio greater than two is generally acceptable.

Here, BH = 2m and B = 0.78m, resulting in a stiffness ratio of 2.56, which is acceptable.

Stemming Length (T)

The ‘stemming length’ refers to the length of the top portion of the blasthole which is not charged with explosives. This is normally filled with an inert material to confine the explosive gases. For a high explosive charge to function properly and release the maximum energy into the rock, the charge must be confined in the borehole. Adequate confinement is also necessary to control the airblast and flyrock.
The commonly used relationship for stemming determination is:
T = (0.7 to 1.3) x B
where T is the stemming length and B is the burden.
The minimum stemming length will be **1.1m**.

Rock Properties

The properties of rock masses that have the most influence on blast design is the:

- Dynamic strength of the rock.
- Spacing and orientation of the planes of weakness.
- Lithology and thickness of the sedimentary bedding planes.
- Velocity of wave propagation.
- Elastic properties of the rock.
- Types of infilling material and tightness of the joints; and
- Indexes of anisotropy and heterogeneity of the rock masses.

As the abovementioned data are not currently available, Section 2.4 presents several different scenarios to account for their likely variations.

Preliminary Blast Patterns

For the purposes of assessment, three preliminary drill and blast patterns have been produced and these are presented in Table A-2 and Table A-3. Patterns A1 and A2 are based on 2m deep holes and pattern A3 is based on 1.5m deep holes. The full patterns can be found in Appendix A.

Patterns A1 and A2

These are based on:

- Blasting within a 23m-wide station, with the blast holes no closer than 1.5m from the diaphragm wall (d-wall), giving, therefore, a blasting width of 20m.
- The assumption that for each blast half of the station width (10m) will be blasted.

- A 10m width of blasting, which at S = 0.9m means 11 spacings = 12 holes across.
- An assumed blast length of 3.9m, and therefore 5 rows of holes at a burden of 0.78m.
- A total, therefore, of 60 holes per blast covering an area of 3.9m x 10m (= 39m2).
- A bench height of 2m, giving a blast volume of 39m2 x 2m (= 78m3); and
- Assuming 90% efficiency of blast, giving an excavation volume of 70.2m3 (1.8m progress downwards).

Table A-2: Summary of Two Blasting Patterns Based on 2m Deep Holes

Pattern	No. of Holes	Length of Holes (m)	Weight of Explosives in Each Hole (kg)	No. of Holes on Each Delay	Weight of Explosives per Delay (kg)	Total Weight of Explosives (kg)	Volume of Excavation (m^3)	Powder Factor (kg/m^3)
Pattern A1	60	2	0.25	1	0.25	15	70.2	0.21
Pattern A2	60	2	0.375	1	0.375	22.5	70.2	0.32

Pattern A3

- To reduce the MIC further a third pattern design, with a depth of 1.5m, is given below. The details of this pattern are:
- Diameter of hole: 32mm;
- Length of hole: 1.5m.
- Density of rock (SGr): 2.7gr/cm3 (an average taken from the Geotechnical Design Report).
- Explosives to be used: cartridge emulsion.
- Diameter of explosive (De): 25mm.
- Length of one cartridge emulsion: 300mm.
- Weight of one cartridge emulsion: 188g.
- Density of explosives (SGe): 1.15-1.23g/cm3.
- Relative bulk strength of explosives compared to ANFO used in calculation (Stv): 161%.
- Burden: 0.7m; (The burden is adjusted based on the above formula to give a stiffness ratio greater than two)
- Spacing: 0.8m.
- Blasting within a 23m wide station, with the blast holes no closer than 1.5m from the d-wall, giving a blasting width of 20m.
- Assuming that for each blast half of the station width (10m) will be blasted.
- A 10m width of blasting, which at S = 0.8m means 13 spacings = 14holes across.
- An assumed blast length of 3.5m, therefore giving 5 rows of holes at a burden of 0.7m.

- Therefore, a total of 70 holes per blast covering an area of 3.5m x 10m (= 35m2).
- A bench height of 1.5m, giving a blast volume of 35 m2 x 1.5m (= 52.5m3); and
- Assuming 90% efficiency of blast, giving an excavation volume of 47.25m3 (1.35m progress downwards).

Table A-3: Summary of a Blasting Pattern Based on 1.5m Deep Holes

Pattern	No. of Holes	Length of Holes (m)	Weight of Explosives in Each Hole (kg)	No. of Holes on Each Delay	Weight of Explosives per Delay (kg)	Total Weight of Explosives (kg)	Volume of Excavation (m^3)	Powder Factor (kg/m^3)
Pattern A3	70	1.5	0.188	1	0.188	13.16	47.25	0.28

In all three patterns, each hole is blasted with a separate delay to minimise the MIC; 60 or 70 different delays are achievable with locally available non-electric LP detonators and additional surface delay connectors. Alternatively, this can be achieved with electronic detonators.

The summary of charge per delay for each pattern is presented in Table A-4.

Table A-4: Summary of Charge per Delay for Each Pattern

Pattern	MIC
Pattern A1	0.25kg
Pattern A2	0.375kg
Pattern A3	0.188kg

The selection of the proposed pattern will depend on the rock condition, noting the allowed PPV, tested by the contractor prior to the blasting operation at the site and an appropriate pattern then developed.

Ground Vibration

The ground vibration is proportional to the quantity of explosive used and the distance away from the blast point, as well as the geological and geotechnical conditions of the rock units in the excavation area and in between the blast and the structure or monitoring point. With a given explosive charge and a given distance, the intensity of vibration can be estimated using the following formula:

$$PPV = K\left(\frac{D}{\sqrt{W}}\right)^{-n}$$

- PPV: predicted ground vibration, expressed as a peak particle velocity (in mm/s).
- D: distance from explosive source to point of interest (in m).
- W: charge per delay (in kg).

- K: site-specific constant value (typically ranging from 100 to 800); and
- n: another site-specific constant value (typically ranging from 0.75 to 1.75).

In Table , the predicted PPV has been calculated for different weights of explosives on each delay. This assumes (based on previous experience and the available information at this stage):

- K = 700; and
- N =1.6.

Table A-4: Summary of Ground Vibration (PPV) From a Blast, Based on Different Weights of Explosives per Delay

Distance From Blast	Weight of Explosives per Delay		
	0.188kg	0.25kg	0.375kg
	Predicted PPV (mm/s)		
1m	183.8	230.9	319.4
1.5m	96.1	120.7	167.0
2m	60.6	76.2	105.4
2.5m	42.4	53.3	73.7
5m	14.0	17.6	24.3
10m	4.6	5.8	8.0
15m	2.4	3.0	4.2
20m	1.5	1.9	2.7
25m	1.1	1.3	1.9
30m	0.8	1.0	1.4
40m	0.5	0.6	0.9
50m	0.4	0.4	0.6
100m	0.1	0.2	0.2

Appendix B – Estimate volume of explosives

Provided by London Bridge Associates for Jacobs IDOM, an estimate of the volume of explosives required per location on MetroLink is given below.

Location	**Estimated Rock Volume (m^3) removed via blasting**	**Estimated Emulsion Explosive (T) Required (Based on 90Kg/150m^3 Rock) ***
Dublin Airport Station	63,600.0	38.2
Northwood Station	23,300.0	14.0
Ballymun Station	16,400.0	9.8
Collins Avenue Station	39,900.0	23.9
Griffith Park Station	50,200.0	30.1
Mater Station	23,400.0	14.0
O'Connell Street Station	12,200.0	7.3
Tara Street Station	57,100.0	34.3
St Stephen's Green Station	58,100.0	34.9
Charlemont Station	45,800.0	27.5
Total estimate	**390,000.0**	**234.0**
		Circa 250t of explosives
Notes: *LBA estimate for the EIAR to be updated post Blasting Trials.		

Appendix C – Not Used

Appendix D: Huntstown data: Review and refinement used in this assessment

Extract from report entitled Blasting and Vibrations produced for Jacobs IDOM by Nitroconsult reference 2131 7813 R01.

Prediction of Vibrations at MetroLink

Since no data from the area exists, predictions must be made from other similar places. The only data from the oolitic limestone that is the dominating rock in the area is from the Huntstown quarry situated northwest of Dublin city.

In Figure D-1 data from Huntstown have been plotted together with data from three other limestone quarries; it shows that the results are similar. The spread in the data is quite big, but that is expected: variations in geology, blasting technique, etc. mean that the outcome from the blast (in terms of vibration) varies and therefore calculations must be made with that in mind.

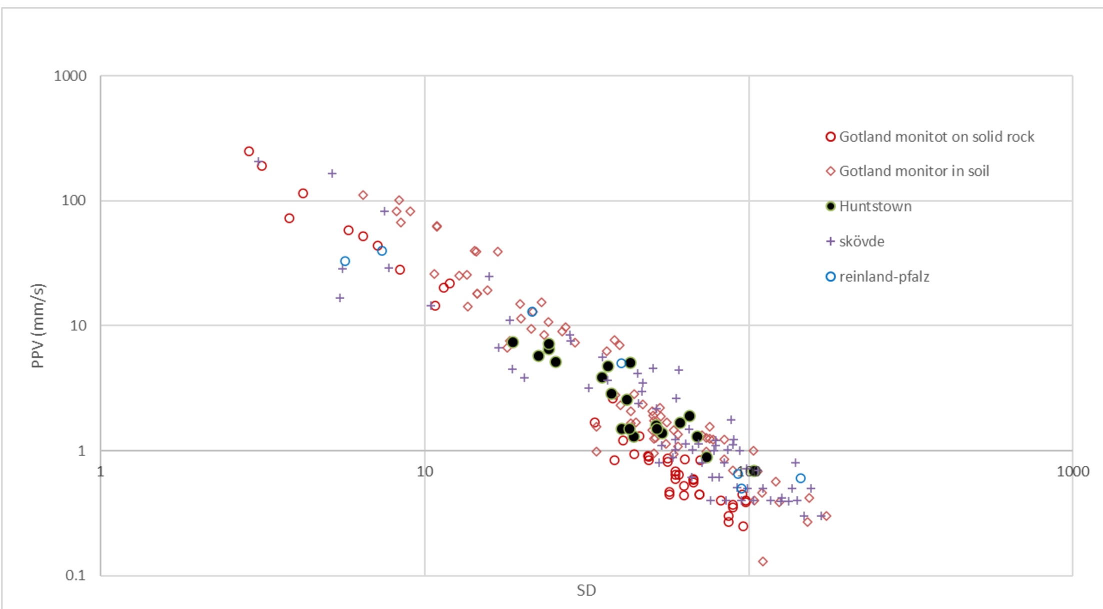

Figure D-1: Comparison Between Four Different Limestone Quarries – PPV v Scaled Distance (SD)

What Figure D-1 tells us is that the data from Huntstown has a good resemblance to other limestone areas and hence we can assume that this data can be used to make predictions. In the analysis of data from Huntstown quarry, only three out of five monitors at the site were used in the calculations. The spread in data from the other two monitoring locations was large and probably due to the resonance effects at those monitoring positions.

The results of analysing the data from Huntstown are shown in Figure D-2.

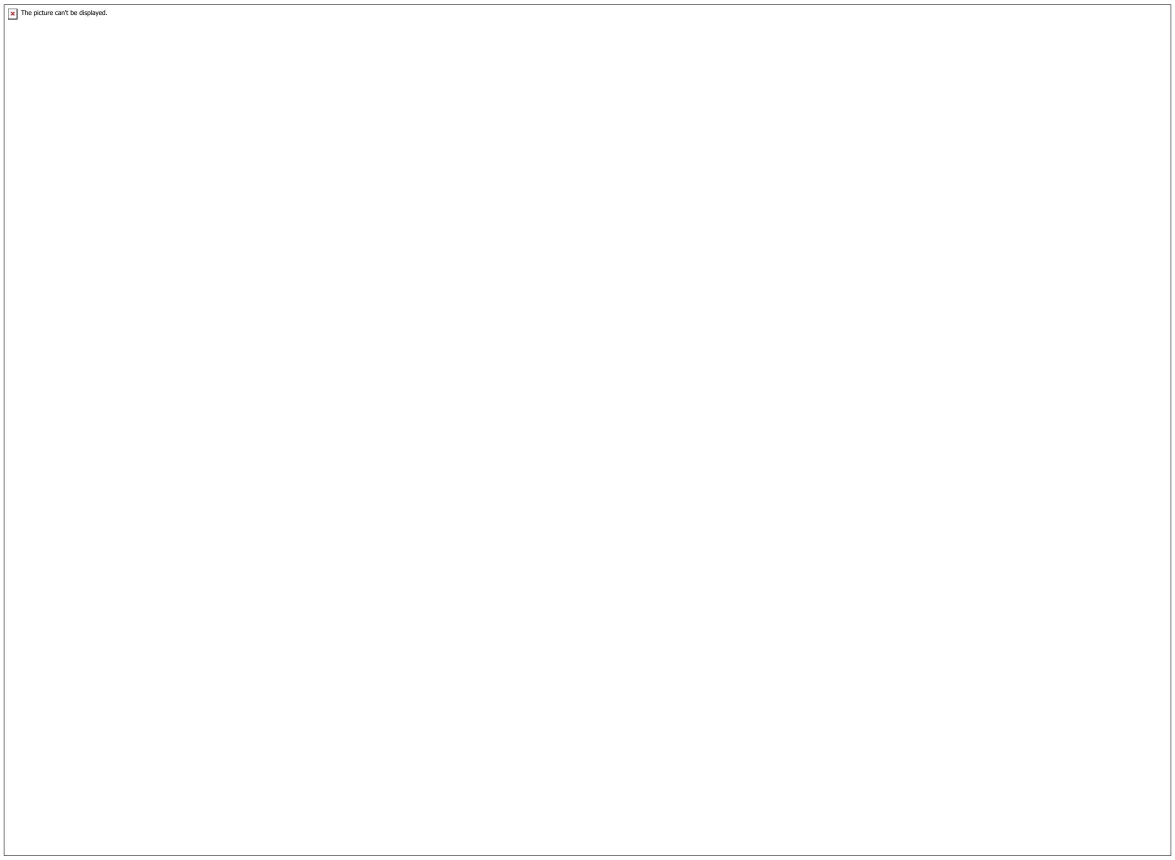

Figure D-2: Regression Analysis of the Data from Huntstown

Where the A parameter in the equation (1) is (depending on probability, i.e., 84% means that its 84% probability that the vibrations will be below that line):

84% => 918

90% => 1009

95% => 1133

98% => 1270

And B=1.495

It should also be noted that the overburden that exists in the area will have an impact on the vibrations (and frequencies). If the soil is soft then this can mean that the vibrations are damped (will be lower) and that the frequencies also become lower; without a test blast, however, it is difficult to know to what extent this will have an effect.

Appendix E: Building and Structural Assessment

Introduction

The purposes of the building and structural assessments are:

- Identify all affected buildings and structures assets within the zone of influence (ZOI). This zone is defined within 50 m from the alignment along the stations plant.
- Classify the affected buildings and structures assets according to their probable reaction and tolerance to vibrations; in order to set appropriate peak particle velocity (ppv) limits for each asset.
- Identify all buildings or assets of architectural heritage interest which might require additional review from the Architectural Heritage Specialist.

Identification of buildings and structures assets within the ZOI

The identification of buildings and structures assets is made based on the information provided by the following building survey data:

- Survey from O'Connell St north made by Thorntons.
- Survey from O'Connell St south made by ORS.
- Building walkover survey, made by Thorntons. It is only an external visual inspection, to supplement previous surveys and identify additional buildings that may be sensitive to settlement and/or vibration.

Surveys were undertaken of key buildings and buildings that were a representative sample of all other buildings in the vicinity. Therefore, in some cases, there are buildings identified within the zone of influence which are classified according to the information of the survey of similar buildings around.

The surveys are described in Appendix A. Building Survey Data.

The building survey locations are mapped on Project Mapper.

https://emeageo.jacobs.com/portal/apps/webappviewer/index.html?id=f47be1b2f460409f8088ea7dff7026dd

Classification of buildings and structures assets

The classification of buildings and structures assets is made according to BS ISO 4866:2010, Annex B. This annex provides simplified guidelines for classifying buildings according to their probable reaction to vibrations, taking into consideration the following factors:

- Category of the structure.
- Foundation.
- Soil.

Some assumptions were made for foundation types and soils based on the form of constructions, since in some cases there were no information. These assumptions are also consistent with those made for settlement study.

Category of the structure

The structures categories are based on age, structural form, use, number of stories. The following table gives a categorization of buildings.

Table B.1 — Categorization of structures according to the building group

Category of structure		Group of building (see B.4) 1	2
← Resistance to vibration decreasing	1	Heavy industrial multistorey buildings, five to seven storeys high, including earthquake-resistant forms Heavy structures, including bridges, fortresses, ramparts	Two- and three-storey industrial, heavy-frame buildings of reinforced concrete or structural steel, clad with sheeting and/or infilling panels of block work, brickwork, or precast units, and with steel, precast or *in situ* concrete floors Composite, structural steel and reinforced-concrete heavy industrial buildings
	2	Timber-frame, heavy, public buildings, including earthquake-resistant forms	Five- to nine-storey (and more) blocks of flats, offices, hospitals, light-frame industrial buildings of reinforced concrete or structural steel, with infilling panels of block work, brickwork, or precast units, not designed to resist earthquakes
	3	Timber-frame, single and two-storey houses and buildings of associated uses, with infilling and/or cladding, including "log cabin" and earthquake-resistant forms	Single storey moderately lightweight, open-type industrial buildings, braced by internal cross-walls, of steel or aluminium or timber, or concrete frame, with light sheet cladding, and light panel infilling, including earthquake-resistant types
	4	Fairly heavy multistorey buildings, used for medium warehousing or as living accommodation varying from five to seven storeys or more	Two-storey, domestic houses and buildings of associated uses, constructed of reinforced block work, brickwork or precast units, with reinforced floor and roof construction, or made wholly of reinforced concrete or similar, all of earthquake-resistant type
	5	Four- to six-storey houses and buildings of associated urban uses, made with block work or brickwork, load-bearing walls of heavier construction, including "stately homes" and small palace-style buildings	Four- to ten-storey domestic and similar buildings, constructed mainly of lightweight load-bearing block work and brickwork, calculated or uncalculated, braced mostly by internal walls of similar material, and by reinforced concrete, preformed or *in situ* floors at least on every other storey
	6	Two-storey houses and buildings of associated uses, made of block work or brickwork, with timber floors and roof Stone- or brick-built towers, including earthquake-resistant forms	Two-storey domestic houses and buildings of associated uses, including offices, constructed with walls of block work, brickwork, precast units, and with timber or precast or *in situ* floors and roof structures
	7	Lofty church, hall, and similar stone- or brick-built, arched or "articulated" structures, with or without vaulting, including arched smaller churches and similar buildings Low heavily constructed "open" (i.e. non-cross-braced) frame church and barn-type buildings including stables, garages, low industrial buildings, town halls, temples, mosques, and similar buildings with fairly heavy timber roofs and floors	Single- and two-storey houses and buildings of associated uses, made of lighter construction, using lightweight materials, prefabricated or *in situ*, separately or mixed
	8	Ruins and near-ruins and other buildings, all in a delicate state All class 7 constructions of historical importance	—

Foundation

There are defined three categories of foundations:

- Class A includes the following types:
  - Linked reinforced concrete and steel piles.
  - Stiff reinforced concrete raft.
  - Linked timber piles.
  - Gravity retaining wall.
- Class B includes the following types:
  - Independent reinforced-concrete piles that are usually connected only at their pile caps.
  - Spread wall footing.
  - Timber piles and rafts.
- Class C includes the following types:
  - Light retaining walls.
  - Large stone footing.
  - Strip foundation.
  - Plate foundation.
  - No foundations (walls directly built on soil).

Soil

Soils are classified into the following types:

- Type a: unfissured rocks or fairly solid rocks, slightly fissured, or cemented sands.
- Type b: horizontal bedded soils, very firm and compacted non-cohesive soils.
- Type c: horizontal bedded soils, poorly compacted firm and moderately firm non-cohesive soils, firm cohesive soils.
- Type d: all types of sloping surfaces with potential slip planes.
- Type e: loose non-cohesive soils (sands, gravels, boulders), soft cohesive soils (clays), organic soils (peat).
- Type f: fill.

The classes of buildings according to the previous factors are shown in the following table. The higher class number, the higher degree of protection required.

Table B.2 — Classification of buildings according to their resistance to vibration and the tolerance that can be accepted for vibrational effects

↓ Level of acceptable vibration decreasing

Class of building[a]	Category of structure (see Table B.1) 1	2	3	4	5	6	7	8
	Categories of foundations (upper case letter) and types of soil (lower case letter) (see B.5 and B.6)							
1	A a							
2	A b	A a	A a	A a				
3		A b B a	A b B a	A b	A a A b			
4		A c B b	B b	A c	A c B a B b			
5		B c	A c		B c	B a		
6		A f		A d	B d	B b C a	B a	
7			A f	A e	B e	B c C b	B b C a	
8						B e C c	B c C b	
9		B f				C d	B d C c	A a
10			B f			C e	B e C d	A b
11				C f	C f		C e	B a
12						C f		B c C a
13							C f	B d C b C c
14								C d C e C f

[a] High class number = high degree of protection required

Peak Particle Velocity (ppv) Limits

According to the classification described in BS ISO 4866:2010 Annex B, all the building identified within the zone of influence were assigned a building class in previous section.
Reference to BS7385-2:1993 and BS5228-2:2009+A1:2014 have been made to set appropriate peak particle velocity (ppv) limits values. The following table sets out the ppv limits required. There are considered the continuous vibration limits being more conservative.

Structure Type	Allowable Vibration (in terms of PPV) at the Closest Part of Sensitive Property to the Source of Vibration, at a Frequency of 4Hz	
	Transient Vibration	**Continuous Vibration**
Reinforced or framed structures. Industrial and heavy commercial buildings	50mm/s	25mm/s
Unreinforced or light framed structures. Residential or light commercial-type buildings	15mm/s	7.5mm/s
Protected and Historic Buildings *Note 1	6mm/s – 15mm/s	3 mm/s – 7.5mm/s
Identified Potentially Vulnerable Structures and Buildings with Low Vibration Threshold	3mm/s	

Note 1: The relevant threshold value to be determined on a case by case basis. Where sufficient structural information is unavailable at the time of assessment, the lower values within the range will be used, depending on the specific vibration frequency.
Note 2: For line 2 of Figure B.1. at frequencies below 4Hz, a maximum displacement of 0.6mm (zero to peak) should not be exceeded.

The following criteria was adopted to set ppv limit, considering both building classes and table of ppv limit values.

- 25mm/s: for reinforced or framed structures, industrial and heavy commercial buildings, which correspond to categories of structure 1 to 5 and building class 1 to 5.
- 7.5 mm/s: for unreinforced or light framed structures, residential or light commercial-type buildings, which correspond to categories of structure 5 to 7 and building class 6 to 11.
- 3 mm/s – 7.5mm/s: for protected and historic buildings. Values determined on a case by case based on the building information.
- 3mm/s: for identified potentially vulnerable structures and buildings with low vibration threshold, which correspond to category of structure 8 and building class 12 to 14.

The detailed classification of all the buildings and ppv limit is shown in the following table. For each building there is a report link with all the information provided by the surveys, or it is indicated which other building is considered similar to it to assume the same information for its classification.

In a few specific buildings, there is no information of them or of representative sample of buildings around them. In that case, assumptions were made based on Google Earth images.

Building ID	Address	Nearby Metrolink Station	Building Description / Age	Building Rating (BRE)	Building / Structure Use	Structural Form	Height (m). No. of stories	Group of building	Category of structure	Protected / Historic Building	Foundation	Category of foundation	Soil	Type of soil	Class of building	ppv limit	Link to Report
B-167	Terminal 2 Short Term Multi-storey car park, Terminal Complex, Dublin Airport, Swords, Co. Dublin	Dublin Airport	Approximately 2010 as part of Terminal 2 Main Building Development.	1-2 Condition Classification.	Short Term Terminal 2 Carpark	Concrete and steel frame, structure. Ground and first floor concrete with floor slabs. Upper floors steel and concrete frame.	9.5m 4 storey and 16m 7 storey approximate	2	2	None	Pile/Column construction most likely on pad foundations with intermediate strip 1.5m–2m	B	Black Boulder Clay (QBL<10m)	b	4	25 mm/s	ML-B167-Multi-storey Carpark Terminal 2 Dublin Airoprt.pdf
B-231	Our Lady Queen of Corballis Heaven Church, Corballis Road North, Dublin Airport, Swords Co. Dublin	Dublin Airport	Occupant believes the building was constructed circa 1964. This timeframe is in line with surveyor's judgement	Building / Structure Condition overall rating: 2	Church	Walls: Cavity construction, brick and masonry. Floor: Solid construction	Bell tower: 19m, surveyors judgment. Church: 4.8m, single storey. Courtyard: 2.8m.	2	7	RPS & NIAH	Judgement, concrete strip foundation, 0.8m-1.0m below ground level.	C	Made Ground (QX)	e	11	7,5 mm/s	ML BS-002-B231 Our Lady Queen of Corballis Heaven, Corballis Road North, Dublin Airport, Swords Co. Dublin..pdf
B-240	Presbytery, Corballis Road North, Dublin Airport, Swords Co. Dublin	Dublin Airport	Judgement 1970.	Building / Structure Condition overall rating: 2	Residential and church sacristy.	Walls: Solid cavity masonry construction. Floor: Solid construction.	Single storey. (part two storey including plant room). Ground level to top of parapet 2.8m.	2	7	None	Judgement: Concrete strip foundation, 0.8m-1.0m below ground level.	C	Made Ground (QX)	e	11	7,5 mm/s	ML BS-002-B240-Presbytery, Corballis Road North, Dublin Airport, Swords, Co. Dublin.pdf
B-127	Gateway Crescent / College View Silloge Road, Dublin 11	Ballymun	Advised by occupant: Early 2000's, in line with surveyors judgement.	Building / Structure Condition overall rating: 2	Sports and Fitness Centre Manager.	Wall: A mixture of glazed curtain walls, hanging tiles, insulated panels. Mixture of masonry block and reinforced concrete walls at basement level. Floor: Reinforced concrete to basement and ground floor. Ground floor level is solid supported on reinforced concrete beams and columns.	Single Storey over basement. 7.95m from pavement to underside of eaves cladding. Part two storey, roof top plant room.	2	3	None	Judgment: Reinforced concrete strip and pad foundations. 0.8m-1.0m below basement	B	Brown Boulder Clay (QBR<10m)	b	4	25 mm/s	ML BS-002-B127Gateway CrescentCollege View, Silloge Road, Dublin 11.pdf
B-129	Ballymun Civic Centre and Garda Station	Ballymun	Four storey c.2000	BRE Classification of damage: Category 0-1	Garda station, civic centre, residential	Concete framed	10m approx	2	5	Archaeology and Cultural Heritage Points - Museums, collections, statues, theatres	Assumed to be 2-3m deep.	B	Brown Boulder Clay (QBR<10m)	c	5	7,5 mm/s	Similar to ML-WO-044 PDF Walkover Report V2.pdf
B-124	Our Lady of Victories, Ballymun Road, Dublin 9	Collins Avenue	Occupier, Fr. Frank advised 1969. Surveyors judgment in line with occupants age of building.	Building / Structure Condition overall rating: 1	Church	Walls: Reinforced concrete frame and brickwork walls. Floor: Solid construction.	10m high and 1no. storey, part two story to rear and front (containing gallery area).	2	5	None	Judgement combination of strip & pad foundations 1.2m below basement level.	B	Brown Boulder Clay (QBR<10m)	c	5	25 mm/s	ML BS-002-B124-Our Lady of Victories Church, Ballymun Road, Dublin 9.pdf
B-142	70 St Mobhi Road, Glasnevin, Dublin 9	Griffith Park	1930's advised by owner	Building / Structure Condition overall rating: 1	Residential	Walls: Solid masonry construction with brick and pebble dashed finishes. Floor: Ground and first floor levels formed in suspended timber.	Two storey. Approximately 5.5m from ground level to the underside of the gutter.	2	6	None	Bricks laid in a stepped fashion, possibly on a bed of concrete. Judgement 0.5m-1.0m below ground level.	B	Brown Boulder Clay (QBR<10m)	c	7	7,5 mm/s	ML BS-002-B142-70 St Mobhi Road, Glasnevin, Dublin 9.pdf
B-117	Phibsborough Rd, Phibsborough, Dublin 7	Glasnevin	Estimated 1980's	Building/Structure Condition Rating: 1	Vacant office building	Assumed pre cast concrete structure, brick faced externally.	Approximately 10 metres height, three stories.	2	5	Fadó Antiques - NIAH The Old Bank - NIAH House No 5, 7, 11, 13, 15 - RPS	Assumed concrete strip foundations.	B	Brown Boulder Clay (QBR<10m)	d	6	7,5 mm/s	ML BS-002-B117 Des Kelly Carpets, Phibsborough Road, Phibsborough, Dublin 7.pdf
B-118	1-8 Guns Cross Quay, Phibsborough Rd, Phibsborough, Dublin 7	Glasnevin	Estimated 1980's	Building/Structure Condition Rating: 1	Residential apartment block	Walls: Pre cast concrete, brick faced Roof: Pitched slate covered roof Floors: Solid concrete Brehon slab and concrete surface to the car parking area	Approximately 10 meters height to eaves, three storey over ground level car park	2	5	None	Assumed concrete strip foundations	B	Brown Boulder Clay (QBR<10m)	d	6	7,5 mm/s	ML BS-002-B118 1-8 Guns Cross Quay, Phibsborough, Dublin 7.pdf
B-121	4/5 Finglas Road, Dublin 11	Glasnevin	Judgement: early 1900's	Building / Structure Condition overall rating: 1	Commercial on ground floor level. Living accommodation to first floor level.	Walls: Solid construction with brick finishes. Timber framed shop front at ground floor level. Floor: Ground floor level solid. Assumed first floor level is formed in timber.	Two storey, approximately 5.4m to the underside of the gutter.	2	6	None	Judgement: Brick foundations laid in a stepped fashion, possibly on a bed of concrete. 0.5m-1.0m below ground level.	B	Brown Boulder Clay (QBR<10m)	c	6	7,5 mm/s	ML BS-002-B121-4 and 5 Finglas Road, Dublin 11.pdf
B-157	Apartments 19-36, The Court, Dalcassian Downs, Dublin 11	Glasnevin	1990 according to plaque on front main entrance.	Building / Structure Condition overall rating: 1	Residential Apartment Block	Brick masonry construction, pitched tile roof on assumed factory made timber roof trusses. Solid ground and upper floors.	Circa 11.5meters, 3 storey height	2	5	None	Unknown, assumed concrete strip 1meter - 1.5meters below ground.	B	Brown Boulder Clay (QBR<10m)	d	6	7,5 mm/s	ML BS-002-B157 Apartments 19-36, Dalcassian Downs, Dublin 11..pdf
B-202	North City Flour Mills, Cross Guns Quay, Dublin 7	Glasnevin	Estimated Early 1800's, major renovation works in midlate 1900's to refurbish into apartments	Building/Structure Rating: 1	Residential apartment block	Walls: Cut stone and traditional masonry construction, precast concrete elements. Roof: Pitched and hipped natural slate covered roof. Floors: Solid concrete floors throughout.	Approximately 18 meters to eaves height, six stories over	1	5	NIAH	Assumed concrete strip (Post major renovation), possible underpinning approximately two metres depth	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	ML BS-002-B202 North City Flour Mills, Cross Guns Quay, Dublin 7.pdf
B-101	Berkeley Road, Phibsborough, Inns Quay, Dublin 7	Mater	Estimated 1875 – NIAH Building Survey Record	Overall Condition Rating: 1	Church / Chapel.	Stonework ashlar.	c.20m to main ridge, c28m front tower. Single storey vaulted to main church area over part basement floor to rear, upper floor gallery to front and over vestry to rear right east corner.	1	7	NIAH	Judgement: Stone footings 1.5m-2m below basement floor level.	C	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	e	11	7,5 mm/s	ML BS-002-B101 Josephs Church Berkeley Road.pdf
B-102	Eccles St, Phibsborough, Dublin 7, Mater Misericordiae University Hospital	Mater	Estimated midlate 1800's	Overall Condition Rating: 1	Hospital	Stonework ashlar.	Three stories, approximately 12-15 meters	1	7	NIAH	Judgement: Stone footings 1.5m-2m below basement floor level.	C	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	c	9	7,5 mm/s	Assumptios made by Google Earth images
B-103	22A Berkeley Road, Phibsborough, Dublin 7	Mater	Estimated midlate 1800's	Overall Condition Rating 3.	First floor:retail Second floor: residential	Masonry random rubble stone and brick.	Two stories, approximately 7 meters	1	6	None	Stone and / or stepped brick footings, 300 – 500mm deep.	C	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	b	7	7,5 mm/s	Similar to B-105 ML BS-002-B105-51 Goldsmith Street - DK Corrected 20.08.19.pdf
B-104	2 St Vincent Street North, Dublin 7	Mater	Estimated midlate 1800's	Overall Condition Rating 3.	Residential single dwelling.	Masonry random rubble stone and brick.	Two stories, approximately 7 meters	1	6	NIAH	Stone and / or stepped brick footings, 300 – 500mm deep.	C	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	b	7	7,5 mm/s	Similar to B-105 ML BS-002-B105-51 Goldsmith Street - DK Corrected 20.08.19.pdf

B-236	15 Berkeley Road, Phibsborough, Dublin 7	Mater	Assumed 1840's	Building/Structure Rating: 1	Ground floor – Café First Floor – Residential (assumed)	Walls: Assumed traditional masonry construction, rendered externally Floors: Solid and assumed suspended timber floor to first floor Roof: Double pitched and slated roof with flat roof sections	Two stories, approximately 7 meters to ridge height	1	6	None	Assumed stepped brick	B	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	b	6	7,5 mm/s	ML BS-002-B236 15 Berkeley Road, Phibsborough, Dublin 7.pdf
B-237	8 Berkeley Road, Phibsborough, Dublin 7	Mater	Estimate 1840's	Building / Structure Condition overall rating: 2	Office – Medical use	Walls: Traditional masonry construction, brick faced to front, rendered to rear Floors: Solid concrete and suspended timber floors Roof: Double pitched and hipped slated roof	Approximately 7 Meters to ridge, two stories	1	6	None	Assumed stepped brick foundations	B	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	b	6	7,5 mm/s	ML BS-002-B237 8 Berkeley Road, Phibsborough, Dublin 7.pdf
B-70	54 O'Connell Street Upper, North City, Dublin	O'Connell	21/04/1905	Building / Structure Condition 0-5: 2 Internal upper floor theatre and ancillary areas. 3	Amusement / Arcade at ground floor. Original cinema / theatre to upper floor not in use.	Poured concrete faced with stone/brick/rendered masonry. Solid ground and upper floors. Sold felt covered concrete flat roof to front section concealed behind stone parapet wall with moulded granite coping. Solid flat roof to rear of cinema (non- accessible) Pitched roof of cinema hall appears to be of asbestos content rising above surrounding flat roof with parapets to front and rear. Portland stone and granite ashlar coursed walls to front principal elevation.	3 Stories approximately 19.5 - 20meters high.	2	5	NIAH	Unknown – judgement traditional concrete strip located 600mm-1000mm below ground.	B	Made Ground (QX)	e	7	7,5 mm/s	ML BS-002-B70 Former Carlton Cinema, 54 O'Connell Street Upper, North City, Dublin 1.pdf
B-76	42 O'Connell Street Upper, Dublin 1	O'Connell	Estimated 1752	4	Original use residential dwelling. Most recent use – hotel. Currently vacant.	Brickwork and random rubble stone.	4 stories over basement. Circa 20 meters to main ridge.	1	8	NIAH & RPS	Unknown. Assumed brick footings 600mm-800mm below basement level.	B	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	d	13	3 mm/s	ML BS-002-B76 Catholic Communit Club 42 O'Connell Street Upper Dublin 1.pdf
B-77	37/38 O'Connell Street Upper, Dublin 1	O'Connell	Built originally approximately 1850 and possibly reconstructed 1936.	Overall condition rating: 1.	Retail banking at ground floor level, strong room and safes at basement	Solid brick and masonry.	18m, 4 stories over basement.	1	5	NIAH	Not known, judgement: brick footings 600mm – 800mm below basement floor level.	B	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	e	7	7,5 mm/s	ML BS-002-B77 AIB 37-38 O'Connell Street Upper.pdf
B-198	65/66 O'Connell Street Upper, Dublin 1	O'Connell	1857, (advised by manager Brendan). Surveyors judgement:1860's.	Building / Structure Condition overall rating: 2	Retail on ground and basement levels. Offices to upper floor levels– Protected Structure Dublin City Council RPS Ref:6032.	Walls: Solid construction, cut stone to front wall. Brick finishes to rear elevation wall. Floor: Basement and ground floor levels solid construction ground floor level appears to be formed in precast concrete slabs, supported on steel beams. Upper floor levels	Four storey over basement. Approximately 15m above pavement.	1	5	NIAH	Unknown-Judgement brick and stone footings laid in a stepped fashion 0.6m-0.8m below basement level.	B	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	e	7	7,5 mm/s	ML BS-002-B198-Carrolls Irish Gifts, 65-66 O'Connell Street Upper, Dublin 1.pdf
B-199	63/64 O'Connell Street Upper, Dublin 1	O'Connell	Judgement 1869	Building / Structure Condition overall rating: 3	Part retail (shop) and commercial (hotel) on ground floor and basement levels. Upper floor levels comprise of hotel accommodation. – Protected Structure Dublin City Council RPS Ref:6031	Walls: Solid construction with a mixture of brick and stone walls. Floor: Solid construction to basement and ground floor levels, concrete to basement floor. Upper floor levels formed suspended timber.	Five storeys over basement, part four storey to rear. Approximately 15m above pavement.	1	6	NIAH	Judgement: Brick footings laid in a stepped fashion, possibly on a bed of concrete. 0.5m-1.0m below basement level.	B	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	e	8	3 mm/s	ML BS-002-B199-Spar, Anna Livia Hotel, 63-64 O'Connell Street Upper, Dublin 1.pdf
B-200	62 O'Connell Street Upper, Dublin 1	O'Connell	c. 1913. Lower two floors rebuilt c. 1990 (NIAH Building Survey Record 50010533)	Building / Structure Condition overall rating: 2	Retail Fast Food Outlet at ground and first floor; Office to Upper floors.	Solid masonry and brick, concrete frame at ground and first floor level.	c.17.5m and five stories over basement.	2	5	NIAH	Judgement: Brick footings 600mm – 800mm below basement floor level.	B	Pre-glacial Sands & Gravels within Brown Boulder Clay (QBRs<10m)	e	7	7,5 mm/s	ML BS-002-B200 McDonalds 62 O'Connell Street Upper.pdf
B-50	155 Townsend Street, Dublin 2	Tara	Assumed to be reinforced concrete frame construction. Constructed 1980's.	The internal and external building fabric and external areas are maintained to a satisfactory standard by the Owner. Overall, B-50 fronting Townsend Street / Spring Garden Lane are in satisfactory condition overall, commensurate with their age and level of maintenance provided by the Owner. BRE Classification of damage: Category 0-1	Vacant. Formerly offices use.	Assumed to be reinforced concrete frame construction. Reinforced concrete basement extends approximately 3.5m below ground level.	26m approx. from street level. 4 Storey over basement.	2	5	None	Foundation type and depth unknown.	B	Alluvial sands and gravels (QAG)	c	5	25 mm/s	191_182-ORS-XX-XX-RP-B-13b-B50.pdf
B-51	Townsend Street, Dublin 2	Tara	Late 20th century buildings	The internal and external building fabric and external areas are maintained to a satisfactory to good standard by the Owner. Overall, B51 is in satisfactory to good condition overall, commensurate with its age and level of maintenance provided by the Owner. BRE Classification of damage: Category 1	Fire Station / Office	Assumed to be in-situ cast reinforced concrete frame construction.	29.285m approx. from street level. 6 Storey over basement. 16m approx. to top of ridge level for the 3 storeys over basement annex to the rear (south)	2	5	Archaeology and Cultural Heritage Points	Assumed to be pad foundations due to form of construction. Depth of foundations unknown. However, pad foundations for low-rise buildings are generally shallow.	B	Alluvial sands and gravels (QAG)	c	5	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B51.pdf
B-54	24-28 Tara St, Dublin 2	Tara	Believed to have been constructed c.2002.	The internal areas and external building fabric and external areas are maintained to a satisfactory to good standard by the Tenants and Owner/Landlord. BRE Classification of damage: Category 0-1 Overall, B54 is in a satisfactory to good condition overall, commensurate with its age and level of maintenance provided by the Tenants and Owner/Landlord.	Office	Assumed to be in-situ reinforced concrete substructure and bolted steel framed superstructure.	36m approx. 7 Storey over basement.	2	5	NIAH	Assumed to be a pile foundation and a combination of slab, pad and strip. Depth unknown.	B	Alluvial sands and gravels (QAG)	c	5	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B54.pdf
B-57	1-2 & 3-4 George's Quay George's Quay, Dublin 2	Tara	1-2 & 3-4 George's Quay was constructed c.1999.	BRE Classification of damage: Category 0-1	Mixed use: Commercial units at ground floor level and residential apartments above.	Presumed to be reinforced concrete frame construction, concrete block infill walls and red brick façades.	16m approx. from street level. 5 Storey.	2	5	None	Assumed to be deep piles and a combination of slab, pad and strip footings based on the building's location to the River Liffey.	B	Alluvial sands and gravels (QAG)	c	5	25 mm/s	191_182-ORS-XX-XX-RP-B-13b-B57.pdf

B-229	11-22 Tara St, Dublin 2, Irlanda	Tara	Constructed around 2000's	BRE Classification of damage: Category 0-1	Office	Assumed to be in-situ cast reinforced concrete frame construction.	31m approx. 6 Storey over basement.	2	5	None	Assumed to be a pile foundation and a combination of slab, pad and strip. Depth unknown.	B	Alluvial sands and gravels (QAG)	c	5	25 mm/s	Similar to B-54 191_182-ORS-XX-XX-RP-B-13b-B54.pdf
B-2	Loreto College, St Stephen's Green, Dublin 2	St Stephen's Green	The original buildings are reported to have been constructed in the 1760's. The original buildings are protected structures, Dublin City Council RPS ref no.'s 7786, 7787 & 7788.	Original Buildings BRE Classification of damage: Category 1-2	Education	Primarily stone / brick frame and facades with assumed timber beams supporting floors.	4 storeys over basement - 20m approx. from street level.	1	5	RPS	Brick / stone basement, extending 2.5 – 3m below street level.	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B2.pdf
B-3	52 St Stephen's Green, Dublin 2	St Stephen's Green	No. 52 was constructed as a Georgian townhouse in c. 1771 and was extended to the rear in c. 1960's (3 - 6 storeys). The link building between No. 51 (see survey report ref B-4 for further details) and No. 52 was constructed in 2000, and restoration work, primarily decorative, was reportedly carried out on the original building at this time. The original building is a protected structure, Dublin City Council RPS ref no. 7785. Mid- to late-20th century extension works are considered modern and as such are not protected structures.	Original Buildings Category 1-2 Extension Buildings Category 1-2	Office	Original buildings are primarily stone / brick frame with assumed timber beams supporting floors.	25m approx. from street level. 4 Storey over basement (original building); 3 – 6 storeys over open-air below-ground level basement (rear extensions).	1	5	RPS & National Monuments	Stone / brick basement to original building, approx. 3m below ground.	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B3.pdf
B-4	50-51 St Stephen's Green, Dublin 2	St Stephen's Green	No.50 was constructed c.1771 as a house. This building is a protected structure. Dublin City Council RPS ref no. 7783. No.51 was constructed c.1760 as a house. This building is a protected structure. Dublin City Council RPS ref no. 7784.	Overall Category 0-1 Basement areas Category 1-2	Office	Assumed to be of masonry and red brick construction.	20m approx. from street level to ridge level. 3 Storey over basement.	1	5	RPS	Assumed to be shallow foundations, based on the form of construction.	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B4.pdf
B-5	47-49 St Stephen's Green, Dublin 2	St Stephen's Green	At the outset, it should be noted that No.47-49 has no intrinsic architectural or heritage merit and is not a historical structure. It is a 1970's modern pastiche office building with neo-Georgian facades. The original Georgian building on this site was demolished in the early 1970's.	Overall BRE Classification of damage: Category 0 Minor movement (potentially differential movement/expansion of the brick) has occurred to the corner courses of brickwork to the central projected elevation of No. 47-49. Vertical uniform crack widths in mortar joints are evident between first and third floors and are 0-5mm wide BRE Classification of damage: Category 2	Office	Assumed to be in-situ cast reinforced concrete frame construction with brick facades to frontage (west) onto St. Stephens Green.	20m approx. from street level. 5 Storey over basement.	2	5	None	Assumed to be pad foundations due to form of construction. Depth of foundations unknown. However, pad foundations for low-rise buildings are generally shallow.	B	Brown Boulder Clay (QBR<10m)	c	5	25 mm/s	191_182-ORS-XX-XX-RP-B-13b-B5.pdf
B-6	44/45 St Stephen's Green, Dublin 2	St Stephen's Green	At the outset, it should be noted that No.44/45 has no intrinsic architectural or heritage merit and is not a historical structure. It is a 1970's modern pastiche office building with neo-Georgian facades. The original Georgian building on this site was demolished in the early 1970's.	Overall BRE Classification of damage: Category 1	Office	Assumed to be in-situ cast reinforced concrete frame construction with brick facades to frontage (west) onto St. Stephens Green.	20m approx. from street level. 5 Storey over basement.	2	5	Archaeology and Cultural Heritage - Museums, collections, statues, theatres	Assumed to be pad foundations due to form of construction. Depth of foundations unknown. However, pad foundations for low-rise buildings are generally shallow.	B	Brown Boulder Clay (QBR<10m)	c	5	7,5 mm/s	Similar to B-5 191_182-ORS-XX-XX-RP-B-13b-B5.pdf
B-7	46 St Stephen's Green, Dublin 2	St Stephen's Green	At the outset, it should be noted that No.46 has no intrinsic architectural or heritage merit and is not a historical structure. It is a 1970's modern pastiche office building with neo-Georgian facades. The original Georgian building on this site was demolished in the early 1970's.	Overall BRE Classification of damage: Category 1	Office	Assumed to be in-situ cast reinforced concrete frame construction with brick facades to frontage (west) onto St. Stephens Green and Hume Street.	20m approx. from street level. 5 Storey over basement.	2	5	None	Assumed to be pad foundations due to form of construction. Depth of foundations unknown. However, pad foundations for low-rise buildings are generally shallow.	B	Brown Boulder Clay (QBR<10m)	c	5	25 mm/s	191_182-ORS-XX-XX-RP-B-13b-B7.pdf
B-8	42/43 St Stephen's Green, Dublin 2 - Boston College.	St Stephen's Green	The buildings were originally constructed as a house and are assumed to have been constructed towards the late 18th century. The original buildings are protected structures, Dublin City Council RPS ref no.'s 7782.	Overall BRE Classification of damage: Category 1	Primarily Education. Second floor of No.42 is leased as offices.	Presumed to be primarily stone / brick frame and facades with assumed timber beams supporting floors.	4 storeys over basement - 13m approx. from street level.	2	5	RPS	Brick / stone basement. Depth of foundation unknown. Assumed to be shallow footings.	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B8.pdf

B-9	41 St Stephen's Green, Dublin 2	St Stephen's Green	No. 41 was constructed as a Georgian townhouse in c. 1745 and extended to the rear in recent years. The original building is a protected structure, Dublin City Council RPS ref no. 7781. Several renovations and extensions have been carried out since the late 20th century, including the rear kitchen extension, the glazed roof to the rear bar extension and the raised terrace over the rear car parking area. Late 20th century extension works are considered modern and as such are not protected structures.	Original Buildings: BRE Classification of damage: Category 1-2 Extension Buildings: BRE Classification of damage: Category 1-2	Restaurant & Bar	Original buildings are primarily stone / brick frame and facades with assumed timber beams supporting floors.	16m approx. from street level. 3 Storey over basement.	1	5	RPS	Brick / stone basement, approx. 2.5m below street level.	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B9.pdf
B-10	39 St Stephen's Green, Dublin 2	St Stephen's Green	No. 39 was constructed in c. 1912 and is a protected structure, Dublin City Council RPS ref no. 7780	Original Buildings: BRE Classification of damage: Category 1-2	Banking / Commercial	The building is primarily concrete frame with stone / brick façade and assumed structural steel beams supporting floors.	15m approx. from street level. 3 Storey over basement.	2	5	RPS	Concrete basement, approx. 3m deep. No drawings available.	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B10.pdf
B-150	15 Dartmouth Square	Charlemont	Two stroty over lower garden level contructued around 1890's	BRE Classification of damage: Category 0-1	Residential	Brick, suspended timber floor	9m approx	1	6	None	Assumed to be 1m deep.	B	Brown Boulder Clay (QBR<10m)	e	8	7,5 mm/s	Similar to ML-WO-007 PDF Walkover Report V2.pdf
B-151	32 Dartmouth Road, Ranelagh, Dublin 6	Charlemont	Two stroty over lower garden level contructued around 1850's	BRE Classification of damage: Category 0-1	Residential	Brick, suspended timber floor	9m approx	1	6	None	Assumed to be 1m deep.	B	Brown Boulder Clay (QBR<10m)	e	8	7,5 mm/s	Similar to ML-WO-005 PDF Walkover Report V2.pdf
B-152	7 Dartmouth Terrace, Ranelagh, Dublin 6	Charlemont	Two stroty building constructed around the early 19th century	BRE Classification of damage: Category 0-1	Residential	Brick, suspended timber floor	6m approx	1	6	None	Assumed to be 1m deep.	B	Brown Boulder Clay (QBR<10m)	e	8	7,5 mm/s	Assumptios made by Google Earth images
B-153	8 Northbrook Ave, Ranelagh, Dublin 6	Charlemont	Two stroty building constructed around the early 20th century	BRE Classification of damage: Category 0	Residential	Assumed to be of modern cavity construction with brick facades.	9m approx	2	6	None	Assumed to be 1m deep.	B	Brown Boulder Clay (QBR<10m)	b	6	7,5 mm/s	Assumptios made by Google Earth images
B-217	47 Ranelagh Road, Dublin	Charlemont	Three storey detached building originally constructed as a house around the late 19th to early 20th century	From our visual inspection of the building and external areas we did observe category 2-3 cracks to the rear (north) elevation.This may indicate previous settlement/movement. BRE Classification of damage: Category 2-3 Generally, the internal and external building fabric and external areas are maintained to a satisfactory standard by the previous Tenants and Owner. Overall, B217 is in satisfactory condition overall, commensurate with its age and level of maintenance provided by the previous Tenants and Owner. BRE Classification of damage: Category 1-2	Vacant and on the market as of September 2019. Last use was mixed use; offices and childcare/crèche facilities. Building and land being sold for development.	Assumed to be of solid masonry and brick construction.	10m approx. to top of ridge level. Three storeys.	1	6	None	Assumed to be shallow stripped foundations based on the form of construction.	C	Brown Boulder Clay (QBR<10m)	d	9	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B217.pdf
B-218	47A Ranelagh Road, Dublin 6	Charlemont	The original church hall date's from about the 1970's. Single storey extensions have been constructed to the rear (north), front (south) and side (east) over the years.	The internal and external building fabric and external areas are maintained to a satisfactory to satisfactory to good standard by the Owner. Overall, B218 is in satisfactory to good condition overall, commensurate with its age and level of maintenance provided by the Owner. BRE Classification of damage: Category 0-1	Church Hall and some community uses.	Assumed to be of solid masonry/concrete block and red brick construction.	8.17m approx. to top of ridge level.	1	7	None	Assumed to be shallow stripped foundations based on the form of construction.	C	Brown Boulder Clay (QBR<10m)	e	11	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B218.pdf
B-219	Ferney, Orchard Lane, Dublin 6	Charlemont	Two storey house constructed c.2010.	The internal and external building fabric and external areas are maintained to a good standard by the Owner. BRE Classification of damage: Category 0-1	Residential	Assumed to be of modern cavity construction with brick facades with steel PFC's incorporated where original derelict mews walls have been retained to the north elevation.	8.1m approx. from street level to top of parapet capping. 2 storey building.	2	6	None	Assumed to be stripped foundations based on the form of construction. Property owner informed us that foundations are believed to be 1.5m deep.	C	Brown Boulder Clay (QBR<10m)	d	9	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B219.pdf
B-220	41/42 Dexter Terrace, Northbrook Road, Dublin 6	Charlemont	Three storey duplex apartments constructed around the mid 1990's.	The internal areas to No.41 and external building fabric and external areas are maintained to a good standard by the Tenants and Owner/Landlords. Overall, B220 is in good condition overall, commensurate with its age and level of maintenance provided by the Tenants and Owner/Landlords. BRE Classification of damage: Category 0-1	Residential. Apartment No.41 occupies first and second floor levels. No.42 occupies ground floor level.	Assumed to be of modern cavity construction with brick facades.	11.4m approx. from street level to top of ridge. Three storey duplex apartments.	2	6	None	Assumed to be stripped foundations based on the form of construction.	C	Brown Boulder Clay (QBR<10m)	d	9	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B220.pdf
B-221	43/44 Dexter Terrace, Northbrook Road, Dublin 6	Charlemont	Three storey duplex apartments constructed around the mid 1990's	The internal areas to No.43 and external building fabric and external areas are maintained to a satisfactory to good standard by the Tenants and Owner/Landlords. Overall, B221 is in satisfactory to good condition overall, commensurate with its age and level of maintenance provided by the Tenants and Owner/Landlords. BRE Classification of damage: Category 0-1	Residential. Apartment No.44 occupies first and second floor levels. No.43 occupies ground floor level.	Assumed to be of modern cavity construction with brick facades.	11.4m approx. from street level to top of ridge.	2	5	None	Assumed to be stripped foundations based on the form of construction.	B	Brown Boulder Clay (QBR<10m)	d	6	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B221.pdf
B-222	19/20 Dexter Terrace, Northbrook Road, Dublin 6	Charlemont	Three storey duplex apartments constructed around the mid 1990's	BRE Classification of damage: Category 0-1	Residential.	Assumed to be of modern cavity construction with brick facades.	11.4m approx. from street level to top of ridge.	2	5	None	Assumed to be stripped foundations based on the form of construction.	B	Brown Boulder Clay (QBR<10m)	d	6	7,5 mm/s	Similar to B-223 191_182-ORS-XX-XX-RP-B-13b-B223.pdf

B-223	21/22 Dexter Terrace, Northbrook Road, Dublin 6	Charlemont	Three storey duplex apartments constructed around the mid 1990's	The internal areas to No.21 and external building fabric and external areas are maintained to a satisfactory to good standard by the Tenants and Owner/Landlords. Overall, B223 is in satisfactory to good condition overall, commensurate with its age and level of maintenance provided by the Tenants and Owner/Landlords. BRE Classification of damage: Category 0-1	Residential. Apartment No.21 occupies first and second floor levels. No.22 occupies ground floor level.	Assumed to be of modern cavity construction with brick facades.	11.4m approx. from street level to top of ridge.	2	5	None	Assumed to be stripped foundations based on the form of construction.	B	Brown Boulder Clay (QBR<10m)	d	6	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B223.pdf
B-224	3 Northbrook Villas, Northbrook Road, Dublin 6	Charlemont	Two storey c.1924	BRE Classification of damage: Category 0	Residential	Solid masonry/concrete construction	9.3m approx. to top of ridge level	1	6	None	Assumed to be shallow stripped foundations based on the form of construction.	C	Brown Boulder Clay (QBR<10m)	d	9	7,5 mm/s	Similar to B-225 191_182-ORS-XX-XX-RP-B-13b-B225.pdf
B-225	4 Northbrook Villas, Northbrook Road, Dublin 6	Charlemont	Two storey c.1924 mid terrace dwelling	BRE Classification of damage: Category 0	Residential	Solid masonry/concrete construction	9.3m approx. to top of ridge level	1	6	None	Assumed to be shallow stripped foundations based on the form of construction.	C	Brown Boulder Clay (QBR<10m)	d	9	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B225.pdf
B-228	Nationwide House, 2 Grand Parade, Dublin 6	Charlemont	Believed to have been constructed c.1964. This building is a protected structure. Dublin City Council RPS ref no. 3280.	BRE Classification of damage: Category 0-1	Vacant Office.	Presumed to be in-situ reinforced concrete with concrete block in-fill walls and faced with Portland stone.	7 Storey over basement.	1	5	RPS	Unknown.	B	Brown Boulder Clay (QBR<10m)	e	7	7,5 mm/s	191_182-ORS-XX-XX-RP-B-13b-B228.pdf
B-242	2 Ranleagh, Dublin 6	Charlemont	End terrace 2 storey contructued around 1890's	BRE Classification of damage: Category 1-2	Vacant	Brick, suspended timber floor	8m approx	1	6	None	Assumed to be 1m deep.	B	Brown Boulder Clay (QBR<10m)	e	8	7,5 mm/s	Similar to ML-WO-001 PDF Walkover Report V2.pdf

Buildings of Architectural Heritage Interest

Based on the information provided by the building survey data, there are some buildings which are considered:

- RPS: Record of Protected Structures
- NIAH: National Inventory of Architectural Heritage
- Archaeology and Cultural Heritage Points

The table below shown the protected and historic buildings. They might require additional review from an Architectural Heritage Specialist.

Building ID	Address	Nearby Metrolink Station	Protected / Historic Building
B-231	Our Lady Queen of Corballis Heaven Church, Corballis Road North, Dublin Airport, Swords Co. Dublin	Dublin Airport	RPS & NIAH
B-129	Ballymun Civic Centre and Garda Station	Ballymun	Archaeology and Cultural Heritage Points - Museums, collections, statues, theatres
B-117	Phibsborough Rd, Phibsborough, Dublin 7	Glasnevin	Fadó Antiques - NIAH The Old Bank - NIAH House No 5, 7, 11, 13, 15 - RPS
B-202	North City Flour Mills, Cross Guns Quay, Dublin 7	Glasnevin	NIAH
B-101	Berkeley Road, Phibsborough, Inns Quay, Dublin 7	Mater	NIAH
B-102	Eccles St, Phibsborough, Dublin 7, Mater Misericordiae University Hospital	Mater	NIAH
B-104	2 St Vincent Street North, Dublin 7	Mater	NIAH
B-70	54 O'Connell Street Upper, North City, Dublin	O'Connell	NIAH
B-76	42 O'Connell Street Upper, Dublin 1	O'Connell	NIAH & RPS
B-77	37/38 O'Connell Street Upper, Dublin 1	O'Connell	NIAH
B-198	65/66 O'Connell Street Upper, Dublin 1	O'Connell	NIAH
B-199	63/64 O'Connell Street Upper, Dublin 1	O'Connell	NIAH
B-200	62 O'Connell Street Upper, Dublin 1	O'Connell	NIAH
B-51	Townsend Street, Dublin 2	Tara	Archaeology and Cultural Heritage Points
B-54	24-28 Tara St, Dublin 2	Tara	NIAH
B-2	Loreto College, St Stephen's Green, Dublin 2	St Stephen's Green	RPS

B-3	52 St Stephen's Green, Dublin 2	St Stephen's Green	RPS & National Monuments
B-4	50-51 St Stephen's Green, Dublin 2	St Stephen's Green	RPS
B-6	44/45 St Stephen's Green, Dublin 2	St Stephen's Green	Archaeology and Cultural Heritage - Museums, collections, statues, theatres
B-8	42/43 St Stephen's Green, Dublin 2 - Boston College.	St Stephen's Green	RPS
B-9	41 St Stephen's Green, Dublin 2	St Stephen's Green	RPS
B-10	39 St Stephen's Green, Dublin 2	St Stephen's Green	RPS
B-228	Nationwide House, 2 Grand Parade, Dublin 6	Charlemont	RPS

Temporary Works

The blasting impacts on partially completed structures, or permanent works in a temporary works situation, must also be considered in the design and planned phasing of the Works.

For these situations the Main Works Constructor appointed with design responsibilities must ensure no damage, or adverse influence on the permanent structures occurs from blastings. Control of blasting and its impact on the permanent structures must follow an established review and assurance process including ongoing validation by agreed monitoring activities with regular follow-up procedures.

Conclusion

Most of the buildings are classified with building class between 1 to 11 which correspond to: reinforced or framed structures, industrial and heavy commercial buildings, unreinforced or light framed structures, residential or light commercial-type buildings. For them the appropriate peak particle velocity (ppv) limit is between 7.5 and 25mm/s.

There are only few buildings classified with building class between 12 to 14 or identified as potentially vulnerable. For them the appropriate peak particle velocity (ppv) limit is 3 mm/s.

For any protected and historic buildings identified it is recommended that an additional review from an Architectural Heritage Specialist takes place to determine if any additional mitigation measures are required before blasting activities take place. Regarding the situations of temporary work, the Main Constructor should guarantee, with monitored processes, no damage is caused to the permanent works during any blasting activities.

Appendix. Building Survey Data

Surveys were undertaken of key buildings and buildings that were a representative sample of all other buildings in the vicinity.

The building surveys data is listed in the following table.

Type of survey	Location	Carried out by
Access to properties	From O'Connell St north	Thorntons
Access to properties	From O'Connell St south	ORS
External visual inspection	From River Liffey to Lissenhall From Lissenhall to Charlemont	Thorntons