APPENDIX J

GROUND VIBRATION AND AIRBLAST OVERPRESSURE

(Informative)

J1 INTRODUCTION

The contents of this Appendix are designed to be informative and are not intended to override existing statutory requirements, particularly with respect to human comfort limits set by various authorities. This Appendix should be read in conjunction with any such statutory requirements and with regard to their respective jurisdictions. The intention of the present recommendations for both human comfort limits and damage limits is to provide information that reflects current best practice globally.

This Appendix addresses two common environmental effects of blasting: ground vibration and airblast. It provides background information, guidelines for measurement and criteria for peak levels.

It is recognized that ground vibration and airblast produced by blasting falls into two categories—

(a) those causing human discomfort; and

(b) those with the potential for causing damage to structures, architectural elements and services.

Generally, human discomfort levels set by authorities are less than the levels that are likely to cause damage to structures, architectural elements and services. Ground vibration and airblast levels are influenced by a number of factors, some of which are not under the control of the shotfirer.

Complaints may arise following a blast and it is recommended that accurate records be maintained. Such records should describe the location of the blast and all the blastholes, the design of the blast in terms of explosives and initiating system usage and ground vibration and airblast measurement data. It is recommended that the records be kept for at least seven (7) years. A longer period of retention of the records may be warranted if a region of the mine, quarry or construction project is blasted over an extended or disrupted period. Standardized criteria for ground vibration and airblast are used to evaluate a blast. There are various jurisdictions and sources for these criteria and this Appendix presents pertinent information and references to it.

The correct measurement of ground vibration and airblast requires systems with adequate sensitivity, dynamic range and frequency response. People may easily confuse the sources of their discomfort. Not only may they assess incorrectly the true level of ground vibration and airblast but they misconstrue the actual source. For example, secondary noise is often attributed to ground vibration but this noise, such as windows and crockery rattling, may have been caused either by the ground vibration or airblast. Persons responsible for, or involved with the blast, should have a good understanding of such issues and be able to communicate that understanding to affected people. Monitoring records may support the communication.

Blasts should be designed according to the prevailing regulatory controls from both a human comfort and damage perspective. All efforts should be made to minimise environmental disturbances.

Information in this Appendix is presented as follows:

(i) Paragraph J1 provides a general introduction.

(ii) Paragraph J2 provides a broad description of the phenomena of ground vibration and airblast.

(iii) Paragraph J3 describes typical measurement system requirements and procedures.

(iv) Paragraph J4 gives examples of maximum levels of ground vibration for human comfort that some authorities have chosen. It also gives levels for the prevention of damage to structures, architectural elements and services from ground vibration.

(v) Paragraph J5 gives examples of maximum levels of airblast for human comfort that some authorities have chosen. It also gives levels for the prevention of damage to structures, architectural elements and services from airblast.

(vi) Paragraph J6 provides guidance for operating practice where ground vibration and airblast are of concern and suggests a protocol for communication in the event of complaints arising from ground vibration and airblast produced by blasting.

(vii) Paragraph J7 provides methods for the preliminary estimation of ground vibration and airblast magnitudes

(viii) Paragraph J8 provides a bibliography of work relevant to this Appendix.

J2 DESCRIPTION OF THE PHENOMENA

J2.1 Ground vibration

Ground vibration from blasting is the radiation of mechanical energy within a rock mass or soil. It comprises various vibration phases travelling at different velocities. These phases are reflected, refracted, attenuated and scattered within the rock mass or soil, so that the resulting ground vibration at any particular location will have a complex character with various peaks and frequency content. Typically, higher frequencies are attenuated rapidly so that at close distances to the source such frequencies will be present in greater proportion than at far distances from the source.

The magnitude of the ground vibration together with ground vibration frequency are commonly used to define damage criteria. The choice of the appropriate damage criterion may require consideration of the frequencies arising from the blast.

Studies and experience show that well designed and controlled blasts are unlikely to create ground vibrations of a magnitude that causes damage. Particular structures such as tall buildings, or abnormal ground conditions such as water-logged ground, should be carefully considered in a specialist study.

Cracks in buildings may be attributable to causes other than ground vibration, including ground or foundation movements (settlement and swell) associated with reactive clay soils during periods of prolonged dry or wet weather.

J2.2 Airblast

Airblast is the pressure wave (sound) produced by the blast and transmitted through the air. Unlike ground vibration there is only one airblast phase but it too is a complex wave-train consisting of various peaks and with a range of frequencies. The sources of airblast include a usually small air pressure pulse generated by the ground vibration, a direct air pressure pulse generated by the rock movement during blasting and an air pressure pulse caused by direct venting of gases from the region of the blast. It is important to recognise that airblast may be reflected by layers within the atmosphere and that the airblast may be refocused at distances remote from the blast.

Airblast may be heard by people if it contains energy in the audible frequency range, typically between 20 Hz and 20 kHz. However, some of the energy is sub-audible and lies in the frequency range between 2 Hz and 20 Hz. Such low frequency airblast is often experienced indoors as secondary audible effects, such as rattling of windows and of sliding doors. A blast perceived as loud may have a low airblast level and a blast that is barely noticeable outdoors may have a high airblast level.

At distances where both effects are above perceptible levels, airblast is usually felt after any ground vibration. Ground-transmitted vibration waves from a blast normally travel faster than the air-transmitted airblast overpressure.

Airblast is generally the cause of more complaints than ground vibration.

Airblast levels that are barely noticeable are much lower than those that will cause damage. Because of a large dynamic range, airblast levels are measured typically on a logarithmic decibel scale (dB). On this scale, an increase of 6 decibels represents a doubling of the sound pressure levels.

Airblast levels may also be reported as an A-weighted (dBA) or C-weighted (dBC) value. These scales adjust the frequency content of the measured airblast time history. Linear-weighting (dBL) implies no adjustment of the frequency content in the measured records. The A-weighting is commonly associated with the hearing response of humans and is most often used for assessing general noise levels associated with machinery and vehicular traffic. The C-weighting, which attenuates the frequencies more than does A-weighting, is often used for impulsive sounds such as the sonic booms of aircraft.

As an example, if a sound level meter measures an airblast level of 115 dBL, the same meter would measure approximately 90 dBA for the same event. The frequency content of the particular airblast time history will determine the relative levels between the dBL and dBA readings.

All airblasts should be reported on the dBL scale, particularly when considering structural and architectural effects, and the other weighting scales should be used as required.

J3 MEASUREMENT

J3.1 General

J3.1.1 *Management*

The proper management of blasting operations demands that records be kept for each blast. As a minimum, this includes the blast location, the blast geometry, the explosives loaded, the initiation design and the location of any man-made or natural structures that may be affected by the blast. Such information is invaluable for continuous improvement of the desirable outcomes from the blast, but also provides information for analyses concerning ground vibration and airblast exceedences.

Measurements of ground vibration and airblast are made in a variety of ways and for different reasons. While a standard approach is recommended, it must be remembered that blasting will have a different end effect on each and every structure. The standard approach is useful for routine monitoring of relatively standard blasts under relatively uniform conditions.

Special monitoring techniques may be required for other conditions, but these are not addressed in this Appendix.

It is emphasized that measurement equipment used should comply with Paragraphs J3.2.1 and J3.3.1 of this Standard. It should be noted that regulatory authorities may require or approve the use of equipment with specifications different from those given in Paragraphs J3.2.1 and J3.3.1 to meet specific situations.

J3.1.2 *Typical blast monitoring guidelines*

The following are intended only as general guidelines, and cannot describe methods for all types of field conditions:

(a) *Read the instrument instruction manual* An operator should be familiar with the instrument and competent in its use. Emphasis must be placed on awareness of maintenance issues.

(b) *Instrument calibration* Instrument calibration must be maintained, be traceable and documented. As a guideline, instrument calibration should be carried out at intervals not exceeding 12 months.

(c) *Pre-blast preparation* The operator must be informed of the monitoring conditions before setting out, particularly the size of blast, the designed effective charge mass per delay, the designed blast duration and distance to all monitoring locations. Other pertinent data that should be noted include user's name, date, time, location, instrument trigger levels and instrument identification number.

(d) *Record the full waveform* The instrument must have sufficient memory capacity available and be configured to save waveforms long enough for the blast design and distance. As a rule of thumb, 3 seconds per kilometre should be allowed plus the blast duration. Under certain circumstances, particularly for airblast recording using a sound level meter with acceptable frequency response, it may be appropriate to use a calibrated instrument that records only peak levels with and without weighting factors.

(e) *Record the blast* The effort of deploying the instrument justifies sufficient care to ensure a successful recording. Once installed on site, the system must be tested, and trigger levels must be as low as possible yet sufficiently above local background to avoid spurious events. Having saved the measurement, the data must be secured and available for any subsequent analysis.

(f) *Ground vibration transducer placement* The ground vibration transducer should be effectively coupled as described in Paragraph J3.2.2.

(g) *Microphone* The microphone should be mounted at a height of not less than one metre with the windshield attached as described in Paragraph J3.3.2.

J3.2 Ground vibration

J3.2.1 *Measuring equipment*

Typically, the measurement of ground vibrations uses transducers for particle velocity (geophone) or particle acceleration (accelerometer). Accelerometers tend to be used in specialist applications due to their (generally) superior specifications. The data from accelerometers may be converted readily to particle velocity by integration, either in hardware or software. The discussion in this clause is restricted to measurements of particle velocity.

Particle velocity is normally expressed in millimetres per second (mm/s). A vibration transducer should produce signals for three mutually orthogonal axes and preferably with one sensor measuring the vertical direction and the other two in horizontal directions. This arrangement enables a rapid assessment of vibrations in a coordinate system applicable to most man-made structures. Data records in three orthogonal directions may be transformed into any other curvilinear coordinate system that is relevant to the structure of concern.

The measurement equipment should record, and be able to play back these signals for the full duration of the blast event. The measurement equipment, or associated software, should indicate the absolute maximum signal value for each of the three components over this duration, referred to as the Peak Component Particle Velocity (PCPV). Also the measurement equipment should indicate the maximum of a root sum of squares calculation for the three components performed over the whole signal duration, referred to as the Vector Peak Particle Velocity (VPPV). Instrumentation noise (including electrical disturbances) measured as a peak value should be less than 10% of VPPV. The frequency range of the measurement equipment must be at least 2 Hz to 250 Hz (–3 dB roll off), with a tolerance of 10% over this frequency range (see Figure J3.2.1). The use of equipment with a frequency response range of 5 to 250 Hz, which was specified in AS 2187.2—1993, should be permitted in the vast majority of situations where this frequency range is adequate. For a digital system, the recommended minimum sampling frequency is 500 Hz.

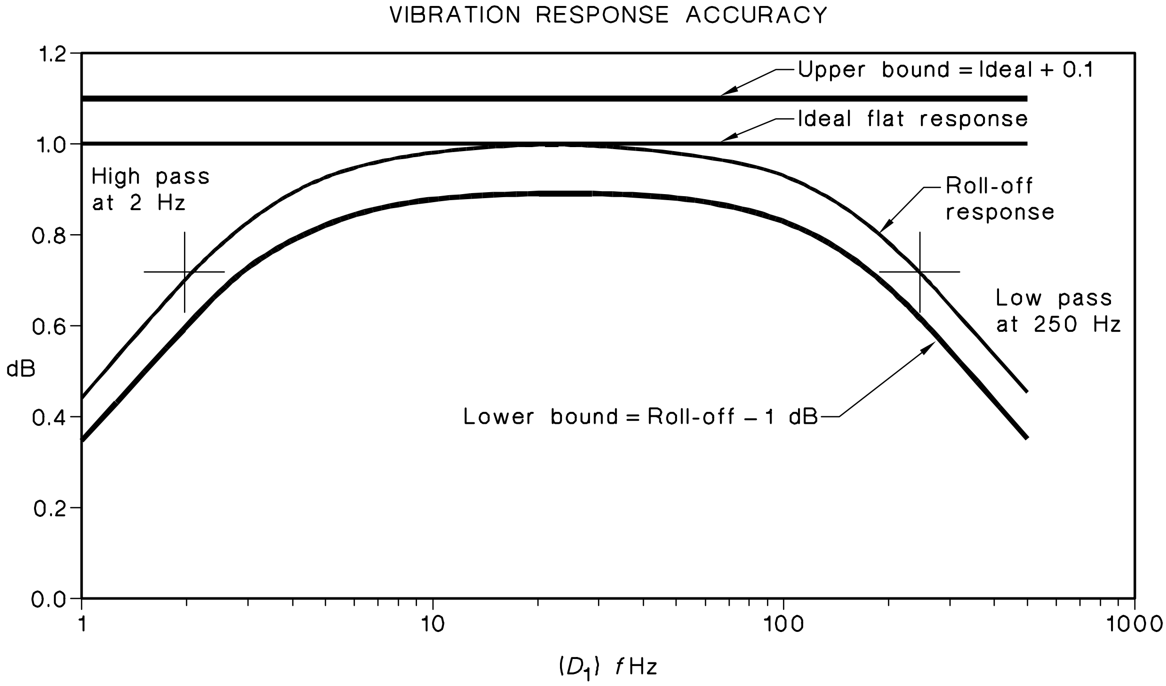

FIGURE J3.2.1 TYPICAL PARTICLE VELOCITY VIBRATION RESPONSE ACCURACY

J3.2.2 *Measuring technique*

The purpose of the measurement is to measure the magnitude of ground vibration that is transmitted to the structure at ground level.

Ground vibrations should normally be measured on the ground near the point of concern. The measurement location(s) should be away from structures that may produce reflections and cause spurious readings. Poor ground conditions for instrument coupling or lack of access should not preclude taking measurements on the foundation of the structure at ground level; however, it should be noted that measurements taken on the structure above ground level can be misleading as they are often exaggerated by structural or modal response. The choice of locations and the process of undertaking ground vibration measurement should be restricted to competent persons.

When setting up the instrument, the operator should estimate the likely range of ground vibration in order to set appropriate scales and trigger levels.

The basis for coupling the transducer is to ensure that it faithfully records the motion of the ground. The preferred coupling method depends on site conditions. Where there is a rigid surface (e.g., concrete or rock) adhesive or mechanical bonding can be used. Where the surface is soil, the transducer can be embedded or fixed to an embedded mount (for example, 200 mm concrete cube or similarly sized cylinder). If measurements are repeated at the same location, an embedded mount is particularly justified for consistency of results. Coupling with soil spikes in soft conditions may lead to exaggerated measurements and is not recommended.

The orientation of all transducers with respect to the blast location should be documented by the operator. The information needs to be sufficient so that each and every component vibration can be placed in the same global coordinate system used for the blastholes within a blast. Such orientation information is also required for triaxial transducers housed in an integrated container.

J3.3 Airblast

J3.3.1 *Measuring equipment*

The measurement of airblast overpressure uses a microphone and the airblast is usually expressed in Pascals (Pa) or decibels Linear (dBL). The measurement equipment should record the absolute maximum pressure level. In general, it is recommended that the measurement equipment record, and be able to reproduce this signal for the full duration of the blast event. The measurement equipment should indicate the absolute maximum signal value in dBL, a logarithmic (decibel) scale with linear weighting referred to a pressure of 20 mPa. This scale does not modify the frequency content of the airblast and may be used for assessing the likelihood of airblast-induced damage. Instrumentation noise (including electrical disturbances) measured as a peak value should be at least 20 dBL less than the measured peak. The frequency range of the measurement equipment must be at least 2 Hz to 250 Hz (–3 dB roll off), with a tolerance of ±1 dBL over this frequency range (see Figure J3.3.1). For a digital system, the recommended minimum sampling frequency is 500 Hz.

Where the airblast measurement is triggered by the ground vibration, the recording duration has to be sufficient for the monitoring distance. As a rule of thumb, 3 s per kilometre is allowed, plus the blast duration.

It is useful for the recording equipment and/or the associated software to have provision for analysing the airblast levels using an A-weighting, C-weighting and the associated sound exposure levels in order to provide extra information relating to human comfort levels.

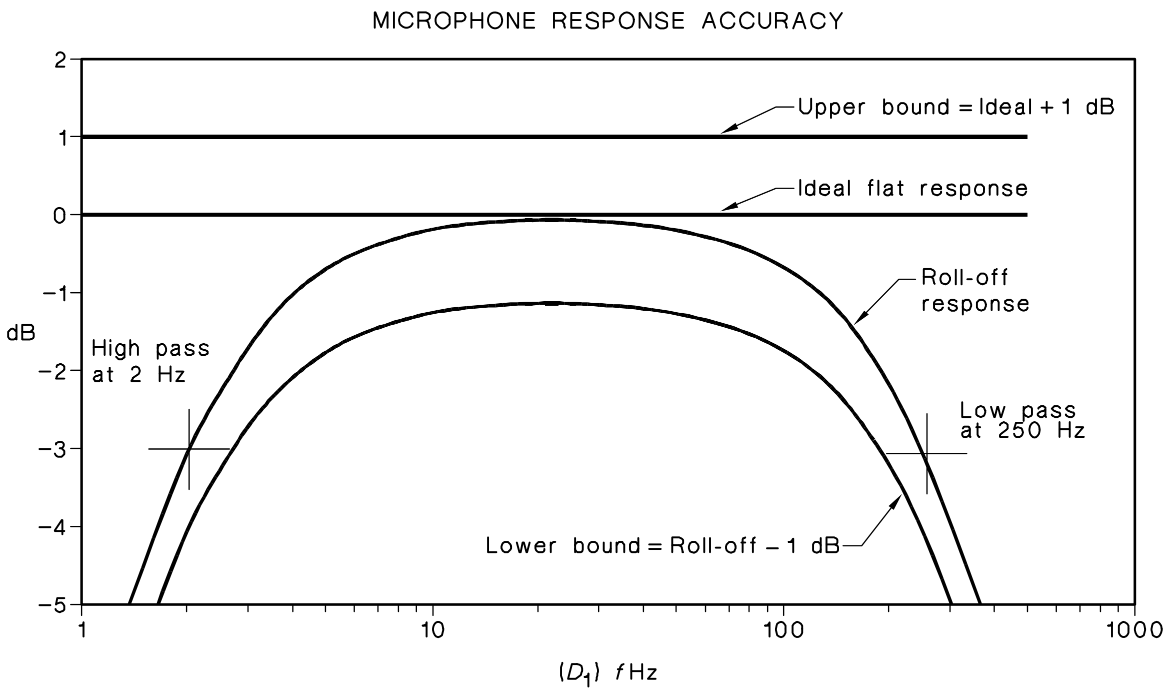

FIGURE J3.3.1 MICROPHONE RESPONSE ACCURACY

J3.3.2 *Measuring technique*

The microphone should be oriented in a direction of maximum sensitivity to the incident sound. A windshield should be fitted in accordance with the manufacturer's recommendations.

The microphone should be mounted on a tripod or similar stable stand and located at least 1 m from ground level unless a specific investigation shows that measurements taken at a lower height are valid. It should be located away from structures that may produce reflections and cause spurious readings.

J3.4 Blast monitoring records

Blast monitoring records provide the data for determining any improvements in blast outcomes, including the management and control of ground vibration and airblast. As a minimum, blast monitoring records should include the following:

(a) The size of the blast in terms of the number of blastholes and the quantity of explosives in each blasthole.

(b) The method of initiation and the timing sequence to be used in the blast.

(c) The date and time of the blast.

(d) The location of the measurement transducers (geophones, accelerometers, microphones).

(e) Instrument trigger levels.

(f) Measurement equipment and operator details.

(g) The location of the blast in relation to the mine, quarry or construction site lease.

(h) The location of any structures and/or persons who may be affected by the blast.

(j) The measured ground vibration and airblast values including the peak particle velocity values for each of the triaxial components, a derived vector peak particle value and the peak airblast levels.

Blast monitoring records should, wherever possible, include the following:

(i) The location of each blasthole collar.

(ii) Face survey information indicating the proximity of the nearest blastholes to any free faces within the blast.

(iii) Full time histories of the ground vibration and airblast responses.

(iv) Weather conditions, especially wind speed, cloud cover and direction and any other notable conditions such as rain.

(v) Information derived from a video of the blast.

(vi) Any subjective information from the shotfirer and any persons who may be affected by the blast.

A copy of these records should be included in the site blast records.

J4 GROUND VIBRATION LEVELS

J4.1 General

The maximum levels for ground vibration for human comfort that some authorities have chosen are set out in Paragraphs J4.2 to J4.5.

NOTE: The maximum levels advised in this Appendix are designed to be informative and are not intended to override existing statutory requirements, particularly with respect to human comfort limits set by various authorities.

The methods of data analysis for these limits are also presented. In part, such analyses are a departure from that described in earlier and other Standards and the intention is to provide sufficient detail so that expert persons may implement these in hardware and/or software.

J4.2 Ground vibration

Vibration transmitted through the ground may cause damage to structures and architectural elements or discomfort to their occupants. The vibration levels at which people become annoyed are well below vibration levels at which damage occurs. The likelihood of such damage or discomfort may be ascertained by measuring the vibration from a blast close to the location of concern such as a building or other structure.

For all limits it is necessary to measure in three orthogonal directions, one in the vertical direction and the other two in perpendicular horizontal directions. Such measurements align with most structural members in man-made structures. From such measurements it is possible to derive the Vector Peak Particle Velocity (VPPV) and the Peak Component Particle Velocity for each direction (PCPV). The magnitude of the vector particle velocity (v_p) is the amplitude of the vector sum of three time-synchronised velocity components directly measured by an instrument. When not measured directly it may be determined by the following Equation:

$$v_p = \sqrt{v_x^2 + v_y^2 + v_z^2} \qquad \ldots\ \text{J4.2}$$

where v_x, v_y and v_z are the synchronized instantaneous velocity components of the x, y and z axes, respectively. The VPPV is the maximum of v_p.

J4.3 Human comfort limits

NOTE: Statutory requirements for human comfort limits for ground vibration may apply in respective jurisdictions.

General guidance on human response to building vibrations is given in AS 2670.2, ISO 2631-2 and BS 6472.

J4.4 Damage limits

J4.4.1 *General*

Frequency independent and frequency dependent guide levels are described in both British Standard BS 7385-2 and the United States Bureau of Mines (USBM) RI 8507. The levels specified are peak component particle velocities, and the methodologies used for assessing the frequencies are similar in both documents.

Frequency-dependent criteria are important for assessing the blast-induced vibration effects on buildings and other structures and are the recommended approach.

J4.4.2 *Frequency-independent levels*

Frequency-dependent criteria may not be readily implemented for all parties concerned with this Standard.

For explosives users who do not have the facilities to use frequency-dependent assessment methods, the levels specified in Table J4.5(B), which are more conservative for most blasting applications, will reduce the potential for damage. The Table should be used in conjunction with the notes that follow it.

Wherever possible, the ground vibration levels from all blasting operations must be limited to the damage limit criteria shown below in Figures J4.4.2.1 or J4.4.2.2 at all sites not in the ownership or control of the organisation commissioning the blasting.

J4.4.3 *Frequency dependent levels*

Frequency-dependent guide levels described in British Standard BS 7385-2 and the United States Bureau of Mines (USBM) RI 8507 are given below. The levels specified are peak component particle velocities, and the methodologies used for assessing the frequencies, are similar in both documents.

The frequency-dependent guide values from BS 7385-2 for the prevention of minor or cosmetic damage occurring in structures from ground vibration are shown in Table J4.4.2.1 and Figure J4.4.2.1 below:

TABLE J4.4.2.1

TRANSIENT VIBRATION GUIDE VALUES FOR COSMETIC DAMAGE (BS 7385-2)

Line	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	15 Hz and above
1	Reinforced or framed structures. Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structure. Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

NOTES:

1 Values referred to are at the base of the building.

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

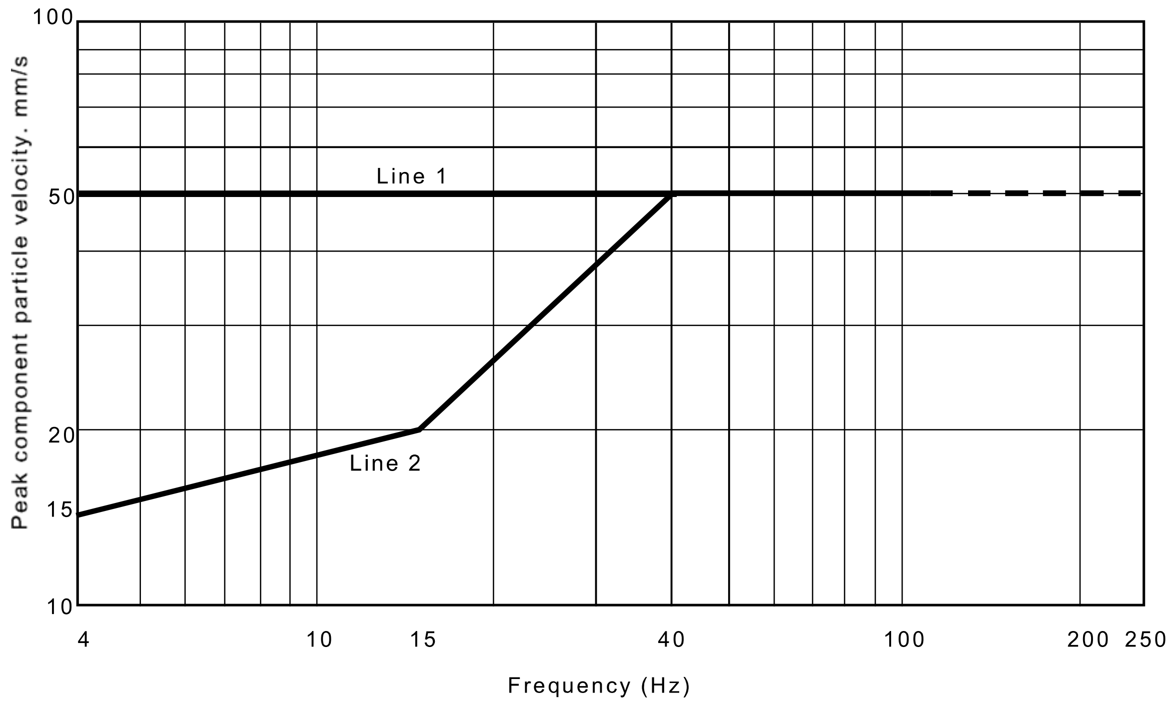

FIGURE J4.4.2.1 TRANSIENT VIBRATION GUIDE VALUES FOR COSMETIC DAMAGE (BS 7385-2)

British Standard 7385-1 damage classification is shown in Table J4.4.2.2.

TABLE J4.4.2.2

BS 7385-1:1990—DAMAGE CLASSIFICATION

Damage classification	Description
Cosmetic	The formation of hairline cracks on drywall surfaces or the growth of existing cracks in plaster or drywall surfaces; in addition, the formation of hairline cracks in the mortar joints of brick/concrete block construction
Minor	The formation of cracks or loosening and falling of plaster or drywall surfaces, or cracks through bricks/concrete blocks
Major	Damage to structural elements of the building, cracks in support columns, loosening of joints, splaying of masonry cracks etc.

The frequency dependent alternative blasting criteria for low-rise residential buildings given in (USBM) RI 8507 are shown in Figure J4.4.2.2 and Table J4.4.2.3.

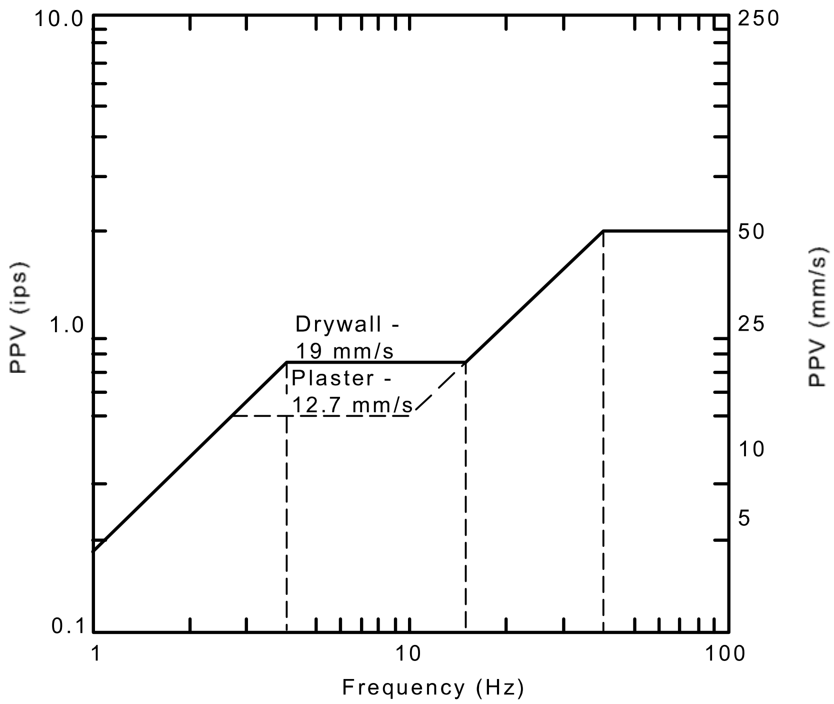

FIGURE J4.4.2.2 USBM 'SAFE' BLASTING VIBRATION LEVEL CRITERIA

USBM damage classifications are shown in Table J4.4.2.3.

TABLE J4.4.2.3

USBM DAMAGE CLASSIFICATION

Uniform classification	Description of damage
Threshold	Loosening of paint; small plaster crack at joints between construction elements; lengthening of old cracks
Minor	Loosening and falling of plaster; cracks in masonry around openings near partitions; hairline to 3 mm cracks (0 to 1/8 in); fall of loose mortar
Major	Cracks of several mm in walls; rupture of opening vaults; structural weakening; fall of masonry, e.g., chimneys; load support ability effected

Authoritative investigations (see Paragraph J8, Item 1) suggest that the guide values and assessment methods given in BS 7385-2 and (USBM) RI 8507 are applicable to Australian conditions, and are recommended for explosives users with the facilities to make use of these methods.

The estimation of the frequency of each vibration component to be used in structural damage assessment is complex. Simple approaches suggested within the BS 7385-2 and (USBM) RI 8507 includes—

(a) frequency of the maximum PPV amplitude peak;

(b) dominant frequency of the component vibration time history; and

(c) zero crossing frequency of the PPV amplitude peak.

The (USBM) RI 8507 and BS 7385-2 methodologies for assessing frequencies have been widely used for many years, and were suitable for use with desktop and laptop computers with the power that was commonly available in the 1980s and early 1990s. It appears that the motion frequencies determined by simple methods, such as zero crossing, are conservative for assessing damage potential.

NOTE: A method under development, which may give greater accuracy, uses the (USBM) RI 8507 frequency-dependent limits (which are similar to the limits specified in BS 7385-2) but with a more accurate methodology for assessing frequencies.

The method has been tested and published [see Fragblast 7–Beijing (1992) which may be found at http://www.isee.org and search their publications]. At the time of writing this Standard, software systems for the practical use of this method by explosives users were being developed, but were not in general use.

J4.5 Recommended ground vibration limits

NOTE: Statutory requirements for human comfort limits for ground vibration may apply in respective jurisdictions.

The maximum levels for ground vibration for human comfort, which some authorities have chosen, are provided in Table J4.5(A). Recommended limits for ground vibration for control of damage to structures are provided in Table J4.5(B).

Frequency-dependent limits have the capacity to precisely deal with the hazards presented by ground vibration and are seen as the basis for best practice blasting. The particular frequency-dependent criteria should be reported with the measurements. All the limits given in Tables J4.5(A) and J4.5(B) are peak component particle velocities, as used in overseas Standards and guidelines. The classification of type of structure may be difficult and when in doubt, a more conservative limit from the nearest description in Table J4.5(B) should be applied.

TABLE J4.5(A)

GROUND VIBRATION LIMITS FOR HUMAN COMFORT CHOSEN BY SOME REGULATORY AUTHORITIES (see Note to Table J4.5(B))

Category	Type of blasting operations	Peak component particle velocity (mm/s)
Sensitive site*	Operations lasting longer than 12 months or more than 20 blasts	5 mm/s for 95% blasts per year 10 mm/s maximum unless agreement is reached with the occupier that a higher limit may apply
Sensitive site*	Operations lasting for less than 12 months or less than 20 blasts	10 mm/s maximum unless agreement is reached with occupier that a higher limit may apply
Occupied non-sensitive sites, such as factories and commercial premises	All blasting	25 mm/s maximum unless agreement is reached with occupier that a higher limit may apply. For sites containing equipment sensitive to vibration, the vibration should be kept below manufacturer's specifications or levels that can be shown to adversely effect the equipment operation

*A sensitive site includes houses and low rise residential buildings, theatres, schools, and other similar buildings occupied by people.

NOTE: The recommendations in Table J4.5(A) are intended to be informative and do not override statutory requirements with respect to human comfort limits set by various authorities. They should be read in conjunction with any such statutory requirements and with regard to their respective jurisdictions.

TABLE J4.5(B)

RECOMMENDED GROUND VIBRATION LIMITS FOR CONTROL OF DAMAGE TO STRUCTURES (see Note)

Category	Type of blasting operations	Peak component particle velocity (mm/s)
Other structures or architectural elements that include masonry, plaster and plasterboard in their construction	All blasting	Frequency-dependent damage limit criteria Tables J4.4.2.1 and J4.4.4.1
Unoccupied structures of reinforced concrete or steel construction	All blasting	100 mm/s maximum unless agreement is reached with the owner that a higher limit may apply
Service structures, such as pipelines, powerlines and cables	All blasting	Limit to be determined by structural design methodology

NOTE: Tables J4.5(A) and J4.5(B) do not cover high-rise buildings, buildings with long-span floors, specialist structures such as reservoirs, dams and hospitals, or buildings housing scientific equipment sensitive to vibration. These require special considerations, which may necessitate taking additional measurements on the structure itself, to detect any magnification of ground vibrations that might occur within the structure. Particular attention should be given to the response of suspended floors.

J5 AIRBLAST LEVELS

J5.1 General

Airblast can cause discomfort to persons and, at high levels, damage to structures and architectural elements, and at very high levels, injury to persons.

The airblast levels at which people become annoyed are well below levels at which damage has been proven to occur. The evaluation of the effects of blasting should separate human response and structural/architectural damage effects of airblast. Of particular importance in this regard is the frequency content of the airblast. For example, an airblast that is inaudible to humans may still be responsible for structural/architectural damage effects. Conversely, an airblast level that causes human discomfort may have negligible structural/architectural damage effects. The limits set out in Paragraphs J5.2, J5.3 and J5.4 below offer a robust means for differentiating such effects and are based upon studies conducted by various workers in blasting.

The sound pressure level [*SPL* (*dBL*)] is defined as follows:

$$SPL = 10 \log_{10} \left(\frac{P}{P_0} \right)^2 \qquad \text{. . . J5.1}$$

where P is the pressure level (Pa) and P_0 is the reference pressure of 20 mPa. It is generally accepted that aural pain will occur in humans for *SPL* greater than 140 dBA for frequencies in the range 20 Hz to 20 kHz and for *SPL* between 160 dBL and 170 dBL for frequencies below 20 Hz.

General control limits currently used in Australia are not frequency dependent. It is probable that continuing research and development will result in the development of frequency-dependent limits and these should be adopted when available.

J5.2 Human comfort limits

NOTE: Statutory requirements for human comfort limits for airblast may apply in respective jurisdictions.

Human comfort limits for airblast are linked to the annoyance produced. Several factors contribute to annoyance by impulsive sounds such as airblast. These include the loudness, duration and number of events plus the time of day and the nature of the disturbance.

J5.3 Damage limits

From Australian and overseas research, damage (even of a cosmetic nature) has not been found to occur at airblast levels below 133 dBL. The probability of damage increases as the airblast levels increase above this level. Windows are the building element currently regarded as most sensitive to airblast, and damage to windows is considered as improbable below 140 dBL.

A limit of 133 dBL is recommended as a safe level that will prevent structural/architectural damage from airblast. Reference to Tables J4.4.2.2 and J4.4.2.3 should be made when classifying damage.

J5.4 Recommended airblast limits

Airblast limits for human comfort chosen by some regulatory authorities are provided in Table J5.4(A). Recommended damage control limits are given in Table 5.4(B). All the limits are expressed as peak linear sound pressure levels. The classification of type of structure may be difficult and, when in doubt, a more conservative limit from the nearest description in Table J5.4(B) should be applied.

TABLE J5.4(A)

AIRBLAST LIMITS FOR HUMAN COMFORT CHOSEN BY SOME REGULATORY AUTHORITIES (see Note to Table J5.4(B))

Category	Type of blasting operations	Peak sound pressure level (dBL)
Human comfort limits		
Sensitive site*	Operations lasting longer than 12 months or more than 20 blasts	115 dBL for 95% blasts per year. 120 dBL maximum unless agreement is reached with occupier that a higher limit may apply
Sensitive site*	Operations lasting for less than 12 months or less than 20 blasts	120 dBL mm/s for 95% blasts. 125 dBL maximum unless agreement is reached with occupier that a higher limit may apply
Occupied non-sensitive sites, such as factories and commercial premises	All blasting	125 dBL maximum unless agreement is reached with the occupier that a higher limit may apply. For sites containing equipment sensitive to vibration, the vibration should be kept below manufacturer's specifications or levels that can be shown to adversely effect the equipment operation

* A sensitive site includes houses and low rise residential buildings, hospitals, theatres, schools, etc., occupied by people.

TABLE J5.4(B)

RECOMMENDED AIRBLAST LIMITS FOR DAMAGE CONTROL (see Note)

Category	Type of blasting operations	Peak sound pressure level (dBL)
Damage control limits		
Structures that include masonry, plaster and plasterboard in their construction and also unoccupied structures of reinforced concrete or steel construction	All blasting	133 dBL maximum unless agreement is reached with the owner that a higher limit may apply
Service structures, such as pipelines, powerlines and cables located above the ground	All blasting	Limit to be determined by structural design methodology

NOTE: Tables J5.4(A) and J5.4(B) are intended to be informative and do not override statutory requirements, particularly with respect to human comfort limits set by various authorities. They should be read in conjunction with any such statutory requirements and with regard to their respective jurisdictions.

J6 OPERATING PRACTICE

J6.1 General

Shotfirers should endeavour to reduce ground vibration and airblast to as low a level as practically possible to reduce the possibility of discomfort, damage, worry or complaint. This should be reinforced by frequent consultation with persons who may be affected by the blast.

Relevant blast personnel should be given regular training in these aspects of blasting. Blast performance should be regularly reviewed and possible improvements implemented to ensure a good relationship is maintained with persons who may be affected by the blast and the regulatory authorities.

Table J6.1 give guidance on the various options available for controlling ground vibration and airblast.

TABLE J6.1

GROUND VIBRATION AND AIRBLAST CONTROLS

Variables	Ground vibration			Airblast		
	Influence on ground vibration			Influence on overpressure		
	Significant	Moderately significant	Insignificant	Significant	Moderately significant	Insignificant
1 Within the control of blasting operators						
Maximum instantaneous charge (effective charge mass per delay)	✓				✓	
Delay interval	✓			✓		
Burden and spacing		✓		✓		
Stemming: Amount			✓	✓		
Type			✓	✓		
Charge length and diameter			✓		✓	
Angle of blasthole			✓			✓
Direction of initiation	✓			✓		
Charge mass per blast		✓				✓
Charge depth			✓	✓		
Covering of detonating cord			✓	✓		
Charge confinement	✓			✓		
Blasthole deviation	✓			✓		
2 Not within the control of blasting operators						
General surface			✓		✓	
Geological conditions	✓			✓		
Wind and weather conditions			✓	✓		
Water saturated ground	✓					✓

J6.2 Ground vibration

Control measures that may be effective in reducing the impact of ground vibration at a particular site may include one or more of the following:

(a) Reducing maximum instantaneous charge (effective charge mass per delay) for example by reducing blasthole diameter or deck loading.

(b) Using a combination of appropriate delays.

(c) Allowing for excessive humps or toe in the blast design.

(d) Optimizing blast design (changing burden and spacing) by altering drilling patterns, delaying layout or alter blasthole inclination from the vertical.

(e) Exercising strict control over the location, spacing and orientation of all blastholes and using the minimum practicable sub-drilling that gives satisfactory toe conditions.

(f) Establishing times of blasting to suit the situation.

J6.3 Airblast reduction

Control measures that may be effective in reducing the impact of airblast at a particular site may include one or more of the following:

(a) Optimizing blast design (changing burden and spacing) by altering drilling patterns, and adjusting maximum instantaneous charge (effective charge mass per delay).

(b) Using a combination of appropriate delays.

(c) Using survey methods, as appropriate, to ensure burden is adequate.

(d) Keeping face heights to a practical minimum.

(e) Ensuring stemming type and length is adequate.

(f) Eliminating exposed detonating cord. Investigate alternative initiation methods.

(g) Eliminating secondary blasting (instead of popping, use rock breaker).

(h) Making extra efforts to eliminate the need for two shots (e.g., better control of drill patterns).

(i) Considering delaying or cancelling the blast by not loading if the weather forecast is unfavourable.

(j) Allowing for the effects of temperature inversion and wind speed and direction on the propagation of airblast to surrounding areas.

(k) Orientating faces where possible so that they do not face directly towards residences.

(l) Varying the direction of initiation.

(m) Exercising strict control over the burden, spacing and orientation of all blastholes.

(n) Taking particular care where the face is already broken or where it is strongly jointed, sheared, or faulted.

(o) Considering deck loading where appropriate to avoid broken ground or cavities in the face (e.g., from back break).

J6.4 Blasting complaints

Complaints arising from blasting operations should be treated sensitively and in a manner that recognizes the potential for blasting to cause environmental impacts. Such impacts fall under the jurisdiction of a variety of regulatory authorities. Those responsible for each blasting operation must be aware of the regulatory regime pertinent to that operation. In any case, they need to act in the best interests of all stakeholders, including neighbours of the mine, quarry or construction project.

Many complaints resulting from blasting in built-up areas are mistakenly attributed to ground vibration. The actual problem is usually airblast, which can be controlled by blasting technique.

Those responsible for blasting operations should ensure that relevant personnel and persons who may be affected by the blast are consulted and advised on the nature, causes and effects of airblast from blasting and the difference between it and ground vibration. They should also recognize the importance of monitoring blasts as a tool for minimizing complaints as well as investigating complaints. It is in the interest of all those concerned in a blasting operation to monitor blasting operations in the event of any claims for damages arising from blasting.

Where the blast operation is in an environmentally sensitive area, all blasts should be monitored.

Records of any complaints associated with blasting should be kept, identifying the nature of the complaint, the particular operation that initiated the complaint, and documenting the action taken.

Any complaints related to blasting should be immediately investigated and a genuine endeavour made to satisfy the concerns raised by the complainant. Those responsible for the blasting operation should act swiftly, undertake follow-up visits and provide feedback to the complainant as to the cause of the problem and what is being done to rectify it.

Many complaints from blasting can be avoided by the adoption of the control measures listed in Paragraphs J6.2 and J6.3 and Table J6.1.

Upon receipt of a complaint, an appropriate investigation should establish the nature of the complaint, the cause of the incident and any response. Independent professional or technical advice may need to be sought.

J7 ESTIMATION OF GROUND VIBRATION AND AIRBLAST LEVELS

J7.1 Introduction

The accurate estimation of ground vibration and airblast levels is a complex task. The blasting process is highly non-linear and the variability of most rock types also contributes to the difficulty in accurate predictions of the environmental outcomes. The random character of the blasting outcomes suggests the need for probability distributions to describe strictly the range of possible ground vibration and airblast levels.

In the absence of either field data or the opportunity to conduct blasting trials in the region of interest, it is possible to estimate likely ground vibration and airblast levels using simple charge weight scaling laws. Such laws incorporate the charge weight per delay and the distance from the blast to the monitoring location. Two site parameters are assumed and these influence the peak level and the rate of decay for the levels.

J7.2 Airblast overpressure

Airblast levels have been commonly estimated using the following cube root scaling formula:

$$P = K_{\mathrm{a}}\left(\frac{R}{Q^{1/3}}\right)^{a} \qquad \text{. . . J7.2}$$

where

P = pressure, in kilopascals

Q = explosives charge mass, in kilograms

R = distance from charge, in metres

K_{a} = site constant

a = site exponent

For unconfined surface charges, in situations that are not affected by meteorological conditions, a good estimate may be obtained by using a site exponent (a) of −1.45, (which corresponds to an attenuation rate of 8.6 dBL with doubling of distance), and a site constant (K_{a}) of 516.

For confined blasthole charges, when using a site exponent (a) of −1.45, the site constant (K_{a}) is commonly in the range 10 to 100.

Airblast is proportional to the cube root of the charge mass. This limits the effectiveness of charge mass reduction as a method of reducing airblast levels; other factors are often more important, especially for confined blasthole charges.

In unfavourable meteorological conditions, it is common for airblast levels to be increased by up to 20 dBL due to the combined effects of an increase with altitude of temperature (an inversion) and/or wind velocity (windshear). Effective assessment of meteorological reinforcement requires accurate measurement of temperature, wind speed, and wind direction, generally at heights up to 1000 m above the ground.

J7.3 Ground vibration

It is useful to be able to estimate the ground vibration expected from any particular blasting operations. As many site factors will affect the transmission of vibration through the ground, the most accurate prediction graph for a site will be that generated from vibration measurements take at the site. However, in the absence of such site data, ground vibration may be estimated using the following equation:

$$V = K_g\left(\frac{R}{Q^{1/2}}\right)^{-B} \qquad \text{. . . J7.3(1)}$$

Where

V = ground vibration as vector peak particle velocity, in millimetres per second

R = distance between charge and point of measurement, in metres

Q = maximum instantaneous charge (effective charge mass per delay), in kilograms

K_g, B = constants related to site and rock properties for estimation purposes

Ground vibration levels depend on the maximum instantaneous charge (effective charge weight per delay), and not the total charge weight, provided the effective delay interval is appropriate.

When blasting is to be carried out to a free face in average field conditions, the following equation may be used to estimate the mean (50% probability of exceedence) vector peak particle velocity:

$$V = 1140\left(\frac{R}{Q^{1/2}}\right)^{-1.6} \qquad \text{. . . J7.3(2)}$$

Equation J7.3(2) is represented in graphical form in Figure J7.3.1 and in tabular form in Table J7.3.1.

NOTE: Equation J7.3(2) and Table J7.3.1 and Figure J7.3.1 (which uses a site constant of $K_g = 1140$, and a site exponent of $B = 1.6$), will provide an estimate of vibration levels in 'average' conditions. In practice, due to variations in ground conditions and other factors, the resulting ground vibration levels can vary from two-fifths to four times that estimated. In cases where the site parameters have not been reliably determined from prior experience, advice should be obtained from suitably qualified and experienced persons, who may recommend initial trial blasts with conservative charge quantities.

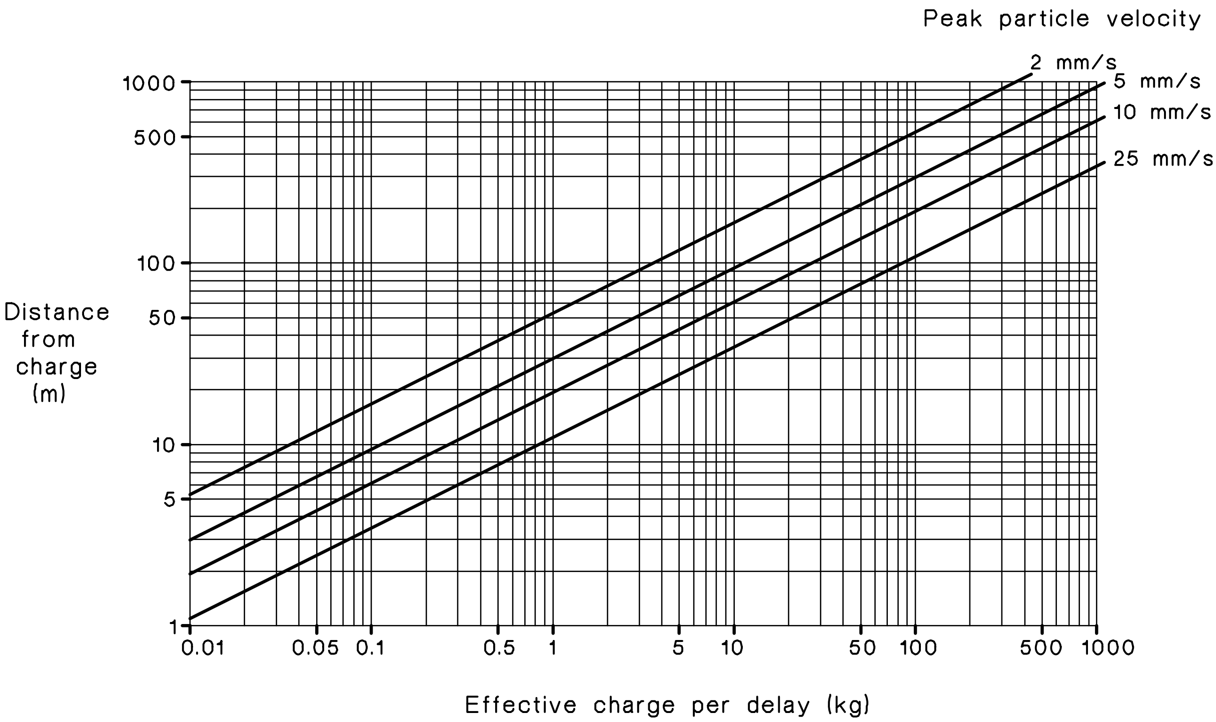

FIGURE J7.3.1 FREE-FACE—AVERAGE FIELD CONDITIONS

TABLE J7.3.1

FREE FACE AVERAGE FIELD CONDITIONS

Vibration (VPPV)	Estimated maximum effective charge per delay, kg													
	Distance, m													
mm/s	1	5	10	20	30	50	80	100	150	200	300	500	800	1 000
2	—	0.010	0.035	0.145	0.3	0.9	2.3	3.6	8	14	32	90	230	360
5	0.001	0.030	0.110	0.450	1.0	2.8	7.2	11.3	25	45	100	280	720	1 130
10	0.003	0.070	0.270	1.050	2.4	6.7	17.2	26.9	60	105	240	670	1 720	2 700
25	0.008	0.210	0.840	3.400	7.6	21.0	54.0	84.2	190	340	760	2 100	5 400	8 400

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